



## ACKNOWLEDGEMENTS

This manual is a collection of exercises developed for Astronomy 1230, *Introduction to Astronomical Observation*. It is intended solely for use at UVa and is thus specific to local conditions and equipment. Earlier incarnations of this course were ASTR 103 (*Night Sky Laboratory*, to 1995) and ASTR 130 (*Introduction to Astronomical Observations* 1996-2008). Major contributions to this manual have been made over the course of many years by a number of faculty members and graduate students, including Robert W. O'Connell, Ronald G. Probst, Robert T. Rood, Philip A. Ianna, Samuel J. Goldstein, Jr., Mercedes Richards, Steven R. Majewski, D. Mark Whittle, Richard Gelderman, Prudence N. Foster, Mark A. Ratliff, Raymond G. Ohl, Jeffrey O. Breen, Christopher Palma, Eric A. Richards, Ronak Y. Shah, Robert W. Spiker, Chih-Yueh Wang, Franz Bauer, Michael H. Siegel, Josh C. Kempner, Jeff Crane, Wayne Winters, Jeff Balsley, Adrienne J. Gauthier, Nicole Gugliucci, Joleen Miller, A. J. Heroux, George Privon, Abel Yang, Rachael Beaton, and George Trammell. The CLEA labs were produced by the Gettysburg College Department of Physics, under sponsorship of the National Science Foundation. Descriptions of these were modified and elaborated at UVa. Other laboratory manuals and various publications for amateur astronomers have been a fruitful source of ideas. However, the development of these ideas as presented here, as well as all errors, inaccuracies, and omissions, are the responsibility of the University of Virginia Astronomy Department.

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## INTRODUCTION TO ASTRONOMY 1230

### General Information

This is an observational/laboratory course intended to familiarize you with the general features of the night sky and the properties of those objects that can be studied with small astronomical instruments, including binoculars, small telescopes, and cameras. It will develop your skills in operating laboratory instrumentation and in making and analyzing scientific observations. It also explores the central role observations have played in the development of modern astronomy and in our interpretation of the structure and evolution of the universe. The knowledge and skills developed in this course will provide an excellent basis for a lifetime avocation in amateur astronomy for those with stronger interests in the subject.

**Syllabus:** A current syllabus containing information on textbooks, assignments, deadlines, equipment checkout, grading policy, and so forth will be provided by your instructor.

**Course Web Site:** There is a home page for this course on the Astronomy Department's World Wide Web server or on Collab. Announcements concerning schedules, requirements, etc., will be posted there, and that is the **first place you should look for information** if you have questions.

**Class Meetings:** A schedule for the course is given in the syllabus. A regular 2-hour lecture will be scheduled each week. The student observatory will be open four nights a week, weather permitting. Attendance at lectures is expected, but you are allowed to set your own schedule regarding lab attendance, subject to the posted deadlines for submitted work.

**The majority of your work in this class will be done during nighttime observing/laboratory sections.** Although you have been assigned to a laboratory section on a particular night, this is purely for registration purposes. **You may use the facilities on any night, Monday through Thursday, during the semester.** Normal operating hours are posted on the Astronomy Web pages and in the syllabus. Labs will be closed during vacations. Observing facilities will also be closed when bad weather (clouds, storms) prevents their use. Information concerning nightly weather conditions will be posted electronically and on a recorded phone message. A few optional "Day" labs are available in the Astronomy Building; TA's can provide details. Optional computer labs can be executed on your own computer via ITC's "Hive" system. Instructions for using the software can be found at <http://www.astro.virginia.edu/class/>.

### General Comments on Requirements

Specific requirements are discussed in the syllabus. You will be asked to complete a selection of lab assignments from this manual, some of which are *required* for all students and some of which are *optional* in the sense that you can choose among several alternatives. There will be one or two in-class examinations during the semester. The Constellation Laboratory involves a nighttime oral quiz on constellation identification. This *Manual* contains complete descriptions of each observing laboratory in the course. Updated information, if any, will be handed out in class or made available on the class Web site.

To prepare for the lab work, you should be sure to **do all of the associated reading beforehand.** In the early labs, this will include material from the Appendices concerning basic astronomical phenomena, astronomical coordinate systems, telescopes, and laboratory write-up standards. Before attempting any particular lab assignment, **you should thoroughly read the corresponding chapter in this manual and do any pre-lab work that is required.** The TA's will expect that you arrive at the observatory familiar with the goals, procedures, and technique for each lab. It is a mistake to try to learn the material "on the fly."

Clear nights without a bright Moon are the best for doing most of the observing assignments in the class. Assignments are designed so that any student can complete the requirements even in the event of a large amount of bad weather. In extreme cases, submission deadlines will be changed to accommodate the weather. To put this another way: **bad weather is not an excuse for missing deadlines.** The TA's keep track of the number of clear nights, and **grading penalties will be imposed** for work submitted after the deadlines.

Personal, employment, academic, or athletic conflicts with observing hours are also not excuses for missing lab deadlines unless extensions have been approved by the instructor in advance. You must adjust your schedule to the observing opportunities available, not vice-versa. Note that it is not possible to make up missed observing work this semester after the last scheduled night of lab operation. You would have to re-take the course the following semester.

Although most students find work in ASTR 1230 to be fun as well as educational, **BEWARE! success in this course depends on your own initiative and diligence.** Because of the unreliability of the weather, procrastination will lead to a poor grade. **Plan now to work steadily on the labs throughout the term, taking advantage of good weather whenever it appears. Start work on labs well in advance of the deadlines.** You are responsible for regularly reviewing deadlines and policies on submitted work posted on the class website.

## Independent Work

Any material submitted for grading in this course is assumed to be entirely your own work and will be regarded as **IMPLICITLY PLEDGED**, whether it is pledged in writing or not. Students are encouraged to work together in setting up and pointing telescopes, as long as each person contributes to the effort. However, when you make an entry on an observing form (describing sky conditions or an object viewed through the telescope, for instance) you must do so **without consulting anyone other than the instructor or a TA.** It is not permissible to copy any material from anyone else's observing sheets. It is not permissible to collaborate with other students on the non-telescopic assignments. You must turn in your original notes and signed observing forms for each lab. Suspected violations of this policy will be referred to the Honor Committee.

If you have questions about this policy, you should consult with the instructor or a TA.

**Signatures:** All lab sheets for observations made at the student observatory must be signed by the instructor or TA supervising the lab session. Sheets without signatures will not be accepted for credit, so don't leave a lab session without signatures.

## Astronomy 1230 as a Laboratory Class

This is a laboratory class, and you should approach it the way you would any other lab class. Prepare in advance so you are ready to take full advantage of the time available. Stay alert for safety hazards. The equipment you will be using in this course is expensive and can be fragile. You must sign all equipment out and back in using the logs posted in the laboratory areas. Treat equipment carefully and with respect. Never touch an optical surface (lens or mirror) with your fingers. Never force anything—difficulty with the equipment is usually a sign that you are doing something wrong. Think before you act. Ask for advice from the TA's when you need it. After use, stow equipment properly and neatly. Report any malfunctions or damage to the TA on duty.

**Laboratory Write-Ups:** You are required to submit written reports for each lab you perform (with one exception). Each section in this manual contains a description of what is required in your writeup for that lab, and many include a post-lab checklist for your writeup. Appendices D and E provide details on how to fill out lab reports. It is essential that you familiarize yourself with these portions of the manual.



## Safety During Astronomical Observations

1. For the most part, you will be working in the dark. Use common sense in moving about. Beware of loose or wet ground (gravel, etc.), lab equipment, and other obstructions in the student observatory area. Walk slowly and carefully when moving from a lighted room into the dark. It will take your eyes several minutes to adapt.
2. **Always bring a flashlight with you.** Please be sure to obtain a **red filter** for your flashlight from us so that you do not ruin other students' dark adaptation. Never shine a light in another person's face. If you must use a white light, cup your hand over the end to block most of the light.
3. The telescopes, which must be moved from the lab office to observing stations outside, are quite heavy. **Never attempt to move a telescope by yourself.**
4. No smoking in the lab area, indoors or outdoors.
5. Be aware that students from other classes will also be using the Observatory area and may not be familiar with these safety precautions. Please report any unsafe or disruptive behavior to a TA.
6. If you are concerned about crime, travel to and from the student observatory in a group. TA's will arrange transportation to McCormick Observatory for optional work there.
7. If an injury of any kind occurs, notify the instructor or TA. If the injury is minor and no supervisor is present, you should still notify the Astronomy Department as soon as possible. If the injury appears even remotely to be serious, call the Rescue Squad (911). You can use the telephone in the student observatory to summon aid.
8. Wear suitable clothing at all times. Remember that even 60° weather is chilling if you are engaged in observing with a minimum of movement for several hours.

# 1 INTRODUCTION TO THE CONSTELLATIONS

## 1.1 Time Estimate

You and your classmates will work together in groups to learn the constellations, after which you will be individually assessed on your knowledge of the night sky. This activity will take about one lab period. No laboratory writeup is required.

## 1.2 Introduction

The purpose of this laboratory is to familiarize you with the general appearance of the night sky, the more prominent constellations and brightest stars. You will be expected to learn about 20 stars, constellations, and astronomical regions in the night sky. Good familiarity with the basic features of the night sky is essential preparation for all other observing exercises in this course. You can learn the constellations on your own, though it may be easier and more fun in a group. Remember that the sky will change significantly from month to month, so that it is useful to set aside some time every few weeks to get familiar with the new configuration.

A *constellation* is a grouping or pattern of stars which depicts or represents something — animals, mythological heroes, etc. These groupings are *man-made*, and the stars in them usually have no physical association; in fact, they may be very far apart in space. While some constellations (e.g. Scorpio, Leo, Orion) look somewhat like the thing that they are supposed to represent, most do not. But then, neither does the George Washington Bridge bear much resemblance to our first President. Bring your imagination to the study of the constellations.

The oldest of our present day constellations originated in Mesopotamia over four thousand years ago. These groups were inherited and added to by successive cultures; the Alexandrine astronomer Ptolemy (ca. 135 A.D.) listed forty-eight constellations in his star catalogue, the *Almagest*. A wave of new constellations appeared in the seventeenth and eighteenth centuries as European explorers and scientists pushed south into uncharted oceans and unmapped skies. At present, astronomers recognize 88 constellations, seventy-four of which are visible from Charlottesville's latitude of  $+38^\circ$  N.

Part of the original motivation for establishing constellations was to utilize the sky as a reliable timepiece. The regular, repetitive procession of the stars indicated when to plant, when the rivers would flood, and so forth. This tradition survives to this day in the agricultural and weather lore found in "farmers' almanacs." Later astronomers used the constellations as a way of roughly mapping the sky. Saying that a star is in Perseus locates it approximately in the sky, just as saying that Paris is in France locates the city approximately on the Earth. Early astronomers were particularly concerned with the locations of the Sun, Moon and planets, and so paid special attention to the star groups lying along the ecliptic — the constellations of the "zodiac."

## 1.3 Lab Write-up

No write-up is required for this lab. At the conclusion of the group activity, a TA will assess your knowledge of the night sky.

## 1.4 Sky Wheels

It is important to familiarize yourself with the format of the star charts you will be using. You can find charts in various printed atlases and in many different formats on the Internet. However, one

of the most convenient (and transportable) kind of star maps useful in locating constellations is called a *sky wheel* or *planisphere*, a circular or oval map which represents the entire sky. This can be adjusted to any time of the night and any day of the year to show you which stars are presently visible. The only limitation is that a sky wheel must be made for one particular terrestrial latitude.

To use a sky wheel, note the date and time. (If the clocks are set for Daylight Savings Time, subtract an hour from your clock time.) On the sky wheel, match the time dial to the date dial. The elliptical shaped opening, the “front” of the wheel, shows the stars viewable at the specified time. The edge of the opening represents the horizon. The center of the elliptical opening is the *zenith* (the point on the sky directly overhead).

If you stand facing, for example, east with the edge of the chart labeled “east” at the bottom, then the stars in the eastern portion of the sky will be found along the bottom portion of the chart. The center of the map will show the stars directly overhead, while the top will show the constellations in the western part of the sky, behind you. It is often easier to lie down to use such a chart. Notice that the wheels you will be using have the constellations along the southern horizon more accurately represented in a different projection on the reverse side.

By rotating the wheel to different times of night, you can simulate motions in the sky and the rise and set of the stars. Depending on your viewing location (local buildings and terrain), a star will probably need to be at least 30 degrees above the horizon for a clear view. You can use the wheel to estimate when, on a given date, a given star is first (or last) viewable. You can also estimate when it *transits*—i.e. when it crosses the great circle on the sky (the *meridian*) running through the north celestial pole and dividing your sky hemisphere in half. That is the time when the star is farthest from the horizon.

Sky charts are *always misleading* in several respects. Most importantly, the angular scale of objects in the sky is *much larger* than on the map. The elliptical window of the sky wheel represents an *entire hemisphere* of the sky, wrapping around you. It can be difficult to make the transfer from a small area on the map to a large area on the sky. You can see the entire chart at once; you cannot see the entire sky at once. Secondly, the *relative brightnesses of stars* cannot be represented properly on a printed map. Remember that a star which is bigger on the map will be brighter in the sky, but not bigger than other stars. Finally, there will be some *distortion*, particularly around the edges of the chart. This is the result of mapping a curved hemisphere onto a flat plane and can only be avoided by reproducing the star chart onto the surface of a globe.

## 1.5 Star Brightnesses and the Magnitude System

The stars have a wide range of brightnesses. Stellar brightnesses were first put on a quantitative scale by the Greek astronomer Hipparchus around 130 BC. He arranged the visible stars in order of apparent brightness on a scale which ran from 1 to 6, with stars ranked “1” being the brightest. The ranks were called *magnitudes*; a star was said to be of the *first magnitude*, *third magnitude*, and so forth. The faintest stars visible to the eye under excellent sky conditions were ranked as sixth magnitude.

After the telescope was invented (1608 AD) astronomers realized that the sky was filled with stars which were many times fainter than those that could be seen with the naked eye. Thus, Hipparchus’ ancient scale, which ended with 6th magnitude, had to be extended to higher (fainter) values. The faintest objects now detected by large telescopes are around magnitude 30. On the bright end of the scale, modern recalibrations in terms of flux (see below) have also forced changes. Bright objects now have zero or negative magnitudes. The brightest star, Sirius, has a magnitude of  $-1.4$ . The Sun and planets were not included in Hipparchus’ scale, but they are today. The Sun is  $-26$  magnitude, while Venus, at its brightest, is  $-4.4$ . So, the brightness of objects studied by astronomers ranges over a total of 56 magnitudes ( $= 30 + 26$ )!

Astronomers still use this *magnitude system* even though it has two seemingly awkward features. The first is that it runs “backwards.” Fainter stars have larger magnitudes. The second is that because it was originally based on the appearance of stars to the human eye, it is a *logarithmic* system. That is, the response of the eye is proportional not to the amount of light received but to the logarithm of the the amount of light received. Most sensory responses in living organisms have this “non-linear” characteristic.

*Magnitude References:* You should become familiar with the magnitude scale by comparing the star magnitudes given on star charts with the appearance of the same stars in the sky with the naked eye. It is useful to memorize the magnitudes of a few conspicuous stars to use as a guide. One handy set of calibrators visible most of the year is the “pan” of the Little Dipper (Ursa Minor), whose four stars are of magnitudes 2, 3, 4, and 5. The star Vega in the constellation Lyra is also a useful reference because it is visible at some time most nights of the year and has a magnitude very near zero (0.03).

*Magnitudes and Light Energy:* The modern magnitude scale is based on quantitative measurements of the flux of light from stars reaching the Earth. These measures are made with special light-sensitive detectors, such as charge-coupled devices (CCD’s). *Flux* is the amount of light energy that is incident on a detector per unit area per unit time. The standard units for this quantity used by astronomers are “ergs per square centimeter per second” [ $\text{erg cm}^{-2} \text{s}^{-1}$ ]. An erg is a very small unit of energy, about equal to that of a jumping flea. As a result of the large distance between us and the stars, we receive little flux from them. The flux from a first magnitude star is only about 4 millionths of an erg per square centimeter per second. Using this much energy from starlight, it would take over 13 billion years (the age of the universe) to warm up a cup of coffee!

The magnitude scale is defined so that two stars which have a flux ratio of 100 differ by 5 magnitudes. For example, a 1<sup>st</sup> magnitude star has a flux 100 times larger than a 6<sup>th</sup> magnitude star, which itself has a flux 100 times larger than an 11<sup>th</sup> magnitude star, and so on. Thus a 1<sup>st</sup> magnitude star has a flux  $100 \times 100 = 10,000$  times larger than an 11<sup>th</sup> magnitude star. In general, a star  $n$  magnitudes brighter than another has a flux  $100^{n/5}$  times larger. In other words, if star 1 has flux  $f_1$  and magnitude  $m_1$ , and star 2 has flux  $f_2$  and magnitude  $m_2$ , then the flux ratio is given by:

$$\frac{f_1}{f_2} = 100^{(m_2 - m_1)/5}$$

Since  $100 = 10^2$ , this converts to:

$$\frac{f_1}{f_2} = 10^{2(m_2 - m_1)/5} = 10^{0.4(m_2 - m_1)}$$

A difference of 1 magnitude corresponds to a flux ratio of  $10^{0.4} = 2.512$ . Notice that if  $m_2$  is bigger than  $m_1$ , then  $f_2$  is smaller than  $f_1$  (the “backwards” characteristic of the magnitude system). Another way of expressing this is to take the logarithm of both sides of the equation:

$$\log\left(\frac{f_1}{f_2}\right) = \log\left(10^{0.4(m_2 - m_1)}\right) = 0.4(m_2 - m_1)$$

which is usually written as

$$(m_2 - m_1) = 2.5 \log\left(\frac{f_1}{f_2}\right)$$

With logarithmic scales, it is possible to “compress” a vast range of values onto a more manageable scale. For example, the faintest objects detected by the most powerful telescopes are 400 billion times lower in flux than 1<sup>st</sup> magnitude stars, but they have a magnitude of only 30.

*Limiting Magnitudes:* For any instrument, including the human eye, there is a minimum detectable amount of starlight and a corresponding “limiting magnitude.” The limiting magnitude for the human eye is between 5<sup>th</sup> and 6<sup>th</sup> magnitude for most people. For telescopes, the limiting magnitude can be much fainter. Any light detector, including the eye, responds to the *total amount of light incident* on it in a given amount of time. This, in turn, equals the *flux of light from the star multiplied by the collecting area* of the instrument. The collecting area of your eye is the open area of the iris, called the pupil. Your pupil becomes larger in darker conditions, but it cannot open beyond a certain maximum size. The maximum diameter of your pupil under dark conditions is about 7 mm (0.7 cm), so the collecting area of your eye is about  $\pi r^2 = \pi(0.7/2)^2 \text{ cm}^2 = 0.385 \text{ cm}^2$ . The collecting area of a telescope can be much larger. An 8-in (20 cm) diameter telescope, for instance, has a collecting area of  $\pi(20/2)^2 \text{ cm}^2 = 314 \text{ cm}^2$ , which is about 800 times larger than your pupil. Thus, with an 8-in telescope you can see stars that produce 800 times less flux (i.e. are 7.3 magnitudes fainter) than the faintest stars visible to your unaided eye. The limiting magnitude for visual observations with your 8-in telescopes is therefore about 13. Modern telescopes have a diameter of up to 10-m, giving them well over a million times the collecting area of your eye.

*Absolute Magnitudes:* The magnitudes discussed so far are called *apparent magnitudes* because they indicate how bright an object appears as measured from Earth. The apparent brightness depends on the intrinsic brightness (how much energy the object is emitting) and how far away the object is. Often it is the intrinsic brightness which is of interest. One way to quantify intrinsic brightness is to imagine placing all objects at the same distance. Conventionally, astronomers use a distance of 10 parsecs (which is 32.5 light years or  $3.1 \times 10^{14} \text{ km}$ ). The *absolute magnitude* is defined to be the apparent magnitude a star would have if it were placed at this distance. Therefore, it is a measure of the intrinsic brightness of the star. For example, the Sun and Antares have absolute magnitudes of +4.8 and −5.2, respectively. If both were placed at a distance of 10 parsecs, the Sun would appear as a rather faint star (+4.8), just visible to the eye, while Antares would dominate the night sky (−5.2). The difference of 10 magnitudes implies Antares radiates 10,000 times more light energy per second than the Sun.

## 1.6 Star Names

The brighter stars have been named and renamed time after time by different cultures and individual astronomers. A star like Sirius has a long list of aliases. The “proper” names of the brightest stars such as Betelgeuse, Antares, Aldebaran, Arcturus, Deneb, and Polaris are variously derived from Arabic, Greek, or Latin. Only about 30 of these are in widespread usage today.

A more systematic naming of stars is based on star catalogs. Today, astronomers have cataloged most stars through about 15th magnitude, the fainter ones being identified and measured automatically using computerized equipment. Stars are named by their numbers in such catalogues (e.g. HD 140283, for the Henry Draper Catalog or SAO 159459 for the Smithsonian Astrophysical Observatory Catalog), or by their Right Ascension and Declination coordinates (e.g. 0640-16 gives the coordinates of Sirius). One of the largest available catalogs is the Hubble Space Telescope Guide Star Catalog, which contains over 15 million stars.

Two historical catalogs are of special interest for the study of brighter stars. Bayer’s *Uranometria* (1603) assigned Greek letters ( $\alpha$ ,  $\beta$ ,  $\gamma$ , etc.) in order of brightness to stars in each constellation. Some 1300 stars have Bayer designations. Sirius is  $\alpha$  Canis Major and Rigel is  $\beta$  Orionis in Bayer’s designation. Unfortunately, because of errors (or in some cases, actual changes in brightness), the order is not necessarily correct. In 1712, Flamsteed produced a catalog in which stars in each constellation were numbered in their Right Ascension order, producing numbers like 61 Cygni or 40 Eridani. Astronomers often use the Bayer or Flamsteed designations for the brighter stars in each constellation.

## 1.7 General Advice on Constellation Study

1. You are encouraged to prepare for this lab by becoming familiar with the night sky on your own. This section provides some general tips on observing the constellations.
2. Before going outside, practice using your sky wheel. Learn to adjust it for the observing date and time. Compare constellations marked on the wheel to the descriptions below. Compare the representations on the wheel to those in *Norton's/Edmund's Sky Atlas*.
3. Some editions of the standard sky wheel have the names of the bright stars marked on them. Others do not. Check yours against the bright stars you are expected to know (see the Observing List for this semester, below). Write in the names of any which are missing. You will have to consult *Norton's/Edmund's* cross-list of Bayer designations against common names.
4. Bring this manual and your sky wheel with you. (Bringing *Norton's/Edmund's* is optional.) Use a flashlight with a **red filter** so you can refer to the charts without causing night-blindness.
5. Find a spot shielded from direct lighting with a clear view of the sky. "Light pollution" from city lights is a very serious detriment to good sky viewing. Best views are on moonless nights in the country, well away from city lights. If you have a chance, do try to learn the constellations at a dark site, but don't observe alone.
6. Give your eyes a few minutes to adjust to the darkness. (So-called "dark-adaption" continues to improve for about 30 minutes in darkness.)
7. Learn to judge the transparency of the sky and the effects of sky brightness (from moonlight or scattered city lights) on the limiting magnitude for visual observations. The best quantitative way to do this is to determine the magnitude of the faintest stars you can reliably detect (e.g. by using the "pan" of the Little Dipper; see above).
8. Orient your map to match the sky. The location of the pole star (Polaris) gives the direction North. At some times of the year, it is easiest to start from other bright constellations (e.g. Orion).
9. Practice translating sizes on your map to angular distances on the sky. For instance, use the "hand-y" measuring scale: with your hand held at arm's length, the width of your index finger is about 1 degree, the width of your closed fist is about 10 degrees, and the distance between the tip of your little finger and the tip of your thumb on your outstretched hand is about 20 degrees. The length of the body of Orion is about 20 degrees; the width of the pan of the Big Dipper is about 10 degrees.
10. Learn to use objects you already know to find new ones. Orion is particularly good for this in the winter sky. For example, the stars in Orion's belt point down to Sirius and up to Aldebaran.
11. Dress appropriately for the nighttime temperature. If the temperature is below  $55^{\circ}$ , pay particular attention to your feet, hands, head, and neck. Several layers of loose clothing are more effective than a single heavy coat.

## 1.8 Laboratory Procedure

The Nightlab Orientation during the first week of class will include instructions on how to use sky wheels. Nights on which you can do the constellation lab (in the week following) will be announced in class.

During the Constellation Lab session, students will work in groups with TA help to become familiar with the brighter constellations and stars that are visible at the time as well as other features such as the Ecliptic, Celestial Equator, and Milky Way. They will instruct one another in locating these and ways to remember them. After the learning sessions are complete, each student will be asked by a TA to demonstrate his/her knowledge of the sky.

What you need to bring to the Nightlab Orientation (first week of class):

1. This lab manual
2. A skywheel (purchase this and the manual at the University bookstore)
3. A small flashlight. Buy a red filter for the flashlight if you can; if not, we can provide filters. You are expected to always have your flashlight with you when you attend observing sessions.

What you need to bring to the Constellation Lab:

1. This lab manual
2. Your sky wheel
3. Your flashlight with red filter
4. Any Constellation Lab materials that were given to you during the Nightlab Orientation

## 1.9 Constellation and Bright Star Lists

The following pages list and describe the major constellations and notable naked-eye objects in them. Circumpolar constellations are visible at any time of the year from most of the United States. The other constellations are listed in order of their transit time, starting in the evening in September. **Conspicuous constellations have double asterisks (\*\*) by their names. Bright stars are underlined. Interesting clusters, nebulae, and galaxies are marked with a single asterisk (\*).**

Following the descriptions of the constellations are the **Fall and Spring Observing Lists**. These are the objects you will be responsible for knowing. The lists emphasize objects which are observable in the evening hours. However, not all of these will be available at a given time. Visibility will also depend on sky conditions. Your instructor will indicate which objects you should be able to find during the group lab activity.

## CIRCUMPOLAR CONSTELLATIONS

- Ursa Major\*\*  
(UMa) The brightest stars in this constellation make up the Big Dipper, one of the most familiar star groupings. When the fainter stars are added, including the two extended paws, the result looks much like a long-tailed bear stalking about the Pole.  $\alpha$  and  $\beta$ , the Pointers of the Big Dipper, point to Polaris. At the crook of the handle are Mizar and Alcor, the Horse and Rider, which are so close they almost look like one star.
- Ursa Minor  
(UMi) The Little Dipper appears to pour its contents into the Big Dipper. Polaris, the Pole Star, is at the end of the handle. It is only of second magnitude and is currently about a degree away from the North Celestial Pole. The four stars in the bowl of the Little Dipper are of magnitudes 2, 3, 4, and 5 and therefore serve as a useful reference set for sky transparency and brightness.
- Draco (Dra) The Dragon coils around the Pole from the bowl of the Big Dipper to the Cepheus. Thuban, midway between the handle of the Big Dipper and the dipper of Ursa Minor, marked the position of the North Celestial Pole 4800 years ago.
- Cepheus (Cep) The King, Cassiopeia's husband, is a rather inconspicuous constellation shaped like a child's drawing of a house.  $\alpha$  and  $\beta$  Cas point to  $\alpha$  Cep.  $\delta$  Cep, the prototype Cepheid variable, varies from 3.6 to 4.3 mag in a period of 5.4 days. Nearby  $\zeta$  (3.6 mag) and  $\epsilon$  (4.2 mag) may be used to estimate the magnitude of  $\delta$  with the naked eye or binoculars.
- Cassiopeia\*\*  
(Cas) The Seated Queen is marked by an irregular "W" shape. It is opposite the Pole from the Big Dipper. The line between Polaris and  $\beta$  Cas is close to 0 hours right ascension and may be used to estimate the sidereal time. The winter Milky Way passes through Cassiopeia.



### OTHER CONSTELLATIONS LISTED IN ORDER OF TRANSIT: FALL TO SPRING

Hercules** (Her)	A line from Arcturus to Vega in Lyra passes through the distinctive “Keystone” group in the center of this irregular figure. Throughout history this constellation has represented a keeling hero incongruously placed upside down with one foot on the head of the Dragon. The red giant <u>Rasalgeti</u> marks his head. The globular cluster *M13 is visible in binoculars and is a beautiful sight in a large telescope.
Lyra** (Lyr)	Brilliant <u>Vega</u> marks the small but unmistakable constellation of the Lyre. Vega passes very near the zenith for observers in the 48 states. Vega was the Pole Star 14,000 years ago and will be again 12,000 years from now. The Sun’s motion through space is carrying it toward a point halfway between $\kappa$ Lyr and $\theta$ Her.
Cygnus** (Cyg)	The Swan flies southward along the Milky Way, with <u>Deneb</u> marking its tail and <u>Albireo</u> its beak. The figure is also known as the Northern Cross. A dark sky will show the Great Rift, an apparent splitting of the Milky Way into two branches caused by clouds of dark dust. Deneb, Vega and Altair form the “Summer Triangle.”
Aquila** (Aql)	Like Cygnus, the Eagle points southward down the Milky Way and west from its brightest star, <u>Altair</u> . This grouping has represented a bird from the earliest times. Altair is a near neighbor of our Sun, only 18 light-years away.
Sagitta (Sge)	The Arrow is a small group of 4 stars located midway between <u>Albireo</u> (the head of Cygnus the Swan) and <u>Altair</u> . Somewhat difficult to see on hazy nights, it nonetheless does resemble an arrow in flight.
Delphinus (Del)	The Dolphin is an unassuming group of 5 stars of similar magnitude located about 15° NE of <u>Altair</u> . It resembles a dolphin leaping from the ocean.
Capricornus (Cap)	The Sea Goat, on the ecliptic west of Sagittarius, is formed by a number of faint stars in the shape of an inverted cocked hat. A line from Albireo to Altair, continued its own length, ends at $\alpha$ Cap.
Aquarius (Aqr)	The Water Carrier is an irregular figure of faint stars on the ecliptic east of Capricornus. A line from $\beta$ through $\alpha$ Peg, prolonged twice its length, ends in the center of the figure. This region of the sky is notable for the presence of many “watery” constellations — Capricornus, Aquarius, Pisces, Piscis Austrinus, and Cetus — but all are inconspicuous or ill-defined.
Pegasus** (Peg)	The most conspicuous part of the Winged Horse is the Great Square of four stars (including one borrowed from Andromeda). The distance between $\alpha$ and $\beta$ Peg is 12°. The remainder of the figure is composed of faint stars scattered over a large area between the Great Square and Cygnus. A line from Vega through $\epsilon$ Cyg leads to <u>Markab</u> in the animal’s shoulder.

Piscis Austri- nus (PsA)	The Southern Fish, low in the south for northern observers, is notable for the presence of <u>Fomalhaut</u> , the Fish's Mouth, the only bright star in this region of the sky. A line from $\beta$ Peg continued south through Aquarius, passes close to <u>Fomalhaut</u> .
Pisces (Psc)	The two Fish are marked by a line of stars running east from the Circlet under the Great Square of Pegasus, and another line running north to Andromeda. The <i>vernal equinox</i> , the location of the Sun as it crosses the celestial equator moving north on the first day of spring, lies $7^\circ$ south of $\omega$ Psc. This used to be called "the first point of Aries," but precession has caused the equinox to shift westward into Pisces.
Andromeda** (And)	Beginning from $\alpha$ And ( <u>Alpheratz</u> ) in the northeast corner of the Great Square of Pegasus, the Chained Lady is formed by two diverging rows of stars running towards Perseus. $\alpha$ And is close to $0^h$ Right Ascension. A line extended from $\beta$ Cas through $\alpha$ Cas intersects <u>Almak</u> ( $\gamma$ And) in the end of the more southerly row. The *Great Spiral Galaxy M31, the nearest large galaxy to our own, can be seen near $\nu$ And with the unaided eye on a dark, clear night.
Triangulum (Tri)	The tiny Triangle is easily found between Almak and Hamal. It was here that Ceres, the first known asteroid, was discovered by Piazzi on New Year's Day, 1801. Triangulum contains the spiral galaxy M33, which is the only other external galaxy visible to Northern Hemisphere naked eye observers besides M31 in Andromeda. But M33 is very faint and can be glimpsed only under exceptional conditions.
Aries (Ari)	A line from $\epsilon$ Cas through Almak, continued as far again, meets <u>Hamal</u> in the head of the Ram. 2,000 years ago the Sun was in Aries on the first day of spring; the astrological sign for Aries is still used for the vernal equinox.
Cetus (Cet)	The Whale is a large, irregular group south and east of Pisces. <u>Mira</u> , the Wonderful, is an irregular red variable star which oscillates between magnitudes 2 and 10 (a factor of over 1500 in flux) in 230 days. <u>Diphda</u> is near the South Galactic Pole.
Perseus** (Per)	The warrior who freed Andromeda is represented by this irregular grouping. A line from $\beta$ And through $\gamma$ And points to <u>Mirfak</u> . The head of the Gorgon Medusa is represented by <u>Algol</u> , the prototype eclipsing variable star. It varies in light from magnitude 2.2 to 3.5 in 2.9 days, as one star of the system passes in front of the other. Algol forms a right triangle with Mirfak and Almak. The rich *Double Cluster h and $\chi$ Per, between Perseus and Cassiopeia, can be seen in a dark sky.
Taurus** (Tau)	The Bull is one of the oldest of the constellations. Taurus lies on the ecliptic, and 4,000 years ago it marked the vernal equinox (the first day of spring). Reddish <u>Aldebaran</u> is the eye of the bull. His horns extend northeast toward Orion and Auriga. Surrounding Aldebaran is a swarm of fainter yellow stars, the <u>*Hyades</u> , a nearby open star cluster. (Aldebaran is not a member, being less than half as far away). Northwest are the bluish <u>*Pleiades</u> or Seven Sisters, another, more compact, open cluster.

Auriga** (Aur)	The Charioteer is a conspicuous, pentagonal grouping north of Orion and Taurus, with which it shares a star. A line from $\kappa$ Ori to $\lambda$ Ori points to bright <u>Capella</u> . Capella is the northernmost of the stars brighter than first magnitude and dips only $8^\circ$ below the northern Charlottesville horizon at its lowest point. The winter Milky Way passes through Auriga.
Orion** (Ori)	The Warrior, one of the most brilliant and easily recognized constellations, dominates the southern winter sky. It is easy to picture him with shield upraised against Taurus, his club held high over his head, his belt across his body, and his sword hanging from the belt. The northernmost star of the belt, $\delta$ Ori, lies on the celestial equator. The brighter stars in Orion provide signposts for finding other winter constellations. Compare the colors of <u>Betelgeuse</u> and <u>Rigel</u> . The *Great Nebula M42, surrounding the middle star of the sword, is a stellar nursery where stars are presently forming. Most of the bright white stars in Orion are young, massive objects forming a loose "association".
Lepus (Lep)	The Hare, a small, irregular group, crouches under the feet of Orion.
Gemini** (Gem)	<u>Castor</u> and <u>Pollux</u> are the heads of the twins. The bodies of the twins are marked by two rows of stars running southwest toward Orion. A line from Rigel to points to Castor. The ecliptic passes through Gemini, and it was here that Herschel discovered Uranus in 1781 and Tombaugh found Pluto in 1931. The star 2 Gem marks the position of the Sun at the summer solstice.
Canis Major** (CMa)	The eye of the Large Dog is marked by the Dog Star <u>Sirius</u> , the brightest star in the sky. Orion's belt points towards it. Sirius' rising just ahead of the Sun warned the Egyptians of the yearly Nile floods. Remarkable color variations produced by atmospheric refraction when Sirius is low in the sky make it a frequent source of UFO reports.
Canis Minor (CMi)	The bright star <u>Procyon</u> dominates a rather barren region west of Orion, between Canis Major and Gemini. Procyon forms a large equilateral triangle with Sirius and Betelgeuse.
Cancer (Cnc)	The Crab is an inconspicuous ecliptic constellation that lies between Gemini and the Sickle of Leo. Near its center is the star cluster *Praesepe (the Beehive), fainter than either the Hyades or Pleiades. It can be seen by the unaided eye in a clear, dark sky and is attractive in binoculars.
Hydra (Hya)	The Sea Serpent is an extremely long ( $100^\circ$ ) and mostly faint constellation. Its head is formed by a small group midway between Regulus and Procyon. From here it coils south and east below Leo and Virgo. A line from $\gamma$ Leo through Regulus points to orange <u>Alphard</u> , the Solitary One, the only bright star in this portion of the sky.
Leo**	The easily-recognized Lion is formed of a sickle followed by a triangle. <u>Regulus</u> marks his heart, <u>Algieba</u> his mane and <u>Denebola</u> his tail. This is another of the very oldest constellations, and has been associated with the Sun from the earliest times. Regulus, named by Copernicus, is almost exactly on the ecliptic.

Corvus (Crv)	A quadrilateral of four stars marks the Crow perched on Hydra's back below Virgo. A line from $\epsilon$ to $\gamma$ Vir, prolonged its length again, intersects $\gamma$ Crv.
Coma Berenices (Com)	Inside the triangle formed by Cor Caroli, Arcturus, and Denebola lies a scattered group of faint stars representing Berenice's Hair. The region is attractive in binoculars but notable mainly as being the location of the North Galactic Pole. Here we are looking directly up out of the disk of our galaxy into intergalactic space. Many thousands of galaxies can be detected in this region by large telescopes.
Canes Venatici (CVn)	The Hunting Dogs, held on leash by Booetes, pursue the Great Bear around the pole. One-third of the way from $\eta$ UMa to Denebola in Leo is <u>Cor Caroli</u> , named in honor of Charles II of England.
Virgo (Vir)	This large, irregular group stretches $50^\circ$ along the celestial equator. Since ancient times it has represented a maiden holding an ear of corn or sheaf of wheat and is associated with the harvest. An arc continued from the Big Dipper's handle through Arcturus points toward <u>Spica</u> , very close to the ecliptic.
Bootes** (Boo)	The arc of the handle in the Big Dipper, continued twice its length, terminates in Arcturus. The kite-shaped figure of this constellation has been taken to represent a Plowman, Wagon Driver, or Herdsman. Arcturus, Denebola and Spica in Virgo form a large equilateral triangle in spring skies.
Corona Borealis (CrB)	Halfway between Arcturus and the Keystone in Hercules lies the partial circlet of seven stars forming the Northern Crown. The Greeks saw this figure as a crown or wreath. The Arabs depicted it as a broken dish, while Australian aborigines call it the Boomerang.
Libra (Lib)	This small group, located on the ecliptic between Virgo and Scorpius, has represented both a Scale (balance) and the Claws of the Scorpion. Its double use is reflected in the names of its brightest stars — <u>Zubenelgenubi</u> , the Southern Claw (a wide double star in binoculars), and <u>Zubeneschamali</u> , the Northern Claw.
Ophiuchus (Oph)	The Serpent-bearer, grasping the Serpent in his hands, is one of the largest constellations, though not very conspicuous. A line across the Keystone from $\eta$ to $\epsilon$ Her points to <u>Rasalhague</u> , the head of the Serpent-Bearer, only $5^\circ$ from <u>Rasalgeti</u> , the head of Hercules. The Serpent (Serpens) is long and thin, running from the Aquila in the east to Corona Borealis in the west.
Scorpius** (Sco)	Scorpius really does look like a cosmic scorpion. South of Ophiuchus and low in the summer sky, it requires a clear sky and unobstructed southern horizon to be seen well. The great "fishhook" shape of its stinger and fiery <u>Antares</u> , the "rival of Mars," in the Scorpion's heart, are unmistakable. The Scorpion's claws were detached by Ptolemy to form the small zodiacal constellation Libra, to the west of Scorpius.

- Sagittarius\*\*  
(Sgr)      The Archer, east of Antares, is easiest to picture as a teapot. Like Scorpius, it requires clear southern skies for a good view. The richest portion of the summer Milky Way passes through Sagittarius and its brilliant star fields and open clusters make for splendid naked-eye and binocular viewing under dark skies. The Sun is located just above the teapot's spout at the time of the winter solstice. The Galactic Center is located in this constellation at an RA of 17h 45m 40s and a Dec of  $-29^{\circ} 00' 28''$
- The Milky Way      This faint, glittering band is produced by the combined light of millions of faint stars in the disk of our Galaxy. It requires a dark sky to be seen well. The summer Milky Way passes through Cygnus, Aquila, Serpens, Sagittarius and Scorpius. Here we are looking generally toward the center of our Galaxy. Binoculars reveal thousands of stars along the Milky Way. The winter Milky Way, passing through Cassiopeia, Perseus, Auriga, and east of Orion, is less conspicuous because here we are looking toward the outer edge of the Galaxy, away from the center.

## FALL OBSERVING LIST

<u>Constellation</u>	<u>Bright Stars &amp; Other Objects</u>
Ursa Minor	Polaris
Cepheus	$\delta$ Cephei
Cassiopeia	
Hercules	
Lyra	Vega
Cygnus	Deneb, Albireo
Aquila	Altair
Pegasus	
Andromeda	Alpheratz, Almak, Andromeda Galaxy
Perseus	Mirfak, Algol
Sagitta	
Delphinus	
Pisces	
Aries	Hamal
Capricorn	
Draco	Thuban
Ursa Major†	Mizar/Alcor
Sagittarius	Galactic Center ( $\alpha = 17^{\text{h}} 46^{\text{m}}$ , $\delta = -29^{\circ} 00'$ )

The Summer Triangle — Vega, Deneb, Altair

North Celestial Pole — projected axis of the Earth's rotation

Celestial Equator — projection of the Earth's equator

The Ecliptic — the plane of the Earth's Orbit

The Milky Way — the plane of our Galaxy

Any of the brighter planets which may be visible: Venus, Mars, Jupiter, Saturn

Estimate sky transparency/brightness using stars of known magnitude

† The “Big Dipper” is only part of Ursa Major; You should recognize the whole constellation.

### SPRING OBSERVING LIST

<u>Constellation</u>	<u>Bright Stars &amp; Other Objects</u>
Ursa Minor	Polaris
Ursa Major†	Mizar and Alcor
Cassiopeia	
Andromeda	Almak
Triangulum	
Aries	Hamal
Perseus	Algol
Auriga	Capella
Taurus	Aldebaran, the Pleiades, the Hyades
Orion	Betelgeuse, Rigel, Orion Nebula
Lepus	
Gemini	Castor and Pollux
Canis Major	Sirius
Canis Minor	Procyon
Cancer	Praesepe (Beehive)
Leo	Regulus

The Winter Hexagon — Sirius, Rigel, Aldebaran, Capella, Pollux, Procyon

North Celestial Pole — projected axis of the Earth's rotation

Celestial Equator — projection of the Earth's equator

The Ecliptic — the plane of the Earth's orbit

The Milky Way — the plane of our Galaxy

Any of the brighter planets which may be visible: Venus, Mars, Jupiter, Saturn

Estimate sky transparency/brightness using stars of known magnitude

† The “Big Dipper” is only part of Ursa Major; You should recognize the whole constellation.

## 2 INTRODUCTION TO BINOCULAR OBSERVING

### 2.1 Time Estimate

This lab requires you to observe and sketch four objects with binoculars. In addition, you will observe and record the colors of a selection of bright stars, study the density of stars near the Milky Way, and study the Moon (if available). It will take about 2 hours to complete this lab.

### 2.2 Introduction

The purpose of this lab is to give you experience in finding your way around the night sky and in using the simplest of astronomical instruments. It is good preparation for the more challenging telescope labs.

Binoculars are extremely useful but often neglected astronomical instruments. In field of view, magnifying power, and light-gathering ability they stand midway between the naked eye and the small telescope. They are an aid to the naked-eye observer in learning the constellations, as they penetrate through scattered city lights or haze to make dim stars brighter. At the telescope, binoculars allow one to examine the vicinity of a faint object and become familiar with the star patterns in the region before attempting to locate the target with a higher power. Binoculars can provide some of the most spectacular views of the Moon, rich star fields, comets, large star clusters, and the Milky Way.

A modern prismatic binocular is essentially a pair of low-power, erect-image telescopes carefully aligned to point parallel to one another. Binoculars are characterized by two numbers, the first expressing the magnifying power and the second the diameter of the objective lenses. For instance, a  $7 \times 35$  binocular magnifies seven times and has lenses 35 millimeters across. For general astronomical use, 35-50 mm diameter lenses and powers in the range  $7\text{-}10\times$  are good choices. Another set of numbers often found engraved on the housing specifies the width of the field of view, usually as so many feet across at 1000 yards distance. This can be converted to an angular field of view with the approximate formula

$$\text{angular field in degrees} = \frac{\text{width of field in feet}}{\text{distance in feet}} \times 57^\circ$$

The two barrels housing each half of a binocular are hinged together on a stiff pivot, to allow their separation to be adjusted for the user's own eye separation. To do this, move the two halves closer together or further apart until the field seen through them with both eyes open is a **single sharp circle**. Movies often show a view through binoculars as two overlapping circles. This is **wrong**, and would soon lead to eyestrain and headaches for the user. Many binoculars have a numbered dial on the end of the pivot pin which allows one to read off the correct separation once found, for quick and easy resetting in the future. Be sure you can comfortably see through both barrels simultaneously.

After setting the separation, the binocular must be focused. There is usually some arrangement allowing each eyepiece to be focused separately. Most commonly, a knob on the pivot pin moves both eyepieces in and out together, while the right eyepiece can also be dialed in and out in its individual mounting. To focus with this arrangement, **close the right eye** and focus with the knob for the left eye; then **close the left eye** and adjust the right eyepiece for sharp focus with the right eye. Double check to be sure the stars are in sharp focus through both barrels. (If you focus on a nearby object, e.g. a streetlamp, you will have to refocus with the knob for the stars.)

Hand-held binoculars have a low magnification because hand tremors make viewing difficult above about ten power. To hold them steadily, place the barrels in the palms of your hands and



brace the thumb and index finger of each hand against your cheek and forehead respectively. This converts the binoculars and head into a single rigid assembly which moves as a unit as the head is moved about. If your head can be supported while observing, this adds to both comfort and steadiness. A reclining lounge chair is very convenient for binocular observers. Failing this, bracing against a wall or tree is helpful. Binoculars can also be adapted to mount on photographic tripods, although this detracts considerably from their convenience in use. Binoculars above ten or twelve power can be successfully used only when tripod-mounted. The Student Observatory has both low and high power binoculars for student use. Get instructions from the TA's before trying to use the tripod-mounted types.

## 2.3 Lab Write-up

You are expected to write up a **brief report of about one page** in the format detailed in the Appendices. Write a short introduction and a description of your observing procedure. Answer the questions posed in the lab. Fill out observing sheets completely, except where noted. Your observing sheets and summary of observed star colors will serve as the Data section of the write-up. The observed stars should be placed in a neat table listing their identities and colors. List them in order of perceived temperature.

## 2.4 Procedure

You are to locate and observe the objects designated in the appropriate section below, filling out the standard observing forms and making sketches where indicated. Before coming to the observatory, use your sky wheel and *Norton's or Edmund's Star Atlas* to locate each target. Fill out the *To Be Completed Before Observing* section of standard observing forms for the *four* objects requiring sketches. [For September "Deep Sky" observing, you have a choice of targets. Which objects are best will depend on sky conditions and time of night, so consult with the TA's at the lab. You can fill out the *Before Observing* section at the lab.] You should identify the bright stars you are expected to observe under "Star Colors" and mark them on your sky wheel if they are not already identified there, but you do not have to fill out an observing form for these.

To complete the forms, under *Telescope* enter the *size* of the binoculars you used (e.g. "7×35"). Instead of *eyepiece used*, enter the *field of view* of your binoculars. You will not be able to measure "seeing" with binoculars, so ignore that entry on the forms. **For suggestions on how to make sketches, see Appendix E.**

## JANUARY OBSERVING LIST

### 1. STAR CLUSTERS

Carefully observe and **sketch** the following three star clusters, **filling out** a standard observing form for **each object**. In your writeup, **compare** the relative size, shape, brilliancy, and color of the clusters:

- (a) Pleiades
- (b) Hyades
- (c) Praesepe (Beehive Cluster)

### 2. THE ORION NEBULA

Carefully observe and **sketch** on a standard observing form the "Great Nebula" in Orion, which surrounds the central star of Orion's "sword." **Note its color and shape** in the

comments. **Comment** on any stars embedded within the nebula. Sweep the binoculars across the nebula to trace its outer regions.

This region is a stellar nursery, containing many young (less than 10 million years old) stars. The Nebula is hot gas, which has been “ionized” by hot (blue-white), recently-formed stars. More stars are presently forming in a dense, cold cloud of molecular gas that lies behind the Nebula from our perspective. The Nebula is streaming off the front surface of this larger cloud. You cannot see this “mother” cloud with ordinary telescopes.

### 3. STAR COLORS

Star colors are a measure of temperature. Hotter stars (over 15000 K) are blue-white, while cooler stars (under 4000 K) are orange-red. Yellow stars have intermediate temperatures. Carefully compare the stars listed below and **rank them by color**, from red through yellow to blue/white. Indicate which star would be coolest and which hottest. You do *not* need to fill out an observing form for these objects.

- (a) Aldebaran
- (b) Procyon
- (c) Rigel
- (d) Betelgeuse
- (e) Capella
- (f) Sirius

### 4. THE MILKY WAY

The Milky Way is the plane of our Galaxy. In January it runs from Cassiopeia through Auriga and on through Canis Major. Since we are looking toward the outer parts of our Galaxy here, this part of the Milky Way is not as bright or conspicuous as that seen in the summer sky.

The mean line of the Milky Way lies about halfway between Betelgeuse and  $\gamma$  Gem. Starting here, sweep the binoculars northeastward toward Ursa Major. **Briefly comment** on how the number of faint stars in the field changes as you move away from the Milky Way. You do *not* need to fill out an observing form or make a sketch.

### 5. THE MOON

If the Moon is in the sky, observe it with the binoculars. **Comment** on the colors you see on the Moon and the number and variety of surface features visible. **Record the phase** of the Moon. You do *not* need to fill out an observing form or make a sketch.

## SEPTEMBER OBSERVING LIST

### 1. THE VEGA STAR FIELD

Vega ( $\alpha$  Lyrae) is the brightest star in the constellation Lyra and is conspicuous in the night sky throughout the summer. Observe the star field around Vega with the binoculars, filling out a standard observing form and **making a careful sketch**. Try to accurately represent the relative brightnesses of stars using dots of different darkness and size. **Mark the directions** to north and east at the edge of the sketch circle.

### 2. STAR COLORS

Star colors are a measure of temperature. Hotter stars (over 15000 K) are blue-white, while cooler stars (under 4000 K) are orange-red. Yellow stars have intermediate temperatures.

Carefully compare the stars listed below and **rank them by color**, from red through yellow, to blue/white. Indicate which star would be coolest and which hottest. You do **not** need to fill out an observing form for these objects.

- (a) Vega
- (b) Altair
- (c) Kochab ( $\beta$  UMi)
- (d) Scheat ( $\beta$  Peg)

### 3. DEEP SKY OBJECTS

Observe **TWO** of the following four objects. Fill out an observing form for each of these, including a careful **sketch**. **Write comments** comparing the appearance of the two objects.

- (a) M13 in Hercules
- (b)  $\eta$  and  $\chi$  Persei (the double cluster)
- (c) M31—the Andromeda Galaxy
- (d) M15 in Pegasus (more difficult)

M13 and M15 are globular star clusters, very dense concentrations of the oldest stars we know (roughly, 13 billion years old). Our galaxy contains several hundred such objects, and these are two of the brightest, consisting of about 100,000 stars each.  $\eta$  and  $\chi$  Persei are a pair of young (about 15 million years) star clusters. They lie in the plane of our Galaxy but in the next spiral arm outside the Sun's. The Andromeda Galaxy is an external star system, but is part of the so-called Local Group of galaxies surrounding our own. It is a spiral galaxy, but its arms are faint and will not be visible in binoculars. It is 2 million light years distant, so the light you see in your binoculars left the galaxy before modern human beings were present on Earth.

### 4. THE MILKY WAY

The Milky Way is the plane of our Galaxy. In autumn it runs from Aquila through Cassiopeia and on past Perseus and Auriga. The center of our Galaxy is in the direction of Sagittarius, but this is too near the horizon for good viewing in September.

Instead, observe the region around the star Deneb ( $\alpha$  Cyg), which is very near the Galactic plane. Use a standard observing form and **sketch** the region. You need not include every faint star in your sketch, but do **estimate** how many individual stars are visible in the field and record that in the "comments" section. In addition, **describe** in a few sentences how the number of stars varies with brightness.

Next, observe a region out of the Galactic plane, around the star Markab ( $\alpha$  Peg). You do **not** need to make a sketch, but again **estimate** the total number of stars.

In your write-up **compare** the two regions.

### 5. THE MOON

If the Moon is in the sky, observe it with the binoculars. **Comment** on the colors you see on the Moon and the number and variety of surface features visible. **Record the phase** of the Moon. You do **not** need to fill out an observing form or make a sketch.

## 2.5 Requirement Checklist

1. Star Colors: ranked with temperature estimate (Fall & Spring)
2. Milky Way: star counts (Fall & Spring), sketch (Fall), and comments on comparison region (Spring)
3. Deep Sky Objects: 2 sketches and comparisons (Fall)
4. Vega Star Field: sketch with directions marked (Fall)
5. Star Clusters: 3 sketches and comparisons (Spring)
6. Orion Nebula: 1 sketch and comments (Spring)
7. Phase of Moon and comments (Fall & Spring if Moon is visible)

For your enjoyment (not as part of the lab requirements), the following pages list some of the most attractive objects for binocular viewing. The stars, planets and brightest star clusters can be seen well even from the city, while the fainter clusters, nebulae, and Milky Way are only at their best in dark, clear country skies.

## BINOCULAR OBJECTS BY CONSTELLATION

### Circumpolar Constellations

Ursa Major	Mizar and Alcor form an attractive, easy double. Galaxies M81 and M82 may be glimpsed on a dark, clear, moonless night but are better seen in a telescope.
Ursa Minor	$\gamma$ and 11 UMi form a wide binocular double. Recall that the four stars in the “pan” of UMi are useful magnitude calibrators (being at mags 2, 3, 4, and 5)
Cassiopeia	$\gamma$ Cas is an irregular variable, varying from 1.6 to 3.0 mag. Many open clusters and star fields can be seen by sweeping slowly through this region.
Cepheus	$\delta$ Cep, the prototype Cepheid variable, can be followed easily in binoculars. $\mu$ Cep, the “Garnet Star”, has a striking color; compare it to nearby $\alpha$ Cep.
Draco	$\nu$ Dra, in the Dragon’s head, can be seen as a pair of equally bright stars.

### Other Constellations (in RA order)

Andromeda	The spiral galaxy M31 is easily located. Using averted vision, sweep your binoculars slowly from side to side and see how far from its center you can trace it.
Triangulum	The spiral galaxy M33 is a large, faint patch between Triangulum and Andromeda. Due to its large size and faintness, it is easier to spot in binoculars than with a telescope. It requires a dark sky to be seen.
Cetus	The variable Mira can be followed in binoculars to below naked-eye visibility. $\chi$ and $\zeta$ form a naked-eye pair, and $\chi$ is also an easy double for binoculars.
Perseus	The double cluster $h$ and $\chi$ presents a fine field in binoculars. The naked-eye eclipsing variable Algol may also be followed in binoculars. $5^\circ$ E of it is the open cluster M34.
Taurus	The Pleiades are more attractive in binoculars than in a telescope. The Hyades fill a binocular field, with Aldebaran providing a striking color contrast.
Auriga	The open star clusters M36, M37, and M38 are readily visible as sparkling patches.

Orion	M42, the Orion Nebula, is easy to find and very impressive in a dark sky. Sweep slowly back and forth to trace its outer extensions. The color difference between Betelgeuse and Rigel is enhanced in binoculars.
Gemini	$\zeta$ Gem varies between 3.7 and 4.5 mag in a 10-day cycle. $\eta$ varies between 3.1 and 3.9 mag in an irregular fashion, averaging 233 days for one cycle. Just NW of $\eta$ is M35, an excellent open cluster for binoculars. The Milky Way passes across the feet of Gemini and this area is covered with faint stars. Compare the colors of Castor and Pollux.
Canis Major	The open cluster M41 can be seen below Sirius.
Cancer	The Praesepe star cluster shows up well in binoculars. Further south, M67 may be visible as a cloudy patch.
Hydra	The head of the Sea-Serpent, below Cancer is a bright open circle of stars in binoculars. NGC 2548 is a large open star cluster which may be found by sweeping westward from Alphard.
Canes Venatici	Observe Y CVn, named “La Superba” for its brilliant color.
Leo and Virgo	These bright spring constellations offer little to binoculars. The galaxies which abound in this region require a moderately large telescope to be seen.
Bootes	$\nu$ Boo, SW of Arcturus, is an easy binocular double. A telescope reveals the fainter star to be a close pair. W Boo is a red irregular variable very near $\varepsilon$ Boo.
Hercules	The Kneeler contains two globular clusters visible in binoculars as bright, fuzzy spots: M13 in the Keystone and M92 N of $\pi$ Her.
Ophiuchus and Serpens	This region is rich in globular clusters bright enough to be seen in binoculars; M5, M10, and M12 are probably the best. U Oph, SW of $\sigma$ , is an eclipsing variable with a 1.7 day period. It varies from 5.8 to 6.5 mag; most of the change takes place in a 5-hour interval and so can be followed in a single evening if one knows in advance when to look.
Libra	Zubenelgenubi is an easy wide double star.
Lyra	$\varepsilon$ Lyr is a wide double star; a telescope reveals each star to also be a close pair. $\delta$ Lyr is another easy double star, one of whose components varies between 4.5 and 6.5 mag irregularly; the other is steady at 5.5. A nice color contrast. $\beta$ is an eclipsing variable which varies over a period of 12.9 days. It is 3.4 mag at maximum light and has two unequal minima, 3.8 and 4.3, over its 13-day cycle.
Cygnus	Albireo, a beautiful double star in small telescopes, may be separated in binoculars if they are held steadily or propped against a tree. The Milky Way runs the length of Cygnus and displays myriads of stars in binoculars. The region around $\gamma$ Cygni is particularly attractive. NGC 7000, the “North America Nebula,” can be seen in a dark, clear sky as a large starry mass E of Deneb. The stars $O^1$ and $O^2$ are a naked eye pair, and $O^2$ is triple in binoculars.

Aquila	$\eta$ Aql is a Cepheid variable, ranging between 3.9 and 5.1 mag over a 7.2 day period. The Milky Way passes through the western half of Aquila.
Scutum	This area is notable for its “star-cloud,” a bright concentration in the Milky Way. The open cluster M11 appears as a smaller bright knot in one corner of this “cloud.”
Scorpius	$\zeta$ Sco is a wide pair with contrasting colors. Just N of it are $\mu^1$ and $\mu^2$ , a naked eye double. The open clusters M6 and M7 can be seen immersed in the Milky Way off the end of the Scorpion’s stinger. The globular cluster M4 can be seen just west of Antares.
Sagittarius	The Archer lies in the direction of the center of our galaxy and is rich in open clusters and glowing gaseous nebula. M8 and M17 are perhaps the best in binoculars, but look also for M20 and M21, in the same field as M8; M16 and M18, near M17; and M23, M24, and M25 in an east-west line between the other two groups of three. Scorpius and Sagittarius, being low in the south, require a clear, dark sky for really good viewing.
Delphinus and Sagitta	These tiny constellations each fit neatly into the field of view of binoculars. Look for M27, the “Dumb-bell Nebula”, as a glowing mass N of $\gamma$ Sag.
Capricornus	$\chi^1$ and $\chi^2$ form a naked-eye double. $\beta$ , just below $\alpha$ , is a binocular double. Both pairs will fit into one field of view. M30 may be glimpsed as a cloudy spot E of 36 and $\zeta$ Cap.
Aquarius	The area of this constellation N of Fomalhaut has many pairs and triples of various colors. The globular cluster M2 may be seen as a bright spot N of $\beta$ Aqr.
Pegasus	$\pi$ and 27 Peg, NW of the Great Square, form a wide binocular double. The globular cluster M15 is visible NW of $\varepsilon$ Peg.

## OBSERVING THE SOLAR SYSTEM

The **Moon** is a fascinating binocular object. Every major feature is visible in seven-power binoculars, and this is a good way to learn your way about the lunar surface before moving to a closer look through the telescope in the Moon Lab.

Binoculars do not have sufficient magnification to show details on the planets but they can make it easy to follow their motion through the sky with respect to the stars. The motions of **Mercury** and **Venus** are readily apparent from day to day. The motions of **Mars** and **Jupiter** may be traced out by plotting their positions from week to week on a star chart. **Asteroids** and the planet **Uranus** can be followed this way also; binoculars are needed to locate them and chart their movements. Jupiter's four brightest moons are visible in binoculars, as are **Saturn's** rings when near their maximum size. The long, filmy tail of a bright **comet** is best seen through binoculars.

**OBSERVING THE SUN WITH BINOCULARS CAN BLIND YOU INSTANTLY AND PERMANENTLY.** Don't do this. Don't even try to project the Sun's image through binoculars onto a piece of paper: the Sun's rays passing through binoculars will melt the cement which holds the prisms and lenses together.



## 3 INTRODUCTION TO SMALL TELESCOPES

### 3.1 Time Estimate

Plan to spend 2 nights working on this lab. Because you will be developing more new skills than in any other lab, this is the most demanding assignment of the semester. Set aside about 2 hours of extra time for prep.

### 3.2 General Description

This lab is intended to familiarize you with the basic operation of small telescopes, as well as provide an introduction to astronomical observation and record-keeping. The basic techniques used here—measuring magnification, seeing, and field-of-view; bore-sighting, faint object searching, and recording visual observations—will be utilized in later observing labs.

Sections 3.5 and 3.6 below give general information on use of the telescopes and observing techniques. **Section 3.7 describes the specific activities for this laboratory.** Section 3.8 describes the telescope alignment procedure necessary for the automatic target acquisition software to work. These are required steps for Lab 4 but are optional for this lab.

Initially, TA's will assist you with the equipment, but by the end of the lab you are expected to be able to prepare a telescope, observe with it, and shut it down *without TA assistance*. (TA's are, however, available to help you transport telescopes to and from storage.) If you work in a group, each person should get enough experience with set-up and operation of the telescope to be able to use one on their own for this and future lab assignments.

### 3.3 Lab Write-up

A **full report** on this lab is required. A general description of the expected format is given in the Appendices. **Sketches made in this lab must be recorded on the standard observing sheets**, unless otherwise noted. Refer to the sample observing sheet (Figure 41) as an example, and read the Appendices for detailed information on how to use these sheets. The introduction, procedure and discussion/conclusion sections should detail your observing technique, summarize your results, and discuss new concepts which you have learned.

### 3.4 Preparation

It is expected that you will be unfamiliar with using telescopes to begin with, and TA's will help with the initial set-up. However, you **must prepare yourself beforehand by doing the following**. Plan to spend two hours on preparation *before* coming to the observatory.

1. **Read Appendices C, D, and E in this manual**, which describe telescope basics, how to write a lab report, and how to use the standard telescope observing forms. This is fundamental information you will need throughout the course.
2. Carefully **read the instructions for this laboratory**.
3. Before going to the Observatory, practice with your sky wheel or other sky atlas until you are able to easily locate the stars to be observed in this lab.

4. *IF YOU ARE OBSERVING IN THE FALL SEMESTER:* Locate the constellation **Delphinus** on your sky wheel. Detailed finding charts are provided in Fig. 3 to help you identify the fainter stars. The moderately bright star in the very northeast corner of Delphinus is known as  $\gamma$  Delphini.  $\gamma$  Delphini is actually a binary star: two stars in orbit around one another.
5. *IF YOU ARE OBSERVING IN THE SPRING SEMESTER:* Locate the constellation **Orion** on your sky wheel, and find the three bright stars which make up Orion's "belt." Detailed finding charts are provided in Fig. 4 to help you identify the fainter stars. Southwest of the easternmost star in the belt is the moderately bright star  $\sigma$  Orionis.  $\sigma$  Ori is actually not one but four stars, all very close to one another. On a typical night only the three brighter stars are visible.
6. **Fill out** the *To Be Completed Before Observing* section of *two* standard observing forms for whichever of these two stars is appropriate and **bring these with you** to the student observatory.
7. **Bring the Manual, your filtered flashlight, and a watch or other device that displays time in seconds to the lab.**

### 3.5 Introduction to the Celestron CPC-800 Telescopes

#### 3.5.1 General Precautions

1. **Do not touch any optical surface for any reason.** Oils from your fingertips can **etch** a fingerprint into the protective coatings on mirrors and lenses. Be especially careful with eyepieces when handling them. Do not attempt to clean or polish eyepieces! If optics are smudged, please bring it to a TA for cleaning.
2. Don't fiddle with screws or adjustments, except to align the finder. If you wish to move the telescope, **use the computerized hand paddle**. If you have any problems with the equipment or find anything missing or damaged, notify the TA's. Do not attempt any repairs yourself.
3. **Avoid touching the finder telescope when moving the telescope.** It can come out of alignment easily, and you will then have to redo the alignment.
4. All knobs and movable parts should move easily. **Do not force pieces** that should be moving but aren't. If something doesn't work right, ask for assistance.
5. When moving around, be careful not to bump into your own or someone else's telescope.
6. The Celestron telescopes are heavy enough that **two people are always needed when moving them into or out of storage**. Be careful not to bump them while moving, as this may misalign the optics.
7. Do **ask the TA's** if you aren't sure about something. Sometimes several people need the TA's at once; **please be patient**.
8. Always treat the telescope with respect and care. Remember, these are expensive precision instruments and can be damaged easily.
9. Don't rush. Plan to take your time doing the lab.

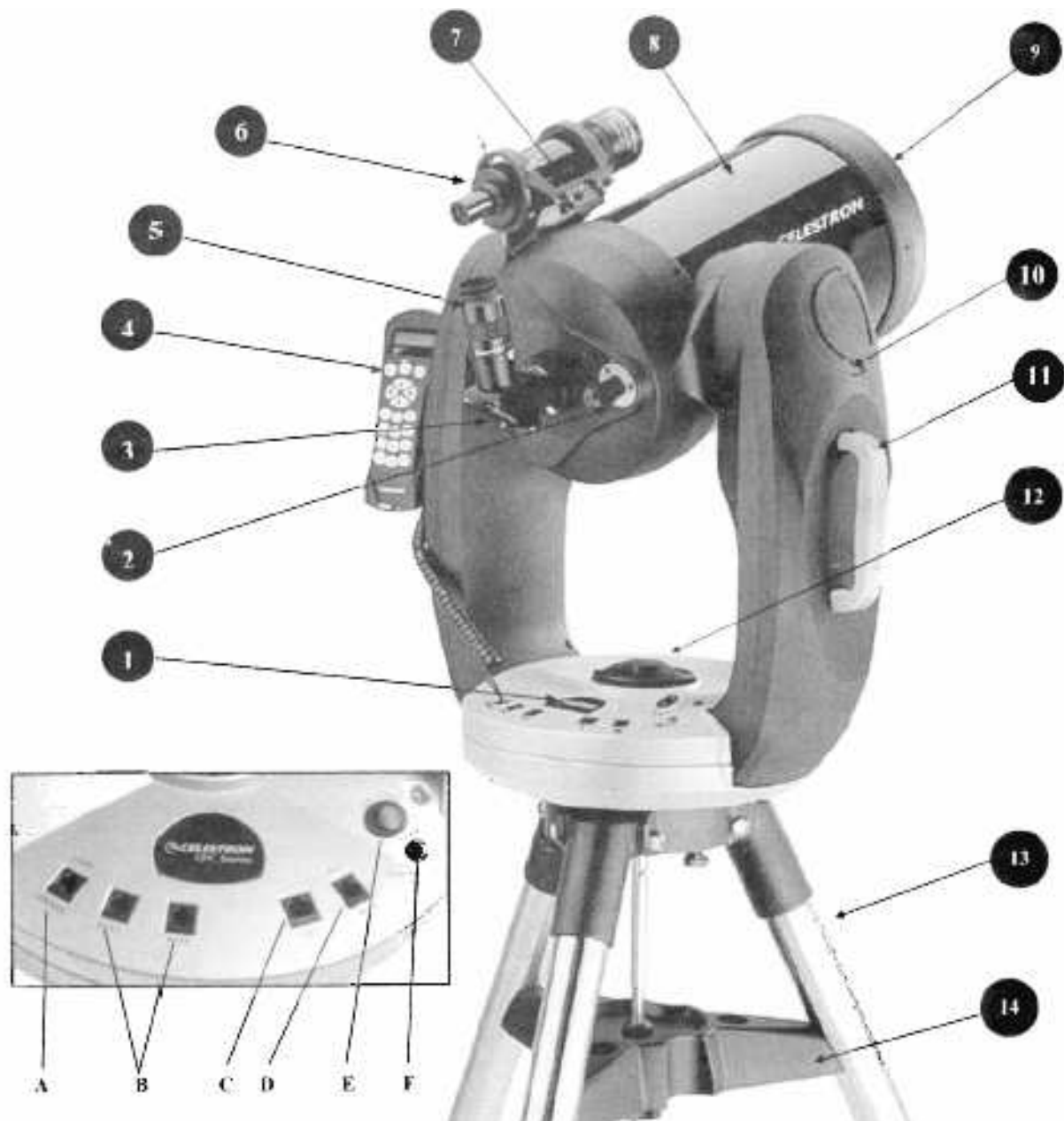


Figure 1: The Celestron CPC-800 Schmidt Cassegrain Telescope. (2) Focusing Knob; (3) Star Diagonal; (4) Hand Control; (5) Eyepiece; (6) Finder Scope; (8) Optical Tube; (9) Lens Cap Cover; (10) Fork Arm; (11) Carrying Handle; (12) Right Ascension Locking Knob; (A) Hand Control Port; (E) Power Switch; (F) 12v Input Jack. The altitude/DEC axis clamp is located at the top of the left fork arm (not shown).

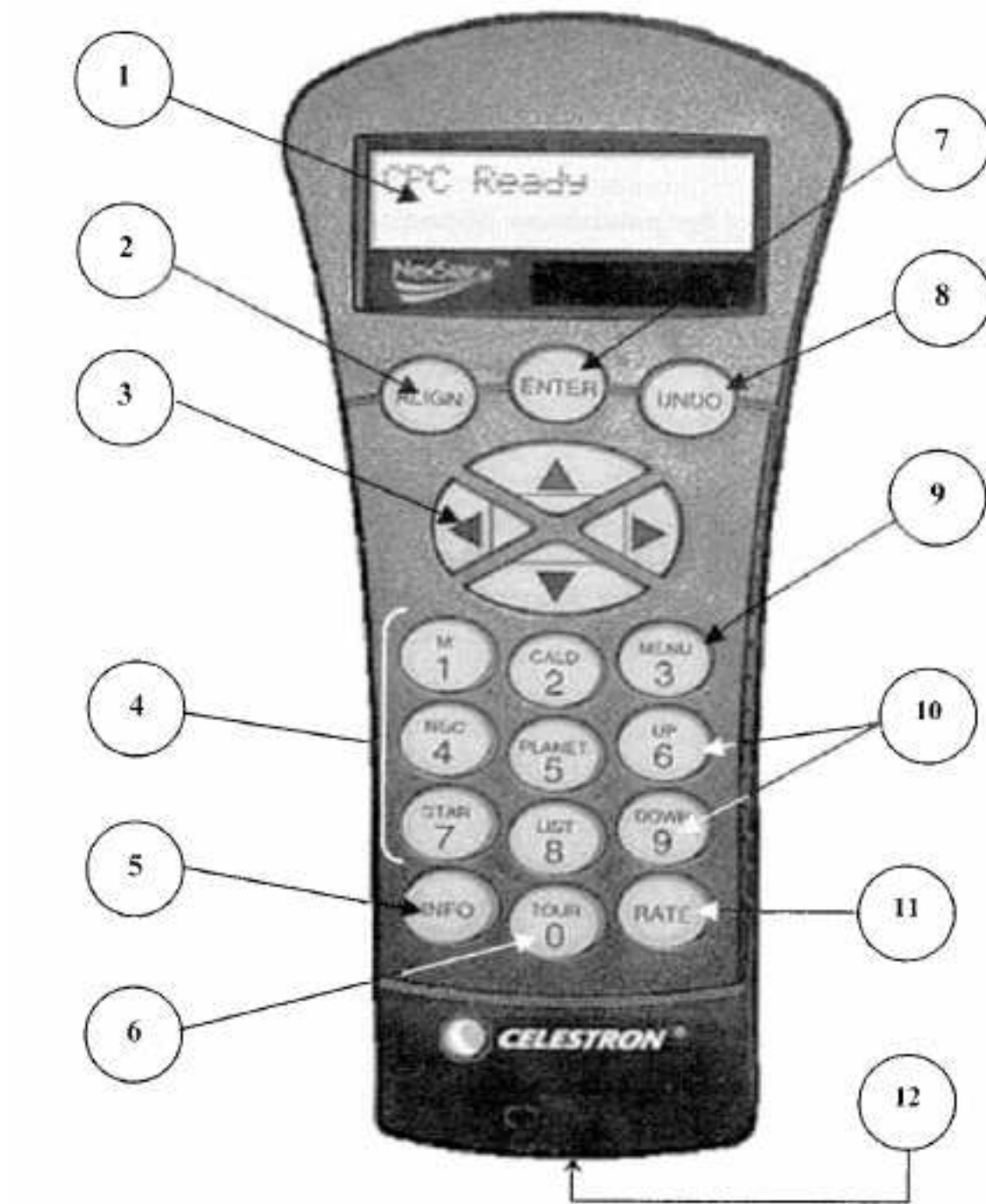


Figure 2: The Celestron CPC-800 Hand Control Unit. (1) LCD data window; (2) Align button; (3) Directional motion keys; (4) Catalog buttons; (5) Info button for database objects; (6) Tour mode; (7) Enter button; (8) Undo button; (9) Menu button; (10) Menu scroll buttons; (11) Rate set button; (12) RS-232 Jack

### 3.5.2 Parts of the Telescope

The telescope is illustrated in Figure 1. The Celestron CPC-800 is an 8-in Schmidt-Cassegrain telescope. Its primary optical element is an 8-in diameter mirror, but it uses a refractive corrector at the front of the telescope tube to improve image quality. A secondary mirror reflects light from the primary back through a small hole in the primary to the eyepiece. This is a “catadioptric” optical design. See Appendix C for more information on the basic features of telescopes and a drawing of this design.

The CPC has a sophisticated computerized command and control system. Only a few of the most frequently used modes are described in this manual. For a complete description, see the CPC manuals kept on reserve in the Student Observatory Office.

The CPC can be mounted in either an Altitude-Azimuth or Equatorial configuration. We will be using an equatorial mount throughout this course.

#### The Control Panel:

The control panel on the base of the telescope (1) consists of a series of ports for the Hand Control Unit and other electronic accessories, the on/off switch for telescope electrical power, and a port for the 12v power jack.

#### RA and DEC Locks:

Two locking knobs serve to clamp the telescope so it stays pointed at the same declination while the motor drive moves it westward during an observation. The RA lock (12) is a large knob in the middle of the base of the telescope. The declination lock (not shown) is a similar knob located on the left-hand side, by the finder. If the knobs are not clamped, the telescope can be moved easily on both axes by hand. This is the only way to point the telescope if it is not powered.

During regular observations, both locks should be tightened firmly, but not excessively, to clamp the telescope to its two axes.

#### The Hand Control Unit (“Paddle”):

The CPC telescopes are computer-controlled and contain a built-in Global Positioning System receiver to determine the location on Earth’s surface and the sidereal time. When these are known, the telescopes can point automatically (“**auto-find**”) to any bright target or location in the sky with good precision. The computer database contains large lists of brighter astronomical targets.

Your telescope will also “**track**” objects in the sky by slowly rotating about its polar axis at the “sidereal rate.” Once a target is centered in either the finder scope or the main scope, the tracking motor can keep it centered for a long period of time.

However, **neither the auto-find nor tracking functions will operate until you have performed a special alignment procedure, which is described in Section 3.8.**

Computerized functions are accessed by the Hand Control Unit (see Figure 2), which will be called the “paddle” below. This contains an LCD display; a numeric keypad; four directional keys (with large arrows); and special buttons for Align, Enter, Undo, Info, and Rate.

With the axis locks clamped and the power on, **you can move the telescope with the four directional keys** as follows: Up Arrow = North, Down Arrow = South, Left Arrow = East, Right Arrow = West. These functions do not require the alignment procedure.

To manually point the telescope at an object, you can “slew” it at a fast rate across the sky by pressing the directional keys. The slew rate can be varied from a very fast 3° per second to a very

slow “guiding” rate. Locate targets using a fast slew rate, center them in the telescope field using an intermediate rate, and then make small corrections to keep them centered during an observation using a guiding rate.

**To adjust the drive rates**, press the “Rate” button. The LCD will show the current rate (9 - the “slew” rate - is the default setting after the telescope has been turned on). Select a different rate by pressing one of the buttons labeled 1-9. Lower numbers correspond to slower rates. (Note: with the six slower rates, intended for adjustments while you are looking through the main telescope eyepiece, the sense of the N/S motion of the motors is **reversed** from that of the 3 fastest rates, so that the Up Arrow moves South and the Down Arrow moves North.)

### 3.5.3 Setting up the Telescope

First, check out a telescope and accessories from the TA’s. Sign the check-out log. Carry the equipment outside to the observing area with the assistance of a partner or the TA. **Do not carry the telescope by the optical tube or the finder scope.** Carry it instead by the handle on the fork or the wedge. Be sure to match the telescope with its corresponding pier (A through H).

Place the telescope so that the bolt on the pier goes through the hole in the center of the wedge and loosely tighten the wedge knob. **Rotate the entire assembly** until the pin attached to the bottom of the wedge can be placed through the hole in the wedge and through the second smaller hole in the top of the pier below the wedge. This ensures that the telescope is properly aligned with north in azimuth. Then **tighten the wedge knob firmly**. This knob stays tightened until the end of the observing session.

With the mounting bolted to the pier; **remove the lens caps from the scope and the finder** and store them where they cannot be stepped on. **Plug in the hand paddle. Plug in the power supply, and turn the power on.** The red light should be on, but the scope will not be aligned yet.

Next, **tighten the RA and DEC locks** firmly but not excessively. Do not unclamp them during your observing session.

Always **start with the lowest power (longest focal length) eyepiece**. Insert the eyepiece into the eyepiece holder and **tighten the set screw** on the side of the barrel.

For your first encounter with the telescopes, practice moving the telescope using the paddle directional controls and practice changing the motor drive rate.

**Finder adjustment: Always begin an observing session by checking the finder telescope alignment.** Point the telescope at a bright star or planet, the Moon, or a bright terrestrial source (e.g. a streetlamp). Center the object in the finder. Then look through the eyepiece. If the object does not also appear in the eyepiece or is seriously off center, the telescope and finder **must be realigned**. You should practice doing this for yourself, although the TA’s will help if you have trouble. The finder is held in place by a pair of screws set against springs. The screws form a right angle. To move the finder, adjust the screws slowly. Only small adjustments are usually needed but often in more than one direction. If the finder is far out of adjustment, you may need to sight along its tube to help with the alignment. Check the focus of the finder as well.

Although it is tempting to use it as a hand-hold, **NEVER TOUCH THE FINDER ONCE IT IS ALIGNED**. That is the quickest way to misalign it.

Once you have a bright celestial object in the main telescope, focus the main eyepiece using the knob next to the eyepiece.

### 3.5.4 Manual Methods for Finding Objects

Without relying on the auto-finding features of the telescopes, you can use several manual methods for locating objects in the sky, depending on their brightness. Start by locating the object on a star map and compare the map with the sky. Find the constellation it is in and the bright stars nearby, so you know where to look. **Always use the lowest power eyepiece** when searching for objects. Be sure the finder is aligned with the main telescope and that the telescope is in focus.

Whenever you have trouble locating objects, refer to the *Checklist for Finding Objects* at the end of this lab.

#### Bore-Sighting:

For bright objects that can be seen with the naked eye, you can use the simplest technique, which is bore-sighting. To find an object in the telescope, first locate its position on the sky. (You might want to find the object in binoculars first.) Set the hand paddle to the highest speed by **pressing the RATE key and then the 9 key**. Then slew the telescope toward the target's position and simply sight along the barrel of the scope or finder as you would with a rifle. This is known as bore-sighting. Because the telescope tube is relatively short, be careful that your eye is immediately adjacent to the tube and that you are looking parallel to the optical axis. It is easier to do this with both eyes open, though that takes a bit of practice. Adjust until you find the object in the finder telescope, then center it. You may want to decrease the slew speed when you get close to make centering easier. Be careful not to bump or move the finder while you are using it.

(Even with the auto-finding facility, you will have to undertake the rest of this procedure for new targets.) Place the object on the cross-hairs in the finder. Then look in the main eyepiece; if the finder scope is properly aligned, the object should be close to the center of the eyepiece field. Center as carefully as possible (probably using a slow slew rate). Now change to a higher magnification (shorter focal length) eyepiece if this is appropriate. Loosen the set screw on the eyepiece holder and remove the eyepiece. Remember to tighten the set screw when you have put the new eyepiece in. You will need to **refocus after changing eyepieces**.

#### Star-Hopping:

For fainter objects, you can **offset from a naked-eye star** to your target using the finder to "hop" from star to star. Several "hops," each consisting of one finder field width, may be necessary. This method is especially useful if your target is close to bright stars or easily recognized star patterns. You will need a good star atlas or a **finding chart** (diagram of the stars in the vicinity of the object). For example, suppose you wish to observe the planetary nebula NGC 2392 in Gemini ( $7^h25^m, +21^\circ$ ). A star map, such as in Norton's or Edmund's, shows it to be off to one side of a cross-shaped star pattern extending southeast from  $\delta$  Gemini. You could begin by centering on bright  $\zeta$  Gem. You would then move northeast to  $\delta$  Gem, then offset again using the star pattern as a guide. Since NGC 2392 looks like a star at low power, using a finding chart is the only sure way of identifying it.

*One axis slewing:* Many students have found this method particularly helpful. If you are careful to **move the telescope in only one axis**, it will sweep along lines of either constant Right Ascension or constant Declination. You can use this technique to locate a faint object. First find a bright star which lies on the same line of right ascension or declination as the desired target in your star atlas. Bore-sight the telescope at the bright star and center it in the telescope field. Then carefully sweep the telescope in the one axis through the appropriate angle to the target. This can be done with either the finder or the main telescope, depending on how bright the target is. You will need to know how large an area of sky is visible through the finder or telescope in order to measure the angle through which it swings. For example, to find the open cluster M10 in Ophiuchus ( $16^h55^m, -4^\circ$ ) you could center the telescope on  $\epsilon$  Oph, then swing about  $9^\circ$  east by

rotating the polar axis. In cases where there are no bright stars with coordinates in common with your target, you can make an offset hop, as described above, before using the one-axis slew.

### Using RA and DEC Coordinates:

Once the telescope has been properly aligned using the technique described in section 3.8 below, you can point it to any given pair of RA, DEC coordinates in the sky by using the *Goto RA-DEC* command on the main menu and entering the values manually using the numeric keypad. To display the coordinates where the telescope is currently pointing, press the "Info" button.

### 3.5.5 Automated Methods for Finding Objects

In addition to the "manual" methods of locating objects discussed above, the CPC telescopes can be used in an "auto-finding" mode. They employ an internal GPS receiver to obtain time/site information and to construct an accurate instantaneous model of the sky. After a special alignment procedure is performed, you can use the onboard object database for computer-controlled object finding and centering in the telescope field of view.

#### Aligning the Telescope for Automated Finding:

With the telescope and equatorial wedge configuration mounted on the pier using the instructions given earlier in this section (see §3.5.3), the telescope is in what is called the **EQ North Alignment** configuration. For this telescope + wedge setup, the alignment procedure that we will use is called **EQ AutoAlign, which is described in Section 3.8 of this lab**. (You will try this procedure at the end of the lab, but otherwise you will only use manual target finding methods in the lab.)

Before attempting alignment, **first verify with your TA** that you have properly set up the telescope on the pier using the instructions in §3.5.3, then return to this section after performing the alignment calibration procedure given in Section 3.8. (Note: Do not unlock the RA/DEC clamps on the telescope for this section. Doing so will require you to repeat the alignment procedure.)

Once the alignment has been completed, you can use the auto-find procedure to find brighter objects, as described in the next section. However, you can also use the manual methods described earlier, the difference being that the telescope will now track the target once you have it centered in the telescope.

#### Selecting an Object for Automated Finding:

Once the telescope is aligned, it will be able to locate objects in the sky and track them as the celestial sphere rotates. You can choose among a large number of objects stored in the CPC's onboard database and command the telescope to point to your choice. This is not only a great convenience but also can help compensate for the challenges associated with locating faint objects in light-polluted skies.

Before trying faint objects, it is a good idea to double check the telescope alignment by using the "Named Stars" list to locate and center a currently-visible bright star in the same part of the sky as your first faint target.

**Stored Catalogs.** The hand control paddle has six special keys, each dedicated to accessing a different catalog of available objects. You have the option of either scrolling through the lists of objects or keying in specific object numbers. Press the LIST key (see Figure 2) to access all of the database objects that have common names — these lists are divided into the groups "Named Stars," "Named Object," "Double Stars," "Variable Stars," "Asterisms," and "CCD Objects." Selecting any one of these categories will allow you to scroll through the alphabetical object lists using the



UP and DOWN arrow keys on the hand paddle. (Hold the keys down to scroll more rapidly.)

Pressing any of the four catalog keys (M, CALD, NGC, or STAR) will allow you to enter a specific object number within the selected catalog. You will see a blinking cursor below the name of the catalog you selected. Then enter the number of the object of interest.

Example: Press the M key to find objects in the Messier catalog. If you are observing in the Fall, key in the numbers “013” for the Hercules globular cluster. If you are observing in the Spring, key in the numbers “042” for the Orion Nebula. If you press the INFO key, you will see useful object information (e.g., RA/DEC coordinates, text information/description, and magnitude).

Example: The STAR key accesses a list of brighter stars extracted from the *Smithsonian Astrophysical Observatory* star catalog. To point the telescope at an SAO star, you must enter the **first four digits** of the star’s six-digit number. Fill in leading blanks with zeros: e.g. to go to SAO 5000 you would enter 0050. The display will then show you the set of stars in the catalog starting with these four digits. Scroll to the one you want.

To find any of the brighter solar system objects that are currently visible from your location, press the PLANET key and scroll through the list.

Once you have found the object of interest, press ENTER, and the telescope will slew to it.

**WARNING: Do not press the ENTER key while someone is touching or looking through the telescope. The movement of the telescope can be rapid enough to cause injury or to damage the telescope if its motion is obstructed. Be sure all hands and any loose clothing are clear of the telescope supports before proceeding.**

If you have selected an object that is currently below your horizon, the CPC telescope will know this and give you a message indicating that the object is beyond your slew limits. If this happens, press the UNDO button to go back and key in a different object.

**Note:** Although you will hear the drives running and see the telescope movement to find your object, the final centering in the field of view requires slower drive speeds and the telescope movement will be less visible. **Be sure to wait until an audible “beep” is heard that indicates the object find procedure is complete before proceeding to touch or look through the eyepiece..** Your object should be very near the center of the field of view. If you cannot find your object in the eyepiece, you may need to perform the alignment procedure again. Ask your TA for assistance if you can’t find a target after two attempts.

### 3.5.6 Closing Down

Put the eyepieces back in their box. Be careful not to touch the lenses. Replace the lens caps and return the telescope to its stow position. Clamp both axes. Unplug the power cord and paddle. Return the binoculars, eyepiece box and any other accessories to the proper cabinet. With a partner or TA to help, unbolt the wedge from the pier, being careful to support the telescope. Return the scope to its cabinet. Sign the log sheet.

## 3.6 Suggestions on General Observing Technique

There are a number of tricks that make observing easier. The first concerns **dark adaptation**. It takes several minutes for your eyes to adjust to the dark when you go outside at night. Your dark vision should continue to improve for about 30 minutes. If you expose your eyes to bright lights, you will have to start over again. The more dark-adapted you are, the better you can see faint objects. For these reasons, **turn off any lights** near the telescope or mask them with paper. Red

light is much less harmful to your night vision than white light. A flashlight with a red filter is essential for consulting writeups or starcharts, changing eyepieces, etc.

Your eye has to be **centered on the light beam emerging from the eyepiece** in order to see everything. Learn to move your head around slowly until you locate the optical axis of the telescope. Don't press your head against the eyepiece. To help center your eye, hold the edge of the eyepiece gently between your thumb and forefinger and rest your head on them. Even under dark sky conditions, you should be able to see the circle corresponding to the edges of the eyepiece field of view. Move your head until you do.

It is easier on the eyes to **observe with both eyes open**. If you are distracted by light in the "free" eye, cover it with one hand or get an eyepatch. "Yo ho ho and a bottle o' rum!"

When observing faint objects, you can see more if you look to one side of an object instead of directly at it. This is because the very center of the retina (the fovea) is slightly less sensitive than the surrounding parts. Try looking to one side, or moving your eyes back and forth, while concentrating your attention on the location of the target. This technique is called **averted vision**.

You must **refocus** when you change eyepieces or if your eyes get tired. For diffuse objects like gaseous nebulae, focus on a nearby star to get the sharpest image. If you wear glasses, you may wear them or not as you choose, but it is better to keep them on when observing with a group to avoid having to refocus between observers. Be careful not to bump the eyepiece with them.

The state of the sky is of course very important. There are three principal factors that govern the quality of the night.

1. Sky clarity or **transparency**. For example, clouds or haze will prevent observing faint objects such as galaxies or nebulae. One way of estimating transparency is to determine the magnitude of the faintest star visible to the naked eye, using your sky atlas. E.g. refer to the four stars in the pan of the Little Dipper, which have magnitudes of 2,3,4,5.
2. Sky brightness resulting from **scattered light**. For example, a full moon, street or city lights can be scattered from the sky itself, so that faint objects are difficult to see against the bright background (this same effect prevents us from viewing stars in the daytime). This is a major problem at the Student Observatory.
3. **Turbulence** in the atmosphere caused by wind or temperature inhomogeneities. Because the atmosphere is an optically-active (refractive) medium, any motions affect the path of light rays through it, in the same way that images waver in the hot air rising over a radiator or hot asphalt. In a telescope, the effects of turbulence appear as motions or blurring of sharply-focused star images. Greater turbulence produces a larger or more rapidly moving image. Turbulence can have a very deleterious effect on telescopic observations. Close double stars or planetary features, for example, are difficult to observe if the image is fuzzy or dancing. These effects are called "**seeing**." Astronomers estimate seeing quantitatively by measuring the **diameter** of star images in seconds of arc. Depending on conditions and location, the seeing can be as little as 0.5 arcsec or as large as 15 arcsec. Winter skies are frequently clear but turbulent due to the passage of cold fronts. Hazy nights sometimes have excellent seeing and may be good nights to observe the Moon, planets, and double stars. Nights on which the stars overhead have a pronounced "twinkle" are likely to have poor seeing. However, even on a night with poor seeing, small windows of good seeing that last for up to a few seconds may pass through your field of view, so be patient.

**Low power eyepieces are the easiest to use.** They view the largest area of the sky, so it is easier to find things or to recover them if the telescope is bumped. They usually give the most satisfactory views of star clusters, diffuse nebulae, and other extended objects, especially if

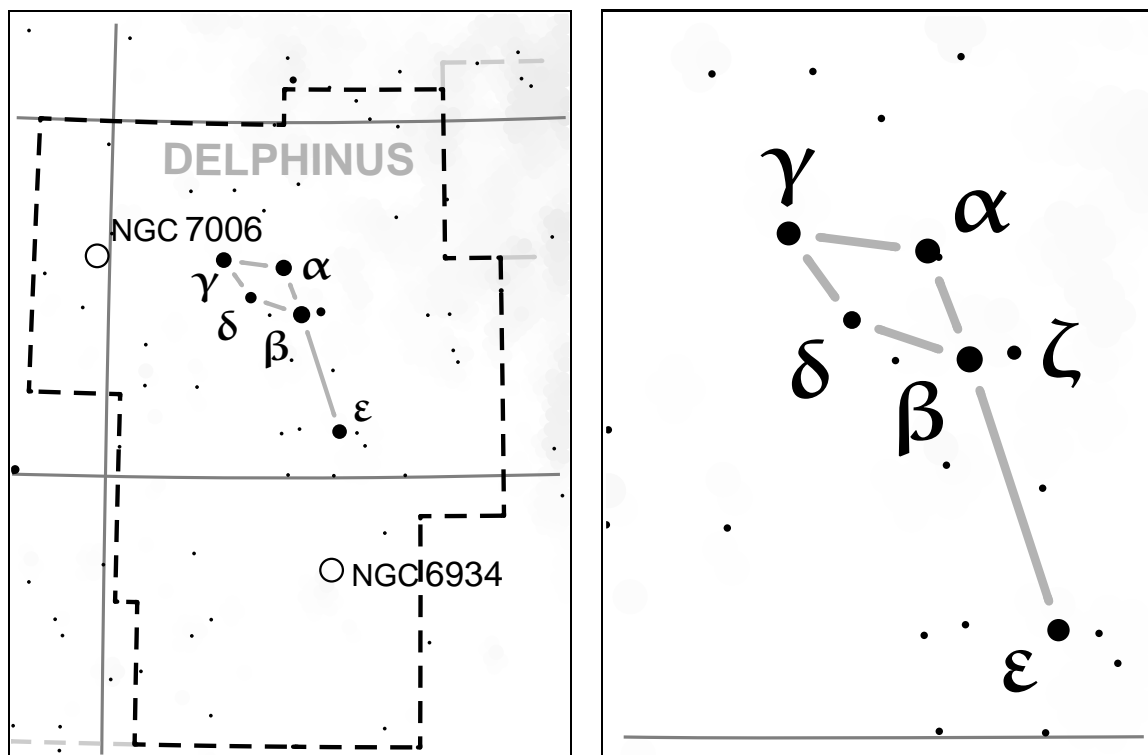


Figure 3: Delphinus for Fall observing. In the above charts, North is toward the top of the page, and East is toward the left of the page.

the seeing is poor. High powers are necessary only for observing the Moon, planets, or close double stars, and are only useful on nights with good seeing.

A major difficulty with smaller, lightweight telescopes is **vibration**. They may shake if bumped or if the wind is blowing, and the effect is greatly magnified when looking through the eyepiece. Move carefully when working around the telescope, be careful when changing eyepieces, and shield the instrument from the wind if possible.

### 3.7 Laboratory Procedure

First, prepare for the lab as described in §3.4 above. Check out a telescope from the TA on duty and make certain that you know how to set it up properly. Steps in performing the lab are numbered sequentially in the following subsections. Each student is expected to do each part of the lab, regardless of the size of the group. Take your time, and be careful and thorough.

In this lab, all objects will be found through **manual** pointing of the telescope. Only at the end, as a prelude to Lab 4, will you practice the alignment and auto-find procedures.

#### A. Practice Finding Bright Stars

First, you must become comfortable with “bore-sighting” to find bright stars. Read the description in §3.5.4 above.

Turn on the telescope power. If it is already on, turn it off for a few seconds, and then turn it back on.

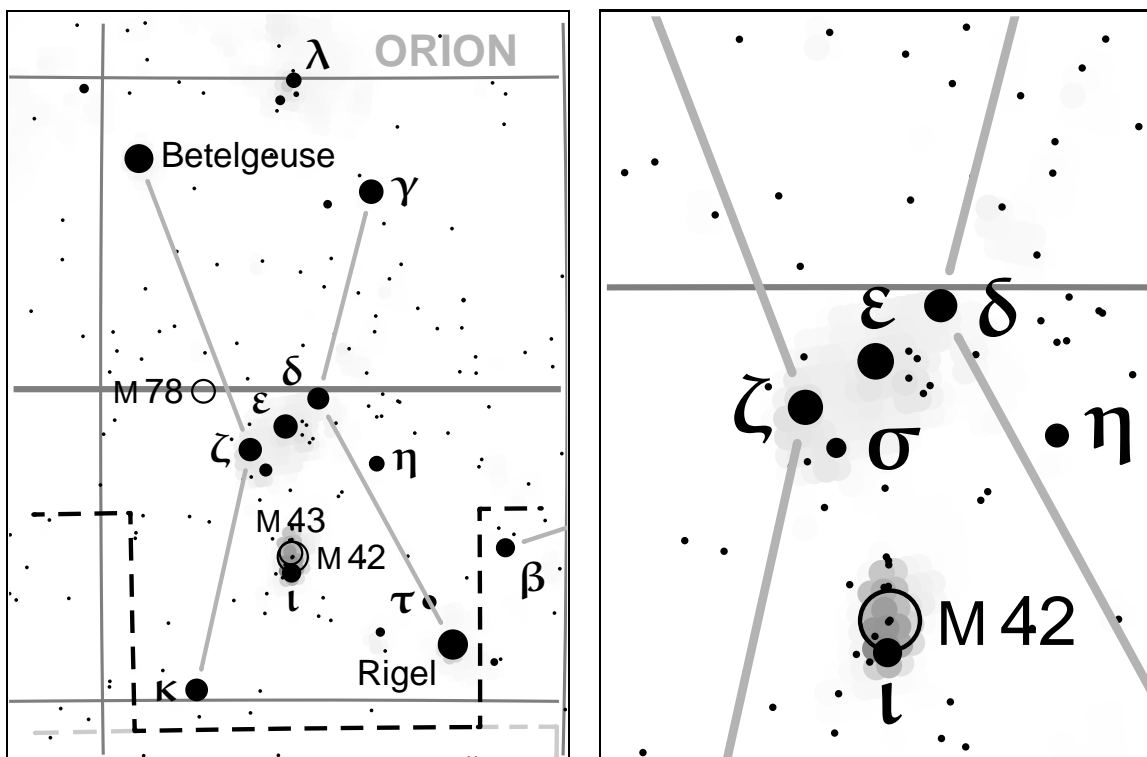


Figure 4: Orion for Spring observing. In the above charts, North is toward the top of the page, and East is toward the left of the page.

1. Choose a bright star that is well above the horizon but is *not* overhead or near the North Pole (where maneuvering the telescope is more difficult).
2. Place the lowest power eyepiece (longest focal length) you have into the eyepiece holder and tighten the setscrew to hold it in place.
3. Bore-sight the telescope on the star, as described in Sec. 3.5.4. It may help to have a second person sighting along the telescope tube from behind the scope. Check your pointing by looking in the finder telescope. If the star is not on or near the crosshairs, re-center it using the hand paddle while looking through the finder. Adjust the slew rate as necessary, but **do not attempt to move the telescope by unclamping the RA or DEC axes.**
4. Now look in the eyepiece. The star should be centered in the field of view. If the star image is not sharp, focus the eyepiece. (If the telescope is far out of focus, you would see only a large diffuse patch of light, often in the shape of a donut.) If the star is centered in the eyepiece but it does not lie on the crosshairs, your finder is out of alignment, and you should follow the re-alignment procedure described in Sec 3.5.3. If you have trouble with this, ask the TA's for help. **It is important that you check finder alignment every time you start observing.**
5. Each member of your group should practice bore-sighting and checking alignment. **Describe** your method for this and all other sections in the "Procedure" section of your writeup.

#### B. Field Orientation

When you feel comfortable with the operation of the telescope, do the following to familiarize yourself with directions as they appear in the eyepiece field. The *orientation* in which the

field appears in the eyepiece (i.e. the directions to north, south, east, west) depends on the number and kind of optical elements between the stars and your eye. If you use the diagonal prism with the eyepiece (which is normal on the Celestron telescopes), the field orientation will change if you rotate the prism. This can be very confusing to beginning observers.

Because your sketches must always have the field orientation correctly identified, there is a standard procedure for determining the north/south and east/west directions in the field.

First, set on a bright star, as in part A.

6. For this part, only use the keys that correspond to north and south. [Note: the north/south direction in the sky where you are pointing is *always* on a line passing through Polaris.]
7. Look through the eyepiece while you move the telescope only in DEC. **If you move the telescope north (towards Polaris), the stars in the field will appear to move south and vice versa.** Note which direction is north in the eyepiece field. Warning: Remember that the sense of motion for the Up/Down buttons changes for rates 1-6. The Up button moves the scope North for rates 7-9 but South for rates 1-6.
8. Center the star in the eyepiece field. Because the telescope is not tracking the stars, they will be seen to drift across the field. Stars will move **from east to west**. Note which direction is east.
9. Use these techniques with the eyepiece alone, the eyepiece with the elbow prism, and the finder telescope. (Remember that you will need to refocus the telescope when you add or remove the elbow prism.) On a separate sheet of blank paper, **draw three circles labelled with the cardinal directions (N,S,E,W)** for:
  - a. the view directly through the eyepiece,
  - b. the view through the elbow and eyepiece, and
  - c. the view through the finder scope.
10. **Comment** on any differences in the relative orientations of the N, S, E, and W points, i.e. the sequence in a clockwise sense. Hand in the drawings and comments with your writeup. Note that you do **not** have to sketch the star field for this part of the lab.

Use this technique for all telescopic observations and **be sure to label all sketches you turn in for this class with N, S, E, & W as seen through the eyepiece.** Warning: the relative orientation of the finder and eyepiece fields will change if you rotate the right angle eyepiece adaptor. Be sure you check the orientation each time you make a sketch.

### C. Sketch Through Binoculars

Now use binoculars to observe the  $\gamma$  Delphini (Fall semester) or  $\sigma$  Orionis (Spring semester) field. These fields are described in §3.4 above. Locate them based on the “Before Observing” section of the standard observing form you prepared before coming to lab.

If you have already performed the Introduction to Binoculars Lab, you will be familiar with binocular use. If not, first adjust the separation between the two barrels of the binocular until you can comfortably look through both simultaneously. Now focus the binoculars. There is usually some arrangement allowing each eyepiece to be focused separately. Most commonly, a knob on the pivot pin moves both eyepieces in and out together, while the right eyepiece can also be dialed in and out in its individual mounting. To focus with this arrangement, **close the right eye** and focus with the **knob** for the left eye; then **close the left eye** and **adjust the right eyepiece** for sharp focus with the right eye. Double check to be sure the stars are in sharp focus through both barrels. (If you focus on a nearby object, e.g. a streetlamp, you will have to refocus with the knob for the stars.)

11. Take one of your prepared observing forms and, in the circle representing the field of view, **carefully and accurately sketch** what you see through the binoculars. **See Appendix E for suggestions on how to make sketches.** Note on your sketch which star(s) make up the  $\gamma$  Delphini/ $\sigma$  Orionis system. Label N, S, E, W directions on the sketch by judging the direction to Polaris (N) and the direction of diurnal motion (W, perpendicular to N). Insert “not applicable” where the estimate of *seeing* belongs, and put the field of view of your binoculars in the space indicated for *eyepiece used*.

Your sketch will be graded on how accurately it represents the view you see. Note how many stars not visible to the naked eye are visible through the binoculars, and comment on this on your observing form. Make certain that you have a feel for the patterns these stars form, so that you recognize the patterns again when using the telescope.

*Before going on to the next task, let a TA examine your completed observing form and initial it.*

#### D. Sketch Through the Telescope

12. Using the *Checklist for Finding Objects*, find  $\gamma$  Delphini/ $\sigma$  Orionis in the finder scope, and center it. Compare the size of the field of view in the finder to that in the binoculars. Which is the larger field? Use a 32mm (or other moderate power) eyepiece and center  $\gamma$  Delphini/ $\sigma$  Orionis in the eyepiece field. (After changing eyepieces, be certain that you tighten the setscrew holding the eyepiece in place.) If the star is not in the field, refer to the *Checklist for Finding Objects*.
13. Using the second prepared observing form, **sketch** the field around  $\gamma$  Delphini/ $\sigma$  Orionis as seen through the telescope eyepiece. Fill out the form as shown in Appendix E, inserting “not applicable” where the estimate of *seeing* belongs (since seeing estimation will be covered below). Label the N, S, E, W directions as described in 3.7b.  
[Re-center the object if it has drifted. Since you have not aligned the telescope yet, it will not properly track.]
14. Change to a 15mm (or other higher power) eyepiece, refocus and recenter  $\gamma$  Delphini/ $\sigma$  Orionis. You do not need to make another sketch, but **note the differences** between the views with the two eyepieces in the *comments* space on the form used for the moderate power sketch.

#### E. Measuring the “Seeing”

“Seeing” is the blurring effect of *turbulence* in the Earth’s atmosphere (see description in Sec. 3.6). Astronomers assess it quantitatively by **measuring the apparent diameter of a star image** in seconds of arc; and they normally use the word *seeing* to refer to this diameter.

Here, we use close double stars to measure the seeing because the separation of the stars provides a ready-made angular scale.

*If you are observing in the FALL SEMESTER:* Use the double star  $\gamma$  Delphini. The distance between the centers of the two stars in  $\gamma$  Delphini is about 10 arcsec.

*If you are observing in the SPRING SEMESTER:* Use the bright star Mizar ( $\zeta$  Ursa Majoris) in the handle of the “Big Dipper.” (Note: equatorially-mounted telescopes are awkward to handle when pointing close to the pole. Be patient in locating Mizar.) With binoculars (or even without them, if you have good eyesight) you can see a fainter companion star named Alcor. Alcor is unrelated to Mizar and is 12 arcminutes away. This pair is not suitable for seeing measurements. However, Mizar itself is a double star: it has a fourth magnitude companion visible only with a telescope. The distance between these two stars is about 15 arcsec.

Alternatives:  $\eta$  Cass, with 10 arcsec separation;  $\beta$  Cygni (Albireo), with 35 arcsec separation; 61 Cygni, with 30 arcsec separation.

Follow this procedure for seeing measurement:

15. Center the telescope on the double star and switch to a high power (15 mm or so) eyepiece. Focus carefully.
16. Estimate the **number of star diameters which could fit between the centers of the two stars** in the pair. **Record this.** (Refer to Figure 5.) In your writeup, use the known separation between the pair to **convert** your number to a seeing disk diameter in arcsec.
17. Carefully watch the star for at least two minutes. **Make notes** on the stability of the images: i.e. changes in the apparent diameters or separation between the two stars. In general, you should expect that changes will be more apparent if the seeing diameter is larger.

It is important to **monitor the seeing every night you observe**, since it determines the image quality potentially obtainable. Measure it once or twice during the night, and record the seeing disk diameter on each observing sheet.  $\gamma$  Delphini and Mizar are easy candidates for this purpose, but any other close binary pair with known separation would also work (see Lab 4 for a list).

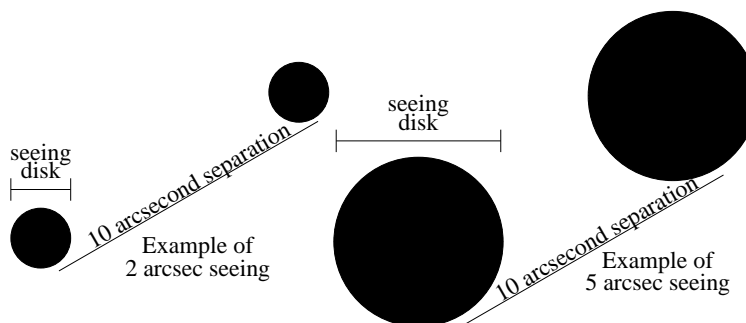


Figure 5: Examples of 2 arcsecond seeing (left) and of 5 arcsec seeing (right). Approximately 5 stellar disks can be fit between the star centers in the left pair while only 2 disks can be fit between the right pair.

## F. Measuring the Field of View

18. Find a relatively bright star near the celestial equator (Altair is a good choice in the fall;  $\delta$  Ori in the spring). Center it in the finder and, using the lowest power eyepiece, check that it is in the main telescope field and centered.
19. Switch to a medium power eyepiece (e.g. 15 mm or 20 mm), and center the star exactly. You may want to do this by strongly defocusing the image until it becomes a huge donut that fills the eyepiece field. The blob of light will be easy to center. Then refocus the star.
20. Note in which direction the star drifts. Remember that stars will drift **west**.
21. Using a slow slew rate, carefully move the star to the far **eastern** edge of the field. You want to place it such that its drift will carry it across the **full diameter of the field of view**. Now **record the time** it takes the star to drift across the entire field of view (in seconds). **Repeat** this measurement three times and fill out a data table like the one below. Be sure to **record the focal length** of the eyepiece you are using.

	1st Try	2nd Try	3rd Try	4th Try
Center star				

22. There are two obvious sources of error in this method. First, you may not catch the start or finish of the crossing exactly. Second, the star may not be centered in the field. The best way to estimate the size of such errors is to **repeat the process from scratch**. Carefully move the telescope randomly in both DEC and RA; then move the telescope back to the star, defocus and recenter the star. Now **remeasure** the time it takes to drift across the field diameter four more times, filling out a data table like the one below. (As in any measuring process, you should not expect to get exactly the same values in each run.)

	5th Try	6th Try	7th Try	8th Try
Recenter star				

23. For your write-up, **calculate the average crossing time** (in seconds) for all (8) of your measurements. Then, **estimate the error** (in seconds) in the measured crossing time from the **deviations** of each measurement from the average. These calculations are described in Appendix D.
24. Finally, in your write-up, **convert** the average crossing time to *degrees of arc on the sky*. Remember a star which is close to the celestial equator moves  $360^\circ$  across the sky in one day ( $24 \times 60 \times 60$  seconds). So in the time it takes the star to cross the eyepiece field, the sky has appeared to move:

$$\frac{\text{crossing time in seconds}}{24 \times 60 \times 60 \text{ sec}} \times 360 \text{ degrees}$$

**That completes the observations for this lab.** However, we recommend that you go on to practice aligning your telescope and try out the auto-find function. That procedure is described in the next section.

**Remember to have the TA's initial your completed observing forms before you leave the observatory.**

### 3.8 Aligning the Telescope for Computer-Controlled Observing

Here, in preparation for Lab 4, we will **practice the special alignment calibration procedure** required to initialize the CPC telescopes for auto-finding mode (see the description in Sec. 3.5.5 above). Although the procedure is relatively fast, you must perform it every time the telescope power is turned on.

1. Turn off the power to the telescope for at least several seconds prior to attempting alignment. Be sure the RA and DEC clamps are tight, and don't unclamp during this procedure. Then turn power on.
2. Check (or re-check) that the finder scope and main scope are aligned by bore-sighting on a bright target. Re-align if necessary. See Sec. 3.5.3.
3. Use the UP/DOWN scroll keys (numeric keys 6 and 9) to scroll to **EQ North Align**. Press ENTER.



4. Date and time information should be displayed on the paddle. It may take a few moments for the display to appear; **wait** until it does. Ensure the time information is correct by pressing the UP/DOWN scroll keys. If the date and time information is correct, press ENTER.
5. Select **EQ AutoAlign** and press ENTER.
6. Use the N/S directional keys to point the telescope at the **celestial equator** by lining up the altitude marker on the telescope with the marker on top of the fork arm. Next, use the E/W directional keys to slew the telescope to the **meridian**, where the fork arms will both be the same distance from the ground.
7. Check the telescope and ensure it is pointed roughly at the intersection between the meridian and the celestial equator. The finder scope should be **on top** of the telescope. Press ENTER.
8. The telescope software will list a possible alignment star. Using your knowledge of the sky (or sky wheel), verify that this star is visible. If so, press ENTER. The telescope will slew to the approximate location of the star. If the star is not visible, use the UP/DOWN scroll keys to select another star, then press ENTER.
9. Wait until the telescope has stopped moving. Press RATE, then 9 to set the fastest slew rate.
10. Using the N/S/E/W directional keys, center the star in the finder scope. Press ENTER.
11. Again, using the directional keys, center the star in the main telescope eyepiece. Press ALIGN.
12. The telescope will ask you to select a second alignment star. For best results you should choose a star that is far away from the first one. Repeat steps 8 through 11 to finish the alignment.
13. Based on the GPS and alignment star data, the computer will establish the coordinate and time systems needed to automatically find and track astronomical objects.

Each member of your group should practice the alignment procedure until they are proficient at it.

**Test the alignment** by using the internal database to locate a bright object. See Sec. 3.5.5. A star cluster or other conspicuous object from the Messier Catalog would be a good test subject, as would a planet. If you can see the object in the finder and main scope without too much adjustment, then you have successfully aligned your telescope.

### 3.9 Requirement Checklist

1. Field orientation sketches (3)
2. Sketch through binoculars on observing form
3. Sketch through telescope on observing form
4. Measurement and calculation of seeing
5. Tables (2), calculations, and error analysis for field of view
6. Your procedure write-up should include steps for **all** the lettered sections under section 3.7 in the lab manual.

### 3.10 CHECKLIST FOR FINDING OBJECTS

1. Telescope properly mounted; polar axis oriented to North
2. Lens caps removed
3. Telescope clamped in both RA and DEC
4. Power on
5. Finder focused
6. **Finder and main scope co-aligned**; check on terrestrial targets, Moon, or bright star. Realign if necessary.
7. **Lowest power eyepiece** (i.e. *longest* focal length) in main scope. **Tighten** set screw so that eyepiece cannot slip.
8. Main scope **focused** (check on bright star field)
9. For boresighting, have a sky map identifying the target. For locating by coordinates have the RA/DEC coordinates. For locating by auto-find, have the name of the target. Know what the target should look like when you locate it.
10. If boresighting:
  - Use binoculars to locate general field (optional)
  - Move telescope to vicinity of target using slew motions
  - Take care to minimize parallax between your eyeline and finder
  - Center target in finder; use cross hairs
  - Center target in main telescope
  - If target is not in finder field, search systematically around position using slew motions. **Double check** pointing against sky map and/or binoculars. If not found in a few minutes, start boresighting procedure again from scratch.
  - If target is expected to be too faint to see in finder scope, make initial pointing as carefully as possible, and double check position against sky map and/or binoculars. Then check main telescope. If not as expected, search systematically around expected position. If not found in a few minutes, start boresighting procedure again from scratch.
11. If using RA/DEC coordinates or the auto-find facility, be sure that the proper **coordinate alignment procedure has been completed**. Targets should be centered in both finder and main telescope. If not there, first check that coordinates/selected name are correct. Then recheck telescope alignment on an obvious (bright) target. If necessary, re-execute alignment procedure.
12. Don't waste more than a few minutes looking for a missing target. Do a reality check on present pointing and then start pointing procedure over again.
13. Go to higher power eyepiece only after confirming target in low power and centering carefully. Be sure to loosen and tighten set screw for eyepiece appropriately. Refocus for new eyepiece.

## 4 TELESCOPE OBSERVING I

### 4.1 Time Estimate

In this laboratory, you will observe and sketch 10 objects in the night sky using the 8-in telescopes. Most students require 2 nights to complete their observations. Clouds or significant moonlight can cause substantial difficulties with this lab.

### 4.2 Introduction

This laboratory is intended to strengthen your skill in using small telescopes and familiarize you with a variety of celestial objects. You will also gain more experience with scientific observation and record keeping.

Bear in mind seasonal restrictions, as most objects are not available for night-time viewing year-round. Use your sky sheel to double-check the visibility of each object on a given night before filling out the observing forms. This lab will expose you to some of the issues involved in planning a professional “observing run,” e.g. choosing dates and observing objects in order of transit time.

### 4.3 Lab Write-up

Record your observations on the standard observing sheets. Your 10 observing sheets should be included as the Data section of your lab report. (A maximum of 10 observations can be turned in for credit; no extra credit will be given for additional observations.)

Remember that the preparatory section of each observing sheet should be filled out **before** you come to the observatory.

A full write-up is required. In particular, discuss any special techniques that you used to find the listed objects. What did you learn?

### 4.4 Procedure

Select **6** objects to observe from either the “Fall” or “Spring” lists given below, as appropriate. Your instructor may wish to modify the list and will usually **add planets that are well placed for observations**.

Select an additional **4** objects to observe from the following section “Observing List of Deep-Sky Objects” or from the online Messier or Caldwell Catalogs. These supplementary objects should not be on the seasonal lists below. The best types of supplementary targets would be star clusters, planetary nebulae, or gaseous nebulae. You should select your list **before** coming to lab based on their observability during Observatory open hours. Don’t attempt objects that are too faint. Galaxies in particular may be difficult (if you want to try galaxies, save them for Lab 7).

Descriptions and suggestions for finding and observing each object are given in the following section, “Observing List of Deep-Sky Objects.” In addition to this brief discussion, it would be helpful to consult online references to get a better understanding of what you are being asked to observe. Use such information to fill in the “Features to Observe” box of the standard observing form.

You can use boresighting to find the brighter targets on your observing lists if you wish, but this lab is intended to be executed **using the auto-find capability** of the Celestron telescopes.

Refer to Section 3.8 under Lab 3 for the **telescope alignment calibration procedure** that you must perform before the auto-find function will work properly. Be sure to have the names of your targets with you and know how to find them in the telescope's computer database.

Remember to **make seeing measurements each night you observe** and include them on your observing sheets. Also remember to **mark the cardinal directions** (North and East will suffice) **on each sketch**.

Most of the objects on the seasonal lists have been chosen to be visible under less than ideal conditions at the Student Observatory. You should start with easy objects and move to more difficult ones as you gain experience. Note that diffuse objects such as nebulae or galaxies require a **dark, clear, moonless** sky to be seen well. Local weather is unpredictable, so take advantage of good conditions when they occur.

You should observe objects in order of setting time—i.e. start with the objects that will set the earliest. This is normally the same as RA order. However, remember that in the Fall, objects with RA's in the range 16–23 hours set before objects with RA's in the range 0–6 hours. Also, take into consideration the limited view of the western horizon from the Student Observatory.

Objects are listed in the seasonal lists in the order in which they are best observed.

### FALL

<u>Object</u>	<u>RA</u>	<u>Dec</u>
M13, Globular Cluster	16 <sup>h</sup> 42 <sup>m</sup>	+36°28'
$\alpha$ Herculis, Rasalgeti (SAO 102680)	17 <sup>h</sup> 15 <sup>m</sup>	+14°23'
$\epsilon$ Lyrae (SAO 67310)	18 <sup>h</sup> 44 <sup>m</sup>	+39°40'
M57, Ring Nebula	18 <sup>h</sup> 54 <sup>m</sup>	+33°02'
$\beta$ Cygni, Albireo (SAO 87301)	19 <sup>h</sup> 31 <sup>m</sup>	+27°58'
M27, Dumbbell Nebula	20 <sup>h</sup> 00 <sup>m</sup>	+22°43'
M15, Globular Cluster	21 <sup>h</sup> 30 <sup>m</sup>	+12°10'
$\delta$ Cephei (SAO 34508)	22 <sup>h</sup> 29 <sup>m</sup>	+58°25'
M31, Andromeda Galaxy	0 <sup>h</sup> 43 <sup>m</sup>	+41°16'
$\eta$ Cassiopeiae (SAO 21732)	0 <sup>h</sup> 49 <sup>m</sup>	+57°49'
$\eta$ and $\chi$ Persei, Double Cluster (NGC 869 and NGC 884)	2 <sup>h</sup> 21 <sup>m</sup>	+57°08'
M45 The Pleiades	3 <sup>h</sup> 47 <sup>m</sup>	+24°07'

Additional objects: (see your instructor)

## SPRING

<u>Object</u>	<u>RA</u>	<u>Dec</u>
M31, Andromeda Galaxy	$0^h43^m$	$+41^\circ16'$
$\gamma$ Andromeda, Almak (SAO 37734)	$2^h04^m$	$+42^\circ20'$
$\eta$ and $\chi$ Persei, Double Cluster (NGC 869 and NGC 884)	$2^h21^m$	$+57^\circ08'$
M45, The Pleiades	$3^h47^m$	$+24^\circ07'$
M42, Orion Nebula and Trapezium	$5^h39^m$	$-05^\circ23'$
M37, Open Cluster	$5^h52^m$	$+32^\circ33'$
M35, Open Cluster	$6^h09^m$	$+24^\circ21'$
M41, Open Cluster	$6^h47^m$	$-20^\circ46'$
M81, Spiral Galaxy	$9^h56^m$	$+60^\circ04'$
$\gamma$ Leonis, Algeiba (SAO 81298)	$10^h20^m$	$+19^\circ50'$
Y CVn (SAO 44317)	$12^h45^m$	$+45^\circ26'$
$\alpha$ Canum Venaticorum (SAO 63256)	$12^h56^m$	$+38^\circ19'$
$\zeta$ Ursae Majoris, Mizar (SAO 28737)	$13^h24^m$	$+54^\circ56'$
M3, Globular Cluster	$13^h42^m$	$+28^\circ23'$

Additional objects: (see your instructor)

## OBSERVING LIST OF DEEP-SKY OBJECTS

This list contains descriptions of some of the better targets for small telescopes, including all of the objects on the observing lists for Telescope Observing Labs I and II. Given for each object are its name, position in epoch 2000 coordinates, brightness in magnitudes, type of object, and the relative difficulty of locating it in a dark, clear sky. The accompanying remarks give basic information and/or suggestions for finding the object. Stars are identified by their common catalog names and their SAO numbers here.

<u>Object</u>	<u>RA</u>	<u>Dec</u>	<u>Mag.</u>	<u>Type</u>	<u>Difficulty</u>
M31	0 <sup>h</sup> 43 <sup>m</sup>	+41°16'	5	galaxy	easy
Also known as the "Great Nebula" in Andromeda, this is the nearest large galaxy to our own. It is a member of the Local Group. It can be seen by the unaided eye on a dark night, 1°5' W of $\nu$ And. Using low power, let it drift across the field or scan the telescope back and forth to see how far out you can trace it. What is the overall shape? How does the brightness vary across it? M31 has two companion galaxies visible in small telescopes: M32, 0°5' S, and NGC 205, 0°75' NW.					
$\eta$ Cassiopeiae (SAO 21732)	0 <sup>h</sup> 49 <sup>m</sup>	+57°49'	3.5	double star	easy
The two components are of magnitudes 3.7 and 7.4, separated by 10". Do you see any difference in color between the two stars?					
M33	1 <sup>h</sup> 34 <sup>m</sup>	+30°40'	7	galaxy	difficult
A nearby spiral galaxy (part of our Local Group) seen face on. The galaxy has rather low surface brightness, so binoculars will give a better view than a telescope. M33 requires a very dark sky to be seen.					
$\gamma$ Andromedae (SAO 37734)	2 <sup>h</sup> 04 <sup>m</sup>	+42°20'	2.3	double star	easy
Almak is a 10" pair of magnitudes 2.3 and 5.1, considered to be one of the most beautifully colored doubles in the heavens. The fainter star is itself a triple star system, with a separation of less than a second of arc.					
$\kappa$ & $\chi$ Persei (NGC 869, 884)	2 <sup>h</sup> 21 <sup>m</sup>	+57°08'	4	open clusters	easy
Just off the northern tip of Perseus, the Double Cluster is visible to the naked eye as a brightening in the Milky Way. The telescope shows many bright stars in distinctive patterns and some colored stars. Pronunciation note: $\chi$ is the greek letter <i>chi</i> pronounced 'kI'.					
M77 (NGC 1068)	2 <sup>h</sup> 43 <sup>m</sup>	−00°01'	8.9	galaxy	difficult
A face-on spiral galaxy containing a bright, concentrated nuclear emission region powered by a supermassive black hole of about 10 million solar masses. Identified as one of the first examples of an active galactic nucleus by Carl Seyfert (1943).					
M45 (The Pleiades)	3 <sup>h</sup> 47 <sup>m</sup>	+24°07'	1.5	open cluster	easy
The Pleiades are equally attractive to the naked eye, binoculars, or telescope. The best views are obtained with a low power and large field of view. Compare the view through the telescope with that through the finder.					
Hyades (Caldwell 41)	4 <sup>h</sup> 27 <sup>m</sup>	+16°00'	0.5	open cluster	easy
At a distance of 150 ly, the Hyades is one of the most nearby clusters. Although the stars appear to cluster around Aldebaran, this brightest star in Taurus is not itself a member of the cluster. The age of the Hyades has been estimated to be about 790 million years old. The angular diameter of the Hyades is 5.5°.					

<u>Object</u>	<u>RA</u>	<u>Dec</u>	<u>Mag.</u>	<u>Type</u>	<u>Difficulty</u>
M79	5 <sup>h</sup> 24 <sup>m</sup>	−24°31′	8	globular cluster	difficult
This small and rather faint cluster is the brightest representative of its class in winter skies. Being far to the south, it requires a clear night for a good view. To find it, go 1° W and 4° S from $\beta$ Lep.					
M1	5 <sup>h</sup> 35 <sup>m</sup>	+22°01′	8.5	supernova remnant	difficult
It was this object that led the French comet-hunter Messier to compile his list of assorted “fixed” nebulous objects, to prevent confusing them with comets. M1 is the visible remains of a violent stellar explosion, a supernova, which was observed by Chinese astronomers in 1054 A.D. as a very bright “new” star. The stellar remnant is a neutron star which produces rapid pulses of radiation; hence, a “pulsar.” M1 is small and faint and requires a clear, dark sky to identify with certainty. Look 1° N and slightly W of $\zeta$ Tau. A large-scale “finding chart” may be helpful. The gaseous filaments which give it the name “Crab Nebula” can only be seen with large telescopes.					
$\sigma$ Orionis (SAO 132406)	5 <sup>h</sup> 39 <sup>m</sup>	−2°36′	3.8	multiple star	easy
This system shows 3 stars in a small telescope, of magnitude 3.8, 6.6 and 6.5, separations 13″ and 43″. The brightest star is a very close double also.					
M42 & $\theta^1$ Orionis (SAO 132314)	5 <sup>h</sup> 39 <sup>m</sup>	−5°23′	5.4	gaseous nebula & multiple star	easy
The Great Nebula in Orion’s sword is the finest gaseous nebula visible from the Northern Hemisphere. Continued gazing will show much fine detail. To see the faint outer parts, place the telescope west of it, turn off the drive and let the nebula drift through the field. The Trapezium, $\theta^1$ Orionis, is a quadrilateral of the stars in the heart of the nebula of mags 6, 7, 7.5, and 8.					
M37	5 <sup>h</sup> 52 <sup>m</sup>	+32°33′	6	open cluster	moderate
This is a bright, fairly compact star cluster, well placed for winter observers.					
M35	6 <sup>h</sup> 09 <sup>m</sup>	+24°21′	5	open cluster	easy
This large, bright cluster is easy to find. It forms a triangle with $\eta$ and 1 Gem. Many bright stars form apparent chains and loops.					
NGC 2244	6 <sup>h</sup> 31 <sup>m</sup>	+04°56′	3.5	open cluster	moderate
Surrounding the mag 5.9 star 12 Monocerotis, this 0 <sup>h</sup> 5 star cluster lies in the center of the Rosette Nebula. The Rosette is a huge, irregular annulus some 80′ in diameter. It appears best through binoculars, but even then is only an aura of the soft light encircling the cluster.					
UU Aurigae (SAO 59280)	6 <sup>h</sup> 37 <sup>m</sup>	+38°27′	5–7	red variable	moderate
UU Aur is a long-period semi-regular variable star worth observing for its color. It is found 1° N and 6°5 E of $\theta$ Aur.					
M41	6 <sup>h</sup> 46 <sup>m</sup>	−20°46′	5	open cluster	easy
A large cluster, easily found in a clear sky 4° S and slightly E from Sirius. Varied colors.					
NGC 2392	7 <sup>h</sup> 29 <sup>m</sup>	+21°00′	8	planetary nebula	moderate
A bright, bluish planetary with a bright central star. Dark structure may be visible in the disk.					
M46	7 <sup>h</sup> 41 <sup>m</sup>	−14°49′	7	open cluster	moderate
A rich open cluster of faint stars about 5500 light years distant. Superimposed on this cluster is NGC 2438, a faint (eleventh magnitude) planetary nebula 70″ across. NGC 2438 is not part of the cluster, but is estimated to be over 300 light years in front of it.					

<u>Object</u>	<u>RA</u>	<u>Dec</u>	<u>Mag.</u>	<u>Type</u>	<u>Difficulty</u>
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M44	8 <sup>h</sup> 40 <sup>m</sup>	+19°41'	3.7	open cluster	moderate
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Also known as Praesepe and the Beehive Cluster, M44 lies 577 ly distant from the Earth and has an angular size of 1.6°. This cluster is thought to have formed from the same large gas cloud as the Hyades, which is of similar age (790 million years).

M67	8 <sup>h</sup> 51 <sup>m</sup>	+11°48'	6	open cluster	moderate
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At an age of about 5Gyr (5 billion years) old, M67 is one of the oldest open clusters known, 2700 light years away; compact, faint.

M81	9 <sup>h</sup> 56 <sup>m</sup>	+69°04'	9	galaxy	moderate
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M82	9 <sup>h</sup> 56 <sup>m</sup>	+69°41'	9	galaxy	moderate
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These two galaxies in Ursa Major can both be seen at once with low power and actually are close companions in space. M82 is an irregular galaxy; photographs reveal a complex system of filaments extending out of it which indicates violent events taking place in its interior. The pair can be somewhat difficult to locate since the action of an equatorial mount becomes tricky at this high northern declination. The best procedure is to find fourth magnitude 24 UMa and swing 2° E from there. Compare the shape, size and brightness of the pair.

γ Leonis (SAO 81298)	10 <sup>h</sup> 20 <sup>m</sup>	+19°50'	2.6	double star	easy
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Algeiba, in the Lion's mane, is a close double star of mags 2.6 and 3.8, separation 4.5". The colors appear to vary from one observer to another; how do they appear to you? An exoplanet was discovered in orbit around γ<sup>1</sup> Leonis in 2009, with some evidence for a second planet.

NGC 3242	10 <sup>h</sup> 25 <sup>m</sup>	−18°39'	9	planetary nebula	moderate
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One of the brightest and easiest of all planetary nebulae, 40" × 35" across, its pale blue disk is easy to see under dark sky conditions.

M65	11 <sup>h</sup> 19 <sup>m</sup>	+13°06'	10	galaxy	difficult
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M66	11 <sup>h</sup> 20 <sup>m</sup>	+12°59'	10	galaxy	difficult
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This pair of spiral galaxies in Leo fit together into the field of a low power eyepiece. To find them, move 1° N, then 17°5 E from Regulus. A third, fainter galaxy may be seen as a long streak N of M66; this is NGC 3628. All three galaxies are of the same type, but are inclined to our line of sight by different amounts. Compare their shapes and brightnesses.

M104	12 <sup>h</sup> 40 <sup>m</sup>	−11°37'	8	galaxy	moderate
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The Sombrero Galaxy is one of the brightest galaxies and relatively easy to find, 11°5 W of Spica or, alternately, 4° S of χ Vir.

Y CVn (SAO 44317)	12 <sup>h</sup> 45 <sup>m</sup>	+45°26'	5–6.5	red variable	moderate
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Also called *La Superba*. A giant "carbon star" with intense red color. It forms a right triangle with α and β CVn.

α Canum Venaticorum (SAO 63256)	12 <sup>h</sup> 56 <sup>m</sup>	+38°19'	2.9	double star	easy
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This star was named Cor Caroli for "Charles' Heart" in honor of Charles II of England. It is an attractive double of mags. 2.9 and 5.6, separation 20". The wide separation makes this a good beginning object for double star observing. Imagine what it would look like if the separation were only a half or a quarter as great (10" or 5"), and remember this when you look at closer pairs.



<u>Object</u>	<u>RA</u>	<u>Dec</u>	<u>Mag.</u>	<u>Type</u>	<u>Difficulty</u>
M64	12 <sup>h</sup> 57 <sup>m</sup>	+21°41'	7	galaxy	moderate

M64 is small and relatively bright but located in a region devoid of bright naked-eye stars. To find it, swing 17° S from Cor Caroli. You might find it interesting to compare M64 with M104 in Virgo and M51 in Canes Venatici (below). All three could be examined with the same instrument and differences in size, brightness, etc. noted.

ζ Ursae Majoris (SAO 28737)	13 <sup>h</sup> 24 <sup>m</sup>	+54°56'	2.4	double star	easy
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Mizar and Alcor form a wide pair which can be seen with the naked eye. Mizar (ζ UMa) is an easy visual double of mags 2.4 and 4.0, separation 15". Each star is also a spectroscopic binary. This was the first double star discovered with the telescope, by Riccioli in 1650.

M51	13 <sup>h</sup> 30 <sup>m</sup>	+47°12'	8	galaxy	moderate
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The "Whirlpool" galaxy, a face-on spiral with an irregular companion. Observe carefully its shape and brightness. To find it, begin at η UMa at the end of the Dipper's handle; move 2° W to fifth-magnitude 24 CVn, then 2° S and 0°5 W to M51.

M3	13 <sup>h</sup> 42 <sup>m</sup>	+28°23'	6.5	globular cluster	moderate
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This bright, compact globular is one of the finest in the spring sky. It is in a rather barren region, but can be located by going 1° N and 14° W from ε Boo.

ε Boöetis (SAO 83500)	14 <sup>h</sup> 45 <sup>m</sup>	+27°04'	2.4	double star	moderate
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Izar is a very close double star. The 2.7 magnitude orange primary is only 3" from the 5.1 magnitude secondary and is a test of the effective resolution.

M5	15 <sup>h</sup> 19 <sup>m</sup>	+2°05'	6.5	globular cluster	moderate
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M5 is large, bright and readily resolved into individual stars. It is 11° N of Zubeneschamali in Libra and lies very close to fifth-magnitude 5 Serpentis. An interesting project would be the comparison of M3, M5 and M13 using the same telescope and magnification on the same night.

M4	16 <sup>h</sup> 24 <sup>m</sup>	−26°32'	7	globular cluster	easy
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This large, fairly open globular is easily found 1°3 W of Antares. Does it appear circular to you?

M13	16 <sup>h</sup> 42 <sup>m</sup>	+36°28'	6	globular cluster	easy
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This is the largest, finest globular cluster in the northern sky and is well placed for summer and fall observing 2°5 S of η Her. Medium and high powers on a good night will "resolve" it, i.e. will separate the fuzzy ball into individual stars.

α Herculis (SAO 102680)	17 <sup>h</sup> 15 <sup>m</sup>	+14°23'	3.1	double star	easy
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Rasalgeti is a cool red giant and an irregular variable star. It has a 5.4 mag companion 5" distant with which it makes a pleasing color contrast. The radius of α<sup>1</sup> is 400 times that of the Sun or about 1.9 astronomical units.

M6	17 <sup>h</sup> 40 <sup>m</sup>	−32°12'	5	open cluster	moderate
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A pretty cluster with many bright stars, 5° N and 1° E of λ Sco in the Scorpion's stinger.

M7	17 <sup>h</sup> 54 <sup>m</sup>	−34°47'	4	open cluster	moderate
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This large cluster is best seen with a low power and wide field. Compare the view through the telescope with that through the finder. Like all southern objects, M7 requires a clear, dark southern sky to be seen well. Find it by moving 6° E and slightly S from ε Sgr.

<u>Object</u>	<u>RA</u>	<u>Dec</u>	<u>Mag.</u>	<u>Type</u>	<u>Difficulty</u>
M23 9°5 S of $\nu$ Oph, this large cluster is located in front of a dark cloud in the Milky Way. It has no sharply defined edges. How large does it appear to you?	17 <sup>h</sup> 57 <sup>m</sup>	−18°59′	6	open cluster	moderate
M20 The Trifid is a small emission nebula with dark absorption lanes above the spout of the Teapot in Sagittarius. 1°5 S is M8.	18 <sup>h</sup> 02 <sup>m</sup>	−23°02′	9	gaseous nebula	moderate
M8 The Lagoon Nebula requires a dark, clear night to be seen well, but is worth the wait. The cluster is easily seen; the nebulosity is more difficult. M8 is 6° N of $\gamma$ Sgr.	18 <sup>h</sup> 04 <sup>m</sup>	−24°23′	6	gaseous nebula & open cluster	moderate
M16 The Eagle Nebula is 2°5 N and slightly W of M17. Averted vision helps bring out the nebula.	18 <sup>h</sup> 19 <sup>m</sup>	−13°49′	6	gaseous nebula & open cluster	moderate
M17 The Omega Nebula, 13°5 N of $\delta$ Sgr, has a distinctive shape. How does it appear to you?	18 <sup>h</sup> 20 <sup>m</sup>	−16°11′	7	gaseous nebula	moderate
$\epsilon$ Lyrae (SAO 67310) This is a “double-double” star just northeast of Vega. Binoculars show a wide pair of fifth-magnitude stars. A telescope at 100 power or more shows each star to be a very close double of equal magnitudes and 2″.3, 2″.8 separation, respectively.	18 <sup>h</sup> 44 <sup>m</sup>	+39°40′	4.5	multiple star	easy
M11 Situated on the edge of the Scutum star cloud in the Milky Way, M11 is one of the most compact galactic clusters. It is visible in the finder as a bright spot in a star-crowded field. Find it by moving 20° N from Nunki ( $\sigma$ Sgr).	18 <sup>h</sup> 51 <sup>m</sup>	−6°16′	6	open cluster	moderate
M57 The Ring Nebula is located halfway between $\beta$ and $\gamma$ Lyr. A small, bright doughnut shape, it requires medium power (65×) to distinguish it from a star. Is it circular? Compare the sky brightness inside and outside the doughnut.	18 <sup>h</sup> 54 <sup>m</sup>	+33°02′	9	planetary nebula	moderate
$\beta$ Cygni (SAO 87302) Albireo is one of the finest colored double stars in the sky. The companion, 5.1 mag, is an easy 35″ distant. Describe the colors; do they appear to change with different powers? Albireo is embedded in the Milky Way and the surrounding regions are rich with glittering faint stars.	19 <sup>h</sup> 31 <sup>m</sup>	+27°58′	3.2	double star	easy
16 Cygni (SAO 31898) A pair of yellowish, solar-type (G2 V spectral type) stars separated by 38″. A third, very faint, red dwarf star orbits 16 Cygni A. One of the first exoplanets was detected (1996) in orbit around 16 Cygni B.	19 <sup>h</sup> 42 <sup>m</sup>	+50°31′	6.0/6.2	double star	easy
M27 Being both large and bright, this is the finest planetary in northern skies. It is known as the Dumbbell Nebula; observe and describe its shape. M27 is located 3° N of $\gamma$ Sge.	20 <sup>h</sup> 00 <sup>m</sup>	+22°43′	7.5	planetary nebula	moderate

<u>Object</u>	<u>RA</u>	<u>Dec</u>	<u>Mag.</u>	<u>Type</u>	<u>Difficulty</u>
$\gamma$ Delphini (SAO 106475)	20 <sup>h</sup> 47 <sup>m</sup>	+16°07'	4.3	double star	easy
This pair has mags 4.3 and 5.1, separation 10". What colors do you see?					
NGC 7000	20 <sup>h</sup> 59 <sup>m</sup>	+44°20'	10	gaseous nebula	difficult
Known as the North American Nebula for its shape. This is a very large (100'), very faint nebulosity illuminated by the nearby star Deneb (3° to the West and at the same 1600 ly distance). The North American Nebula is best observed with binoculars or with a telescope at lowest power and a wide field eyepiece on a dark clear night.					
NGC 7009	21 <sup>h</sup> 04 <sup>m</sup>	-11°22'	8	planetary nebula	difficult
Called the Saturn Nebula from its appearance in large telescopes, this is a small disc 1° W and 6° N of $\theta$ Cap. It is roughly 30" across; observe $\beta$ Cyg, a double star of 35" separation, to get an idea of how large this is on your telescope. Is it perfectly circular?					
61 Cygni (SAO 70919)	21 <sup>h</sup> 07 <sup>m</sup>	+38°45'	5.2/6.0	double star	easy
A pair of K-type stars, somewhat less massive than the Sun. Separation is 30.3". Important historically because these were the first stars to have their distances measured (in 1838 by Friedrich Bessel, using the parallax method). Bessel's attention was drawn to the pair by their large "proper motion" with respect to other stars of 3.5" per year. 61 Cygni is 3.48 parsecs or 11.4 light years from the Sun. Only 16 other stars (mostly below naked eye visibility) are nearer the Sun.					
M15	21 <sup>h</sup> 30 <sup>m</sup>	+12°10'	6.5	globular cluster	moderate
One of the finest globulars in fall skies, M15 is 3°5' W and 2°5' N of $\epsilon$ Peg. Note its shape carefully.					
M2	21 <sup>h</sup> 33 <sup>m</sup>	-0°49'	7	globular cluster	moderate
$\beta$ Aquarii is a fine starting point for a tour of fall globulars. 5° N is M2; 18° N and slightly W is M15 in Pegasus, while 18° S and slightly E is M30 in Capricornus. Compare these clusters using the same telescope on the same night for all three.					
$\mu$ Cephei (SAO 33693)	21 <sup>h</sup> 44 <sup>m</sup>	+58°47'	3.7-5	red variable	easy
A red supergiant, known as the "Garnet Star." Its radius is 1650 times that of the Sun. Comment on its color. Variable, with a period of 2-2.5 years.					
$\delta$ Cephei (SAO 34508)	22 <sup>h</sup> 29 <sup>m</sup>	+58°25'	(3.8)	double star	easy
This is a wide double star with attractive colors, the companion star being mag 6.3, 41" distant. The brighter star is the prototype Cepheid variable; it varies from mag 3.6 to 4.3 in 5.4 days.					
19 Psc (SAO 128374)	23 <sup>h</sup> 46 <sup>m</sup>	+3°29'	5.3	red star	moderate
An irregular variable "carbon star", one of the reddest stars visible. 19 Psc is just east of the Circlet of Pisces, 6°5' W and 11°5' S of $\gamma$ Peg.					

## OBSERVING THE SOLAR SYSTEM

Since planets are continually moving against the background of stars, you will need to obtain their current positions from a current ephemeris or web site. The positions of Mercury and Venus change noticeably from night to night.

**Mercury:** The innermost planet is never far from the Sun as seen from the Earth,  $28^\circ$  at most. It is difficult to observe, being visible only at dusk and dawn close to the horizon. Its motion against the stars is faster than any other planet's. Binoculars will aid in finding it and following its day-to-day motion. A telescope will show phases. It is very difficult to detect markings on Mercury's surface.

**Venus:** Like Mercury, Venus appears alternately as a morning and evening star. However, it attains a much greater angular distance from the Sun ( $48^\circ$ ) and so can be regularly seen well above the horizon in a dark sky. Both phases and a considerable change in its apparent size are visible in a telescope. Its maximum brightness is so great,  $-4.4$  mag, that some observers prefer to view it in twilight to reduce the effects of glare. Venus is the brightest planet seen from Earth. Venus is often mistaken by non-astronomers for a "UFO."

**Mars:** The "red planet" is unmistakable to the naked eye by its orange-red color. It is easily observable for periods of about three months every two years, when Mars and the Earth are on the same side of the Sun and fairly close. Closest approaches occur at about 16 year intervals. At these times Mars is brilliant at  $-2.8$  mag, and the Martian disc reaches its maximum apparent size of 25 arc seconds. Small telescopes will show the polar ice caps and the larger dark markings on the Martian surface. Long term observations reveal that the caps and the coloration of certain regions to change with the Martian seasons. Since Mars' rotational period is nearly the same as the Earth's, it takes several weeks of observation to view the entire surface. The infamous Martian "canals" were an optical illusion.

**Jupiter:** The largest planet is visible for several months every year. The slightest optical aid will show the four brightest moons, discovered by Galileo. Charting their changing positions from night to night can be an interesting exercise. The disc of the planet is relatively large ( $45''$  at opposition) and many features can be seen. The most prominent are dark bands and a large, oval, orange or reddish blotch, the "Great Red Spot." These are actually cloud features near the top of Jupiter's atmosphere, produced by the terrific jet streams resulting from its rapid rotation (10 hrs.). Another result of this short rotation period is that all of Jupiter's "surface" can be seen in one night.

**Saturn:** Saturn is famous for its bright ring system. It can also be observed for several months every year. The disc of the planet is relatively featureless compared to Jupiter, showing the darker polar regions and perhaps a belt or two. Its fascination lies in its ring system. Small telescopes will show the two brighter rings and a dark gap between them known as Cassini's division. Their apparent tilt changes from  $28^\circ$  "up" to  $28^\circ$  "down" over a thirty-year period; thus they appear edge-on every fifteen years, and are invisible in small telescope at these times. Saturn's brightest moon, Titan, is easily visible.

**Uranus:** Small ( $4''$ ) and faint (6th mag), Uranus is of interest primarily for its peculiar green color. Once identified, its motion from night to night can be observed and plotted on a detailed star chart. Recently, by occultation of distant stars, a ring system has been detected around Uranus, but this is not visible with a small telescope.

**Neptune:** Neptune is still smaller and fainter than Uranus ( $2''.5$ , 8th mag) and high power is needed to confirm that it is a disc, not a point. Neptune's motion can also be tracked from night to night with the telescope.

- Pluto: Pluto is too faint to be seen in a small telescope, but you would be able to photograph it. It is indistinguishable from a faint star. You would need an excellent finding chart to locate it.
- Asteroids: Thousands of these chunks of celestial debris orbit the Sun between Mars and Jupiter. Most are small and very faint. The three brightest, Ceres, Pallas, and Vesta, can reach 6th to 7th magnitude at opposition. Their daily motion may be followed in binoculars or the telescope.
- The Moon: The surface of the moon offers a fascinating variety of features and details to the telescope — large and small maria (“seas”), ringed plains, craters, mountains, rilles (clefts or cracks), rays (bright streaks), etc. Learn the major features with low power and a moon map, then explore the details at higher power. Features are best seen when close to the terminator, the line of sunrise (or sunset) on the lunar surface. The low Sun angle here creates strong shadows and heightens relief. Some features vanish utterly under the vertical illumination of the full moon. However, this can be the best time to examine the bright rays extending for great distances from some craters.
- The Sun: Because of its intense light and heat, the Sun can be a dangerous object to observe. **NEVER LOOK AT THE SUN THROUGH AN UNFILTERED TELESCOPE OR BINOCULARS. IT WILL BLIND YOU INSTANTLY AND PERMANENTLY.** The Sun’s light can be reduced to a safe level through the use of special filters. The safest technique is to project its image onto a small screen. Your instructor will demonstrate the available equipment and its proper use. The objects of greatest interest on the Sun are sunspots, cooler regions on the surface which appear dark in comparison to their surroundings. They appear, develop, and then vanish over weeks or months. Their total numbers increase and decrease over an eleven-year period. Their changing size and shape can be monitored, while mapping their motion across the solar disc from day to day allows the determination of the Sun’s rotational period. Special filters can be used to isolate the atomic lines of hydrogen, and these permit you to see solar prominences—large, flame-like struc

## 5 TELESCOPIC OBSERVATION OF THE MOON

### 5.1 Time Estimate

This lab requires 1-2 nights of observation while the Moon is in the first 10-12 days of its cycle of phases. You need to consult the astronomical event calendar for the current semester and plan ahead in order to complete this lab. You can get extra credit by doing the last two parts of the lab near full Moon (but you must do the required parts as well to get the credit).

### 5.2 Lab Write-up

A full write-up is required. Your sketches will make up the data section. Questions which appear in the lab should be answered in the Discussion section.

### 5.3 Introduction

The Moon (“Luna”) is close enough to Earth that a large number and variety of features can easily be seen on its surface with a small telescope. In this laboratory you will examine systematically various types of lunar features and consider mechanisms for their formation.

First we must learn some terminology.

The Moon is in a **resonant orbit**. This means that its rotation on its axis has been strongly influenced by its revolution around the Earth. In the Moon’s case, it rotates on its axis once every time it orbits the Earth. As a result, Earth always sees the same side of the Moon.

As the Moon orbits the Earth, half of its surface is sunlit at all times. However, the portion of the illuminated surface which we see from Earth changes as the Moon revolves around the Earth. This gives rise to the **phases** of the Moon. The exact phase is specified by the time elapsed since the preceding new Moon. A “first quarter” Moon, for example, is a seven-day-old Moon. The edge of the visible disc is called the **limb**. The line of shadow crossing the surface, separating the lit and unlit portion, is the **terminator**. Lunar features are best seen when they are close to the terminator. The long shadows they cast then cause them to stand out in relief. These are similar to the long shadows you see on Earth near sunrise or sunset.

The names of lunar features may seem strange or obscure. The largest features, being the easiest to see, were discovered and named soon after the invention of the telescope. Craters were named after famous scientists and mathematicians, while the “seas” were given fanciful poetic names. Because this system was devised about 1650, many of the once-famous persons immortalized by large craters are no longer well known. Subsequent great scientists such as Einstein got stuck with third-rate craters or had to wait for a place on the far side of the Moon.

Based on the examination of the rocks brought back from Apollo astronauts, it is now believed that Luna is composed of material which is very similar to that on the Earth’s exterior. For this reason, the most popular theory for the Moon’s formation is that Earth was struck by a Mars-sized body while still in its molten state. The debris hurled upward by the impact created a short-lived ring, similar to Saturn’s rings. The debris eventually dispersed but a large portion of it coalesced to form the Moon.

### 5.4 Physical Processes

The surface features of the Moon have been ascribed to two major causes. The first is **cratering**, large or small bodies striking the surface and creating craters. Cratering activity

was most intense about 4.5 billion years ago, soon after the Moon formed when the early Solar System was filled with debris. The initial intense bombardment heated the lunar surface and churned it violently. After a period of cooling, heat released by radioactive decay melted the interior of the Moon and gave rise to **vulcanism**, the release of molten material onto the surface by volcanoes or by welling up through deep cracks. This was followed by a final cooling of the Moon to its present frozen state. Large cratering events are very rare today, and vulcanism is likewise inactive.

Other minor processes are still at work, modifying the surface on a small scale. **Erosion** occurs from the constant rain of micrometeors and solar particles blasting the surface. This gradually wears features away and creates a fine powder on the lunar surface. Erosion on the Moon is exceedingly slow. In the last four billion years, not a single major surface feature has been erased. By contrast, craters on the Earth have a lifetime of a few tens of thousands of years. **Moonquakes** have been detected by seismometers left behind by Apollo astronauts. They are low-energy events, imperceptible without instruments. No definite changes of any kind have been seen on the Moon in three centuries of observation.

## 5.5 Requirements

You are to locate, observe and describe lunar features from each of the *nine non-optional sections* in the lab. Various questions are asked in each section to guide your observing. Include the **three indicated sketches** as well as your answers to these questions in a lab report. The questions are to be neatly and clearly answered in full sentences on your own paper in the conclusion section of the lab report. Start each response on a separate line with the question number shown.

The last two sections of the lab are **optional**. They require observations **near full moon**. Your instructor will tell you how much extra credit you can receive for doing these in addition to the required nine sections of the lab.

For each section give the following information in your report:

1. Date and time of observations
2. Telescope used and group members, if any
3. Observing conditions (weather and sky)
4. Phase of moon specified by days and fractions of a day since the preceding new moon

For the three sketches, use a standard telescope observing form, filled out in the usual way. You are not required to draw a finding chart, but see the discussion below on locating objects on the lunar surface. The given circle is to indicate the field of view of the eyepiece. Draw your sketch to fit such a scale.

Be neat and accurate. You cannot record all the detail, but you should try to show the major features as they appear, with the goal that if you looked at the sketch in a year you would easily recognize the observed object.

## 5.6 Observing Procedure

Read the whole lab over carefully before coming to the Observatory.

You will use the 8" telescopes for your observations. It is recommended that you use a low-power eyepiece and a **lunar filter**. Because the moon is so bright, observing it can be difficult, even painful, especially when it is full. A lunar filter, which you can obtain from the TA, will improve the contrast of features on the Moon's surface while reducing the glare.

For the non-optional work in this lab, **you must observe the Moon while it is near first quarter phase.** Best would be right at first quarter (7 days after new Moon), but weather (or weekends) may prevent this. You can attempt the lab any time up to about 12 days after new Moon—beyond that, the shadow geometry will prevent you from making about half of the observations required. During the first few days of the phase cycle, the Moon sets soon after sunset. (Shadow geometry improves again late in the phase cycle, but the Moon is only visible then in the early morning, and all the teaching assistants have gone home to play “Oblivion.”) Therefore, **you have a narrow window of only about 8 days each month in which to perform this lab.**

The last two optional sections of the lab can only be performed within 2 days of full moon. Four of the non-optional sections could also be done near full Moon.

*Review the questions you are expected to answer carefully before starting the lab.* The sections *do not* have to be observed in order. While some questions do refer to previous sections, careful note-keeping should enable you to answer these out of order. Tip: sections 1–4 are less dependent on observing near first quarter than the remaining sections and can be done near full Moon.

The hardest part of this lab is learning how to locate features on the Moon’s surface. Coordinates for some features are quoted in lunar latitude and longitude below. These are oriented in the same manner as coordinates on the Earth’s surface. However, the orientation you see through your telescope will depend on the optical arrangement of the telescope. **The first step, therefore, is to determine what orientation the four cardinal directions (N,S,E,W) in lunar coordinates will take as seen through your telescope eyepiece.**

Once you have done this, consult a lunar map, such as those in *Norton’s Star Atlas* or *Edmund Mag 5 Star Atlas*. Familiarize yourself with the most prominent features which will be visible near first quarter phase. The best approach is to make a hardcopy of a lunar map from the Web and to **mark on it all the features you are expected to find.** This will greatly facilitate your work at the telescope. Reconnaissance with binoculars is also strongly recommended.

Before each observing session, determine the phase of the Moon and the approximate position of the terminator. There is a large scale chart of the Moon on the wall of the 1230 night lab. You can use this to decide which features are best placed for observation. The map is a valuable aid in identifying features, but you may not use it to sketch from.

## 1. AN OVERVIEW OF THE MOON

Using the lowest power eyepiece, examine the Moon as a whole. You need not focus on details, instead get a feel for extremes — rough vs smooth; light vs dark; the smooth relatively featureless areas (the lunar seas or **maria**) vs the heavily cratered regions (the **highlands**).

1. How are these terrains distributed over the surface? Are they mixed together, or separated into different portions of the surface? Note any regions (north, southeast, central, etc.) which seem to be dominated by one type of terrain.

2. Are maria and highlands the same shade? Note the similarities or differences.

**Sketch #1** — Make a sketch showing the phase of the Moon and the location and general shape of maria and highland areas.

## 2. REGULAR MARIA

Observe either Mare Serenitatis or Mare Imbrium.

3. How heavily cratered is the mare compared to the highlands? Do craters on the mare surface appear to follow some pattern, or are they distributed randomly?

4. What is the overall shape of the mare? Observe the jagged mountain ranges near the mare. Is there a relationship evident between these features?



5. Reread the part of the Introduction on physical processes. From this information and the appearance of the mare, suggest a theory to explain its formation.

### 3. IRREGULAR MARIA

Observe one of: Mare Fecunditatis, Mare Vaporum, Mare Nubium.

6. Is it more or less cratered than the regular mare? Is there a relationship between this mare and the mountain ranges?

7. Compare the coloring of the irregular mare surface to that of the regular mare. Which appears more uniform?

8. Discuss similarities or differences in the shape of the two types of mare. Which has a better defined shape?

9. What aspect of your theory of regular mare formation works, or does not work, as applied to irregular mare? Modify your theory to account for the differences between the two types of maria.

### 4. CRATER OVERVIEW

Using the full range of eyepieces, view craters at various magnifications. Many thousands of craters may be seen. We will not focus on any particular crater in this section, but notice how craters near the **terminator** show greater detail than those near the **limb**.

10. What is the general shape of the craters? Do all craters look alike, or do any differ substantially from this shape?

11. Consider the size range of craters. Does there appear to be an upper limit on their sizes? A lower limit?

12. As the size gets smaller, do you see fewer, more, or about the same number of craters?

### 5. CRATERS WITH INTERIOR PEAKS

This is a subclass of craters which have mountains inside them. You should easily find many of these.

13. Consider the size range of peaked craters. Are there upper or lower limits to their sizes?

Observe **one** of the following at high magnification:

Arzachel (2°W, 18°S)

Copernicus (20°W, 10°N)

Theophilus (27°E, 12°S)

Werner (4°E, 28°S, just east of Regiomontanus)

14. Examine the slope of the crater walls. Which side is steeper, the inner wall or the outer? How can you tell?

15. Do the outside walls slope down smoothly? The inside walls? Describe their appearance.

16. Examine the shadow of the crater rim. Is it jagged or smooth in outline? What does this indicate about the profile of the crater walls?

17. Do the mountains inside appear to be higher or lower than the crater walls? How can you tell?

18. Is there one prominent peak, or a group of equal peaks? Are they in the exact center of the crater or offset?

**Sketch #2** — Make a high magnification sketch of the crater you have described.

### 6. WALLED PLAINS

Observe **one** of the following at high magnification:

Walter (0°E, 33°S)

Clavius (15°W, 59°S)

19. Compare the appearance of this feature to the crater with central peaks above. Compare size, shape, height and structure of walls, presence of interior mountains, etc.
20. Which looks more worn down, the walled plain or the crater with the central peak? Which do you think is older?
21. You should see some craters on or inside the walls of the feature. Compare their size and structure to the walled plain as a whole. Which do you think formed first, and why?
22. Did you see any of these smaller, secondary craters in the craters with central peaks? What does this tell you about the relative ages of the walled plains vs peaked craters? Is this answer consistent with the ages from #22?
23. Compare the walled plain to the regular mare you observed. Note similarities and differences.

## 7. MOUNTAIN RANGES

Find and observe **two** of the following mountain ranges:

Haemus Mts. (10–20°E, 15°N)

Caucasus Mts. (10°E, 30–40°N)

Apennines (10°W–5°E, 15–25°N)

Alps (0°E–W, 45°N)

Carpathians (20–30°W, 15°N)

Briefly describe each range separately.

24. Most mountains on Earth have eroded to soft profiles due to active wind and water erosion. Only the youngest Earth mountains are still high and rugged. Use differences in appearance to rank the ranges you observed from oldest to youngest.
25. Are there many craters in the mountain ranges? Compare the cratering in the ranges with the southern highlands. What does this imply about the relative ages of mountain ranges vs highlands?

## 8. OTHER CRUSTAL FEATURES

The Moon has a variety of features caused by shrinking and settling of the surface and by lava flowing onto the crust. There are several types which differ in appearance when seen at a low Sun angle (see Figure 6):

rille — a cleft or valley in the surface

scarp — a fault, with one side of the crust lifted higher than the other

ridge — a low continuous uplift of the surface

These are illustrated by their appearance from above under a low Sun angle and in profile

Find **one** of the following features and describe it. Decide what type of feature it is.

Rupes Altai (20–30°E, 20–30°S)

Rima Ariadaeus (15°E, 6°N, south of Julius Caesar)

Rima Hyginus (7°E, 8°N)

Rupes Recta (8°W, 22°S)

**Sketch #3** — Sketch the observed crustal feature at high magnification. Indicate in your sketch from which direction the Sun is shining.

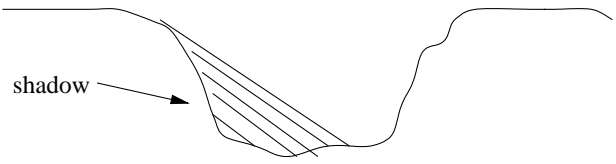
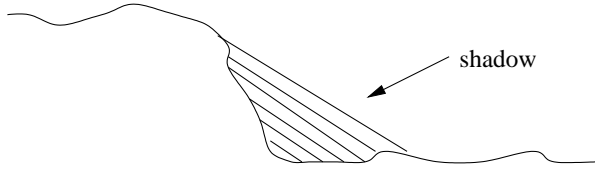
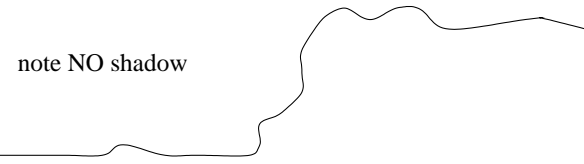
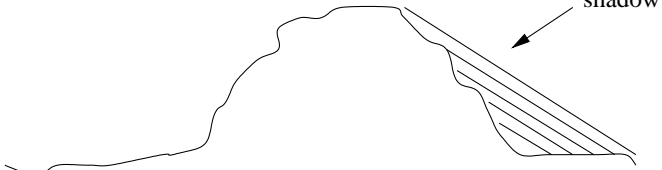
Description of feature	Profile of feature (sunlight from left)
Rille: Seen as a bright line with a shadowed edge.	
Scarp: Seen as either a dark or bright line depending on orientation to the sun.	
	
Ridge: Note reversed appearance compared to rille.	

Figure 6: Lunar Surface Features

### 9. RAY SYSTEMS [OPTIONAL SECTION: do at full Moon only.]

Lunar rays are created by a thin layer of light-colored pulverized rock ejected to great distances when a large crater is formed. This material darkens with age, so only young craters have visible ray systems.

26. Describe the visible ray systems. Compare extent and color from crater to crater.

27. How many rayed craters are there? Using a lunar map, identify the rayed craters.

**Sketch #4** — Make a sketch of the ray system at low power. Include enough general features to place the rayed craters accurately. Identify the rayed craters on the sketch as well as the brightest spots or areas.

### 10. COMPARING THE PHASES [OPTIONAL SECTION: do at full Moon only.]

The appearance of the Moon changes dramatically with the phases. Ray systems that are striking at full Moon are not visible during crescent phases. Other features are only seen near the terminator.

28. Locate the crater with interior mountains that you observed, or will observe, for section 5. Compare its appearance at the two different phases. What details are more apparent near full Moon? What details are more apparent near quarter phase?

29. For the Moon as a whole discuss at least two other changes, besides the ray systems or peaked craters, that occurred between observations.

### **5.7 Requirement Checklist**

1. Answers to questions 1-25
2. Phase of the moon sketch
3. High magnification crater sketch
4. High magnification crustal feature sketch
5. Answers to questions 26-29 (optional)
6. Ray system sketch (optional)

## 6 PULSATING VARIABLE STARS

### 6.1 Time Estimate

This lab requires you to make 2–4 observations each week, weather permitting, over the course of the semester. It does not require a telescope. While little time is required for any individual observation, a consistent pattern of observing is absolutely necessary. **You must start this lab early in the semester to execute it properly.**

### 6.2 Introduction

Many stars do not shine with a steady light but vary considerably in brightness over intervals of hours, days, or months. One class of stars which vary is that of the Cepheid variables, named after  $\delta$  Cephei,<sup>1</sup> the first star in this group whose variations were discovered. Cepheids vary in brightness by as much as a factor of two over a period of a few days. The variations repeat in a regular cycle which is always the same for any one star. One of the most familiar stars, Polaris (the North Star), is a Cepheid, although its brightness changes are not great enough to be easily detected.

Cepheids are intrinsic variable stars (i.e. the cause of the variation is an instability inside the star itself). The outer layers of the star cannot get into a balanced, stable state. They alternately expand and cool down, then contract and heat up. This pulsing in and out, and the accompanying temperature change, causes the variation in light output. Cepheids are generally stars that are several times more massive than the Sun and nearing the ends of their lifespans. These massive stars are rather rare to begin with and they pass through the pulsing stage of their lives relatively quickly. This means that at any given time, very few stars are Cepheids.

Despite their small numbers, Cepheids are very important as astronomical “yardsticks.” The period of the light variations of a Cepheid is closely related to its average brightness. By measuring the period, we can determine its intrinsic brightness. Comparison of the intrinsic and apparent brightnesses then gives its distance. Cepheids are bright enough to be seen in nearby galaxies and provide an important method for determining their distances.

In this laboratory you are to make regular observations of a Cepheid variable over a span of many weeks, estimating its brightness by comparison with nearby non-varying stars. **This can be done with the naked eye or with binoculars.** You will use your observations to determine the period of the variations, the way the light varies in time (i.e. the *light curve*), and the star’s actual distance from the Sun. Read the entire laboratory before starting.

### 6.3 Observations

Below are data for three prominent Cepheids:  $\delta$  Cephei,  $\zeta$  Geminorum, and  $\eta$  Aquilae. Given are the average apparent visual magnitude and period of the Cepheids and the apparent magnitudes of two nearby, non-variable reference stars.

$\delta$ CEPHEI		
Star	Mag. m	Period (days)
$\delta$	4.0	5.366
$\zeta$	3.6	N/A
$\epsilon$	4.2	N/A

---

<sup>1</sup>The variation of  $\delta$  Cep was discovered in 1784 by John Goodricke, an English amateur astronomer and deaf mute. He also discovered the regular variation of several other stars, among them Algol and  $\beta$  Lyrae.

$\zeta$ GEMINORUM		
Star	Mag. m	Period (days)
$\zeta$	3.9	10.151
$\lambda$	3.6	N/A
$\tau$	4.3	N/A
$\eta$ AQUILAE		
Star	Mag. m	Period (days)
$\eta$	4.1	7.177
$\beta$	3.7	N/A
$\mu$	4.4	N/A

Choose one of the stars which is high in the sky at the time of year you are working. Locate it in a star atlas (e.g. *Norton's*, *Edmund's*). Make a good finding chart for the Cepheid and the two comparison stars.

Use your chart to locate the Cepheid and the comparison stars. Estimate the brightness of the Cepheid on a relative scale of 1 to 5 by comparison to the reference stars. Assign the number 1 to the brighter comparison star and 5 to the fainter. For example, if the Cepheid appeared to be about half way between the two comparison stars in brightness, it would be rated “3.” To compare the stars to each other, look back and forth rapidly between them. You may wish to try binoculars as well.

Observe your star as often as possible. At the beginning of this project it would be valuable to observe it every night for 1–2 weeks (weather permitting). Continue to observe it as often as you can. The greater the number of observations the better your result will be. Note that the star can be observed at any place from which it is visible, not just from the night lab. The observations will take just a few minutes once you have become familiar with the positions of the variable and comparison stars.

Maintain a log of your observations. For every observation, **record the date, time of day, your location, weather conditions, equipment used (if any), and the estimated brightness of the Cepheid.**

## 6.4 Determining The Period

First, **convert** each date of observation to a day of the year without months (e.g. March 15 = day 74). Then convert the hours of the day to a decimal fraction (e.g. 8 pm = 20 hr/24 hr = 0.833 day).

**Plot** your brightness estimates against the times of observation (with magnitude on the y-axis and time on the x-axis). The brightness scale will be “backwards,” with 1 (brightest) at the top and 5 (faintest) at the bottom. You should see the brightness changing in a regular, periodic fashion, with all cycles of equal length.

**Draw** a **smooth** curve through the plotted points. You should not expect your curve to hit every point exactly, because of unavoidable errors in your estimates. To **get the period**, read from the graph the time of the first maximum, subtract it from the time of the last maximum, and divide by the number of cycles between the two. You must know the pattern of the light curve well enough that you do not miss a cycle. If there is a gap in your observations due to bad weather, use the observations on either side to continue the smooth curve across the gap and determine the number of cycles you missed.

The period determined using the entire set of data is probably the most accurate. An over-simplified method of **estimating the error** in your data is to note that your time measurements were taken only once a day and could thus be off by plus or minus half a day.

**QUESTION:** Does the known period of the Cepheid (as listed at the end of this laboratory) fall in the interval between (your period - error) and (your period + error)? Compare your value to the known period of the star.

## 6.5 Determining The Light Curve

To determine the exact variation of the light over time (i.e. the precise shape of the curve), you need to have many observations over just one cycle. To obtain this you will “fold” all of your observations, covering many cycles, into a single cycle. You use the period to shift your observations in time. You could use the period computed from your data, but for greater accuracy you may adopt the known period given for each variable.

To fold your data, **compute** for each observation the *phase* of the star at the time of observation. This tells in what part of its cycle it was at this time. To do this

1. Choose as a starting point about one day before your first maximum; call this starting point “base time” or *BT*.
2. For each observation, compute the elapsed time (*ET*) between starting point and observation time (*OT*):

$$ET = OT - BT$$

3. Divide by the known period to get a number *N.xx*:

$$\frac{ET}{period} = N.xx$$

where *N* is the whole number of cycles elapsed since *BT* while the fraction *.xx* is the phase of the current cycle. For example, *N.xx* = 5.40 means the star was fourth-tenths (0.40) of the way through the 5th cycle since *BT* when you observed it.

4. Drop the whole number *N* and keep the decimal fraction *.xx*; this is the *phase*. It will always be between zero and one.

Now **make a graph** of brightness vs. phase to obtain the light curve. Draw a smooth curve through the average of your data.

**QUESTION:** How do the variations in brightness behave? Does it take the star about as long to get brighter as it does to fade away, or does one part of the light cycle happen more quickly than the other?

## 6.6 Determining The Distance

You will now use the relationship between period and absolute magnitude to find the distance to your star. (Ask at TA if you are having trouble with these calculations!) This relation was discovered by Henrietta Leavitt in 1912, by studying Cepheids in the Large Magellanic Cloud (LMC), a nearby satellite galaxy of the Milky Way. Since the distance to the LMC is much greater than the thickness of the LMC, she was able to assume that all the stars in the LMC are the same distance away.

Using the period you determined above, obtain the absolute magnitude *M* from the graph (see Figure 7) of Leavitt’s relation of period vs. absolute magnitude (i.e. find your value for the period on the x-axis and read off the corresponding *M* value on the y-axis with respect to the curve). From your observations, determine the average apparent brightness of the Cepheid, *m*:

1. Subtract the magnitude  $m_1$  of the brighter comparison, listed at the end of the laboratory, from that of the fainter,  $m_2$ . This gives the magnitude range ( $MR$ ) covered by the 1 to 5 scale you used.
2. From your data or plot, determine the average brightness of your star on the 1 to 5 scale. Divide this average by 5 to get the fraction of the scale ( $FS$ ) at which your Cepheid has its average.
3. Compute the average magnitude of the variable star. This can be done as follows

$$\bar{m} = m + (MR \times FS)$$

Here  $\bar{m}$  is the average magnitude of the variable star and  $m$  is the magnitude of the brighter comparison star.

For example: Suppose your brighter comparison star had an apparent magnitude of  $m_1 = 3.5$  (=1 on the 1–5 scale) and the fainter  $m_2 = 4.3$  (=5 on the 1–5 scale). This would yield a  $MR = (4.3 - 3.5) = 0.8$ . If your Cepheid had an estimated average of 2.5 on the 1–5 scale, it had  $FS = 2.5/5 = 0.5$  or was halfway between the comparison stars in brightness at magnitude 3.9. ( $3.5 + 0.8 \times 0.5 = 3.9$ )

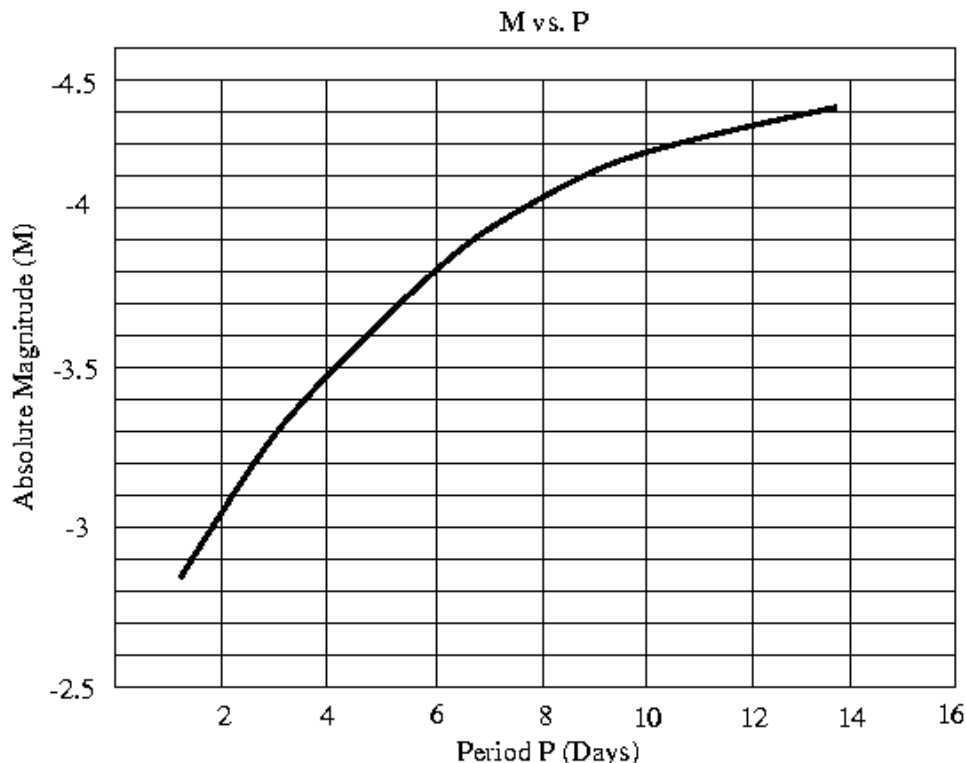


Figure 7: The relation between period and average absolute magnitude for Cepheids. Note absolute magnitude  $M$  is a *negative* number.

Use the following formula (based on the exact definition of magnitude) to find the logarithm of the distance in parsecs:

$$\log D = \frac{m - M + 5}{5}$$

Ten raised to this power gives the distance to your star in *parsecs* ( $10^{(\log D)} = D$ ). Compute the distance and record it in your writeup.



Now use the known period and precisely measured average apparent magnitude (listed as “mag. m” at the end of the lab.) to obtain  $M$  and compute  $D$  for the Cepheid. Compare your results as a percent accuracy (see Appendix D).

**QUESTION:** Comment on the quality of your measurement.

## 6.7 Lab Write-up

You may want to try a preliminary determination of the period of the star about halfway through the semester and discuss the result with your instructor. At the end of the semester, a full report will be due. Use the same format which is required for all other lab write-ups (see Appendix D). Turn in your finding chart and your original observing log sheets. Present your observations and the results of computations in a neat tabular form similar to the examples shown below. Answer all questions in your Discussion section.

SAMPLE DATA TABLE						
Date	Time	Mag.	Decimal Day	Elapsed Time	Phase	
3/15/01	8:00 PM	3	74.83	1.83	.40	
3/16/01	10:20 PM	4	75.93	2.93	.67	
.	.	.	.	.	.	
.	.	.	.	.	.	
.	.	.	.	.	.	

## 7 TELESCOPE OBSERVING II

### 7.1 Time Estimate

In format, this lab is similar to Telescope Observing I, but the target objects are more challenging. Expect to spend at least 2 nights observing in order to complete this lab.

### 7.2 Introduction

This laboratory provides additional experience using small telescopes. **Using the auto-find or GOTO RA/DEC features of the Celestron CPC telescopes, you are to locate and observe 12 objects, keeping written records in the same format as the first telescope observing lab.**

You are responsible for selecting your own target list from the categories listed below. Use the *Observing List of Deep-Sky Objects* given in Lab 4 or online sources (e.g. the Messier or Caldwell Catalogs) to make up a potential target list of about 15 objects that should be visible during normal lab hours. Determine whether these are included on the internal lists of the CPC telescope. If not, obtain the RA/DEC coordinates for the targets and load those into the telescope as needed.

Although the auto-find feature makes it easier to locate objects in the sky, for fainter targets you will definitely want to wait for a clear, moonless night. Use hazy or moonlit nights for brighter objects.

### 7.3 Observing List

Your target list must **not** include any of the objects given on the seasonal list for this semester in Lab 4. It can, however, include up to 4 objects from the list for the alternate semester.

There are seven categories listed below. Include **at least one object** in each of categories 2-7 but **not more than 3** in any category. Planetary observing (item 1) is optional. Observe 12 objects in all.

1. Planets: you can include Uranus and/or Neptune, if these are up
2. Binary stars with a component separation of less than 5"
3. Open star clusters
4. Globular star clusters
5. Diffuse nebulae
6. Planetary nebulae
7. Galaxies

### 7.4 Lab Write-up

Your lab write-up should follow the same format as that for Telescope Observing I. Remember to **do seeing measurements each night** you observe and include them on your observing sheets.

Include your master list of about 15 targets and indicate which, if any, you attempted to find but could not.

## 8 ASTROPHOTOGRAPHY

### 8.1 Time Estimate

This lab will require 1-2 nights (4-8 hours) of observation, depending on the weather, the number of students competing for astrophotography equipment, and your familiarity with the equipment. You must have completed all the required observational labs to be eligible for this lab. Students wishing to borrow the lab's equipment will complete the requirements during a special lab time organized by the TA with potential trips to darker sites (such as McCormick or Fan Mountain Observatories). Students who wish to use their own equipment, must confirm with the TA that their own equipment will satisfy the requirements of the lab.

### 8.2 Introduction

The goal of this laboratory is to learn the techniques for photography of the night sky using cameras attached to small telescopes. Even with modest equipment, it is possible to produce impressive and beautiful astronomical photographs. You will not be able to do as well as the professional color-separation pictures you see in textbooks and on the walls of the Astronomy Department, but you may be impressed with the photographs taken with only modest equipment.

Photographic recording of images is one of the most important technologies introduced to astronomy. The first astronomical photographs were made late in the 19<sup>th</sup> century. Photography offered two revolutionary capabilities: first, it provided permanent records of astronomical observations. Second, it permitted very long exposure times and hence the detection of faint objects far beyond the capability of the human eye. Under dark conditions, the eye integrates a light signal for a few tenths of a second. Film, even though it may be relatively insensitive, can integrate the signal for hours, providing a detectability thousands of times fainter than the eye. The impact of photography on astronomy was profound.

Although it was the dominant detection device used in astronomy for 100 years, film has now been superseded by modern electronic detectors, especially the Charge Coupled Device (CCD). The main advantages of CCD's are much higher sensitivity than film (factors of over 10 $\times$ ), a response which is directly proportional to the amount of light (linear response), and inherently digital output allowing computer processing. CCD's or related technologies are used in all video or digital cameras today. However, the presence of "dark current" (a temperature dependent signal even in the absence of light) means that many commercially-available digital cameras are not well suited for long astronomical exposures under dark sky conditions. Professional CCD cameras used by astronomers employ cooling systems to keep them at temperatures near  $-100^{\circ}\text{C}$  to eliminate the effects of dark current.

This lab was originally written for standard film photography with 35-mm single-lens reflex (SLR) cameras but with the wide availability of digital cameras it has been redesigned with digital single-lens reflex cameras (DSLR) in mind. Most digital cameras emulate the behavior of film cameras and so learning the terms associated with film photography is useful for the aspiring digital astro-photographer.

Normally, students will use digital cameras. However, if you wish to use a film camera, please consult with the TAs. In this case, we recommend you use color slide film which can be processed commercially. The TA's can arrange to have the film processed or the student can take care of the processing privately, but the student is ultimately responsible for the cost. We further recommend that students do not pay for printing, but instead use the Astronomy Department's equipment to scan in 35mm negatives and 35mm mounted slides. The TA will be able to help the student do this in the Astronomy Department Audio/Visual Laboratory.

A student with access to a 35mm SLR or a mid-level DSLR camera with interchangeable lenses will probably be able to use it for most, or all, of the requirements of the laboratory. **However, “point and shoot” cameras cannot be used successfully.** The department can provide all necessary film and digital astrophotography equipment for students who do not have access to private equipment. Hands-on instruction for using the equipment will be scheduled by the TA’s.

The usual procedure for this laboratory is for the TA’s to hold an introductory/organizational meeting explaining all aspects of the lab. Attendance at this meeting is **mandatory** for anyone intending to do the lab. Camera equipment can then be checked out of the night lab for use in the night lab. The TA’s may schedule additional special observing sessions at dark sky locations.

A good reference for the principles and procedures of astrophotography with standard cameras and small telescopes is *Astrophotography for the Amateur* by Michael A. Covington (QB 121.C68.1999).

### 8.3 Lab Write-up

Your lab report will include your best photographs as well as the required written sections. The student will be asked to provide **a digital version of their lab report** for the TA since a print-only version rarely captures the full image quality.

### 8.4 Requirements

Each lab report will include a Data section containing information on **all** the photographs you took (including ones you do not ultimately select for submission). Generate a table with the following information for each photo.

1. Subject and Location of Photograph
2. Date and time photo was taken
3. Camera type, lens type and f-stop used
4. Camera number and image-file name
5. Exposure time, ISO number, white balance
6. Sky conditions (i.e. darkness, transparency, seeing)
7. Whether included in the final selection, and if not then explain why (e.g. out of focus, too faint, too dark, etc. . . )
8. Any digital post-processing applied to the photograph (if applicable)

It is expected that you will take considerably more than the required number of photos. Astrophotography is mastered by trial and error. Experimenting with exposure times, f/stops, etc. . . and getting adequate processing eat up time and exposures. The photos you turn in should be your best work. For these photographs, make sure you also give the above information on the same page or a facing page as the photo.

The TA’s will tell you how many of each type of photograph you are expected to turn in. Here is a list of the various types which are usually part of the laboratory:

#### 1. Fixed Camera Method

- (a) **Star trail exposure of 20 min or longer**, centered on the north pole and including some foreground object (e.g. part of a building or tree)

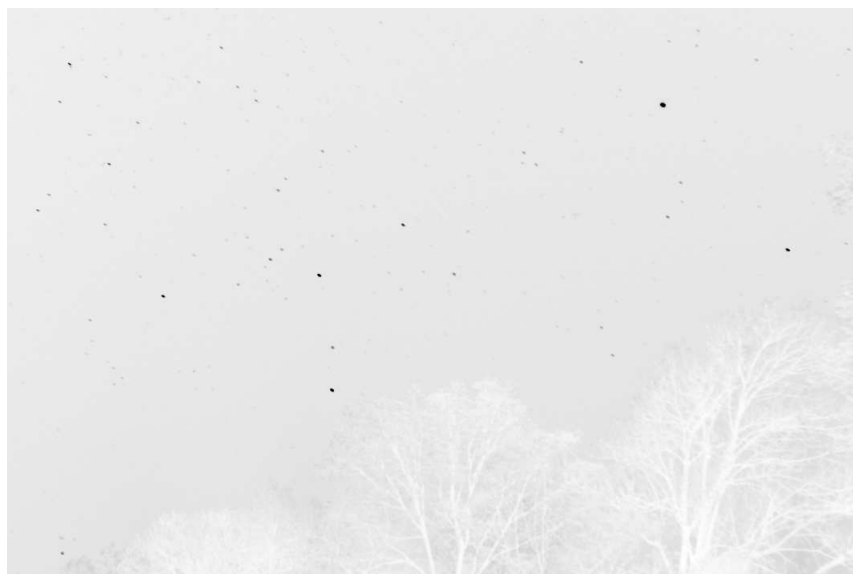


Figure 8: Canis Major photographed using the fixed camera method. The photo has been color inverted for reproduction purposes. A higher resolution version of this photo can be found at <http://www.astro.virginia.edu/class/astrophotography>. Photo by Joe Schaffner, Astr1230; Spring 2009.

- (b) **Short exposure photos of a night scene including an astronomical object** in the composition (e.g. the Rotunda with the Moon in the sky over it)
- (c) **Short exposure, fixed camera photos** of bright constellations or star fields (e.g. Orion or the Pleiades)
- 2. **Motor-Driven Tracking Method**
  - (a) **Long exposure (5 min. or longer) photos** of constellations (preferably the same ones photographed above)
- 3. **Through a Telescope**
  - (a) **Short-Medium exposure photos** of targets, taken through a telescope. Short exposures of bright targets like the Moon and planets are best. Medium exposure using the telescope tracking on deeper sky objects such as M42, M31, M5.

Each photo will be graded on whether it meets the above basic documentation, whether it illustrates the proper technique, and on its composition and aesthetics.

## 8.5 Film Speed (ISO)

Films vary enormously in their sensitivity to light, and the night sky is *much* fainter than the everyday scenes for which films and cameras are commonly designed. Quantitatively, film sensitivity is measured by the **ISO** number, where a large number indicates a more sensitive film. For instance, a 200 ISO film is less sensitive to light than a 1600 ISO film, so you would need to expose longer for a given subject. High speed films tend to sacrifice quality for speed (e.g. they are grainier).

For students choosing to use film, either color slide or color print film can be used. Slide film tends to show fainter stars, have better dynamic range, and give a darker sky background.



Figure 9: An example of a night scene from the VLA (Socorro, NM). A higher resolution version of this photo can be found at <http://www.astro.virginia.edu/class/astrophotography>. Photo by Rachael Beaton and George Privon, Fall 2007.

We do not recommend black and white film for commercial processing because it requires a custom process and is therefore more expensive and troublesome.

DSLR cameras use the concept of film speed to express the sensitivity of the CCD detector to light. DSLR cameras, however, have the advantage of being able to change the ISO for each individual exposure. We recommend that students start with the lowest ISO for their first attempt at a photo and then adjust the ISO based on feedback from the first image. Just as with film, using a higher ISO will reduce the final quality of the image, therefore to get the best image quality, use the lowest ISO possible to obtain the desired image. The TA will be able to advise special situations which may demand using a higher ISO (e.g. obtaining good photos of the moon or of a planet).

## 8.6 CCD Basics

A CCD (Charge-Coupled Device) is a thin silicon detector which has been physically divided into a two-dimensional grid. When light strikes one particular square on the grid, called a **pixel**, an electron is freed from the silicon. As the CCD is exposed to light for some length of time, these free electrons build up in direct proportion to the amount of light striking the detector at that location. When the exposure is complete, a read-out register counts the number of electrons in each pixel and records this number digitally. A computer program can then be used to reconstruct the image by noting the varying intensities of light at different pixel locations.

The first CCD was a product of Bell Labs in 1970. CCDs made their astronomy debut in the mid-70's, gained great popularity in the mid-80's, and have since largely replaced traditional photographic methods as the preferred tool of astro-imaging. Among other things, they are much more sensitive (particularly to red light), they provide a signal that is directly proportional to the amount of light (linear response), and their output is inherently digital, allowing easy processing using a computer.

Commercial CCDs, like those used for this lab, are designed to record three images together – one red, one green and one blue – and these are combined automatically to yield a color image in JPEG form (it is sometimes possible to keep the images separate using “RAW” form but we won't use this mode in this lab). In different lighting conditions it is necessary to combine the red, green, and blue images with slightly different weighting factors (for example,

incandescent lighting over emphasizes red, so the red image needs to be suppressed). You will have to experiment a bit with the white balance setting for your different images. In practice, the “incandescent” setting seems to work best for low light-level pictures.

## 8.7 Planning Your Observing Run

A little planning can save you lots of wasted time. For example, if you want to photograph the Moon or planets against a particular foreground scene, consult a sky calendar and planisphere first to find out when the object will be best placed in the sky. Take the field of view of your lens into account. An object which is very high may not fit in the frame with your intended scene, while an object which is very low might be blocked by something in the foreground. A wide angle lens will make the Moon appear tiny. Find a spot where trees and lighting do not get in the way. City lights are the biggest obstacle to getting good constellation photographs.

For constellation photography, do some indoor planning with your star atlas and planisphere. A cardboard frame representing the angular field of your camera is a big help. A 50mm lens, for example, covers a rectangle of  $27^\circ \times 40^\circ$  against the sky. Experiment to find the best way to center a constellation in the field of view. You may find it is too big to fit, or too small to be interesting, and can then choose a different subject without wasting film. Also, be mindful of the relative brightness of the stars in your constellation as well as the phase and location of the moon. A full moon will wash out all but the brightest objects in its vicinity.

## 8.8 Procedure

### 8.8.1 Data Log

Make a **data log** to record your work. The data log should contain an entry for every image taken and should show the “trial and error” learning process clearly. An example data log is given below.

Subject & Location	Date & Time	fstop	Camera	Exposure Time (sec)	Lens	ISO	WB	Conditions	Reason not used
Ort, OH	4/21 9:21	4.5	C	15	50 mm	400	Cloudy	Hazy	Lens was not focused (oops)
Gem, SO	4/21 9:57	1.8	C	13	50 mm	400	Cloudy	Hazy	Condensation
Gem, SO	4/21 9:59	1.8	C	13	50 mm	200	Cloudy	Hazy	Condensation, red field due to poor WB
Gem, SO	4/21 10:08	1.8	C	15	50 mm	200	Fluorescent	Hazy	Condensation
Gem, SO	4/21 10:10	2.0	C	30	50 mm	100	Fluorescent	Hazy	Condensation
Gem, SO	4/21 10:14	1.8	C	30	50 mm	400	Fluorescent	Hazy	Double image, condensation
Canis Maj, OH	4/22 8:28	1.8	B	20	50 mm	200	Fluorescent	Clear	Foreground not in focus

Figure 10: Example Data Table. Joe Schaffner, Astr1230; Spring 2009.

## 8.9 Equipment

The following DSLR equipment is available for check out in the Night Lab.

### 1. DSLR Camera

The Astronomy Department has four Canon Rebel Rebel Xsi cameras. Figures illustrate the basic buttons on the camera (high resolution versions can be found here: <http://www.astro.virginia.edu/class/astrophotography>). The required TA organizational meeting will explain the function of the cameras in more detail. Each

camera has 2 GB of storage and is packaged with the cables needed to download the photos to a computer.

## 2. **Wireless Remote**

Each camera is equipped with a wireless remote which controls the shutter. The remote will allow the student to take a photo without touching the camera, for example when the camera is attached to the telescope or during long exposures to prevent jarring. When the camera is operated in “Bulb” mode the first click of the remote will open the shutter and the second click will close the shutter. This device, thus, allows for exposures of indefinite length. The TA will explain how to configure the camera for use with the remote.

## 3. **50 mm Lenses**

The Astronomy Department has four camera-dedicated 50 mm fixed field of view (FOV) lenses which are packaged with each camera. These lenses are best used for larger scenes, such as full constellations.

## 4. **200 mm Tele-Photo Lenses**

The Astronomy Department has two 200 mm Tele-Photo lenses. These magnify the image but have a correspondingly smaller field of view, so they’re best used for photographing small regions of the sky such as star clusters or double stars.

## 5. **Fish Eye Lenses**

The Astronomy Department has two 10 mm Fish-Eye lenses. These lenses have a very large field of view, though with significant image distortion near the periphery. They can create stunning images which combine large areas on the sky with large foreground regions.

# 8.10 Astro-Photography Methods

The procedure for each required astrophotography method is described next.

## 1. **Fixed Camera Method**

For the first part of the laboratory you will need a camera with a **50 mm lens**, a **tripod** to hold the camera steady during the exposure and a **wireless remote** to open and close the shutter without jarring the camera.

### (a) **Star Trails**

If the shutter is left open for several minutes while the camera is pointed in a fixed direction, the stars will appear to move across the frame as the Earth rotates under the sky. On the resulting photo, each star will have produced a trailed image.

You can practice with some shorter exposures, but for the first shots you intend to turn in, deliberately leave the shutter open for **15-30 minutes**, centered on Polaris. The star images will trail across the film in concentric arcs with the Celestial North Pole as the center. Be sure to include an interesting foreground object to reference the horizon and improve the aesthetics/composition (e.g. the dome housing the telescope at McCormick Observatory, another building, or a tree). The background sky light will fog the film for long exposure times. One should, as always, experiment with different f/stops and exposure times, depending on the light conditions.

Students should also be aware of passing *airplanes* which will leave bright streaks on the photo if they fly through the field of view during an exposure. In such a situation, students should place a dark object, such as a hat, in front of the lens until the plane passes. **BE CAREFUL NOT TO BUMP THE CAMERA!**

A good star trail picture will have an interesting and well exposed foreground object with sharp clear star arcs in a dark sky.



(b) **Night Scene**

To capture an astronomical object against a foreground night scene you will have to compromise on exposure time, f/ stop and ISO. A scene with artificial lighting will be well exposed in 1/30 of a second or less, but this is too short an exposure even for bright stars (which require at least a few seconds). Thus, a brightly lit foreground and a faint constellation make a poor combination. Instead, the main objects in your composition should be a bright object, such as a gibbous or full Moon or a planet, and a faintly lit foreground, avoiding direct lights and dark shadows. (McCormick observatory dome makes a good foreground in exposures of **15-30 sec.**) The f/ stop should be at its smallest possible value (widest aperture), e.g. f/1.8-3.5. Be sure to take a number of shots of the same scene, changing the shutter speed, aperture and even the ISO. Your pictures will be judged on exposure, composition and how crisp the images are.

(c) **Short Exposure Constellation Shots**

An exposure of **3-30 seconds** should catch all stars visible to the naked eye and bring out features in a bright constellation that cannot be seen without binoculars or a telescope (e.g. M42 in the constellation Orion appears very colorful when the constellation is photographed). Constellations near the pole can have longer exposures, while constellations near the Celestial Equator require short exposures to prevent star trails. A 50 mm lens will cover large constellations and still let in enough light for short exposure times. For best results, shoot this with the aperture wide open (f/1.8-f/2.5, exposure times can be short to avoid star trails). A lens up to 135mm may be used with longer exposures to isolate a particular constellation pattern. Take care, however, to keep exposures short enough to ensure point-like star images, with no trailing. The amount of trailing for an exposure time will depend on the focal length of the lens.

A good picture will clearly show a constellation pattern, with no visible trailing of star images. Enhanced colors and features that are not normally visible to the naked eyes are additional qualities to strive for.

2. **Motor-Driven Tracking Method**

To photograph fainter stars or faint, diffuse objects like nebulae or the Milky Way, exposure times of several minutes are necessary. To hold the image steady on the film, the camera must track the stars across the sky as a clock-driven telescope does.

(a) **Piggy Back Method**

The simplest way to provide the tracking motion is to attach the camera on top of a well-aligned, motor-driven telescope, so it rides piggy-back to follow the stars. The telescope serves no purpose other than to hold the camera and track the sky. Telescopes G and H have piggybacks permanently attached to the telescope. The TA can show you how to properly attach the camera to the mount.

(b) **GOTO Mount**

An alternative is to use a special **GOTO mount**, which is essentially a telescope drive you can mount on top of a camera tripod and uses a 12 volt DC power source. Screw the GOTO onto the tripod as you would a camera. Using the tripod controls, set up the GOTO mount so you can see Polaris through the finder located in the GOTO mount. When this is done the mount is polar aligned, and, when turned on, will track the stars. Remember, once you have lined up the mount with Polaris, do not touch the tripod controls. Otherwise you may lose the alignment of the mount. If you are having trouble seeing polaris through the finder, fire a laser through the goto mount and see where the laser points to in the sky. Remember to never look directly into the laser.

Now you can use the GOTO controls to move the camera anywhere in the sky. The GOTO mount can be plugged into an outlet using a 12 volt DC adapter (or by using

car battery clips located in the GOTO storage case). Plug in the drive, then flip the switch marked “POWER”. A red light on the side of the mount should come on and you will hear the drive tracking. If the light does not come on, check to make sure the plugs are connected properly.

For the longer exposures it is a good idea to stop down the aperture to about an f/stop of 4 or 5.6. This prevents stray light from fogging the shot.

It is recommended that exposure time be fixed at **5–20 minutes** and several shots of each scene be taken with differing f/stops.

If your GOTO mount is perfectly aligned, you will not have any star trailing present in your photos. Although most tracked shots will not have perfect point-like star images, the trailing should be minimized. As usual, a dark sky and easy-to-discern constellation patterns are positive features. The long exposure, tracked photos should bring out many more details than were in the short exposure fixed-camera method pictures.

### 3. Methods Using a Telescope

There are obvious limitations to using small camera optics to observe the sky. The combination of a camera with a telescope is an obvious next step. Unfortunately, you need specialized equipment to really do a good job of photography through a telescope. Here, we use two relatively crude methods which combine a camera with a telescope. The telescope essentially acts as a telephoto lens of very long focal length.

#### (a) Prime Focus Photography

The most rewarding technique involves mounting the camera body onto the back of the telescope, in place of the eyepiece. This is accomplished with the use of a piece of equipment called a **T-adaptor**. One end of the T-adaptor screws onto the back of the telescope and the other end screws into the camera adaptor T-ring. The T-ring attaches to the camera in place of the lens. This method utilizes the light collecting power of the telescope and its long focal length. Once attached, the telescope focus will need to be adjusted to give a sharp image (and will be at a significantly different location than with the eyepiece).

In practice, one is using the telescope as a 2000 mm tele-photo lens.

#### (b) Afocal Photography

Another method is called *afocal photography*. Here, you keep the camera lens on the camera body and take photographs with the camera aimed through the eyepiece of the telescope. This method takes advantage of the fact that when an eyepiece has been focused for your eye, it is producing a parallel output beam. The camera, if focused for infinity, can convert this beam to a sharp image in the film plane. No special equipment is required, but alignment is tricky, and you will do best with a tripod for the camera. Find your target in the telescope, and focus the eyepiece for your eyes (wear your glasses, if any). Then, with the camera focussed for infinity, line it up with the eyepiece and snap the picture. You may have to adjust the distance between the eyepiece and camera for best filling of the field of view. For bright objects, short exposures, and narrow fields of view, this is a quick and acceptable technique.

#### (c) Eyepiece Projection

A second but more reliable technique, also confined to narrow fields of view, is *eyepiece projection* photography. Here, you remove the camera lens and use the eyepiece to project an enlarged image of the target directly onto the camera CCD plane. A special adaptor is needed which mounts to the telescope at one end and the camera at the other. On the Celestron 8-in telescopes, remove the diagonal eyepiece holder and place the camera assembly on the main optical axis of the telescope. The adaptor includes a sleeve to hold the eyepiece in place. Be sure the eyepiece faces the normal direction. The distance between the lens and the film plane is fixed, so to

focus the image, you must adjust the distance of the adaptor/camera assembly from the telescope primary (using the telescope's eyepiece focusing adjustment) while looking through the viewfinder of the SLR camera. This can be tricky. Special camera bodies with more precise focusing screens are available.

Though the telescope, any vibration will be magnified. When taking a picture, you will find it helpful to follow these steps:

- (a) Find the target and focus the telescope/camera.
- (b) When you are ready to expose, announce that fact to everyone in the vicinity. Ask them not to touch the telescope and to stand still when they are near the telescope.
- (c) When taking a long exposure shot, the actual act of pressing the shutter release may jiggle the telescope if the camera is attached to it. To prevent this from happening, hold a large dark object (such as a clipboard or dew cap) in front of the dew shield. Then trip the shutter release. Continue to block the view of the telescope for a few seconds to let the vibrations die down. After three or four seconds, unblock the view so the film can expose. When the exposure is done, block the view again, then release the shutter to end the exposure.
- (d) It is difficult to determine what exposure you need to get a good shot. Thus you will have to **bracket** your pictures (i.e. estimate the exposure time needed and then take several shots with faster and slower speeds). This will ensure that you will get the correct exposure.

Afocal or eyepiece projection photography can yield beautiful pictures of the Moon and planets. Photos of distant galaxies and nebulae are more difficult because of the longer exposures needed and should be attempted only after success on brighter targets. Good prints require trial and error and the printing of the negatives becomes as important as the initial setup to the final success.

## 8.11 Post-Processing

For this lab no additional digital processing is required, but students may edit their photos if they wish. The student should check with the TA to see if post-processing is permitted for submission of their photos.

Students who wish to use film will need to have the film processed at a retail camera shop. Students are advised not to use 1 hour photo style processing. Once the film is processed, the student has the option of scanning their film using the film scanners available in the Audio/Visual lab of the Astronomy Department or the Digital Media Lab at Clemons Library.

Students are required to submit digital versions of their photographs in addition to submitting printed copies.

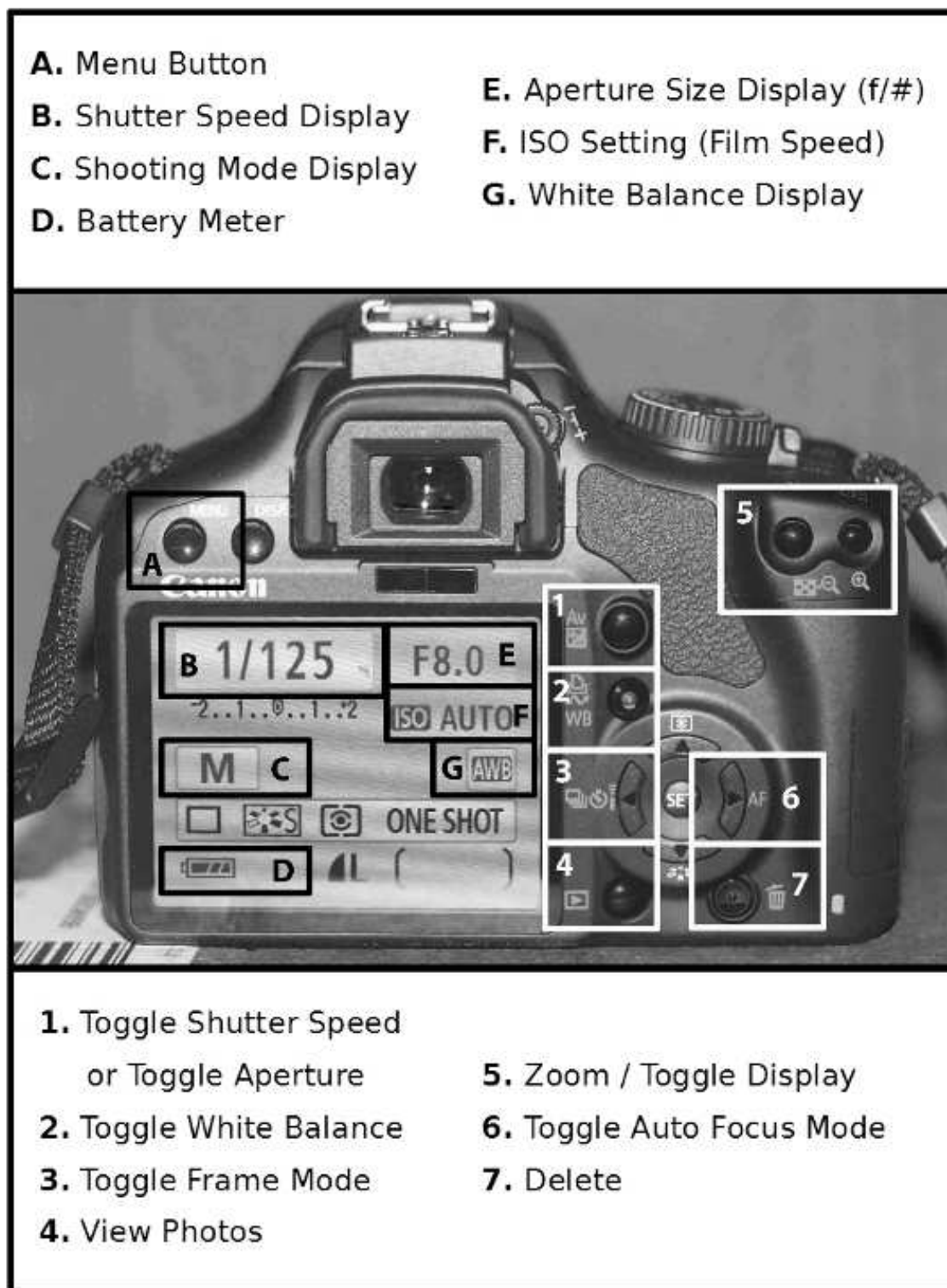


Figure 11: Diagram of the back of the Canon Rebel Xsi displaying buttons commonly used in this lab. A higher resolution version of this photo can be found at <http://www.astro.virginia.edu/class/astrophotography/>.

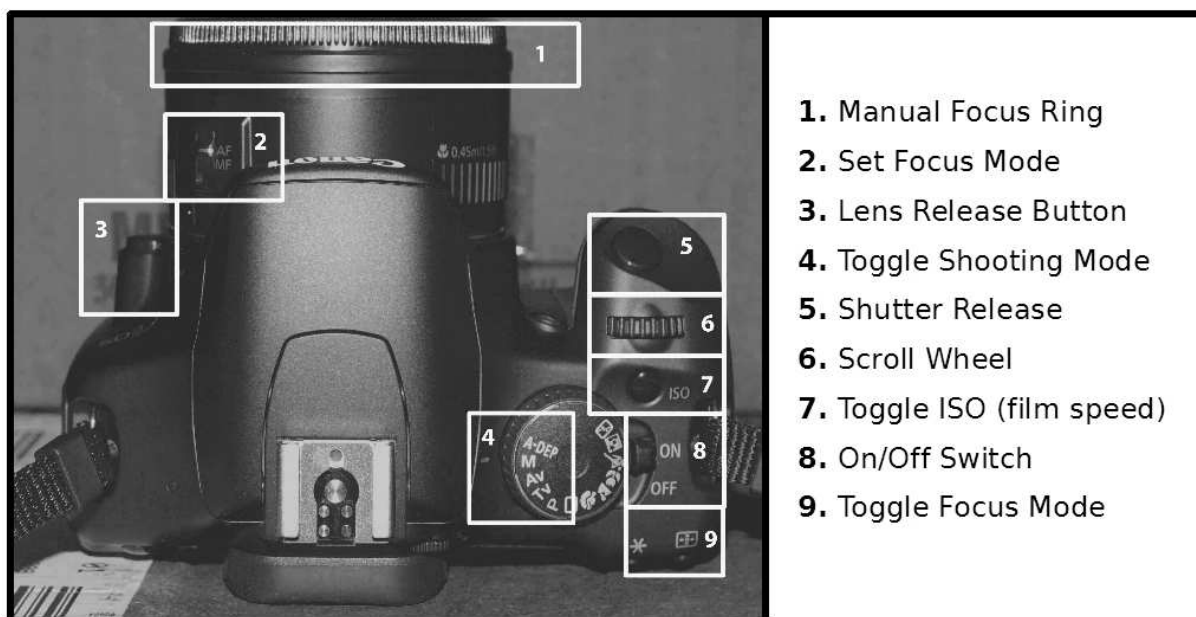


Figure 12: Diagram of the back of the Canon Rebel Xsi displaying buttons commonly used in this lab. A higher resolution version of this photo can be found at <http://www.astro.virginia.edu/class/astrophotography/>.

## 8.12 Camera Description

### Lens

The DSLR has interchangeable lenses, of which the 50 mm and 200 mm lenses are available. The number refers to the focal length, and the longer the focal length the higher the magnification, the smaller the field of view, and the less light falls on the CCD.

### Focus Ring

Although most lenses have an auto focus option, for the purpose of astro-photography, the lenses should be focused manually. For images of astronomical objects, the focus should be set on infinity ( $\infty$ ). To obtain images of objects in the foreground, however, students will need to illuminate these objects with a flash light and manually focus the camera on the objects. Manual focusing with a camera works just like manual focusing with a telescope. The accuracy of focusing will depend heavily on the f/ stop used in a photograph. The f/ stop sets the depth of field of an image (discussed below).

### Aperture: f/ stop

This adjusts the diameter of the open area of the lens and hence determines how much light reaches the film. The *focal ratio* or *f/stop* is defined to be the ratio of the camera focal length to the diameter of the lens opening. The numbers shown (f/stops 1.8, 2.8, 4.0, 5.6, ...) are chosen so that changing the aperture from one setting to the next changes the amount of light striking the film by a *factor of two*. The *higher* the number, the *smaller* the lens opening and the less light will strike the focal plane for a given exposure time. Most astronomical photos require smaller f/stops (wider apertures) because these f/stops are 'faster,' they accumulate more light in the same amount of time than a more narrow aperture.

In the situation that you are photographing two scenes together, one nearby and the other far away, you will want to choose a higher f/stop (e.g. f/8). The reason is that a low f/stop (wide aperture) cannot get both scenes in focus at the same time. (The reason is that images from objects at different distances fall at slightly different distances behind the lens, and only one of the will coincide exactly with the CCD detector. If the lens is wide, then the tolerance for a mismatch between the location of the image and CCD is more severe, and the range of distances that are “in focus” is smaller. One says that the “depth of field” is shallow for low f/stops ).

### **Shutter Speed Control**

The shutter also controls how much light reaches the CCD by how long it stays open. The shutter speed control gives the denominator of the exposure time: 1, 2, 4, 8, 15, ... indicates 1, 1/2, 1/4, 1/8, 1/16, ... seconds. A change in setting of one of these steps changes the amount of light by a factor of two. Any camera used for astrophotography must have a time exposure setting, usually indicated by “B” or Bulb setting. When set to bulb, the camera will expect a signal from the user both to open and then close the shutter (instead of closing the shutter on its own).

### **8.13 Requirement Checklist**

Specific requirements will be given at the introductory session.

## 9 METEOR SHOWER OBSERVATIONS

### 9.1 Time Estimate

This lab requires you to observe a meteor shower for one night. This observation will be done outside of the laboratory, usually in the early morning hours between midnight and dawn. A dark site and clear weather are important. A moonless night is desirable but not necessary; however, you should avoid times around Full Moon. **Advance planning is essential**, as meteor showers only occur at certain times of the year (See Table I).

### 9.2 Introduction

**Meteors** are bits of cosmic debris (icy or rocky) which, while following their paths through space, intersect the Earth. The intense heat generated by friction as they rush through the atmosphere causes them to glow. They range in size from objects as small as grains of sand to large rocks weighing several hundred pounds. Usually they are completely vaporized and vanish in a streak of light. **Fireballs** are very bright meteors which may light up the entire landscape. Fireballs may exhibit sudden bursts of light or explode. Any objects which survive the heat of entry and strike the Earth's surface are referred to as **meteorites**.

Meteors originate primarily from comets, being the debris swept out of the comet by particles and radiation from the Sun. As a comet orbits the Sun, it leaves a trail of dust behind which also orbits the Sun along the comet's path. Periodically, the Earth intersects a comet orbit along which swarms of particles are moving, causing an unusually large number of meteors to enter the atmosphere. Such an event is referred to as a **meteor shower**. Since the particles are spread out around the comet's orbit, and the Earth may spend some time in the vicinity as it orbits the Sun, these showers can last several nights, usually with a well-defined peak of activity occurring somewhere in the interval. Because all the meteors in a swarm are moving parallel to each other through space, it will appear to an observer watching them that they are all diverging from a single point in the sky. That is, from the observer's perspective, the objects appear at the point called in drafting the "vanishing point" and appear to diverge from this point as they get closer (the "railroad track effect"). This point is called the shower **radiant** and is designated by the constellation in which it appears to lie.

In addition to ice and dust particles moving in swarms, interplanetary space is filled with an evenly distributed thin cloud of small particles. This is due to the gradual breakup and dispersal of swarms. These other particles intersect the Earth at random times and in random directions, giving rise to a "background" of **sporadic** meteors unassociated with showers. Under clear, dark sky conditions, you could see perhaps 10–20 sporadic meteors per hour, mostly not very bright.

### 9.3 Requirements

In this lab, you are to observe a meteor shower for three hours, noting the magnitude, direction, etc. of every meteor seen in a chosen area of the sky on a star map. Using your data, you are to deduce the approximate position of the radiant, the brightness distribution of shower meteors, and the zenithal hourly rate. Your observations and calculations are to be written up in an orderly fashion.

## 9.4 Equipment

You will need the following:

1. A watch or clock.
2. A light, wooden straight edge, like a yardstick, about three feet long.
3. A photocopy of a sky map for recording data. This should contain the expected radiant of the shower but also cover a large section of the sky around it, say about  $80^\circ$  in diameter.
4. Norton's/Edmund's Sky Atlas or a planisphere and a good knowledge of the constellations
5. A notebook and red-filtered flashlight.
6. Suitable warm clothing.
7. You do not need binoculars to observe meteors (since you want to see as much of the sky as you can at all times), but if you have a pair, bring it along just to look at other things in the sky.

## 9.5 Observations

You **must have a clear, dark sky**, which means you will have to observe from some convenient and dark, but safe, place outside of town. Don't observe alone. Avoid hazy nights and moonlight. Pick a location where you can see the appropriate part of the sky (and preferably all) without any obstruction. Students have had good success observing from the Blue Ridge Parkway. Most showers are best observed after midnight.

Choose a shower to observe from the list at the end of this laboratory. Your instructor can suggest the most promising showers for the current semester. Watch only the area of the sky in the vicinity of the radiant which can be seen without moving your head. Enter in your notes the **date**, the **times** at which you started and stopped observing and the **area of the sky** observed. Specify the area either in terms of RA and Dec. of the boundaries, or by the stars around the edges of the field. Also note the presence of clouds, artificial lights, moonlight, etc., which might interfere with your observations. For every meteor you see, record the following:

1. Direction and length of path.
2. Brightness.
3. Unusual behavior.
4. Confidence level of the observation.

Explanations and suggestions are given below:

**Direction and path length.** As soon as a meteor is seen, hold up the straight edge at arm's length against the sky along its path. Note which stars are closest to the path. Estimate the path length by comparison with the separation between a pair of stars nearby. The length and direction of path can then be marked directly on your star chart. See Fig. 13 for an example.

**Brightness.** Estimate it by comparison with nearby stars. Later, you may look up the magnitudes of these stars and deduce the magnitude of the meteor. See Fig. 13.

**Unusual behavior.** Most meteors are quick, white flashes of light. If one was strongly colored, left a smoke trail, fragmented, seemed to make a noise, or was otherwise out of the ordinary, make a note.



**Confidence level.** This is an estimate of the reliability of the data, made at the time they are recorded. You might rate your observations as:

1. Normal reliable observation
2. Observation obtained under some difficulty
3. Unreliable observation

Common causes of unreliability include interference from lights, a meteor just glimpsed at the edge of the field of vision, a rushed observation due to a high rate of meteors, etc. Outline your rating method in your notes.

If the rate of meteors is so high that all of the above data cannot be observed and recorded in the intervals between events, do the following:

1. During the first half of the session, keep an accurate count and make brightness estimates.
2. During the second half, determine the direction of flight of every meteor possible. You may miss a few while making notes.

## 9.6 Lab Write-Up

From your notes and/or star chart, “reduce” your data on every meteor to a neat, tabular form. Convert brightness estimates to magnitudes. See figure 14 for an example.

To determine the position of the shower radiant, **plot** the flight paths on a star atlas and extend them backwards until they intersect. They will not intersect in a single point, because (a) the radiant has a finite area, (b) some of the meteors may be sporadic meteors unassociated with the shower, and (c) a straight line on your atlas is not a true representation of the meteor’s path through the sky. **Give the boundaries** of the region where most of the paths intersect.

Eliminate any obvious non-shower sporadic meteors. Then **make a histogram** showing the distribution of observed meteors in brightness. Divide the magnitude range into one-magnitude intervals, thus:

interval	1:	0.5 - 1.5 mag.
interval	2:	1.6 - 2.5 mag.
interval	3:	2.6 - 3.5 mag.
.	.	.
.	.	.
.	.	.

**Convert** your count of the number of meteors to a zenithal hourly rate. This is the number you would have seen if you had been at the point on the Earth directly facing into the stream, instead of at your true position part way round the Earth’s curve where some meteors were below the horizon. To do this:

1. Divide the total number of meteors observed (or the number counted in the first half of the session as explained above) by the fraction of an hour which you observed. For example, if you observed for 190 minutes, compute

$$\frac{\text{number seen}}{(190/60)}$$

This gives the observed hourly rate.

2. Calculate the angle  $\theta$  where  $\theta = \text{altitude of radiant (degrees)} + 6^\circ$ . The  $6^\circ$  is a correction for haze near the horizon.
3. Divide the observed rate by the  $\sin(\theta)$  to find the zenithal hourly rate.

You are to hand in your final table of results, computations, histograms, and the plot showing the path intersections. Also hand in your rough notes and plots made while observing. These will be graded on the basis of completeness, clarity, accuracy, and neatness. The required sections listed in Appendix D are to be included.

## 9.7 List of Prominent Showers

Given in Table I are the shower name, date of peak activity, the interval during which the hourly rate is at least 25% of the maximum approximate hourly rate, the total range during which shower members may be seen, and the maximum approximate hourly rate. Table II lists (for the same showers) the shower name, the location of the radiant, and comments. The instructor may have additional comments concerning the best showers.

TABLE I

Name	Peak	> 25%	Total Range	Hourly Rate
Quadrantids	Jan. 3	14 hours	Jan. 1–6	50
Lyrids	April 21	2 days	April 19–24	5–15
$\eta$ Aquarids	May 4	3 days	April 21–May 12	10–30
June Lyrids	June 15	–	June 10–21	8–10
$\delta$ Aquarids	July 29	2 weeks	July 15–Aug. 18	10–30
$\alpha$ Capricornids	Aug. 1	10 days	July 17–Aug. 21	5
Perseids	Aug. 12	4.5 days	July 25–Aug. 18	50
Draconids	Oct. 10	6 hours	Oct. 7–10	–
Orionids	Oct. 22	2 days	Oct. 2–Nov. 7	25
Taurids	Nov. 1	30 days	Sept. 15–Dec. 15	5–10
Leonids	Nov. 17	4 days	Nov. 14–20	5
Geminids	Dec. 14	2.5 days	Dec. 4–16	50

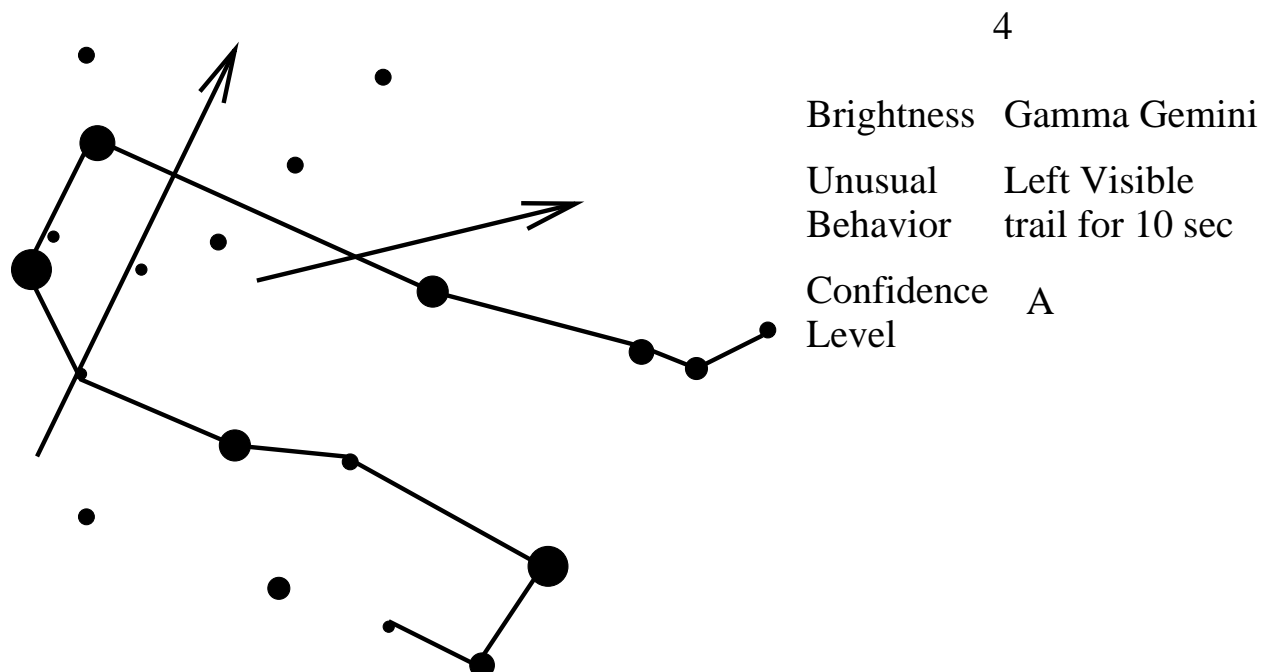


Figure 13: Two meteors seen passing through Gemini. You draw the path in your star atlas and make notes of their appearance.

TABLE II

Name	Radiant	Comments
Quadrantids	Between Boötes and handle of Big Dipper.	Reliable shower, but most meteors are faint. Radiant rising after midnight.
Lyrids	Between Lyra and Hercules.	Individual meteors bright, but shower as a whole is faint. Morning hours best.
$\eta$ Aquarids	Near Water Jar in Aquarius.	Rather far south, requiring a clear southern horizon. Radiant rising after 2 AM. Debris from Halley's Comet, as are the October Orionids (below).
June Lyrids	Just south of Vega.	Mostly faint. Radiant up all night. Discovered by amateurs in 1966.
$\delta$ Aquarids	Two radiants: one in Water Jar and one near $\delta$ Aquari.	Two diffuse groups with a broad peak and poorly defined radiants. Shower members bright.
$\alpha$ Capricornids	Near $\alpha$ Capricorni.	Bright meteors with some fireballs. Radiant can be confused by $\delta$ Aquarid meteors.
Perseids	Between Perseus and Cassiopeia.	Fast meteors, with some trains and fireballs. Radiant well placed after midnight. Most reliable of all showers.

TABLE II (CONTINUED)

Name	Radiant	Comments
Draconids	Head of Draco.	Usually poor, but intense when immediately following passage of the parent comet Giacobini-Zinner. This indicates material not yet well-dispersed around the origin. Radiant highest in early evening.
Orionids	In Orion's upraised club.	Derived from Halley's Comet like the $\eta$ Aquarids above. Very fast, mostly faint; a morning shower.
Taurids	Between Hyades and head of Cetus.	Slow, bright meteors with fireballs. Diffuse radiant, well placed after 10 PM.
Leonids	Sickle of Leo.	Striking Earth head-on, very fast. Many bright, some fireballs. Cometary material is apparently clumped into dense regions behind the comet (Tempel-Tuttle) and elsewhere around the orbit, so shower is usually weak but occasionally spectacular. Very good in 1998 and 1999. A morning shower.
Geminids	Near Castor.	Bright meteors in a strong, reliable shower. Well placed after 10 PM.

## 9.8 Note on Advanced Planning

Meteor showers only occur at certain times of the year so it is vital that you plan in advance. This should include selecting a site for observation off Grounds.

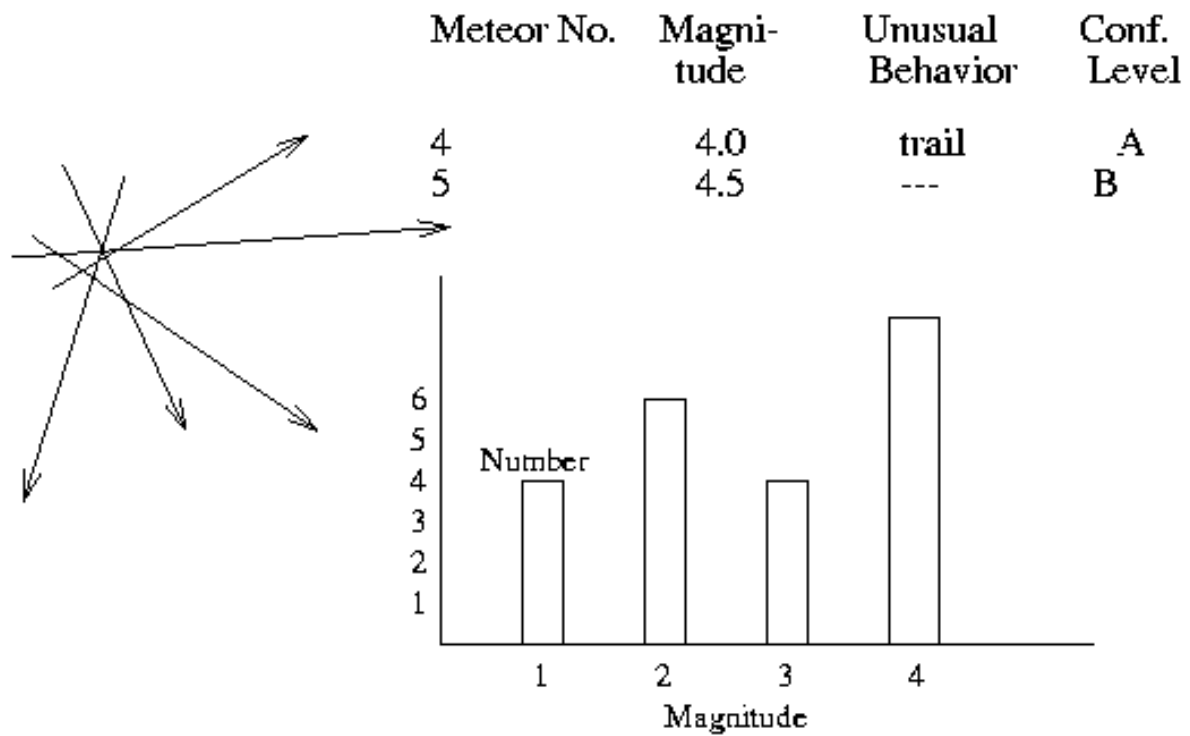


Figure 14: From your drawing, you obtain information on the position and direction and convert your observational record to the above histogram form. Note how the paths are extended backward to determine the radiant (above left). The histogram shows the brightness distribution at one magnitude intervals (above right).

## 10 ROTATION OF THE SUN FROM SUNSPOT OBSERVATIONS

### 10.1 Time Estimate

This lab requires you to make several daytime observations of the sun over the course of 1-2 weeks. The observations should take less than fifteen minutes each. Contact the TAs for dates and times of solar telescope availability.

### 10.2 Introduction

Sunspots are areas of intense activity on the Sun's surface associated with strong magnetic fields. They appear darker than the surrounding surface, because they are cooler and give off less radiation. The exact number of sunspots varies from day to day, as spots are created, evolve, and disappear. The average number varies in a cycle of about 11 years. The last solar maximum occurred in 2000.

Spots change not only in appearance and number but in position. Spots appear to move across the surface of the Sun because the Sun itself is rotating about an axis, and because the Earth is orbiting the Sun and our own position changes from day to day. In this laboratory you will use observations of spot positions made over several days to determine the rotation period of the Sun and the orientation of its axis. We are assuming that a given spot is fixed in place on the Sun's surface and does not drift about.

The laboratory work involves three main steps. First, you must obtain a series of drawings of the Sun showing sunspot positions over an interval of several days. Second, you will transform the apparent position of a spot on the flat image of the Sun to its true position on the Sun's spherical surface. Third, you will determine the rotation period of the Sun by measuring the angular motion of the spot from day to day.

To do the laboratory you will need a series of blank diagrams, a protractor, compass, and ruler. Some simple arithmetic is also necessary. Read through the entire laboratory before beginning.

### 10.3 Lab Write-up

As usual, you are required to produce a complete write-up. You will turn in your original sketches and calculations as your data section.

### 10.4 Observations

**WARNING: NEVER LOOK THROUGH THE TELESCOPE AT THE SUN. BLINDNESS CAN RESULT.**

A "Sunspotter" telescope can be set up outside the Astronomy Building on clear days for viewing the Sun Monday through Friday, though prior arrangements with a TA are necessary. The telescope projects an image of the Sun onto a screen. You are to copy this image onto your own diagrams.

Each day you observe the Sun, carefully copy the positions of all visible sunspots onto a diagram. To determine West, note which direction the Sun drifts. As the Earth rotates, the Sun will continually drift westward out of the field. To determine South, gently tilt the telescope northward. The Sun will appear to move directly South in the field. Label the directions N, S, E, and W and date and time of the observation. You will need at least five

diagrams covering a six to twelve day interval, so you should plan to draw the Sun every clear day for the duration of the experiment. The best results are obtained if the diagrams are of consecutive days. (Tip: check the long-range weather forecast before beginning.)

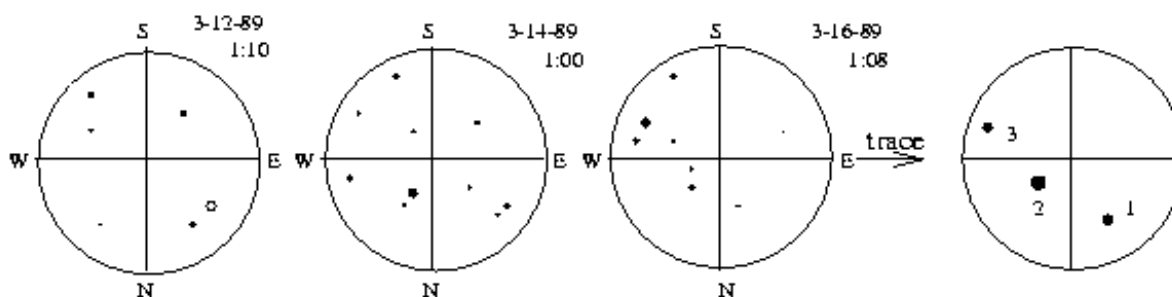


Figure 15: Sample sunspot observations.

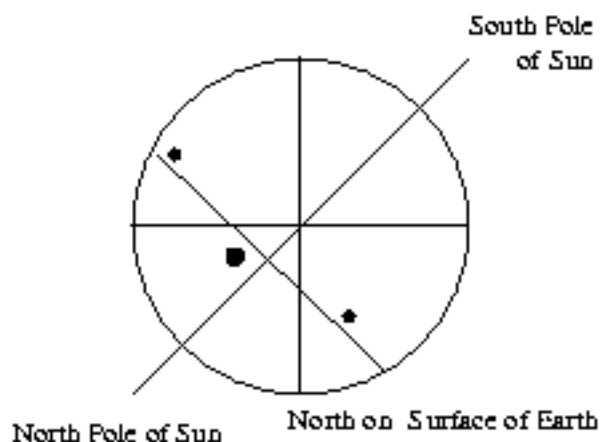


Figure 16: Determination of the Sun's rotation axis.

### 10.5 Transforming Spot Positions

When you have a sufficient number of observations, arrange all your diagrams side by side in order. Compare the spot patterns from day to day. Find a spot or spot group you can identify on every diagram. Notice how its position changed over the interval of your observations. Mark it on each diagram thus: — • —. Now take a blank diagram and trace each day's observation of this spot onto it. Be careful to line up the axes and trace the position carefully. Number the positions in order as in figure 15. If you are unable to follow any of the spots for five days, you will have to collect more data before continuing.

You now have a diagram showing the positions of a single spot over the interval of your observations. The positions should fall nearly along a straight line across the Sun. Draw the

straight line which comes closest to passing through all the spot positions. If an observation seems to deviate substantially from the line, re-check your diagrams to see if you have misidentified the spot.

By measurement on your diagram, find the center of the line through the spot positions. Draw a line from this point to the center of the circle and extend it across the circle on either side. This is the rotational axis of the Sun, the line from the Sun's north pole to its south pole. Notice that it does not line up exactly with the N-S line of your diagram, which represents the rotational axis of the Earth. This is because the Earth is tilted in its orbit with respect to the plane of the ecliptic. This causes the axis of the Sun to appear to swing back and forth during the course of the year (see figure 17).

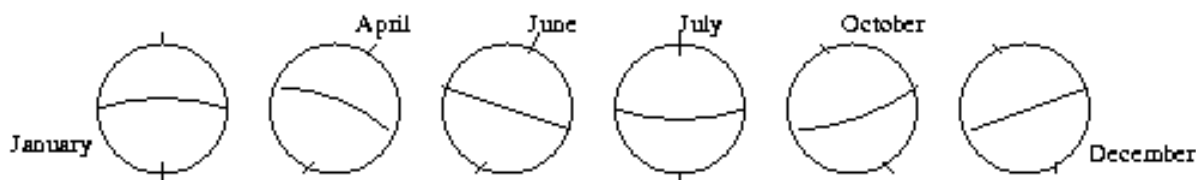


Figure 17: Position of the Sun's Poles and Equator as seen from Earth at Different Times of the Year.

In addition to this apparent swinging from side to side, the Sun also appears to tilt slightly toward and away from us. The location of the Sun's poles and equator at various times of year is shown in the diagram above. Because of the tilting, the path of a spot across the solar image is actually slightly curved. However the effect is fairly small and we ignore it in this laboratory for simplicity.

The image of the Sun is a flat surface, and your diagram so far shows the spot's apparent position on this surface. The actual surface of the Sun is a curved surface, a sphere. You need to know the true positions of the spot on this surface.

Consider figure 18. If we could look down on the Sun from above its pole, we would see it as in the upper part of the diagram. The positions 1, 2, 3, ... represent a sunspot moving along steadily from day to day. The angle between each pair of positions is the same, and the true distance  $X$  on the solar surface is the same. However we view the Sun "sideways", in the plane of the paper. We see the spots projected onto a straight line to positions 1', 2', 3', ... Notice that the apparent distance  $X'$  between positions varies. This is because a spot is moving almost radially along our line of sight near the edge of the Sun, but across our line of sight near the center. You will now use the same idea to work backwards from apparent positions to true positions.

Place the point of a compass at the center of the line through the spot positions and set its length equal to the distance from the center of the line to the edge of the Sun (see figure 19). Draw a semi-circle from one end of the line around to the other end as shown. The line representing the Sun's axis is also shown on the diagram. Now project your spot positions from the line onto the semi-circle, by drawing a line through each spot perpendicular to the spot line (or parallel to the Sun's axis). The intersection of this projection line with the semi-circle marks the true position of the spot on the curved surface of the Sun. The positions on the semi-circle show the actual motion of the spot from day to day.



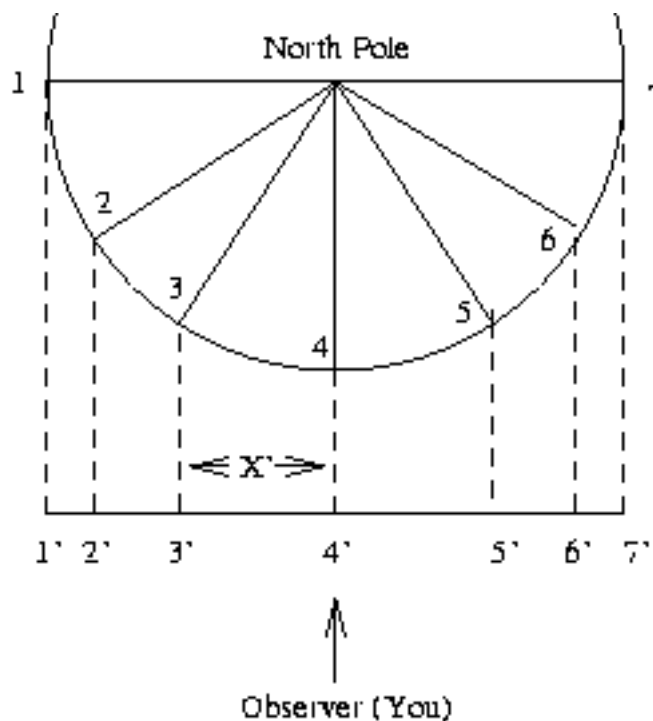


Figure 18: The Motion of Sunspots (looking down on the Sun's north pole).

### 10.6 Determining the Rotation Period

In this section you will determine the Sun's angular speed, i.e. how many degrees it turns per day, and use this to compute how many days it takes to turn  $360^\circ$  — one full rotation. As you work through this part of the laboratory, create a data table, using the sample entries as a guide.

First enter the observation number, date, and time. Give the time on a 24-hour clock: e.g. 11 a.m. = 11:00, 2 p.m. = 14:00. Then convert the time to a decimal fraction; first minutes to fractions of an hour, then hours to fractions of a day. For example, 2:15 p.m. = 14:15 =  $14 \frac{15}{60}$  hours = 14.25 hours; and  $14.25 \text{ hours} / 24 \text{ hours} = 0.59 \text{ days}$ . Also be sure all times are on the same system, either standard time or daylight savings time. (If some of your observations are on standard and some on daylight savings, correct the daylight savings times to standard times by subtracting one hour.) To compute the decimal date, convert each date to a day of the year without months: e.g. March 15 = day 74, September 15 = day 258. All these conversions will make it easier to graph the data below.

Now use a protractor to measure the angle around the semicircle from the starting point  $O$  to the projected spot position  $P$  (see figure 20). For this spot position  $P$ . Enter this angle in your table.

Next you will determine the angular speed graphically. For each sunspot, plot the date and angle on a graph of angular position versus time (decimal date) as in Figure 21. Adjust the scales of the graph to cover the range of available data and to fill a standard  $8.5 \times 11$  page of graph paper.

Your sunspot was rotating with the Sun at constant speed. If your drawings and measurements were perfect, the points on your graph would lie exactly on the straight

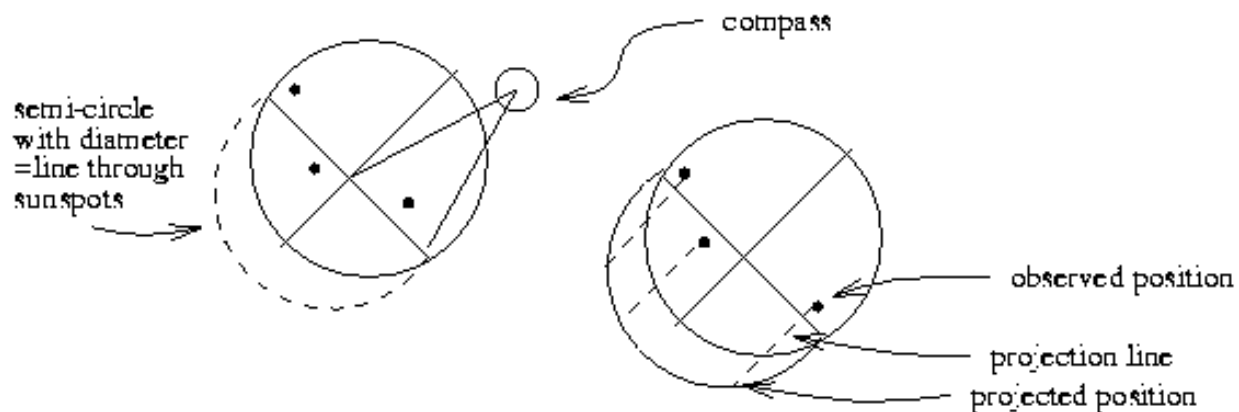
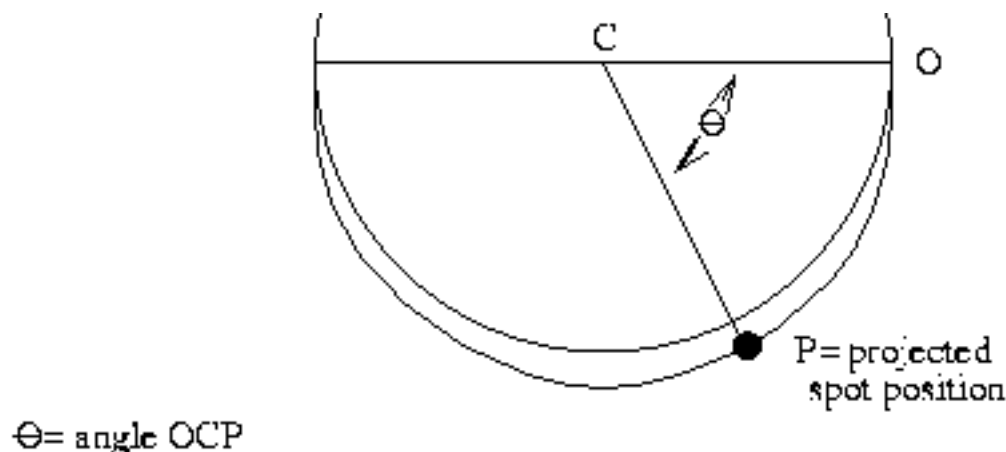


Figure 19: Using a compass

Figure 20: Measuring the angle  $\theta$ 

line. However, your data will not be perfect, due to unavoidable errors in plotting positions, measuring angles, etc. To determine the angular speed, draw on the graph a straight line which fits the observations as well as possible (see Figure 21). The slope of this line (i.e. the change in angle per change in time) would be the angular speed. The section on graphs in “How to Write a Lab Report,” has suggestions on how best to do this.

You may find that one of your data points deviates substantially from the general run of data (see figure 22). If this occurs, re-check your work to see if there is some mistake which accounts for the discrepancy. If you can't find any, you may eliminate this point from your data before fitting the line. Show the bad point on the graph and indicate that it was not used in plotting the best-fit line. You should drop no more than one point and should have at least four good data points left.

Now determine the angular speed of rotation from the slope of your line (see figure 22). Pick a convenient point on the line at each end, determine the corresponding angle and time for each point, and calculate the slope:

$$\frac{\text{change in angle}}{\text{change in time}} = \frac{\theta_2 - \theta_1}{T_2 - T_1} = \text{angular speed in degrees per day}$$

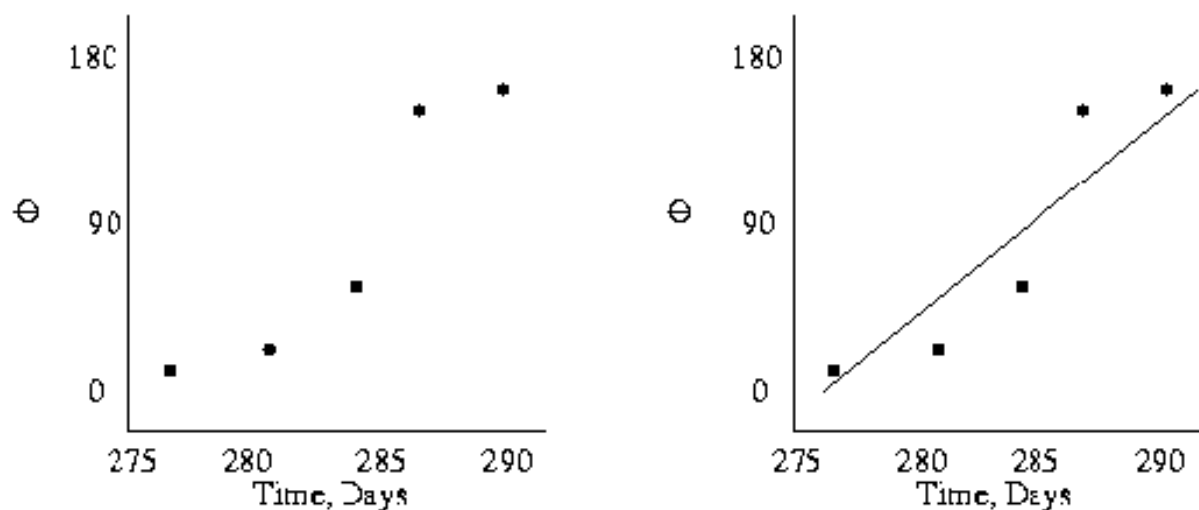


Figure 21: Plotting the data (left) and fitting the line (right).

Finally, to get the observed rotation period, find

$$P(\text{period in days}) = 360^\circ / \text{angular speed}$$

Enter your determinations of the change in angle and time, the angular speed, and period in your data table.

Compare your value for the period with the established value of 27.27 days, first as a difference in days and then as a percent error.

$$\text{percent error} = \frac{\text{difference in days}}{\text{accepted value}} \times 100$$

Enter these values in your data table.

The period you have found is the *synodic period*, the apparent rotation period of the Sun as seen from the Earth. However, the Earth is orbiting the Sun, so the portion of its surface we see changes from day to day. The rotation period of the Sun as seen from a fixed point in space such as a distant star is called the *sidereal period*. The sidereal period is shorter than the synodic period. This concept is illustrated in figure 23.

Suppose the Sun has a sidereal period of 30 days; then in 15 days it completes half a revolution. At day 1 we see a spot on the edge of the Sun. 15 days later, the spot is at the other edge as seen from a star. But the Earth has moved also, so the spot appears not to have reached the edge as seen from the Earth. It will take somewhat longer for it to appear to reach the other edge. Thus, the synodic period is longer than the sidereal period.

To find the sidereal period of the Sun, we can use the relation

$$\frac{1}{\text{sidereal period}} = \frac{1}{\text{synodic period}} + \frac{1}{\text{earth's period}}$$

or

$$\frac{1}{S} = \frac{1}{P} + \frac{1}{E}$$

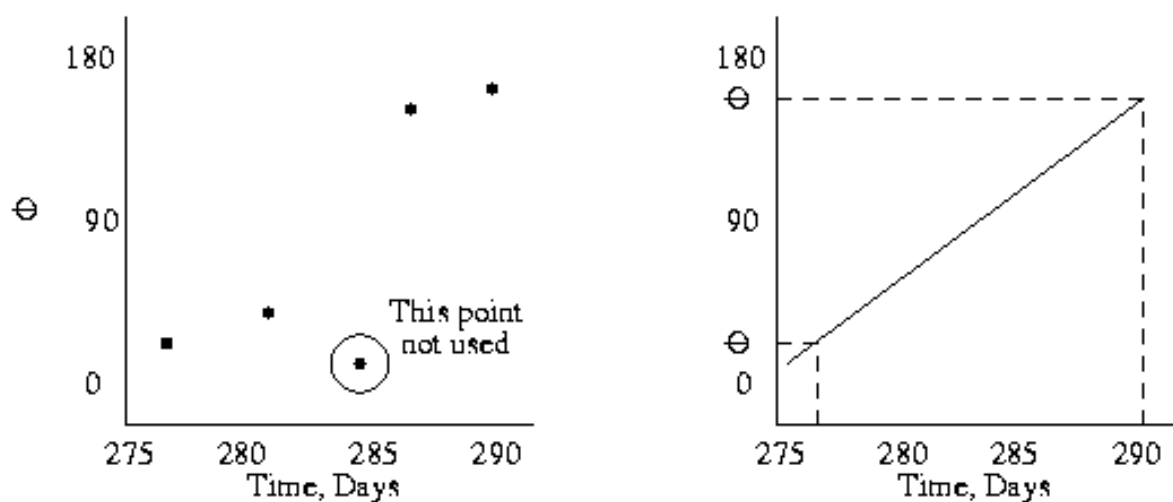


Figure 22: Dropping a bad data point (left) and determining the slope (right).

Use your value of the synodic period  $P$ , and the known value of the Earth's period  $E = 365.25$  days, to find the sidereal period  $S$ . Enter your value for the sidereal period in the data table.

SAMPLE SUNSPOT LAB DATA TABLE

Obs. No.	Date	Time	Decimal Date	Best Fit Angle	Worst Fit Angle
1	Jan 25	11:55	25.49	6°	10°
2	Jan 26	12:00	26.50	11°	16°
3	Jan 27	11:55	27.49	22°	24°
4	Jan 28	12:10	28.51	36°	38°
5	Jan 31	12:00	31.50	79°	72°
6	Feb 2	12:15	33.51	115°	107°

## 10.7 Error Analysis

There are two basic sources of error to consider in this lab. There is error in the observation and measurement process and error in the data reductions. The first includes problems such as proper paper alignment, jotting down the spots accurately, and dealing with wind. The second involves the processes used to get from the data to the solar rotation period estimate. This kind of error includes problems like drawing an accurate line through the data points. Error estimates are crucial to good astronomy. It is important to know both the source and magnitude of errors in the quantities you are trying to determine. In this part of the lab you will estimate both kinds of error and will understand better why error analysis is important.

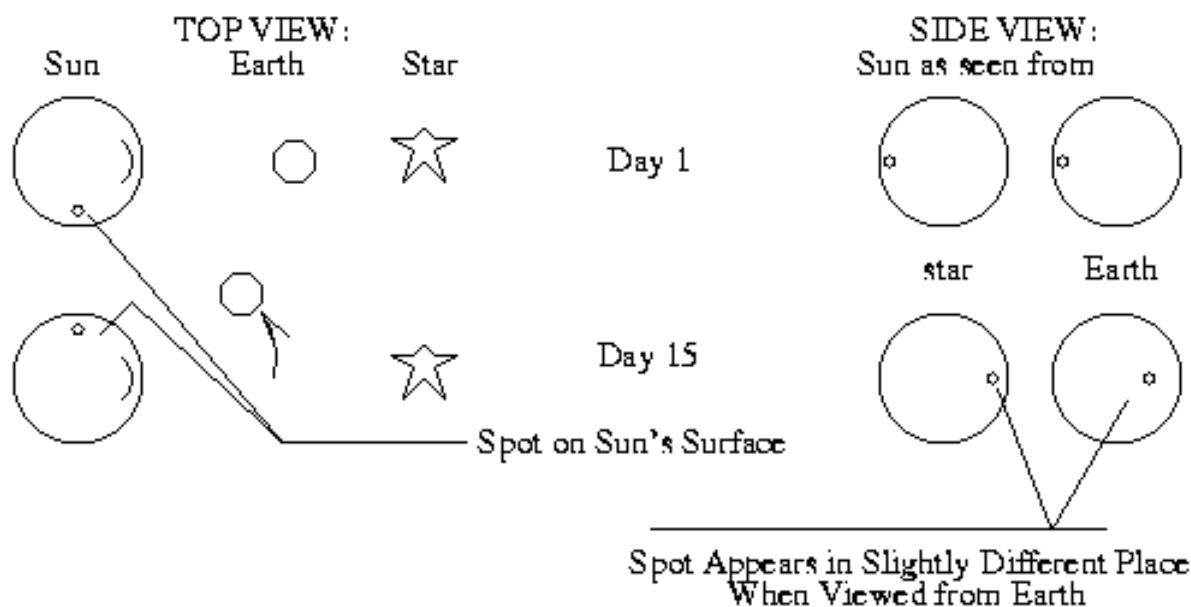


Figure 23: An illustration of synodic versus sidereal time. At day 1 (top), the sunspot appears in the same place as viewed from Earth and a distant star. On day 15 (bottom), the sunspot has moved. However, the Earth has moved as well. Thus, the spot appears to be in a different place when viewed from the Earth and when viewed from a distant star.

1. Comment on how the data taking process in this lab could be improved. Be specific.
2. List three of the greatest sources of error in the measurement process. (Simply saying “human error” is not valid. Be specific!)

To estimate the errors in the data reductions you will need to:

1. Retrace the spots you chose to follow onto one diagram.
2. Draw a line through the data points which is as different from your original line as possible and yet still a plausible summary of the data. The original line is referred to as the best fit line and the one you just drew the worst fit line. Label the drawing well (see figure 24).
3. Repeat the process of determining an angular speed for this “worst fit” to the data just as you did for the best fit line. Show your work. Record this worst speed.

The error due to calculations can be estimated by:

$$\text{difference in speed} = \text{best fit speed} - \text{worst fit speed}$$

and

$$\% \text{ error} = \frac{\text{difference in speed}}{\text{best fit speed}} \times 100$$

Calculate these values, showing your work.

1. List probable sources of this error.

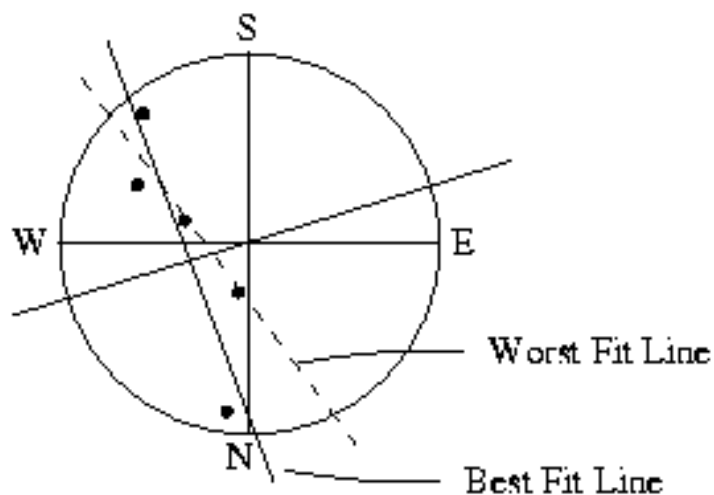


Figure 24: Best Fit and Worst Fit Lines

2. List one or more assumptions used in this lab which might have contributed to the error.
3. Can you think of any other way to improve this lab?
4. If you were reading a paper and the authors reported a 50% error, what would you think of their result and their work?
5. Finally, if everything in your lab had gone more smoothly, do you believe your measurements and calculations would yield the exact answer?

### 10.8 Requirement Checklist

In addition to a full write-up,

1. Data sheets and table for all observations
2. Diagrams, plots, and calculations of angular speed, periods, and errors
3. Error analysis with new graph, calculations, etc.
4. Answers to 5 questions regarding errors above

## 11 DETERMINATION OF THE SPEED OF LIGHT FROM ECLIPSES OF IO

### 11.1 Time Estimate

This laboratory requires observation of eclipses of Jupiter's moon Io. With careful planning and good luck, this can be done in one night, but it is better to count on spending several nights. Only on certain nights will the appropriate Io events be observable during open Observatory hours. Favorable placement of Jupiter in the sky does not occur every semester (and we require eclipses during lab hours). Read the section below on predicting eclipse events. Extensive calculation will also be required.

### 11.2 Introduction

Because of the relatively large ratio of Jupiter's diameter to the radii of the orbits of the Galilean satellites, the small inclination of the satellite orbits to the ecliptic, and their short periods, there are many eclipses involving these satellites as they enter and leave Jupiter's shadow. In particular Io, with a period of less than two days, is eclipsed several times a week. The motion of Io is exceedingly regular, so the times of the eclipses can be predicted to great accuracy.

However, the times that the eclipses are **observed** on Earth are delayed by the finite speed of light. Since the distance between Jupiter and Earth is constantly changing as the two planets orbit the Sun, the time delay is changing also. The orbits are well known, so the distances are known. By comparing the change in distance to the change in observed time of eclipse, the speed of light can be determined. The first measurement of the speed of light was made using this method by Ole Roemer in 1675.

In this laboratory you will make the observations necessary for your own estimate of the speed of light by timing several Io eclipses during the semester. The observations are outlined in the following section, and the computations in the third section. The geometry and formulas used are derived in the section 11.6.

### 11.3 Observations

#### Predicting the Eclipses

The moment at which Io disappears into Jupiter's shadow or reappears coming out of the shadow must be precisely timed. Disappearances are observable before Jovian opposition and reappearances after opposition. The diagrams show this in terms of the relative positions of Jupiter, its shadow, the satellite, and the Earth (see figure 25).

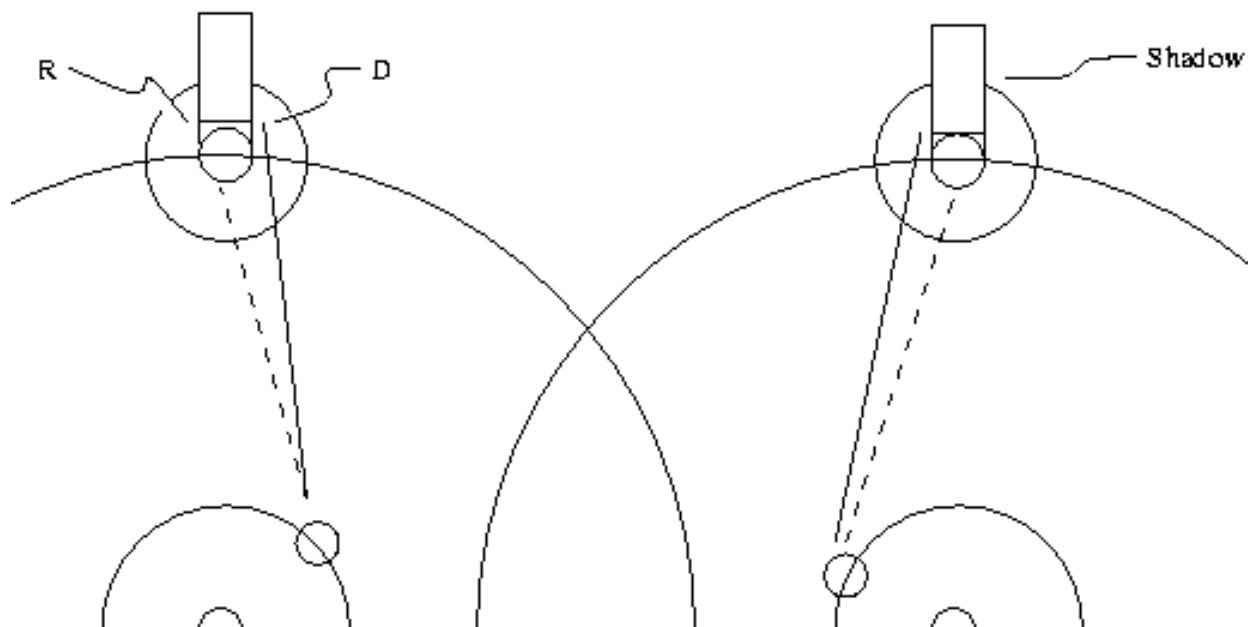


Figure 25: Before (left) and after (right) opposition. Disappearance D is visible before opposition and reappearance R after opposition.

The approximate time of an eclipse (within five minutes) can be found in the *Astronomical Almanac* for the current year, in the section “Satellites of Jupiter, Times of Geocentric Phenomena.” This tabulates eclipses, transits (passage of a satellite or its shadow in front of the planet) and occultations (passage of a satellite behind the planet), for the four bright Galilean satellites. A *sample* section of this table (*not* valid for the current semester) is reproduced in figure 26.

The abbreviations used in the table are as follows:

- (a) I, II, III, IV denote which satellite;
- (b) Tr, Sh, Oc, Ec denote the type of event: transit, shadow transit, occultation, eclipse;
- (c) I, E, D, R denote ingress, egress (for transits) and disappearance, reappearance (for occultations and eclipses).

We are interested in eclipses of Io, satellite I, so are looking for events of the form I.Ec.D. (Io, eclipse, disappearance) or I.Ec.R. The date and time of each event is given in Universal Time. A subtraction must be made to get local clock time: subtract 5 hours to get Eastern Standard, 4 hours to get Eastern Daylight Savings Time.

Using the table, find all events occurring this semester and determine their local time. Be careful in the time subtraction, as the **date** will change back one day if the time moves back past midnight. Tabulate all events which occur when (1) Jupiter is above the horizon, (2) the sky is dark enough to see it, and (3) the hour is reasonably convenient. Generally there are a few evening eclipses every month meeting all these restrictions.

Begin immediately to observe and time as many events as possible. Bad weather may interfere for some, so don't count on getting some particular event late in the semester.



## SATELLITES OF JUPITER, 1998

### DYNAMICAL TIME OF GEOCENTRIC PHENOMENA

JANUARY											
d	h	m		d	h	m		d	h	m	
0	0 15		IV.Tr.I.	8	3 18		II.Oc.D.	16	11 51		I.Oc.D.
	3 33		III.Tr.I.		7 43		II.Ec.R.		14 48		I.Ec.R.
	5 04		IV.Tr.E.		11 26		IV.Oc.D.		20 57		IV.Tr.I.
	7 11		III.Sh.I.		12 41		I.Tr.I.				
	7 12		III.Tr.E.		13 27		I.Sh.I.	17	0 23		II.Tr.I.
	8 59		IV.Sh.I.		14 59		I.Tr.E.		1 42		II.Sh.I.
	10 48		III.Sh.E.		15 44		I.Sh.E.		1 44		IV.Tr.E.
	13 17		I.Oc.D.		16 13		IV.Oc.R.		3 15		II.Tr.E.
								24	11 15		I.Tr.I.
									11 46		I.Sh.I.
									13 32		I.Tr.E.
									14 03		I.Sh.E.
								25	7 01		III.Oc.D.
									8 11		IV.Oc.D.
									8 24		I.Oc.D.

Figure 26: Satellites of Jupiter, Times of Geocentric Phenomena.

### Timing the Eclipses

Very accurate times must be obtained for the eclipses — an accuracy of one second is necessary. The best convenient technique makes use of a short wave radio and a tape recorder.

First tune the radio to the National Bureau of Standards time signal station WWV (2.5, 5, 10, 15, 20 MHz). WWV broadcasts a “tick” once a second and a tone on every minute together with a voice announcement of the Universal Time. Set up the tape recorder so it records both the WWV signals and your voice.

Beginning about ten minutes before the predicted eclipse time, observe Jupiter through the telescope and watch for the event. When the disappearance or reappearance occurs, make a recordable comment — “mark”, “time”, etc. Let the recorder continue to record time signals for another couple of minutes. To get the time of the event, rewind the tape and play it, counting the number of seconds ticks between your comment and the next minute tone and time announcement. This gives the Universal Time to one second accuracy.

It is important to set up the equipment early and test the system before attempting to observe an event. Set up at least a half hour ahead and try everything out on a trial run before the actual observation. It is frustrating to be a minute too late and miss the event, or not get a recording because something was unplugged. In cold weather, the radio and/or recorder may not work well if they get very cold. It may be necessary to enclose them in a box with a heater or to have someone hold them in his lap and keep them warm with body heat. A trial run under actual observing conditions lets you find and correct such problems.

## 11.4 Reductions

### Known values and assumptions

For the purposes of this experiment we assume that Jupiter and the Earth are both orbiting the Sun in circular orbits at constant speed, and that Io orbits Jupiter likewise. We need the distances from the Sun,  $R$ , and sidereal periods  $P$  of the Earth and Jupiter, the synodic period of Io, the time of the most recent opposition (from the Ephemeris, “Geocentric and Heliocentric Phenomena”), and the observed times of the eclipses. Some of this information is tabulated here:

$$R_E = 1.496 \times 10^8 \text{ km}; \quad P_E = 365.26 \text{ days}$$

$$R_J = 7.783 \times 10^8 \text{ km}; \quad P_J = 4,332.6 \text{ days}$$

$$P_{IO} = 1.7699 \text{ days} = 1^d 18^h 28^m 36^s$$

Time of Most Recent Opposition (from Ephemeris):

### Procedure

The reduction procedure is outlined here step by step. Work through it carefully, checking your arithmetic as you go. Make sure your calculator is in *degree* mode when taking sine and cosine of angles.

1. Determine the angular speeds of the Earth and Jupiter:

$$\Omega_E = \frac{360^\circ}{P_E} \quad \Omega_J = \frac{360^\circ}{P_J}$$

For each observation, do steps 2 through 5 below:

2. Determine the time difference  $t_n$  between the eclipse and the closest opposition:

$$t_n = \text{time of eclipse} - \text{time of opposition}$$

This involves finding the time difference in days, hours, minutes and seconds, then converting to seconds. It is easy to make a mistake here. Be careful in counting days, and double-check your results.

3. Determine the eclipse index  $n$ . This is the number of the eclipse since opposition:

$$n = t_n / P_{Io} \text{ (rounded to nearest whole number)}$$

4. Find the angle between the position at opposition and the position at eclipse of Earth ( $\theta$ ) and Jupiter ( $\phi$ ). I.e. how many degrees did Earth and Jupiter travel around their respective orbits in time  $t_n$ :

$$\theta = \Omega_E \cdot t_n \quad \phi = \Omega_J \cdot t_n$$

5. Find the Earth-Jupiter distance  $d_n$ :

$$d_n^2 = R_E^2 + R_J^2 - 2 \cdot R_E \cdot R_J \cdot \cos(\theta_n - \phi_n)$$

Tabulate the eclipse index  $n$ , time  $t_n$ , and distance  $d_n$  for each event.

6. Now take the eclipses in pairs, and for each pair find the speed of light  $c$ :

$$c = \frac{d_n - d_m}{t_n - t_m - (n - m)P_{Io}}$$

Use all possible pairs of eclipses. **Tabulate** your results.

7. There will be some scatter in your results due to observational errors and approximations. This is to be expected. Look for any outstandingly discordant results. Recheck the arithmetic on these. In particular, if a large discrepancy occurs every time a particular eclipse observation is used, recheck the time computation. If nothing wrong can be found with the arithmetic in such a case, the observation itself is probably faulty and can be discarded.
8. Average your remaining results to get a final value for  $c$ . Compare your value to Roemer's result,  $2.35 \times 10^5$  km/sec, and to the presently accepted value of  $2.99 \times 10^5$  km/sec.

### 11.5 Lab Write-Up

In your write-up, outline the observations and mention any difficulties. Present your computations and results in tables. Also **answer the following questions**:

1. By observing an eclipse one has located Io in space to a precision of one Io diameter. At the distance of Jupiter, what angle does this correspond to?
2. How long does it take Io to move through its own diameter? The precision of your timings is some fraction of this value, since you time the moment at which enough of Io's surface is sunlight for it to be visible. This is approximately constant for one observer with a given size telescope.
3. Assuming observational errors are constant, we might expect to get a more accurate result when the difference in distance between events is large. Compare your results for a large distance difference (eclipses at the beginning and end of the semester) with results for a small distance difference (events close together in time).
4. Discuss briefly the sources of error in the experiment as we have performed it, and how they might be reduced. Consider the principles on which the experiment is based, the observational technique used, and the assumption made in the reductions.

### 11.6 Geometry and formulae

Let opposition occur at time  $t = 0$ . The Earth is at  $E_o$ , Jupiter at  $J_o$ , and the Sun, Earth, and Jupiter are in line. We observe the  $n$ th eclipse after opposition at time  $t_n$ . The Earth is at  $E_n$  and Jupiter at  $J_n$ . The distance between them is  $d_n$  (see figure 27).

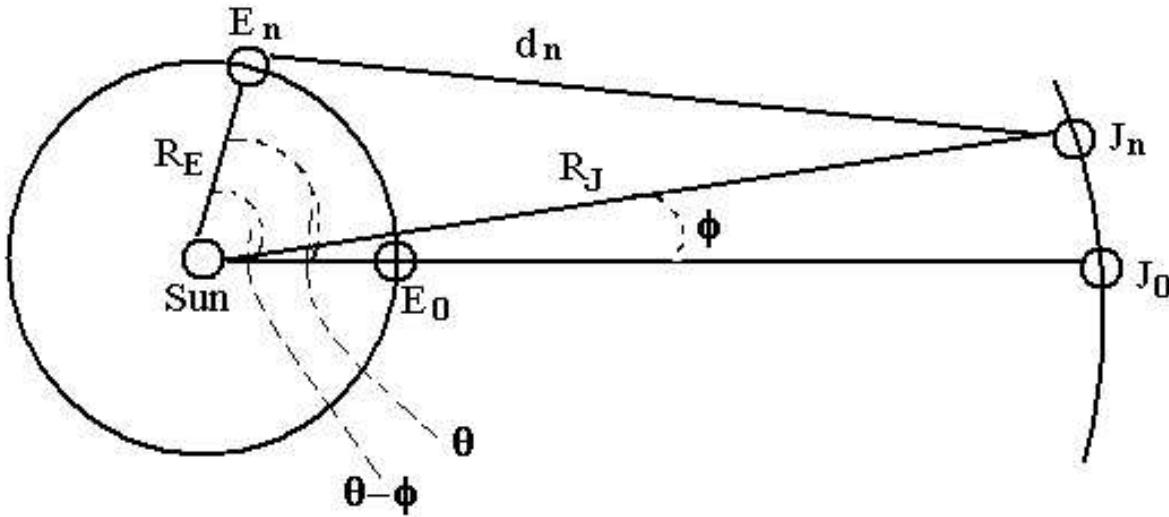


Figure 27: Geometry diagram.

We observe the eclipse at time  $t_n$ , but it actually occurred at some earlier time  $t'_n$ . The difference is due to the light travel time over distance  $d_n$ . The relation between the two times is

$$t_n = t'_n + \frac{d_n}{c}; \quad t'_n = t_n - \frac{d_n}{c}$$

The distances  $R_E$ ,  $R_J$  are known. We want to find  $d_n$ . Consider the planets' motion around the Sun since opposition. Jupiter orbits the Sun with some angular speed  $\Omega_J$ , so many degrees per day; likewise for the Earth, at angular speed  $\Omega_E$ .

Their angular travel around their orbits from opposition to time  $t_n$  is

for Earth,  $\theta_n = \Omega_E \cdot t_n$  ;

for Jupiter,  $\phi_J = \Omega_J \cdot t_n$

where  $\phi_n$  is determined approximately because we are using the observed time at Earth,  $t_n$ , not the Jovian time  $t_n'$ . Jupiter's angular speed is slow enough that this is a good approximation.

For the triangle formed by  $E_n'$ ,  $J_n'$ , and the Sun we now have two sides and the included angle ( $R_E$ ,  $R_J$ ,  $\theta_n - \phi_n$ ) and can find  $d_n$  using the Law of Cosines:

$$d_n^2 = R_E^2 + R_J^2 - 2 \times R_E \times R_J \times \cos(\theta_n - \phi_n)$$

Suppose we have observed **two** events, the  $m^{th}$  and  $n^{th}$  events since opposition, at times  $t_m$  and  $t_n$ . We can determine the distances  $d_m$ ,  $d_n$  as above. The two events occurred at Jupiter at times  $t_m'$ ,  $t_n'$ . The difference between the two times at Jupiter is equal to the period of Io times the number of Io revolutions between the two events:

$$t_n' - t_m' = (n - m) \cdot P_{Io}$$

Here we use the synodic period of Io, which effectively removes Jupiter's motion around the Sun from the problem.

Now we substitute for the (unknown) times  $t_n'$ ,  $t_m'$  using the observed times  $t_n$ ,  $t_m$  plus the time delay:

$$t_n' - t_m' = (t_n - \frac{d_n}{c}) - (t_m - \frac{d_m}{c}) = (n - m) \cdot P_{Io}$$

Rearranging the equation, we solve for the speed of light  $c$ :

$$c = \frac{d_n - d_m}{(t_n - t_m) - (n - m) \cdot P_{Io}}$$

Thus we find  $c$  using only previously known or observed quantities.

## 12 NAVIGATION BY THE SUN

### 12.1 Time Estimate

This lab requires you to observe the sun one hour before and one hour after meridian transit. You should be ready to begin working at 11 AM local time and take readings until 1 PM local time. If it is daylight savings time, you should work from noon local time until 2 PM. You should arrive at least 15 minutes early to set up the equipment.

**THIS LAB CAN ONLY BE DONE BETWEEN SEPT. 10 AND APRIL 5.**

### 12.2 Introduction

For this lab we will monitor the transit of the sun. You will use techniques that have been used for centuries by navigators and explorers to find one's position on the earth using sextant readings of celestial objects. While determining one's *latitude* accurately has long been achievable (since the time of the Greek mathematicians), only since the invention of accurate timekeeping devices has it been possible to determine confidently one's *longitude*. As your timekeeping device in this lab you will use the official U.S. Naval Observatory clock in Washington, D.C., accessed via radio or internet. Along with the Davis sextant and the proper time, you will need an Artificial Horizon to do this lab.

### 12.3 Lab Write-up

A full write-up is required in the style outlined in Appendix D.

### 12.4 Latitude and Declination

As you know from lecture, the lines of longitude and latitude on the earth correspond to lines of right ascension and declination on the celestial sphere (imagine “lifting” the longitude and latitude lines off the globe and onto the sky). For any observer, the line of declination that passes through the zenith is equal to the latitude of the observer. Thus, if one knew the declination of any object in the sky and measured its angular distance from the zenith *at the time of its meridian passage* (i.e. the point when it is neither rising nor setting and when it is highest in the sky), one could determine the latitude simply as the declination of that object plus the angle from that object to the zenith (measured as a positive angle if the object is south of the zenith and as a negative angle if the object is north of the zenith). Figure 28 shows the geometry of the meridian line for a northern observer at mid-latitudes. Note that observers in the northern hemisphere have available a convenient object for latitude measurement, the North Star or Polaris. This star is very nearly (though not exactly) at a declination of 90 degrees, so that it would be straight overhead for an observer at the North Pole of the earth. For any other observer in the Northern Hemisphere, their latitude is approximately equal to 90 degrees minus the angle between the North Star and the zenith.

In reality, it is rather difficult to determine precisely the position of the zenith where there is no fixed reference object. Ancient mariners solved this problem by making their measurements with reference to their horizon, which is much easier to define *when at sea*. For this purpose the sextant, with its combination of mirrors and (in the past) smoked glass, was invented. The sea horizon is approximately 90 degrees from the zenith, but *not exactly* because the finite distance of the navigator's eye above the sea allows him or her to see the curvature of the earth. Navigators at sea (often in a crow's nest position) must account for their height

above the water in their measurements (amounting to a latitude error of, for example,  $1/20$  degree for a 10 foot elevation).

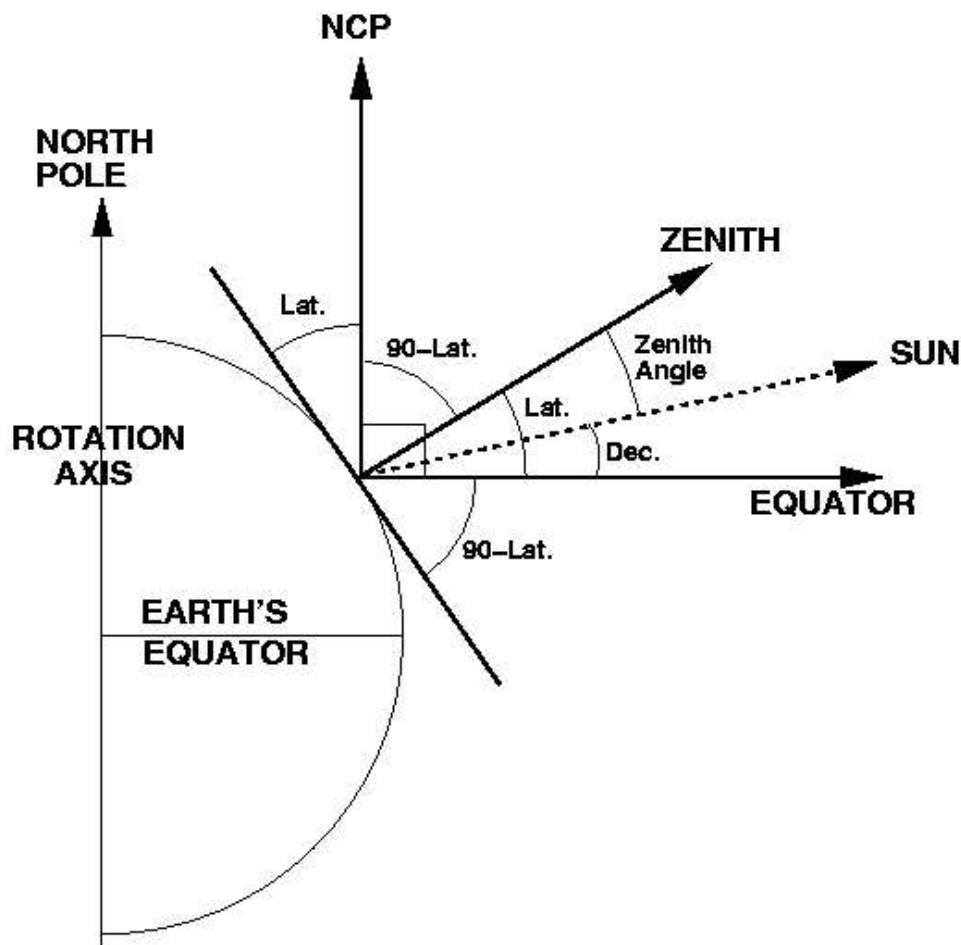


Figure 28: Various angles from sea when the Declination of the Sun in North

An additional problem for the navigator is that measurements of latitude by use of objects of known declination *must* be made when the object is on the meridian, for this is the only point when an object's zenith angle is directly related to *only* the longitude and declination. At other times, the zenith angle is a combination of the object declination, the observer's latitude, *and* the object's hour angle (related to the sidereal time); the latter is an additional complication and was difficult to ascertain before the invention of accurate clocks. One solution is to make many measurements of an object's horizon angle over the course of more than an hour; the measurement giving the highest horizon angle is closest to when the object passed through the meridian as the earth turned.

Obviously, horizon measures only make sense when one has access to the *true horizon*, that is, the horizon unobstructed by local phenomena (buildings, trees, mountains, etc.). For mariners at sea, this is not generally a problem, but for landlubbers, finding the true horizon is a significant problem. In this lab we will use a "trick" to overcome the lack of a true horizon, making use of an *artificial horizon*.

## 12.5 Longitude and Right Ascension

Unlike the situation with latitude, where every line on the earth corresponds to one and only one line of declination on the sky, lines of longitude do not correspond to any single line of right ascension, since the earth is constantly rotating beneath the celestial sphere. Indeed, this is the principle by which we measure longitude; the rotating earth makes the sky act like a giant clock with the observer's meridian acting like the hour hand. By comparing one's local sky clock with any other standardized clock, one can determine one's distance from that standard clock.

One knows from experience that the earth is divided into time zones, but time zones are a relatively recent invention necessitated by modern society's ability to travel quickly and communicate instantly to distant places. Previously, time was reckoned locally by reference to the sun ("local noon"), so that each community enjoyed a different time from even its neighboring community. Since the earth rotates 360 degrees in 24 hours, two communities separated by 1 degree of longitude (e.g., Charlottesville and Richmond) had clocks different by 4 minutes.

In this lab, you will measure your "local noon" to determine your longitude with respect to the *prime meridian* – which corresponds to longitude = 0 degrees. The prime meridian was established by convention to be the longitude running through Greenwich Observatory, in Greenwich, England. This is the location corresponding to the world's standard clock, which measures *Universal Time* or *Greenwich Mean Time (GMT)*. You can determine your longitude by comparing your "local noon" to that of the clock in Greenwich, England, which is keeping track of GMT.

Historically, the problem with determining longitude, in the days before long distance communication was feasible, was how to know what the time was on the standard clock. Ideally, a ship at sea would have on board a clock synchronized to the Greenwich clock (or some other port of known longitude), and comparisons to this clock could be made at local noon on the sea. However, until about a century ago, timepieces were simply not accurate enough, and the mechanisms were notorious for losing or gaining time, especially with changes in temperature, humidity, and turbulent seas. The number of ships lost at sea due to navigational errors in longitude became so problematical, that in 1714 Queen Anne of England offered a prize of 20,000 pounds sterling to the first person that could solve the "longitude problem," defined as being able to determine one's longitude to one half degree, or 34 miles! You will be able to do much better than this in this lab. The longitude prize however was not claimed for some 50 years (the fascinating story of the "longitude prize" is given in the book "Longitude," by Dara Sorel).

For accurate time, the TA will be keeping track of the US Naval Observatory clock.

## 12.6 The Sextant

*Please follow TA instructions on using the sextant in the introductory session prior to the lab!*

Carefully remove the Davis Sextant from the plastic box. Figure 29 identifies the various elements of the sextant. Note that the index arm may be adjusted coarsely, with the spring-loaded quick release levers on the bottom, or by turning the micrometer drum. Be sure to squeeze the levers completely when doing a coarse adjustment and, when any coarse adjustment is completed, that you turn the micrometer drum at least one full turn either way to ensure proper re-engagement of the gears (if this is not done, you may experience erroneous readings). Also, to avoid "backlash errors," always make the final fine adjustments of the sextant by turning the drum from smaller to higher angle.

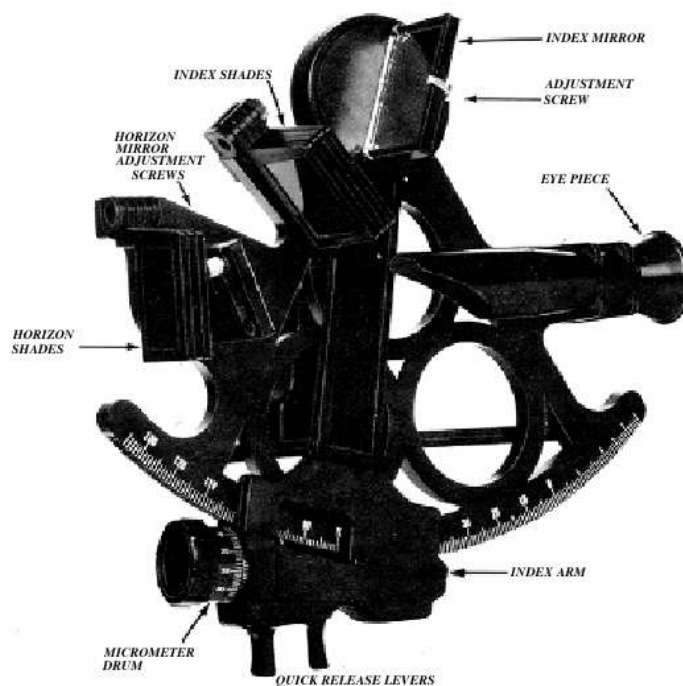


Figure 29: The sextant

Ask the TA to show you how to read angles precisely from the sextant. The scale along the arc allows one to read the position of the index arm in degrees (read to the right of the index line on the stationary part of the sextant). You will need to find angles more precisely than this. Note that one “nautical mile” on the surface of the earth corresponds to 1 minute of arc (1 degree contains 60 arcminutes, 1 arcminute contains 60 arcseconds), so that an error of 30 arcminutes would put a mariner 30 nautical miles off course (a nautical mile = 1.15 “statute miles,” which are the miles more familiar to you).

The micrometer drum allows you to measure fractions of an arcminute. The outer revolving arm is divided into minutes of arc, which you read by reference to the long line on the opposing, stationary scale (if the long line is between two lines on the rotating drum, choose the line of *lower* value). The extra lines on the stationary scale are a *Vernier scale*. To read the Vernier scale for fractions of an arcminute, find the one short line on the stationary scale that is directly opposite any line on the rotating drum. Count the number of spaces this short line is away from the long line at the top of the stationary scale. Each space corresponds to  $\frac{2}{10}$  of an arcminute, this is the precision to which you should record your readings in this lab. Add the full degrees, arcminutes, and fractions of an arcminute to get the full angle reading. Make sure you understand how to read angles with the sextant well, before you proceed with this lab.

Note that some of the sextants have an illumination for the scales for use at night. To turn on this light, use your thumb to push the button at the top of the hand grip of the sextant.

You can use the sextant either with no magnification with the sight tube or with a 3x magnification telescope. The sight tube and telescope tube each pull apart into two pieces. *Do not attempt to remove the telescope or sight tube from the sextant in one piece by pulling laterally to the plane of the sextant through the mounting brackets.* Instead, separate the sight tube or telescope into two pieces along the tube (i.e., pull off the non-eyepiece end of the sight



tube or the eyepiece end of the telescope, and pull the remaining mounted piece through the mounting brackets).

### 12.7 Adjusting the Optics of the Sextant

In order for you make accurate measurements with the sextant, the various mirrors must be in proper alignment. Ask the T.A. to help you with the Index Mirror adjustment, the Horizon Mirror adjustment, and the Index Error adjustment.

### 12.8 Measuring the Altitude of the Sun or Moon with the Artificial Horizon

**Before looking at the sun with your sextant, always make sure to position several index shades (colored glass filters) in front of both the horizon mirror and the index mirror.** Choose whatever combination of shades gives you a clear image of the sun without glare.

If one had access to the true horizon, one would use the sextant to measure the angular distance of an object from the true horizon. The left half of the horizon mirror is not aluminized, so that one can see directly through the glass. Here the true horizon would be viewed. The right half of the horizon mirror reflects an image of the object whose position you are measuring to your eye, after it reflects off the index mirror as well. Figure 30 shows the geometry of the mirror optics.

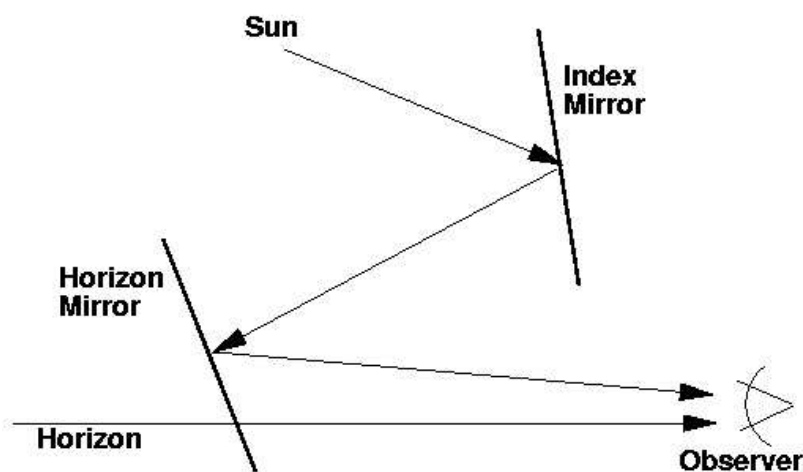


Figure 30: Geometry of the mirror optics

To make a sextant measurement, the arc of the sextant (attached to the index mirror) is moved until the reflected image of the object you are measuring appears on the right half of the horizon mirror. The correct reading is had when you can artificially place the center of the object on the right (aluminized) side of the horizon mirror directly in line with the true horizon line on the left (clear) side of the horizon mirror. If horizon shades are used, you can get a semi-mirror on the left side of the horizon mirror, and actually see an image of the object on the true horizon on the left hand side of the mirror.

Because we generally cannot see the true horizon, we instead make use of an artificial horizon. Assemble the artificial horizon and fill it with water. The level of the water does not matter.

Enclose the assembly with the clear glass covers. You should use the coldest water you can find to prevent frequent fogging. Position the artificial horizon on level ground, with one end facing directly into the sun so that a shadow is cast only on the side of the assembly away from the sun; no shadow should be visible on the sides.

Instead of a true horizon measurement, we will compare the image of the sun as reflected through the mirror system of the sextant to the image of the sun as reflected off the water's surface in the artificial horizon. Thus, you will be viewing with the sextant on a downward angle towards the water. The geometry of the situation is shown in Figure 31. Note that with this particular technique, the angle that you measure is twice the angle one would have measured had you made reference to the true horizon. Thus, all of your measurements will need to be divided by two to get the true altitude of your object above the true horizon.

With the water absolutely still, sight into the artificial horizon and find the water-reflected image of the sun or moon in the left side of the horizon mirror. If viewing the sun make sure you have proper eye protection with the filters.

Next, squeeze the quick release levers and move the index mirror until you can find the image of the sun or moon reflected through the mirror system of the sextant. For an extended object like the sun or moon, there are three ways to make a proper measurement. If one lines up the two images of the sun or moon exactly, then one makes a direct reading of the horizon angle. Use the micrometer drum to make the precise alignment. With horizon filters in place, you should be able to overlay the two images on the left side of the horizon mirror.

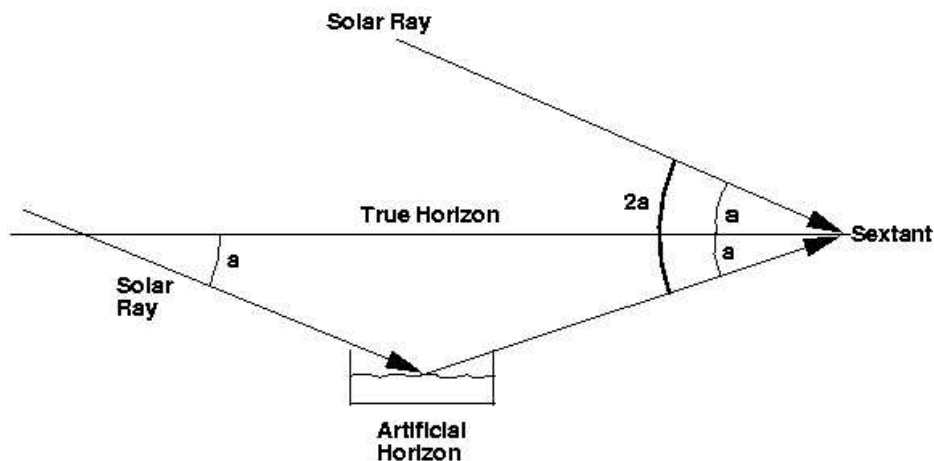


Figure 31: Geometry of the sextant view

Some people find it easier to do limb observations of the sun, and this option is left to you. For a lower limb observation, the bottom of the sextant mirror image should be lined up with the top of the image reflected in the water (which, is an upside-down image of the object). For an upper limb observation, the top of the sextant mirror image should be lined up with the bottom of the image reflected in the water. When you measure the lower limb of the sun, you need to add one-half the diameter of the sun (16 arcminutes) to your measurement. An upper limb observation requires you to subtract the same amount. If you use limb observations, you should make all three types of observations, direct and upper and lower limb, to remove positioning errors.

## 12.9 Solar Measurements

You should be ready to begin observations approximately an hour before meridian passage of the sun. Since, in principle, you don't know when meridian passage is for your longitude (your local time generally is standardized to your time zone's middle longitude, not necessarily *your* longitude), begin working at 11 AM local time and take readings until 1 PM local time. If it is daylight savings time, you should work from noon local time until 2 PM.

It is best to work in teams of three, one person to make sightings, one to record the readings and one to keep the time of the observations. Contact the TAs to schedule lab times and location.

Make sure your sextant has correctly adjusted mirrors before you begin. **Make sure not to bump the sextant during the observations, otherwise the mirrors may jar out of alignment.**

You should try to make a measurement as often as possible, but at least once every four minutes. You will need to keep moving the artificial horizon over the course of the two hours. It is easiest to make your sightings close to an announced time on the radio. To do so, track the sun in anticipation of the announcer, and use the alignment at the time of the time stamp announcement.

You should keep track of the following on your data sheet (the last three columns you will fill in later):

Date:

Viewing Location:

Observers:

Declination of the Sun on this Day (from Table 2):

Equation of Time on this Day (from Table 2):

### DATA

Measurement Number	GMT	Arc reading	upper/lower limb or direct?	horizon angle	semi-diameter correction	true sun angle
1	17:03	106° 28.4'	upper	53° 14.2'	-16.0'	52° 58.2'
2	17:06	106° 36.0'	direct	53° 18.0'	+0.0'	53° 18.0'
3	17:09	106° 47.8'	lower	53° 23.9'	+16.0'	53° 39.9'
.						
.						
.						

Once you have made your observations, you should fill out the table with the needed corrections. You will need to divide your sight readings by two because of the use of the artificial horizon. Put the result in the fifth column ("horizon angle"), which is meant to be the measurement you would have made, had you made true horizon sightings. You will also need to make a correction of 16.0 arcminutes for all limb observations, subtracting 16.0 for the upper limb observations and adding 16.0 for lower limb observations. In so doing, you will obtain the position of the *center* of the sun, which you should place in the final column.

Note that these calculations involve math with sexagesimal numbers. If you are not used to dealing with these types of calculations, see section B.3.

## 12.10 Calculating Longitude and Latitude

Begin by **making a plot** of your true sun angle versus Universal Time (GMT). **Draw a smooth curve** through the points. The peak of the curve gives you the highest position of the sun on this day, and tells you when meridian passage occurred. **Read off the highest**

**angle** of the sun from your plot. The time when your true sun angle was highest defines your “local noon.” This time might not be measured best by the single highest point on your curve. You may obtain a better estimate of local noon by **averaging pairs of times** on either side of the peak when the sun was at the same angle. The more pairs of points you can average, the better.

Note that the highest position you have calculated has been artificially inflated by a phenomenon known as atmospheric refraction. As light from the sun or any object passes through an atmosphere of increasing density before reaching you, the light rays are bent in such a way as to make them appear as if they came from a higher altitude than they actually did (Figure 32). From Table 1, estimate the amount of refraction affecting your highest measurement of the sun’s altitude. You should subtract this small refraction correction from your highest measured solar altitude to obtain the true altitude at this point of time.

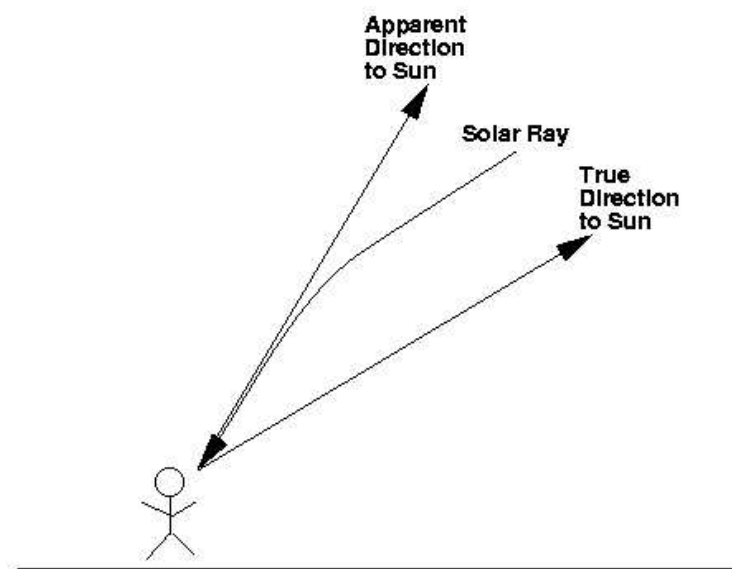


Figure 32: Light is bent by atmospheric refraction before it reaches you. The effect (greatly exaggerated here) is to make objects appear higher in the sky than they really are.

From Table 2, find the declination of the sun on the day you took the readings. In the table, an “S” for the declination means that the sun is south of the celestial equator, and its declination is therefore negative. An “N” means it is north of the celestial equator, and the declination is positive. From your measurement of the sun’s highest horizon angle, and the sun’s known declination on this day from the table, determine the horizon angle,  $H_zA$ , of the celestial equator on your meridian. ( $H_zA \text{ Sun} - \text{Dec Sun} = H_zA \text{ equator}$ )

If your latitude is LAT, the highest the celestial equator reaches for you (at your meridian) is given by  $90 \text{ degrees} - \text{LAT}$  (see Figure 26). Calculate your latitude, LAT, using the horizon angle of the celestial equator that was determined in the previous step.

Convert the time of your solar meridian passage (your “local noon”) into decimal hours. For example, if meridian passage occurred at 18:12 Universal Time, this is the same as saying it occurred at 18.20 hours, since 12 minutes is  $1/5$  of an hour (see Appendix B for more details). Note, that by definition, noon occurs at 12.00 hours in Greenwich, England, which is the prime meridian (longitude = 0 degrees). Since the earth turns 360 degrees every 24 hours, it rotates 15 degrees every hour. From your plot, you should be able to calculate your *approximate* longitude, which is measured as a number of degrees west of the prime

meridian (when you specify your longitude, it is important to specify “W” or “E” of the prime meridian). That is,  $15 \times (\text{local noon in } UT - 12) = \text{approximate longitude}$ .

Note that the longitude you have calculated is not strictly correct, and needs to be adjusted for one more effect. The earth does not *revolve* about the sun at a constant speed throughout the year, because the earth’s orbit is not perfectly circular (recall Kepler’s Laws). This slightly affects the length of the solar day (the time from one solar transit across our meridian until the next as the earth *rotates* on its axis) see Figure 33. Clocks and watches, therefore, keep the time of a fictitious or “mean” sun that travels across the sky at the same average speed throughout the year. The time of the *true* sun transit across your meridian lags or precedes the time it would have if the earth’s orbit were round (which is the assumption used in our calculations to this point). The difference in time between the true sun transit and the “mean” sun transit is called the “equation of time.” In Table 2, find the equation of time for the date of your observations. If the equation of time is listed as “W”, then you would *add* the equation of time to your “W” measurement of longitude. If the listed equation of time is “E”, *subtract* the equation of time from your “W” longitude measurement.

Note there is a secondary effect on the apparent motion of the sun having to do with the fact that the yearly motion of the sun is along the ecliptic and not parallel to the equator. This effect has also been corrected by the equation of time table.

Your write up for this lab should include your data tables, your plot of solar angle as a function of time, your calculation of the time of your local noon from pairs of symmetric points on the curve, your calculation of longitude and latitude, a *qualitative* analysis of your errors in this experiment, and answers to Questions 1-3 below.

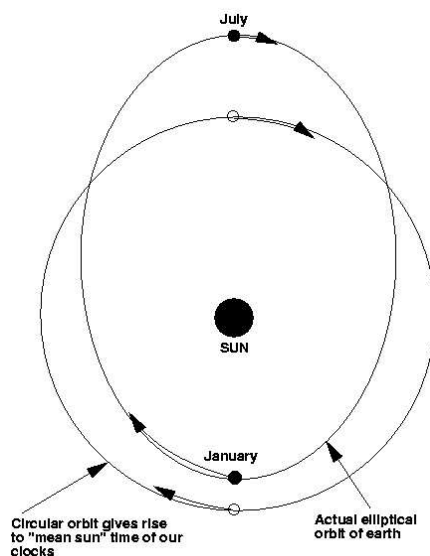


Figure 33: The earth has an elliptical orbit so that it is closer to the sun in January than in July. Because of Kepler’s second law, the earth moves faster in its orbit when it is closer to the sun. Thus, in January, the earth moves faster than it would were it on a circular orbit, and in July it moves slower than it would were it on a circular orbit. This means we have to apply the “equation of time” to correct our “local noon” measures for the “mean solar” time of our clocks.

### 12.11 Discussion Questions

1. The actual longitude and latitude of nearby McCormick Observatory is  $78^{\circ} 31' 24''$  W and  $38^{\circ} 02' 00''$  N. What is the error in your measurement of both longitude and latitude?
2. Note that one arcminute of latitude corresponds to a fixed distance of one nautical mile on the surface of the earth. However, since lines of longitude are not fixed distances from one another on the surface of the earth, but converge towards the poles, one arcminute of longitude corresponds to one nautical mile only on the equator; elsewhere, one arcminute of longitude corresponds to  $(1.0) \times \cos(\text{LAT})$  nautical miles. With this information, calculate how many nautical miles and statute miles (1 nautical mile = 1.15 statute miles) your measured longitude and latitude error is away from McCormick Observatory.
3. Imagine you are the navigator on a ship crossing the Atlantic Ocean 150 years ago. You had synchronized your clock to GMT when you left England, but now, a month later, this clock (unbeknownst to you) is eight minutes slow. You measure your latitude to be  $45^{\circ}$ . How far off course do you calculate your longitude in miles, and in which direction are you off, east or west?

### 12.12 Requirement Checklist

In addition to your full write-up,

1. Data table
2. Sun angle plot
3. ALL calculations (local noon, longitude, latitude)
4. Qualitative assesment of errors
5. Answers to three questions in the manual

**TABLE 1**  
**Refraction as a Function of Altitude for**  
**1 Atmosphere of Pressure at  $10^{\circ}\text{C}$**   
**(from Norton's 2000.0)**

<u>Altitude</u>	<u>Refraction</u>
$20^{\circ}$	$2'.7$
$25^{\circ}$	$2'.1$
$30^{\circ}$	$1'.7$
$35^{\circ}$	$1'.4$
$40^{\circ}$	$1'.2$
$45^{\circ}$	$1'.0$
$50^{\circ}$	$0'.8$
$55^{\circ}$	$0'.7$
$60^{\circ}$	$0'.6$
$65^{\circ}$	$0'.5$
$70^{\circ}$	$0'.4$
$80^{\circ}$	$0'.2$
$90^{\circ}$	$0'.0$

TABLE 2

## APPROXIMATE DECLINATION AND EQUATION OF TIME OF THE SUN

	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE	
	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /
01	23 01S	E0 54	17 12S	E3 24	07 44S	E3 09	04 23N	E1 01	14 57N	W0 44	22 00N	W0 36
02	22 56S	E1 00	16 54S	E3 27	07 19S	E3 06	04 49N	E0 57	15 18N	W0 45	22 08N	W0 33
03	22 51S	E1 08	16 36S	E3 29	06 57S	E3 03	05 11N	E0 53	15 31N	W0 46	22 18N	W0 31
04	22 47S	E1 15	16 20S	E3 30	06 35S	E2 59	05 35N	E0 48	15 52N	W0 48	22 23N	W0 28
05	22 38S	E1 18	16 00S	E3 31	06 11S	E2 55	05 56N	E0 43	16 10N	W0 49	22 31N	W0 27
06	22 33S	E1 28	15 44S	E3 31	05 47S	E2 53	06 20N	E0 39	16 26N	W0 51	22 38N	W0 23
07	22 26S	E1 35	15 25S	E3 31	05 24S	E2 50	06 44N	E0 34	16 45N	W0 52	22 45N	W0 21
08	22 17S	E1 38	15 05S	E3 32	05 02S	E2 46	07 05N	E0 30	17 00N	W0 54	22 50N	W0 18
09	22 10S	E1 45	14 47S	E3 33	04 37S	E2 42	07 25N	E0 25	17 15N	W0 55	22 53N	W0 15
10	22 01S	E1 52	14 26S	E3 34	04 14S	E2 38	07 50N	E0 23	17 32N	W0 56	22 59N	W0 12
11	21 50S	E1 58	14 08S	E3 35	03 53S	E2 33	08 11N	E0 18	17 48N	W0 56	23 03N	W0 09
12	21 42S	E2 02	13 49S	E3 34	03 26S	E2 31	08 35N	E0 14	18 03N	W0 56	23 08N	W0 06
13	21 33S	E2 08	13 28S	E3 34	03 03S	E2 26	08 54N	E0 11	18 20N	W0 57	23 10N	W0 03
14	21 21S	E2 16	13 10S	E3 34	02 41S	E2 21	09 17N	E0 06	18 33N	W0 57	23 16N	00 00
15	21 11S	E2 21	12 49S	E3 34	02 15S	E2 17	09 40N	E0 03	18 46N	W0 57	23 18N	E0 03
16	21 00S	E2 27	12 25S	E3 33	01 51S	E2 14	10 00N	W0 01	19 03N	W0 57	23 19N	E0 06
17	20 47S	E2 32	12 08S	E3 32	01 30S	E2 09	10 23N	W0 04	19 16N	W0 56	23 22N	E0 09
18	20 36S	E2 37	11 44S	E3 31	01 05S	E2 08	10 44N	W0 09	19 27N	W0 56	23 25N	E0 12
19	20 25S	E2 41	11 25S	E3 30	00 43S	E2 01	11 03N	W0 12	19 41N	W0 56	23 25N	E0 15
20	20 12S	E2 46	11 02S	E3 29	00 17S	E1 56	11 22N	W0 15	19 53N	W0 55	23 25N	E0 19
21	19 57S	E2 49	10 43S	E3 27	00 05N	E1 51	11 43N	W0 18	20 06N	W0 54	23 27N	E0 23
22	19 44S	E2 54	10 20S	E3 26	00 31N	E1 47	12 05N	W0 21	20 19N	W0 53	23 27N	E0 25
23	19 31S	E2 59	09 56S	E3 23	00 54N	E1 42	12 26N	W0 24	20 30N	W0 51	23 25N	E0 29
24	19 18S	E3 01	09 33S	E3 21	01 18N	E1 38	12 43N	W0 27	20 43N	W0 50	23 24N	E0 31
25	19 04S	E3 07	09 12S	E3 17	01 41N	E1 33	13 06N	W0 30	20 53N	W0 49	23 23N	E0 36
26	18 50S	E3 10	08 47S	E3 16	02 03N	E1 29	13 24N	W0 33	21 03N	W0 48	23 22N	E0 39
27	18 32S	E3 12	08 30S	E3 14	02 27N	E1 24	13 44N	W0 35	21 15N	W0 46	23 21N	E0 42
28	18 16S	E3 16	08 06S	E3 10	02 50N	E1 19	14 05N	W0 38	21 24N	W0 44	23 19N	E0 45
29	18 00S	E3 18			03 14N	E1 15	14 20N	W0 39	21 33N	W0 42	23 16N	E0 46
30	17 46S	E3 20			03 38N	E1 10	14 40N	W0 42	21 43N	W0 41	23 12N	E0 51
31	17 27S	E3 23			04 00N	E1 06			21 50N	W0 38		

	JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /	Dec. ° /	Eq. ° /
01	23 06N	E0 53	18 07N	E1 33	08 25N	E0 02	03 00S	W2 31	14 19S	W4 06	21 43S	W2 43
02	23 03N	E0 56	17 55N	E1 33	08 06N	W0 01	03 25S	W2 35	14 37S	W4 06	21 53S	W2 41
03	23 01N	E0 59	17 37N	E1 32	07 42N	W0 06	03 48S	W2 41	14 57S	W4 07	22 03S	W2 35
04	22 56N	E1 03	17 23N	E1 32	07 21N	W0 12	04 10S	W2 46	15 16S	W4 07	22 11S	W2 30
05	22 49N	E1 05	17 05N	E1 31	06 58N	W0 18	04 34S	W2 50	15 32S	W4 07	22 18S	W2 25
06	22 45N	E1 09	16 50N	E1 29	06 37N	W0 23	04 56S	W2 54	15 52S	W4 06	22 26S	W2 19
07	22 37N	E1 12	16 32N	E1 27	06 14N	W0 28	05 20S	W3 00	16 10S	W4 06	22 35S	W2 12
08	22 32N	E1 13	16 15N	E1 25	05 52N	W0 32	05 44S	W3 05	16 27S	W4 05	22 41S	W2 04
09	22 25N	E1 14	15 59N	E1 23	05 30N	W0 35	06 07S	W3 10	16 45S	W4 04	22 45S	W2 00
10	22 19N	E1 17	15 41N	E1 20	05 06N	W0 42	06 30S	W3 13	17 00S	W4 03	22 52S	W1 53
11	22 11N	E1 19	15 25N	E1 18	04 45N	W0 49	06 52S	W3 15	17 18S	W4 01	22 58S	W1 44
12	22 01N	E1 23	15 06N	E1 17	04 21N	W0 54	07 15S	W3 20	17 34S	W4 00	23 02S	W1 39
13	21 54N	E1 24	14 47N	E1 14	03 57N	W0 58	07 37S	W3 24	17 51S	W3 58	23 06S	W1 32
14	21 44N	E1 25	14 29N	E1 12	03 34N	W1 03	07 58S	W3 29	18 08S	W3 55	23 10S	W1 25
15	21 37N	E1 26	14 12N	E1 09	03 13N	W1 09	08 20S	W3 32	18 22S	W3 52	23 16S	W1 17
16	21 25N	E1 27	13 51N	E1 06	02 48N	W1 15	08 45S	W3 34	18 38S	W3 50	23 19S	W1 10
17	21 17N	E1 29	13 35N	E1 03	02 25N	W1 21	09 06S	W3 36	18 53S	W3 48	23 22S	W1 03
18	21 05N	E1 30	13 15N	E1 00	02 03N	W1 24	09 30S	W3 42	19 07S	W3 45	23 23S	W0 56
19	20 55N	E1 32	12 54N	E0 57	01 40N	W1 31	09 45S	W3 44	19 23S	W3 41	23 24S	W0 48
20	20 46N	E1 33	12 37N	E0 52	01 16N	W1 36	10 12S	W3 46	19 35S	W3 37	23 25S	W0 41
21	20 35N	E1 35	12 15N	E0 50	00 52N	W1 41	10 33S	W3 48	19 50S	W3 35	23 27S	W0 33
22	20 23N	E1 36	11 58N	E0 44	00 29N	W1 47	10 55S	W3 50	20 03S	W3 31	23 27S	W0 24
23	20 10N	E1 37	11 36N	E0 41	00 05N	W1 52	11 15S	W3 52	20 16S	W3 25	23 26S	W0 18
24	19 58N	E1 37	11 16N	E0 36	00 17S	W1 56	11 35S	W3 54	20 28S	W3 21	23 25S	W0 11
25	19 44N	E1 36	10 54N	E0 33	00 40S	W2 01	11 58S	W3 57	20 41S	W3 16	23 24S	W0 02
26	19 31N	E1 36	10 35N	E0 28	01 05S	W2 08	12 16S	W3 59	20 52S	W3 14	23 23S	E0 04
27	19 19N	E1 36	10 14N	E0 24	01 28S	W2 11	12 36S	W4 02	21 02S	W3 08	23 22S	E0 12
28	19 06N	E1 35	09 53N	E0 20	01 52S	W2 16	13 00S	W4 03	21 13S	W3 02	23 19S	E0 19
29	18 50N	E1 35	09 30N	E0 16	02 15S	W2 21	13 20S	W4 04	21 24S	W2 59	23 16S	E0 26
30	18 38N	E1 35	09 11N	E0 13	02 38S	W2 28	13 39S	W4 05	21 36S	W2 53	23 12S	E0 35
31	18 23N	E1 34	08 48N	E0 08			13 57S	W4 06			23 07S	E0 41

## 13 CLEA - THE MOONS OF JUPITER

This is a computer lab in which you will estimate the mass of Jupiter based on observations of its four largest moons.

This lab generally requires 2-3 hours of computer work plus several hours of analysis and writeup time. A manual and worksheet may be obtained at <http://www.astro.virginia.edu/class>. As with all labs, a full write-up is required. Please note that you must write your purpose, procedure and conclusion sections on your own. Pages torn from the lab manual will not be accepted.

All CLEA labs have two versions at <http://www.astro.virginia.edu/class>. The first is for Astronomy 1210/1220 while the second is for Astronomy 1230. **You will not receive credit for doing the wrong lab.** Please be certain that you perform the correct lab exercise.

## 14 CLEA - HUBBLE'S LAW

This is a computer lab in which you will use simulated redshift and magnitude data for several galaxies to estimate the Hubble constant and subsequently the age and size of the Universe.

This lab generally requires 2-3 hours of computer work plus several hours of analysis and writeup time. A manual and worksheet may be obtained at <http://www.astro.virginia.edu/class>. As with all labs, a full write-up is required. Please note that you must write your purpose, procedure and conclusion sections on your own. Pages torn from the lab manual will not be accepted.

All CLEA labs have two versions at <http://www.astro.virginia.edu/class>. The first is for Astronomy 1210/1220 while the second is for Astronomy 1230. **You will not receive credit for doing the wrong lab.** Please be certain that you perform the correct lab exercise.

## 15 CLEA - CLASSIFICATION OF STELLAR SPECTRA

This is a computer lab in which you will learn how to classify stars and roughly determine their distances by examining their spectra.

This lab generally requires 2-3 hours of computer work plus several hours of analysis and writeup time. A manual and worksheet may be obtained at <http://www.astro.virginia.edu/class>. As with all labs, a full write-up is required. Please note that you must write your purpose, procedure and conclusion sections on your own. Pages torn from the lab manual will not be accepted.

All CLEA labs have two versions at <http://www.astro.virginia.edu/class>. The first is for Astronomy 1210/1220 while the second is for Astronomy 1230. **You will not receive credit for doing the wrong lab.** Please be certain that you perform the correct lab exercise.

## 16 CLEA - PHOTOELECTRIC PHOTOMETRY OF THE PLEIADES

This is a computer lab in which you will use simulated observations of the Pleiades star cluster to generate a color-magnitude diagram and estimate its distance.



This lab generally requires 2-3 hours of computer work plus several hours of analysis and writeup time. A manual and worksheet may be obtained at <http://www.astro.virginia.edu/class>. As with all labs, a full write-up is required. Please note that you must write your purpose, procedure and conclusion sections on your own. Pages torn from the lab manual will not be accepted.

All CLEA labs have two versions at <http://www.astro.virginia.edu/class>. The first is for Astronomy 1210/1220 while the second is for Astronomy 1230. **You will not receive credit for doing the wrong lab.** Please be certain that you perform the correct lab exercise.

## A APPENDIX: SKY PHENOMENA

The following pages explain the basic phenomena which can be observed in the night sky with the naked eye. They compare **what is**, with what we see.

## B APPENDIX: COORDINATE SYSTEMS IN ASTRONOMY

Astronomers need a systematic and universal method for finding a given point on the celestial sphere. The method they use is called the *Equatorial Coordinate System*.

Navigators use a two-angle coordinate system for finding places on the Earth's surface. The two terrestrial coordinates are *latitude* and *longitude*. Both of these are *angles* measured with respect to fiducial lines on the Earth's surface. Latitude measures the angle north or south between a location and the Earth's equator while longitude measures the angle east or west between a location and the Prime Meridian (running through Greenwich, England).

The Equatorial Coordinate System is very similar. Coordinates are measured with respect to the *celestial equator*, the *celestial poles*, and the *vernal equinox*. These are shown in Figure 34. The extended axis of the Earth's spin runs directly through the celestial poles while the celestial equator is the projection of the Earth's equator onto the sky. The celestial poles are exactly  $90^\circ$  from the celestial equator.

### B.1 Right Ascension and Declination

There are two coordinates in the equatorial system, *right ascension* and *declination*. Just as in the case of the terrestrial system, two angles suffice to locate any point on the celestial sphere (see Figure 34). Declination or DEC is analogous to latitude. It is the angular distance in degrees from the celestial equator. It is measured along a great circle through the celestial poles (see Figure 34). Declination is positive in the northern half of the sphere, negative in the southern half. A point on the equator has a declination of zero.

The other coordinate, right ascension or RA, is analogous to longitude. It is an angle measured eastward<sup>2</sup> along the equator.

The zero point for RA is the vernal equinox. The vernal equinox and autumnal equinox are the points where the *ecliptic*, the apparent annual path of the Sun in the sky, crosses the celestial equator. The ecliptic is tilted  $23.5^\circ$  with respect to the equator because the Earth's rotation axis is inclined  $23.5^\circ$  to the plane of its motion around the sun (see item 3 in the previous section). The vernal equinox is in the constellation Pisces, and the Sun crosses this point moving north on the first (official) day of spring (around March 21). RA is the angle measured eastward along the equator from the vernal equinox to the great circle through the point in question and both celestial poles. This great circle is called the *hour circle* of the point (see figure 34).

By tradition, RA is normally quoted in hours, running from  $0^h$  to  $24^h$ . Beware the confusion between “minutes” and “seconds” of *time* and “minutes” and “seconds” of *arc*. Along the equator, 1 hour of time equals  $15^\circ$  of arc, one minute of time is  $15'$  (15 minutes of arc), and one second of time is  $15''$  (15 seconds of arc). (Because of the convergence of lines of constant RA toward the poles, this conversion only holds at the equator. At higher or lower DEC, a given change in RA is a *smaller* distance in degrees.) DEC is quoted in degrees, minutes, and seconds of arc.

RA and DEC are often denoted by the Greek letters  $\alpha$  and  $\delta$ , respectively.

The RA and DEC coordinates of the planets, the Sun, and the Moon change daily as they move in the sky with respect to the stars. On the other hand, the RA and DEC coordinates for stars do not change appreciably in the course of a year. Stellar coordinates do, however, change slowly because of the *precession* of the Earth's rotation axis. But these effects are not

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<sup>2</sup>Eastward is the direction toward which the Earth rotates and is opposite to the direction towards which the celestial sphere appears to rotate.

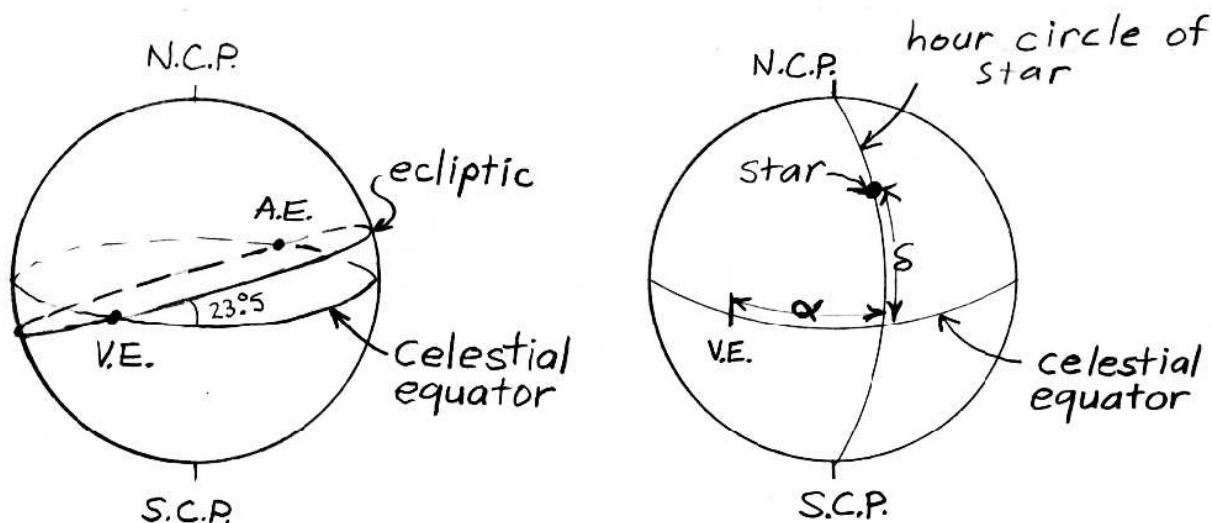


Figure 34: Right ascension and declination ( $\alpha$  and  $\delta$ ) as seen from the outside of the celestial sphere, in the right-hand drawing. The left-hand drawing shows the ecliptic, inclined at  $23.5^\circ$  to the equator, and locates the vernal equinox (V.E.) and autumnal equinox (A.E.). The vernal equinox is the reference-point for  $\alpha$ , while the equator is the reference for  $\delta$ .

obvious for small telescope observations except over a period of about 10 years. (Precession is the reason coordinates are referred to a particular “equinox.” If you try to use coordinates for equinox 1950, say, instead of 2000, there will be an appreciable correction needed to locate your target.)

## B.2 Hour Angle and Altitude

The next problem is to locate an astronomical object in the sky at a particular time on a particular night. Because of the spin of the Earth on its axis, the part of the universe you can see is constantly changing. The *horizon plane* is defined to be the (theoretical, flat) plane which is tangent to the Earth’s surface at your location. You can only see objects which are above your horizon. Each point on the Earth’s surface has a different horizon plane, and all of these are continuously moving with the Earth’s rotation (except for the two horizons exactly at the Earth’s north and south poles).

In order to locate an astronomical object, you need to know what part of the sky is directly over your horizon plane at a given moment. Although a star will always lie at a given angular distance from the pole or equator (as determined by its DEC), its position in the other (east-west) angular coordinate with respect to your horizon changes during the night. To determine this, we need to introduce another reference circle in the sky and a measure of the time of day.

The reference circle is your *meridian*. The point directly overhead (i.e. perpendicular to your horizon plane) is known as the *zenith* (see figure 35). The great circle through the celestial poles and the zenith is called the meridian. When a star crosses the meridian, or “transits,” its distance from the horizon is greatest<sup>3</sup> and it is best placed for observation.

<sup>3</sup>Stars cross an observer’s meridian twice per day, once with maximum elevation and once with minimum elevation. The crossing with minimum elevation is usually below the horizon and not visible. But for stars near the visible celestial pole, both transits are visible.

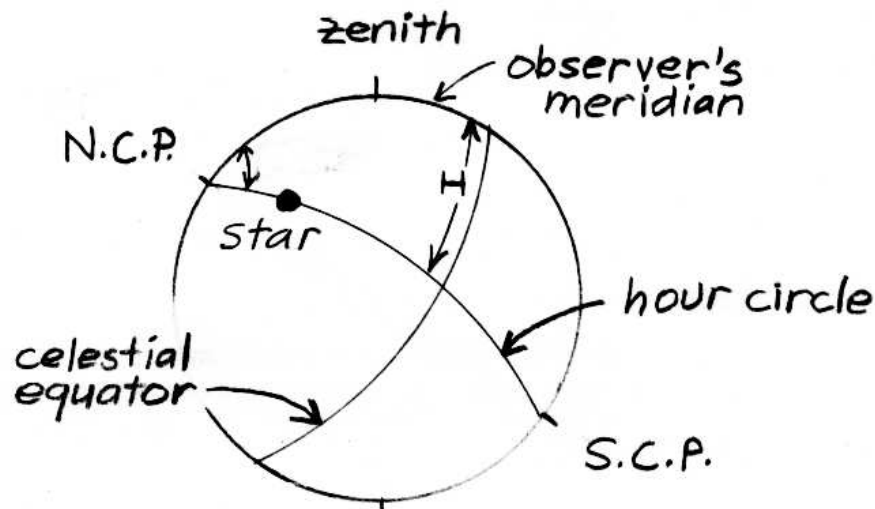


Figure 35: Hour Angle ( $H$  here) is the angular distance between the hour circle of the star and the local meridian, measured parallel to the equator. This view is from outside the celestial sphere.

The *hour angle* or HA is then defined to be the angle measured along the equator between the hour circle of the star and the meridian (see Figure 35). Hour angle is positive to the *west*, i.e. after transit (see Figure 36). It is usually measured in hours. Thus, the hour angle represents how long it has been since an object crossed the meridian. A star with an HA of  $-1$  will be on the meridian in one hour while one with an HA of 2 crossed two hours ago. An HA of 21 hours is equivalent to  $HA = -3$ .

Astronomical time of day is measured by *sidereal time*, or ST. ST is defined to be the hour angle of the vernal equinox. Since the vernal equinox is also the zero point of the RA scale, ST is also equal to the RA, or  $\alpha$ , of an object now on the meridian. In equation form, the hour angle for any object is simply the sidereal time (ST) minus the object's right ascension:

$$HA = ST - \alpha$$

Sidereal time runs faster than the mean solar time that our watches use by 3 minutes and 56 seconds per day, a result of the Earth's orbital motion around the sun. This means that the sidereal time at a given standard time changes continuously by 2 hours per month (adding up to 24 hours in a year). Observatories have special clocks to track sidereal time. Since the difference in rate between sidereal time and mean solar time is small, you can set your watch to the current sidereal time, and it will track ST well enough for your use over the course of an observing session. The following table gives the sidereal time for 9 PM EST for selected dates throughout the year. (Remember to convert from Daylight Time to Standard, if necessary.)

DATE	ST @ 9PM EST
Jan. 21	5
Feb. 21	7
Mar. 21	9
Apr. 21	11
Sep. 21	21
Oct. 21	23
Nov. 21	1

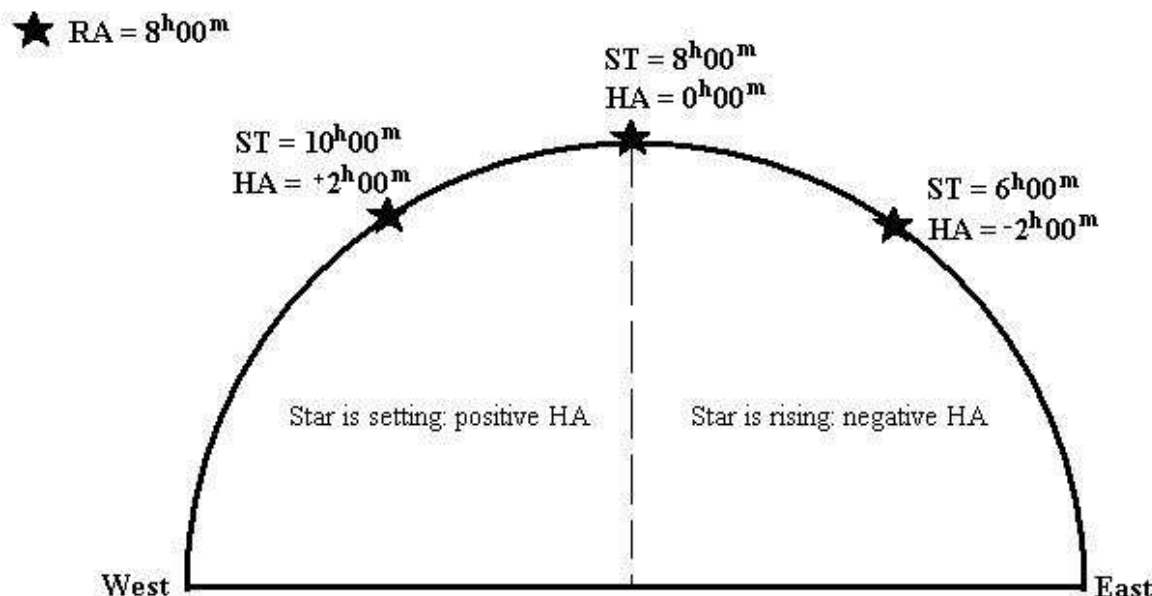


Figure 36: The Hour Angle of a star with  $\alpha = 8^h00^m$  for three different times. Note that the star reaches its highest point when  $HA=0$ . This view is from an observer on Earth facing North

Knowing HA and DEC, you can locate any object in your local sky. Of course, HA is constantly changing, so this causes practical difficulties. Most modern small telescope mounts contain clock drives which automatically compensate for changes in ST and permit you to set coordinate dials using RA rather than HA.

The star  $\beta$  Cassiopeia (Caph) has an RA near  $0^h$  and is always above the horizon in Charlottesville. It can be used visually in conjunction with Polaris as a crude “sidereal time clock,” since its hour angle approximately equals the sidereal time. (The dial of this “clock” runs counterclockwise, however.)

Another useful local coordinate is *altitude* or ALT. Altitude is the angle between an astronomical object and the horizon plane. Because of lights, haze, seeing, or local obstacles, it is often difficult to observe objects at altitudes less than  $30^\circ$ . The altitude may be calculated from an object’s hour angle, its declination, and the latitude from which it is observed; but this involves trigonometry and will not be covered here. (The other coordinate used in the alt-az local system is the *azimuth*. It is defined as the angle measured clockwise along the horizon from due north through east to the point where a great circle passing through an object and the zenith crosses the horizon. We will not discuss azimuth further here.)

It is easy to calculate an object’s altitude when it crosses the meridian (i.e. has  $HA = 0$ ), however. Consult figure 37. There we see that the altitude above the southern horizon for an object on the meridian is  $SALT = DEC + (90^\circ - LAT)$  where LAT is the latitude of the observing site. The altitude above the northern horizon is  $NALT = (LAT + 90^\circ) - DEC$ . Objects with  $DEC = LAT$  cross through the zenith ( $SALT = NALT = 90^\circ$ ). The celestial equator (where  $DEC = 0^\circ$ ) has  $SALT = 90^\circ - LAT$  on the meridian.

Solar system objects, which lie near the ecliptic, have altitudes on the meridian which vary with the time of year. The maximum altitude of the sun occurs on June 21 when its  $DEC = 23^\circ5'$  and  $SALT = 113^\circ5' - LAT$ . Since for Charlottesville,  $LAT = 38^\circ$ , the maximum  $SALT$  for the sun is  $75^\circ5'$ . Its minimum  $SALT$  on the meridian (Dec. 21,  $DEC = -23^\circ5'$ ) is  $28^\circ5'$ .

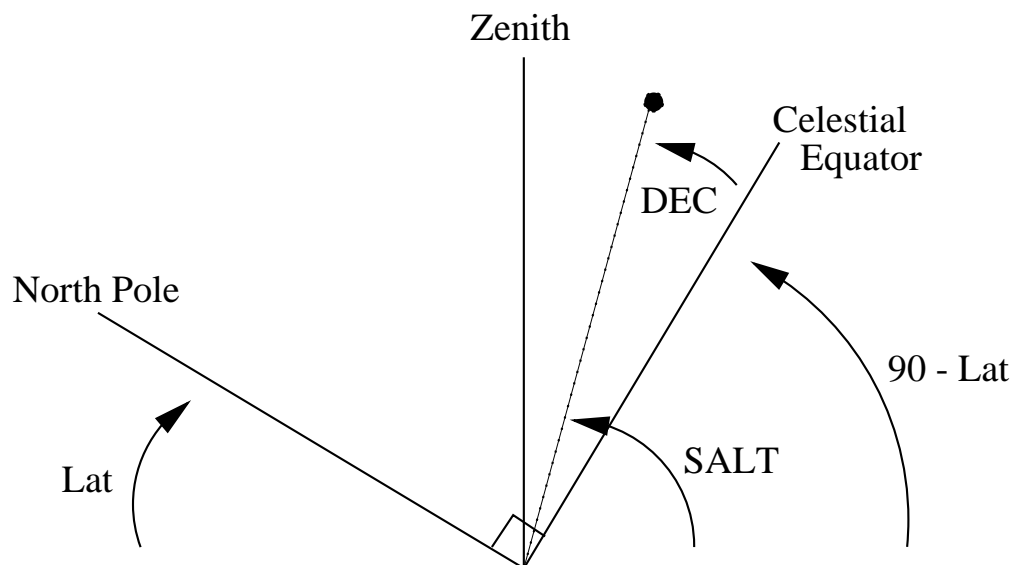


Figure 37: A view of a slice through the observer's meridian showing the relationship of a star's declination  $DEC$  and the observer's latitude  $Lat$ , to the altitude of the star above the Southern horizon  $SALT$  when it is on the meridian. The horizontal line is the horizon plane.

This large difference in the altitude of the sun implies a large change in the amount of sunlight incident per square meter of Earth's surface, and hence produces the change in the seasons.

The moon's orbit is slightly more extreme. It is inclined  $5^\circ$  to the ecliptic, so its maximum and minimum  $SALT$ 's are  $80^\circ 5'$  and  $23^\circ 5'$ . The full moon is always directly opposite the sun in the sky, so the  $SALT$  of the full moon is large when the  $SALT$  of the sun is small (December) and vice versa. Of the bright planets, only Mercury has an orbital inclination greater than  $5^\circ$  from the ecliptic.

### B.3 Sexagesimal Mathematics

The coordinate units used in astronomy use sexagesimal numbers, a convention going back to the time of the Babylonian astronomers. This means that a given unit is broken up into 60 parts, rather than the familiar 10 (the decimal system). For example, an hour is broken into 60 minutes of time. Similarly, a degree is broken into 60 arc minutes, and an arc minute into 60 arc seconds.

In doing sexagesimal arithmetic you must remember to convert using factors of 60, not 10. A standard method is to convert all units to the smallest significant unit (e.g. minutes of arc), perform the operation and then convert back. You can also do arithmetic directly if you are careful. E.g. to find the hour angle of a star with  $RA = 9^h 45^m$  if the sidereal time is  $ST = 11^h 30^m$ , first rewrite the ST as  $10^h 90^m$ , then subtract the hours and minutes of RA separately, and arrive at the answer  $HA = 1^h 45^m$ .

To convert from sexagesimal to decimal you need to divide by 60. For example, to convert  $14^\circ 18'$ , divide 18 arcminutes by 60 arcminutes per degree to get 0.3 degrees. Add this to the original 14 degrees to get  $14.3^\circ$ . To convert back, take the decimal portion, 0.3 degrees, and multiply it by 60 arcminutes per degree to get 18 arcminutes. This will bring you back to your starting point of  $14^\circ 18'$ . Remember, if you are using seconds, you must first convert into arcminutes, then degrees, or simply use the conversion that there are 360 arcseconds per degree.

## C APPENDIX: TELESCOPE BASICS

Read this material before reviewing the procedure for Laboratory 3 (Introduction to Small Telescopes). *Norton's Star Atlas* also contains a chapter on telescopes, which you can read for more details.

### C.1 Telescope Optics

A telescope gathers light from the stars and focuses it to form an image. The main optical element (either a lens or a mirror) is called the **objective** or the **primary**. For visual use, the image formed by the objective is magnified and examined with an **eyepiece**. The more common optical designs are described below (see Fig. 38).

1. The **refractor** is the most familiar form of telescope. The objective is a transparent lens of shaped glass. The first astronomical refractor was used by Galileo (1610). Modern refractors use a closely-spaced combination of lenses to form the image. The lenses are made of different types of glass and have surfaces of differing curvature.
2. The **reflector** was invented by Gregory and Newton in the late 17th century. The primary is a concave mirror. A reflective coating on the front surface of the mirror reflects the incoming light back upon itself. Other mirrors are then used to direct the light to various foci outside the telescope tube. In a *Newtonian* reflector, a small, flat *secondary* mirror set at a  $45^\circ$  angle reflects the light through the side of the tube. In a *Cassegrain telescope*, the secondary mirror reflects the light back toward a hole in the center of the primary, so the beam emerges below the main mirror. In either case, the secondary mirror obscures only a small fraction of the telescope primary and normally has very little influence on the quality of the image. All large professional telescopes are now reflectors, as are most amateur telescopes.
3. **Catadioptric** (“lens-mirror”) telescopes use a combination of lenses and mirrors to form the image. In the usual arrangement, incoming light passes first through a large, thin lens and is then reflected by a series of mirrors. These designs are more compact but more difficult to manufacture (and hence more costly) than simpler types. They are popular for amateur telescopes. A standard version is the “Schmidt-Cassegrain” design, which adds a specially shaped Schmidt refractive corrector to a Cassegrain primary and secondary.

In order to produce a concentrated image at the telescope’s focal plane, the surface of the primary must be carefully *figured* so that light rays which enter the primary at larger radii are deflected through larger angles. It is not possible to do this for rays that are incident on the primary at larger angles, so the *field of view* of the telescope (the angular area on the sky which is in good focus) is always limited. The thin auxiliary lens in the Catadioptric designs produces a wider field of view.

To work well, telescope optics must be figured to high precision. Light is an electromagnetic wave, and in order to produce good images, optical surfaces should not introduce disturbances (variations from the desired perfect conditions) which are larger than one wavelength of light. The rule of thumb for a good telescope mirror, for instance, is that it not have deviations from the desired shape (e.g. a parabola) which are larger than one-quarter wavelength of light. But the wavelength of green light is about  $5 \times 10^{-5}$  cm, so a good mirror must be figured to a tolerance of about  $10^{-5}$  cm. This is very demanding. Good techniques for such precision were not developed until the 1800’s; earlier telescopes were very crude by today’s standards.

To get a feel for what this kind of precision implies, imagine that a modern 8-m diameter telescope mirror were blown up to the size of the United States—3000 miles in diameter.



Then, the largest deviation from a perfect surface allowed by the rule of thumb on this gigantic mirror would be only about 3 inches! Modern professional telescope mirrors are usually figured to higher precision than this.

The purpose of the eyepiece is to convert the light beam emerging from the main telescope optics so that it can be viewed by the human eye. The eye, of course, contains its own adjustable lens. However, the lens cannot focus on the strongly converging or diverging light beam from the telescope optics. On the other hand, the lens is well adapted to viewing distant objects. The light rays coming from distant objects are parallel to one another. Therefore, eyepieces convert the light rays emerging from the telescope optics into a parallel beam. The eye responds the same way it would to the light rays from a real object at a large distance and focuses these on the retina. Despite the fact that the rays are parallel, the view you see is a high magnification enlargement of the image formed in the focal plane of the telescope. Eyepieces must be moved to the proper distance from the focal plane so that the image is in focus. This distance equals the focal length of the eyepiece.

## C.2 Functions of a Telescope

Telescopes have three important functions: they collect more light than does your eye, they magnify astronomical objects, and they make images sharper.

*a) Light Gathering Power:* In most applications, this is the most important function of a telescope. The collecting area of your eye is the open area of the iris called the pupil. Your pupil becomes larger in darker conditions, but it cannot open beyond a certain maximum size. The maximum diameter of your pupil under dark conditions is about 7 mm (0.7 cm), so the collecting area of your eye is about  $\pi r^2 = \pi(0.7/2)^2 \text{ cm}^2 = 0.385 \text{ cm}^2$ . The collecting area of a telescope can be much larger. An 8-in (20 cm) diameter telescope, for instance, has a collecting area of  $\pi(20/2)^2 \text{ cm}^2 = 314 \text{ cm}^2$  which is about 800 times larger than your pupil. Thus, with an 8-in telescope you can see stars that produce 800 times less flux than the faintest stars visible to your unaided eye. There are only about 2000 stars detectable by the naked eye (over the whole sky). But there are over 5,000,000 detectable in an 8-in telescope! Modern instruments can have a diameter of up to 10 m, giving them over two million times the collecting area of your eye.

*b) Magnification:* Magnification is the increase in *apparent angular size* of objects as seen through a telescope. The amount of magnification depends on the combination of the particular telescope objective and eyepiece used. Eyepieces come in different focal lengths, which provide different magnifications. The focal length is marked on the end or the side. Low-power eyepieces generally have longer barrels, and high power eyepieces have shorter barrels. The magnification is found from the formula

$$\text{magnification} = \frac{\text{focal length of telescope}}{\text{focal length of eyepiece}}$$

High magnifications are useful for some kinds of observing (terrestrial scenes and planets, for instance). But they are not optimal for observing deep sky objects (nebulae and galaxies) since these have low surface brightnesses, which are reduced further under magnification. No small telescope is capable of actually resolving the image of a star, so high magnifications offer little advantage for stellar observations (except in observations of multiple stars). Most of your observations will be made with magnifications of 50–200 $\times$ .

*c) Sharpness* The sharpness or resolution of an astronomical image increases with the size of objective of the telescope. (This assumes that all of the optical components are of high quality, which is not always the case with mass produced amateur-type telescopes). For

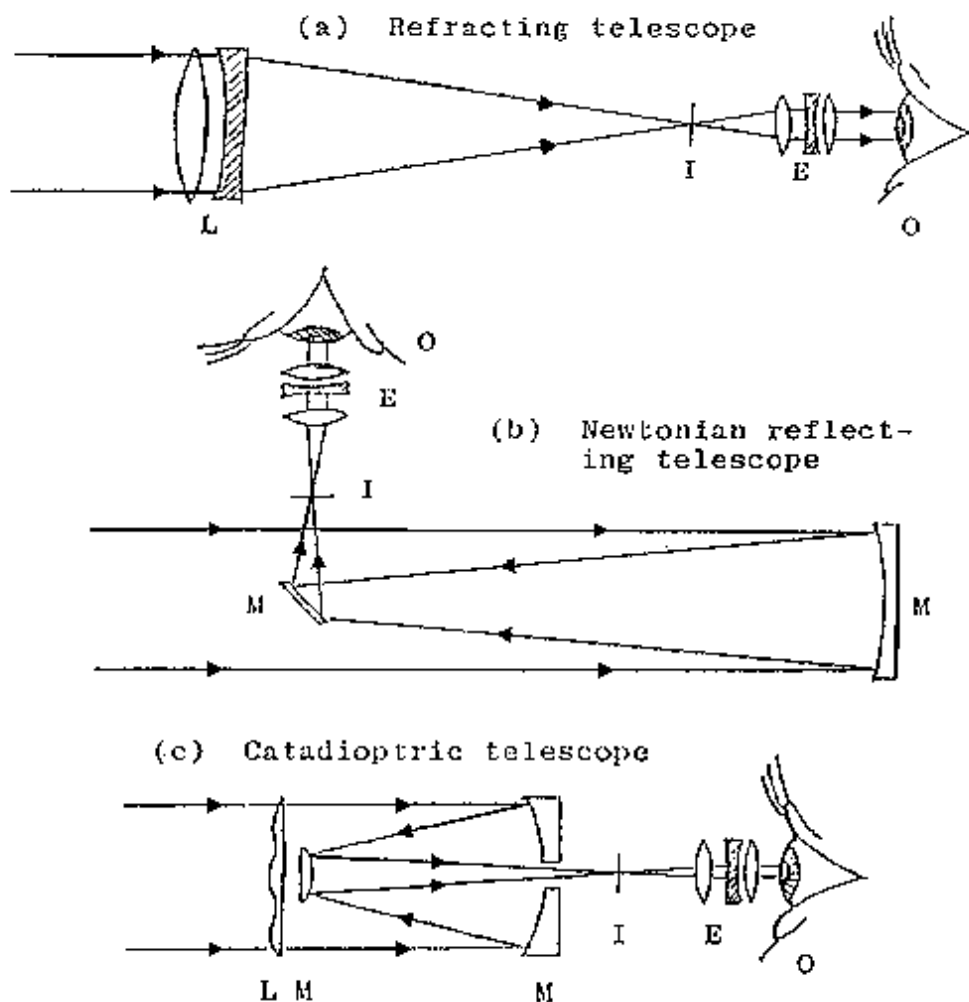


Figure 38: Common optical designs for telescopes. Lenses  $L$  and/or mirrors  $M$  form an image  $I$  which is magnified by an eyepiece  $E$  and examined by the observer  $O$ .

instance, the diameter of the smallest feature you can resolve on the surface of the Moon is, in principle, half as large with a 16-in telescope as with an 8-in. However, in most situations with telescopes over 8-in, it is the stability of the atmosphere which governs the sharpness of an image rather than the optics of the instrument. The Hubble Space Telescope takes much sharper images than much larger telescopes on the ground mainly because it is outside the Earth's atmosphere.

### C.3 Parts of the Telescope

The telescope that you will use for this course is a Schmidt-Cassegrain type catadioptric telescope. The mechanical parts are described below.

The telescope consists of a **tube** which contains the optical parts and keeps them aligned. It also carries the **focus adjustment** on the back and the auxiliary **finder telescope**. The eyepiece is in position behind the focal plane, where the light rays converge to form the image.

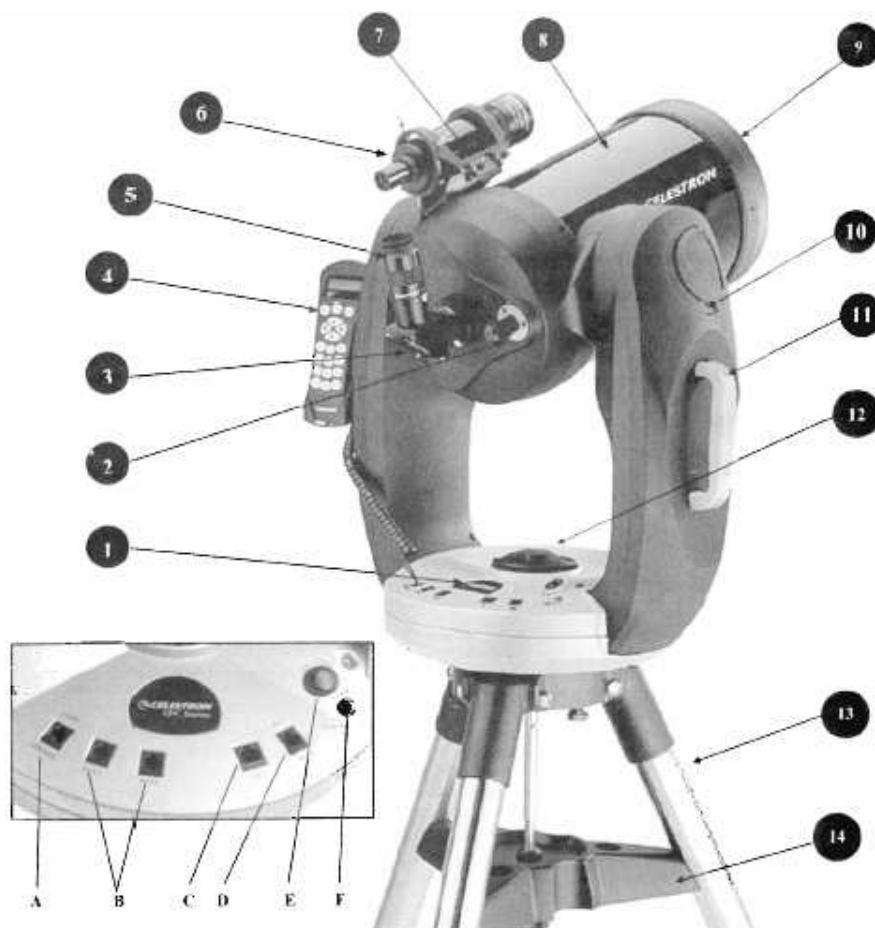


Figure 39: The Celestron CPC-800 Schmidt Cassegrain Telescope. (2) Focusing Knob; (3) Star Diagonal; (4) Hand Control; (5) Eyepiece; (6) Finder Scope; (8) Optical Tube; (9) Lens Cap Cover; (10) Fork Arm; (11) Carrying Handle; (12) Right Ascension Locking Knob; (A) Hand Control Port; (E) Power Switch; (F) 12v Input Jack

The focus adjustment changes the separation between the eyepiece and the image at the focal plane.

The **finder scope** is a complete, low power telescope used to initially locate an object. It views a *much larger area* of the sky than the main telescope. It has cross hairs for centering a star, and adjustment screws to line it up so it points in exactly the same direction as the main telescope. When a star is centered on the cross hairs, it should also be centered in the eyepiece of the main telescope. The adjustment screws occasionally loosen, so you may have to adjust the pointing of the finder. To do this, point the telescope at a distant object and center it in the main telescope. Then move the finder by loosening and tightening the adjustment screws until the object is also centered in the cross hairs.

The **eyepiece holder** is designed for easy interchange of eyepieces. It may hold these in by friction, or there may be a set-screw which needs to be tightened after the eyepiece is inserted. Do not overtighten, and be sure to loosen this before changing eyepieces. A swiveling **right-angle diagonal prism** is often used with the holder on Cassegrain telescopes to permit less awkward observing positions.

The **telescope mounting** carries the tube assembly, allowing it to be pointed to all parts

of the sky. There are two basic types of telescope mounts. **Equatorial mounts** were the most common for most of the 19th and 20th centuries because they are able to track objects with only one motion. One axis of rotation, the polar axis, points at the North Celestial Pole. Rotating the telescope around this axis turns the telescope east and west, which allows it to follow the stars. The **declination axis** is at right angles to the polar axis. Rotation about this axis turns the telescope north and south. This axis is locked as the telescope tracks objects using the polar axis. There are many sub-types of equatorial mounts. In the “German” mount, the declination axis carries the tube at one end and a dead weight for balance at the other. In the “fork” mounting, the polar axis is split into two arms and the telescope swings between them; the declination axis is formed by a bearing on either side of the tube.

The other basic type of telescope mount is the **altitude-azimuth (or “alt-az”) mount**. Here, there is a vertical axis, which allows the telescope to move in azimuth (parallel to the horizon), and a horizontal axis which allows it to move in altitude (perpendicular to the horizon). Alt-az mounts are favored for very large telescopes because they are easier to engineer. Their disadvantage is that motions about **both** axes are required to track the motion of an object (which moves along a line of constant declination, not constant altitude or azimuth). However, this is now straightforward with computer-controlled telescopes, and many recent models of amateur telescopes feature computer-controlled alt-az mounts. A small practical difficulty is that alt-az telescopes cannot track objects near the zenith well.

Your mounting may have **clamps** to lock the axes in place, **slow motions** to turn the axes slowly and smoothly for finding and following objects, **setting circles** or **coordinate displays** for locating objects using their right ascension and declination, or a motor drive for automatically moving the telescope from east to west to follow the stars’ motions. Computer-controlled telescopes offer many convenience features such as automatic target finding. Read Lab 3, “Introduction to Small Telescopes,” for instructions on how to operate your particular telescope.

## D APPENDIX: HOW TO WRITE A LAB REPORT

Most of the laboratories in this manual require you to submit a written report, and many require tabulation of data, graphing, calculation and error analysis. Presented here are some suggestions and rules of thumb for doing these things properly.

### D.1 Organization and Presentation

Your lab report is expected to be well organized, neatly presented, and clear. For this reason, hand-written work, other than the standard observing forms and data sheets provided with some of the laboratories, will not be accepted. Do not submit pages torn out of the lab manual. You should word-process or type up the text of submitted labs.

Your lab report should be divided into sections. The sections listed below and are the *minimum* requirements. You may add additional sections at your discretion. However, if one of the sections listed below is not included, the lab report will be considered incomplete.

1. **Introduction.** What was the purpose of the lab? What did you do and why? What were you hoping to achieve? This section should be one or two paragraphs describing the basics of the experiment. Do not go into details. Simply outline what was done.

*Example:*

The purpose of this laboratory was to characterize the observational properties of some deep sky objects, such as open and globular clusters, galaxies, and nebulae. We observed and sketched the appearances of M31, M13, M57, M15, M45, and M27 over the course of the semester. We then made comparisons between our observations and the physical nature of these objects that we learned in class.

2. **Procedure.** List step by step how you did the lab. The purpose of this section is to help the reader recreate what you did or assess the reliability of the outcome. You want to explain how you obtained your results, giving all pertinent details of your technique. Describe any equipment you used and how you used it. (A detailed description of the standard telescopes is not necessary.) Note difficulties that arose and how you overcame them. You should include any formulae that you used. **Imagine that the person reading your lab is a classmate and you are giving him or her an outline of how to repeat your experiment.** Include important items, but refrain from providing too much detail and extraneous information (e.g. "I arrived at the observatory at 9:17 pm, I got the telescope from the TA, I took it outside, I set it up, I took the lens cap off...").

*Example:*

1. On September 2 at 8:30 p.m., we checked out Telescope B and set it up.
2. With the aid of our finding chart, we found M13 in our telescope by using the bore-sighting method and a 32 mm (low power) eyepiece.
3. We switched to a 12 mm eyepiece and sketched the object including the brightest 50 or so stars. There were many fainter stars in the field.
4. For this and all other objects in the lab, we determined the cardinal directions (N, E, S, W) of our field. To determine East and West, we turned off the clock drive and watched the stars drift westward and noted these directions on our drawing. To find North and South, we ... etc.

3. **Data.** This section presents your basic observational results. It is here that you will put observing forms, tables, graphs and any other data. **You must include all the original data forms as you recorded them at the telescope.** (For CLEA labs,

this section will consist of the answer forms given to you by the TA but **not** the CLEA manual itself.) This should show the salient results of the work you did in the lab. This is also where you will discuss the errors in your experiment.

4. **Discussion and Conclusions.** In at least one or two paragraphs, state your **final** results and make any remarks you deem necessary. **Be sure to include** answers to any discussion questions posed in the lab as well as any comments or comparisons the lab asked you to make. You should also try to summarize the high points of the lab here and discuss the degree to which you fulfilled the purpose you presented in the Introduction. What did you get out of the lab? If you feel so inclined, this is your chance to wax philosophical.

## D.2 Tables

A table is often the best way to present large amounts of information concisely. Some suggestions:

1. Make the table large enough that all labels and entries are legible.
2. Organize the table in a logical fashion—for example, raw data on the left side, intermediate results in the middle columns, and final results on the right side.
3. Label the rows and columns clearly and always give the units used for all data.

## D.3 Graphs

Graphs are frequently useful for presenting data and results in pictorial form. Many common mistakes occur in setting up the graph, before any data are entered. **Read the instructions below and avoid these errors!**

1. Make the graph large enough! If in doubt about the appropriate size, use a full sheet of graph paper. Too big is better than too small.
2. Put a title on the graph — what does it show?
3. Clearly label the axes and give the units used.
4. Choose the range covered by each axis to match the range of available data. For example, if you wish to graph angles from  $93^\circ$  to  $213^\circ$ , one axis might be marked off from  $90^\circ$  to  $220^\circ$ . Using a range of  $0^\circ$  to  $360^\circ$  would be a pointless waste of space and would make the plot hard to read.
5. Mark and label the scale on each axis.
6. Plot data neatly, without smudgy erasures. Use ink or sharp, dark pencil for the final copy. Be sure the data points are clearly visible.

Usually you will want to plot several data points, then draw a mean line through them to indicate the trend of the data. It is important to realize that your data are not infinitely accurate. Think of each point as the center of a fuzzy area representing the uncertainty of the measurement (see discussion of uncertainty below). To draw a line through the data, *do not connect the points dot-to-dot!* Instead, draw a *smooth curve* following the general trend of the plotted points. Try to get about as many points above the line as below it. This is an averaging process which smooths out errors and fluctuations in the individual measurements. Occasionally you may know or assume that the data should fit a straight line, in which case you can use a ruler. Otherwise, a smooth freehand curve is best.

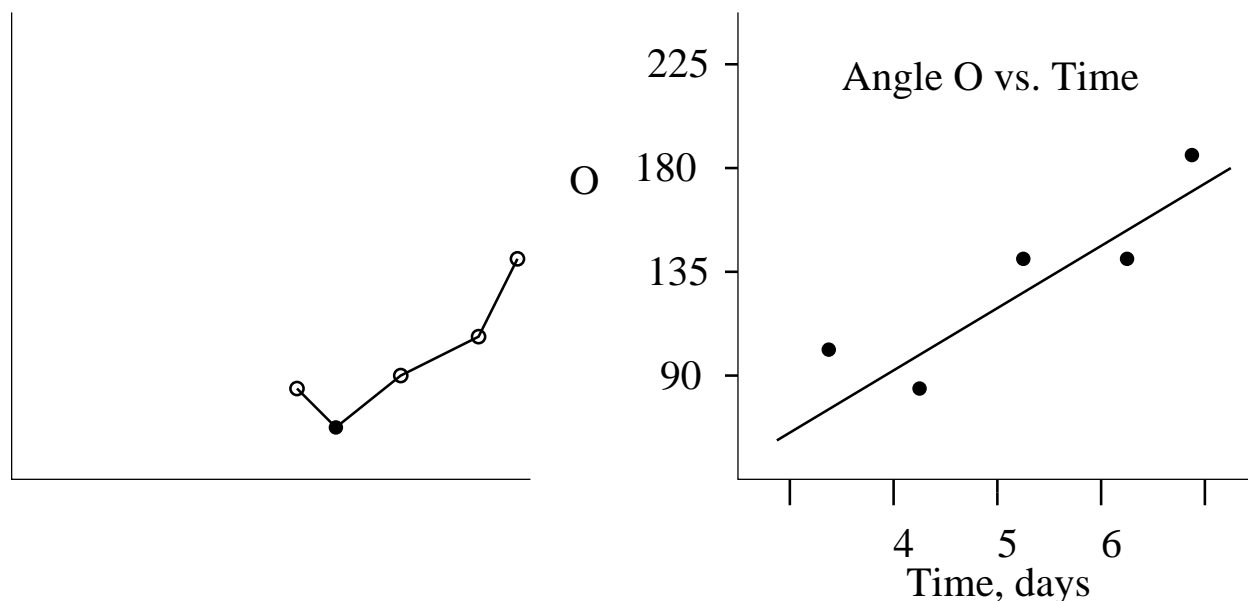


Figure 40: (Left) Poor graphing — no labels, axis scales poorly chosen, improper curve fitting technique, does not fill page. (Right) The same data properly graphed and fitted with a straight line.

## D.4 Numerical Calculations

Some of the laboratories require you to make mathematical calculations with your measured data. When presenting a calculation in your write-up, give each step in a logical sequence down the page. Clearly write out the equation being used, the numerical values, and the result. Give units at each step. Keeping track of units helps avoid errors.

Example:

$$\frac{P \times A}{F} = \frac{2.612 \text{ gm} \times 9.60 \text{ cm}}{1.3 \text{ sec}} = 19 \frac{\text{gm cm}}{\text{sec}}$$

If a calculation is repeated several times for different values, give one in detail as an example and present the remainder in a table.

## D.5 Error Analysis

If you carefully count the number of words on this page you would probably obtain exactly the right number. It is usually easy to count things with little uncertainty. However, if you measure the length of this page with a ruler five times, the numbers you obtain will have a scatter to them. This scatter is called *measuring error* or *uncertainty*. Measuring uncertainty can result from: (1) your inability to read the ruler the same way each time the measurement is repeated, a limit caused in part by the readability of the markings on the ruler; (2) irregularities in the edge of the ruler; (3) difficulty in keeping the ruler perpendicular to the paper edges being measured; and (4) other difficulties. It is not possible to make infinitely precise or accurate measurements, no matter how good your equipment is. All physical measurements have inherent errors and must be interpreted taking this into account.

In everyday usage, the word “error” implies a mistake, for instance misreading the ruler and assigning 12.5 instead of 22.5 for a length. The “errors” we are discussing here, however, are

not mistakes. They can be minimized by being careful but not avoided altogether. Instead, *error is inherent in the measurement process*. Avoidable errors are assumed to have been avoided (i.e. the scientist is assumed to be competent). (Note that the kind of measuring uncertainty we are discussing here is *not* the same as the fundamental uncertainty in the physical properties of atomic-scale systems described by Heisenberg's Uncertainty Principle.)

All valid scientific measurements therefore consist of *two parts*: the best estimate of the value being measured *and* the uncertainty in that estimate. For instance, the measurement of the length of this page might be expressed as follows: the length  $L = 21.3 \pm 0.2$  cm. Here, 21.3 cm is the best estimate of the length of the page. The 0.2 cm is the estimate of the uncertainty in the length measurement, considering all of the sources of error mentioned above. The uncertainty is a statistical estimator. It implies that if you repeated the whole set of length measurements a large number of times, only two thirds of those trials would yield a length measurement between 21.1 and 21.5 cm. In one third of the cases, the measured length would lie below 21.1 or above 21.5 cm.

There are two different aspects of error determination: *precision* and *accuracy*. Precision refers to how well determined a measurement is. The smaller is the uncertainty with respect to the measured value, the more precise is the measure. Precision is often expressed in terms of a *percentage*  $P = 100.0 \times (\text{uncertainty})/(\text{measured value})$ .

There is no general rule of thumb for what is "good" precision. That depends on the application. In some cases, you should be able to measure to better than 1% precision. In others, 20% might be acceptable. If in doubt, ask a TA.

Precision describes how well determined the estimate of a value is, but it does not describe how close to the *true value* is the estimate. For instance, you may be making very careful measurements of the page of paper with a ruler which was incorrectly marked by the manufacturer. Your estimate is very precise, but it isn't close to the actual length of the page. *Accuracy* is a measure of conformity between an estimate of a quantity and the correct value of that quantity. It is much more difficult to evaluate accuracy than to evaluate precision. In this course you will be asked to comment on accuracy only in those cases where the quantity you are measuring is actually well known (e.g. the length of the day or the rotation period of the Sun).

The standard method for estimating the uncertainty in a measurement is *to repeat it a number of times*. There will be a *scatter* in the results. Large scatter implies low precision, while small scatter implies high precision. Here is the method for quantitatively estimating the precision in a measurement:

1. Collect a number of repeated measurements. Suppose you have  $N$  of these.
2. Compute the *average value* of those measurements by summing them and dividing by  $N$ . The average value is the best estimate of the quantity being measured. Call this average value  $M_{avg}$ .
3. For each measurement, compute the *deviation* from the average,  $d = M - M_{avg}$ , where  $M$  is the individual measured value.
4. The scatter in the measurements is then quantified by computing the *average deviation*. For our purposes, we are interested in the size but not the direction of the scatter. Therefore, compute the average deviation ( $ad$ ) by summing the magnitudes of the individual deviations *without regard to sign* and dividing by  $N$ .
5. The estimated uncertainty in the average value you measured is then given by the average deviation divided by  $\sqrt{N}$ . You would quote your result as:

$$M_{avg} \pm ad/\sqrt{N}$$

or:

$$M_{avg} \pm 100. \times (ad/\sqrt{N})/M_{avg} \%$$



6. For example, if you made 6 measures of the separation between the two components of a binary star and obtained the following values (in arcsecs): 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, then the best estimate for the separation and its uncertainty would be:

$$2.35 \pm 0.06 \text{ arcsec}$$

or:

$$2.35 \pm 2.6\% \text{ arcsec}$$

Averaging a large number of careful measurements will cancel low values against high values and the overall *precision* will improve. However, this will not necessarily give a more *accurate* answer. If the uncertainty has a pattern, as in the case of a scale which reads 2 lbs even when no weight is on it, that error is said to be *systematic*. Systematic errors will not cancel with averaging and may only be removed through calibration of the measuring device.

In most situations, measurements of several different quantities are combined in order to produce a final result. For instance, you can use the orbital period of a satellite of Jupiter together with its distance from the planet to estimate Jupiter's mass. To determine the effect on the mass of the different uncertainties in the period and distance measures, the errors must be *propagated* mathematically to the result. Any labs in which you must propagate uncertainties have formulae with which to do so.

## D.6 Significant Figures

The general precision of a measurement is implicitly specified by the number of digits in the number quoted for it. Thus it is implied that a measurement of "1.000 meters" is more precise than one of "1.0 meters." A ruler showing only tenths of a meter can differentiate between 1.0 and 1.1 meters in length, but not between 1.000 and 1.001 meters. It does not make sense to quote an answer as  $L = 1.0139485 \pm 0.1$  meters, because the scatter of 0.1 meters renders all those numbers in the second and higher decimal places meaningless. On the other hand, a millimeter ruler *can* be read to a precision of 0.001 meters and justifies quoting values like 1.000 meters. The number of digits you quote for an estimate should be consistent with the precision of the measurement.

When making calculations involving measured quantities, care must be taken to keep the measurement precision in the final answer. A pocket calculator may give 10 significant figures, but *you should round off your quoted answer to a number that reflects the precision of the data you have*. The rest is garbage.

The accuracy of your final result can be no better than the least accurate number in the calculation. Use this as a rough guide: During the course of a calculation, keep one more significant figure than the least accurate number used at each step. Then round off your final result to the same number of significant figures as the least accurate number in the entire calculation.

Example:

3.037	least accurate number in first step, 4 significant figures
<u>+ 1.5429</u>	
1.9684	keep 5 significant figures in result of first step
<u>x 2.39</u>	least accurate number in entire calculation
4.70	final result rounded to 3 significant figures

### D.7 A Word to the Wise

Pay attention to all questions that are asked in the Manual write-up for each lab. Not only should you answer all of these, but they should focus you toward the more important parts of the lab. **Don't** merely restate the text in the Manual for your descriptions of introduction and procedure. You should summarize, **in your own words** based on your own understanding, the purpose of the lab and the procedure you used.

Finally, it is important to get feedback on your work. Therefore, you are strongly encouraged to stop by during TA office hours and go over your graded labs.

## E APPENDIX: FILLING OUT AN OBSERVING FORM

To record most of the telescopic observations you will make in this course, you will be expected to use a **standard observing form**. You can download from the course website a digital copy of the standard blank observing form (shown in figure 42) or pick up copies in the Observatory Support Office. Be careful in filling out observing forms, as they will be graded according to relatively strict standards.

**Before going to the telescope complete the boxed area of the form.** You will be much better prepared for lab if you do this at home or in the library, prior to coming to the Observatory.

*For each form fill in:*

**Lab** — give the lab number for which this observation is being made

**Observer** — your name

**Object Name** — One or more of the formal names the object may have

**Physical Nature** — e.g. double star, galaxy, planetary nebula, etc.

**Features to Observe** — A brief reminder of what you are expected to observe, given the limits of your intended instrument on a typical night. Short descriptions of each object are given in the Manual. For more detailed descriptions, refer to online resources (some of which are listed on the course website).

**Planned Observing Date** — fill this out when you initially make up the form. The actual observing date may differ.

**Coordinates** — Look up the Right Ascension (RA) and Declination (Dec) of the object in the Manual or another reference. Use coordinates with “epochs” near the current year. For solar system objects, the coordinates should be specific for your planned observing date.

**Local Time of Transit:** use your star wheel or another means to estimate the time at which the object will cross the local meridian and is therefore highest in the sky. Indicate whether this is EST or EDT.

**Finding Chart** — The purpose of a finding chart is to enable you to locate the target easily. Even when using an automated telescope, it is important to confirm that it is pointing in the right direction. Therefore, your chart should be fairly carefully executed. Draw a sketch of the region surrounding the object from Norton’s/Edmund Sky Atlas. Make sure that your sketch covers an area of sky which is appropriate to the object you are trying to find. For example, if you are looking for a faint galaxy in the constellation Leo, drawing the whole constellation in the finding chart is not helpful; you should focus on the area immediately surrounding the object. If, on the other hand, you are looking for Albireo, a bright double star which is part of the visible constellation Cygnus, a larger scale drawing of the constellation would suffice. Be sure to *indicate the orientation of the cardinal directions (north, south, east and west)* on the chart. You do not need a finding chart for bright solar system objects like the Moon or Jupiter, but you would need one for a fainter planet like Neptune. A useful test of the quality of your chart: *would another student be able to locate the object using it?*

*Now you’re ready to go to the telescope.*

At the telescope, you will complete the form and make a sketch of your observations. You’ll need to fill in the following.

**Group Members** — others you are working with for this particular observation.

**Date of Observations** — date of actual observations.

**Location** — where observations are being done.

**Temperature** — Use the thermometer at the Student Observatory. Estimate the temperature if you are not at the observatory.

**Wind** — estimate the speed and direction

**Scattered light** — estimate the extent to which streetlights, moonlight or other light sources interfere with your observation

**Seeing** — a measure the steadiness and size of the star images given in seconds of arc. In the Introduction to Small Telescopes Lab, you will learn to make quantitative estimates of seeing by estimating the image diameters (“seeing disk”) or image motion from a close double star of known separation. With experience, you should be able to estimate seeing without such an elaborate procedure. However, you must quote seeing in seconds of arc. General descriptions such as “good”, “fair”, or “excellent” are not acceptable.

**Transparency** — a measure of sky clarity. Note the amount of cloud cover, what type of clouds (low thin clouds, high haze, thick cumulus, etc...) are present and if they effect your observation. A quantitative way to estimate transparency is to give the magnitude of the faintest star you can reliably detect with your naked eye (e.g. use the stars in the “pan” of the Little Dipper = Ursa Minor).

**Telescope** — size and type of telescope you use, e.g., an eight inch Schmidt-Cassegrain. Include the identifier of the telescope: e.g. A, B, etc. If using binoculars, give the size (e.g.  $7 \times 35$ ).

**Eyepiece Used for Sketch** — focal length (F.L.) of eyepiece. Each eyepiece has its focal length in millimeters marked on it.

**Magnification** — Magnification = (F.L. of scope)/(F.L. of eyepiece). The 8” Celestrons used in the student observatory have F.L. = 2032 mm.

**Comments** — note colors, shapes, relative brightnesses, rough numbers of stars, difficulty of object to see, aesthetics, etc. Emphasize features which are impossible to draw or special conditions that affected observations. You should write thoughtful comments on each observation you make.

**Sketch** — the large round circle is to represent the full field of view in the eyepiece; draw the object to scale inside this. Sketches require a fair amount of work. They must be done carefully and accurately. This is to be a scientific drawing, not an “artist’s impression.”

*Tips on making sketches:*

1. Use pencil. Draw a “negative” image, with darker pencil representing brighter regions. Try to capture all the main features.
2. Draw to scale, with the given circle representing the edge of the field of view. Carefully pencil-in dots for the stars in their correct relative positions. Represent relative brightness correctly. Draw faint stars as small pinpoints and brighter stars as darker, but not too much larger, points.
3. Label the sketch N, S, E, & W; use the technique described in the Introduction to Small Telescopes Lab to find the directions in the telescope field.
4. Double check your sketch for accuracy. All the stars seen should be represented (if not, explain why it would not be feasible to do so). Brighter stars should be distinct from fainter stars. Distances between stars should be scaled appropriately. Nebulosity or extended features should be shown with correct outlines and shading to represent brightness.
5. Make notes on the drawing if you wish. If the object is small, you may want to make an additional, enlarged drawing to show details.

6. The sketch is the most important part of the observation in the early labs, so do a good job. See Figure 41 for a sample sketch.

**Pledge** — By signing the pledge you signify that all the work on the page is your own.

**Lab TA (initials)** — when you've finished your observations have the TA sign your forms. **Only work signed or initialed by a TA will be graded.** NOTE: the TA's signature only verifies the date and time; it does *not* indicate that you have done the work satisfactorily. If you have questions about the quality of your work, ask the TA's directly about that.

**Recopying your records:** Your records/sketches must be made at the telescope *at the time you make your observations*, not later. Human memory is fallible. If you wish to recopy your handwritten notes more neatly, you may do so, provided they are copied word for word. In all cases, *your original records must be turned in* together with the copies. *Do not recopy or modify sketches.*

**Group work and collaboration: REREAD THE PARAGRAPHS ON INDEPENDENT WORK IN THE GENERAL INFORMATION SECTION OF THIS MANUAL.** You may collaborate in setting up the telescope, adjusting it, and finding objects. But each person is to make and record his/her own observations. You may not collaborate in any way on record keeping.

The following page shows an example observing form (Figure 41) after a successful observation. Note the thorough comments and the carefully drawn sketch. Also remember to add the compass directions outside the sketch area. Figure 42 shows a blank observing form; you can download a digital version of this from which to make copies from the course website.

Lab: 7

Observer: Richard Gelderman

## Planning Section - To be completed before arriving at lab

Object Name: NGC 31

Finding Chart:

Physical Nature: open cluster

Features to Observe:

group of stars (~1.5 arcmin across).

look for nebulosity to south.

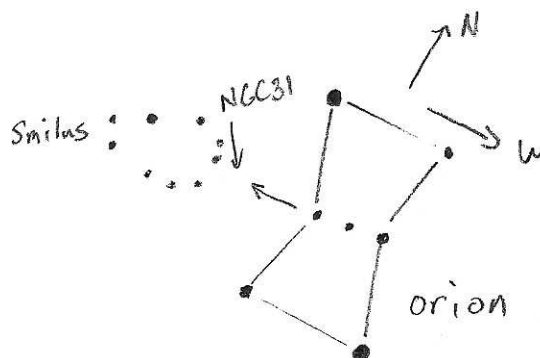
note colors of stars and total number

Planned Observing Date: Jan / 16 / 2008

Coordinates: RA - 28<sup>h</sup> 99<sup>m</sup>

Dec - 104° 77'

Local Time of Transit - 22:30 EST



## Data Section - To be completed during observing

Group Members:

solo

Date of Observation: Jan 20 2008

Location: Astronomy Nightlab

Sky Conditions:

temperature - 29° F

wind - gusts from west

scattered light - full moon + city lights

seeing - 5 arcsec (from Mizar)

transparency - clear, no clouds

Telescope: F

Eyepiece used for sketch: 20 mm  
(or FOV for binoculars)

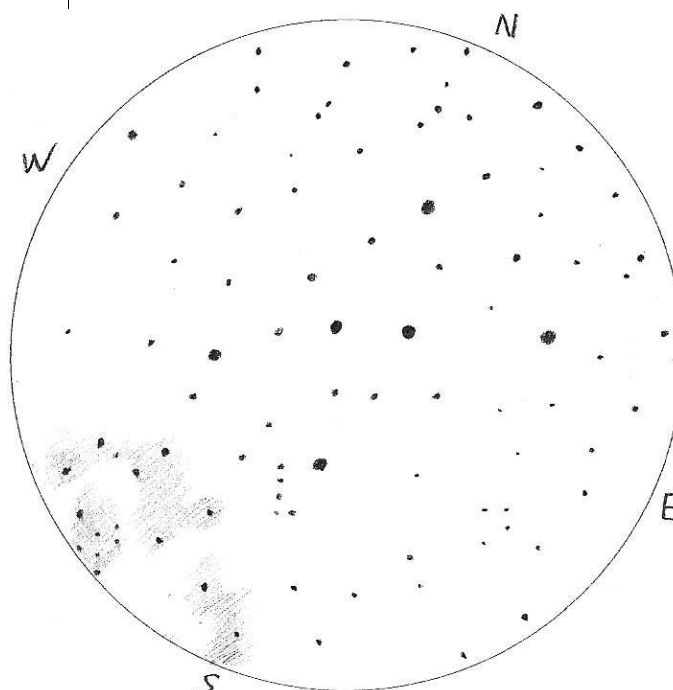
Magnification: 2000mm/20mm = 100X

Comments:

Most stars faint and randomly oriented. Six center stars brighter by a lot and appear much more red. Also seem to form hourglass shape.

Cluster bigger than field of view, but sketch centered on brightest stars, with nebula still visible.

About 40 stars visible as distinct with 100 or more scattered throughout.

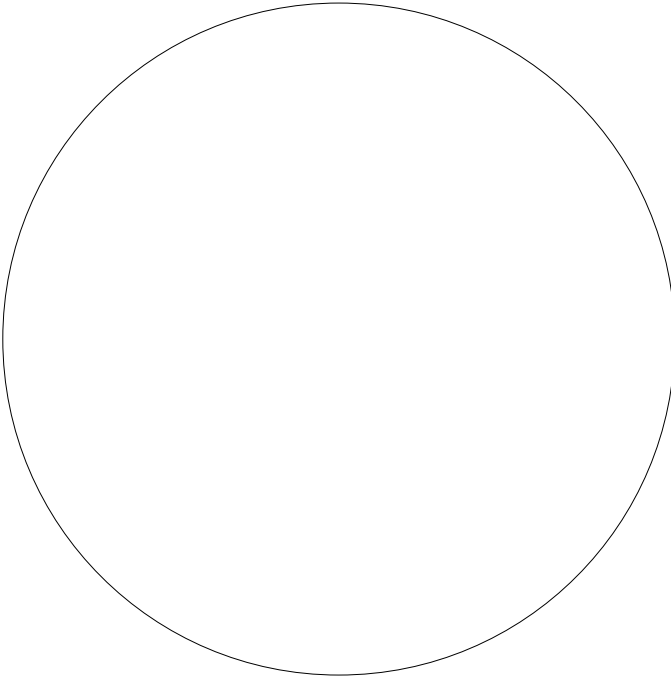


Pledge:

Lab TA Initials:

This original must be turned in with lab report

Figure 41: Sample Observing Sheet

Lab:	Observer:
Planning Section - To be completed before arriving at lab	
Object Name:	Finding Chart:
Physical Nature:	
Features to Observe:	
Planned Observing Date:        /        /	
Coordinates:        RA -	
Dec -	
Local Time of Transit -	
Data Section - To be completed during observing	
Group Members:	Date of Observation:
	Location:
Sky Conditions:	Telescope:
temperature -	Eyepiece used for sketch:
wind -	(or FOV for binoculars)
scattered light -	Magnification:
seeing -	
transparency -	
Comments:	
<div style="position: relative; width: 100%; height: 100%;">  </div>	
Pledge:	Lab TA Initials:

This original must be turned in with lab report

Figure 42: Blank Observing Sheet