

PROBLEM SET 3

DUE WEDNESDAY OCTOBER 8

Please use *cgs* units and the standard symbols defined in class in working problems. Define any new symbols used, and work problems algebraically *before* plugging in numbers. Show all your work, and remember to give the units of all answers. Please write clearly and use only one side of each page. 2 points maximum for each labeled part of a problem.

Most of these problems involve statistical concepts developed in Lecture 6.

- (1a) Four measures of the V-band photon rate of a certain source with a particular telescope-instrument combination yield values of 1100, 1200, 1300, and 1400 photons per second. What is the estimate of the mean rate and the standard error in the mean rate? What is the best estimate of the variance of the parent distribution of the rate? Does it appear that the scatter in these observations is dominated by the photon statistics of the source?
- (1b) Assuming that the process governing the random errors of measurement remains stationary, approximately how many total measurements must you make to yield a final signal-to-noise in the mean rate of 200 (based on the standard error of the mean)?
- (2a) The nearby starburst galaxy M82 is estimated by several methods to have a star formation rate in its dusty central regions of $2\text{-}10 M_{\odot} \text{ yr}^{-1}$, which implies a supernova rate of $\sim 0.1 \text{ yr}^{-1}$. However, no new supernova has been detected by radio telescopes in the starburst core for the last 20 years. What is the probability that this "supernova deficit" has occurred by chance?
- (2b) What is wrong with the following statement (found in an observing proposal submitted by well-regarded astronomers): "Admittedly, if the SN rate is 0.1 yr^{-1} then over 20 years this is not too unlikely ... although conversely this implies a $>90\%$ chance of a supernova over the next few years."
- (2c) How many years (total) must elapse without a supernova to be able to reject the proposed SN rate of 0.1 yr^{-1} with 95% confidence?
- (3) You are observing a very faint source which produces only 1 detected photon per second against a bright background which produces 20 detected photons per second over the area of the source. How long do you have to integrate to obtain a signal-to-noise ratio for the source's flux (based on photon statistics alone) of 10? Assume that you are using an array detector which permits measurement of a very large number of samples of the bright background.
- (4) Cosmic rays can be a serious hindrance to CCD imaging with space telescopes because of the sensitivity of these detectors to electrons released by CR impacts. Suppose the cosmic ray rate for a CCD detector with 15 micron pixels on the Hubble Space Telescope is 100 CR hits per second per square cm of detector. You are planning to make two exposures of a given target, with the intention of rejecting cosmic ray hits by comparing the two and rejecting any pixel which contains a significant electron count on

only one. However, the method fails if cosmic rays hit the same pixel on both exposures. Call this a "multi-hit." What is the maximum integration time per exposure you can use and still keep the number of multi-hits to below 5% of the pixels? Assume that each cosmic ray affects only a single pixel (this is not a good assumption in practice!).

- (5) What photometric precision (i.e. signal-to-noise ratio) would be needed to unambiguously detect the effects of a Jupiter-like planet in transit against the disk of a Sun-like star? (The answer does not depend on the distance to the star, but the feasibility of actually doing the experiment does. In what way?)

ROMPS: Review the expectations for working on ROMPs as discussed in PS-1. Remember to explicitly state assumptions.

- (6) The Orion Nebula is faintly visible as a fuzzy patch to the naked eye. It is about 30' in diameter. From spectroscopic analysis, its electron temperature is ~ 10000 K. How do you know the Nebula cannot possibly be optically thick at 5000 \AA ? [Note: this is a *very simple* problem. Your answer should be correspondingly simple!]
- (7a) Suppose you wanted to pursue a program of observations of supernovae in distant galaxies which required about 50 new SNe identifications a year. If a typical luminous galaxy produces a supernova only once a century, how large a volume of space (in Mpc^3) would you have to survey?
- (7b) If you wanted to "stare" at a single field, say 30 square arcminutes in projected area, how faint (in apparent V-magnitude) would be the most distant galaxies you would have to detect? [For a first cut at a problem like this, you can assume a static universe, ignoring effects related to expansion or relativity.]
- (8) As a follow-up to problem (8) from PS-1, show that the naked-eye detection limit of 6^{th} magnitude is indeed a photon-starvation effect rather than a background brightness effect. Estimate the relative flux received from the night sky background in the same spatial resolution element as a 6^{th} magnitude star. Adopt a surface brightness for the night sky of $\mu = 20$ magnitudes per square arcsecond, typical of suburban sky brightnesses.