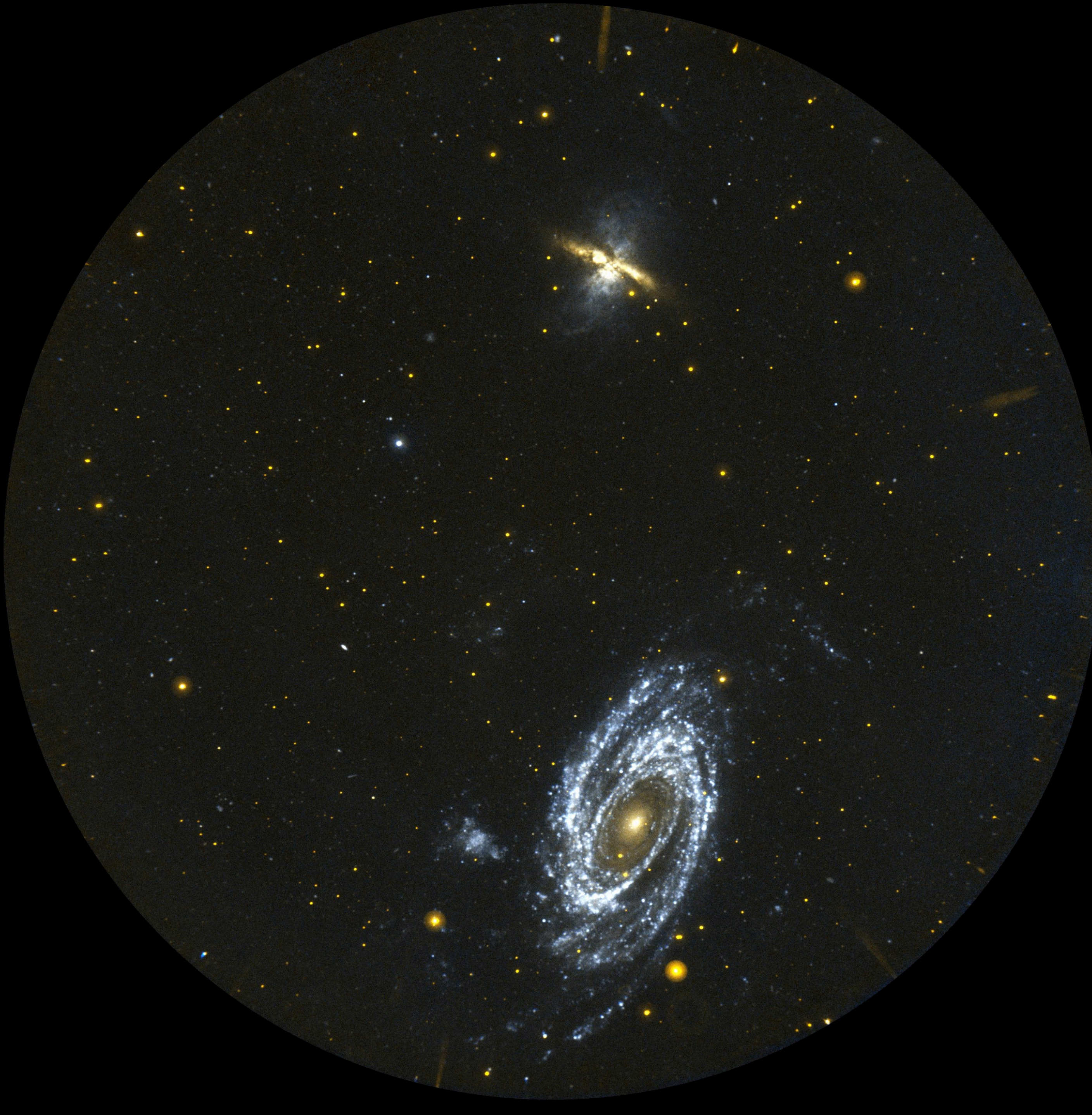
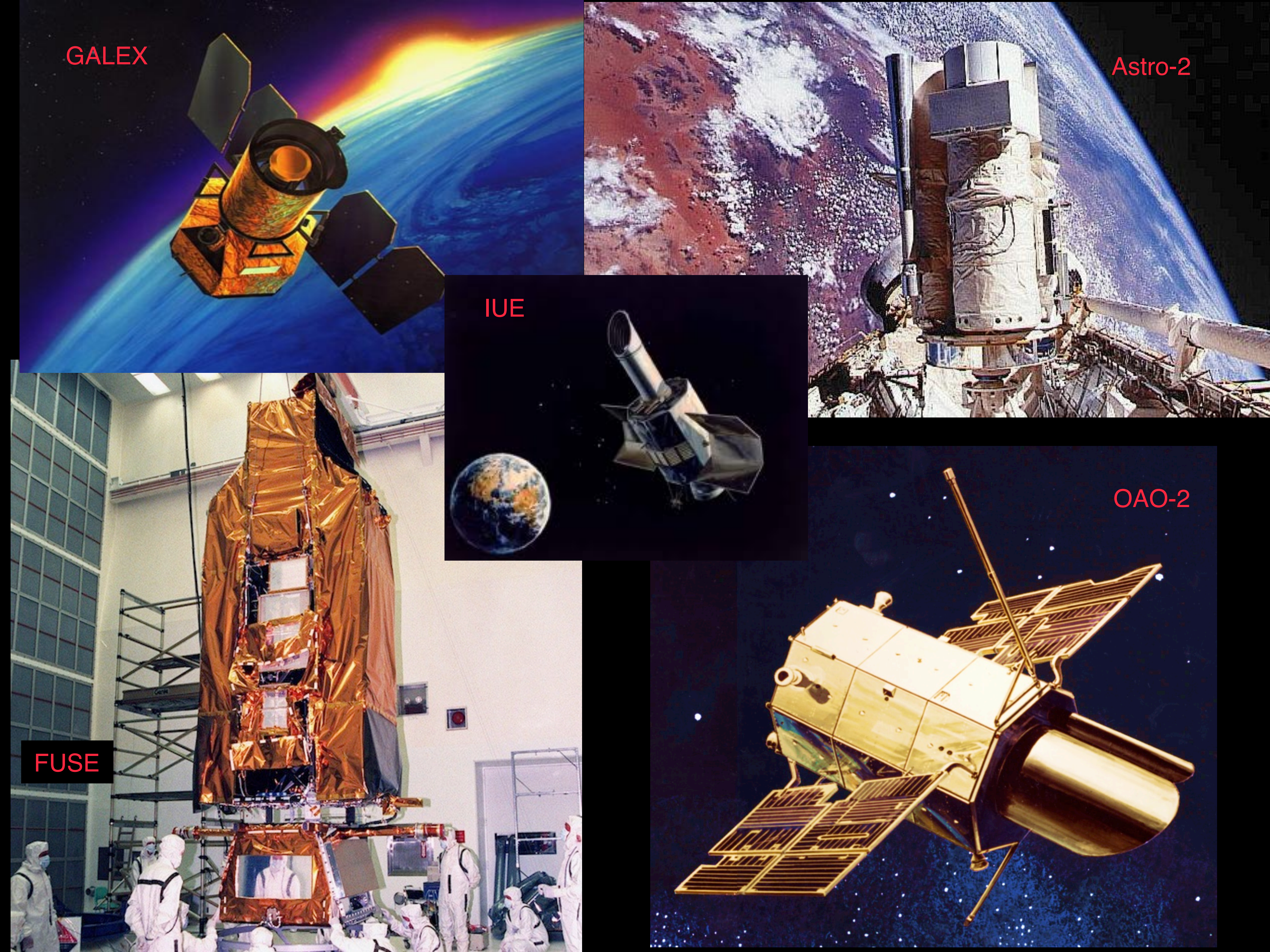
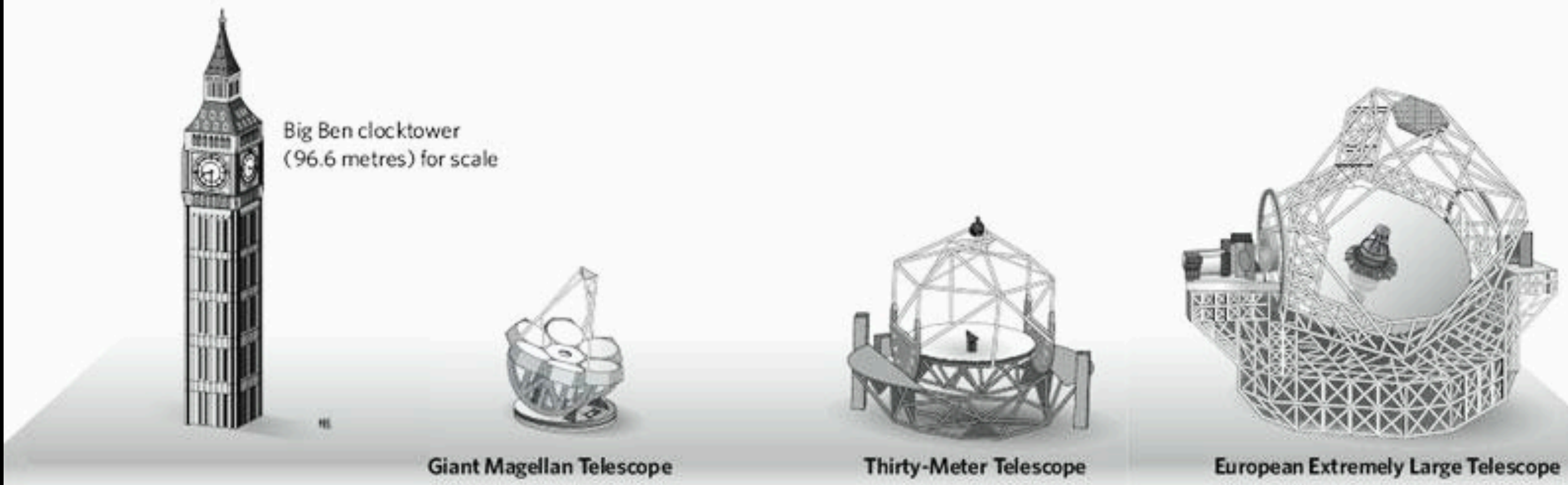


The Once and Future World of Ultraviolet Astronomy


GALEX
Astro-2
IUE
OAO-2
FUSE

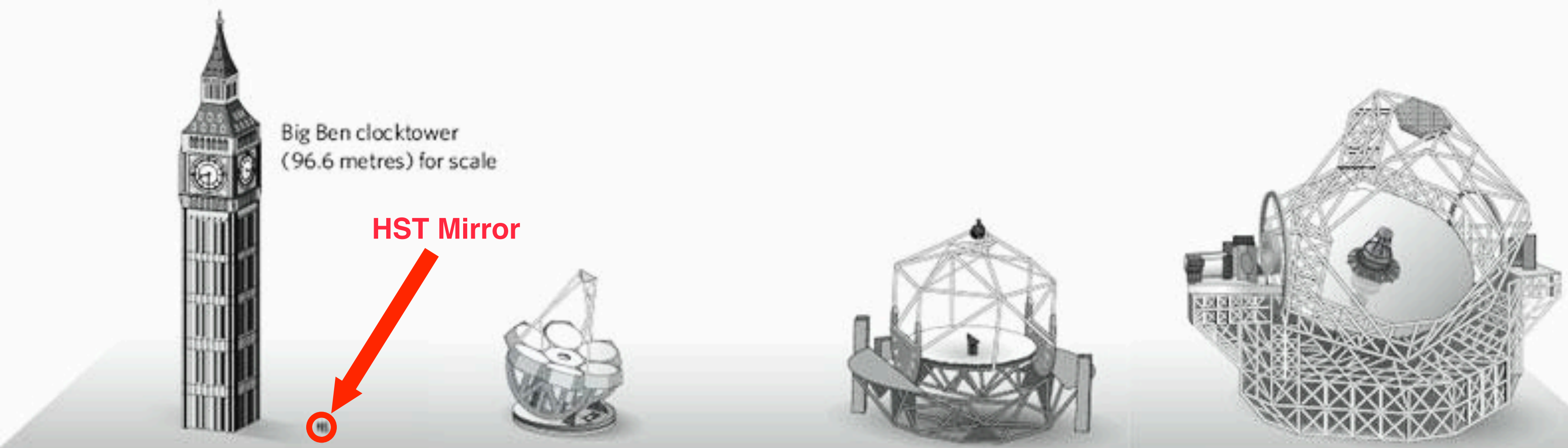
HST: 1990 – 2018(?)

Era of Giant Telescopes (2020 --)



	Giant Magellan Telescope	Thirty-Meter Telescope	European Extremely Large Telescope
Telescope diameter	25.2 metres	30 metres	42 metres
Component mirror segments	7 (8.4-metre segments)	492 (1.44-metre segments)	984 (1.45-metre segments)
Cost	US$600 million	US$754 million	€900 million (US$1.37 billion)
Planned location	Chile	Candidates: Hawaii; Mexico; three sites in Chile	Candidates: Canary Islands; Morocco; Argentina; two sites in Chile
Planned construction period	2010–2017 (First mirror already cast)	2009–2016	2010–2017
Technical advantages	Adaptive optics integrated within secondary mirror Shortest focal length means it has the smallest and cheapest structure	Mirror segments are comparatively cheap and more easily replaced Similar scaled-up version of the existing Keck telescopes	Five-mirror design results in a flat focal plane and better images Similar mirror-segment size to the TMT, so greater vendor choice
Financial advantages	Potential support from $34-billion Harvard endowment or Texas billionaire George Mitchell	$200-million gift from Intel founder Gordon Moore	Steady European funding stream
Disadvantages	Only one place can make the mirrors Gaps in mirror limit the effective aperture to 21.5 metres	Adaptive optics performed after the light leaves the telescope, so the 'natural seeing' mode cannot benefit from adaptive corrections to wind effects	Biggest and most expensive design No similar design experience Reflections through five mirrors reduce light levels

Era of Giant Telescopes (2020 --)



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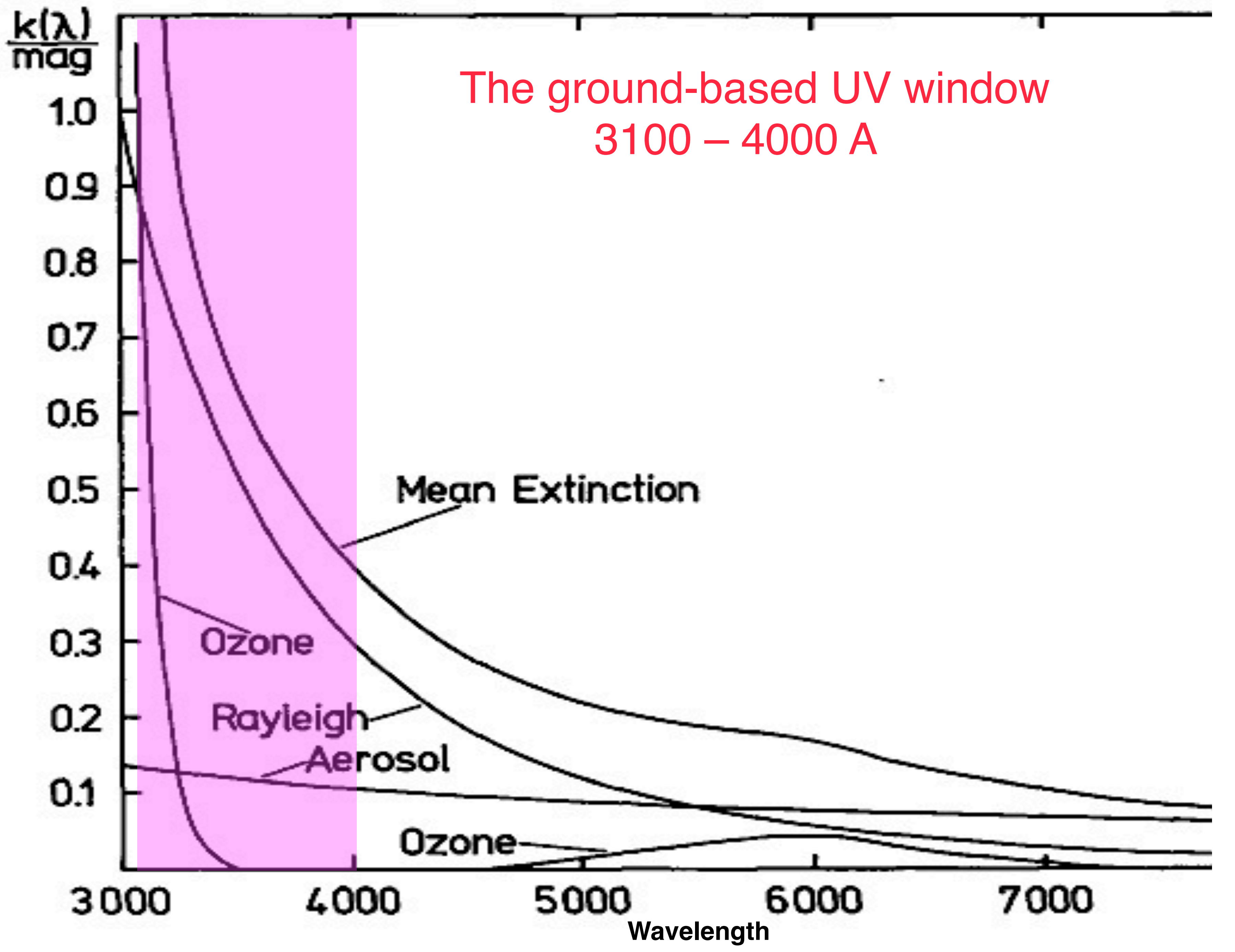
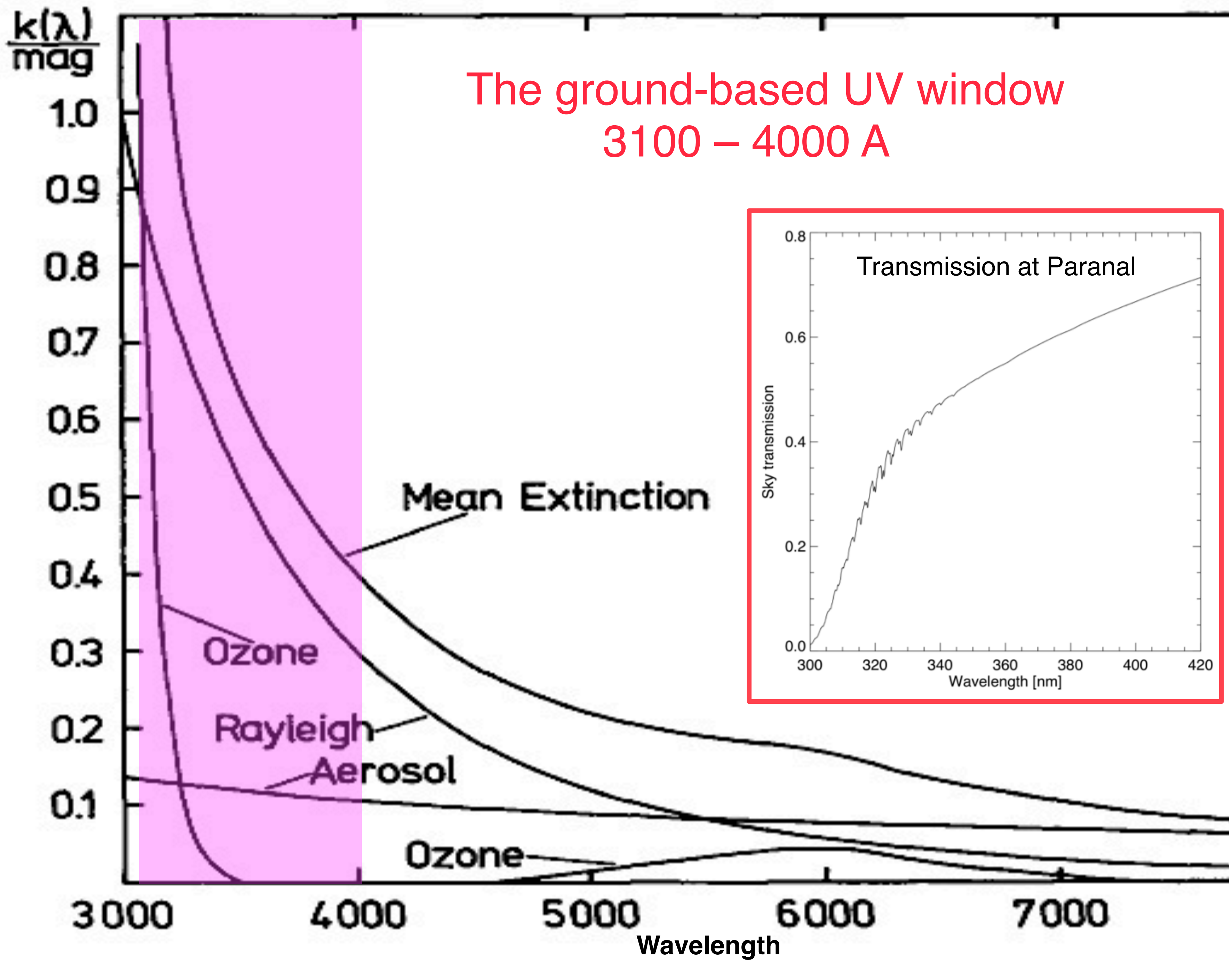
Where is the UV *indispensable* (or nearly so)?

1969-1974 {
- UV upturn in old populations (UVX)
- Multiphase ISM
- IGM $z < 2$

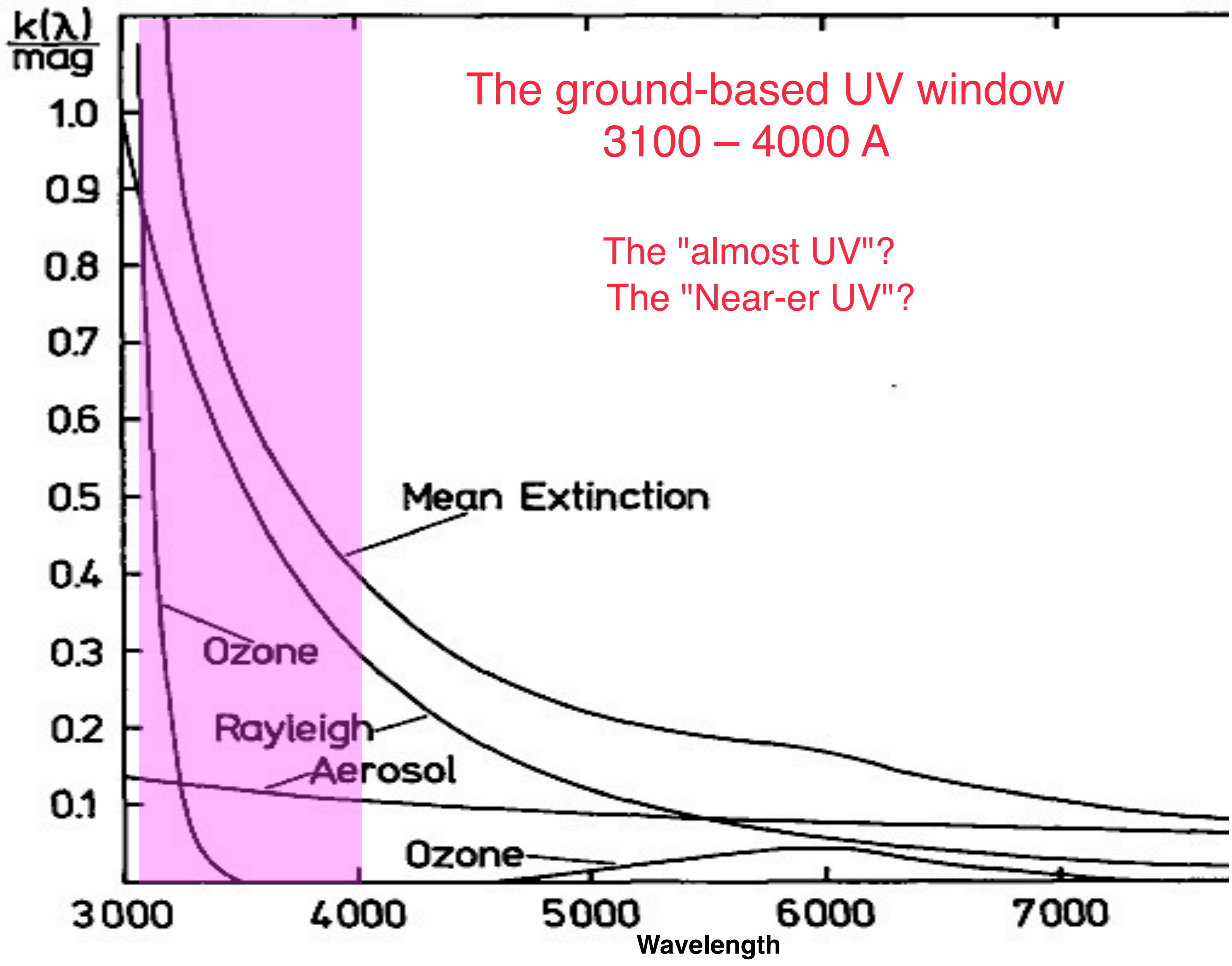
- Galaxy SFR's and SFH's
- YSO star-disk-planet interactions
- Exoplanets
- Globular clusters
- AGN's



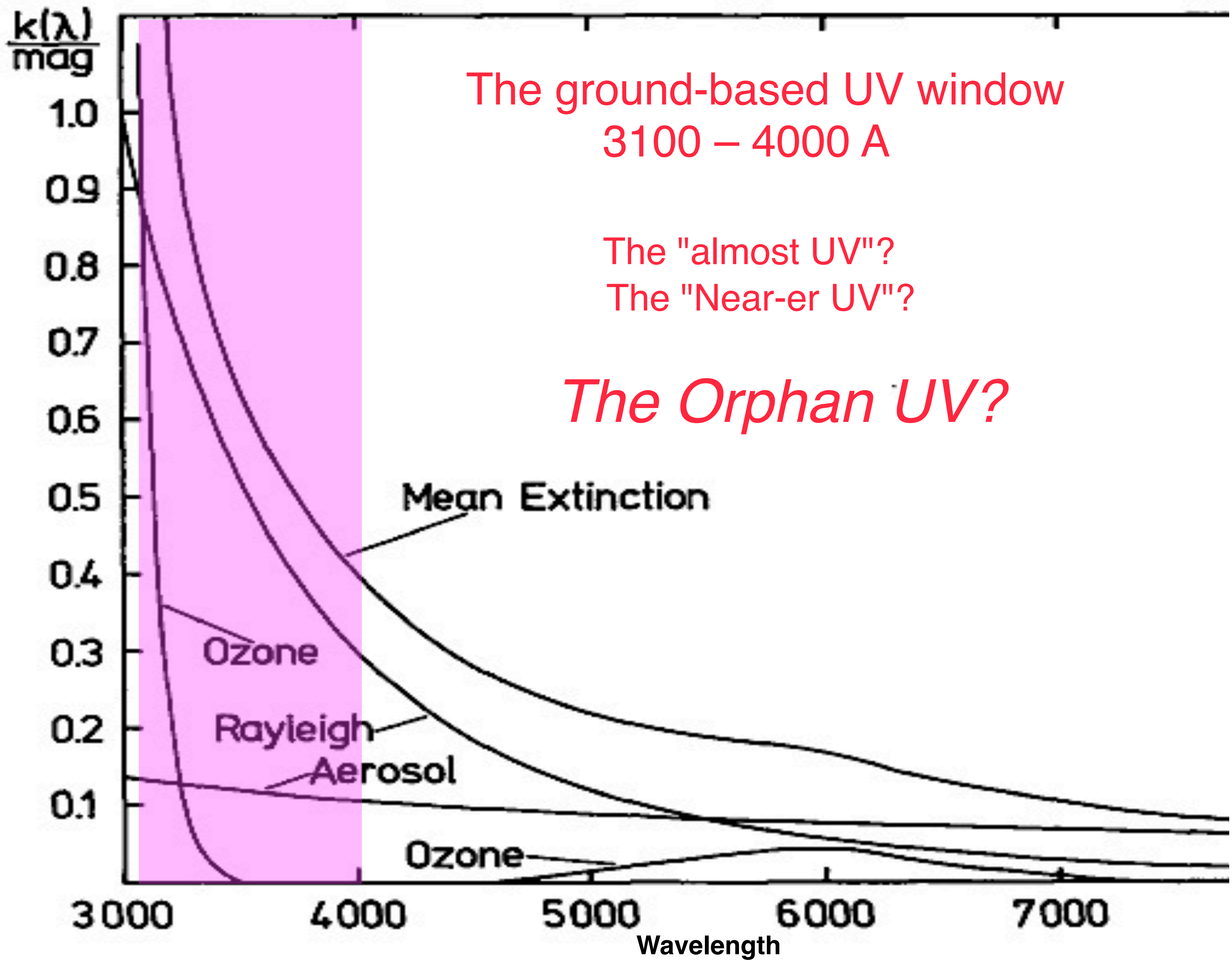
k(λ)/mag
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
The ground-based UV window
3100 – 4000 A
Mean Extinction
Ozone
Rayleigh
Aerosol
Ozone
3000
4000
5000
6000
7000
Wavelength



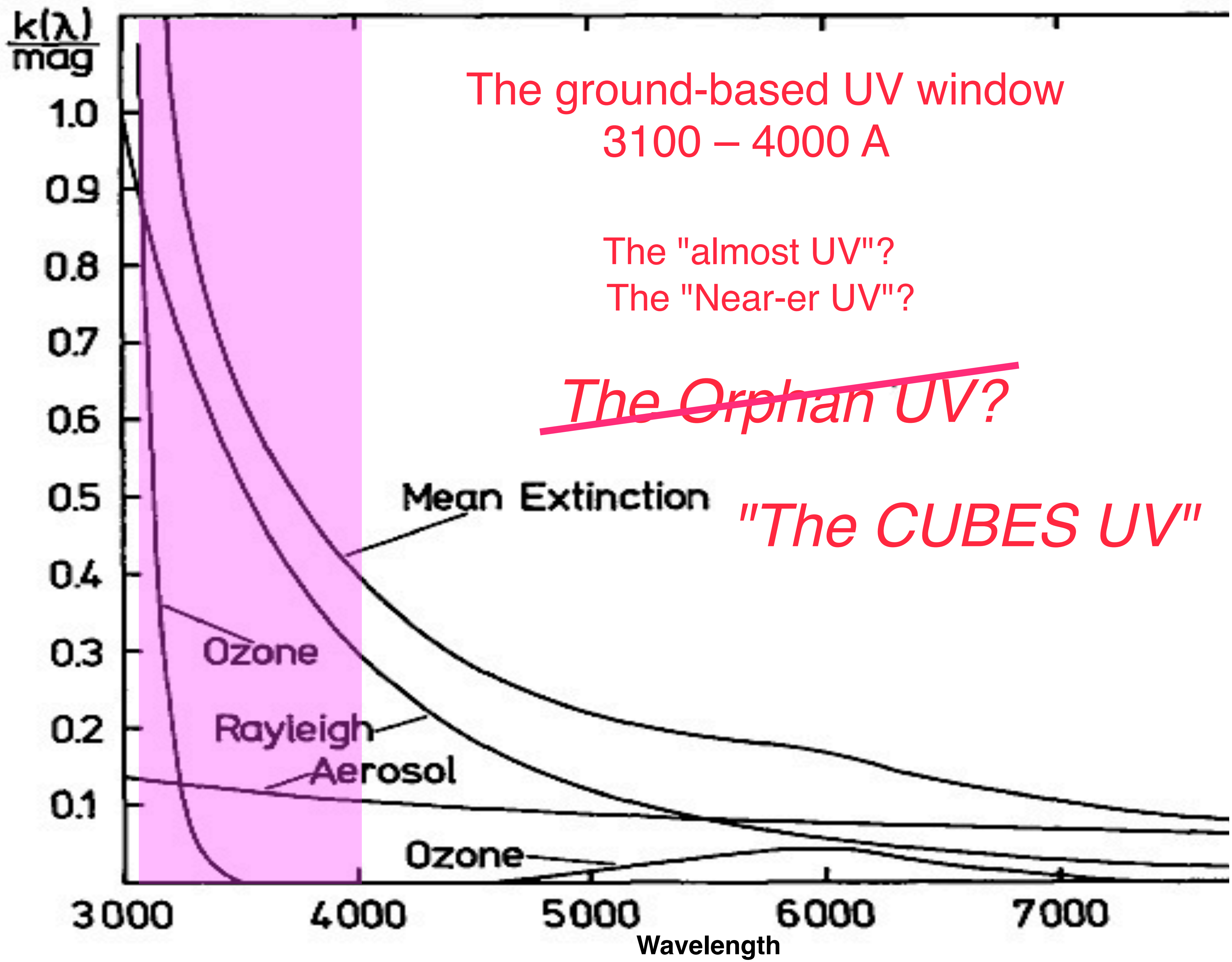
The ground-based UV window
3100 – 4000 A
k(λ)/mag
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Mean Extinction
Ozone
Rayleigh
Aerosol
Ozone
3000
4000
5000
6000
7000
Wavelength
Transmission at Paranal
Sky transmission
0.0
0.2
0.4
0.6
0.8
300
320
340
360
380
400
420
Wavelength [nm]



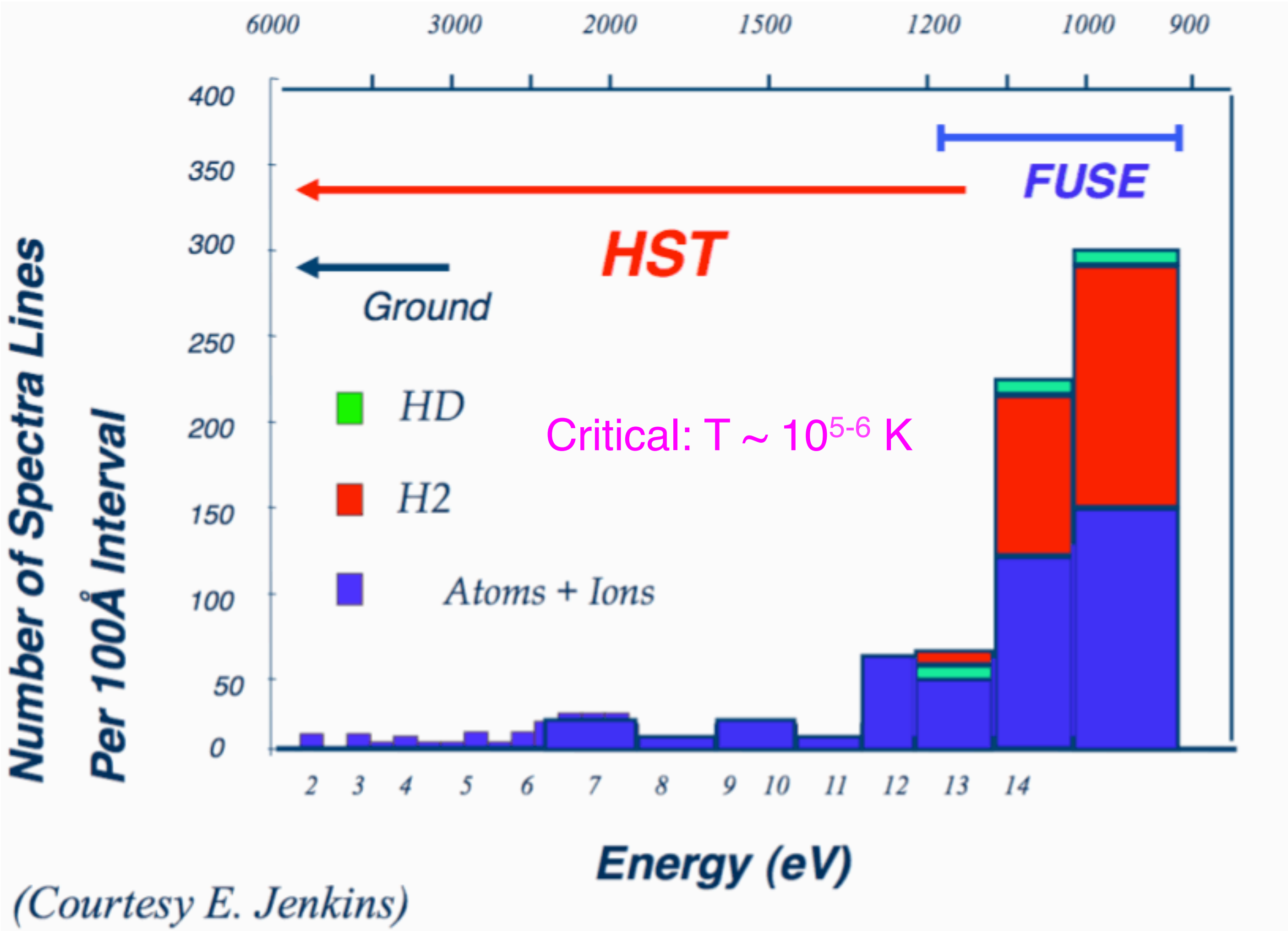
k(λ)
mag
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
The ground-based UV window
3100 – 4000 A
The "almost UV"?
The "Near-er UV"?
Mean Extinction
Ozone
Rayleigh
Aerosol
Ozone
3000
4000
5000
6000
7000
Wavelength



The ground-based UV window
3100 – 4000 A
The "almost UV"?
The "Near-er UV"?
The Orphan UV?
k(λ)
mag
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Mean Extinction
Ozone
Rayleigh
Aerosol
Ozone
3000
4000
5000
6000
7000
Wavelength

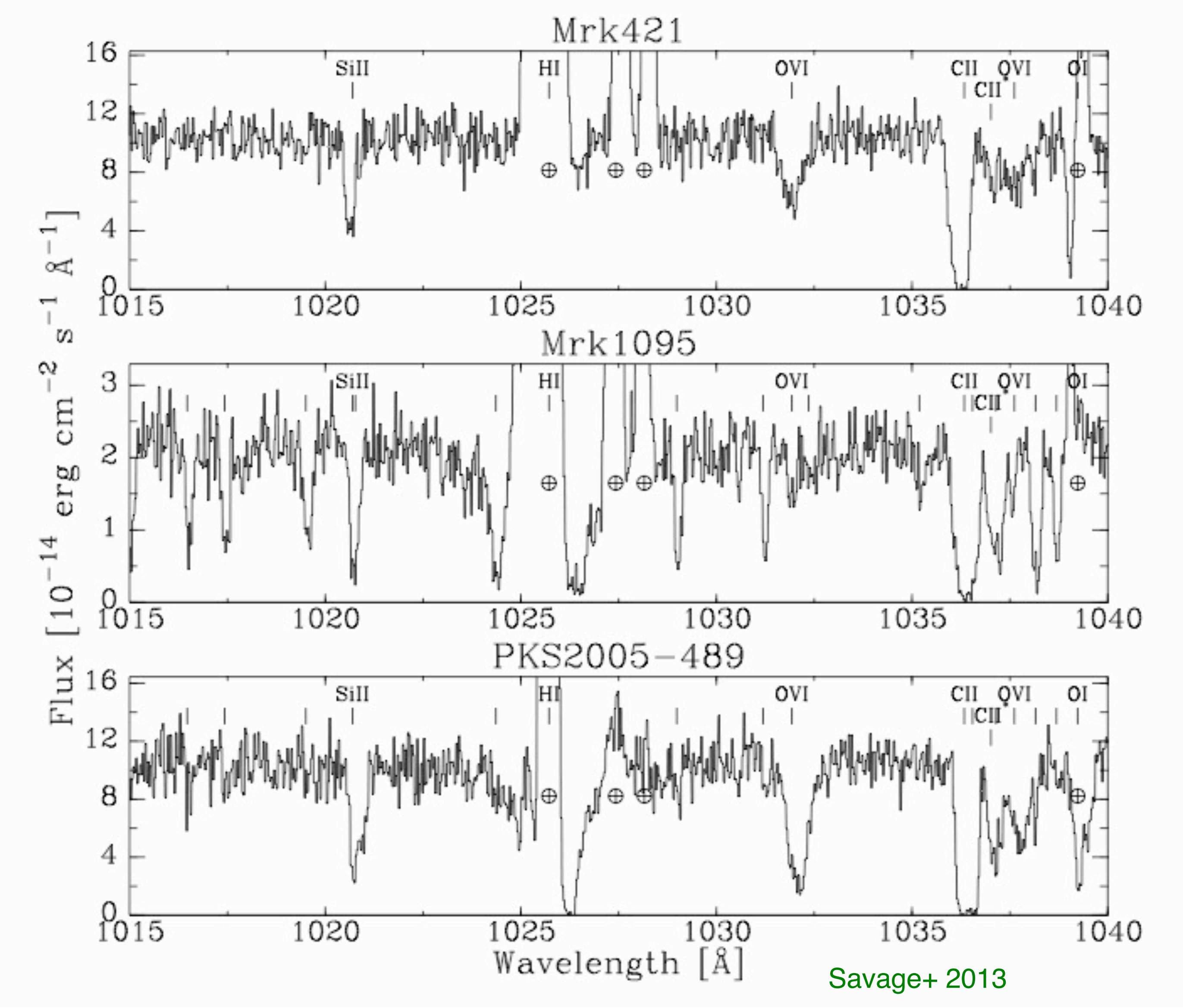

The ground-based UV window
3100 – 4000 A
The "almost UV"?
The "Near-er UV"?
The Orphan UV?
"The CUBES UV"
k(λ)/mag
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Mean Extinction
Ozone
Rayleigh
Aerosol
Ozone
3000
4000
5000
6000
7000
Wavelength

ISM/IGM/CGM



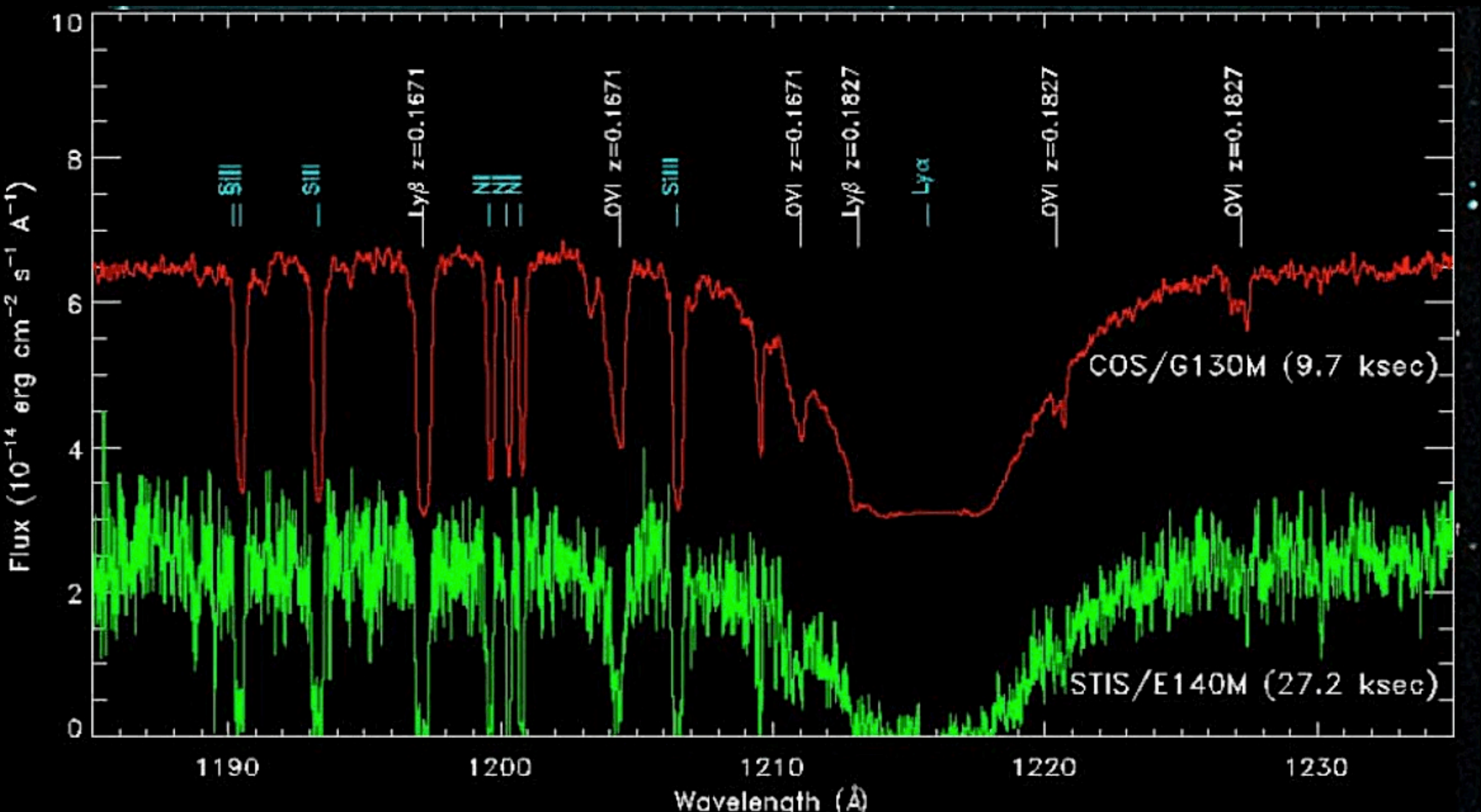
6000
3000
2000
1500
1200
1000
900
400
350
300
250
200
150
100
50
0
FUSE
HST
Ground
HD
H2
Atoms + Ions
Critical: T ~ 10^5-6 K
Number of Spectra Lines
Per 100Å Interval
2
3
4
5
6
7
8
9
10
11
12
13
14
Energy (eV)
(Courtesy E. Jenkins)

Hot Milky Way ISM seen against distant AGN (FUSE)



Savage+ 2013

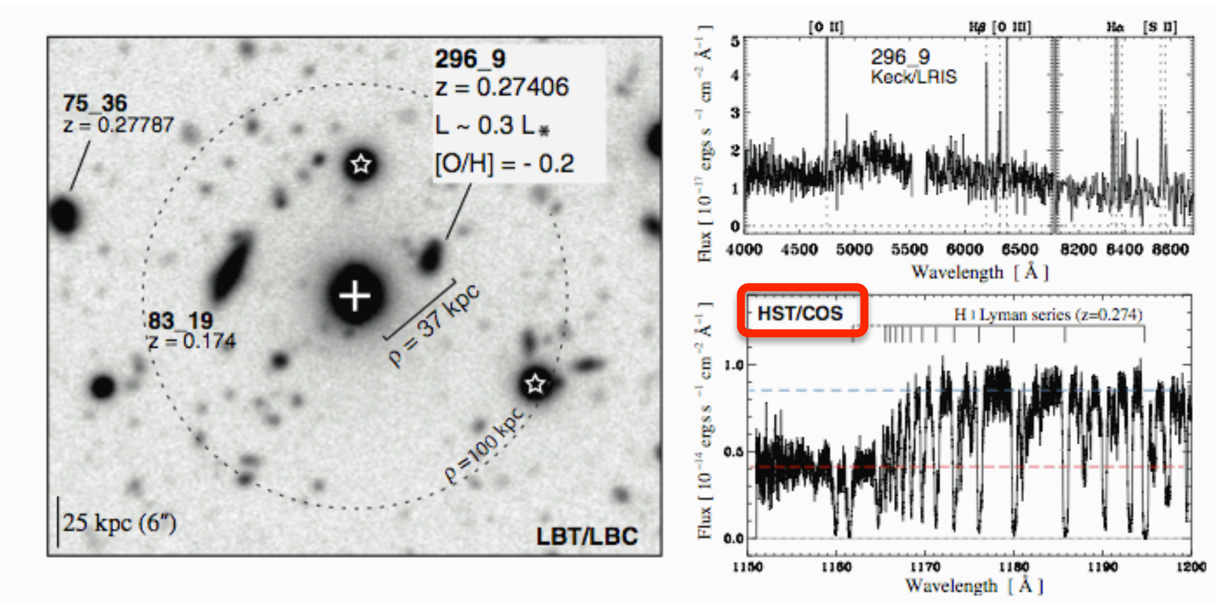
IGM Absorption Spectrum (HST/COS)



Danforth, Keeney, France, et al.

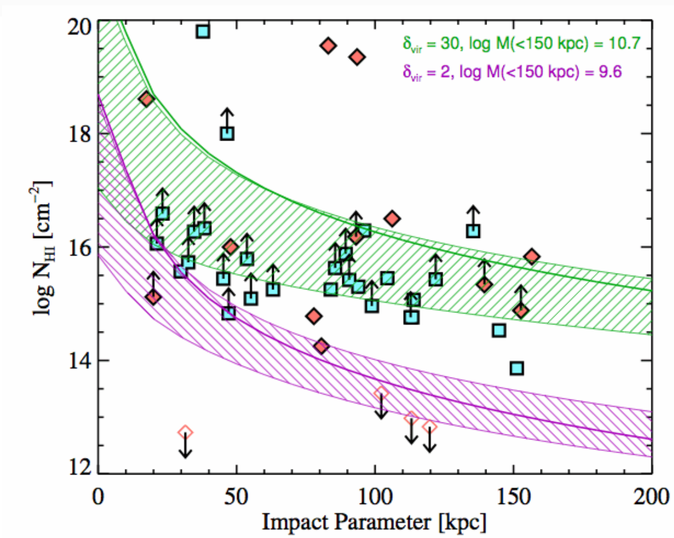
Courtesy Jim Green

Spectroscopic evidence for circumgalactic cold accretion



Low metallicity Lyman limit system at z = 0.27

Ribaudo+ 2011

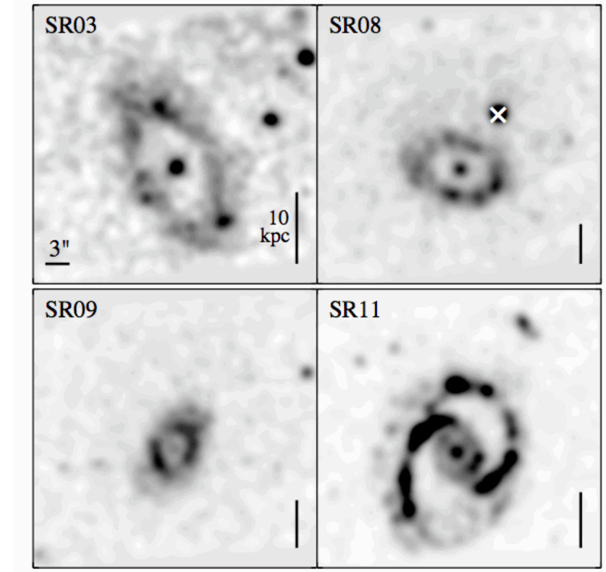


HI features (HST/COS) in halos of distant galaxies: $M_{gas} \sim M_{stars}$

Tumlinson+ 2013

GALEX/Bigiel+ 2010

UV imaging evidence for CGM: "XUV" star formation



HST/Fang+ 2012

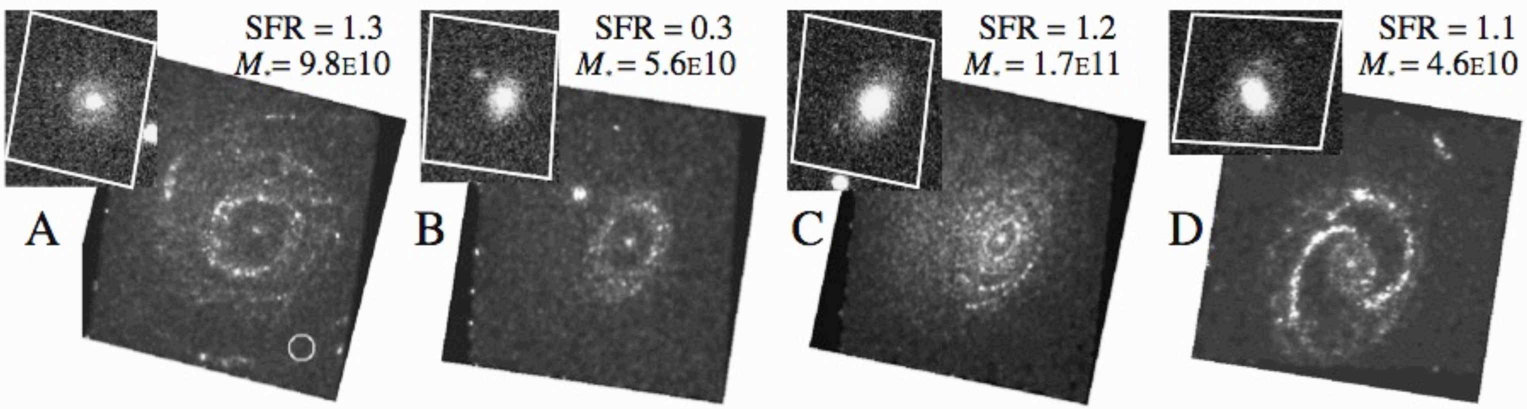
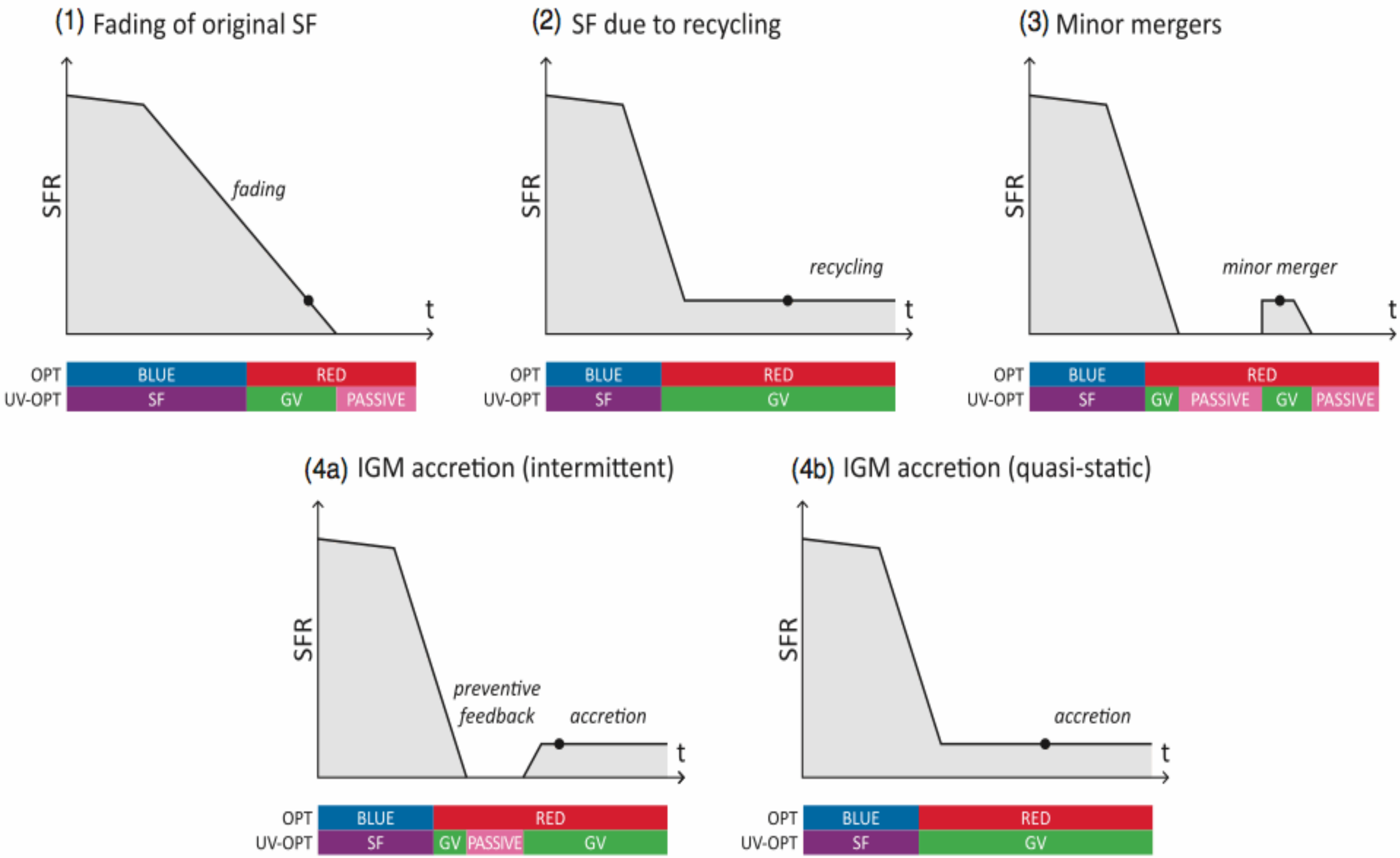


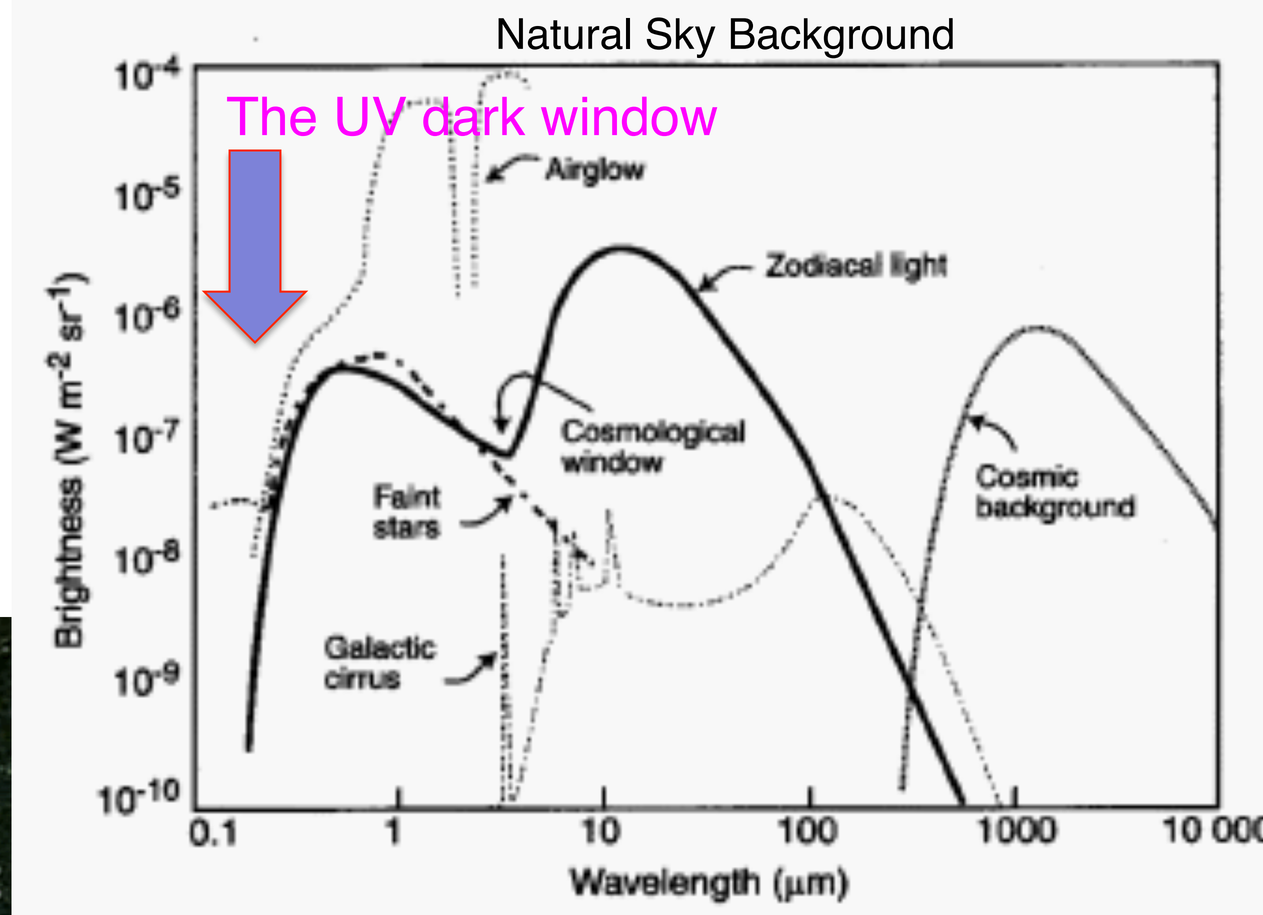
Figure 3. *HST* ACS/SBC far-UV images of several strong UV-excess galaxies. Insets show SDSS *g*-band image. ACS images are $\sim 33''$ across ($\sim$ 63 kpc). SFRs are given in $M_\odot \mathrm{yr}^{-1}$ and stellar masses in $M_\odot$.

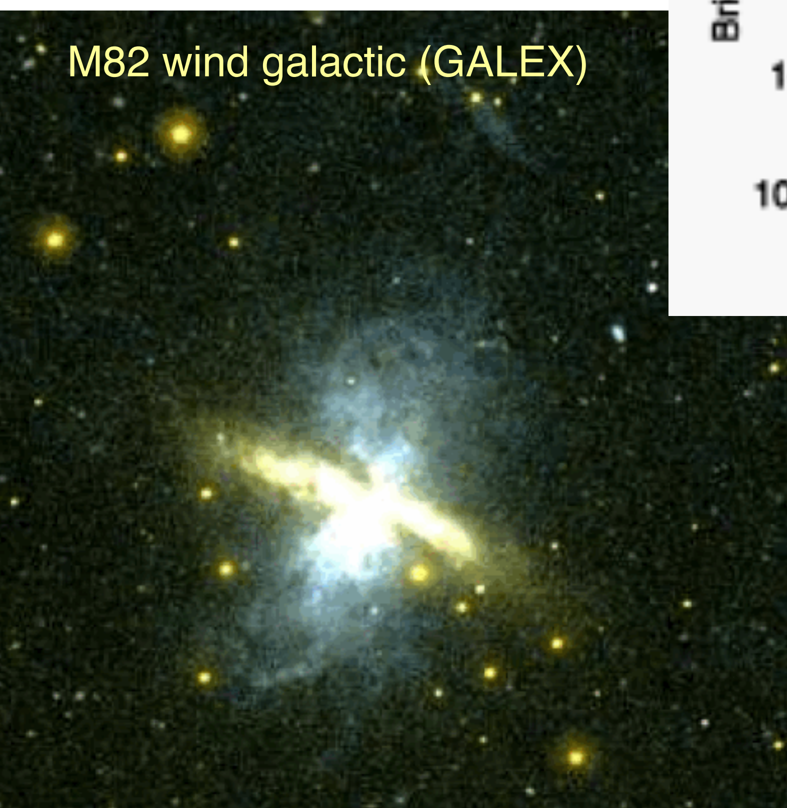
Salim & Rich 2010

UV/optical discrimination between late epoch star formation histories in early-type galaxies (Salim+ 2012)

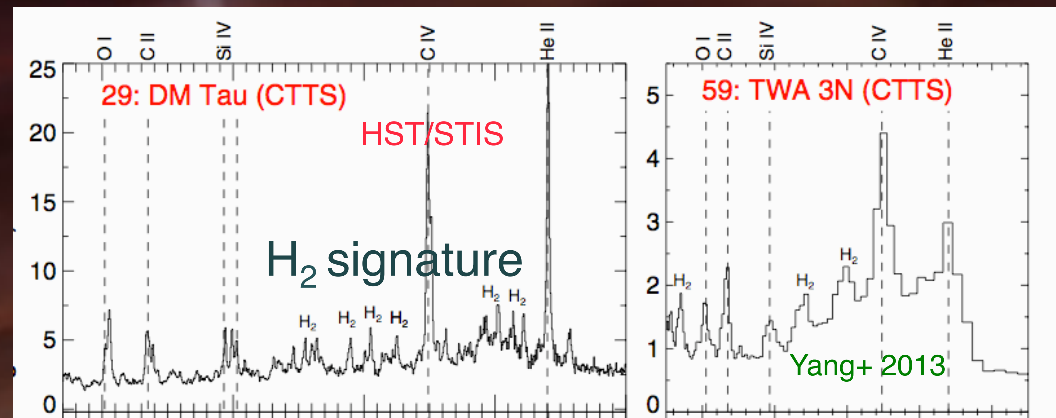


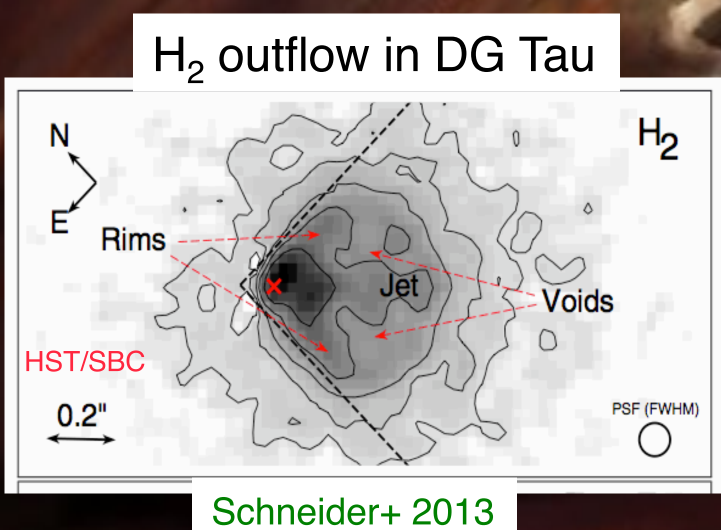
Low-surface brightness UV science





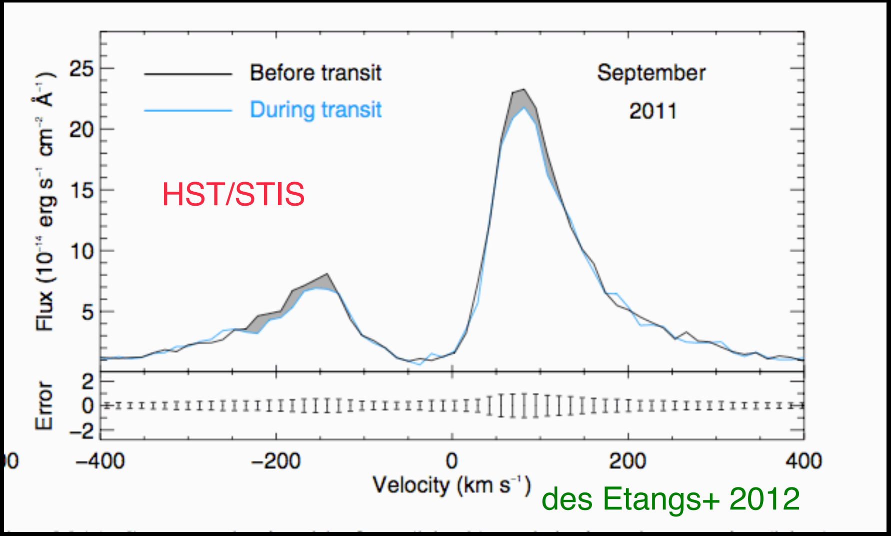
Assembly and physics of protoplanetary disks

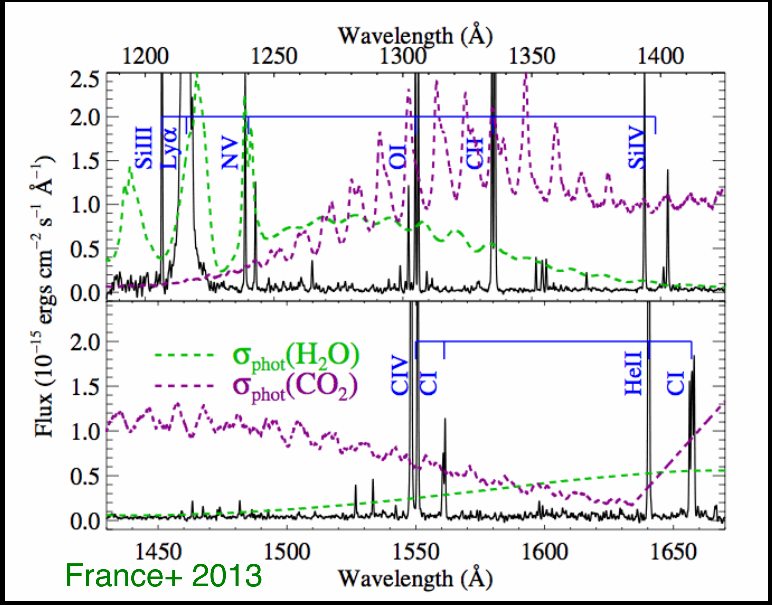




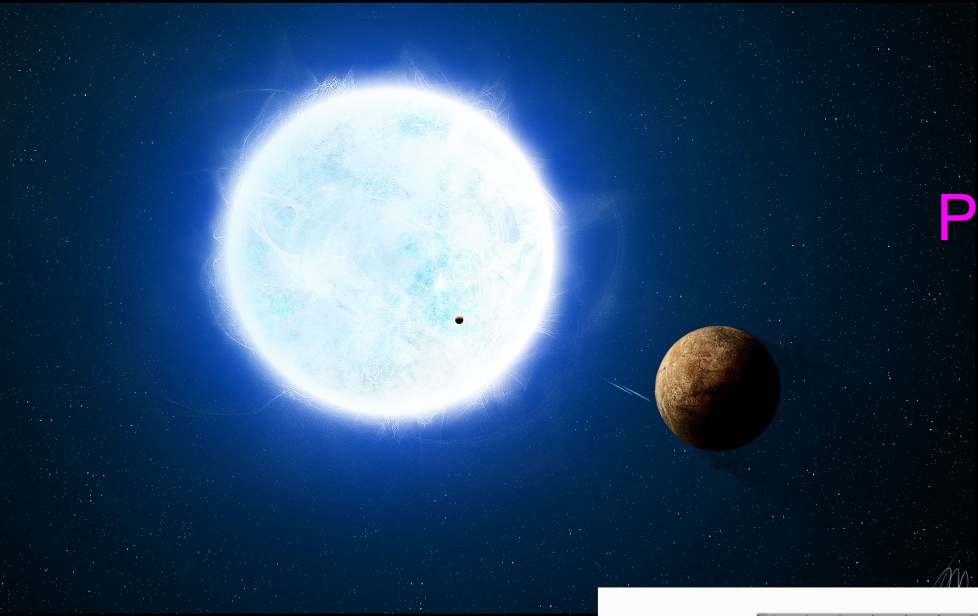
The dangerous lives of exoplanets

Ly-alpha traces evaporation of a hot Jupiter atmosphere



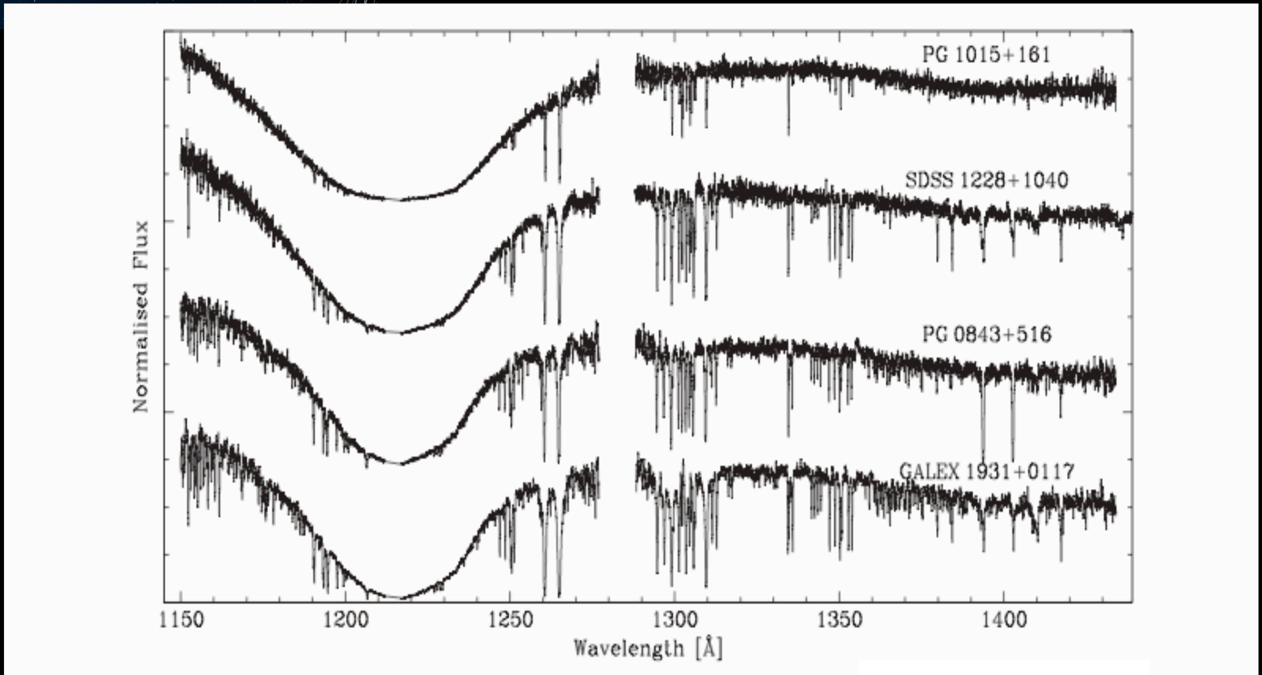


H_2O and CO_2 photo-dissociation by dM UV flares



Probing terrestrial exoplanets by their pollution of white dwarf atmospheres

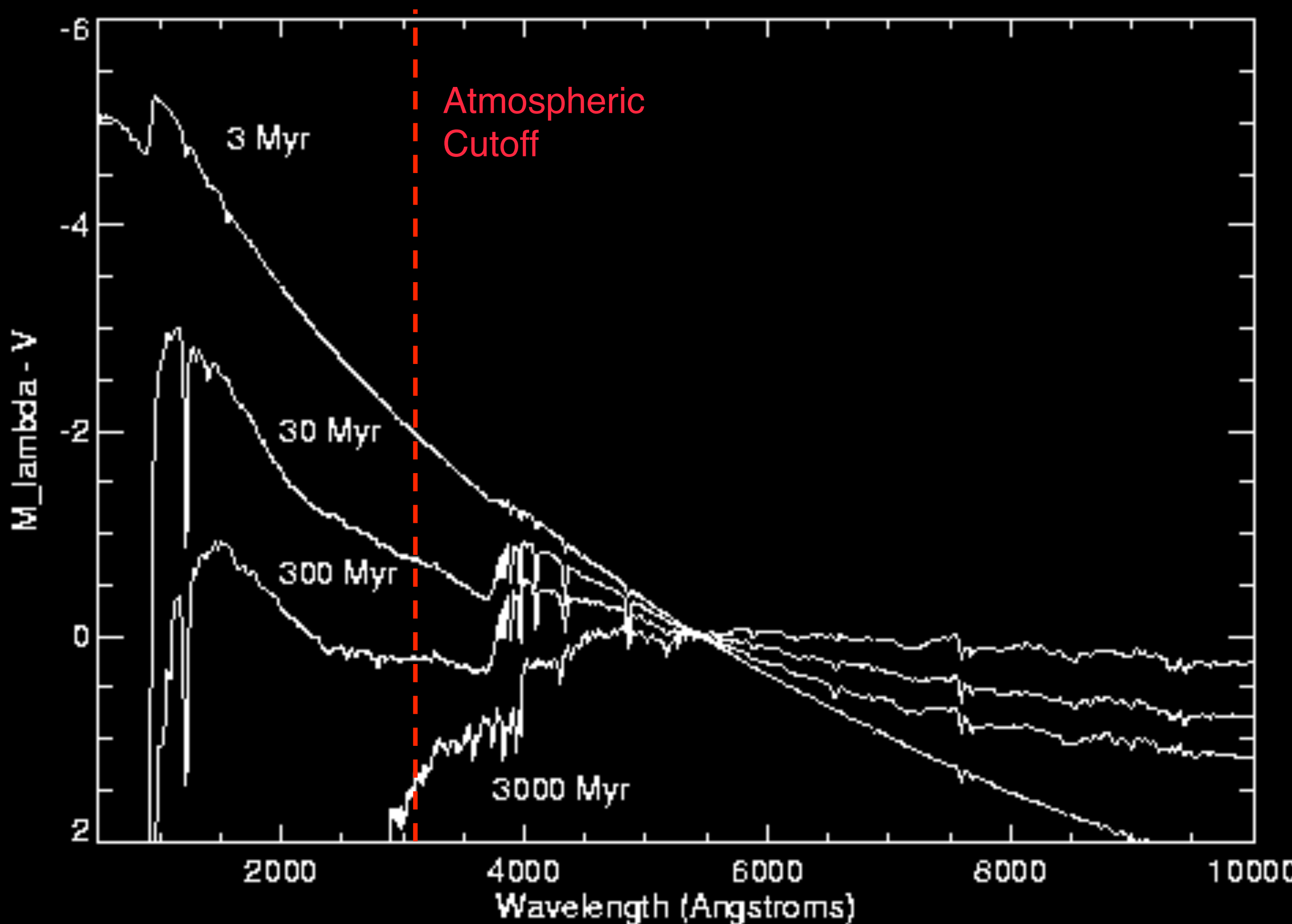
Planetary metallic features in far-UV spectra of white dwarfs (HST/COS)



Gaensicke+ 2012

UV Determination of Galaxy Star Formation Rates and Histories

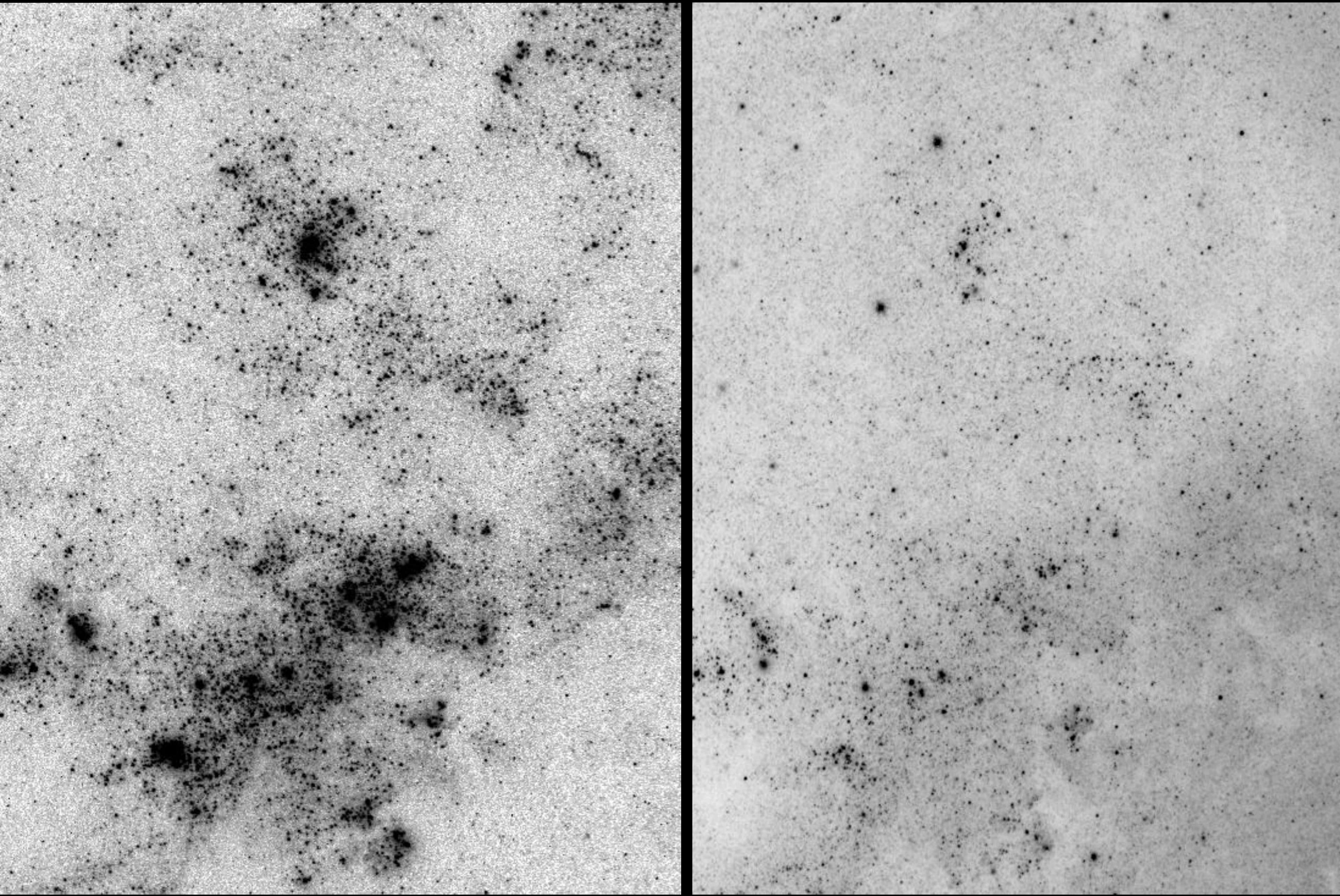
Integrated energy distributions of stellar populations: UV sensitivity to age



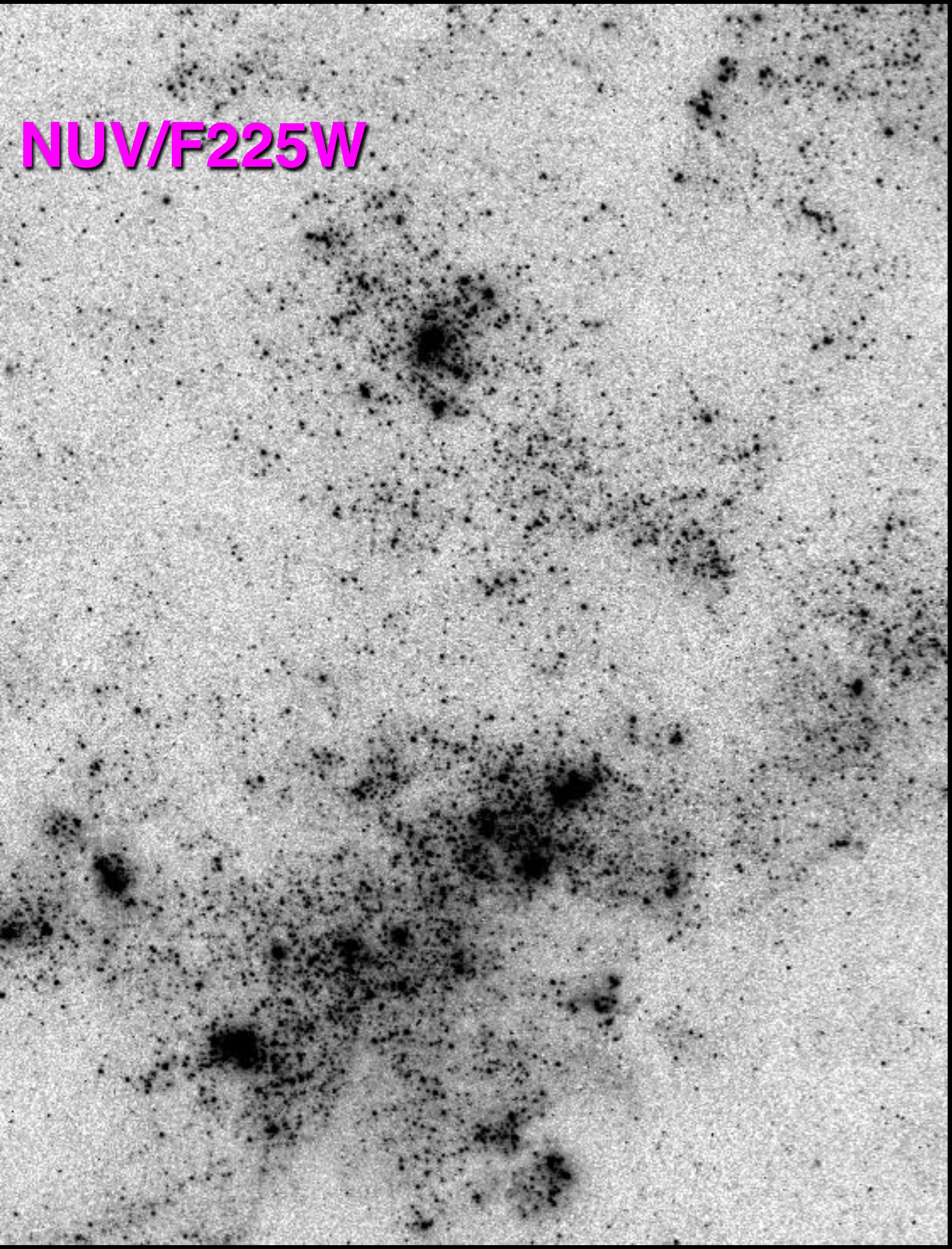
Dust: the bane of UV studies of star formation

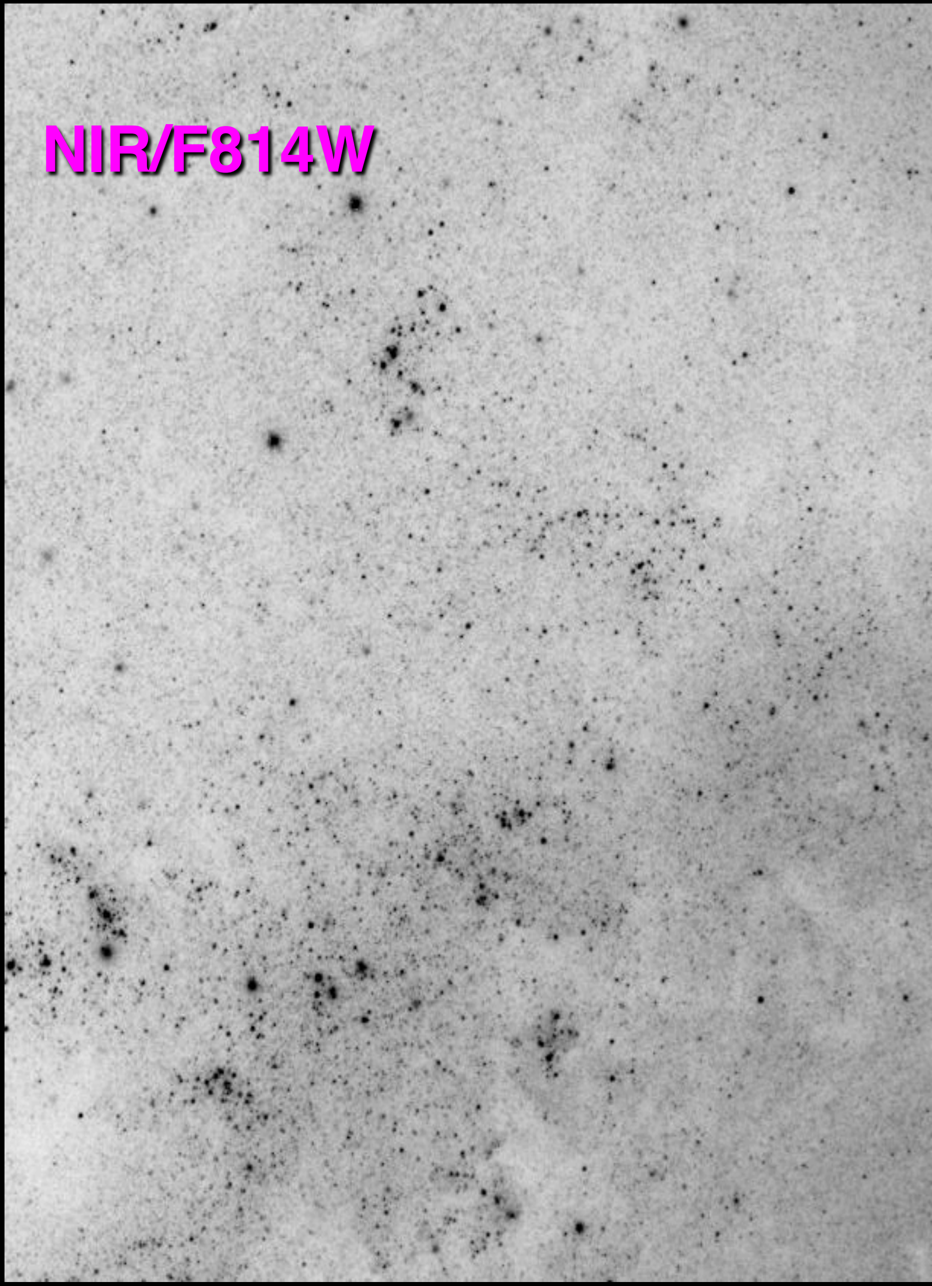
Dust: the bane of UV studies of star formation?

M83: NUV vs NIR bands (HST/WFC3)



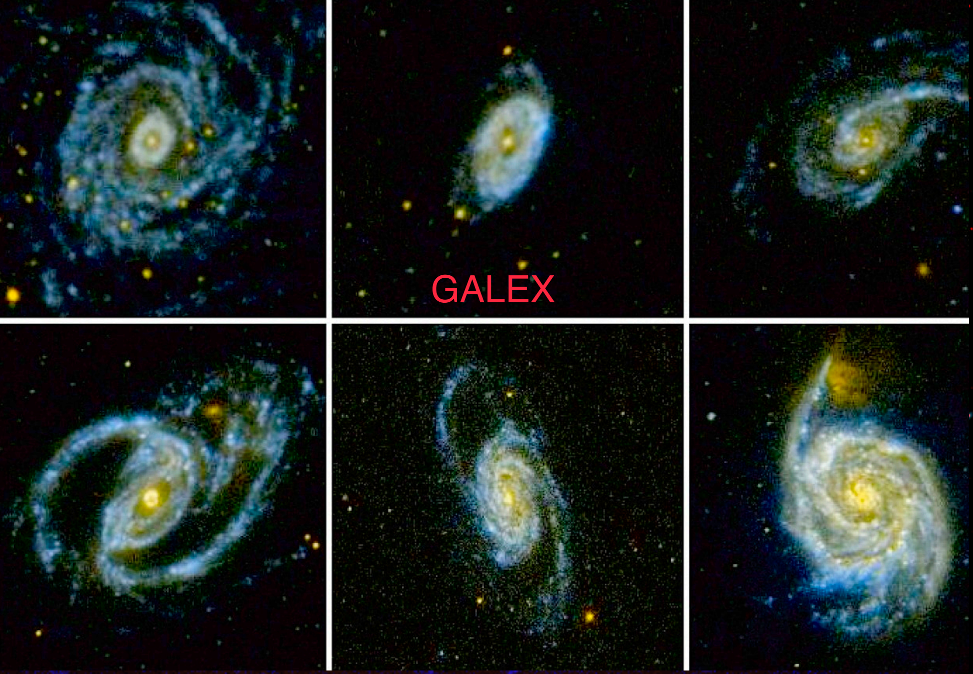
M83: NUV vs NIR bands (HST/WFC3)

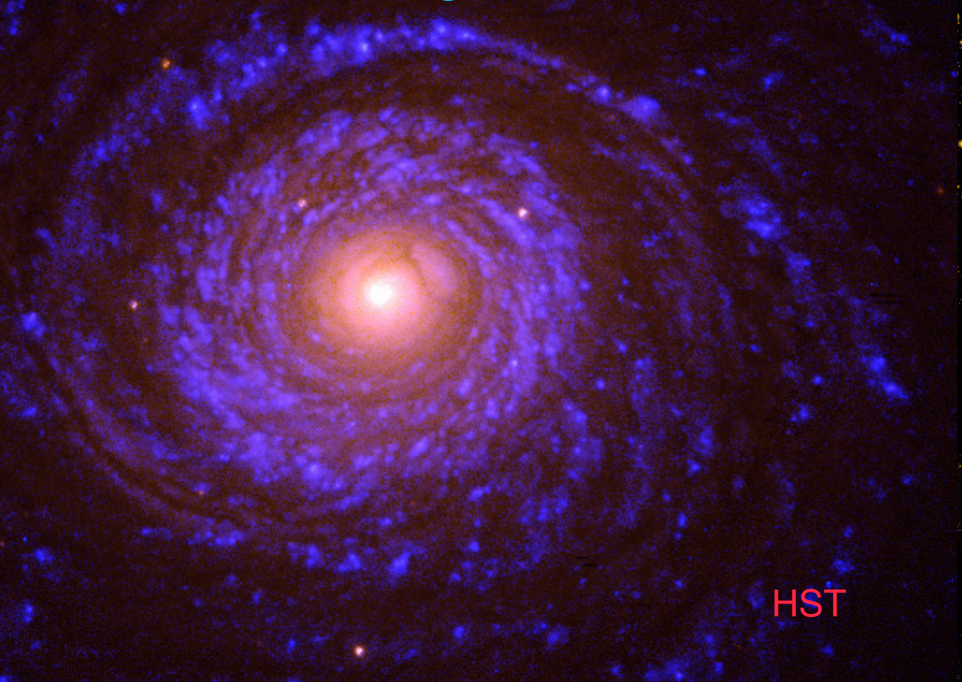




M83: NUV-to-blue band composite (WFC3)

Most galactic environments are ~transparent in the UV



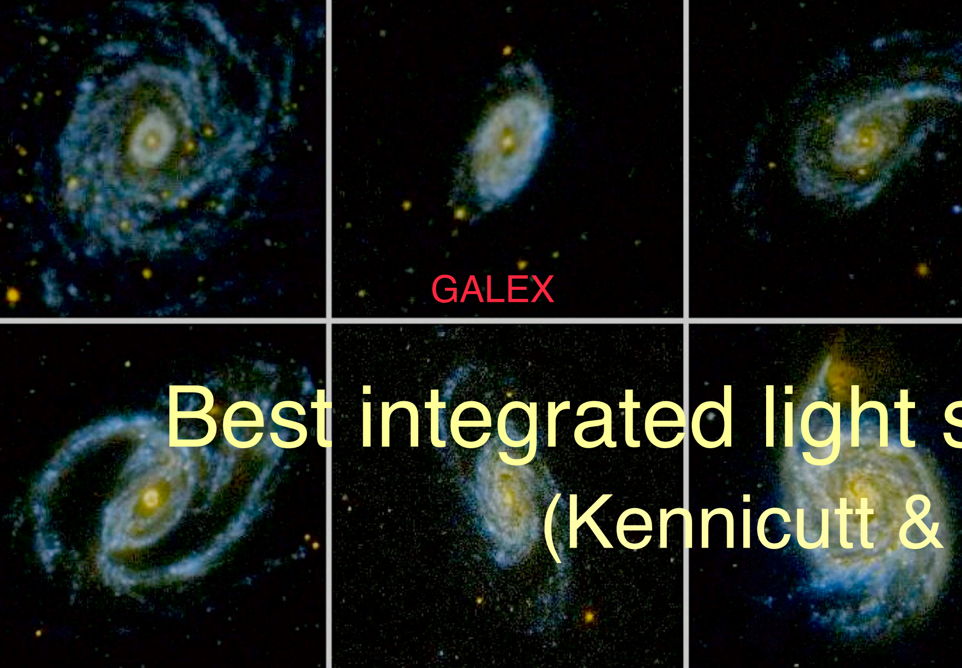


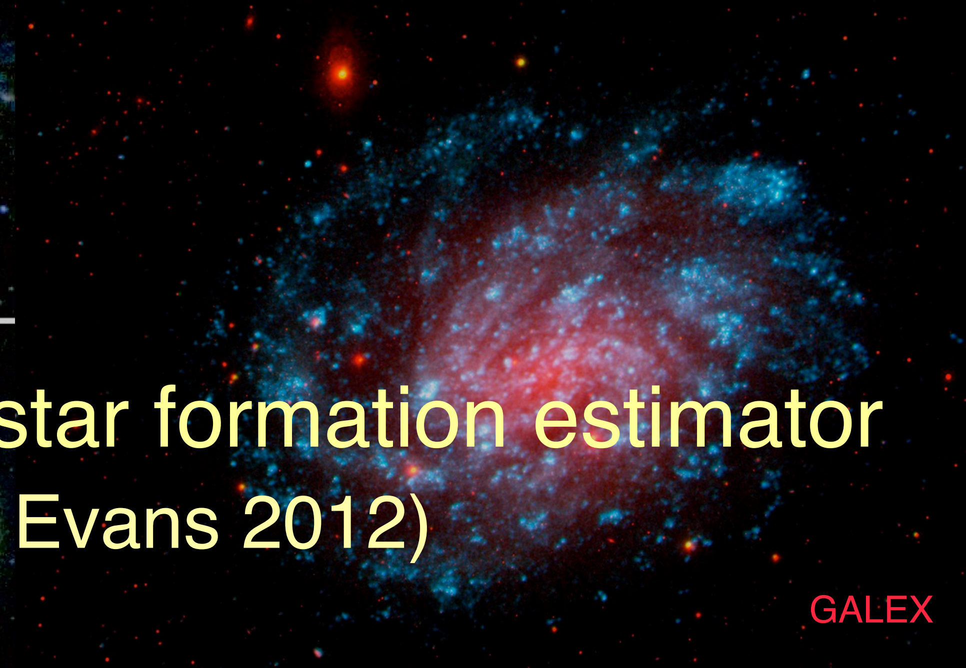
Best integrated light star formation estimator

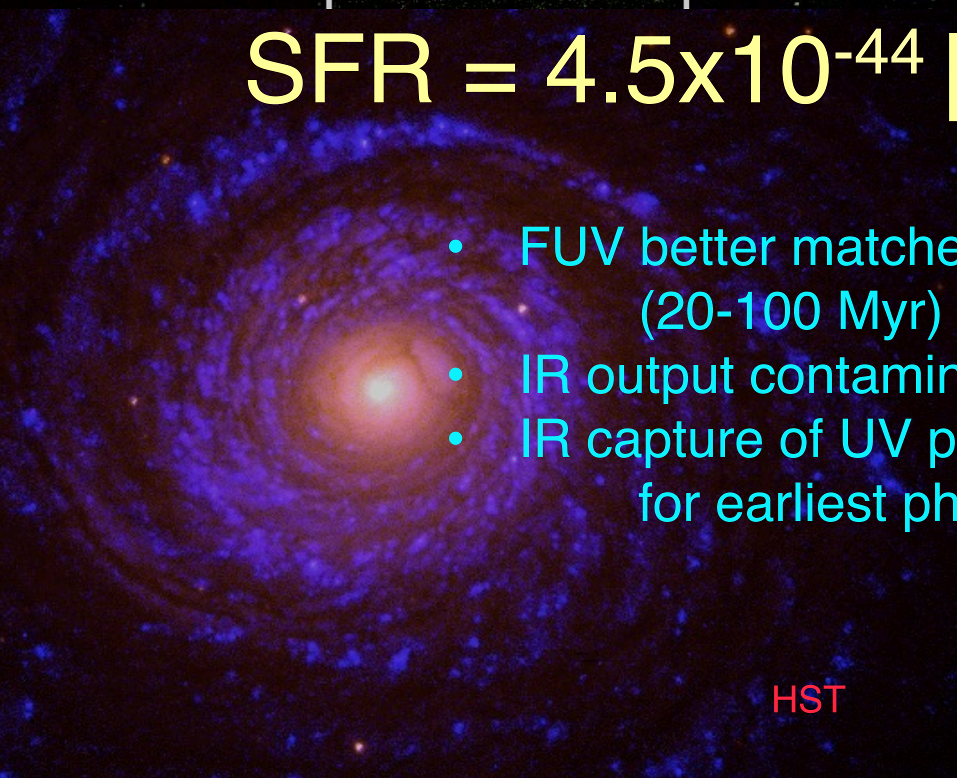
(Kennicutt & Evans 2012)

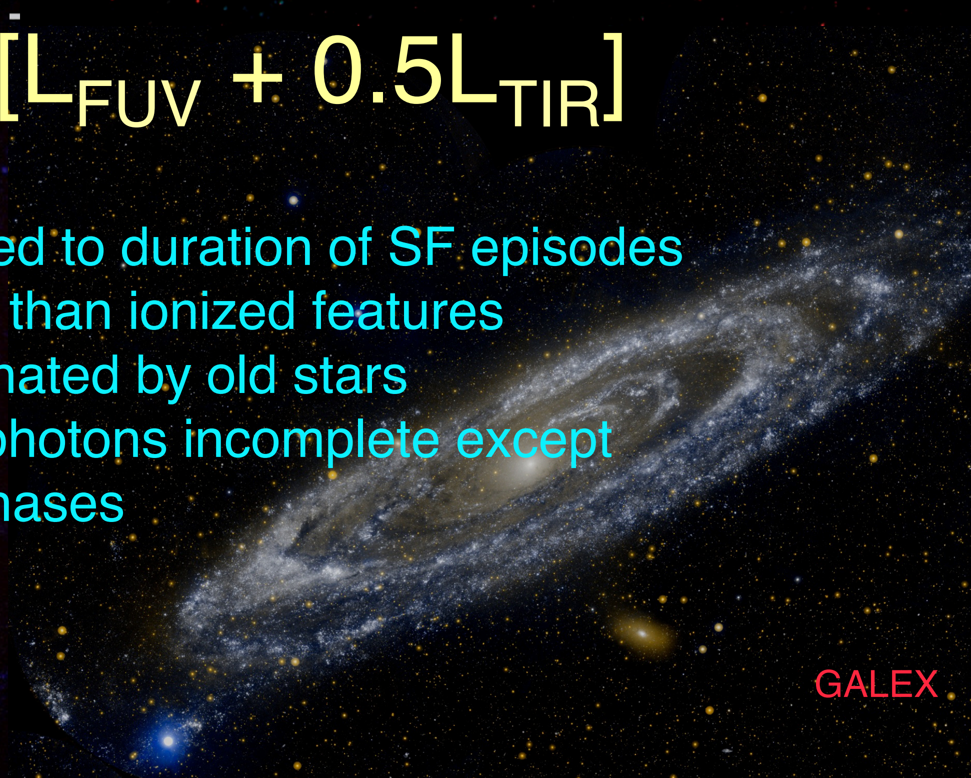
$$SFR = 4.5x10^{-44} [L_{FUV} + 0.5L_{TIR}]$$

- FUV better matched to duration of SF episodes (20-100 Myr) than ionized features
- IR output contaminated by old stars
- IR capture of UV photons incomplete except for earliest phases

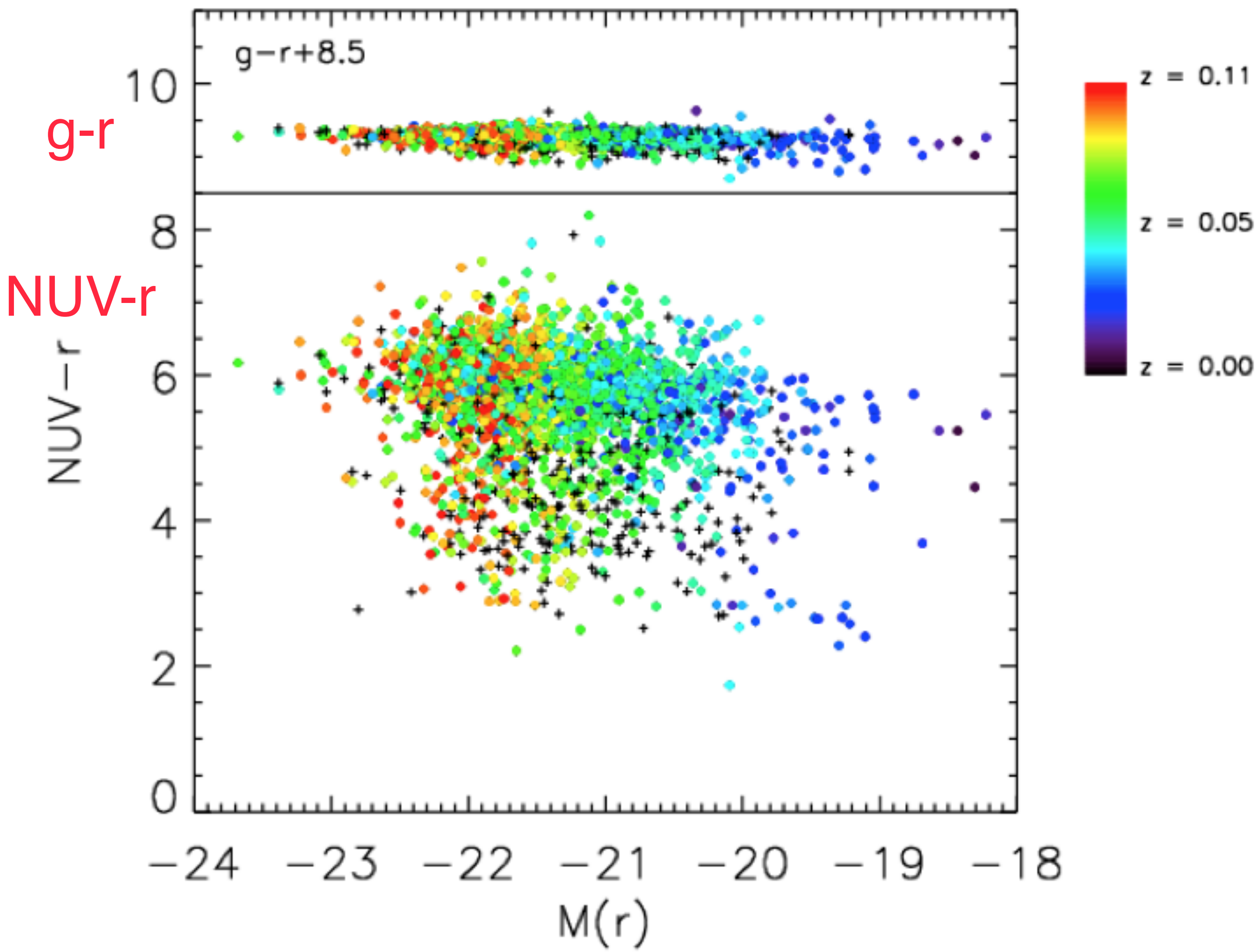








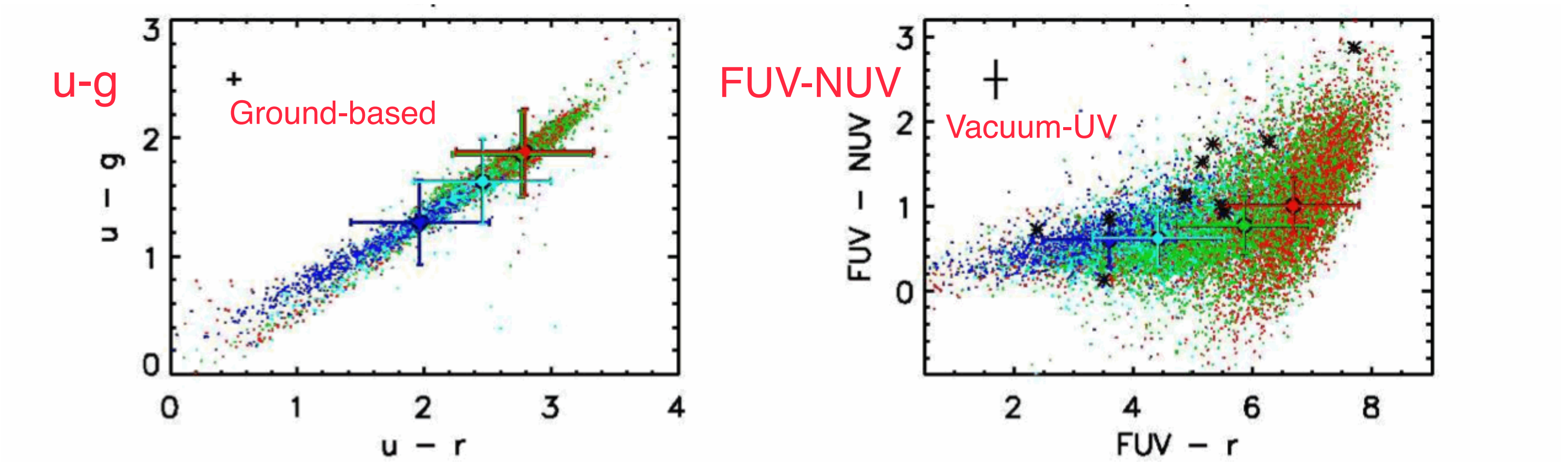
GALEX/UV revelation of complex star-formation histories (0.1-1 Gyr) in ETG's (~ 30%)



Kaviraj et al., ApJS, 173, 619 (2007)

Early-type galaxies: dispersion in (GALEX + SDSS) colors

Vacuum-UV contains new/independent information on stellar populations
(even CUBES UV won't help)



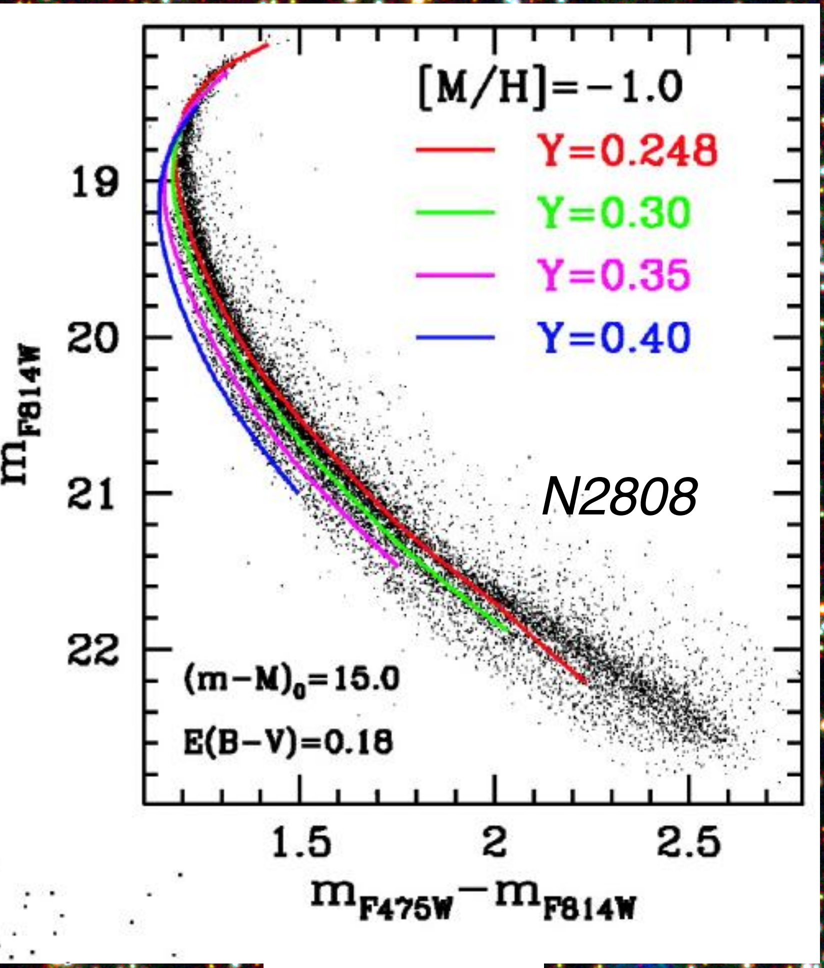
Ree+ (2011)

The UV perspective on globular clusters

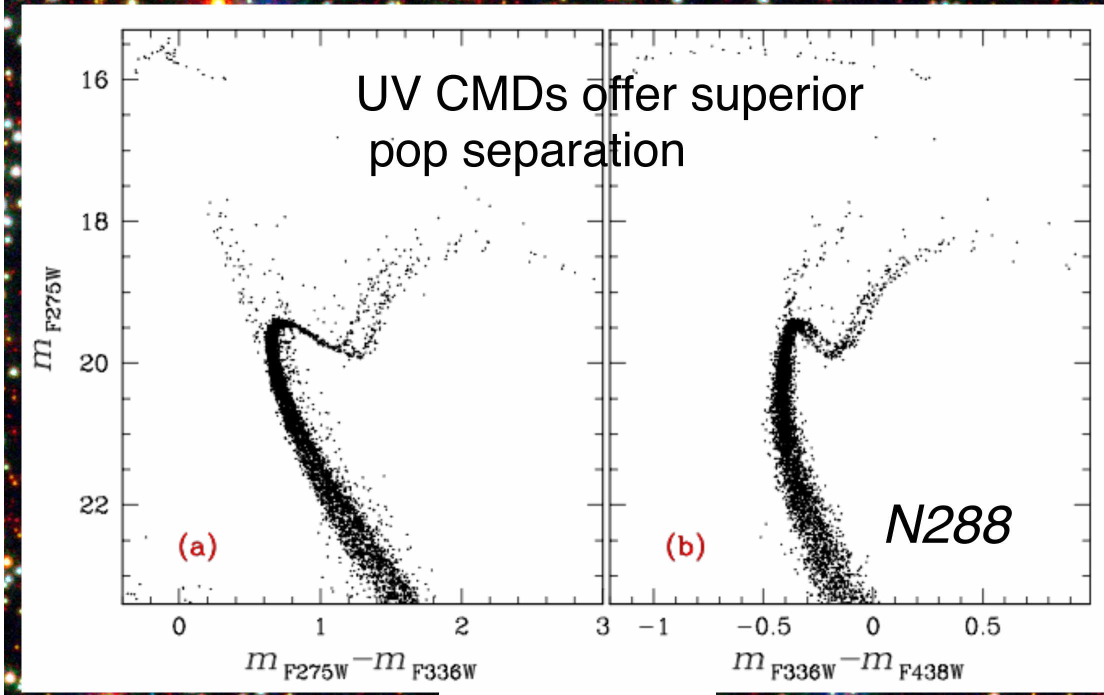
Omega Centauri – HST/WFC3
225W, 336W, 814W

Multiple Populations in Globular Clusters

M4
LMS MF

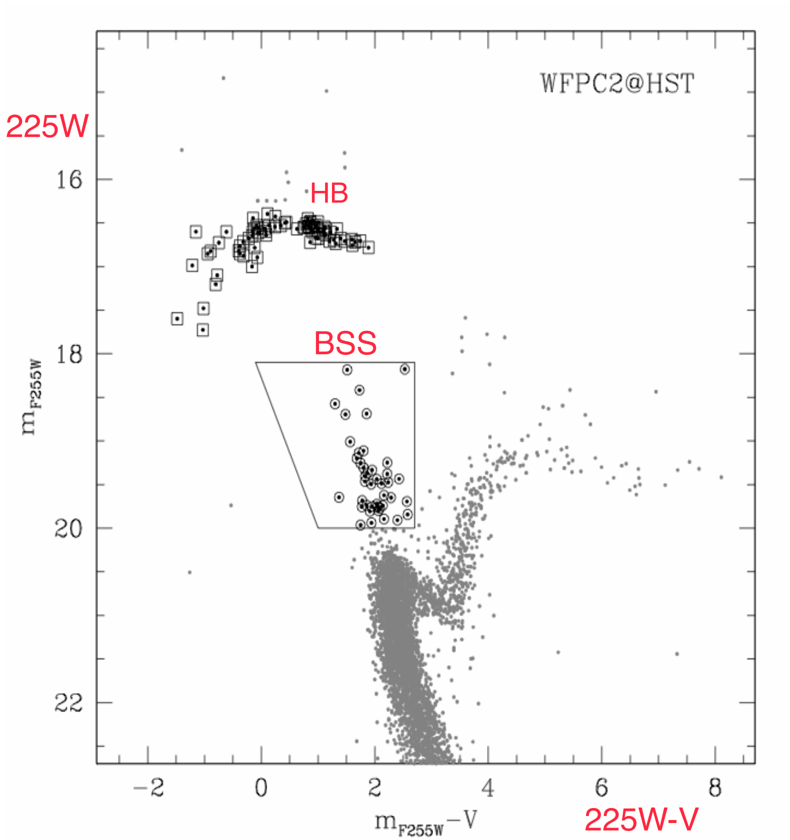


(Piotto+ 2007)

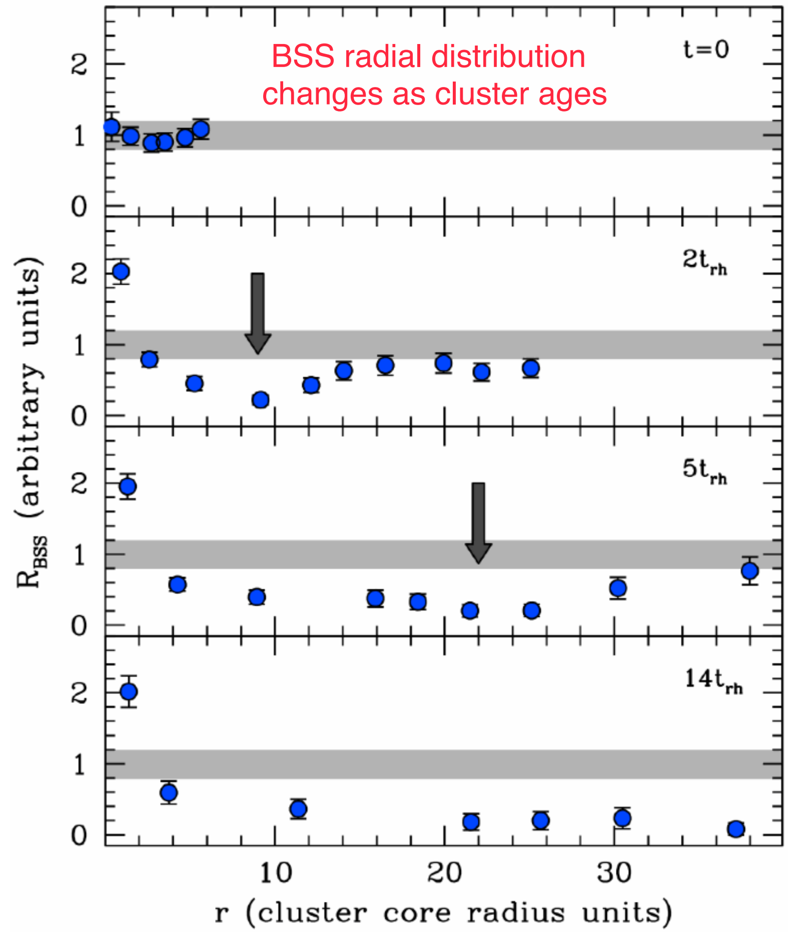


(Piotto+ 2013)

UV identification of (binary) Blue Stragglers as tracers of cluster dynamical evolution



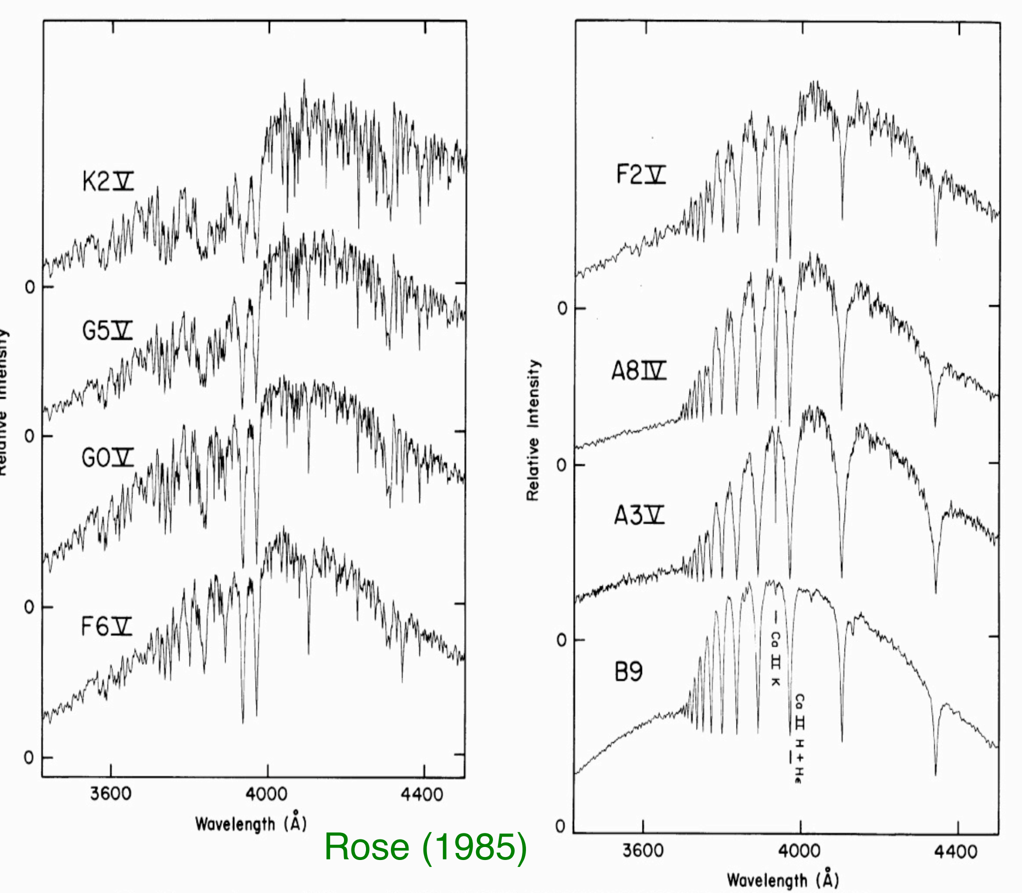
Dalessandro+ (2013)



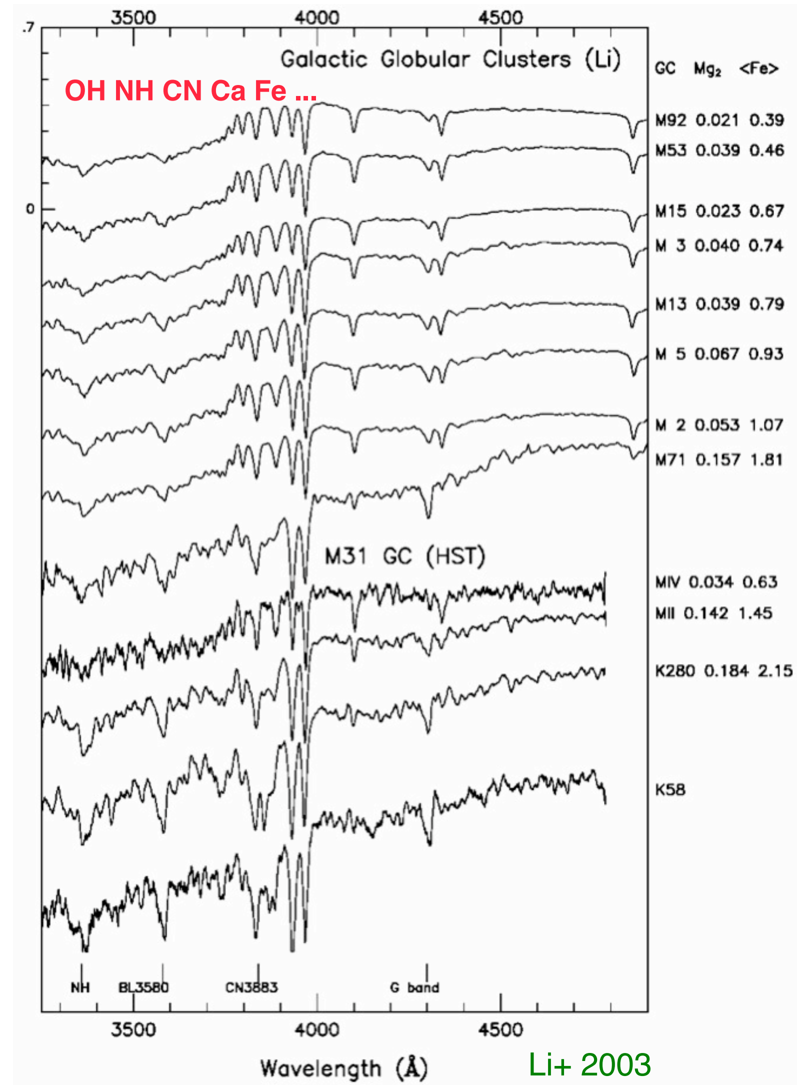
Ferraro+ (2012)

Dynamical "chronometer"

Old stellar population integrated light discriminants in the CUBES UV



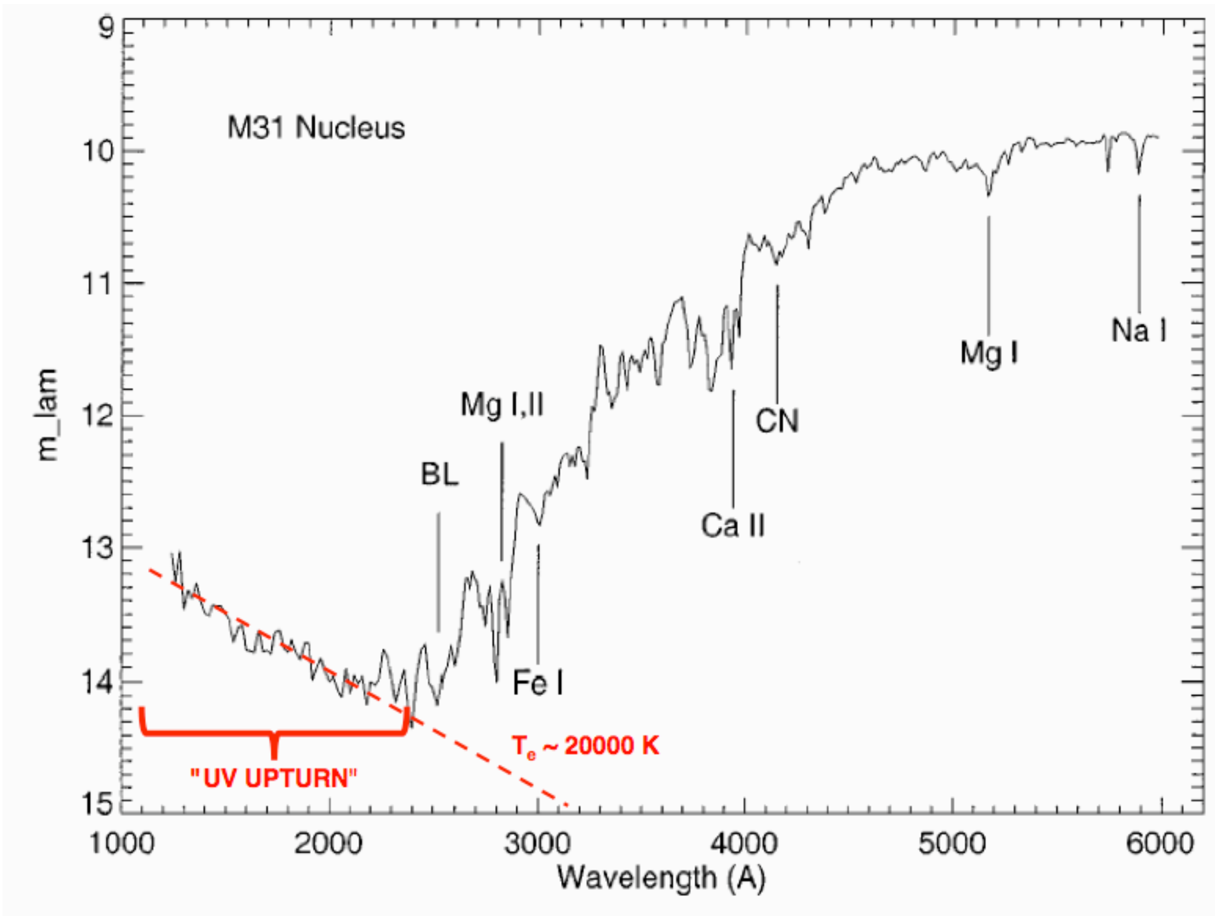
Rose (1985)



Li+ 2003

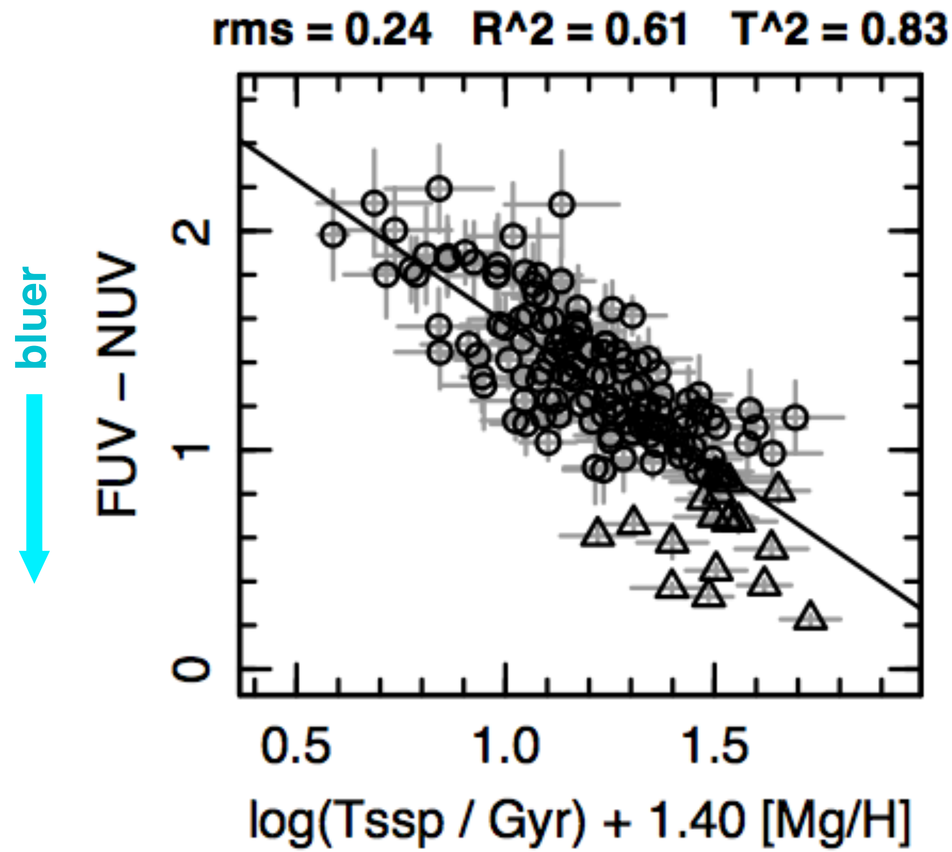
<u>Most</u> of the information on older stellar populations is at wavelengths < 4500 A

The "UV Upturn" in early-type galaxies: recent results



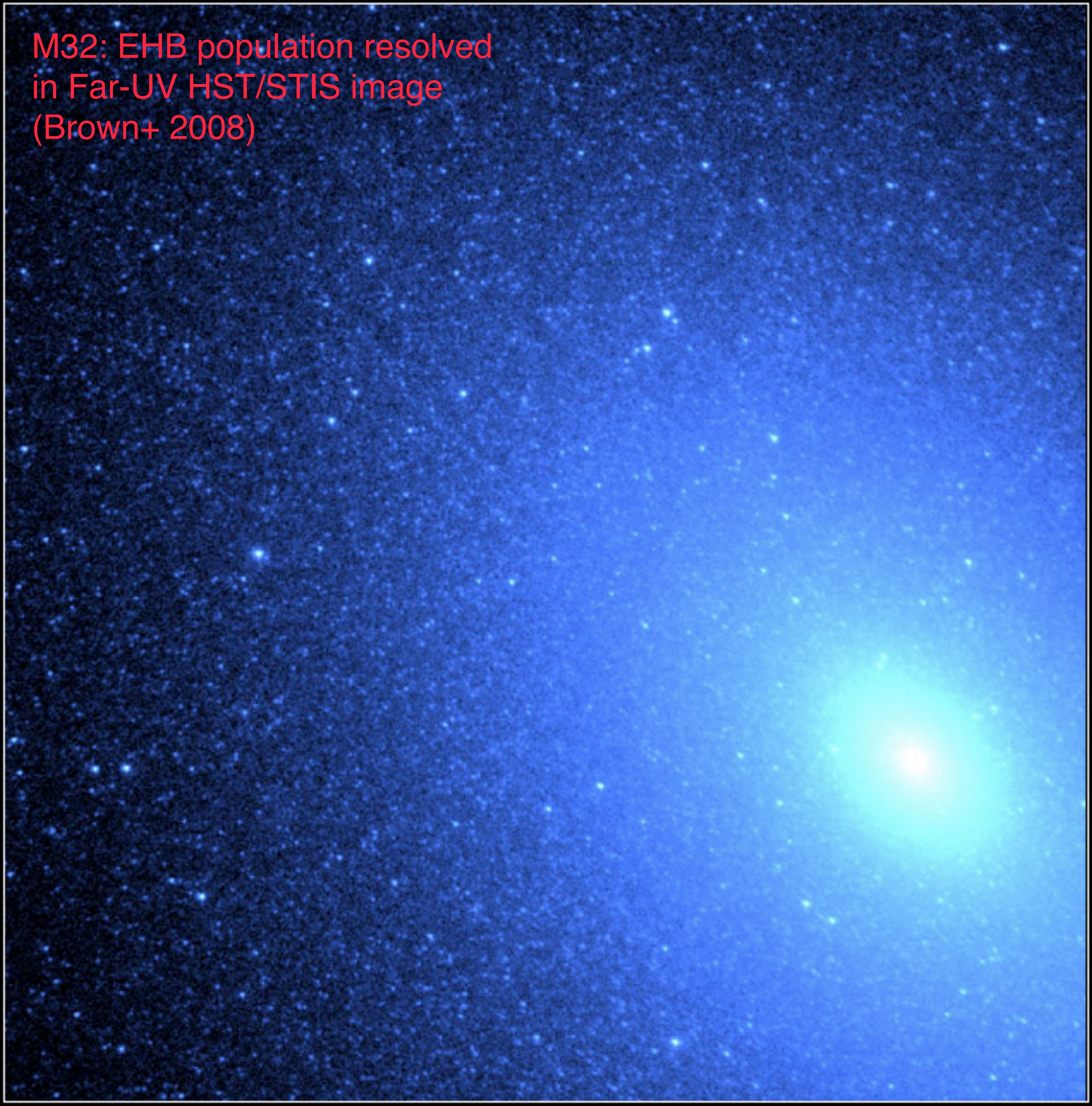
Accepted interpretation: extreme horizontal branch (EHB) & related He-burning stars in the dominant, old, metal-rich population

UVX: Confirm correlation with properties of old population (Coma Cluster)



GALEX photometry combined with optical spectroscopy

Smith+ MNRAS, 421, 2982, 2012


M32: EHB population resolved
in Far-UV HST/STIS image
(Brown+ 2008)

UV CMD for M32 (Brown+ 2008): EHB confirmed as source of UVX

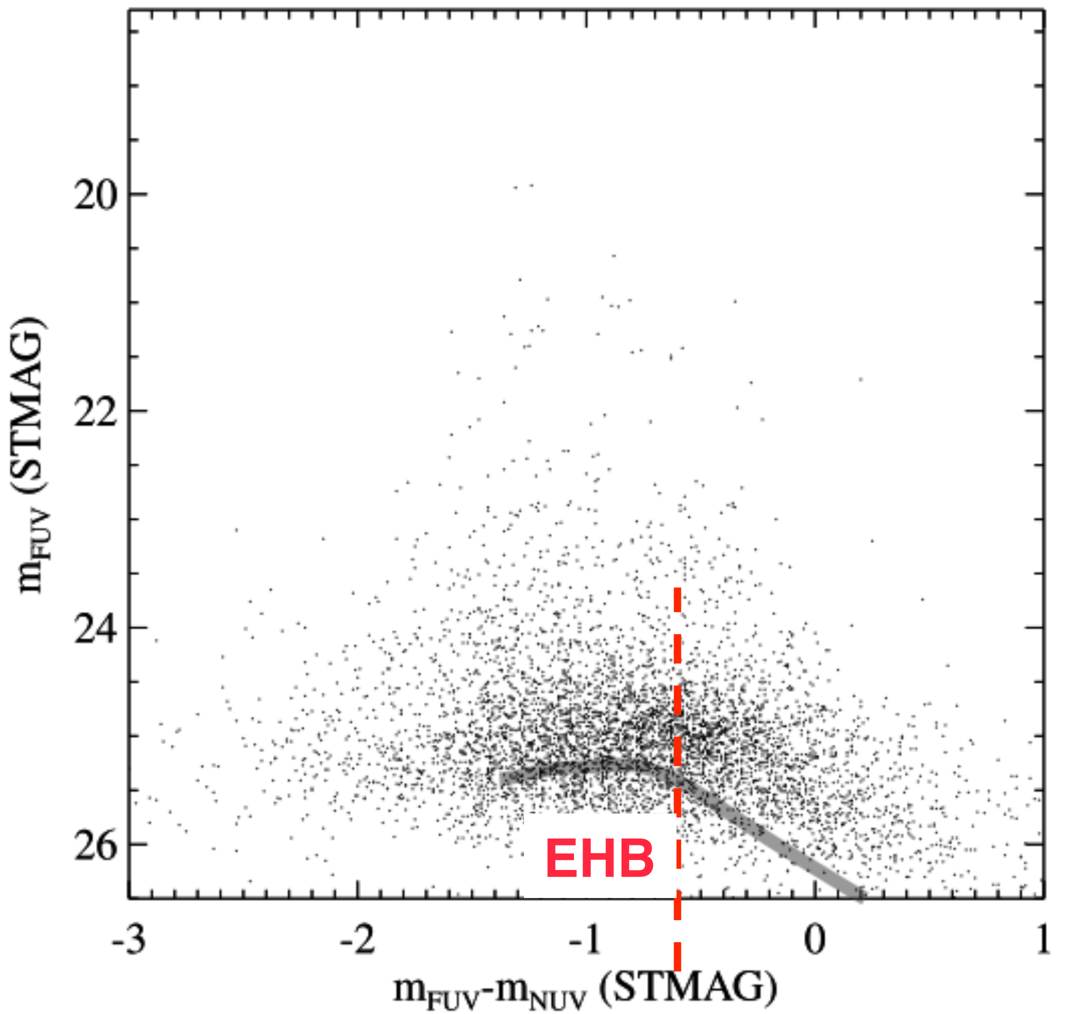


FIG. 3.—UV CMD of M32. The EHB and UV-bright post-HB stars are clearly resolved. A solar metallicity ZAHB is plotted for reference (*gray curve*).

UV CMD for M32 (Brown+ 2008): But....

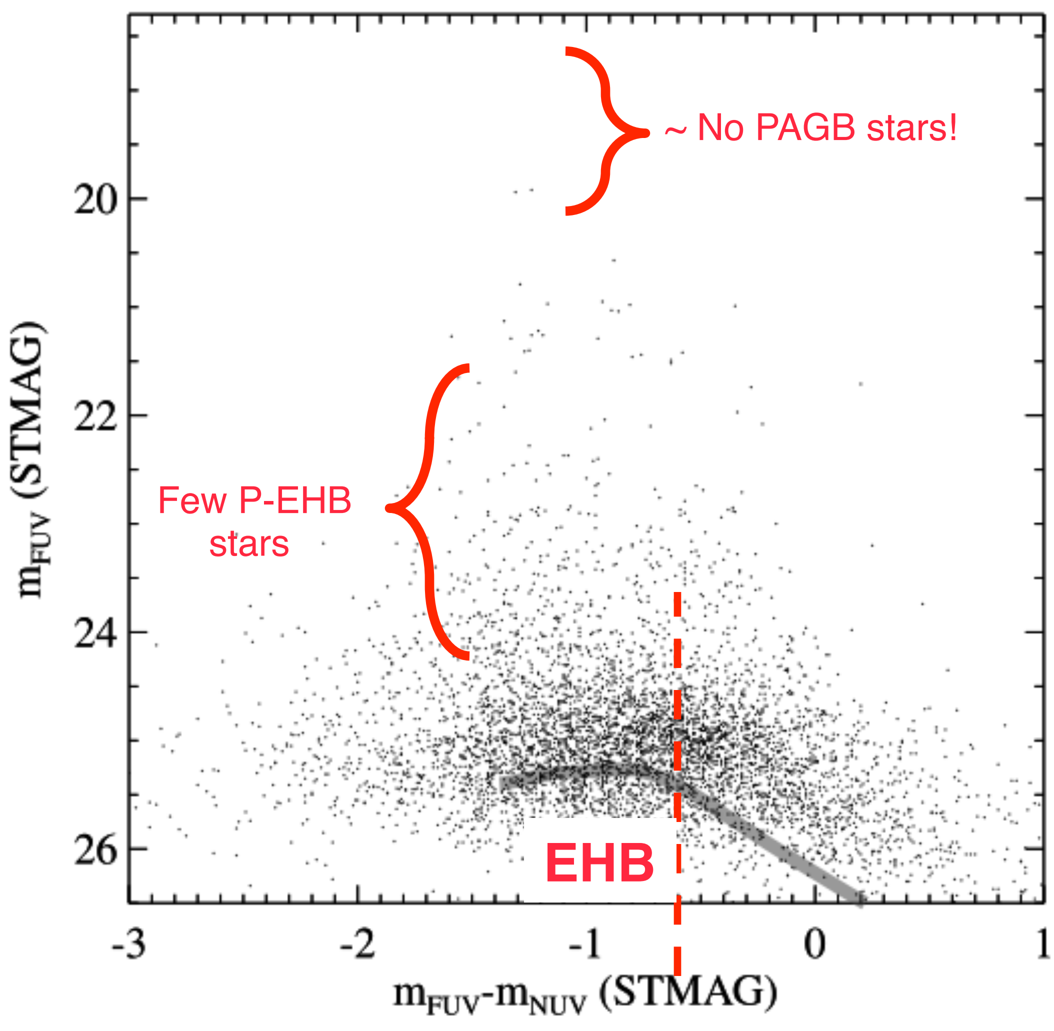
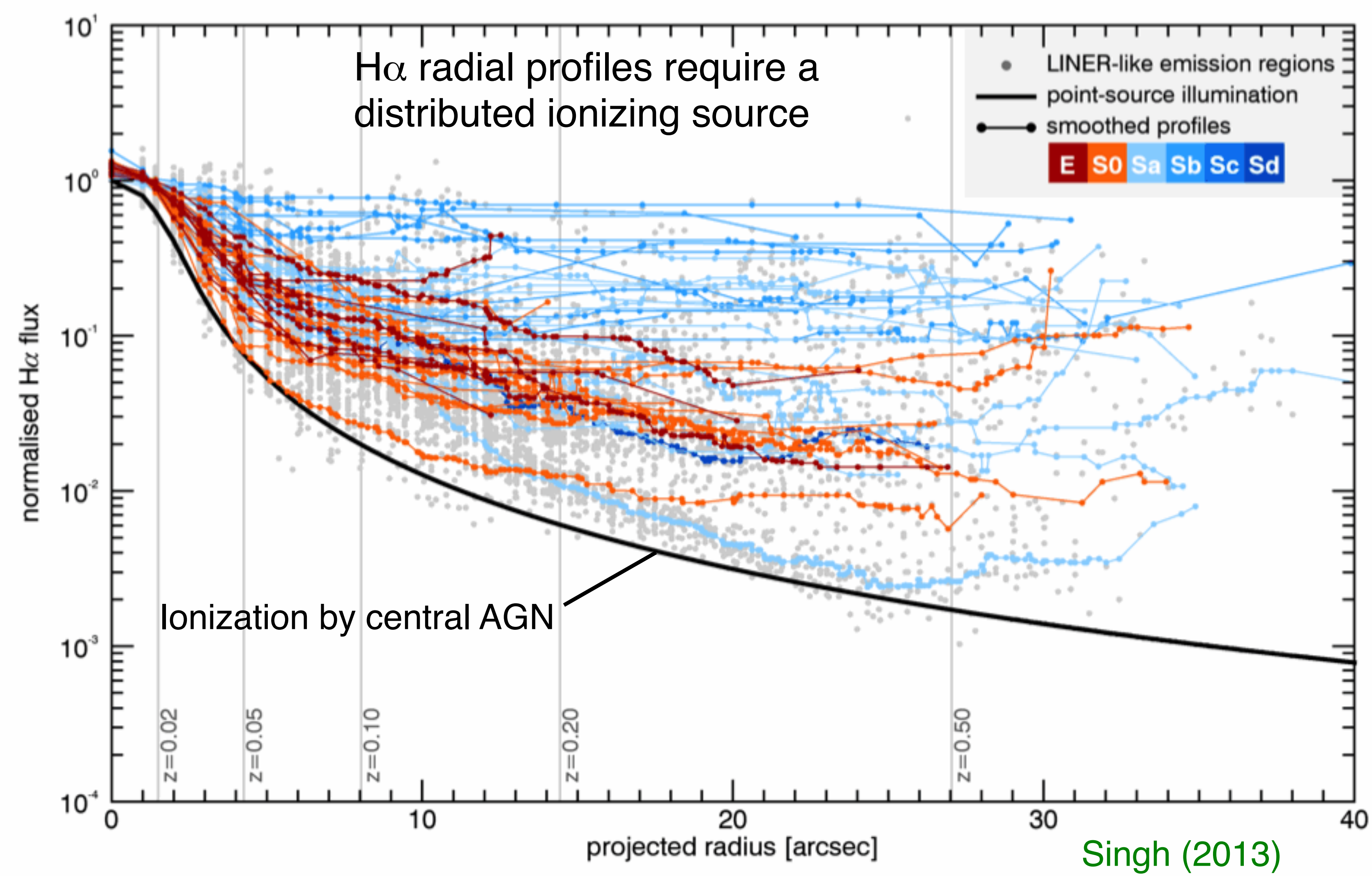


FIG. 3.—UV CMD of M32. The EHB and UV-bright post-HB stars are clearly resolved. A solar metallicity ZAHB is plotted for reference (*gray curve*).

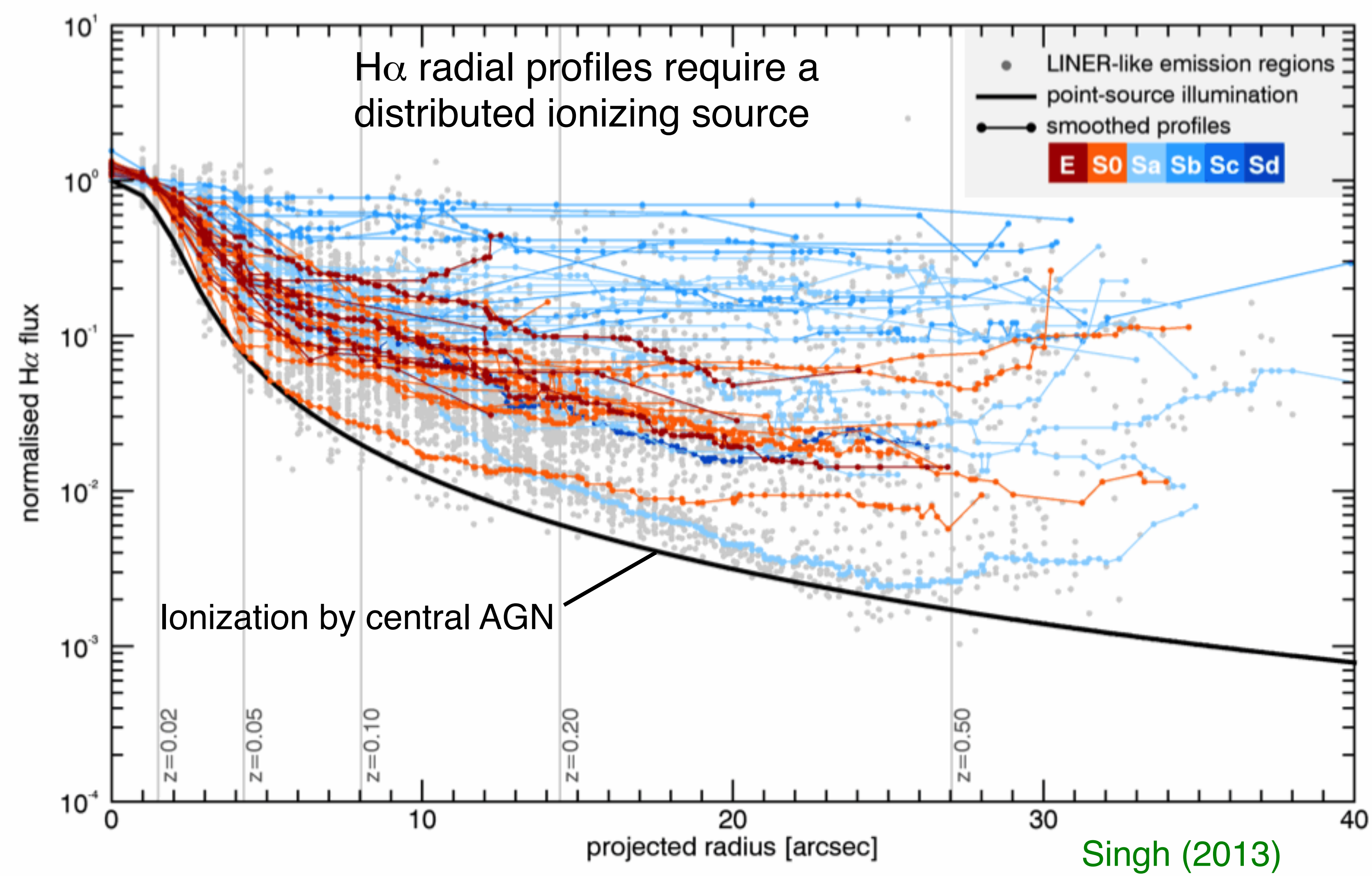
Most ionization in "LINERS" originates not from AGN but instead from hot, low-mass EHB and PAGB stars



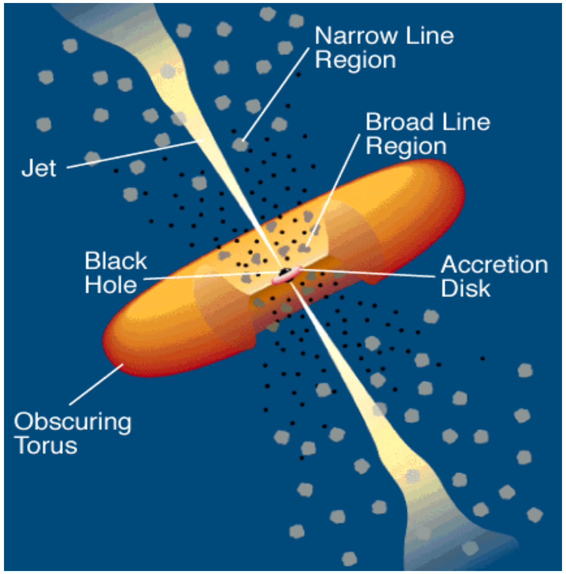
Singh (2013)

"LIERS"

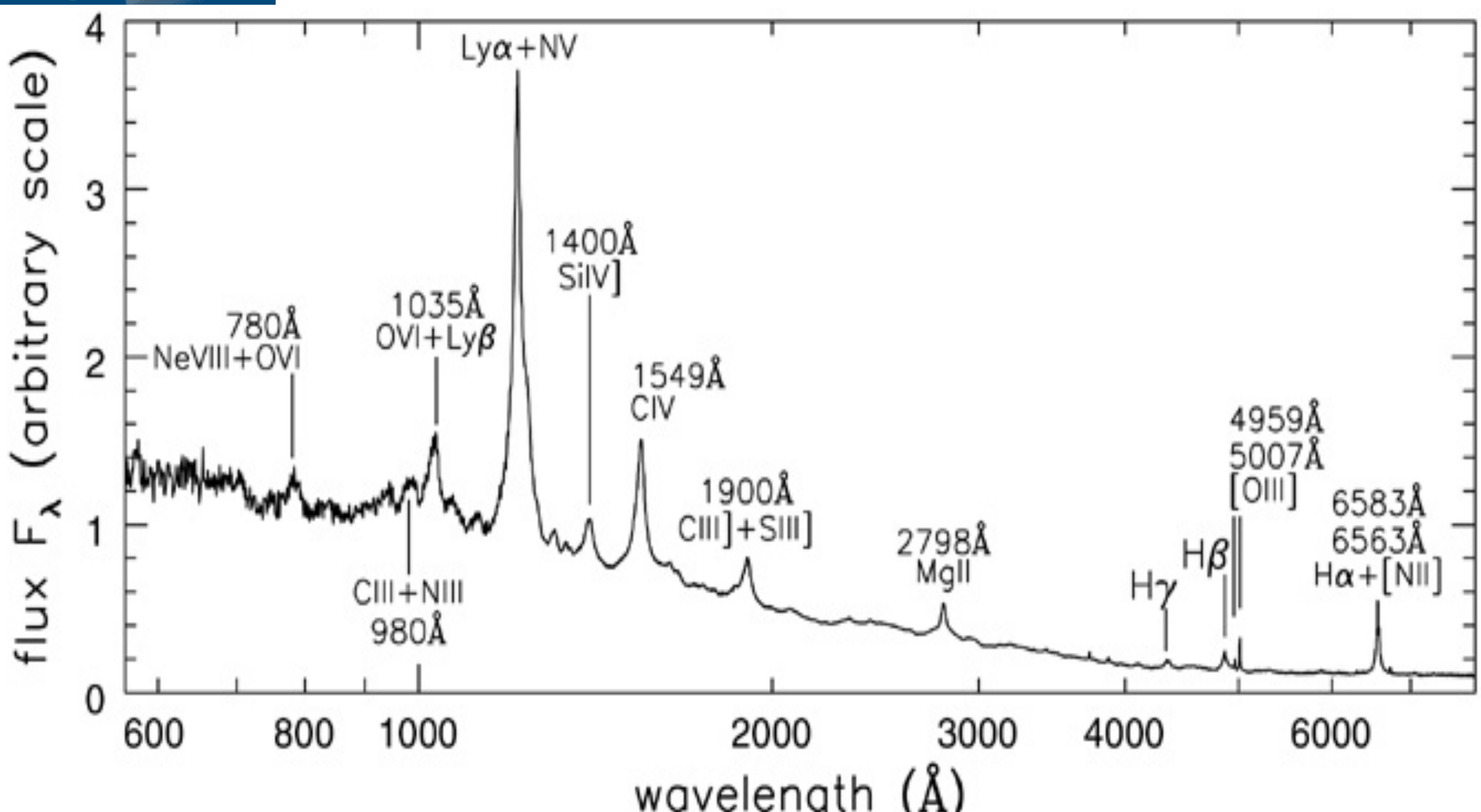
Most ionization in "~~LINERS~~" originates not from AGN but instead from hot, low-mass EHB and PAGB stars



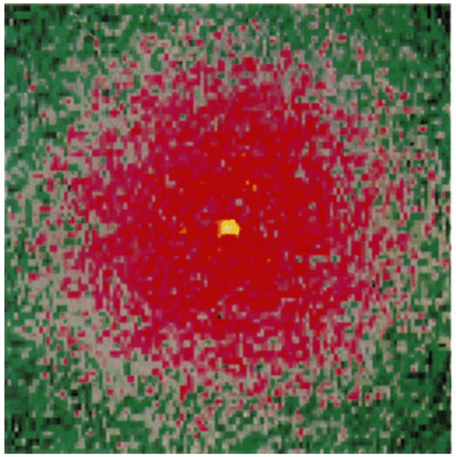
Singh (2013)



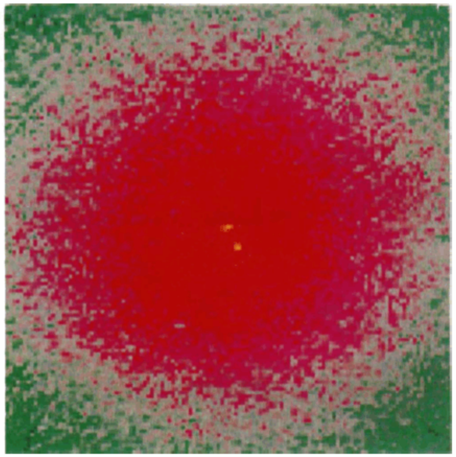
AGN: rich UV spectra are prime diagnostics of physical properties



UV Nuclear Flares: Tidal Disruption Events



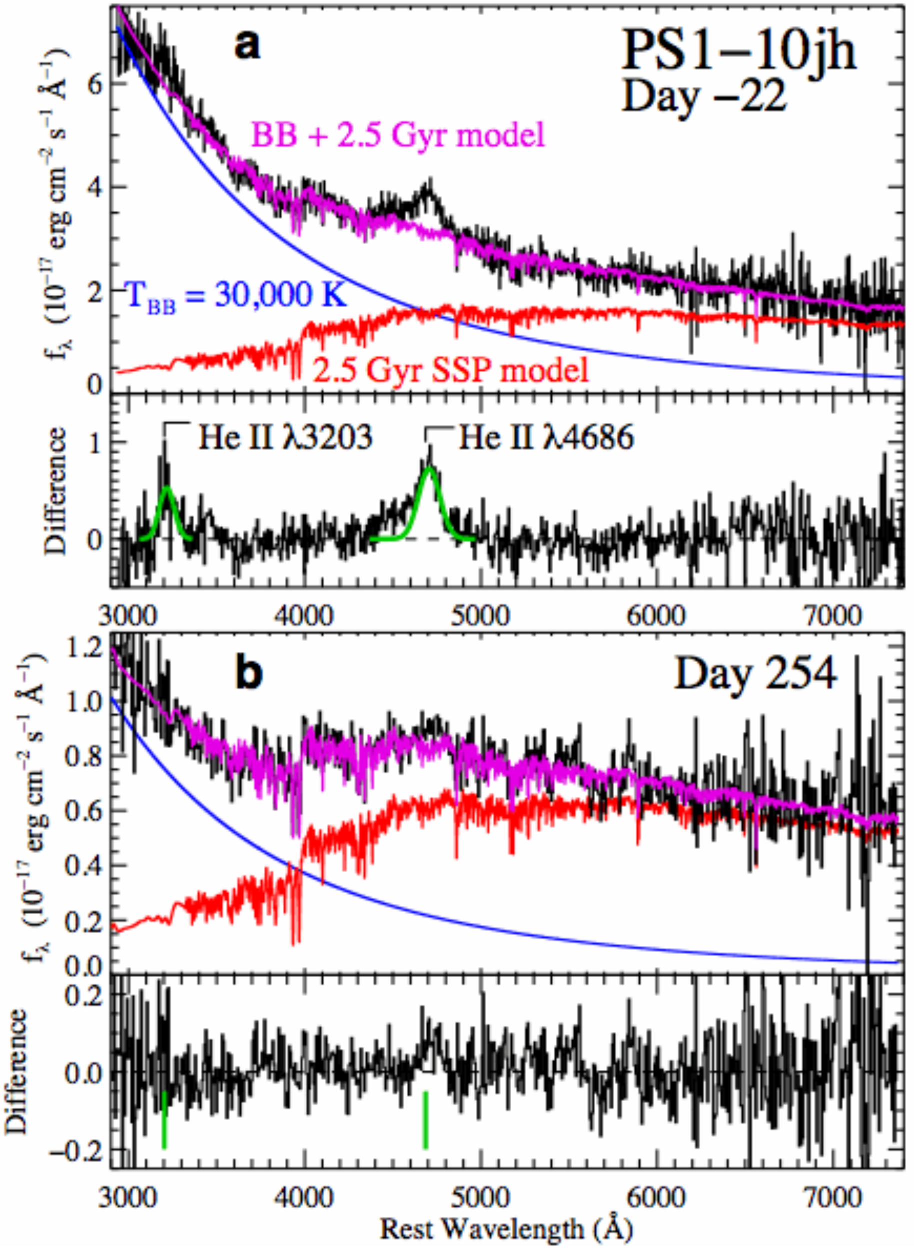
1993



1991

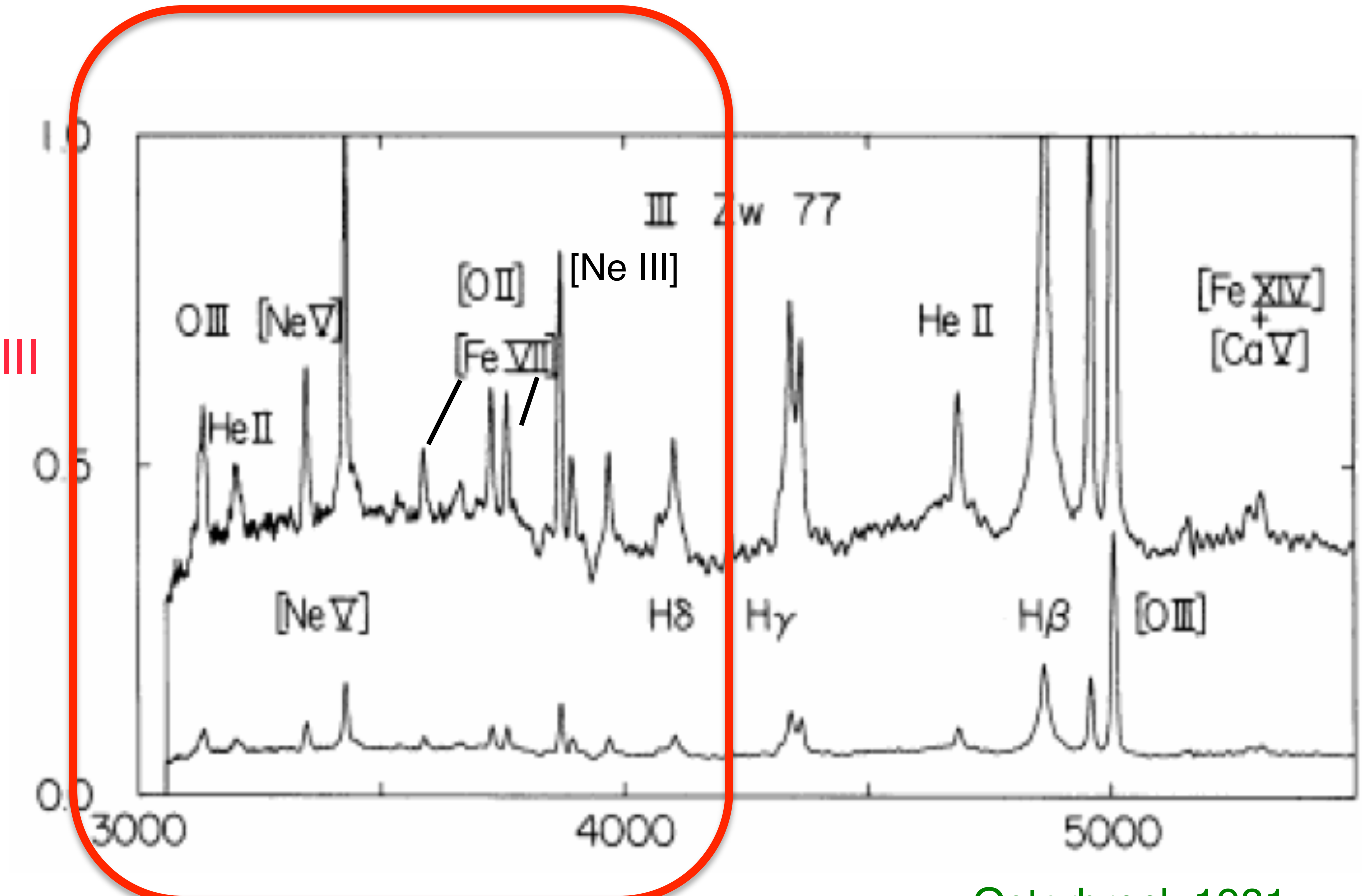
First detection: NGC 4552 (Renzini+ 1995)

UV flare from tidal disruption of
a He-rich stellar core (Gezari+ 2012)



Potential UV flare diagnostic features in CUBES UV

High excitation (Ne III, Ne V, Fe VII, He II); Bowen fluorescence OIII



Osterbrock 1981

Prognostication?

Shifting Scientific Tides

- Leading non-UV areas: cosmology, early universe, molecular clouds, obscured star formation (ALMA, JWST).....IR interest may begin to saturate.
- Transients (LSST)
- Exoplanets and planetary formation
- CGM and related low-SB problems
- Stellar astronomy, including binaries

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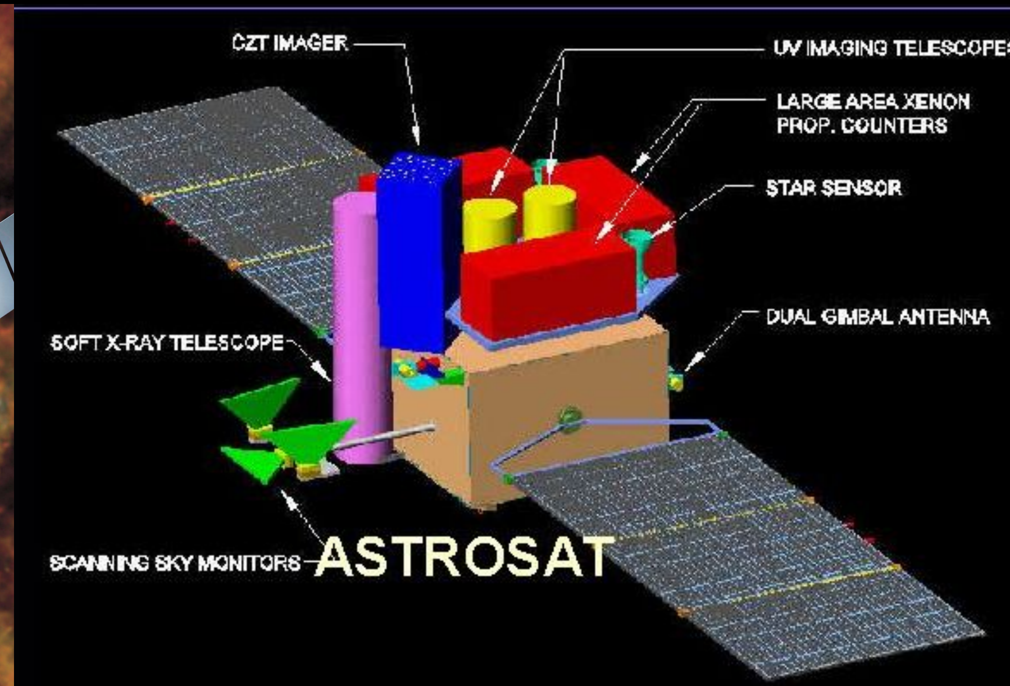
- Exoplanets and planetary formation
- CGM and related low-SB problems
- Stellar astronomy, including binaries (despite Princeton)

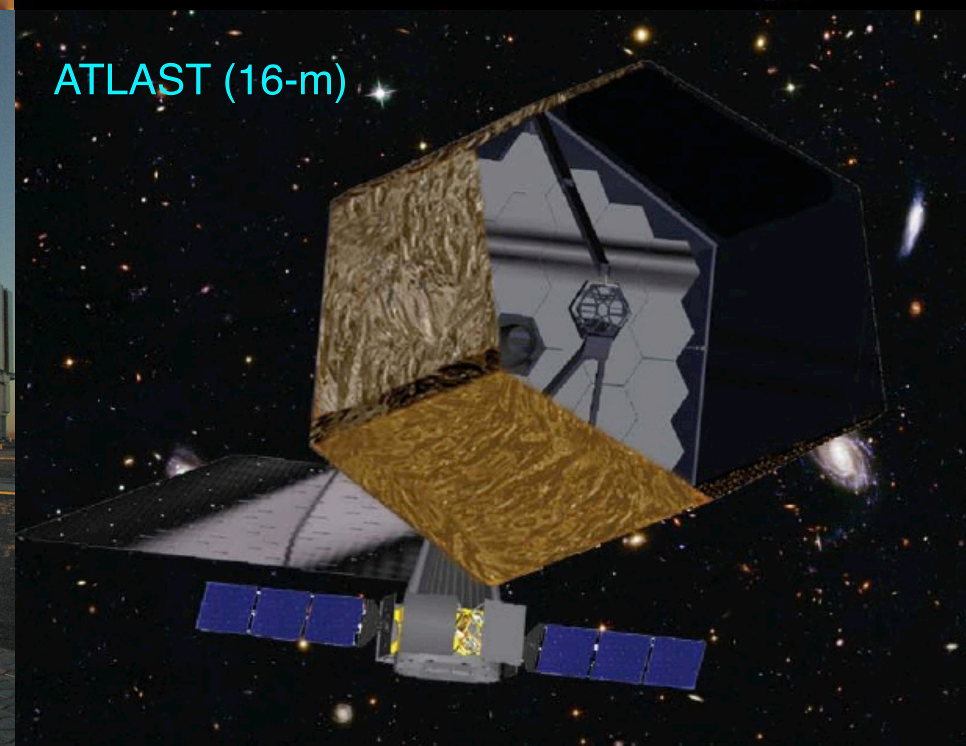
Technical Priorities
(not new!)

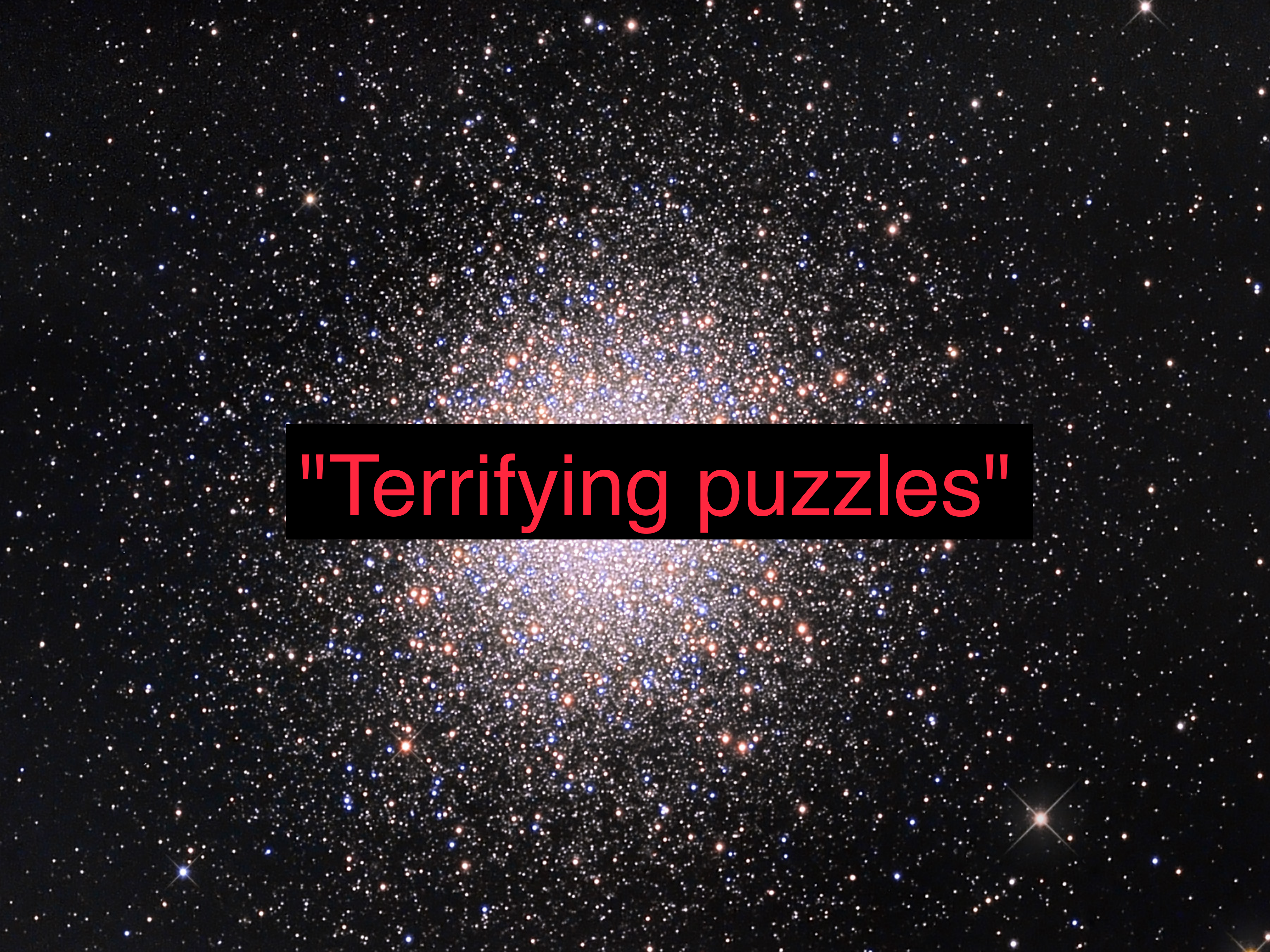
- Detector QE to > 80% 90-320 nm
- Successful flight tests/astronomy from candidate detectors.
- Single mirror coating with high performance 90-320 nm


WSO-UV


CZT IMAGER
UV IMAGING TELESCOPE
LARGE AREA XENON
PROP. COUNTERS
STAR SENSOR
DUAL GIMBAL ANTENNA
SOFT X-RAY TELESCOPE
SCANNING SKY MONITORS
ASTROSAT


CUBES


ATLAST (16-m)


"Terrifying puzzles"

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