Lecture 1: Introduction

view of the Earth behind Saturn from Cassini on July 19, 2013 (upper left), the Earth/Moon from MESSENGER at Mercury (lower left), and Hubble Space Telescope observations of binary neutron star merger GW 170817 from http://antwrp.gsfc.nasa.gov/apod/ap100901.html and https://www.nasa.gov/press-release/nasa-missions-catch-first-light-from-a-gravitational-wave-event

Rutgers Physics 346: Observational Astrophysics   January 19, 2021

Who am I?

Prof. Eric Gawiser

What do I do?

My research group and I study distant galaxies to probe the nature of the Universe and to understand how typical galaxies like the Milky Way formed

Where can you (not) find me?

(Serin Physics Building room W303)
Canvas Mail to gawiser@rutgers.edu
Virtual Office Hours: TBD by Zoom Poll

What should I do in lecture?

Lectures are recorded and will be posted on Canvas.

Please stay muted with video off.
Ask questions any time in the Zoom chat.
Raise Hand to ask an audio question at next stoppage.

Watch for Polls and Breakout Rooms.

Feel free to stay on after lecture until 5:00pm
for further questions. Audio & video are encouraged
for these “Office” “Hours"

Any questions on using Zoom?

Why take this course?

It fulfills a requirement
for the Astrophysics major and minor

But why study observational astrophysics?

Lots of reasons!
Most of all, because there is a beautiful, amazing
Universe out there for us to explore!

You aren't just students, you are explorers!
Caveat: exploration can be frustrating and challenging

Course information

Website at
http://www.physics.rutgers.edu/ugrad/346

Canvas site: canvas.rutgers.edu
https://rutgers.instructure.com/courses/106732
includes a Chat and Discussions: please use them!

Let's look at the course website & syllabus

Any questions on the course website?

Exams

There are no exams for 346.

Summary

What is your job?

- Zoom to class
- be respectful
- do the work
- ask/answer questions
- learn
- give feedback
- don't cheat
- have fun!

What is my job?

- Zoom to class
- be respectful
- grade the work
- answer/ask questions
- learn
- take your feedback into account
- have fun!

Any questions on course requirements?

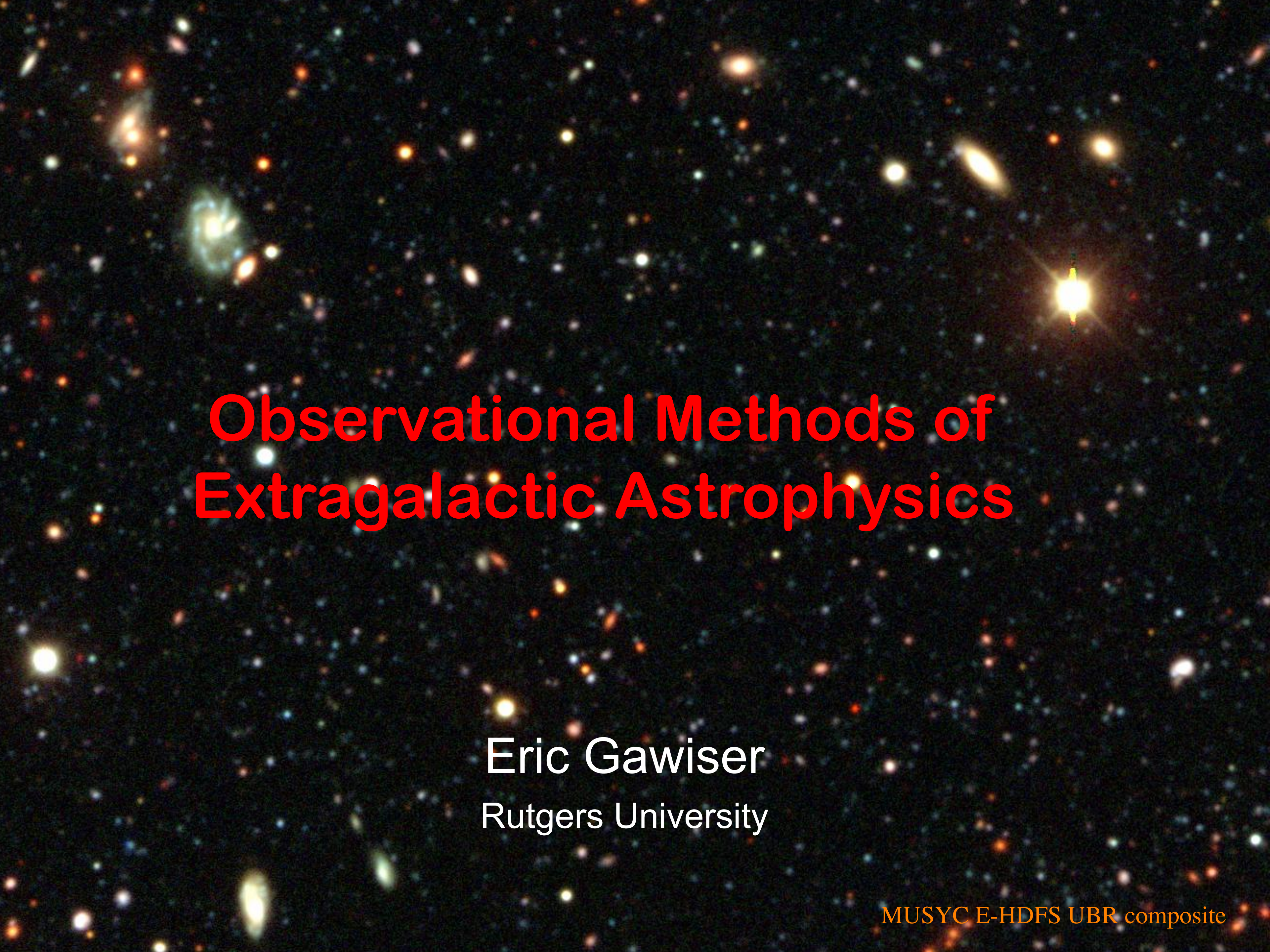
Homework for Thursday, Jan. 21

Do: Quiz #1 will appear on Canvas Assignments at 4:40pm, due at 9pm tonight.
Instructions for setting up access to the astrolab server will be posted on Canvas and announced by email; these must be completed before the beginning of Thursday's 3:20-4:40pm Project Meeting.

Observational Methods of Extragalactic Astrophysics

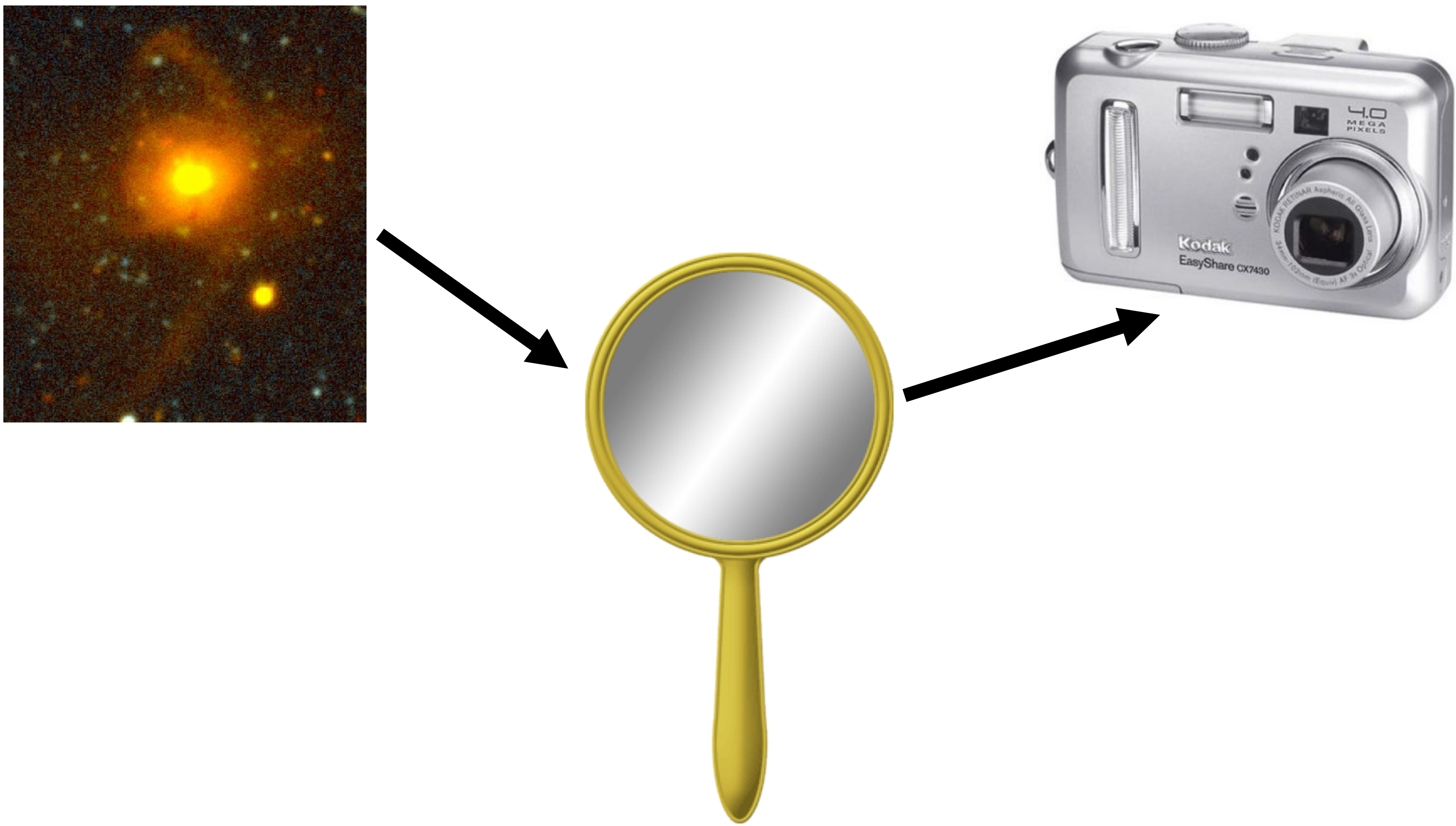
Eric Gawiser

Rutgers University

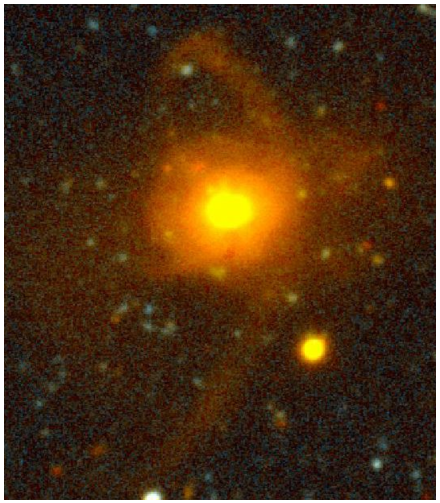


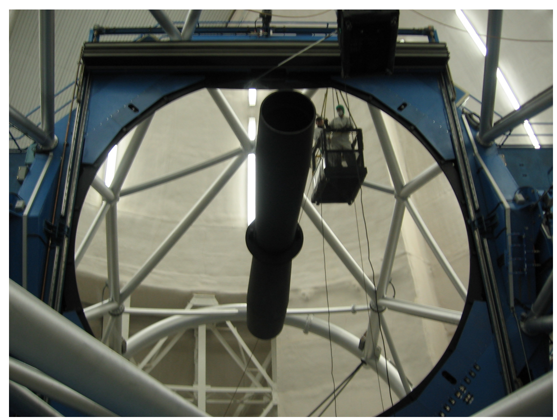
MUSYC E-HDFS UBR composite

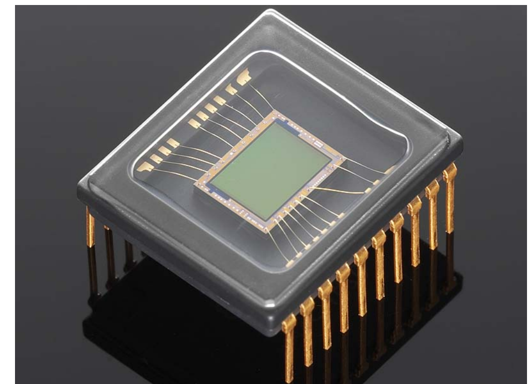
Observational astrophysics



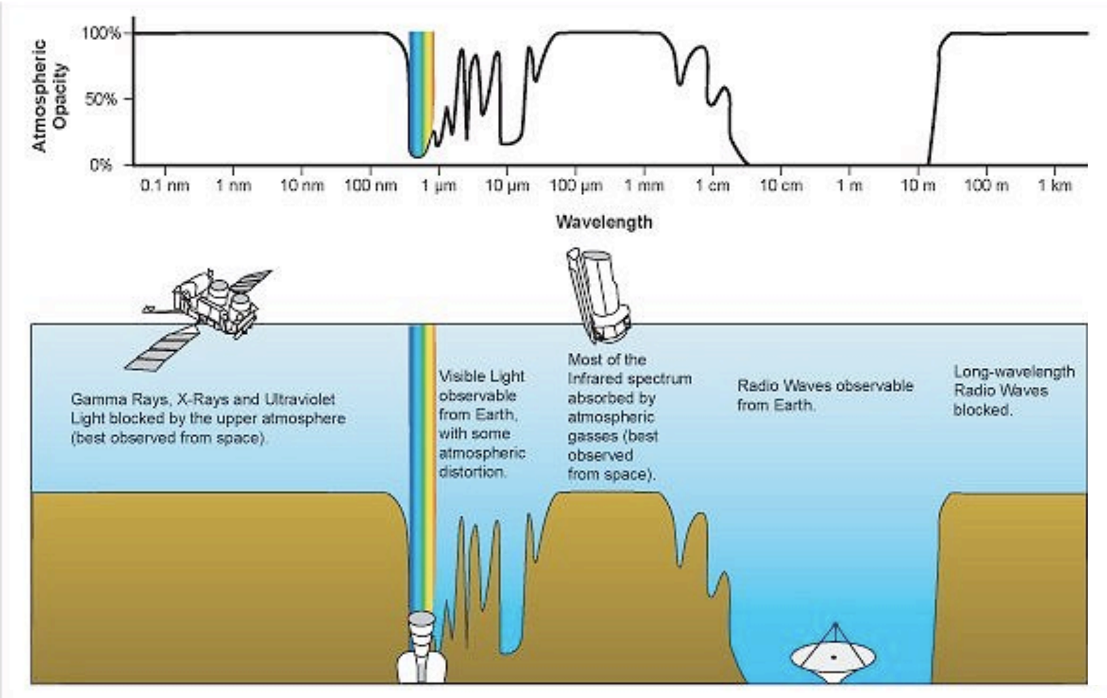
Observational astrophysics







Wavelengths available for astronomy



wavelengths	window
< 300 nm	absorbed by ozone
300-900 nm	UV-visible-near IR window
1-5 μm	IR window between H_2O and CO_2
8-20 μm	IR windows
1.3 cm-1.9 mm,	centimeter/millimeter windows
1.8-1.1 mm	millimeter window
0.8, 0.45, 0.35 mm	submillimeter windows
2 cm-10 m	radio window
> 10 m	ionospheric absorption

Must observe X-rays, UV, mid-infrared from space

Choose to observe optical, near-infrared, microwave from space for better resolution, less background

Current Astronomical Satellites

- Gamma-rays: SWIFT
- X-rays: Chandra, XMM
- UV: GALEX
- UV/Optical/NIR: HST
- Mid-IR/Far-IR: Spitzer, Akari, Herschel
- Microwave: WMAP, Planck

The World's Largest Optical/NIR Telescopes

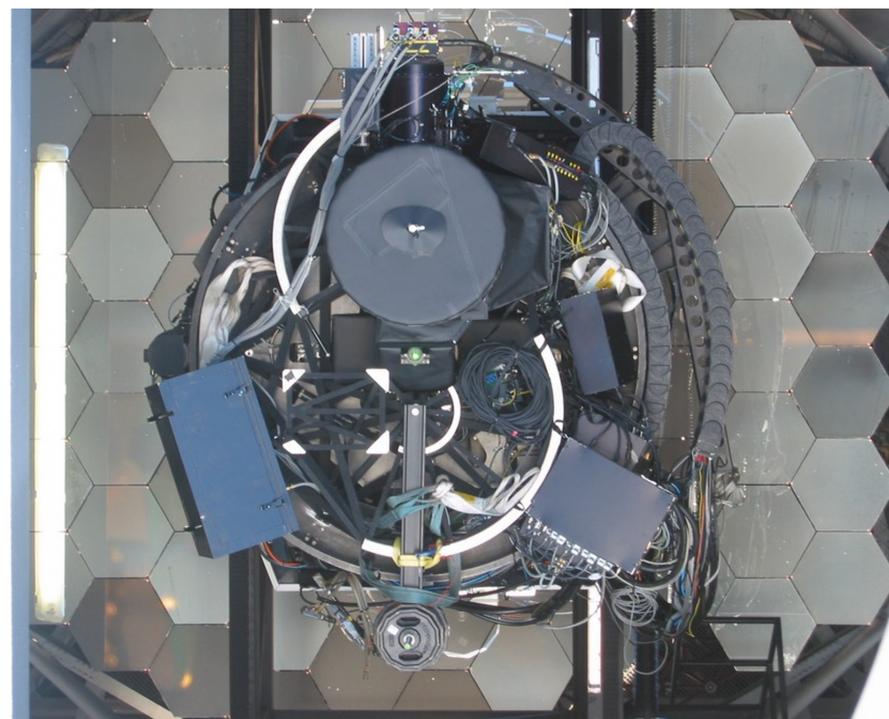
- 12m: Large Binocular Telescope
- 10m: South African Large Telescope (SALT), Keck (x2)
- 8m: Very Large Telescope (x4), Gemini (x2), Subaru, Hobby Eberly Telescope (HET)
- 6.5m: Magellan (x2),
  Multiple Mirror Telescope (MMT)
- 4m: many, including Blanco at CTIO
  (Cerro Tololo Interamerican Observatory)

South African Large Telescope (SALT, 10m)

KwaZulu Natal, Rutgers have access

Instruments up top are SALTICAM, Robert Stobie Spectrograph (RSS)

SCS will use for spectroscopic follow-up of clusters discovered in SZ with ACT

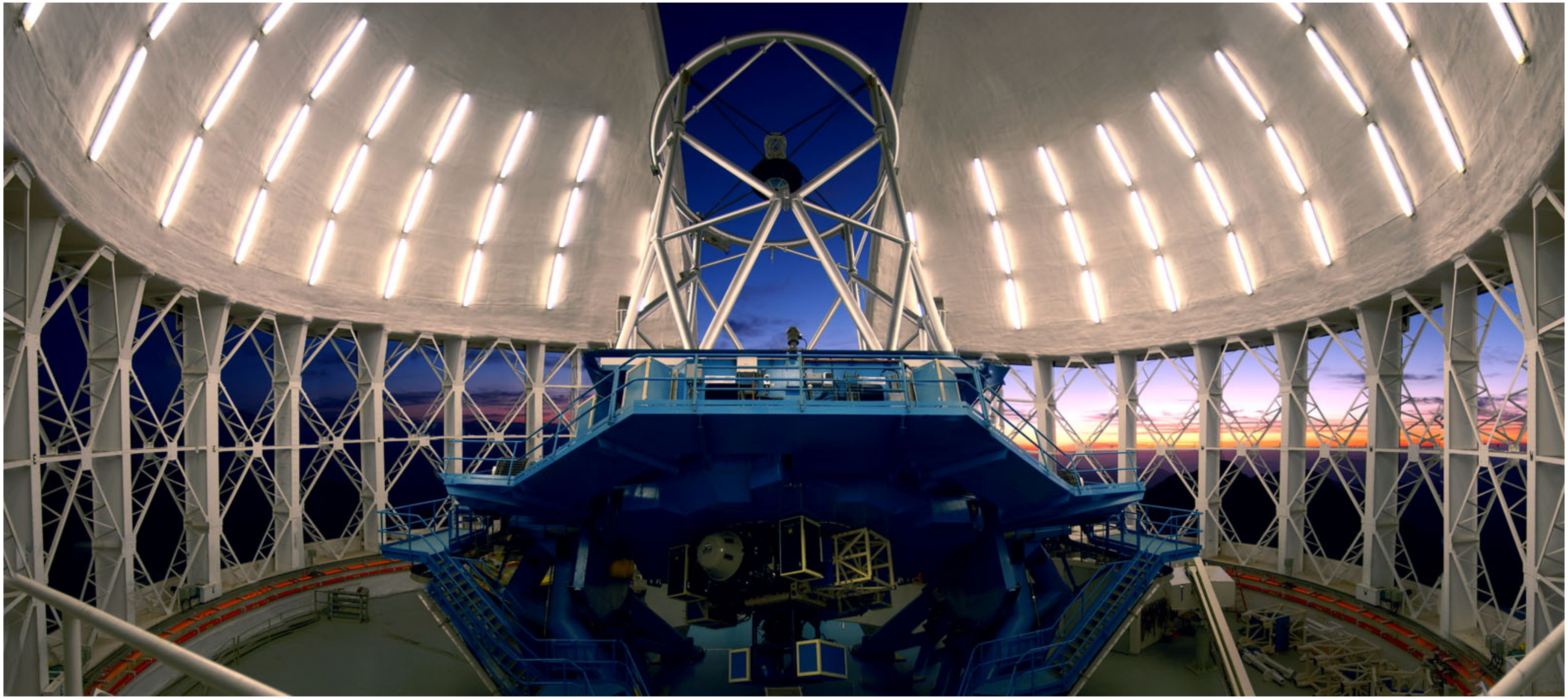


Telescopes on Mauna Kea

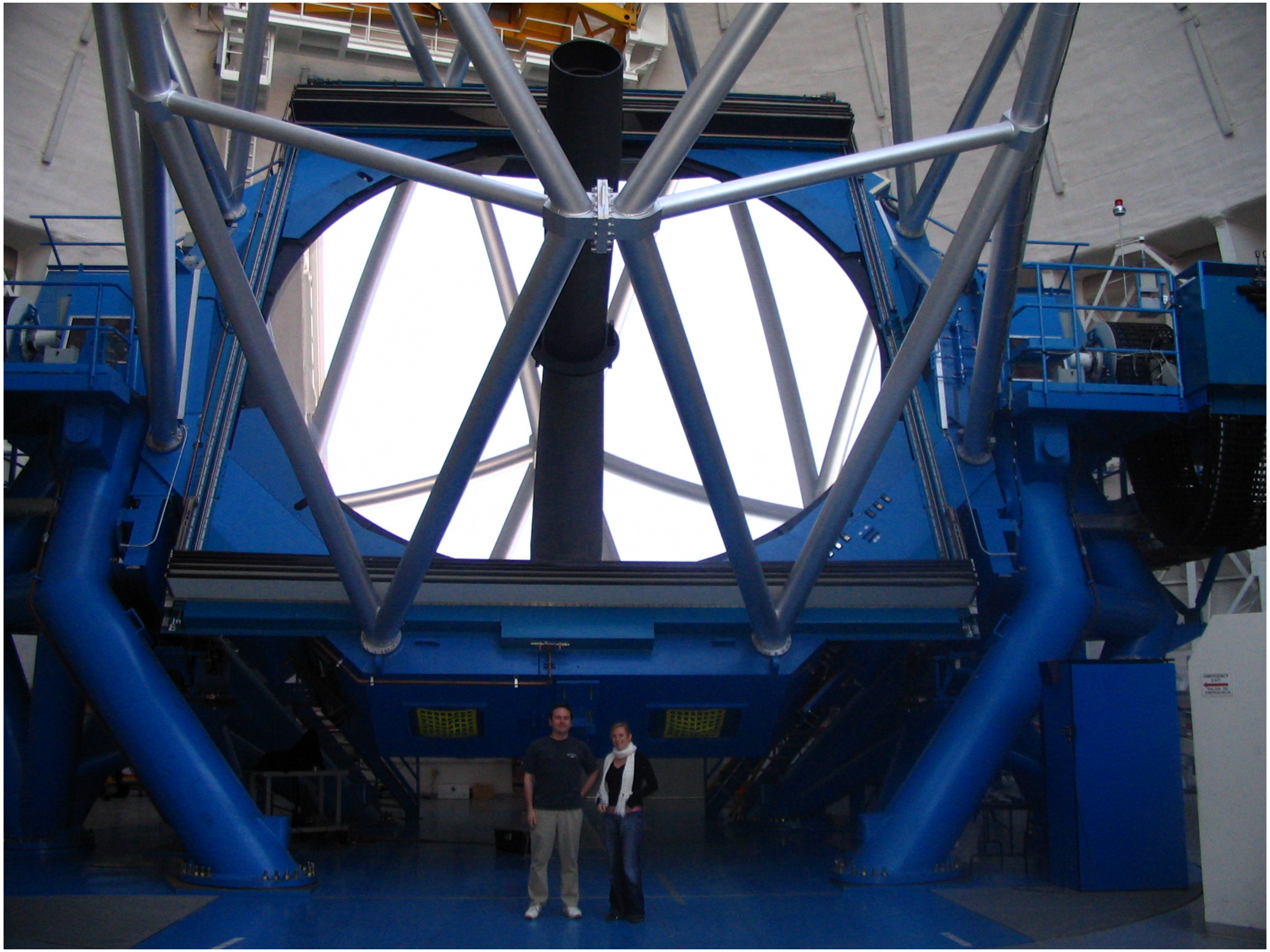
Atacama Desert & Andes Mountains in Chile

8-meter Gemini telescope

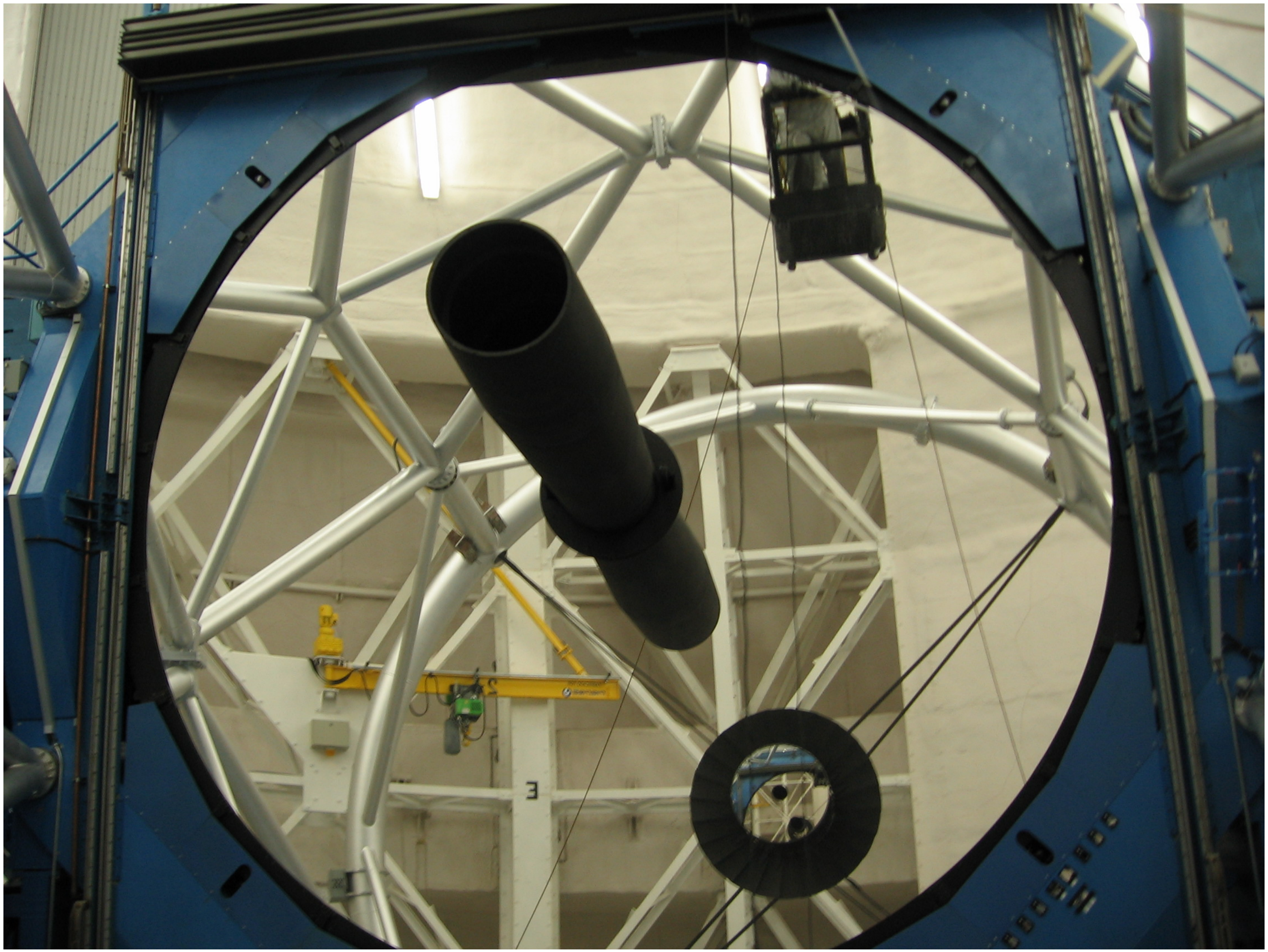
Gemini telescope at sunset



8-meter Gemini mirror!



8-meter Gemini primary mirror with reflected secondary

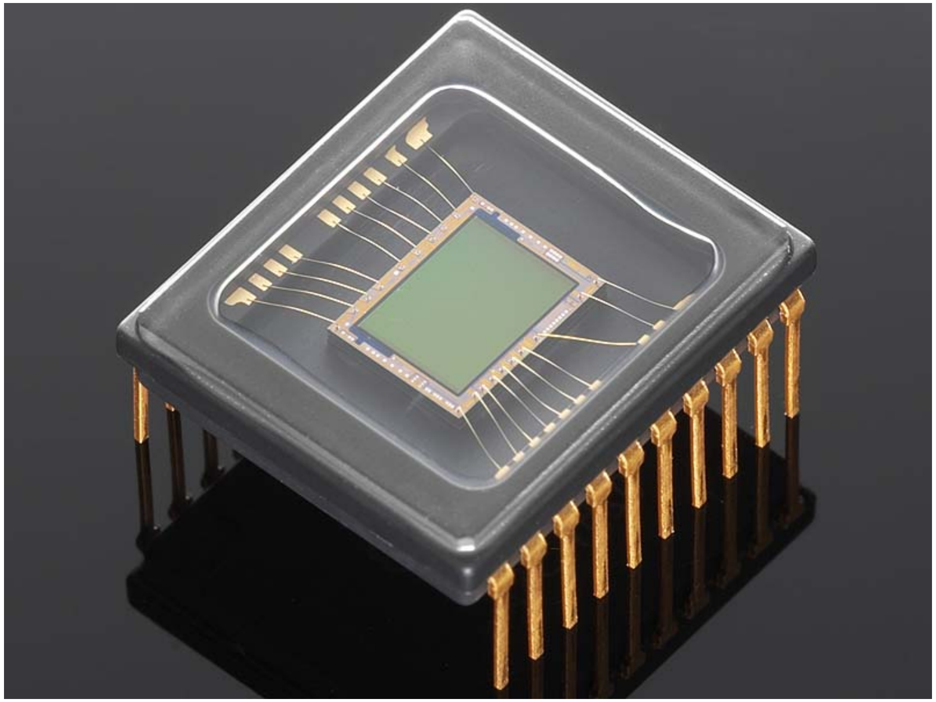


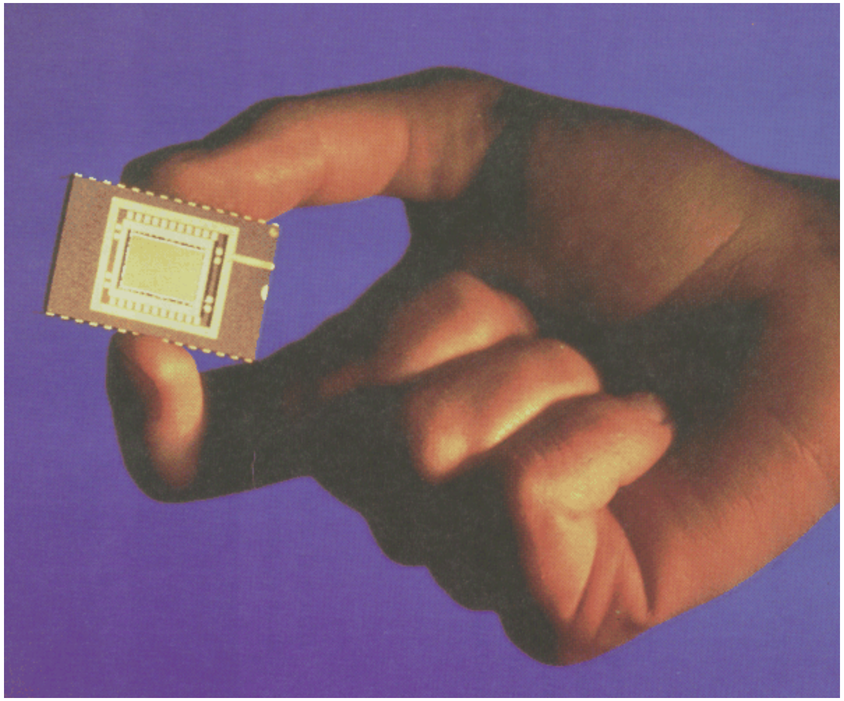
Cleaning the primary mirror with…

Gemini secondary

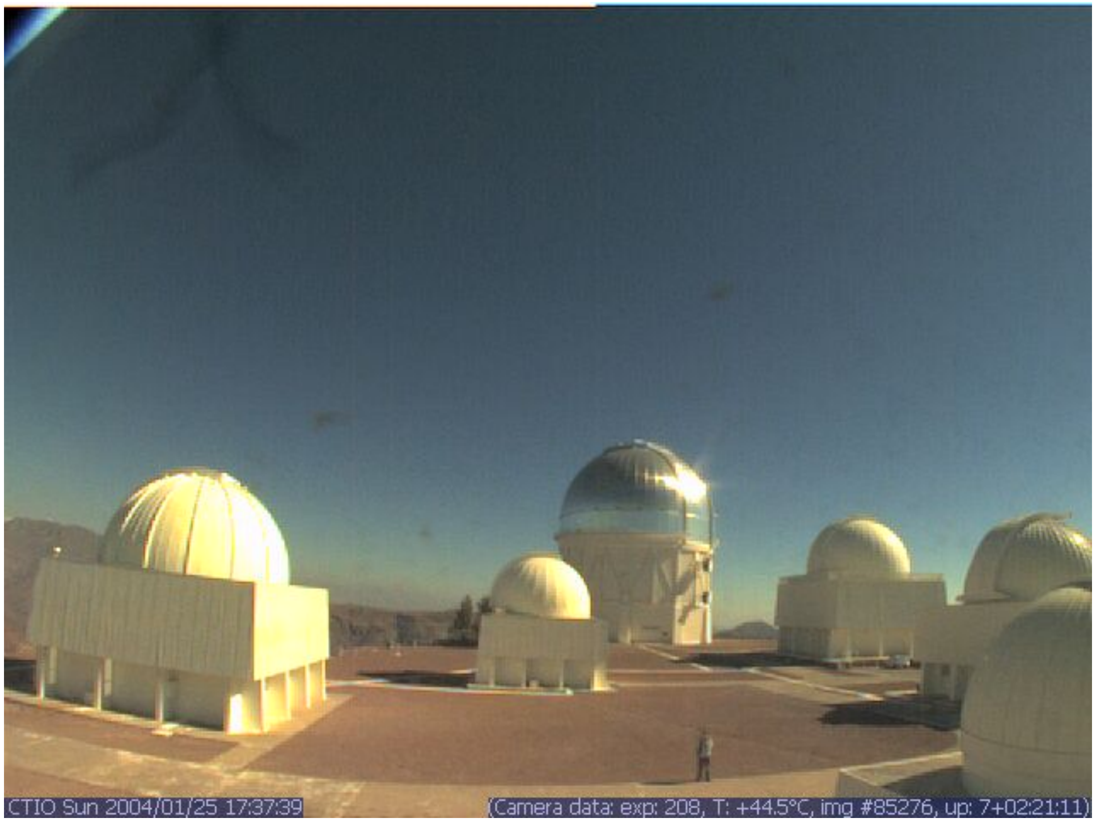
Gemini instruments

Charge Coupled Device = CCD





Telescopes at CTIO



Data Equation: Imaging

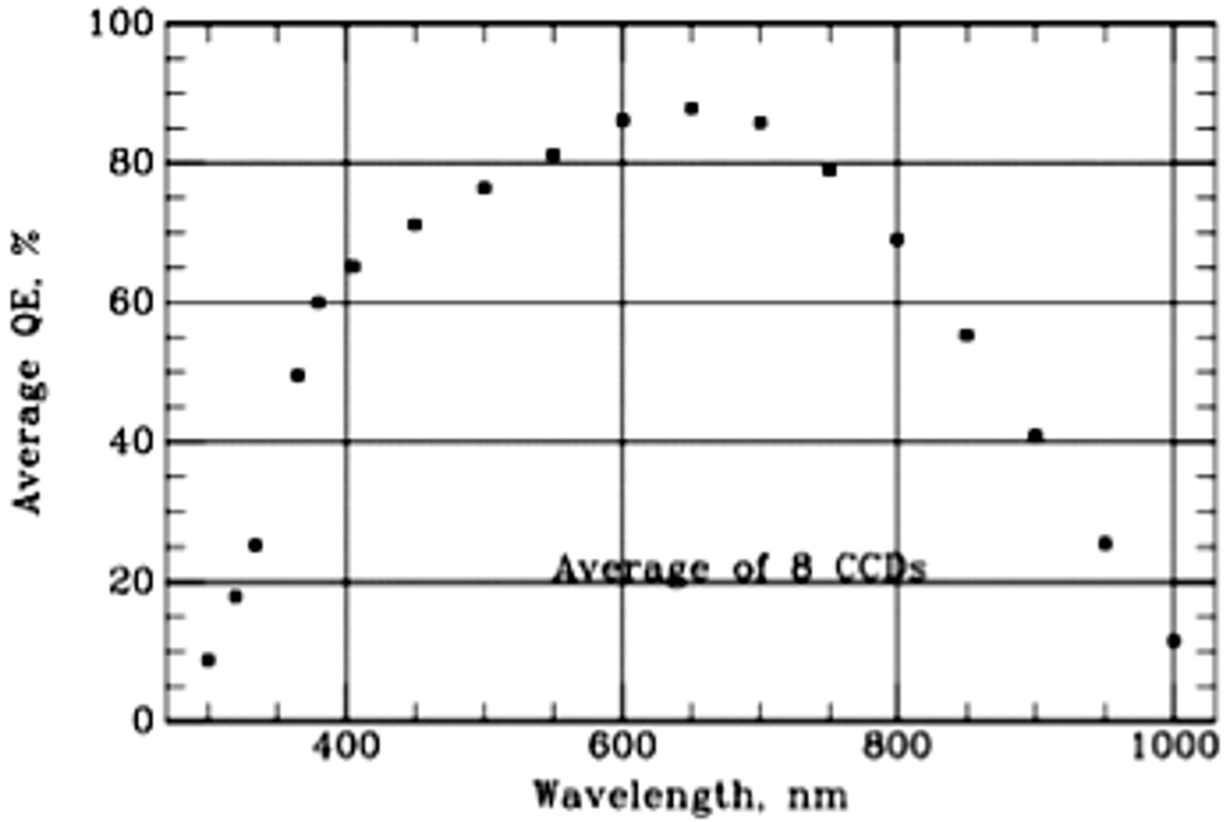
Start with sources (j) with flux densities $f_\lambda(\lambda,t)$ [ergs/cm^2/s/Å],
multiply by atmospheric transmission,
convolve with PSF,
add background, and
multiply by telescope/detector/filter transmission:

$$F_\lambda(\mathbf{r},\lambda,t) = \left[\sum_j f_{\lambda,j}(\lambda,t) A_{tel} T_{atm}(\lambda,t,X) PSF(\mathbf{r}(\mathbf{\Omega}_j(t)),\mathbf{r},\lambda,t) + B(\mathbf{r},\lambda,t)\right] T_{tel}(\lambda,\mathbf{r}) T_{qe}(\lambda,\mathbf{r}) T_{filt}(\lambda,\mathbf{r})$$

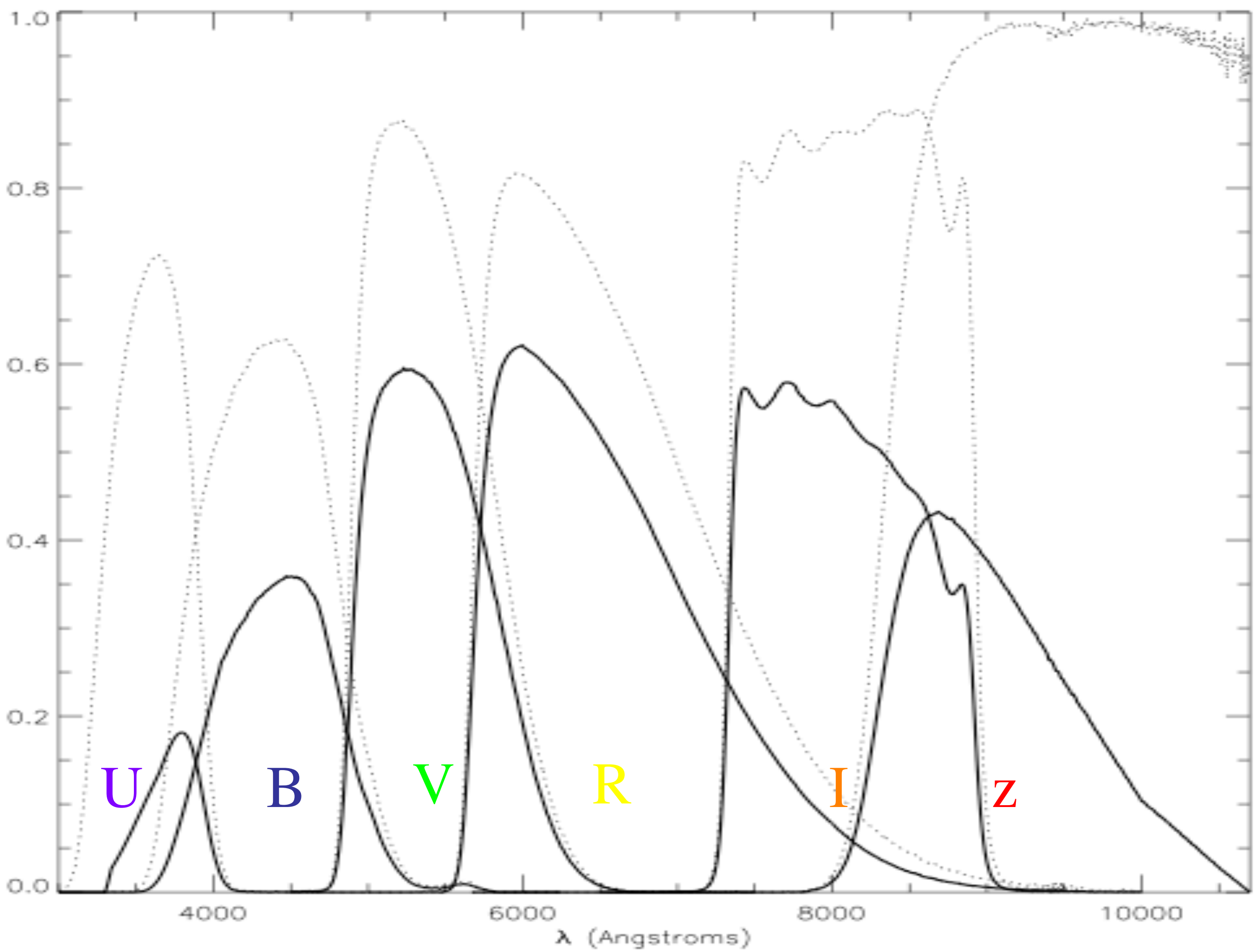
Yields F_λ[ergs/s/Å] received at location **r** on focal plane.
Number of photoelectrons in image i at pixel (x,y) results from dividing by energy per photon,
integrating over wavelength, time, and pixel area,
adding bias, dark current, fringing, cosmic rays, and bad pixels

$$N_i(x,y) = \int_\lambda \int_t \int_{pixel} \frac{F_\lambda(\mathbf{r},\lambda,t)}{(hc/\lambda)} d\mathbf{r}\, dt\, d\lambda + bias(x,y) + Dark * t_{exp} + Fr(x,y) t_{exp} T_{qe}(x,y) + CR(x,y,i) + BP(x,y)$$

Typical Optical CCD Quantum Efficiency



Optical Filters (UBVRIz)



Filter only (dotted), with CCD QE and atmospheric transmission (solid)

Data Reduction Pipeline: Imaging

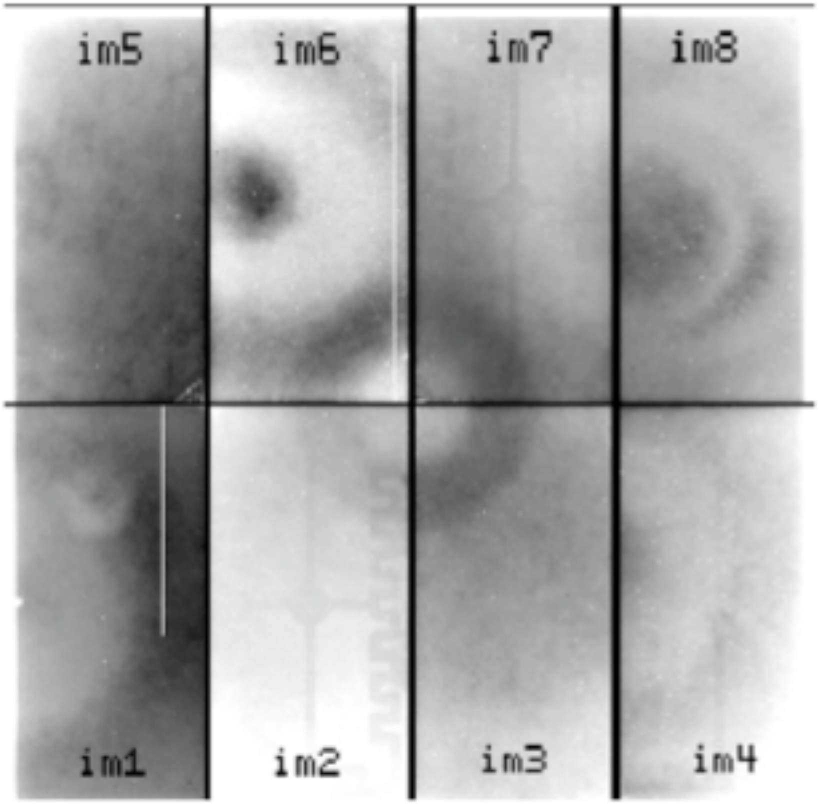
$$N_i(x,y) = \int_\lambda \int_t \int_{pixel} \frac{F_\lambda(\mathbf{r},\lambda,t)}{(hc/\lambda)} d\mathbf{r}\, dt\, d\lambda + bias(x,y) + Dark * t_{exp} + Fr(x,y) t_{exp} T_{qe}(x,y) + CR(x,y,i) + BP(x,y)$$

- Mask and replace bad pixels and cosmic rays
- Subtract bias using overscan/zeros
- Subtract dark current
- Flat-field by dividing by domelamp or twilight "flat" image
- Subtract fringes using "fringe template"
- Assume $F_\lambda(\mathbf{r}, \lambda, t)$ constant over pixel, λ, t $\rightarrow F_\lambda(\mathbf{r}, \lambda_{eff}, t_i)$

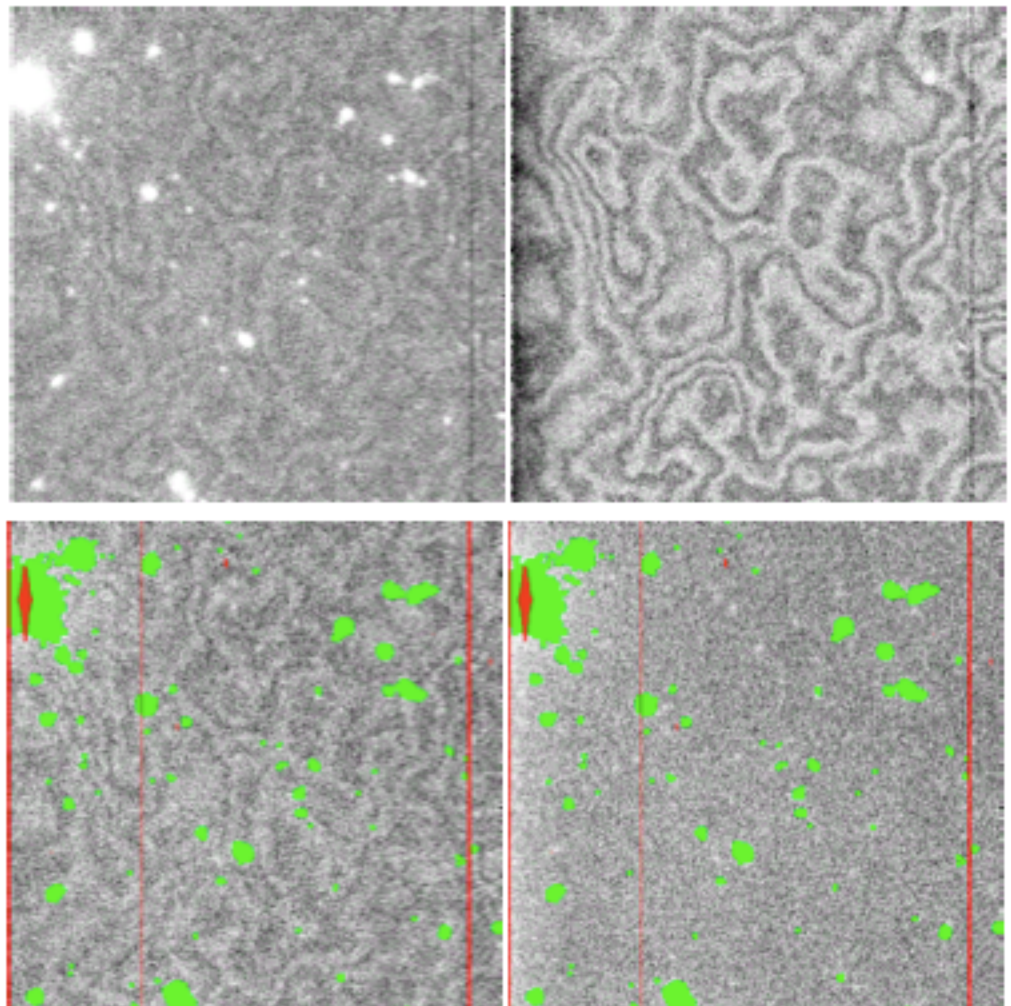
$$F_\lambda(\mathbf{r},\lambda,t) = \left[\sum_j f_{\lambda,j}(\lambda,t) A_{tel} T_{atm}(\lambda,t,X) PSF(\mathbf{r}(\mathbf{\Omega}_j(t)),\mathbf{r},\lambda,t) + B(\mathbf{r},\lambda,t)\right] T_{tel}(\lambda,\mathbf{r}) T_{qe}(\lambda,\mathbf{r}) T_{filt}(\lambda,\mathbf{r})$$

- Create and divide by "superskyflat" to get better estimate of $T_{qe}(\mathbf{r})$
- Project onto tangent plane $\mathbf{r} \rightarrow \mathbf{\Omega}(\mathbf{r})$
- Subtract background
- Combine multiple exposures, ignoring masked pixels
- Photometric calibration yields just the PSF-convolved sources

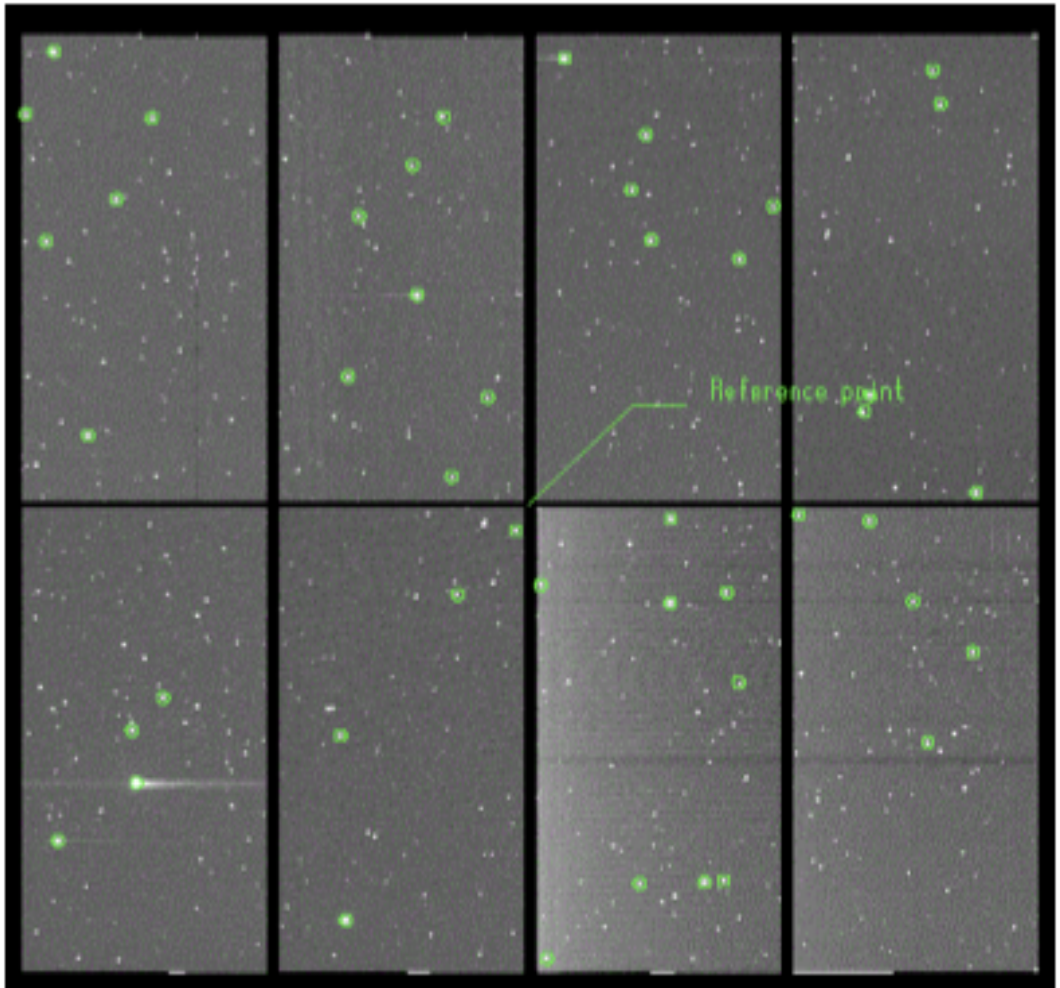
Flat field image

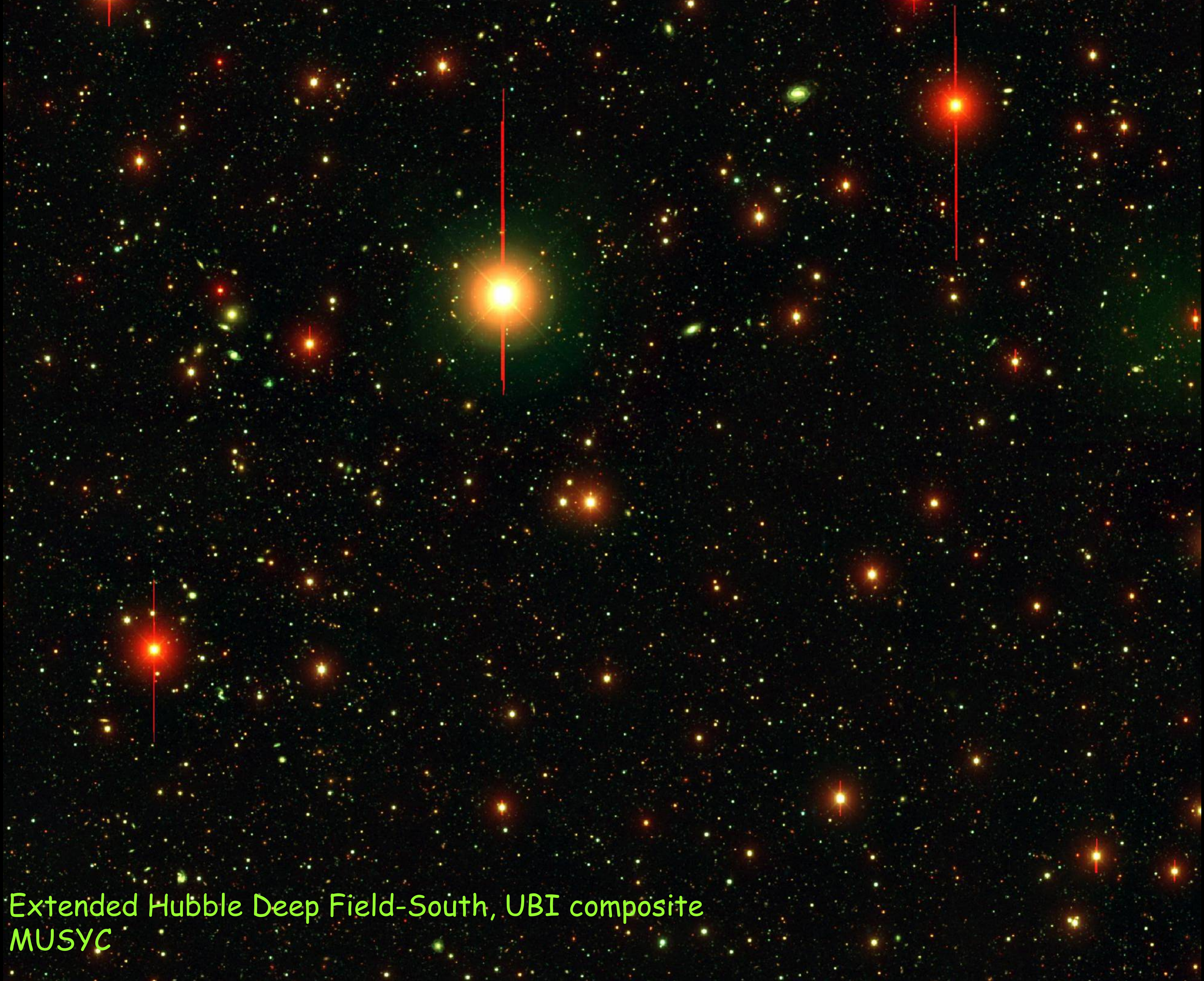


Fringe mask construction & subtraction



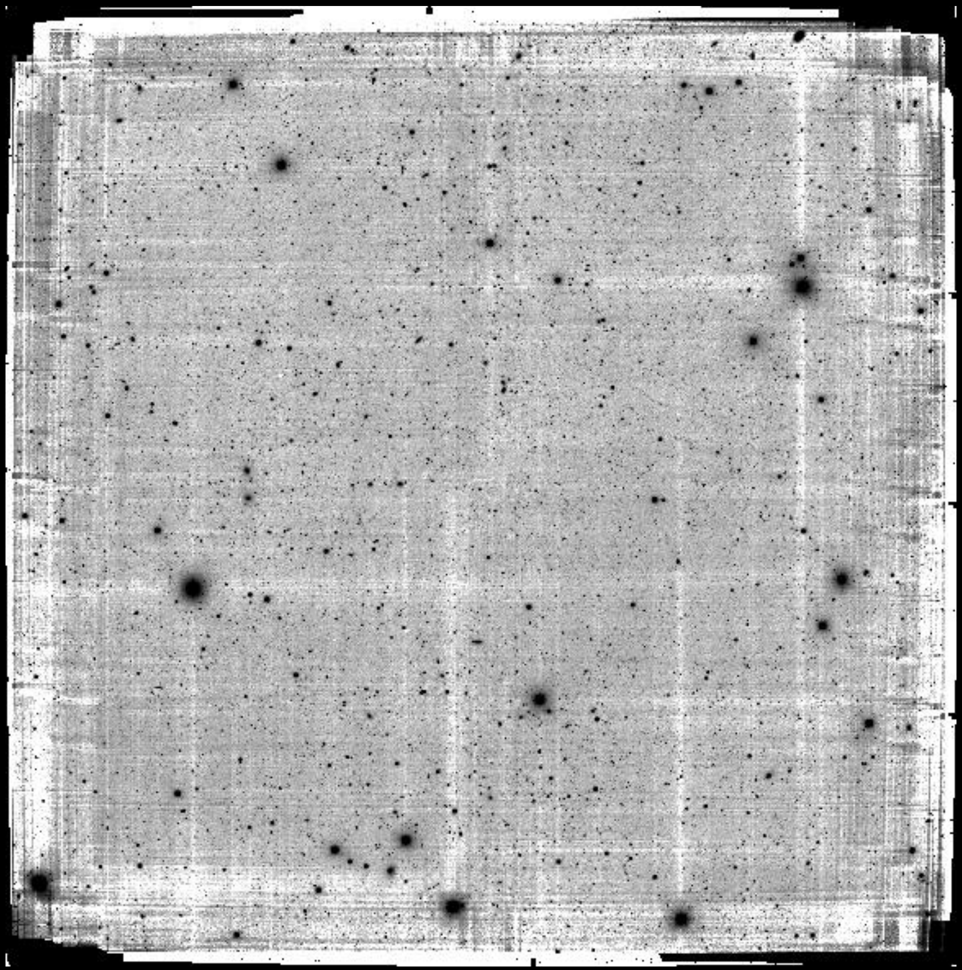
Astrometric calibration



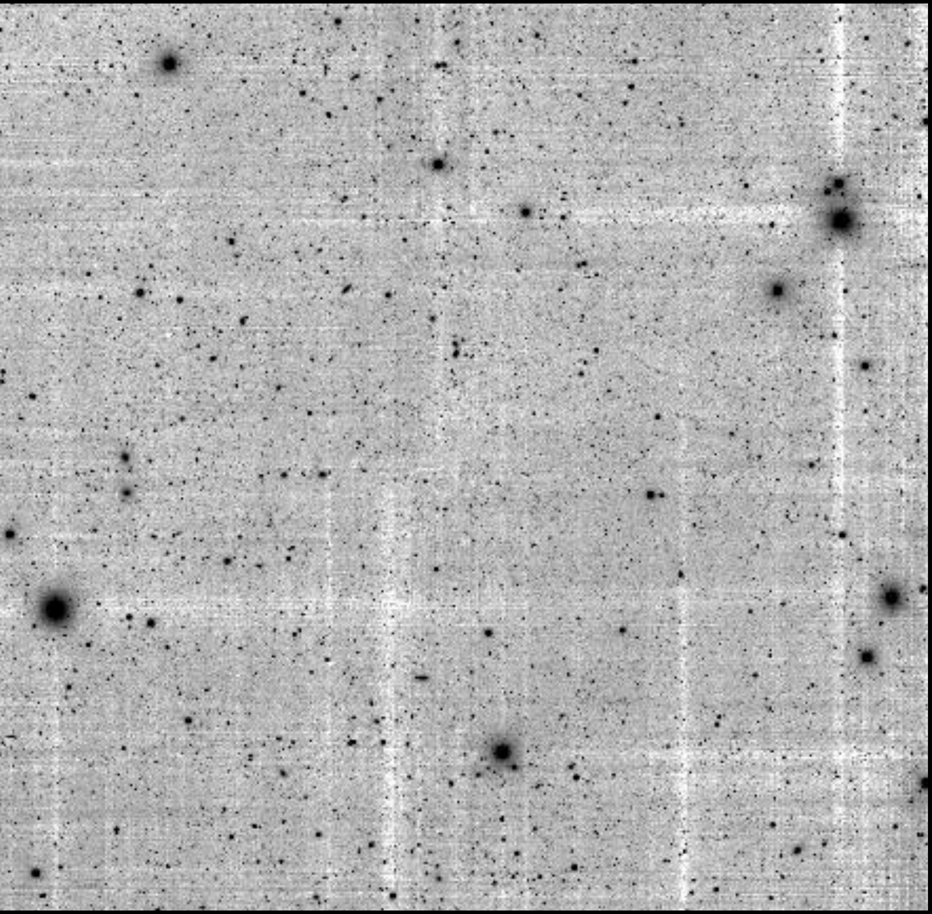


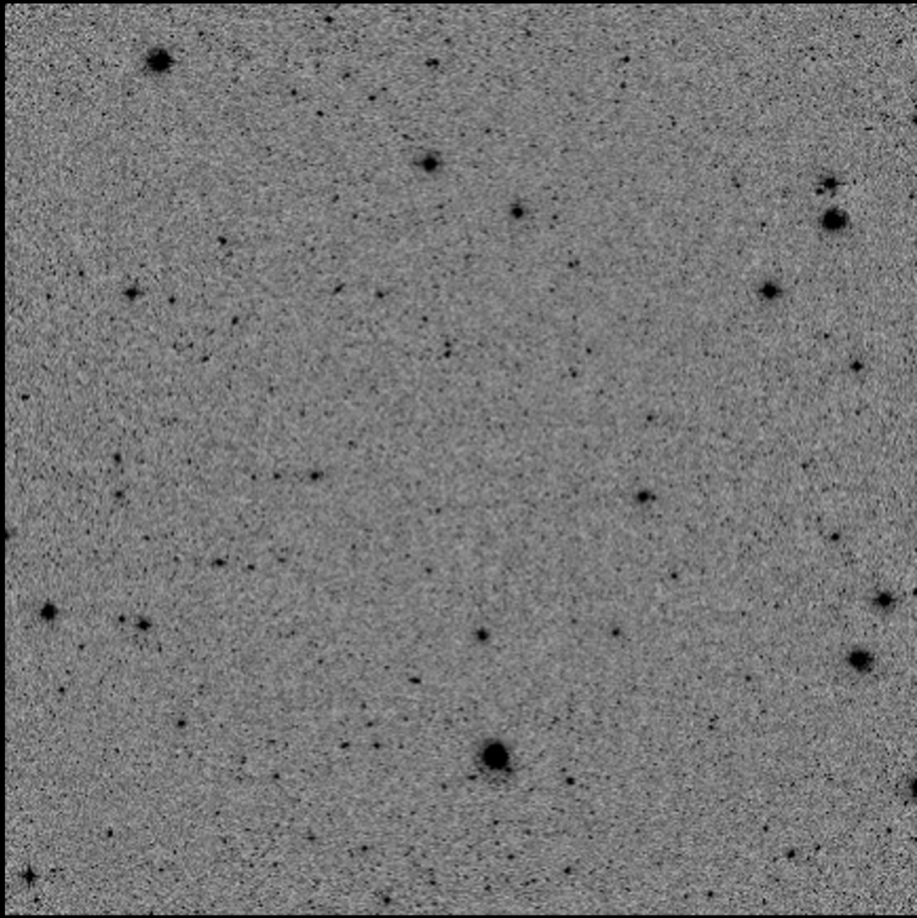
Extended Hubble Deep Field-South, UBI composite
MUSYC

Extended Hubble Deep Field-South, UBI composite
MUSYC



GOODS:
CDF-S U-band
CTIO 4m





GOODS:
CDF-S U-band
CTIO 4m

MUSYC U-band image