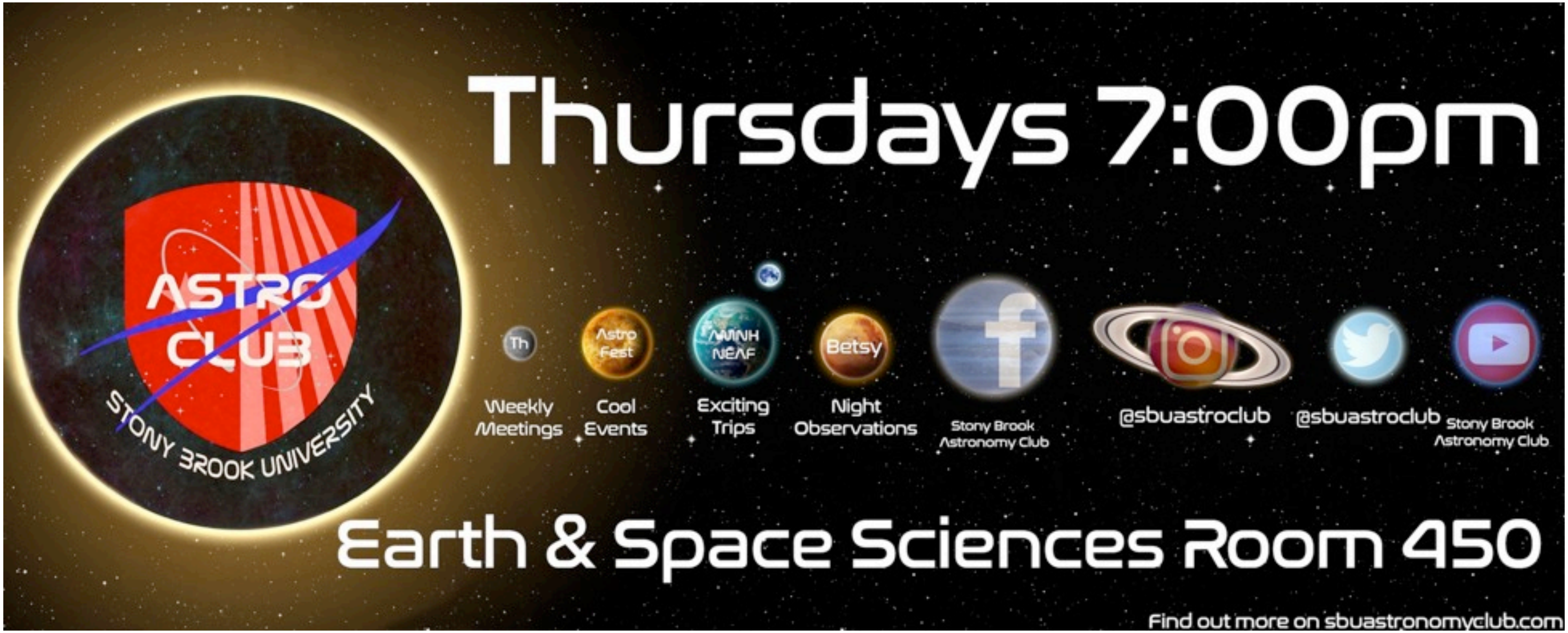
PHY 517 / AST 443: Observational Techniques in Astronomy

Lecture 3: Telescopes / CCDs / Photometry / Exoplanet Lab

Astronomy Club



first meeting this week

http://sbuastronomyclub.com/

Open Nights

monthly public lectures by SB Astronomy group, followed by observing

http://www.astro.sunysb.edu/openight/

CURRENT SCHEDULE

Academic Year 2016-17

FALL 2016

Sept 2, 2016	Prof. James Lattimer	Where Do Elements Heavier Than Iron Come From?
Sept 30, 2016	Prof. Doug Swesty	Ripples in Space-time: Detecting Gravitational Waves
Oct 28, 2016	Prof. Alan Calder	–
Dec 2, 2016	Dr. Simone Dall'Osso	–

SPRING 2017

Jan 27, 2017	Prof. Marilena Loverde	–
Mar 3, 2017	Prof. Fred Walter	–
Apr 7, 2017	Prof. Neelima Sehgal	–
May 5, 2017	Prof. Michael Zingale	Computing the Stars

SB Astronomy Seminar

presentation on current research by invited visitors

http://astro.sunysb.edu/astro/seminars_share.html

SBU ASTRONOMY

DATE / TIME / LOCATION

Unless otherwise noted, seminars are held on Wednesday's at 1:30pm in ESS 450. Cookies and tea will follow the talk.

JOINT SBU / BNL COSMOLOGY SEMINARS

The Joint SBU / BNL Cosmology Seminar Series will be held interleaved with the astronomy seminars, on the dates noted on the schedule here.

ASTRONOMY SEMINARS

OUR WEEKLY SEMINARS FOCUS ON CURRENT TOPICS IN ASTRONOMY AND ARE OPEN TO EVERYONE

date	name / title	institution	host
9/7/2016			
9/14/2016	John Silverman	Kavli IPMU	Jin Koda
9/15/2016	Ann Almgren	LBNL	IACS
	(IACS seminar 1pm) Next-Generation AMR		
9/22/2016	Will Farr - Cosmology Seminar @ SB (1:30pm)	U. of Birmingham	Neelima Sehgal
(Thursday)			
9/29/2016	Cosmology Seminar @ BNL	TBA	Anze Slosar
9/28/2016	Cosmology Seminar @ SB	TBA	Neelima Sehgal
or 9/30/2016			
10/5/2016			
10/7/2016	Gus Evrard (2pm)	U. Michigan	Michal Simon
(Friday)			
10/12/2016	Giovanni Cabass	La Sapienza Unive	Marilena LoVerde
	CMB Spectral Distortions: A Window on Inflation at Small Scales		

Logistics

we are migrating the data reduction starter scripts to *python*

you should install python on your laptop; best via the anaconda distribution

https://www.continuum.io/downloads

why:

- python is becoming ubiquitous in astronomy
- it is also used much beyond astronomy
- it is free!
- it has lots of documentation on the web

```python
import sys
import numpy
from astropy.time import Time
from astropy import units as u
from astropy.coordinates import SkyCoord
from astropy.coordinates import AltAz
from astropy.coordinates import EarthLocation

### converts (Ra, Dec, JD) to (Az, Alt, UTC) for Mt. Stony Brook

# the first argument is the name of the input file (text file, 3 columns: Ra, Dec, JD)
# the second argument is the name of the output file (text file, 3 columns: azimuth, altitude, UTC)

input=sys.argv[1]
output=sys.argv[2]

# location of Stony Brook
observing_location = EarthLocation(lat=40.914224*u.deg, lon=-73.11623*u.deg, height=0)

# read in the input file
transits=numpy.loadtxt(input)

# define the Ra, Dec pairs
coords=SkyCoord(transits[:,0]*u.deg,transits[:,1]*u.deg, frame='icrs')

# define the observing times
times=Time(transits[:,2], format='jd')

# do the transformation to AltAz
aa = AltAz(location=observing_location, obstime=times)
aacoords=coords.transform_to(aa)

# specify output timeformat to be in UTC
times.format='fits'

# write output file
numpy.savetxt(output,numpy.transpose([aacoords.az,aacoords.alt,times]), fmt="%.6f %.6f %.30s")
```

Example

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from astropy import units as u
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```

Example

can run interactively

or be executed as a script:

```
[anja@ki-ls08 exoplanet]$ python rdj2aau.py rdj.dat aau.dat
```

Teamwork and Github

the data reduction and lab reports will be done in teams

lab reports have to be written in LaTeX (like astronomical journal papers), which is similar to programming

GitHub: version tracking + so much more!

excellent tool for collaborative work on code and documents, standard IT tool

new webpage for course: https://github.com/anjavdl/PHY517_AST443_Fall2016/wiki; will try out GitHub Classroom

to get acquainted, watch https://www.youtube.com/watch?v=2g9lsbJBPEs

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Unwatch 2 Star 0 Fork 1

<> Code Issues 0 Pull requests 0 Wiki Pulse Graphs Settings

PHY 517 / AST 443 – Observational Techniques in Astronomy, Fall 2016 — Edit

6 commits 1 branch 0 releases 1 contributor

Branch: master New pull request Create new file Upload files Find file Clone or download

Anja B. von der Linden Merge branch 'master' of github.com:anjavdl/PHY517_AST443_Fall2016 Latest commit 8af2328 11 minutes ago

exoplanet	updated commeting	12 minutes ago
README.md	Update README.md	3 days ago

README.md

PHY 517 / AST 443 – Observational Techniques in Astronomy

Astronomers explore the universe by detecting and analyzing light from all over the elecromagnetic spectrum. We concentrate on a subset of techniques for detection of photons at visible and at radio wavelengths.

This is a three-quarters lab and one-quarter lecture course. The laboratory component entails obtaining and analyzing astronomical data with optical and radio telescopes. Three distinct observational experiments will be

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Edit | New Page

anjavdl edited this page 15 seconds ago · 5 revisions

General Information

Credits: 3 (PHY 517) or 4 (AST 443)

Instructor: Anja von der Linden (anja.vonderlinden 'at' stony brook.edu, ESS 453)

Office hours: Tuesday 2-3pm & Thursday 3-4pm

TAs:

- Drew Jamieson (andrew.jamieson 'at' stony brook.edu)
- Lucie Baumont (lucie.baumont 'at' stony brook.edu)

Suggested texts:

- Measuring the Universe, G. Rieke (Cambridge University Press, 2012)
- Data Reduction and Error Analysis for the Physical Sciences, P.R. Bevington & D. K. Robinson (McGraw-Hill Higher Education, 2003)
- Practical Statistics for Astronomers, J.V. Wall & C.R. Jenkins (Cambridge University Press, 2008)

Prerequisites: AST 203 ; some programming experience

Pages 3

- General Information
- Lab 1: Exoplanet transit
- Astro Software

Clone this wiki locally

https://github.com/anjavdl/

Clone in Desktop

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J2000.0 coordinates from http://exoplanet.eu/catalog/ #1

Edit | New issue

Open **NamHoNguyen** opened this issue 16 minutes ago · 1 comment

NamHoNguyen commented 16 minutes ago

The RA and Dec coordinates of the host stars obtained from the catalog were recorded for the epoch J2000.0, which is at noon of January 1, 2000. We're observing the stars 16 years after this epoch so there must be some deviation in the coordinates. Is this difference negligible, and does it depend on the position of the chosen star?

"*Right ascension for "fixed stars" near the ecliptic and equator increases by about 3.3 seconds per year on average, or 5.5 minutes per century, but for fixed stars further from the ecliptic the rate of change can be anything from negative infinity to positive infinity. The right ascension of Polaris is increasing quickly. The North Ecliptic Pole in Draco and the South Ecliptic Pole in Dorado are always at right ascension 18h and 6h respectively.*" from https://en.wikipedia.org/wiki/Right_ascension

NamHoNguyen changed the title from **J2000.0 coordinates from http://exoplanet.eu/catalog/all_fields/?f=%22transit%22+IN+detection** to **J2000.0 coordinates from http://exoplanet.eu/catalog/** 10 minutes ago

anjavdl commented just now — Owner

Labels

None yet

Milestone

No milestone

Assignees

No one—assign yourself

2 participants

Notifications

Unsubscribe

You're receiving notifications because you commented.

Lab reports

are due 4 weeks after the observations are taken

you HAVE TO check in with the TAs at least once a week to ensure you are making progress

lab reports should be submitted as group reports

each report has a primary author - this person is NOT writing the report by her-/himself, but is in charge of organizing the process

indicate in each section who did what

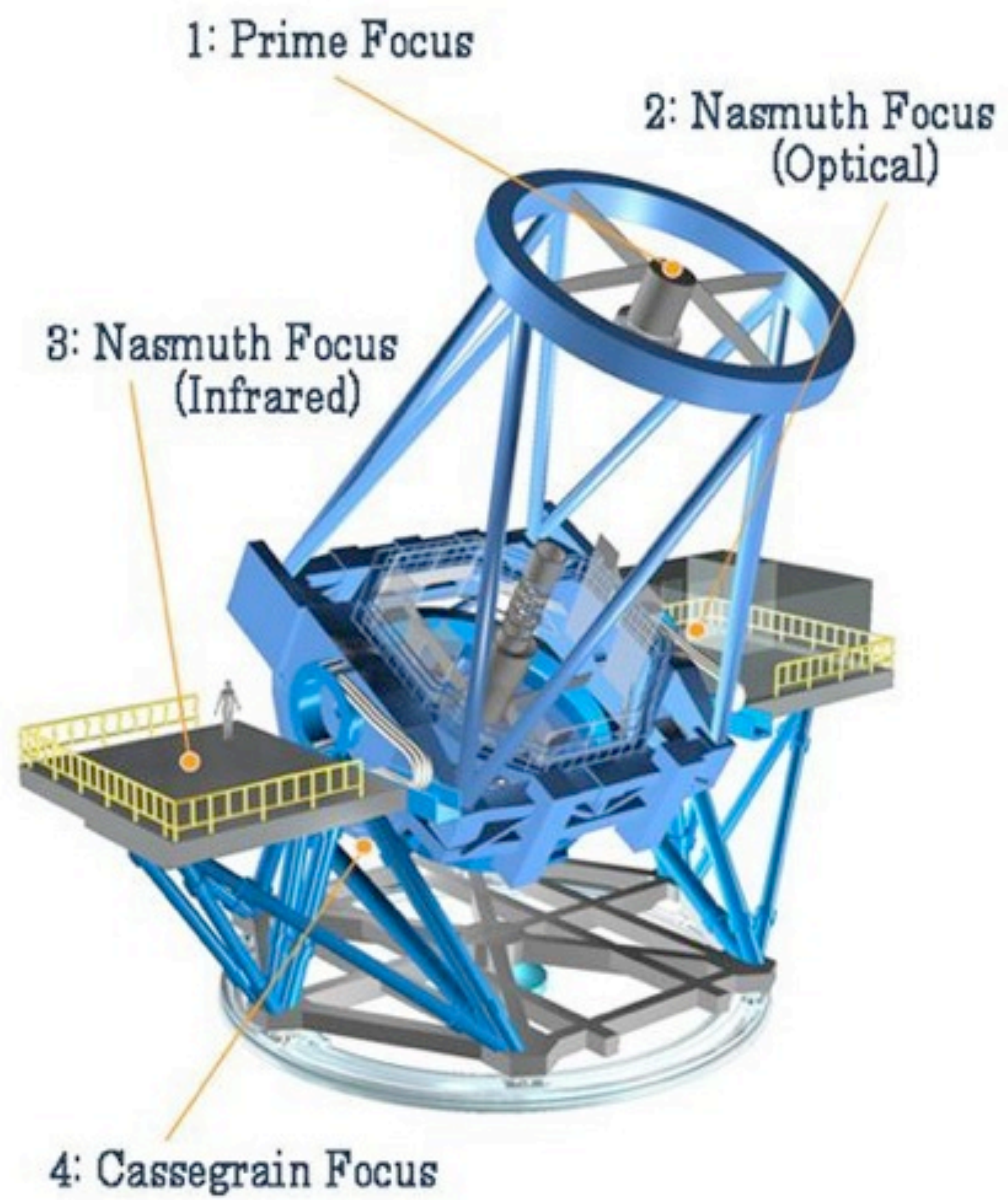
your groups of 3 people remain fixed; there are 3 labs → everybody gets to be first author on one report

(A little bit about)

Telescopes

Big telescopes

- all big telescopes are reflectors (mirror telescopes)
- big lenses are too expensive / impossible to make
- many big telescopes have several instruments mounting points (at different foci)



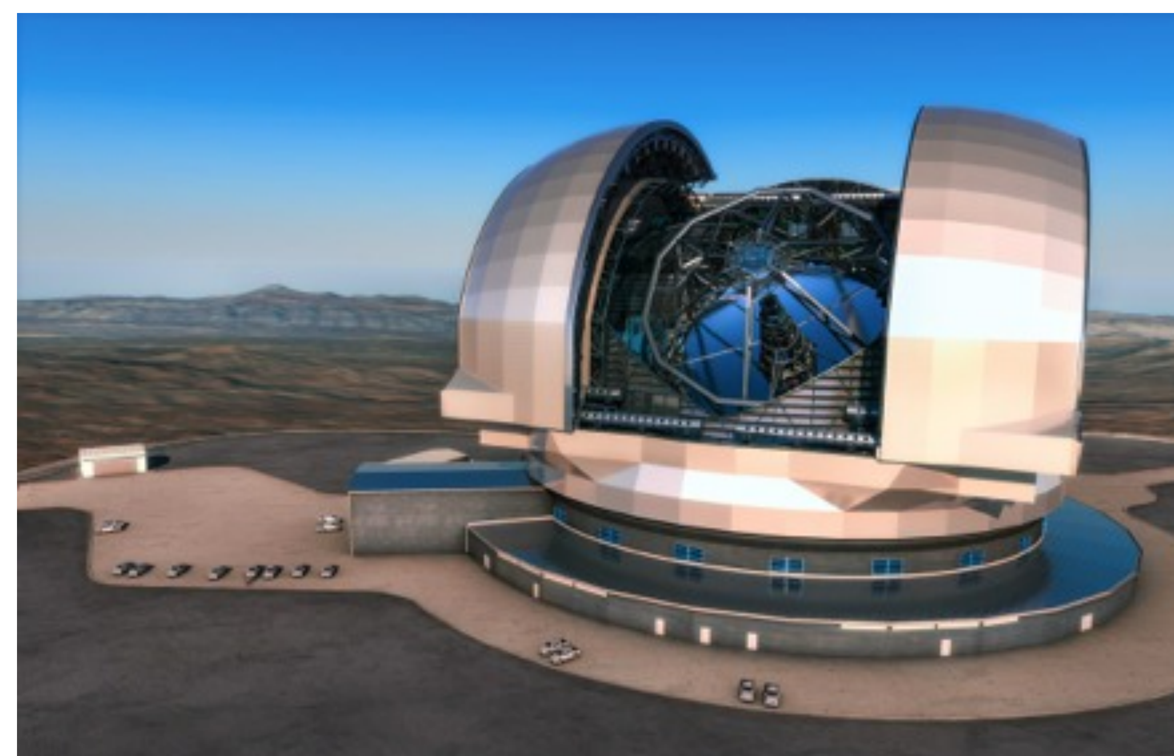
(c) MBTA Corporation Japan #150132

Aperture

- most (new) things in astronomy are faint (but not all!)
- need to gather as much light as possible
- the diameter of the mirror (aperture) is one of the main characteristics of a telescope

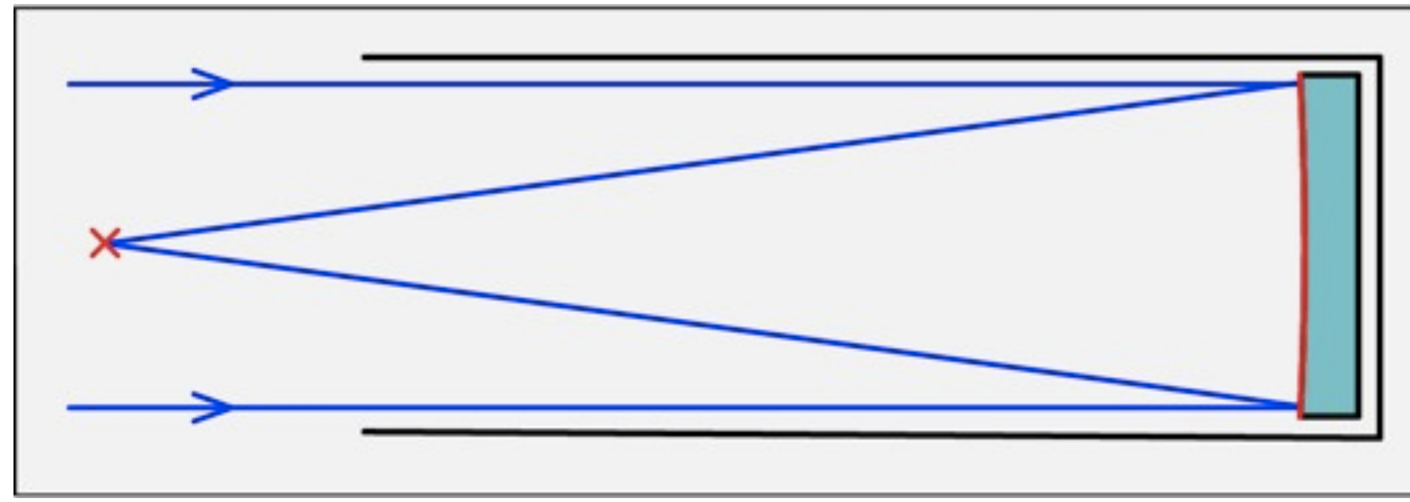
Keck Telescopes: 10m

next generation: 30m telescopes (~2025)

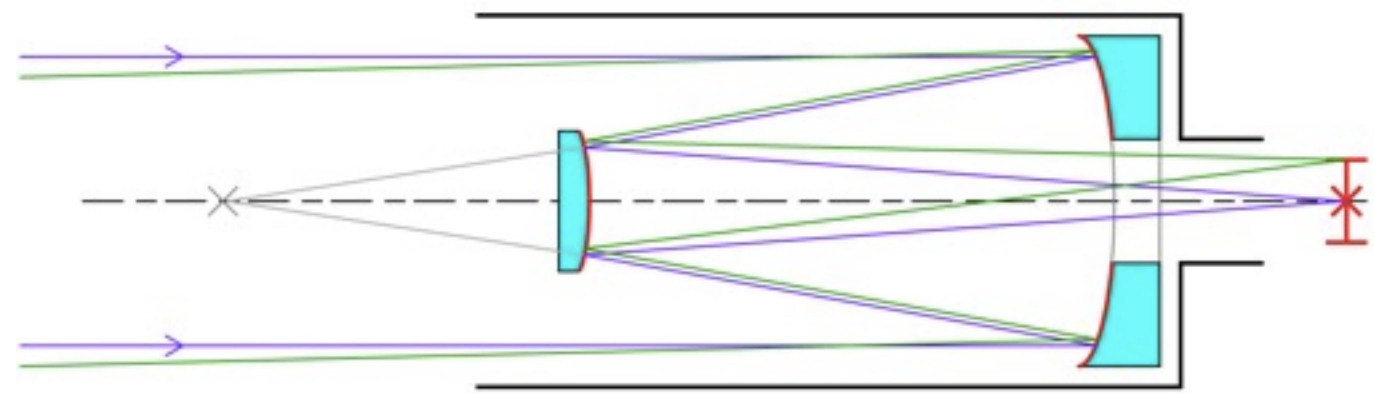


Telescope foci

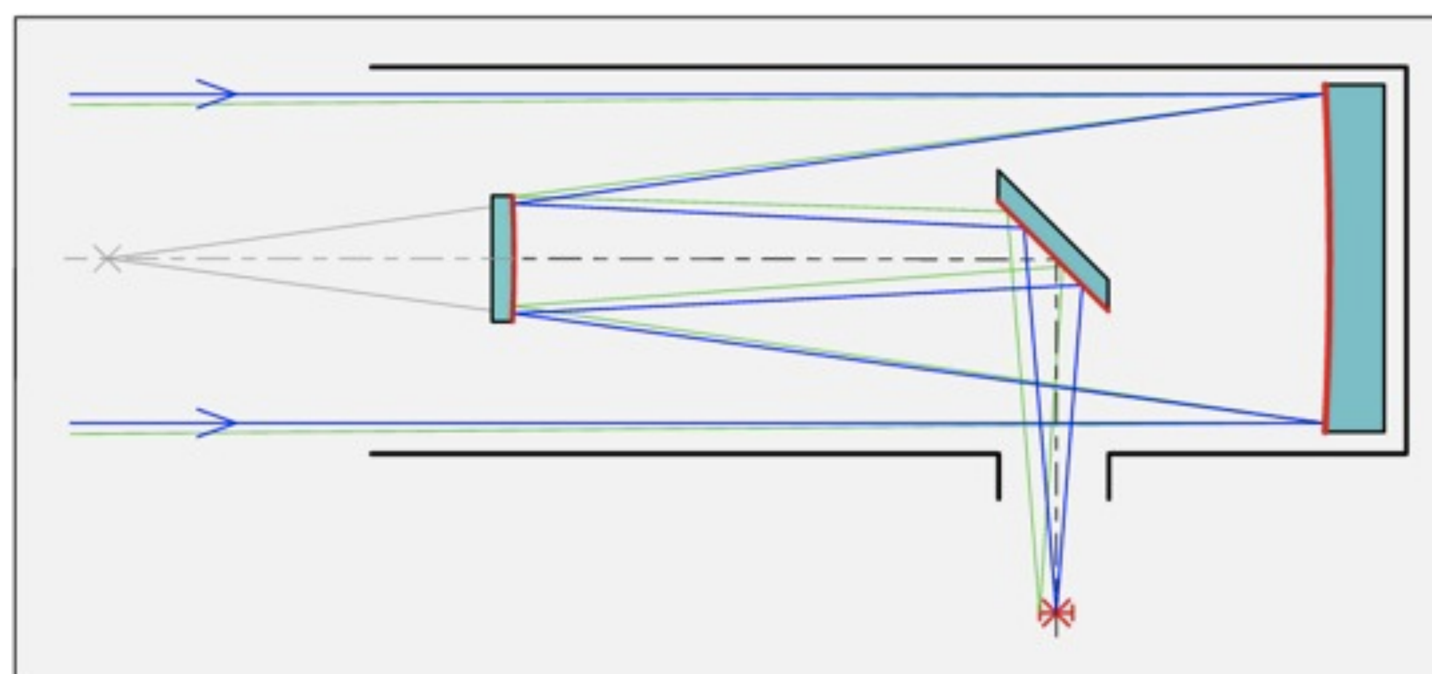
- prime focus: focus of primary mirror



- Cassegrain focus: secondary mirror in front of prime focus; secondary focus behind primary mirror

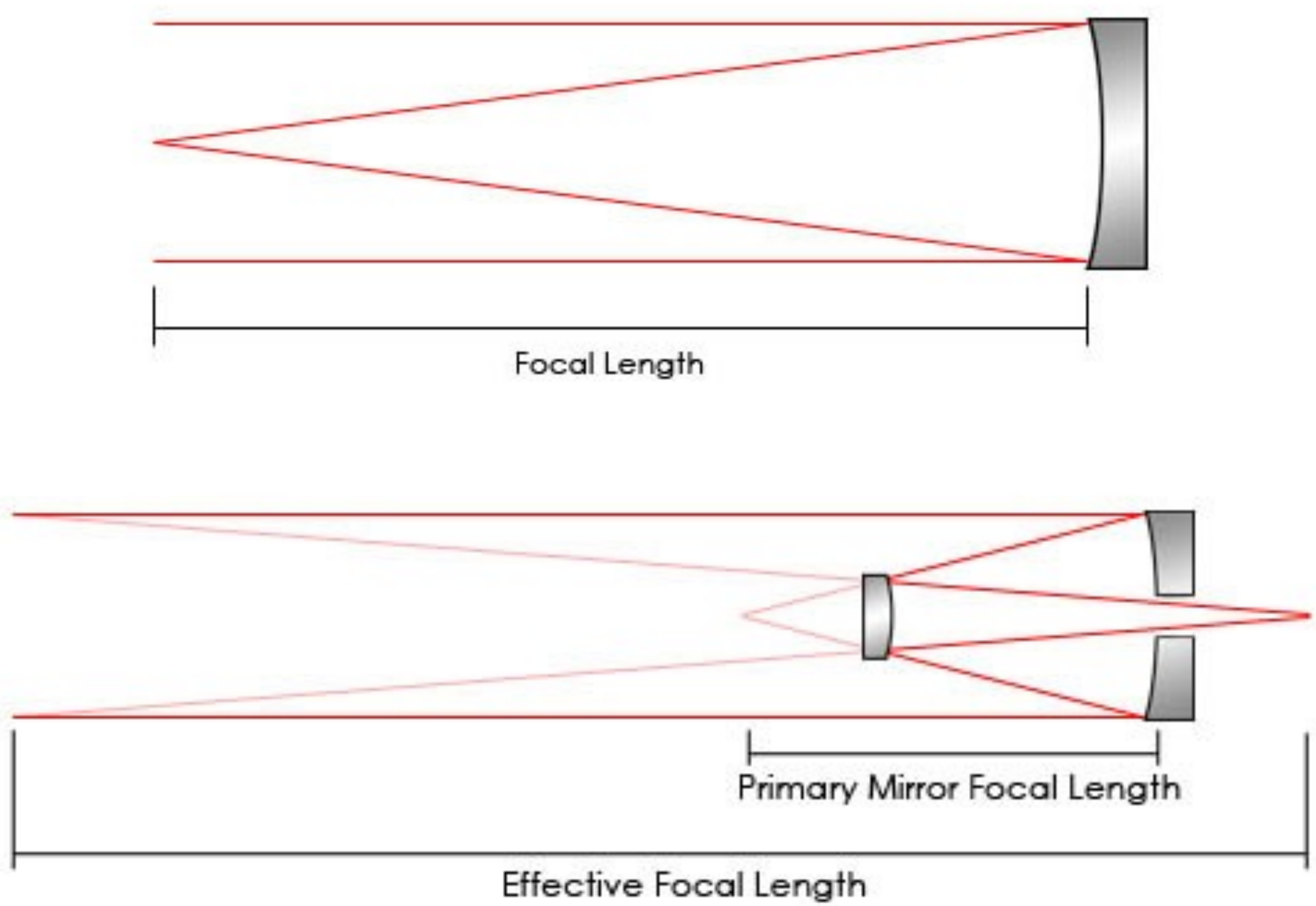


- Nasmyth focus: pick-up mirror, can be placed through mount axis



Focal length

distance from mirror / lens to the focus place



Focal ratio ("f number")

distance from mirror / lens to the focus place

$$\text{focal ratio} = \frac{\text{focal length}}{\text{aperture}}$$

measure of how "fast" the lens / mirror is

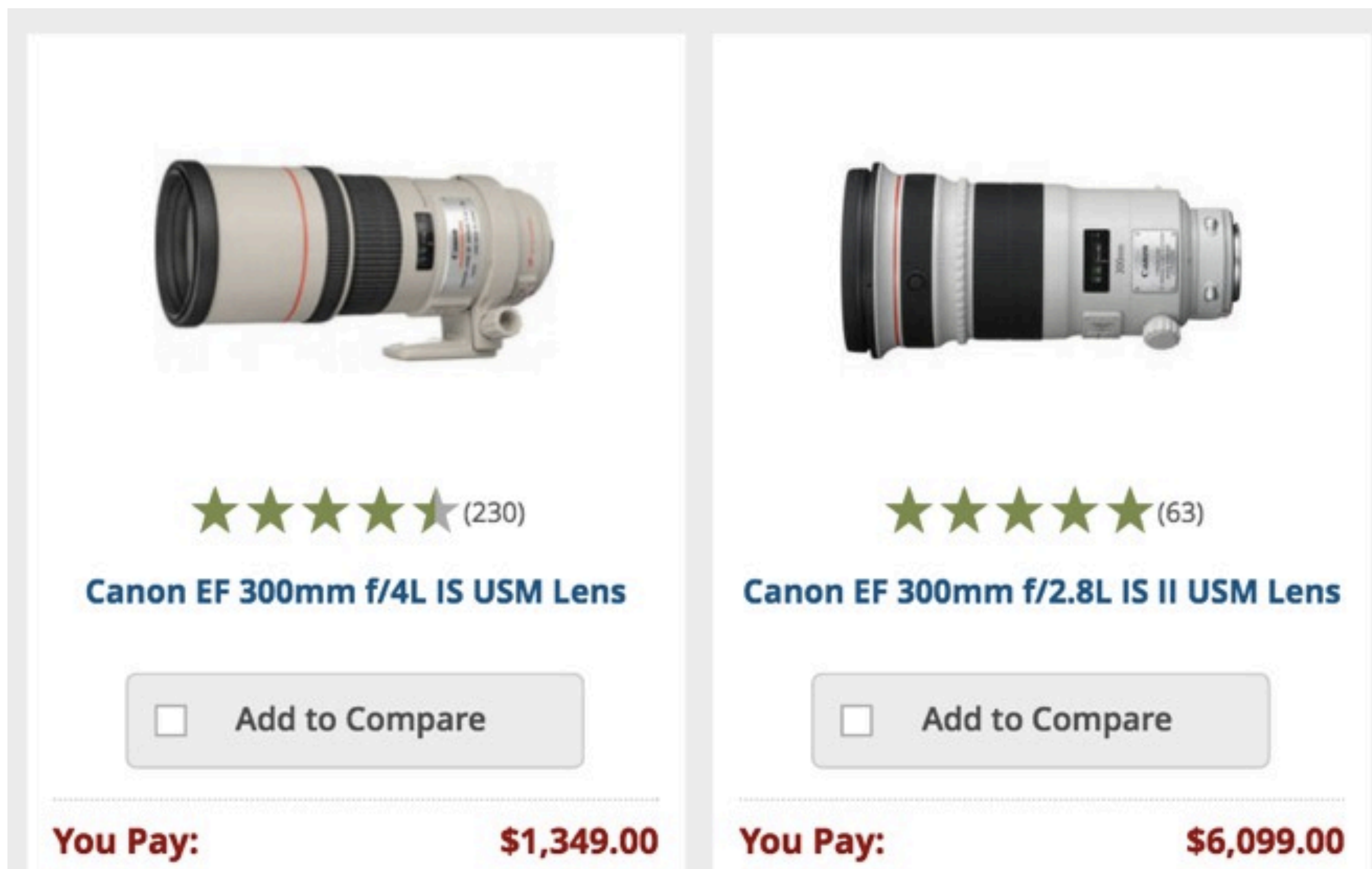


Plate Scale

how big is the image / how much sky does the detector see?

$$\theta \approx \tan\theta = \frac{y}{f}$$

$$\frac{d\theta}{dy} = \frac{1}{f}$$

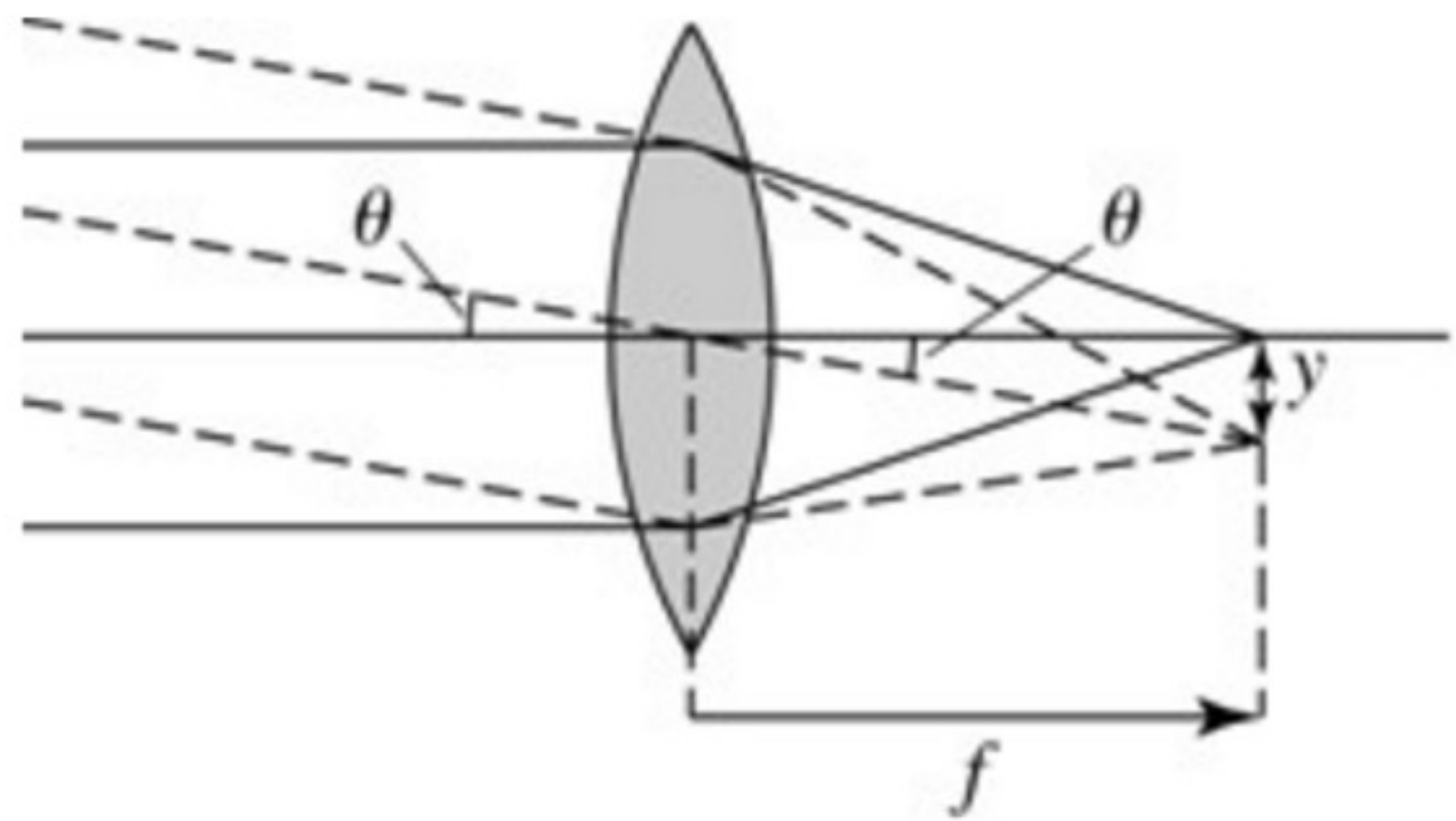


plate scale = (focal length)$^{-1}$

units: arcseconds / mm

CCDs

CCDs

- CCD: "charge-coupled device"
- CCDs are the detectors of choice over much of the electromagnetic spectrum (X-rays to infrared)
- replaced photographic plates
- similar to detectors found in digital cameras

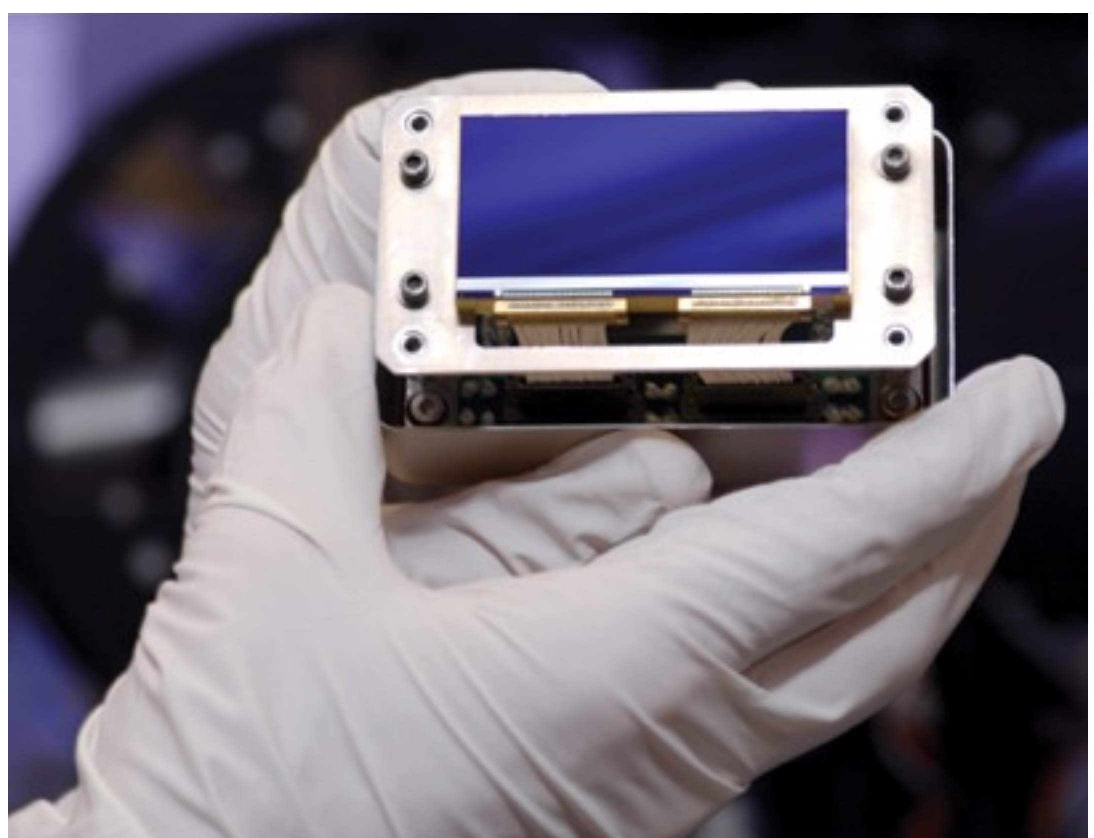
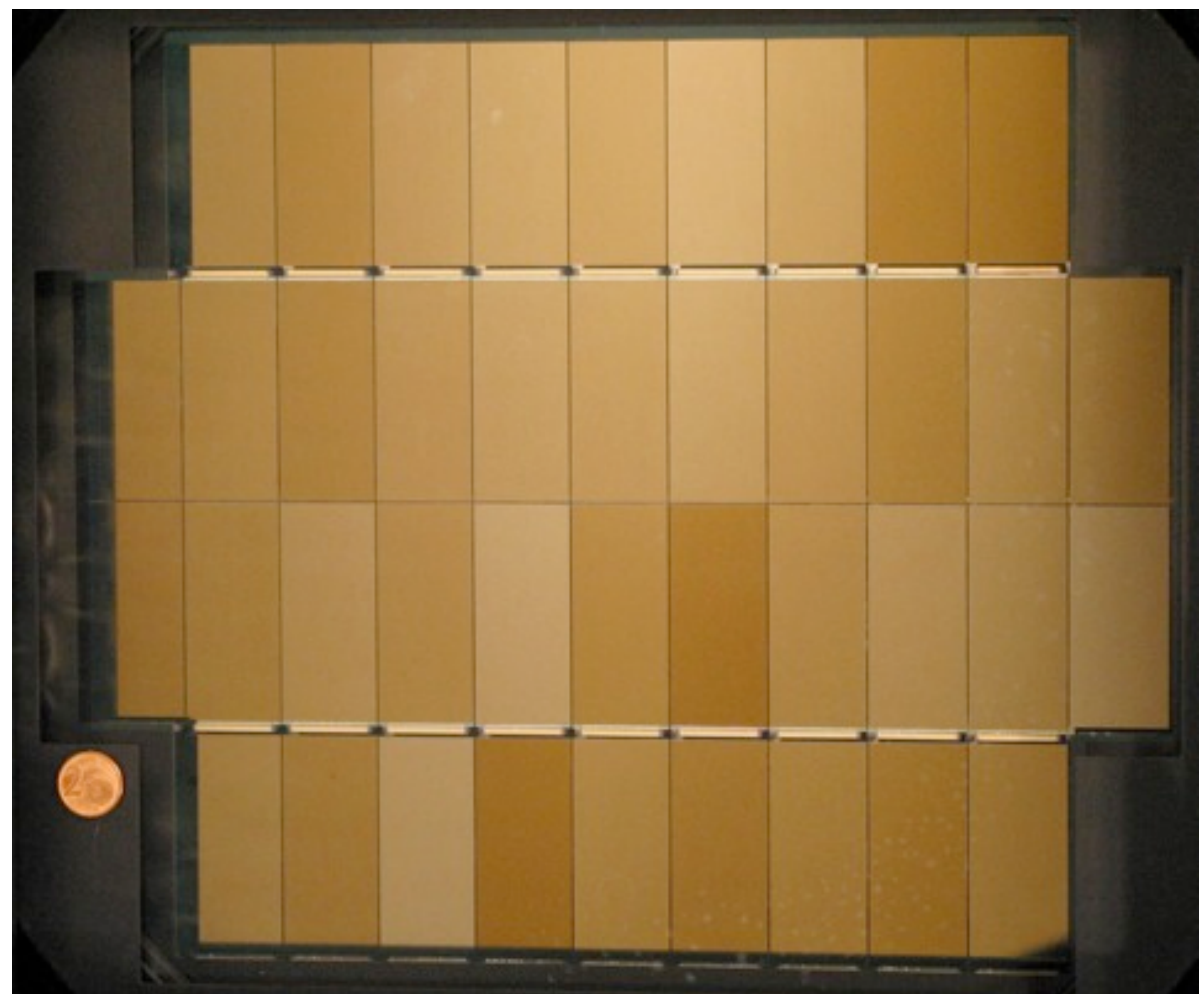


Figure 3. Kepler CCD in handling jig.

CCDs - Advantages

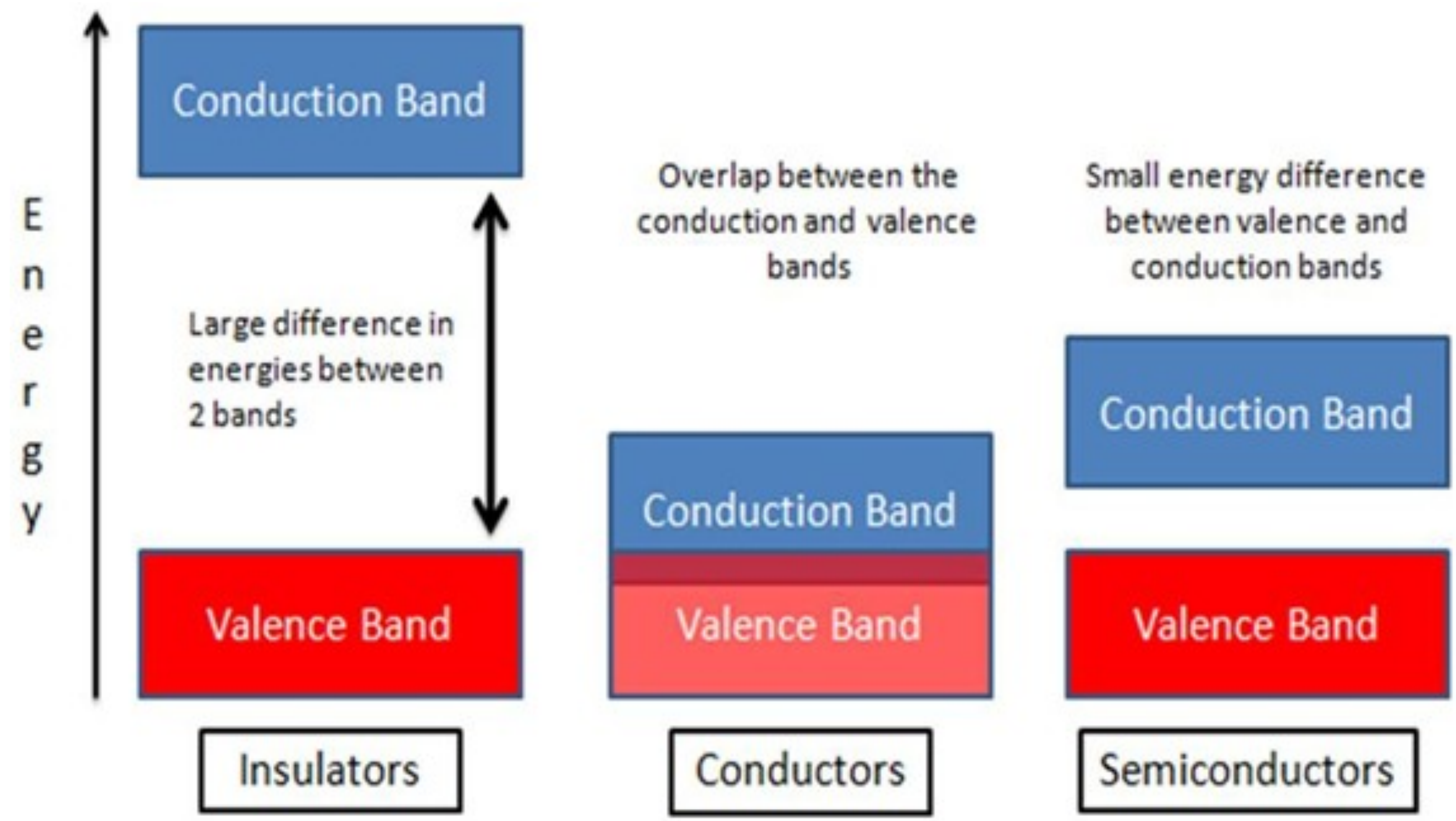
- (nearly) linear response $N_{\mathrm{electrons}} \propto N_{\mathrm{photons}}$
- high sensitivity
- low noise (especially when cooled)
- built-in digitization



CFHT MegaPrime

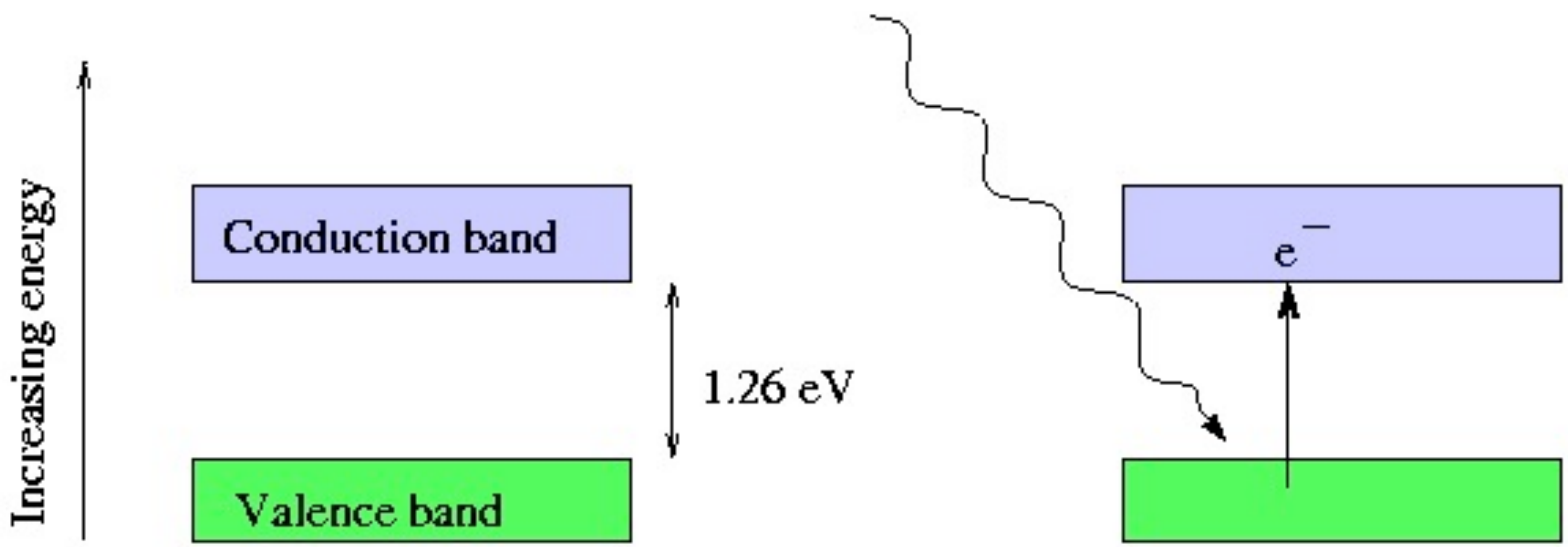
Semi-Conductors

- CCDs are made of semi-conducting silicon wafers
- key feature: small energy gap between "valence band" (energy levels of outermost bound electrons) and "conduction band" (energy levels of free electrons)



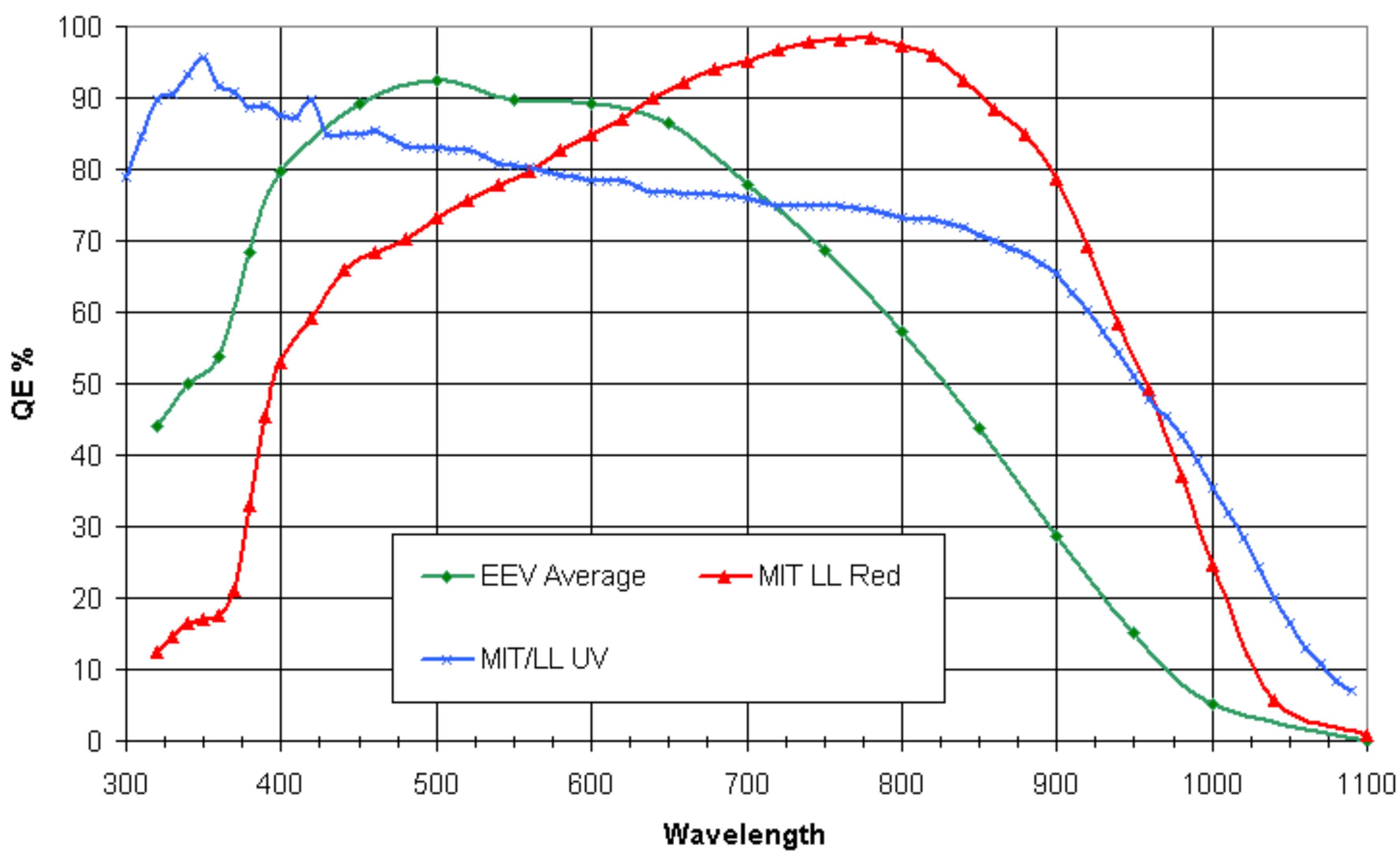
Photoelectric effect

- light is quantized, "photons" $E = h\nu$
- when a photon is absorbed, the energy is transferred to an electron → "jumps" into conduction band



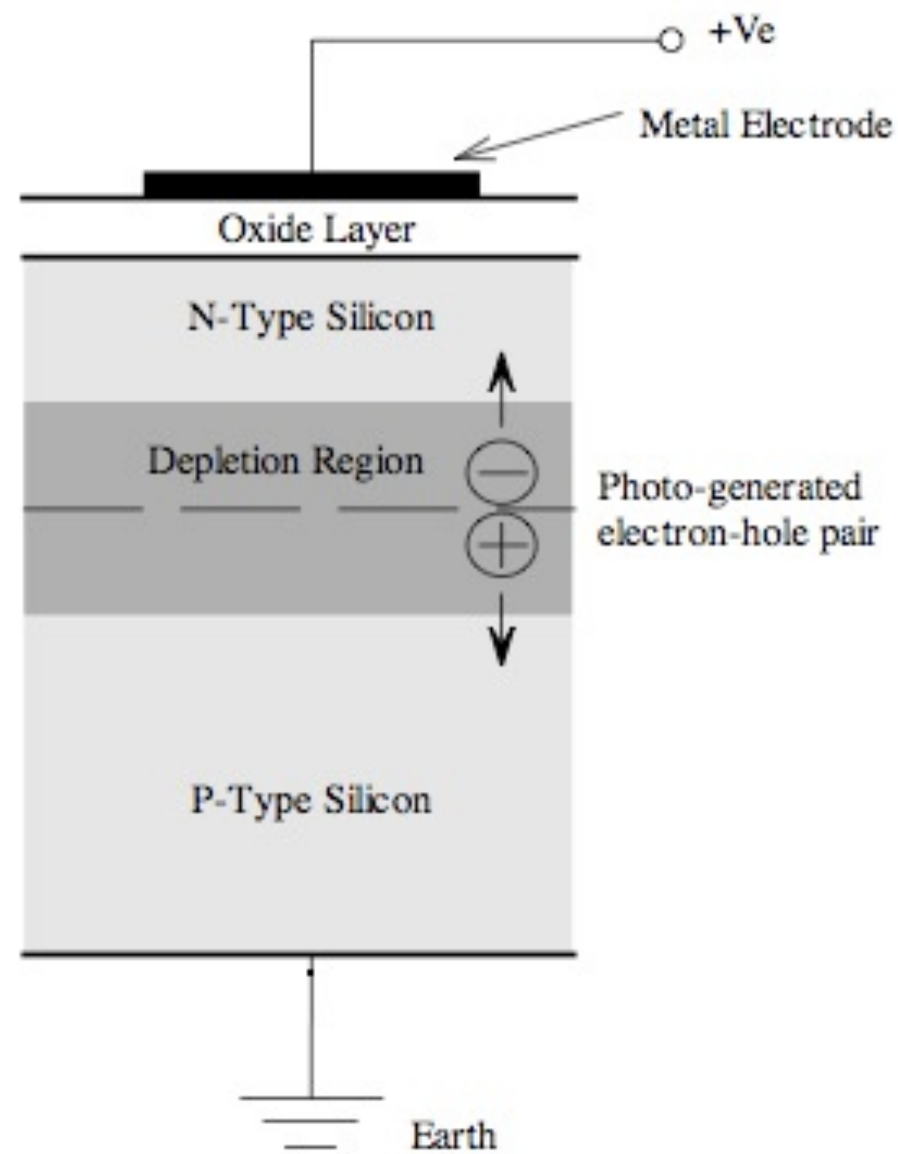
CCD Quantum Efficiency (QE)

- fraction of photons that are detected
- depends on wavelength
- different technologies lead to red vs. blue optimized CCDs



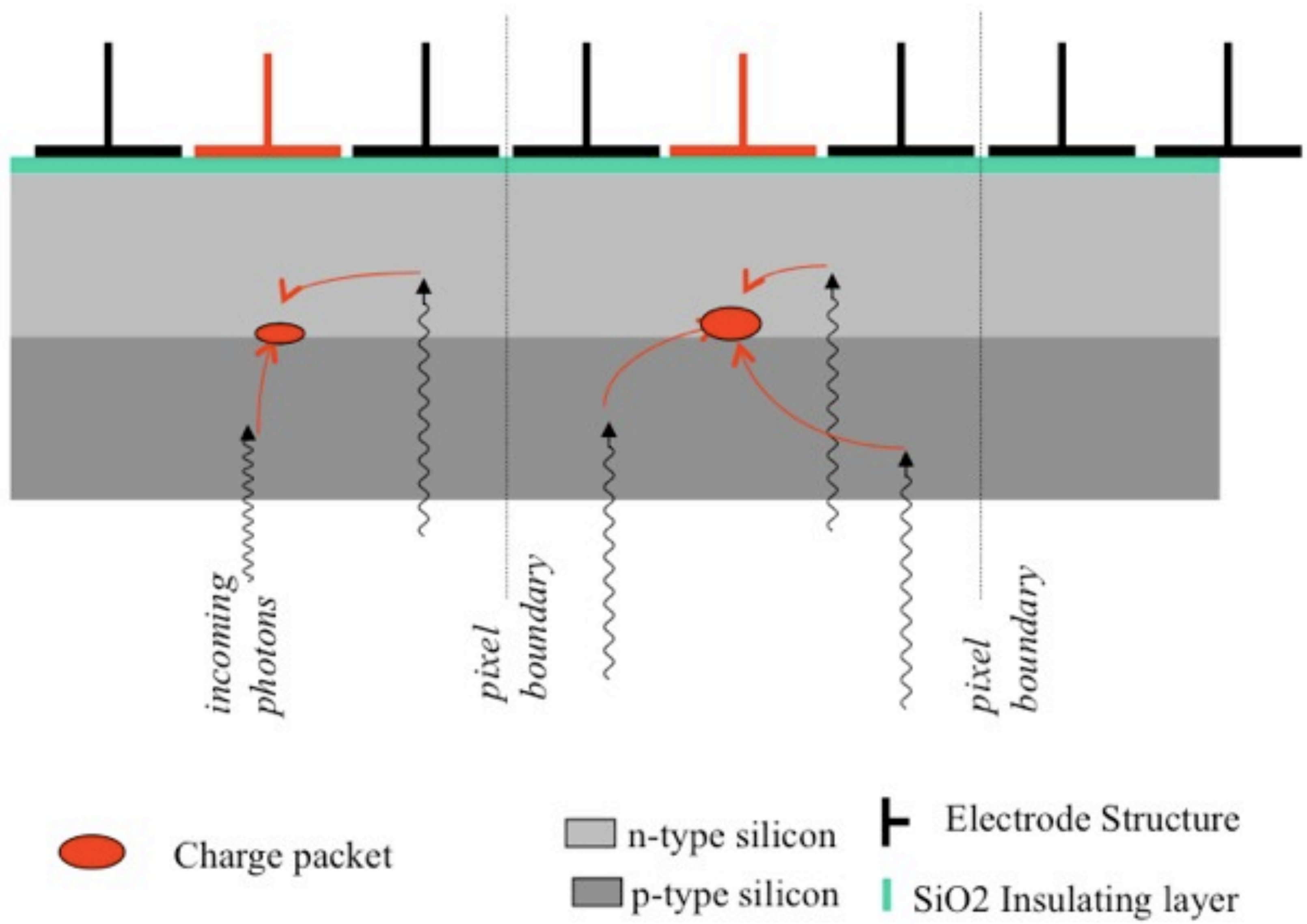
One pixel

- apply an electric field to keep electrons / holes separated



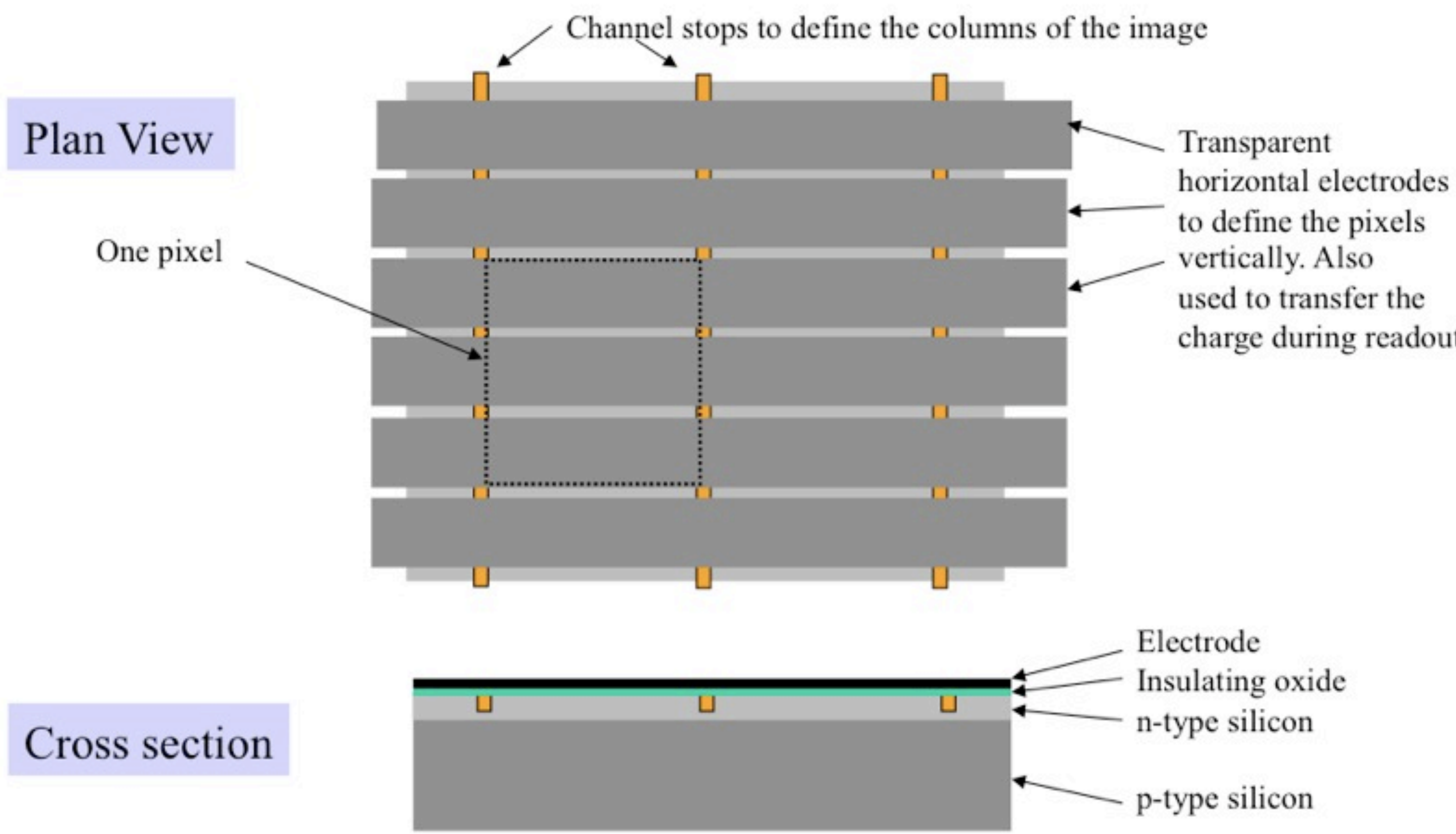
Many pixels

- pixels are defined by the electric field generated by the applied electrodes



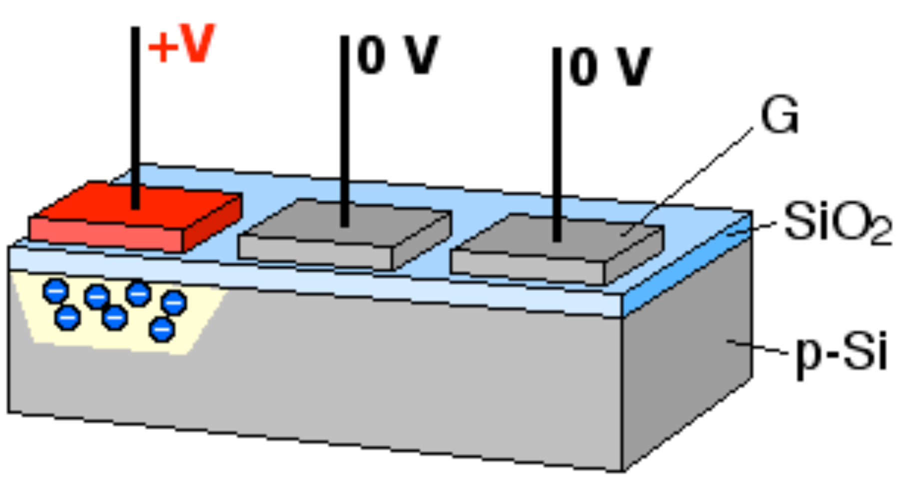
Many pixels

- ... and by insulator strips between columns



Reading out CCDs

- "rainbuckets on conveyor belts" analogy
- 1 conveyor belt = 1 CCD column
- in practice: modulate the electric fields to move pixel charges



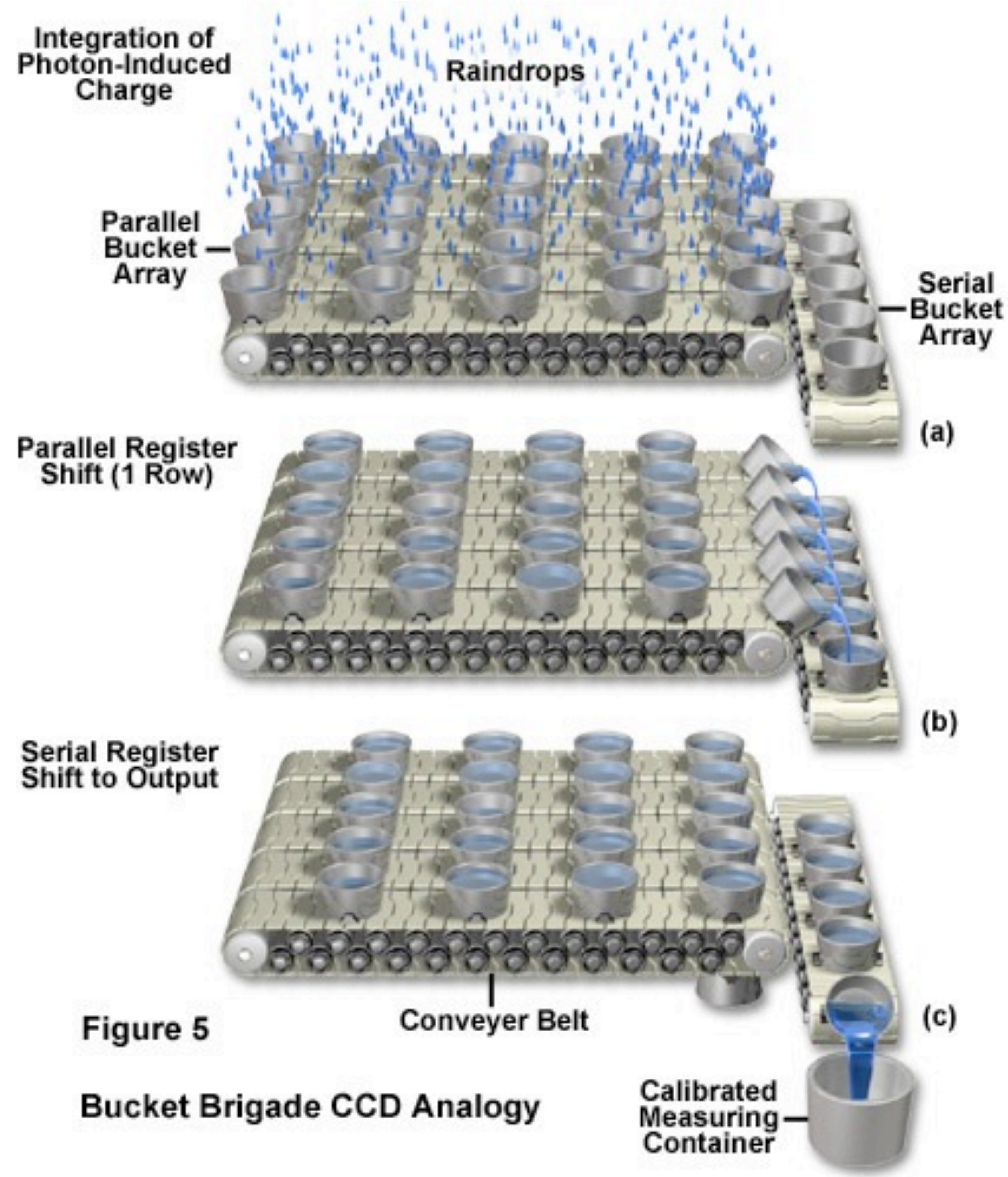


Figure 5

Bucket Brigade CCD Analogy

Assembling the Image

- each charge collection is passed to an amplifier and analog-to-digital converter (ADC)
- final output: "counts" or ADUs (analog-to-digital units) → *integer value*
- can apply rescaling: "gain"

$$\text{gain G} = \frac{N_{\text{electrons}}}{N_{\text{counts}}}$$

Full Well Capacity

- each pixel can only hold a limited charge → *full well capacity*, of the order of 100 000 e^-
- ADCs have a maximum output value, e.g. 16-bit = 2^{16} = 65536 counts
- gain should be chosen roughly so that ADC maximum ~ full well
- typically, gain ~ 2-4

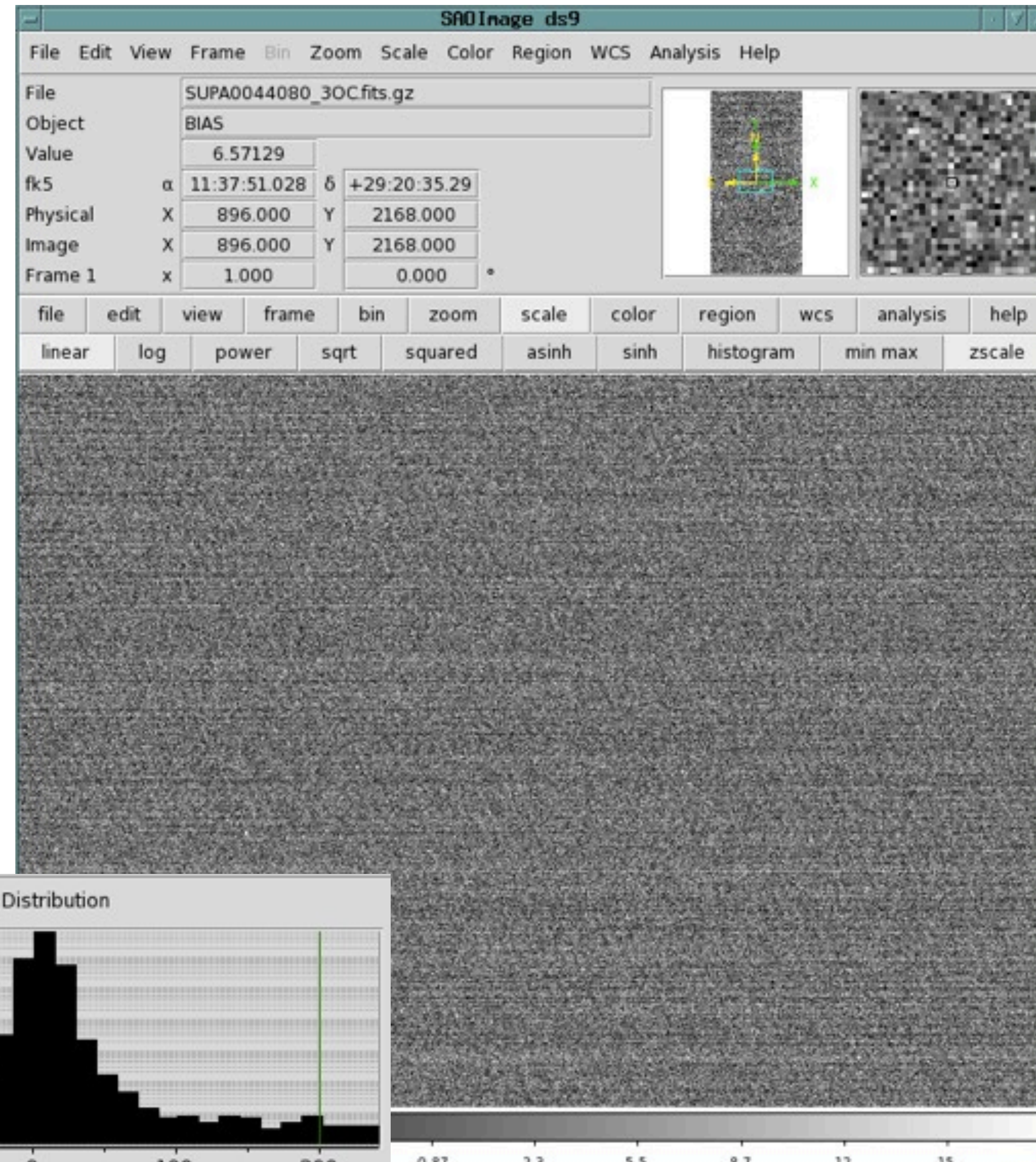
Read-out noise and bias level

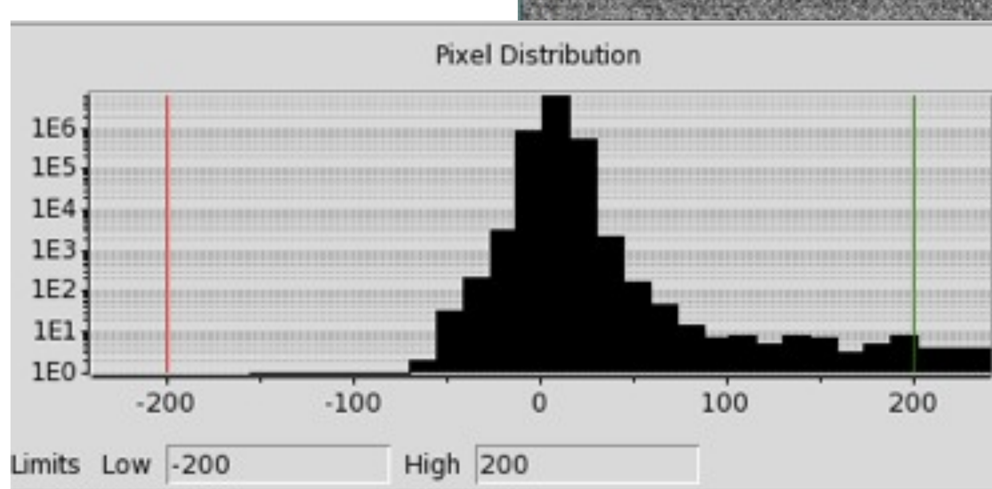
- various electronics can introduce noise into the signal before it reaches the ADC, e.g. the amplifiers
- the slower the read-out, the lower the noise

- bias level: an electronically induced offset which ensures that the ADC always gets a positive input
- the bias needs to be subtracted so that the counts are proportional to the signal

Bias images

- images with 0s exposure time
- single bias frame: pixel values scatter around the bias level, width of this distribution is the read-noise
- master bias frame (median or average of many bias frames): read-noise is averaged out, remaining structure is due to electronics





$$\sigma \sim 5e^-$$

Overscan region

- problem: the bias level may not be stable
- images on large astronomical cameras come with an overscan region
- each row is clocked out more often than there are physical pixels
- can be used as an in-situ estimate of the bias level
- use the extra pixels to estimate the bias level of each row; subtract it from entire row
- the overscan is subtracted from all images (including bias frames)

Dark current

- the energy gap in the semi-conductor is small → thermal noise leads to extra charge accumulation
- proportional to the exposure time
- cooling the CCDs significantly mitigates dark current
- professional astronomical CCDs cooled to -100˚C → almost no dark current

- dark frame: images taken with closed shutter, same exposure time, same temperature as science frames
- similar to bias frames; need to be subtracted

Flat-field

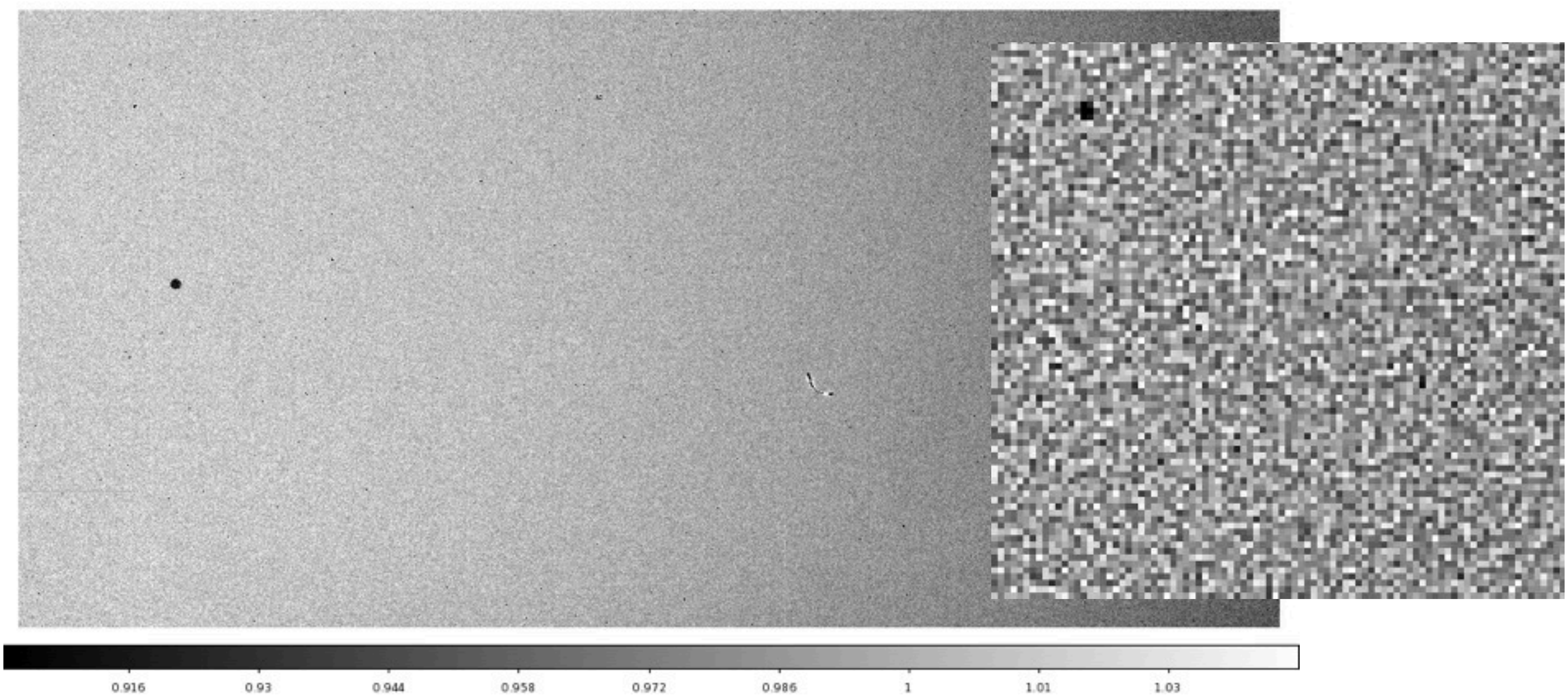
- the pixels in a CCD do *not* have uniform sensitivity
- due to variations in silicon crystal, electric field, pixel size, illumination (vignetting)

$$N_{\mathrm{electrons}} \; = \; A_{ij} \; N_{\mathrm{photons}}$$

- A_{ij} different for each pixel
- need to correct for differences for meaningful measurements

Flat-field

- flat-field: take an image of a spatially uniform source of light (e.g. the twilight sky, or a screen in the dome)
- input signal ($N_{photons}$) is the same for each pixel; variations in N_{counts} are due to different sensitivies



Flat-field

- flat-field is a *multiplicative* correction (unlike bias / dark)

- in practice: take a series of flat-field images
- correct each flat image by the bias image (overscan if available)
- average the flat-field images (reduces counting noise) → master flat-field

- each science image needs to be corrected by the master bias (or dark) and the master flat-field:

$$\frac{\text{science image} - \text{master bias}}{\text{master flat}}$$

Types of flat fields

dome flats:

✓ easy

✓ constant conditions

– not entirely uniform

– different spectrum than astronomical objects

Types of flat fields

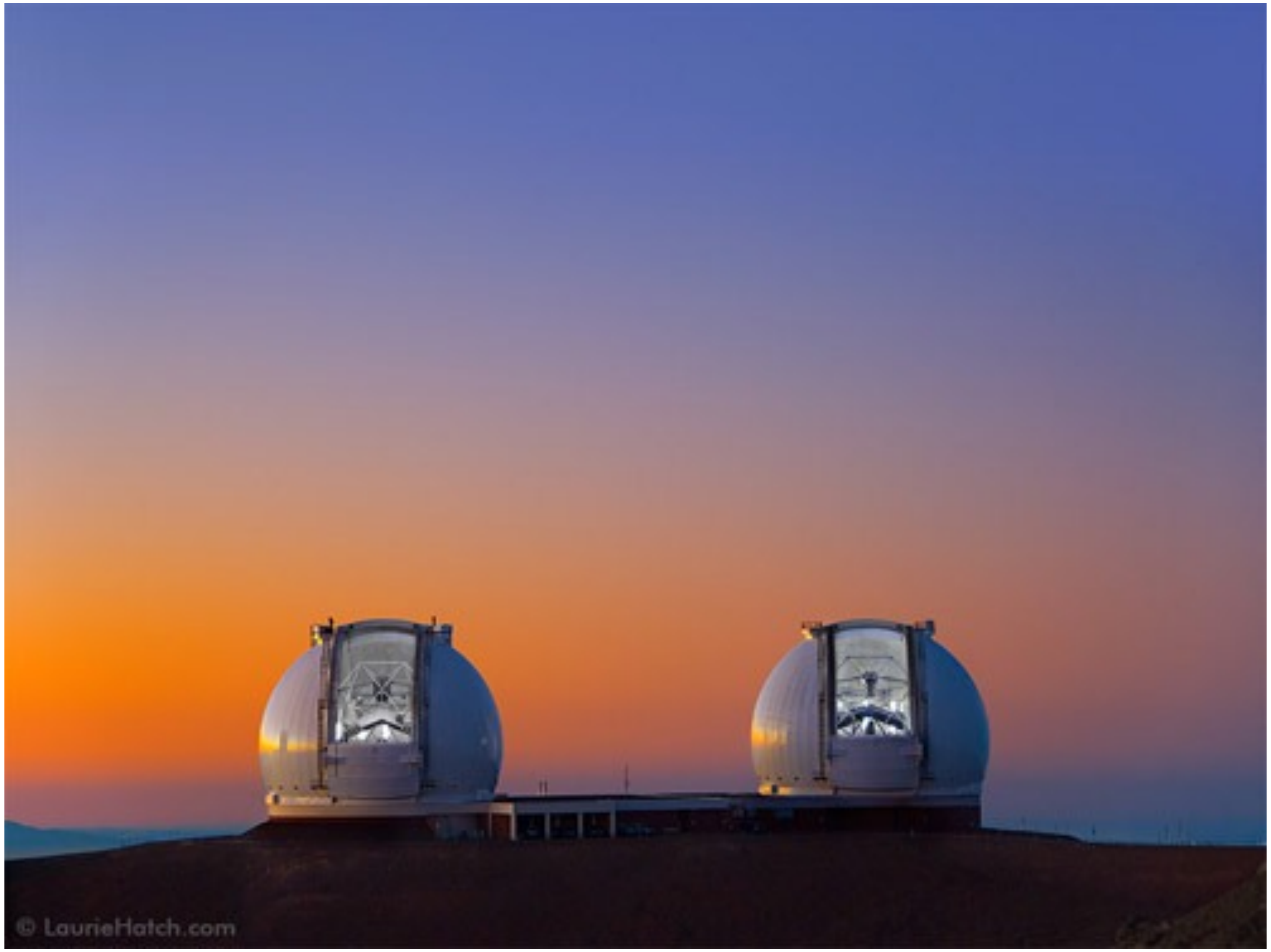
twilight flats:

✓ same “source”

✓ almost uniform

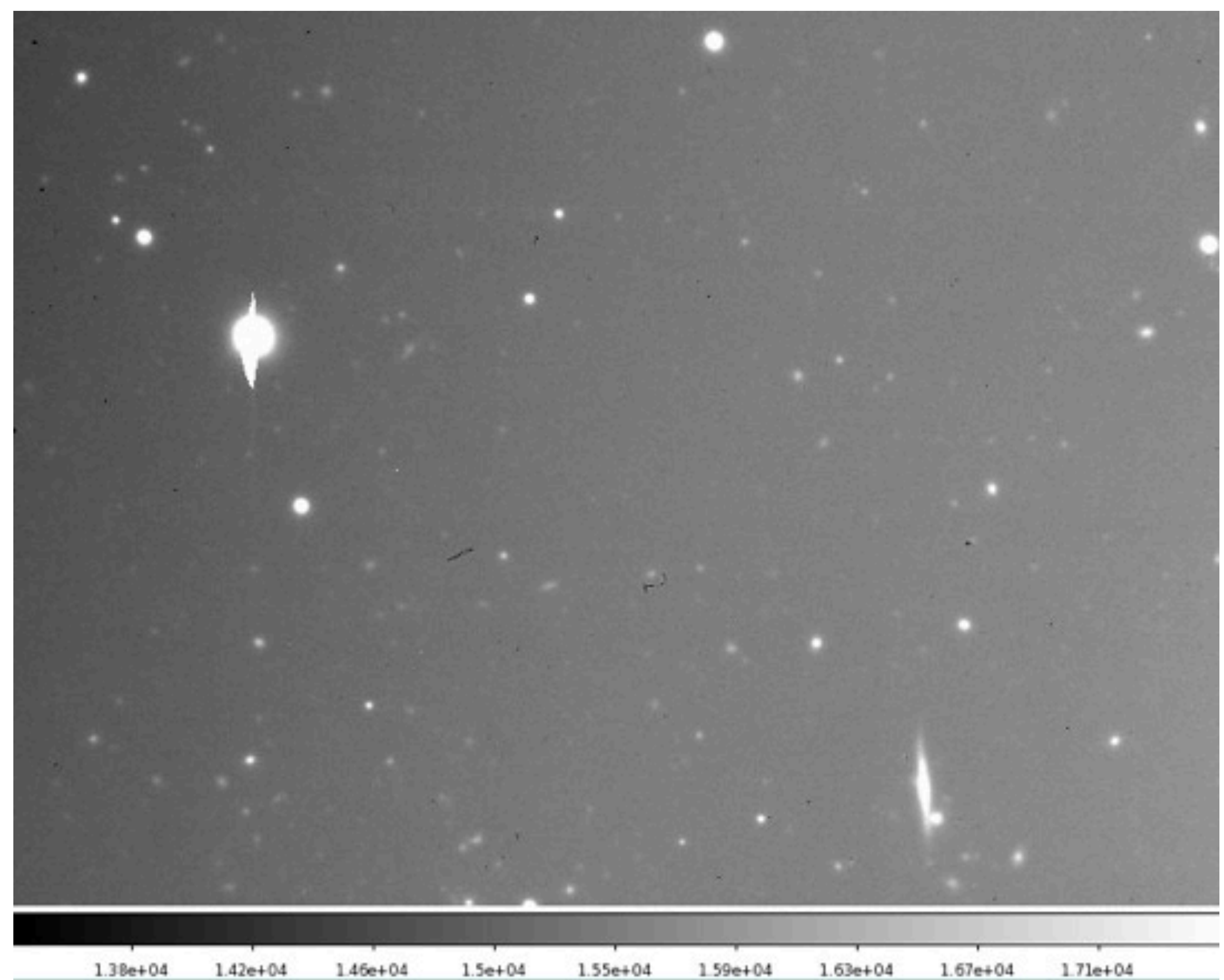
– variable

– difficult



Types of flat fields

night-sky flats: if observations of several different targets are taken in one night, can average these images into flat-fields assembled from the sky background (best to mask out detected objects)



✓ most similar to data

✓ uniform

– need "empty" fields

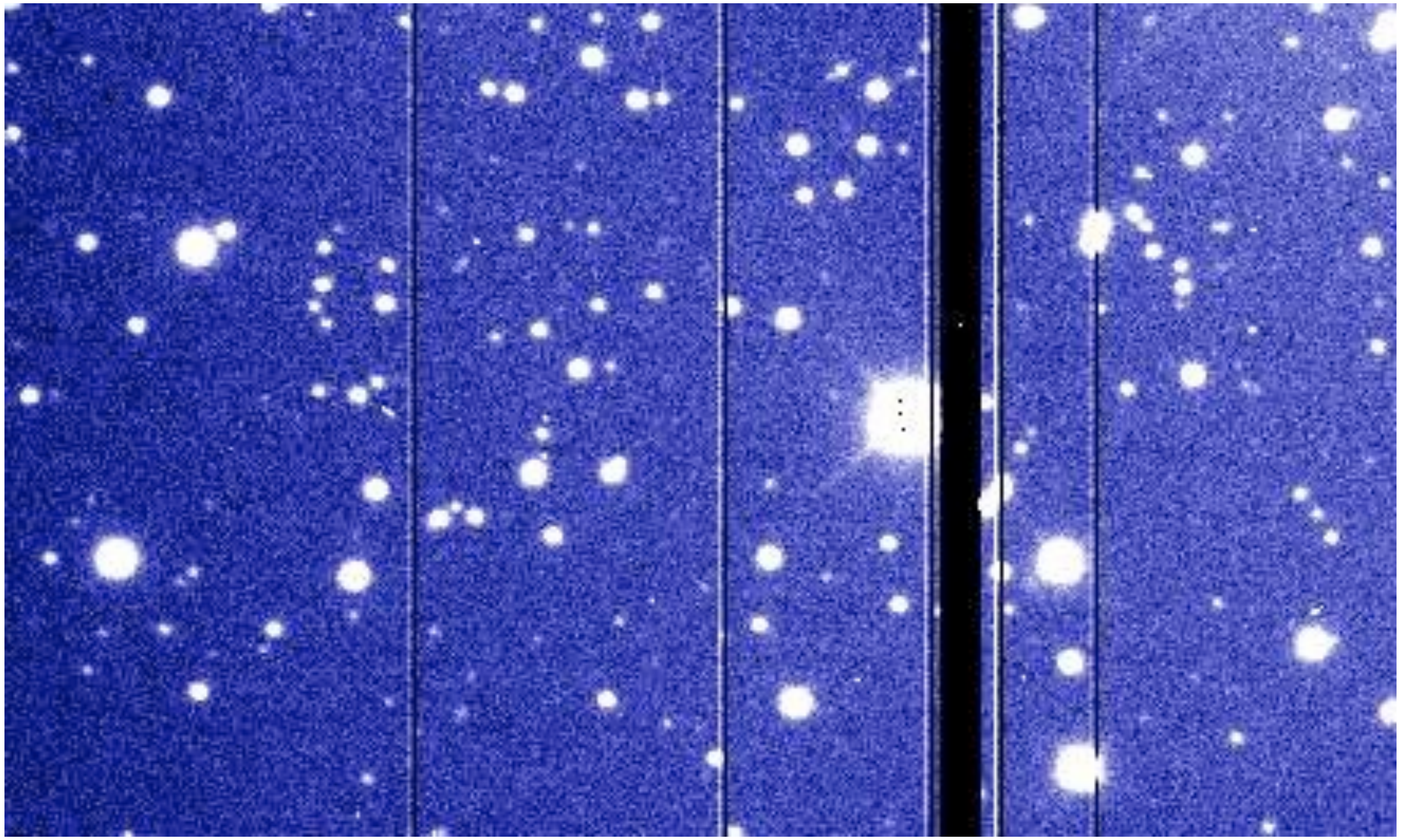
– need a lot of images

Artefacts

dead pixels / columns / rows: no (or little) response

hot pixels / columns / rows: very high noise

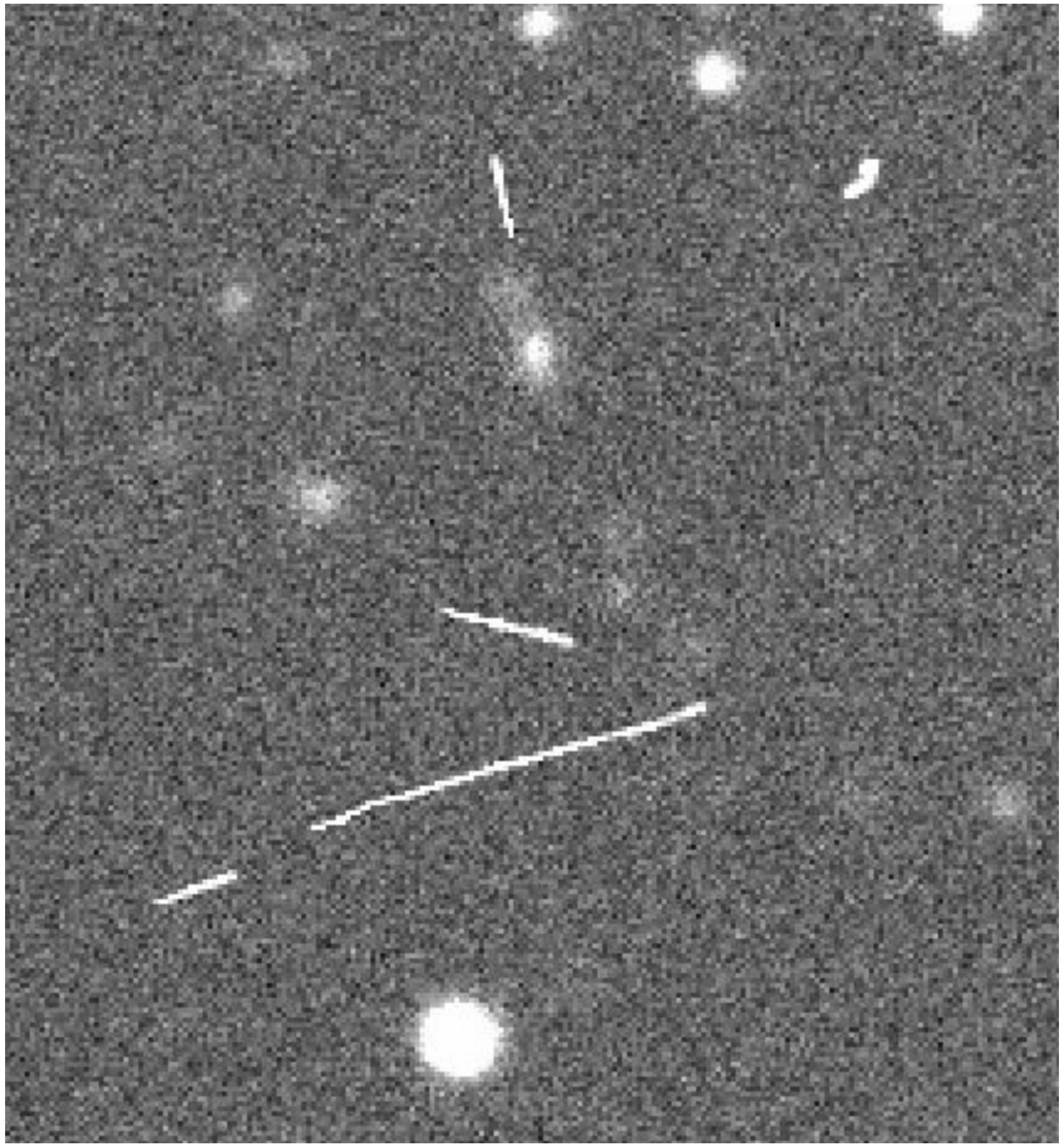
signal is not recoverable; pixels need to be masked in all exposures



Artefacts

cosmic rays: charged particles hit the CCD

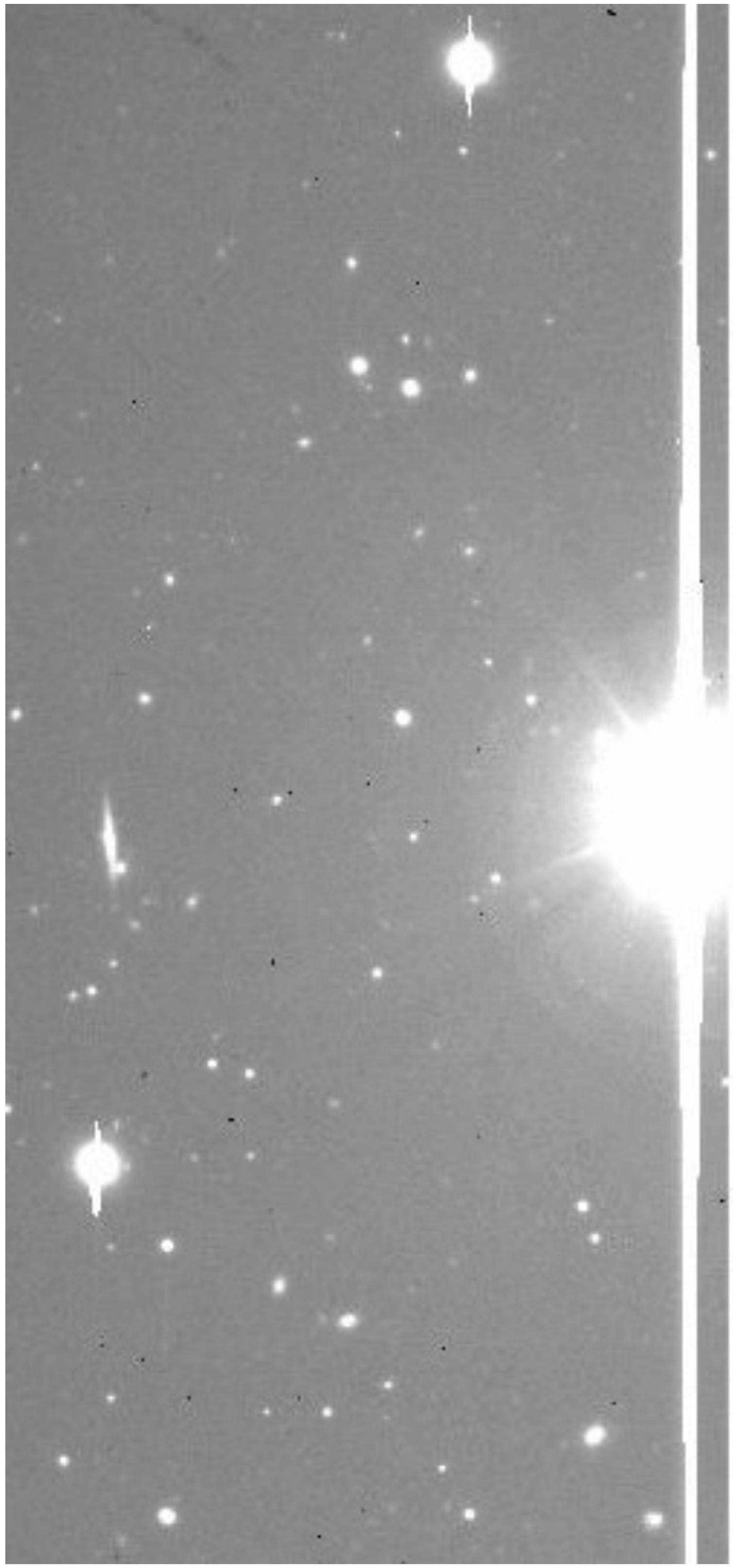
need to be masked - single exposure



Artefacts

saturation spikes: when full well capacity is reached, electrons spill over into neighboring pixels

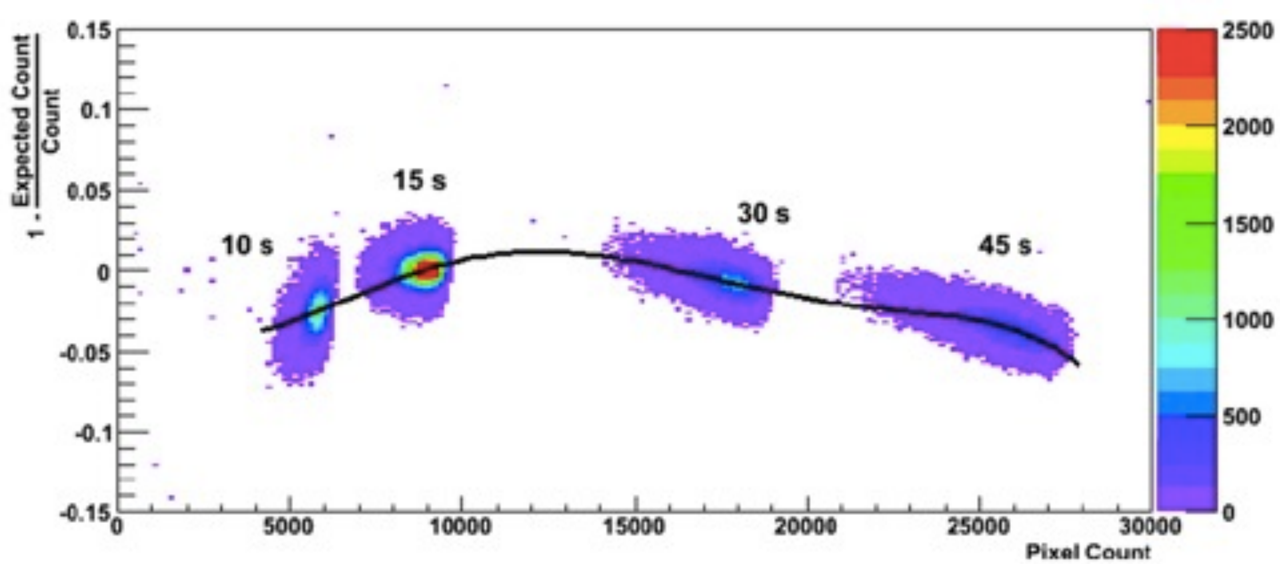
need to be masked -
single exposure

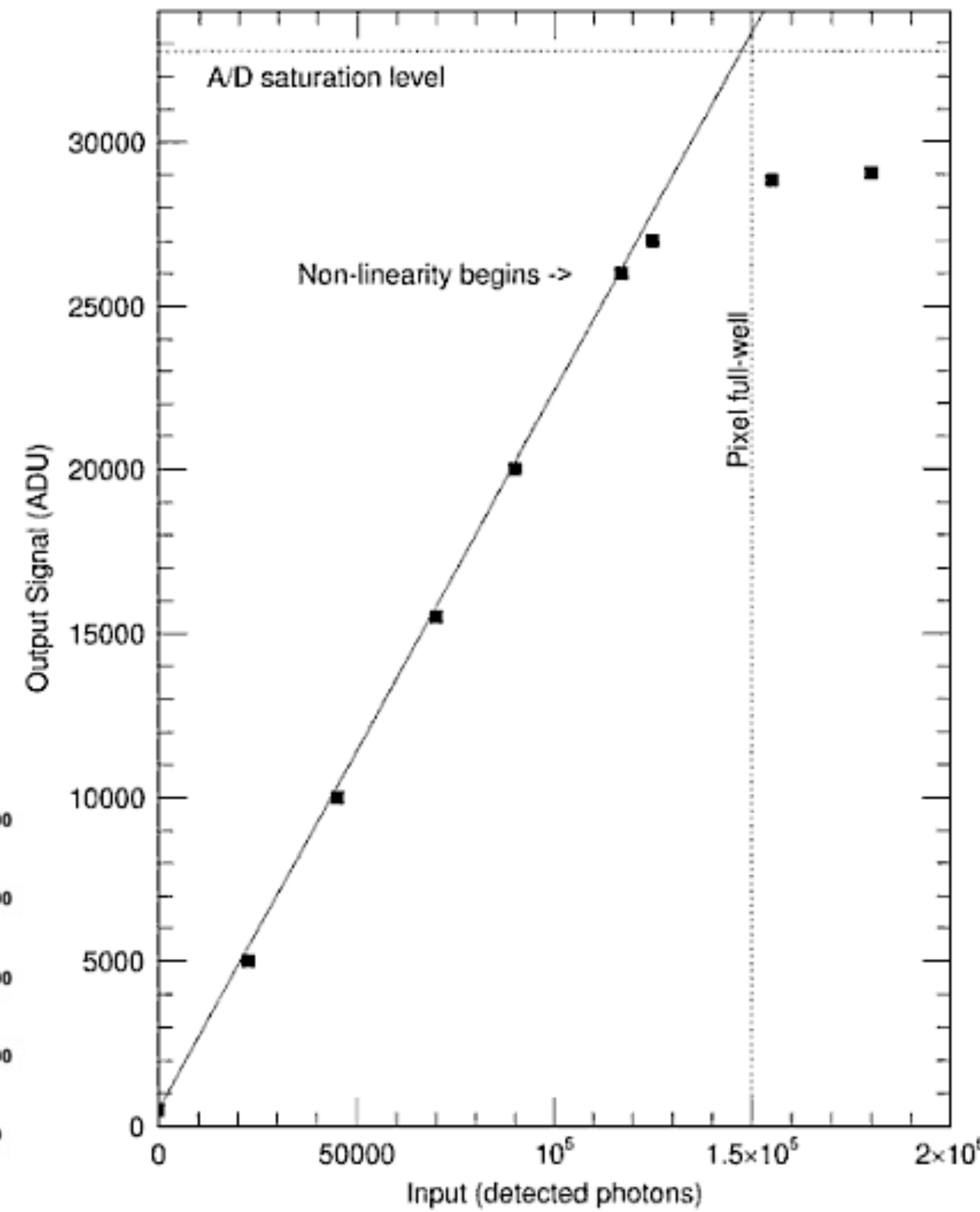


Artefacts

non-linearity: even before saturation level is reached, response becomes non-linear

can be measured from dome-flats





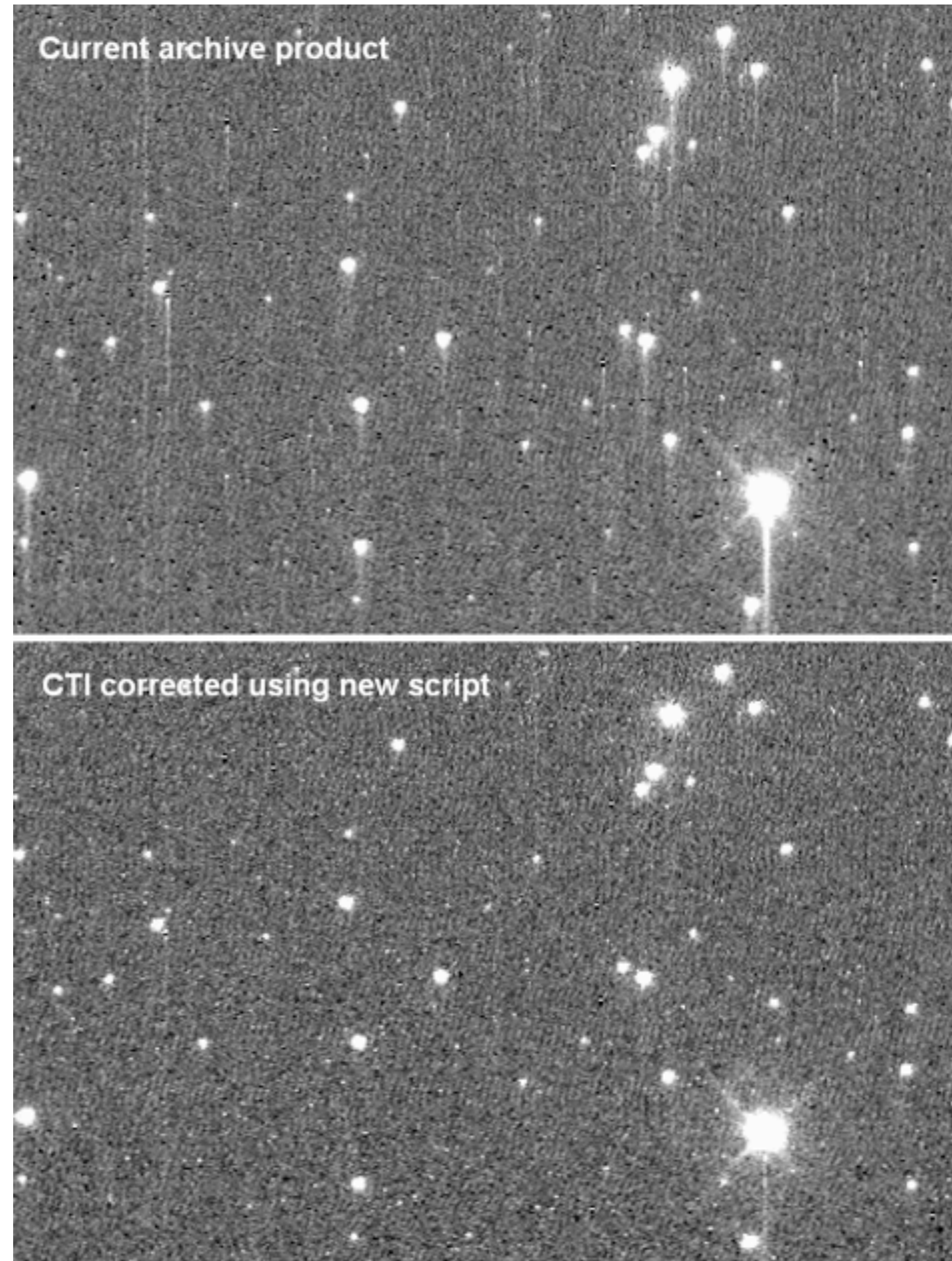
Artefacts

Charge Transfer Inefficiency (CTI): not all electrons are transferred from one pixel to the next during read-out

Charge Transfer Efficiency (CTE): fraction of photons that is transferred

CTI is a significant problem for Hubble's cameras because of radiation damage

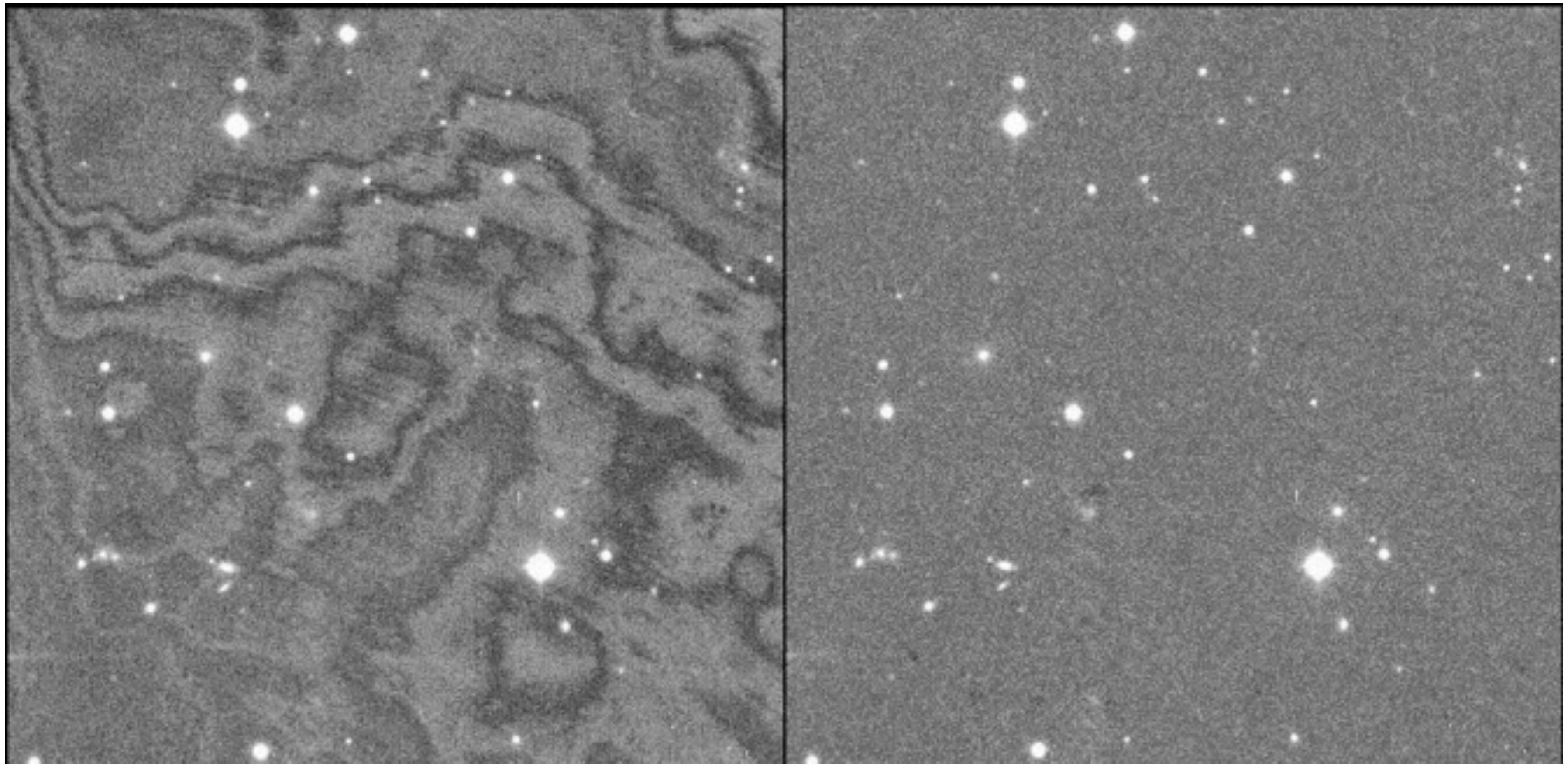
correction based on re-distributing charge



Artefacts

fringing: some light is reflected within the CCDs → leads to interference with incident light

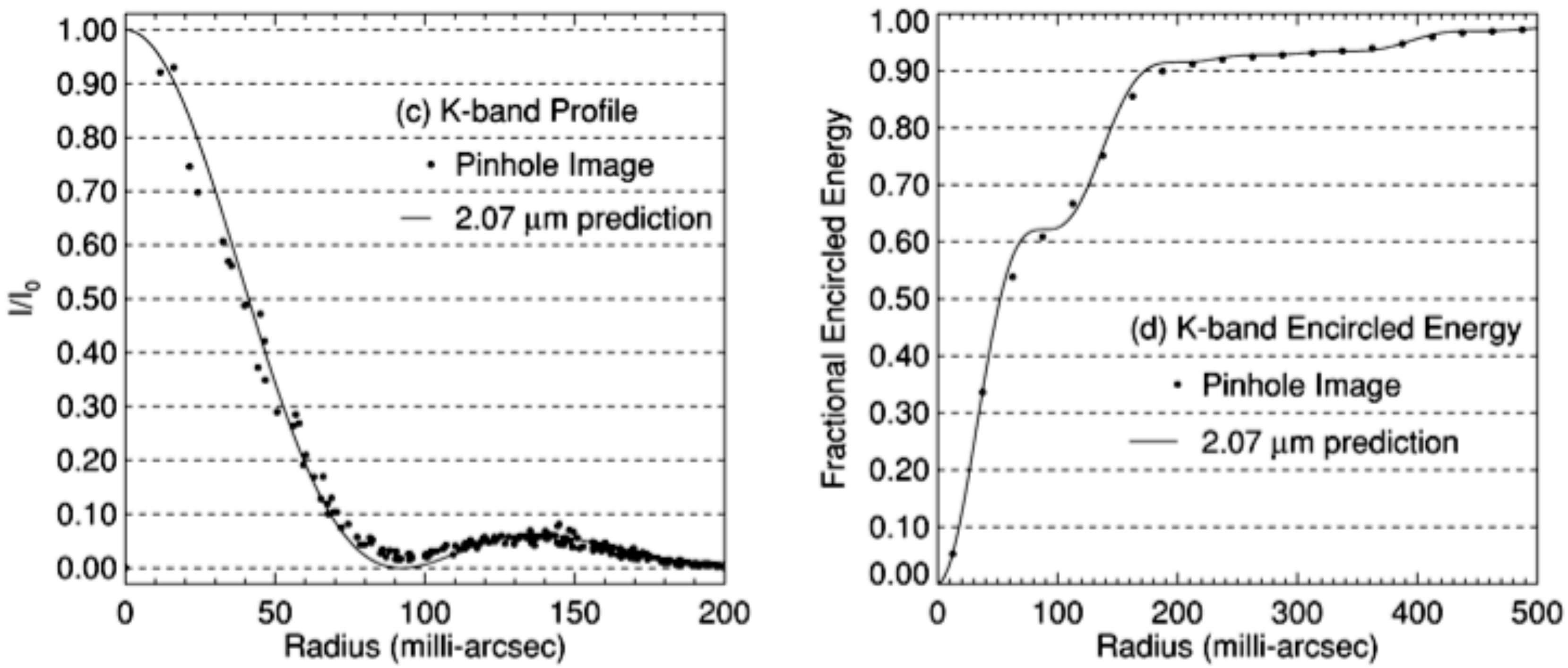
fringing increases with wavelength, and decreases with thickness of CCDs



needs to be modeled; e.g. by subtracting a heavily smoothed image

Aperture Magnitudes

the light of each object is distributed over many pixels, need to measure flux by integrating over these pixels



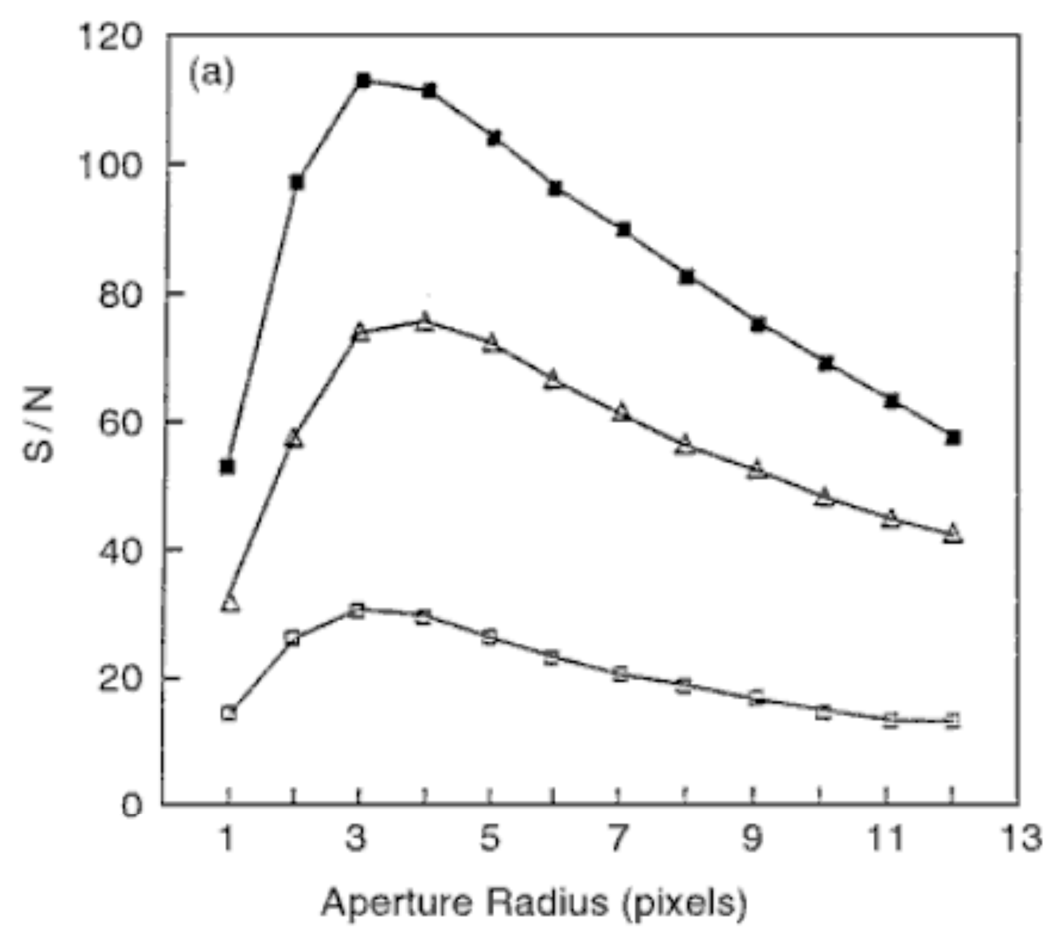
point spread function (PSF): shape of the light distribution of a point source (star)

Aperture Magnitudes

the larger the aperture, the more light from the source is captured

but also: pixels far from the center have a lot of counts from the sky background, and little flux from the object
→ contribute mainly noise

need to optimize the aperture in which to measure



Signal-to-Noise

signal S = total counts - background counts

noise contributions:

- shot noise from source $N_{\mathrm{object}} = \sqrt{S} = \sqrt{s_{\mathrm{object}} \times t}$
- sky noise $N_{\mathrm{sky}} = \sqrt{S_{\mathrm{sky,total}}} = \sqrt{\mathrm{n_{pix}} \times \mathrm{s_{sky,pixel}} \times \mathrm{t}}$
- dark current noise $N_{\mathrm{dk}} = \sqrt{\mathrm{n_{pix}} \times \mathrm{s_{dk}} \times \mathrm{t}}$
- read-out noise ($\sqrt{n_{e^-}}$)

$$N_{\mathrm{ro}} = \sqrt{\mathrm{n_{pix}} \times \mathrm{RON}^2} = \mathrm{RON} \times \sqrt{\mathrm{n_{pix}}}$$

Signal-to-Noise

total signal-to-noise: can add noise components quadratically

$$
\begin{aligned}
SNR &= \frac{S}{N_{\mathrm{total}}} \\
&= \frac{S}{\sqrt{N_{\mathrm{object}}^2 + N_{\mathrm{sky}}^2 + N_{\mathrm{dk}}^2 + N_{\mathrm{ro}}^2}} \\
&= \frac{s_{\mathrm{object}} \times t}{\sqrt{s_{\mathrm{object}} \times t + n_{\mathrm{pix}} \times s_{\mathrm{sky}} \times t + n_{\mathrm{pix}} \times s_{\mathrm{dk}} \times t + n_{\mathrm{pix}} \times \mathrm{RON}^2}}
\end{aligned}
$$

“CCD signal-to-noise equation”

Signal-to-Noise

in general, you do not want to be limited by dark current and read-out noise!

limiting case1: very bright object $N_{\rm object} >> N_{\rm other}$

$$SNR = \frac{S}{N_{\rm object}} = \frac{s_{\rm object} \times t}{\sqrt{s_{\rm object} \times t}}$$

$$= \sqrt{s_{\rm object} \times t} \propto \sqrt{t}$$

Signal-to-Noise

in general, you do not want to be limited by dark current and read-out noise!

limiting case 2: faint objects $N_{\rm sky} >> N_{\rm other}$

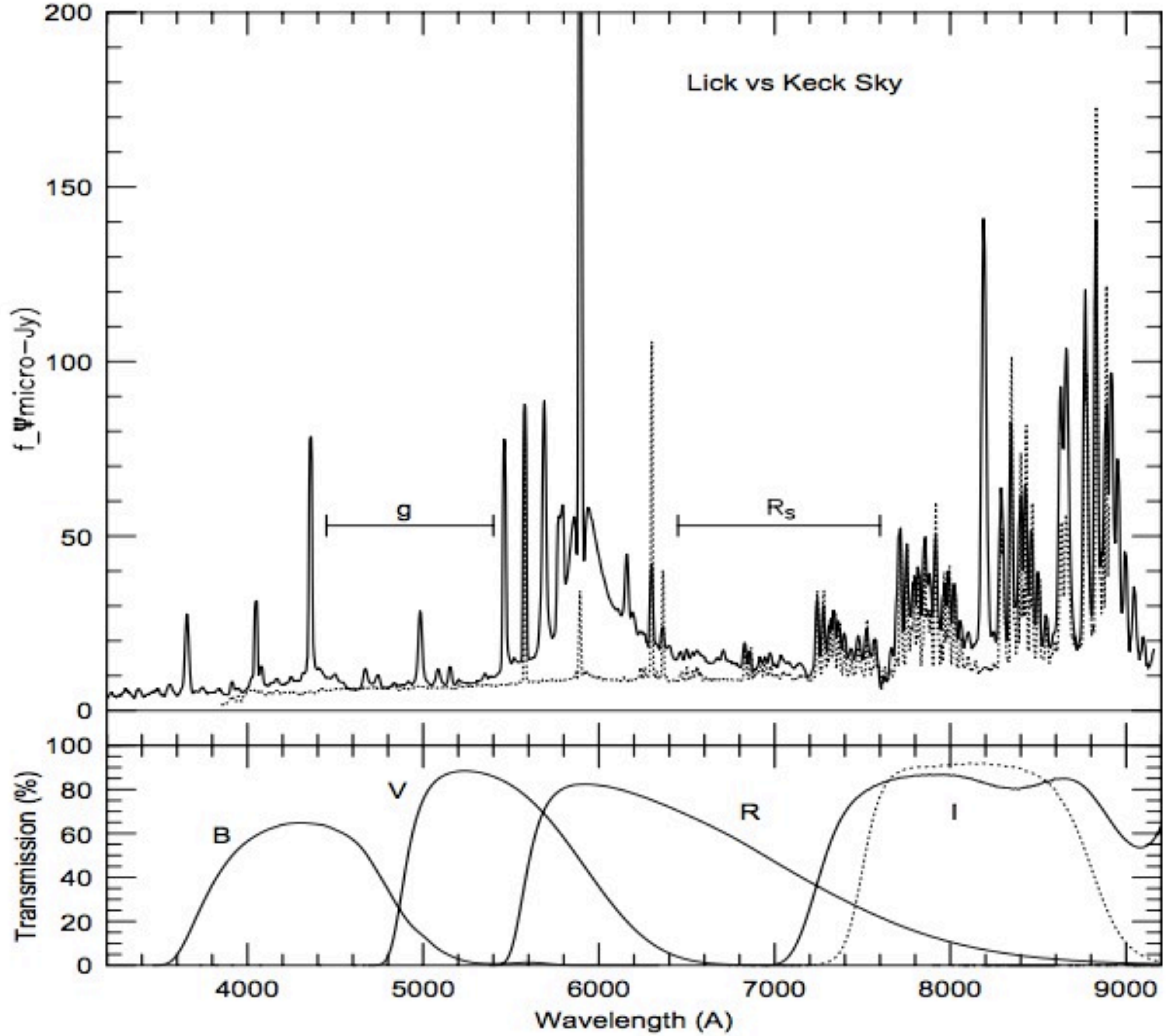
$$SNR = \frac{S}{N_{\rm sky}} = \frac{s_{\rm object} \times t}{\sqrt{s_{\rm sky} \times n_{\rm pix} \times t}} \propto \sqrt{t}$$

Sky Background

limits most astronomical observations!

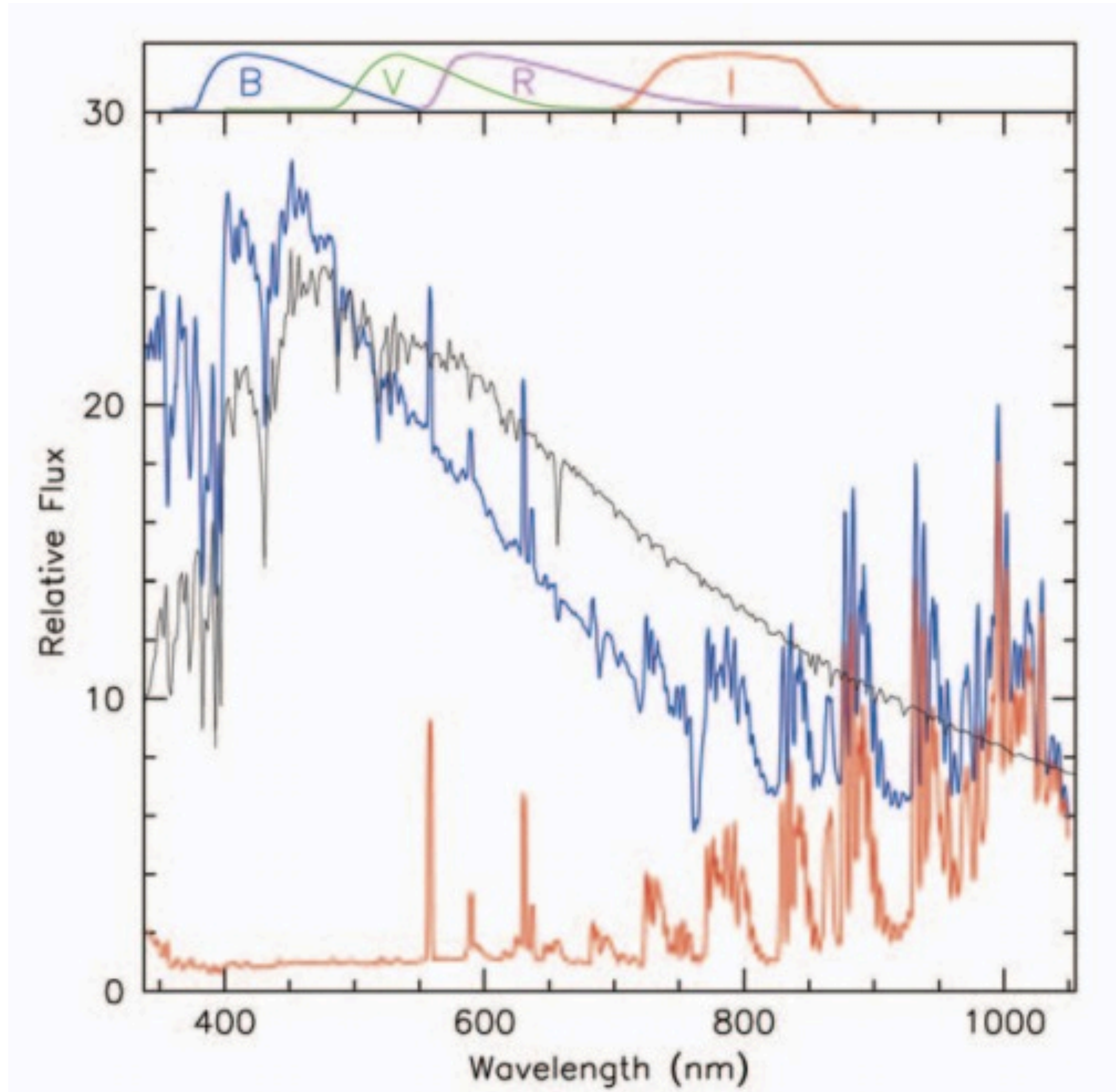
always present:
emission from
atmosphere

(+city lights)



Sky Background

moonlight: not a big problem in the infrared; detrimental in the very blue



Sky Background

twilight:

Sun at -6° : "civil twilight", still bright

Sun at -12° : "nautical twilight", can see bright stars

Sun at -18° : "astronomical twilight"

twilight is scattered light (blue)

observations in different filters are affected differently

sky is "dark" in red filters before -18°

Exoplanet Lab

Time-series photometry

1. you will take many observations of the same objects
2. determine the aperture within which to measure the flux
3. measure the flux of the target star, plus comparison stars
4. plot (relative) magnitude as function of time

Preparation

1. calculate the FOV of the camera (look up the telescope manual and camera manual on the old course webpage)

2. make appropriate finder charts, using e.g. https://www.aavso.org/apps/vsp/

3. double-check transit times; did you take heliocentric corrections into account?

4. read the instructions on how to operate the camera: http://www.astro.sunysb.edu/anja/PHY517_AST443/quick-start_guide_to_CCDSoft.pdf

At the Telescope

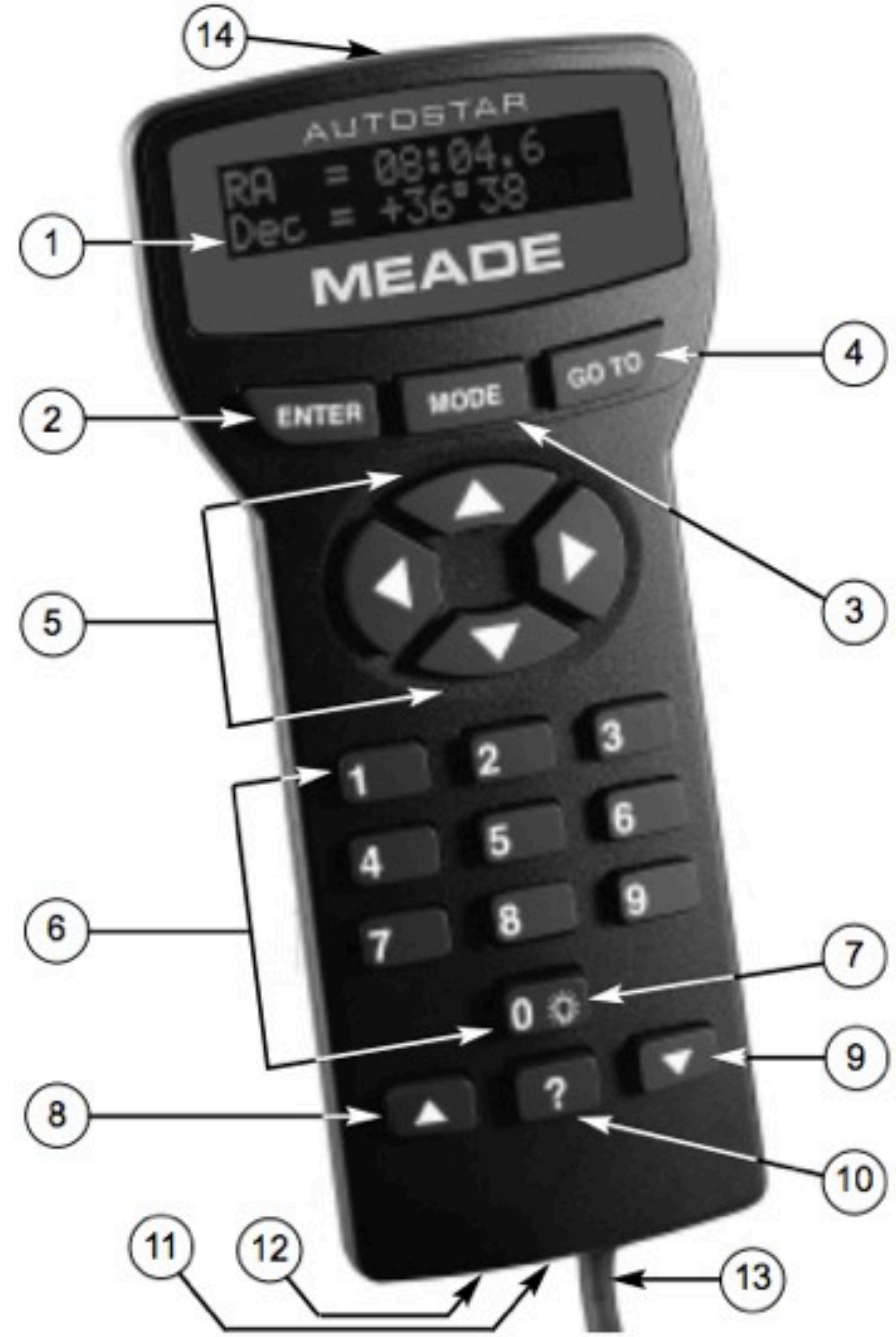
1. take all the necessary calibration date, before and/or after your observations!
2. we will try to get the autoguider to work...
3. make sure the telescope is tracking correctly
4. remember to move the dome!

Telescope Start-Up Procedure

1. open both doors (use the cord)
2. light switches are by the doors, both white and red
3. switch on power to the dome
4. open the top shutter
5. open the bottom shutter
6. when shutters are fully open, take off telescope cover / caps
7. plug in telescope power cord
8. switch on the mount (on/off at base)

The Hand Panel

- Enter / Mode / scroll up/down keys (2/3/8/9): navigate the menu (mode → "back")
- GoTo new object: select in menu, press Enter, then press GoTo
- GoTo coordinates: "User Object"
- Arrow keys: slew in RA (left/right) or Dec (up/down)
- Change slew speed: press 1, use scroll up/down to change



http://www.meade.com/downloads/dl/file/id/27/product/0/497_autostar_computer_controller_manual.pdf

Telescope Telescope Shut-Down Procedure

1. **PARK the telescope** (hand panel → utilities)
2. switch off the drives
3. unplug telescope power
4. replace telescope caps / cover
5. close bottom shutter
6. close top shutter
7. **switch off power for the dome**
8. fill out observing logbook
9. turn off all lights / close all doors