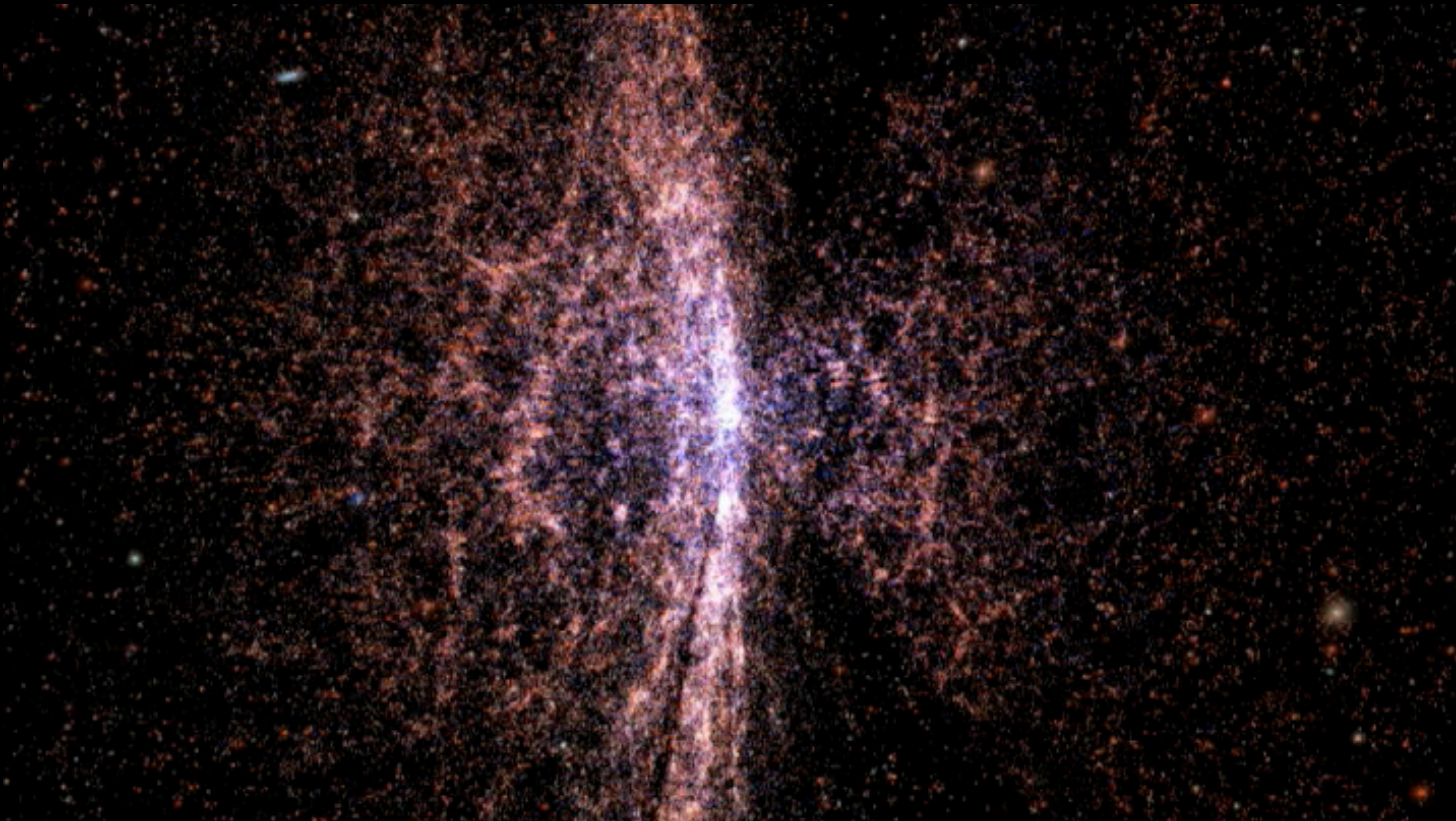
Overview of Optical Data

Lindsey Bleem
Argonne National Laboratory

CMB-S4 Summer School
Aug 18, 2021



"Optical/NIR" Surveys typically cover wavelengths of ranges 0.3-1.2 um

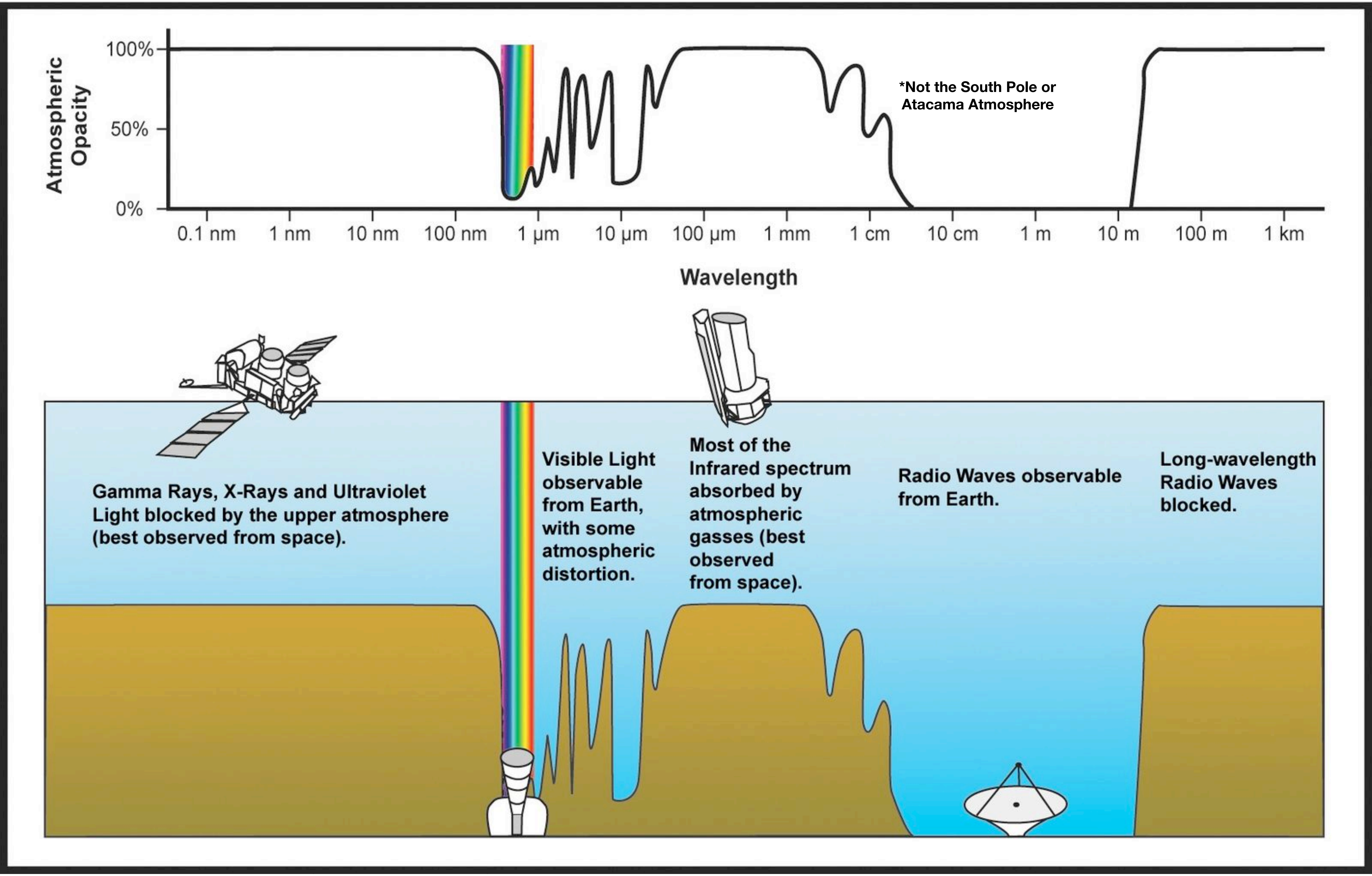
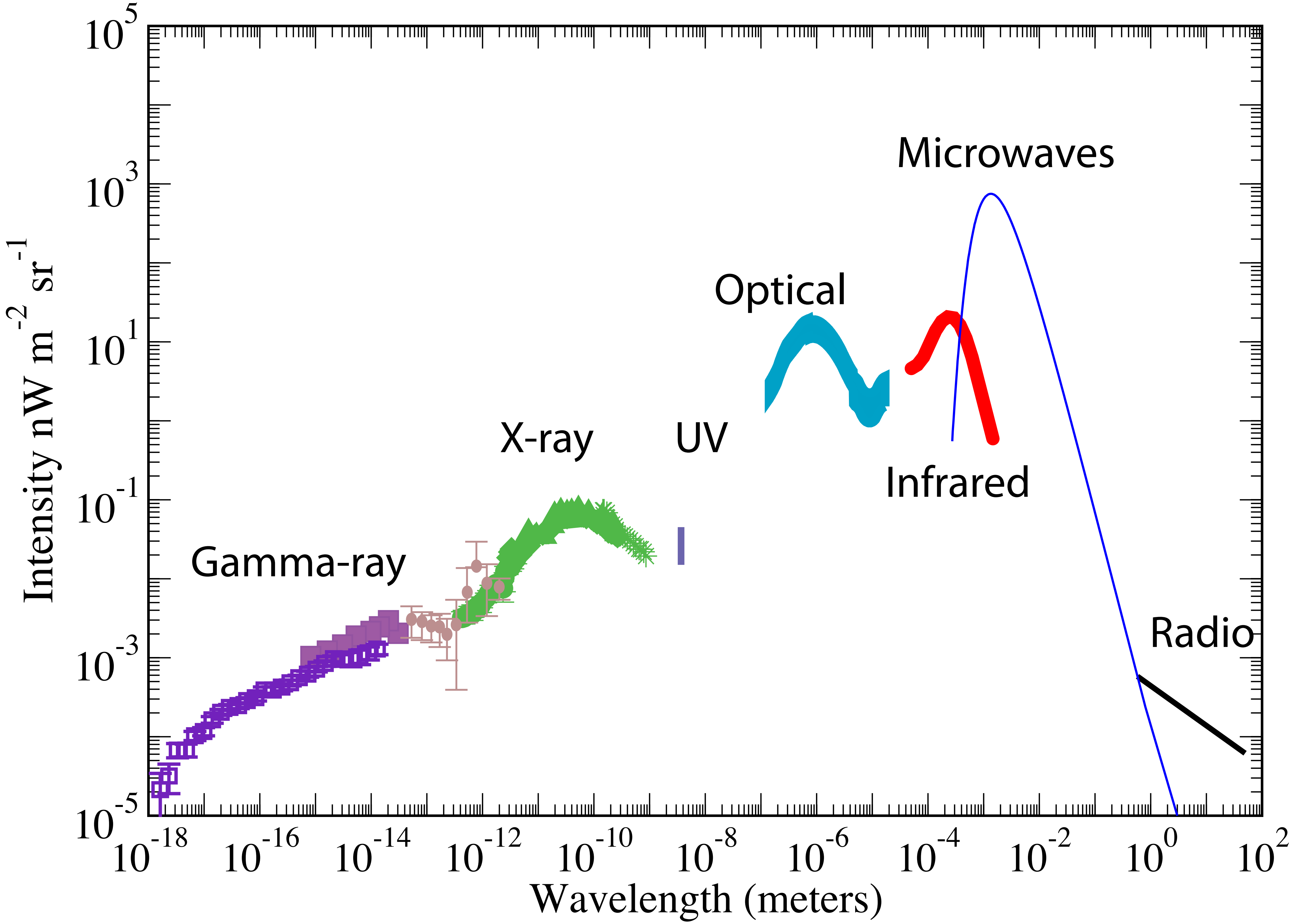


Image Credit: NASA



A. Cooray
1602.03512

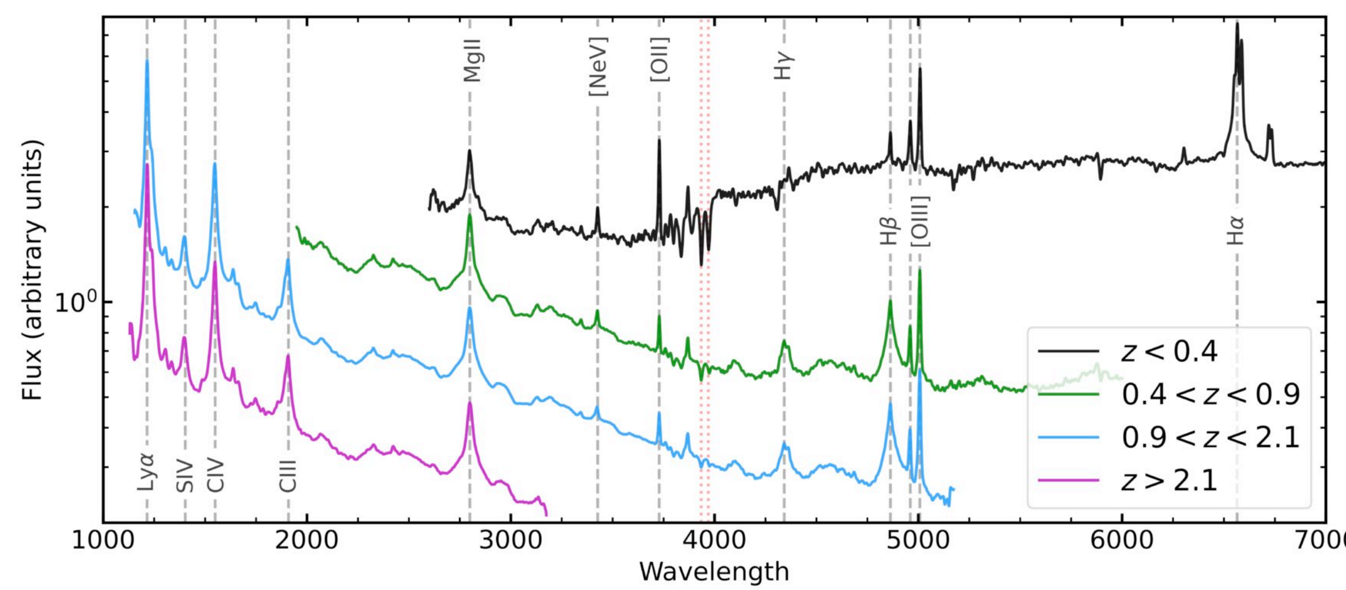
LSST DESC
Dark Energy Science Collaboration

Imaging

DARK ENERGY SPECTROSCOPIC INSTRUMENT

Spectroscopic

(Deep Lens Survey)



(Victoria Fawcett,DESI)

LSST DESC
Dark Energy Science Collaboration

Imaging

DARK ENERGY SPECTROSCOPIC INSTRUMENT

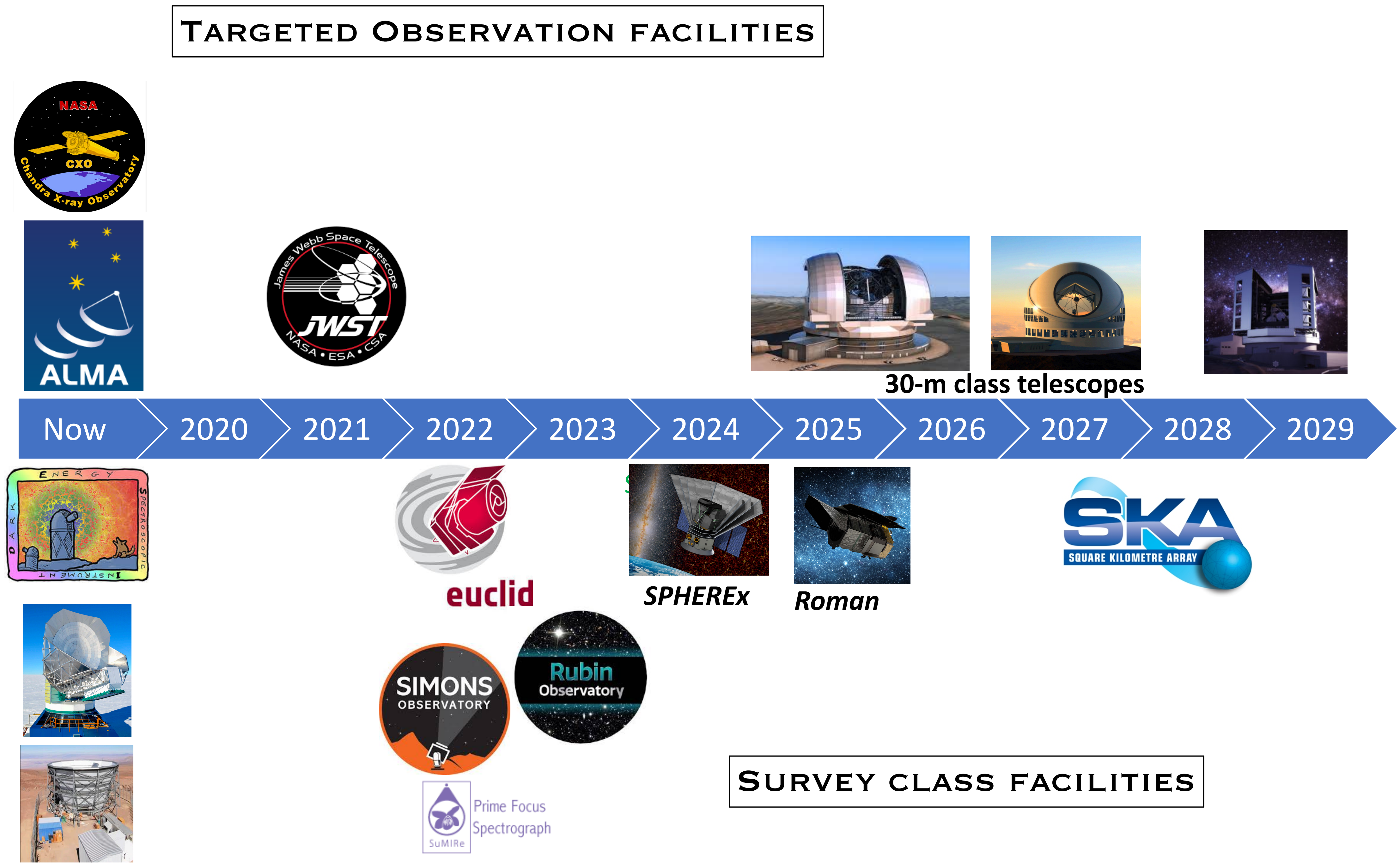
Spectroscopic

LSST DESC Science Roadmap

Version v2.5

The SRM is structured around the working groups in the Collaboration: those focused on primary cosmological probes (weak and strong gravitational lensing, large scale structure including galaxy clustering and baryonic acoustic oscillations, galaxy clusters, and Type Ia supernovae) and those that provide essential inputs to enable the primary probe analyses. For each, the SRM lays out a set of key research priorities. The deliverables that make up the simulation, processing and analysis pipelines and related software infrastructure are organized into key products for each working group.

https://lsstdesc.org/assets/pdf/docs/DESC_SRM_latest.pdf



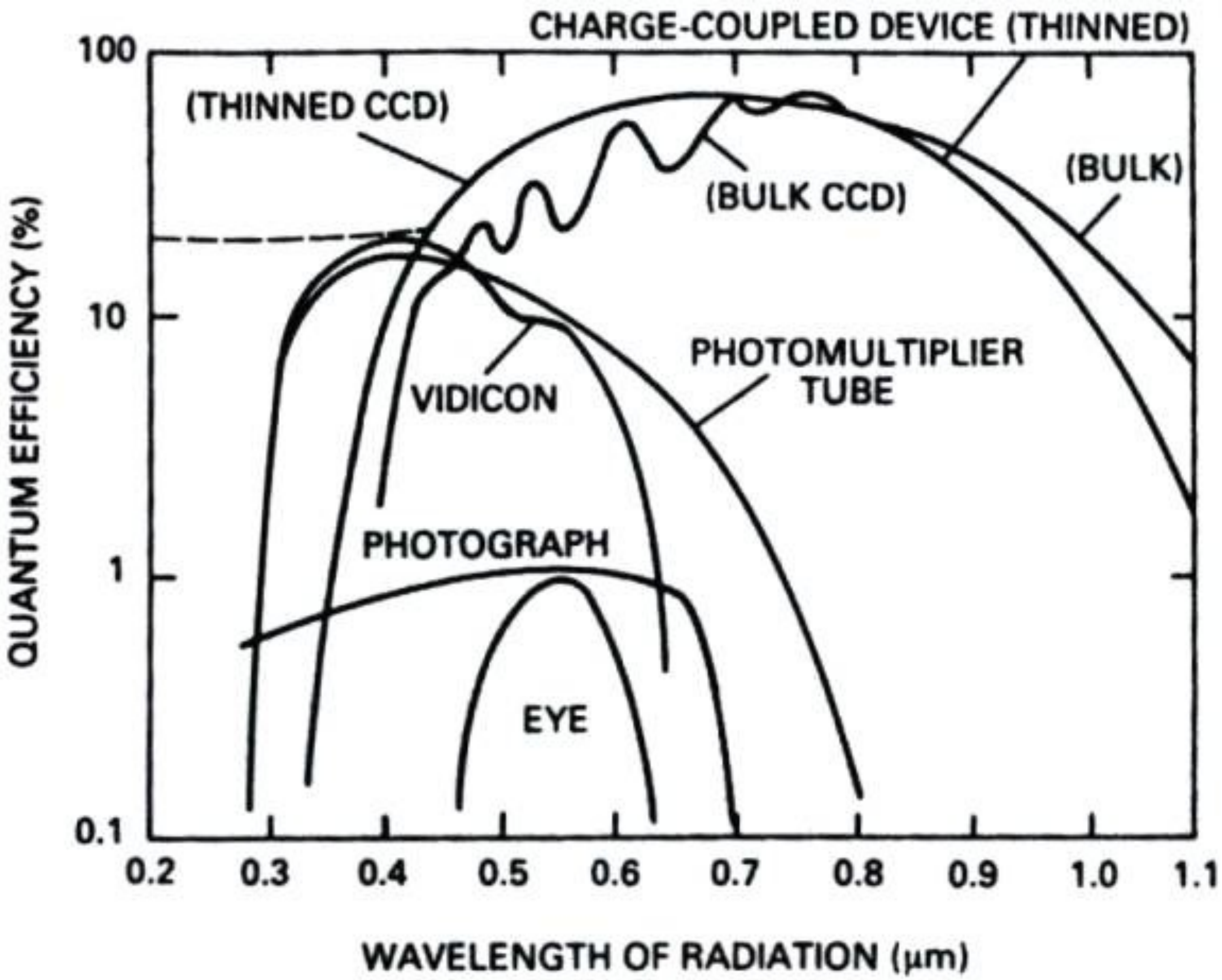
L Bleem & A Gonzalez

CMB-S4 Summer Collaboration Meeting
Aug 12th 2020

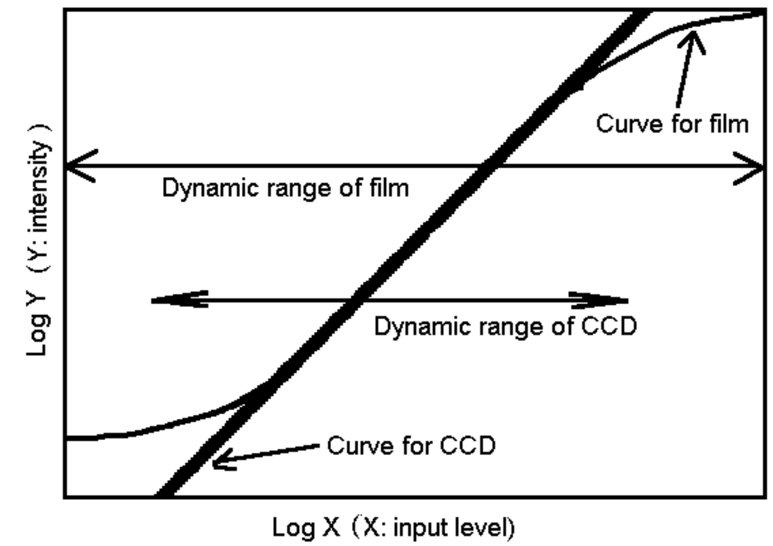
How do we measure this? (Part 1)

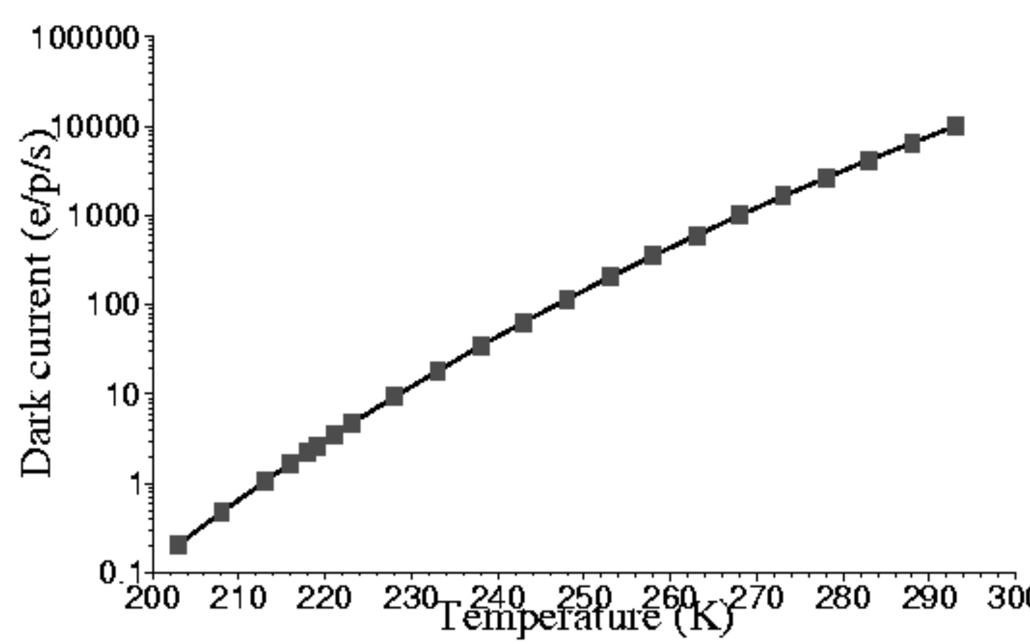
There are a lot of high level similarities between how optical and CMB instruments have evolved.

I.S. McLean, 1997, *Electronic Imaging in Astronomy – Detectors and Instrumentation*



Linearity

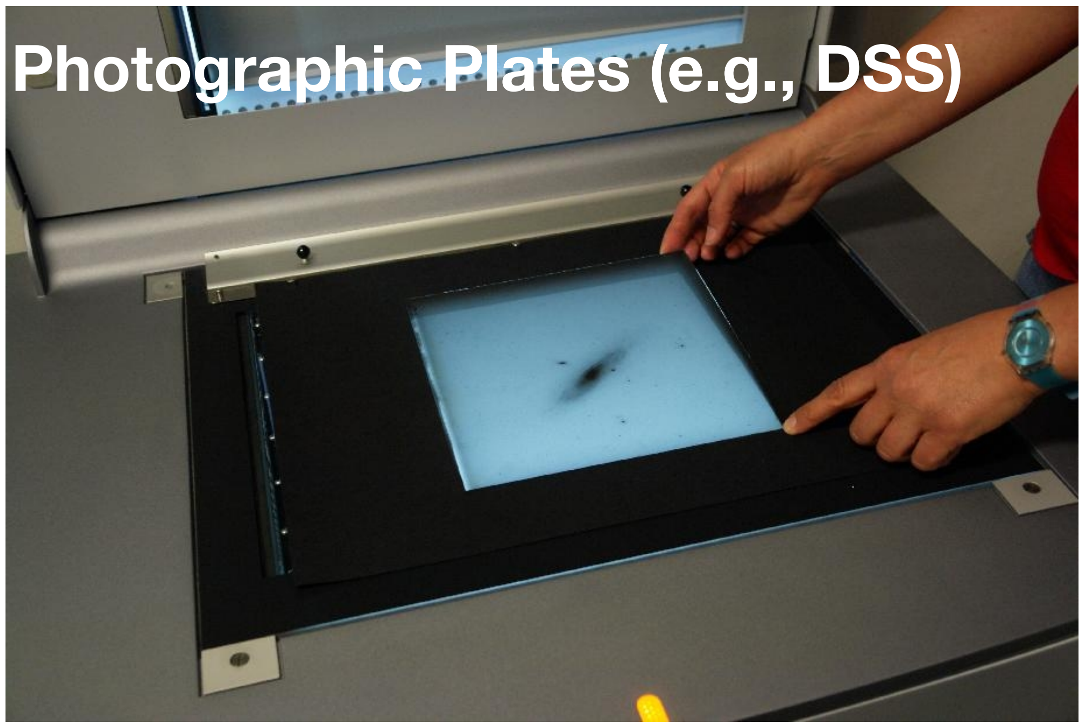


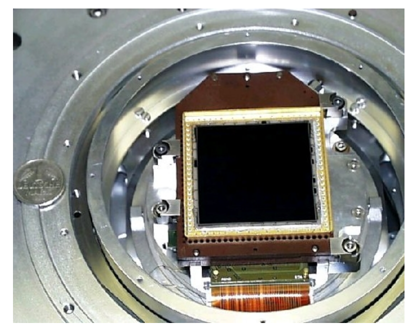


At the base our fundamental detector unit, the CCD, has excellent absorption properties, low noise (when cooled), and is very linear over a wide dynamic range.

A big challenge has been scaling up production of CCD arrays to have high uniformity and in parallel the development of low-noise readout capable of reading out such large arrays very quickly.

Array Size

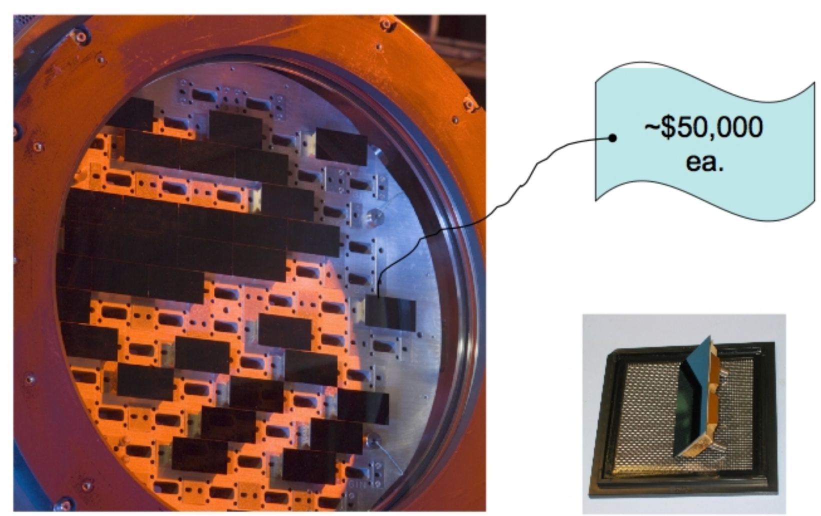




VLT FORS2 CCD

3 Gigapixels, LSST.org

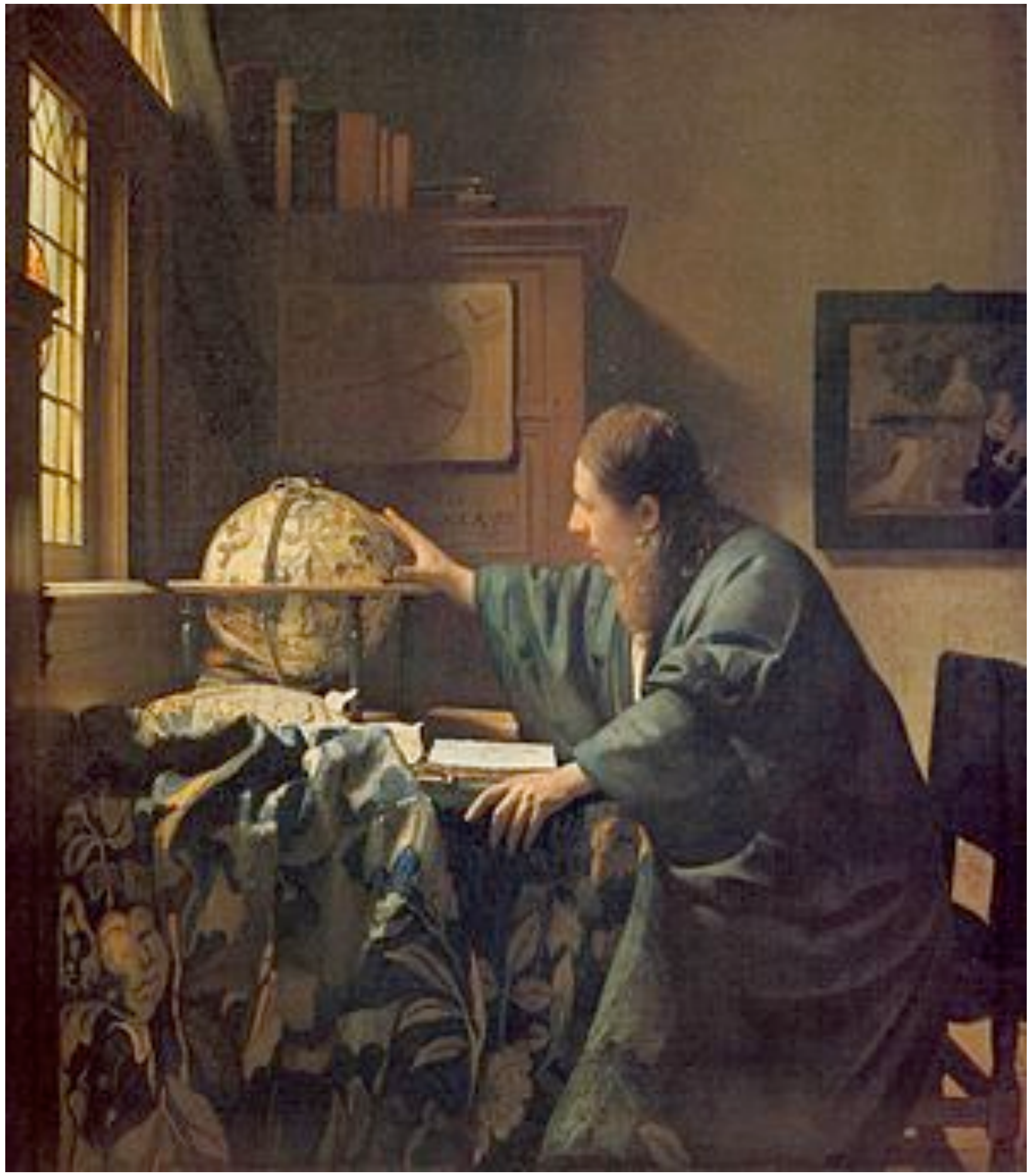
2. How much does a CCD cost?



How do we measure this? (Part 2)

Planning

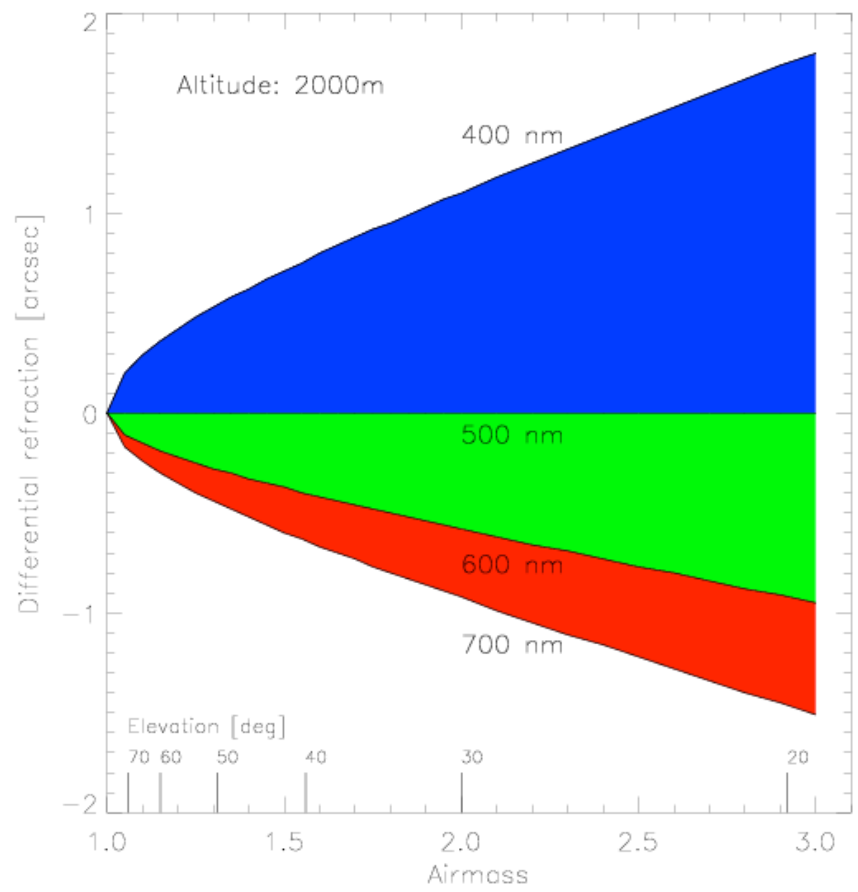
- Target Visibility
- Scientific Objective
  - filter choices
  - lunar phase
  - observation strategy



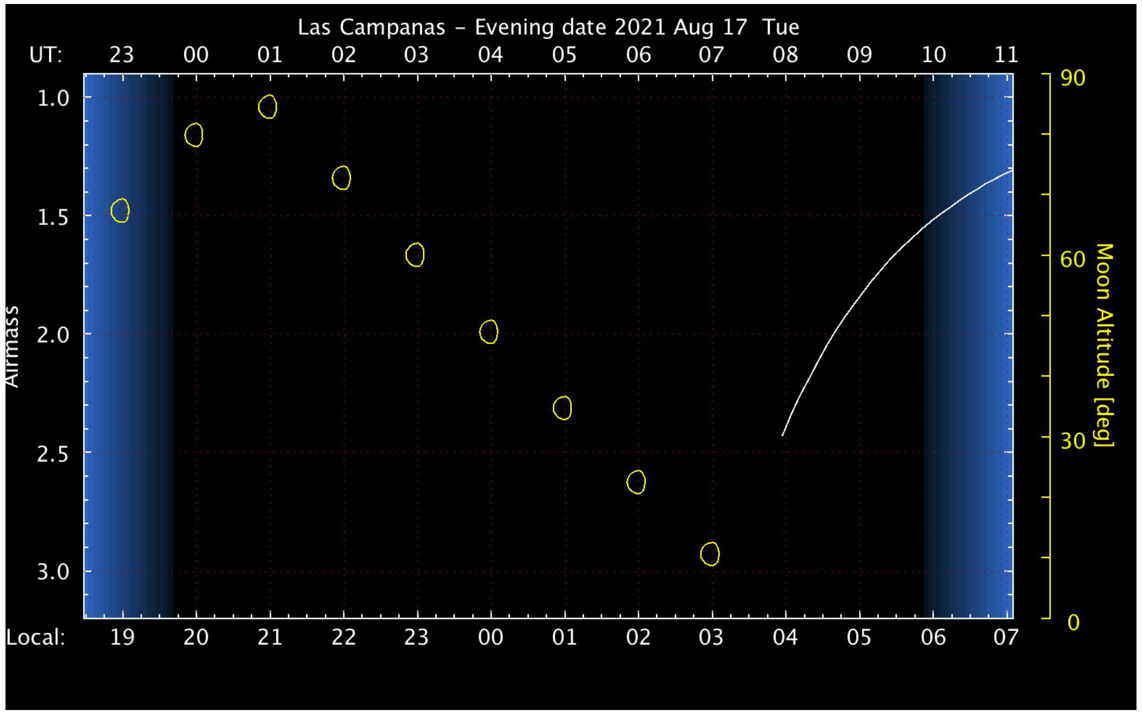
Johannes Vermeer

Target Visibility

- Airmass - path length relative to zenith
- Seeing ~airmass^0.6
- Differential Atmospheric Refraction

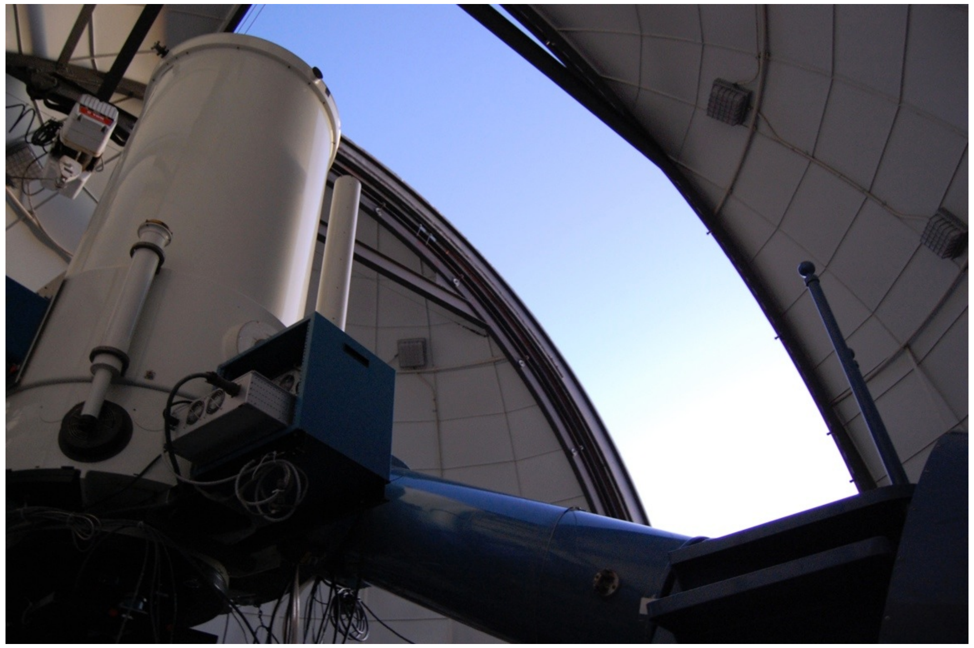


HTTP://WWW.ASTRO.UNI-BONN.DE/~MISCHA/OBSTIPS/AIRMASS.HTML



Observing Plan

- Filter Choice
  - Bright v/s Dark Time
  - Air Glow
  - Dither Strategy



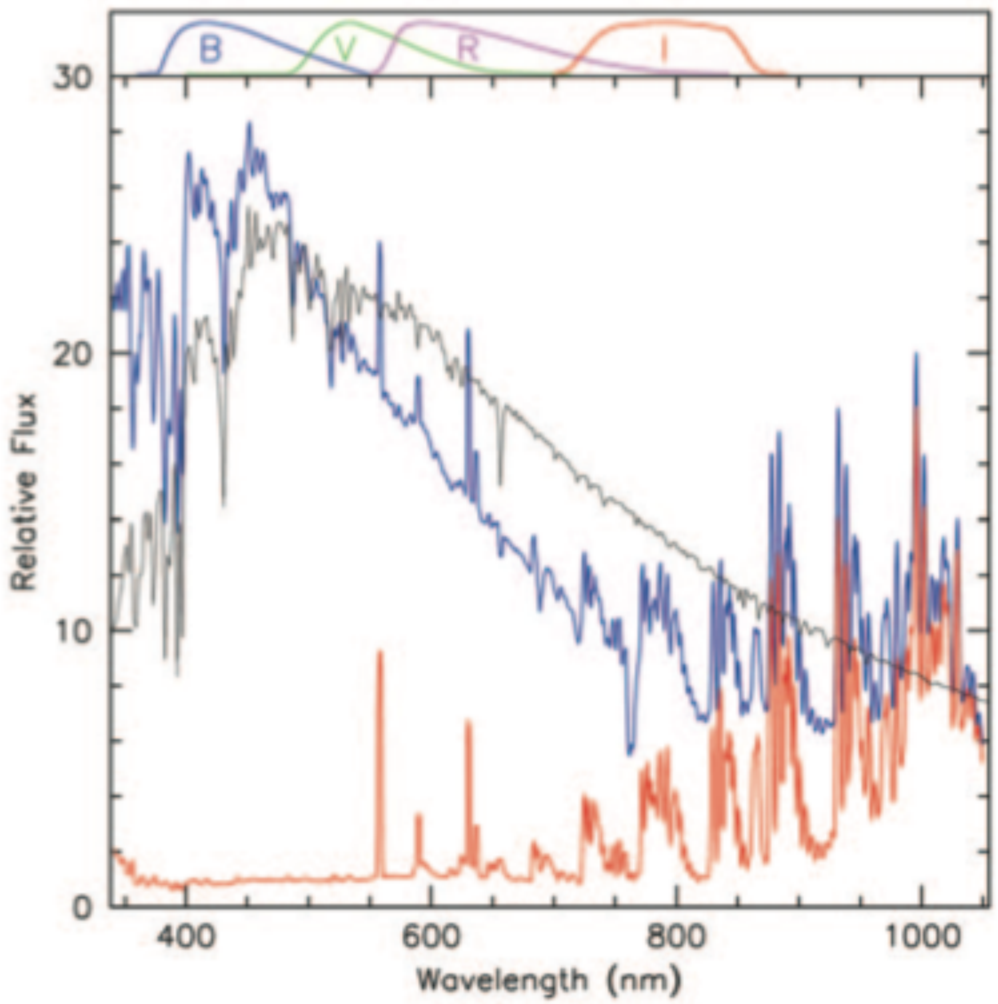
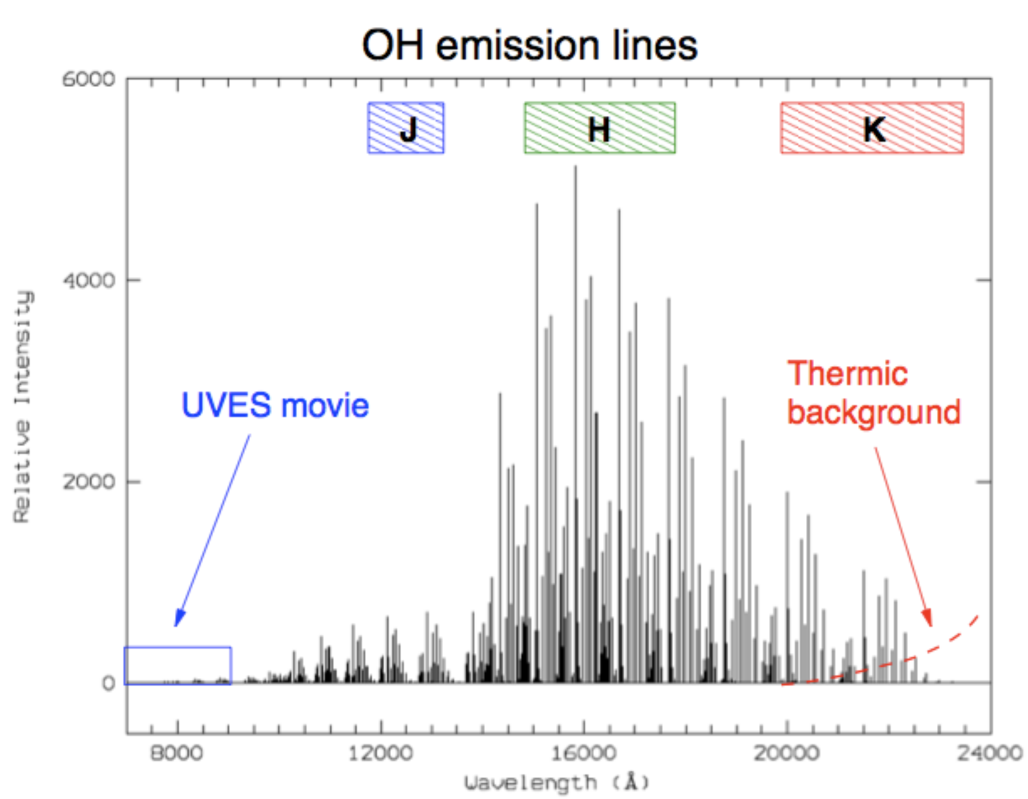


Figure 2: Comparison between the night sky spectrum during dark time (red line, Patat 2003) and bright time (blue line). The latter was obtained with FORS1 on September 1, 2004 using the low dispersion grism 150I and no order sorter filter. Due to the very blue continuum, the spectral region at wavelengths redder than 650 nm is probably contaminated by the grism second order. Both spectra have been normalized to the continuum of the first one at 500 nm. For comparison, the model spectrum of a solar-type star is also plotted (black line). For presentation, this has been normalized to the moonlit night sky spectrum at 500 nm. The upper plot shows the standard *BVRI* Johnson-Cousins passbands.

Patat 2003

Observing Plan

- Air Glow

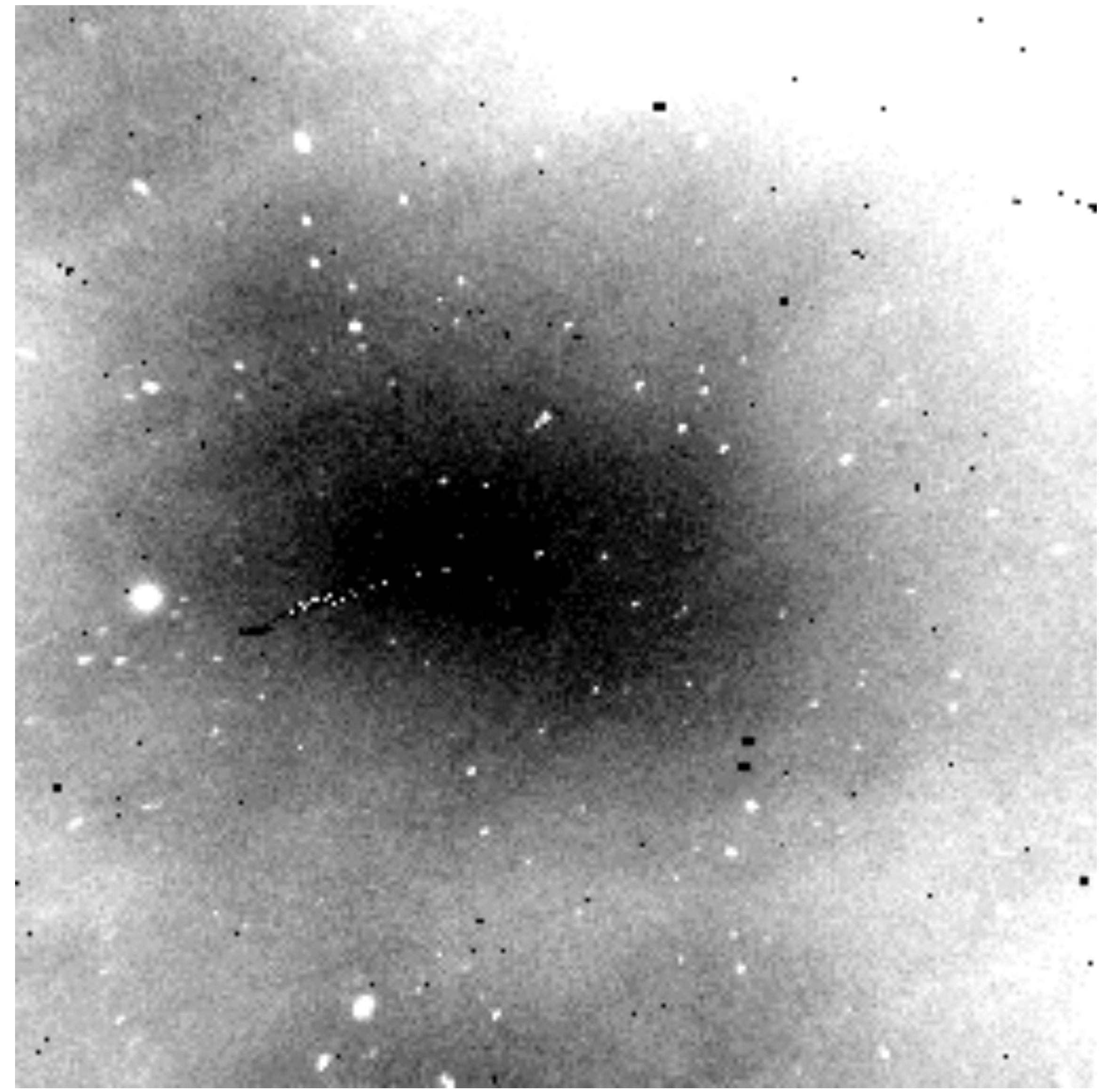


Night sky brightness:
[mag / arcsec^2]

$$B = 22.7$$
$$V = 21.9$$
$$R = 21.0$$
$$I = 20.0$$
$$J = 16.0$$
$$H = 14.5$$
$$K = 13.5$$

Short exposure times:
30, 20, 10s in J, H, K

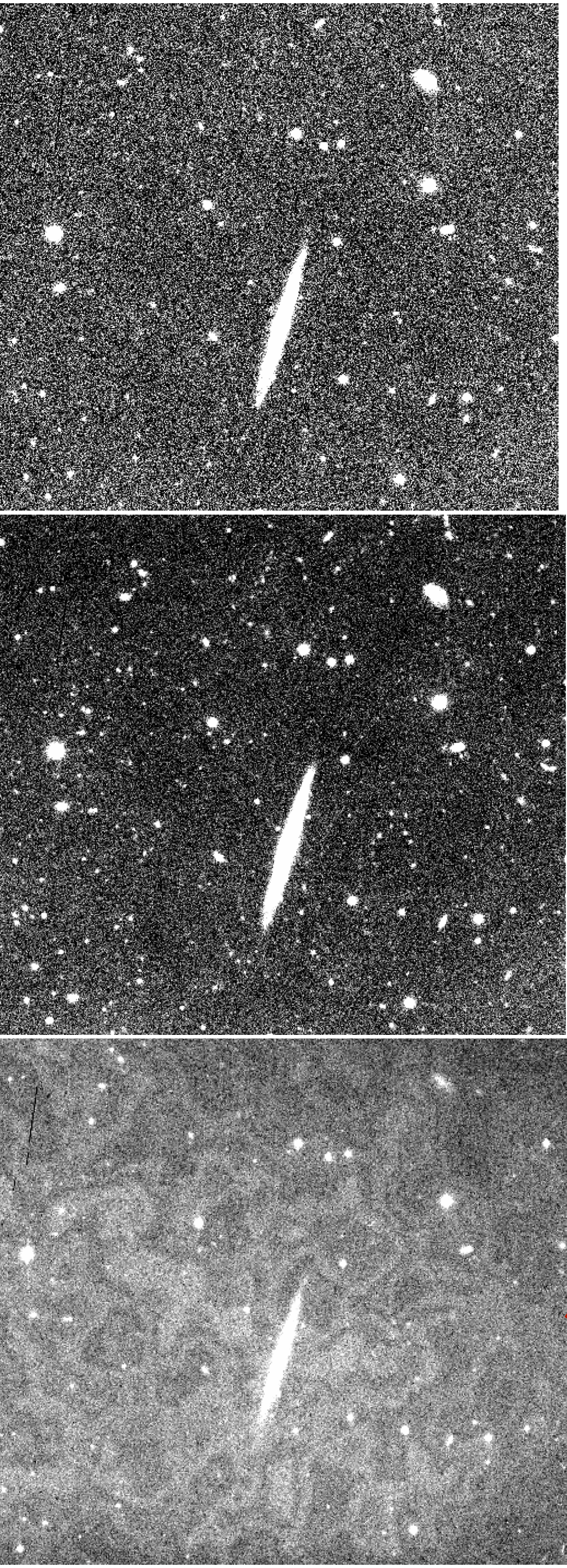
Mischa Schirmer

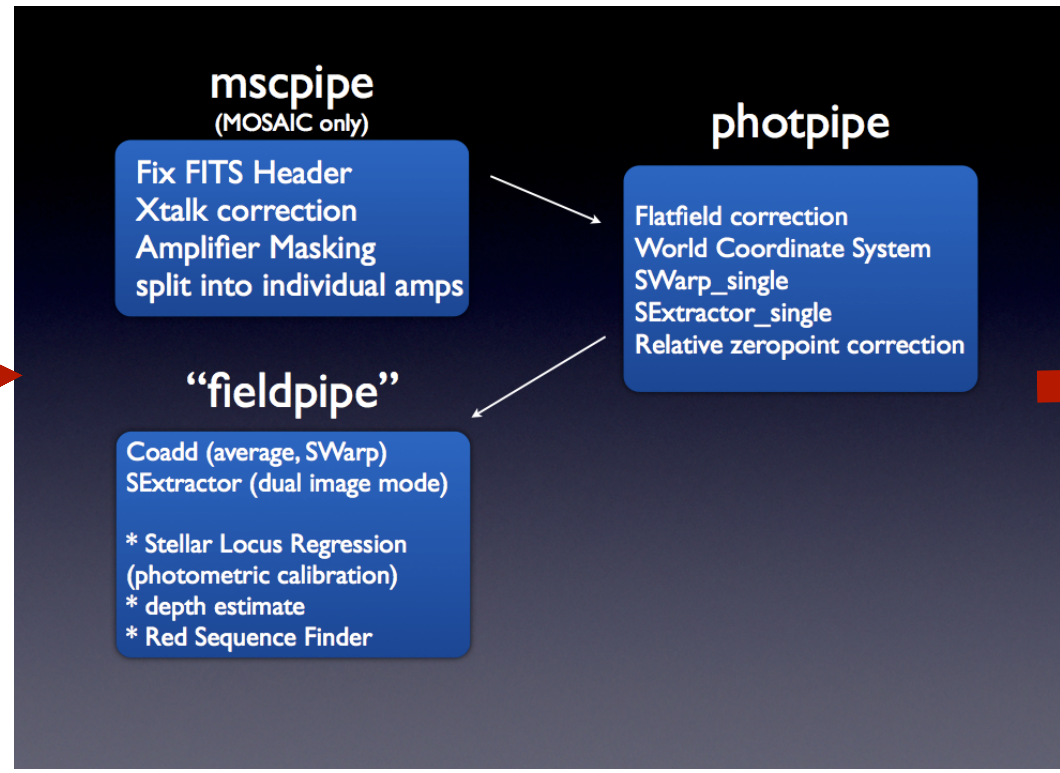


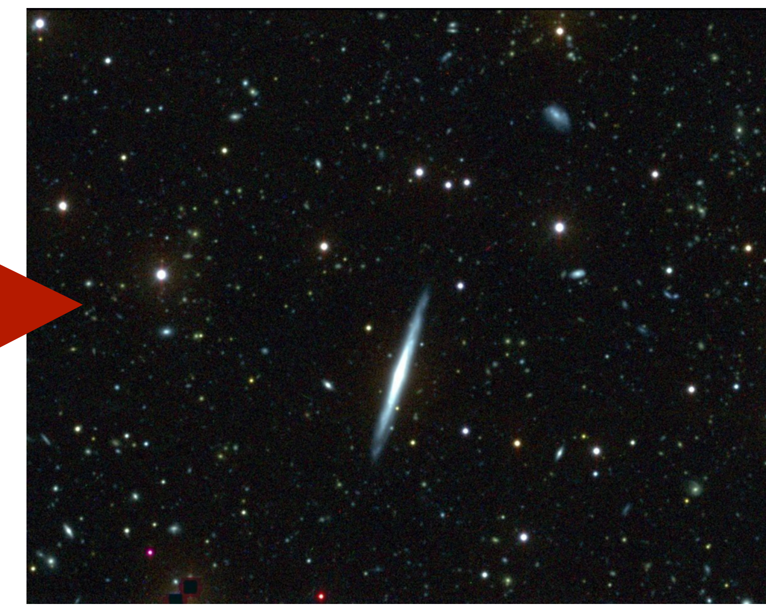
WIDE-FIELD AIRGLOW EXPERIMENT
FOR THE 2-MICRON ALL-SKY SURVEY
(2MASS)

1SEC MOVIE = 7.5 MIN

Blanco Cosmology Survey (80d^2)
>15,000 Individual Exposures
(Including Calibration Files)







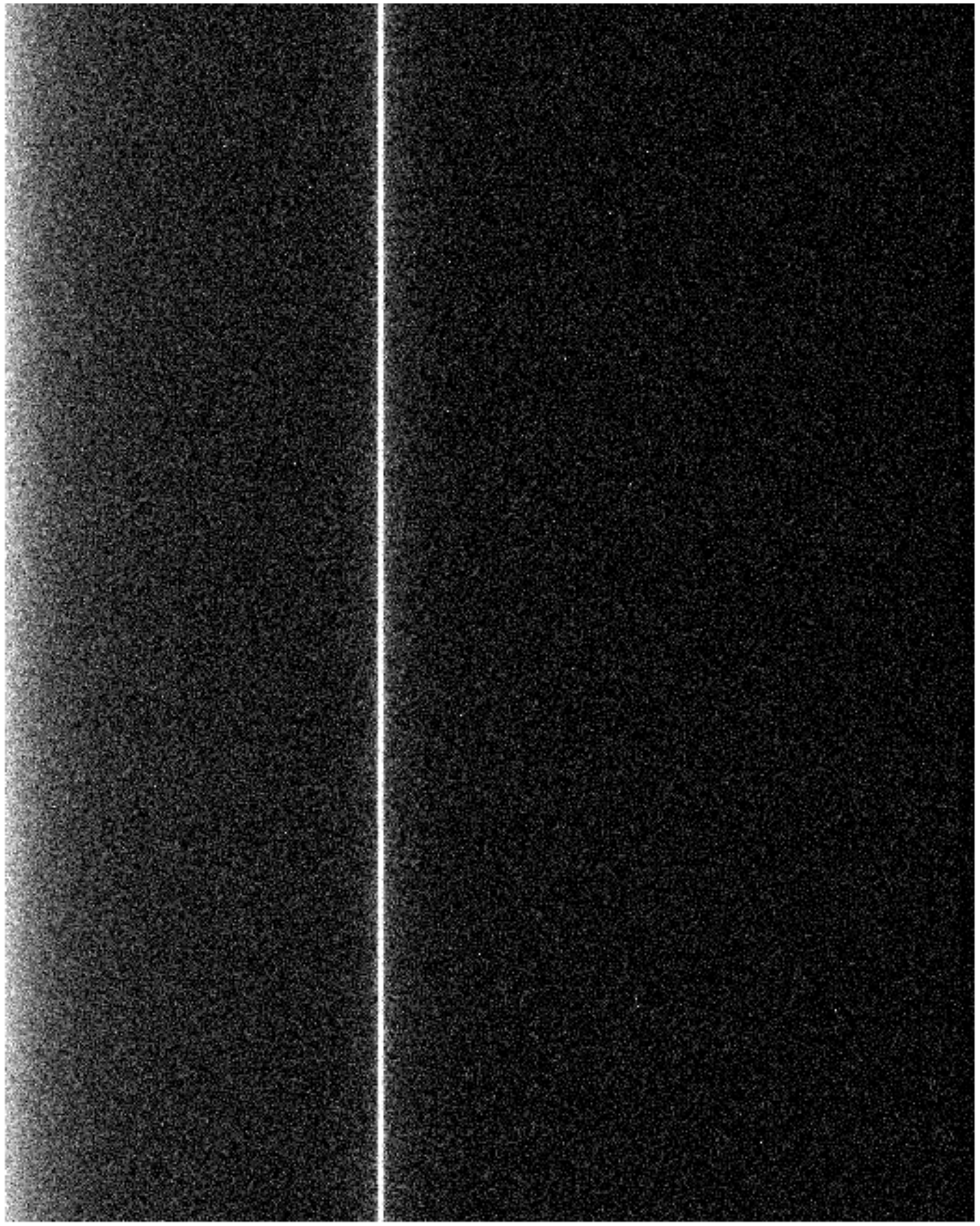
Bleem+2015ApJS..216...20B

Raw Images -> Science

- Calibration Files
  - Bias
  - X-talk corrections (mosaic cameras)
  - Flat Fielding
  - Fringe Frames
- Distortions
  - WCS, PSF

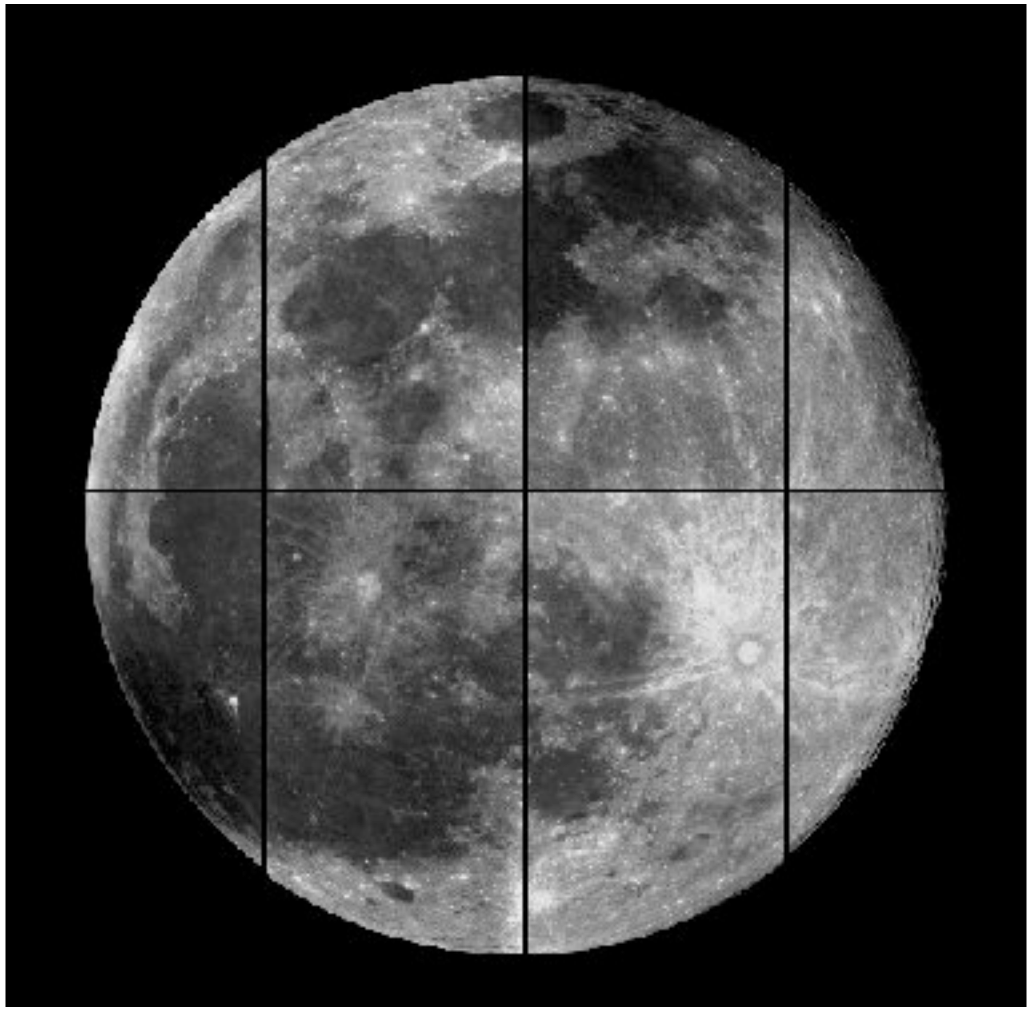
Bias

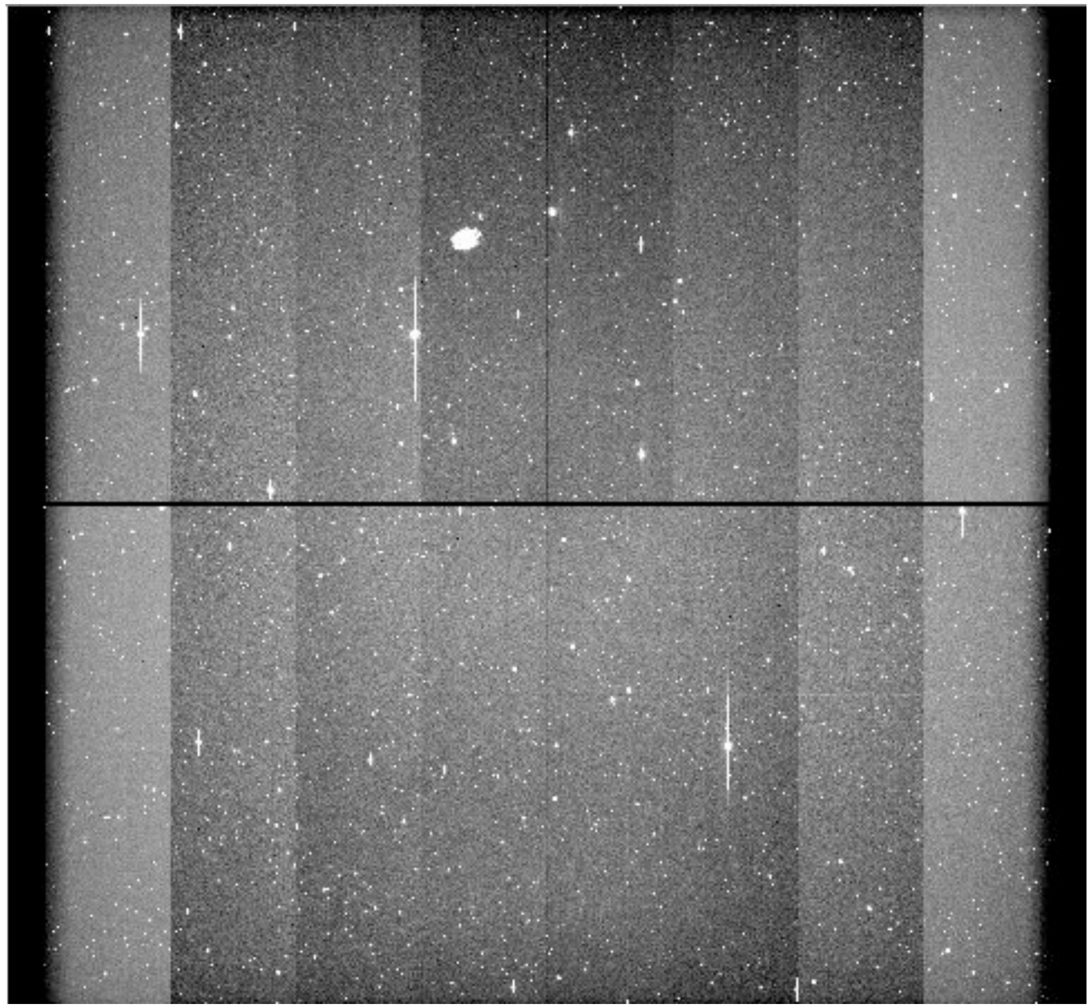
- 0 second (dark) exposures that allow us to correct for pixel to pixel structure in the read noise of an image
- Take a decent number and average to get a master bias that we will then apply to all images for a night.



EXAMPLE BIAS SWOPE 0.9M

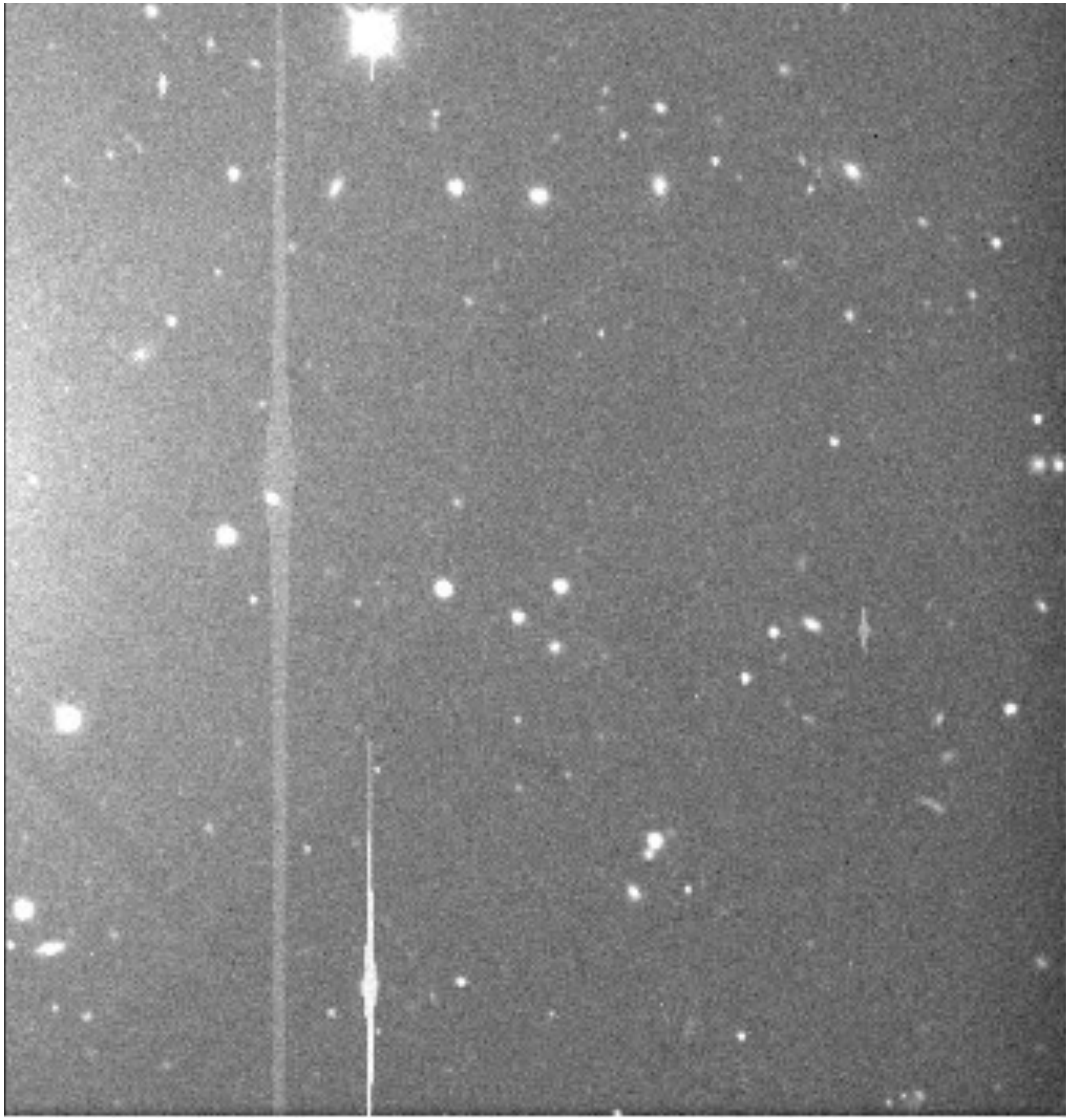
X-Talk Corrections





NOAO MOSAIC I

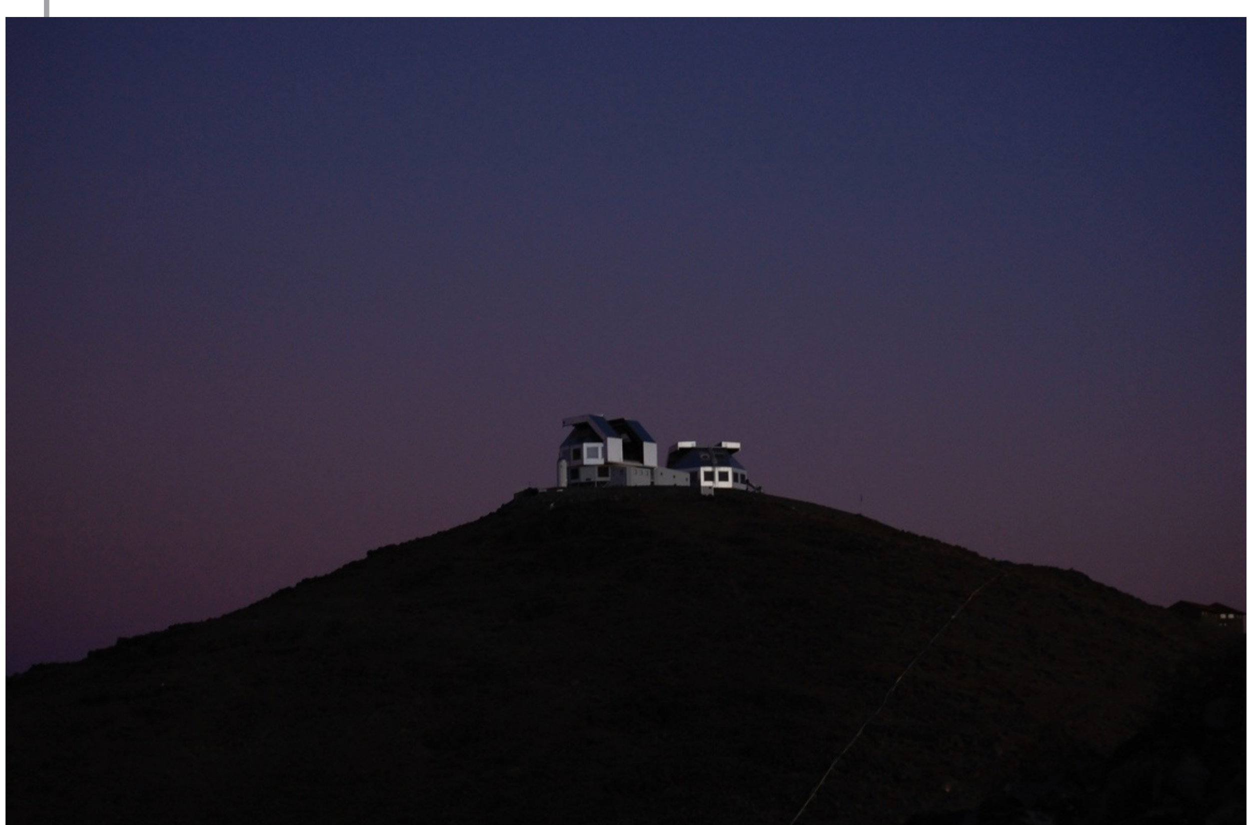
X-Talk Corrections



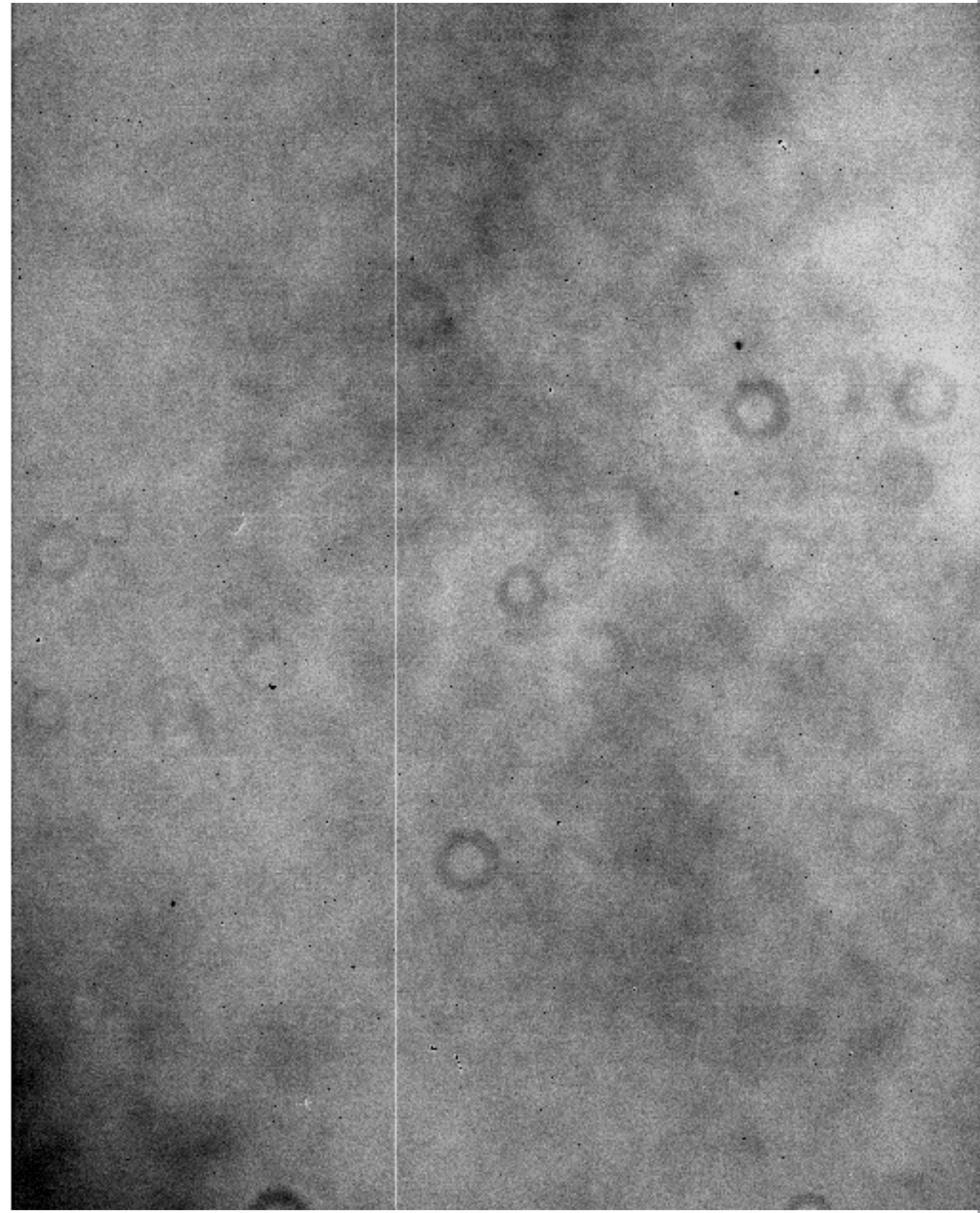
Blanco 4m g-band

Flat Fielding

- Need to measure relative gain of all of the pixels
- Dome Flats
- Twilight/Sky Flats



Magellan at Twilight

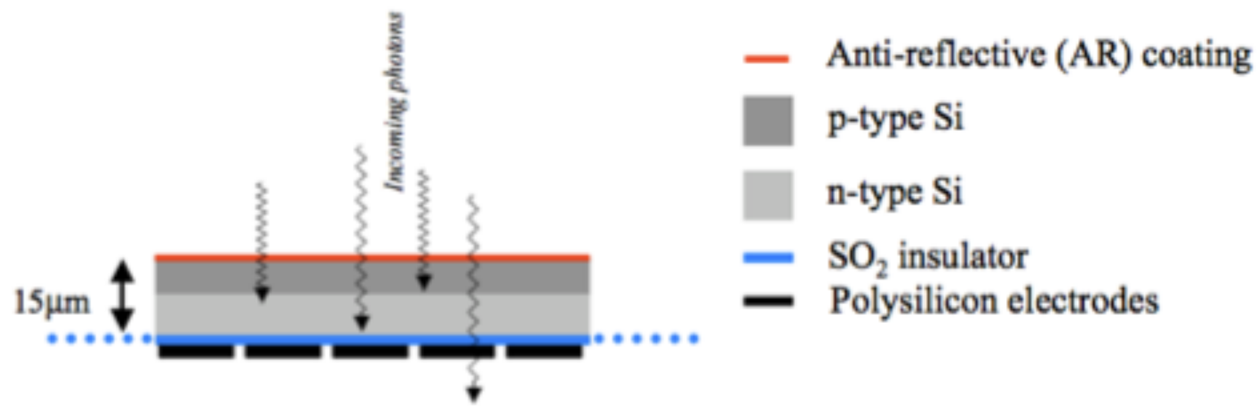


Swope 0.9m Dome flat

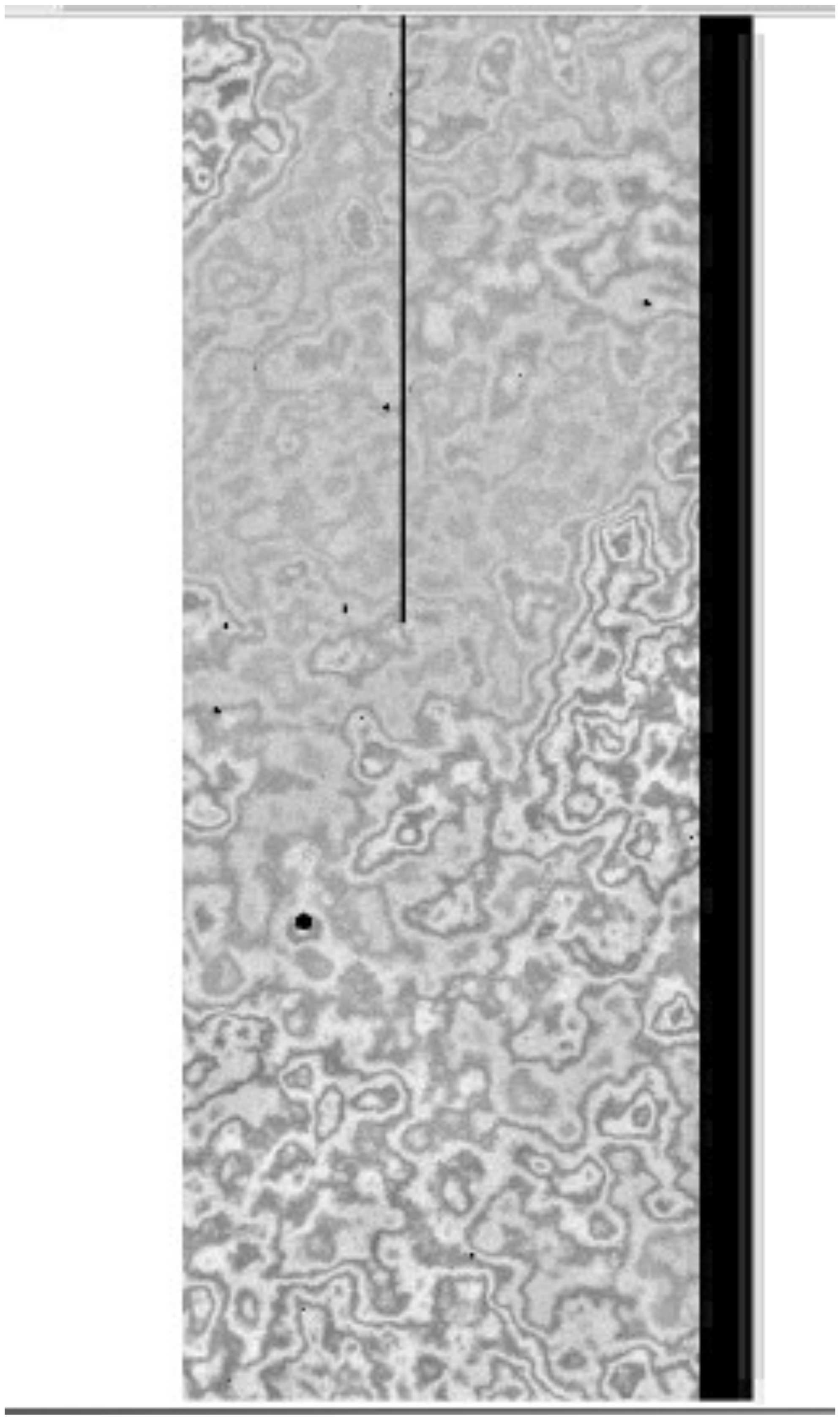
Fringe Frames

- Caused by thin-film interference effects in the detector
- Mitigate CCD design

Thinned Back-side Illuminated CCD

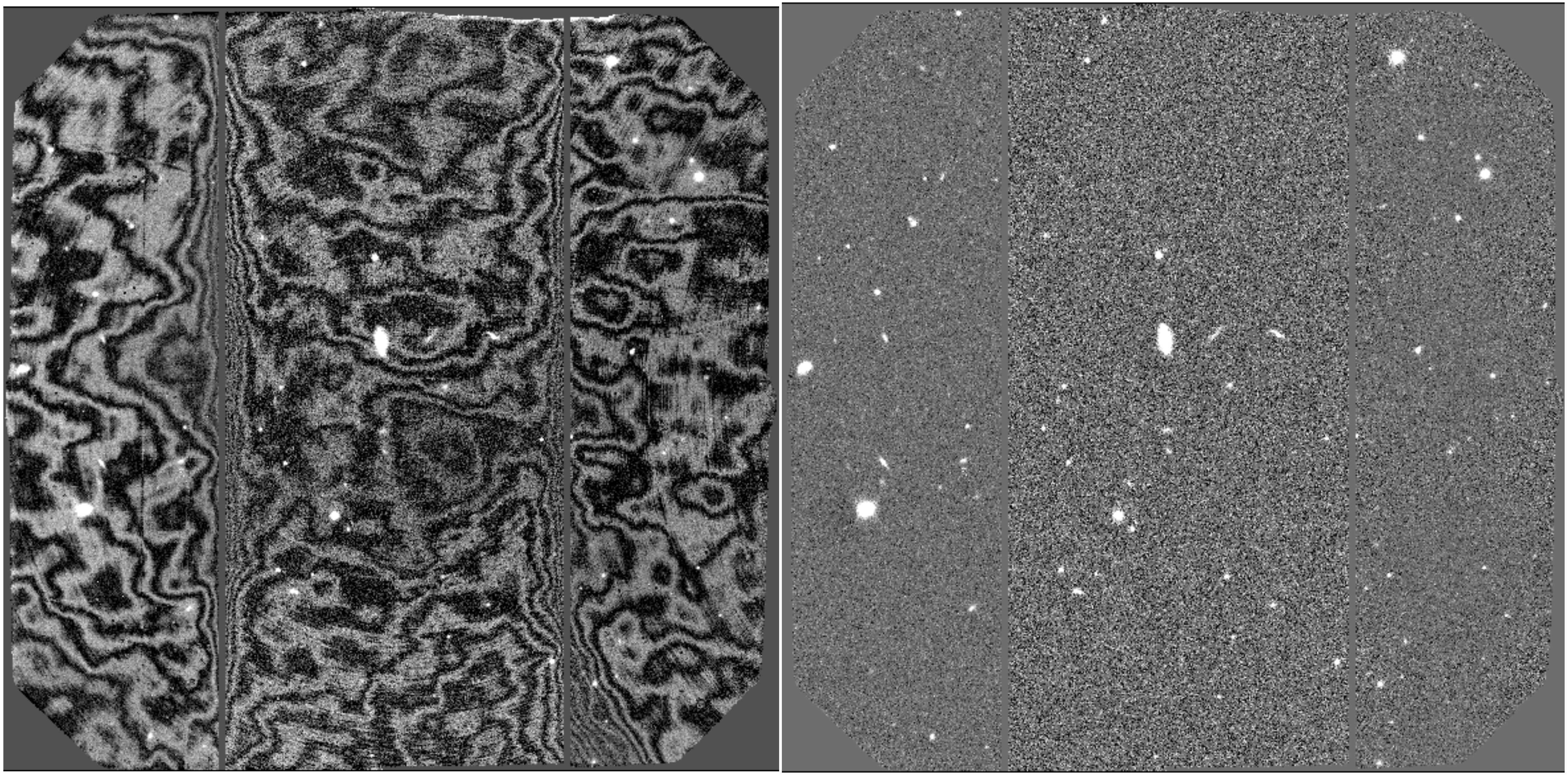


Graham



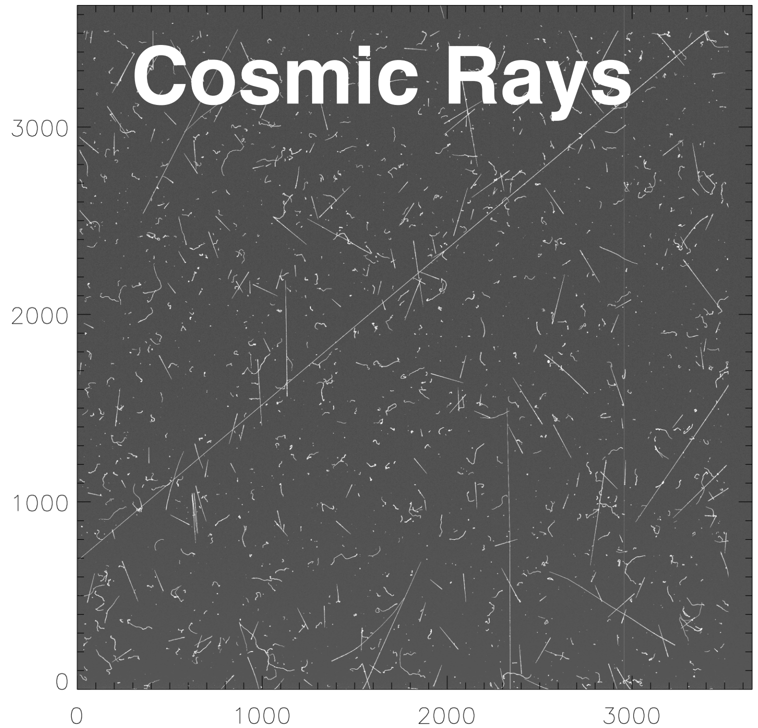
BLANCO 4M Z-BAND FRINGE FRAME

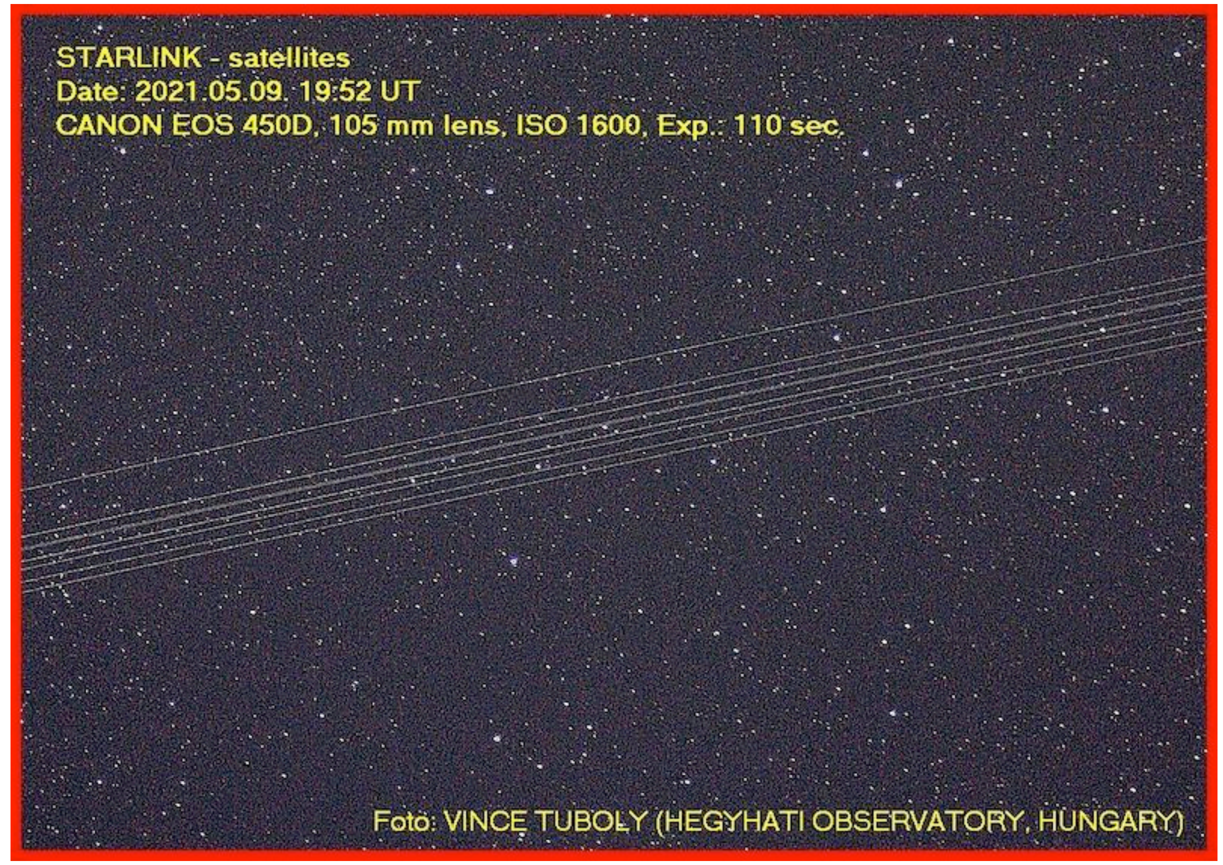
Fringing: Subtraction

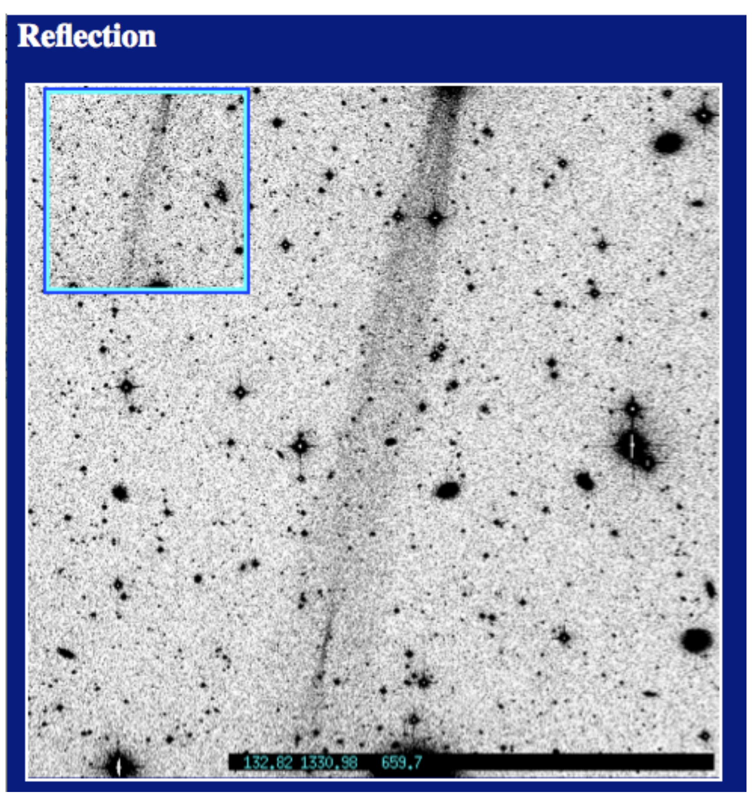


GMOS-N

Masking Bad Data

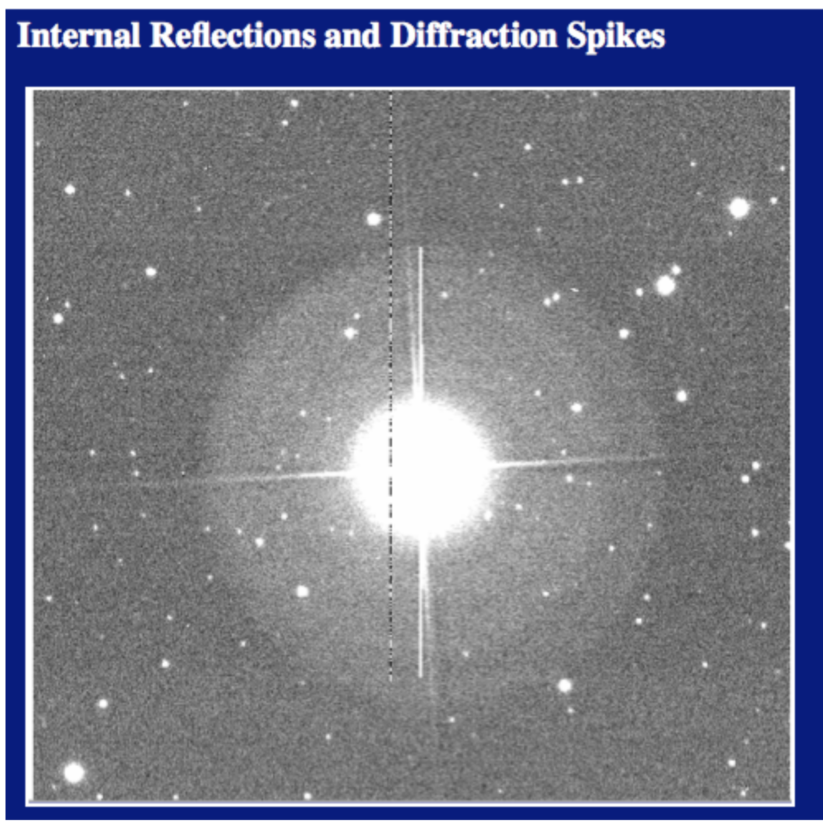






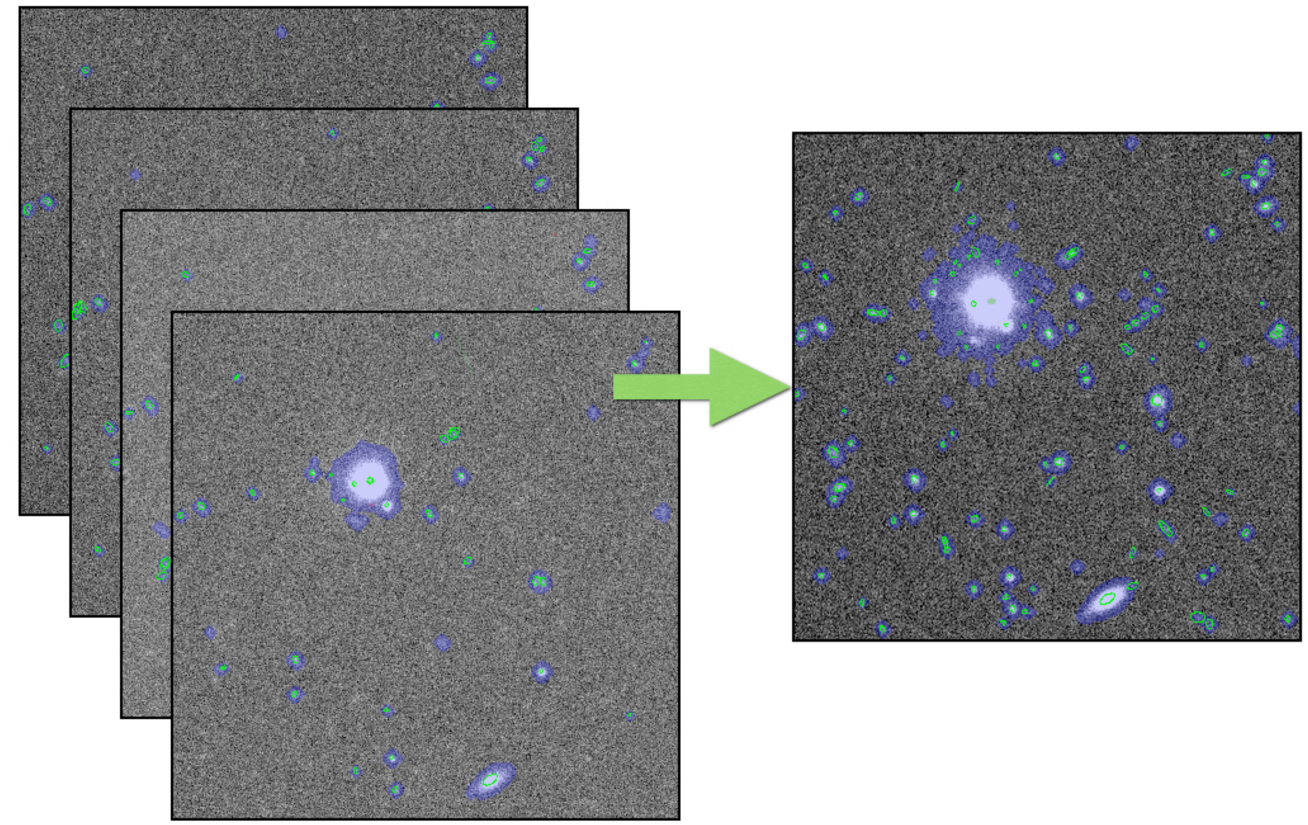
Bleeding & Blooming

The black strip is due to a gap in the CCD mosaic



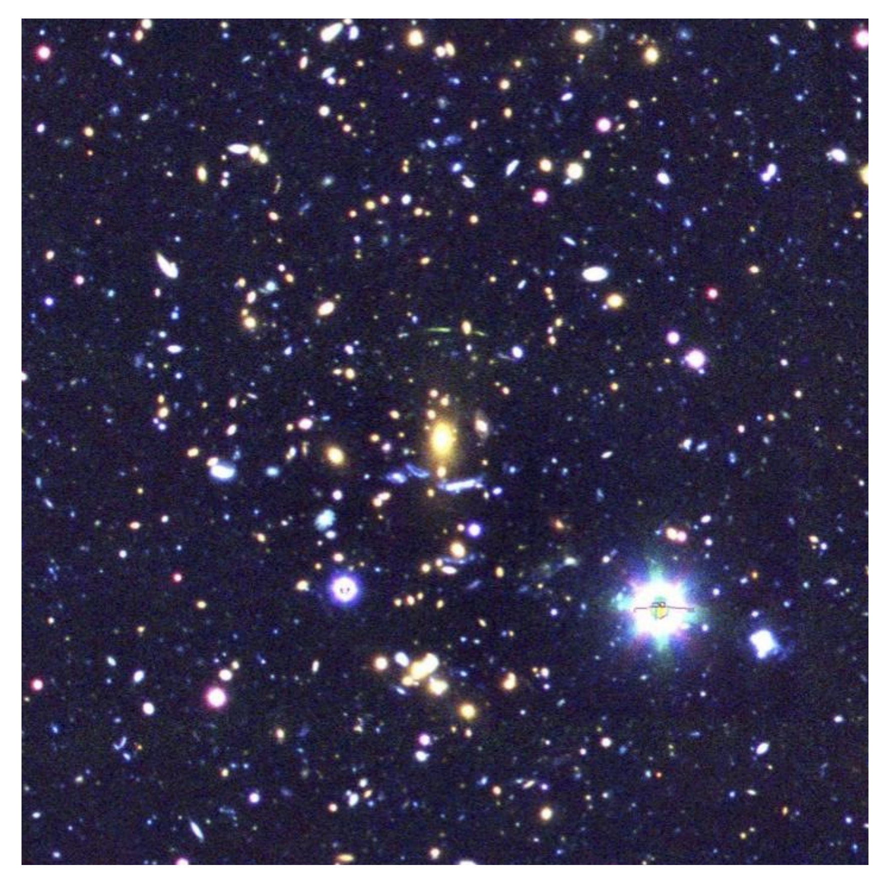
HTTP://MIRASOLINSTITUTE.ORG/OBS_MISHAPS/MISHAPS.HTML

Coaddition



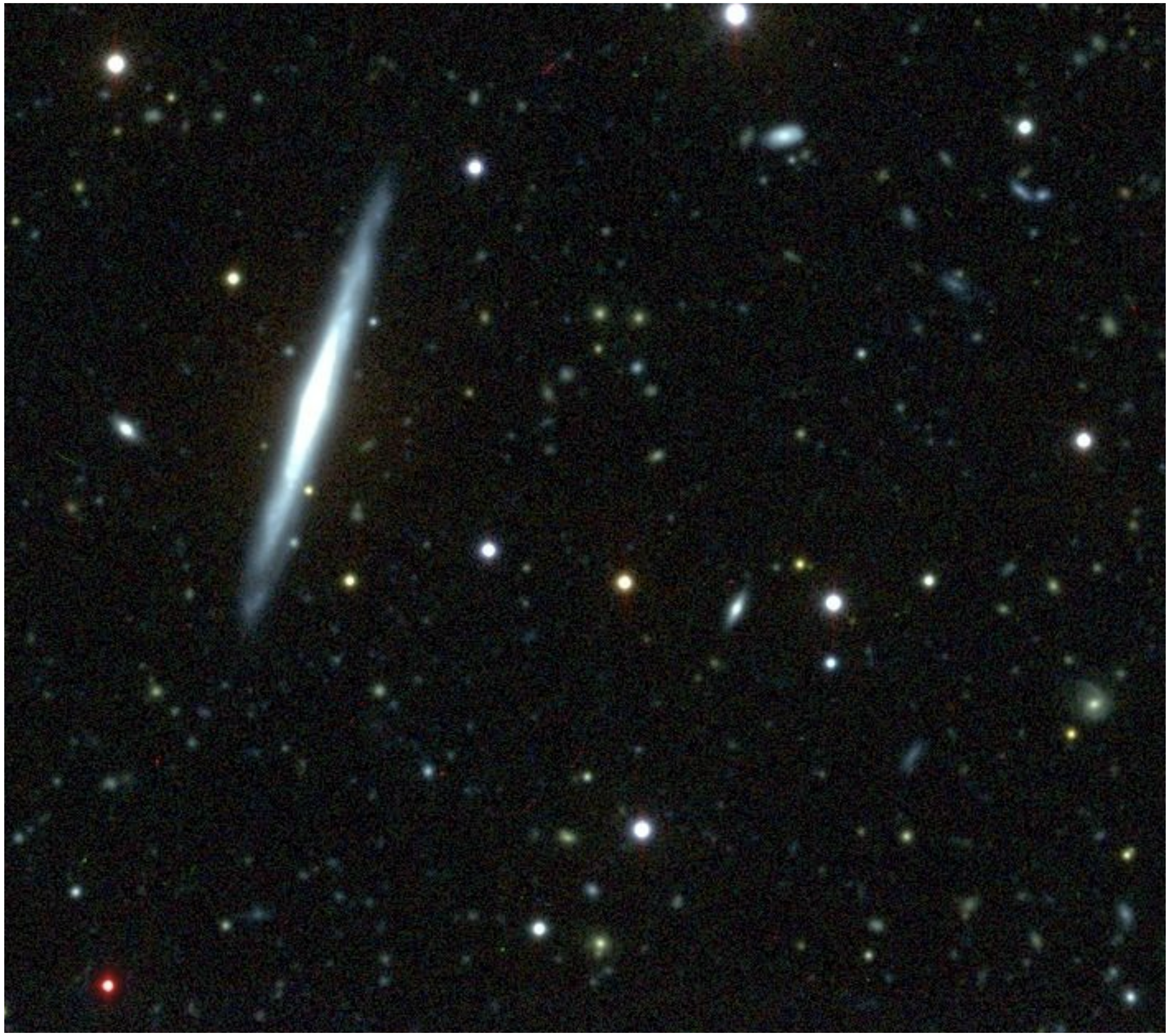
- Relative Calibration
- Noise estimation for image weights
- World Coordinate Registration
- Reprojection of images to common map projection
- Weighted Sum and Global Calibration

https://hsc.mtk.nao.ac.jp/ssp/pipeline/



Photometry

- Sextractor
- DAOPhot
- Photo (SDSS)
- And many more!



BCS0508-5223

Sextractor

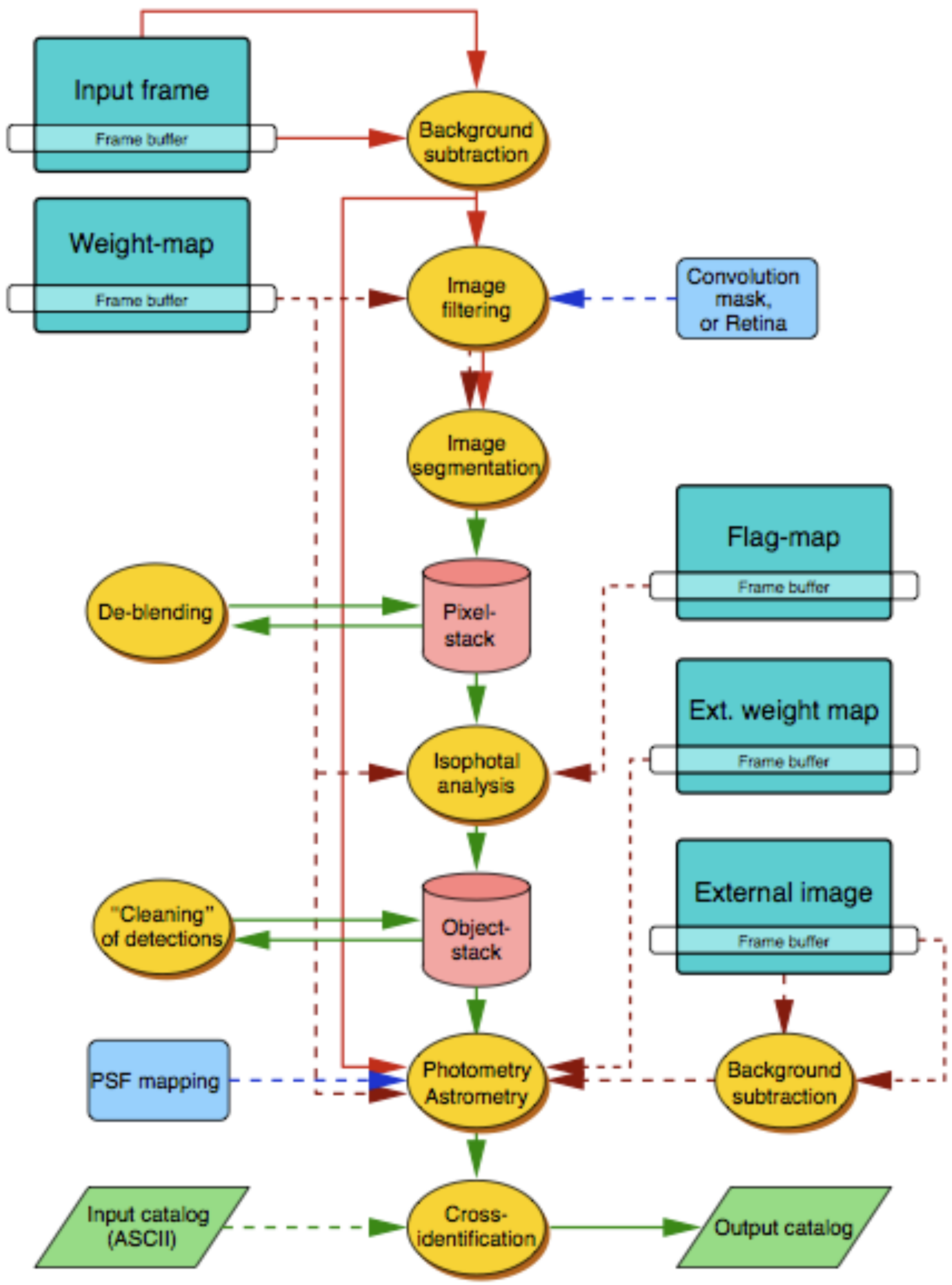
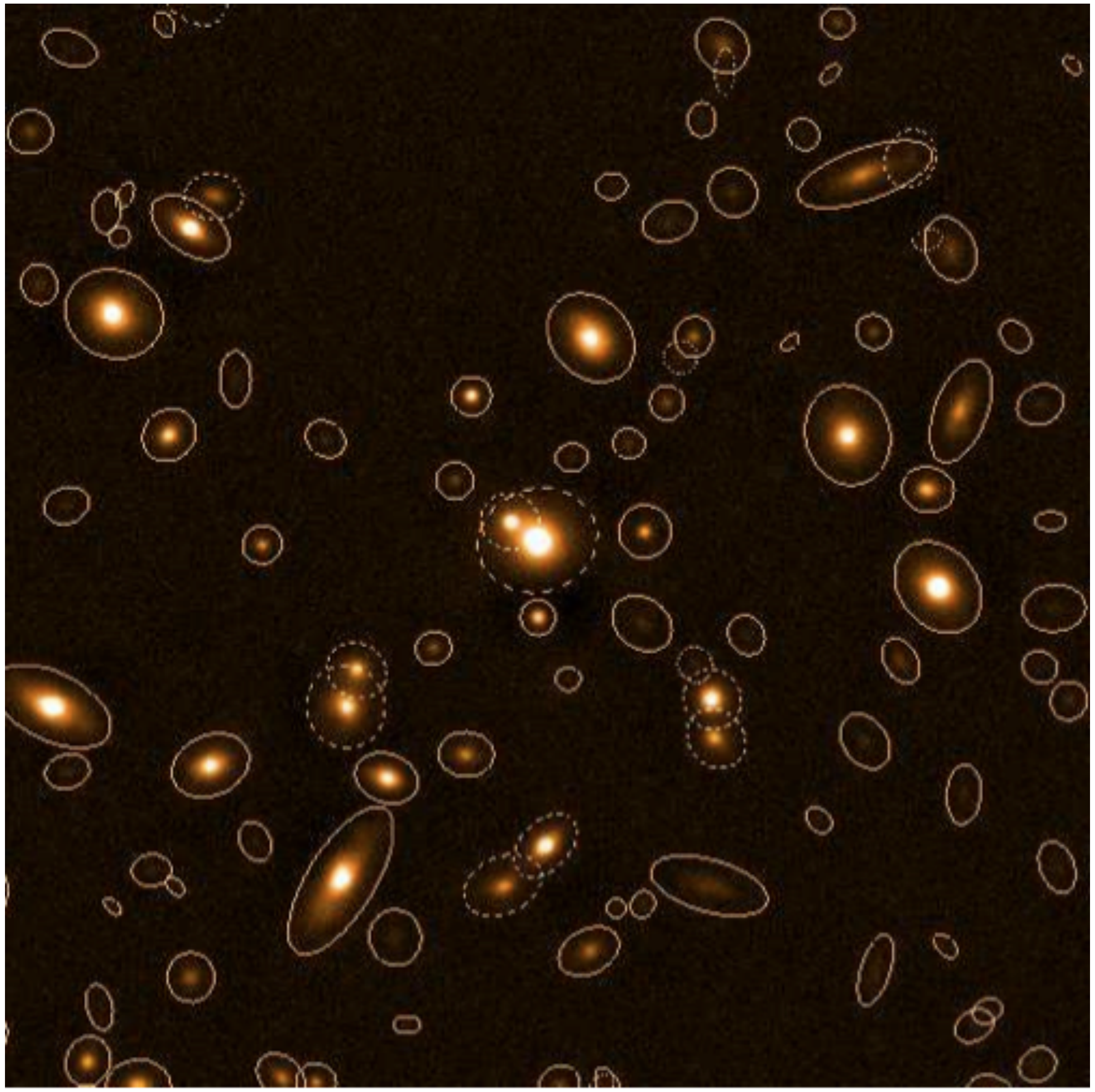
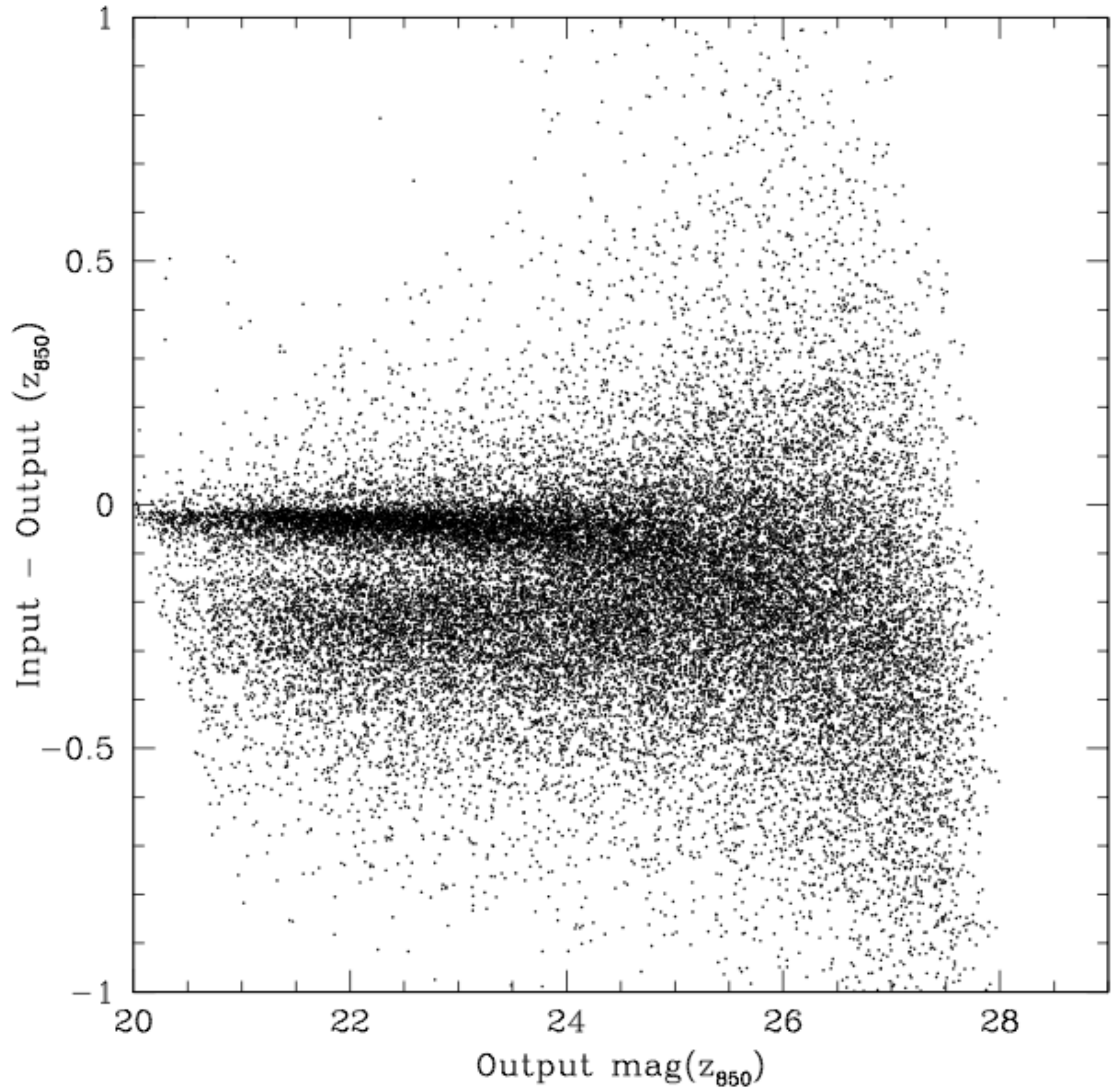


Figure 1: Layout of the main SExtractor procedures. Dashed arrows represent optional inputs.



E. Bertin

Sextractor



GOODS SIMULATIONS --
2 POPULATIONS: DISKS AND SPHEROIDS

HTTP://WWW.STSCI.EDU/SCIENCE/GOODS/CATALOGS/R1.0Z_README/#6.0

Photometric Calibration

- Standard Stars
- Stellar Locus Regression (SLR)

Performing photometric calibrations

- In general, standard stars (usually from the compilations of **Landolt** or **Stetson** should be observed at a variety of zenith distances and colours.
- They should be at approximately the same airmasses at the target field.

$$m_{\text{calib}} = m_{\text{inst}} - A + Z + \kappa X$$

- This is a simple least-squares fit. But in general a system of equations will have to be solved:

$$\begin{aligned}
U &= U_{\text{inst}} - A_u + Z_u + C_u(U - B) + \kappa_u X \\
B &= B_{\text{inst}} - A_b + Z_b + C_b(B - V) + \kappa_b X \\
V &= V_{\text{inst}} - A_v + Z_v + C_v(B - V) + \kappa_v X
\end{aligned}$$

EXTINCTION*AIRMASS

COLORTERM

ESTIMATED GALACTIC EXTINCTION

ZEROPOINT

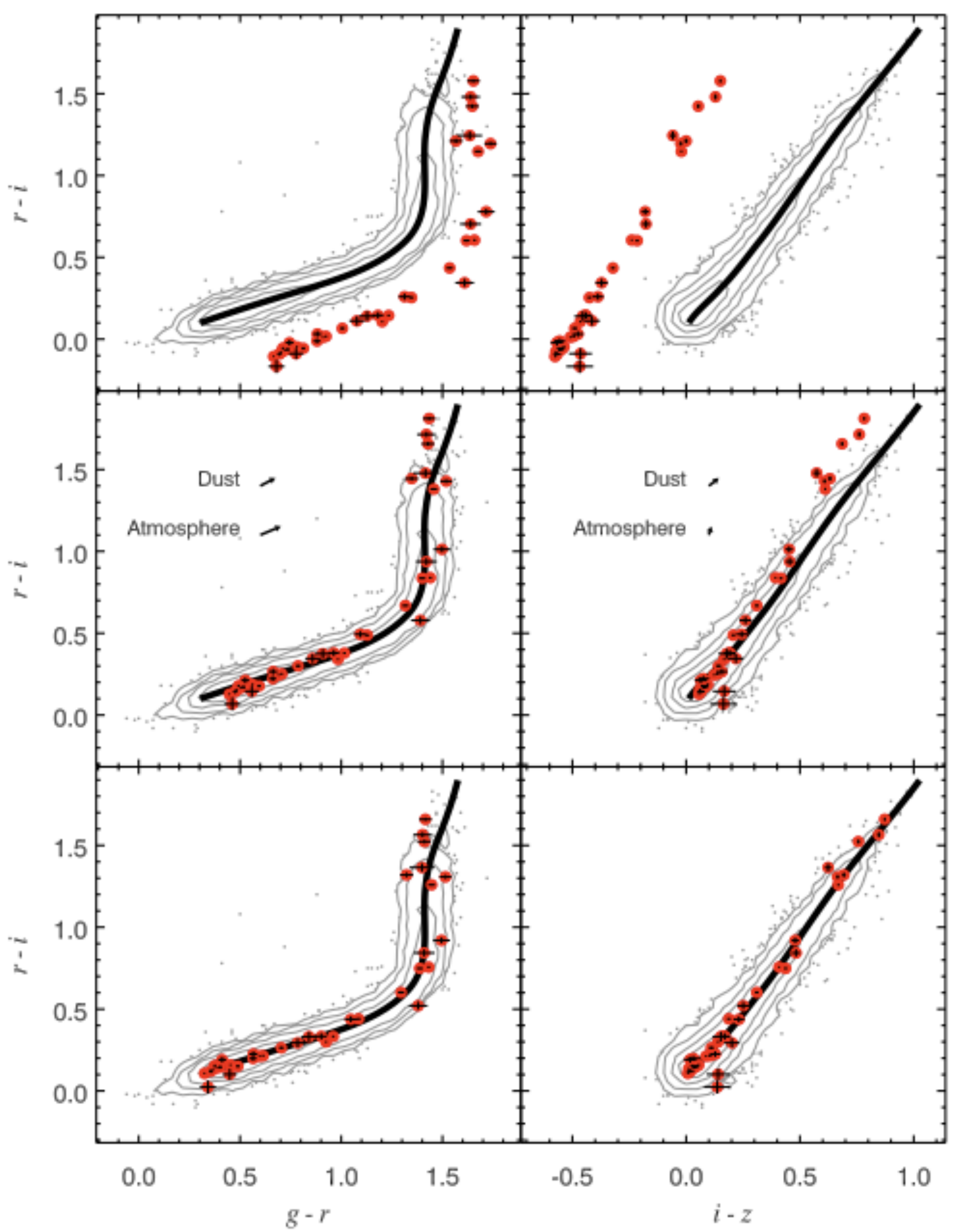
source: Henry Joy McCracken

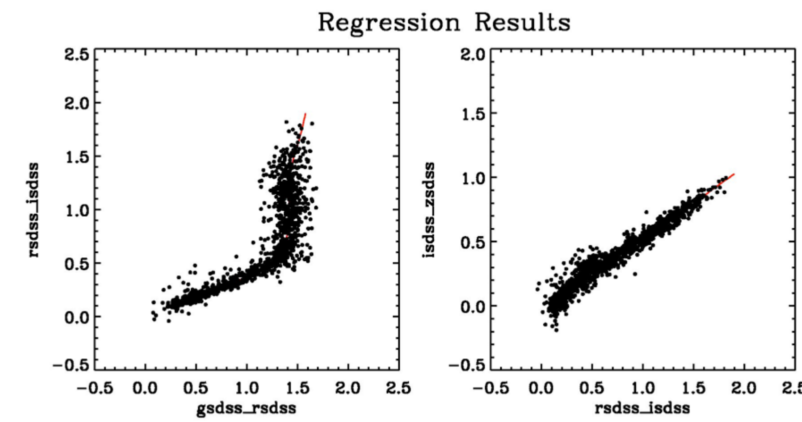
SLR

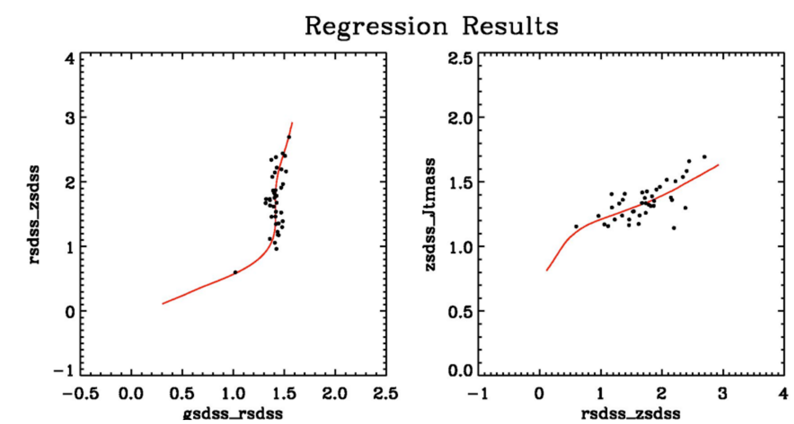
STELLAR LOCUS REGRESSION: ACCURATE COLOR CALIBRATION AND THE REAL-TIME DETERMINATION OF GALAXY CLUSTER PHOTOMETRIC REDSHIFTS

F. William High, Christopher W. Stubbs, Armin Rest, Brian Stalder, and Peter Challis
Department of Physics and Harvard-Smithsonian Center for Astrophysics, Harvard University, Cambridge, MA, USA; high@physics.harvard.edu
Received 2009 January 30; accepted 2009 April 24; published 2009 May 27

HIGH ET AL.





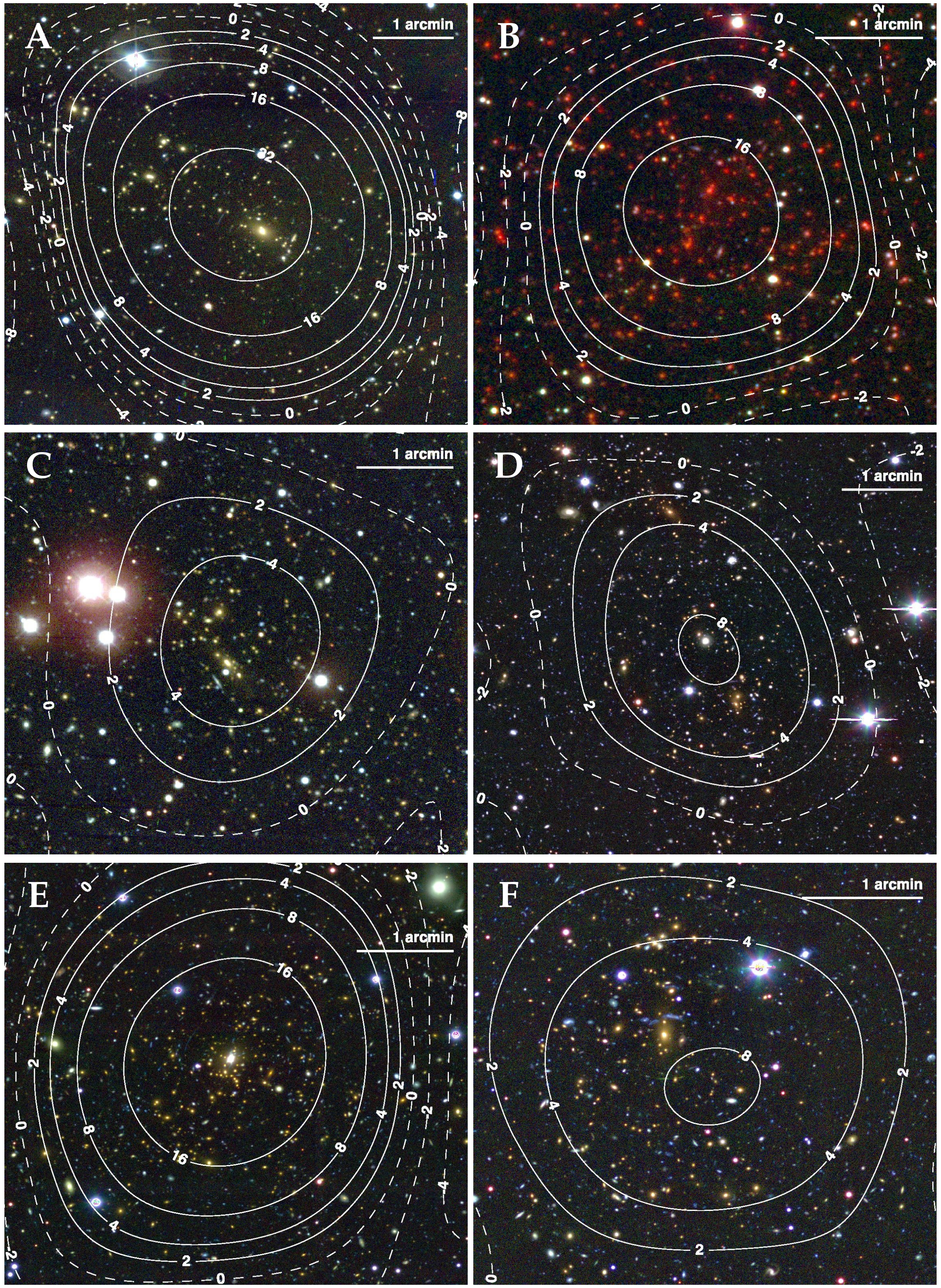


$$(g-r) = (g_0 - r_0) + (a_g - a_r) + (E_g - E_r) + (A_g - A_r) + b_g(g_0 - r_0) - b_r(r_0 - i_0) + c_g X_g(g_0 - r_0) - c_r X_r(r_0 - i_0) \quad \text{(A2a)}$$

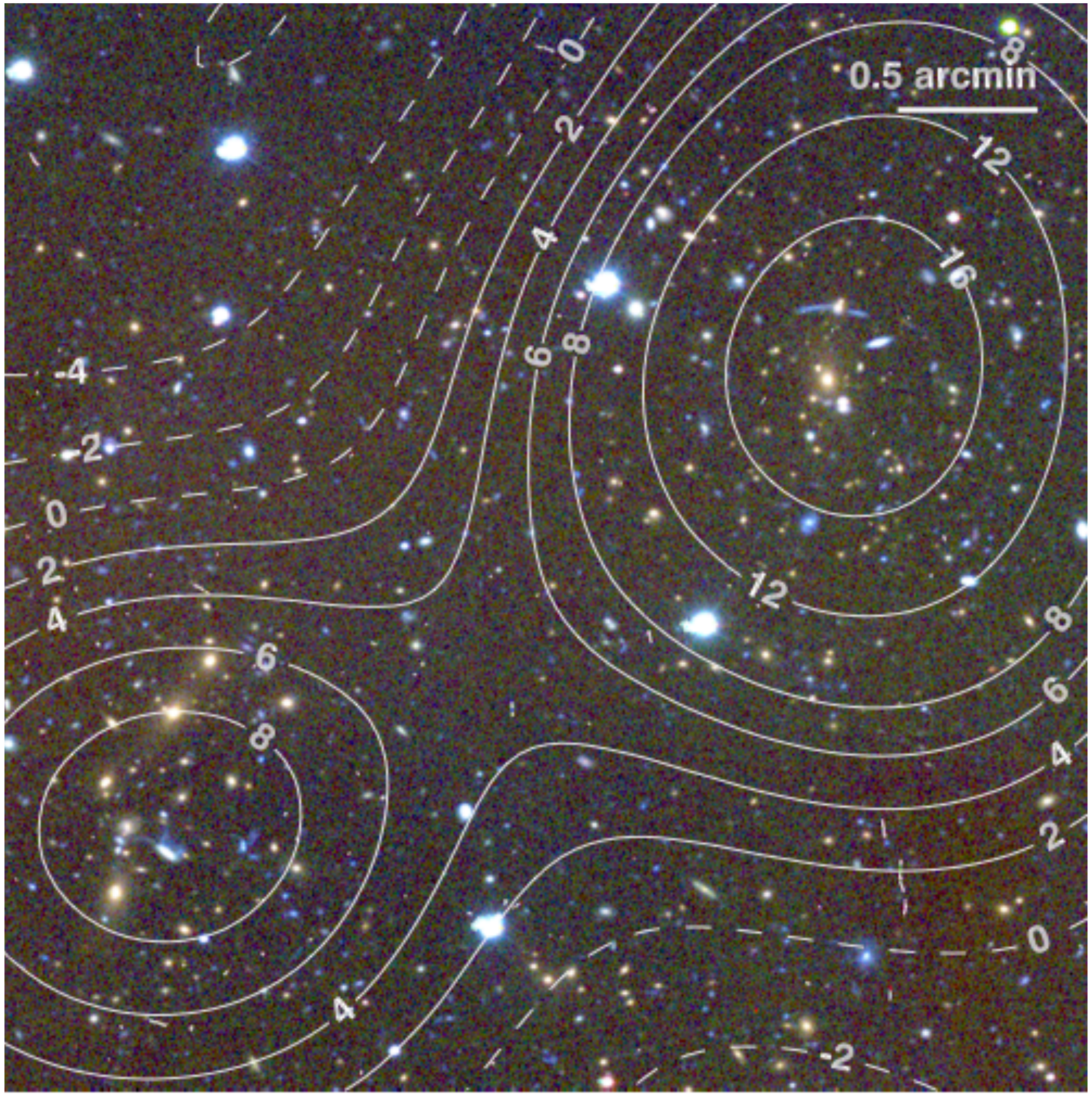
Example how we use this data

Allen et al Annu. Rev. Astron. Astrophys. 2011. 49:409-470

Cluster Redshifts



Bleem+15



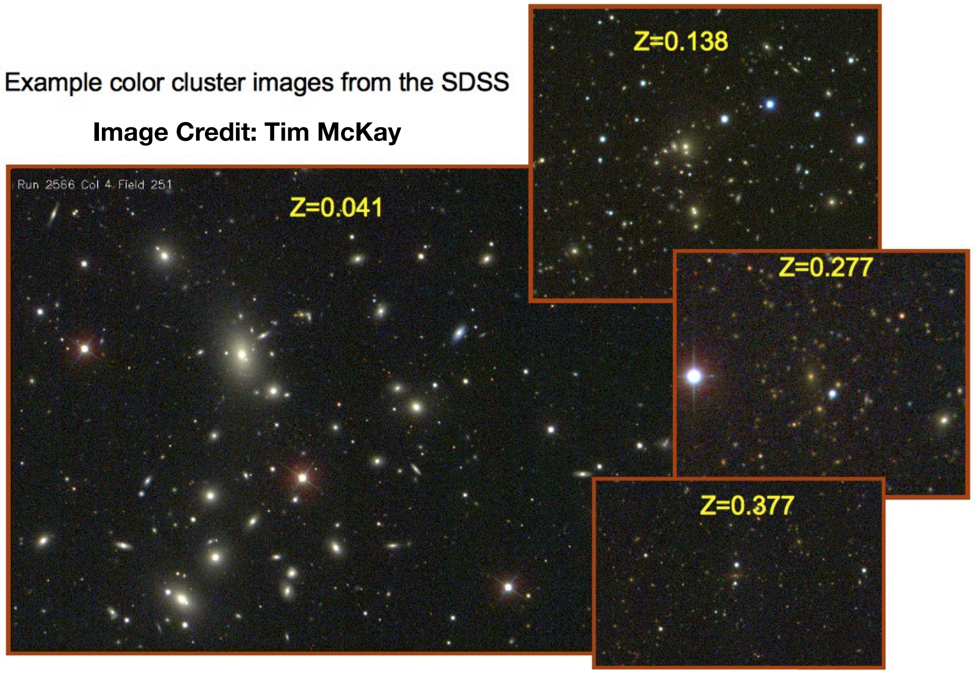
Huang+20

How we measure cluster redshifts

- **Photometrically**
  - **Red Sequence Redshifts (e.g., SDSS, DES, HSC, LSST)**

Example color cluster images from the SDSS

Image Credit: Tim McKay



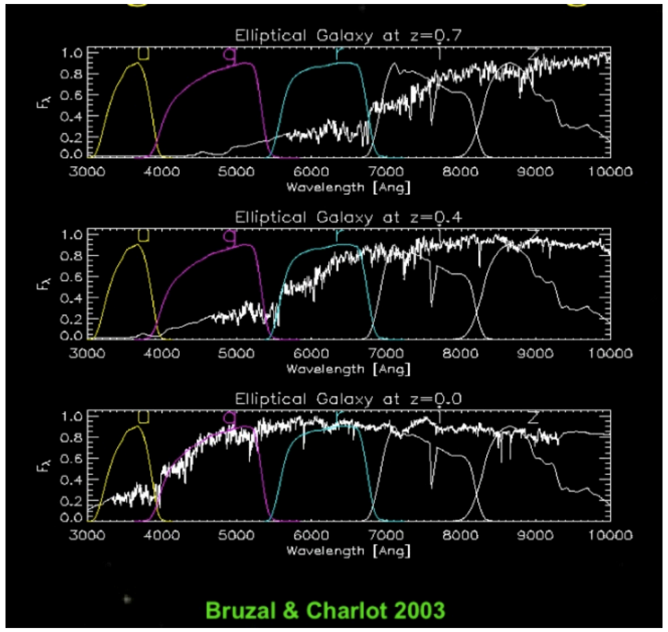
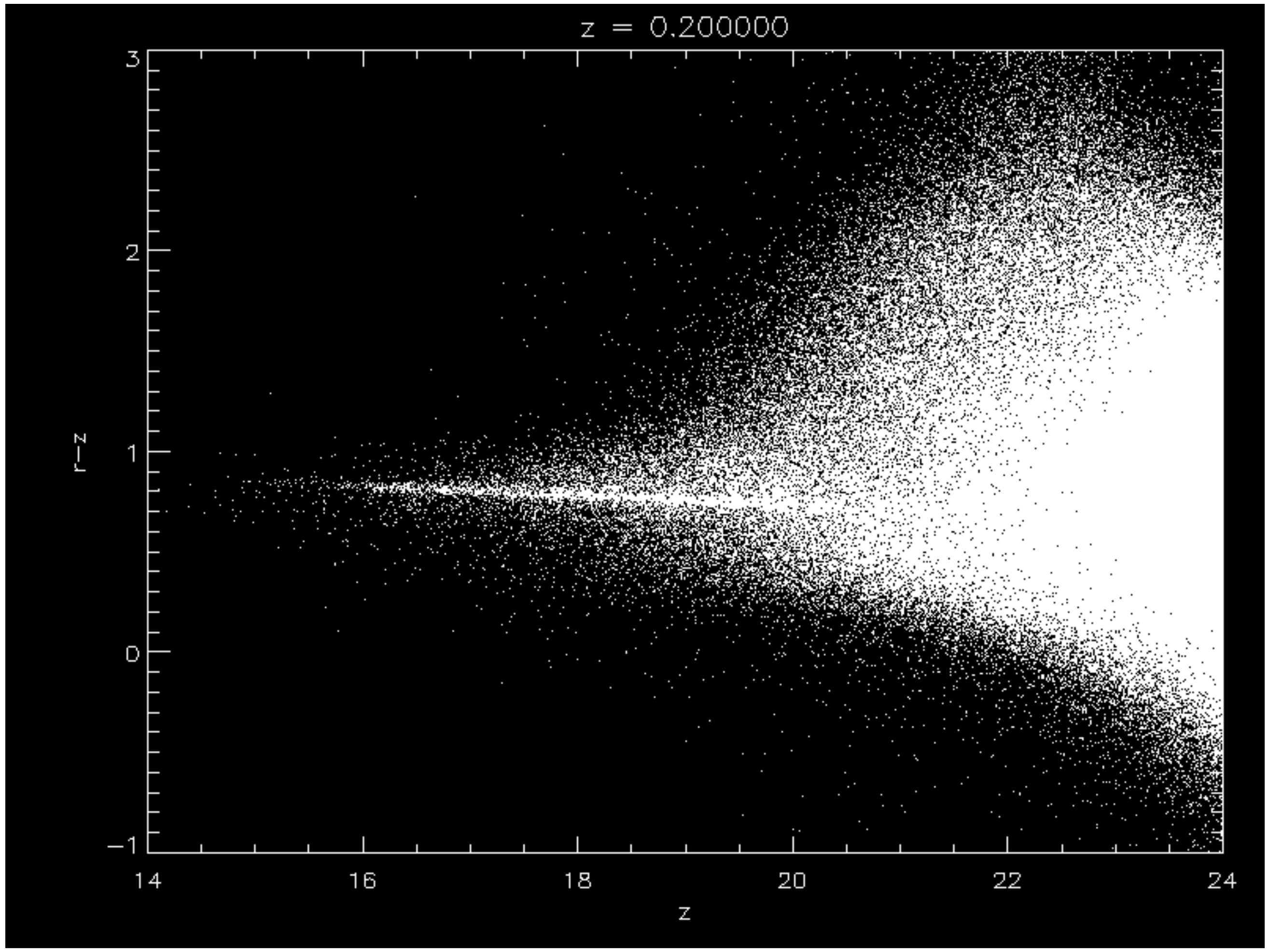


Image: J. Hao

How we measure cluster redshifts

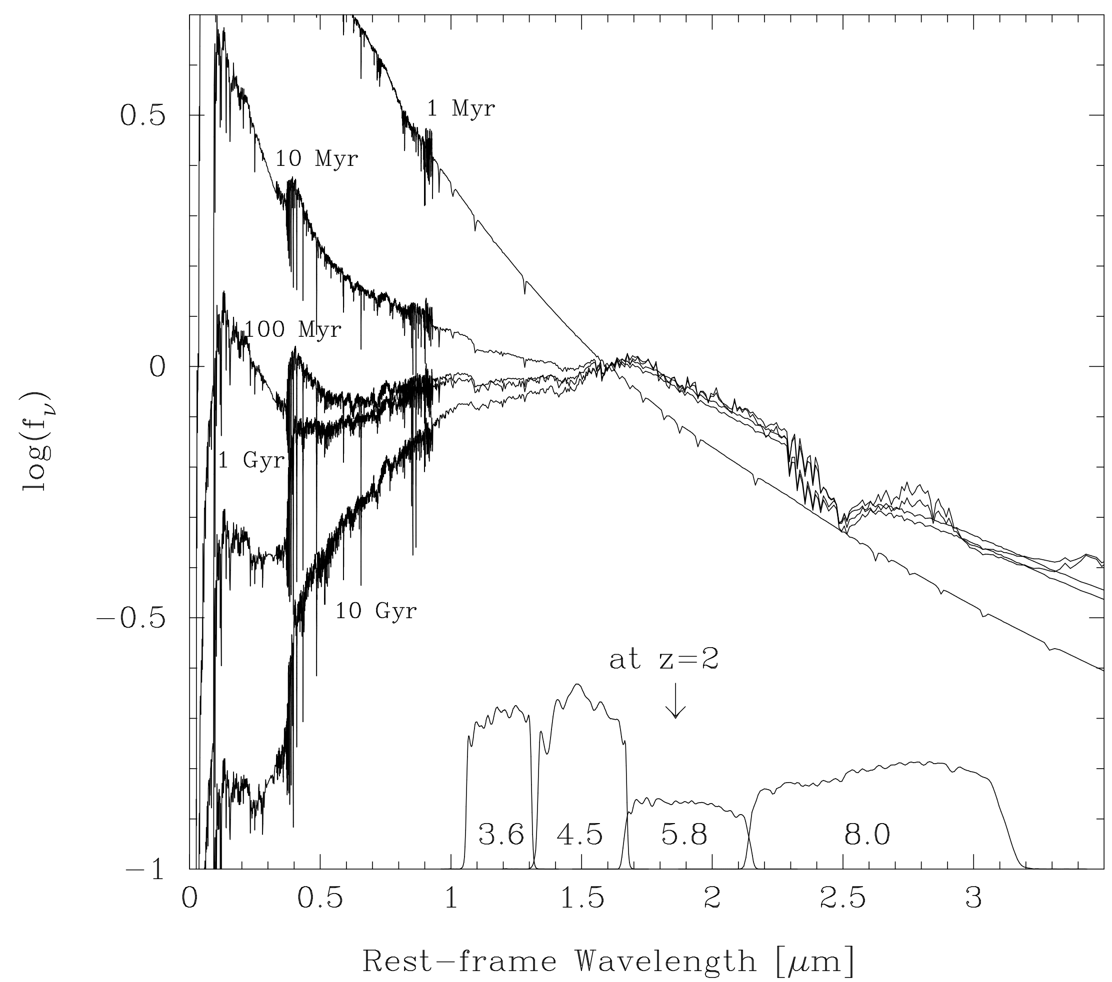
- **Photometrically**
  - **Red Sequence Redshifts (e.g., SDSS, DES, HSC, LSST)**



The red sequence of RCS-2 galaxy clusters as a function of redshift (Credit: Ben Koester).

How we measure cluster redshifts

- **Photometrically**
  - **Red Sequence Redshifts (e.g., SDSS, DES, HSC, LSST)**
  - **1.6 um "Stellar Bump" (*Spitzer*, WISE, *SPHEREx*)**



Sorba and Sawicki 2010ApJ...721.1056S

CMB-S4

How we measure cluster redshifts

- **Photometrically**
  - **Red Sequence Redshifts (e.g., SDSS, DES, HSC, LSST)**
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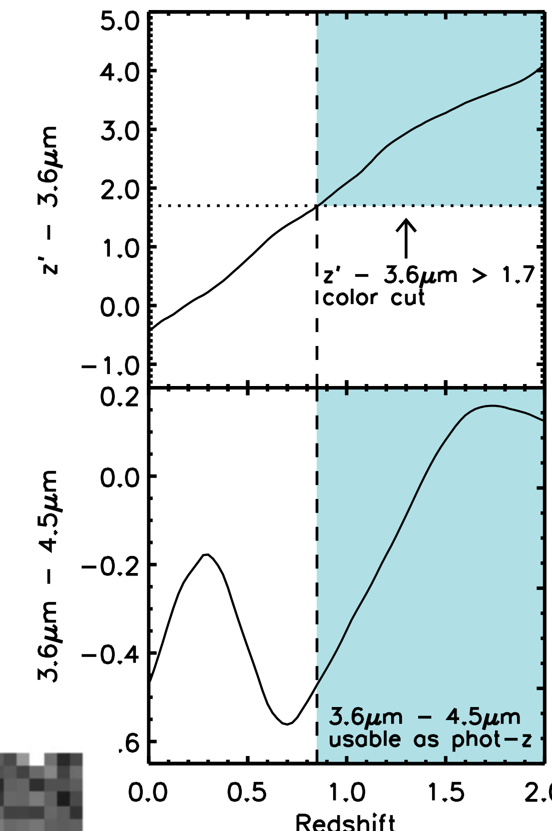
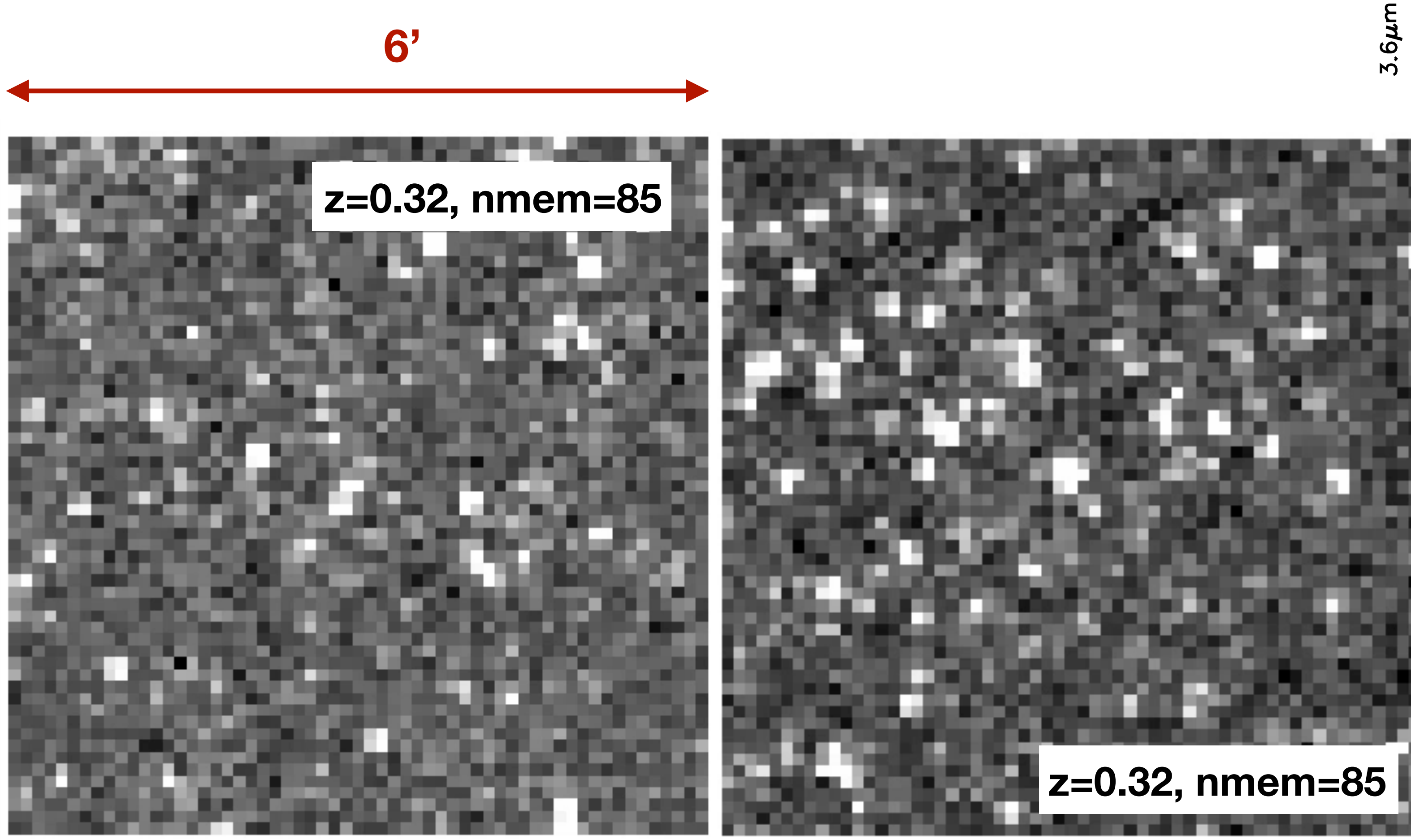


Muzzin et al. 2013ApJ...767...39M

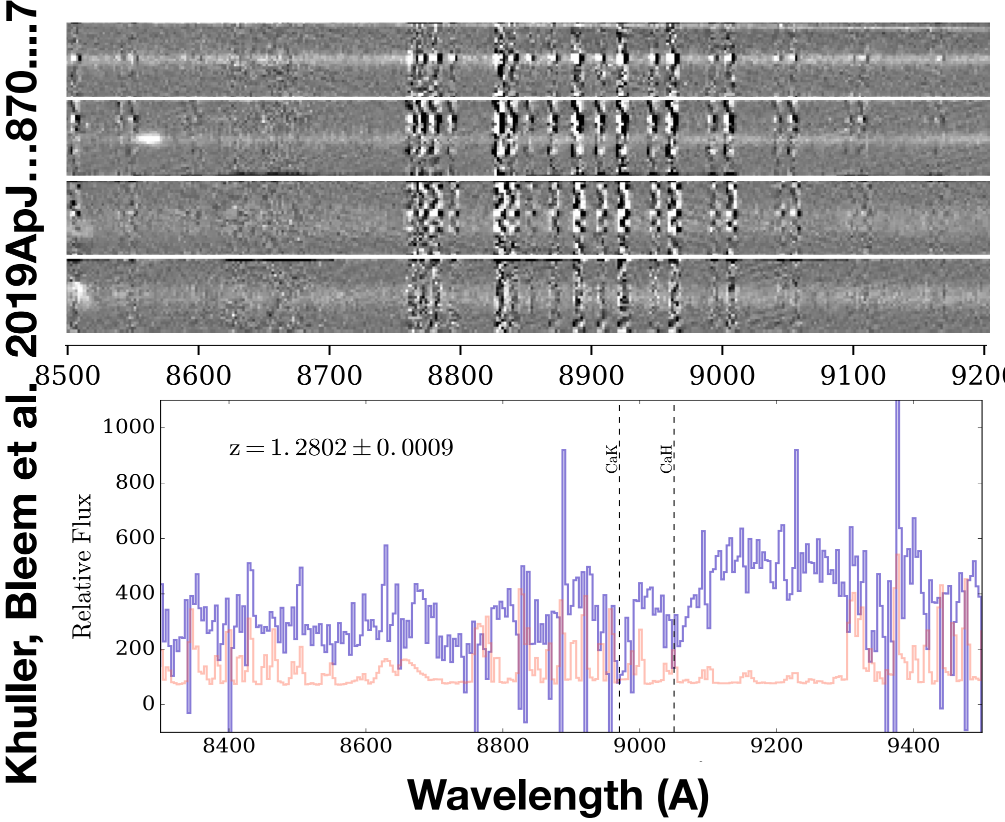


COSMOs groups;
Sims from SPHEREx team

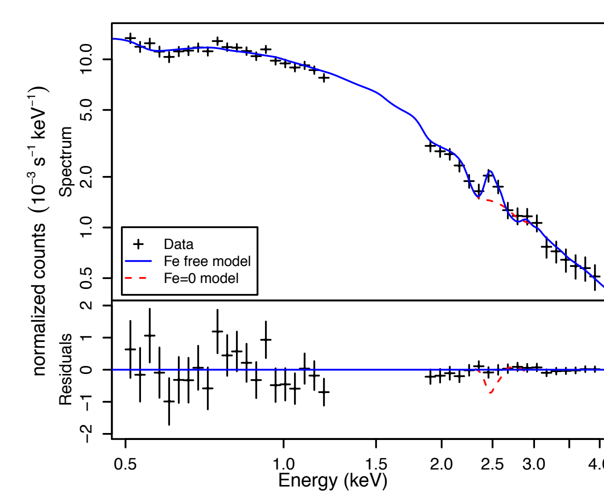
How we measure cluster redshifts

- Photometrically
  - Red Sequence Redshifts (e.g., SDSS, DES, HSC, LSST)
  - 1.6 um “Stellar Bump” (*Spitzer*, WISE, *SPHEREx (R~40)*)
  - Clustering in Photo-z space (Optical + IR surveys)
- Spectroscopically
  - Optical/NIR

Khuller, Bleem et al. 2019ApJ...870....7K



Mantz et al. 2020MNRAS.496.1554M



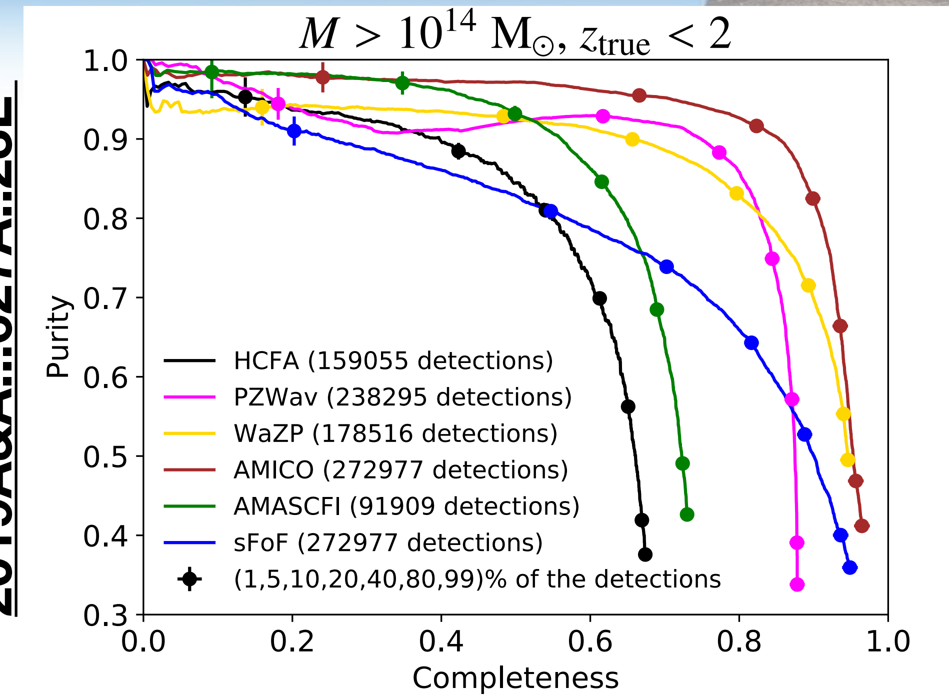
SPT-CLJ0459

CMB-S4

A Path Forward

- The combination of wide-field Euclid, LSST, and SPHEREx survey data will provide excellent coverage out to z~1.7 (maybe even up to z~2).
- The deep surveys from e.g., Roman will help us to even better characterize this performance.
- For astrophysical characterization extensive followup will be required.

Euclid Collaboration 2019A&A...627A..23E



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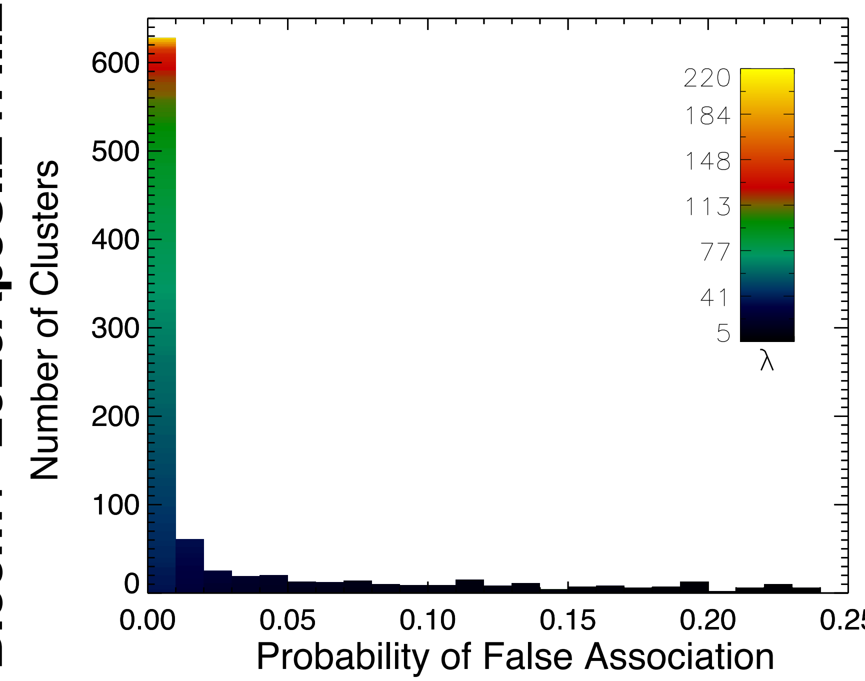

Questions?