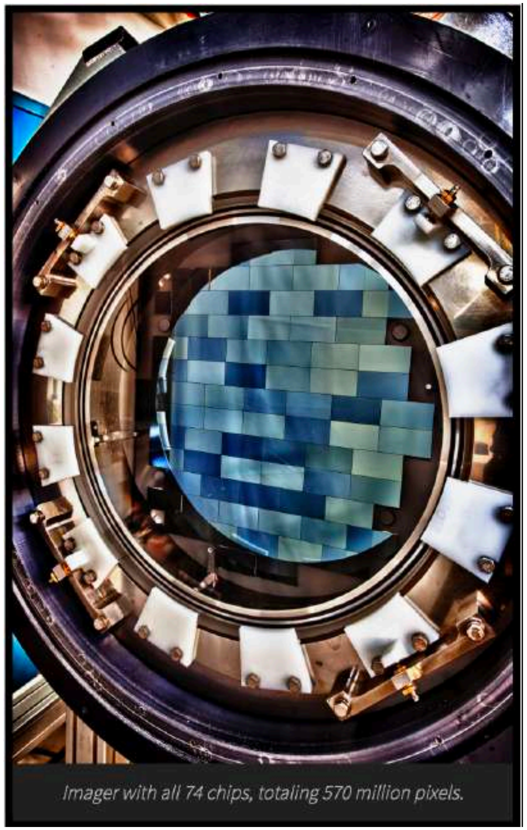
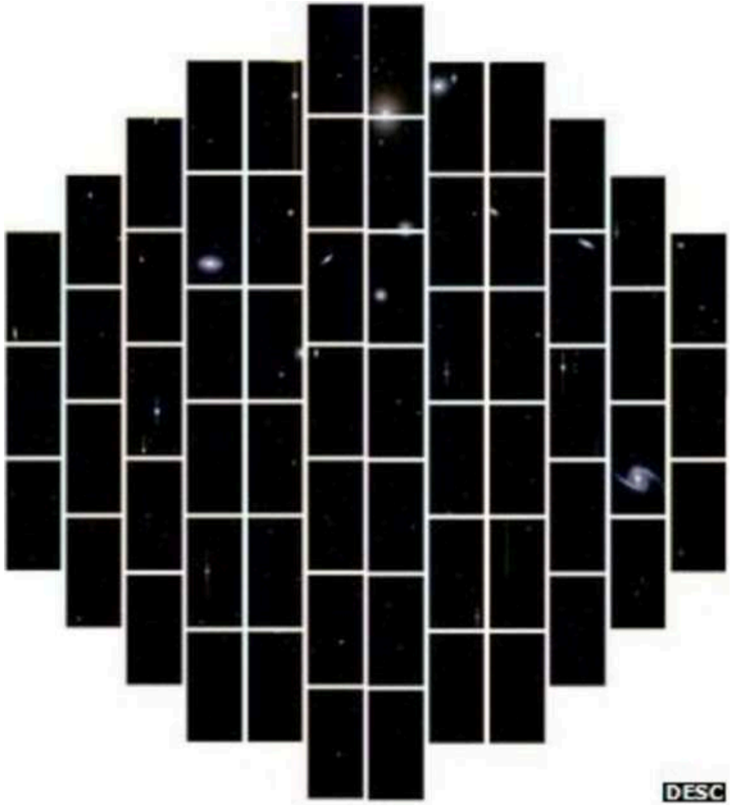
Lecture 4: An Optical Imaging Survey with the Dark Energy Camera

CTIO 4m telescope + DECam





Rutgers Physics 346: Observational Astrophysics February 9, 2021

Quiz #3: Graded with solution available on Canvas.

Q: Describe, using pictures if you want, (a) an astronomical observation that has high **angular** resolution and low **spectral** resolution, and (b) an astronomical observation that has low **angular** resolution and high **spectral** resolution.

A: (a) High angular resolution is achieved with large space telescopes or ground-based adaptive optics in the optical/IR or with interferometry arrays in the microwave/radio. The most common example of low spectral resolution is a broad-band image, which has a resolution factor of about $\lambda/\Delta\lambda$=10. So a good example would be an image with Hubble Space Telescope.

(b) High spectral resolution is achieved via spectroscopy, when the bandwidth of the observation is divided into hundreds or thousands of spectral channels. Low angular resolution occurs in poor seeing conditions or when the field-of-view of a telescope is large and the detector doesn't cover that field-of-view with very many pixels; on some smaller space-based telescopes, each pixel can be 4-5" in diameter. A good example would be an integrated spectrum from the Green Bank Telescope or an X-ray spectrum taken with the XMM telescope.

Comments: Note that angular and spectral resolution are set on an absolute scale by the telescope+instrument combination and are not affected by which objects are observed e.g., you can take a well-resolved, detailed image of the Moon with a low angular resolution camera. I gave back a lost point of credit if you cited your sources, and I followed such links to try to better understand any misconceptions in what you wrote.

Coherent vs. Incoherent Detection

Coherent detectors measure phase and amplitude of incoming photons; sensitive to polarization of incident radiation. This is standard in radio astronomy.

Incoherent detectors measure only power of incoming radiation; not sensitive to phase or polarization. This is standard in optical/IR, although polarimeters can be built.

Coherent detection can deliver much higher spectral resolution and beats the strong but incoherent thermal noise.

However, it only detects one polarization, is strongly bandwidth-limited, and coherent detectors are highly complex electronically and can therefore only be fabricated as small arrays of receivers.

Incoherent Detection of a Photon

- It passes through a filter with some $\Delta\nu$.
- It hits a detector, which converts it to a small electrical signal: we now have a large number of events $\{|E(t)|^2\}$.
- The electrical signal is multiplied by a (DC) amplifier: we now have $\{G\,|E(t)|^2\}$ for gain G.
- The output of the amplifier is passed through an *integrator*, which records the mean signal over some time interval (intuitively, it makes no sense to carve up our data stream on such small intervals that there aren't any photons left in some of the time steps).

Coherent Detection of a Photon

- The telescope captures radiation at a sky frequency $\nu_{\rm sky}$ (sometimes this is written as "RF" for "radio frequency").
- A local oscillator (LO) circuit generates a tone at a frequency $\nu_{\rm LO}$ that is nearly (but not exactly) equal to the sky frequency.
- The signals from the sky and the LO are combined in some sort of *mixer*, whose output is the *intermediate frequency* (IF) that is their difference. If you take the product of two signals at $\nu_{\rm sky}$ and $\nu_{\rm LO}$, then the result will contain a term proportional to $\cos(2\pi\nu_{\rm IF}\, t)$. All we need is a little low-pass filtering, and we can pass the IF signal (only) through to be amplified.
- The amplified signal is recorded by some sort of backend spectrometer. In general, we refer to the *frontend* as all parts of the system (excluding the telescope) that convert waves into $\nu_{\rm IF}$ signals, and the *backend* as the electronics that process the IF signals afterwards.

Calibration

Want to interleave science observations with those of calibrator sources with known positions and spectra.\

This will allow us to calibrate:

1. Location on the sky that was observed
2. Brightness of objects in the science data
3. Wavelength/frequency of spectroscopic data
4. Angular and spectral resolution of the data

When writing an observing proposal, think about how you will reduce and calibrate your data, and include that!

Flux Calibration

Optical: Vega is the primary calibrator; secondary standard stars available in Johnson-Cousins UBVRI filters; in grizy filters across most of the sky, can use stars in your science field with photometry from SDSS, Pan-STARRS, or Dark Energy Survey

Near-IR: JHK_s calibrators from Persson+1998, 2MASS photometry available in same bands across full sky

Mid-IR: Martin Cohen's papers covering 1.2-35 microns

mm/sub-mm: Planets (Jupiter, Uranus, Neptune) and their moons (Titan, Ganymede, Callisto) – prefer "point sources"

Radio: Mars and quasars tied to Cas A spectrum from Baars+1977 (Mars-Baars?)

Observational Checklist

1. Get an idea
2. Write a proposal
3. Once awarded time, prepare for the observations
4. Take the data (either remotely, at the telescope, or in queue mode)
5. Reduce the data to final images/spectra and catalogs
6. Analyze the data
7. Publish

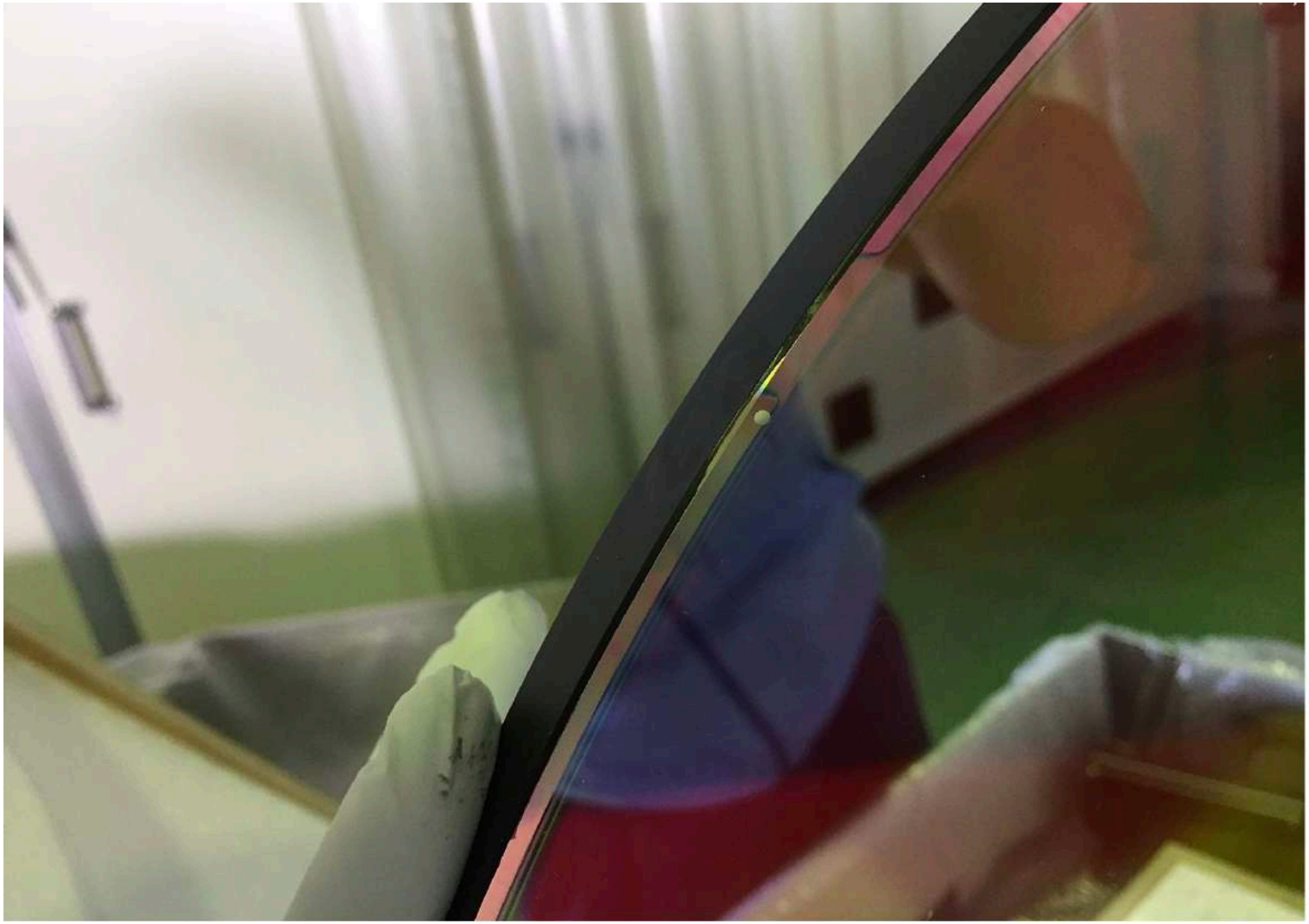
I will now present the
ODIN (One-hundred-square-degree DECam Imaging in Narrowbands)
Survey as a (partially) worked example.

ODIN: The Ideas

1. Find largest samples yet of Lyman Alpha Emitting (LAE) galaxies at z=4.5,3.1,2.4 corresponding to 0.7,1.4,2.1 Gyr after the Big Bang
2. Identify the largest ever sample of galaxy protoclusters as strong overdensities in the angular distribution of LAEs
3. Find largest samples of Lyman Alpha Nebulae (a.k.a. Lya Blobs) via diffuse emission
4. All of this can be accomplished by building 3 custom narrow-band filters for the Dark Energy Camera centered at (419, 501, 673) nm with FWHM of (8,8,10) nm
5. It just requires someone giving us 3 months of observing time on the CTIO4m+DECam…

ODIN: The Filters

Purchased from Asahi Ltd. (Japan) for $70K @



ODIN: Proposal

NOAO Observing Proposal *Survey proposal* **Panel:** *For office use.*
Date: April 7, 2020 **Category:** High Z Galaxies

A 100 Deg^2 DECam Narrow-band Survey for the LSST Era: Tracing the Largest Cosmic Structures in the Distant Universe

PI: Kyoung-Soo Lee **Status:** P **Affil.:** Purdue University
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CoI: Changbom Park **Status:** P **Affil.:** Korea Institute for Advanced Study
CoI: Robin Ciardullo **Status:** P **Affil.:** Penn State University
CoI: Yi-Kuan Chiang **Status:** P **Affil.:** Ohio State University
CoI: Arjun Dey **Status:** P **Affil.:** NSF OIR Lab
CoI: Steven Finkelstein **Status:** P **Affil.:** University of Texas Austin

Stephen Appleby
Jenny Greene
Caryl Gronwall
Sungryong Hong
Ho Seong Hwang
Woong-Seob Jeong
Hwihyun Kim
Dustin Lang
Alexie Leauthaud
John Moustakas
David Schlegel
Alexandra Pope
Hyunmi Song
Frank Valdes
Yujin Yang
Humna Awan
Adam Broussard
V. Ramakrishnan
Yun Huang

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
In the distant universe, redshifted Lyα emission provides a unique view into the large-scale structures of the universe and the nascent galaxies that trace them. In the new era of deep wide-field imaging ushered in by the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST), one crucial application of Lyα mapping will be its unique capability to identify the rarest massive cosmic structures, or 'protoclusters'; these systems will evolve into present-day galaxy clusters. We propose a DECam survey to image an unprecedented volume (91 deg^2 to AB$\sim$26) with three custom narrow-band filters to sample Lyα emission at $z \sim 2.4$, 3.1, and 4.5, straddling the crucial epoch in which the mass assembly in cluster galaxies reached its peak. In conjunction with deep public broad-band imaging, we will i) conduct a search for protoclusters; ii) identify a large number of rare extended Lyα nebulae and study their relationship with the large-scale structure; and iii) determine the masses of halos hosting Lyα-emitting galaxies as a function of their physical properties through angular clustering measurements. In addition to the immediate scientific return, the proposed data will have a lasting legacy value well beyond 2023 when LSST begins and generates even deeper broad-band data and coordinated follow-up spectroscopy. Significant additional science will result from synergy with DESI, HETDEX, Euclid, SPHEREx, WFIRST, and JWST.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-4m	DECam	78	dark	Sep - Jan	Jul - Mar

ODIN: Response

NOIR Lab

Cerro Tololo Inter-American Observatory
Community Science and Data Center
Gemini Observatory
Kitt Peak National Observatory
Vera C. Rubin Observatory

Dr. Kyoung-Soo Lee
Purdue University
525 Northwestern Ave
West Lafayette, Indiana 47907-2036
United States

July 17, 2020

RE: Proposal ID: 2020B-0201: *A 100 Deg^2 DECam Narrow-band Survey for the LSST Era: Tracing the Largest Cosmic Structures in the Distant Universe*

Dear Dr. Lee:

The Telescope Allocation Committees (TAC) for NSF's National Optical-Infrared Astronomy Research Laboratory met recently to review proposal for surveys beginning in the second semester of 2020. I am pleased to inform you that the observing proposal noted above has been granted observing time on the basis of advice from these Committees. Congratulations

Because the COVID-19 pandemic may delay preparations to install your custom narrow band filter in DECam I have decided to postpone the start of your survey to the 2021A semester. The nominal allocation of time to your program is therefore

Semester 2021A	8 nights	dark	Feb-Mar, Jul
Semester 2021B	18 nights	dark	Aug-Jan
Semester 2022A	8 nights	dark	Feb-Mar, Jul
Semester 2020B	18 nights	dark	Aug-Jan
Semester 2023A	8 nights	dark	Feb-Mar, Jul
Semester 2023B	18 nights	dark	Aug-Jan

The 5 dark nights allocated to your pilot program 2020A-0282 *A Narrow-band DECam Survey for the LSST Era* that were carried over to semester 2020B will also be scheduled during the same period preferentially in B semesters. Thus, your total time allocation is 47 nights.

The attached note provides feedback from the TAC and our technical review of the proposal that you may wish to consider.

I wish you a successful observing program.

S. R. Heathcote

Steve Heathcote, Associate Director CTIO, Mid-Scale Observatories
NSF's National Optical-Infrared Astronomy Research Laboratory

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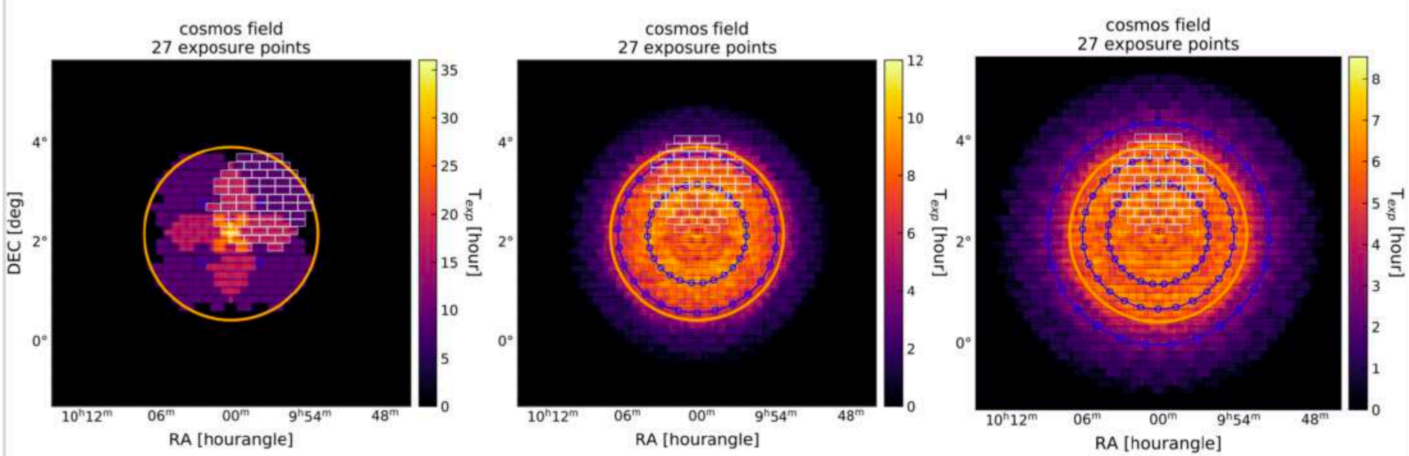
ODIN: Preparations

Needed a much more detailed pointing strategy than described in proposal to achieve a ~uniform survey of LSST Deep Drilling Field circles using smaller ~circular DECam focal plane

Extensive simulations led to a 2-ring strategy

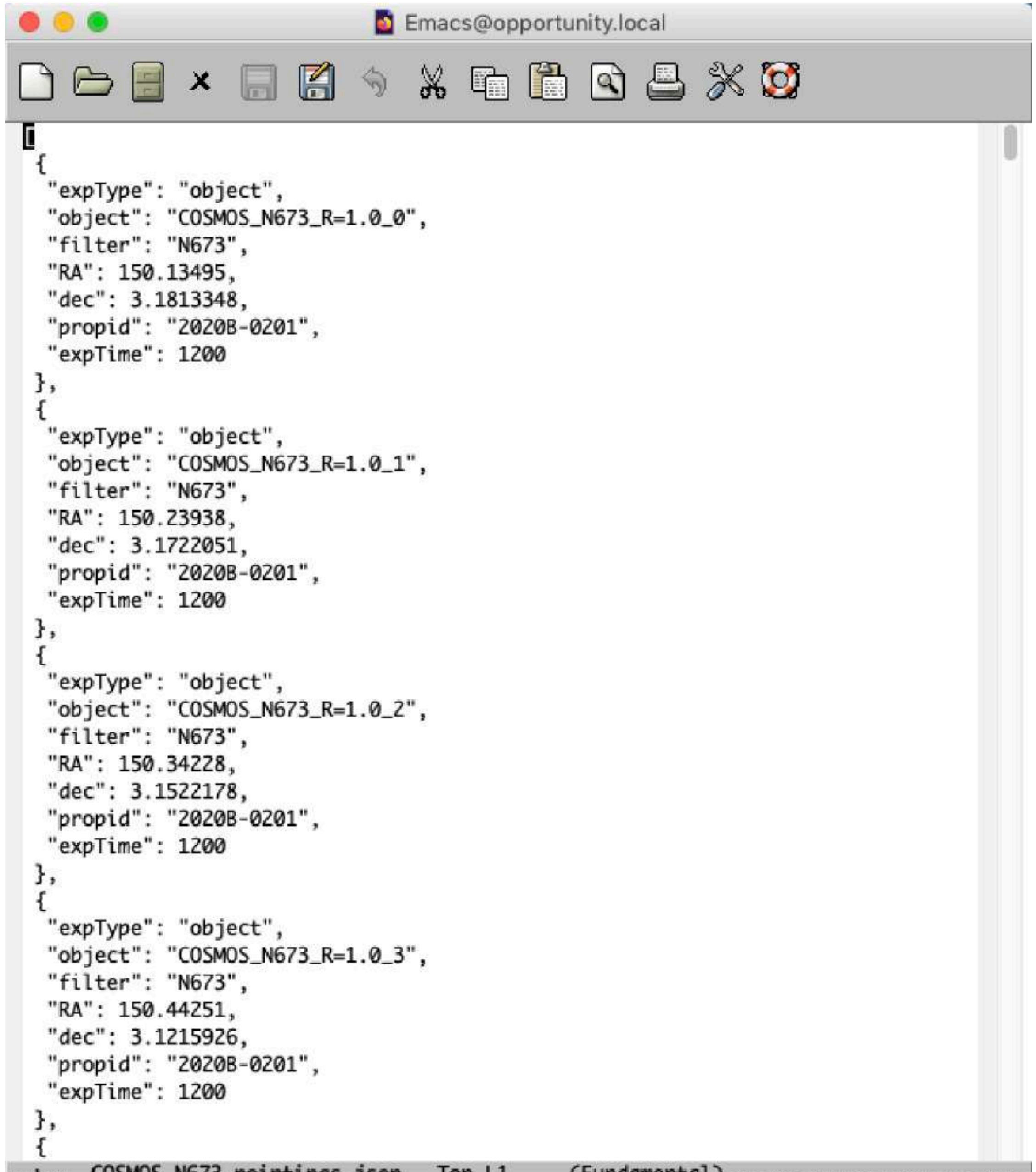
Options



- Option #1: 4 pointings with small dithers
- Option #2: two rings (27 dithers per ring)
- Option #3: three rings (27 dithers per ring)

ODIN: Preparations

DECam is run by scripts in .json format like these:

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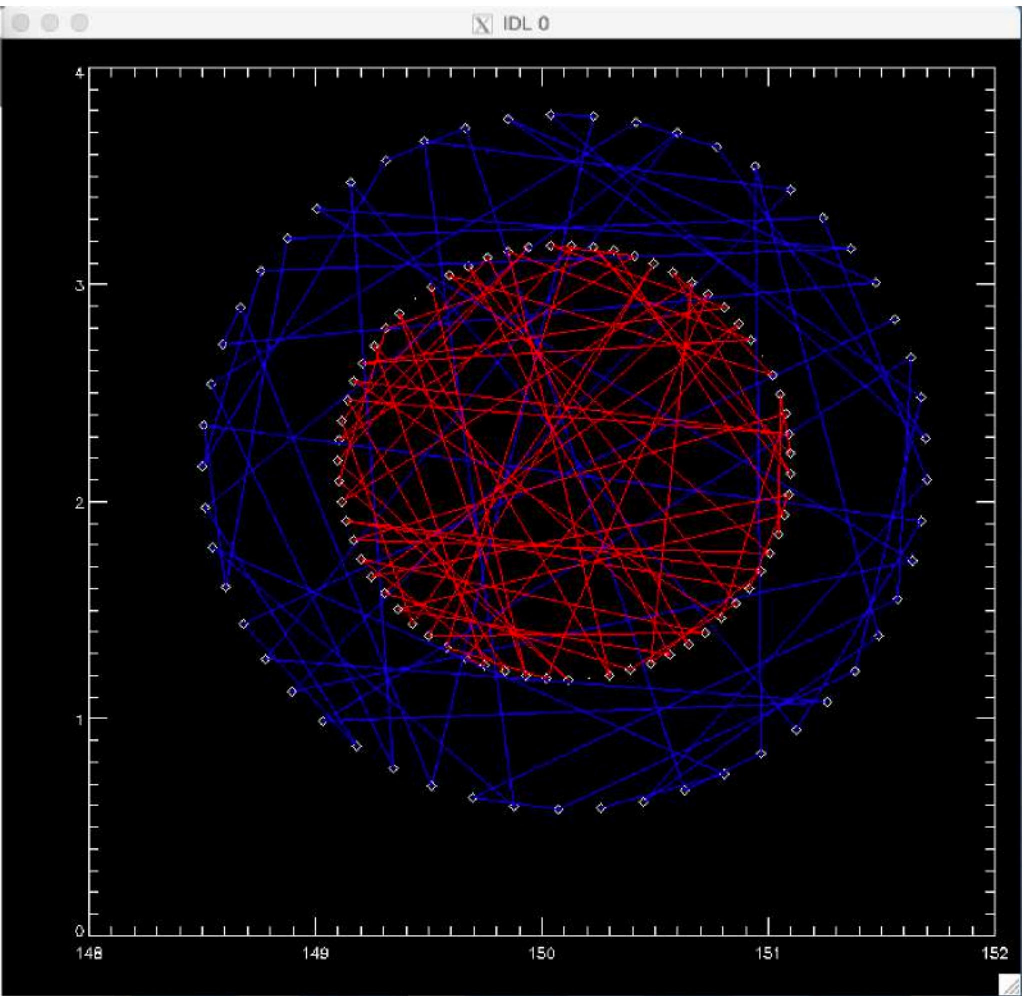
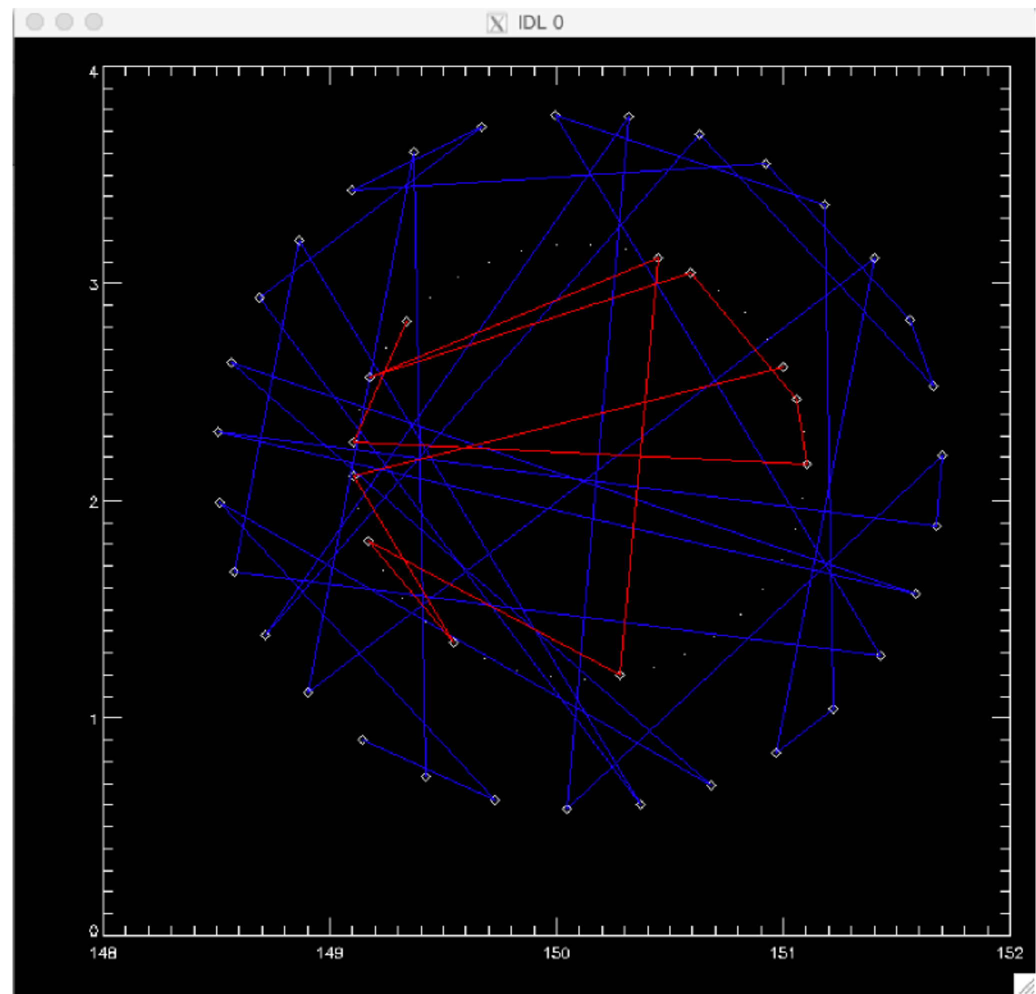
ODIN: Preparations

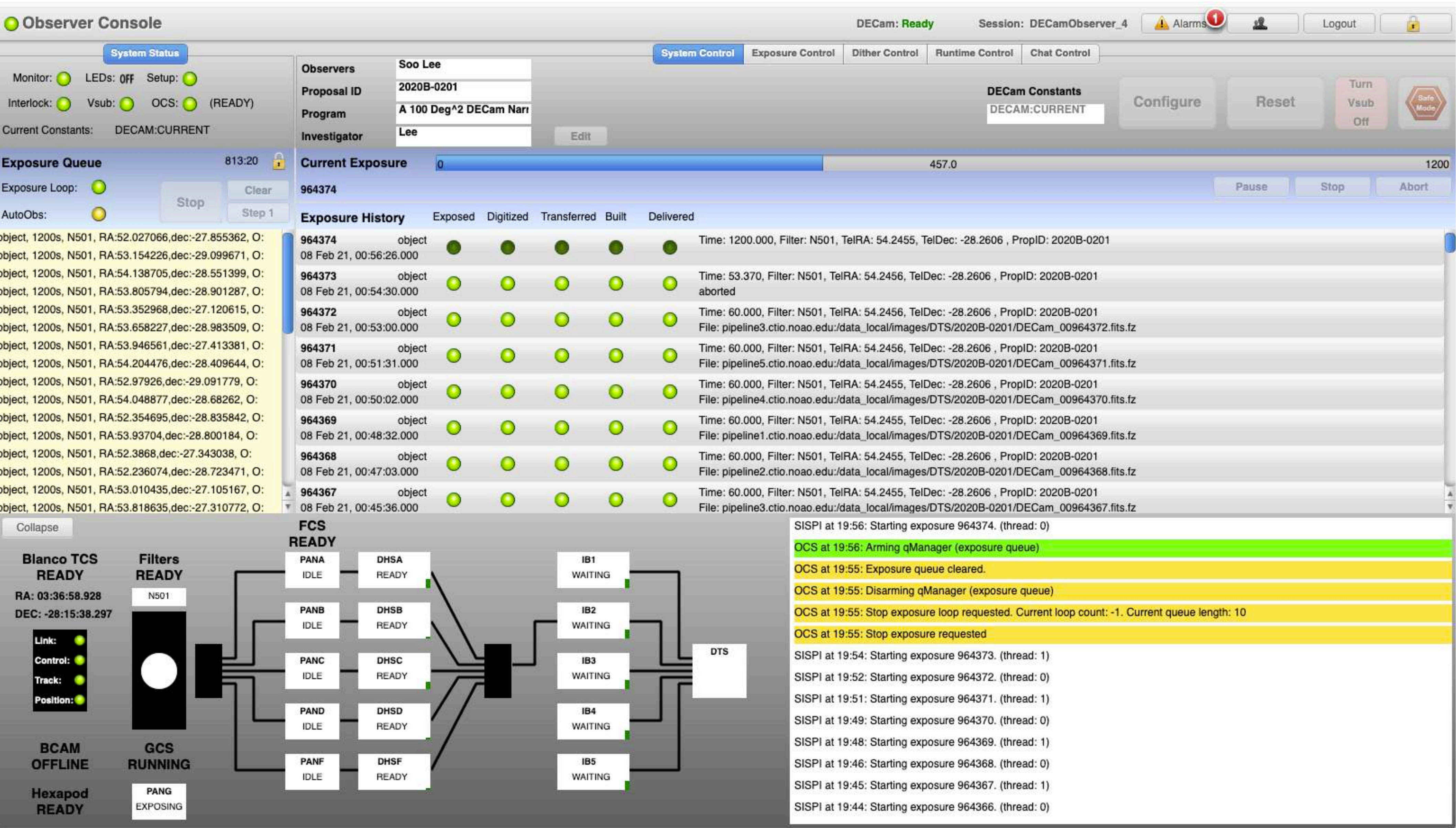
Need to track which observations are made each night and output updated scripts for following night





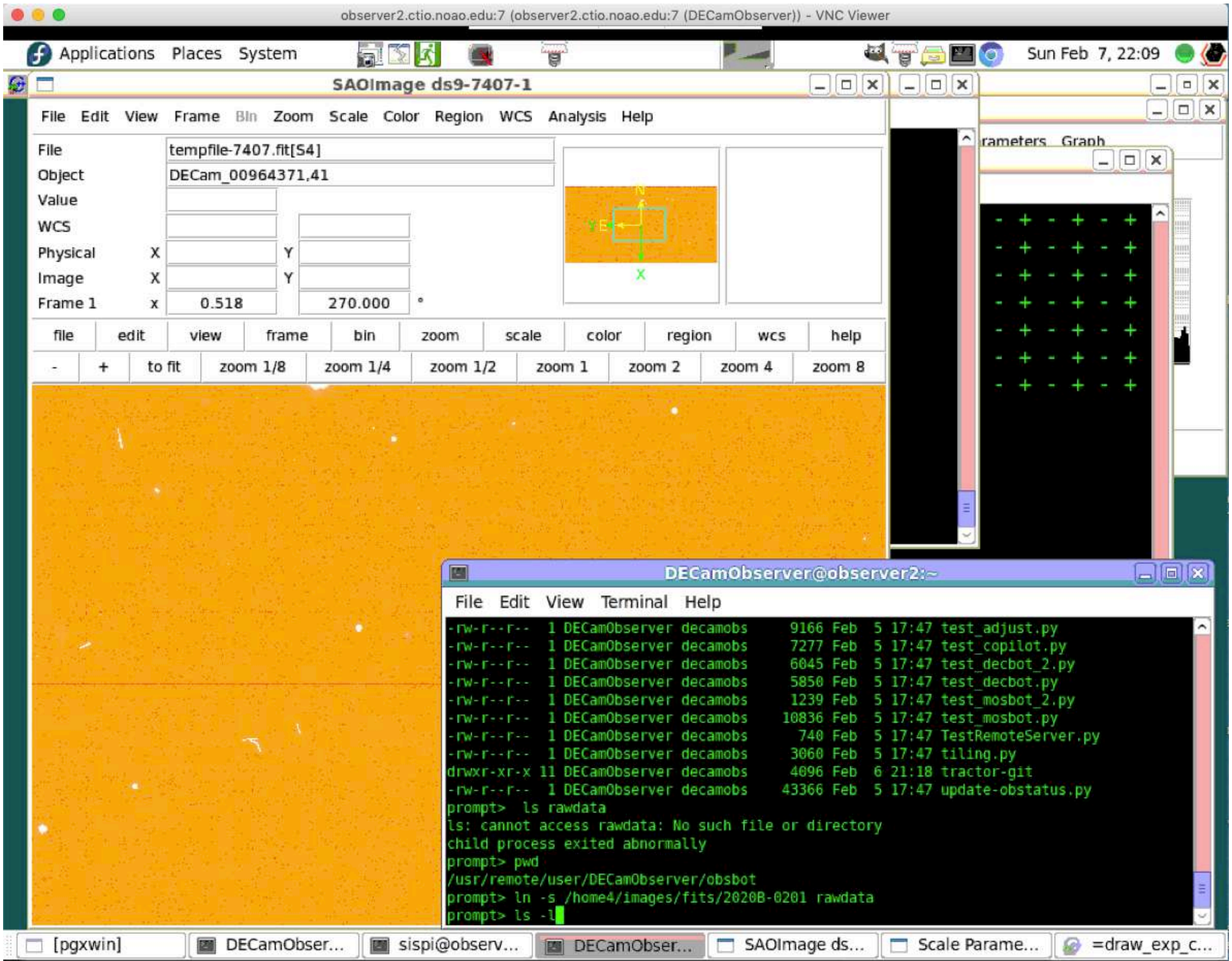
ODIN: Observing Feb. 7-14, 2021

Actual DECam observing is then pretty simple through browser GUI:



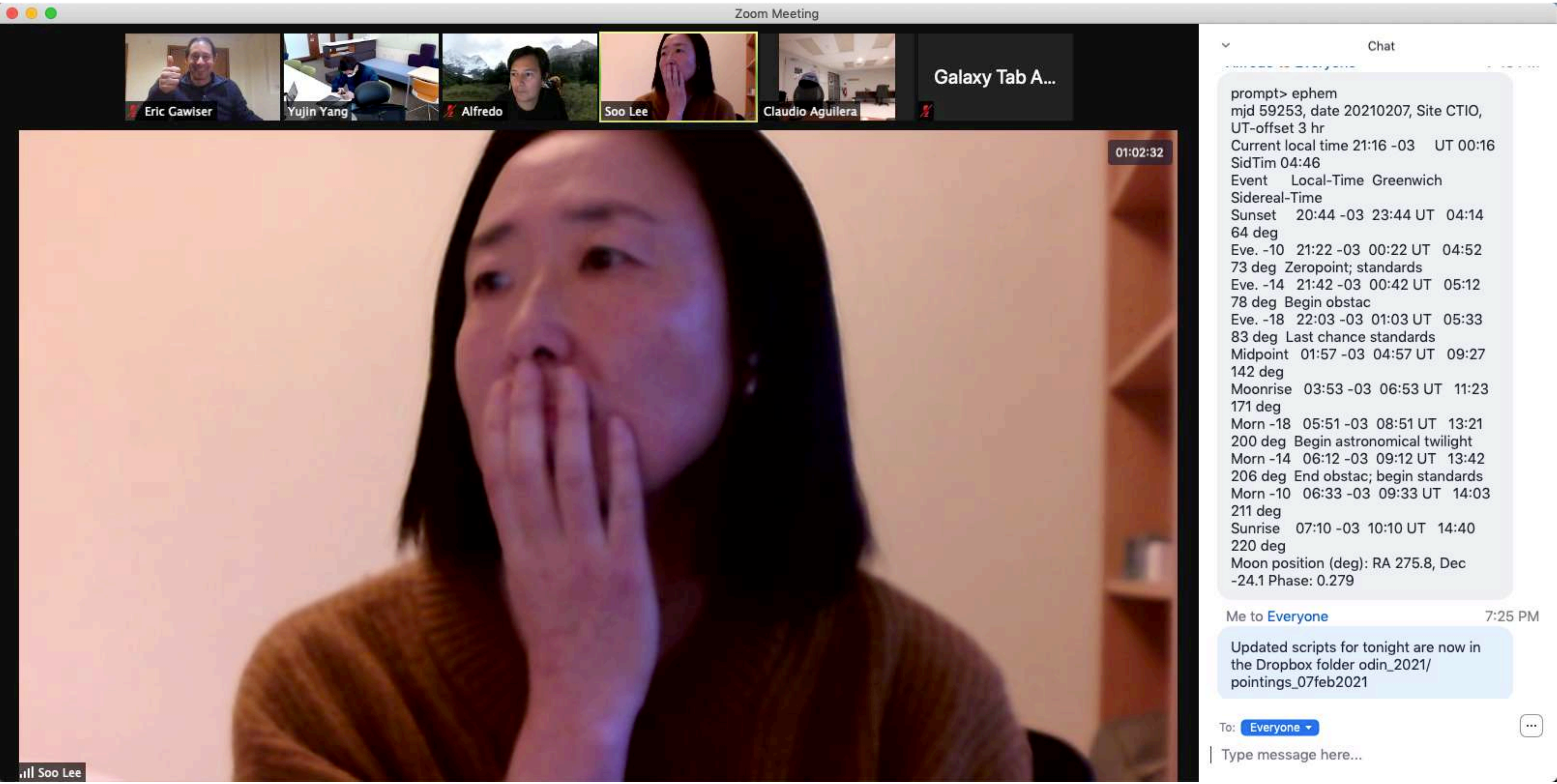
ODIN: Observing Feb. 7-14, 2021

Real-time data analysis:

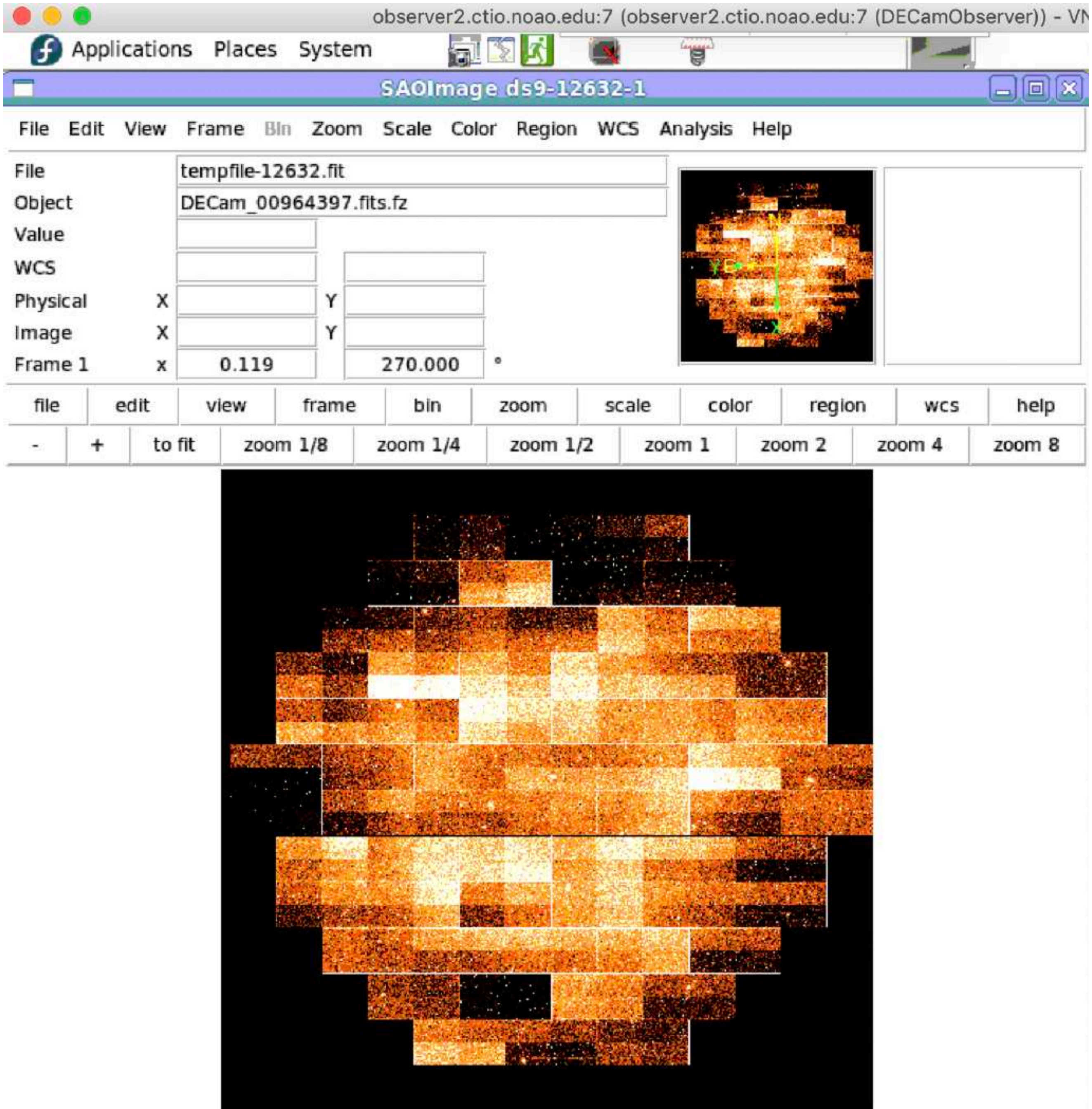


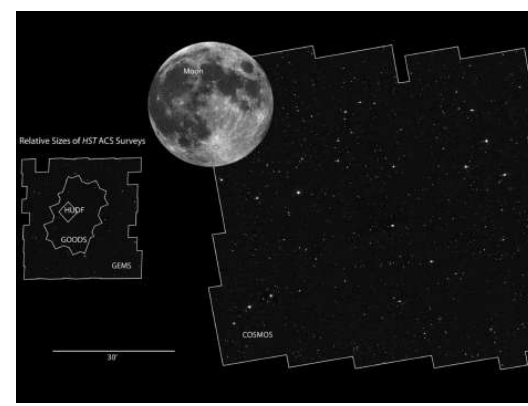
ODIN: Observing Feb. 7-14, 2021

While everyone talks to the Telescope Operator via Zoom:



ODIN: Observing Feb. 7-14, 2021

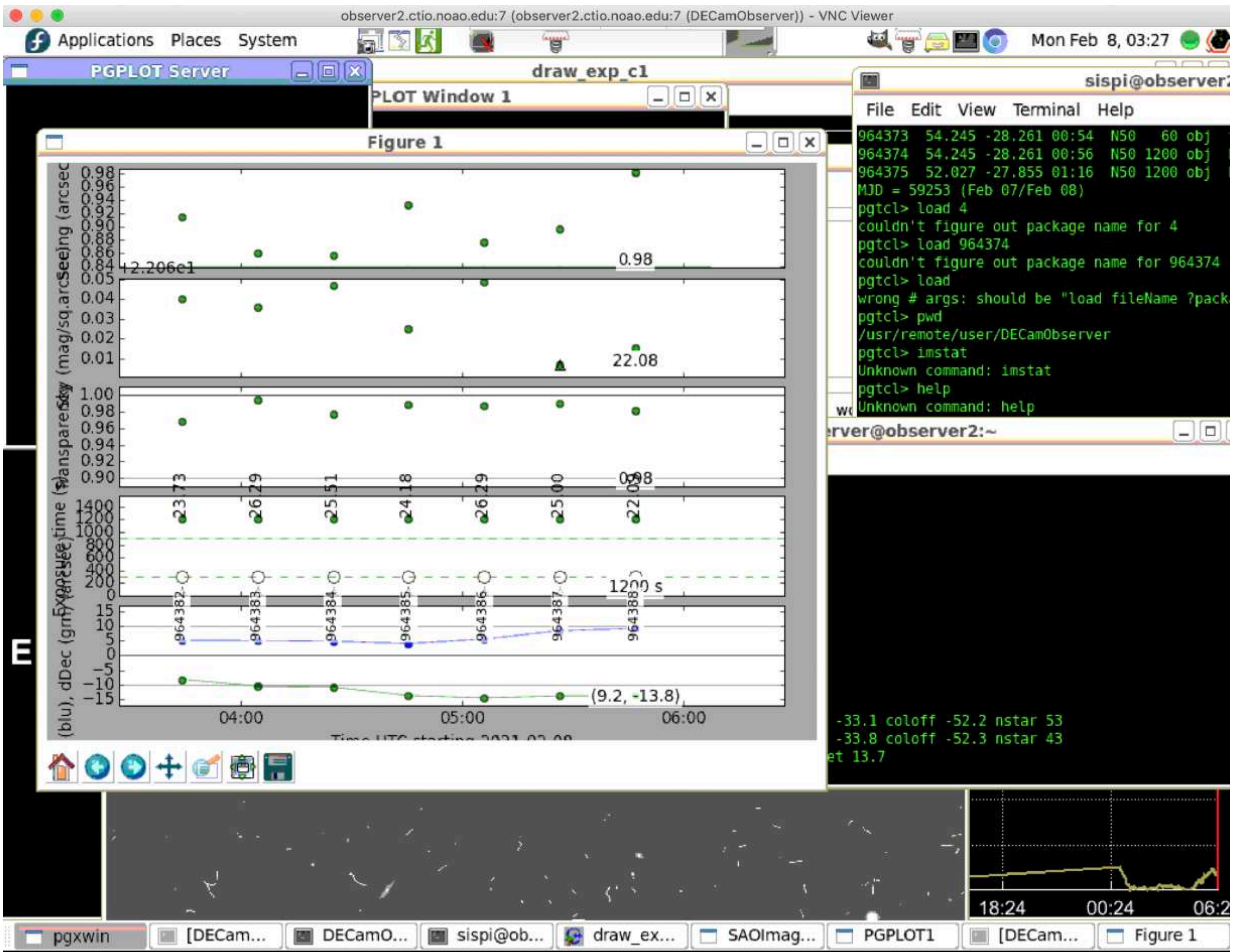




vs. the public COSMOS HST image, **to scale**

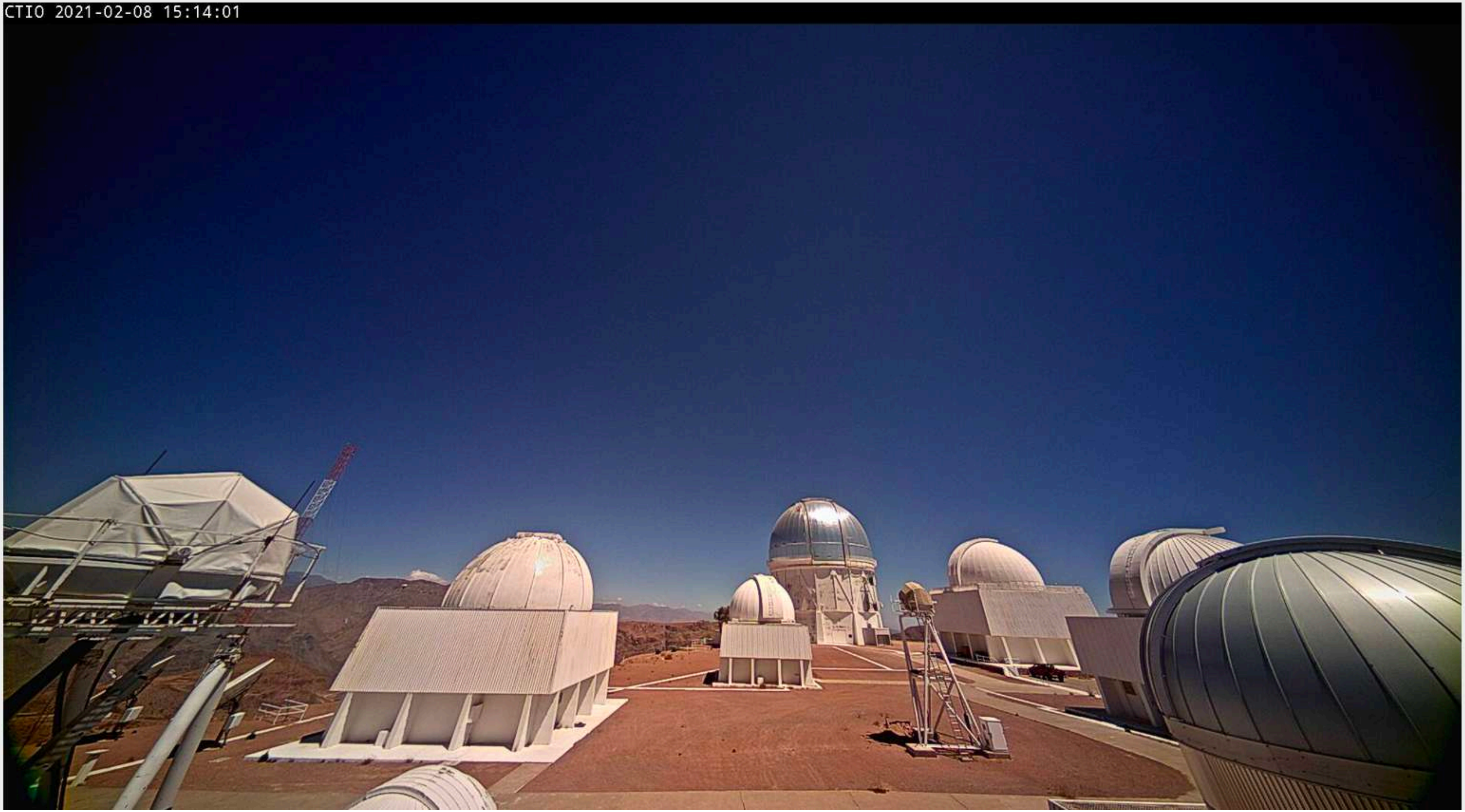
ODIN: Observing Feb. 7-14, 2021

Tracking seeing, sky brightness, transparency, exposure time, pointing errrors



ODIN: Observing Feb. 7-14, 2021

Blanco Webcams



ODIN: Observing Feb. 7-14, 2021

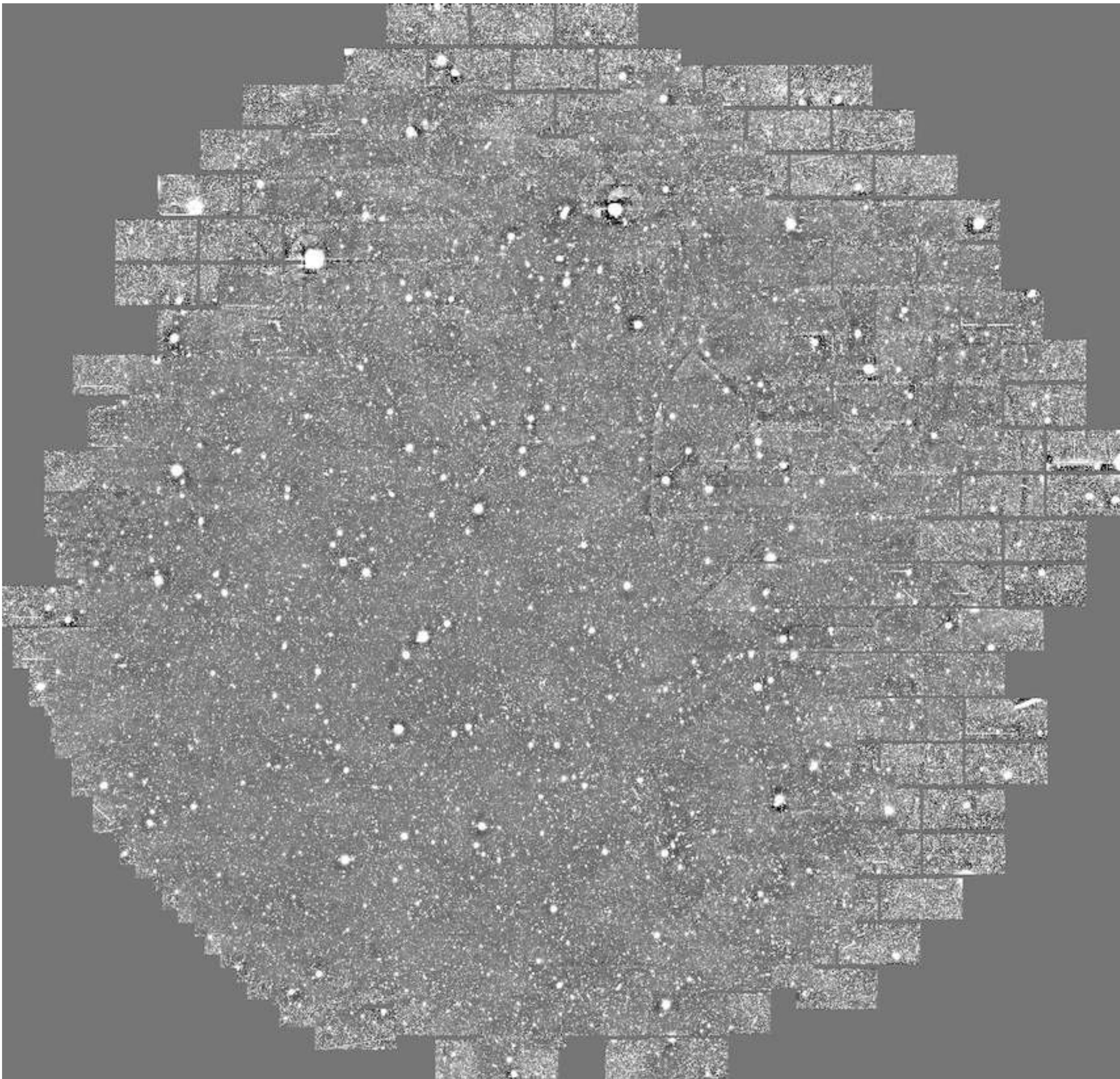
Blanco Webcams

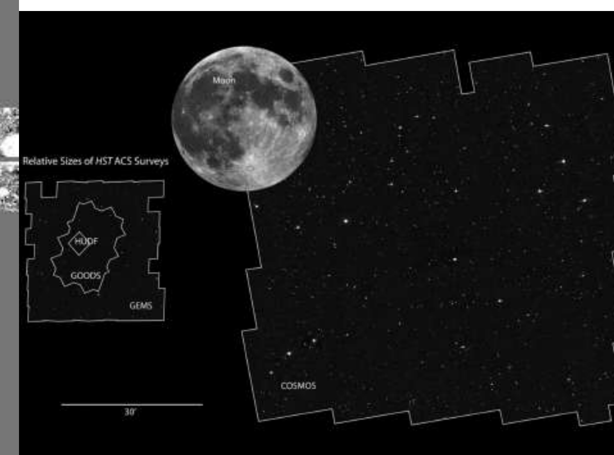
ODIN: Observing Feb. 7-14, 2021

Blanco Webcams

<u>ODIN: Observing Feb. 7-14, 2021</u>

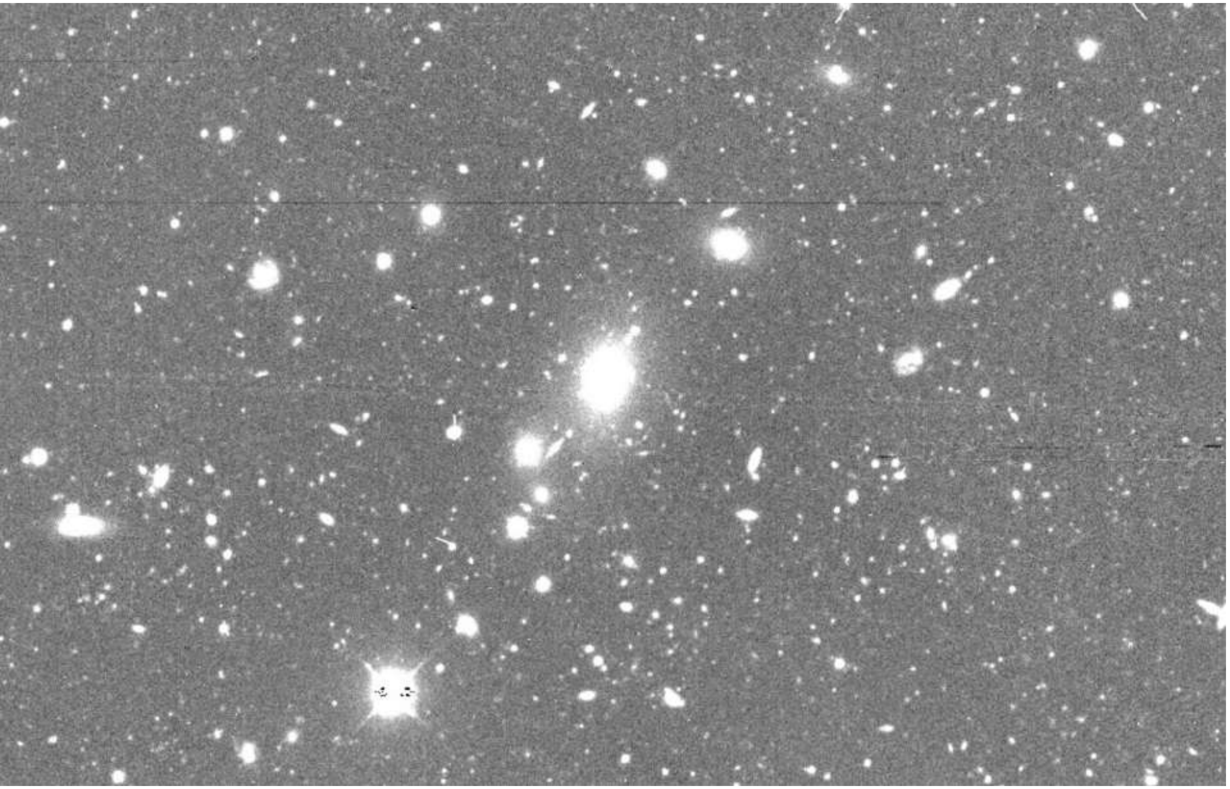
Starting to reduce the data with the DECam Community Pipeline

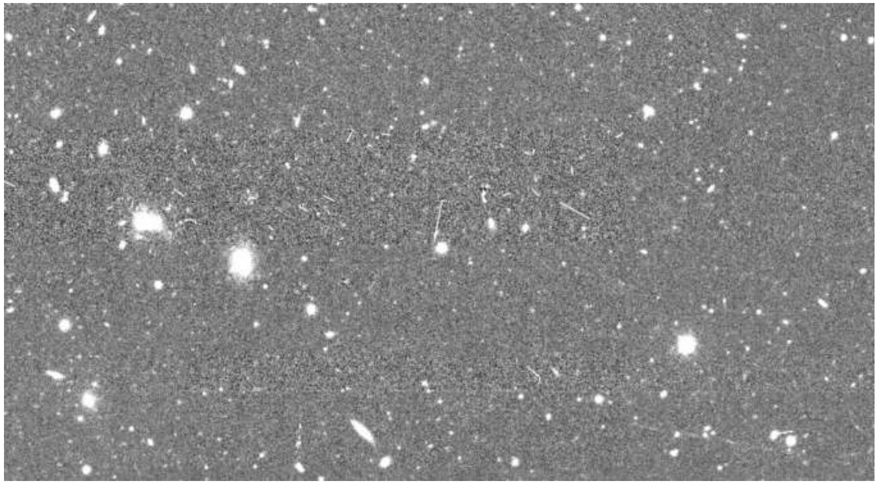




vs. the public COSMOS HST image, **to scale**

ODIN: Observing Feb. 7-14, 2021





Starting to reduce the data with the DECam Community Pipeline: zoom in enough and find a LOT of Cosmic Rays!

Observational Checklist

1. Get an idea
2. Write a proposal
3. Once awarded time, prepare for the observations
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Homework for Thursday, Feb. 11

Due: Quiz #4 will appear on Canvas Assignments at 4:40pm, due at noon tomorrow (Feb. 10).

Do: Be ready to work with your project group for most of the session. We will perform “Data Checks” by asking your group to show us that you have obtained the data for your project and are ready to begin analysis.

Any questions?