VERA C. RUBIN OBSERVATORY

System On-sky Test Plan

System On-sky Test Plan Working Group:
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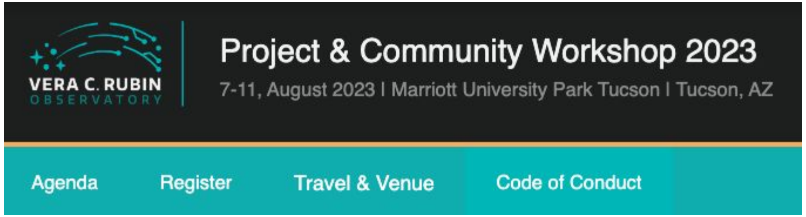
Rubin Observatory Project and Community Workshop
9 August 2023

NSF AURA U.S. DEPARTMENT OF ENERGY SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST CORPORATION

Reminder - Code of Conduct



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- Andrew Connolly (ajc@astro.washington.edu),
- John Franklin Crenshaw (jfc20@uw.edu), and/or
- Alysha Shugart (ashugart@lsst.org).

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full code of conduct

Check name-tags for these contact comfort level stickers.

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Use the confidential email rubin2023-covid@lists.lsst.org to request a test, report your test results, or ask questions.

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If you feel unsafe at any time send an email to rubin2023-helpline@lists.lsst.org

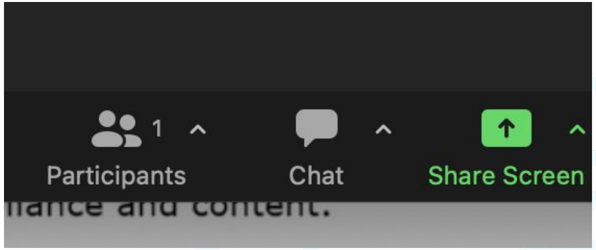
Reminder - Virtual Participation

Virtual participants should be muted when they're not speaking.

In-person participants should speak into the room microphone(s), or the chair should repeat all questions into the microphone, so that the virtual participants can hear what is said.

In the Rubin2023_PCW Slack Space, all participants can use the session's channel for Q&A and discussion.

The channel name convention is, e.g.:
#day1-mon-slot3a-intro-to-rubin



In Zoom, use the chat to:
- request to unmute to ask a question, or
- type your question so someone can speak it aloud.

The Zoom "raise hand" feature is generally harder for moderators to track, and is not preferred, but may be used at the discretion of the session chair.

Agenda

11:00 – 11:45 Walk-through of current draft system on-sky test plan

- Objectives
- Context: calibration hardware, AOS, data processing campaigns
- Current draft plan
- Proposed science programs

11:45 – 12:00 Small-group discussion

12:00 – 12:30 Whole-group discussion

This is an interactive session!
Please leave your questions, ideas, comments on the
live notes doc
or Slack channel
#day3-wed-1100-system-test-plan

System On-sky Test Plan

To make the most efficient use of on-sky commissioning time with the integrated system, we plan to **interleave engineering and science activities**:

- Bring tests as far forward in time as possible
- Maximize opportunities for “thinking time” and iteration
- Prioritize early tests that yield actionable information on system performance

We have developed a draft **System On-sky Test Plan** to describe the sequence of on-sky and in-dome data acquisition, data processing, and verification campaigns with LSSTCam considering calibration systems, AOS commissioning, and Science Programs together (SITCOMTN-075).

System On-sky Test Plan Objectives

(1) **Locate each activity within the context of the overall commissioning schedule**

- Identify predecessors, successors, and activities that can run in parallel

(2) Provide sufficient detail to **guide effort over the next year** to prepare for LSSTCam on-sky commissioning, e.g.,

- data taking → scripts / scheduler configuration
- data reduction → campaign management (e.g., which subset of visits? Science Pipelines payload?)
- data analysis → analysis software and visualization tooling (e.g., analysis_tools)
- verification → test plans, test cycles, test cases

See System Engineering Methods for Verification and Validation ; Update from Science Pipelines

System On-sky Test Plan Strategies

To the extent possible, concentrate efforts on a modest number of observing programs and associated data processing campaigns that support multiple investigations:

- simplicity / prioritization
- efficient use of finite time and personnel resources
- more streamlined communication / documentation
- more straightforward scheduling
- enable analyses that were not originally planned / anticipated

Iterating on Draft System On-sky Test Plan

Synthesize initial input (normative system requirements, AOS commissioning, calibration hardware, Science Pipelines needs, input from science community, …)

Develop **narrative success-oriented draft test plan**

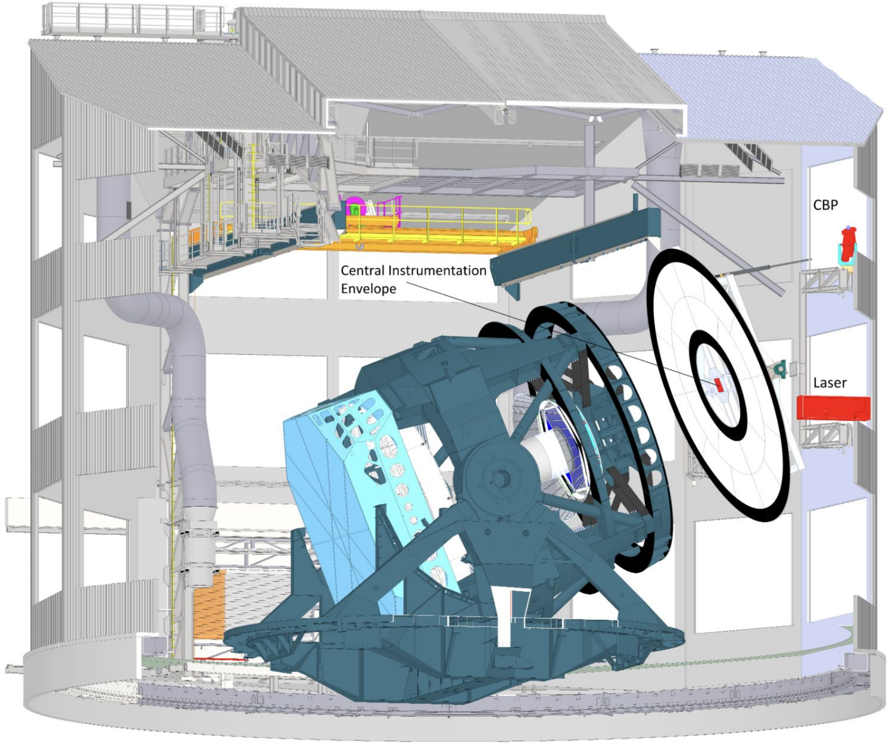
- Initial focus on logical sequence of activities rather than exact duration / dates
- Initial focus on datasets needed rather than exact details of implementation and scheduling
- Group activities and associated example datasets according to **system states** when the data could first be collected in a useful / efficient way (logical flowchart to plan activities)

Share draft test plan broadly (e.g., current session), including descriptions of proposed datasets, and **iterate to convergence**! Complete draft technote SITCOMTN-075.

Thanks to everyone for sharing your expertise and ideas

Calibration Hardware Systems, Active Optics System, and Data Processing Campaigns

Calibration Hardware Systems



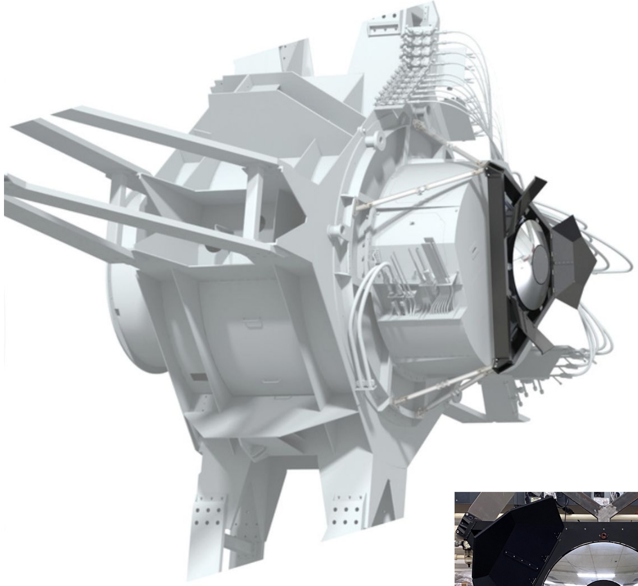
Ingraham et al. 2022 SPIE

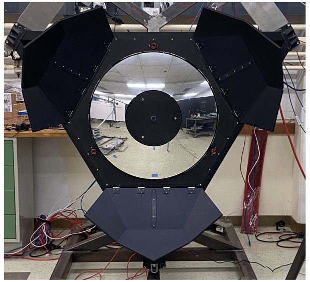
- Calibration (flat field) screen
- Central Instrumental Envelope
  - Houses projection optics
  - LEDs for “white light” or “dust flats”
  - Tunable laser for monochromatic flats
- Collimated Beam Projector (CBP)
  - Projects images on LSSTCam

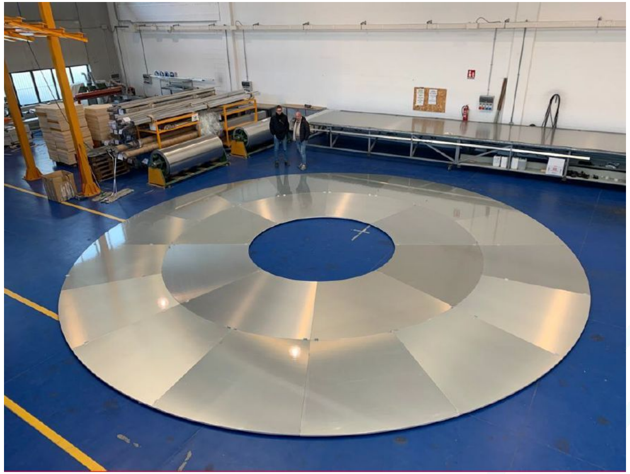
Not seen in this view:

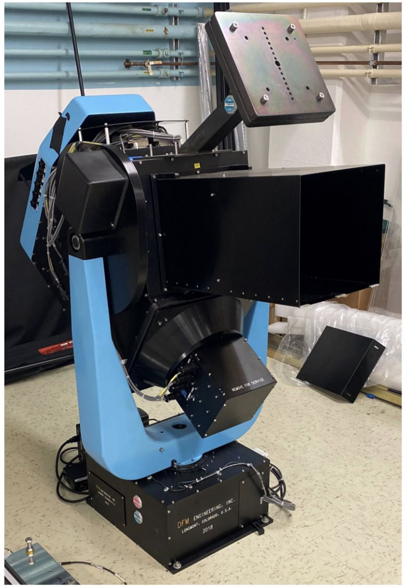
- Reflector (illuminator) optic
- Illumination characterization hardware
  - Fiber-fed spectrographs
  - Photodiodes

Calibration Hardware Systems





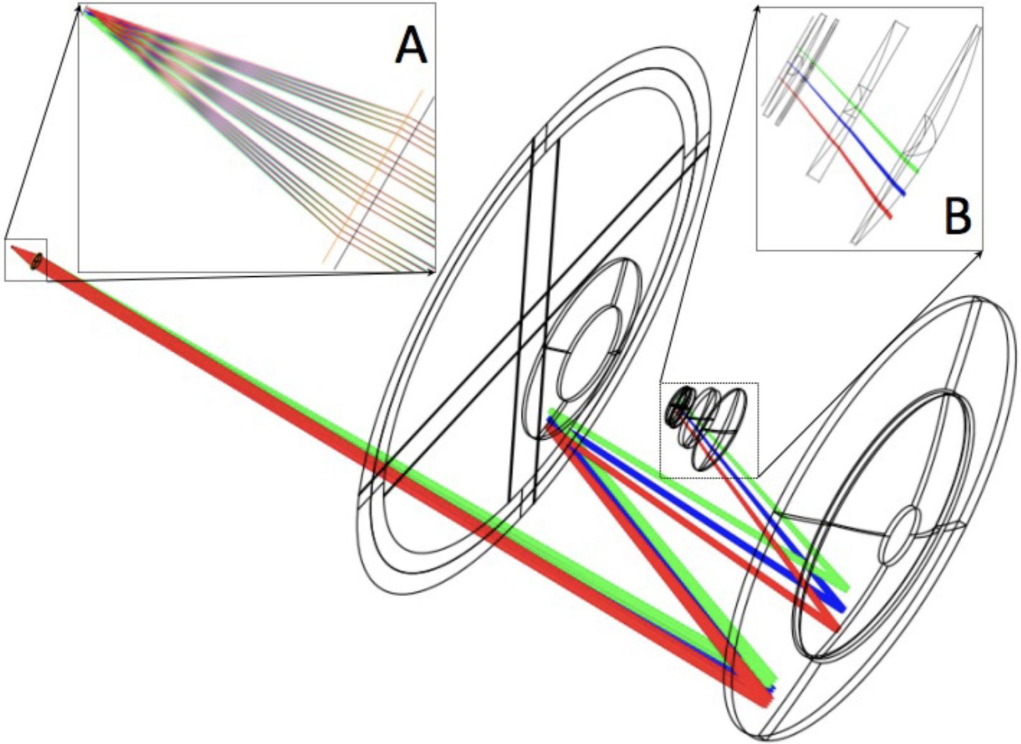




Calibration Hardware Systems

CBP is designed to measure system response to focused light

- Delivers a 24.1cm diameter collimated beam (small compared to pupil)
- Illuminates the full field of view including wavefront sensors and guider chips



Static CBP mode: fixed CBP pointing and telescope pointing; scan through wavelength, but no dithering

Dynamic CBP mode: dither CBP and telescope to illuminate pupil and placing spots; many degrees of freedom; create pseudo star flat

See Countdown to AOS Commissioning

Active Optics System (AOS)

Degrees of Freedom controlled by AOS:

- Relative positions and orientations of M1M3, M2, and LSSTCam: 5 degrees of freedom for each of the M2 and Camera positioning hexapods relative to M1M3)
- Surface figures of the mirrors: 20 bending modes on each mirror; similar to Zernike modes

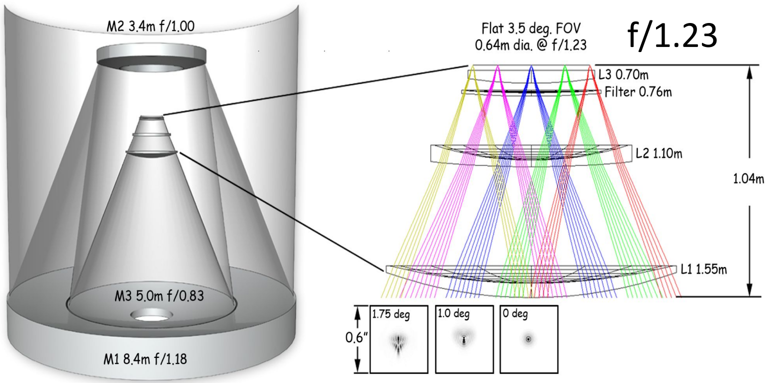
AOS Control Layers:

- **Laser Tracker system:** at start of night, align camera and M2 relative to M1M3 using hexapod/rotators
- **Open-loop / Look-Up Table (LUT):** active control; systematic corrections applied to the degrees of freedom based on temperature and gravity. Uses linear interpolation
- **Closed-Loop Control Algorithm:** active control; based on wavefront estimation, derives optical state of system and computes offsets to LUT to be applied to degrees of freedom

Goal: Reach better than seeing-limited image quality over a 3.5 deg FoV

FWHM Allocation:
- Telescope 0.25”
- Camera 0.30”
- Optical design 0.08”

Current projected system IQ: 0.34”



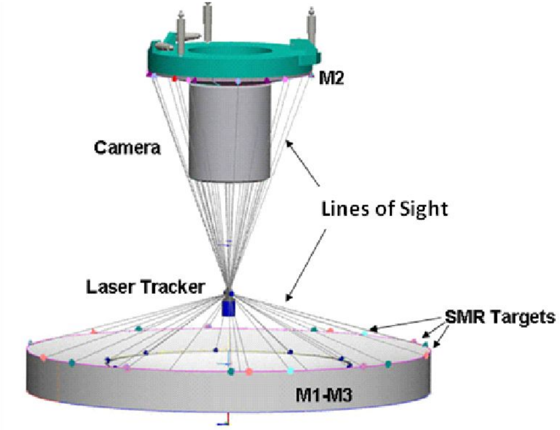
AOS Initial Alignment System

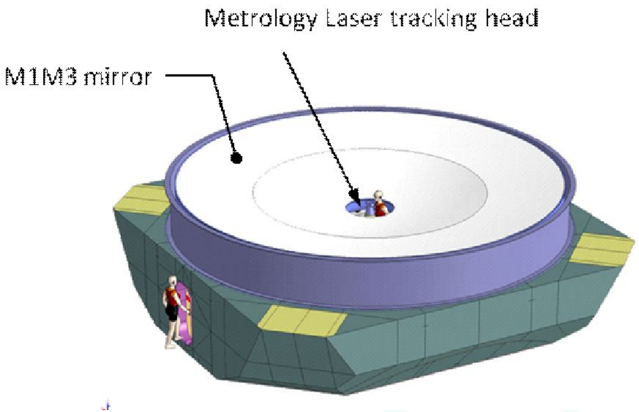
The initial alignment system will be used before each night to align the M2 mirror and the camera with respect to the M1M3 mirror using the hexapod/Rotators

Both mirrors have retroreflectors mounted on the periphery of the mirrors/mirror systems.

- On the edge of the M1M3.
- On the tangent pads for M2.

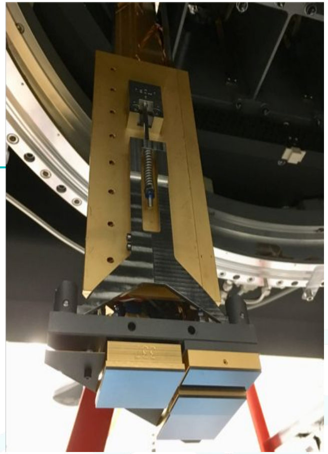
The locations of the tangent pad SMRs relative to the optical axis were established during the optical testing





The API between the Laser Tracker controller and the Alignment System CSC is complete
Laser tracker set-up on the Telescope

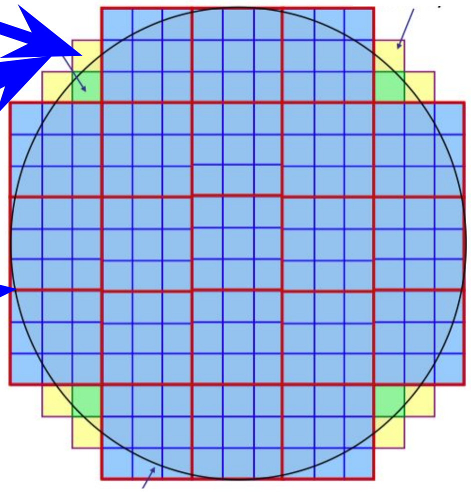
Wavefront Sensor: Curvature Sensing

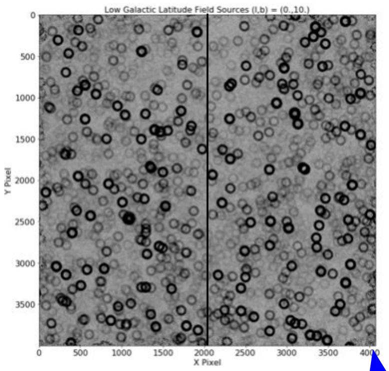


Wavefront Sensors (4 locations)

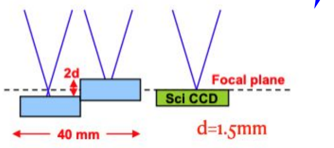
Guide Sensors (8 locations)

3.5 degrees
634mm diameter





Wavefront Sensor Layout



Curvature Sensor Side View Configuration

The focal plane of LSSTCam has 189 science sensors, 4 wavefront sensors and 8 guide sensors

Simulated intra and extra images for one of the wavefront sensors. They were obtained using a complex simulation tool called PhoSim.

Modes of Operation:

- LSSTCam Corner WFS Mode
- LSSTCam Full Array Mode

What matters is the image quality on the science detectors. We will evaluate the calibration sensitivity to the offsets between the science sensors and the WFS

AOS Commissioning

Substantial previous and ongoing work related to simulations, integration and test, and commissioning prep

Plan for **complexity ramp-up** during the on-sky commissioning phase

- Start with rigid-body motion DOFs (hexpods), followed by a few mirror modes
- Start with central science raft before expanding to full FOV
- Test under wide range of conditions
  - Telescope pointing (mostly elevation, possibly also azimuth), camera rotation, filter, seeing, temperature, stellar density, background level (twilight, filter, proximity to moon, etc.), corners and full-array mode, exposure time / number of snaps

Additional System Optimization Parameters

LSSTCam operations (extended operation, different orientations, different dome temperatures, configuration tuning)

Potential contributions to image quality include:

- Atmospheric seeing
- Dome and local seeing (temperature gradients)
- Static optics
- Dynamic optics (oscillations in primary support, top end)
- Telescope mount (tracking errors, oscillations)
- Instrument and sensor effects

Want to understand distribution of performance across wide range of conditions …

Planned Data Processing Campaigns

- Rapid Analysis @ summit (realtime)
- Prompt Processing @ USDF (realtime)
- "Next Morning" DRP-like processing @ USDF
  - As lightweight as an end-of-night report (single-frame processing) or as heavyweight as a full DRP
  - Need to combine visits for some metrics
- Regular DRP processing of curated datasets @ USDF
  - Process curated subsets at regular intervals with updated versions of Science Pipelines
  - "Incremental" DRP through coadd measurement
  - "Cumulative" DRP through coadd measurements

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Now part of routine processing of AuxTel imaging surveys

See Update from Science Pipelines

Science Verification and Validation Infrastructure and Tooling Ecosystem

- Data reduction
  - **Science Pipelines** – library of software components and the algorithms and processing pipelines assembled from them
  - **Middleware** – handles distributed processing and data access, including Butler for persisting and retrieving data products
  - **Infrastructure** – consisting of computing, storage, networking hardware, and system software
- Generating science performance metrics and plots in pipelines
  - **analysis_tools** – Science Pipelines package for generating science performance metrics and plots as part of a pipeline using science data products as input (e.g., source and object catalogs)
- Database services
  - **Sasquatch** – service for recording, displaying, and alerting on telemetry data and metrics
- Interactive / ad hoc analysis
  - **Jupyter notebooks** – web interface for interactive processing and analysis; part of Rubin Science Platform
- Visualizing results
  - **RubinTV frontend** – monitoring data quality during nighttime operations
  - **Jupyter notebooks** – web interface for interactive processing and analysis; part of Rubin Science Platform
  - **Chronograph** – dashboard to visualize time series
  - **Plot Navigator** – web interface searching and displaying diagnostic plots
- Documentation
  - **Technotes** – searchable library of technical documentation
  - **pipelines.lsst.io** – documentation for Science Pipelines (guides, API, tutorials)

See Commissioning Science Validation Bootcamp 22-24 May 2023, Update from Science Pipelines

Current Draft
System On-sky Test Plan

System First Light

System Fight Light is achieved when we can routinely acquire science-grade imaging across the full focal plane, and have a well understood technical path towards meeting the Construction Completeness criteria

Criteria:

- Observe any set of target fields with airmass < 2 and acquire science-grade images for at least an hour with cadence similar to baseline LSST survey
- System performance acceptable for LSST science, e.g., delivered image quality, system throughput, ISR
- Near realtime-monitoring of data quality to inform nighttime operations
- Automated data transfer and ingest at USDF
- Functional capability to produce coadd and difference images
- Information content to support “press ready” images for System First Light celebration

(note non-linear time scale)

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System On-sky Test Plan Overview Timeline

LSSTCam Installed on TMA

First Photon
First on-sky images; focal plane readout

System First Light
Science-grade functional observatory

Enter Full / Survey Operations
Meet SRD specifications for single-visit performance

Data Preview 2 Release
Validate full suite of science Prompt and Data Release data products

5 weeks — Camera cooldown

12 weeks — Acceptable image quality center of FoV; Acceptable image quality full FoV; Acceptable image quality full FoV, airmass < 2

18 weeks — System optimization; Full rehearsal

6 months — **Full / Survey Operations**

Calibration Systems

Calibration Hardware Install and Functional Testing

Initial Calibration Data
First LED flats; initial monochromatic flats, CBP pointing testing

Calibration Data
Full range monochromatic flats, static CBP data collection

Validate Calibration Data Products
Ongoing calibration data collection and analysis

All calibration products delivered

AOS Commissioning

Focus Sweep and Alignment

Hexapod Validation
- Wavefront retrieval tests
- Hexapod sensitivity matrix (full array mode)
- Hexapod LUT tests
- Hexapod closed loop

Full DOF Validation
- Sensitivity matrix (full array mode)
- LUT Improvement
- Control loop tests

Verification analysis for System First Light

Verification analysis to support Operations Readiness Review

Verification analysis w/ full Science Validation Surveys

Science Verification & Validation

"First Look" Science Programs
- Analysis of in-focus images
- Exposure Time Scans
- Bright Star Scans
- Pilot Dense Dithered Star Field

Small-Field Science Programs
- Dense Dithered Star Field
- Pilot Deep Drilling Field
- Crowded Stellar Fields

Science Validation Surveys
Deep: ~100 deg^2 *ugrizy* to 10-yr LSST WFD equivalent depth → then increase depth
Wide: ~1000 deg^2 *griz* to 1-yr LSST WFD equivalent depth → then increase area

Survey scale Data Release Processing and science performance analysis for Science Validation Surveys

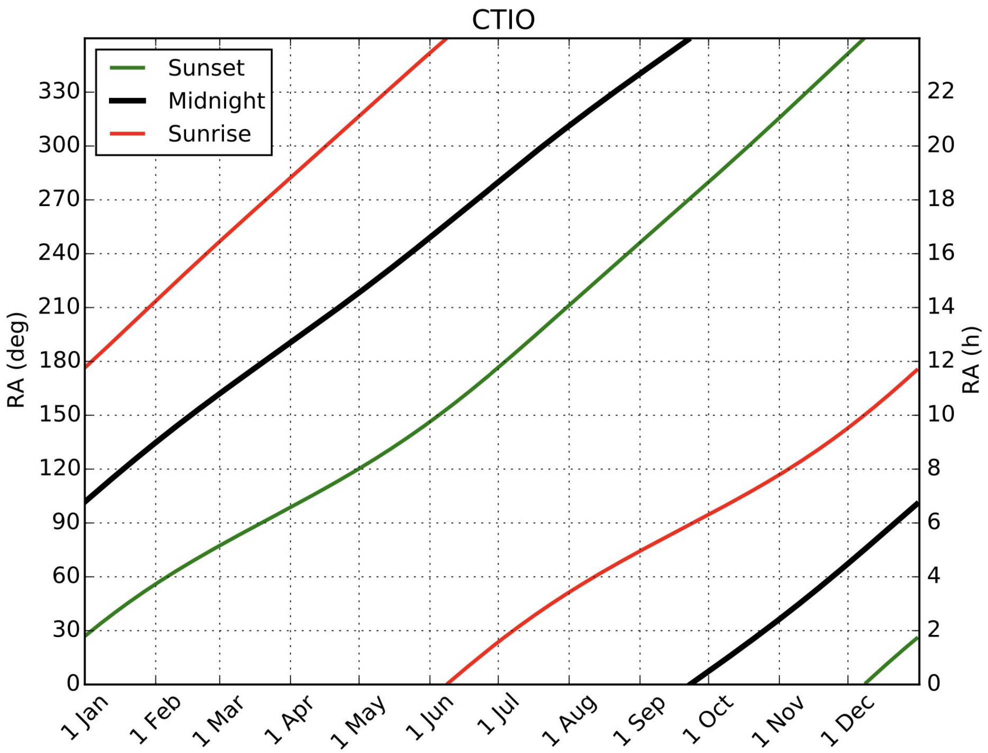
Construction Papers Complete

Flexible Scheduling Options

Develop flexible science verification observing plans that could be performed with scheduler:

- Opportunistic observations once system has been tuned at a given pointing
- During second half of the night (after engineering activities have sufficient data for offline analysis); fields overhead during the second half of the night will be visible for next several months

Cloudy nights could be used for in-dome calibration data



Calibration Systems (1/2)

Calibration Screen + Structure Installed on Dome [prior to M1M3 install, date TBD]

- Install Calibration hardware (laser, projector, CBP) [following cal screen installation, must be complete by M1M3 install; duration: 2 weeks]
- Functional Testing of Calibration hardware [following cal hardware installation, must be complete by 1st photon; duration: 1 month]
- Calibration of CBP [following cal hardware installation, must be complete by 1st photon; duration: 6 weeks]
- Camera installed [June 2024 (?)]
- Install Reflector [following camera install; duration: 2 days]
- Align system [following install reflector, must be complete by 1st photon; duration: 5 days]

First Photon

- LED Flats 1 (note: these will be taken nightly) [immediately following First Photon; duration: 1Night]
- Monochromatic flats 1 (10 wavelengths per ugrizy+ filters) [following LED Flats 1; duration: 1 night]
- CBP pointing testing (daytime possible) [following LED Flats 1; duration: 14 days]
- On-sky testing 1 (initial dense dithered start field and twilight) [following LED Flats 1, must be complete before On-sky testing 2 + 2 weeks; duration: 1 night]
- On-sky testing 2 (test chromatic response of camera)[following On-sky testing 1, must be complete before First Light; duration: 1 night]
- Static CBP 1 (must be dark) [following CBP pointing testing, must be complete before First Light; duration: 2 nights]
- Monochromatic flats 2 (dark, full range, no filter priority)

Calibration Systems (2/2)

System First Light

- LED flats 2 (note: these will be taken nightly) [following First light; duration: not sure this even needs to be in the schedule]
- Static CBP 2 [following First Light, needs to be complete prior to ORR complete; duration: 6 nights]
- Monochromatic flats 3 [following First Light, needs to be complete prior to ORR complete; duration: 3 nights]
- On-sky testing 3 (used for final calib product) [following First Light; duration: 5 nights]
- Development of calibration products and analysis [following LED flats 2, Static CBP 2, Monochromatic flats 3, On-sky testing 3, and needs to be complete prior to ORR complete; duration: 2 months]

ORR Complete

- All calibration products delivered (milestone, same as ORR complete)

Interleaving AOS Commissioning and Science Programs

Single-frame Processing of In-focus Images
AOS driving; SVV uses subset of in-focus on-sky images for functional testing of Science Pipelines

First Photon → Focus Sweep and Alignment →

Hexapod Validation

- Wavefront Retrieval Tests
- Hexapod Sensitivity matrix — Full array mode
- Hexapod LUT Tests
- Hexapod Closed-Loop

Acceptable image quality in center of field of view

→

Full DOF Validation

- Sensitivity matrix — Full array mode
- LUT Improvement
- Control Loop Tests

→ Full / Survey Operations

Acceptable image quality across full field of view at a particular airmass

Begin Small-field Science Programs

- Dense Dithered Star Fields
- Deep Drilling Field
- Crowded Stellar Fields

Expected Duty Cycle:
AOS driving nighttime activities
SVV driving nighttime activities

SVV in second half of the night; potentially lower efficiency / more frequent re-focus

Begin "First Look" Science Programs

- Exposure Time Scans
- Bright Star Scans
- Initial Dense Dithered Star Fields

Acceptable image quality across full field of view for any airmass < 2, including after large slews → System First Light

Begin Science Validation Surveys
SVV survey mode observing; AOS and SVV coordinate data taking to sample range of observing conditions; AOS analyzes data for ongoing system optimization in parallel

Progression of System States (1/2)

System State	Commissioning Needs and Corresponding Data Taking Activities
LSSTCam at Level 3 Ready for Data Acquisition	● Produce post-ISR unflattened images → biases, darks, PTC
LSSTCam on TMA Ready for Data Acquisition **(starts at First Photon)**	● Initial system response → LED flats; twilight flats, initial monochromatic flats, CBP pointing testing ● Camera chromatic response → monochromatic flats, static CBP ● AOS commissioning → Focus sweep and alignment
Acceptable image quality in center of FoV	● AOS commissioning → hexapod validation (sensitivity matrix, WEP, LUT, closed loop) ○ System optical throughput (zeropoints) → Single-frame processing of in-focus images ● Amplifier offsets → Exposure time scans ● Evaluate ghosts and scattered light, measure extended PSF profile → Bright star scans

Progression of System States (2/2)

System State	Commissioning Needs and Corresponding Data Taking Activities
Acceptable image quality across full FoV at a particular pointing	• AOS commissioning → full DOF validation (sensitivity matrix, LUT, closed loop) • Reference flat + instrument astrometric model → Dense Dithered Star Fields • Evaluate DDF dithering strategy → DDF • Evaluate performance in crowded fields → Crowded Fields
Acceptable image quality across full field of view for any airmass < 2, including after large slews **(starts at System First Light)** Ready for survey-mode observations	• Validate full suite of calibration products → full monochromatic flats, static CBP • Science Verification and Validation at survey scale → Science Validation Survey ○ System Optimization → continue AOS full DOF closed loop testing
System performance in survey mode meets SRD design specifications	• Full Operations Rehearsal / Prepare for ORR → Complete Science Validation Survey

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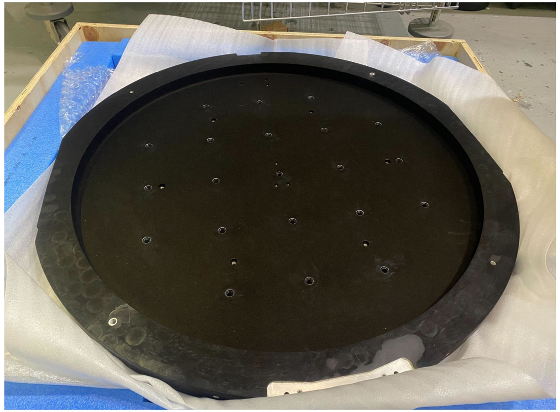
Verification Campaigns

Early verification opportunity
Expect to verify and meet design specification

	AOS Comm. in-focus	Monochrom. Flats, Static CBP	Exposure Time Scans	Bright Star Scans	Dense Dithered Star Field	Deep Drilling Field	Crowded Fields	SV Survey: Deep	SV Survey: Wide
Single-visit image quality (e.g., PSF FWHM, ellipticity)									
Scattered light (not predicted)									
Interaction of ISR w/ on-sky data w/ camera installed on telescope									
Single-visit astrometric and photometric calibration									
Science Performance: Alert Production									
Science Performance: Deep Coadds									
Ghosts (predicted)									
Optical Throughput									

Specialized Data-taking Modes

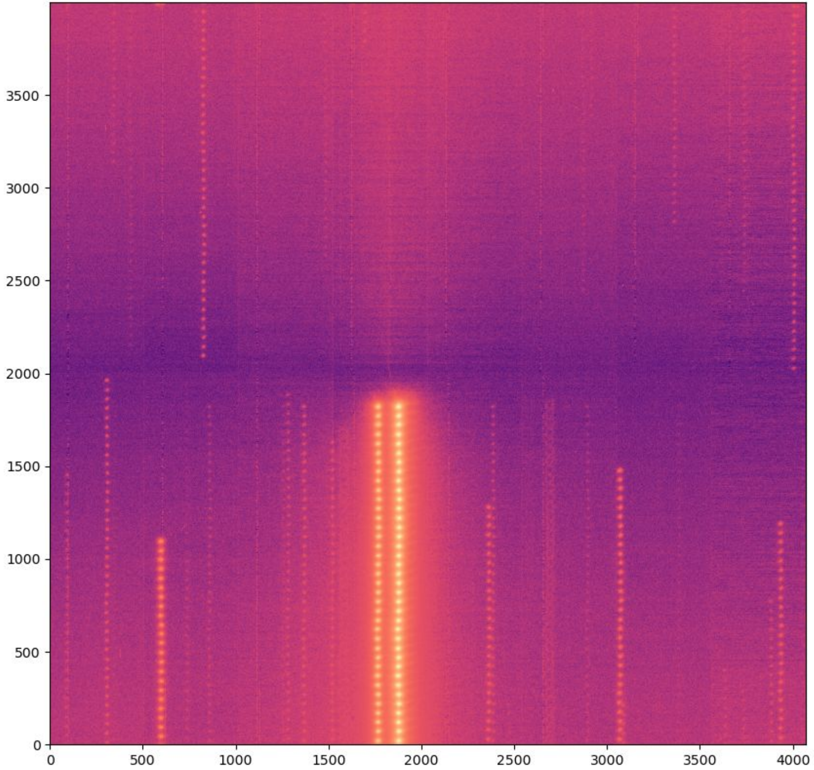
Additional examples of specialized data-taking modes to incorporate into plan?



Pinhole camera

Stuttered imaging and strip-chart imaging

Chris Stubbs, Craig Lage, Claire-Alice Hebert, HyeYun Park, Tony Johnson



Proposed Science Programs

🚧 In-progress technote draft version with more detailed information in tabular format

Once released, the technote will appear at ls.st/sitcomtn-075

Proposed Science Programs

🚧 In-progress [technote draft version] with more detailed information in tabular format

Once released, the technote will appear at

ls.st/sitcomtn-075

Example table (Dense Dithered Star Field)

Attribute	Notes
Primary Objectives	• Determine reference flat (illumination correction) independent of CBP • Determine instrumental astrometric model
Additional Goals	• Initial testing of building coaddition and difference imaging
Prerequisites	• LED flats have been acquired • Monochromatic flats have been acquired (iterations approaching System First Light)
Total Visits	120 visits × 6 epochs = 720 visits (8 hrs total; 6 epochs of 80 min each)
Overlapping Visits	30 visits in each of ugri (dark time) or rizy (bright time) in each epoch; epochs span range of airmass; comparable to single year of LSST WFD integrated exposure
Band Coverage	ugrizy (4 bands in a given epoch is sufficient)
Area	Central region of ~10 deg^2 (focal plane dithers around a single central pointing)
Pointing / Sky Region	Region of moderately high stellar density, but not so dense that blending is a concern. Low interstellar extinction
Visit / Exposure Time	Standard visit
Dither Pattern	Dithers from sensor scale up to focal plane scale with translation (rotation needed??) around a central pointing so that the same stars appear on many different sensors across the focal plane
Cadence	Repeated visits within a single epoch. Alternate between filters within an epoch so that stars are observed in griz bands within a single epoch.
Time Baseline	~80 minutes within epoch; epochs can be on separate nights (close spacing preferred)
Delivered Image Quality	• 0.7 arcsec system contribution to PSF FWHM across the full FoV • 1.0 arcsec delivered PSF FWHM across the full FoV
Airmass distribution	Observe same field in in three epochs to sample a range of airmass: 1.0, 1.4, 2.0
Environmental Conditions	• Photometric
Representative Dataset Types	DRP mode: • Source, Object, ForcedSource, DiaSource, DiaObject, DiaForcedSource AP mode: (could be replay) • DiaObject, DiaSource, DIAForcedSource
Success Criteria	• Verification of astrometric and photometric internal solution • Verification of acceptable image quality across full FoV across range of airmass as part of System First Light milestone

TABLE 4: Dense Dithered Star Field

Schedule Planning Assumptions

On-sky data:

For the purpose of estimation, take a typical night to be ~8 hours. Consider an average time between visits of ~40 seconds (90 visits per hour). This corresponds to ~720 visits per night, and realistically somewhat less due to filter changes, slews, variable environmental conditions, etc. Allowing 85% efficiency, average of ~600 visits per night, or ~18000 visits per 30 nights.

LSSTCam filter wheel swaps:

5 filters at a time; filter swaps only during day; swaps likely to coincide with lunar cycle

Science Program: AOS Commissioning In-focus

Objectives:

- Re-verification of infrastructure to collect and transfer data, process images with Science Pipelines, produce and visualize QA metrics and plots
- Using reference stars for astrometric (wcs) and photometric (zeropoint) solutions, PSF determination
- Initial re-verification of ISR / calibration products with in-focus images
- Initial studies of delivered image quality
- Initial check of optical system throughput (zeropoint) relative to expectation

Science Program: AOS Commissioning In-focus

Observations:

Data-taking driven by AOS commissioning needs; begin testing with subset of in-focus images

- Prerequisites: LED flats
- Expect several thousand (partially) in-focus visits over a period of several weeks
- Heterogeneous delivered image quality; anticipate gradients in delivered image quality across the FoV
- For many tests, expect visits to be scattered across sky (scanning in elevation and azimuth) and that analysis will focus on individual visits at this stage, i.e., conservatively plan that same fields will not be repeated
- DRP mode: source

Science Programs: Snap Testing

Objective: Compare performance of visits consisting of 2 x 15 sec snaps versus a single 30 second exposure

Observations:

Issues to consider

- Cosmic ray identification and removal
  - Need good enough image quality to provide representative challenge of identifying cosmic rays (functional testing can begin once achieving acceptable image quality over part of the focal plane)
- Latency of AOS closed-loop control updates
  - Requires stable AOS closed-loop performance to make comparison (later stages of commissioning)
  - Part of planned set of AOS commissioning tests

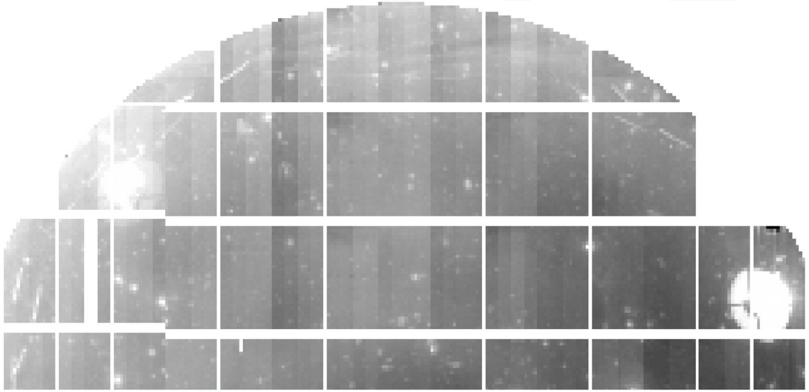
Science Program: Exposure Time Scan

Objectives:

- Verify that ISR corrects offsets between amplifiers (pattern continuity algorithm)

Observations:

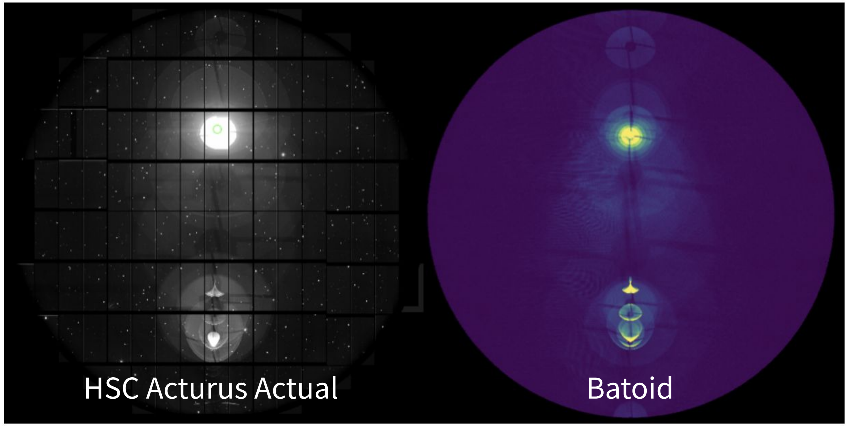
- Prerequisites: LED flats, monochromatic flats
- Series of visits with exposure times ranging from 1 second to 300 seconds
- 2 visits × 20 exposure times × 6 bands = 240 visits (anticipate roughly 1 hr per band)
- ugrizy bands
- Single pointing, minimal dither
- Avoid regions with bright sources
- Could begin with 2.0 arcsec delivered PSF FWHM



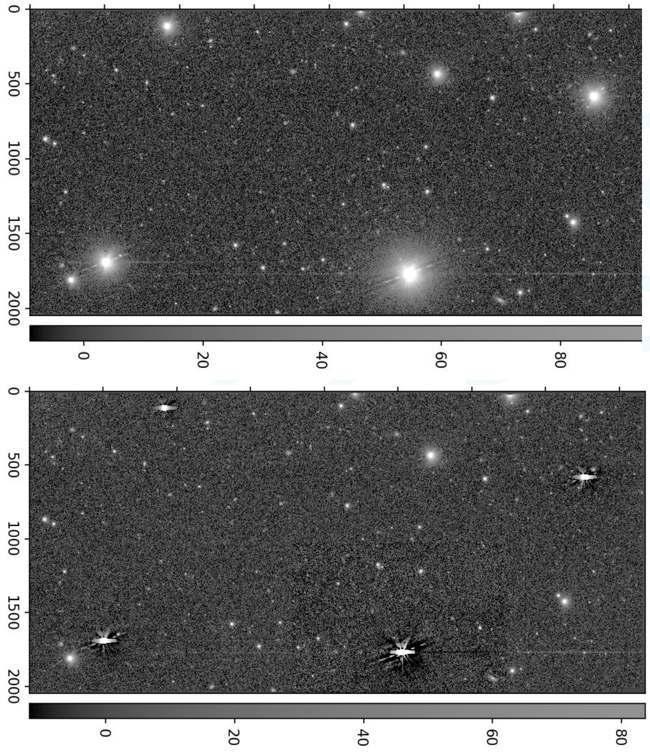
Science Program: Bright Star Scans

Objectives:

- Characterize ghosts and (unpredicted) scattered light
- Bright star profile / wings of the PSF
- Robustness of single-frame processing to presence of bright stars; appropriate mask design for bright stars
- Test ISR including crosstalk, saturation, and bleed trails

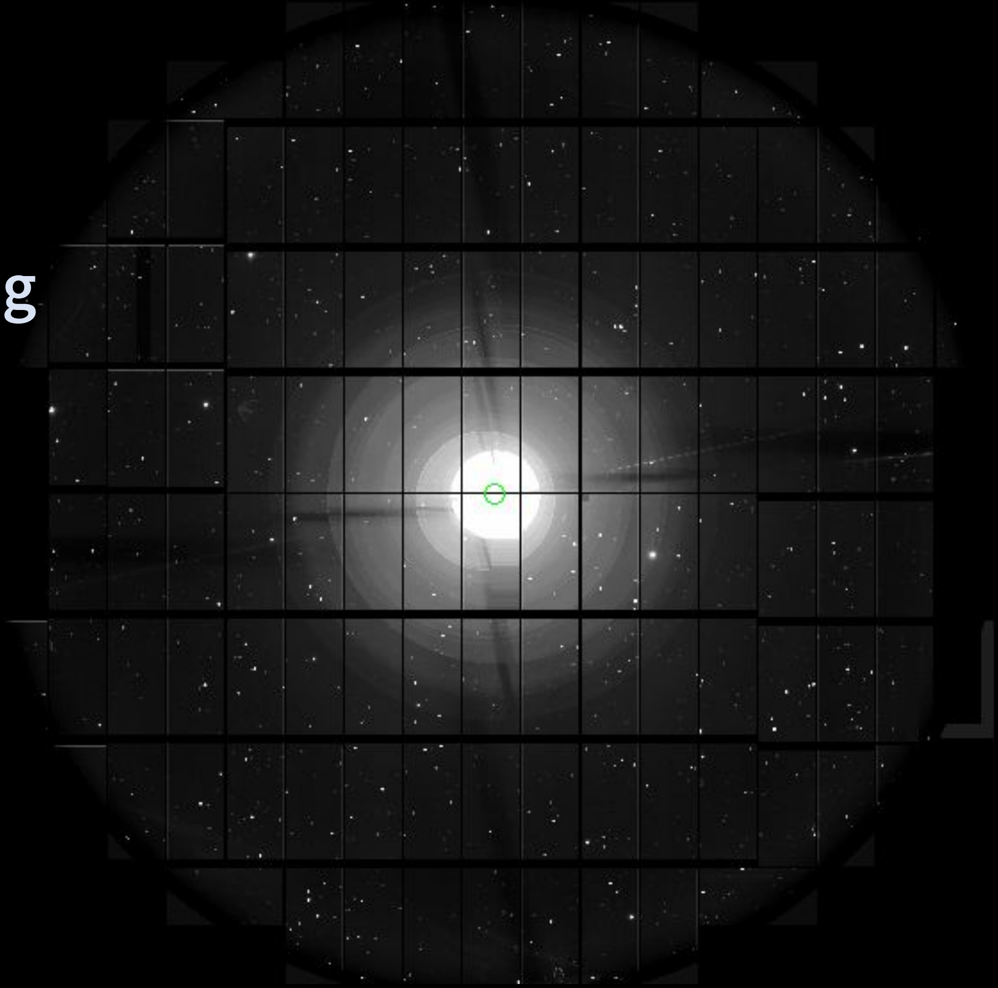


Josh Meyers



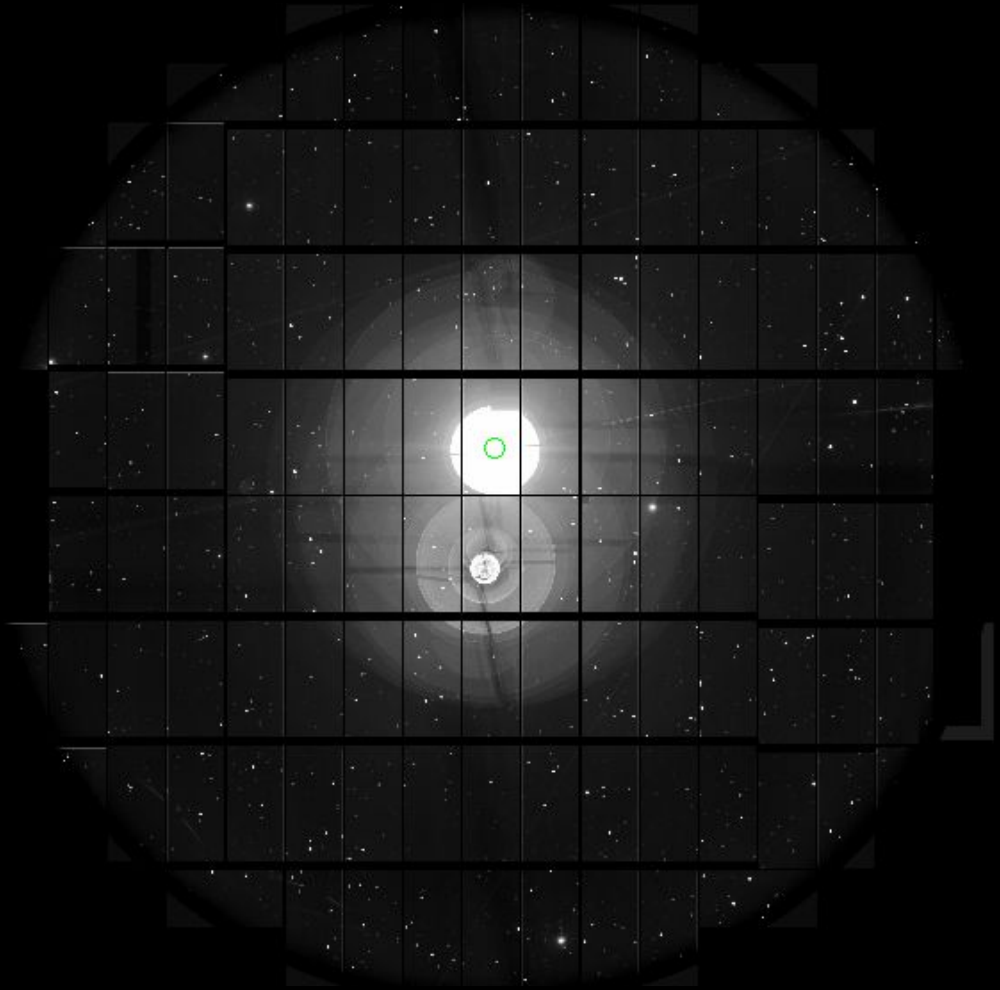
Ghosts:

Bright Star Scan Observing Campaign

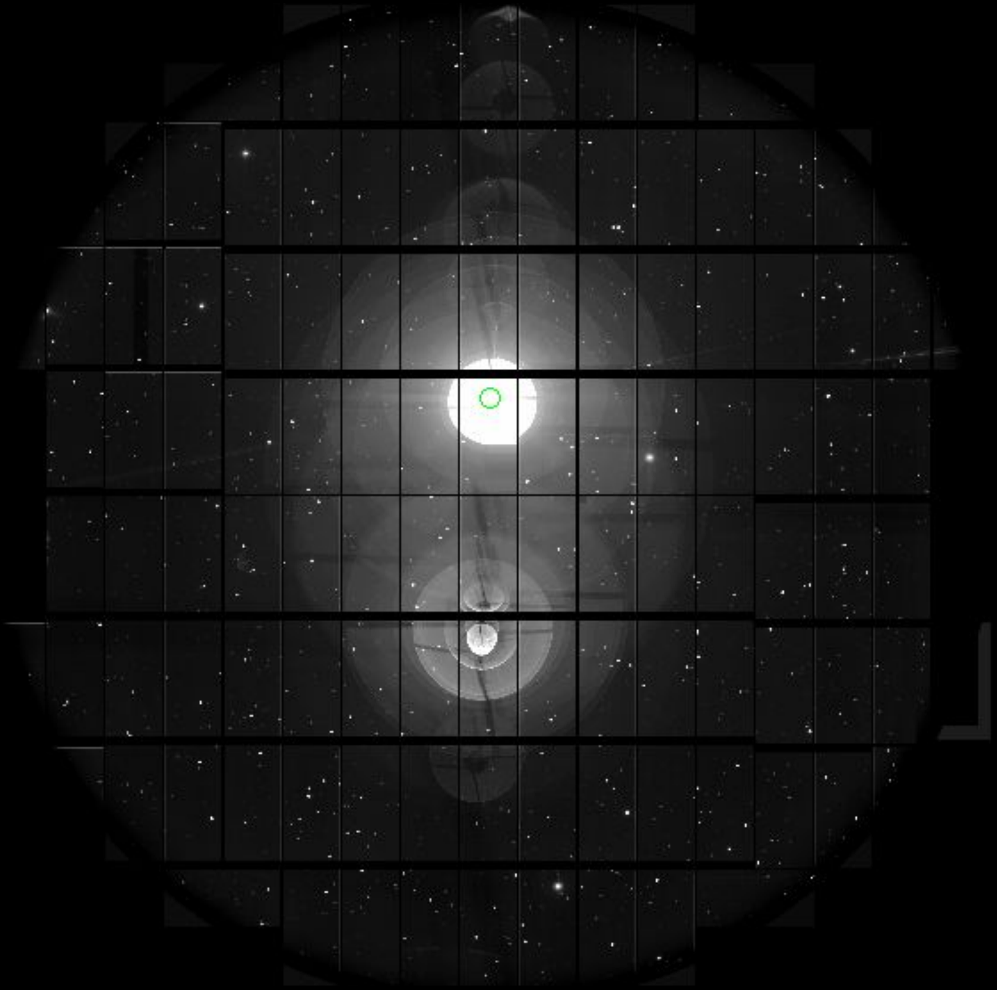


Arcturus (Hokule`a)
Robert Lupton, Jim Gunn
Time courtesy of
Satoshi Miyazaki and the HSC collaboration

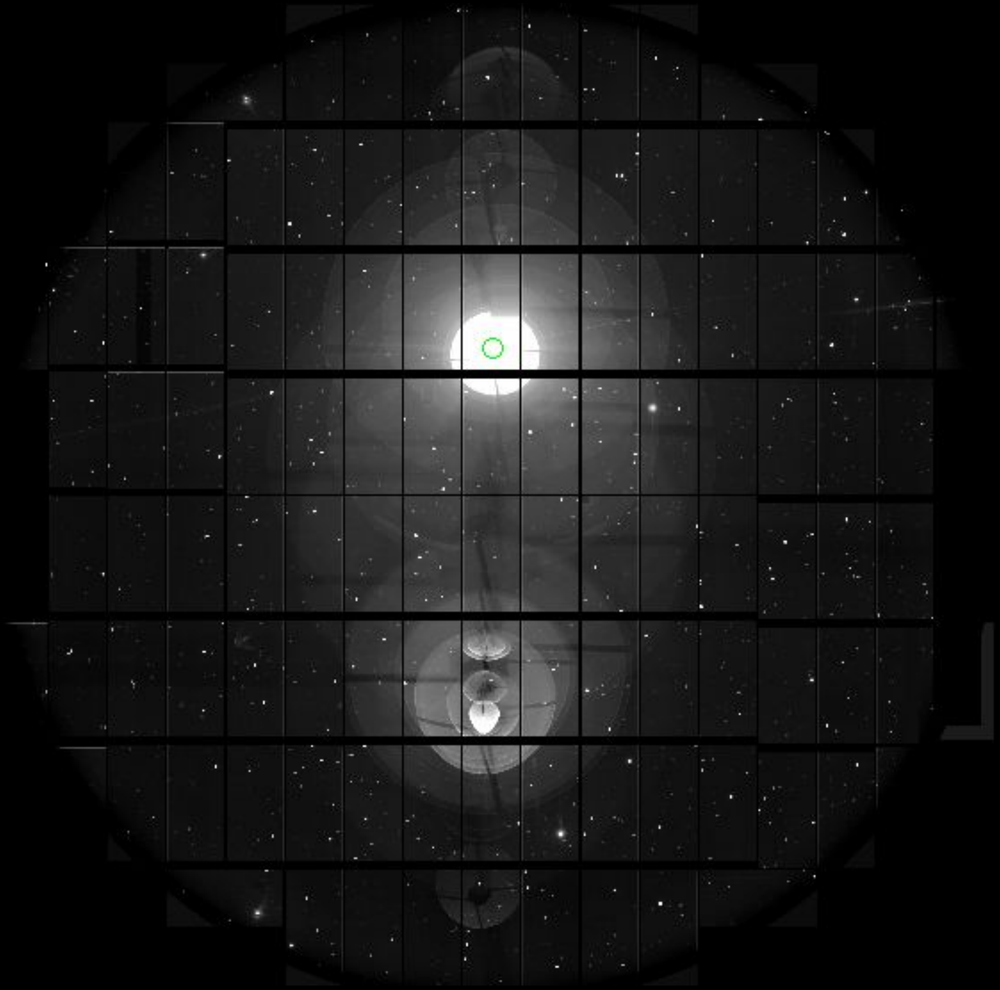
Ghosts



Ghosts



Ghosts



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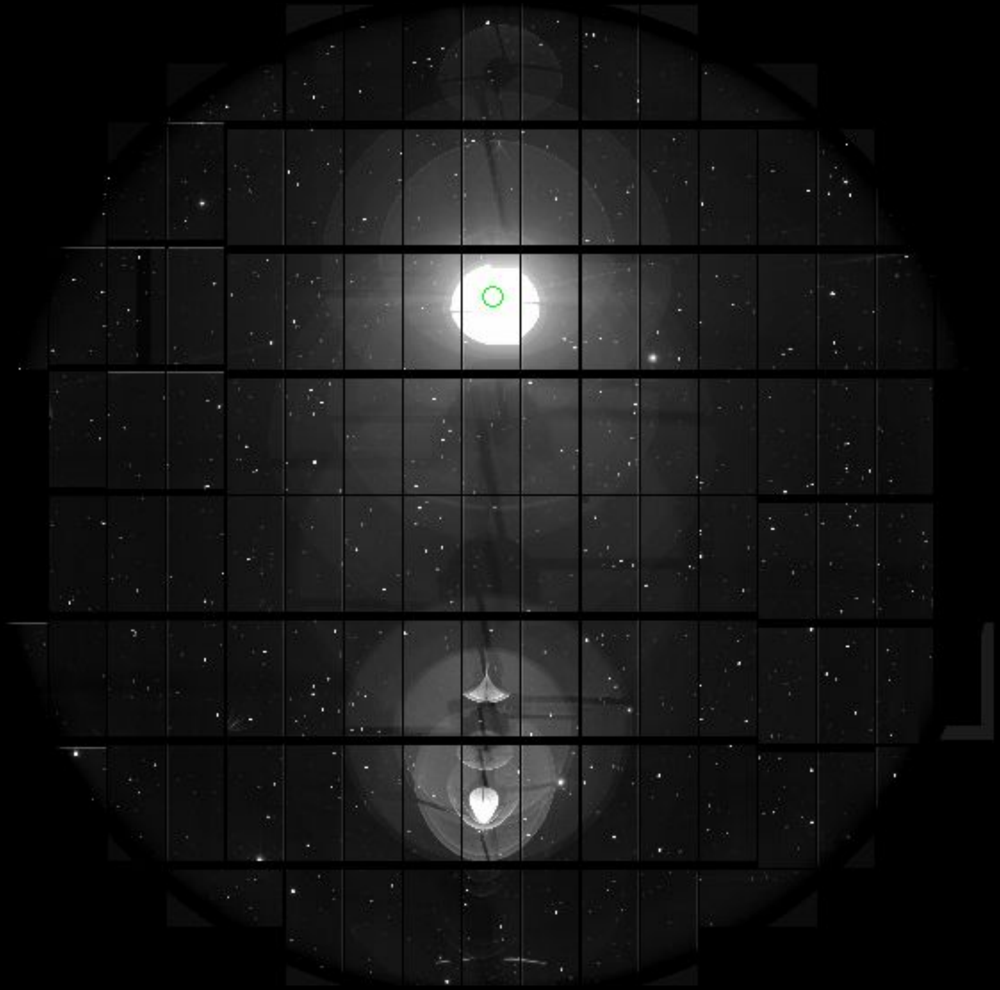

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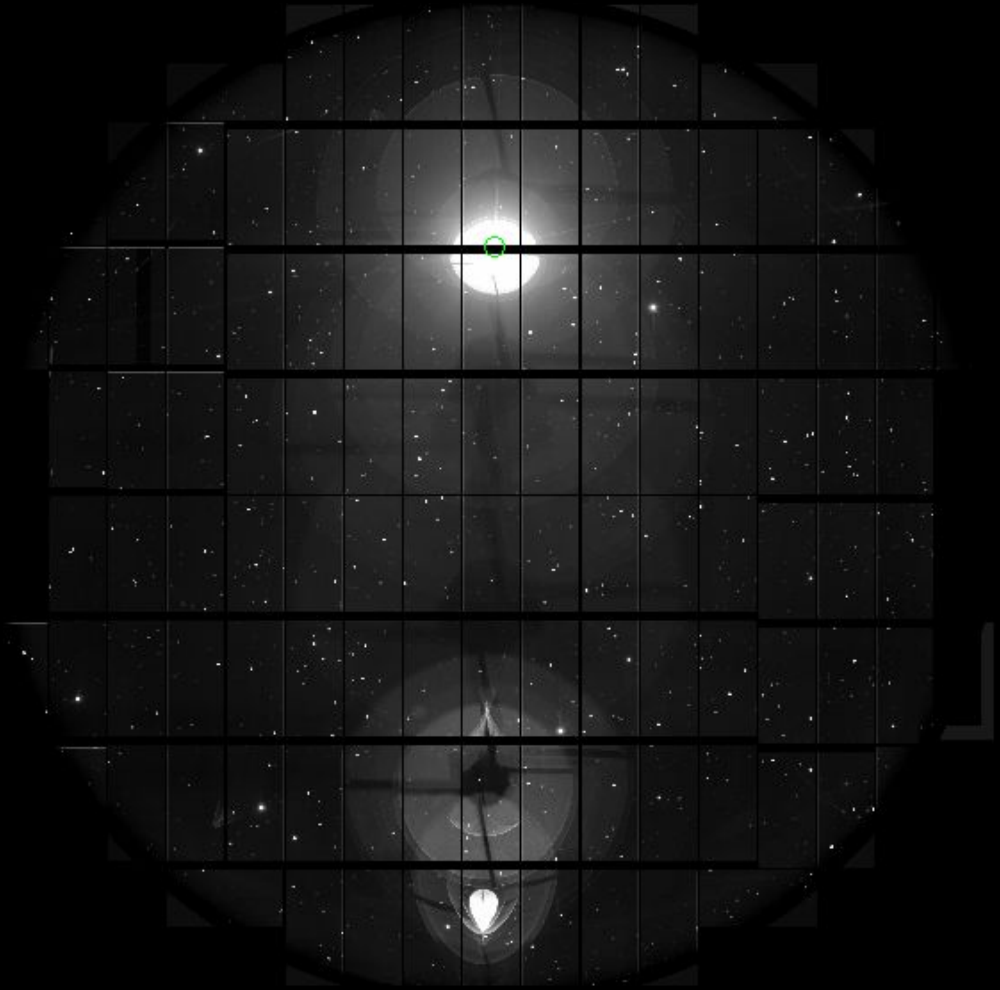

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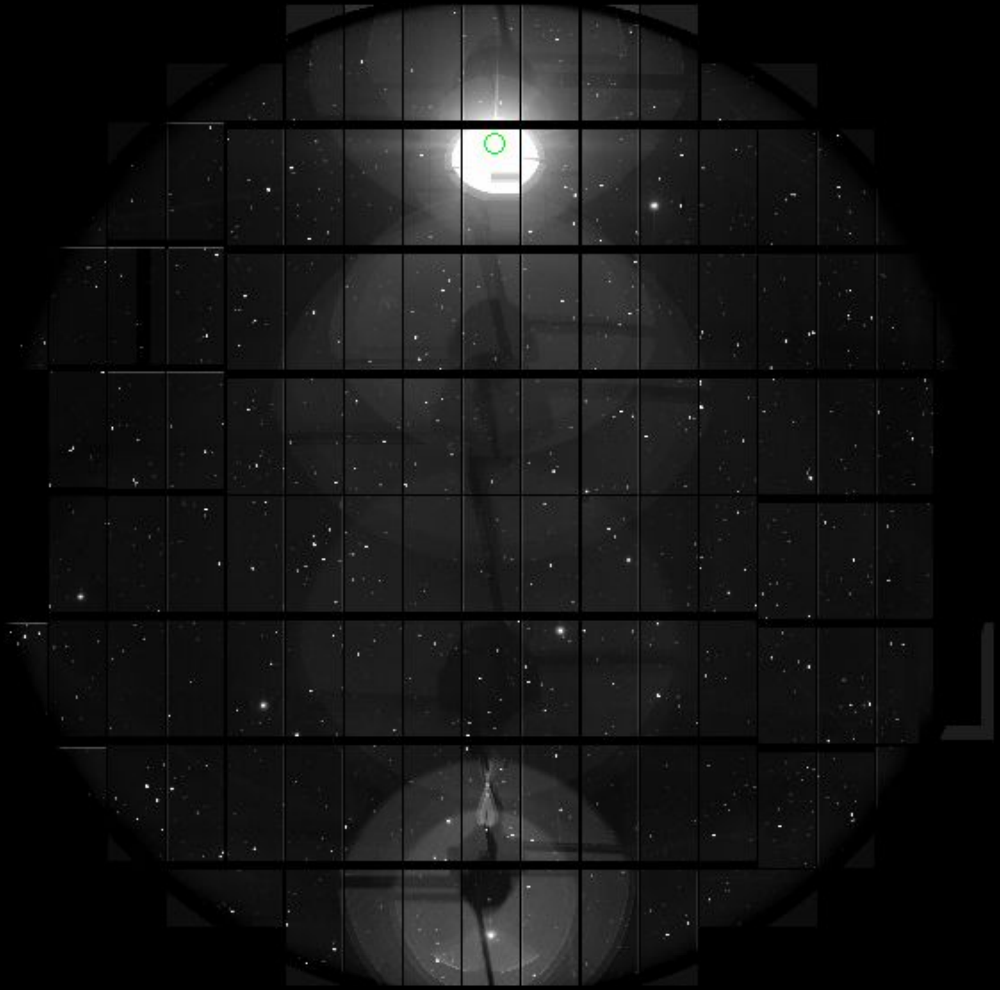

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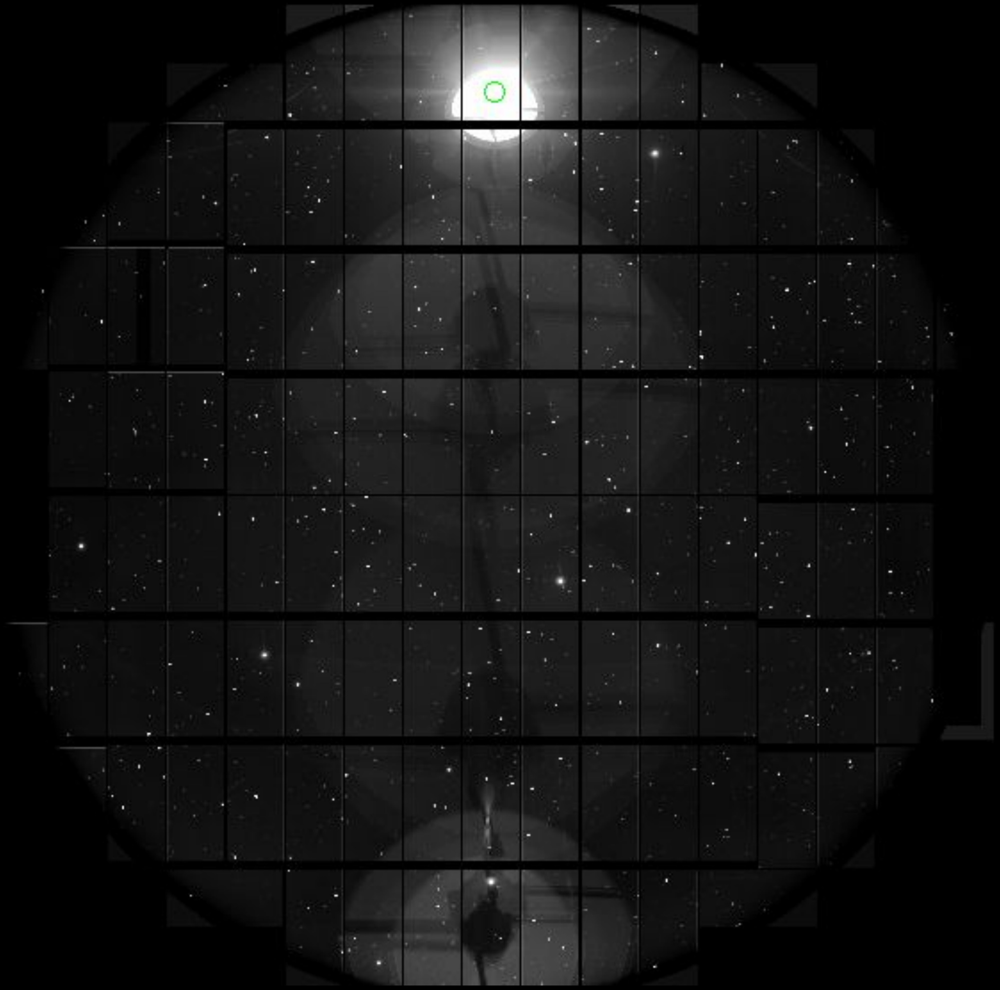

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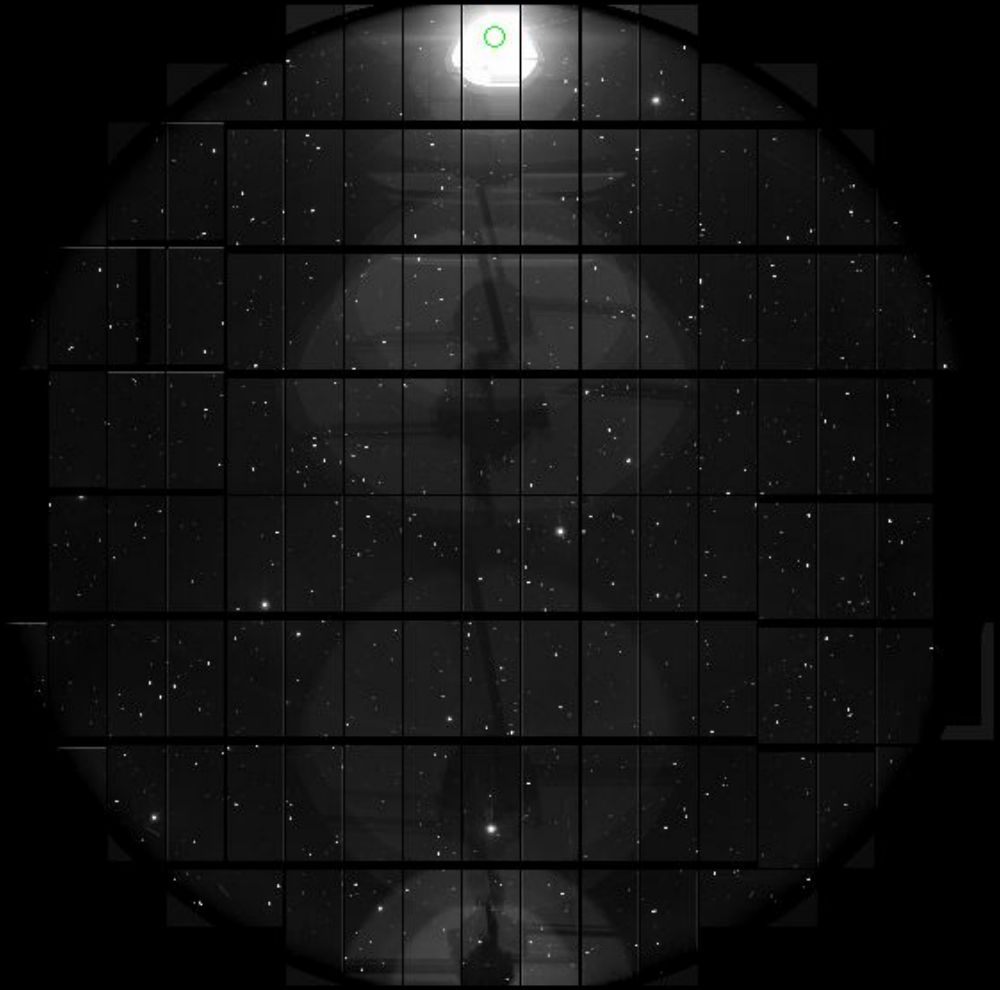
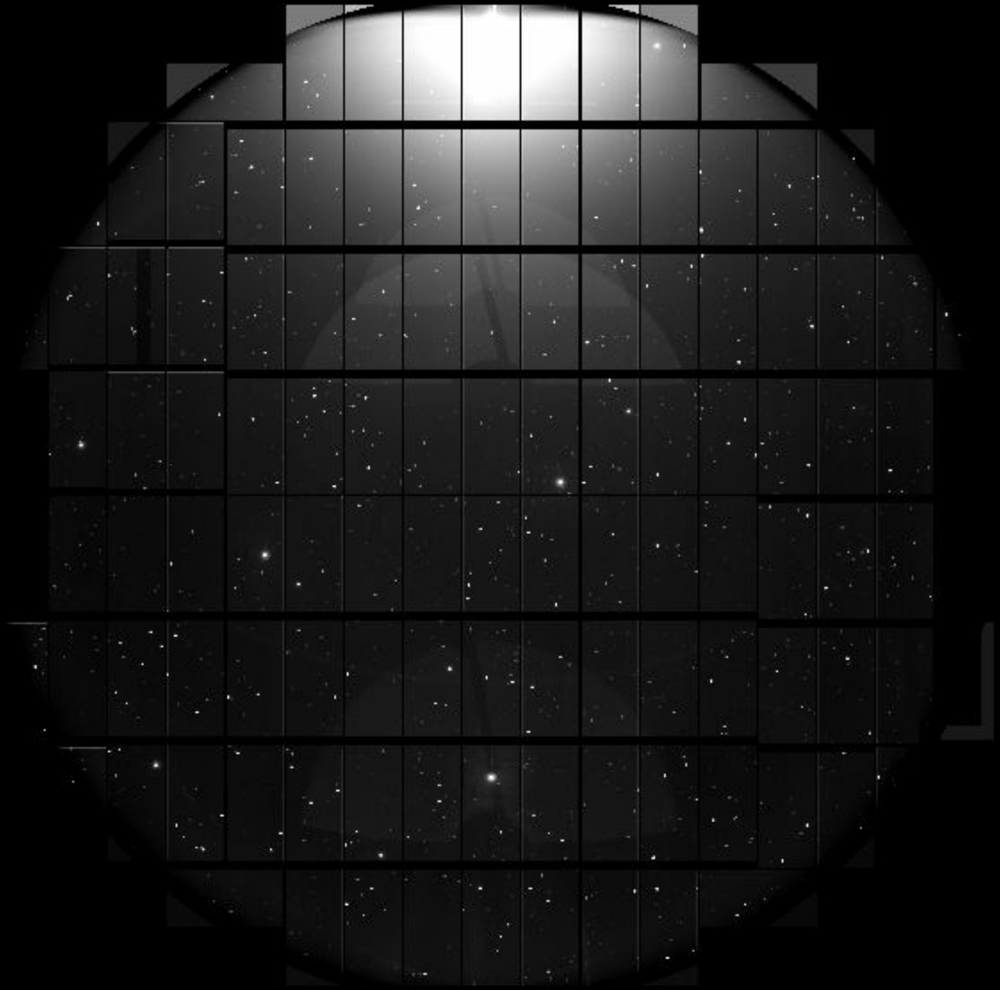
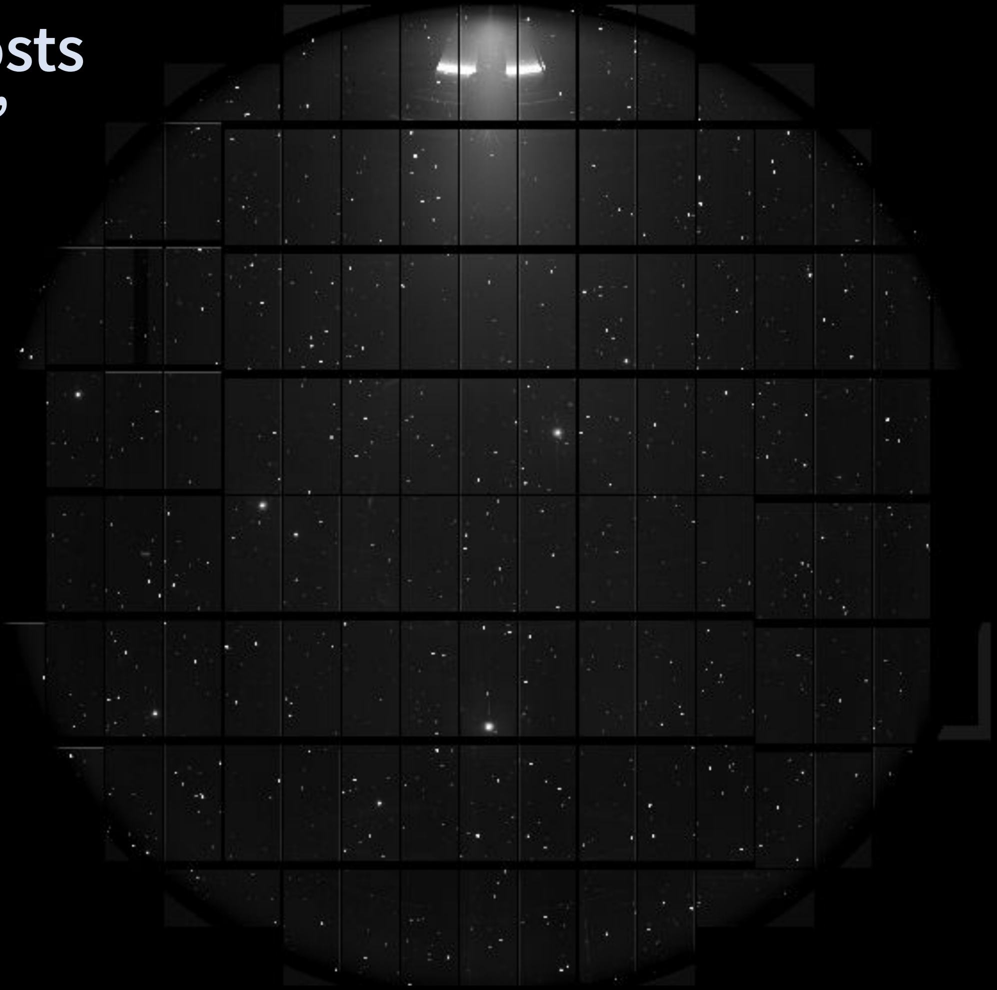


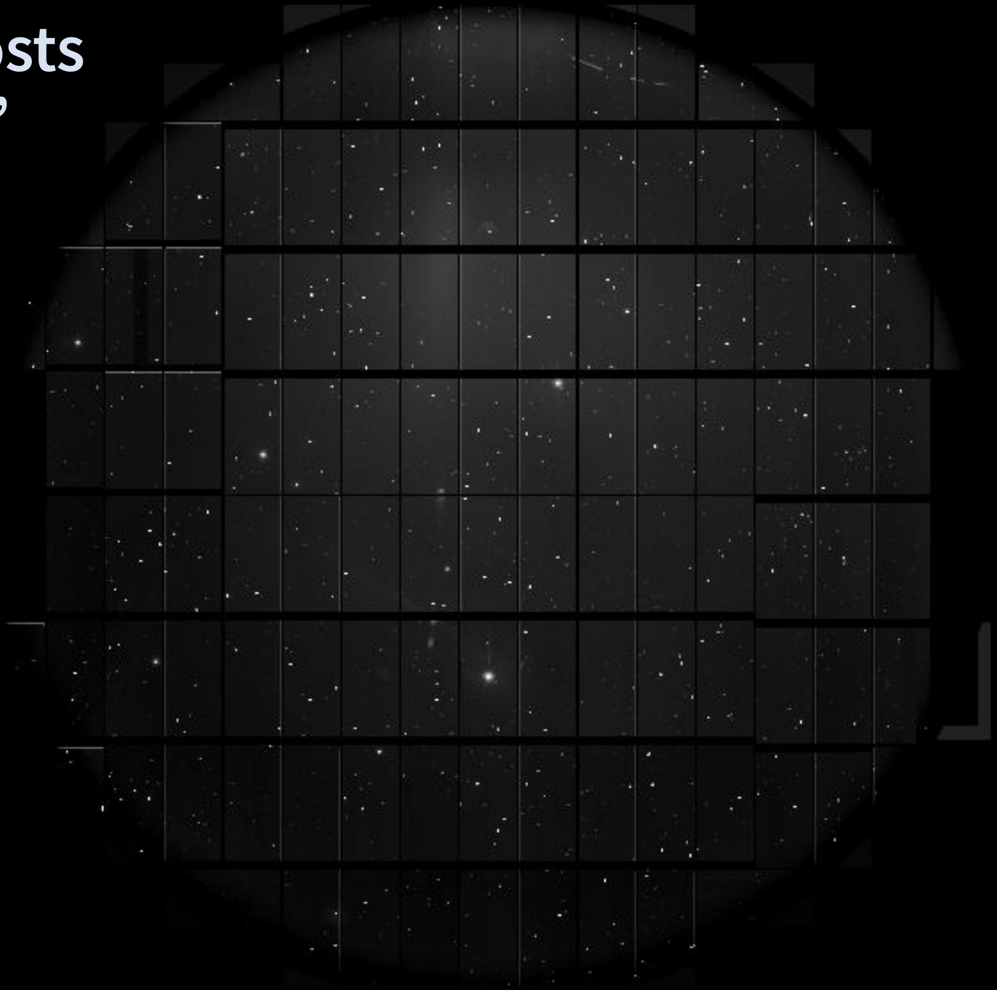
Ghosts

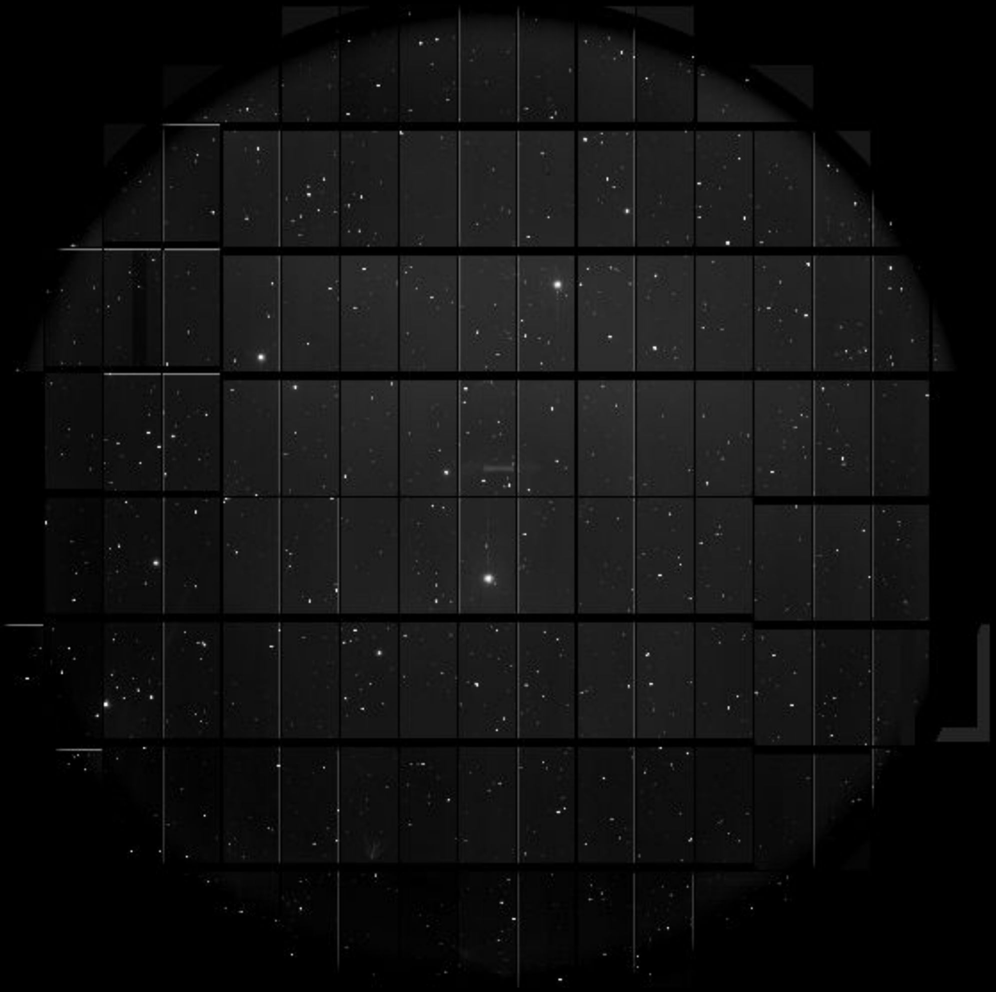


Unimaged ghosts aka “ghoulies”



Unimaged ghosts aka “ghoulies”





VERA C. RUBIN OBSERVATORY

Science Program: Bright Star Scans

Observations:

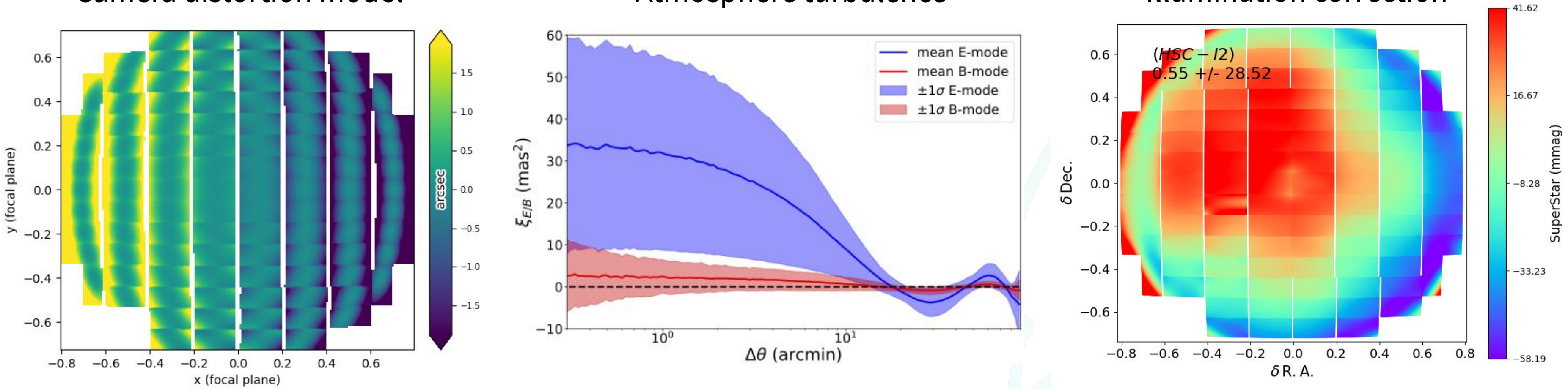
- Prerequisites: LED flats, monochromatic flats
- 4 fields × 30 visits × 6 bands = 720 visits (scheduled with observations in 3 bands per epoch?)
- Fields containing a star bright enough to compromise measurements on:
  - Amplifier
  - Detector
  - Raft
  - Significant fraction of focal plane
- ~10 deg^2 per field
- Scan pointing across bright star so that the object appears at multiple locations on the focal plane as well as slightly outside the field of view
- Could begin with 2.0 arcsec delivered PSF FWHM across the full FoV
- DRP mode: Source, Object

Science Program: Dense Dithered Star Field

Objectives:

- Determine reference flat (illumination correction) independent of CBP
- Determine instrumental astrometric model
- Initial testing of coadding and difference image analysis

Camera distortion model | Atmosphere turbulence | Illumination correction



Science Program: Dense Dithered Star Field

Objectives:

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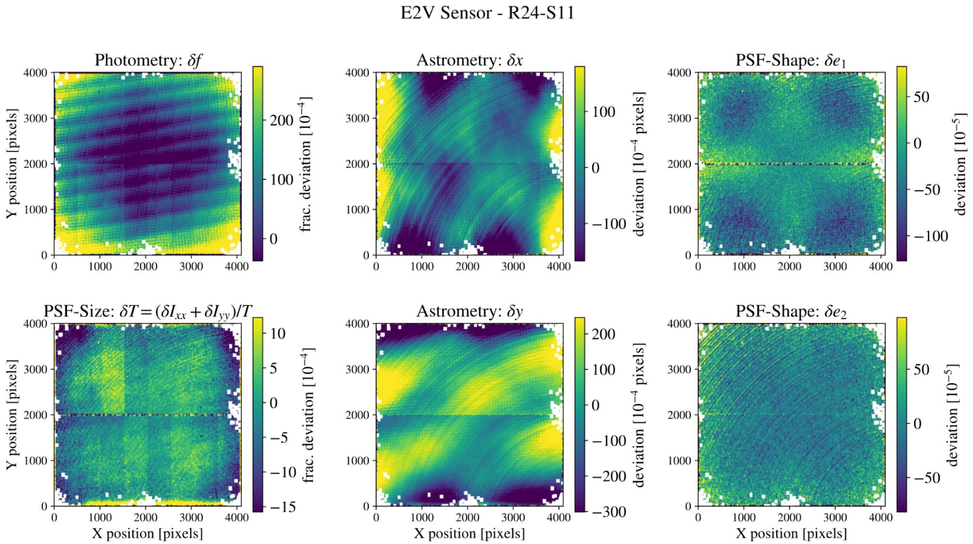
- Determine instrumental astrometric model
- Initial testing of coadding and difference image analysis

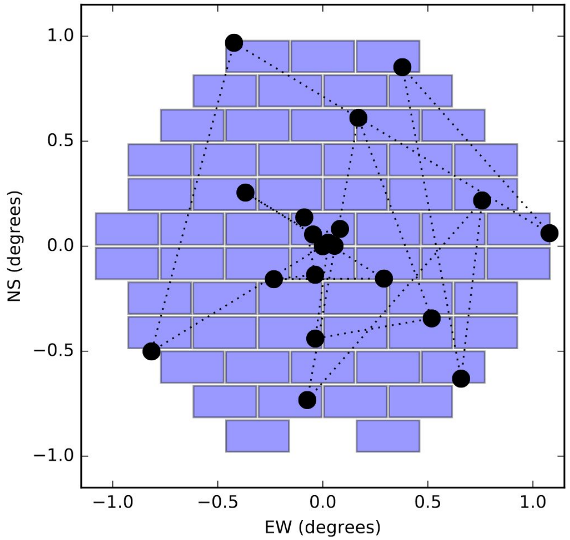


Fine scale variations in astrometric and photometric response (e.g., lateral E-field effects such as tree rings, picture frame)
Plot from Johnny Esteves

Science Program: Dense Dithered Star Field

Observations: Plan to repeat pattern in multiple iterations; anticipated to be primary dataset for demonstrating achievement of System First Light

- Prerequisites: LED flats, monochromatic flats (iterations approaching System First Light)
- 30 visits x 4 bands x 6 epochs = 720 visits (8 hrs total; 6 epochs of 80 min)
- 30 visits in each of ugri (dark time) or rizy (bright time) in each epoch
- ~10 deg^2 central region; dithers from sensor scale up to focal plane scale with translation around a central pointing so that the same stars appear on many different sensors across the focal plane
- Moderately high stellar density, but not so dense that blending is a concern; low interstellar extinction
- Repeated visits within a given epoch; epochs can be on different nights
- Can begin when no strong gradients in PSF across field of view
- Span 1 < airmass < 2 ; requires photometric conditions
- DRP mode: Source, Object, ForcedSource, DiaSource, DiaObject, DiaForcedSource
- AP mode: DiaObject, DiaSource, DIAForcedSource



Example DECam star dither pattern
Bernstein et al. 2017
arXiv:1703.01679

Science Program: Deep Drilling Fields

Objectives:

- Verify that scattered light and other artifacts can be mitigated with nominal LSST DDF dither strategy and acceptable masking
- Demonstrate building coadds from large number of overlapping visits
- Test difference image analysis

Fig. 18. Remaining optical ghosts and satellite trails in UD-COSMOS. The image is in gri and is approximately $23' \times 19'$.

Science Program: Deep Drilling Fields

Observations:

- Prerequisites: Acceptable image quality across full FoV at a particular airmass; bright star scan
- 5 epochs × 40 visits × 6 bands = 1200 visits (schedule as 6 epochs w/ 200 visits per epoch given 5 filters in LSSTCam at a time; ~2 hrs per epoch)
- Band coverage (u, g, r, i, z, y) = (200, 200, 200, 200, 200, 200)
- ~10 deg^2 targeting an LSST DDF
- Nominal LSST DDF dithering strategy; might need to apply variety of transational offsets and rotator angles to sample LSST distribution
- Epochs on separate nights
- DRP mode: Source, Object, ForcedSource, DiaSource, DiaObject, DiaForcedSource
- AP mode: DiaObject, DiaSource, DIAForcedSource

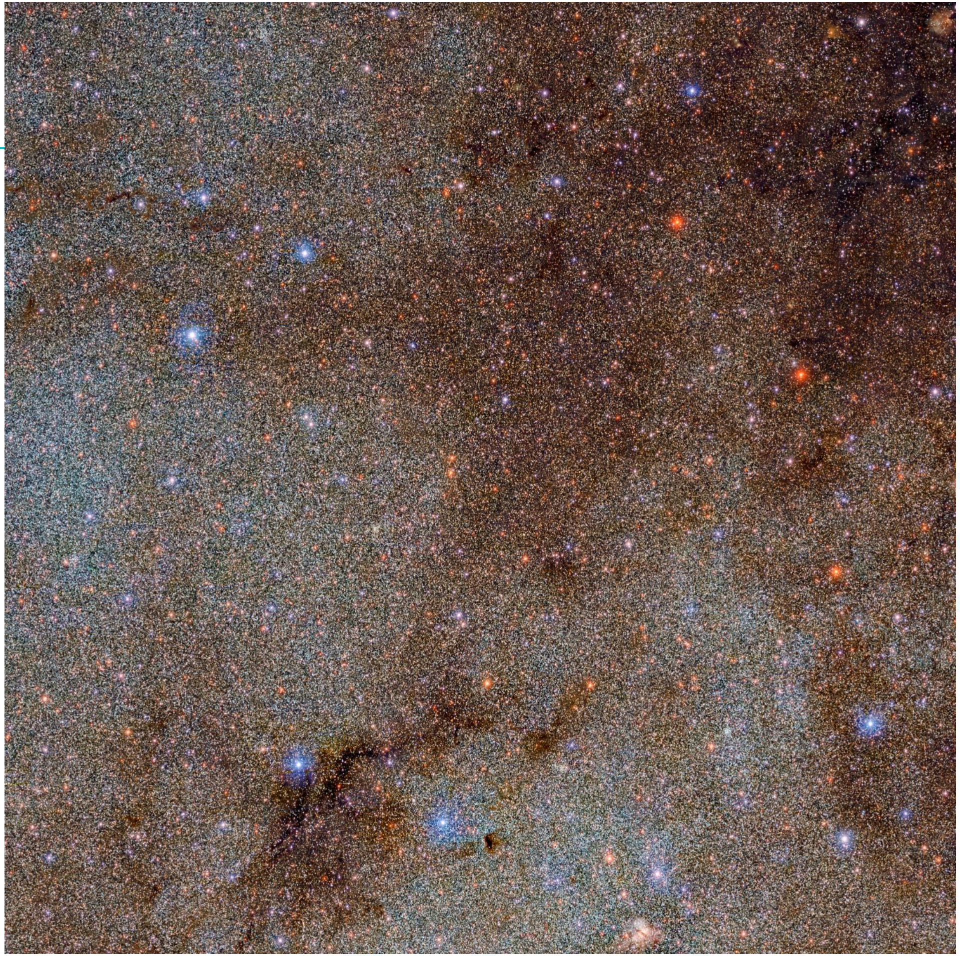
Fig. 18. Remaining optical ghosts and satellite trails in UD-COSMOS. The image is in gri and is approximately $23' \times 19'$.

Science Program: Crowded Fields

Objectives:

- Evaluate scientific performance of DIA in a high density stellar field with enough repeated visits and dithers to be representative of LSST WFD over the Galactic plane
- Characterize deblending for deep coadds in crowded fields
- Characterize interstellar extinction effects

http://decaps.skymaps.info/viewer.html



Science Program: Crowded Fields

Observations:

- Prerequisites: Acceptable image quality across full FoV at a particular airmass; bright star scan
- 4 pointings × 15 visits per band × 5 bands × 4 epochs = 1200 visits (16 total epochs of 75 visits each)
- ~10 deg^2 per field
- Up to ~60 partially overlapping visits
- Nominal WFD dither pattern
- ugrizy
- High stellar density regions (e.g., Galactic plane, LMC/SMC, globular cluster, resolved galaxy) sampling a range of stellar densities, interstellar extinction, stellar populations
- Epochs on different nights
- DRP mode: Source, Object, ForcedSource, DiaSource, DiaObject, DiaForcedSource
- AP mode: DiaObject, DiaSource, DIAForcedSource

Science Program: Science Validation Surveys

Organize Science Validation surveys into small set of multi-purpose programs:

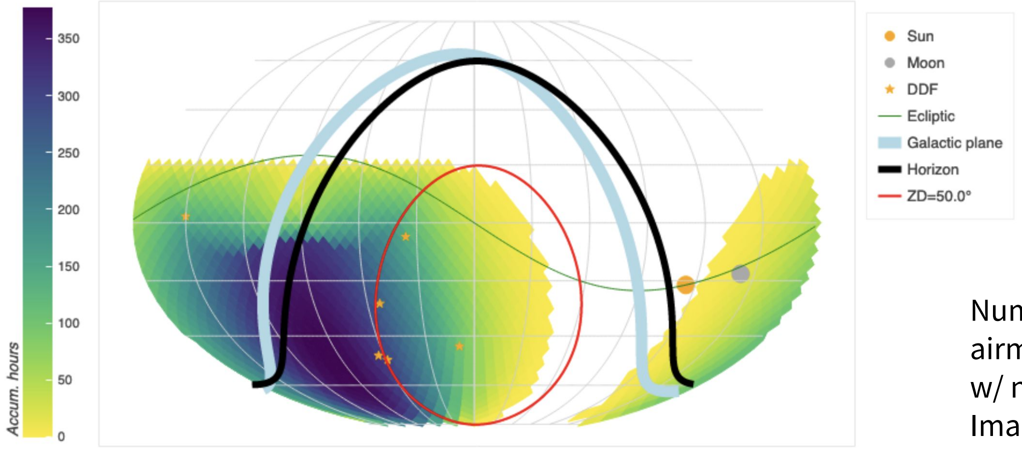
- **simplicity** and team focus
- **scalability** given schedule uncertainty
- **system optimization might be ongoing** and delivered image quality might be improving over time
- **mitigate weather and engineering time losses** (especially considering the lunar cycle)
- provide **longer time baseline** for difference imaging tests by building templates early and regularly returning to same fields
- enable **direct comparisons** between data quality taken under different observing conditions and operational configuration, including advanced stages of AOS commissioning and environmental control
- produce datasets with a combination of area, depth, band coverage, and temporal sampling to yield high **legacy value**, even after the start of the LSST 10-year survey

Science Program: Science Validation Surveys

Objectives: Evaluate survey-scale AP and DRP science performance; full rehearsal of operational procedures

Interleave **Deep** and **Wide** survey components (minimum 30 nights):

- **Deep:** ~100 deg^2 *ugrizy* to 10-yr LSST WFD equivalent depth → then increase depth
- **Wide:** ~1000 deg^2 *griz* to 1-yr LSST WFD equivalent depth → then increase area



Number of hours each (RA, dec) coordinate is visible at airmass < 1.55 during a 60 night window in December-January w/ no weather losses
Image: Eric Neilsen

Science Program: Science Validation Surveys – Deep Component

Optimized for testing coadds at LSST 10-year survey full depth and beyond

Observations:

First 30 days

- 11 pointings × 825 visits per pointing = 9075 visits (~ 15 night equivalents)
- 825 visits / pointing (u, g, r, i, z, y) = (56, 80, 184, 184, 160, 160)
- 100 deg^2 in single contiguous region overlapping an LSST DDF; nominal LSST WFD dither pattern (might need intra-night translational offsets and rotator angles to simulate expected LSST distribution)
- Steadily build integrated exposure during the survey
- During a 30 day period, each pointing would receive average of 25 visits on each night
- DRP mode: Source, Object, ForcedSource, DiaSource, DiaObject, DiaForcedSource
- AP mode: DiaObject, DiaSource, DIAForcedSource

Extension

- Increase to 20-year LSST WFD exposure, 1650 visits / pointing, (u, g, r, i, z, y) = (112, 160, 368, 368, 320, 320)

Science Program: Science Validation Surveys – Wide Component

Optimized for testing alerts at survey scale, both infrastructure and science validation

Observations:

First 30 days

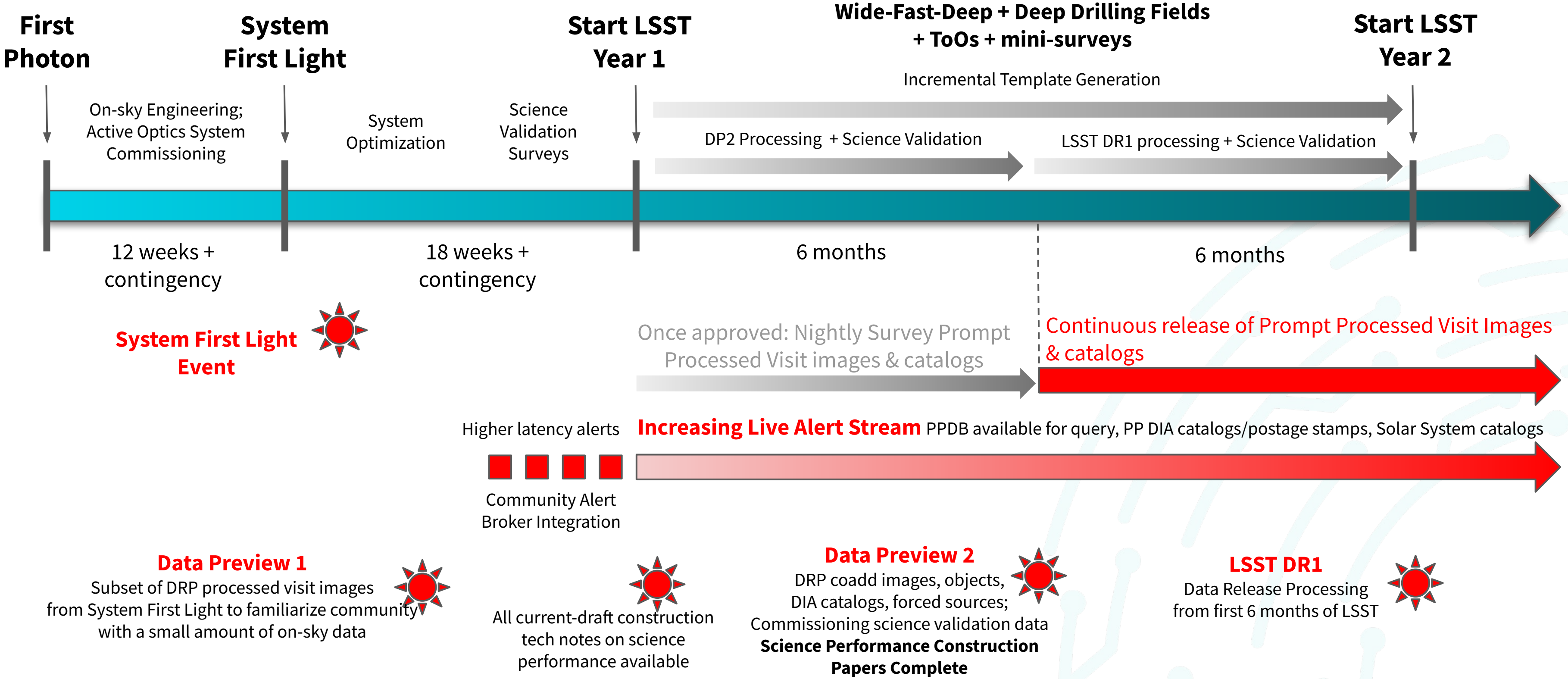
- 110 pointings × 80 visits per pointing = 9000 visits (~ 15 night equivalents)
- 80 visits per pointing (g, r, i, z) = (20, 20, 20, 20)
- 1050 deg^2 in single contiguous region placed to optimize scheduling flexibility, considering the SV survey Deep region; span range of stellar density; cross ecliptic
- Steadily build integrated exposure during the survey; consider prioritizing template coverage early
- Solar System cadence
- During a 30 day period, each pointing would receive average of ~2.6 visits on each night
- DRP mode: Source, Object, ForcedSource, DiaSource, DiaObject, DiaForcedSource
- AP mode: DiaObject, DiaSource, DIAForcedSource

Extension

- Increase area coverage; attempting to maintain depth uniformity

Early Science Program Overview Timeline

See Early Science



Small-group Discussion

Small-Group Discussion

Take ~15 min to chat with folks around you

Example topics:

- *Questions regarding planned commissioning activities?*
- *Suggestions regarding the design of specific observing programs*
- *Are there additional tests that should be considered to address particular aspects of system performance?*
- *Suggestions to efficiently organize / consolidate / schedule commissioning activities*

Please add your questions, ideas, comments, and suggestions to live notes doc

Whole-group Discussion