VERA C. RUBIN OBSERVATORY

Active Optics Summary/Status

Rubin's Optical System with Active Optics

- Unique three-mirror optical design accommodates a 3.5-degree field of view feeding a large camera
    - 8.4-meter Primary Mirror (M1), borosilicate 3.5-meter Secondary Mirror (M2), ULE, 72 Actuators
    - 5.0-meter Tertiary Mirror (M3), borosilicate
    - High quality optics camera

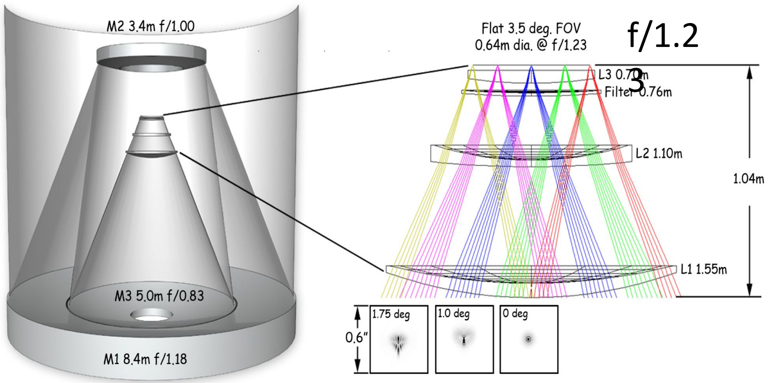
Goal: Reach better than the seeing limited image quality over a 3.5 deg FoV

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

Current projected system IQ: 0.34”

- From a Paul-Baker design: the design has been optimized to reduce sphericity in the various elements.

- The surfaces of all three mirrors, and the six degrees of freedom orientation of the camera and M2, are controlled by an active optics system.
    - M1M3: 156 Actuators / 6 hardpoints
    - M2: 72 Actuators



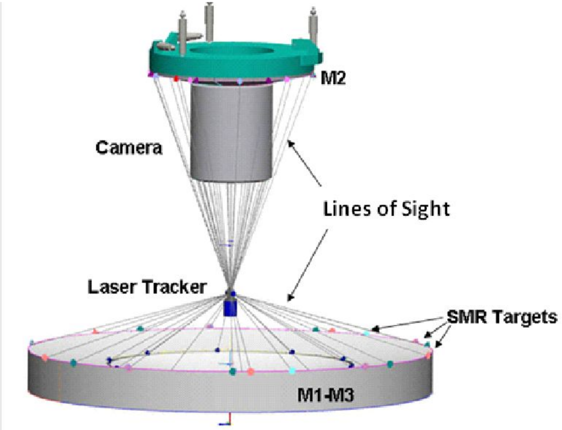
Initial Alignment System

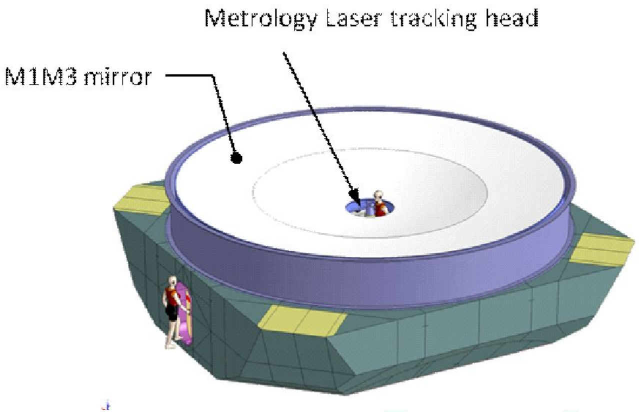
The initial alignment system will be used before each night to align the M2 mirror and the camera with respect to the M1M3 mirror using the hexapod/Rotators

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 almost complete
Laser tracker set-up & we've been testing the system in the tunnel lab in Tucson

Active Optics Description

The Active Optics Systems (AOS) is designed to optimize the image quality by controlling the surface figures of the mirrors and maintaining the relative position of the three optical systems (M1M3 mirror, M2 mirror and the camera). The AOS consist of two control components:

- **Open-Loop Component (or Look-Up-Table LUT)**: Most telescopes have an Active Optics System to compensate for intrinsic aberrations of each mirror, gravity mostly and in some instances for temperature.

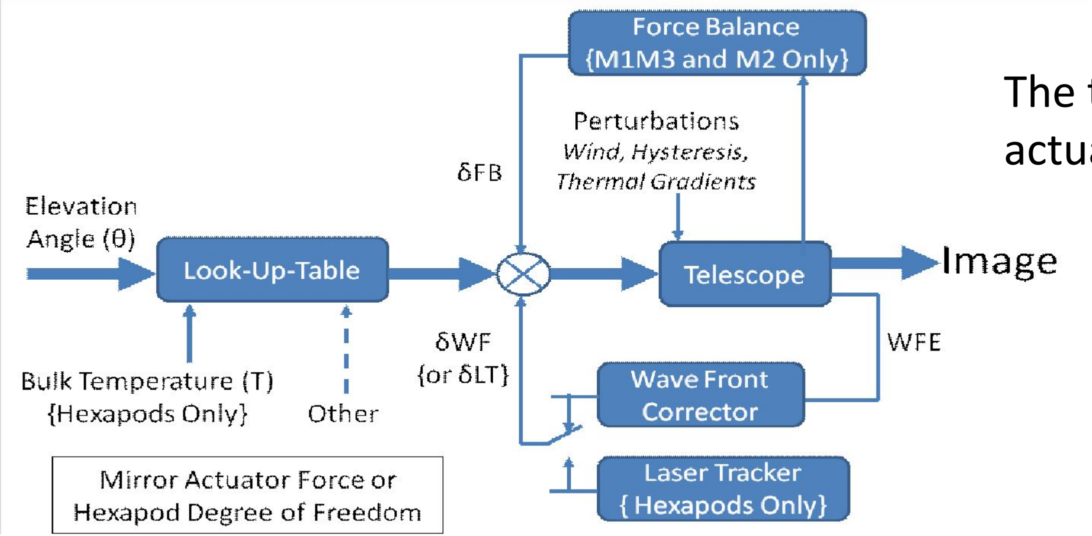
  This is done using an open loop model created from Finite Element Analysis (FEA) model and validated on sky.

- **Real-time Closed-loop Component**: Rubin's requirements on resolution and depth pushes the AOS to add a real time feedback control to in addition compensate for temperature and hysteresis. (This is done using **curvature wavefront sensors** on the periphery of the detector and sending offsets to the open loop model)

What are we controlling?

Degrees of Freedoms: M1M3, M2 and Rigid bodies (M2 and Camera hexapods)

- 20 bending modes on each mirror (similar to Zernike modes)
- 5 Degrees of freedom for both the M2 and Camera positioning hexapods



The total force commanded to the mirror actuators is a sum of:

- Static support (mirror surface intrinsic error correction)
- Look-Up Table (LUT) values
- Hardpoint force balance offset (δFB)
- Wavefront sensor offset (δWF)

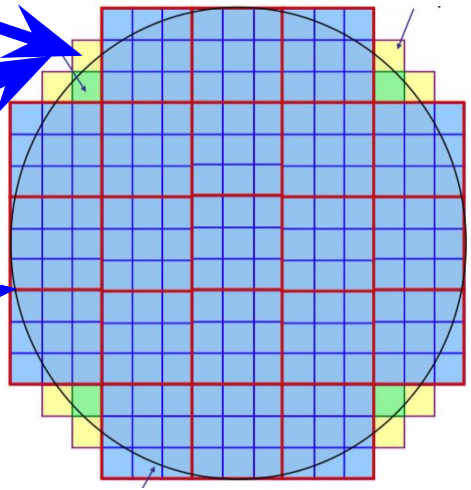
Laser Tracker Alignment System for initial alignment at the beginning of a night

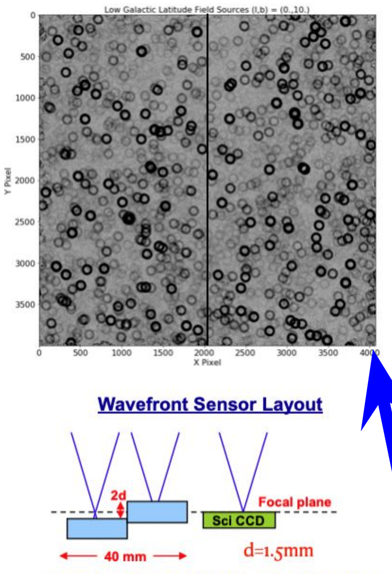
Wavefront Sensor: Curvature Sensing

Wavefront Sensors (4 locations)

Guide Sensors (8 locations)

3.5 degrees
634mm diameter



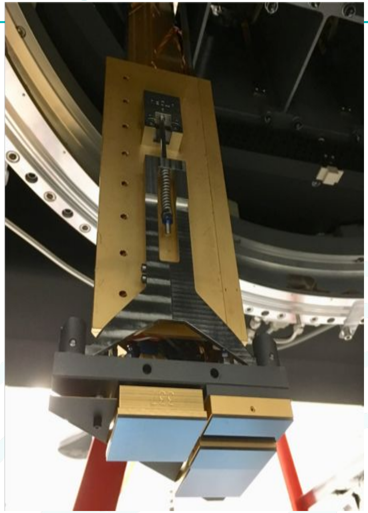


Wavefront Sensor Layout

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.



Split sensors: because of the fast f-number (f/1.23) and crowded focal plane, using a beam splitter and delay line or physically moving the detector will not work.

Wavefront Sensor Feedback Calibration

- 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 as follow:

➢ Measure of the wavefront error at the center of each detectors by defocusing the camera in and out of focus (using the camera hexapods) and applying the same algorithm developed for the 4 corners WFS

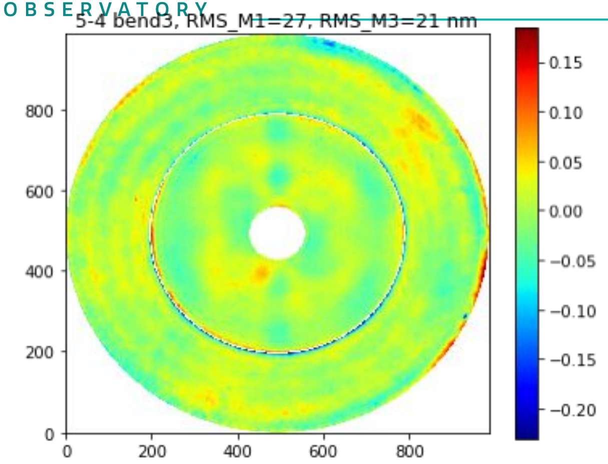
➢ Compare the resulting correction with the correction found with the 4 corner WFS

➢ Update the Look-Up-Table accordingly for different zenith angles

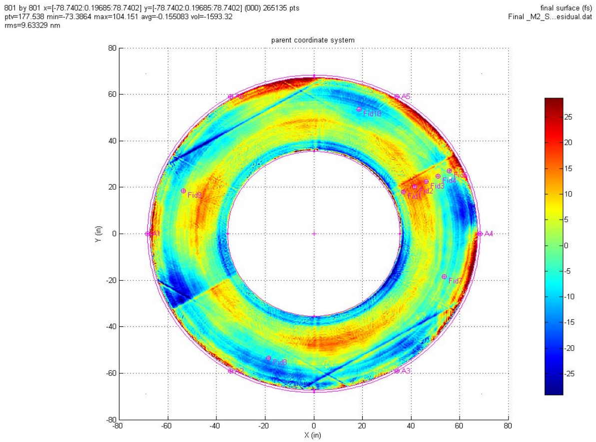
- The tasks used to calibrate the wavefront sensors and those needed to verify the optical reconstruction will be interleaved. It is expected that these two activities will have to iterate with each other to achieve desired performance.

- In the process, we will look for degeneracy in the system and verify our ability to reconstruct the state/perturbations of the system for both controlled and uncontrolled Degrees of Freedom

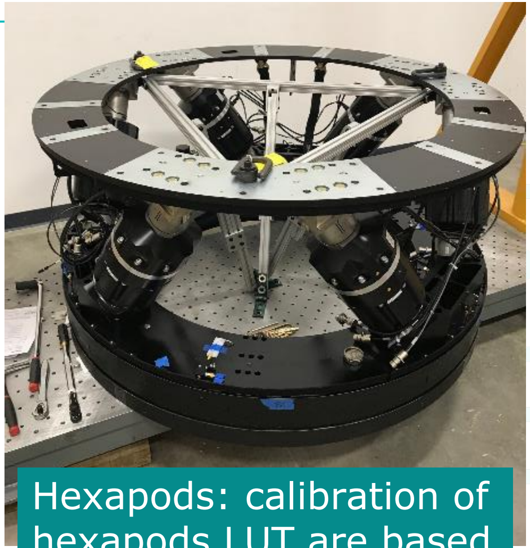
Building the Look-Up-Table



M1M3: calibration of the M1M3 LUT for zenith pointing only; horizon forces are based on FEA.



M2: calibration of the M2 LUT done for several orientations.



Hexapods: calibration of hexapods LUT are based only on FEA.

Look-Up-Table model has first been calculated from FEA

Limited verification with optical feedback (In the factory)
Current knowledge:
- M1M3: known to 1% at Zenith, 10% at horizon
- M2: known to 1%

Verification on the telescope

Closed-Loop Algorithm

WFS/ComCam/ LSSTCam images

Image Ingestion

Wavefront Estimation Pipeline

Process the WFS data to define what the wavefront errors are either for each corner rafts or for the science detectors (each CCD of ComCam or LSSTCam).

Wavefront Error (Zernike Coefficients)

Optical Feedback Controller

Apply corrections to the Camera Hexapod, M2 Hexapod, M1M3 and M2

Force Offsets

This is a Gen3 pipetask