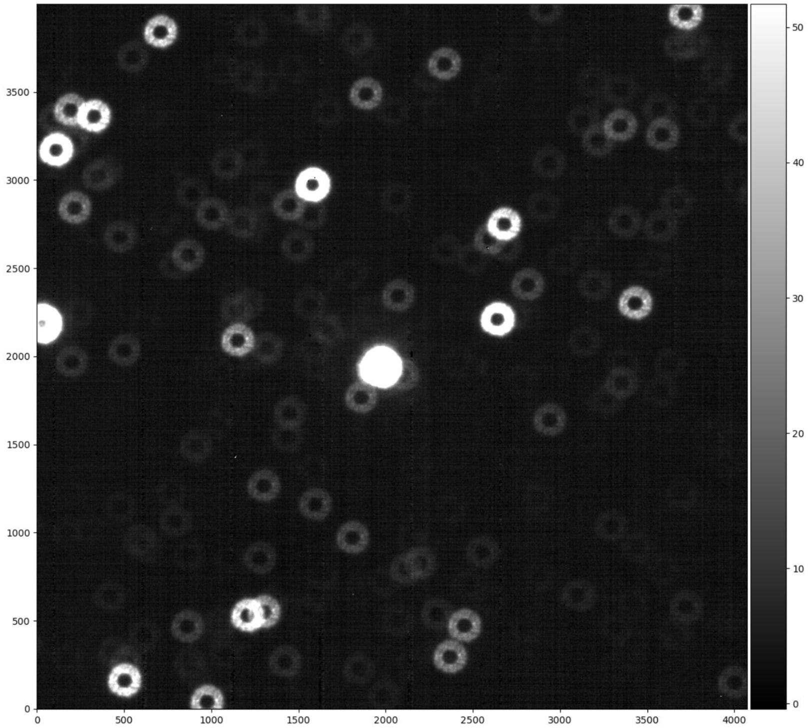
Countdown to AOS Commissioning

AOS Team

Vera C. Rubin Observatory

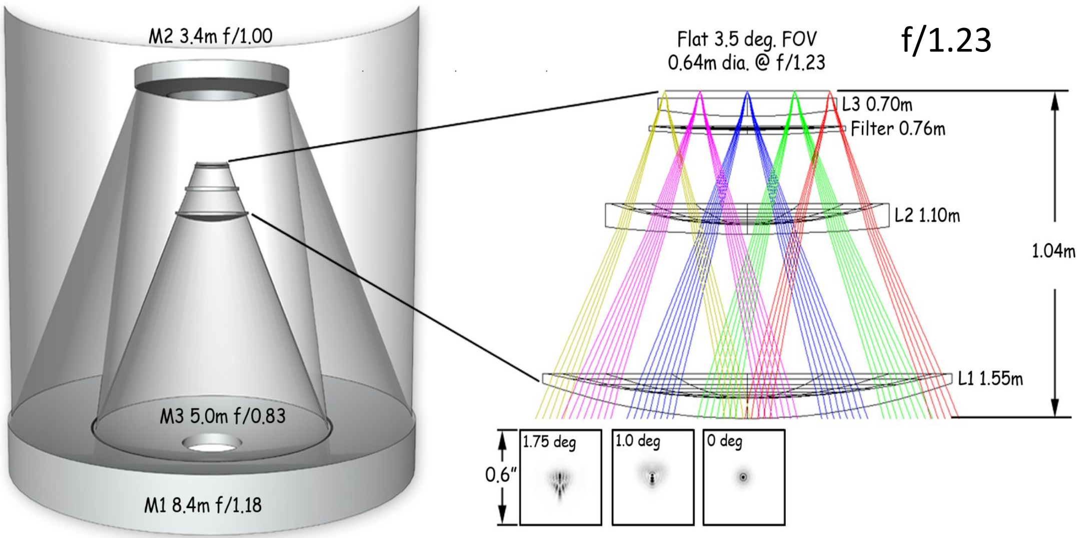
Agenda

1. Overview of commissioning - timeline, what will be tested when, priorities (Andy Connolly/Sandrine Thomas)
2. Status of ImSim for AOS - what is tested and validated and what is not (Bryce Kalmbach)
3. Work through description of tests
   - Rationale (what we will test and its objectives)
   - SImulations/Observations
   - How we will need to analyze/process the data
   - Discussion on the test data and how we will generate it (focus on functionality needed, input catalogs, resources to generate and store the data)
   - AuxTel as a test-bed



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

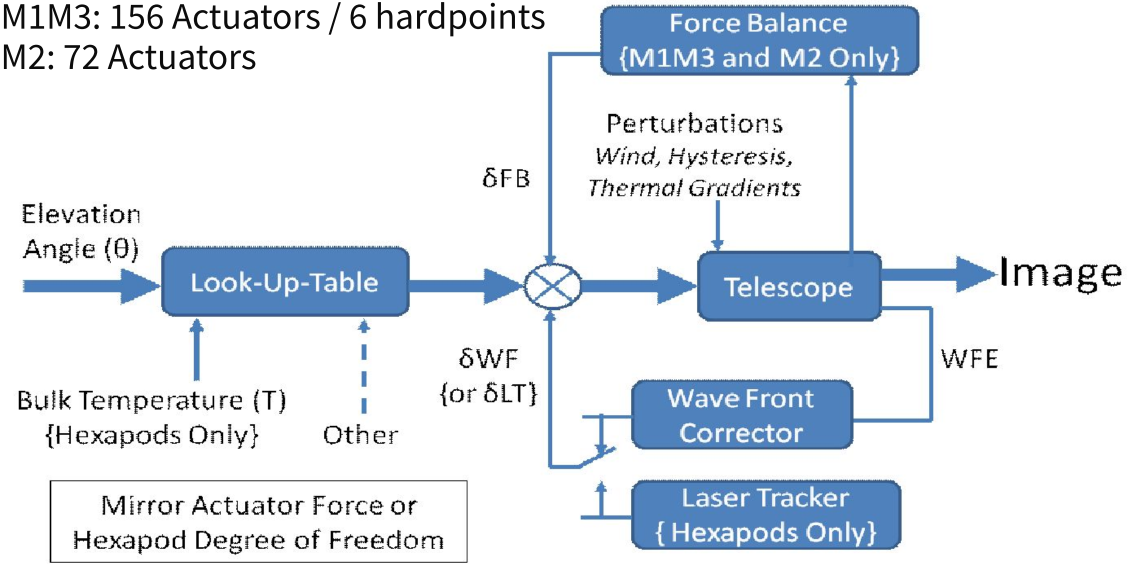
FWHM Allocation:
- Telescope 0.25"
- Camera 0.30"
- Optical design 0.08"

Current projected system IQ: 0.34"

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).

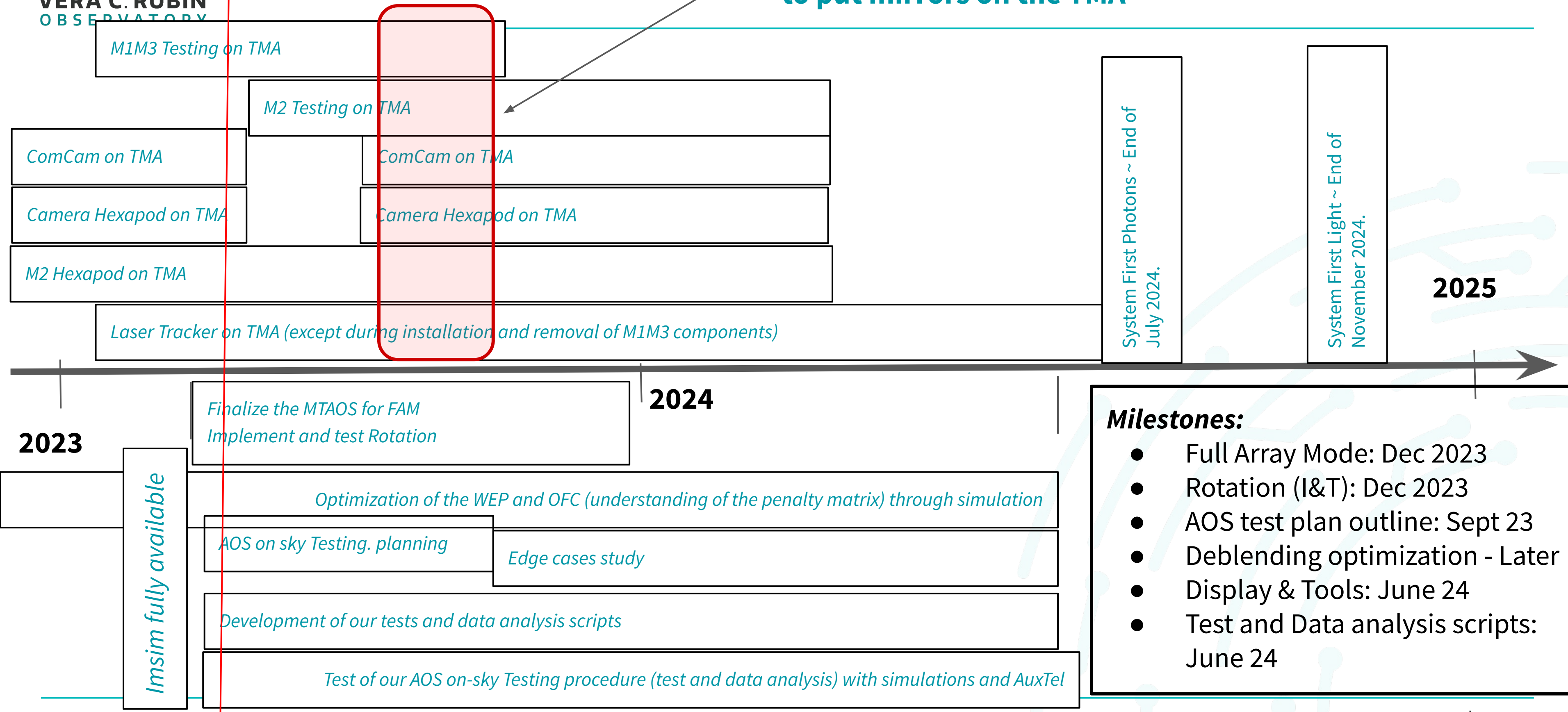
- M1M3: 156 Actuators / 6 hardpoints
- M2: 72 Actuators



- **Open-Loop Component (or Look-Up-Table LUT)**: compensation for intrinsic aberrations of each mirror, gravity mostly and in some instances for temperature.
- **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)

AOS Timeline

Opportunity to do final test with surrogate to prove the system works as expected and is safe to put mirrors on the TMA

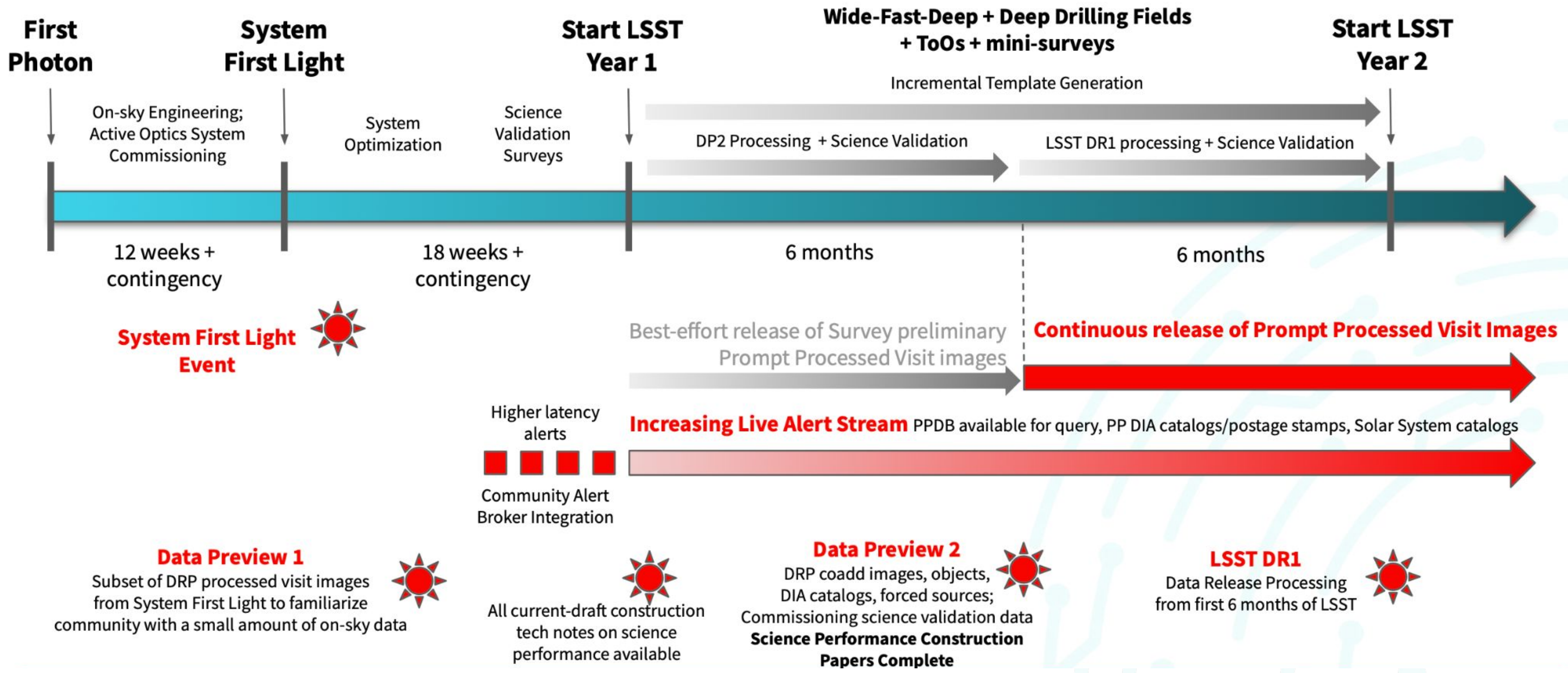


Milestones:

- Full Array Mode: Dec 2023
- Rotation (I&T): Dec 2023
- AOS test plan outline: Sept 23
- Deblending optimization - Later
- Display & Tools: June 24
- Test and Data analysis scripts: June 24

First Light to First Science

First photon is ~9 months after LSSTCam arrives on summit : July 2023



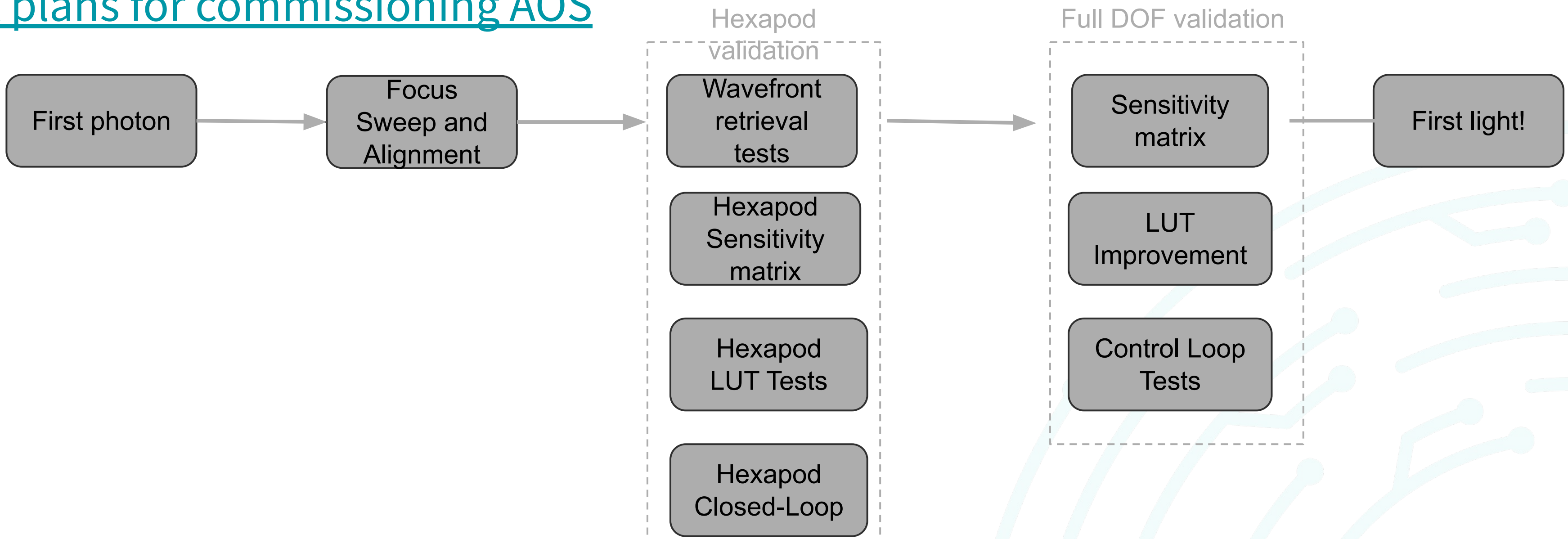
Credit: Keith Bechtol

AOS Commissioning Timeline

- **Simulation Phase**: *(Ongoing until ~Jan 2024)*
  - Test AOS algorithm in a simulated environment
  - Demonstrated system convergence and image quality performance under 2 modes of operations: Full-Array Modes (ComCam and LSSTCam), LSSTCam WFS for low, medium and high density fields. (
  - Focused on pipeline optimization (donut deblending, pairing/stacking, vignetting impact, Kalman filtering…).
- **Integration Phase** *(Ongoing until ~July 2024)*
  - Integrate AOS software and hardware on the summit (Spread Testing or on TMA Testing)
  - Ongoing M1M3, M2 and Hexapods look-up-table preliminary tests (some using the M1M3 Laser Tracker)
  - Use of AuxTel for some verification tests using real data
- **Commissioning Preparation Phase**: (*Ongoing until ~July 2024)*
  - Test development, observation scripts, and analysis notebooks
  - Visualization and tool development
- **Commissioning Phase:** *(First photon July 2024 - First Light November 2024)*
  - AOS Commissioning Tests: Alignment, WEP pipeline, LUT characterization, Closed Loop tests
  - Test of the full pipeline using the corner wavefront sensors.

Goals and Priorities

Test plans for commissioning AOS

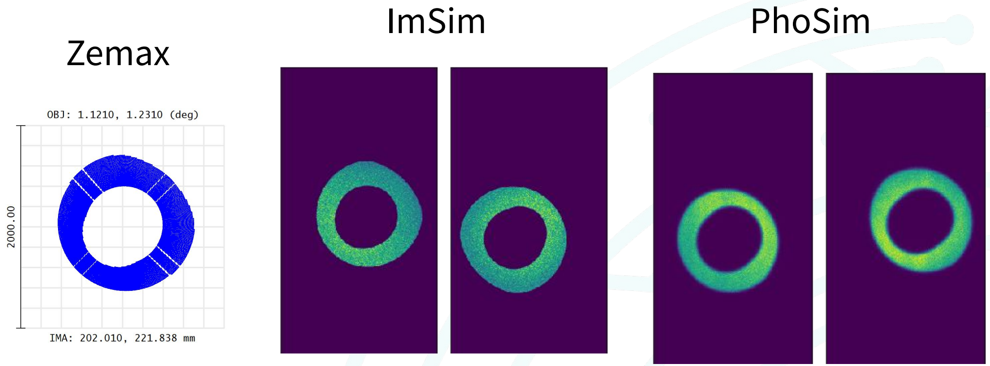


Need to evaluate AOS for: **Rotator angle (coordinate systems and signs)**, Seeing conditions, Low- or high-density field**,** Airmass, Bright stars,Time of night (temperature related), Filter choices

We need to simulate these tests to develop the analyses, visualizations, and debugging

ts_imsim update (Bryce)

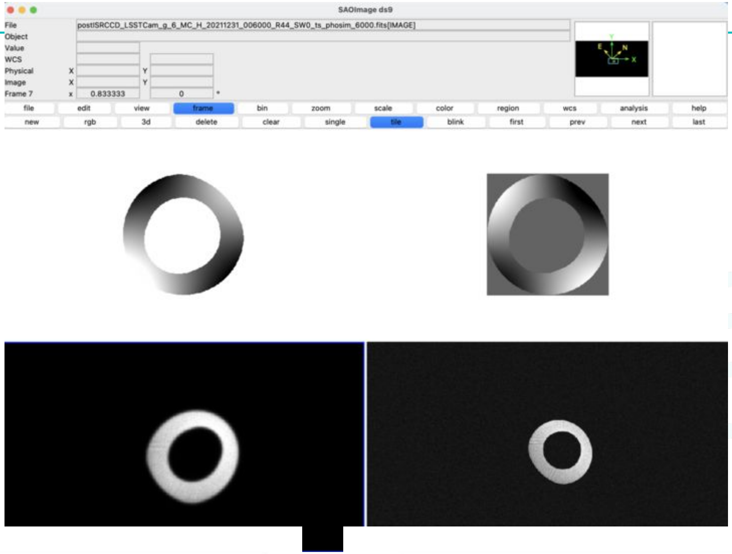
- Started work to transition from using Phosim for AOS simulations to exclusively using imSim
- Have baseline functionality in place available as a Closed Loop Command line task
  - Simulating donuts on wavefront sensors
  - Simulating OPD (Optical Path Difference)
  - Measuring Wavefront in terms of Zernikes with ts_wep
  - Saving results from each iteration to a butler repository
  - Using ts_ofc to calculate corrections and providing them as input to imsim for next iteration

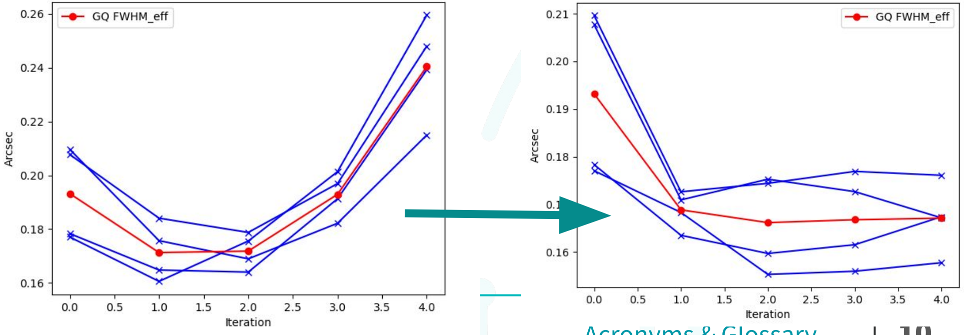


Credit: Josh Meyers

ts_imsim update (Bryce)

- Currently working on convergence of closed loop
  - Appears to be related to discrepancy between imsim and phosim realization of bending modes.
  - Inverting certain zernikes leads to convergence.
- Future Features
  - Validate performance with camera rotation
  - Add additional camera settings (LSST FAM)
  - Move to use the SkyCatalog interface for generating input
  - Tie in to use OpSim so we can simulate sequences of observations with realistic observing conditions





Reference Wavefront Generation

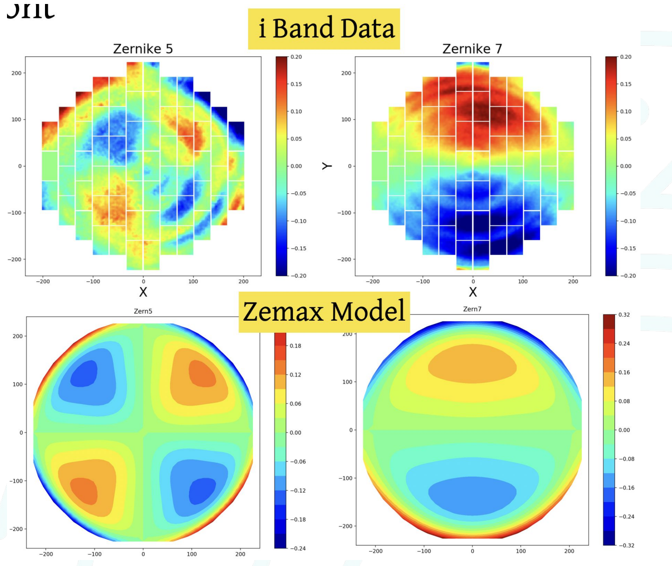
- **Description:**

  Generate a reference wavefront (intrinsic wavefront) for the telescope when perfectly aligned.

  - Take multiple images out of focus with small dithers to cover all the science raft with donuts.
  - Generate reference wavefront W(x,y) for the whole focal plane.

- **Number of observations:**
  - Take 100 out-of-focus Full Array Mode images doing small dithers.
  - Repeat for each filter

- **Observing conditions:**
  - Good density (get 500k to 1M donuts, over the full focal plane with multiple exposures)



Measured reference wavefronts vs zemax model from DECam, A. Roodman

Reference Wavefront Generation

- **Datasets:**
  - With imsim, generate images in full-array mode of the entire focal plane at a medium density field.
    - Do we want realistic (with blends) or uniform distribution; what density do we need; do we need rotation; range of filters?
    - Do we want to simulate discontinuities in focal plane?
  - Do small dithers at a certain ra, dec, until we have a finely sampled focal plane
  - Ingested in butler. How to select this dataset?
- **Analysis:**
  - Generate scripts / notebooks that take those images and compute the reference wavefront
    - Map of Z4, Z5 for each exposure
    - Subtract low-order polynomial fit
    - Combine exposures to make giant map to Z4,Z5
  - Study atmospheric error correlations between zernikes on the corner sensors
- **Visualization:**
  - Plots of zernikes across the focal plane
- **AuxTel Rehearsal:**
  - Test approach in AuxTel by looking at a medium density field, and doing a couple of small dithers. If we see the results make sense, scale up with the number of dithers.
  - Address “bias donut” issue observed in AuxTel

Focus and Centering Alignment

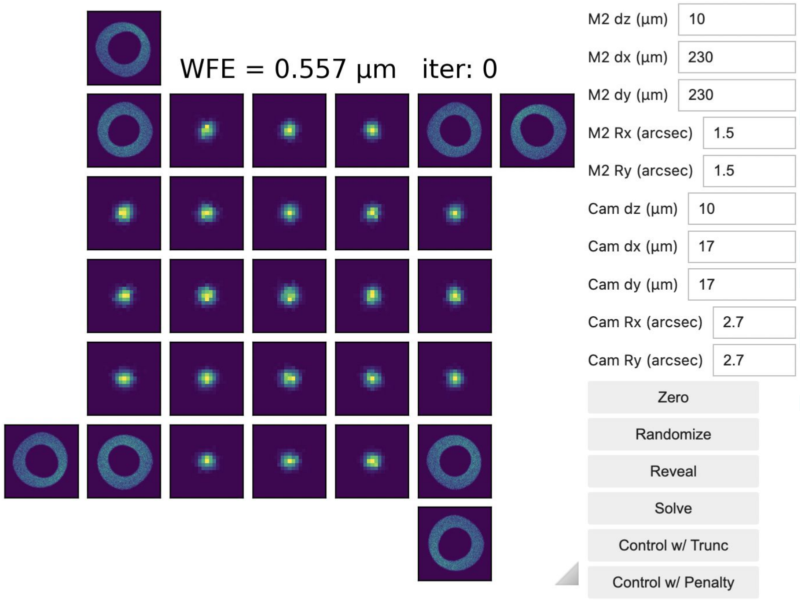
- **Description:**

  Focus sweep to determine a good focus and alignment.

  - Uses system pre-aligned laser tracker
  - Go through focus, centering, and measure the PSF shape/intensity, and donut sizes. (making sure we go through focus for the donuts).
  - Use "paired" defocus images on the detector to measure the wavefront.
  - Uses initially 7 non-degenerate rigid body modes.
  - Take lower order modes/zernikes measurements (maybe up to 11 modes).

- **Number of observations:**
  - As needed while observing the sharpness of the PSF.

- **Observing conditions:**
  - Find a very bright star and take 2s (very short) exposure to be able to react "faster".



Alignment game, J. Meyers

Focus and Centering Alignment

- **Datasets:**
  - Misalign the telescope with the worst-case expected misalignment after using the laser tracker
  - Perturb the bending modes with “realistic” amplitudes given the expected PSF FWHM.
  - W/ imsim generate images of the perturbed telescope, then perform the focus sweep and other rigid body motion degrees of freedom tweaks.
    - Are there constraints on how fast we need to do this; can it be a single star (or small number)
- **Analysis:**
  - Scripts / Notebook that given a series of image from the focus sweep determine what was the right correction for the rigid-body motions considered.
    - Do we need to process WFS and Science Sensors at the same time? Is this processing different from normal WFS operations
- **Visualization:**
  - Real-time images of the focal plane - cutouts at the center?
  - Real-time wavefront zernikes on the corners and plot of their evolution over time
  - PSF FWHM plot over time
- **AuxTel Rehearsal:**
  - Focus sweep already rehearsed during the sensitivity matrix generation
  - Other ideas?

Full-Array Mode + Sensitivity Matrix

- **Description:**
  - Take triplets of intra, extra, and in-focus data with Full-Array Mode at a variety of conditions.

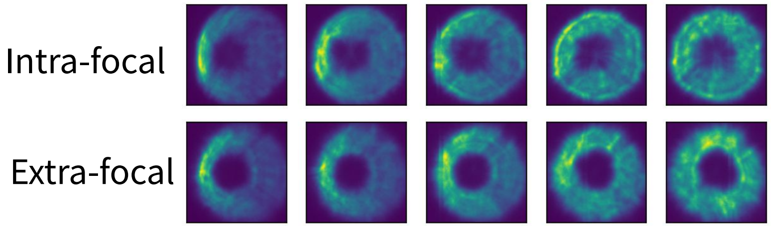
  Generate sensitivity matrix.

  - Change multiple DOF, one at a time.
  - Fit lines on how Zk depend on DOF at different field points.

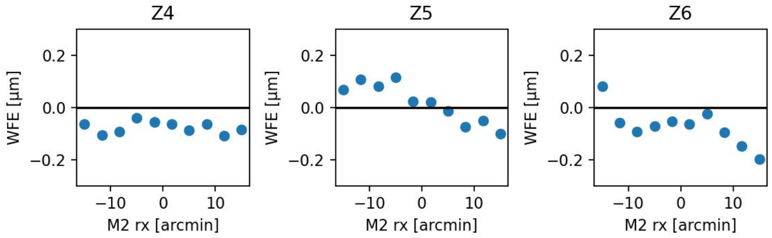
- **Number of observations:**
  - For each DOF (50), take images triplets (3 exposures) close to zenith, going through 10 values for each DOF.

- **Observing conditions:**
  - Low density
  - High elevation, Slow moving
  - Different SNR conditions

Scanning AuxTel M2 tilt angle



Measure d(wavefront) / d(degree-of-freedom)



Full-Array Mode + Sensitivity Matrix

- **Datasets:**
  - With imsim generate fields of the in-focus focal plane perturbing one degree of freedom at a time (work of Bekah Polen + Chris Walter)
  - Input data is NOT the same as for reference wavefront generation (with different conditions). Implement temperature dependence?
- **Analysis:**
  - Script / Notebook that fits the curves to give the coefficients for the sensitivity matrix and gives an uncertainty on those coefficients
- **Visualization:**
  - Plots of how different zernikes change as a function of bending mode
  - Overall comparison of previous sensitivity matrix at each field position and for each DOF with updated one.
- **AuxTel Rehearsal:**
  - Done with Auxtel!
  - Interesting to see where the sensitivity matrix becomes non-linear in case it does in Auxtel

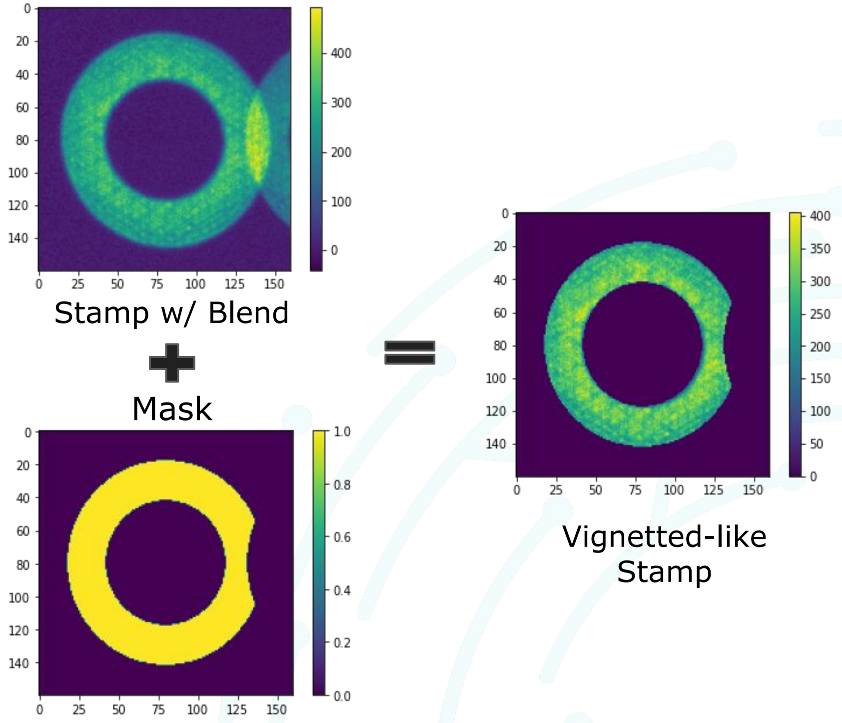
Deblending + Vignetting

- **Description:**

  Validate the wavefront estimation using experimental vignetted and blended donuts.

  Experiment with the wavefront estimation algorithms, deblending and masking approaches in different fields.

- **Observing conditions:**
  - Different atmospheric seeing conditions
  - Different SNR conditions
  - Low-density field



Deblending + Vignetting

- **Datasets:**
  - With imsim, with the same perturbations, generate a series of crowded and non-crowded fields.
    - Create series of targeted blends/vignetting as well as dense fields?; range of filters?; generate data for training ML approach?; range or perturbations to include in tests;
    - Use same data as sensitivity matrix or reference wavefront?
- **Analysis:**
  - Notebooks / scripts that can take full image of the sensor and compare the wavefront estimates for different subset of selected donuts
    - Find blended donut next to isolated donuts -> compare zernikes
- **Visualization:**
  - Cutouts of blended and vignetted donuts
  - Plots of mismatch between different wavefront estimation algorithms.
  - Comparison of zernikes blended and non-blended donuts
- **AuxTel Rehearsal:**
  - Observe medium to high density fields, and experiment with current algorithms to see performance.

Full Loop Test

- **Description:**
  - Simulate the entire data flow that we will have on-sky
    - Perturb the telescope with some realistic set of DOF
    - W/ imsim generate an in-focus image at a given elevation angle, applying elevation
    - Run the sensor images through ts_wep and obtain estimated zernikes
    - Perform optical state estimation + Compute corrections with closed loop
    - Apply corrections
    - Re-do the process
  - Do this in imsim (ts_imsim imgClosedLoop) and with ts_mtaos
  - Study corrections derived and experiment with gains and penalties
- **Number of observations:**
  - Set of five observations at a given positioning
- **Observing conditions:**
  - Medium density field with isolated and blended stars
  - Different atmospheric conditions

Full Loop Test

- **Datasets:**
  - W/ Imsim perturb the telescope with a realistic set of degrees of freedom (bending modes + hexapods)
  - Feed images through mtaos system
    - Just WFS or FAM; speed requirements to test the loop; implement large elevation changes perturbing the mirror?;
    - Is temperature varying from observation to not? Do we want to start with a simplified control loop?
- **Analysis:**
  - Notebook that summarizes performance of wavefront estimation part
  - Notebook to quantitatively evaluate convergence (gains) of corrections
  - Notebook that analysis resulting corrections in the degenerate mode basis (penalties)
- **Visualization:**
  - Plots of donuts + wavefront in the corners
  - Evolution of PSF FWHM
  - Plots of the corrections for each DOF over time
- **AuxTel Rehearsal:**
  - Currently tested - corrections are not perfect. Is it related to the intrinsic wavefront we are currently using?