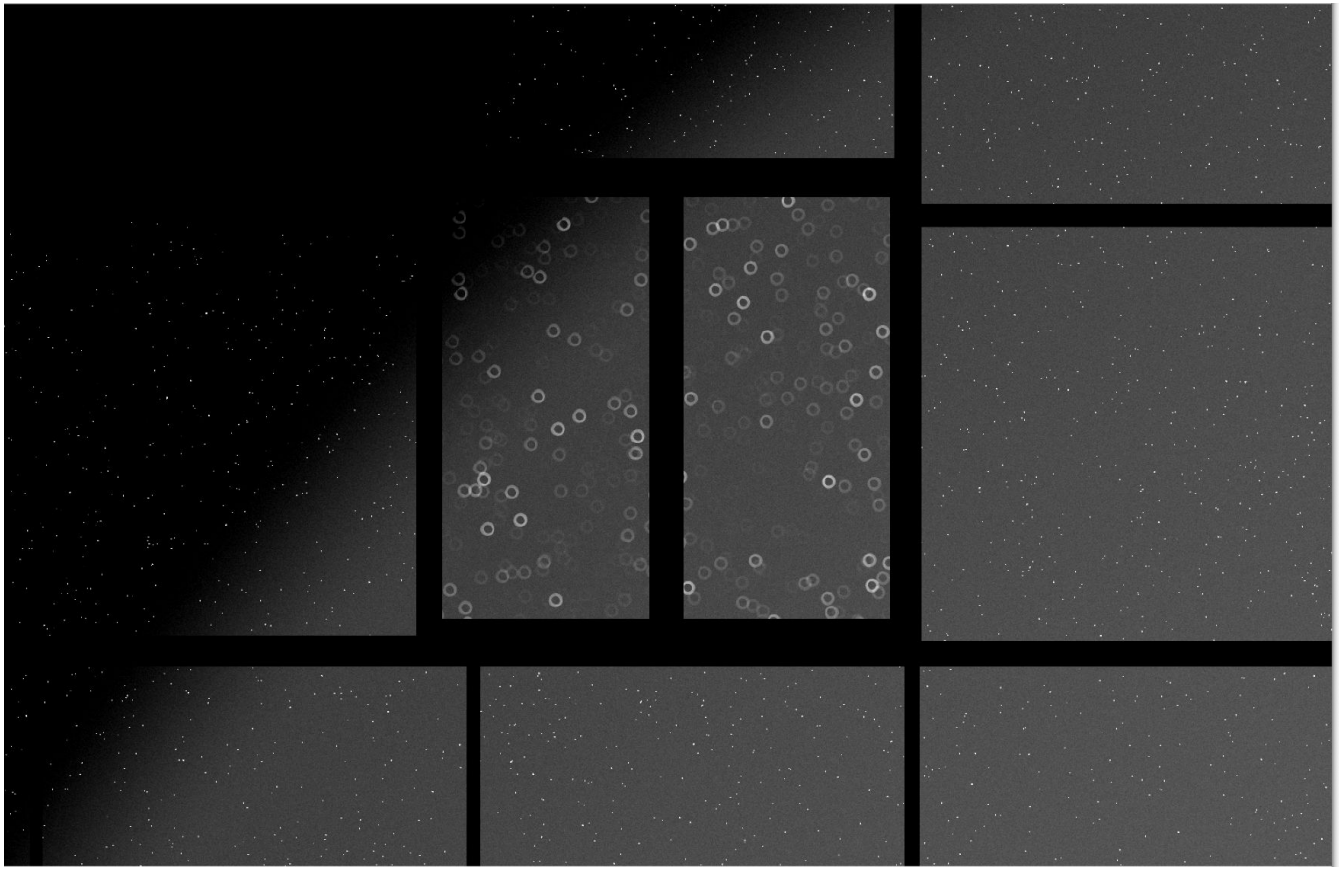
imSim: Commissioning AOS



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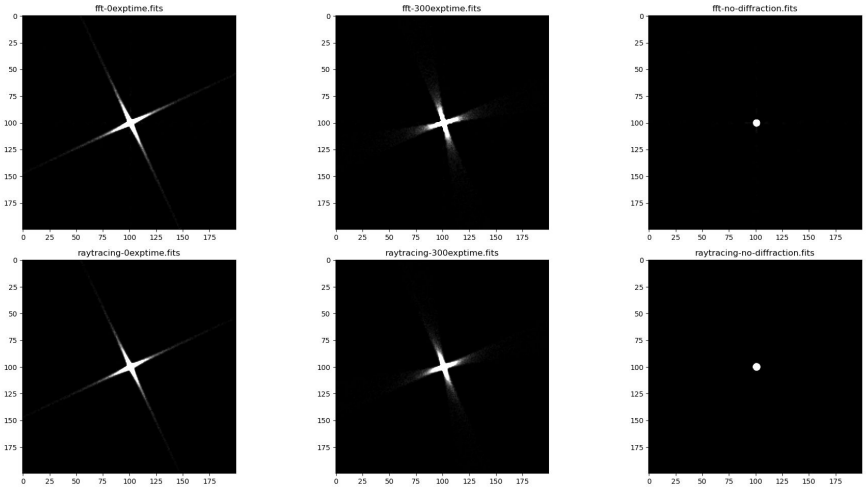
imSim development team
and *Rubin AOS team*
SLAC
Rubin Project and Community Workshop
August of 2023

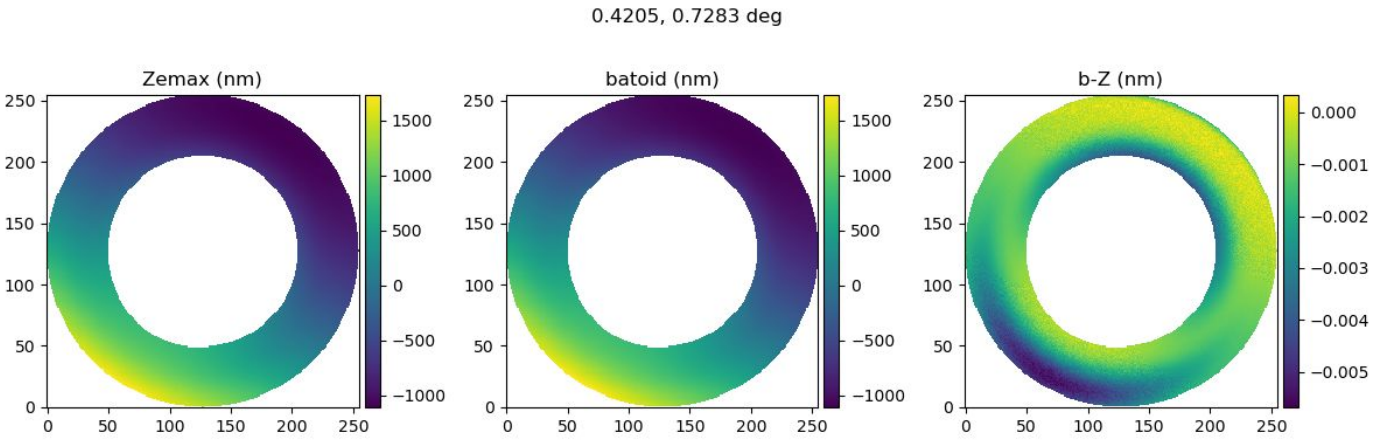
What's new in optics?

- Diffraction spikes
  - Statistical diffraction model (Coffey 1999)
    - Extra photon kick based on distance to nearest edge.
    - No field-dependence in pupil mask yet.
  - Field rotation
    - Spider (=> spikes) rotate relative to sky during exposure.
- For AOS, purpose is to make images realistically annoying; I think we've achieved that.



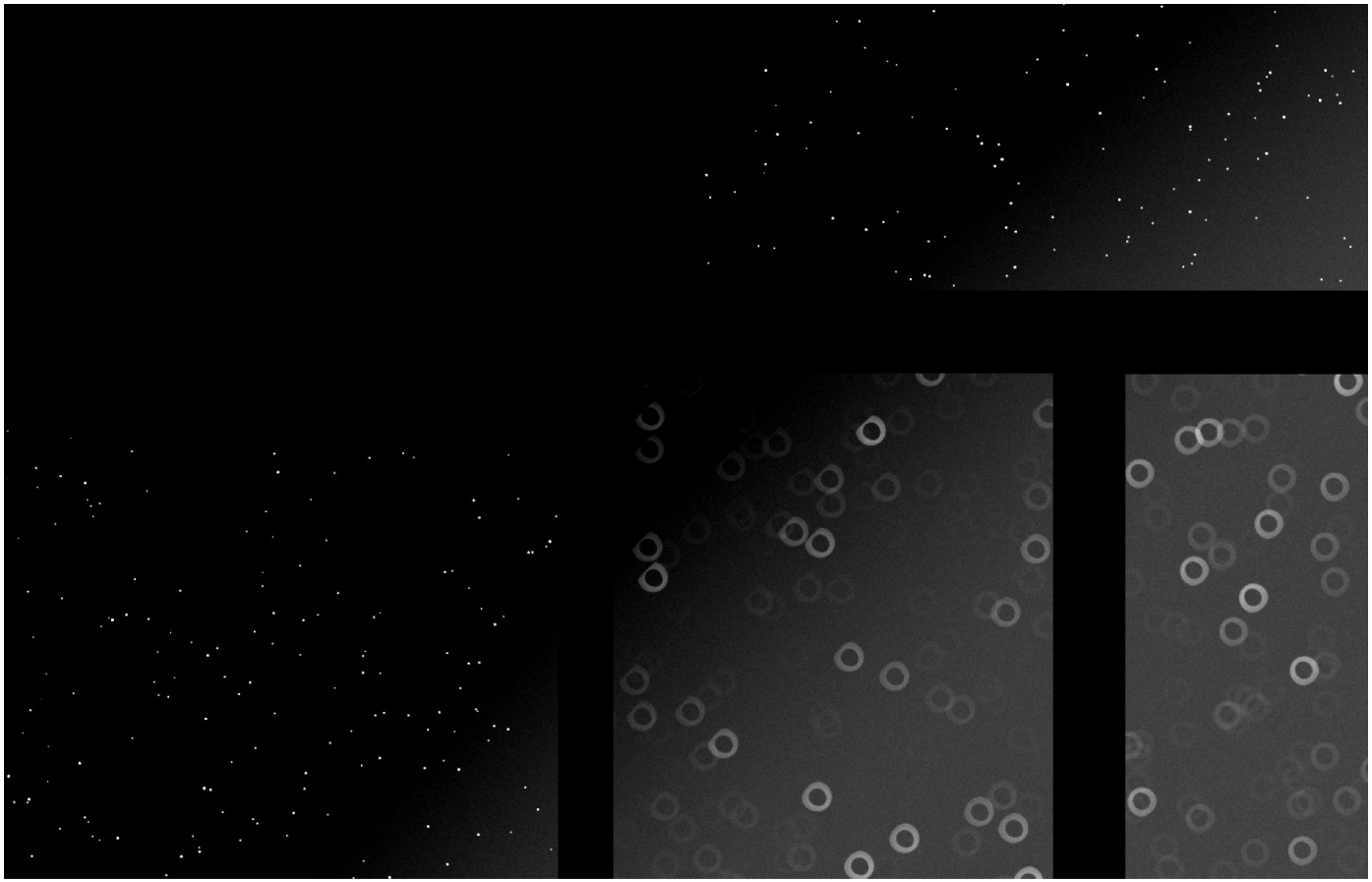
What's new in optics?

- Batoid (eyers314/batoid) for real raytracing
- We have converted Zemax baseline designs to batoid format:
  - v3.3 (design)
  - v3.12 (as-built)
    - Includes "aspheric slide", focal plane tilt, Zernike sag perturbations on L1S1, L2S1, r&i filters
  - v3.14 (latest), have not yet converted
- Single raytrace comparison with Zemax good to better than 1nm in all surface intersections. OPD comparisons good to 10s of pm.
- Add simple perturbations (displacement, tilt, Zernike additions to sag)



Vignetting

- Emergent object vignetting!
  - Consistent polynomial model for vignetting of background

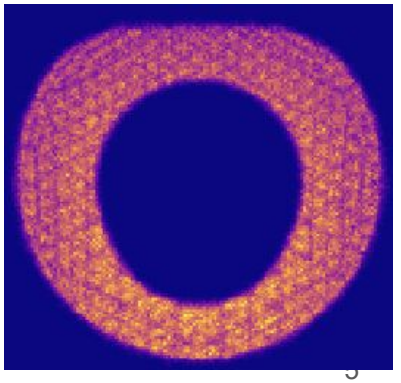


Optical perturbations

- We use the batoid_rubin (:jmeyers314/batoid_rubin) package to modify baseline optics using outputs of FEA models.
- All surfaces have FEA model for gravitational deformation as function of zenith angle:
- M1M3 has thermal FEA model perturbations for
  - Bulk temperature
  - Gradients along x, y, z, and r.
- M2 has thermal FEA model perturbations for
  - Gradients along z and r.
- We can actuate individual M1M3 or M2 actuators
- We can displace/tilt optics (i.e., we have hexapod control)
- Interface for bending modes.

M1M3 print through

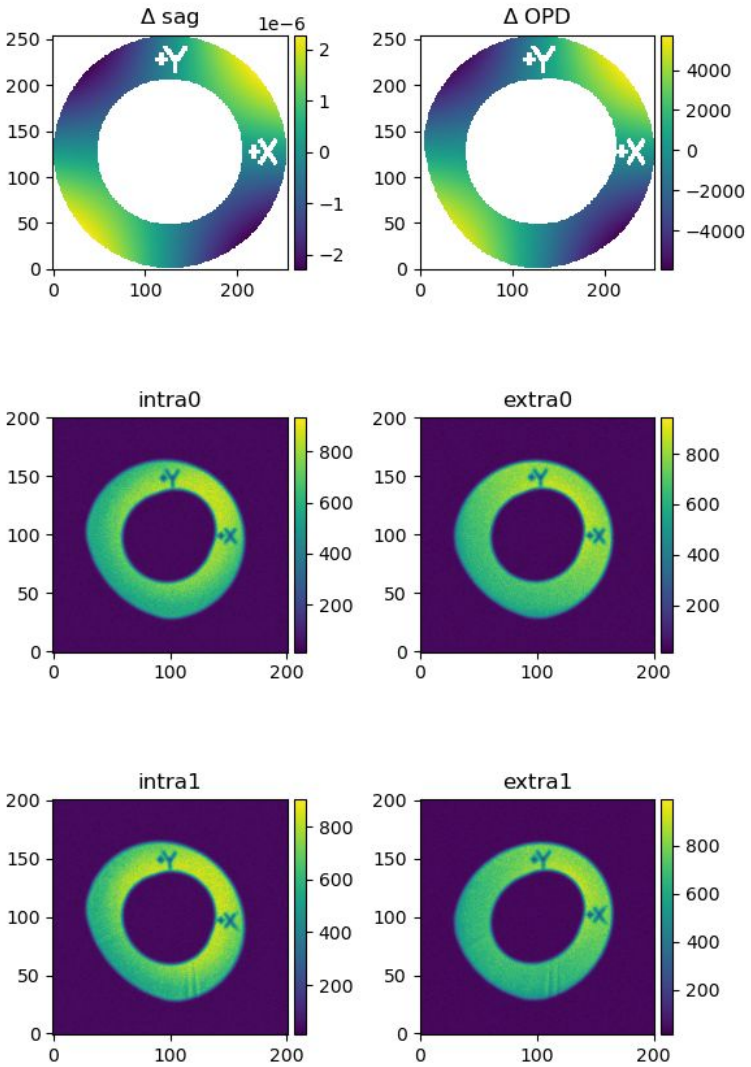
print through in donut



Live demo

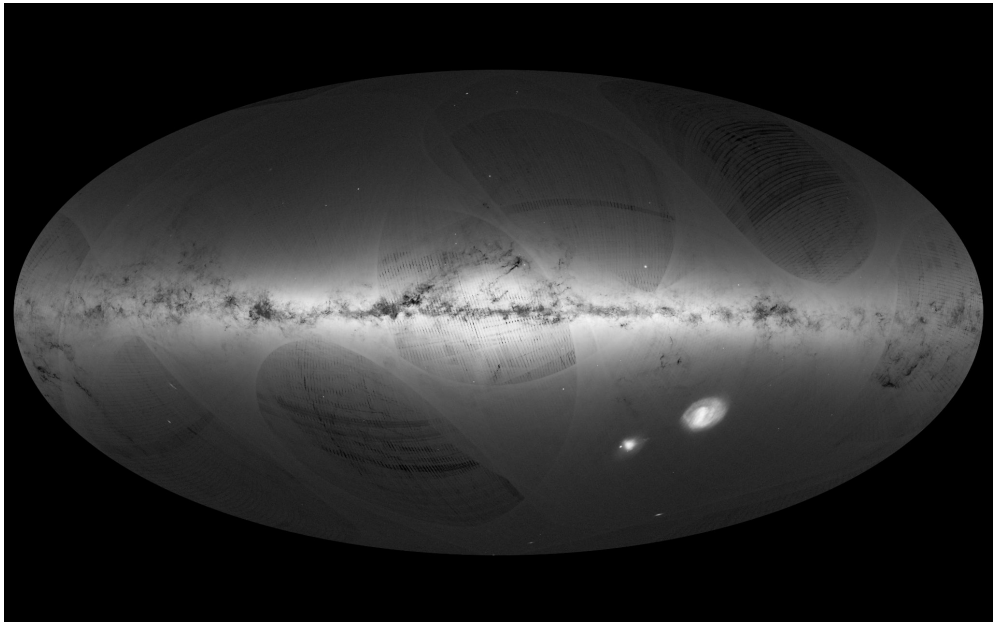
OPDs and sags

- Surface sag and OPD are now optional outputs of ImSim.
- Sag files include surface vertex global coordinate and alignment
- Verify coordinates: Build a “+X” and “+Y” out of rectangular obscurations on M1
- Now we know which side of the donut or OPD corresponds to which side of M1.
- In process of verifying bending mode coordinate conventions this way.



Gaia as an input catalog

- AOS software designed to dead reckon donut cutouts using reference catalog + initial WCS.
  - (Can also fall back to donut detection).
- We can now simulate stars drawing from that same reference catalog; good for tests!
- SED strategy: vary black-body temperature to fit Gaia r & b fluxes, use BB SED for ugrizy => chromatic effects present!



ESA/Gaia/DPAC

Other possibilities

- Collimated Beam Projector
  - Do spots measurably move when you push on the mirror?
- Phase screen in entrance pupil (PR coming)

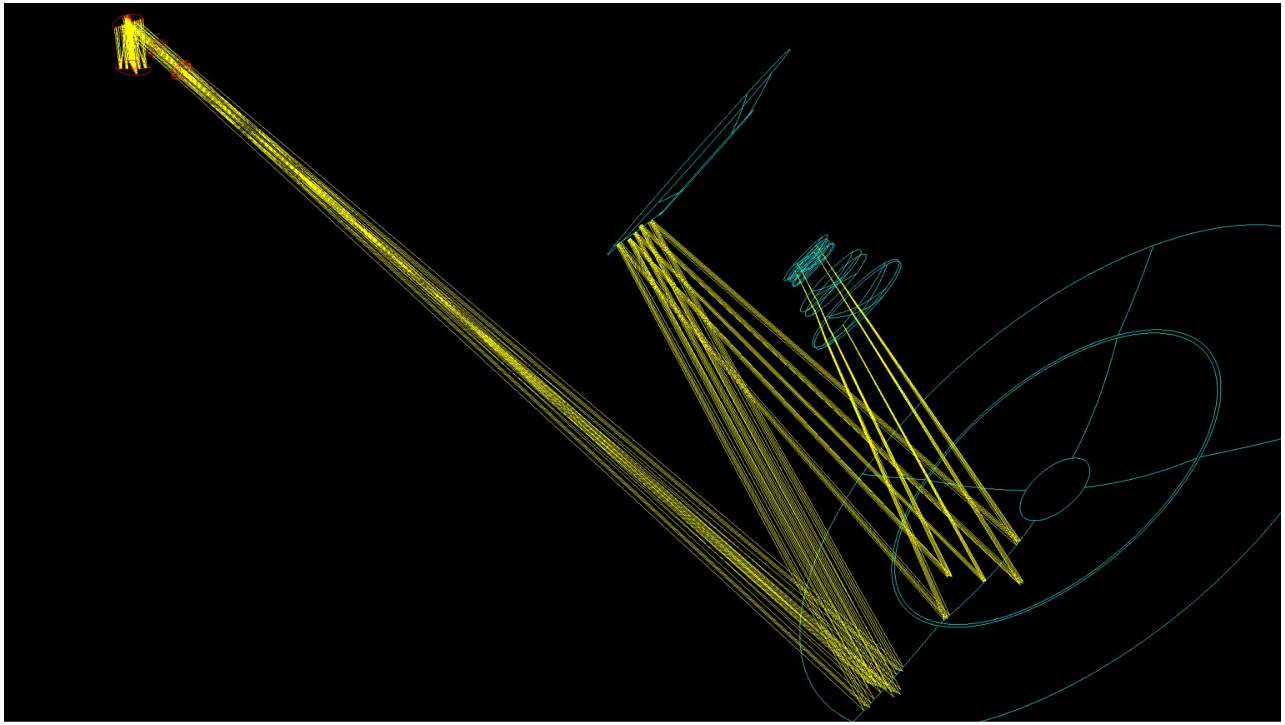


Image Quality Error budget - What we have

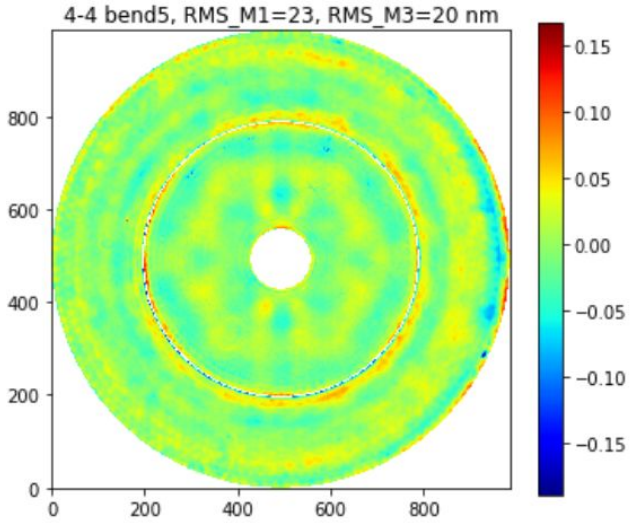
- Realistic correlated atmospheric wavefront contributions. (~0.04 arcsec)
- Realistic camera charge-diffusion, tree-rings, brighter-fatter. (~0.26 arcsec)
- As-built optics v3.12 (~0.16 arcsec)
- FEA gravitational print through, thermal effects (~0.14 arcsec)
- M1M3 zenith LUT
- (Noisy) actuators (~0.023 arcsec)

- Wavefront sensing errors (ts_wep) (~0.076 arcsec, includes atm above)
- Mirror figure misestimation (ts_ofc) (0.04 arcsec)
- Some time-lag from history of zenith pointing in OpSim (~0.01 arcsec)

Image Quality Error budget - What we lack

- Measured polishing errors (~0.11 arcsec)
- Dynamic alignment errors (~0.07 arcsec)
- Hexapod actuator errors (~0.02 arcsec)
- Wind-shake, buffeting (~0.047 arcsec)
- Dome seeing (~0.088 arcsec)
- Tracking errors/jitter (~0.073 arcsec)
- Detailed time lag errors (~0.01 arcsec)
- Focal plane non-flatness (~0.03 arcsec)
- M2/hexapod LUTs

Measured M1M3 surface residuals



In DC2, we mimicked these missing effects by convolving a 0.4 arcsec Gaussian into our final PSF.

We could do the same in ImSim 2.0, or add Gaussian random field to surface sags using specified structure function.

Generally, have many effects but haven't compared directly with error budget.

Commissioning needs

- Exercise AOS pipeline
- Prepare analysis notebooks ahead of time
- Develop visualizations, e.g., RubinTV

- Specific simulateable tasks:
  - Reference wavefront (don’t control anything, just drift)
  - Sensitivity matrix (See Bekah’s talk)
  - Closed-loop sims (See Bryce’s talk)
  - LUT refinement