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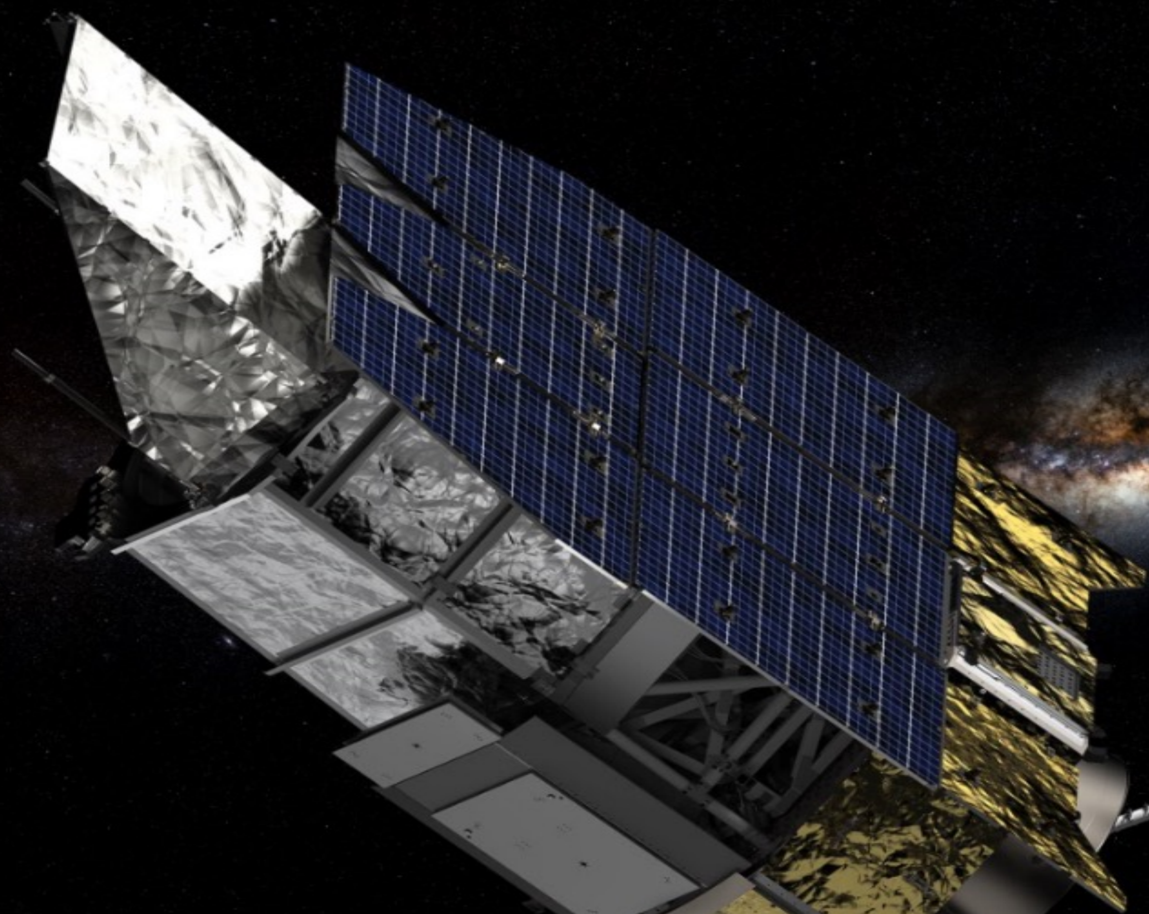

CGI Observing Scenario 11 Modeling Results

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JATIS Journal of Astronomical Telescopes, Instruments, and Systems

RESEARCH PAPER

End-to-end numerical modeling of the Roman Space Telescope coronagraph

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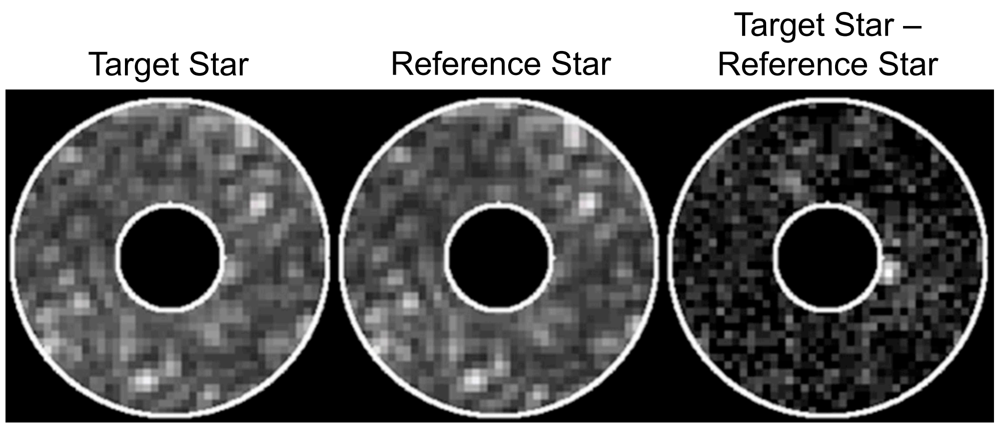
The Need for Time Series Modeling

ROMAN CORONAGRAPH

- Evaluate post-processing techniques (e.g., RDI, ADI, KLIP)
  - These will be used to recover embedded exoplanets and circumstellar disks
- Verify the CGI error budget
  - Predicts dark hole changes analytically using model-derived sensitivities to allocate performance requirements

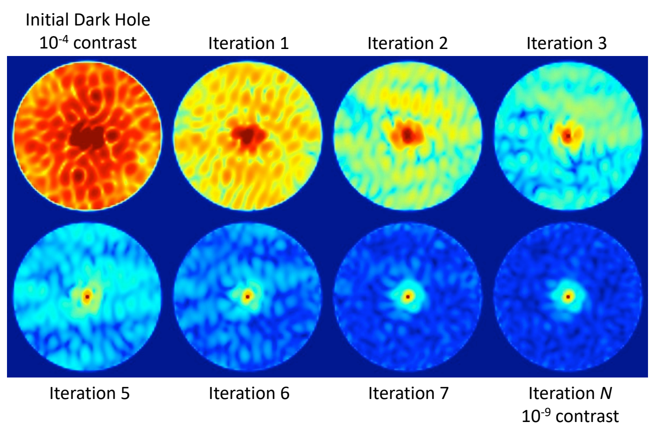


Time Series Models

- Diffraction model (including LOWFS)
  - Computes the dark hole by propagating the wavefront through the system model using Fourier-based algorithms
- STOP model
  - Structural, Thermal, and Optical Performance
  - Finite-element modeling of thermally-induced structural deformations
  - Ray tracing to derive resulting wavefront changes
- Dynamics model
  - Structural perturbations induced by reaction wheel vibrations
  - Primary effect is rapid pointing error (jitter)

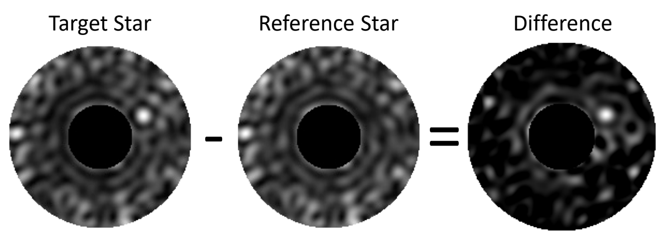
The Dark Hole

The initial dark hole:
The dark hole immediately after running high-order wavefront control



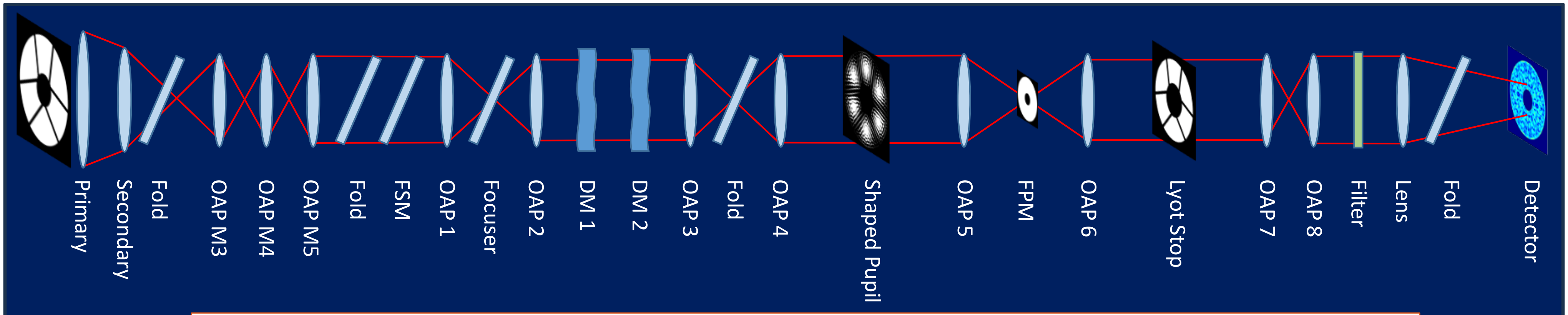
Modeled using:
Diffraction

The "dynamic" dark hole:
The dark hole as it varies over time due



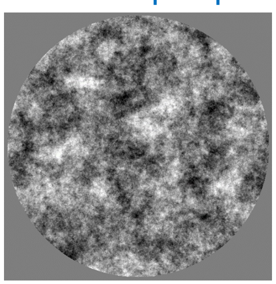
Modeled using:
STOP, pointing

Roman+CGI Unfolded Layout

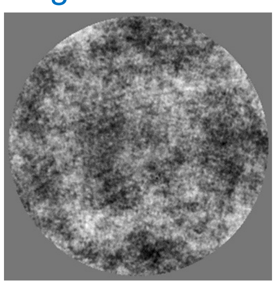


Broadband image = multiple monochromatic images x 4 polarization components

Optic polishing errors

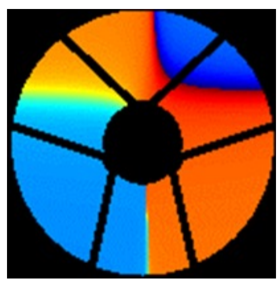


Synthetic



Measured

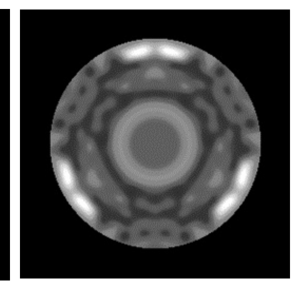
Polarization-dependent aberrations



Deformable mirrors

Masks

SPC pupil mask



HLC focal plane mask

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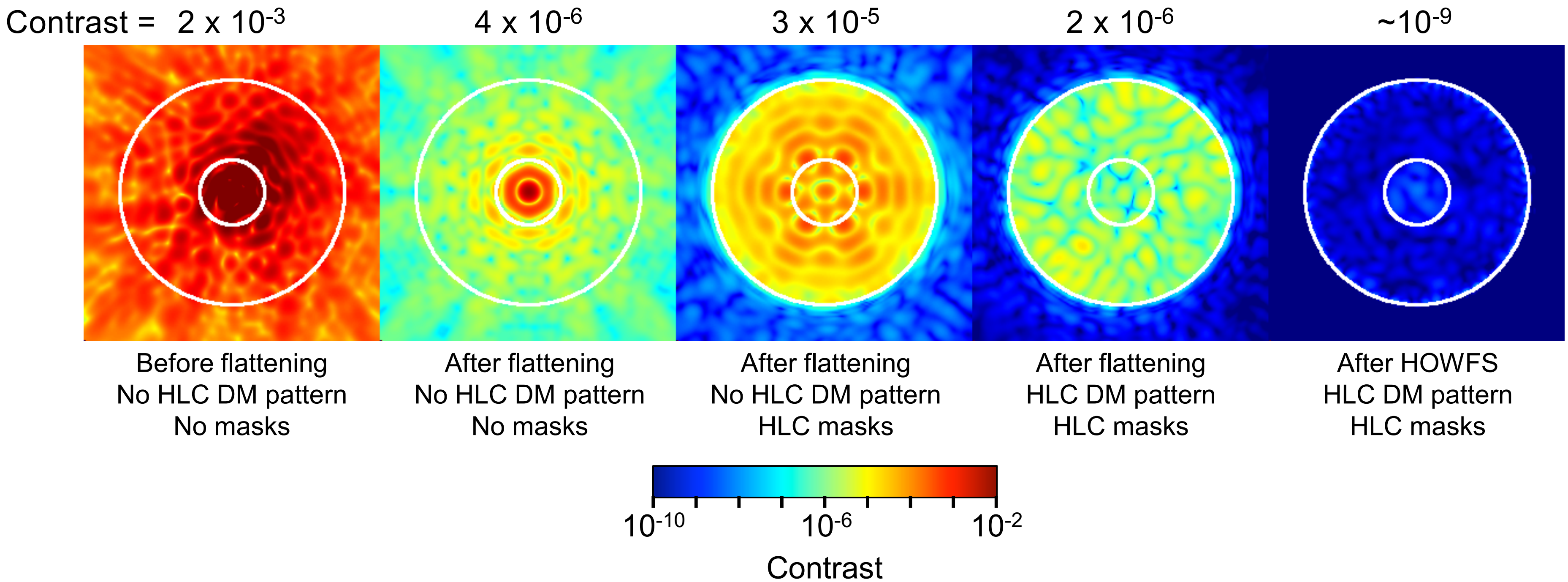
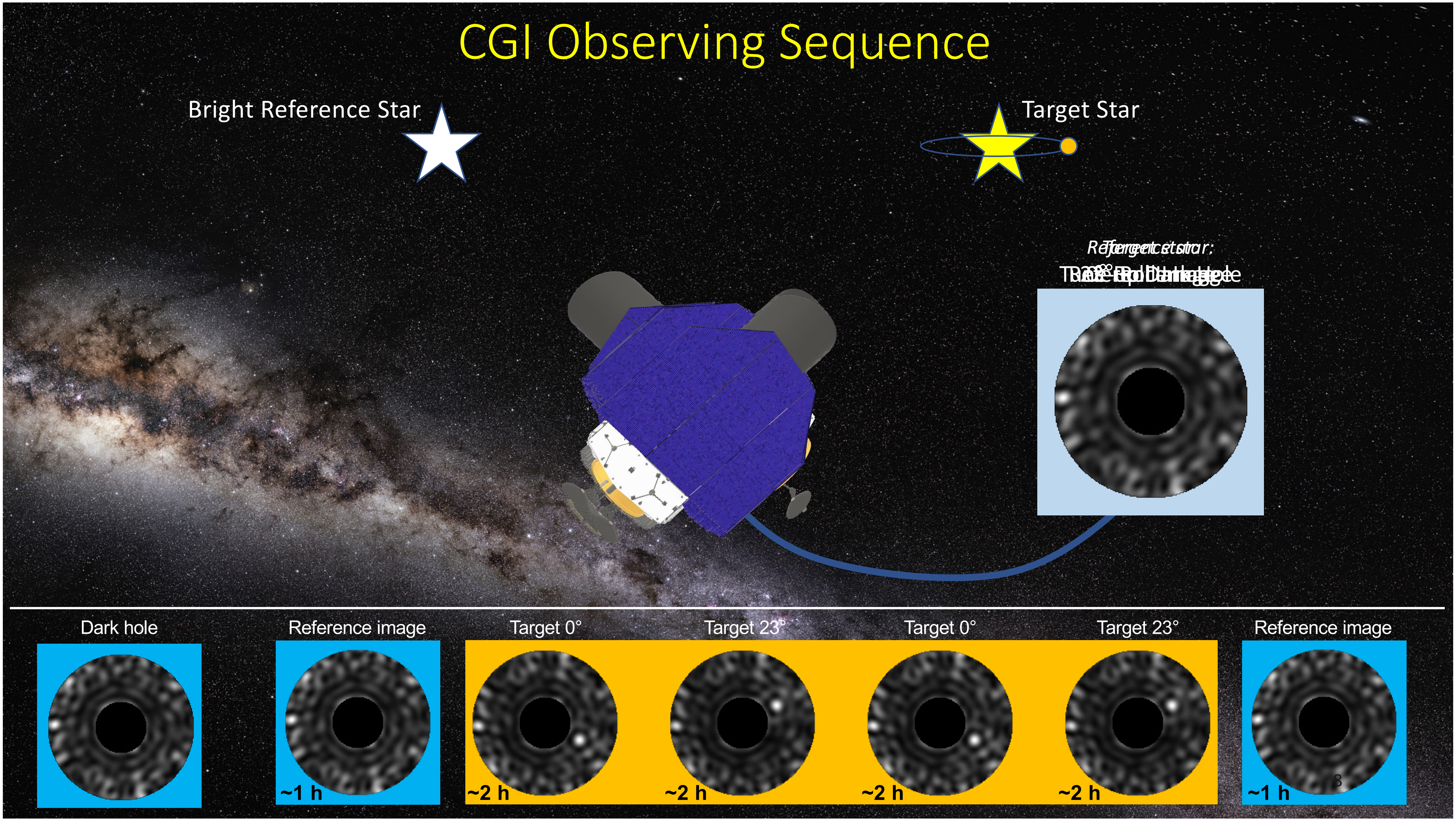
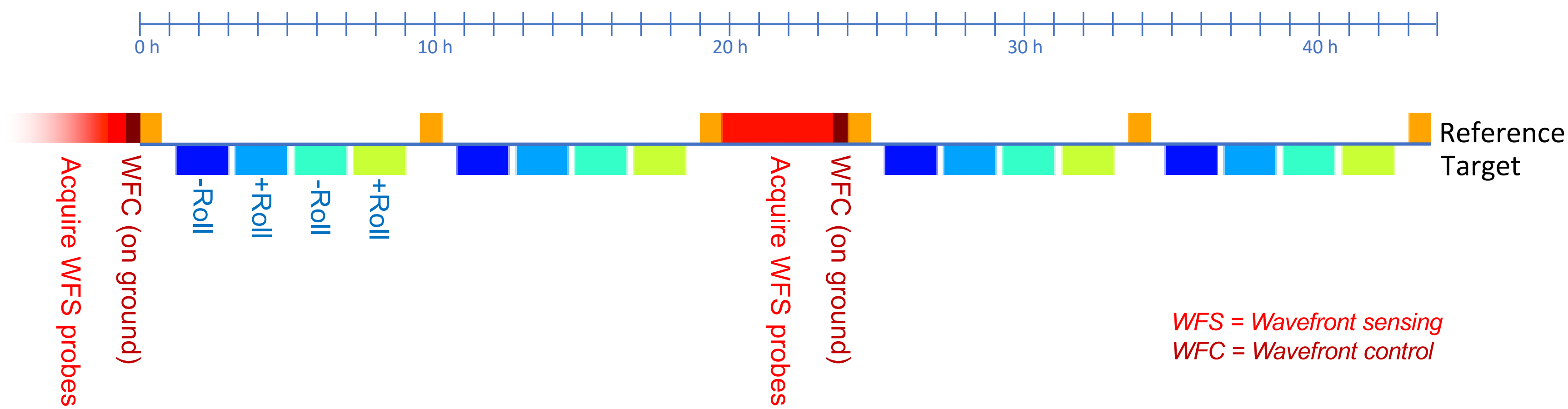
CGI Wavefront Control



The same wavefront control algorithms are used in the models, testbeds, and on-orbit


CGI Observing Sequence
Bright Reference Star
Target Star
Dark hole
Reference image
~1 h
Target 0°
~2 h
Target 23°
~2 h
Target 0°
~2 h
Target 23°
~2 h
Reference image
~1 h
8

Observing Scenario 11 Timeline



WFS = Wavefront sensing
WFC = Wavefront control

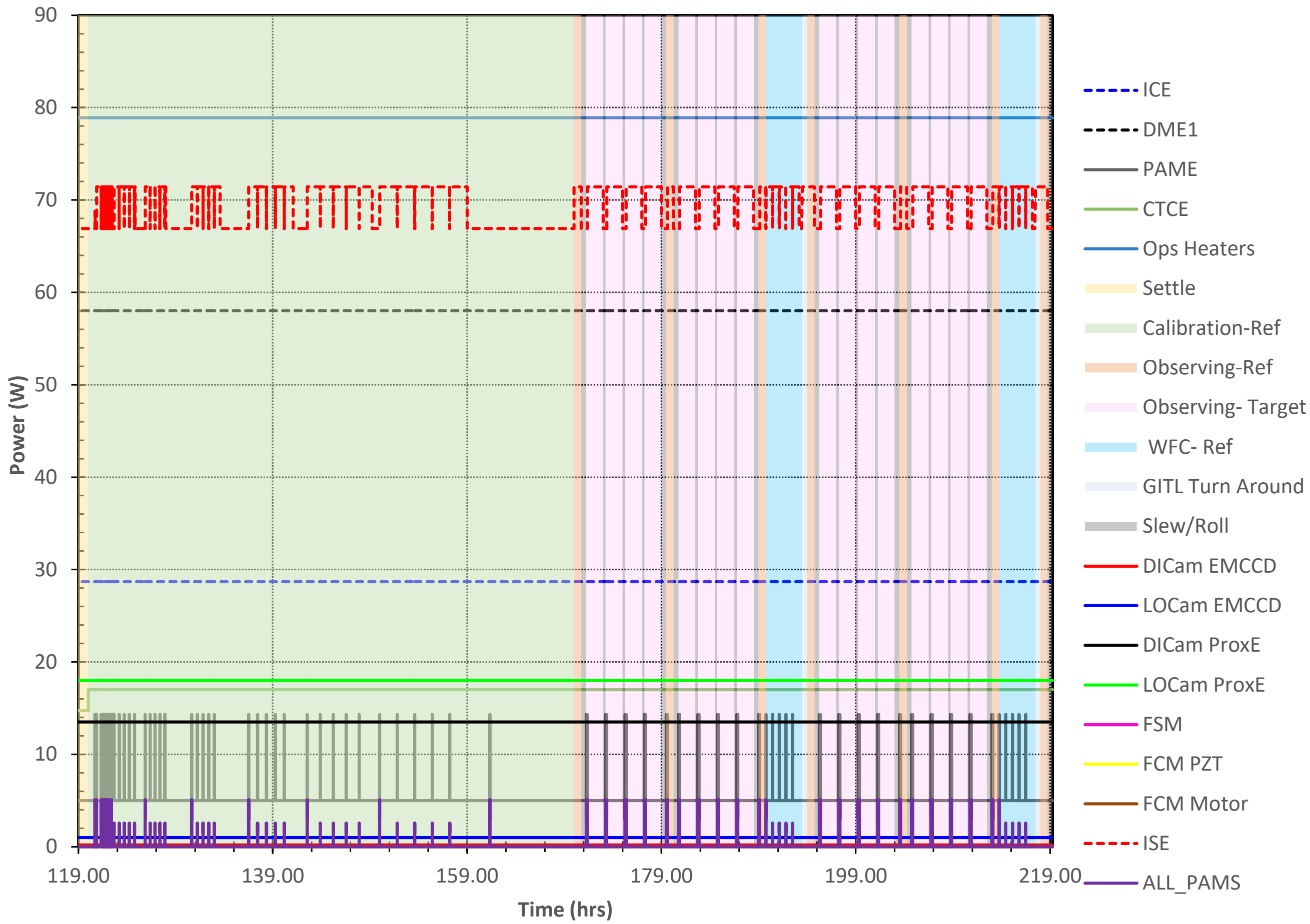
OS11 Orbital Parameters

Times begin at 2026-05-21 00:00:00 UTC, sun moves as seen from Earth, locations are accurate at t in each line

All positions are expressed as sequential (yaw, pitch, roll) right-handed rotations, with initial orientation aligning x (telescope boresight) toward the north ecliptic pole,

				Attitude Angles			Thermal Desktop Vectors							
Row	**Mode**	**Pointing**	**Time (hrs)**	**Yaw-θ_z (°)**	**Pitch-θ_y (°)**	**Roll-θ_x (°)**	**t [s]**	**x_sun**	**y_sun**	**z_sun**	**x_planet**	**y_planet**	**z_planet**	**r / r_planet**
5	Settle	HLS	0.00	125.5	-4.6	0.0	0	0.08	0.00	1.00	0.00	0.00	-1.00	20.00
6	Settle	HLS	120.00	125.5	-4.6	0.0	432001	0.08	0.00	1.00	0.00	0.00	-1.00	20.00
7	Calibration	zet Pup	120.50	-149.3	-8.3	10.3	433801	0.14	0.18	0.97	0.00	0.00	-1.00	20.00
8	Calibration	zet Pup	170.75	-149.6	-9.3	12.0	614700	0.16	0.21	0.97	0.00	0.00	-1.00	20.00
9	Observing	47 UMa	171.25	-58.7	-6.3	-12.5	616500	0.11	-0.21	0.97	0.00	0.00	-1.00	20.00
10	Observing	47 UMa	173.00	-58.7	-6.4	-12.5	622801	0.11	-0.22	0.97	0.00	0.00	-1.00	20.00
11	Observing	47 UMa	173.25	-58.7	-6.4	13.5	623701	0.11	0.23	0.97	0.00	0.00	-1.00	20.00
12	Observing	47 UMa	175.00	-58.7	-6.5	13.4	630001	0.11	0.23	0.97	0.00	0.00	-1.00	20.00
13	Observing	47 UMa	175.25	-58.7	-6.5	-12.6	630901	0.11	-0.22	0.97	0.00	0.00	-1.00	20.00
14	Observing	47 UMa	177.00	-58.7	-6.5	-12.6	637201	0.11	-0.22	0.97	0.00	0.00	-1.00	20.00
15	Observing	47 UMa	177.25	-58.7	-6.5	13.4	638101	0.11	0.23	0.97	0.00	0.00	-1.00	20.00
16	Observing	47 UMa	179.00	-58.7	-6.6	13.4	644401	0.11	0.23	0.97	0.00	0.00	-1.00	20.00
17	WFC	zet Pup	179.50	-149.7	-9.5	-13.7	646201	0.16	-0.23	0.96	0.00	0.00	-1.00	20.00
18	WFC	zet Pup	180.25	-149.7	-9.5	-13.7	648901	0.16	-0.23	0.96	0.00	0.00	-1.00	20.00
19	Observing	47 UMa	180.75	-58.7	-6.7	13.3	650701	0.12	0.23	0.97	0.00	0.00	-1.00	20.00
20	Observing	47 UMa	182.50	-58.7	-6.7	13.3	657000	0.12	0.23	0.97	0.00	0.00	-1.00	20.00
21	Observing	47 UMa	182.75	-58.7	-6.7	-12.7	657900	0.12	-0.22	0.97	0.00	0.00	-1.00	20.00
22	Observing	47 UMa	184.50	-58.7	-6.8	-12.8	664200	0.12	-0.22	0.97	0.00	0.00	-1.00	20.00
23	Observing	47 UMa	184.75	-58.7	-6.8	13.2	665100	0.12	0.23	0.97	0.00	0.00	-1.00	20.00
24	Observing	47 UMa	186.50	-58.7	-6.9	13.2	671400	0.12	0.23	0.97	0.00	0.00	-1.00	20.00
25	Observing	47 UMa	186.75	-58.7	-6.9	-12.8	672300	0.12	-0.22	0.97	0.00	0.00	-1.00	20.00
26	Observing	47 UMa	188.50	-58.7	-6.9	-12.8	678600	0.12	-0.22	0.97	0.00	0.00	-1.00	20.00
27	WFC	zet Pup	189.00	-149.7	-9.7	12.6	680400	0.17	0.22	0.96	0.00	0.00	-1.00	20.00
28	WFC	zet Pup	194.75	-149.7	-9.8	12.8	701102	0.17	0.22	0.96	0.00	0.00	-1.00	20.00
29	Observing	47 UMa	195.25	-58.7	-7.2	-13.0	702902	0.12	-0.22	0.97	0.00	0.00	-1.00	20.00
30	Observing	47 UMa	197.00	-58.7	-7.2	-13.0	709201	0.13	-0.22	0.97	0.00	0.00	-1.00	20.00
31	Observing	47 UMa	197.25	-58.7	-7.2	13.0	710101	0.13	0.22	0.97	0.00	0.00	-1.00	20.00
32	Observing	47 UMa	199.00	-58.7	-7.3	12.9	716401	0.13	0.22	0.97	0.00	0.00	-1.00	20.00

OS11 CGI Power Profile



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OS11 Reaction Wheel Speeds

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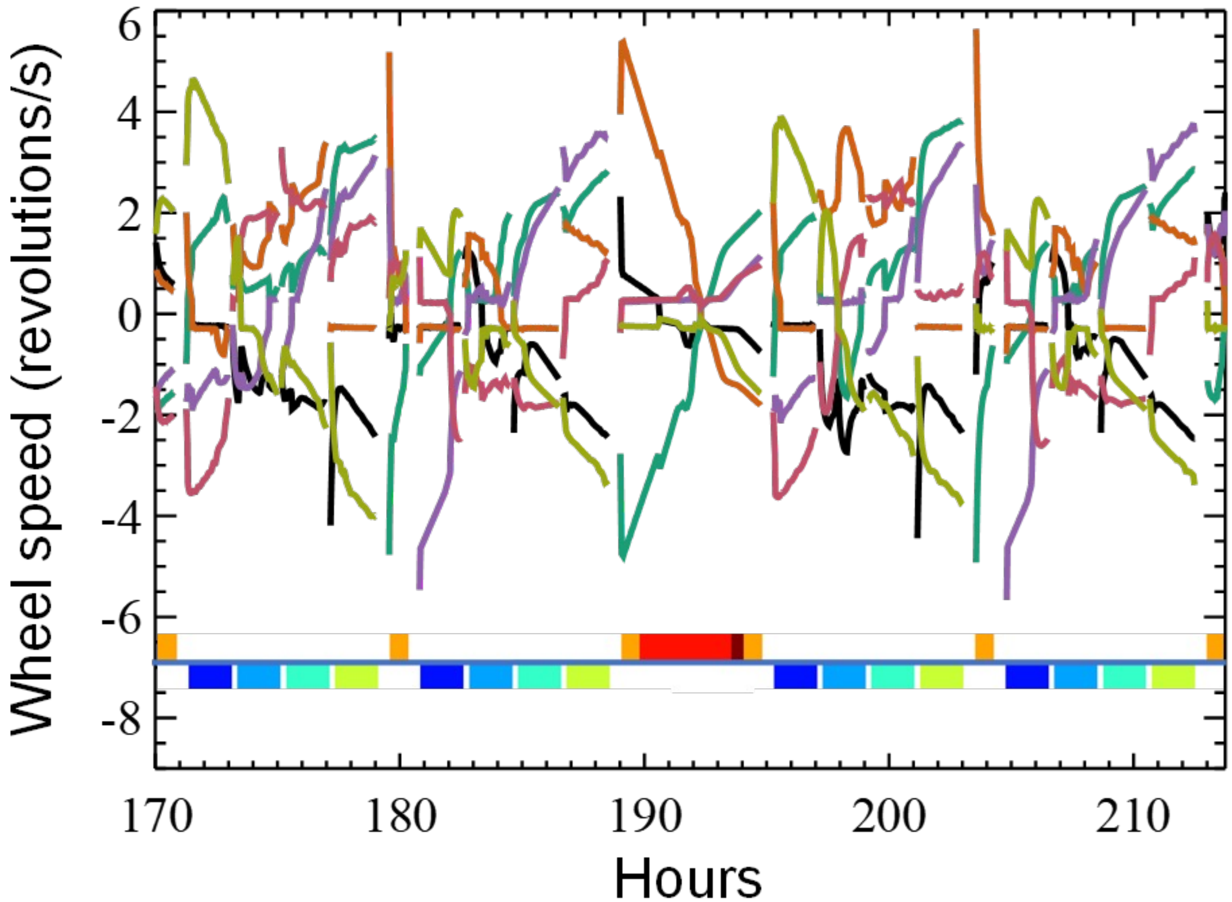
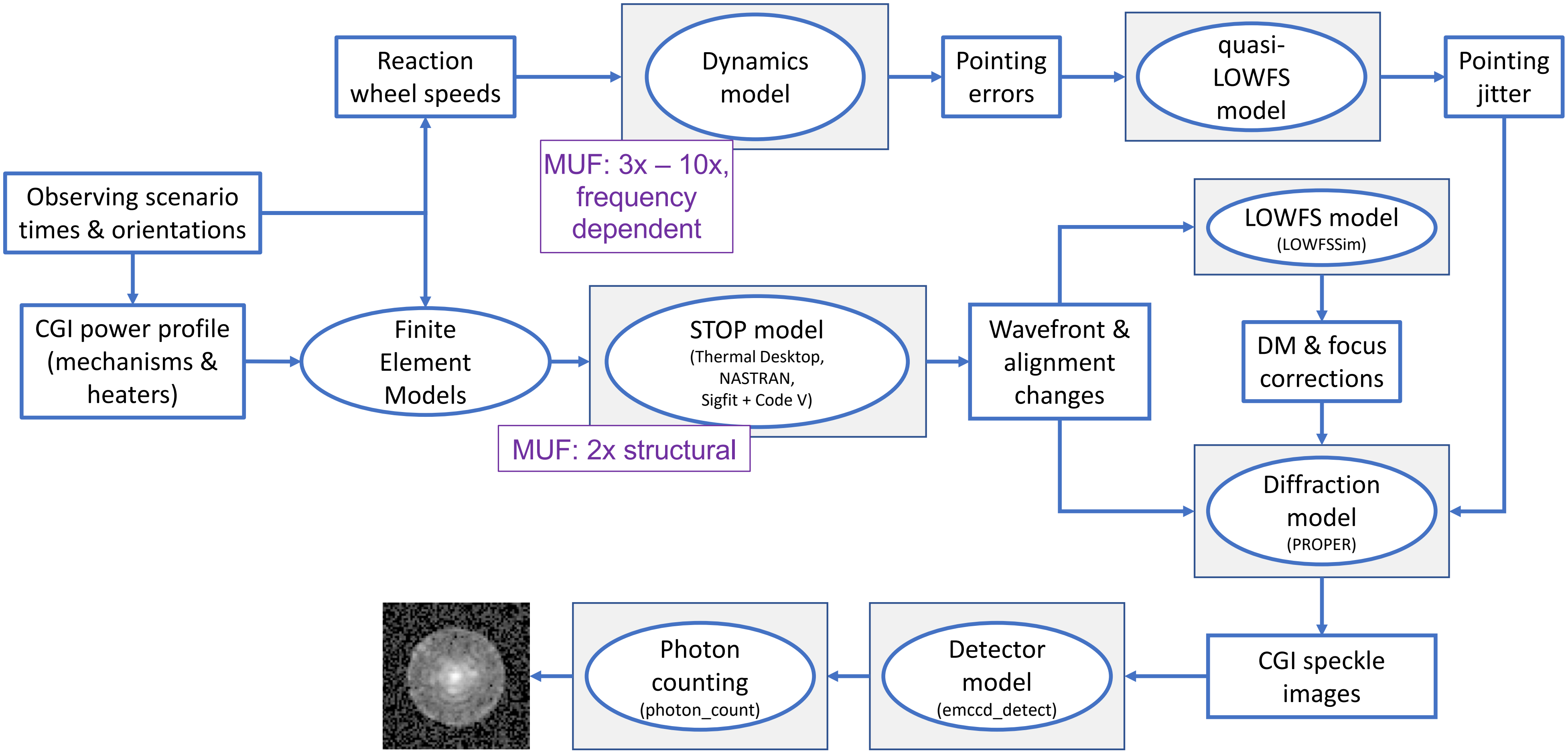
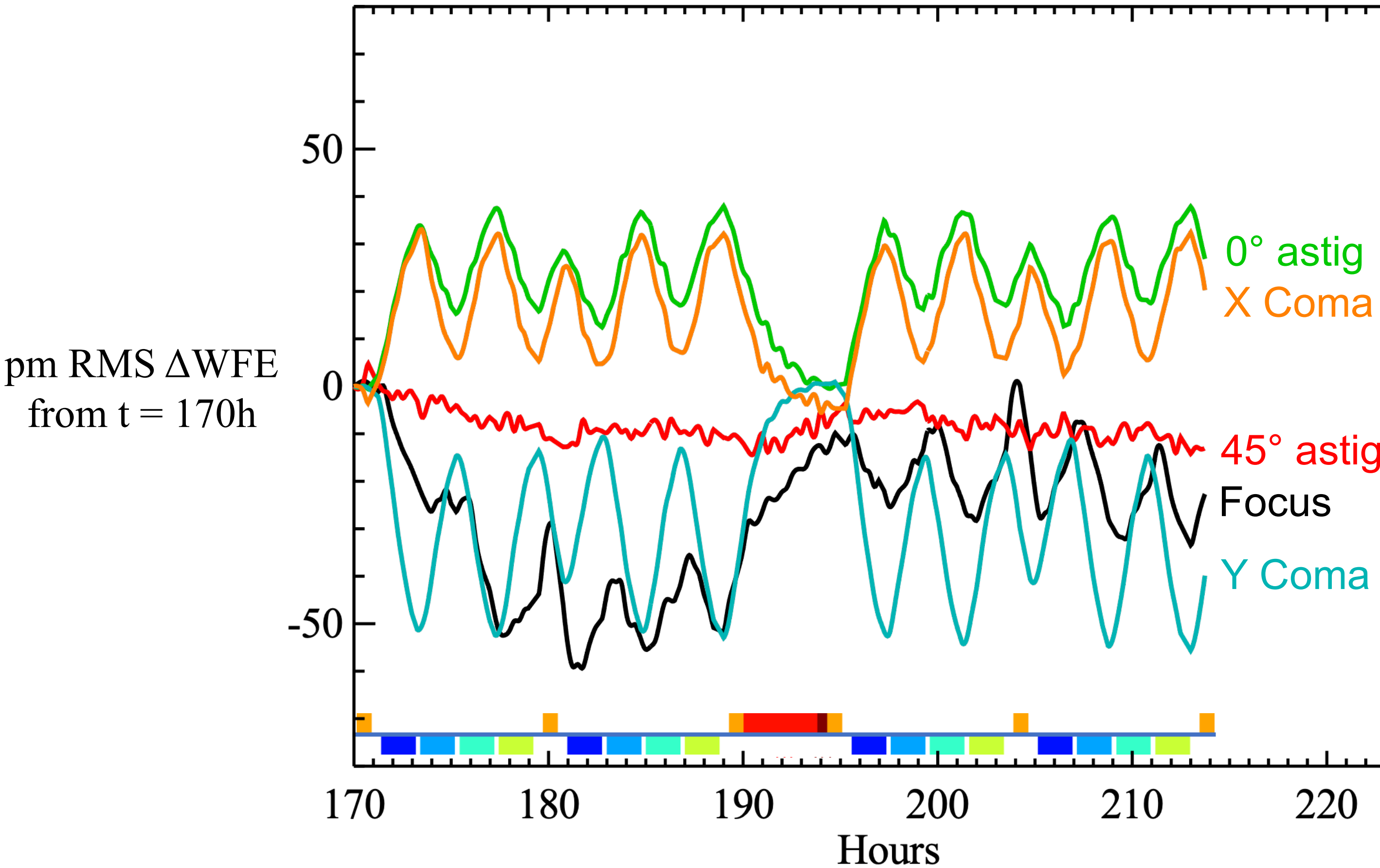


~30 min to slew
~15 min to roll

OS Time Series Computation Process



OS11 Low-Order Aberration Variations
(before LOWFS correction)



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OS11 Low-Order Aberration Variations

(after LOWFS correction on DM1)

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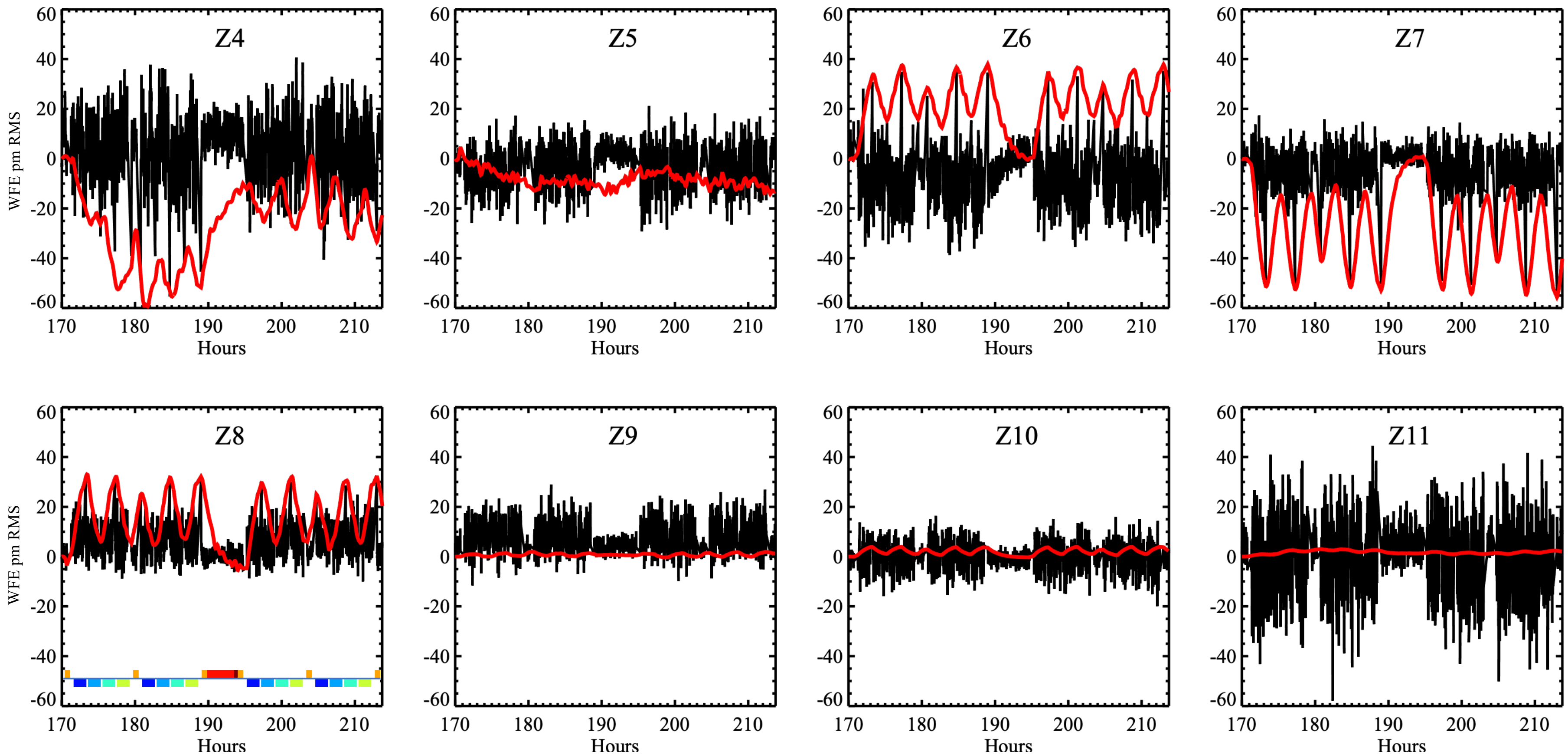
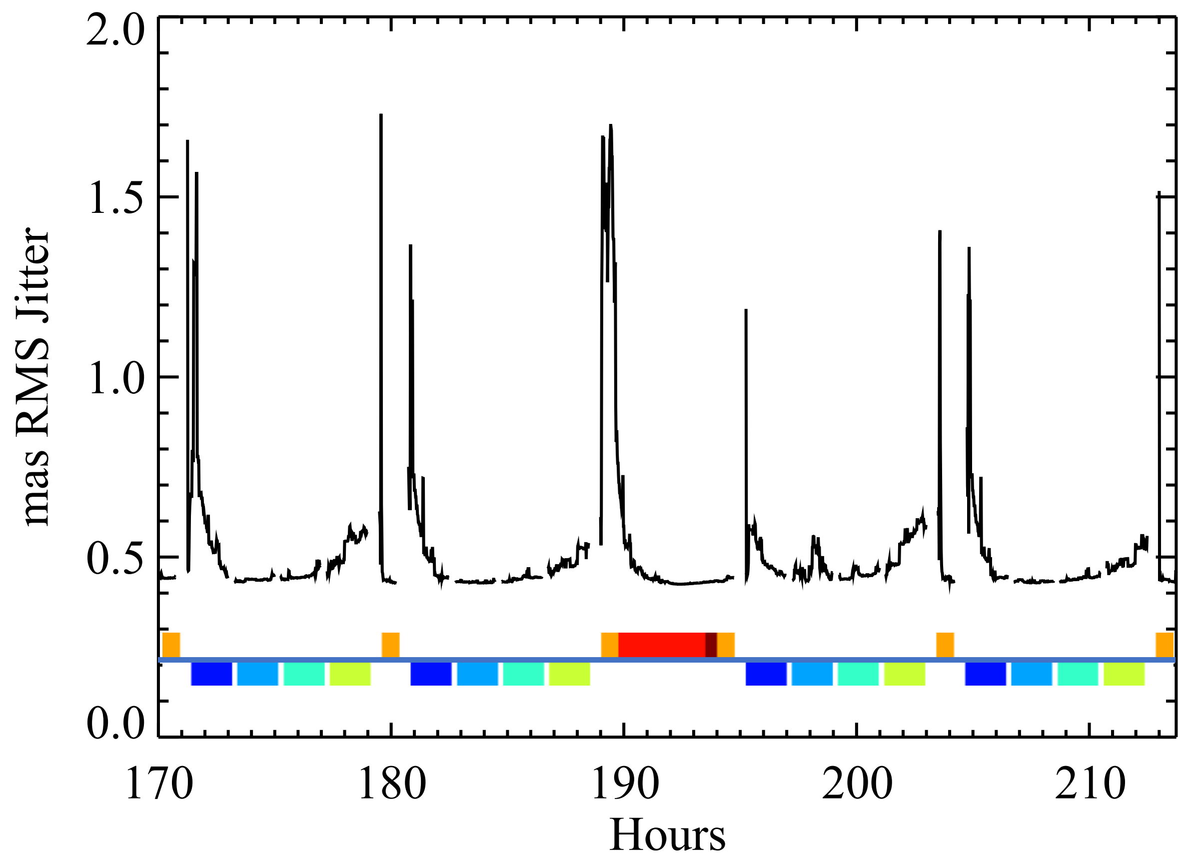


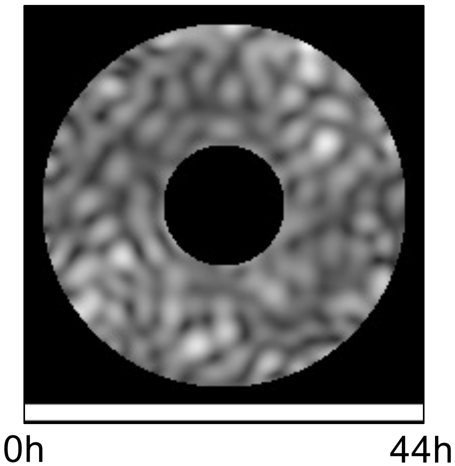
red = STOP-computed zernikes, black = LOWFS-corrected zernikes (1 m timesteps)

OS11 Pointing Jitter

(after Fast Steering Mirror correction)

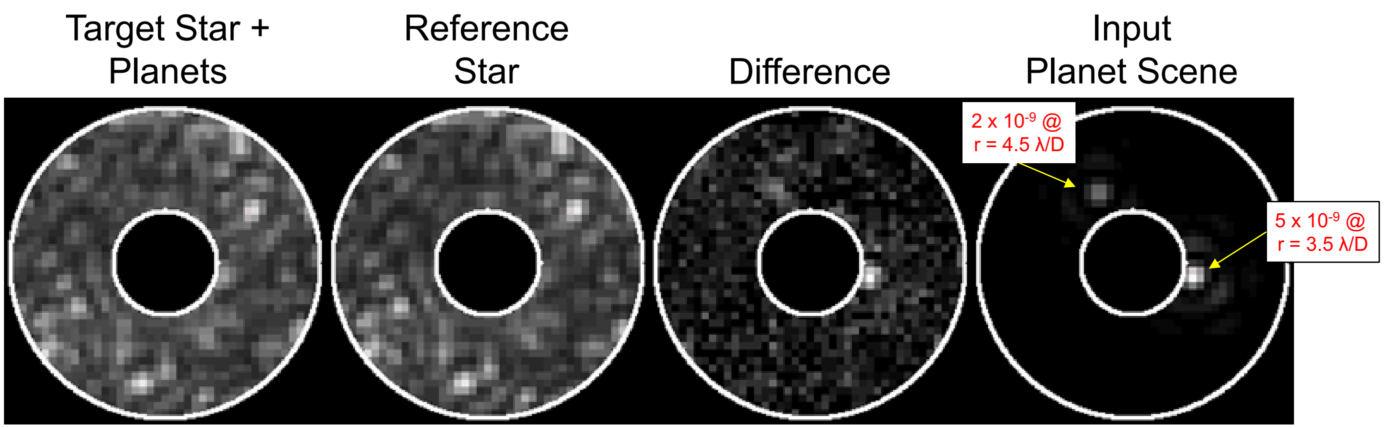


OS11 HLC Band 1 Results

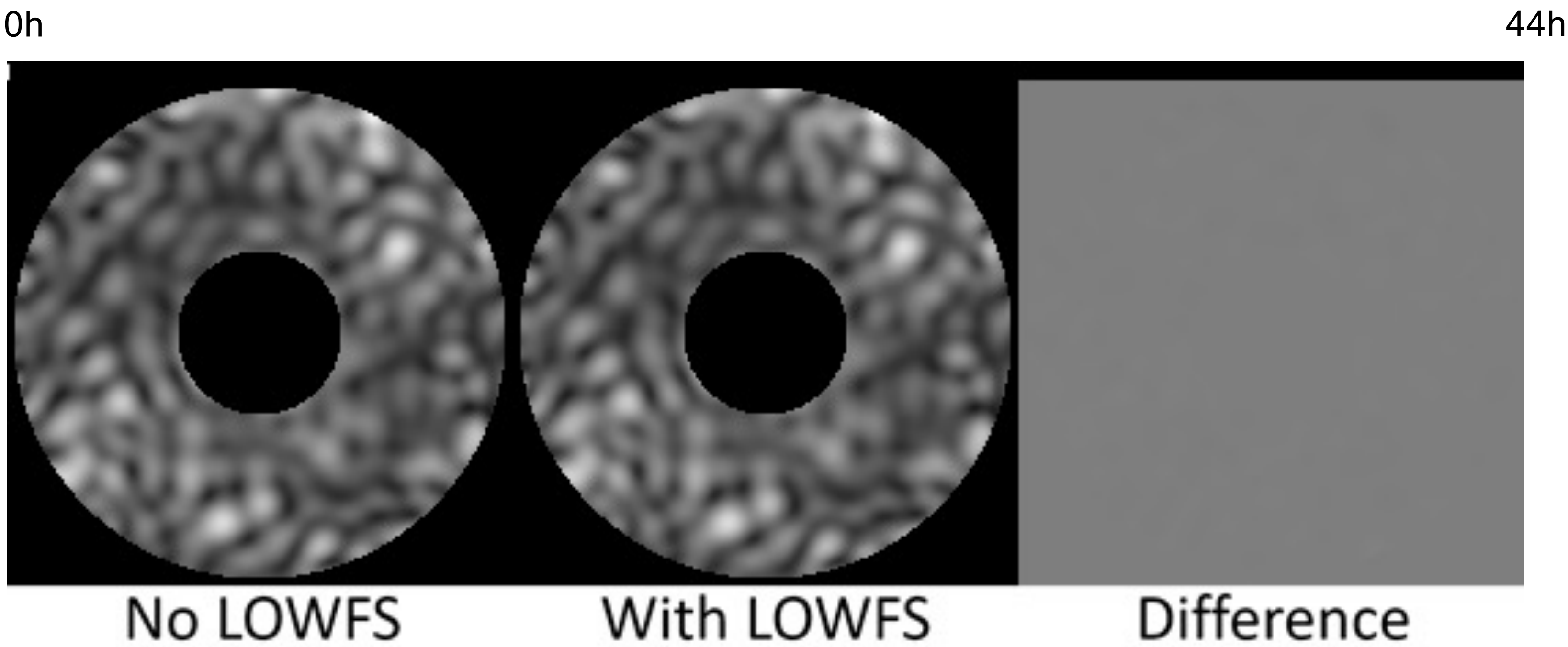


CGI OS11 Speckle Time Series
HLC Band 1
(no detector noise)

Time series available from:
https://roman.ipac.caltech.edu/sims

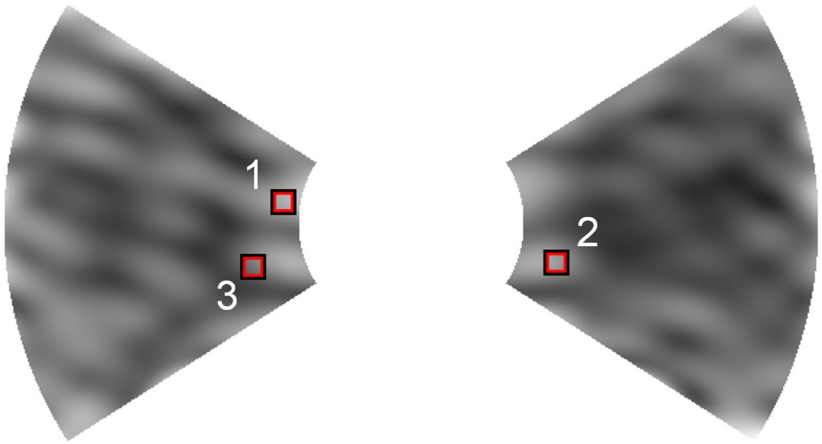


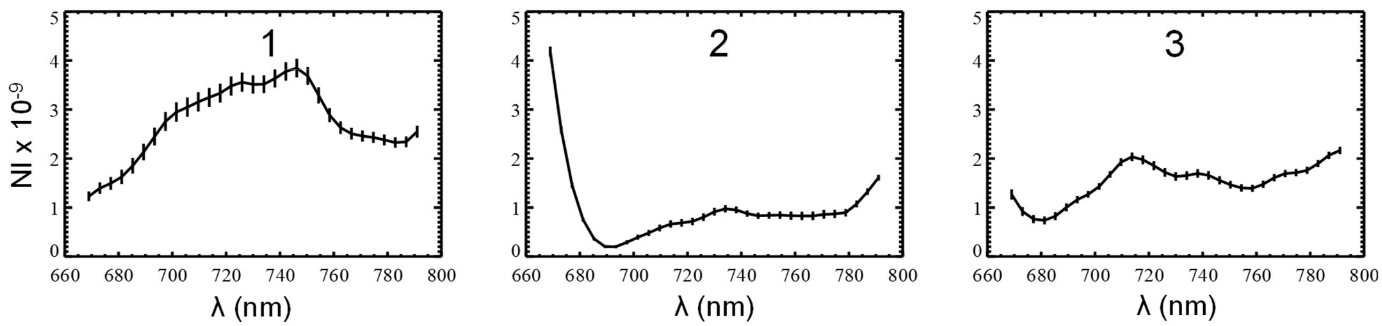
OS11 HLC Band 1 – Without, With Z4-Z11 LOWFSC



Jitter not included

OS11 SPC-Spec Band 3 Results





Error bars show intensity variation relative to mean over OS11

OS11 HLC Postprocessing Gains

	Noiseless			Noisy		
Post-Processing Method	5σ contrast	Gain	FAC	5σ contrast	Gain	FAC
No MUFs						
No sub., single roll minus	1.0×10^{-8}			1.3×10^{-8}		
No sub., single roll plus	1.0×10^{-8}			1.3×10^{-8}		
No sub., roll combined	8.0×10^{-9}			9.6×10^{-9}		
cRDI, single roll	2.2×10^{-9}	4.7		8.7×10^{-9}	1.5	
cRDI, roll combined	1.5×10^{-9}	5.3	1.2	6.1×10^{-9}	1.6	1.1
cADI, roll combined	6.2×10^{-10}	12.8	2.6	7.7×10^{-9}	1.3	0.9
KLIP RDI, roll combined	1.2×10^{-9}	8.3	**1.7**	5.9×10^{-9}	2.0	1.4
With MUFs						
No sub., single roll minus	2.7×10^{-8}			2.9×10^{-8}		
No sub., single roll plus	2.7×10^{-8}			3.0×10^{-8}		
No sub., roll combined	2.1×10^{-8}			2.2×10^{-8}		
cRDI, single roll	3.6×10^{-9}	7.4		1.3×10^{-8}	2.3	
cRDI, roll combined	2.5×10^{-9}	8.4	1.1	8.5×10^{-9}	2.6	1.1
cADI, roll combined	1.1×10^{-9}	18.8	2.5	1.1×10^{-8}	2.0	0.9
KLIP RDI, roll combined	1.9×10^{-9}	14.3	**1.9**	8.1×10^{-9}	3.5	1.5

From Ygouf et al. "Roman Coronagraph Instrument Post Processing Report – OS11 HLC Distribution" (2024)

Summary

- The OS11 simulations show that the speckle stability is
  - worst for brief periods after slews when the reaction wheels are spinning down
  - otherwise dominated by residual coma, which is roll-dependent
  - may be improved by tuning the LOWFS for the lower wavefront changes compared to requirements
- Advanced post-processing techniques (e.g. KLIP) provide an improvement of up to 2x over classical RDI
  - the more unstable the system, the greater the improvement factor
- Error budget was verified using a previous OS
- OS11 time series are provided on roman.ipac.caltech.edu for the 3 base modes (HLC, SPC-Spec, SPC-WFOV)
- Revised OS11 coming? Maybe. I don't know.