Jet Propulsion Laboratory
California Institute of Technology

WFIRST Coronagraph Technology and Key Risks

Feng Zhao
Jet Propulsion Laboratory
California Institute of Technology
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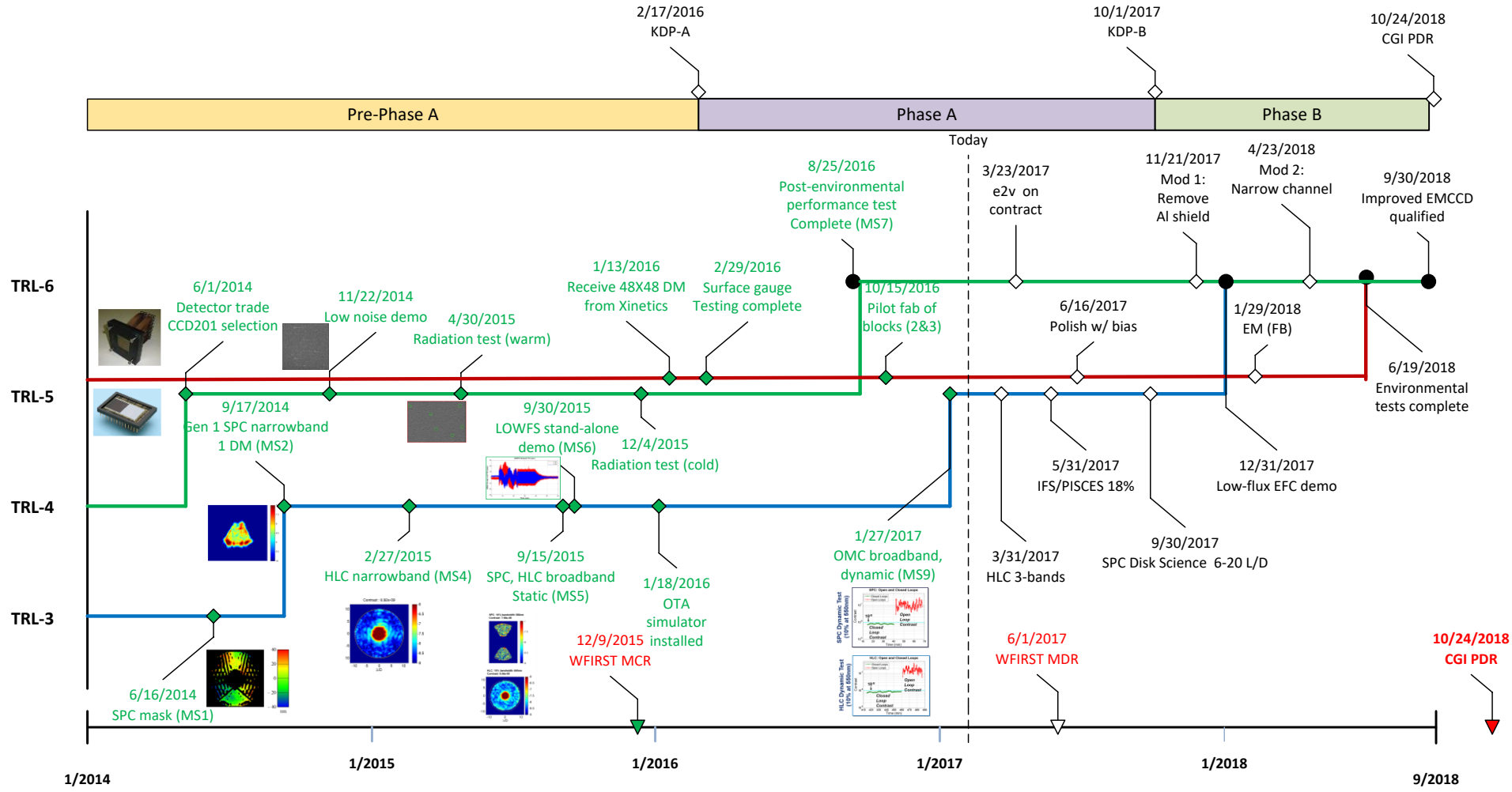
California Institute of Technology

Coronagraph Technology Maturation



Occulting Mask Coronagraph (OMC) system

Deformable Mirror (DM)

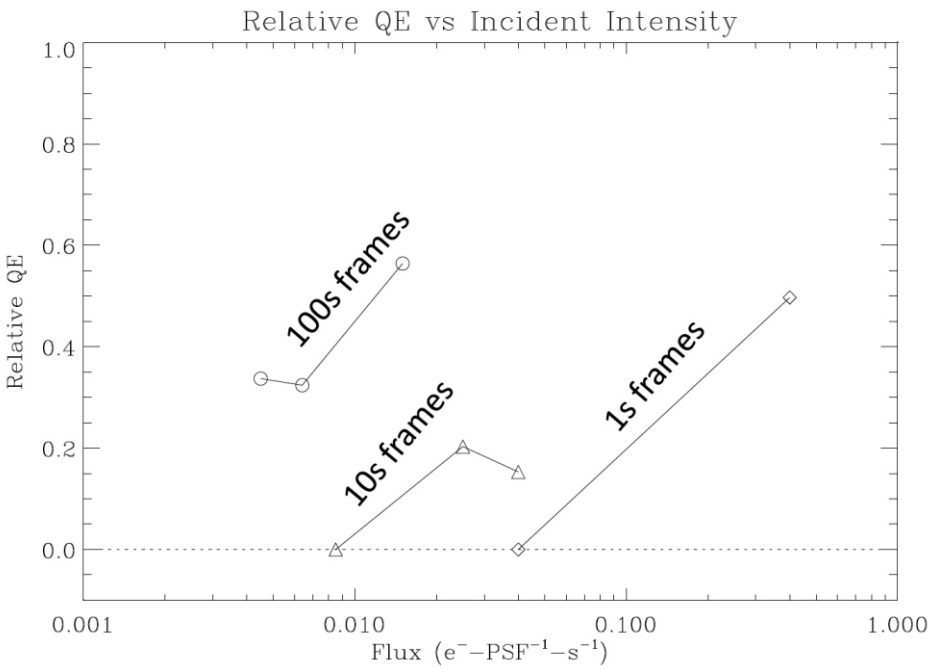
Low noise detector (EMCCD)

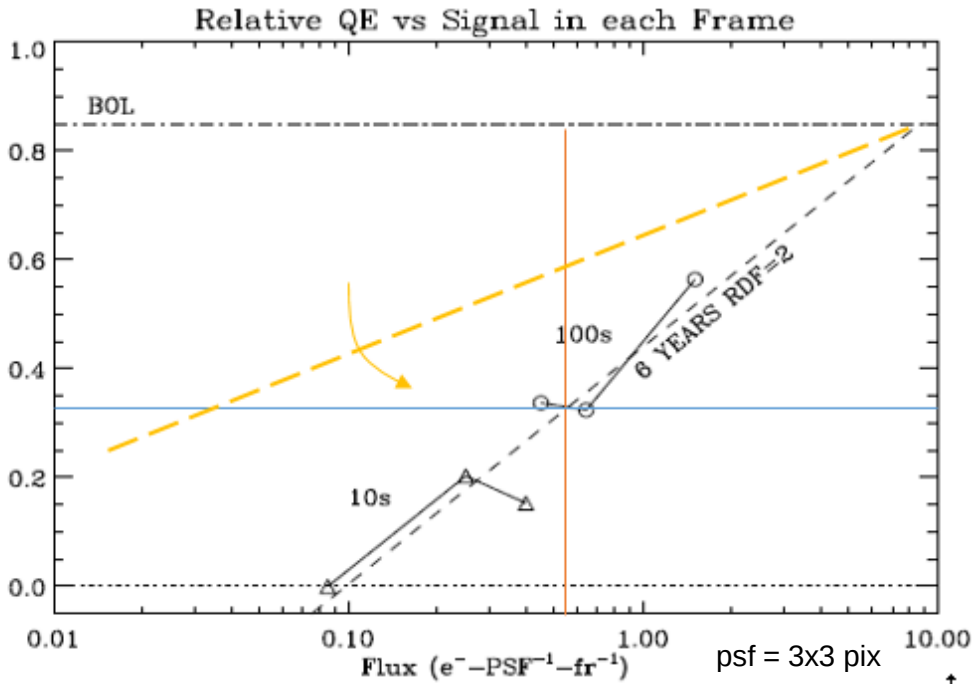
Based on Funding Scenario FY16/17 with over guide approved (1/2017)

Key Risks

- **Significant progress has been made in advancing coronagraph technology (retiring technology risks) since 2014.**
- **Future key risks are in both technology (critical environments such as low-flux, and observatory level implementation complexities):**
  - Science yield degradation due to lower post-processing gain
    - As result of EMCCD flux-dependent CTE at low flux
  - Performance degradation in LOW Flux/Convergent Rate Demo:
    - Due to DM actuator creep
  - Performance degradation due to CGI-Payload interface complexity
    - AFTA pupil change and pupil (mis)-alignment
  - Performance degradation in orbit due to deviation from “Test-as-you-fly” rule
    - As a result of unexpected OTA WFE in CGI channel (including polarization due to stress birefringence on M1 coatings – 250K operating temperature)
    - As a result of unexpected stray-light in CGI channel
    - As a result of unexpected jitter (both pointing and wavefront)

EMCCD Lower limit of performance

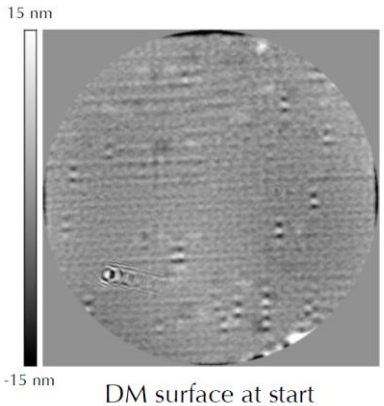




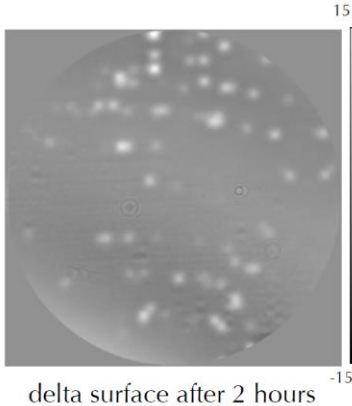
- As the signal level decreases, the fractional loss due to traps increases
- By increasing the exposure time, dark current (per frame) can fill traps
- Experiment is currently on-going (t_exp = 100 sec), but extrapolation above (black dotted line, right plot) shows a theoretical limit in e-/psf/fr with current COTS sensor design
- Risk: flux-dependent CTE (QE) effects on (1) post-processing gain; and (2) ability to extract planet spectra are not assessed, potentially degrade science yields.
- Possible mitigations: (1) on-board detector calibration; (2) improve radiation resistance (such as narrowing channel EMCCD, other detectors)

DM Actuator Drift

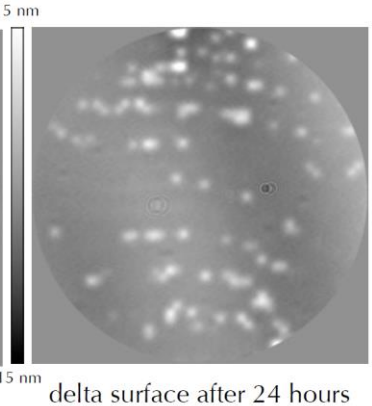
- **Observed DM actuator drift on testbeds (OMC, Vacuum Surface Gauge)**
- **Mostly the ~6% "outlier" actuators**
- **Cree**
- **Potential impacts: (1) low-flux (long integration time needed) performance degradation, and/or longer dark hole convergence**
- **Possible mitigations, example: (1) con-ops such as DM voltage change limits, chopping, etc., (2) use LOWFS to measure (partially) DM drifts**



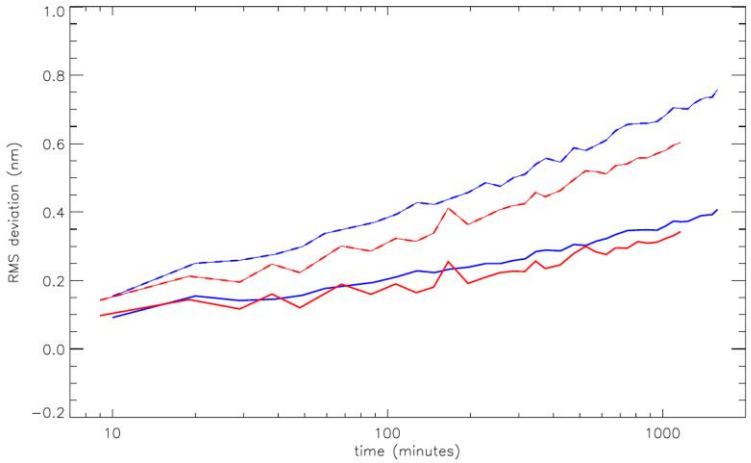
DM surface at start
(1.8 nm rms = λ/350 rms)



delta surface after 2 hours

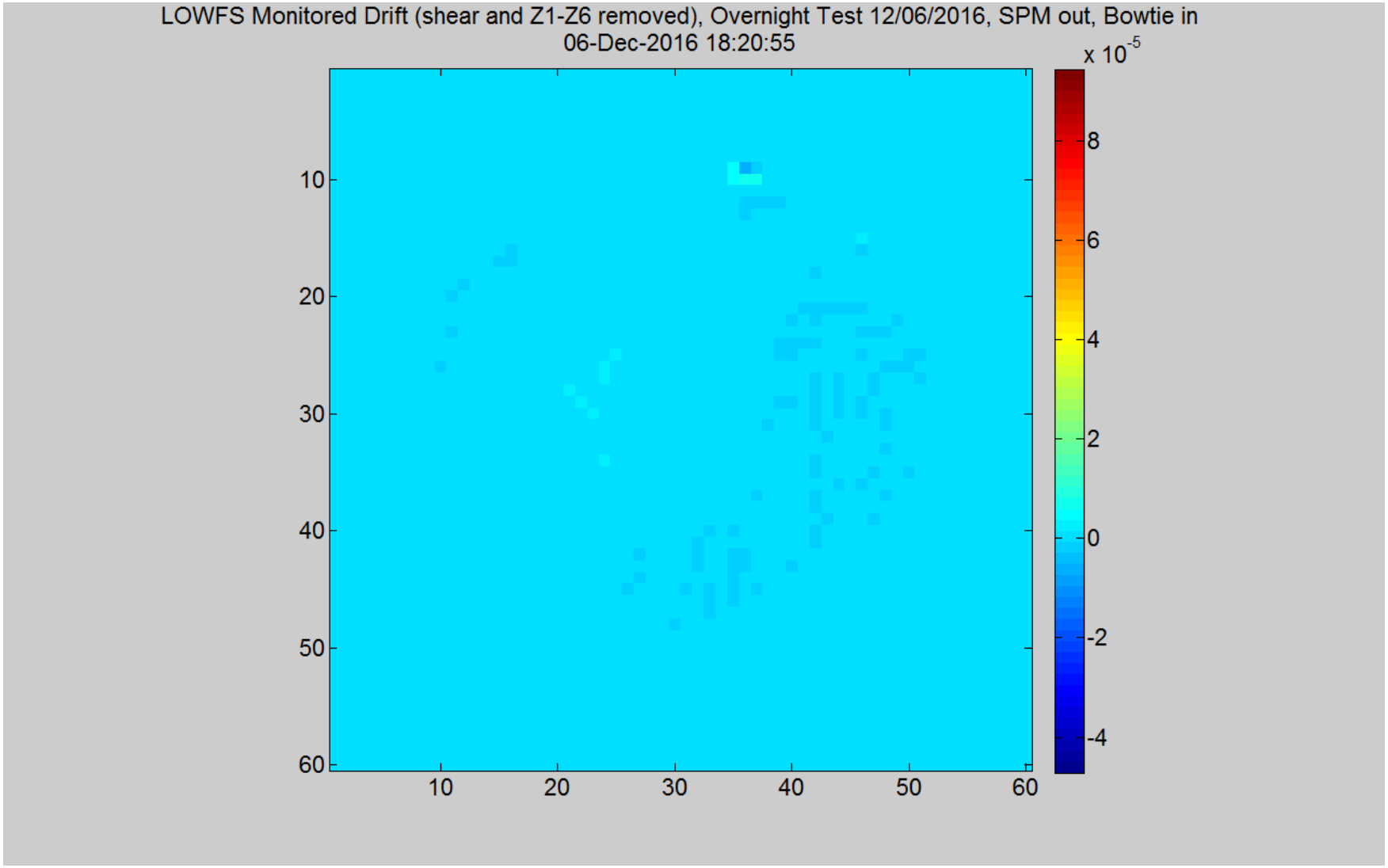


delta surface after 24 hours



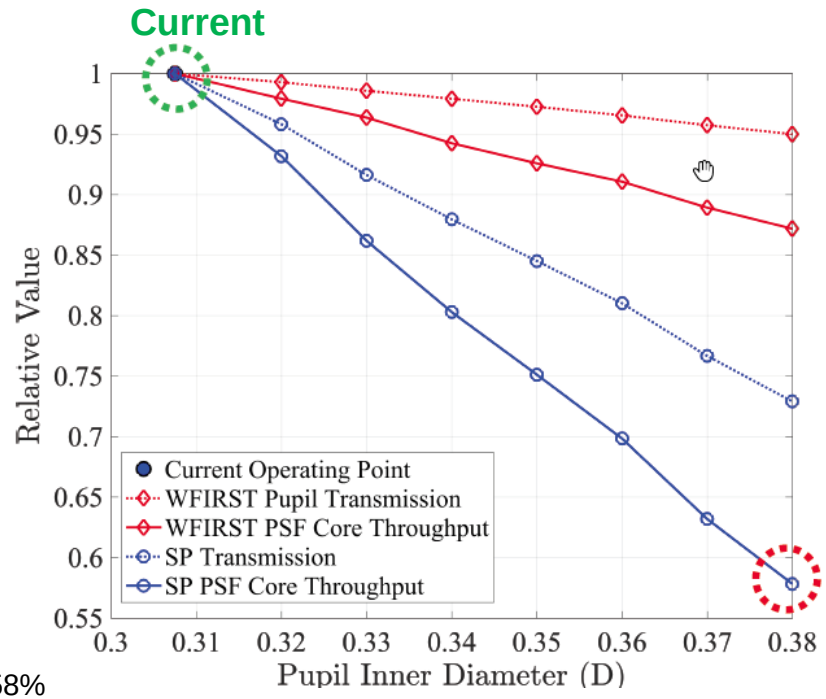
- *Evolution of RMS actuator deviations from flat over a period of ~20 hours.*
- *Blue: no preset voltage, Red: 100 volt precondition voltage, both prior to 30-volt-flat setting.*
- *Dashed curves = RMS including all actuators.*
- *Solid curves: RMS after rejecting "3-sigma outlier" actuators.*
- *Outliers represent 6.7% and 5.5% of the non-conditioned and 100-volt-conditioned actuator populations, respectively.*

LOWFS measurement in the Testbed

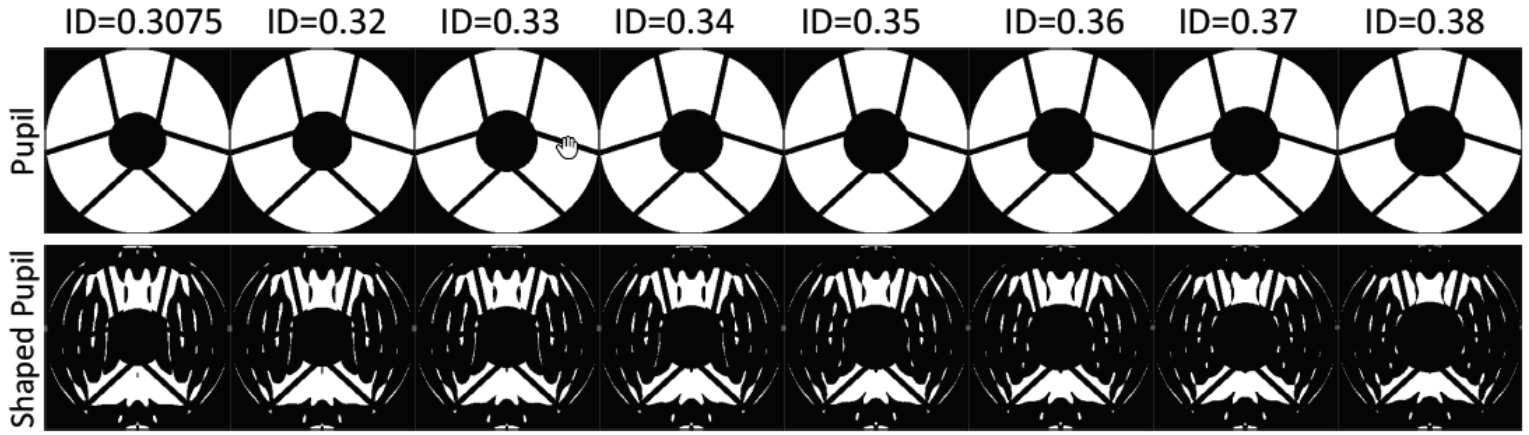


Telescope Pupil Change Impact

- **AFTA pupil has been a challenge to coronagraph performance (2103 ACWG)**
- **We have learned to come up with coronagraph designs to accommodate the pupil**
- **There is a possibility that the pupil obscuration gets worse in order to suppress stray light for WFI**
- **This can have a significant impact on the science yield.**



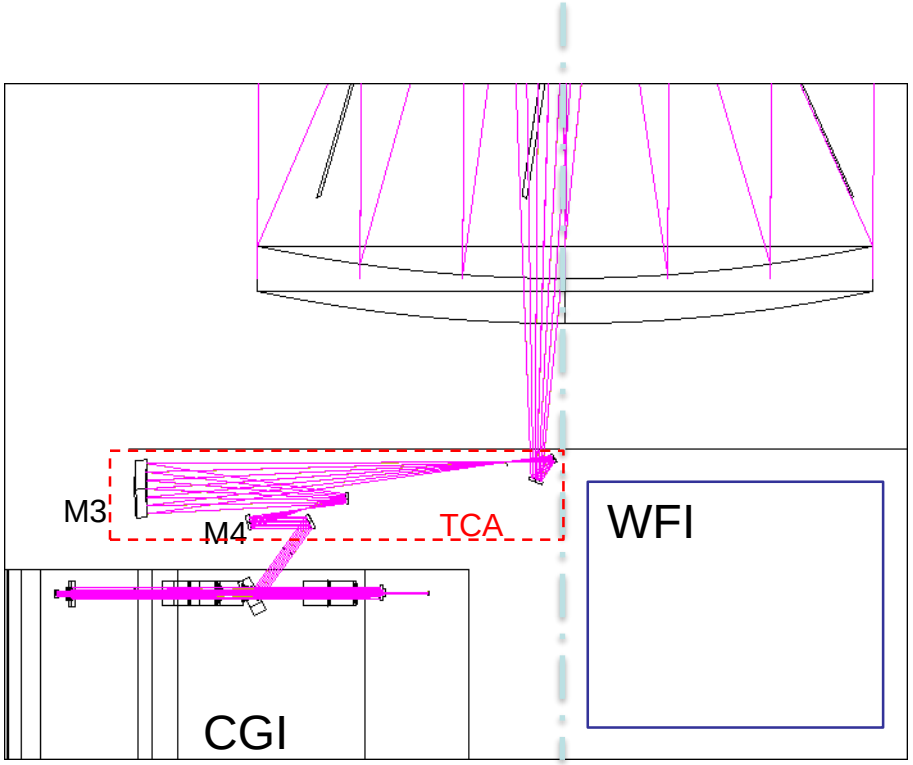
Preliminary results show that Relative to Cycle 6 WFIRST pupil, an ID=0.38D secondary obstruction would reduce SPC throughput to 58% of current level (PSF core throughput of ~2%).



Courtesy of A.J. Riggs

Pupil Alignment

- Pupil alignment error budget and alignment approach are being developed
- There is a possibility that we may “enlarge” pupil obscuration (by adding a new pupil at the CGI entrance) to accommodate fabrication and alignment errors
- Performance degradation due to the use of “larger” pupil obscuration
- Mitigation: active trades are on-going



Deviation from "Test-as-you-fly" rule

- **Coronagraph performance testing ("dark hole" digging") at the Payload (CGI + Telescope) and Observatory (Payload + S/C) is not possible before launch due to a number of reasons, such as M1 gravity sag ~ μm**
- **Potential in-orbit errors:**
  - Unexpected jitter (both pointing and wavefront)
    - Possible mitigation: additional sensors such as accels for more robust sensing/control system
  - M2 to be re-aligned for best WFE in WFI channel, resulting larger than expected CGI channel pupil shear/magnification
    - Possible mitigations: add tip/tilt adjustment to TCA fold mirror, additional mask mechanism translation stroke
  - Polarization error due to stress birefringence on telescope coatings at different operating temperature
    - Make coronagraph more robust to polarization error?
  - Additional WFE not captured with the "OTA simulator" that requires DM stroke to compensate for
  - "Star/planet simulator" not representative to the astronomical scenes

Summary

- **We have made significant progress advancing coronagraph technology for obscured pupil telescopes such as AFTA**
  - Achieved performance in the lab ~1.6E-9 at 10% bandwidth
    - Static environment
    - High photon flux
- **Additional challenges, especially in low-flux (i.e., longer duration) environment**
  - Drifts from the system, such as deformable mirrors
  - Detector flux-dependent characteristics at low flux levels as a result of radiation degradation (EMCCD)
- **Payload and Observatory level coronagraph performance testing (i.e., "dark hole") is not readily possible before launch.**
- **Therefore, understanding and demonstration of Payload and Observatory level coronagraph performance in-orbit is essential, for future flag-ship observatories**

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