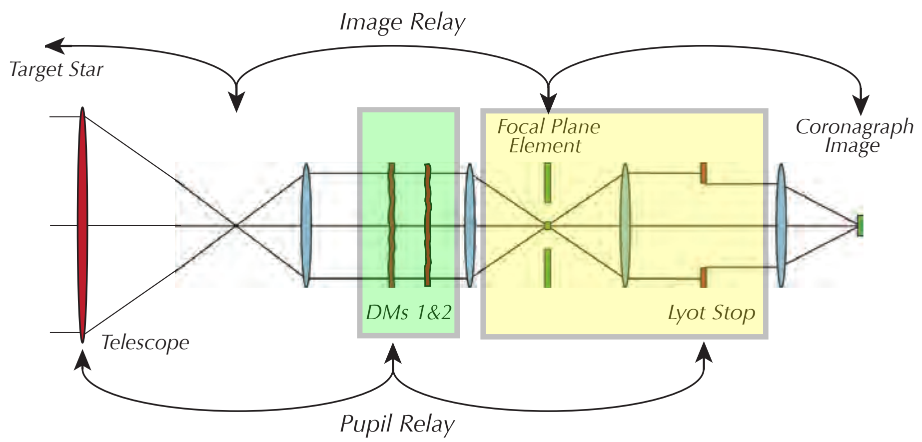
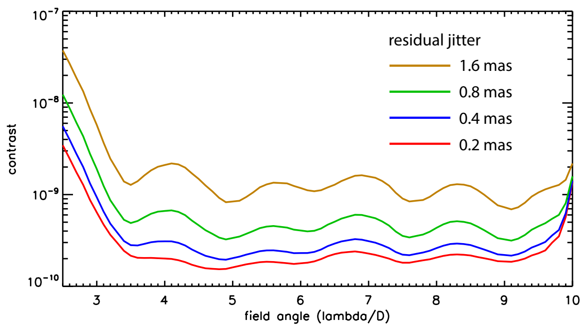
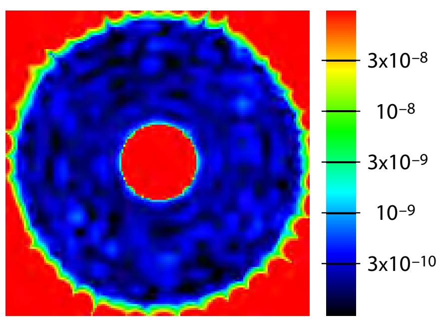
Managing the Wavefront for High Contrast Imaging from Space

WFIRST-AFTA coronagraph development for high-contrast direct imaging of mature exoplanet systems in reflected starlight







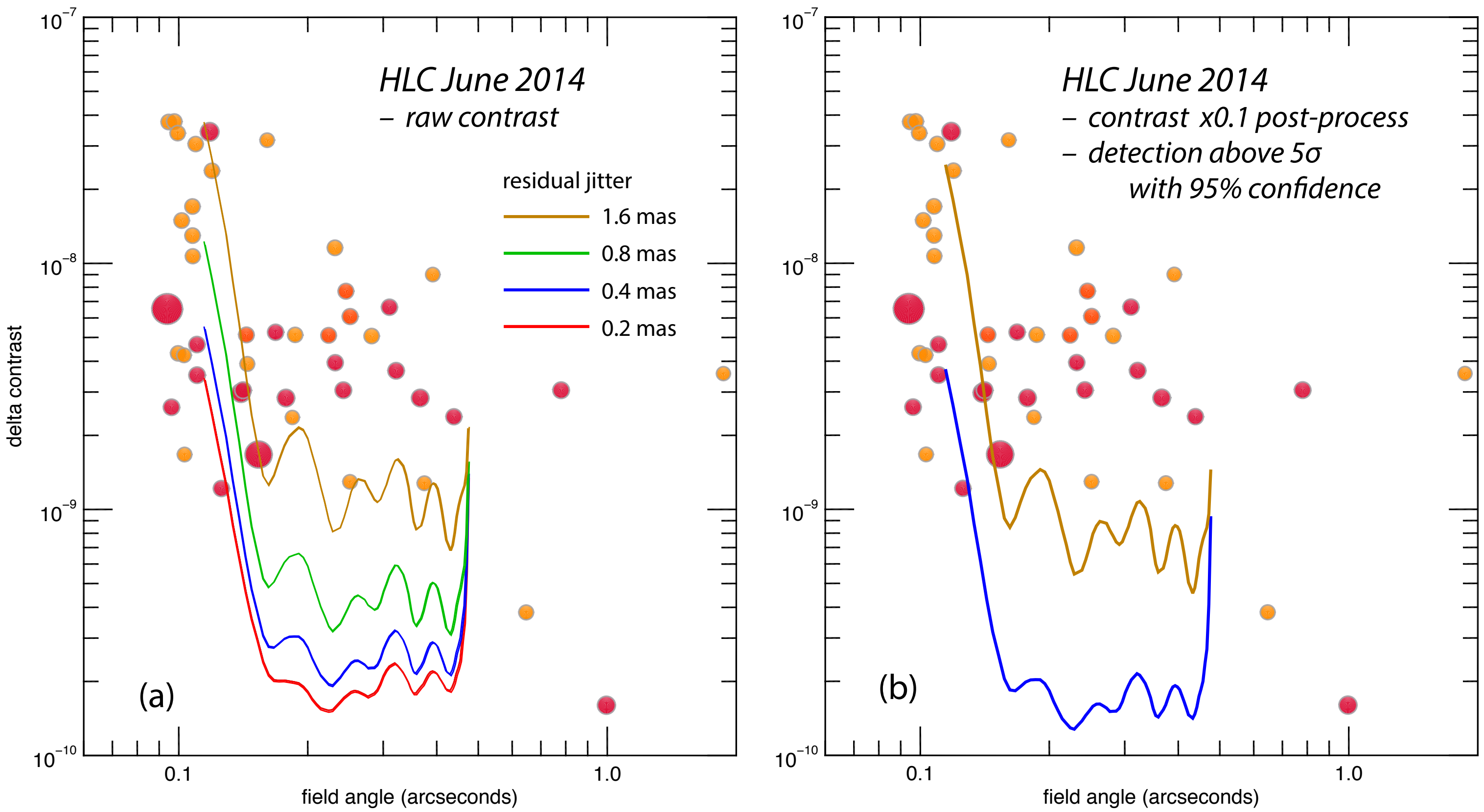
John Trauger and many others in the AFTA mission development team

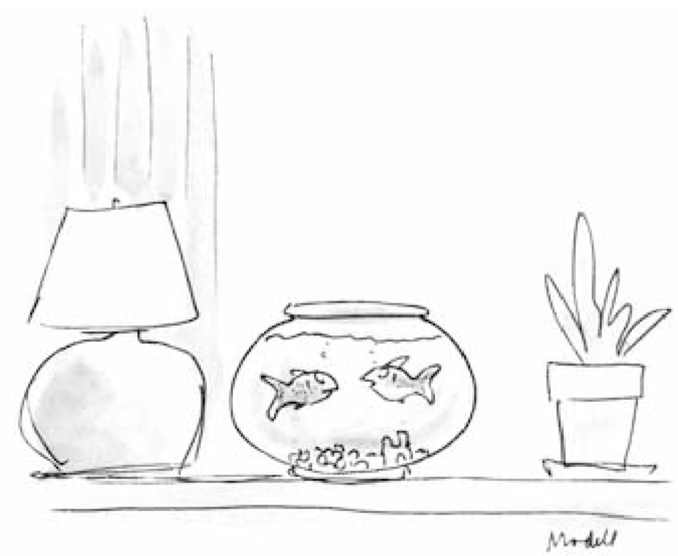
Jet Propulsion Laboratory / Caltech

Pathways towards Habitable Planets II – Bern – July 2015

Managing the Wavefront for High Contrast Imaging from Space

- The WFIRST-AFTA mission will ***enable, for the first time, the science*** of direct imaging and spectroscopy of cool mature planets from space, while ***responding to new engineering challenges***
- High contrast imaging at the 1e-9 level requires a space platform for ***unprecedented telescope wavefront stability***
- High contrast imaging requires ***complex (amplitude and phase) wavefront correction***
- Refinements to the ***coronagraph designs*** continue, as ongoing engineering analyses provide improved knowledge of the AFTA telescope performance.





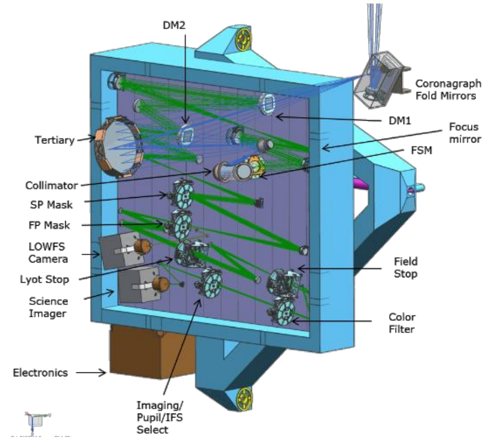
"I'll tell you something else I think. I think there are other bowls somewhere out there with intelligent life just like ours."

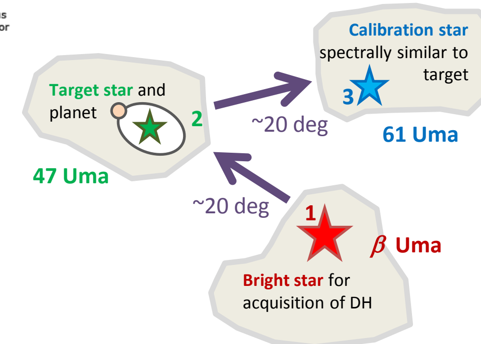
Frank Modell (1987)

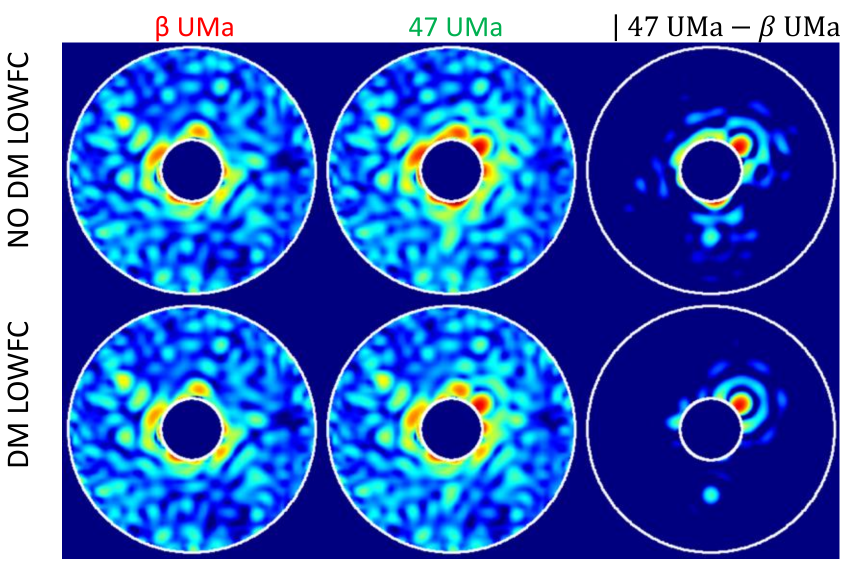
Performance Expectations for the WFIRST AFTA Coronagraph

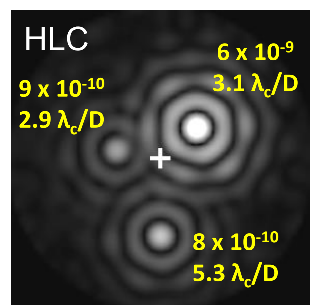
Bijan Nemati
Jet Propulsion Laboratory, California Institute of Technology; Pasadena, CA

WFIRST AFTA Coronagraph

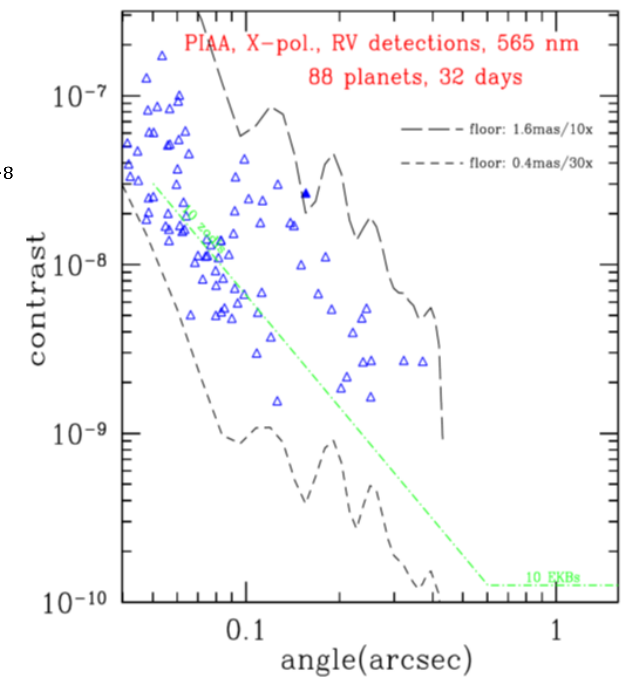








2.9 λ_c/D = 0.136”



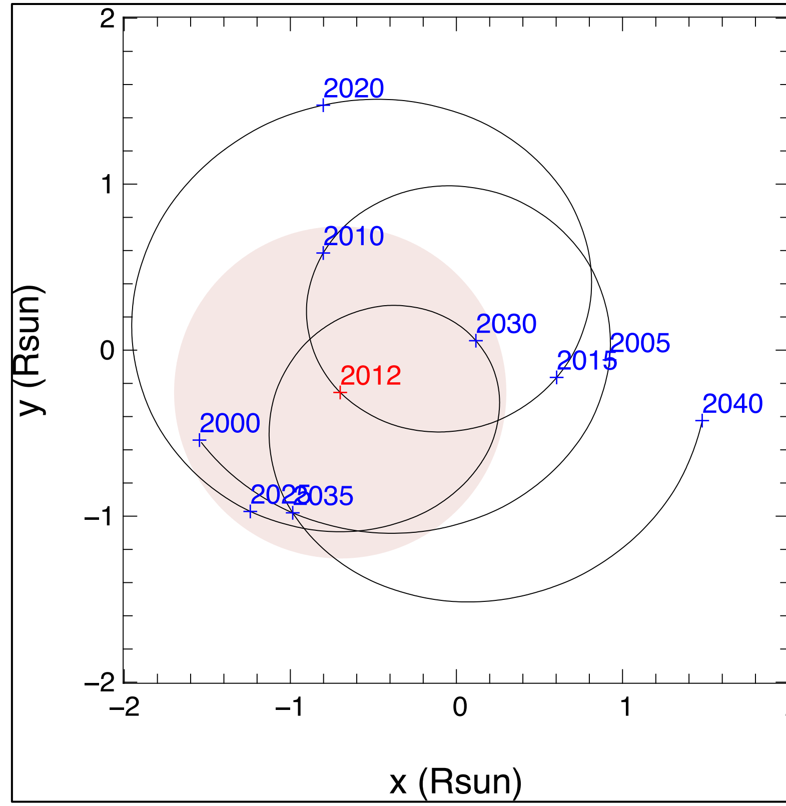
sciencesconf.org:pathways2015:66886

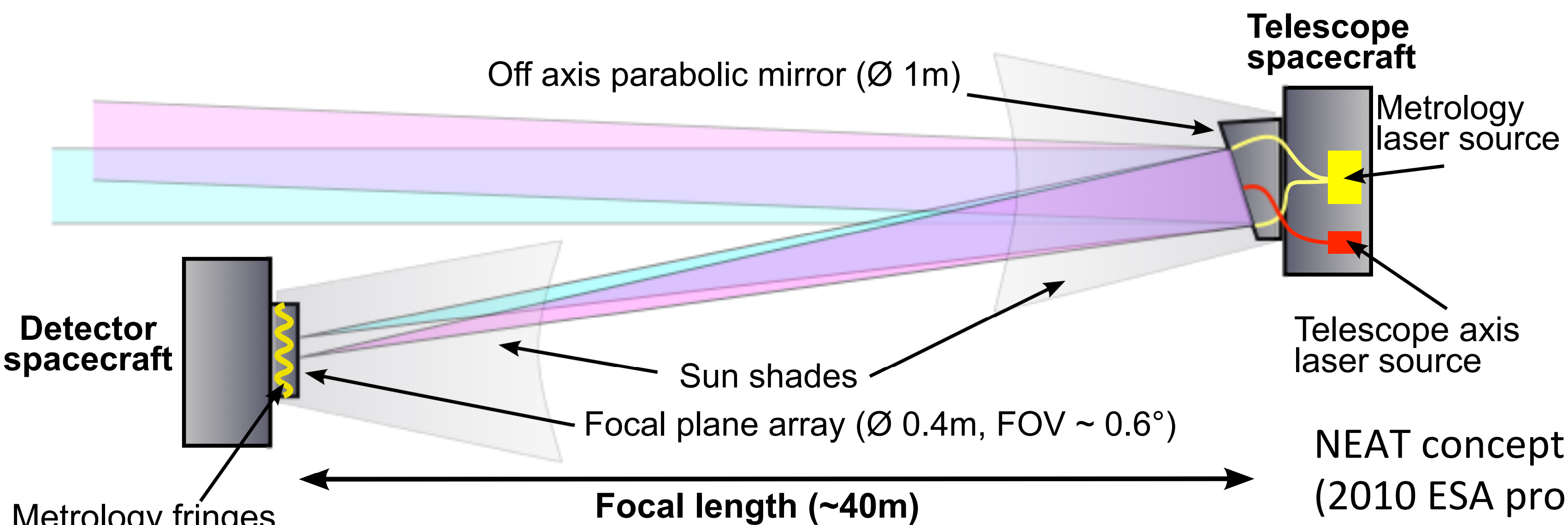
The Detector Interferometric Calibration Experiment: a demonstration of sub-µas astrometry for nearby exo-Earth detection

Antoine Crouzier, Fabien Malbet, François Hénault, DICE team
Poster #66469

$$A = 3\mu as \frac{M\text{planet}}{M\text{earth}} \times \left(\frac{M\text{star}}{M\text{sun}}\right)^{-1} \times \frac{R(\text{AU})}{1\text{AU}} \times \left(\frac{D(\text{pc})}{1\text{pc}}\right)^{-1}$$

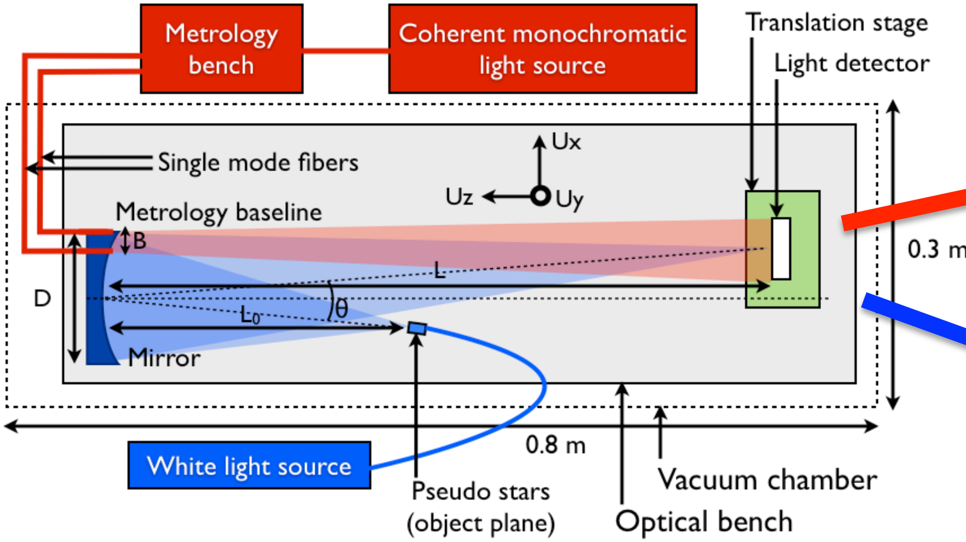
Astrometric signal of an Earth in the habitable zone of a Sun, @10 pc: 0.3µas.

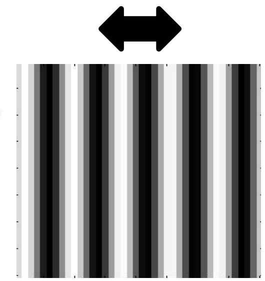


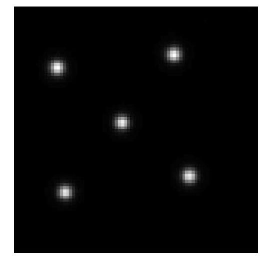


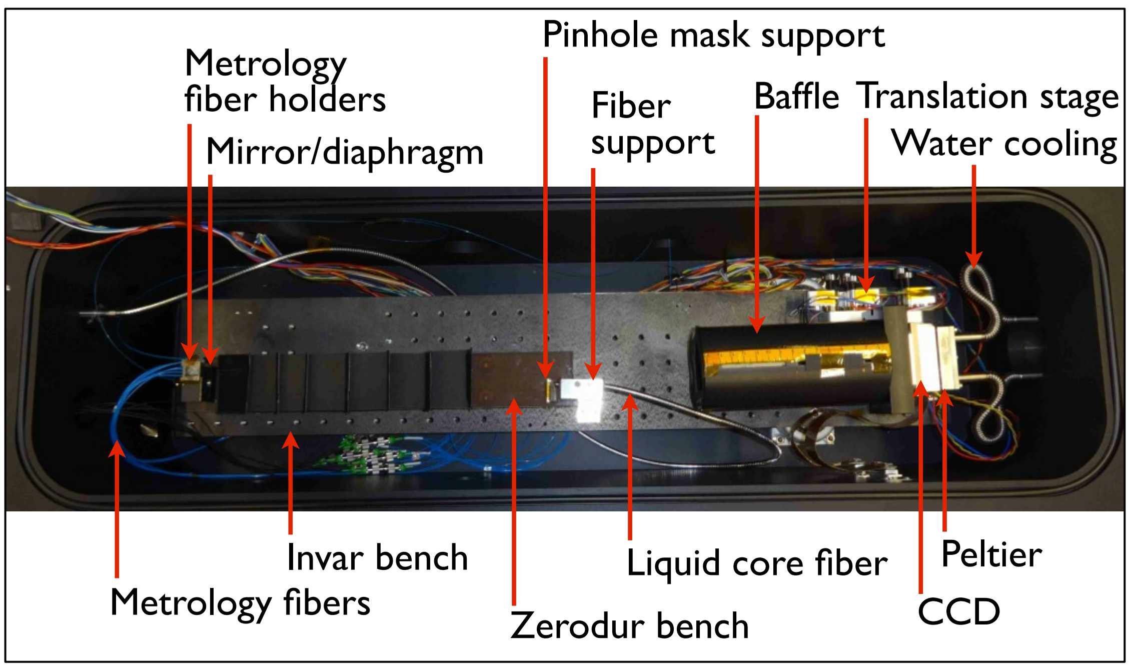
NEAT concept
(2010 ESA proposal)

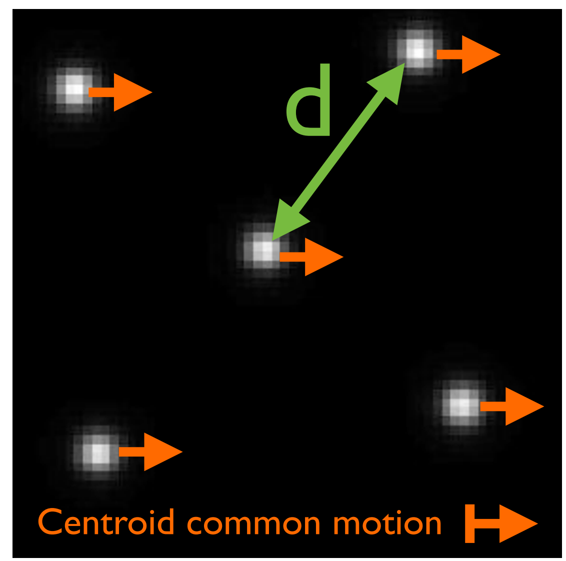
DICE (Detector Interferometric Calibration Experiment)











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Speckle Area Nulling (SAN) for dark-hole adaptive optics control

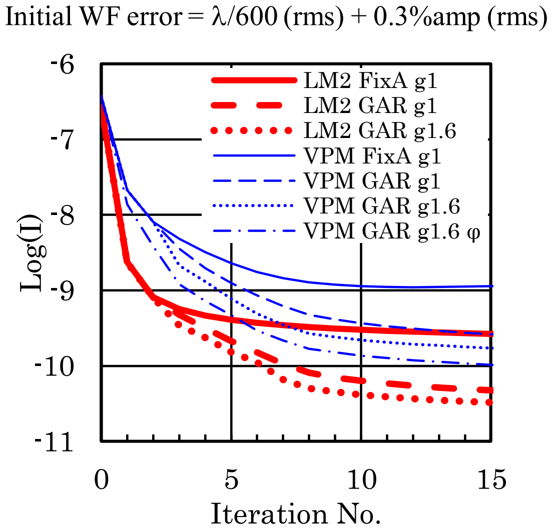
*M.Oya(Nihon Univ. /NAOJ) , J.Nishikawa, M.Horie, K.Sato, N.Murakami, T.Kotani, S.Kumagai, M.Tamura, Y.Tanaka, T.Kurokawa

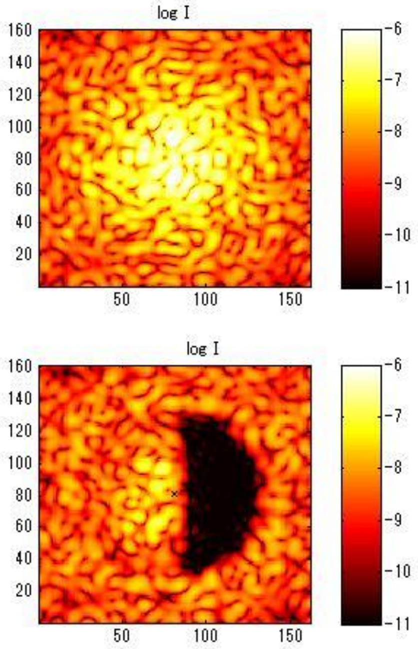
The speckle Area Nulling(SAN) Algorithm

The SAN is one of the dark-hole algorithm, and it is an extension of Speckle Nulling.

- without Optical Model
- Quick Reduction at Wide Area

Simulation result





The SAN worked by Lyot mask and Vortex mask coronagraph
The contrast was reduced by 2.5-3 orders of magnitude.

Experimental setup

- Deformable Mirror : 12x12 BMC
- Coronagraph : Achromatic Vector Vortex Coronagraph

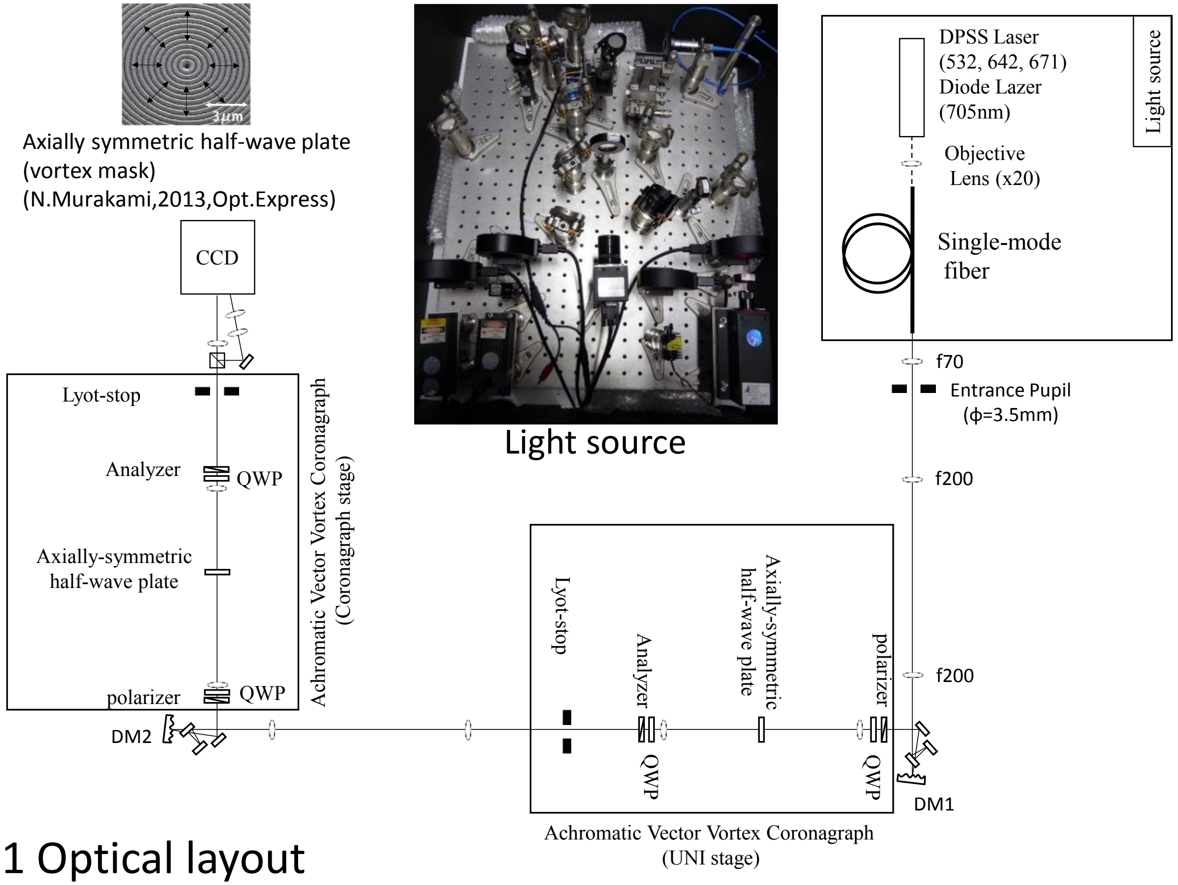


Fig.1 Optical layout
In this experiment was not used.

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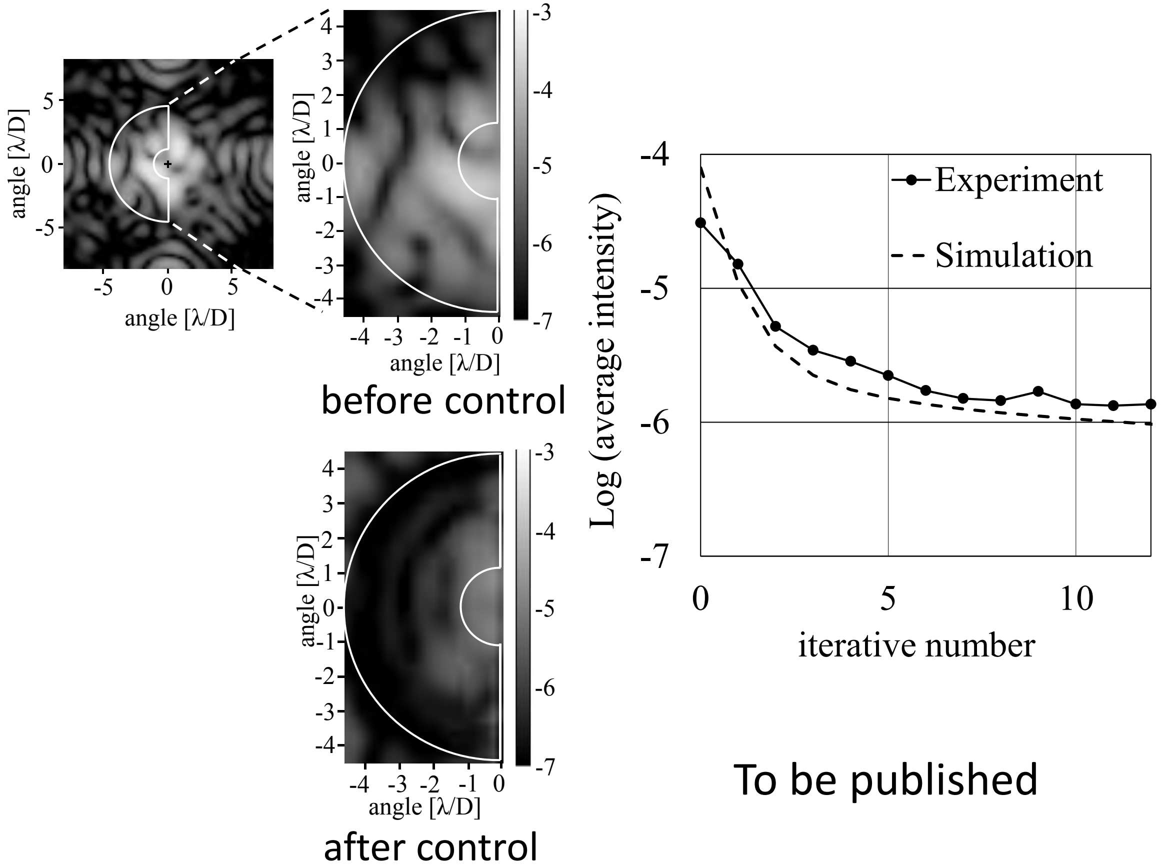
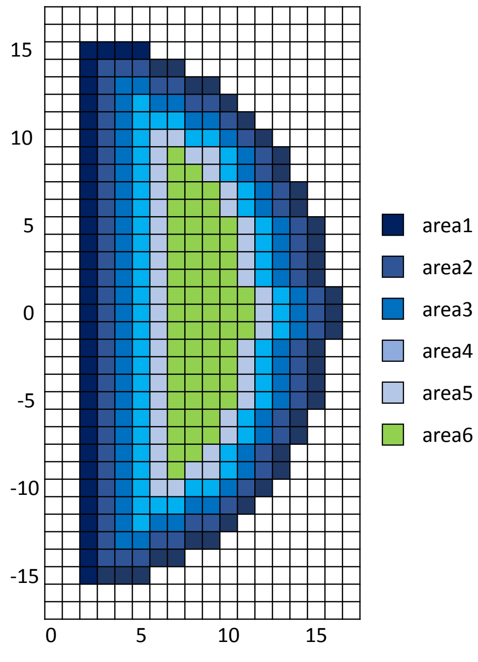
Vortex mask Experimental Result @671nm

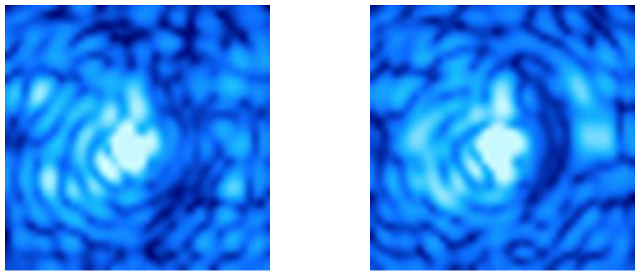


To be published

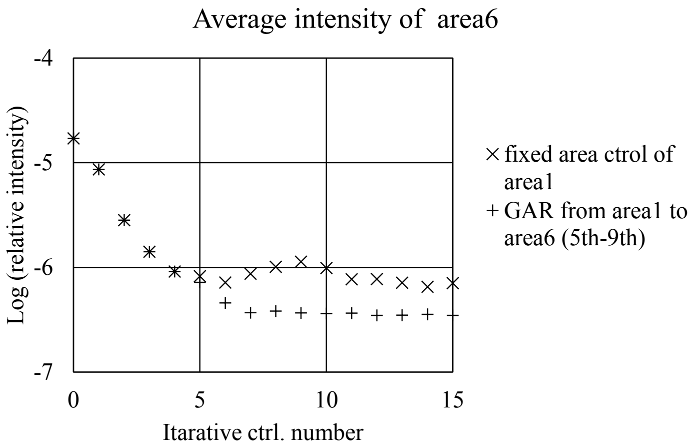
GAR(Gradual Area Reduction) Result



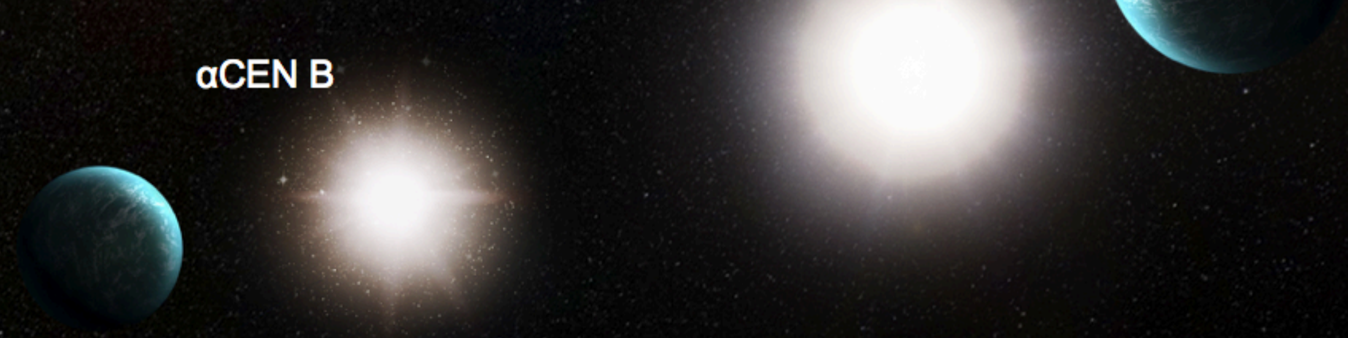
control area(0.3[λ/D/pixel])



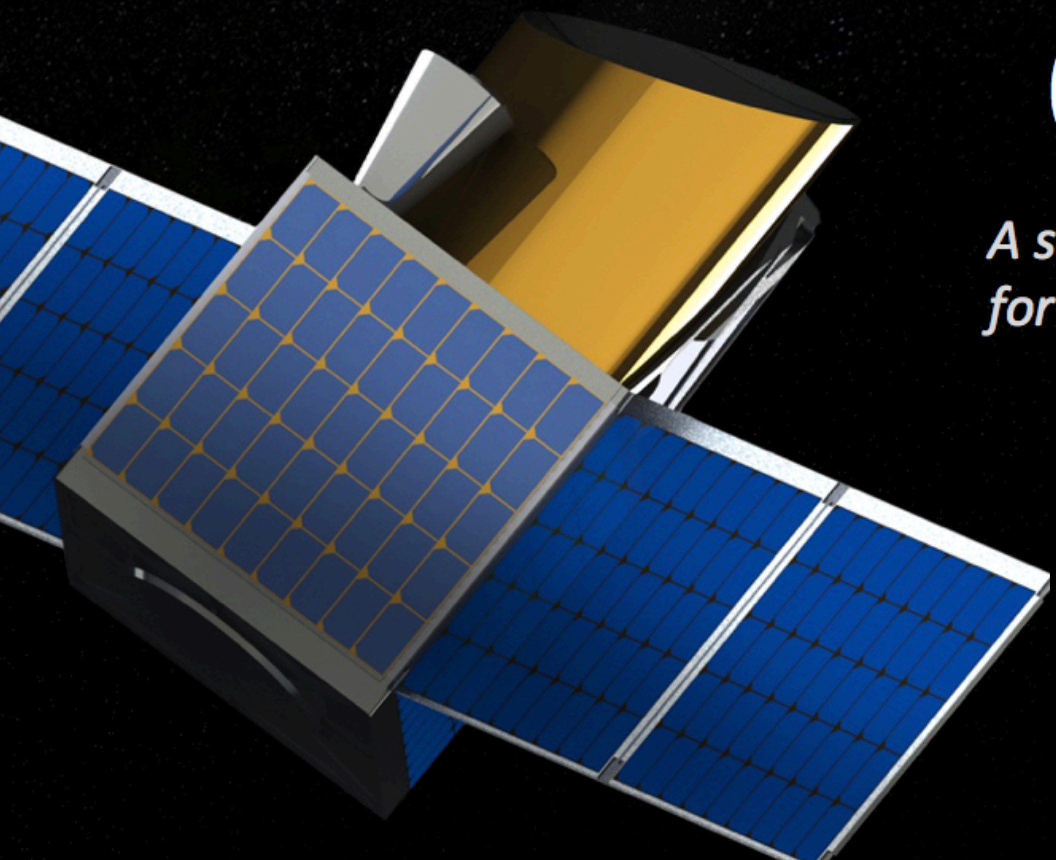
fixed area control GAR control (5^{th}-9^{th})



The SAN was successfully wide area of speckle and quick reduction in experiment.
The intensity of areal speckles were reduced by 4.4E-2 (@0.97-4.4λ/D).
GAR was successfully, and the contrast was improved 0.3 orders of magnitude(@2.1-3.3λ/D).



A comprehensive direct imaging exoplanet technologies demonstrator in space



Centaur

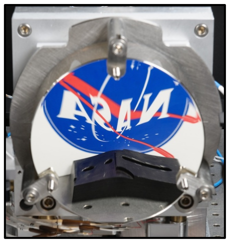
A scientific and technology pathfinder for direct imaging exoplanet missions

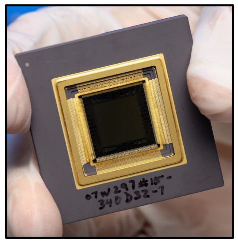
PI: Eduardo Bendek, DPI: Ruslan Belikov

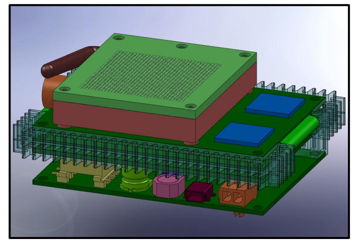
Mission Time Life and Orbit	APRA or MoO, 1-Year. Low-Earth, 800km Sun Synchronous
Spacecraft Bus	Millennium SS Bus (30x30x30 cm)
Telescope	Unobstructed 15cm, Full Silicon Carbide
Coronagraph architecture	Baseline: PIAA Embedded on Secondary and tertiary telescope mirror.
Coronagraph performance	1×10^{-7} raw 5×10^{-9} @ 1.0” (With ODI) 1×10^{-9} @ 1.2”

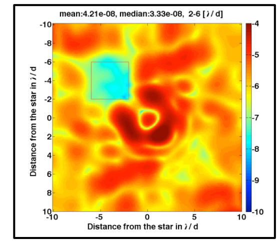
Centaur is a scientific and technology pathfinder for larger exoplanet missions with rapid and low-cost development

Technology demonstrator for

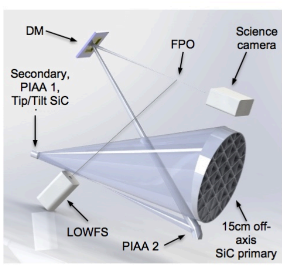

PIAA

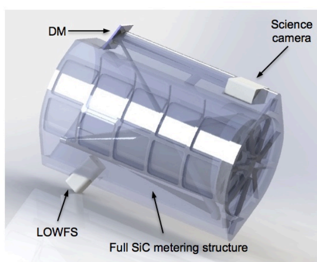

DM

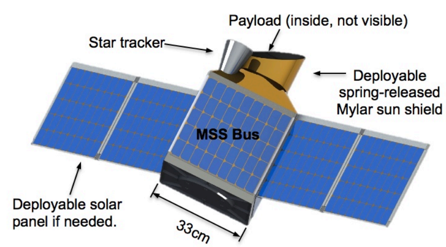

DM Controller

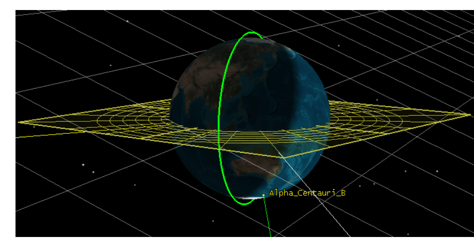

MSWC

EM CCDs

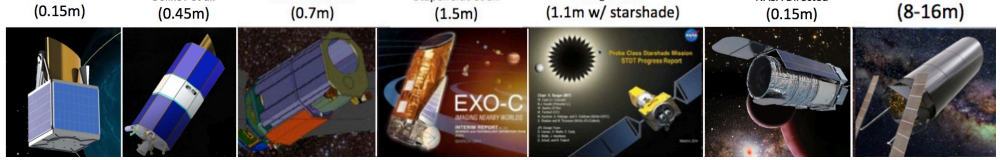








Centaur	ACESat	EXCEDE	Exo-C	Exo-S	AFTA-C/WFIRST	ATLAST
Bendek et al.	Belikov et al.	Schneider et al.	Stapelfeldt et al.	Seager et al.	NASA Directed	
(0.15m)	(0.45m)	(0.7m)	(1.5m)	(1.1m w/ starshade)	(0.15m)	(8-16m)

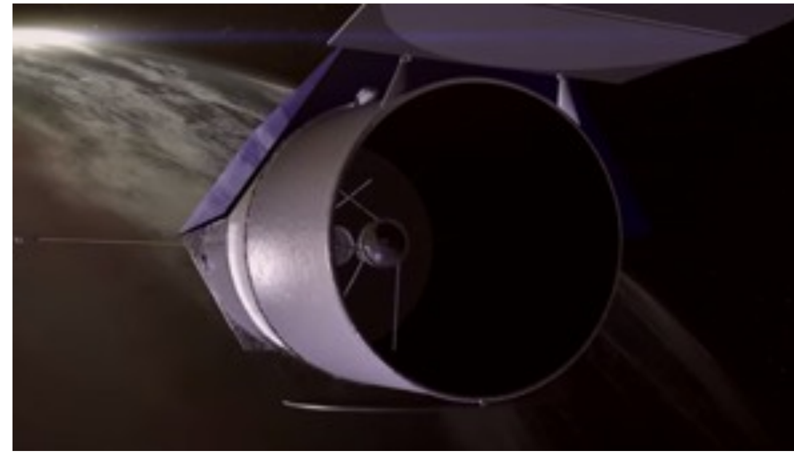


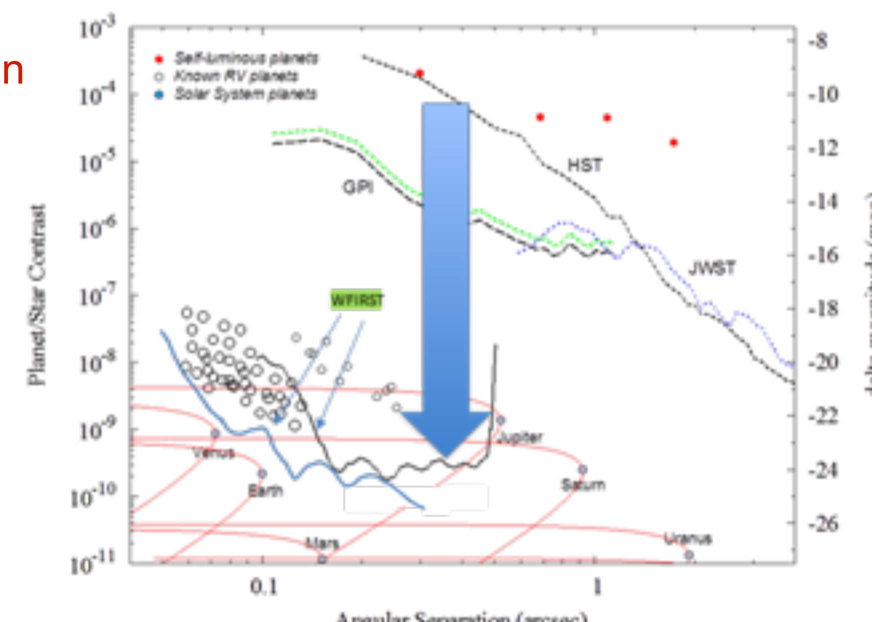
WFIRST Coronagraph Instrument Summary

Planned to be the first active, high contrast coronagraph in space

- 2nd instrument on WFIRST-AFTA mission, planned 2016 Phase A start, 2024 launch option
- 2.4 meter obscured pupil telescope
- Occulting Mask Coronagraph (OMC) architecture:
  - High contrast imaging using precision wavefront sensing and control
  - Shaped pupil and hybrid Lyot coronagraph modes
  - PIACMC is a backup
  - 2 deformable mirrors (Xinetics)
  - Exoplanet direct imaging technology demo
  - Precursor science for future exo-Earth mission
- JPL led team with participation from many US institutions:

  Princeton University, University of Arizona,
  NASA Goddard, NASA Ames, STScI,
  Caltech/IPAC, Northrop-Grumman Xinetics





WFIRST Coronagraph Technology Demonstration Sequence

✔ Coronagraph Designs Work with AFTA Telescope "as is" (Computer Model)

↓

✔ Demonstrate Fabrication of Key Starlight Suppression Components

↓

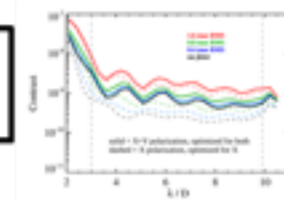
✔ Demonstrate Starlight Suppression in Narrowband Light

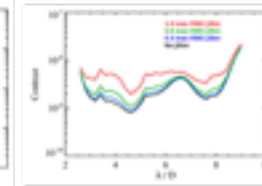
↓

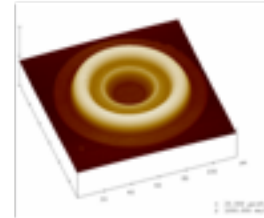
in progress — Demonstrate Starlight Suppression in Broadband Light

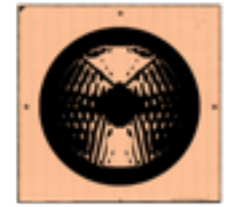
↓

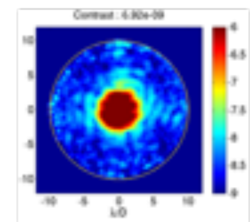
Demonstrate Starlight Suppression in Broadband Light, with Simulated Jitter and Drift from "as-is" Telescope

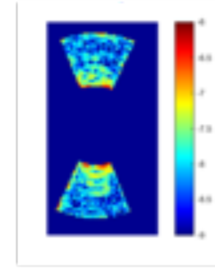












- **9 key milestones set by NASA for 2014-2016.**
- **Progress reviewed by independent Technical Analysis Committee**
- **Successfully met first 4 milestones; Technology development program on track**