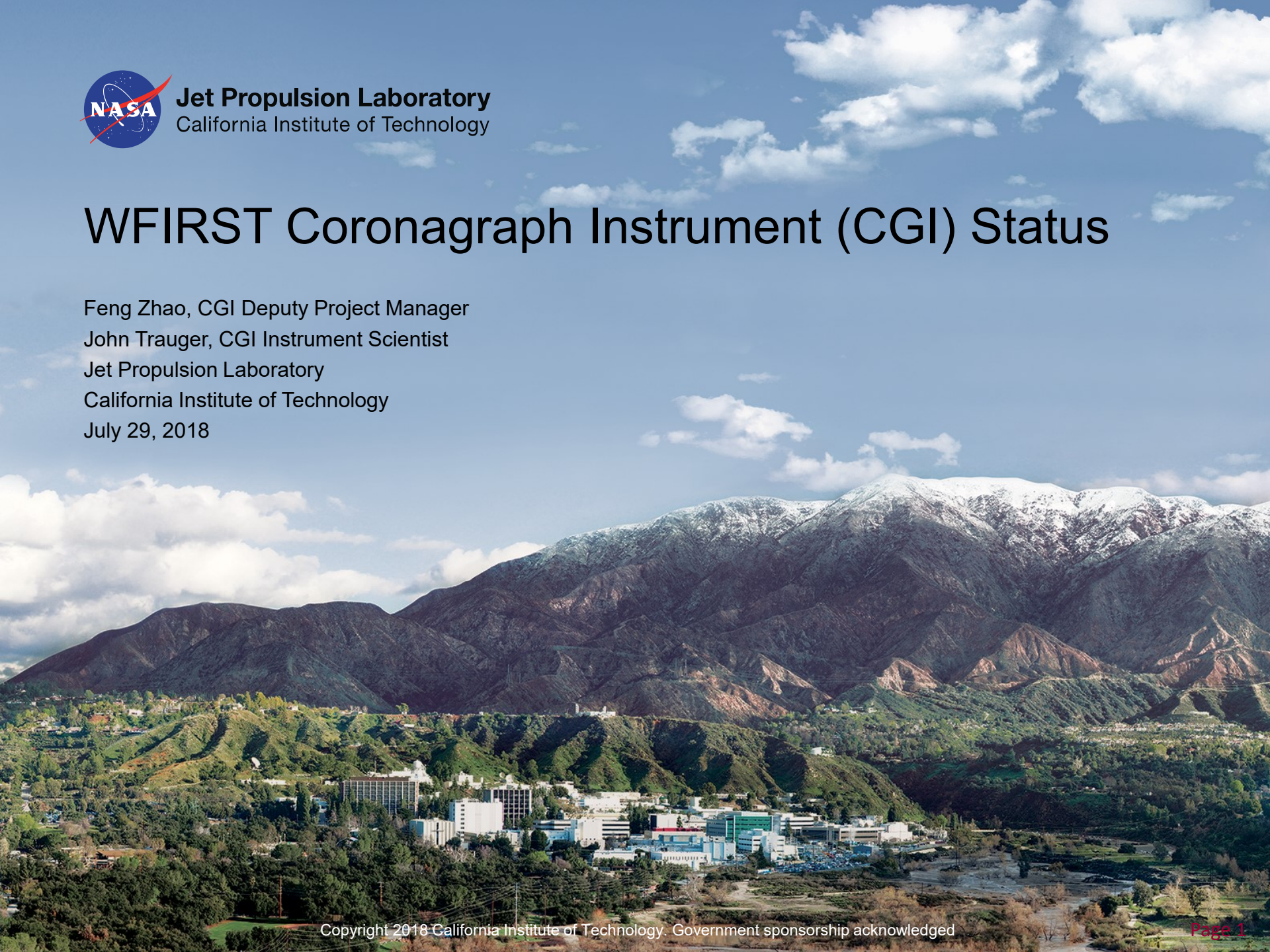

Jet Propulsion Laboratory
California Institute of Technology

WFIRST Coronagraph Instrument (CGI) Status

Feng Zhao, CGI Deputy Project Manager
John Trauger, CGI Instrument Scientist
Jet Propulsion Laboratory
California Institute of Technology
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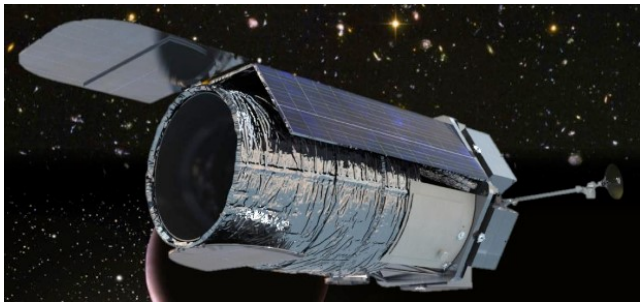
Outline

- WFIRST Coronagraph Instrument (CGI) re-cap
- CGI current capabilities
- CGI Participating Scientists Programs (PSP)
- Summary

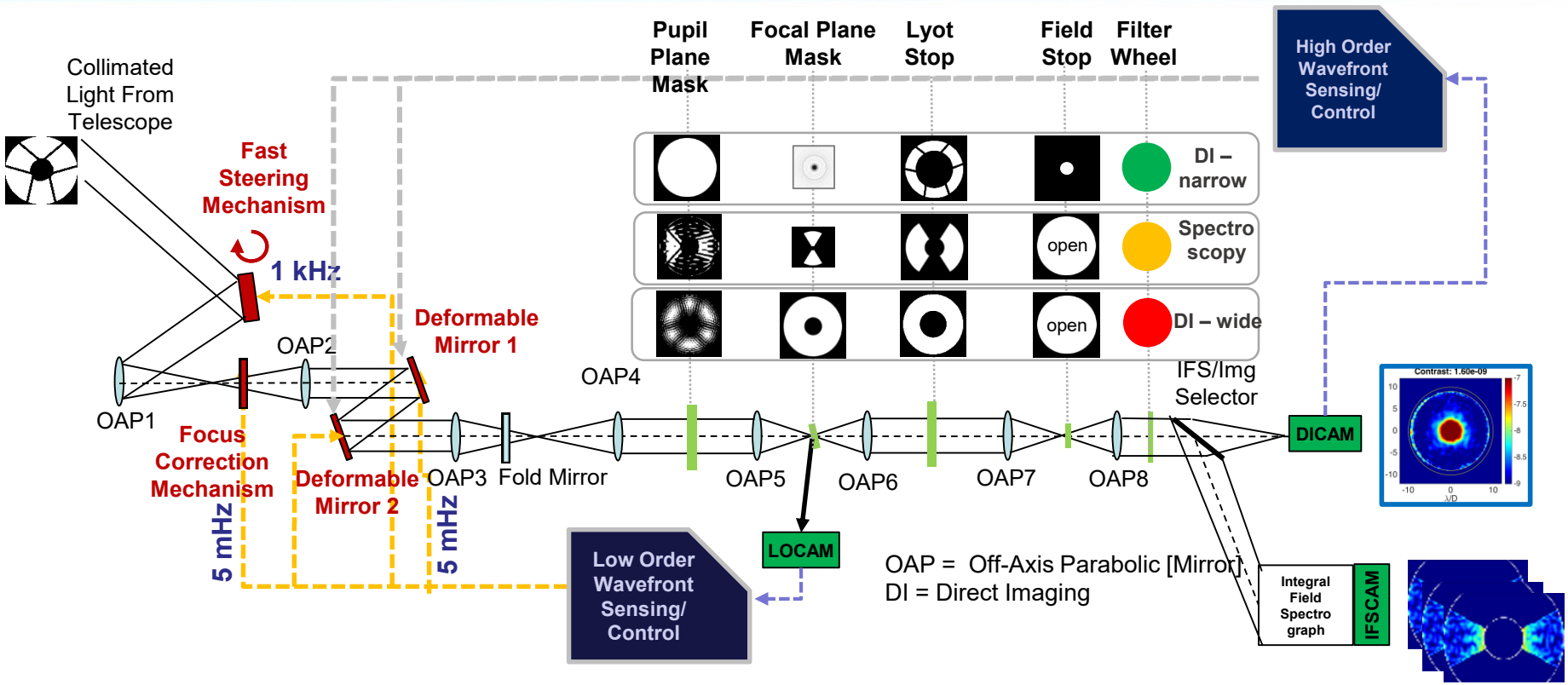
WFIRST Coronagraph Instrument (CGI)

- **Coronagraph (CGI) is the 2nd instrument on WFIRST,**
  - Exo-planet direct imaging technology demonstration
  - Participating Scientists Programs (PSP)
- **Coronagraph instrument is managed by JPL**
  - Instrument Project Manager: Peg Frerking
  - Deputy Instrument Project Manager: Feng Zhao



- **Other coronagraph partner institutions:**
  - NASA centers:
    - GSFC (responsible for integral field spectrograph)
  - Industry:
    - Northrup Grumman Xinetics (deformable mirror)
    - Boston Micromachines Corp (deformable mirror)
    - e2v (Electron Multiplying CCD – EMCCD)
  - Science Investigations Teams (SIT):
    - SIT #1 PI: Bruce Macintosh, Stanford University
    - SIT #2 PI: Maggie Turnbull, SETI Institute
  - Coronagraph Adjutant Scientist (CAS):
    - Jeremy Kasdin, Princeton University
  - Science Center:
    - IPAC/Caltech, STScI
  - Potential International Partners:
    - Germany -- Max Planck Institute of Astronomy (mask filter wheels)
    - UK – e2v (EMCCD)
    - Japan – JAXA (polarization module)
    - France – LAM/CNES (Super-polished coronagraph optics)

CGI Functional Overview



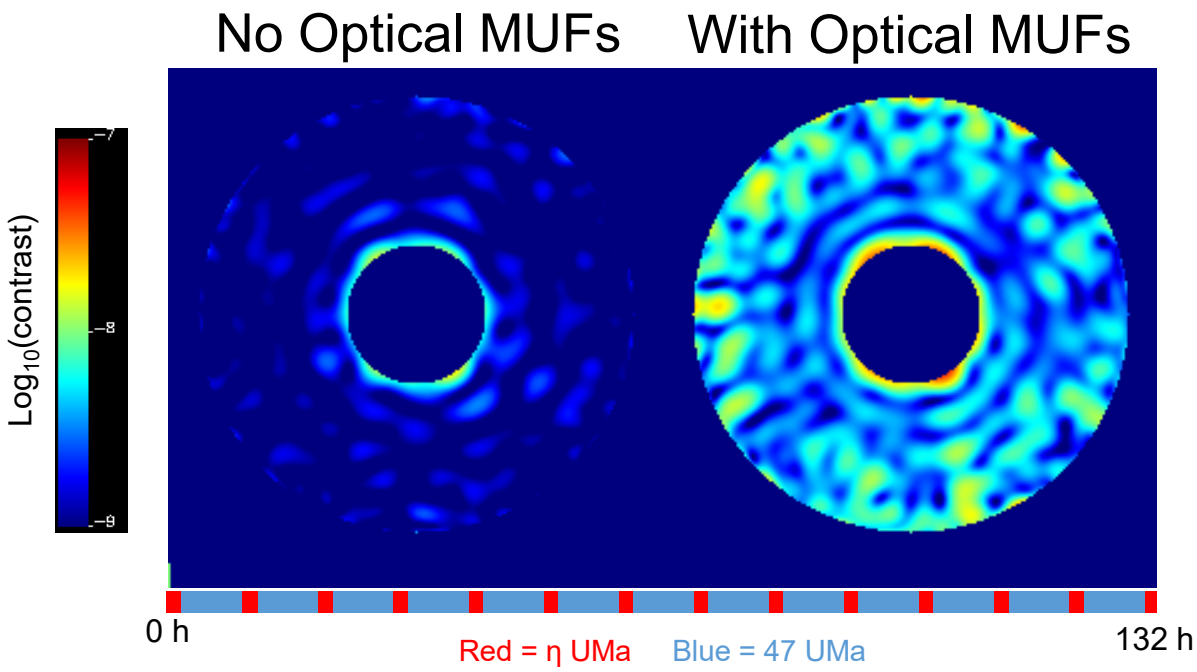
- **Active components**
  - Fast Steering Mirror (FSM) for line of sight control
  - Focus Correction Mechanism (FocM) for focus control
  - Deformable mirrors (DM1, DM2) for wavefront control
- **Control loops**
  - High order wavefront sensing and control (HOWFS/C) for achieving starlight suppression
  - Low order wavefront sensing and control (LOWFS/C) for continuously maintaining starlight suppression

Active Wavefront sensing and control enables CGI ~1000x deeper starlight suppression than previous space coronagraphs

Status Since WIETR Report

- **CGI has passed Systems Requirement Review (SRR) in May 2018!**
- **WFIRST in in Phase B**
- **The Coronagraph Instrument is a technology demonstration only**
- **Reduction in modes and science center role (descoping)**
- **Requirements established using standard engineering practice**
  - Model uncertainty factors (MUFs)
  - Margins and reserves
- **Design to be "starshade ready" to support possible starshade rendezvous mission (pending Decadal recommendation)**
- **Participating Scientists Programs (PSP)**

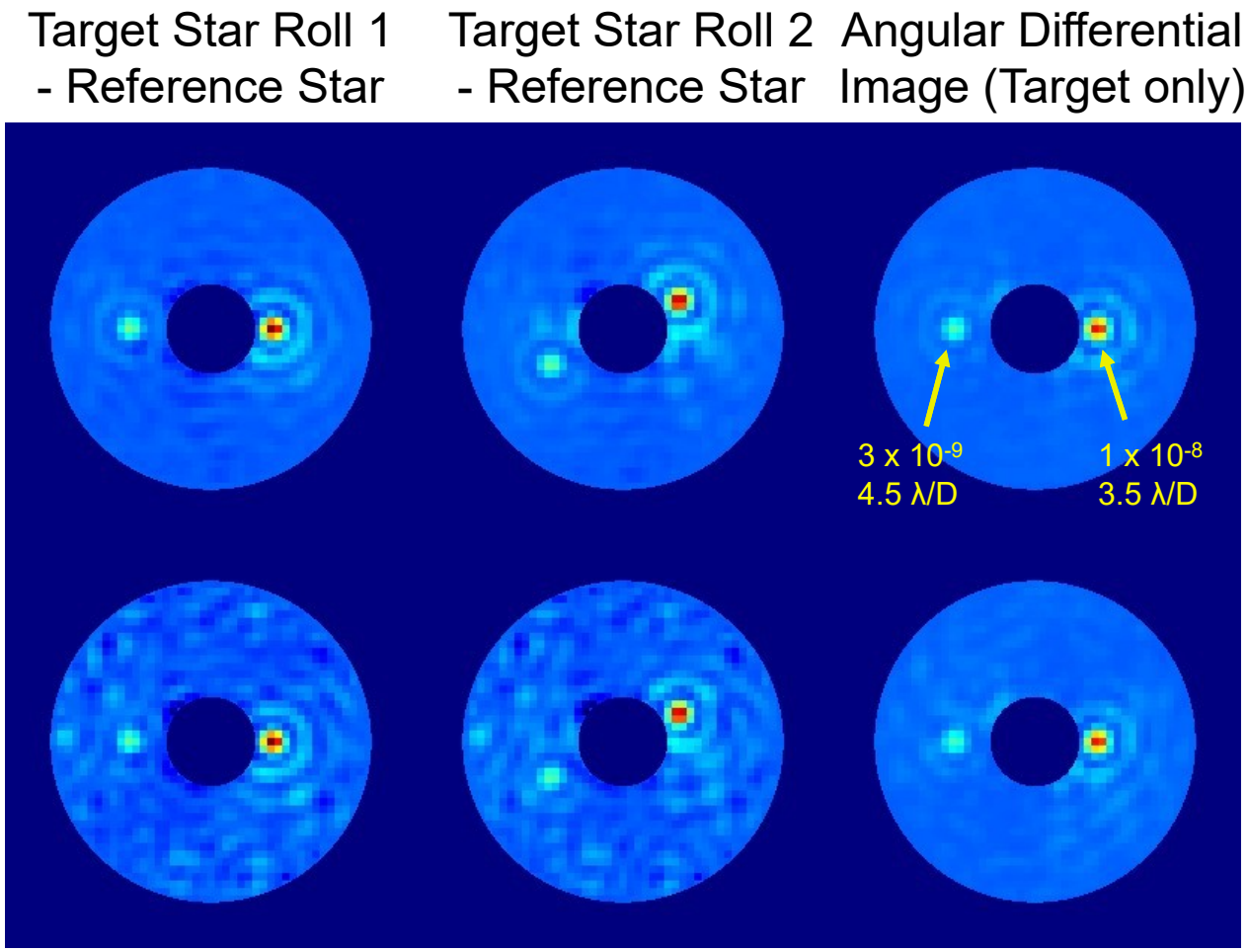
Operations Scenario #6 (OS6) Simulations -- Speckle Field Time Series



Includes: static aberrations (surface errors & polarization), high and low order wavefront control, thermally-induced wavefront aberration & pupil position changes, deformable mirror thermal drift, pointing & wavefront jitter, stellar diameters & colors

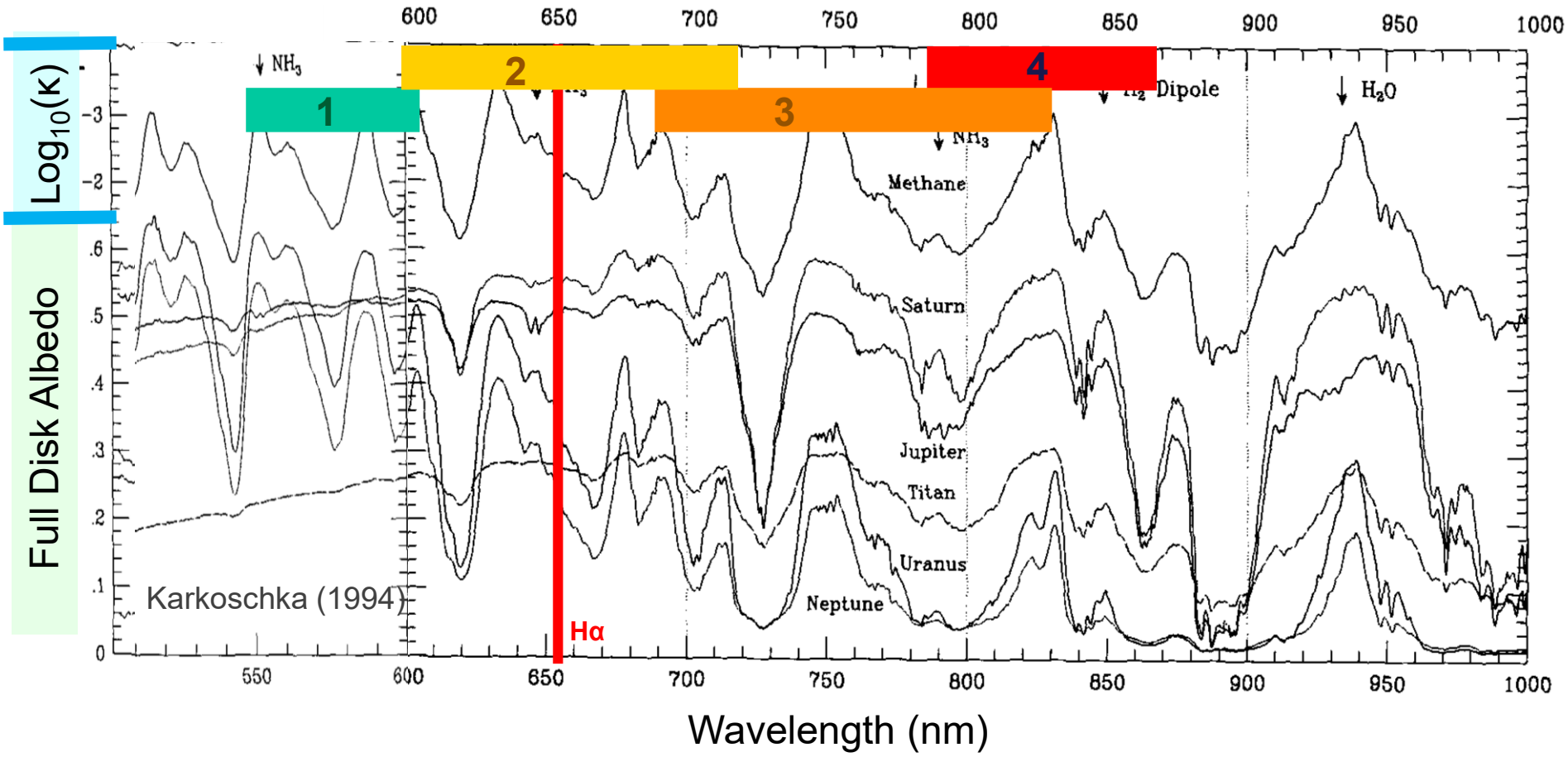
This OS6 simulated time series data available at
wfirst.ipac.caltech.edu

Differential Imaging



Field incident on detector shown. Detector effects not included

CGI Filters



- **Post-WIETR descope: number of color filters (and associated coronagraph masks) reduced**
- **No change in the number of slots in the filter wheel**

CGI Operating Modes

➢ Three Required Technology Demonstration Modes:

Name	CGI Filter	λ_{center} (nm)	BW	Channel	Masks	Working Angle	Can use w/ linear polarizers	Starlight Suppression Region
Imaging w/ Narrow FoV	1	575	10%	Imager	HLC	3-9 λ/D	Y	360°
Spectroscopy	3	760	18%	IFS	SPC	3-9 λ/D		130°
Imaging w/ Wide FoV	4	825	10%	Imager	SPC disk	6.5-20 λ/D	Y	360°

➢ Other possible modes with required masks and filters:

CGI Filters	λ_{center} (nm)	BW	Channel	Masks	Working Angle	Can use w/ linear polarizers	Starlight Suppression Region
2	660	18%	IFS	SPC	3-9 λ/D		130°
2	660	18%	Imager	SPC	3-9 λ/D	Y	130°
3	760	18%	Imager	SPC	3-9 λ/D	Y	130°
4	825	10%	Imager	HLC	3-9 λ/D	Y	360°
4	825	10%	IFS	HLC	3-9 λ/D		360°

3 primary Tech Demo Modes identified in CGI requirements. Other mask combinations exist and can be used during participating Scientists program.

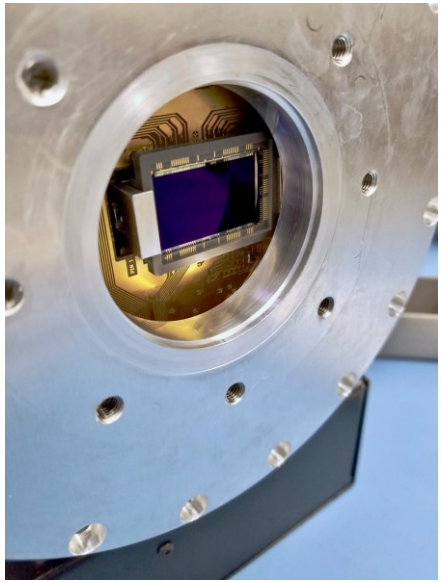
CGI Low-noise Detectors

Science Cameras (Direct imaging and IFS)

Item		Requirement@5 years		CBE (5 years)	Margin
Total Noise@165K (σ^2)					
575 nm	Band 1	41.0 e^--px^{-1}–hr^{-1}	@6s	19.6	52.2%
760 nm	Band 3	3.7 e^--px^{-1}–hr^{-1}	@80s	2.8	24.3%
825 nm	Band 4	28.1 e^--px^{-1}–hr^{-1}	@10s	11.0	60.9%

Engineering Camera (LOWFS)

Item		Requirement	CBE (5 years)	Margin
Total Noise@165K (σ^2)		158.8 e^--s^{-1}	126.7	19.8%
	Read	5 e^-	4	
	CIC	<0.1 e^--$pixel^{-1}$-fr^{-1}	0.03	
	Dark	<1 e^--$pixel^{-1}$-s^{-1}	<0.00056	
Full Well		25,000 e^-	29,200	16.8%
Frame rate		1000 frames-s^{-1}	1961	96%
Latency		0.5 ms	0.25	96%
Bits		14	14	□

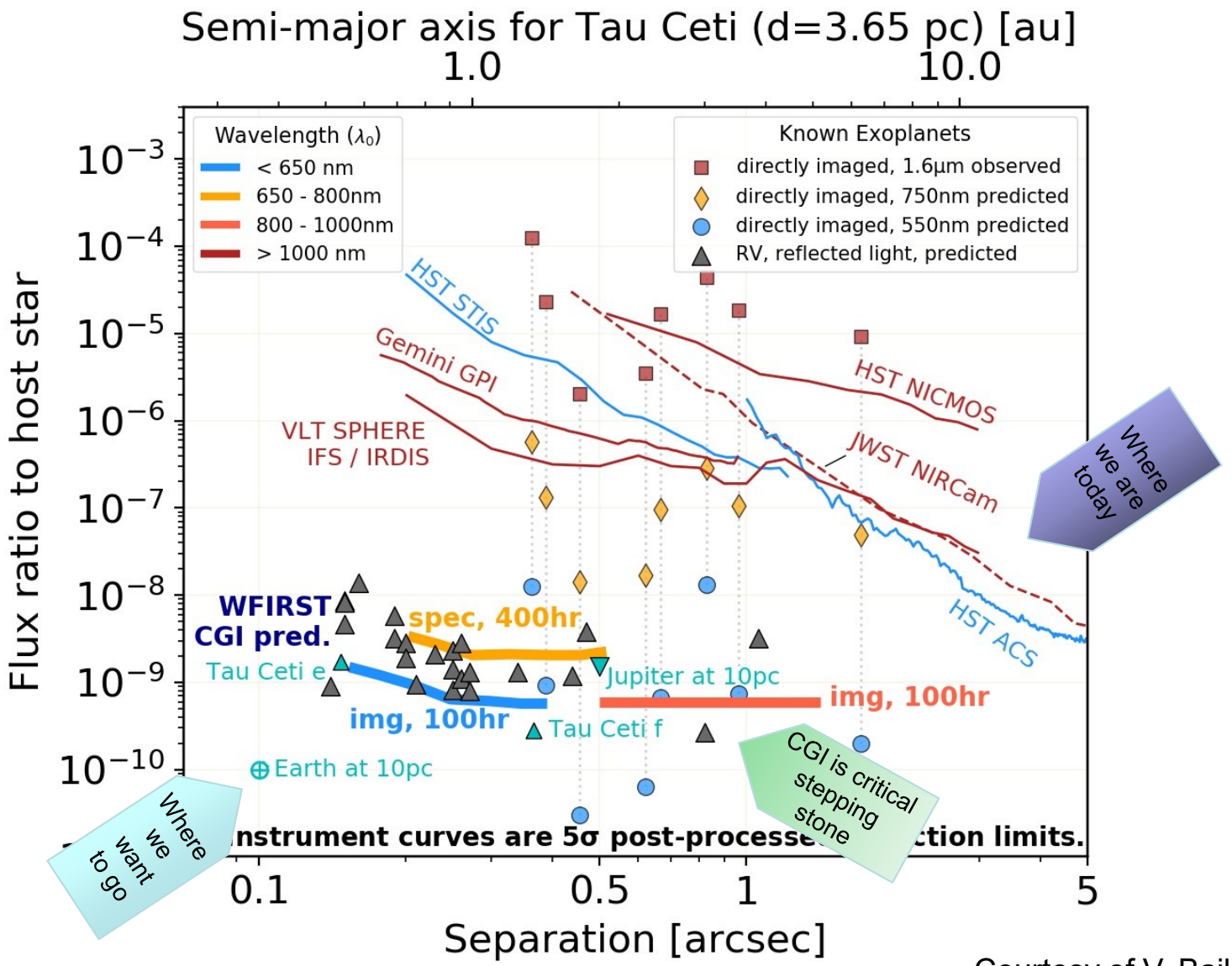


e2v 1K X 1K Electron Multiplying CCDs
For all cameras, running at different modes

Infusing New Wavefront Sensing & Control algorithms

- CGI is an actively controlled instrument, performance driven by both hardware (masks, DMs) and algorithms/software (DM solutions)
- CGI plans to fly the most capable flight-ready processor, optimized with both CPU and FPGAs
- WFIRST supports CGI software uploads during Phase E
- Welcome new algorithms development from future PSP teams
- CGI maintains an ops testbed during Phase E, that can proof-test new algorithms before upload

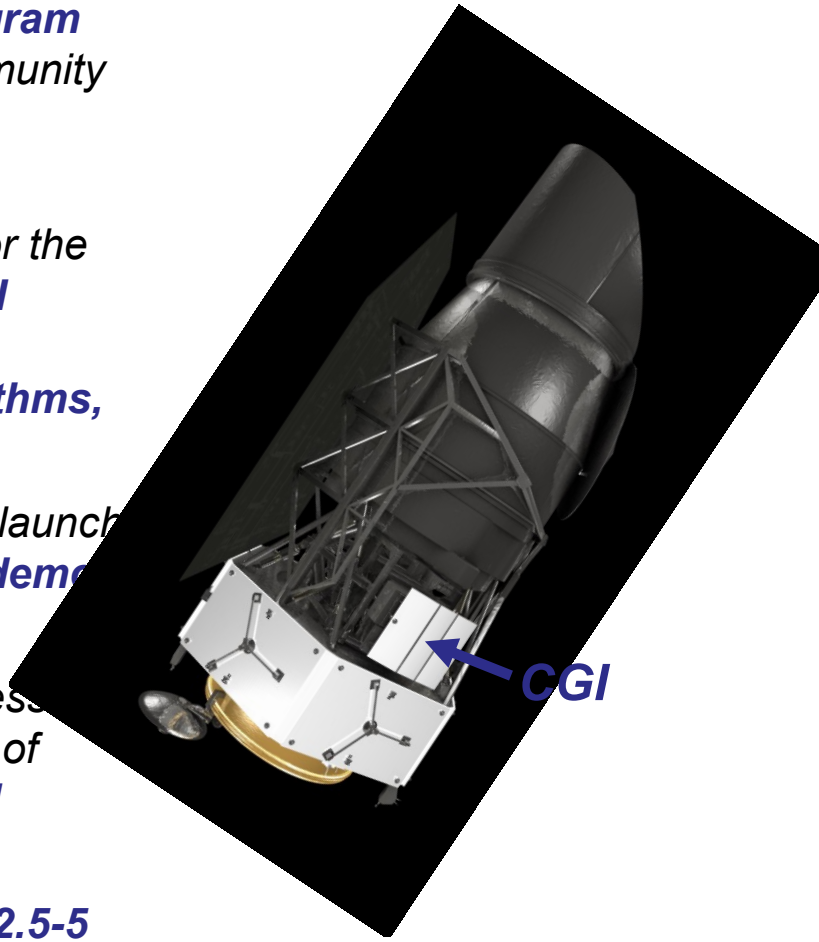
CGI is a Pathfinder for Direct Imaging and Spectroscopy of Earth-like Exoplanets



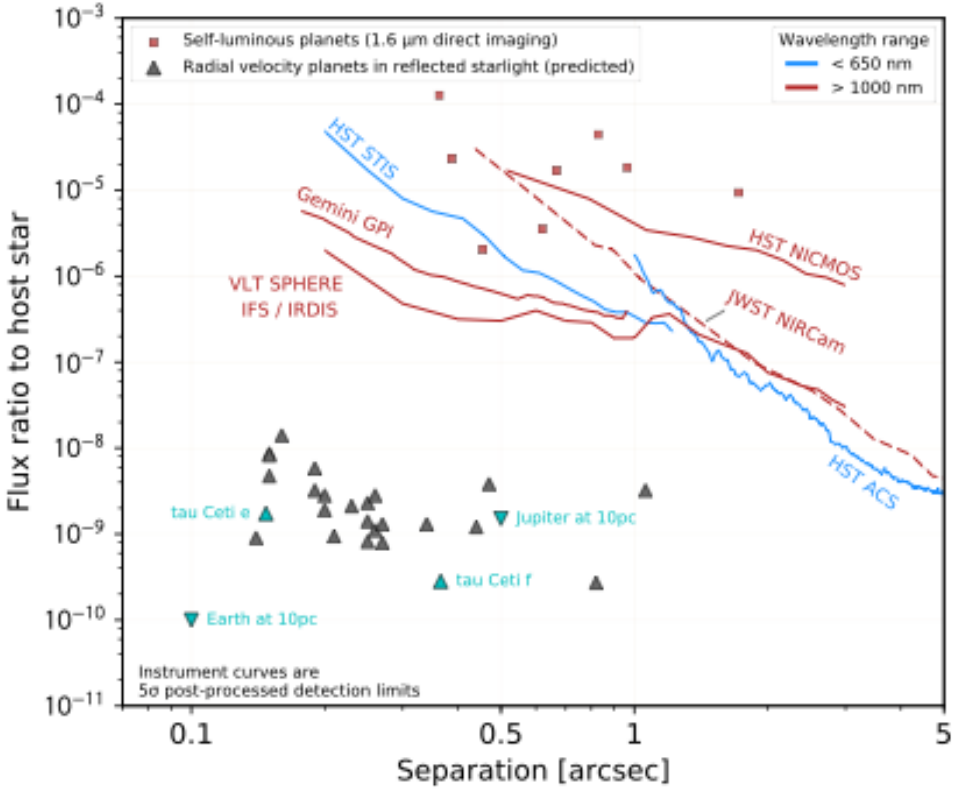
Courtesy of V. Bailey

Participating Scientist Program

- *NASA envisions a **Participating Scientist Program (PSP)** that engages the general exoplanet community in high-contrast direct imaging astronomy.*
- *Due to budget constraints, there will not be a traditional General Observer support program for the CGI — instead, the **PSP will work with the CGI project to develop science target priorities, observing strategies, data processing algorithms, and data analysis.***
- *The PSP team is intended to be in place before launch and to **fully participate in the 18-month tech demo program.***
- *Following initial CGI commissioning and a success technology demonstration in the first 18 months of operations, **the PSP may guide additional CGI observations during years 1.5-2.5.***
- *"If warranted," **science observations in years 2.5-5 with an augmented PSP** (with further community selections) or full a GO program.*

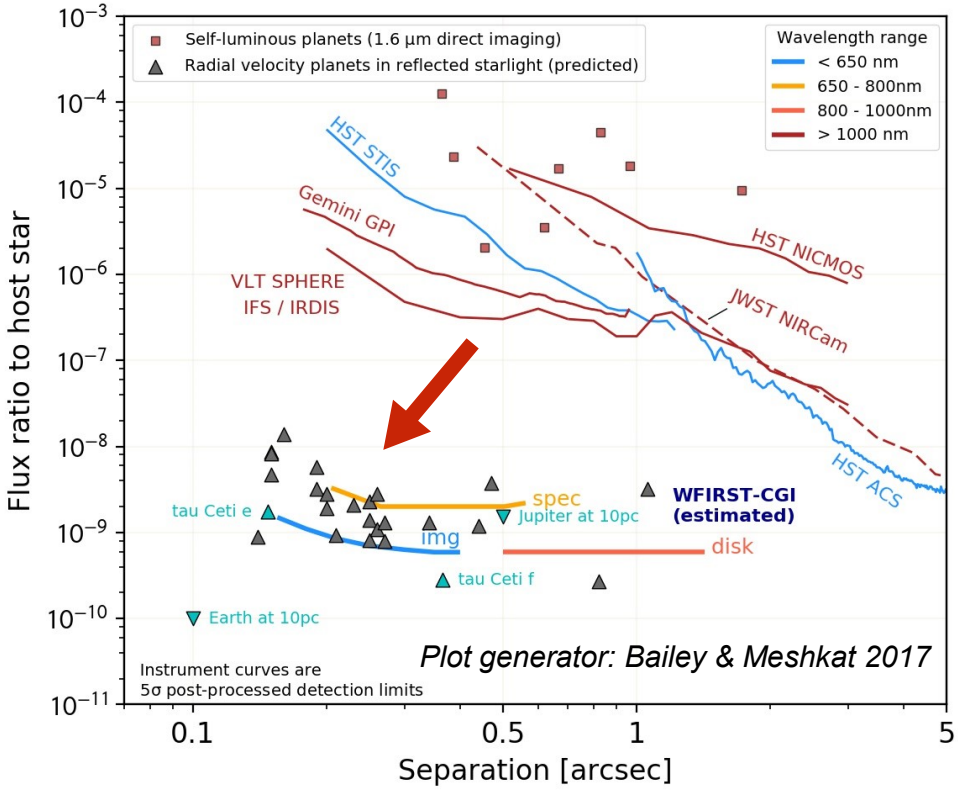


Direct Imaging of Exoplanets: 2018



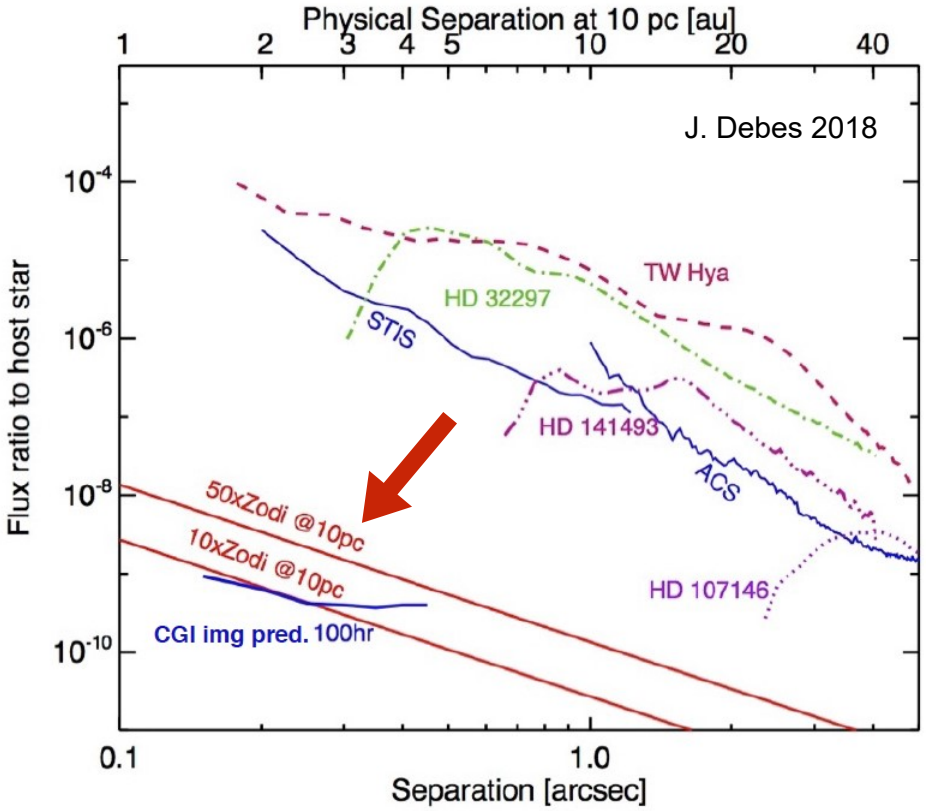
*Direct imaging and spectroscopy of **young self-luminous exoplanets** have been achieved from ground and space observatories. Direct imaging of **mature cool exoplanets in reflected starlight** is currently beyond the reach of conventional techniques, as illustrated by the estimated brightness of a sample of known radial velocity exoplanets.*

CGI pioneers coronagraph technologies



Early estimates of the CGI flux ratio curves *for three observing configurations (direct imaging at short and long wavelengths, and integral field spectroscopy) are based on* ***currently demonstrated static and dynamic testbed performance*** *and observatory optical disturbance models provided by the WFIRST project.*

CGI sensitivity for circumstellar disks



*Early estimate of the **CGI sensitivity for imaging of low-luminosity disks** associated with a V=5 star. Surface brightness is represented in terms of flux ratios per imaging resolution element. Comparisons are made with previously-imaged disks in visible scattered light, and with HST instrument sensitivities.*

Summary

- CGI is pioneering all elements of an advanced coronagraph in space
- CGI team is making excellent progress
- ➢ CGI current performance estimates would result in exciting science through participating Scientists programs
- CGI is a Pathfinder for Direct Imaging and Spectroscopy of Earth-like Exoplanets