Nancy Grace Roman Space Telescope Coronagraph Instrument Dark Hole Algorithms WG

Kick-off meeting

Nov 13, 2020

Agenda

- Orientation, intro to ground-in-the-loop (30 min)
- Round table introductions (15 min)
- Simulation tool demos (15 min)
- Open discussion (30 min)
  - ideas for meeting format, future topics
  - how can we help?

Purpose of working group

- Support research on algorithms that could enhance the value of the CGI tech demo.
- Information conduit from CGI Project on instrument design, operations constraints, and simulation inputs.
- A forum to present and comment on various concepts and lab demos for alternative HOWFS algorithms.

Members

Roman Project / CGI
Vanessa Bailey (JPL)
Eduardo Bendek (JPL)
Eric Cady (JPL)
Tyler Groff (GSFC)
Brian Kern (JPL)
John Krist (JPL)
Bertrand Mennesson (JPL)
Bijan Nemati (U.AH)
Camilo Mejia Prada (JPL)
A J Eldorado Riggs (JPL)
Marie Ygouf (JPL)
Neil Zimmerman (GSFC)

Roman Science Investigation Teams
Ewan Douglas (U.Arizona)
Jessica Gersh-Range (Princeton)
Jeremy Kasdin (U. San Francisco)
Bruce Macintosh (Stanford)
Avi Mandell (GSFC)
Leonid Pogorelyuk (Princeton)
Laurent Pueyo (STScI)
Susan Redmond (Princeton)
Maggie Turnbull (SETI)

IPAC / Science Support Center
Tiffany Meshkat
Patrick Lowrance

STScI / Science Operations Center
Julien Girard

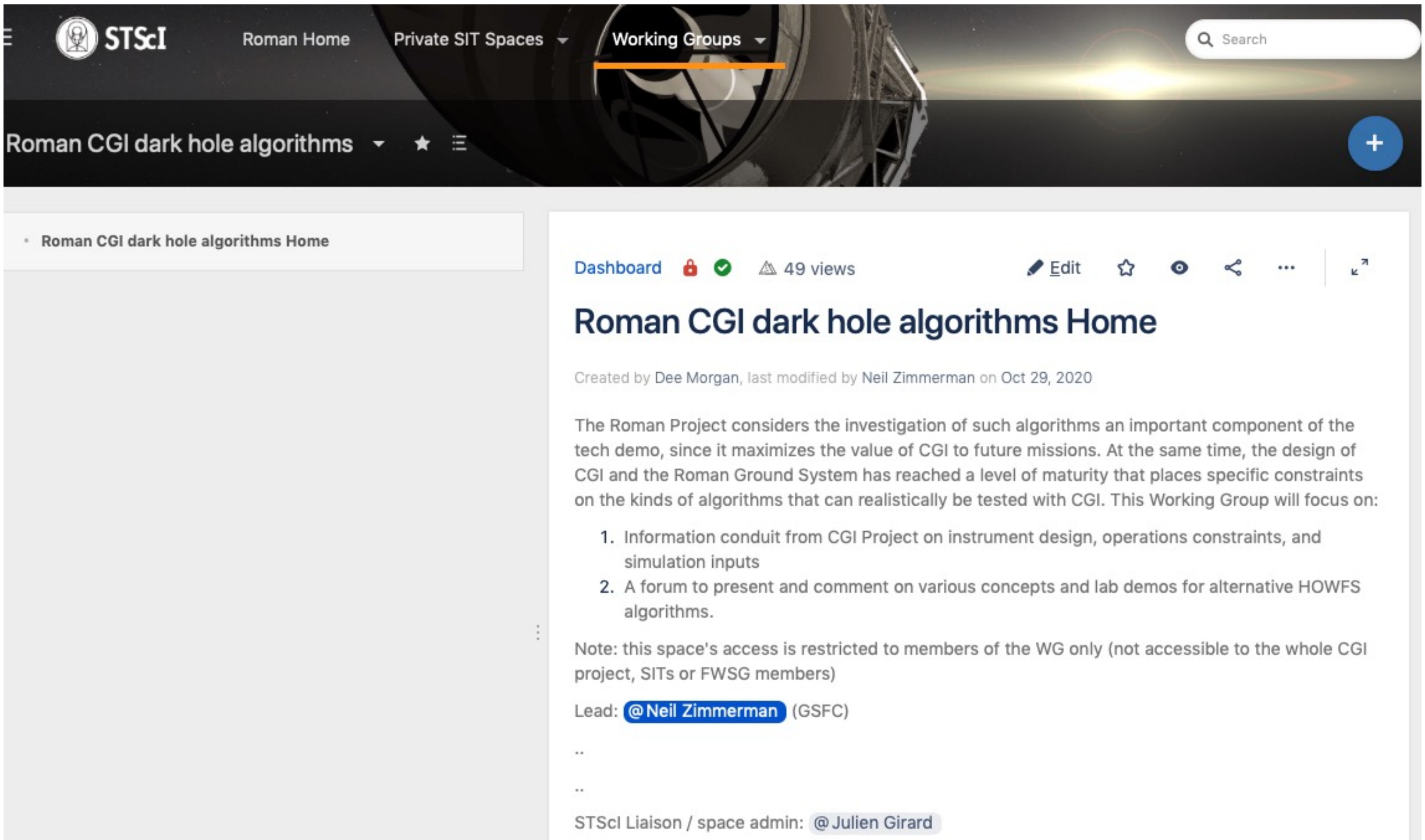
Other US
Rus Belikov (Ames)
Olivier Guyon (U.Arizona/NAOJ)
Dan Sirbu (Ames)
Karl Stappelfeldt (NASA ExEP)

International partners
Pierre Baudoz (Obs. Paris)
Steven Bos (Leiden)
Wolfgang Brandner (MPIA)
Vincent Deo (NAOJ)
Markus Feldt (MPIA)
Johan Mazoyer (Obs. Paris)
Frans Snik (Leiden)

STScI “outerspace” platform for materials, notes

https://outerspace.stsci.edu/display/RDHA/Roman+CGI+dark+hole+algorithms+Home

Contact Julien Girard (jgirard@stsci.edu) to get access.

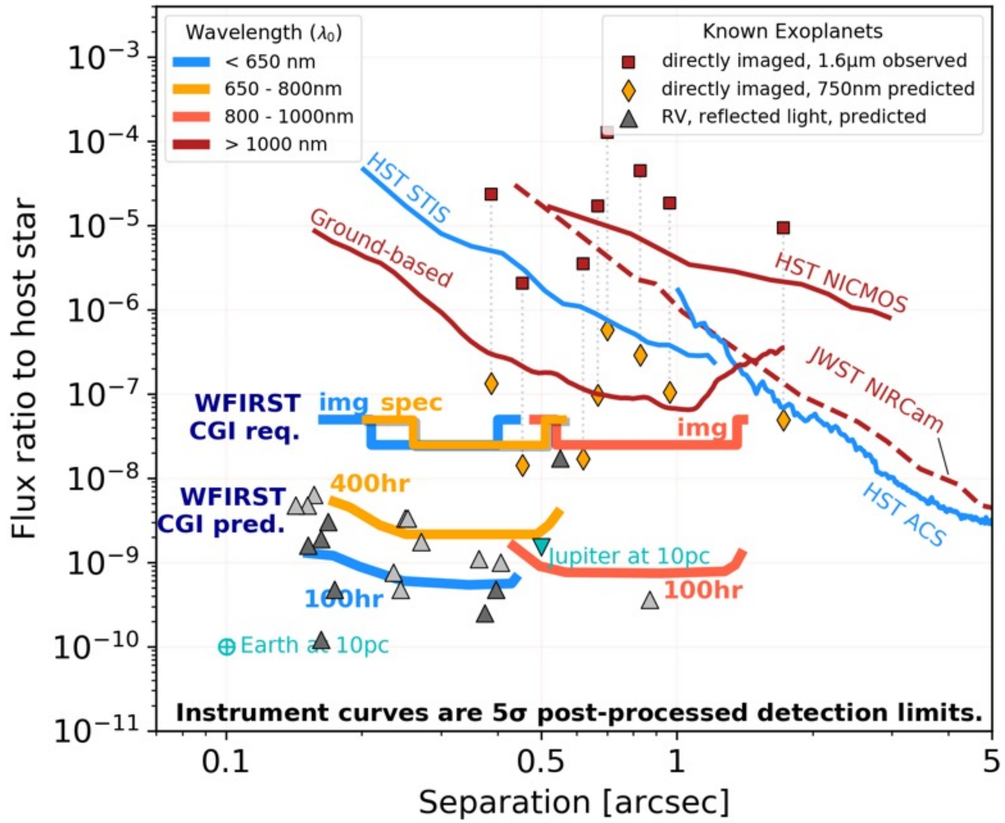


CGI in context

(from https://roman.ipac.caltech.edu/Introductory_Slides.html)

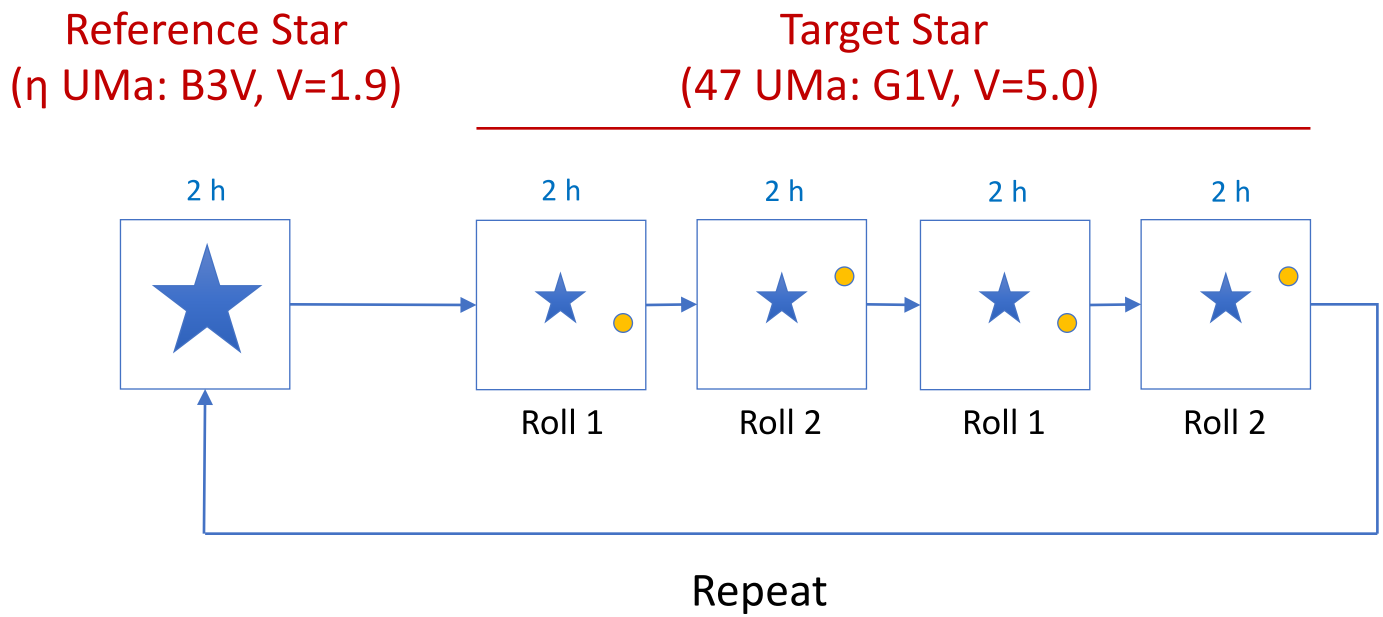
- **CGI** is a technology demonstration of space-based direct imaging and spectroscopy
  - will be **~100-1,000 times better** than any current facility
  - a **critical stepping stone** in preparation for future exo-Earth missions
- A **Community Participation Program** will enable members of the community to engage in the technology demonstration phase.
  - If warranted by instrument performance, the CPP may perform science operations beyond the 18 month technology demonstration period.

https://github.com/nasavbailey/DI-flux-ratio-plot



"RV" planets: planets already detected using the Radial Velocity technique and with minimum masses > 0.25 Jupiter mass

Baseline observing scenario



CGI Official Modes Table

Jan 2, 2019

CGI Filter	λ_{center} (nm)	BW	Channel	Mask Type	Working Angle	Can use w/ linear polarizers	Starlight Suppression Region
1	575	10%	Imager	HLC	3-9 λ/D	Y	360°
3	730	15%	IFS	SPC bowtie	3-9 λ/D		130°
4	825	10%	Imager	SPC wide FOV	6.5-20 λ/D	Y	360°

These three “official” modes will be fully commissioned before launch.
ie: the flight hardware will by fully tested with flight software prior to launch.

Wavefront control is part of the tech demo

One of the five Technology Demonstration Objectives held at the Program Level:

The CGI will support development and in-flight demonstration of coronagraph software that could enhance the capability or simplify the architecture of future missions. WFIRST would fulfill this objective by demonstrating the ability to modify the wavefront sensing and control algorithms during the prime science mission.

Mission operations

Slides that follow are excerpts from Ground System PDR (Part 2) held in July 2020:

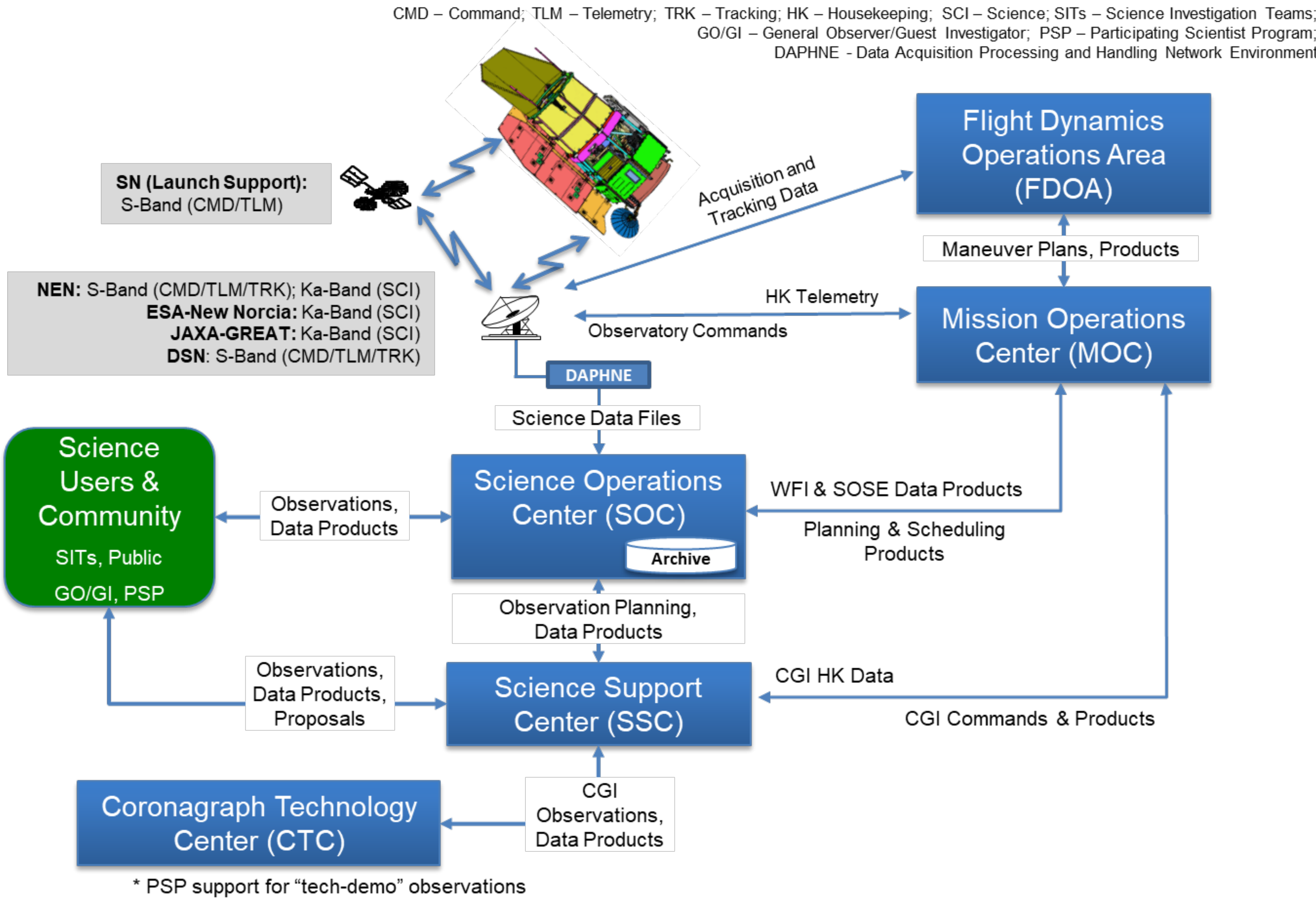
- Mission Operations Concept (Chris Connor / GSFC)
- Science Support Center CGI Operations and Data Management (Tiffany Meshkat, Jim Ingalls / IPAC)
- Coronagraph Technology Center (Eric Cady / JPL)

HOWFSC/GITL

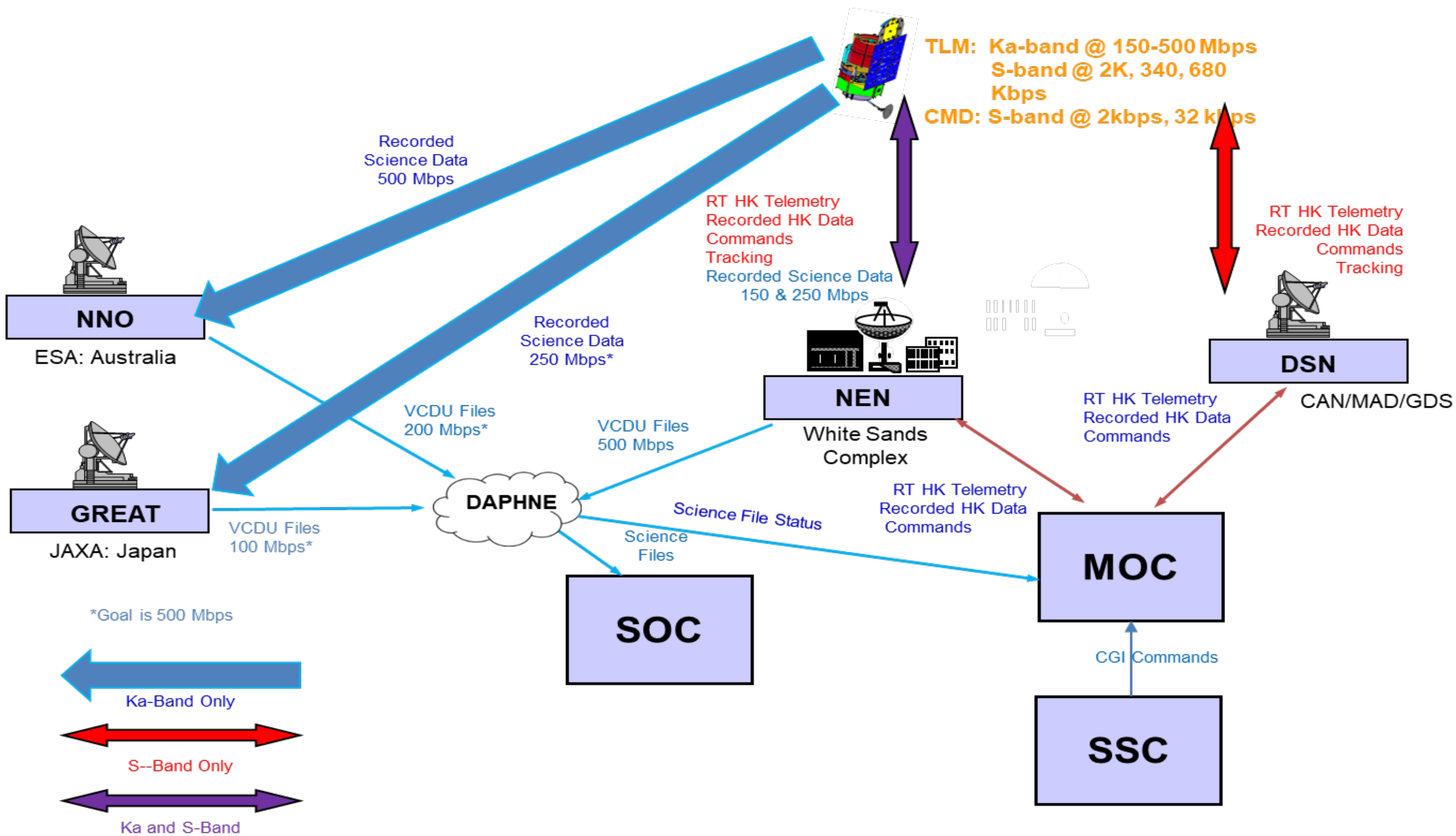
Background:

- High-order wavefront sensing and control (HOWFSC) is a necessary but computationally-expensive activity CGI must perform to meet its contrast requirements
- Up until Mission PDR, HOWFSC was slated to be performed by CGI flight software
- NASA tiger team raised concerns about CGI flight software schedule risk and recommended CGI move to a ground-in-the-loop (GITL) wavefront sensing and control scheme. This recommendation was evaluated and accepted by the Roman project.
  - This would offload the computationally-expensive parts to the ground
    - Images are sent down via S-band
      - stacked, cleaned and cropped to minimize data volume
      - Chosen after trade on other options (no onboard cleaning)
    - Deformable mirror (DM) settings and camera settings for the next control iteration are sent back up
  - Baseline algorithms <u>not changed</u> to minimize additional scope
    - FSW would have run hands-off; GITL algorithms will not require operator-in-the loop either

Ground System



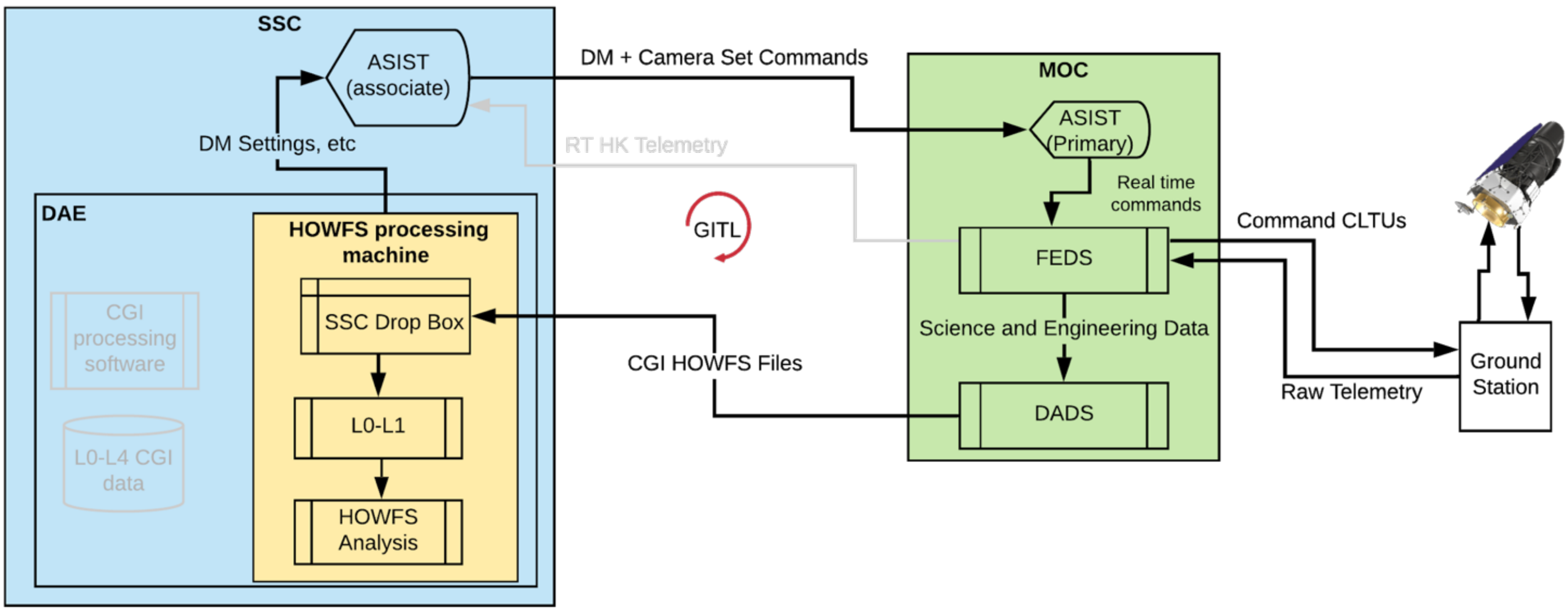
Communications architecture



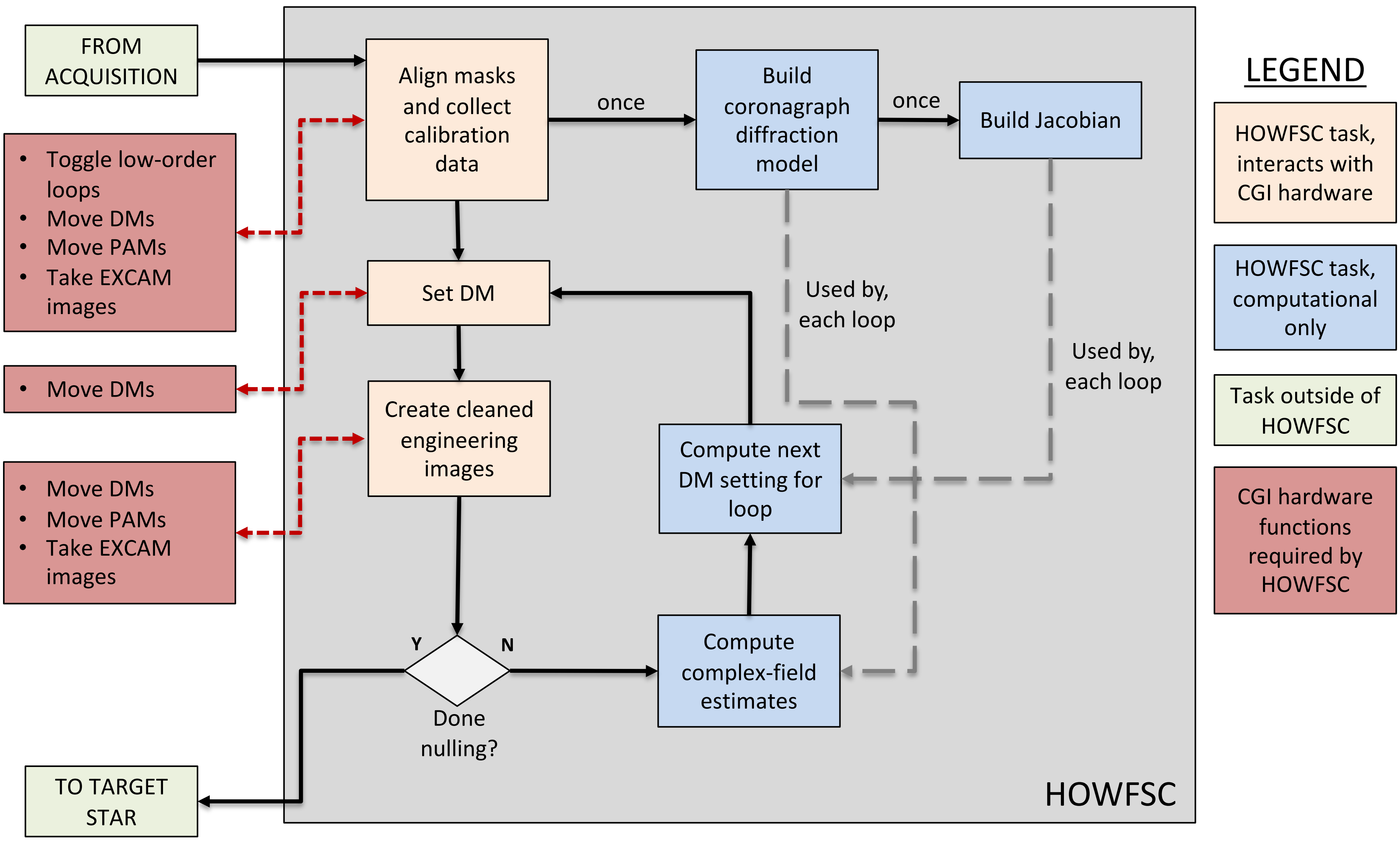
SSC and CTC mission operation roles

	SSC responsibility	CTC responsibility
CGI Health and Safety	• Assess and trend health and safety • Receive and store HK telemetry • Lead anomaly response for CGI	• Define alarm limits and responses • Support anomaly responses as necessary
CGI Commanding	• Generate and validate all CGI command scripts • Commanding during nominal ops • Scheduling and commanding interface	• Deliver CGI command dictionary • Design data collection scripts and deliver to SSC • Create Observation Specifications
CGI Data Processing	• Receive and process CGI data to Level 1 • Validate and deliver Level 1/2/3/4 data and calibration reference files to SOC for archiving	• Process CGI data to Level 2/3/4 • Analyze calibration data and produce calibration reference files • Deliver Level 2/3/4 data and calibration files to SSC
CGI flight software updates	• Deliver CGI flight software updates to MOC	• Maintain CGI flight software • Deliver software updates to SSC
GITL HOWFSC	• Operate GITL HOWFSC software • Validate products and deliver to MOC	• Develop and deliver GITL HOWFSC software
I&T support (pre-Phase E)	• Support Instrument, Payload and Observatory I&T • Deliver I&T data from all 3 to SOC	• Support Instrument, Payload and Observatory I&T as CGI ground lead • Deliver Instrument I&T data to SSC
Other	• Lead CGI commissioning training	• Operate CGI testbed

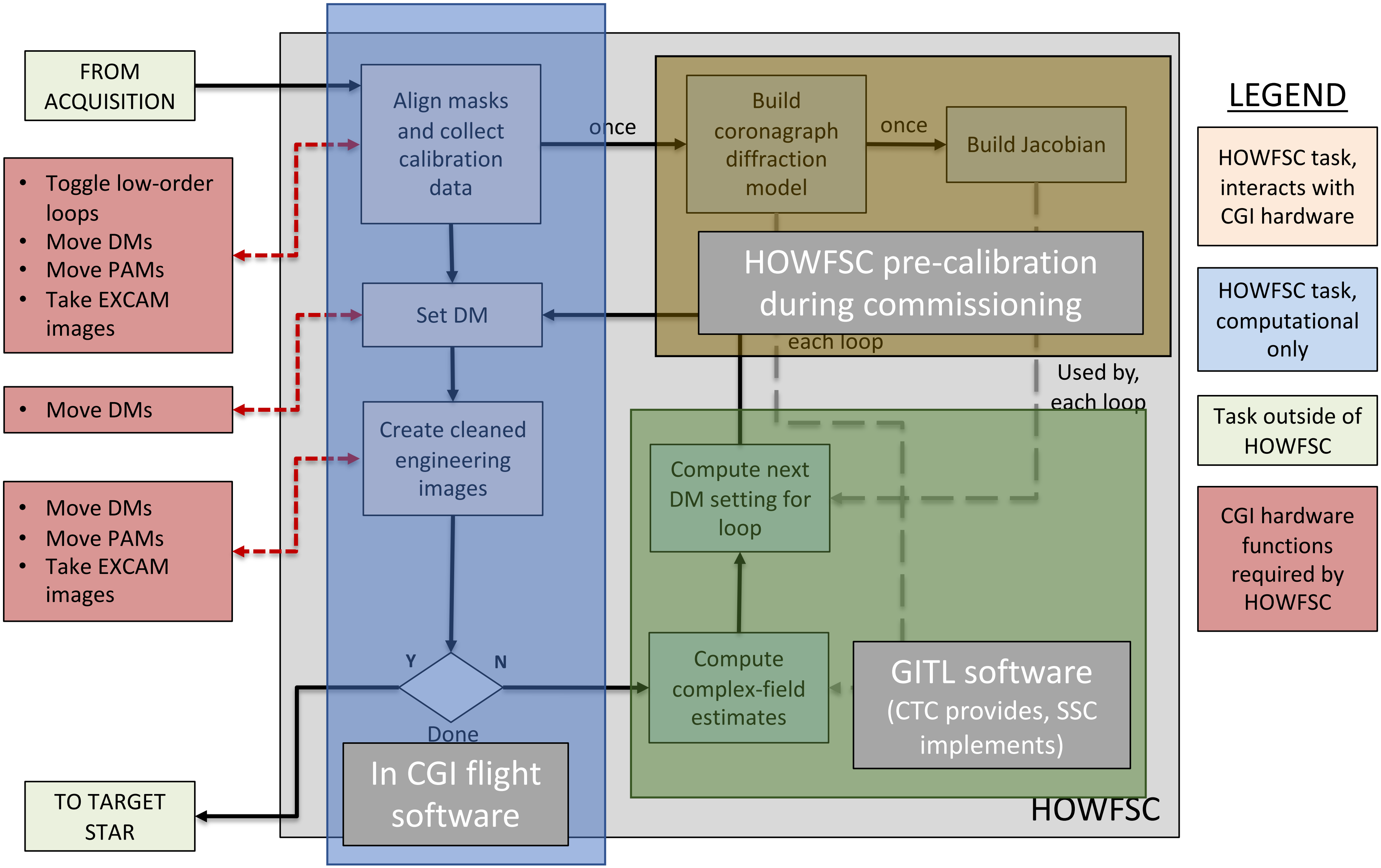
High Order WFS&C with Ground in the the Loop (GITL)



HOWFSC operation flow



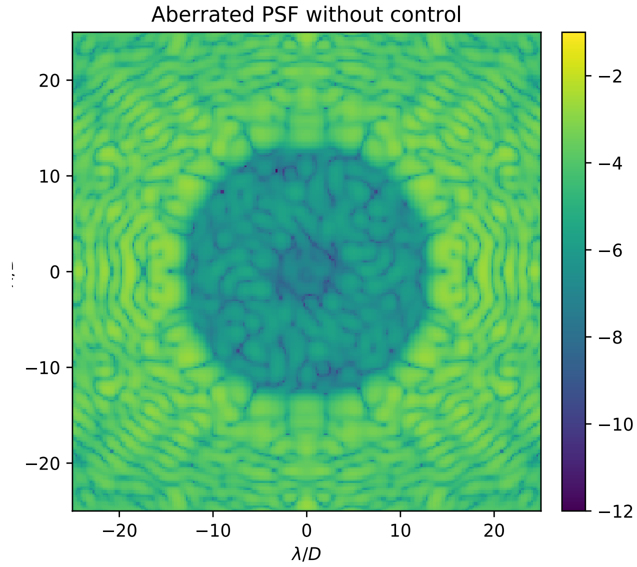
HOWFSC operation flow



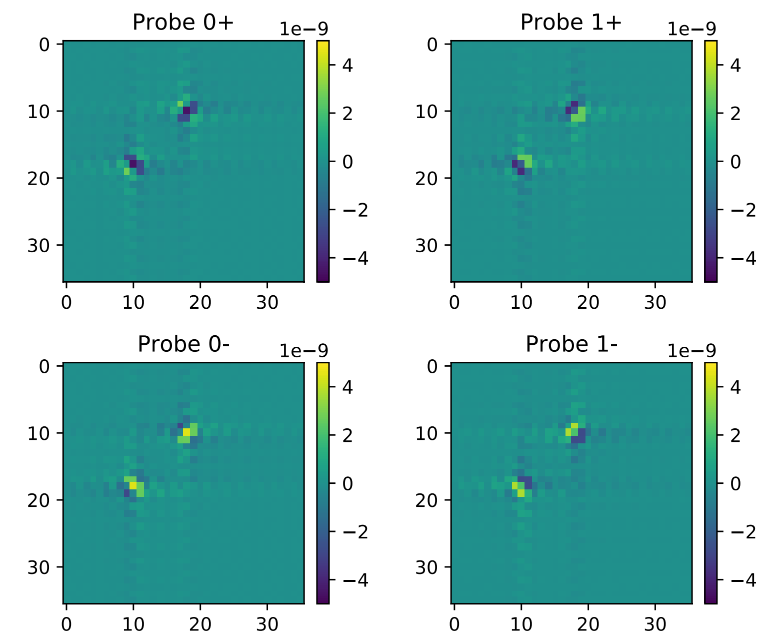
borrowed from Roser Juanola-Parramon, GSFC

Pair-wise electric field estimation

- **Pair-wise difference imaging** allows the estimation of the EF from a set of intensity images
- These images are created by setting a predefined DM shape or **probe pairs**
- Uses model to predict how probes affect the EF at the image plane
- The **probe** shape depends on:
  - Shape and size of the dark zone
  - Telescope design
  - Coronagraph design
  - Number of DM actuators

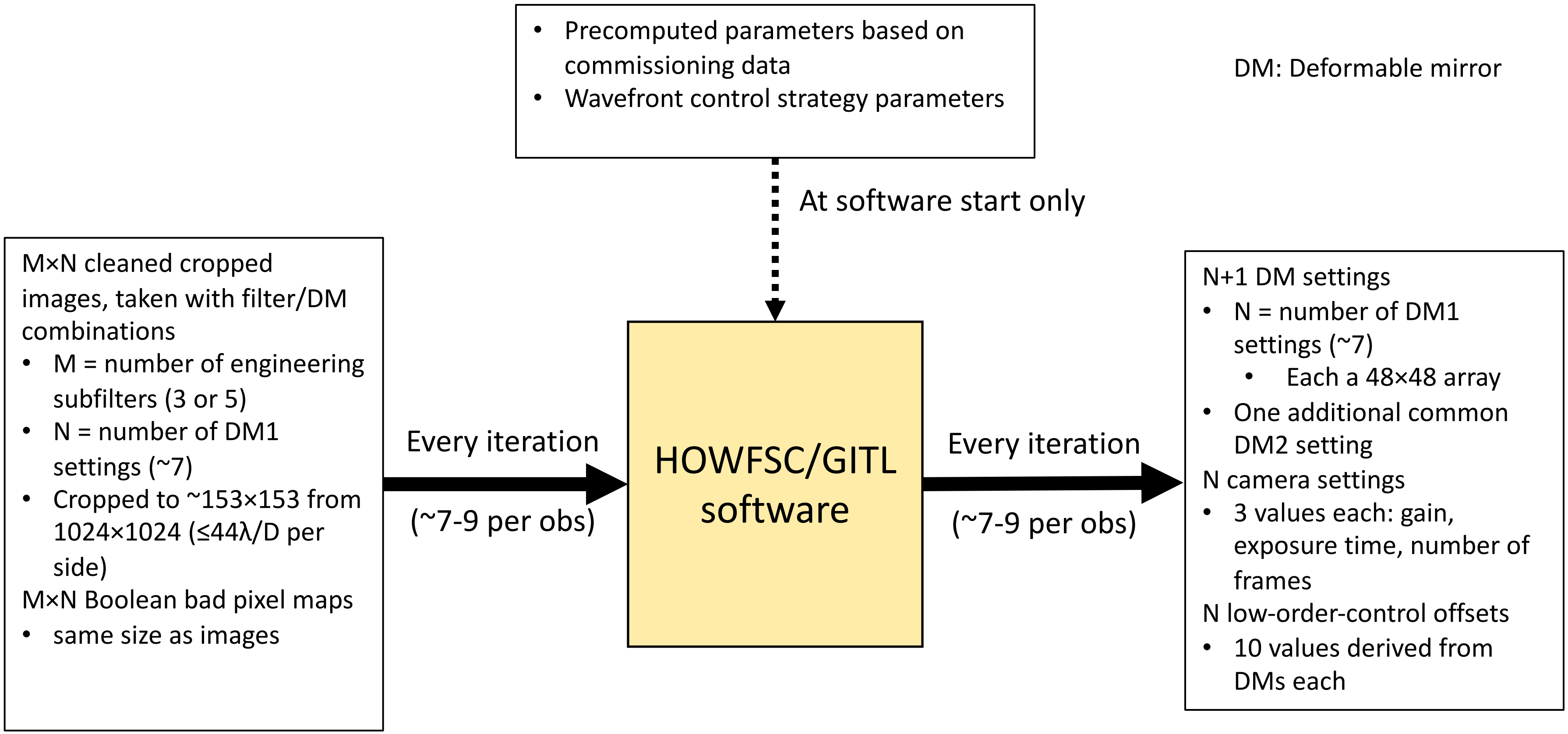


Probes used to estimate the EF (2 pairs):



Give'on, Kern, Shaklan, Moody, Pueyo; Proc. SPIE (2007); https://doi.org/10.1117/12.733122

Detailed HOWFSC/GITL interface



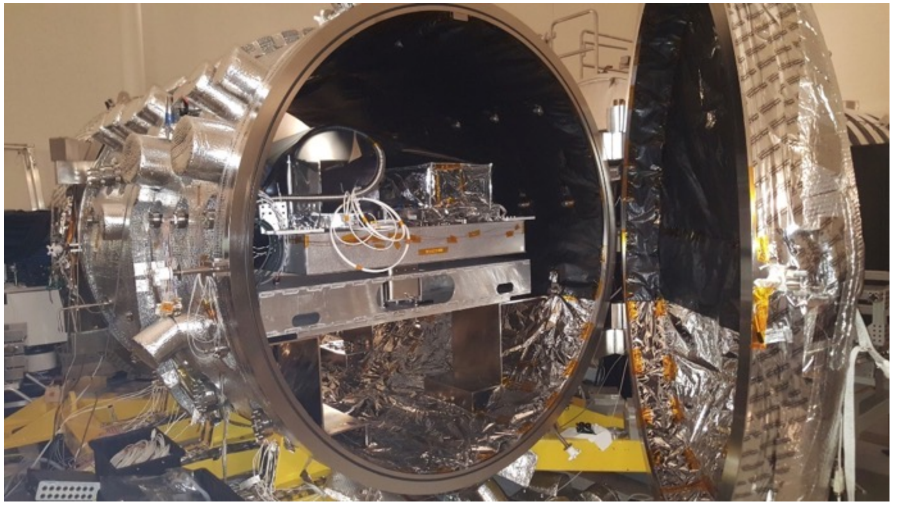
- Interface will be specified in detail in a Software Interface Specification
- Outputs wholly determined by inputs and startup parameters
  - No operator-in-the-loop required

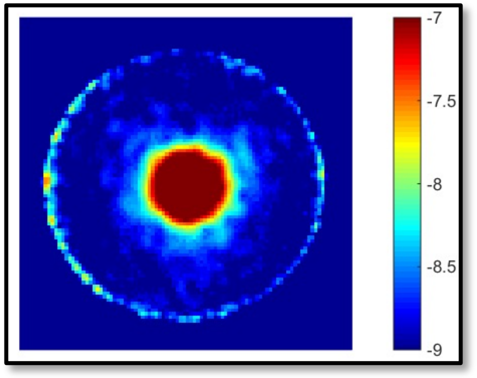
CGI Testbed

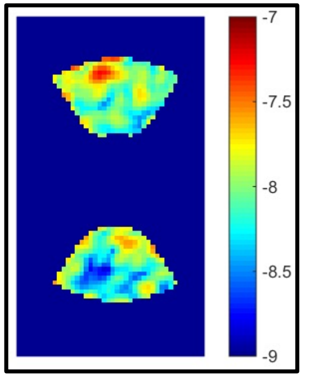
CGI has optical testbeds of increasing fidelity since 2014

- Final one will be Systems Testbed for functional testing of system-level optical behavior
- Built from Performance Testbed, which has demonstrated better than 10^{-8} contrast with flight-like coronagraphs
- Includes all CGI EDUs, and functional substitutes for missing ones

Systems Testbed will be maintained past I&T to become the testbed for CGI commanding in Phase E







Resources hosted by IPAC

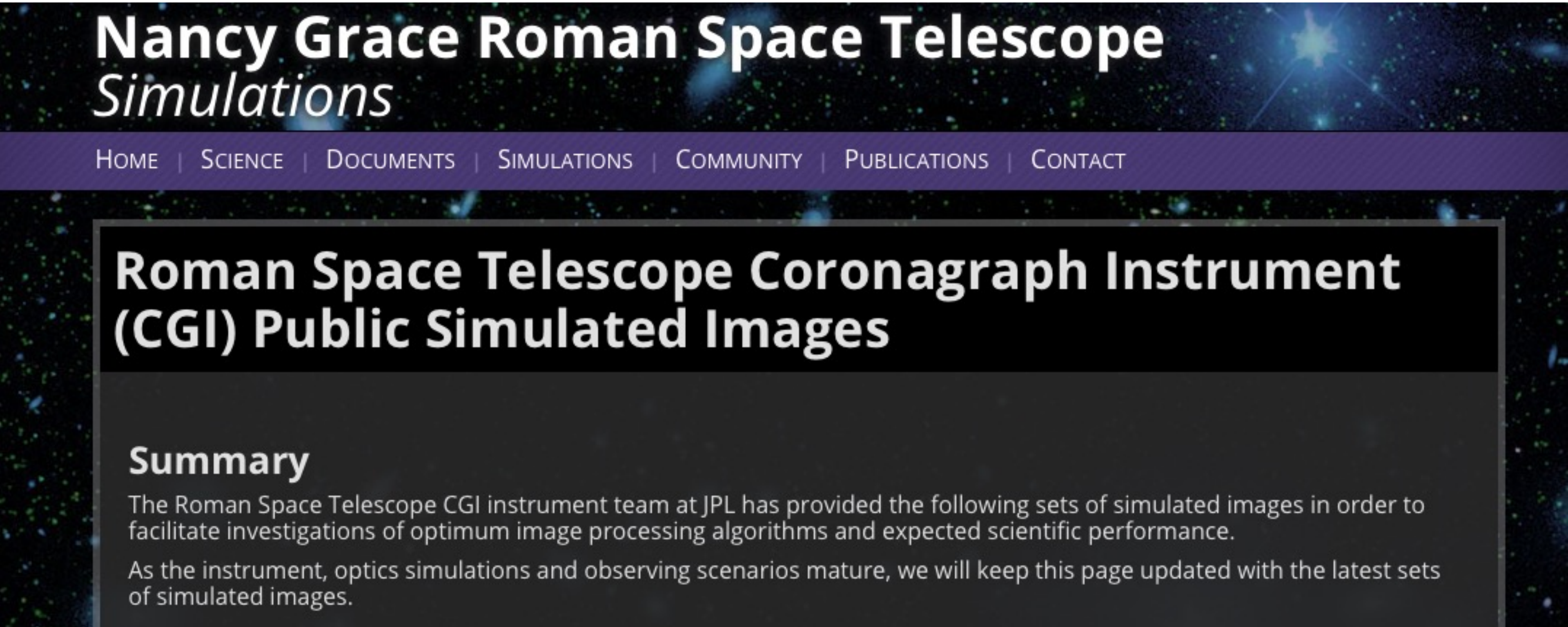
- Simulations:

https://roman.ipac.caltech.edu/sims/Simulations_csv.html#instrument

https://roman.ipac.caltech.edu/sims/Coronagraph_public_images.html

- Parameter database

https://roman.ipac.caltech.edu/sims/Param_db.html



Other public simulation tools

- FALCO (A J Riggs):

https://github.com/ajeldorado/falco-matlab

- Lightweight Space Coronagraph Simulator (Leonid Pogorelyuk)

https://github.com/leonidprinceton/LightweightSpaceCoronagraphSimulator

- Others? Let us know

Additional CGI reference info compiled by JPL Project Science team

CGI Installed Coronagraphs

Jan 2, 2019

CGI Filter	λ_{center} (nm)	BW	Mask Type	Working Angle	Starlight Suppression Region
1	575	10%	HLC	3-9 λ/D	360°
2	660	15%	SPC bowtie	3-9 λ/D	130°
3	730	15%	SPC bowtie	3-9 λ/D	130°
4	825	10%	SPC wide FOV	6.5-20 λ/D	360°
4	825	10%	HLC	3-9 λ/D	360°

These five masks will be installed in CGI. However, only those listed in the "official modes table" correspond to CGI requirements and will be officially supported for the tech demo phase.

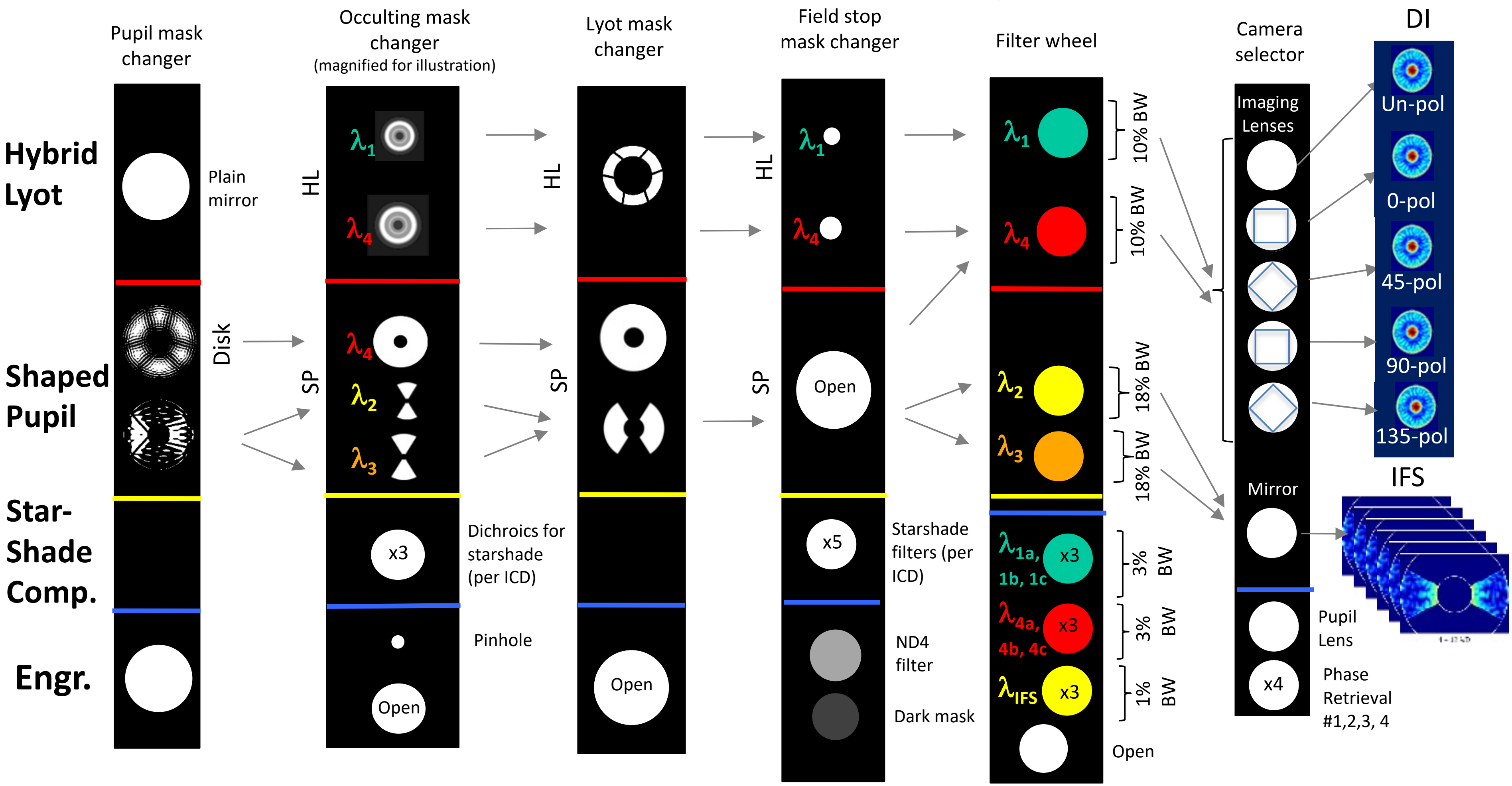
Only 1 orientation of each SPC bowtie is baselined.

λ_1 = 575 nm, 10% λ_2 = 660 nm, 15% λ_3 = 730 nm, 15% λ_4 = 825 nm, 10%

Last modified: Jan 2, 2019

CGI Baseline

Jan 2, 2019



λ_1=575 nm, 10% (annular, 3-9 λ/D)

λ_2=660 nm, 15% (bow-tie / IFS, 3-9 λ/D)

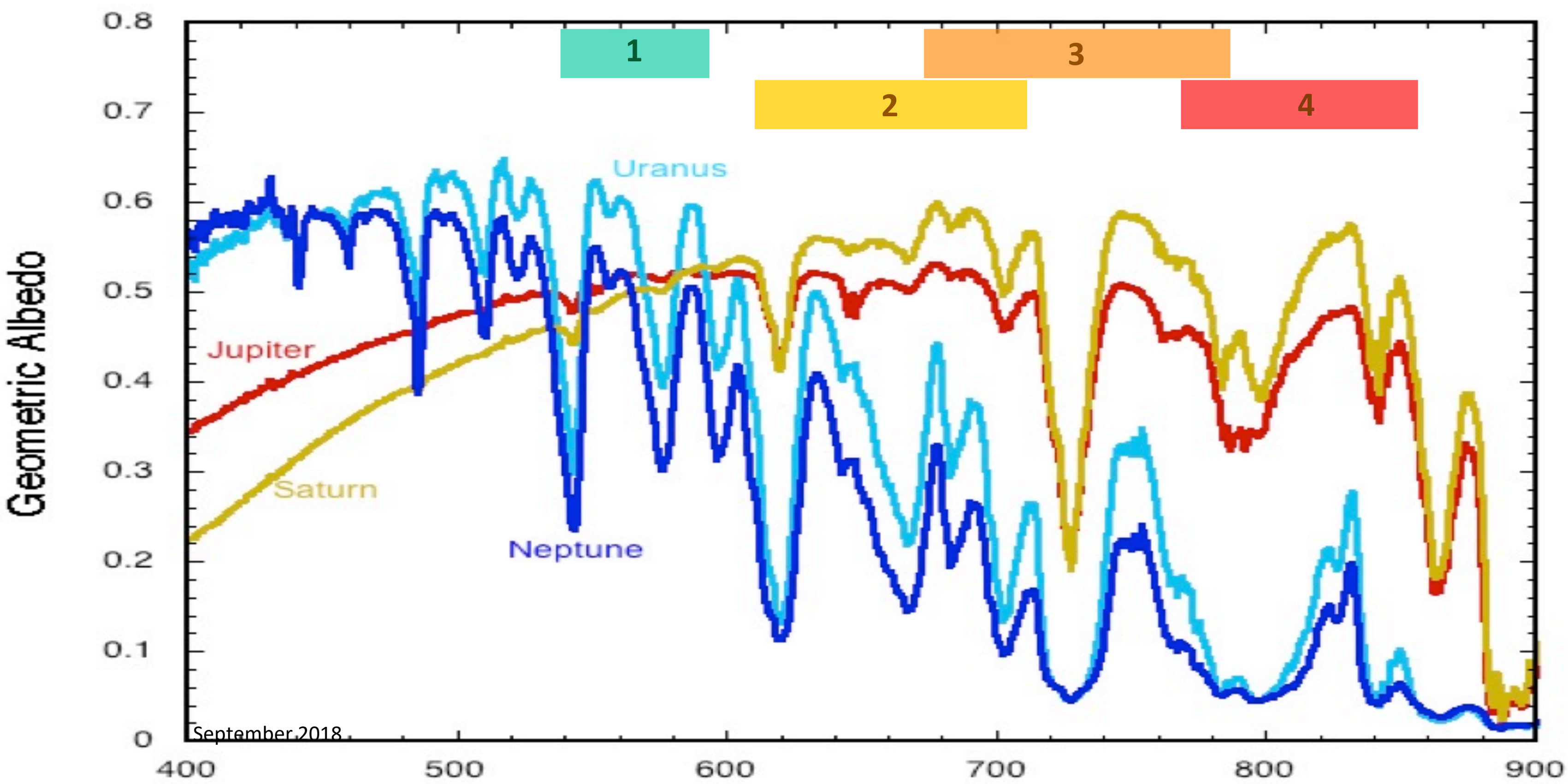
λ_3=730 nm, 15% (bow-tie / IFS, 3-9 λ/D)

λ_4=825 nm, 10% (annular, 3-19 λ/D)

Diagram not to scale

Baseline Science Filters

Jan 2, 2019



λ_1 = 575 nm, 10% λ_2 = 660 nm, 15% λ_3 = 730 nm, 15% λ_4 = 825 nm, 10%

WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
DARK ENERGY • EXOPLANETS • ASTROPHYSICS

CGI Full Filter List

Jan 2, 2019

	Band #	λ (nm)	BW	Δλ (nm)	λ_{min} (nm)	λ_{max} (nm)
Bandpasses	1	575	10.1%	58	546	604
	2	660	15.2%	100	610	710
	3	730	15.1%	110	675	785
	4	825	9.9%	82	784	866
Wavefront Control Engineering Bandpasses	1a	555.7	3.5%	19.3	546	565.3
	1b	575.0	3.4%	19.3	565.3	584.7
	1c	594.3	3.3%	19.3	584.7	604.0
	4a	797.7	3.4%	27.3	784.0	811.3
	4b	825.0	3.3%	27.3	811.3	838.7
	4c	852.3	3.2%	27.3	838.7	866.0
IFS Engineering Bandpasses	2a	656.3 (TBR)	1%	6.6	653.0	659.6
	3a	710 (TBR)	1%	7	706.5	713.5
	4a	825 (TBR)	1%	8.2	820.9	829.1

Other: ND4 neutral density filter

Last modified: Jan 2, 2019

Starshade Filter List

Jan 2, 2019

	λ (nm)	BW	Δλ	λ_{min} (nm)	λ_{max} (nm)	mode
Starshade Science Bands	488.5	26.0%	127	425	552	img
	707.5	26.1%	185	615	800	img
	728	19.8%	144	656	800	IFS
	884.5	26.1%	231	769	1000	img
	910	19.8%	180	820	1000	IFS