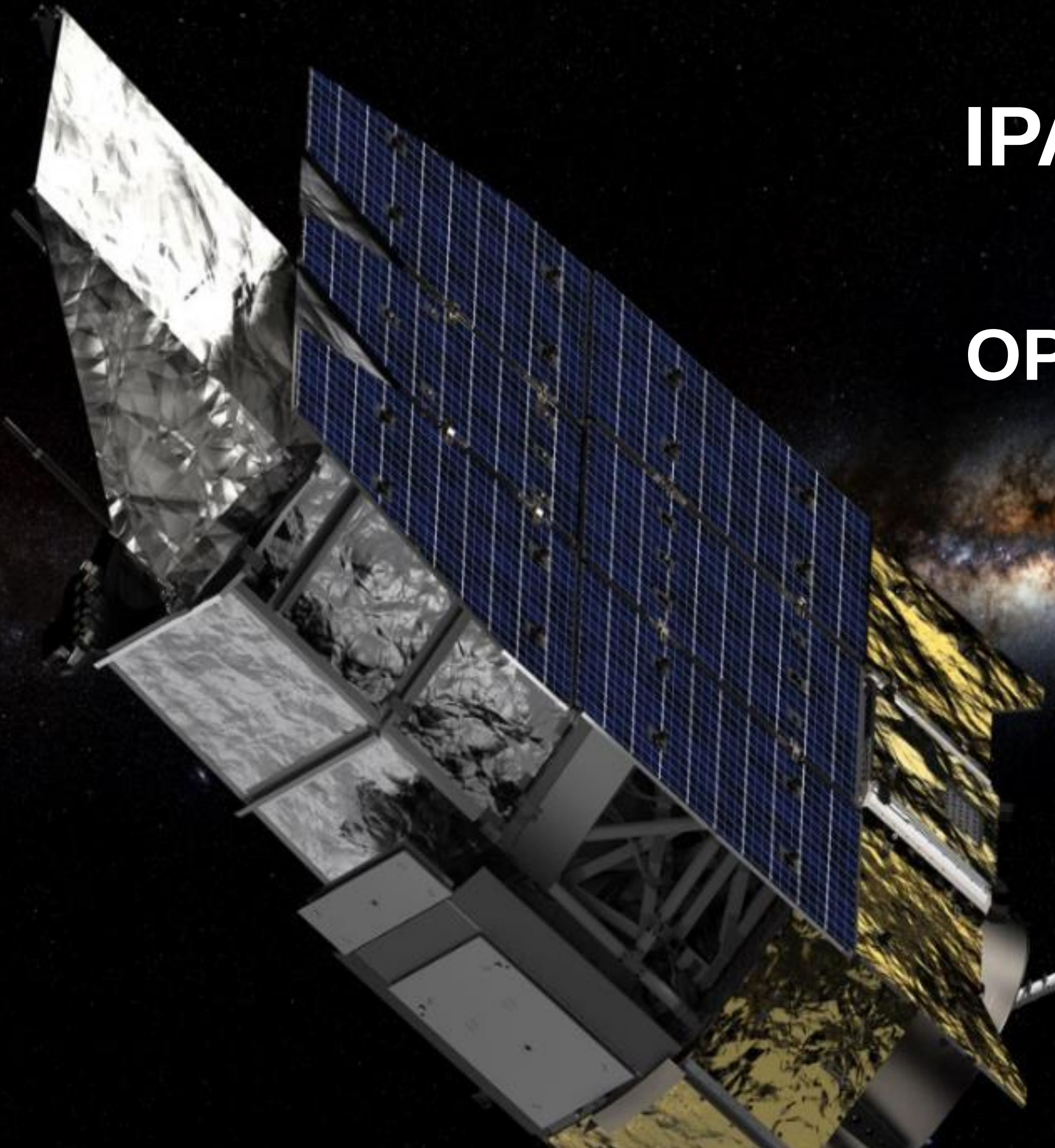
ROMAN SPACE TELESCOPE

IPAC Science Support Center

Coronagraph Instrument

OPERATIONS SYSTEM and DATA MANAGEMENT SYSTEM



Jim Ingalls (SSC/COS Lead)

Alexandra Greenbaum *(SSC/CDMS Lead)*

26 August 2024

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• JAPAN AEROSPACE EXPLORATION AGENCY • LABORATOIRE D’ASTROPHYSIQUE DE MARSEILLE •
• CENTRE NATIONAL d'ÉTUDES SPATIALES • MAX PLANCK INSTITUTE FOR ASTRONOMY •

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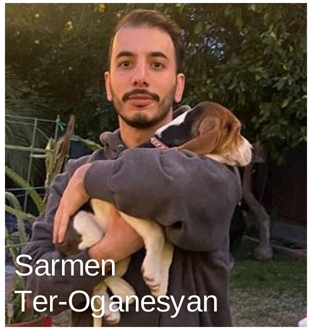


Summary of IPAC Role on Roman

- **IPAC manages the Science Support Center (SSC), responsible for:**
  - Managing the proposal submission and peer review process for observing time allocation (General Astrophysics Surveys) and for data analysis funding
  - Implementation of science data pipelines for (1) for wide-field spectroscopy with the grism and prism, and (2) Galactic Bulge Time Domain Survey
  - Participation in Coronagraph Instrument (CGI) operations: Commanding, Data Analysis Environment for Ground-in-the-Loop adjustments and for Tech Demo
  - Astronomical community engagement for Roman exoplanet science and wide-field spectroscopy
- **During Operations (Phase E), SSC is responsible for:**
  - Running proposal cycles; operating science data pipelines; operating CGI; maintaining and updating software and systems

SSC CGI Roles and Responsibilities

- **Exoplanet Community Support** (community engagement)
  - Public Website
  - CPP support
  - Meetings and workshops (including this one)
- **Coronagraph Instrument Operations**
  - Commanding and telemetry monitoring
  - Develop tools to create observations
  - HOWFSC/GITL operations, including commanding and uplink
  - Assess and trend health, safety and instrument performance
- **Coronagraph Instrument Data Management**
  - Develop and operate Data Analysis Environment (DAE) for CTC and CPP
  - Process L0–L1 data and deliver to SOC for archiving
  - Validate and deliver L2 – L4 CGI data (calibrated, higher products) produced by CTC to SOC for archiving
  - HOWFSC/GITL data processing

Ground System architecture

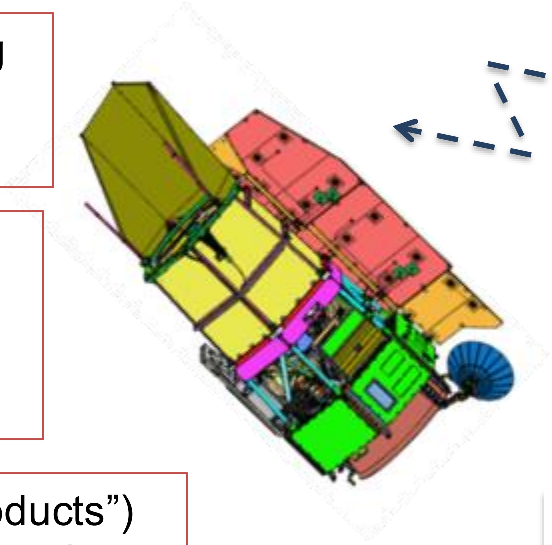
HOWFSC = high-order wavefront sensing and control
GITL = Ground In The Loop

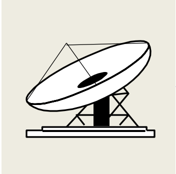
Data Downlink/Uplink:
Ka-Band (observation data)
S-Band (commands, housekeeping and HOWFSC data)

Raw observation image files ("L1 data products") will be in STScI Archive < 72hr after observation.

CGI scheduling: weeks or months in advance to ensure ground station contact during critical HOWFS GITL periods.

Does not support 'joysticking' or mid-observation changes!





Housekeeping Data and HOWFSC/GITL Images

Observatory Commands

Mission Operations Center (MOC; GSFC)

Observation Data Files

Science Operations Center (SOC; STScI)

Data Archive

Observation Planning & Scheduling Products

Observation Planning & Data Products

Science Support Center (SSC; IPAC)

- Observation Data Analysis Environment
- HOWFSC Processing Environment
- ASIST Cmd and Tlm workstations

CGI Housekeeping/HOWFSC Data

CGI Commands & Products

Observation Specifications & Data Products

Coronagraph Community Participation Program (CPP)

Coronagraph Technology Center (CTC; JPL)

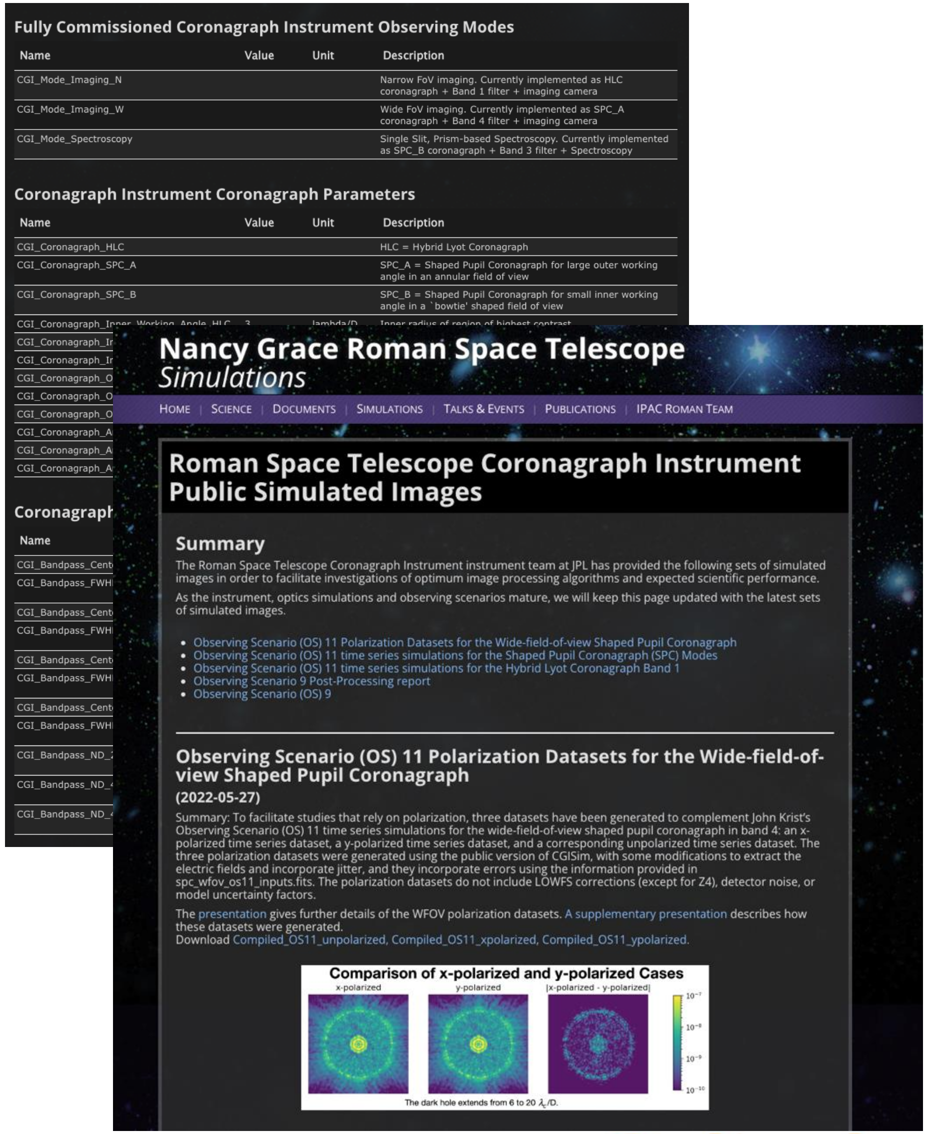
Caltech

Responsibilities

	SSC Responsibility	CTC Responsibility	CPP
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 procedures • Commanding during nominal ops • Scheduling and commanding interface	• Deliver CGI command dictionary • Design data collection procedures and deliver to SSC • Create Observation Specifications	• Support creation of Observation Specifications
CGI Data Processing	• Receive and process CGI data to Level 1 • Validate and deliver Levels 1/2/3/4 data and calibration reference files to SOC for archiving	• Process CGI data to Levels 2/3/4 • Analyze calibration data and produce calibration reference files • Deliver Levels 2/3/4 data and calibration files to SSC	• Provide algorithms for L2/3/4 data processing and associated observation calibrations
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	
Community Engagement	• Host instrument parameters on website • Support observers • Manage press releases, conference coordination	• Preparatory work in community • Engage community in making the most of Tech Demo observations • Communicate results via peer-reviewed publications	

SSC at IPAC Exoplanet Community Support

- **Public Website** (roman.ipac.caltech.edu)
  - CGI instrument parameters (eg., bandpasses, FOVs, DQE)
  - CGI simulated images and simulation code
  - Microlensing simulations and parameters
- **CGI Community Participation Program Support**
  - Team internal wiki hosted at IPAC
- **Meetings and Workshops hosted by SSC**
  - "Science in Our Own Backyard": 18-20 Jun 2019
  - First in-person meeting of CPP: 7-9 Feb 2024 (7 US, 4 International PI's and their groups)
  - "Challenging Theory with Roman": 9-12 Jul 2024
  - CGI Test Results Information Session (this meeting): 26-27 Aug 2024



CGI Operations and Data Management at SSC

CGI Operations System (COS)

- SSC operates CGI through a combination of real-time and event-driven operations

- Observation planning & specification: SSC translates observation designs into onboard command sequences

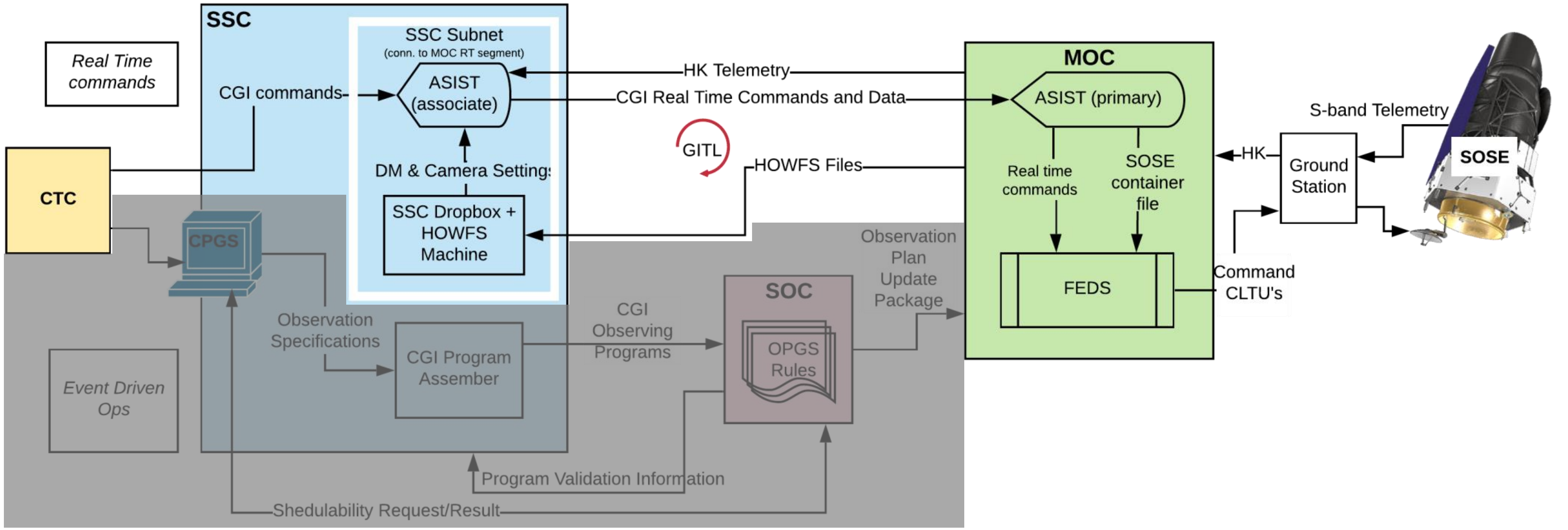
CGI Data Management System (CDMS)

- Data Analysis Environment: SSC provides a processing environment, level 1 products, and mechanism to receive higher level (2-4) data products for archiving in the official Roman Archive at SOC.

Community interfaces

- HOWFSC/GITL runs autonomously as SSC: SSC processes data from scheduled High Order Wavefront Sensing activities and manages the Ground in the Loop

Real-Time Operations

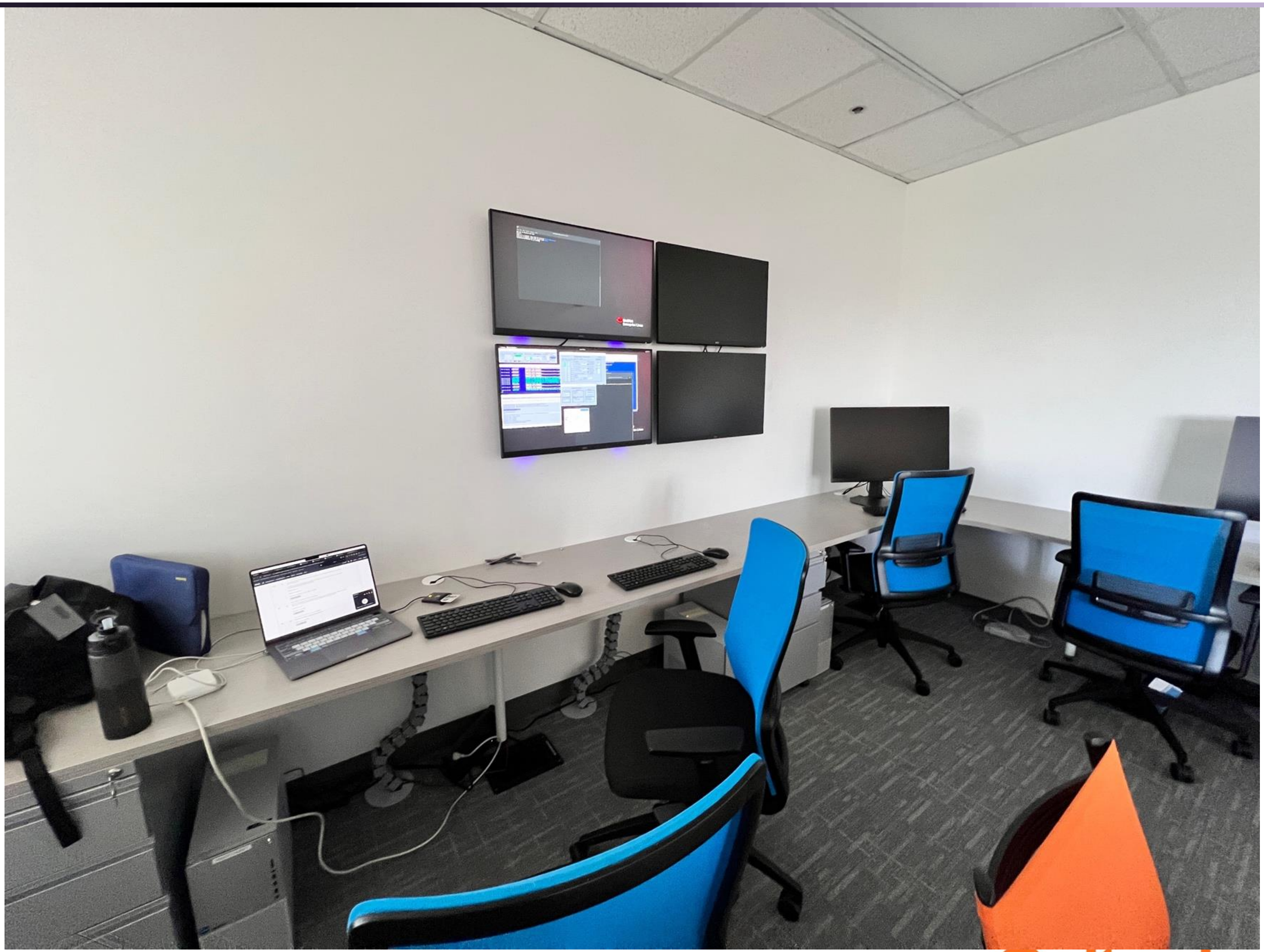


For **Real-time** operations, the SSC will host one or more workstations connected via the MOC to the spacecraft enabling **sending of commands and viewing telemetry** in real time.

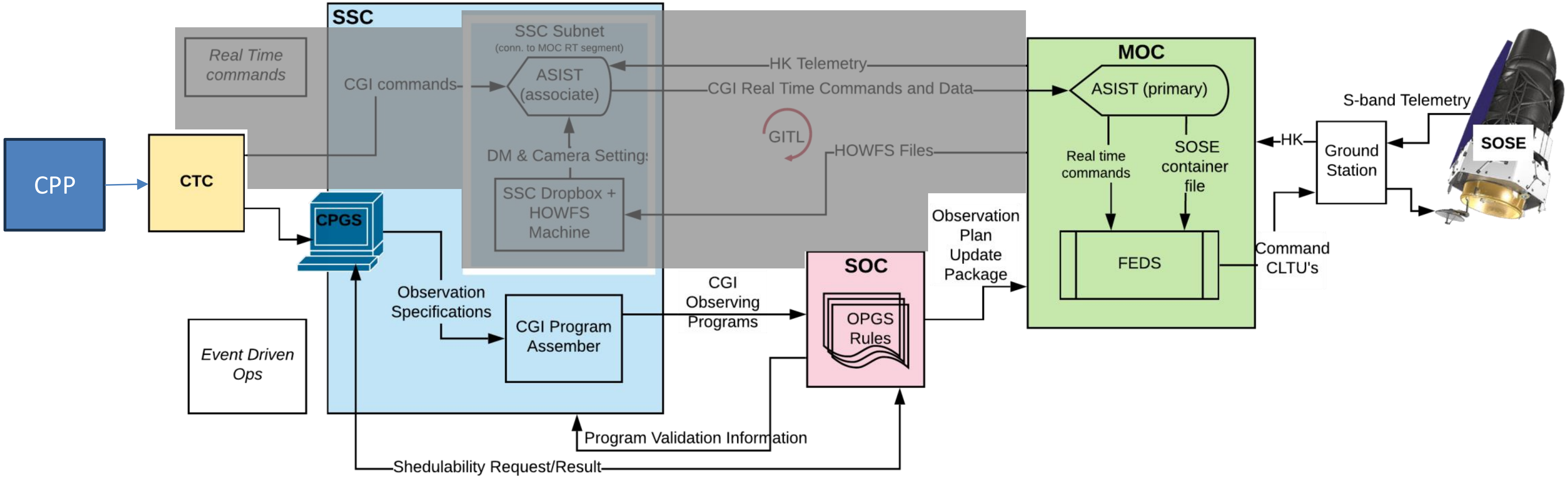
Example uses: Commissioning, instrument health & safety, anomaly resolution

Roman Coronagraph Operations at IPAC

- 6 computers (3 Ops; 3 test) running **ASIST** (Advanced Spacecraft Integration and System Test) command and telemetry software.
- Command-line interpreter of **STOL** (Systems Test and Operations Language)
- Dedicated connection to MOC at GSFC
- Tested in Mission Readiness Tests 1 (3/2024) and 2 (8/2024), including commands that reached the spacecraft.



Event-Driven: Planned Observations



For **Event-Driven** operations, the S/C Science Observation Sequence Engine (SOSE) interprets sequences of high-level commands that were pre-scheduled into an Observation Plan by the ground system (CTC->SSC->SOC->MOC).

Example uses: schedule tech demo observations & calibrations

Observation Preparation and Specification

SSC interprets the wishes of CGI users (CTC, CPP) into a language understood by ROMAN: STOL command scripts and visit files

- Observers submit their observing parameters using **CPGS**, a web based graphical interface built by SSC.

- The output of CPGS is delivered to SOC to construct a Roman **Observation Plan**, an ordered list of Visit Files which execute on the observatory.

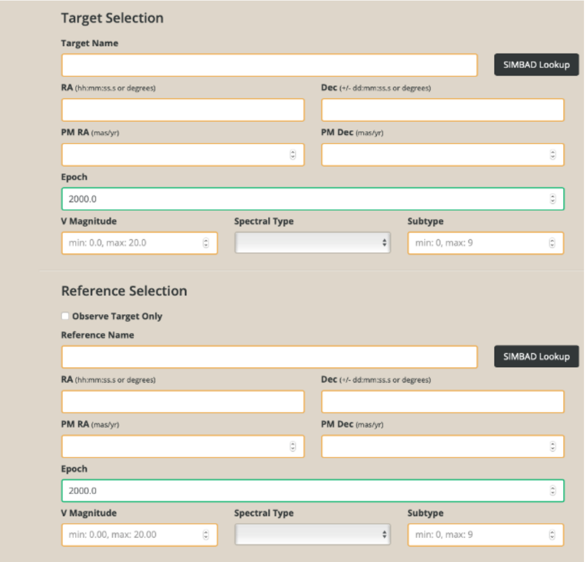
- **Visit Files** are the means by which observations are scheduled in advance, and contain **sequential calls to on-board STOL procs**. Visit files are designed by CTC, adapted to the ground system data model by SSC, and codified in software by SOC

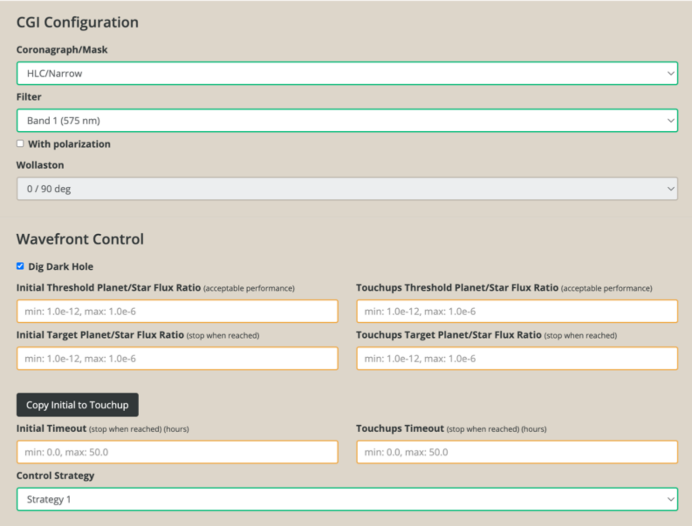
- All CGI flight software (FSW) commands and telemetry are invoked via **scripted command procedures ("procs")** written in GSFC's Systems Test and Operations Language (STOL). Procs are designed by CTC and built by SSC.

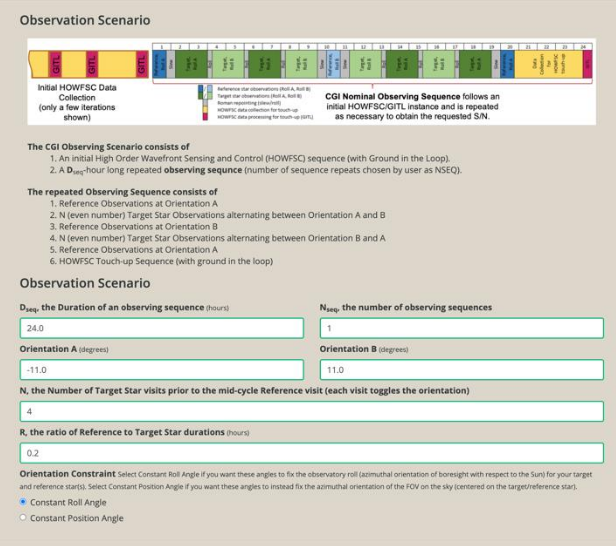
Observation planning and specification: CPGS

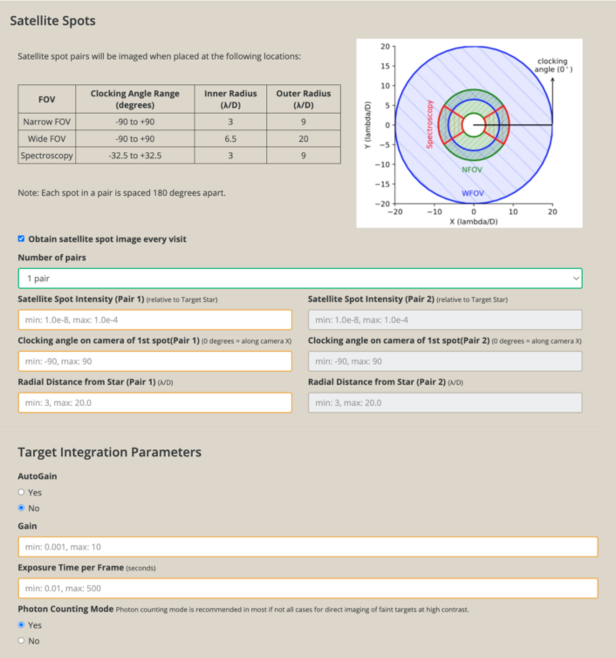
CPGS (command product generation Software) is the first step in the process of creating a CGI observation.

- Web-based tool designed to allow users to select targets and choose from the subset of baseline modes.
- Tool includes the ability to check observability with project planning and scheduling (SOC) based on target, observation specifications, and other observations in the queue.





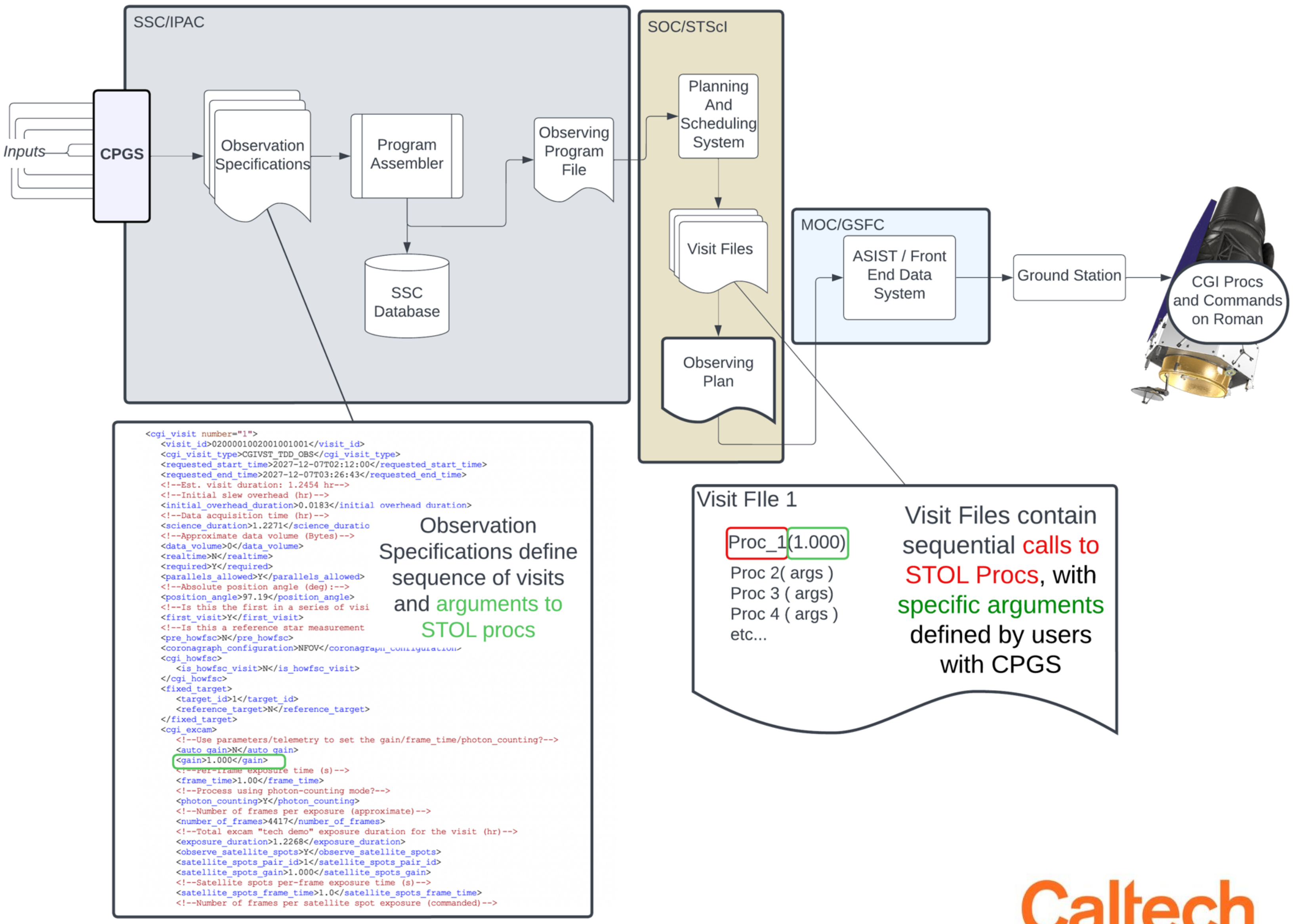




CPGS tutorial for CPP members:
https://collaboration.ipac.caltech.edu/display/romancoronagraph/Observation+Planning+Working+Group+Meeting+Notes

Observation planning and specification: Visit File Creation

- CPGS output is fed into the SOC scheduling system to create **visit files**, which carry out pre-scheduled observations via calls to STOL command scripts (”**procs**”).
- CTC defines STOL procs and visit file types needed to operate CGI.
- SSC writes procs to GSFC flight ops standards
- SSC translates visit file designs into a form compatible with CPGS input fields and SOC database.
- SSC works with SOC and Mission Systems to create the baseline visit file template for each type.



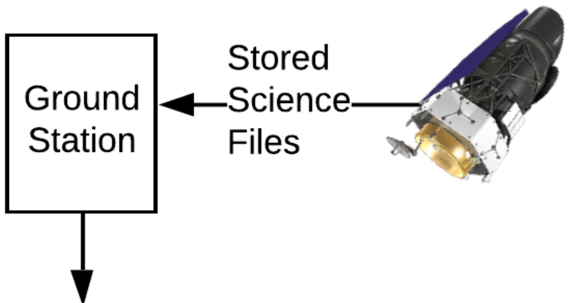
CGI Operations System (COS) Status

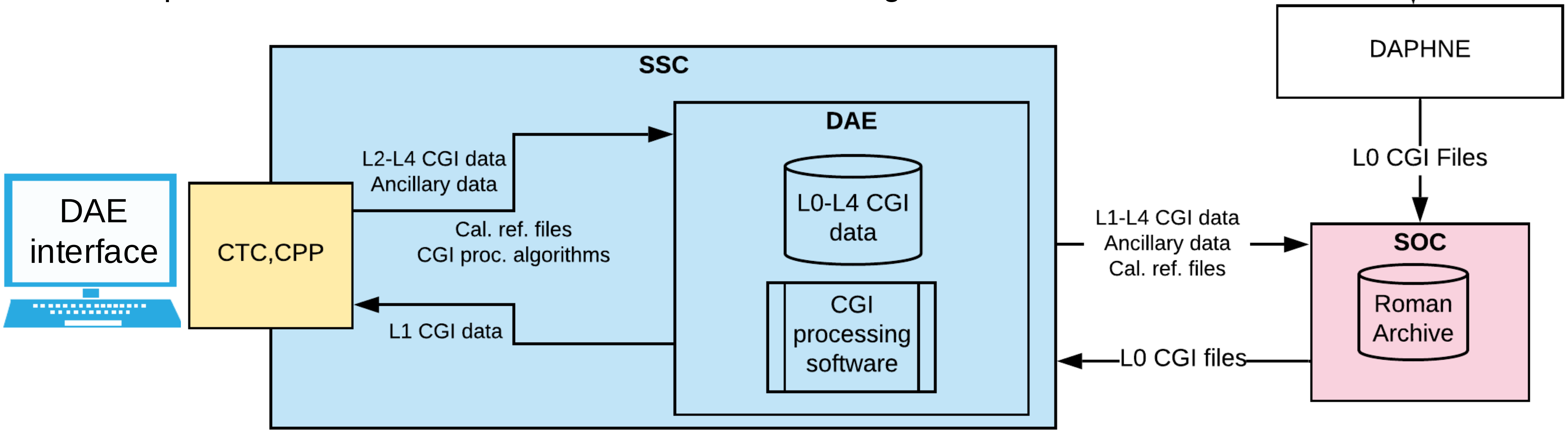
- Mission Readiness Tests (MRTs) 1 and 2 demonstrated real-time commanding, telemetry, and data transfer capability between SSC and MOC.
- SSC has built 100+ flight procs for use during CGI FFT (winter 2023) and TVAC (spring 2024) (eg., see slides on HOWFSC later).
- SSC-written flight procs were used to carry out a CGI-S/C interface test in June 2024. An ad-hoc visit file (hand-edited, not produced via the Ground System) was used.
- The capability of the Ground System to create and execute visit files to carry out Tech Demo Observations is being built. These will be the first “official” CGI visit files tested, in MRT 6 (Dec 2024)
- Subsequent MRTs (spring 2025 onward, see backup slide) test the capability of the Ground System to create and execute HOWFSC, commissioning, and calibration observations on CGI.
  - CTC is preparing “Rev D” of STOL proc and visit file designs
  - SSC is using prelim Rev D to update STOL procs, create Visit file templates, and make CPGS adjustments to carry out observations. Results will be ready for testing in 3 stages: (Fall 2024; bulk of capability), (Summer 2025; general calibration), (Spring 2026; spectroscopy/polarimetry)

The Coronagraph Data Analysis Environment

SSC provides a Data Analysis Environment to process EXCAM imaging/spectroscopy data to support the technology demonstration

- Rapidly process all raw telemetry into standard formats for astronomers
- Provide the processing environment for community members and technologists to perform higher level CGI data processing.
- Perform data quality assessments and header validation, and sends the processed data at each level to SOC for archiving



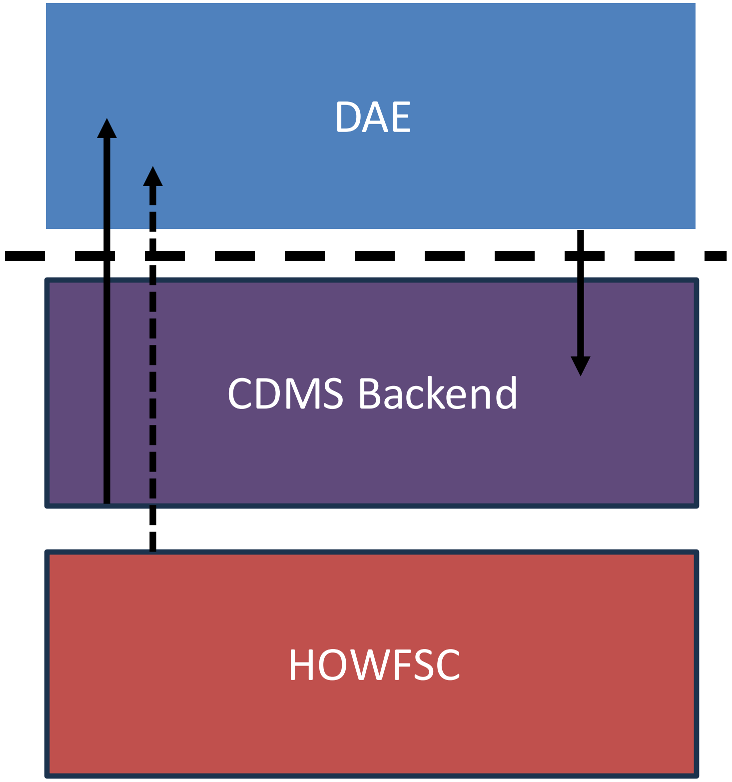


DAE Resources and Data Flow

All official data products (L1-L4) will be made publicly available in the Roman archive

What the DAE provides:

- Direct access to L1 data, once generated
- Processing resources
- Common location for coordination of tools and data
- Summary of ancillary telemetry



CGI Data Management System (CDMS) pipeline

- Automated L0 to L1 processing, delivery L1 to SOC for archiving
- Working with CPP/CTC to finalize data formats
- Data quality assessment, support performance monitoring & report
- Validate L2-L4 for format/integrity & anomalies
- Deliver L2-L4, ancillary and calibration data to SOC for archiving
- Also automated data processing for HOWFSC Ground in the Loop

CDMS Pipeline Tools in Action (CGI I&T)

Prototype L0→L1 software allowed processing of raw telemetry from CGI for image acquisition and HOWFSC loop during FFT and TVAC

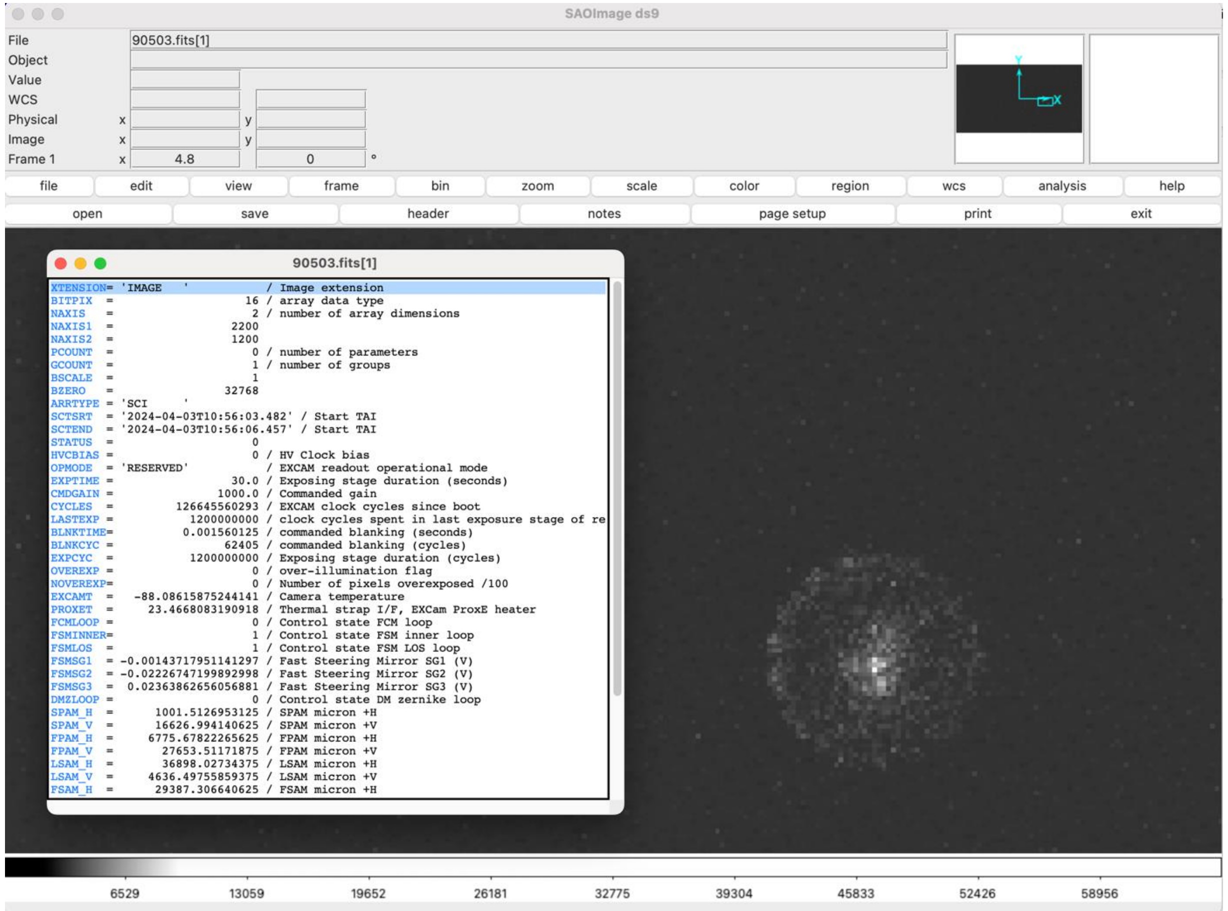
CTC software & testing infrastructure

Run CGI HOWFSC Data Collection → L0→ L1 → CTC GITL → HOWFSC Pipeline incl. command procedures

Wrapper/glue for Analysis (CTC)

L0→ L1 For Normal EXCAM Operation (non-HOWFSC) → L1→L2

SSC tools in blue boxes

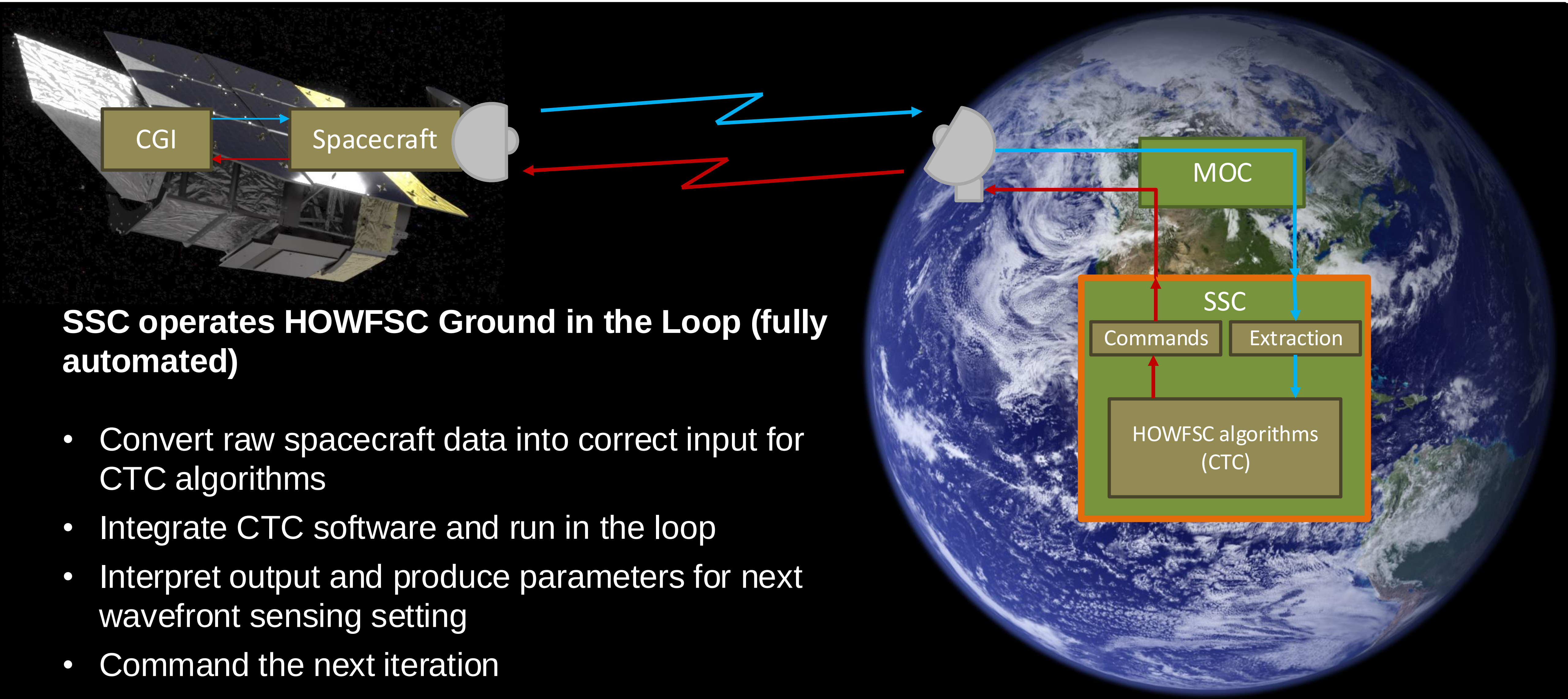


Being integrated into official CPP Pipeline

CGI Data Management System (CDMS) Status

- Expect to have a prototype DAE available this Fall for testing by CPP and CTC where the CGI Data Reduction Pipeline can be deployed
- CDMS modules built and used and integrated into CTC software for I&T processing and HOWFSC loop
- Data processing for HOWFSC loop demonstrated for Ground System Release 2 April 2024
- CDMS pipeline high level architecture & database in progress
- With feedback from CPP, updating file formats & header schema

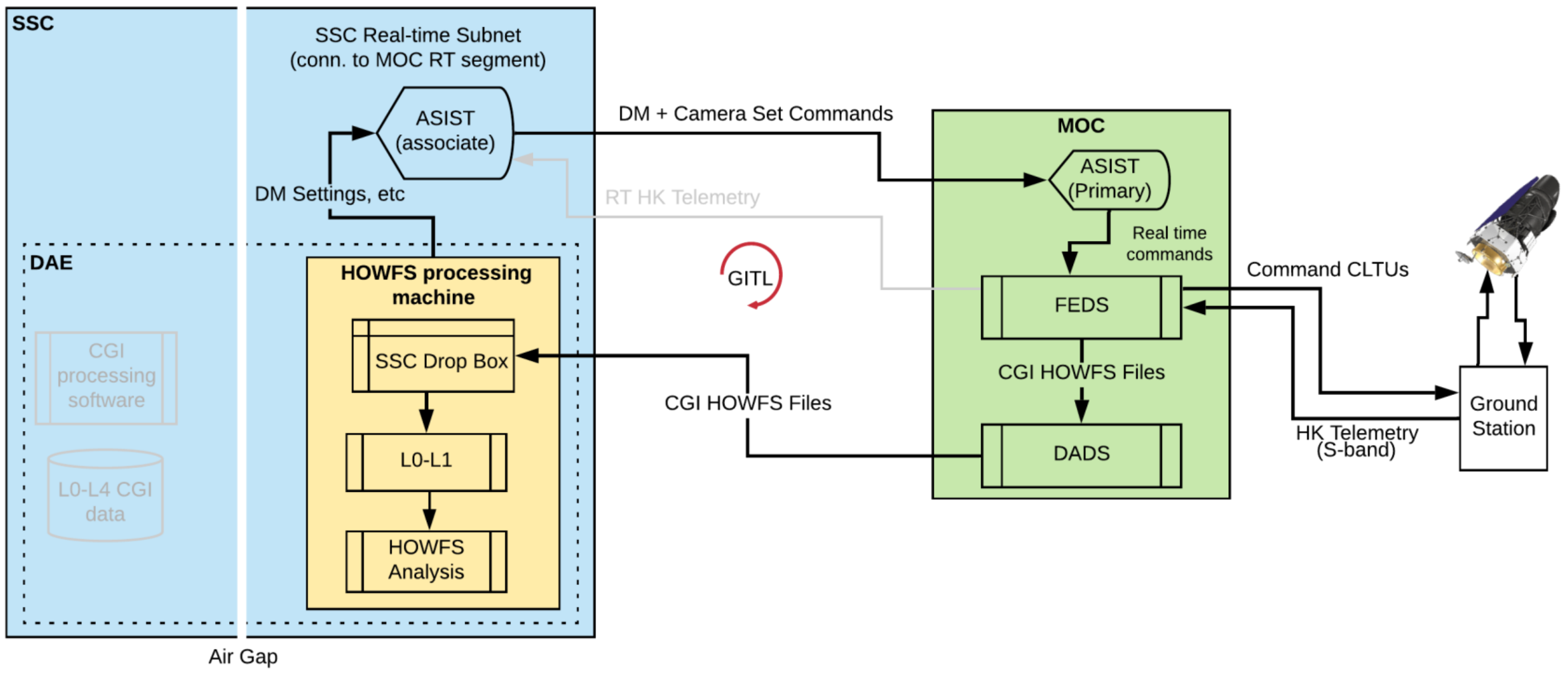
High Order Wavefront Sensing and Control at IPAC



SSC operates HOWFSC Ground in the Loop (fully automated)

- Convert raw spacecraft data into correct input for CTC algorithms
- Integrate CTC software and run in the loop
- Interpret output and produce parameters for next wavefront sensing setting
- Command the next iteration

Event-Driven/Real-Time Hybrid Operations: HOWFSC

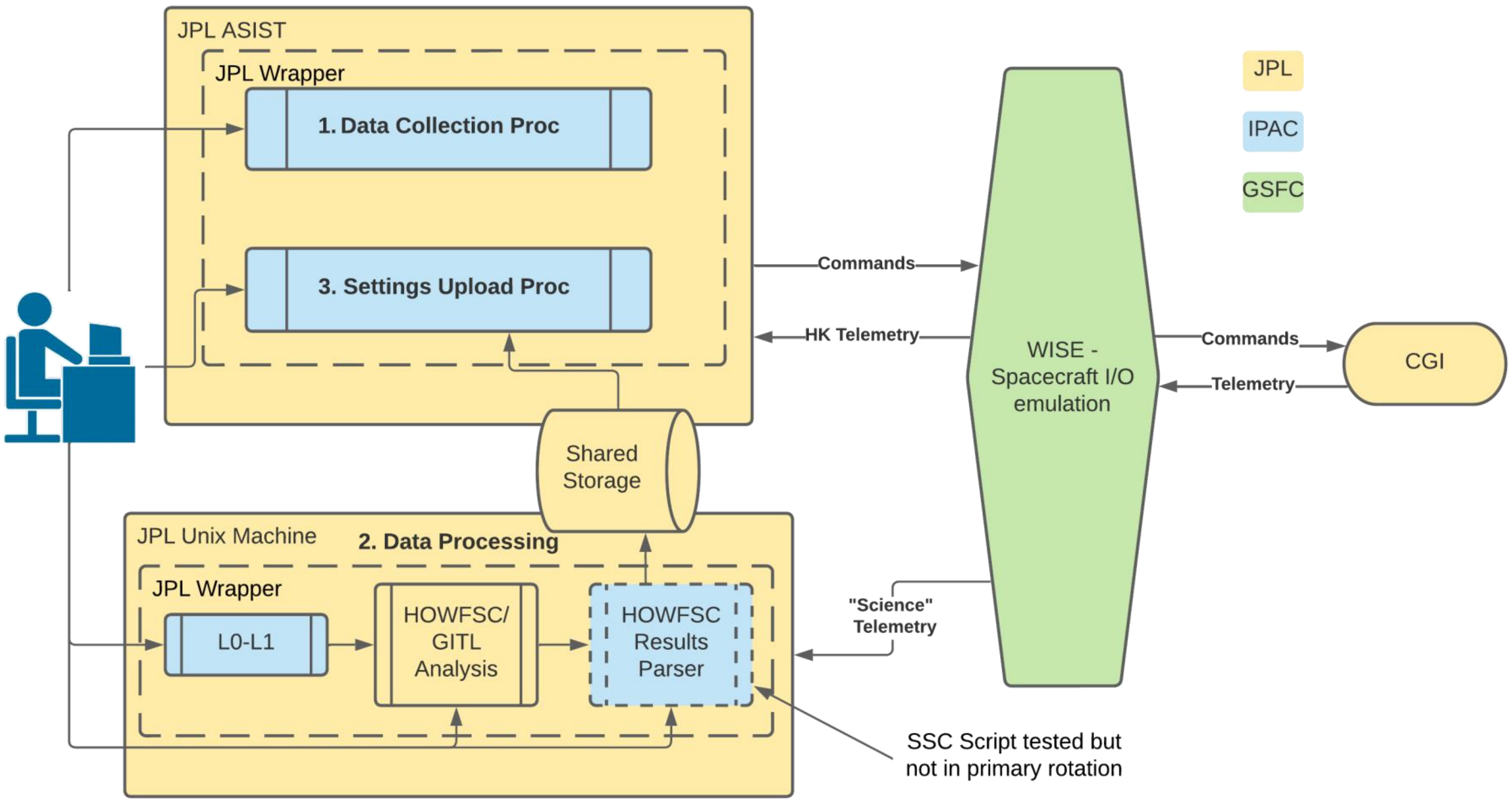


1. Event-driven command sequence begins the process on board.
2. Prioritized HOWFSC data downlinked from the Housekeeping Recorder via S-band; HOWFSC files routed by MOC directly to SSC dropbox.
3. HOWFSC machine processes data to “HOWFSC-L1” and performs calculations using CTC software.
4. Autonomous ground procedure produces new settings, uploads them to CGI, and enables event-driven processes to continue.

SSC Supports HOWFSC in action: Instrument I&T

- Both during FFT and TVAC, SSC-written flight STOL procs were used for HOWFSC data collection and upload of new settings
- L0-L1 software was used during all Instrument I&T processing of EXCAM data, including HOWFSC
- Execution was invoked by JPL wrapper scripts, as opposed to flightlike methods (visit files, automated pipeline)

HOWFSC/GITL Testing during Instrument I&T
(eg. FFT-27, TV-30)



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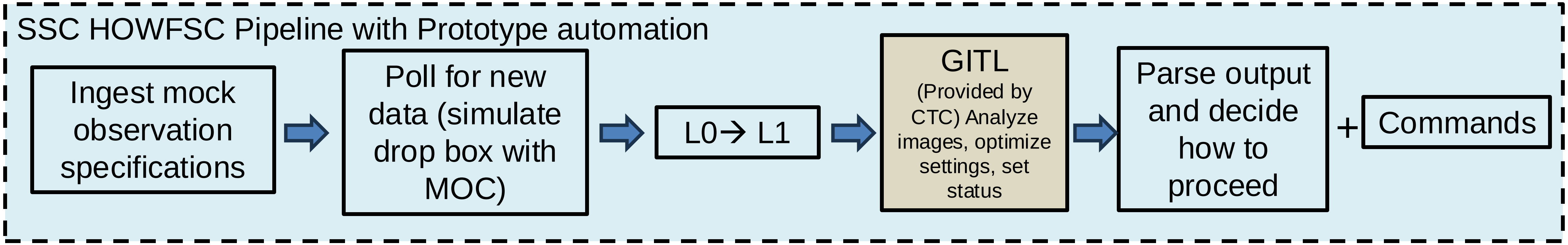
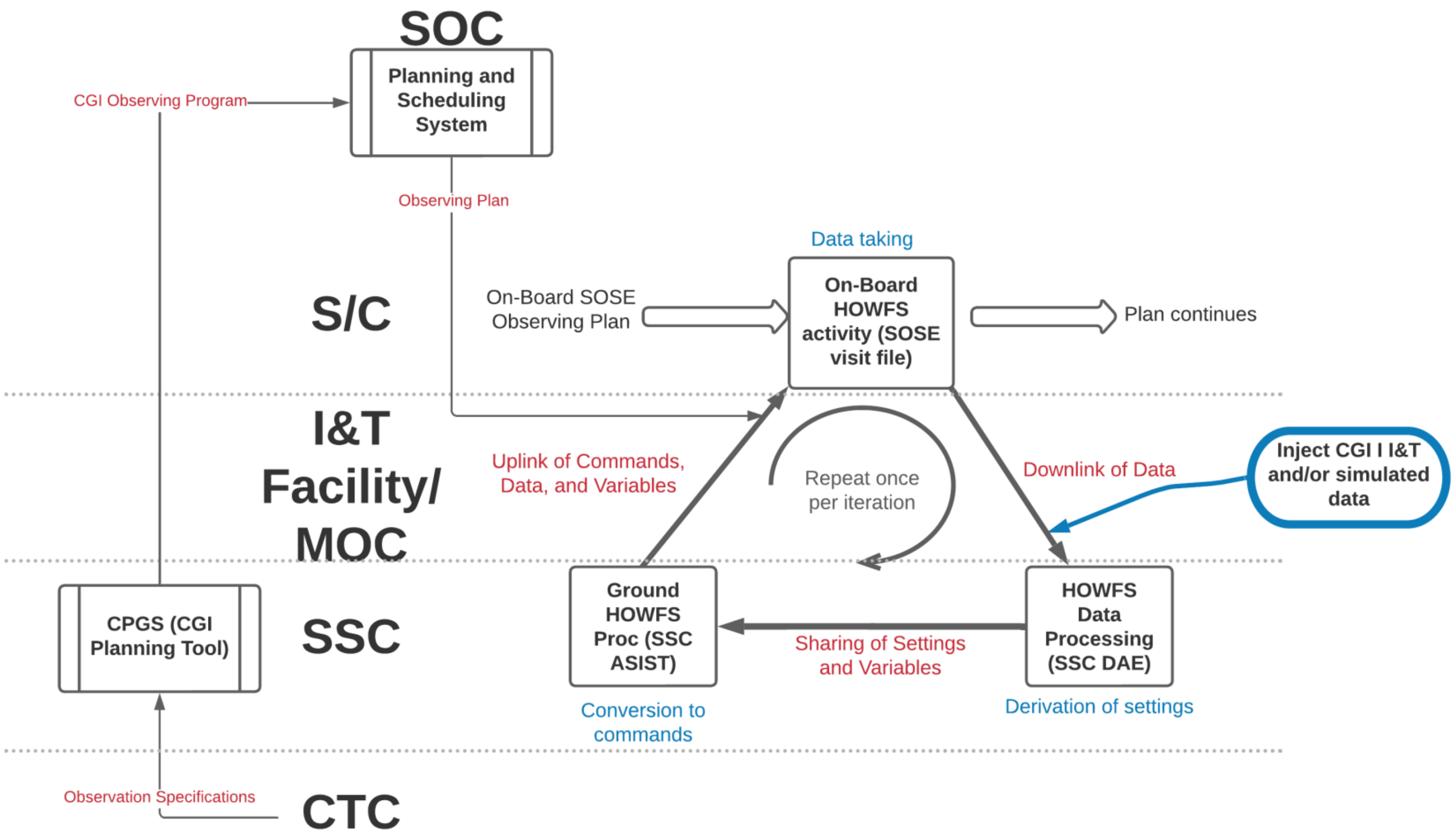
SSC Supports HOWFSC in action: pipeline at IPAC

- Prototype of Nominal Ops HOWFSC processing pipeline verified at SSC (raw data to commands, no instrument) in May 2024

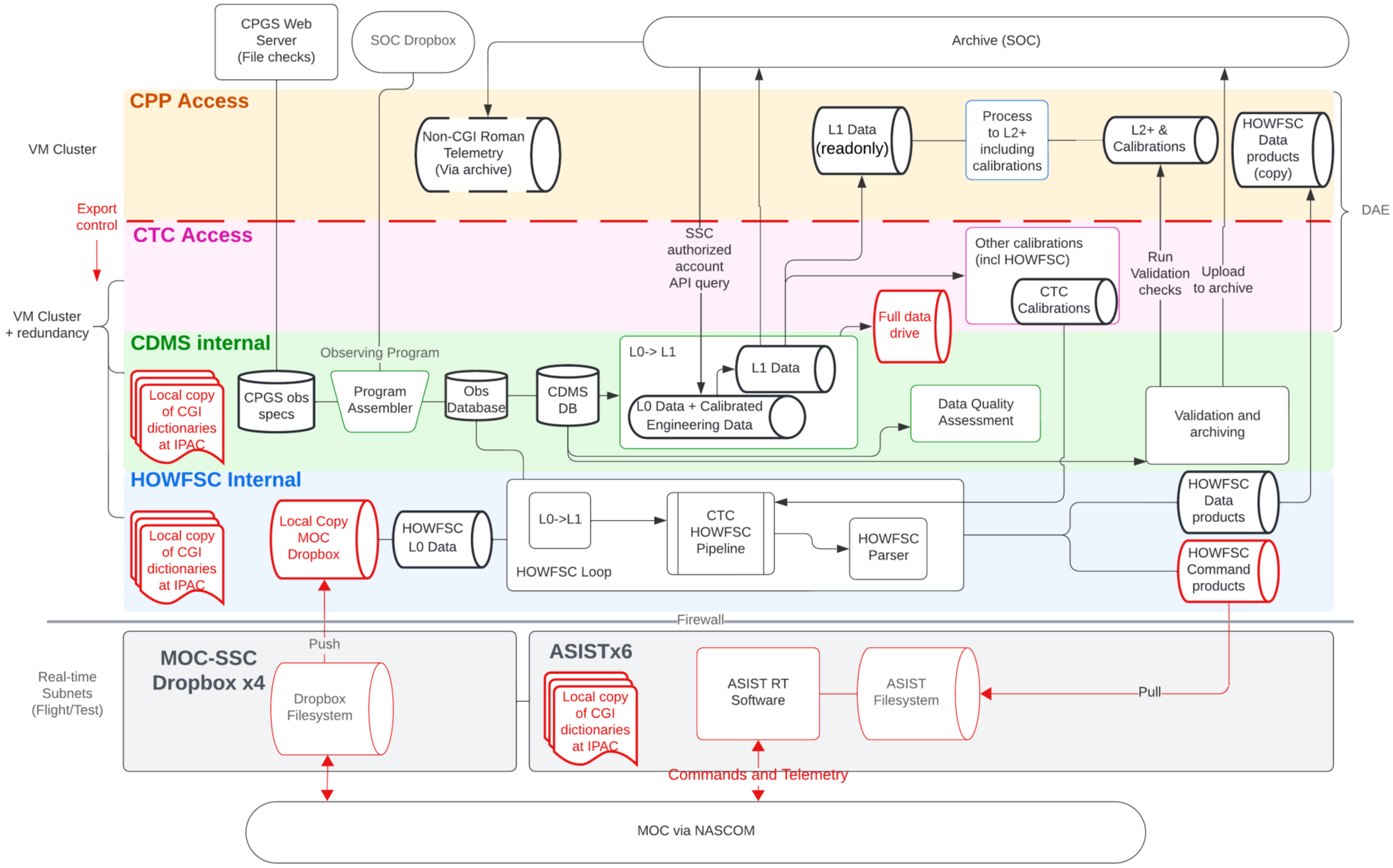


SSC Supports HOWFSC in action: Roman I&T



- HOWFSC Upload proc (along with other SSC-written procs) was used in the Spacecraft/CGI interface test June 2024 just after instrument delivery.
- HOWFSC/GITL operational aspects will be the focus of Mission Readiness Test (MRT) 7c and 8 (Day in the Life with HOWFSC) in spring/summer 2025
- Operational aspects of HOWFSC/GITL will also be exercised during MRT 9 (Week in the Life) in 2026
- As there will be no appropriate light source in Observatory I&T, we will use measurements taken during Inst. I&T for the download portion.

Operations and Data Management Software Systems



- Operations and Data Management software are highly integrated.
- Different user types require multiple levels of data security
- Real-time subnet (bottom) is mature and essentially ready for operations.
- Next steps:
  - CPGS obs specs into CDMS
  - Prototype DAE

Upcoming milestones

- **Visit file definition based on CTC prototypes**
  - Work with CTC, SOC, and Mission Systems to finalize visit file definitions to carry out all aspects of data acquisition, calibration, engineering, etc
  - Adjust CPGS interface and observation specification creation to support all visit file types
- **Update CGI procs to latest post-TVAC designs of CTC**
  - New conops for thermal, adjustments to HOWFSC, calibration, fault protection, functional testing
  - Verification on Functional Testbed (FTB) in collaboration with CTC
- **Demonstrate data ingest with TVAC data**
  - More finalized file formats
  - Publicly archive TVAC data
- **Integration of observation specifications (COS) with data management system (CDMS)**
  - Tie Observation ID to data products
  - Incorporate observation configuration into headers
- **Stand up Data Analysis Environment for user testing**
  - Prototype available in Fall 2024
  - Deploy prototype Coronagraph Data Reduction Pipeline (from CTC)
  - Exercise data exchange for L1-L4 products
  - Assess resources needed and make adjustments ahead of launch

Summary

- **CGI SSC Team is working with the Roman Ground and Mission systems, and community, to get the most out of the Tech Demo**
  - Design and command observations flexibly and efficiently
  - Execute HOWFSC/GITL efficiently
  - Support observation planning and data analysis by CTC and CPP
  - Deliver data & documentation to Roman Archive
  - S/W tools and processes have been exercised during CGI FFT, I&T, and for interface test with S/C
  - SSC will be ready to support on-orbit operations starting with IOC/Commissioning
- **Community support by SSC is currently focused on CTC and CPP, but could extend to archival investigations**
  - Public data will provide great training sets for graduate students and early-career researchers, may well enhance tech demo returns
  - Documentation provided by CTC/CPP a good foundation but may need augmentation for archive users
  - Suggestions welcome for optimal use of limited support resources

EXTRA SLIDES

Data Levels

- Level 0: Raw packetized science data received at the Roman ground stations. The data taken on the science recorder are transferred to the DAPHNE cloud, then to the SOC. The data taken on the housekeeping recorder are transmitted to the MOC. The SSC accesses these data from the SOC and the MOC.
- Level 1: Raw, uncalibrated images (FITS or equivalent) with formatted engineering telemetry and appropriate metadata. Generated by the SSC, transmitted to the SOC. Also stored in the DAE.
- Level 2a: Calibrated images, not coadded. Produced by CTC and participating scientists in the DAE, validated for format, naming convention and data quality by SSC, transmitted to the SOC.
- Level 2b (coadded): Coadded calibrated images. After coadding, the data will be flat-fielded. Produced by CTC and participating scientists in the DAE, validated for format, naming convention and data quality by SSC, transmitted to the SOC.
- Level 3: Photometric, astrometric and wavelength calibrated images. Produced by CTC and participating scientists in the DAE, validated for format, naming convention and data quality by SSC, transmitted to the SOC.
- Level 4: PSF subtraction and spectral extraction. Produced by CTC and participating scientists in the DAE, validated for format, naming convention and data quality by SSC, transmitted to the SOC.

Items in Blue are responsibility of CTC+PS+CPP

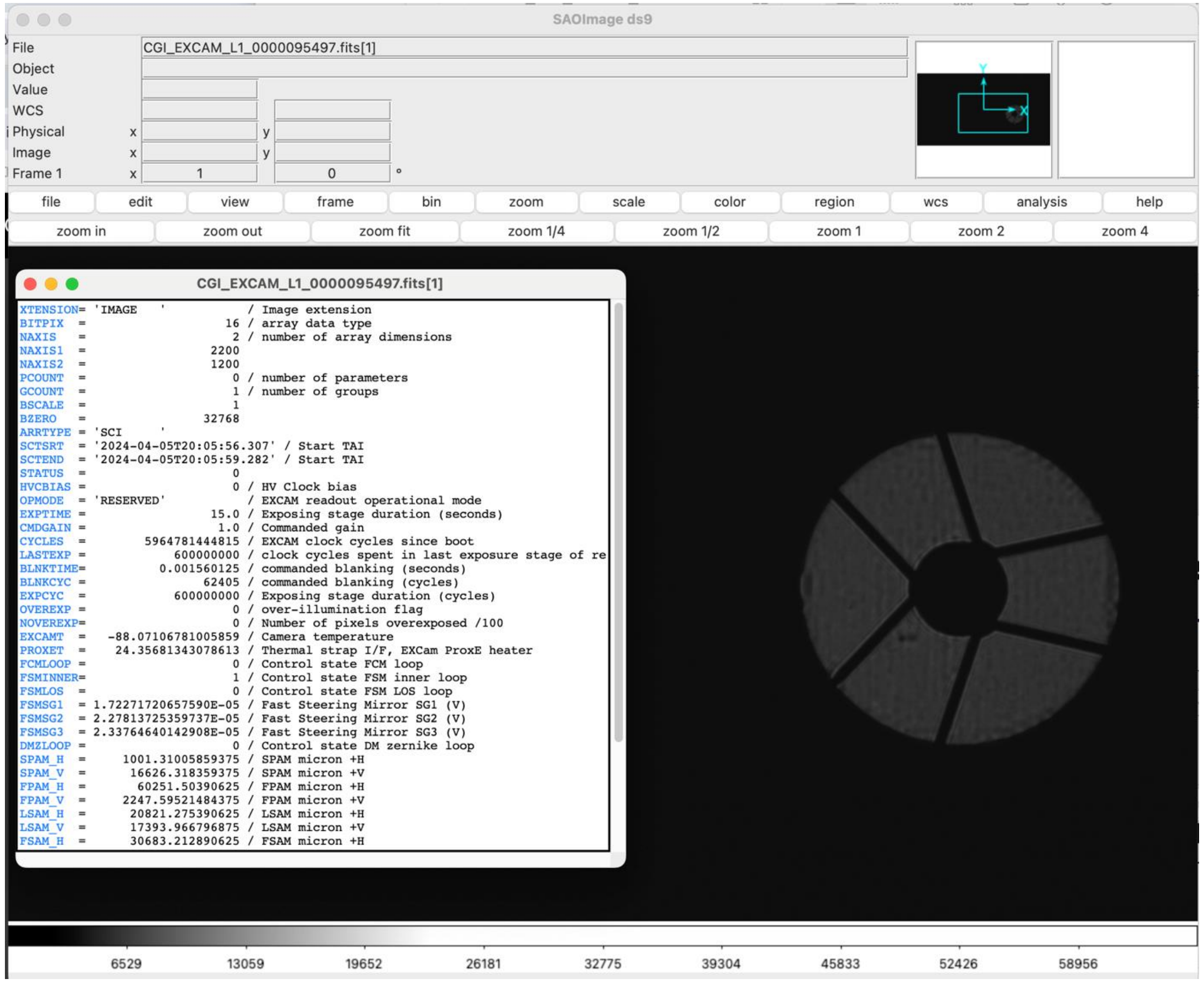
Real Time and Event-Driven Operations

	Real Time	Event-Driven
What is it?	Command-line control with telemetry view	Autonomous, pre-built control sequences
Why do we use it?	“Immediate” access to hardware and telemetry	Most efficient way of routine observation and engineering
How do we control the CGI?	Commands entered at a dedicated workstation	Graphical user interface (GUI) tool (“CPGS” [Command Product Generation Software]) produces specifications files that translate to procedure calls
Where is it accessible?	SSC will have an “associate” workstation onsite	N/A (visit files are uploaded and run autonomously)
When will it be used?	Instrument integration and test (II&T), Observatory integration and test (OI&T), HOWFSC/ GITL*, commissioning, anomaly resolution	OI&T, Commissioning, Phase E (technology demonstration)

* HOWFSC/GITL uses the Roman Ground System real-time infrastructure, but in an autonomous, “hands off” fashion.

Mission Readiness Tests with SSC/CGI key role

- MRT 1b: Tlm & Cmd data flow with Flatsat – March 2024
- MRT 2b: Tlm & Cmd data flow with Spacecraft – Aug 2024
- MRT 6b: momentum unload – Dec 2024
- MRT 7c: Day in the life (DITL) HOWFS/GITL – March 2025
- MRT 7d: DITL “CGI Science” – March 2026
- MRT 8: DITL live observatory – Jun-Sept 2025
- MRT 9: “Week in the Life” – TBD 2026
- MRT 13b1: Commissioning Instrument checkout (TVAC) – Jun-Sept 2025
- MRT 13b2: Commissioning Instrument Checkout (Ambient) – Feb 2025
- MRT 13d: Payload Focus and Alignment – Mar 2026
- MRT 15a: Observatory contingency with flatsat – Feb 2026
- MRT 15b: Observatory contingency with SCIPA/Obs -- Feb 2025/Dec 2025/Mar 2026
- MRT 18c: CGI FSW Upload – Dec 2025
- MRT 19: 10-day automated all-up test – TBD 2026


SAOImage ds9
File CGI_EXCAM_L1_0000095497.fits[1]
Object
Value
WCS
Physical x y
Image x y
Frame 1 x 1 0 °
file edit view frame bin zoom scale color region wcs analysis help
zoom in zoom out zoom fit zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4
CGI_EXCAM_L1_0000095497.fits[1]
XTENSION= 'IMAGE   ' / Image extension
BITPIX = 16 / array data type
NAXIS = 2 / number of array dimensions
NAXIS1 = 2200
NAXIS2 = 1200
PCOUNT = 0 / number of parameters
GCOUNT = 1 / number of groups
BSCALE = 1
BZERO = 32768
ARRTYPE = 'SCI   '
SCTSRT = '2024-04-05T20:05:56.307' / Start TAI
SCTEND = '2024-04-05T20:05:59.282' / Start TAI
STATUS = 0
HVCBIAS = 0 / HV Clock bias
OPMODE = 'RESERVED' / EXCAM readout operational mode
EXPTIME = 15.0 / Exposing stage duration (seconds)
CMDGAIN = 1.0 / Commanded gain
CYCLES = 5964781444815 / EXCAM clock cycles since boot
LASTEXP = 600000000 / clock cycles spent in last exposure stage of re
BLNKTIME= 0.001560125 / commanded blanking (seconds)
BLNKCYC = 62405 / commanded blanking (cycles)
EXPCYC = 600000000 / Exposing stage duration (cycles)
OVEREXP = 0 / over-illumination flag
NOVEREXP= 0 / Number of pixels overexposed /100
EXCAMT = -88.07106781005859 / Camera temperature
PROXET = 24.35681343078613 / Thermal strap I/F, EXCam ProxE heater
FCMLOOP = 0 / Control state FCM loop
FSMINNER= 1 / Control state FSM inner loop
FSMLOS = 0 / Control state FSM LOS loop
FSMSG1 = 1.72271720657590E-05 / Fast Steering Mirror SG1 (V)
FSMSG2 = 2.27813725359737E-05 / Fast Steering Mirror SG2 (V)
FSMSG3 = 2.33764640142908E-05 / Fast Steering Mirror SG3 (V)
DMZLOOP = 0 / Control state DM zernike loop
SPAM_H = 1001.31005859375 / SPAM micron +H
SPAM_V = 16626.318359375 / SPAM micron +V
FPAM_H = 60251.50390625 / FPAM micron +H
FPAM_V = 2247.59521484375 / FPAM micron +V
LSAM_H = 20821.275390625 / LSAM micron +H
LSAM_V = 17393.966796875 / LSAM micron +V
FSAM_H = 30683.212890625 / FSAM micron +H
6529 13059 19652 26181 32775 39304 45833 52426 58956