Project Status

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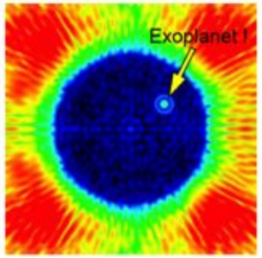
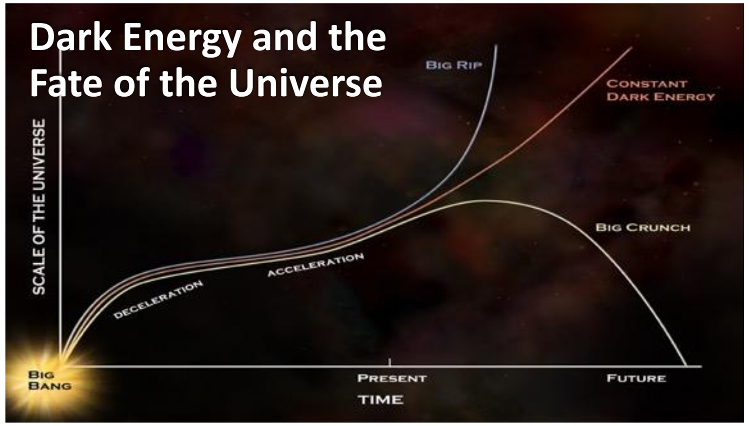
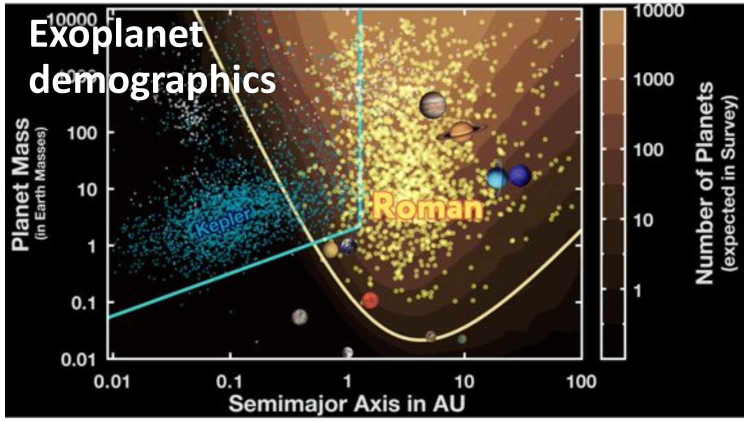
ROMAN SPACE TELESCOPE

Roman Mission Objectives

- **Wide Field Infrared survey**
  - Imaging and spectroscopy to >26.5 AB mag
- **Expansion history of the Universe**
  - Using supernova, weak lensing and galaxy redshift survey techniques
- **Growth of Structure in the Universe**
  - Weak lensing, redshift space distortions and galaxy cluster techniques
- **Exoplanet Census**
  - Statistical census of exoplanets from outer habitable zone to free floating planets
- **General Astrophysics Surveys**
  - Devote substantial fraction of mission lifetime to peer reviewed program
- **Coronagraph technology demonstration**
  - Demonstrate exoplanet coronagraphy with active wavefront control



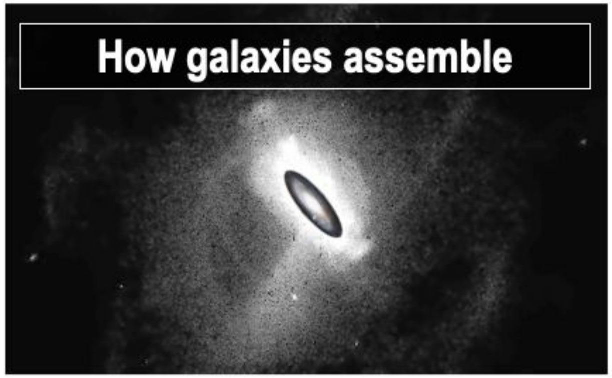


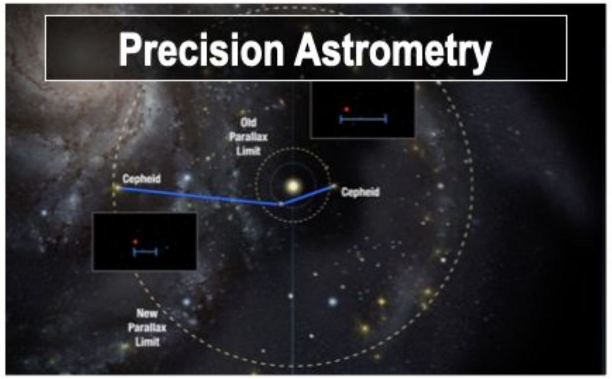


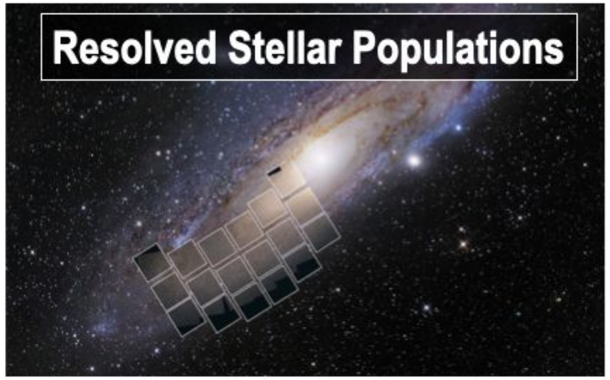

Evolution of the Universe

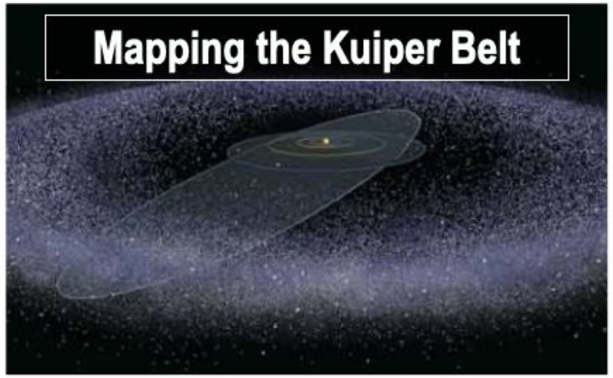

Universe of galaxies

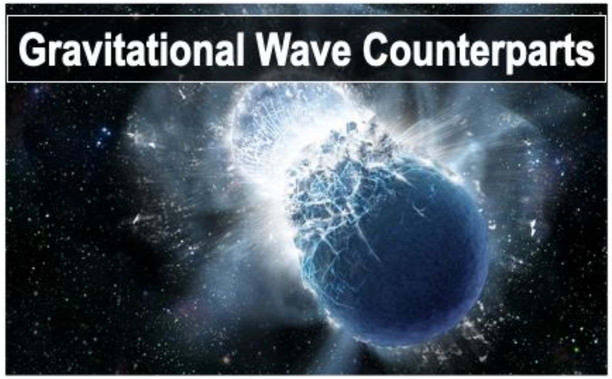

Mapping dark matter


How galaxies assemble

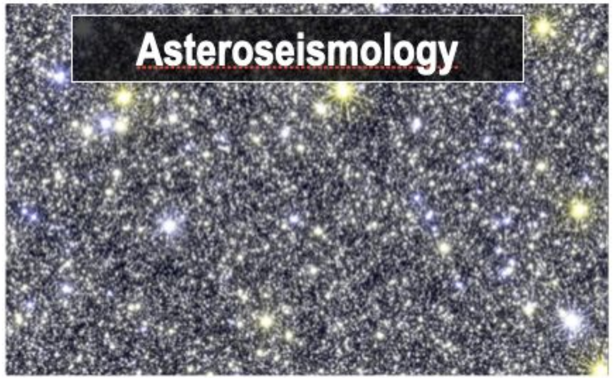

Precision Astrometry
Old Parallax Limit
Cepheid
Cepheid
New Parallax Limit

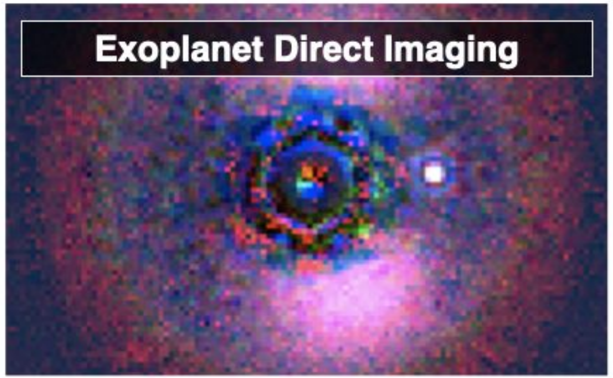

Resolved Stellar Populations

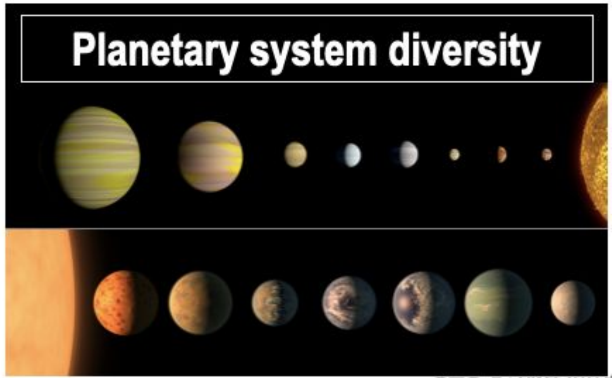

Mapping the Kuiper Belt


Gravitational Wave Counterparts

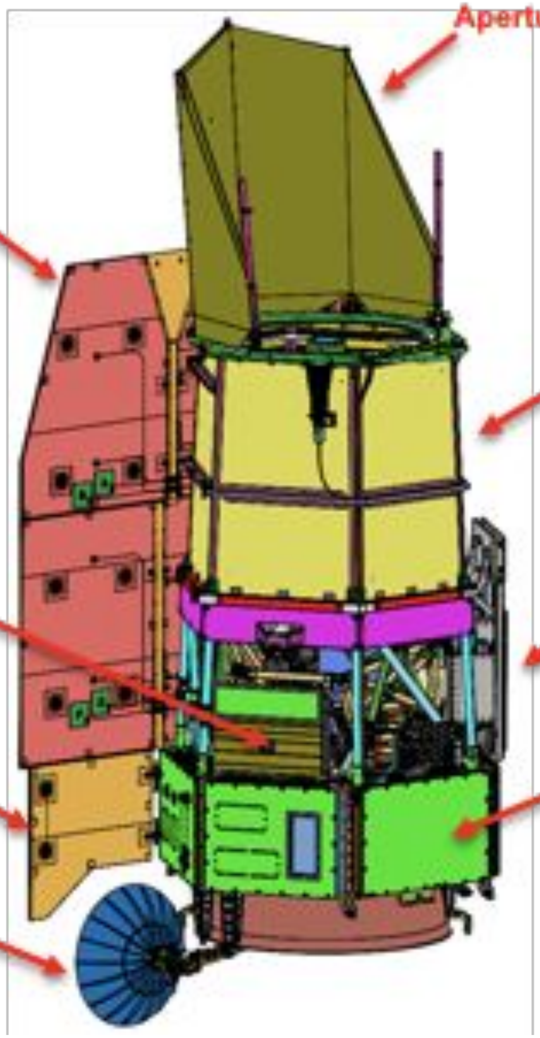

Stellar Nurseries


Asteroseismology


Exoplanet Direct Imaging


Planetary system diversity

Roman Observatory and Instruments



Telescope: 2.4m aperture

Two Instruments:

Wide Field Instrument

- Vis/Near IR bandpasses (0.48 – 2.3 micron)
- Field of view 0.281 deg^2 (~200× HST WFC3-IR)
- 18 4k × 4k detectors (288 Mpixels)

Coronagraph Instrument

- Visible bandpass
- Contrast 10^{-8}-10^{-9}

Data Volume: 11 Tb/day

Orbit: Sun-Earth L2

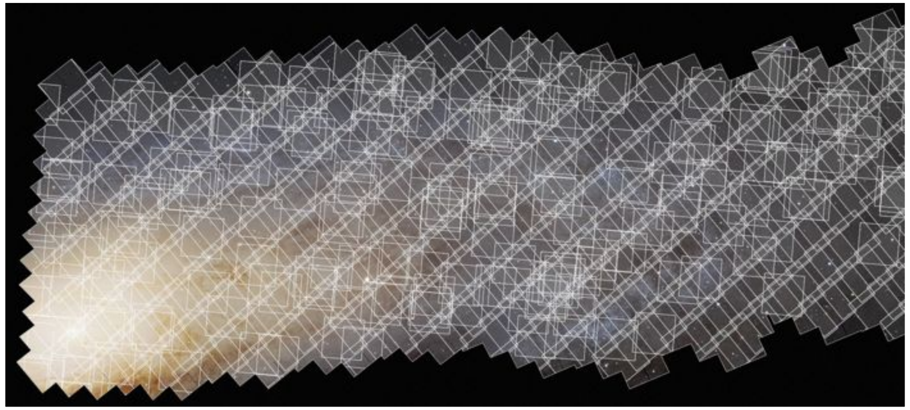
Launch: before May 2027 (Currently Oct 2026)

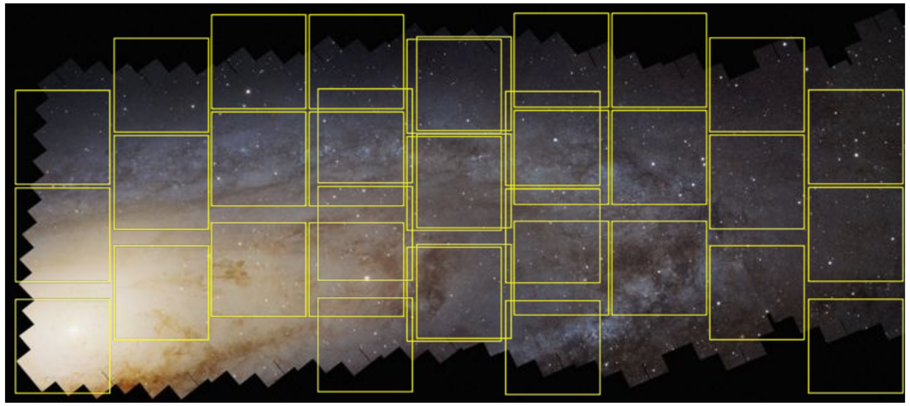
Mission Duration: 5 yr, 10yr goal

https://roman.gsfc.nasa.gov/science/technical_resources.html

Roman as a Precise Survey Facility

- **The power of Roman is not *just* that it has a large field of view:**
  - Very efficient observations
    - Rapid slew & settle
    - no Earth occultations
    - no South Atlantic Anomaly
  - Well understood and stable PSF
    - Stable thermal environment (L2 orbit, thermal control of all parts of the optical system)
    - Rigid optical structure with vibration isolation from the spacecraft
    - Stable attitude control
  - Excellent flux calibration
    - Relative calibration system





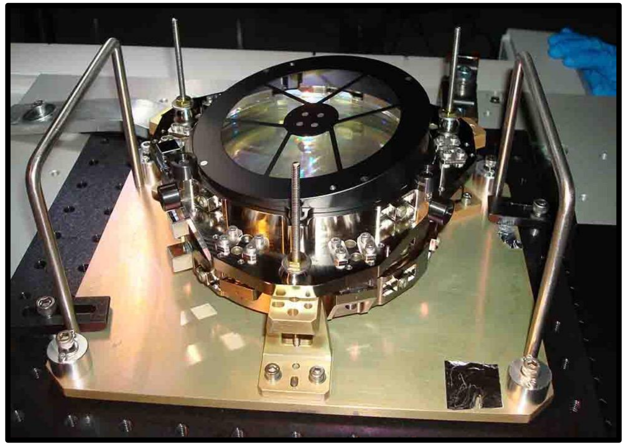
For details, see Akeson et al. 2019 https://arxiv.org/abs/1902.05569

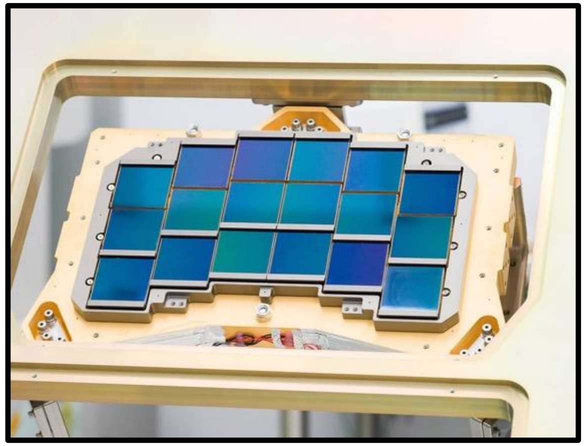
Project Status

- **Launch Vehicle selection process completed; SpaceX awarded launch contract**
- **Telescope**
  - All optics coated, currently in integration, assembly and test of optical telescope assembly
- **Spacecraft**
  - Procurement of flight subsystems underway (all contracts awarded)
  - Initial delivery of panels and portions of S/C structure, expect receipt of flight hardware through end of CY
  - First ESA contribution to Roman (star trackers) being shipped
- **Ground system**
  - Construction started (groundbreaking) for dedicated ESA antenna at New Norcia, AU
  - Req'ts review passed for dedicated antenna at White Sands, NM

Project Status – Wide Field Instrument

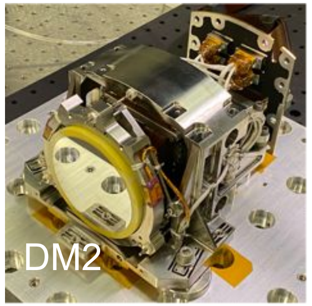
- **Wide-Field Instrument**
  - Optical bench through vibration testing, Ball portion starting assembly
  - Element wheel through testing, flight filters to be installed soon
  - Flight detectors characterized, installed, & aligned in flight mosaic plate
  - Flight electronics being assembled, engineering test unit electronics testing completed
  - Flight grism completed testing, prism soon; to be delivered late summer to Ball for wheel integration
  - relative calibration system in fabrication & assembly

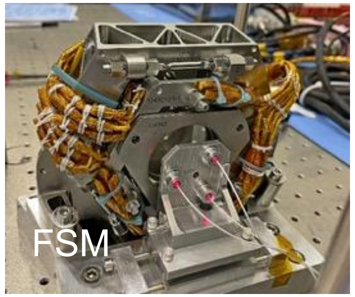


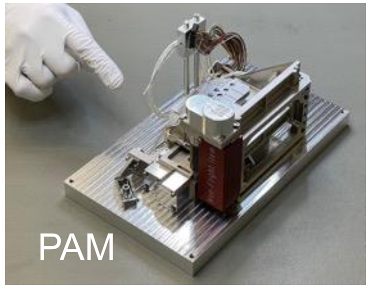


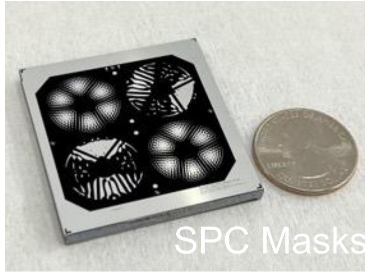
Roman Coronagraph Instrument Status

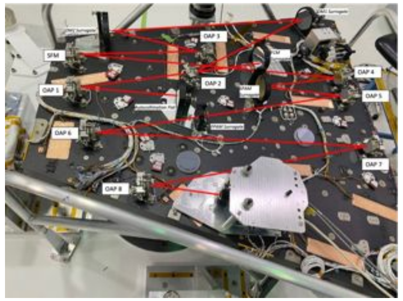
- Coronagraph Instrument passed its System Integration review successfully on June 14 2022
- Most assembly-level hardware delivered. CGI Flight Assemblies now in Final Assembly and Testing Phase
- Both flight DMs are assembled. Vibe and TVAC thermal cycling tests completed successfully. Performance stability tests on-going
- Both flight cameras (ExCam and LoCam) assembled and shielded. Completed decontamination bake, thermal balance and waveform optimization. Next are vibe and TVAC tests
- All Precision Alignment Mechanisms (PAMs) completed testing at MPIA and received at JPL. Starting to bond components
- All flight masks completed and selected in May 2022
- Flight optical bench coming together rapidly! OAPs and other static optics have been installed. Total wavefront error from these components is >2x better than the reqt (14.1nm vs 39.7nm)











Roman Data and Simulations to the Community

- **Working with MAST and SOC to make selected DCL data publicly available**
  - Motivated by a desire to make sure that the data behind science team papers (by Chris Hirata's group) are available to all
- **IPAC working with SN teams to ingest new image/spectr. simulations**
  - Posted Supernova Survey WFI image simulations (Wang et al., arXiv:2204.13553) consisting of new YJHF images with visits at multiple roll angles over 200 days – continue working with authors to obtain full set of simulations to serve.
  - Working to receive and post simulated WFI prism spectroscopic observations of Type Ia supernovae (B. Joshi et al., arXiv:2205.12949).

Simulated image template | *Simulated image with SN injected* | *After template subtraction*

Roman Budget and Schedule

Cost and Schedule – some definitions

- **Management Agreement (MA)**
  - Agreement between NASA HQ and Roman project
  - Includes schedule and funding reserves held/controlled by the Roman project
- **Agency Baseline Commitment (ABC)**
  - Agreement between NASA HQ and stakeholders (e.g. congress)
  - Relative to MA, includes additional schedule and funding reserves held/controlled by NASA HQ
  - It is a big deal to change this!

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Cost and Schedule Status

- **Baseline schedule in Feb 2020**
  - MA launch readiness date: Dec 2025
  - ABC launch readiness date: Oct 2026
- **Carefully tracked covid-related cost and schedule impacts separately from everything else, assuming covid impacts continue through Sept 2021**
  - Covid Replan schedule (May 2021):
    - MA launch readiness date: July 2026
    - ABC launch no later than: May 2027
    - (i.e. 7 month schedule slip, cost increase of $382M to both MA and ABC)
- **Critical Design Review (Sept 2021)**
  - Independent cost and schedule assessment: mission is achievable within ABC cost and schedule with high confidence
  - Issue – inadequate project reserves within MA cost and schedule
    - Shift MA launch date by 3 months; no change to ABC
      - MA launch readiness date: October 2026
      - ABC launch remains no later than: May 2027

- **Current Status**
  - Project is working to improve schedule margin lost from continuing supply chain delays and the resolution of technical issues
  - Optimization of the integration and testing flow at higher levels of assembly across the project is in process, and is anticipated to provide the needed schedule relief.

Roman Observations and community engagement

Roman Science community engagement - Goals

- **Community definition and ownership of Core Community Surveys**
  - Community defined: Broad, inclusive process; Astrophysics included in all decisions
  - Community owned: Not directed by any single team; data have no proprietary access

- **Ability for people to engage with Roman project / Science Centers / science community independently of proposal selection**
  - Via technical joint working groups and community-led science consortia

- **Science community funding**
  - Variety of award sizes and durations
  - Multiple funding opportunities between now and launch for support for people at US institutions to work independently or with existing science teams/consortia
  - Long term, stable support of teams to allow development of software/pipelines etc in partnership with Roman Science centers

Roman Observations

- **Three Core Community Surveys address the 2010 Decadal Survey science goals while providing broad scientific power**
  - **High Latitude Wide Area Survey**
    - Wide area multiband survey with slitless spectroscopy
    - Enables weak lensing and galaxy redshift cosmology mission objectives
  - **High Latitude Time Domain Survey**
    - Tiered, multiband time domain observations of 10s of deg^2 at high latitudes
    - Enables Type Ia supernova cosmology mission objectives
  - **Galactic Bulge Time Domain Survey**
    - ~<15 min cadence observations over few deg^2 towards galactic bulge
    - Enables exoplanet microlensing mission objectives
- **Minimum 25% time allocated to General Astrophysics Surveys**
- **90 days for Coronagraph technology demonstration observations, within first 18 months of mission**

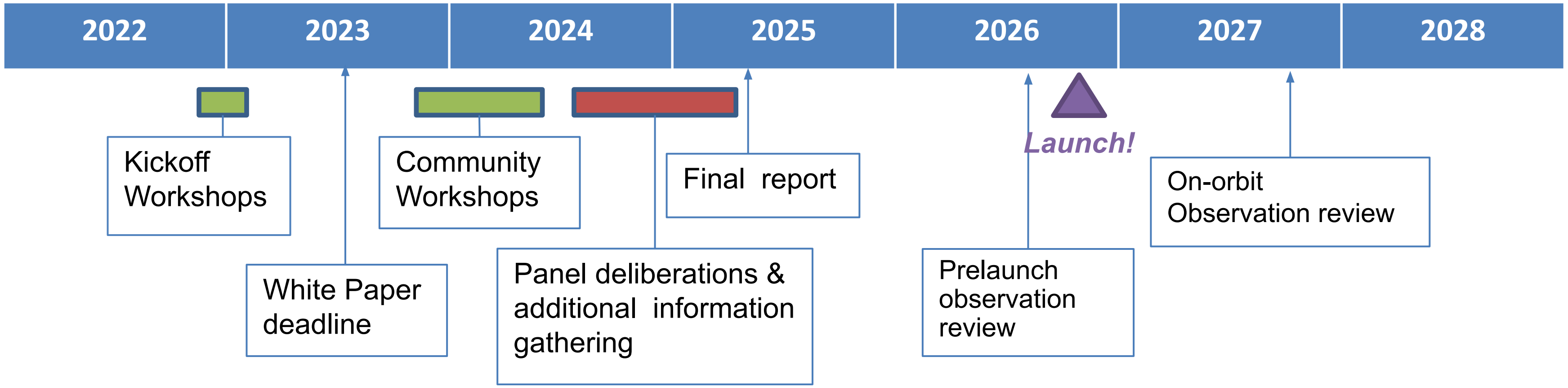
Core Community Surveys are for Everyone

- **Core Community Surveys:** a significant fraction of the prime mission used for revolutionary surveys of unprecedented scale.

Core Community Surveys definition will be via an open process, maximizing the overall science return while meeting the cosmology and exoplanet science requirements

Community Definition of Core Surveys

- **Workshops to inform community about Roman capabilities**
  - Outline available parameter space for each survey
  - Constraints are that each survey provides data needed to meet the science requirements, and at least 25% time (TBC) is retained for General Astrophysics Surveys
- **White paper call for papers detailing science that can be done with the survey**
  - Encourage development of metrics/figures of merit, and description of specific observational needs
- **Additional workshops to enable community cooperation and consensus**
  - Provides a forum for iterative development of survey concepts



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Non-Advocate review

- **Astro2020 recommendation for non-advocate review of balance of observing time between core community surveys and general astrophysics surveys**
- **NASA requested that this be conducted by the Committee for Astronomy and Astrophysics**
  - Sub-committee formed to conduct the study, kicked off last February

Charge: Question 1

- **Background:** Current observing plan is to allocate 75% of prime mission observing time to 3 Core Community Surveys + 3 months of CGI observations and to allocate at least 25% to General Astrophysics Surveys proposed by the community.
- **Core community surveys will be decided by open community process**
- **Question: Should this community process**
  - (1) Continue as is and maximize the utility of Core Community Surveys for general astrophysics science within the 75/25 split
  - (2) Focus the Core Community Surveys on cosmology and exoplanet requirements and optimize for shortest possible Core Community Surveys
  - (3) Relax the 75/25 split between Core Community Surveys and General Astrophysics Surveys to enable greater optimizations of the Core Community Surveys for general astrophysics science

Charge: Question 2

- **Background**: Within the General Astrophysics Surveys, the Baseline plan allows for 30 selected proposals over the Roman prime mission lifetime across three proposal cycles. Experience with both the Hubble Space Telescope and the Chandra X-ray Observatory has demonstrated that peer reviews do not do a good job of comparing small programs to large programs. For both Hubble and Chandra, time is explicitly set aside for, and competed, to enable large programs.
- **Question**: How should the Roman project the balance between the fractions of time allocated to large/medium/small General Astrophysics Surveys (i.e. allocate more time to large coherent observations, or allocate more time to a multitude of smaller independent ones)? How should the Roman project set the overall number of General Astrophysics Surveys (note that increasing the number of General Astrophysics Surveys, even holding total time constant, will come at increased cost to the mission)?

Non-Advocate Review of Roman Observation Plan

- **Presented material describing the design reference mission**
  - Brief description of each survey, along with a quick sketch of possible additional primary science drivers beyond cosmology and exoplanet microlensing
  - Assessment of each relative to FoM from the science requirements document (to show margin relative to science requirements)
  - Roll up of execution times for each survey, calibration, mission overhead and 25% GA surveys to show that this leaves unallocated days (i.e. explicit margin)
  - Discussion of implicit margin (e.g. in slew times, throughput etc)
- **Additional presentations from the project outlining plans for community process to define the core surveys, considerations for GA surveys, etc**
  - https://asd.gsfc.nasa.gov/romancaa/
- **Committee also heard from Roman Science Interest group, STScI, IPAC, members of the science community**
- **Report to come (originally due by July 15)**

Roman Data Management and Analysis

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Roman Data Management and Analysis

- **Big Data and Surveys**
  - Data accumulated per week likely to be >>100x *Hubble*
  - Downloading and processing exceeds resources typically available
  - Both catalogs and pixel-level data sets provide unique science opportunities
  - Many scientists/teams using same observation

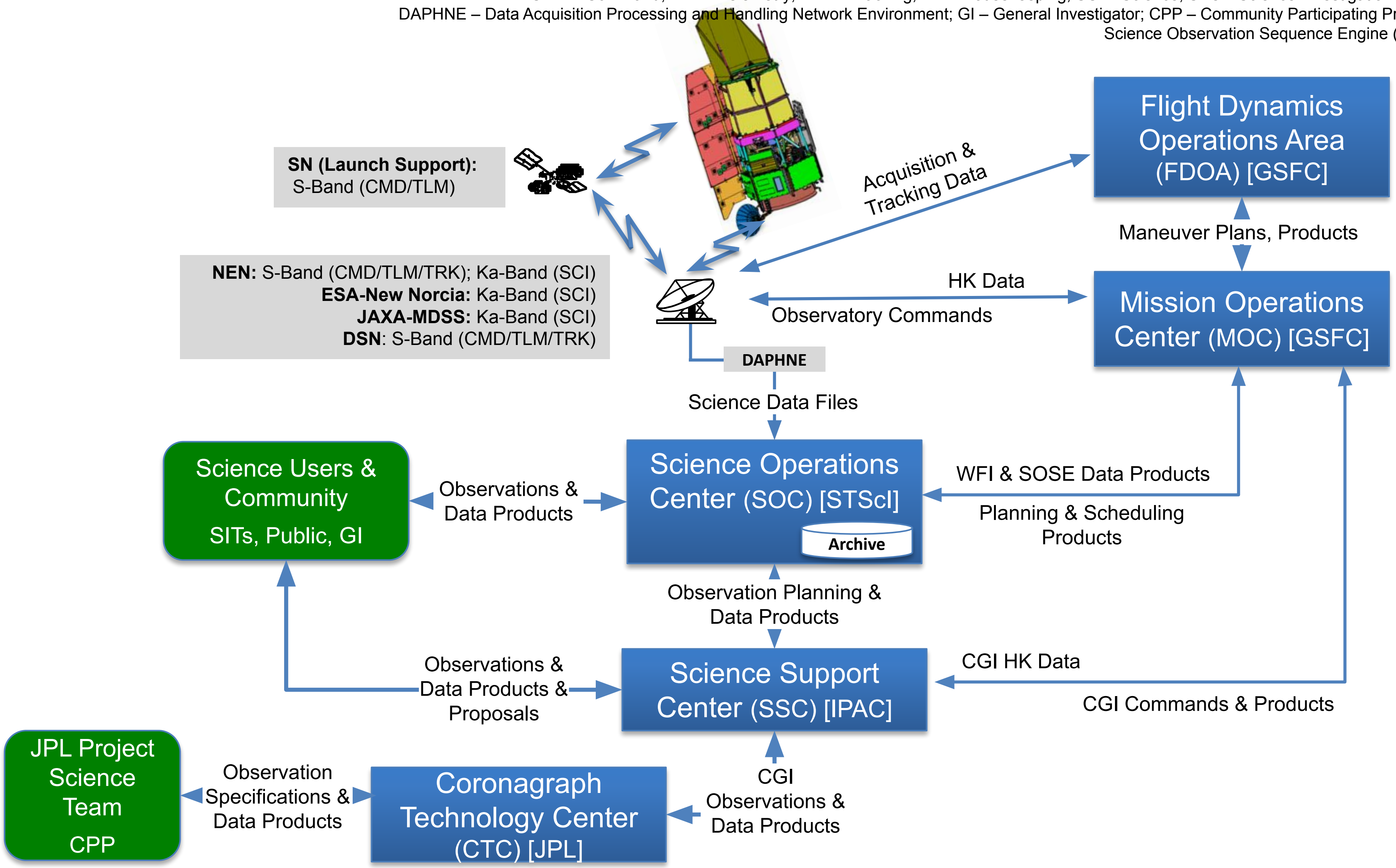
- **Maximizing Science Value of the Data/Archives**
  - Generate significant high level data products by Science Centers: calibrated and mosaiced images, extracted spectra, catalogs (including redshifts,+) etc
    - Robust, professionally developed pipelines for processing that is likely to be needed by many groups
    - Staged in the cloud and co-located with significant computational resources
    - Open source, modular imaging pipeline facilitates custom reprocessing

- **Data storage & Analysis**
  - Cloud-based high-level data processing brings software to the data
  - Science platform with JupyterLab environments ease access, sharing and repeatability
    - Software environment for the community in sync with mission data processing

All Roman data are immediately available with no proprietary period

Ground System Architecture

CMD – Command; TLM – Telemetry; TRK – Tracking; HK – Housekeeping; SCI – Science; SITs – Science Investigation Teams; DAPHNE – Data Acquisition Processing and Handling Network Environment; GI – General Investigator; CPP – Community Participating Program; Science Observation Sequence Engine (SOSE)



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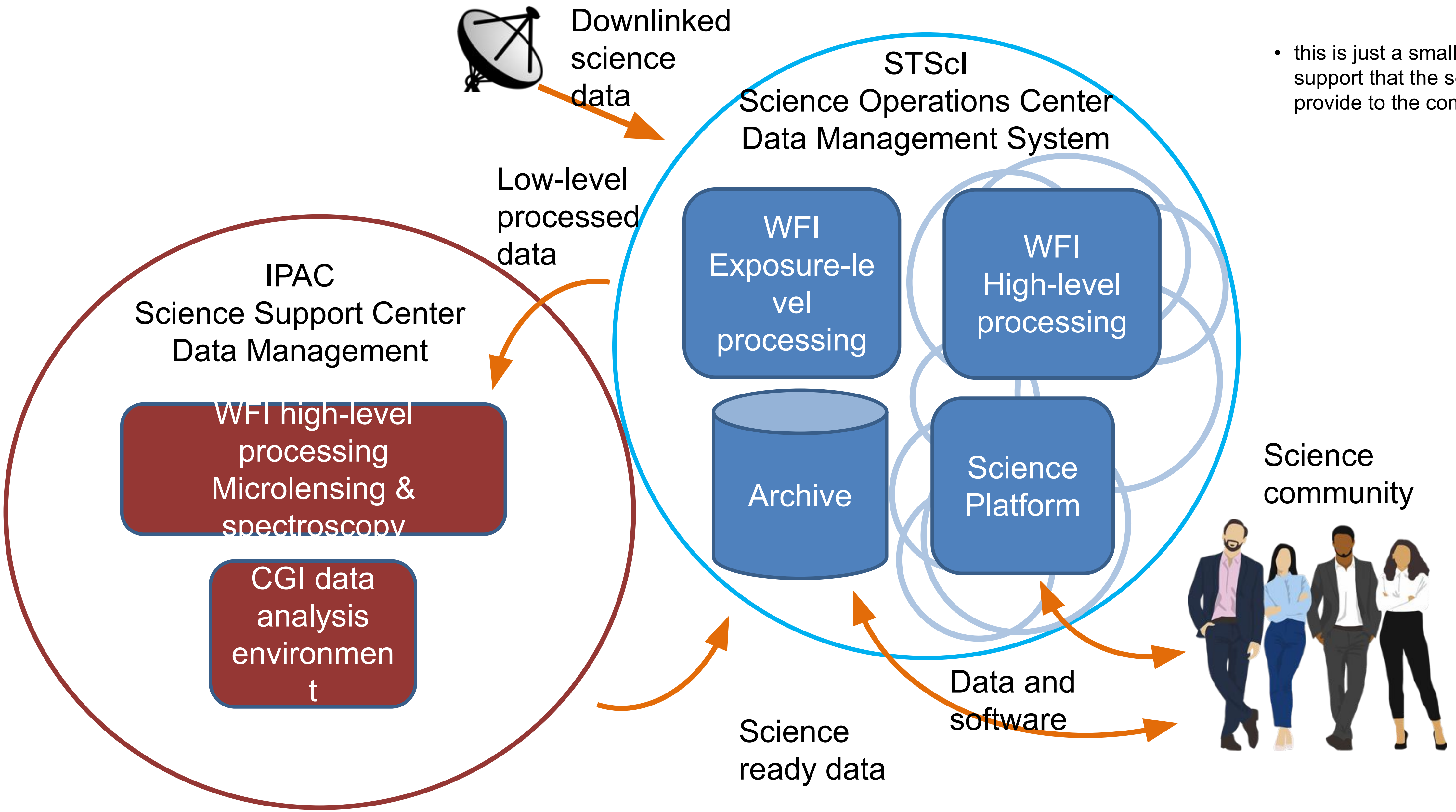
Roman Science Data Flow



- this is just a small part of the support that the science centers provide to the community

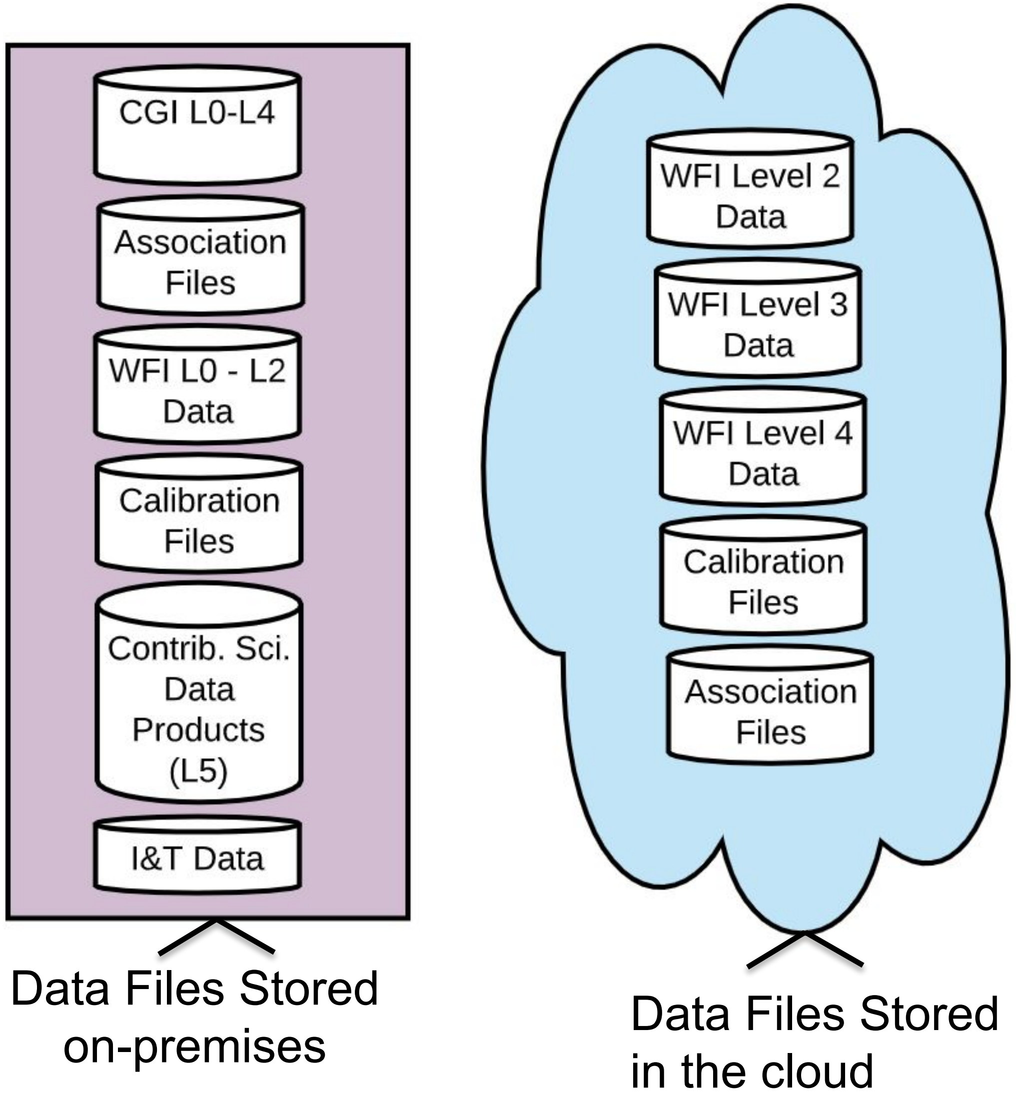
WFI Data Level Reference

Data Level	Description	Comment
0	**Packetized data as it arrives from the spacecraft**	Level 0 data is identical with raw packetized science telemetry as transmitted from the Observatory and received at the ground stations.
1	**Uncalibrated “raw” individual Exposures**	Level 1 products are in the form of uncalibrated individual exposures consisting of raw pixel information formatted into the shape of the detectors.
2	**Calibrated Individual Exposures**	Level 2 data products are corrected for instrument artifacts, with slope fitting, outlier rejection, and other procedures to obtain a true mapping of the scene flux. Calibrated exposures have appropriate astrometric and geometric distortion information attached, and with the exception of grism/prism data, are in units that have known scaling with flux.
3	**Data Resampled to a Regularized Grid and Combined**	Level 3 products are groups of calibrated exposures resampled to a regularized grid, removing the geometric distortion of the original pixels.
4	**Derived Data**	Level 4 products are usually focused on sources/objects rather than pixels or celestial coordinates. These can contain traditional data (such as positional, size and shape information) or complex data such as extracted spectra or postage-stamp images of the relevant source from all contributing images.
5	**Community-Contributed Products**	Community generated data products that can be of arbitrary form and complexity. Encompass any data that is returned to the SOC for archival storage by contributing scientists or groups and may include data that could be described as any of the previous levels.

Archive Data Volume At Mission End

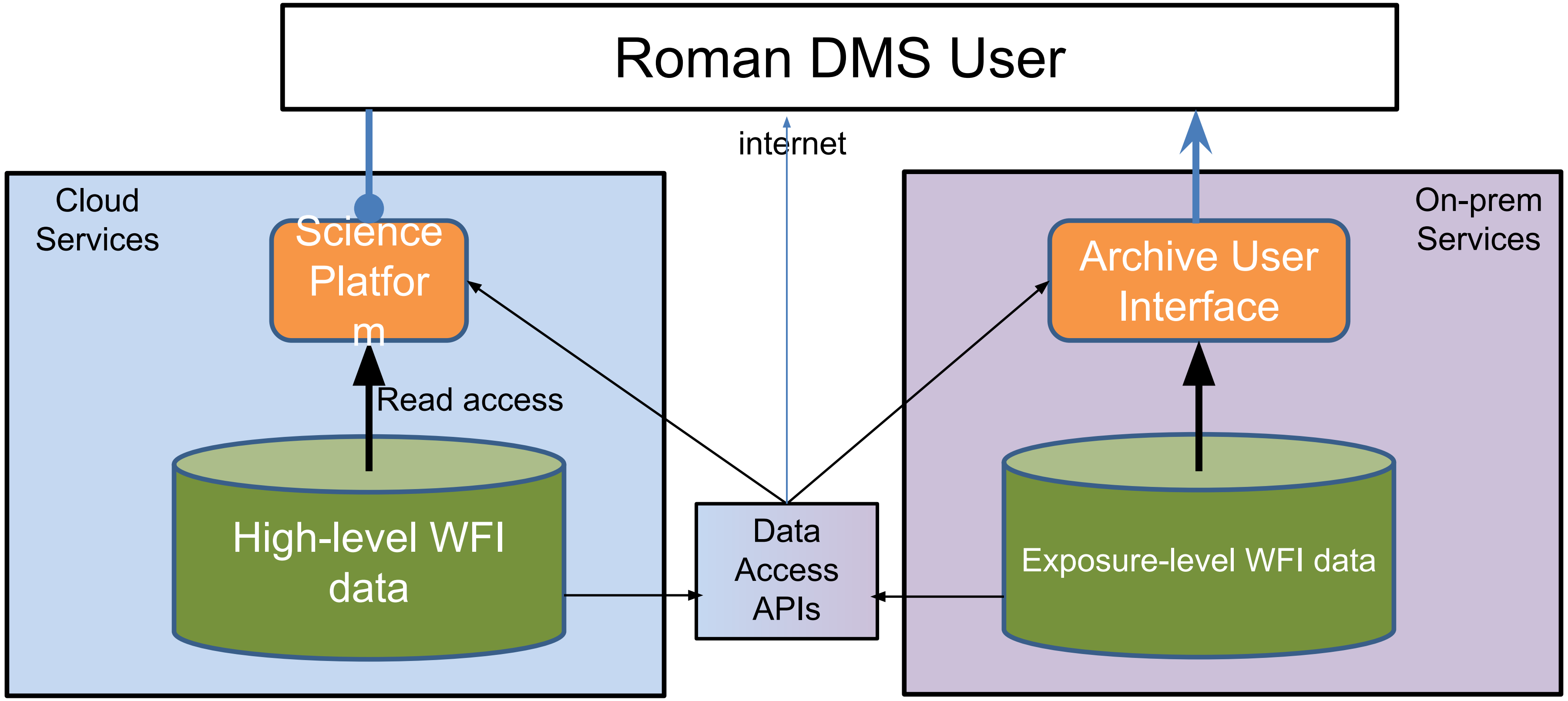
These values are estimated based on the Design Reference Mission

- **WFI products by data level**
  - Level 0: 1.92 PB
  - Level 1: 3.06 PB
  - Level 2: 4.56 PB
  - Level 3: 3.74 PB
  - Level 4: 1.79 PB
  - Level 5: 0.2 PB
  - I&T: 5.54 PB
  - Calibration: 44TB
- **CGI data products**
  - All non-I&T: 0.02 PB
  - I&T: 240 TB
- **Data products by location**
  - On-premises: ~ 16.57 PB
  - Cloud: ~ 9.71 PB



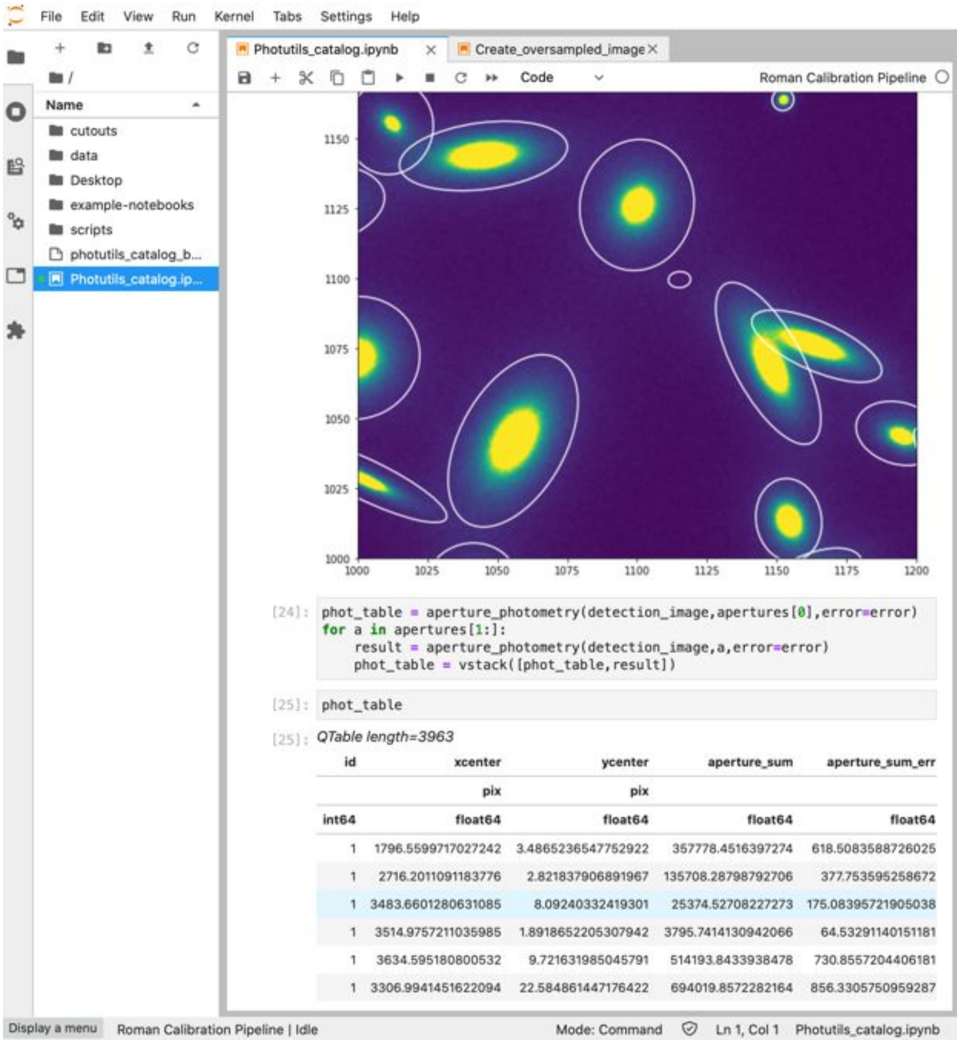
Accessing Roman Data and compute resources

- **STScI archive services**
  - Bring data to the users
- **Roman Science Platform**
  - Brings users to the data



Roman Science Platform

- **JupyterHub instance**
  - Roman science calibration pipeline software installed and configured
  - Full Python + Astropy ecosystem installed and configured
  - Ability to install other packages and your own code
- **Cloud-based Flexible, scalable architecture**
  - Simple to add CPU & storage
  - High-throughput access to the data
  - Can scale up resources (e.g. GPUs or additional managed cloud services) as science needs & technology evolves



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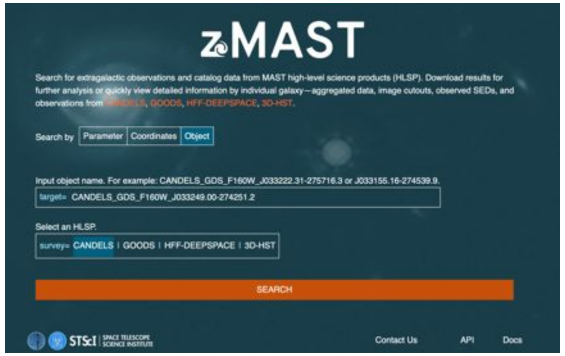
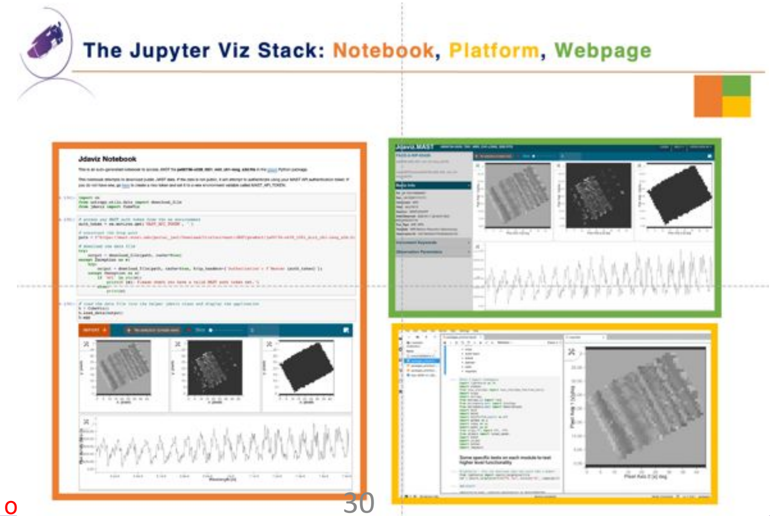
Archive

- **All Roman Science Data are Public and retrievable from MAST**
  – Includes flight data, Integration & Test, & high-level community products
- **Expect archive services to evolve**
  – Currently incorporating Jupyter analysis & visualization tools for JWST
  – Improving access to high-level products with services like z.mast and exo.mast
- **Higher-level products will be available in the cloud as well**





A new Era of Big Data

- **The Roman Data Management system is scoped to:**
  - handle Roman data volumes
  - Provide convenient access to all Roman science data
  - Make Roman science inclusive and accessible by
    - providing significant computing resources next to the data via the Roman science platform
    - Centralizing generation of high-level data products of broad general use

- **Anticipate that elements of the system will evolve and improve based on developments/experience within the science centers and elsewhere**
  - E.g. building on science platform experience with other missions/observatories
  - Learning from the Rubin and Euclid experiences etc

- **Investments in big data infrastructure that is beyond the scope of the Roman mission could have a significant impact on Roman science return**
  - Additional data mining or exploration functions beyond what is currently available in MAST
  - Machine learning tools
  - Joint processing with Rubin data
  - Curated complementary data - e.g. co-locating co-added Rubin data for the Roman survey footprint

The Road Ahead

- **Successful Mission Critical Design Review, Sept 2021**
  - Observatory design is complete, proceeding with building flight hardware

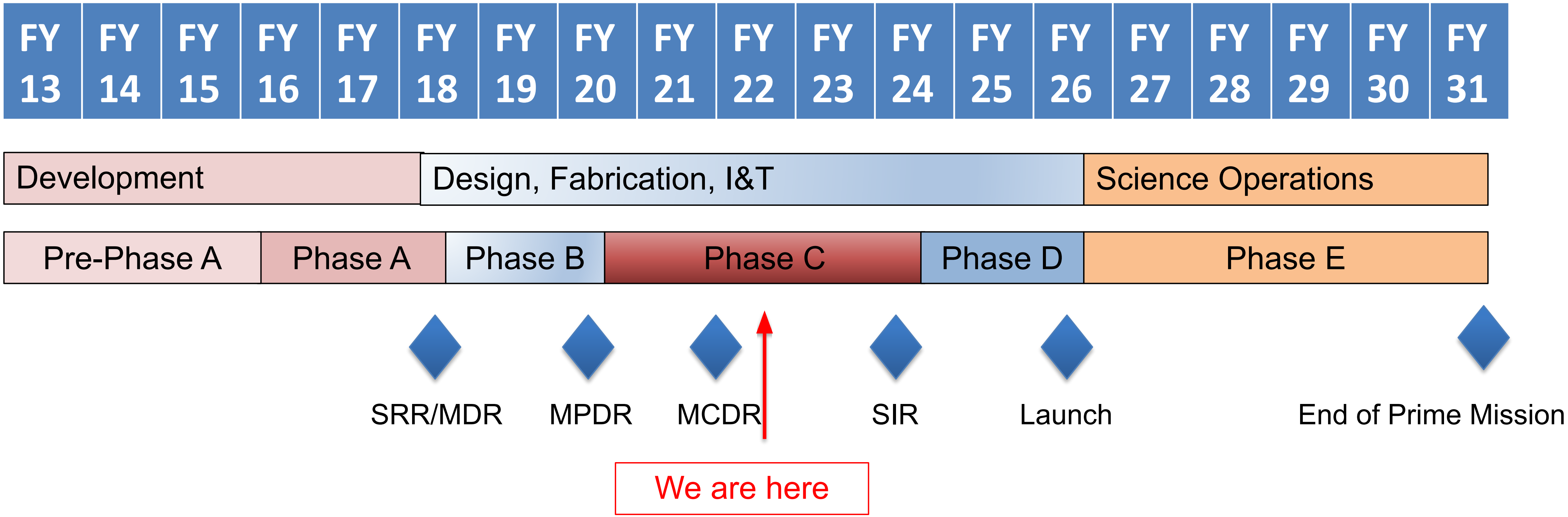
- **Opportunities to engage with Roman**
  - Monthly lecture series: https://roman.ipac.caltech.edu/Lectures.html
  - Planning to start monthly project status updates
  - Final ROSES proposal call out in few weeks
  - Community process to define Core Community Surveys kicking off late 2022/2023

- **Astro2020**
  - Recommendation for non-advocate review of balance of observing time between core community surveys and general astrophysics surveys
    - Now ongoing with CAA subcommittee

- **Exciting to see things coming together**

Backup

Timeline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FY 23
FY 24
FY 25
FY 26
FY 27
FY 28
FY 29
FY 30
FY 31
Development
Design, Fabrication, I&T
Science Operations
Pre-Phase A
Phase A
Phase B
Phase C
Phase D
Phase E
SRR/MDR
MPDR
MCDR
SIR
Launch
End of Prime Mission
We are here

Covid-19 impacts

- **COVID-19 operations March 2020 - September 2021 affected project efficiency and global supply chains during project's planned peak years**
- **Roman execution efficiency April 2020 – March 2021 averaged 70%**
  - On-site work constraints, collaboration challenges etc
- **Global supply chains experienced significant impacts**
  - Increased no-bids; bid durations increased, sometimes doubling; vendors unable to offer expediting options; deliveries slipped, sometimes without warning; choke points developed,
  - Extremes of the supply chain impacts resulted in very large delays in a handful of significant deliveries;
    - 6 months longer for the WFI Beryllium Element Wheel
    - Global shortages in supply chain for raw materials drove multi-week delays from all composite vendors; put optical bench on critical path along with the element wheel
  - Schedule slack and then reserves were adjusted, applied, and eventually consumed to mitigate the impact to critical path -- led to an overall schedule replan

Why the Cloud?

- **Putting both the computing and the science-ready data in the commercial cloud offers the following benefits:**
  - Convenient scalability for both data volume and computational demands
  - Flexible solutions for specific computing needs (e.g. GPUs or I/O optimized computing)
  - Lower total costs to NASA relative to multiple on-site installations
- **Benefits to the science users include:**
  - Efficient access to the data
  - Computing resources for exploratory work are available with no need to write a grant proposal
  - Local IT and software support costs are greatly diminished
  - Easier collaboration with astronomers across institutions
  - A powerful and stable science software environment

Science Team Community Briefing (Nov 15-19)

- https://roman.gsfc.nasa.gov/science/workshop112021/

- **Each WFI science investigation team organized a session**
  - Survey optimization and considerations
  - Simulations
  - Quantitative evaluation of broad range of science questions
  - Precursor observations (and results!)

- **Also reports from Calibration and detectors working groups**

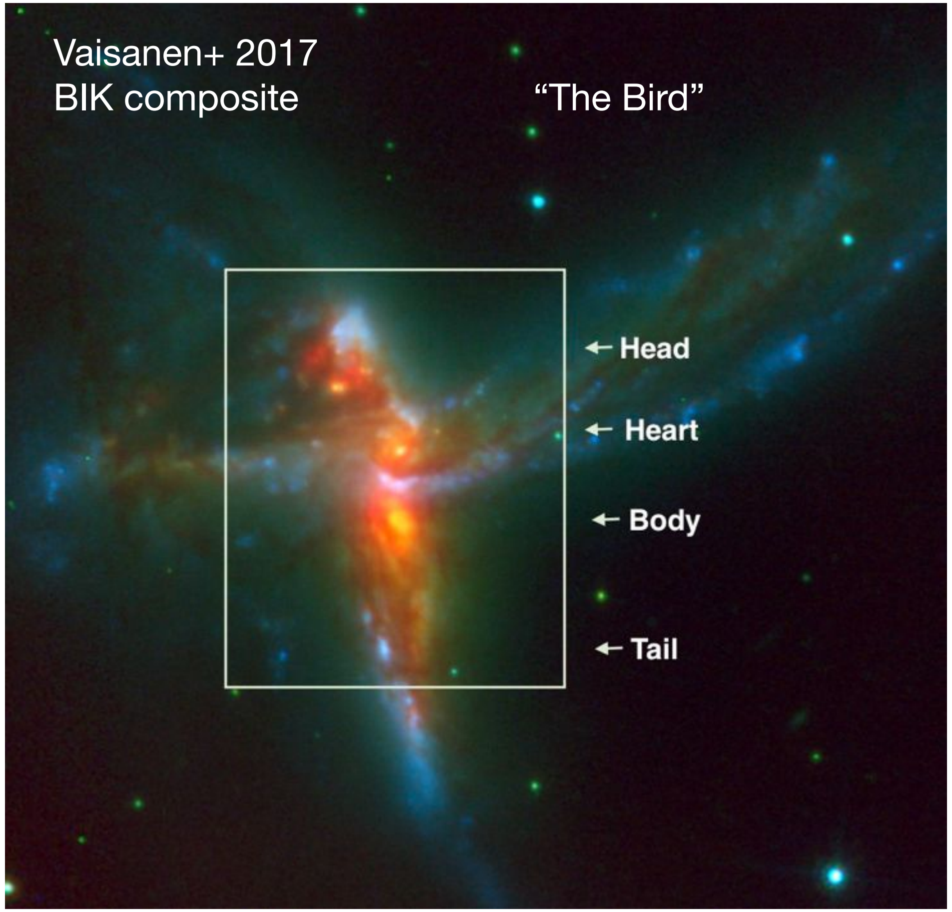
- **Excellent attendance**
  - Several hundred people over the course of the week

- **Supported by SOC/STScI**
  - Hosting virtual meeting, moderating sessions, recording archiving talks

Meetings, workshops and conferences

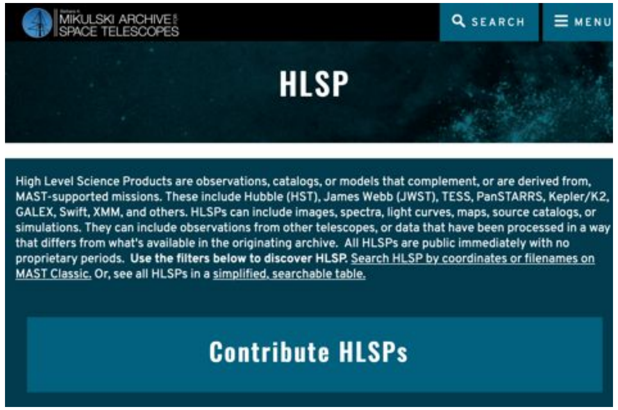
- **Exploring the Transient Universe with the Nancy Grace Roman Space Telescope (Feb 8-10)**
  - Lots of excellent talks
  - Discussions on how to optimize the core community surveys
- **Joint Processing Splinter Session (Jan 11)**
  - Largely science focused discussion of benefits/needs for joint Roman-Rubin-Euclid analysis
  - Originally planned to be in-person at AAS
- **Cosmology with the Nancy Grace Roman Space Telescope (Jan 27)**
  - Discussed each of the core cosmology investigations, followed by a panel discussion exploring other cosmology probes with Roman

Transients from Ultra Luminous Infrared Galaxies (ULIRG) (Tom Reynolds)



Community-Contributed Products

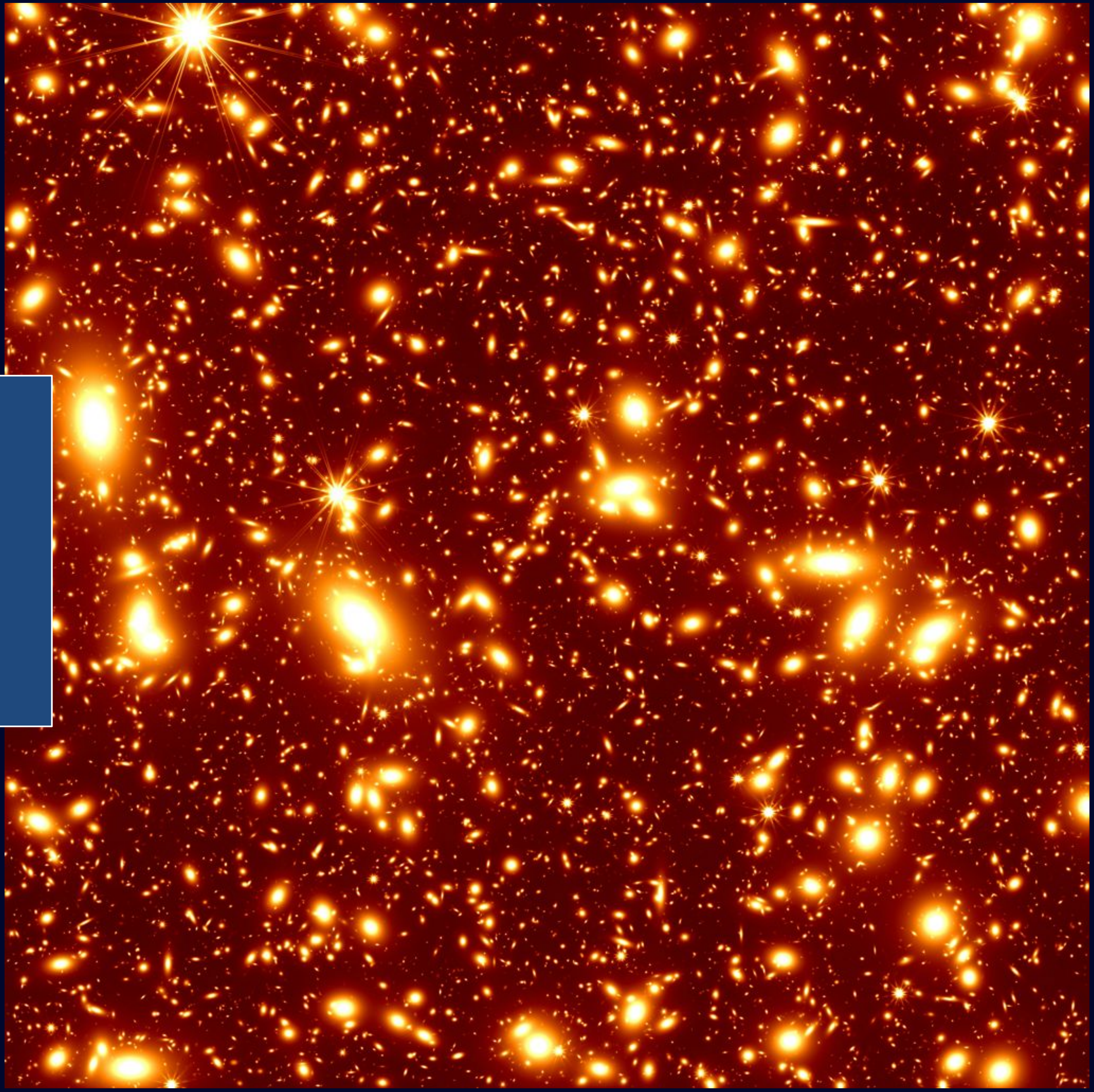
- **Public data products contributed by the science community are likely to be widely used. Examples include:**
  - Joint photometry with complementary data sets
  - Photometric redshifts that use complementary data sets
  - Value-added catalogs of derived properties (e.g. from SED fitting)
  - Hybrid spectroscopic and photometric catalogs
  - Survey-level calibrations
    - Improved astrometry & photometry after constraining for consistency across the full survey
    - Window functions, masks, PSF kernels, etc.
  - Transient-free template images
- **Details & cadence to be defined through future community engagement and opportunities**



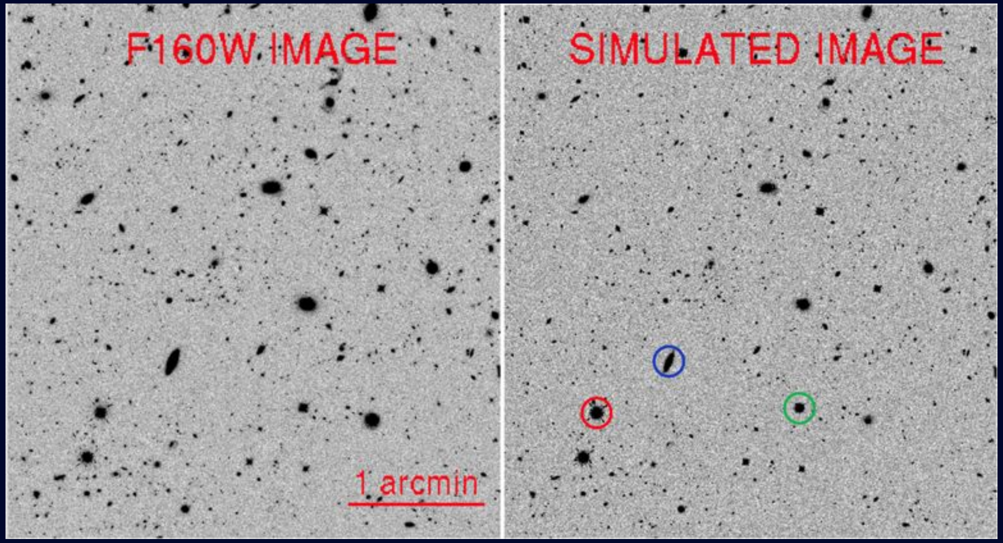
HLS representative Level 2 calibrated image data

Single SCA

(courtesy A. Bellini)



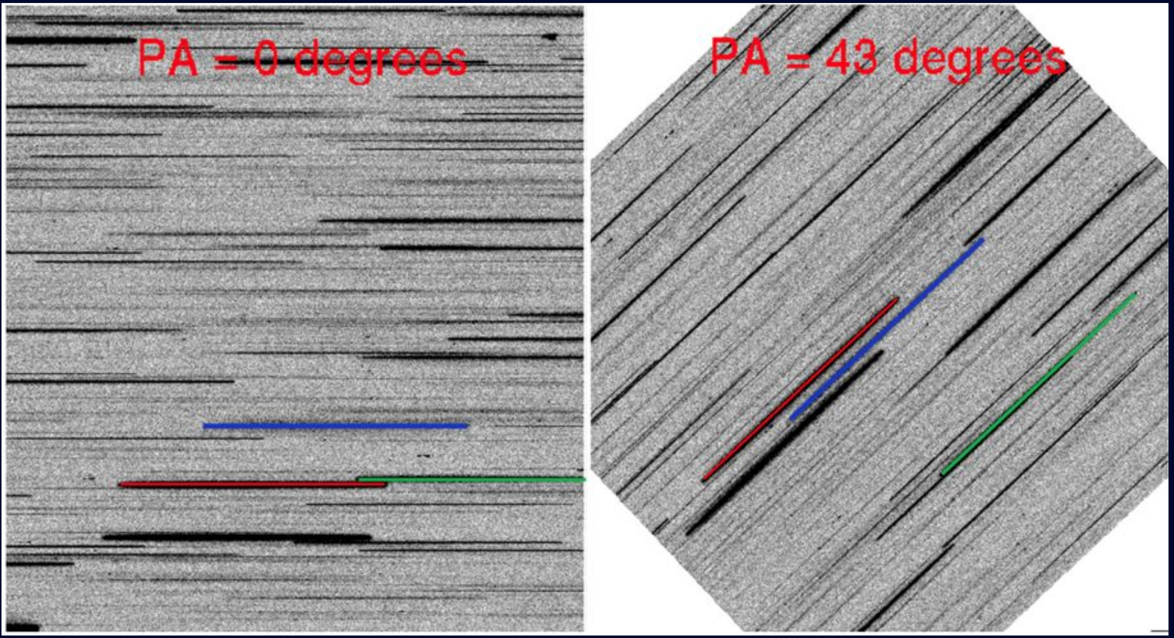
Simulated Grism Level 2 Data



Roman multi-position-angle grism simulations

Single SCA
(Wold et al. 2021)

Simulated sources are populated based on spectral constraints of actual objects within the COSMOS field. Sources with red, blue and green circles around them show different overlaps with different PAs.

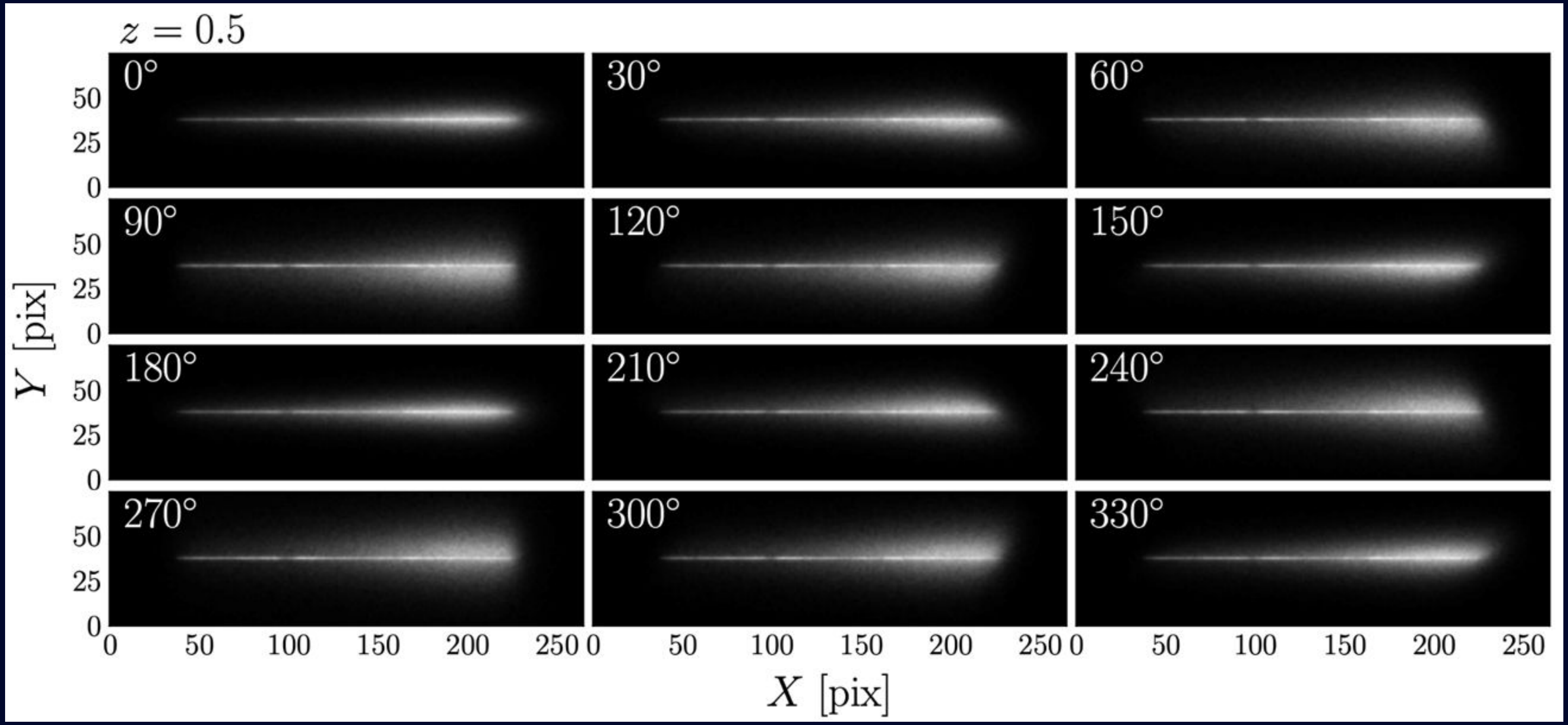


(courtesy S. Malhotra)

Simulated Prism Level 2 Data

These are simulated 2D cutouts of prism data.

The size of the scene is 8.25 arcsecond x 8.25 arcsecond, or 75 x 75 pixels



(courtesy Tri Astraatmadja)