STScI | SPACE TELESCOPE SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Nancy Grace Roman Space Telescope Science Operations Center (SOC)

Harry Ferguson

July 7, 2021

OUR VISION

Expanding the frontiers of space astronomy

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

OUR MISSION

We help humanity explore the universe with advanced space telescopes and archives

OUR STRATEGIC GOALS

Excel in the science operations of NASA's current and future astrophysics flagship missions

Advance state-of-the-art astronomical research, archives, and tools for scientific discovery

Make the world's astronomical information accessible to all

Promote an inclusive, equitable workplace and cultivate a diverse, engaged workforce

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SOC Responsibilities & Design

STScI provides the Science Operations Center (SOC) within a distributed Ground System Architecture

Planning & Scheduling
All mission observations

WFI Data processing
Details depend on mode

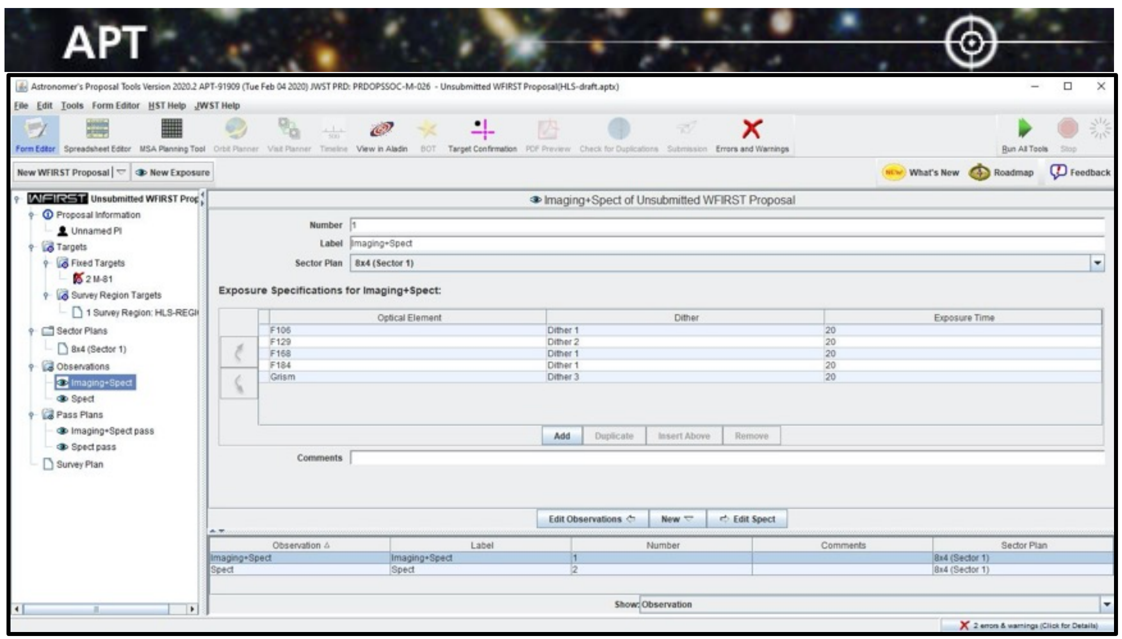
Archive
for all observations

Community interface for WFI imaging
User support , documentation, public outreach

Remaining Ground System functions: IPAC, GSFC, …

Planning and Scheduling System

- Adapted from HST/JWST “Astronomer’s Proposal Tool”
- Significant heritage for other parts of scheduling system
- Campaign-scheduling approach to long-term planning
    - Optimize surveys while allowing interleaving of different programs



Roman APT Example: High Latitude Wide Area Survey with imaging+spectroscopy

Community Engagement

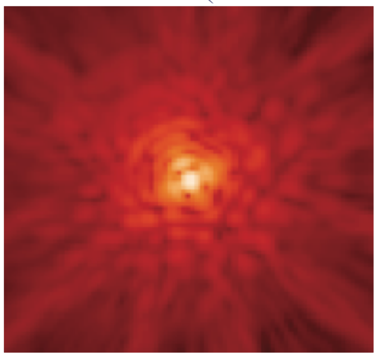
- **Science Conferences**
  - Example: recent virtual meeting (~300 attendees)

- **Website** (http://www.stsci.edu/roman)
- **Outerspace** collaboration site for Project, Science Team, and advisory committees
- **STScI Newsletter** articles
- **American Astronomical Society (AAS)** and other professional meetings – demos/splinters/townhalls
- Handouts and print products about the observatory & science

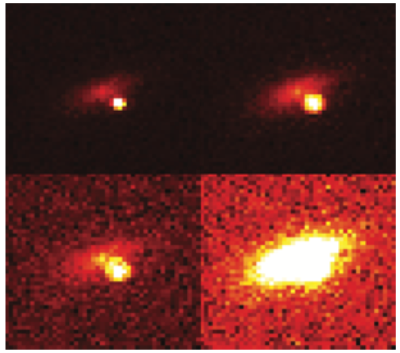
STScI Roman staff answer questions at the STScI AAS booth.

Simulation Tools & Applications

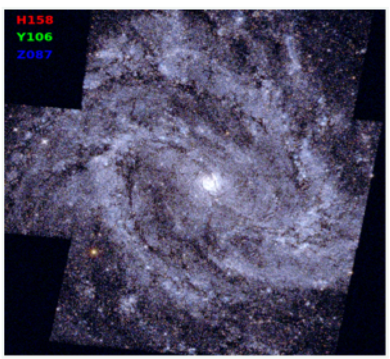
(https://www.stsci.edu/roman/science-planning-toolbox)



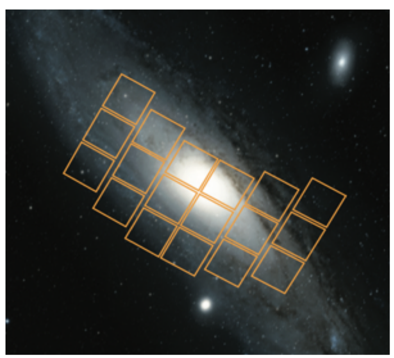
WebbPSF
Wavelength Dependent PSF Simulator



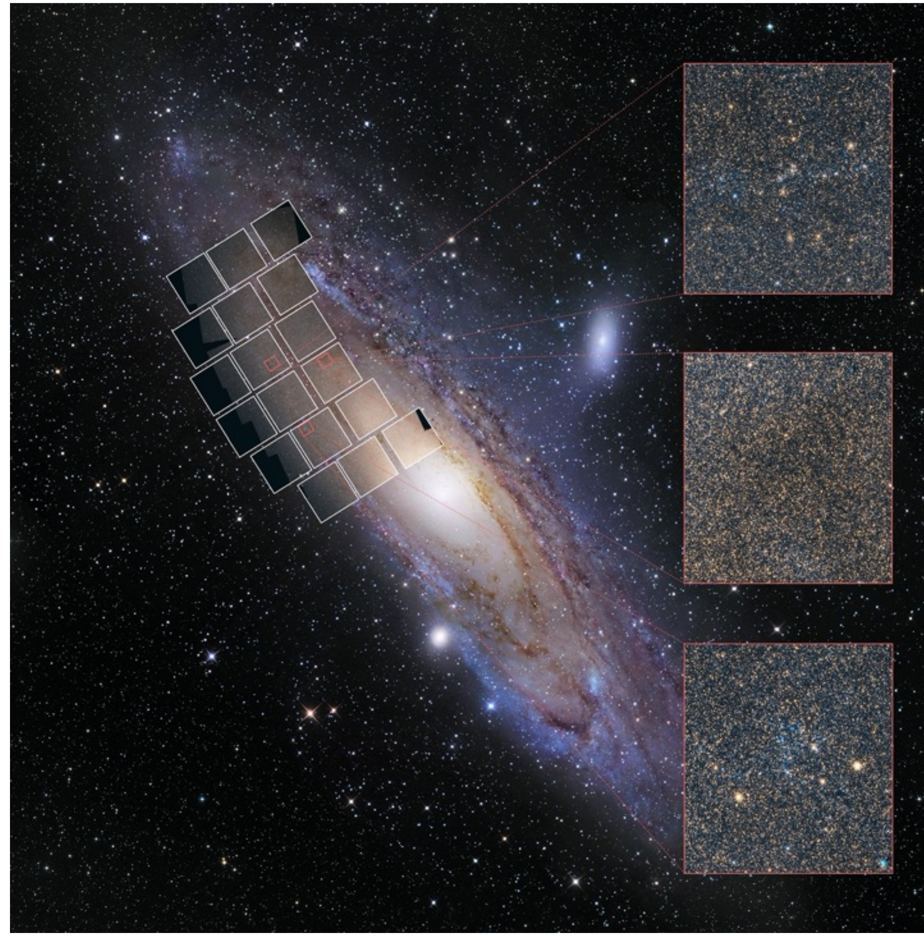
Pandeia
3-D (x,y,λ) Exposure Time Calculator and Image simulator



STIPS
Image Simulator



Field of View Overlay



Simulated Roman Observation of Andromeda
(B. Williams with aid of STIPS)

Complementary to tools developed by the community and other partners

Working Groups, User Support, Documentation, etc.

- **SOC Scientists perform a range of activities**
  - (co-)chair project-wide Working Groups with project and community scientists on a range of scientific and technical topics
  - Organize Hack Days, Focus Meetings, Jamborees, etc.
  - User support of Science Teams (or are themselves co-investigators)
  - White papers and documentation to inform the community about Roman's scientific capabilities & opportunities

Solar system science with the Wide-Field Infrared Survey Telescope

Bryan J. Holler et al.

Astrometry with the Wide-Field Infrared Space Telescope

The WFIRST Astrometry Working Group:

Roman coronagraphic operations: lessons learned from the Hubble Space Telescope and the James Webb Space Telescope

John H. Debes et al.

Etc, etc, etc……

Journal of Astronomical Telescopes, Instruments, and Systems

An Ultra Deep Field survey with WFIRST

Anton M. Koekemoer (STScI), R. J. Foley (UCSC), D. N. Spergel (Princeton/CCA), M. Bagley (UT Austin)R. Bezanson (Pittsburgh), F. B. Bianco (NYU), R. Bouwens (Leiden), L. Bradley (STScI), G. Brammer (NBI), P. Capak (Caltech), I. Davidzon (Caltech), G. De Rosa (STScI), M. E. Dickinson (NOAO), O. Doré (JPL), J. S. Dunlop (ROE), R. S. Ellis (UCL), X. Fan (Arizona), G. G. Fazio (CfA), H.

arXiv.org > astro-ph > arXiv:1907.07184

ASTRO 2020

Search...

Help | Advanced

Astrophysics > Instrumentation and Methods for Astrophysics

On the need for synthetic data and robust data simulators in the 2020s

Molly S. Peeples (STScI/JHU), Bjorn Emonts (NRAO), Mark Kyprianou (STScI), Matthew T. Penny (Ohio State), Gregory F. Snyder (STScI), Christopher C. Stark (STScI), Michael Troxel (Duke), Neil T. Zimmerman (GSFC), John ZuHone (Harvard-Smithsonian CfA)

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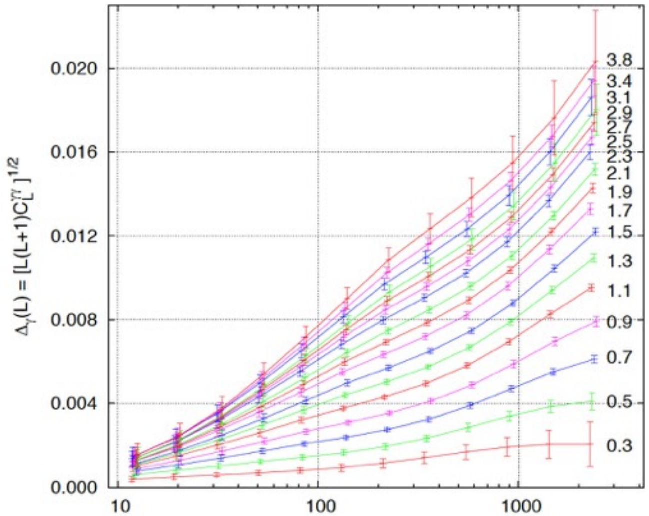
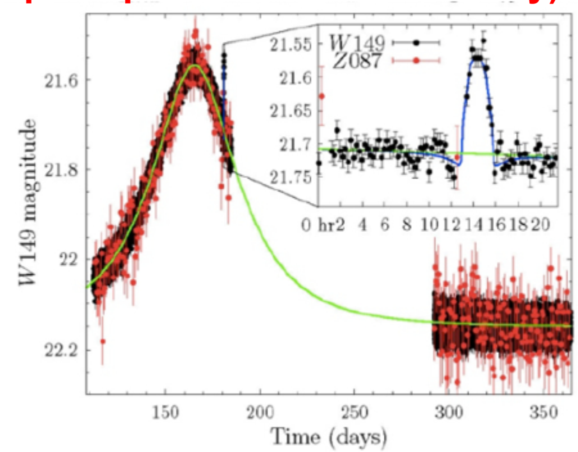
WFI/Imaging Calibration Planning

0.05% PSF shape (impacts cosmic shear)



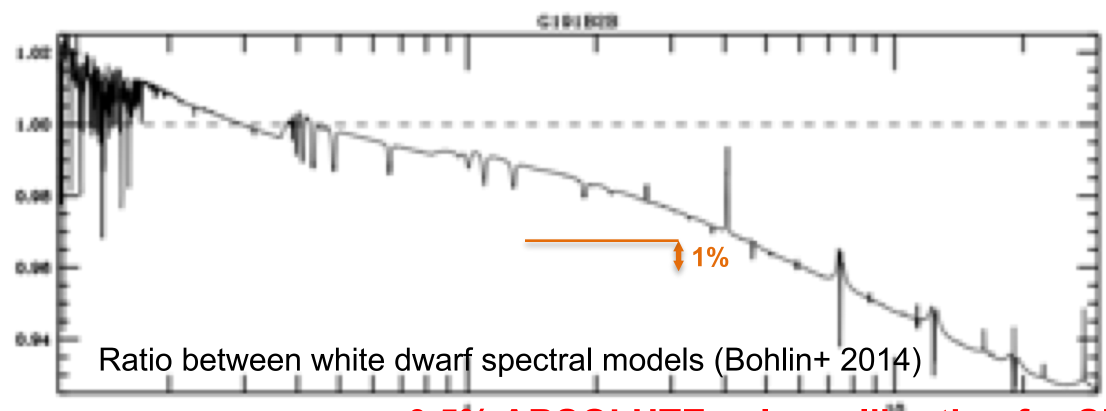
Expected shear power spectrum[L]
(Science Definition Team report, Spergel+ 2015)

0.1% Photometric stability for microlensing (maps to planet mass uncertainty)



Simulated microlensing event (S. Carey)

- Required accuracies up to ~10x better than what is available on other missions (e.g., Hubble)



Ratio between white dwarf spectral models (Bohlin+ 2014)

0.5% ABSOLUTE color calibration for SNe (maps to luminosity distance vs redshift)

Public Outreach

Roman field-of-view activity, used for the Apollo 50th Celebration on the National Mall and the AAS Student Outreach activity

Roman viewable in 3D using
STScI STAR Augmented Reality App

YouTube MinutePhysics Video (>0.5M views)
"How Do We Know the Universe is Accelerating?"
https://www.youtube.com/watch?v=tXkBfkeJJ5c

The Data Management System

NASA Astrophysics *Big Data*:

- Data accumulated per week likely to be >>100x *Hubble*
- Both catalogs and pixel-level data sets provide unique science opportunities
- Downloading and processing exceeds resources typically available
- Most research will be *archival*, given the survey nature of the mission

Barbara A. MIKULSKI ARCHIVE FOR SPACE TELESCOPES

Science data products from multiple mission partners

- Calibrated and mosaiced images, extracted spectra, catalogs, etc.
- Staged in the cloud and co-located with significant computational resources
- Open source, modular imaging pipeline facilitates custom reprocessing

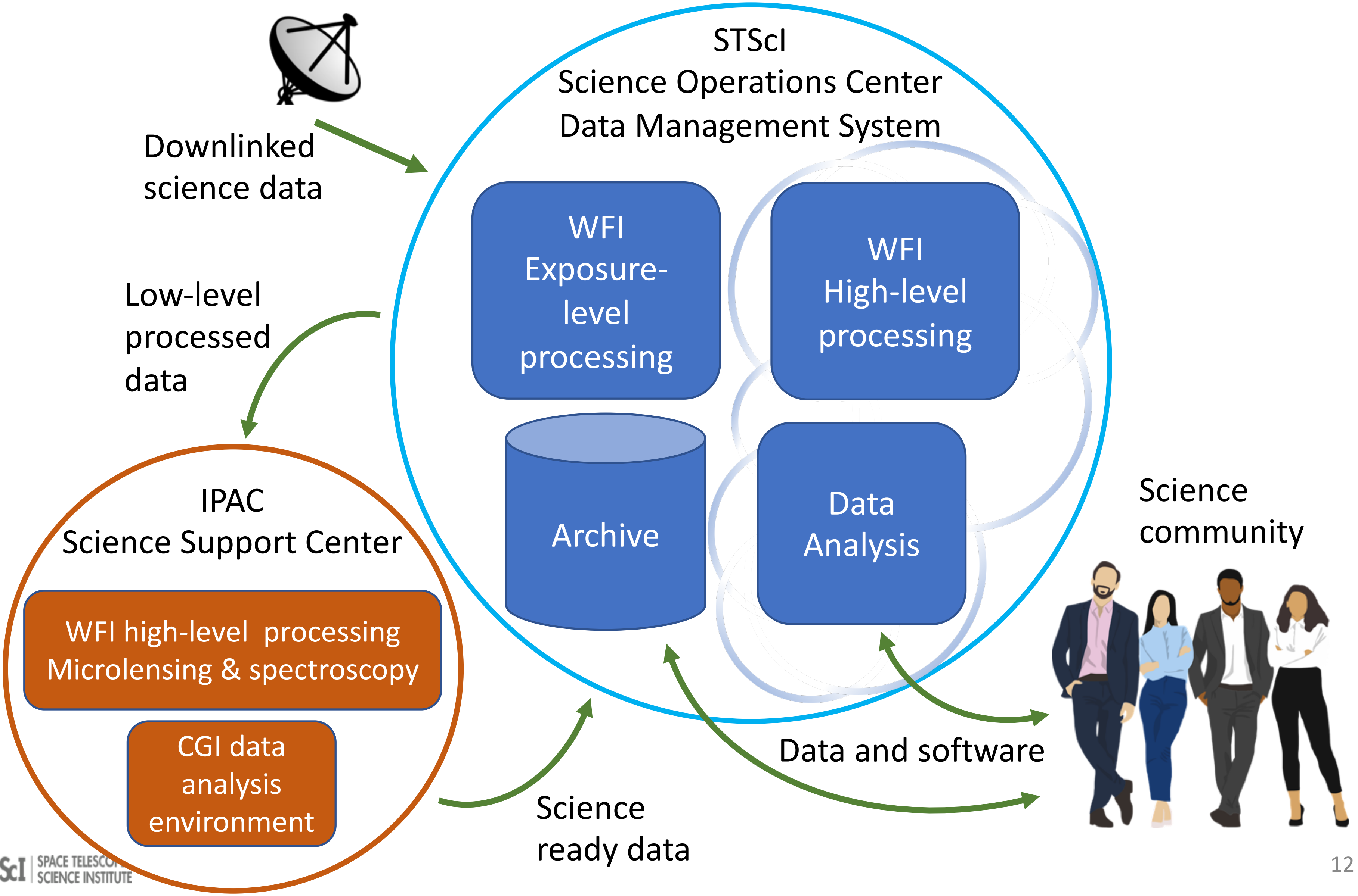
Data storage & processing

- Cloud-based high-level data processing brings software to the data
- JupyterLab environments ease access, sharing and repeatability
- Software environment for the community in sync with mission data processing

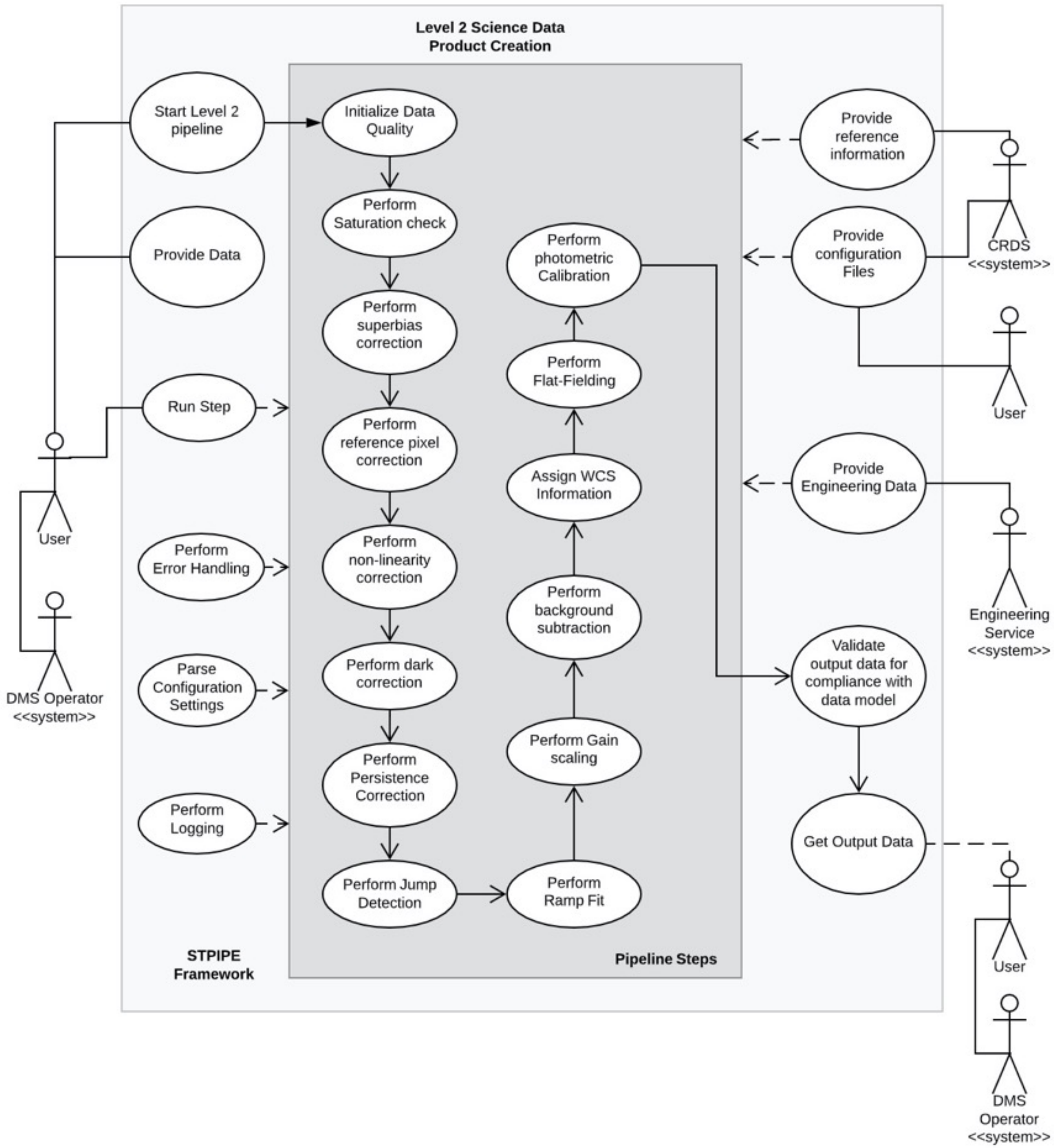
jupyter

AWS

Roman Data Management



Exposure Level Processing Flow

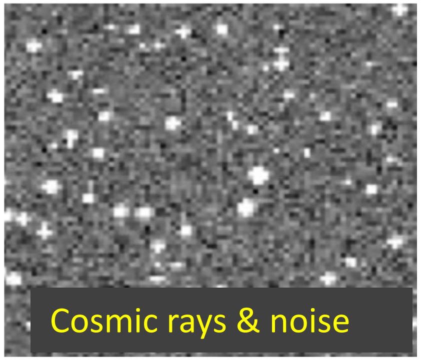


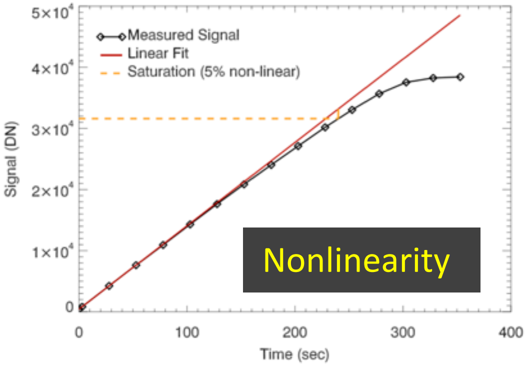
Data Products

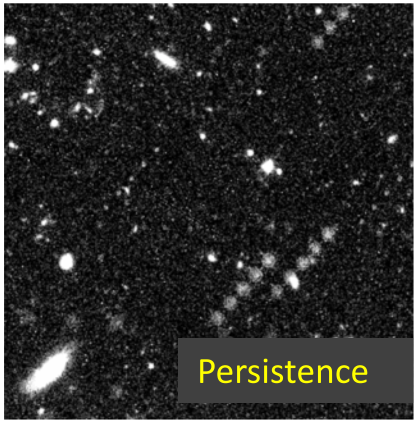
- **Array data**
  - Level 1 – raw
  - Level 2 – instrument signatures removed; aligned to Gaia to <1.3 mas precision
  - Level 3 – rectified and co-added
  - Level 4 – segmentation maps associated with catalogs
  - Queryable Empirical PSF library
  - Level 5 – community contributed products
- **Tabular data**
  - Level 4
    - Static Object catalogs
    - Variability catalogs (from aperture photometry and difference imaging)
    - Idealized source-injection: Catalog of inputs vs. outputs (photometry, sizes, shapes)
  - Level 5
    - Community-contributed products
- **Availability (levels 1-4)**
  - At the individual FOV level within 2 days of receipt of last relevant data
  - Consistently-calibrated data of survey areas released within 6 months

Simulations: Instrumental Signatures

- **Intended as a tool for pipeline development & testing**
  - Not optimized for use in a pipeline
- **Input**
  - An image in counts/second in the band (produced by idealized simulation tool)
- **Operations**
  - Simulates the individual readouts & the grouping of readouts done onboard
  - Instrument signatures to be included:
    - Cosmic Rays
    - Nonlinearity
    - Interpixel capacitance (if not using an empirical PSF)
    - Basic persistence model
    - Readout noise & dark current (Simple model)
  - Not included:
    - Intra-pixel sensitivity variations
    - Brighter-fatter effect
    - Sophisticated readout model (e.g. 1/f bias drifts)
- **Output**
  - Image in the format of the inputs to pipeline level 2



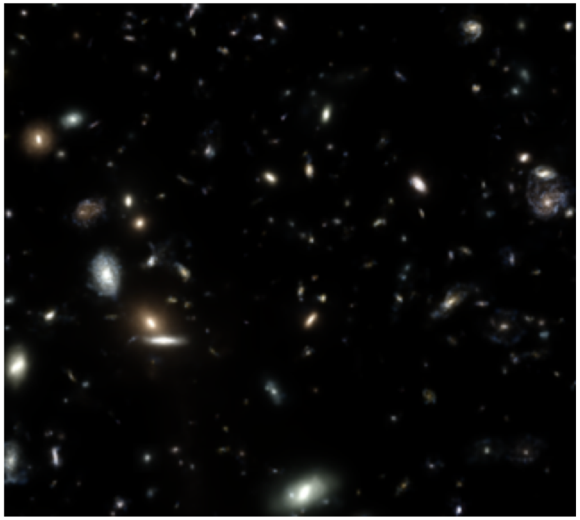




Simulations: Idealized

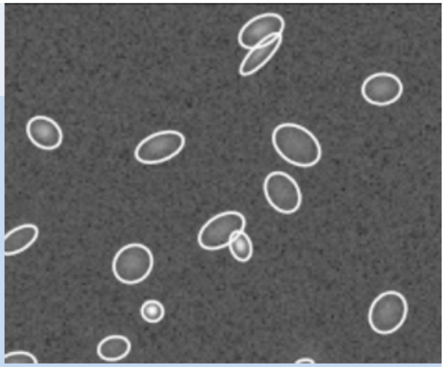
- **Intended both to be both by the SOC and as a user tool for custom analysis**
- **Can be used to inject sources into images, or create entirely new images**

- **Inputs:**
  - Parameters to describe the properties of individual sources
  - Parameters to describe the collection of individual sources
- **Operations:**
  - Apply the instrumental throughputs (using synphot)
    - SEDs or data cube in physical units -> Images in counts/s
  - Convert the model shapes into an image
  - Convolve with the point-spread function
  - Add background
  - Apply geometric distortions (if simulating level-2 outputs)
  - Resample to the appropriate detector pixel geometry
  - Add noise
- **Outputs:**
  - Source “truth” catalog constructed from the input distributions
  - Images in the format of Level 2 output products (i.e. calibrated, but unrectified images), or Level 3 output products (rectified)



Catalogs: Static

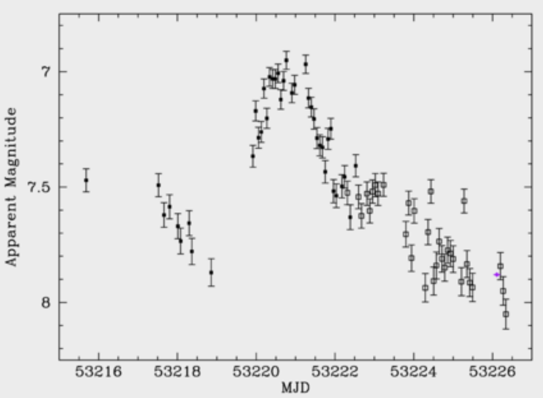
- **Primary cosmology-related goal is to enable accurate photometric redshifts**
- **Accurate, well-characterized photometry and shape measurements will also enable a wide range of general astrophysics**
- **Inputs:**
  - Level 3 images



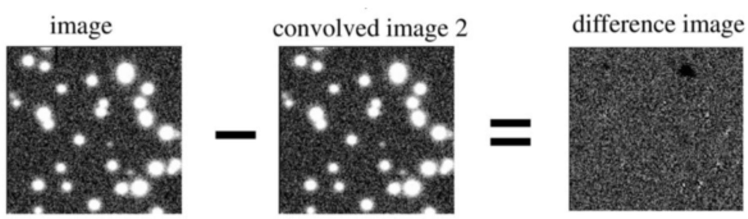
- **Operations**
  - Estimate and subtract background
  - Convolve with a detection kernel
  - Identify connected pixels above a noise-dependent threshold
  - Hierarchically de-blend overlapping sources
  - Measure fluxes through apertures
    - With and without convolution by a PSF-matching kernel to correct all photometry to one reference PSF
  - Measure shapes
  - Star-galaxy classification based on shapes (only)
  - Compute photometric redshifts from multi-band (Roman only) photometry
- **Outputs**
  - Level 4 catalogs including uncertainties computed from noise model
    - Photometry, positions, shapes, & local background estimates
    - Astrometry aligned to Gaia
  - Level 4 segmentation maps
  - Catalogs of input & output parameters for injected artificial sources

Catalogs: Variability

- **To be run in the pipeline to satisfy the requirement for time-domain information for variable sources**



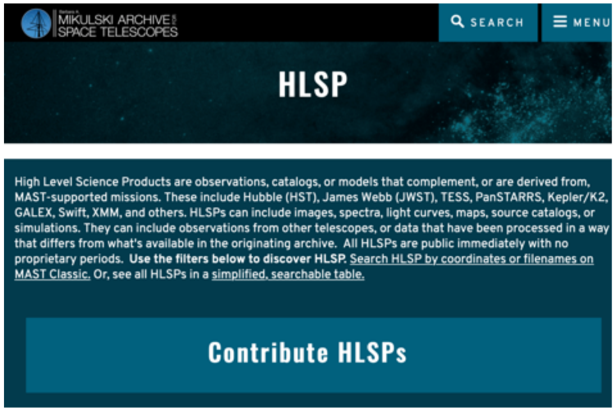
- **Photometry-based variability catalogs**
  - Inputs
    - Release-level merged survey catalogs
    - Individual images (level 2 or level 3)
  - Operations
    - Compare flux in static catalog to fluxes in individual images
  - Outputs
    - Database of the individual-image photometry for the entire survey area with variability index
- **Difference-imaging variability catalogs**



  - Inputs
    - Individual rectified images that overlap spatially
  - Operations
    - Convolve with PSF-matching kernel if needed
    - Subtract a template constructed from all but the most recent image
    - Identify point-sources in the difference above a threshold
  - Outputs
    - Level 4 catalog of sources that exceeded the threshold along with associated metadata

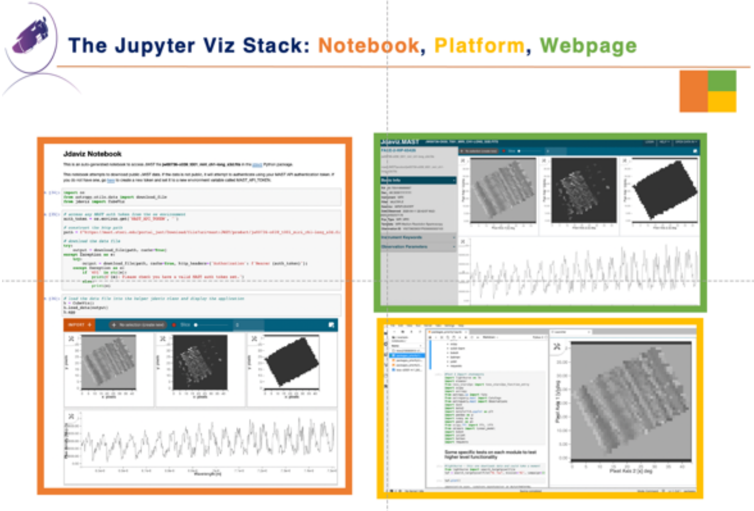
Community-Contributed Products

- **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**



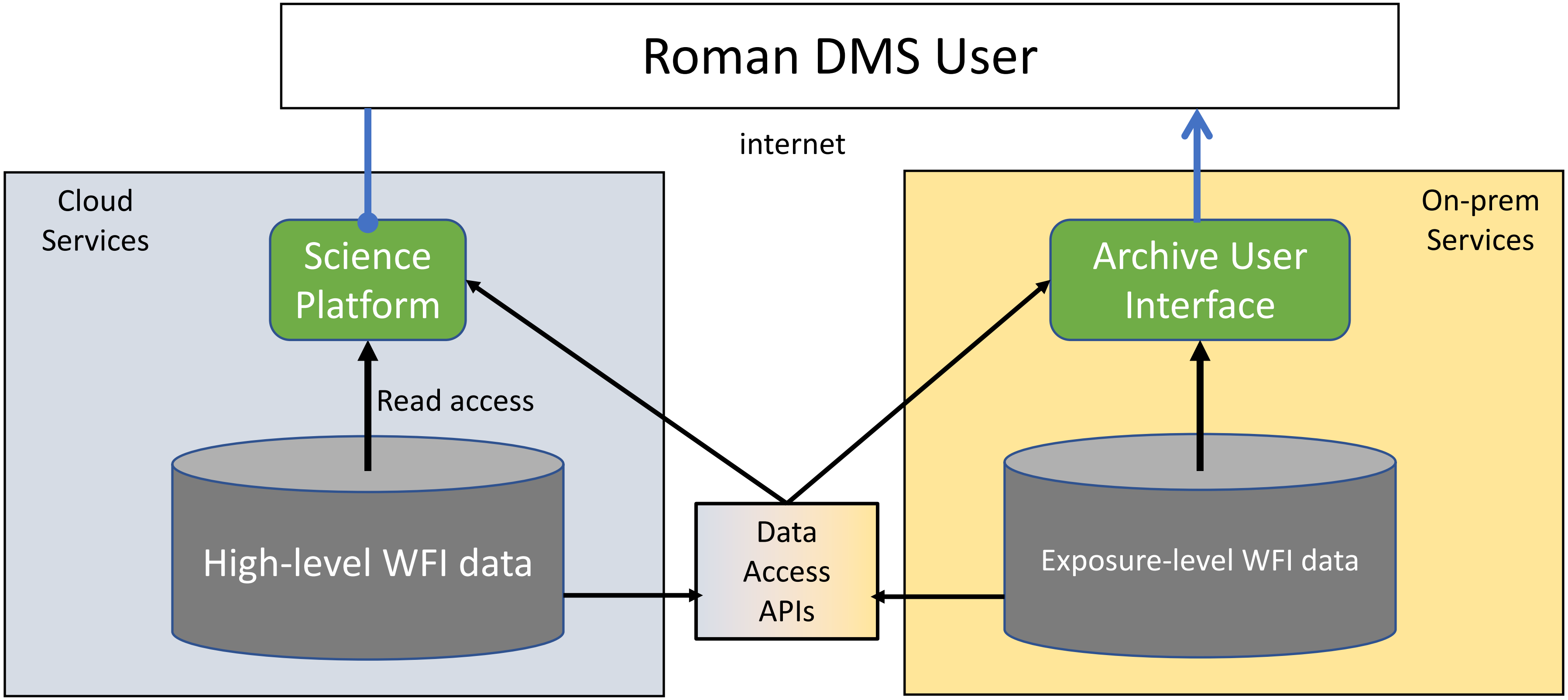
Archive

- **All Roman Science Data are Public and retrievable from MAST**
  - Includes data from SOC, SSC, 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**
  - SOC produced Level 2 and beyond
  - SSC high-level products



Accessing Roman Data

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

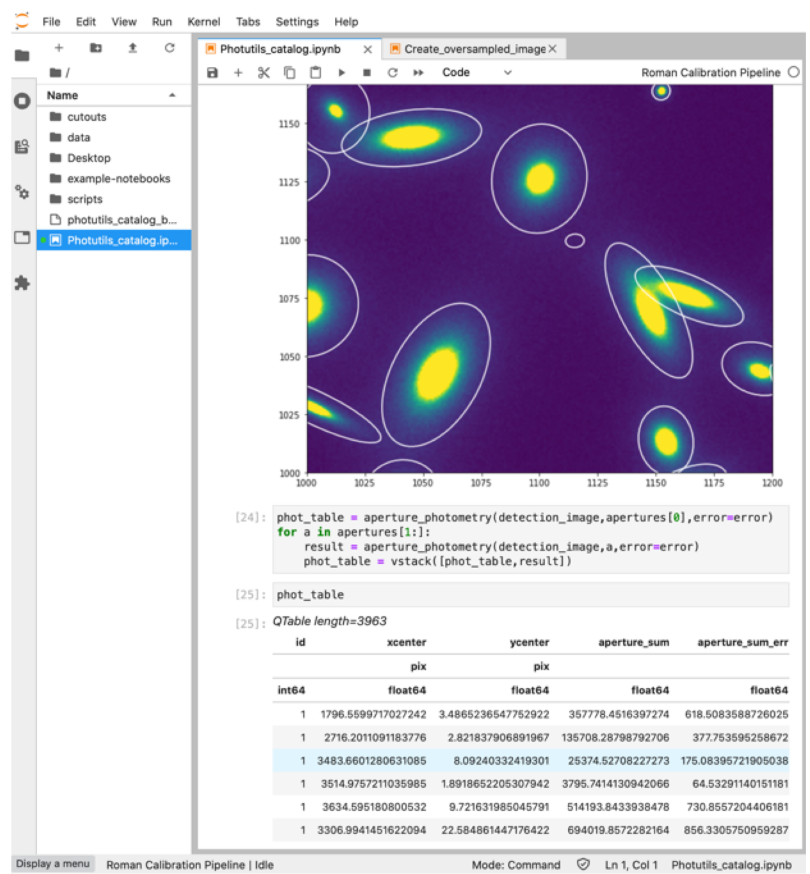


Why the Cloud?

- **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

Community use of the HLPP

- **Log in with your MyST account**
- **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
- **Flexible, scalable architecture**
  - Simple to add CPU & storage
  - High-throughput access to the data
  - Can scale up resources (e.g. GPUs or neural engines) as science needs & technology evolves



Concept for managing Roman platform

- **The platform should provide a sufficient base level of resources**
  - Most NASA Roman grants wouldn't need a computing line item.
  - Projects needing exceptional resources could still apply for funds
  - Allows much more global optimization for science than case where funds are locked in small grants.
- **Tier concept to support most users**

Tier	Users	Typical sky area processed per user
Entry	5000	A few
Research	1500	Tens to hundreds
Consortium	50*	Hundreds to thousands

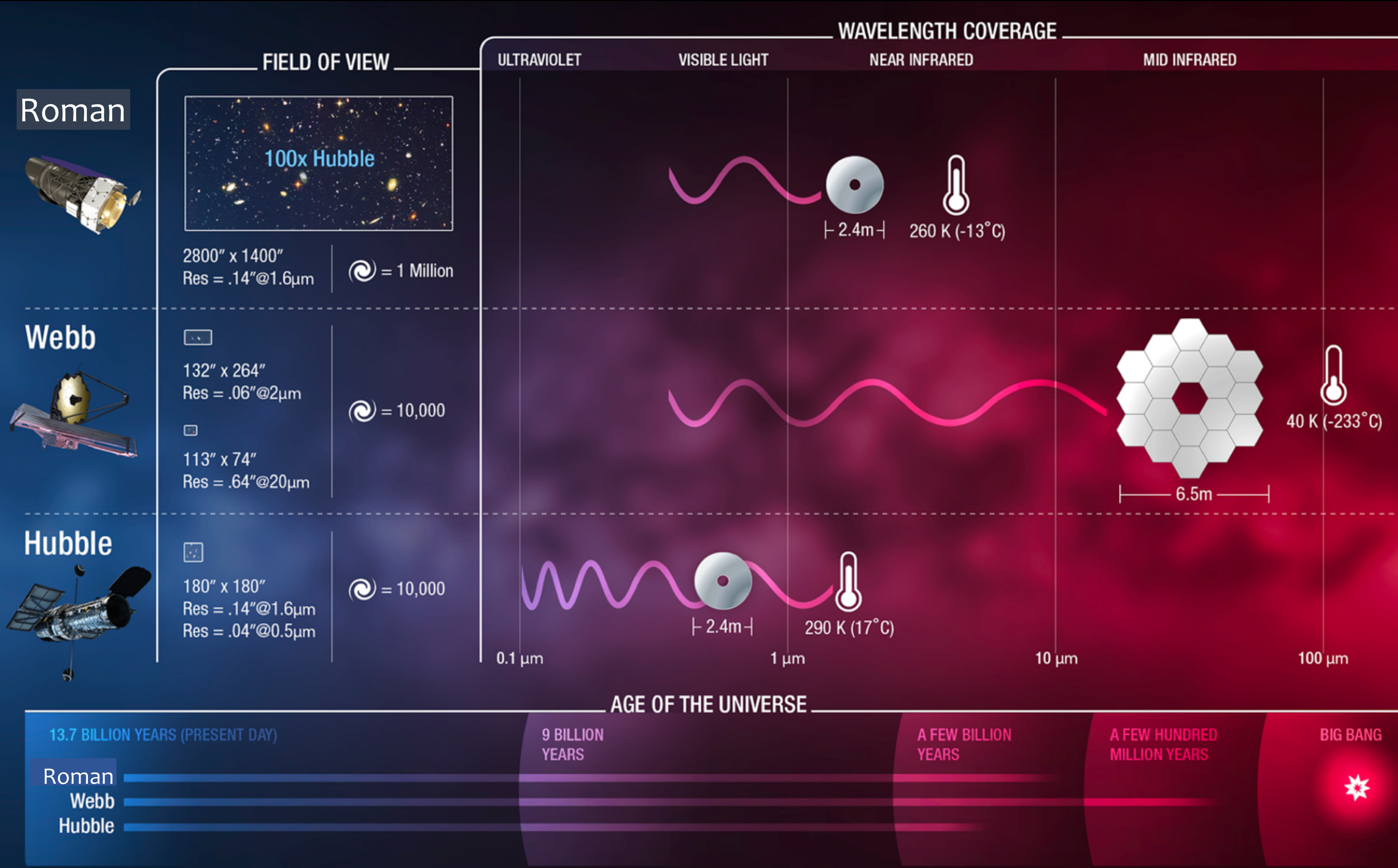
  - Very lightweight process at entry & research levels
  - *Consortium level: multiple users share resources
  - Will require periodic renewal
- **Looking to to enable ~1000 Roman papers/year**
  - The Roman-data-intensive work; not all the computing
  - Not long-term archival storage of intermediate projects

Concluding Remarks

- Roman is a unique observatory that will advance a wide range of astrophysical questions, and is complementary to other exciting missions and projects for the coming decade
- In its role as the Science Operations Center, STScI is working collaboratively with all other mission partners and the astronomical community to make Roman a success
- Excellent progress has been made on the design of the Roman SOC; system development has now started
- The Roman Data Management System at STScI will be the key to unlocking Roman's scientific potential, including innovative approaches to address Roman's key Big Data challenges

Backup Slides

Great Observatory Comparison



Instrument Capabilities

Roman Space Telescope Imaging Capabilities			
Telescope Aperture (2.4 meter)	**Field of View** (45′x23′; 0.28 sq deg)	**Pixel Scale** (0.11 arcsec)	**Wavelength Range** (0.5-2.3 μm)

Filters	**F062**	**F087**	**F106**	**F129**	**F158**	**F184**	**F213**	**W146**
Wavelength (μm)	0.48-0.76	0.76-0.98	0.93-1.19	1.13-1.45	1.38-1.77	1.68-2.00	1.95-2.30	0.93-2.00
Sensitivity (5σ AB mag in 1 hr)	28.5	28.2	28.1	28.0	28.0	27.5	26.2	28.3

Roman Space Telescope Spectroscopic Capabilities				
	Field of View (sq deg)	**Wavelength (μm)**	**Resolution**	**Sensitivity (AB mag) (10σ per pixel in 1hr)**
Grism	0.28 sq deg	1.00-1.93	461	20.5 at 1.5 μm
Prism	0.28 sq deg	0.75-1.80	80-180	23.5 at 1.5 μm

Roman Space Telescope Coronagraphic Capabilities					
	Wavelength (μm)	**Inner Working Angle (arcsec)**	**Outer Working Angle (arcsec)**	**Detection Limit***	**Spectral Resolution**
Imaging	0.5-0.8	0.15 (exoplanets) 0.48 (disks)	0.66 (exoplanets) 1.46 (disks)	10^{-9} contrast (after post-processing)	47-75
Spectroscopy	0.675-0.785				

Roman Space Telescope Advisory Committee

- Beth Willman (NSF's National Optical-Infrared Astronomy Research Laboratory) - Chair
- Zach Berta-Thompson (U. Colorado)
- Enzo Branchini (Roma Tre University)
- Wendy Freedman (U. Chicago)
- Josh Frieman (Fermilab)
- Lori Lubin (U. California-Davis)
- Rafaella Margutti (Northwestern University)
- John Mather (GSFC)
- Kristen McQuinn (Rutgers University)
- Matthew Penny (LSU)
- Adam Riess (JHU/STScI)
- Zeljko Ivezic (U. Washington, LSST)

Advises the STScI Director on all aspects of STScI's involvement in the Roman mission in order to ensure successful science operations and to maximize the observatory's scientific productivity.

https://www.stsci.edu/roman/about/roman-advisory-committee-rstac

- Dominic Benford (NASA HQ, Roman Space Telescope Program Scientist, ex-offio observer)
- Julie McEnery (GSFC Roman Space Telescope Project Scientist, ex-officio)
- Neill Reid (STScI, RSTAC Executive Secretary, ex-officio)
- David Spergel (Flat Iron Inst., Roman Wide-Field Instrument Adjutant Scientist, ex-officio)

Acronym List

- AAS (American Astronomical Society)
- AWS (Amazon Web Services)
- CGI (Coronagraph Instrument)
- DMS (Data Management Subsystem of SOC)
- GI (archival Guest Investigator)
- GO (Guest Observer)
- GSFC (Goddard Space Flight Center)
- IPAC (Infrared Processing and Analysis Center, at Caltech)
- MAST (Mikulski Archive for Space Telescopes)
- PSS (Planning and Scheduling Subsystem of SOC)
- SOC (Science Operations Center at STScI)
- SSC (Science Support Center at IPAC)
- WFI (Wide Field Imager)
- WFIRST (Wide Field Infra-red Survey Telescope)