Enabling Time-domain Science for Roman with RAPID

Roman ***A***lerts ***P***romptly from ***I***mage ***D***ifferencing

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TDAMM-SIG Community Meeting
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RAPID

Roman Alerts Promptly from Image Differencing

A Project Infrastructure Team for Roman

Mansi Kasliwal (PI; Caltech)
Ben Rusholme (Pipeline Development Lead; IPAC)
Schuyler Van Dyk (Science Definition Lead; IPAC)
Roberta Paladini (Galactic transients, Inclusion Lead; IPAC)
Lin Yan (Testing and Validation Lead; Caltech)
Ashish Mahabal (Machine Learning Lead; Caltech)
Joe Masiero (Solar System Objects Lead; IPAC)
Russ Laher (Senior Applications Developer; IPAC)
Jacob Jencson (Testing and Validation Scientist; IPAC)

Nancy Grace Roman Space Telescope

NASA flagship observatory

2.4 m primary mirror

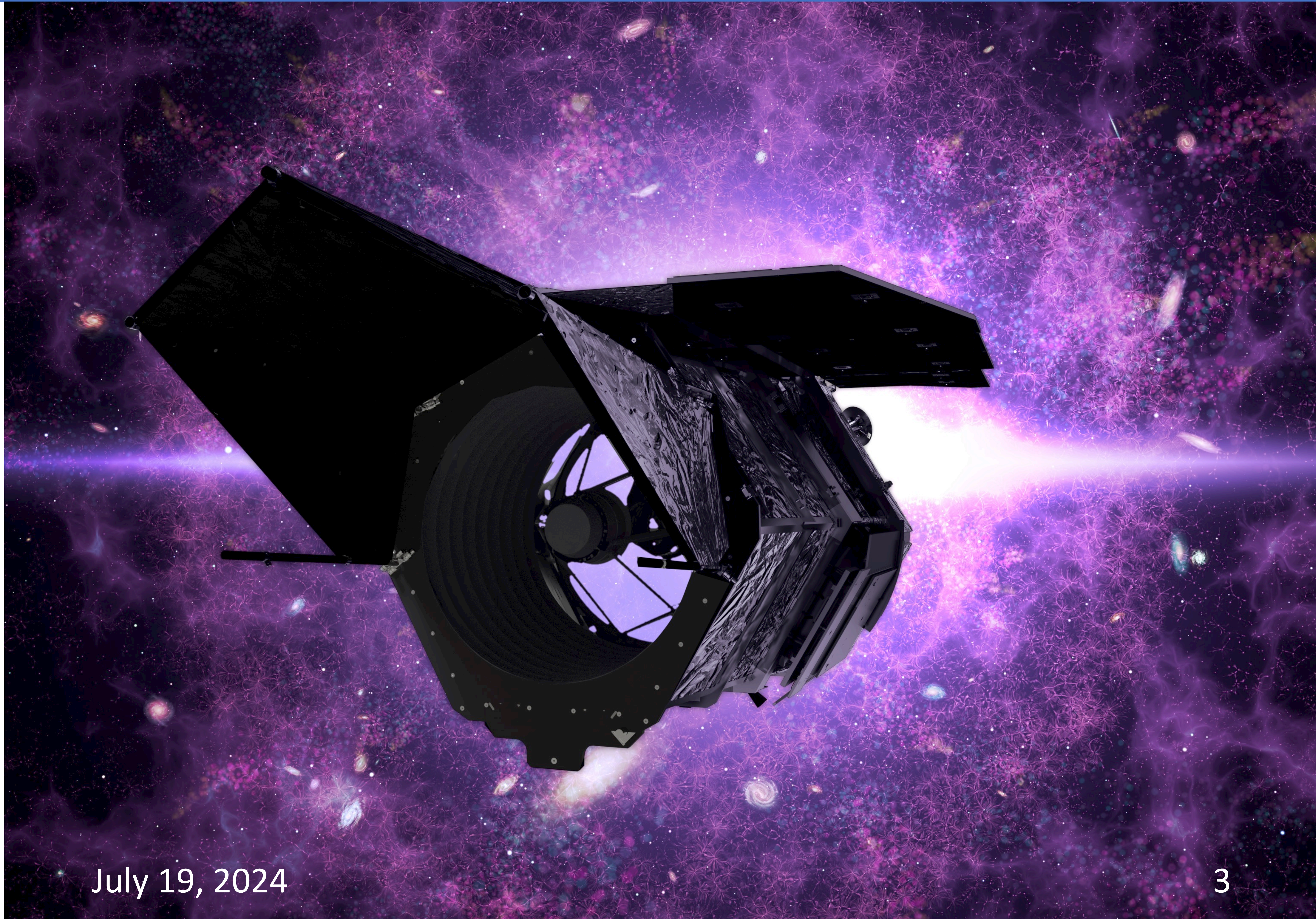
Wide-Field Instrument (WFI)

- NIR 0.48 – 2.30 μm
- 18 of H4RG-10 (300 Mpix)
- 0.28 deg^2 FOV
- 0.11” pixel scale

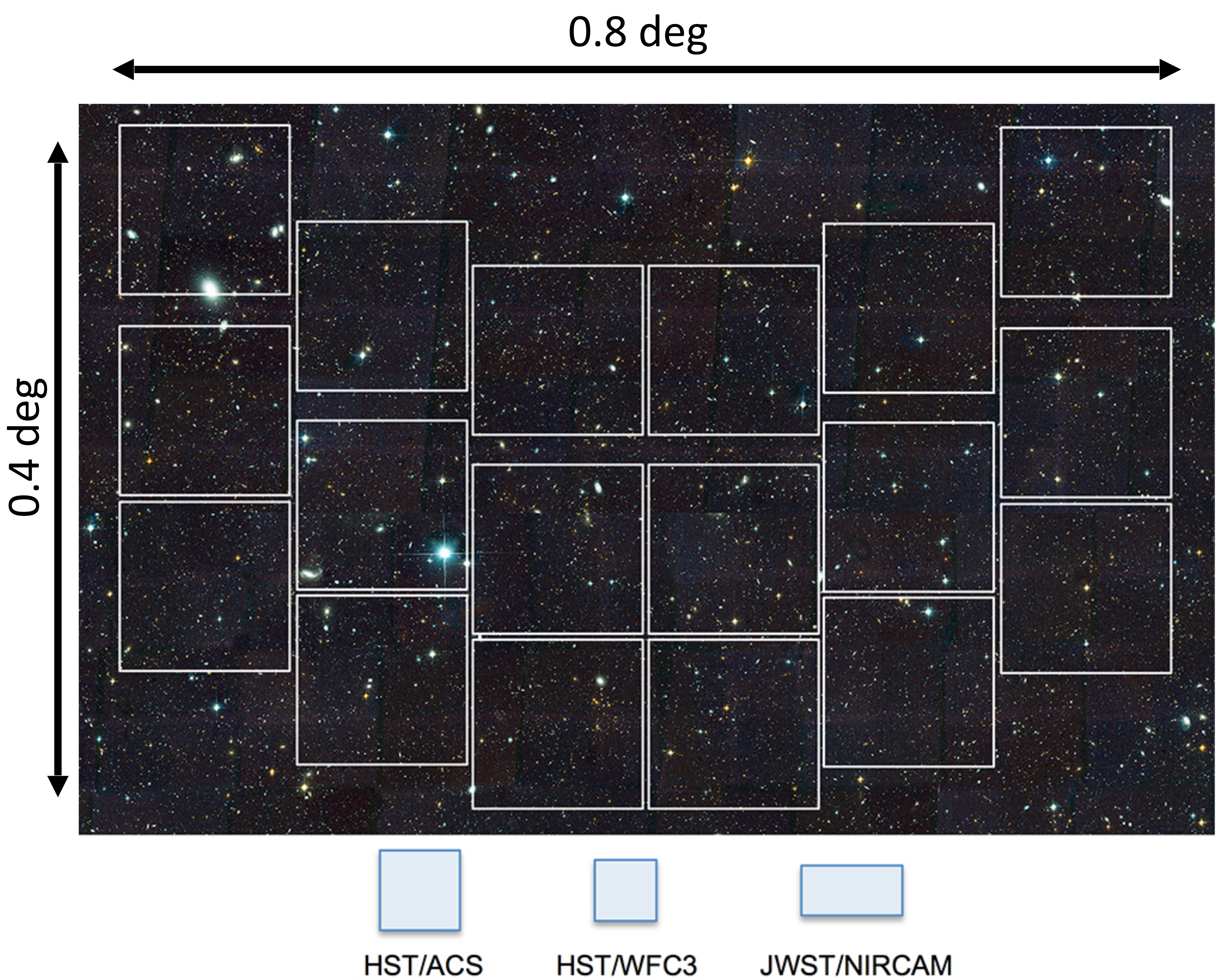
Launch by May 2027

Sun – Earth L_2 orbit

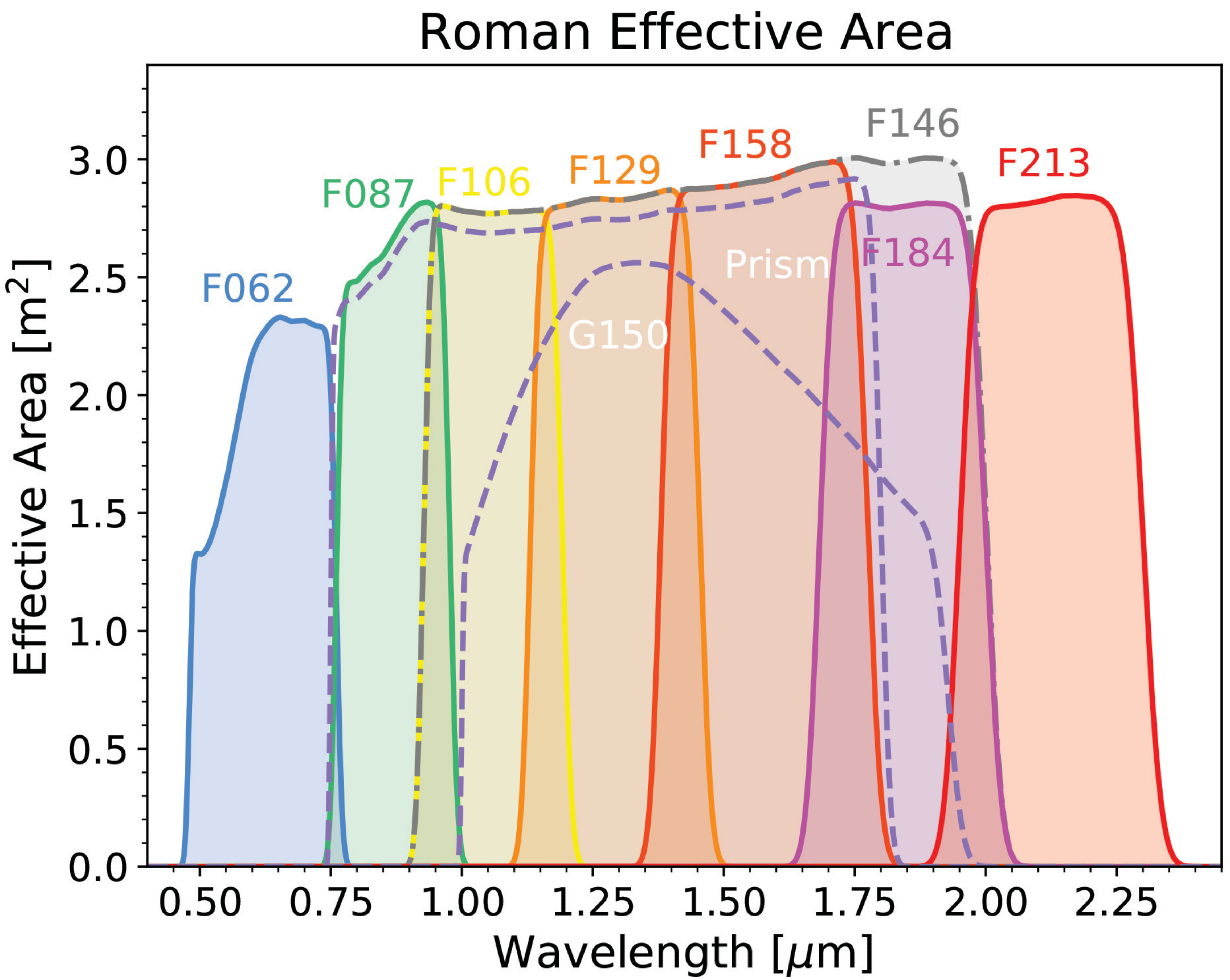
5+5 year nominal/extended mission



Roman Wide-Field Instrument (WFI)



0.11 “/pix   28.0 AB 1 hr in F158



Notional Observing Program for Roman

RAPID will perform image-differencing for **every** Roman WFI image with an available reference.

	Program	Area	Filters/ Grism/ Prism	Fraction of time
Core Community Surveys (CCSs)	High Latitude Wide Area	2000 deg^2	Y106, J129, H158, F184 + Grism	40%
	High Latitude Time Domain	20 deg^2	TBD Filters + Prism	10%
	Galactic Bulge Time Domain	2 deg^2	W149	20%
	General Astrophysics	N/A	Any	25%
	Coronagraph	N/A	N/A	5%

Infrared Time-domain Potential for Roman

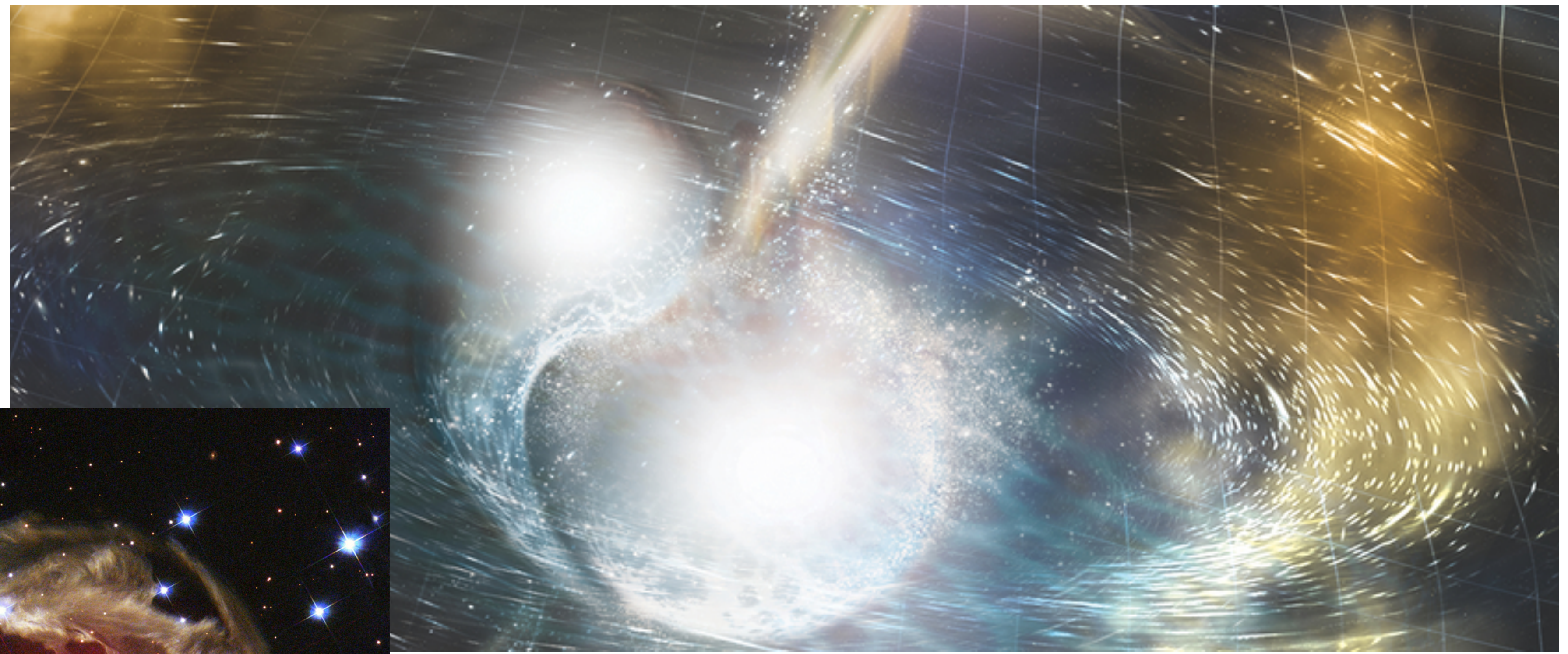
I. High opacity, e.g. synthesis of heavy elements

II. Self-enshrouding, e.g. stellar mergers

III. Milky Way extinction, e.g. Galactic variables

IV. Highest redshift, e.g. hot blue transients

V. Host obscuration, e.g. supernovae



NSF/LIGO/Sonoma State University/A. Simonnet

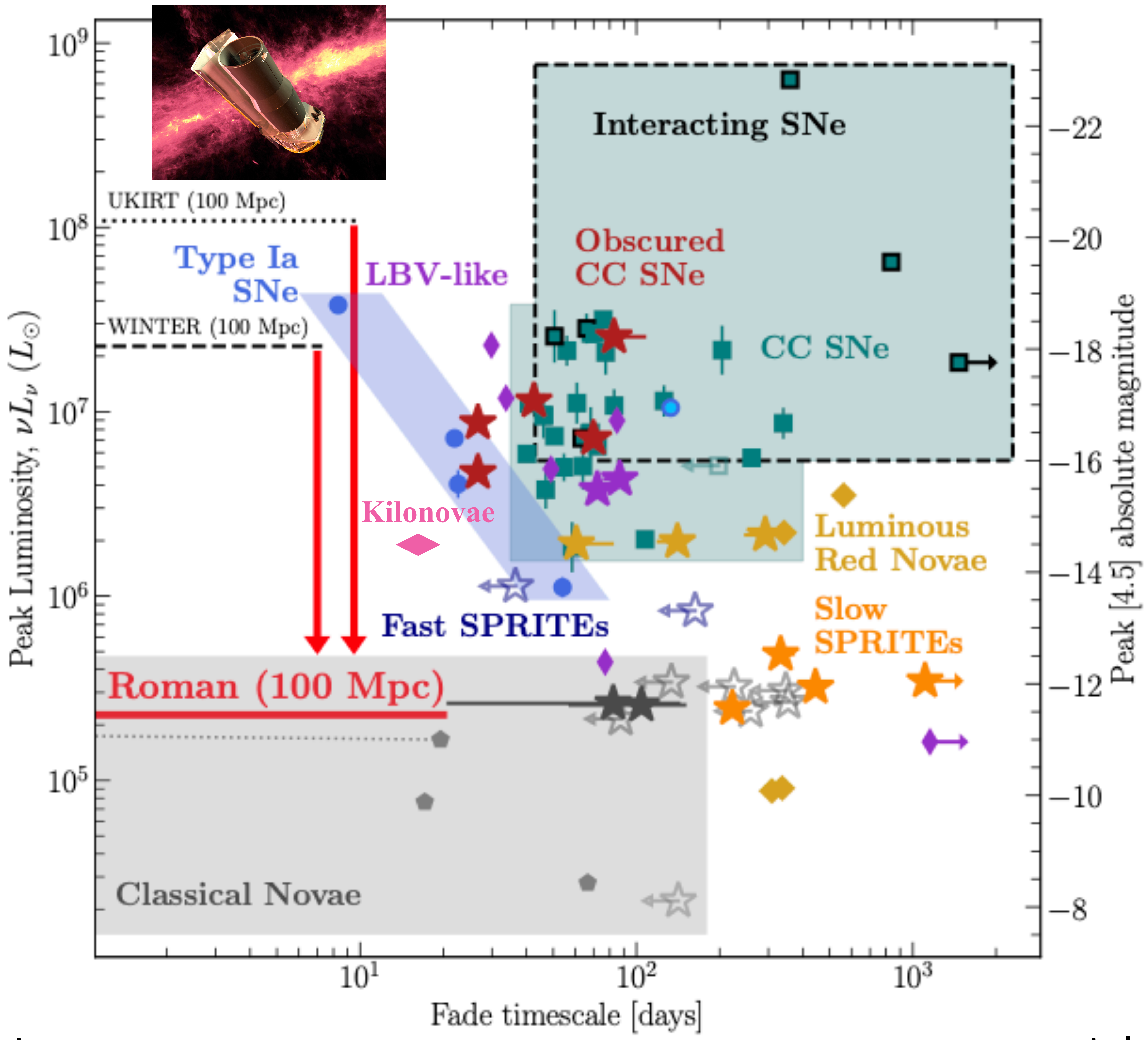
V838 Mon - H. Bond, NASA, ESA

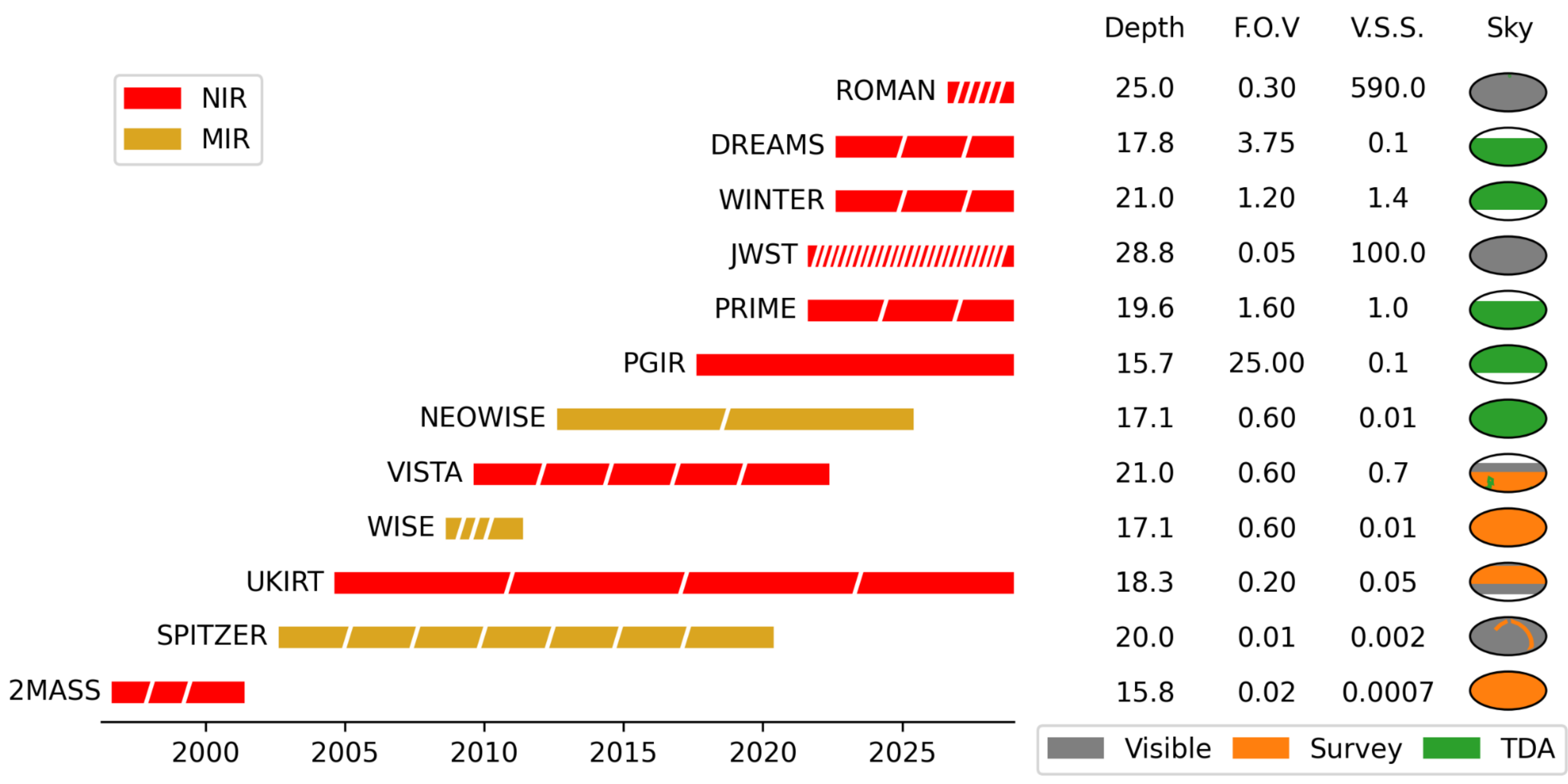
Visible

Infrared

Spitzer/NASA-JPL/T. Bourke

Infrared Time-domain Potential for Roman





V.S.S. = volumetric survey speed (normalized to PRIME)

Roman Project Infrastructure Teams (PITs)

Primary responsibilities of each selected PIT:

1. To develop and maintain such infrastructural tools and capabilities as are needed to address the proposal's focus
2. Support Community Science Collaborations
3. Support the Roman project in partnership with the Science Centers

5 Teams Selected:

- Cosmology with the Roman High Latitude Imaging Survey
- Roman Galactic Exoplanet Survey (RGES)
- Cosmological Measurements with Type Ia Supernovae
- Roman Galaxy Redshift Survey
- RAPID: Roman Alerts Promptly from Image Differencing

RAPID Aims to Provide 4 Services

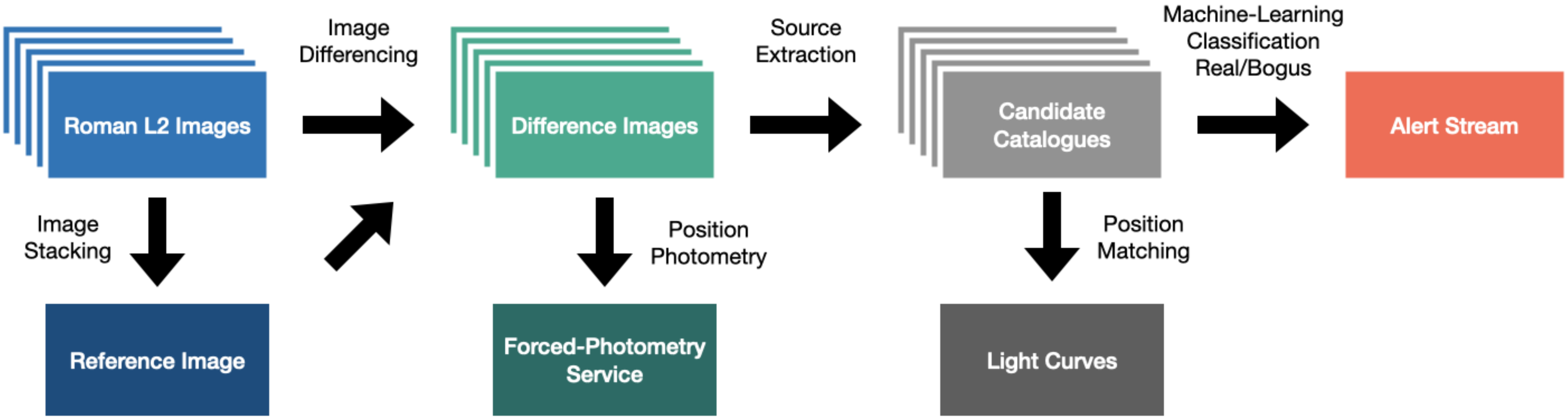
1. Rapid image-differencing of every new Roman image from a reference image
2. Prompt public alert stream of all Roman transient and variable candidates
3. Source-matched light curve files for every identified Roman candidate
4. Forced-photometry service for photometric history at any observed location

There was no previous plan to deliver a rapid time-domain discovery alert system.

Important to start now

- Develop a prompt Roman time-domain alert system in the years before launch
  - ➡ ***We need to be ready on Day 1***
- Pipelines, algorithms, schema need to be defined and tested well in advance
- Product specifications and example alert packets need to be communicated to downstream consumers (astronomers, event brokers) to allow enough time to prepare for our products
- The prompt alert system will need to be validated and tuned in operations …
- … but, the system needs to be in place before Roman data are acquired

RAPID Pipeline Overview

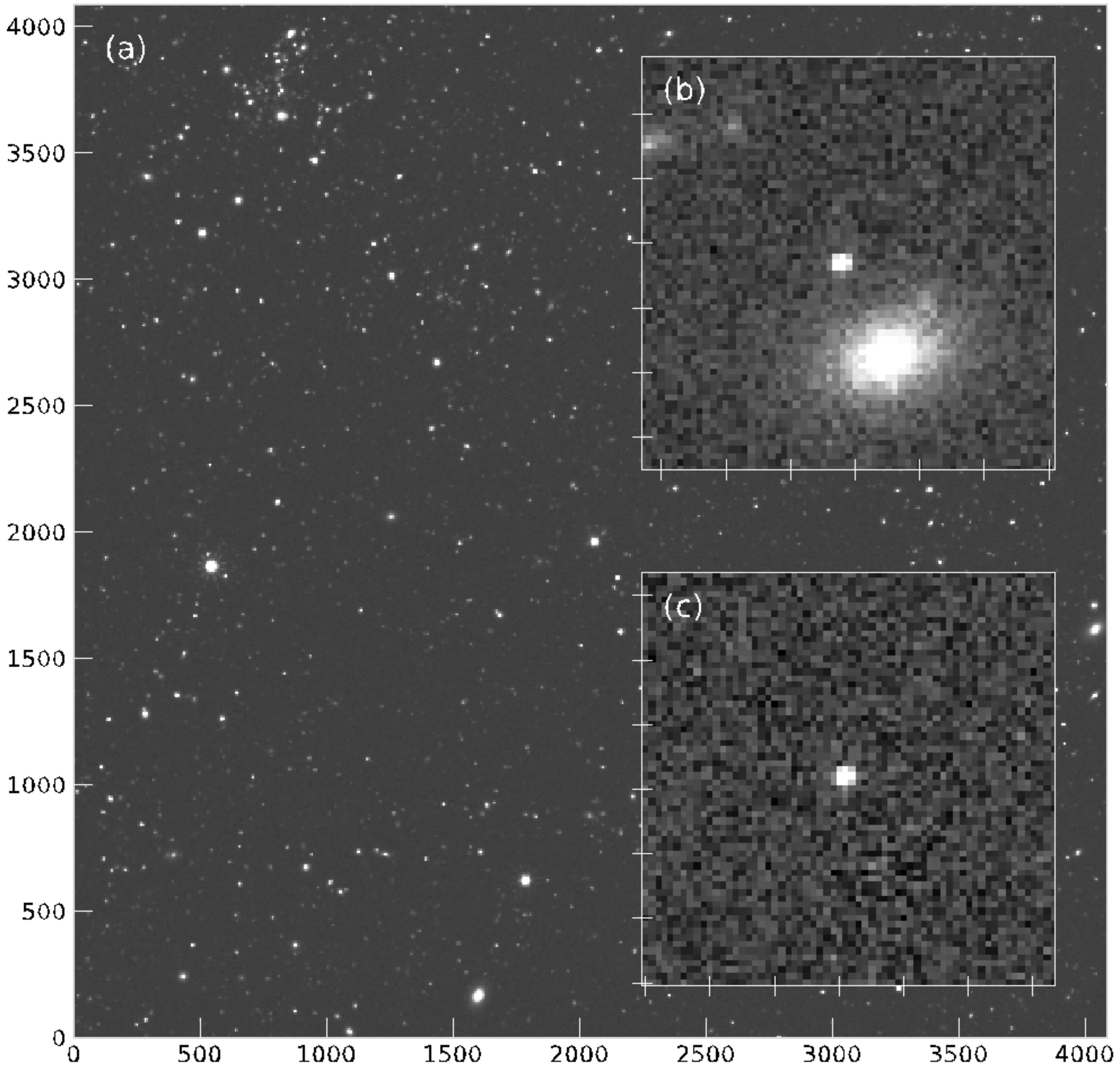


Low Latency is High-priority for RAPID

- Pull calibrated Level-2 WFI data from the SOC staging location
  - ➡ (< 48 hour turnaround)
- Execute image differencing and prompt public alert broadcasting (< 1 hour)
  - ➡ Includes initial source classification via machine learning
- Offer forced photometry on difference images
- Append and release light curve history of sources
- Archive public alerts via STScI MAST

} (< 24 hours)

Dynamically Buidling Reference Images



Proof-of-concept image differencing of a single simulated Y-band Roman SCA. From Wang et al. (2022).

Challenges:

- No fixed on-sky field grid
- No set orientation
- No constant exposure time

➡ Repeat visits of the same sky will only partially overlap, with different depths

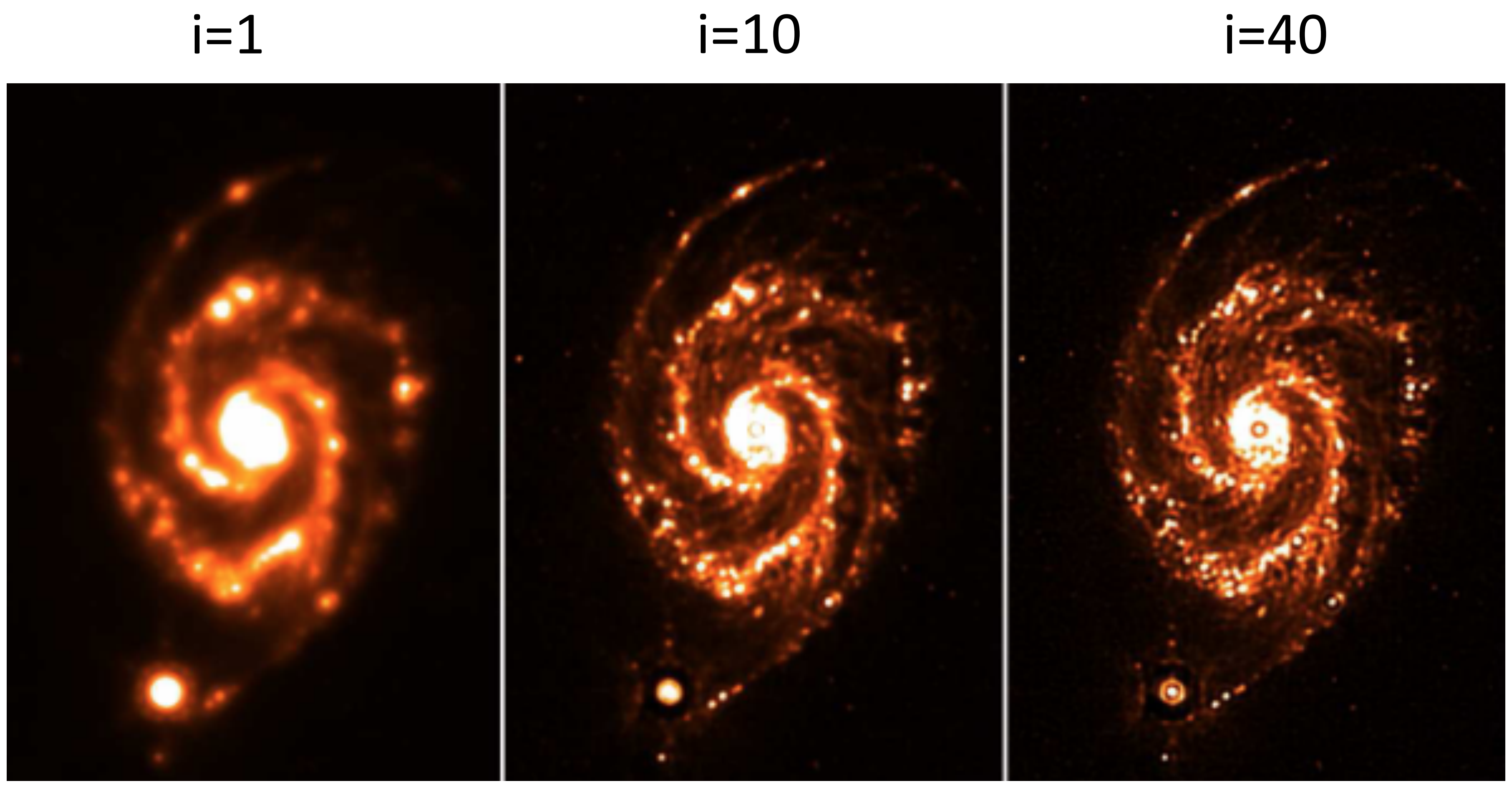
Working plan:

- Define fixed sky grid with cells 1/9 of Roman FoV (per available band)
- For each new image, identify which cells completely or partially overlap fixed grid
- If overlap >50%, add to counter of cells and increment the exptime at sky position
- Nominally, first epoch of a given cell becomes the reference image
- That reference image superseded by next deeper exposure
- Next shallower exposure triggers image differencing
- May build reference mosaics, or adopt SOC mosaics as available

AWAICGEN: Legacy IPAC Software

Developers (IPAC): F. Masci and J. Fowler

- Image reprojection to common grid
  - Use WCS with distortion (SIP keywords)
  - Common zero point & background matching
  - Optional bad-pixel mask & sigma image
  - Optional area-weighted interpolation
  - Upsampling option
- Capable of image co-addition
  - PRF-weighted averaging or inverse-variance weighting
  - Optional iterative Hi-Res method (maximum SNR correlation)
    - Allows for non-isoplanatic PRFs
    - Prior noise-variance weighting
    - Uncertainty estimation
    - Ringing-suppression
  - Products are coadd, coverage, and sigma images
- https://web.ipac.caltech.edu/staff/fmasci/home/icore.pdf
- May use SWarp to avoid resampling new images for subtraction



Optimizing Image-differencing

- *Challenges*: mismatch in roll angle, undersampled PSF
- *Plan:* Test and tune various difference imaging algorithms to optimize
- *Metric*: maximal recovery of injected simulated light curves and minimal false positives

Considering **ZOGY** (Zackay, Ofek & Gal-Yam 2016) and **SFFT** (Hu+ 2022)

ZOGY:

- ☑ Numerically stable & symmetric
- ☑ Optimal for transient detection
- ☑ Minimual tuning
- ☑ Significant IPAC experience from ZTF
- ☐ Requires PSFs
- ☐ Spatial variation requries subdivisions

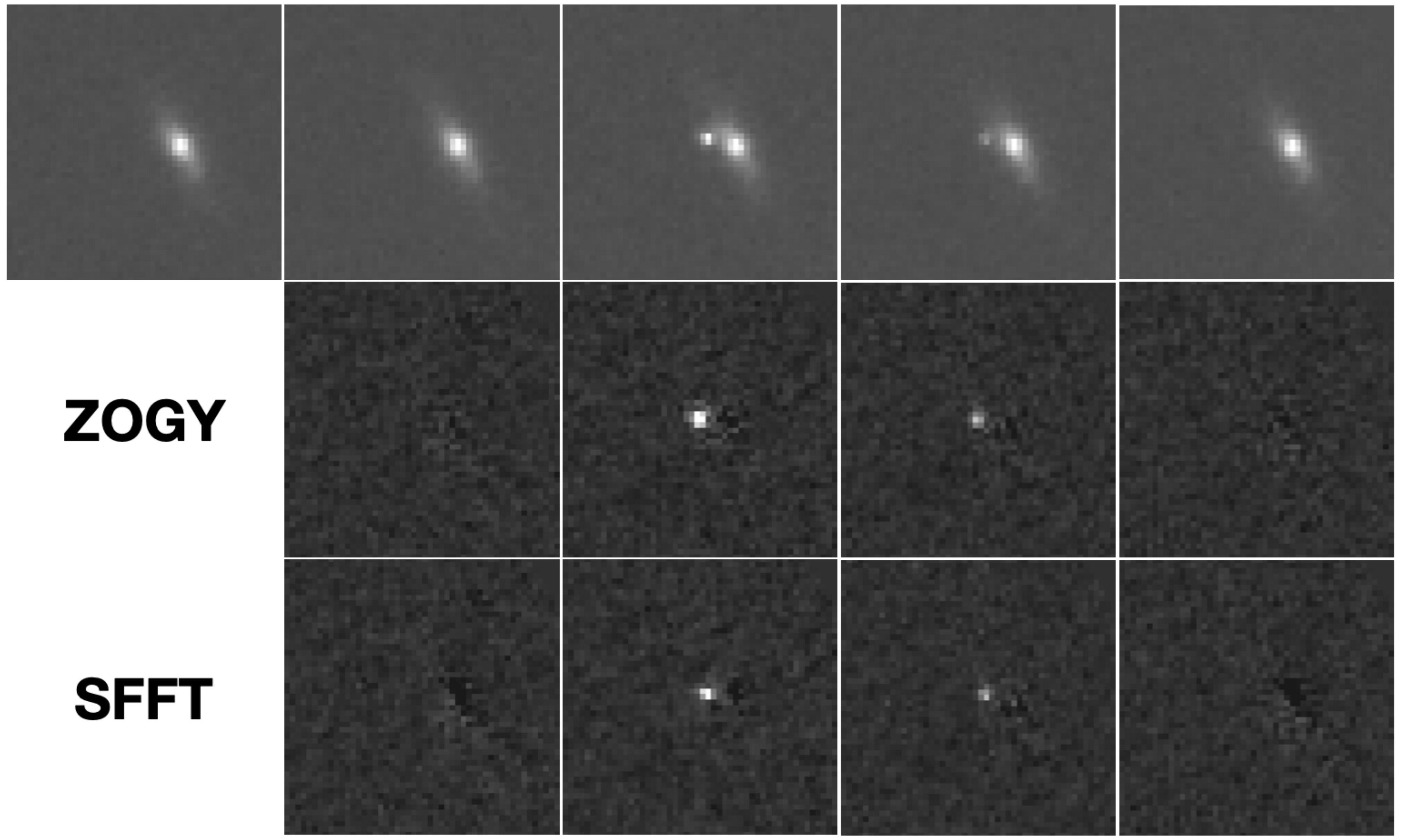
SFFT:

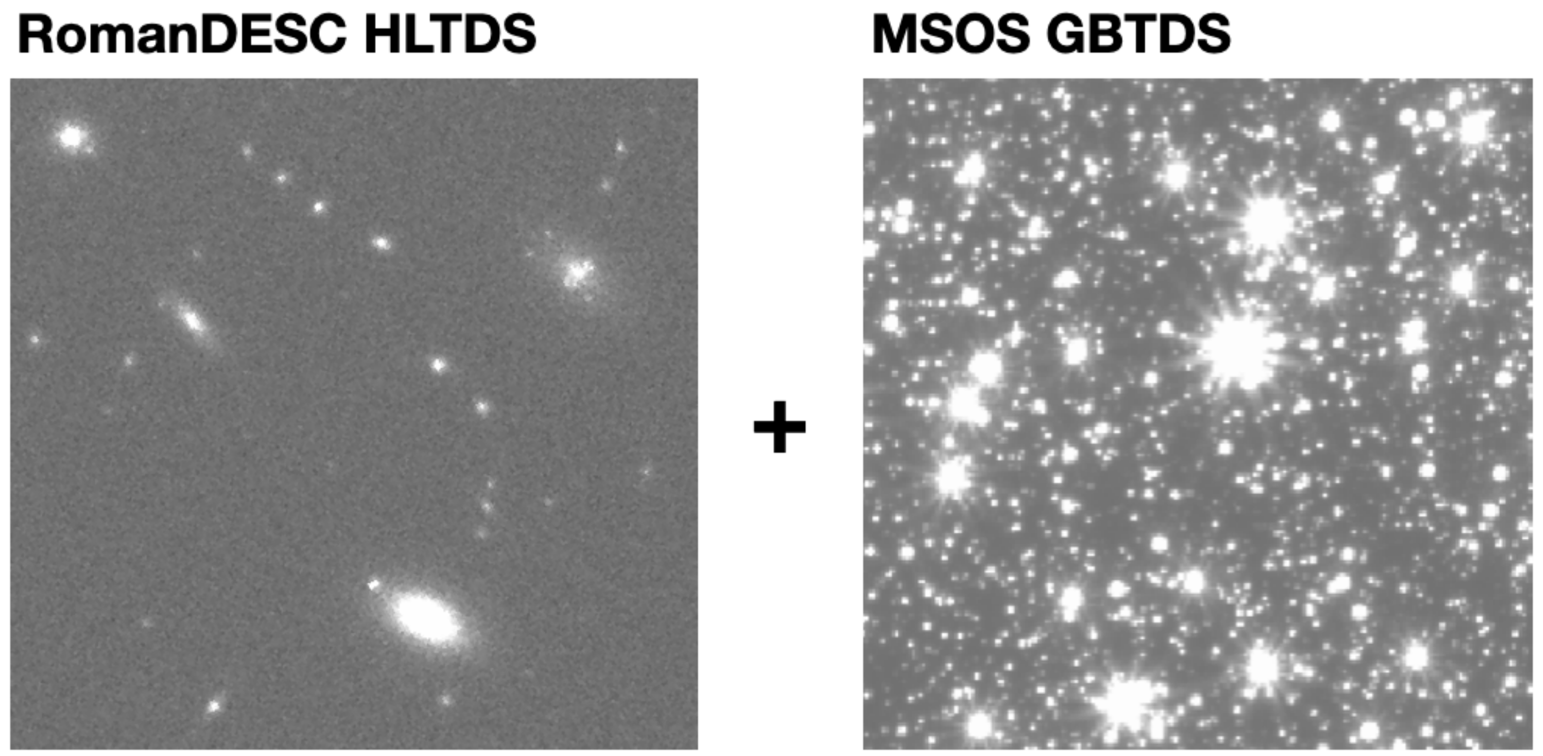
- ☑ Fast on GPUs
- ☑ No knowledge of PSFs required
- ☑ Handles spatial variations
- ☐ But… many parameters, significant tuning

Optimizing Image-differencing

Tests underway with NASA OpenUniverse HLTDS Simulations:
https://irsa.ipac.caltech.edu/data/theory/openuniverse2024/overview.html
(Thank you Michael Troxel, Alina Kiessling, Dan Scolnic, Rebekah Hounsell, Rick Kessler)

- Also considering cost, speed, resources, etc.
- Current simulations are “perfect” - will test on real HST/JWST data
- Examine performance across environments, e.g. Galactic vs extragalactic, galaxy nuclei
- Expand tests to Microlensing Science Operations System (MSOS) simulations of GBTDS *(Thank you MSOS and RGES PIT)*
- Consider algorithmic improvements, e.g., Hybrid SFFT (Hu+ 2024), TRANSLIENT (Springer+ 2024)

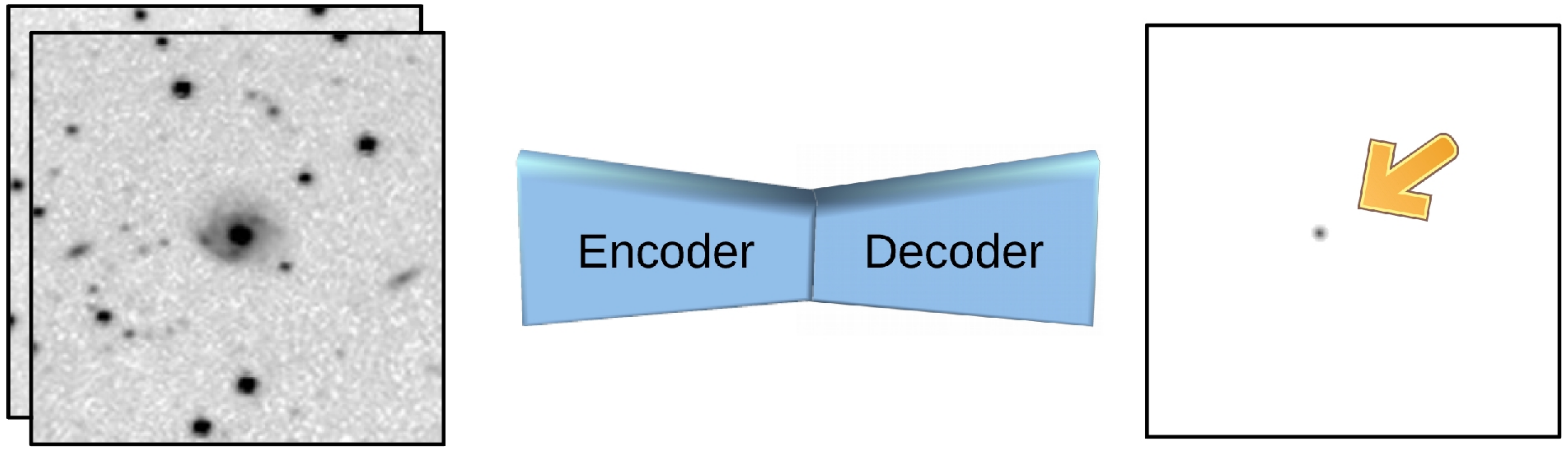


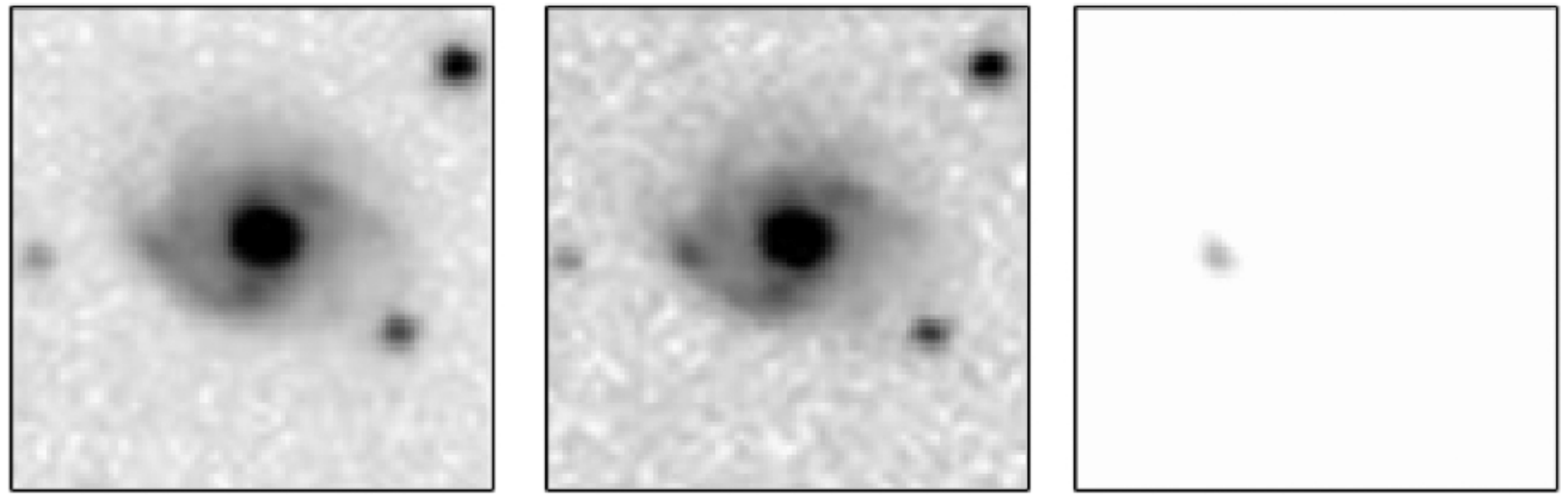


Source Classification via Machine-Learning

- Hierarchical binary source deep-learning classifiers robustly and successfully implemented in ZTF
- Allows users to choose thresholds
- Real/bogus score to flag artifacts
- Classifications included in alert packets
- Led by Ashish Mahabal (Caltech), exploring current available simulations to:
  - ➡ start detecting & classifying injected transients
  - ➡Understand issues near edges, etc.
  - ➡ Monitor for artifacts due to saturated transients, diffraction spikes, etc.
  - ➡ training at the catalog vs. image level
- Using convolutional neural networks (CNNs) and may explore other ML techniques/workflows
- Exploring transfer learning with TransiNet, a transient detector without image subtraction

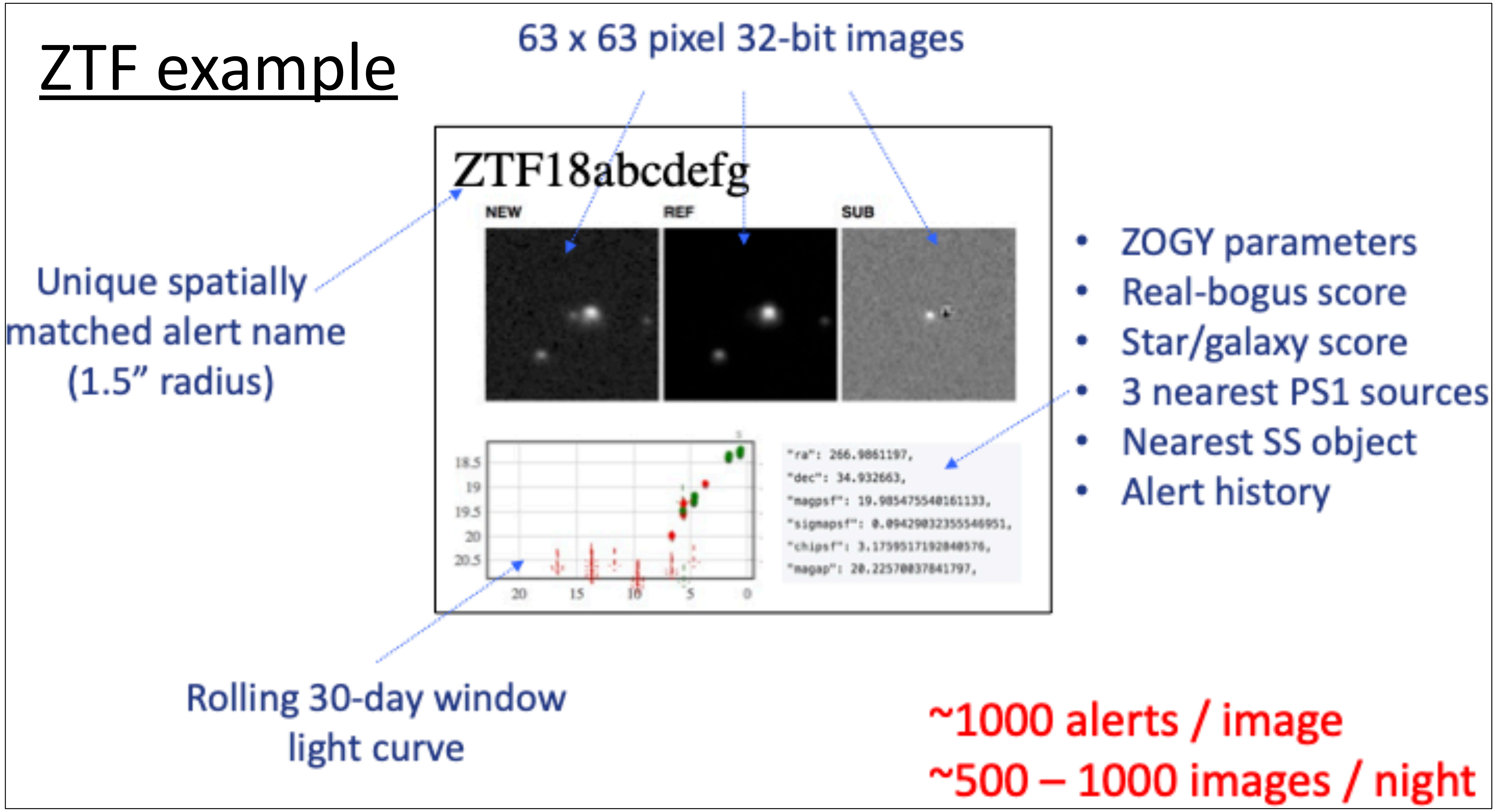
“Image subtraction” for hunting transients without subtraction





TransiNet, based on convolutional neural networks (CNNs); Sedaghat & Mahabal (2017)

Prototyping Alert Stream Schema



Raw stream to be picked up by brokers (ALeRCE, Fink, ANTARES, Lasair, etc.)

Stream could easily be extended for use by HLTDS and GBTDS

Looking for feedback on, e.g., other content (Rubin?) to include

Community Engagement

- Roman Time-domain Working Group: https://outerspace.stsci.edu/display/RSWGS/Description+of+Roman+Working+Groups
  - ➡**S**trategic **T**ime-domain **R**esearch and **I**nfrastructure **D**evelopment for Roman **E**xploration (**STRIDE**), chaired by Ashish Mahabal of RAPID
  - ➡Enable open communications across PITs, SOC, SSC, and TDA community
  - ➡Monthly virtual meetings (First Fridays; Next meeting **Fri, Aug 2 @ 10 AM PT, 1 PM ET**)
- Looking for your input on adding transients to exisiting Roman simulations:
  - ➡low-lum. SNe, FBOTs, ILRTs, LRNe, AGN flares, SN-impostors, novae, IIn’s, Ia-CSM, Galactic variables and transients, and your favorite class

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We want your input and feedback!

RAPID is hiring!

Currently 2 open positions:

- Application Developer (Early career, Python/SQL)
- Staff Scientist (to be posted AAS soon, for late/end this CY)

Please forward to any potential candidates!

Further opportunities in FY25