Microlensing with the Roman Galactic Bulge Time Domain Survey
a Detector Simulation

Exploring the Transient Universe with the the
Nancy Grace Roman Space Telescope
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Layout

- ❑ **Microlensing with the Roman Galactic Bulge Time Domain Survey**
- ❑ **Roman Science Support Center (SSC) at IPAC**
  - ✓ **Microlensing Science Operation System (MSOS)**
- ❑ **A detector simulation**
  - ✓ **Purpose of the simulation**
  - ✓ **Toolbox for the image and star simulation**
  - ✓ **The Simulated Bulge scene**
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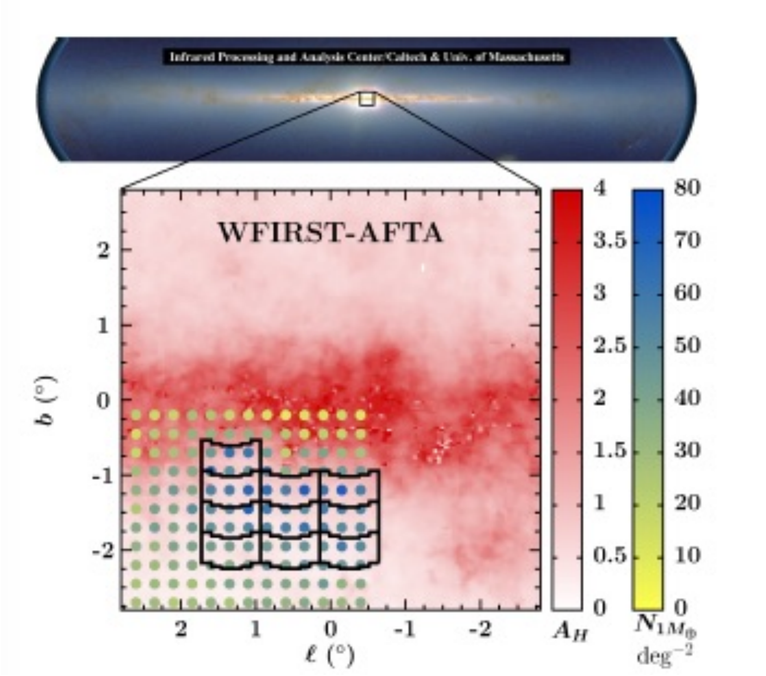
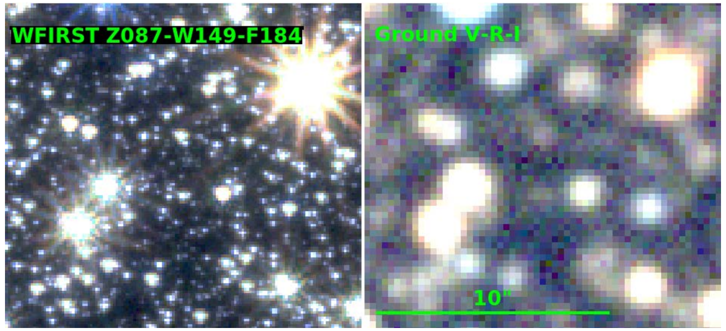
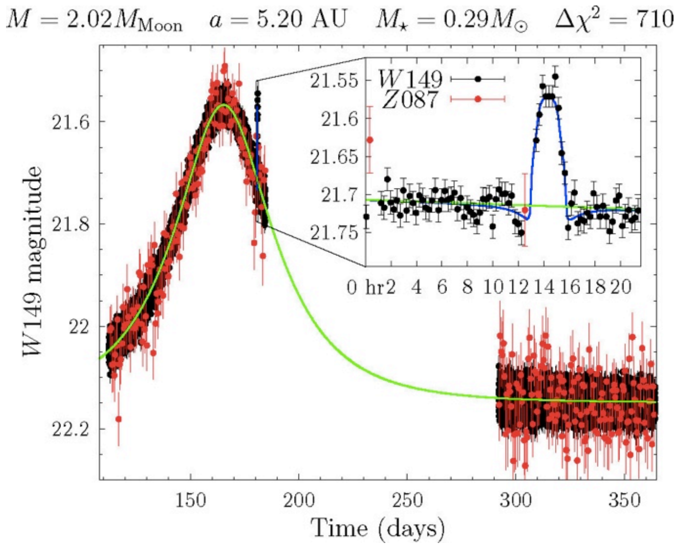
  - ✓ **Noise, Sky, Crowding**
  - ✓ **Jitter simulation**
  - ✓ **Persistence simulation**
  - ✓ **Simulation for microlensing events**
  - ***Acknowledgements: S. Carey (Calecth/IPAC), M. Penny (LSU) for the microSIT (PI: S. Gaudi, OSU)***
- ❑ **MSOS photometry pipeline: prototype analyses**
- ❑ **Summary: Moving Forward**

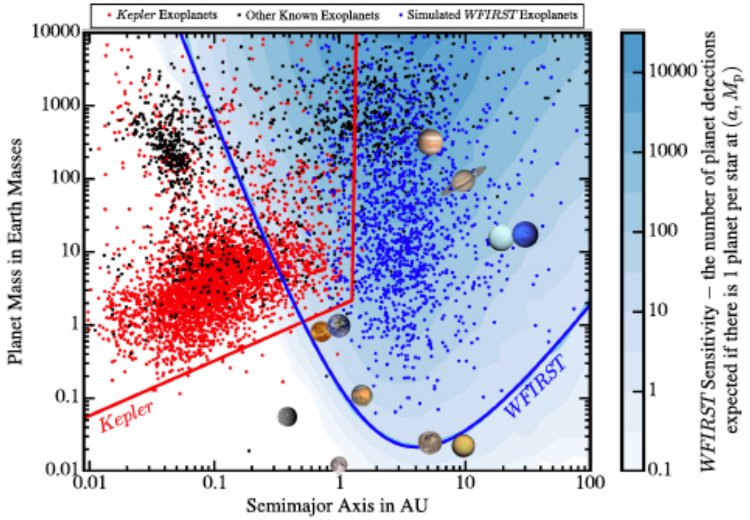
Microlensing with the Roman Galactic Bulge Time Domain Survey





- **Notional Survey Observational Strategy**
  - area of the survey: 2 square degree
  - duration: 60-72days x 6 seasons along 5 years
  - cadence: 15 minutes in primary Wide filter
  - yield: $\sim 3\times10^4$ microlensing events and $\sim 10^3$ bound exoplanets and bonus free floating planets
  - data volume: $\sim 40{,}000$ epochs with Wide filter for $\sim 10^8$ monitored stars

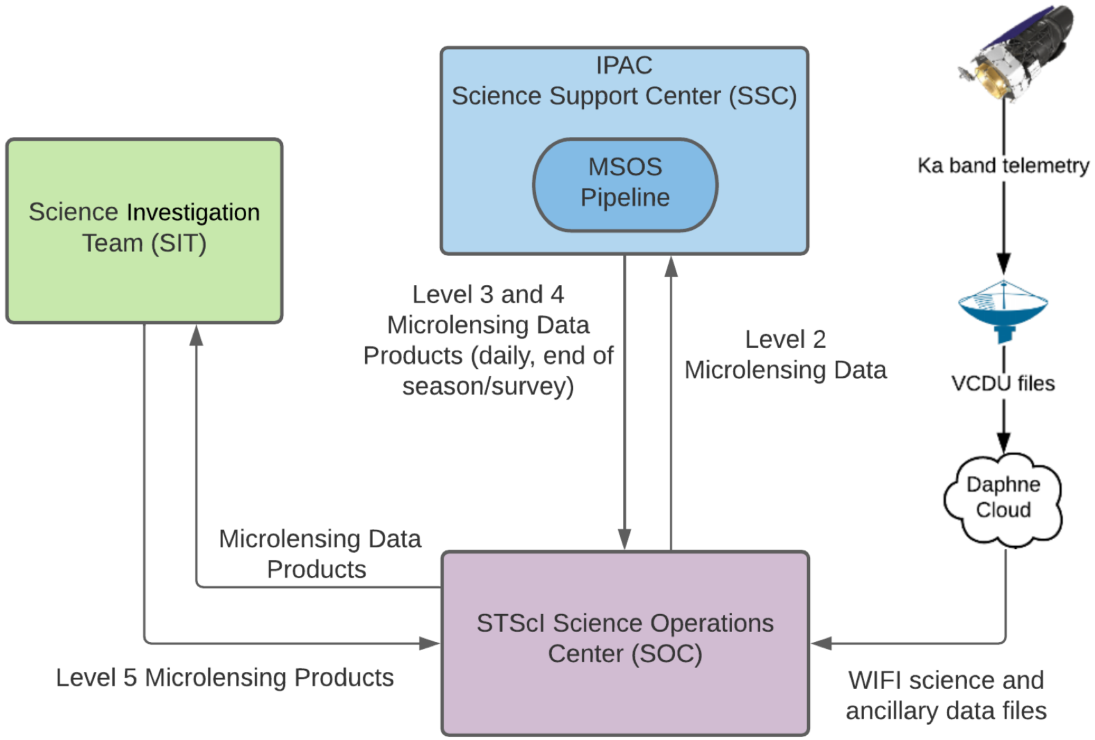




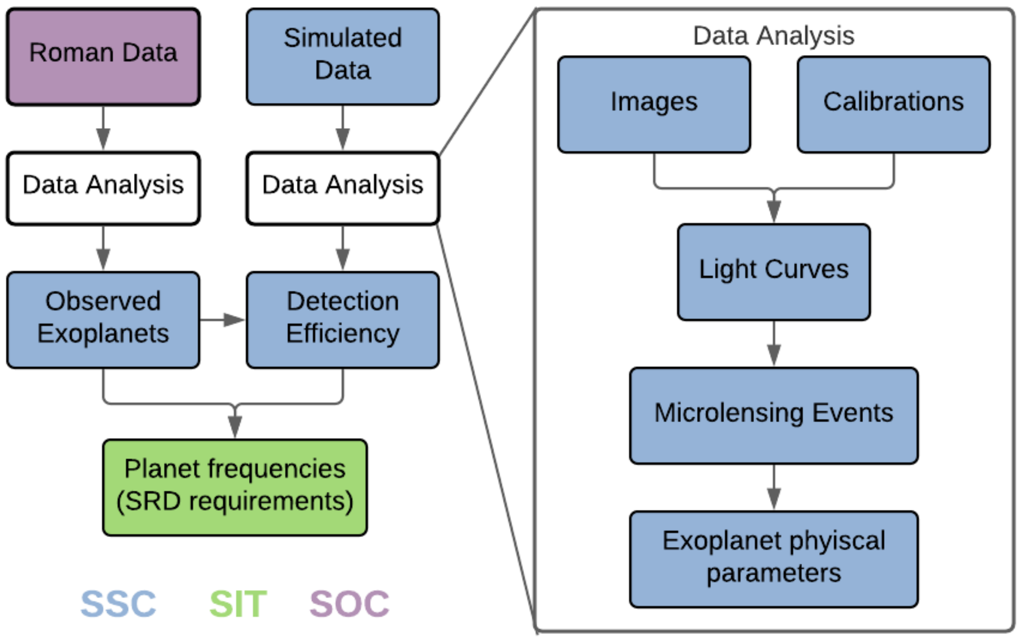
Penny et al, 2019

Microlensing Science Operation System (MSOS) at the Science Support Center (SSC) at IPAC

High-level data flow



High-level Science flow



(lead: R. Akeson)

A detector simulation: Testbed for the MSOS pipeline at SSC/IPAC

framework: a primary goal of the image analysis for the microlensing survey consists in light curve photometry and astrometry for the ensemble of monitored stars (in a very crowded field with overall order of 200 million monitored stars) with expected over 40,000 epochs in the primary wide filter

- Impact on photometry and astrometry (in particular for planetary microlensing events)
  - Astrophysical effects
    - Underlying photon noise (from the astrophysical scene)
    - crowding
    - proper motion
    - PSF variations
    - ....
  - Detector/observatory effects
    - Detector/observatory noise (read out, thermal,...)
    - Jitter
    - Sampling-up the ramp
    - Intrapixel sensitivity variations
    - Classical non-linearitities
    - IPC
    - Brighter Fatter Effect
    - Persistence
    - PSF variations
    - ....

Toolbox for the simulation

image and star simulation

- Astrophysical scene, crowded star fields toward the Bulge : star density, luminosity function, star proper motion from GULLS (M. Penny et al 2019)

- Microlensing Population: relative proper motion, source/lens brightness, microlensing parameters (M. Penny et al , 2019)

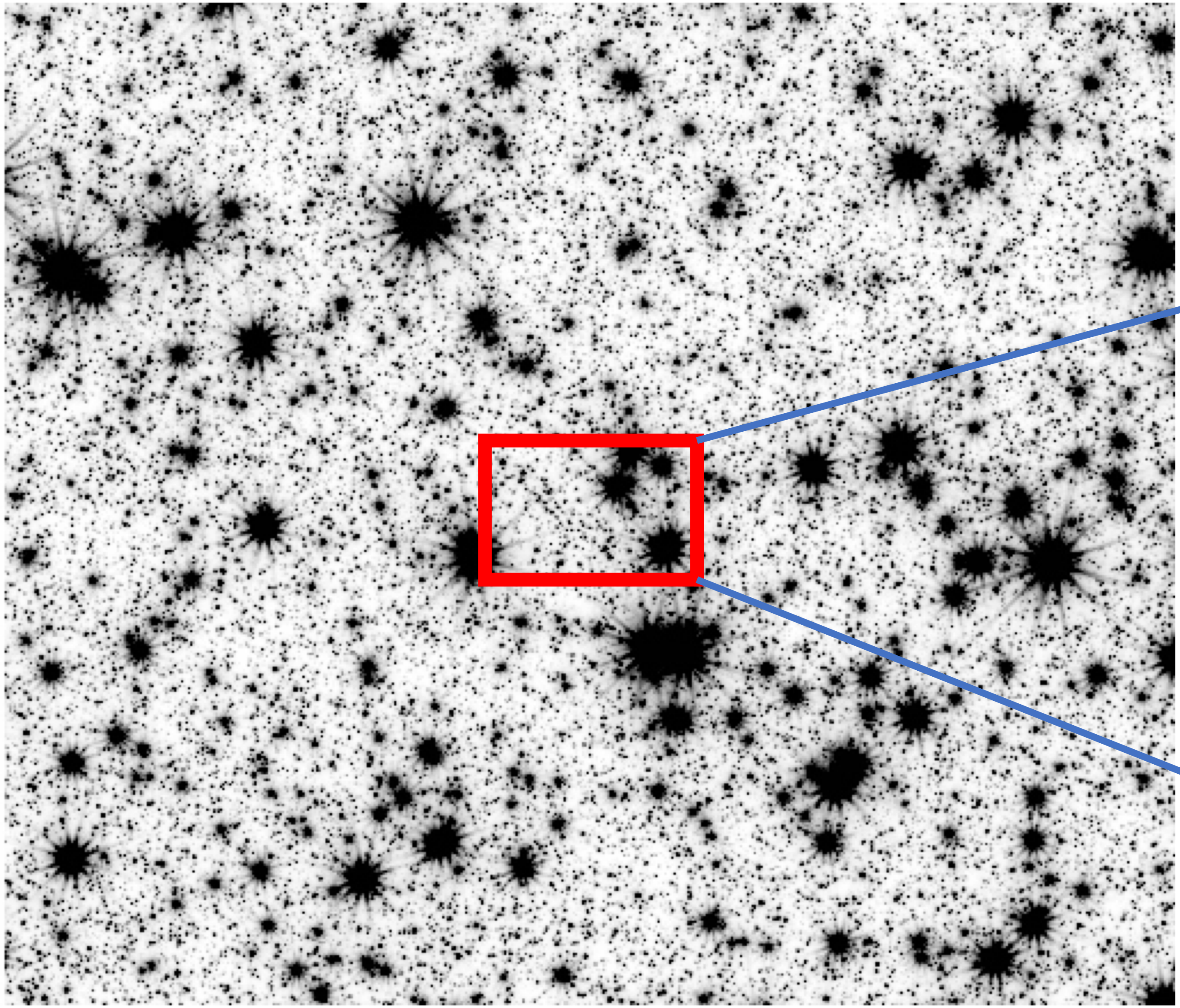
- Instrument and observatory models and noise specification from GULLS (M. Penny et al, 2019) and various sources related to the Roman project

- PSF model from WebbPSF (Perrin, Long et al @ STScI)

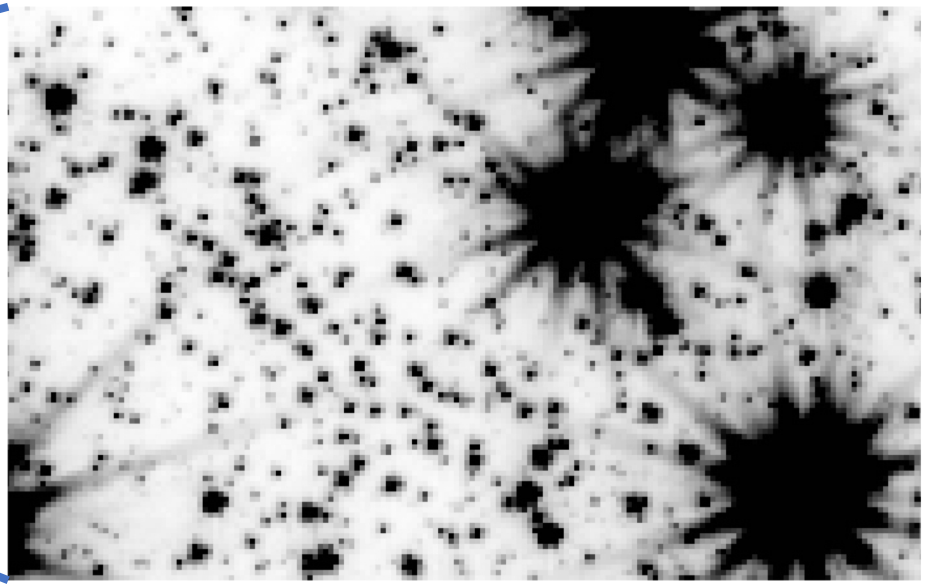
- Image, star simulation and test photometry model based upon prior analyses on Spitzer/IRAC data (SCN et al, 2015) – underlying strategy similar to ePSF analysis (Anderson and King, 2000)

- Microlensing Magnification with VBBinaryLensing (Bozza 2010, Bozza et al 2018)

The simulated Bulge Scene



A 1.9’x1.9’ W149 52s exposure time image, about 1/16th of a $4096\ x\ 4096$ detector with over $100{,}000$ stars, and a 0.3’ x 0.2’ close up

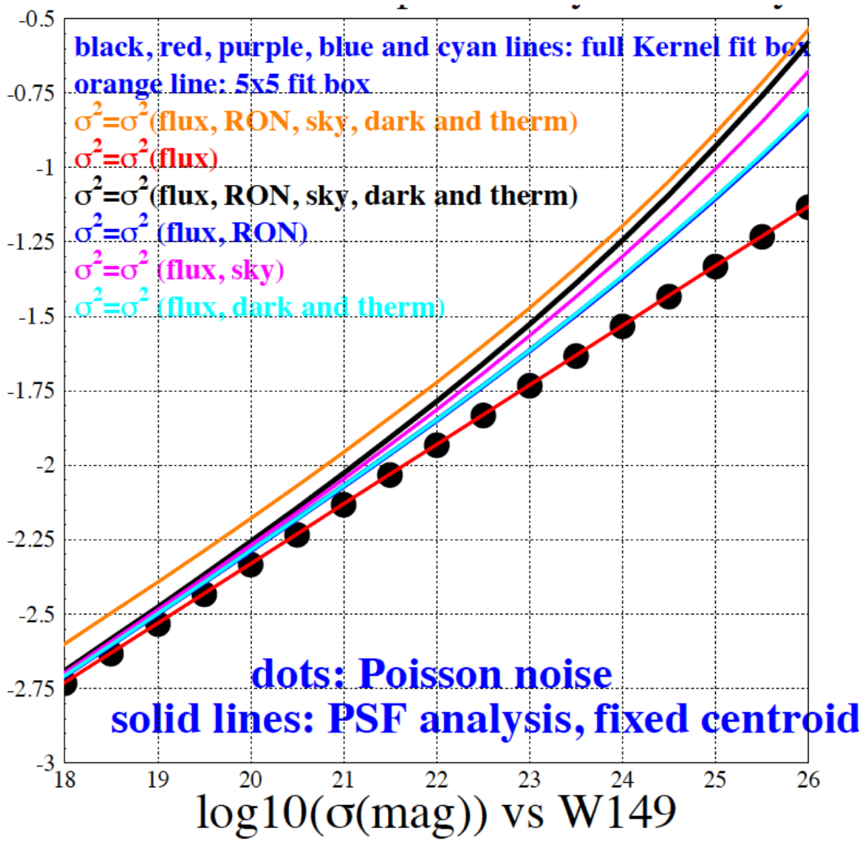


Recipe for the simulation

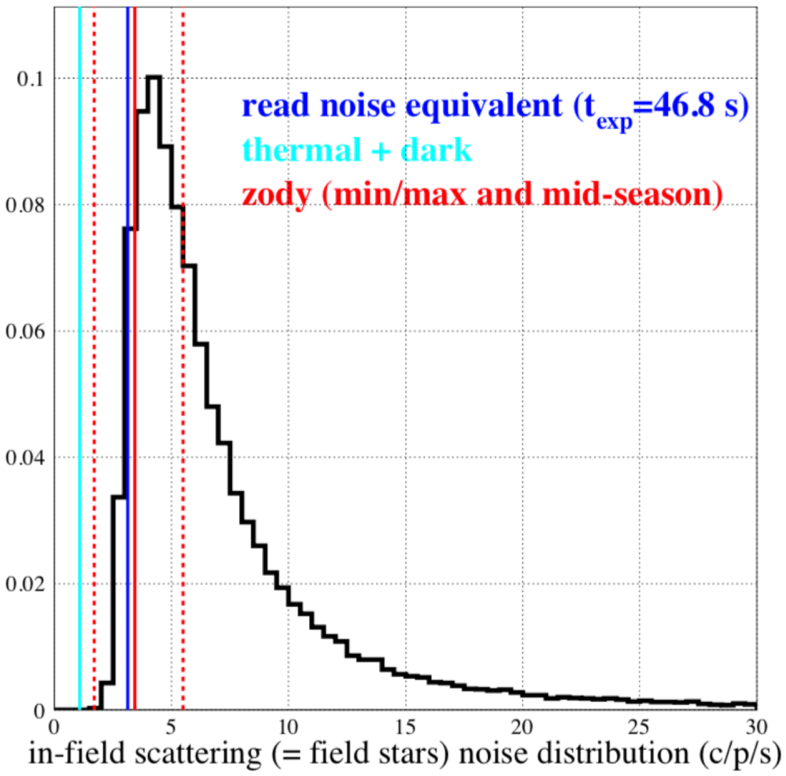
- Input an oversampled PSF (typical oversample values over = 5 or 9, from WebbPSF), and here we have two possible paths to get to simulate point-like sources (stars) with arbitrary pixel phases (extended sources are not simulated)
  - build over x over effective PSFs and carry out the simulation at the pixel level (conceptually similar to Anderson and King 2000 ePSF framework, one difference is that we use bilinear interpolation)
  - carry out the simulation at the sub-pixel level (which in particular easily allows for the introduction of intrapixel sensitivity effects) and resample at the end
- Generalization: simultaneous analysis with different PSFs to account for different star spectral types and PSF variations across the field of view (WebbPSF provides a variety of PSF for different spectral types and PSF model across the full WFI field of view)
- Simulation of the background: detector plus sky, with corresponding noise (input instrument and noise specifications)
- Loop over the star catalog (input astrophysical scene) and simulate stars with corresponding (Poisson) noise
- Wrap up including read out noise
- Optional: include additional detector/observatory effects beyond ideal noise realization (input observatory and detector model)
- Output:
  - images and corresponding uncertainty maps
  - (optional): (test) photometry an astrometry for simulated stars

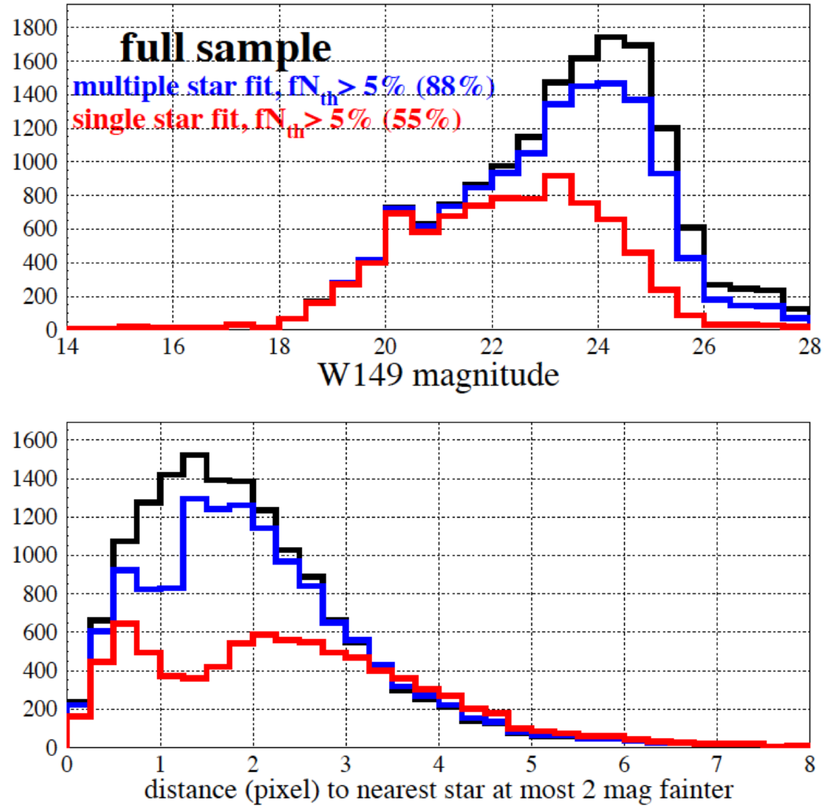
Noise, Sky, Crowding……

isolated star photometry noise analysis



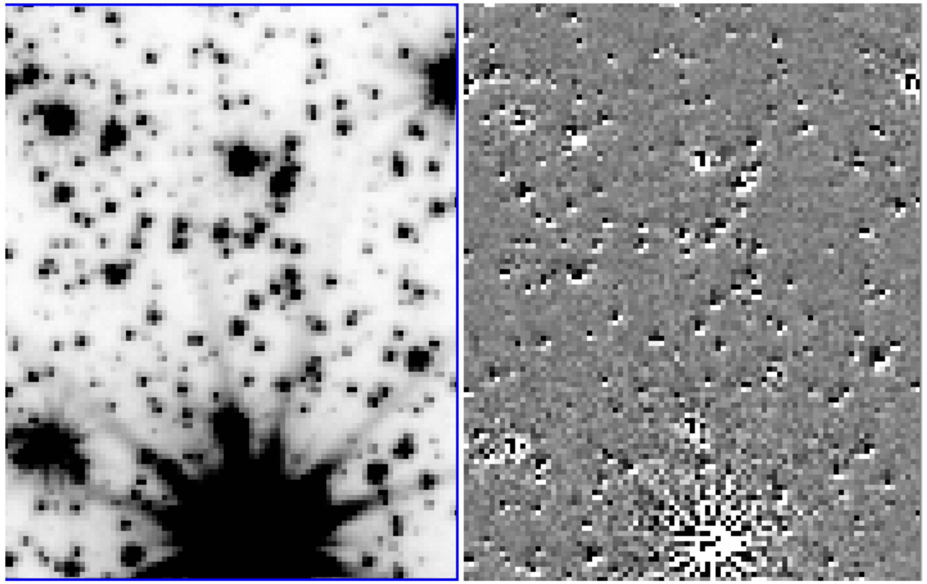
noise from crowded scene



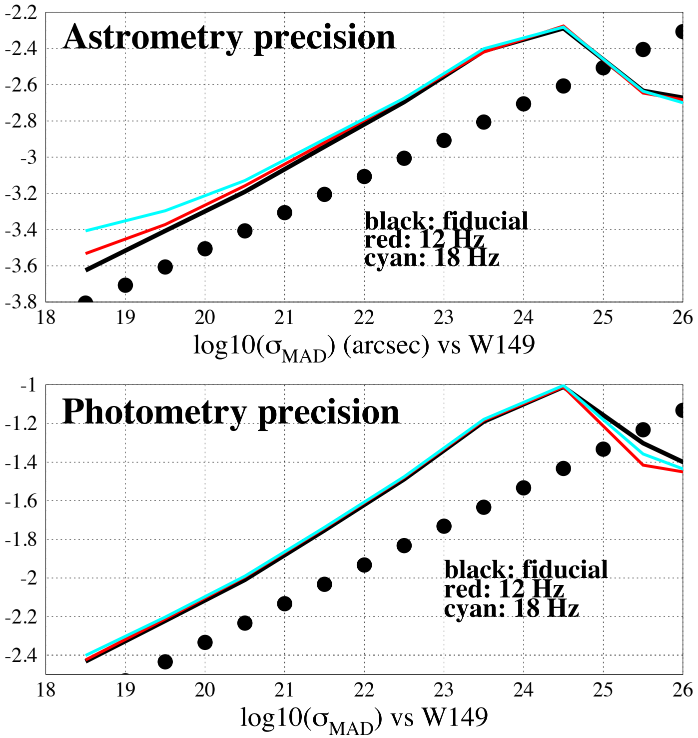


Jitter Simulation

- description: high-frequency oscillations of the observatory modeled summing up (for each exposure) several sub-exposures each slightly offset versus previous one
- key parameters: frequency and model for the offset
- fiducial model: combination of two modes *(Spergel et al 2015, Bellini et al 2017, Stoneking et al 2017)*
  - gaussian offset from the nominal position, to simulate "Fine Guiding System", with sigma=4.4 mas and nu=6 Hz
  - higher frequency random walk, sigma=14mas, nu=12-18 Hz



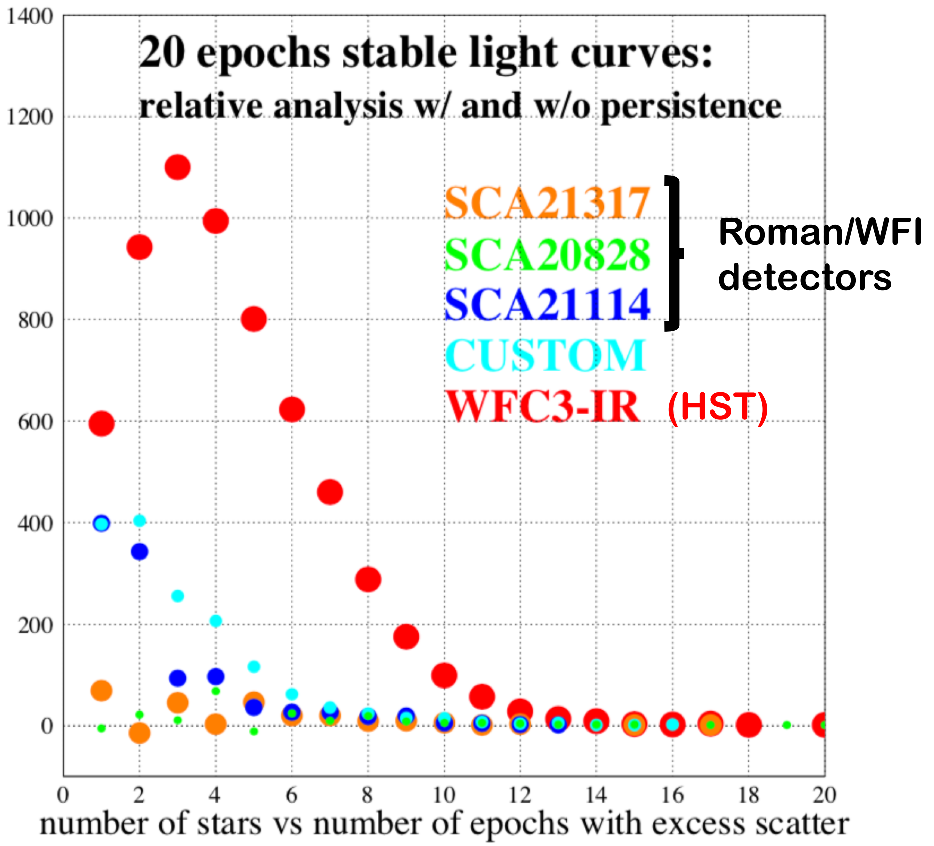
jittered image (with centroid offset and broadening of the PSF) and residual vs fiducial one



Astrometry and photometry stability analysis along a light curve (carried out with the same underlying PSF)

Persistence Simulation

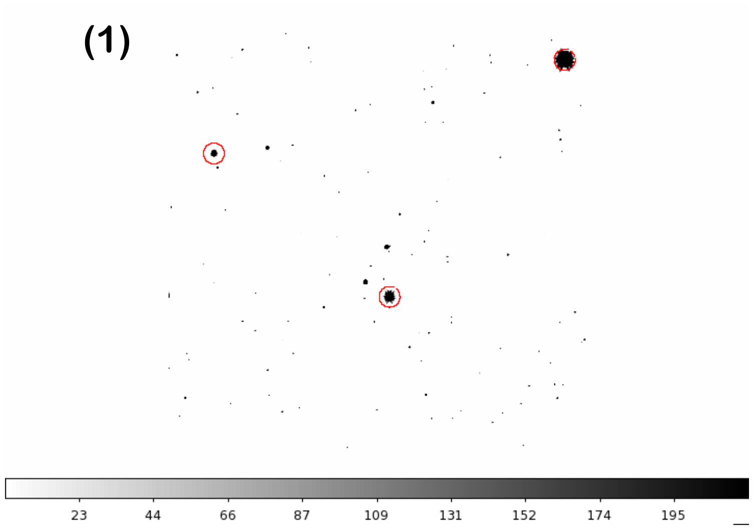
- description: ghost image of earlier exposures (related to traps in the detector out of which charges previously accumulated are, along time, slowly released even after the end of a given exposure); a strongly non-linear effect relevant especially for very bright/saturated stars; modeled building a persistence “signal” map from stars from previously exposed images and adding it to the science exposure (caveats: the model does not include intrinsic patchy nature of the effect; self-persistence, namely the effect within the same exposure; a noise model for the persistence)
- key parameters: decay time; amplitude and threshold value (about full well depth) for the effect
- fiducial model: empirical parametric model by Long et al (2012) for WFC3-IR; internal note from the Roman project (Kruk, 2020)
- note: laboratory data show the effect is expected to be significantly smaller for Roman/WFI than in HST WFC3-IR



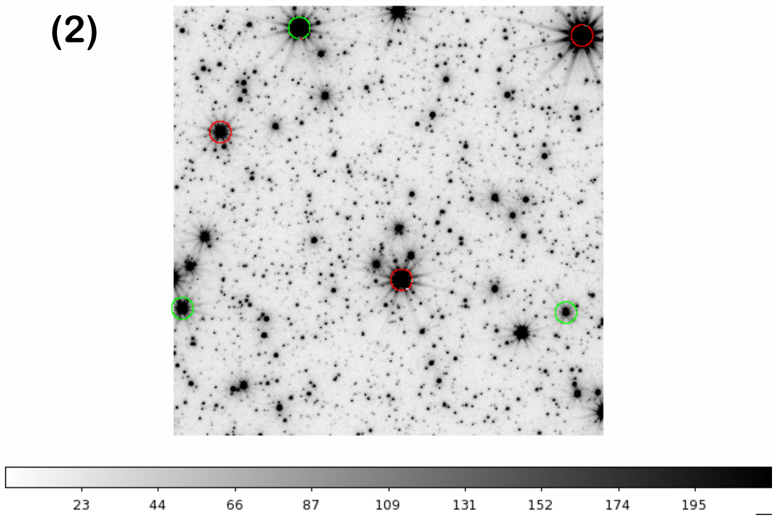
excess scatter introduced by persistence vs fiducial case

Persistence Simulation

(1)



(2)



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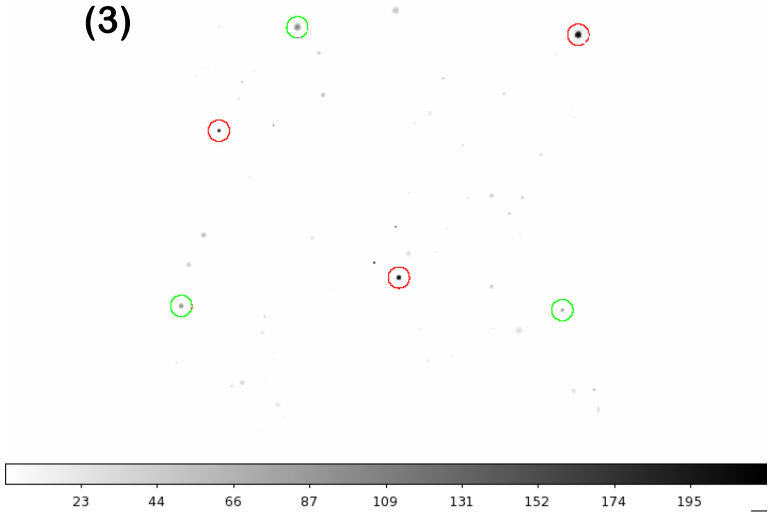
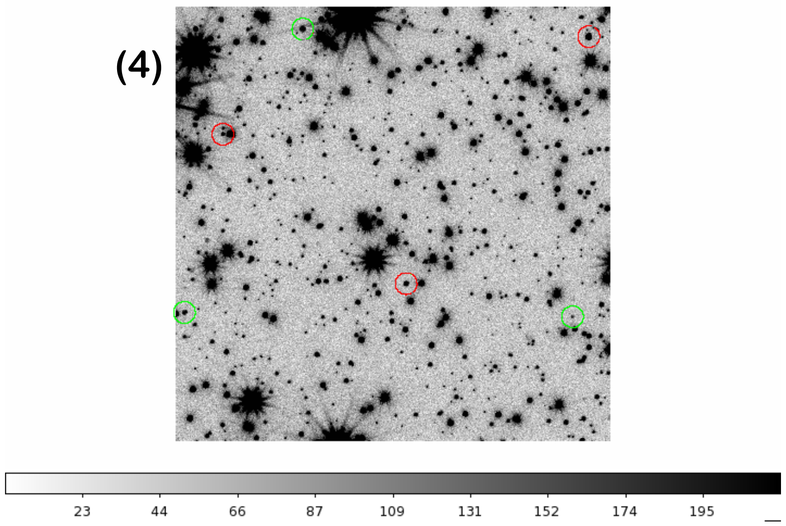
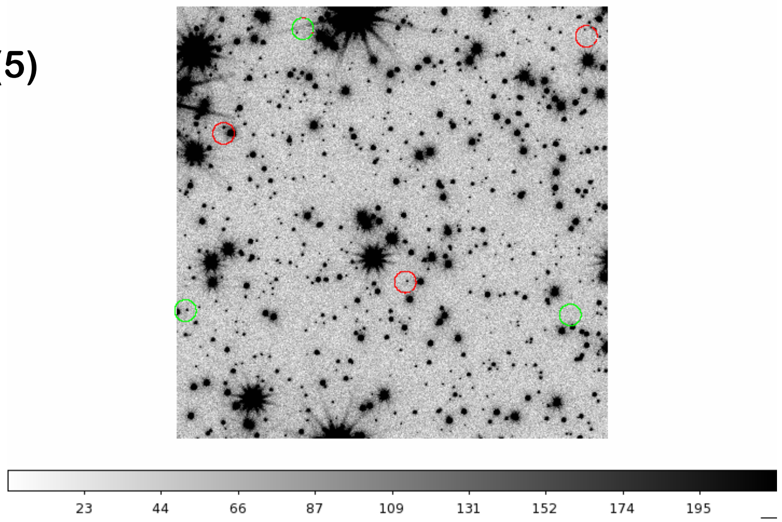


(4)



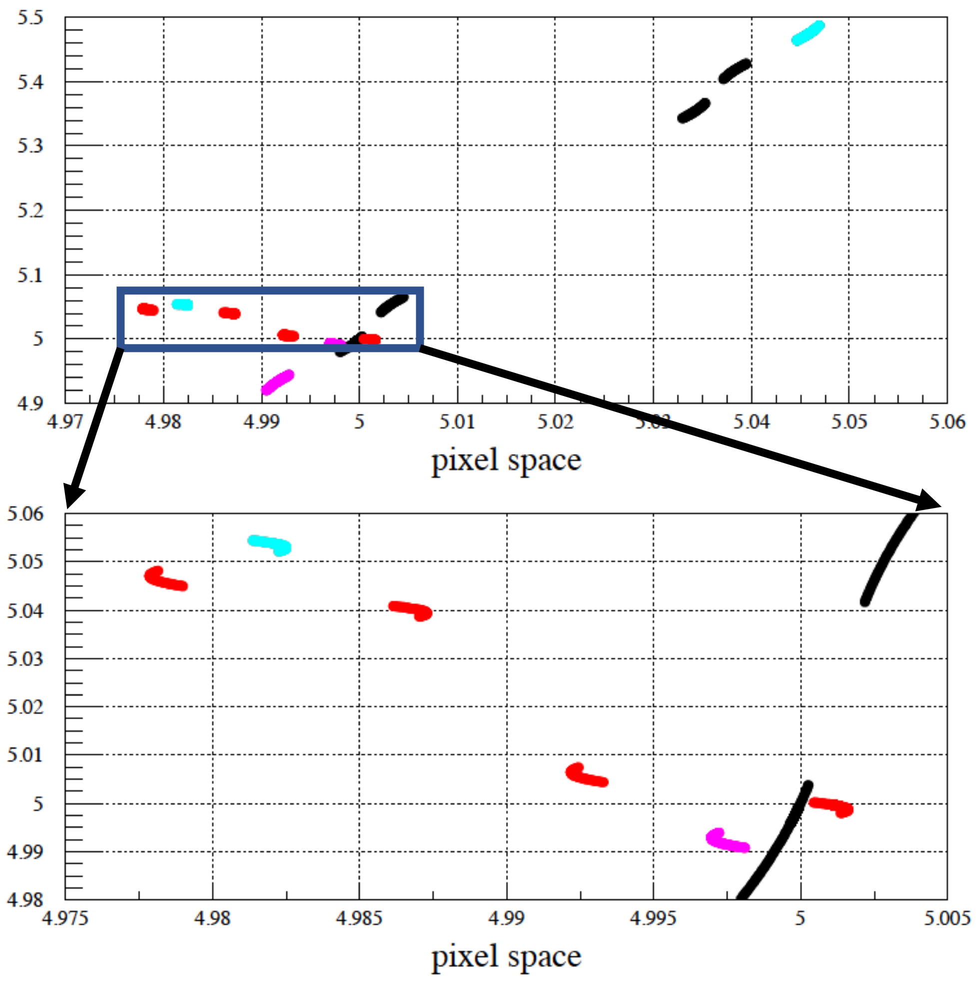
(5)



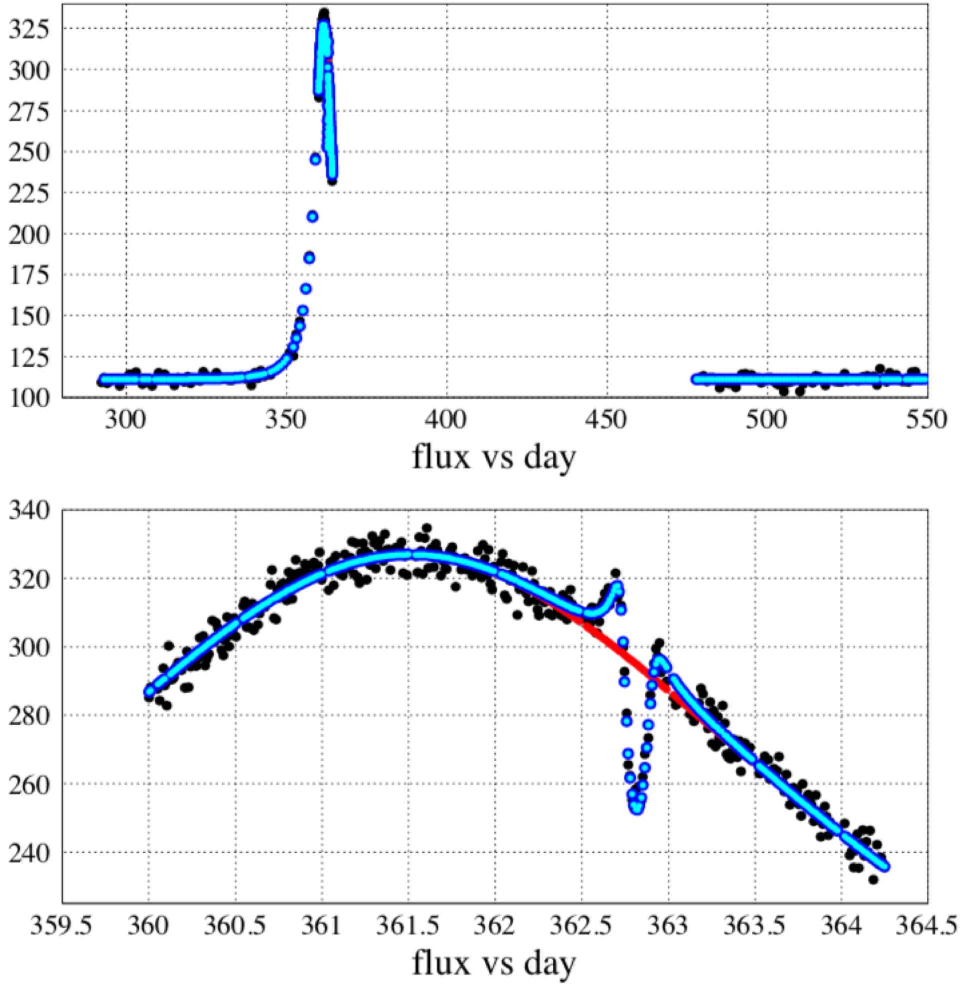
(1) persistence map from prior image
(2) persistence map from ensemble of prior images
(3) same as (2), color scale as (4)
(4) astrophysical scene (a sparse field), with persistence signal
(5) the same astrophysical scene, persistence turned off

Simulation for Microlensing Events

Roman: first simultaneous microlensing and high resolution imaging lens flux analysis survey



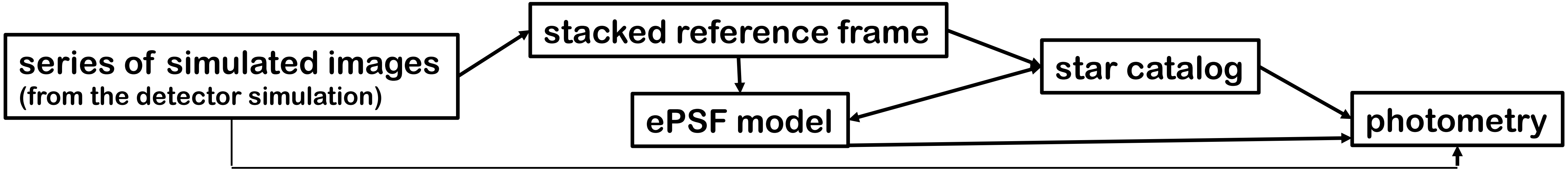
lens and source parallax and proper motion

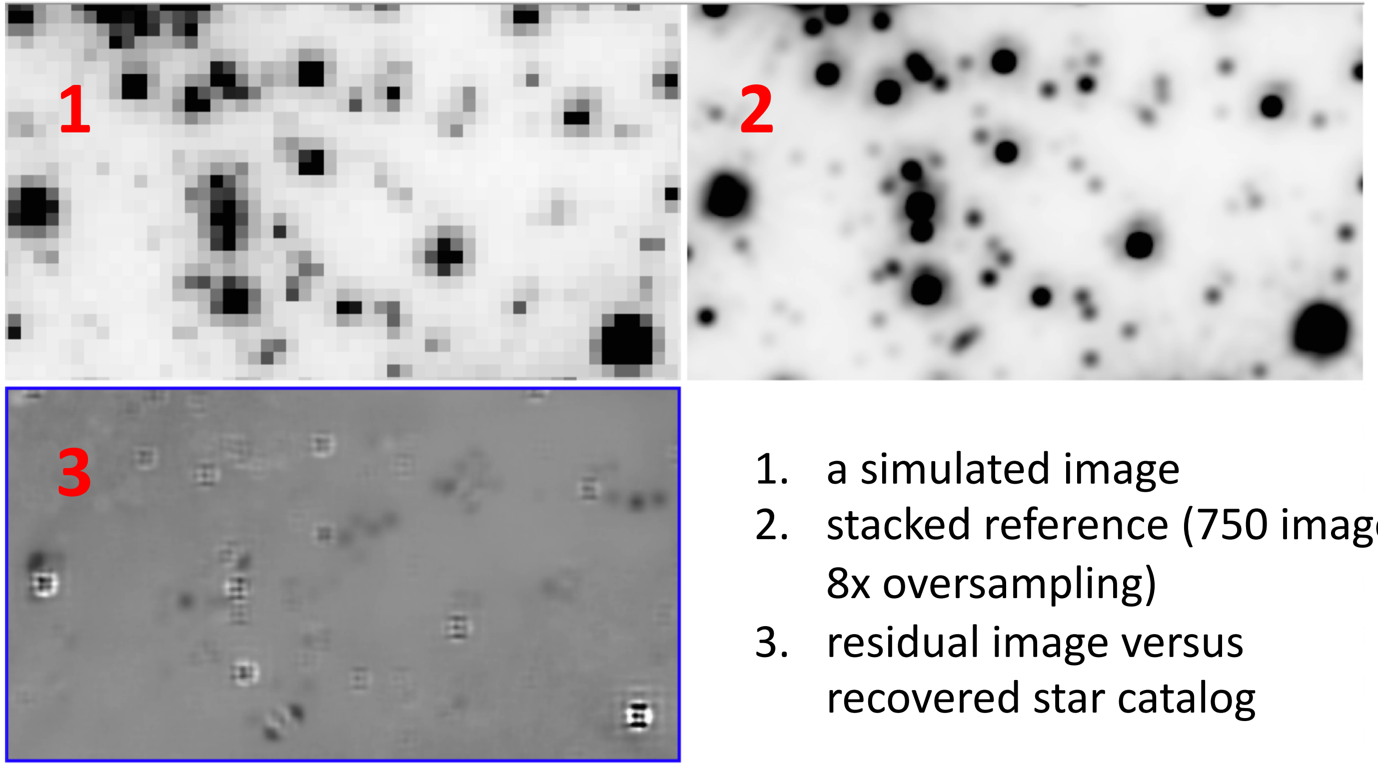


a microlensing planetary light curve

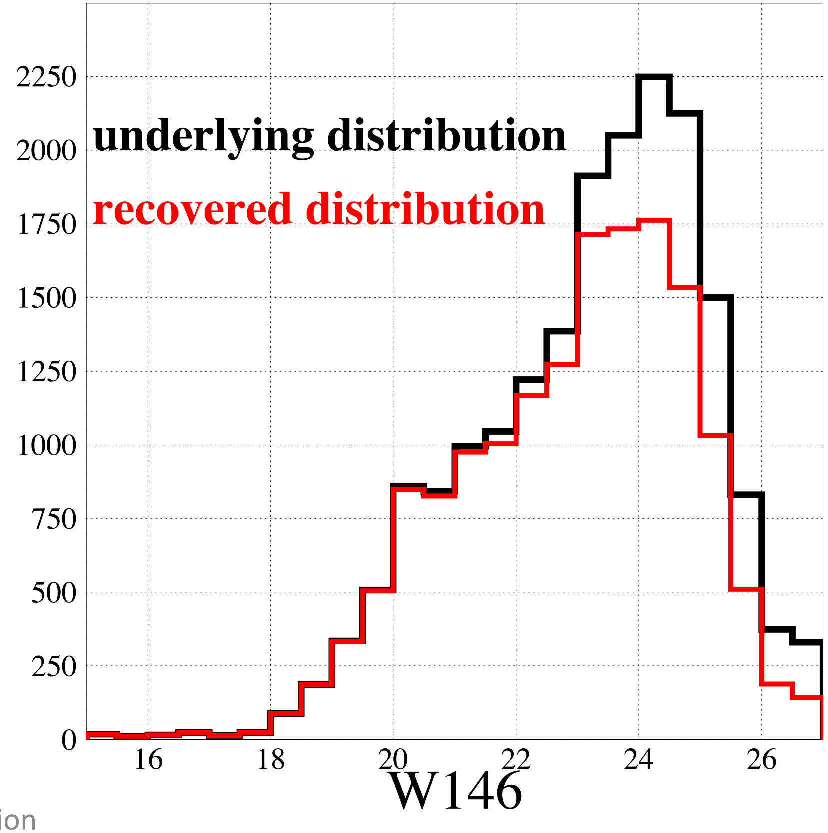
MSOS photometry pipeline at IPAC: prototype analyses

based upon codes developed by Jay Anderson (within the microSIT)





1. a simulated image
2. stacked reference (750 images, 8x oversampling)
3. residual image versus recovered star catalog



Summary: moving forward

- ❑ keep detector simulation updated
  - ✓ versus Galactic model
  - ✓ versus understanding of the Roman/WFI detector
- ❑ devise tailored calibration and analysis strategies for the survey
- ❑ integrate with additional simulation products/tools
- ❑ end-to-end processing for MSOS pipeline at SSC