Circumbinary planets with the Nancy Grace Roman Space telescope

Eamonn Kerins
University of Manchester
Eamonn.Kerins@manchester.ac.uk

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Nancy Grace Roman Space Telescope (Roman)

- Formerly **WFIRST**: Top large mission recommendation of 2010 US Astrophysics Decadal Review. Reaffirmed in 2020 review.

- Capable of conducting wide-area and time-domain surveys with sensitivity and resolution comparable to Hubble

- **Core surveys:**
  - Cosmology through the High Latitude Wide Area Survey (weak lensing) + High Latitude Time Domain Survey (supernovae)
  - Exoplanet microlensing and transit surveys through the **Galactic Bulge Time Domain Survey**

- Roman will also carry a coronograph for direct imaging. HWO technology demonstrator.

- At least 25% of first 5 years will be open to general astrophysics. A Galactic plane survey will comprise part of the general astrophysics program.

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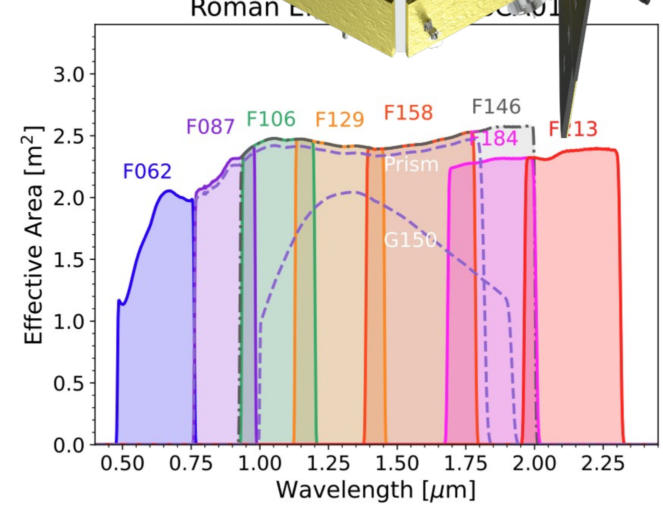
Nancy Grace Roman Space Telescope (Roman)

- Scheduled for launch late 2026 (NLT mid 2027) to Earth-Sun L2
- 2.4m primary, 5-year nominal mission, 10-year design
- **Wide Field Instrument (WFI):**
  - 18 4kx4k CCDs. 0.11 arcsec pixels, 0.28 sq deg fov (>100x HST)
  - Multi-band optical/near-IR photometry (0.5-2.3 um). 5σ point source sensitivity of ~25 in 55 secs
  - grism (1.0-1.9 um, R~600) & prism (0.8-1.8 um, R~100) slitless MOS
- **Coronagraph demonstrator** for direct imaging. 100hr, 5σ contrast of 2e-9 at 5 λ/D for V<=5 host (c.f. Jupiter at 10 pc)
- Huge 10 Tbits/day downlink. **Data will be World public**
- ESA formally involved in Roman
- Survey speed will be 1400x Hubble
  A 1-day survey with Roman would take almost 4 years of observing time with Hubble



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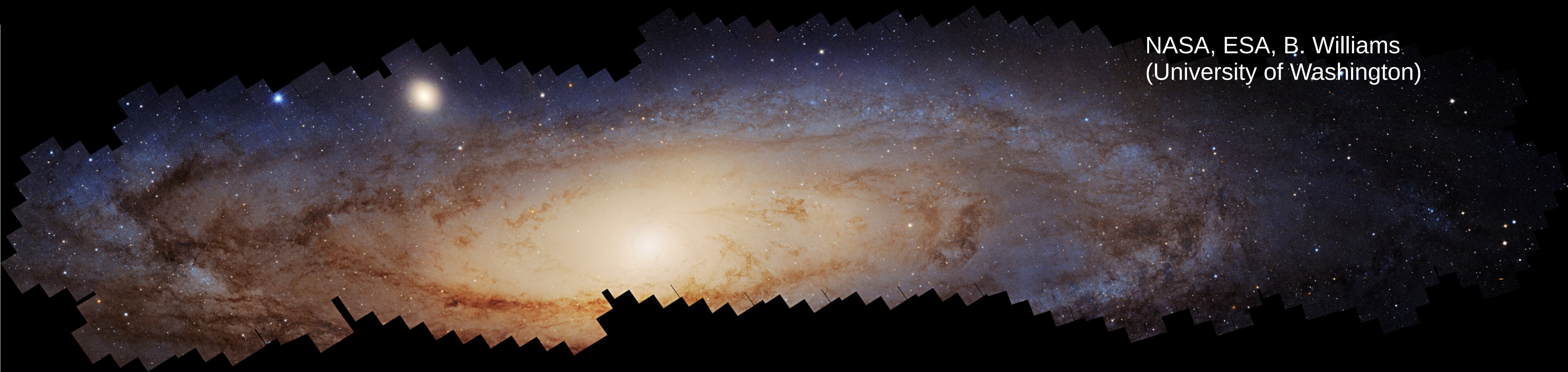
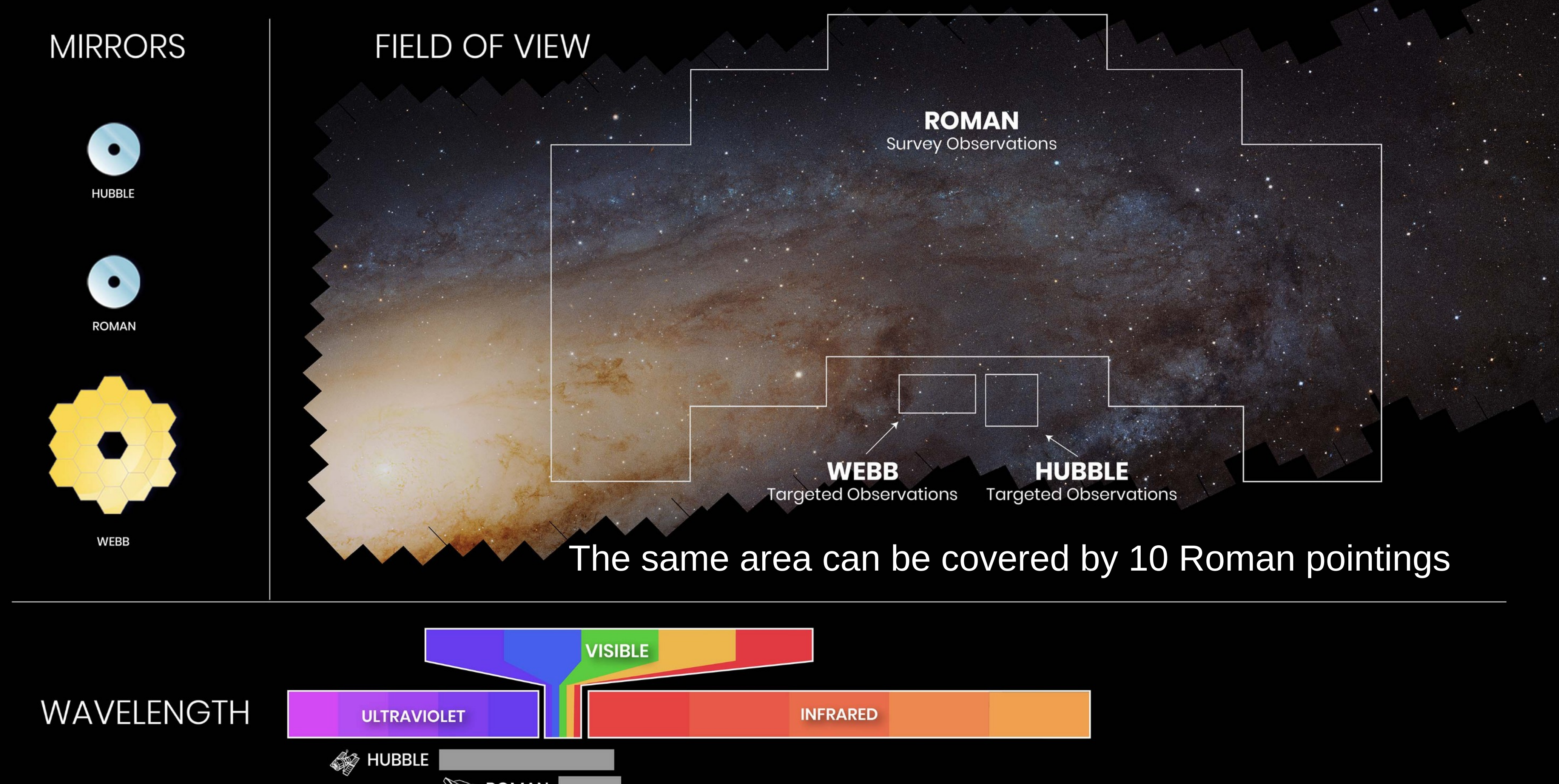
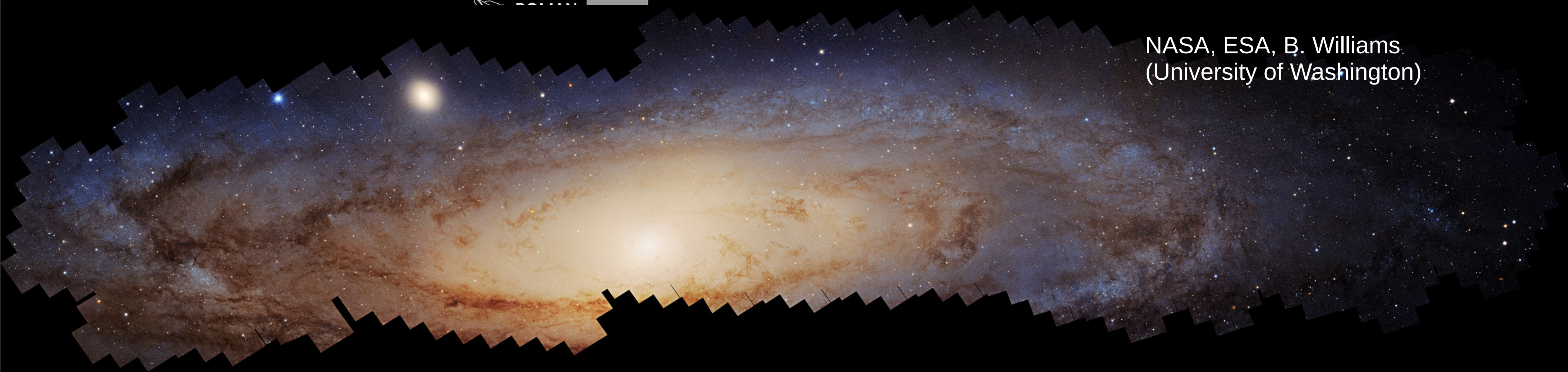
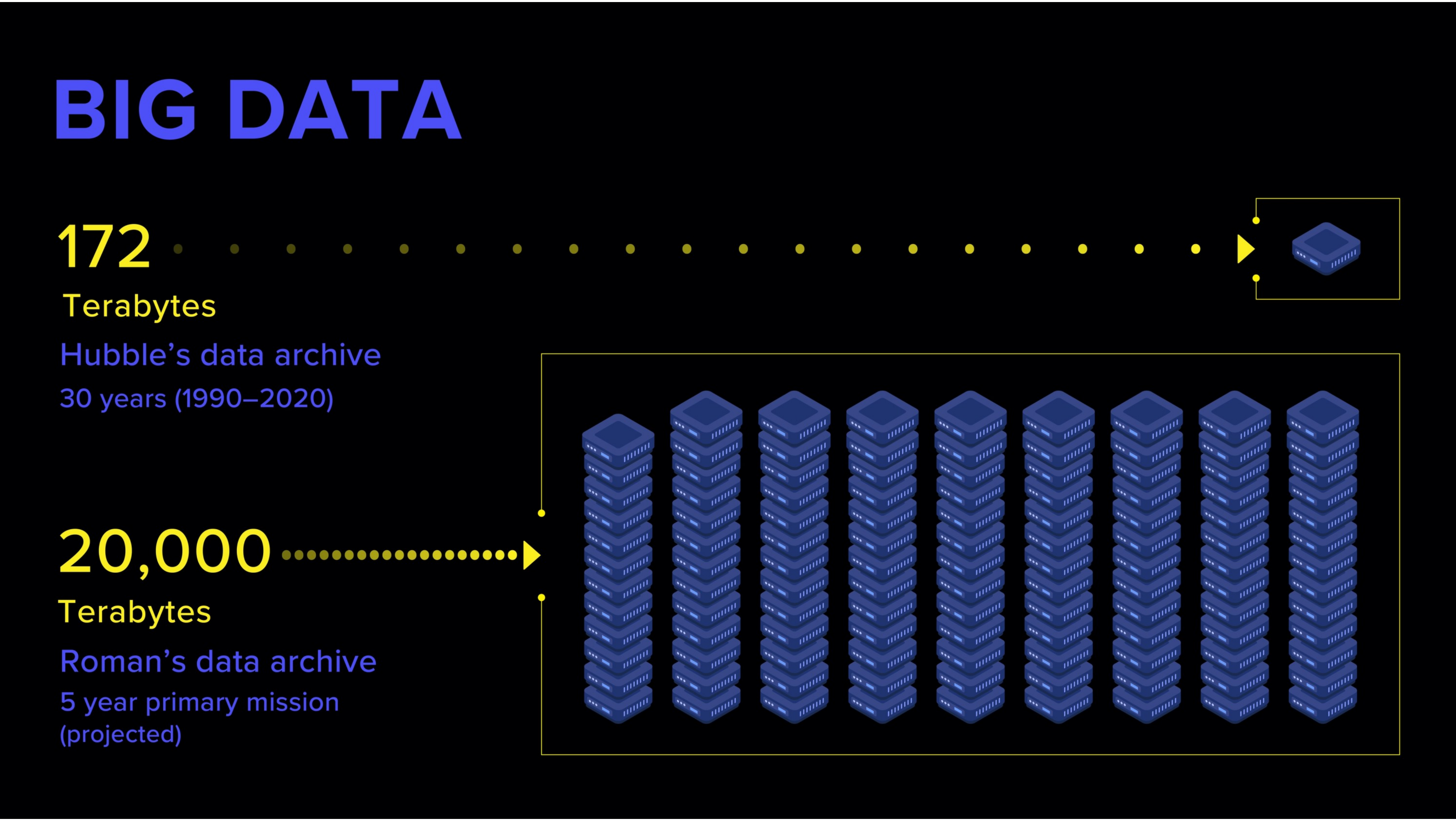
2.5 billion pixel HST image mosaic
of M31

10 years in the making
1000 Hubble orbits




MIRRORS
HUBBLE
ROMAN
WEBB
FIELD OF VIEW
ROMAN
Survey Observations
WEBB
Targeted Observations
HUBBLE
Targeted Observations
The same area can be covered by 10 Roman pointings
WAVELENGTH
VISIBLE
ULTRAVIOLET
INFRARED
HUBBLE


NASA, ESA, B. Williams
(University of Washington)



Unprecedented data volume for a space mission

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Roman hardware

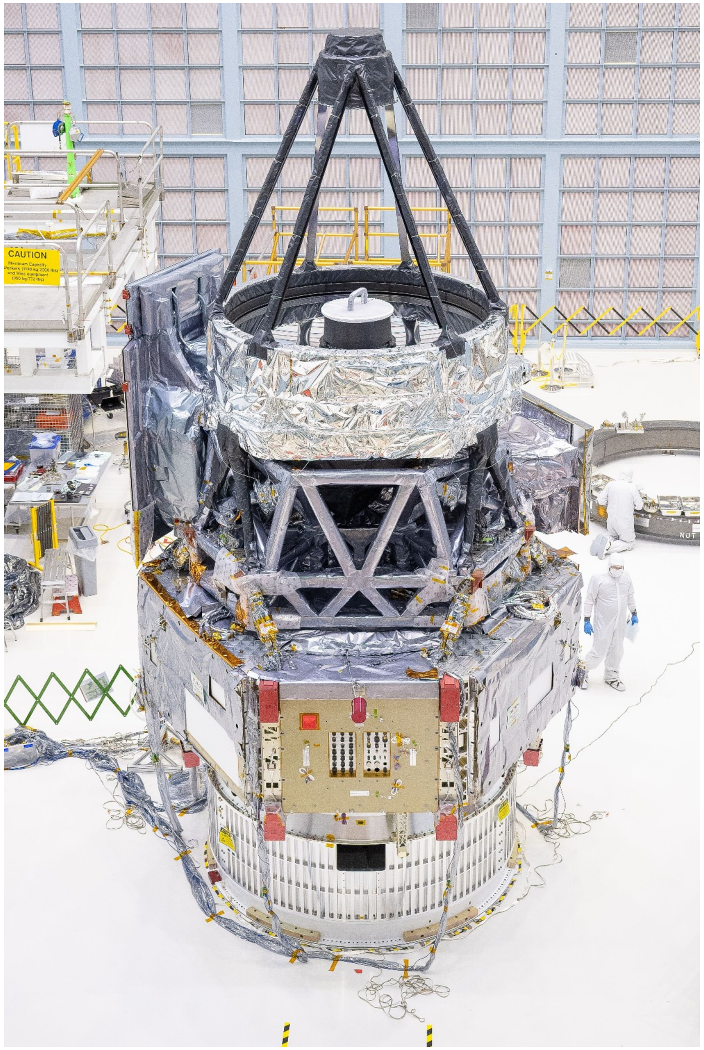
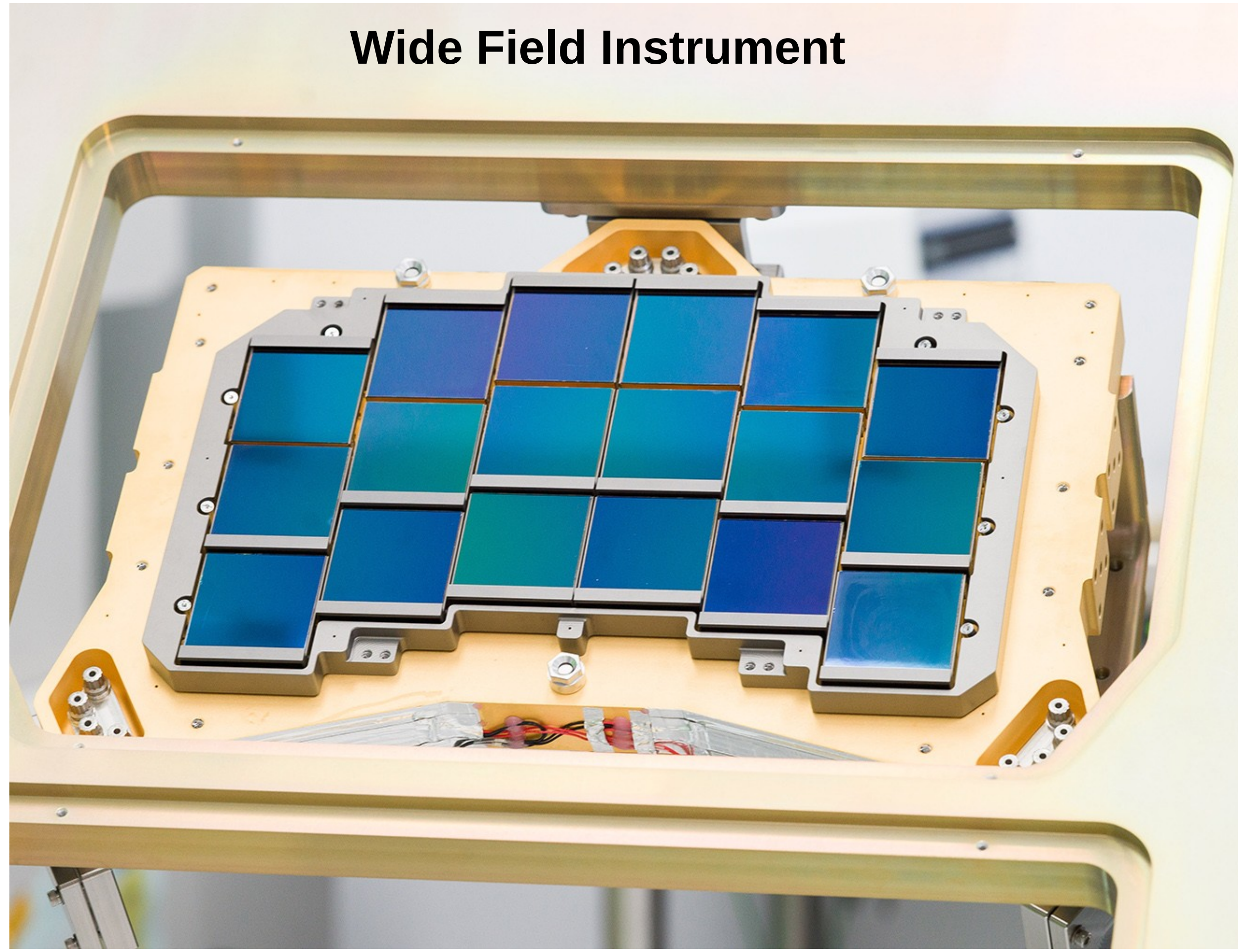


Photo credit: Stefano Casertano



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Galactic Bulge Time Domain Survey

- Survey ~2 sq deg of inner Galaxy with 15 min cadence for 6 x 70-day seasons spanning 5 years. 70-day seasons must each be centred on spring/autumn equinox due to observability constraints.
- GBTDS science driver: census of cool exoplanets using **microlensing**
- Discover ~1400 cool bound planets down to Mars mass using microlensing (Penny et al 2019). Direct mass and distance measurements
- Find hundreds of free-floating planets (FFPs)
- Potentially rarer systems: exomoons, ...
- Science goals:
  - Cool planet census down to Earth mass, including FFPs
  - Planet demography across Galactic distances

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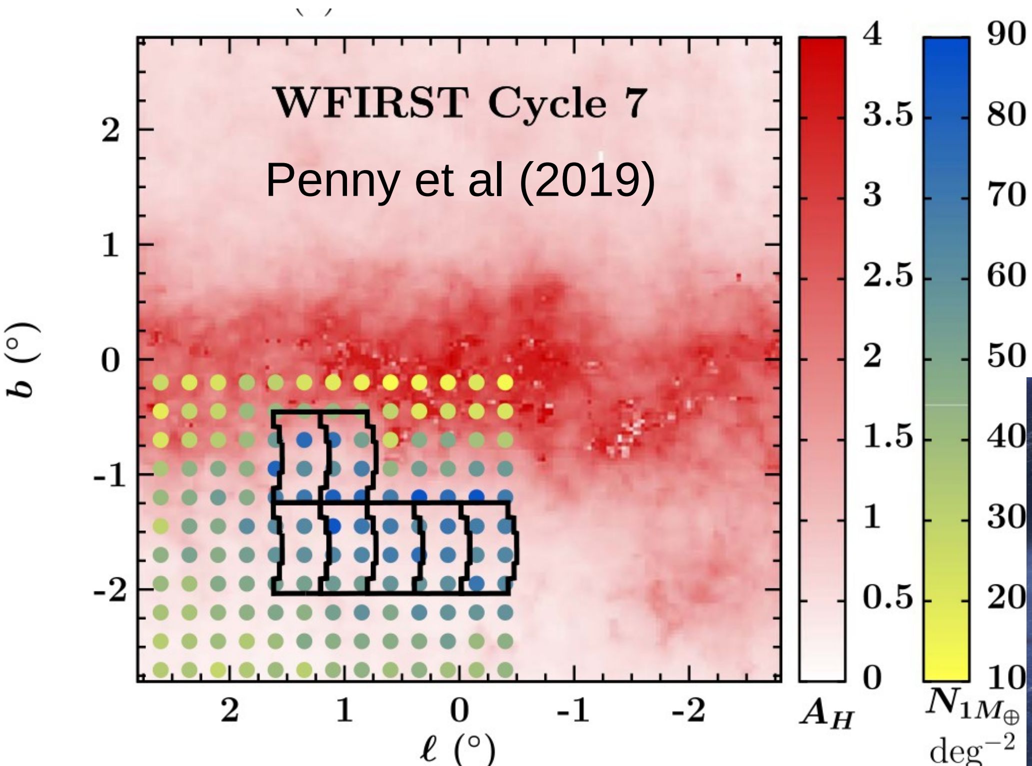
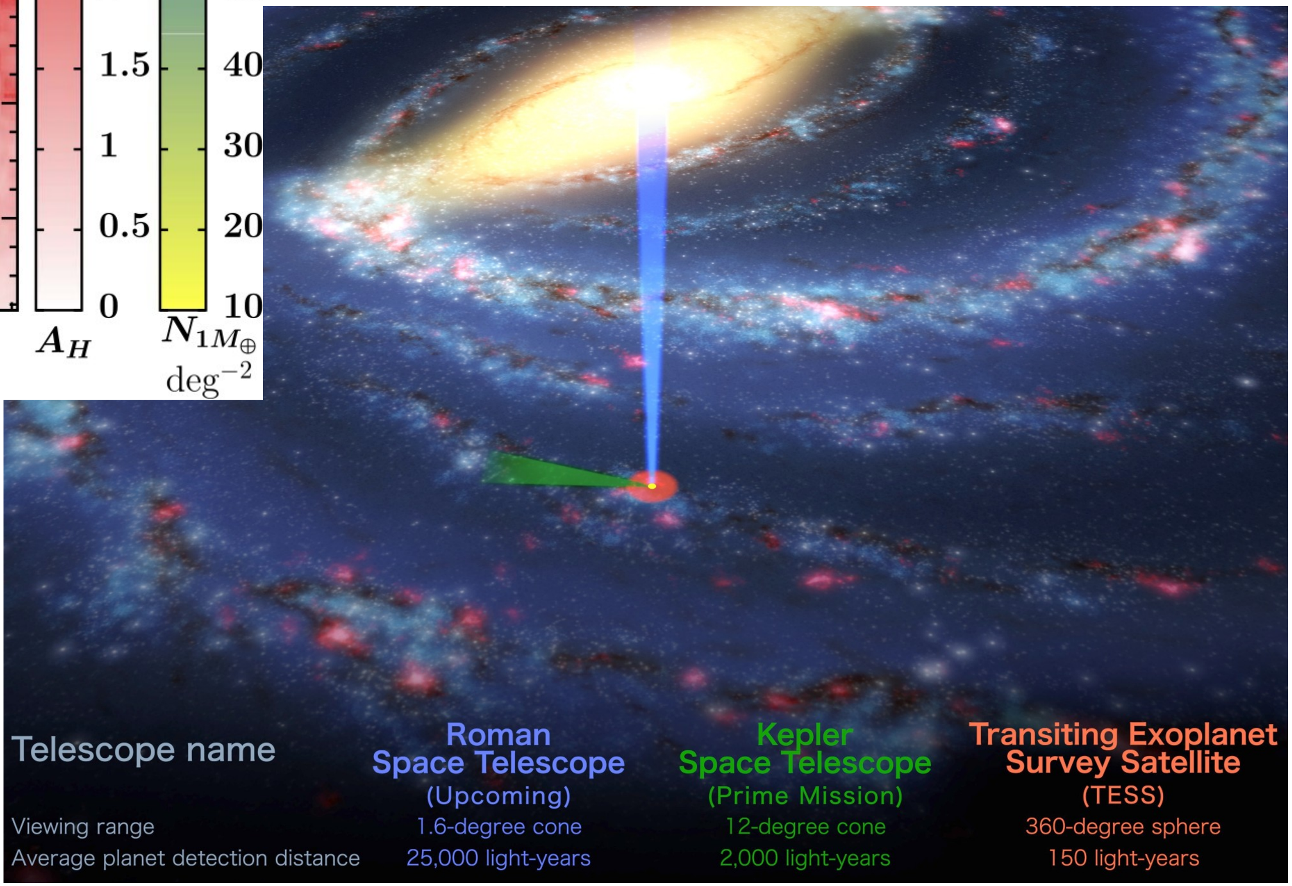
Exoplanets with GBTDS



Compared to Kepler and TESS, Roman will probe planetary architectures across Galactic distances



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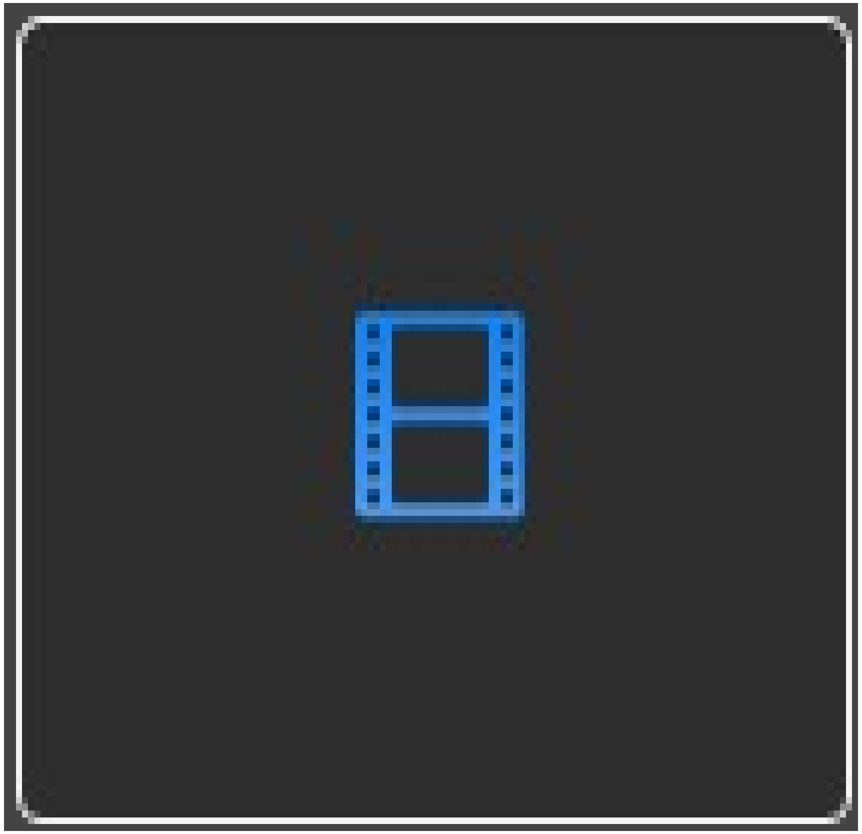
Microlensing



Animation: Scott Gaudi (OSU)

- Foreground host and its planet distorts, magnifies and multiply images light from a background star
- Images are unresolved – observed lightcurve results from their combined brightness vs time. Foreground system does not have to be directly detectable
- Main lightcurve signal from the host stars lasts weeks to months
- Perturbation due to planet lasts for hours (for Earths) to days (for Jupiters)
- Rare effect: hundreds of millions of stars must be monitored over months at frequencies of tens of minutes.
- Planetary signals detectable for host separations typically at or beyond the snow line

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Planet masses from microlensing

$$\text{Event timescale } (t_{\rm E}) = \frac{\text{Angular Einstein radius } (\theta_{\rm E})}{\text{Lens-source relative proper motion } (\mu_{\rm rel})}$$

$$\text{Lens mass } (M) = \frac{\theta_{\rm E}^2}{\kappa \times \text{relative parallax } (\pi_{\rm rel})}$$

$$\kappa = \frac{4G}{c^2 \text{au}} \qquad \pi_{\rm rel} = \frac{\text{au}}{\text{Lens distance}} - \frac{\text{au}}{\text{Source distance}}$$

Need to obtain measurements of $t_{\rm E}, \mu_{\rm rel}, \pi_{\rm rel}$

- Always measure $t_{\rm E}$
- Pre/post event astrometry, or finite source size effects, can obtain $\mu_{\rm rel}$
- Simultaneous separated observations, or detection of host lens flux, can obtain $\pi_{\rm rel}$

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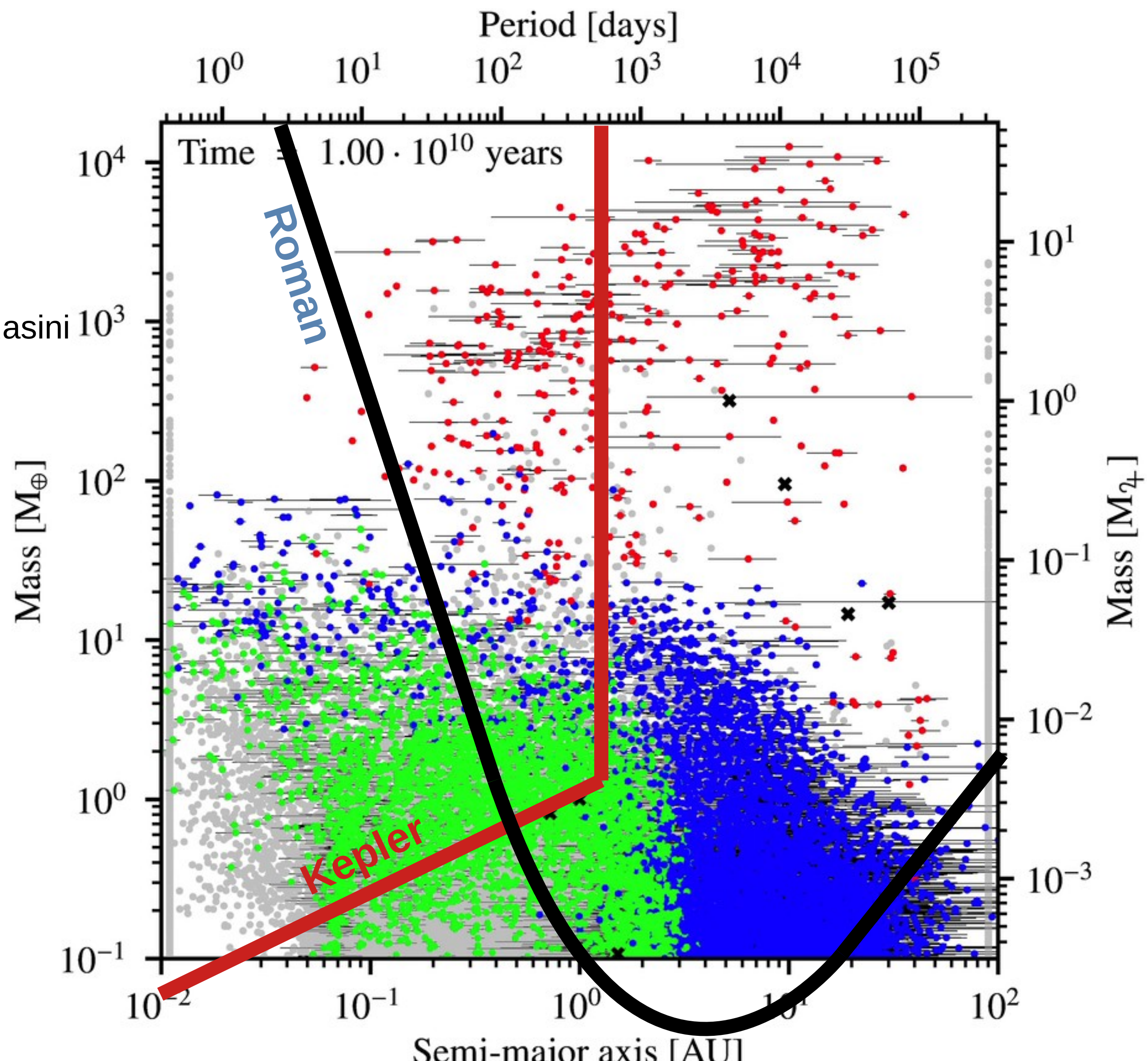
Roman and planet formation

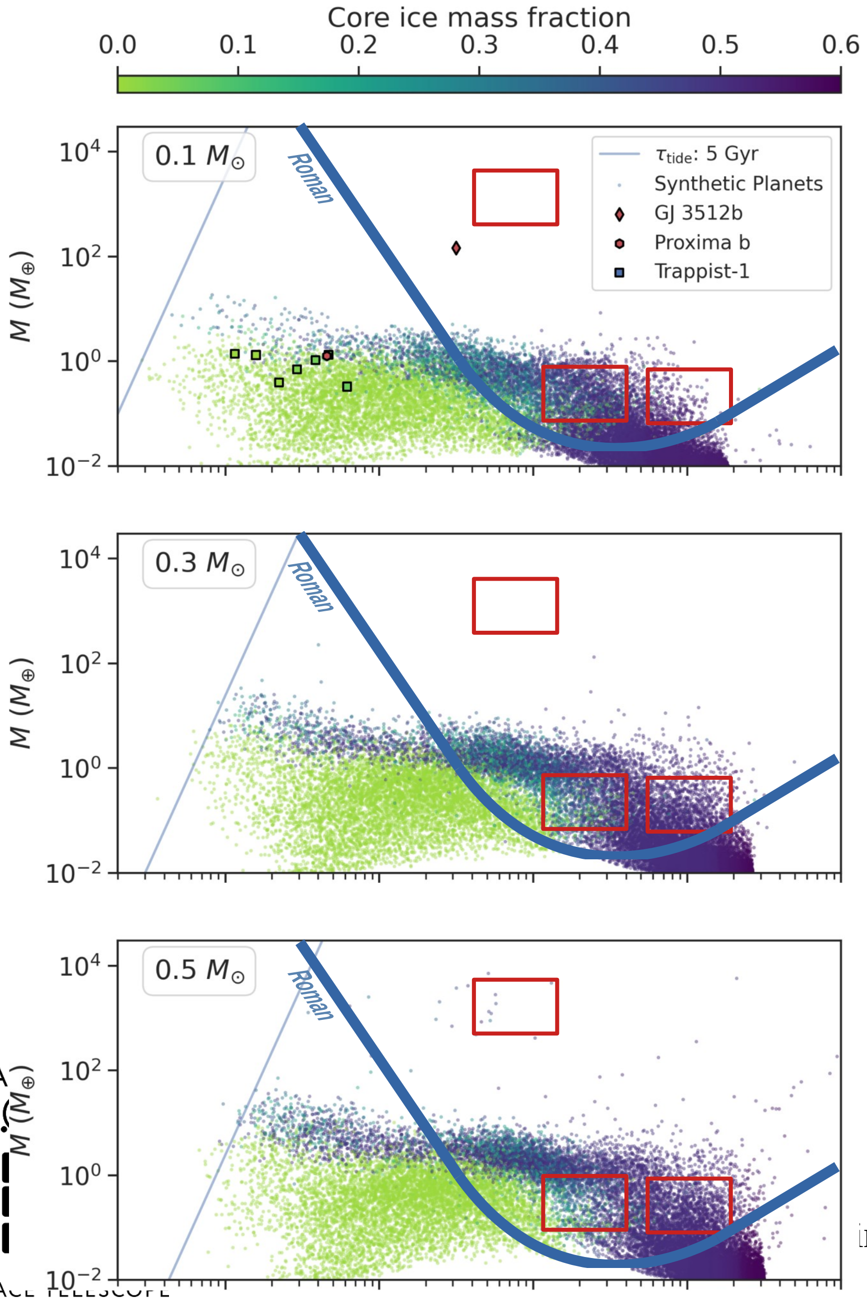
Simulations by Emsenhuber, Mordasini et al. (2021)



Sensitivity curves from Penny et al (2019)

Roman and planet formation

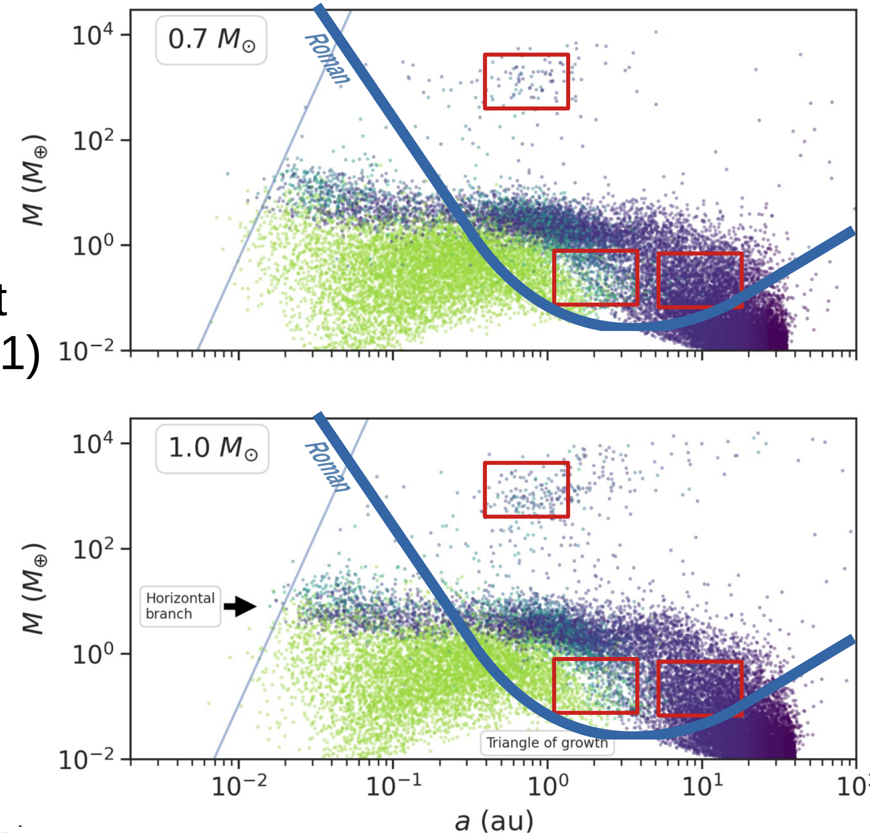
Roman sensitivity curve from Penny et al (2019)



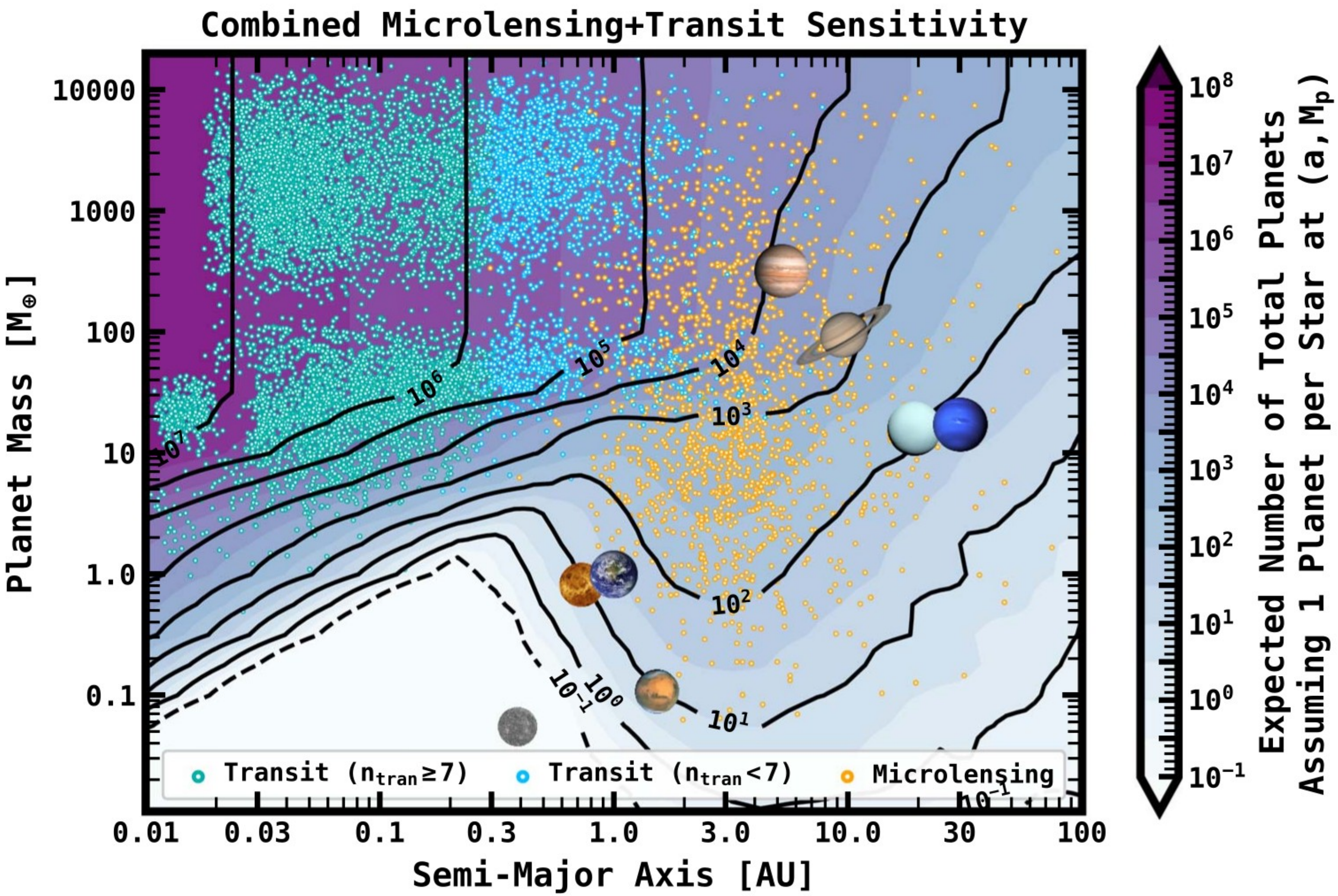
NGPPS simulations from the Mordasini-led Bern Planet Formation Group

Each panel based on 1000 simulated systems, each seeded with 50 planet embryos

Burn et al (2021)



Roman transiting planets



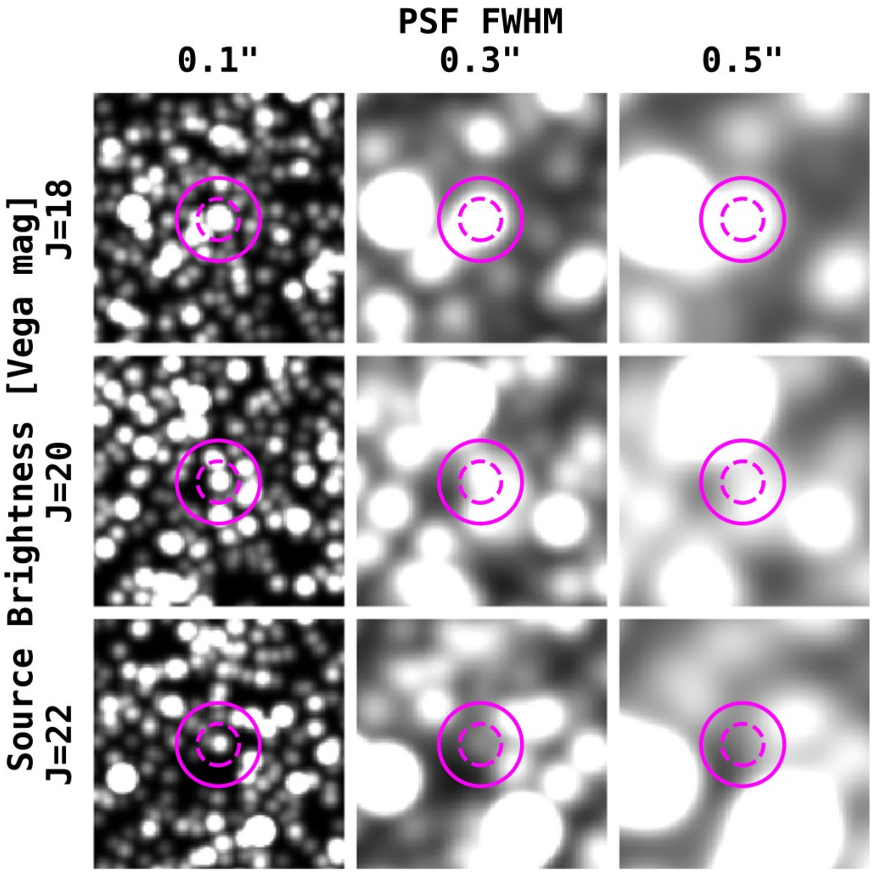
Wilson et al (2023)

The survey will also find 60,000-200,000 distant transiting planets

Provides sensitivity to rare transit subsets such as CBPs

What about contaminants?

- Roman has three main weapons to decontaminate its transit sample:
  - Resolution



Wilson et al (2023)

What about contaminants?

- Roman has three main weapons to decontaminate its transit sample:
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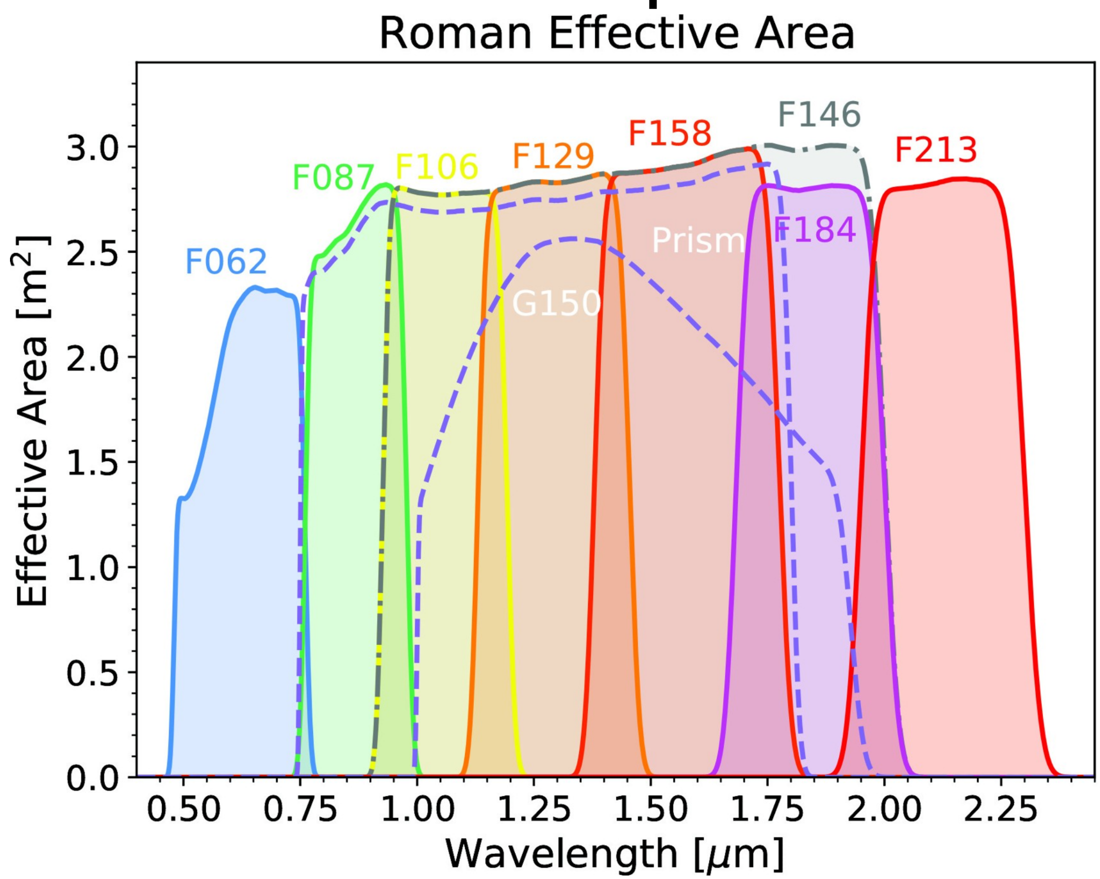
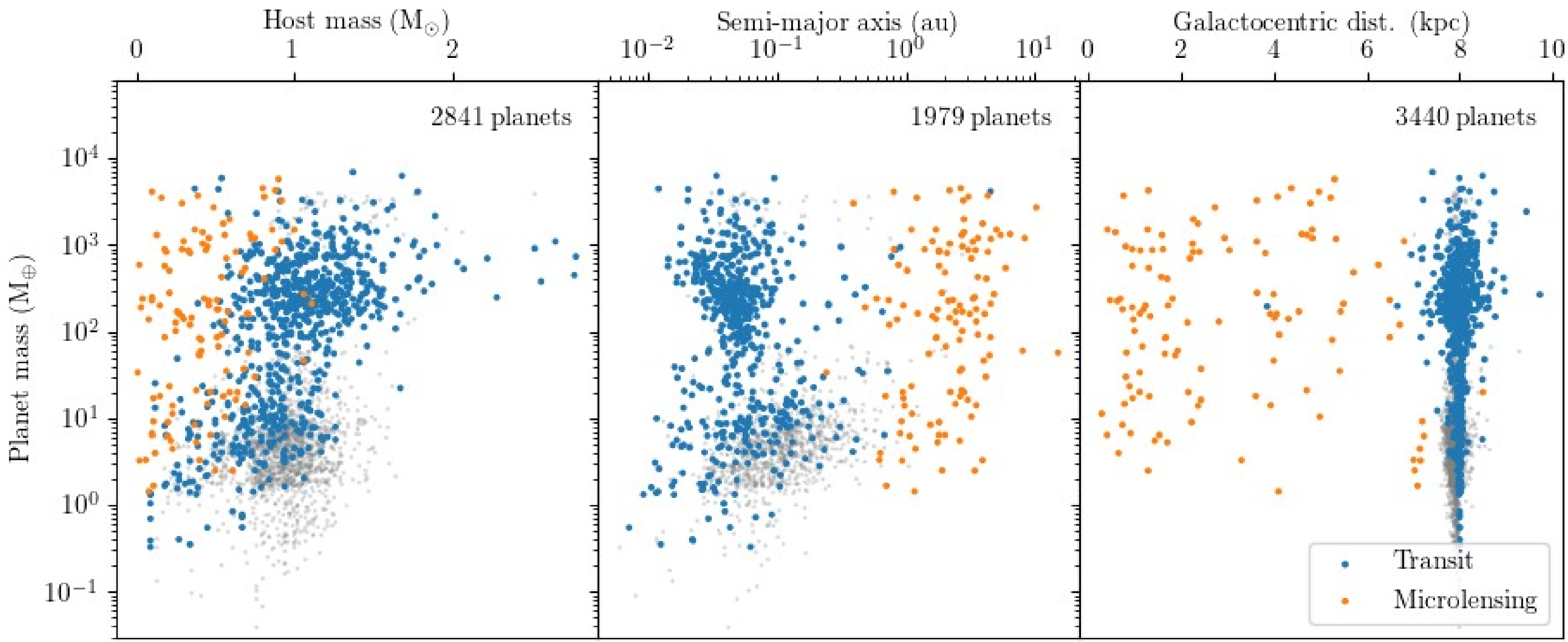
  - Colours



What about contaminants?

- Roman has three main weapons to decontaminate its transit sample:
  - Resolution
  - Colours
  - Time: potential 4.5-year baseline between first and last observing seasons. Expecting relative astrometry to ~1/100th pixel (~1 mas)

Microlensing vs transit samples



Microlensing vs transits

Two relevant Roman GBTDS science teams:

- Roman Galactic Exoplanet Survey (RGES) Project Infrastructure Team. PI: Scott Gaudi (OSU). Focussing on microlensing photometry, selection and analysis tool development for community use

- Transits in the Roman Exoplanet Survey (TRExS) PI: Robby Wilson (Goddard). Focussing on transit science

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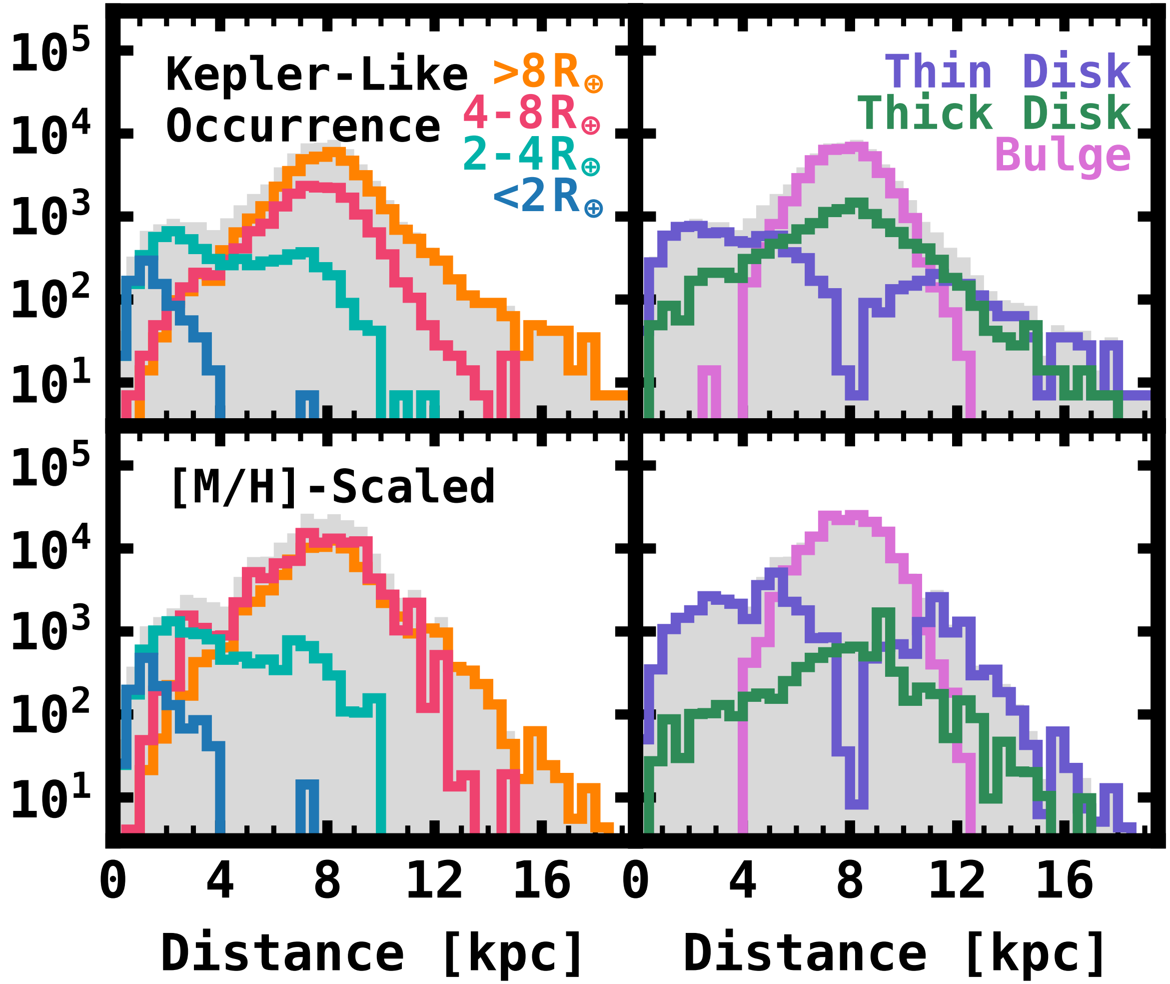
Microlensing+transit demography



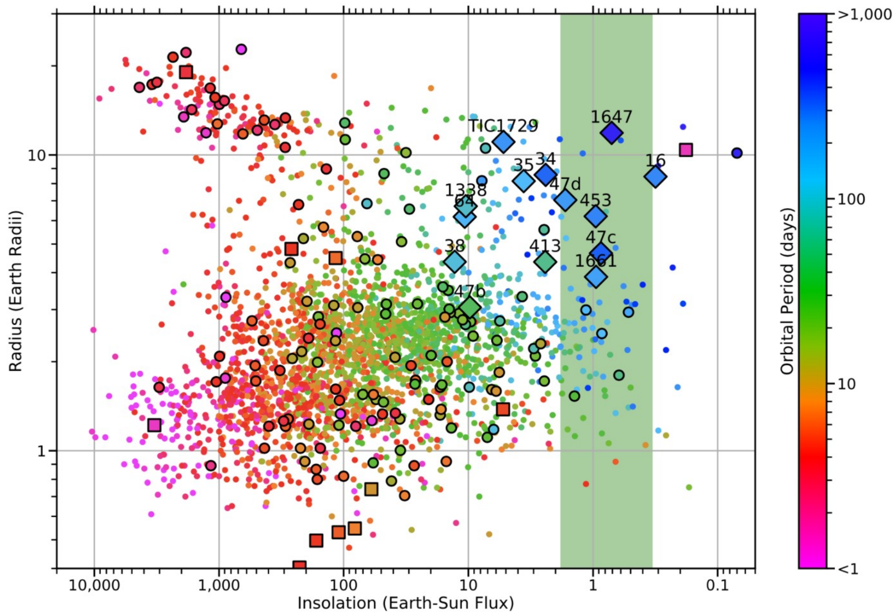
Roman transit and microlensing populations will span similarly large Galactic distances and will probe multiple stellar populations.

(Wilson et al 2023)

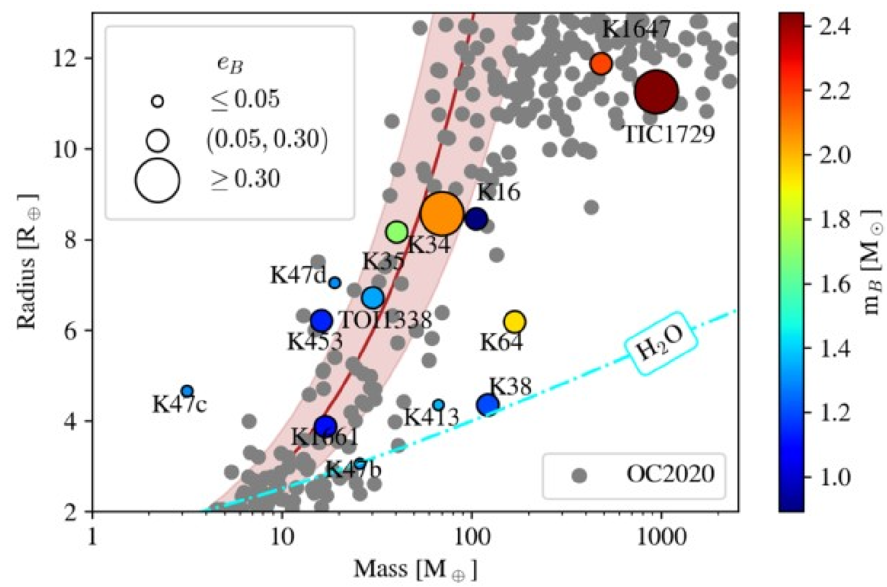
Roman will be the first survey to combine two techniques to find large numbers of planets across the hot and cold planet regime

Roman transiting CBPs

- With up to 200,000 Roman transit detections, we may expect several hundred CBPs, based on simple scalings of Kepler statistics.
- But, each Roman GBTDS observing season is expected to be ~70 days, somewhat shorter than most observed CBP periods
- The precise CBP haul will therefore be sensitive to the spread of the six Roman GBTDS observing seasons across the 5-year nominal mission baseline
- But should be possible to investigate period ratios for hundreds of systems

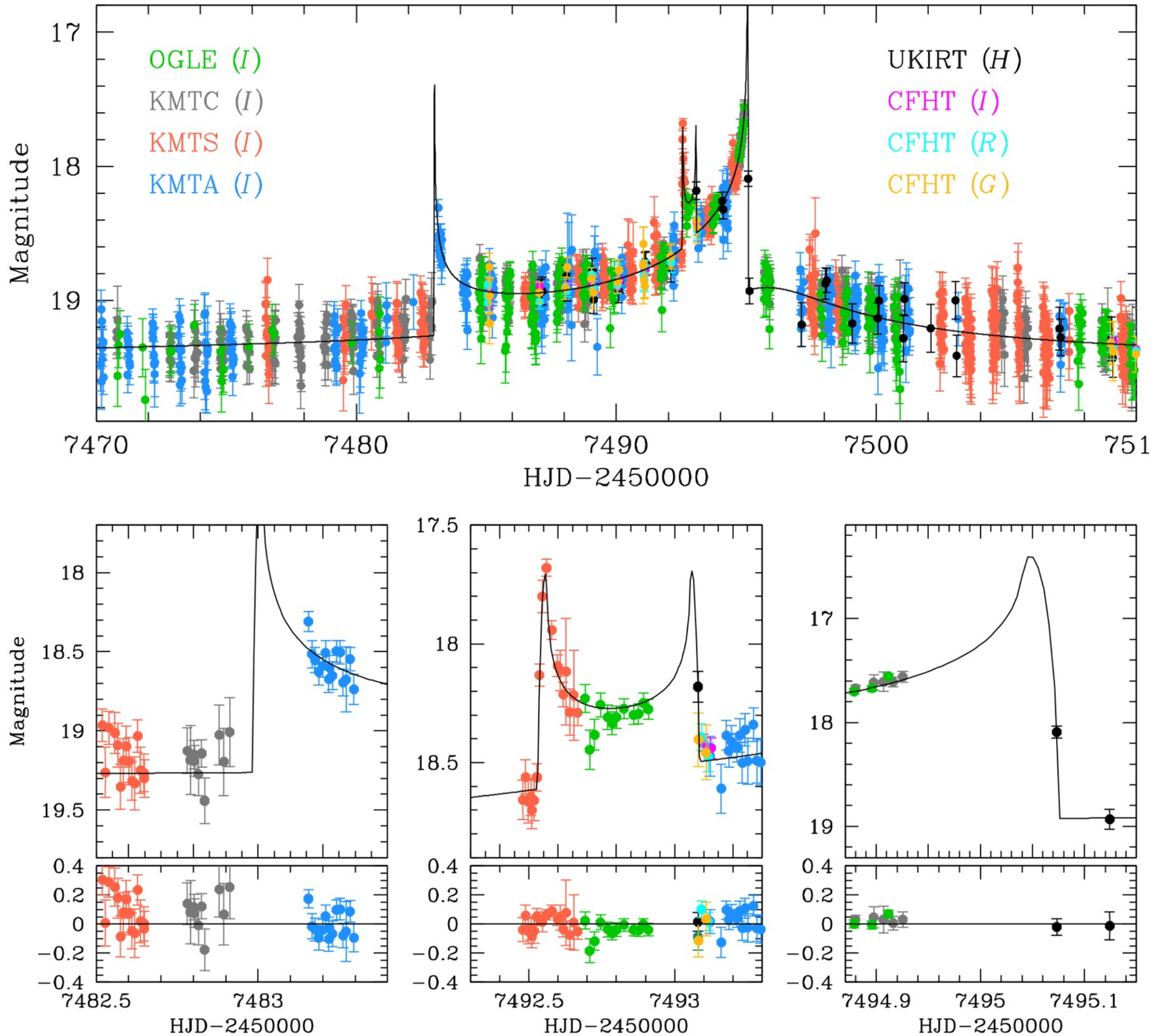


Kostov (2023)



Gianuzzi, Giuppone & Cuello (2023)

Roman microlensing CBPs



OGLE-2016-BLG-0613LABb (Han et al 2017)

- 3 candidate CBP systems discovered to date from ground-based microlensing surveys, from 225 planetary systems
- CBPs represent 3-lens systems. Very complex to model - degeneracies are common
- Scaling current numbers, Roman may be expected to find perhaps ~20 such systems
- Deep high resolution imaging and long time baseline will be important for providing constraints on proper motion that can help break degeneracies

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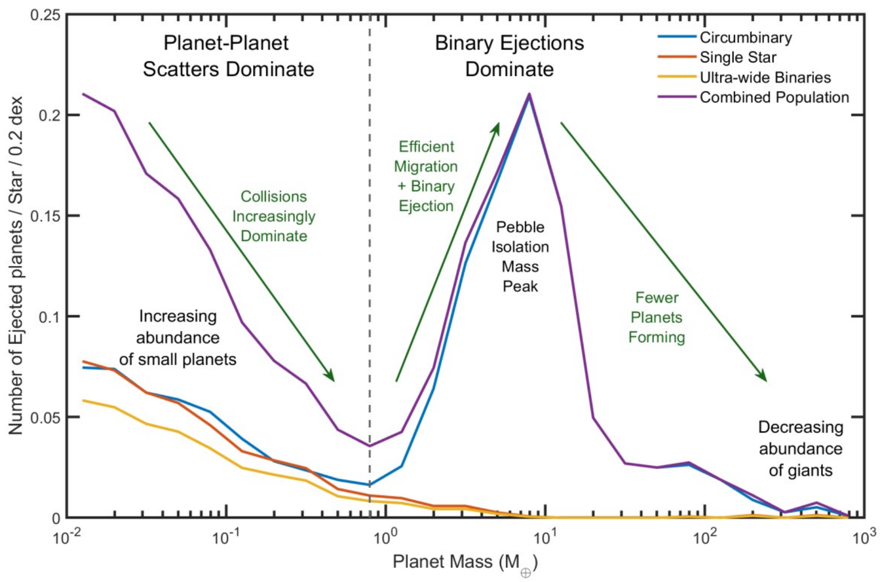
Microlensing + Transit CBPs

- The locations of CBPs observed so far strongly suggest they have migrated from their point of origin
- The relative number of CBPs detected by Roman through microlensing (cool regime) and through transits (hot regime) may provide important clues on CBP migration history

The CBP – FFP connection



Coleman & DeRocco (2024)

- A substantial Galactic population of Earth-mass FFPs is now implicated from separate ground-based microlensing studies by OGLE, KMTNet and MOA
- A recent analysis of Kepler K2 Campaign 9 data has also uncovered 4 new Earth mass FFP candidates (McDonald et al 2021)
- Some studies suggest that CBP systems could be a major reservoir for ejected planets that comprise the FFP population (e.g. Nelson 2003, Coleman 2024)
- Extrapolation of the ground-based microlensing survey results indicate that Roman may be expected to find hundreds of FFPs
- Measuring masses, distances and motions of FFPs directly may be possible using both Roman and, e.g. Rubin, PRIME or ESA Euclid to observe events simultaneously

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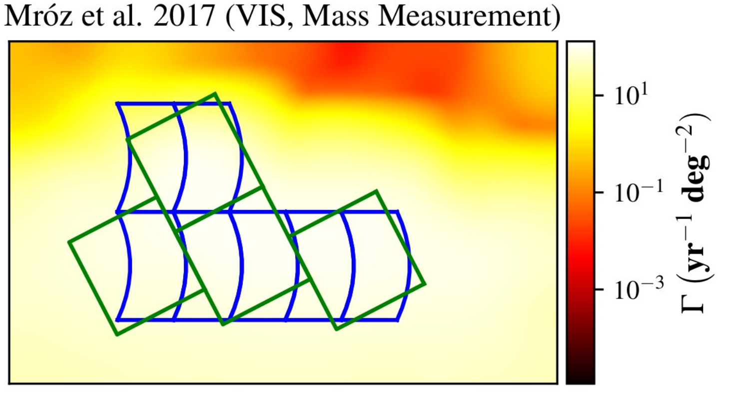
Euclid+Roman simultaneous observations

- Euclid and Roman will both be on Earth-Sun L2 halo orbits.
- Unless unlucky, they should be separated by several hundred thousand km.
- Provides baseline for relative parallax measurement of FFPs
- Should yield ~140 direct FFP mass measurements over GBTDS lifetime.

Separated simultaneous microlensing measurements are the only way to obtain direct masses of FFPs. **Roman cannot do this alone.**



MaBuLS-2 microlensing simulations of the rate of FFP events with direct mass measurement via Euclid (VIS) + Roman simultaneous observations (Bachelet et al 2022)

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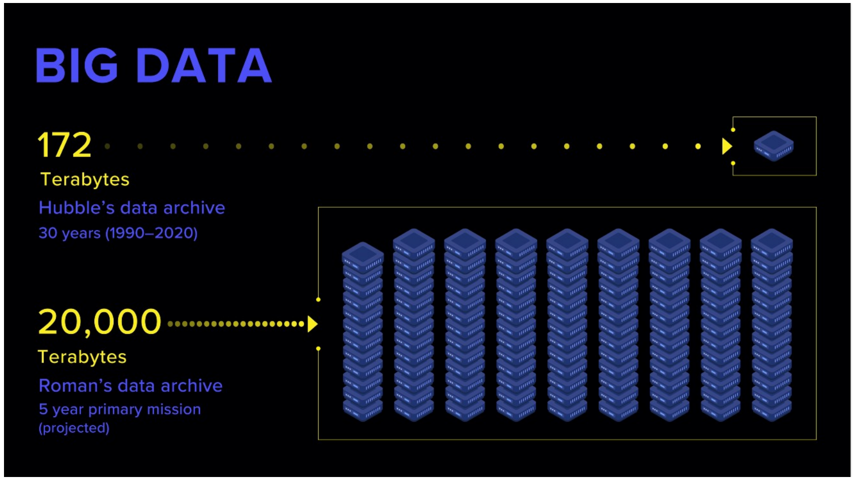
The data challenge



- Roman data will be world public but it will be too large to download
- Like Rubin, working with Roman data will involve running codes on a science platform operating in the cloud
- It is planned that the Roman Science Platform will be hosted via an Amazon AWS
- Roman Project Infrastructure teams have been formed to develop a standard set of tools for the user community to do science on the data
- But these tools will not be all encompassing. There are no plans currently for tools to find CBP candidates
- Community input is welcomed

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Summary

- Roman will be a transformative facility for wide-area and time-domain survey astrophysics
- 1400x HST survey speed
- Exoplanet survey will find ~1400 cool bound planets and hundreds of FFPs using microlensing, as well as 60-200 thousand transiting planets
- With such large statistics we may look forward to catalogues of hundreds of CBPs that will shed light on their migration history and their connection with the FFP population
- Data volume will be huge – now is the time to organise and to become involved in order to develop necessary tools and prepare for the data challenge!