The Roman Galactic Exoplanet Survey Will Find the Coolest Planets

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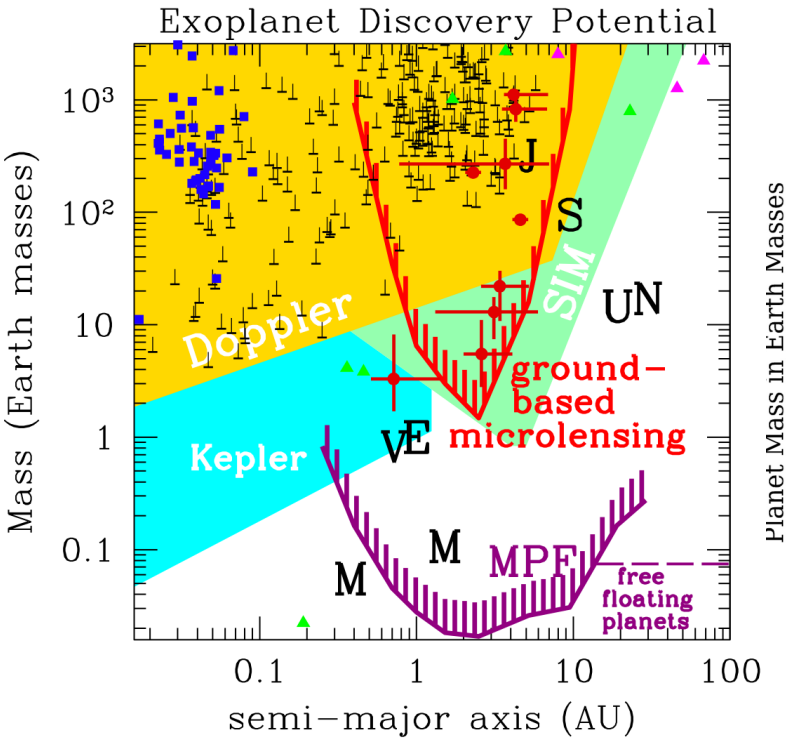
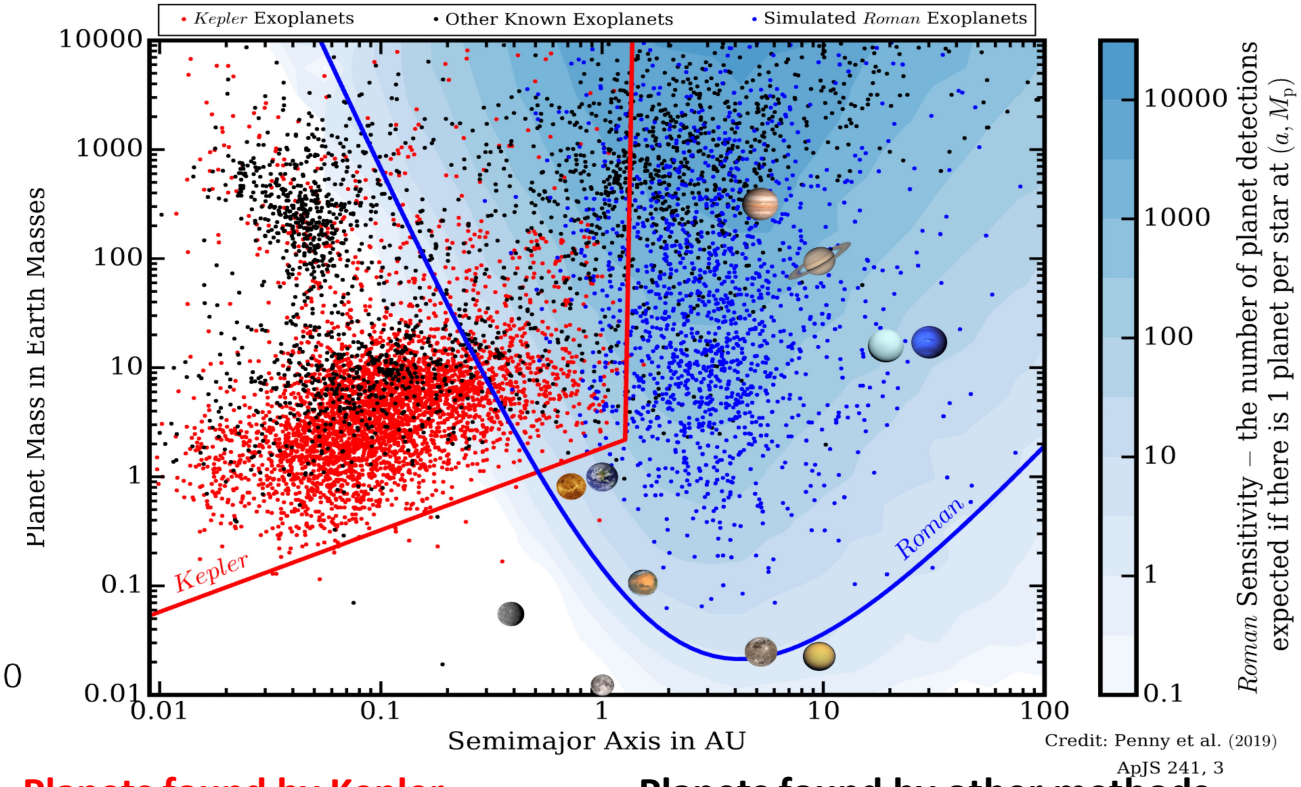
July 13, 2026

A Complete Statistical Census of Exoplanets



Predicted sensitivity for the Microlensing Planet Finder (MPF) in Astro2010 submission



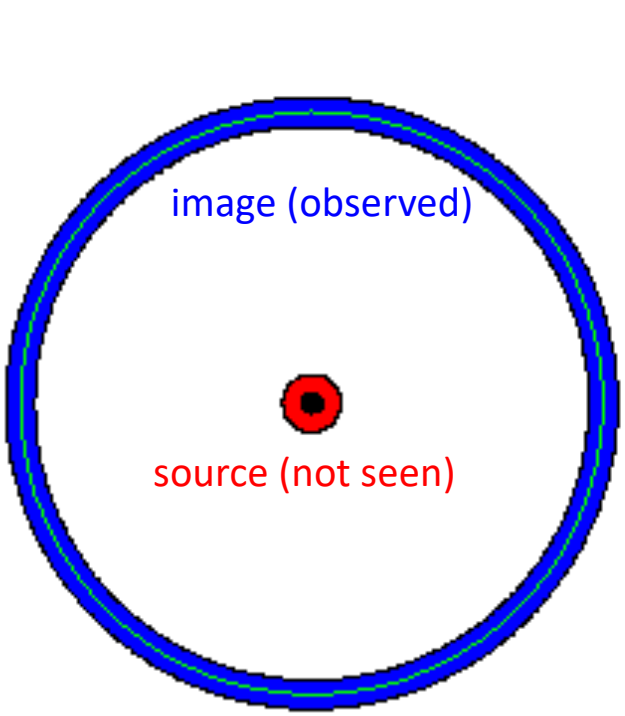
Planets found by Kepler **Planets found by other methods**

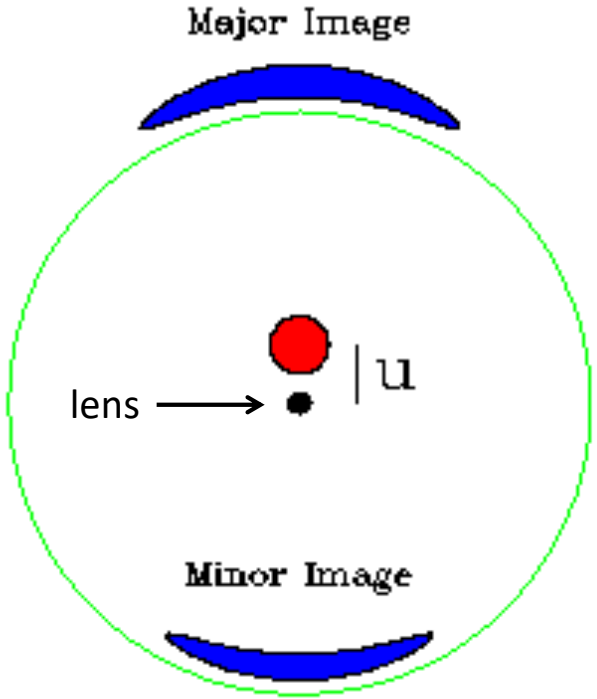
Planets predicted to be found by the Roman Galactic Exoplanet Survey (RGES) (Penny et al. 2019)

Outline

- Astro2010 selection
- Post-Astro2010 developments
  - Exoplanet mass ratio function shows no "sub-Saturn desert" due to runaway gas accretion
  - Roman's exoplanet mass measurement methods find that the planet hosting probability scales as $M_{\rm host}^{1}$ for fixed mass ratio, q
    - verified by radial velocity measurements
  - Rogue planet discoveries from MOA, OGLE, and KMTNet
    - **Most planets are cold and lonely!**

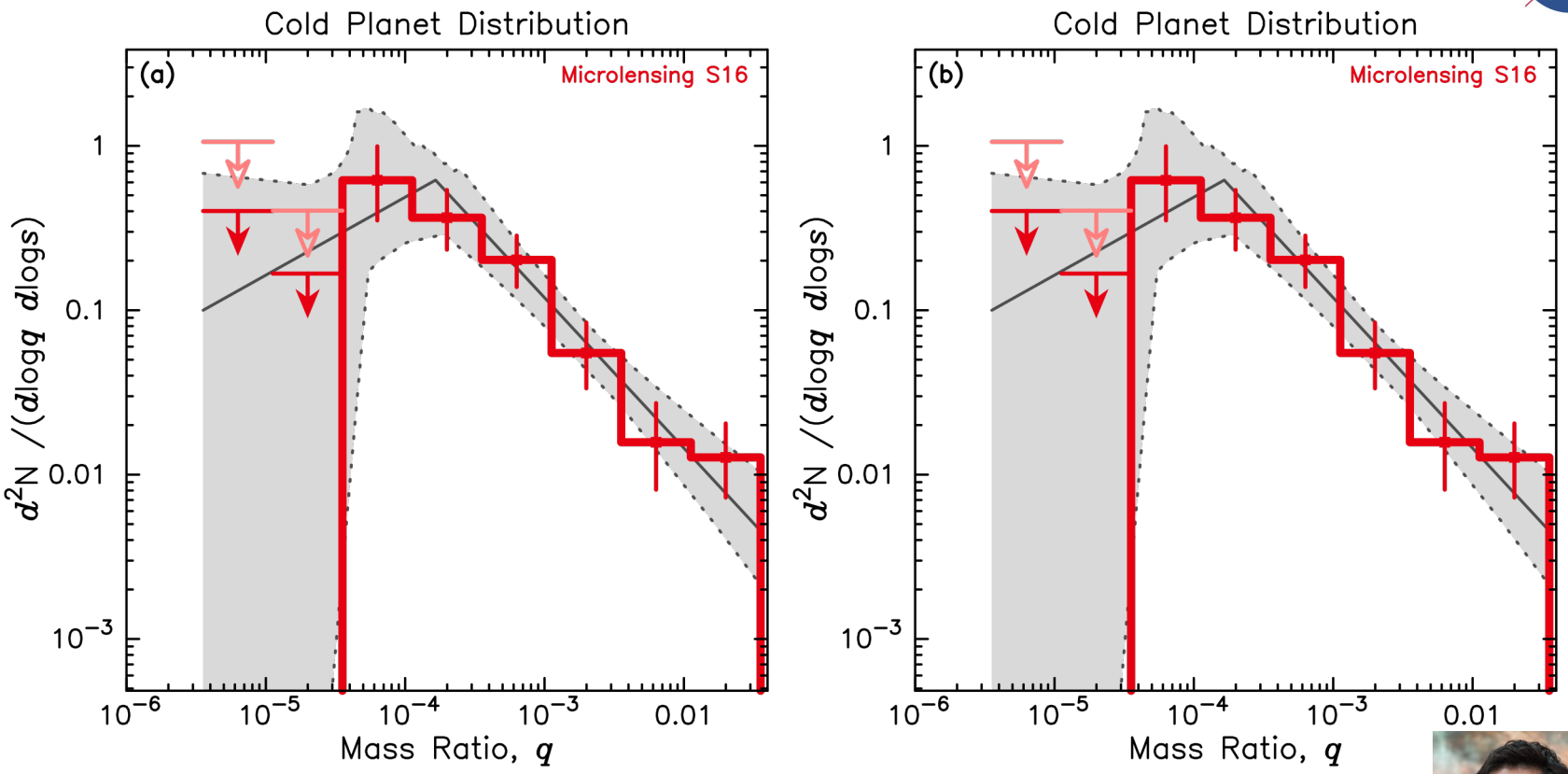
Lensed Images (Einstein 1936)

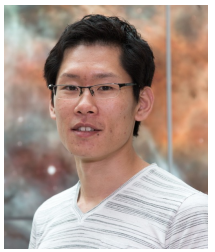




When source is distant, we see distorted, magnified images. Perfect alignment gives an "Einstein Ring" image, and images are highly magnified near the Einstein ring when the alignment is nearly perfect. Planets are most easily detected near the Einstein ring (typically at 2-3 AU) when they distort one of the lensed image. $2\mathrm{AU} \approx \sqrt{D_{\mathrm{Lens}} R_{\mathrm{sch}}}$

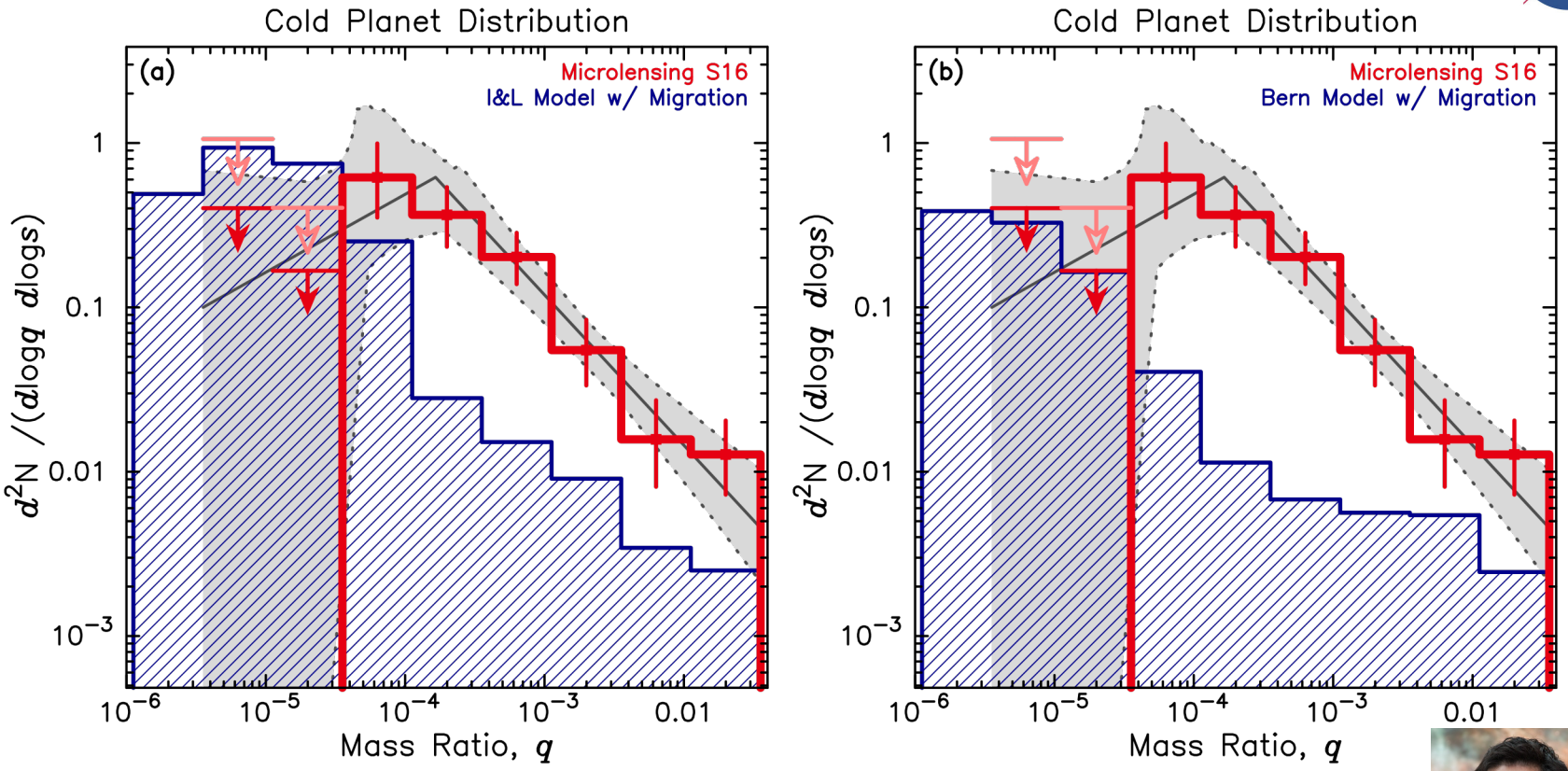
Comparison to Population Synthesis Models

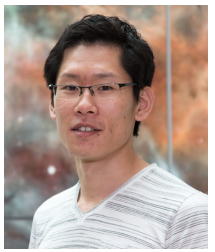




Turning off migration improves the cold planet distribution, but does not generate enough planets at q ~ 1-5 × 10^{-4}, about 20-80 $M_\oplus$ (Suzuki+18)

Comparison to Population Synthesis Models





Turning off migration improves the cold planet distribution, but does not generate enough planets at $q \sim 1\text{-}5 \times 10^{-4}$, about 20-80 $M_\oplus$ (Suzuki+18)

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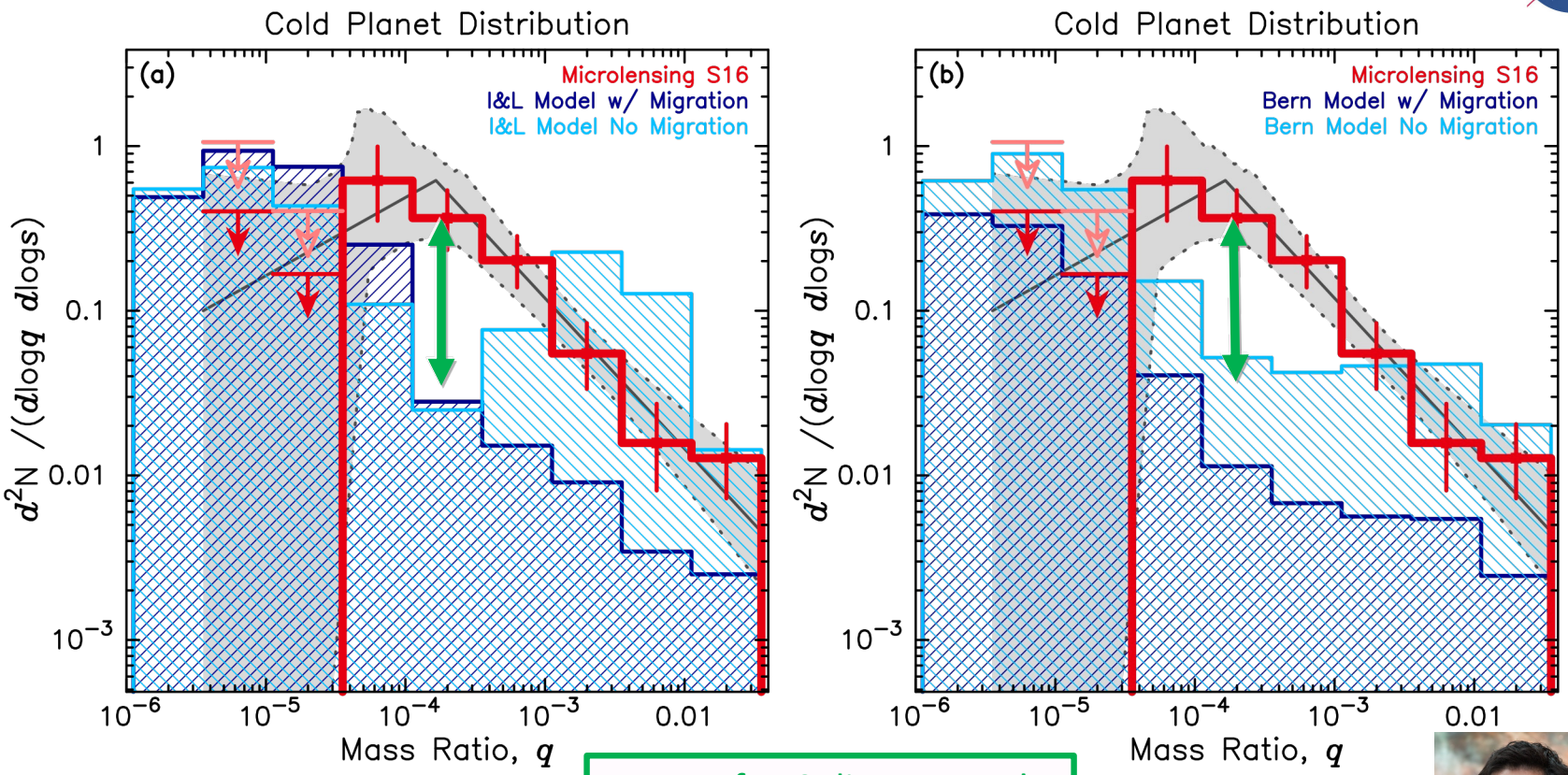
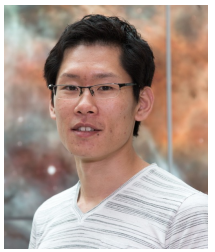
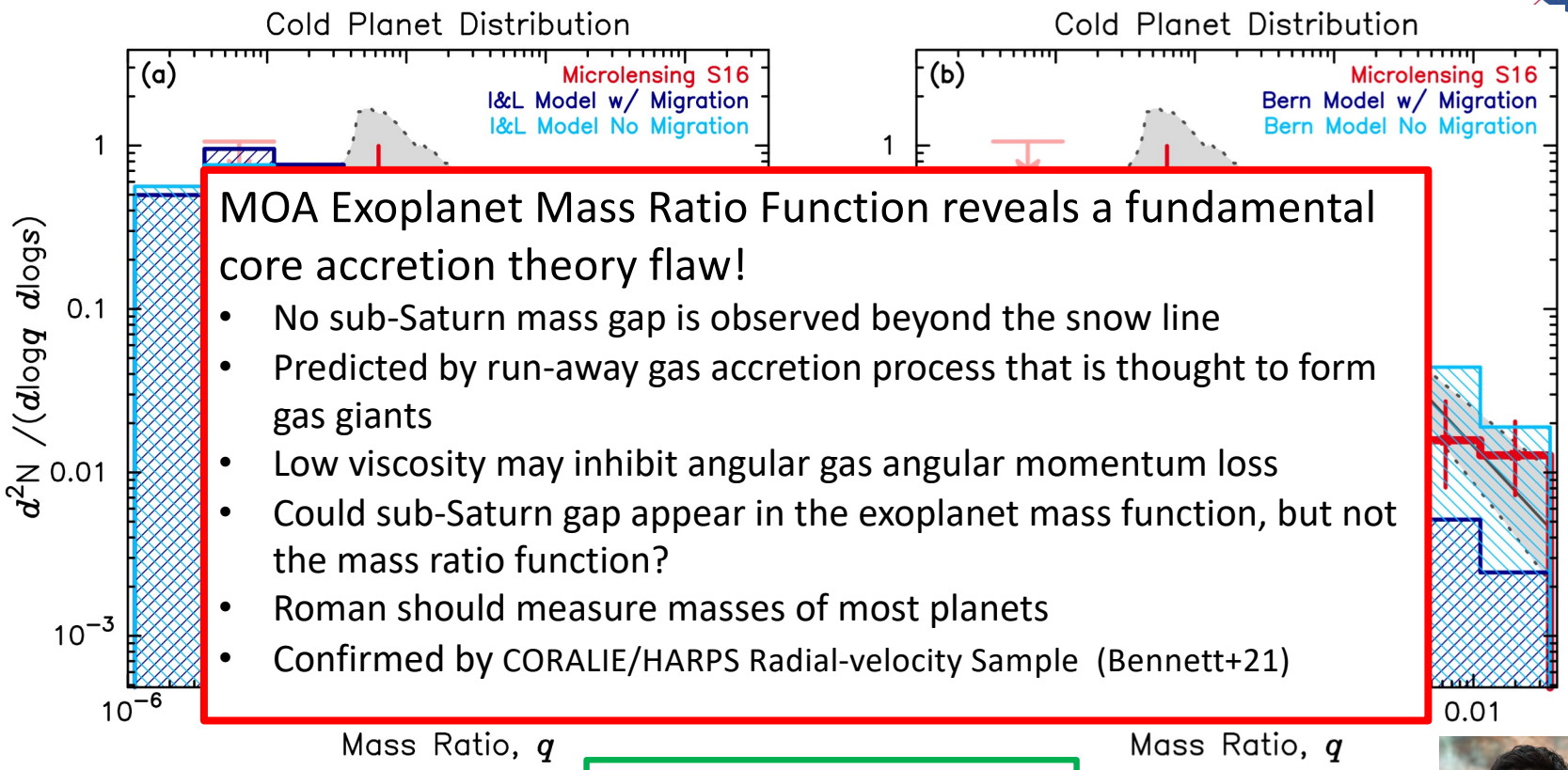


Factor of ~10 discrepancy!

Turning off migration improves the cold planet distribution, but does not generate enough planets at q ~ 1-4 × 10^{-4}, about 20-80 $M_\oplus$ (Suzuki+18)



Comparison to Population Synthesis Models

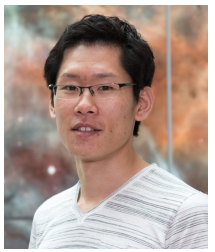


MOA Exoplanet Mass Ratio Function reveals a fundamental core accretion theory flaw!

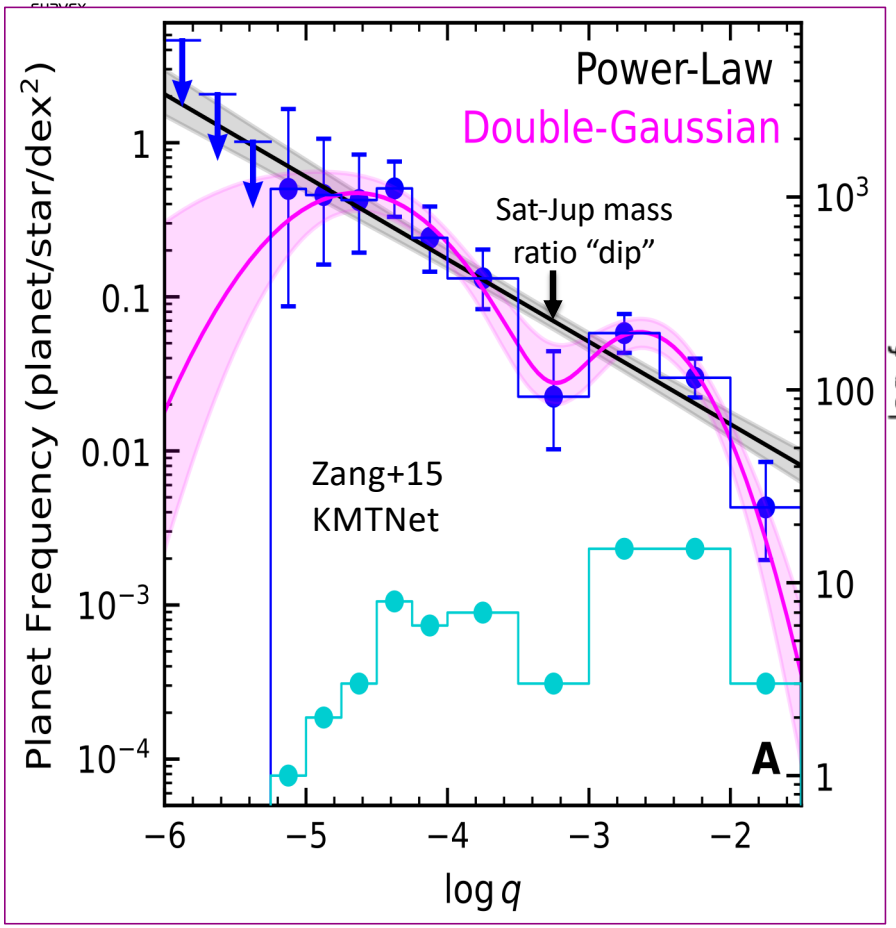
- No sub-Saturn mass gap is observed beyond the snow line
- Predicted by run-away gas accretion process that is thought to form gas giants
- Low viscosity may inhibit angular gas angular momentum loss
- Could sub-Saturn gap appear in the exoplanet mass function, but not the mass ratio function?
- Roman should measure masses of most planets
- Confirmed by CORALIE/HARPS Radial-velocity Sample (Bennett+21)

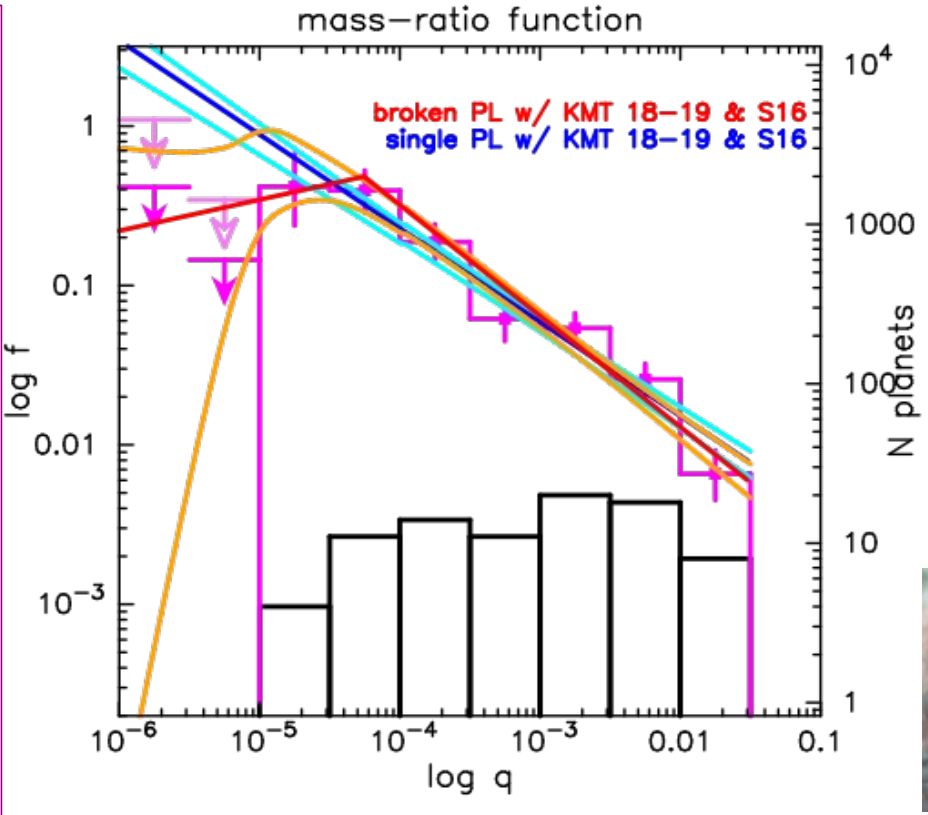
Factor of ~10 discrepancy!

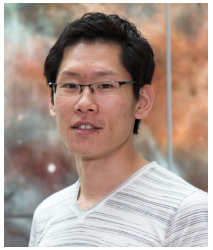
Turning off migration improves the cold planet distribution, but does not generate enough planets at $q \sim 1\text{-}5 \times 10^{-4}$, about 20-80 $M_\oplus$ (Suzuki+18)



Comparison to KMTNet results



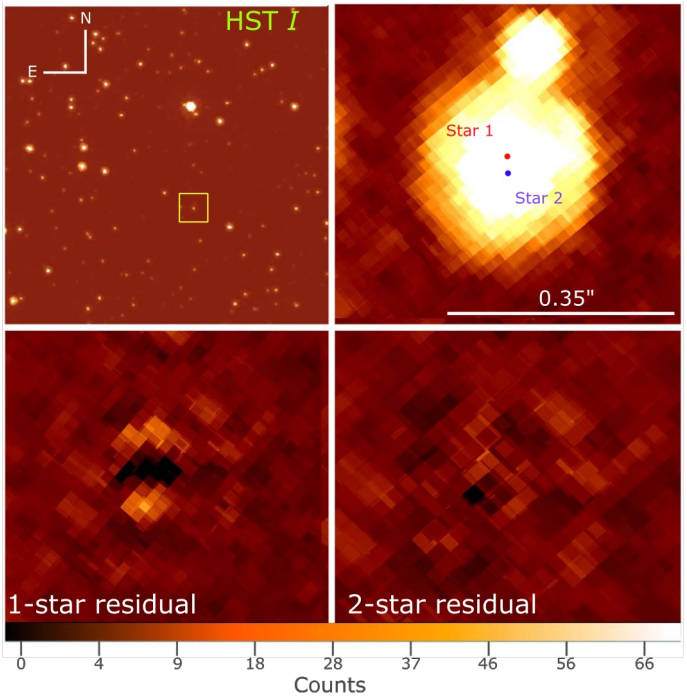


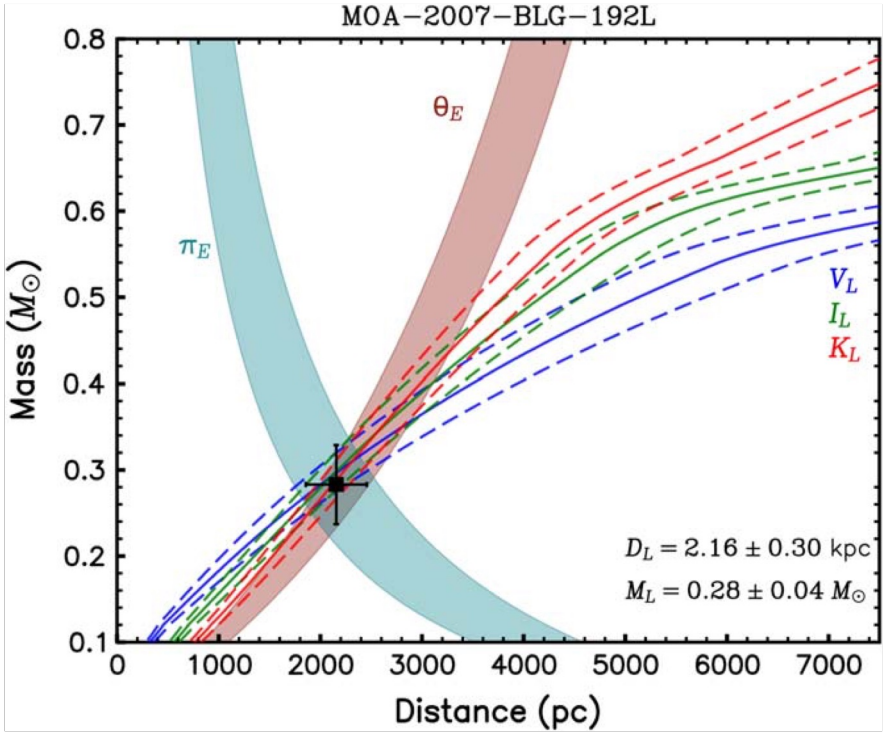


Combination of 55 KMTNet planets and 29 MOA planets removes dip in KMTNet-only analysis (Suzuki+26)

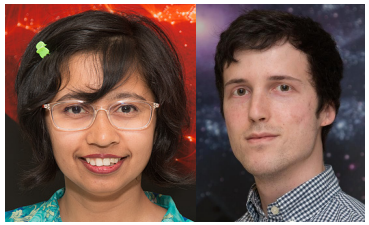
More recent KMTNet data seems to confirm smooth of this "dip"

Roman's High Angular Resolution Imaging Yields Mass Measurements





Mass Measurement method developed by Goddard team and collaborators



Aparna Bhattacharya

Sean Terry

Katie Vandorou

Natalia Rektsini

Terry+24 use HST + Keck to measure the lens magnitudes and lens-source relative proper motion yielding planet masses for MOA-2007-BLG-192 host and planet.

Roman imaging will reveal host and planet masses for most planetary microlensing events!

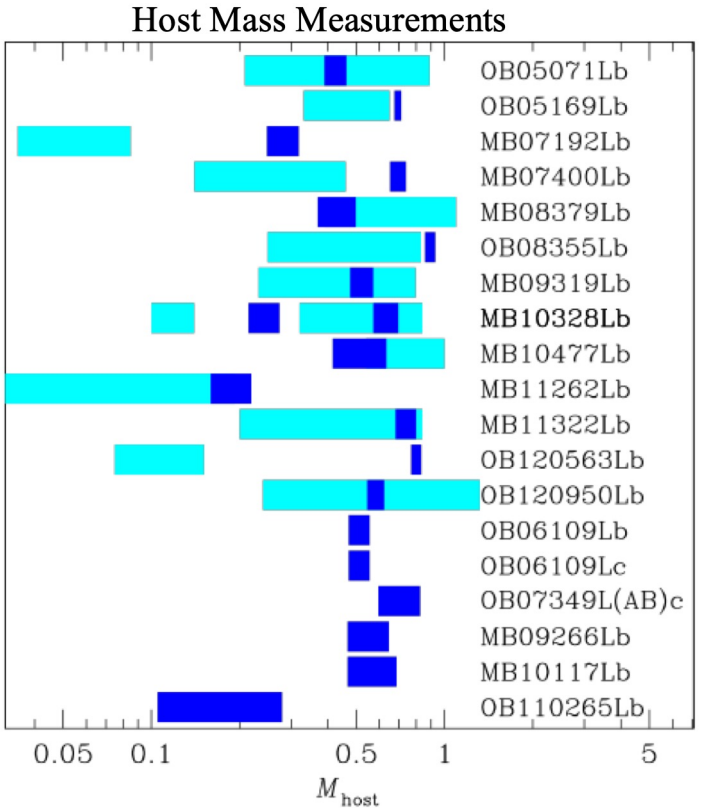
Cool Planet Host Mass Dependence

Bennett+26 (in prepation)

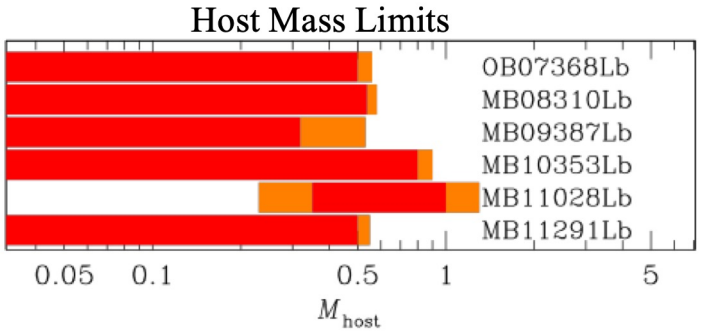
- 29 planets (in 28 events)
- 19 planets with mass measurements
- 6 planets with mass limits
- 4 planets without limits due to giant source and no π_E measurement

Host mass dependence at fixed mass ratio, q, scales as $\sim M_{\rm host}^{1.0\pm0.3}$ for $q \geq 5\times10^{-5}$

- implies more mass measurements for Roman due to brighter host stars and more π_E measurements



Discovery paper estimated host mass in **cyan**, and measured mass in **blue**.

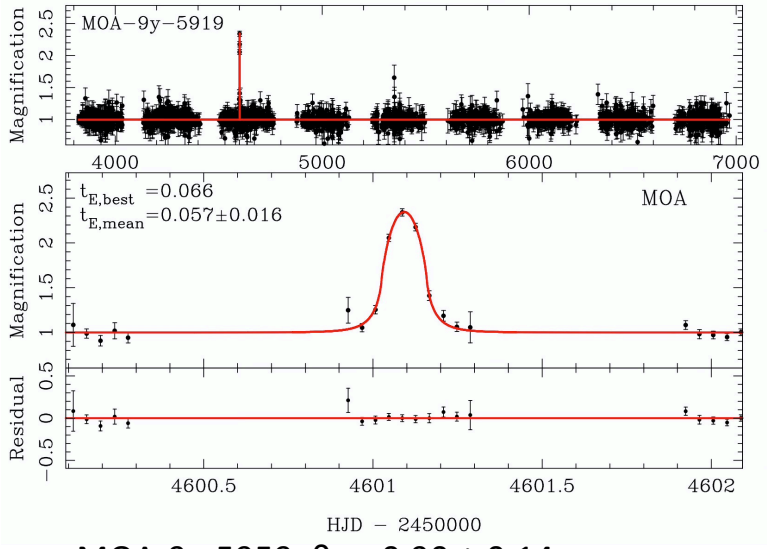


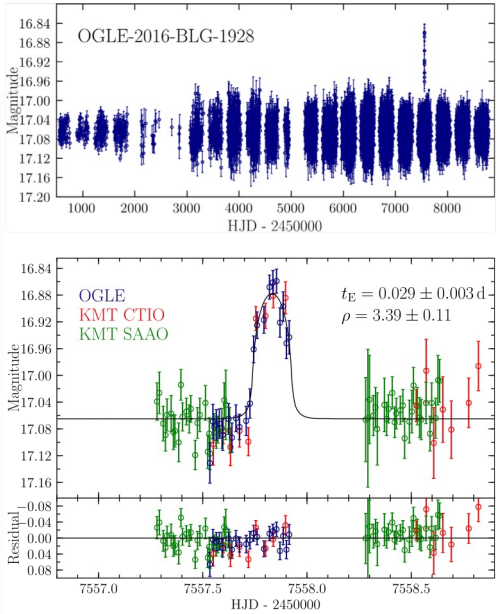
Allowed mass range in **red**, and 1-σ mass range in **orange**

Low Mass Free-Floating Planets (FFPs) Seem to be Common

Free-floating Planet Mass Function from MOA-II 9 yr Survey toward the Galactic Bulge

Takahiro Sumi[1], Naoki Koshimoto[1,2,3], David P. Bennett[2,3], Nicholas J. Rattenbury[4], Fumio Abe[5], Richard Barry[2], Aparna Bhattacharya[2,3], Ian A. Bond[6], Hirosane Fujii[5], Akihiko Fukui[7,8], Ryusei Hamada[1], Yuki Hirao[9], Stela Ishitani Silva[2,10], Yoshitaka Itow[5], Rintaro Kirikawa[1], Iona Kondo[1], Yutaka Matsubara[5], Shota Miyazaki[11], Yasushi Muraki[5], Greg Olmschenk[2], Clément Ranc[12], Yuki Satoh[1], Daisuke Suzuki[1], Mio Tomoyoshi[1], Paul . J. Tristram[13], Aikaterini Vandorou[2,3], Hibiki Yama[1], and Kansuke Yamashita[1]
(MOA Collaboration)





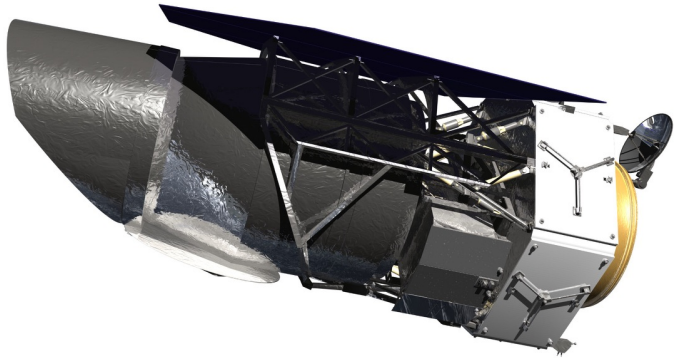
2 likely sub-Earth-mass planets found by OGLE and MOA

MOA solves for FFP mass function

MOA-9y-5959 $\theta_E = 0.90 \pm 0.14$ μas, $t_E = 0.057 \pm 0.016$ days Koshimoto+23

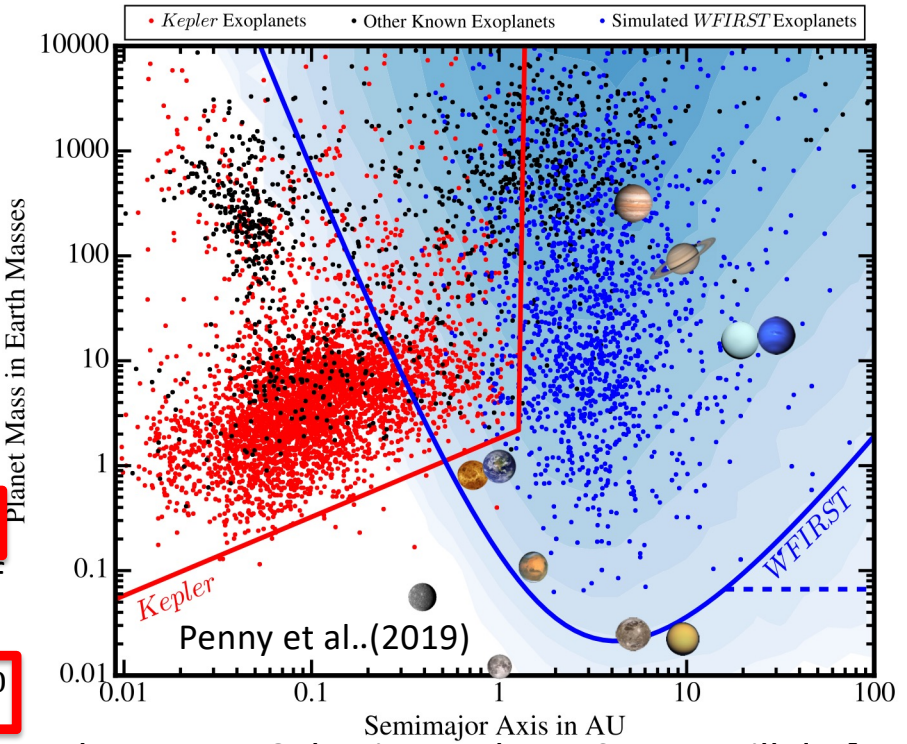
OGLE-2016-BLG-1928 $\theta_E = 0.84 \pm 0.06$ μas, $t_E = 0.029 \pm 0.003$ days Mroz+20

Free-Floating Planet (FFP) Mass Function Implications



Most Planets Are Free! There are $5.6^{+6.4}_{-3.8}$ FFPs per known bound planet, but the total mass of bound planets is a little larger.

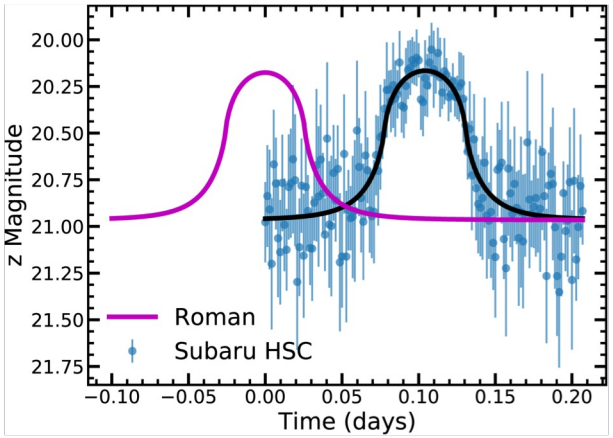
The Roman Space Telescope will find 990^{+1850}_{-560} FFPs down to the mass of Mars, including 580^{+1730}_{-420} between the masses of Mars and Earth (Sumi+23)



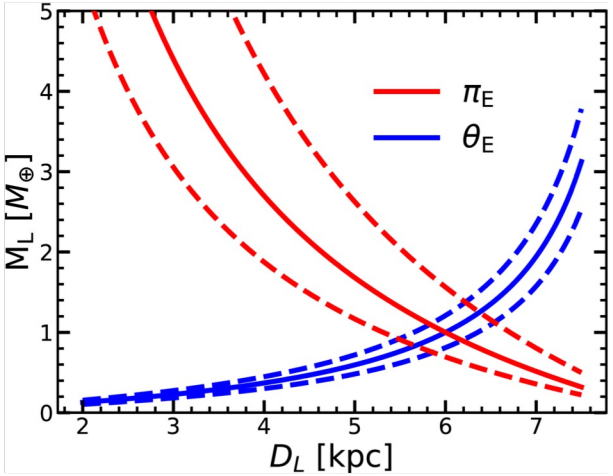
The Roman Galactic Exoplanet Survey will do for wide orbit exoplanets what Kepler did for transiting planets.

NANCY GRACE ROMAN SPACE TELESCOPE

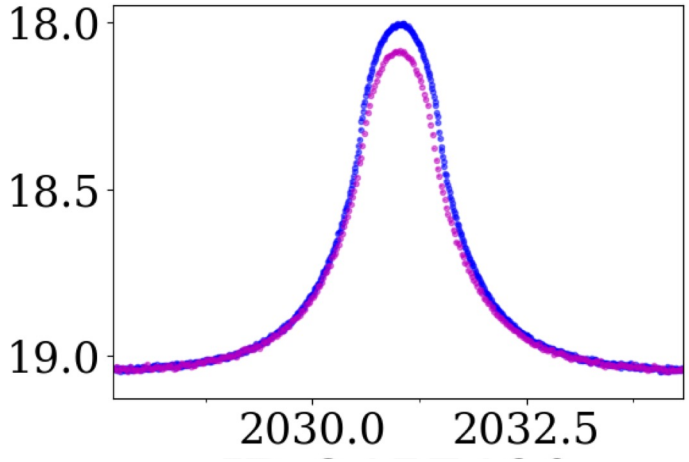
FFP Mass Measurements with Simultaneous Roman + Euclid (or Subaru, Blanco+DECam, …) Observations



Simulated Roman & Subaru data for a $1M_{\oplus}$ FFP



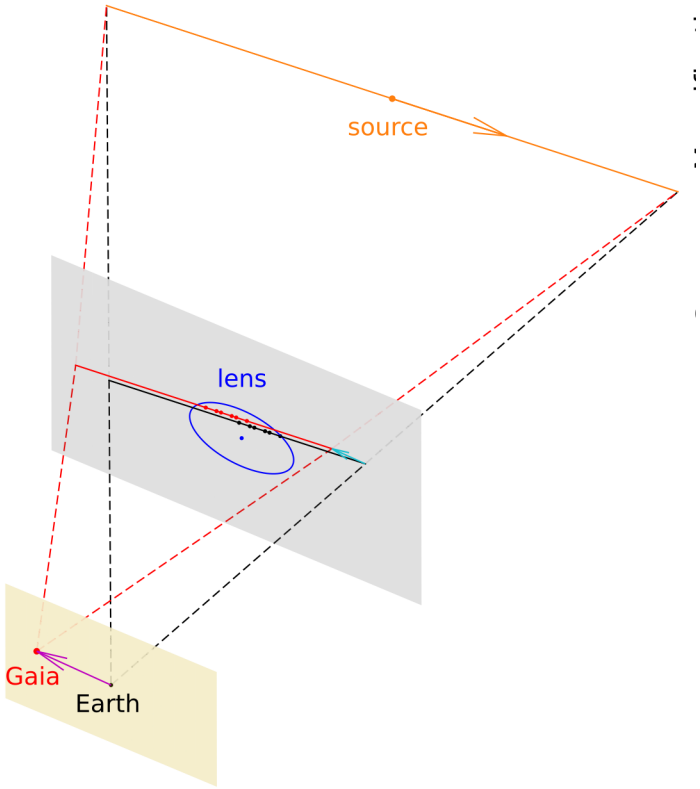
⇒ mass-distance relations from μlens parallax & finite source

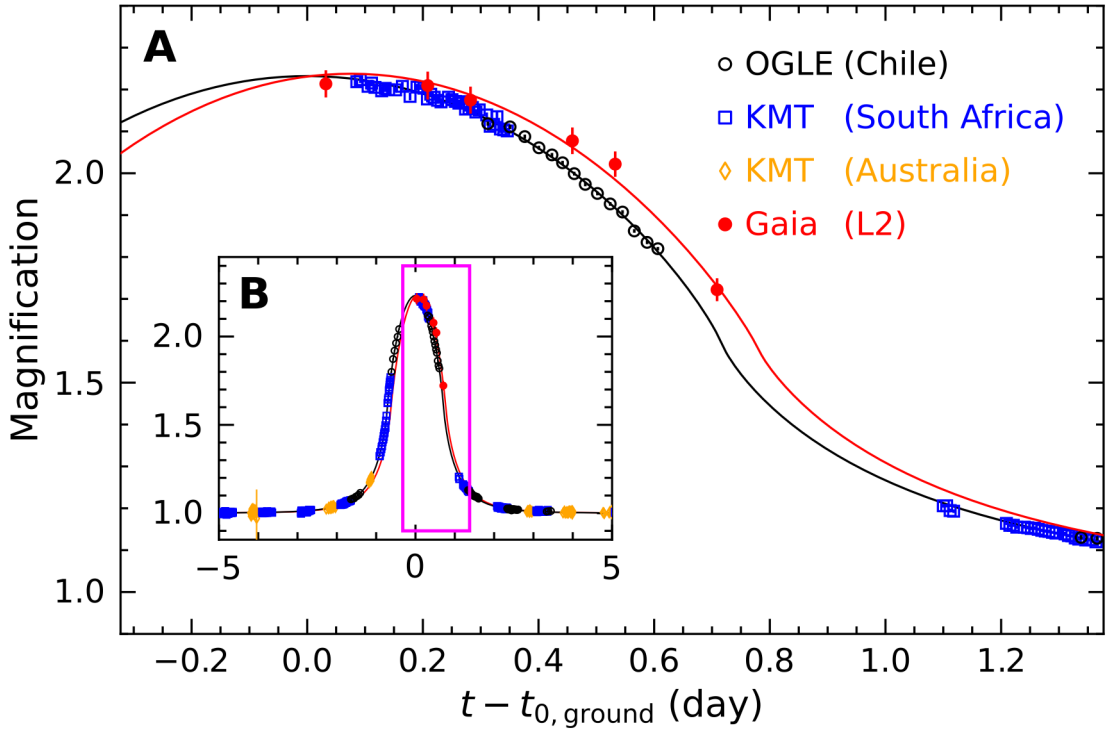


Simulated Roman & Euclid data for a $97M_{\oplus}$ FFP

Simultaneous observations by Roman and another wide FOV telescope on Earth or in a different L2 halo orbit can determine lens mass

FFP Mass Measurement Demonstrated w/ Gaia!





Finite source effects plus microlensing parallax using **observations from Earth and L2** for KMT-2024-BLG-0792 yield a mass $M_p = 70^{+24}_{-18} M_\oplus$ for this FFP candidate (Dong et al. 2026)

Roman will Search for Possible Host Stars for FFP Candidates that Provide no Microlensing signal

- Apply the same methods that are used to measure masses of bound planet host stars