Motivation for Roman Galactic Exoplanet Survey (RGES) and Science Investigation Team

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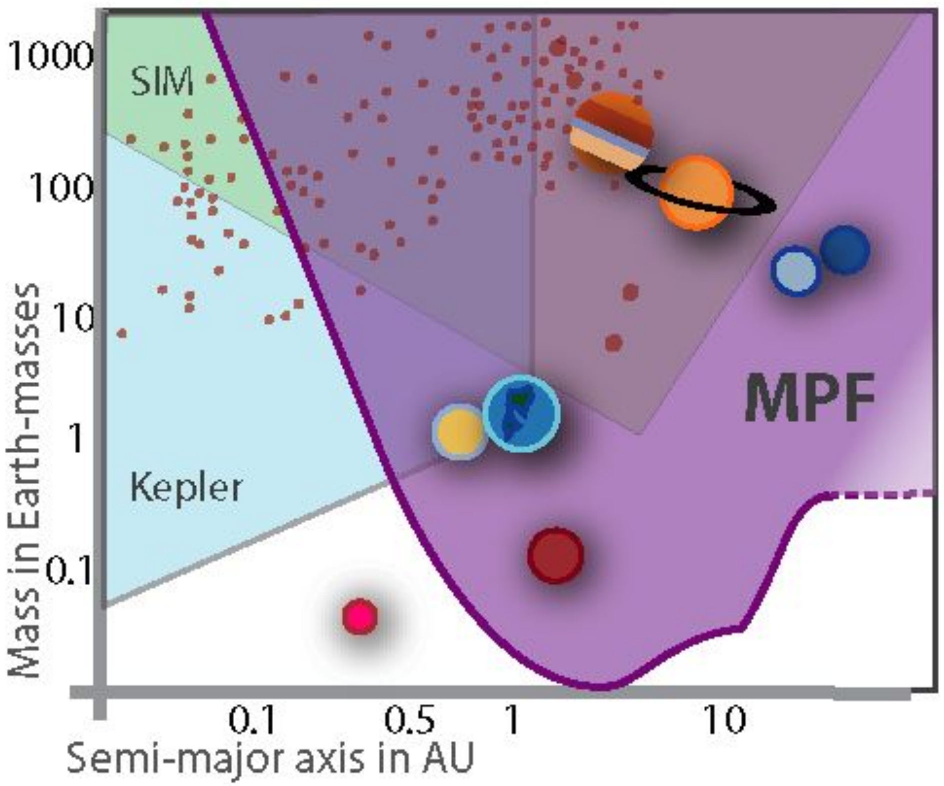
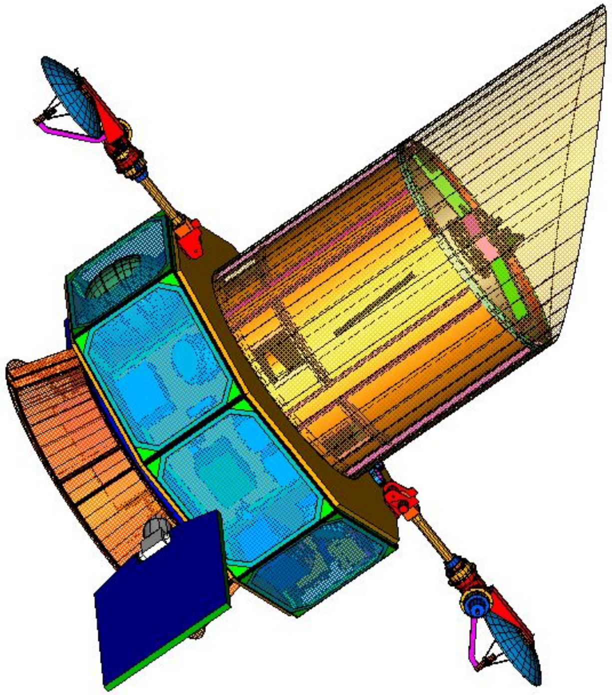
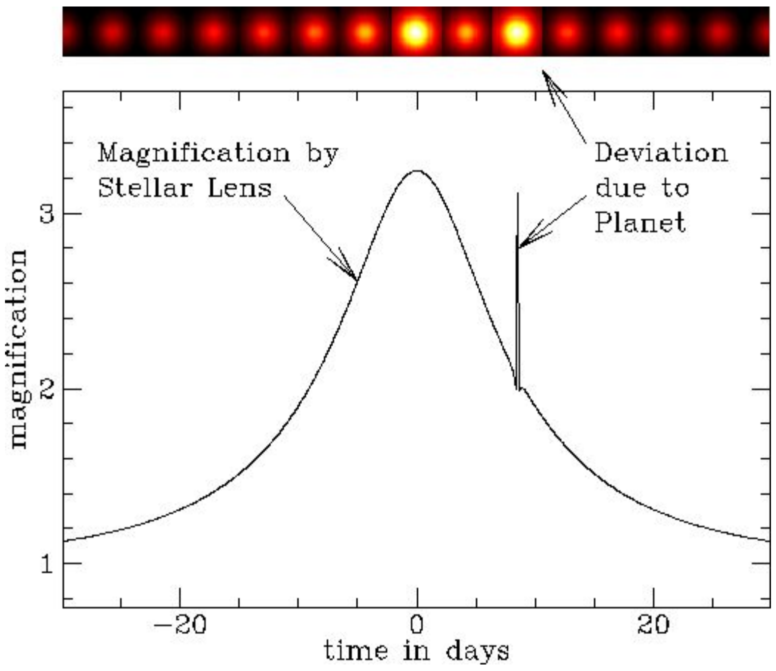
November 16, 2021







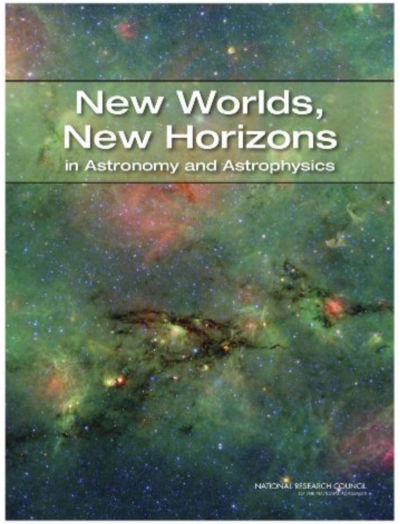
Why Do We Need Exoplanet Demographics?

The National Academy's

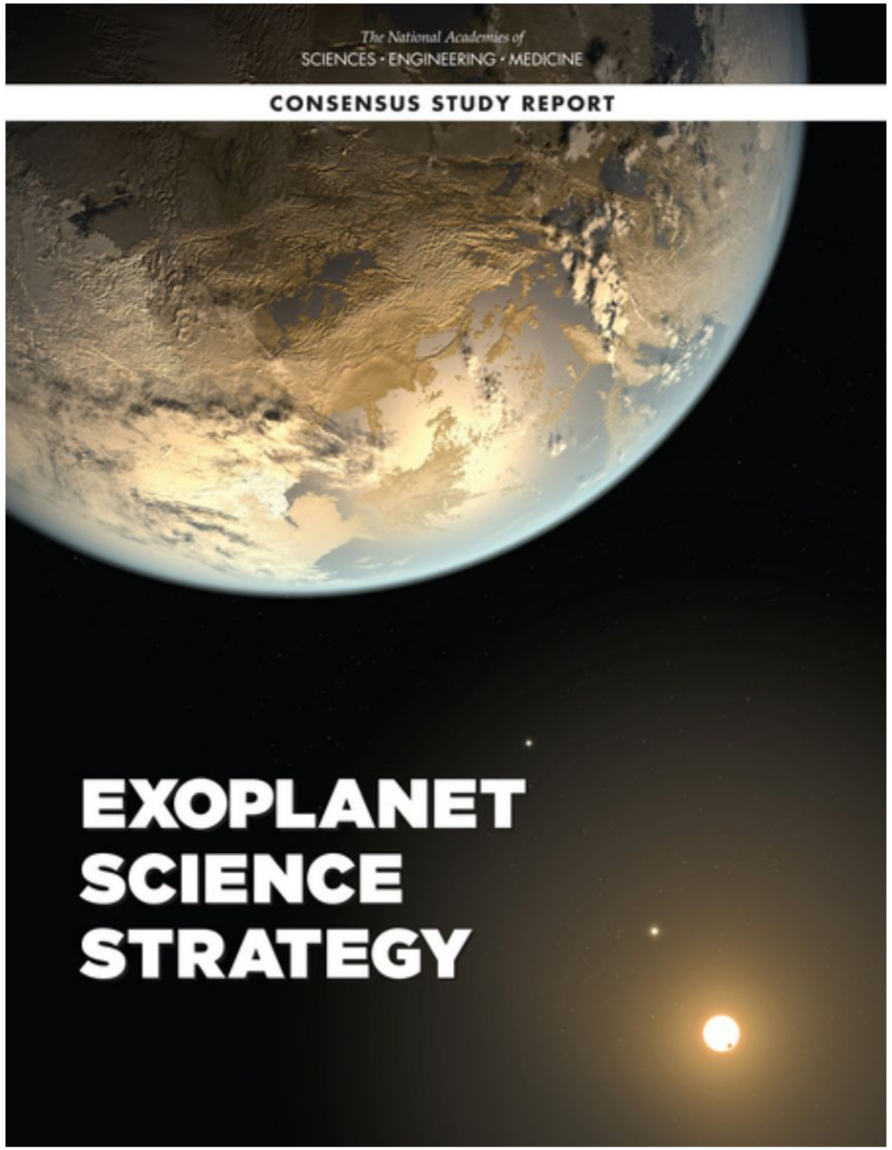
2018 Exoplanet Science Strategy Report

Recommendation:

"NASA should launch WFIRST to conduct its microlensing survey of distant planets and to demonstrate the technique of coronagraphic spectroscopy on exoplanet targets."



The New Worlds of the Astro2010 Decadal Survey are Microlens Worlds



Planet Formation Theory vs. Exoplanets

Inner planets are small and rocky

Kepler finds hot sub-Neptunes in short period orbits!

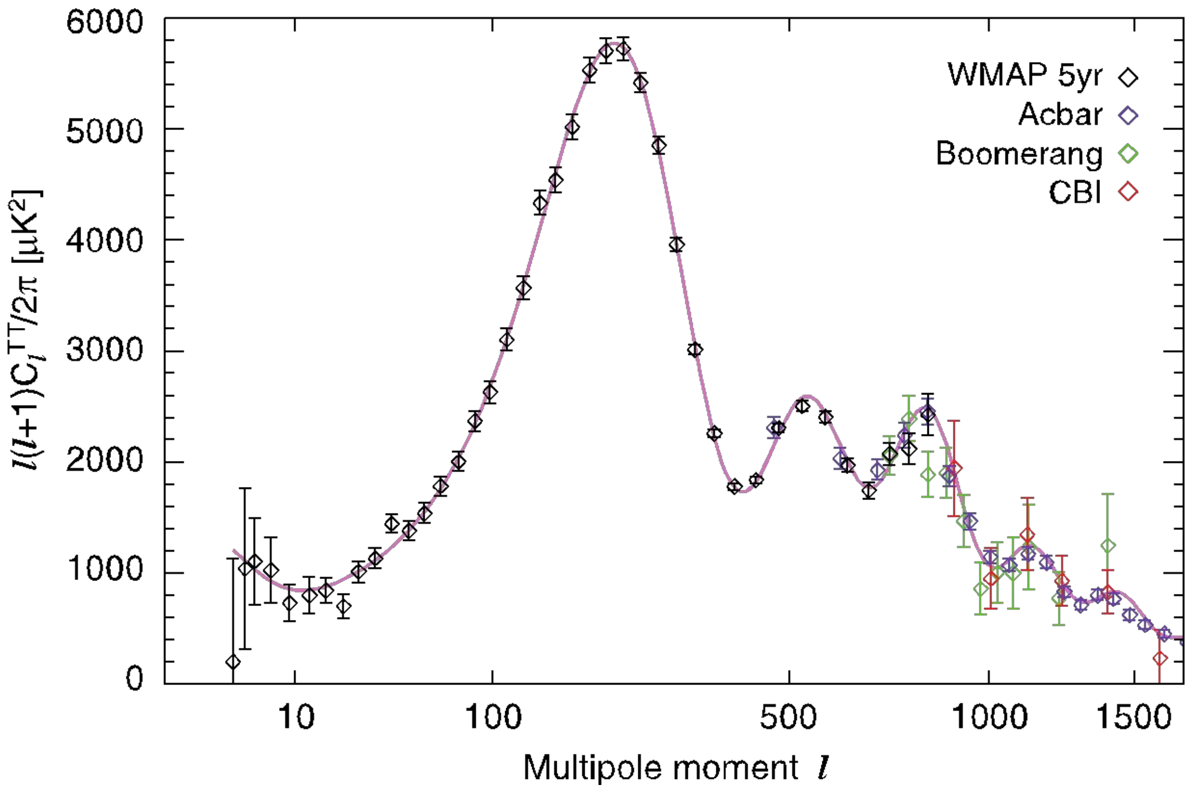
Gas giants are only found beyond the snow line

Hot Jupiters!

Giant planets either quickly grow to be gas giants or are stuck at Neptune size

Intermediate mass giant planets are common! Suzuki et al. (2016,2018)

Cosmology Theory is "Easy"



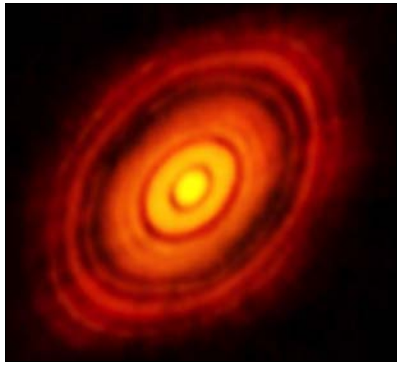
Bond & Efstathiou (1987) predict CMB Doppler Peaks from 1st principles

WMAP, Boomerang, and later Planck, confirmed these Cosmic Microwave background anisotropy predictions (2003-2009).

Planet Formation Theory is Not "Easy"

- Core Accretion Theory based on Solar System
  - Protoplanetary disks are observed to form
  - Our Solar System is co-planar, likely formed in a disk
  - Saturn, Uranus, Neptune, and possibly Jupiter have rocky cores
  - Small rocky planets inside snow line, Giant planets outside snow line
  - Giant planet mass gap between Neptune (17 $M_{\oplus}$) and Saturn (95 $M_{\oplus}$)

HL Tau

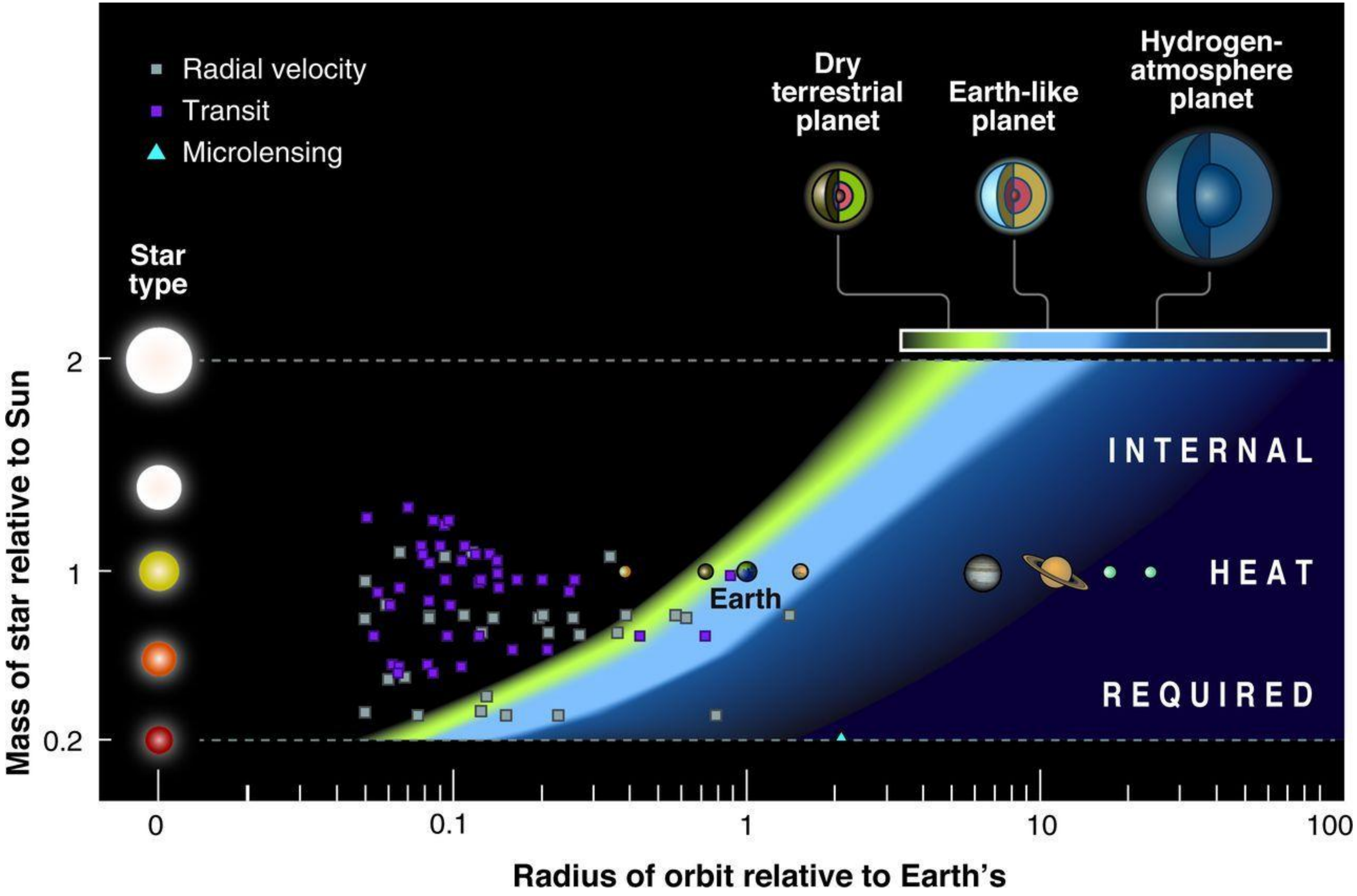


- Physics is too complex to calculate from first principles – Let's Guess!
  - What is the structure of protoplanetary disks – minimum mass solar nebula disk?
  - How can planetesimals form? – "meter-barrier", "bouncing barrier", etc.
  - Do planets migrate – if so, how fast and in which direction?
  - Does runaway gas accretion imply that intermediate mass giant planets (20-90 $M_{\oplus}$) are rare?

Exoplanet theory makes no grand predictions. Progress comes from observations, with theoretical interpretation following the discoveries.

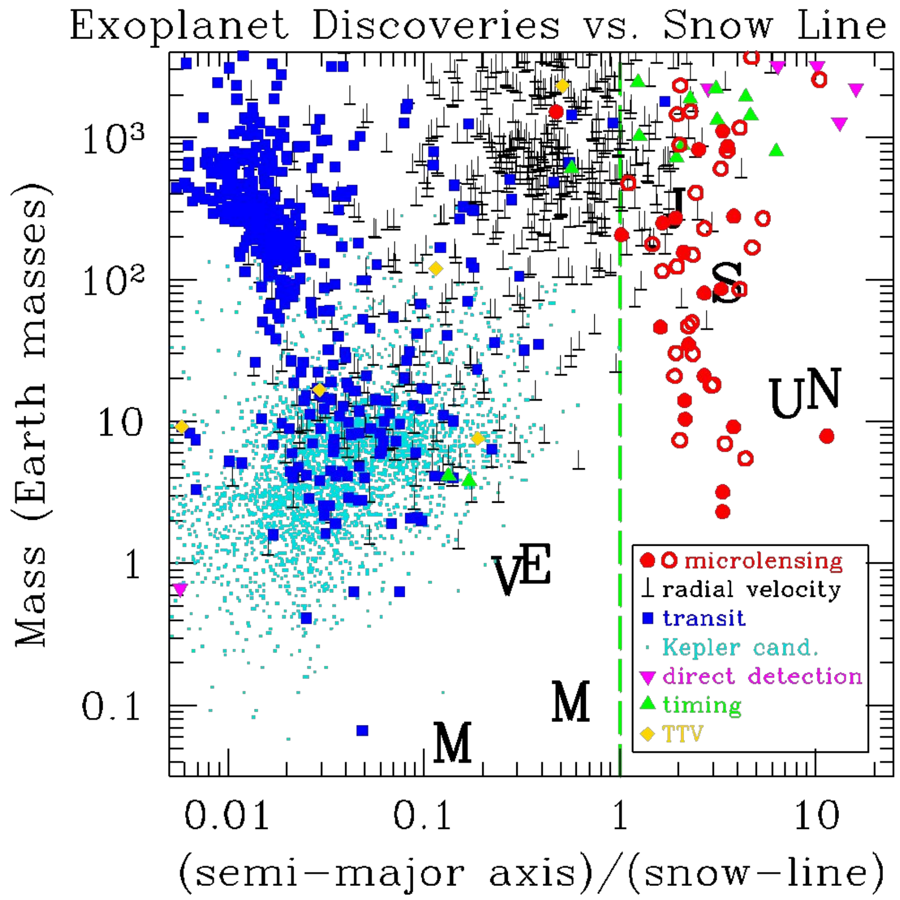
Why Do We Need Demographics? – Just Find Earth 2.0?

- We have a poor understanding of habitability
- Depends on planetary and atmospheric composition
- Many of Kepler's planets have H_2/He atmospheres that could push HZ outward
- We think life may require water, but water abundance depends on formation history
- A better understanding of planet formation is needed, and Exoplanet Demographics is needed for this



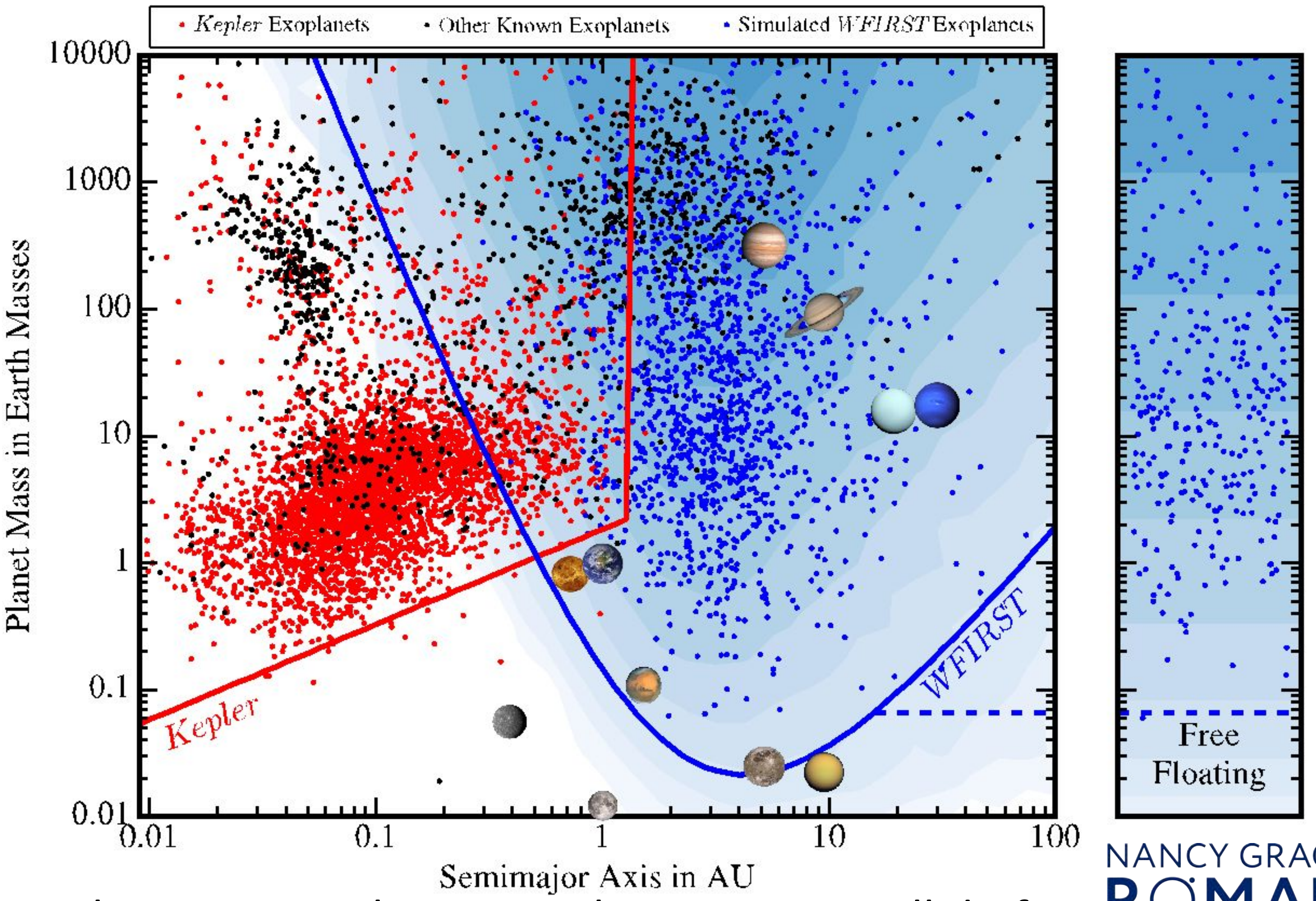
Seager, "Exoplanet Habitability", Science May 2013

A Galactic Bulge Microlensing Survey Has Unique Sensitivity to Wider Orbit Planets



Ground-based microlensing is now our most sensitive method for planets orbiting beyond the snow line.

Penny et al. (2019)

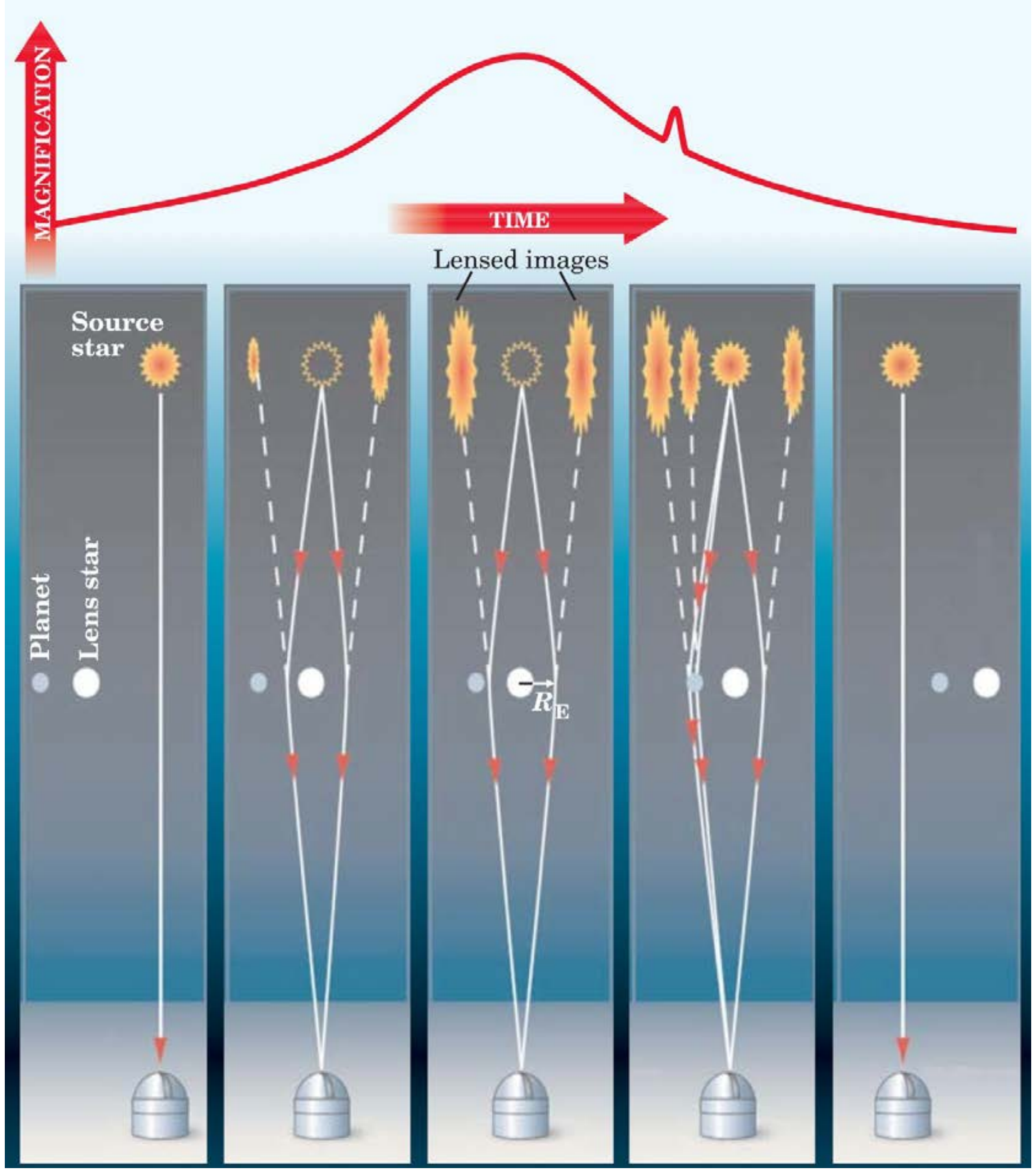


The Roman Galactic Exoplanet Survey will do for wide orbit exoplanets what Kepler did for transiting planets. (See Samson Johnson's talk).

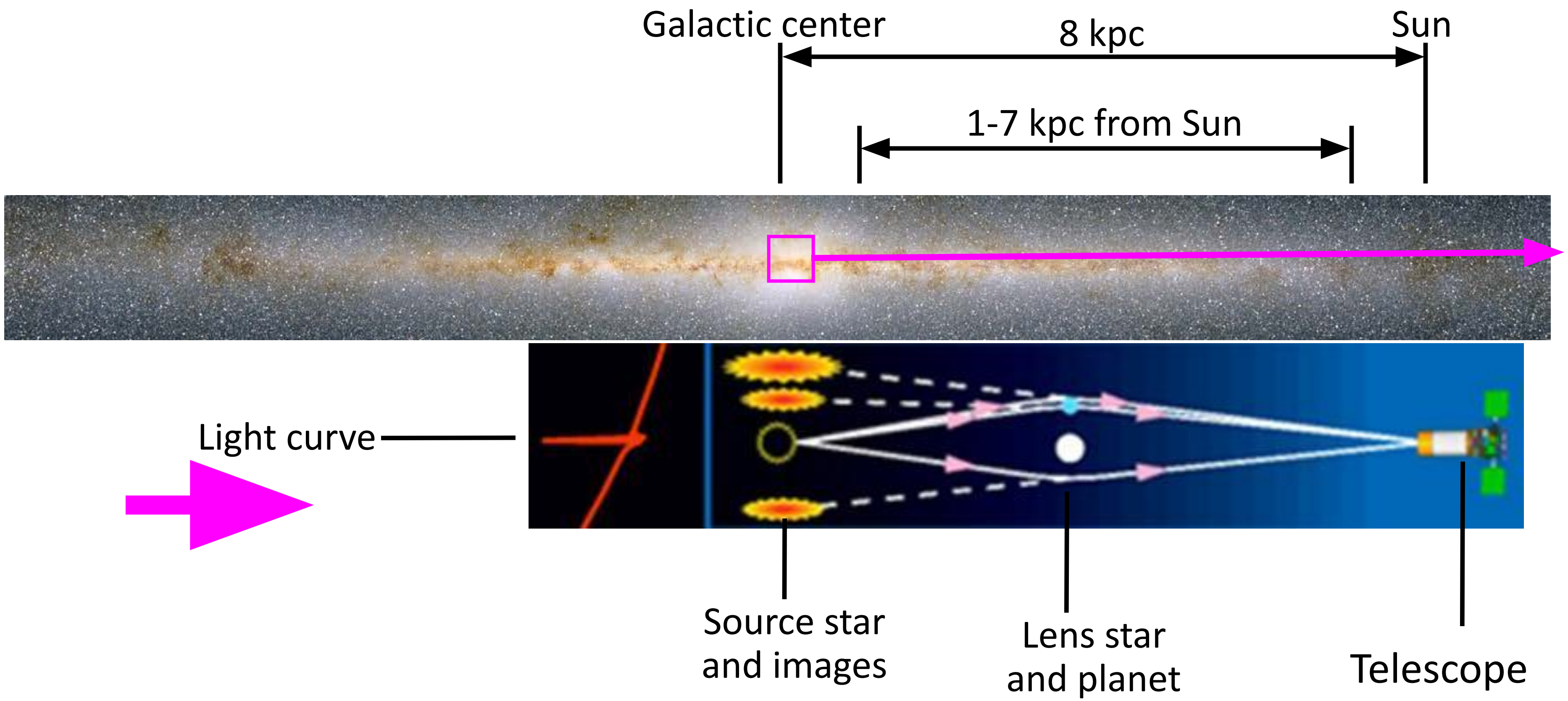
NANCY GRACE ROMAN SPACE TELESCOPE

The Physics of Microlensing

- Foreground "lens" star + planet bend light of "source" star
- Bending angle = $4GM/(rc^2)$
- Multiple distorted images
  - Only total brightness change is observable
- Sensitive to planetary mass
- Low mass planet signals are rare – not weak
- Stellar lensing probability ~a few $\times 10^{-6}$
  - Planetary lensing probability ~0.001-1 depending on event details
- Peak sensitivity is at 2-3 AU: the Einstein ring radius, R_E

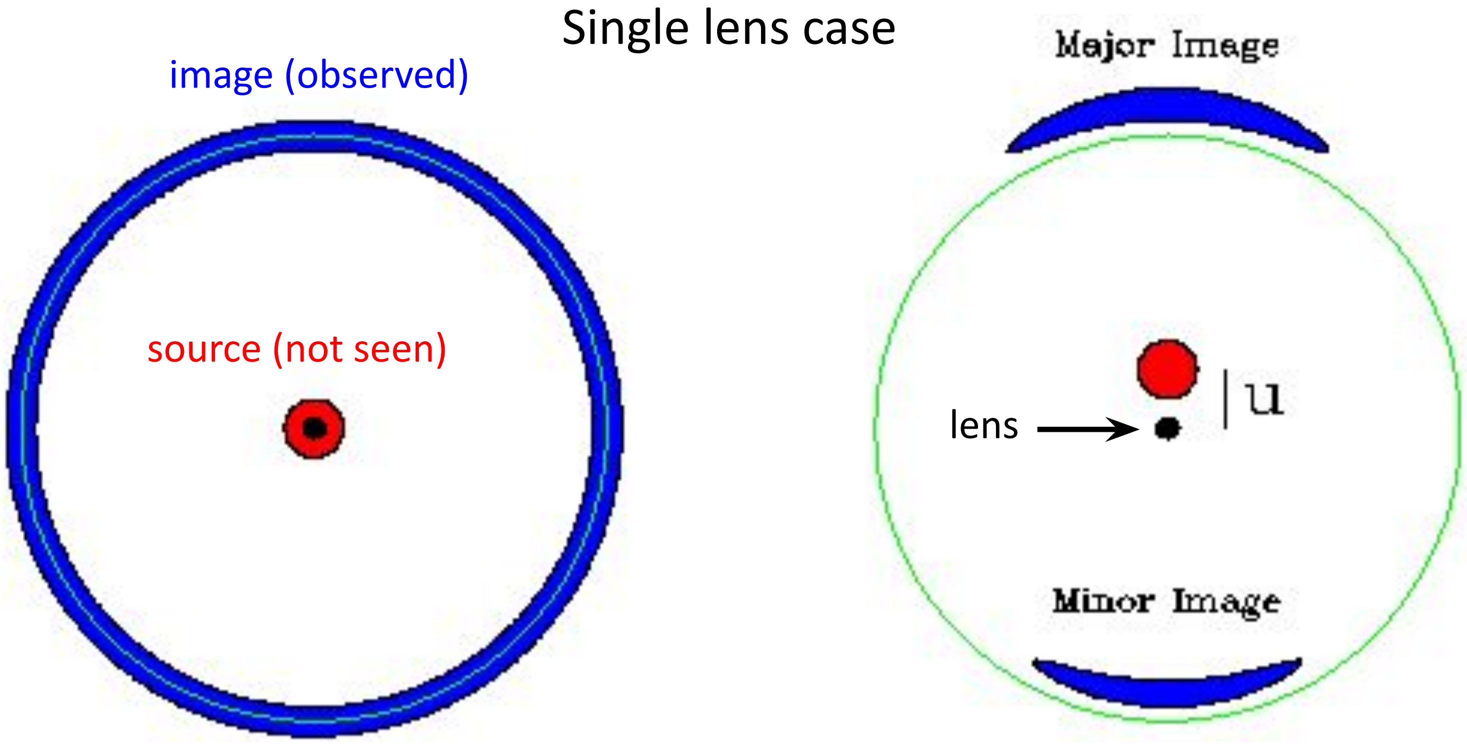


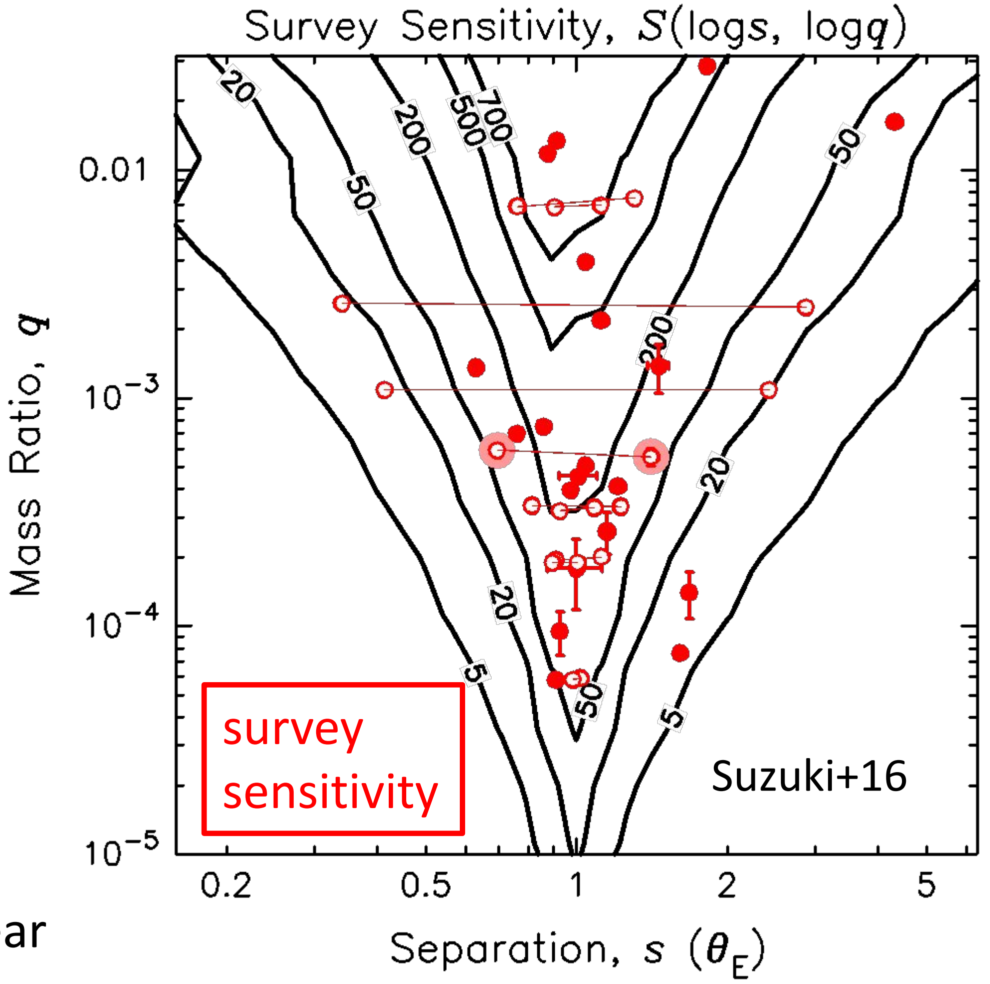
Microlensing Target Fields are in the Galactic Bulge



100s of millions of stars in the Galactic bulge in order to detect planetary companions to stars in the Galactic disk and bulge.

Einstein Ring and Lensed Images (Einstein 1936)

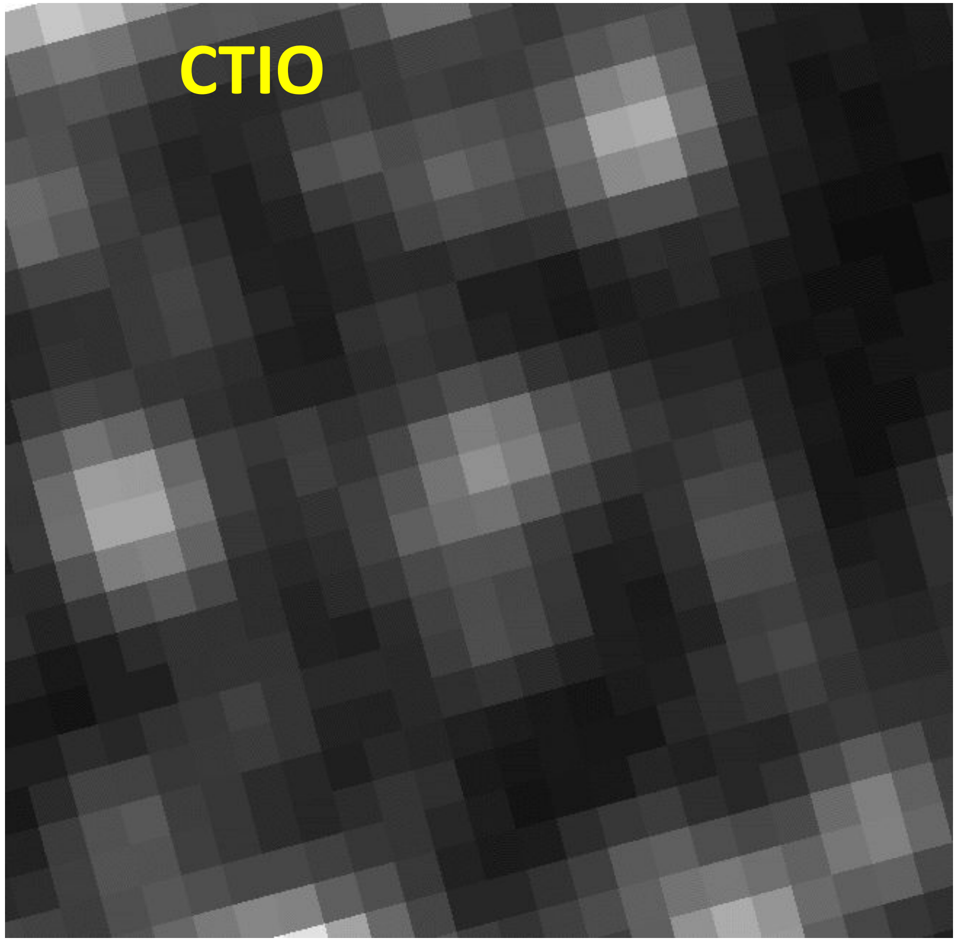


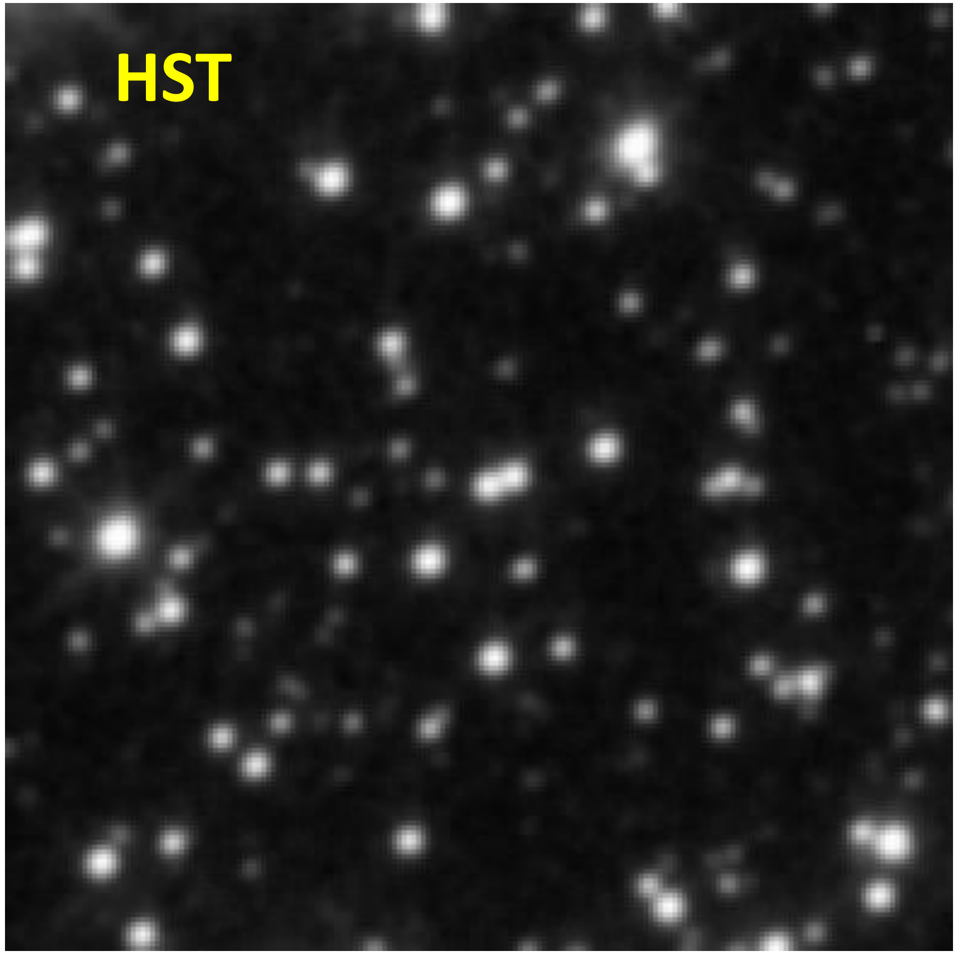


Microlensing is most sensitive to planets at projected separations near the Einstein Ring, which is typically 2-3 AU for source stars in the Galactic bulge (Gould & Loeb 1992).

Ground-based sensitivity to low mass planets is limited to planets near the Einstein ring.

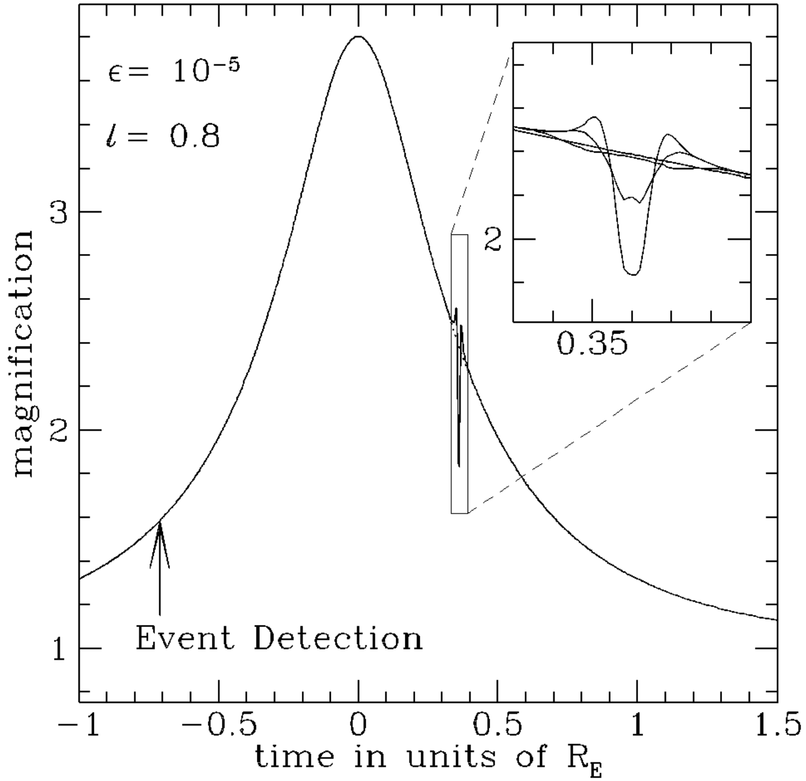
Ground-based Confusion, Space-based Resolution

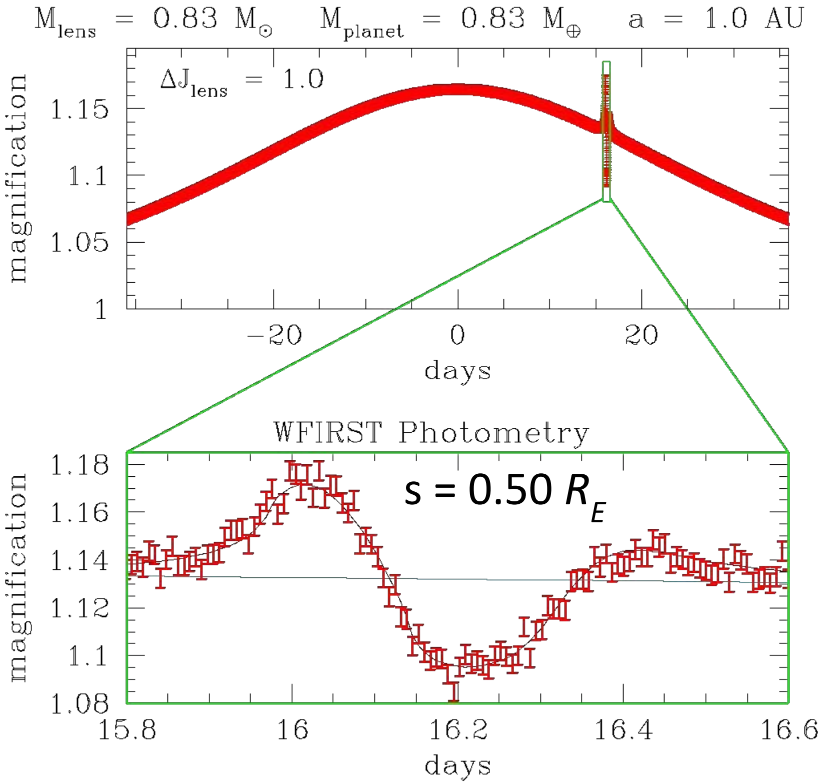


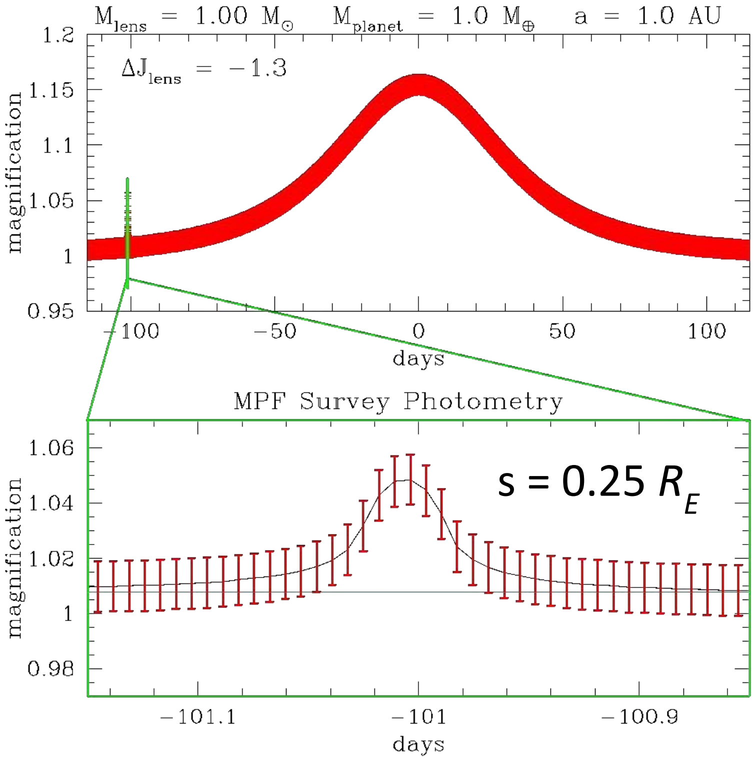


- With space-based imaging, most bulge stars are resolved.
- Blending of stellar images prevents the detection of planetary signals at low magnification for main sequence source stars

A Space-Based Microlensing Survey is Needed



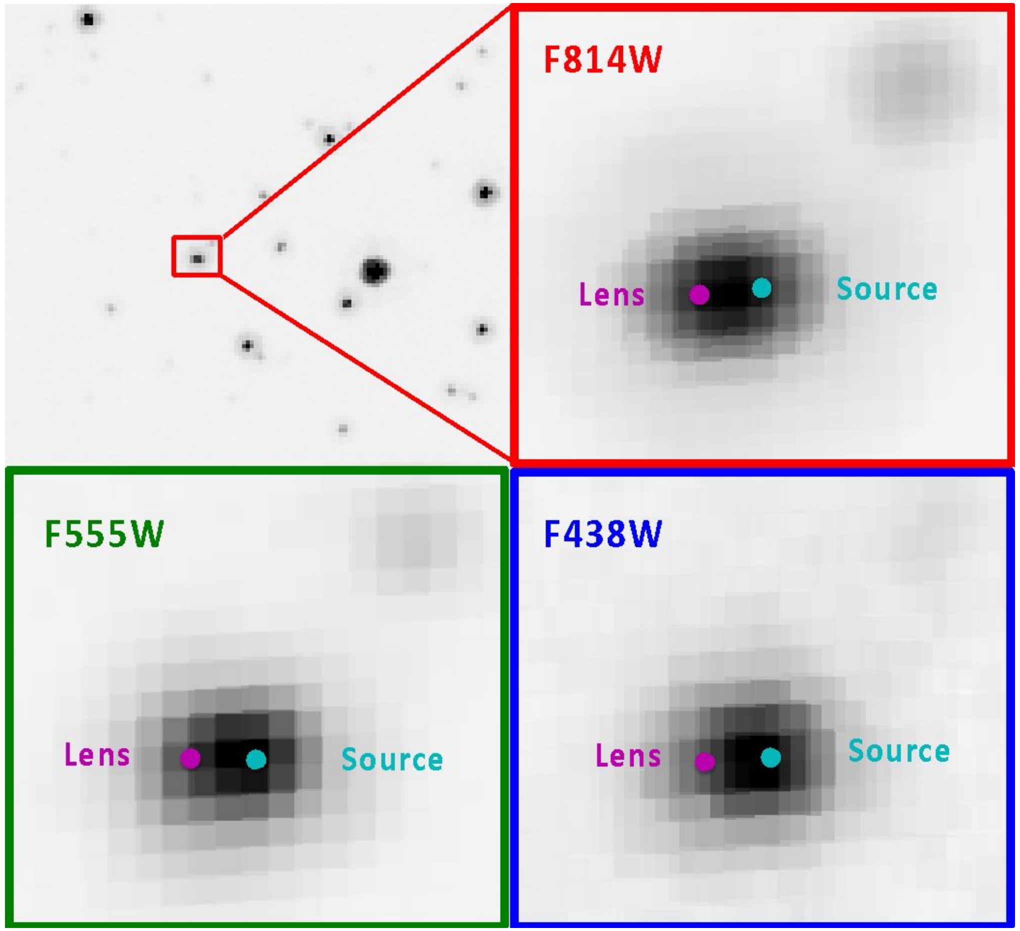




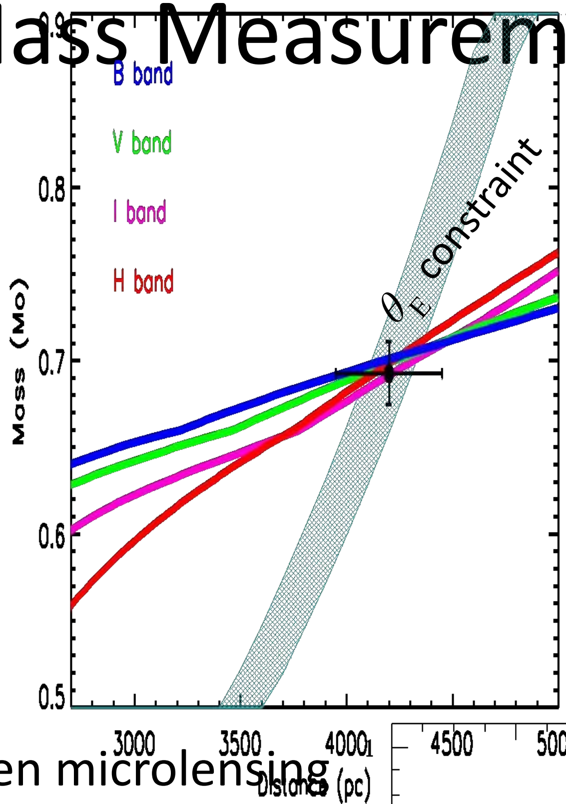
Bennett & Rhie (1996) show that Earth-mass planetary signals inside the Einstein ring are washed out by finite source effects for giant source stars.

To find low-mass planets at a wide range of separations including near the Habitable Zone, Bennett & Rhie (2002) propose the Galactic Exoplanet Survey Telescope (GEST) in 2000 and 2001. **The 2001 GEST proposal was the first combined exoplanet microlensing and dark energy mission.**

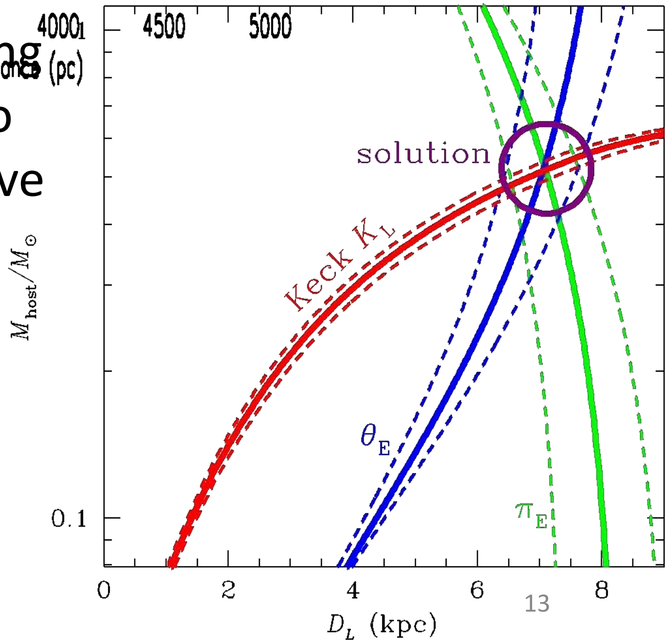
Space-Based Microlensing Enables Mass Measurements



Event OGLE-2005-BLG-169

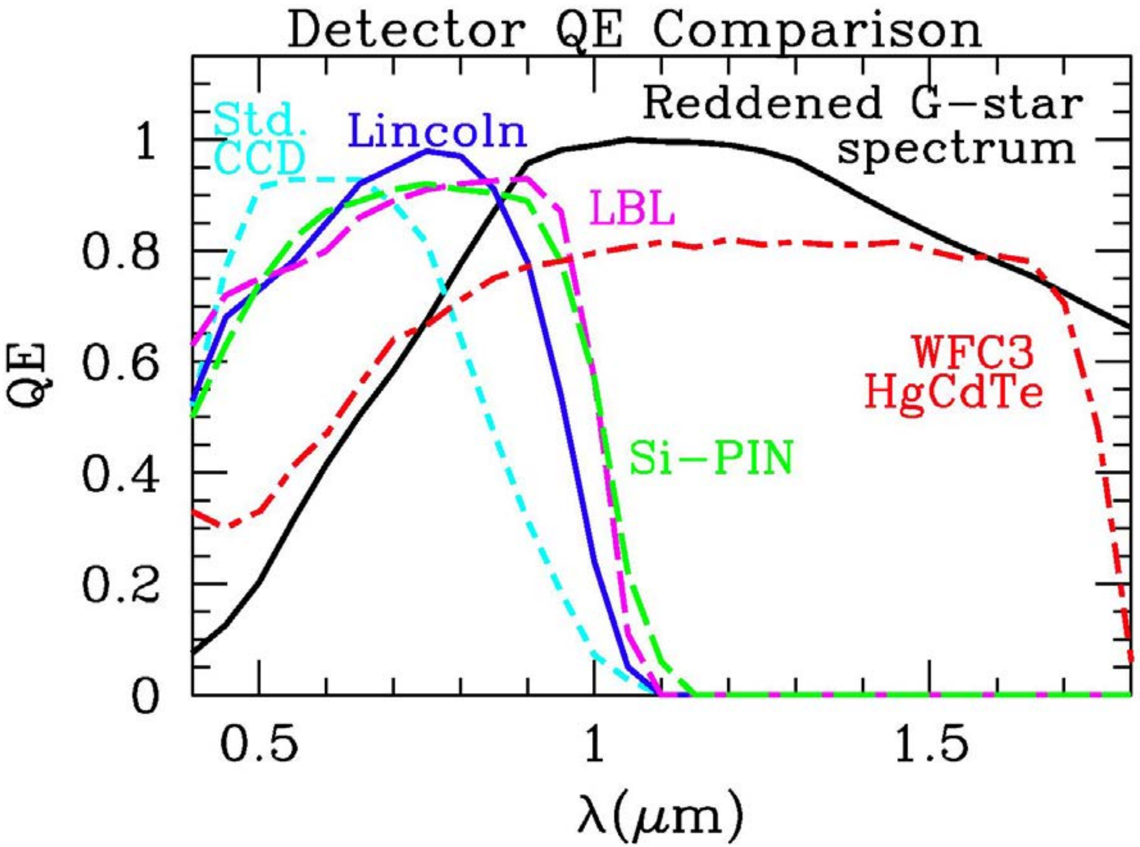


When microlensing parallax, π_E, is also measured, we have redundant constraints.

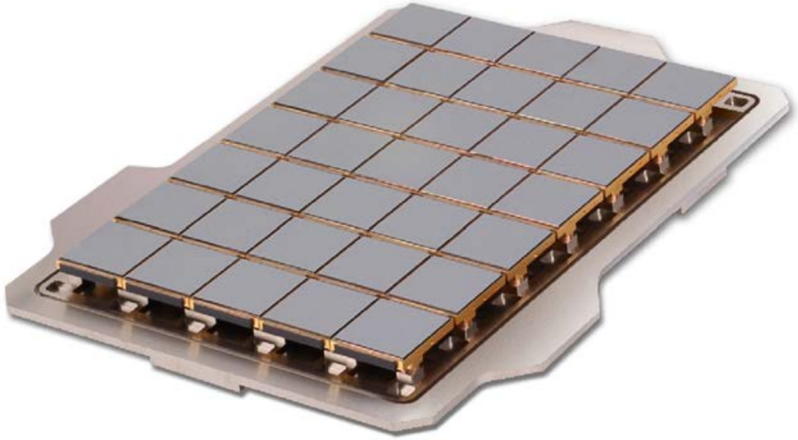


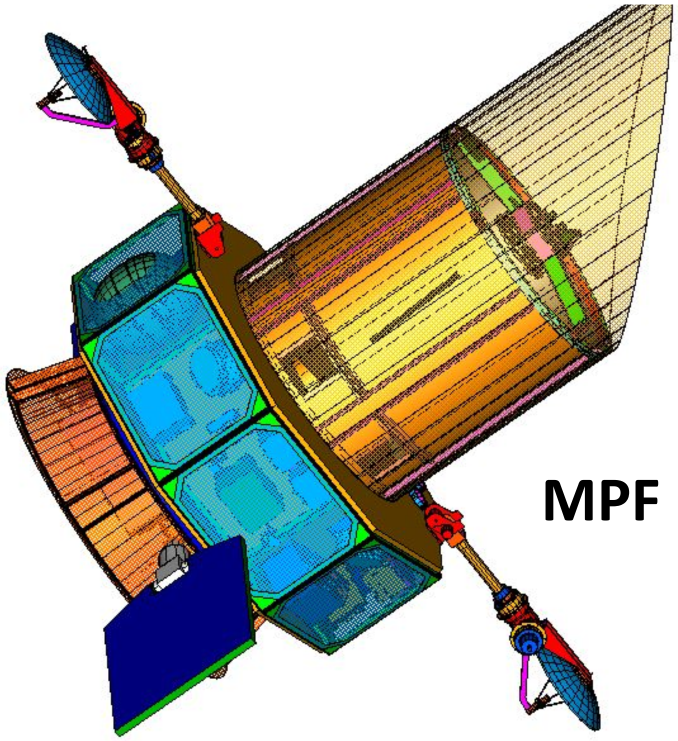
High resolution imaging allows measurement of host star brightness and lens-source relative proper motion, μ_{rel}, which gives the angular Einstein radius, θ_E, yielding the lens system mass and distance – See Aparna Bhattacharya's talk

An Infrared Survey is Better: **Microlensing Planet Finder**



Higher QE for reddened stars and flatter IR main sequence luminosity function give much higher detection rate for an IR survey. Proposed to Discovery Program in 2004 and 2006, and then to Decadal Survey in 2010.





Outstanding Issues as of 2016: for SIT to investigate

- 2.4m “AFTA” primary selected
- Microlensing rate unmeasured in the Infrared
- Realistic survey simulations needed to optimize survey, for trade studies and observing proposal preparation.
- Mass measurements via host star detection and brightness measurements
  - Only one example prior to 2016
  - Does it affect choice of fields and color filters?
- How do detector features and defects affect sensitivity?
- How to broaden the exoplanet microlensing community and workforce?
- How design data reduction and analysis pipeline?
  - Photometry + Astrometry pipeline
  - Light curve analysis pipeline