WFIRST-AFTA

(Wide Field Infrared Survey Telescope - Astrophysics Focused Telescope Assets)

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SCIENCE DEFINITION TEAM

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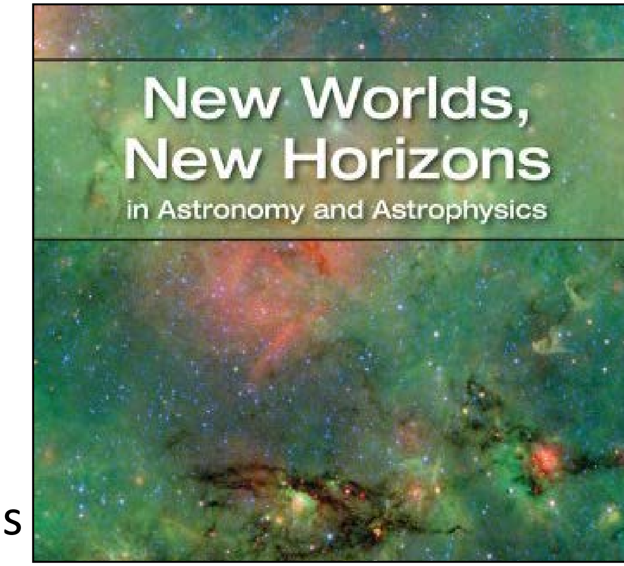
WFIRST-AFTA

Double #1 Decadal Survey Rank



- The US prioritizes its large space and ground-based astronomy programs through Decadal Surveys
  - 2010 Version: New Worlds, New Horizons
  - Considered a model for other science fields
- #1 Large Space Mission: Wide Field Infrared Space Telescope (WFIRST)
- #1 Medium Space Mission: New Worlds Technology Development Program
- Enabled by the gift of 2.4m space telescope optics from the [redacted] (redacted)

WFIRST-AFTA Instruments

Wide-Field Instrument

- *Imaging & spectroscopy over 1000s sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

Coronagraph (option now baselined)

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- 10^{-9} contrast
- 100 milliarcsec inner working angle at 400 nm

Requires tech. development ASAP for early 2020s launch

WFIRST-AFTA Exoplanet Science

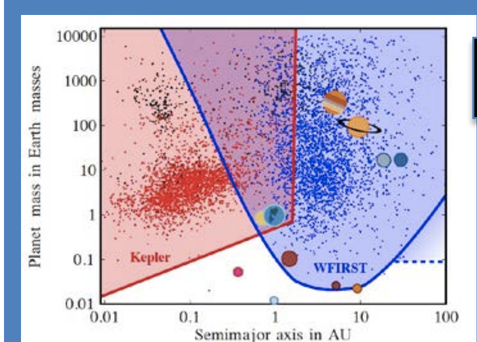
The combination of microlensing and direct imaging will dramatically expand our knowledge of other solar systems and will provide a first glimpse at the planetary families of our nearest neighbor stars.

Microlensing Survey

Monitor 200 million Galactic bulge stars every 15 minutes for 1.2 years

2800 cold exoplanets
300 Earth-mass planets
40 Mars-mass or smaller planets
40 free-floating Earth-mass planets

Complete the Exoplanet Census

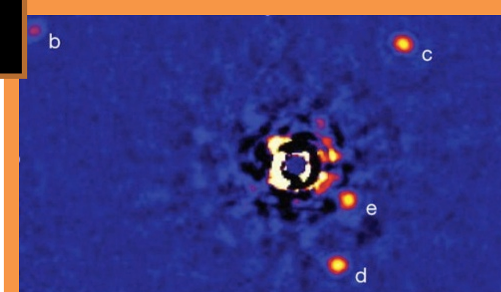


High Contrast Imaging

Survey up to 200 nearby stars for planets and debris disks at contrast levels of 10^{-9} on angular scales > 0.2"
R=70 spectra and polarization between 400-1000 nm

Detailed characterization of up to a dozen giant planets.
Discovery and characterization of several Neptunes
Detection of massive debris disks.

Discover and Characterize Nearby Worlds



- How diverse are planetary systems?
- How do circumstellar disks evolve and form planetary systems?
- Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?

Toward the "Pale Blue Dot"

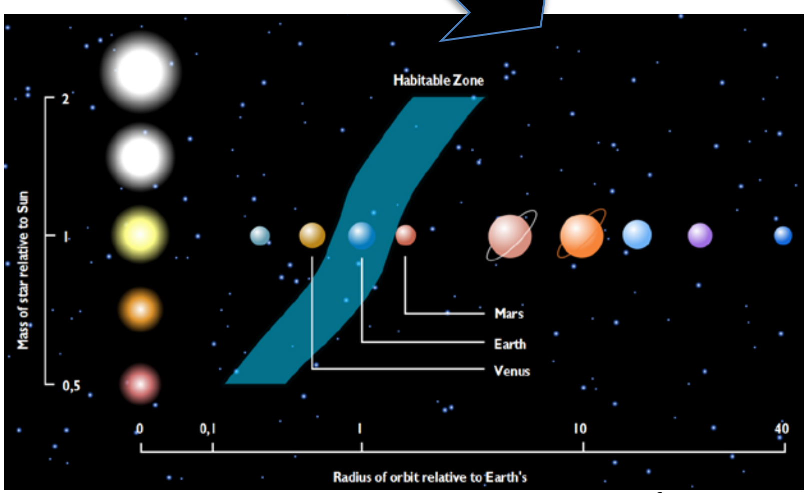
AFTA will lay the foundation for a future flagship direct imaging mission capable of detection and characterization of Earthlike planets.

Microlensing Survey

- Inventory the outer parts of planetary systems, potentially the source of the water for habitable planets.
- Quantify the frequency of solar systems like our own.
- Confirm and improve Kepler's estimate of the frequency of potentially habitable planets.
- When combined with Kepler, provide statistical constraints on the densities and heavy atmospheres of potentially habitable planets.

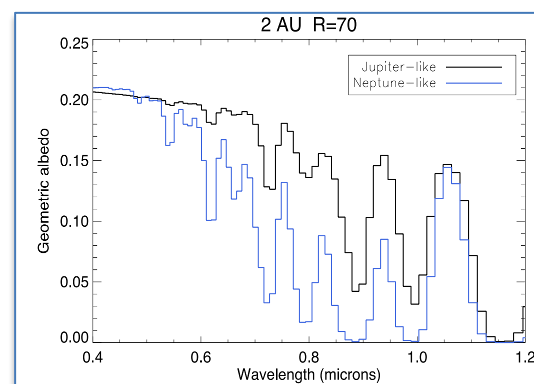
High Contrast Imaging

- Provide direct images of planets around our nearest neighbors similar to our own giant planets.
- Provide important insights about the physics of planetary atmospheres through comparative planetology.
- Assay the population of massive debris disks that will serve as sources of noise and confusion for a flagship mission.
- Develop crucial technologies for a future mission, and provide practical demonstration of these technologies *in flight.*

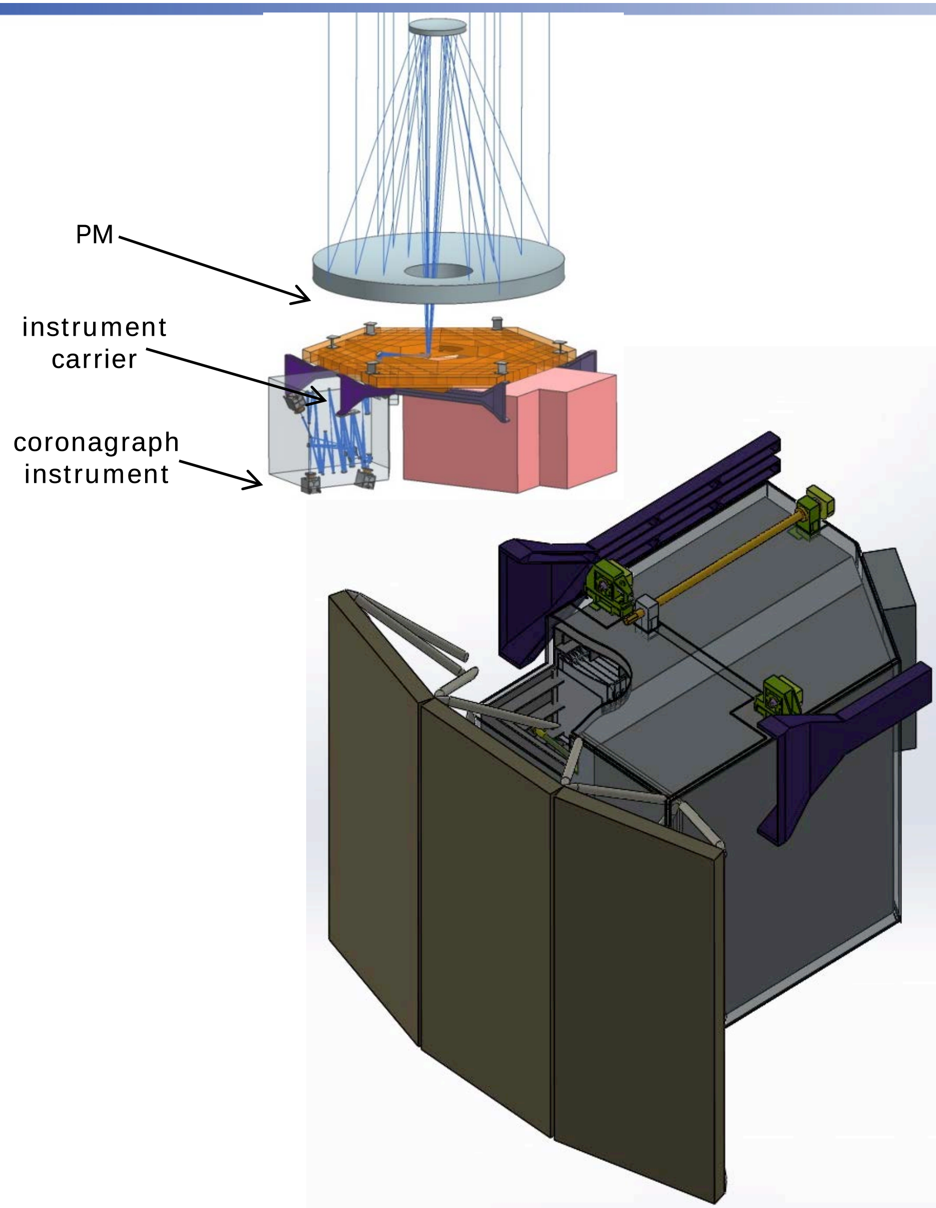


Courtesy of Jim Kasting.

Science and technology foundation for the New Worlds Mission.



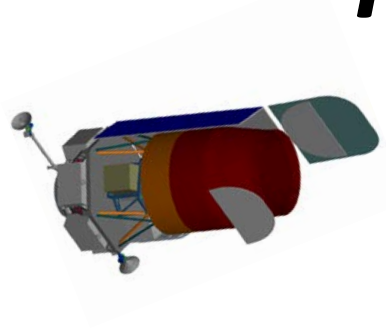
Coronagraph Instrument



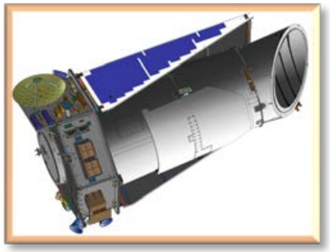
Mass (w/ contingency)	~178kg
Power (w/ contingency)	~215W
Temperature	20C for instrument
Temperature	~150k for cameras
Data volume	~30 Gbits/day
Orbit	GEO synchronous
Mission duration	6 years (with ~1 year for coronagraph)
Imaging	0.4 – 1.0 microns,4.8" FoV 0.009" pixel scale, 1kX1K EMCCD
Integral field spectrograph	0.6 – 1.0 microns R~70

Paper 9143-25 "WFIRST-AFTA coronagraph design update", Goullioud, et al

Exoplanet Microlensing Survey

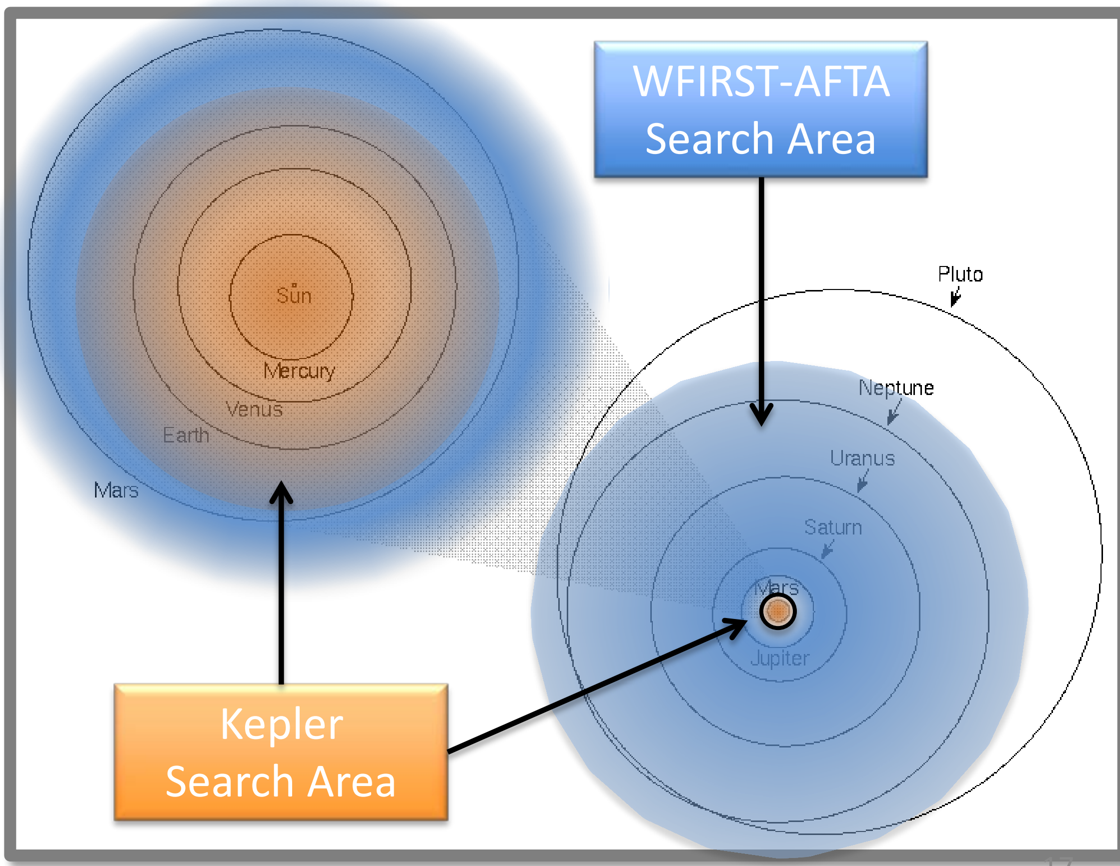


Together, Kepler and WFIRST-AFTA complete the statistical census of planetary systems in the Galaxy.

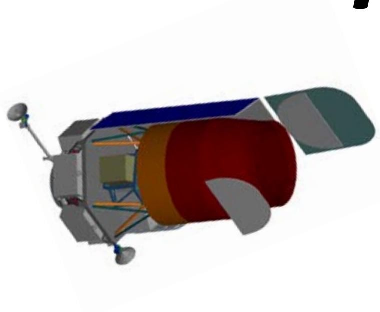


AFTA will:

- Detect 2800 planets, with orbits from the habitable zone outward, and masses down to a few times the mass of the Moon.
- Be sensitive to analogs of all the solar system's planets except Mercury.
- Measure the abundance of free-floating planets in the Galaxy with masses down to the mass of Mars



Exoplanet Microlensing Survey



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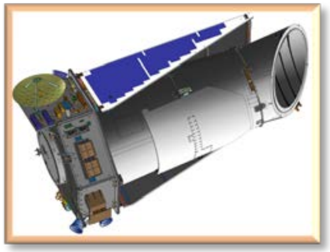

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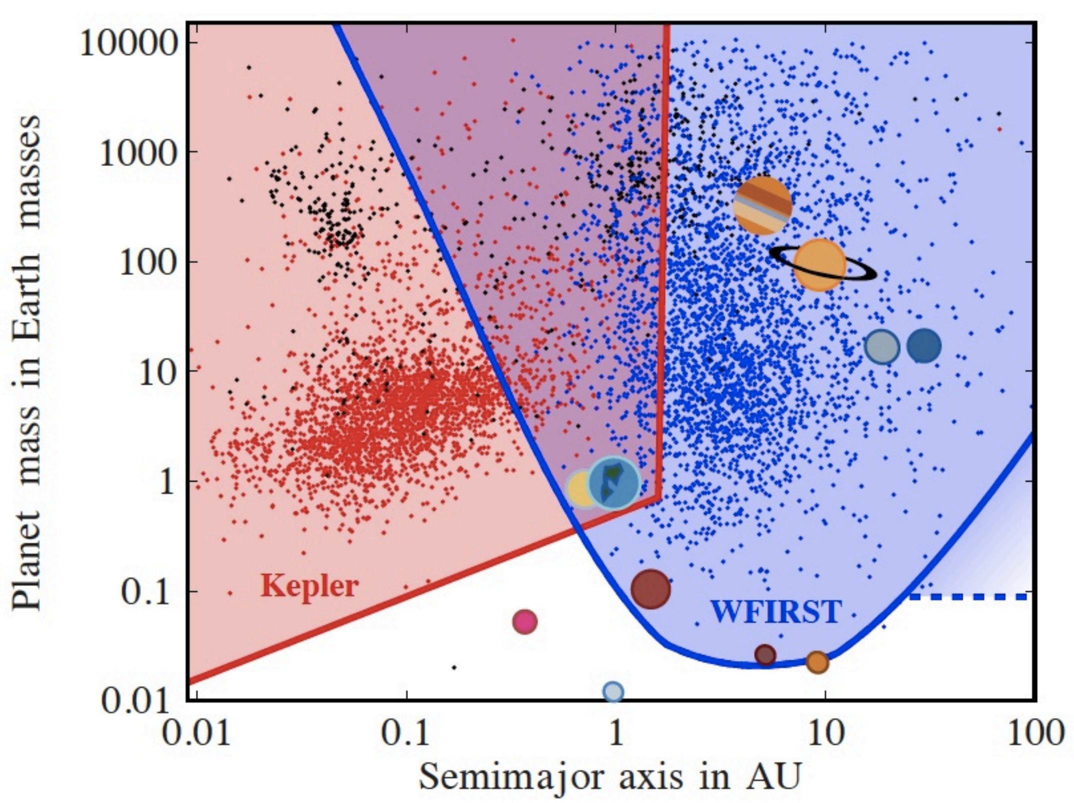
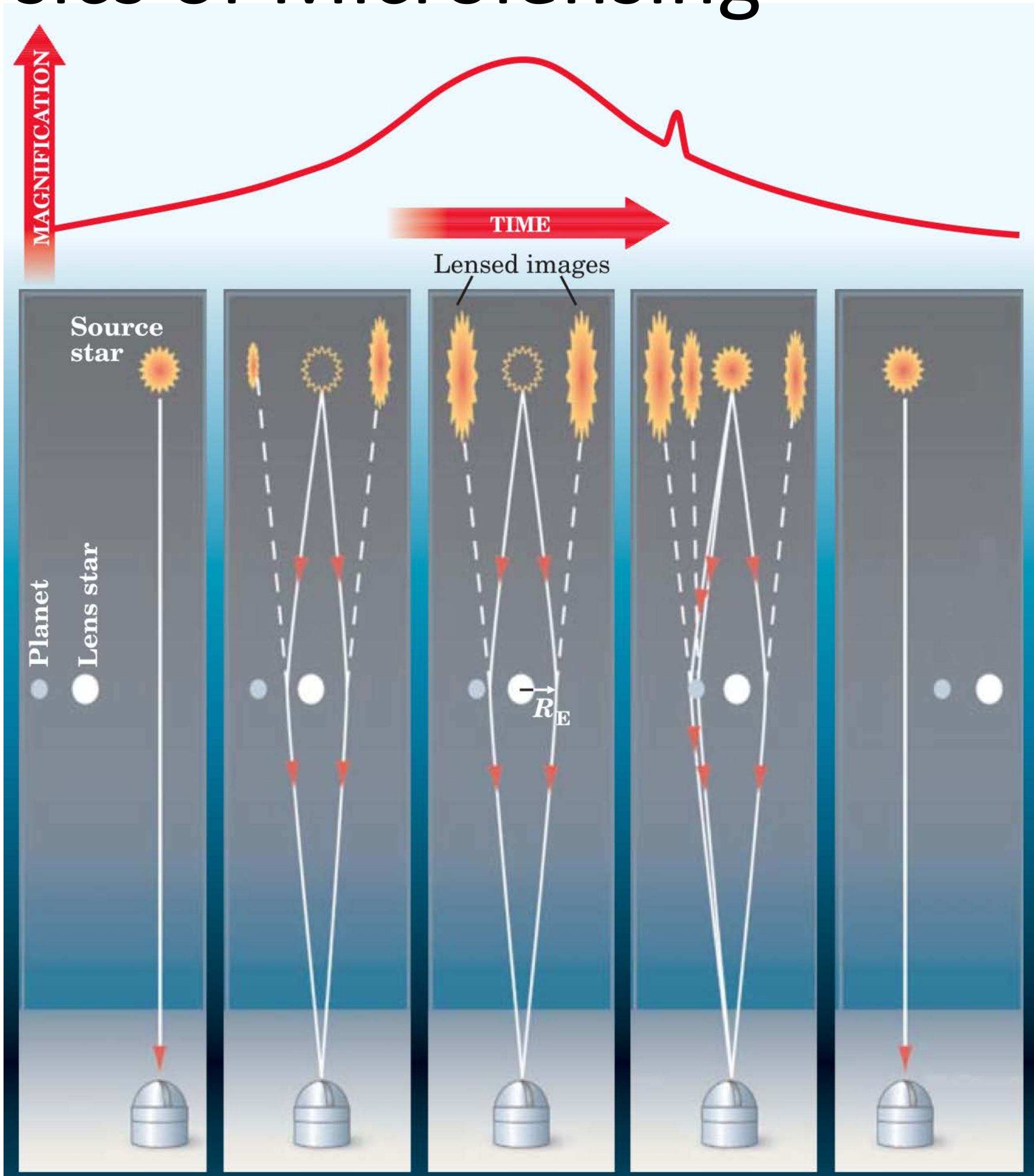
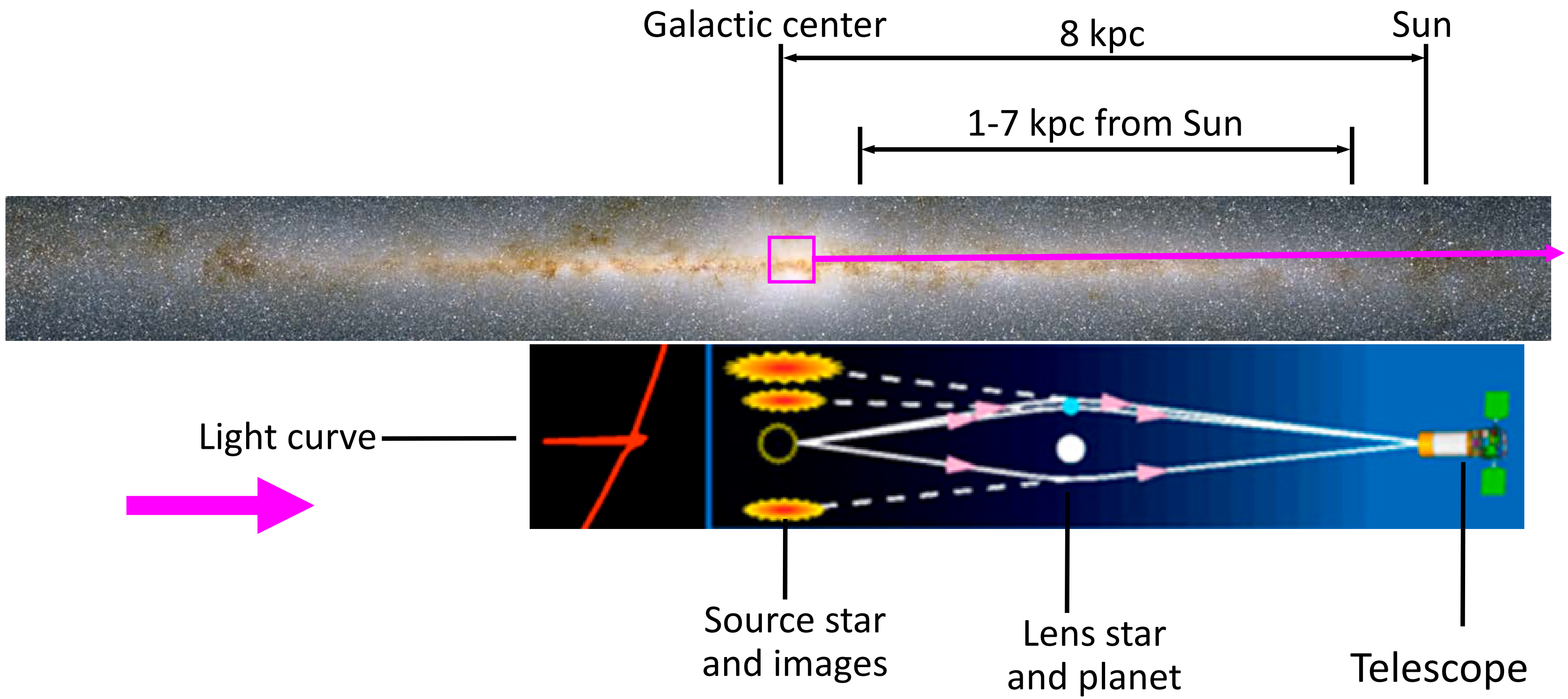


The Physics of Microlensing

- 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

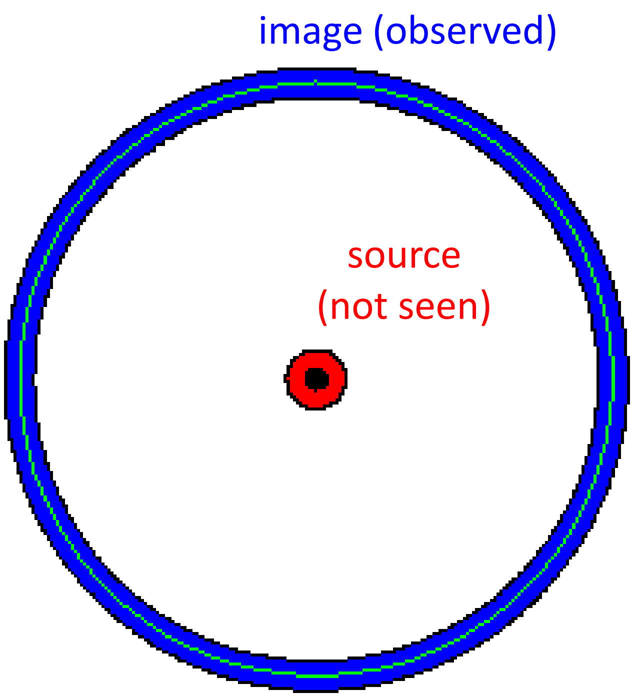


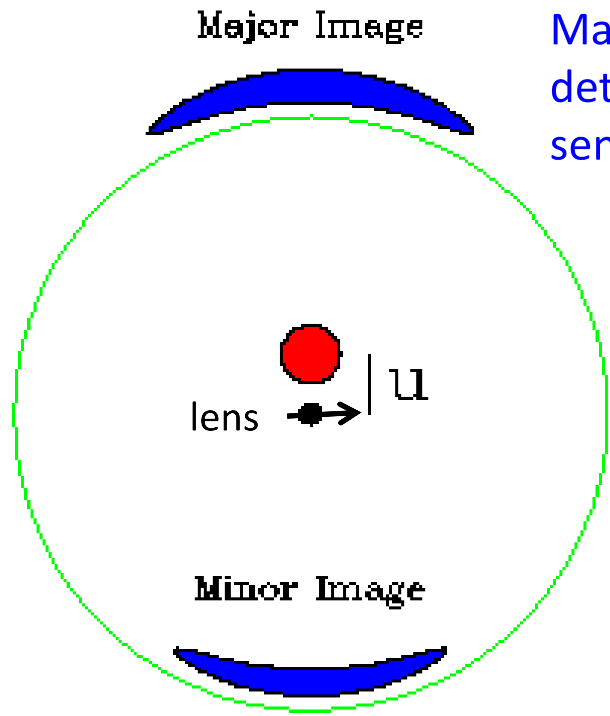
Microlensing Target Fields are in the Galactic Bulge



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

Lensed Images (Einstein 1936)





Maximum planet detection sensitivity at $R \sim R_E$

When source is distant, we see distorted, magnified images. If the alignment is perfect, we see an “Einstein Ring”. The Einstein Ring radius is

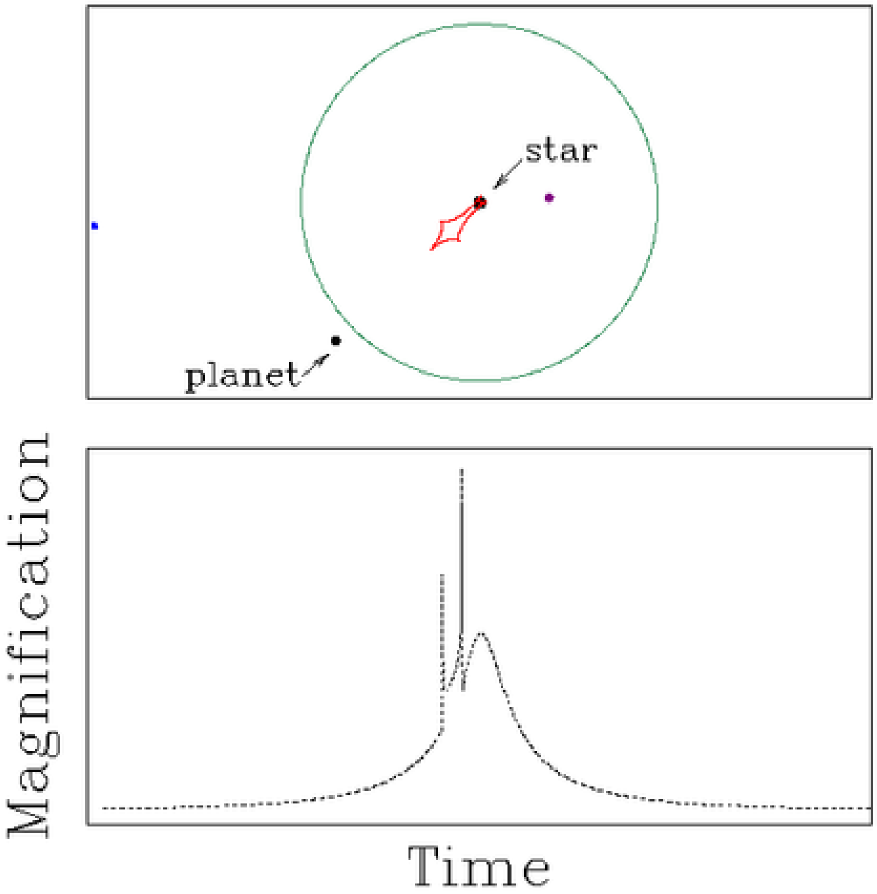
$$R_E = 2\sqrt{GMD_L(D_S - D_L)/(D_S c^2)}$$

- roughly the geometric mean of the lens distance and Schwartzschild radius ~ a few AU

Lensed images at μarcsec resolution

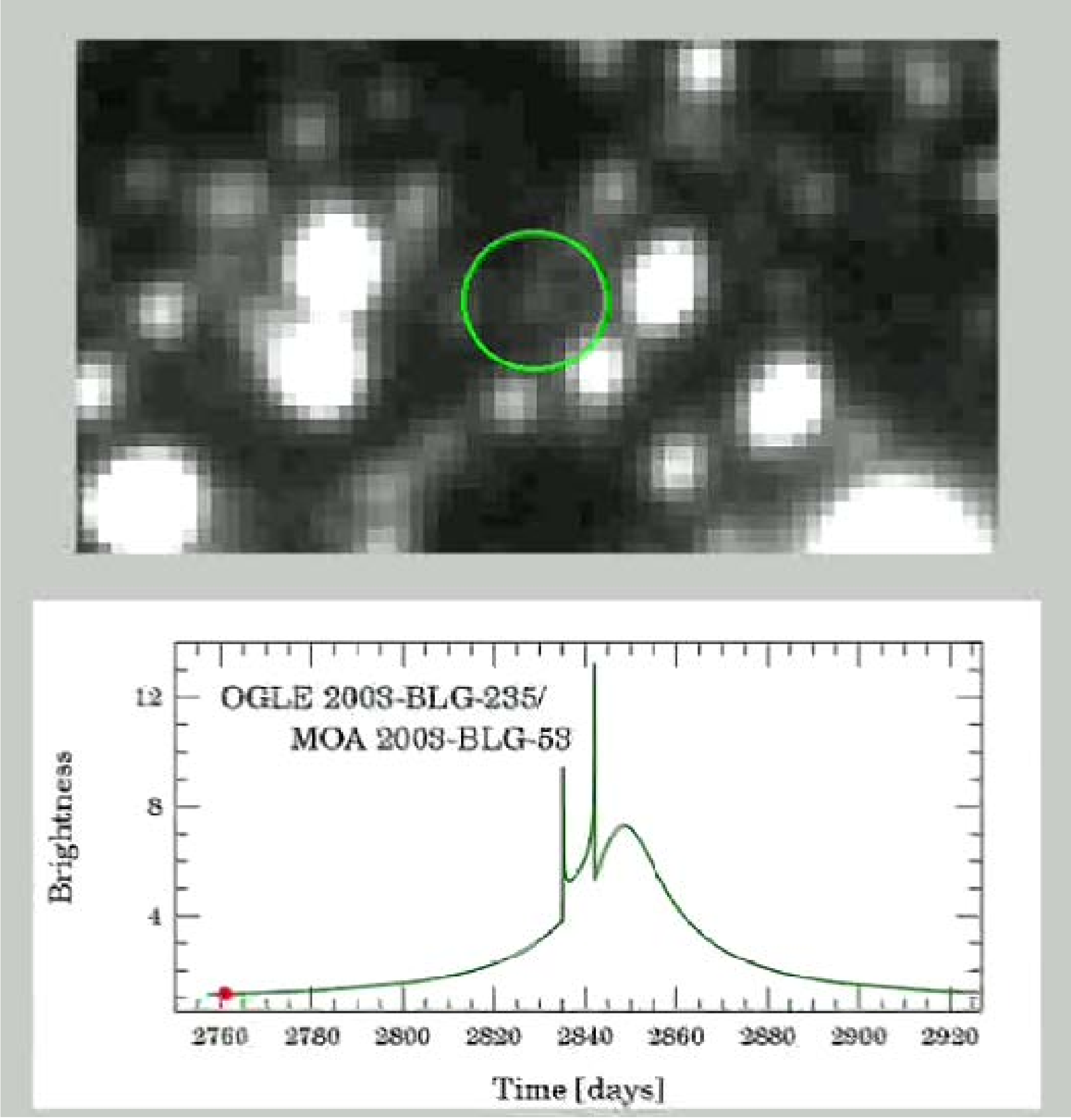
View from telescope

A planet can be discovered when one of the lensed images approaches its projected position.



Simulated Lightcurve of 1st Planetary Event

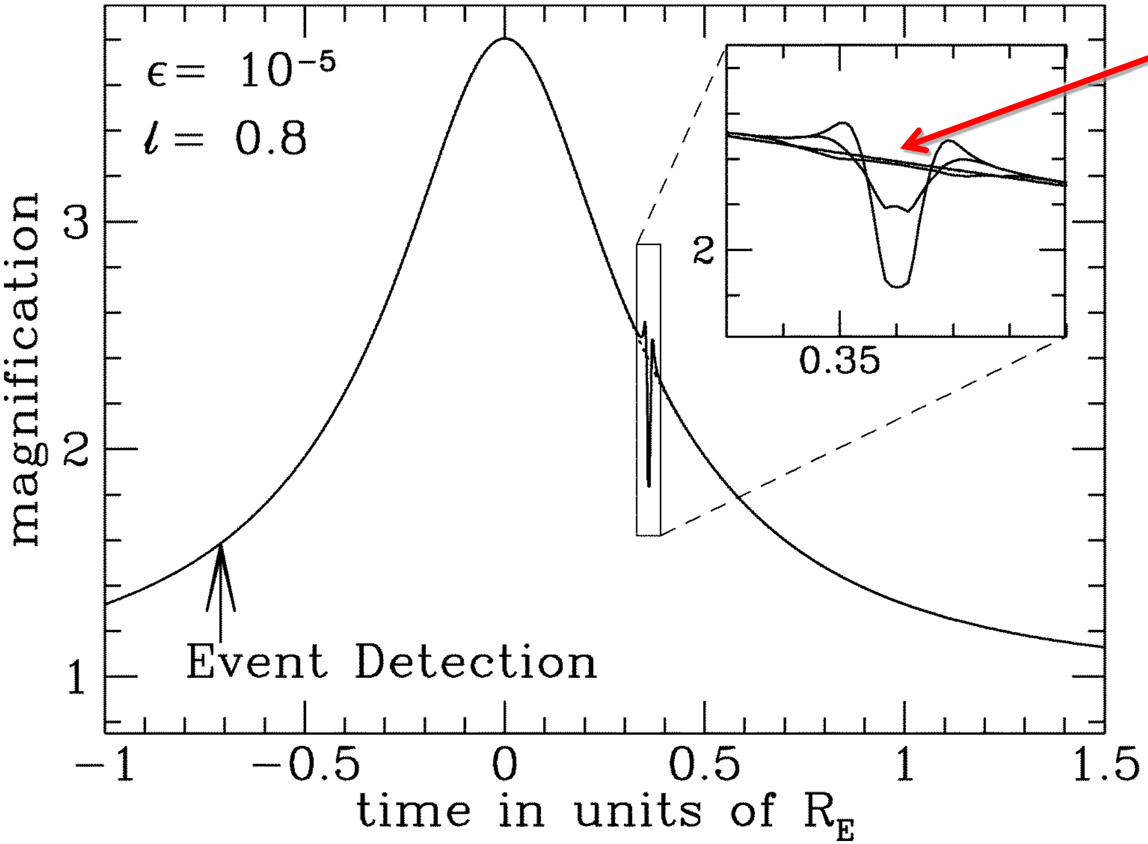
Simulated version of actual data



Best fit light curve simulated on an OGLE image

How Low Can We Go?

No signal for giant sources



(Bennett & Rhie 1996)

Limited by Source Size

angular Einstein radius

$$\theta_E \approx \mu\text{as}\left(\frac{M_p}{M_\oplus}\right)^{1/2}$$

$\updownarrow$

$$\theta_* \approx \mu\text{as}\left(\frac{R_*}{R_\odot}\right)$$

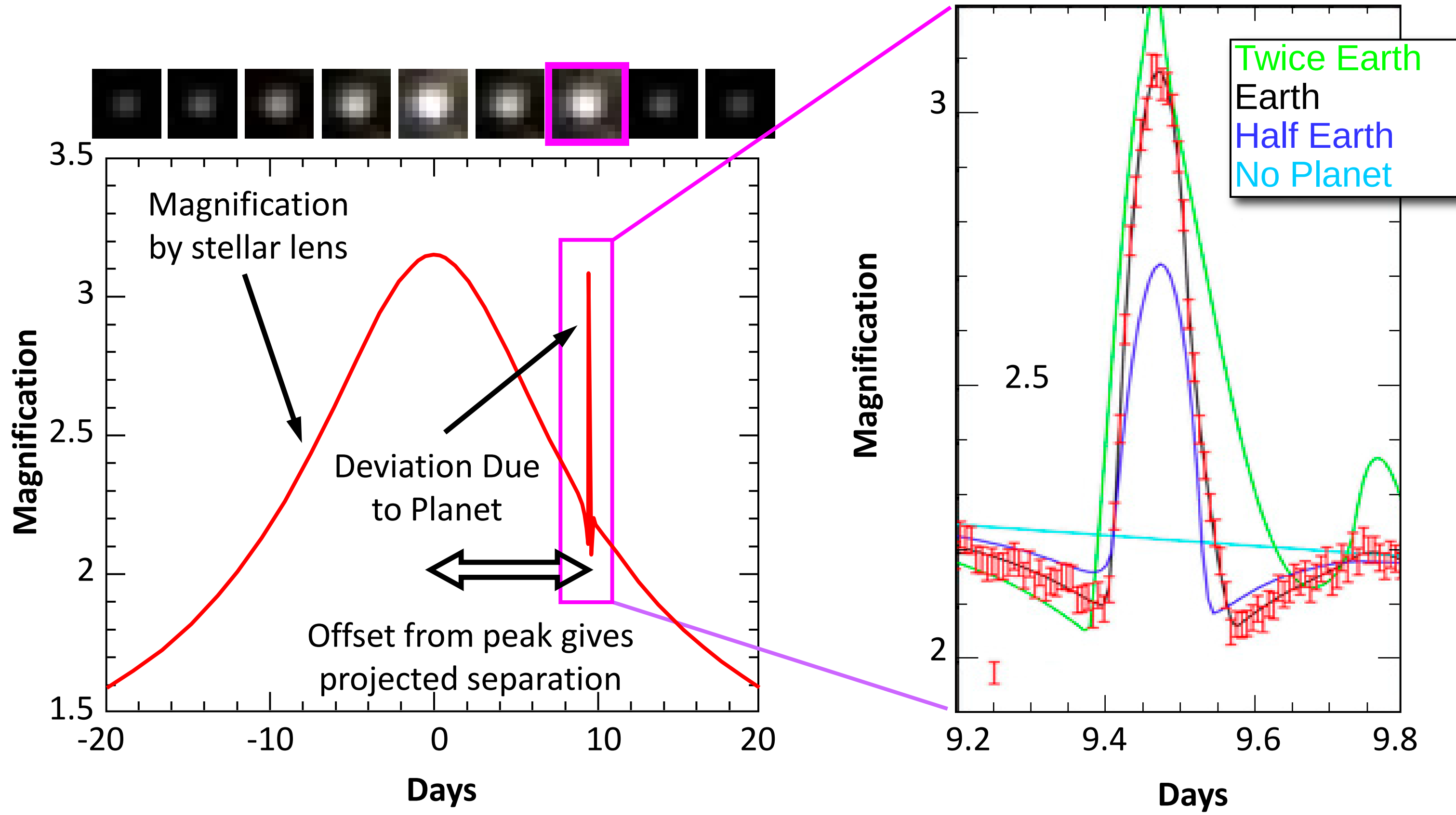
angular source star radius

For $\theta_E \geq \theta_*$:
low-mass planet signals are rare and brief, but not weak

Mars-mass planets detectable
if solar-type sources can be monitored!

Extraction of Exoplanet Light Curve Signal

Time-series photometry is combined to uncover light curves of background source stars being lensed by foreground stars in the disk and bulge.



Planets are revealed as short-duration deviations from the smooth, symmetric magnification of the source due to the primary star.

Detailed fitting to the photometry yields the parameters of the detected planets.

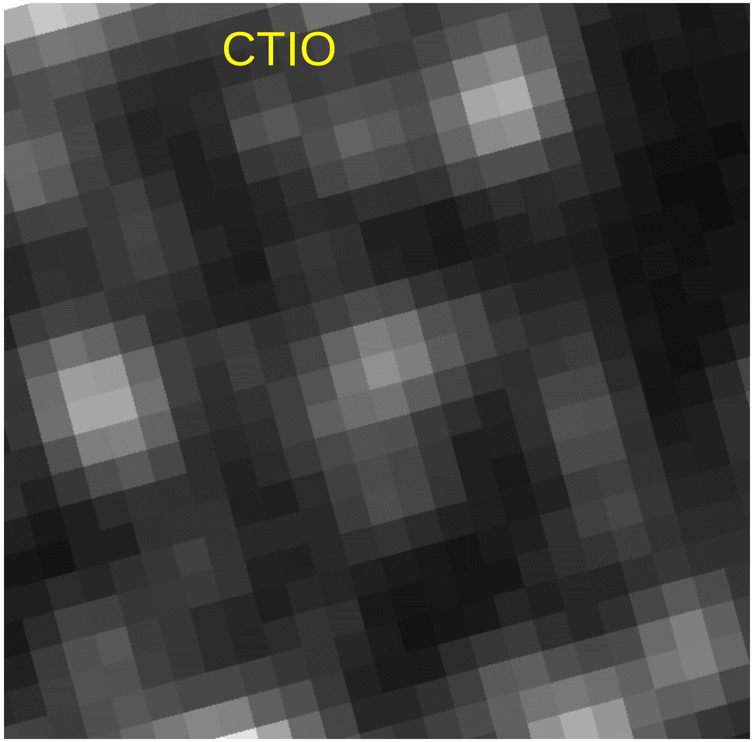
Finite Source Effects & Microlensing Mass Distance Relation

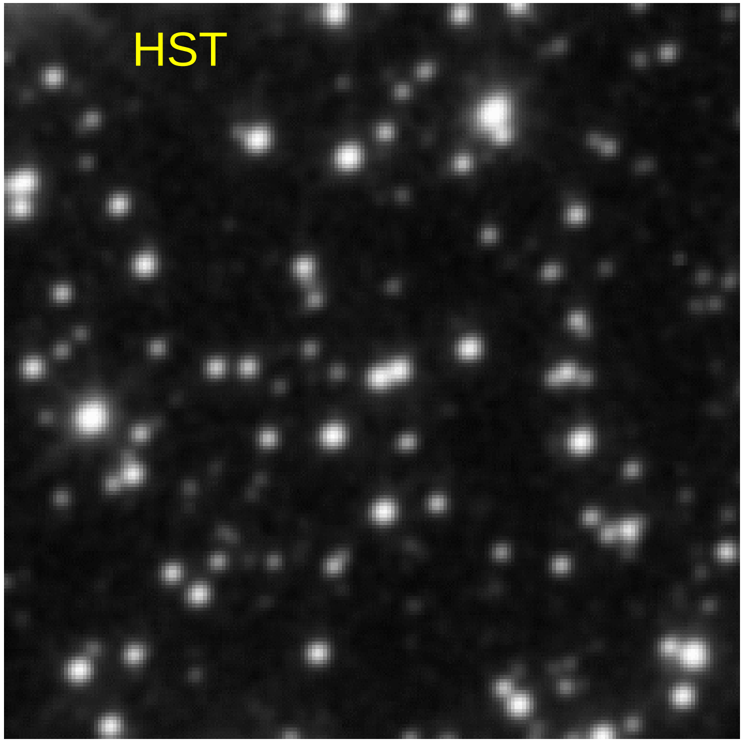
- The angular Einstein radius, $\theta_E = \theta_* t_E / t_*$, is measured for almost all planetary events
- θ_E yields a mass-distance relation
- Combine with a mass-luminosity relation to get host star masses

mass-distance relation:

$$M_L = \frac{c^2}{4G} \theta_E^2 \frac{D_S D_L}{D_S - D_L}$$

Ground-based confusion, space-based resolution

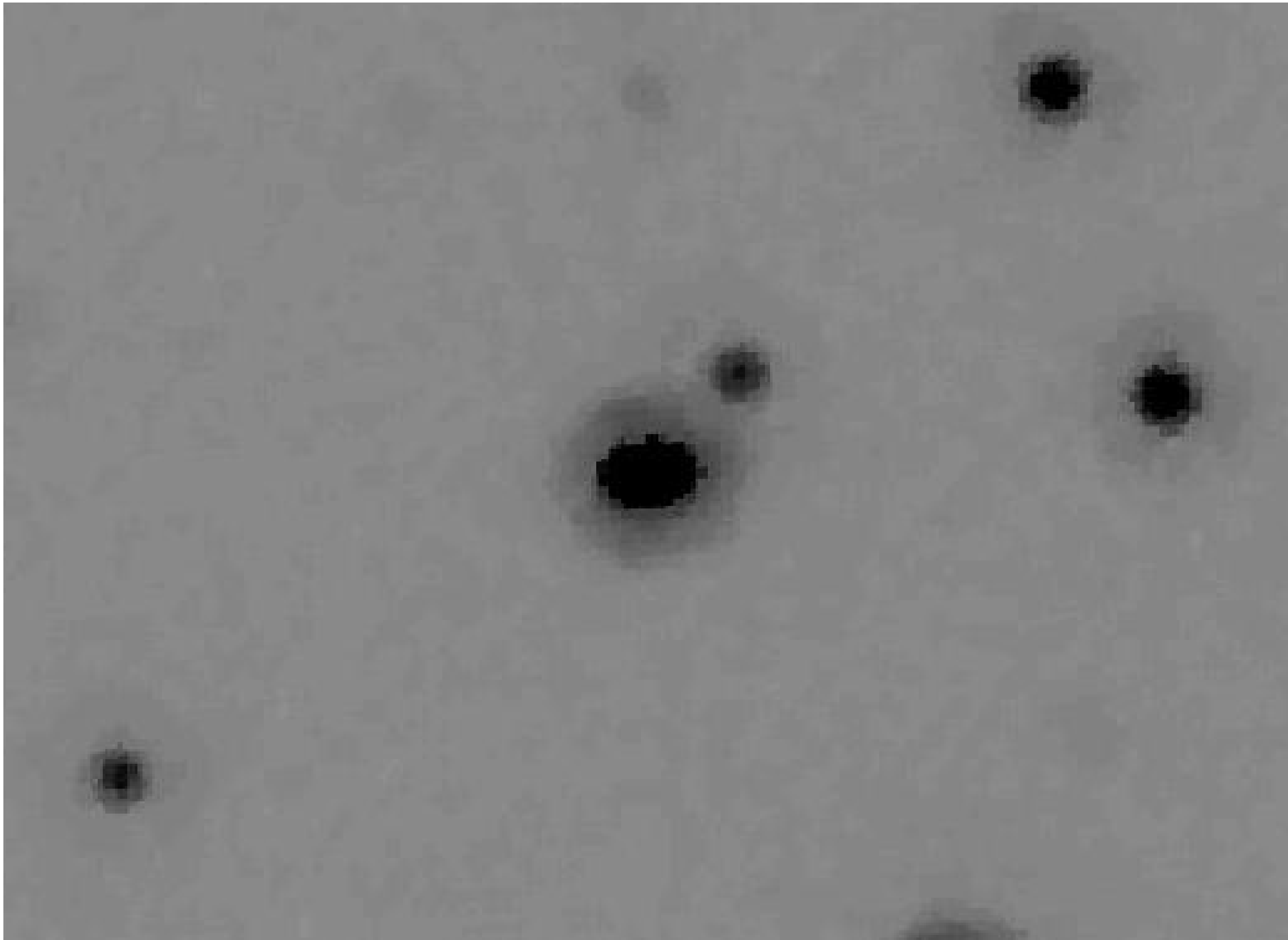




- Prime targets for low-mass planets are main sequence stars, which are not resolved from the ground
- With space-based imaging, most bulge stars are resolved.
- WFIRST-AFTA will detect and measure masses for more host stars

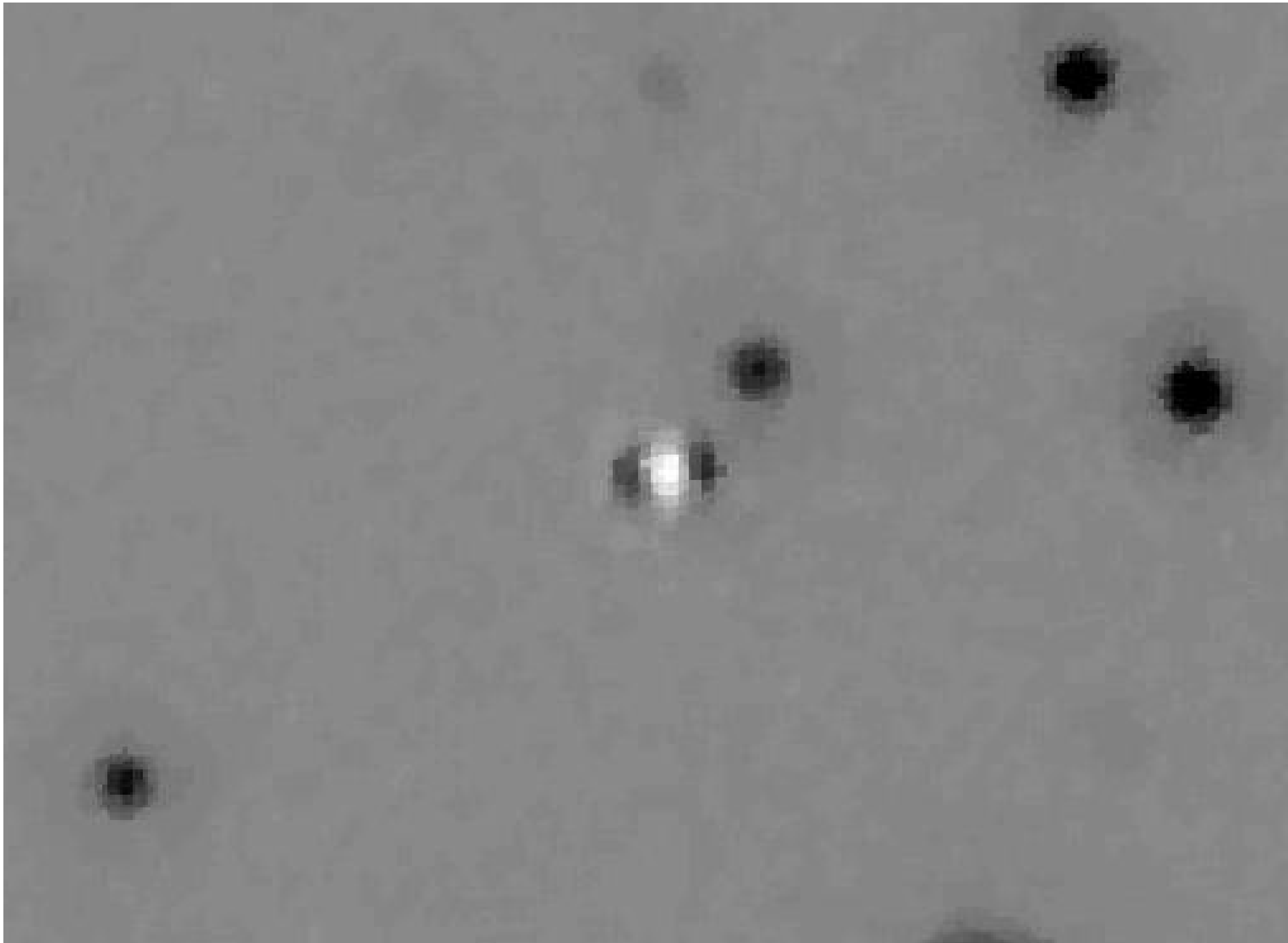
Stacked HST I-band Image of OGLE-2005-BLG-169 Source

Source *looks* elongated relative to neighbors



PSF for a Single Star Subtracted

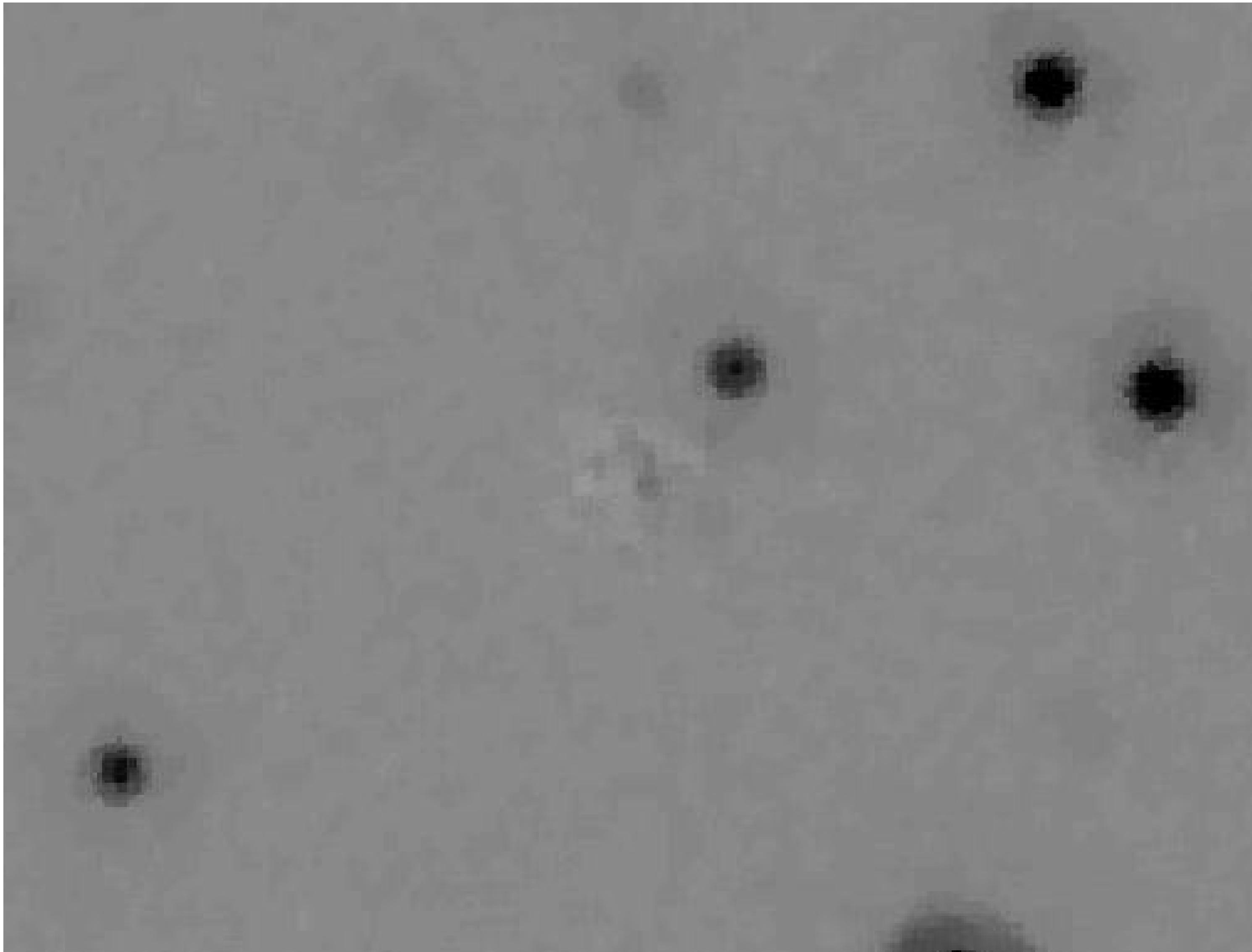
Residuals in X when we subtract a PSF from each image and stack…



Fit and Subtract Two Stars: Source & Lens

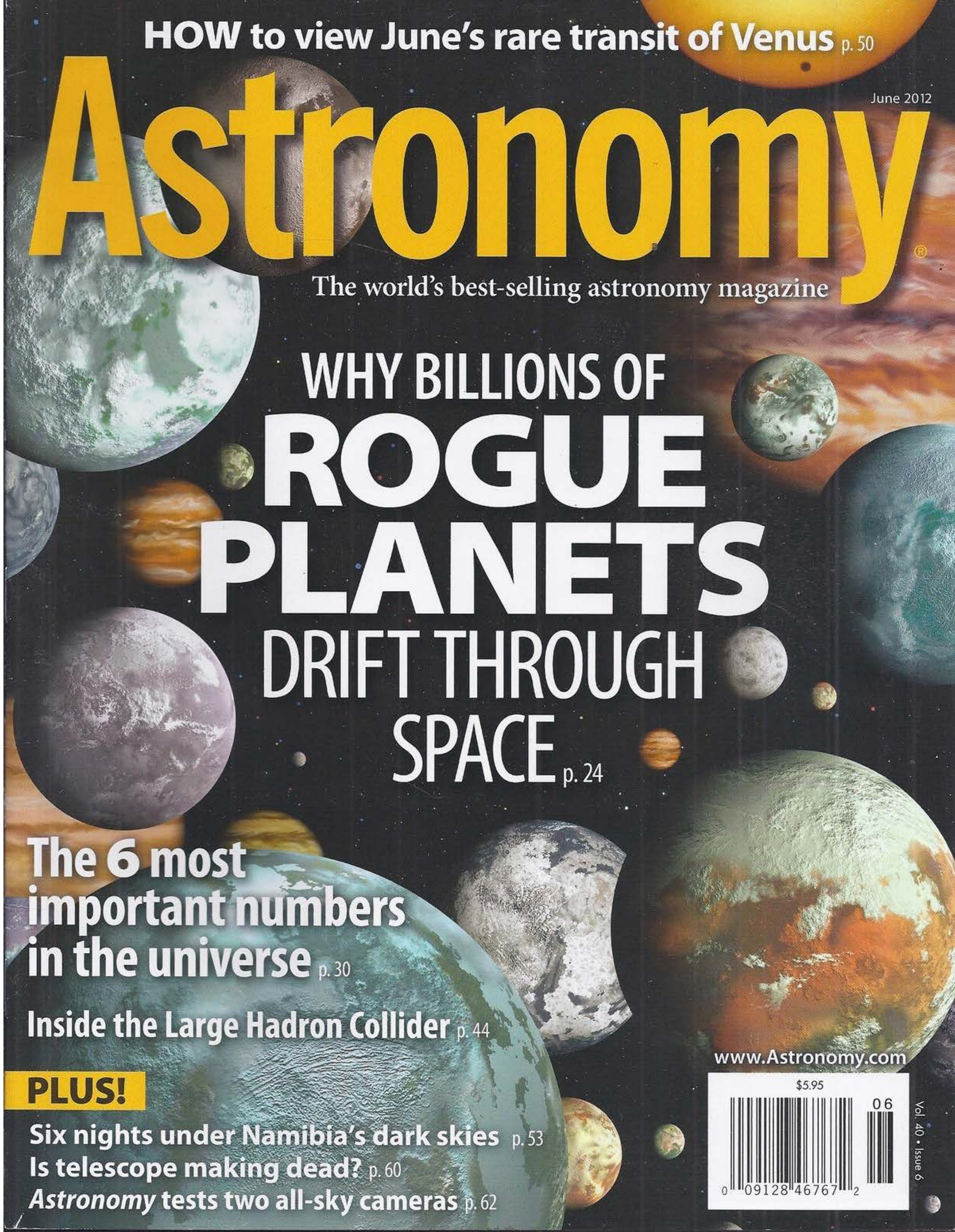
Very good subtraction residuals when we fit for *two* sources

Lens brightness gives its mass



Rogue Planet Population

Sumi et al. (2011)
Nature, 473, 349

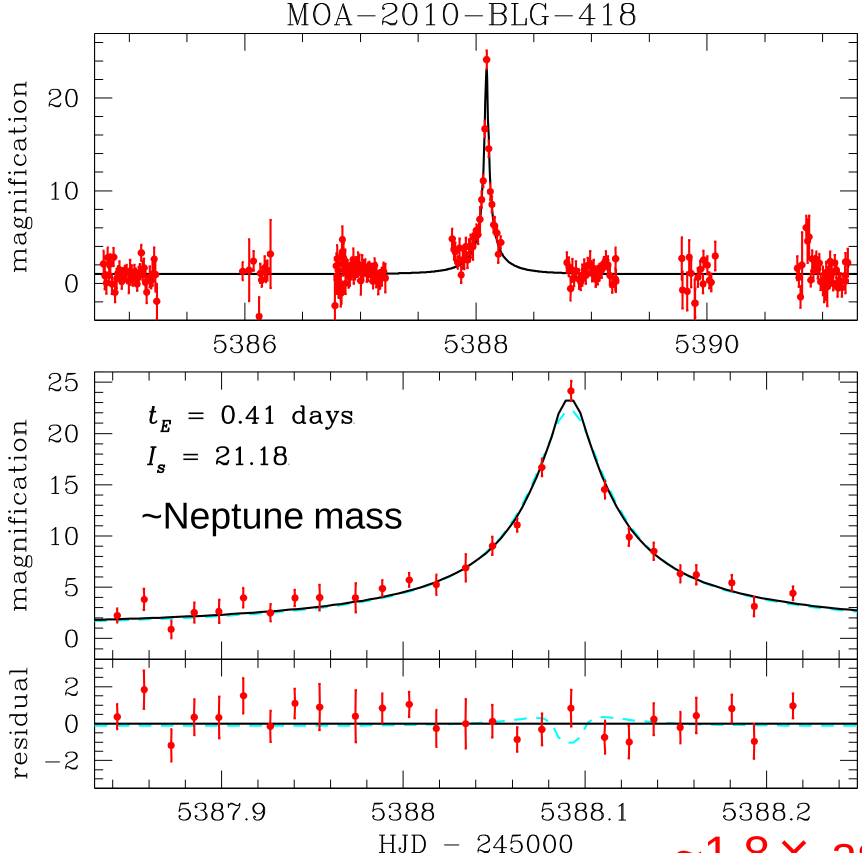


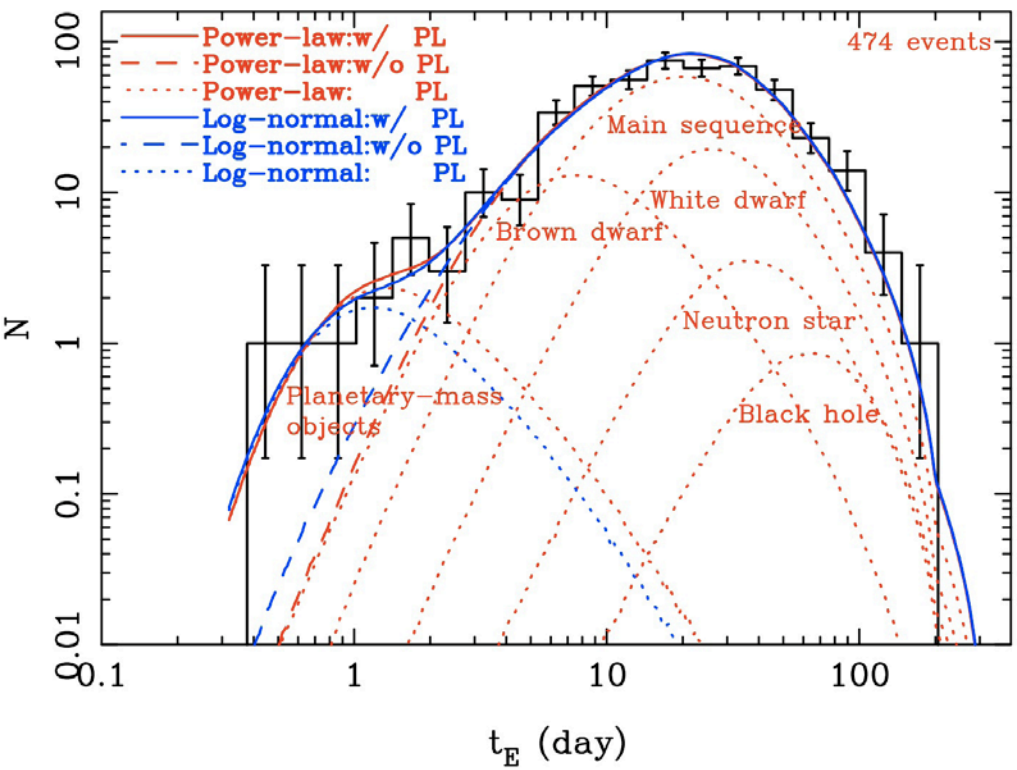
Free Floating Planet Events have t_E < 2 days

$$t_E = \frac{R_E(M,D)}{v_t} \sim \sqrt{M/M_J}\ day$$

~20 days for stars

M: lens mass
M_J: Jupiter mass
D: distance
v_t: velocity





~1.8 × as Many FFP as stars!

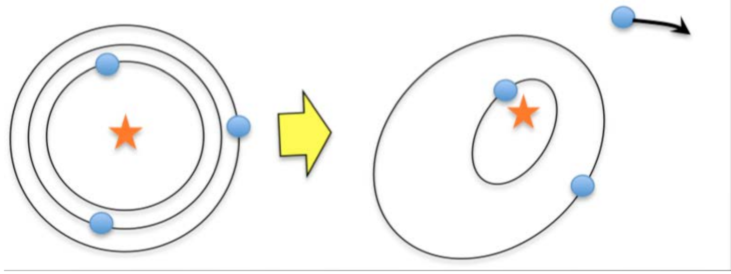
Sumi et al. 2011

WFIRST can detect Earth-mass FFP

Formation Scenarios

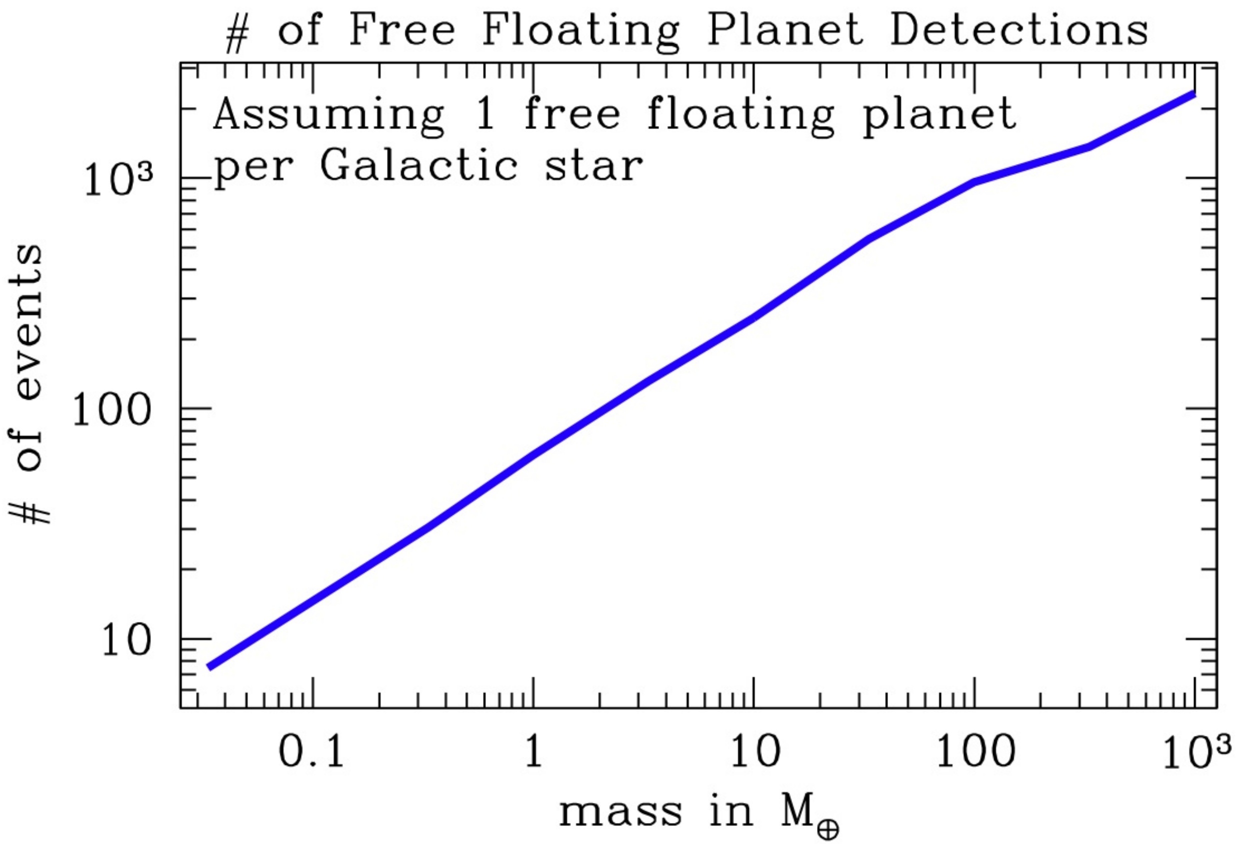
1. Formed like stars through gas cloud collapse (sub-brown dwarfs)
   – Hard to form Jupiter-mass objects
   – Planetary-mass sub brown dwarf can explain only 1 or 2 short events.
   – Abrupt change in mass function at Jupiter
   – Unlikely
2. Formed around a host star, and then removed from orbit
   – Stellar death – mass loss

   – Gravitational scattering



   - By a star – binary system or dense cluster
   - by a planet
   - Evidence:
     – Hot Jupiters orbiting hot stars have high obliquities (Winn et al. 2010, Triaud et al. 2010)
     – Hot Jupiters are alone (Latham et al. 2011)
     – No desert for short-period super-earths (Howard et al. 2010)
     – scattering more important than planet-disk interactions

WFIRST-AFTA's Predicted Discoveries



The number of expected WFIRST-AFTA planet discoveries.

WFIRST-AFTA

- Addresses the “big” questions of astronomy that are NASA strategic plan for astronomy (p. 14):

“discover how the universe works,

explore how it began and evolved, and

search for Earth-like planets”

- Enables a wealth of science across astronomy

- Stunning images will both excite public and reveal new insights into the nature of our universe.