WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

Mass Measurements of Microlensing Exoplanets

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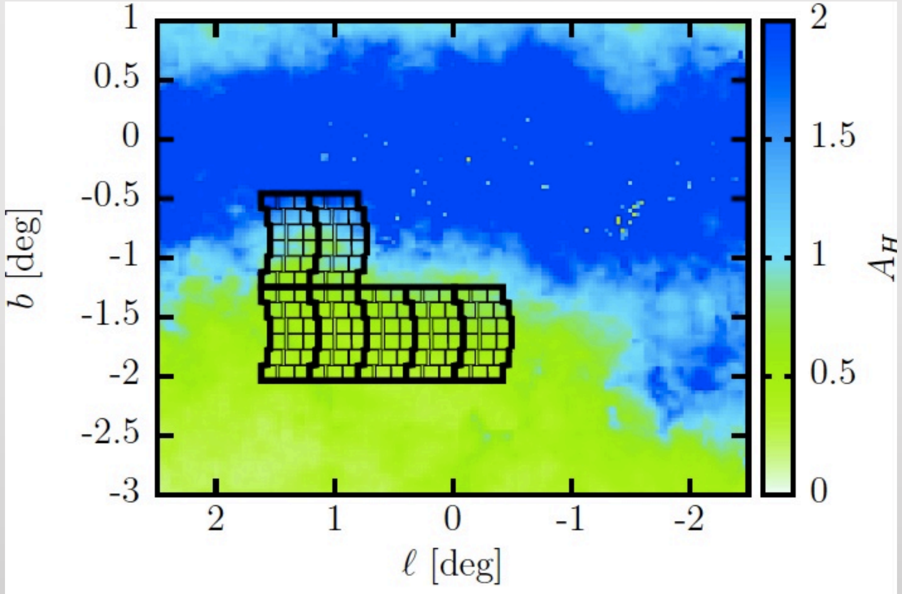
AAS

Jan 10, 2018

MICROLENSING SURVEY

- 6 seasons – each of 72 days
- 6 seasons spread over 4.5 years including first 2 and last 2 bulge seasons
  - 3 early seasons, 3 late seasons
- 7 galactic bulge fields
- Filters:
  - Wide band W149 (Each field once every 15 minutes) ~ 40000 images of each field
  - F184 every 12 hours ~ 800 images of each field
  - Z087 or R062 (Red) every 12 hours ~ 800 images of each field

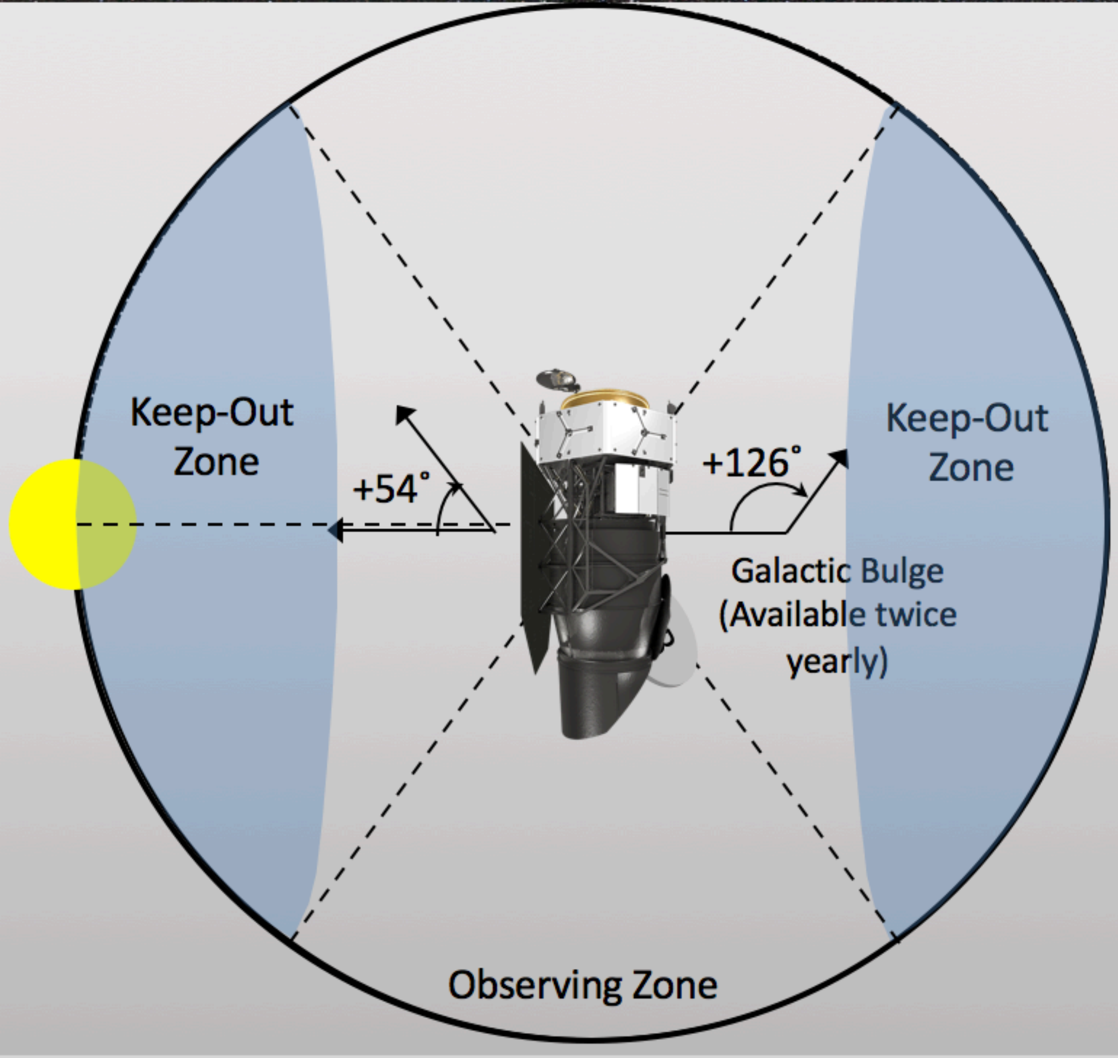


Credits: M. Penny

MICROLENSING SEASONS

- Solar panels restrict range of Sun-spacecraft angle to ~72º range
- Can observe bulge for 72 days twice a year in Spring and Autumn

(Note this does not correspond with the bulge season on earth which is April - September)



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Mass Measurements of Microlensing Exoplanets

We need 2 of 3 following for mass measurements:

- Finite Source Effect
  Angular Einstein Radius, θ_E
- Lens Detection
  Lens Flux in High resolution Follow up
- Microlensing Parallax Effect
  Parallax vector

The primary requirement for WFIRST Microlensing survey is getting mass measurements of at least 50% of the WFIRST microlensing exoplanet discoveries, where as most light curve fittings provide only with the planet-host mass ratio.

Mass Measurements of Microlensing Exoplanets

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Astrophysics • Dark Energy • Exoplanets

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Mass Measurements of Microlensing Exoplanets

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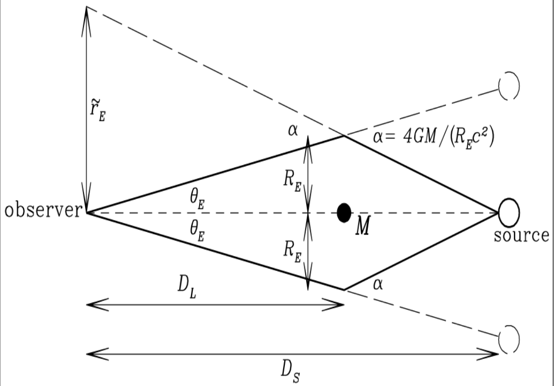
Methodology

Finite Source Effect

Lens Detection

Parallax Effect



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

×

$$M_L = \frac{c^2}{4G}\tilde{r}_E^2 \frac{D_S - D_L}{D_S D_L}$$

↓

$$M_L = \frac{c^2}{4G}\tilde{r}_E \theta_E$$

The planet and host system is the lens system

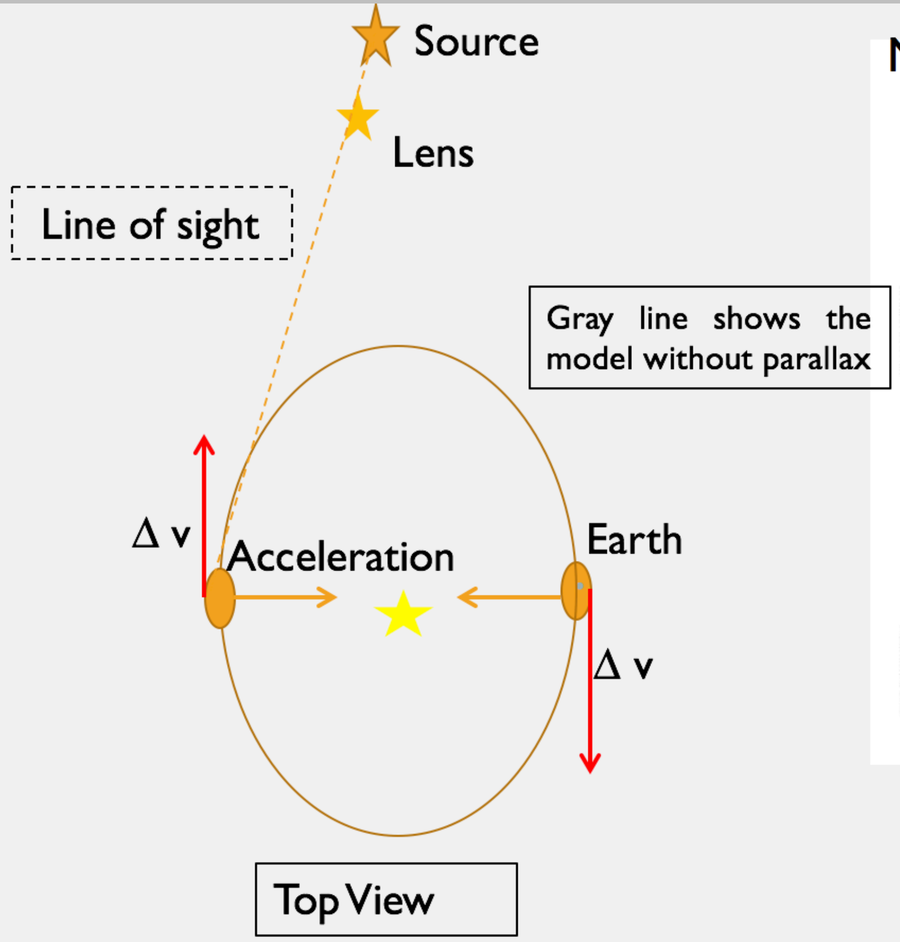
Mass Measurements of Microlensing Exoplanets

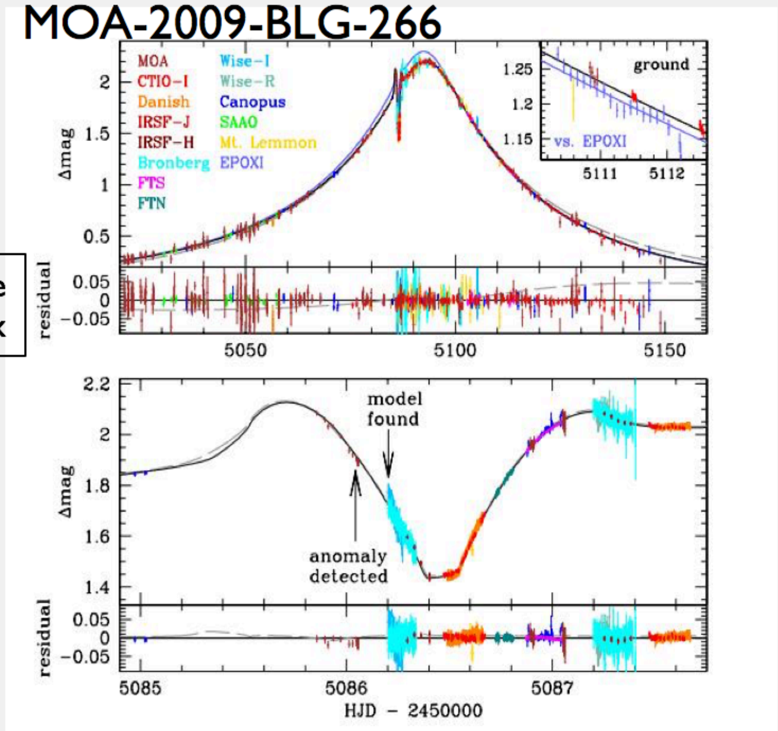
Results

Finite Source Effect

Lens Detection

Parallax Effect





$M_H = 0.56 \pm 1.7\ M_\odot$

$M_P = 10.4 \pm 0.09\ M_\oplus$

$a_\perp = 3.2^{+1.9}_{-0.5}$ AU

Muraki et al 2011, ApJ 741, 22

Mass Measurements of Microlensing Exoplanets

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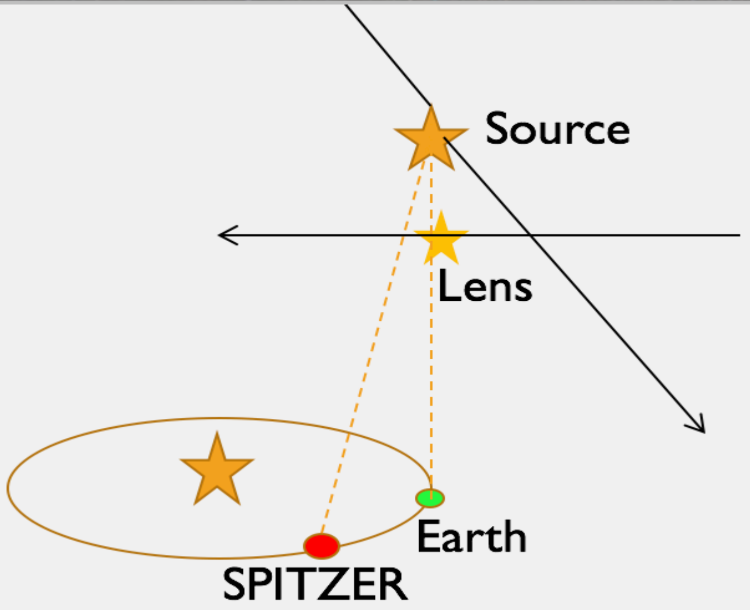
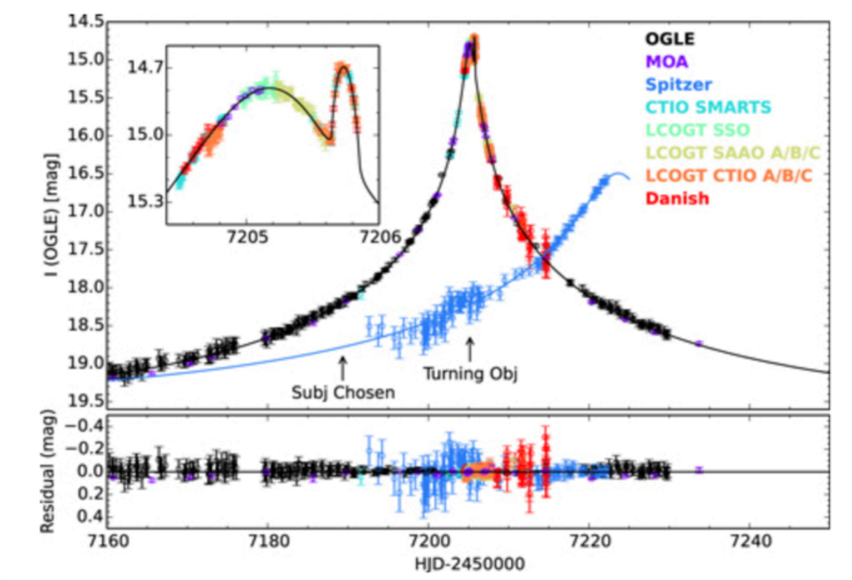
Satellite - Ground Parallax with Spitzer



Satellite Parallax

OGLE-2015-BLG-0966



Results: $M_H = 0.38\ M_\odot$

$M_P = 21\ M_\oplus$

Street+, 2016, ApJ, 819

Results

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Will this work for WFIRST?

- WFIRST will observe in spring and autumn and measure mass using orbital parallax
  - Requires long- time baseline
- Satellite-ground parallax can be used with WFIRST and LSST
  - WFIRST sources will be faint and may not be observed with other ground facilities
  - WFIRST season will not much overlap with ground bulge season
  - WFIRST will be only 0.01 AU from earth in L2 as opposed to 1 AU
    - For planetary events – will require rapid response or wide field
    - Parallax and mass measurement for earth mass free floating planets
    - LSST observing time needed on the overlapping period with WFIRST season

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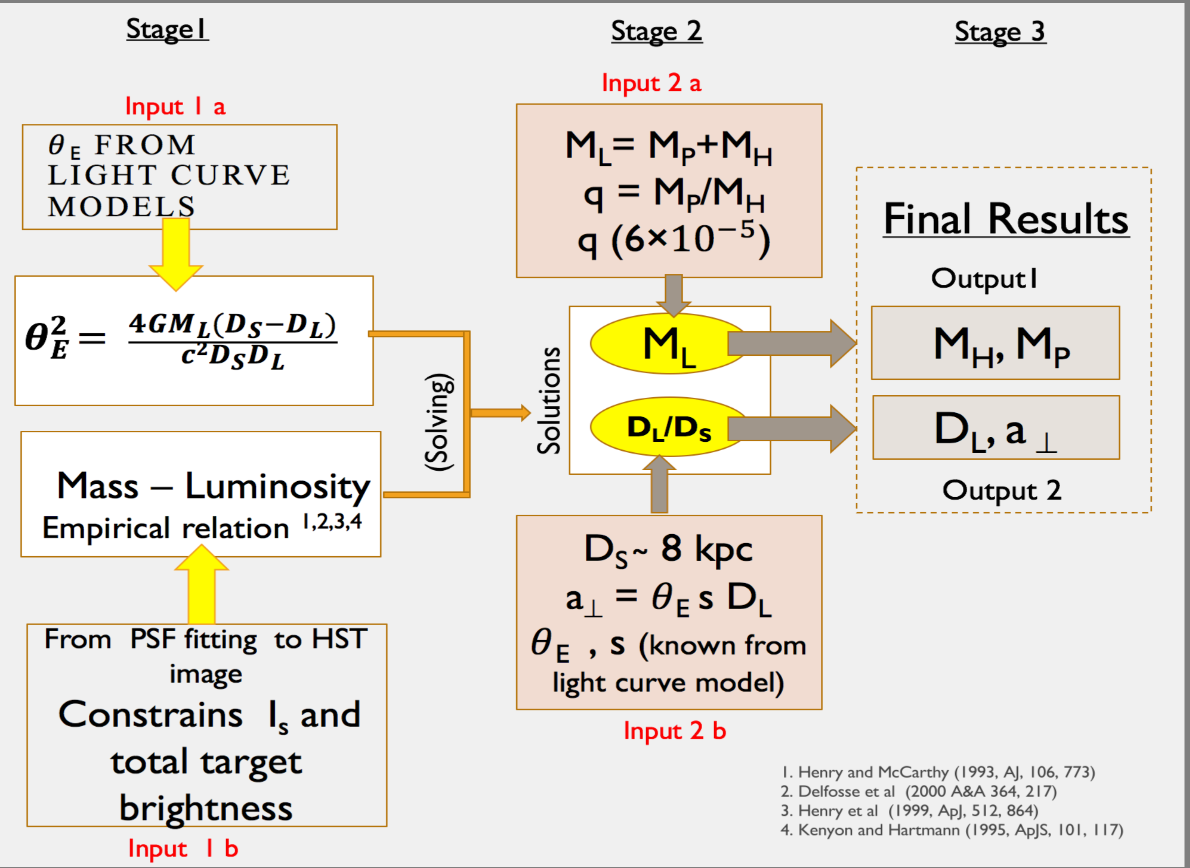

1. Henry and McCarthy (1993, AJ, 106, 773)
2. Delfosse et al (2000 A&A 364, 217)
3. Henry et al (1999, ApJ, 512, 864)
4. Kenyon and Hartmann (1995, ApJS, 101, 117)

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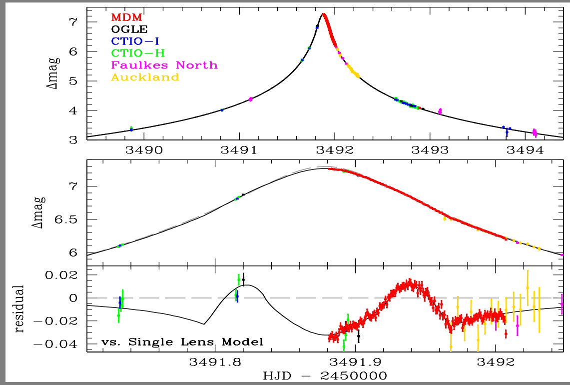

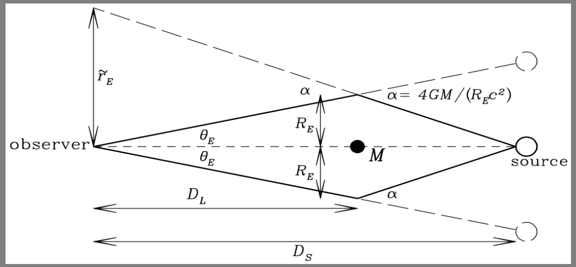

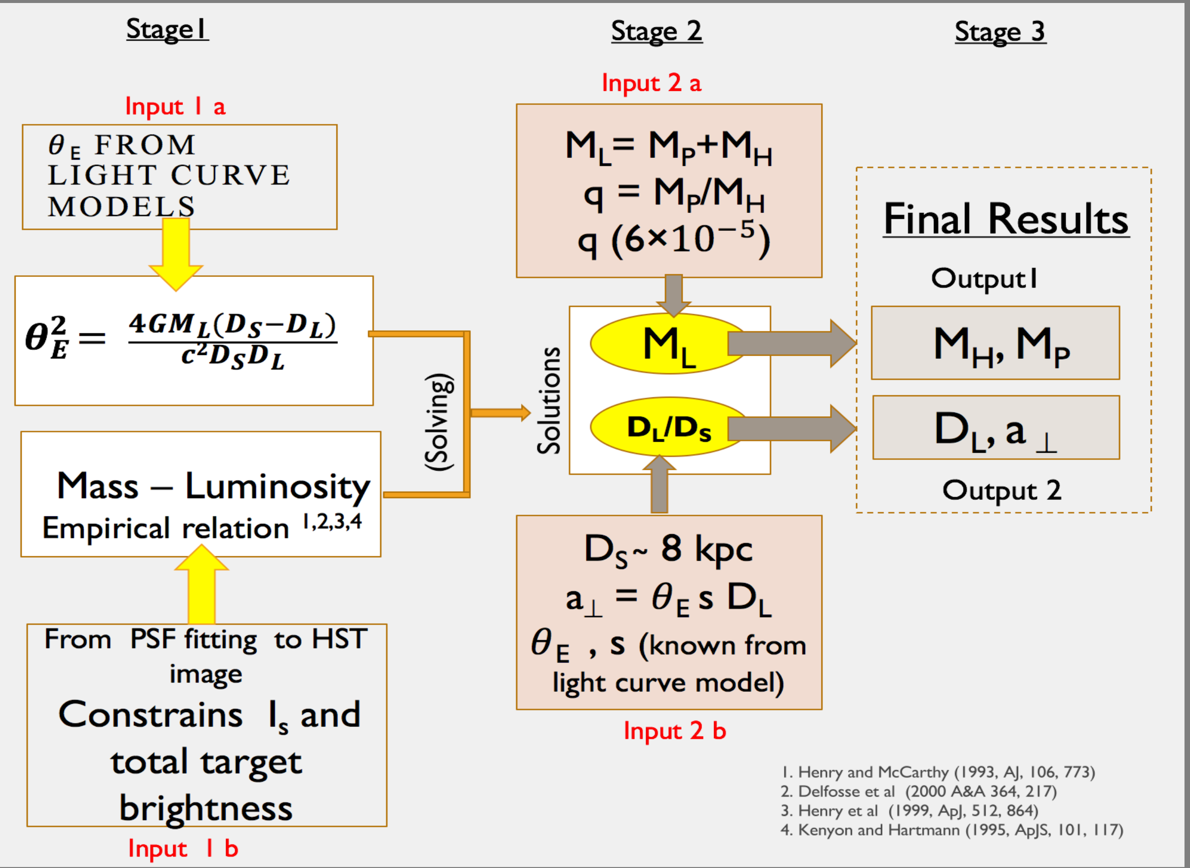

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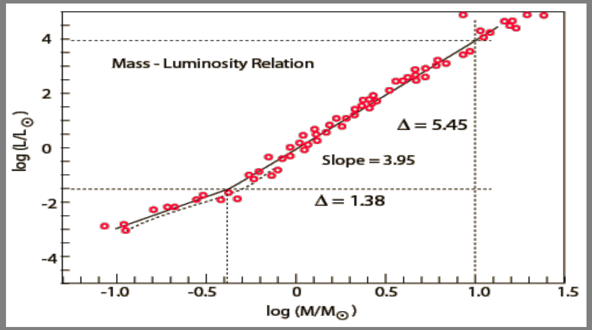

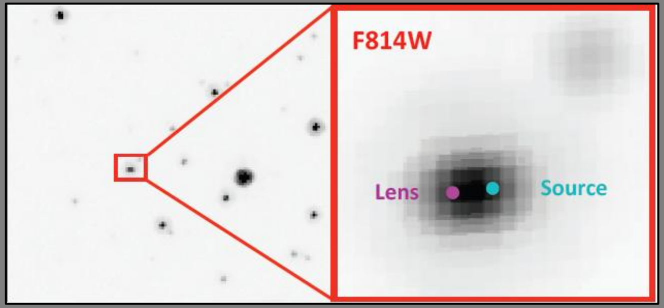

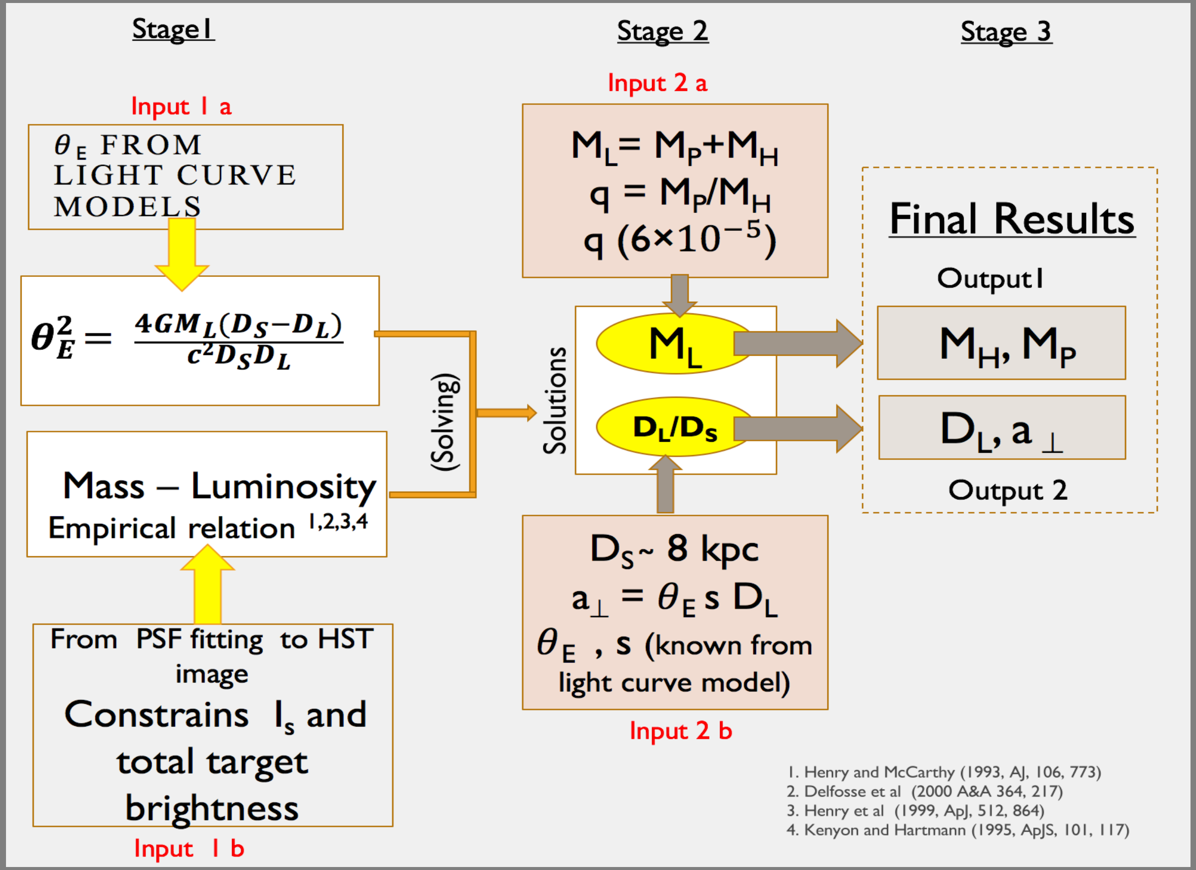

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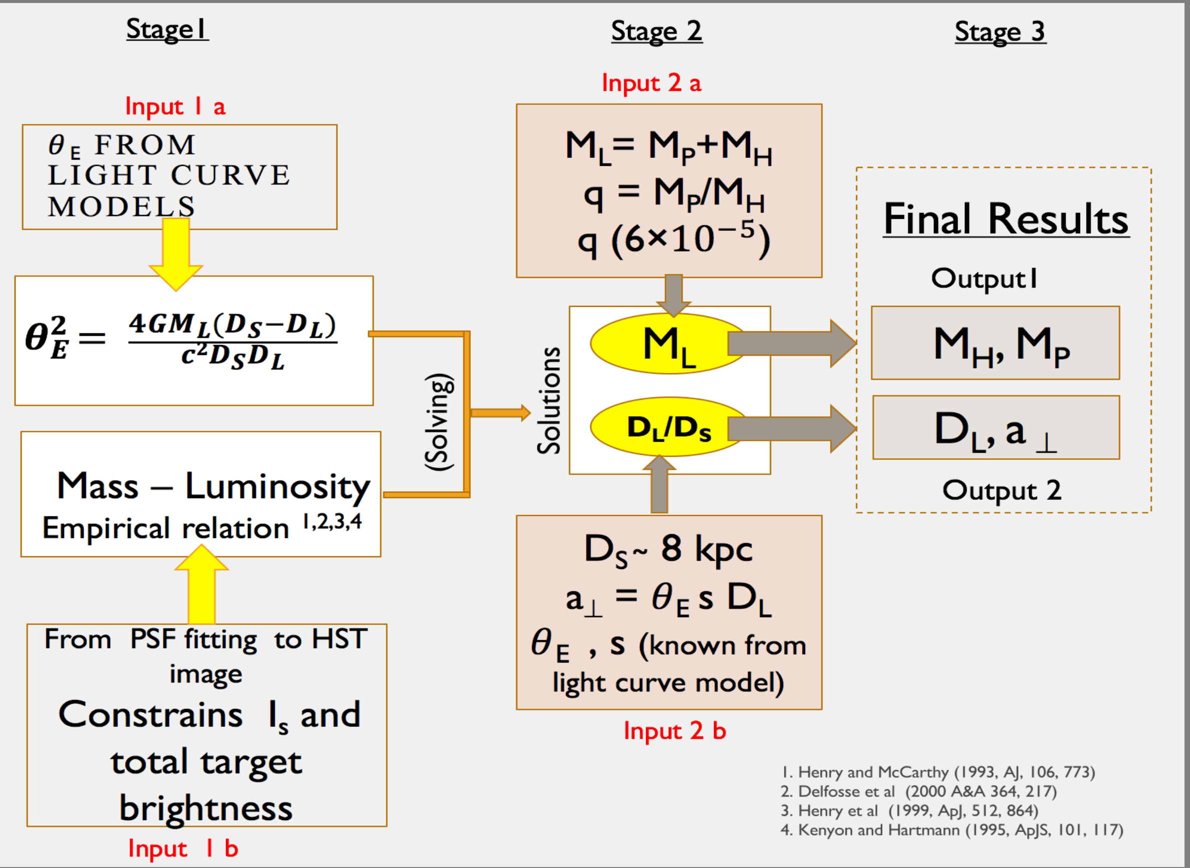

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Results

Finite Source Effect

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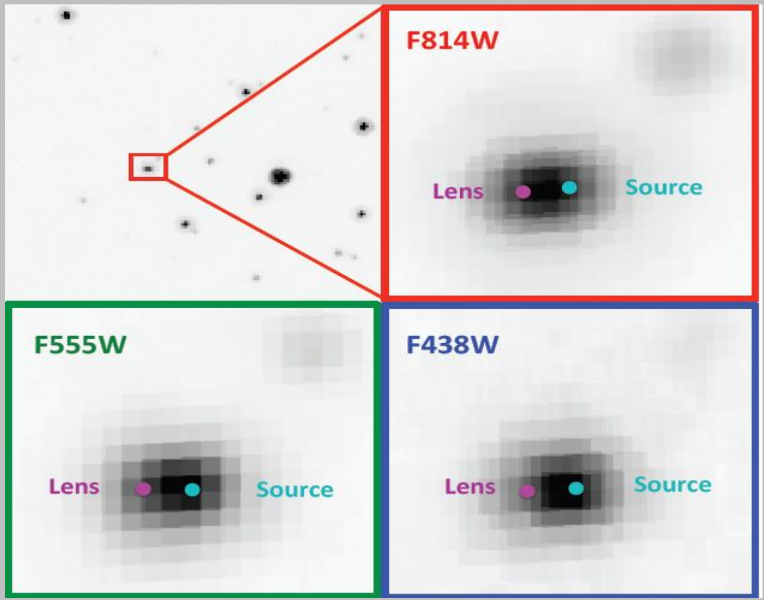
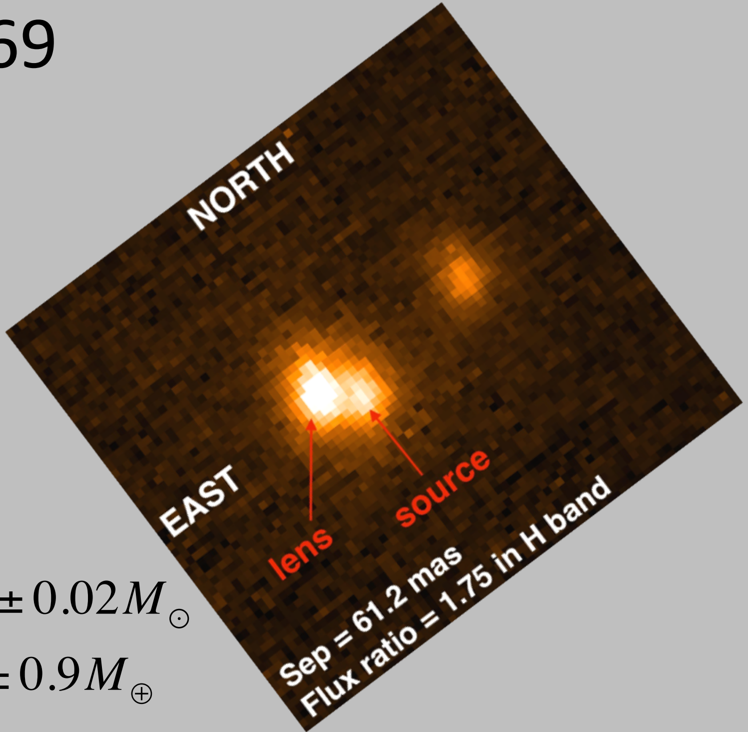
OGLE-2005-BLG-169



Follow-up taken with HST 6.5 years after the peak of the event

$$M_* = 0.69 \pm 0.02 M_\odot$$
$$m_p = 14.1 \pm 0.9 M_\oplus$$
$$a_\perp = 3.5 \pm 0.3 \text{ AU}$$
$$a_{3d} = 4.0^{+2.2}_{-0.6} \text{ AU}$$
$$D_L = 4.1 \pm 0.4 \text{ kpc}$$



Follow-up taken with Keck AO 8.3 years after the peak of the event

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Results

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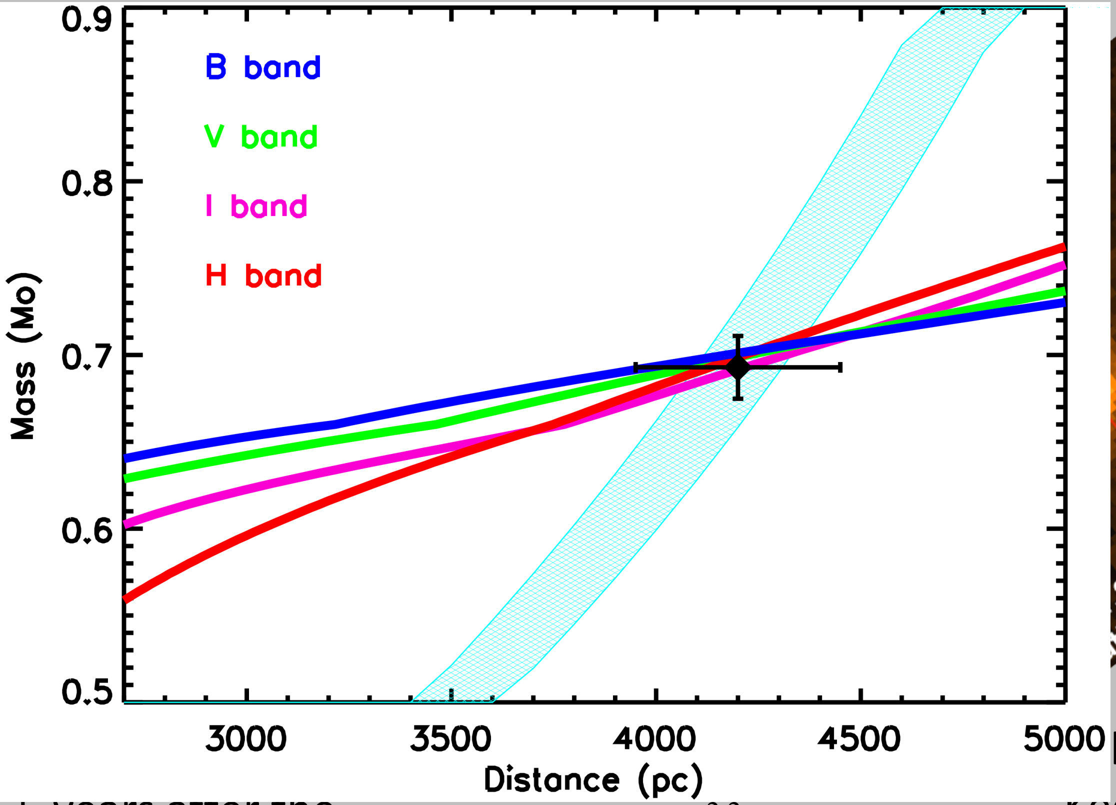
Follow-up taken with HST 6.5 years after the peak of the event



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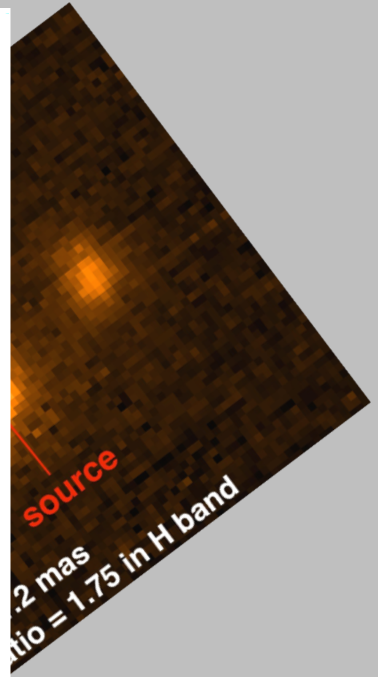

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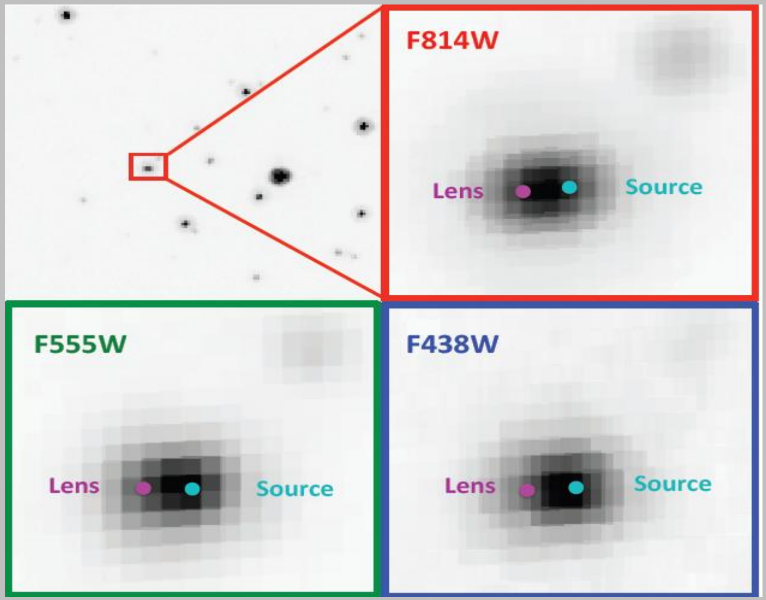
OGLE-2005-BLG-169



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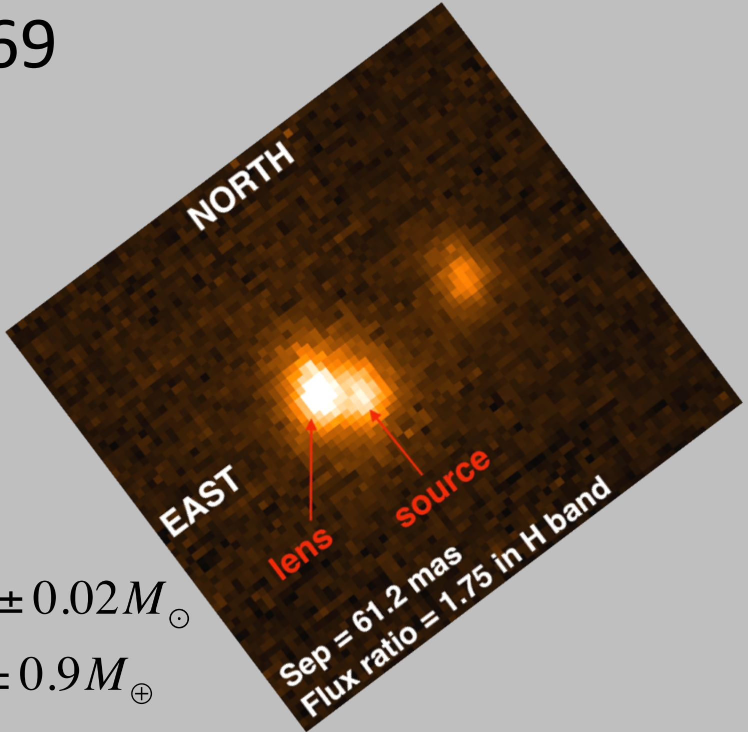

Follow-up taken with Keck AO 8.3 years after the peak of the event

Mass Measurements of Microlensing Exoplanets

Finite Source Effect

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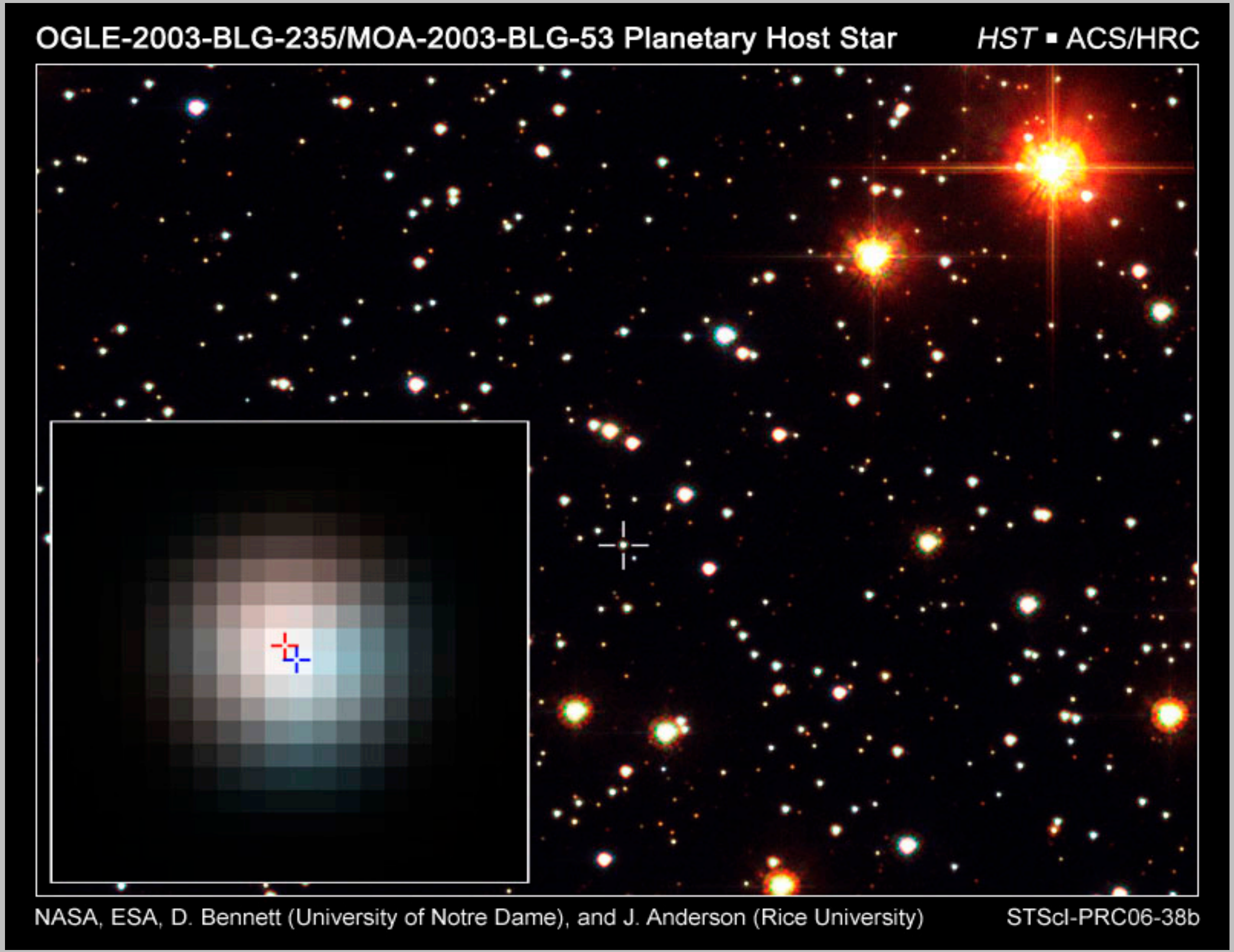
Parallax Effect

- If the lens and source are too close, lens can be detected through centroid shift method
- If lens and source have different colors then their centroids will shift different amount in follow-up images in different passbands



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Methodology

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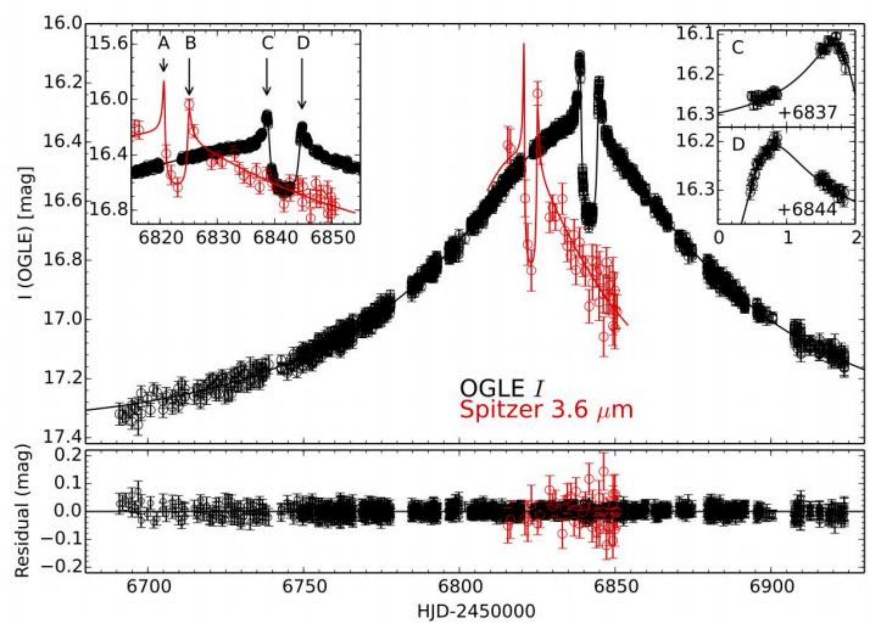
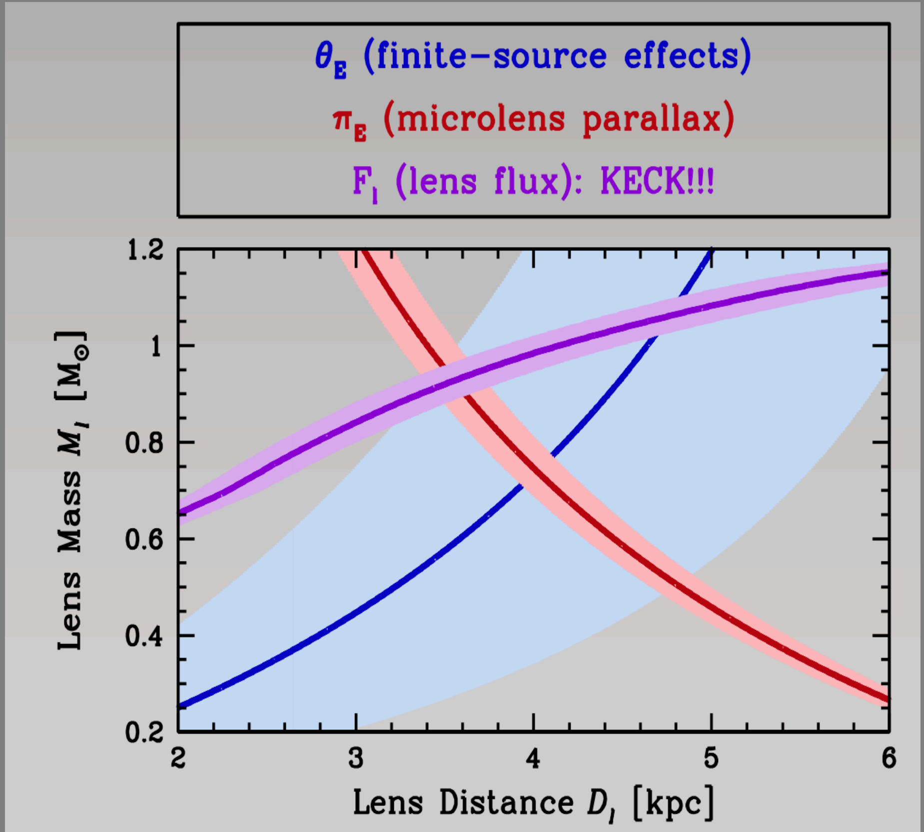
OGLE-2014-BLG-0124

No finite Source Effect Detected



Udalski+ 2015



Credits: C. Henderson

Mass Measurements of Microlensing Exoplanets

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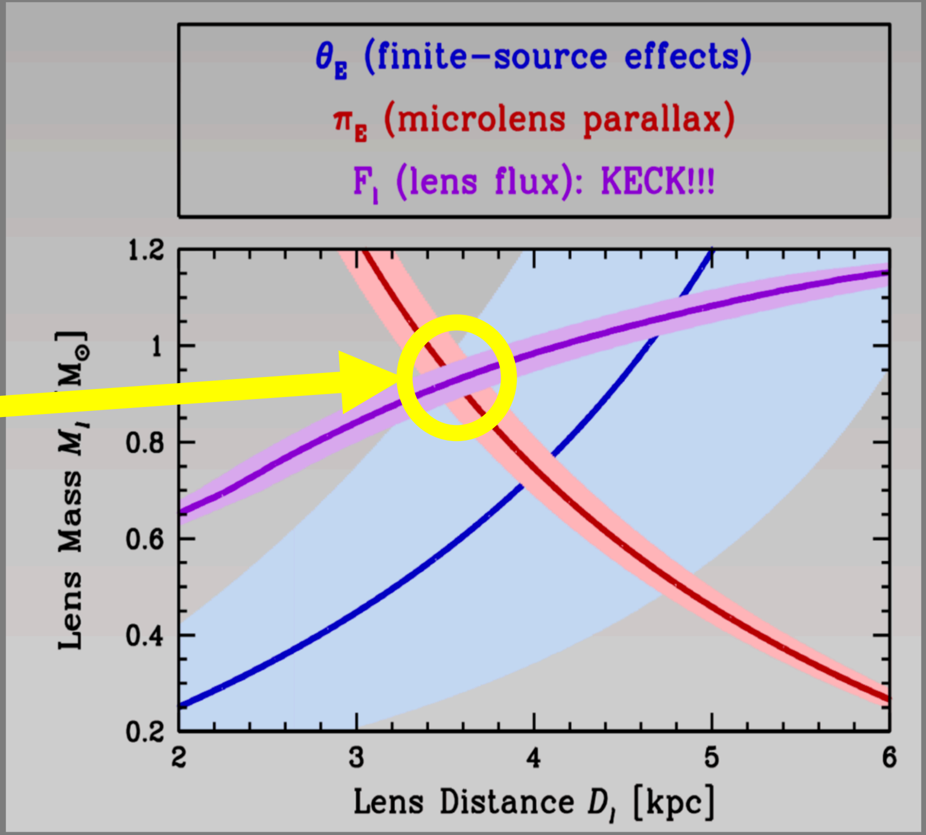
OGLE-2014-BLG-0124

No finite Source Effect Detected

From Beaulieu+ 2017:

$M_H = 0.89\ M_{sun}$
$M_P = 0.64\ M_J$
$D_L = 3.5$ kpc



C. Henderson Talk Thu: 11.00-11.10 am Session. 310. Extrasolar Planets V

Mass Measurements of Microlensing Exoplanets

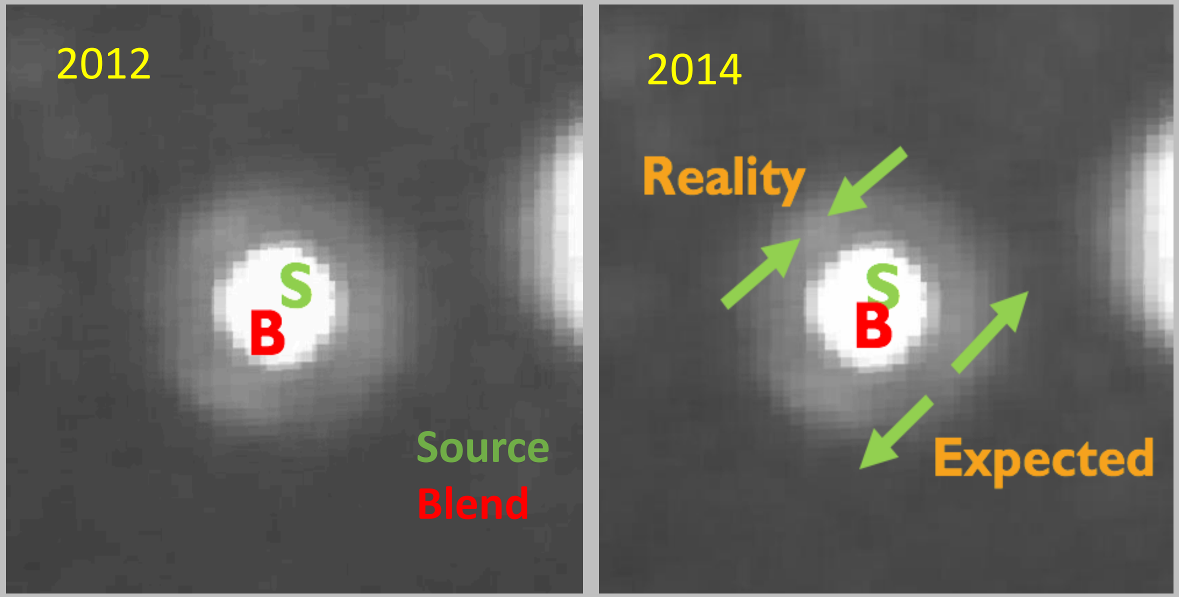
Finite Source Effect

Lens Detection

Parallax Effect

NOT ALL EXCESS FLUX IS PRIMARILY DUE TO THE LENS

The excess flux could be due to the binary companion to the source, lens or a nearby unrelated star.



MOA-2008-BLG-310

Bhattacharya+2017

Mass Measurements of Microlensing Exoplanets

Challenges

Finite Source Effect

Lens Detection

Parallax Effect

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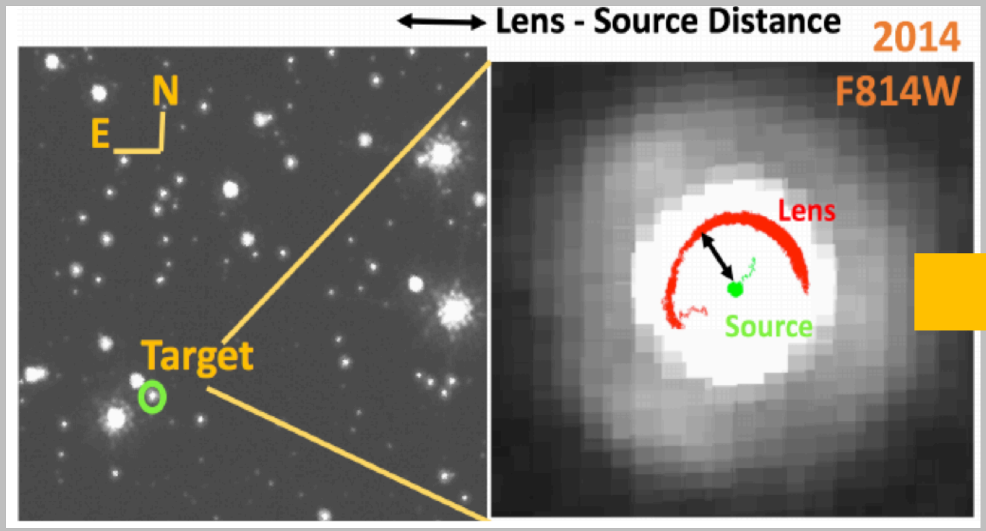

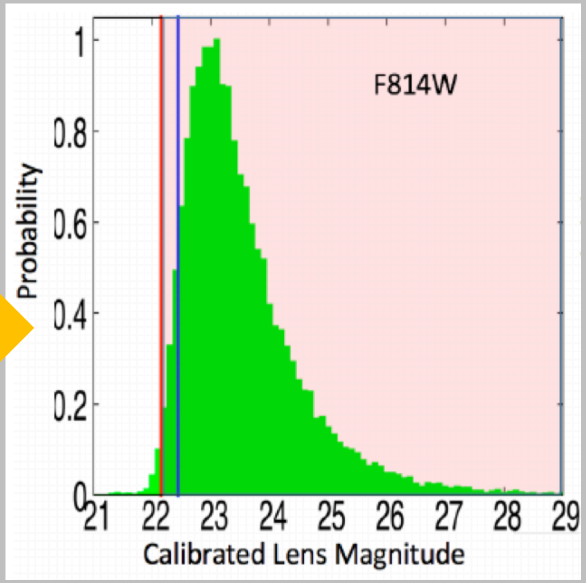

We can still get the upper limit on host and planet masses

MOA-2008-BLG-310

Bhattacharya+2017

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MICROLENSING SURVEY

- WFIRST will follow-up its own discoveries, it will be a self follow up survey
- The primary methods of mass measurements will be lens detection + finite source effect or lens detection + parallax
  - It is already shown with only 8 images in each passbands in HST that this method works
  - With >20000 images we will be able to map the PSF more precisely

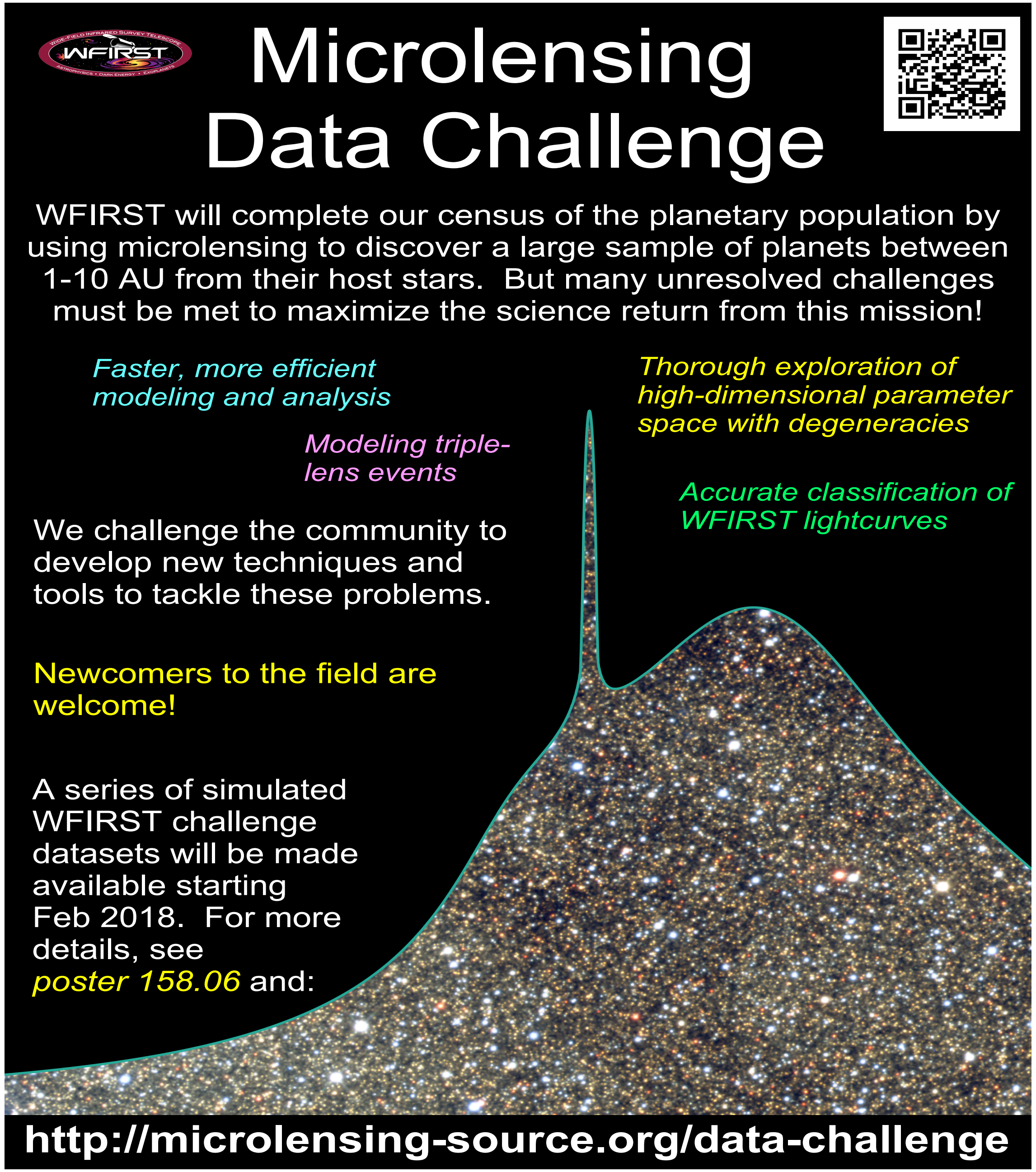
In preparation of WFIRST:

- KSMS (Keck Strategic Mission Support)
  - 10 half nights each year for 2 years
  - Observe High-Res Follow Up of at least 60 events including planetary and stellar binary to further develop the mass measurement method
- Open Source Microlensing Light Curve Fitting Routines including fitting planetary events
  - PyLIMA (Led by E. Bachelet) Talk: Wed 2.50-3.00 pm E. Bachelet Session 228. Extrasolar Planets IV
  - MuLAN (Led by C. Ranc)
  - VBBinaryLensing (Led by V Bozza)
  - MuLens Model (Led by R Poleski)

Challenges

- There are only 3 multi-planet systems discovered. We are still understanding multi-planet and other complicated light curve fittings.
- For lens detection presence of binary contaminations need to be considered. Luckily even in presence of companions we can still put an upper limit on exoplanet mass.
- More man power – to increase the small community:
  - UKIRT Microlensing data release (https://exoplanetarchive.ipac.caltech.edu/docs/UKIRTMission.html)
  - MOA 2006-2014 data release around 2019
  - DATA CHALLENGE (http://microlensing-source.org/data-challenge/)

Supported by a NASA Exoplanets Research Program grant NNX15AC97G



Releasing in International Microlensing Conference 2018 in Auckland, New Zealand

Jan 25 – 28, 2018

https://www.physics.auckland.ac.nz/en/about/international-microlensing-conference.html

Codes: http://microlensing-source.org/software/
Resources: http://microlensing-source.org/resources/
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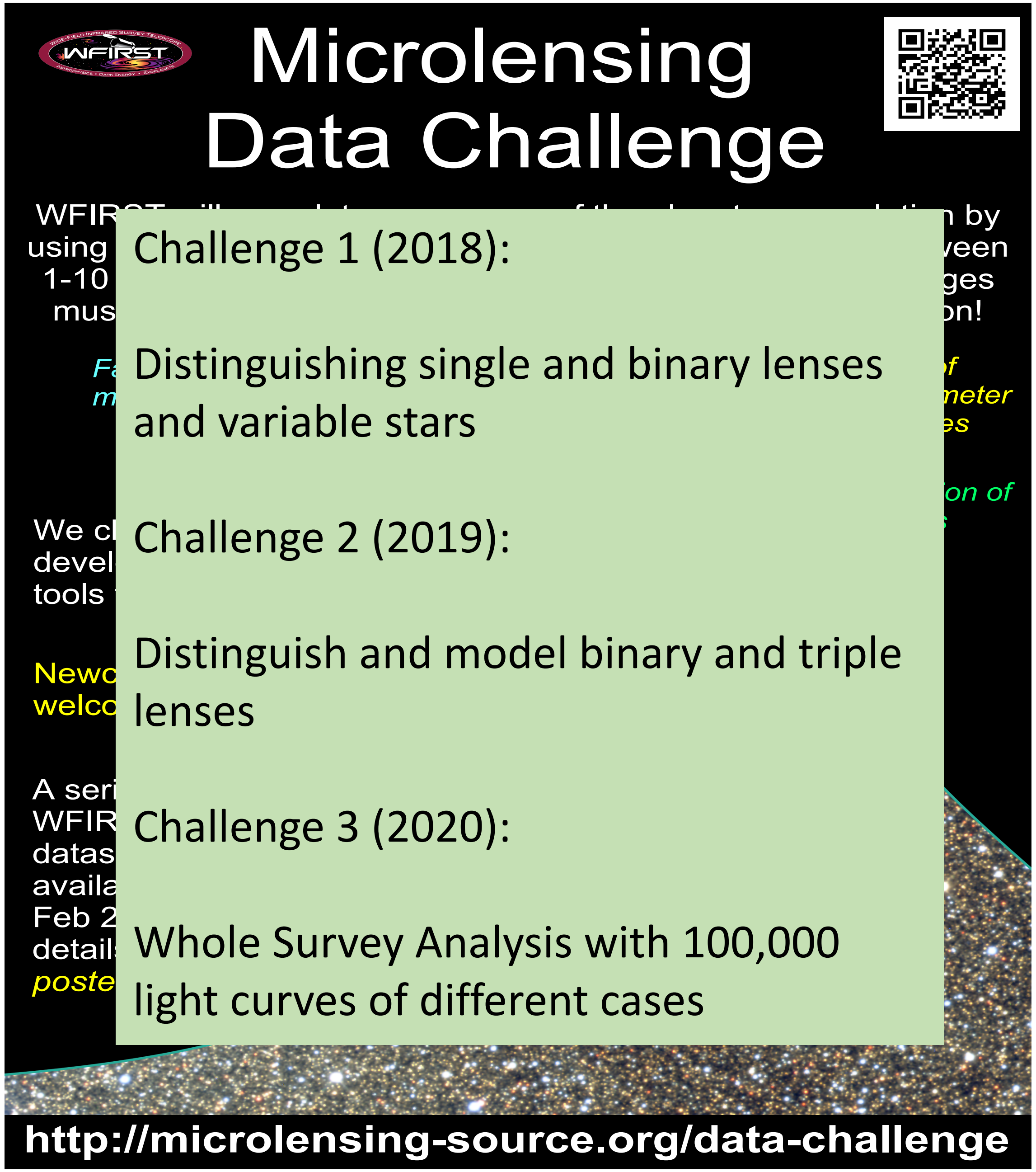

Challenge 1 (2018):

Distinguishing single and binary lenses and variable stars

Challenge 2 (2019):

Distinguish and model binary and triple lenses

Challenge 3 (2020):

Whole Survey Analysis with 100,000 light curves of different cases

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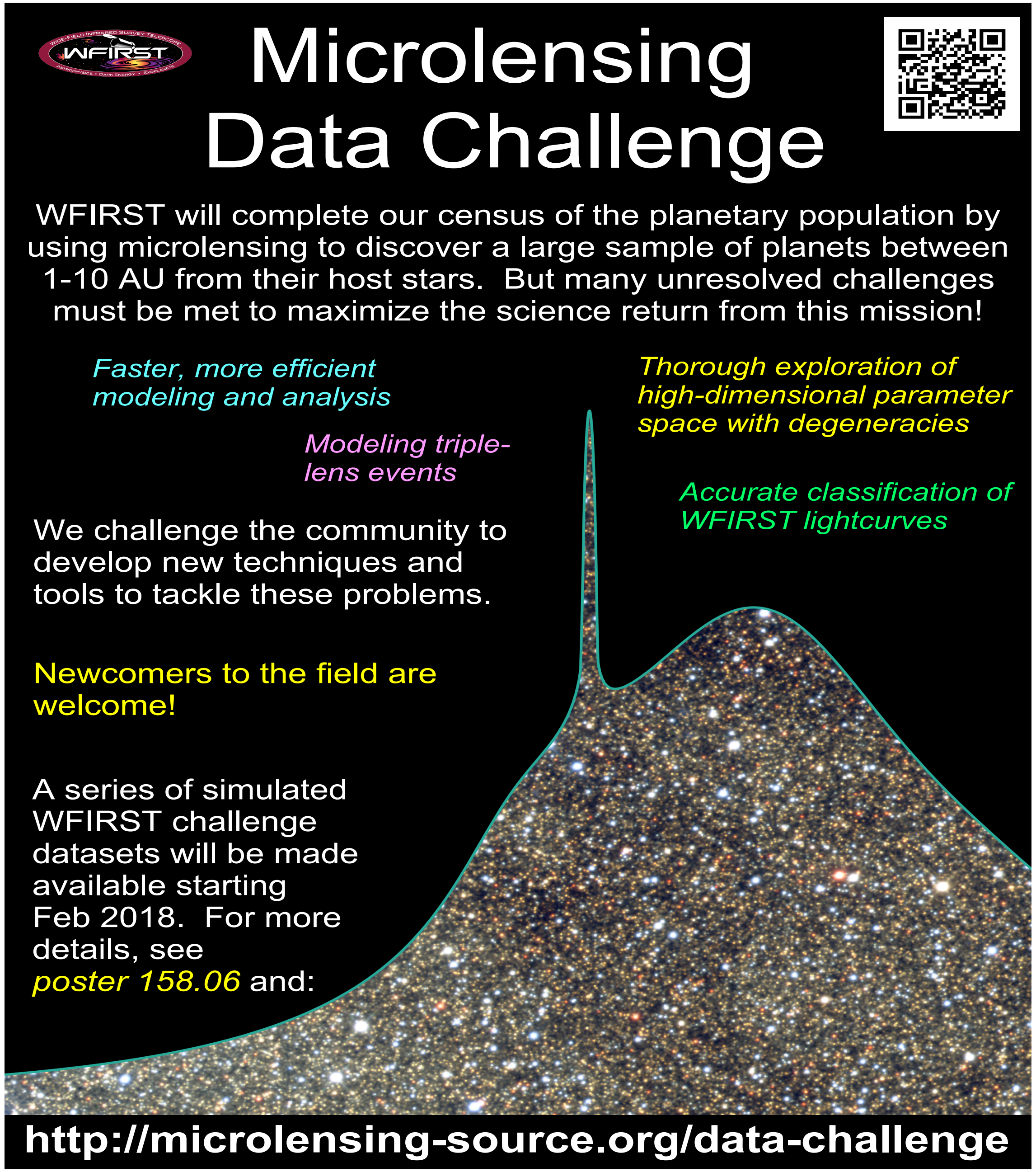

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STAY TUNED!!!