Characterization of Microlensing Planetary Systems by AO Imaging

A new discovery paper:
"***OGLE-2012-BLG-0563Lb: a Saturn-mass Planet around an M Dwarf with the Mass Constrained by Subaru AO imaging***", Fukui et al. submitted
The paper will appear on astroph TONIGHT.

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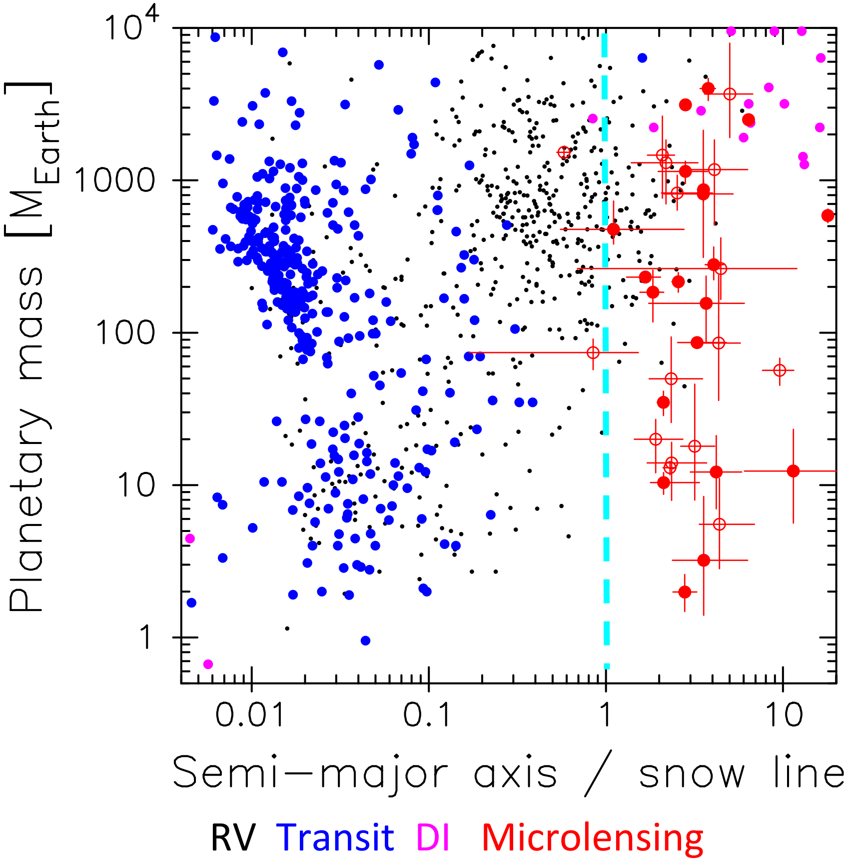
2015 June 30
31st International Colloquium of the Institut d'Astrophysique de Paris
From Super-Earths to Brown Dwarfs: Who's Who?

Features of Microlensing



- Unique method sensitive to planets outside the snowline "**Birth place**" of giant planets
- Sensitive to low-mass stars including late M dwarfs
- Suitable to test the planetary formation theories
- **~35** detections ⇒ need to increase the statistics

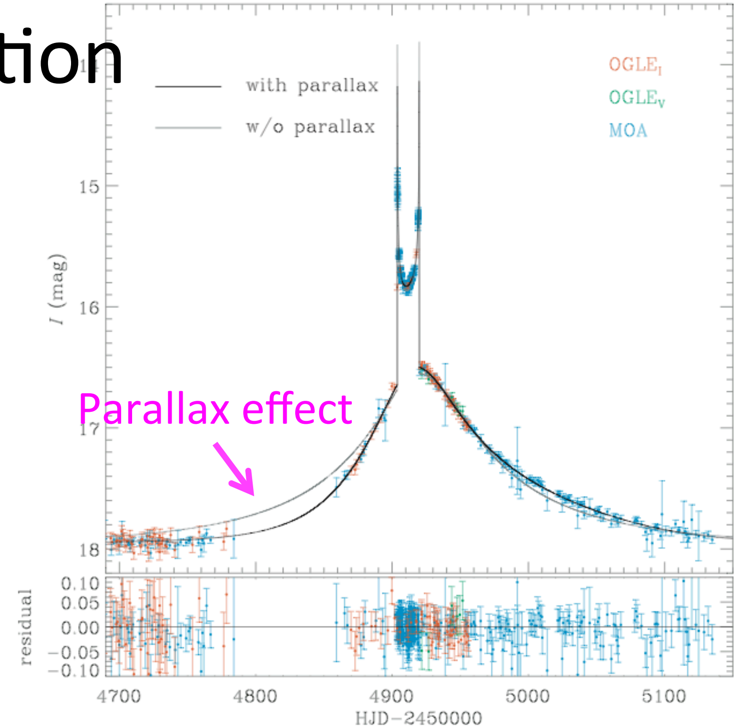
Hard to follow up..., but at least

host stars can be characterized by AO imaging

- **Mass**
- **Metallicity**

Problems on Mass Determination

- The mass (and distance) of planetary systems can be determined from light curve if both "**finite source**" and "**parallax**" effects are detected
- Although finite source effect is detected in most events, parallax is not detected in about half events



Without parallax…

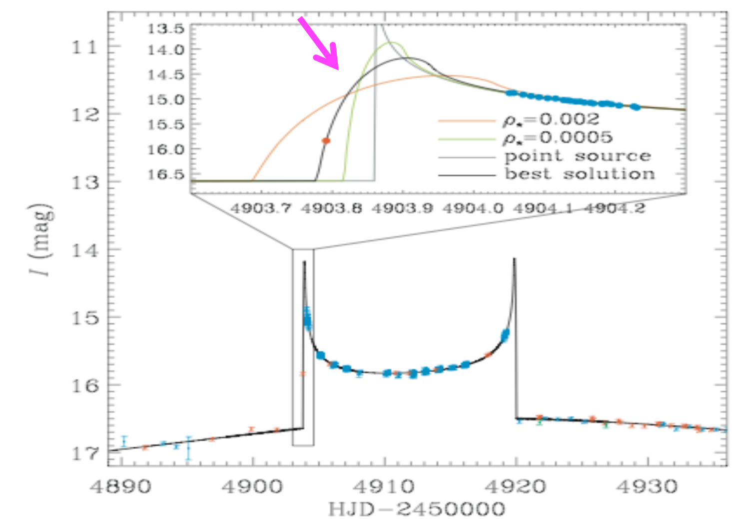
Method1: Bayesian approach

Stochastic estimation using Galactic-model priors

- Stellar mass function
- Stellar number-density distribution
- Stellar velocity distribution

⇨
- Inaccurate for individual systems
- Assumes a uniform planet occurrence for all types of stars

Finite source effect



Hwang et al. 2011

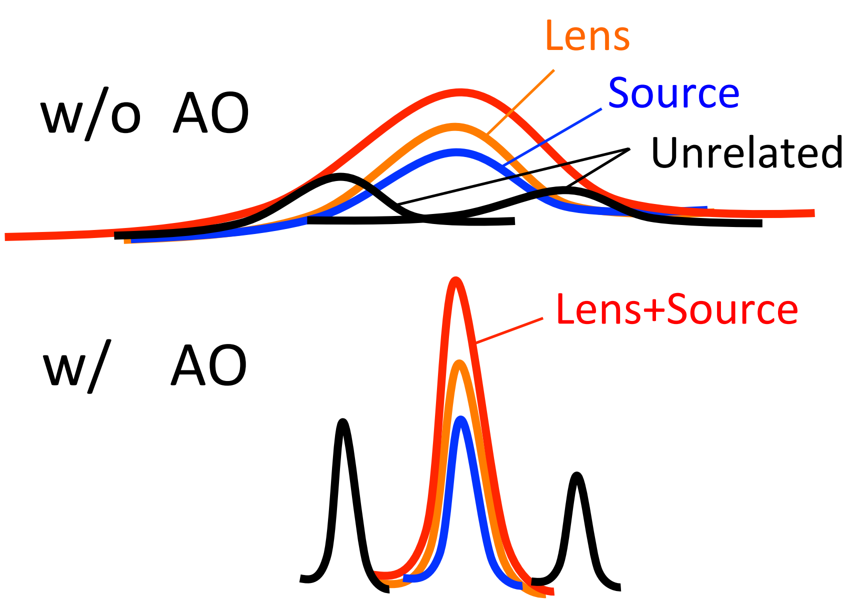
Method2: Extracting Emission from the Host Star

- The finite-source effect provides the Einstein angular radius θ_E, which is **a function of mass and distance**
- From the brightness of the host star, **another mass-distance relation** can be obtained via some stellar models
- **High-resolution imaging** is required to separate the **lens+source object** from unrelated stars
- The host (lens) star's flux is extracted by **subtracting source's flux from the lens+source composite flux**

Einstein angular radius:

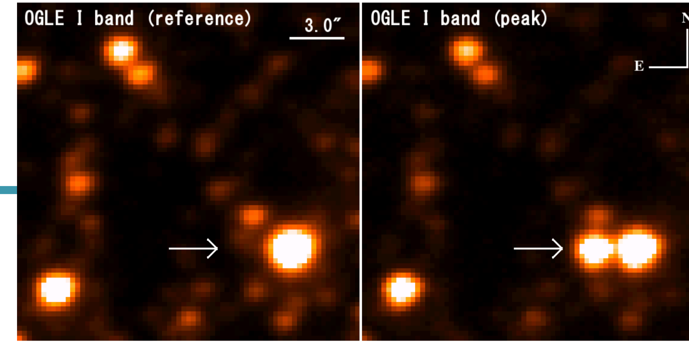
$$\theta_E = \sqrt{\frac{4G}{c^2} M_L \left(\frac{1}{D_L} - \frac{1}{D_S} \right)}$$

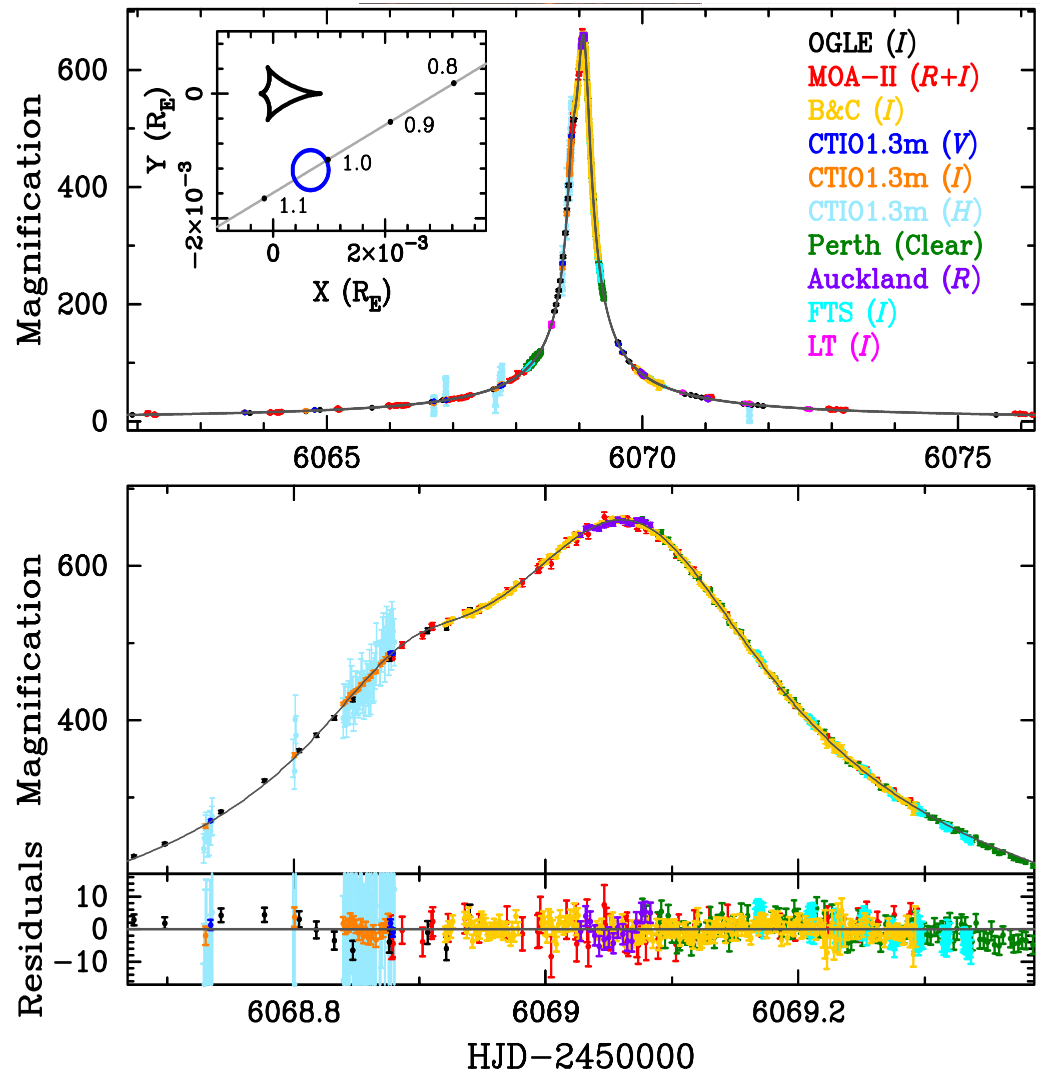
G: Gravitational constant
c: Speed of light
M_L: Mass of the lens
D_L: Distance to the lens
D_S: Distance to the source



OGLE-2012-BLG-0563

- Discovered in 2012 by OGLE and MOA as a high magnification (~600 times) event
- Intensive follow-up observations provide **an excellent light curve**
- **A clear planetary feature** was detected near the peak
- Finite source is detected, but **parallax is not detected**





AO observations with Subaru/IRCS

- Date : 2012 July 28
  (2 months after the event)
- Telescope: 8.2m Subaru
- Filters : J, H, and K’
- Seeing with AO: ~0.2’’

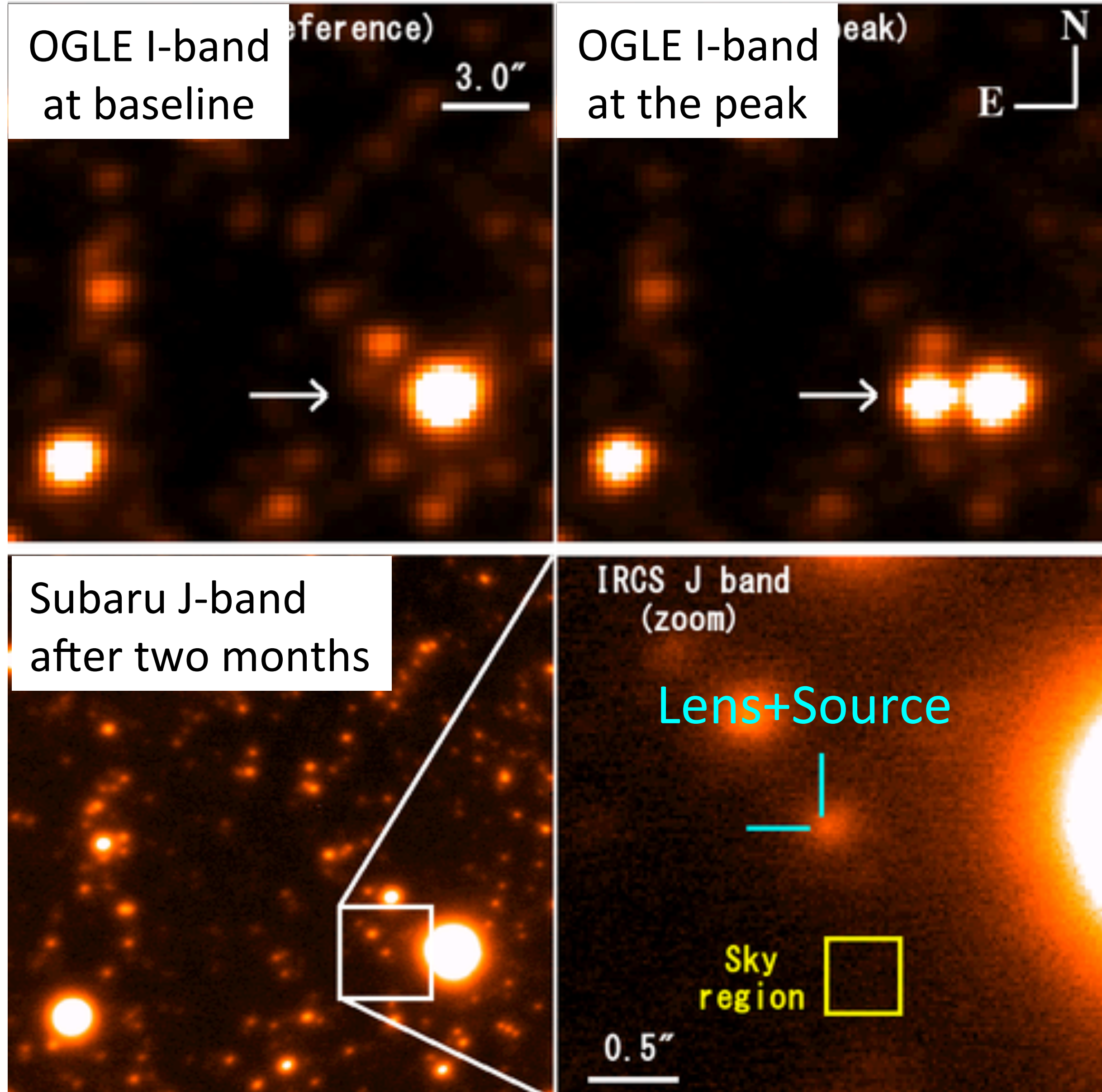
- Identified source+lens object in three bands
- Subtracting source’s brightness

⇒ Detected the excess flux due to the lens (host) star

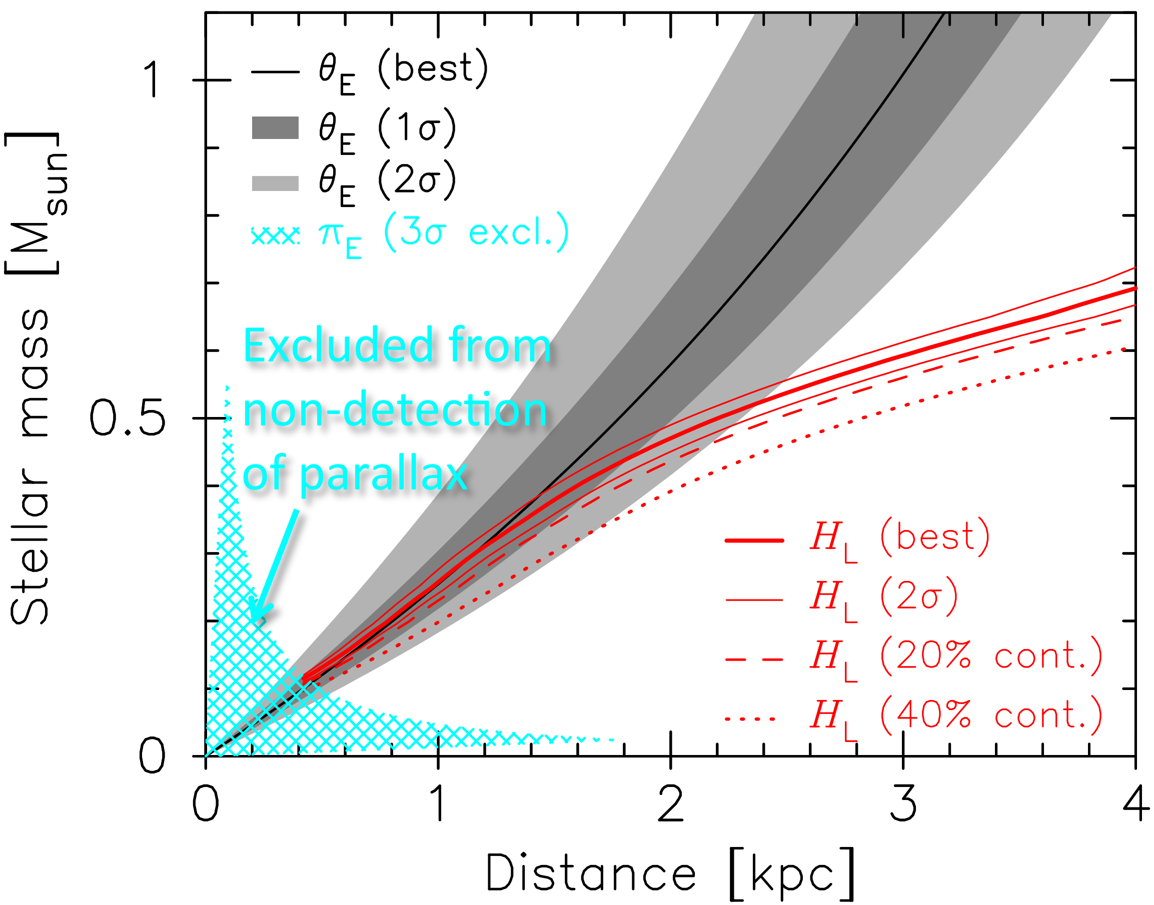
$J = 18.33 \pm 0.09$

$H = 17.80 \pm 0.07$

$K_s = 17.69 \pm 0.11$



Constraint on Mass and Distance



Results:

M_s = **0.34**$^{+0.12}_{-0.20}$ [M_{Sun}]

D = **1.3**$^{+0.6}_{-0.8}$ [kpc]

M_p = **0.39**$^{+0.14}_{-0.23}$ [M_{Jup}]

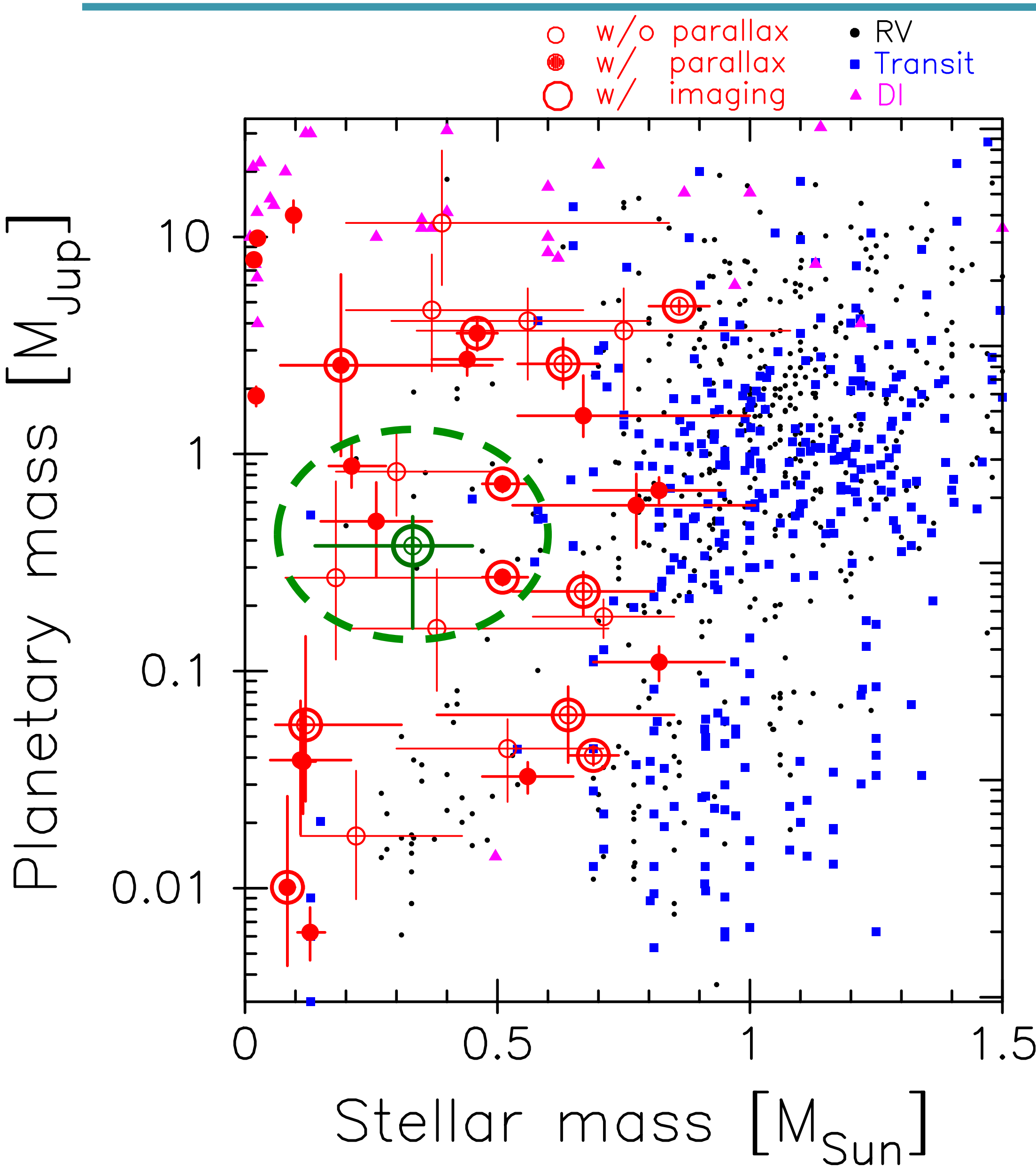
(**123**$^{+44}_{-73}$ [M_{Earth}])

a (close) = **0.90**$^{+0.52}_{-0.50}$ [AU]

a (wide) = **5.2**$^{+3.1}_{-2.9}$ [AU]

M dwarf orbited by **a cold Saturn**

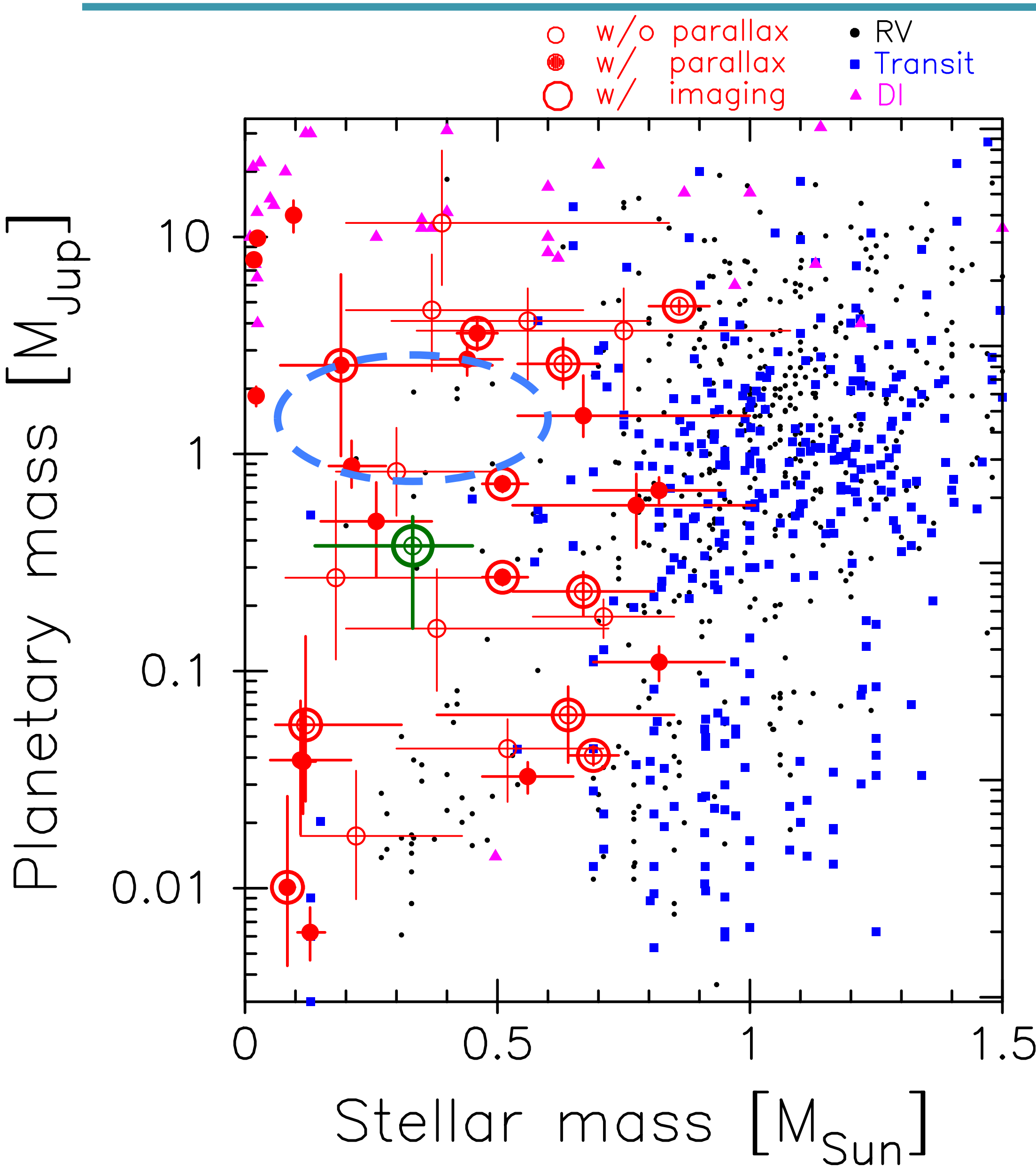
Stellar Mass v.s. Planetary Mass



- **The third M dwarf system** with the lens detected, and **the first one** for which the mass was determined from θ_E and lens flux alone

⇒ AO imaging can play an important role even for M dwarfs

Stellar Mass v.s. Planetary Mass



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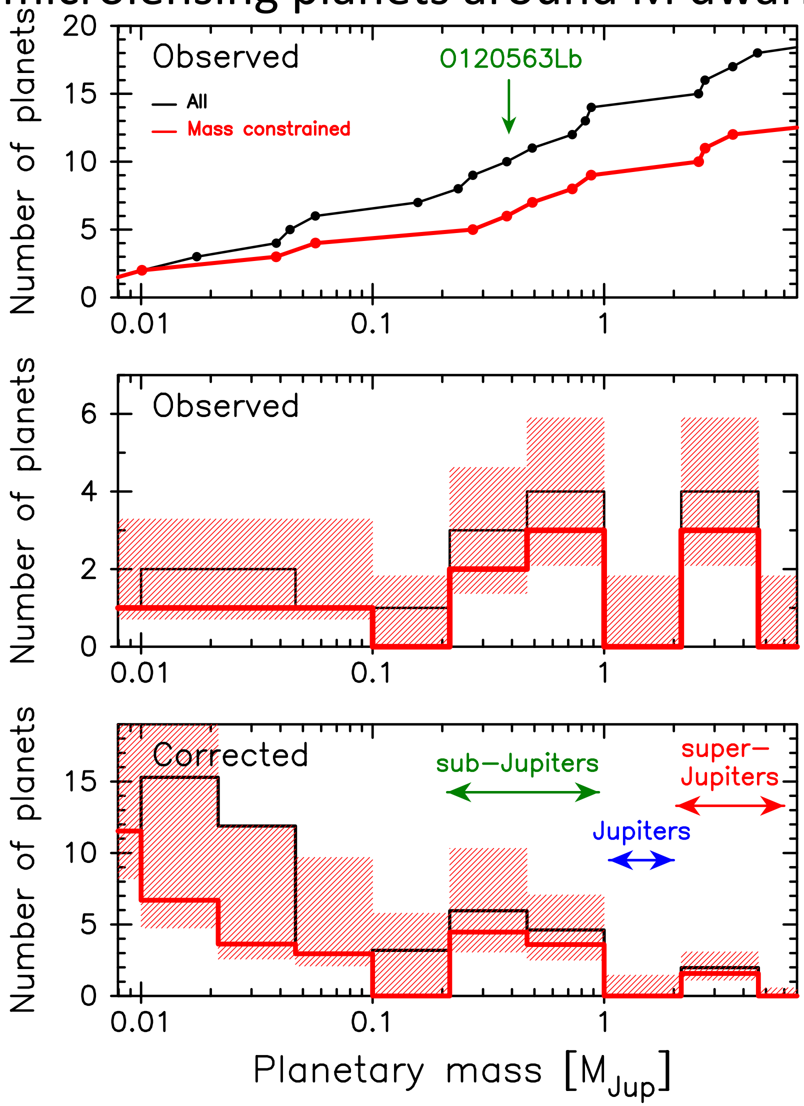
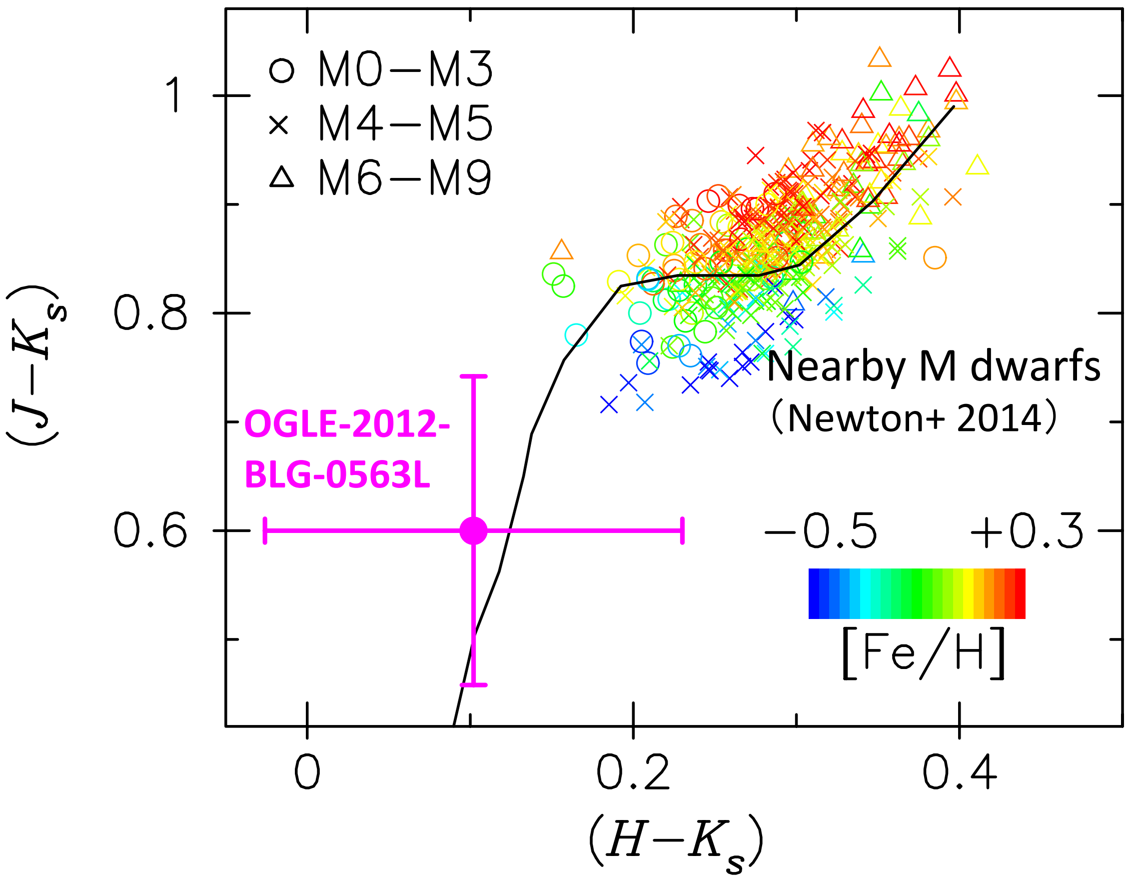
Possible Paucity of Jupiters around M dwarfs

Mass distribution for microlensing planets around M dwarfs



- There seems **a pileup of sub-Jupiters** and **a lack of Jupiters**, although not still significant (~2 sigma)
- If true, then it might be a consequence of core-accretion
- Some super-Jupiters ($M_p > 2 \times M_{jup}$) might have formed by other mechanisms

Implication for Metallicity from the Colors



- Estimate (J-Ks) and (H-Ks) colors of the host star
- Marginally consistent with **low-metallicity mid-to-early M dwarfs**
- First metallicity inference for a microlensing host star

The large errors mainly come from **several calibration steps** to derive the brightness of the source star, which can significantly be reduced by future, spatially resolving observations

Summary

- **OGLE-2012-BLG-0563** is a high magnification event showing a clear planetary signature with a mass ratio of ~10^{-3}, but without a parallax signal

- Combining with the lens flux obtained with Subaru/AO imaging, we find that the lens system is composed of an M dwarf orbited by a cold Saturn

- There seems a possible pile-up of sub-Jupiters around M dwarfs, in contrast to a possible paucity of Jupiters

- We for the first time infer the metallicity of a microlensing host star, which can be tested by future high resolution imaging