Exploring the brown dwarf desert with gravitational microlensing

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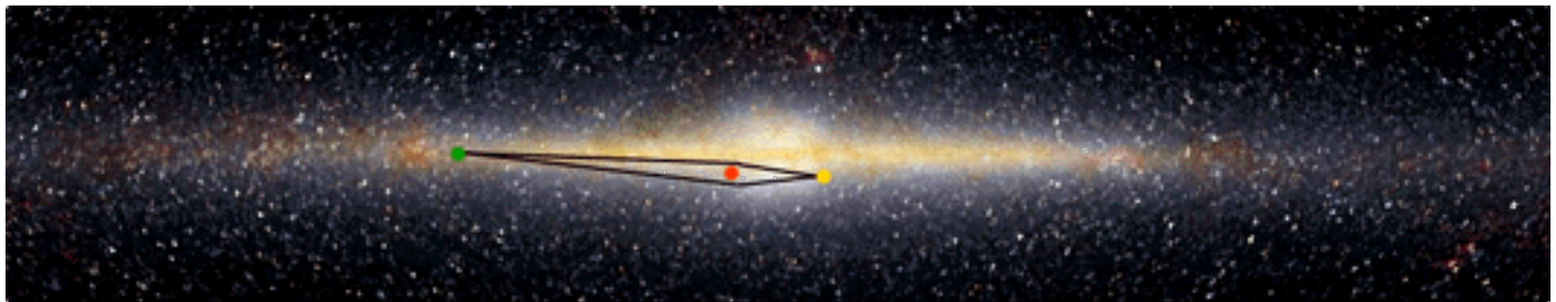
From super-Earths to brown dwarfs: who's who? — Paris

Thursday 2nd July 2015

Gravitational microlensing effect

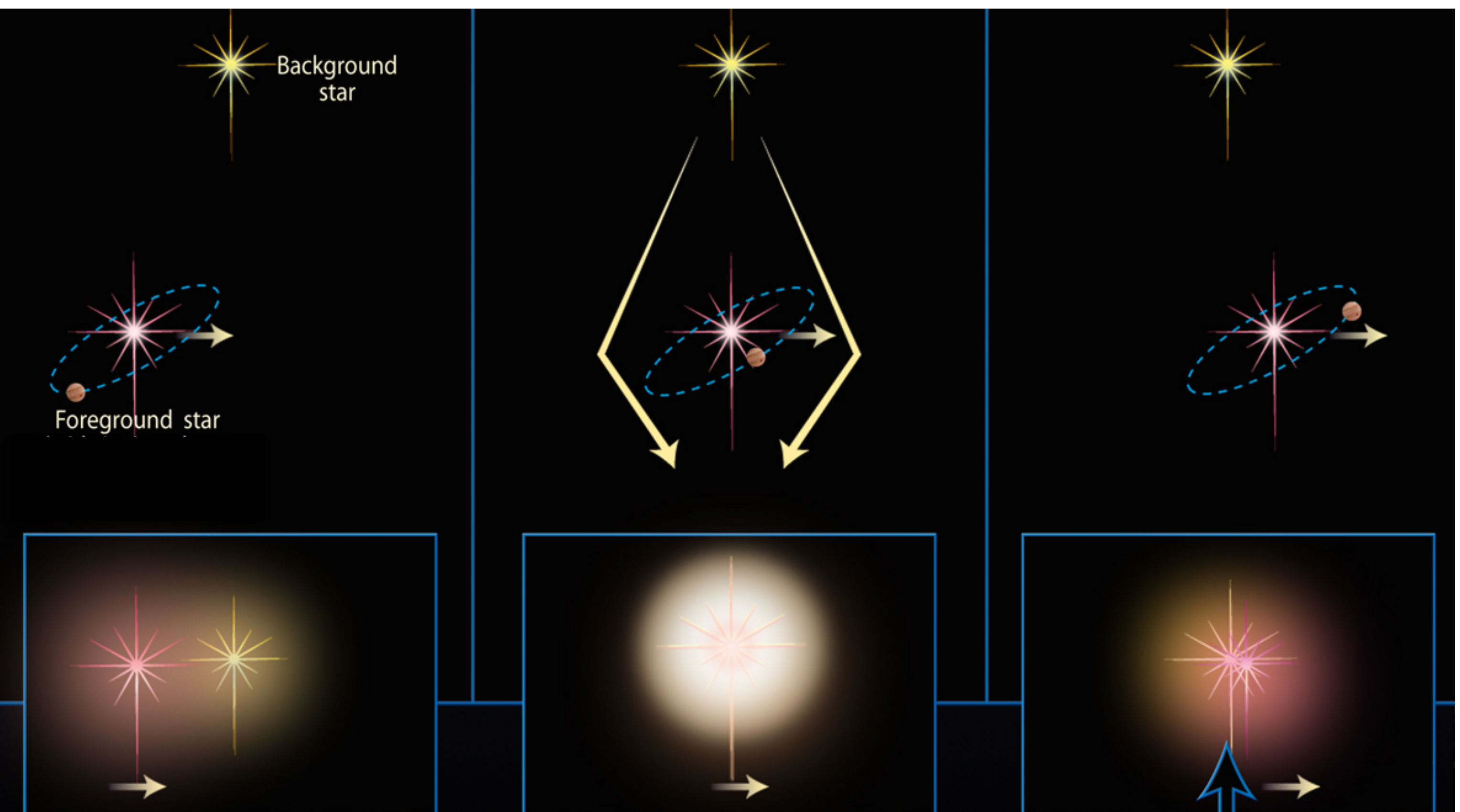
Deflexion due to a star. microlens

High sensitivity to the **mass distribution** in the lens plane.



Credit: MOA collaboration

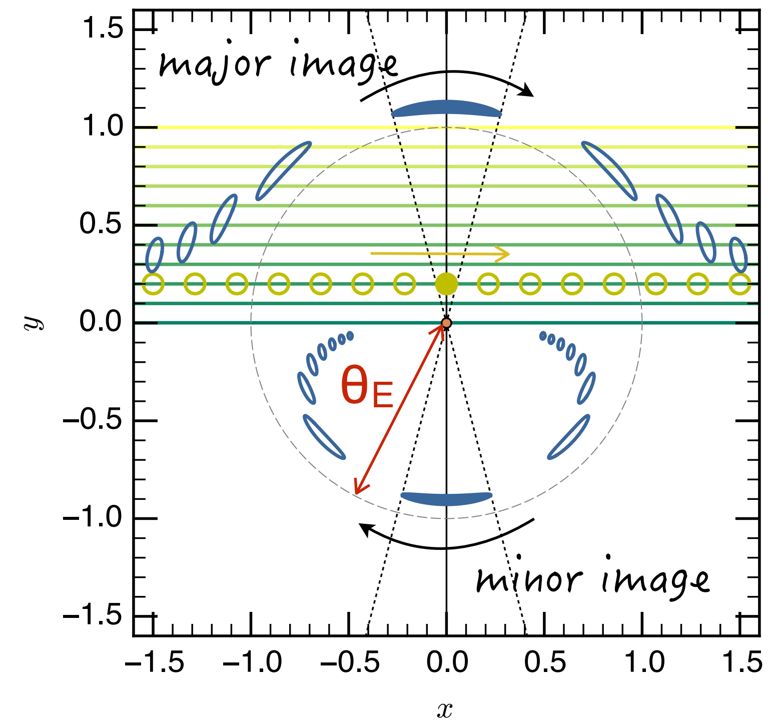
Binary lens model



Adapted from NASA, ESA, A. Feild, D. Bennett, and J. Anderson

Multiple images not resolved

Single lens model



Angular scale: Einstein radius θ_E

Typical values

$\theta_{\mathrm{E}} \approx 1\,\mathrm{mas}$

$D_{\mathrm{L}} \in [0.5\,;8]\,\mathrm{kpc}$

$D_{\mathrm{S}} \approx 8\,\mathrm{kpc}$

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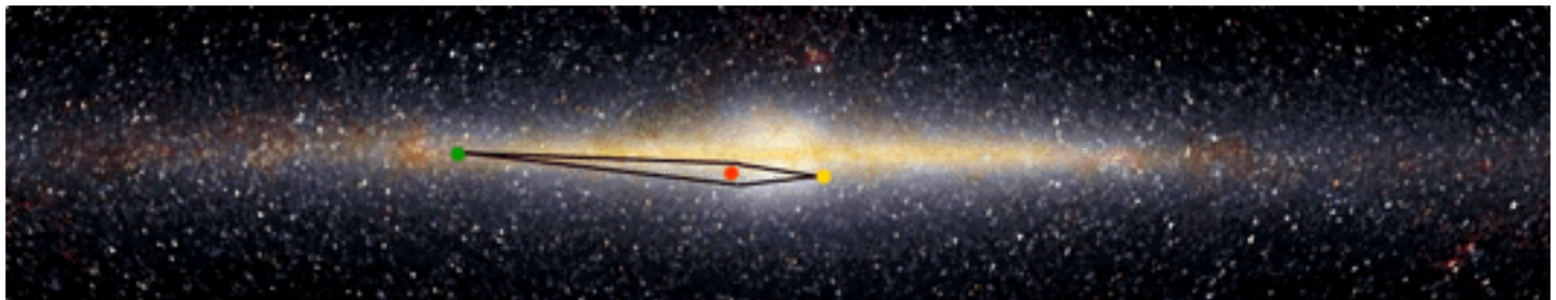

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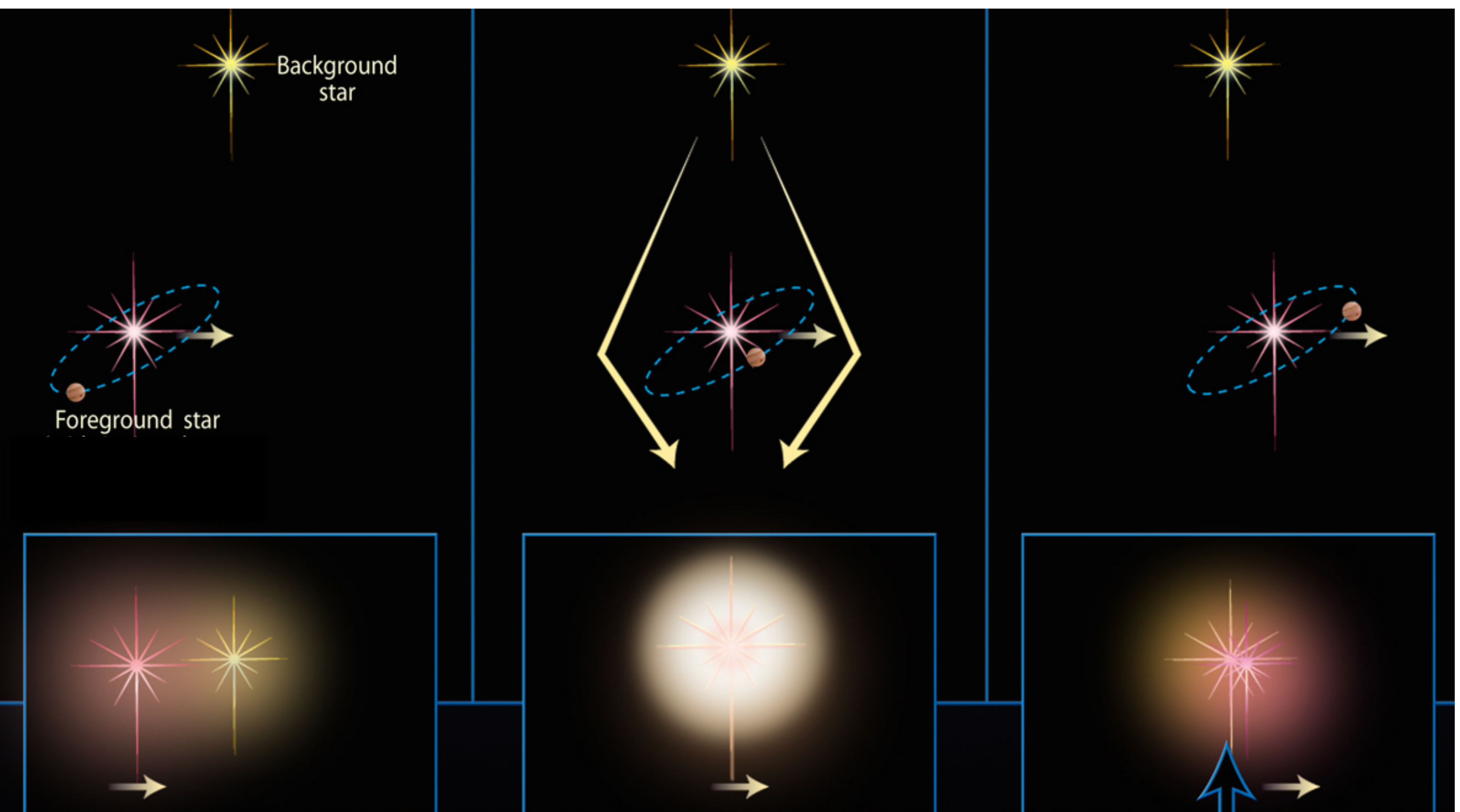

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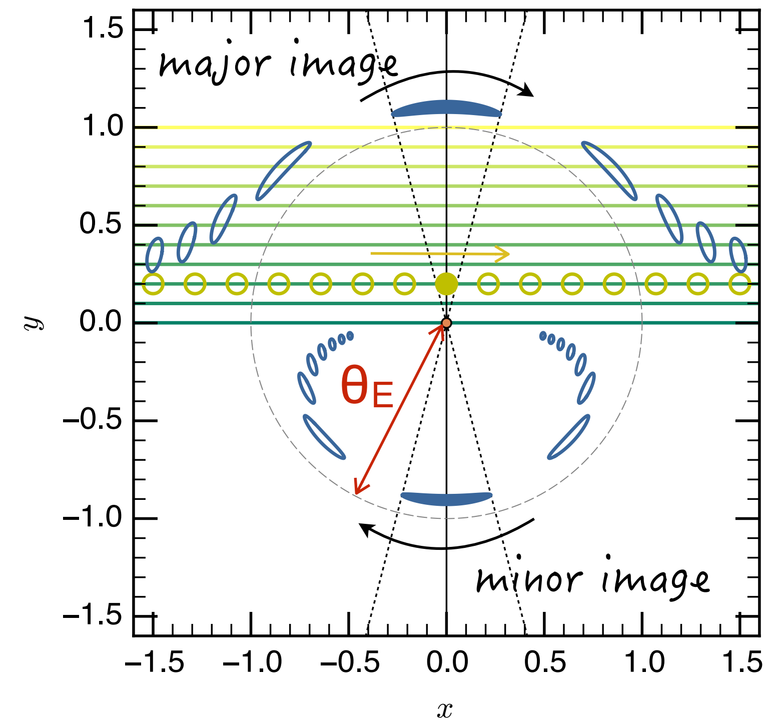

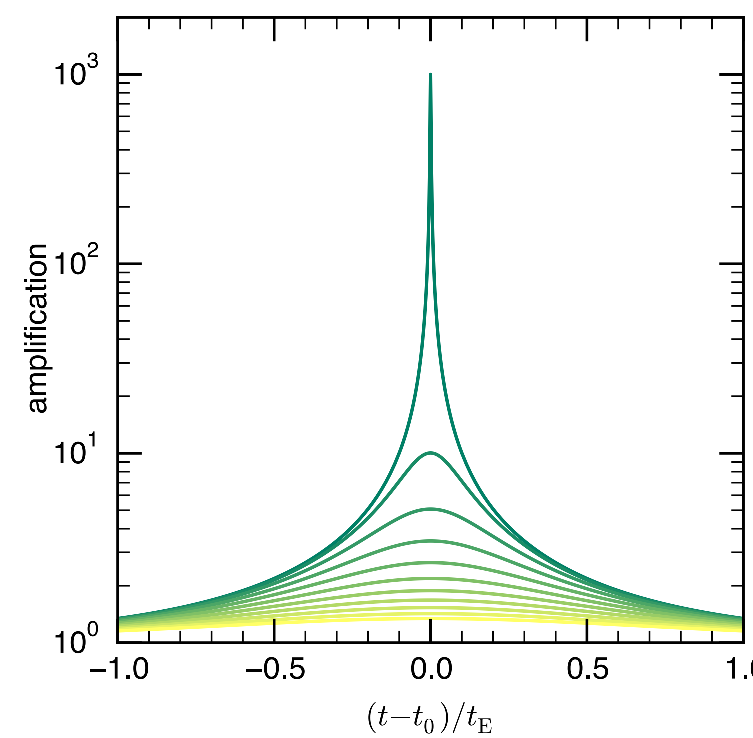

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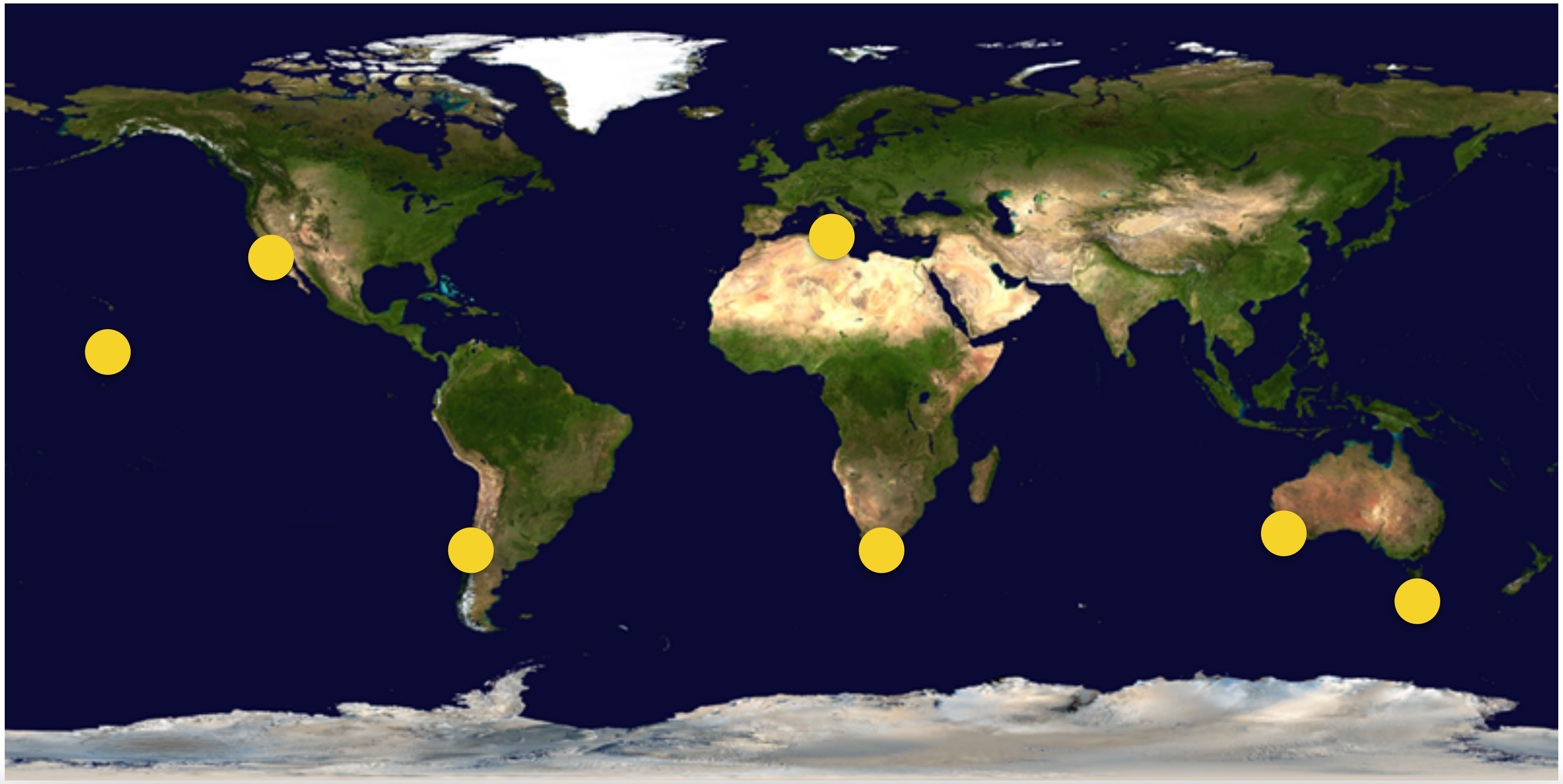
Events detection and follow-up

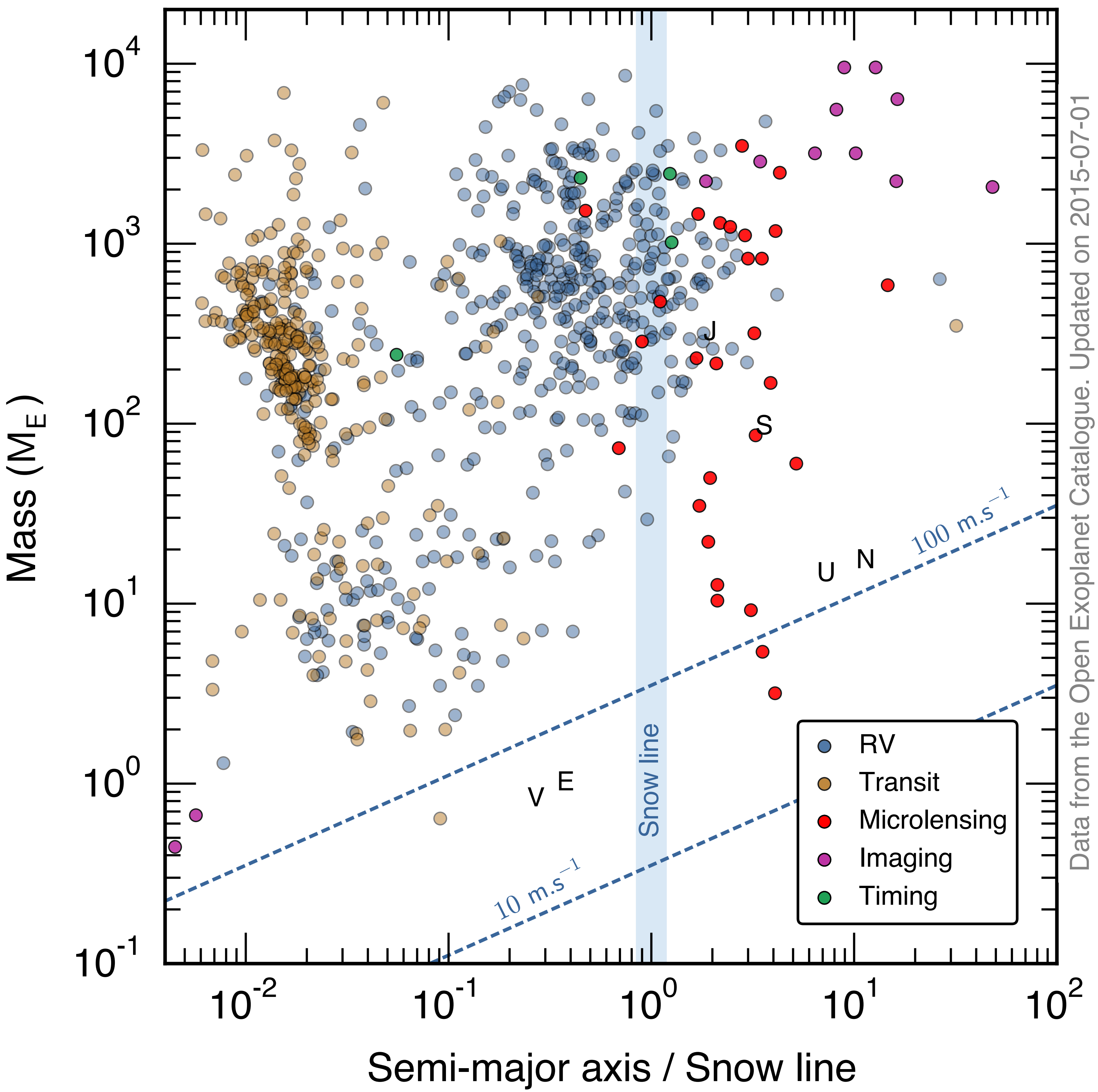
- **Magnification as a function of time ➜ source flux as a function of time**
- **Light curve:** flux from the source as a function of time

International collaborations:
KMTNet, μFUN, MOA, OGLE, PLANET, RoboNet...



1. How can we model a light curve with anomalies?
2. How can we determine masses?

Microlensing among exoplanets detection techniques



35 planets published

- **orbits: 0.5-10 AU**
- **masses down to Earth**
- **beyond the snow line**

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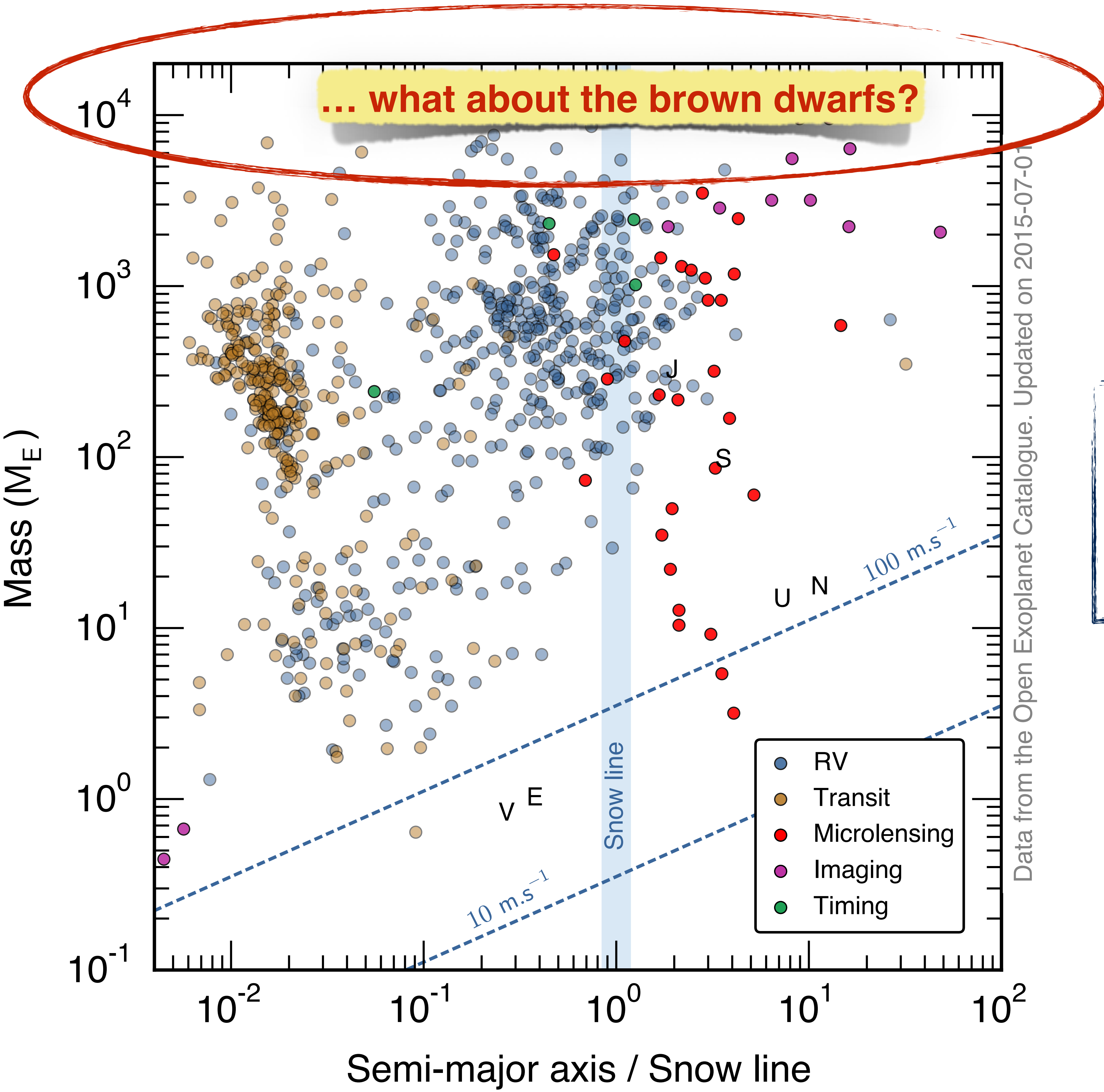

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Brown dwarfs detections through microlensing

- **Isolated brown dwarf**

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- **Brown dwarfs companion to stars**

  OGLE-2008-BLG-0510/MOA-2008-BLG-369 [Bozza et al. 2012/Shin et al. 2012a]: massive BD / M dwarf.

  OGLE-2011-BLG-0172/MOA-2011-BLG-104 [Shin et al. 2012b]: 21 M_J orbiting a M dwarf.

  MOA-2011-BLG-149 [Shin et al. 2012b]: 20 M_J orbiting a M dwarf.

  MOA-2009-BLG-411 [Bachelet et al. 2012]: 52 M_J orbiting a M dwarf.

  MOA-2010-BLG-073 [Street et al. 2013]: 11 M_J orbiting a M dwarf.

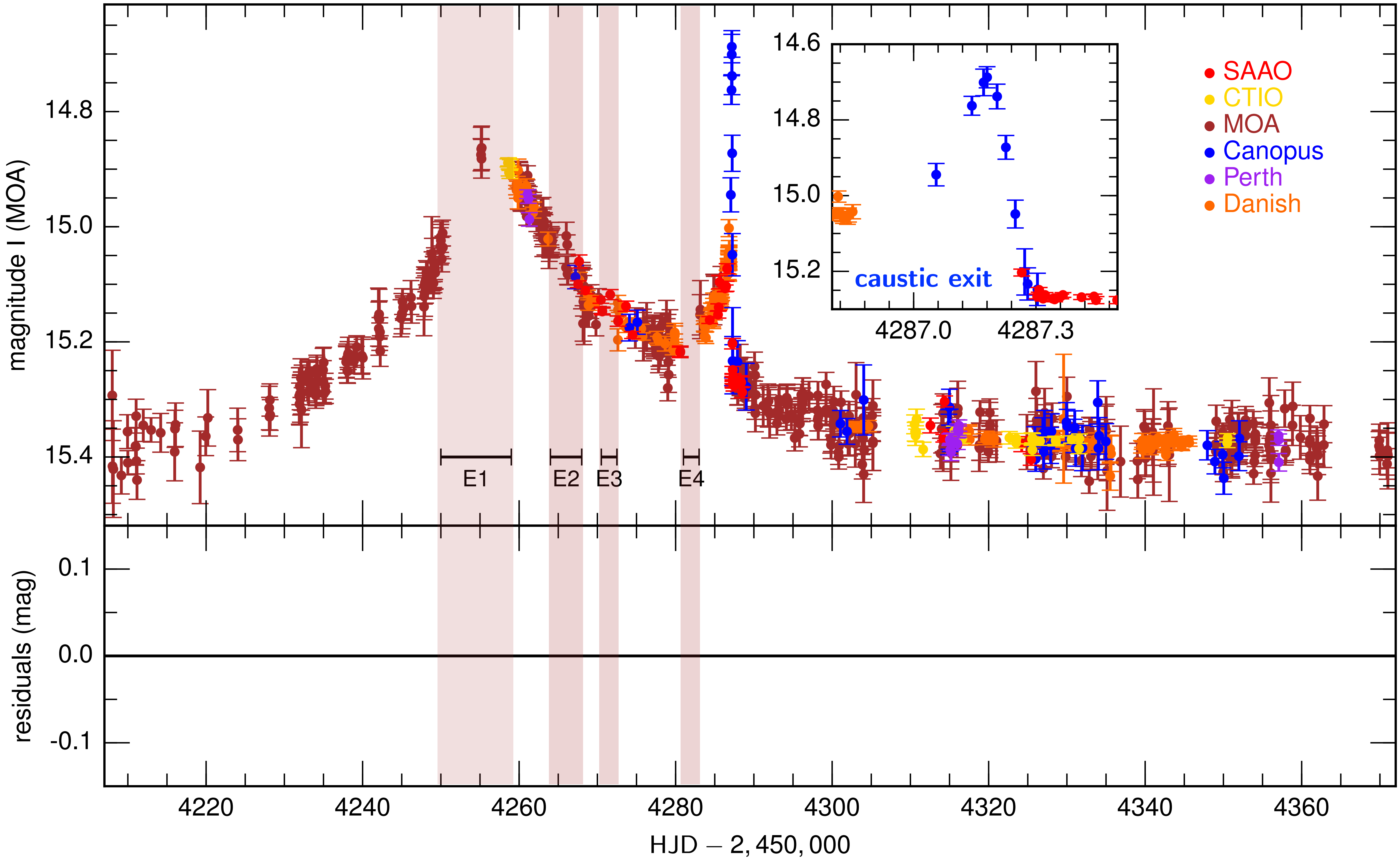
  OGLE-2013-BLG-0102 [Jung et al. 2015]: 13 M_J orbiting a host at BD/star boundary.

  OGLE-2013-BLG-0578 [Park et al. 2015]: 33.5 M_J orbiting a M dwarf.

  MOA-2007-BLG-197 [Ranc et al. 2015, in press]: 41 M_J orbiting a **Solar-type star**.

The challenge of MOA-07-197 interpretation

Where is the caustic entry?



[Ranc et al. 2015, in press (arXiv:1505.06037)]

MOA-2007-BLG-197

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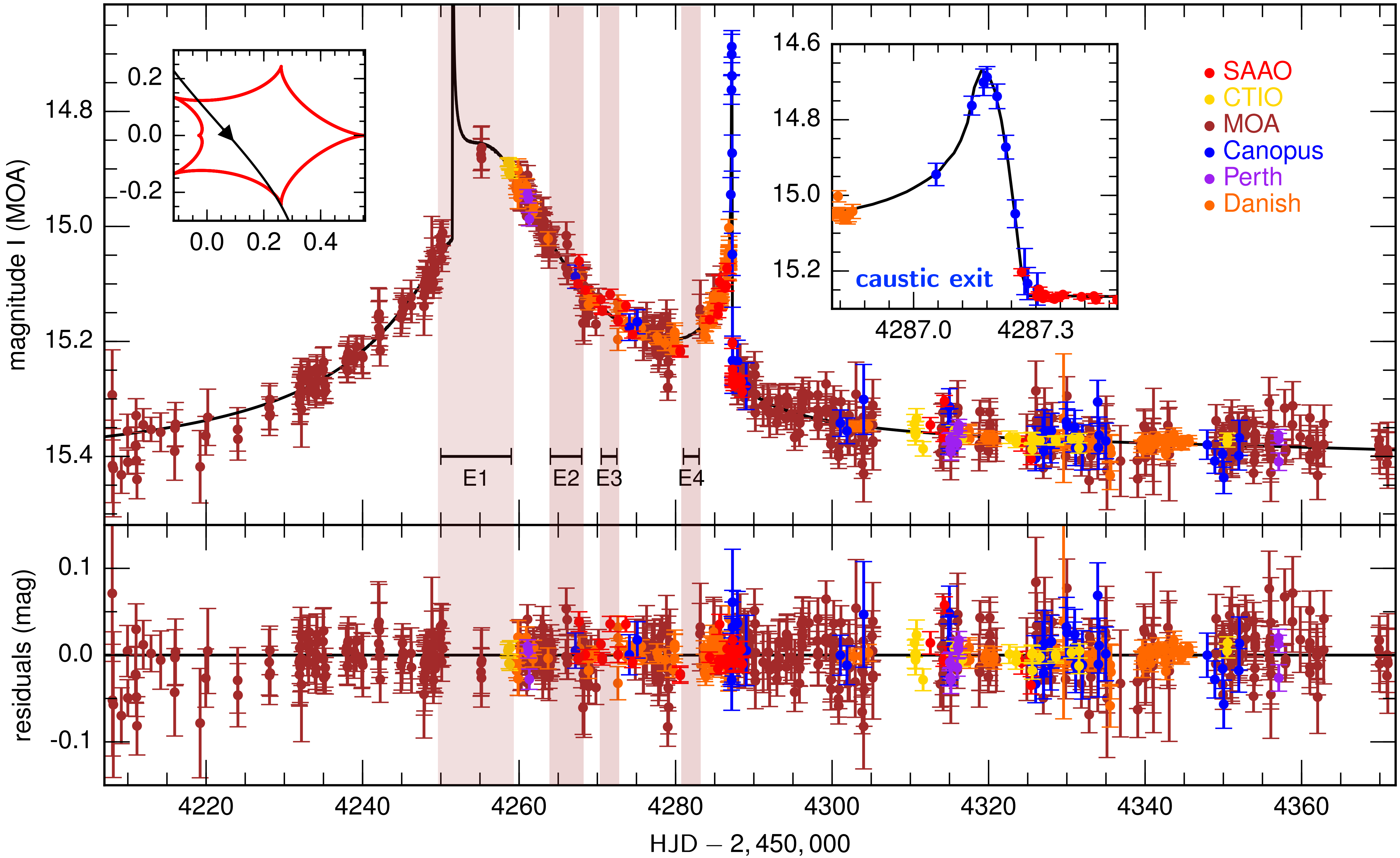

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MOA-2007-BLG-197

MOA-2007-BLG-197 modelling

✦ 11 Parameters fitted

- **caustic structure**
- source/lens motion
- timescales
- source property
- annual parallax
- lens rotation

$$\rho = \frac{\theta_S}{\theta_E}$$

$$\theta_E = 2.8542 \text{ mas} \left(\frac{M_S}{M_\odot}\right)^{1/2} \left(\frac{\pi_{rel}}{1 \text{ mas}}\right)^{1/2}$$

$$\pi_{rel} = 1 \text{ mas} \left(\frac{1 \text{ kpc}}{D_L} - \frac{1 \text{ kpc}}{D_S}\right)$$

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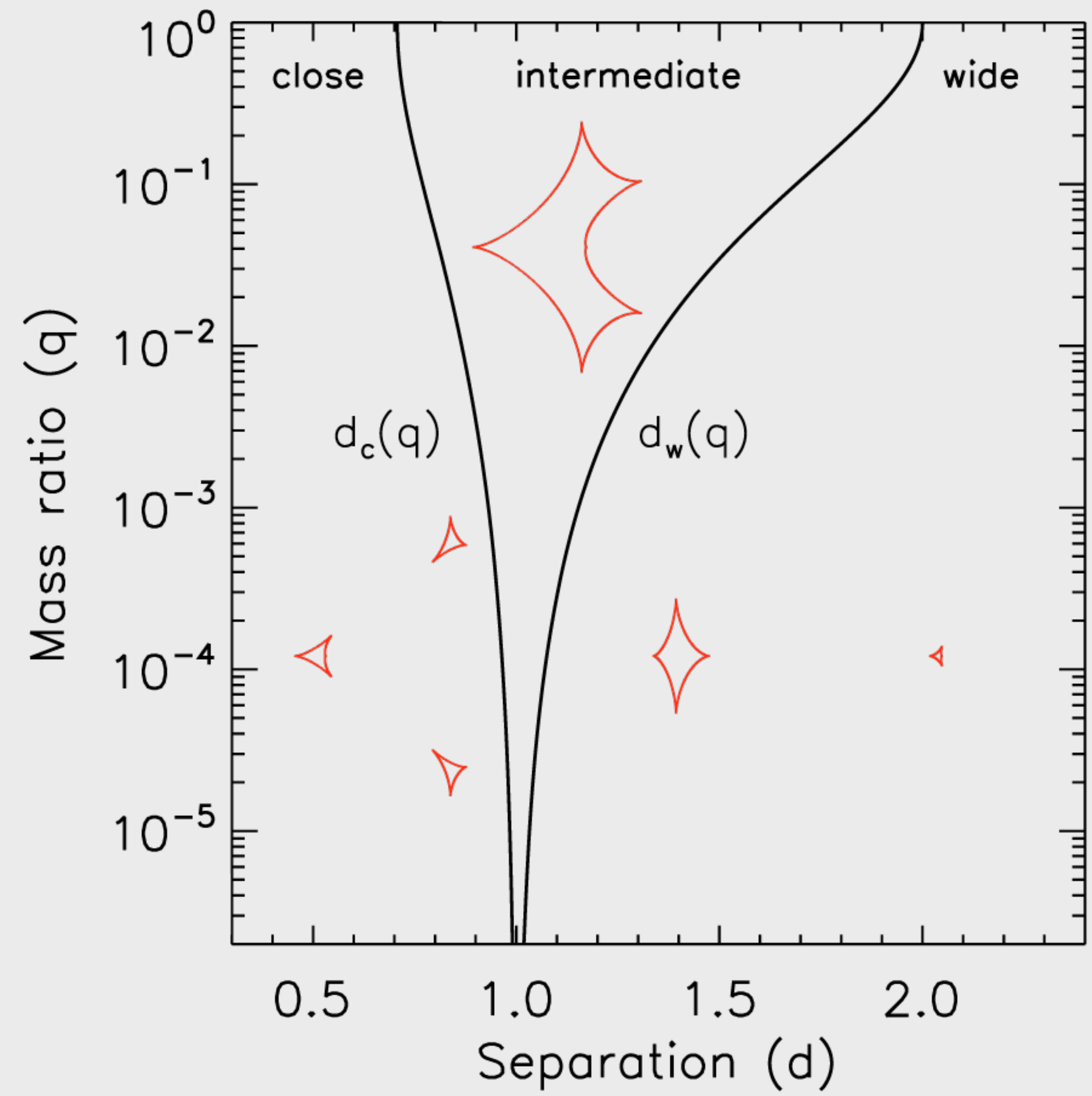
Caustic structure



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Degeneracy between parallax and orbital motion

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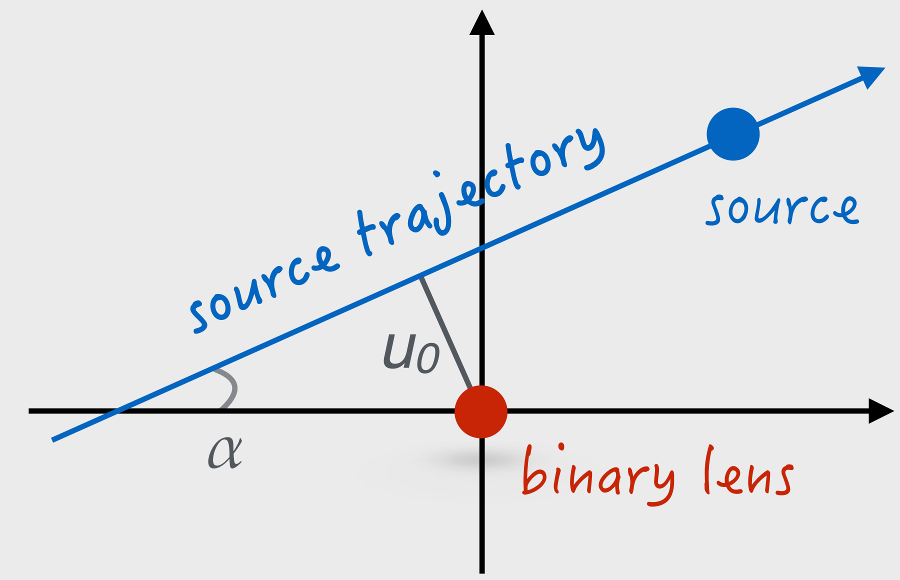
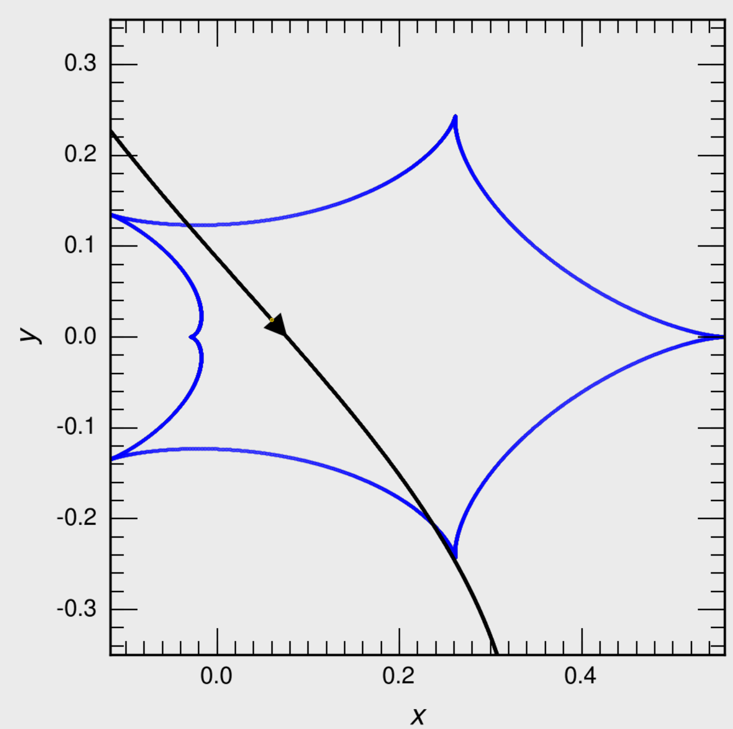
Parallax

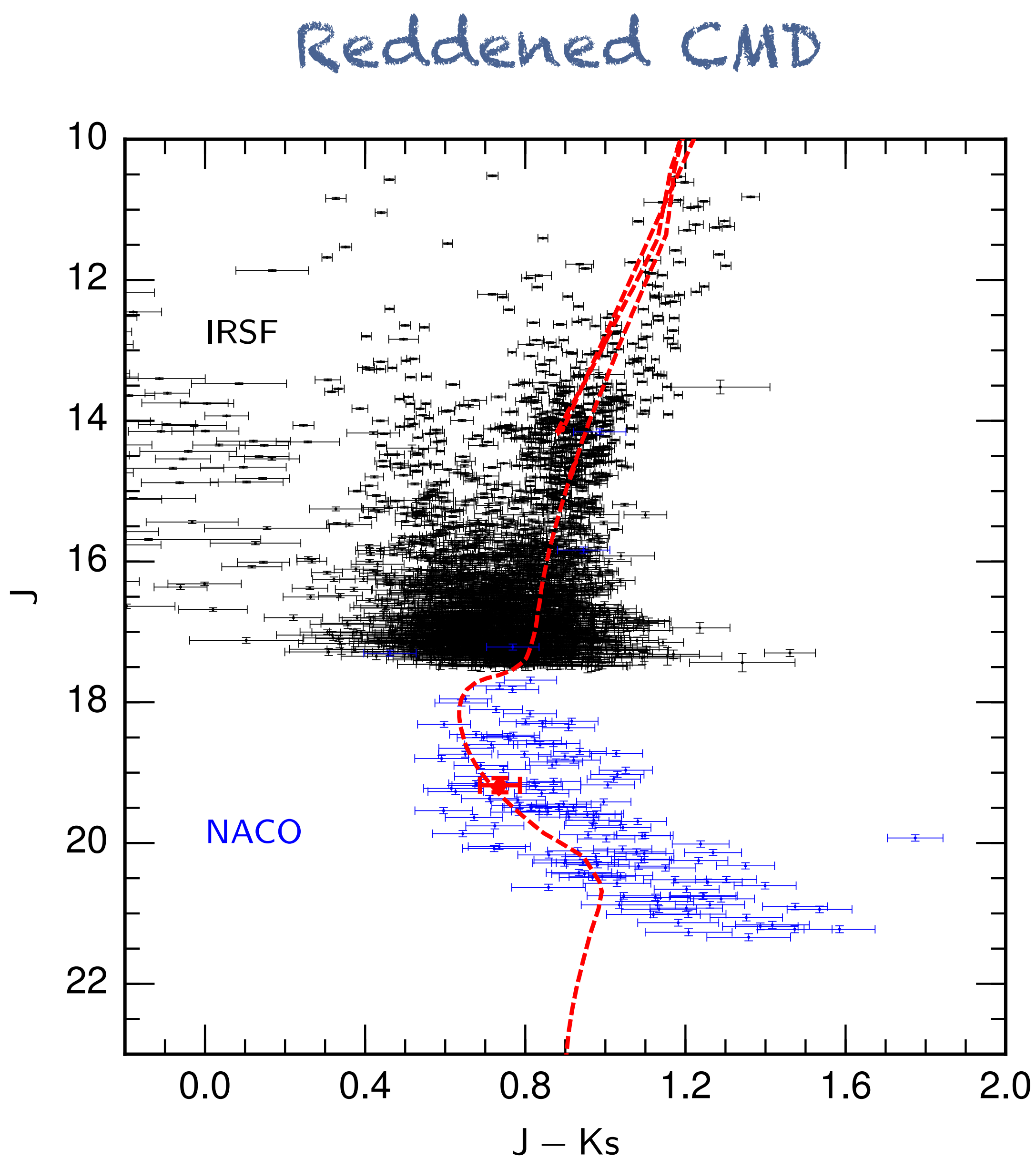


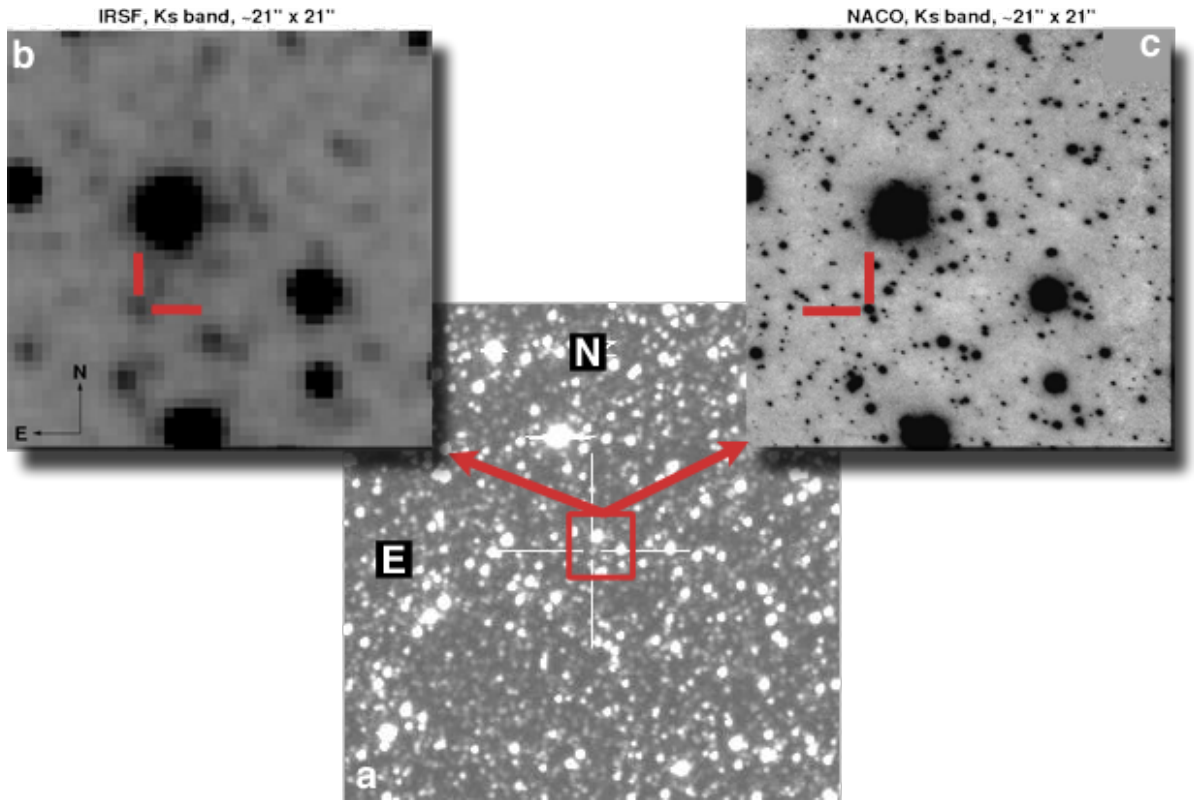
$$u^2 = \sqrt{\tau(t)^2 + \beta(t)^2} \quad \text{with} \quad \tau(t) = u_0 + \boldsymbol{\pi}_\mathbf{E} \cdot \mathbf{\Delta s}_\perp$$

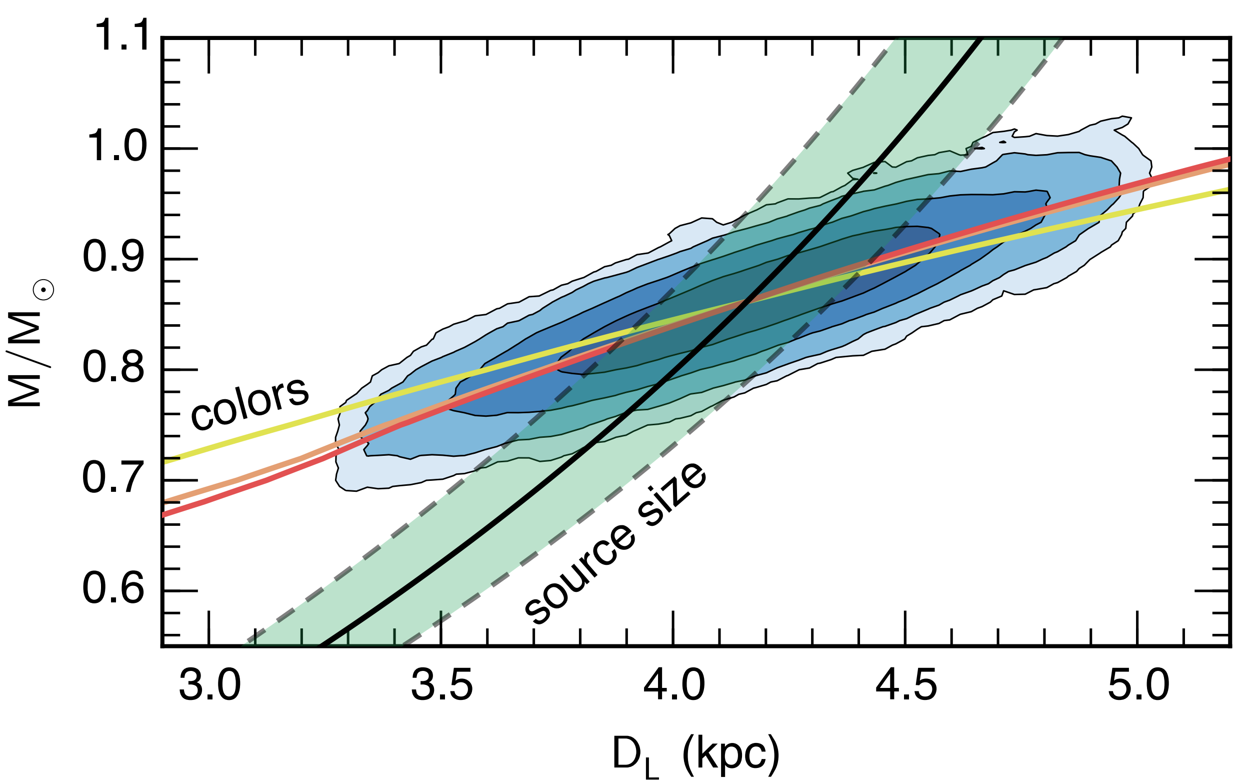
$$\beta(t) = \frac{t - t_0}{t_E} + \boldsymbol{\pi}_\mathbf{E} \times \mathbf{\Delta s}_\perp$$



Additional measurements from NaCo

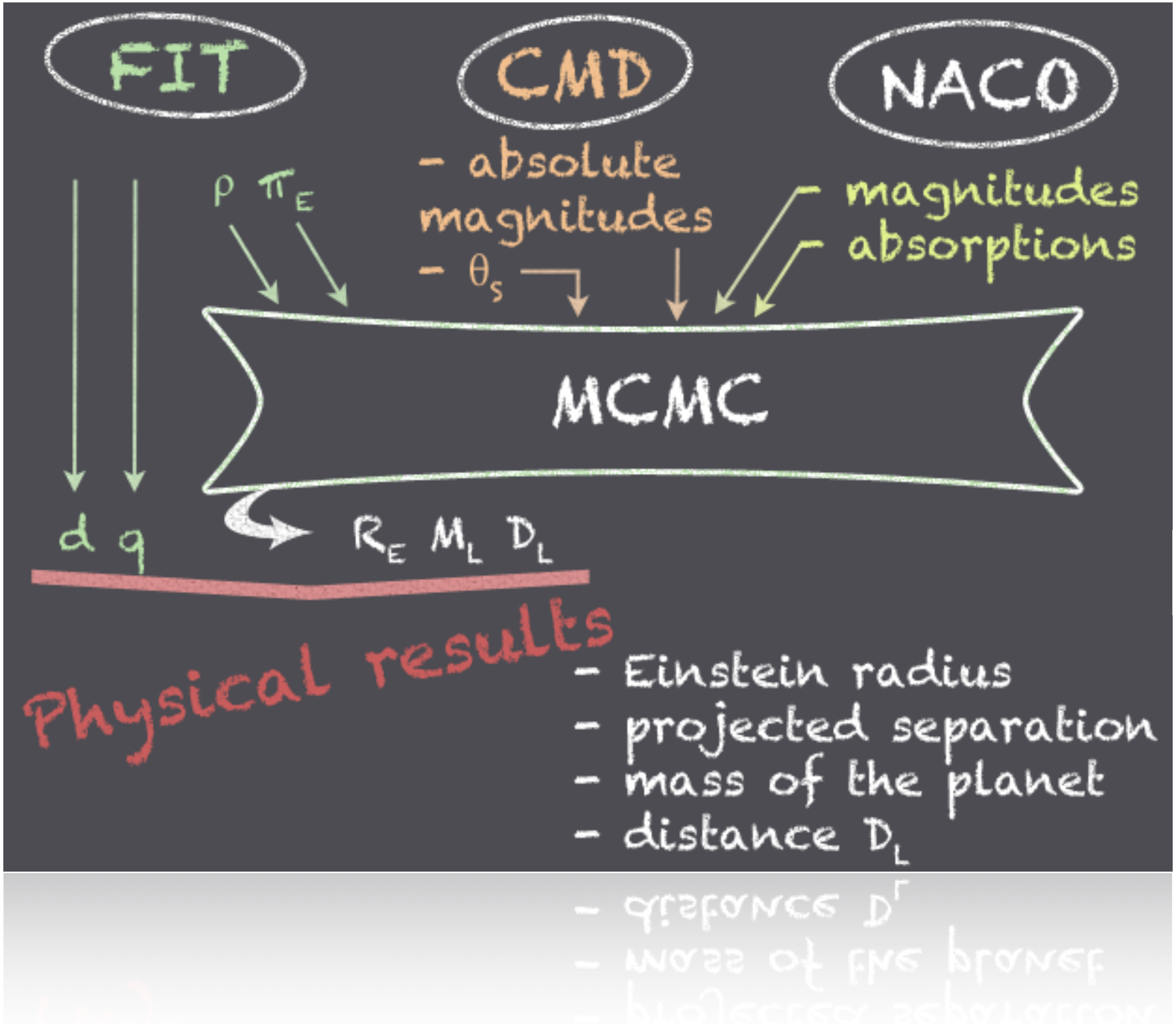






- High resolution AO images in J, H, Ks
- Blending also detected in J, H, Ks from NACO
- **Blending = LENS**

Bayesian re-construction



Priors

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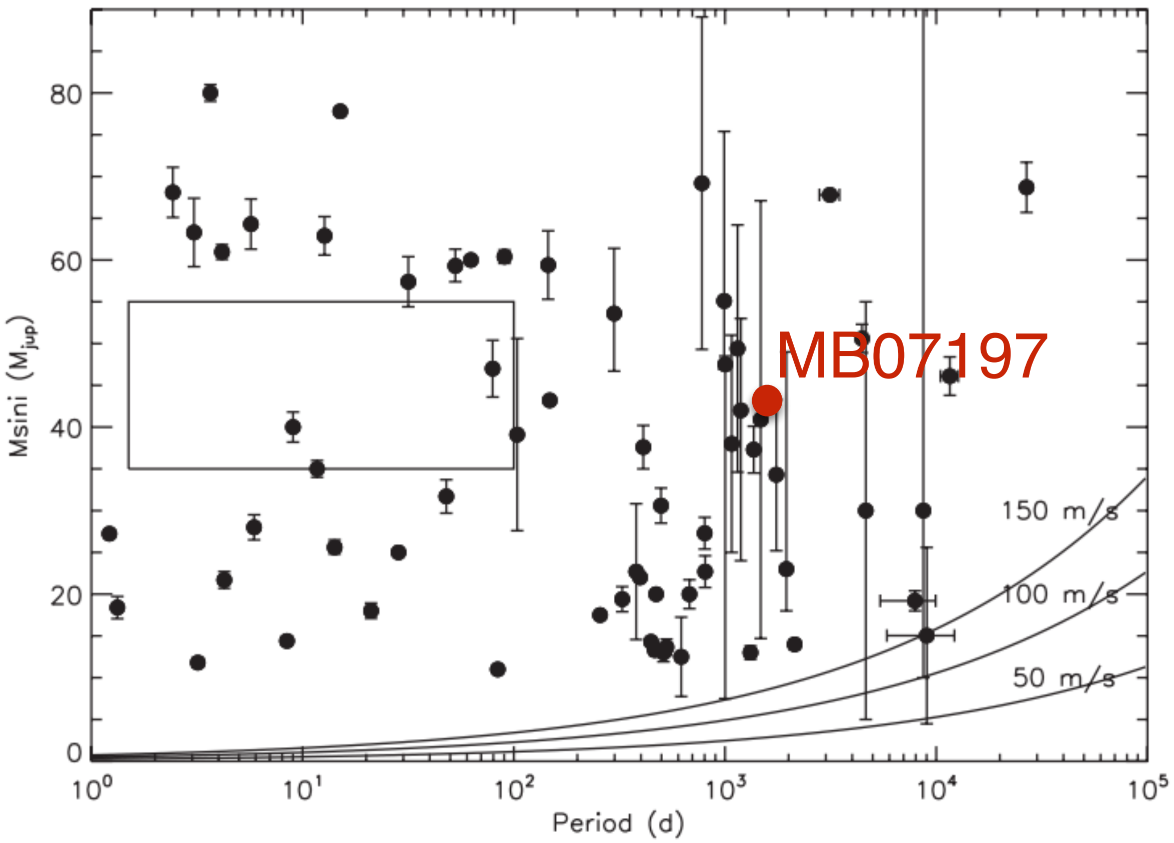
The first BD orbiting a Sun-like star via microlensing



62 brown dwarfs orbiting solar-type stars

Ma & Ge (2014)

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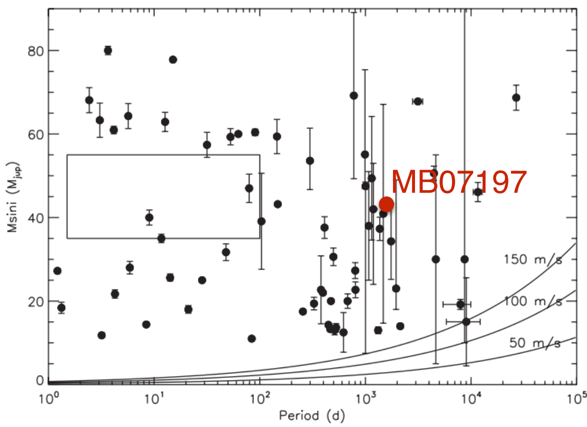

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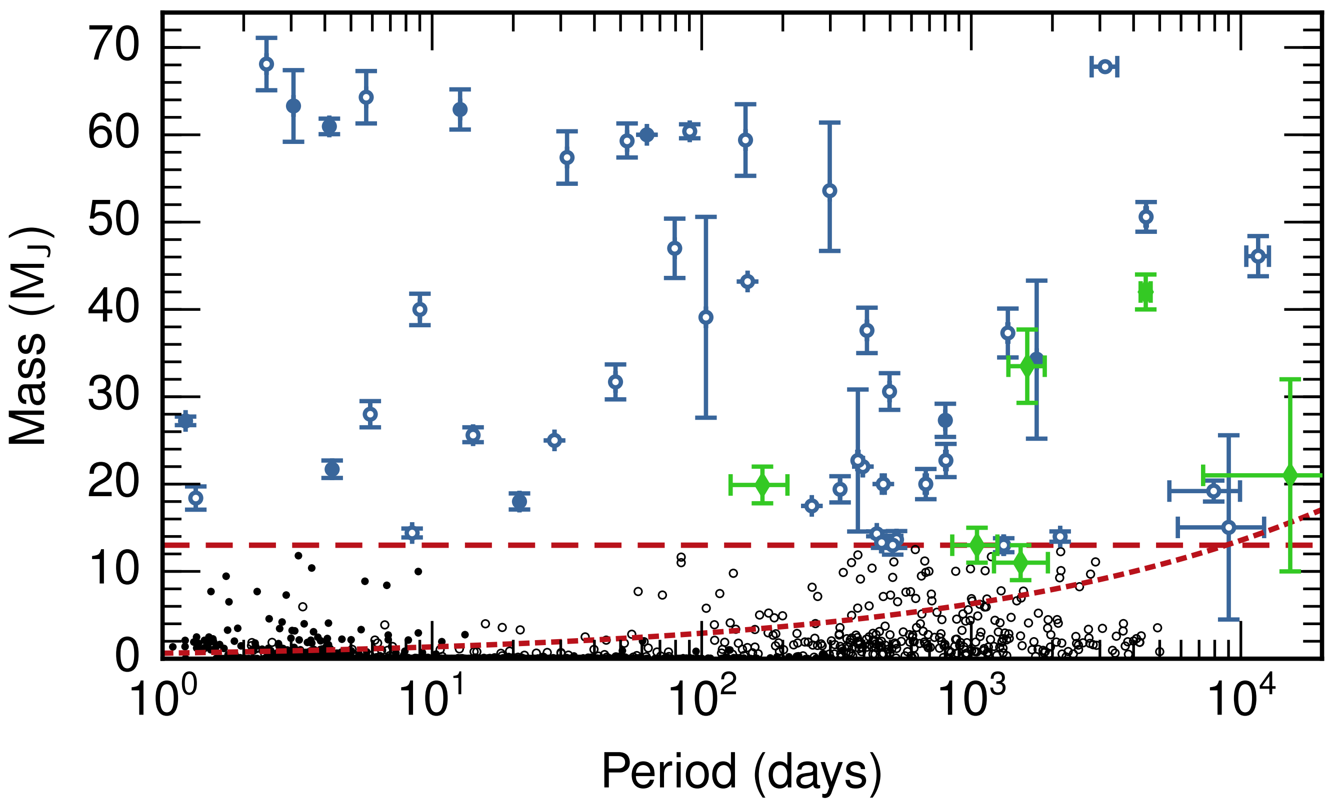

11 brown dwarfs through microlensing

- 1 isolated
- 3 brown dwarfs hosting planets at short orbital periods
- 8 brown dwarfs companion to M dwarfs at long orbital periods
- 1 brown dwarf companion to a solar like star

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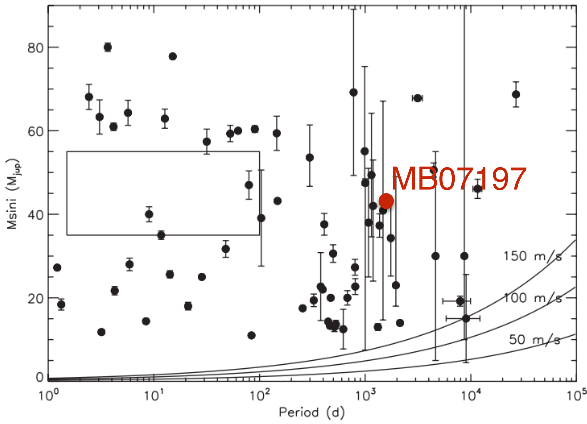

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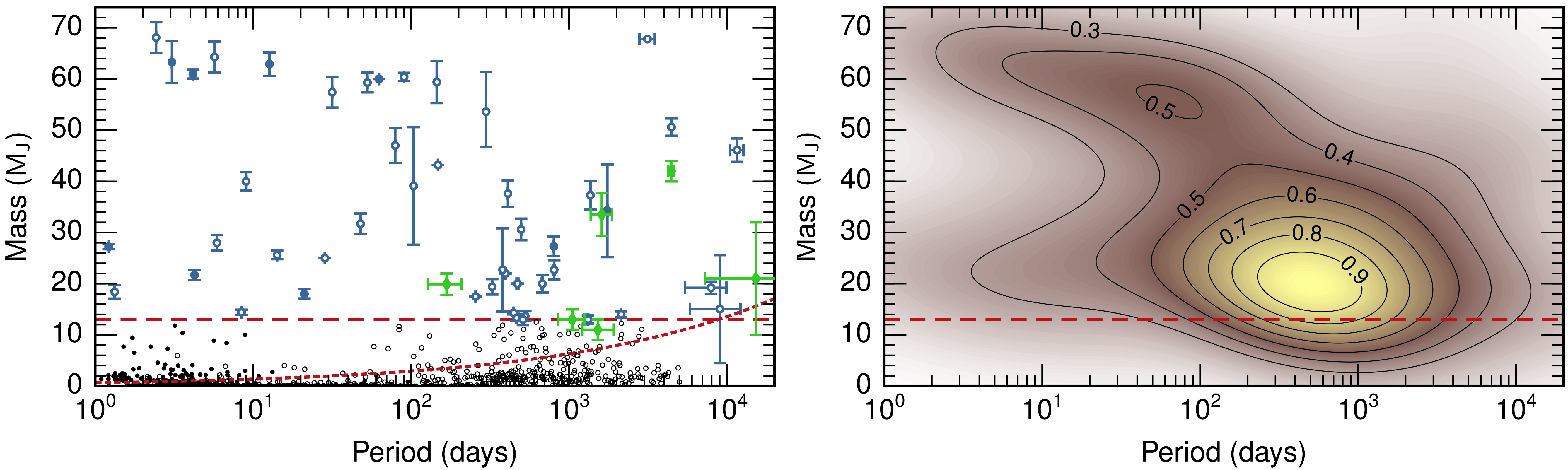

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Summary and Perspectives

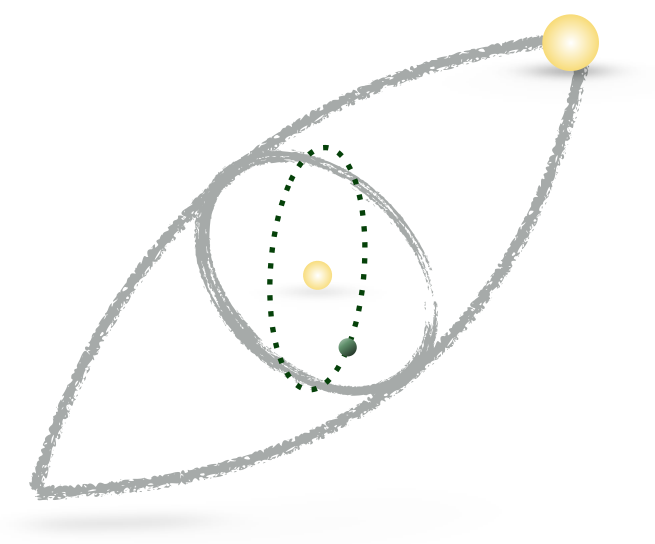
✦ **Analysis of MOA 2007-BLG-197.** [Ranc et al. 2015, in press (arXiv:1505.06037)]

- Detection of the first BD orbiting a Sun-like star using microlensing
- **Geometrical** and **orbital motion/parallax** degeneracies characterised.
- VLT NACO measurements lead to a well constrained mass of the lens.

✦ **Brown dwarf desert.**

- At **short orbital periods** and **intermediate masses**.
- What about **long orbital periods** and **high masses**?

  ➜ idea of a complex **brown dwarfs landscape.**
- What are the dominant formation mechanisms?



✦ **Perspectives.**

- Gravitational microlensing: powerful technique to **explore the BD landscape**.
- Good constrains on the formation/destruction scenarios from future **BD detections orbiting low mass stars**.
- Contribution of microlensing in this domain will increase in the future.