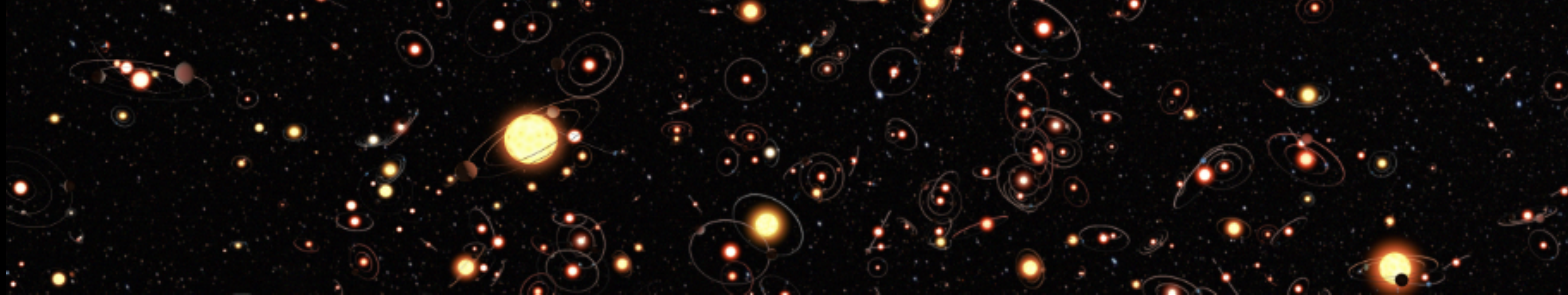
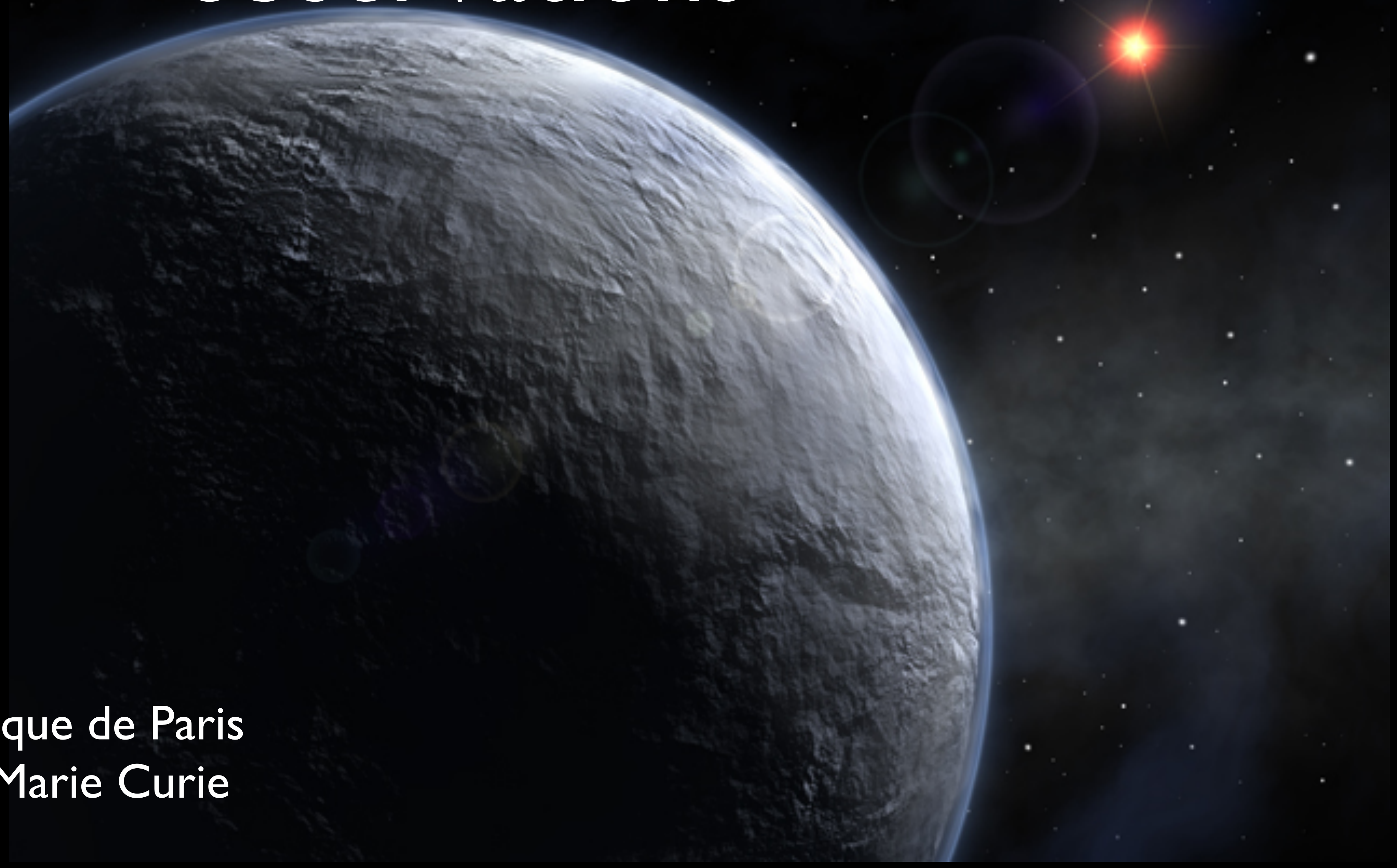


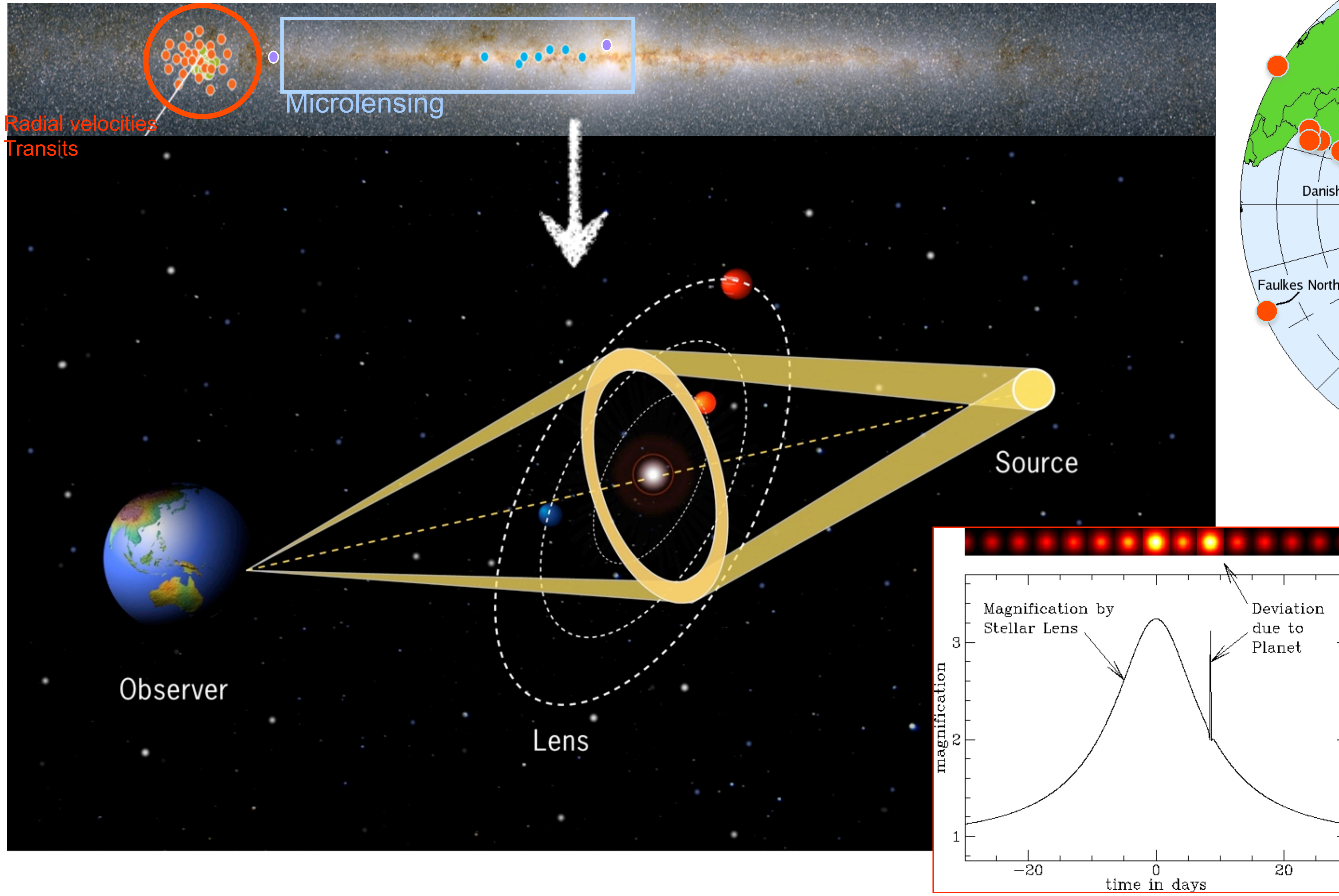
Planet abundance from PLANET 2002-07 observations

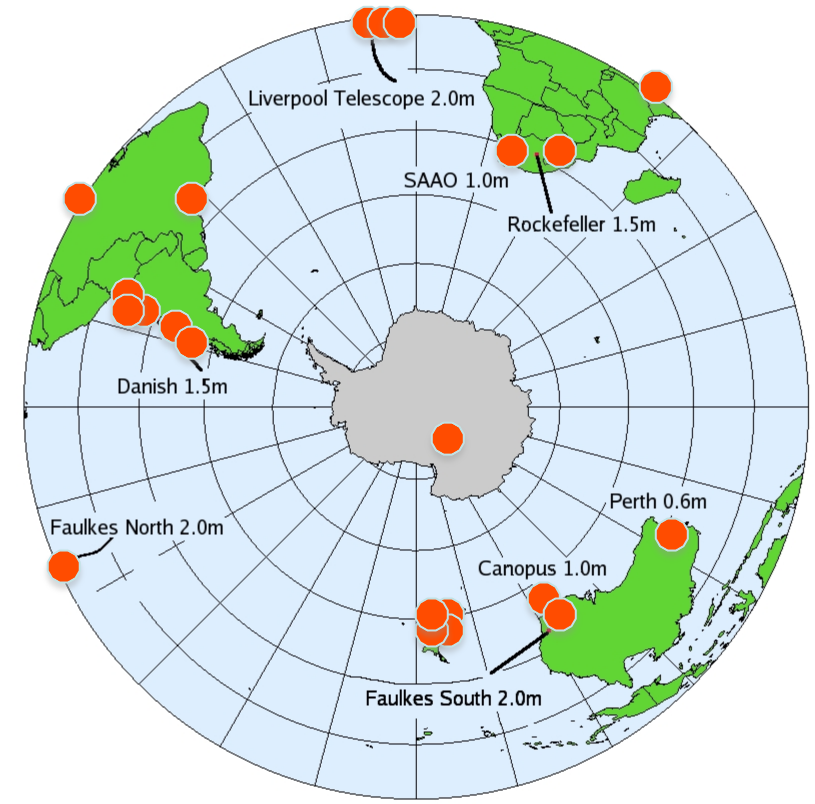


Collaborations :
PLANET
OGLE

Arnaud Cassan
Institut d'Astrophysique de Paris
Université Pierre et Marie Curie

Ground-based microlensing : alert + follow-up strategy

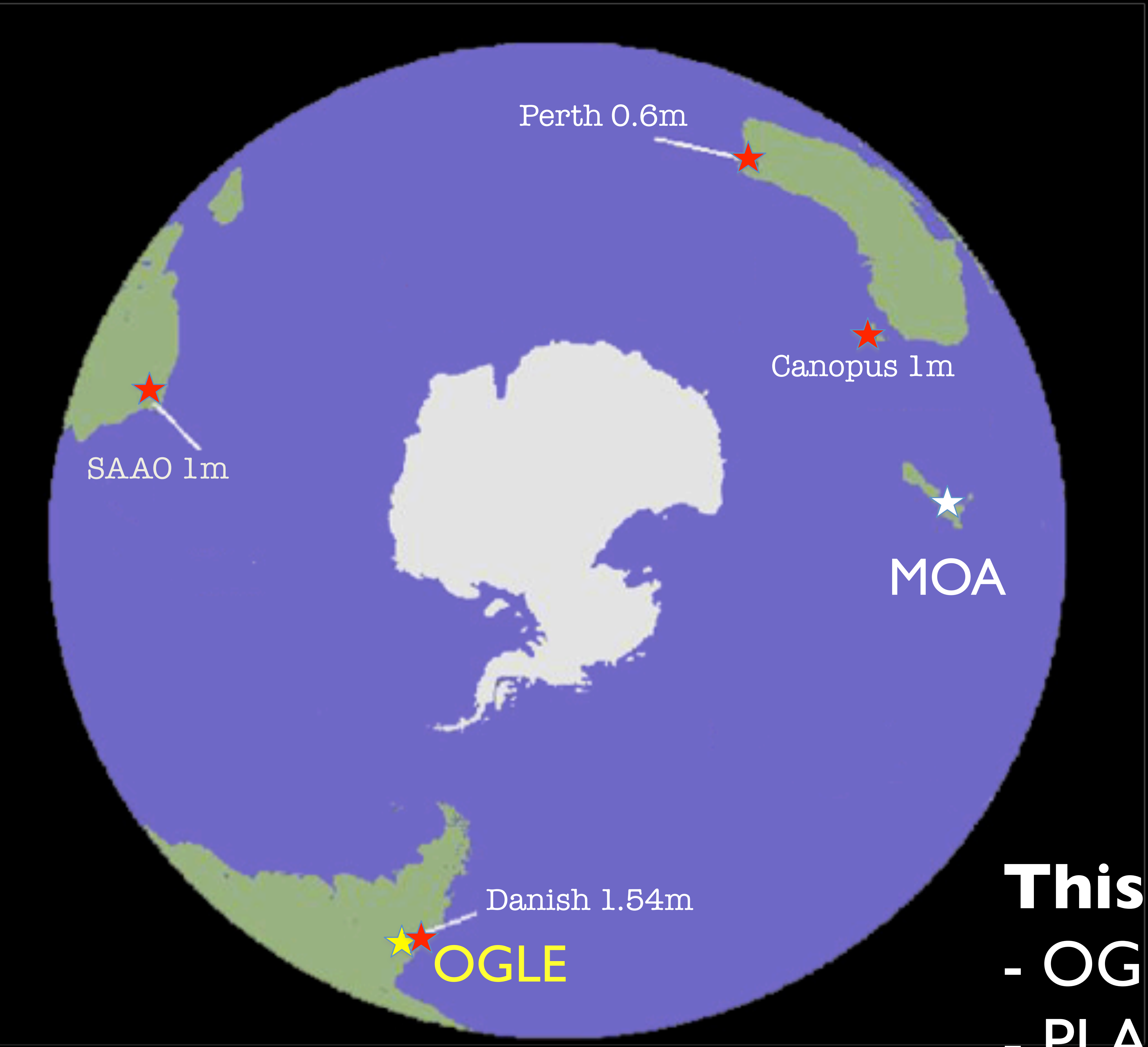




Alerts : OLGE, MOA

Follow-up : PLANET, μ FUN, RoboNET, MiNDSTEp, ++

PLANET Network 2002-07



This analysis :

- OGLE alerts
- PLANET follow-up

1995-2002 : no planet detections ?

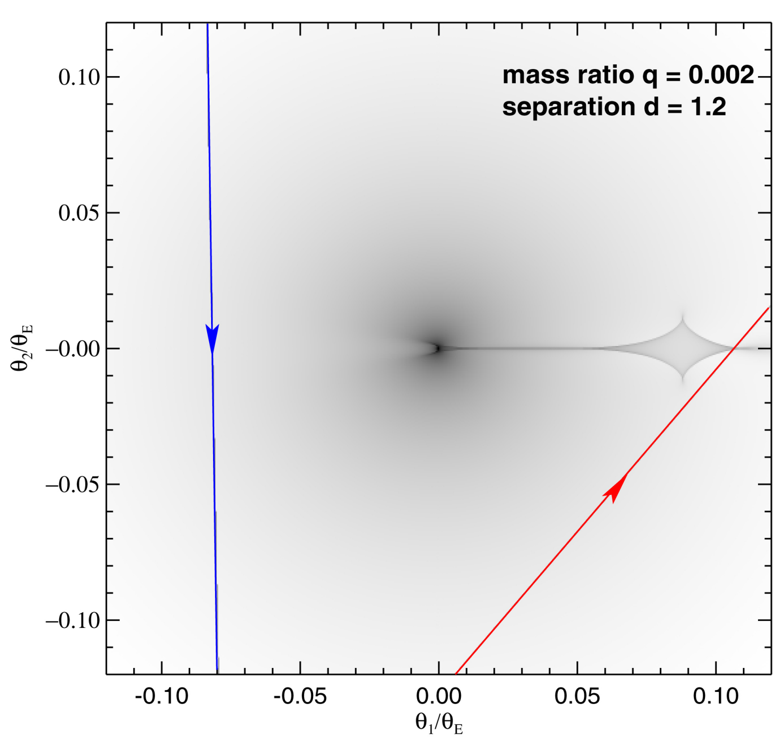
If giants planets at 1 AU were frequent, microlensing would detect many planets (ex. Griest & Safizadeh 1998, Gould & Loeb 1992)

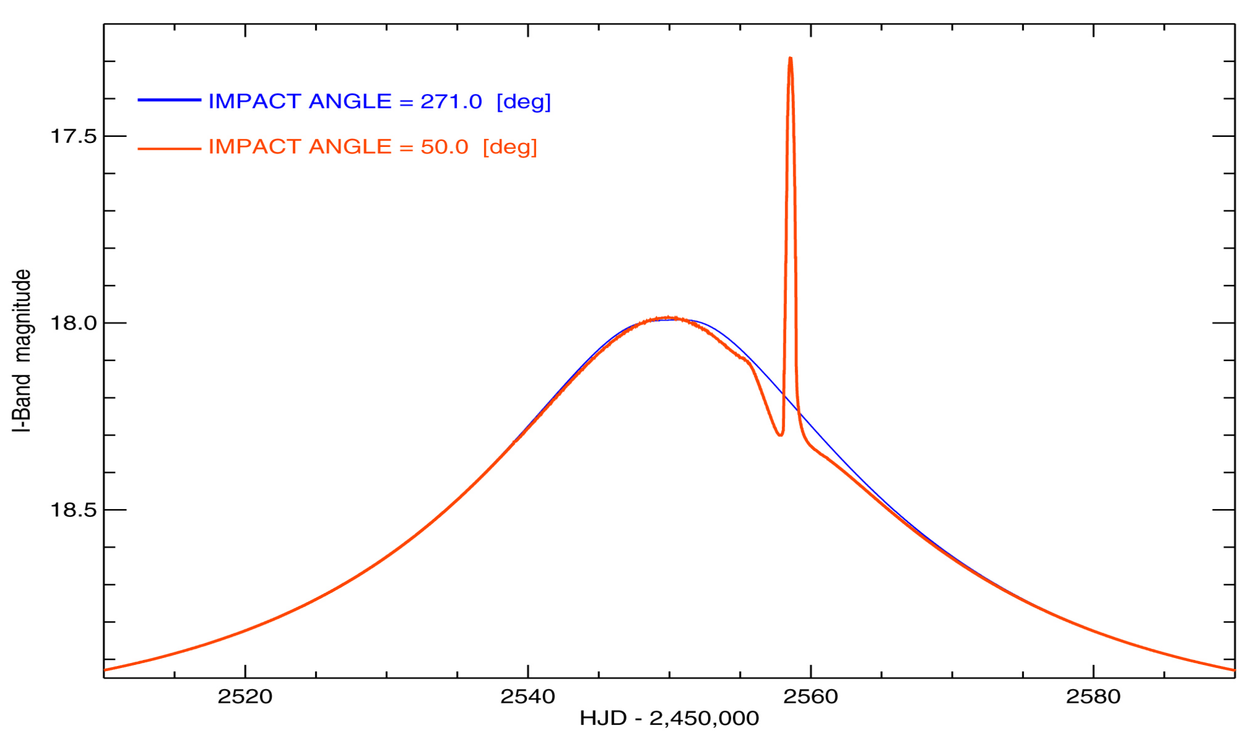
... but until 2003, we could not find them !

⇒ First analysis to constraint the frequency of exoplanets

(Gaudi *et al.* 2002, Tsapras *et al.* 2003, Snodgrass *et al.* 2004)

How to miss a planet orbiting a microlens star

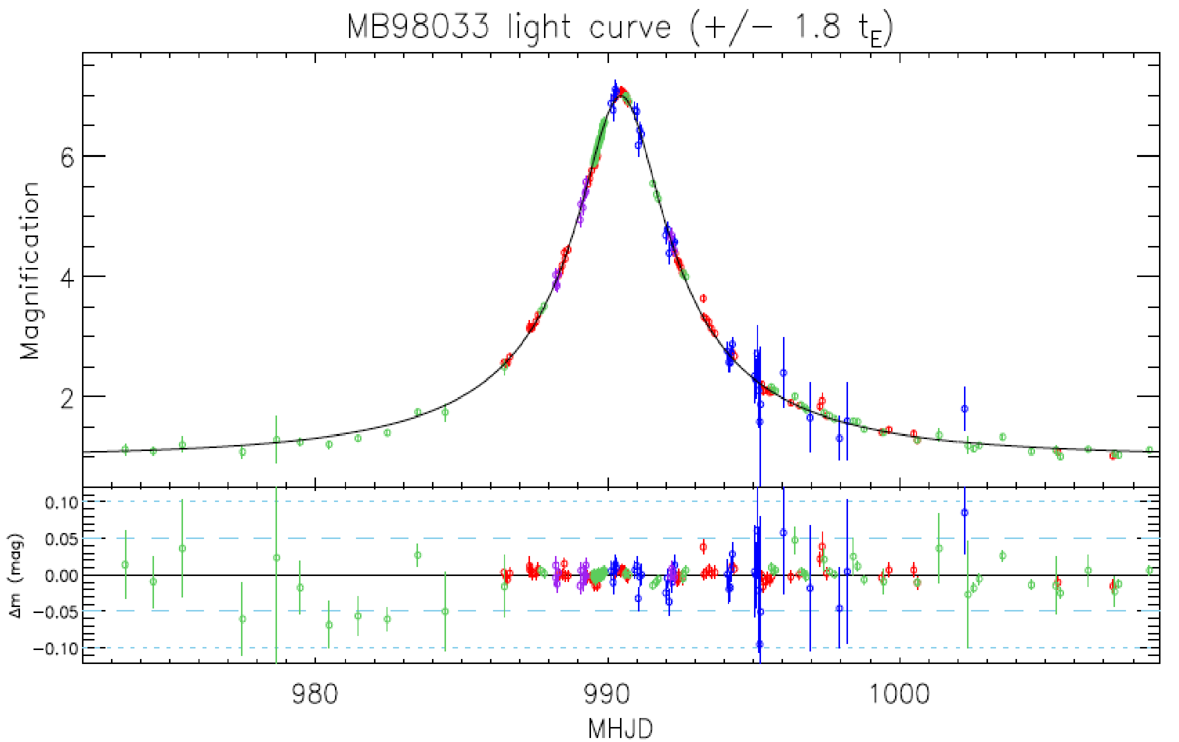




The method : Light curve modeling

- For every individual microlensing event, detection efficiency is computed using Gaudi & Sackett (2000)

- Light curves selection criteria :



1. the event does not show any kind of anomaly (including parallax, finite-source effects, source or lens binarity),
2. PLANET has obtained at least 20 data points for at least one site and passband,
3. the fractional uncertainty in the obtained impact parameter u_0 for the adopted model does not exceed 50 % .

+ *few other technical things...*

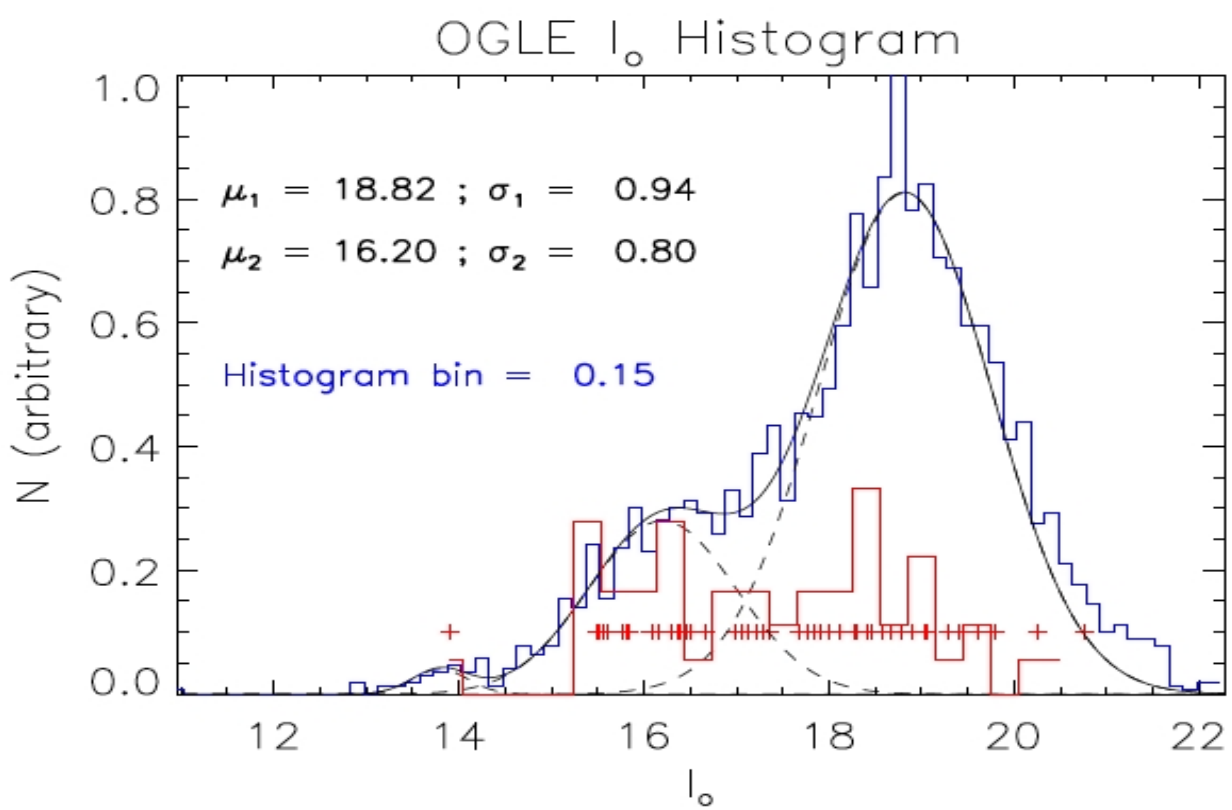
- In 2002-07 :

OGLE alerts: 389, 462, 608, 597, 581, 610

PLANET targets: 40, 51, 98, 83, 96, 72

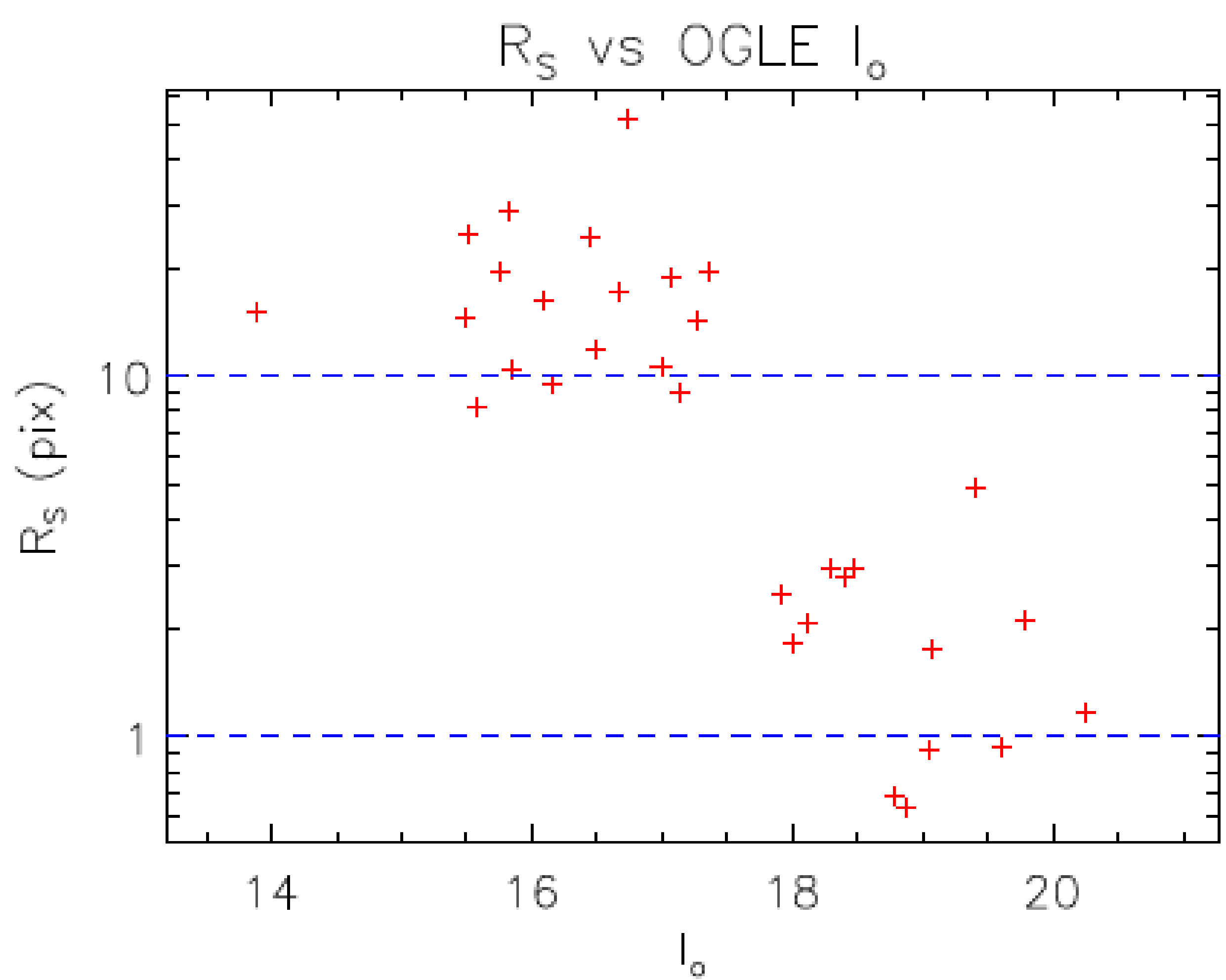
[ratio PLANET/OGLE : ~10-16%, mean 13%]

Detection efficiency : estimating finite-source effects



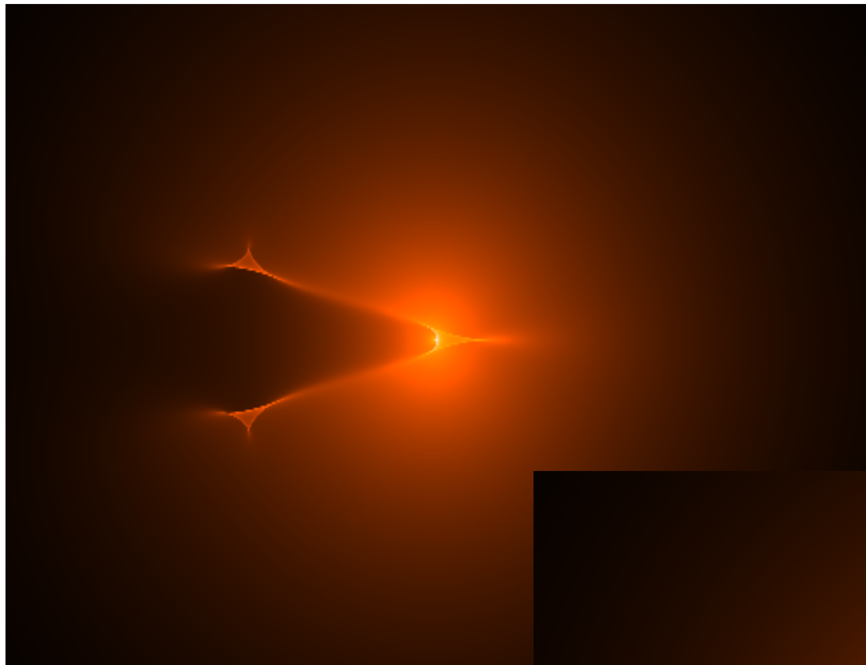
OGLE Magnitude I

For a couple of events available on 2MASS : check with surface brightness relations the *I* vs. *Rs* estimation

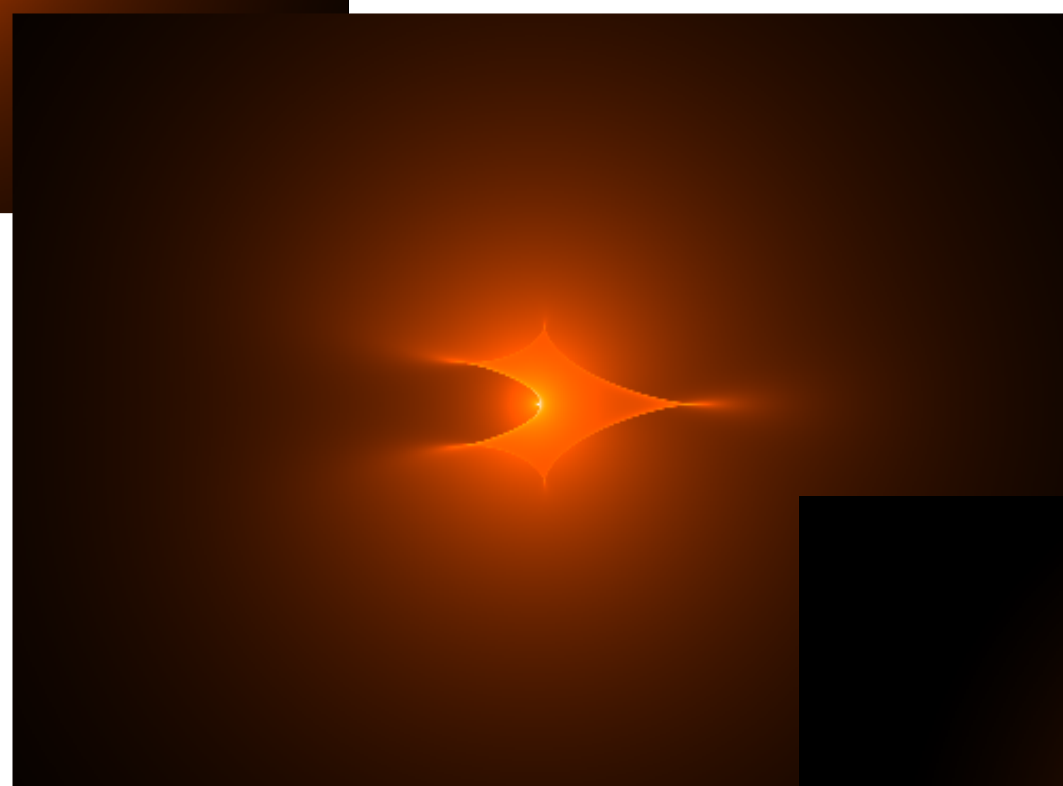


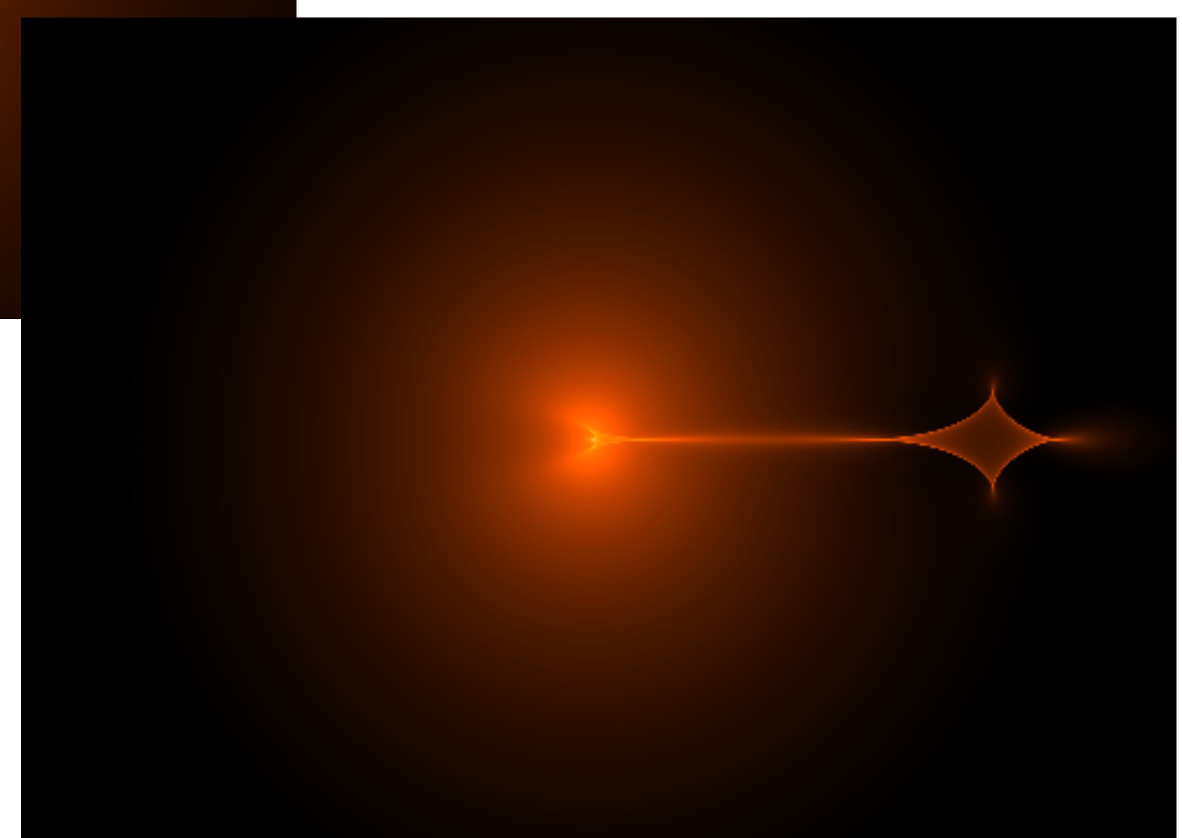
Estimated source radius

Magnification maps



- 230 pre-computed magnification maps
- Convolved with 3 different source radii
- 400 fitted trajectory / map

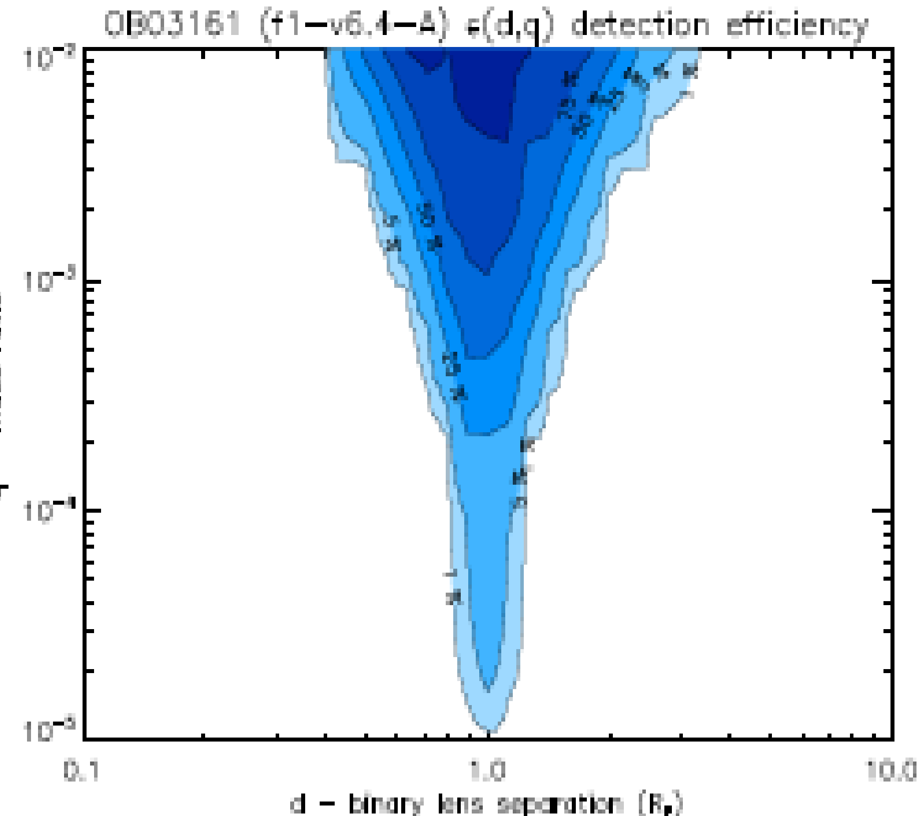




Wambsganss (1999)
Kubas *et al.* (2008)

Detection efficiency : modeling finite-source effects

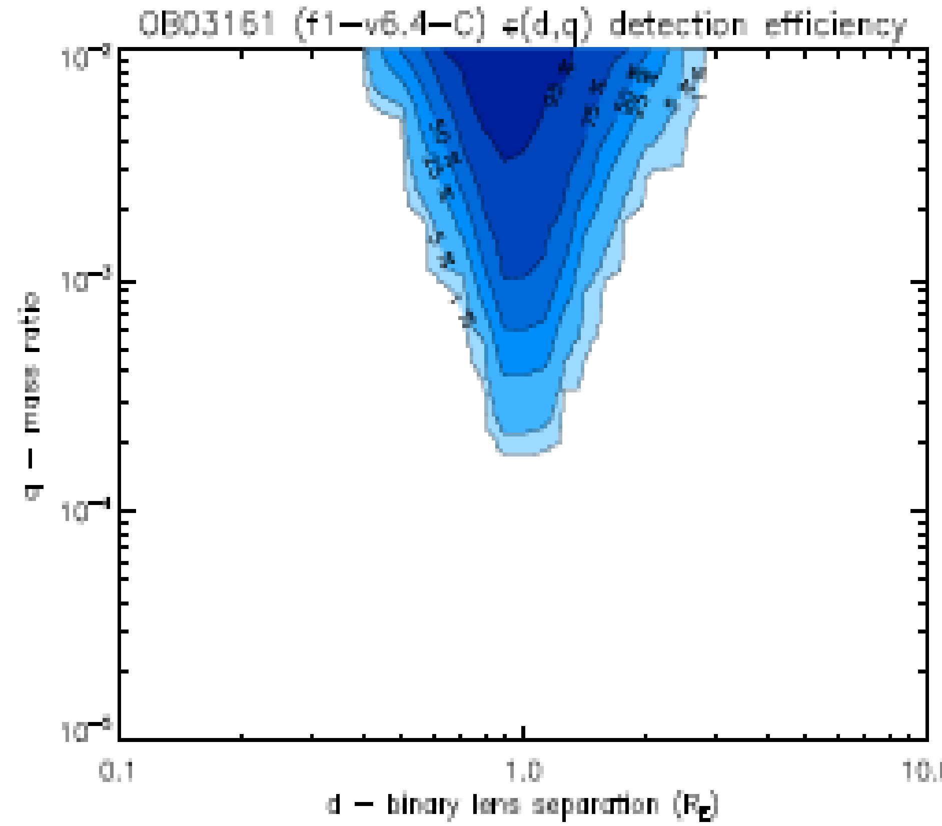
$Rs = 10^{-3}\ R_E$



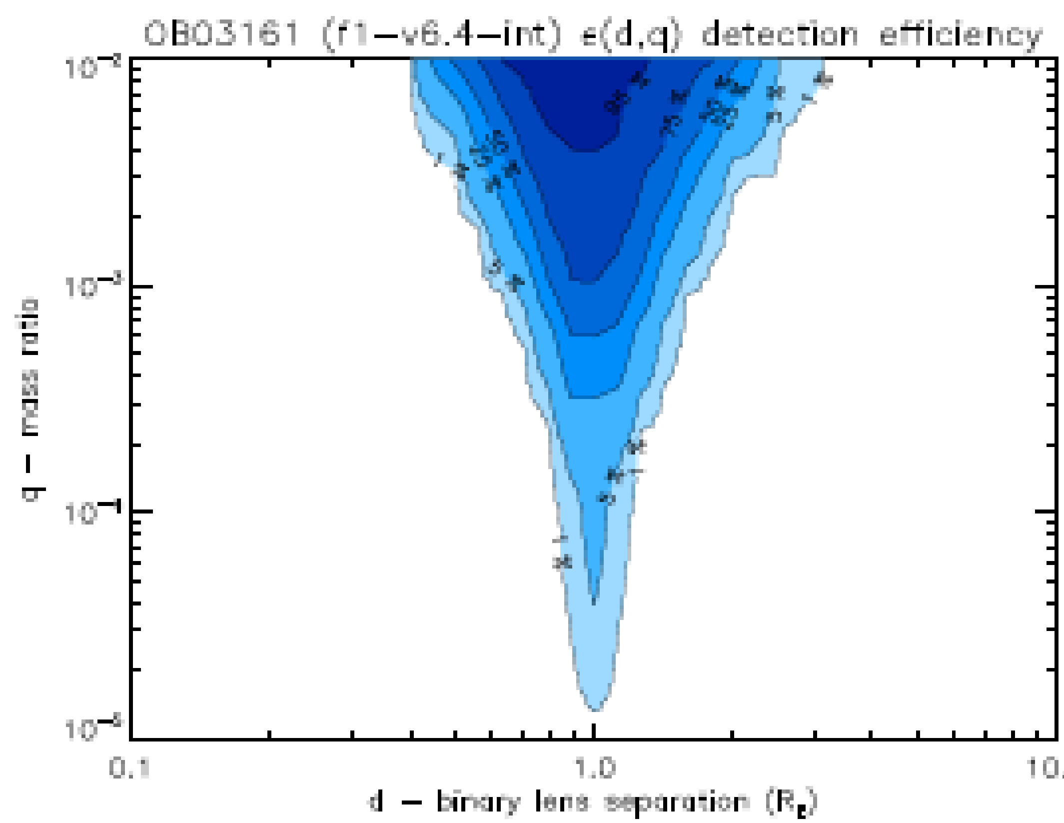
Star-planet mass ratio

Star-planet separation (R_E)

$Rs = 10^{-2}\ R_E$



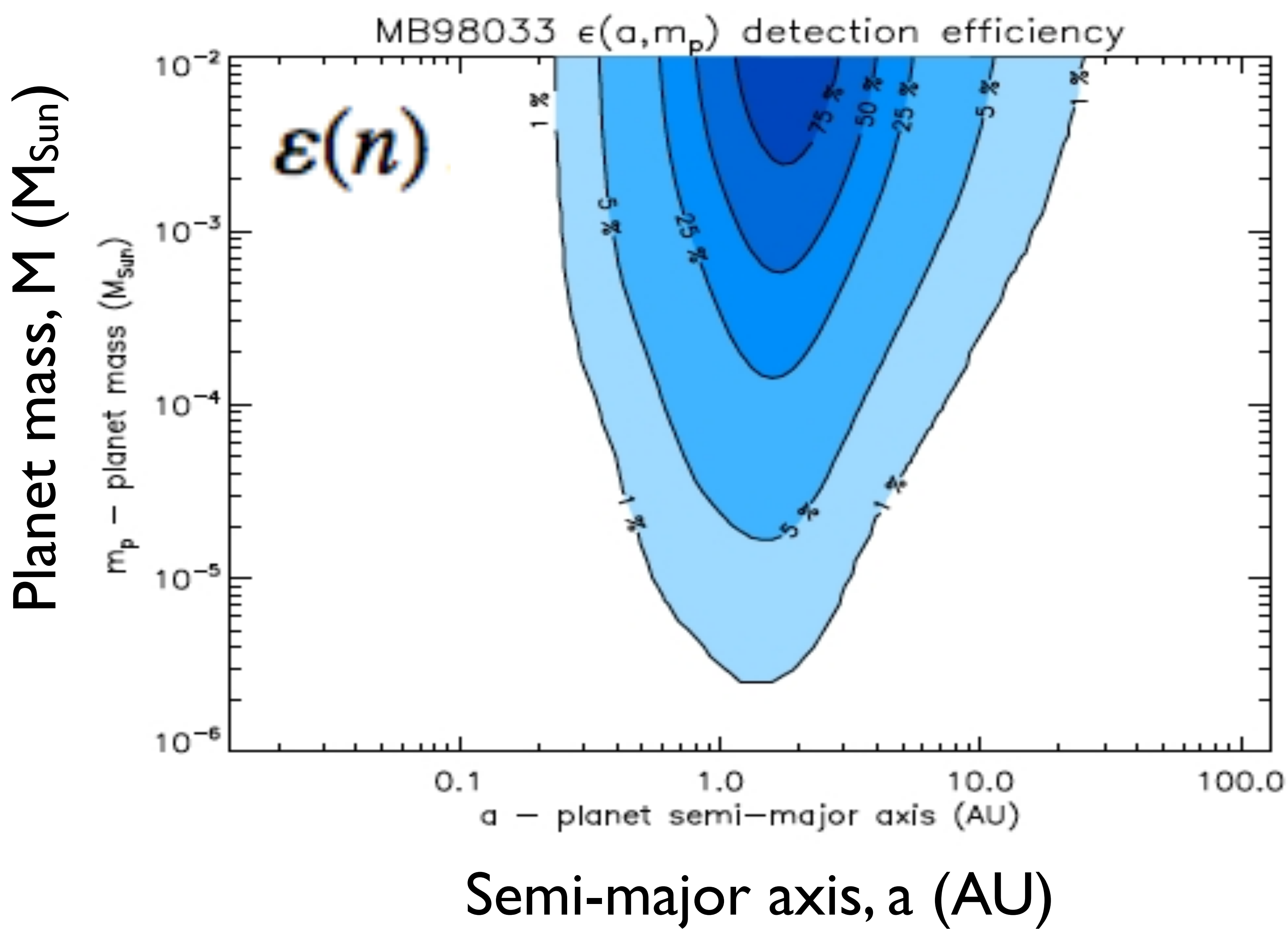
Interpolated efficiency diagram ➜



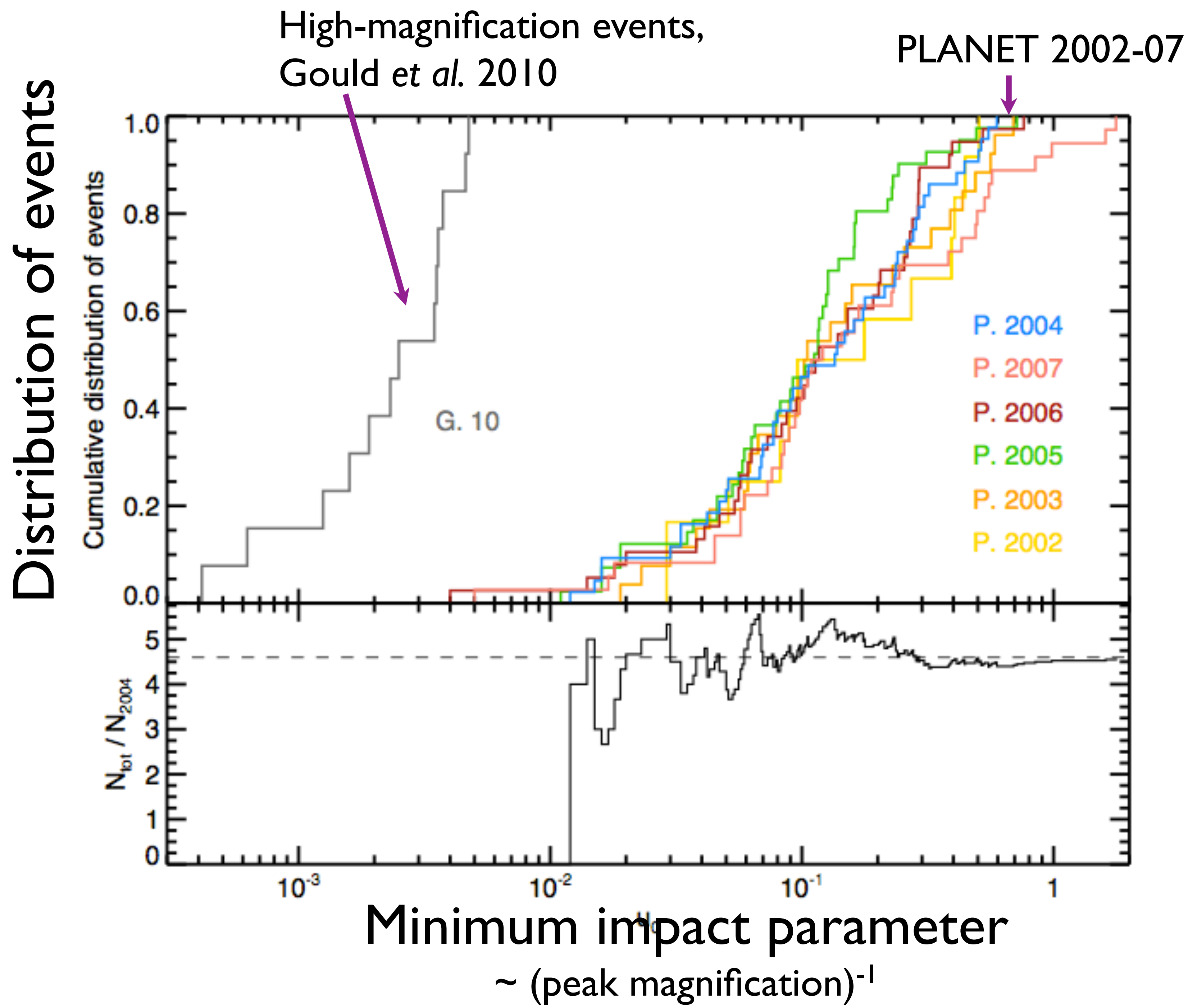
Detection efficiency in physical parameters

Conversion (d,q) →(a,m) using a Galactic model (Dominik, 2006)

Detection efficiency of individual microlensing event *n* :



Comparing PLANET seasons, 2002 to 2007



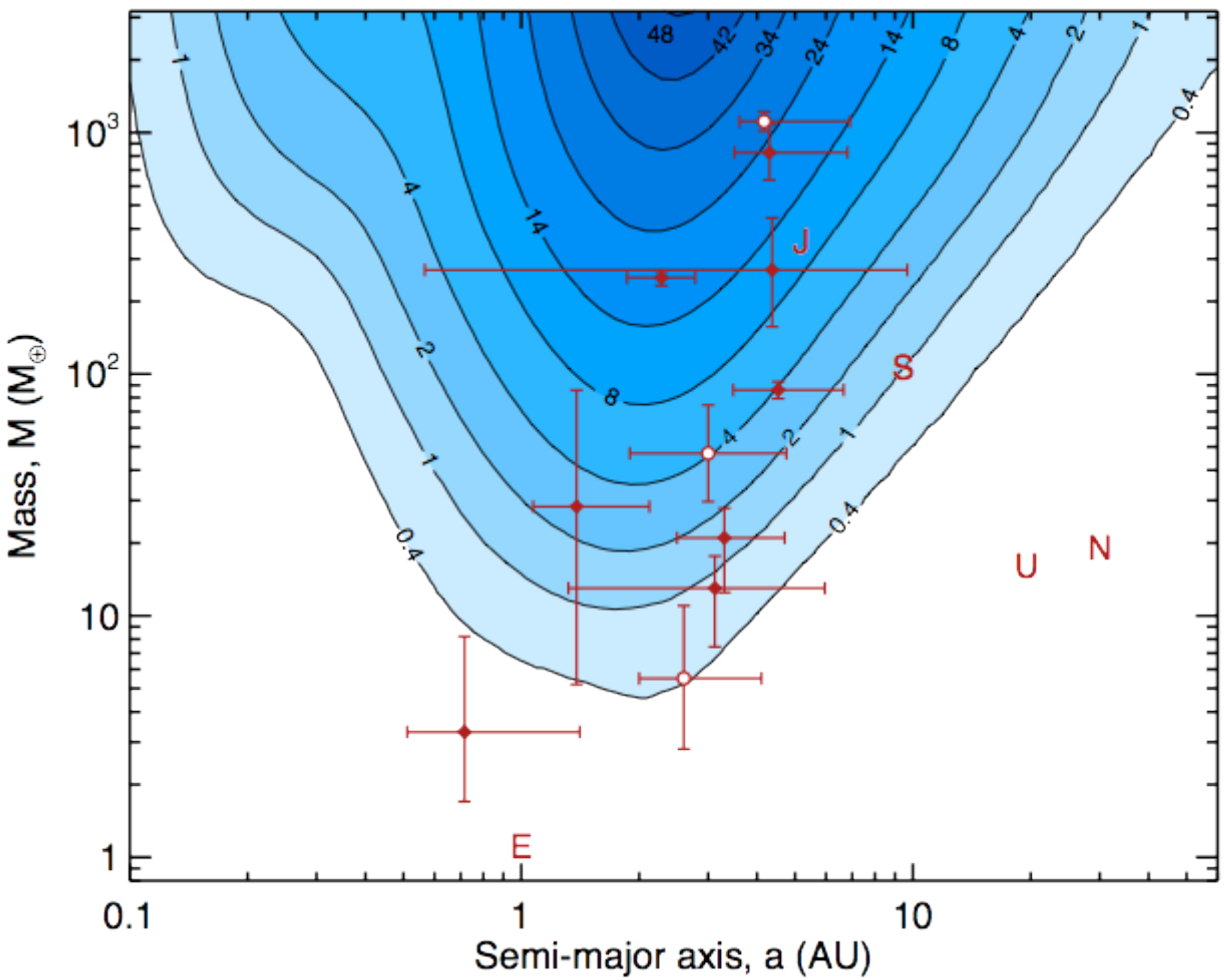
➡ Observing strategy is homogeneous in 2002-07

➡ Correction for incompleteness, using 2004 as a reference

Detection sensitivity - PLANET follow-up, OGLE alerts 2002-07

Blue contours are the expected number of detections if all stars have one planetary companion :

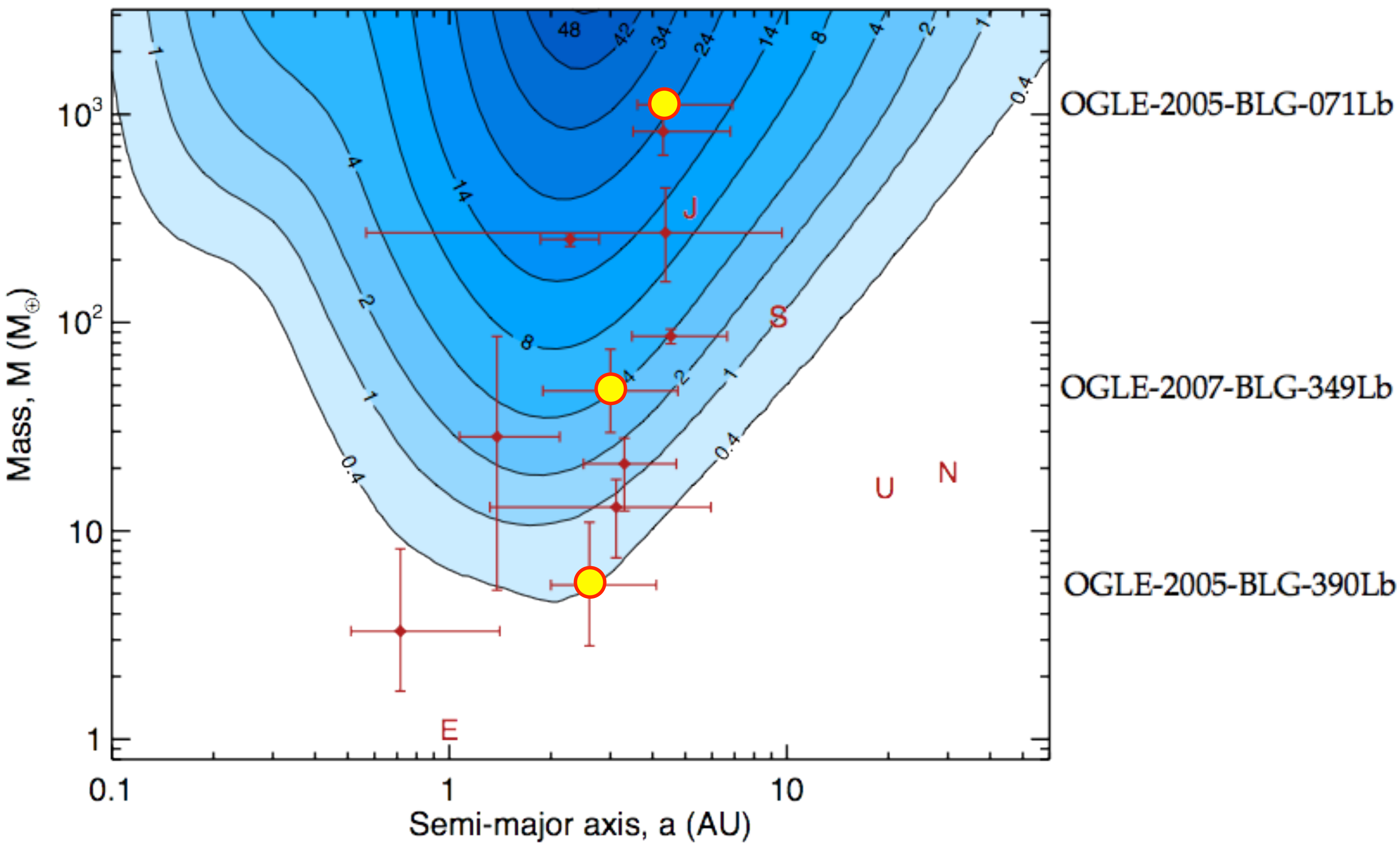
$$S(\log a, \log M) \equiv \sum_{n=1}^{N} \varepsilon(n)$$



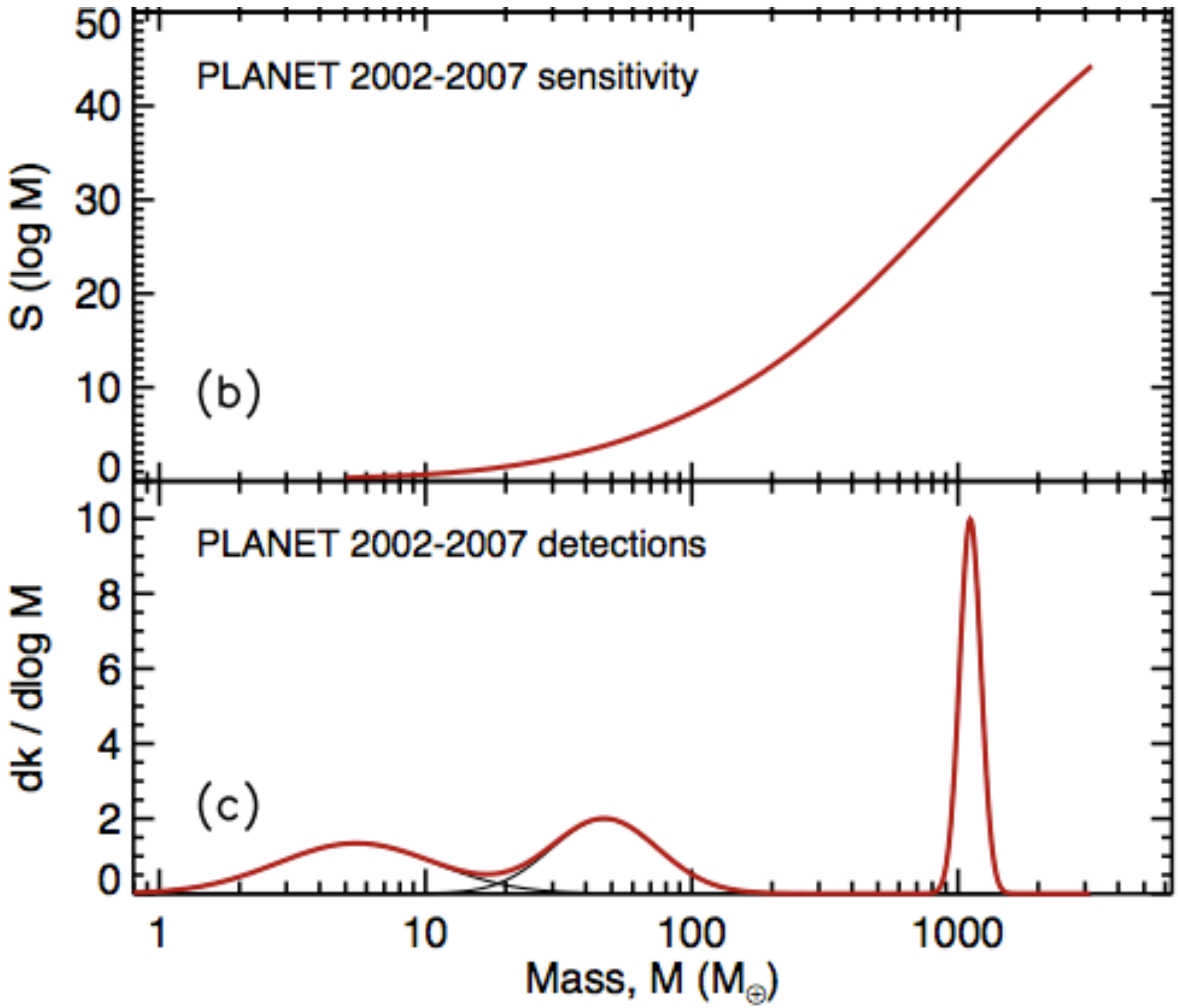
Detections - PLANET follow-up, OGLE alerts 2002-07

Red-yellow points are detections which are **compatible** with PLANET observing strategy

NB: Requirement : "controlled experiment" (*cf.* Gould *et al.* 2010)



Sensitivity and detections : PLANET 2002-07



Constraining a power-law planetary mass function

Step 1.

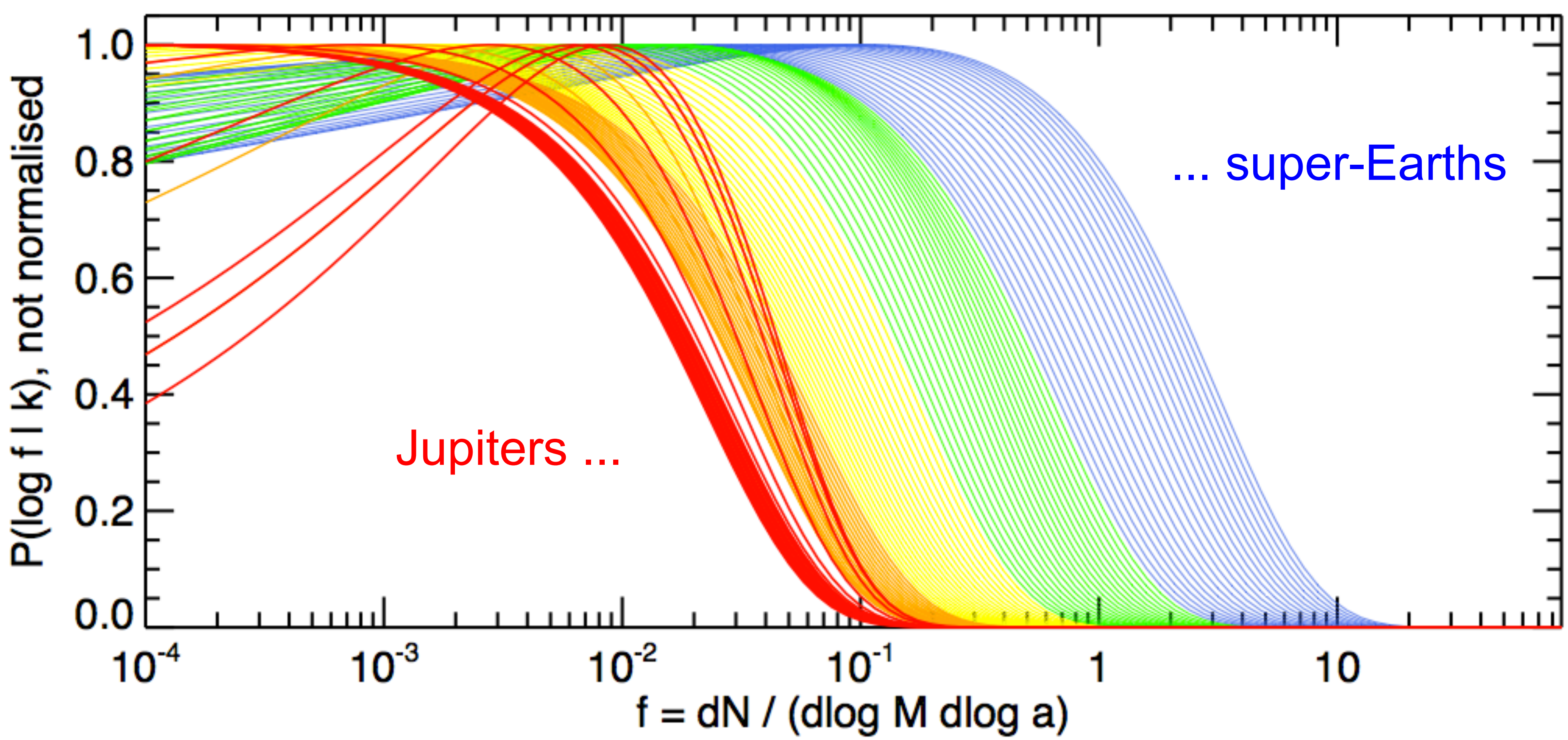
$$f(a\,M) \equiv \frac{dN_p(a, M)}{d\log a\, d\log M}.$$

Expected number of planets: $E = \int S(a, M)\, f(a, M)\, d\log a\, d\log M$,

Poisson density of k detection: $P(k|E) = \frac{E^k \exp(-E)}{k!}$, $P(\log f) = 1.$

Bayes theorem: $P(\log f|k) = \frac{P(k|E)\, P(\log f)}{\int P(k|E)\, P(\log f)\, d\log f}.$

Step 2. Then, sub-divide into a large number of bins (eg. here 200):

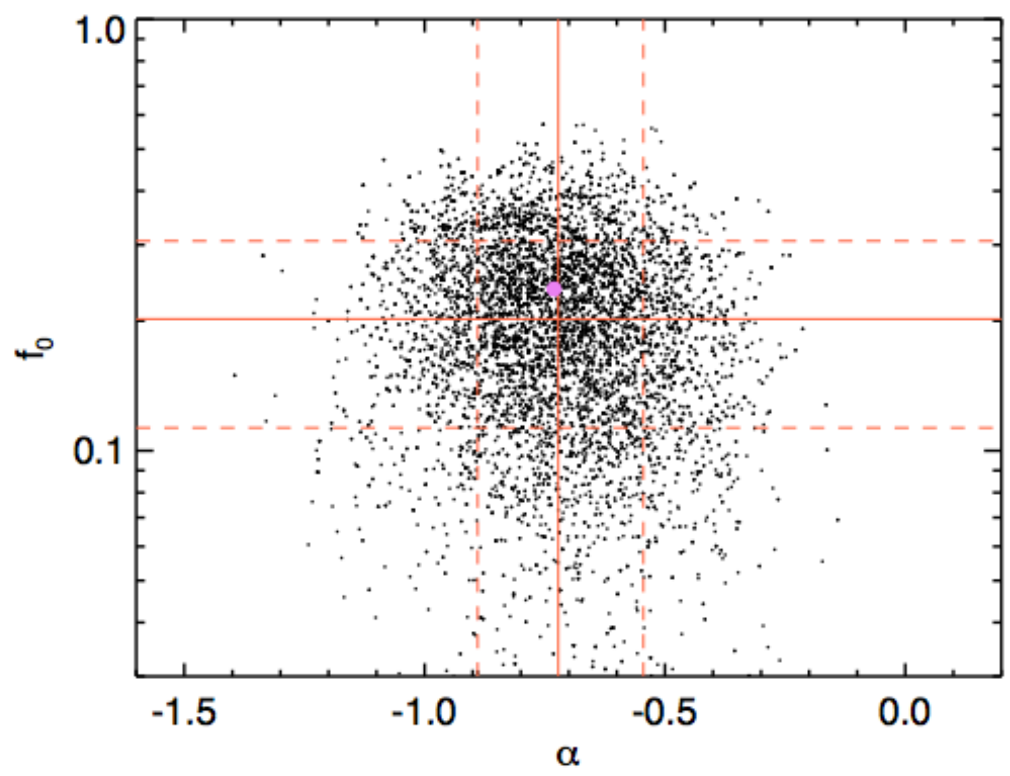


Power-law planetary mass function

Step 3. We want to constrain the power-law planet mass function:

$$f(a, M) = f_{\oplus} \, (M/M_{\oplus})^{-\alpha}.$$

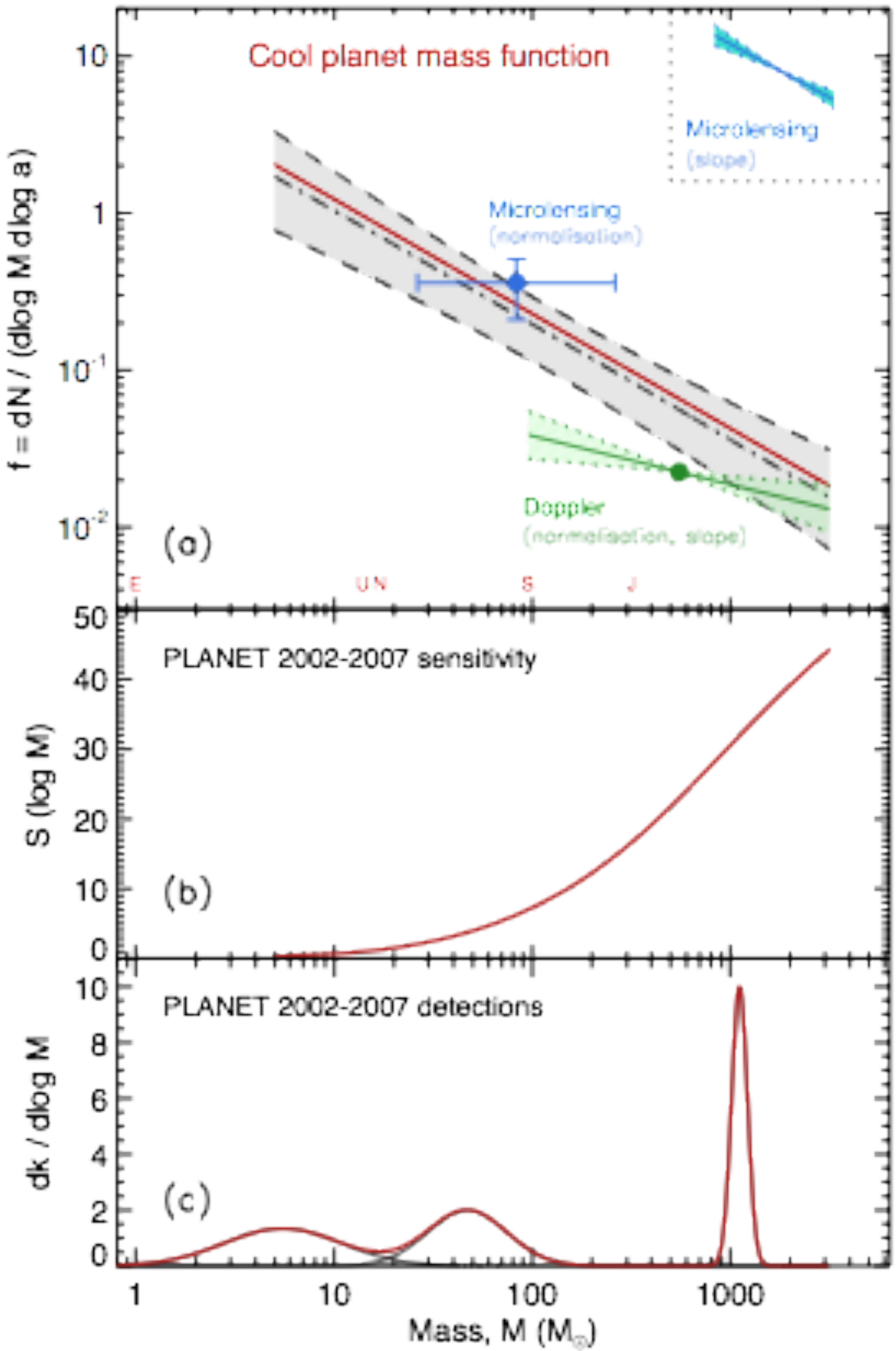
Perform a MCMC run with a large number of bins in mass....



... and determine f_o and α

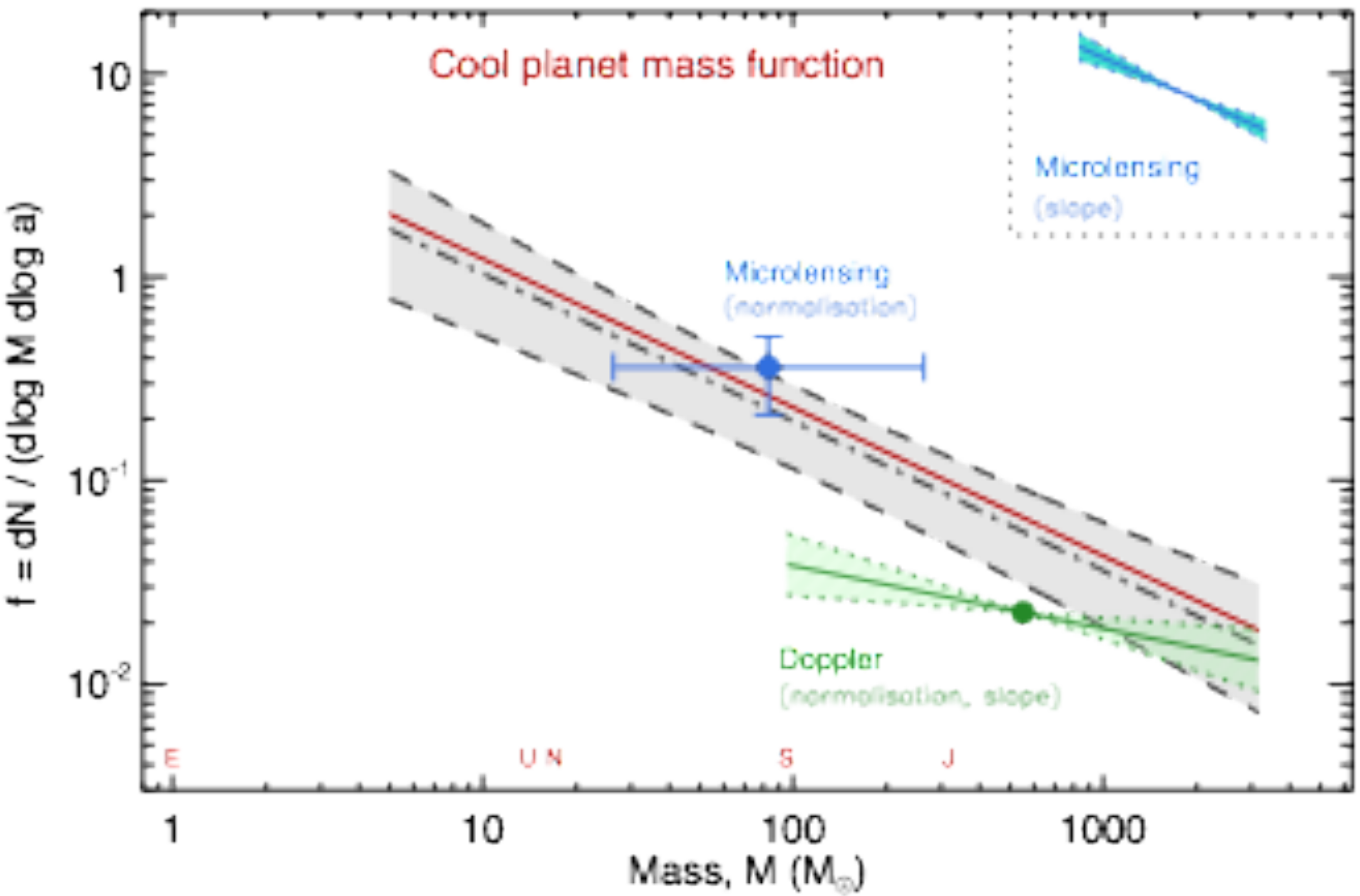
Step 4. Combine with previous results of Gould et al. (2010) and Sumi et al. (2010).

Constraint on the planetary mass funciton



$$\alpha = -0.73 \pm 0.17$$
$$f_0 = 10^{-0.62\pm0.22}$$
$$M_0 \simeq M_{\rm Sat} = 95\, M_\oplus\,.$$

Planetary mass function



- Most microlensing host stars are low-mass stars

- Abundances for planets within:
0.5 to 10 AU
5 M_{Earth} to 10 $M_{Jupiter}$

- Super-Earths and Neptune-like planets are more abundant than Jupiter-like planets

On average :

→ 2/3 of stars have a super-Earth

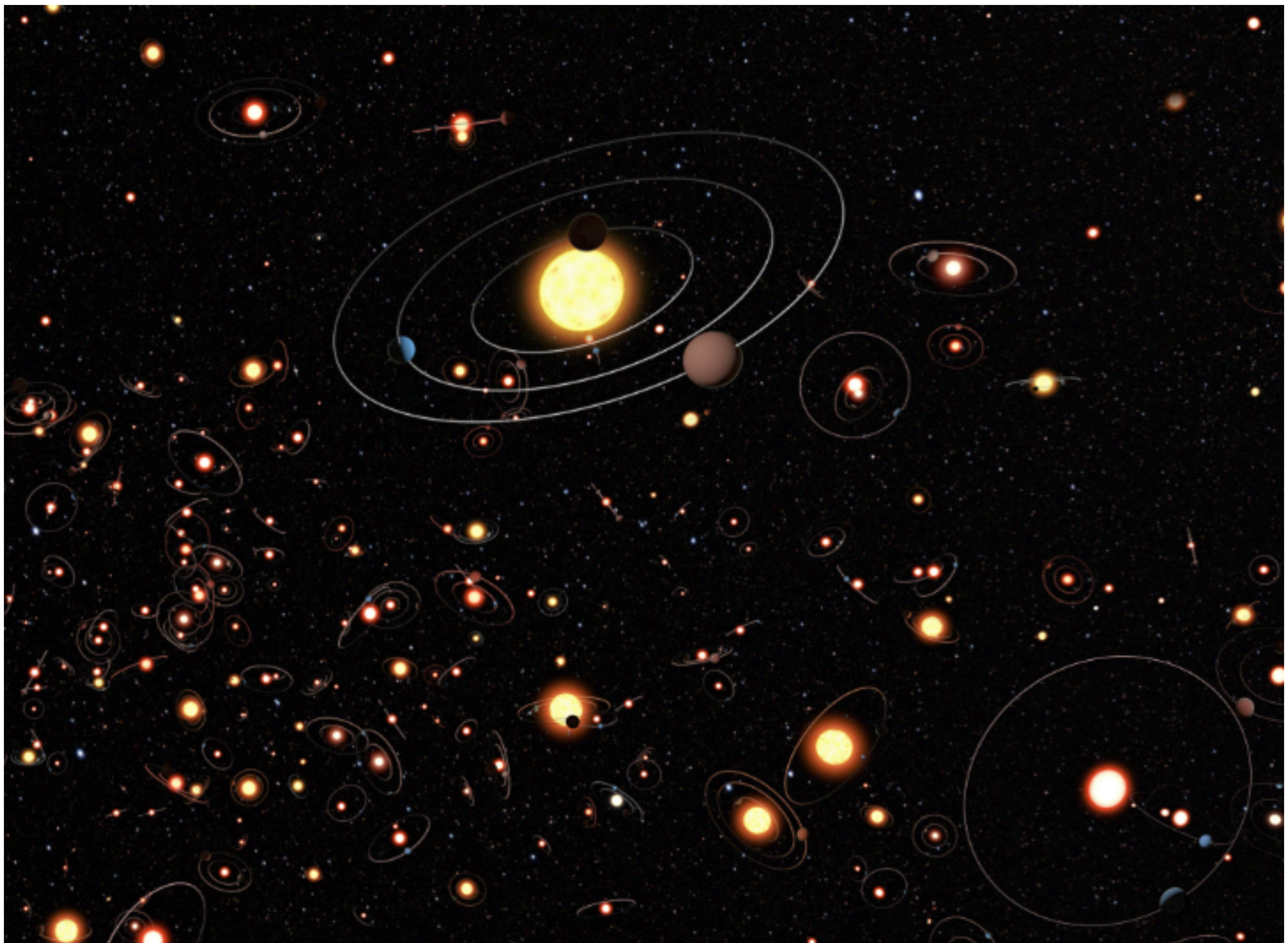
→ 1/2 of stars have a Neptune

→ 1/6 of stars have a Jupiter

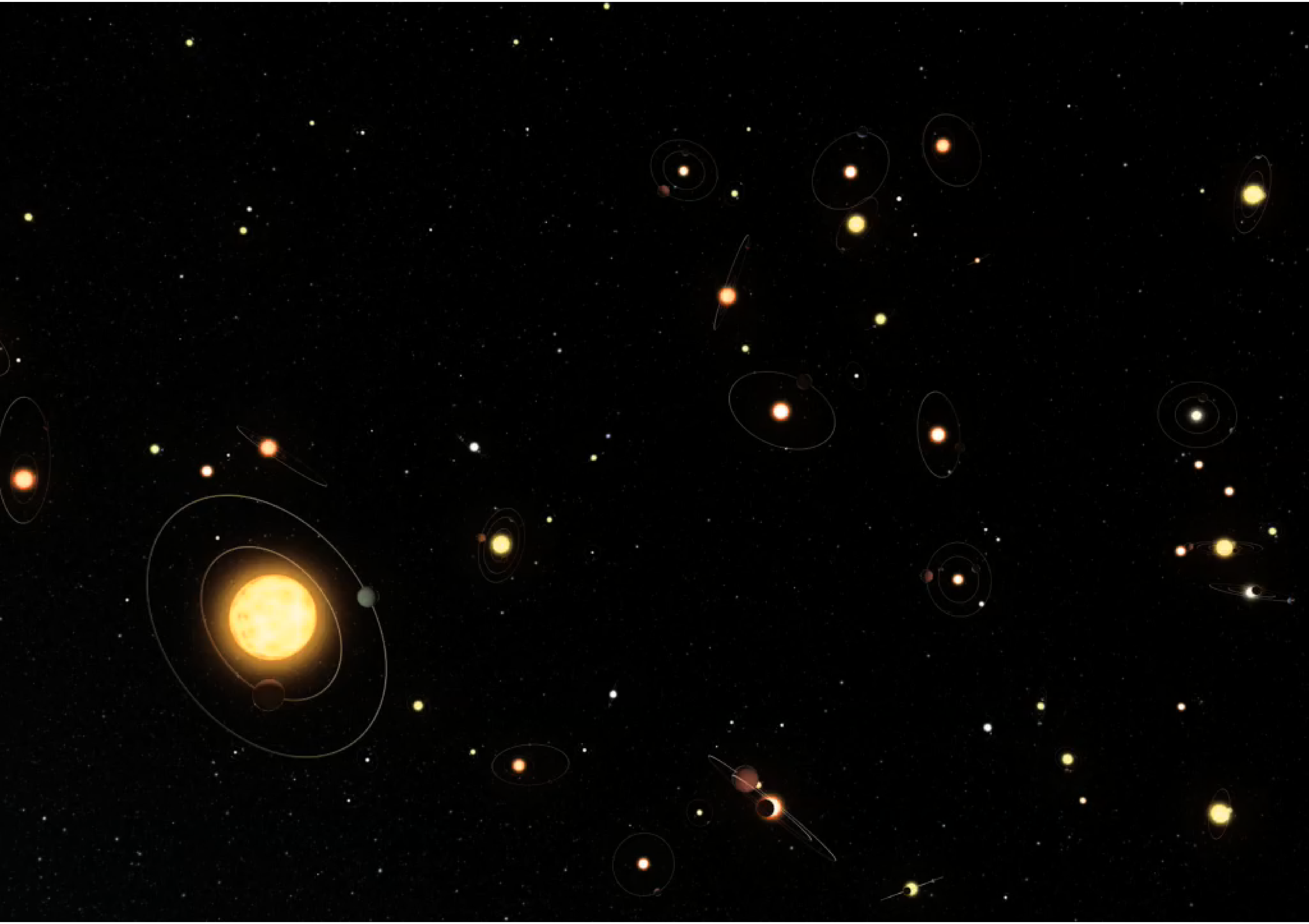
→ One or more planets per star

One or more bound planets per Milky Way star from microlensing observations

Cassan *et al.* 2012



© ESO/M. Kornmesser



Thank you !