Searches for exoplanets

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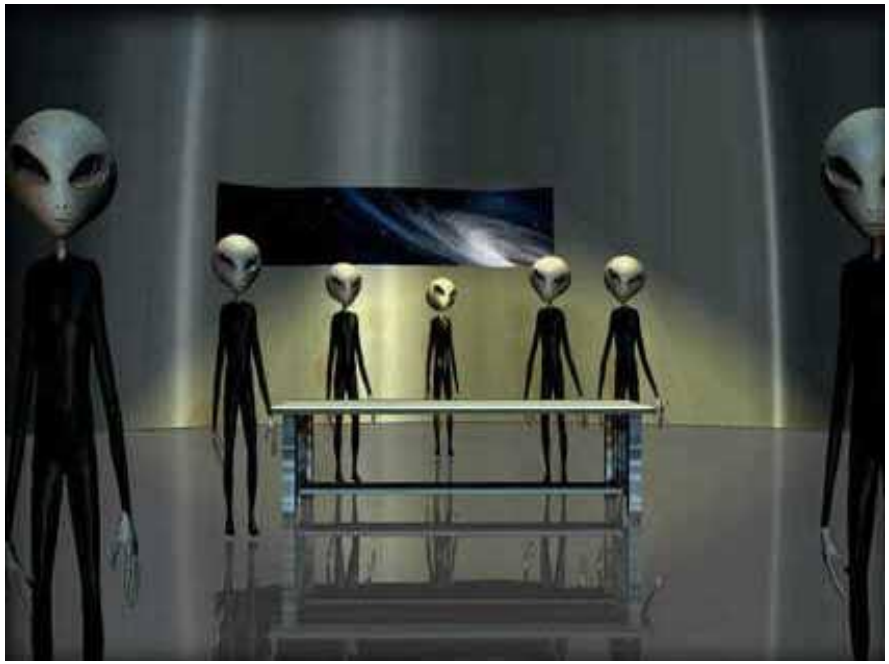
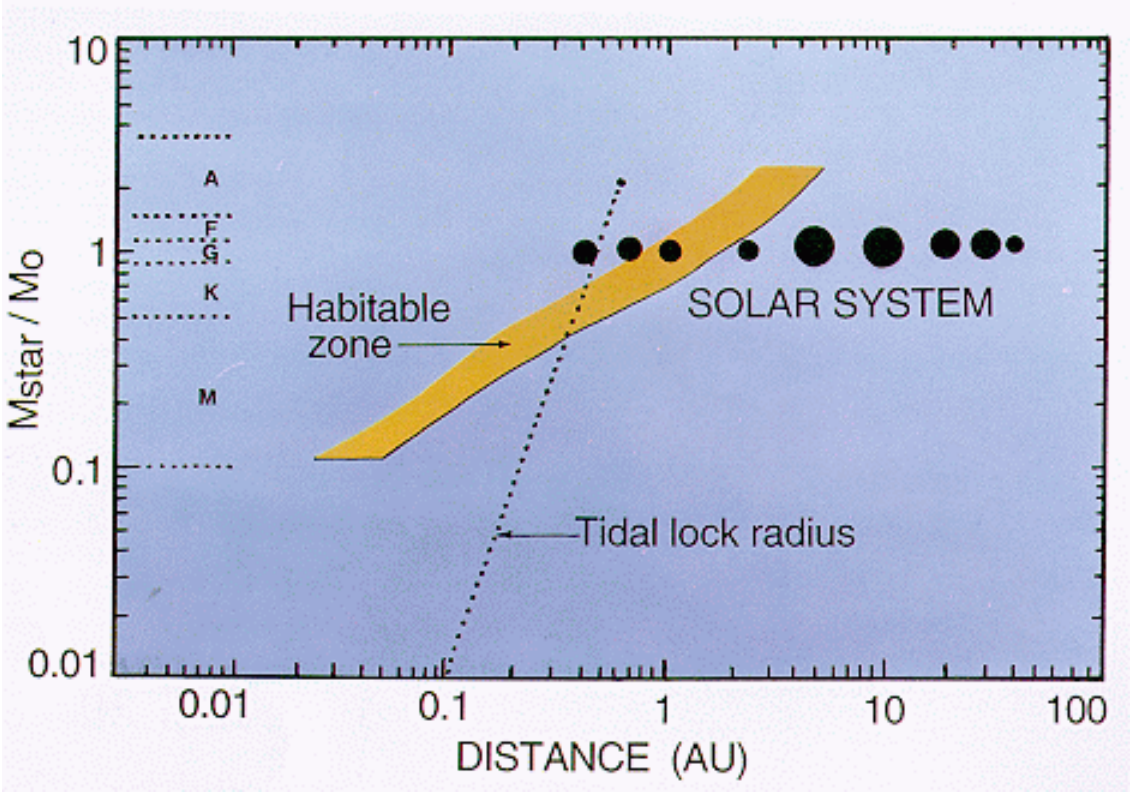
LHC Days Split, 8.10.2010.

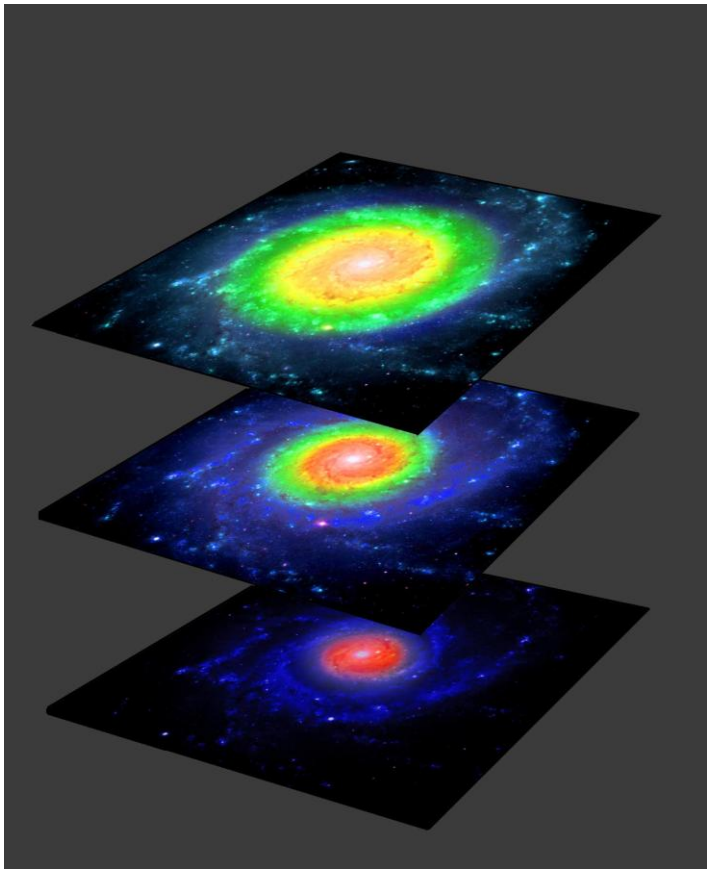
Why do we search for exoplanets?



- Extraterrestrial life?
- Exobiology
- Understanding of the **structure** and **formation** of planetary and stellar systems

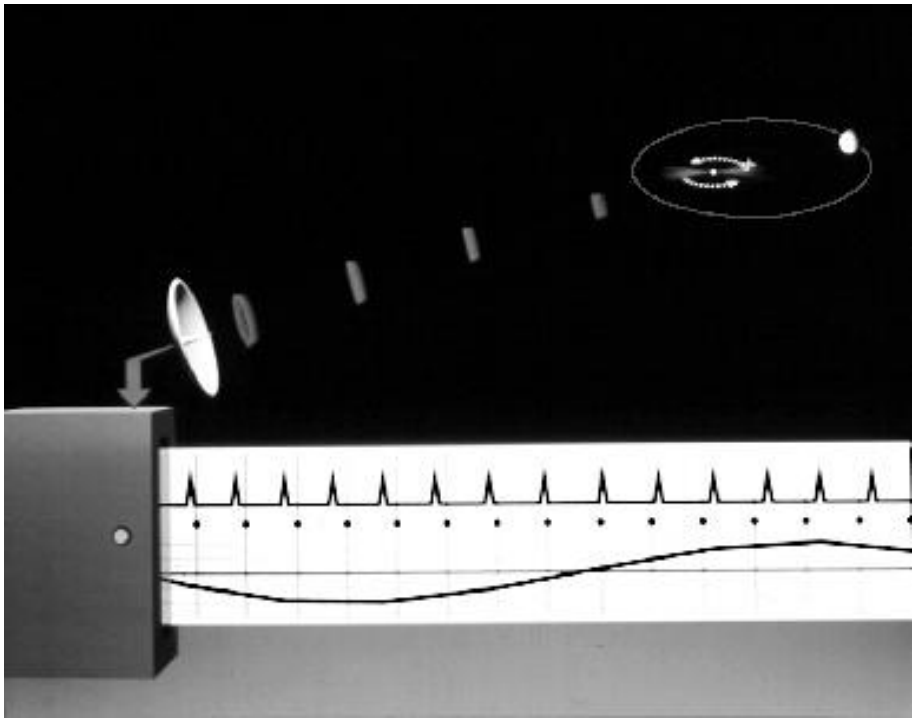
Habitable zone





Liquid water!

History



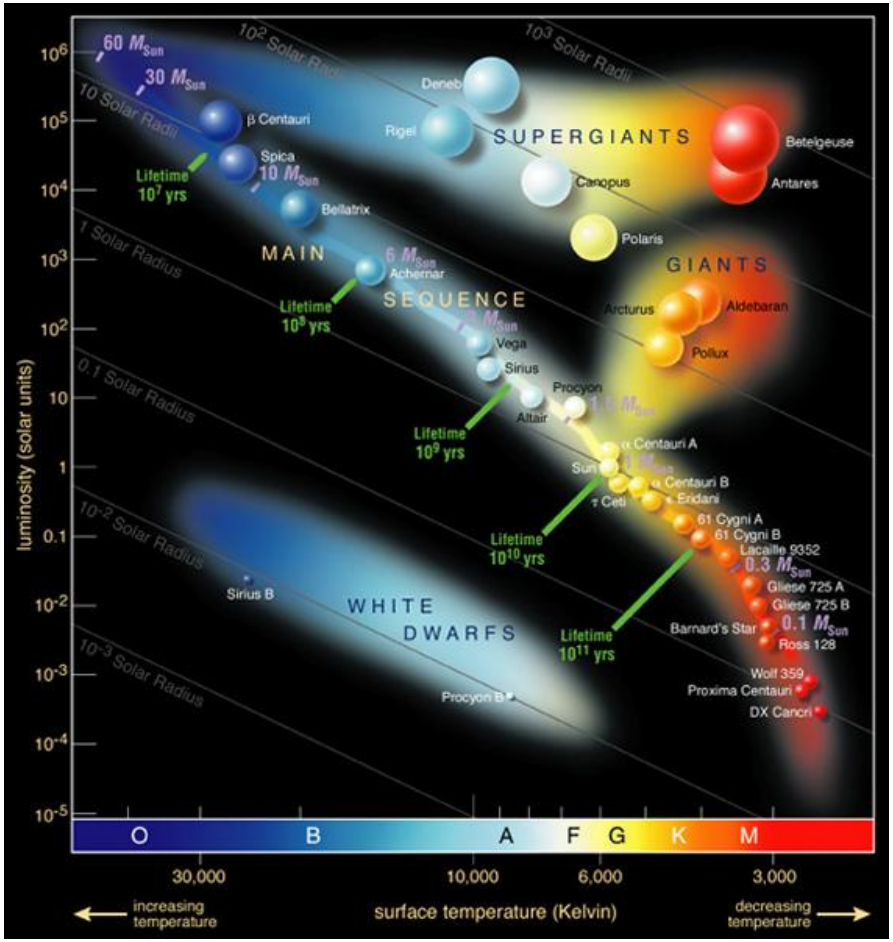
- **First** planets detected outside of the Solar systems: orbiting ***pulsars***
- Arecibo radio telescope (Wolszczan & Frail **1992**)
- Measuring **anomalies in pulsation period**
- Few planets detected:

$$m \approx 10^{-4} \rightarrow 10^{3} M_{Earth}$$

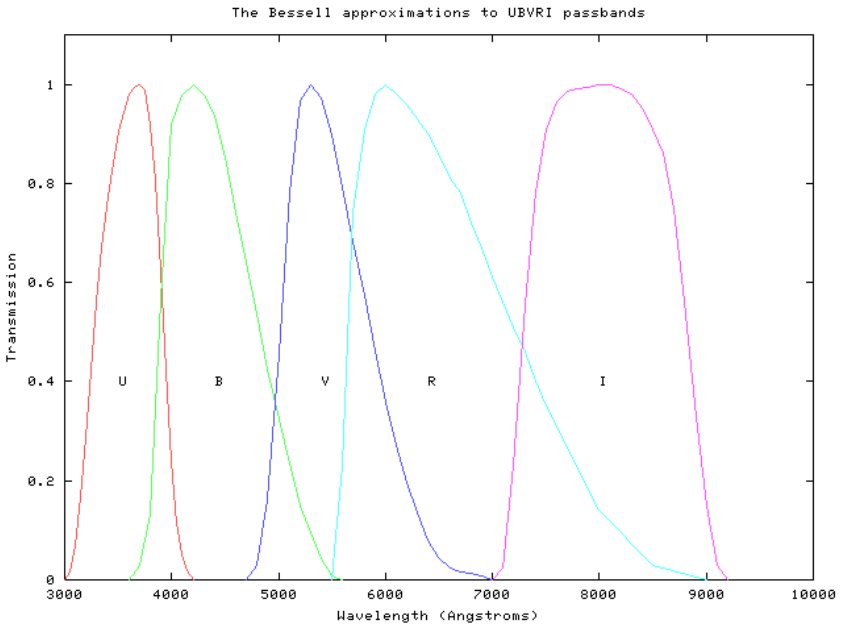
Extrasolar planet definition?

- Pulsars formed by supernova explosion
  - planets formed by mass ejection?
- "**Extrasolar planet** is a planet **orbiting a star** different from the Sun" (IAU)
- Definition excludes planets orbiting pulsars, and free-floating planets
- At the moment **around 500** exoplanets detected
- Mainly by indirect detection methods (optical observations of stars)

Optical photometry



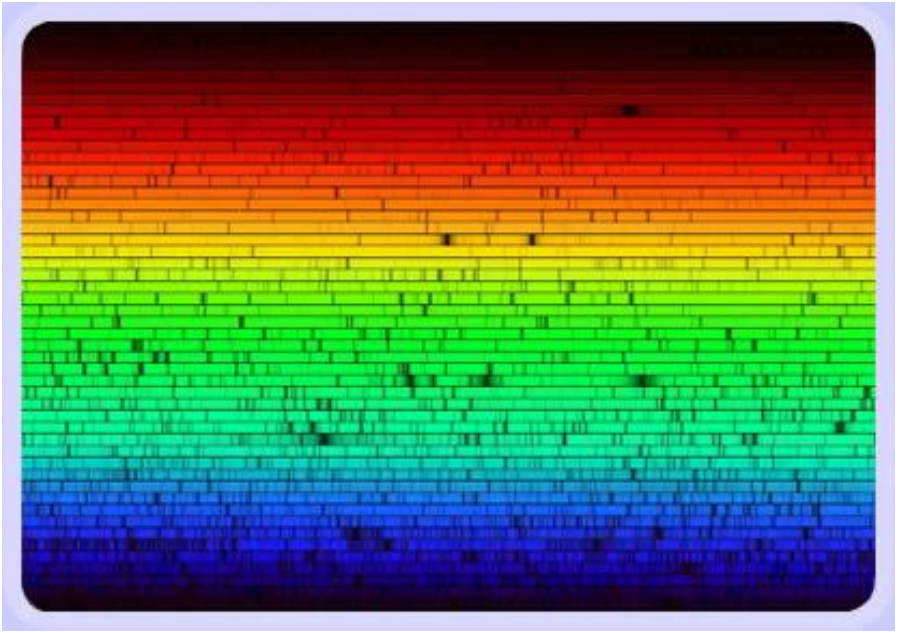
UBVRI photometric system



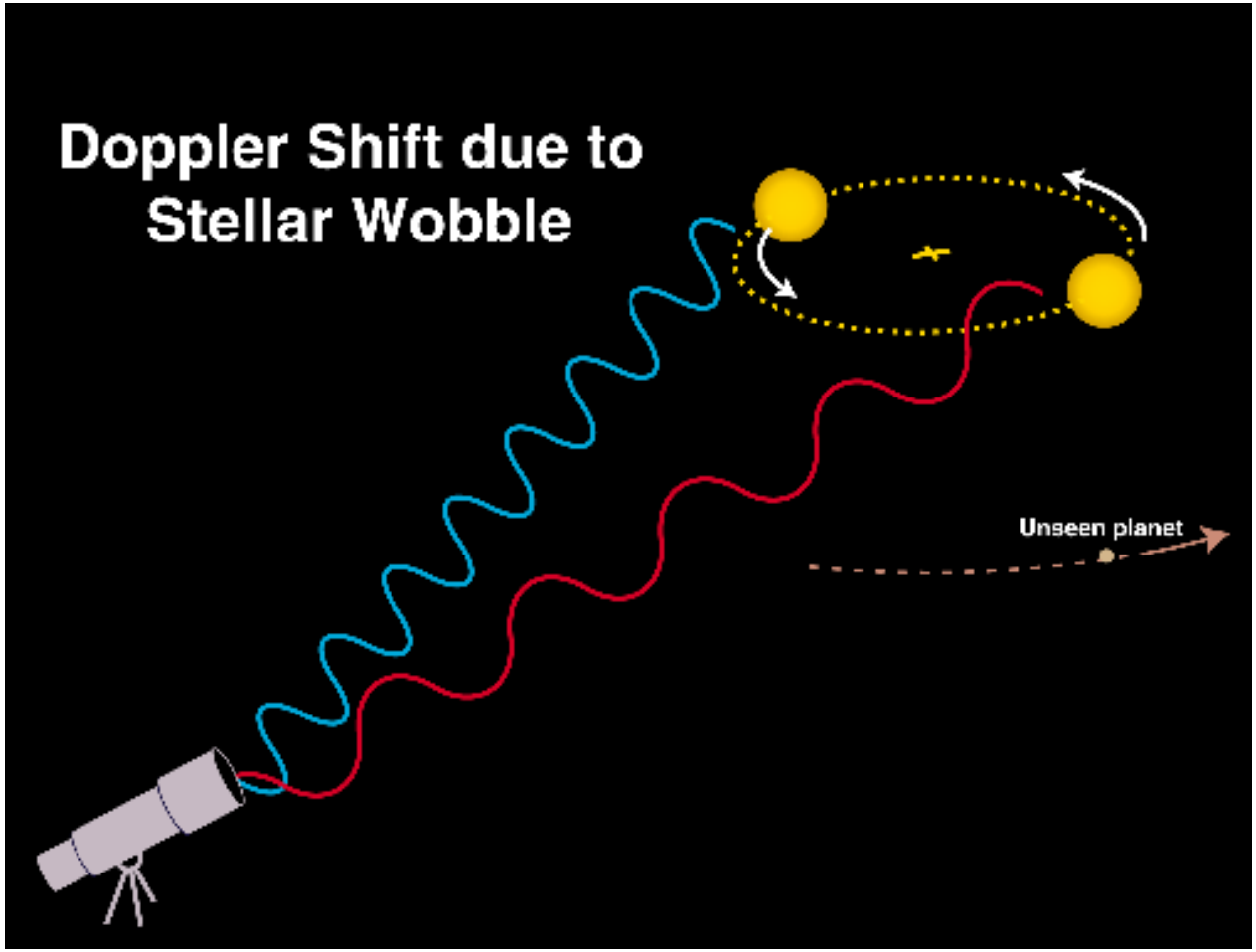
Optical spectroscopy

The HARPS Spectrograph and the 3.6m Telescope

ESO PR Photo 25a/04 (25 August 2004)



Radial velocities (Doppler)

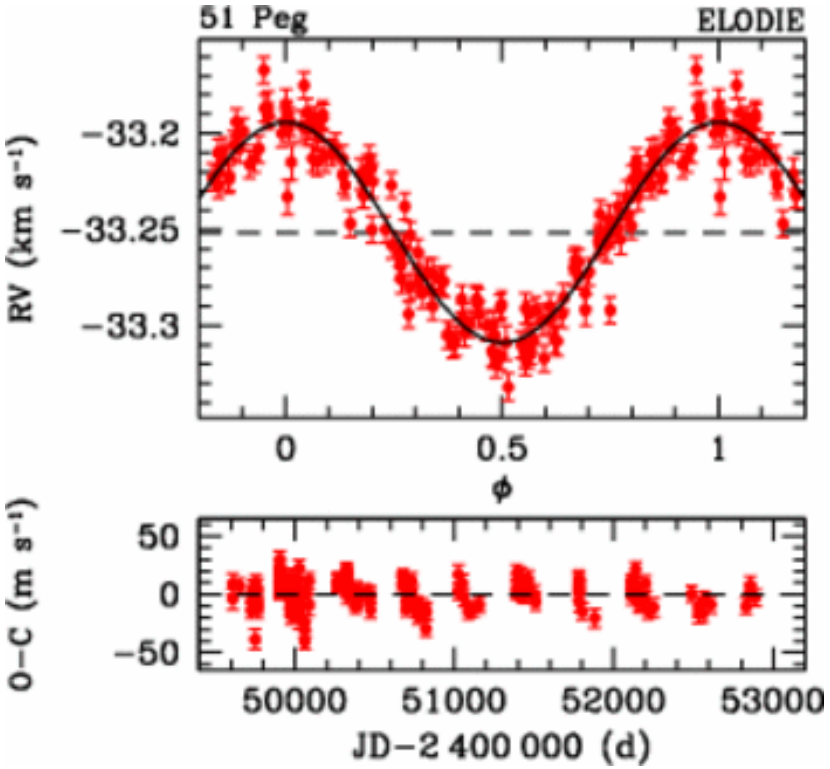


Radial velocities

- *Only the **lower mass limit** can be determined!*

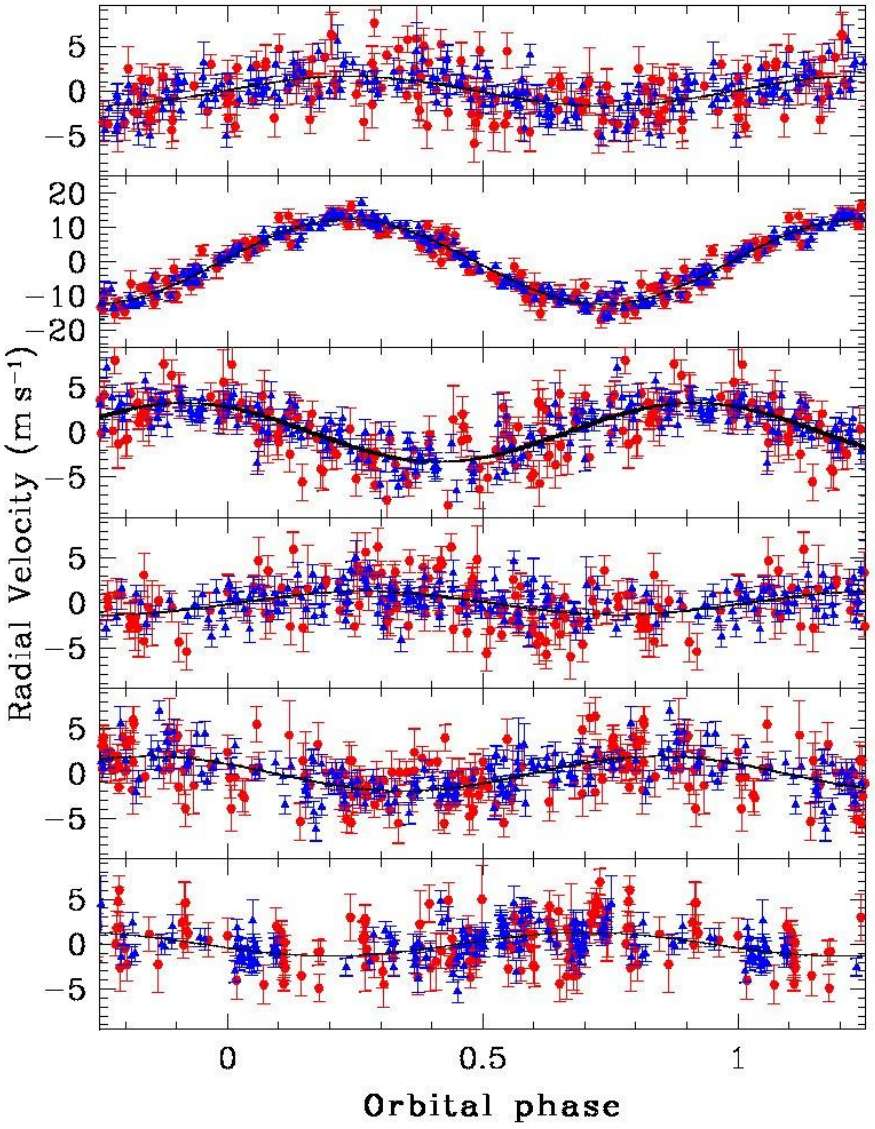
- 51 Pegasi b
  (Mayor & Queloz 1995)
  - “hot Jupiter”:
  m=0.5M(Jup), T=1200K

- First detection of a planet orbiting a main-sequence star



Radial velocities

- **Gliese 581** system
- 6 planets so far
- discovery of a "3-Earth mass habitable planet" announced last week (Vogt et al. 29.09.2010)



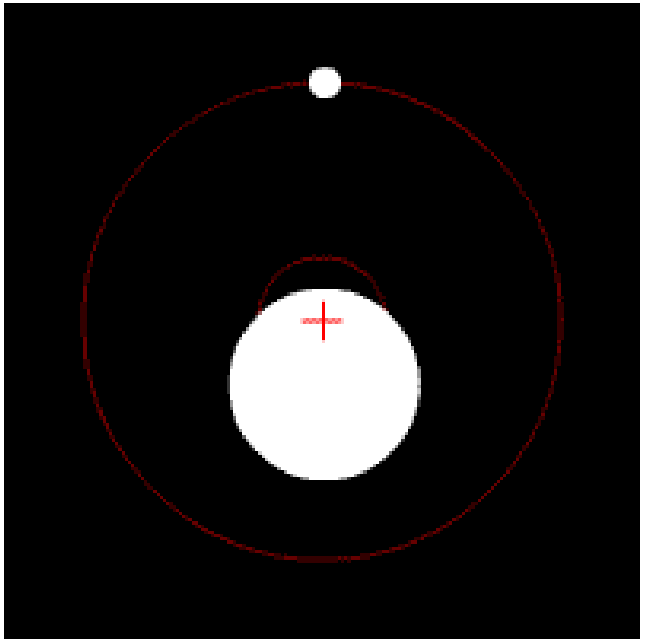
Radial velocities + Astrometry

- Out of 490 planet detections, 459 by RV
- The most efficient method for...
- detecting extrasolar planets?
- detecting planet candidates?
- For ex. HD 43848:

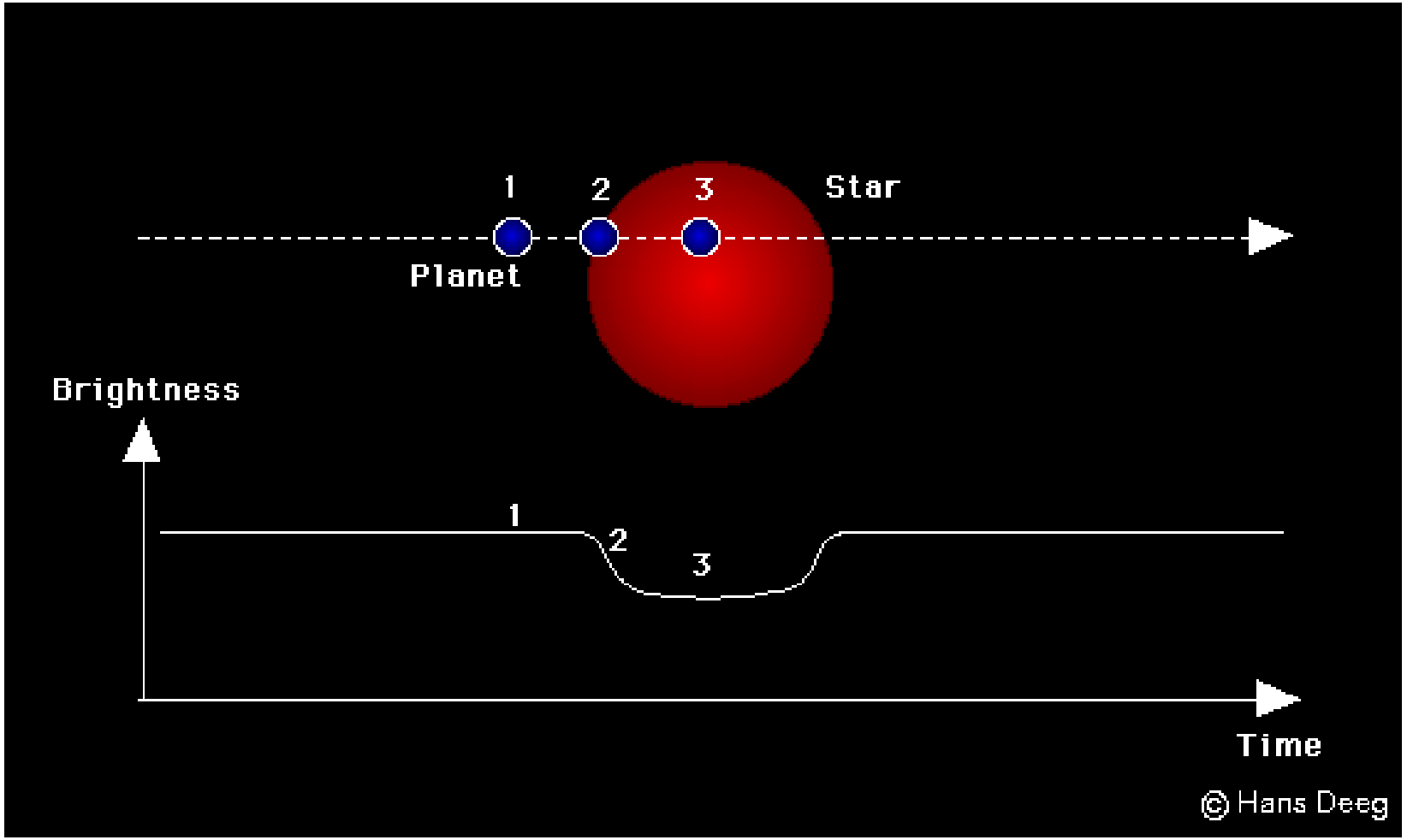
  The former mass of 25 MJ (planet) has now been revised to 102 MJ (brown dwarf) using astrometry (Sahlmann et al. 29.09.2010)

Astrometry

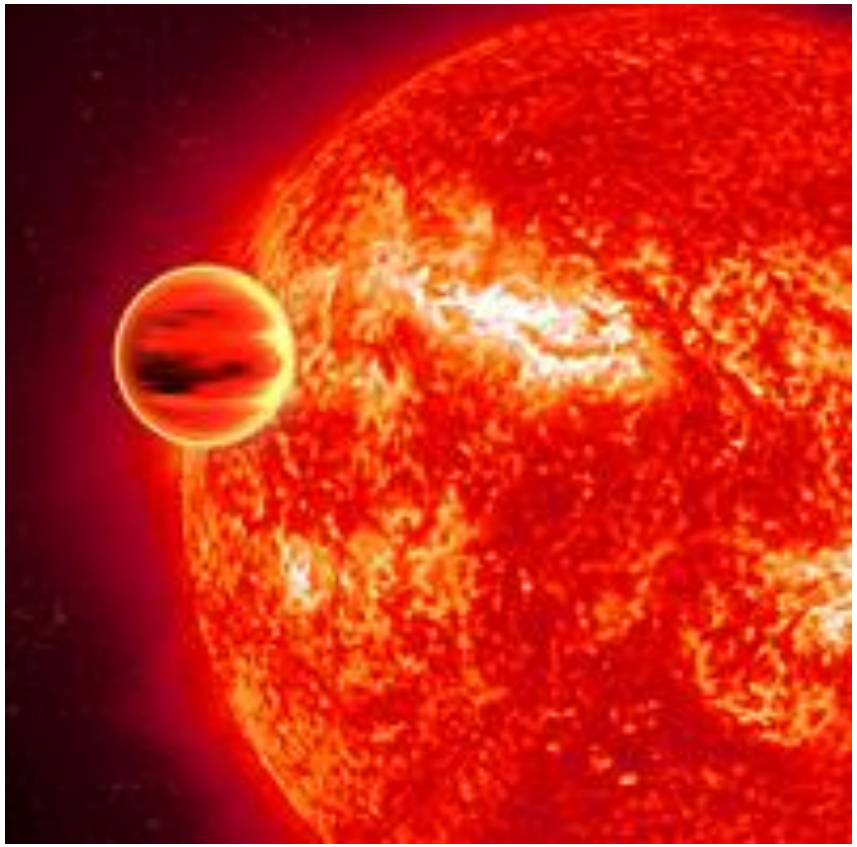
- Precise **position** measurements that can reveal the orbit eccentricity and the mass from the planet candidates detected by RV
- Satelites (Hipparchos, GAIA)



Transits

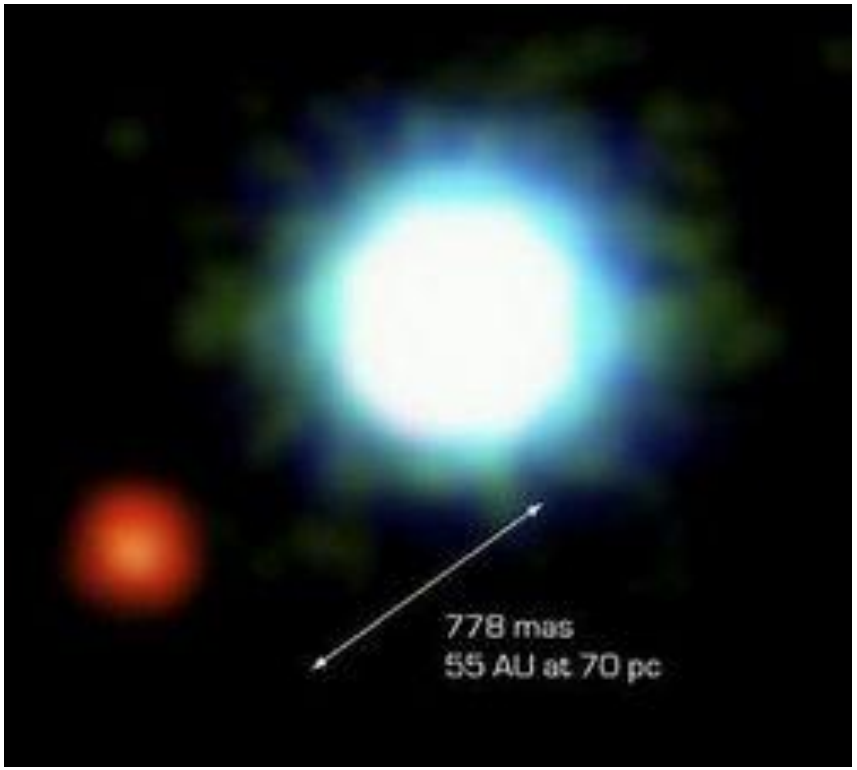


Water vapour detected in the atmosphere of a hot Jupiter transiting planet (Tinetti et al, 2007)

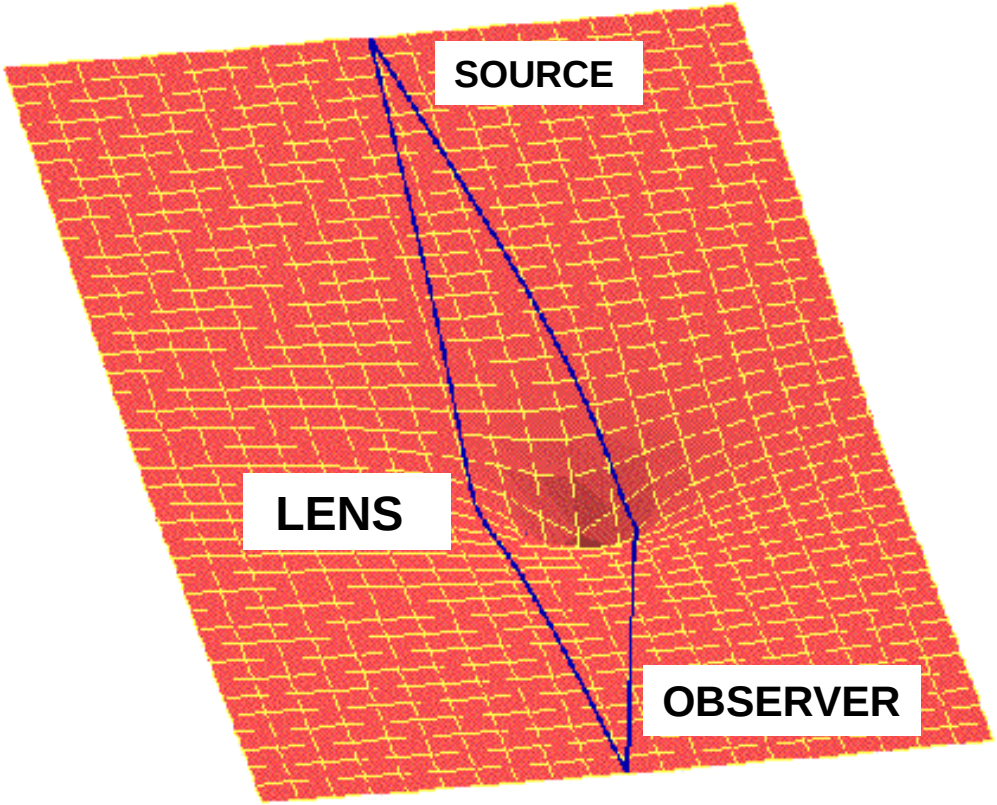


Direct imaging

- First detection: 2M1207b orbiting **a brown dwarf** (Chauvin et al. 2004)
- VLT IR image
- m ~ 3 up to 22M(Jup)
- massive planets in wide orbits

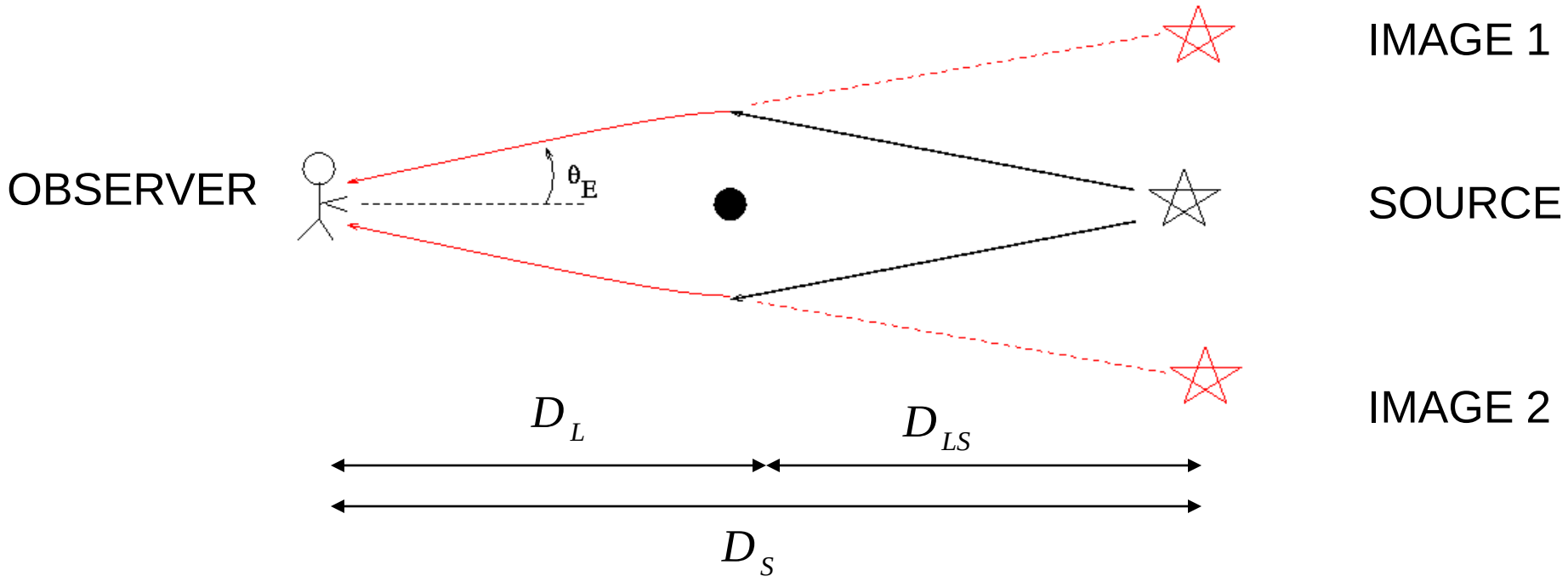


Gravitational lensing



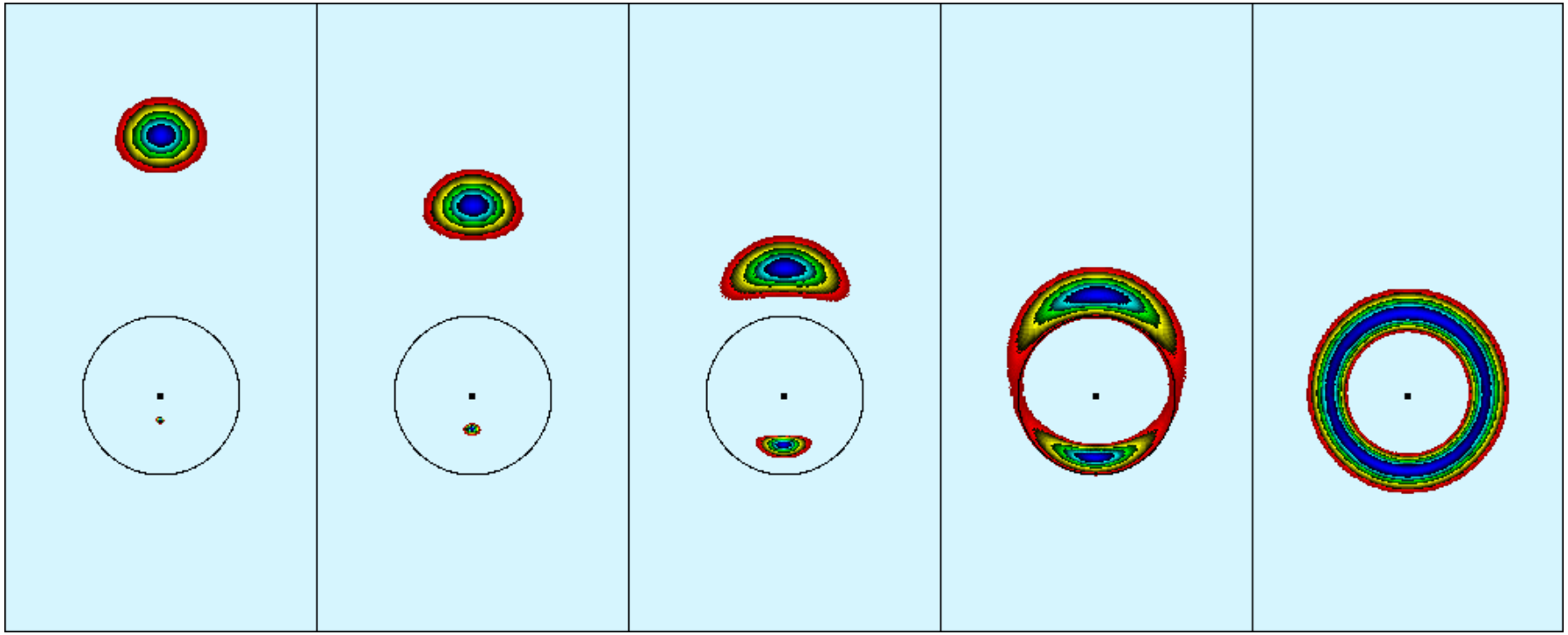
- Gravitational field
- Mass – deflects the light ray
- Larger mass => larger deflection angle

Single Point Mass Lens

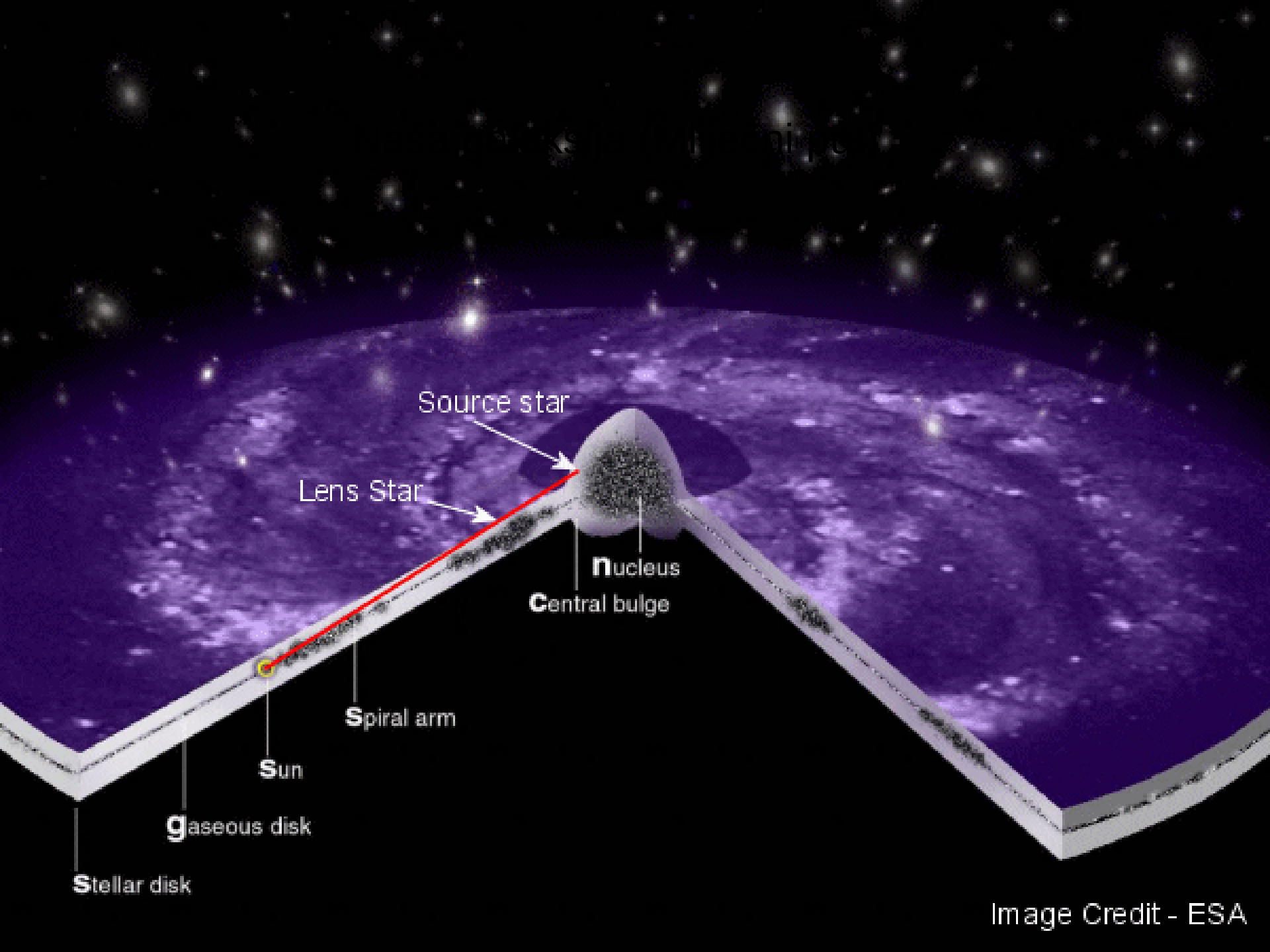


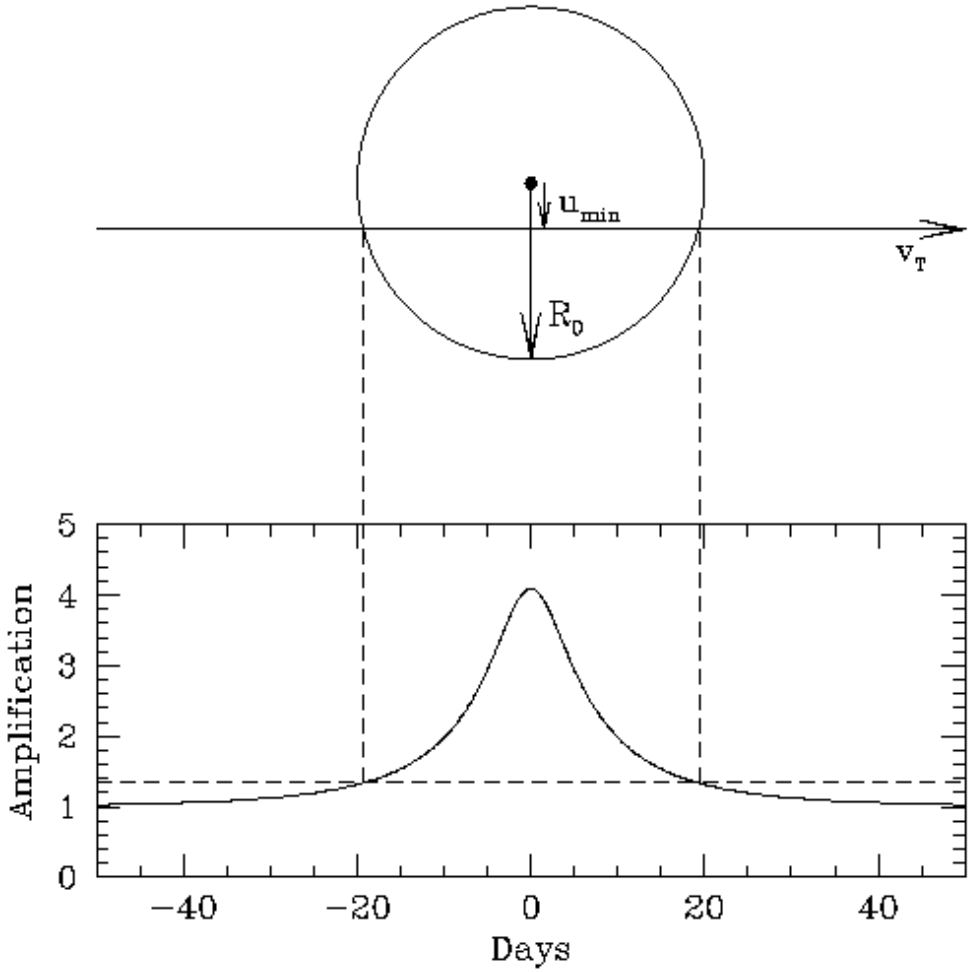
Einstein radius: $$R_E = \sqrt{\frac{4GM_{tot}D_{LS}}{c^2 D_L D_S}}$$

Einstein ring



Cluster of galaxies Abell 2218 as a gravitational lens


Source star
Lens Star
nucleus
Central bulge
Spiral arm
Sun
gaseous disk
Stellar disk
Image Credit - ESA



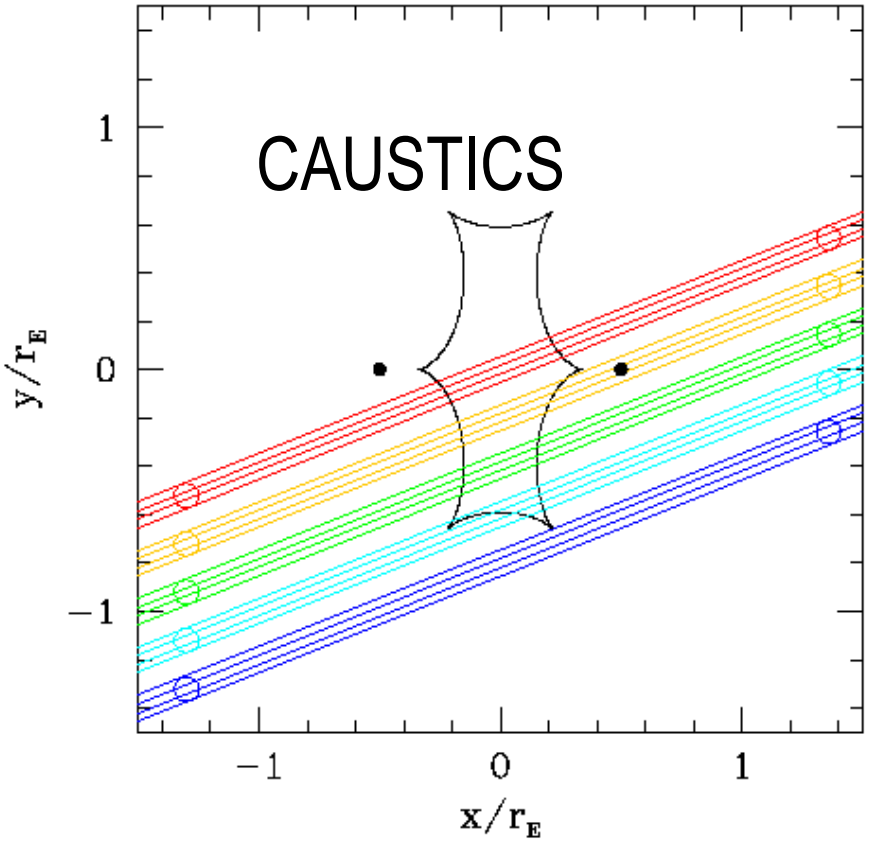
Microlensing effect: **the star and the image cannot be resoved**

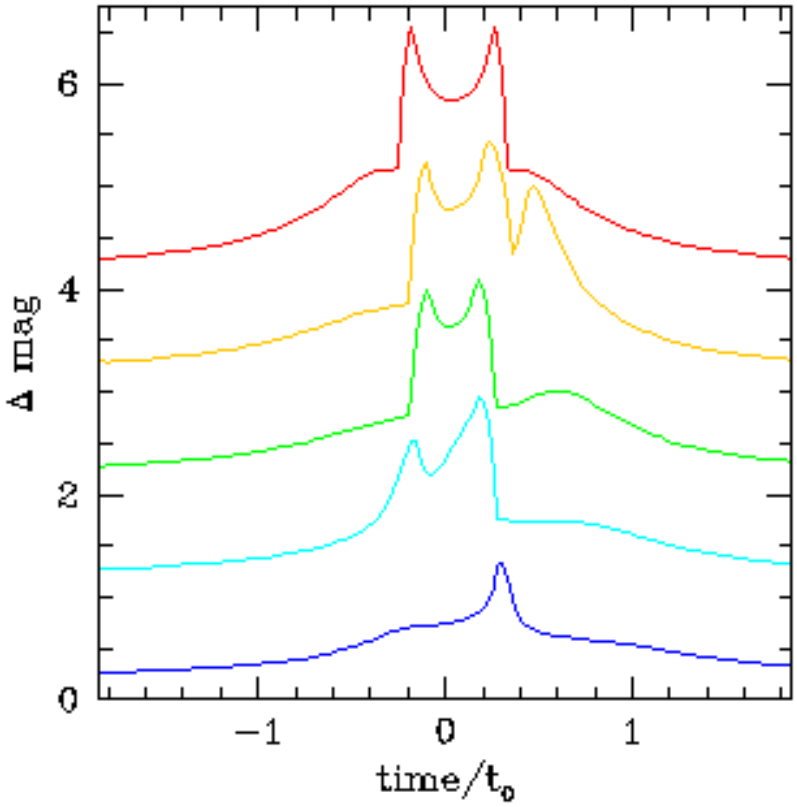
- magnification

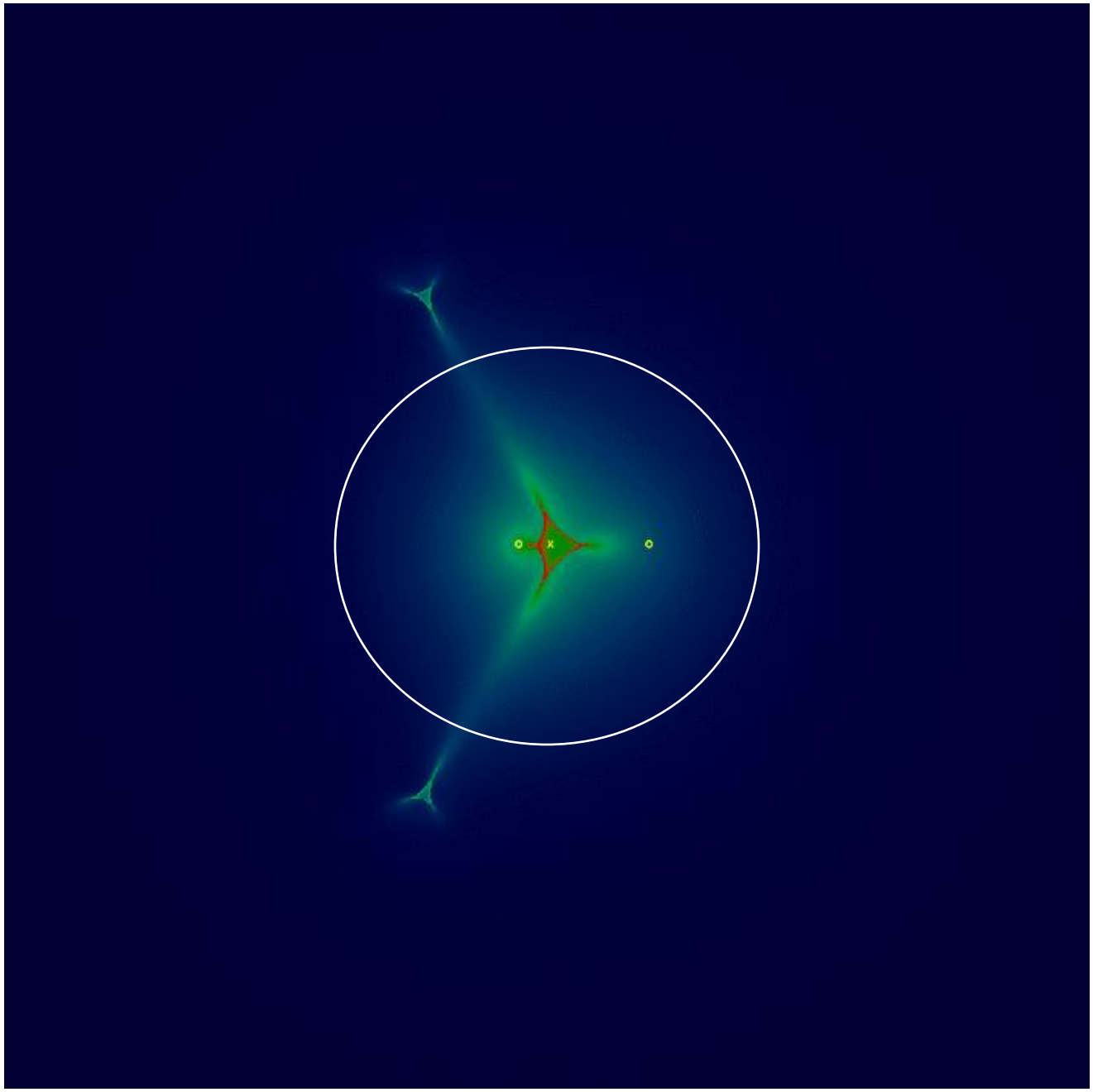
Source – 1 star
Lens – 1 star

Optical light curve

Binary lens







$M_{tot} = 1 M_{Sun}$

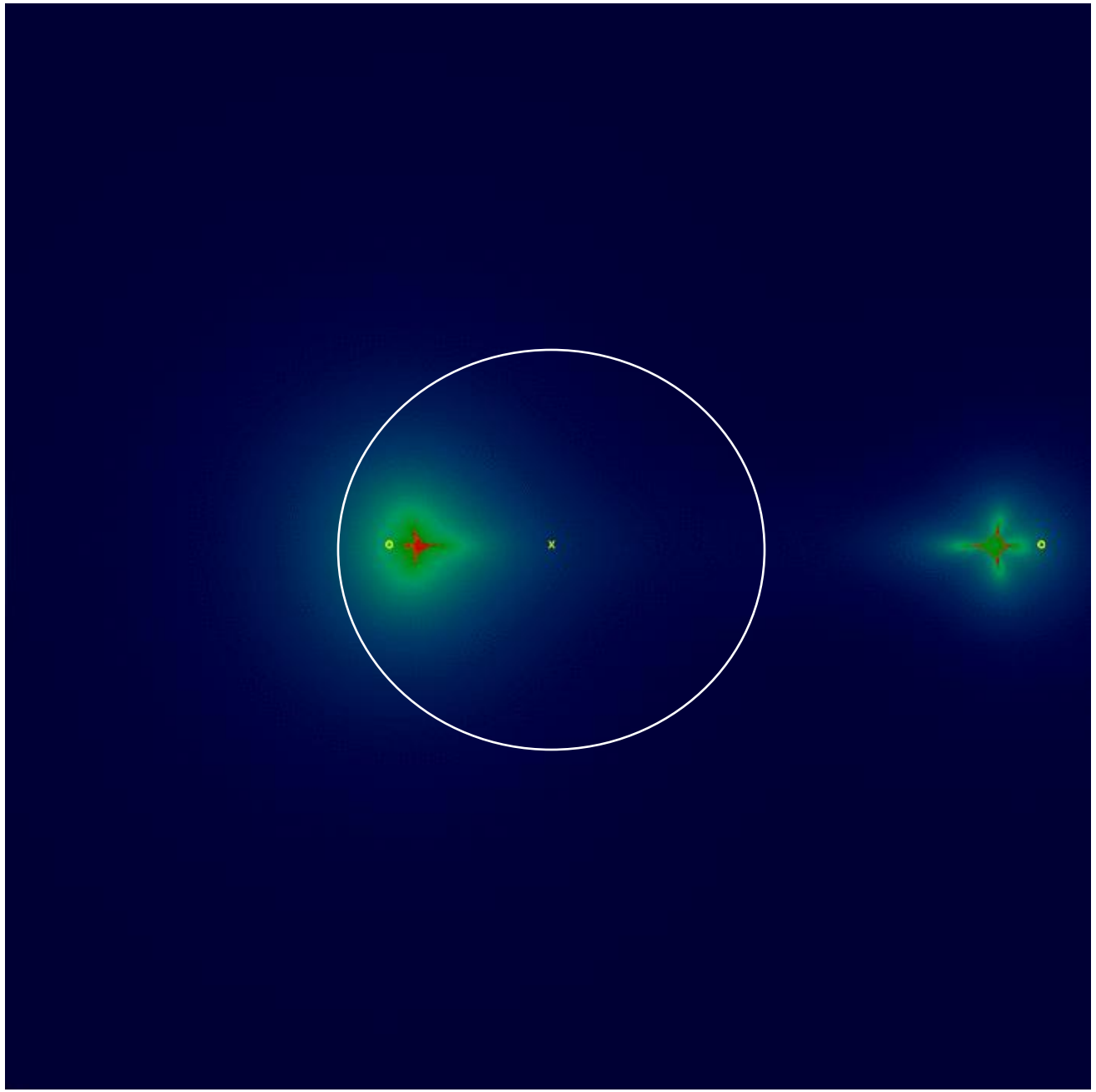
$q = 0.3$

$d = 0.6 R_E$

$5 R_E \equiv$

$1000 \ pix$

$1 pix \approx 5 R_{Sun}$



$M_{tot} = 1 M_{Sun}$

$q = 0.3$

$d = 3.0 R_E$

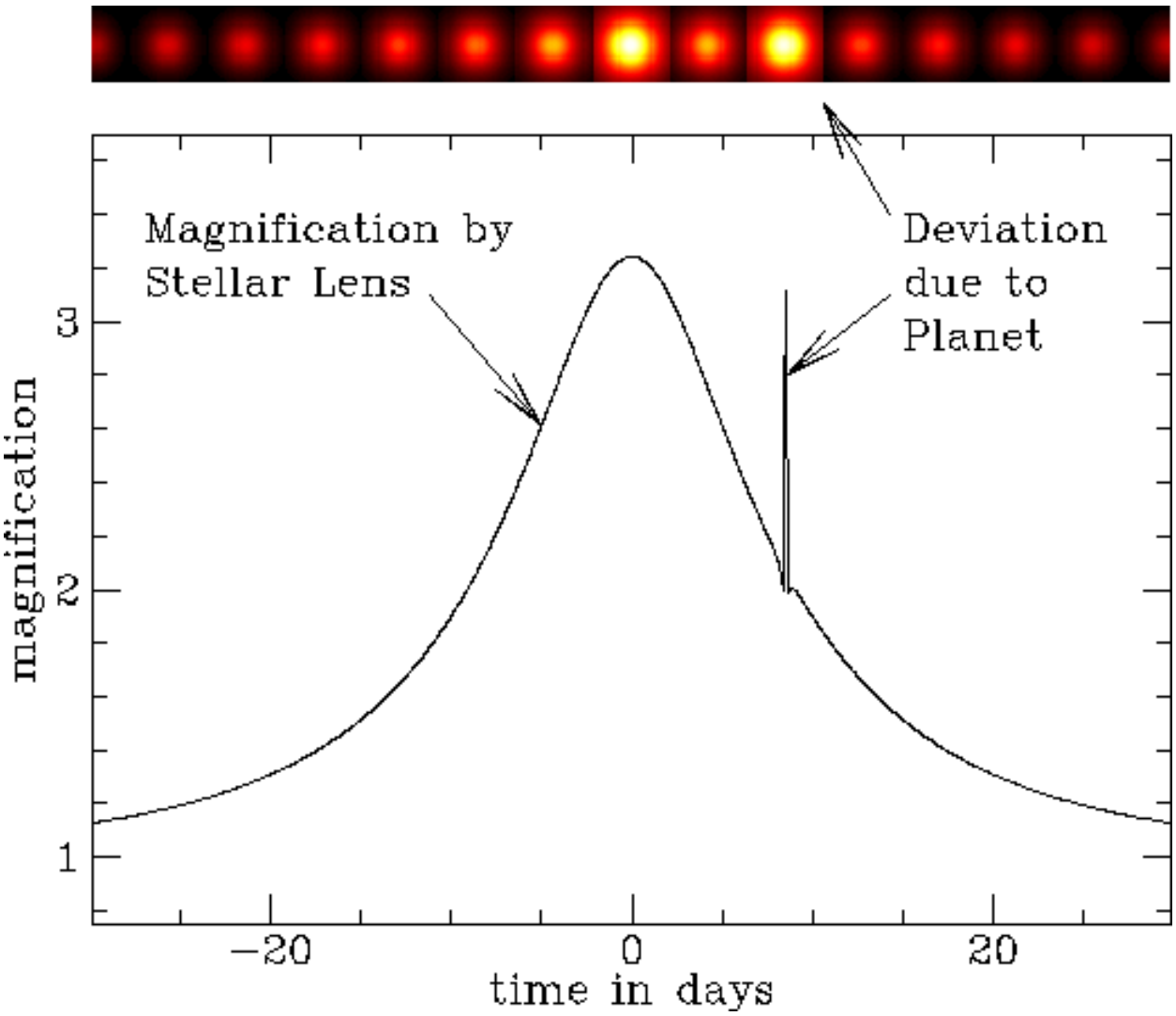
$5 R_E \equiv$

$1000 \ pix$

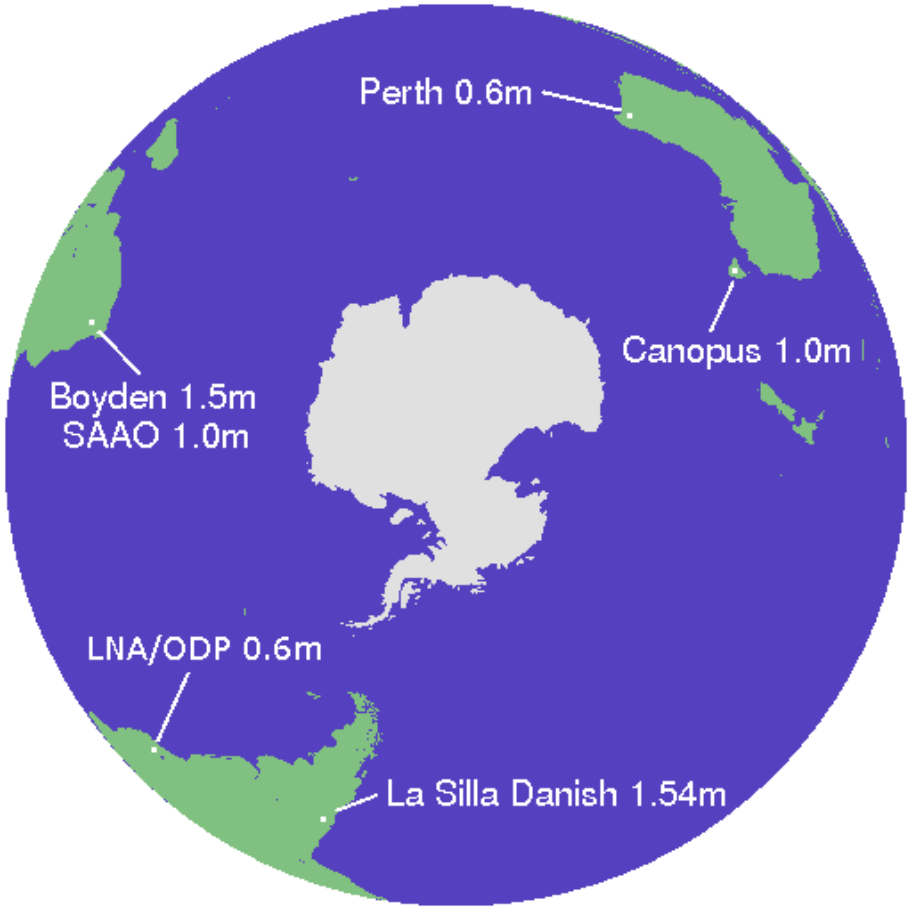
$1 pix \approx 5 R_{Sun}$

y

x


Magnification by
Stellar Lens
Deviation
due to
Planet
magnification
3
2
1
−20
0
20
time in days

Microlensing surveys

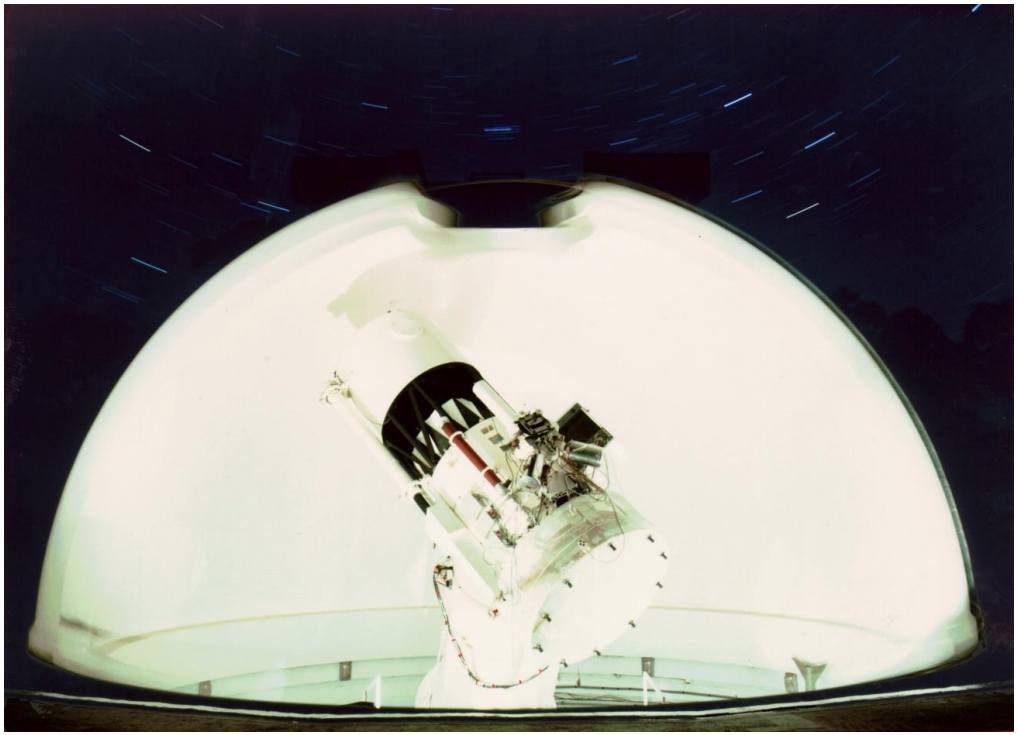


OGLE and **MOA:**
Wide-field
monitoring, alerts

MicroFUN - PLANET
(*Probing Lensing Anomalies NETwork*)
- 24-hour follow-up photometric observations
- very dense data sampling
- *I&(V,R)* photometric bands

PLANET Telescopes

Chile: 1.5 m



Tasmania (Australia): 1.0 m

OGLE-2005-BLG-390

$\alpha = 17\,h 54\ \text{min}\ 19.2\,s$

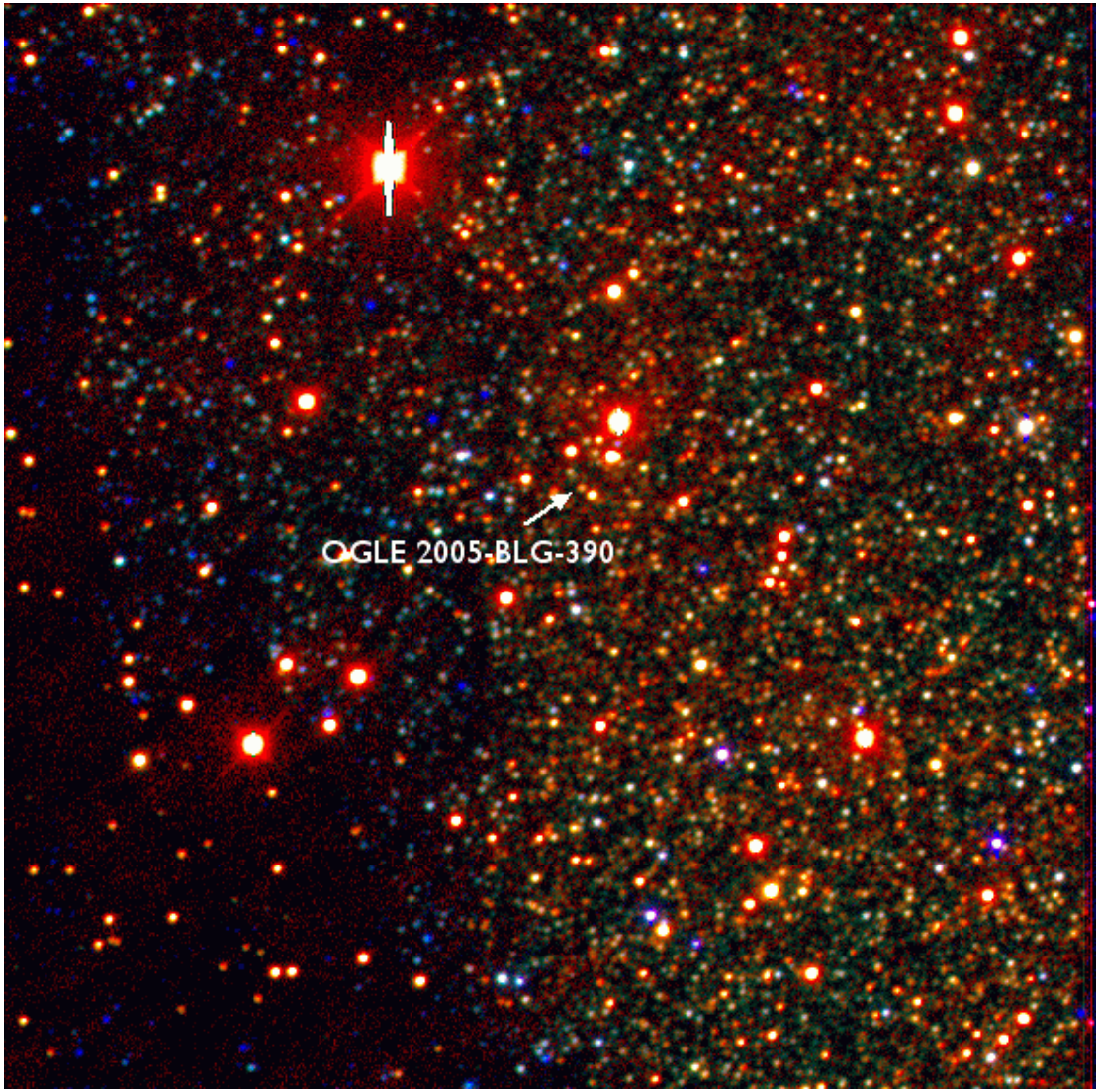
$\delta = -30^\circ 22' 38''$

I photom. band

G4III type source star

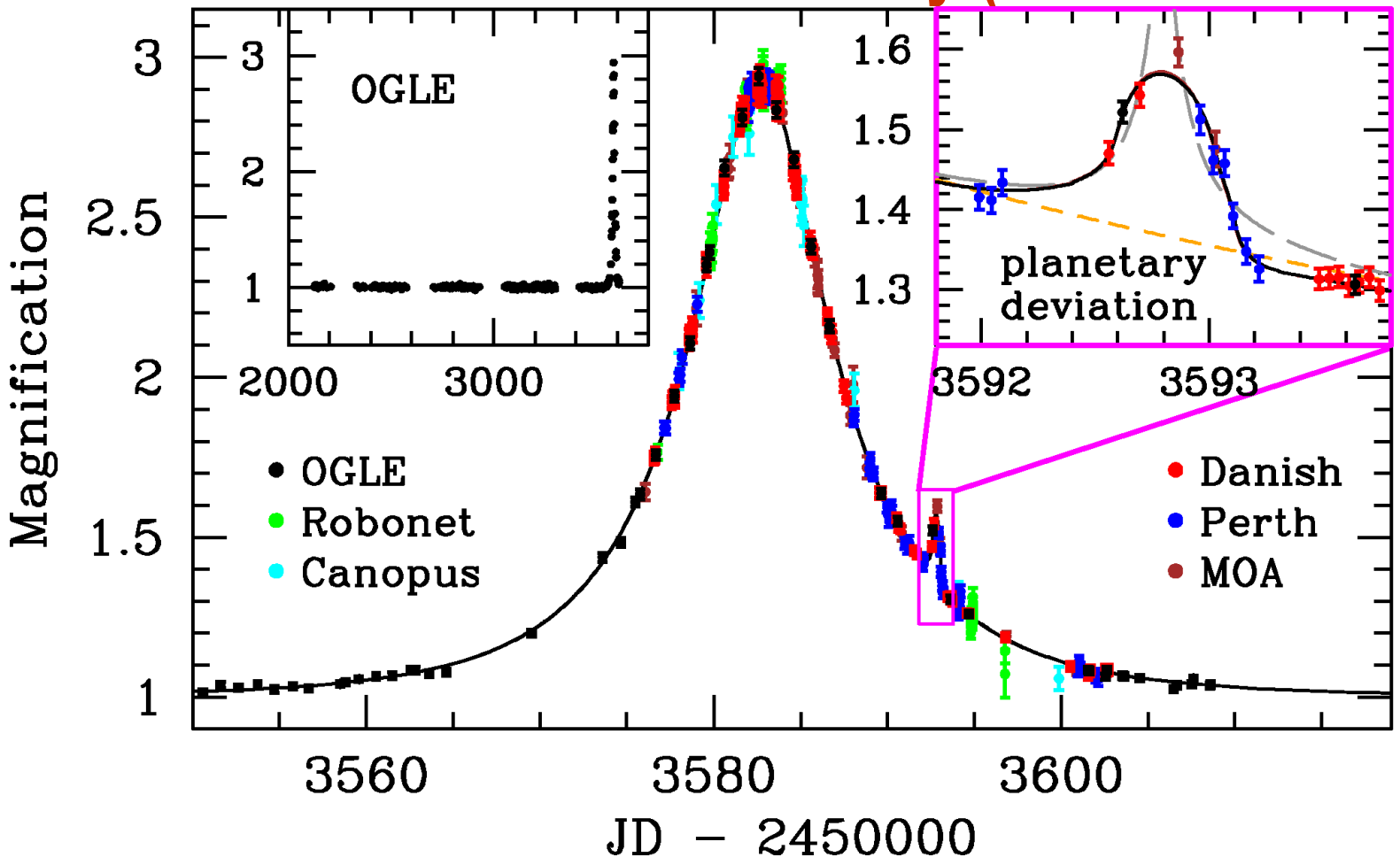
$R_{G*} \sim 10\, R_{Sun}$

$T_{G*} \sim 5200\ K$

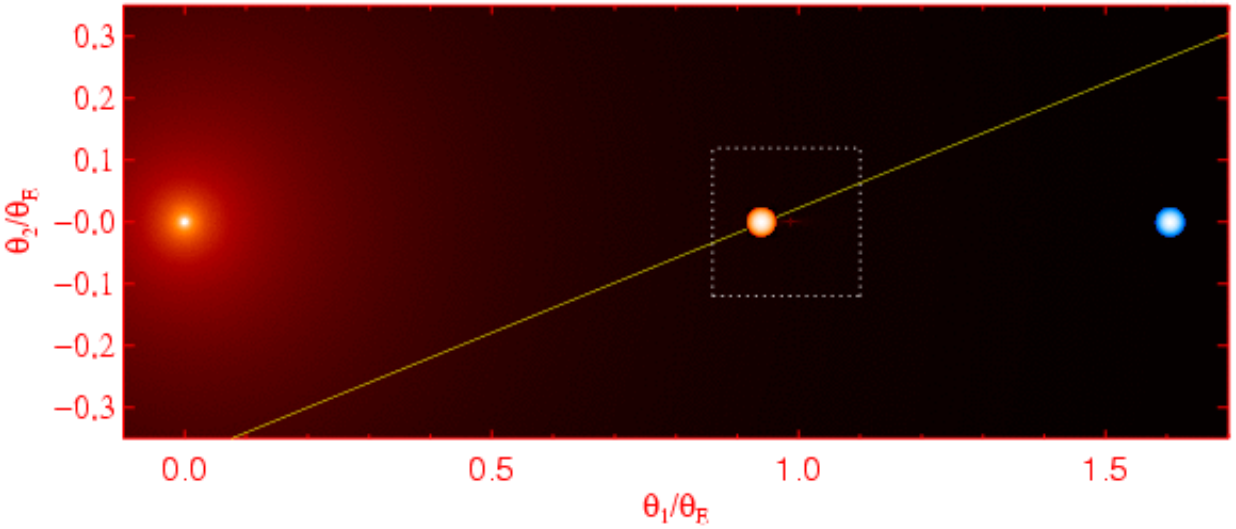


0.5‘x0.5‘

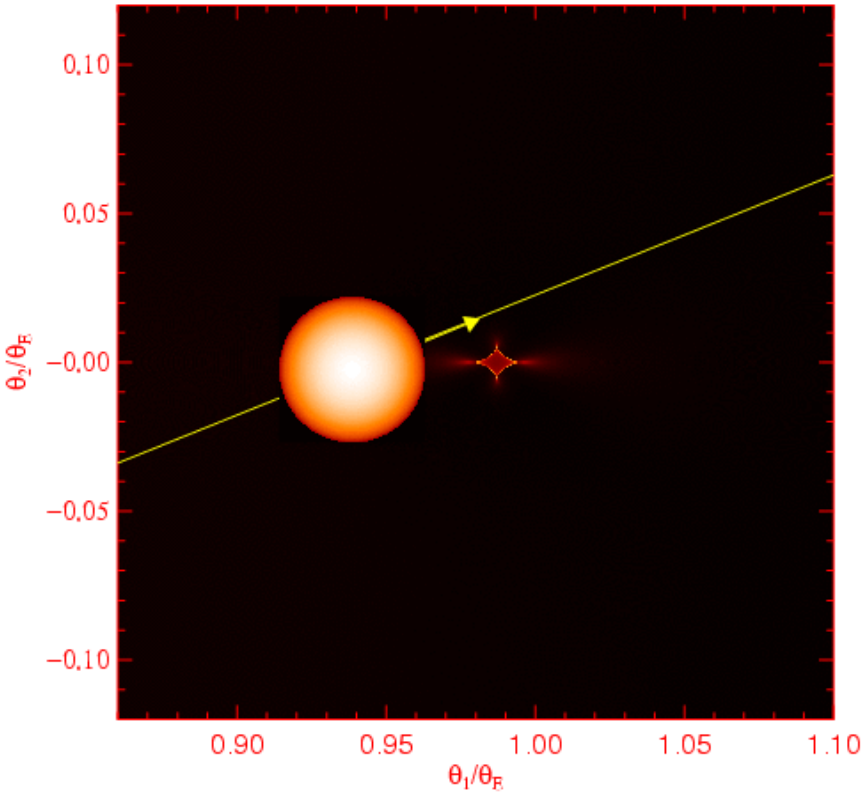
OGLE 2005-BLG-390Lb discovery (~ 5 Earth masses)



Beaulieu, Bennett,..., Dominis,... et al.: (PLANET/RoboNet, OGLE, MOA), 2006, *Nature*



The source path (G giant) relative to the lens system (Planet + M star)



FINITE SOURCE EFFECT

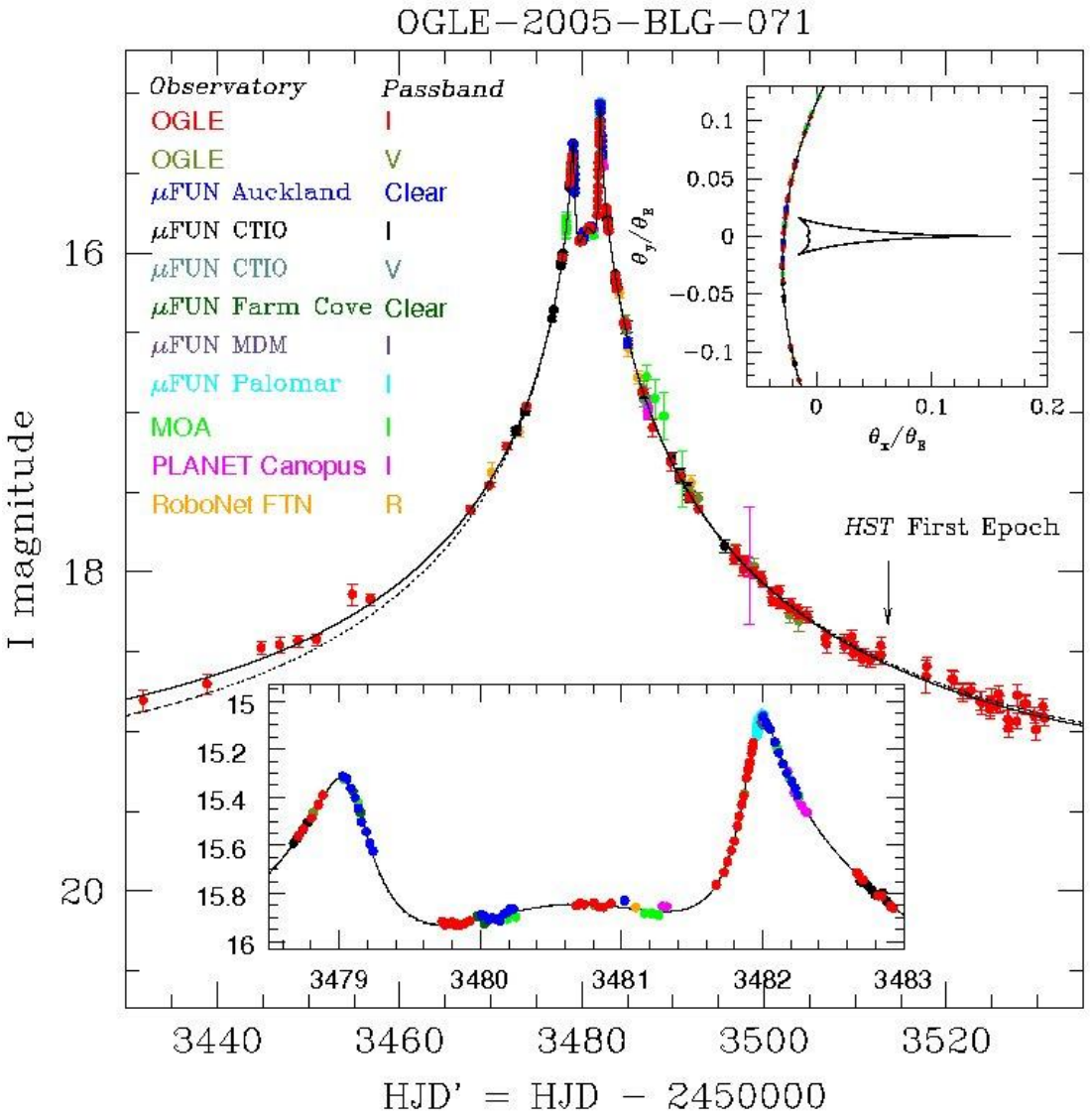
$$R_{*source} \Rightarrow m_P$$

$$m_p \approx 5 m_{Earth}$$

A massive planet OGLE-2005-071Lb

M = 3 M(Jupiter), r=3.6 A.U.

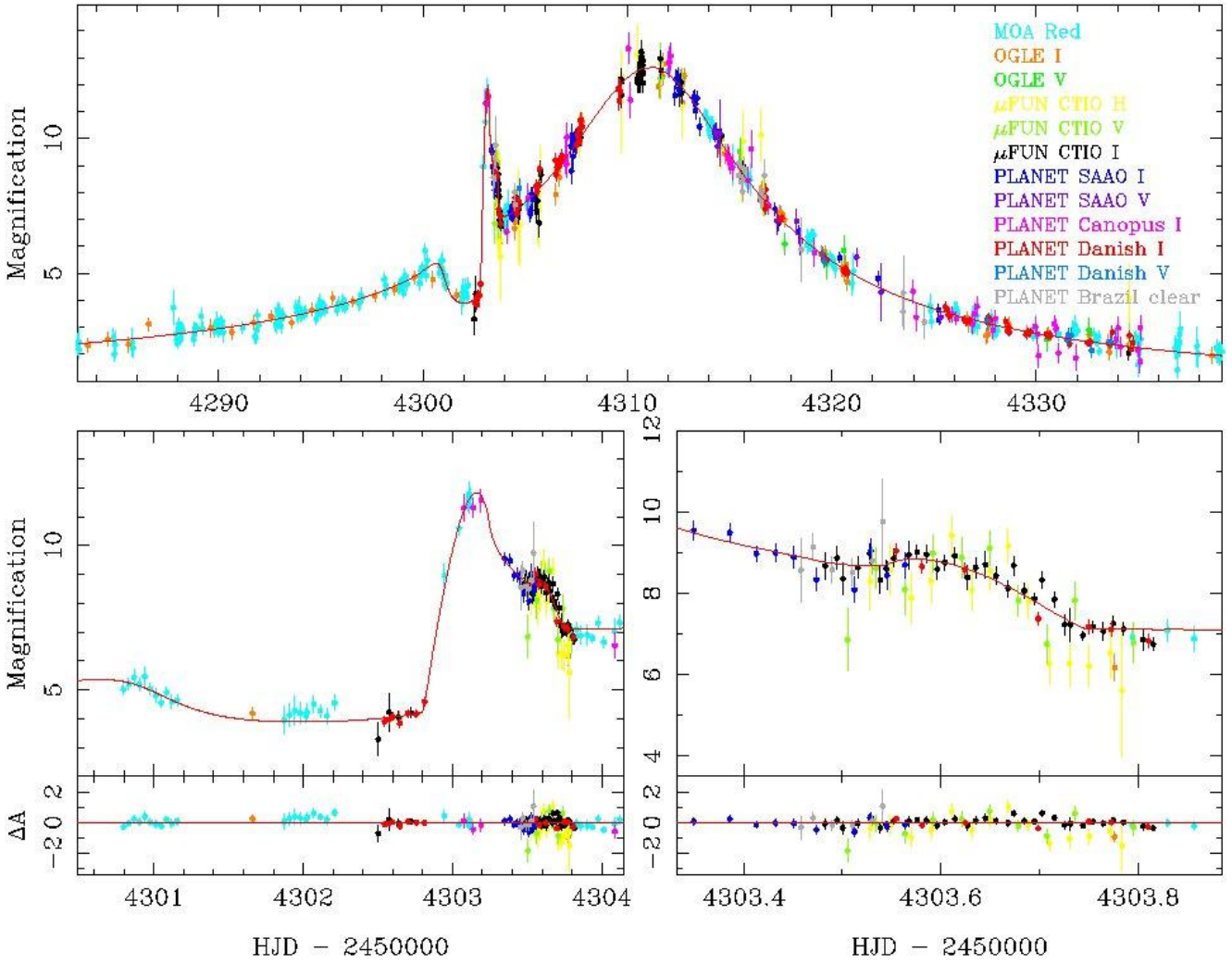
Long-lasting event
- Parallax effect



Collaborations PLANET, OGLE, MOA, ApJ (2009)

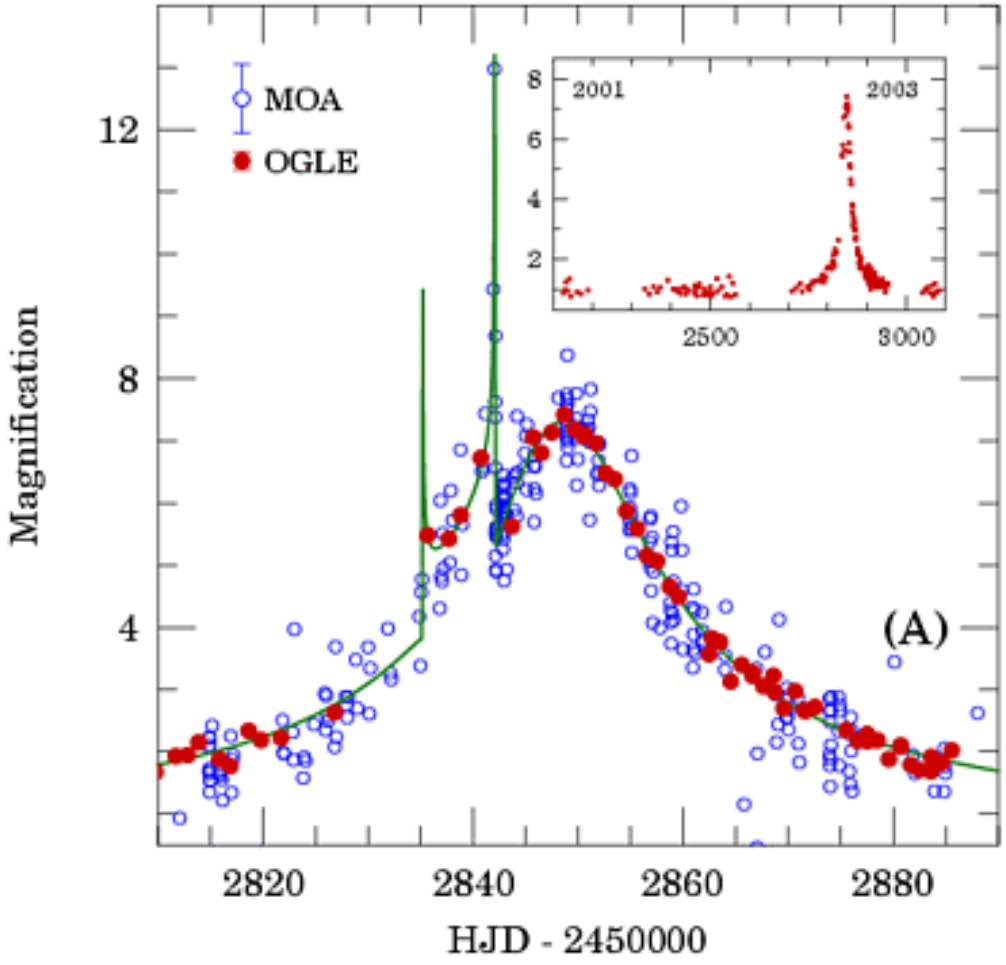
A cold Neptune-mass planet OGLE-2007-368Lb

M = 20 M(Earth), r=3.3 A.U.



Collaborations PLANET, OGLE, MicroFun, ApJ (2010)

First planet detection using microlensing (MOA-2003-BLG-053 / OGLE-2003-BLG-235)



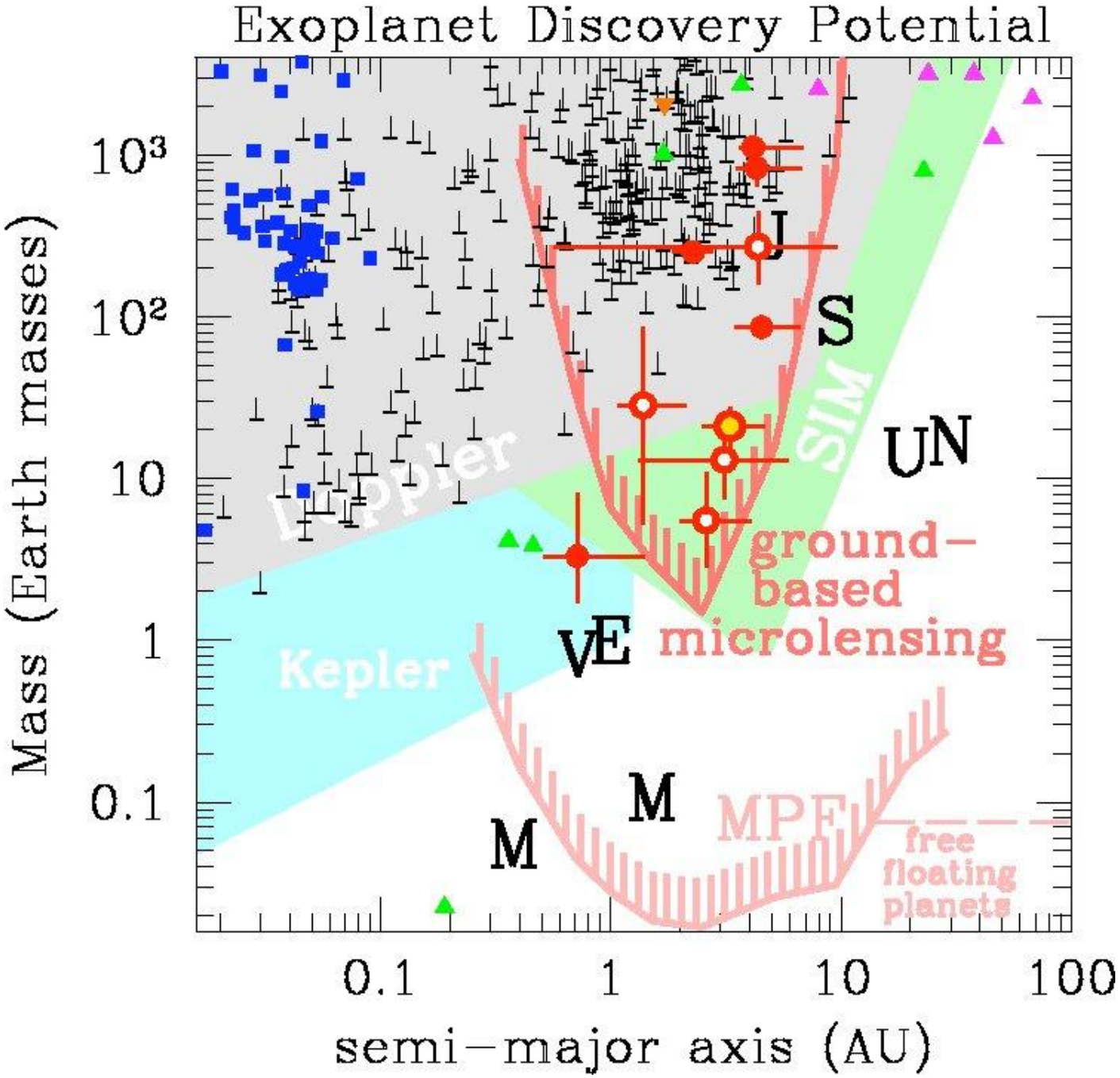
1.5 Jupiter mass planet

q=0.004

a=3 A.U.

D=5.2 kpc

Bond et al. (2004)


Exoplanet Discovery Potential
Mass (Earth masses)
10³
10²
10
1
0.1
0.1
1
10
100
semi−major axis (AU)
Doppler
SIM
Kepler
ground−
based
microlensing
MPF
free
floating
planets
J
S
UN
VE
M
M

Conclusion

- There is no “best method” for detecting exoplanets
- Methods are complementary
- Planet discoveries in last few years => Earthlike planets are much more common than thought before