AS3012: Exoplanetary Science

Stephen Kane

srk1

Room 226

Detection Methods Covered So Far

(1) Direct methods

(2) Astrometry → position

(3) Radial velocity → motion

(4) Transits → brightness

Effects of a planet on the parent star

(5) Gravitational lensing

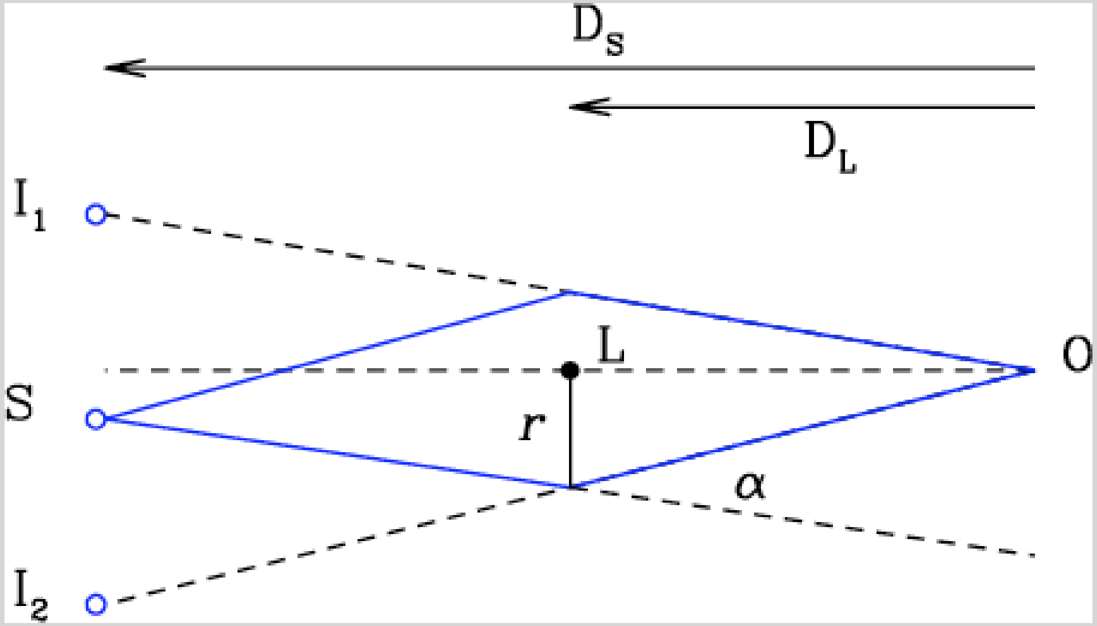
Effects of a planet on a background star

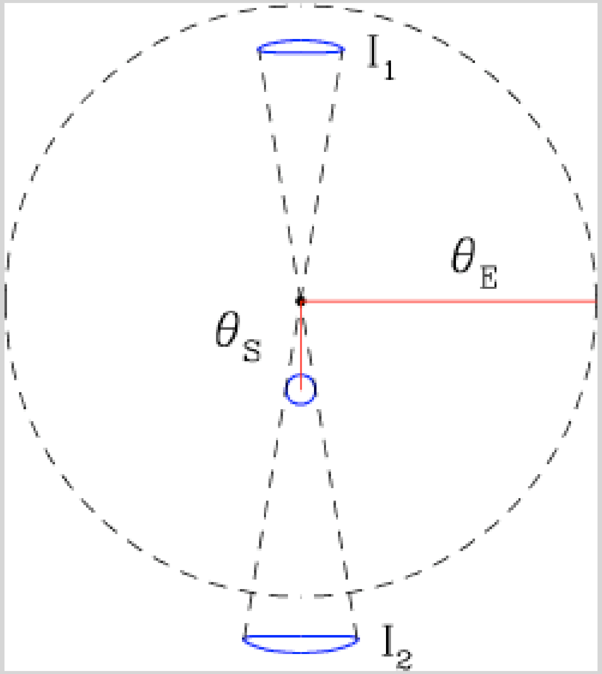
Gravitational microlensing

- Einstein first proposed gravitational lensing in 1936 as a consequence of general relativity
- Occurs when light is deflected by the gravitational field of stars, compact objects, clusters of galaxies, large-scale structure, etc
- For galactic distances (involving stars and/or compact objects), this is call gravitational *microlensing*

Simplest case to consider: a foreground object of mass M (the **lens**) lies along the line of sight to a more distant background object (the **source**). In this case, the deflection of a light ray at a distance *r* is given by:

$$\alpha = \frac{4GM}{c^2 r}$$



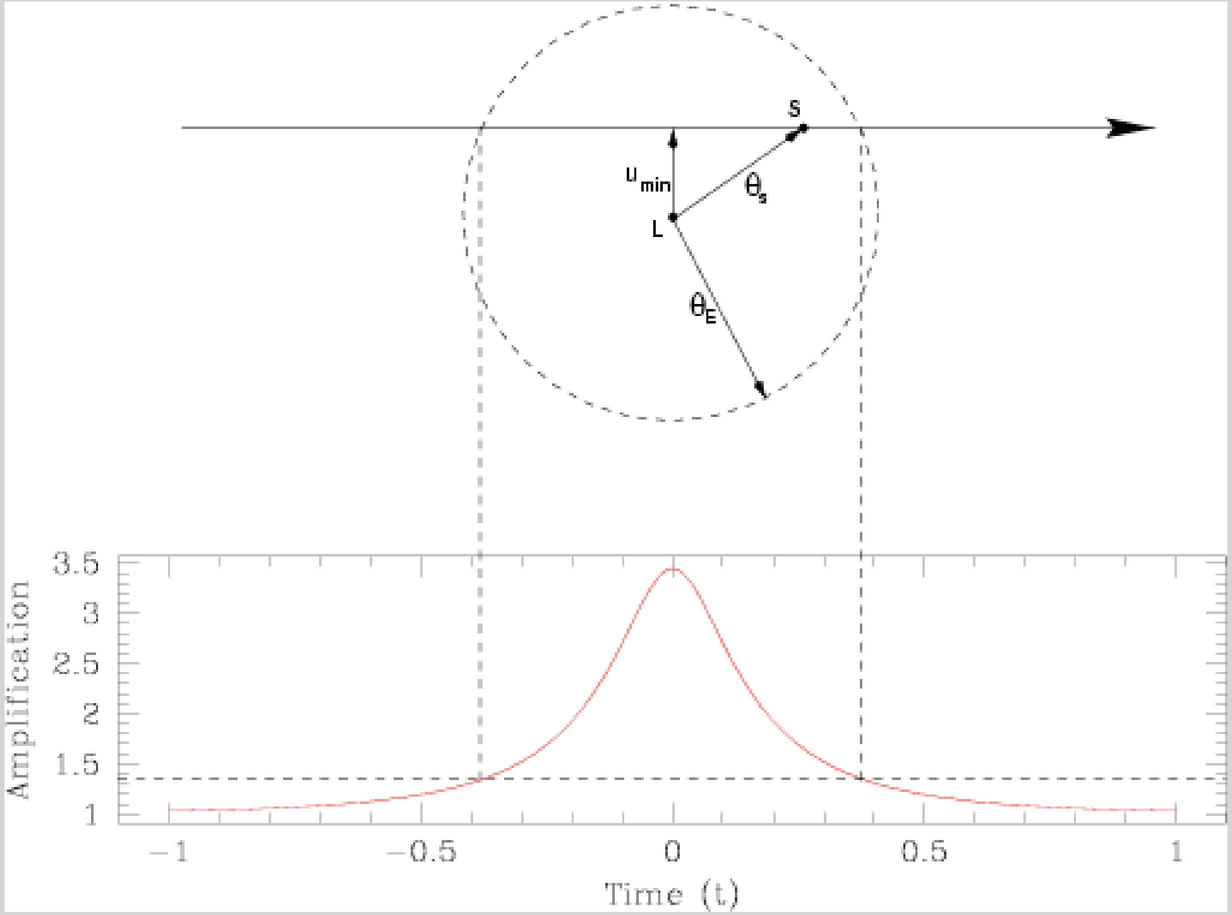


The angular *Einstein ring radius* is defined as:

$$\theta_E = \sqrt{\frac{4GM}{c^2}\frac{(D_S - D_L)}{D_L D_S}}$$

which corresponds to a physical size of $R_E = D_L \theta_E$

Gravitational lensing **conserves surface brightness**, so the distortion of the image of the source across a larger area of sky implies **magnification**.



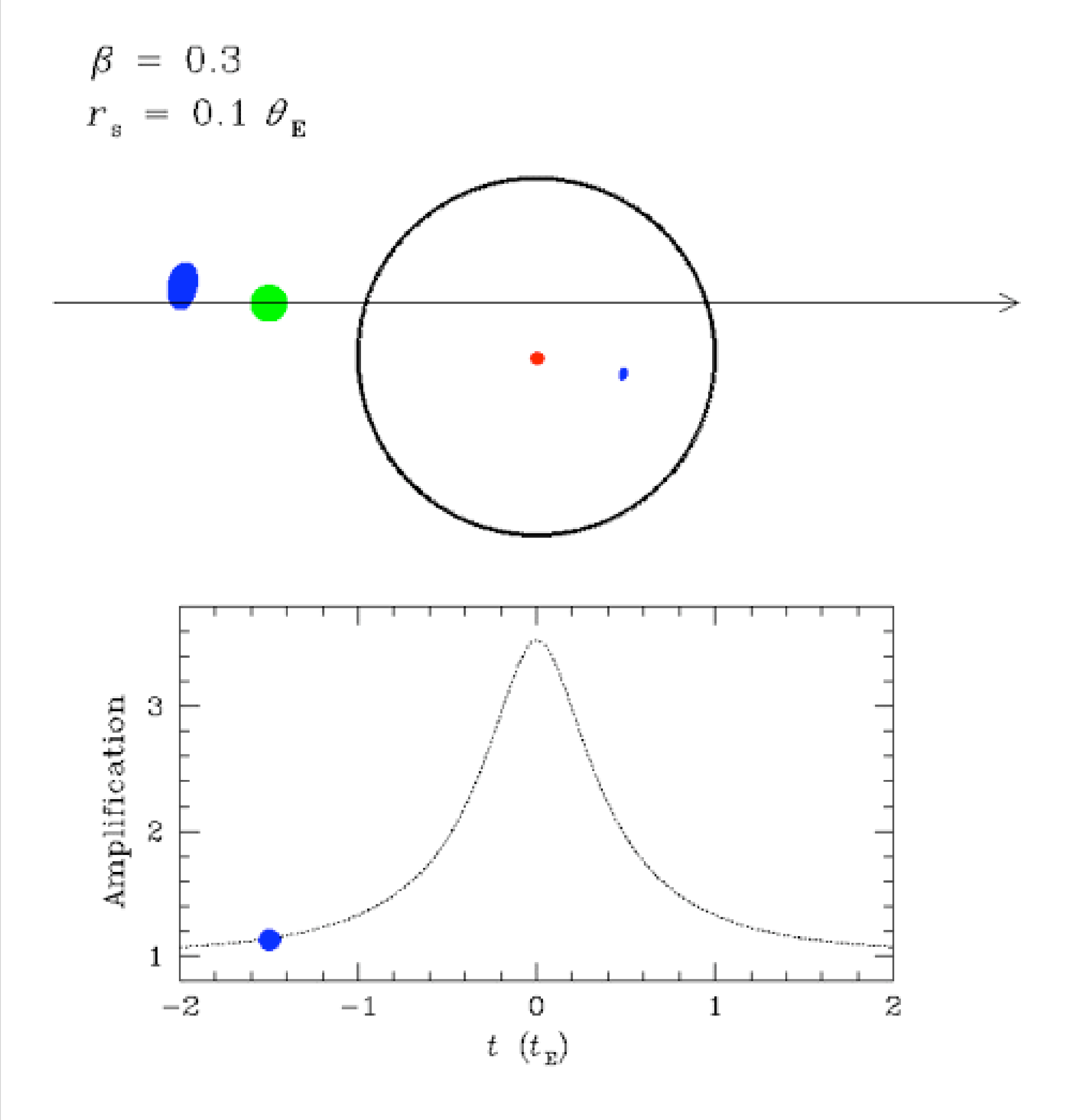
The total amplification due to the combined images of the source is:

$$A = \frac{u^2 + 2}{u\sqrt{u^2 + 4}}$$

where the dimensionless *impact parameter* $u \equiv \theta_S / \theta_E$

The *characteristic time scale* of an event is normally defined as the time taken for the source to move with respect to the lens by one Einstein ring radius

$$t_E \equiv \frac{R_E}{v_\perp} \propto \sqrt{M}$$



Notes:

(1) The peak amplification depends upon the impact parameter, small impact parameter -> large amplification of the flux from the source star

(2) For $u = 0$, apparently infinite magnification! In reality, finite size of source limits the peak amplification

(3) Rule of thumb: significant magnification requires an impact parameter smaller than the Einstein ring radius

(4) Microlensing is achromatic – all wavelengths affected equally

(5) Chances of microlensing occurring for a particular star is around 1 in a million – any given star only microlensed once

(6) Duration of event is a function of the mass, distance, and velocity of the lens

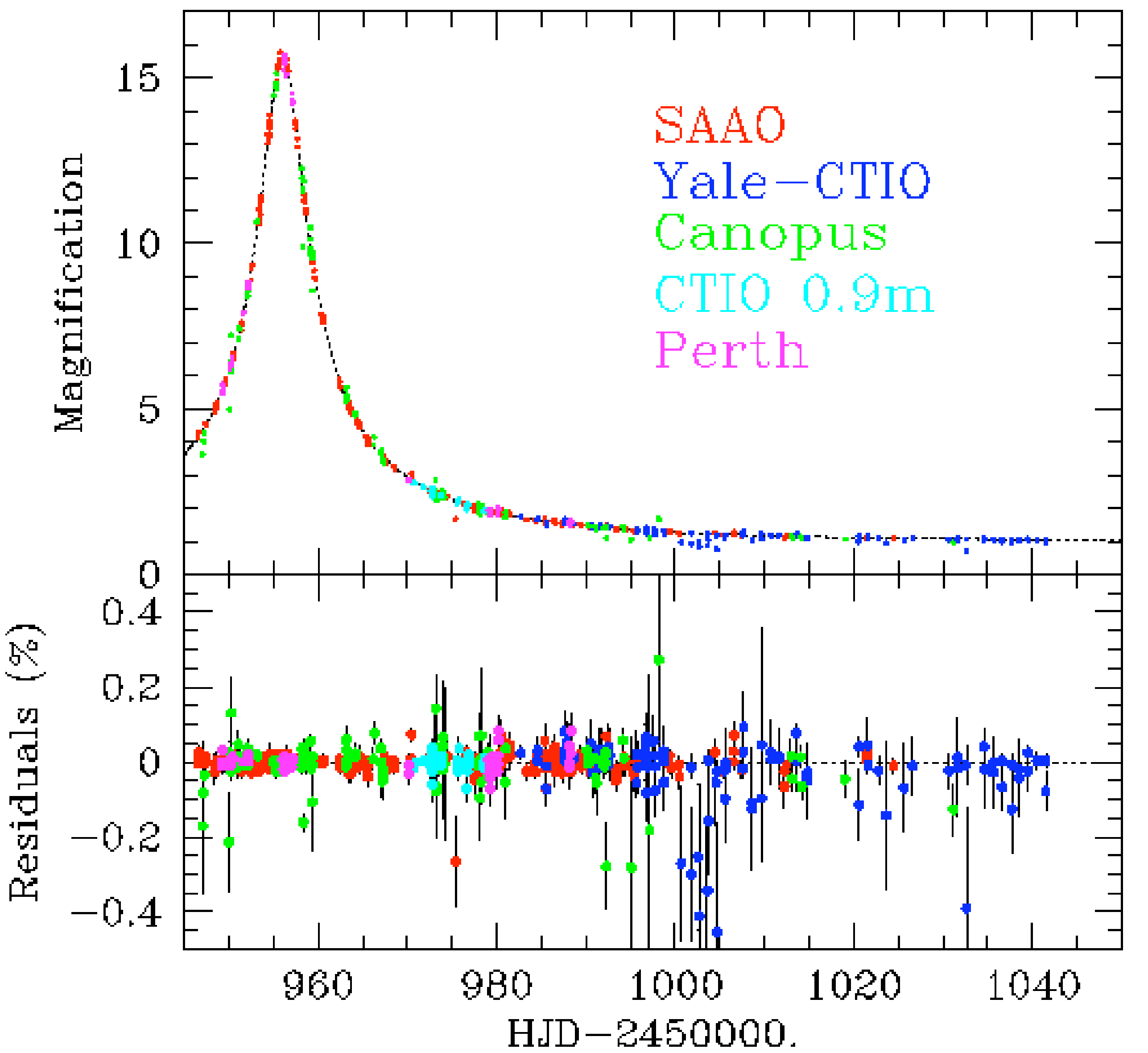
Several groups have monitored stars in the Galactic bulge and the Magellanic clouds to detect lensing of these stars by foreground objects (*MACHO, EROS, MOA, OGLE projects)*. Original motivation for these projects was to search for dark matter in the form of compact objects in the halo.

Timescales for sources in the Galactic bulge, lenses ~ halfway along the line of sight:

- Solar mass star ~ 1 month
- Jupiter mass planet ~ 1 day
- Earth mass planet ~ 1 hour

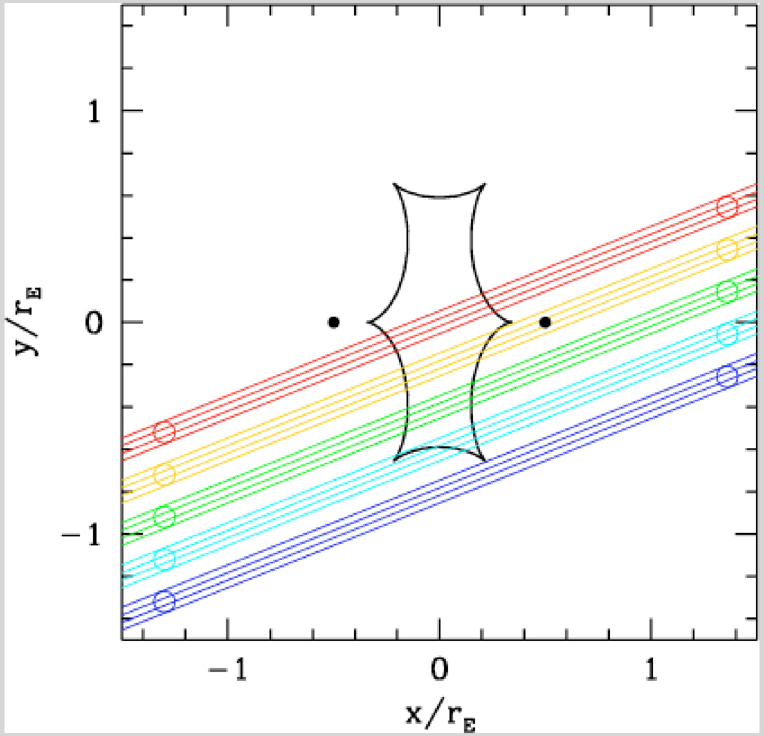
The dependence on $M^{1/2}$ means that all these timescales are observationally feasible. However, lensing is a very **rare event**, all of the projects monitor millions of source stars to detect a handful of lensing events.

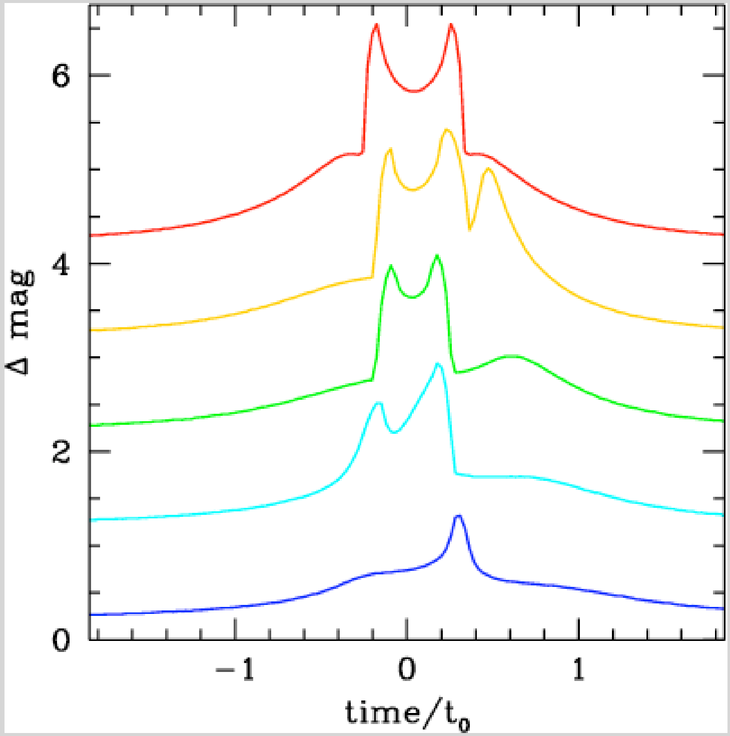
Lensing by a single star

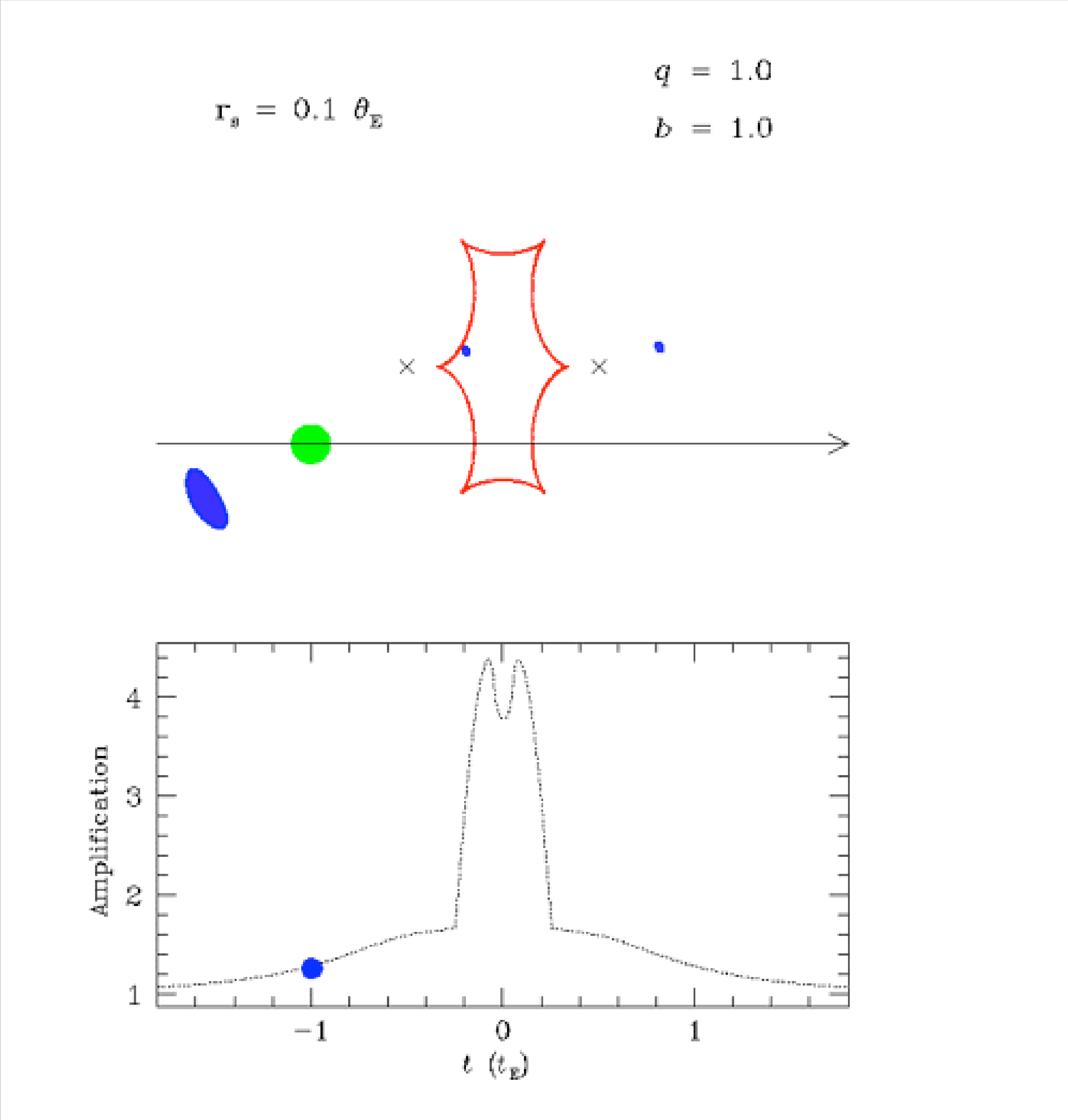


Microlensing anomalies

• Deviations from the standard point lens-point source light curve are referred to as *microlensing anomalies*
• The most interesting anomaly occurs in the case of a binary lens







$r_s = 0.1\ \theta_E$
$q = 1.0$
$b = 1.0$
Amplification
1
2
3
4
−1
0
1
$t\ (t_E)$

What has this to do with planets?

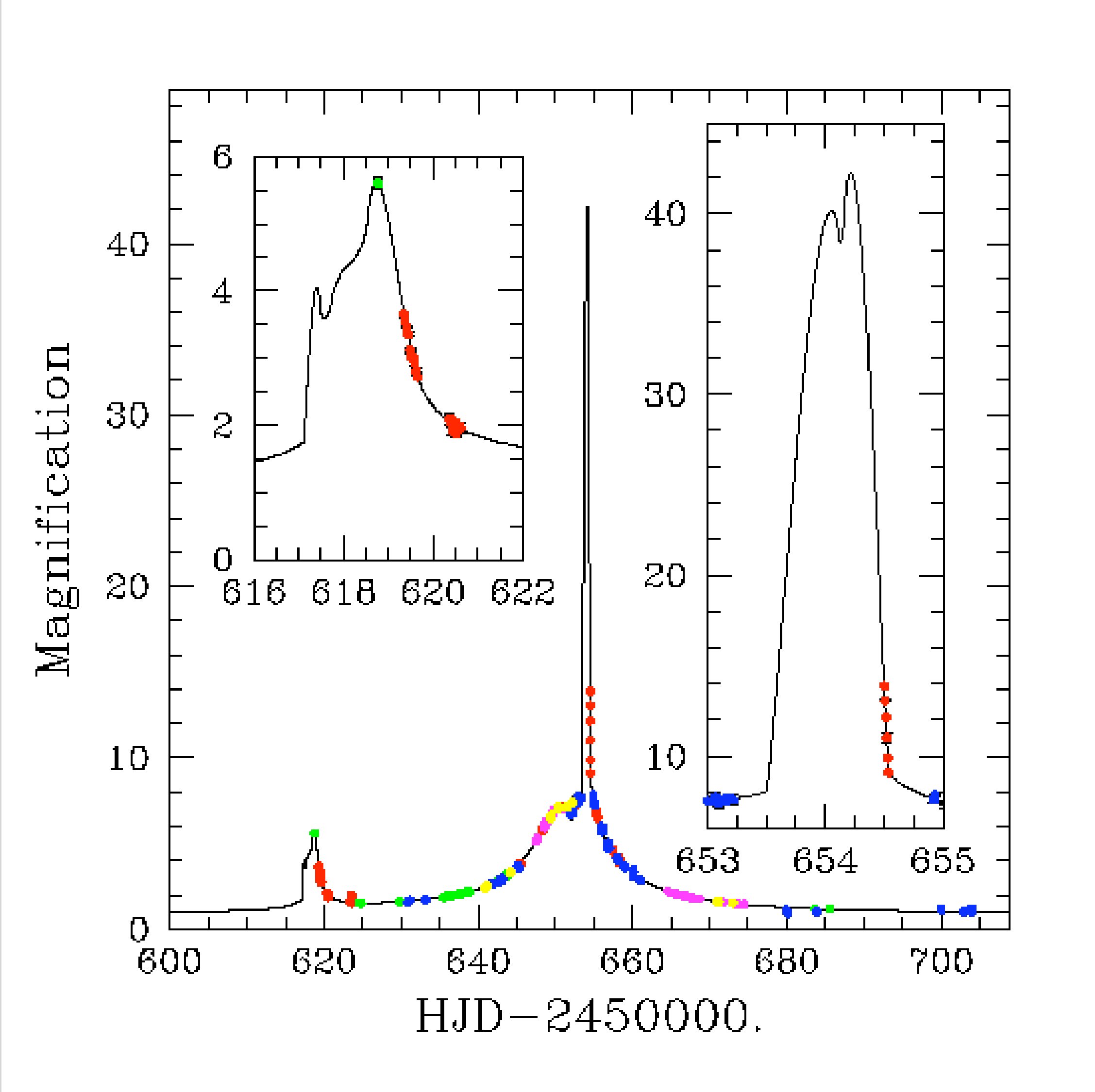
Light curve for a binary lens is more complicated, but a characteristic is the presence of sharp spikes or **caustics**. With good enough monitoring, the parameters of the binary doing the lensing can be recovered.

Orbiting planet is just a binary with mass ratio $q \ll 1$

Planet search strategy:

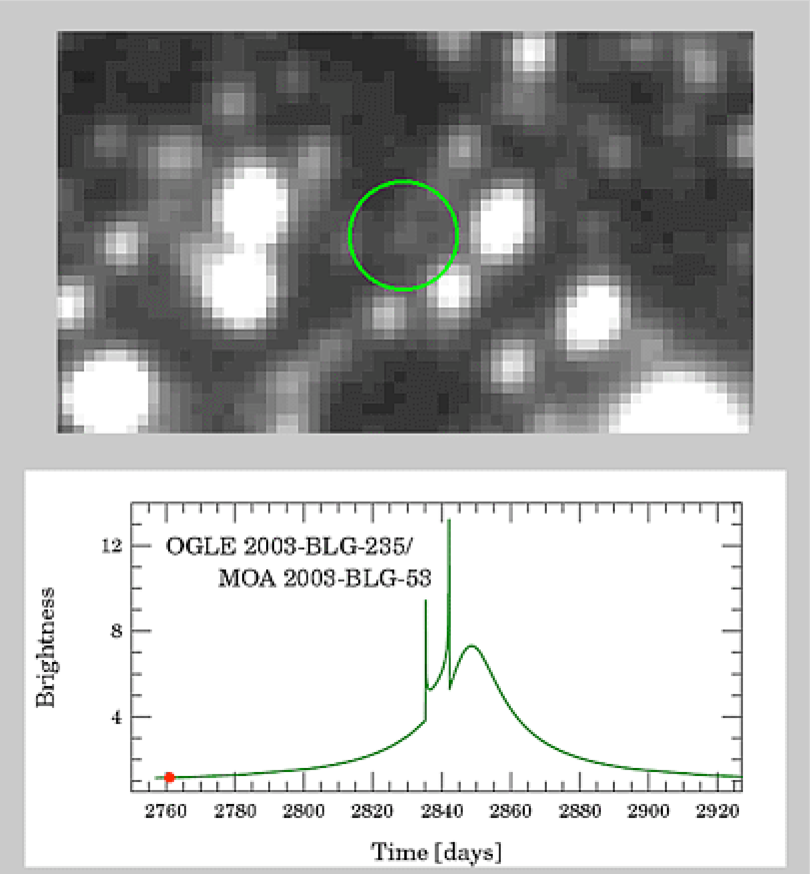
- Monitor known lensing events in real-time with dense, high precision photometry from several sites
- Look for deviations from single star light curve due to planets
- Timescales ~ a day for Jupiter mass planets, ~ hour for Earths
- Most sensitive to planets at $a \sim R_E$, the Einstein ring radius
- Around 3-5 AU for typical parameters

Many complicated light curves observed

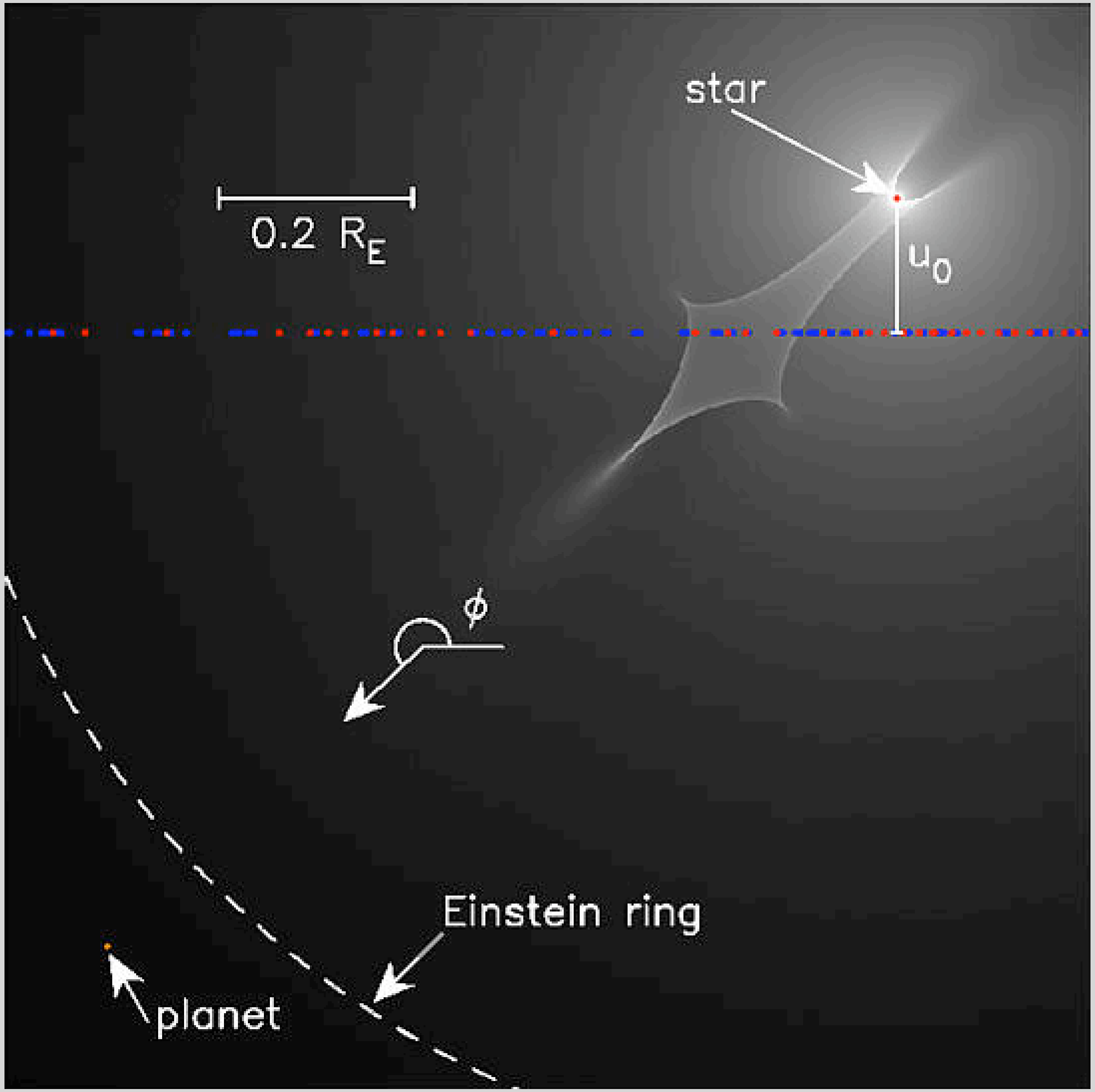


In this case, rotation of a binary lens results in complicated behaviour

OGLE-2003-235: First microlensing planet

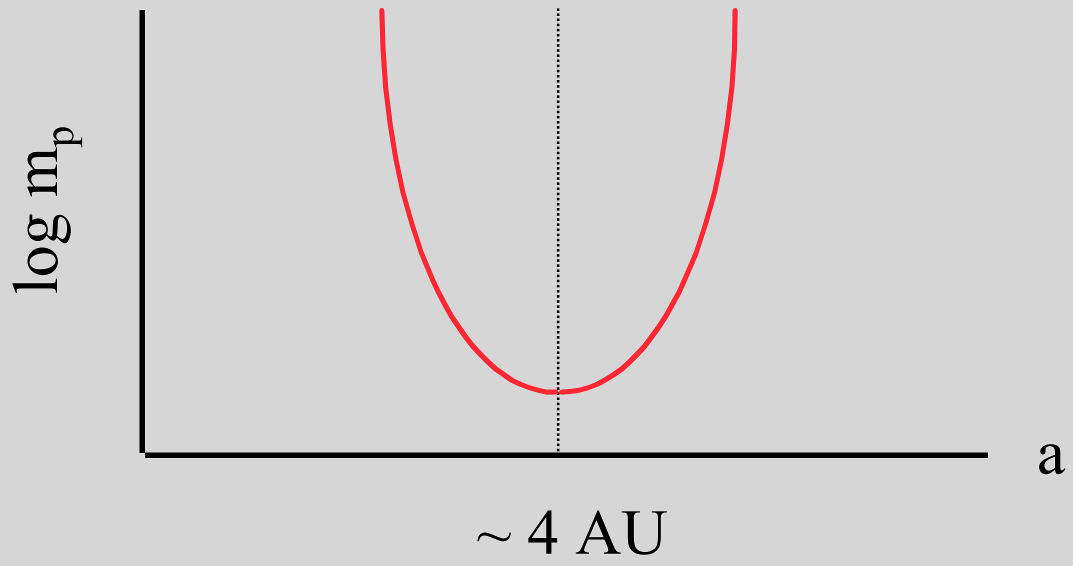


The estimated parameters are a 1.5 Jupiter mass planet orbiting at around 3 AU from the parent star


star
0.2 R_E
u_0
ϕ
Einstein ring
planet

Sensitivity to planets

Complementary to other methods:



Actual sensitivity is hard to evaluate: depends upon frequency of photometric monitoring (high frequency needed for lower masses), accuracy of photometry (planets produce weak deviations more often than strong ones)

Very roughly: observations with percent level accuracy, several times per night, detect Jupiter, if present, with 10% efficiency

Where are the microlensing planets?

- Monitoring of microlensing events requires a lot of time, a lot of patience, and a lot of telescope time around the world
- Some planet detection claims have been made, but alternative explanations have also been offered
- Degeneracy in microlensing light curves (in parameter space, noone can hear you scream!)