GAIA, Microlensing and Brown Dwarfs

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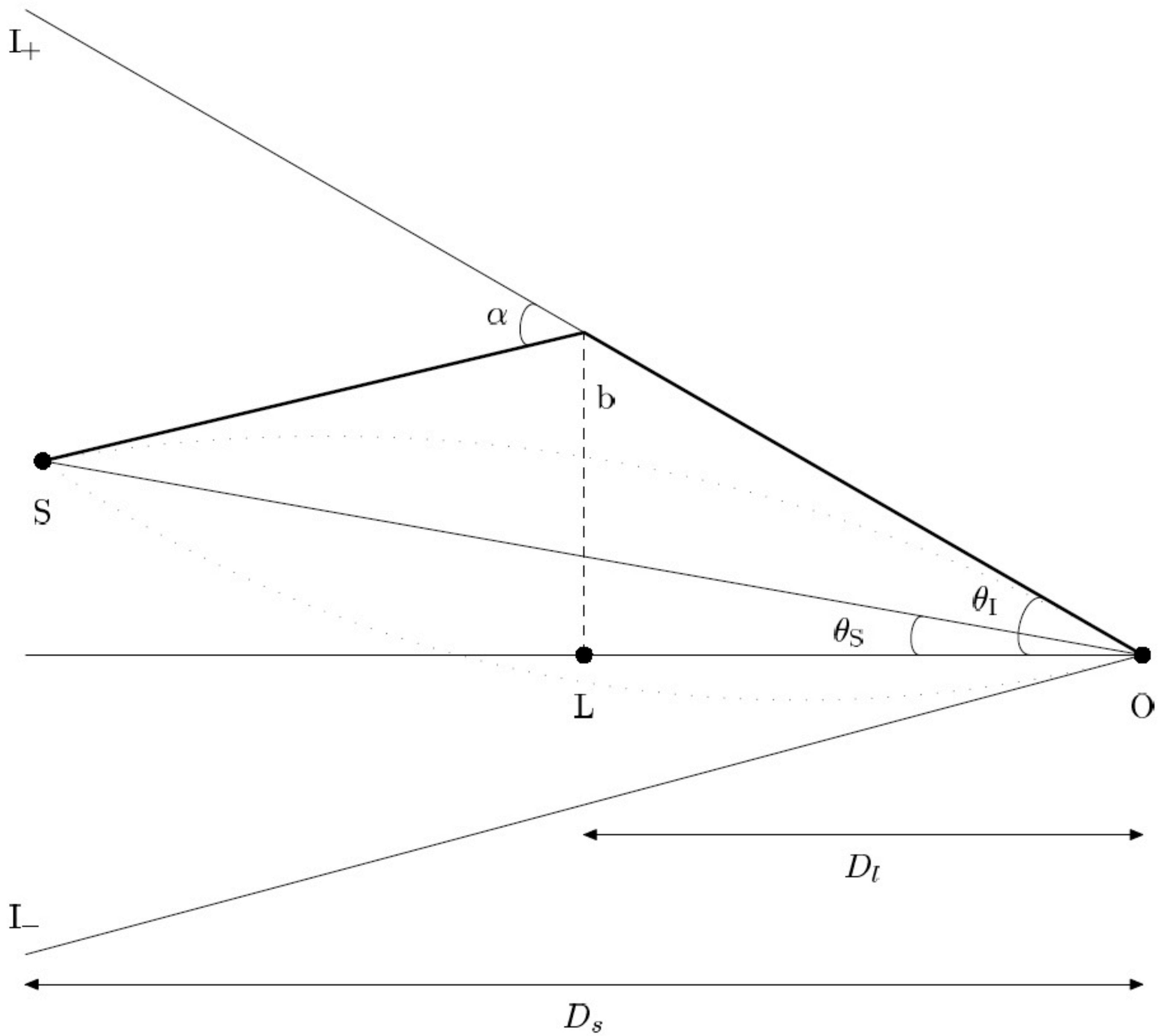
Hipparcos

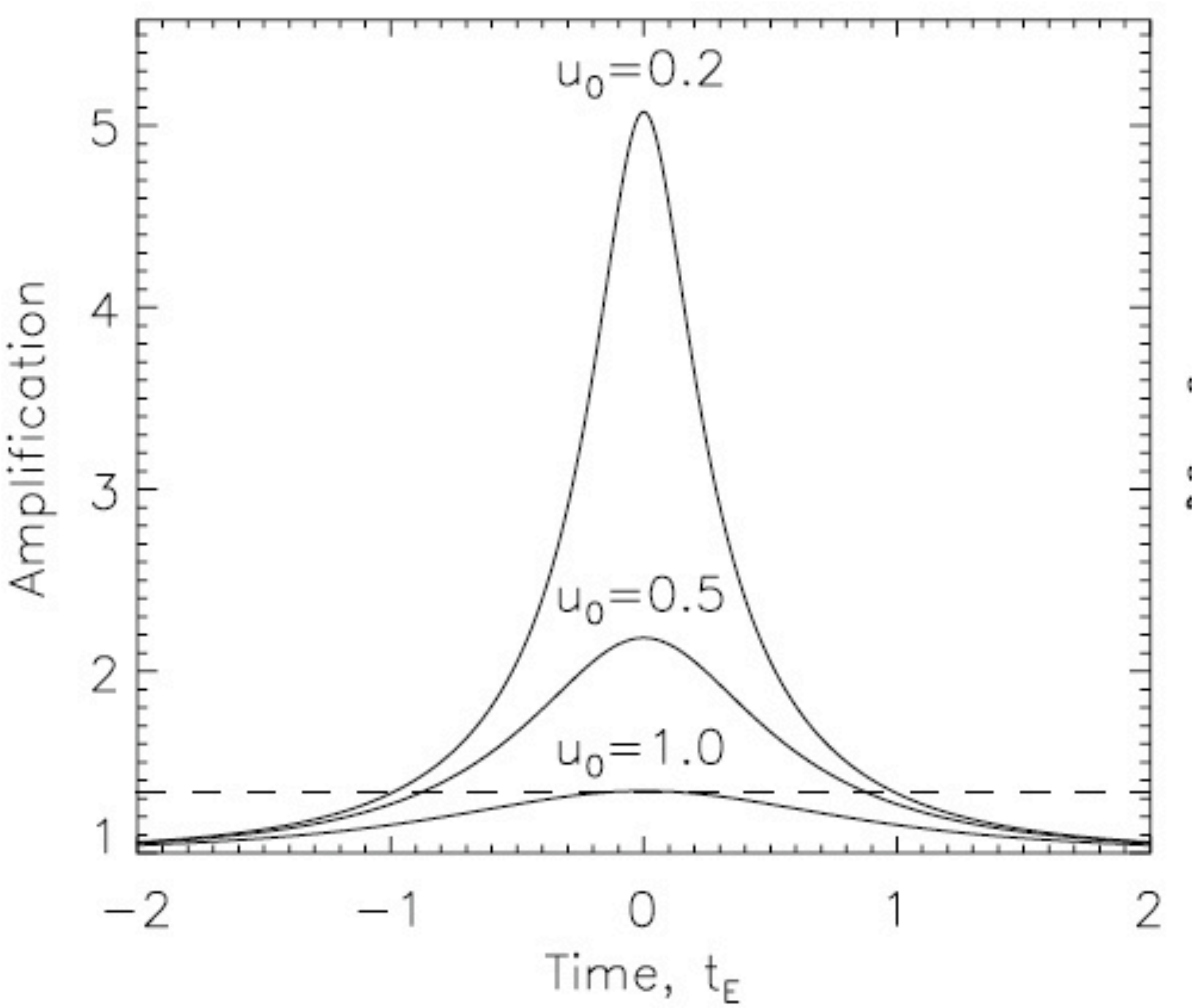
"I do not wish to embarrass my European friends more praise than it deserves. But two facts about Hipparcos seem to me of fundamental importance. First, it is the first time since Sputnik in 1957 that an outstanding new development in space science has come from outside the United States. Second, it is the first time since Uhuru that an outstanding new development has come from a small and relatively cheap mission."

(Freeman Dyson, "Infinite in All Directions")

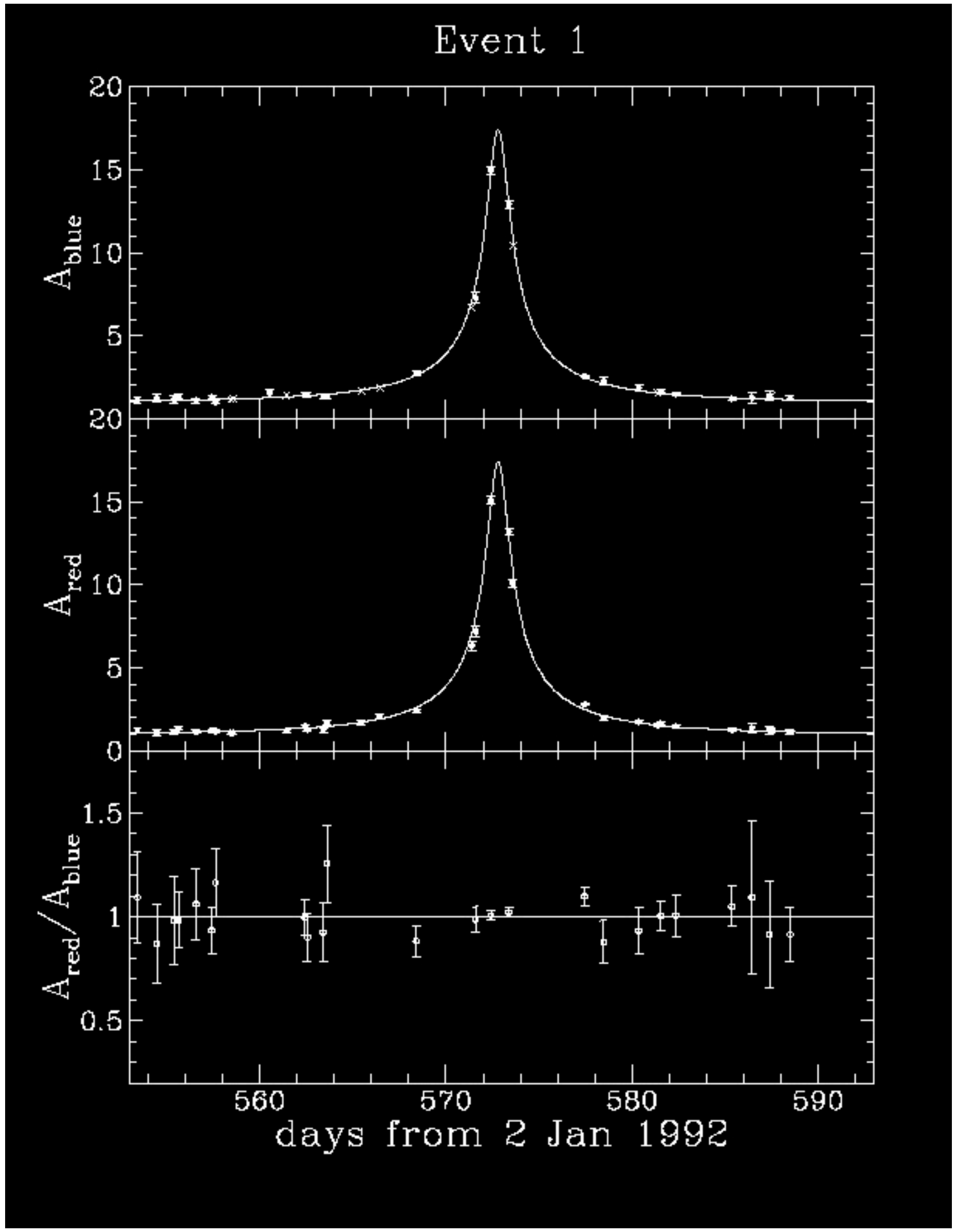
Microlensing



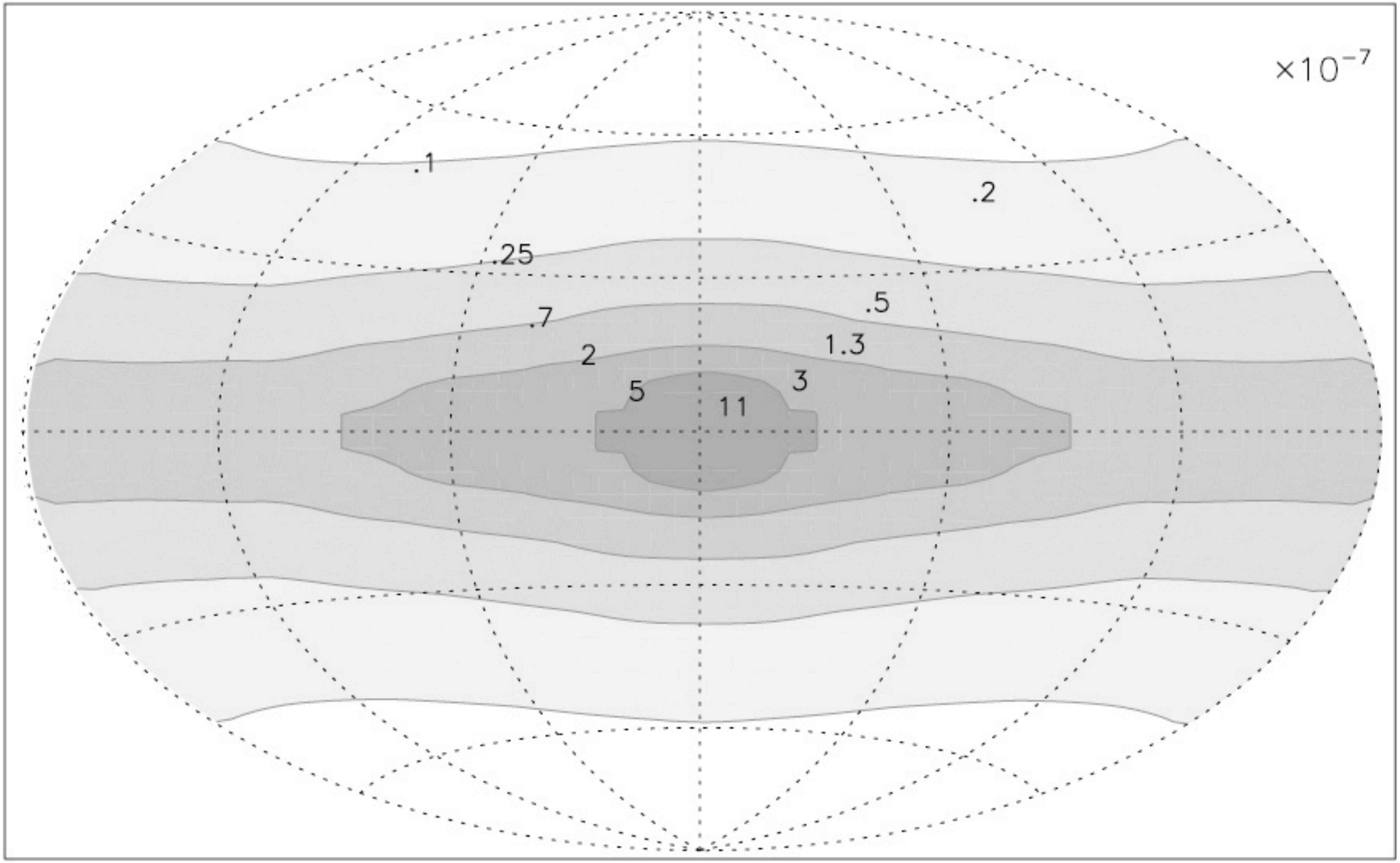
Photometric microlensing



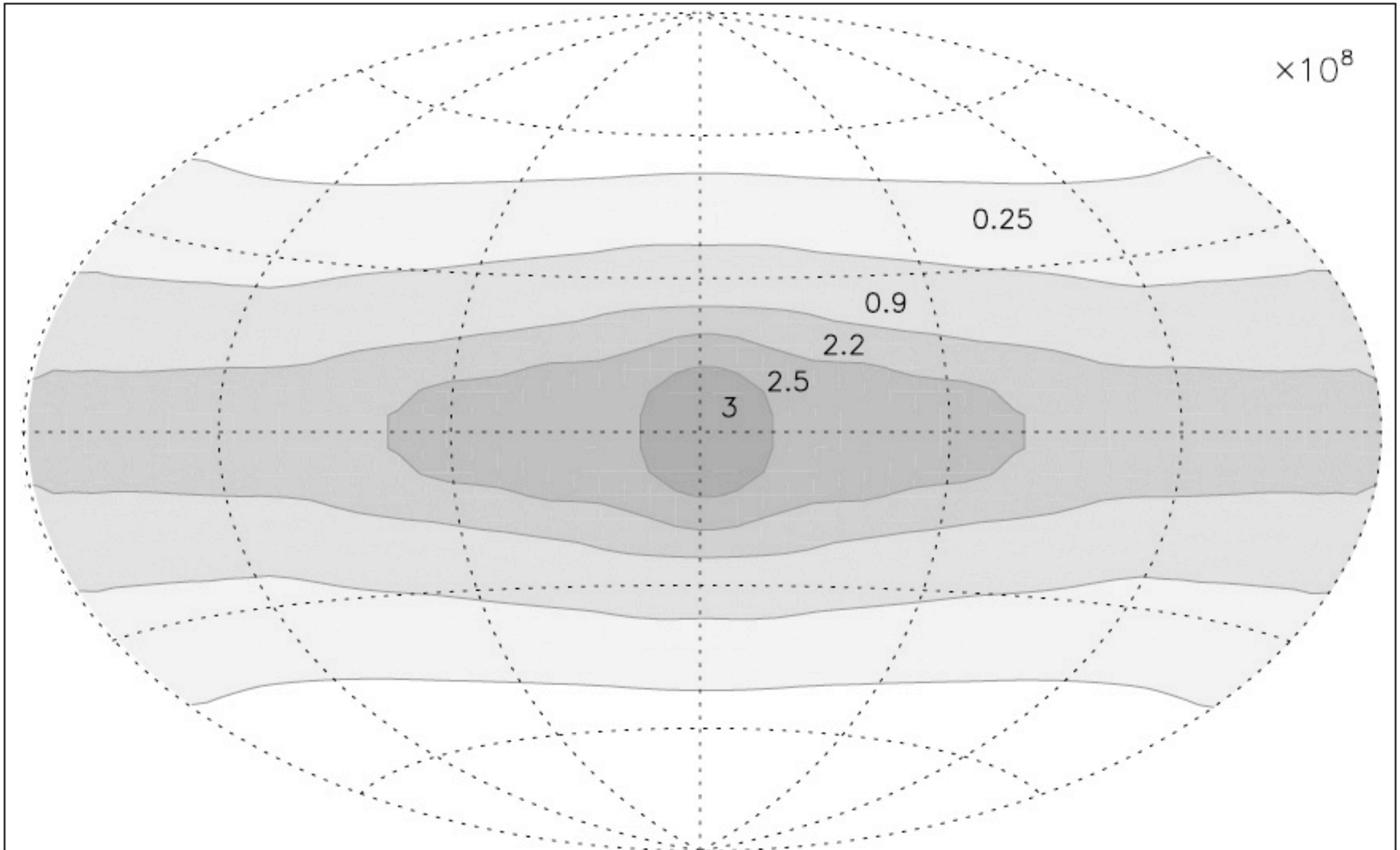
Paczynski 1986; Alcock et al 1993



Photometric microlensing



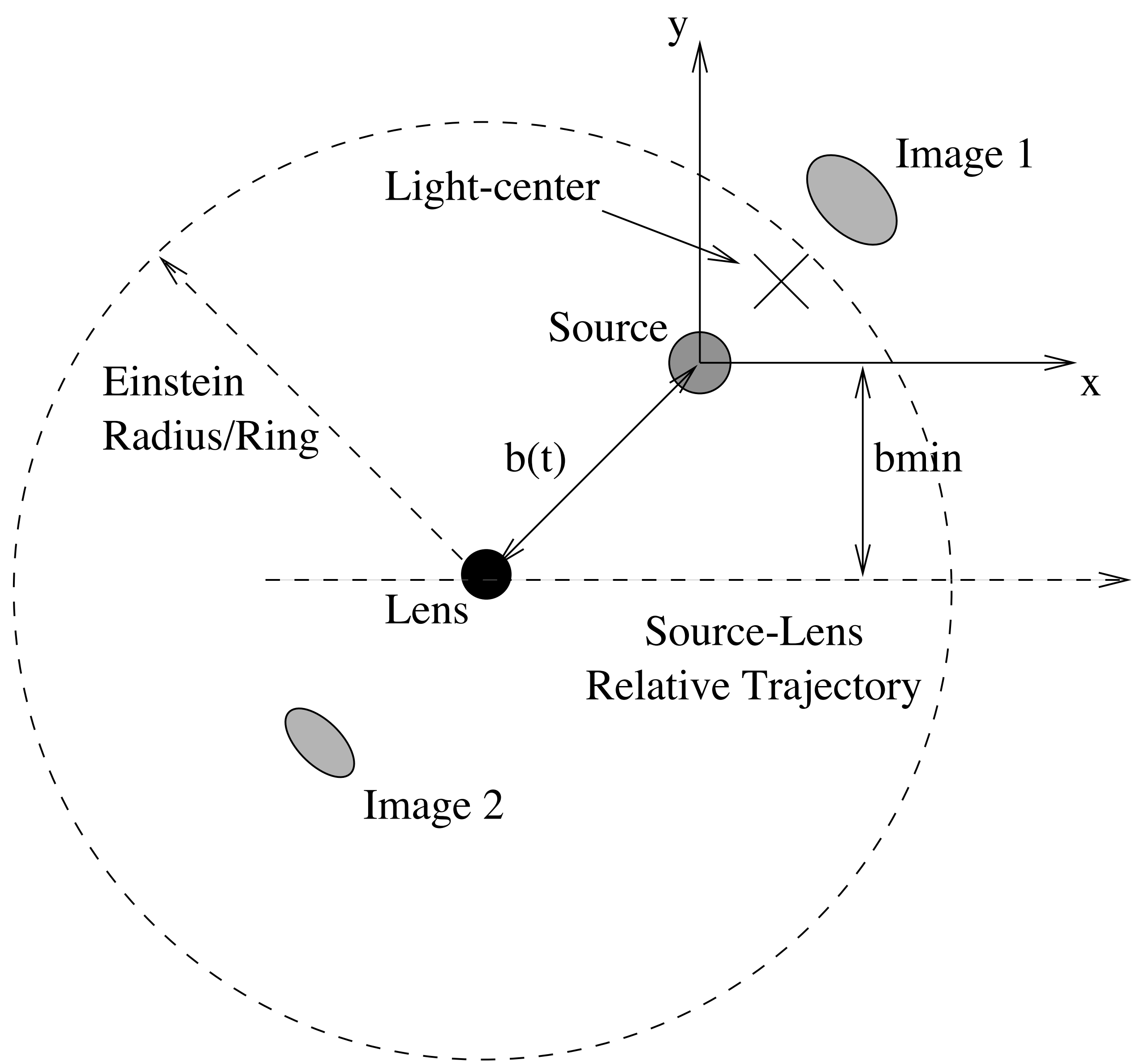
Photometric microlensing



Photometric microlensing

- All-sky averaged photometric microlensing optical depth is ~ 5 x10^{-7}.
- The typical duration is 2-3 months, so there are a total of ~ 8,000 -10,000 photometric microlensing events during the Gaia mission.
- GAIA's sampling is sparse and many of the events will be missed.

Lensing Geometry

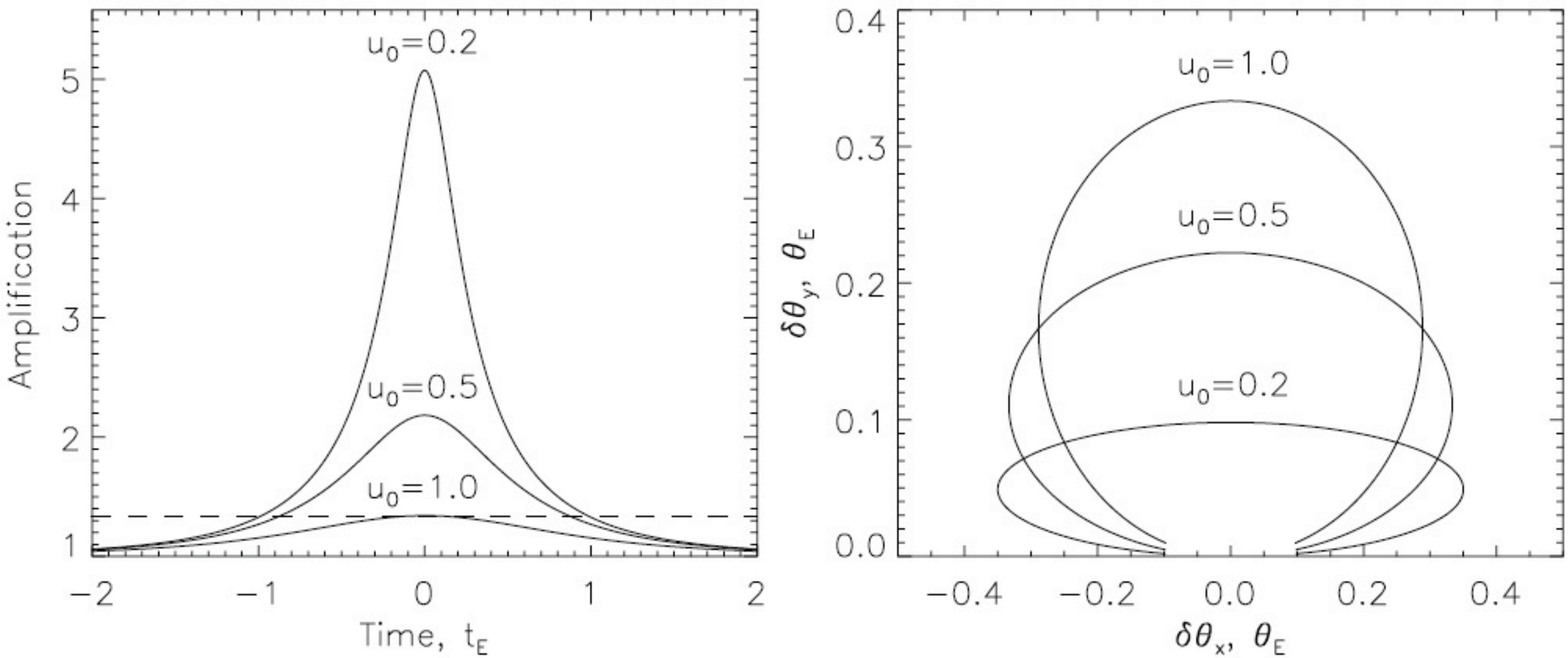


Astrometric microlensing is the name given to the excursion of the light centroid.

Astrometric Microlensing

- The two images of a microlensed source are unresolvable. GAIA can measure the small deviation (of the order of a fraction of a mas) of the centroid of the two images.
- The cross-section of a lens is proportional to the area it sweeps out on the sky and so the product of lens proper motion and angular Einsetin radius.

Astrometric microlensing



The encounter time spans a much larger range -10t_E to 10t_E for astrometric microlensing.

Astrometric microlensing

Angular separation of source and lens is given by

$$\boldsymbol{\theta}_{\rm sl}(t) = \boldsymbol{\theta}_{\rm sl,0} + \mu_{\rm sl} t + \mathbf{P}_{\rm sl}$$

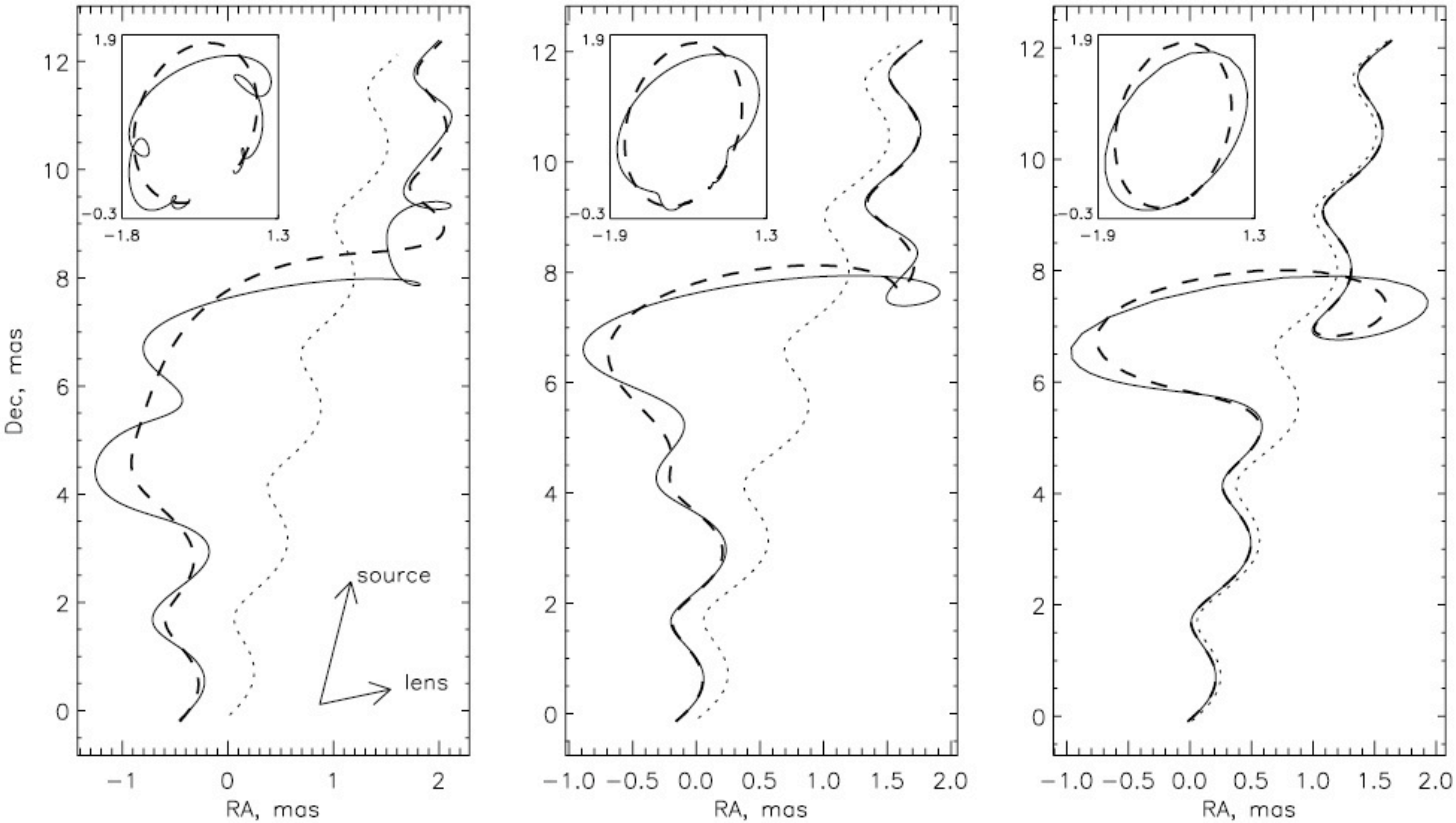
Microlensing introduces an additional shift of the source centroid. If S(t) is the image centroid then

$$\mathbf{S}(t) = \boldsymbol{\theta}_{\rm s}(t) + \boldsymbol{\theta}(t), \qquad \boldsymbol{\theta} = \frac{\boldsymbol{\theta}_{\rm sl}(t)}{(\theta_{\rm sl}(t)/\theta_{\rm E})^2 + 2}.$$

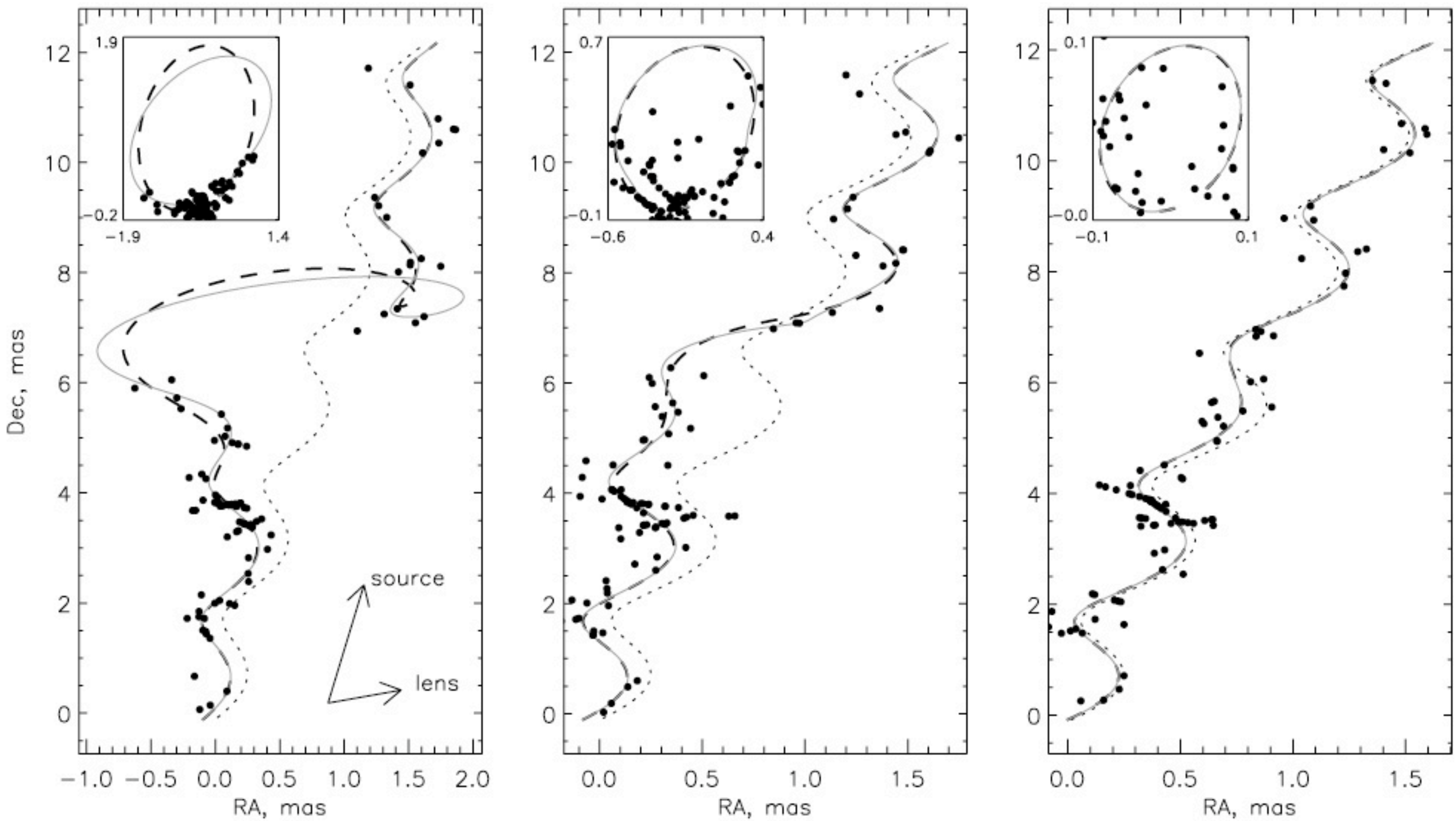
where the Einstein radius is

$$\frac{\theta_{\rm E}}{\mathsf{mas}} = \left(\frac{M}{0.12 M_\odot}\right)^{1/2} \left(\frac{\pi_{\rm sl}}{\mathsf{mas}}\right)^{1/2}$$

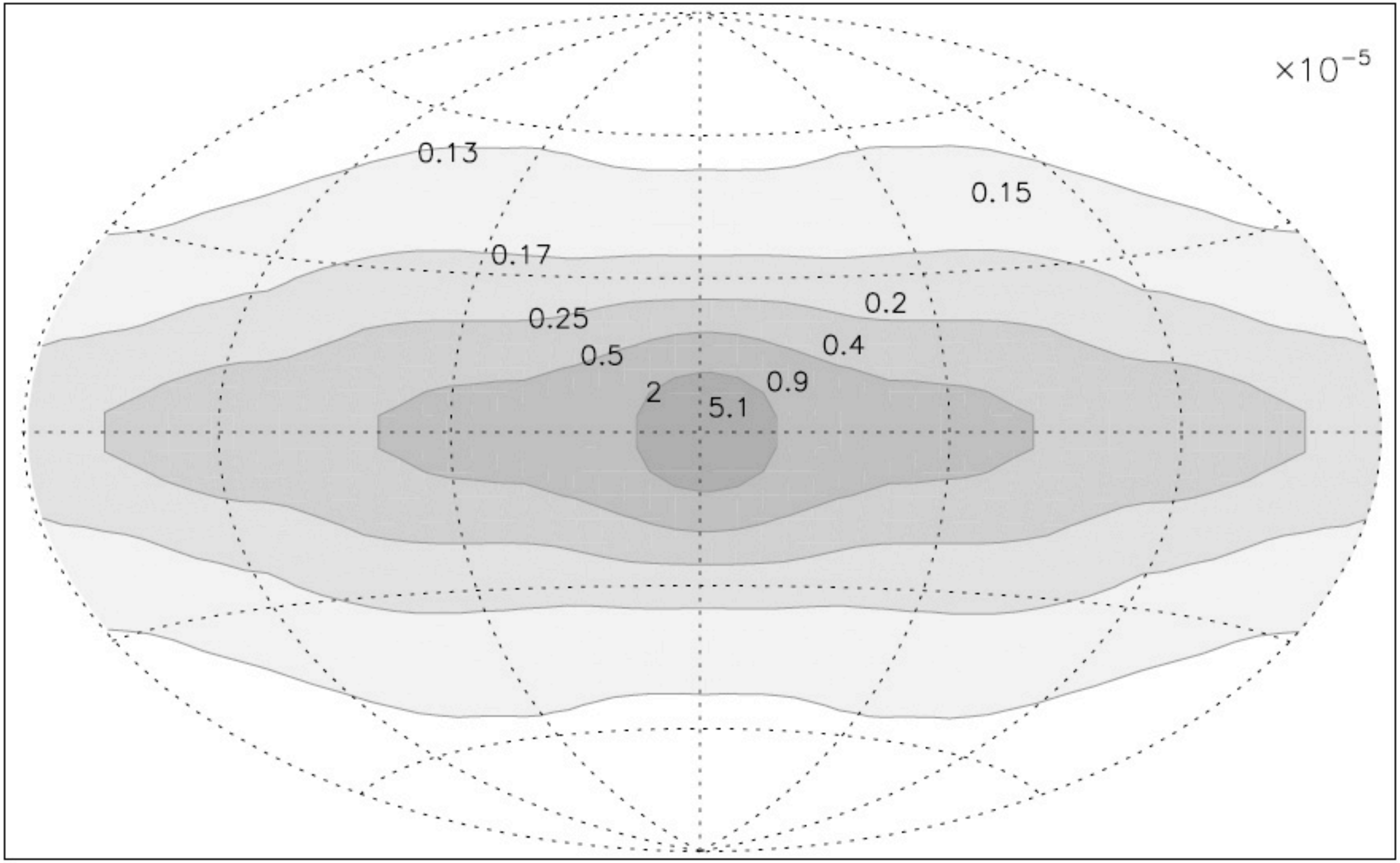
Astrometric microlensing



Astrometric microlensing



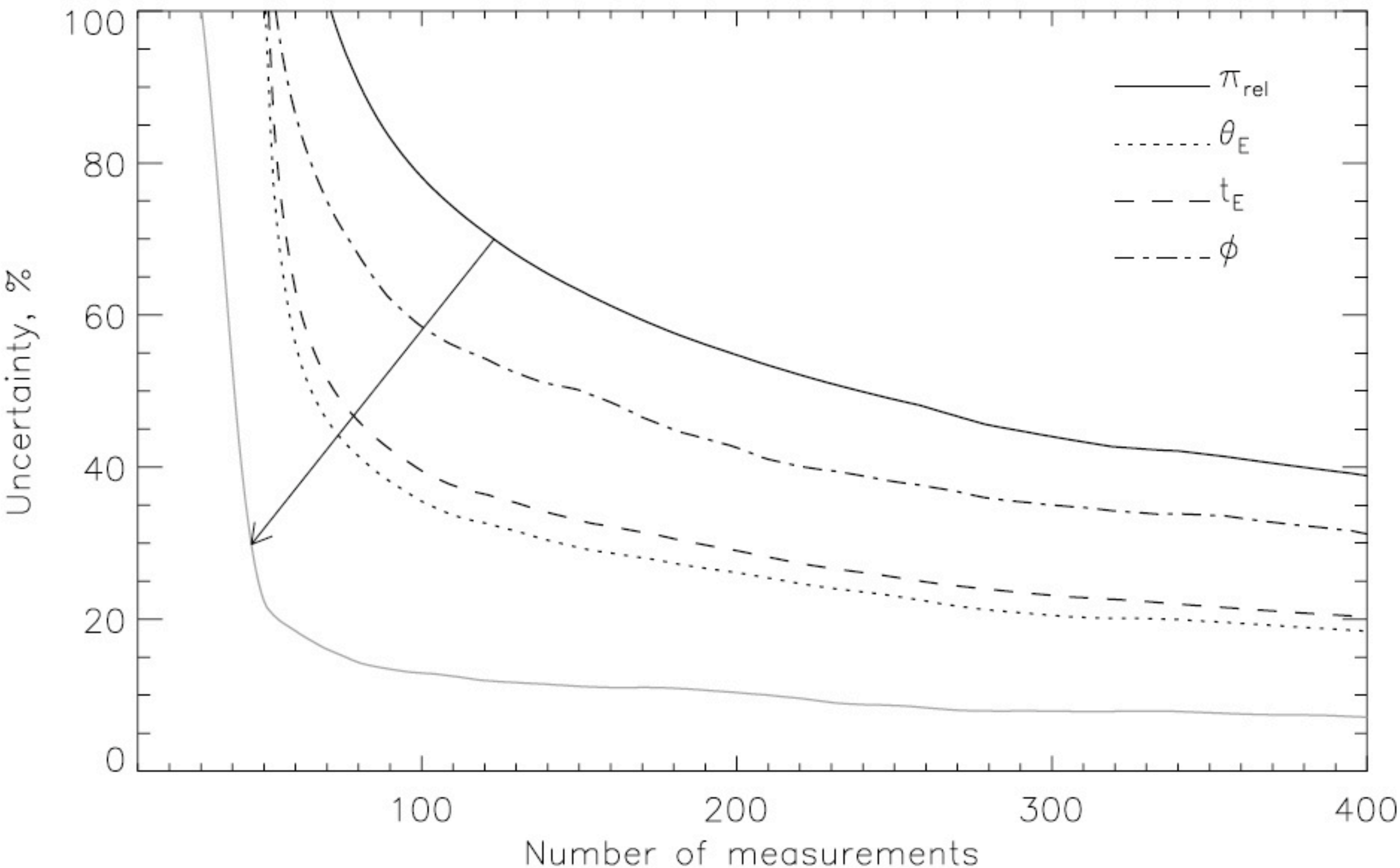
Astrometric microlensing



Astrometric microlensing

- During the GAIA mission, there are ~ 15,000 astrometric microlensing events (which have a centroid shift greater than 5σ and a closest approach during mission lifetime).
- Some of these events cannot be identified as the S/N is too low and any identification algorithm will generate too many false positives.

Astrometric microlensing



Astrometric microlensing

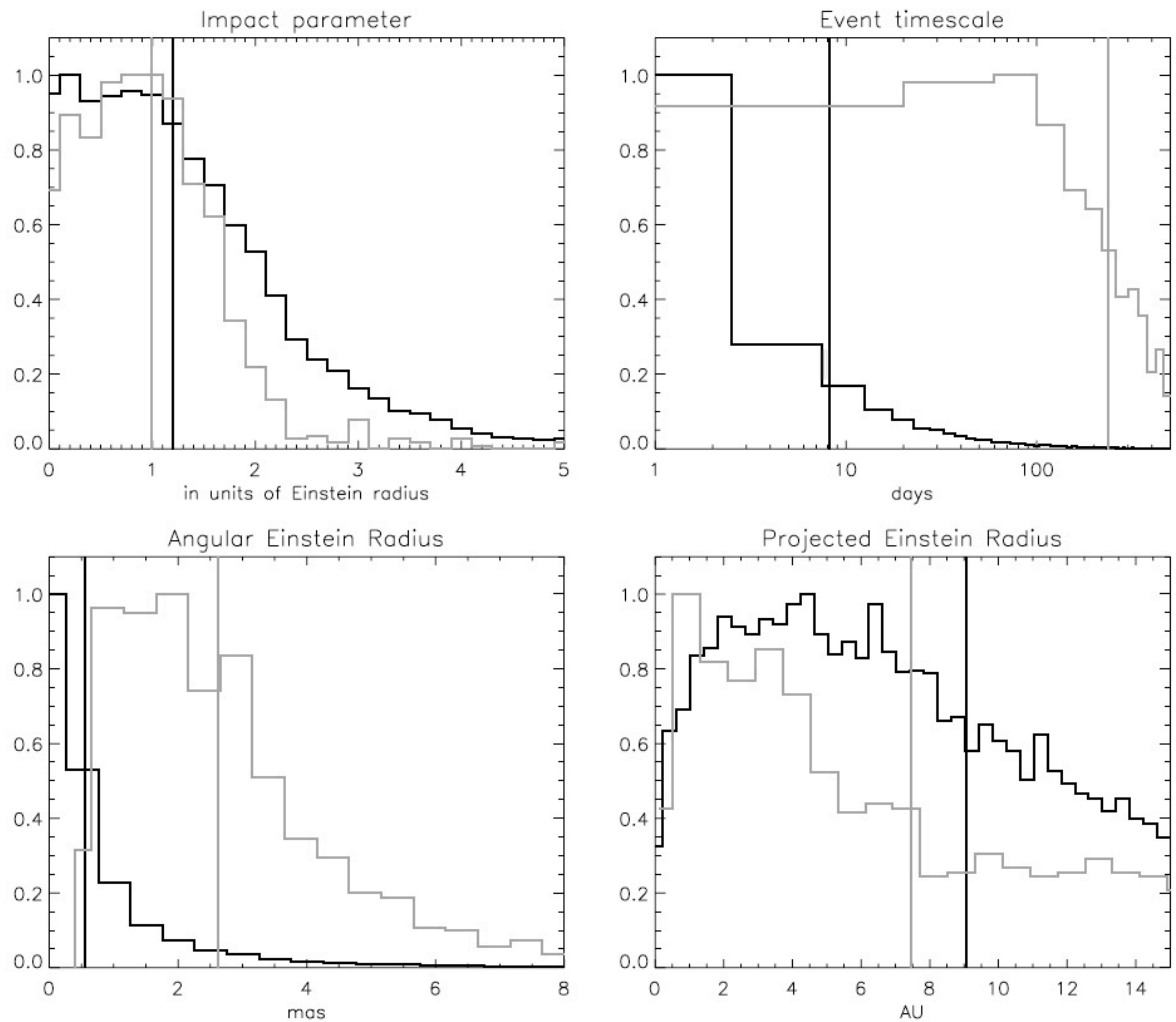
- Mass is measurable if the relative parallax π_{rel} and angular Einstein radius θ_E are.
- Close lenses with long timescales provide the best circumstances for measuring $\pi_{rel.}$
- There is considerable improvement if photometric data are available from the ground. Many of the events towards the Bulge will be monitored by OGLE-IV.
- This motivates the GAIA science alerts program to trigger events (Wyrzykowski & Hodgkin 2012).

Astrometric microlensing

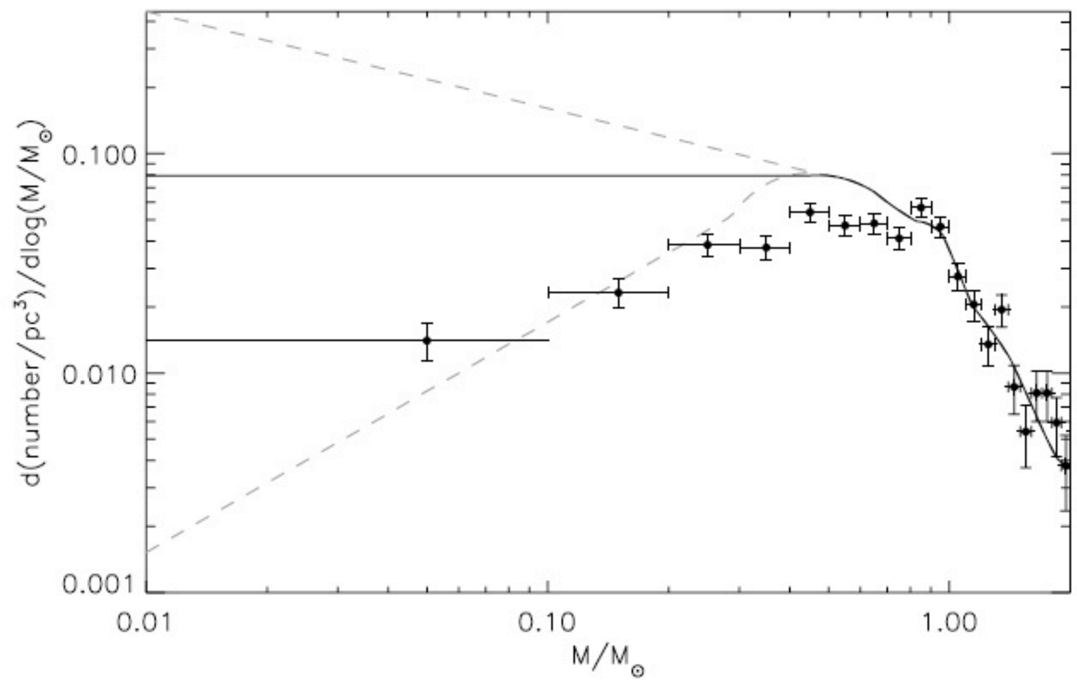
We create a set of 15,000 microlensing events from Monte Carlo simulations in a bar/bulge, disk and halo model of the Galaxy. We compute the error in the estimated mass of the lens using a covariance analysis.

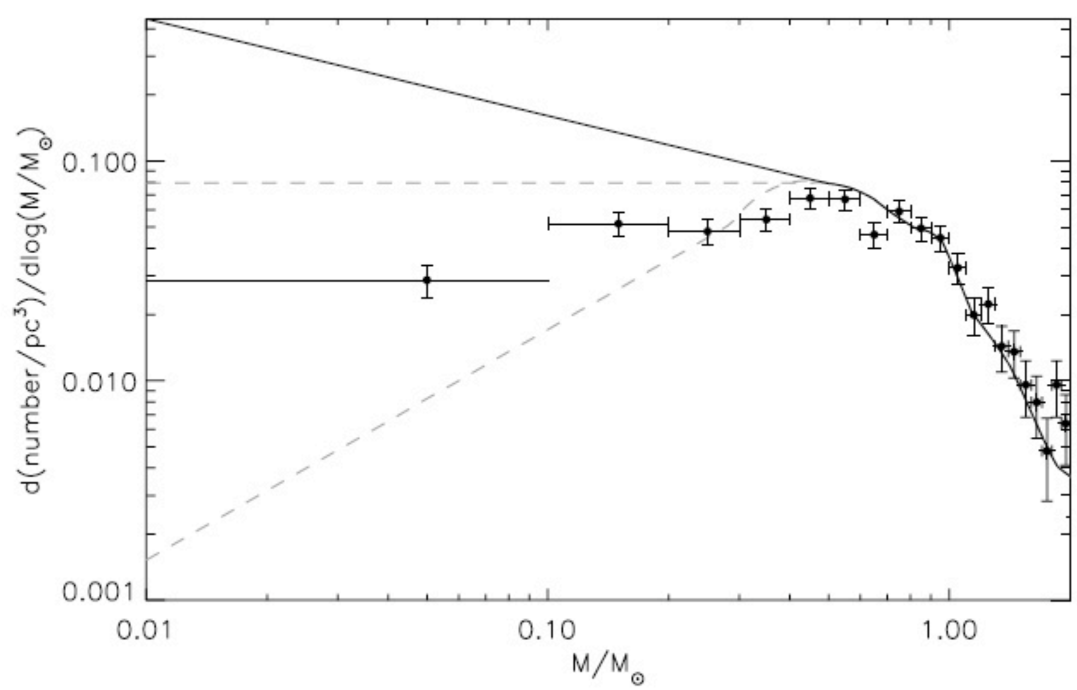
$N(\sigma_M < 50\%)$	10 %
$N(\sigma_{t_{\rm E}} < 50\%)$	42 %
$N(\sigma_{\theta_{\rm E}} < 50\%)$	50 %
$N(\sigma_{\pi_{\rm sl}} < 50\%)$	12 %

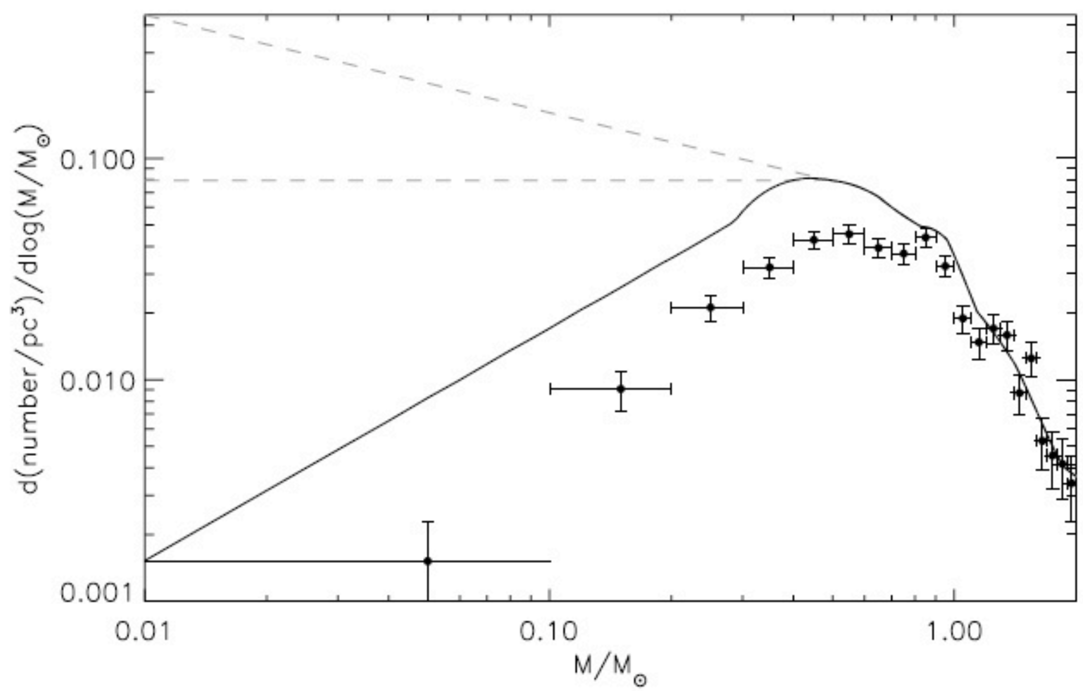
Astrometric microlensing



Astrometric microlensing







Belokurov & Evans 2002

Astrometric microlensing

- The MFs are reproduced accurately above 0.3 solar masses. Below this mass, the MFs fall below the true curves due to the bias against smaller Einstein radii.
- Of course, this can be corrected by calibration against simulations.
- MFs with spikes of white dwarfs and neutron stars can be easily recovered. This is the regime in which GAIA's astrometric microlensing signal is most sensitive.

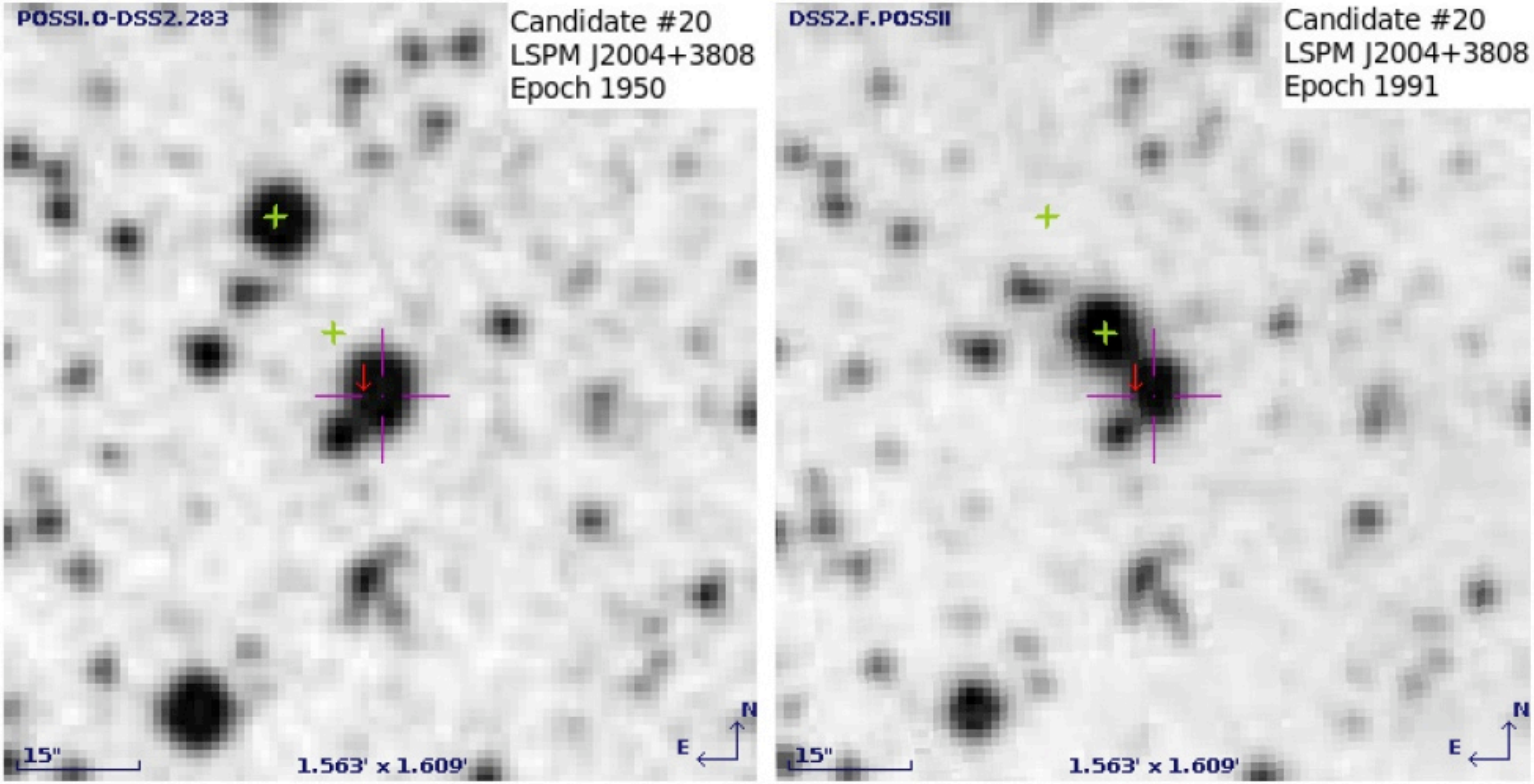
Astrometric microlensing

- An attractive feature of astrometric microlensing is that events can be predicted (Paczynski 1995) if the lens proper motion is known.
- Paczynski estimated a sample of a few hundred high proper motion stars is needed to detect a microlensing event a year.
- So, samples of a few hundred high proper motion (> 300 mas/yr) brown dwarfs should give a few viable candidates for GAIA.

Astrometric microlensing

- Faint stars are favoured because the light centroid shift of the source star is less affected than with a bright lens.
- Close stars are favoured, as the centroid shift is larger for closer stars. So, this is ideal for determining masses of nearby brown and M dwarfs.
- Proft et al. (2011) found two very good (7 reasonable) candidate M or white dwarf lenses.

Astrometric Microlensing



Lens is M dwarf 43 pc away. Centroid shift is ~ 2000 μas. Source is 12 mag star.

Proft et al. 2011

Astrometric Microlensing

- High proper motion brown dwarfs are beginning to be known in sufficient numbers to make this feasible (Burningham et al 2013, Smith et al. 2014).
- GAIA’s early data releases will also provide further high proper motion candidates.
- GAIA’s final release will also provide a large number of predictable microlensing events which could be observed astrometrically with interferometry.

Conclusions

- Microlensing is the only way of measuring the masses of objects irrespective of their luminosity. GAIA is a good instrument for making a complete inventory of the Solar neighbourhood.
- High proper motion brown dwarfs are potentially very important targets as lenses for GAIA. Sample sizes of ~ 100s should be enough to provide viable candidates.

Astrometric microlensing

The probability of detecting microlensing events is

$$\tau = D_{\rm s} \int_0^1 dx \int_0^\infty dM \, \frac{\rho(x)}{M} \Sigma(x, M) f(M),$$

where Σ is the area in the lens plane for which source positions yield the astrometric effect and f(M) is the mass function. The centroid shift varies by more than 5σ if the sources lies within a radius $u_a R_E$ where

$$u_{\rm a} = \sqrt{\frac{T_{\rm life} v}{5\sqrt{2}\sigma_{\rm a} D_{\rm l}}} = \sqrt{\frac{T_{\rm life}\theta_{\rm E}}{5\sqrt{2}\sigma_{\rm a} t_{\rm E}}}.$$

Astrometric microlensing