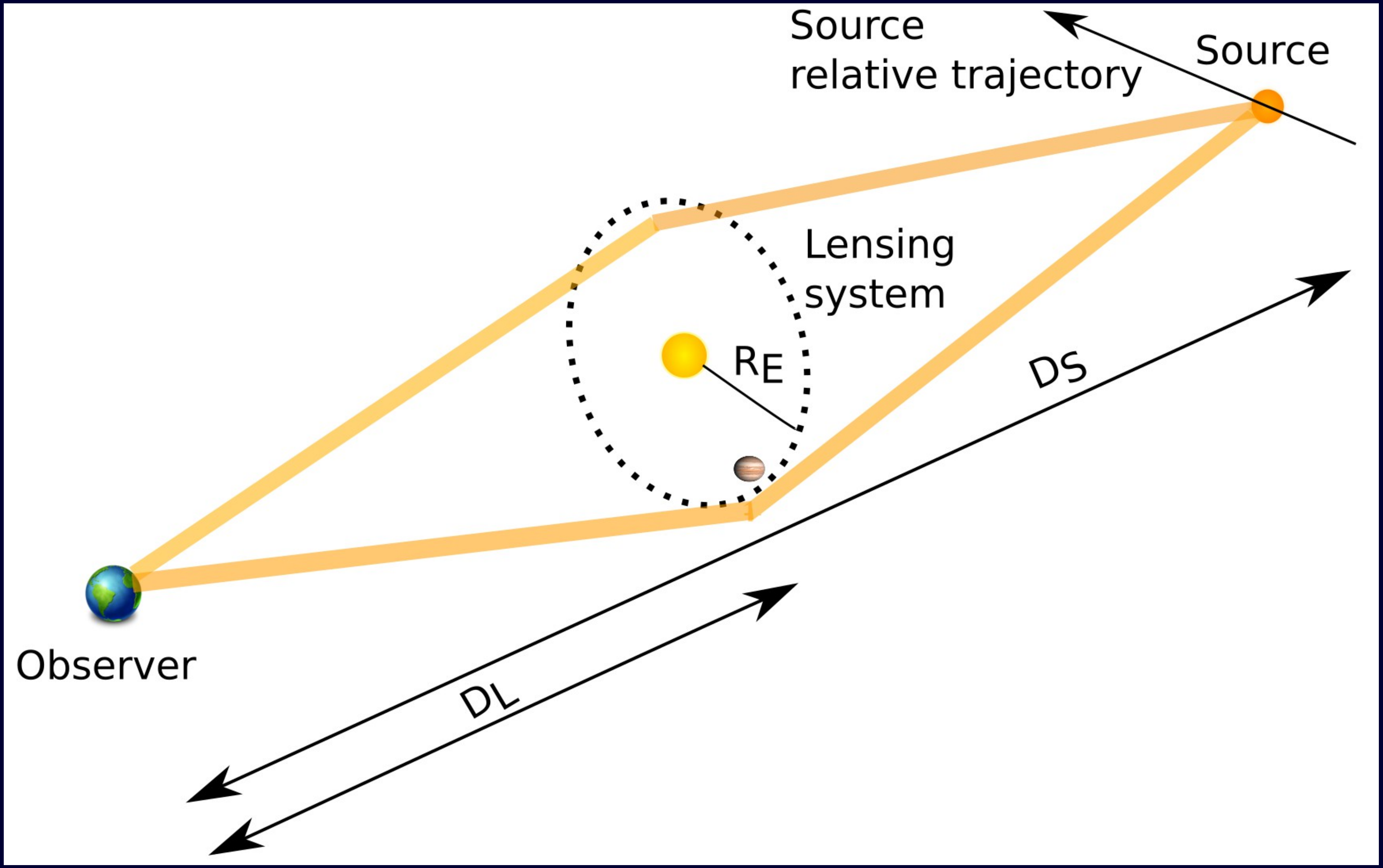
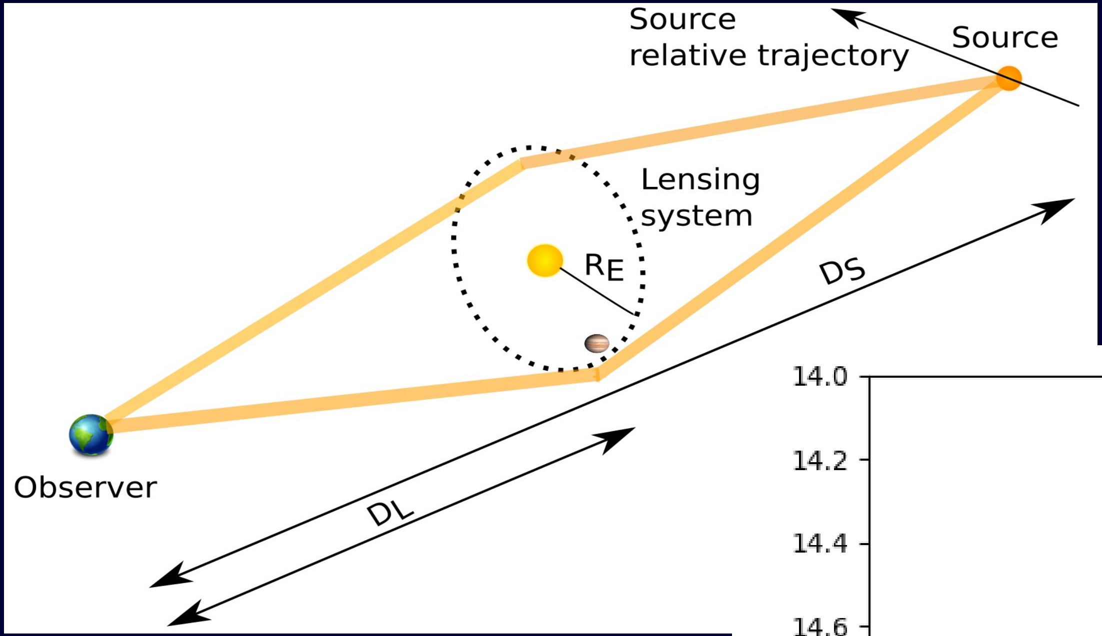
Observational Needs of Microlensing Surveys

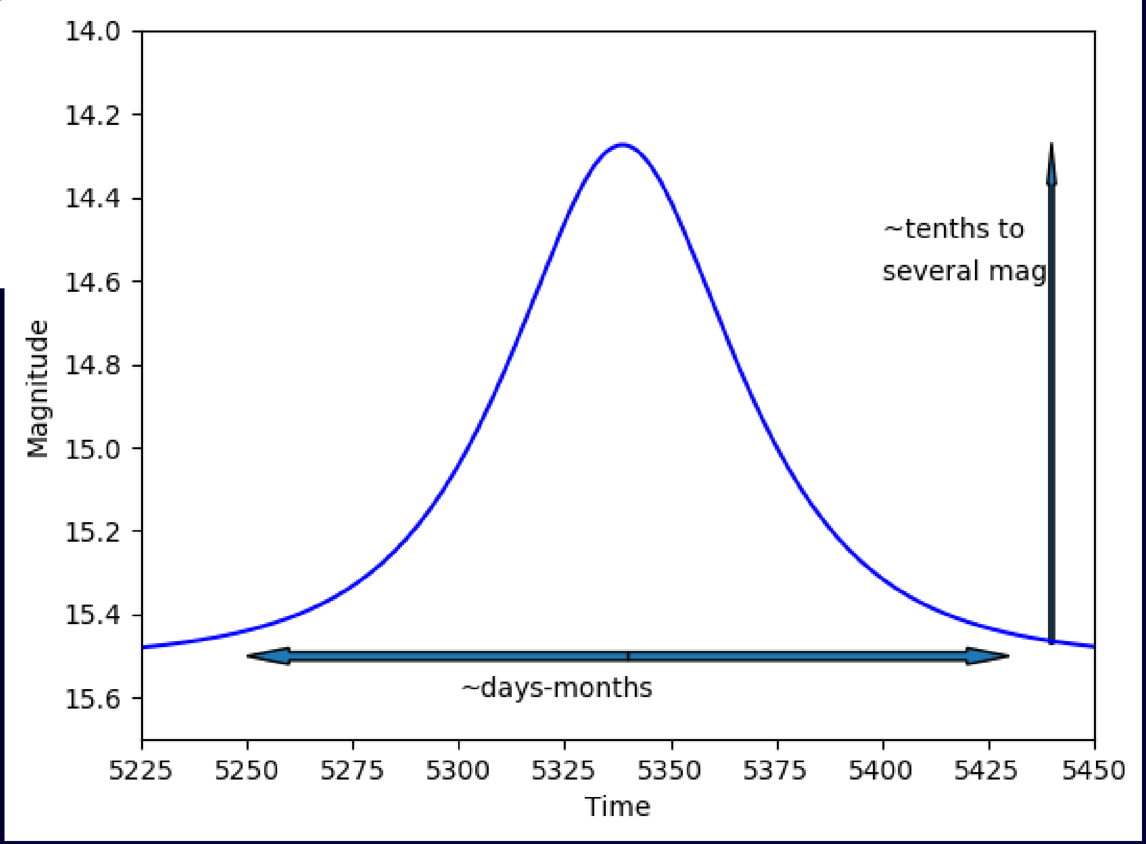
Rachel Street
Las Cumbres Observatory

What is microlensing?



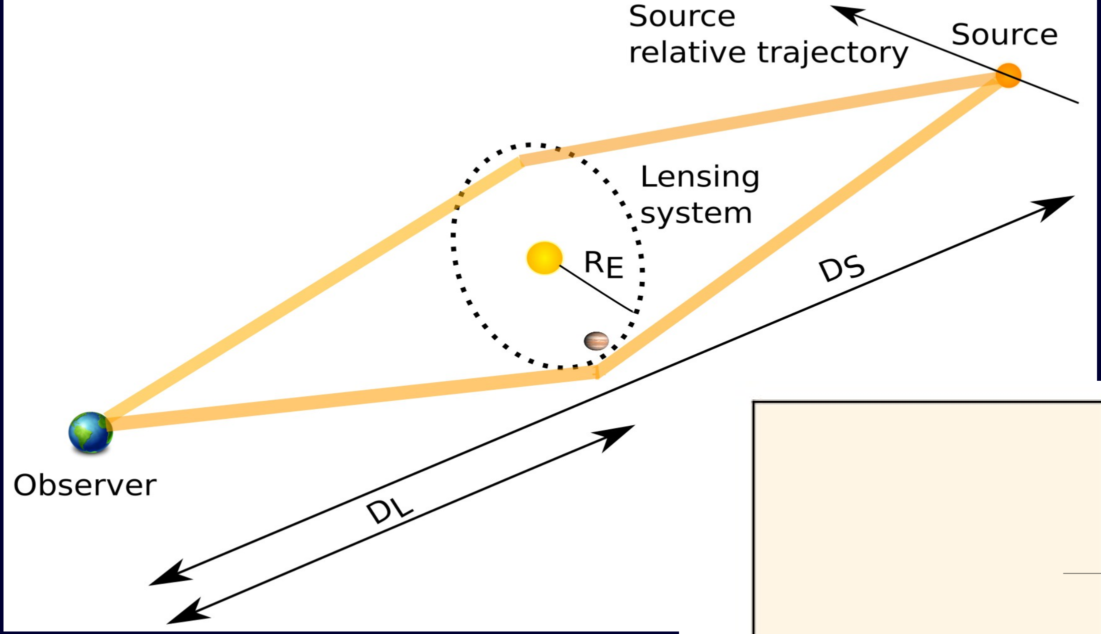
What is microlensing?



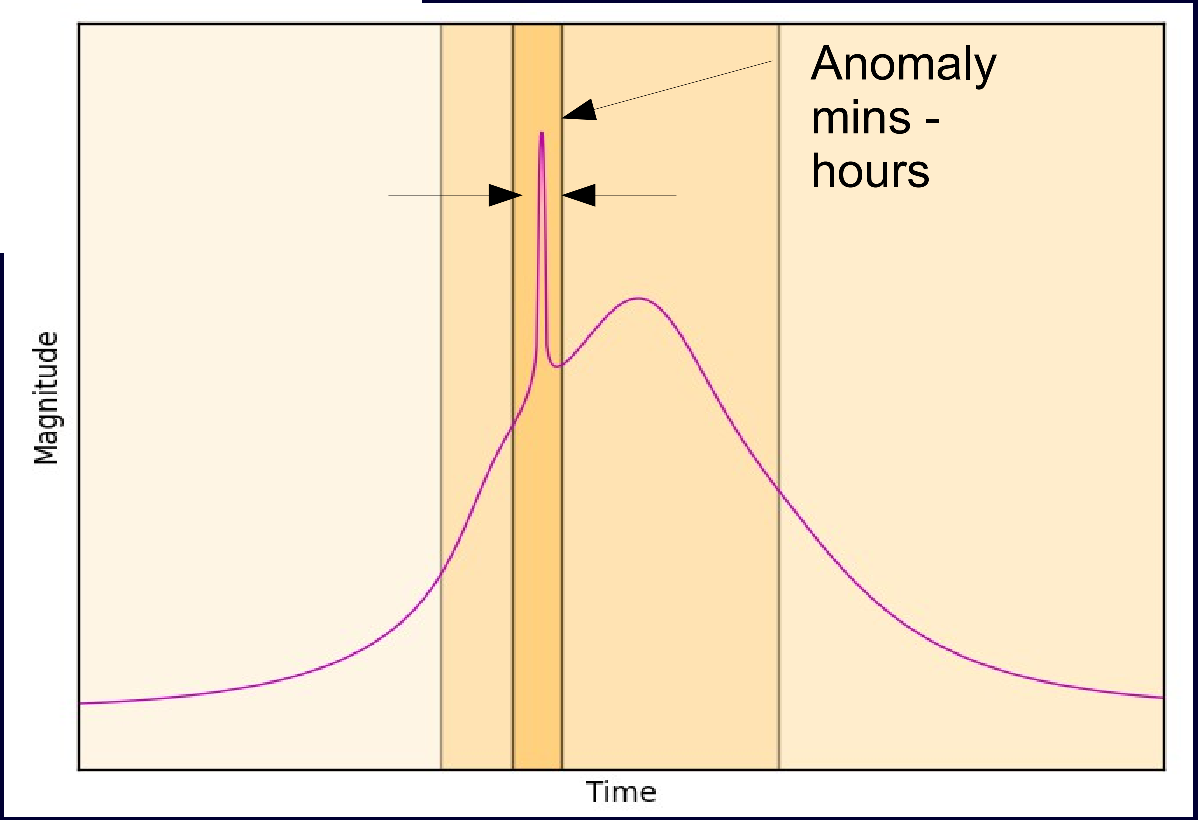


Need long lightcurve baseline

What is microlensing?



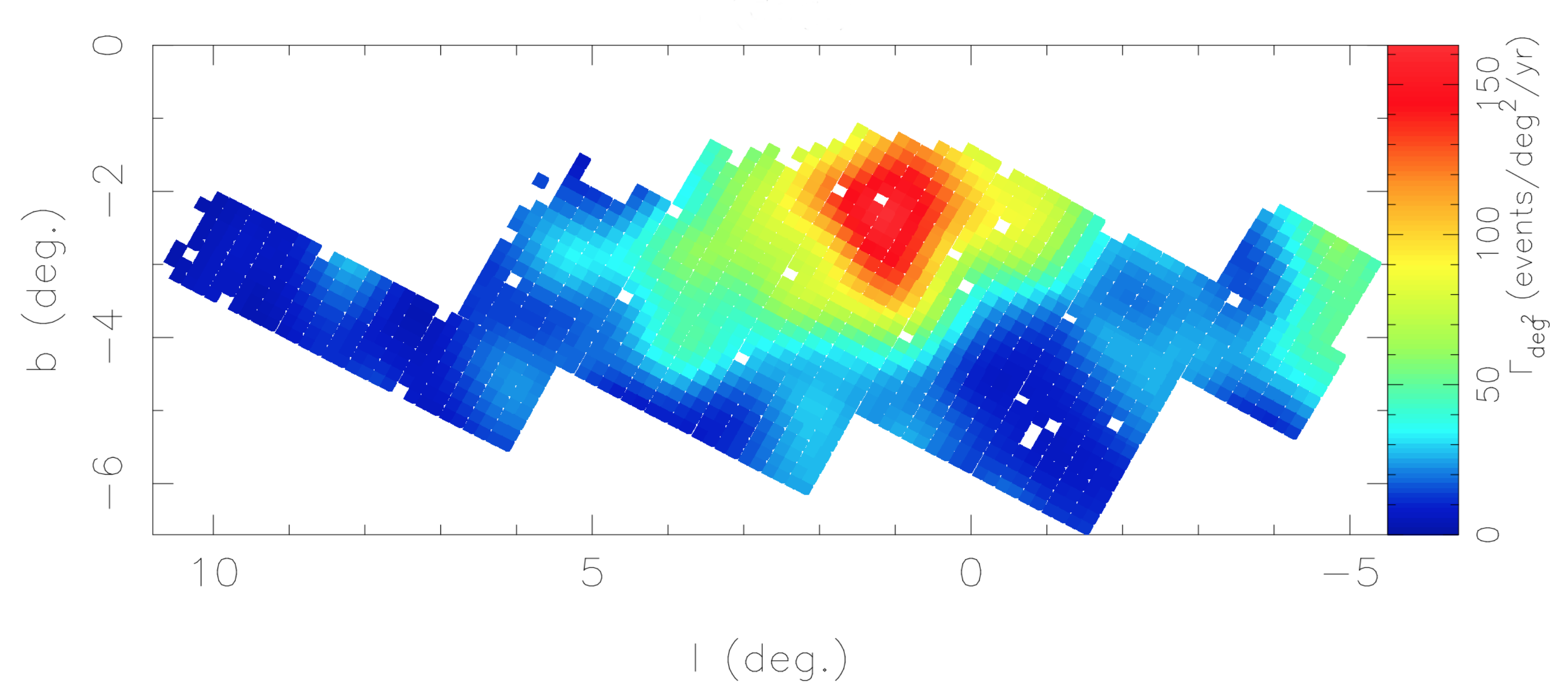
But the light is from the unrelated source star
– not usually from the lens



Short timescale anomalies demand high-cadence observations

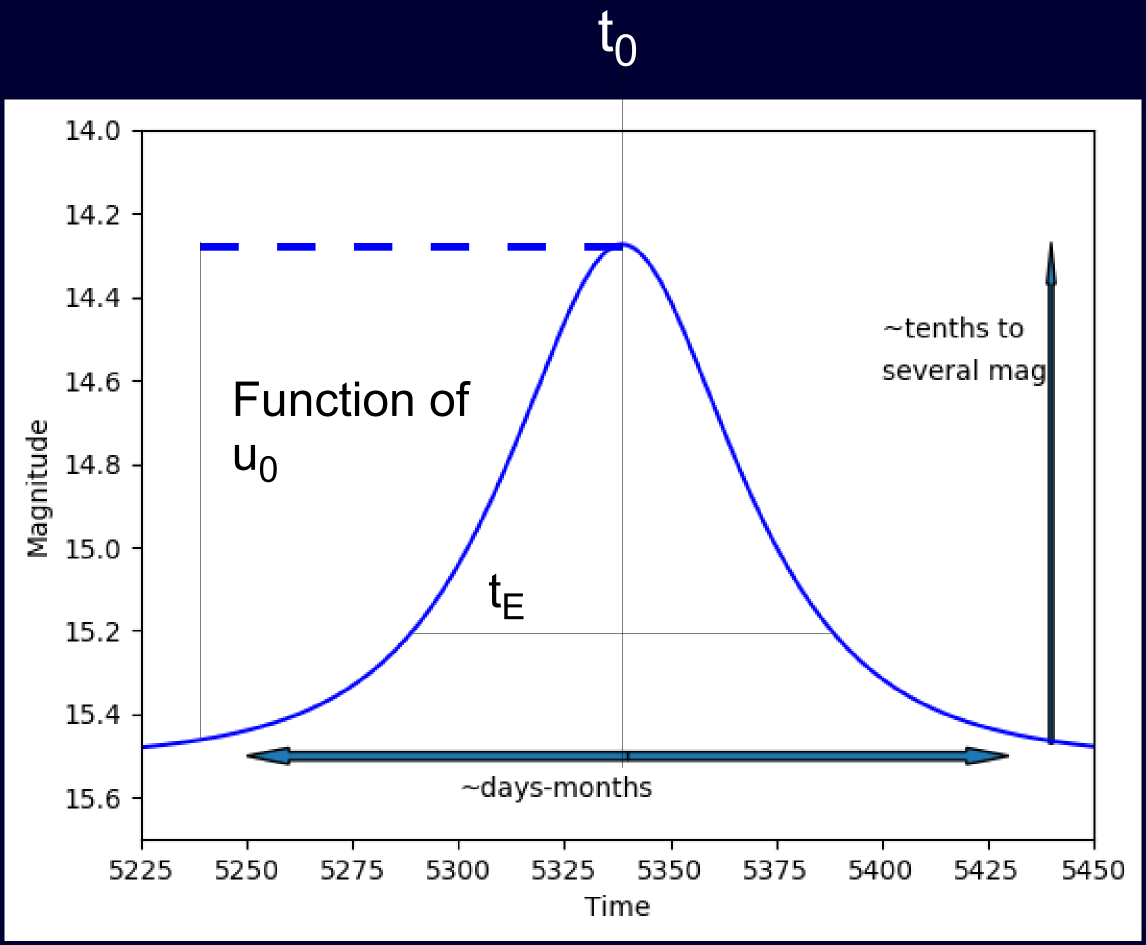
Microlensing rate

Intrinsically rare phenomenon, optical depth ~3.8 x 10^{-6}
→ Must survey millions of stars simultaneously



Microlensing event rates in the Galactic Bulge, from Sumi et al. 2013

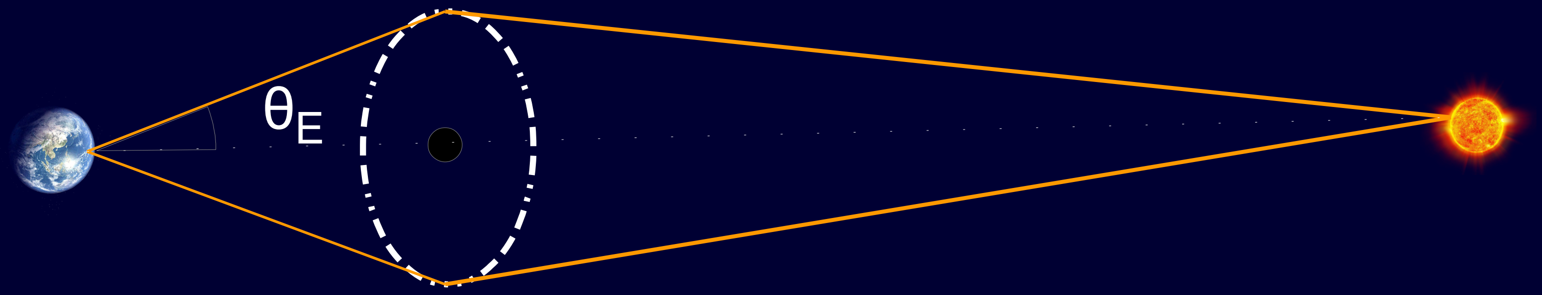
What can we learn from a microlensing event?



Point-source, point-lens events have only 3 parameters, that can be measured from the lightcurve

→ but second-order effects are required to understand the nature of the lens

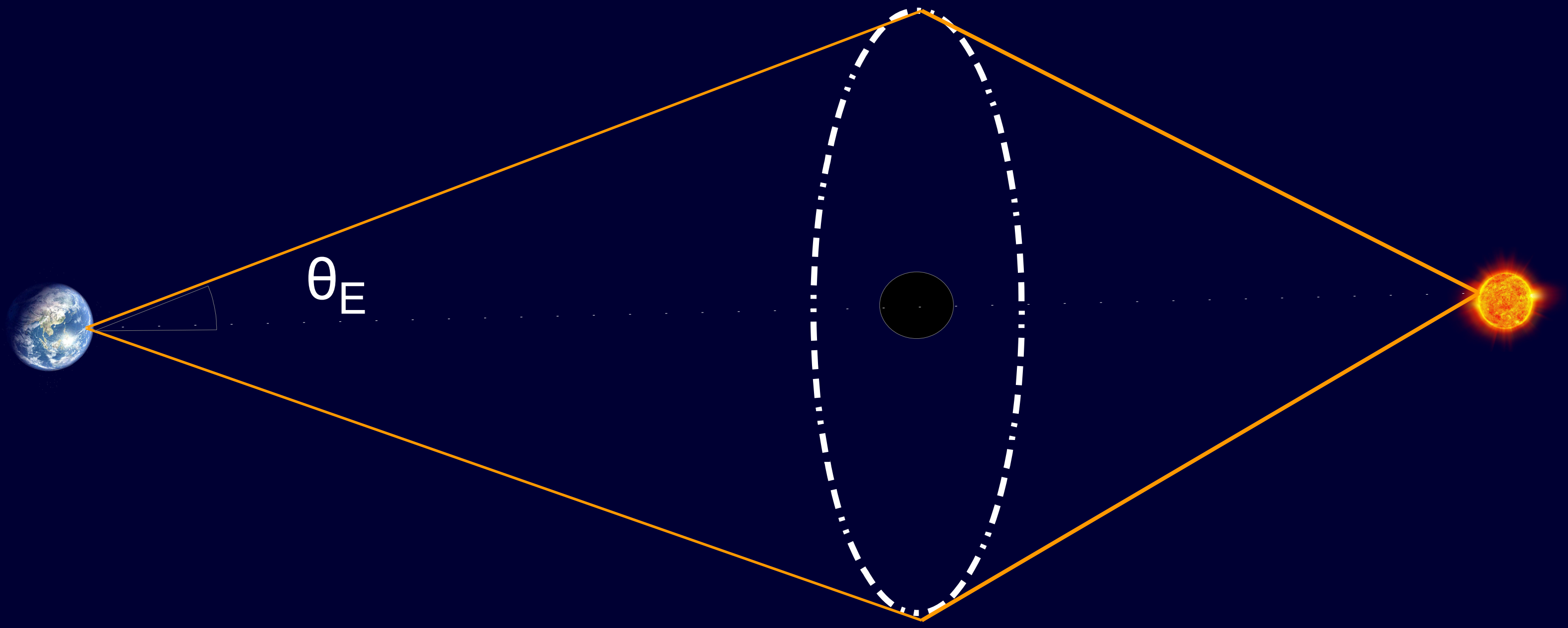
Mass and Distance in Microlensing



Angular Einstein radius depends on both M_{Lens}
...and the source and lens distances

$$\theta_E = \sqrt{\frac{4G\,M_L\,D_{LS}}{c^2\,D_L\,D_S}}$$

→ different techniques to achieve this



Characterizing the lens

We'd like to measure M_{Lens}...

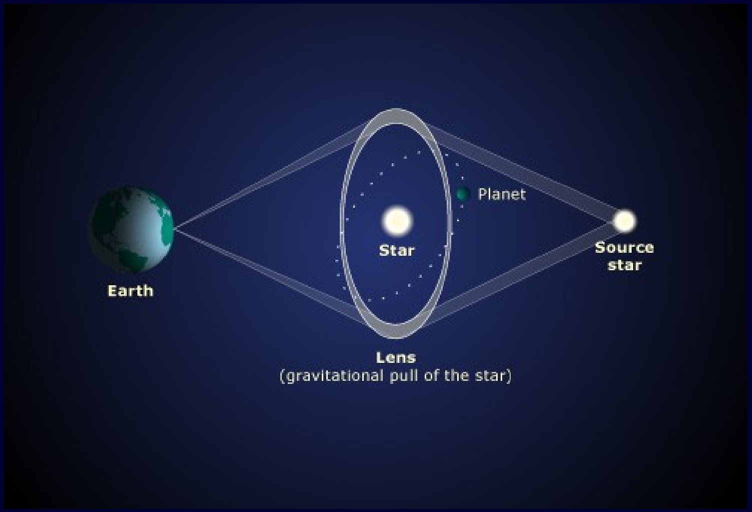
$$M_{Lens} = \frac{c^2\, AU}{4G}\,\frac{\Theta_E}{\pi_E}$$

...so we need to measure

θ_E the angular Einstein radius
π_E the parallax

$$\rho = \frac{\Theta_S}{\Theta_E} = \frac{t_S}{t_E}$$

ρ angular source size parameter
θ_S the angular source radius
t_S, t_E source, Einstein ring crossing times

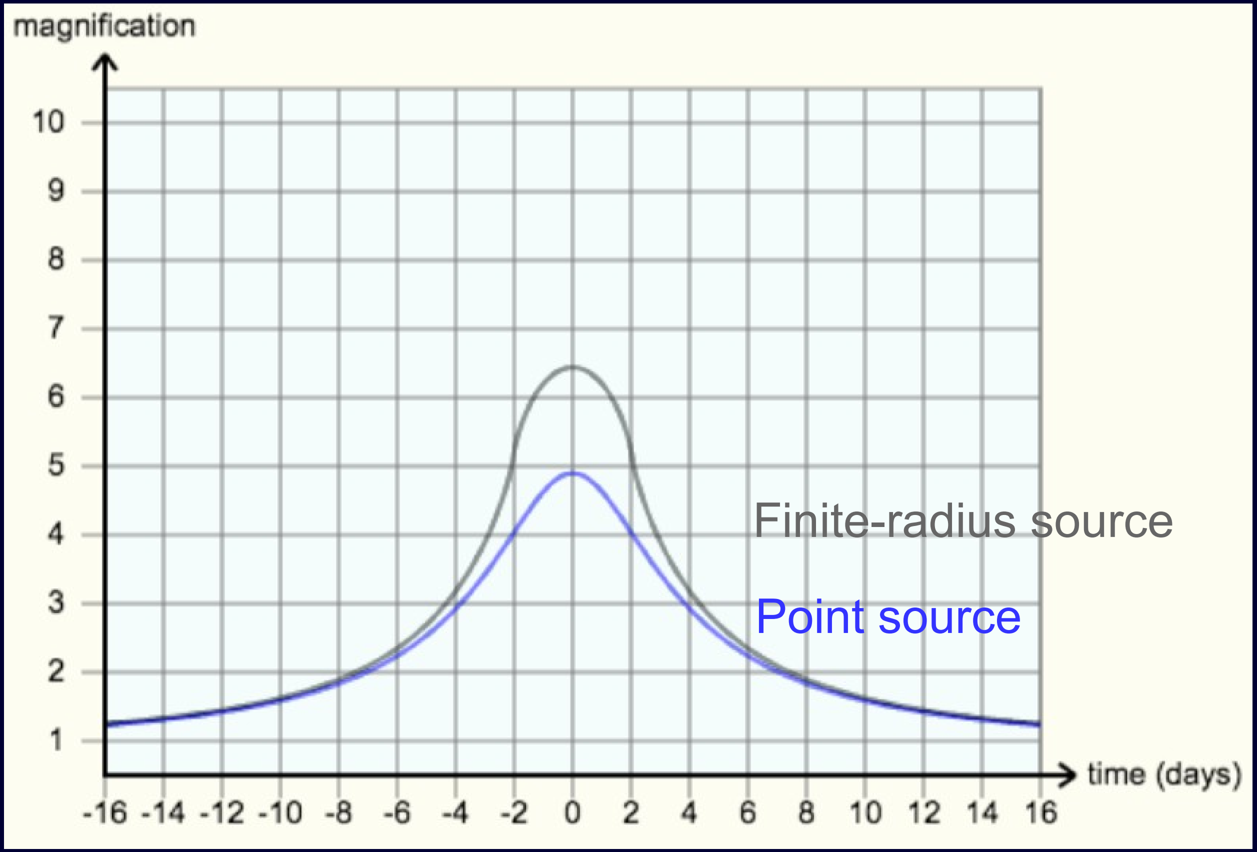


Finite Source Effects

Measured from lightcurve:

ρ angular source size parameter
t_E Einstein crossing time
t_S source crossing time

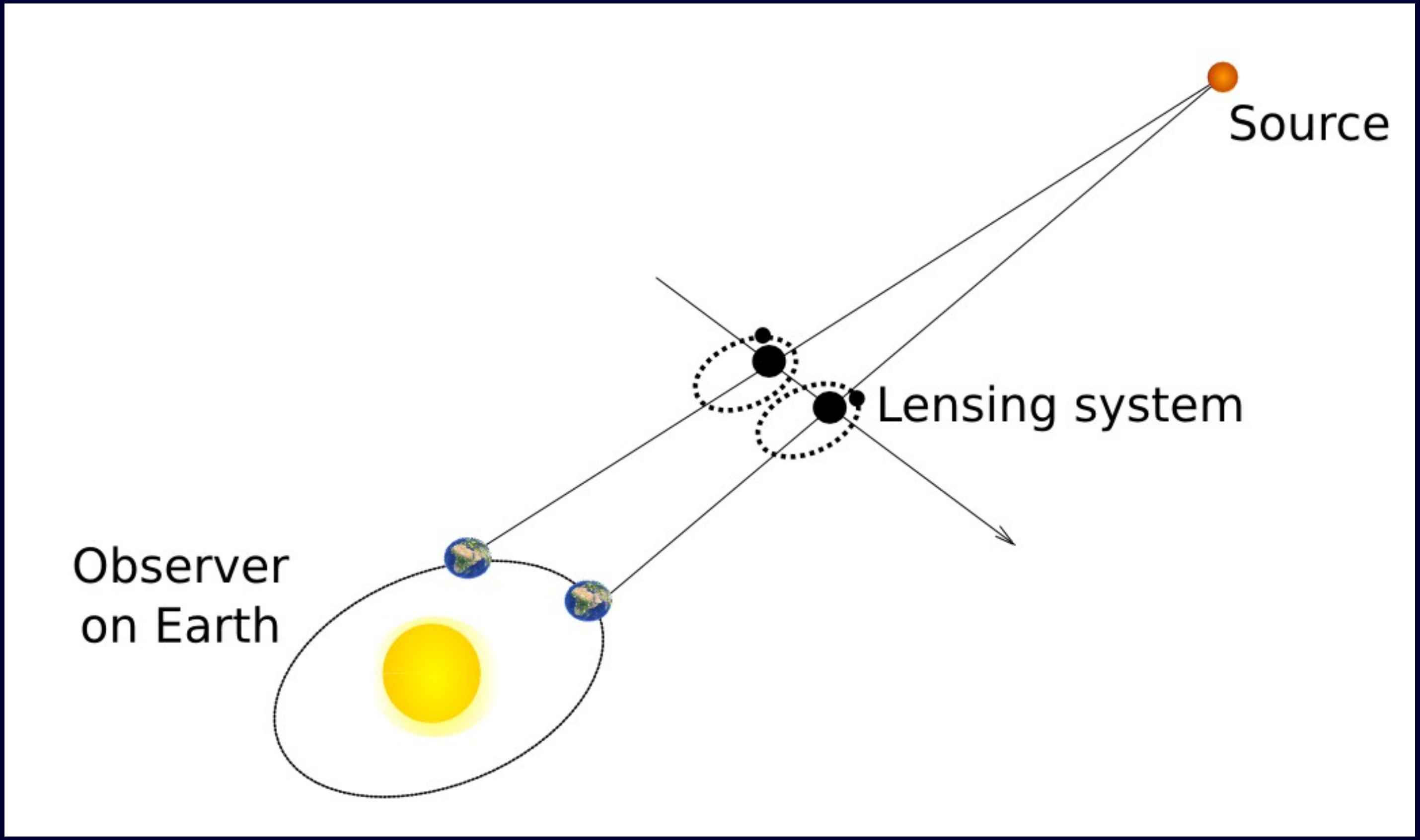
u_0 impact parameter
t_0 time of peak magnification



We can extract M_{Lens} if we know the angular size of the source and the parallax

Methods of measuring Parallax

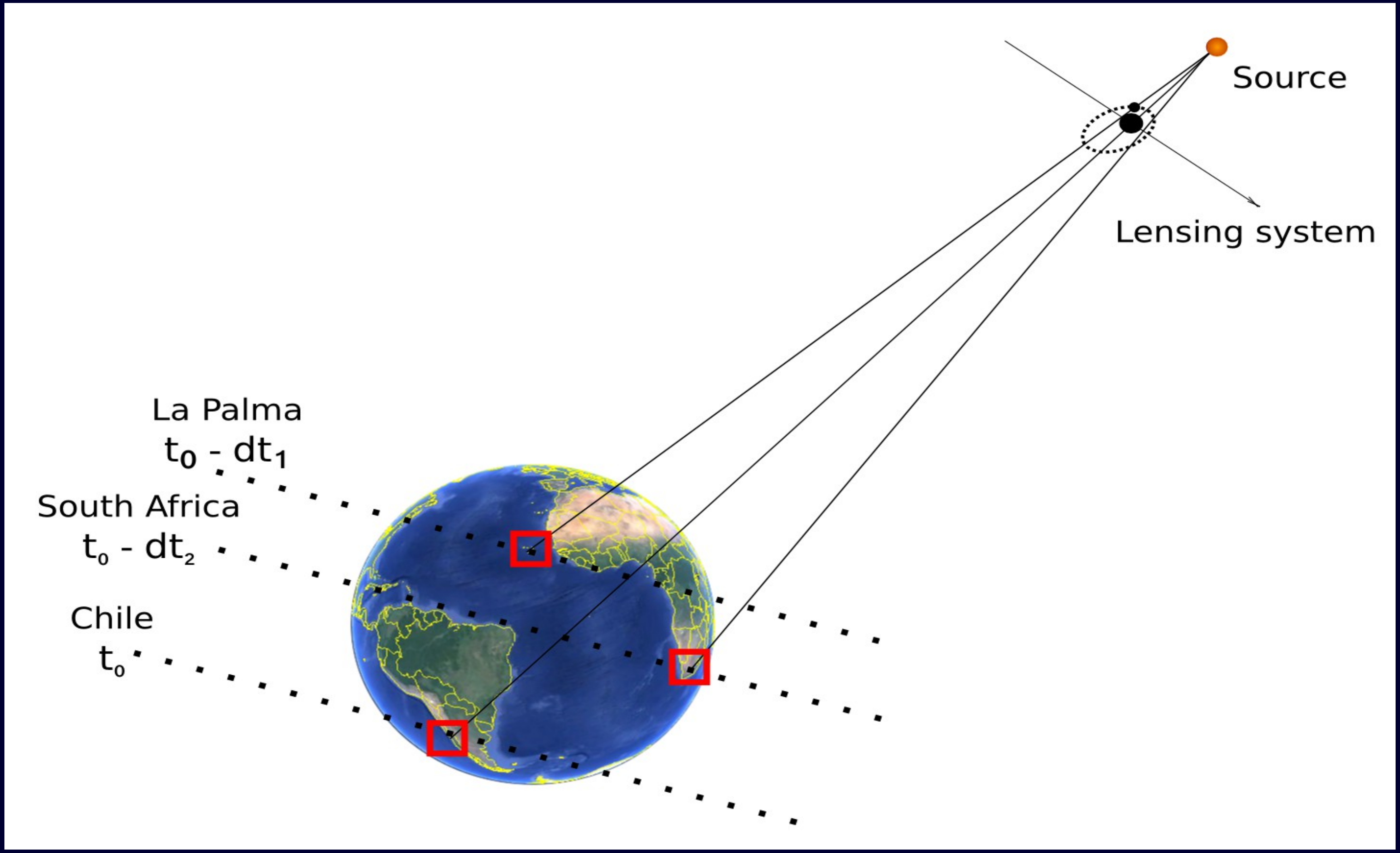
Earth orbit or “annual parallax”



Pros: Requires photometry from a single site
Cons: Only possible for long timescale events (tE>30d)

Methods of measuring Parallax

Terrestrial parallax

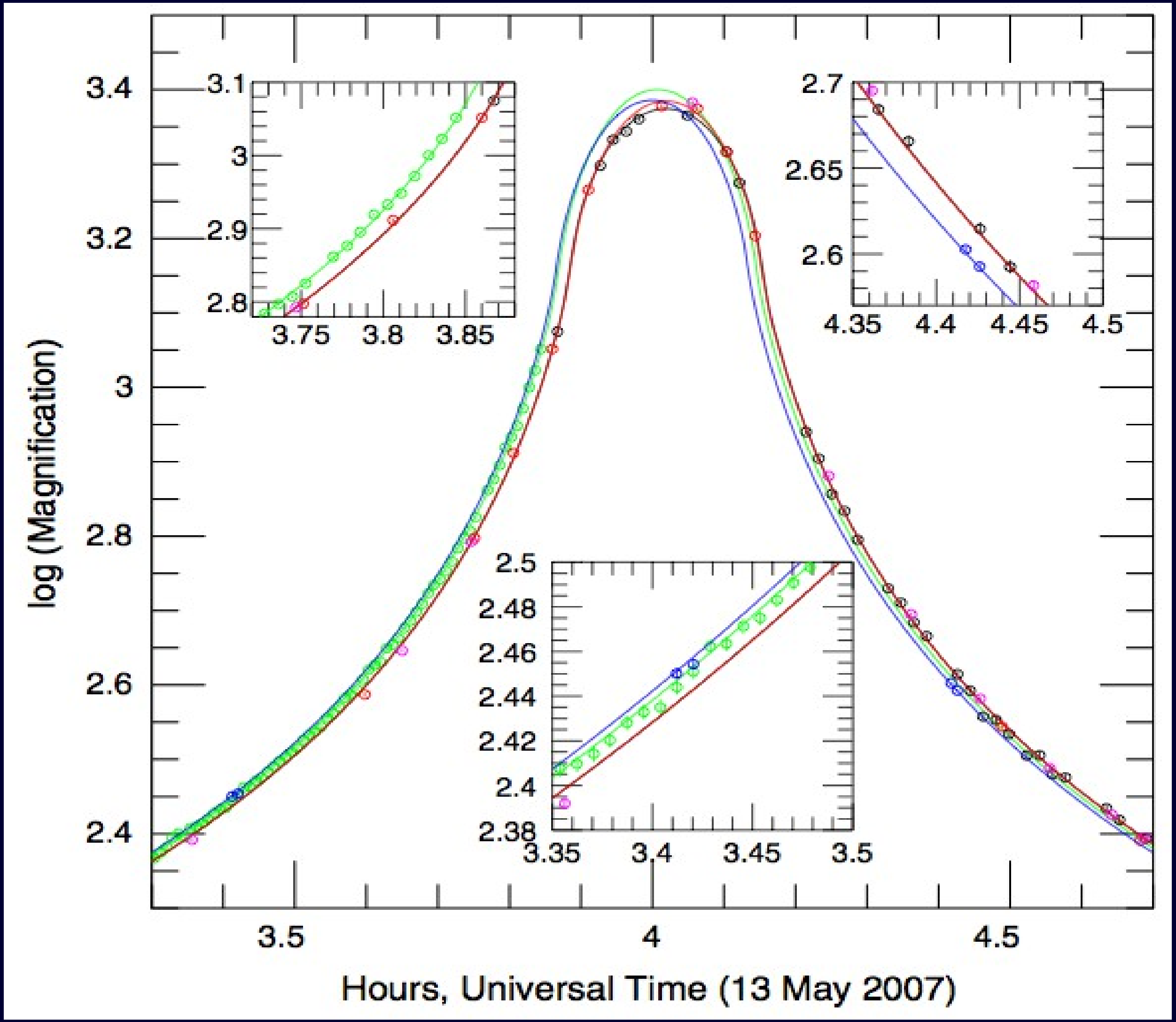


Pros: Requires only ground-based photometry
Time differences ~1min

Cons: Only detectable for rare, very high magnification events
Needs weather to cooperate in both hemispheres

Methods of measuring Parallax

Terrestrial parallax

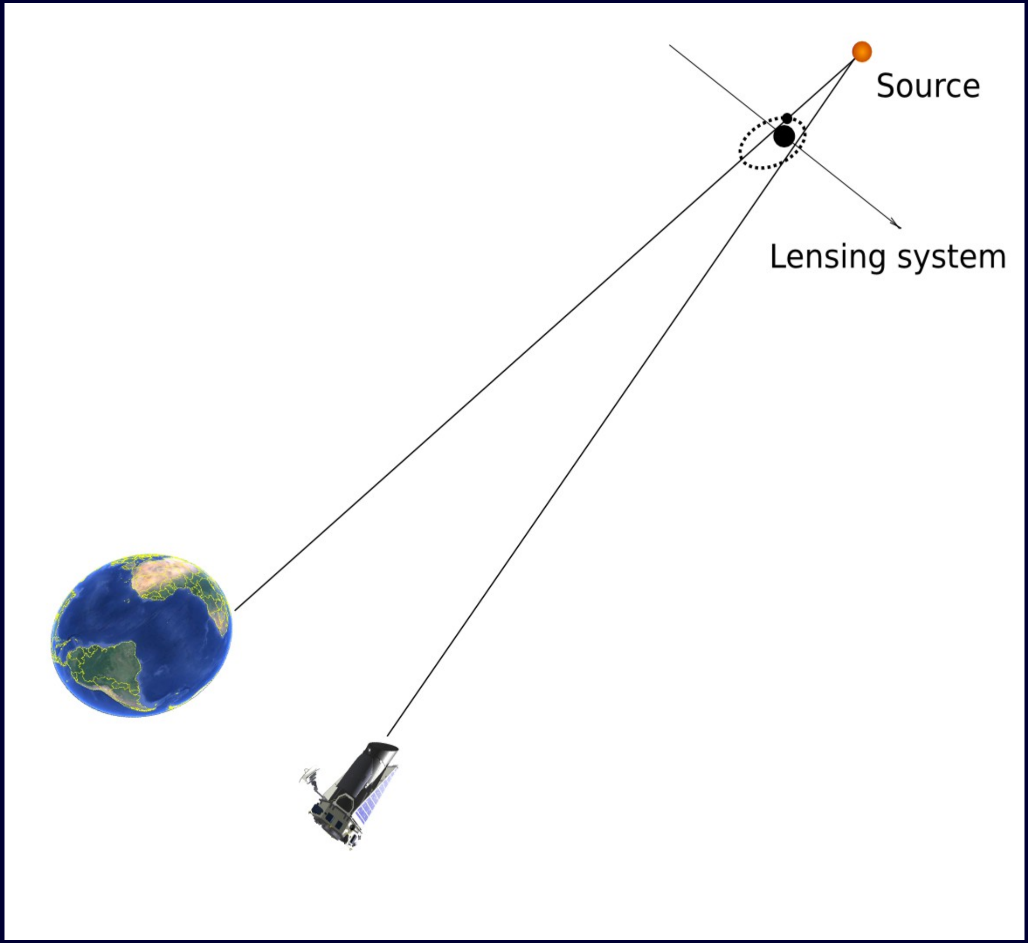


OGLE-2007-BLG-224

From: Gould, A. et al. 2009, Fig 1.

Methods of measuring Parallax

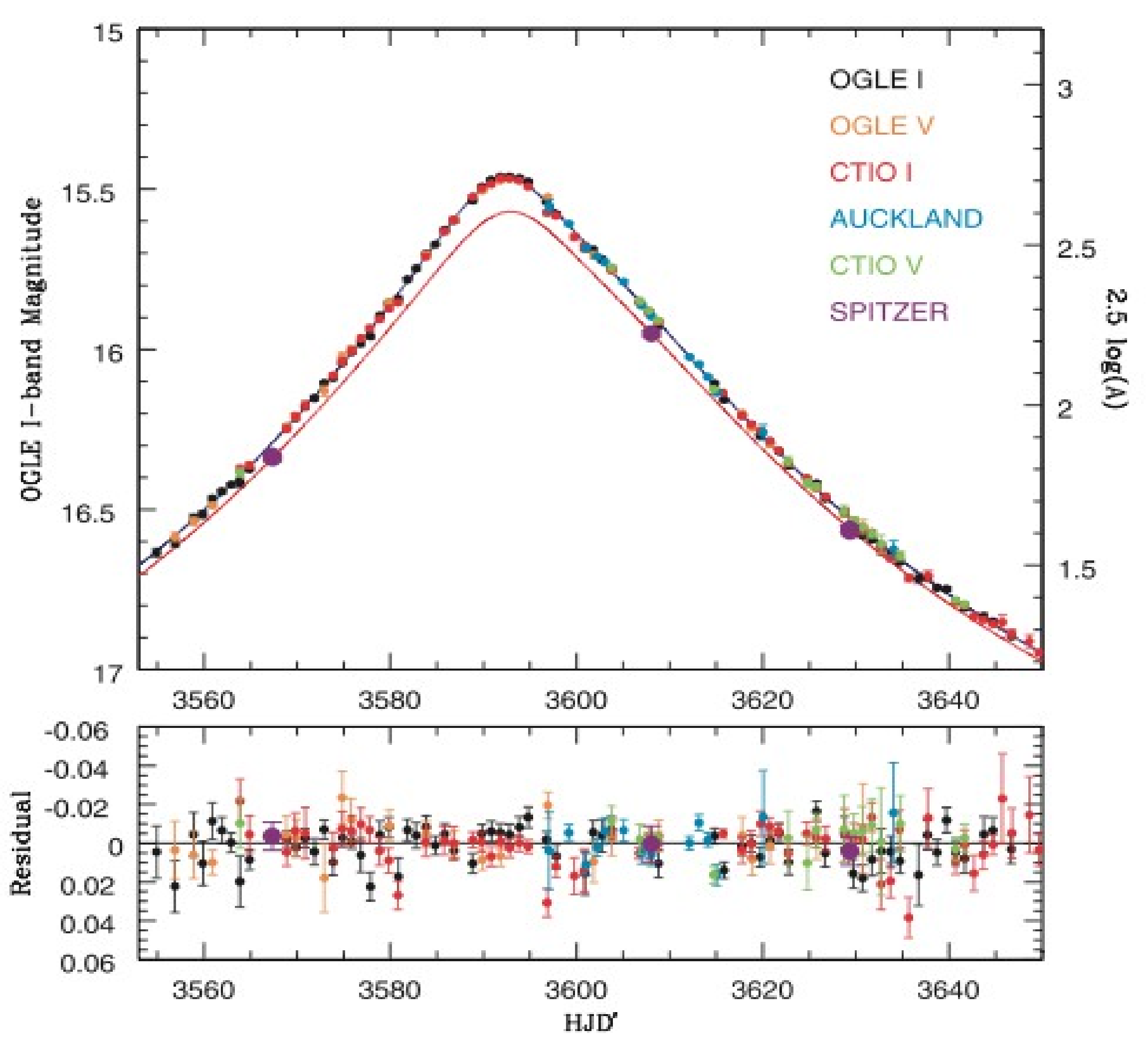
Space parallax



Pros:	Measures parallax for virtually all events
	Can detect planets that would be undetectable from Earth
Cons:	Requires simultaneous photometry
	Requires a space-mission at the right separation

Methods of measuring Parallax

Space parallax



OGLE-2005-SMC-001

From Dong, S. et al., 2007, Fig 4.

See also results from
Spitzer Microlensing Program
K2/Campaign 9

Photometric Precision

Magnification depends on angular separation of lens-source

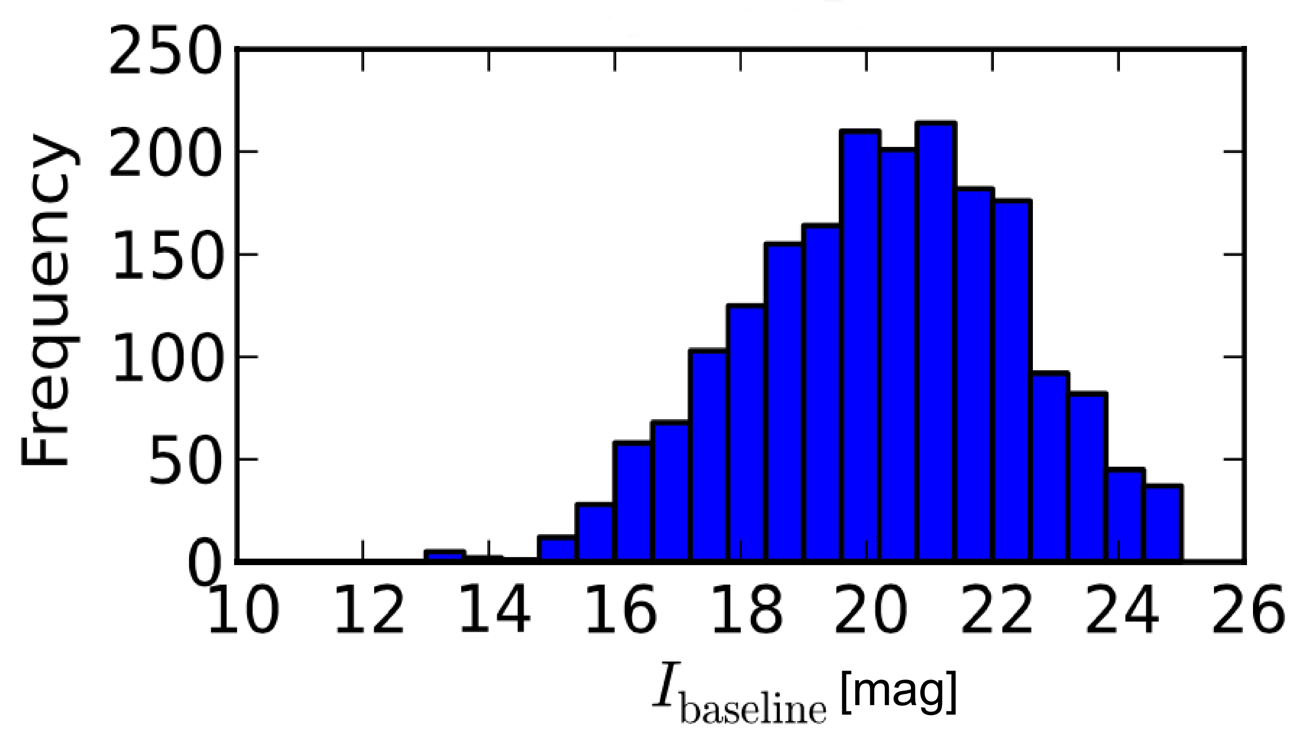
$$A_{\mathrm{tot}} = \frac{u^2 + 2}{u\sqrt{u^2 + 4}}$$

→ so even low-mass lenses can result in a strong signal:
(Δ brightness ~0.01 – several mag)

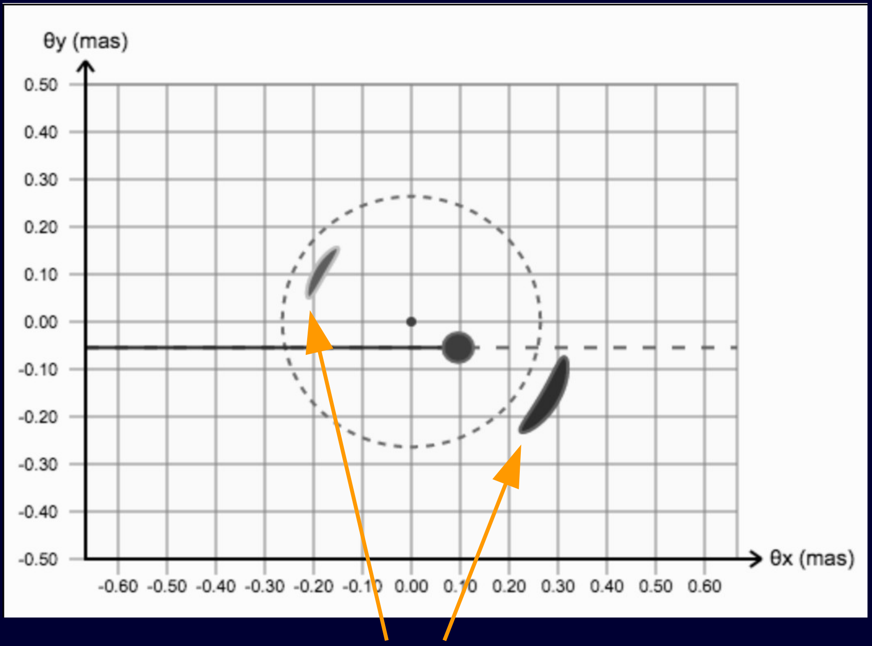
Survey telescopes:
1m – 2m class

Follow-up telescopes:
0.3m – 1m

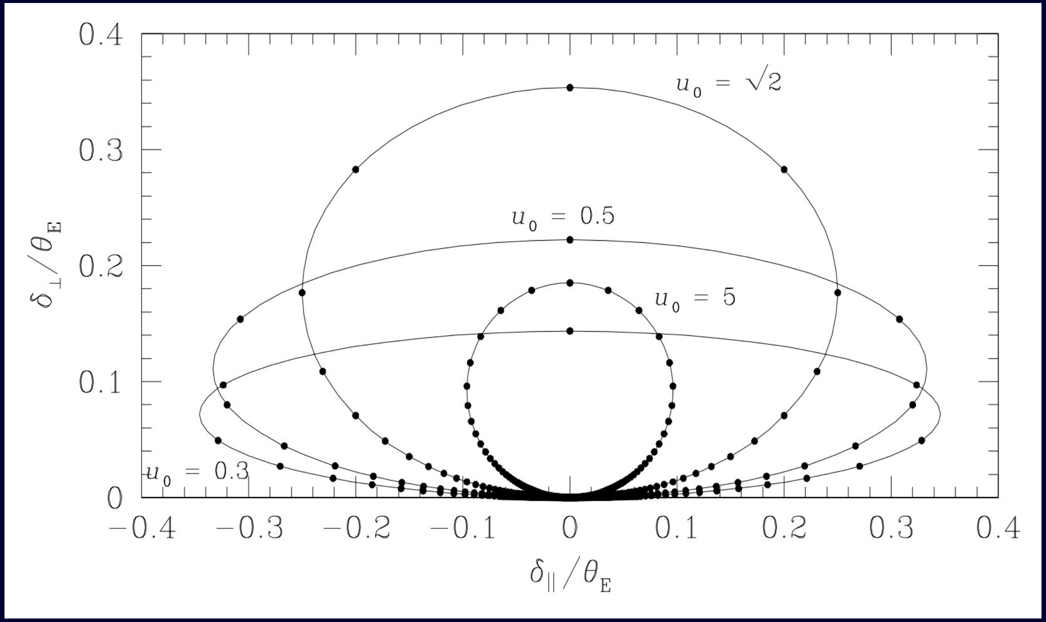
Distribution of source star unlensed brightness



Astrometric Microlensing



Images of source created by lensing



...photo-center movement during event
From Dominik & Sahu, 2000

Displacement of the centroid can also be used to measure θ_E
→ Typically δ ~ tens μas

$$\vec{\delta}(\vec{u}) = \frac{\vec{u}}{u^2 + 2}\,\theta_{\mathrm{E}}$$

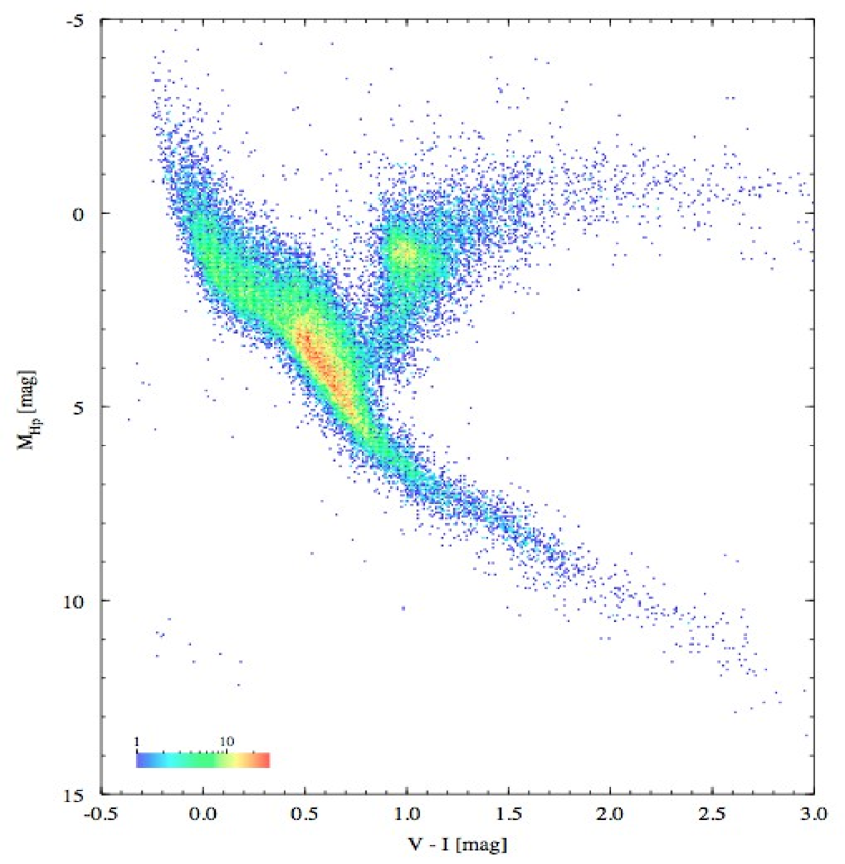
Know Thy Source Star

Sources stars necessarily distant, so often faint

D_S ~ 4-8 Kpc
I~16-21mag

Spectroscopy is challenging, interferometry unfeasible

→ Photometric spectral typing

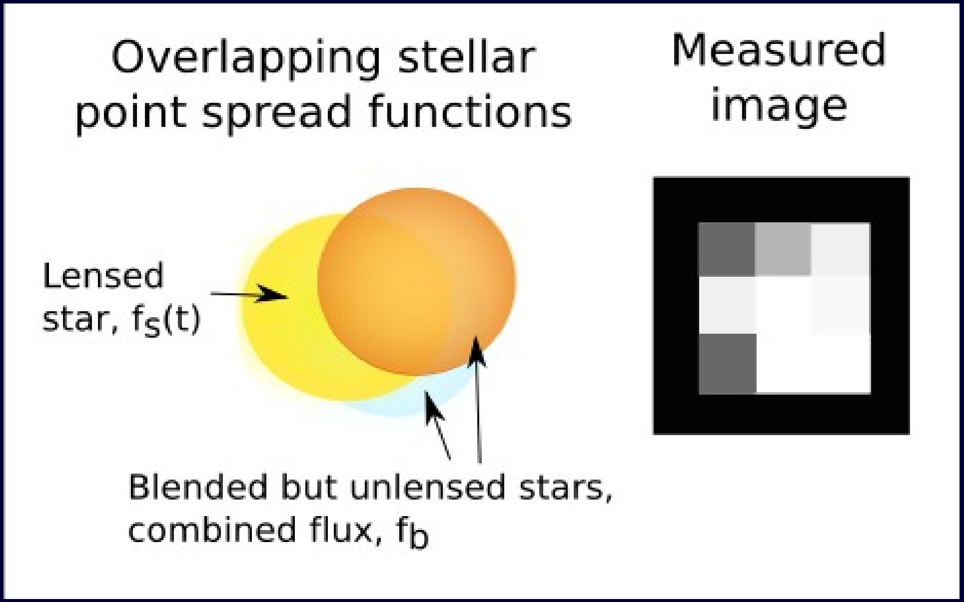


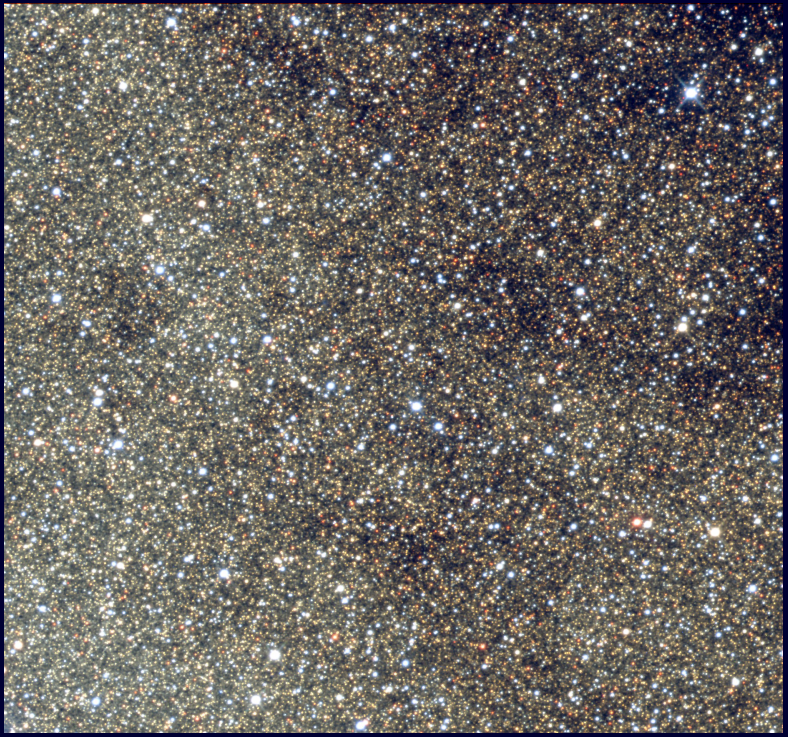
But:
Blending and extinction

Blending

Must survey dense star fields in the Galactic Bulge
→ Need high spatial resolution

Every star is blended!





~10 arcmin

Blending

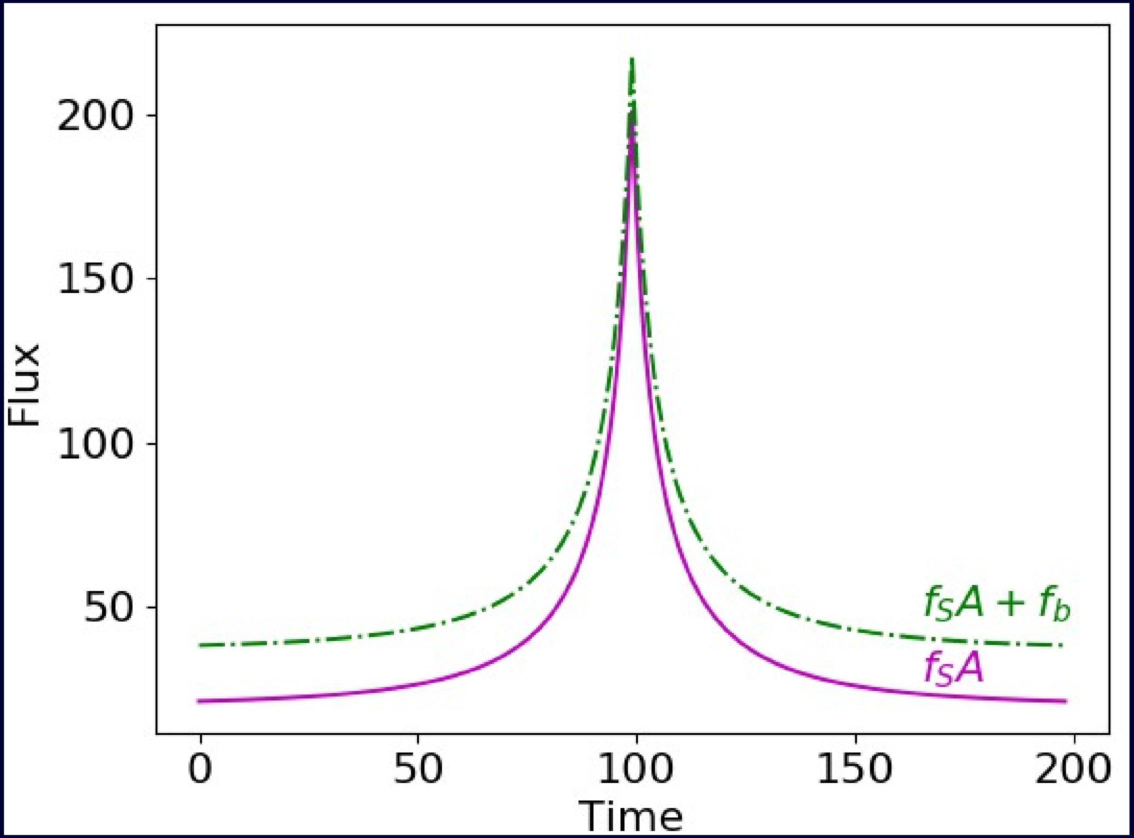
Only the lensed star brightens consistently with a microlensing model during the event

$$f(t) = f_s(t)A(u(t)) + f_b$$

f_S source flux

f_b blend flux

A(u(t)) lensing magnification as a function of time



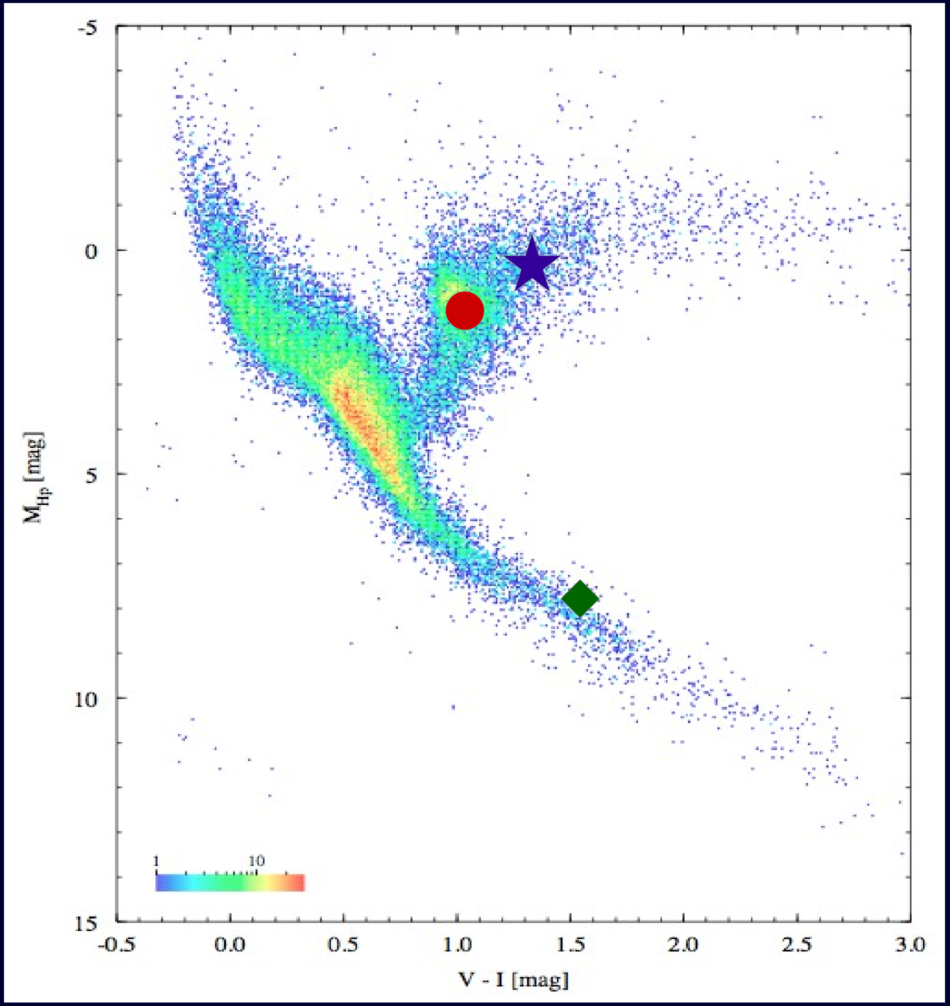
Extinction

Fields often have high and spatially-variable extinction
→ Use Red Clump as a calibration tool

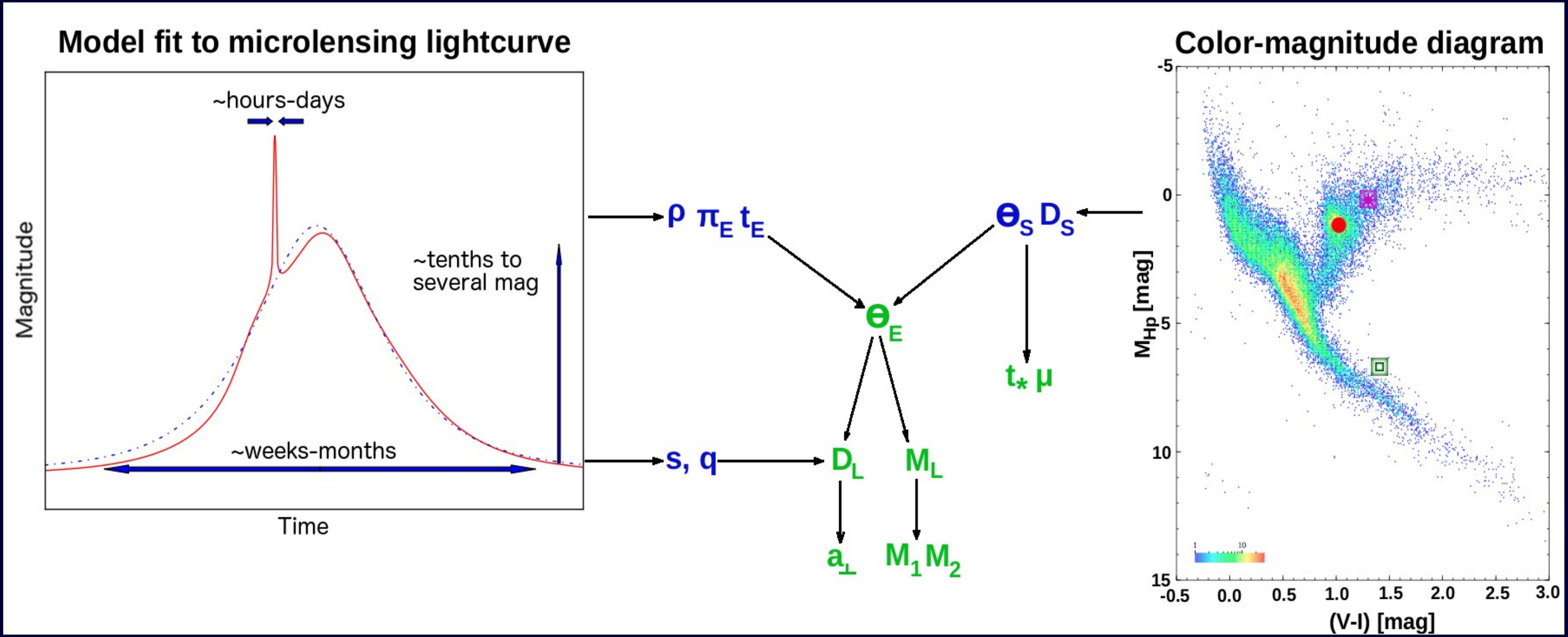
Need to measure source and blend flux in multiple bands
→ Two-filter lightcurves

Source spectral type → stellar radius
+
Source distance

→ source angular radius



Microlensing's Critical Observables



1) High- (but variable) cadence, long-baseline lightcurve (single filter)

2) Low-cadence lightcurve over peak (different filter)

Microlensing Surveys

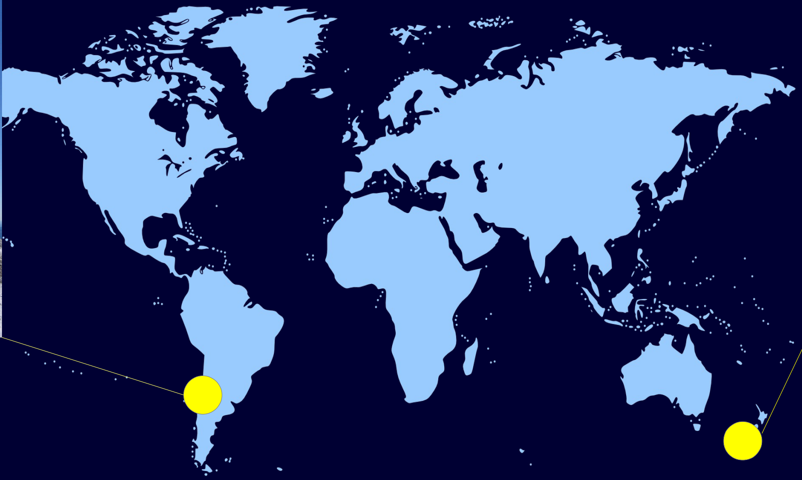
Ground-based, single-site: OGLE, MOA

0.3-0.6 arcsec/pixel
1.4-2.2 sq.deg. field of view

Deliver long-baseline lightcurves with day-gaps
Most data in I or R, lower cadence lightcurves in V

Follow-up provides high-cadence lightcurve at critical times

OGLE 1.4m, Chile



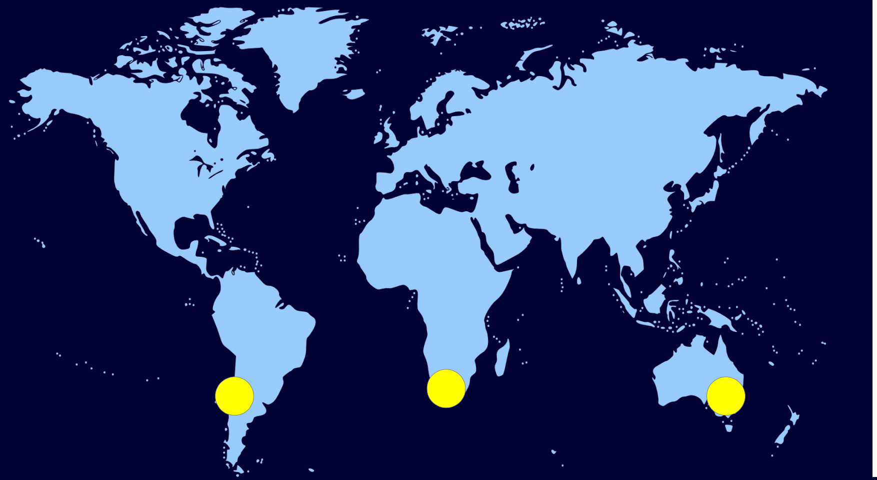
MOA 1.8m
New Zealand

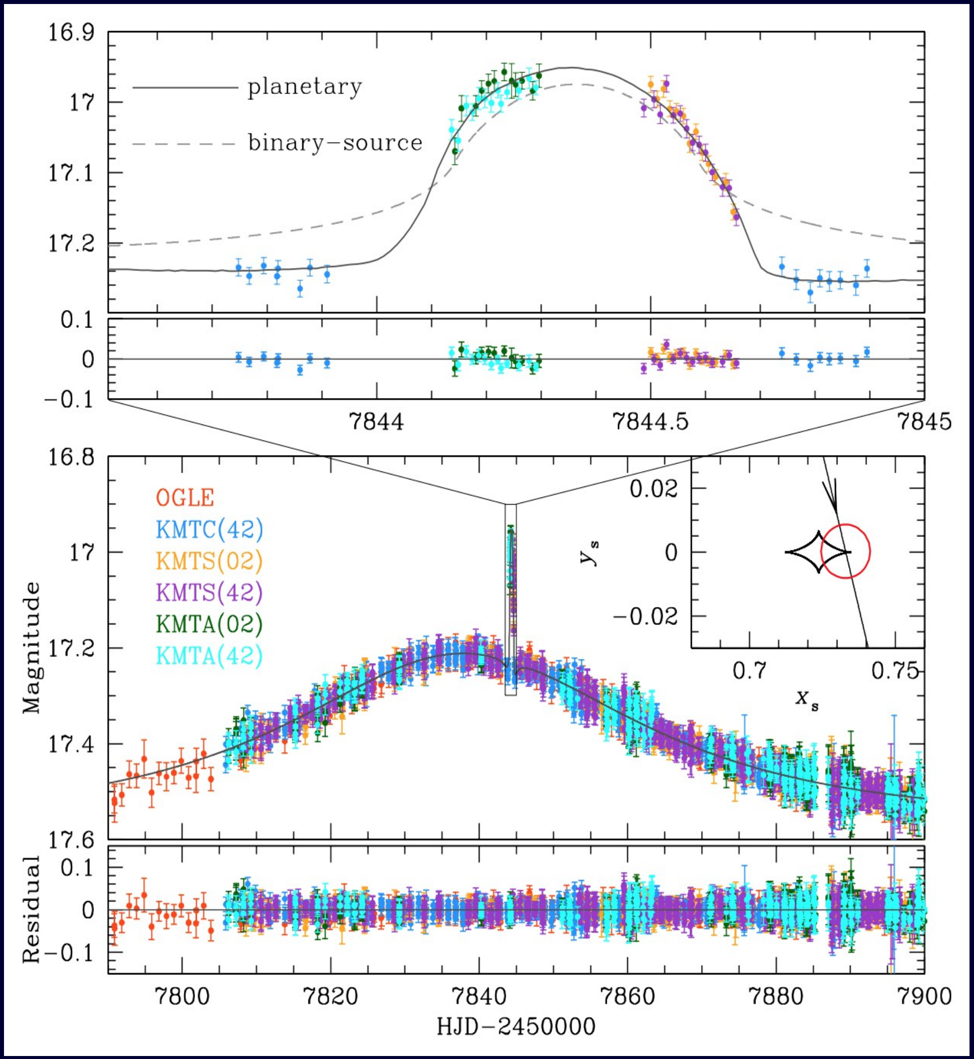
Microlensing Surveys

Ground-based, multi-site: KMTNet

- 3 x 1.6m telescopes
- 0.4 arcsec/pixel
- 2x2 deg field of view

Provide mostly complete lightcurves
Most data in a I, lower cadence lightcurves in V





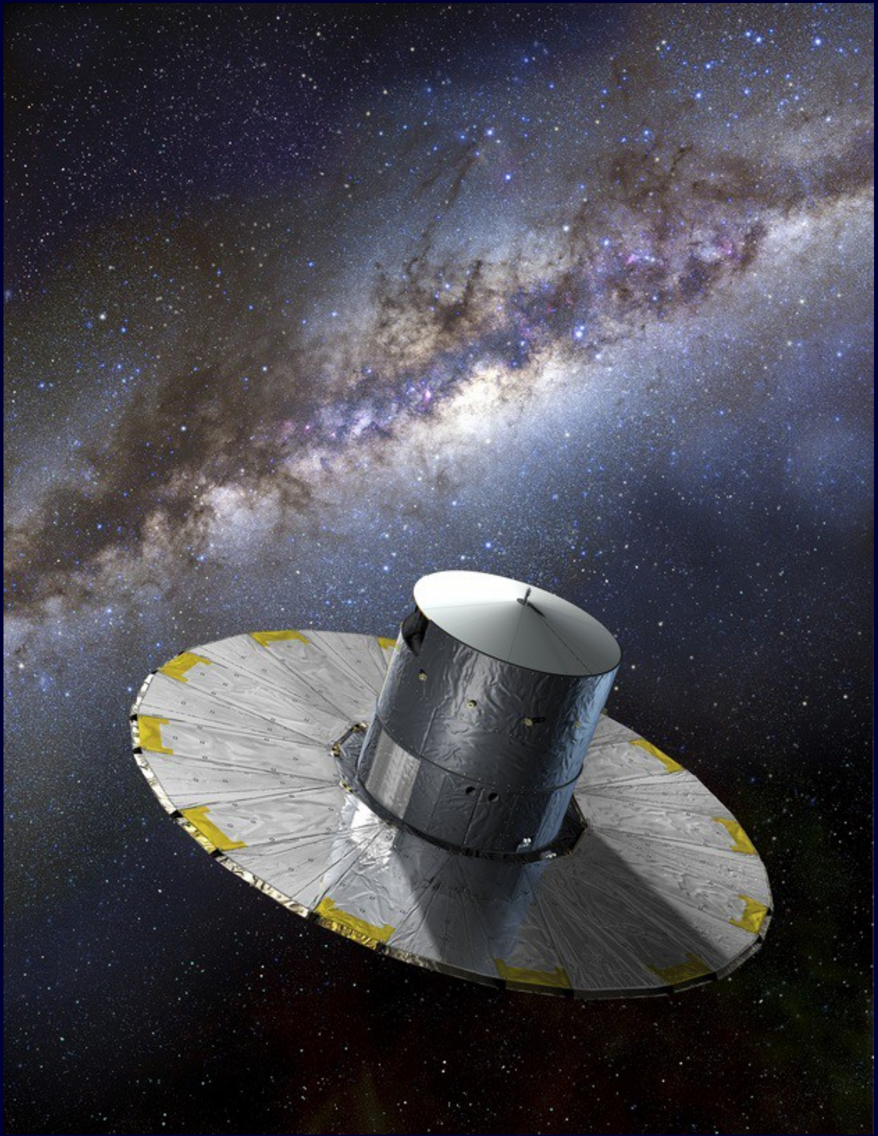
From Hwang et al. 2017

Microlensing Surveys

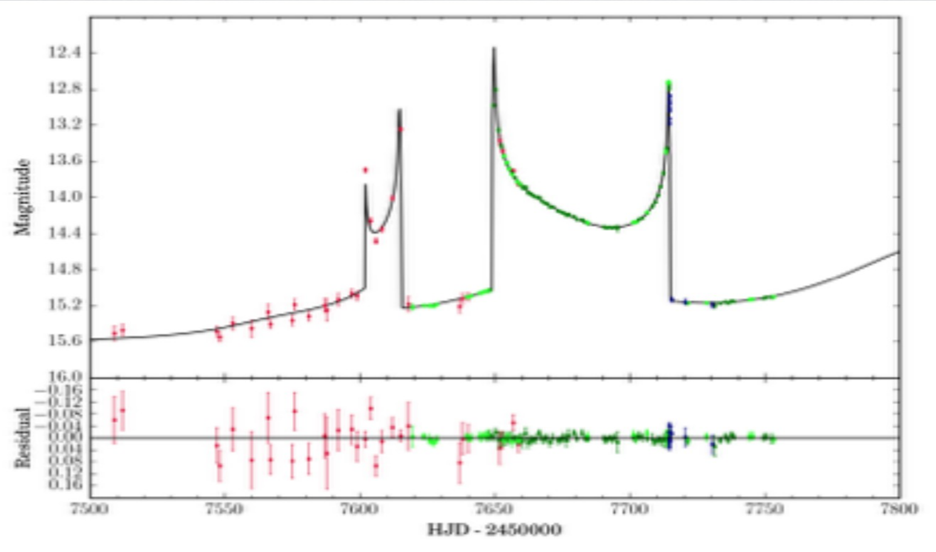
Space-based: Gaia Mission
Ongoing: 2013 – 2018

Precision astrometry + photometry

Predicted to detect:
~25,000 astrometric microlensing events
~400 photometric microlensing events
[Belokurov & Evans 2002]



→ Follow-up photometry required



Future Microlensing : WFIRST Surveys

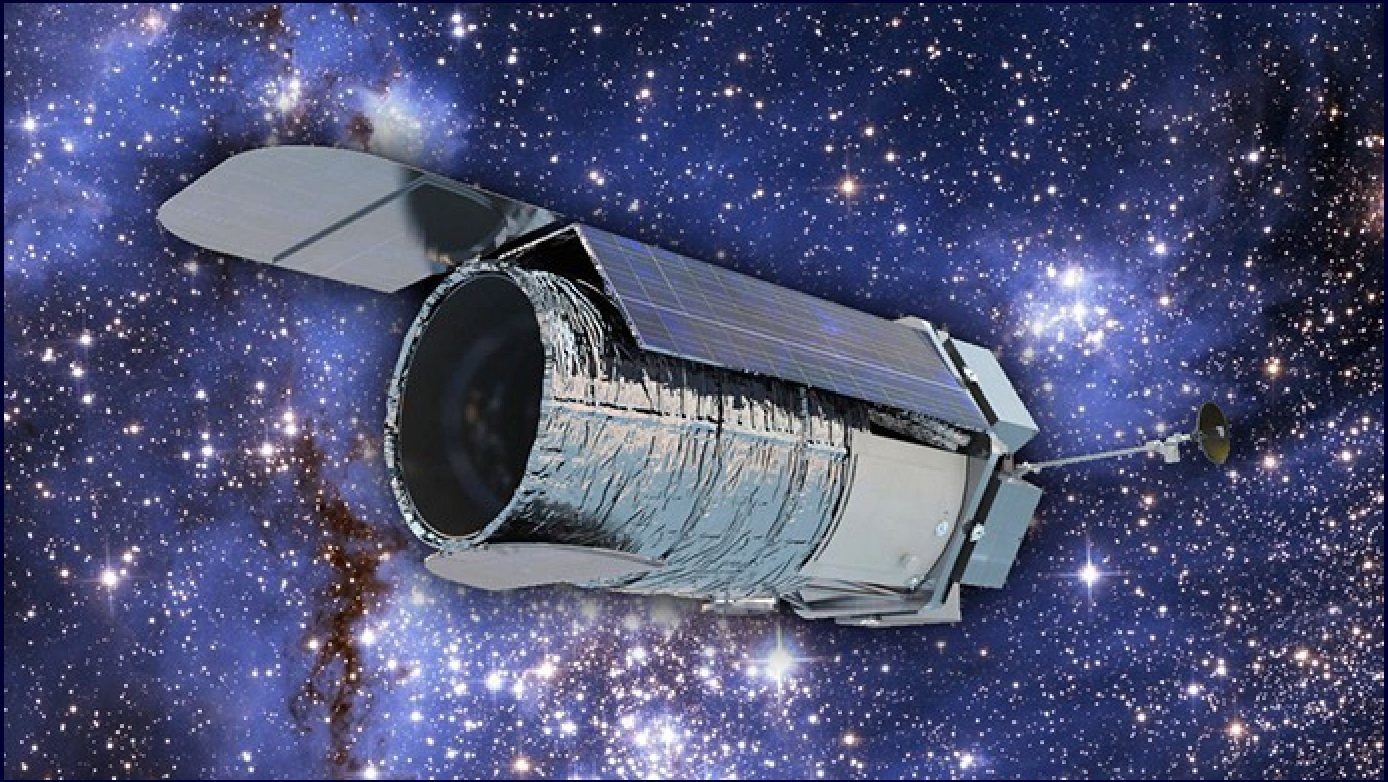
Launch: ~mid 2020s

L2 orbit

2.4m NIR telescope with wide-field imager
0.28sq. deg field of view
Multiple filters between 0.7 – 2.0 μm

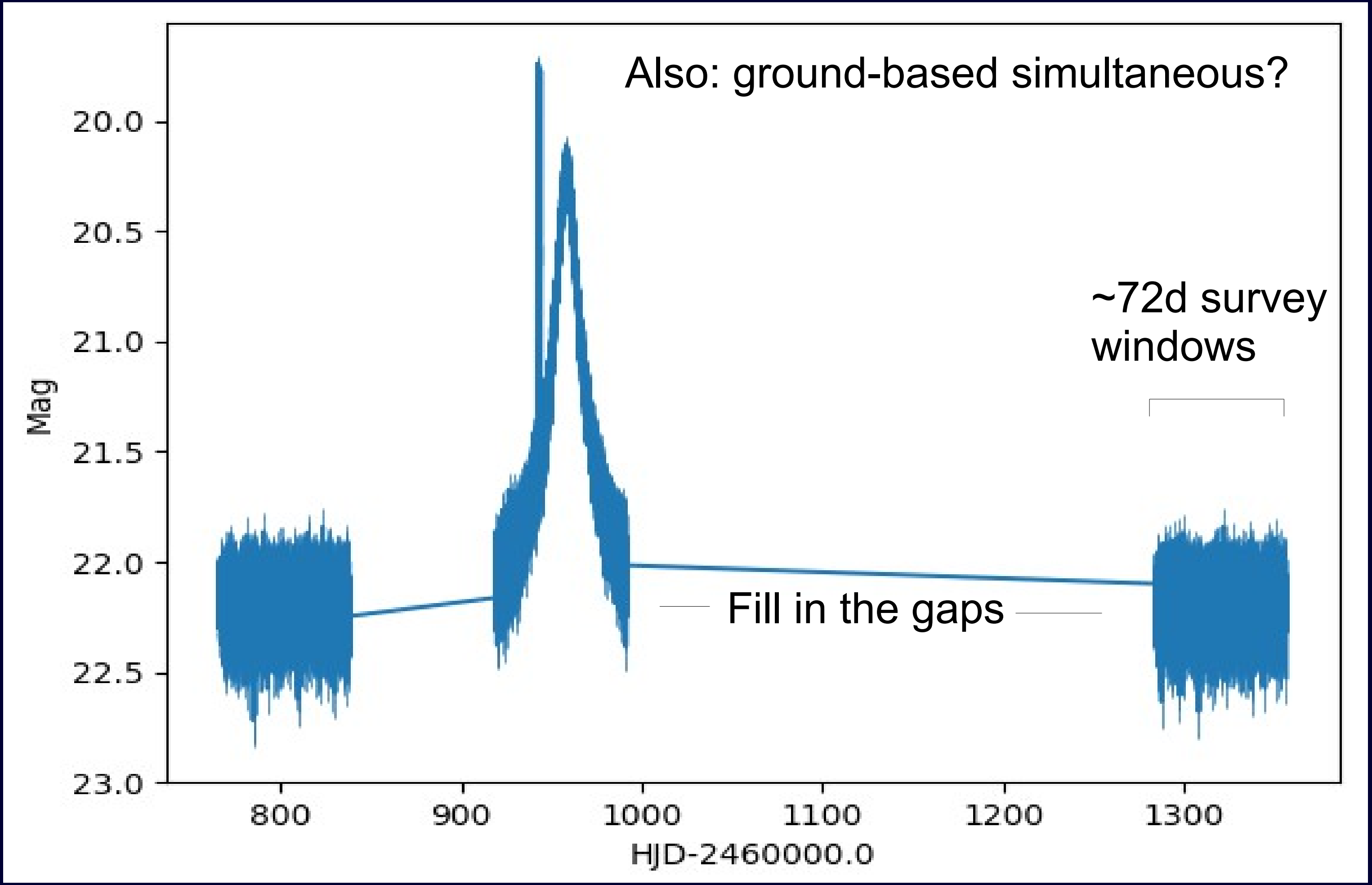
Will monitor 200 million Bulge stars

Will discover ~3000 planetary events



WFIRST follow-up

Simulated planetary microlensing event as seen by WFIRST



Also: ground-based simultaneous?

~72d survey windows

Fill in the gaps

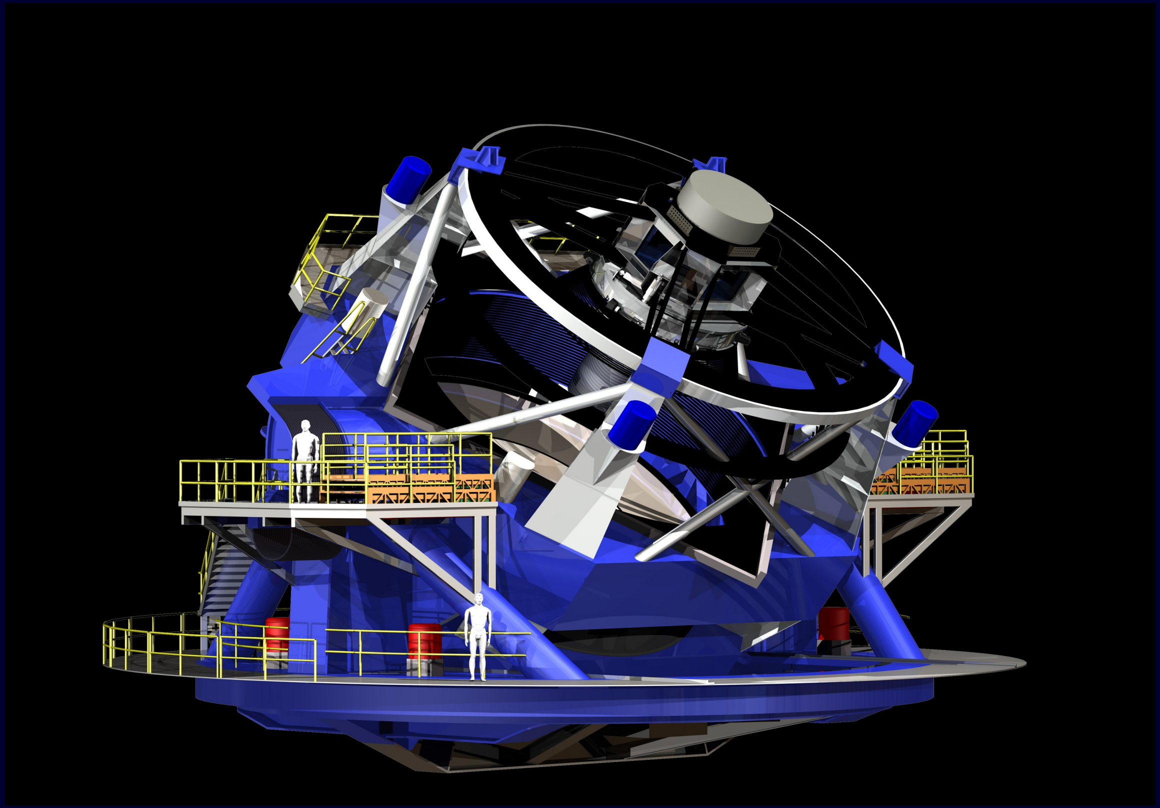
Simulation by: E. Bachelet

Future Microlensing : LSST Surveys

Under construction in Chile
Science operations begin 2023

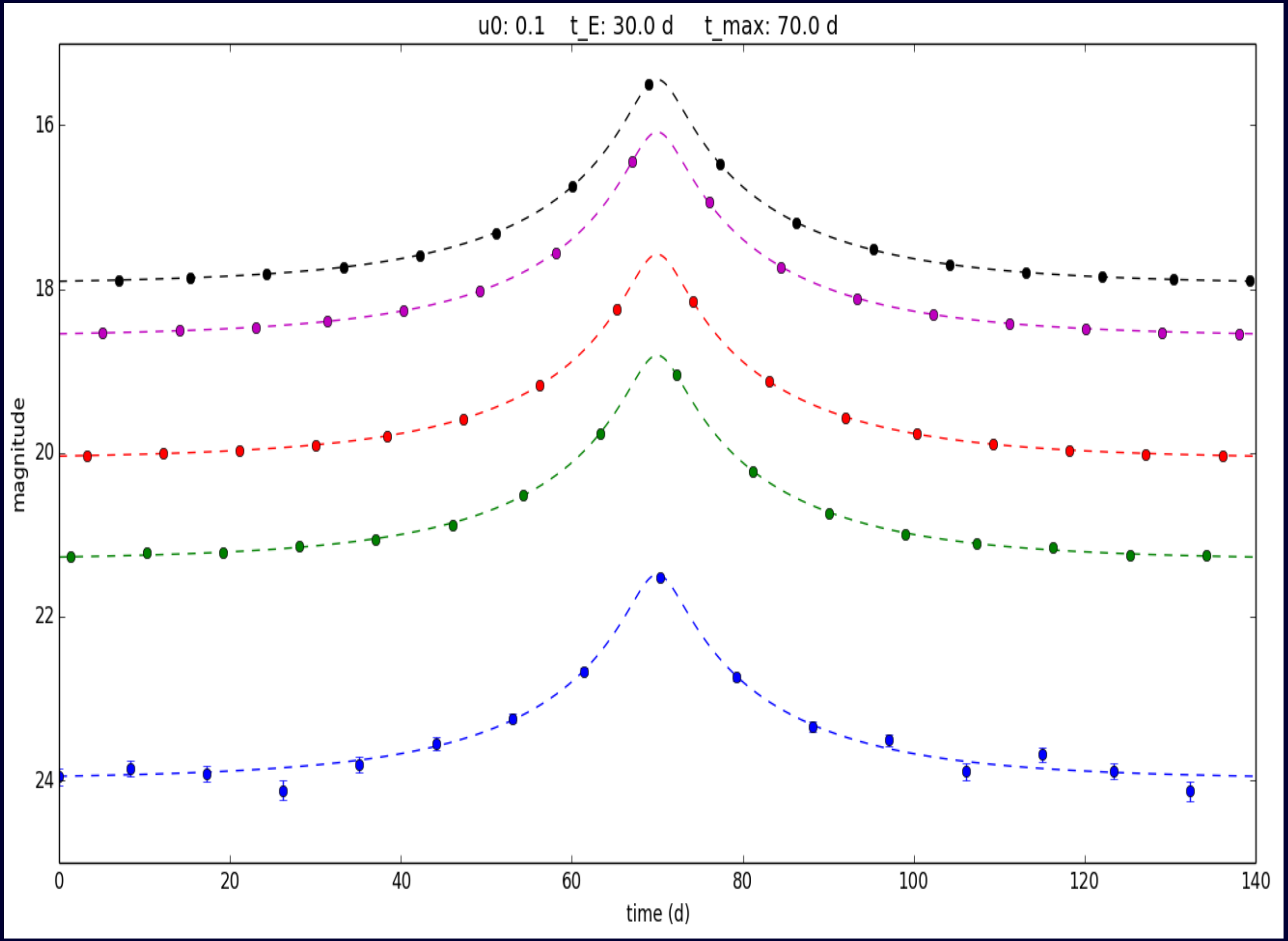
8.4 m optical telescope
3.5 deg field of view
Multiple filters, 0.3 – 1μm
0.2 arcsec/pixel

→ “deep”, “wide” and “hi-res”



LSST follow-up

Simulated lightcurves from LSST's Main Survey

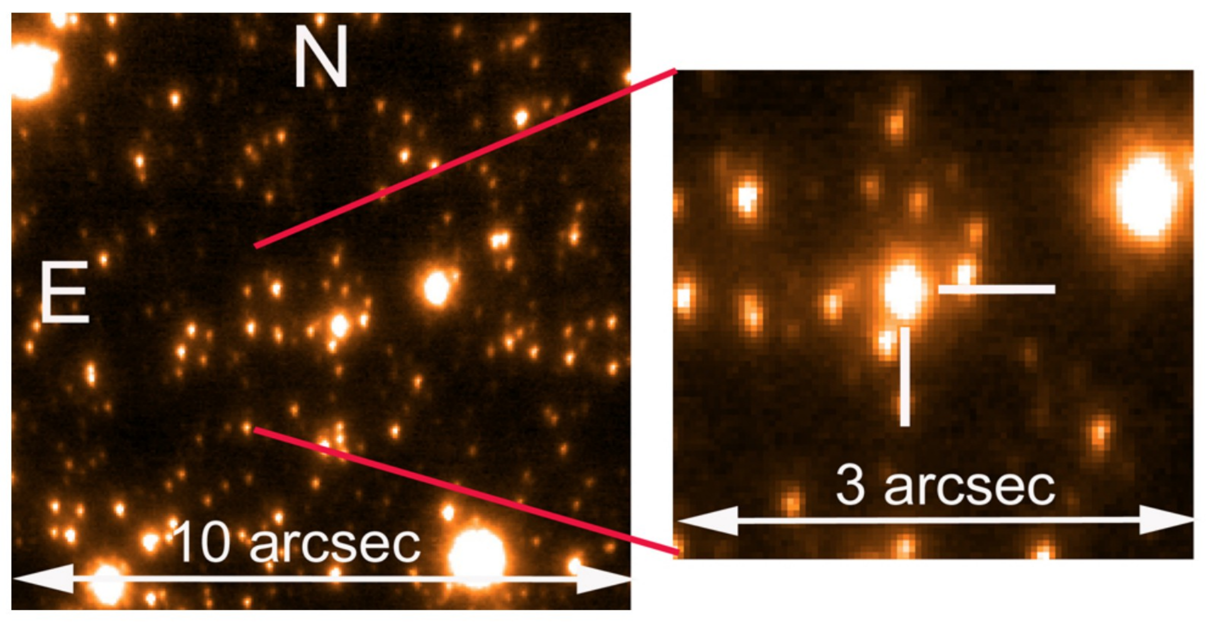


Higher-cadence photometry needed around peak

Special Project coordinated with WFIRST?

Simulation by S. Cross

AO imaging of microlensing targets



Keck AO imaging of
OGLE-2014-BLG-0124

Beaulieu et al. 2017

Distinguish source from blended stars

Place better constraints on source type and parameters

Long baseline AO can detect lens system flux

See talk by C. Henderson

Observational Needs of Microlensing Surveys

- Photometry of millions of stars with multi-year baseline
- Medium-high spatial resolution (~0.2 arcsec/pix)
- RMS~0.01mag, limiting magnitude I~21mag
- High cadence (~4 hr^{-1}), single-filter lightcurve
- Low cadence (~1 day^{-1}) lightcurve over event peaks in a second filter
- Simultaneous data from widely-spaced sites
- High precision timeseries astrometry
- AO imaging