MICROLENSING PLANET DETECTION VIA EARTH ORBIT SATELLITES

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Why gravitational microlensing?

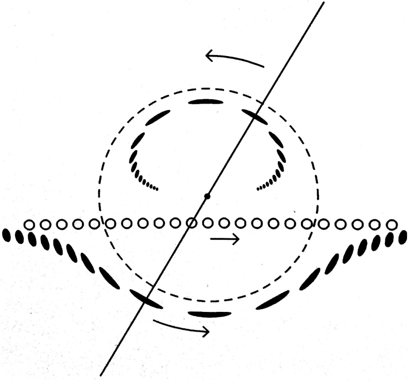
μLENSING

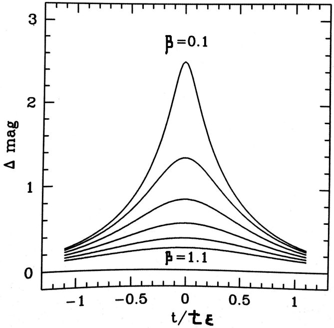
A unique method to measure the mass of isolated, dark objects in the Galaxy.

Goal

A measurement of mass and abundance of free-floating planets and brown dwarfs to test planetary formation theories.

The Einstein timescale t_E

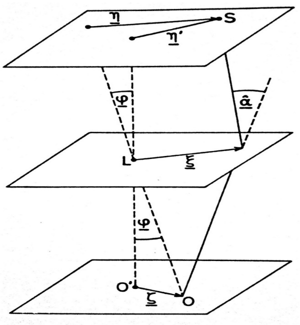




$$t_E = 1\,\text{day}\left(\frac{M}{M_{\text{Jup}}}\right)^{1/2}\left(\frac{4D_L(D_S - D_L)}{{D_S}^2}\right)^{1/2}\left(\frac{D_S}{8\,\text{kpc}}\right)^{1/2}\left(\frac{200\,\text{km}\,\text{s}^{-1}}{V}\right)$$

THE LENS MASS M AND DISTANCE D_L ARE HIDDEN IN t_E.

The μlensing parallax π_E



$$\pi_E = \left(\frac{1\,\mathrm{AU}}{D_L} - \frac{1\,\mathrm{AU}}{D_S}\right)\frac{1}{\theta_E}$$

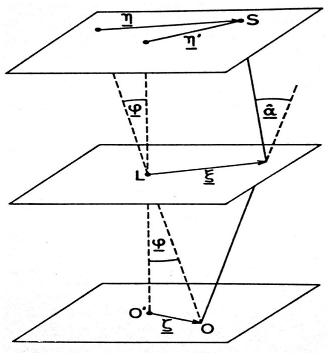
The parallax method

$$M = \frac{\theta_E}{\kappa \pi_E}$$

- θ_E is measured at high magnifications and in binary lens events.

DEGENERACY IN t_E RESOLVED!

The μlensing parallax π_E



Two strategies:

- Two or more inertial observatories.
- A single non-inertial observatory:
  - HST (Honma 1999)
  - WFIRST in GEO (Gould 2013)

Single non-inertial observatory

- No 4-fold degeneracy (Gould 1994)
- No coordination between several observatories

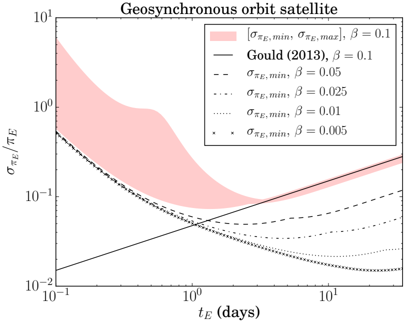
WFIRST in geosynchronous orbit (Gould 2013)

Gould (2013) performs an analytical Fisher Matrix analysis for a geosynchronous satellite with $\sigma_{\mathrm{mag}} = 0.01$ and 3-min exposures.

$$\frac{\sigma_{\pi_E}}{\pi_E} = 10\% \left(\frac{t_E}{20\,\mathrm{days}}\right)^{1/2} \left(\frac{\beta}{0.05}\right) \left(\frac{6.6\,R_\oplus}{R}\right), \quad P \ll \beta t_E \text{ and } \beta \ll 1$$

A WFIRST-like GEO satellite could provide masses and distances for most standard planetary events ($t_E \approx 20\,\mathrm{days}$).

Geosynchronous orbit satellite (Mogavero, Beaulieu 2016)



A GEO satellite is naturally optimized for t_E of few days

Let $t_E^\star$ be the timescale which minimizes σ_{π_E}/π_E:

$$t_E^\star \propto P\,\beta^{-1}, \qquad \frac{\sigma_{\pi_E,\mathrm{min}}}{\pi_E}\left(t_E^\star\right) \propto P^{1/2}\,\beta^{1/2}\,R^{-1}$$

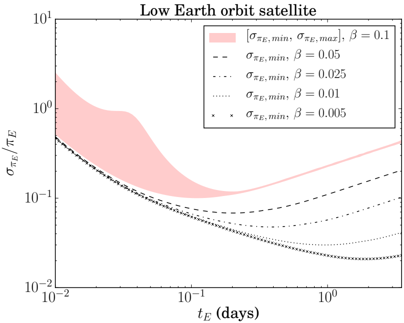
Geosynchronous orbit satellite (Mogavero, Beaulieu 2016)

$$t_E = 1\,\mathrm{day}\left(\frac{M}{M_{\mathrm{Jup}}}\right)^{1/2}\left(\frac{4D_L(D_S - D_L)}{{D_S}^2}\right)^{1/2}\left(\frac{D_S}{8\,\mathrm{kpc}}\right)^{1/2}\left(\frac{200\,\mathrm{km\,s^{-1}}}{V}\right)$$

A geosynchronous orbit satellite could:

- detect π_E for free-floating lenses with masses $\sim M_{\mathrm{Jup}}$
- discover planets in tight orbits around low-mass brown dwarfs

Low Earth orbit satellite (Mogavero, Beaulieu 2016)



A LEO SATELLITE IS NATURALLY OPTIMIZED FOR t_E OF FEW HOURS

$\frac{\sigma_{\pi_E,\mathrm{min}}}{\pi_E}(t_E^\star) \propto P^{1/2}\,\beta^{1/2}\,R^{-1}$ and Kepler's third law $P^2 \propto R^3$:

$$\frac{\sigma_{\pi_E,\mathrm{min}}}{\pi_E}(t_E^\star) \propto \beta^{1/2}\,R^{-1/4}$$

ONLY A FACTOR OF $(6.6)^{1/4} \approx 1.6$ BETWEEN A GEO AND A LEO!

Low Earth orbit satellite (Mogavero, Beaulieu 2016)

$$t_E = 1.3\,\text{hours}\left(\frac{M}{M_\oplus}\right)^{1/2}\left(\frac{4D_L(D_S - D_L)}{{D_S}^2}\right)^{1/2}\left(\frac{D_S}{8\,\text{kpc}}\right)^{1/2}\left(\frac{200\,\text{km s}^{-1}}{V}\right)$$

FINITE SOURCE SIZE EFFECTS EASILY DETECTABLE:

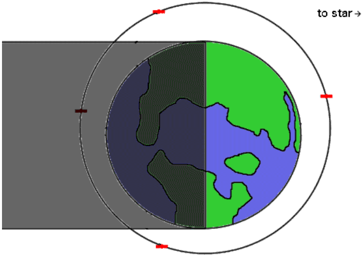
$$\frac{\beta}{\rho} = 0.5\left(\frac{\beta}{0.1}\right)\left(\frac{t_E}{0.1\,\text{days}}\right)\left(\frac{R_\odot}{R_S}\right)\left(\frac{D_L}{2D_S}\right)\left(\frac{V}{200\,\text{km s}^{-1}}\right)$$

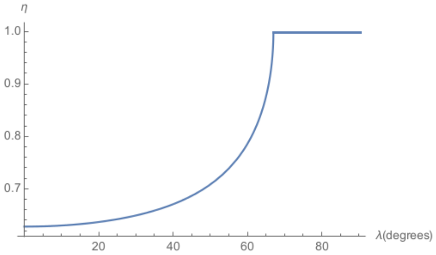
A LOW EARTH ORBIT SATELLITE COULD:

- discover free-floating planets of few Earth masses

THE FRACTION η OF THE ORBITAL PERIOD AVAILABLE TO OBSERVE THE SOURCE STAR:

$$\eta = 1 - \frac{1}{\pi} \arcsin\left[\sqrt{1 - \left(\frac{R}{R_\oplus}\right)^2 \sin^2\lambda} \Big/ \frac{R}{R_\oplus}\cos\lambda\right]$$





$R = R_\oplus + 550\,\text{km}$

Conclusions

A geosynchronous orbit satellite could:

- detect π_E for free-floating objects with masses $\sim M_{\text{Jup}}$
- discover planets in tight orbits around low-mass brown dwarfs

A low Earth orbit satellite could:

- discover free-floating planets of few Earth masses

Limitations:

- strong requirements on photometry: $\sigma_{\text{mag}} = 0.01$, $f = (3\,\text{min})^{-1}$
- Earth's umbra in case of LEO

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Microlensing planet detection via geosynchronous and low Earth orbit satellites

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ABSTRACT

Planet detection through microlensing is usually limited by a well-known degeneracy in the Einstein timescale t_E, which prevents mass and distance of the lens to be univocally determined. It has been shown that a satellite in geosynchronous orbit could provide masses and distances for most standard planetary events ($t_E \approx 20$ days) via a microlens parallax measurement. This paper extends the analysis to shorter Einstein timescales, $t_E \approx 1$ day, when dealing with the case of Jupiter-mass lenses. We then study the capabilities of a low Earth orbit satellite on even shorter timescales, $t_E \approx 0.1$ days. A Fisher matrix analysis is employed to predict how the 1-σ error on parallax depends on t_E and the peak magnification of the microlensing event. It is shown that a geosynchronous satellite could detect parallaxes for Jupiter-mass free floaters and discover planetary systems around very low-mass brown dwarfs. Moreover, a low Earth orbit satellite could lead to the discovery of Earth-mass free-floating planets. Limitations to these results can be the strong requirements on the photometry, the effects of blending, and in the case of the low orbit, the Earth's umbra.

Key words. gravitational lensing: micro – parallaxes – planets and satellites: detection – brown dwarfs