Predicting Microlensing Events

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Microlensing

\[ L_+ \]

\[ S \]

\[ L \]

\[ O \]

\[ \alpha \]

\[ \theta_S \]

\[ \theta_I \]

\[ D_l \]

\[ D_s \]
Photometric microlensing

Paczynski 1986; Alcock et al 1993
Photometric microlensing
Photometric microlensing

- All-sky averaged photometric microlensing optical depth is \( \sim 5 \times 10^{-7} \).
- The typical duration is 2-3 months, so there are a total of \( \sim 8,000 -10,000 \) photometric microlensing events during the Gaia mission (Belokurov & Evans 2002).
- GAIA’s sampling is sparse and many of the events will be missed.
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 Einstein radius.
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

\[
\theta_{sl}(t) = \theta_{sl,0} + \mu_{sl} t + P_{sl}
\]

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

\[
S(t) = \theta_s(t) + \theta(t), \quad \theta = \frac{\theta_{sl}(t)}{(\theta_{sl}(t)/\theta_E)^2 + 2}.
\]

where the Einstein radius is

\[
\frac{\theta_E}{\text{mas}} = \left( \frac{M}{0.12M_\odot} \right)^{1/2} \left( \frac{\pi_{sl}}{\text{mas}} \right)^{1/2}
\]
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.
Microlensing

- GAIA is an astrometric mission. Microlensing plays to the strengths of the mission.
- Belokurov & Evans (2002) suggested triggering events on photometry was possible.
- Maybe … but there is any easier way that has not yet been properly explored.
Astrometric microlensing

- A very attractive feature of astrometric microlensing is that events can be predicted (Paczynski 1995) if the lens proper motion is known.

- This has not yet been fully exploited for the GAIA mission.

- Other applications include e.g., Sahu’s (2014) HST investigations of Proxima Centauri.
Astrometric microlensing

If the proper motion is $\dot{\theta}$, then area on the sky that a lens sweeps out in 5 year mission lifetime is

$$A \approx 0.024 \left( \frac{M}{0.08M_\odot} \right)^{1/2} \left( \frac{10\text{pc}}{D_d} \right)^{1/2} \left( \frac{\dot{\theta}}{300\text{mas yr}^{-1}} \right)$$

Assuming a source density of 0.15 stars per square arcsec means that samples of 10s of high proper motion stars will yield detectable events (Evans 2014).
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 known objects that are fast moving — such as brown and M dwarfs.
Astrometric microlensing

- Proft et al. (2011) used PPMXL (Roeser et al. 2010) catalogue of 9000 million sources. They used LSPM-North (Lepine & Shara 2005), PPMX (Roeser et al. 2008) and the OGLEBLLG (Sumi et al. 2004) catalogue for the lenses.

- Proft et al. found two very good (7 reasonable) candidate M or white dwarf lenses.

- However, the white dwarf lens had epoch of closest separation in January 2014.
Astrometric Microlensing

Lens is M dwarf 43 pc away. Centroid shift is $\sim 2000\ \mu as$. Source is 12 mag star.

Proft et al. 2011
Astrometric microlensing

- There is scope to do many more studies along these lines.
- An interesting set of lens candidates is brown dwarfs. Accurate masses for L and T dwarfs would be particularly scientifically valuable.
- High proper motion dwarfs are beginning to be known in sufficient numbers to make this feasible.
Astrometric Microlensing

• The UKIDSS Large Area Survey (Burningham et al 2013, Smith et al. 2014) has found ~ 100s high proper motion brown dwarfs. They have also been many discoveries of high proper motion brown dwarfs colour-selected from the all-sky, multi-epoch WISE data.

• The total number of high proper motion dwarfs/brown dwarfs exceeds ~2000. (Investigations ongoing).
Conclusions

• Astrometric microlensing offers prospects of measuring masses of lenses to excellent accuracy.

• This is a pretty application of Gaia, but it is important to acquire the complementary photometry.

• Predicting microlensing is much easier than alerting. We should pick the low-hanging fruit first.
Conclusions

• Comparatively low numbers of high proper motion stars are needed to yield events (of the order of tens). This is because most of the optical depth to astrometric microlensing is in nearby, high proper motion lenses.

• The total number of high proper motion dwarfs/brown dwarfs exceeds \( \sim 2000 \). This dataset is being examined now.
Astrometric microlensing

The probability of detecting microlensing events is

\[
\tau = D_s \int_0^1 dx \int_0^\infty dM \frac{\rho(x)}{M} \Sigma(x, M) f(M),
\]

where \( \Sigma \) 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 \( 5\sigma \) if the sources lies within a radius \( u_a R_E \) where

\[
\begin{align*}
u_a &= \sqrt{\frac{T_{\text{life}} \nu}{5\sqrt{2} \sigma_a D_1}} = \sqrt{\frac{T_{\text{life}} \theta_E}{5\sqrt{2} \sigma_a t_E}}.
\end{align*}
\]
Astrometric microlensing

[Graph showing trends and parameters related to microlensing]