Simulating Observation of Weak Planetary Signals in Microlensing Events

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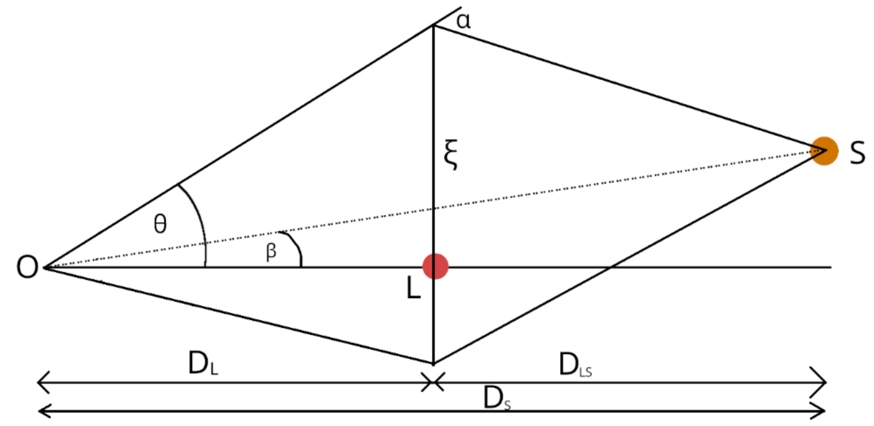
Aim

Simulate a realistic three-step microlensing survey to analyse the precision vs cadence question in the context of weak planetary signals.

What is gravitational lensing?

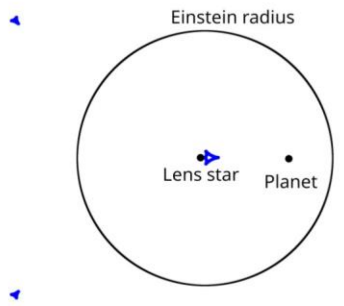
The gravitational field of a 'lens' star moving across the line of sight to a more distant 'source' star will temporarily deflect additional light towards the observer. The shape of the resulting light curve can provide detailed information on the lens star.



$$\beta = \theta - \frac{4GM_L}{c^2\theta}\frac{D_S - D_L}{D_L D_S}$$

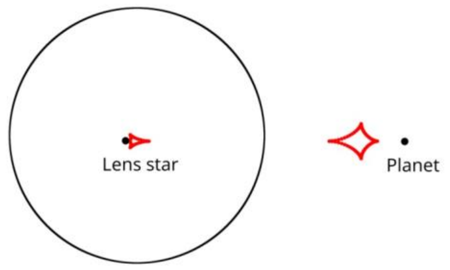
Caustic: the set of points for which the solution to the lens equation results in infinite magnification.

If the source star passes near or through a caustic region, a planetary signal will be present even if the entire lens system was otherwise undetectable.



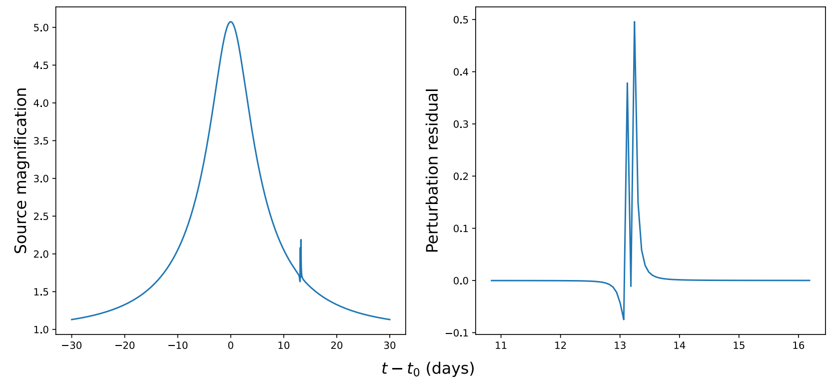
Close planetary caustics to left of Einstein radius

Close central caustic near lens star



Single wide planetary caustic to right of Einstein radius

Central caustic near lens star



This signal may be magnitudes greater than the noise level even in cases where:

- The planet is beyond the snow line
- The planet is of order Earth-mass or below

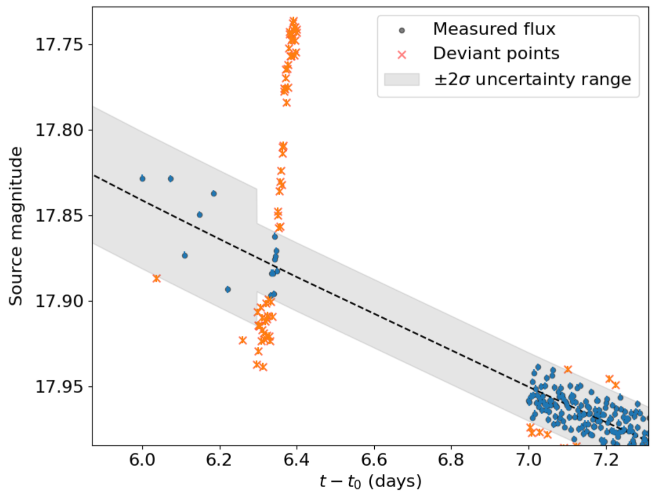
Motivation

Better microlensing search strategies would lead to a deeper understanding of planetary populations, providing data for theoretical work in:

- *Planet formation*
- *Stellar system architecture*
- *Astrobiology and habitable systems*

Correlated noise

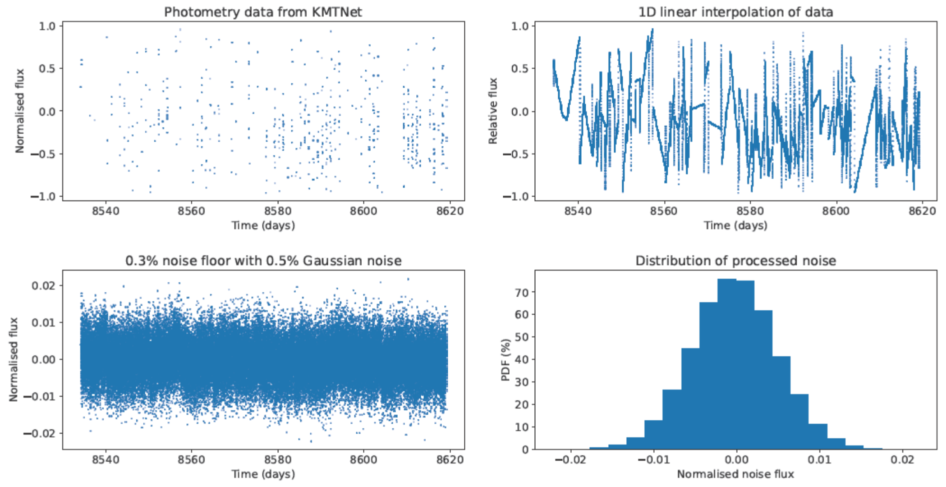
Noise in astronomical observations is rarely entirely random or independent. Atmospheric effects, detector noise, and intrinsic stellar processes can drown out or even mimic low S/N planetary signals in microlensing light curves.



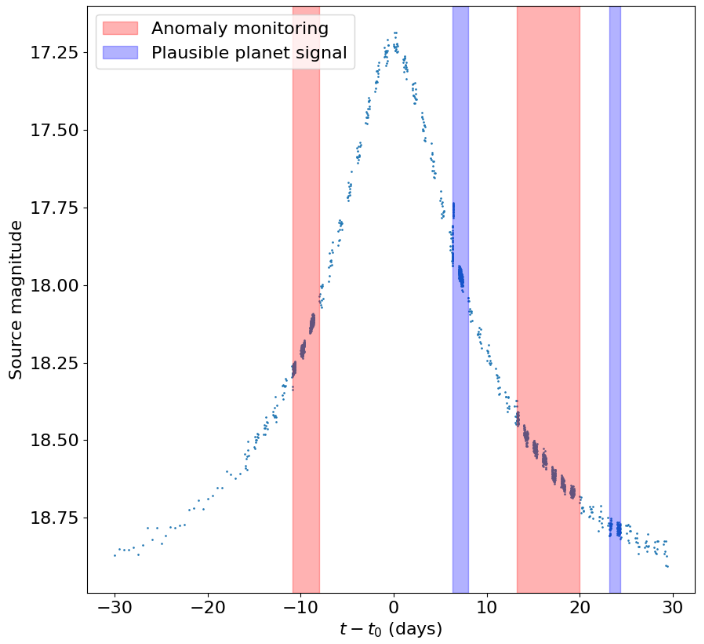
Computational methods

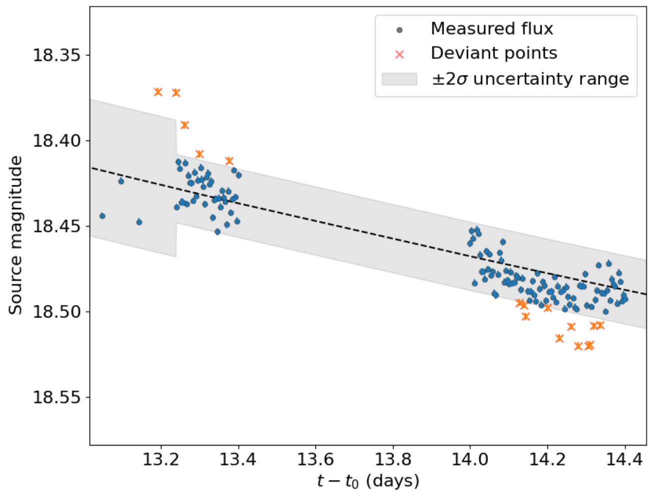
To generate model light curves, I used the MulensModel Python package (1). OGLE and KMTNet microlensing data was treated for use as the correlated noise floor using primarily B-spline interpolation.

Injecting model signals into real microlensing survey data avoids the assumptions of parameterised noise models.



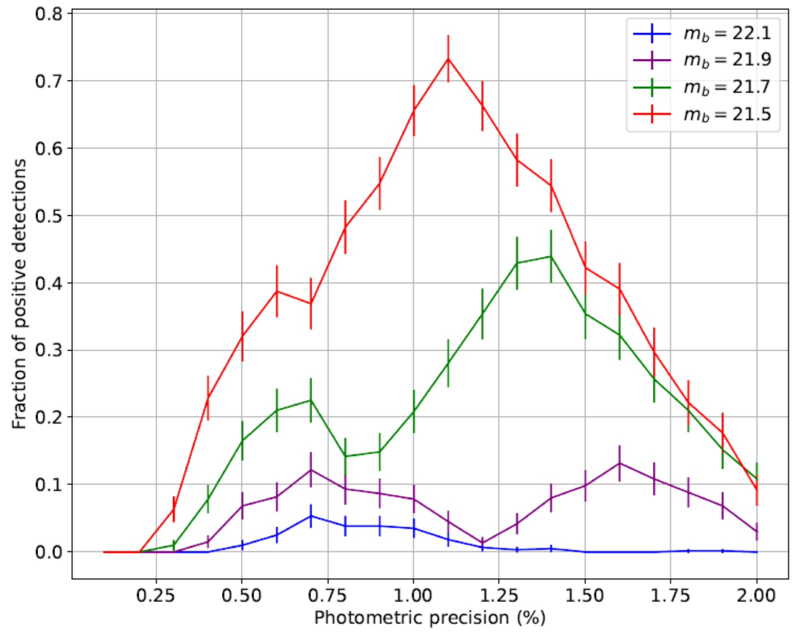
To allow for 'real-time' simulation, the OGLE early warning system (2) was simulated via a control algorithm. Two consecutive points deviating by more than 2-σ on the same side of the model triggered an anomaly monitoring mode. Five points meeting these criteria constituted a planetary signal detection.

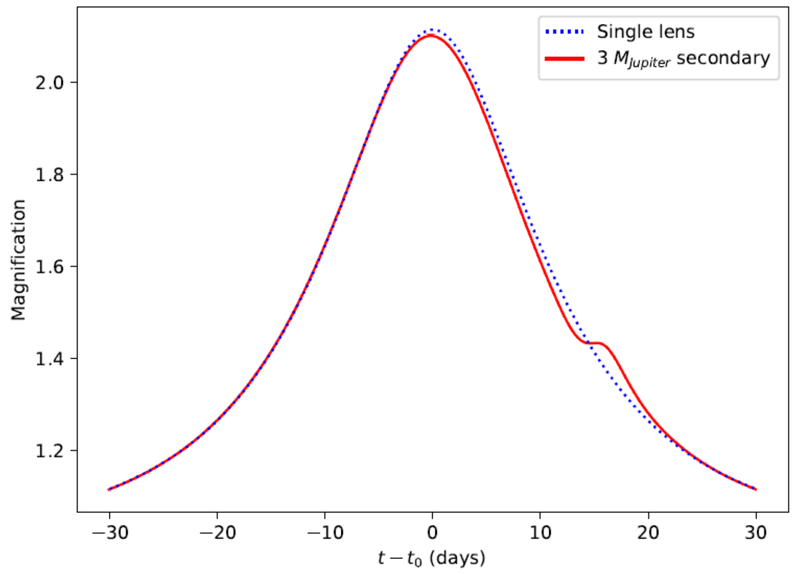




Results

- In cases of limiting magnitude across a wide range of planetary parameters, millimagnitude precision generally led to the highest detection efficiency.
- For lunar mass objects, source size generally dictates higher imaging cadence requirements.
- Results indicate that a variable survey strategy may produce highest detection rates and reduce survey bias.





References

(1) Bozza, V., 2010, MNRAS, 408:2188-200
(2) Udalski, A., et al., 1994, Act. Astron. 44:227-34