

# **Observations of gravitational microlensing events with OSIRIS**

*A Proposal for a Cruise Science Observation*

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# 1 Scientific Justification

If a foreground star happens to pass close to the line-of-sight from the observer to an observed background star, the bending of light due to the gravitational field of the foreground “lens” star yields a characteristic transient brightening of the background “source” star, commonly referred to as “microlensing event”.

Since the geometry depends on the position of the observer, two different observers, e.g. on Earth and on a spacecraft, will in general register symmetric light curves that peak at different times with a different magnitude. Together with the characteristic time-scale of the observed event, the differences between these curves allow measurement of the effective perpendicular velocity of the observer with respect to the lens-source line, which for an observer at rest is a combination of the velocities and distances of source and lens star.

In contrast, from ground-based observations alone one is solely left with the event time-scale in the vast majority of cases, which happens to be a convolution of the lens mass, the relative parallax between lens and source star, and their relative proper motion as seen from the observer, while none of these quantities can be determined individually.

About 5 % of the microlensing events can be expected to involve a configuration where the source star passes over the extended caustic pattern created by a lens binary, either being a binary star or a star with orbiting planet (a planetary system can well be approximated as a single star with just one planet that dominates the microlensing effect). In this case, the light curve reveals the time in which the source star moves by its own angular radius on the sky, relative to the lens star. With the angular radius being determined from the luminosity and colour of the source star, one obtains the absolute value of the relative proper motion between lens and source star. The satellite-based parallax measurement then leads to a direct measurement of the mass of the lens star. We will show below that ~50 events will be observed with OSIRIS, therefore a few events involving a lens binary are expected.

The most exciting anticipated result would be obtained if we are lucky enough to catch a planet of 0.5 to 2  $M_{\text{earth}}$ , in which case our observations would make a crucial difference by providing the mass of the planet with an uncertainty of 20 %, rather than a factor of two with the conventional observing method from Earth only. This estimate, however, depends on the assumed model of the structure of the Milky Way. Moreover, the nature of its parent star would be clarified by determining its mass to the same uncertainty.

To our best knowledge only one microlensing event has been observed from two different vantage points already: OGLE-2005-SMC-001. This was done from Earth and *Spitzer* with a projected separation of 0.2 AU. Rosetta will have a projected distance between 1.6 and 4 AU from Earth (see Figure 1), which is optimal for lensing events toward the Galactic bulge. Because of its Earth-trailing orbit around the Sun *Spitzer* can never observe the bulge during the main microlensing season on Earth, i. e. June - September, making it from the start less suited for the observations proposed here than Rosetta.

## 2 Feasibility

With the rather large field-of-view of  $(2.2 \text{ deg})^2$  provided by OSIRIS, one can cover roughly 3/5 of the area of sky monitored by OGLE (Optical Gravitational Lensing Experiment) with just 8 fields. This sample can be expected to include 50 ongoing microlensing events at any time. If the time available for observations in the bulge is very limited, then the area to be covered can be reduced, producing correspondingly fewer events.

A signal-to-noise ratio higher than 50 was achieved for an observation of asteroid Steins with an apparent brightness of 16.6 (Küppers et al. 2007); this is better than most microlensing observations from the ground. We may therefore assume that the error margins of the photometric measurements carried out with OSIRIS allow theoretical modelling of the event with the required accuracy.

The number of available events critically depends on the limiting magnitude! The sensitivity of the camera - reaching point sources of about 19 mag - is good enough for any event spotted by OGLE or MOA (Microlensing Observations in Astrophysics), but it cannot readily be applied to the dense star fields close to the Galactic Centre. From an image that was taken with OSIRIS at Right Ascension 18h 2m, declination -23d 30m (galactic latitude  $-0.38^\circ$ ), we concluded that source confusion becomes a problem for brightness fainter than 16 mag. We note, however, that it is possible to get light-curves with Rosetta also for blended sources, because the brightness of all nearby stars will be known from ground-based observations and can therefore be subtracted!

The typical duration of a microlensing event is several weeks. About 5-7 points of the light curve are needed. We therefore request 7 observations of the galactic centre region, about equally spaced during a 25 day active checkout or an equivalent time span. One full frame image per pointing will be sufficient. Slightly overlapping fields will be used to check for photometric consistency.

We request seven repetitions of a one-dimensional raster pointing (8 positions along the galactic equator,  $2^\circ$  step size between positions). The total data volume of the 56 full frame images is around 225 MB (assuming lossless compression with a compression ratio of 2). A total duration of 4 hours per raster (30 min. per raster point incl. spacecraft slew overhead) will be sufficient.

The following modifications could be envisioned should either the repeated raster pointing or the data volume not be feasible:

1. If the data volume is not feasible, only a window containing the most interesting microlensing event in each field could be read out. It would be necessary to adjust the time line slightly (startx and stopx command in CRBSetup commands) about 1 – 2 weeks before the first execution. This would provide us with the best microlensing event in each field, but would reduce the expected number of observed events from ~50 to 8.
2. If the repeated raster scan is not feasible, full frame observations of just one field containing the best microlensing event seen by ground-based observers could be taken. This results in a total of 6-10 events. Operationally, seven repetitions of a single staring observation would be required. The total data volume would be approximately 28 MB. It will probably require a slight change of the pointing (up to  $8^\circ$ ) 1 – 2 weeks before the first observation (when the best event will be known from ground-based observations).

We would strongly prefer not to apply one of these modifications because they would

- Reduce the science output by a largely reduced statistics (50 events vs. < 10)
- Require late changes to either the pointing or the timeline

### 3 Time slot for the observations

The following criteria were used to find the best time slot for the observations

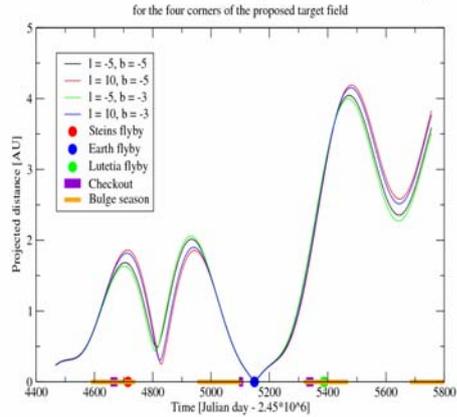
- Spacecraft solar elongation constraints are not violated
- The solar elongation should be above  $90^\circ$  to minimize straylight for OSIRIS
- The projected distance between the Earth and Rosetta should be at least 0.7 AU. This constraint obviously eliminated the Earth flybys and their associated active checkouts.
- The galactic centre must be observable from Earth (for near-simultaneous ground-based observations)
- The tangential velocity (relative to the field) between Earth and Rosetta should be maximized. This constraint is relatively weak (at higher velocities we get additional information) and can be relaxed, if necessary.

Table 1 shows all observation opportunities during the mission. The Sept. 2008 (Steins flyby), May 2009, Sept. 2010 and May 2011 opportunities are somewhat preferred over the others because of the higher velocity, but any of the dates in Table 1 would be acceptable.

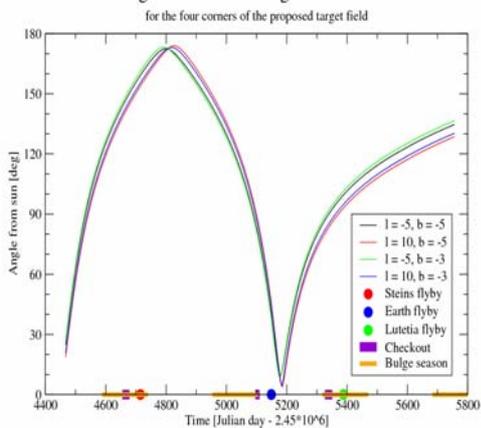
*Table 1: Timeslots for possible observations of gravitational microlensing with OSIRIS. The first column lists the months that fulfil all requirements, with Rosetta mission events in parentheses. The second column lists the projected geocentric distance, the third column the tangential velocity between Earth and Rosetta (relative to the galactic centre), and the last column the solar elongation of the galactic centre as seen from Rosetta*

Proposed time	Distance [AU]	Velocity [km/s]	Solar Elongation [deg.]
2008-Jul (Active checkout PC8)	1.6	3	150
2008-Sep (Steins flyby)	1.7	7	160
2009-May (-)	1.9	8	150
2010-Jun (after active checkout PC12)	2.1	3	90
2010-Jul (Lutetia flyby)	3.0	5	100
2010-Sep (-)	4.0	8	110
2011-May (-)	2.8	7	130

Distance of Rosetta from Earth, projected into the observer plane



Angular distance of target from the sun



Tangential relative velocity, projected into the observer plane

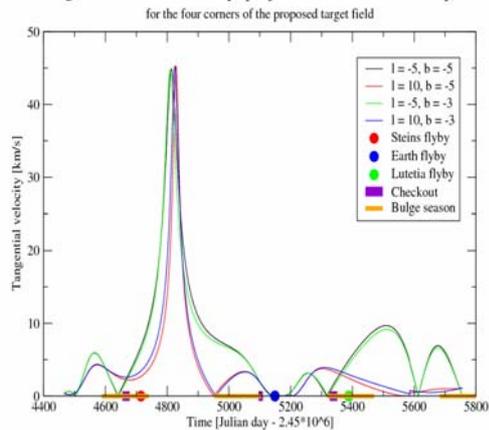


Figure 1 Relevant geometry parameters during the Rosetta cruise phase. The yellow bar (Bulge season) shows when the galactic centre region is observable from Earth. The four curves are for the corners of the fields that will be covered by OSIRIS.

## 4 Team

M. Dominik is a Royal Society University Research Fellow at the University of St Andrews and specialised on the interpretation of light-curves from microlensing events. He will determine the properties of source and lens from the photometric points obtained with OSIRIS.

M. Burgdorf is Project Scientist for a network of robotic telescopes that has been used extensively for the observation of microlensing events in the last few years. If the events seen by Rosetta are not observed often enough by OGLE or MOA, for example to characterize an anomaly, he will try to make additional time available on the Liverpool and Faulkes Telescopes by special request for a Target of Opportunity. In this case he will also reduce the data and complement the existing light-curves with additional photometric points.

B. Grieger had worked on gravitational lensing, particularly on the parallax effect, and is currently liaison scientist for the AMIE camera of the SMART-1 spacecraft. He will provide the geometric information (relevant components of distance and relative velocity) for the observations and support the retrieval of source and lens properties.

M. Küppers has extensive experience with the OSIRIS cameras and will take care of the pipeline reduction of the data and the subsequent point source photometry.

## 5 References

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