Extragalactic Exoplanets – Higher Cadence Observations of SMC

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November 2018

Abstract

We propose to increase LSST cadence for the Small Magellanic Cloud which will enable finding dozens of microlensing events annually and potentially, a few planetary events over the course of the survey. These would be the first extragalactic exoplanets ever discovered and will give us a unique constraint on the planet formation and evolution under different environments. We discuss what changes in the LSST observing strategy are required. Presented analysis takes into account an extensive photometric follow-up program.

1 White Paper Information

Please contact Radek Poleski, `poleski.1@osu.edu`, with any questions about this white paper.

1. **Science Category:** Exploring the Changing Sky
2. **Survey Type Category:** mini survey
3. **Observing Strategy Category:** an integrated program with science that hinges on the combination of pointing and detailed observing strategy (e.g., search for variable stars in the LMC/SMC).

2 Scientific Motivation

The deep understanding of planet formation and evolution requires studying planets in a wide range of environments. Currently known exoplanets are situated in the Milky Way and most of them are found close to the Sun because of higher sensitivity of transit and radial velocity techniques for brighter (hence nearby) host stars. Discovering extragalactic exoplanets is even more challenging than finding the Milky Way planets because of larger distances. High cadence observations of the Small Magellanic Cloud (SMC) by LSST will allow finding extragalactic exoplanets using gravitational microlensing technique.

Microlensing is sensitive to the lens mass, not light, hence, allows finding very faint objects. Microlensing searches of exoplanets toward M31 have not yet found planets, mainly due too small number of events (Ingrosso et al. 2009; Calchi Novati et al. 2014; Lee et al. 2015). The other possibility of finding extragalacitc exoplanets with LSST — transit method applied to LMC — requires a dedicated Deep-drilling field (which is larger effort than proposed here) and candidate transit will be very difficult to confirm using even the next generation 30-m telescopes (Lund et al. 2015; Jacklin et al. 2015). In Mróz & Poleski (2018) we proposed to observe SMC with higher cadence, so that microlensing events can be found early and detection of planetary signatures in these events could be done using LSST data (if cadence is high enough) or using photometric follow-up observations from smaller telescopes. SMC is elongated along the line-of-sight and the microlensing events observed toward SMC are almost exclusively self-lensing, i.e., both the lens and the source are in SMC (Sahu & Sahu 1998; Wyrzykowski et al. 2011).

There are thousands of microlensing events discovered so far toward the Galactic bulge. Among these events, about 70 planetary events have already been published and more are being analyzed. The planetary companion to the microlensing host star shows its presence via short-lasting anomaly (Mao & Paczyński 1991; Gould & Loeb 1992) ontop of a point-source point-lens event (Paczyński 1986). The length of the anomaly is on the order of Einstein timescale of the host event multiplied by a square root of the mass ratio. Galactic bulge microlensing events have typical Einstein timescales of ≈ 20 days, hence, giant planets produce signals that last on the order of 1 day. Current Galactic bulge microlensing surveys (mainly KMT, OGLE-IV, and MOA-II, but also Wise and UKIRT) have cadence of up to 15-20 minutes which allows robust detection of gas- and ice-giant exoplanets using survey data only (e.g., Yee et al. 2012; Poleski et al. 2014; Shvartzvald et al. 2016). The alternative approach is to follow-up events found by surveys with a network of follow-up telescopes which can have small field-of-view cameras and, in many cases, smaller apertures. Follow-up observations are particularly useful for high-magnification events (peak magnification $\gtrsim 100$), which both have higher planet detection efficiency and can be recognized in advance (Griest & Safizadeh 1998; Gould et al. 2010). Median Einstein timescale for SMC events is ≈ 3 times longer than Galactic bulge events which leads to a longer timescales of anomalies. One-hour cadence in the SMC should be enough to find high mass-ratio planets efficiently.

The LSST telescope and camera have unique capability to study microlensing events toward SMC. The photometry from the on-going microlensing surveys is not deep enough to allow finding large enough number of SMC events. LSST field of view is large enough to cover almost whole region of interest in just a single pointing.

It is possible that planet frequency in the SMC is lower than in the Solar neighborhood. The correlation between stellar metallicity and planet frequency is well known (Fischer & Valenti 2005; Wang & Fischer 2015), but without performing proposed experiment we cannot be sure if it applies to smaller-mass hosts and wider orbit planets, which are probed by microlensing. Below we present expected yield that assumes fiducial planet frequency rate and request the experiment with yield of a few planets so that, scientifically interesting upper limits on the planet frequency can be derived if no planet is detected.

3 Technical Description

3.1 High-level description

XXX

3.2 Footprint – pointings, regions and/or constraints

The large field of view of LSST allows covering almost the entire sky-region of interest in a single pointing. It would be best to center the pointing at R.A. = $0^{\mathrm{h}}58^{\mathrm{m}}$, Dec. = $-73°00'$.

3.3 Image quality

Constraints on the image quality (seeing).

XXX

3.4 Individual image depth and/or sky brightness

XXX

3.5 Co-added image depth and/or total number of visits

XXX

3.6 Number of visits within a night

XXX

3.7 Distribution of visits over time

XXX

3.8 Filter choice

XXX

3.9 Exposure constraints

XXX

3.10 Other constraints

XXX

3.11 Estimated time requirement

XXX - table below

3.12 Technical trades

XXX

4 Performance Evaluation

XXX

In our simulations of detection efficiency, we have included intensive photometric follow-up observations. The best follow-up would be uniform and 24-hour coverage of every on-going microlensing event with high photometric accuracy. SMC lies close to the South celestial pole and there is a limited number of observatories with good astronomical climate that can observe SMC. There is a large number of telescopes located in Chile, but they cover a narrow range of longitudes. Outside Chile, the only observatories with large aperture telescopes are Siding Spring Observatory (Australia) and South African Astronomical Observatory (South Africa). The number of clear nights and seeing are better for Chilean observatories. Taking all these aspects into account, we divide follow-up observations into Chilean and non-Chilean. For Chilean observatories, we assume observations are taken when the SMC center is at the altitude $> 30^{\circ}$ and Sun is at the altitude $< -15^{\circ}$ as seen from Cerro Pachón. We select nights for which these conditions are fulfilled for at least 30 min. and assume uniform cadence of 1 h. To simulate the impact of clouds, we remove epochs for which there is no LSST observations (in any field) 1 h prior or after considered follow-up epoch. There are in

Properties	Importance
Image quality	
Sky brightness	
Individual image depth	
Co-added image depth	
Number of exposures in a visit	
Number of visits (in a night)	
Total number of visits	
Time between visits (in a night)	
Time between visits (between nights)	
Long-term gaps between visits	
Other (please add other constraints as needed)	

Table 1: **Constraint Rankings:** Summary of the relative importance of various survey strategy constraints. Please rank the importance of each of these considerations, from 1=very important, 2=somewhat important, 3=not important. If a given constraint depends on other parameters in the table, but these other parameters are not important in themselves, please only mark the final constraint as important. For example, individual image depth depends on image quality, sky brightness, and number of exposures in a visit; if your science depends on the individual image depth but not directly on the other parameters, individual image depth would be '1' and the other parameters could be marked as '3', giving us the most flexibility when determining the composition of a visit, for example.

total ten optical telescopes in Chile that have aperture of 4 m or larger. We assume that follow-up observations will be conducted using a $\approx$ 4-m aperture telescope and the same exposure time as for LSST. The same accuracy should be achievable using longer (and still reasonable) exposure times on a 2-m class telescopes. To account for airmass, seeing, and sky transparency on photometric accuracy, we use the accuracy of the closest LSST observation with additional correction of $\delta m_5 = -0.53$ mag added to 5σ depth of LSST (for this we use the i-band observations in a few fields close to SMC), see Ivezić et al. (2018).

The potential follow-up telescopes outside Chile have smaller apertures and poorer weather conditions. We simulate these additional follow-up epochs assuming there is a single epoch per night and it is shifted by 12 h relative to observations in Chile. Additionally, we select half of the nights only. To obtain photometric accuracy of these data, we follow the same procedure as for Chilean follow-up observations.

For each event, the follow-up observations are assumed to start 12 h after the event detection and end $3t_{\mathrm{E}}$ after the event peaks.

The above strategy leads to on average 1400 follow-up epochs for Chilean observatories over 10-month long season in `baseline_2018a` run. For non-Chilean observatories there are on average 120 follow-up epochs per season.

(Suzuki et al. 2016), (Udalski et al. 2018)

(Marigo et al. 2017)

5 Special Data Processing

Describe any data processing requirements beyond the standard LSST Data Management pipelines and how these will be achieved.

No special data processing is needed.

6 References

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