# Microlensing Returns from LSST

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# Large Synoptic Survey Telescope

Next-generation, ground-based astronomy project

Currently under construction at Cerro Pachón, north-central Chile

Key dates:

- Engineering first light 2019
- Science first light 2021
- Full ten-year survey expected to commence January, 2022

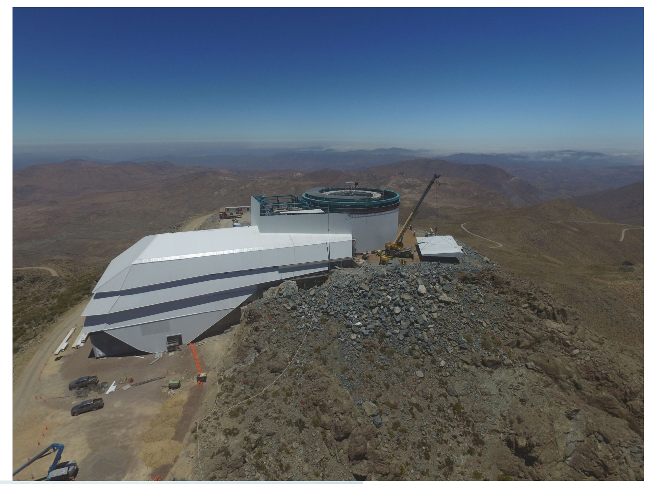


*Image credit: LSSTC (Top); SLAC (Left)*

# Large Synoptic Survey Telescope

Unique three mirror design:

- 8.4-m primary;
- 3.4-m secondary;
- 5.0-m tertiary

3.2 Gigapixel CCD camera

64 cm diameter flat focal plane @ f/1.23

3.5° field-of-view; 6.5-m mean effective aperture

319.5 $m^2deg^2$ etendue

Pixel pitch: 10μm; 0.2″

Median seeing: ~0.7″

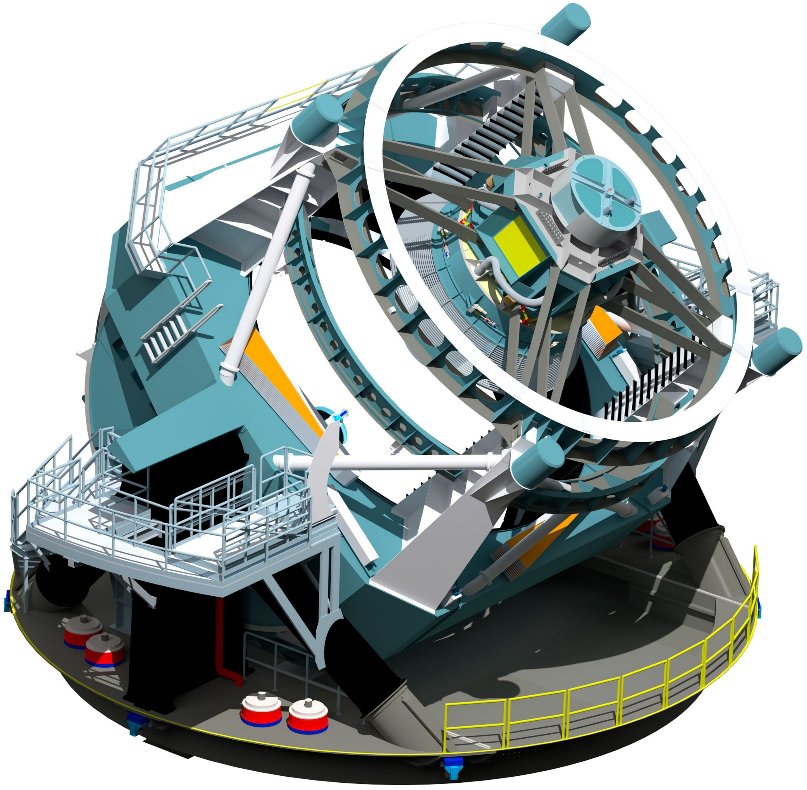


*Image credit: LSSTC*

# Large Synoptic Survey Telescope

*Image the entire visible sky every three nights for ten years*

Observations in six-passbands:

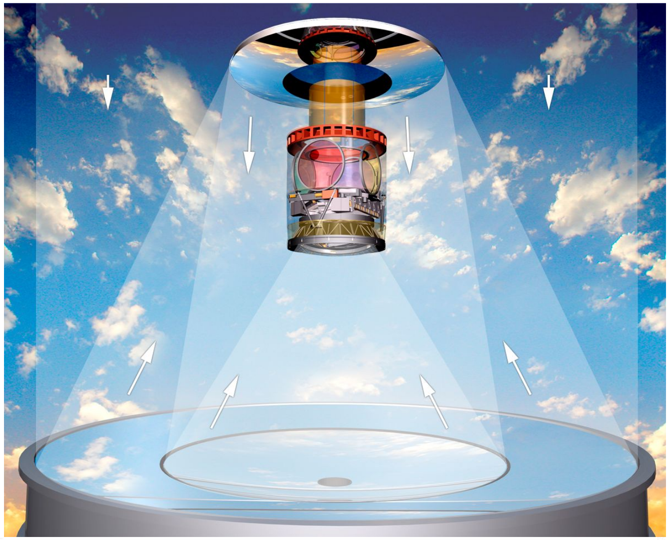
UV, optical, near-IR

Single visit limiting magnitudes:

u = 23.9; g = 25.0; r = 24.7; i = 24.0; z = 23.3; y = 22.1 (co-added r =27.5)

Near real-time alerts (< 60 seconds latency)

~10 000 alerts per visit ≅ 10 million events per night; ~30 TBs of data



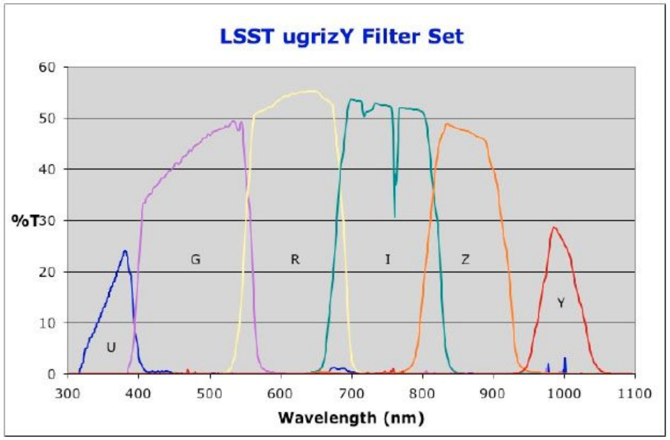



*Image credits: LSSTC*

# Observing Strategy

Each visit consists of two 15 sec exposures, back-to-back, same filter

5.5 million images from 2.75 million pointings, over ~25 000 $deg^2$, in 10 years

Main, Wide-Fast-Deep, survey: ~18 000 $deg^2$, ~800 visits

North Ecliptic Spur

Five Deep Drilling fields: ~10 000 visits

Mini surveys: e.g. Galactic plane, SCP, overlap with WFIRST fields

*How would these pointings best be allocated?*

# Microlensing: LSST versus current surveys

$$t_E = \frac{\theta_E}{\mu_{rel}}$$

Typical bulge event, timescale ~ 20 days; planetary deviations ~ hours

| | | | |
|---|---|---|---|
| OGLE-IV | 1.4 $deg^2$ (85 GB fields) | > 10 mins | I < 21 (GB) |
| MOA-II | 2.2 $deg^2$ (22 GB fields) | > 15 mins | |
| KMTNet | 4.0 $deg^2$ (27 GB fields) | > 8 mins | |
| LSST | 9.6 $deg^2$ | 0.33-0.5/night @ WFD | I < 24 |

i.e. Currently: ~100 $deg^2$ (~10 LSST fields); ~10/night

LSST is fast – but not fast enough on its own

*Let's assume some type of extended Galactic plane survey, but $n_{obs} < \mu_{lens}$/night*

# Microlensing: what can we do instead?

*Wide-Deep = Faint objects over large region of sky*

**Wide-binaries**

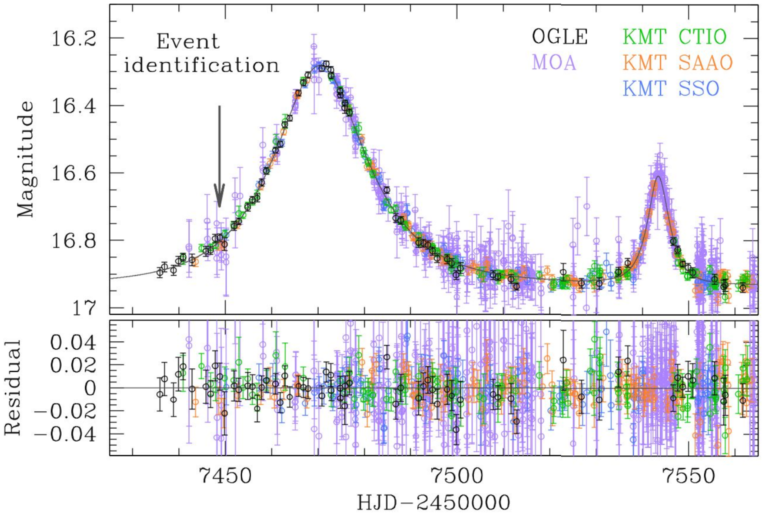
Two (or more) regions of magnification separated by return to baseline mag.

Repeating signal weakens for lower mass/more widely separated outer lens

LSST offers deep images, low PSF:

> Use high quality photometry to push detection thresholds to lower mag and extend parameter space

Synergy with WFIRST: extend baseline with LSST observations




*OGLE-2016-BLG-0263Lb (Han, et al., 2017)*

*$M_p = 4.1M_J$; a = 6.5 AU; $t_E$ = 15.3 days;*

*73 days, peak-to-peak*

# Microlensing: what can we do instead?

*Wide-Deep = Faint objects over large region of sky*

**Mesolensing**

High probability lensing at low optical depth (e.g. towards M31, Local Group, etc.)

Event rate, $\Gamma(\theta_E, \mu_{rel}, N_*, F)$; $\theta_E(M_L, D_L)$

$\theta_E$ and $\mu_{rel}$ increase as $D_L$ decreases:

Nearby objects (< 1 kpc) sweep out larger region of sky sensitive to lensing

Dwarf stars, stellar remnants, free-floating planets?

$\sim 10^2$ NS, $\sim 10^3$ dwarf star events? (*Di Stefano, 2008*)

More ways to verify lens for nearby events

# Microlensing: what can we do instead?

**Other opportunities**

Intermediate mass black holes

Planetary microlensing in Deep Drilling Fields (e.g. GB and/or MCs)

Overlap with WFIRST fields will allow parallax measurements to be made

**Rolling cadence?**

Baseline observations to constrain long timescale events

Roll up $n_{obs}$ for a limited-time, high(er) cadence survey in the plane

Less demanding than extending WFD; potential to satisfy no. of science cases

*Ultimately: cadence determines mass range probed by LSST*

# Microlensing: how do we measure the science cases?

**Operations Simulator (OpSim)**

Simulates field selection and image acquisition for full ten-year survey:

- Optimises based on science requirements, observing history, and simulated environmental conditions

- Includes sophisticated model of telescope, camera and dome; detailed environment model with real historical weather data

Outputs ten-year time series complete with pointings and image properties:

- e.g. RA-dec, filter, seeing, airmass, sky brightness, position of Sun and Moon

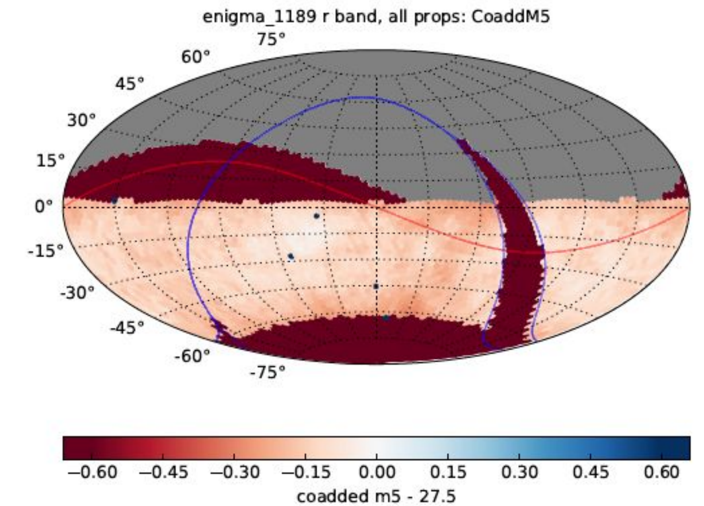
*Allows robust comparison of competing observing strategies*

# Microlensing: how do we measure the science cases?

**Metrics Analysis Framework (MAF)**

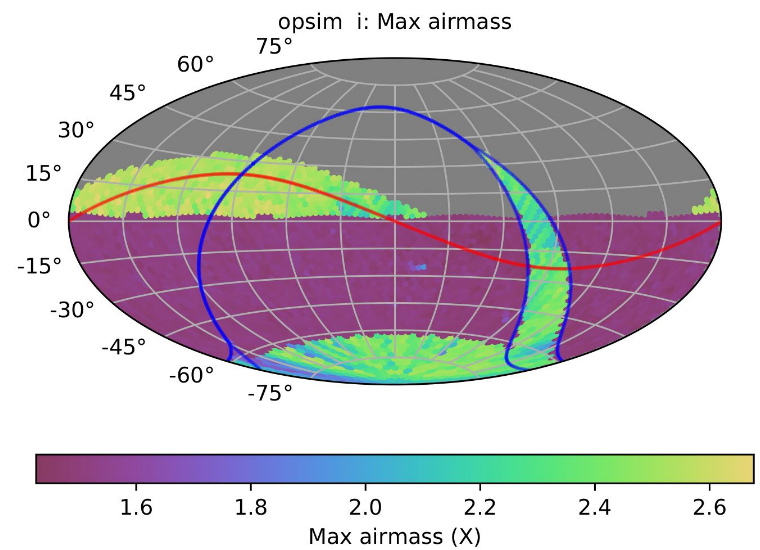
Python-based framework of software tools used to analyse OpSim metadata

Easily customisable and extendable



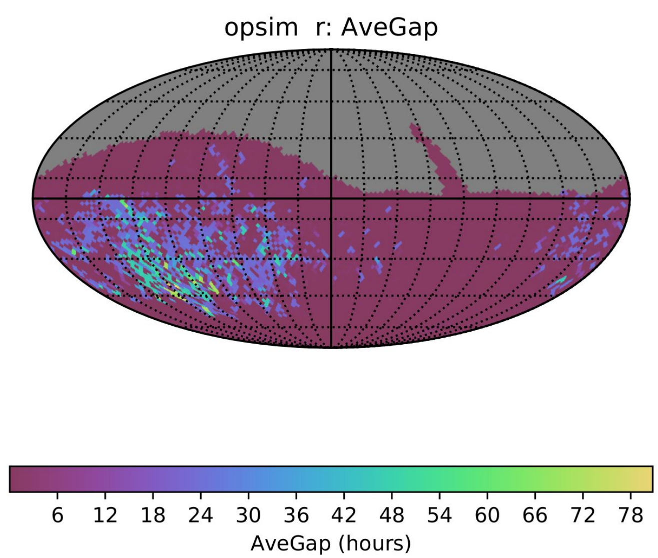

Slicers: split dataset into smaller subsets

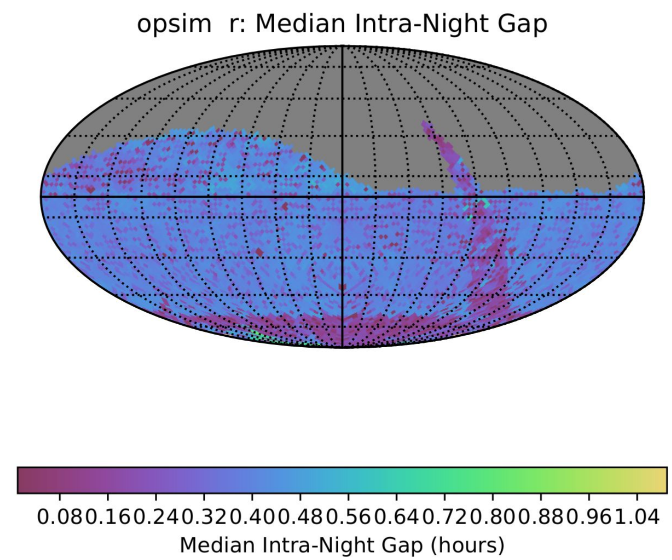
Metrics: returns some value for each slice

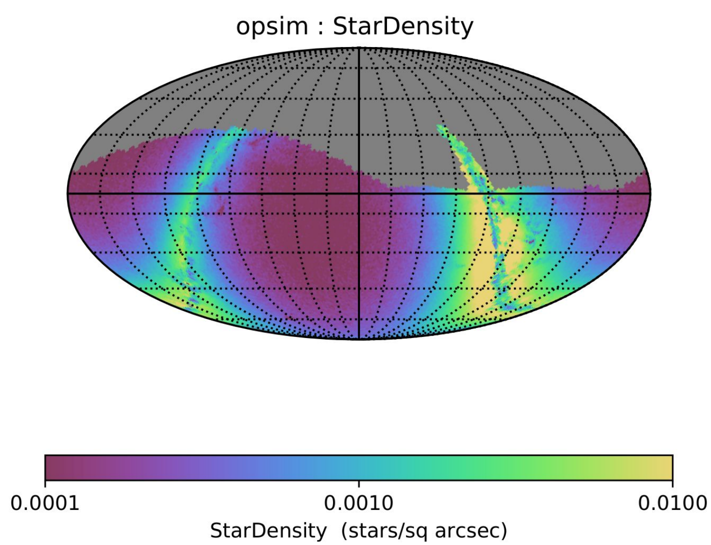


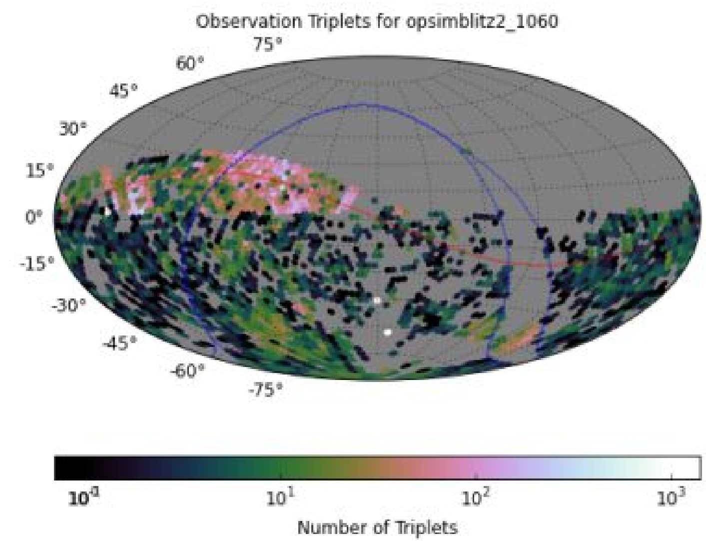

Can slice by field, sky position, obs. with specific characteristics, etc.

# Microlensing: useful metrics



# Microlensing: how do we measure the science cases?

*Background*

*Lensing population*

*Observation window*

*Figure of merit*

# Microlensing: going forward

**Special Project for Milky Way and Microlensing Science**

White Paper currently being drafted (coordinated by Rachel Street)

Describe science drivers qualitatively

Use metrics to characterise suitability of competing observing strategies for the proposed science cases (in progress)

Proposals due October 2018 – happy to hear other suggestions!

Final recommendations on observing strategy late 2020

*Overall aim: Inform final observing strategy to maximise microlensing science returns from LSST*

Thank you