Quasar Microlensing with the LSST

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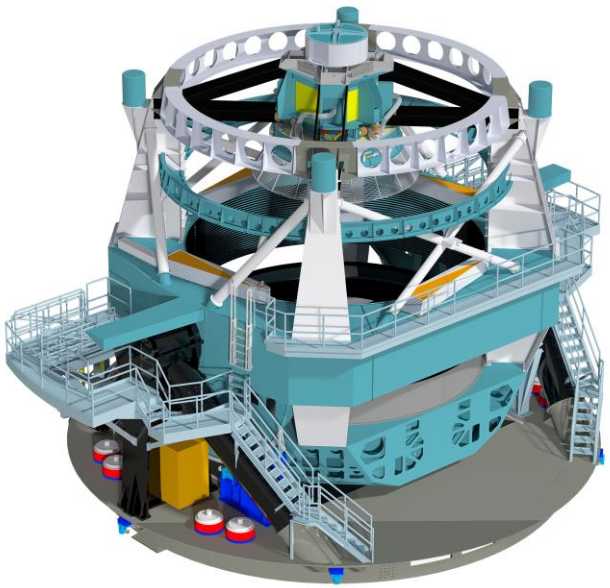
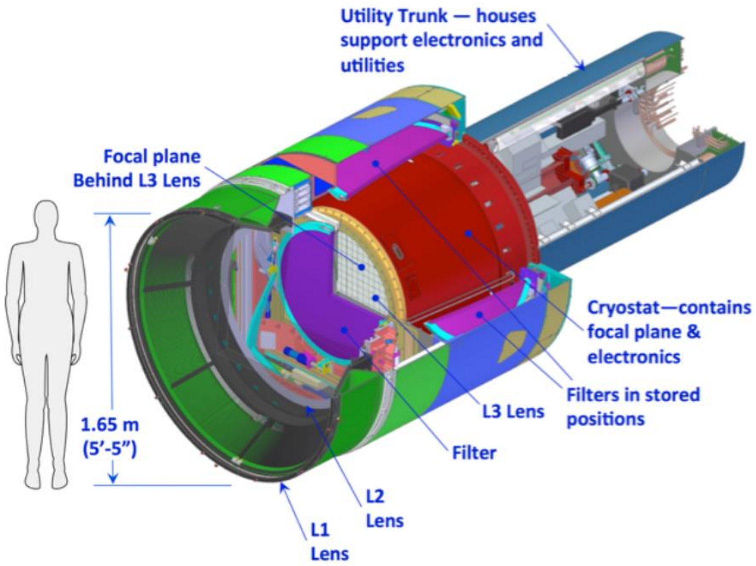
Fondecyt
Fondo Nacional de Desarrollo Científico y Tecnológico
CONICYT
GOBIERNO DE CHILE

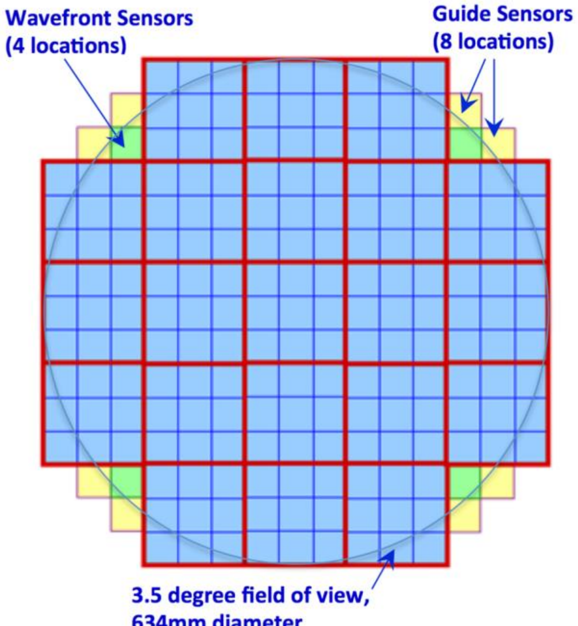
MILLENNIUM INSTITUTE OF ASTROPHYSICS

LSST Basics

- Optical and NIR survey from Cerro Pachon
- 8m (6.7 effective) telescope
- 9.6 square degrees fov camera
- 3.2 Gpix (189x16Mpix)
- ugrizy filter system
- 10 years







Science Goals and Constraints

- The Nature of Dark Matter and Understanding Dark Energy
- Cataloging the Solar System
- Exploring the Changing Sky
- Milky Way Structure and Formation

- Single visit depth
- Image quality
- Photometric accuracy
- Astrometric accuracy
- Optimal exposure time
- The filter complement
- The distribution of revisit times, including survey lifetime
- Coadded survey depth
- Distribution of visits on the sky and total sky coverage
- The distribution of visits per filter
- Data processing and access

Universal Cadence – Deep Wide Fast

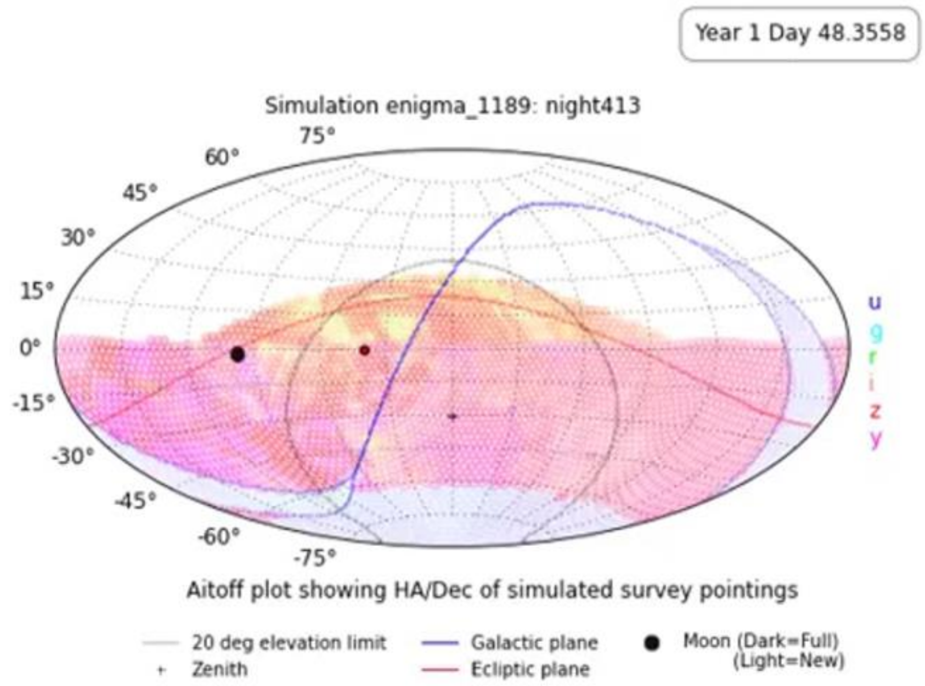
- 2 x 15 second exposures
- Optimizes the amount of sky covered per night
- AM < 1.4
- Uniform coverage
- 18,000 square degrees
- 85% of the available observing time

Special Surveys (15% remaining)

- Galactic Plane (GP)
  - Broader wedge close to the Galactic Center (constant stellar density)
  - Reduced number of observations due to confusion in stacked data
- South Celestial Pole (SCP)
  - 1.4 AM limit does not allow the WFD to go there missing the Magellanic Clouds
  - Shallow depth
- North Ecliptic Spur (NES)
  - Complete the ecliptic
  - Higher Airmass
  - No u band
- Deep Drilling Fields
  - Single pointings
  - 5 times more exposures
  - Magnitude fainter
  - Better sampling

Operations Simulator

- "The Operations Simulator (OpSim) is an application that simulates the field selection and image acquisition process of the LSST over the 10-year life of the planned survey."
- Combines:
  - Science requirements
  - Telescope mechanics
  - Environmental conditions
  - Etc.
- Delivers:
  - Field selection
  - Image Acquisition Process



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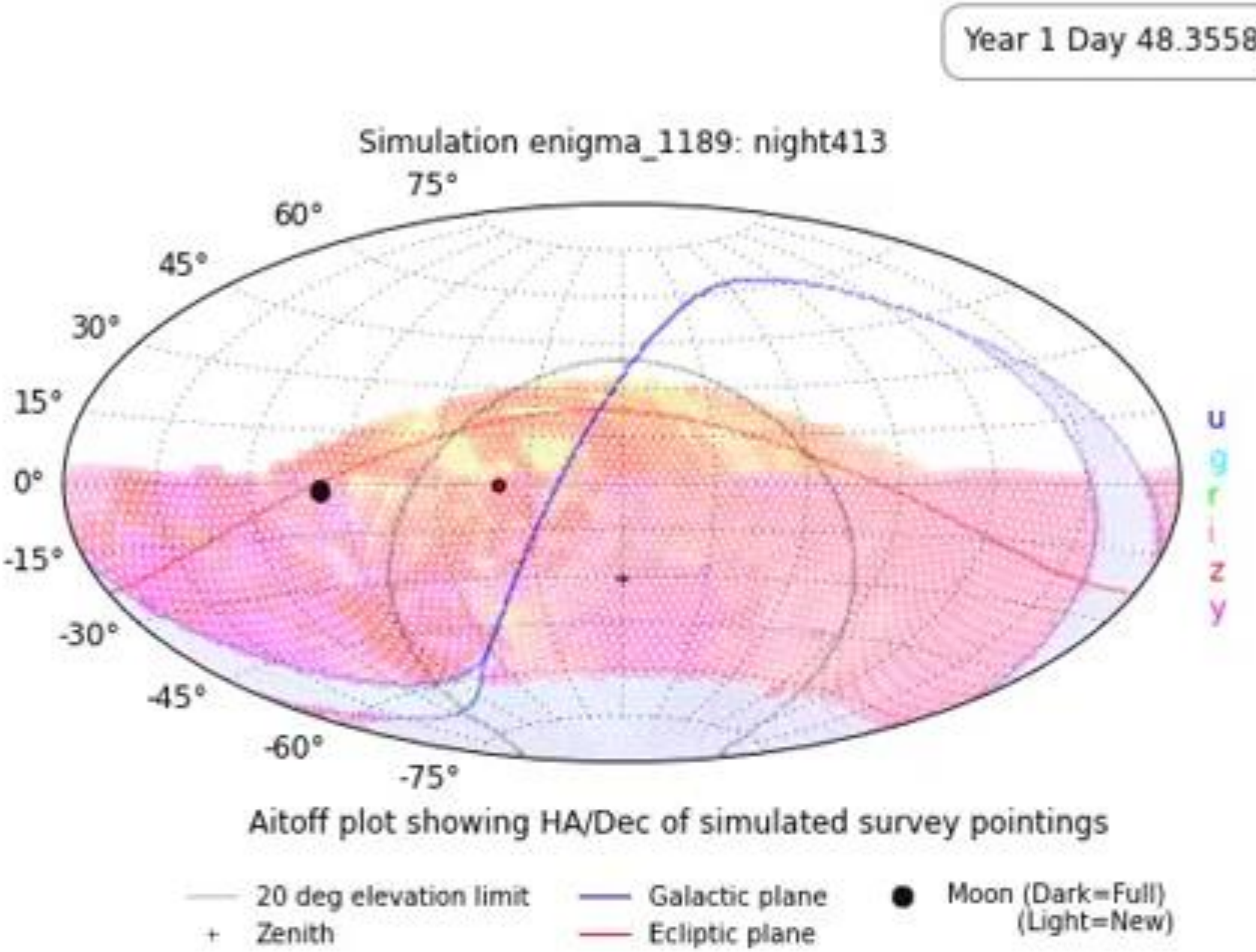
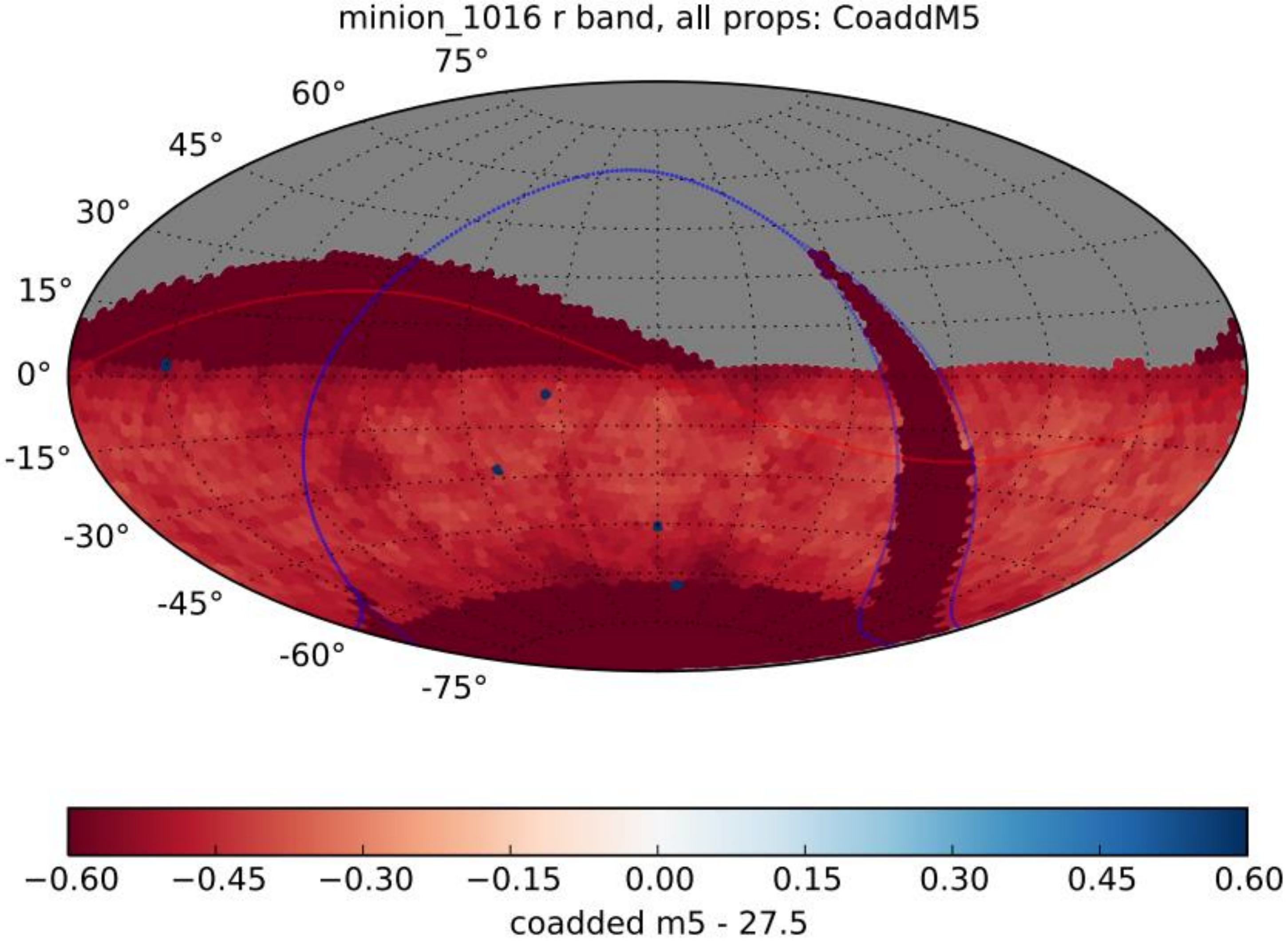


Current Baseline Observing Strategy (minion_1016)

- 2,447,931 Visits
- Time spent: 85.1% → WFD; 6.5% → NES; 1.7% → GP; 2.2% → SCP; 4.5% → DDFs
- Median number of visits per night → 816
- Median slew time → 4.8 sec
- Total exptime → 73.4 Msec (efficiency → 73%)
- Median coadded depth → 25.4, 27.0, 27.1, 26.4, 25.2, 24.4 (WFD)
- Median FWHM → 0.77 (r band)

Minion_1016, Metrics analisys (MAF)



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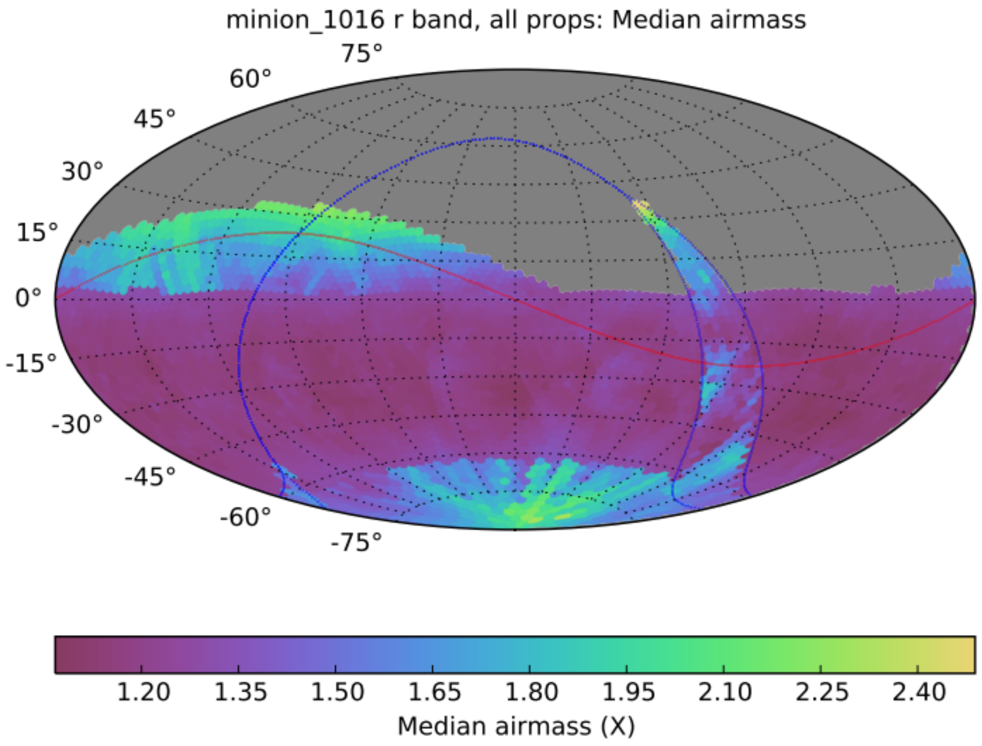

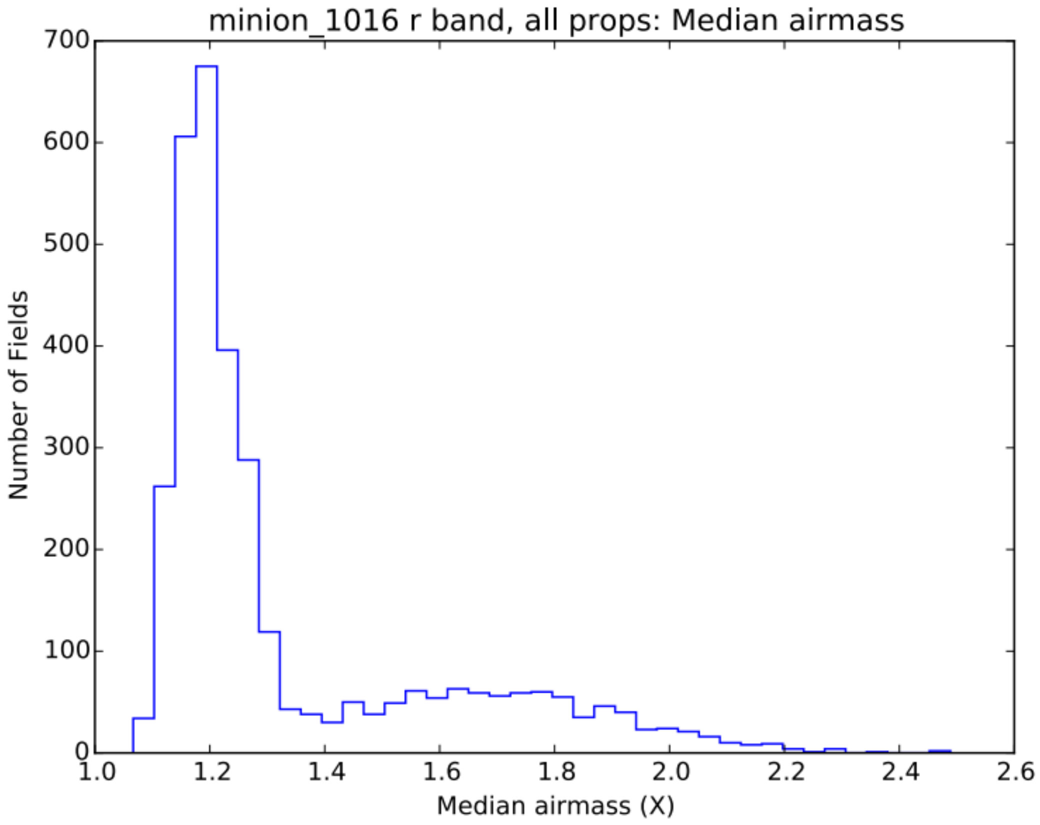

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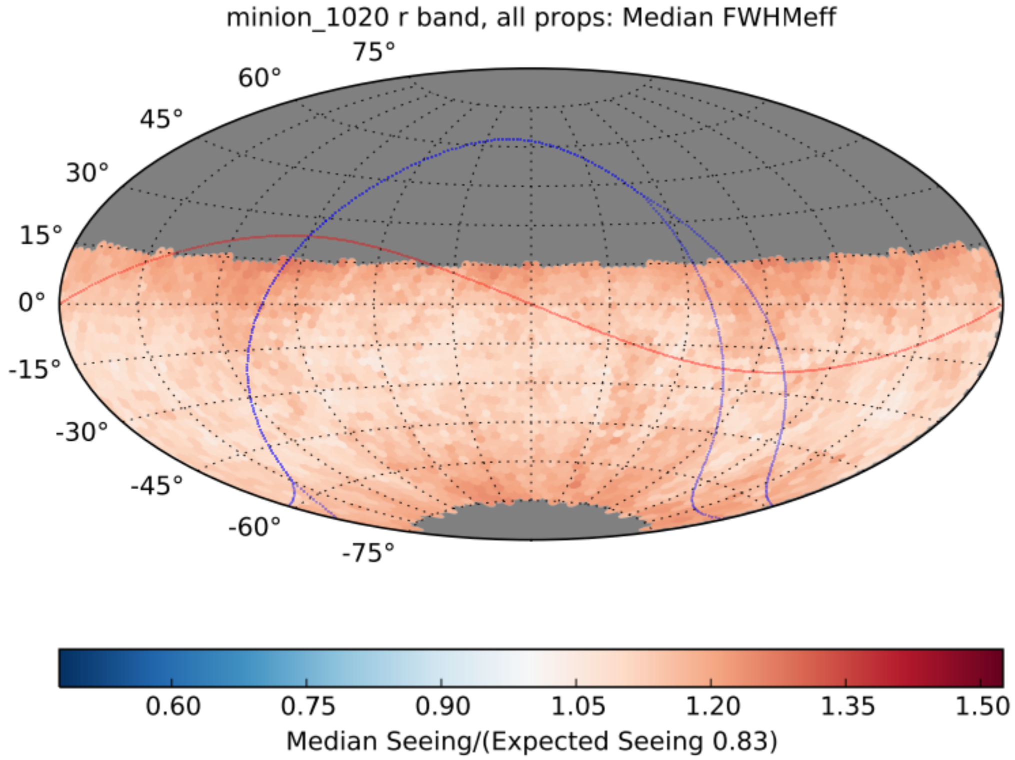
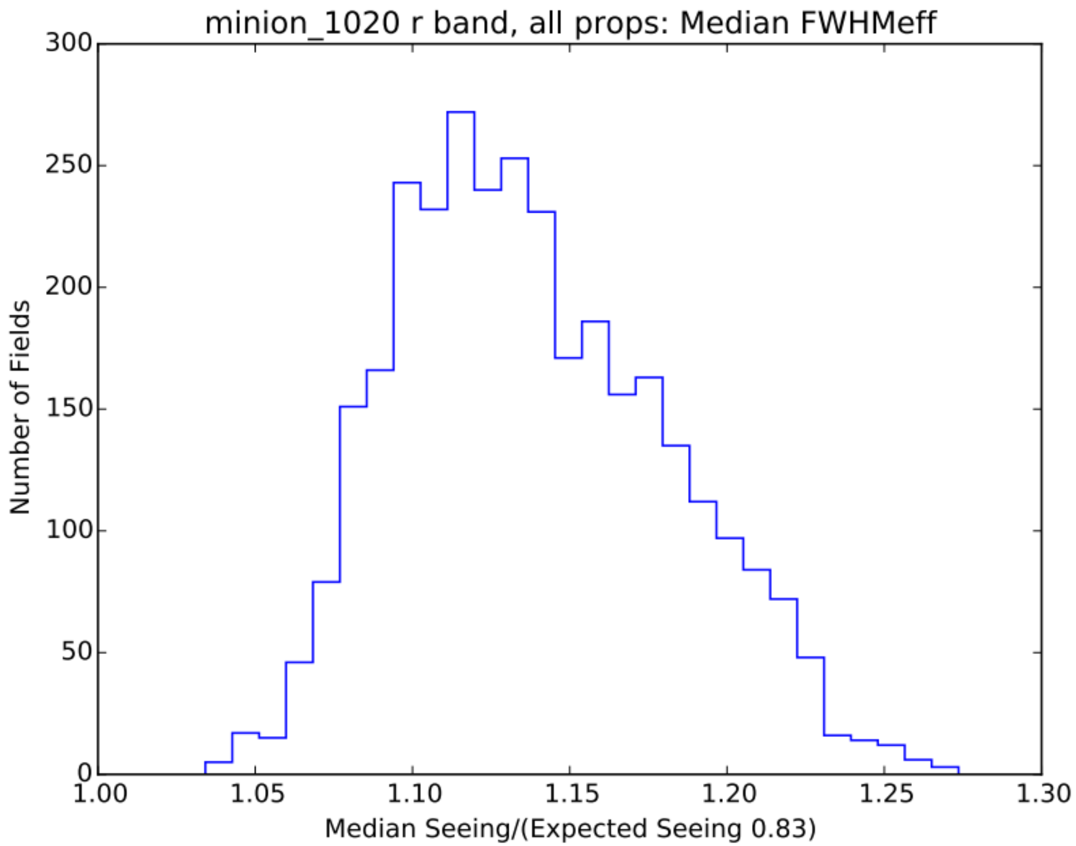
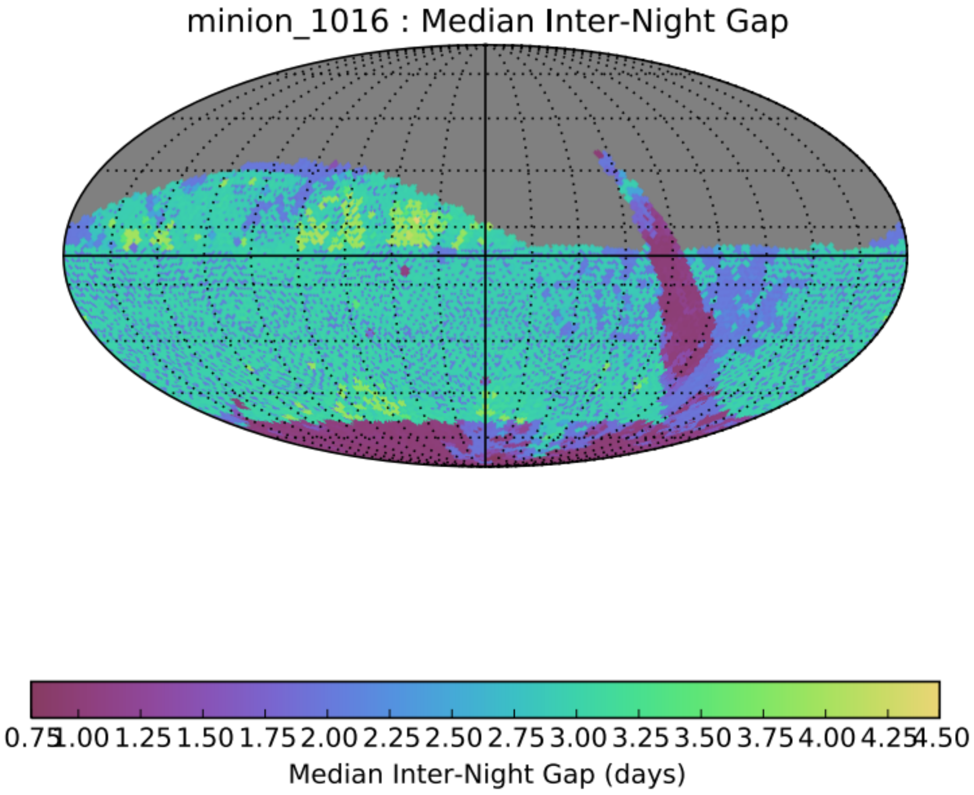
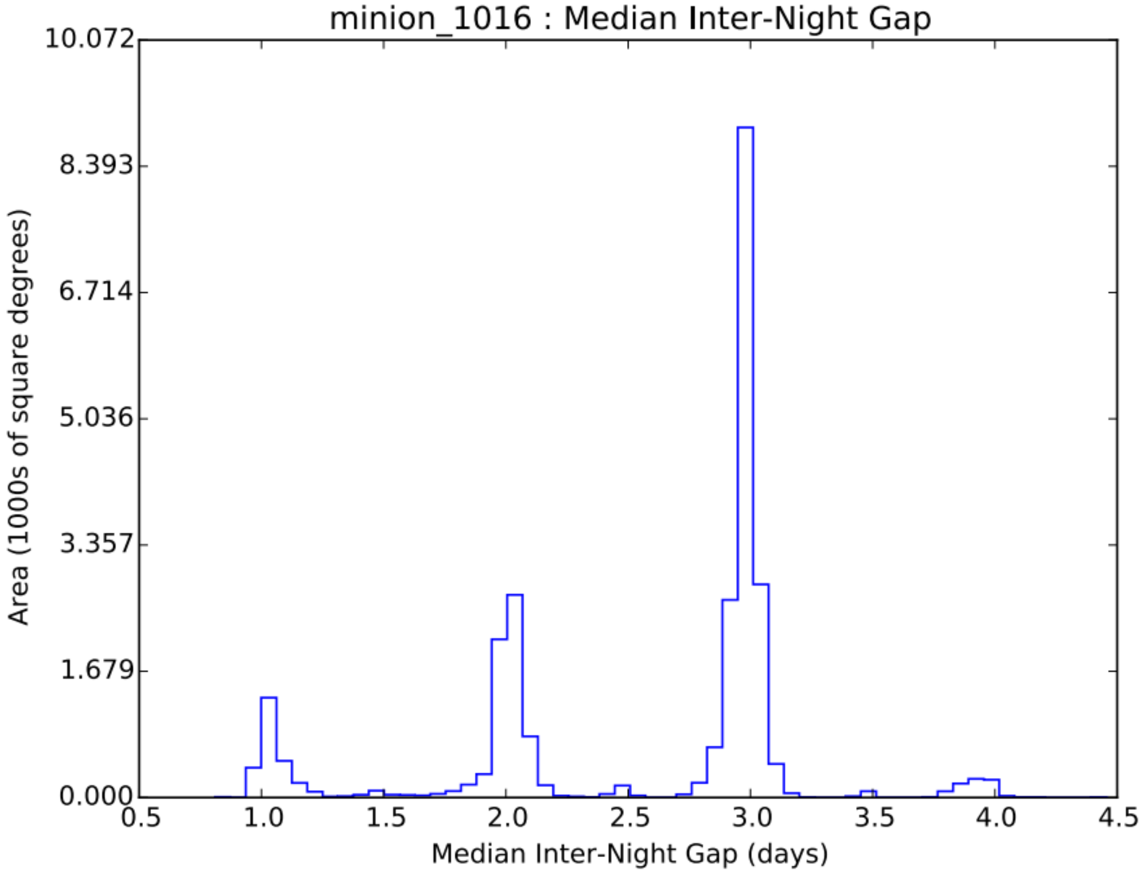


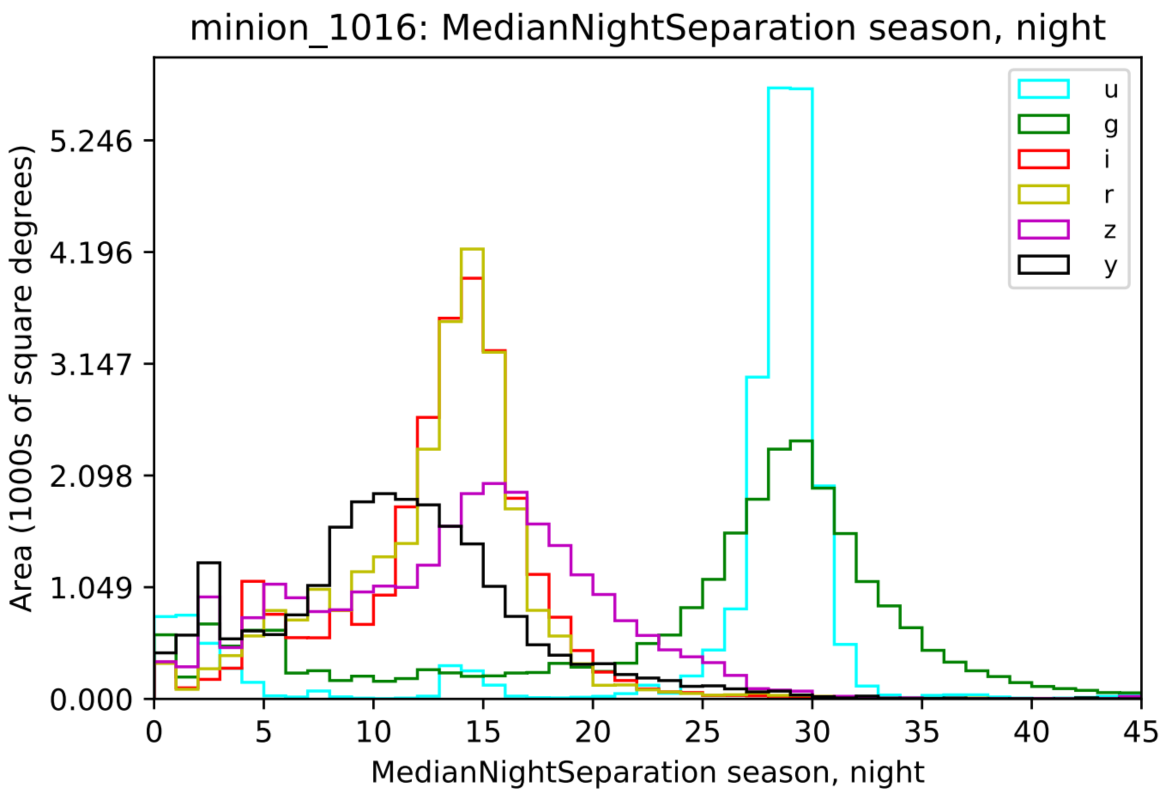


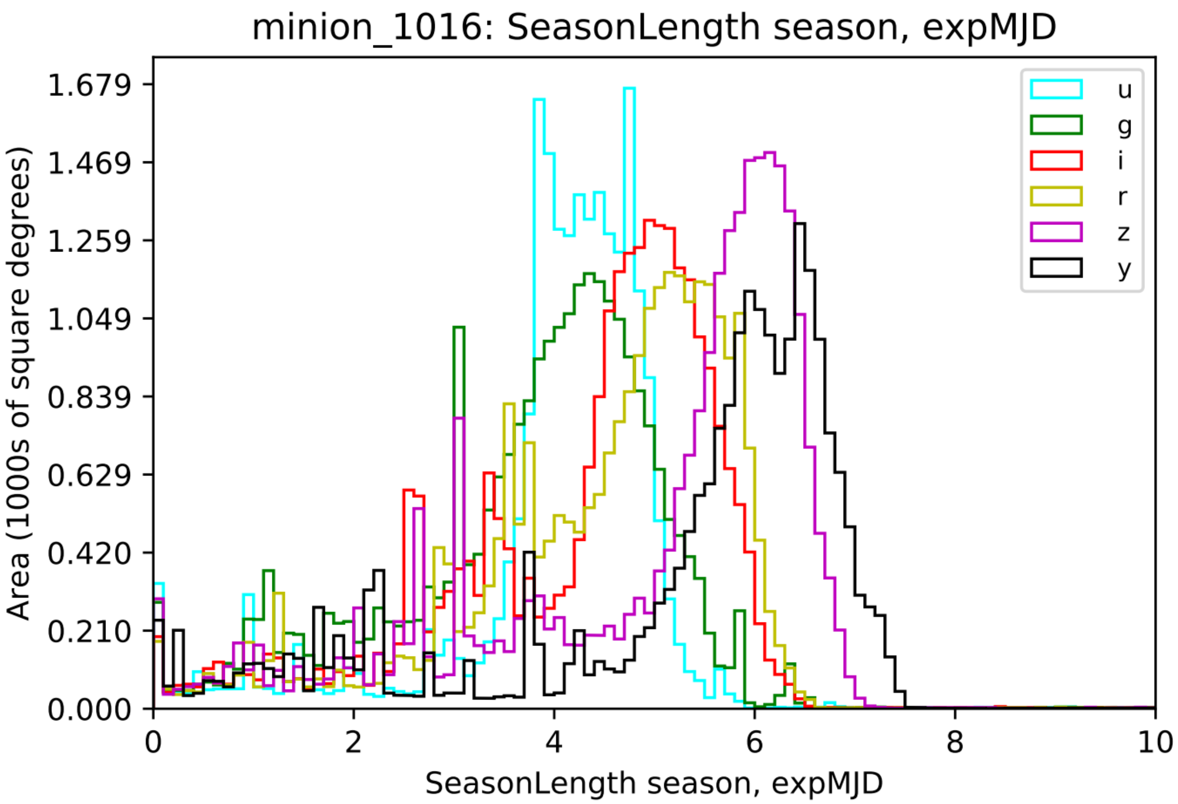
Minion_1016, Cadence



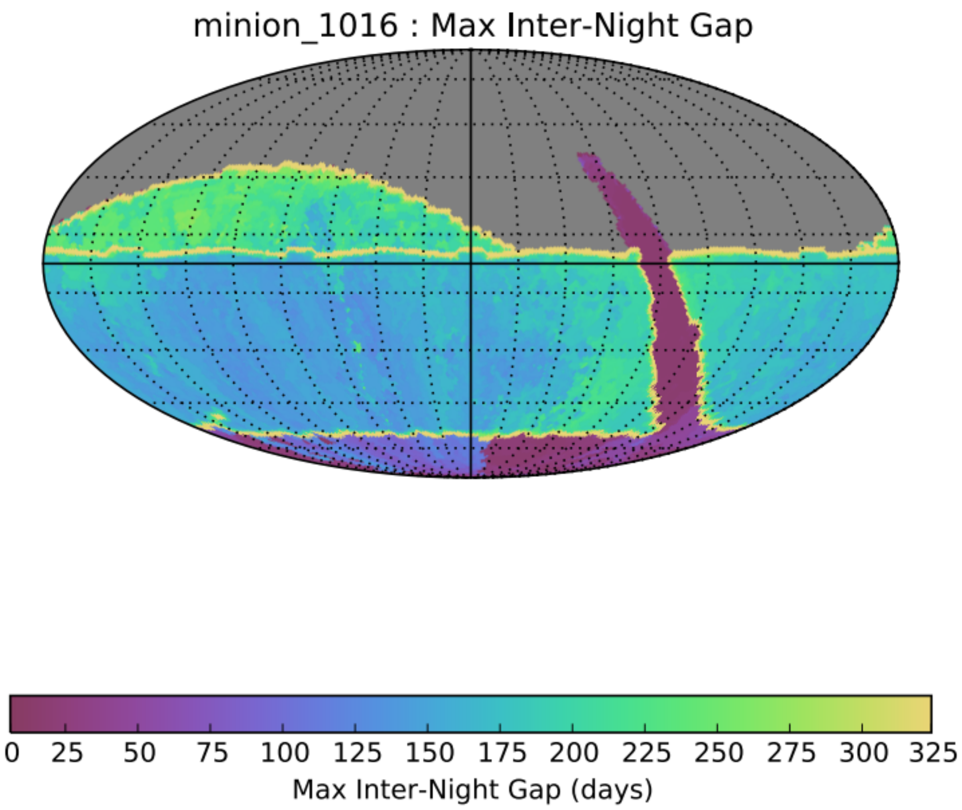


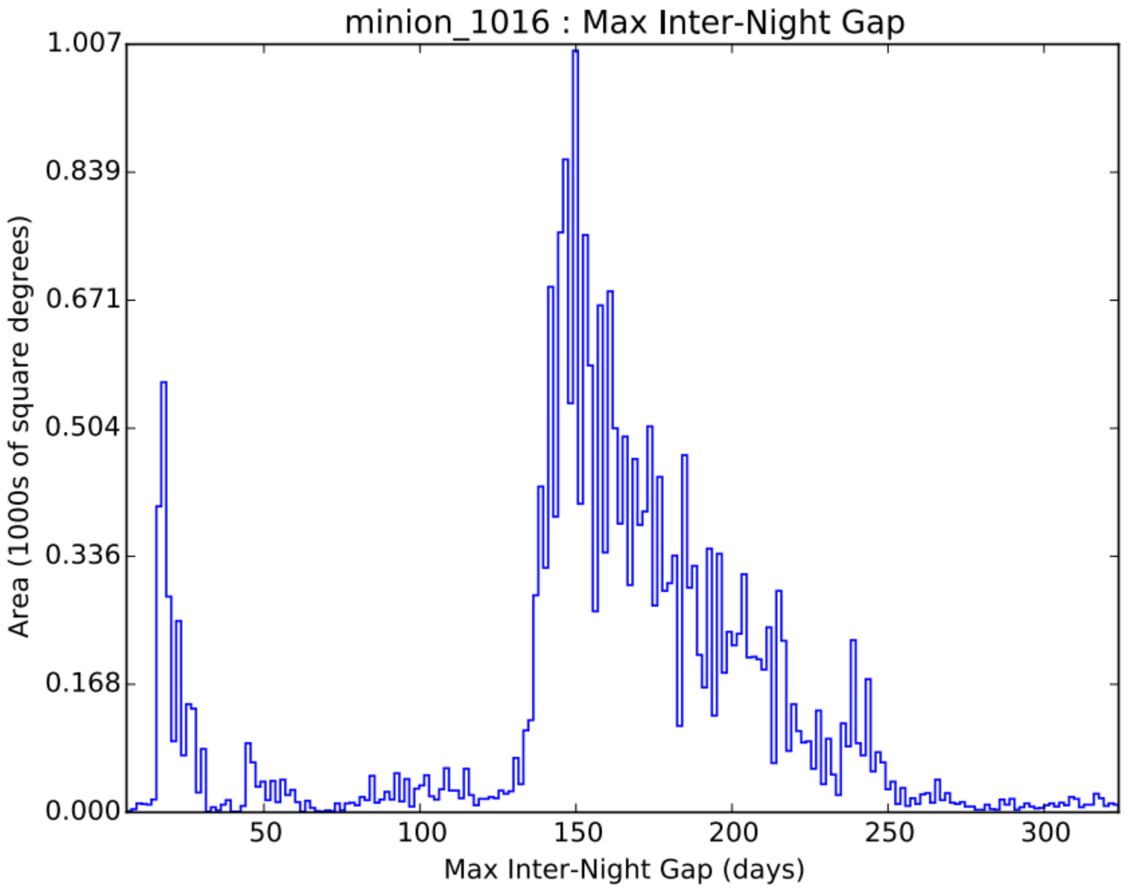
Minion_1016, Cadence and Season length per band





Minion_1016, worst cases





The LSST Quasar Microlensing Simulator

σ_0	$\rightarrow$	Source size
ν	$\rightarrow$	Thermal slope of accretion disk
z_l, z_s	$\rightarrow$	Lens and Source Redshifts
κ, γ, s	$\rightarrow$	Macro model parameters
$\sigma_{lens}, \sigma_{source}$	$\rightarrow$	Peculiar Velocities
$\sigma_\star$	$\rightarrow$	Lens stellar velocity dispersion
RA, DEC	$\rightarrow$	Lens coordinates
$\Delta RA, \Delta DEC$	$\rightarrow$	Image (relative) coordinates
$Baseline$	$\rightarrow$	Base magnitude (per band)

Opsim output

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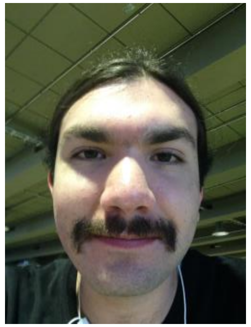

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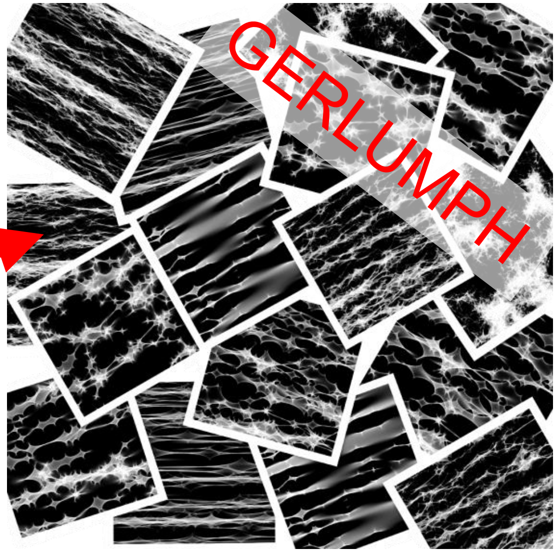

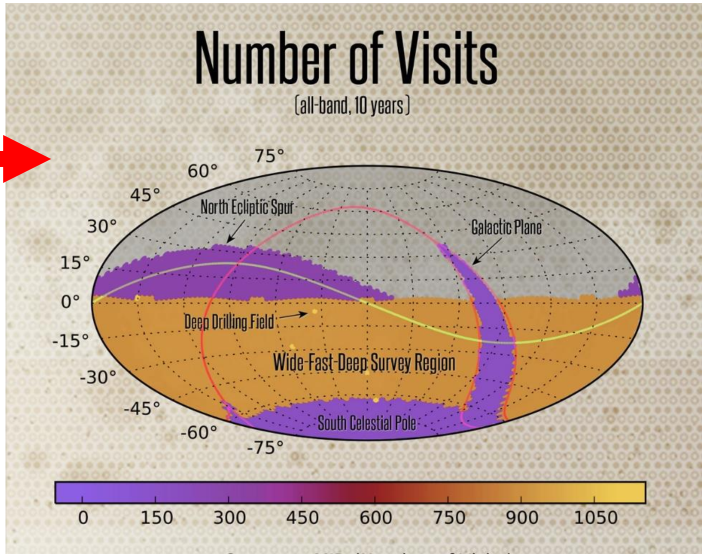

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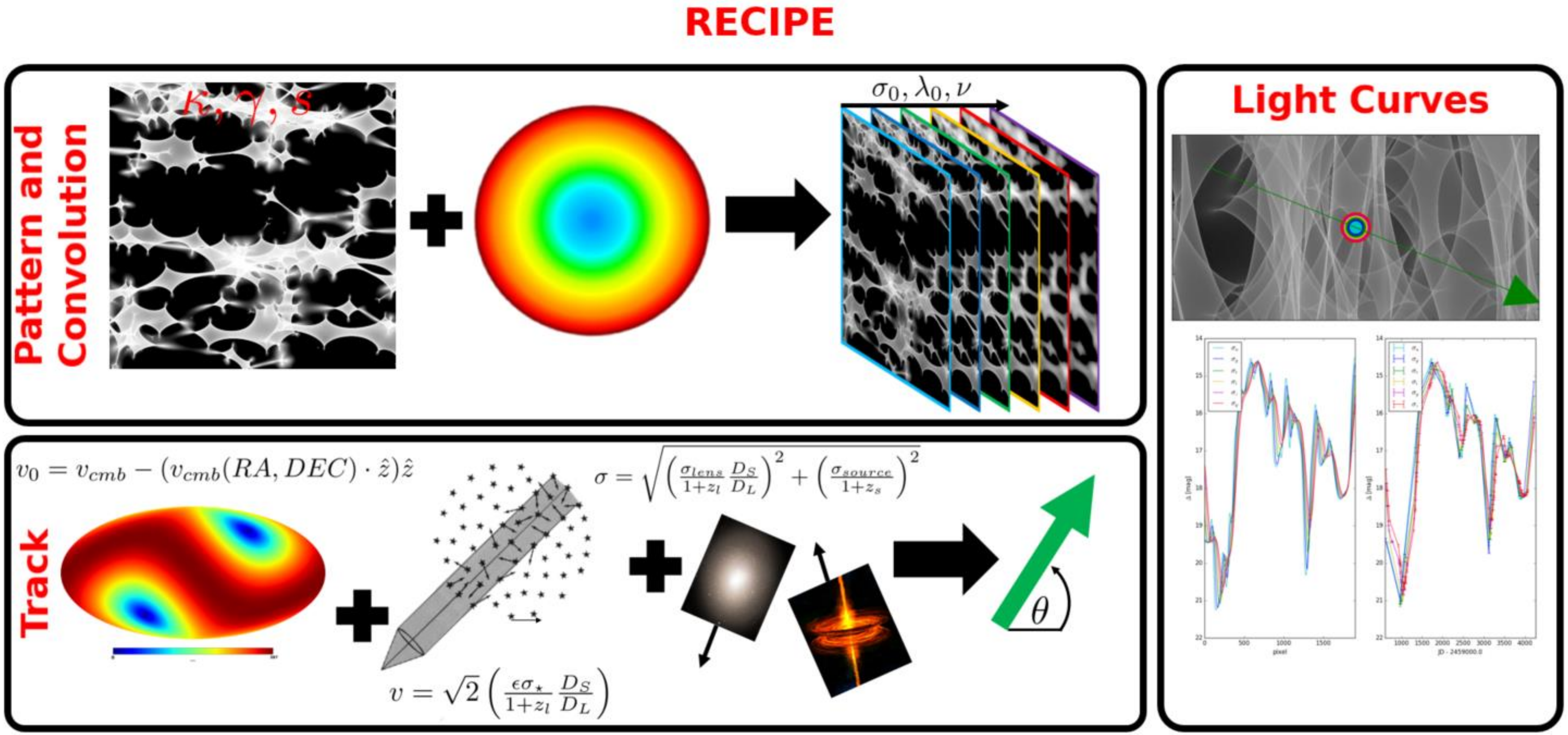
The LSST Quasar Microlensing Simulator



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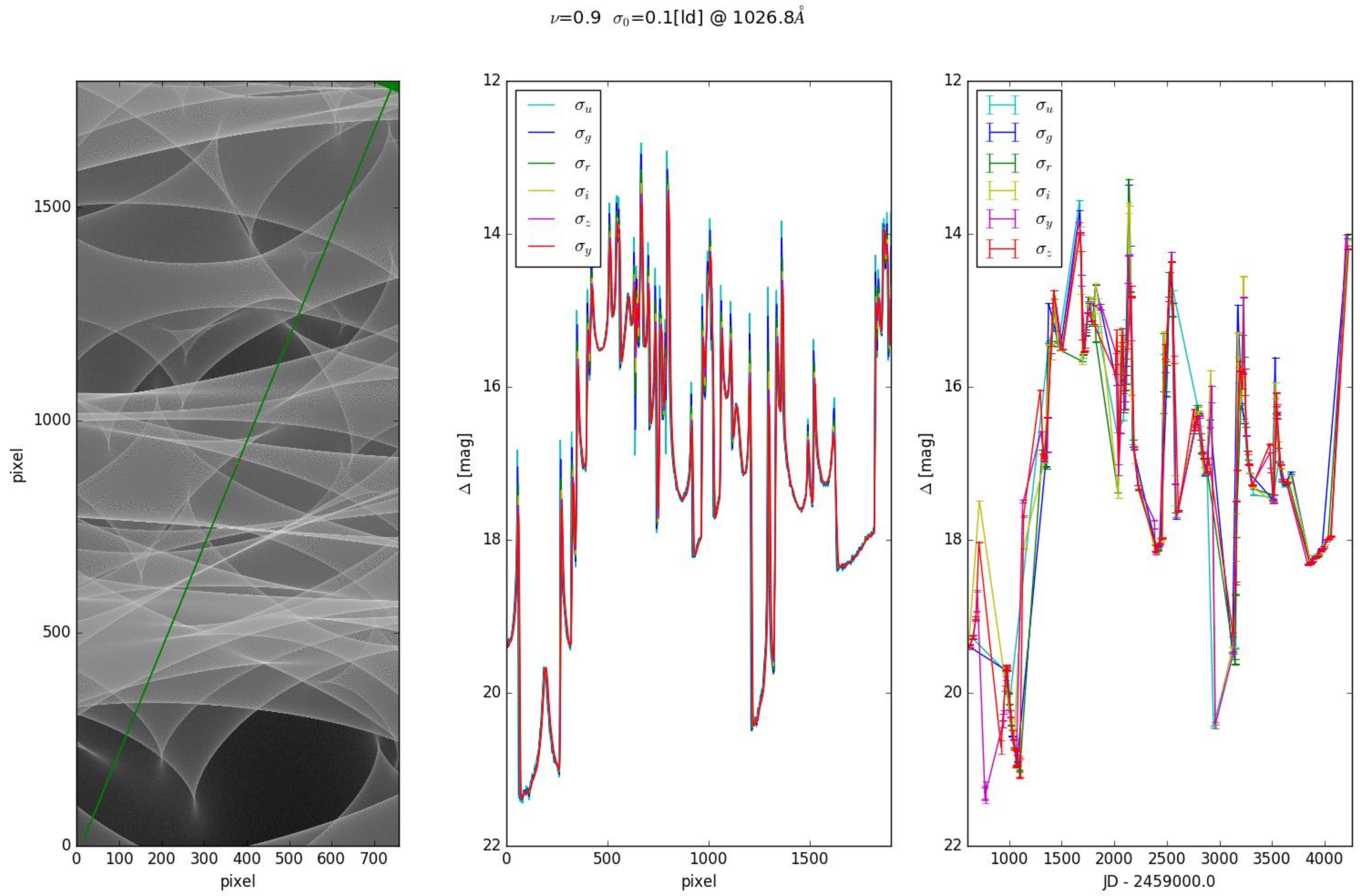
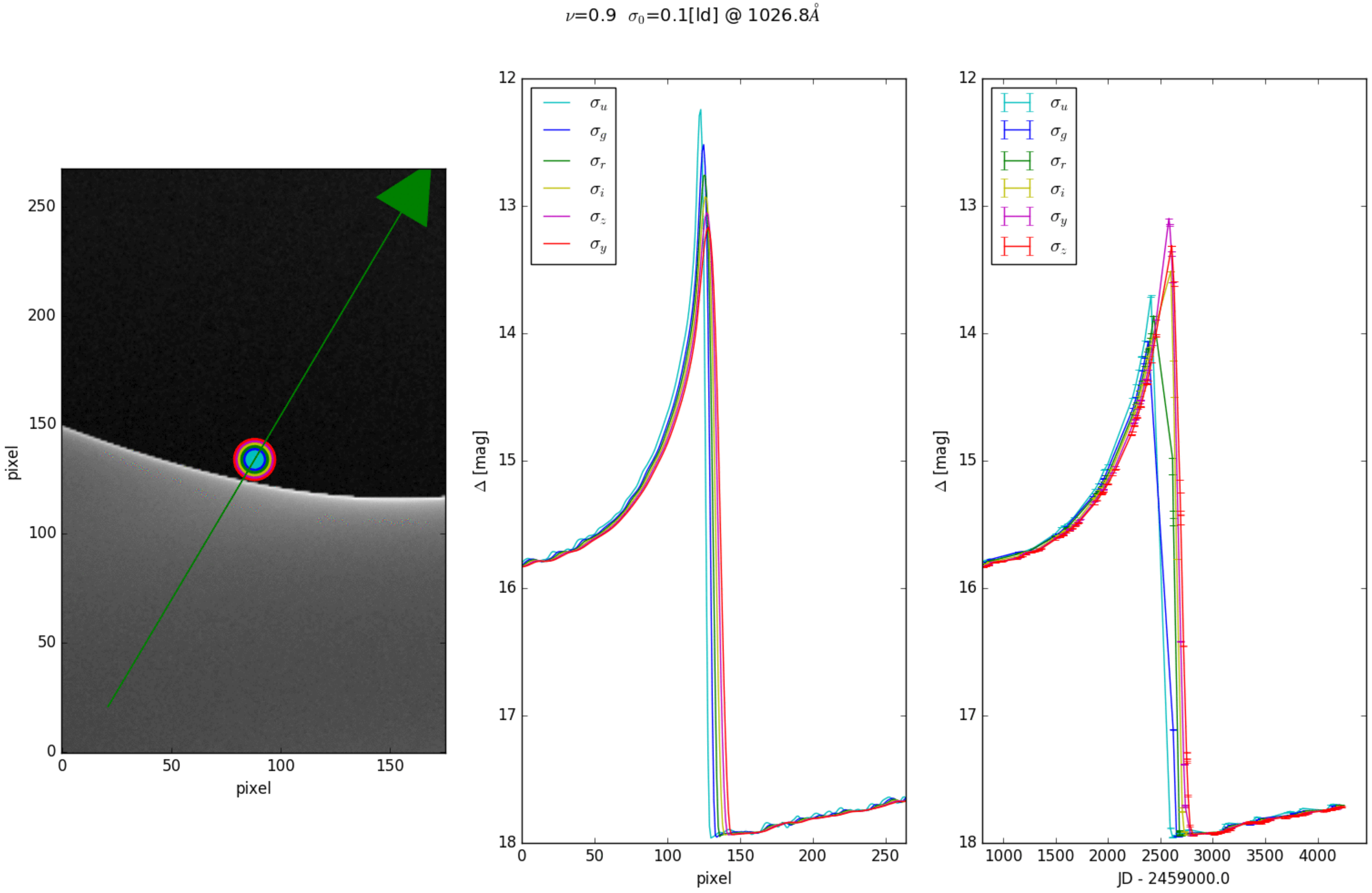
The LSST Quasar Microlensing Simulator

RXJ1131-1231

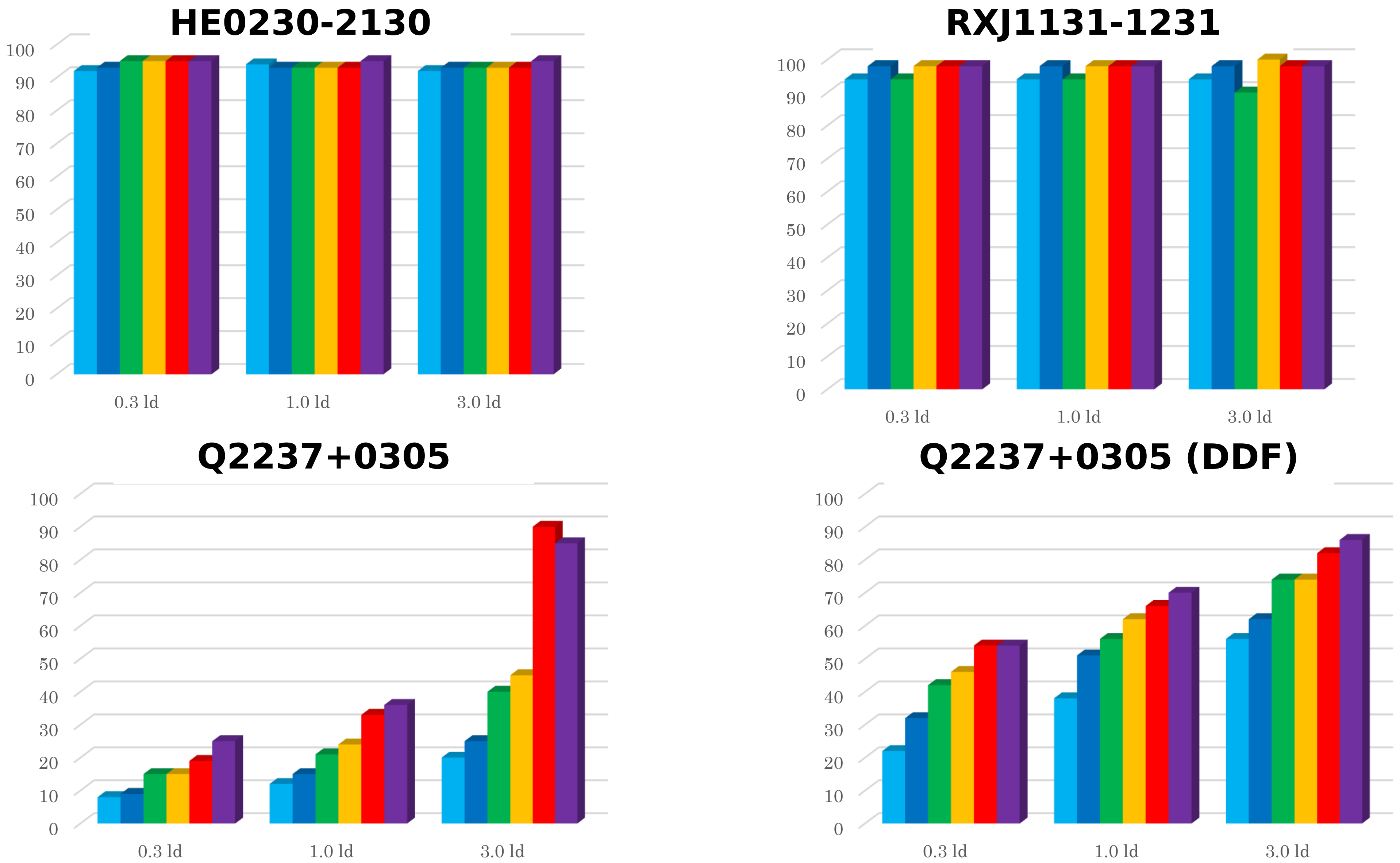


The LSST Quasar Microlensing Simulator

HE0230-2130



LSST QMD: minion_1016



LSST QMS V2.0

GERLUMPH

GPU-Enabled, High-Resolution, cosmological MicroLensing parameter survey

Centre for Astrophysics and Supercomputing - Swinburne University of Technology

LSST light curve simulator

This tool extracts high resolution light curves from the GERLUMPH maps, sampled according to some LSST observing strategy, and is described in detail in Anguita et al. 2017 (in prep.).

The source can be set to be either a series of analytical Gaussian profiles, or uploaded custom user profiles. Once the remaining parameters below are also set, the light curves will be computed on Swinburne's gSTAR supercomputer.

The output data are compressed, as described in Anguita et al. 2017 (in prep.). We further provide two python programs to decompress and plot the light curve data. Instructions to run these auxiliary programs are included in the tarball:

download decompression and plotting programs

Currently there is a limit of 10,000 requested light curves per batch.

Magnification map

κ	0.4	Surface mass density at lensed image
γ	0.4	Shear at lensed image
s	0.3	Percentage of smoothly distributed matter
mass	1	Mean microlenses' mass in $M_\odot$

Source profile

Gaussian source with parameters:

σ_0:	1.0	[ld]
λ_0:	1026.8	[A]
ν:	1.33	
inclination:	0	°
orientation:	0	°

Other parameters

	☑	vcmb
z_s	2.0	Source redshift
z_l	0.2	Lens redshift
σ_{disp}	300.0	Lens stellar velocity dispersion
σ_{gal}	250.0	Lens peculiar velocity (dispersion)
σ_{source}	250.0	Source peculiar velocity (dispersion)

LSST specifications

Opsim	minion_1016	Opsim output
years	10.0	Number of survey years
RA	12.325	Right ascension in hours
DEC	-20.58	Declination in degrees
ΔRA	1.0	Image offset from lens (RA)
ΔDEC	1.0	Image offset from lens (DEC)
Baseline u	18.0	u-band baseline magnitude
Baseline g	18.0	g-band baseline magnitude
Baseline r	18.0	r-band baseline magnitude
Baseline i	18.0	i-band baseline magnitude
Baseline z	18.0	z-band baseline magnitude
Baseline y	18.0	y-band baseline magnitude

Derived quantities

Pixel size in the source plane:	0.0803	[ld]
Einstein radius in the source plane:	32.1362	[ld]

Output

N_{lc}	1	number of light curves
	☐	full data
	☑	degraded data (x15 smaller file size)

SUBMIT

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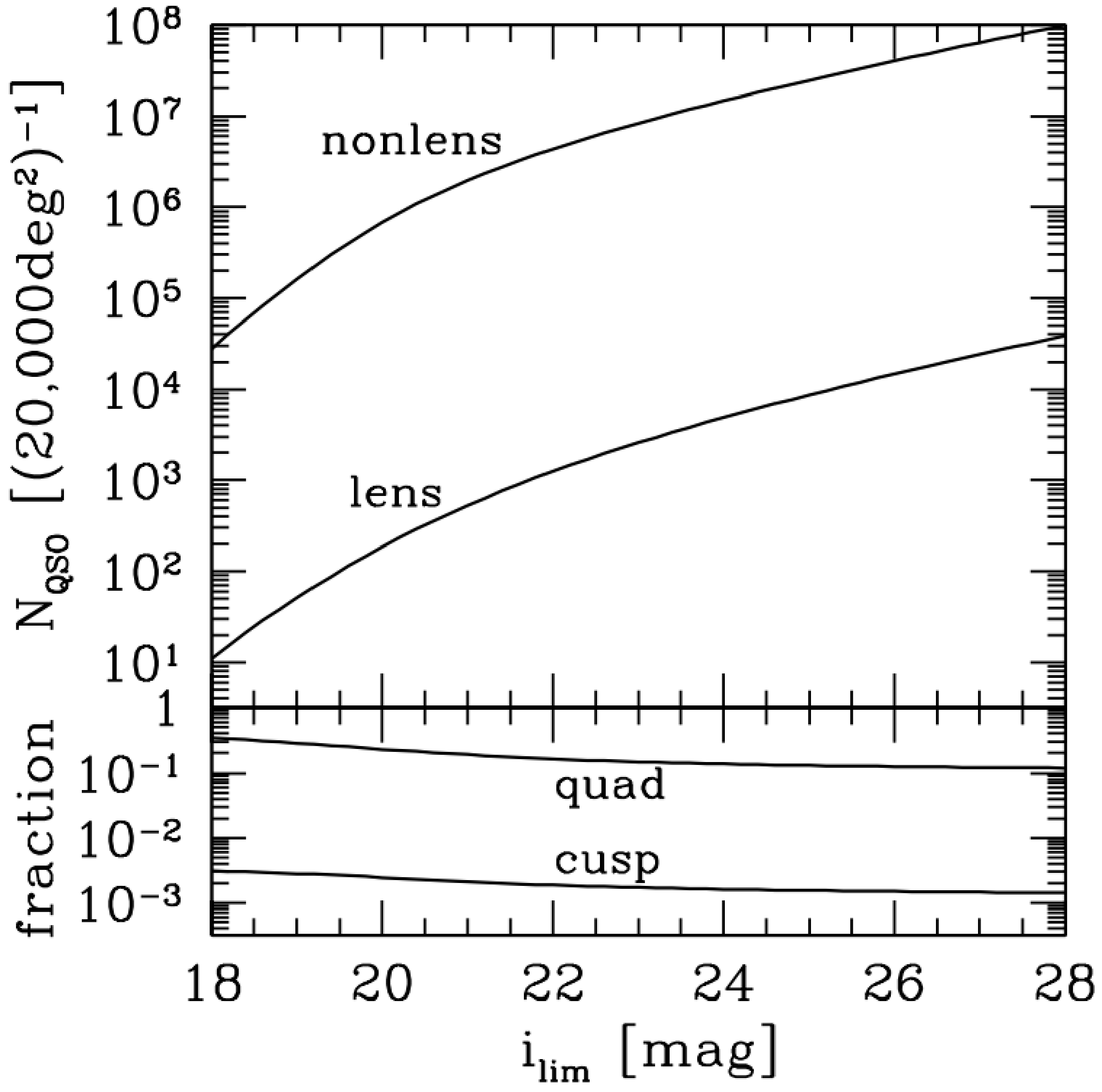
How many systems?

- Oguri and Marshall 2010
  - 8000 lensed quasars (15% quads)
  - 3000 with measured time delays



Time Delay Challenges TDC

- Teams
  - Evil Teams → Simulate realistic time delay light curves
  - Good Teams → Attempt to measure time delays
- TDC1: single band variability, including single band microlensing: finished
  - Liao et. al 2015 + Observing Strategy Whitepaper (more in a minute)
  - ~500 with well measured time delay (cosmography quality) using minion_1016
  - Stacking bands
- TDC2: coming this year
  - Multiband intrinsic variability
  - Thermal (multiband) model (SS73) for the accretion disk
- TDC3: 2018?
  - Several thermal models for accretion disks (using LSST QMS)
  - Good Teams can (will?) fit for AGN models → measure LSST accuracy for accretion disk models

Observing Strategy Whitepaper http://ls.st/o5k

Science-Driven Optimization of the LSST Observing Strategy

Welcome to the online community thinking about LSST survey strategy ("cadence"), with quantifications via the Metric Analysis Framework.

We are writing a white paper on this topic, primarily composed of a set of individual science cases that are either very important, and somehow stress the observing strategy, and describing how we expect them to be sensitive to LSST observing strategy. MAF metric calculations are then being designed and implemented: these form the quantitative backbone of the document. You may have heard of the coming "Cadence Wars" - this white paper represents the "Cadence Diplomacy" that will allow us, as a community, to avoid, or at least manage, that conflict. We welcome contributions from all around the LSST Science community.

Phil Marshall et al.

Observing Strategy Whitepaper

- A more specific Science Book (2009)
- Living document (feel free to join!)
- Sections defining all science objectives
- One Figure Of Merit (FOM) per science objective
  - Common or specific metrics and/or a combination
  - Need to be dimensional (comparable between science topics), i.e.:
    - "information gained"
    - "how much it is worth"
- Result to be applied to optimize the baseline observing strategy

Whitepaper Chapter Section Templates

- Introduction
  - A short preamble goes here. What's the context for this science project? Where does it fit in the big picture.
- Target measurements and discoveries
  - Describe the discoveries and measurements you want to make.
  - Describe their response to the observing strategy. Qualitatively, how will the science project be affected by the observing schedule and conditions? In broad terms, how would we expect the observing strategy to be optimized for this science?
- Metrics
  - Quantifying the response via MAF metrics: definition of the metrics, and any derived overall figure of merit.
- OpSim analysis
  - how good would the default observing strategy be, at the time of writing for this science project?
- Discussion
  - what risks have been identified? What suggestions could be made to improve this science project's figure of merit, and mitigate the identified risks?
- Zeljko's 10 questions

OS Whitepaper: Preliminary Results

12.1 Summary of Cadence Constraints

Željko Ivezić

The authors of the preceding chapters' science cases provided guidelines for improving the baseline LSST cadence, via their 10-question conclusions sections. We now summarize this input, extracting a number of recommendations for the Project to take on. The most important action items for the Project Team include i) implementation, analysis and optimization of the "rolling cadence" idea, and ii) execution of a *systematic* effort to further optimize the ultimate LSST cadence strategy.

The production and analysis of several families of rolling cadence simulations by the Project should be the highest priority, because this baseline cadence modification might provide more significant science benefits than any other proposed modification.

Rolling cadence Opsim output coming in 2017

Thanks!