Prospecting for Low Mass X-ray Binary Periods with LSST

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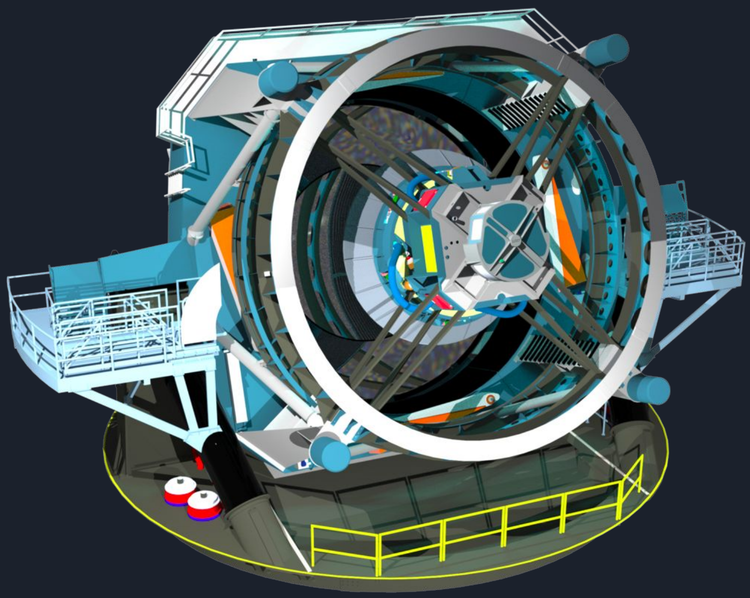


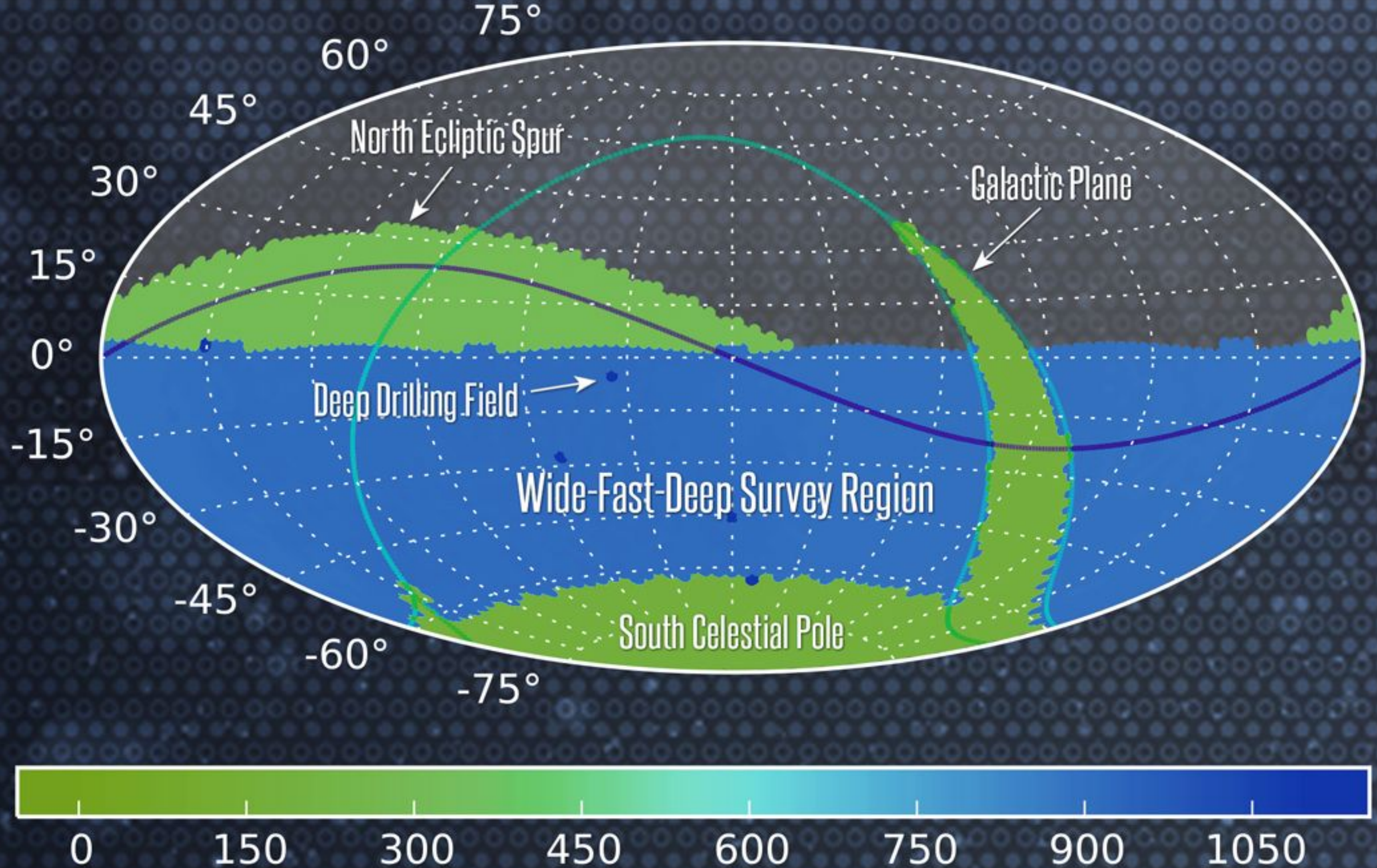
UNIVERSITY OF Southampton

LSST Large Synoptic Survey Telescope

EPSRC Engineering and Physical Sciences Research Council

Number of Visits

(all-band, 10 years)

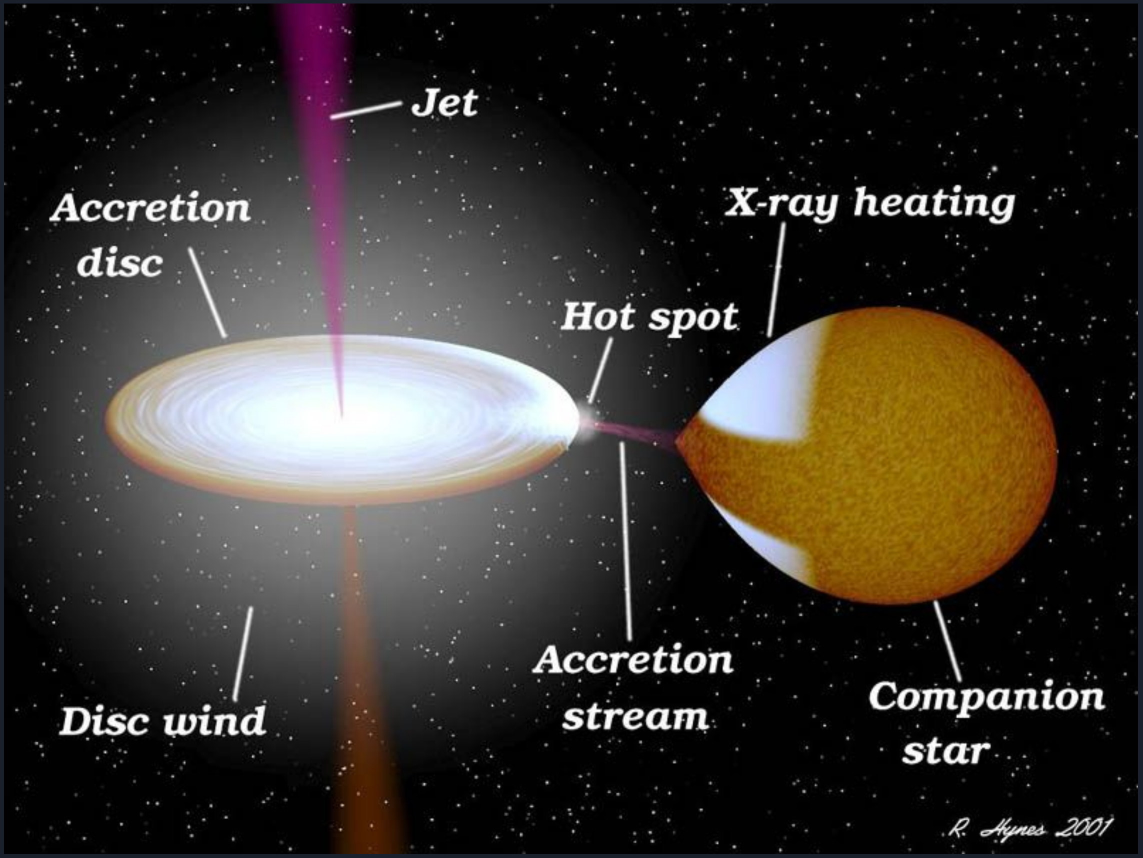


Low Mass X-ray Binaries

Low mass companion star ($<1M_{\odot}$) in orbit around a black hole or neutron star

Compact object accretes matter via Roche Lobe overflow, forming an accretion disc

Many LMXBs exhibit very bright, rare X-ray outbursts separated by decades of quiescence



Credit: NASA/R. Hynes

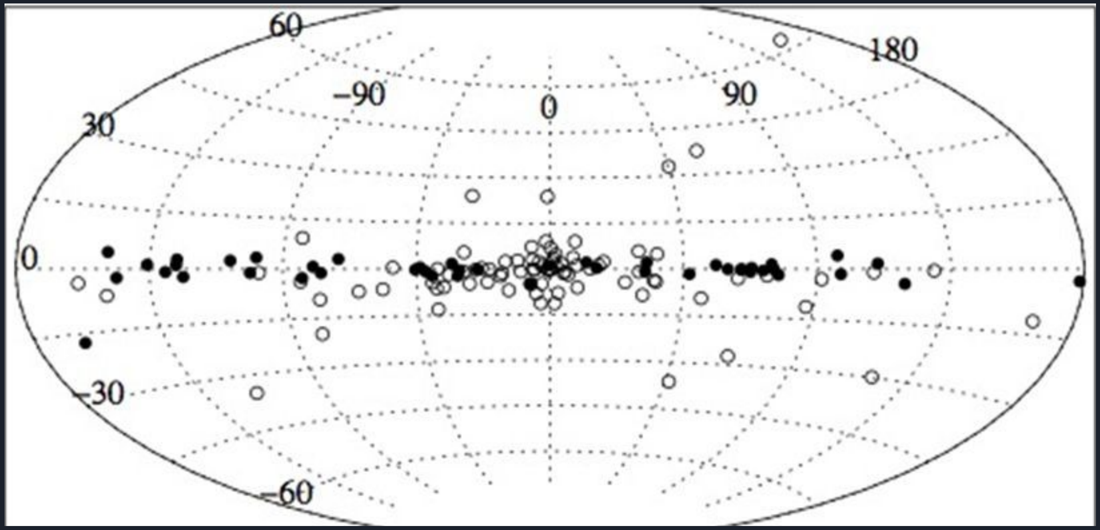
LMXB Population

Estimated to be thousands of LMXBs within the Milky Way however, there are only ~200 known systems.

~60 of which are thought to contain a black hole

~20 dynamically confirmed black hole masses

~90% of known systems reside in the Galactic Plane

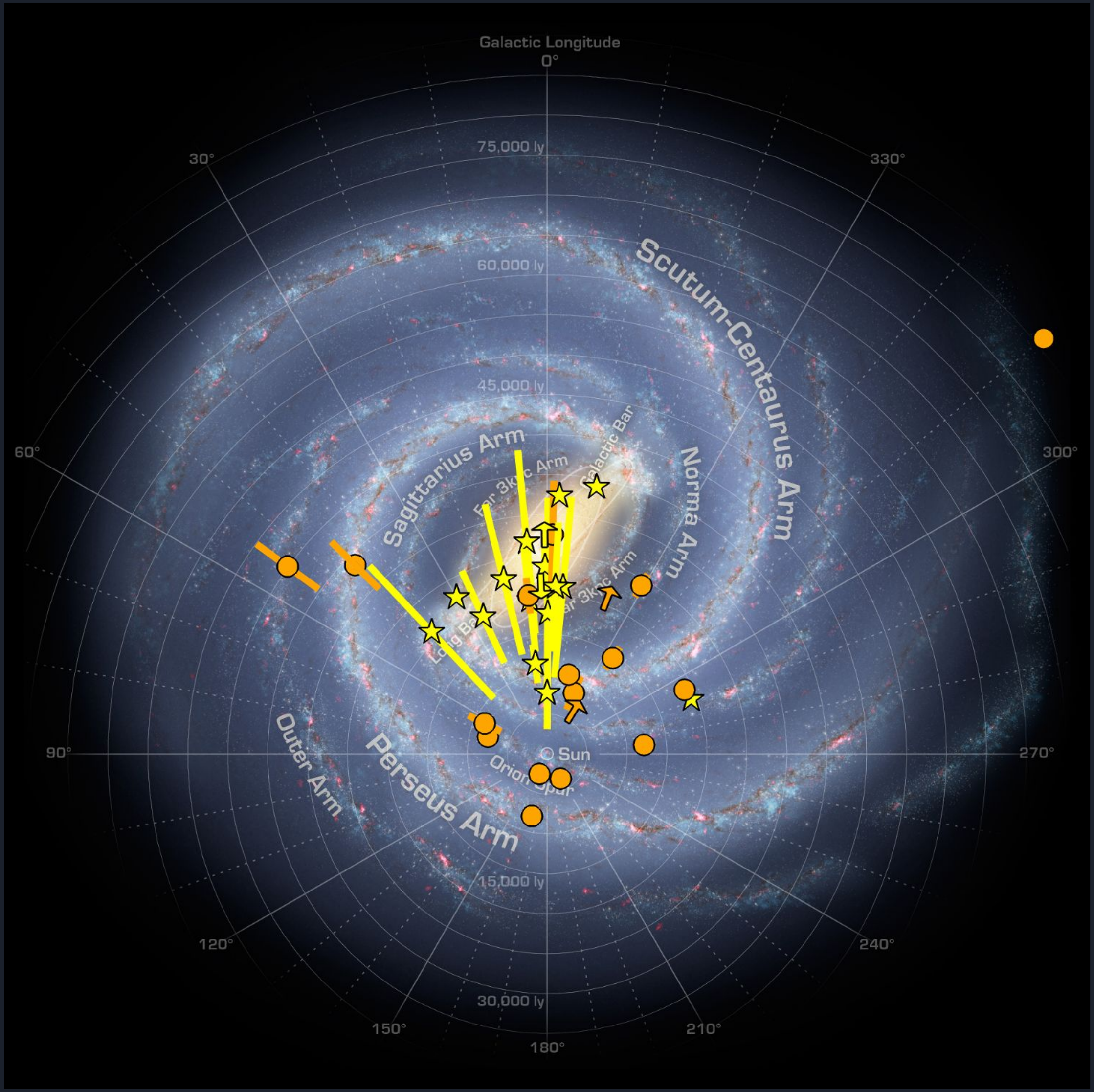


Grimm et al. 2002

Extinction from Galactic gas and dust means that the vast majority are too faint to observe routinely in the optical.

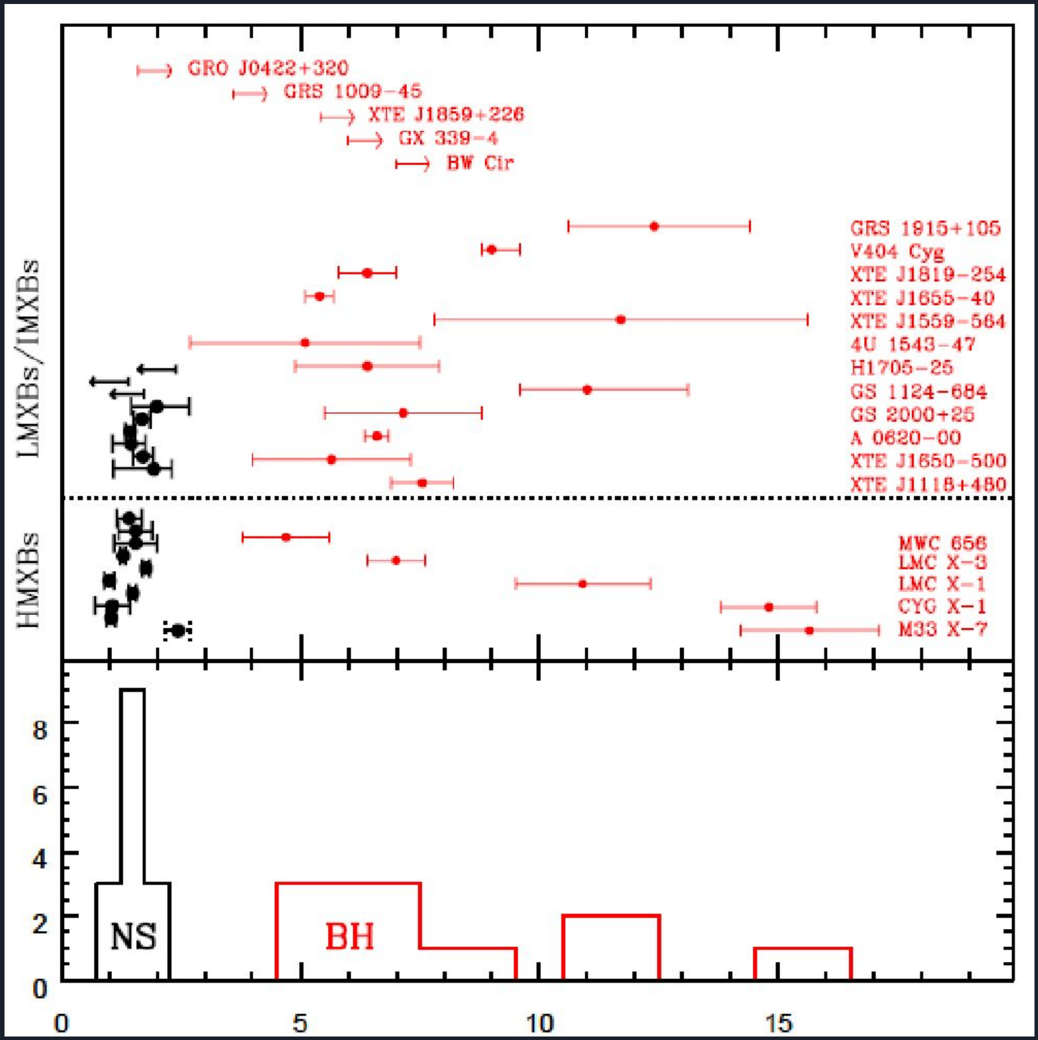
Penetrating through the Galactic Extinction

- Galactic distribution of 35 BHTs, dynamically confirmed marked as orange circles and stars represent BH candidates (Corral-Santana et. Al 2015)
- Due to Galactic extinction, LMXBs are only found relatively locally in the Galaxy
- The large collecting area of LSST will penetrate further into the Galaxy, particularly in the redder filters



Corral-Santana et al. 2016

NS/BH mass Distribution



Casares et al. 2017

Observations of the periodic variability of LMXBs can be used in conjunction with spectral information to determine the masses of the binary components.

21 realistic masses of BHs 5-16 M_O

Typical errors 30%

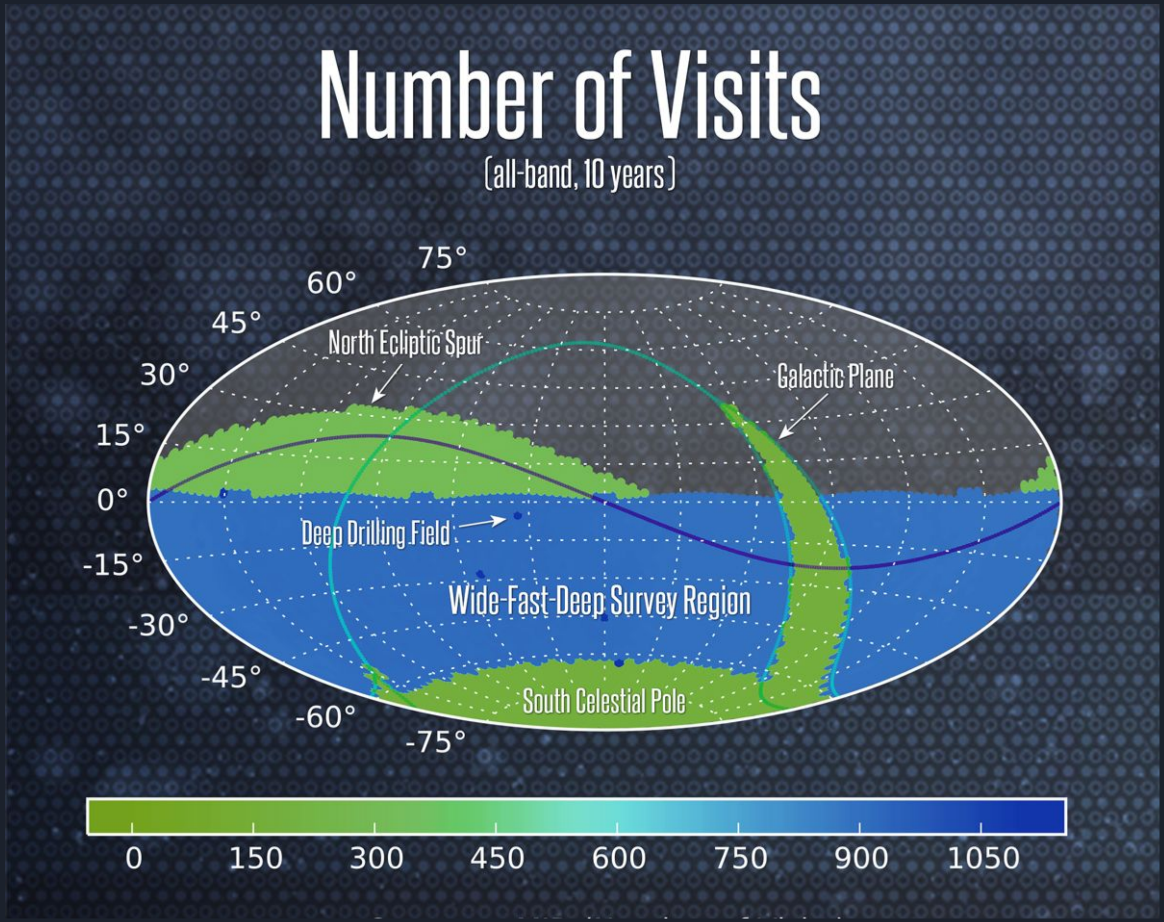
Goals: improve statistics and reduce errors to 10%

Credit: Phil Charles

The Operations Simulator (OpSim)

Simulates field selection and image acquisition process of LSST

Outputs a detailed record of the telescopes movements throughout the 10 year survey

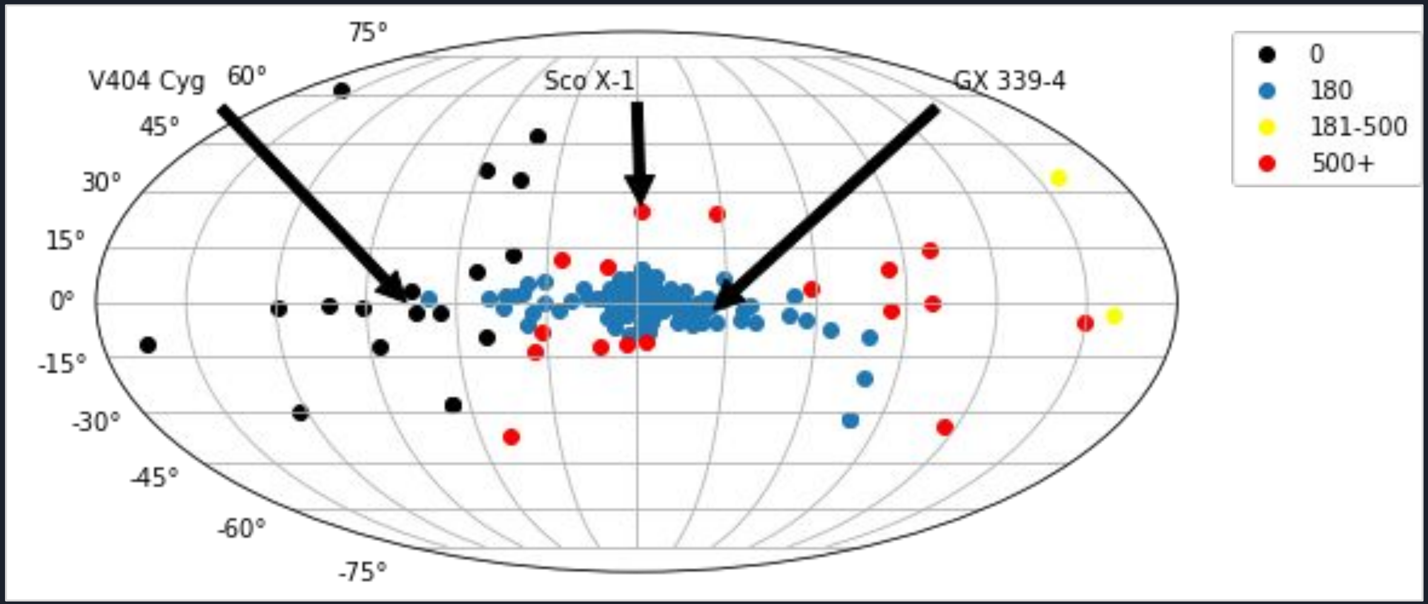


The Baseline Strategy Minion_1016

Location of 180 LMXBs referenced with the results of the current baseline strategy, Minion_1016

Each dot represents a field that contains at least one LMXB

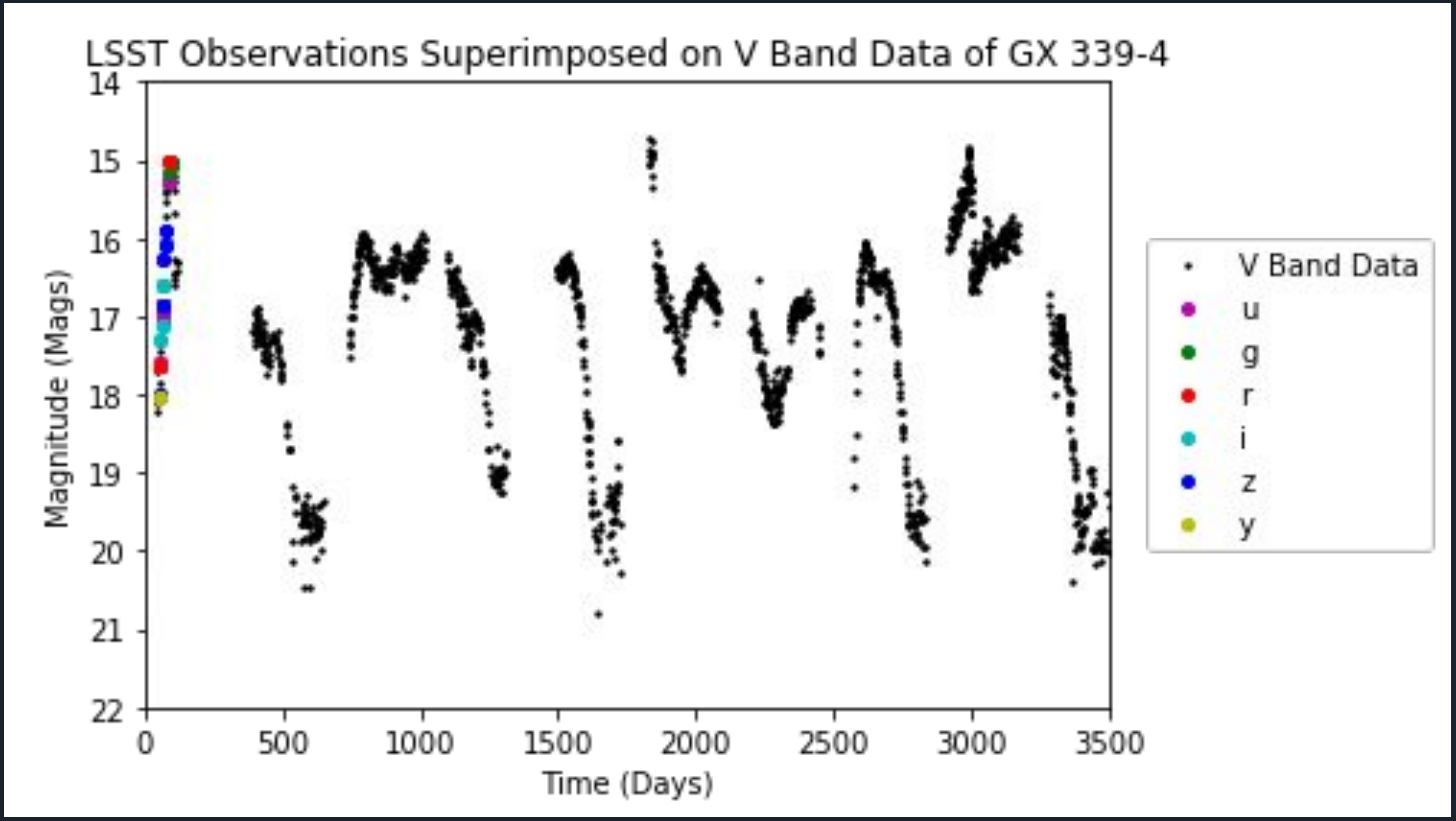
Numbers represent the total observations made in all filters over the full 10 year survey



Galactic Plane Observations in Minion_1016

Observations taken throughout the survey of the region containing GX 339-4 were superimposed onto the optical SMARTS data

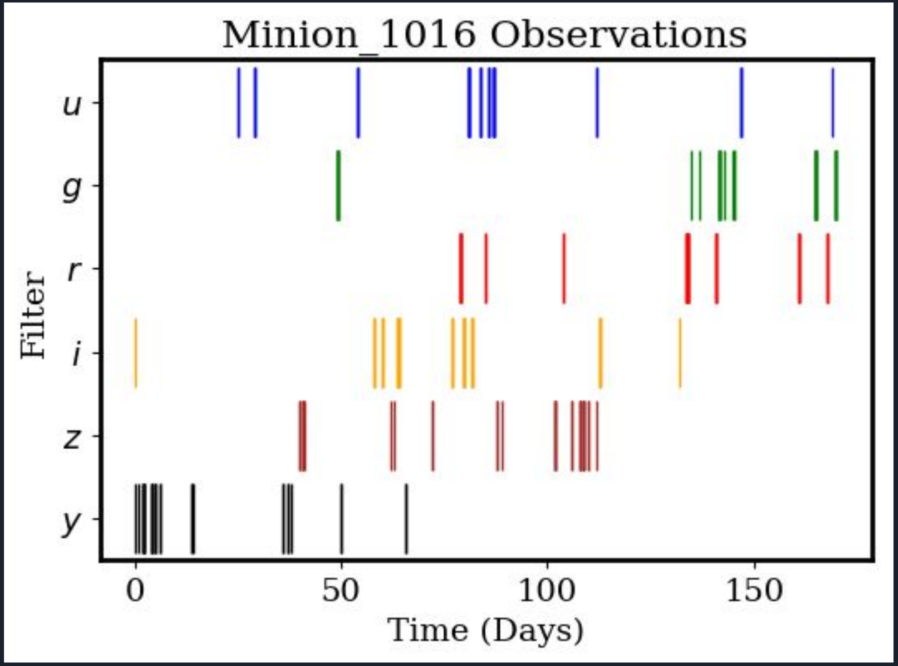
All Galactic Plane observations are taken during the first 7-10 months



Galactic Plane Observations in Minion_1016

Each line represents an observation of GX 339-4 taken by LSST, colour denotes the filter

The observations are very clustered with it being common for ⅙ of all observations per filter per field within the 10 year survey to occur within 2 hours



Alternative Strategies

Minion_1016 - baseline strategy

Minion_1016j - baseline strategy with random time jitter between ± 1 day for each observation

Minion_1020 - observations distributed evenly amongst all fields

astro_lsst_01_1004 - baseline strategy with Galactic Plane included in the main survey region

LMXB light curves

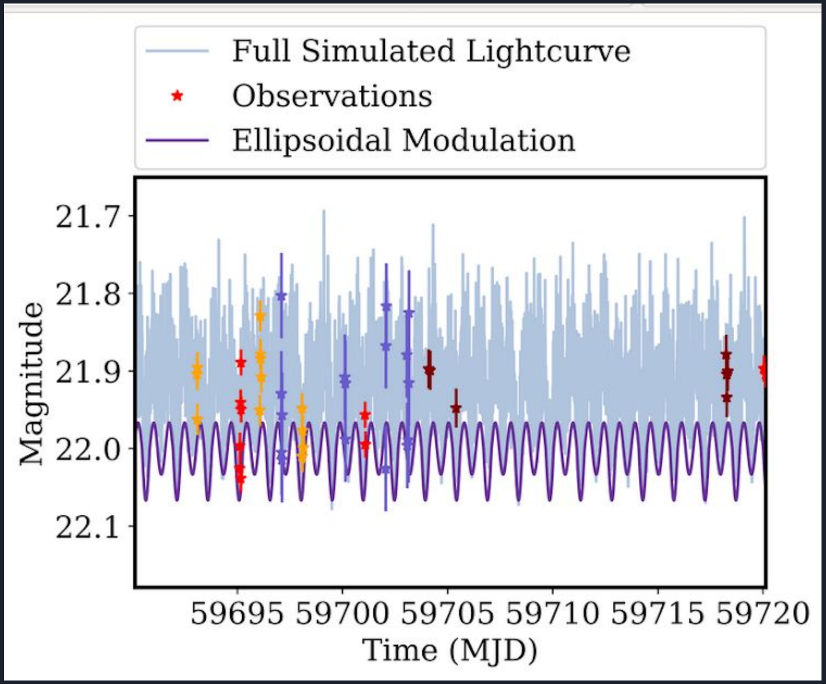
10 year simulated light curves composed of a base magnitude corresponding to the donor star, plus optical variation.

Light curves sampled by LSST observations (shown as *s)

Optically variability composed of two parts:

Ellipsoidal Modulation - due to orbital motion

Flaring - red noise thought to be due to inconsistencies in the accretion flow



Johnson et al. Submitted

Period Recovery - Method

A Multi-band Lomb-Scargle algorithm was used to recover the periods (VanderPlas and Ivezic 2015)

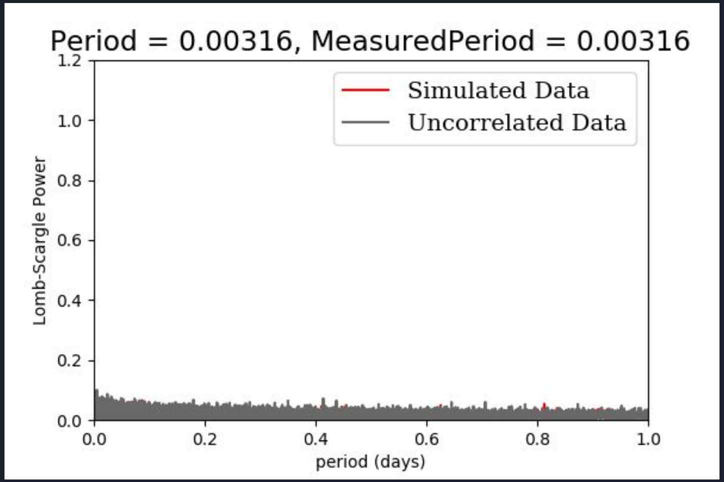
To determine the significance:

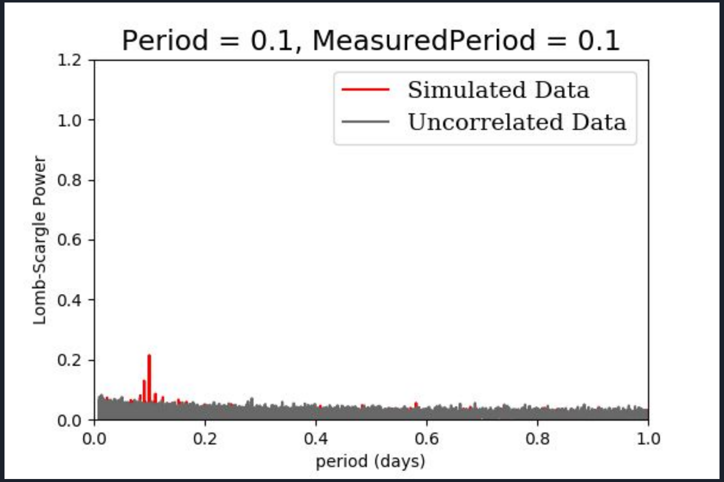
Magnitudes and dates in the light curve were shuffled, creating an uncorrelated data set

LS algorithm was evaluated over uncorrelated data set and the maximum peak recorded

This was repeated 10,000 times

Significance was then the number of times the highest power from the simulated data set was higher than that of the uncorrelated one





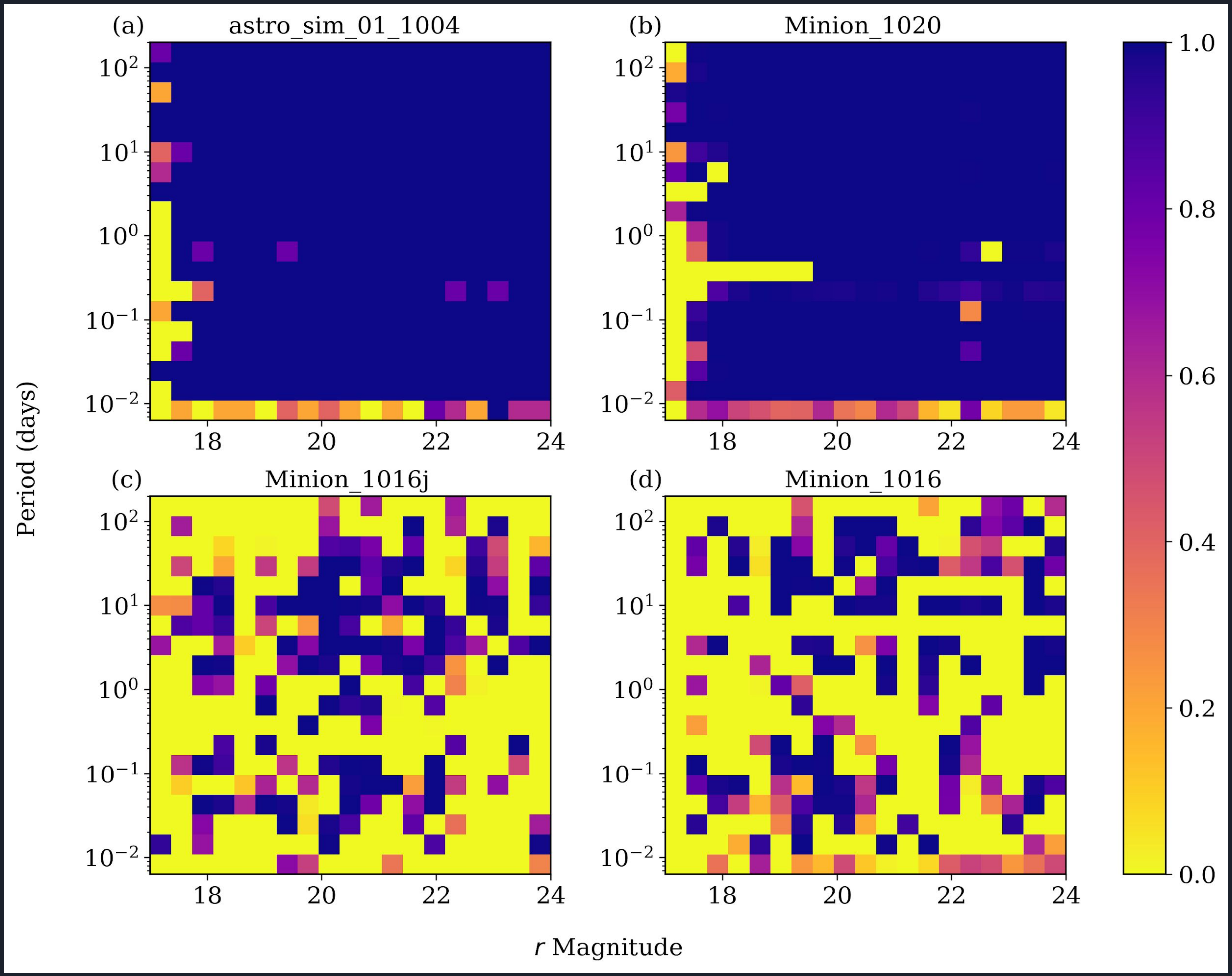
Period Recovery - Results

The multi-band Lomb-Scargle algorithm was applied to the results from the sampled lightcurve to determine what periods could be recovered.

Period ranges from ~9 minutes to 200 days to encompass all known LMXBs

Magnitude range from 17-24 mags in *r*, motivated by the visible range for LSST

Colour denotes significance



Johnson et al. Submitted.

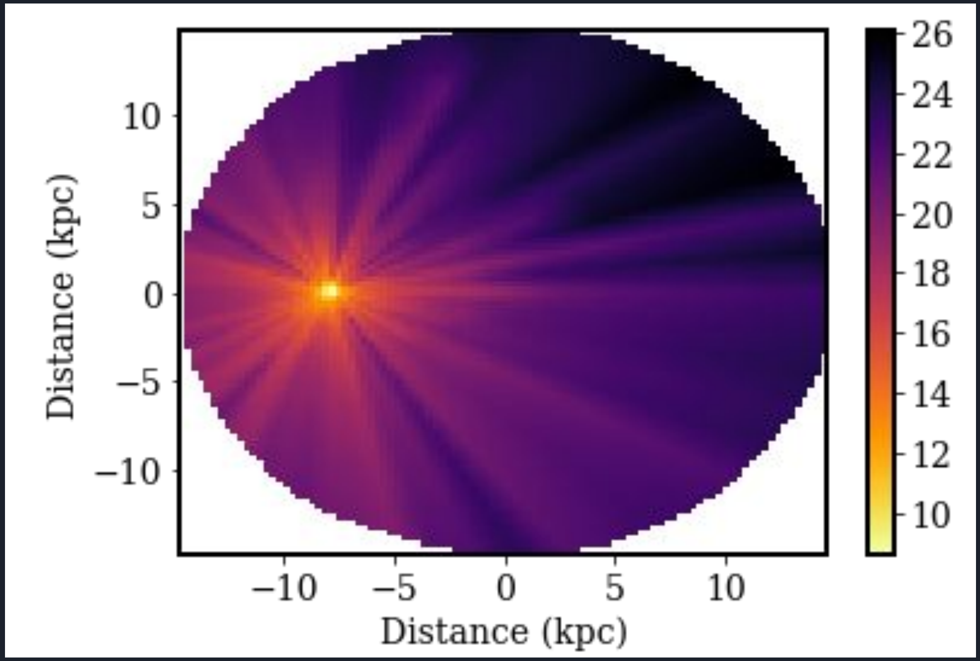
Adapting the Results to the Milky Way

To find the number of LMXB periods we can expect to recover in the Milky Way, the results were combined with:

A Gaussian LMXB period distribution with mean~2 days and std ~5 days

An exponential LMXB spatial distribution with scale length 3 kpc

Bayestar Milky Way Dust maps (right)
Earth is at (-8,0), Galactic centre at (0,0)
Colour denotes *r* magnitude of *K*-type star at all positions in the Milky Way



Period Recovery - Results

A conservative estimate for the Milky Way LMXB population of 1300 systems was used to calculate the number of periods we can expect to recover.

Observing Strategy	Total Number of Observations	Period Recovery (%)	Period Recovery in the Milky Way (%)	Period Recovery in the Milky Way (No. of Systems)
Minion_1016	180	43	11	143
Minion_1016j	180	43	11	143
Minion_1020	540	95	35	455
astro_lsst_01_1004	661	97	36	468

The more observations, the better the recovery rate.

Summary

-LMXBs are important tools in understanding the properties of compact objects

-LSST has the potential to expand the known population of LMXBs and measure their variable properties

-The current observing strategy is not ideal for transient Galactic science

-The limiting factor for period determination of LMXBs with the current baseline strategy is the number of observations

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