Large Synoptic Survey Telescope

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Investigating LSST's Sensitivity to Periodic Stellar Variability Using RR Lyrae Stars

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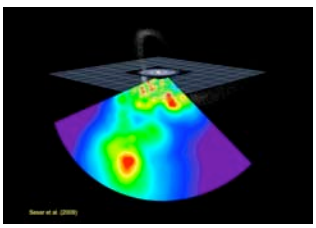
We have investigated LSST's capability to recover RR Lyrae lightcurve periods, shapes and Fourier parameters as a function of apparent magnitude and LSST survey length. An LSST simulation tool was used to sample authentic ugriz RR Lyrae lightcurves as observed in Stripe 82 data from the Sloan Digital Sky Survey. A subset of 30 RRab and 10 RRc lightcurves, which fully sampled the template and period-amplitude space, was placed in 1007 locations on the sky to obtain a statistically relevant sample of the sky and LSST's observing cadences. The period and lightcurve recovery capability was investigated for LSST survey lengths of 1, 2, 5 and 10 years, and the simulation tool returned each lightcurve with realistic photometric errors based on historic seeing and weather data at the LSST site. A period was considered successfully determined if it was within 0.1% of the input value. We found that two years of data were sufficient to recover periods for 90% of RR Lyraes with mean g-magnitudes brighter than mag-23 in the deep survey data, while closer to six years of data were required for the main-survey fields to recover the periods at the same efficiency.

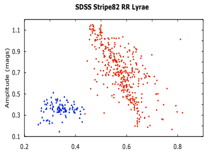
RR Lyrae and Galactic Structure

A major objective of modern astrophysics is to understand the details of galaxy assembly and evolution. Periodic variable stars such as RR Lyrae provide a means for mapping the galactic structure and accretion history through relating stellar (e.g. metallicity) and pulsational parameters (period and amplitude of pulsation) with evolutionary parameters (e.g. luminosity). Overdensities in RR Lyrae distributions are indicative of galactic substructure related to evolutionary history. We report initial results from our study to investigate LSST's ability to recover the pulsational characteristics of RR Lyrae variables.

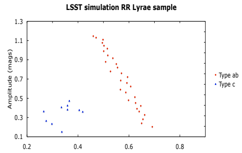


RR Lyrae Lightcurves

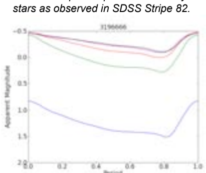
We have obtained 483 authentic RR Lyrae light curves from Sloan Digital Sky Survey (SDSS) Stripe 82 data in five photometric bands (*ugriz*), which are similar to the *ugrizy* system adopted for LSST photometry. The light curves used for our study were originally presented in Sesar et al. (2009). Below are the amplitude vs. period diagrams for the 483 stars in the Sesar et al. survey and the subset of 40 RR Lyrae stars used in our simulated LSST surveys, which uniformly sample the Sesar et al. data set.

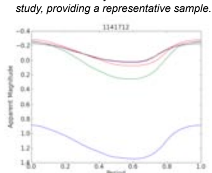


Period - Amplitude plot of 483 RR Lyrae stars as observed in SDSS Stripe 82.

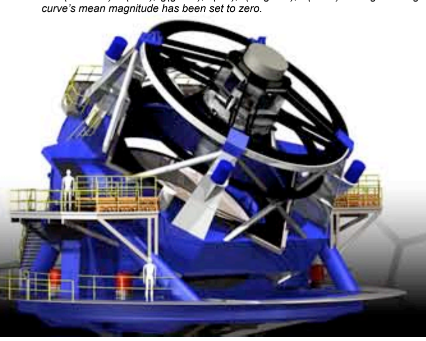


Subset of 40 RR Lyrae stars used in our study, providing a representative sample.



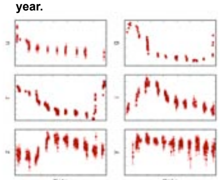


Template ugriz light curves of a SDSS Stripe 82 RRab star (3106666) and a RRc star (1141712). u(blue), g(green), r(red), i(magenta), z(black). The g-band light curve's mean magnitude has been set to zero.

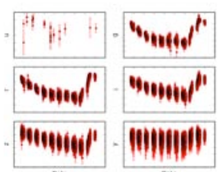


Multi-cadence LSST Observation Simulations

A subset of 1007 fields were selected for five regions of the sky that LSST will observe with different cadences. These regions have been designated Universal Cadence fields (N = 400), Overlap fields (N = 400), North Ecliptic fields (N = 100), Milky Way fields, (N = 100) and Deep Drilling fields (N=7). Each *ugrizy* RR Lyrae model (N = 40) was placed in each field and sampled with the LSST simulation tool, which returned realistic limiting magnitudes and photometric scatter based on historic seeing, calculated arimass, zodiacal light, and moonshin . The stellar magnitudes ranged from 20th to 28th with Δ = 0.5 mag, for survey lengths from 1 to 10 years with Δt = 1 year.



Simulated Universal Cadence observations for a star with g-mag = 22 for a 10 year survey.



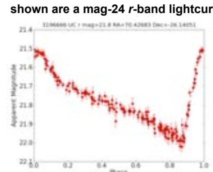
Deep Drilling at g-mag = 22 for 10 years.

Analysis

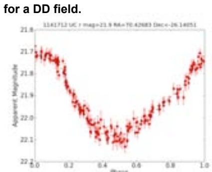
The frequency of the unequally spaced time-sampled and noised periodic data was fit using periodograms and least squares estimation methods (Reiman 1994). The phased simulated observations were then fit via a Chi-square minimization by a six-term Fourier series of the form:

$$m(t) = A_0 + \sum_i A_i \cos\left[2\pi i (t - t_0) + \phi_i\right]$$

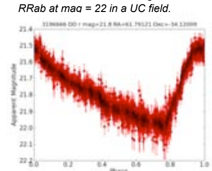
The calculated period and Fourier parameters were compared with the input values. We show phased and fitted 10-year *r*-band lightcurves below for mag-22 RRab and RRc stars in both UC and DD fields. Also shown are a mag-24 *r*-band lightcurves for a DD field.



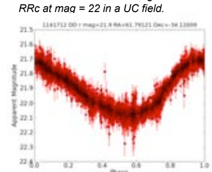
Phased and fitted r-band light curve of a RRab at maq = 22 in a UC field.



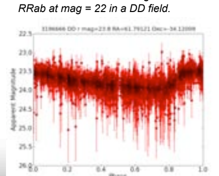
Phased and fitted r-band light curve of a RRc at maq = 22 in a UC field.



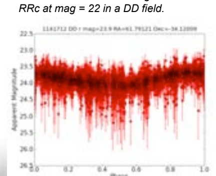
Phased and fitted r-band light curve of a RRab at mag = 22 in a DD field.



Phased and fitted r-band light curve of a RRc at mag = 22 in a DD field.



Phased and fitted r-band light curve of a RRab at mag = 24 in a DD field.

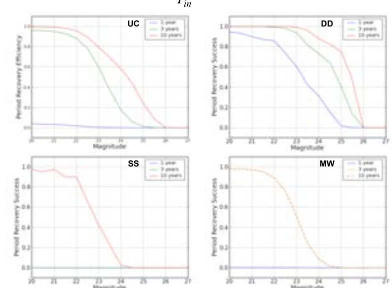


Phased and fitted r-band light curve of a RRc at mag = 24 in a DD field.

Period Recovery by Cadence

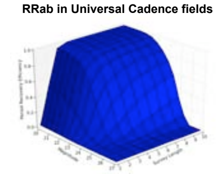
Plots of the successful period recovery rates are shown below for 1-, 3-, and 10-year surveys as a function of stellar magnitude. A successful period recovery was defined as possessing a fractional error in the fitted period to within 0.1% of the input period in two of the three *gri* bands:

$$\frac{\left|P_{fit} - P_{in}\right|}{P_{in}} \leq 0.001 * P_{in}$$

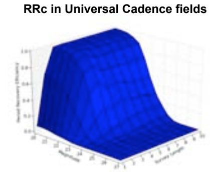


Period Recovery by Stellar Type

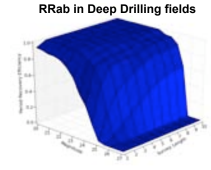
RRab in Universal Cadence fields



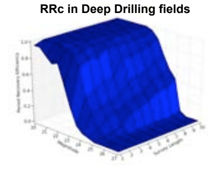
RRc in Universal Cadence fields



RRab in Deep Drilling fields



RRc in Deep Drilling fields



Conclusions

The results reported here illustrate LSST's ability to recover the lightcurves of periodic variable stars. RR Lyrae periods, amplitudes, mean magnitudes, Fourier phase differences, and Fourier amplitude ratios were recovered for a significant fraction of stars to magnitude 25.5 despite the larger photometric scatter. If realized, these results would represent orders of magnitude increase in the number well-observed RR Lyrae stars allowing LSST to probe Milky Way halo substructure over a much larger fraction of the sky and beyond the Milky Way tidal radius. Future work will involve automated template fitting and color evolution studies related to stellar typing.

Acknowledgements

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