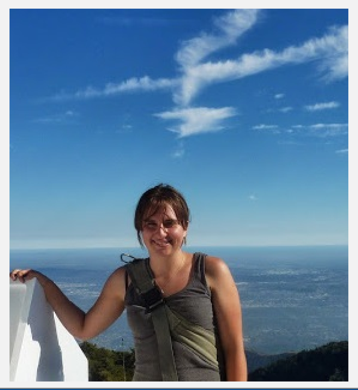
Timescale-dependent “Red-Noise” and the X-ray Binary SMC X-1



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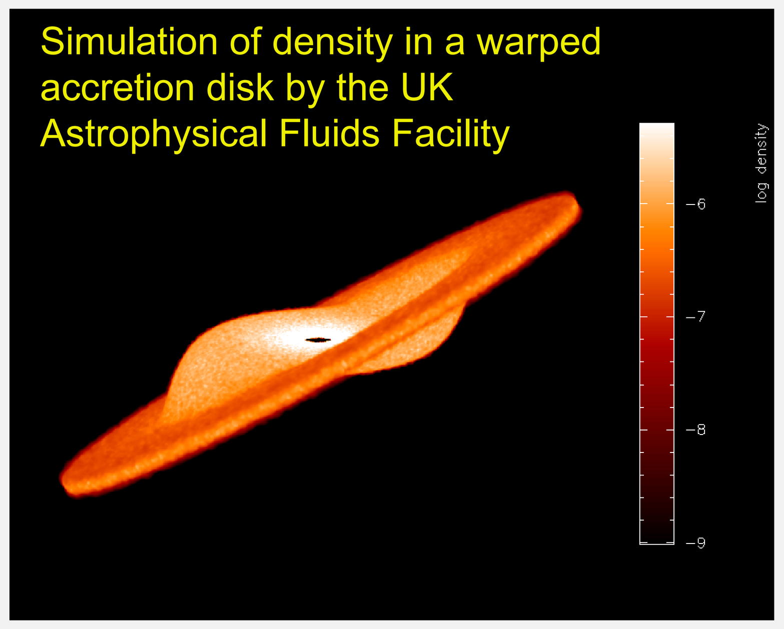
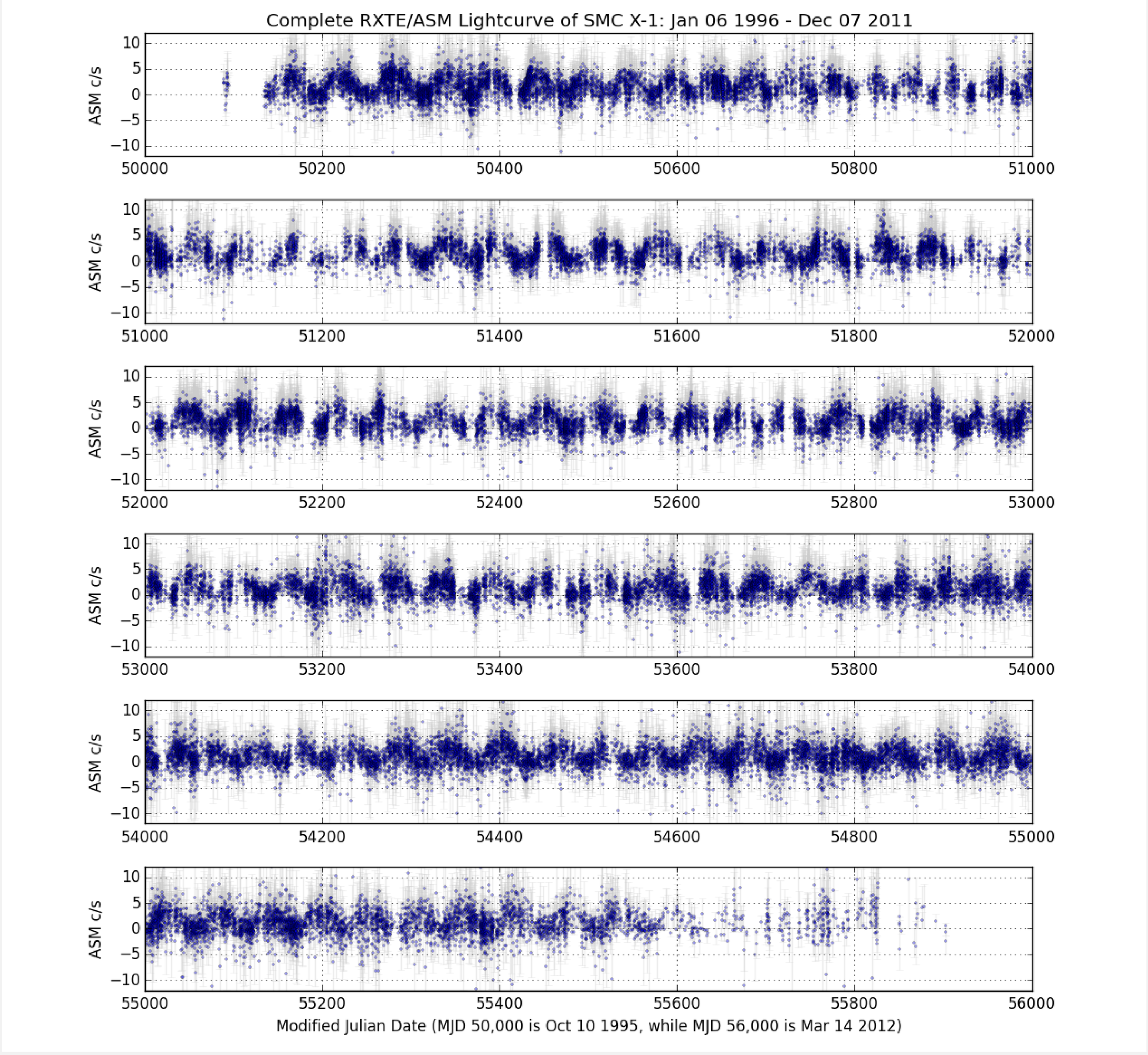


0. Abstract

A growing number of X-ray binaries show superorbital X-ray periodicities, in which the accretion disk surrounding the neutron star accretor is thought to warp and precess on a timescale tens-hundreds of times as long as the binary orbital period. We have used the Rossi X-ray Timing Explorer (XTE) to show that in at least one case - the high-mass X-ray binary SMC X-1 - the accretion disk precession is likely directly linked to the flow of accreted mass through the disk, as changes in the X-ray pulse period and accretion disk superorbital period apparently follow each other (Dage & Clarkson 2015 in prep).

To estimate realistic measurement errors on this behavior, however, we must accurately simulate the complicated a characteristics of the longterm XTE lightcurve used in the analysis, to determine (i) the true statistical significance level of detected signals, and (ii) the true measurement error on the detected periodicity as it evolves over time. This has required implementation of timescale-dependent “red noise” into our tests, in which the power of noise fluctuations depend somewhat strongly on the fluctuation timescale - a property manifestly present in the XTE lightcurve of our target source (as is typical for this instrument on this satellite). I present the current status of our measurements and our robust uncertainty estimates using the Timmer & Koenig (1995) algorithm to generate appropriate noise, and outline the expected next steps in this project. Since the XTE satellite has de-orbited, we expect this work to result in the definitive paper on the long-term X-ray behaviors of SMC X-1.

1. The data: 15 years of X-ray variation

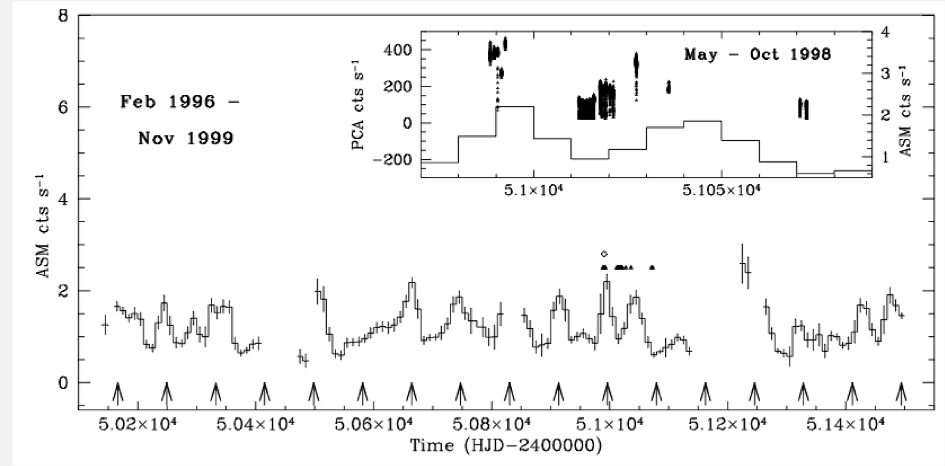


Above: The ASM lightcurve of SMC X-1 over the mission lifetime of the XTE satellite. Points are randomly sampled roughly 0-20 times per day in the 0.2-12 keV energy range.

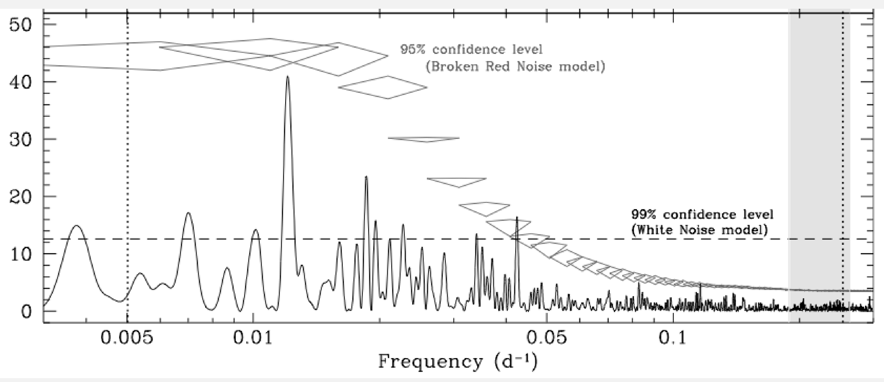
1B: Dataset Properties

Energy Range	0.2-12 keV
Time Resolution	90 seconds
Sampling	(Random) 0-20 per day
Years Active	1996-2012

2. The Challenge: Timescale-dependent “Red-Noise” Complicates Detection of Periodicities:



Top panel: XTE/ASM lightcurve of the short-period (~3000s) X-ray binary XB1916-053, from Homer et al. (2001 MNRAS 322, 827). A stable superorbital variation would imply a precessing accretion disk…



… and indeed the Lomb-Scargle periodogram does show a strong peak near 50 days, well above the 99% significance level to timescale-independent “white noise” (**Bottom panel** also from Homer et al. 2001).

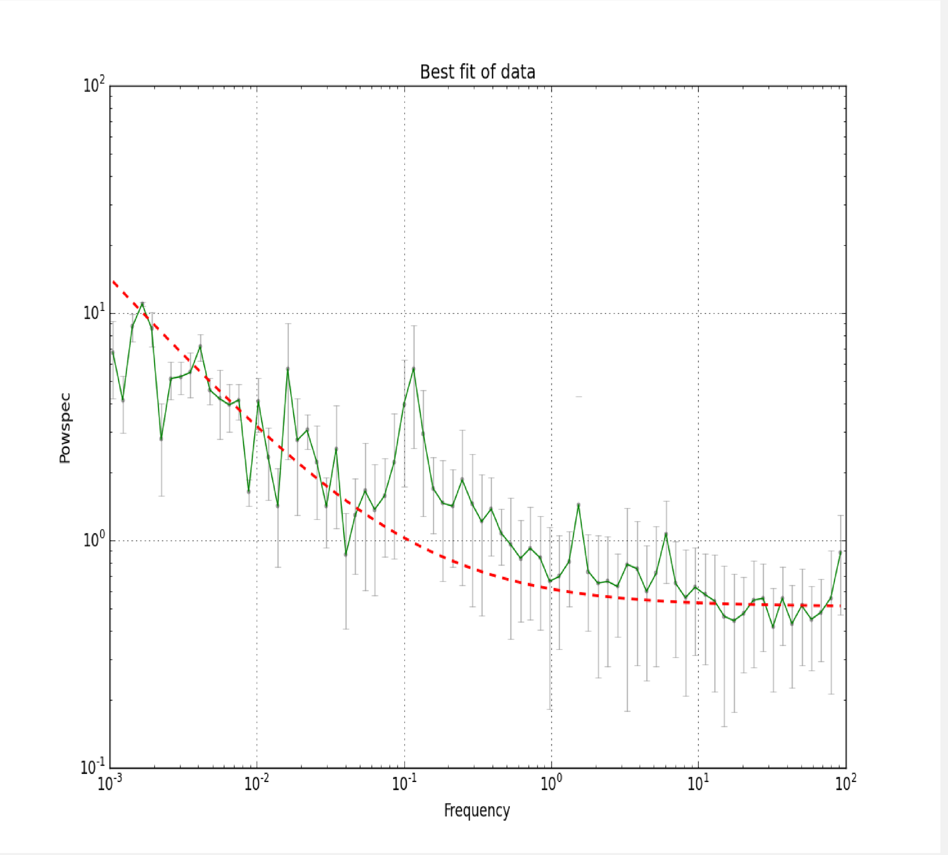
However, the detection of periodicity is ***not*** significant against timescale-dependent “Red-noise” (diamonds).

Indeed, red-noise has confounded detections in a range of astrophysical fields, including (i) extrasolar planet detection from the ground (e.g. Pont et al. 2006 MNRAS 273, 231) and (ii) falsifying the claim of gas blobs detected on their innermost stable circular orbit near the Milky Way’s central black hole (Do et al. 2009 ApJ 691, 1021)

3. We Detected a Varying Superorbital Period from SMC X-1. Is This Significant Against a Realistic Noise Model?

X-ray spectroscopy (e.g. Vrtilek et al. 2005 ApJ 626, 307) suggests the longterm periodicity in SMC X-1 is related to accretion disk precession. **If the superorbital period does indeed vary together with the pulse period, this would be the first concrete detection of a causal link between changes in mass transfer rate and accretion disk warping.**

However, like XB1916-053, the SMC X-1 dataset **does** show timescale-dependent red-noise (right). To characterize this, we use CERN's MINUIT routines, which have been used for decades in particle physics and are particularly well-suited to models with a large range in scales and on which physical constraints such as positivity may be indicated (as is the case here).



When this was applied to the binned XTE/ASM power spectrum (green, above), it produced a fit of the data (red dashed lines) according to the function A ν**(-α) +B. Those parameters were used to generate fake lightcurves in Monte Carlo trials (below).

4. Simulating Detections Under a Realistic Red-noise Model, and Determining the Significance Level

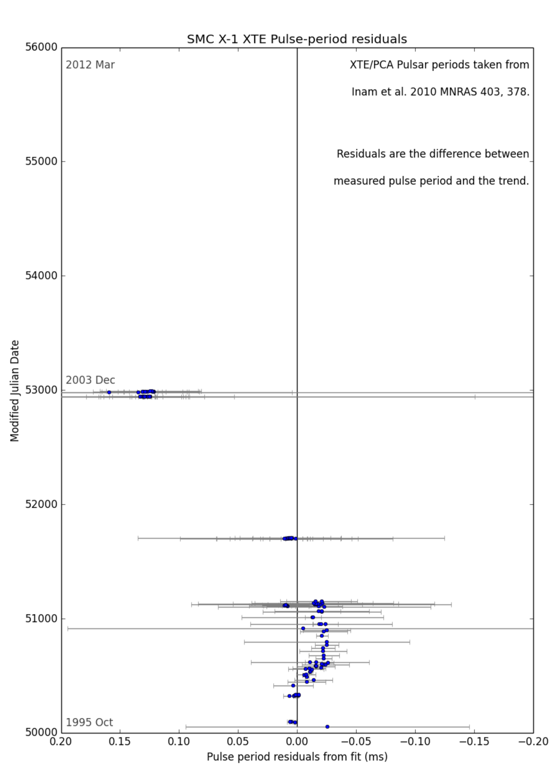
Fake power spectra were generated by creating random gaussian deviates in Fourier amplitude and phase under the envelope of the best-fit model parameters, inverse Fourier-transformed to evenly-sampled lightcurves, and finally sampled at the true XTE/ASM sample times to produce a realistic pure-noise lightcurve (this is the algorithm of Timmer and Koenig 1995 A&A 300, 707).

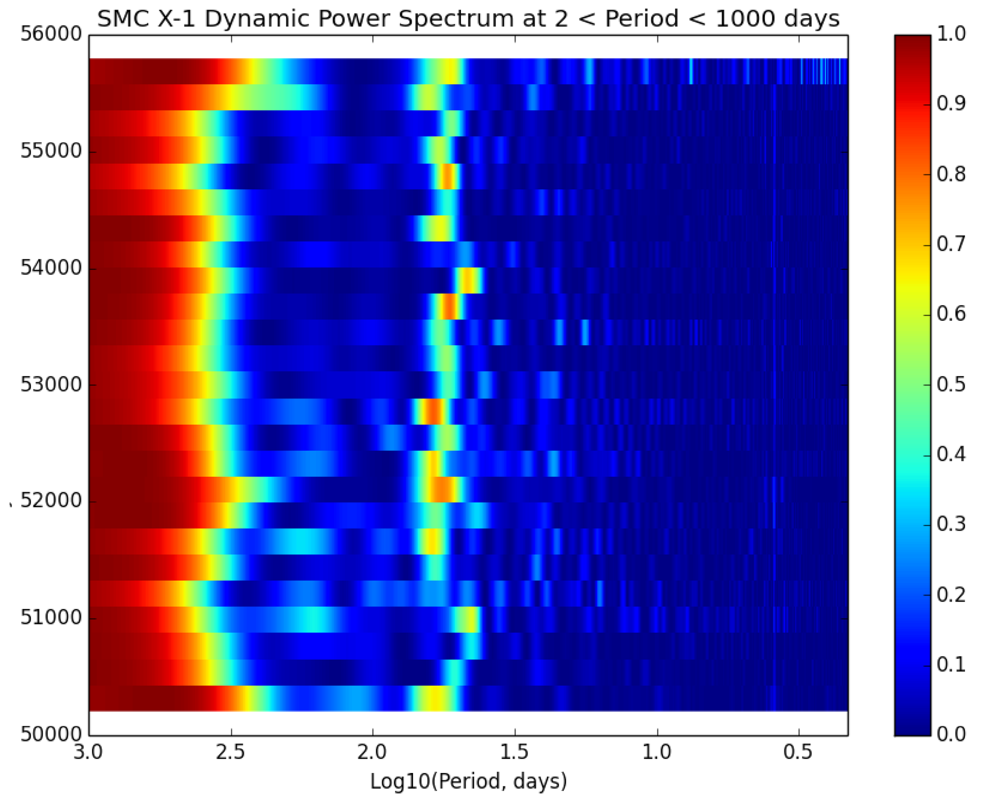
Each fake dataset was then run through the exact same routines used on the real ASM/XTE data for SMC X-1. A side by side comparison of the Lomb-Scargle periodograms (below) shows many similarities between the real and fake data, although the real signal (middle panel below) is rather more persistent than temporary signals due to Red-noise (right panel below).

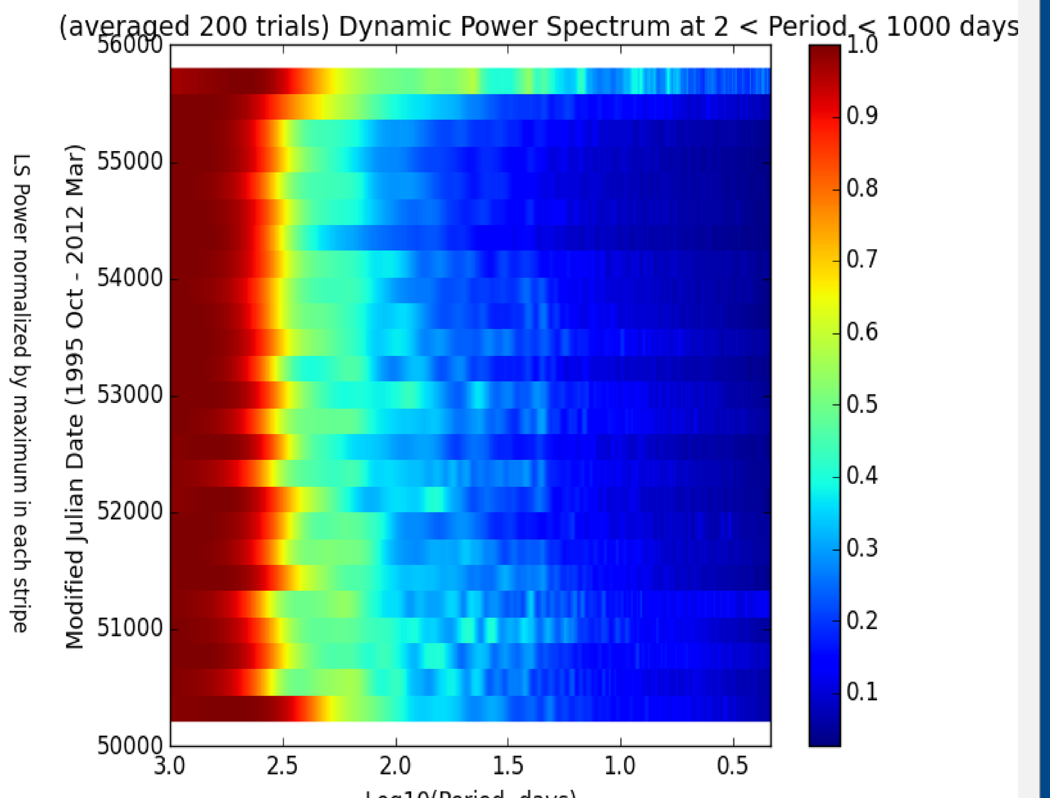
Left panel: Residuals in X-ray pulse periods assembled by Inam et al. (2010 MNRAS 403, 378). A visual correlation between variations in pulse period residual (left) and superorbital period near log(Period)=1.7 is apparent.

Middle panel: Lomb-Scargle power spectrum from the XTE/ASM data of SMC X-1, over the same time interval.

Right panel: As the middle panel, but for pure timescale-dependent red-noise.



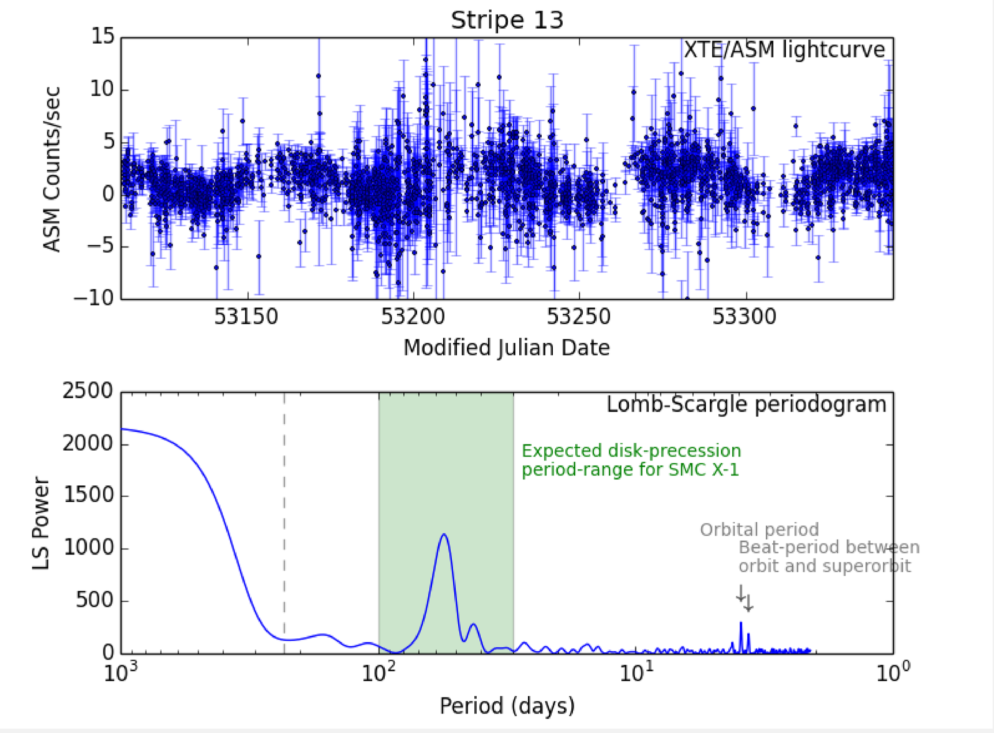


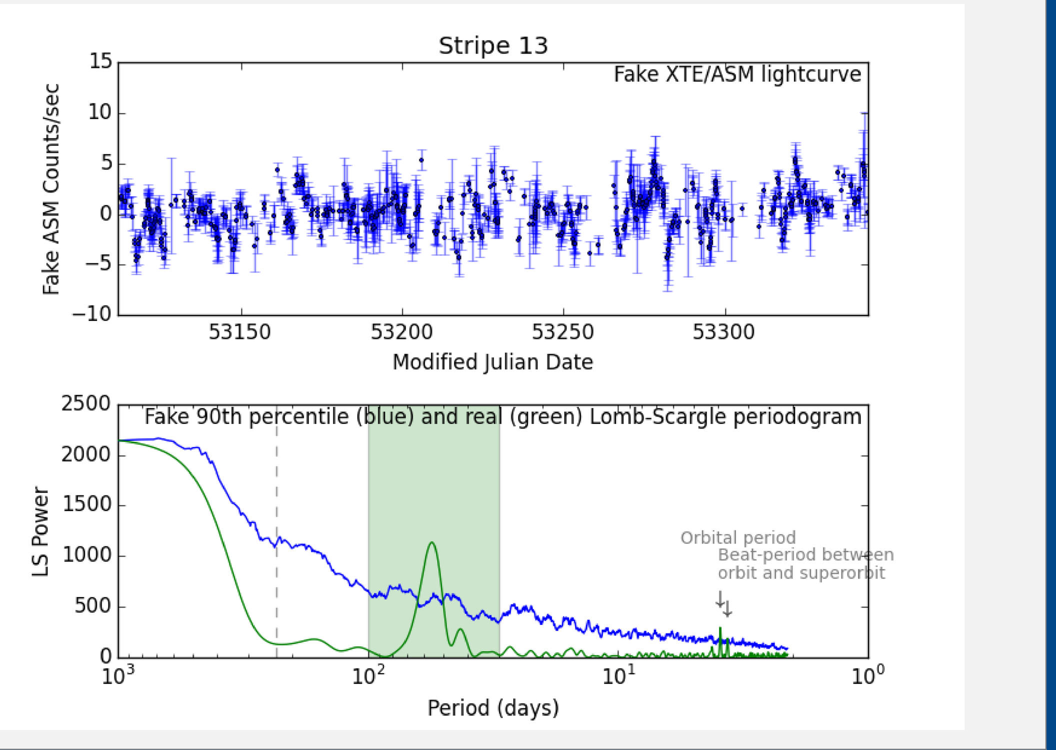


Top row: ASM lightcurve for a single “strip” from the time-series, for real (left) and fake (right) data.

Bottom row: Lomb-Scargle periodogram of the ASM lightcurve over the strip, plotted in a log-linear scale.

Note: the bottom-right power spectrum shows the level beneath which 90% of fake trials report a signal at the given power or lower– and thus represents our 90% significance level under Red-noise.





5. Conclusions

1. **Timescale-dependent red-noise IS present in the SMC X-1 dataset**
2. **However, we still clearly detect coherent modulations**
3. **The varying superorbital modulation is “real.”**

6. Acknowledge-ments

This work was only possible because of the efforts of the ASM/RXTE team at MIT and NASA/GSFC. Data was obtained through the High Energy Astrophysics Science Archive Research Center Online Service, provided by NASA/GSFC.

This research made use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration, 2013).