Search for possible period for Scorpius X-1

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Outline

Paper

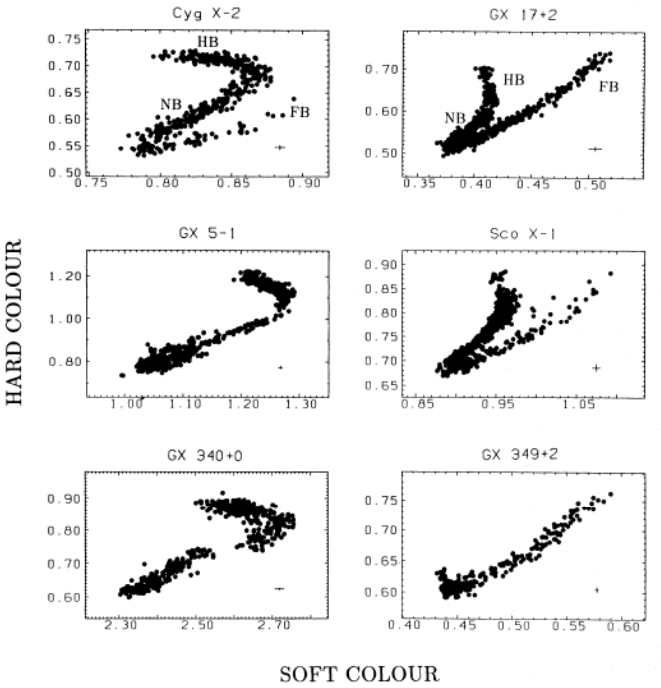
- Millisecond Pulsars in X-Ray Binaries (Deepto Chakrabarty 2004)
- The X-Ray Spectral Changes of Scorpius X-1 (C. F. Bradshaw et al.2003)
- Millisecond X-Ray Pulsars in Low-Mass x-Ray Binaries (Nicholas E. et al. 1997)
- Kilohertz Quasi-periodic Oscillation Peak Separation is Not Constant in Scorpius X-1(van der Klis et al. 1997)

RXTE data

- Power spectrum
- Epoch folding

Future work

Bright low-mass X-ray binaries (LMXBs) have been classified into two major groups—the higher luminosity Z and the lower luminosity atoll sources.



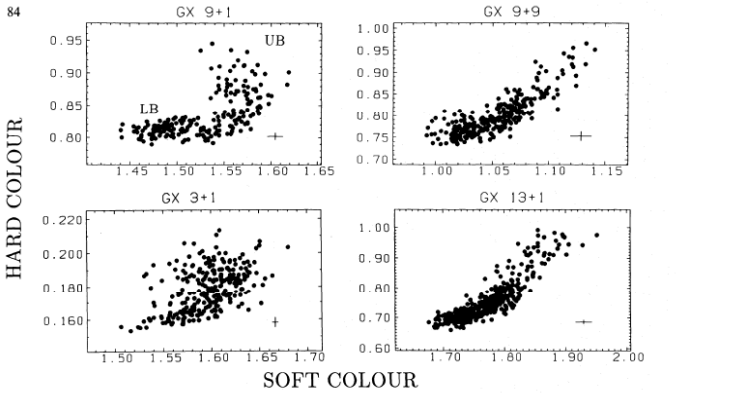


Fig. 2a (see also Fig. 1a). X-ray colour-colour diagrams of atoll sources in the banana state. Lower banana (LB) and upper banana (UB) are indicated

(Hasinger & van der Klis 1989)

Typically the hard colours was calculated as the count rate ration of the 6-20 keV to the 4.5-6keV band and the soft colours as 3-4.5keV/1-3keV.

radio pulsars

- Almost radio pulsars are single objects that radiate away their rotational energy in the form of relativistic particles and magnetic dipole radiation
- all radio pulsars are losing angular momentum and slowing down

X-ray pulsars

- X-ray pulsars are members of binary star systems and accrete matter from either stellar winds or companion star.
- The accreted matter transfers angular momentum to the neutron star causing the spin rate to increase or decrease. X-ray pulsars exhibit a variety of spin behaviors.

- LMXB NSs to be progenitors of millisecond radio pulsars because such rapid spin frequencies must occur in accreting low-magnetic-field neutron stars.

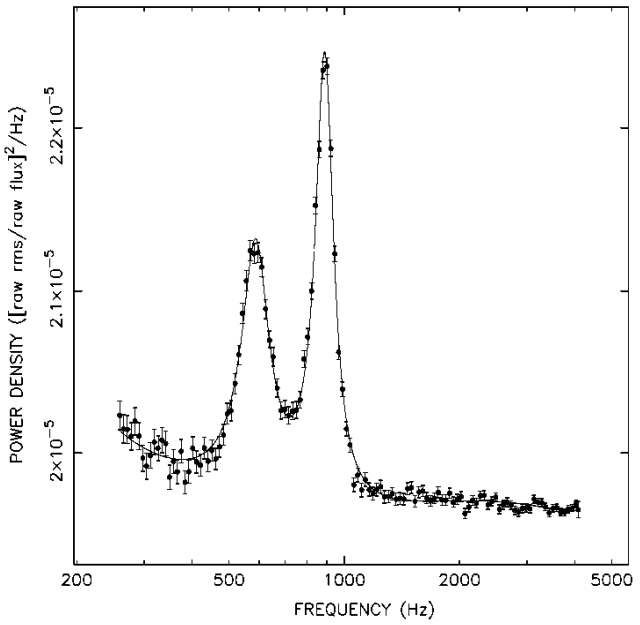
Millisecond Variability in Accreting Neutron Stars

RXTE has identified three distinct classes of millisecond variability in accreting neutron stars:

- KILOHERTZ QUASI-PERIODIC OSCILLATIONS
- X-ray burst oscillations
- Persistent accretion-powered pulsations

KILOHERTZ QUASI-PERIODIC OSCILLATIONS

- The kilohertz quasi-periodic oscillations (kHz QPOs) were discovered at NASA's Goddard Space Flight Center in February 1996, just two months after RXTE was launched.
- Two simultaneous quasi-periodic oscillation peaks ("twin peaks") in the 300–1300 Hz range and roughly 300 Hz apart occur in the power spectra of low-mass X-ray binaries containing low-magnetic-field neutron stars of widely different X-ray luminosity L*x.*
- These oscillations are believed to arise in the inner accretion disk flow, where the dynamical time scale is of order milliseconds.



van der Klis et al 1997b

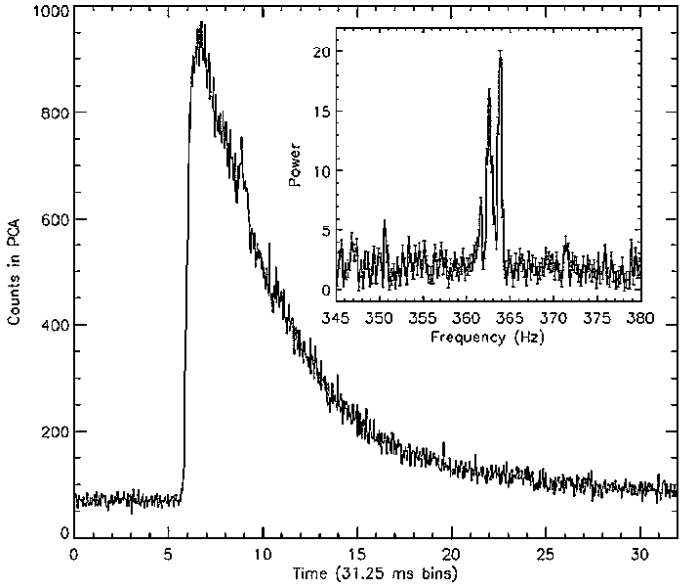
X-ray burst oscillations

- This leads to a burst of X-ray emission with a rise time of typically *<1s, and a 10^1–10^2 s exponential decay* resulting from cooling of the neutron-star atmosphere.

- The first incontestable type 1 burst oscillation was discovered with RXTE in a burst that occurred on February 16, 1996, in the reliable burst source 4U 1728–34. An oscillation with a slightly drifting frequency near 363 Hzwas evident in a power spectrum of 32 s of data starting just before the onset of the burst (Strohmayer et al 1996a,b,c; Figure 3). The oscillation frequency increased from 362.5 to 363.9 Hz in the course of 10 s.

- These are nearly coherent millisecond oscillations observed only during thermonuclear X-ray bursts.

- It was suspected that the millisecond oscillations were somehow tracing the stellar spin.



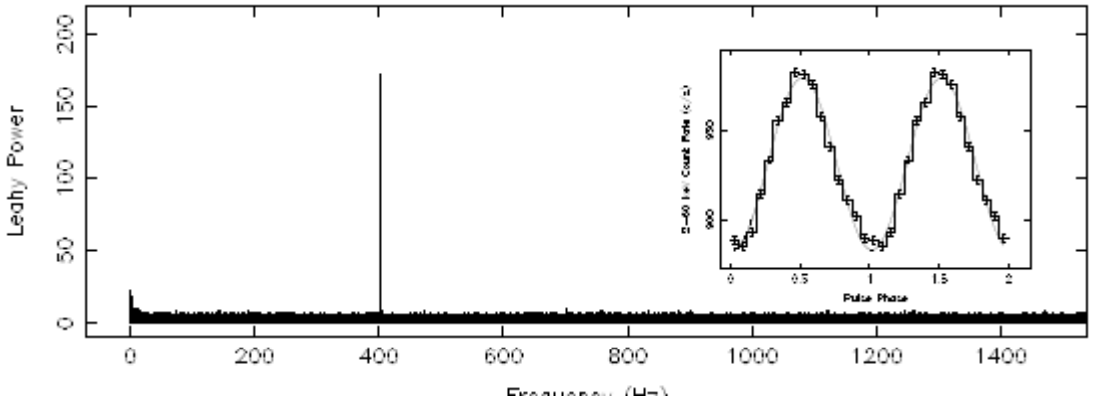
A burst profile and its power spectrum (inset) showing a drifting burst oscillation in 4U 1728–34 (Strohmayer et al 1996c)

Persistent accretion-powered pulsations

- These are the objects originally expected by the recycling hypothesis, NS/LMXBs whose persistent (nonburst) emission contains coherent millisecond pulsations.

- why is it so difficult to find persistent millisecond pulsations in most NS/LMXBs? It should be noted that none of the millisecond X-ray pulsars has been detected as a radio pulsar.

Fourier power spectrum showing coherent 401 Hz X-ray pulsations in the persistent pulsar SAX J1808.4−3658. The inset shows the highly sinusoidal pulse profile. Adapted from Wijnands & van der Klis (1998).



Why most neutron stars in LMXBs are not pulsars?

- the most of the NSs have magnetic fields that are too weak to channel the accretion flow

  (Although there is evidence for radio pulsars with fields much weaker than 10^8 G.)

- the neutron stars in non-pulsing LMXBs are surrounded by a scattering medium that attenuates pulsations

- The gravitational self-lensing might attenuate the pulsations

(Deepto Chakrabarty 2004)

- a strict upper limit on the neutron star spin rate is given by the centrifugal breakup limit, up to 3 kHz depending upon the neutron star equation of state (Cook, Shapiro, & Teukolsky 1994; Haensel, Lasota, & Zdunik 1999).

- The lower QPO frequency is a beat between a characteristic frequency in the inner accretion disk (the higher QPO frequency) and the neutron star spin. The crucial evidence that supports this conclusion came from observations of 4U 1728234 by Strohmayer et al. (1996),

- Kilohertz quasi-periodic oscillation peak separation is not constant in Scorpius X-1

- They conclude that the magnetospheric beat-frequency model is now unlikely to explain the kilohertz QPO in Sco X-1. (van der Klis et al. 1997)

The Rossi X-ray Timing Explorer Mission

http://heasarc.gsfc.nasa.gov/docs/xte/xtegof.html

(1995-present)
low-earth orbit (about 600 km and 23 deg inclination)

- Probes the physics of cosmic X-ray sources by making sensitive measurements of their variability over time scales ranging from milliseconds to years.

Payload :

- Proportional Counter Array (PCA)
  Detectors: 5 proportional counters
  Energy range: 2 - 60 keV Energy resolution: < 18% at 6 keV
  Time resolution: 1 microsec
- High Energy X-ray Timing Experiment (HEXTE)
  15-250 keV energy range, 2 X 800 sq cm
- All-Sky Monitor (ASM)
  2-10 keV energy range, 2.25*10^-3counts/s per camera sensitivity

- **Science Array Files**

The science array format is used for data binned at regular intervals by the spacecraft electronics. Examples are the PCA Standard 2 configuration, which contains 129-channel spectra accumulated every 16 seconds, and HEXTE multi-scalar Bin mode, which contains light curves in 1-8 spectral bands. The data occupy the XTE_SA extension in the form of regularly accumulated arrays or histograms.

- **Science Event Files**

The science event format is used for unbinned data, i.e. for individual events. An example is the PCA Good Xenon configuration which contains time-stamped events with 256-channel resolution, PCU ID and anode ID. The science data occupy the XTE_SE extension in the form of event words - binary-encoded descriptions of the individual events. This format is more compact than the column-based format used for ROSAT and ASCA event-lists, and is fundamentally different.

- **Binned Data mode yields data in a time-series of regularly accumulated histograms of pulse** height (energy), time and event type.

- **Single-Bit Code mode generates a stream of ones and zeros representing events and clock ticks.** Generic Single-Bit configurations have names like SB_125us_0_249_1s.

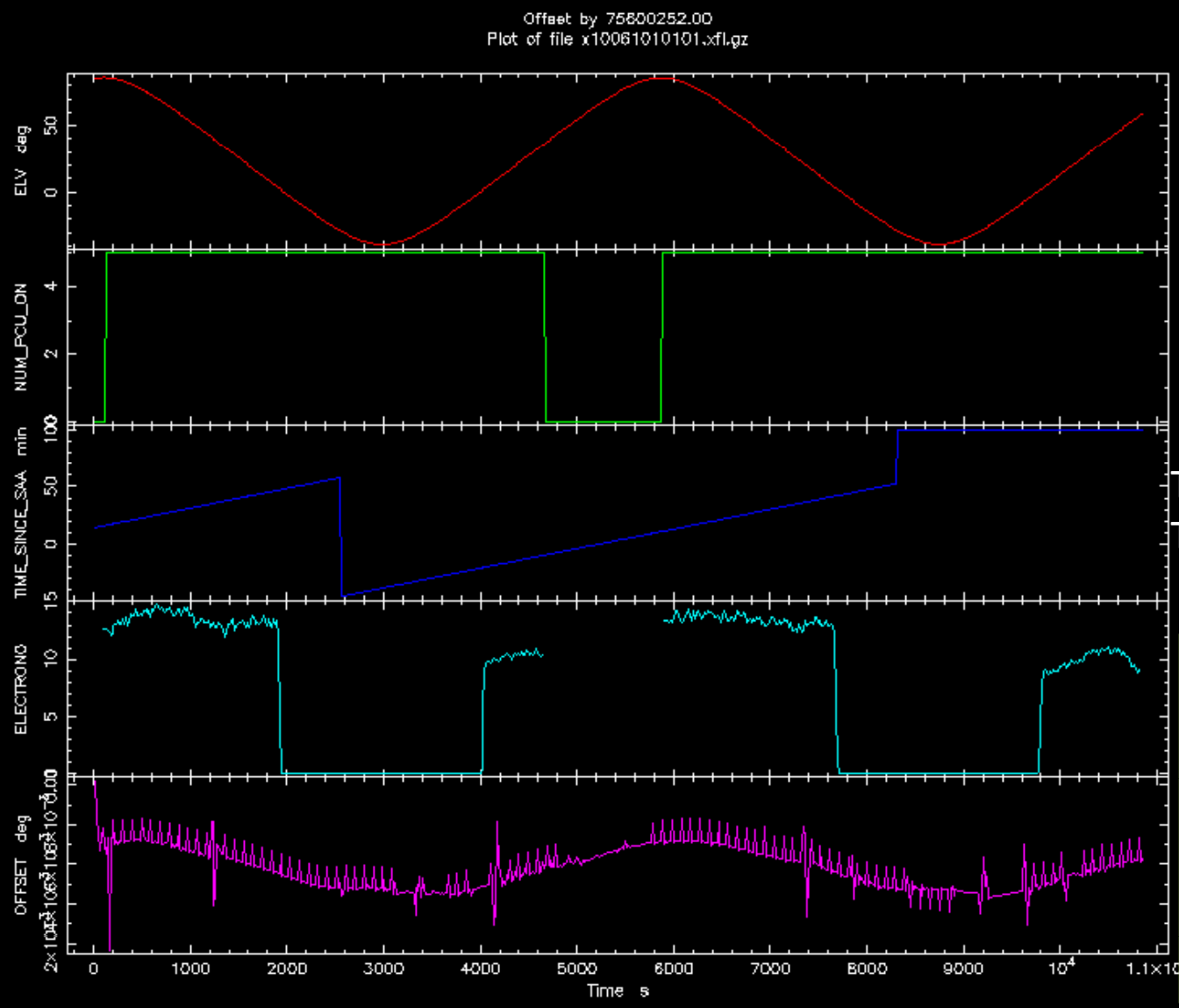
PCA data reduction

- Download RXTE data of Scorpius X-1 from High Energy Astrophysics Science Archive Research Center(HEASARC).
- Use XDF to find the files of Binned Data mode.

  ex: B_125us_1M_0_87_H
- Examine the filter file
- Make the GTI file

B_ttt_ccX_0_hh_B, where ttt is the time bin size, cc is the number of energy channels, X selects the channel boundary option, hh specifies the upper channel boundary, an B is one of Q,H or F specifying that 4, 8 or 16 bit bins have been used.

Scorpius X-1



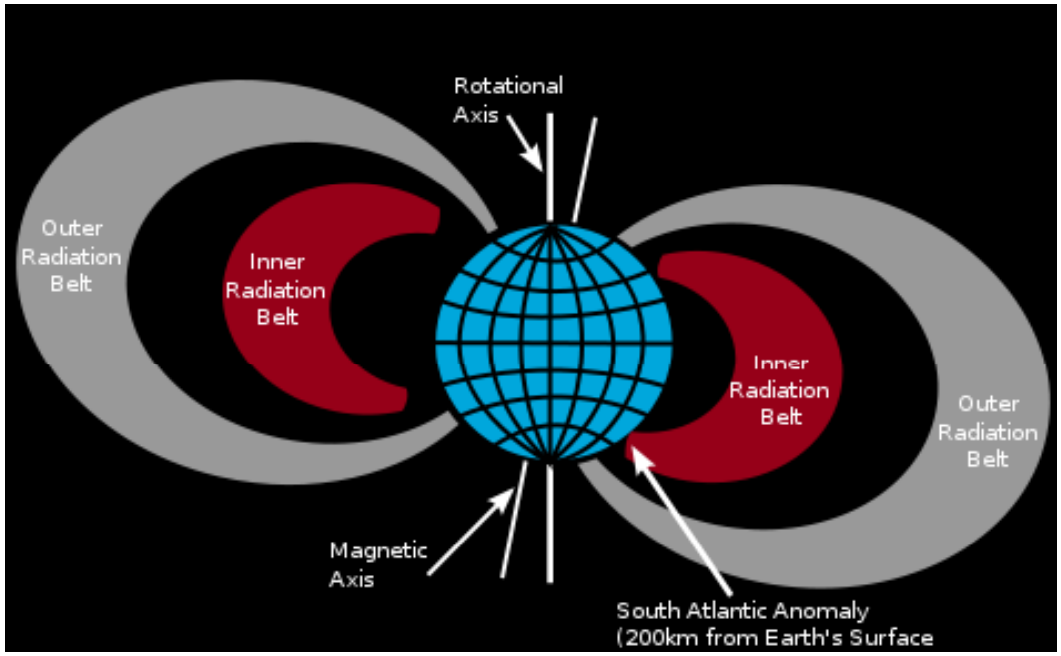
ELV > 10

NUM_PCU_ON

TIME_SINCE_SAA < 0
TIME_SINCE_SAA > 30

Create a GTI

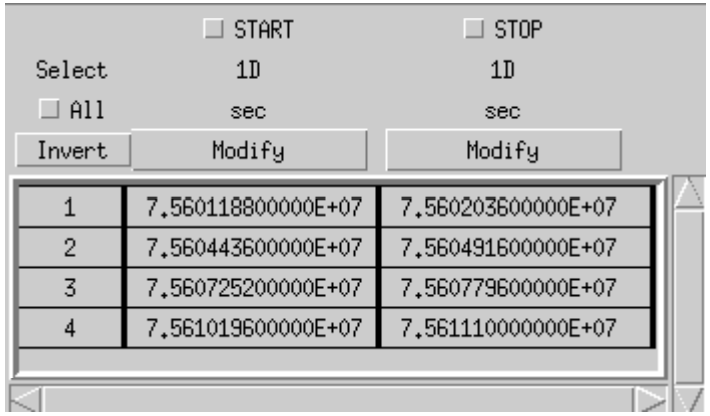
- Were there any Earth occultations?
- How many PCUs were on?
- Were there any SAA passages during observation?
- Was there significant electron contamination?
- Was the pointing stable?



http://en.wikipedia.org/wiki/File:South_Atlantic_Anomaly.svg

The South Atlantic Anomaly (or SAA) is the region where Earth's inner Van Allen radiation belt makes its closest approach to the planet's surface. Thus, for a given altitude, the radiation intensity is greater within this region than elsewhere.

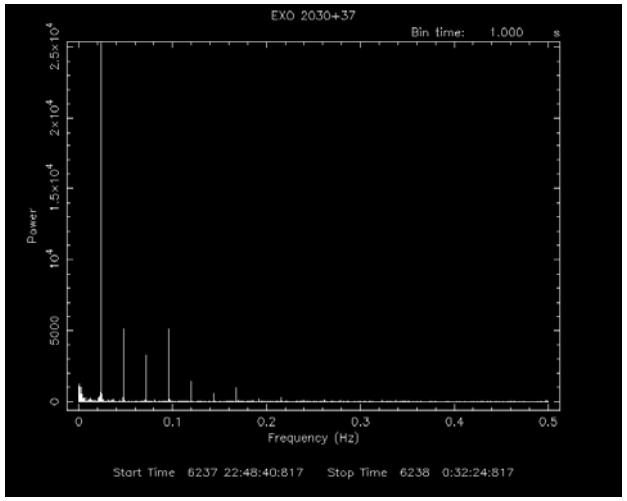
After data reduction …



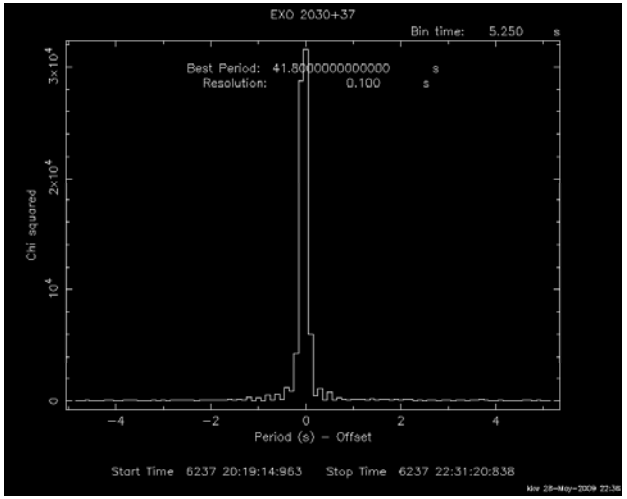
Data analysis process

- Extract a light curve
- make the power spectrum
- Search for the period of light curve

EXO 2030+375

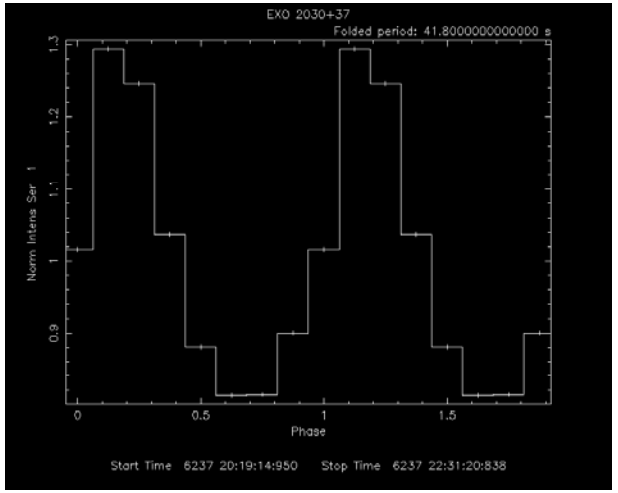


Powspec



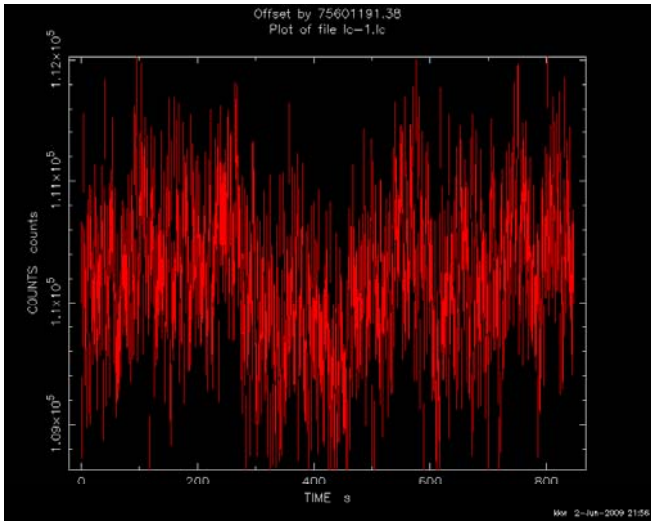
efsearch

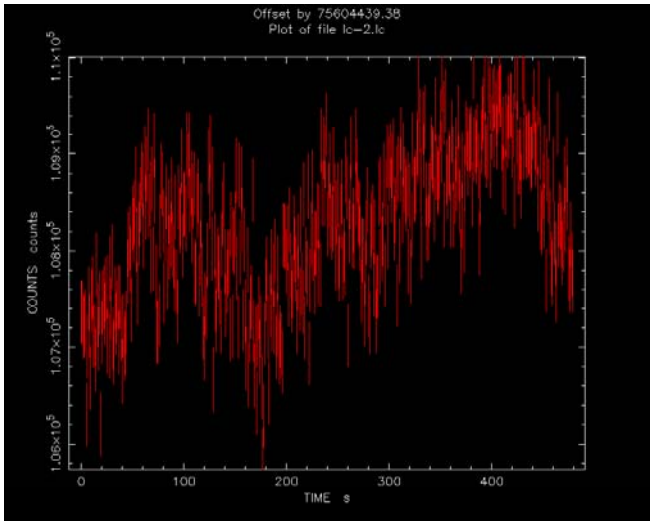
efold



Scorpius X-1 light curve

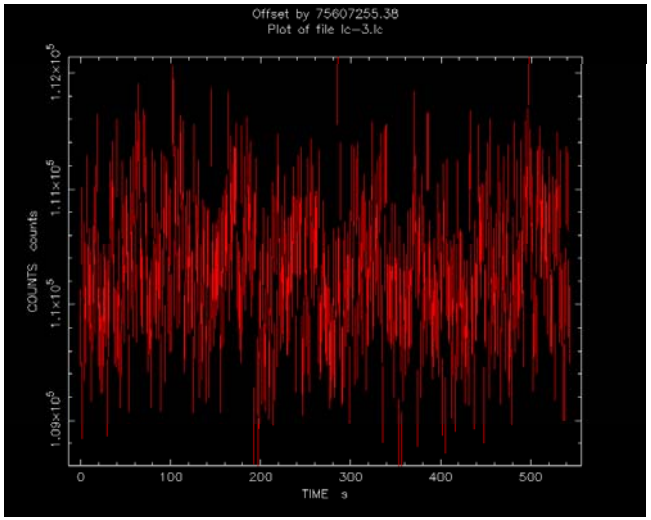
A

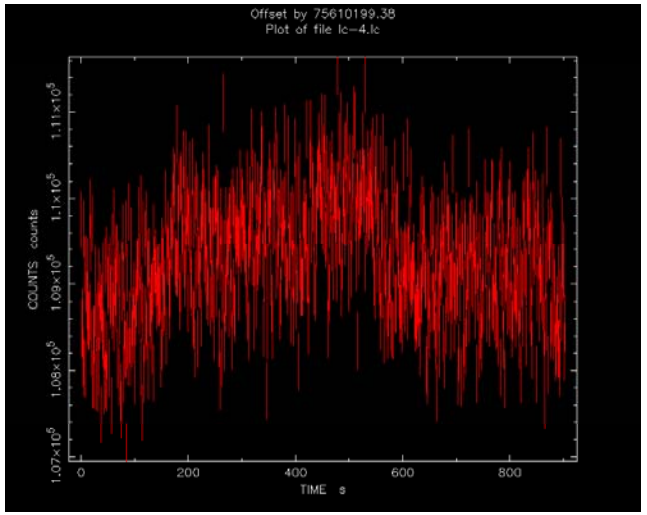




B

C

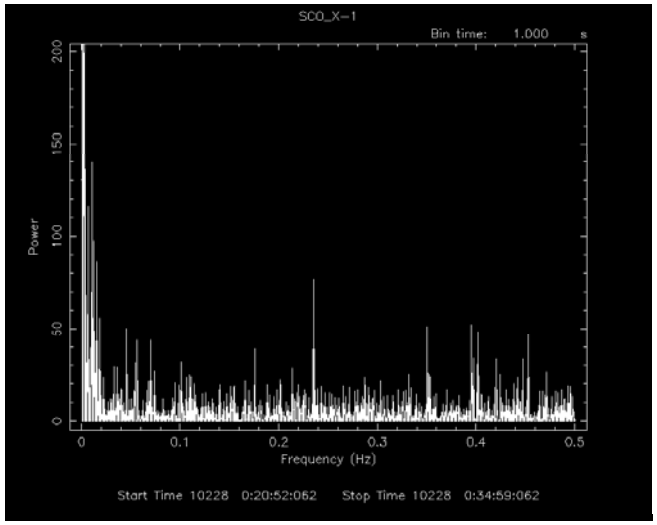


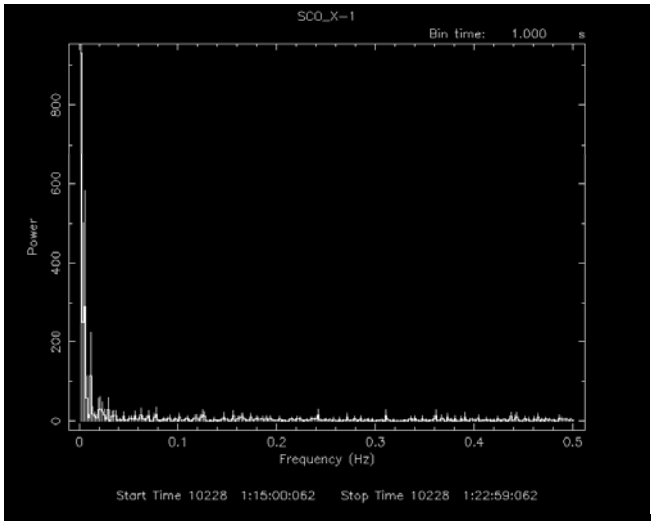


D

Scorpius X-1 power spectrum

A





B

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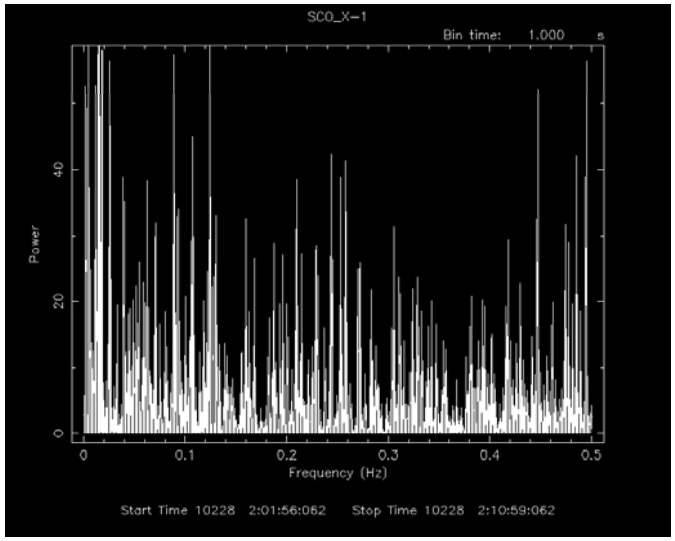
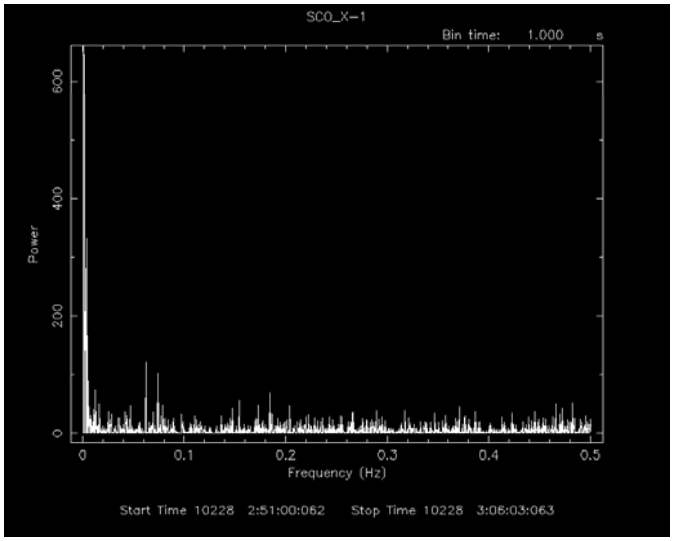
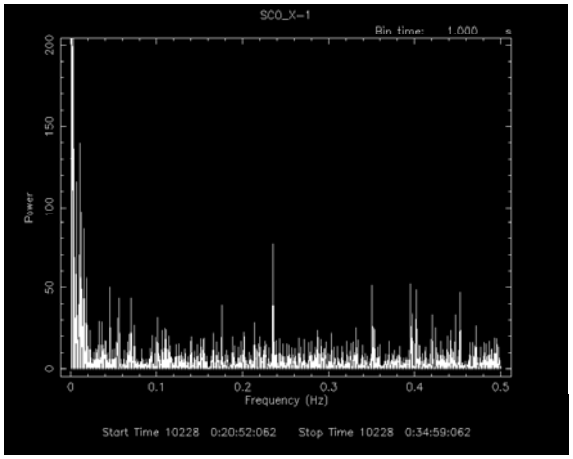




D

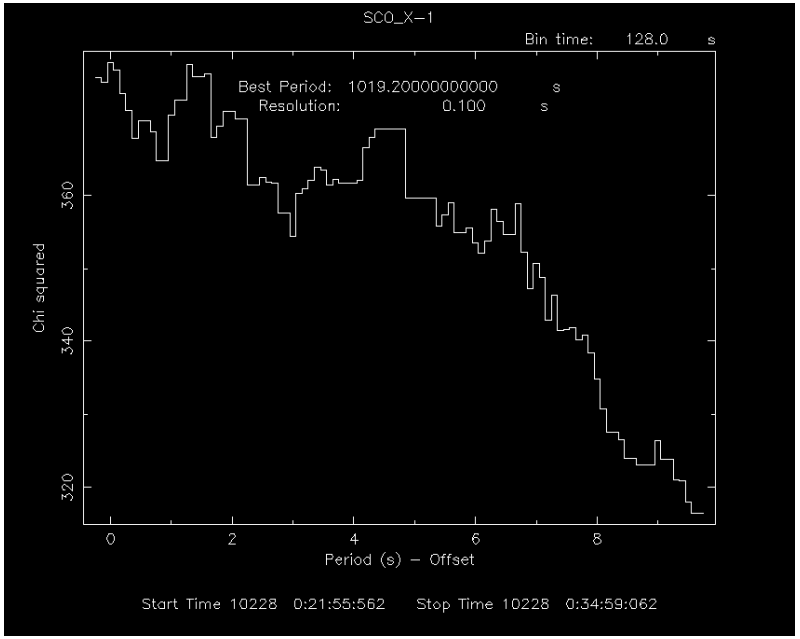
Scorpius X-1

A



efsearch

A-1



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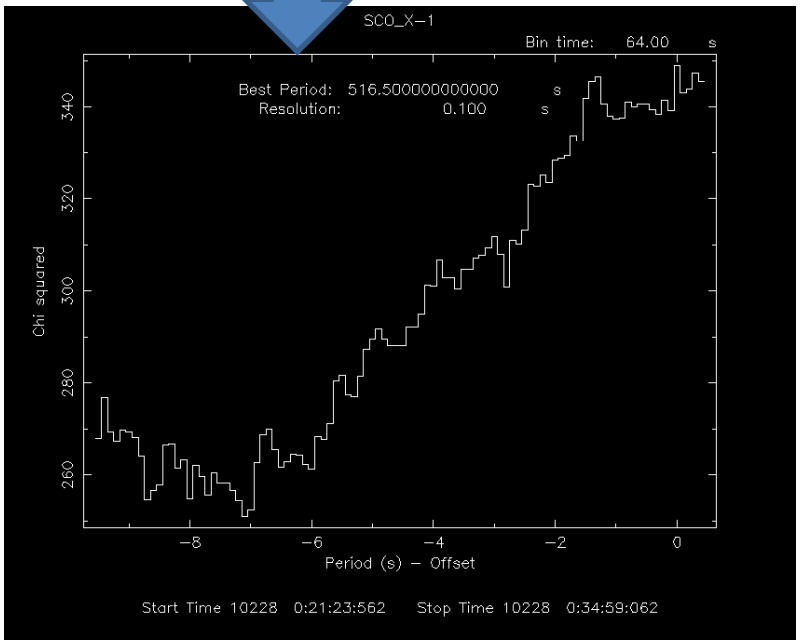

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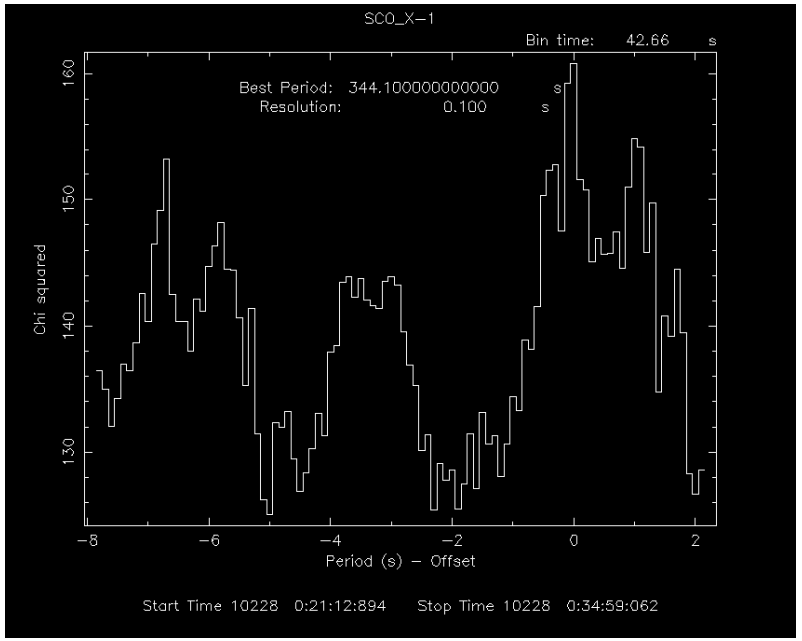
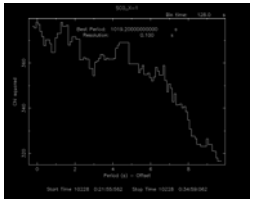
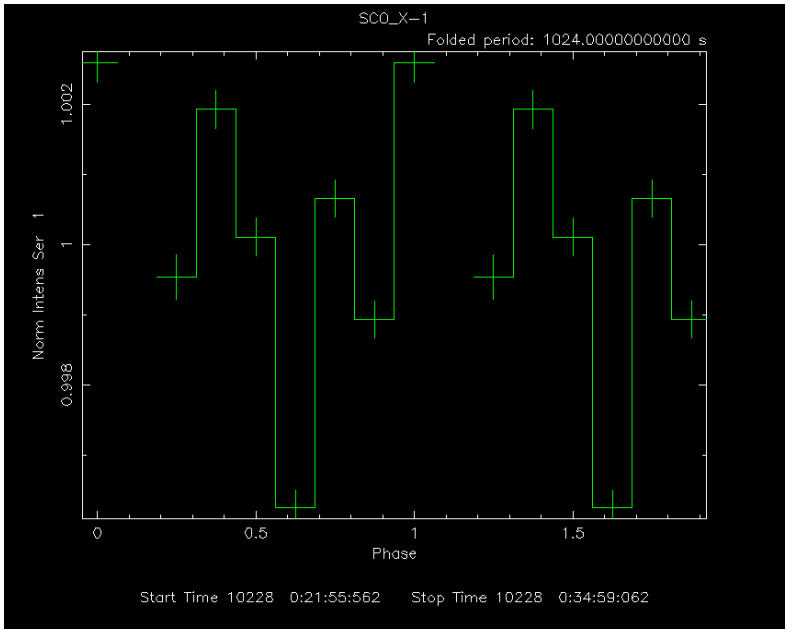
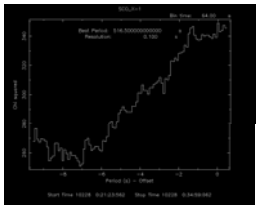


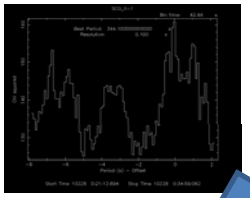
Scorpius X-1



A-1



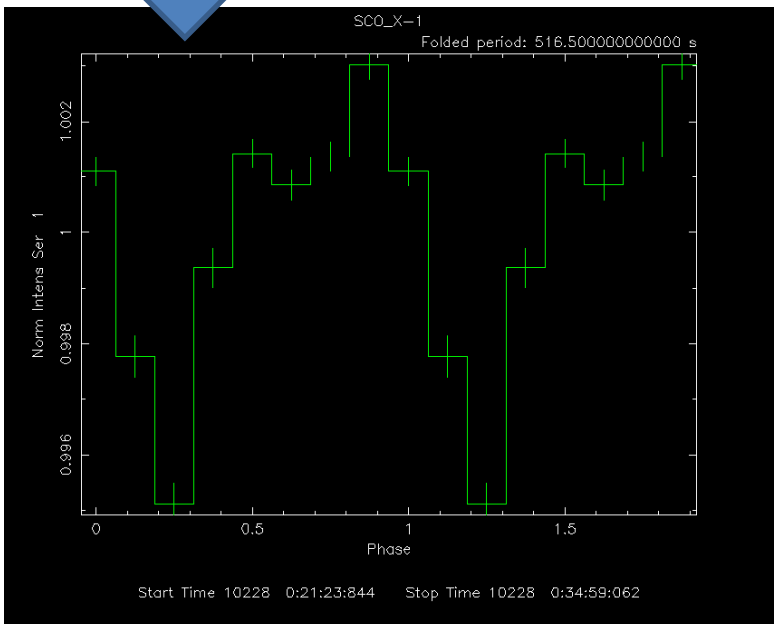


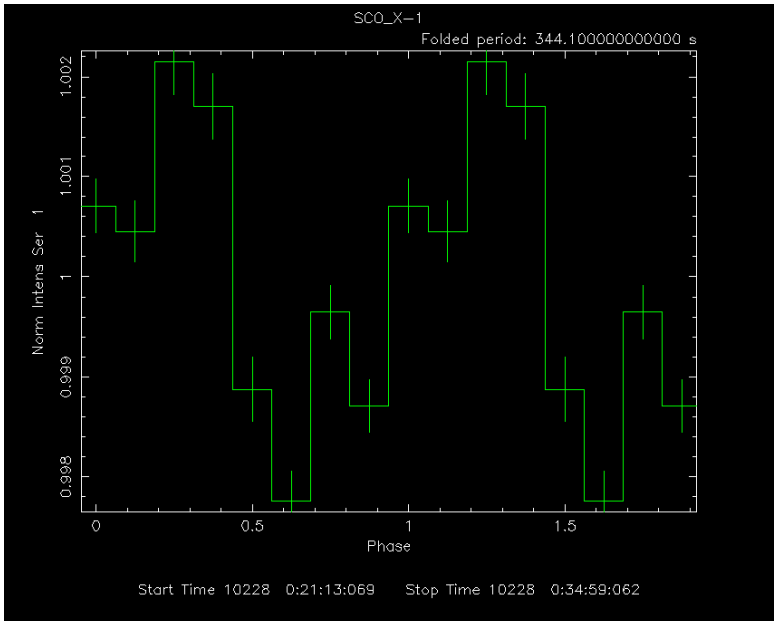


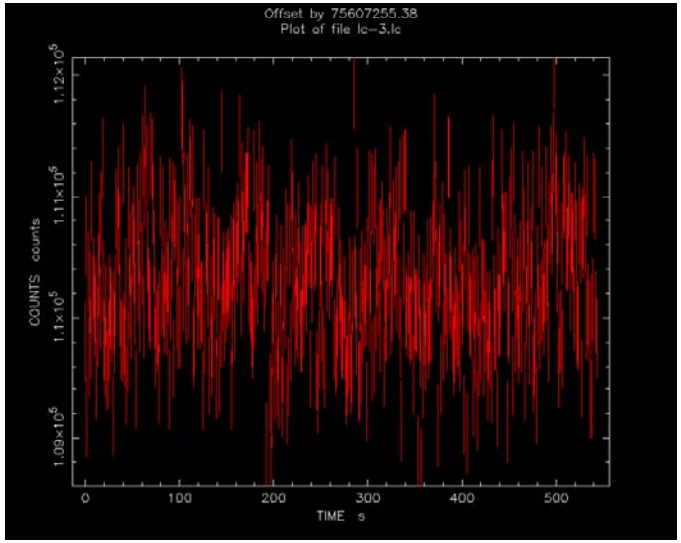
A-3

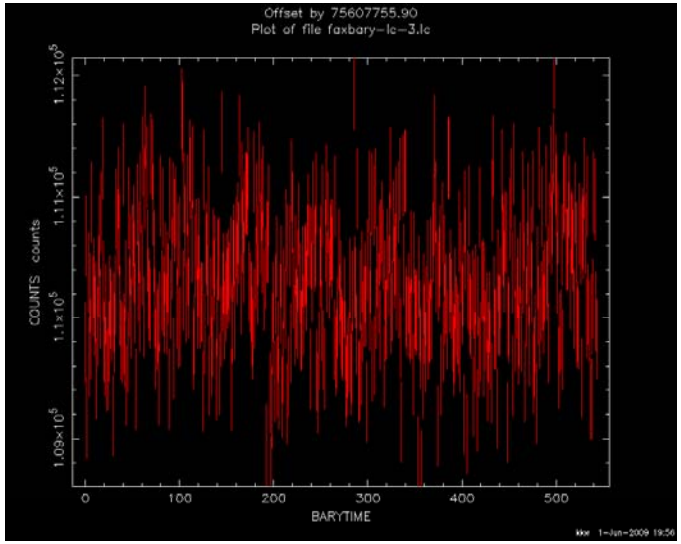
A-2

efold









Barycenter correction routine for XTE light-curve

The center of mass of a system

	TIME	0(	:R	:A	BARYTIME
Select	1D	1D	1D	1D	1D
All	s	un	un		
Invert	Modify	di	di	di	Modify
1	7.560725537843E+07	1	3	1	7.560775589521E+07
2	7.560725637843E+07	1	3	1	7.560775689519E+07
3	7.560725737843E+07	1	3	1	7.560775789517E+07
4	7.560725837843E+07	1	3	1	7.560775889515E+07
5	7.560725937843E+07	1	3	1	7.560775989514E+07
6	7.560726037843E+07	1	3	1	7.560776089512E+07
7	7.560726137843E+07	1	3	1	7.560776189510E+07
8	7.560726237843E+07	1	3	1	7.560776289508E+07
9	7.560726337843E+07	1	3	1	7.560776389507E+07
10	7.560726437843E+07	1	3	1	7.560776489505E+07
11	7.560726537843E+07	1	3	1	7.560776589503E+07
12	7.560726637843E+07	1	3	1	7.560776689501E+07
13	7.560726737843E+07	1	3	1	7.560776789500E+07
14	7.560726837843E+07	1	3	1	7.560776889498E+07
15	7.560726937843E+07	1	3	1	7.560776989496E+07

Future work

- H-test method

  It’s a test for uniformity for which the probability distribution is an exponential function. This test has been shown to have a very good power against most light curve shapes encountered in X-ray and γ-ray astronomy and therefore makes the detection of sources with a larger variety of shapes possible.

- Lomb & Scargle method

- Thank you