X-Ray Timing

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Submission Date: November 3, 2024

Abstract

X-ray timing involves identifying timing signatures of various astrophysical sources. This involves examining their light curves and identifying 'good time intervals' which contain scientifically valuable data. It also involves producing power spectra for these sources in order to identify their characterstic frequencies. These frequencies reveal physical properties of the sources being studied, and allow us to probe compact objects which cannot otherwise be resolved with imaging telescopes. The power spectra may also be used for model fitting which further helps us understand the nature of the sources and their periodic properties. In this report, we present timing analysis of a periodic and an aperiodic source. For the periodic source, we identify its period and perform phase folding to obtain its pulse profile. For the aperiodic source, we identify quasi-periodic oscillations (QPOs) and find a theoretical fit to its power spectrum. We use data collected with the LAXPC instrument of the satellite AstroSat.

1 Theoretical Background

1.1 AstroSat and LAXPC

X-ray astronomy encompasses imaging, spectroscopy, and timing. An X-ray observatory can have any or all of these functions. In general, X-ray observatories are space-based due to the atmospheric absorption of high-energy radiation. The Large Area X-Ray Proportional Counter (LAXPC) aboard the Indian satellite AstroSat is a gas detector used for spectroscopic and timing applications. There are 3 LAXPC units aboard the satellite. A gas detector consists of a chamber filled with gas such that an incident X-ray photon causes a cascade of electrons through the gas which can be detected by electrodes in the chamber. In the case of the LAXPC, there are five detection layers within the gas chamber.

Since these detectors are generally placed in space-based observatories, they are inundated by cosmic rays which are high energy charged particles and can thus initiate the same cascade of electrons as the signal of interest. The photons of interest will always enter the gas from the pointing side of the detector. Thus, in order to discount all detections due to cosmic ray illumination, LAXPC has detectors lined along the other three sides of the gas detector outside the main detection volume. These additional detectors are known as 'veto' detectors. Charged particles that enter the photon detection volume will always escape the gas chamber after exciting the gas. When they leave the volume, they will also be detected by these additional detectors. Now, if we discount all events which occur simultaneously in the main volume and the veto detectors, we will remove all effects of cosmic rays.

Now, since detection relies on the gas being ionised, we need the gas to be in its 'active' state in order to detect incoming photons. However, after a certain number of incident photons, all the gas in the chamber will be ionised. This will prevent the next detection until the gas returns to its active state. The amount of time taken for the detector to recover from a detection and be ready for the next detection is known as 'dead time'. Corrections for dead time must be applied offline during analysis. The higher the frequency of variation in the observed signal, the larger is the required dead time correction. Since it is often the charged particle incidence rate and not variation in the signal that produces dead time effects, we need to characterise both in order to compute the dead time correction.

1.2 Timing Analysis

In order to perform timing studies, we require various different kinds of data from the satellite. Information regarding each event recorded by the detector is stored in an 'event file'. The voltage recorded by the anode in the detector is stored digitally. This digital value is known as a 'channel number'. The recorded data contains the time, channel number and anode layer ID for each event. This data can also include a rough estimate of the energy corresponding to each channel.

Since each incoming photon creates a cascade of electrons, there is a probabilistic relationship between the energy of the photon and the voltage generated at the detector. For any given detector, we can characterise this probability distribution. This relationship is represented as a matrix and stored in a *response matrix file* (.rmf).

A *background file* is used to characterise the background over which the signal is recorded. Further, satellite data is presented as a continuous time series for the entire duration of the observation. However, during the observation, the source might be eclipsed by the Earth, or the detector may be switched off temporarily. Such intervals, where the data are not scientifically useful, are known as 'bad time intervals'. In general, we require a 'good time interval' (gti) file which contains the time stamps at which the good time intervals begin and end for the entire observation. In order to create a gti file, we can inspect the 'lightcurve' associated with the observation. A lightcurve is given by the recorded intensities plotted against observation time. Outliers in the lightcurve correspond to bad times in the observation. Once we have these files, we can begin timing analysis.

1.3 Crab Pulsar: A Periodic Source

The Crab pulsar is a periodic source. Pulsars are highly magnetized rotating neutron stars that emit coherent radiation from a narrow radiation cone along their magnetic axis. They have short, highly regular rotation periods. The signal from the Crab pulsar is highly periodic and contains signatures of the pulsar rotation. We want to characterise these signatures by finding the period of rotation and the pulse profile. However, before we can do this, we need the time recorded in our observations to be in an inertial frame of reference rather than in the satellite frame of reference.

The event file contains the time stamps for photons hitting our detector. We need to transform these to an inertial frame. The closest possible inertial frame is the 'local standard of rest' which is the frame of reference of the barycenter of our solar system. Thus, we must find the conversion from the recorded time to the time at which the same photon would have arrived at the solar system barycenter, i.e., we need to find the relative motion of this point and the satellite. Such a relative motion correction for the satellite is time-dependent, and accounts for the motion of the satellite around the Earth, the Earth around the Sun, as well as perturbations due to the other bodies in the solar system. This correction is important for signals that are coherent over a long time, such as the Crab pulsar.

We can identify the periodic signal by constructing a power spectrum. A power spectrum is intensity plotted against frequency. For a periodic source, we can identify the relevant frequency in the spectrum. The spin phase of the source, ϕ with rotation period P, is given by the fractional part of $\frac{t-t0}{P}$. Here, $t-t0$ is time calculated from some reference $t0$ which is typically specific to the telescope. If we define $F = \frac{t-t0}{P}$, then $\phi = F - \text{floor}(F)$. We can find the pulse profile associated with the Crab pulsar by plotting intensity against rotation phase ϕ. Now, taylor expanding F, we find,

$$F = \phi_0 + \nu(t-t0) + \frac{1}{2}\dot{\nu}(t-t0)^2 \qquad (1)$$

where $\nu = \dot{\phi}$ and ϕ_0 is a reference phase associated with the reference time $t0$. Since the reference time and phase can be chosen arbitrarily as long as they are defined consistently for the entire observation, we can set ϕ_0 to be 0. For a pulsar with a constant rotation rate, the first two terms of Equation (1) are sufficient. However, the Crab pulsar is known to be slowing down at a rate of 36 nanoseconds per day. Thus, we can improve our estimate of the rotation phase and thus our evaluation of the phase profile by using the higher order terms in the Taylor expansion.

1.4 MAXI J1535-571: An Aperiodic Source

Compact X-ray sources accrete matter through accretion disks. These disks can undergo various kinds of oscillations which are not coherent over long periods of time. These oscillations occur for short durations unpredictably and these bursts are not phase coherent with each other. This is in stark contrast to pulsars which show coherence for a long time. We can find the frequencies associated with each of these oscillations in the power spectrum of the source. The frequency peaks will not be as sharp as with pulsars and each feature will have some width associated with it. Such features asre known as quasi-periodic oscillations (QPOs).

Since each feature has a finite width associated with it, we can define a quality factor 'Q' which is the ratio of the frequency of the feature to the width of the feature. This measures the number of cycles over which the oscillation is phase coherent. The typical duration of oscillations is given by the inverse of the width of the features. For the Crab pulsar, this duration was smaller than our bin sizes, but it is typically much longer for QPOs. Since the signal is not coherent for long durations, the Barycentric correction is not very important for such sources. Further, our analysis here is based on the power spectrum which is independent of such corrections. The barycentric correction affects the phase of the observations. A power spectrum is created by squaring the frequency values which removes all phase information, and thus is unaffected by the correction.

Disk oscillations which produce QPOs can be modeled as damped harmonic oscillations. Thus, their signatures in the power spectrum are lorentzians. In order to understand the nature of the QPOs, we need to identify the lorentzians which constitute the power spectrum. This allows us to understand the frequency and amplitude of the oscillations which cause the QPO. Further, the timing signatures of the QPO such as spectral lags can reveal crucial information about the source. Spectral lags in such sources are due to comptonization, and their nature reveals the geometry of the source. Such timing analysis becomes very important for understanding compact sources which cannot be resolved with imaging devices.

In order to characterise the observed power spectrum, we create a model of the source spectrum using lorentzians. We iteratively modify this model to minimise the residuals and to obtain our final best-fitting model. This procedure is executed on the HEASOFT module XSpec.

2 Data and Software Used

Both sets of data used for this analysis were obtained using the Large Area X-ray Proportional Counter (LAXPC) instrument aboard the Indian satellite AstroSat. The first data set is an observation of the Crab pulsar obtained in 2016. The event file and a preliminary good time interval (gti) file are available. We also make use of values of the spin period derivative and double derivative of the Crab pulsar calculated using the Ooty Radio Telescope (ORT) in our analysis. The second set of data used here is an observation of MAXI J1535-571, a black hole X-ray binary, from a 2017 AstroSat LAXPC observation. The event file and a preliminary gti file are both available.

The ftools package, and the timing analysis package Xronos of the HEASOFT package were used for analysis. Spectral model fitting for the second set of data was performed using the HEASOFT package XSpec.

3 Analysis

We launch heasoft using the command `heainit` in order to access ftools and xspec for analysis.

3.1 Crab Pulsar Timing

We have AstroSat LAXPC data from the Crab pulsar in the form of an event file ('ObsID406_02741_event.fits') and a preliminary good time interval file. Before we begin timing analysis, we must ensure that this data does not contain any bad time intervals. Thus, we begin by creating a light curve for the entire observation. We do this by making a histogram of the time column in the event file using the ftools command `fhisto`. We use the command `fhisto ObsID406_02741_event.fits lc_1s_2741.fits TIME 1.0`.

Now, we can plot this lightcurve using the ftools utility `fplot`. We use the command `fplot lc_1s_2741.fits` and then specifying the columns (here, 'X' and 'Y') to be plotted. We can also open this lightcurve in fv and thus identify where the bad times begin and end. In Figure (1), bad times are easily identified as having near-zero counts and through sudden deviation from the mean. Once we have identified the time stamps corresponding to these times, we can accordingly edit the gti file using fv again.

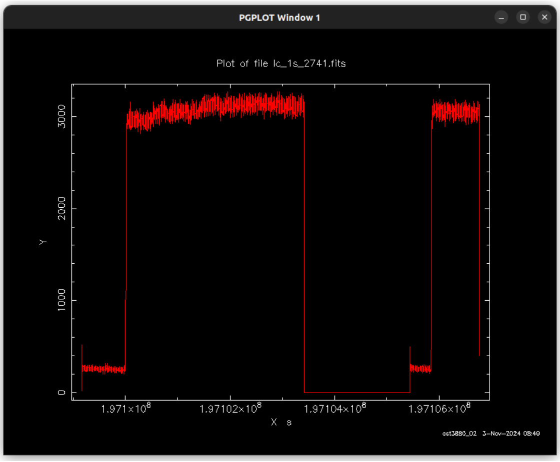

Figure 1: Light curve of the entire data plotted by creating a 1s histogram of the TIME column of the event file.

Now, we want to create an event file which contains only the events corresponding to the good time intervals we have identified. To do so, we can use the command `fltime ObsID406_02741_event.fits modified_gti.fits crab_filteredevents.fits`. We can again create a light curve using the new event file with the `fhisto` command and plot it using `fplot`. We use this plot to verify that there are no further bad times remaining in the data.

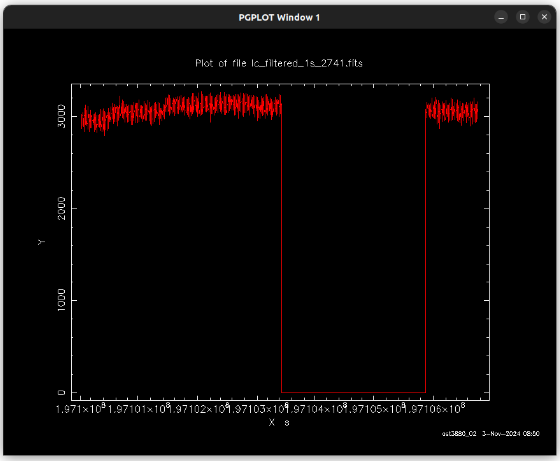

Figure 2: Light curve of the good times in the observation plotted by creating a 1s histogram of the TIME column of the filtered event file.

Now, before we proceed with timing analysis, we must perform barycentric correction in order to obtain a timing signature independent of our satellite-based frame of reference. The barycentric correction utility AstroSat is `as1bary`. Before we can perform the correction, we must identify the pointing RA and Dec coordinates for our observation. These values are present in the FITS header of the event file. We use the command

```
as1bary -i ObsID406_02741.orb -f
crab_filteredevents.fits -o
crab_barycorr_events.fits-ra 83.63308
-dec 22.01446 -ref FK5
```

to create a new event file which contains the barycorrected times. The TIME column in the new event file should be in units of barycentered dynamic time (TDB). We now have the final version of the event file with which we can begin timing analysis.

We start by creating a lightcurve. Since we want to identify the timing signatures of the Crab pulsar, we need good resolution in the light curve. We will thus choose 1ms binning for this lightcurve. We create the lightcurve using the `lcurve` utility of the `Xronos` package intended for X-ray timing. We run `lcurve`, and then enter the following parameters when prompted.

number of time series	1
ser. 1 filename	crab_barycorr_events.fits[1]
window	-
newbintime	0.001
number of newbins/interval	7599128
name of output file	lc_crab_barycorr_1ms.flc

Table 1: Parameters for `lcurve`.

Here, we have specified newbintime according to the desired resolution, and chosen the largest permissible number of newbins/interval as reported by Xronos. Now that we have a high resolution light curve, we can create a power density spectrum in order to understand the nature of the periodic signal from the Crab pulsar. With 1 ms binning, we can at most measure 500 Hz variations (Nyquist rate). The entire duration of our light curve is 7600 s. This dictates that the minimum frequency of variations we can measure is 10^{-4} Hz. However, we know *a priori* that we do not need such fine resolution to understand Crab's timing signature. Thus, we can break up the entire duration of the light curve into smaller chunks and find the power spectrum for each of those individually before averaging them to obtain our final power spectrum. We use the command `powspec`, and then specify the following parameters when prompted.

filename	lc_crab_barycorr_1ms.flc[1]
newbintime	0.001
number of newbins/interval	8192
number of intervals/frame	INDEF
rebin results?	no

Table 2: Parameters for `powspec`.

We keep the newbin time as 1 ms since we don't want to reduce the maximum frequency measurable. We reduce the number of newbins/interval such that we obtain a resolution of 0.125 Hz. Setting the number of intervals/frame to INDEF chooses the maximum possible number by default such that we can get most of the data output to a single frame.

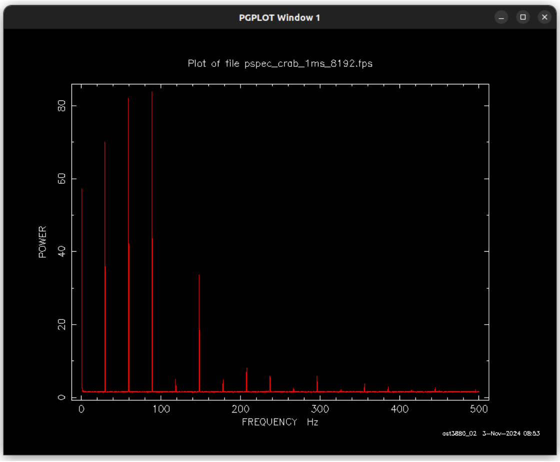

Figure 3: Power spectrum produced using the `powspec` command.

We see that the power spectrum contains a very sharp peak at the fundamental frequency and several harmonics. Such a power spectrum is characterstic of a pulsar. We find that the entire signal is contained in 1 bin, i.e., the coherence of the signal is longer than the duration of the lightcurve. In other words, the width of the feature is less than our bin size of 0.12 Hz. Now, in order to identify the frequency at which we find the periodic signal, we want to closely examine both the fundamental and the harmonics in the plot. We can plot the power spectrum using fv, and thus identify the approximate frequency of the fundamental (∼29.66 Hz). In order to improve our estimate, we can do the same for the 10th harmonic. We know that the 10th harmonic must occur approximately at 296.66 Hz. We identify the feature nearest to this frequency and use a tenth of its frequency as our initial estimate for the frequency of the pulsar signal. This gives us a frequency of 29.650878 Hz, or a period of 0.033726 s.

We identify the number of significant digits in the period estimate with some simple error analysis. We used a bin size of 0.125 Hz, but we reduced the error in frequency to 0.0125 Hz by using the 10th harmonic for our estimate. For a period P and a frequency ν, we know that $\Delta P = P\frac{\Delta\nu}{\nu}$. This gives us an estimate of the error in period as 0.00001416s.

Now, in order to improve our estimation of the period, we can use the Xronos task `efsearch` which can take in an estimate of the period and provide a better estimate up to a specified resolution. We use the command `efsearch` and enter the following parameters when prompted.

filename	lc_crab_barycorr_1ms.flc[1]
window	-
epoch	INDEF
period	0.033726
phasebins/period	128
no. of newbins/interval	INDEF
resolution for period search	1.e-6
no. of periods to search	128
output file	crab_1microsec.fes

Table 3: Parameters for `efsearch`.

The 'period' parameter is where we enter our initial estimate of the period, we let the program pick the number of newbins/interval as per our chosen phasebins/period and resolution. Since the timing is extremely sensitive, we enter a resolution of 1 order of magnitude lower than the used estimate. We want to obtain the frequency of the pulsar with a resolution of 1 ns. We know *a priori* that Crab slows down at a rate of 36 ns/day. We have a 1 ms lightcurve with ∼ 7599128 bins, i.e., 7600 seconds or 0.1 day. Thus, Crab slows down by about 3.6 nanoseconds in the duration of our observation. Thus, a nanosecond resolution is good enough for our timing analysis.

In order to obtain this resolution, we iteratively run `efsearch` for lower resolutions until we obtain the period at the desired resolution. This function folds the signal at the estimated period and finds the true period by maximising the chi-squared fit to a flat line. The larger the chi-squared value, the better the period fit since whenever periods are correctly added up, we get a high peak and a correspondingly large deviation from a flat line. After performing this search, the final period obtained is 0.033720668 s.

Now, we want to fold the signal in order to characterise the profile of the pulse. To do so, we use the command `efold` and then enter the following parameters when prompted.

number of time series	1
filename	lc_crab_barycorr_1ms.flc
windowing	-
epoch	INDEF
period	0.033720668
phasebins/period	-8
no. of newbins/interval	INDEF
no. of intervals/frame	1
name of output file	crab_profile_bary.fef

Table 4: Parameters for `efold`.

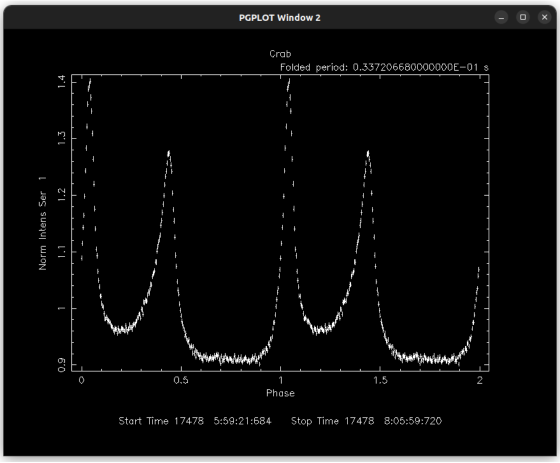

Figure 4: Phase profile for the Crab pulsar obtained using the `efold` command.

The number of phasebins/period is entered as a negative power of 2 such that -8 corresponds to 256 phasebins/period. This gives us the phase profile for Crab. However, this analysis does not factor in the higher order terms in the Taylor expansion of the frequency in Equation (1).

We can improve our estimation of the pulse profile by considering another term (the $\ddot{\nu}$ term). To obtain these terms, we use values of $\nu, \dot{\nu}$ provided to us by the Ooty Radio Telescope (ORT). However, the time reference used by the ORT to calculate these values is not the same as the time reference used by AstroSat in obtaining the data we are using. Thus, we must first calculate the offset between the ORT time and the AstroSat time.

We begin by opening the event file (with filtered Barycorrected events) with fv. We then use the 'calculator' tool in fv to calculate this offset. We define a column with the keyword 'OFFSET' and populate all values in that column as 'TIME-t0' where TIME is the keyword which stores AstroSat time values in the event files and t0 is the ORT reference time ('epoch'). We next create a column 'FF' which contains values ($\nu\times$ OFFSET + $1/2\times\dot{\nu}\times$ OFFSET $\times$ OFFSET). Finally, we define a column 'PHASE' with values (FF - floor(FF)). Now, finally, we can create the pulse profile by creating a histogram of the PHASE column in this file. We use the command `fhisto` again.

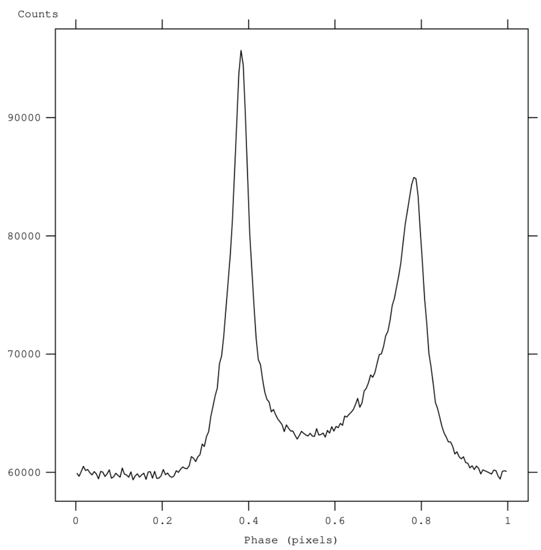

Figure 5: Phase profile of the Crab pulsar obtained using the phase derivatives from the Ooty Radio Telescope (ORT).

3.2 Aperiodic (QPO) Timing

We have been given an eventfile ('maxij1535_laxpc_1536_10584.evt') and a preliminary gti file. The eventfile contains an observation of total duration 2000 seconds. We can create a histogram of the TIME column in the event file to obtain the light curve for the entire observation. We use 1 second binning in order to identify the good time intervals. We use the command `fhisto maxij1535_laxpc_1536_10584.evt lc_maxij1535_laxpc_1s.fits TIME 1.0` to generate the lightcurve.

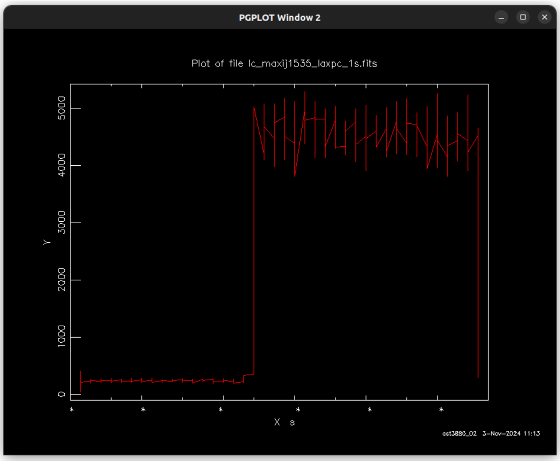

Figure 6: 1s light curve for the full observation of MAXI J1535-571.

We can then use fv to identify the time stamps of the good time intervals and edit the gti file accordingly. Now, we use `fltime` to filter the event file such that only the events in the newly identified good time intervals are retained. We use the command `fltime maxij1535_laxpc_1536_10584.evt ObsID1536_10584.gti filtered_events_maxij1535.fits`. Finally, we create a 10ms bin light curve using the filtered event file using the command `lcurve` and entering the following parameters when prompted.

number of time series	1
ser. 1 filename	filtered_events_maxij1535.fits[1]
window	-
newbintime	0.01
number of newbins/interval	58901
name of output file	lc_maxij1535_10ms.flc

Table 5: Parameters for `lcurve` for maxij1535.

We can now create a power spectrum for the entire observation using the command `powspec` and entering the following parameters when prompted.

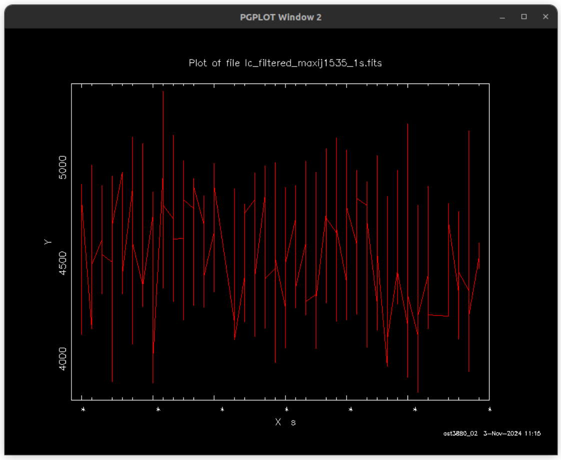

Figure 7: 1s light curve for the filtered event file of MAXI J1535-571.

filename	lc_maxij1535_10ms.flc[1]
newbintime	0.01
number of newbins/interval	2048
number of intervals/frame	INDEF
rebin results?	no
output	pspec_maxij_10ms.fps

Table 6: Parameters for `powspec` for maxij1535.

With a newbin time of 0.01 seconds, we can find a maximum frequency of 50 Hz. Plotting the power spectrum, we can see a peak corresponding to a quasi periodic oscillation (QPO).

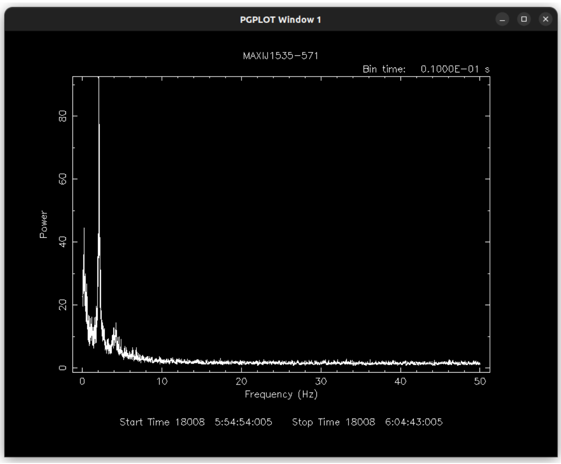

Figure 8: Full power spectrum of MAXI J1535-571 plotted using `fplot`.

Before we can characterise the QPO, we must remove the effect of background counts from the observation. In order to remove this effect, we can create a background file. In order to characterise the QPO using X-Spec, we need a phase height analyser (.pha), response matrix file (.rmf), and a background file. We begin by creating a .pha file from the power spectrum file. A .pha file must contain the channel number and time. To create this, we can use `fdump`. We can run the command

```
fdump pspec_maxij_10ms.fps powspec_ascii.txt
columns=POWER,ERROR rows=- prhead=no
showcol=no showunit=no
```

which enters all the rows of the FITS file into a text file along with row numbers. The row numbers act as channel number substitutes in the .pha file. We can now run the command `ascii2pha` and enter the following parameters when prompted.

ASCII pha datafile	powspec_ascii.txt
output filename	maxij1535_powspec.pha
channel data present	yes
input data type	2
lines to be read	-
first legal detector channel	1
no. of legal detector channels	1024
telescope name	AstroSat
instrument	LAXPC
detector name	lx10
filter in use	NONE
exposure time (s)	589.0

Table 7: Parameters for `ascii2pha` to create the .pha file.

Next, to create a background file, we estimate the level of background counts from the power spectrum. Att high frequencies, we find the base value which gives us the background counts. We find that this value for our data is about 2.0 as seen in Figure (8). We can thus create a model background with a value 2.0 at all frequencies. Thus, we can create a file with as many rows as there are channels in the .pha file (here, 1024). Each row should contain the value 2.0 and an error 0.0. The error is 0.0 since we're using a model background. Once we have created this text file ('background.txt'), we can use the command `ascii2pha` with the following parameters when prompted.

ASCII pha datafile	background.txt
output filename	back.pha
channel data present	no
input data type 2- [rate]	2
lines to be read	-
first legal detector channel	1
no. of legal detector channels	1024
telescope name	AstroSat
instrument	LAXPC
detector name	lx10
filter in use	NONE
exposure time (s)	589.0

Table 8: Parameters for `ascii2pha` to create the background .pha file.

Before we begin fitting with X-Spec, we have one last thing left to change. The first channel frequency may not be in the .pha file. We must enter the first frequency and the step. Now, we can launch X-Spec.

We can load the data onto X-Spec with the command `data maxij1535_powspec.pha`, and the background using `backgrnd back.pha`. On plotting this data, we find that there is no data beyond channel 200. We can thus use `ignore 200-**`. Further, channel 1 in a power spectrum always contains the DC part of the signal, and thus can be ignored using `ignore 1`.

We can now create a dummy response file on X-Spec using the command `dummyrsp 0.048828125 50.0 1024 linear 0.0 0.048828125`, where the arguments are the lowest value of energy (here, frequency) in the pha file, its highest value, number of ranges, log/linear, channel offset, channel width. This creates a temporary file with a diagonal response matrix. We can now use `setplot energy`, and rescale to focus on the region of the spectrum which shows the QPO with `setplot command r y 1 2000`. While this is treated as an energy spectrum on X-Spec, we are still working with the power spectrum. We have only packaged the power spectrum as an energy spectrum in order to allow fitting using X-Spec.

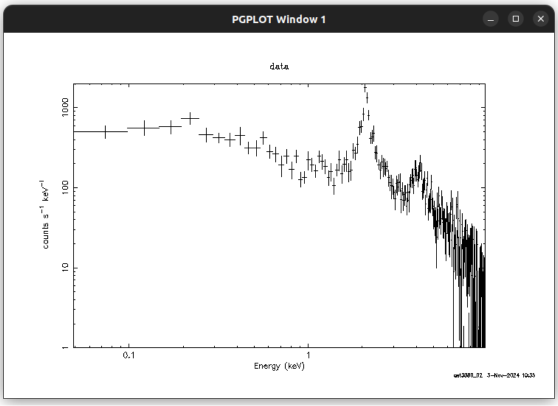

Figure 9: Power spectrum of MAXI J1535-571 on X-Spec.

We can immediately see that there must be at least 3 lorentzian components in the power spectrum- one centered at 0 that gives the overall shape of the spectrum, one centered at around 2 Hz and another centered at about 4 Hz. In order to find the lorentzian fit, we must closely guide the fitting process in X-Spec. We start the fitting with `model lorentz+lorentz+lorentz` and then enter approximate values for the center, width, and height of each lorentzian. After setting these approximate values, we can plot the model along with the data and the fitting residuals using `plot ldata delchi`. We can plot the theoretical model using `plot model`. This allows us to identify the discrepancies between the theoretical model and the data. We can modify our theoretical model to better match the data. Each parameter has an associated parameter number with it, and we can use the command `newpar` followed by the parameter number ot modify it. We then enter the new value of the parameter. Once our estimated theoretical model is close to the observed model, we can run reduced chi-squared fitting for 100 iterations with the command `fit 100`. This gives the best fitting values of the model parameters starting from the estimated values. We repeat this process of modifying parameters until we obtain a chi-squared values that is of the order of the number of bins used for fitting.

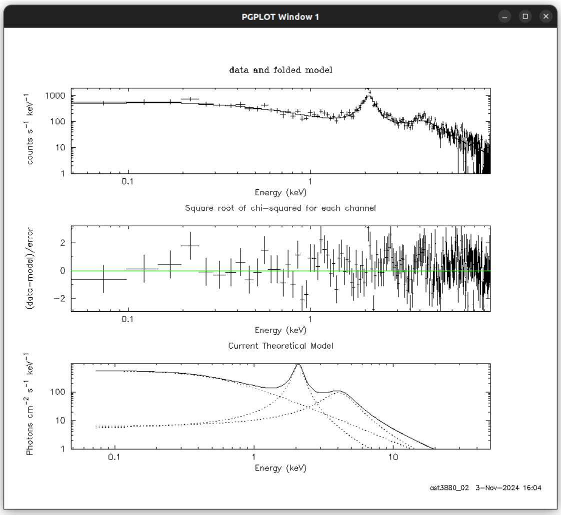

Figure 10: Fitted model of 3 lorentzians describing the power spectrum of MAXI J1535-571.

This is a fairly good fit to the power spectrum, and gives us a reduced chi-squared value of 237.54 using 198 bins for fitting. However, we can see that there is a dip in the theoretical model in between the peaks at 2, 4 Hz. To remedy this, we can add another lorentzian and repeat the same fitting procedure. On using 4 lorentzians, we find a good fit with the parameters listed in Table 9. Figure (11) shows the theoretical model, observed power spectrum, and residuals of the fit. This is a better fit to the power spectrum, and gives us a reduced chi-squared value of 217.49 using 198 bins for fitting.

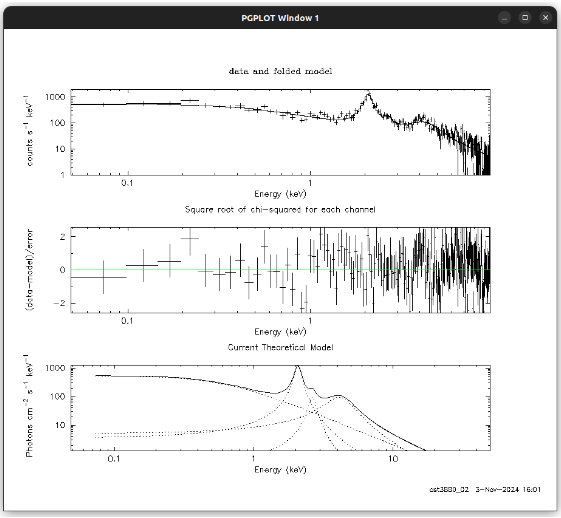

Figure 11: Best fitting model of 4 lorentzians describing the power spectrum of MAXI J1535-571.

Model	Parameter	Value	Error	Unit
lorentzian 1	LineE	5.41454×10^{-4}	0.161965	keV
lorentzian 1	Width	1.23844	0.135811	keV
lorentzian 1	Norm	525.864	39.8059	
lorentzian 2	LineE	2.08408	8.06531×10^{-3}	keV
lorentzian 2	Width	0.224654	2.70656×10^{-3}	keV
lorentzian 2	Norm	418.992	27.3719	
lorentzian 3	LineE	4.12297	6.90965×10^{-2}	keV
lorentzian 3	Width	1.96450	0.202184	keV
lorentzian 3	Norm	269.703	23.8036	
lorentzian 4	LineE	2.65492	4.05148×10^{-2}	keV
lorentzian 4	Width	0.316646	0.130014	keV
lorentzian 4	Norm	47.0198	15.4687	

Table 9: Final parameters for the best fitting model of 4 lorentzians describing the power spectrum of MAXI J1535-571.

4 Discussion

Editing the good time interval file is an important part of performing X-ray timing analysis. In general, this is a difficult task since the lightcurve contains a very large number of rows, making it difficult to manipulate. Further, AstroSat time is reported in terms of seconds since launch and is thus a very large number ($\mathcal{O}(10^8)$). This makes identifying the time stamps at which bad times begin and end a very difficult task. In order to make this easier, we plot the lightcurve in terms of its FITS row numbers rather than times. Once we have identified the row numbers corresponding to all bad times, we use the FITS table to find the corresponding times. We can then use these numbers to populate or edit the gti file as needed.
We found that the power spectrum for the quasi-periodic source MAXI J1535-571 had three peaks corresponding to different oscillation frequencies in addition to broad band noise (given by the lorentzian centered at ~ 0 Hz). These three oscillations, for a relativistic system with a bright accretion disk around a black hole, will typically correspond to the Keplerian frequency, vertical oscillation of the accretion disk, and Lens-Thirring precession. The Keplerian frequency is associated with the Keplerian orbit of the accreting matter around the comapct object. It is typically the largest frequency in the power spectrum. Hence, the Keplerian frequency in our source must be ~ 4.12Hz. The other two frequencies at ~ 2.08 and ~ 2.65 Hz could be due to either vertical oscillation or precession.
Lens-Thirring precession is a general relativistic frame dragging effect due to the presence of a rotating massive body. All three of these frequencies are affected by the mass and spin properties of the black hole, and thus we can use them to find these properties. A change in accretion rate will cause all three of these frequencies to change with respect to each other. In general, larger collecting areas for X-ray timing telescopes allow us to pick up more counts and thus better identify all three frequencies to characterise black holes.

5 References

1. XSpec User Manual version 12.8.1 by Arnaud, Dorman, Gordon. NASA HEASARC, 2013.