Rijksuniversiteit Groningen

Oscillation and Photospheric Radius Expansion in X-ray Bursts

Author:
Jasper Pluijmers

Supervisor:
dr. Mariano Mendez
dr. Olaf Scholten

July 8, 2015

Abstract

During thermonuclear X-ray bursts, two properties are occasionally observed. These properties are the so-called photospheric radius expansion and burst oscillation. I analyzed the X-ray burst data that was available from 2 source: 4U 1728-34 and 4U 1636-53 and tried to find if there is a correlation between these two properties and why this correlation may exists. I found that there is indeed a correlation, but probably not a causation. Both properties are influenced by the mass accretion rate and the photospheric radius expansion is also influenced by the chemical composition of the fuel at the time of the burst. Due to both their properties being influenced by the mass accretion rate, the two seem correlated.

Contents

1 Introduction

In this thesis I study type-1 X-ray bursts. This section explains what they are and where they occur. Before we talk about the bursts themselves we have to tell something about the place where these bursts come from. These bursts happen in systems that are called 'low-mass X-ray binaries'. This means that, in this system, there are 2 stars orbiting each other of which one is a very dense neutron star. The other star (from now on called donor star) can be a normal main sequence star, which is of course a lot less dense. The gravitational potential of a binary system forms a so called Roche-lobe, see fig 1. As you can see there are 2 tear shaped potentials that are connected at a the end, on this point the gravitational potential is zero. This is also called the L_1 lagrangian point. At some point in time the donor star can

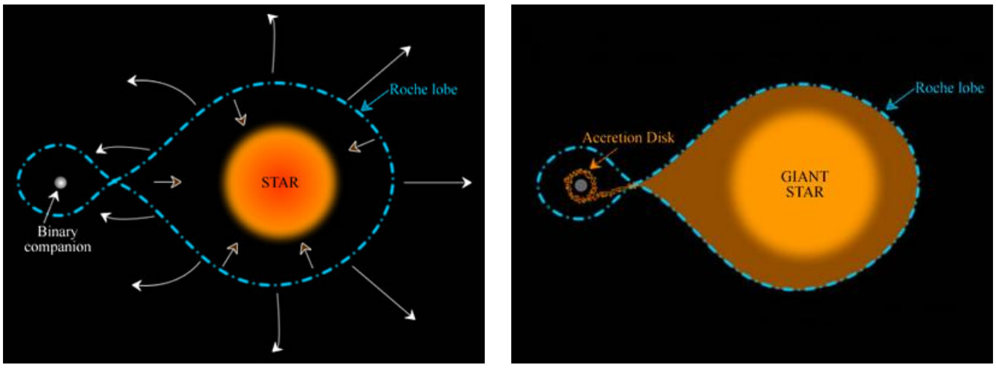


Figure 1: The blue line indicates the roche lobe, everything inside of this region is gravitationally bound to the star. On the left picture you see a normal situation in which the donor star is within its own roche lobe. On the right picture you see the situation in which the donor star has outgrown its roche-lobe and matter is beginning to flow to the neutron star.[1]

grow bigger than its roche lobe and matter will 'spill' from the donor star to the neutron star over this L_1 lagrangian point. Because the stars are orbiting around each other, this is not a direct stream from one to another, but it forms an accretion disk around the neutron star. This matter will keep falling to the neutron star and will form a layer around it. At some point this layer will become so dense that it will burn unstably in a thermonuclear explosion. This burning we see as a burst, a peak in the light curve (figure 2). The time scale of these bursts is a few to tens of seconds and they can happen each couple of hours or days[2]. During these bursts there a are few effects that are noticed in some, but not all bursts. First, there is an oscillation in the light signal. This oscillation is likely caused by the rotation of the neutron star itself[3]. At some point the burst has to start in a single point, where the density gets critical[2]. If the star itself rotates this will look like an oscillation in the light curve. Besides that, there is something that is called photospheric radius expansion (PRE), which is an expansion of the top layer of the neutron star, coinciding with the burst. This expansion happens because the star reaches the Eddington limit, the maximum luminosity a star can have while still being in balance with the gravitational force[2]. If a star has a luminosity higher than the Eddington luminosity, the radiative pressure causes the outer layer to expand. These effects do not show in every burst, even within the same source. There are some running theories that say these effects are affected by the mass accretion rate from the donor to the neutron star[2]. This mass accretion rate ($\dot{M}$) changes over time, which also changes the oscillations and PRE's. The mass accretion rate can not be measured on itself, although it is thought that a parameter based on the colour of the source says something about this $\dot{M}$. This parameter is S_a and is further explained in the next section. The purpose of this thesis is to analyse the presence of PRE and oscillations in bursts. First I will try to find if there is a correlation between the two, then I will try to explain this correlation on the basis of earlier published work.

2 Data Collection

In this chapter I will show how the data that I will use in the rest of the paper were collected. In this thesis, data from 2 sources are used: 4U 1728-34 and 4U 1636-53. All the used data were collected by the Proportional Counter Array (PCA), an instrument on board of the Rossi X-ray Timing Explorer (RXTE). The RXTE is an X-ray satellite which has 3 instruments on board, the other instruments are the All-Sky Monitor (ASM) and the High Energy X-ray Timing Experiment (HEXTE). At the time of writing this thesis the RXTE was already decommissioned; it was operative from December 30, 1995 until January 5, 2012. Named after the X-ray physicist pioneer Bruno Rossi, its goal was to look at black holes, neutron stars, X-ray pulsars and X-ray bursts. The PCA instrument has 5 independent detectors that have a combined collecting area of 6500 cm^2. All of them operate in the range of 2-60 keV and can give event information timed to 1-microsecond.
The PCA instrument has 2 standard modes. Standard-1 mode observes with a time resolution of 0.125 s in a single band within the 2-60 keV range. The standard-2 mode observes with a resolution of 16s with 129 channels divided over the 2-60 keV range.
In this thesis we use data published earlier bij Zhang et al.[3]. These data were retrieved from all available data until the data of the paper from the Proportional Counter Array. For 4U 1636-53(from now on 1636) these were 1490 observations (as of 2013).
To retrieve this data, Zhang et al. first used the standard-1 mode to check if there was a burst observed. For 4U 1728-34 (from now on 1728) they made 0.25 s light curves out of this standard-1 data and checked if it contained a burst; for 1636 they did the same, but with 0.5 s light curves. This resulted into 121 bursts for 1728 and 336 bursts for 1636. Subsequently the data wherein bursts were found were looked into in higher detail. Apart from the standard modes there is high-time resolution data available for each observation. Most of this data had a resolution of at least 125 μs. This allowed them to extract a spectrum every 0.25 s for the length of the burst. To then find the radius of the stars at different times they fitted a single-temperature blackbody to the high resolution spectra. Using for 1728 a distance of 5.2 kpc and a column density, N_H, of $2.3 \times 10^{22} cm^{-2}$ and for 1636 a distance of 5.95 kpc and a N_H of $0.36 \times 10^{22} cm^{-2}$ that, blackbody, radius can be calculated. These radii are then used to determine if the burst is a PRE-burst.
To check if the bursts show oscillations Zhang et al. made Fourier power density spectrum (PDS) of 2 s data segments for the length of the bursts. The start time of these segments were 125 μs after the start time of the last segment. The probability of getting a certain frequency can be estimated using a χ^2 distribution with 2 degrees of freedom. These properties can be plotted in a single plot as seen in figure 2

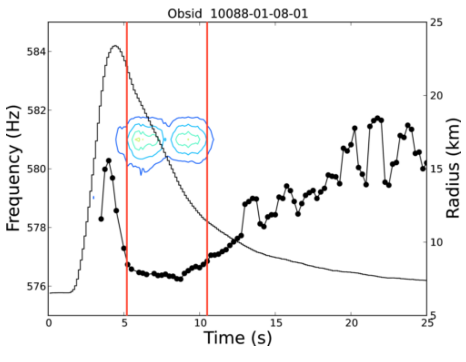


Figure 2: A PRE burst with tail oscillations. The black histogram shows the light curve, the colored contour lines show the spectrum power values and the black dots, connected with lines, show the blackbody radius. [4]

Of these data a spectrum was generated every 0.25s for the duration of the burst for both 1636 and 1728. The colour of the sources was determined using the standard-2 data. To be able to make the colour-colour diagrams 2 colours need to be defined. These so called hard and soft colours were defined as the $\frac{9.7-16.0}{6.0-9.7}$ keV and $\frac{3.5-6.0}{2.0-3.5}$ keV count rate ratios respectively. Out of these Colour-Colour Diagrams the S_a curve can be determined, this is done by defining $S_a = 1$ at the top right turn of the diagram and $S_a = 2$

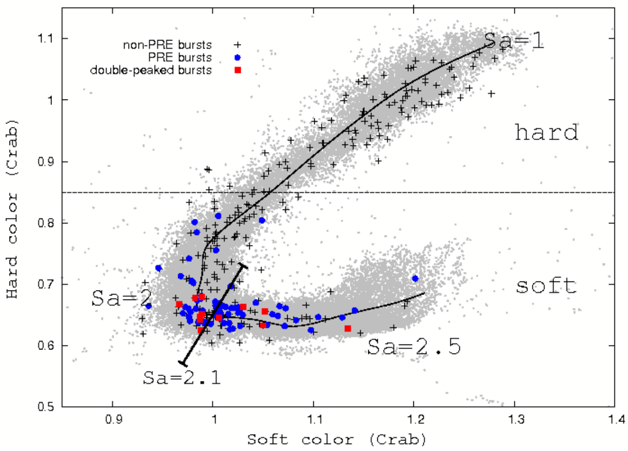


Figure 3: Example of a colour-colour diagram of the source 4U 1636-53[4]

at the bottom left turn. The S_a is then the spline that follows the observations and passes through these points (see figure 3).

3 Methods

This chapter will make the reader acquainted with the statistical methods that I will use in this thesis. In the first section I will explain contingency tables and their applications. Afterwards I will explain 3 tests: χ^2, correlation strength by entropy, and the Kolmogorov-Smirnov test.[5]

3.1 Contingency Tables

3.1.1 Basics

When dealing with a lot of data it is a good idea to display them in an orderly way. In the case of nominal variables this can be nicely done in the form of a contingency table. Nominal variables have discrete distinct options. In a contingency table you put all the options of the first variable on the rows of the tables and the options of the second variables on the columns of the table. The entries of the table then become the frequency of that particular combination of variables. If for example your population consists of 100 people and your variables are sex and hair colour (let us only consider brown and blond) the table could look like figure 1.

To be able to analyse these kind of tables we need to agree on some notations. First of all we denote

	male	female	
blond	26	35	61
brown	27	12	39
	53	47	100

Table 1: Example of a contingency table, the right and bottom most numbers are the row and column totals, respectively. The number in the bottom right corner is the total of the population

the total number of entries in the table as N. The individual entries will be written as N_{ij}, where this value will be on the ith row and the jth column. In our example the value of N_{12} will be the amount of blond females, so 35. The row and column totals, also called marginals, can be written as $N_{i.}$ and $N_{.j}$, respectively. When looking at the example, $N_{1.}$ would be 61, which is the amount of blond people, male or female. $N_{.j}$ would be the amount of females, including the blond and the brown haired females. See table 2 for a table with this notation filled in. Apart from that we need to define the expectation value for any N_{ij}, which is n_{ij}.

	male	female	
blond	N_{11}	N_{12}	$N_{1.}$
brown	N_{21}	N_{22}	$N_{2.}$
	$N_{.1}$	$N_{.2}$	N

Table 2: Example of the same table as 1, but instead of numbers the variables are filled in

3.1.2 χ^2-test

The first thing you can do when you have a contingency table is a χ^2 test. The χ^2 test is a test that will give you the probability that the variables in the table are not correlated to each other. To start you have to draft a null hypothesis (H_0), in this case the null hypothesis says there is no correlation between the two variables. The final result of the complete χ^2 test is the probability that this H_0 is correct.
The test basically comes down to comparing the results you got to the results you would expect on the basis of the H_0. Because our null hypothesis is that there is no correlation, we want to test for the case in which the value of one of the variables does not impact the other variable at all. In our example, we would assume that being a male or female does not matter for being blond. This means that the percentage of males that are blond should be the same as the percentage of females that are blond and thus the same as the percentage of the total population that is blond. Because of this, the ratio of the expectation value of a cell and its column total is the same as the ratio of the cell next to it divided by that cell's column total and the same as the row total divided by the total population, N. This can be written mathematically as:

$$\frac{n_{ij}}{N_{.j}} = \frac{N_{i.}}{N} \tag{1}$$

We can then rewrite this easily to:

$$n_{ij} = \frac{N_{i.}N_{.j}}{N} \tag{2}$$

This gives everything we need to calculate the χ^2 statistic, which is given by the next formula:

$$\chi^2 = \sum_{i,j} \frac{(N_{ij} - n_{ij})^2}{n_{ij}} \tag{3}$$

This χ^2 statistic by itself does not tell you that much. It does however help you with calculating the probability that the H_0 is correct. To do this you first need to know degrees of freedom your data has. In the case of a contingency table this is the amount of rows times the amount of columns, minus the amount of rows, minus the amount of columns plus one. This adds up to a degree of freedom of one for a two by two table. To then calculate the probability, one needs the χ^2-probability function, which is:

$$p_\chi(\chi, f) = \Gamma\left(\frac{f}{2}, \frac{\chi}{2}\right) = \frac{1}{\Gamma(\frac{f}{2})} \times \int_0^{\frac{\chi}{2}} e^{-q} t^{\frac{f}{2}-1} dq \tag{4}$$

Wherein χ is the χ^2 statistic from formula 3, f the degrees of freedom, $\Gamma(x, y)$ the incomplete gamma function from 0 to x with y degrees of freedom, and $\Gamma(x)$ the gamma function of x. In this paper I am mostly interested in the probability that H_0 is not correct, which is given by the inverse of this probability, so:

$$p = 1 - p_\chi \tag{5}$$

3.2 Correlation Strength by Entropy

The χ^2 probability only tells you if there is a correlation between the variables; it tells you absolutely nothing about how strong such a correlation would be. For this we use a different method, which is called entropy. The outcome of this method is what we call the 'mutual dependency', which is a number between zero and one which basically tells you how likely you are to know the value of one of the variables if you know the other one. This is thus a measurement of the strength of the correlation, but only if you know there is a correlation (for example by using the χ^2 test). To get to this mutual dependency we first need to define the entropy of the variables, which is a way of saying how useful it is to ask for a certain variable when you want to know the properties of an object (for example a burst). Which for our case would be to ask for PRE/no PRE or oscillation/no oscillation, which in the equations will be denoted as x and y. The formula for this entropy is:

$$H(x) = -\sum_i p_{i.} \ln p_{i.} \tag{6}$$

$$H(y) = -\sum_j p_{j.} \ln p_{j.} \tag{7}$$

wherein

$$p_{ij} = \frac{N_{ij}}{N} \tag{8}$$

You can combine this into the entropy of both questions together:

$$H(x,y) = -\sum_{i,j} p_{ij} \ln p_{ij} \tag{9}$$

However, what we want to know is what the entropy is of one of the questions if you already know the other one, as this will give you a sense of the strength of the correlation. The entropy of a question Y, given X and vice-versa,is:

$$H(y|x) = -\sum_{i,j} p_{ij} \ln \frac{p_{ij}}{p_{i.}} \tag{10}$$

$$H(x|y) = -\sum_{i,j} p_{ij} \ln \frac{p_{ij}}{p_{j.}} \tag{11}$$

Now we have defined these entropies, we can define the dependency. First there is the dependency of y on x:

$$U(y|x) \equiv \frac{H(y) - H(y|x)}{H(y)} \tag{12}$$

and the other way around:

$$U(x|y) \equiv \frac{H(x) - H(x|y)}{H(x)} \tag{13}$$

These dependencies give a value between zero and one, where zero means that there is no association between the two variables, while one implies that if you know the first variable, you will definitely know the second variable. We would like to get this statistic down in a single variable, which we can do by treating x and y symmetrical. This boils down into the following equation:

$$U(x,y) \equiv 2 * \left[\frac{H(y) + H(x) - H(x,y)}{H(x) + H(y)}\right] \tag{14}$$

This is the mutual dependency that will be used in the rest of the thesis and will, just like the other dependency, be a number between 0 and 1 which tells you how strong the correlation is between the two variables.

3.3 Kolmogorov-Smirnov Test

The third test I will use is the Kolmogorov-Smirnov test. There are actually two Kolmogorov-Smirnov tests. The purpose of the first one is to test if a data set could have been drawn from a known distribution. The purpose of the second test is to test if two data sets have been drawn from the same parent distribution. I will only use the second test, so I will not explain the first one. The H_0 in this case is the hypothesis that both data sets are drawn from the same parent distribution. The end result is the probability that H_0 is correct. For this test we need to convert our data set into a cumulative distribution function (CDF). For a data set with N points, we denote this CDF as $C_N(x)$. This is a function that at point x gives you the fraction of the datapoints smaller than or equal to that x. Some properties of these function are that they can only rise, are constant in between data points, and always start at 0 and go to 1, see fig 4.

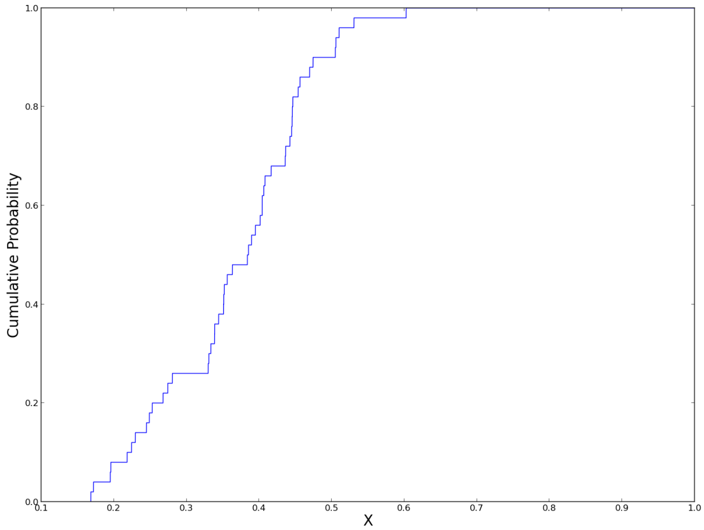


Figure 4: An example of a CDF of a non defined variable 'X', as you can see it goes in steps, starts at 0 and ends at 1

There are quite a few ways to compare difference CDF's, the Kolmogorov-Smirnov test uses the Kolmogorov-Smirnov statistic. This statistic is the absolute maximum value of the difference between two CDF's. Or, mathematically put, if I have two CDF's, $C_{N_1}(x)$ and $C_{N_2}(x)$, the Kolmogorov-Smirnov statistic D is given by the formula:

$$D = \max_{-\infty \leq x \leq \infty} |C_{N_1}(x) - C_{N_2}(x)| \tag{15}$$

We can then use this statistic to calculate the probability using this formula:

$$p = Q_{KS}([\sqrt{N_e} + 0.12 + \frac{0.11}{\sqrt{N_e}}] \times D) \tag{16}$$

Wherein $Q_{KS}(x)$ is the following function:

$$Q_{KS}(x) = 2\Sigma_{j=1}^{\infty}(-1)^{j-1}e^{-2j^2x^2} \tag{17}$$

and N_e is a way to write down the effective number of points in your data sets, which is calculated using N_1 and N_2, the number of points in your first and second set.

$$N_e = \frac{N_1 N_2}{N_1 + N_2} \tag{18}$$

Equation 16 now finally gives you the probability that the H_0 is true.

4 Results

4.1 Contingency Table Results

1636	no-PRE	PRE	
no-Osc	235	12	247
Osc	32	57	89
	267	69	336

Table 3: Contingency table of 1636

1728	no-PRE	PRE	
no-Osc	16	56	72
Osc	32	17	49
	48	73	121

Table 4: contingency table of 1728

In table 3 and 4 you can see the contingency tables that show the frequency of the combination of the presence of oscillations and photospheric radius expansion. The results of the statistical tests on these tables can be seen in table 5. Both of the tables have a degree of freedom of 1, which together with the χ^2-statistic give the probability that H_0 is correct. For 1636 this $p = 2.1 \times 10^{-32}$ and for 1728 $p = 2.0 \times 10^{-6}$. Both of these probabilities are so low that you can discard the H_0 with high confidence, so the photospheric radius expansion and the detection of oscillation are most likely correlated. The third entry in table 5 is the mutual dependency based on entropy, which is 0.35 for 1636 and 0.14 for 1728.

Object	χ^2-statistic	χ^2-probability	mutual dependency
1636	140	2.1e-32	0.35
1728	23	2.0e-06	0.14

Table 5: The χ^2-statistic, which together with the degrees of freedom gives you the χ^2-probability. The third column denotes the mutual dependency

4.2 S_a Results

First cut	no-PRE	PRE	
no-Osc	106	0	106
Osc	6	0	6
	112	0	112
Second cut	no-PRE	PRE	
no-Osc	70	11	81
Osc	10	21	31
	80	32	112
Third cut	no-PRE	PRE	
no-Osc	59	1	60
Osc	16	36	52
	75	37	112

Table 6: Contingency tables of 1636, cut in parts based on their S_a

Table 6 shows the contingency tables of parts of the whole data table of 1636, but cut on the basis of S_a. Each cut consists of 112 bursts, chosen like this so there would be 3 groups of equal size. The first cut is taken from $S_a = 1.066 - 1.689$ As you can see this changes the proportions quite a bit. Table 7 shows how the χ^2statistics work on each segment of the cut data. I can not do the statistics on the first segment, because there is no PRE found in that cut. This is because one of the row totals is zero which makes the degree of freedom of the table zero. While I can say nothing specific, it is clear that there are no PRE bursts in this cut and the chance on an oscillation in this cut is only $\frac{6}{112}$. In the other two segments the probability that H_0 is correct of $p = 1.4 \times 10^{-8}$ for the second cut and $p = 3.4 \times 10^{-14}$ for the third cut. So it is safe to say that here, too, PRE and oscillation are correlated. The mutual dependency increases with S_a from 0.23 in the second cut to 0.46 in the third cut.

I did the same thing for 1728, but cut in 2 parts as this source has less data available. I chose a

cut #	χ^2-statistic	χ^2-probability	dependency
first	-	-	-
second	32	1.4e-08	0.23
third	57	3.4e-14	0.46

Table 7: χ^2 statistics and mutual dependency of the different cuts based on their S_a in 1636

First cut	no-PRE	PRE	
no-Osc	8	49	57
Osc	0	5	5
	8	54	62
Second cut	no-PRE	PRE	
no-Osc	8	7	15
Osc	32	12	44
	40	19	59

Table 8: Contingency tables of 1728, cut in parts based on their S_a

cut #	χ^2-statistic	χ^2-probability	dependency
first	0.37	0.81	0.035
second	1.9	0.17	0.026

Table 9: χ^2 statistics and mutual dependency of the different cuts based on their S_a in 1728

first cut of 62 bursts and a second cut of 59 bursts. The first cut has $S_a = 1.06 - 1.69$ and the second cut has $S_a = 1.74 - 2.71$, with no data between 1.69 and 1.74. The resulting contingency tables are seen in 8 and the χ^2 probabilities can be found in table 9. You can see that the number of bursts in each cut is fairly low and the probabilities of $p = 0.81$ and 0.17 are too high to discard the H_0. In this case we can not say that oscillations and PRE are correlated or not. Due to the fact that we can not say they are correlated or not, the mutual dependency also does not say anything. In figure 5 and 6 you can see a histogram which shows, in each bin, the fraction of bursts that showed, or did not show one of the properties. As you can see in 1636, both the oscillations as well as the PRE appear mostly in the higher S_a ranges. With the PRE showing exclusively for S_a higher than 1.6, but oscillation also sporadically show on the lower end. On the contrary, for 1728 the properties show on the opposite sides of the histogram, with oscillations appearing mostly at higher S_a (but also some on the lower end) and the PRE's showing mostly at the lower end of the S_a. When looking at these plots be aware that it could be the case that the sources were observed more at some S_a than other S_a value. I have tried to compensate for this by taking the ratio of bursts with one property relative to the number of bursts and not the absolute number, but this does not help when there are no bursts with PRE at all.

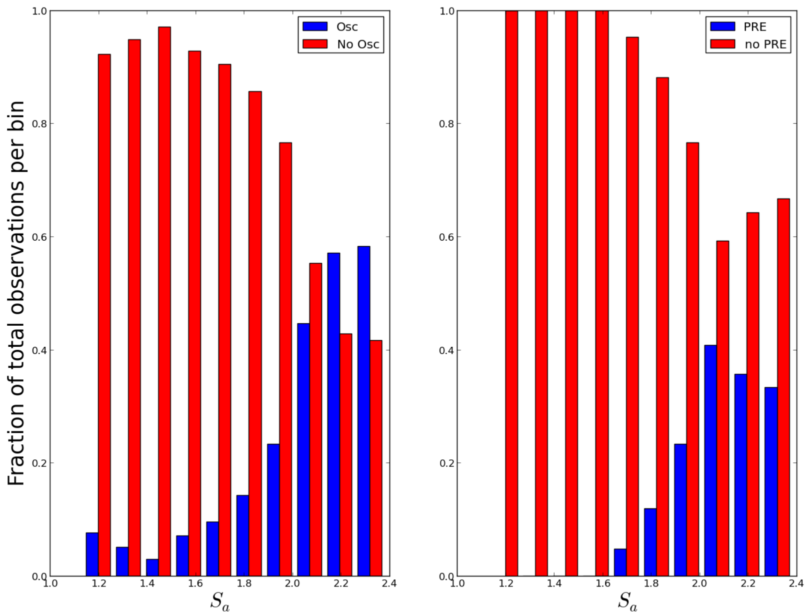


Figure 5: Histogram of the ratio of bursts with or without PRE/oscillation to the total number of bursts for 1636 as a function of S_a

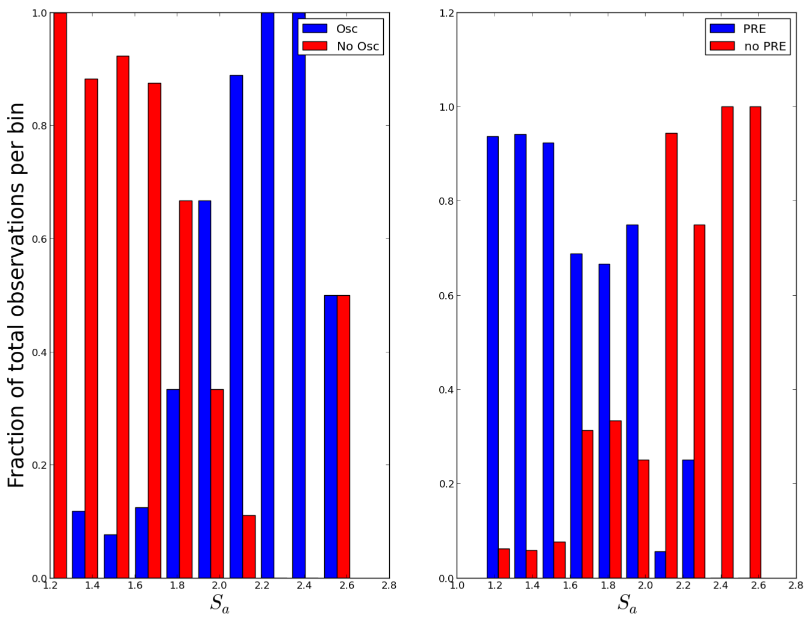


Figure 6: Histogram of the ratio of bursts with or without PRE/oscillation to the total number of bursts for 1728 as a function of S_a

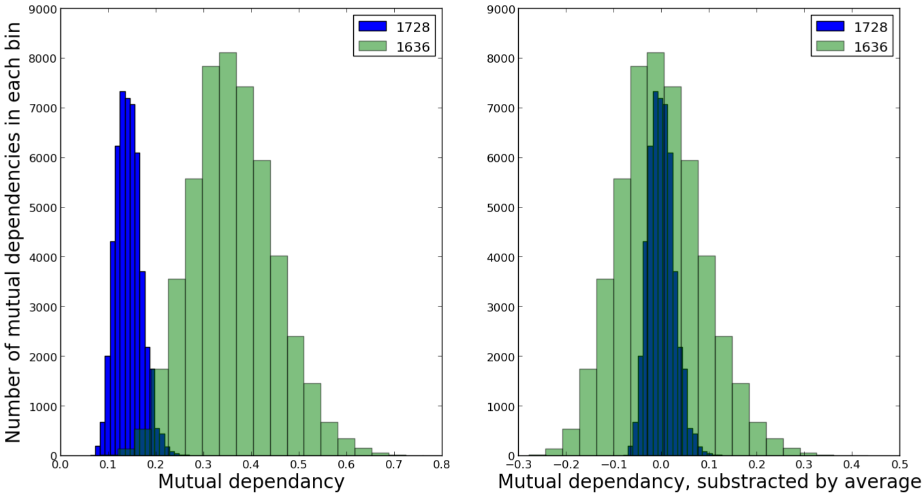


Figure 7: These histograms show a set of 50000 mutual dependencies between PRE and burst oscillation. Each of these mutual dependencies was calculated on the basis of 100 random bursts out of the burst data available. The right graph shows the histograms, but substracted by their average, so they could be overlaid and compared purely on their shape.

4.3 K-S Results

To check whether the correlation between the two sources is different because the sample size in 1636 is much bigger, I took 5×10^4 samples of 100 burst observations of both sources so that they can be compared with equal sample size. All these samples were randomly chosen from the whole set of observations. For all these samples I calculated the mutual dependency between PRE and oscillation, which you can see histograms of in figure 7 (left side). To check if the two data sets could come from the same parent distribution I ran a Kolmogorov-Smirnov test. As I want to compare the shapes of the 2 histograms, the data was first corrected by subtracting their average value. This caused the two histograms to overlap. It turned out that the probability that they are drawn from the same parent distribution is a converging sum with the first entry being 10^{-45}. This is obviously very small, so they are not from the same parent distribution. The difference thus comes from the source, not the statistics.

5 Discussion

5.1 Overview of the Results

I found that burst oscillations and photospheric radius expansions during X-ray bursts are significantly correlated in both sources, with a chance of not being correlated of $p = 2.1 \times 10^{-32}$ and $p = 2.0 \times 10^{-6}$ for 1636 and 1728, respectively. The strength of these correlations, however, are different for both sources, at 0.35 for 1636 and 0.14 for 1728. Difficulties arise when we add S_a to the analysis, as the sources behave quite differently from each other. When split in parts, in 1636, the oscillations and expansions are still definitely correlated. The strength of this correlation seems increase with S_a, from 0.23 to 0.46. This does not show at all in 1728, where the χ^2 test gave probabilities of $p = 0.81$ and $p = 0.17$. Furthermore, the place on the colour-colour diagram where the PRE's take place is different for the 2 sources. 1636 shows PRE exclusively in the higher end of S_a, while 1728 shows them mostly at the lower end. The oscillations, both in 1728 and 1636, show mostly at the higher ends of S_a, although not exclusively, as they seem to happen everywhere.
The differences in the strength of the correlation of the two sources can be explained in two ways. The first one is a statistical reason: there are 336 entries in the burst table for 1636 and 121 entries for 1728. A lower sample base also means that the statistics become more uncertain. However I tested both sources

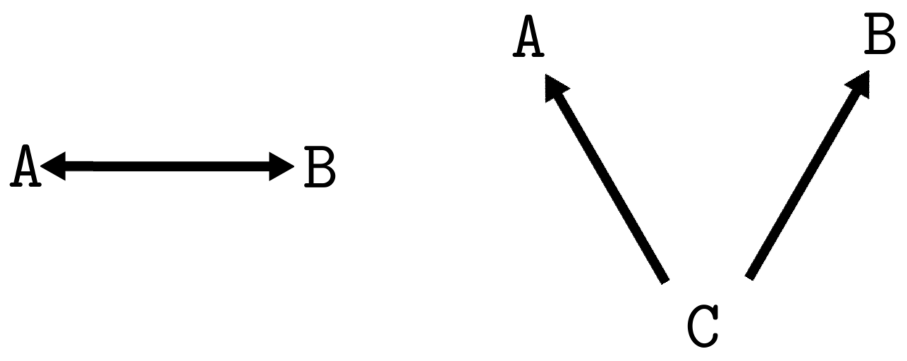


Figure 8: Correlation does not imply causation. On the left you see the case that variables A and B influence each other, while on the right side you see a third variable influencing both of them. Both of these cases can show the same signs of correlation.

with equal sample bases of 100 entries and 1636 still had mutual dependencies around 0.35, while 1728 staid at 0.14. It could also be that the 2 sources are intrinsically different, this means the mechanisms would influence each other in different ways. The way we observe these oscillations and expansions are the same, however, so it would be strange if they are intrinsically different in both the sources.

5.2 In the Context of the Literature

This gives rise to a new question: PRE and oscillations are definitely correlated, but do they also cause each other? As we know, correlation does not imply causation. This can be explained, for example by introducing a third variable which influences both our variables. (figure 5.2) In our case we have a pretty strong contender for this third parameter, which is the S_a. In the literature S_a is considered a parameter that is a function of the mass accretion rate: $\dot{M}$[4]. The problem with this is that the 2 sources do not behave the same relative to this mass accretion rate. While 1636 shows oscillations and PRE's at high S_a, 1728 shows the opposite correlation as PRE are observed at low S_a. This could still mean that the oscillations are correlated with the mass accretion rate, but for PRE there is obviously something different going on. It is suggested that the fuel at the time of the burst influences the burst [6]. The main variability in the fuel is the ratio of H/He. This depends on 2 things: most important is the chemical composition of the donor star, there is a large range of H/He ratios a star can have, and thus accrete onto the neutron star. This does not determine the whole composition at the moment of the burst, as hydrogen can burn into helium already in a stable way when it falls onto the neutron star[2]. The fuel changes the way the energy gets released, due to different fusion processes taking place. Helium burns with the fast triple-α process, which releases a big amount of energy in short time. While hydrogen, on the other hand, burns through the much slower rp-capture process, using the products of the He burning[6]. A higher ratio of H/He could thus mean that the burning goes much slower, during which the Eddington limit is not reached. This argument is also strengthened by the observation of different lengths of bursts, some show a sharp peak and a short tail, while other bursts are less sharp and have a longer tail[4]. A good explanation could thus be that the donor star in 1728 has a lower H/He ratio and thus shows PRE at low $\dot{M}$. The donor star in 1636 would than have a higher H/He ratio and can only show PRE when a certain part of that hydrogen has burned into helium before the burst, which happens faster at high $\dot{M}$. In 2010, Galloway et al[7] suggested that 1728 is an ultracompact binary, this means that the donor star most probably shed off its outer, hydrogen rich, layers. What is left is a helium rich core, which would be the fuel for the bursts. Only 1728 does not show PRE at high S_a, while there should still be a lot of helium present in those situations. Muno gives an explanation for this[6]. If $\dot{M}$ is higher the temperature is also higher, due to this the column density of helium which is enough to cause a burst is lower. If that column density is lower, the amount of fuel is less than in a burst with lower $\dot{M}$, so the burst will produce less energy and not hit the Eddington limit.

Oscillations are thought to originate in the spinning of the neutron star itself. The burst has to start at one point, which will be brighter for some time. If the star is spinning, this starting spot has to spin as well, which can be observed as an oscillation. The neutron star keeps spinning, so it is strange that the oscillations can't be observed at all busts. In 2001, Muno et al presented the idea that this irregular observations are influenced by the rotational speed of the neutron star[8]. Our sources spin at around 350 Hz and 600 Hz for 1728 and 1636, respectively, and they both behave the same on the account of oscillations and S_a. Based on the fact that our sources both show oscillations at the same S_a regions, that doesn't seem to be the case. On top of that, this conclusion was ,retrieved on basis of a very small data sample, which makes it not less credible. In 2004 Muno talked about a possible corona around the neutron star, which is a layer of plasma. Because this plasma is full of charged particles, photons emitted by the neutron star can be scattered in different direction. This means that some photons reach us later than others, this will flatten the oscillation signal. If the oscillation signal is flattened there is no way for us to observe if the oscillation was present in the first place. Muno said that an optical depth of $\tau \approx 3$ will already attenuate the burst oscillations by a factor of 2, which would be enough for us to miss it. Evidence of such corona's can be found in the spectrum of the sources. These spectra consist of a thermal blackbody part, which originates in the accretion disk, and a power-law part. The corona is thought to be seen as the power law part of the spectrum of the source. In 2002, Gierlinski and Done[9] showed for a different source (4U 1608-52) that this power law part only shows at low S_a, and thus at low $\dot{M}$. This would mean that at lower $\dot{M}$ the corona is much more prevalent than at high $\dot{M}$ and thus prevents us from observing the oscillations if the burst happens when the source is in those stages.

5.3 Conclusion

The different mutual dependencies are not caused by a difference in sample size, but are different because the sources behave differently. Figure 5.2 was not the right depiction of the situation, as most probably PRE and oscillations are not only influenced by one third factor. Instead, the ability for a burst to have PRE is influenced by both the mass accretion rate and the fuel at the time of the burst. Oscillation is most probably not influenced by both of these, but the ability for us to observe the presence of an oscillation in the signal is influenced by the mass accretion rate.

5.4 Future Work

A lot of research can still be done on the subject of PRE and oscillations in X-ray burst and low mass x-ray binaries in general. A big problem is the amount of data available. While 1636 had a respectable sample base of bursts, consisting of 336 observed bursts, 1728 only had 112 instances of an observed burst. This causes problems in the statistics and skews with the data. For example the histograms in figure 5 and 6 wherein we can not know if columns with zero PRE's or oscillations do never show them or do not show up because there was not enough observed when the source was in those regions.
There was also data available that I did not yet do anything with. The oscillations in the bursts are not all the same, in reality some oscillations occur in the rise of the burst, some oscillations occur in the tail and some occur in both the tail and the rise (table 10) . This could be a very important feature of oscillations, but at this stage I did not have enough data to say anything useful about it.

6 Appendix

6.1 Tables

The data used in the thesis is found in these tables, table 1 for 4U 1636-53 and table 2 for 4U 1728-34

obsid	PRE	os	Sa	60032-01-18-00G	0	0	1.5	60032-05-11-02	0	0	1.066
				60032-01-18-00G	0	0	1.541	60032-05-11-02	0	0	1.122
10088-01-07-02	0	0	2.382	60032-01-18-00G	0	0	1.526	60032-05-12-00	0	0	1.236
10088-01-07-02	0	0	2.357	60032-01-18-01	0	0	1.631	60032-05-13-00	0	0	2.096
10088-01-08-01	0	0	2.436	60032-01-18-01	0	0	2.094	60032-05-14-00	0	0	1.213
10088-01-08-030	0	0	2.451	60032-01-18-02	0	0	2.265	60032-05-15-000	0	0	1.675
10088-01-09-01	0	0	2.112	60032-01-19-000	0	0	1.278	60032-05-15-00	0	0	1.604
30053-02-02-02	0	0	2.012	60032-01-19-000	0	0	1.337	60032-05-17-00	0	0	1.567
30053-02-01-02	0	0	2.03	60032-01-19-00	0	0	1.331	60032-05-18-00	0	0	2.151
30053-02-02-00	0	0	2.082	60032-01-20-000	0	0	1.29	60032-05-19-00	0	0	2.151
40028-01-02-00	0	0	2.141	60032-01-20-01	0	0	1.992	60032-05-21-000	0	0	1.953
40028-01-04-00	0	0	2.093	60032-01-23-03	0	0	1.314	60032-05-21-000	0	0	1.64
40028-01-06-00	0	0	2.105	60032-01-23-03	0	0	1.506	60032-05-21-000	0	0	2.113
40028-01-08-00	0	0	2.124	60032-01-23-03	0	0	2.124	60032-05-21-00	0	0	1.804
40030-03-04-00	0	0	1.854	60032-01-23-01G	0	0	1.836	60032-05-22-000	0	0	1.61
40031-01-01-06	0	0	1.869	60032-01-23-01G	0	0	1.625	60032-05-23-000	0	0	1.711
40028-01-10-00	0	0	2.107	60032-05-01-00	0	0	1.64	80425-01-01-00	0	0	1.922
40028-01-13-00	0	0	2.101	60032-05-01-00	0	0	1.278	91024-01-08-00	0	0	1.854
40028-01-13-00	0	0	2.091	60032-05-01-00	0	0	1.815	91024-01-10-00	0	0	1.858
40028-01-14-01	0	0	1.906	60032-05-02-00	0	0	1.431	91024-01-12-00	0	0	2.124
40028-01-15-00	0	0	1.84	60032-05-02-00	0	0	1.48	91024-01-16-00	0	0	2.065
40028-01-18-000	0	0	1.76	60032-05-03-00	0	0	2.293	91024-01-23-00	0	0	2.127
40028-01-18-00	0	0	1.74	60032-05-03-00	0	0	2.128	91024-01-24-00	0	0	2.108
40028-01-19-00	0	0	1.744	60032-05-03-00	0	0	2.101	91024-01-24-00	0	0	2.126
40028-01-20-00	0	0	1.706	60032-05-03-01	0	0	1.242	91024-01-27-00	0	0	2.098
50030-02-01-00	0	0	2.063	60032-05-04-00	0	0	1.284	91024-01-35-00	0	0	1.953
50030-02-02-00	0	0	2.066	60032-05-04-00	0	0	1.23	91024-01-40-00	0	0	1.175
50030-02-04-00	0	0	2.021	60032-05-05-000	0	0	1.29	91024-01-42-00	0	0	1.266
50030-02-05-01	0	0	1.78	60032-05-05-000	0	0	1.804	91024-01-46-00	0	0	2.293
50030-02-05-00	0	0	1.847	60032-05-05-00	0	0	1.531	91024-01-54-00	0	0	2.104
50030-02-09-000	0	0	1.78	60032-05-05-00	0	0	1.39	91024-01-62-00	0	0	2.235
50030-02-10-00	0	0	1.772	60032-05-05-00	0	0	1.296	91024-01-68-00	0	0	1.631
60032-01-01-000	0	0	1.728	60032-05-06-00	0	0	1.242	91024-01-69-00	0	0	1.776
60032-01-01-000	0	0	1.862	60032-05-07-00	0	0	1.431	91024-01-73-00	0	0	1.981
60032-01-06-000	0	0	1.882	60032-05-07-01	0	0	1.45	91024-01-75-00	0	0	2.12
60032-01-06-000	0	0	1.922	60032-05-08-00	0	0	1.367	91024-01-75-00	0	0	1.684
60032-01-04-04	0	0	1.818	60032-05-08-00	0	0	1.367	91024-01-77-00	0	0	1.46
60032-01-04-04	0	0	1.772	60032-05-09-00	0	0	1.343	91024-01-78-00	0	0	1.804
60032-01-06-01	0	0	2.004	60032-05-09-00	0	0	1.367	91024-01-80-00	0	0	1.486
60032-01-09-00	0	0	1.967	60032-05-09-00	0	0	2.197	91024-01-82-00	0	0	1.425
60032-01-09-01	0	0	2.094	60032-05-09-00	0	0	2.062	91024-01-83-00	0	0	2.207
60032-01-10-00	0	0	2.024	60032-05-10-000	0	0	1.165	91024-01-88-00	0	0	1.666
60032-01-10-02	0	0	2.021	60032-05-10-000	0	0	1.122	91024-01-89-00	0	0	1.657
60032-01-11-01	0	0	1.947	60032-05-10-00	0	0	2.153	70034-01-01-01	0	0	1.956
60032-01-11-01	0	0	1.224	60032-05-10-00	0	0	1.44	91027-01-01-000	0	0	1.349
60032-01-12-000	0	0	1.296	60032-05-10-00	0	0	2.212	91027-01-01-000	0	0	1.49
60032-01-12-000	0	0	1.396	60032-05-11-01	0	0	2.108	91027-01-01-000	0	0	1.278
60032-01-12-000	0	0	1.379	60032-05-11-01	0	0	2.128	91027-01-01-00	0	0	1.772
60032-01-13-01	0	0	1.44	60032-05-11-02	0	0	1.26	70034-01-01-000	0	0	1.476
60032-01-14-01	0	0	1.47	60032-05-11-02	0	0	1.103	70034-01-01-000	0	0	2.284

70034-01-01-000	0	0	2.039	93087-01-03-00	0	0	2.176	94087-01-09-00	0	1	1.631
70034-01-01-00	0	0	1.224	93087-01-06-00	0	0	2.12	94087-01-20-00	0	1	2.186
91024-01-03-10	0	0	1.296	93087-01-07-00	0	0	2.102	94087-01-28-00	0	1	2.141
91024-01-12-10	0	0	2.207	93087-01-24-00	0	0	2.112	94087-01-29-00	0	1	1.858
91024-01-22-10	0	0	2.071	93087-01-34-00	0	0	1.653	94087-01-31-00	0	1	1.748
91024-01-24-10	0	0	1.516	93087-01-50-00	0	0	1.792	94087-01-33-00	0	1	1.367
91024-01-30-10	0	0	1.562	93087-01-53-00	0	0	1.942	94087-01-38-00	0	1	1.557
91024-01-41-10	0	0	1.689	93087-01-61-00	0	0	1.788	94087-01-38-00	0	1	2.127
91024-01-49-10	0	0	2.137	93087-01-63-00	0	0	2.123	94310-01-01-00	0	2	1.788
91024-01-72-10	0	0	1.889	93087-01-65-00	0	0	2.134	94087-01-50-00	0	2	2.21
91024-01-41-00	0	0	1.825	93087-01-66-00	0	0	2.113	94087-01-54-00	0	2	2.352
91024-01-14-10	0	0	1.343	93087-01-69-00	0	0	1.117	94087-01-55-00	0	2	2.137
92023-01-09-00	0	0	2.134	93087-01-76-00	0	0	1.175	94087-01-80-00	0	2	2.165
91152-05-01-00	0	0	1.772	93087-01-78-01	0	0	1.964	94087-01-87-00G	0	3	2.199
91152-05-01-00	0	0	2.033	93087-01-95-00	0	0	2.134	94087-01-90-00	0	3	2.143
91152-05-01-00	0	0	1.915	93087-01-22-10	0	0	2.131	94087-01-95-00	0	3	1.804
92023-01-12-00	0	0	1.45	93087-01-22-10	0	0	1.32	94087-01-06-10	0	3	2.194
92023-01-22-00	0	0	2.085	93087-01-24-10	0	0	1.325	94087-01-25-10	0	3	2.357
92023-01-24-00	0	0	2.112	93091-01-02-00	0	0	2.158	94087-01-25-10	0	3	1.929
92023-01-32-00	0	0	1.919	93087-01-28-10	0	0	2.322	94310-01-03-000	1	0	2.05
92023-01-52-00	0	0	1.869	93087-01-33-10	0	0	2.179	94087-01-31-10	1	0	1.788
92023-01-55-00	0	0	1.892	93087-01-42-10	0	0	1.384	94437-01-01-000	1	0	1.825
92023-01-61-00	0	0	1.552	93087-01-42-10	0	0	1.408	94437-01-01-000	1	0	1.784
91152-05-02-00	0	0	1.882	93087-01-51-10	0	0	1.48	94437-01-01-000	1	0	1.879
92023-01-72-00	0	0	2.065	93087-01-54-10	0	0	1.331	94437-01-01-010	1	0	1.822
92023-01-80-00	0	0	2.148	93087-01-55-10	0	0	1.32	94437-01-01-010	1	0	1.947
92023-01-84-00	0	0	2.16	93087-01-57-10	0	0	2.127	94437-01-01-01	1	0	1.715
92023-01-06-10	0	0	1.792	93087-01-63-10	0	0	1.711	94437-01-01-01	1	0	2.088
92023-01-10-10	0	0	2.155	93087-01-66-10	0	0	1.414	94437-01-02-000	1	0	1.995
92023-01-24-10	0	0	1.72	93087-01-70-10	0	0	1.414	94437-01-02-000	1	0	2.14
92023-01-28-10	0	0	1.402	93087-01-91-10	0	0	1.349	94310-01-04-00	1	0	2.071
92023-01-28-10	0	0	1.242	93087-01-98-10	0	0	1.349	94310-01-04-00	1	1	2.188
92023-01-31-10	0	0	1.278	93087-01-04-20	0	0	1.23	94310-01-04-00	1	1	2.151
92023-01-33-10	0	0	1.266	93087-01-09-20	0	0	1.84	94310-01-04-00	1	1	2.137
92023-01-44-10	0	0	1.296	93087-01-24-20	0	0	1.165	94310-01-04-00	1	1	2.113
92023-01-49-10	0	0	1.308	93087-01-27-20	0	0	1.117	94087-01-45-10	1	1	2.376
92023-01-60-10	0	0	1.302	93087-01-28-20	0	0	1.117	94087-01-65-10	1	1	2.108
92023-01-74-10	0	0	1.254	93087-01-38-20	0	1	2.214	94087-01-69-10	1	1	2.376
92023-01-76-10	0	0	1.254	93087-01-44-20	0	1	2.186	94087-01-70-10	1	1	2.136
91024-01-10-10	0	0	1.296	93087-01-47-20	0	1	2.138	94087-01-73-10	1	1	2.071
91024-01-83-10	0	0	1.425	93087-01-48-20	0	1	1.869	94087-01-74-10	1	1	2.24
91024-01-84-10	0	0	1.466	93087-01-51-20	0	1	1.873	94087-01-83-10	1	1	2.024
92023-01-09-20	0	0	1.402	93087-01-52-20	0	1	1.825	95087-01-08-00	1	1	2.076
92023-01-11-20	0	0	1.402	93087-01-56-20	0	1	1.967	95087-01-13-00	1	1	2.128
92023-01-12-20	0	0	1.367	93087-01-61-20	0	1	2.042	95087-01-15-00	1	1	2.239
92023-01-20-20	0	0	1.308	93087-01-66-20	0	1	1.314	95087-01-16-00	1	1	2.311
92023-01-23-20	0	0	2.183	93087-01-68-20	0	1	2.357	95087-01-39-00	1	1	1.953
70036-01-02-00	0	0	2.174	93087-01-71-20	0	1	1.278	95087-01-40-00	1	1	2.148
70036-01-02-00	0	0	1.32	94087-01-01-00	0	1	1.17	95087-01-42-00	1	1	2.104
92023-01-97-10	0	0	1.165	94087-01-06-00	0	1	2.101	95087-01-43-00	1	1	2.079

95087-01-61-00	1	1	2.165
95087-01-37-10	1	2	2.134
95087-01-47-10	1	2	2.14
95087-01-59-10	1	2	2.093
95087-01-70-10	1	2	2.265
95087-01-79-10	1	2	2.057
95087-01-82-10	1	2	2.091
96087-01-03-00	1	2	1.989
96087-01-07-00	1	2	2.079
96087-01-12-00	1	2	2.302
96087-01-36-00	1	2	2.146
96087-01-37-00	1	2	2.063
96087-01-38-00	1	2	2.082
96087-01-46-00	1	2	2.074
96087-01-66-00	1	2	2.006
96087-01-70-00	1	2	2.083
96087-01-74-00	1	2	2.045
96087-01-76-00	1	2	2.085
96087-01-79-00	1	2	2.094
96087-01-85-00	1	2	2.133
96087-01-86-00	1	2	2.25
96087-01-01-10	1	2	2.225
96087-01-02-10	1	2	2.094
96087-01-19-10	1	2	2.138
96087-01-44-10	1	3	2.098
96087-01-45-10	1	3	2.071
96087-01-50-10	1	3	2.088
96087-01-53-10	1	3	2.34
96087-01-59-10	1	3	2.153
96087-01-61-10	1	3	2.183
96087-01-61-10	1	3	2.124
96087-01-65-10	1	3	2.16
96087-01-65-10	1	3	2.256
96087-01-67-10	1	3	2.058
96087-01-71-10	1	3	2.321
96087-01-81-10	1	3	2.124
96087-01-83-10	1	3	2.03
96087-01-83-10	1	3	2.11

Table 10: The data table for 1636. The first column of the table is the observe ID. The second and third column are for PRE and oscillation. A 0 means that the property has not been observed, in the case of PRE a 1 means it has been observed. In the case of oscillation, the 1,2 and 3 stand for oscillation in the rise of the burst, oscillation in the cooling phase of the burst and oscillations in both phases. In this thesis, all 3 of this options were assumed the same. The last column is the S_a at the time of the burst.

obsid	PRE	OS	Sa								
				40033-06-02-03	1	0	0.750	70028-01-01-00	1	0	0.750
				40033-06-02-03	1	1	0.375	70028-01-01-10	0	0	0.625
10073-01-01-000	1	1	0.500	40033-06-02-04	1	0	0.375	70028-01-01-12	1	0	0.625
10073-01-01-00	1	1	0.375	40033-06-02-05	1	1	0.250	90406-01-01-00	0	1	0.500
10073-01-02-000	0	0	1.375	40033-06-03-01	1	0	0.750	91023-01-02-00	0	1	0.375
10073-01-02-00	0	1	0.375	40033-06-03-020	1	1	0.250	92023-03-03-00	1	0	0.750
10073-01-02-00	0	1	0.250	40033-06-03-020	1	1	0.250	92023-03-23-00	0	1	0.625
10073-01-03-000	0	1	0.625	40033-06-03-05	1	1	0.250	92023-03-35-00	1	0	0.750
10073-01-04-000	0	1	0.625	40027-06-01-00	1	0	1.000	92023-03-41-00	1	1	0.250
10073-01-04-00	0	0	0.750	40027-06-01-02	0	0	1.125	92023-03-52-00	0	1	1.125
10073-01-06-00	1	0	1.250	40027-06-01-03	1	0	1.375	92023-03-76-00	0	1	1.750
10073-01-07-00	1	0	1.375	40027-06-01-08	1	0	0.750	92023-03-83-00	0	1	0.375
10073-01-08-000	1	0	1.250	40027-08-01-01	1	0	1.250	92023-03-87-01	0	1	0.875
10073-01-09-000	1	0	0.875	40027-08-03-00	1	0	1.000	92023-03-95-00	0	1	0.875
20083-01-01-01	0	1	1.500	40019-03-02-000	0	1	2.375	92023-03-02-10	1	0	1.000
20083-01-01-020	0	1	1.250	40019-03-02-000	0	1	0.500	92023-03-06-10	1	0	0.375
20083-01-02-01	0	1	0.500	40019-03-02-00	0	1	0.375	92023-03-08-10	0	0	0.875
20083-01-02-01	0	1	0.625	40019-03-02-00	0	1	0.500	92023-03-10-10	0	1	0.750
20083-01-02-000	0	1	1.375	40019-03-01-06	0	0	0.375	92023-03-16-10	1	1	0.375
20083-01-04-00	0	1	0.875	50023-01-07-00	0	0	0.750	92023-03-20-10	0	0	0.500
20083-01-04-00	0	1	0.250	50029-23-02-01	1	0	1.250	92023-03-27-10	1	0	0.625
20083-01-04-01	1	1	0.375	50029-23-02-02	0	0	1.000	92023-03-34-10	1	0	0.875
20083-01-04-01	1	1	0.375	50023-01-21-00	1	0	1.125	92023-03-44-10	1	0	0.750
30042-03-01-00	1	0	0.875	50023-01-22-00	1	0	1.375	92023-03-44-00	1	0	1.250
30042-03-03-01	1	0	1.000	50023-01-23-00	1	0	1.000	92023-03-64-00	0	1	0.500
30042-03-06-00	1	0	1.500	50030-03-02-000	1	0	0.500	92023-03-64-10	0	1	0.750
30042-03-06-00	1	0	1.250	50030-03-03-02	1	0	1.375	92023-03-70-00	1	1	1.000
30042-03-07-01	1	0	1.000	50030-03-04-00	1	1	1.125	92023-03-71-00	1	0	0.750
30042-03-07-00	1	0	1.500	50030-03-04-02	1	1	0.500	92023-03-73-00	1	0	0.500
30042-03-10-00	1	0	0.500	50030-03-05-03	1	0	1.125	92023-03-65-10	0	0	1.000
30042-03-11-00	1	0	1.000	50030-03-05-02	1	0	1.375	92023-03-66-10	1	0	0.875
30042-03-12-00	1	0	0.500	60029-02-01-00	1	0	1.125	92023-03-73-10	0	1	0.500
30042-03-12-00	1	0	0.750	50030-03-06-00	1	0	1.625	92023-03-76-10	0	1	1.375
30042-03-13-00	0	0	0.875	50030-03-06-02	0	0	1.000	92023-03-83-10	1	0	1.250
30042-03-14-00	1	0	0.250	50030-03-08-02	0	1	0.250	95337-01-02-000	1	1	0.500
30042-03-15-00	0	0	0.375	50030-03-08-00	0	1	0.500	95337-01-02-000	0	1	0.250
30042-03-17-00	1	1	0.250	50030-03-09-01	0	1	1.500	95337-01-03-000	0	0	0.375
30042-03-20-00	1	0	1.375	70028-01-01-070	1	0	0.875	96322-01-05-02	1	0	0.750
40033-06-01-00	1	0	1.000	70028-01-01-070	0	0	0.875	96322-01-05-000	1	0	1.000
40033-06-02-00	1	0	0.875	70028-01-01-070	0	0	0.875	96322-01-05-000	1	0	1.000
40033-06-02-01	1	1	0.875	70028-01-01-02	1	0	0.750	96322-01-05-00	1	0	0.875

Table 11: The data table for 1728. The first column is the observe ID, the second and third are the PRE and oscillations, respectively. Wherein 0 means not observed and 1 means that the property was observed. The last column is the S_a at the time of the burst.

6.2 Extra Graphs

To further clarify the difference between different kinds bursts there are some extra graphs in this section. These graphs are all taken from source 1636.

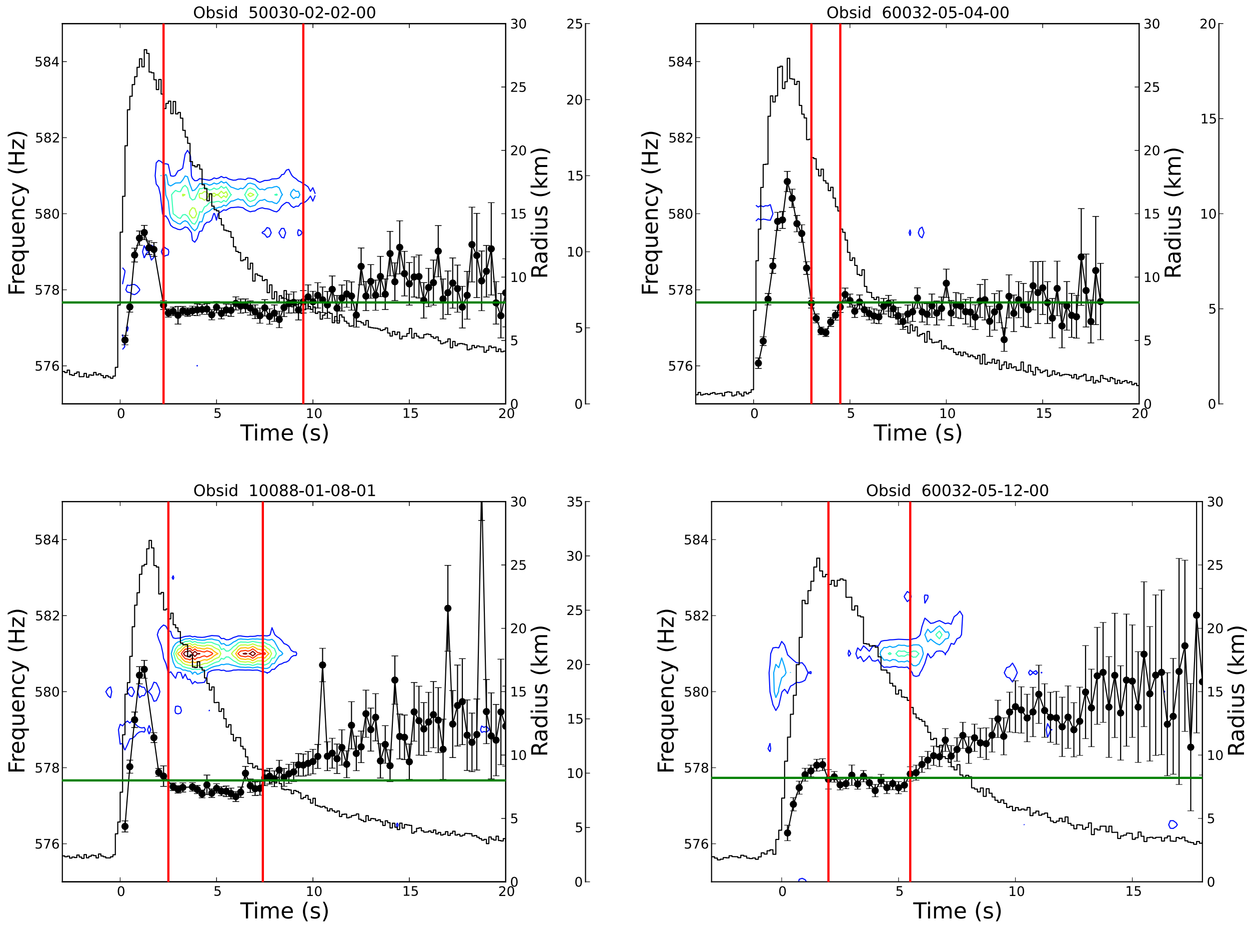
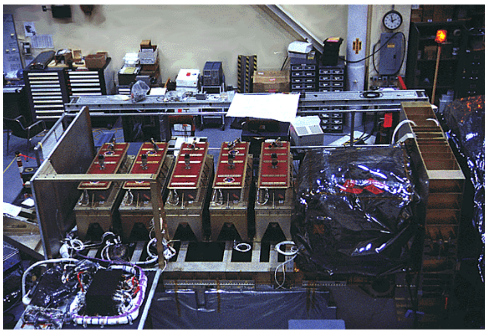


Figure 9: The left graphs show bursts with oscillations and PRE. The top right graph shows a burst with PRE, but without oscillations. The bottom right graph shows a burst with oscillations, but without PRE. In each graph the black histogram shows the light curve of the burst. The intensity, in units of 1000 counts s^{-1}, is shown by the scale plotted to the right, outside of each panel. The colored contour lines show constant power values, increasing from 10 to 80 in steps of 10 (in Leahy units), as a function of time (x axis) and frequency (left y axis). Black circles connected by a line show the blackbody radius as a function of time at. (see the right y axis), with error bars at the 90% confidence level. [3]

6.3 The Satellite: RXTE

As mentioned before, the data from this thesis was all retreived using the RXTE, short for the Rossi X-ray Timing Explorer Mission. This satellite was live for 16 years and its data was used in over 1900 publications and over 90 PHD theses. These RXTE researches also won some prizes, including 4 Rossi prizes (199,2003,2006 and 2009) and the Dutch NWO Spinoza price. A lot of this research focused on the most spectacular objects in the universe, neutron stars and black holes. To accomplish this, the satellite had 3 main instruments: the Proportional Counter Array (PCA), the High Energy X-ray Timing Experiment (HEXTE) and the All-Sky Monitor (ASM). The PCA covered the lower part of the spectrum (2-0 keV) and the HEXTE the higher part(15-250 keV). On top of that the ASM scanned 80% of the sky each orbit.[10]



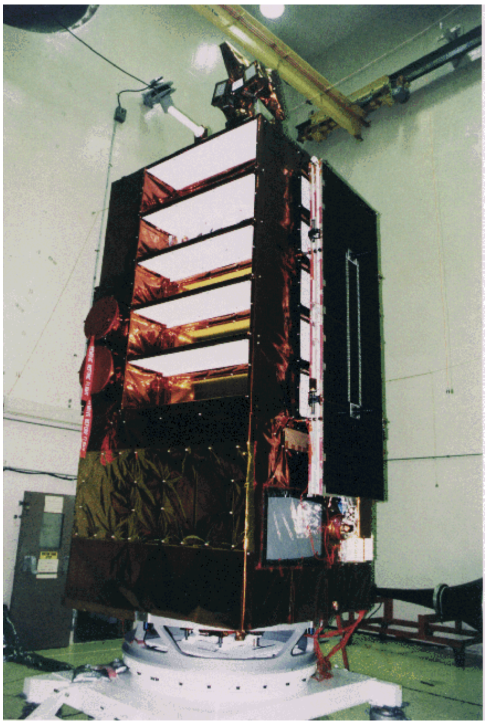


Figure 10: Left picture shows the assembly of the RXTE, the right picture shows the RXTE when it was complete.[10]

References

[1] Swinburne University of Technology. Roche-lobe. astronomy.swin.edu.au/cosmos/R/Roche-lobe, jun 2015.

[2] T. Strohmayer and L. Bildsten. New Views of Thermonuclear Bursts. *ArXiv Astrophysics e-prints*, January 2003.

[3] G. Zhang, M. Méndez, T. M. Belloni, and J. Homan. Coherent oscillations and the evolution of the apparent emission area in the decaying phase of radius-expansion bursts from 4U 1636-53. *Monthly Notices of the Royal Astronomical Society*, 436:2276–2285, December 2013.

[4] G. Zhang, M. Méndez, and D. Altamirano. The cooling phase of Type I X-ray bursts in 4U 1636-53. *Monthly Notices of the Royal Astronomical Society*, 413:1913–1921, May 2011.

[5] William T. Vetterling Brian P. Flannery William H. Press, Saul A. Teukolsky. *Numerical Recipes in C*. Cambridge University Press, 1992.

[6] M. P. Muno, D. K. Galloway, and D. Chakrabarty. The Effect of Neutron Star Rotation on the Properties of Thermonuclear X-Ray Bursts. *apj*, 608:930–934, June 2004.

[7] D. K. Galloway, Y. Yao, H. Marshall, Z. Misanovic, and N. Weinberg. Radius-expansion Burst Spectra from 4U 1728-34: An Ultracompact Binary? *apj*, 724:417–424, November 2010.

[8] M. P. Muno, D. Chakrabarty, D. K. Galloway, and P. Savov. Millisecond Oscillations and Photospheric Radius Expansion in Thermonuclear X-Ray Bursts. *Astrophysical Journal*, 553:L157–L160, June 2001.

[9] M. Gierliński and C. Done. The X-ray spectrum of the atoll source 4U 1608-52. *Monthly Notices of the Royal Astronomical Society*, 337:1373–1380, December 2002.

[10] NASA. Rxte guest observer facility, March 2013.