GRO J1008-57: high precision timing and spectral evolution

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Abstract

We present preliminary results of the analysis of *RXTE*, *Swift*, and *Suzaku* data of the transient high mass X-ray binary (HMXB) GRO J1008-57 taken during outbursts in 2005 and 2007. The lightcurves show pulsations with a pulse period around 93.7 s. By analysing pulse arrival times the Doppler shift of the pulse period due to the orbital motion of the system is investigated. We find that the orbital parameters derived from previous outbursts between 1993 and 1996 have to be updated to explain the measured delays of the arrival times. Further on, a slight spin up of the neutron star during the brightest parts of the 2007 outburst is detected.

The spectrum of GRO J1008-57 can be well explained by an absorbed cutoff powerlaw with additional black body and iron fluorescence emission. While the equivalent hydrogen column density N_H stays constant over the outbursts, the powerlaw index Γ increases and the black body cools down with decreasing luminosity. At high luminosities an absorption like feature around 23 keV is visible in the PCA spectra of the 2007 outburst, which might be interpreted as cyclotron resonant scattering feature (CRSF). It is not, however, confirmed by the *Suzaku* data.

Introduction

The transient high mass X-ray binary GRO J1008-57 consists of a neutron star and a Be type companion (Coe at al., 1994). The pulse period of the neutron star is around 93.5 s (Shrader et al., 1999) and the orbital period of the system is 247.8 d (Coe et al, 2007). Mass accretion from the circumstellar disc of the Be type star is possible close to periastron. Thus X-ray outbursts occur once per orbit.

Theory predicts so-called cyclotron resonant scattering features (CRSF) or cyclotron lines (Schönherr et al., 2007, and references therein). These lines are connected to the magnetic field strength of the neutron star. In the spectrum of GRO J1008-57 a fundamental cyclotron line at 88 keV is claimed, which would imply that this neutron star has one of the strongest magnetic fields known (Grove et al., 1995; Shrader et al., 1999).

RXTE monitored the outbursts of GRO J1008-57 in 2005 and 2007 starting at maximum luminosity and during the decay. The latter outburst was also observed by *Swift* and *Suzaku*. The ASM lightcurve of the outbursts including the times of individual observations are shown in Figure 1.

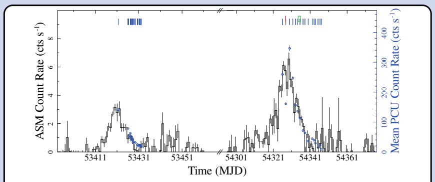


Figure 1: The ASM lightcurves of the outbursts of GRO J1008-57 in 2005 (left) and 2007 (right). The pointed observations of *RXTE* (blue), *Swift* (red), and *Suzaku* (green) are marked above.

Timing Analysis

The lightcurves of the 2007 outburst recorded by *RXTE*-PCA, *Swift*-XRT, and *Suzaku*-XIS3 are analysed to investigate the pulse period evolution. Using Epoch Folding (Leahy et al., 1983) a pulse period of 93.73(7) s is found and no clear evolution is seen within the uncertainties during the outburst.

To further increase the accuracy a pulse profile from each observation is created. Therefore, the lightcurves are first corrected for binary motion using the orbital parameters shown in Table 1. The resulting profiles are more or less stable during the outburst. Thus the phase shift of each profile to a reference one can be determined by cross-correlation. The time dependence of these shifts allows the determination of the pulse period change, which results in $\dot{P} = -1.41(6) \times 10^{-8}\,\mathrm{s\,s^{-1}}$. This value is three times larger than the value found by Coe et al. (2007). This discrepancy might be caused by orbital effects, since the orbital parameters are not well constrained and the reference time τ is 14 years ago relative to the 2007 outburst. To investigate this problem a method has to be used, which is based on phase connection and can model both, orbital parameters and the pulse ephemeris, simultaneously.

Table 1: Orbital Parameters of GRO J1008-57 as found by Coe et al. (2007).

P_{orb}	247.8(4) d
e	0.68(2)
$a \sin i$	530(60) lt-s
ω	-26(8)°
τ	49189.8(5) MJD

Pulse Arrival Times

Pulse arrival times $t(n)$ are defined as the occurence of a specific pattern, the pulse profile, in the lightcurves. Based on a reference pulse at t_0 the arrival time of the pulse number n is given by

$$t(n) = t_{\mathrm{emit}}(n) + \frac{z(t_{\mathrm{emit}}(n))}{c}$$

where $t_{\mathrm{emit}}(n)$ is the emission time of the pulse in the rest frame of the neutron star,

$$t_{\mathrm{emit}}(n) = t_0 + Pn + \frac{1}{2}\dot{P}Pn^2 + \ldots$$

and z the time shift caused by the orbital motion.

Fitting pulse arrival times for the 2005 and 2007 outbursts with a constant pulse period results in strong residuals. Monte Carlo simulations were used to distinguish between spin changes and a Doppler shift due to uncertain orbital parameters. We find that an uncertainty in the orbital period may lead to a spurious spin change of the order of $10^{-8}\,\mathrm{s\,s^{-1}}$. The same change is found in the data when using phase connection (see before). Thus, the arrival times are used to update the orbital period:

$$P_{\mathrm{orb}} = 249.46(11)\,\mathrm{d}$$

Further on, a spin change of the neutron star is only needed during maximum luminosity of the 2007 outburst:

$$\ddot{P} = 3.4(1) \times 10^{-14}\,\mathrm{s\,s^{-2}}$$

The residuals of the model and the disentangled observed pulse period is shown in Figure 2 (lower panel). The pulse ephemeris at low luminosities in 2005 and 2007 is constant within the uncertainties (upper panel, solid line), although a slight spin down is observed during maximum luminosity in the 2007 outburst.

Pulse Profiles

The pulse profiles of GRO J1008-57 are strongly energy dependent. Figure 3 shows an example profile at different energy intervals. At energies below 6 keV a clear double peaked structure is seen, where both peaks are nearly of equal strength. At higher energies the peak directly after the lowest count rate drops significantly, until it vanishes completely for energies above 21 keV. This behavior is also seen in other transient source, e.g., 4U 0115+634 (Müller et al., 2010; see also poster "4U 0115+63: A Bonanza of CRSFs").

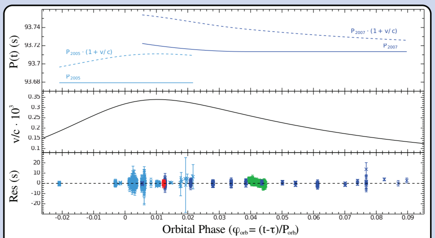


Figure 2: The results of the arrival times fit of GRO J1008-57. The lower panel shows the deviation of the model to the arrival times during the outburst in 2005 measured by *RXTE* (light blue) and in 2007 by *RXTE* (dark blue), Swift (red), and *Suzaku* (green). The resulting updated orbital parameters lead to a Doppler shift modulation v/c as shown in the middel panel.

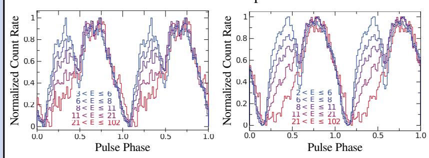


Figure 3: The energy resolved pulse profiles of GRO J1008-57 at low (left) and high luminosities (right). The double peak structure at energies below 6 keV evolves to a single peak for energies above 21 keV.

Spectral Evolution

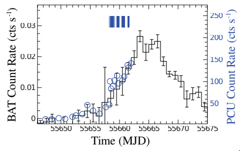
At its discovery the spectrum of GRO J1008-57 was explained by a Bremsstrahlung model with a temperature of 32 keV (Shrader et al., 1999). Using this model to fit the *RXTE*-PCA spectrum of the 2007 outburst, however, fails. At energies below 15 keV a broad emission feature is visible in the residuals. Figure 4 shows a successful fit using a cutoff powerlaw with an additional black body and a narrow Kα iron line. This model works well during the outburst of 2007 as well as during 2005.

The parameter evolution of the above model during the 2007 outburst of GRO J1008-57 is shown in Figure 5. The column density n_H does not show any correlation with luminosity. At the end of the outburst, were the luminosity is low, the photon index Γ increases, indicating that the source gets softer. At the same time the black body temperature kT decreases, which can be interpreted as a cooling due to the lower mass accretion. Similar trends are also seen in the data of the 2005 outburst.

Outlook

Using the updated orbital parameters an outburst of GRO J1008-57 was successfully predicted to be between April 3 and 15, 2011. The maximum in the BAT-lightcurve, which is shown in Figure 7, is around April 13 (MJD 55665). Thus the orbital period is constrained well. The performed *RXTE* observations will be used to further constrain the orbital parameters and to look for CRSFs.

Figure 7: The *Swift*-BAT lightcurve of the outburst in April 2011, which was predicted using the updated orbital parameters. *RXTE* observations are marked above.



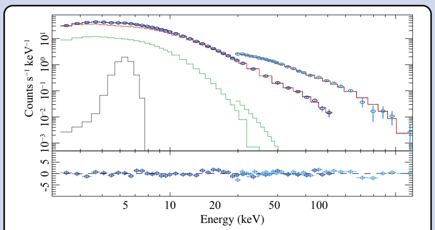


Figure 4: Spectrum of GRO J1008-57 as observed with *RXTE*-PCA (dark blue) and HEXTE (light blue). The lower panel shows the residuals of the used model, which consists of an absorbed cutoff powerlaw (red), a black body (green) and a narrow iron line at 6.4 keV (grey).

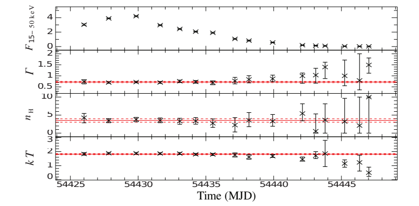


Figure 5: Parameter evolution of the used model described in the text during the 2007 outburst and the source luminosity in the first panel. The description is given in the text.

Cyclotron Lines

The first three *RXTE* spectra are summed due to constant continuum parameters. An absorption like feature around 23 keV is present in the PCA residuals, which is not confirmed by the HEXTE data (see Figure 6) and is in contradiction with the Suzaku spectrum. The latter, however, was observed at much lower luminosities. If interpreted as cyclotron line, this might be explained by changing line parameters as expected from theory (Schönherr, 2007, and references therein). The data does not allow, however, a confirmation of the claimed cyclotron line at 88 keV. Further observations are necessary to clarify the existence of cyclotron lines.

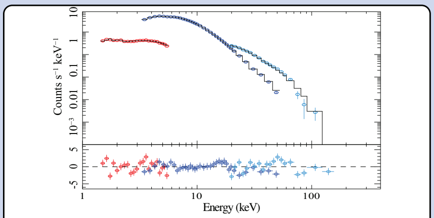


Figure 6: The summed first three *RXTE*-PCA (dark blue) and HEXTE (light blue) and the *Swift*-XRT spectrum (red) of GRO J1008-57. The PCA residuals show an absorption like feature at around 23 keV.

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