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 53.7 s. By analysing pulse arrival times the Doppler shift of the polar region was determined. 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 cut-off powerlaw with additional black body and iron fluorescence emission. While the equivalent hydrogen column density $N_{\text{H}}$ stays constant over the outbursts, the powerlaw index $\Gamma$ increases and the black body cool down with decreasing luminosity. Low 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.

**Abstract**

**Introduction**

The transient high mass X-ray binary GRO J1008-57 consists of a neutron star and a Be type companion (Coe et al., 1994). The pulse period of the neutron star is around $39.5\,\text{s}$ and the orbital period of the system is $247.8\,\text{d}$ (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 (Schinipher et al., 2007), and references therein). These lines are connected to the magnetic field strengths 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; Shafer 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 lightcurves of the outbursts including the times of individual observations are shown in Figure 1.

**Tuning Analysis**

The lightcurves of the 2007 outburst recorded by RXTE/PCA, Swift-XRT, and Suzaku-XIS3 are analysed in order to investigate the pulse evolution period. Using Epoch Folding (Leahy et al., 1988), a pulse period of 93.7(7) s is found and no coherent wave is seen in the onsets of the outbursts.

To further increase the accuracy a pulse profile from each observation is created. These profiles are first corrected for binary motion using the orbital parameters shown in Table 1. The resulting profiles are more or less stable across the outburst. Thus the pulse phase 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 $\dot{\nu} = \left(3.4 \pm 1.0 \times 10^{-9}\right)\,\text{s}\,\text{s}^{-1}$. 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 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 ephemeres, simultaneously.

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\dot{\nu}$</td>
<td>$\left(3.4 \pm 1.0 \times 10^{-9}\right),\text{s},\text{s}^{-1}$</td>
</tr>
<tr>
<td>$a_{\text{eq}}$</td>
<td>$580(50),\text{R}_\odot$</td>
</tr>
<tr>
<td>$\omega$</td>
<td>$261^\circ$</td>
</tr>
<tr>
<td>$i$</td>
<td>$40(4),\text{MD}$</td>
</tr>
</tbody>
</table>

**Pulse Arrival Times**

Pulse arrival times ($\tau_0$) are defined as the occurrence of a specific pattern, the pulse profile, in the lightcurves. Based on a reference pulse at $\tau_0$, the arrival time of the pulse number $n$ is given by $\tau_n = \tau_0 + \frac{\tau_0}{\nu} + d\,\tau_0$, where $\tau_n$ is the arrival time of the $n$th pulse in the rest frame of the neutron star.

$$t_{\text{p},n} = t_{\text{p},0} + \frac{t_{\text{p},0}}{\nu} + d\,t_{\text{p},0} \quad \ldots$$

and 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 variations 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 $1\,\text{s}$ in 14 years, which is substantial and can be confirmed by the onsets of the 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+634: A Bonanza of CRSSs".

**Spectral Evolution**

At its discovery the spectrum of GRO J1008-57 was explained by a Bremsstrahlung model with a temperature of $32\,\text{keV}$ (Shafer et al., 1999). Using this model for 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 keV iron line. This model works well during the 2007 outburst 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 $N_{\text{H}}$ does not show any correlation with luminosity. At the end of the outburst the luminosity is low; the photon index $\Gamma$ increases, indicating that the source gets softer. At the same time the black body temperature $T_b$ 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 magnitude of the outburst is $3$-4 magnitudes, which is shown in Figure 7 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 CRSS.

**Cyclotron Lines**

The first three RXTE spectra are summed due to constant continuum parameters. An absorption like feature around 23 keV is not visible, which is not confirmed by the HEXT 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 expected cyclotron line at 88 keV. Further observations are necessary to clarify the existence of cyclotron lines.

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