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The orbital X-ray light curve of GX301-2

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Abstract.
GX301-2 is an x-ray pulsar in an eccentric orbit (e=0.47) with a massive early-type stellar companion. The neutron star accretes from the stellar wind and exhibits regular flares approximately 1.4 days prior to periastron passage. Long-term continuous x-ray monitoring of GX301-2 by the RXTE/ All-Sky-Monitor has now been carried out for a period of 5 years. These data now comprise the best observations of the orbital x-ray light curve. The main flux peak just prior to periastron is clearly seen, as well as a secondary broad peak near apastron. CGRO/ BATSE observations have provided new improved orbital parameters. Modeling of GX301-2 orbital light curve, using the new orbital parameters, and including the stellar wind, is carried out.

1 Introduction

GX 301-2 (also known as 4U 1223-62) is pulsar with a 680 s rotation period, in a 41.5 day eccentric orbit (Sato et al. (1986)). The mass function is 31.8 M_{sun}, making the minimum companion mass 35 M_{sun} for a 1.4 M neutron star. The companion Wray 977 has a B2 Iae spectral classification (Parkes et al. (1980)).

The neutron star flares regularly in X-rays approximately 1-2 days before periastron passage, and several stellar wind accretion models have been proposed to explain the magnitude of the flares and their orbital phase dependence (e.g. Leahy (1991); Haberl (1991)). The modeling by Leahy (1991) and Haberl (1991) was done using TENMA and EXOSAT observations, respectively, which cover many short data sets spaced irregularly over orbital phase. More recently better orbital phase coverage has been obtained by CGRO/BATSE (Koh et al. (1997)), which however has much lower sensitivity that the previous studies.

The spectrum of GX301-2 has been well studied by TENMA (Leahy and Matsuoka (1990), Leahy et al. (1989a), Leahy et al. (1989b)) and more recently by ASCA measurements (Saraswat et al. (1996)). The latter study illustrates the complexity of the GX301-2 spectrum- four components are necessary: i) an absorbed powerlaw with high column density; ii) a scattered powerlaw with much lower column density; iii) a thermal component with temperature of 0.8 keV; iv) a set of six emission lines (including the iron line at 6.4 keV).

Long-term monitoring of GX301-2 has been carried out by the All-Sky-Monitor (ASM) on board RXTE. This provides the best measurement of the orbital light curve of GX301-2 yet. Here are presented the results of the analysis of the x-ray orbital time variability of GX301-2 from the RXTE/ASM data.

2 Data Analysis

The RXTE/ASM dwell data and dayly-average data were obtained from the ASM web site. The data reduction to obtain the count rates and errors from the satellite observations was carried out by ASM/RXTE team, and the procedures are described at the web site. The ASM count rates used here include the full energy range band as well as the three sub-bands 1.3-3.0 keV, 3.0-5.0 keV and 5.0-12.1 keV. The data covered the time period MJD50087.2 to MJD51969.9. Fig. 1 shows the light curve for the whole time period using the dayly-average full energy band data. The regular outbursts every 41.5 day orbital cycle are seen, as well as the variabiltiy from cycle to cycle.

An epoch folding analysis was carried out on the full energy range band data, with the chisquared statistic used to assess the reality of variability at any given trial period. The dayly-average data were folded into 32 bins for periods in a range around 41.5 days, giving maximum chisquared of 6404 at a period equal to the known orbital period of 41.498 days, within errors. (The period error from epoch folding is 0.05 day significantly greater than the error of 0.002 day from x-ray timing analysis). Next the three sub-bands were analyzed. The orbital light curve for these bands and the full

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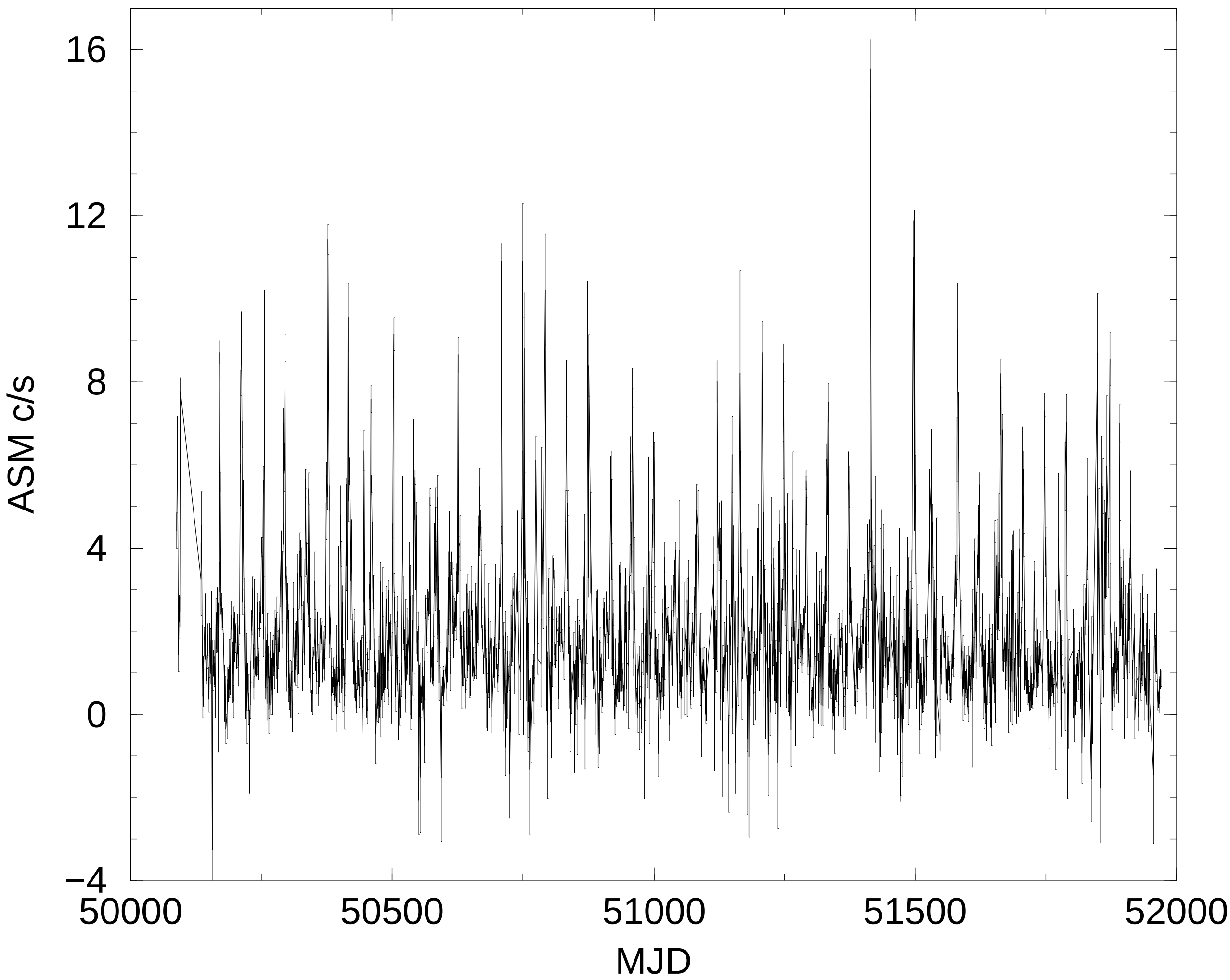

Fig. 1. GX301-2 ASM full band light curve using dayly-average data.

energy range band are shown in Fig. 2.

3 Comparing models to the data

The current work involves comparing various models to the RXTE/ASM orbital light curve. Work in progress includes fitting to previous data on column densities, which is incomplete over orbital phase. A least squares fit of the models to the 5-12.1 keV band light curve were carried out. The 5-12.1 keV band was chosen as it is insensitive to the column density and thus is proportional to the x-ray luminosity of the pulsar.

3.1 Pure wind model

A spherically symmetric wind has been shown to not produce the main flux peak prior to periastron (Leahy (1991), Haberl (1991)). However, both of those studies did not include an azimuthal component in the wind, which would be expected due to the rotation of the primary. This component is small but does shift the phase of the main flux peak. The wind velocity law here is taken to be that of Castor, Abbott, Klein (1975) but with an additional azimuthal component due to stellar rotation. The accretion rate is taken to be the Bondi-Hoyle accretion rate (e.g. see Leahy (1991)). The best-fit model is shown in Fig. 3, and demonstrates that a peak prior to periastron does occur. However the shape of the light curve for the wind only model is a very poor fit, both around periastron and apastron.

3.2 Wind plus disk model

An additional dense, slowly expanding circumstellar disk around Wray 977 was postulated by Pravdo et al. (1995) to explain the CGRO/BATSE light curve, which shows the pre-periastron main flux peak and also a secondary flux peak at pre-apastron. The CGRO/BATSE data is from a significantly shorter period (about 1.5 years) than the RXTE/ASM data (5.2 years). The RXTE/ASM data shows the apastron flux peak is very broad (see Fig. 2 here) and is centered approximately on orbital phase 0.55. A circumstellar disk is crossed by the pulsar twice per orbital period at positions $180°$ apart, which

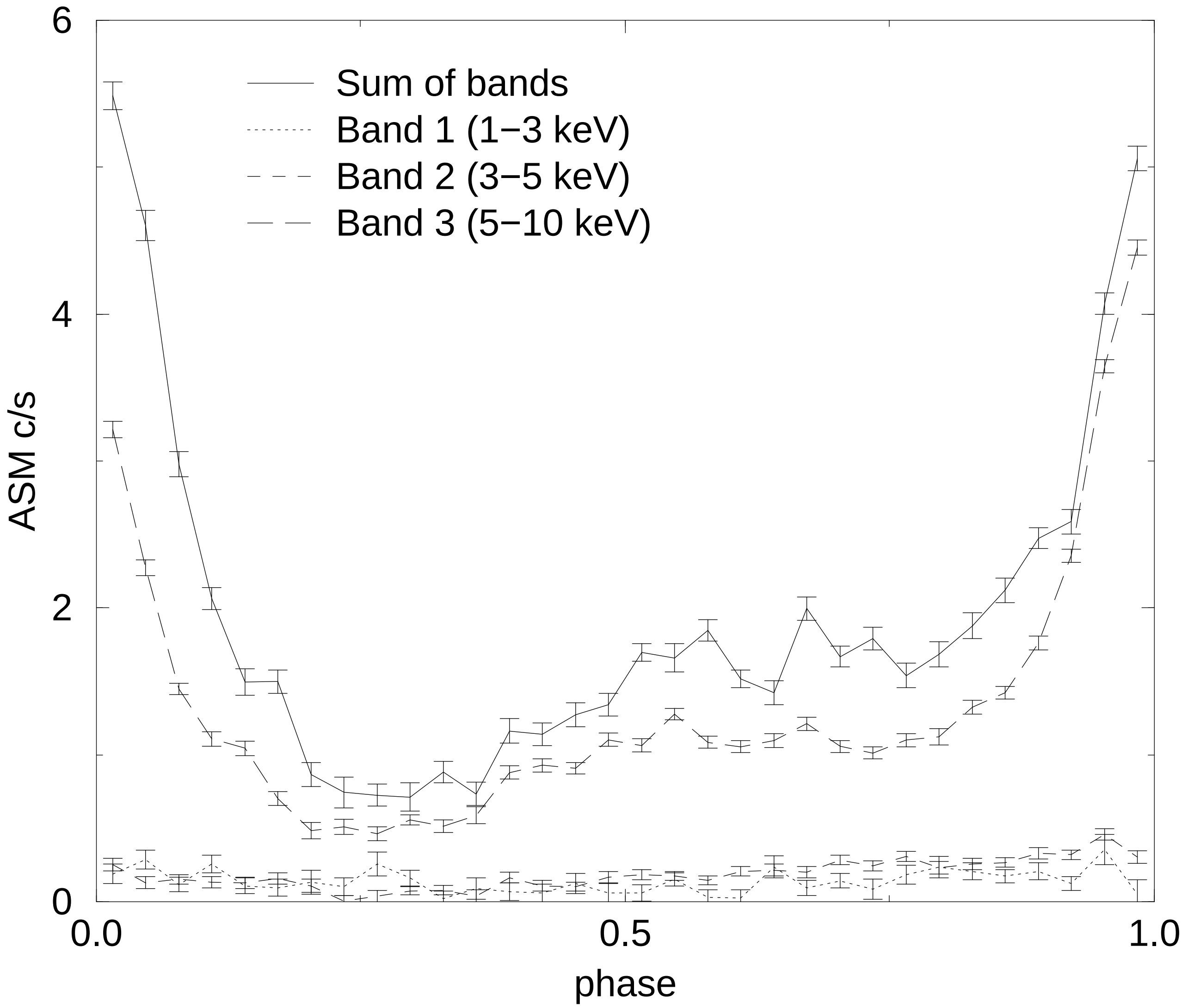

Fig. 2. Orbital light curve of GX301-2 from the ASM dayly-average data.

translates to a phase difference which can be different than 0.5 depending on the position of the first crossing. This is due to the eccentric orbit. To test whether a disk could explain the two peaks seen in the RXTE/ASM light curve, the disk model was fitted to the data. The resulting best-fit disk model is shown in Fig. 3: it is unacceptable. It turns out that the disk cannot fit both the pre-periastron and apastron flux peaks with the known position of periastron from the pulse timing.

3.3 Wind plus stream model

This type of model was used by Haberl (1991) and Leahy (1991) in different forms to fit the less complete data from EXOSAT and TENMA. The basic idea (the description in Haberl (1991) is followed here) is that the pulsar causes a denser stream of gas to leave the primary star, along with the rest of the wind, from the point on the primary facing the neutron star, as proposed by Stevens (1988). The motion of the stream as it flows out from the primary can be calculated from the rotation of the primary assuming it flows at the same speed as the rest of the wind. However the initial acceleration of the stream from the surface is quite uncertain, yet has a major effect on the position of the stream.

Here, the stream is hypothesized to be a spiral stream which is crossed twice by the pulsar during its orbit. The light curve depends only on the stream density where it is crossed by the pulsar. Thus the model only specifies the over-density and the Gaussian width of the stream where it crosses the orbit of the pulsar. The density and position of the stream at other locations than where it crosses the pulsar orbit is important for the column density as a function of orbital phase. Studying the column density variation with orbital phase is work in progress. The best fit stream model is shown in Fig. 3. This model does produce a satisfactory explanation of the data. It is noted that a stream which crosses the pulsar orbit only once per orbit is not a good fit to the data.

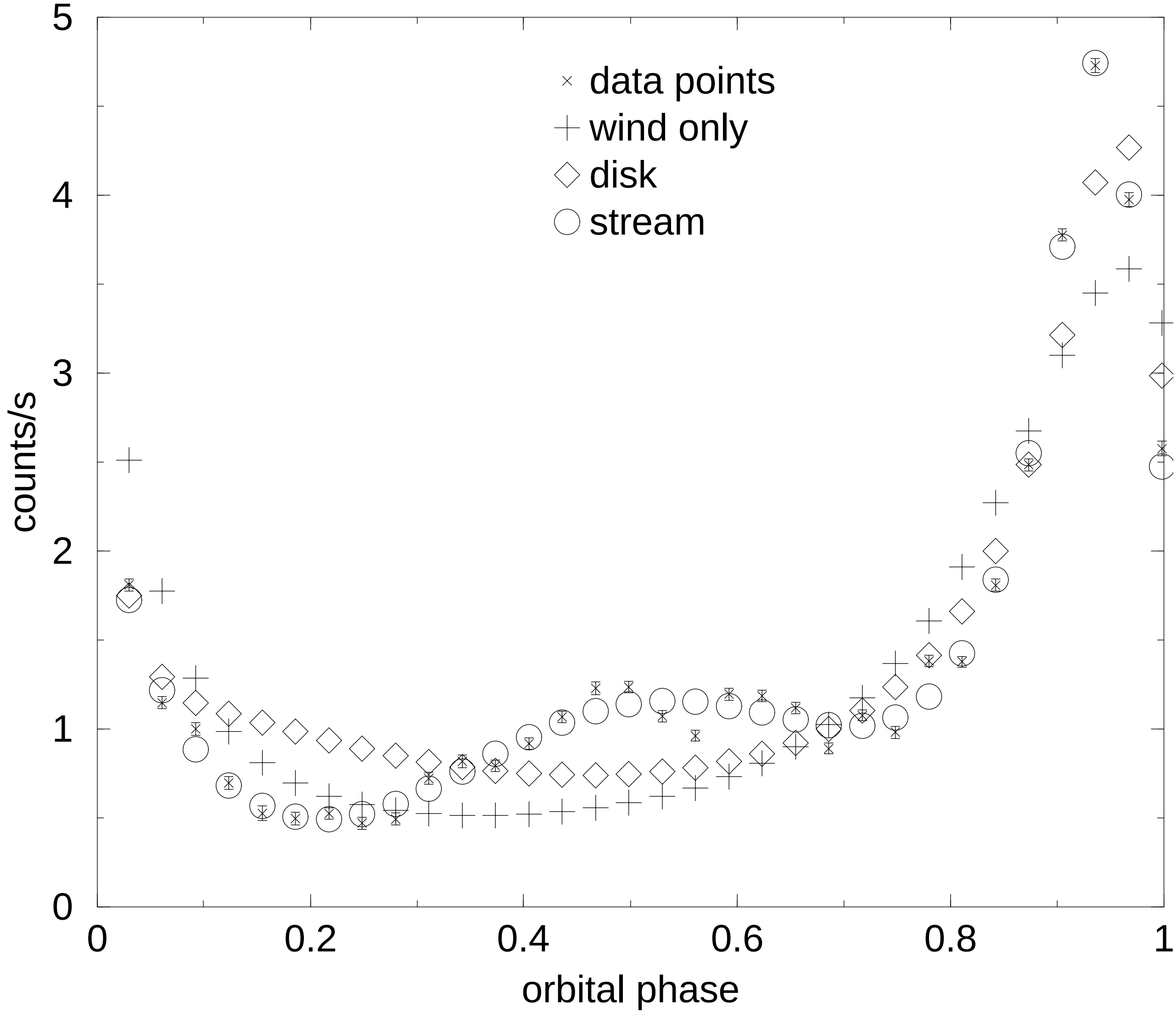

Fig. 3. Light curve of GX301-2 compared to the models (see text).

4 Conclusion

The RXTE/ ASM lightcurve is the best measurement yet of the orbital lightcurve of GX301-2 It shows the main pre-periastron peak and also a broad apastron flux peak. Model fitting shows that a wind-only or wind plus circumstellar disk cannot fit the observations but that a wind plus two stream model is viable.

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