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WATCH observations of the X-ray pulsar GX 301-2

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Abstract. — The wind-fed X-ray pulsar GX 301-2 has been observed by the all-sky X-ray monitor WATCH during the period January 1990-January 1992. During the periastron passage of October 1991 an extremely bright outburst was observed which for a time made the pulsar the brightest source in the hard X-ray sky. The pulse period was determined as $P = 678.05 \pm 0.45$ s which extends the long spin-up episode observed since 1984. The GX 301-2 system is known to exhibit a recurrent outburst preceding periastron at phase 0.95. We have also identified another recurrent activity period near orbital phase 0.78. Flaring near this phase was seen previously in an observation by HEAO-1 in 1978.

Key words: X-rays: binaries — stars: neutron — pulsars: GX 301-2.

1. Introduction.

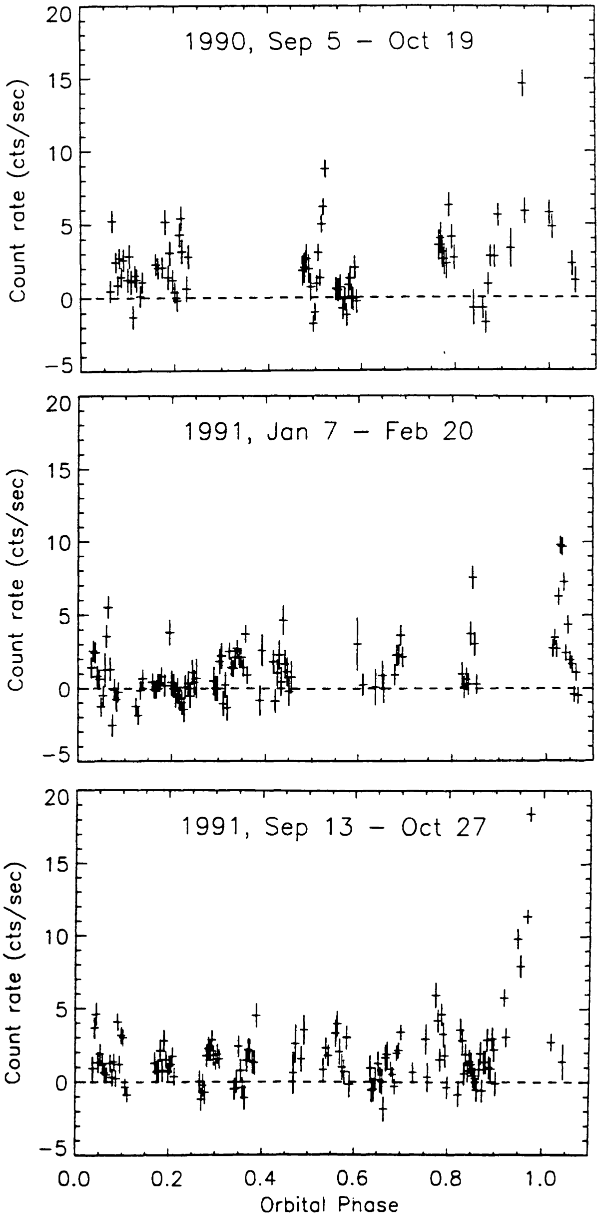
The X-ray source GX 301-2/4U 1223-62 was discovered in April 1969 (Lewin *et al.* 1971). Prior to the launch of Vela 5B, only observations of limited duration were made using balloons and rockets. The VELA satellites observed the source for 7 years and began a more systematic study of the object (Priedhorsky & Terrell 1983).

The optical counterpart was subsequently identified with the supergiant Wray 977, a star of spectral type B1.5 Ia (Vidal 1973; Bradt *et al.* 1977) at a distance of 1.8 ± 0.4 kpc (Parkes *et al.* 1980). GX 301-2 was among the first X-ray pulsars discovered when pulsations of 700 s were observed (White *et al.* 1976). For GX 301-2, the X-ray emission is powered by accretion from a stellar wind, since Wray 977 is unlikely to fill its Roche lobe at any orbital phase.

The recurrence of strong outbursts reported by Watson, Warwick and Corbet (1982) (WWC) led to a determination of the orbital period as 41.5 days. This was confirmed by Sato *et al.* (1986) by combining the pulse arrival times measured with Hakucho with Ariel 5 and SAS 3 data. The orbit turned out to be the most eccentric among the X-ray binary pulsars ($\epsilon = 0.47$). By taking into account the absence of X-ray eclipses (Rothschild & Soong 1987) together with a radius of the primary of 43 $R_\odot$ and a mass function of $f(M) = 31.9 \pm 0.8 M_\odot$ (Sato *et al.* 1986) and the assumption of a primary mass of $35 - 40 M_\odot$ and $1.4 M_\odot$ for the neutron star, the inclination is restricted to $70° < i < 78°$.

The strong outbursts of the GX 301-2 system are associated with the periastron passage of the neutron star. The outbursts are, however, not precisely at periastron (phase 0.0), but with the peak centered at phase 0.95 ($\approx$ 2d) earlier (WWC). Several models have been proposed to explain the X-ray flux within the context of eccentric-orbit accretion models (WWC, Kelley *et al.* 1980; White & Swank 1984), They predict a peak in the X-ray flux near periastron arising from the proximity to the primary. They are unable, however, to explain why the outbursts should come before the periastron passage.

Stevens (1988) developed a model, taking into account the dynamical effects of the neutron star on the stellar wind from the primary. The mass loss rate of the primary is enhanced close to the periastron passage, strongly amplifying the X-ray outbursts. Using data from EXOSAT White and Swank (1984) found that the spectra of GX 301-2 exhibited a variable level of photoelectric absorbtion correlating with the orbital phase. Haberl (1991) proposed, that this is consistent with the wind forming a dense gas stream through which the neutron star passes twice. These passages then results in a strong outburst near phase 0.95 and a weaker one near phase 0.3, with activity minima at phases 0.15 and 0.7.


1990, Sep 5 – Oct 19

1991, Jan 7 – Feb 20

1991, Sep 13 – Oct 27

FIGURE 1. X-ray light curves for GX 301-2 in the energy range 6-15 keV plotted relative to orbital phase. Each point in the light curves represents ≈ 4 hours of integration with $\pm 1\sigma$ error bars plotted. For clarity, the light curves are extended to phase 1.1 in order to show the outburst near the periastron passage. (One Crab-unit is ≈10 counts/s in this energy band).

2. Observations.

The WATCH all-sky monitor (Lund, 1985) on board GRANAT has been observing GX 301-2 since January 1990. Figure 1 shows three light curves in the energy range 6-15 keV which cover the periods 1990 September 5 to October 19, 1991 January 7 to February 20 and 1991 September 13 to October 27 with an averaged coverage of ≈58%. No positive detection of this source was made in the energy band from 15 to 150 keV.

The bright outburst near phase 0.95 is very noticeable in two of our light curves (no data for this phase was obtained in February 1991). The outburst was particularly strong during October 1991, where, in the 6 to 15 keV band the pulsar was the brightest source in the X-ray sky.

We would like to draw the attention to the short flare which occurs at phase 0.78 in the two light curves with data at this phase and, in addition, to a flare seen at phase 0.52 on 1990 September 26. Data from 1990 January 19-20 also show flaring activity at phase ≈0.5.

The pulse period has also been determined. It has changed from 685.8 ± 0.2s on 1990 January 20 (Brandt *et al.* 1990) to 678.05 ± 0.45s on 1991 October 20. The source was in a bright state during both epochs.

3. Discussion.

3.1. THE X-RAY LIGHT CURVE.

From a partial analysis of two years of observations of the GX 301-2 system we have found a number of significant flares in addition to the one that recurs regularly near periastron. When combining our data with earlier observations we find evidence for recurrent activity in this system also near phases 0.78 and (possibly) 0.5.

The activity at phase 0.52, close to the apastron passage, is not predicted by either the simple symmetric wind model or the enhanced mass-loss model. The time scale of ≈ 1 d may indicate some structure in the wind with a size significantly smaller than the primary. The activity at phase 0.78 has been observed previously by HEAO 1 in February 1978 (Rothschild & Soong 1987) in the 13-170 keV energy band.

Periodic activity at these orbital phases is not an obvious consequence of models where the enhanced mass-loss is induced via the interaction between the neutron star and the wind of the giant primary. We expect to continue the analysis to cover, as completely as possible, all orbital phases.

3.2. THE SPIN UP EPISODE SINCE 1984.

The long-term monitoring of the pulse period is important for the study of the change in the rotation rate of the neutron star crust. This could be caused either by the external torques arising from variations in the stellar wind from the companion or through the coupling between the crust and the neutron star interior.

For GX 301-2, the pulse period variations observed from 1975 to 1984, appeared to be random and included both spin-up and spin-down periods. This may be a quite normal feature of wind-fed pulsars as discussed by Nagase (1989). A continuous spin up episode has, however, been observed since 1984. The Tenma data from that epoch, when combined with our observations, gives a decrease of the period at an average rate of $\dot{P}/P = -4.46 \times 10^{-3}\,\mathrm{yr}^{-1}$, a relatively high value, which may be associated with an enhancement of the mass-loss rate of the primary. This would be consistent with the extreme brightness of the source at the periastron passage in October 1991.

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