A major outburst from the X-ray binary RX J0520.5-6932.

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ABSTRACT

We report on the analysis of 8 years of MAssive Compact Halo Objects (MA-CHO) data for the source RX J0520.5-6932. A regular period of 24.4 days has been confirmed, however this is manifest almost entirely in the red part of the spectrum. A major outburst, lasting approximately 200 days, was observed which increased the apparent brightness of the object by approximately 0.15 magnitudes without significantly altering its V-R colour index. This outburst was also seen in X-ray data. The evidence from this analysis points to the identification of this object as a Be/X-ray binary with a periodically variable circumstellar disk and a very early optical counterpart.

Key words: Be stars - X-rays: binaries: Magellanic Clouds.

1 INTRODUCTION

1.1 Be/X-ray binaries

Most High Mass X-ray Binaries (HMXBs) belong to the Be class, in which a neutron star orbits an OB star surrounded by a circumstellar disk of variable size and density (Negueruela and Coe 2002).

The optical companion stars are early-type O-B class stars of luminosity class III-V, typically of 10 to 20 solar masses that at some time have shown emission in the Balmer series lines. The systems as a whole exhibit significant excess flux at long (IR and radio) wavelengths, referred to as the infrared excess. These characteristic signatures as well as strong Hα line emission are attributed to the presence of circumstellar material in a disk-like configuration (Coe 2000, Okazaki and Negueruela 2001).

The mechanisms which give rise to the disk are not well understood, although fast rotation is likely to be an important factor, and it is possible that non-radial pulsation and magnetic loops may also play a part. The disk is thought to consist of relatively cool material, which interacts periodically with a compact object in an eccentric orbit, leading to regular X-ray outbursts. It is also possible that the Be star undergoes a sudden ejection of matter (Negueruela 1998).

Be/X-ray binaries can present differing states of X-ray activity varying from persistent low or non-detectable luminosities to short outbursts. Systems with wide orbits may tend to accrete from less dense regions of the disk and hence show relatively small outbursts. These are referred to as Type I and usually coincide with the periastron of the neutron star. Systems with smaller orbits are more likely to accrete from dense regions over a range of orbital phases and give rise to very high luminosity outbursts, although these may be modulated by the presence of a density wave in the disk. Prolonged major outbursts, which do not exhibit signs of orbital modulation, are normally called Type II (Negueruela 1998).

1.2 Previous observations of RX J0520.5-6932

The X-ray source RX J0520.5-6932 was discovered by ROSAT on 11 Feb 1991 at a luminosity of $5 \times 10^{34}$ ergs/s and identified with a $V \sim 14$ magnitude star (Schmidtke et al., 1994). An analysis of the Optical Gravitational Lensing Experiment (OGLE) data by Coe et al. (2001) revealed the presence of a 24.45 day periodic modulation of about 0.03 magnitudes. In the same paper a spectral type of O9V was proposed for the optical counterpart.

2 OPTICAL AND IR PHOTOMETRY

In 1992 the MAssive Compact Halo Objects project (MA-CHO) began a survey of regular photometric measurements of several million Magellanic Cloud and Galactic bulge stars (Alcock et al. 1993).

The MACHO data on RX J0520.5-6932 (Database identification number 78.6464.23) cover the period July 1992 to January 2000 and consist of lightcurves in two colour bands described as blue and red. Blue is close to the standard V passband and Red occupies a position in the spectrum about halfway between R and I (Alcock et al. 1999). Transformation equations are given in the same paper which enable these values to be converted to V and R and, where appropriate, we have used the latter, adopting the convention used by Schmidtke et al. (2003) to refer to them as $V_{MAC}$ and $R_{MAC}$. However, because they depend on a combination of both blue and red values to obtain the conversions,
and because, as we explain later, we have found significant differences in the modulation of the two lightcurves, we have used the original MACHO values for the purposes of analysis. Out of a total of 1678 observations, 1546 were used, the remainder being rejected because of the value of the errors (9.999 magnitudes).

It was immediately evident that, in both colour bands, there was a large isolated peak at about MJD 49810 (Apr 1995) extending over a period of approximately 200 days (Figure 1). At its maximum, this corresponded to an increase in magnitude of about 0.15 above the mean, or a 15% change in flux. A blue minus red colour index did not however reveal any significant change in the relative brightness of the two colour bands over the duration of the peak or throughout the rest of the observations. No other comparable peak was found anywhere else in this dataset or in the previously published OGLE data (Coe et al, 2001) which do not cover the date of this outburst.

Both MACHO lightcurves were tested for periodicity using the Starlink PERIOD Lomb-Scargle algorithm and a regular period of $24.44 \pm 0.05$ days was detected in the red curve. A consistent period could not, however, be detected when the blue curve was analysed using the whole dataset. A comparison of the period profiles at 24.4 days is shown in Figure 2. A weak period of 24.4 days was however detected in the blue curve during the 500 days immediately preceding the outburst. The modulation of the red curve amounted to a magnitude of 0.02 equating to a variation in flux of 2%. Coe et al. (2001) have detected a modulation in the OGLE I band of 0.03 magnitudes or 3% flux change.

The optical period was present during the outburst. The latter, however, had a rather complex profile which could not reliably be subtracted from the underlying continuum without distorting the data, moreover it only covered about 7 cycles of the optical period so that attempts to plot the profile of the 24.4 day period did not yield meaningful results.

Significant differences in the characteristics of the modulation were not found when the data were divided into three epochs, i.e: before the outburst (up to MJD 49730), during the outburst (MJD 49730 - 49920) and after the outburst (after MJD 49920).

Using the STARLINK programme DIPSO, measured photometric magnitudes were plotted against the spectrum of a model stellar atmosphere (Kurucz, 1979). U, B, V and I were taken from average OGLE values as published by Coe et al. (2001). The R value was taken from direct measurements published in the same paper. IR magnitudes were taken from the NASA/IPAC Infrared Science Archive 2MASS Second Incremental Release Point Source Catalog (PSC) (2000 March) (http://irsa.ipac.caltech.edu/) and have the following values: $J=14.4 \pm 0.06$, $H=14.2 \pm 0.07$, $K=14.3 \pm 0.1$. These observations are dated 20 Dec 98 (MJD 51167). The combined graph is shown in Figure 3. The model atmosphere shown corresponds to a temperature of 31000 K (log g=4) and is consistent with an O9 star. After normalising the model in the V band and applying an E(B-V)=0.32 (Coe et al, 2000) there is a small indication of an infra-red excess.
3 OPTICAL SPECTROSCOPY

Spectroscopic observations in Hα of the optical counterpart to RX J0520.5-6932 were made with the SAAO 1.9m telescope on 12 Nov 2001 (MJD 52225) and again on 14 Dec 2002 (MJD 52622). A 1200 lines mm$^{-1}$ reflection grating blazed at 6800 Å was used with the SITe CCD which is effectively 266 x 1798 pixels in size, creating a wavelength coverage of 6160 Å to 6980 Å. The intrinsic resolution in this mode was 0.42 Å/pixel. The Nov 2001 spectrum is shown in Figure 4 and was measured to have an equivalent width of 5.2 ± 0.2 Å. By Dec 2002 the equivalent width had reduced to 2.0 ± 0.6 Å.

The Nov 2001 (MJD 52225) line is narrow and has a sharp single peak. The Dec 2002 (MJD 52622) line is less well defined and, because it is much weaker, a clear shape cannot be discerned.

4 X-RAY DATA

In addition to the original X-ray detection in Feb 91 (MJD 48298), 2 further ROSAT detections have been catalogued, on 05 Mar 92 (MJD 48686) and 24 Aug 93 (MJD 49223) (White et al. 2000). These showed a variation in flux of a factor of 2 over the three measurements.

After the discovery of the optical peak in the MACHO data, an analysis of the Burst And Transient Source Experiment data (BATSE) was carried out over the same period. BATSE, on board the Compton Gamma Ray Observatory, provided near continuous monitoring of the whole sky during 1991-2000, in the hard X-ray band (Fishman et al., 1989). The data types available from the 8 LADs (Large Area Detectors) are the 16-channel continuous or "CONT" data, sampled at 2.048 s intervals, and the 4-channel discriminator or "DISCLA" data sampled every 1.024 s. The data presented in this paper make use of the "CONT" data in the 20-70 keV range and further make use of the Earth Occultation Technique. The EOT takes advantage of the periodic eclipsing by the Earth of a source by measuring its total flux twice in each 93 minute orbit, once as it moves behind the Earth’s limb and then again when it reappears (Harmon et al., 2002).

5 DISCUSSION

This analysis revealed a concurrent X-ray outburst with a similar profile. This is shown, on the same timescale as the optical data, in Figure 5. Signal to noise constraints determined that the minimum binning duration had to be too long to permit detection of the 24.4 day period in the BATSE data.

From the BATSE data we are able to determine the X-ray flux at the outburst peak to be ∼20 mCrab. Assuming a distance of 50 kpc to the LMC this implies an intrinsic X-ray luminosity of ∼8 x 10$^{38}$ erg/s. The significance of the outburst may be estimated from the 100d BATSE samples shown in Figure 5 and is found to be approximately 13 sigma. The flux was not detectable outside the outburst.

The observational evidence summarised above supports the identification of this variable X-ray source with a Be/X-ray transient. The detection of a prominent Hα line in the spectrum points strongly to the presence of a circumstellar disk, indicating a Be X-ray binary, although the line shows no indication of a broadened double peak which might indicate a rapidly rotating disk viewed from an angle close to the plane of rotation. It can be concluded from this, and from the relatively small value of the Hα equivalent width, that the system is being observed from an angle close to the axis of rotation and that the circumstellar disk is small. This is supported by the relatively small value of the observed infra-red excess in the Dec 98 (MJD 51167) 2MASS data. The greatly diminished Hα equivalent width in Dec 2000, as compared with the previous year, further suggests a highly variable disk regime. The well-established relationship between the Hα EW and intrinsic (J-K) can be used to ensure we have agreement on the small size of the circumstellar disk (Coe et al, 1993). Using E(B-V)=0.32 we determine (J−K)$_0$ = −0.1 and we have measured the Hα EW to be in the range 2-5 Å. Comparing these values with the correlation diagram shown...
in Figure 4 of Coe et al. (1993) clearly indicates that we are dealing with a Be system with an unusually small disk and our values agree with the general trend of the data in this figure.

The isolated optical flare seen in the MACHO data appears to be similar in size and duration to those identified as type-1 Be star candidates in the Small Magellanic Cloud by Mennickent et al. (2002). As such the rise in luminosity is evidence for an outburst although it is somewhat surprising in that it is not accompanied by any significant change in the blue minus red colour index (unlike the stars in Mennickent et al. which tend to be redder when brighter). The discovery of a concurrent X-ray peak in the BATSE data lends support to the conjecture that this event signals a major episode of high mass accretion and X-ray emission by its neutron star companion. It should be mentioned in passing that an isolated giant X-ray outburst would be described as a Type-II outburst by contrast with the optical classification used earlier.

The 24.4 day optical modulation in the red MACHO data, which was also present in the OGLE I data, may represent the binary period of the system. The almost complete absence of modulation in the blue curve suggests that this effect is occurring in the circumstellar disk and could be explained if a periodic distortion were being occasioned by the eccentricity of the neutron star orbit. It is possible that the latter is, in fact, causing the disk to alternate between resonant states (Okazaki et al., 2002).

Two other Magellanic Cloud systems with modulated optical lightcurves have already been reported by Charles et al. (1983) for A0538-66 and Schmidtke et al. (2003) for RX J0058.2-7231. It would therefore seem that this is not an isolated phenomenon but may be representative of an optically variability typical of some Be/X-ray binaries.

It might be anticipated that, if the modulation in the red curve were solely attributable to the circumstellar disk, it would not be present around the time of 2MASS observations (20 Dec 98 - MJD 51167) when any evidence for infra-red excess was not observed. Unfortunately this is difficult to test because there is a gap in the MACHO data immediately prior to that date and also the timespan required to properly observe a period (about 5 cycles) would be long enough for the disk to have reappeared. We note also that the depth of modulation (2-3%) is well within the errors of the IR magnitudes. The relatively low infra-red excess observed in Figure 6 may simply indicate that the disk is very small and the variation in the Hα equivalent width is probably due to its changing size.

Using theoretical and empirical evidence we should be able to predict the neutron star spin frequency from its orbital period (Corbet et al., 1999). A pulsar in an orbit of 24.4 days would thus be expected to have a pulse period of about 3-4 seconds. However, so far, no convincing detection at this frequency has been associated with this object.

From the X-ray and optical data presented here it is possible to determine values for the Lx/Lopt ratio both during, and outside the outburst. The optical luminosity is integrated over the range 400 -700 nm and is calculated assuming that the R band flux quoted in Coe et al (2001) is valid during quiescence and is representative of the whole optical range. For the outburst it assumed that the optical brightness increased by the 0.15 magnitudes reported here. For the X-ray, the BATSE luminosity during the outburst of ∼20 mCrab was used in conjunction with an assumed Crab-like spectrum integrated over the range 2 - 100 keV. For the quiescent state a 3σ upper limit of ≤10mCrab was determined. Using these values the quiescent Lx/Lopt is found to be ≤100, and the outburst Lx/Lopt to be ∼230. Though these values are at towards the top end for a HMXB system (Bradt & McClintock, 1983) the event reported here is undoubtedly a substantial Type II outburst.

The identification of this system with an O9 star, if it is correct, represents the discovery of a Be X-ray binary with a counterpart of an unusually, although not uniquely, early spectral type. Further study may determine whether this has any bearing on the isolated nature of the optical/X-ray outburst and the evident variability of the circumstellar disk.

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