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The optical and radio counterpart of the X-ray Nova Ophiuchi 1993*

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Abstract. We have identified the optical and radio counterparts of the X-ray transient GRS 1716–249 (Nova Oph 1993). The photometric and spectroscopic properties of Nova Oph 1993 suggest that this object is a low mass X-ray binary system in outburst, caught during an early stage.

Key words: stars: novae, cataclysmic variables – neutron: Nova Oph 1993 – X–rays: stars

1. Introduction

X-ray novae are one of the exceptional signatures for the presence of massive stellar remnants. Contrary to classical novae which are a consequence from accretion onto a white dwarf, X-ray novae result from accretion onto a neutron star (e.g. van Paradijs and Verbunt 1984). However, the study of this class of objects is of great interest because in several cases, notably A0620–00 (Nova Mon 1975, McClintock and Remillard 1986), GRS1121–68 (Nova Muscae 1991, Remillard et al. 1992), and GS 2023+338 (V404 Cyg, Casares et al. 1992), the accreting object is very probably a black hole. In this paper we report the discovery of the optical and radio counterparts of the new X-ray source GRS 1716–249 (Nova Oph 1993).

2. The discovery

The hard X-ray transient GRS 1716–249 ≡ GRO J1719-24 was discovered with SIGMA on GRANAT (Ballet et al. 1993) and with BATSE on the Compton Gamma Ray Observatory (Harmon et al. 1993) as a new X-Ray source on September 25, 1993. At galactic coordinates $l = 0.1^o$, $b = 7.1^o$ it is now known as the X-ray Nova Ophiuchus 1993. For several weeks after outburst it became one of the brighter hard X-ray sources in the sky rivaling with Cygnus X-1. The source spectrum was found to be particularly hard in the 20-320 keV band; it could be well fit with a thermal bremsstrahlung model with kT = 70-100 keV, which is reminiscent of black hole candidates (Ballet et al. 1993, Harmon et al. 1993). In the 0.5-10 keV energy band large-amplitude fluctuations on time scales $\leq$ 1 second, similar to Cygnus X-1, have been reported by the ASCA team (Tanaka 1993)

The optical counterpart was identified (Della Valle et al. 1993) near the edge of the SIGMA error circle as a 'reddish' star of V=16.65 and (B–V)= 0.9 on a CCD frame obtained on October 5 with the Dutch 0.9-m telescope at the ESO La Silla Observatory. In the radio Nova Oph 1993 was detected (Mirabel et al. 1993) with the VLA in the C/D configuration on October 3 as a flat spectrum compact radio source with flux densities of 4.6±0.4 and 4.9±0.2 mJy at λ20 cm and λ6 cm, respectively. The reported position for the radio source was $\alpha = 17^h16^m32.52^s$ $\delta = -24^o58'01.1''$ (equinox 1950.0), with a positional accuracy of $\sim$1". The optical and radio positions coincide within the errors of the astrometric measurements.

3. Observations

The comparison between the subarcsecond image of Nova Oph 1993 (Fig. 1) obtained at La Silla on 8 October with the 2.2m telescope and the UK and ESO Schmidt plates (Fig. 2) does not show any sign of the progenitor at the position of the nova constraining the apparent magnitude of the progenitor to be fainter than R $\gtrsim$ 20, V $\gtrsim$ 21, and B $\gtrsim$ 21.5. The optical light curve of Nova Oph 1993 (Fig. 3 upper panel) shows that the rise to maximum was missed. Nova Oph 1993 was observed at V =16.65, therefore the amplitude of the outburst was $\gtrsim$ 4.4 magnitudes.

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* Based on observations made at the European Southern Observatory, La Silla, Chile.

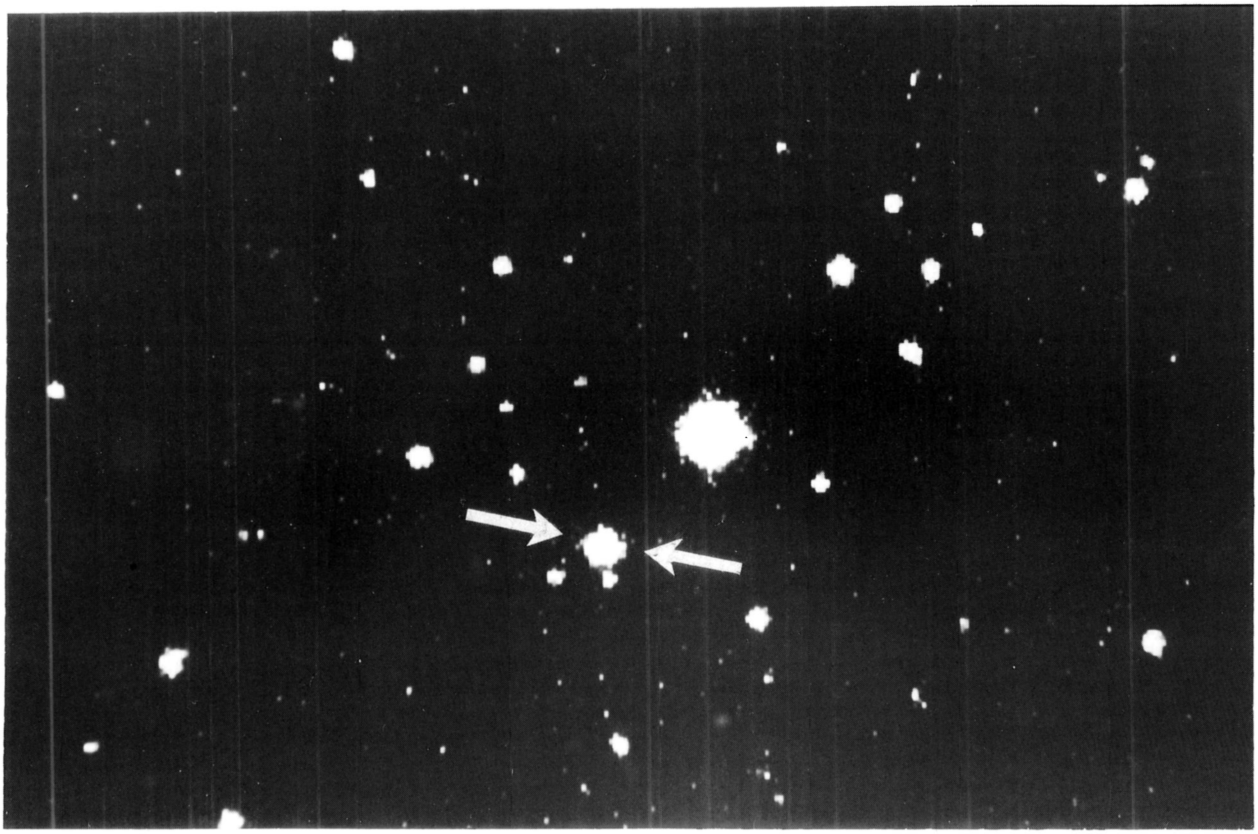

Fig. 1. Nova Oph 1993 during the outburst. The CCD frame was obtained on October 8 1993 (seeing 0″.8) with the 2.2m/MPI telescope (60s in B). The nova is indicated by arrows

The light curve of N Oph 1993 mimics well the early photometric evolution of Nova Muscae 1991 (see Fig. 3 lower panel) during its plateau stage. In particular the comparison between the two light curves would suggest that Nova Oph 1993 may have reached $V_{max} \approx 16.3$. Variations in brightness of ≈ 0.2 mag on a time scale of ≈ 1 day were detected throughout the first 15 days past maximum in B and V colors. Since the brightenings are, on average, larger by an order of magnitude than the typical photometric error, we believe that they are real, and at this stage we cannot exclude the possibility that they are signatures of 'humps' like those discovered by Bailyn (1992) during the early photometric evolution of Nova Muscae 1991.

The observed spectrum of the nova (average of two spectra with the 1.5m telescope on October 5 plus other two spectra with the 2.2m telescope on Oct 8) is shown in Fig. 4 (upper panel). The two most noticeable features are the flat shape of the continuum below the 5500 Å , which is a consequence of the heavy interstellar absorption toward the nova, and the lack of prominent emission lines typical of X-ray novae at maximum. The only exceptions are the double peaked Hα (peak-to-peak separation of 720 km s^{-1}, EW=13.4), Hβ (EW=1.3) and perhaps He II at 4686 (EW $\lesssim 1.5$). The interstellar absorptions are due to Na D doublet, and the two interstellar blends at 5780 Å and 6280 Å.

Additional radio observations of the radio counterpart were carried out with the VLA in its D (lowest angular resolution) configuration. On October 24 we measured flux densities of 3.6±0.5, 4.4±0.1, 4.6±0.1, and 4.4±0.2 at λ20, 6, 3.5, and 2-cm, respectively. The lack of variability with respect to the October 3 observations and the flat spectrum suggests that we have observed a thermal component ejected in the past. New observations made during 1994 February 7 showed that the λ6 cm flux density had dropped to only 0.5±0.1 mJy. On 1994 March 27 the source was below a detection limit of 0.1 mJy at 6 cm.

4. Discussion

A first indication of amount of interstellar absorption comes from using the empirical relation between the color excess and the strength of the interstellar absorption lines of Na D (Barbon et al. 1990, Della Valle and Duerbeck 1993). From the analysis of the spectra we derive EW=1.9 Å for the equivalent width of NaD, which implies a color excess of E(B–V)≈ 0.75 ± 0.2. The strength of the interstellar absorption bands (Herbig 1975) yields E(B–V)=0.6–0.9. By assuming $\langle (B-V)_0^{max} \rangle = -0.1$ for LMXBs (van Paradijs and McClintock 1994) a color excess of E(B-V) ≈ 1 is derived. This is consistent with the hydrogen column density of 4×10^{21} cm^{-2} estimated from the measure-

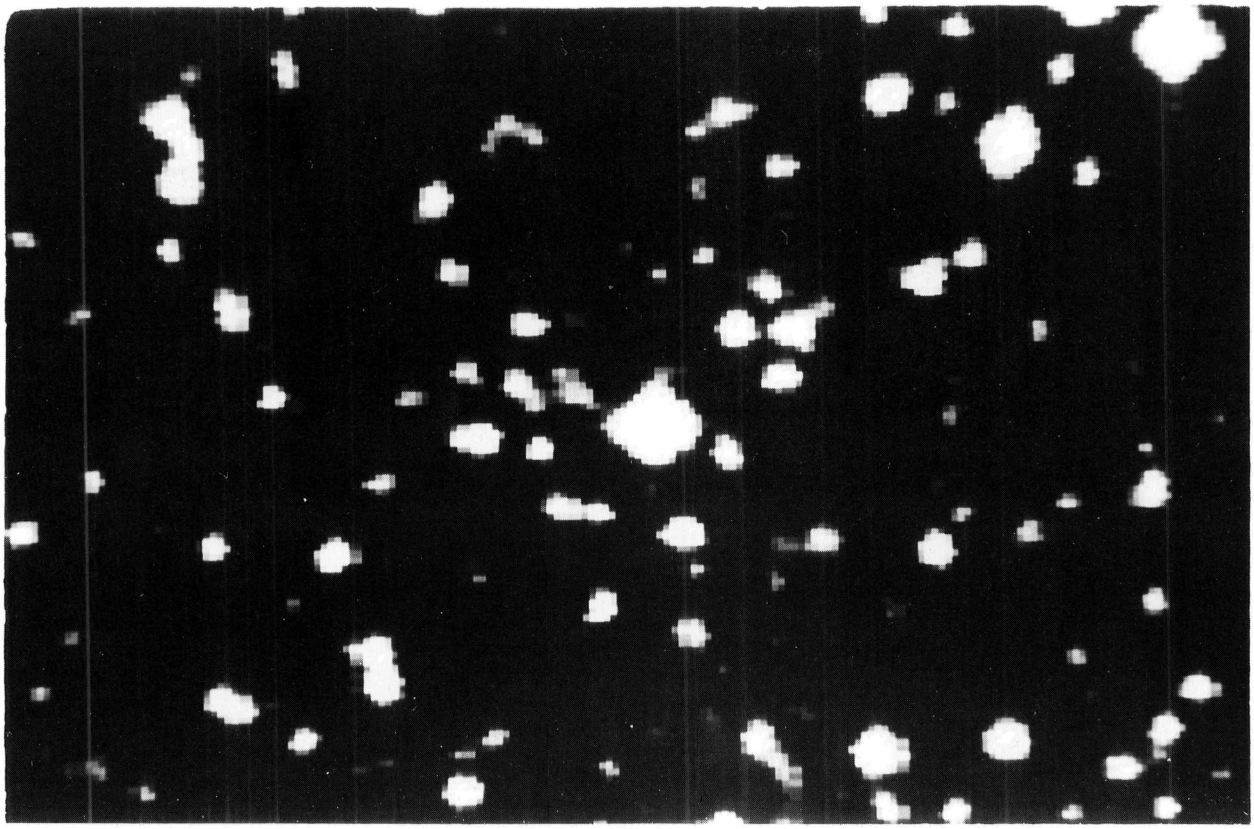

Fig. 2. Reproduction of the J plate of the UK survey. No progenitor is visible at the position of the nova

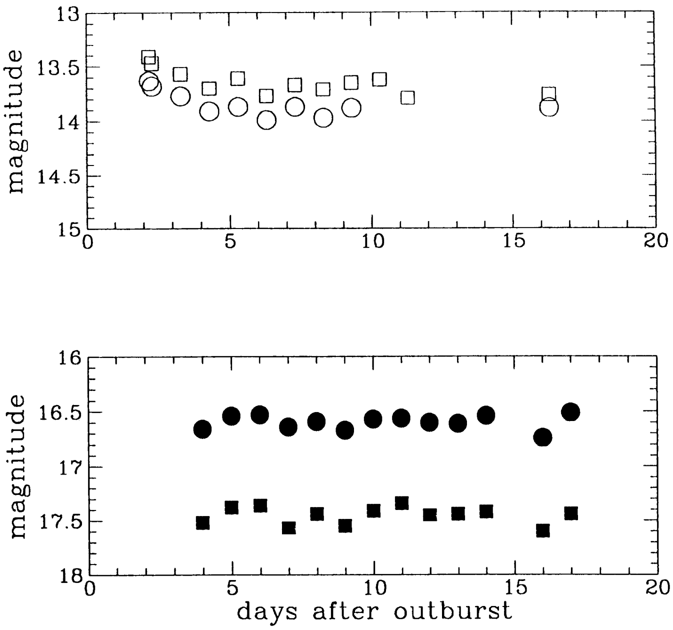

Fig. 3. Upper panel: light curve of Nova Oph 1993. The circles and the squares represent V and B magnitudes respectively. All the observations were obtained at La Silla with the 0.9m and 2.2m telescopes. Lower panel: light curve of Nova Muscae 1991 (from Della Valle et al. 1991)

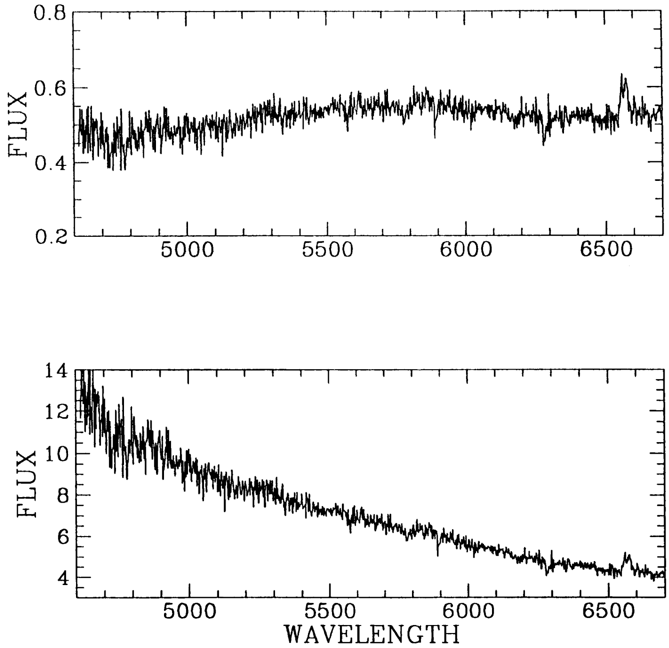

Fig. 4. Upper panel: observed spectrum of nova Oph 1993. Lower panel: spectrum of nova Oph 1993 after the correction for interstellar absorption (ordinate: 10^{-15} erg cm^{-2} s^{-1} Å^{-1}). We have assumed E(B–V)=0.9

ments by ASCA at soft X-rays (Tanaka 1993), which also gives E(B-V) $\approx$ 1. On the other hand, with the Nancay radio telescope we obtained at λ21 cm spectrum along the line of sight to the nova, from which we infer a column density of atomic hydrogen of 2.5×10^{21} cm^{-2}. A CO(1$\rightarrow$0) survey (de Geus 1990) of this region of the sky indicates an additional column density of 2×10^{21} cm^{-2} in the form of molecular gas, implying a total column density of 4.5×10^{21} cm^{-2} which corresponds to E(B–V)$\approx$ 1.0. Finally, from the Balmer decrement (case B of Osterbrock 1974) we get E(B–V)$\approx$ 1.15. In the following we shall adopt a total absorption $\langle E(B-V)\rangle = 0.9 \pm 0.2$.

The distance of the Nova Oph 1993 is possibly the most uncertain quantity to be determined. Our estimate comes from the relation between the EW of NaD absorption lines and the distance (Charles et al. 1989) which yields $d \approx 2$ kpc. From this and the apparent magnitude at maximum, we derive (after applying the correction for reddening) an absolute magnitude M_V(max) of 1.9 mag which is fairly close to the average absolute magnitude at maximum of low mass X-ray binaries $\langle M_V(\max)\rangle = 1.2$ (van Paradijs 1981). If taking this last figure at face value, we derive, for the distance of Nova Oph 1993, an upper limit of $\approx$ 2.8 kpc. In the following we shall adopt $\langle d\rangle = 2.4$ kpc. The knowledge of the distance and the upper limit to the brightness of the progenitor (V$\approx$ 21) enable us to constrain the spectral type of the progenitor. After taking into account the correction for absorption, according to $A_V = 3.2 \times E(B-V)$, and the uncertainty on the distance, $M_v \gtrsim 6$ for the absolute magnitude of the progenitor is derived. In terms of spectral type, this corresponds to the absolute magnitude of a low-mass main sequence star of spectral type $\approx K$ (or later) (Allen 1981) which is quite typical for a low-mass X-ray binary system.

After applying the correction for interstellar absorption (Fig. 4, lower panel) the energy distribution of the nova in the range 4600-6700 Å is $\approx 1.7 \times 10^{-11}$ erg cm^{-2} s^{-1}. The blue continuum can be fitted by a black body with a temperature of $\approx$ 20000K implying the total flux of the nova in the range 1000-10000 Å to be $\approx 2.1 \times 10^{-10}$ erg cm^{-2} s^{-1} corresponding to $L_{opt}^{max} \approx 1.5 \times 10^{35}$ erg s^{-1}. Since the X-Ray Luminosity of the source in the band 0.1–100 keV reported by Ballet et al. (1993), Harmon et al. (1993) and Tanaka (1993), is $\approx 3 \times 10^{-7}$ erg s^{-1} cm^{-2} the ratio L_X/L_{opt} turns out to be $\approx 1.4 \times 10^3$ and $L_X \approx 2.1 \times 10^{38}$ erg s^{-1}, which is close to the Eddington limit of a collapsed object of 1.6 $M_\odot$. Within the uncertainties this X-ray luminosity is comparable to that of A0620-00 and Nova Muscae 1991 (see van Paradijs and McClintock 1994 and references therein). These two objects are known to be, as Nova Oph 1993, sources of transient radio continuum emission (Owen et al. 1976; Kesteven and Turtle 1994).

Altogether these data support the idea that we have observed a low mass X-ray binary system during a violent episode of mass accretion onto the compact object.

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