X–RAY SELECTED WOLF-RAYET STARS

The discovery of Th35-42 and prospects for future X-ray surveys

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Abstract. The X-ray source 1E 1024.0-5732, serendipitously discovered with the *Einstein Observatory*, was previously interpreted as a rapidly spinning neutron star, accreting matter from its massive early-type companion, the emission-line star Th35-42. However, new *ROSAT* data do not support the presence of a neutron star in this source. A more likely scenario, also indicated by recent optical spectroscopy, involves X-ray emission from the colliding winds of a WR+O binary. Surprisingly, this star remained unnoticed during an extensive optical search for new Wolf-Rayet stars, carried out in this region of sky. Stimulated by the discovery of this first X-ray selected WR star, we have undertaken a search for similar objects in the data from the *ROSAT* All Sky Survey.

Key words: stars: Wolf-Rayet – X-rays – binaries – colliding winds

1. Introduction

Wolf-Rayet stars are rare objects: fewer than 200 are known in our Galaxy (van der Hucht, these proceedings). Their study, besides the obvious interest in the context of stellar evolution and of the phenomena related to the exceptional mass loss in WR stars, is relevant to the comprehension of the star formation processes on the overall galactic scale. In addition, being very luminous objects, they can be used to trace the galactic structure out to large distances and as powerful probes of the interstellar medium. These are the main motivations behind the extensive searches aimed at the discovery of new WR stars, which, up to now, have been carried out mainly in the optical domain.

As shown by the identification of 1E 1024.0-5732 (Th35-42) as a new WR+O system (Mereghetti *et al.* 1994), X-ray observations might be an efficient way to find new WR candidates. The X-ray luminosities predicted by theoretical models of colliding wind binaries (Myasnikov & Zhekov 1993; Stevens, Blondin & Pollock 1992) are higher than those presently observed in the majority of the WR+OB stars, which have been discovered on the basis of optical observations. It is possible that more X-ray-luminous WR stars are still undiscovered, for instance owing to the emission lines dilution by

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their bright O-type companions, which can hide such systems from emission line surveys.

Motivated by these considerations and by the serendipitous discovery of 1E 1024.0-5732 (Th35-42) (Section 2), we have undertaken an extensive search for other X-ray selected WR stars in the *ROSAT* All Sky Survey. The strategy of this search and the first results are described in Section 3.

2. Th35-42: the first X-ray selected Wolf-Rayet star

The X-ray source 1E 1024.0-5732 ($f_x \approx$ 1–2 10^{-12} ergs cm^{-2} s^{-1}) was discovered with the *Einstein Observatory* by Goldwurm, Caraveo & Bignami (1987) and identified with the early-type (O5) emission line star Th35-42 (Thé 1966; this star was also called Wack 2134, due to its position in the emission-line star catalogue of Wackerling 1970). On the basis of its high $f_x/f_{\rm opt}$, the discovery of an X-ray periodicity at 61 msec (Caraveo, Bignami & Goldwurm 1989), and evidence of long term X-ray variability, this source was explained as a rapidly spinning neutron star powered by accretion from a massive companion. However, this interpretation was not without problems (Mereghetti & Belloni 1994): Firstly, accretion onto a magnetized neutron star with such a high rotational speed is possible only if its magnetic field is very low (at variance with the periodic flux modulation) and/or if the mass accretion rate is very high (incompatible with the observed luminosity of 1E 1024.0-5732). Secondly, its $f_x/f_{\rm opt}$ value, very sensitive to the poorly determined interstellar absorption, could be compatible with emission from a normal O-type star, if N_H were smaller than a few 10^{21} cm^{-2}. In any case, with possibly the shortest spin period ever observed in an accreting X-ray pulsar, 1E 1024.0-5732 was a very interesting source deserving to be studied with *ROSAT*. We therefore observed it with the PSPC instrument in July, 1992, obtaining the following results (see Mereghetti *et al.* 1994 for details): (i) the precise localization ($\pm 3''$) of the X-ray source confirmed its optical identification with Th35-42; (ii) no evidence for the 61 msec periodicity was found, with an upper limit on the pulsed fraction incompatible with the *Einstein* detection. This result weakens the evidence for X-ray emission from a compact object; (iii) thermal *Bremsstrahlung* fitted the X-ray spectrum for $kT > 0.9$ keV and $N_H = (9 \pm 3) \times 10^{21}$ cm^{-2}, yielding an unabsorbed 1.0-2.4 keV flux of 2.8–4.3 $\times 10^{-12}$ ergs cm^{-2} s^{-1}.

We noticed that the only published spectrum of Th35-42 (Caraveo *et al.* 1989) is very similar to those of some WR stars discovered in the emission line survey of Shara *et al.* (1991), suggesting a similar classification for Th35-42. It is surprising that these new WR stars (WR19a, WR20a and WR20b) have been found in the same region of the sky as Th35-42 (within $\sim$1 degree), but Th35-42 was not detected as a potential WR candidate in the Shara *et al.* survey. A new spectrum of Th35-42, subsequently obtained by Shara &

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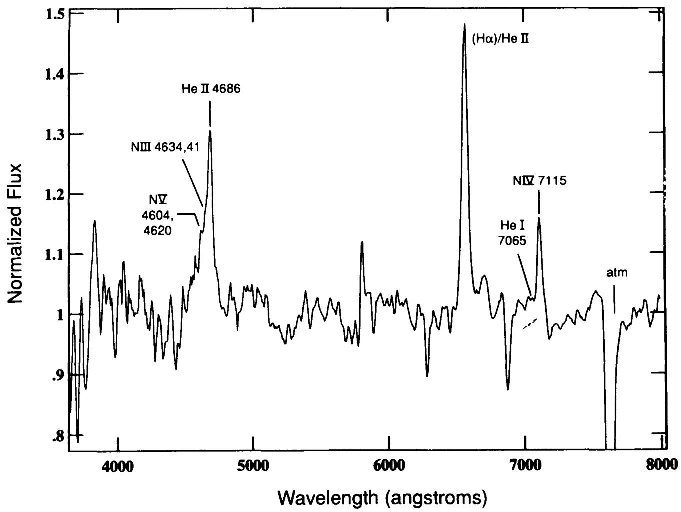

Fig. 1. Optical spectrum of Th35-42

Drissen (priv. comm.) with the 1.6m *CTIO* telescope, confirmed the WR classification (see Fig.1). In particular, with N IV λ7115 much stronger than He I λ7065, Th35-42 is probably of subtype WN6 or earlier. The presence of weak N V $\lambda\lambda$4604,4620 supports subtype WN6 (although WN5 cannot be ruled out), and excludes subtypes WN4 or earlier. The FWHM of the He IIH$_\alpha$ emission line is 40 Å, corresponding to an expansion velocity of 1855 km s^{-1}, quite normal for a WR star. The equivalent widths of the emission lines (17 Å for He II λ4686, 24 Å for He II λ6563, and 6 Å for N IV λ7115) are about ten times smaller than in strong-lined (single) WR stars, but comparable to those of other known WR+O binaries, suggesting the presence of a luminous O-type companion in Th35-42. If this is confirmed by further optical spectroscopy, the enhanced level of X-ray emission ($L \approx 10^{34}$ ergs s^{-1} assuming $d = 5$ kpc) might well result from shock-emission in the colliding winds of the two stars. Diffuse optical and X-ray emission possibly associated with Th35-42 is discussed by Mereghetti & Belloni (these proceedings).

3. X-ray selected Wolf-Rayets in the *ROSAT* All Sky Survey

During the period 1990 August – 1991 January, with additional observations in 1991 February and August, the *ROSAT* satellite performed the first all-sky survey carried out with an X-ray imaging instrument (Trümper 1983). During this survey, almost the whole sky was observed down to a flux-limit of $\sim 10^{-13}$ ergs cm^{-2} s^{-1}, leading to the detection of roughly 60000 soft X-ray sources (Voges 1992). How many new WR stars will be found among these

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X-ray sources? A rough estimate can be made by scaling, in sky coverage and sensitivity, the *Einstein Observatory* results, which have led to the discovery of *at least* one new WR star (*i.e.,* Th35-42). The average *ROSAT* exposure time in the survey at low galactic latitude (~400 s) will yield a sensitivity similar to that obtained in the much longer *Einstein* pointed observations. The latter covered only a very small fraction (a few %) of the ~7000 square degrees within 10 degrees from the galactic plane, where the new WR stars are likely to be found. Therefore, we expect *at least* a few tens of new WR stars to be discovered in the *ROSAT* survey X-ray data. Unfortunately, these really X-ray selected WRs will be recognized only after detailed optical identification work on all the sources, a task that will not be completed in a short time!

Meanwhile we looked for a faster way to discover some of these new WR candidates, characterized by an enhanced level of soft X-ray emission. Our search is based on the early-type emission-line star catalogue of Wackerling (1970). This catalogue contains more than 5000 objects, subdivided in different classes: B-type (~3000 stars), OB-type (442), O-type (101), stars in planetary nebulae (36) and WR stars (133). For ~1400 objects no spectral classification is available. The first step in our search consists in extracting all possible *ROSAT* X-ray detections within 3 arcmin from the Wackerling optical positions. This has now been completed for about half of the catalogue (*i.e.,* all but the B-type stars), resulting in more than 80 correlations. The possible sources found with this automatic procedure must be carefully analysed in order to eliminate all the spurious detections (*e.g.,* due to the presence of extended X-ray emission, chance co-incidences of unrelated sources, instrumental effects, or other artifacts, ..), as well as those objects which are already known to be X-ray emitters of a different kind. The resulting set of X-ray emitting Wackerling objects will be sorted in order of decreasing X-ray *vs.* optical flux ratio in order to select the most promising candidates for further optical investigation.

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DISCUSSION:

Pollock: Do you make anything of "another" coincidence between an X-ray bright W-R binary and a COS-B γ-ray source? There have been a few others.
Mereghetti: There are at least two other "coincidences" between W-R and COS-B sources - (WR 125 and WR 140). The models for γ-ray emission proposed, e.g. for WR 140 can be applied also to Th 35-42 to explain the 2CG 284-00 γ-ray source. However, this would require a higher γ-ray luminosity, owing to the greater distance of Th 35-42.
Becker: One way to ensure the quick discovery of these new X-ray selected WR stars would be to release a catalog of the ROSAT Survey sources.
Mereghetti: I agree with you, but I'm afraid this will not happen very soon!
Cherepashchuk: Did you try to investigate rapid X-ray variability of the newly discovered WR star? Investigation of such a variability (on timescales from 1 minute to 1 hour) is very important for direct detection of clumping structure of WR wind.
Mereghetti: The ROSAT observation of Th 35-42 is made of 7 intervals of about 1500 sec. each, spread over 1.5 days. There is no evidence for flux variations between these intervals. On the other hand, only variations greater than ~30% could have been detected, due to the limited counting statistics, which also prevents searches on shorter timescales.
Meurs: So far, you have been relying on a known optical catalogue to inspect the ROSAT Survey. How are you getting to the X-ray selected WR stars that you are interested in?
Mereghetti: The "truly" X-ray selected WRs will be eventually discovered by optically identifying the X-ray sources found in the ROSAT Survey, but this will take a lot of time. With the "short term" project described here, we hope to find a few objects that have been noticed to have emission lines but have not been recognized as WRs. (As happened for Th 35-42).

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