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An Hα nebula possibly associated with the central X–ray source in the G 266.2−1.2 supernova remnant

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Abstract. We report the discovery of a small Hα nebula positionally coincident with the candidate neutron star AX J0851.9−4617.4 located at the center of the supernova remnant G 266.2−1.2. The nebula has a roughly circular shape with a diameter of ∼6″ and a flux of $\sim 10^{-2}$ photons cm^{-2} s^{-1} in the Hα line. Considering the uncertainties in the distance and energy output from the putative neutron star, we find that such a flux can be explained either in a bow-shock model or assuming that the nebular emission is due to photo-ionization and heating of the ambient gas.

Key words. stars: individual: AX J0851.9−4617.4 – stars: neutron – HII regions

1. Introduction

The X–ray source AX J0851.9−4617.4 is a strong neutron star candidate, very likely associated with the shell-like supernova remnant G 266.2−1.2 (Aschenbach 1998). AX J0851.9−4617.4 was first seen with the *ROSAT* satellite (Aschenbach 1998; Aschenbach et al. 1999) and subsequently studied with *ASCA* (Slane et al. 2001) and *Beppo*SAX (Mereghetti 2001). Its location, very close to the geometrical center of G 266.2−1.2 , suggested an association with this young remnant, but the situation was complicated by the presence of two early type stars (HD 76060 and Wray 16–30) that might have been responsible for the observed X–rays from AX J0851.9−4617.4 , as well as by the presence of other X–ray sources in the vicinity (Mereghetti 2001).

The picture was finally clarified thanks to the accurate localization obtained with the *Chandra* satellite (Pavlov et al. 2001). The absence of any optical counterparts at the *Chandra* position, down to magnitudes $B \sim 22.5$ and $R \sim 21$, implies a very high X–ray to optical flux ratio, consistent with an isolated neutron star. The soft spectrum of AX J0851.9−4617.4 , well described by a blackbody with $kT_{\rm BB} \sim 0.4$ keV, is similar to that of other compact X–ray sources found in supernova remnants, such as, e.g., CasA (Mereghetti et al. 2002) and G 296.5+10.0 (Pavlov et al. 2002). For an assumed distance of 1 kpc the X–ray luminosity of AX J0851.9−4617.4 is $\sim 10^{32}$–10^{33} erg s^{-1}. No pulsations have been detected so far.

Here we present optical images of the central region of G 266.2−1.2 showing the presence of a small Hα nebula at the position of AX J0851.9−4617.4 .

2. Observations

We obtained images of the central part of G 266.2−1.2 from the public archive of the European Southern Observatory (ESO). The data were acquired with the Wide Field Imager (WFI) at the 2.2-m MPG telescope at La Silla. They consist of 5 min long exposures in the *R*, *B* and Hα filters taken on 2001 January 5.

To derive a photometric calibration we used the *R* and *B* band magnitudes of several field stars as reported in the USNO A-2 and GSC II catalogs (excluding objects with discrepant values). We found that the star closest to the error circle of AX J0851.9−4617.4 (star Z of Pavlov et al. 2001) has magnitudes $B \sim 19$ and $R \sim 17$, in agreement with the estimate of these authors. The limiting magnitudes of the ESO WFI images are $B \sim 23$ and $R \sim 22$. No objects are visible in the *Chandra* error region in these two bands.

The image in the Hα filter shows, besides a remarkable nebula probably associated to the B[e] star Wray 16–30 (Thé et al. 1994), the possible presence of a slightly extended faint source at a position compatible with that of AX J0851.9−4617.4 .

The reality of such a source is confirmed by the deeper images obtained with the UK Schmidt Telescope (UKST) at the Anglo-Australian Observatory as part of the Hα survey of the Southern Galactic Plane and Magellanic Clouds (SHS, Parker & Phillipps 1998). This survey consists of long exposures (3 hr) in the Hα filter and contemporaneous

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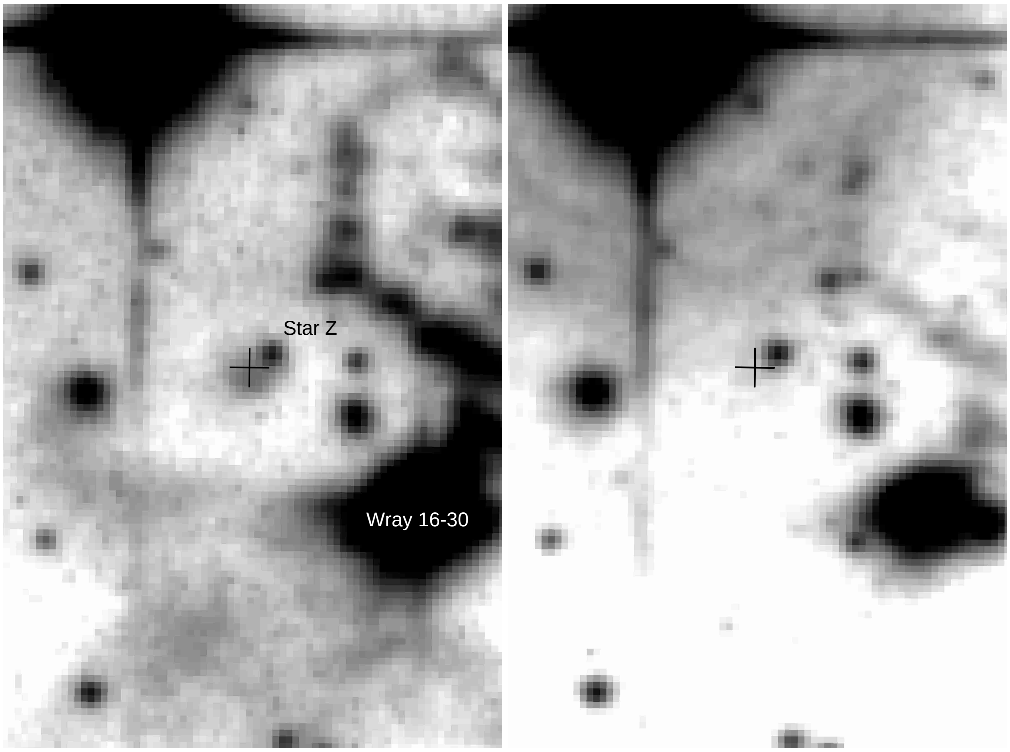

Fig. 1. Hα (left) and R band (right) images of the central region of G 266.2−1.2 North is to the top, East to the left. The cross indicates the position of AX J0851.9−4617.4 (RA(J2000) = $8^{h}52^{m}01^{s}.38$, Dec(J2000) = $-46°17'53''.34$, Pavlov et al. 2001). To locate it, we performed an astrometry based on the coordinates of a number of stars from the GSC II catalog. The rms of our astrometry fit is 0.07″; taking into account possible systematic errors in the GSC catalogue, we estimate an overall error <1″.

15 min Short-Red (SR) broad-band exposures. These plates, digitised with the SuperCOSMOS facility (Hambly et al. 2001), provide an unprecedented combination of coverage (6.5° × 6.5°), resolution (∼1″) and sensitivity (5×10^{-17} erg cm^{-2} arcsec^{-2} s^{-1}). A region[1] of ∼0.8′ × 1.2′ around the position of AX J0851.9−4617.4 is shown in Fig. 1. These data clearly show a roughly circular nebula with diameter $\theta \sim 6''$ at the position of the X–ray source. Such a nebula is only visible in the Hα filter, while it is not detected in the R band plates. All the diffuse Hα emission is well highlighted in Fig. 2, which shows the ratio of the Hα and R images. The nebula, labeled with A, is coincident with the X–ray source and appears well separated from all the other diffuse features permeating this region.

We have derived the R–Hα color of a number of stars and of diffuse features also visible in the R image. There is some evidence that nebula A has a higher value of R–Hα ($\gtrsim$4) than other diffuse features of comparable Hα brightness.

Unfortunately, at this stage, the SHS on-line survey does not provide a photometric calibration. To estimate the flux of nebula A, we performed a rough calibration of the Hα image as follows. We first computed the Hα fluxes corresponding to the R magnitudes of a sample of GSC II stars present in our image, assuming blackbody spectra with the appropriate stellar temperatures. We then derived the relation between the instrumental magnitudes and the Hα fluxes. This relation was found to have a small dispersion and allowed us to transform the instrumental Hα magnitude −11.8 ± 0.2 of nebula A to a flux of $\sim(1 \pm 0.2) \times 10^{-2}$ photons cm^{-2} s^{-1} in the Hα line.

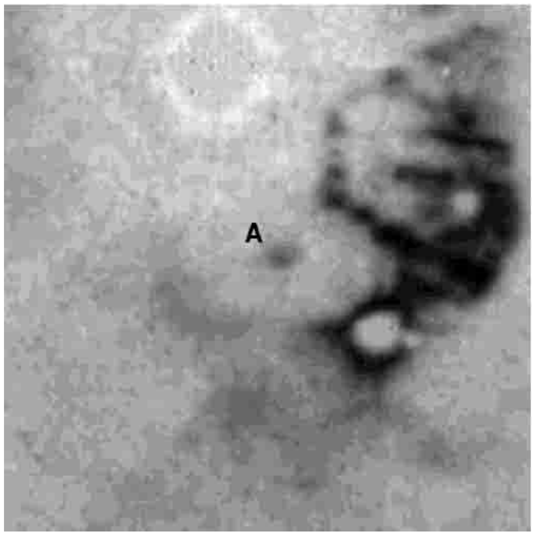

Fig. 2. Ratio of the Hα and R band images.

3. Discussion

"Balmer line-dominated" nebulae have been detected close to four radio pulsars and to the radio-quiet neutron star RX J1856.5−3754 (see, e.g., Chatterjee & Cordes 2002, and

[1] The data were kindly provided to us before public release by Mike Read, Institute for Astronomy, Edinburgh, UK.

Table 1. References. (1) Bell et al. (1995); (2) van Straten et al. (2001); (3) Jones et al. (2002); (4) Kulkarni & Hester (1988); (5) Cordes et al. (1993); (6) Chatterjee & Cordes; (7) Kaplan et al. (2002); (8) van Kerkwijk & Kulkarni (2001).

Name	Hα Flux ph/cm^2 s	Log $\dot{E}_{\rm rot}$ erg/s	D kpc	$v_{\rm min}$ km s^{-1}	$v_{\rm max}$ km s^{-1}	ref.
J0437−4715	2.5×10^{-3}	34.07	0.139 ± 0.003	90	280	1,2
B0740−28	5×10^{-5}	35.16	1.9 ± 0.5	190	360	3
B1957+20	1.09×10^{-2}	35.20	1.5 ± 0.4	160	800	4
B2224+65	1.1×10^{-3}	33.08	2.0 ± 0.5	1300	3700	5,6
J1856.5−3754	2×10^{-5}	32.9[a]	0.14 ± 0.04	160	330	7,8

[a] Assumed value (no period is known for this object).

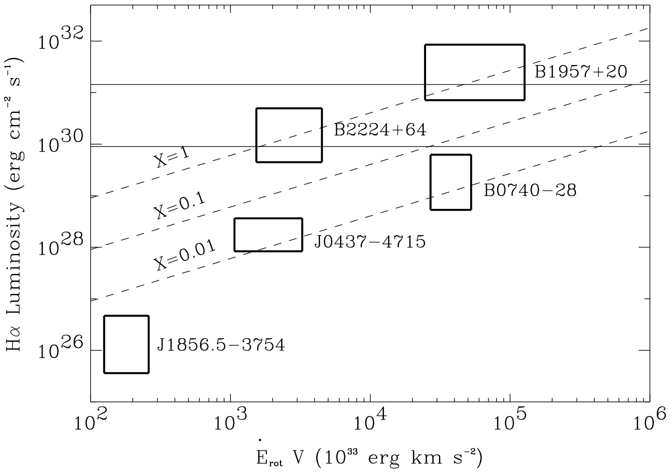

Fig. 3. Hα luminosity versus $v\dot{E}_{\rm rot}$ for the 5 known Hα nebulae associated to neutron stars.

references therein). Such nebulae, typically characterized by an arc-shaped or by a "cometary" morphology, can be explained as bow-shocks in the ambient gas produced by the hypersonic motion of a neutron star with a strong relativistic wind. In this model, the expected Hα luminosity is proportional to the neutron star velocity v, the rotational energy loss $\dot{E}_{\rm rot}$, and the fraction X of neutral hydrogen in the interstellar medium:

$$L_{\rm H\alpha} \propto v\dot{E}_{\rm rot}\ X. \qquad (1)$$

We have plotted in Fig. 3 the luminosity of the known Hα nebulae associated to neutron stars versus the quantity $v\dot{E}_{\rm rot}$. The sizes of the rectangles reflect the possible range of velocities allowed by the measurements and/or limits on proper motion, distance, and angle i between the pulsar velocity and the line of sight available in the literature (see Table 1 for details). After accounting for different plausible values of X in the range 0.01–1, these data are well explained by relation (1), with the normalization factor derived by Cordes et al. (1993) (dashed lines). The only exception is RX J1856.5−3754 for which the period is unknown and therefore the $\dot{E}_{\rm rot}$ estimate is uncertain.

We have also indicated in Fig. 3 the luminosity of nebula A, for assumed distances in the 0.5–2 kpc range (solid lines). It can be seen that an explanation in terms of the bow-shock scenario is, at least energetically, possible. In this hypothesis, we can derive limits on v and $\dot{E}_{\rm rot}$ as a function of the assumed values of distance and X. Considering the small displacement from the SNR center ($\lesssim 10'$) and the lack of evidence for a high value of $\dot{E}_{\rm rot}$ (e.g. a bright X–ray or radio synchrotron nebula), we are led to the conclusion that a relatively small distance is favored, unless the neutron star velocity is close to the line of sight direction (see Pellizzoni et al. 2002 for more details).

In an alternative interpretation, the nebular Hα emission might be produced by photo-ionisation and heating of the ambient gas by the extreme-ultraviolet radiation of the neutron star. Such photo-ionisation nebulae were predicted to exist around rapidly moving, hot neutron stars by Blaes et al. (1995). Van Kerkwiijk & Kulkarni (2001) proposed that this model could be responsible for the nebula associated to the nearby neutron star RXJ 1856.5-3754. Following these authors, considering a pure hydrogen gas nebula and a ionised fraction $X \sim 50\%$ for the emitting region, we find that the blackbody emission with $kT \sim 0.4$ keV from AX J0851.9−4617.4 leads to a gas temperature $\sim 10^5$ K due to heating by photo-ionisation. This implies plasma emission dominated by collisional excitation, with an expected Hα photon rate, integrated over the whole emitting region, given by:

$$F_{\rm H\alpha} \propto \frac{V\,X\,(1-X)\,n_{\rm H}^2\,q}{4\pi\,D^2} \qquad (2)$$

where $V \sim (\theta D)^3$ is the emitting volume and q is the rate of collisional excitations (Osterbrock 1989; Anderson et al. 2000; van Kerkwijk & Kulkarni 2001). For $X = 0.5$ and $q = 3.7\times10^{-10}$ cm^3 s^{-1}, appropriate for $T = 10^5$ K, we find that the density required to match the observed photon rate of $\sim10^{-2}$ ph cm^{-2} s^{-1} is $n_{\rm H} \sim 5D_{\rm kpc}^{-0.5}$ cm^{-3}. Therefore, reasonable density values (<5 cm^{-3}) can only be obtained for $D > 1$ kpc.

4. Conclusions

We have discovered a faint ($\sim10^{-2}$ ph cm^{-2} s^{-1}) Hα nebula positionally coincident with the point-like X–ray source AX J0851.9−4617.4 , which is thought to be the compact remnant associated to SNR G 266.2−1.2. Although this region contains several diffuse Hα features, the positional coincidence and the possible evidence for a peculiar color, compatible with a pure Balmer emission line spectrum, suggest a relation between the Hα nebula A and the putative neutron star. In fact, although the lack of a period and spin-down measurement for

AX J0851.9−4617.4 make the energetics somewhat uncertain, we have shown that the luminosity of the nebula is compatible with the predictions of the two models which have been invoked to explain a few Hα nebulae associated to different kinds of neutron stars.

Different distances are favored by the two scenarios. The model based on photo-ionization suggests a distance greater than ~1 kpc, consistent with that inferred from X–ray absorption in the G 266.2−1.2 SNR (Mereghetti & Pellizzoni 2001). In the case of a bow-shock nebula, the most likely distance is smaller than ~0.5 kpc, due to the presumably small value of $\dot{E}_{\rm rot}$ and the lack of evidence for a high transverse velocity for the neutron star. Of course we cannot exclude a greater distance in the bow-shock scenario if the neutron star has a high velocity close to the direction of the line of sight. Although this might be consistent with the circular symmetry of the nebula, we note that the chance probability for, e.g., $i < 10°$ is only ~7%.

More detailed investigations are required to confirm the proposed association between nebula A and AX J0851.9−4617.4 and eventually to discriminate between the two possible mechanisms. In particular, deeper imaging with high resolution can provide information on the shape of the nebula, while high-resolution spectroscopy is needed to measure the width of the Hα line. In the bow-shock model one should see a major fraction of the emission with velocity widths comparable to the shock velocity, larger than that of the narrow lines expected in the photo-ionisation model with thermal velocities $\lesssim$40 km s^{-1} (Raymond 1991).

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