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THE CONNECTION BETWEEN THE VELA SUPERNOVA REMNANT, THE OPTICAL NEBULA RCW 37, AND THE YOUNG X-RAY SUPERNOVA REMNANT RX J0852.0−4622

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RESUMEN

Investigamos la asociación entre la nebulosa del Lápiz (RCW 37, NGC 2736), el fragmento D/D′ observado en rayos-X en el remanente de supernova Vela, y el recién descubierto (en rayos-X) remanente de supernova RX J0852.0−4622) en Vela. Los perfiles de la línea [O III] 5007 Å de RCW 37 muestran la cinemática de esta nebulosa por primera vez. Un elipsoide parcial de velocidades está presente en el arreglo posición-velocidad de los perfiles de línea. La cinemática y la morfología pudieran sugerir que la estructura de RCW 37 es la de una sabana delgada curvada de emisión óptica que está sujeta a una expansión sistemática. Una explicación sencilla para los datos es que RX J0852.0−4622 estalló dentro del remanente más grande y antiguo de Vela y que parte del gas eyectado de la supernova se ha incrustado en la pared densa y fría del remanente viejo. La sábana delgada de emisión óptica entonces traza el borde interior de esta pared chocada mientras que la emisión en rayos-X denota el gas calentado por choques. Este modelo predice que la distancia a RX J0852.0−4622 debe ser la misma que la del remanente de Vela, recientemente medida como del orden de 250 pc.

ABSTRACT

The association between the Pencil nebula (RCW 37, NGC 2736), the Vela X-ray fragment D/D′ and the recently discovered new X-ray supernova remnant (RX J0852.0−4622) in Vela is investigated. [O III] 5007 Å line profiles of RCW 37 are presented that show the kinematics of this nebula for the first time. A partial velocity ellipse is present in the pv array of line profiles. The kinematics and morphology could suggest that the structure of RCW 37 is that of a thin curved sheet of optical emission that is undergoing a systematic expansion. A simple explanation for the data is that RX J0852.0−4622 has occured within the older, larger Vela SNR and that a portion of the supernova ejecta from RX J0852.0−4622 has impacted the pre-existing cold dense wall of the Vela SNR. The thin sheet of optical emission then traces out the inside edge of this shocked wall while the X-ray emission marks shock-heated gas. This model predicts that the distance to RX J0852.0−4622 will be that of the main Vela SNR which has been recently measured to be of order 250 pc.

Key Words: **HYDRODYNAMICS — ISM: JETS AND OUTFLOWS — STARS: WINDS, OUTFLOWS**

1. INTRODUCTION

RX J0852.0−4622 is a young nearby supernova remnant (SNR) discovered (Aschenbach 1998; Iyudin et al. 1998) near the southeastern perimeter of the well known Vela SNR. RX J0852.0−4622 has generated much interest since the distance and age could be as low as 200 pc and 700 yr, respectively, and thus it could have been generated by the nearest SN explosion in recent human history.

The SNR was discovered in *ROSAT* hard X-ray data (shown as contours in Figure 1) and at these energies has a shell-like morphology. There is no obvious optical counterpart to the main body of the SNR but Redman et al. (2000) showed that a fragment of X-ray emission (labelled D/D′ by Aschenbach, Egger, & Trümper 1995) coincides closely with a bright optical nebula, RCW 37. The X-ray fragment is located just beyond the main circular body of the remnant and is clearly visible in hard X-ray images. The main X-ray shell is not complete and there is a break in the emission in a direction coincident with that of the X-ray fragment and with RCW 37 (see Fig. 1). Redman et al. (2000) suggested that RCW 37 is physically associated with RX J0852.0−4622 and represents a venting of hot gas from the interior of the remnant to beyond the roughly circular shell as delimited in the X-ray.

RCW 37 (NGC 2736) was discovered in the 1840s and is a bright optical nebula known to amateur astronomers as the Pencil Nebula (Figure 2). The unusual, intricate morphology of the nebula and its large size and brightness make it surprising that there have been few studies of this object. Redman et al. (2000) suggested that its funnel-like appearance could be taken to indicate that there is indeed a collimated flow of hot gas taking place from the

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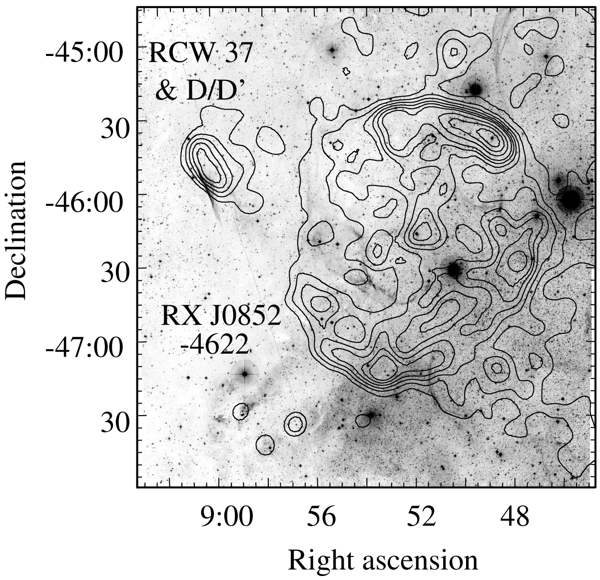

Fig. 1. Contour map of RX J0852.0−4622 from the RASS hard X-ray discovery data of Aschenbach (1998) overlaid on ESO IIIaJ optical images. RCW 37 and X-ray fragment D/D′ coincide to the upper left of the picture.

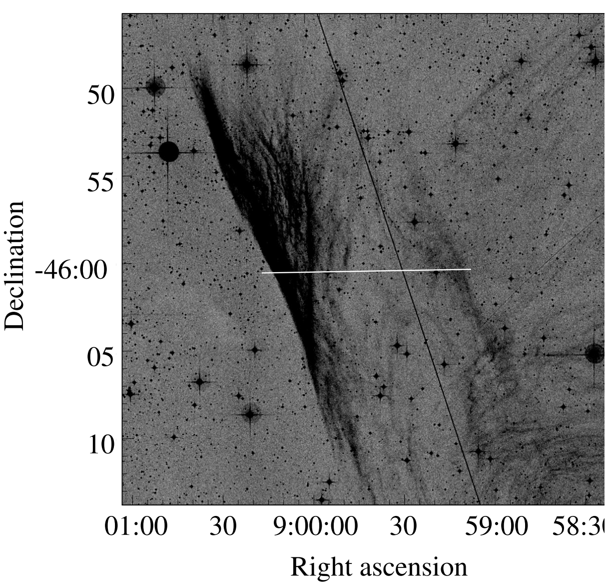

Fig. 2. ESO image of RCW 37 with the five overlapping MES slit positions marked with a white line. The sloping thin dark line is a satellite trail.

remnant interior. Alternatively, a pre-existing cloud could be being shocked by escaping hot gas. Redman et al. (2002) obtained new optical forbidden-line profiles from RCW 37 from an extended slit position across the filamentary bulk of RCW 37 and

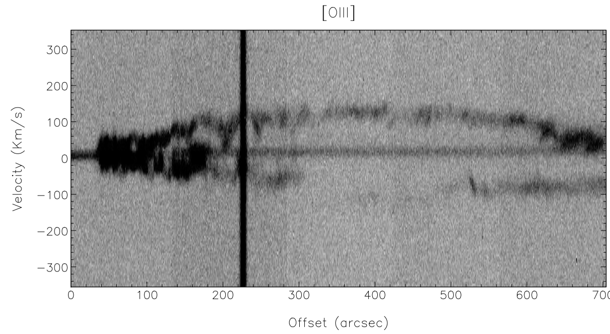

Fig. 3. Position-velocity array of [O III] 5007 Å line profiles mosaiced from five consecutive slit positions. The dark vertical line is the spectrum of a star intersected by the slit. The vertical axis is heliocentric radial velocity.

these results are presented here. The kinematics are discussed and used to argue that RX J0852.0−4622 is embedded within the older, larger Vela SNR.

2. OBSERVATIONS AND RESULTS

Contours of the smoothed hard ($E > 1.3$keV) RASS discovery data of RX J0852.0−4622 are shown in Fig. 1 overlain on an ESO archive IIIaJ (green) image of the region. Fig. 2 is an ESO archive green image of RCW 37. Spatially resolved, longslit echelle spectra of the [O III] 5007 Å and [S II] 6716 & 6731 Å emission lines were obtained with the Manchester echelle spectrometer (Meaburn et al. 1984) at the Anglo-Australian Telescope; see Redman et al. (2002) for full details. Data were obtained from five slightly overlapping east-west slit lengths to produce an effective slit length of about 700″ whose position is marked on Fig. 2. The data from each slit were reduced and mosaiced together.

A negative grayscale representation of a position-velocity (PV) array of [O III] 5007 Å line profiles is displayed in Fig. 3. The following features can readily be seen. Throughout the data at zero heliocentric radial velocity there is faint background [O III] 5007 Å emission. The bright eastern edge of the nebula begins at an offset of around 40″. The data here exhibit velocity knots and small velocity loops that correspond to the complex filaments readily seen in Fig. 2. With increasing offsets, the line profiles begin to split. At offsets of greater than about 300″ the profiles are no longer split and only a single faint component at positive velocities (up to $\sim 120\,\mathrm{km\,s^{-1}}$) is present. The positive velocity component then approaches the systemic with increasing offset. The bright feature at around 700″ is the western edge seen in Fig. 2. There is a negative velocity component from offsets of 550″ onwards that is due to the irregular background diffuse emission and not associated with RCW 37.

RCW 37 exhibits a curved morphology (see Fig. 2) but there is also a parallel line of emission to the west. The new kinematic data across RCW 37 are nearly exactly those expected of a funnel of circular cross-section undergoing radial expansion. However, one difficulty with this interpretation is that such a funnel would be pointing to the center of the young SNR. A more plausible interpretation is that the nebular gas is in the form of a thin 'wavy sheet' (Hester 1987) of emission, which at the eastern side overlaps along the line of sight. At the western side the single thin sheet curves to become edge on, forming the western edge. The whole system appears to be undergoing a bulk expansion generating double-peaked line profiles at the eastern side where the sheet overlaps itself.

3. RCW 37, RX J0852.0−4622 AND THE OLD VELA SNR

The velocity structure and X-ray properties described above may be explained in the following simple way. We suggest that RX J0852.0−4622 exploded within the main Vela SNR. The Vela SNR is approximately 11,000 yrs old and by this stage it will have swept up the interstellar medium into a cold dense shell at its boundary. The unusual optical morphology, and X-ray properties of RCW 37 and D/D′ are simply due to a localized venting of hot gas from RX J0852.0−4622 impacting the old wall of the Vela SNR. This creates an X-ray 'hot spot' and a curved sheet of optical emission tracing the inside edge of the old shell wall. Dubner et al. (1998) have mapped the whole Vela SNR in H I and find it to be a located in a thin shell closely correlated with the X-ray emission of Aschenbach et al. (1995). This is the wall with which we conjecture the blast wave is interacting. The hot gas may even have caused localized expansion of the wall at this point—the eastern boundary of the Vela SNR as mapped in soft X-rays by Aschenbach et al. (1995) is distorted at the position of RCW 37 and D/D′.

The differing X-ray spectral properties of feature D/D′ and RX J0852.0−4622 led Slane et al. (2001) to conclude that the two objects are unrelated to each other. However, in the context of the above scenario, differing X-ray properties are expected since the X-ray gas in fragment D/D′ has only recently impacted the dense neutral wall of the older Vela SNR resulting in non-equilibrium ionization. For more detailed discussion see Redman et al. (2002).

Estimates of the distance to RX J0852.0−4622 are very uncertain, if it is not assumed to be physically associated with the old Vela SNR. Duncan & Green (2000) have summarized some of the difficulties. Our optical study offers a clear distance constraint if RX J0852.0−4622 was generated within the Vela SNR. Cha, Sembach, & Danks (1999) have used optical absorption lines towards a significant sample of OB stars in the direction of the Vela SNR to constrain the distance as 250 ± 30 pc with a conservative upper limit of 390 ± 100 pc. Clearly, if indeed RX J0852.0−4622 is located within the older Vela SNR then the distance is constrained to be ~ 250 pc. We note that if subsequent studies firmly indicate that RX J0852.0−4622 lies well beyond the old Vela SNR, then our model can be ruled out.

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