THE PECULIAR X-RAY MORPHOLOGY OF THE SNR G292.0+1.8 : EVIDENCE FOR AN ASYMMETRIC SUPERNOVA EXPLOSION

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A high resolution X-ray image from the Einstein Observatory of the young supernova remnant G292.0+1.8 (MSH11-54), previously noted as peculiar in terms of its spectral and morphological properties at optical and radio wavelengths, also shows an unusual X-ray morphology. Instead of a limb-brightened X-ray shell characteristic of most SNRs, the remnant consists of a central bar-like feature superposed on an ellipsoidal disc of approximately uniform surface brightness. We attribute the bar emission to a ring of oxygen-rich material ejected in the equatorial plane of a massive rotating progenitor, and the uniform disc component to emission from material with roughly cosmic composition heated by the accompanying blast wave. This interpretation provides observational support for the rotating precursor model of a Type II supernova discussed by Bodenheimer and Woosley.

1. INTRODUCTION

The supernova remnant (SNR) G292.0+1.8 has attracted considerable attention recently since it is only the second galactic SNR (after the fast moving knots in Cas A) to show an optical spectrum dominated by oxygen emission. The oxygen-rich material in these SNRs is believed to be alpha-processed ejecta from the relatively recent explosion of a massive ($\sim$25 $M_\odot$) star. Thus the study of such remnants offers the potential of probing both the nucleosynthetic processes in Population I stars and the dynamics of Type II supernova explosions.

At radio wavelengths, G292.0+1.8 (MSH11-54) shows a bright central peak of about 2 arcminutes extent, surrounded by a faint plateau of approximately 10 arcminutes diameter (Lockhart et al. 1977). No radio shell is present. The optical counterpart (Goss et al. 1979) consists of faint and irregular nebulosity visible only in the emission lines of oxygen and neon. Murdin and Clark (1979) found the velocity dispersion of the oxygen and neon rich material to be in excess of 2000 km s^{-1}, consistent with G292.0+1.8 being a young (<2000 years) remnant in which

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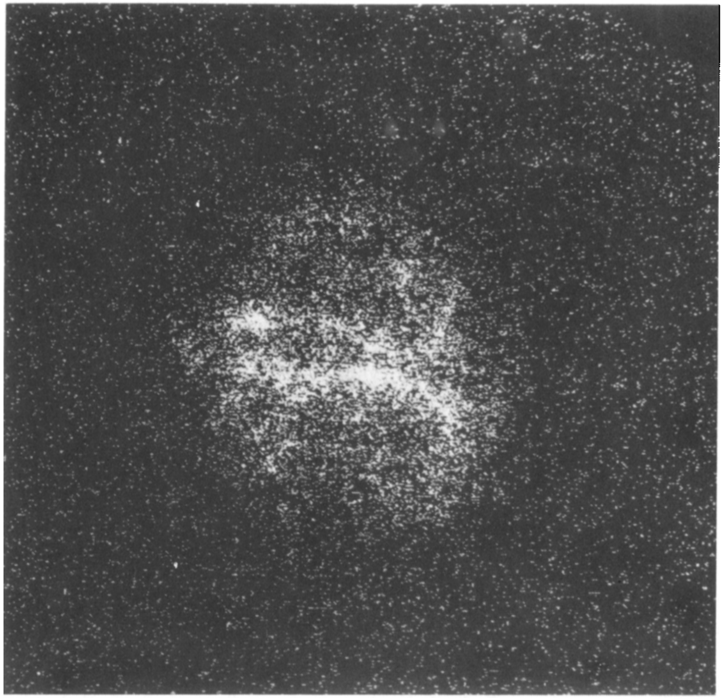

Fig. 1a X-ray image of G292.0+1.8 recorded by the High Resolution Imager on the Einstein Observatory. The number of counts per 2 arc-second square pixel ranges from 0 to 5. North is at the top and East is to the left.

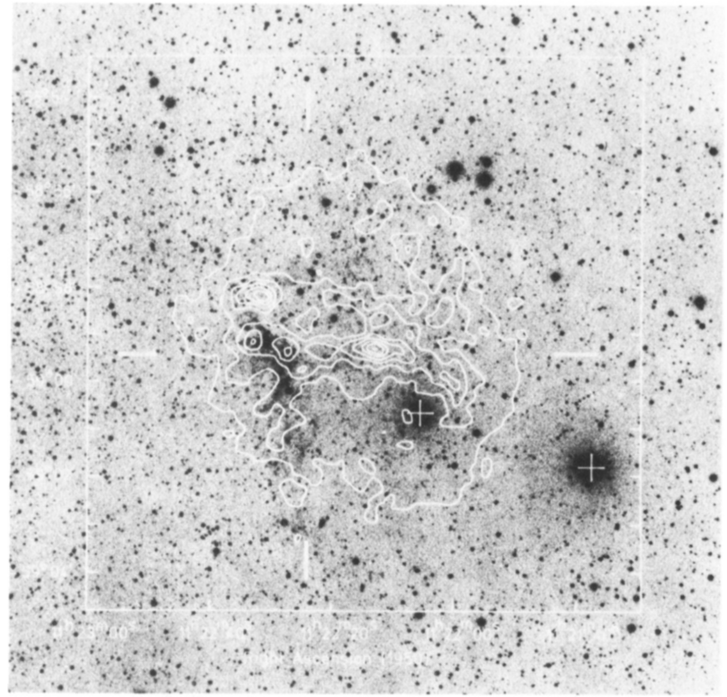

Fig. 1b Smoothed X-ray contour diagram of G292.0+1.8 overlaid on an [OII] $\lambda 3727$ exposure taken at the prime focus of the AAT by Murdin and Malin. The two crosses denote SAO stars used for alignment purposes, while the intersection of the four edge marks defines the centroid of the radio peak measured by Lockhart et al. (1977). Figures 1a and 1b are to a similar scale.

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the supernova ejecta has not yet been contaminated by swept-up interstellar material. In this paper we report the first X-ray image of G292.0+1.8 which we interpret in terms of an asymmetric Type II supernova explosion (see also Tuohy, Clark and Burton 1982).

2. OBSERVATIONS AND RESULTS

The X-ray image of G292.0+1.8, obtained using the High Resolution Imager on the Einstein Observatory (Giacconi et al. 1979), is displayed in Figure 1a. Figure 1b shows the X-ray data as a smoothed contour map overlaid on an [OII] $\lambda 3727$ photograph taken at the prime focus of the Anglo-Australian Telescope (Murdin and Malin, private communication). The intersection of the four edge marks defines the centroid of the radio peak measured by Lockhart et al. (1977).

The X-ray emission from G292.0+1.8 is confined to an ellipsoidal "disc", punctuated by a bright central feature bisecting the disc in an E-W direction. The emission from this central "bar" is irregular, and furthermore, shows bifurcated structure having a mean separation of ~ 1 arcminute. The dimensions of the disc are 8 arcminutes by 6.5 arcminutes, with the N-S elongation being almost perpendicular to the central bar. Away from the bar, the disc emission has a relatively uniform surface brightness without limb-brightening (see also Figure 3 in Tuohy, Clark and Burton 1982). The X-ray image shows no evidence of a point source that could be associated with a neutron star.

The correlation between the X-ray and optical features in Figure 1b is not striking; the two dominant hotspots in the X-ray bar lie away from any significant optical nebulosity. The brightest [OII] nebulosity is located at the eastern extremity of the X-ray bar, and coincides with two small knots in the X-ray image. A spur of X-ray emission running to the south appears to be associated with a similar southerly extension of the [OII] emission. The centroid of the radio peak lies near the bright [OII] nebulosity and is approximately midway between the two hotspots in the X-ray bar. Thus it is probable that the peaked radio component, which shows evidence for E-W extension, is associated with the X-ray bar, while the broad radio plateau referred to earlier can be ascribed to the X-ray disc.

The X-ray image accurately delineates the extent of G292.0+1.8 for the first time. The angular size and the distance to the remnant of $\gtrsim 3.7$ kpc (Caswell et al. 1975) imply a mean linear diameter of $\gtrsim 7.8$ pc. This diameter is consistent with the young age of the remnant ($\lesssim 1600$ years) inferred from optical velocity data (Murdin and Clark 1979).

3. DISCUSSION

The X-ray structure of G292.0+1.8 reported here is unique amongst the ~ 50 SNRs for which X-ray maps have now been obtained. Neither of

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the two principle morphological classification criteria are met, namely shell-like structure or centrally peaked (Crab-like) X-ray emission. Initially it was thought that G292.0+1.8 *was* Crab-like on the basis of the centrally condensed radio structure (Lockhart et al. 1977, Goss et al. 1979). Doubt was cast on this classification by Weiler (1978) and van den Bergh (1979), and also by the failure to observe a synchrotron X-ray spectrum (Clark, Tuohy and Becker 1980). Thus the cumulative optical and X-ray data now rule out any close relationship between G292.0+1.8 and the Crab Nebula.

A plausible explanation of the unusual X-ray morphology of G292.0+1.8 follows from the recent work of Bodenheimer and Woosley (1980, 1982) and Woosley and Weaver (1981,1982). They have discussed firstly the collapse of a non-rotating 25 $M_\odot$ star, and find that the outward moving shock produced by the "bounce" of the iron core at nuclear density travels only part way out before being extinguished by infalling material and by the photo-disintegration of ^{28}Si. The net result is that a supernova explosion does not accompany stellar collapse. However, when stellar rotation is invoked, the impeding effect of the centrifugal motion on the infalling oxygen-rich envelope leads to rotational braking. Inertial overshoot of this material occurs, followed by an outward radial bounce, which, powered by explosive nucleosynthesis, results in the ejection of mass in the *equatorial* plane. The effect of the equatorial expulsion of oxygen would be to form an expanding ring of ejecta. Such a ring, if viewed nearly edge-on at an angle of $\sim 10^o$, could mimic the oxygen-rich nebulosity and the bifurcated X-ray bar of G292.0+1.8.

Velocity mapping of isolated portions of the optical nebulosity, which is concentrated along the X-ray bar, show complex motions (Danziger and Goss, private communication). It is impossible to model these in isolation. However, a preliminary assessment of velocity data covering the complete remnant (Murdin and Clark, in preparation) show a general expansion commensurate with the equatorial ejection model. Some deviation from a simple planar ring model would not be unexpected in view of the evidence for a distorted ring of ejecta in the oxygen-rich SNR, 1E0102.2-7219 (Tuohy and Doptia, 1982, 1983).

The origin of the uniform X-ray disc remains to be understood. Woosley and Weaver (1982) have considered the explosin of a 25 $M_\odot$ rotating precursor further, and find that while the oxygen-rich material is ejected equatorially, a portion of the kinetic energy is likely to be shared with the outer (un-processed) envelope of the star, creating a nearly spherical shockwave. Ejection of some of this envelope material, together with matter swept up from the interstellar medium, would lead to the formation of the observed X-ray disc in G292.0+1.8. Presumably as the remnant evolves further and more material is swept-up, a limb-brightened shell will develop. The lack of limb-brightening at this time might also be explained in part by a radial decrease in interstellar density away from the site of the explosion resulting from pre-supernova mass loss.

Markert, Canizares and Winkler (1981) have recently obtained direct evidence for a ring of X-ray emitting material in another oxygen-rich SNR, Cas A, from an analysis of the velocity structure of the S XV line. These authors attribute the X-ray ring in Cas A to either the asymmetric ejection mechanism of Bodenheimer and Woosley described above, or alternatively, to the effect of a spherically symmetric supernova explosion interacting with inhomogeneous interstellar material that is fortuitously arrayed to the line of sight. This latter explanation now appears unlikely in view of the evidence for a similar X-ray ring in a second oxygen-rich SNR, G292.0+1.8.

The occurrence of asymmetric Type II supernova explosions is given further support by the optical velocity mapping of N132D by Lasker (1980). Lasker finds the inner oxygen-rich material in this remnant to be expanding as an inclined ring with a velocity of 2250 km s^{-1}. Similar velocity mapping of the young oxygen-rich SNR in the Small Magellanic Cloud by Tuohy and Doptia (1982,1983) has also provided compelling evidence for an asymmetric Type II supernova explosion.

Our interpretation of the X-ray structure of G292.0+1.8 has two implications. Firstly, the two spatial components should have distinctly different compositions; the bar component should be dominated by oxygen, neon, etc., as with the optical remnant, while the disc emission should be characteristic of roughly cosmic material. Secondly, X-ray velocity differences of over 2000 km s^{-1} should exist within the bar material of G292.0+1.8, analogous to those detected in Cas A.

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DISCUSSION

DICKEL: One of the most important characteristics of Cas A is the intensity variation in the filaments which are quite detectable over a few years. If a second epoch optical photograph does not exist, one should be taken soon.

TUOHY: At present only one high quality optical photograph of G292.0+1.8 exists, and that is the [OII] λ3727 exposure taken at the prime focus of the Anglo-Australian Telescope in 1980 by Murdin, Clark and Malin. This plate would be suitable for comparison with later epoch measurements.