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THE CLUMPY CIRCUMSTELLAR MEDIUM AROUND YOUNG SUPERNOVA REMNANTS

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Each of the youngest supernova remnants known in the Milky Way, Cas A, Kepler's SNR, and Tycho's SNR, shows a different morphological structure caused by different conditions in the progenitor stars and their surroundings. In all three cases, however, the observed shells have a thickness of about 1/4 the radius, a sharp outer edge, and significant brightness irregularities. These features require that the circumstellar medium be highly clumped.

To investigate the phenomenon, models of the expansion have been constructed using a one-dimensional spherical hydrodynamic code. As a supernova shock moves down the external density gradient of the star, material behind the shock begins to go into free expansion. Then as surrounding material is encountered a reverse shock moving back into the ejectum will be formed. Until the expansion has swept up about eight times the ejected mass when the situation can be considered as a point explosion in its surroundings, the dynamics are controlled by conditions between the shocks. This region is also where the synchrotron radio emission from relativistic electrons trapped in magnetic fields arises. Initial particles and fields are accelerated and amplified by eddy motion at the interface between the ejected and swept-up material and at the boundaries of clumps. Polarimetry shows that these SNR have a net radial orientation of their magnetic fields apparently from stretching by Rayleigh-Taylor instabilities at the contact surfaces. Without clumps the observed shell is much too narrow and steep on the inside.

To simulate true three-dimensional structure with the one-dimensional model, random contributions from several runs with varying parameters for the clumps were summed along the line of sight. The results shown in the figure were made from different summations of four runs having random spacings of the clumps with a mean separation of 5×10^{17} cm. Their Gaussian sizes were 1×10^{17} cm $\pm$ 10% and their peak densities were $3.6+10^{24}$ gm cm^{3} $\pm$ 10%. The latter was typically 10 times the mean density between clumps. These conditions were able to reproduce the varying brightness distributions of both the type I remnants, Kepler and Tycho. Whether the clumpiness is a result of presupernova mass loss or a general property of the interstellar medium is not known.

The remnant of the type II SN, Cas A, with its larger mass and greater brightness, requires correspondingly more massive clouds but the same type of phenomenon prevails. In this case, the material presumably came from the star as indicated by its observed composition.

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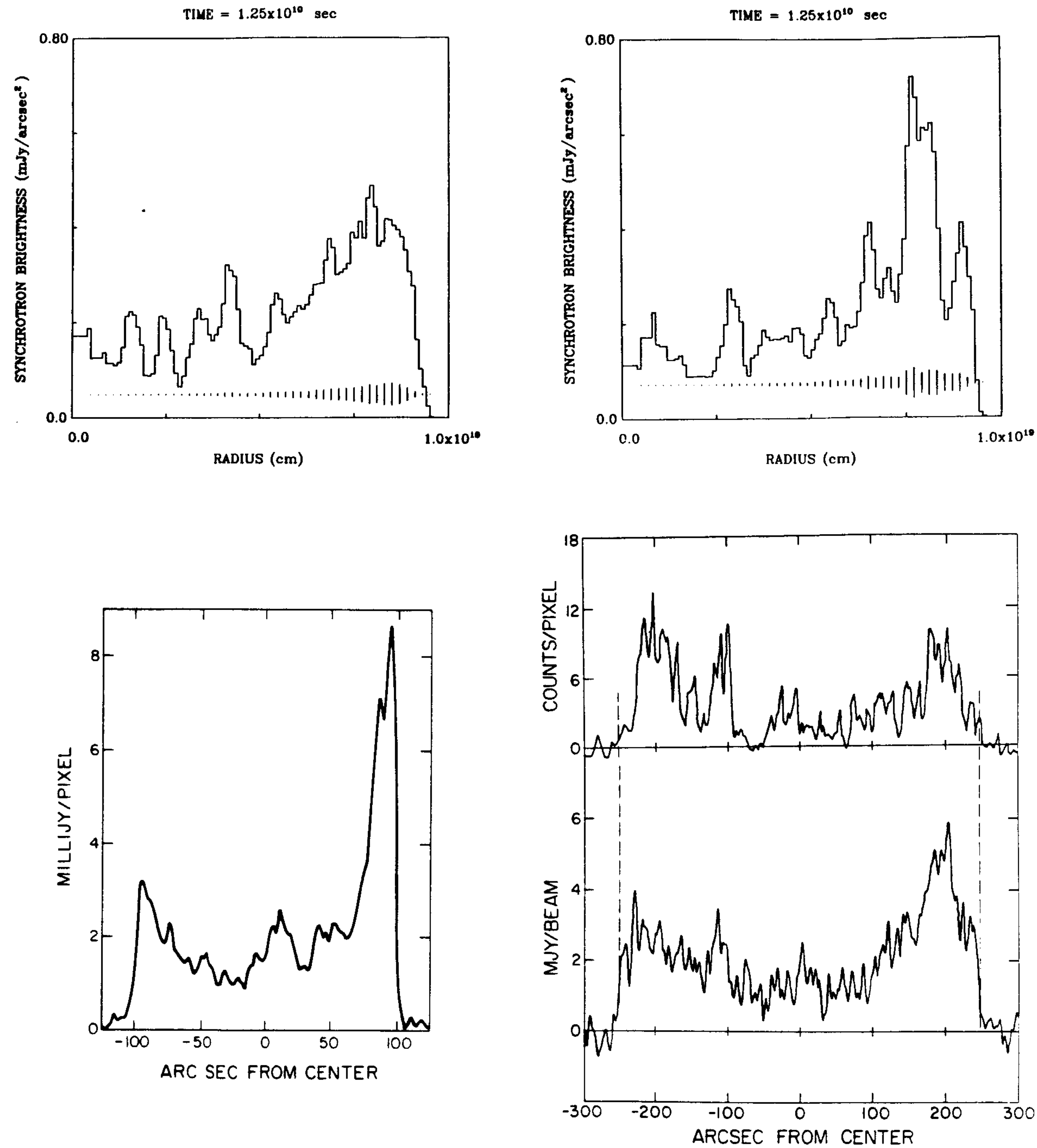

Figure:
Upper - Radial slices of the predicted radio synchrotron emission at a wavelength of 20 cm from two different summations of the four runs of the model type I SNR expanding into the clumpy medium described in the text. The time is 400 years after the explosion. The vertical vectors near the bottom represent the polarized power in a direction corresponding to a radial magnetic field.
Lower Left - South-north slice through the 20 cm radio emission from Kepler's SNR. A pixel represents a 1".75 by 2".75 Gaussian beam. The left side can be compared with the figure above.
Lower Right - South-north slices through the 11-cm radio and soft x-ray emissions from Tycho's SNR. The resolution was 4". The rim on the right can be compared with the modeled emission above.