MODELS FOR X-RAY EMISSION FROM TYCHO'S REMNANT

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Abstract: We reexamine the X-ray emission from Tycho's remnant using results from hydrodynamic models computed with a detailed spherically symmetric code. The observed synchrotron radio contours (Green and Gull 1983) appear to require a cloudy circumstellar medium (Dickel and Jones, 1985; Dickel, Eilek, and Jones 1987), thus we explore the X-ray emission properties of similar models. We find that they tend to produce broad shells of X-ray emission that resemble the observed X-ray map of Tycho (Seward, Gorenstein, and Tucker 1983). A simple hydrodynamic model can satisfy both radio and X-ray observations, but it has little similarity to the evolution of remnants in cloudy media dominated by thermal conduction (McKee and Ostriker 1977). More work needs to be done to ensure that the spectrum as well as the X-ray map can be modeled with the same cloudy circumstellar medium, although we believe it will not be difficult to obtain as good a statistical agreement with the spectral data as other models have achieved (e.g. Hamilton, Sarazin, and Szymkowiak 1986).

Many authors have considered the effect of a cloudy medium on the evolution of supernova remnants, and we will not repeat their arguments. Instead we offer a progress report on a project to reproduce all the general radio and X-ray features of remnants such as Tycho with a simple hydrodynamic model that demonstrates the need for a cloudy circumstellar medium.

Dickel, Eilek, and Jones (1987) have shown that many small cloudlets are required in circumstellar space to reproduce the general morphology of the radio maps of Tycho's remnant. We ask what the X-ray emission will be from the models that satisfy the radio maps. By computing the nonequilibrium ionization balance in every cell of a hydrocode on every timestep, we can compute X-ray snapshots of the models both in spectrum and surface brightness. We use improved versions of programs from the atomic physics and X-ray spectrum code system of Raymond and Smith (1977). A joint fitting process is required, since elemental abundances in different parts of the remnant will lead to different X-ray emissivities per gram in different parts of the remnant, so that a change in abundances to fit the spectrum changes the map. This joint procedure has not yet been carried out, but it is straightforward.

The hydrodynamic calculation discussed here is the same as discussed by Dickel, Eilek, and Jones (this Colloquium), a presupernova stellar model exploded into a cloudy interstellar medium. For details of the models, please

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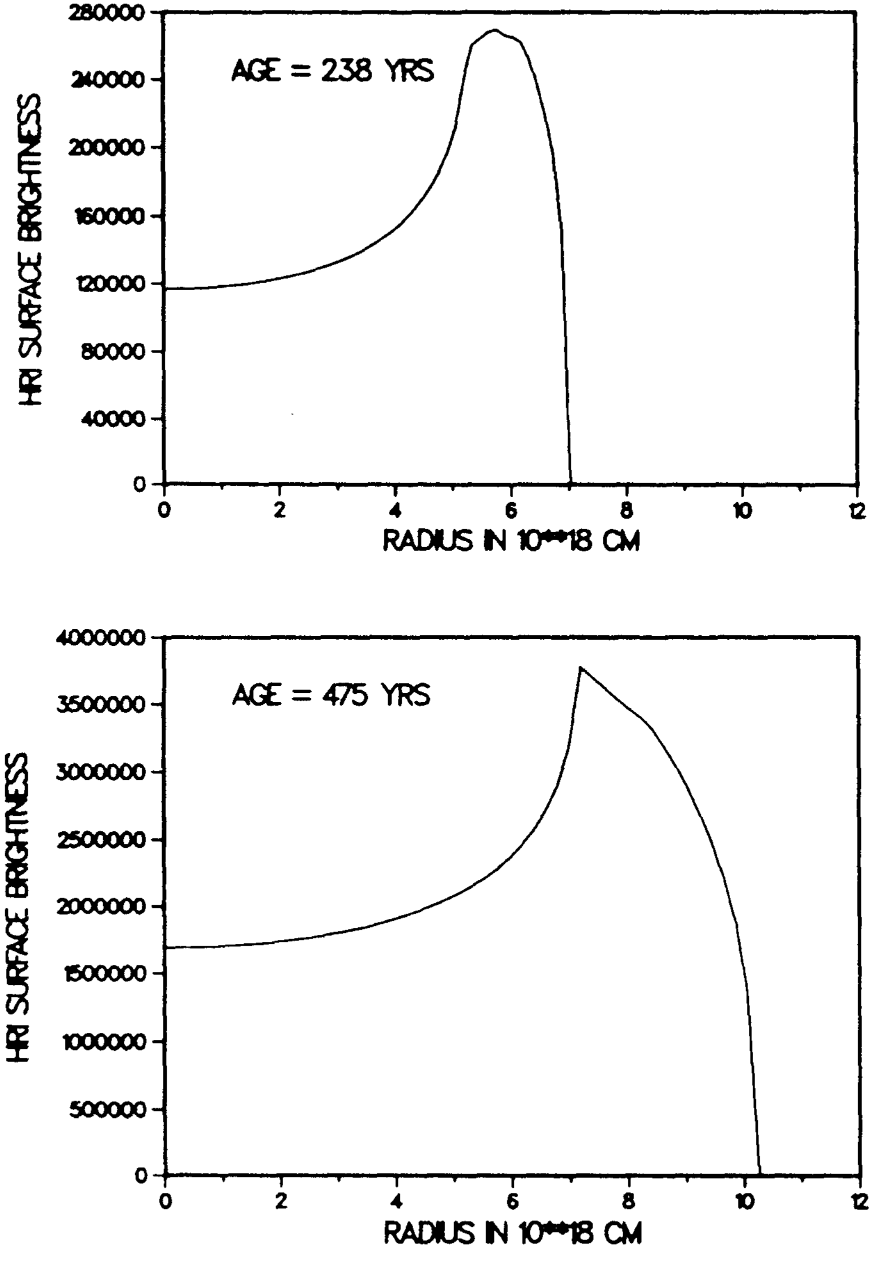

Figure 1: X-ray surface brightness profiles computed from a hydrodynamic computation of the evolution of a supernova remnant in a cloudy medium. The units of surface brightness are arbitrary. The time since explosion is shown in each panel.

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see their paper, but note here that there is no thermal conduction in these models (cf. McKee and Ostriker 1977), since it does not necessarily affect the dynamics of remnants. In the Figure we present the X-ray surface brightness of this model at two times, computed by folding the X-ray emissivity in each cell of the hydrocode (i. e. in each spherical shell) through the response of the High Resolution Imager on the Einstein Observatory. The shell structure in these profiles is the region between the forward and reverse shocks, while the falloff toward the center has a shape dictated by the limb brightened shell. These profiles can be compared to the HRI map of Tycho (Seward, Gorenstein, and Tucker 1983) for radial profiles. The X-ray emission in the map is distinctly broadened in radius near the edge, a characteristic of cloudy models. Our spherically symmetric model cannot reproduce the tangential clumping without further tricks to represent the average behavior of clumps, but we have modeled the overall features by including fine radial zones.

Several simple statements can be made about these models. They should have no trouble satisfying the best X-ray spectral data on Tycho, which is probably the data from the Solid State Spectrometer on the Einstein Observatory (Becker et al. 1980) and from HEAO-1 (Pravdo and Smith 1979; Pravdo et al. 1980). Recently Hamilton, Sarazin, and Szymkowiak (1986) gave a detailed discussion of fits to the spectral data, and we see no difficulty in principle to matching their goodness of fit. However, in spite of the great effort made by those authors to fit the spectrum of Tycho, they comment that their model does not predict the observed expansion parameter of the remnant. One way to ameliorate this serious problem is to replace models with homogeneous circumstellar media with cloudy models.

In summary, we have used a simple hydrodynamic model to show that it can satisfy all the following observed features of Tycho: The observed expansion rate at the current epoch, the general radio and X-ray morphology, and the detailed X-ray spectrum.

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