THEORETICAL THERMAL X-RAY MAPS OF SUPERNOVA REMNANTS IN NON-UNIFORM MEDIA

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Abstract.

The evolution of a supernova remnant resulting from an explosion near the edge of a molecular cloud is calculated with a 2-D hydrodynamical code (axial symmetry assumed). Cooling effects have been included. 1 kev X-ray maps of the remnant at different evolutionary times and different viewing angles are presented.

1. INTRODUCTION

A number of possible physical effects could cause supernova remnants to be non-spherical, including (1) an asymmetric stellar explosion due to rotational effects (Bodenheimer and Woosley 1982, see also Bisnovatyi-Kogan 1983), (2) small scale inhomogeneities in the interstellar medium (Chevalier and Theys 1975), (3) the interaction of two remnants (Ikeuchi 1978, Cox and Smith 1974, Jones et al. 1979, Bodenheimer et al. 1982), (4) an explosion inside of and near the edge of a molecular cloud (Tenorio-Tagle et al. 1982), (5) the interaction of a supernova remnant with an exterior cloud (Sgro 1975, McKee and Cowie 1975, Bychko and Pickel'ner 1975), and (6) the effect of a density gradient perpendicular to and out of the galactic plane (Chevalier and Gardner 1974, Sanders 1976, Möllenhoff 1976, Bodenheimer et al. 1983, Tenorio-Tagle et al. 1983).

In the following we shall consider mechanism (4) using a 2-D hydrodynamical code (see Bodenheimer et al. 1982,1983 and references therewithin). We assume that a 10^{51} erg explosion occurs 1 pc inside a cloud of molecular hydrogen of density $n = 10^3$ cm^{-3} and temperature T = 10 K. The partially ionized intercloud medium was assumed to have a density of $n = 1$ cm^{-3} and to be in pressure equilibrium with the cloud material. Rotation and self-gravity were not included, and cooling within the remnant was calculated according to Cox and Daltabuit (1971).

From the resulting density and temperature structure of the remnant we were able to solve the equation for radiation transfer in the optically

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thin case for various evolutionary times and different "viewing" angles. We present some of the results of these calculations in a series of diagrams over the next few pages. A more complete description including other cases considered is forthcoming (Tenorio-Tagle et al. 1982). Similar X-ray maps resulting from mechanism(3) are also in preparation (Bodenheimer et al. 1982).

2. RESULTS

The numerical results are shown in Fig. 1 to 5 for selected evolutionary times. In Fig. 1a (1b) we show the density (temperature) contour lines in a meridional cut 1.58 million years after the supernova explosion. The corresponding 1 kev X-ray map for an "observer" located in a direction 90 degrees from the symmetry axis (edge-on view) is shown in Fig. 1c. A similar set of contour diagrams are shown in Fig. 2abc for the supernova remnant 3.97 million years after the explosion (note the change in distance scale). In Fig. 3 (6.95 million years) the temperature structure is not shown. Instead, we display the 1 kev contour maps for three viewing angles: 90^o (3b), 60^o (3c) and 30^o (3d). At this time the total 1 kev X-ray flux had decreased to 10^{14} erg s^{-1} Hz^{-1}. In Fig. 4 (11.3 million years) and Fig. 5 (33.9 million years) the density, velocity and temperature structure is shown for still later evolutionary times. Note that even at these late stages the part of the remnant moving into the molecular cloud evolves as a spherical explosion would.

Fig. 1a Density contours and velocity structure of remnant 1.58 million years after a supernova explosion inside a molecular cloud (bottom part of diagram). The explosion site is indicated with a cross. The maximum (minimum) contour level is indicated by an M (m) corresponding to the density given in the lower left-hand corner. The arrows give the direction and magnitude of the velocity at the arrows' tips. The magnitude for the standard length arrow is given in the lower right-hand corner.

Fig. 1b Same as Fig. 1a for the temperature contours. The maximum (minimum) contour level is indicated by a T (t) corresponding to the temperature given in the lower left-hand corner.

Fig. 1c X-ray (1 kev) contour map for the supernova remnant displayed in Fig. 1ab at a viewing angle of 90°. The total 1 kev flux of the source is given in the lower right-hand corner. The contour levels are spaced logrithmically in intervals of one order of magnitude.

Fig. 2 Same as Fig. 1 for an evolutionary age of 3.97 million years.

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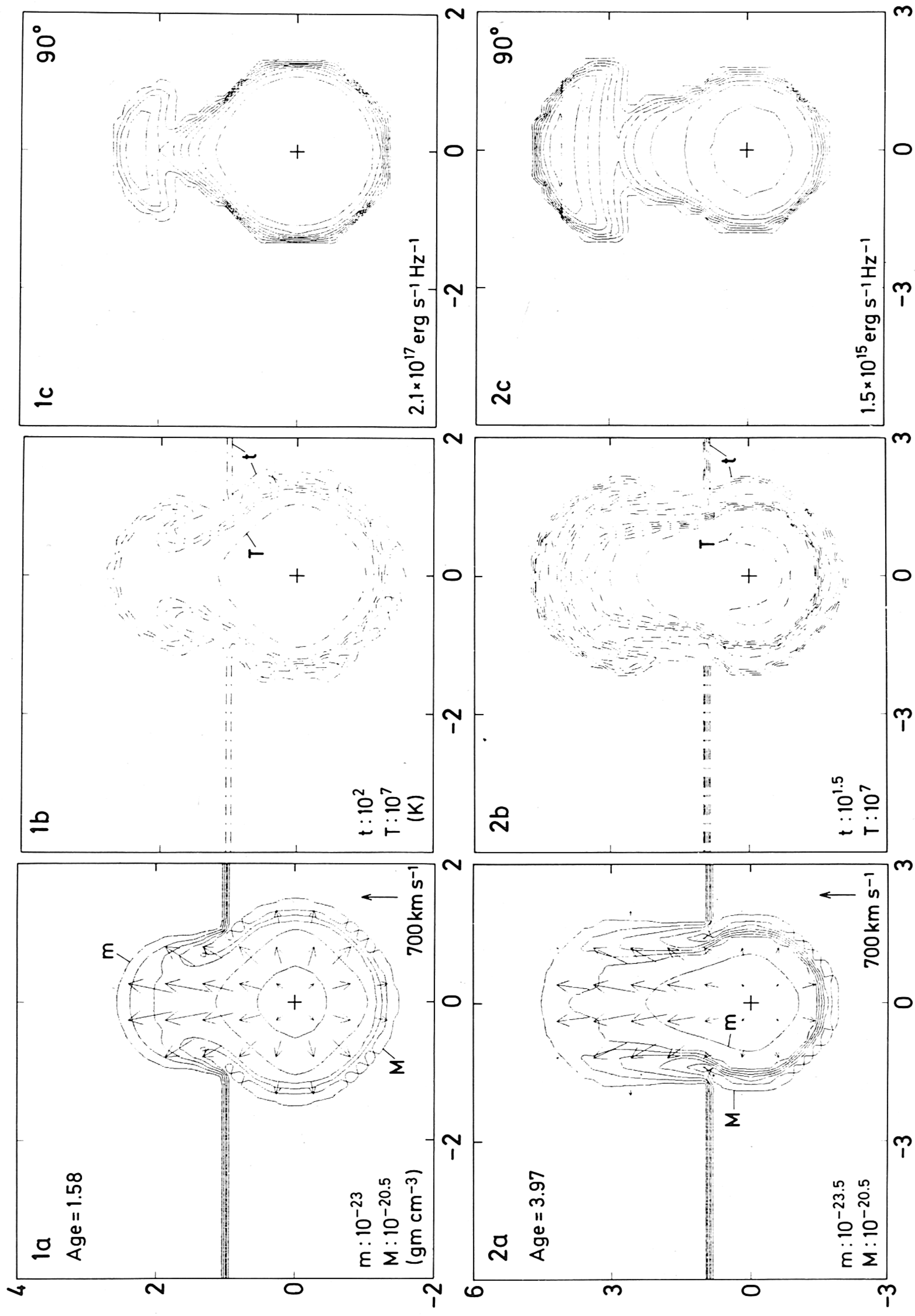
1a
Age = 1.58
m : 10−23
M : 10−20.5
(gm cm−3)
700 km s−1
1b
t : 10²
T : 10⁷
(K)
1c
90°
2.1 × 10¹⁷ erg s−1 Hz−1
2a
Age = 3.97
m : 10−23.5
M : 10−20.5
700 km s−1
2b
t : 10¹·⁵
T : 10⁷
2c
90°
1.5 × 10¹⁵ erg s−1 Hz−1

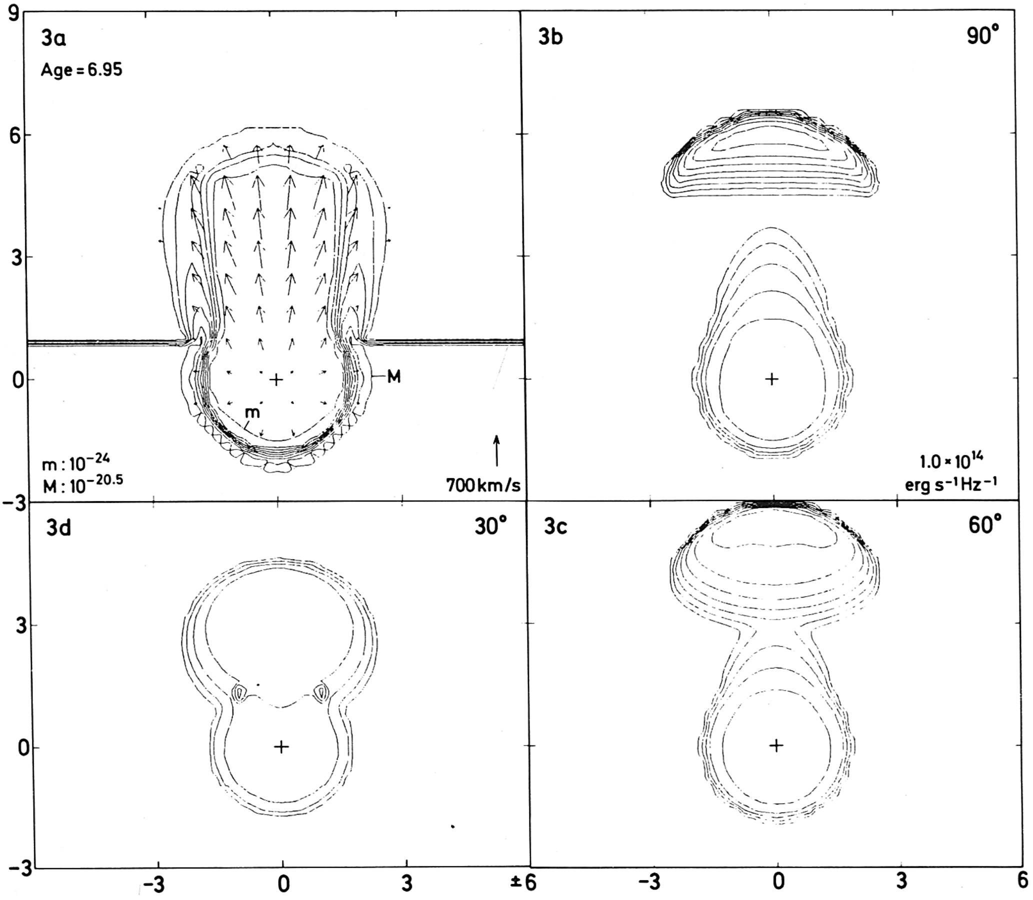

Figure
3a) Same as Fig. 1a for an evolutionary age 6.95 million years.
3b) Same as Fig. 1c for the remnant shown in Fig. 3a (viewing angle: 90°)
3c) Same as Fig. 1c for the remnant shown in Fig. 3a (viewing angle: 60°)
3d) Same as Fig. 1c for the remnant shown in Fig. 3a (viewing angle: 30°)

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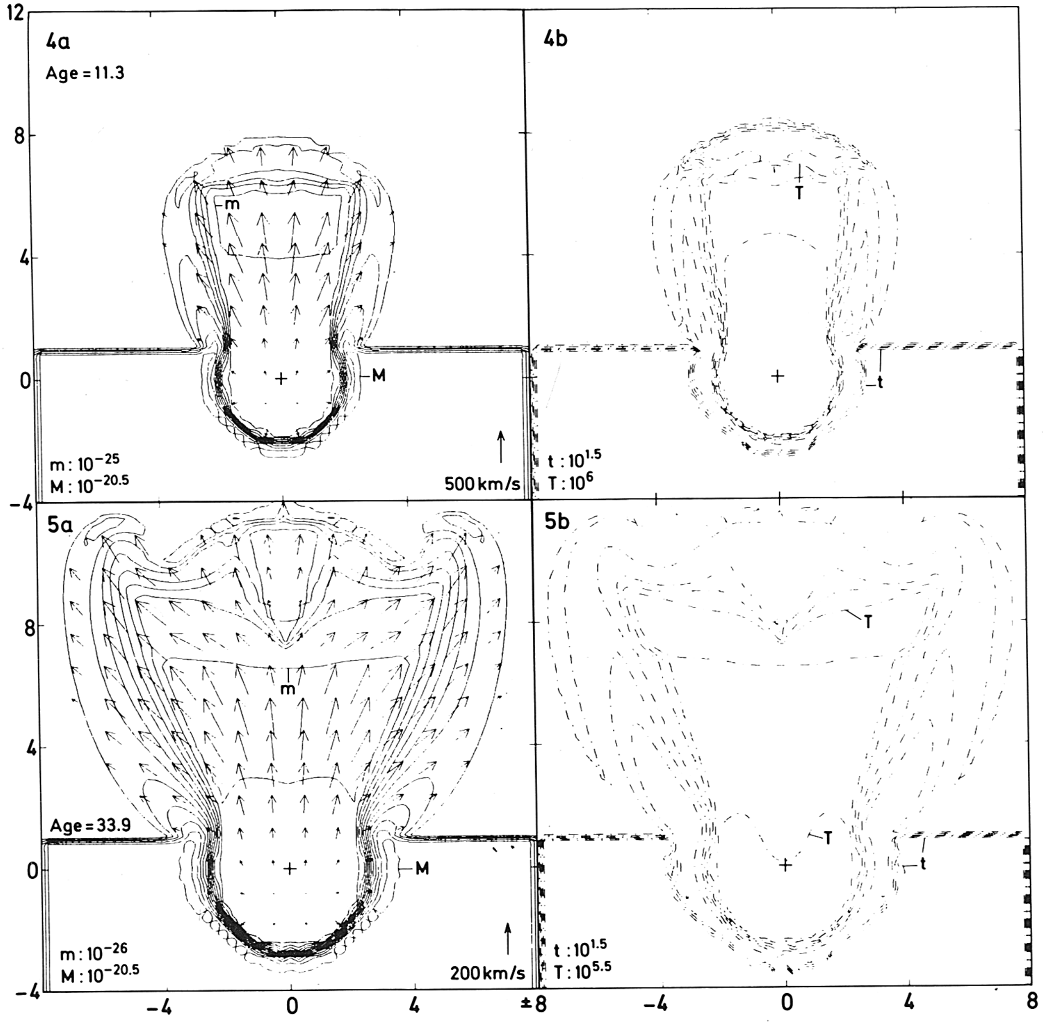

Fig. 4 *Same as Fig. 1ab for an evolutionary age: 11.3 million years*
Fig. 5 *Same as Fig. 1ab for an evolutionary age: 33.9 million years*

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