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THE SPECTRUM AND EVOLUTION OF COMPACT SNR: SN AND AGN

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RESUMEN

Se presentan la evolución dinámica y el espectro emitido por una remanente de supernova compacta que evoluciona en un medio circumestelar con una densidad de 10^7 cm^{-3}. La radiacion emitida por la región chocada es capaz de autoionizar al gas que se enfría, asi como a una zona grande alrededor de la explosión. Los cocientes de las líneas emitidas en las regiones fotoionizadas son similares a las observadas en núcleos de galaxias activas.

ABSTRACT

The evolution and spectra from a compact supernova remnant evolving in a high-density circumstellar medium with a density of 10^7 cm^{-3} are presented. The radiation emitted by the shocked region can self-ionize the cooling shell and a large region of the surrounding medium. The resulting line ratios from the photoionized zones are similar to those observed in active galactic nuclei.

Key words: **GALAXIES: ACTIVE — ISM: SUPERNOVA REMNANTS — SUPERNOVAE**

1. INTRODUCTION

The idea that strongly radiative supernova remnants (SNR) can be the source of the broad emission lines in active galactic nuclei (AGN) has been discussed in the literature over several years (see recent review by Terlevich *et al.* 1993). One of the most interesting features of this model is that a SNR evolving in a high-density environment becomes radiative in short time scales, when the shock front moves at large speeds, and can emit energetic radiation and achieve high luminosities. In particular, recent models of SNR in densities with 10^7 cm^{-3} (Terlevich *et al.* 1992) indicate that most of the SN energy is emitted in less than 10 yr, and can reach total luminosities in excess of 10^{43} erg per event. Moreover, a semi-analytical treatment of the emitted spectra indicates that the cooling shocks can generate large photoionized regions whose line ratios mimic those observed in the broad line regions of AGN. This connection between SNR and AGN has been strengthened by observations of a new class of supernovae which show an optical spectrum with very broad lines, resembling those detected in Seyfert galaxies (Filippenko 1989; Stathakis & Sadler 1991).

Here we continue this study and present the evolution of a SNR in an ambient density of 10^7 cm^{-3} using a hydrodynamical model that calculates, in addition to the usual dynamical variables, the energy loss term due to optically thin radiative cooling of the plasma.

2. NUMERICAL SIMULATIONS

The hydrodynamical equations were explicitly time differenced in one dimensional Lagrangian form assuming spherical symmetry, while the time dependent radiative cooling rate for each parcel was computed with a table interpolation scheme based on the Raymond & Smith (1977) ionization code, assuming collisional equilibrium was valid at all times. This last assumption is not likely to hold once temperatures fall below 10^7K and strong cooling begins, as the cooling time at these densities is typically much shorter than the sound crossing time in the gas; thus, the gas cools faster than collisions can maintain an equilibrium ion population, resulting in an over-ionized plasma at a given electron temperature. We are presently exploring the more realistic non-equilibrium cooling suggested by the conditions of this model, but the vast amounts of computer time required to follow out-of-equilibrium ion concentrations warrants extending the study of equilibrium models as far as possible.

With these inherently short cooling times, it was necessary to limit the time step to a value characteristic of the shortest cooling time encountered on a given pass through the computational grid. Effectively, during one time step no parcel could radiate more than 5% of its internal energy. Initially, 2000 grid points with separation $\Delta r = 3 \times 10^{13}$ cm were used to construct the initial conditions, homologously scaled from the supernova ejecta model results of Woosley *et al.* (1988). Here the ejecta were described by the following density and velocity power laws: $\rho(t=0,r) = (1.6 \times 10^{32})r^{-3}$ g cm^{-3} and $v(t=0,r) = (4.5 \times 10^{-8})r$ cm s^{-1}, where r ranged from 3×10^{15} cm to 3×10^{16} cm from the explosion site, meshing smoothly into the ambient medium at the outer radius (see Tenorio-Tagle *et al.* 1990 and Franco *et al.* 1993). This configuration represents approximately 1.86 $M_\odot$ of ejecta with a total kinetic energy of 0.76×10^{51} erg. For convenience, we begin the time count at this point in the evolution of the remnant.

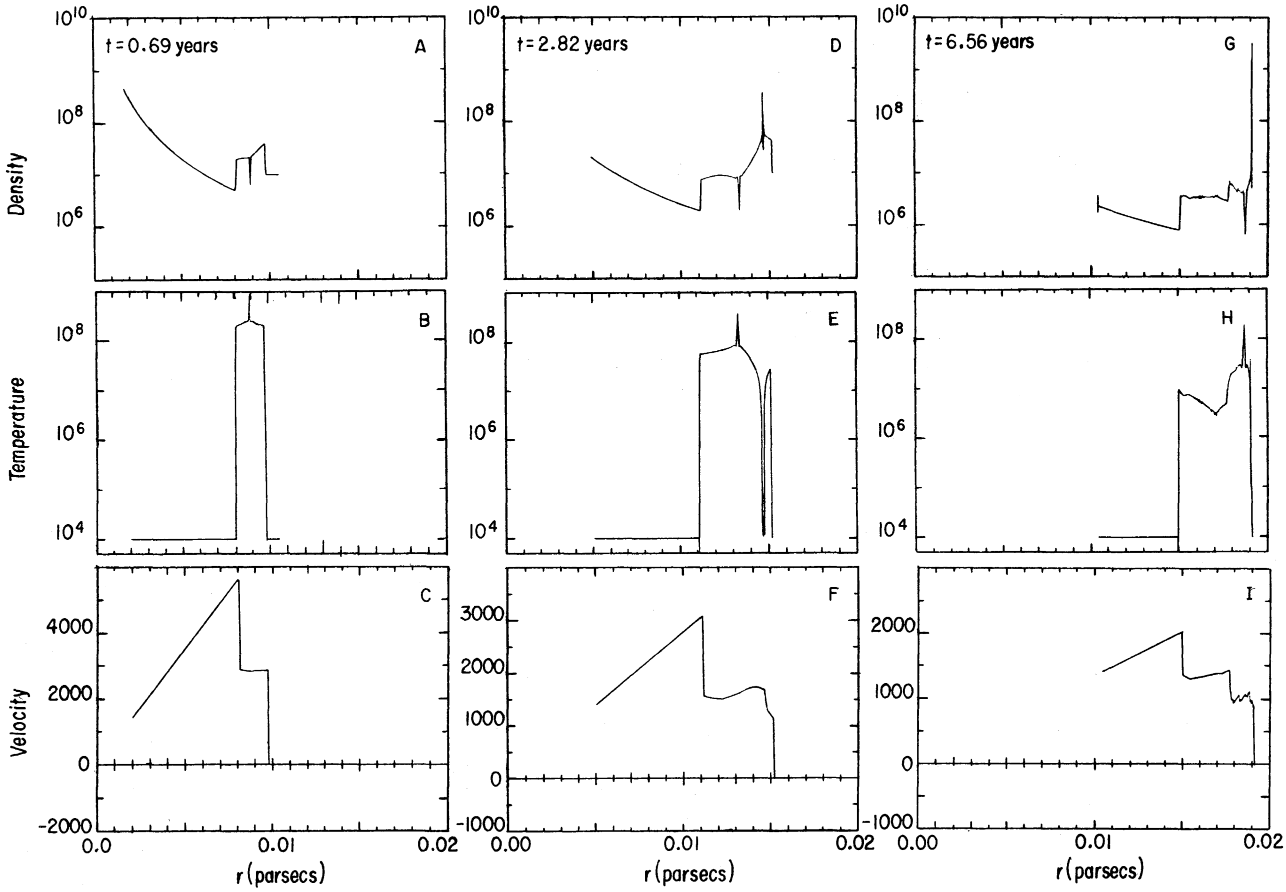

Fig. 1– Structure of a compact remnant at t=0.69 yr (a-c), t=2.82 yr (d-f), and t=6.56 yr (g-i). Shown are the log of the density (cm^{-3}), temperature (K), and velocity (km s^{-1}) as a function of distance from the explosion center (pc).

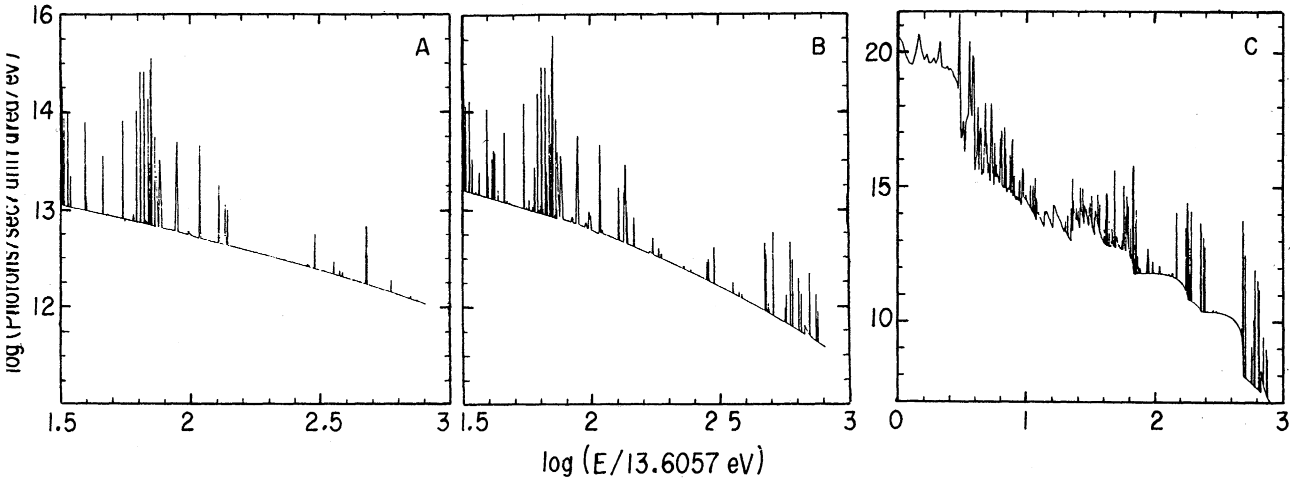

Fig. 2– Spectra of the compact remnant for a) t=0.69 yr, b) t=2.82 yr, and c) t=6.56 yr.

3. RESULTS

Figures 1a-1c show the dynamical variables at $t = 0.69$ years, clearly displaying both the forward and reverse shocks separated by a thin contact discontinuity. Strong cooling has not yet begun, and temperatures remain high ($T > 10^8$K) in the shocked material. To reduce the computation time, evolution of the unshocked ambient medium was followed only very near the forward shock, and since the dynamical effect of the unshocked ejecta is dominated by the high expansion velocities, thermal pressures are negligible in this region so for convenience the temperature was artificially set to 10^4K there throughout the calculation.

The next evolutionary time displayed ($t = 2.82$ years) in Figures 1d-1f is immediately after strong cooling has occurred behind the forward shock front, forming a thin, dense shell of gas. At $t = 3.11$ years (not shown), numerous secondary shocks are seen in the cooled region where the swept up mass is rapidly condensing. Eventually, a second thin shell forms behind the reverse shock, the beginnings of this feature already apparent at $t = 6.56$ years in Figures 1g-1i.

Once the model is run, UV/X-ray spectra can be generated from the temperature and density data for any time period using equilibrium ion concentrations. The spectra for the times shown in Figure 1 appear in Figure 2. These spectra are integrated over the entire grid, and are binned in 10 eV bins running from 10 eV to

TABLE 1

Computed line ratios for the BLR at $t \sim t_{sg}$

Line	Paper I	Present paper
Ly_α	1.11	0.47
H_β	1.0	1.0
H_α	2.95	3.31
$P\alpha$	0.20	0.24
Balmer C	34.6	49.15
HeI 5876	0.13	0.07
HeII 4686	0.01	–
HeII 1640	0.10	0.01
CII 1335	0.03	0.04
CII] 2326	0.07	0.08
MgII 2798	1.89	3.94
Total Fe cooling	12.1	14.0
$\log L$ H_β(erg)	41.18	41.08

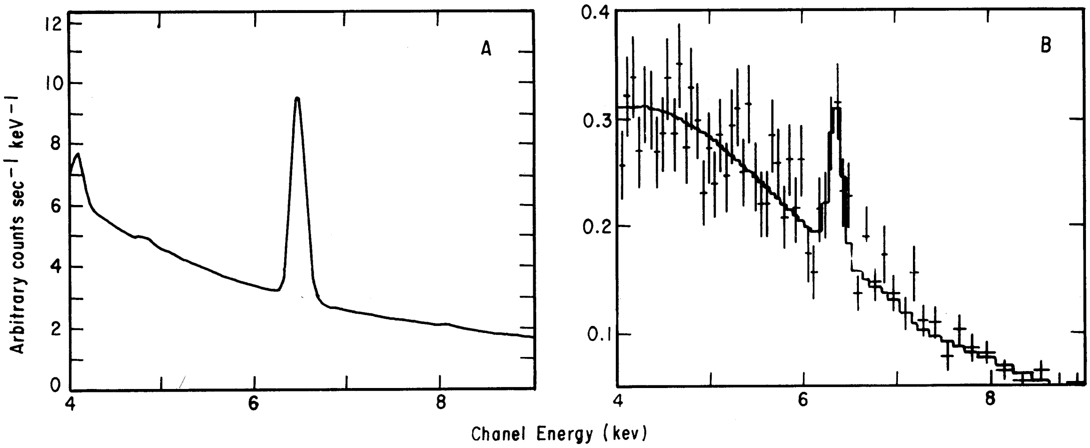

Fig. 3- The Fe K_α line. a) Emission from a compact remnant at t=2.82 yr. b) Observed spectrum in NGC 4152 (Weaver *et al.*1992).

10 keV. These data are then input to a photoionization code (Ferland 1990) and the ionization of the ambient gas, and external thin shell, is computed. The resulting emission from some selected lines, normalized to the total emission in H_β, are given in Table 1. The Table also shows the values for the line ratios obtained for the outer shell in Paper I with a simplified semi-analitical version of the spectra from the cooling shock. These ratios compare well, indicating that the semi-analitic approximation to the spectra in equilibrium is adequate, and are similar to the observed values of the sample of AGN compiled by Kwan & Krolik (1981). Finally, Figure 3 displays the 6.4 keV Fe K_α line observed in the Seyfert 1 NGC 4152 with the Broad Band X-Ray Telescope by Weaver *et al.* (1992), and the model emission of the same line at t=2.8 yr.

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