X-RAY LINE EMISSION FROM SUPERNOVA REMNANTS AND MODELS FOR NONEQUILIBRIUM IONIZATION

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ABSTRACT

An extensive grid of nonequilibrium ionization models for the X-ray spectra of adiabatic supernova remnants (SNRs) is described. The models are compared to the SSS spectra of remnants in the LMC, the Tycho SNR, and SNR 1006. In Tycho, we show that the observed spectrum requires significantly enhanced abundances of Si and S, and that this conclusion is independent of the detailed ionization and thermal structure in the remnant. We find that the SSS spectrum of SNR 1006 can be fit reasonably by a thermal emission model with abundances of about one half solar. In this model, the weak line emission results from the very low ionization state in the remnant, and not because the X-ray emission is non-thermal. We argue that the failure to detect strong Fe line emission in young Type I SNRs poses a severe problem for models of Type I SN, which predict that most of the ejecta be iron. Finally, the results of UV observations of a star behind SNR 1006 are mentioned; these observations show that the remnant contains a large amount of rapidly moving, <u>cold</u> iron.

NONEQUILIBRIUM IONIZATION MODELS

An extensive grid of nonequilibrium ionization models for the X-ray spectra of adiabatic supernova remnants (SNRs) has been calculated. The calculations assume a Sedov solution for the hydrodynamics of the blast wave, and integrate the ionization equations for the plasma behind the shock. A considerable effort was made to ensure that all processes which can affect the ionization and emission of a highly underionized or equilibrium plasma were included and accurately represented. The details of the atomic physics are given in Hamilton, Sarazin, and Chevalier 1982 (hereafter Paper I).

The Sedov solution is completely characterized by three parameters, which may be taken to be the age of the remnant t, its conserved energy E, and the ambient interstellar hydrogen density n_0. However, the <u>shape</u>

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of the X-ray spectrum of a remnant is determined by just two parameters, the shock temperature T_S, and the collisional timescale parameter $\eta \equiv n_0^2 E$ (see Paper I). This second parameter characterizes the rate at which the plasma relaxes to ionization equilibrium.

While previous calculations have been limited to isolated values of η, our calculations give a complete grid of models for the range $49 \leqslant \log \eta \leqslant 53$ and $6.25 \leqslant T_S \leqslant 8.25$ (cgs units), covering much of the astrophysically interesting domain of values for these parameters.

Because the heating rate of electrons due to plasma instabilities in the shock is uncertain, two grids of models have been calculated, in which the electrons are either assumed to be in equipartition with ions everywhere, or to be heated by Coulomb collisions with ions behind the shock.

The resulting grid of model spectra is given in Paper I. In addition to graphs of the spectra, we give contour plots for many important plasma diagnostics as a function of the two model parameters, T_S and η. For those requiring more information, the detailed model spectra are available on fiche or on a computer tape from the authors.

These model spectra may be extended to other physical models using the scaling relations given in Hamilton and Sarazin (in this volume, and 1982).

COMPARISON TO OBSERVED SPECTRA

The model spectra have been used to fit the SSS spectra of the three LMC remnants N132D, N63A, and N49 (Clark et al. 1982). These remnants are old enough that nonequilibrium effects are not terribly important. The remnants can be fit with abundances that are about 1/2 of solar. The required supernovae energies are $E_{SN} \sim 2 \times 10^{51}$ ergs, and these high energies may explain the unusually high surface brightness of these remnants.

The Tycho SSS spectrum shows extremely strong X-ray line emission (Becker et al. 1980a). The fit to this remnant requires very high abundances of Si and S, as compared to solar. Several temperature components are necessary, suggesting that the ejecta in this remnant are clumpy. We have shown that the conclusion about the high abundances of Si and S is independent of the detailed ionization or thermal structure in these models; no solar abundance plasma can produce lines as strong as those seen in Tycho.

The SSS spectrum of SNR 1006 is relatively featureless (Becker et al. 1980b), and it has been suggested that the X-ray emission is nonthermal (Reynolds and Chevalier 1981). We find that the SSS spectrum can be fit by a thermal model in which the weak line emission results from a very low nonequilibrium ionization state.

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In either SNR 1006 or Tycho, the mass of iron which has been heated to X-ray emitting temperatures is limited to $\leqslant 0.05\ M_\odot$.

PROBLEMS WITH TYPE I SNRs

These results suggested at least two problems with the structure of remnants of Type I SN. First, the measurements of the proper motion of the remnants suggest that they are adiabatic (e.g., the paper by Strom in this volume). However, the high abundances deduced from the X-ray spectra suggest that the ejecta are dynamically important.

Second, observations and theories for Type I SN suggest that they eject $\sim M_\odot$ of iron (e.g., the paper by Kirshner in this volume). However, very little hot iron is observed in the X-ray spectra. One possiblity is that the bulk of the iron in the historical Type I SNRs is cold. Evidence supporting this suggestion comes from a recent UV spectrum of a star behind SNR 1006 (Wu et al. 1982), which shows that this remnant contains a large mass of rapidly expanding, cold iron.

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