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"Observational Study of Ion-Electron Equilibration and of Cloud Evaporation in Supernova Remnants Under the HEAO-2 Guest Investigator Program"

for the period June 1, 1985 to September 30, 1986

by

Richard G. Teske

Department of Astronomy

The University of Michigan

Ann Arbor, Michigan 48109

(NASA-CR-179922) OBSERVATIONAL STUDY OF ION-ELECTRON EQUILIBRATION AND OF CLOUD EVAPORATION IN SUPERNOVA REMNANTS UNDER THE HEAO-2 GUEST INVESTIGATOR PROGRAM Final Project Report, 1 Jun. 1985 - 30 Sep. 1986 N87-13365

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I. Summary of Accomplishments

This project had two goals. The first was to make observations of three selected supernovae remnants (Cygnus Loop, IC 443 , and Puppis A) in the forbidden coronal iron lines [Fe X] $\lambda6374$ and [Fe XIV] $\lambda5303$, compare the resulting data quantitatively with *Einstein* images of the same objects, and attempt to determine (a) the process by which ion and electron energies are equilibrated behind the shock front in the ISM and (b) whether cloud evaporation occurs within the hot remnant interiors. The second goal was to make preparations to model spatially-resolved X-ray emission for Sedov-Taylor blast wave models of SNR under conditions of non-equlibrium ionization. The computations will be intended to provide results that can be directly compared with *Einstein* HRI and IPC data.

Observations of all three target SNR were obtained (Table 1), but those on the Cygnus Loop are poor and must be repeated. Reduction, analysis, and publication of the Puppis A data is complete. Reduction and analysis of the IC 443 and Cygnus Loop data was incomplete at the end of the report period.

The computer program for predicting the spatial distribution of HRI and IPC counting rates was complete at the end of the report period, and final testing of it had begun.

II. Observations

A log of observing trips and their outcome is given as Table 1.

a. Puppis A

A specially-designed image reducing camera was constructed for obtaining the Puppis A images at Cerro Tololo Inter-American Observatory in January 1985. The data were of excellent quality and show for the first time the structure of the coronal gas in an SNR on a scale approaching 2.6" arc. A preliminary report was presented at the Charlottesville AAS meeting (Teske 1985). The coronal iron line observations were compared with the *Einstein* HRI mosaic of Puppis A prepared by Petre *et al.* (1982); two separate investigations have resulted. In the first, Teske and Petre (1986a) addressed the question of whether the "eastern X-ray knot" is an example of a cool cloud evaporating into the hot SNR interior. We concluded that the knot is a "complicated combination of the effects of shock heating plus evaporation. The initial encounter of the ICM shock front with a denser region of the interstellar medium (a 'cloud') has led to shock heating and the production of strong forbidden iron and X-ray emission. Subsequently, evaporation of the cloud increased the emission measure in the cloud vicinity, causing an augmentation of the iron and X-ray brightness there."

In the second investigation, Teske and Petre (1986b) examined the spatial surface brightness profiles of the red and green iron lines and of the HRI count rates, across the Puppis A shock front. Both the optical and X-ray data are consistent in showing a nearly flat gradient of ionization behing the shock. We were unable to match the observed forbidden line surface brightness distributions with a single Sedov-Taylor model, and have ascribed the failure - together with the flat ionization gradient which is not predicted by the similarity solution - to the inhomogeneous structure of the gas behind the shock front at the location observed. We believe that this result has "important implications for the determination of SNR shock front models by means of fitting X-ray data with Sedov-Taylor models."

b. IC 443

In 1983 and 1984 I secured a few CCD frames of IC 443 observed through the red filter. These were of poor quality because of an uncertainly-identified noise source (probably in a read-write buffer of the MIT MASCOT instrument [Meyer and Ricker 1980]). A Michigan undergraduate has examined the data under my supervision and reduced what was reliable; we have published the result (Gensheimer and Teske 1986).

In January and February 1986 I secured good frames of this SNR in each Fe line, with the image reducer. By the end of the report period the data were being reduced.

c. Cygnus Loop

Data-taking on the Cygnus Loop have been plagued by problems - principally by bad weather. This object is observable all night only during the period of worst weather at the McGraw-Hill Observatory. In August of 1985 clouds, rain, and equipment failure interfered; in August of 1986 clouds were present for all of the 7 nights assigned to me. Four poor quality frames were obtained with the MIT MASCOT in June 1985; I am still working on them and intend eventually to publish. An extend observing run has been requested for June/July 1987 which I hope will complete the data-taking on this object.

d. Other SNR

In January and February 1986 I obtained three frames on Tycho's remnant in the [Fe XIV] green line. There is no clear signal down to 20% of the night sky level. Two green line frames of the Monoceros Loop were made at locations selected after discussion with Dr. D. Leahy (e.g. Leahy, Naranan, and Singh 1985) but again there is no obvious signal in the data. I have started to develop two computer routines which are intended to "dig out" faint information from the frames. One depends on calculation of local median values of the non-stellar abackground for showing the presence of faint nebulosities; the other looks for faint surface brightness structures by means of an F-test (see, e.q. Petro *et al.* 1984; Bevington 1969). These have not yet been applied to real data.

In July 1986 I was assigned 5 nights on the CTIO 1.5 m reflector. During the only two clear half-nights I secured green line frames on fields containing SN 1006, RCW 103, SN185 = RCW 86, and Kepler's remnant. These are not yet analyzed.

III. Computation of X-ray Surface Brightness Distributions

Most of the work described in this section has been accomplished by graduate student Mr. Diab Jerius under my supervision.

My code for computing Sedov-Taylor blast wave models (Teske 1984) has been updated and installed in the astronomy department's VAX 11/750 computer. Two versions are available: one assumes that ion-electron equilibration takes place on a time-scale shorter than the ionization time of prevalent ionic species; the other assumes that ion and electron energies are equilibrated by Coulomb collisions. Both versions assume that the sole ionization process behind the shock is collisional ionization via electron impact, and that the sole inverse processes are radiative and dielectronic. Account is taken of photoionization ahead of the shock by assuming that all atomic species come through the shock with four electrons already lost.

Ionization and recombination rates are calculated for ten atomic species by routines very kindly sent to me by A. J. S. Hamilton; the species are C, N, O, Ne, Mg, Si, S, Ca, Fe, and Ni. To these we have added rates for Ar (Shull and van Steenberg 1982), Al (Mewe and Gronenschild 1981), and Na (Mewe and Gronenschild 1981).

Model SNR are divided into 99 shells (100 boundaries). The output of the blast wave programs is a file of positions, temperatures, densities, and ionic fractional abundances on each boundary. A separate, post-processing code prepared by Mr. Jerius uses the file as input data to compute the radial distribution of emergent X-radiation, as it would look projected against the sky, from the extreme edge almost to the center. The emergent spectrum for $3 \leq \lambda \leq 130$ Angstrom ($0.1 \leq E_{h\nu} \leq 4.1$ keV) is computed for 99 positions distributed along the projected remnant radius. Our ultimate aim is to convolve these 99 spectra with the IPC and HRI curves of effective area *vs* photon energy to obtain predicted surface brightnesses.

Computed emissivities include contributions from free-free, free-bound, and two-photon continua; to them we have added the emission from 358 spectrum lines. At each stage of code preparation we have been careful to check the results with hand calculations and, if possible, with results published by others. At the end of the report period we were still at it. The goal is to be at least 95% sure there are fewer than 1% errors.

Atomic data for computing the line emissivities has been taken from the references marked with an asterisk in Table 2. The list given in the Table is not exhaustive; while it contains the major references searched by us, not all references we actually looked at are contained in it.

We plan to compute X-ray surface brightness models for the HRI and IPC observations of Puppis A and the Cygnus Loop, and to publish these soon. We intend to present this work at the symposium on The Interaction of Supernova Remnants with the Interstellar Medium to be held in June, 1987, in Penticton.

TABLE 1

Observing Trips and their Outcome

Month	Observatory	Nights Assigned /Nights Usable	Program Object(s)
Jan '85	CTIO	5/5	Puppis A
June '85	McGraw-Hill	2/7	Cygnus Loop
Aug '85	McGraw-Hill	0/3	Cygnus Loop
Jan '86	McGraw-Hill	2 1/2 / 5	IC 443, Tycho
Feb '86	McGraw-Hill	1/7	IC 443, Monoceros B
July '86	CTIO	2/5	SN 1006, RCW 86, RCW 103,Kepler's
Aug '86	McGraw-Hill	0/7	Cygnus Loop

TABLE 2

References Searched for Atomic Data for X-ray Line Emissivities

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