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SPATIALLY RESOLVED SPECTROSCOPY OF THE SNR IC443

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IC 443 is a supernova remnant of intermediate age, i.e. a few thousand years. It is especially interesting because part of its periphery is expanding into a molecular cloud while other sections are expanding into a typical interstellar medium of much lower density. Since the evolution of a supernova remnant through its various phases is affected by the density of the medium it expands into with the reasonable assumption that the supernova explosion was approximately symmetric we have an opportunity to observe a single object in two phases simultaneously.

It was observed by ASCA in April, 1993 for a short period during the PV phase and more thoroughly in a 42 ksec exposure in March, 1994. The latter measurement provides most of the results that have been reported. Most of the analysis took place after the grant ended but is included here for completeness. The data was sent simultaneously to US and Japanese PIs. We worked independently. The software set of FTOOLs was used to construct images and spectra. They were judged to be rather unintuitive and not at all user friendly. I found I was using one FTOOL to read the header to obtain information that would only be provided to another FTOOL. The Japanese investigators were more successful. They analyzed the data and published results more rapidly. The scientific results summarized below are based primarily on their publications.

Since IC 443 is an interesting example of a middle aged SNR in which a variety of processes are occurring it is one of a class. Further results will be included within a more general context in a more comprehensive article on SNRS that will be published and written eventually in collaboration with others.

IC 443 exhibits shell-like emission in hard X-rays and extended soft X-rays with thin thermal spectra. It resembles SN 1006 in these respects. IC 443 contains hard X-rays in a semi-circular shell surrounding the thermal component. The total hard X-ray flux in the ASCA FOV is only a half of the Ginga hard component; which suggests that the hard X-rays are not confined only in the shell but some are extended larger than the ASCA FOV of eq 1 degree diameter. Japanese investigators examined the spatial structure of the thermal component and analyzed the GIS spectra with a non-equilibrium plasma model, and found no systematic variation of the interstellar absorption across the remnant. The above was reported by Ozaki et al. (IAU Symposium No 188, Kyoto, 1997).

Evidence for shock acceleration of cosmic rays to high energies (10 TeV) was found by Keohane et al, (Ap.J.. 484. 350. 1997). X-ray imaging spectroscopy with ASCA reveals two regions of particularly hard emission: an unresolved source embedded in an extended emission region, and a ridge of emission coincident with the southeastern rim. Both features are located on part of the radio shell where the shock wave is interacting with molecular gas, and together they account for a majority of the emission at 7 keV. Though we would not have noticed it a priori, the unresolved feature is coincident with one resolved by the ROSAT HRI. Because this feature overlaps a unique region of flat radio spectral index ($\alpha < 0.24$), has about equal light-crossing and synchrotron loss times, and a power-law spectrum with a spectral index of $\alpha = 1.3 \pm 0.2$. The conclusion of Keohane et al, is that the hard X-ray feature is synchrotron radiation from a site of enhanced particle acceleration. Evidence against a plerion includes a lack of observed periodicity (the pulsed fraction upper limit is 33%), the spectral similarity with the more extended hard region, the location of the source outside the 95% error circle of the nearby EGRET source, the fact that it is nestled in a bend in the molecular cloud ring with which IC 443 is interacting, and the requirement of an extremely high transverse velocity ($geq5000$ km s^{-1}). Furthermore, they say that the anomalous feature is most likely tracing enhanced particle acceleration by shocks that are formed as the supernova blast wave impacts the ring of molecular clouds.

The ASCA measurements were combined with higher energy data from the XTE and GRO missions in an analysis by Sturner et al. (Bull.Am.Astron.Soc., 191, #40.06, 1997). That comparison of spectroscopic data produced evidence for the shock acceleration of cosmic ray electrons to TeV energies in the supernova remnant IC 443. The ASCA data clearly indicate a nonthermal spectral component in the 2-10 keV energy band. Spatial analysis of these data shows that this emission is localized in two small regions of the remnant, one of which exhibits a very flat radio spectrum with index -0.24. In XTE, they show that this nonthermal component extends up to at least 15 keV. It has been proposed that IC 443 is related to the unidentified EGRET source 2EG J0618+2234. This led Sturner et al to analyze the archival EGRET data from this source as well as data from an observation of IC 443 made with the OSSE instrument on CGRO. They report that EGRET data can be well fit by a power law with a photon index near 2. The OSSE observations yielded only upper limits but require that the spectrum of the EGRET source flattens between 1 MeV and 100 MeV. Their study combines these data with published radio and TeV gamma-ray data to produce a nonthermal multiwavelength spectrum for IC 443 which was fit with a cosmic ray interaction model. This model calculates the synchrotron, bremsstrahlung, inverse Compton, and neutral pion decay emission produced by locally accelerated cosmic rays interacting with ambient matter, soft photon fields, and magnetic fields. They find that by approximating the remnant as having two distinct spatial components, one with a flat radio spectrum where the nonthermal x-rays are produced and the other with a softer radio spectrum and no nonthermal x-rays, the nonthermal multiwavelength spectrum of IC 443 can be fit.