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Final Report on EXITE/IPC Observations of SN1987A and Southern Targets NASA Grant NAGW-1721

Summary

The Energetic X-ray Imaging Telescope Experiment (EXITE) was developed to a flight-ready status and conducted two flights (May 18, 1988, and May 8-10, 1989) from Alice Springs, Australia, as part of the campaigns to observe the supernova SN1987A. The basic operation of the detector and gondola systems in the laboratory was tested on the first flight and found to meet expected performance values. A bizarre "balloon tape" insulation problem, however, prevented normal telescope pointing on the first flight so no data on SN1987A or other targets were obtained. Following a successful second EXITE flight from Ft. Sumner, NM, in October 1988, the experiment was flown again on a successful 30 hour flight as part of the final 1989 supernova campaign. A second x-ray imaging experiment from MSFC was also flown (piggy-back) for this third flight. Good data were obtained on the supernova and a variety of high priority galactic targets, and final analysis is still in progress. Preliminary results from this flight, which was partially supported by this grant, are presented here.

1 Introduction

The Energetic X-ray Imaging Telescope Experiment (EXITE) (Grindlay et al 1986, Garcia et al 1986) conducted its first flight on May 18, 1988, from Alice Springs, Australia, as part of a recent campaign to observe SN1987A. Because of a thermal-induced "balloon tape" failure, the telescope was unable to point on the supernova and only engineering data were obtained, although an important verification of basic instrument performance and background levels was carried out. After payload modifications and improvements, a second flight was conducted on October 8-9, 1988, from Ft. Sumner, NM, on a variety of northern hemisphere targets. This flight was a success, and showed that the the basic science objectives could be achieved on a second SN1987A flight. Because of the declining Compton scattered gamma ray continuum and the possible detection of the suspected pulsar, it was important that the March-May 1989 campaign include an instrument with good sensitivity and imaging resolution for continuum observations in the 30-200 keV band. EXITE provided this capability, and offered the highest angular resolution of any of the five investigations scheduled to fly during this final campaign to observe SN1987A.

During the final(April-May 1989) SN1987A campaign, the EXITE payload also included the high pressure Xe imaging proportional counter (IPC) hard x-ray detector developed by Ramsey and Weisskopf (1986) together with its own coded mask to provide complementary sensitivity and angular resolution at energies below 80 keV. The accomodation of this IPC detector with EXITE, and the supernova science as well as galactic center source observations, were the primary motivation for this grant activity.

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2 Scientific Objectives

The hard x-ray continuum emission of the supernova SN1987A is an important complementary measurement to that of the ^{56}Co line emission, since it arises in part due to the Compton downscattering of the line in the expanding shell of the remnant. As the remnant becomes increasingly optically thin to the 847 and 1238 keV photons from decay of ^{56}Co, the continuum should decrease. The relative slope, as well as flux, of the continuum at low energies (i.e. below 100 keV) can help to further determine the density profile of the expanding ejecta as well as the degree of mixing of synthesized ^{56}Co. If the line flux decays faster than the continuum flux, for example, mixing or density parameters are affected. Unfortunately the predicted Compton continuum flux for April 1989 (e.g. Kumagai et al 1989) was expected to be only $\sim 10^{-6}$photons/ cm^2-sec, or below the detection threshold of most instruments. The Compton continuun from ^{57}Co (below 122 keV) is also likely to be weak but the EXITE/IPC telescopes have peak sensitivity at these energies.

A second, and now more compelling, reason for conducting continuum measurements at hard x-ray energies is the search for the pulsar at energies where it may be detectable. The calculations of Kumagai et al (1989) indicated that the most likely band for the detection of the pulsar, either an isolated pulsar or an accreting pulsar, is ~30-50 keV. Thus the departure of the spectrum shape (from that expected from continued downscattering of the ^{56}Co continuum) is a likely indicator that the pulsar exists.

As pointed out by Covault, Braga and Grindlay (1988), EXITE is the only instrument now developed which has sufficient angular resolution to clearly and unambiguously isolate the supernova from the neighboring source LMC X-1 at energies above 30 keV. With a separation of only 0.6 degree, resolution of $\sim 0.3°$ is needed to cleanly isolate the two objects, which may have similar hard x-ray spectra (both in slope and amplitude) and similar soft x-ray (i.e. below 20 keV) spectra as well (cf. discussion by Covault, Braga and Grindlay 1988). The EXITE angular resolution is 20 arcmin, and source positions can therefore be centroided to a fraction of this value which is dependent on signal to noise An additional objective of the EXITE flight on SN1987A, then, was to measure the hard x-ray spectrum of the black hole candidate LMC X-1.

The major secondary objective of the flight was to observe the galactic center region for a higher angular resolution view of the puzzling hard x-ray source 1E1740-2942 that had been detected by Skinner et al (1987) as the dominant hard x-ray source in the galactic center region at 2-20 keV x-ray energies with the Spacelab experiment. This source had also been observed with the Caltech GRIP imaging detector, but at lower angular resolution. The third major objective of the EXITE flight was to observe the black hole candidate GX339-4 for the first time at hard x-ray energies. This source had been reported as a hard x-ray source by the HEAO-A4 experiment (Nolan et al 1982) but has not been confirmed (for its identification) by an imaging hard x-ray experiment.

3 Performance of EXITE on its May 1989 Alice Springs Flight

The third flight of EXITE, together with the MSFC IPC detector as mentioned above, was launched on May 8, 1989, from Alice Springs, Australia. The flight was very successful, with a total of more than 24 hours of float data obtained. The gondola pointing systems and absolute aspect systems were improved with the addition of a newly designed sunsensor and integrating CCD TV cameras for nighttime aspect. Sources were acquired within about 0.5° of the center of the field of view (post-flight measurements showed that the collimators on EXITE were misaligned with the optical axis of the telescope by 0.5°) and tracked with rms deviations of $\lesssim$ 5 arcmin. Good images were obtained on the Crab which allowed absolute calibrations of flux and spectral sensitivities to greater accuracy than had been possible with the Ft. Sumner flight. The image and spectrum of the Crab are shown in Figures 1 and 2 below.

This second EXITE flight from Alice Springs ("Alice II") was carried out with the MSFC hard x-ray IPC detector "piggy-backed" on the EXITE telescope and gondola. The two telescopes were co-aligned and viewed the same target. Power and telemetry, as well as commands, for the MSFC instrument were independent of EXITE, however, so integration was conceptually simple. The MSFC instrument, on its first flight, performed well also and yielded Crab images of comparable quality to those from EXITE shown below.

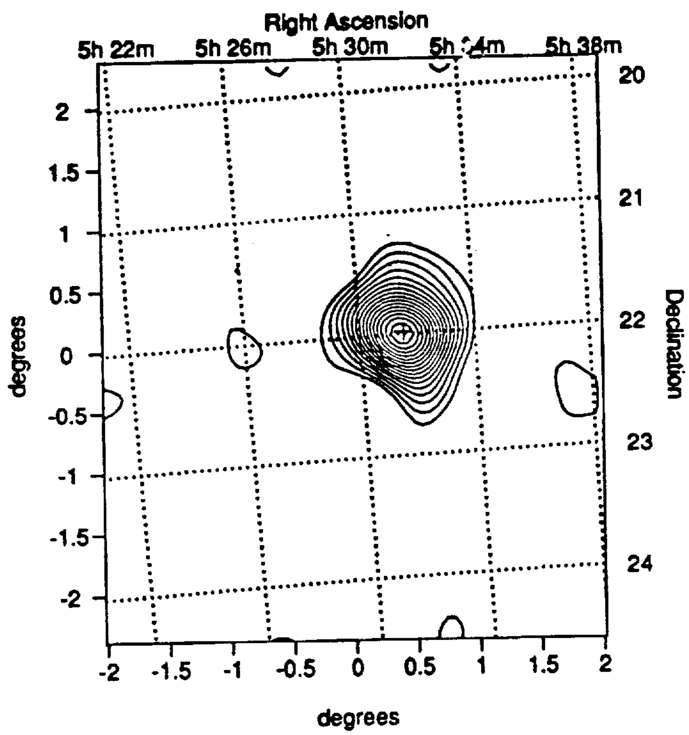

Figure 1: Crab image (20-100 keV) obtained with EXITE/Alice II flight.

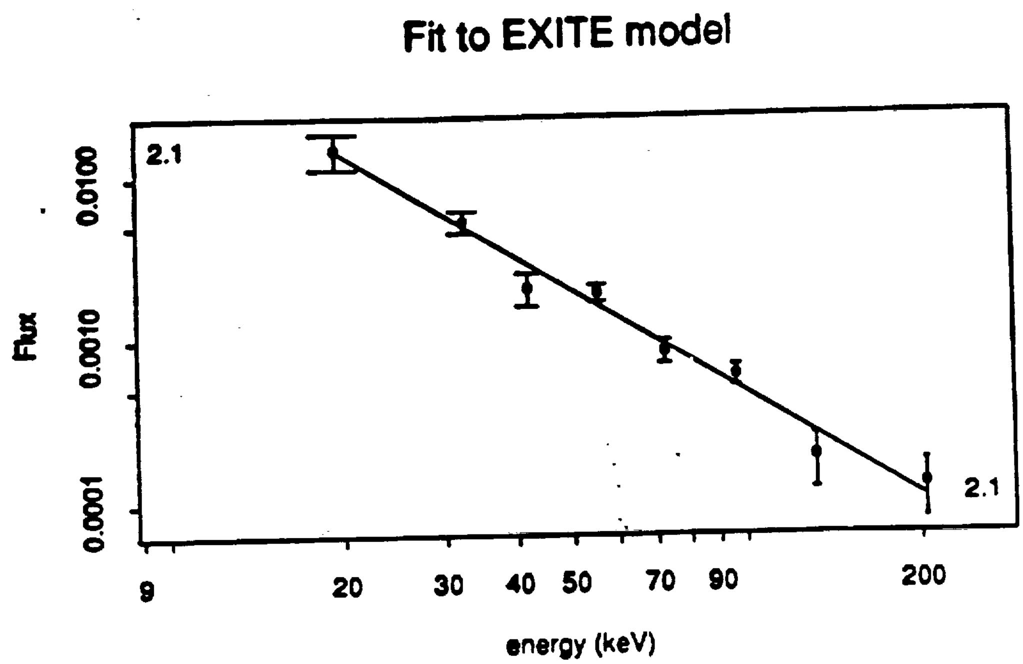

Figure 2: Crab spectrum obtained with EXITE/Alice II flight.

The Crab observations showed that the telescope achieved its desired sensitivity and performance levels. Results of the supernova and galactic source observations are summarized in the next section.

4 Results of the Alice II Flight: SN1987A and Galactic Sources

4.1 SN1987A

The supernova field was successfully observed for a total of about 4 hours on the first day of the flight (UT May 9) and then again for about 2.5 hours on the second day, under control from our downrange telemetry station in Longreach, Queensland.

We did not detect the supernova SN1987A in our data, though analysis is still continuing since final post-flight calibrations have not been yet included. The actual observed Crab spectrum (Fig. 2) has been used to update the sensitivity expected for EXITE for detection of the hard x-ray spectrum reported for SN1987A most recently by Sunyaev et al (1990). The expected sensitivity includes not only the actual observed backgound spectrum (from the Alice Springs flight) but also the explicit effect of the energy-dependent spatial resolution of the detector as actually measured for the flight configuration of the detector and electronics; neither of these could be included in the pre-flight estimates of sensitivity given by Covault et al (1988). Results of this calculation for sensitivity give our upper limit as F_x(30-110 keV) $\lesssim 3 \times 10^{-5}$ photons/cm^2-sec-keV. This limit is for a 4 sigma detection with a total of 2×10^4 seconds observation time on the supernova. As indicated, EXITE is most sensitive to detecting the supernova in the 30-150 keV range, where its angular resolution surpasses previous balloon and satellite experiments.

The EXITE upper limit is a factor of ~3 above the near-simultaneous HEXE/Mir limit of Sunyaev et al (1990), which themselves represent a much longer (30 hour) exposure time. The fact that our upper limit also includes the nearby black hole candidate LMC X-1 also means that the Mir results for this epoch were probably not significantly contaminated by LMC X-1, which they otherwise could not resolve.

4.2 Galactic Center and GX339-4

The galactic center region was observed for a total exposure time of about 2 hours. A planned second exposure on the galactic center, which would have been of slightly longer duration, was unfortunately not possible to carry out when the balloon package was out of telemetry range from Alice Springs and not yet in command and control from the down-range station. Nevertheless, our results on the galactic center region contain a potentially important discovery: the possible presence of a new transient source in the galactic center source complex. In Figures 3 and 4 below we show the hard x-ray images obtained by EXITE in a broad band (Figure 3) and narrow band (Figure 4). The broad band image shows the persistent source 1E1740.7-2942 as being detected at a flux level very consistent with the results from the lower resolution Caltech gamma-ray imager GRIP the year before (Cook et al 1991). The spectrum of the EXITE detection of the "1E" source is also consistent with the GRIP results. In the narrow band from 82-111 keV, however, the image in Figure 4 shows a new and much brighter source which we have tentatively called EXS1730-2858. This possible transient source shows a remarkably flat spectrum. When extrapolated back to the lower x-ray energies detectable with the Ginga all sky monitor, it would be expected to give a flux of about 200 mCrab in the 6-20 keV "hard" band, or at just about the confusion limit for the galactic center region. Unfortunately, no ASM coverage of this region is available for the time of our observation. Before publishing this possible discovery, we are carrying out further analysis of the images (and spectra) using the new post-flight re-calibration of the detector.

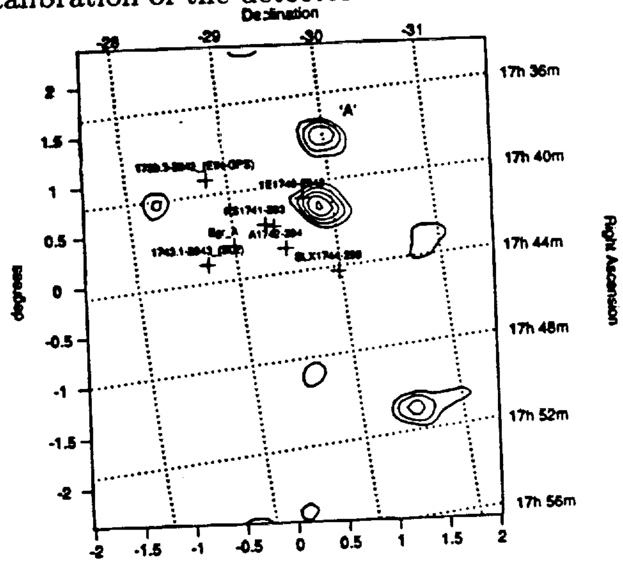

Figure 3. EXITE hard x-ray image of galactic center region (48-153 keV).

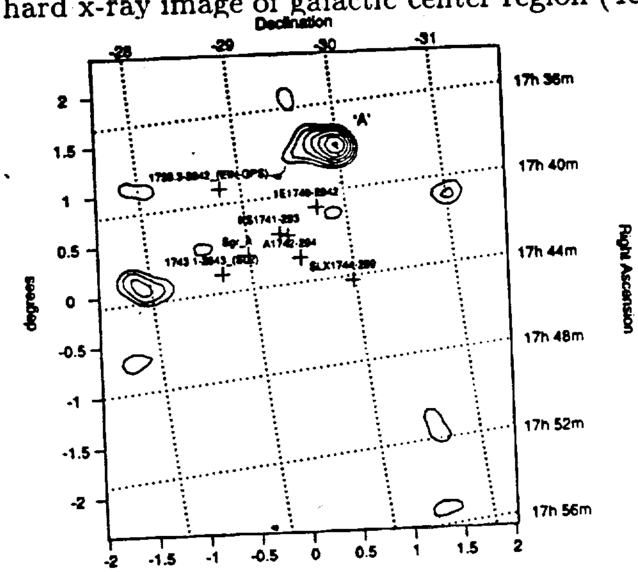

Figure 4. EXITE hard x-ray image of galactic center region (82-111 keV).

The black hole candidate GX339-4 was observed just after the galactic center for a total exposure of also about 2 hours. It was detected, as shown in Figure 5 which is the first hard x-ray image of this source. This object had been claimed as a hard x-ray source on the basis of its detection with the non-imaging HEAO-A4 experiment (Nolan et al 1982). However possible source confusion effects in the galactic bulge (as made clear recently with the discovery, with the imaging telescope SIGMA on the Soviet Granat satellite, of a new hard x-ray source within 1 degree of the bright galactic source GX5-1) had always made this identification somewhat questionable. The EXITE image, and spectrum (Figure 6), which shows the source to be in a similar state as in the HEAO observations, are an important new finding and are being prepared for publication by Covault et al (1991).

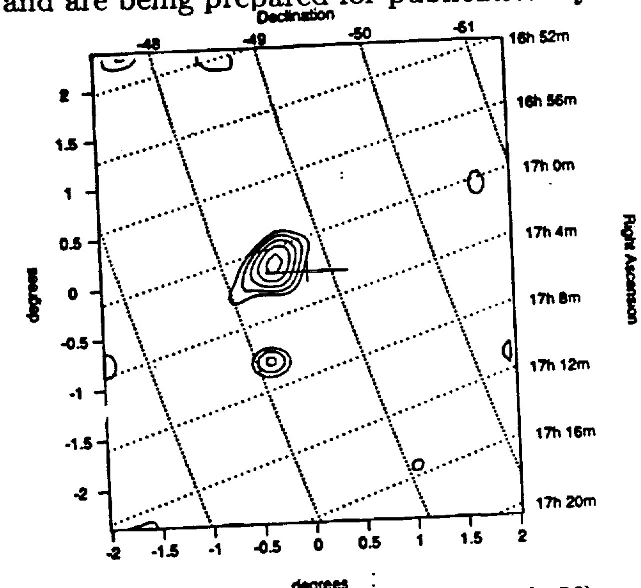

Figure 5. EXITE hard x-ray image of GX339-4 (36-63 keV).

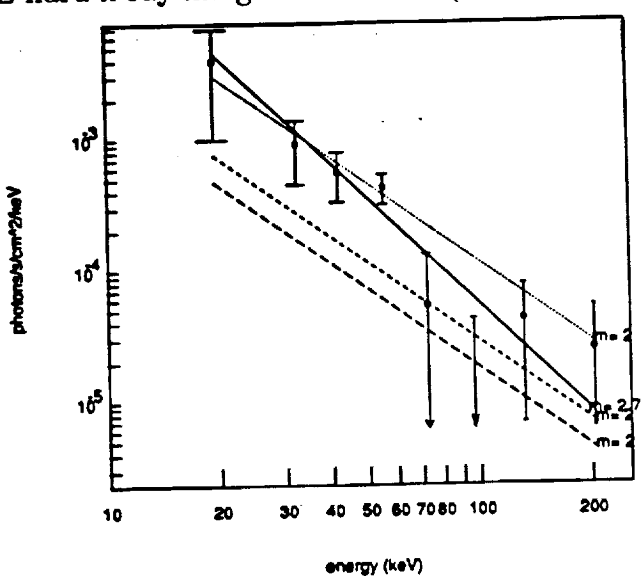

Figure 6. EXITE hard x-ray spectrum of GX339-4 compared with HEAO results.

5 Conclusions

The EXITE program to observe the supernova SN1987A and various galactic center region targets as part of the final SN1987A campaign from Alice Springs, Australia, in May 1989 was a success. Although the supernova was not detected, interesting limits were obtained and analysis is continuing. Among the galactic source targets observed were the first hard x-ray image of the black hole candidate GX339-4 and the discovery of a possible new transient source in the galactic center region. The EXITE instrument and gondola performed well, and are now in the final process of being upgraded for their next flight with a new detector system.

6 References

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