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FINAL TECHNICAL REPORT FOR NAG 5-1557

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Titles of Research:

(1) The X-Ray Population in Globular Clusters

(2) Three Crab-Like SNR in the Large Magellanic Cloud

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FINAL TECHNICAL REPORT

FOR NASA ROSAT GRANT NAG 5-1557

This document is to serve as the requisite Final Technical Report on grant NAG 5-1557 which was awarded under the NASA ROSAT Guest Investigator Program to Columbia University (Prof. D.J. Helfand, PI).

In response to the NASA Research Announcement describing the first round of Guest Investigations to be carried out under the US-German ROSAT program (AO-1), the PI submitted several proposals, three of which were accepted in part:

"The X-ray Population in Globular Clusters" had one target, NGC7099, scheduled as a priority A observation, and funds were provided for data reduction and analysis.

'Three Crab-like SNR in the Large Magellanic Cloud" had one target, N158A, scheduled as a priority A target. The PI on this proposal was Dr. F.D. Seward from the Smithsonian Astrophysical Observatory to whom the bulk of the funds for analysis were provided; a small amount was awarded to Columbia for collaborative activities and was appended to the grant for the PI's proposal described above.

"X-rays from Nearby Radio Pulsars" had one target, PSR 1929+10, selected as a priority C observation which ultimately was scheduled for over 40 ksec of PSPC observing time. Although the initial letter describing the results of the AO1 peer review indicated that funds in the amount of $10K would be forthcoming for analysis of these data were the target to be scheduled, a subsequent letter withdrew this offer and directed that the funds awarded under the other accepted programs should be used for this purpose. We describe here the current status of all three programs as of May 31, 1993, the termination date of the grant in question.

The X-ray Population of Globular Clusters.

Approximately 40 ksec of HRI integration time was accumulated for the awarded cluster target NGC7099. Unfortunately, owing to an operations error, the pointing position was offset from the cluster center by 40 arcminutes, placing the target system outside of the field of view. These data have been received and a cursory analysis has been conducted. Several dozen X-ray sources were detected, and the point source density and diffuse background radiation level will be useful for comparison with the cluster data when it is finally taken, although the existing data have little independent scientific value. At long last, the correct target position has finally been scheduled for observation during the current semester of operations; a fraction of the data were collected in May 1993, with the remainder scheduled for the coming month. No data had been received at Columbia by the end of the current grant, but it is expected shortly and some way will be found to analyze it, as it represents one of the deepest pointings in the ROSAT program at a high-central-density globular cluster and holds considerable promise for uncovering intermediate-luminosity X-ray binaries in this system, the chief objective of our original proposal.

Three Crab-like SNR in the Large Magellanic Cloud.

A net integration time of 18,126 s was accumulated by the ROSAT HRI on the approved target of this program, the SNR 0540-69.3 (N158A). These data have been reduced and analyzed, and the results have been prepared for publication with the proposal PI F.D. Seward as principal author. The chief results are as follows:

— diffuse patchy emission from a region 55″ in diameter is detected from the region surrounding the bright pulsar-powered synchrotron nebula which was first detected by the Einstein Observatory (Seward, Harnden, and Helfand 1984 ApJ Letters, 287, L19). This emission accounts for $\sim 20\%$ of the total remnant X-ray luminosity.

— interpretation of this emission as arising from the shock-heated material surrounding the progenitor star yields a supernova explosion energy of 1.5×10^{51}

ergs and an ambient density of 0.67 cm^{-3}, both plausible values for a remnant age of $\sim$ 1200 years. The model predicts a shell temperature of $\sim$ 5.5 keV, a result which can be tested with upcoming ASCA observations.

— pulsed radiation from the central 50-msec pulsar was detected. The pulse period and pulse shape were consistent with previous measurments. The pulsed fraction is only $\sim$ 20% in the soft ROSAT band (compared to $\sim$ 35% in the *Einstein* band) implying that the pulsar spectrum is harder than that of the surrounding nebula.

X-rays from Nearby Radio Pulsars.

Although no funds were explicitly awarded for this project, given the status of the above observations, it occupied a substantial fraction of our effort under the AO-1 program. As noted above, a long observation of the pulsar PSR 1929+10 was achieved. The source was easily detected as a relatively hard, point-like, pulsed X-ray emitter. An extensive analysis effort has revealed the following:

— an X-ray luminosity of $\sim 5 \times 10^{29}$erg s^{-1} corresponding to a ratio of X-ray to spindown luminosity of $\sim 10^{-4}$

— a thermal spectrum for the emission with a temperature of $\sim 4 \times 10^{6}$K

— no evidence of spatial extent near the pulsar, but a possible $\sim 10'$ trail of diffuse emission extending in the direction opposite that of the object's proper motion (see Wang et al. 1993, *Nature*, submitted)

— X-ray pulses at the radio period with a pulsed fraction of $\sim$ 28%

— near coincidence between the radio and X-ray pulse peaks

— an upper limit to the temperature of the whole surface of the neutron star of $\sim 3 \times 10^{5}$K, consistent with current cooling models

— an inferred polar cap emitting region only $\sim$ 50 meters in radius!

These observations lead to the following advances in our understanding of rotation-powered pulsars as well as a number of conflicts with existing models:

— an emitting area smaller than the canonical polar cap (defined by the open

magnetospheric field lines), suggesting the dominance of higher order multipoles on the surface of the star.

— from the time delay between the X-ray and radio pulse peaks, a limit on the altitude of the radio emission zone consistent with current models.

— a conflict with the predictions of both temperature and luminosity for all published polar cap and outer gap emission models for radio pulsars

— through use of the well-determined magnetic field geometry of the star inferred from radio polarization observations, evidence for the detection of gravitational light bending near the surface of a neutron star. For a 1.4 $M_{\odot}$ object, this leads to a direct measurement of the neutron star's radius of between 10.8 and 15 km.

The results of this work and their important implications for a number of areas in neutron star physics and pulsar phenomenology have been described in two presentations at the *American Astronomical Society* meetings of January and June 1993 (Yancopoulos et al. 1992 BAAS and 1993 BAAS) and in a long paper which is being submitted for publication in the *Astrophysical Journal* (Hamilton, Yancopoulos, and Helfand 1993).