UHURU ADVANCED STUDIES AND GUEST-INVESTIGATOR PROGRAM

Grant NGR 09-015-211

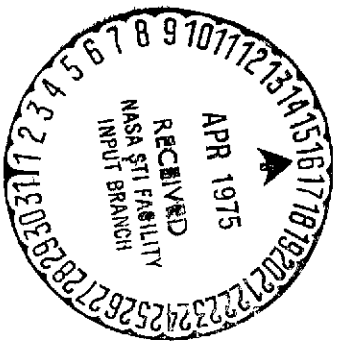
Final Report

Principal Investigator
Dr. Riccardo Giacconi

April 1975

Prepared for

National Aeronautics and Space Administration
NASA Headquarters
Washington, D.C. 20546



Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

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FINAL REPORT

1. SATELLITE OPERATIONS

During the period July 1973 to satellite turn-off in January 1975, the UHURU satellite operated in the solar-power-only-mode, with data reception only at the Quito Station. Owing to sun-angle restrictions and to the degraded performance of the on-board transmitter, the daily average amount of data received was about 100 to 200 sec. We have utilized the satellite in this mode to study several particularly strong galactic X-ray sources. For example, during the past year we spent approximately 6 months monitoring the galactic plane and 6 months monitoring SCO X-1 and Her X-1.

2. SOFTWARE DEVELOPMENT

The transfer of much of the UHURU program to the Smithsonian Astrophysical Observatory (SAO) has involved the utilization of a different computer from that used at American Science & Engineering (AS&E). Substantial time has been spent in translating and modifying the programing system for use on the CDC6400 at SAO, particularly in two areas. The first deals with writing programs that allow data tapes produced at AS&E or Goddard Space Flight Center (GSFC) to be read at SAO. This conversion has been completed, tested, and documented so that the converted tapes can be easily read. The second area of effort has been in converting AS&E standard utility and data-processing programs for use at SAO. Several programs have been converted thus far, allowing the analysis of spectral data, aspect (orientation) corrections to intensity data, and the study of pulsating X-ray sources all to be conducted at SAO.

Another major effort in software development has been the complete transfer from AS&E of all IBM PL1 programs. This has meant the acquisition of all relevant card decks, their transfer to the Harvard IBM facility, and modification and consolidation of different components of the processing system. This project is nearly complete. Over the past 18 months modifications have been made in this processing system, and further modifications are continuing. As a result, significant improvements have been made in the peak finding procedure and rough spectral-analysis programs. These should increase the efficiency of detection of weak X-ray sources, and provide a more reliable background determination which will result in more accurate spectral measurements.

A new program for aspect determination, based on magnetometer data, has been developed and is nearly completed. The rest of the processing system has to be modified and this task is also nearly completed. When this new system is completed, it will be possible to complete a systematic analysis of the bulk of the UHURU data.

3. DATA ANALYSIS

Most of the first 40 daytime data sets and the nighttime data have been processed at GSFC. The benefits of this were: (1) The daytime data could be examined in a systematic way (2) The nighttime data were reprocessed using the improved processing system (see previous section) (3) 7-track tapes necessary for the 7-track SAO CDC6400 computer were made. These new 7-track tapes, produced on the GSFC IBM machines, have been converted to achieve CDC6400 compatibility and the associated printout has been microfilmed, making these data readily available to all personnel at SAO.

4. SCIENTIFIC RESEARCH

Continued scientific research efforts have been carried out at the Smithsonian

Astrophysical Observatory. Several scientific papers have been published or submitted for publication in the literature. In addition, members of the UHURU group at SAO have presented invited papers at seminars, colloquia, and various scientific meetings. A complete bibliography of publications is given in Section 6 and a list of the talks presented at meeting is given in Section 7.

Research using UHURU data has continued in three basic areas. The first area, galactic research, has centered primarily on obtaining detailed information on the time variability of intense sources. This includes the X-ray binary sources and those strong sources that to date do not exhibit eclipses. Detailed studies of the particularly interesting sources Cen X-3, Her X-1, Cyg X-1, and Cyg X-3 have also been carried out, including spectral analysis and comparisons of the behavior of these sources with theoretical models for the X-ray emission. The second area concerns extragalactic research. A more detailed analysis of the X-ray data from clusters of galaxies has been conducted, as well as a detailed analysis of the spectra of the strongest cluster sources and their spatial extent. For the class of unidentified high-latitude sources, a statistical analysis has been carried out in detail in an attempt to discern the true nature of these sources. The third major area of UHURU research has been the study of particular extragalactic sources, or classes of objects, to determine spectral parameters, extent, upper limits of X-ray emission, and contribution to the X-ray background.

A joint effort is also under way with the California Institute of Technology (Cal Tech) group of Dr. G. Garmire as a guest investigator to determine the systematic contributions of trapped radiation, earth background, and cosmic-ray-induced events in the background measurements obtained by UHURU.

5. GUEST INVESTIGATOR PROGRAM

We have from time to time supplied data and assistance to several guest investigators who have used UHURU data for scientific research. In some instances, these guest investigators have visted with the UHURU group at SAO, such as Dr. Garmire and Dr. W. Tucker. In other cases, data have been made available to guest investigators at their institutions, for example, Dr. C. Sagan at Cornell University and Dr. M. Oda at the University of Tokyo. We list below some of the recent guest investigators who have received information and data from the UHURU group.

AFFILIATION	GUEST INVESTIGATOR
Cal Tech	G. Garmire, P. Agrawal
Columbia University	R. Novick, M. Weisskoff, R. Angel
Cornell University	C. Sagan
GSFC	S. Holt, E. Boldt, P. Serlemitsos
Institute for Advanced Study at Princeton University	J. Bahcall, N. Bahcall, A. Yahil, Y. Avni, P. Joss, J. Peebles
Lockheed Palo Alto Research Laboratory	R. Catura, W. Zauman
Massachusetts Institute of Technology	H. Bradt, W. Lewin, G. Clark, S. Rappaport, J. McClintock, P. Joss
Cambridge University	A. Fabian
Mullard Space Science Labs	P. Sanford
University of California, Berkeley	J. Silk, S. Lea
University of California, Livermore	F. Seward
University of California, San Diego	M. Ulmer
University of Tokyo	M. Oda
University of Wisconsin	W. Kraushaar, P. Coleman, A. Bunner, D. McCammon, F. Williamson

UHURU PUBLICATIONS

1971

An X-ray Scan of the Galactic Plane from UHURU. R. Giacconi, E. Kellogg, P. Gorenstein, H. Gursky and H. Tananbaum. 1971: Ap. J. 165, L27.

Measurement of the Location of the X-ray Sources Cygnus X-1 and Cygnus X-2 From UHURU. H. Tananbaum, E. Kellogg, H. Gursky, S. Murray, E. Schreier and R. Giacconi. 1971: Ap. J. 165, L37.

Detection of X-rays from the Seyfert Galaxies, NGC 1275 and NGC 4151 by the UHURU Satellite. H. Gursky, E. Kellogg, C. Leong, H. Tananbaum and R. Giacconi. 1971: Ap. J. 165, L43.

X-ray Observations of the Virgo Cluster, NGC 5128 and 3C273 from the UHURU Satellite. E. Kellogg, H. Gursky, C. Leong, E. Schreier, H. Tananbaum, and R. Giacconi. 1971: Ap. J. 165, L49.

X-ray Pulsations from Cygnus X-1 Observed from UHURU. M. Oda, P. Gorenstein, H. Gursky, E. Kellogg, E. Schreier, H. Tananbaum and R. Giacconi. 1971: Ap. J. 166, L1.

Discovery of Periodic X-ray Pulsations in Cen X-3 from UHURU. R. Giacconi, H. Gursky, E. Kellogg, E. Schreier and H. Tananbaum. 1971: Ap. J. 167, L67.

A Strong X-ray Source in the Coma Cluster Observed by UHURU. H. Gursky, E. Kellogg, S. Murray, C. Leong, H. Tananbaum and R. Giacconi. 1971: Ap. J. 167, L81.

X-ray Observations of GX 17+2 from UHURU. H. Tananbaum, H. Gursky, E. Kellogg and R. Giacconi. 1971: Ap. J. 168, L25.

Further Observations of the Pulsating X-ray Source Cygnus X-1 from UHURU. E. Schreier, H. Gursky, E. Kellogg, H. Tananbaum and R. Giacconi. 1971: Ap. J. 170, L21.

X-ray Sources Near the Galactic Center Observed by UHURU. E. Kellogg, H. Gursky, S. Murray, H. Tananbaum and R. Giacconi. 1971: Ap. J. 169, L99.

X-ray Emission from the Magellanic Clouds Observed by UHURU. C. Leong, E. Kellogg, H. Gursky and R. Giacconi. 1971: Ap. J. (Letters), 170, L67.

Variable X-ray Sources Observed by UHURU. E. Kellogg. Presented at the International Astronomical Union Colloquium on Variable Stars, Bamberg, Germany, August, 1971.

1972

Observations of the Extended X-ray Source in the Perseus and Coma Clusters From UHURU. W. Forman, E. Kellogg, H. Gursky, H. Tananbaum and R. Giacconi. 1972: Ap. J. 178, 309-316.

Relationship Between X-ray Luminosity and Velocity Dispersion in Clusters of Galaxies. A. B. Solinger and W. H. Tucker. 1972: Ap. J. 175, L107.

Advanced X-ray Observations. H. Gursky. 1972: Publication of the Astronomical Society of the Pacific. 84, 99-109.

UHURU Results on Galactic X-ray Sources. H. Tananbaum. In X- and Gamma-Ray Astronomy. Bradt and Giacconi (Eds.) (D. Reidel Pub. Co., Boston, U. S. A.), 1973.

UHURU Results on Extragalactic X-ray Sources. E. Kellogg. 1972: IAU Symposium, No. 55 (Dordrecht: Reidel), 171.

Observation of a Correlated X-ray-Radio Transition in Cygnus X-1. H. Tananbaum, H. Gursky, E. Kellogg, R. Giacconi and C. Jones. 1972: Ap. J. 177, L5-L10.

Discovery of the Binary Nature of SMC X-1 from UHURU. E. Schreier, R. Giacconi, H. Gursky, E. Kellogg and H. Tananbaum. 1972: Ap. J. 178, L71-L75.

Observations of Galactic X-ray Sources. H. Gursky. 1973; In Black Holes; DeWitt and DeWitt (Eds.) (New York: Gordon & Breach).

Observations of Cygnus X-3 by UHURU. D. Parsignault, H. Gursky, E. Kellogg, T. Matilsky, S. Murray, E. Schreier, H. Tananbaum, R. Giacconi and A. Brinkman. 1972: Nature-Phys. Sci., 239, 123-125.

The Extended X-ray Source at M87. E. Kellogg, H. Gursky, H. Tananbaum and R. Giacconi. 1972: Ap. J. 174, L65.

A New Transient Source Observed by UHURU. T. A. Matilsky, R. Giacconi, H. Gursky, E. M. Kellogg and H. Tananbaum. 1972: Ap. J. 174, L53.

Discovery of a Periodic Pulsating Binary X-ray Source in Hercules from UHURU. H. Tananbaum, H. Gursky, E. Kellogg, R. Levinson, E. Schreier and R. Giacconi. 1972: Ap. J. 174, L143.

X-ray Emission from Rich Clusters of Galaxies. H. Gursky, A. Solinger, E. Kellogg, S. Murray, H. Tananbaum, R. Giacconi and A. Cavaliere. 1972: Ap. J. 173, L99.

The UHURU Catalog of X-ray Sources. R. Giacconi, S. Murray, H. Gursky, E. Kellogg, E. Schreier and H. Tananbaum. 1972: Ap. J. 178, 281-308.

Evidence for the Binary Nature of Cen X-3 from UHURU X-ray Observations. E. Schreier, R. Levinson, H. Gursky, E. Kellogg, H. Tananbaum and R. Giacconi. 1972: Ap. J. 172, L79.

A Model for the Centaurus X-3 Phenomenon. G. R. Blumenthal and A. Cavaliere, W. K. Rose and W. Tucker. 1972: Ap. J. 173, 213.

1972: (cont.)

A Mechanism for the X-ray Pulsations in Cyg X-1. G.R. Blumenthal and W.H. Tucker. 1972: Nature-Phys. Sci., 235, 97.

The Association of X-ray Sources with Bright Stars. H. Gursky. 1972: Ap. J. (Letters) 175, L141.

1973

Clusters of Galaxies with a Wide Range of X-ray Luminosities. E. Kellogg, S. Murray, R. Giacconi and H. Gursky. 1973: Ap. J. 185, L13.

Evidence for the Binary Nature of 2U 1700-37. C. Jones, W. Forman, H. Tananbaum, E. Schreier, H. Gursky, E. Kellogg and R. Giacconi. 1973: Ap. J. 181, L43.

UHURU Observations of the Binary X-ray Source 2U 0900-40. W. Forman, C. Jones, H. Tananbaum, H. Gursky, E. Kellogg and R. Giacconi. 1973: Ap. J. 182, L103.

Correlation Analysis of X-ray Emission for Cygnus X-1. A.C. Brinkman, D. Parsignault, E. Schreier, H. Gursky, E. Kellogg and R. Giacconi. 1973: Ap. J. 188, 603.

X-ray Observations of NGC5128 (Centaurus A) From UHURU. W. Tucker, E. Kellogg, H. Gursky, R. Giacconi and H. Tananbaum. 1973: Ap. J. 180, 715-724.

The Number Intensity Distribution of X-ray Sources Observed by UHURU. T. Matilsky, H. Gursky, E. Kellogg, H. Tananbaum, S. Murray and R. Giacconi. 1973: Ap. J. 181, 753.

The X-ray Structure of the Vela X Region Observed from UHURU. E. Kellogg, H. Tananbaum, F.R. Harnden, Jr., H. Gursky, R. Giacconi and J. Grindlay. 1973: Ap. J. 183, 935.

Further X-ray Observations of Hercules X-1 from UHURU. R. Giacconi, H. Gursky, E. Kellogg, R. Levinson, E. Schreier and H. Tananbaum. 1973: Ap. J. 184, 227.

Binary X-ray Sources. R. Giacconi. In Gravitational Radiation and Gravitational Collapse. C. DeWitt-Morette (Eds.), 147 (D. Reidel Pub. Co., Dordrecth, Holland).

The UHURU Satellite. R. Giacconi. For publication in BRITANNICA YEARBOOK OF SCIENCE AND THE FUTURE, 1973.

Radio Stars and X-ray Sources. J. Bahcall and E. Kellogg. 1973: Nature-Phys. Sci., 244, 135.

Thermal-Bremsstrahlung Interpretation of Cluster X-ray Sources. S. Lea, J. Silk, E. Kellogg and S. Murray. 1973: Ap. J. 184, L105.

X-ray Astronomy. R. Giacconi. THE PHYSICS TEACHER. March 1973: 11, No. 3, 135.

Progress in X-ray Astronomy. R. Giacconi. PHYSICS TODAY. May 1973: 26, 38.

Gamma-Ray Bursts Seen By UHURU. D. Koch, H. Gursky, H. Tananbaum and E. Kellogg. Proceedings of Conference on Transient Cosmic Gamma- and X-ray Sources. September 20-21, 1973: 16.

Proceedings of the 16th International Solvay Congress on Physics. September 24-28, 1973: Brussels, Belgium.

1973: (cont.)

Description of Small-Scale Fluctuations in the Diffuse X-ray Background. A. Cavaliere, A. Friedland, H. Gursky and G. Spada. 1973: Ap. J. 182, 405-410.

X-ray Spectrum of the Tycho Supernova. P.L. Coleman, A.N. Bunner, W.L. Kraushaar, D. McCammon, F.O. Williamson, E. Kellogg and D. Koch. Ap. J. 185, L121-L125.

The Third UHURU Catalog of X-ray Sources. R. Giacconi, S. Murray, H. Gursky, E. Kellogg, E. Schreier, T. Matilsky, D. Koch and H. Tananbaum. 1974: February Supplement Series, Ap. J. 237, 27, 37-64.

On The Nature of the Unidentified High Latitude UHURU Sources. S.S. Holt, E.A. Boldt, P.J. Serlemitsos, S.S. Murray, R. Giacconi, E.M. Kellogg and T.A. Matilsky. Ap. J. 188, L97-L101.

The Binary X-ray Stars - The Observational Picture. H. Gursky and E. Schreier. Presented at IAU Symposium No. 67, Moscow, USSR - August 1974.

1974

Optical Studies of UHURU Sources VIII. Observations of 92 Possible Counterparts of X-ray Sources. C. Jones, T. Chetin and W. Liller. 1974 Ap. J. (Letters) 190, L1-L3.

Geomagnetic Background Events Observed by UHURU. D. Schwartz. Proceedings of Conference on Particle Contamination of Low Energy X-ray Astronomy Experiments. GSFC, April, 1974.

Observations of Circinus X-1 from UHURU. C. Jones, R. Giacconi, W. Forman and H. Tananbaum. 1974 Ap. J. 191, 2, L71.

UHURU Observations of Short-Time Scale Variations of the Crab. W. Forman, R. Giacconi, C. Jones, E. Schreier and H. Tananbaum. 1974 Ap. J. 193, L67-L70.

Studies of Cluster X-ray Sources: Size Measurements. E. Kellogg and S. Murray. Ap. J. 193, L57-L60.

Comments on the Diffuse X-ray Background: 2-82 keV. D.A. Schwartz. Presented at the International Conference on X-rays in Space, Calgary, Alberta, Canada.

X-ray Astronomy in the UHURU Epoch and Beyond. E.M. Kellogg. On the occasion of the Newton Lacy Pierce Prize Lecture presented at the 143 Meeting of the AAS. Rochester, N.Y., August 1974.

Studies of Cluster X-ray Sources: Energy Spectra for the Perseus, Virgo, and Coma Clusters. E. Kellogg and J.R. Baldwin and D. Koch. Sub. to Ap. J., Oct., 1974.

Galactic X-ray Sources. M.P. Ulmer. Presented at the International Conference on X-rays in Space, Calgary, Alberta, Canada, 1974.

Further Observations of Cygnus X-3 with the UHURU Satellite. R.W. Leach, S.S. Murray, E.J. Schreier, H.D. Tananbaum, M.P. Ulmer and D.R. Parsignault. To be published in the Ap. J.

Upper Limits on 2.5-Sec Pulsations from Her X-1. Y. Avni, J.N. Bahcall, P.C. Joss, E. Schreier, D.Q. Lamb. 1974: Ap. J. (Letters), 188, L35.

7. SEMINARS AND COLLOQUIA

TITLE	SPEAKER	MEETING	DATE
Binary X-ray Sources	R. Giacconi	IAU Sym., Warsaw	Aug. 73
Observational Results on Compact Galactic X-ray Sources	R. Giacconi	IAU Solvay, Brussels	Aug. 73
Activity in Intergalactic Space	E. Kellogg	Univ. of Maryland	Oct. 73
Cluster X-ray Sources	E. Kellogg	Univ. of Cal., Santa Cruz	Nov. 73
Extragalactic X-ray Sources	E. Kellogg	Harvard University	Nov. 73
Galactic X-ray Sources	E. Schreier	APS, Berkeley	Aug. 73
Progress in X-ray Astronomy	E. Schreier	NY Academy of Science	Nov. 73
Binary X-ray Sources	H. Tananbaum	IAU General Assembly, Sydney	Aug. 73
Stellar X-ray Sources	H. Tananbaum	IAU Symposium # 60	Sept. 73
Binary X-ray Sources	H. Tananbaum	Dartmouth College	Oct. 73
Sizes and Spectra of Cluster X-ray Sources	E. Kellogg	AAS Meeting, Tucson	Dec. 73
Further Obs. of the Transient X-ray Source 3U1543-47	T. Matilsky	AAS Meeting, Tucson	Dec. 73
Search for X-ray Emission from the Flare Star AD Leo	J. Grindlay	AAS Meeting, Tucson	Dec. 73
A Study of Short Time Scale Variability of Intense Galactic X-ray Sources as Observed by UHURU	W. Forman	APS Meeting, Tucson	Dec. 73
UHURU Observations of the Binary Nature of Cir X-1	C. Jones	APS Meeting, Tucson	Dec. 73

TITLE	SPEAKER	MEETING	DATE
Observations of the Periodically Varying X-ray Sources Cygnus X-3	R. Leach	APS Meeting, Tucson	Dec. 73
Short Term Behavior of Strong Galactic X-ray Sources	C. Jones	Mullard Space Science Laboratory	June 74
Binary X-ray Stars	H. Gursky	IAU Conference on Various Stars, Moscow	July 74
Pierce Lecture	E. Kellogg	Univ. of Rochester	Aug. 74
Comments on the Diffuse X-ray Background:2-82 keV	D. Schwartz	Calgary, Canada	Aug. 74
Galactic X-ray Sources	M. Ulmer	Calgary, Canada	Aug. 74
Short Time Scale Variability of Strong Galactic X-ray Sources	W. Forman	Trieste, Italy	Sept. 74
X-ray and Optical Observations of Galactic X-ray Sources	C. Jones	Harvard College Obs.	Nov. 74
X-ray Observations of Cyg X-3	M. Ulmer	NRAO	Nov. 74
Short Time Scale Variability of Galactic X-ray Sources	W. Forman	AAS Meeting, Gainesville, FL	Dec. 74
Advances in X-ray Astronomy	H. Gursky	AAS Meeting Gainesville, FL	Dec. 74
Spectra of Galactic X-ray Sources	C. Jones	AAS Meeting Gainesville, FL	Dec. 74
Her X-1 and Cen X-3 Revisited	R. Giacconi	7th Texas Sym. Dallas, TX	Dec. 74
Parameters of Binary X-ray Sources	H. Tananbaum	7th Texas Sym. Dallas, TX	Dec. 74