

TITLE: COOPERATIVE RESEARCH IN HIGH ENERGY ASTROPHYSICS BETWEEN JHU AND GSFC  
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This grant was awarded to establish and support cooperative research programs between the Center of Astrophysical Sciences (CAS) at the Johns Hopkins University and the Laboratory for High Energy Astrophysics (LHEA) at the NASA/Goddard Space Flight Center (GSFC). The goals of the program are to facilitate, encourage and initiate, (1) sharing of resources, knowledge and expertise in the general area of research in High Energy observational and theoretical astrophysics, and relevant databases; (2) new collaborations and projects between the two institutions and its scientists, (3) training and mentoring of JHU students and junior researchers by way of connecting them with appropriate researchers and experts at the LHEA.

Dr. T. Yaqoob, a Research Scientist, is the coordinator for CAS/LHEA coop activities. These have involved arranging seminars and special talks given by scientists at the two institutions, coordinating collaborative research and work on observing proposals, training students and post-doctoral researchers, and importing mission-specific expertise from LHEA.

Many collaborative projects between JHU and GSFC researchers have been successfully completed, resulting in 36 papers published in refereed journals plus one PhD thesis. Details of these are given below. The research has covered a wide variety of topics, benefiting from combining and pooling the expertise of researchers at the two institutions. Particularly strong areas of research have been the study of (i) Starburst galaxies and the starburst/AGN connection; (ii) atomic features in AGN X-ray spectra, including soft X-ray signatures of outflows and the intergalactic medium, as well as signatures of strong gravity; (iii) multiwavelength observations of extragalactic sources; (iv) variability studies of active galaxies, (v) high-redshift quasars; and (vi) the CXRB and discrete sources from X-ray deep fields.

In this final report a summary is given of activities over the period of performance of the award, organized by principal personnel (listed alphabetically, after the coop coordinator). Following this summary is a list of publications resulting from these activities.

#### SUMMARY OF ACTIVITIES

Dr. T. Yaqoob (coop coordinator)

Dr. Yaqoob, in collaboration with scientists from JHU and LHEA, has been working on studying the Fe K line emission and photoionized outflows in active galactic nuclei (AGN) using proprietary and archival data from current and past X-ray astronomy missions. A particular emphasis has been on utilizing the highest energy resolution currently available (with the Chandra High Energy Gratings) to address two particular problems. One is the deconvolution of narrow Fe K line emission components from the overall line profile in order to understand the effects of strong gravity

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in the vicinity of a black hole. This information can be used to help interpret lower resolution (but higher throughput) data from missions such as ASCA, RXTE, BeppoSAX and XMM-Newton. The second area of research has been to understand the physics of the photoionized outflows from high-resolution X-ray spectroscopy, including the connection between the X-ray and UV absorbers, using simultaneous X-ray and HST observations.

With collaborators from Prague University, Dr. Yaqoob has also been involved in theoretical work on a code which ray-traces photon trajectories in the space-time of a Kerr black hole. The code is more accurate and generalized than other, currently available codes and allows the user for the first time to constrain the black-hole angular momentum parameter from real data. It will be useful to researchers at JHU and GSFC, as well as to the larger community for modeling X-ray spectra. A paper has been submitted for publication.

With collaborators from JHU and LHEA, Dr. Yaqoob has been involved with a Chandra observation (PI, Yaqoob) which revealed evidence of a much-sought-after signature of the hot intergalactic medium. Only a few other reports in the literature exist so far, but if they are vindicated, they will have important implications for constraining the baryon fraction in the universe.

In addition to mentoring the JHU post-doctoral researchers Barry McKernan, and Mariko Ninomiya, Dr. Yaqoob has been training and mentoring graduate students including Jonathan Gelbord and Urmila Padmanabhan. Jonathan Gelbord obtained his PhD in 2002 and Urmila Padmanabhan is beginning her thesis research in the area of X-ray spectroscopy.

Dr. Yaqoob has also been working with personnel from the ASCA Guest Observer Facility at GSFC on in-flight instrumental calibration work for ASCA, as well as science preparation and planning (with Dr. Peter Serlemitsos from GSFC) for Astro-E2, the high-resolution Japanese/US X-ray spectroscopy mission to be launched in 2005.

In 2001, the coop hosted an international workshop entitled 'X-RAY EMISSION FROM ACCRETION ONTO BLACK-HOLES', held at Johns Hopkins University, 20-23 June. The workshop was well-attended, with over 100 participants from institutions around the world, with significant participation by members from CAS and LHEA. The Scientific Organizing Committee, consisting of scientists from both CAS and LHEA, as well as external members, put together a comprehensive program of 22 invited speakers who are leading experts in the field, plus 14 contributed talks. Including posters, more than 80 papers were presented in total. Bibliographic entries for each paper have since been submitted to the ADS (Astrophysical Data System) database. The workshop was very productive, and further details of the program, including the full papers for many of the contributions, can be found at <http://www.pha.jhu.edu/groups/astro/workshop2001/>.

Dr. John Cannizzo (GSFC) has been visiting JHU to collaborate on theoretical work with Ethan Vishniac (JHU) and Insu Yi (KIAS). They are studying the effect of coronal mass injection and mass loss on the evolution of soft X-ray transients. The work is an extension of previous work by John Cannizzo (ApJ, 534, 35L, 2000) on the effect of irradiation-induced evaporation from the disk on a typical 'FRED' outburst.

Dr. E. Colbert (JHU), an associate research scientist, in collaboration with K. Weaver (GSFC/JHU), J. Mulchaey, R. Mushotzky (GSFC), and J. Krolik (JHU) published a paper on the X-ray reflectors in the Seyfert 2 galaxy NGC 1068. In collaboration with K. Weaver (GSFC/JHU), Colbert worked

on the kpc-scale X-ray jet/wind seen with Chandra in the Seyfert galaxy NGC 2110. Colbert also worked on a major project, in collaboration with T. Heckman (JHU), A. Ptak (JHU), K. Weaver (GSFC/JHU), and D. Strickland (JHU), studying a sample of 62 starbursting and normal spiral, and elliptical galaxies observed with Chandra. The sample will enable important statistical analyses to be made.

J. Gelbord (JHU), a graduate student, worked with T. Yaqoob (JHU/GSFC), K. Weaver (GSFC/JHU) and T. Heckman (JHU), completing his PhD thesis in 2002. His thesis was entitled "Probing Circumnuclear Matter in Seyfert Galaxies with X-ray Spectroscopy."

Dr. Nancy A. Levenson (JHU), a post-doctoral researcher, studies AGN and Galactic supernova remnants primarily at X-ray energies. In collaboration with K. A. Weaver (GSFC/JHU) and T. M. Heckman (JHU), she conducted research on Seyfert galaxies that contain strong circumnuclear starbursts. The starbursts obscure the active nuclei, in some cases resulting in misclassification of the intrinsic sources at optical wavelengths. Dr. Levenson, with the above collaborators together with Prof. J. Krolik (JHU) also published a paper on unusually strong Fe K emission lines from starburst galaxies.

Dr. Barry McKernan (JHU), a post-doctoral researcher, joined CAS in August 2001. In collaboration with T. Yaqoob (JHU/GSFC), I. George (GSFC/UMBC), T. J. Turner (GSFC), and T. Kallman (GSFC), he worked on analysing Chandra grating data for several Seyfert galaxies, measuring the absorption and emission features present in the spectra, which indicate massive winds with an outflow velocity of several hundred km/s. The data also constrain the ionization state and density of the circumnuclear material. Dr. McKernan also constructed model grids using the photoionization code XSTAR to help interpret the data.

M. Ninomiya (JHU), a post-doctoral researcher, in collaboration with T. Yaqoob (JHU/GSFC), has been conducting a large statistical X-ray study of the complete sample of high redshift quasars observed during the entire lifetime of the ASCA X-ray astronomy satellite. One of the goals of this study was to investigate a correlation between the X-ray absorption and redshift in these quasars, suggested by an earlier, but smaller study in the literature. The correlation was confirmed and has potentially significant cosmological consequences.

U. Padmanabhan (JHU), a graduate student, in collaboration with T. Yaqoob (JHU/GSFC), K. Weaver (GSFC/JHU), I. George (GSFC/UMBC), T. J. Turner (GSFC/UMBC), K. Nandra (GSFC/USRA), T. Dotani (ISAS, Japan), has been working on various projects involving spectroscopy and diagnostics of the iron K lines in AGN using ASCA and Chandra data. She has also been working on a project investigating correlations between optical, UV, X-ray properties and black-hole mass in AGN.

Dr. Kim Weaver (GSFC/JHU), in collaboration with T. Heckman (JHU), E. Colbert (JHU), and A. Ptak (JHU) has been working on various projects related to X-ray observations of starburst galaxies and understanding the phenomena associated with them in theoretical context. A graduate student, J. Grimes (JHU), supervised by T. Heckman (JHU) has also been involved in this work.

Below is a list of papers in which details of the above research and results can be found. The list covers the period of performance of

this report and therefore includes only publications relevant to this grant award. Only those papers are listed that involved collaboration between scientists from both JHU and GSFC, and for which the first author was either at JHU or GSFC.

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Papers published in refereed journals over the lifetime of the coop.

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