The Role of Dark and Normal Matter in Galaxies

PI: Jimmy Irwin, Assistant Professor, Department of Physics and Astronomy

Submitted for consideration in the Mathematics and Natural Sciences category

Abstract: The Big Bang theory predicts that most of the matter in the Universe is in the form of non-interacting dark matter, with "normal" matter (hot and cold gas, stars, planets, etc.) constituting only 17% of the total dark+normal matter content. Observational studies of large clusters of galaxies confirm this dark–to–normal matter ratio. However, it is still unclear whether smaller mass systems (i.e., galaxies) share the same dark/normal matter ratio, which if the same would indicate that the structure formation mechanism is self-similar across all mass scales. The amount of dark/normal matter in galaxies must be determined in the very outskirts of galaxies to be cosmologically useful, a spatial regime that is fraught with systematic uncertainties due to low signal-to-noise of the available data in these regions with current instrumentation.

The quantities needed to address this issue can be obtained with telescopes designed to detect the X-ray emission from galaxies. However, great care must be taken in handling the detector background when dealing in the low signal-to-noise regime. The Japanese X-ray telescope *Suzaku* has the lowest detector background of any current X-ray telescope, and is best-suited for this study. Being able to parameterize and statistically subtract this detector background is a difficult process. I propose to begin a collaboration with Dr. Eric Miller of MIT, who is one of the world's experts in understanding the *Suzaku* instrument, to determine the dark/normal matter ratio in galaxies.

Jimmy Irwin

Summary: I am requesting funds to visit Dr. Eric Miller at MIT for six weeks to collaborate on a project to use the Japanese X-ray telescope *Suzaku* to determine the fraction of dark and normal matter in galaxies.

Background and Science Objectives:

Modern cosmological models of the Universe make very specific predictions on the amount and type of matter created by the Big Bang. Most of the matter created in the first three minutes following the Big Bang is predicted to be in an exotic form that has not yet been firmly identified to date – so-called "dark" matter. Since dark matter is not expected to interact with other matter except through its gravity, our only means of studying the properties of dark matter is to measure the gravitational effects of dark matter on the "normal" matter we see in galaxies and clusters of galaxies. (Here, when we refer to normal matter, we mean baryonic matter that composes gas, stars, planets, and dust within and between galaxies.)

The most current cosmological models predict that a majority of the matter created in the Big Bang is in the form of dark matter, with the more familiar form of normal baryonic matter composing only 17% of the total mass. One means of observationally testing this prediction is to determine the baryon fraction in clusters of galaxies, the largest gravitationally bound systems in the Universe composed of hundreds to thousands of galaxies all within the same gravitational well. In clusters of galaxies, the majority of the normal baryonic mass is in the form of a very hot (100 million Kelvin) tenuous X-ray–emitting gas that permeates the entire structure, while the sum of the constituent galaxies contributes a much smaller amount. X-ray observations of this hot halo allows for the determination of both the mass of the hot gas, and the total (dark+baryonic) mass of the cluster (if the gas is assumed to be in hydrostatic equilibrium within the potential well of the cluster). When the hot gas and galaxy masses are combined, their total mass comes to about 17% of the total mass of the cluster, as predicted from theory.

The agreement between theory and observation is strong confirmation that we are on the right track in understanding large scale structure formation. But whether this relation holds down to the mass scales as small as individual galaxies is an unanswered question. Giant elliptical galaxies also harbor hot (10 million Kelvin) tenuous X-ray–emitting atmospheres like galaxy clusters, although much less luminous and on smaller spatial scales. Ideally, one could compute dark and baryonic matter profiles much like in clusters to test the 17% baryonic fraction claim. However, since the X-ray halos of elliptical galaxies are much fainter than those of clusters, detecting the X-ray emission in the outskirts of galaxies (where constraints on the baryon fraction are most cosmologically useful) is very challenging. Other sources of X-ray contamination, including detector noise, particles masquerading as X-ray photons, and the unrelated cosmological X-ray background, greatly hinder the detection of X-rays from the galaxy in question.

Of all the current X-ray telescopes, the Japanese telescope *Suzaku* has the lowest X-ray background count rate, due in part to its orbit around Earth, as well as its detector design. Thus, *Suzaku* is currently the only X-ray telescope capable of detecting the faint X-ray emission in the outer parts of galaxies. However, the mirrors of *Suzaku* are such that its ability to spatially resolve X-ray emission is somewhat limited (in other words, the mirrors have a large point spread function). This inability to resolve extended galaxy X-ray emission from randomly distributed X-ray point sources emanating well *behind* the galaxy of interest creates issues (the point sources look extended too). Furthermore, X-rays emanating from the cosmic X-ray background (present in all parts of the sky at varying intensities) further complicates matters. Correcting for all these effects is quite difficult, and few in the X-ray astronomy community who attempt it do it correctly. So while *Suzaku* provides the only means to detect the faint X-ray emission from the outskirts of galaxies, the data from this telescope has to be dealt with extremely carefully in order to obtain believable results.

Dr. Eric Miller from the Massachusetts Institute of Technology is one of the world's leading authorities on handling the unique issues that *Suzaku* data presents, as attested to by his extensive publication record on the topic (see publication list on Page 5). Dr. Miller's scientific area of expertise is X-ray emission from clusters of galaxies rather than elliptical galaxies, but the technique he uses to handle the *Suzaku* data is fully applicable to elliptical galaxies. A collaboration with Dr. Miller would be invaluable in learning the intricacies of *Suzaku* data reduction, which is absolutely required for a project of this nature.

The *Suzaku* data for this project has already been collected, and resides in a national data archive provided by NASA available for everyone to download, so data collection is not an issue. Perusal of this archive reveals that there are currently deep *Suzaku* observations of at least a half a dozen galaxies of a variety of optical luminosities and presumably a variety of total masses, allowing us to determine baryon fractions for galaxies on a variety of mass scales. At one week each, it will take approximately six weeks to work through the available data. Adequate computing capability to perform the work will be provided by the laptop computer I will take with me. Dr. Miller and MIT have agreed to host me in the event this proposal is accepted.

Funding Request: Here, I request funds to visit Dr. Eric Miller at the Massachussetts Institute of Technology in Cambridge, MA (budget below) for six weeks in Summer 2013 to learn from him the complexities of dealing with *Suzaku* X-ray data.

Relation to Previous Work of the PI: I have extensive experience in studying the X-ray emission from elliptical galaxies (see attached CV), although until now my work has been confined to the brighter, inner parts of galaxies. The project described in this proposal will provide a substantial extension to my existing area of expertise.

Judging the Success of the Project: The success of the project will be judged based on two criteria: (1) publications and (2) generated outside funding. Given that the crucial data is already available in the data archive, Dr. Miller's expertise in handling the data combined with my expertise in the proposed science should result in at least one publication in a leading astrophysics journal. External funding for continuation of this project will be sought from NASA's Astrophysics Data Analysis Program (ADAP), a funding program through which I have been awarded more than $1 million throughout my career.

Suzaku-Related Publications of Dr. Eric Miller

"Metal Transport by Gas Sloshing in M87", including E. D Miller, 2010, MNRAS, 405, 91

"Suzaku Observations of Abell 1795: Cluster Emission to r_{200}", Bautz, M., Miller, E. D., et al. 2009, PASJ, 61, 1117

"New CTI Correction Method for Spaced-Row Charge Injection of the Suzaku X-Ray Imaging Spectrometer" including E. D. Miller, 2009, PASJ, 61, 9

"The Lack of Strong O-Line Excess in the Coma Cluster Outskirts from Suzaku", Takei, Y., Miller, E. D., et al. 2008, ApJ, 680, 1049

"*Suzaku* Observations of the North Polar Spur: Evidence for Nitrogen Enhancement", Miller, E. D. et al. 2008, PASJ, 60, 95

Budget Justification

Funding is requsted to allow PI Jimmy Irwin to visit Cambridge, MA for six weeks in Summer 2013 to collaborate with Dr. Eric Miller at MIT in order to learn how to correctly handle background and resolution issues that the *Suzaku* X-ray telescopes imparts on the collected data. In detail, I request funds for:

Housing: Having checked craigslist for sublets in Cambridge, MA, a typical sublet price is about \$2000/month. For six weeks, this amounts to **\$3000**.

Airfare: From orbitz.com, a round-trip flight from Birmingham, AL to Boston, MA in Summer 2013 is **\$370**.

Transportation To/from Airport: Estimated \$100 each way, for a total of **\$200**.

Subway Pass for Travel To/From MIT each day: Boston MTBA subway webpage quotes a monthly pass price of \$70, so six weeks is **\$105**.

Food: An estimated \$30/day on food is requested, which for 45 days amounts to **\$1350**.

Total: \$5025

CURRICULUM VITAE

Jimmy A. Irwin
Department of Physics & Astronomy, University of Alabama, P.O. Box 870324, Tuscaloosa, AL 35487-0324
(205) 348-3791 jairwin@ua.edu

POSITIONS

Aug. 2009 – present	**Assistant Professor**	Department of Physics & Astronomy, University of Alabama
Aug. 2009 – present	**Visiting Assistant Professor**	Astronomy Department, University of Michigan
Apr. 2003 – Aug. 2009	**Assistant Research Scientist**	Astronomy Department, University of Michigan
Sep. 1999 – Aug. 2002	***Chandra* Fellow**	Astronomy Department, University of Michigan
Sep. 1997 – Aug. 1999	**Postdoctoral Research Fellow**	Astronomy Department, University of Michigan
Fall 1992 – Aug. 1997	**Graduate Research Assistant**	Astronomy Department, University of Virginia

EDUCATION

1995 – 1997	**University of Virginia** Ph.D. Astronomy, August 1997	Charlottesville, VA
1992 – 1995	**University of Virginia** M.A. Astronomy, January 1995	Charlottesville, VA
1988 – 1992	**Indiana University** B.S. Astronomy and Astrophysics, May 1992, Summa Cum Laude, Phi Beta Kappa	Bloomington, IN

ACCEPTED FUNDED PROPOSALS (PI only) Total: $2,315,478 (career; $1,332,173 since arriving at UA)

4-year NASA Astrophysics Data Program – 2010-2014 - $500,483
5-year NASA Long term Space Astrophysics 2005-2010 $595,519
Chandra AO-14 $32,912
Chandra AO-13 $205,965
Chandra AO-11 (2) $96,690
Chandra AO-9 $45,524
Chandra AO-6 $36,478
Chandra AO-5 (2) $88,500
Chandra AO-4 (2) $82,845
Chandra AO-3 (2) $67,270
Chandra AO-2 $35,000
Chandra AO-1 $30,000
XMM-Newton AO-10 $57,202
XMM-Newton AO-6 $61,972
XMM-Newton AO-4 $50,500
XMM-Newton AO-3 (3) $133,800
XMM-Newton AO-2 $47,701
XMM-Newton AO-1 $32,500
Suzaku AO-4 $30,425
HST Cycle-12 $78,030
HST Cycle-19 $6162

Note: Postdocs and graduate students under my direction have brought to UA an additional $411,865.

POSTDOCS / GRADUATE STUDENTS ADVISED

Fall 2012 - present	Peter Maksym - postdoc	University of Alabama (RSP Fellow)
Fall 2012 - present	Dacheng Lin - postdoc	University of Alabama
Fall 2010 - present	Evan Million – postdoc	University of Alabama
Fall 2010 - present	Ka-Wah Wong - postdoc	University of Alabama
Fall 2010 - present	Mihoko Yukita - postdoc	University of Alabama
Fall 2009 - present	Yuanyuan Su – graduate student	University of Alabama
Fall 2004 – Summer 2006	Chris Mullis - postdoc	University of Michigan

IN THE NEWS

NASA Press Release – "Massive Black Hole Implicated in Stellar Destruction" – January 2010
NASA Press Release –"NASA's Chandra Observatory Images Gas Flowing Toward Black Hole"–July 2011

RESEARCH AREAS

Intermediate-Mass Black Holes
potential tidal disruption of stars by IMBHs within globular clusters, ultraluminous X-ray sources (ULXs)
X-ray Binary Populations of Galaxies
NS vs BH primaries; X-ray luminosity functions; globular cluster habitat of XRBs; long-term variability
Globular Clusters
testing dynamical history with X-ray binaries, black holes and globular clusters
X-ray Emission From Hot Gas in Early-type Galaxies
L_X / L_B dispersion problem, metallicity of hot gas, accretion history of early-type galaxies
Clusters/Groups of Galaxies
temperature and abundance profiles; gravitational lensing from groups of galaxies
Hot Gas Around Supermassive Black Holes
testing accretion flow models by studying gas within the Bondi radius of a SMBH

RELEVANT & SELECTED PUBLICATIONS

"Hot Diffuse Emission in the Nuclear Starburst Region of NGC 2903"
Yukita, M., Swartz, D., Tennant, A., Soria, R., & Irwin, J., ApJ,, in press
"X-Ray Searches for Emission from the WHIM in the Galactic Halo and the Intergalactic Medium"
Bregman, J. N., Otte, B., Irwin, J. A., Putman, M. E., & Lloyd-Davies, & E. J.; Brüns, C. 2009, ApJ, 699, 1765
"Elemental Abundances in the X-Ray Gas of Early-Type Galaxies with XMM-Newton and Chandra Observations"
Ji, J., Irwin, J. A., Athey, A., Bregman, J. N., & Lloyd-Davies, E. J. 2009, ApJ, 696, 2252
"The Size of the Cooling Region of Hot Gas in Two Elliptical Galaxies"
Bregman, J. N., Otte, B., Miller, E. D., Irwin, J. A., ApJ, 642, 759, 2006
"ROSAT X-Ray Colors and Emission Mechanisms in Early-Type Galaxies"
Irwin, J. A., & Sarazin, C. L., ApJ, 499, 650, 1998

"Luminous [O III] and [N II] From Tidally Disrupted Horizontal Branch Stars"
Clausen, D., Sigurdsson, S., Eracleous, M., & Irwin, J.A., MNRAS, 424, 1268, 2012
"Resolving the Bondi Accretion Flow toward the Supermassive Black Hole of NGC 3115 with Chandra"
Wong, K.-W., Irwin, J. A., Yukita, M., Million, E. T., Mathews, W. G., & Bregman, J. N., ApJ, 736, L23, 2011
"Evidence for an Intermediate Mass Black Hole in an Extragalactic Globular Cluster from Optical Emission Lines"
Irwin, J.A., Brink, T., Bregman, J. N., & Roberts, T. P., ApJ, 712, L1, 2010
"The Search for Million Degree Gas Through the N VII Hyperfine Line"
Bregman, J. N., & Irwin, J. A., ApJ, 666, 139, 2007
"The Remarkable Stability of Probable Black Hole Low-Mass X-ray Binaries in Nearby Galaxies"
Irwin, J. A., MNRAS, 371, 1903, 2006