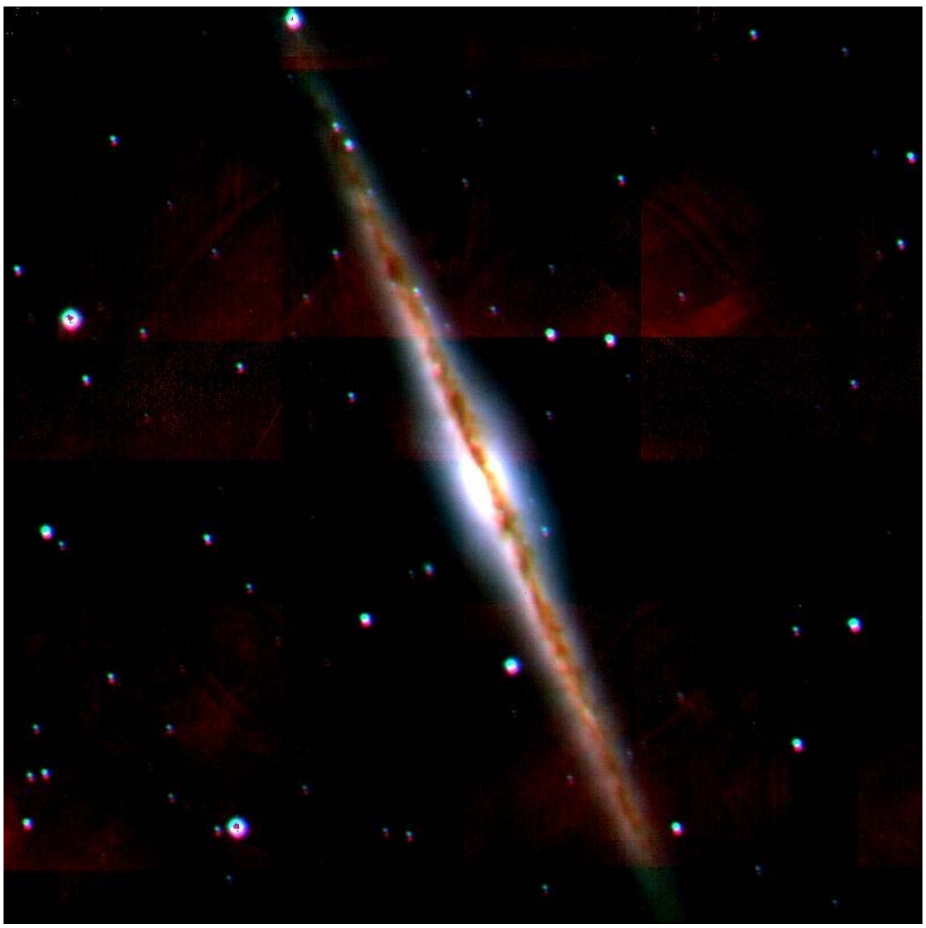
Boston University
Institute for Astrophysical Research
Annual Report
June 2005



An infrared image of the edge-on spiral galaxy NGC 891 taken with the IAR's newest instrument, Mimir

James M. Jackson, Director
Kimberly Paci, Fiscal Administrator

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Summary

The Institute for Astrophysical Research marked a very successful 7th year in its mission to foster research in astrophysics at Boston University. With the successful deployment of the Mimir near-infrared instrument at Lowell Observatory's Perkins Telescope, the IAR now has access to three state-of-the-art instruments. In addition to Mimir, MIRSI (the Mid-InfraRed Spectrometer and Imager at NASA's Infrared Telescope Facility) and PRISM (the optical Perkins ReImaging SysteM at Lowell) continue to operate beautifully. The Galactic Ring Survey, a seven-year project to map the distribution of molecular gas from a large portion of the inner Milky Way, completed its observations in April.

The IAR continues a vigorous research program. IAR members published twenty-five scientific papers in refereed journals. Among the scientific highlights are: (1) the detection of the most powerful radio outburst known in the Universe, (2) the detection of the long-sought spin-flip spectral line of deuterium, and (3) the debunking of the puzzling result known as the Holmberg effect, which purported to show that small, satellite galaxies are located primarily along the poles of rotating spiral galaxies.

In FY2005, total IAR grant expenditures, including new and continuing grants, was $924,406. IAR members submitted twenty new funding proposals totaling over $4M in requests. The IAR received a total of $1,248,412 in grant income, including twelve new awards totaling $827,966.

Institute Mission

The mission of the IAR is to promote and facilitate research and education in astrophysics at Boston University. The IAR accomplishes this mission by: (1) administering research grants, (2) enhancing the visibility of IAR members with funding agencies and in the astrophysics community, (3) coordinating the use of Boston University astrophysics facilities, and (4) promoting the design, development, and operation of Boston University instruments and telescopes.

Faculty, Staff and Students

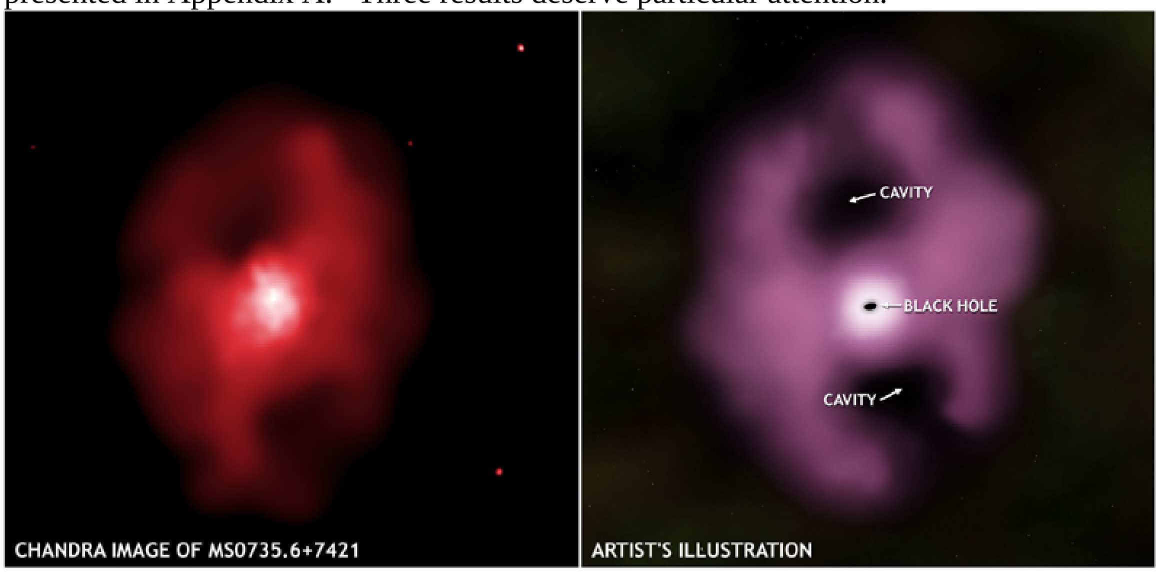
During this past year, the IAR membership consisted of faculty, staff, and students involved in astrophysical research. Faculty members included Professors Thomas Bania, Dan Clemens, James Jackson, Kenneth Janes, and Alan Marscher, Associate Professor Tereasa Brainerd, and our newest addition, Assistant Professor Elizabeth Blanton. Research Associates affiliated with the IAR included Senior Research Associate Dr. Svetlana Jorstad, Research Associates Drs. Jill Rathborne and Ronak Shah and Research Fellow Dr. Kathleen Kraemer. IAR staff members included Senior Research Associate Dr. Amanda Bosh, stationed in Flagstaff, Arizona at the Lowell Observatory site on Mars Hill and IAR Fiscal Administrator Ms. Kimberly Paci.

Graduate students conducting astrophysical research with IAR faculty during the past year included Loren Anderson, Ingolfur Augustsson, Nina Bonaventura, Monica Brucker, Edward Chambers, Ritaban Chaterjee, Francesca D'arcangelo, Edmund Douglass, Paul Howell, Alexis Johnson, Emily Mercer, and Suwicha Wannawichian,. Undergraduate students working within the IAR included Amy Caluori, Michael Dormody, Jason Eastman, James Kim, Richard Lavoie, Michael Martin, Gila Roman,. Daniel Salem, Joshua Shiode and Elizabeth Taber.

Dr. Andrei Sokolov defended his PhD dissertation, entitled "Theoretical Study of Multifrequency Emission Variability in Blazars" and received his degree in August 2004. Dr. Sokolov is the IAR's sixth PhD recipient.

Scientific Highlights

Over the past year IAR members published a number of significant scientific papers, including twenty-five papers in refereed journals and twenty-nine conference proceedings and abstracts. A complete list of all of last year's IAR publications is presented in Appendix A. Three results deserve particular attention.

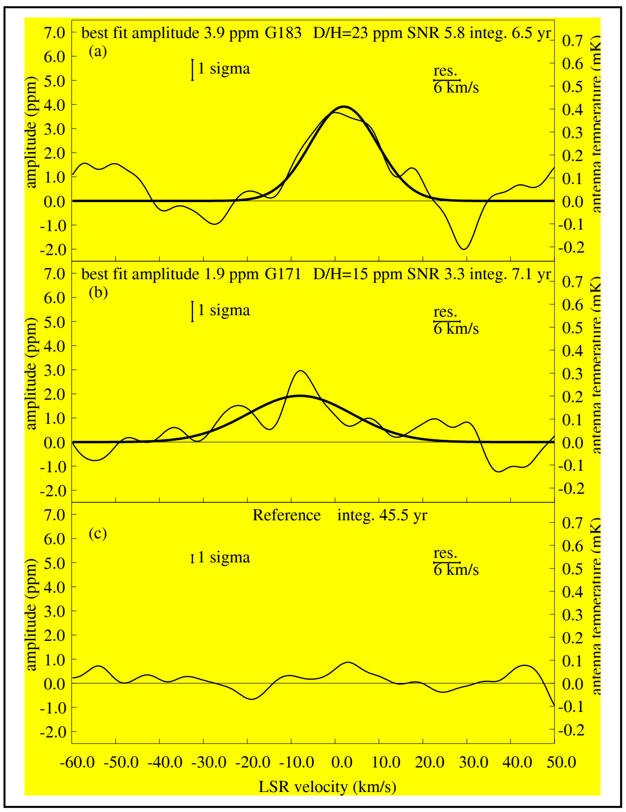


A Powerful Outburst from a Supermassive Black Hole

In a study led by B. McNamara of Ohio University, IAR member Prof. Elizabeth Blanton was a key member of a team that found the most powerful radio outburst known in the Universe. Their study, published in *Nature*, shows that the outburst came from a supermassive black hole deep in the center of a giant elliptical galaxy, which is itself in the center of a large cluster of galaxies called MS0735.6+7421. Giant elliptical galaxies, which form from cannibalizing a large number of smaller galaxies within a galaxy cluster, often host very massive black holes that sometimes produce powerful jets and radio lobes. When the team examined the X-ray emission from this cluster, giant cavities were found in the X-ray-emitting gas. These cavities were formed when an energetic outburst generated twin radio lobes that pushed aside the hot gas. There is evidence that shocks from the interaction of the radio lobes with the X-ray gas is preventing cooling of the gas and the formation of stars in the central galaxy.

The Deuterium Spin-Flip Transition

Astronomers have spent the past 45 years trying to detect the 327 MHz spin-flip transition of deuterium (a rarer, heavier form of hydrogen) in the Milky Way's interstellar medium. Bania is part of a team led by A.E.E. Rogers that has finally detected this Holy Grail of radio astronomy. Because deuterium formed very soon after the Big Bang, the abundance of deuterium provides important information about the early Universe. The team has measured the deuterium-to-hydrogen (D/H) ratio by detecting the hyperfine ground state transition of deuterium at 327 MHz (92 cm). The emission arises from interstellar gas in the region of the Galactic anticenter (*l*=183 deg) where the deuterium signal is expected to be strongest due to velocity crowding. Using these deuterium and existing hydrogen observations, they model the effects of beam dilution, spin temperature, and absorption of continuum to derive a D/H ratio of 2.3 ±1.5 x10^{-5} by number.



The detection of the deuterium line is shown to the right. The peak in the middle of the top panel shows that the line is clearly detected. The second panel shows a more tentative detection toward a second position that confirms the result. Finally, the bottom panel shows that no line is detected when pointing the telescope to a blank portion of the sky.

Reversing the "Holmberg Effect"

Professor Brainerd has continued her work on the fundamental nature of the dark matter halos that surround large galaxies in the universe and, in particular, she has focused her efforts on whether or not the dark matter halos of galaxies are in agreement with the predictions of the popular Cold Dark Matter (CDM) theory. Last year, Brainerd has debunked a long-standing observation that satellite galaxies have a strong preference to be clustered near the minor axes of their host galaxies. This observation, known commonly as the Holmberg effect, has puzzled astronomers for nearly 40 years because, if correct, it leads to the dynamically untenable conclusion that the disks of large spiral galaxies are oriented perpendicularly with respect to the largest principle axes of their dark matter halos. Using the large, publicly available

Sloan Digital Sky Survey (SDSS), Professor Brainerd has shown that, contrary to previous claims in the literature, satellite galaxies are not preferentially clustered near to the minor axes of their hosts. Rather, the satellites are in fact preferentially clustered near to the major axes of their hosts. This has completely resolved the puzzle; the Holmberg effect does not exist and claims of its existence were caused by systematic effects in small data sets.

Instrumental Program

IAR members are actively engaged in building state-of-the-art astronomical instrumentation. FY 2004 marked a major milestone in the IAR with the completion and deployment of its third major instrument, Mimir. Mimir, along with PRISM and MIRSI, allow IAR astronomers to study astronomical objects at wavelengths that span the optical, near-infrared, and mid-infrared.

Mimir at the Perkins telescope, Co-PIs Dan Clemens (IAR) and Marc Buie (Lowell).

Mimir

The IAR’s newest instrument, Mimir, was successfully deployed this past year. Mimir, named after a Norse god, is a new facility-class infrared instrument built at our IAR lab and at Lowell Observatory. Mimir saw “first light” on the 1.8 meter Perkins telescope outside Flagstaff, Arizona on August 19, 2004. Boston University and Lowell Observatory share equal use of this telescope and its instruments.

Mimir is a multi-function instrument that covers a broad wavelength range and allows users to perform complex observations with a single instrument. The three main functions

Mimir performs are imaging (much as a camera takes pictures), spectroscopy (decomposing infrared light into its constituent colors), and polarimetry (measuring how the infrared light is polarized). Mimir's wavelength coverage is from 1 to 5 micrometers, or from about twice the wavelength of green light to about ten times that wavelength.

Mimir has successfully completed its engineering tests and is now available for use by the general astronomical community. Its wide field of view and its polarametric capability make it a unique resource.

Mimir infrared image of the nearby Orion star-forming region. Mimir's wide field easily captures all of this complex region in a single pointing. The picture reveals the ionization bar at the lower left as well as the deeply embedded K-L star-forming core in the upper right (the orange region). The large number of stars in the region is a testament to the efficiency of this molecular cloud to making new stars. Interestingly, the four bright Trapezium stars - the ones most easily seen at optical wavelengths - are too bright for Mimir and are saturated, producing the artificially blue/green colors seen (middle of image).

PRISM

After two years of fundraising and three years of construction, we put PRISM into regular use for wide-field imaging in the spring of 2004. In its first year of operation, PRISM has made a little over 20000 exposures on over 100 nights of observing. About 15 astronomers from BU, Lowell and other institutions have used PRISM. BU projects include monitoring stellar activity (starspots), monitoring blazar variability and polarization, searching for old star clusters and observing occultations of stars by planetary rings. A new program of supporting observations for a planetary search program will begin in the fall.

The original plan for PRISM spectroscopy was to use conventional grisms, but a new method for making diffraction gratings has become available. These new gratings, called "Volume-Phase holographic" (VPH) gratings make it possible to design a grism with much better spectral resolution over a larger spectral region at lower cost than a conventional grism. Undergraduate student Jason Eastman took on this project and completed the design and construction in a few months. We were able to get a few hours of good weather in an otherwise cloudy observing run to test the VPH grism. The VPH grism works just as it was designed to work, yielding a spectral resolution, R = 2000, at

H-alpha. The PRISM spectroscopic mode should now be considered operational and will be used for old open cluster studies in the fall.

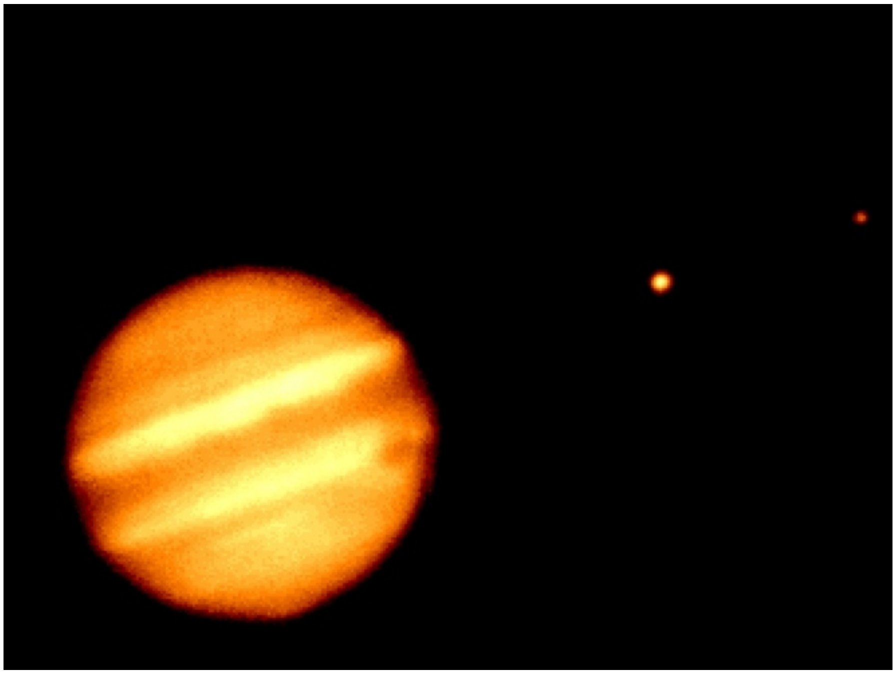
The polarimetric mode is also now ready for use. The blazar research group (Marscher and Jorstad) will begin monitoring variability in blazar polarization in the coming summer.

Two new NSF grants that depend in part on PRISM (Marscher's blazar program, and the PREST program discussed below) have come in during the past few months and one more PRISM-related proposal is still under review at the NSF. PRISM is best suited for long-term surveys and monitoring programs, so it will be a while yet before major PRISM papers come out. But PRISM is also well-suited to short student projects, and there are three draft papers in the works with new results on interesting old open clusters. Graduate student, Nina Bonaventura has begun her PhD thesis using PRISM and Mimir.

A PRISM image of the Owl nebula. The Owl is a so-called "planetary nebula", in which the hot star at the center of the shell has expelled its outer atmosphere. The star is nearing the end of its life, and the hot core will soon become a "white dwarf," a very compact object about the size of the earth but containing the mass of an entire star.

MIRSI

MIRSI, the Mid-InfraRed Spectrometer and Imager, is a wide-field mid-infrared camera deployed to NASA's Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. This past year, the IAR entered into a long-term agreement with the IRTF to make MIRSI available to the community as a facility-class instrument. The demand for use of MIRSI is quite high; the IRTF can only make available about one-sixth of the proposed requests.



A MIRSI image at 8.7 microns of Jupiter and its moons Io and Callisto.

IAR astronomers are using MIRSI to study deeply embedded star-forming regions. Such regions heat the surrounding dust and gas clouds, which emit primarily at mid-infrared wavelengths. Because MIRSI is equipped with the largest commercially available mid-infrared detector array, it can make superlative wide-field images of planets, star-forming regions, and evolved stars.

Lowell Observatory Partnership

The IAR continues its partnership with Lowell Observatory to share the use of the 72-inch Perkins telescope on Anderson Mesa near Flagstaff, Arizona. Boston University and Lowell have entered into a new five-year agreement for equal use of the telescope and its facilities. In addition, the IAR is actively engaged in seeking support to join Lowell in its newest project, the Discovery Channel Telescope.

PREST

In June 2004 the NSF Astronomy program initiated a "Program for Research and Education with Small Telescopes" (PREST) to provide support for groups like our BU/Lowell Observatory collaboration. The IAR and Lowell submitted a joint proposal to improve the capabilities and educational mission of the Perkins Telescope. Our proposal received the highest ranking of over 50 proposals in the initial round.

Our project has two primary components. The Lowell part will be used for improvements to the telescope and the dome to improve telescope efficiency and image quality. On the BU side, we have funds to support a graduate-student-in-residence in Flagstaff and to provide travel funds to bring both graduate students and undergraduates to Flagstaff to participate in the observing at the site. We have already brought a dozen students to Flagstaff, 8 of them as part of the undergraduate upper-level lab course. Three other undergraduate students have completed independent study projects and graduate student Nina Bonaventura has begun her PhD research.

This grant will make it possible to integrate the Perkins Telescope into our curriculum and to enable students to participate in the research enterprise. Several of the students who participated during the past semester are continuing to work informally on the research projects they began in Flagstaff.

DISCOVERY CHANNEL TELESCOPE

Lowell Observatory is designing and building the Discovery Channel Telescope, a new 4-meter diameter telescope optimized for wide-field imaging, monitoring, and surveys. These unique capabilities are an excellent match to the research interests of IAR faculty. The IAR has therefore proposed that the University should join with Lowell Observatory and the Discovery Channel to construct and instrument this state-of-the-art 4-meter telescope in Northern Arizona. A wide-field camera planned as the key instrument for the telescope will give the DCT greater capacity for surveys of the sky by a factor of about four over existing telescopes. A companion wide-field, high-angular resolution infrared camera will help to give the telescope unique capabilities.

The Discovery Channel has generously funded a large portion of the project. A partnership between Boston University and the Discovery Channel would prove enormously beneficial to both parties for furthering their educational missions.

The DCT is a logical next step to strengthen the existing partnership between Boston University and Lowell Observatory; it will enable large-scale surveys and synoptic studies, not open to BU astronomers on the existing national and international telescopes, such as Gemini, the VLT or Keck telescope. The DCT will put our partnership ahead of groups developing the next generation of large survey telescopes such as Pan-STARRS or the LSST. The connection to the Discovery Channel will permit innovative and exciting educational initiatives, with the potential for involving a large number of BU students.

Seminar Series

The IAR Astrophysics Seminar Series on Tuesday afternoons brings external astrophysicists from the local area as well as from across the nation to Boston University to present their recent work and to consult with IAR faculty and students. During the past year, the IAR sponsored seminars by twenty-one astrophysicists from across the nation. Students prepare for upcoming seminars through the Astrophysics Journal Club, which meets Friday afternoons. The seminar schedule is shown in Appendix B.

Future Activities

During the upcoming year, we will continue the Perkins telescope partnership with Lowell Observatory. MIRSI will be deployed to the Infrared Telescope Facility, and Mimir and PRISM to the Perkins telescope. These instruments will greatly improve the quantity, quality, and stature of our scientific publications in the upcoming next few years.

We will continue to promote the Discovery Channel project as our first priority for a new telescope facility. The DCT will provide both cutting-edge research opportunities and also important educational capabilities to help propel us to the next tier of front-line research institutions. In addition, the DCT will provide important exposure of Boston University and the IAR to the public.

As our new instruments and telescopes (MIRSI, Mimir, PRISM) come on-line, we need to position ourselves to make the new discoveries that these unique capabilities will make possible. However, as many of our faculty have made the transition from observational to instrumental programs, we have fewer faculty devoted to observing and analysis. The IAR needs a new, young astrophysics faculty member who will utilize our instruments and telescopes to conduct world-class research and to secure our rise in scientific stature. That person should be sought and hired within the next 2 years.

Appendix A: Publications

Articles in Referred Journals

Agustsson, I. and Brainerd, T. G. 2005, "The Distribution of Satellite Galaxies in a Lambda-CDM Universe", submitted to ApJ, astro-ph/0505272

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Brainerd, T. G., 2004, "Anisotropic Distribution of SDSS Satellite Galaxies: Planar (not Polar) Alignment", submitted to ApJL, astro-ph/0408559

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Clarke, T. E., Sarazin, C. L., Blanton, E. L., Neumann, D. M., & Kassim, N. E., "Low-Frequency Radio Observations of X-Ray Ghost Bubbles in A2597: A History of Radio Activity in the Core", Astrophysical Journal v. 625, P.748-753 (2005)

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Jackson, J., "Jackson: The Harold Jeffreys Lecture: Mountain roots and the survival of cratons", Astronomy and Geophysics v. 46, P.33-2 (2005)

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McKenzie, D., Jackson, J., & Priestley, K., "Thermal structure of oceanic and continental lithosphere [rapid communication]", Earth and Planetary Science Letters v. 233, P.337-349 (2005)

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Appendix B: Seminar Series Schedules

Institute for Astrophysical Research Seminar Series
Fall 2004

September 7	David Goldberg (Drexel University) Galaxy Flexion: Gravitational Lensing to Second Order
September 14	Christine Jones (Harvard/CfA) The Impact of AGN Outbursts on Hot Gas in Elliptical Galaxies
September 21	Robert Kirshner (Harvard/CfA) The Accelerating Universe: Exploding Stars and Dark Energy
September 28	Bob Millis and Tom Sebring (Lowell Observatory) The Discovery Channel Telescope
October 5	Dan Clemens (IAR) Mimir -- Our Near-Infared Imager, Spectrometer, and Polarimeter on the Perkins Telescope
October 12	Oleg Gnedin (Ohio State) Formation of Globular Clusters in Hierarchical Cosmology
October 19	Rescheduled to Dec. 7
October 26	Svetlana Jorstad (IAR) Highly Variable Apparent Speed of the Quasar 3C 279
November 2	Alexey Vikhlinin (Harvard/CfA) Cosmology with Chandra Cluster Data
November 16	Dawn Peterson (UVA) The Pre--Main Sequence and Brown Dwarf Populations of OMC 2/3: A Multiwavelength Study
November 30	Ben Oppenheimer (American Museum of Natural History) The Lyot Project: Toward Exoplanet Imaging and Spectroscopy
December 7	Kris Sellgren (Ohio State) Spitzer Space Telescope Observations of the Reflection Nebula NGC 7023

Institute for Astrophysical Research Seminar Series
Spring 2005

January 28 Friday	Dan Harris (CfA) The Jets of the Radio Galaxies M87 and 3C 120
February 1	Phil Uttley (NASA/GSFC) Variability of Radio-Quiet AGNs and the AGN/X-Ray Binary Connection
February 15	Anil Bhardwaj (NASA/MSFC) X-Rays from Solar System Bodies
February 25 Friday	Luis Ho (Carnegie Observatory) Black Hole Demographics in the Local Universe
March 1	Martin Elvis (CfA) Quasar Winds
March 15	Glenn Ciolek (RPI) MHD Shocks & Waves in Dusty Clouds
March 22	Randy Phelps (NSF) Newborn Stars, Old Open Clusters and the Evolving Scientific Workforce
April 5	Bruck Carney (U. North Carolina) TBA
April 12	Tim Slater (U. Arizona) Are You Teaching if No One Is Learning? Impact of Astronomy Education Research on ASTRO 101
April 26	Pavel Denisenko (Dartmouth Col.) Nucleosynthesis in Low-Mass Red Giants