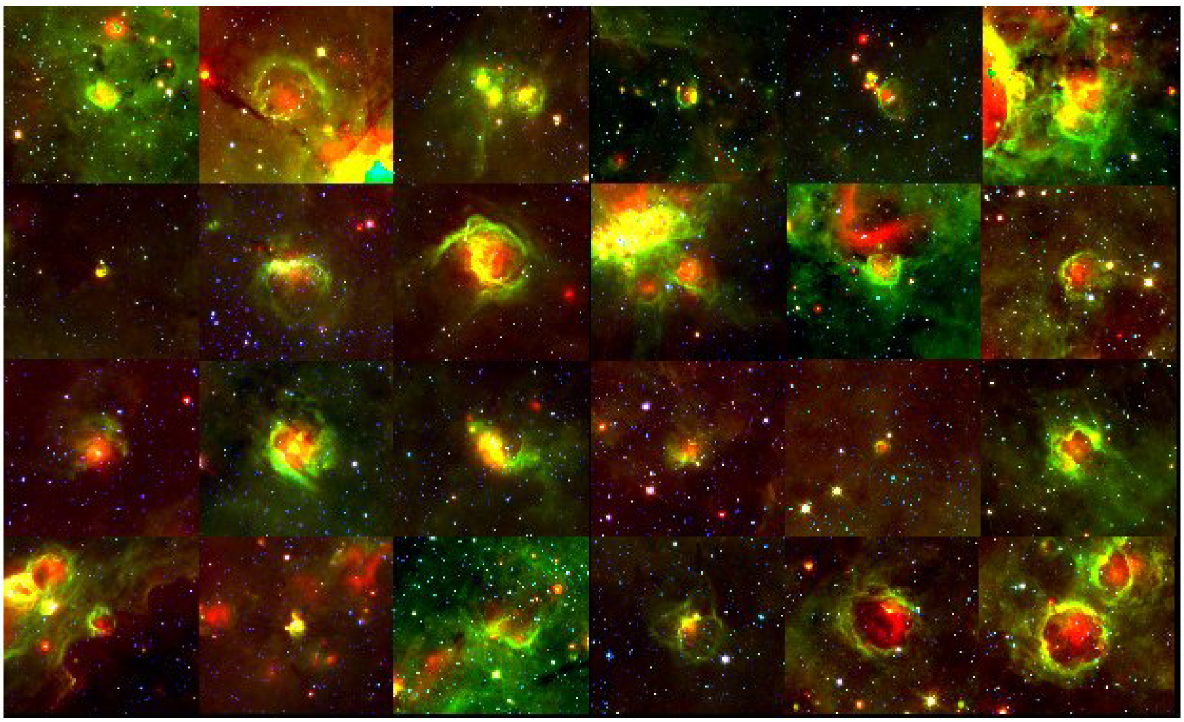
Boston University
Institute for Astrophysical Research



Twenty four of the 488 new Milky Way H II regions discovered by the GBT HRDS research team. These are composite infrared images from the GLIMPSE/MIPSGAL surveys made by NASA's Spitzer Space Telescope. Each image is 5 arcminutes on a side. Red: MIPSGAL 24 micron emission, Green: GIMPSE 8 micron emission, Blue: GLIMPSE 4.5 micron emission.

Annual Report
June 2010

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Introduction

Summary

The Institute for Astrophysical Research marked a successful 12th year in its mission to foster research at Boston University. All of our state-of-the-art astronomical instruments (Mimir and PRISM at Lowell Observatory, and MIRSI at NASA's Infrared Telescope Facility) are operating well and are returning exciting results.

The IAR continues its vigorous research program. In the past year, IAR members published 38 scientific papers in refereed journals. Among our scientific highlights are: (1) the completion of the Green Bank Telescope H II Region Discovery Survey, (2) the acquisition of an extraordinarily deep X-ray image of galaxy cluster Abell 2052, and (3) the assembly of the largest ever catalog of binary stars.

In FY2010, total IAR grant expenditures, including new and continuing grants, was $1,335,461.57. IAR members submitted 15 new funding proposals totaling over $3.39M in requests. The IAR received a total of $1.5M in grant income, including 6 new awards totaling $846,886.

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 within the astrophysics community, (3) coordinating the use of Boston University astrophysics facilities, (4) promoting the design, development, and operation of Boston University instruments and telescopes, (5) regularly sponsoring seminars and professional meetings, and (6) actively engaging students of all levels in research. The IAR jointly operates the Perkins Telescope, along with Lowell Observatory.

Faculty, Staff and Students

In FY2010, IAR personnel included faculty members in the Department of Astronomy: Professors Thomas Bania, Dan Clemens, James Jackson, Kenneth Janes, and Alan Marscher; Associate Professor Tereasa Brainerd (IAR Director); and Assistant Professors Elizabeth Blanton and Andrew West. Other personnel included Senior Research Scientist Dr. Svetlana Jorstad, Post-doctoral Associates Dr. Manasvita Joshi and Dr. Jonathan Foster, Post-doctoral fellow Dr. Ivan Agudo, Visiting Researchers Dr. Kathleen Kraemer and Dr. Kevin Covey, Senior Research Scientist Mr. Brian Taylor (Telescope Support Scientist stationed in Flagstaff, AZ at Lowell Observatory), and IAR Fiscal Administrators Ms Kimberly Paci (07/09-11/09) and Ms Xiomara Forbez (1/10-present).

IAR graduate research students in FY2010 were: Ingolfur Agustssson, Jan Marie Andersen, Loren Anderson, Dipesh Bhatterai, Ritaban Chatterjee, Christopher Claysmith, Francesca D'Arcangelo, Edmund Douglass, Susanna Finn, Paul Howell, David Jones, Ji-Hyun Kim, Chad Madsen, Michael Malmrose, Dylan Morgan, Michael Pavel, April Pinnick, Patricio Sanhueza, Laura Sturch, Joshua Wing, and Moncia Young. IAR undergradute research students in FY2010 were: Elizabeth Barris, Meredith Bartlett, Brandon Harrison, Sadia Hoq, Christopher Janiszewski, Robert Marchwinski, Joshua Mascoop, Julie Moreau, Kyle Schluns, Jessica Stellman, Hally Stone, Nora Watson, Trey Wenger, and Bertie Wright. In addition to these students, IAR members are also working with research students at other institutions: Saurav Dhital (Vanderbilt University), Daria Melnik (St. Petersburg State University, Russia), John Sebastian Pineda (Massachusetts Institute of Technology), Noel Richardson (Georgia State University), Ivan Troizikij (St. Petersburg State University, Russia), and Christine Trombley (Rochester Institute of Technology).

Science Highlights

Completion of the Green Bank Telescope H II Region Discovery Survey

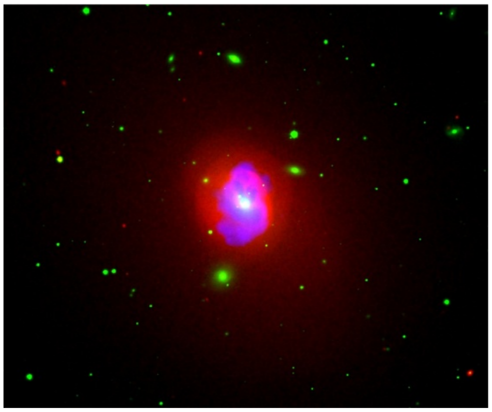
Professor Bania and former BU graduate student Dr. Loren Anderson have now completed a multi-year project known as the Green Bank Telescope (GBT) H II Region Discovery Survey (HRDS). The GBT HRDS used over 250 hrs of telescope time to discover a large population of previously unknown star formation sites in our Milky Way galaxy. A collection of 24 of these new objects is shown on the cover of this report. These formation sites of massive, OB-type stars were found using the NRAO Green Bank Telescope at 3 cm wavelength (X-band) to discover recombination line emission from the nebulae. Since recombination lines are optically thin at 3 cm wavelength, it was possible to detect the H II regions across the entire disk of our Galaxy. Survey targets were selected based on spatially coincident 24 micron and 21 cm continuum emission. Professor Bania and Dr. Anderson detected 602 discrete recombination line components from 448 lines of sight, or 95% of the sample targets, which more than doubles the number of known H II regions in the region of the Milky Way that they studied. The distribution of the H II regions across the Galactic disk shows strong, narrow (about 1 kpc wide) peaks at Galactic radii of 4.3 kpc and 6.0 kpc. The longitude-velocity distribution of the H II regions gives unambiguous evidence for Galactic structure, including the kinematic signatures of the radial peaks in the spatial distribution, a concentration of nebulae at the end of the Galactic Bar, and nebulae located on the kinematic locus of the so-called 3 kpc Arm.

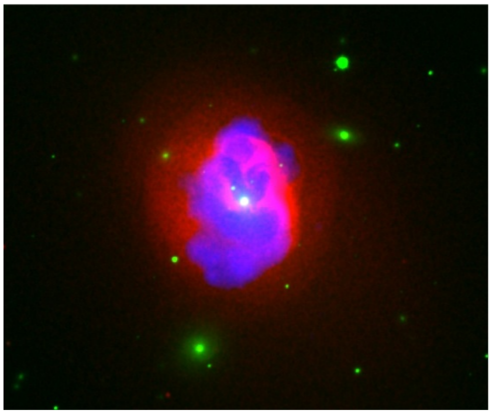
For these new HRDS nebulae Professor Bania's team, which also includes Dr. Dana Balser (NRAO) and Professor Bob Rood (University of Virginia), will determine the nebular kinematic distances, luminosities, metallicities (via the electron temperature, T_e), and helium abundances (^{4}He/H=Y). Both T_e and Y provide important constraints on models for Galactic chemical evolution, GCE. Knowing the Galactic location of the new nebulae allows them to identify objects that will provide the most robust GCE constraints. The HRDS found 25 new first quadrant nebulae with negative LSR velocities, placing them in the GCE-critical region beyond the Solar orbit at R_{gal} ~ 9 kpc to 12 kpc. The HRDS also gives a more accurate census of HII regions and their properties, providing a fair sampling of nebulae at all stages of their evolution, and increasing our knowledge of Galactic structure.

Professor Bania and Dr. Anderson announced the initial results of the GBT HRDS at the June 2010 meeting of the American Astronomical Society (AAS) in Miami, FL. The HRDS generated a lot of excitement at the meeting; there were press releases from the AAS, NASA, and NRAO. Professor Bania and Dr. Anderson also gave one of the AAS meeting Press Conferences. A significant amount of media attention was devoted to their work, including several dozen internet and newspaper articles (e.g. Fox News, Wired, Science News, ScienceDaily, Astronomy Now, etc.)

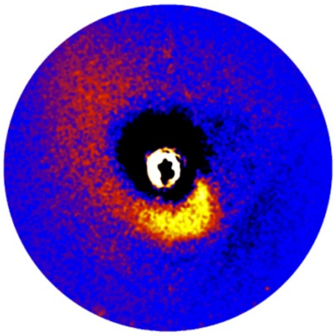
Deep X-ray Observations of Galaxy Cluster Abell 2052

Prof. Blanton's research focuses on clusters of galaxies, particulary clusters with large radio sources driven by the accretion of matter onto supermassive black holes in the galaxies in cluster centers. Professor Blanton recently received 500 ksec of data on the cooling flow cluster Abell 2052 from the Chandra X-ray Observatory. When the new data are combined with previous, existing data, the total observation is approximately 650 ksec, or over seven days of integration on the source! Exquisite detail is revealed in the image, including bubbles inflated by the AGN-associated radio source, narrow filaments, and loops. A shock with a Mach number of 1.2, driven by the radio source, is seen surrounding the cluster center. The temperature rise associated with this shock has now been measured, and such temperature rises associated with shocks in cooling flows are only rarely seen since they are generally weak and very difficult to detect. At larger scales, a 'spiral' of excess emission is seen in the X-ray gas when subtracting an average beta-model from the X-ray emission. This excess emission may be due to gas flowing into the cluster center, feeding the cooling flow, and may be related to a merging sub-group. It also may be related to 'sloshing' of the cD galaxy in the center of the cluster potential induced by a merger.





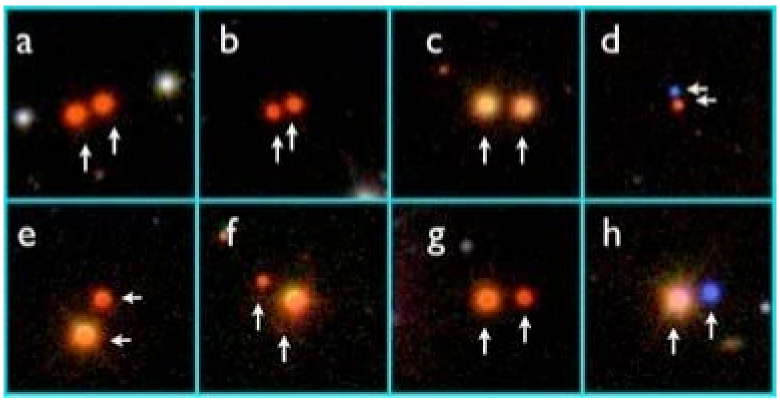
Left: Composite image of the cooling flow cluster Abell 2052, where red shows the Chandra X-ray emission, blue shows the VLA 4.6 GHz radio emission, and green shows the r-band optical emission from the Sloan Digital Sky Survey. Bubbles in the X-ray emission have been evacuated by the radio source associated with the central AGN, and the radio emission extends to fill a number of features, including the bubble to the north west that is bounded by a narrow filament. A shock is seen in the X-ray emission as the jump in surface brightness extending in an ellipse around the cluster center, exterior to the radio source. The image is approximately 280 kpc by 240 kpc. Right: A zoom-in on the central region of the image shown on the left. This better reveals the detailed interaction between the radio source and the X-ray emitting intracluster medium. Relative scalings between the radio, X-ray, and optical have also been changed in this view. The image is approximately 145 kpc by 120 kpc.



Residual Chandra X-ray image of Abell 2052 in the 0.3 keV to 2 keV band, after subtracting off a 2-dimensional "beta" model. The spiral-like structure seen in the X-ray gas may be related to infalling gas feeding the cooling flow, or motions in the intracluster medium related to "sloshing" of the cD galaxy in the central potential (induced by a merger). The radius of the circle is 339 arcsec (or 238 kpc at the redshift of the cluster).

SLoWPoKES: A Large Sample of Wide Low-Mass Stellar Pairs to Test Models of Stellar and Galactic Evolution

Professor West, working with Mr. Saurav Dhital (Vanderbilt University) and Professor Keivan Stassun (Vanderbilt University), has helped to collect and analyze the largest catalog of binary stars ever assembled. The recently published sample, dubbed the Sloan Low-mass Wide Pairs of Kinematically Equivalent Stars (or "SLoWPoKES") contains more that 1200 wide (1000-100000 AU) pairs that contain as least one low-mass star. Because these pairs are thought to be coeval, they can be used to help constrain and characterize current models of binary star formation, stellar evolution, and Galactic chemical evolution. These pairs also represent some of the most weakly bound systems in the Galaxy due to their low masses and large physical separations. The initial results found that many of the SLoWPoKES pairs must be young (< 1 billion years old) because they do not have sufficient binding energies to survive dynamical encounters in the Milky Way.



50 arcsec by 50 arcsec composite images of multiple systems found in the SLoWPoKES survey. Pictured are "identical twins" (a-c), high-mass ratio pairs (e-g), and white dwarf-M dwarf pairs (d,h). Individual components are marked with arrows. More than 1200 wide, low-mass binaries, including more than 30 triple systems, have been identified in the survey.

Professor West and the SLoWPoKES team have been concentrating their observational follow-up effort on using the statistical platform that the SLoWPoKES sample provides to test current age-activity relations for M dwarfs. Although important for understanding the details of stellar astrophysics, a robust age-activity relation for M dwarf stars (which constitute 70% of the stellar population of the Galaxy) has greater utility for constraining the dynamical, chemical and star formation history of the Milky Way. A spectroscopic campaign is in its final stages that will examine the magnetic activity (as traced by H-alpha) for more than 300 SLoWPoKES stars and investigate the slope and scatter of the age-activity relationship as a function of stellar mass (or spectral type).

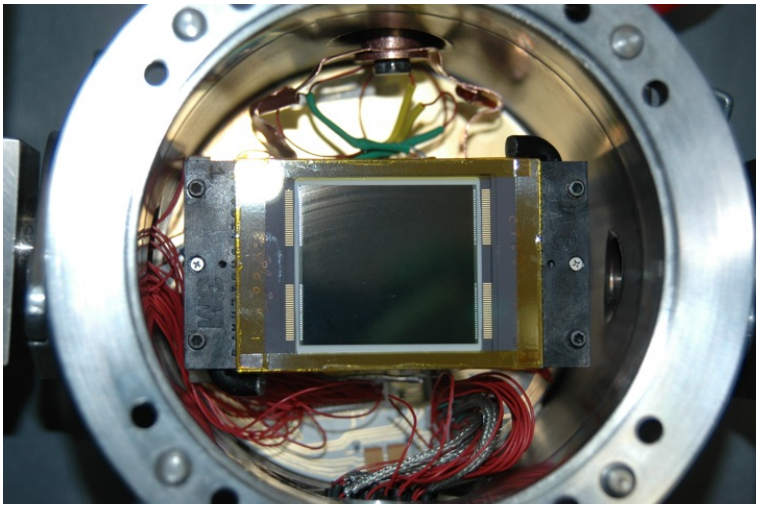
Instrumentation Program

The IAR faculty members have designed and built three state-of-the-art astronomical instruments to date: Mimir and PRISM which operate on the Perkins Telescope at Lowell Observatory, and MIRSI which operates on NASA's Infrared Telescope Facility in Hawaii. The combination of these instruments allows IAR astronomers to carry out investigations over wavelengths that span the optical, near-infrared, and mid-infrared regions of the electromagnetic spectrum. In addition, HIPO (the High Speed Imaging Photometer for Occulation), has been built by Lowell Observatory personnel and the IAR's Telescope Support Scientist, Brian Taylor. HIPO will be used for observations on board a specialized airplane. Lastly, Professor Clemens has begun work on a new instrument (Flexi) that will capitalize on the science that can be done with Mimir.

PRISM

The Perkins Re-Imaging SysteM (PRISM) instrument is a key component of the partnership between BU and Lowell Observatory to operate the Perkins Telescope. PRISM is a facility-class instrument for optical imaging, spectroscopy, and polarimetry. PRISM continues to be the most heavily used instrument on the Perkins telescope, and was scheduled for 188 nights in the past year. PRISM continues to operate almost flawlessly. In last year's report, we indicated that we had just received a grant from the Mt. Cuba Astronomical Foundation (located in Delaware), to purchase a new detector for PRISM. Brian Taylor has installed the new detector, and it is working magnificently. The readout time (the time it takes to read an image and store it on the computer) is only a few seconds, compared to almost a minute for the previous detector. The effect of this has been to double the efficiency of the telescope for most types of projects. In addition to its greatly improved readout speed, the new detector has a more uniform sensitivity across the image, lower background noise, and it can be programmed for more flexible operation. In short, the new detector has greatly enhanced the effectiveness of Perkins/PRISM.

The PRISM website is http://www.bu.edu/prism.



PRISM's new detector.

Mimir

Mimir is a facility-class instrument for near infrared imaging, spectroscopy, and polarimetry. Mimir continues to operate well on the Perkins telescope, supporting a wide variety of science programs for BU, Lowell Observatory, Georgia State University (GSU), and outside visiting investigators.

In the past year, a remotely operated power relay has allowed Mimir's helium compressor to be restarted after minor power outages. This has relieved Brian Taylor of the need to travel to the Perkins site just to push a single button (often in times of heavy snowfall and unplowed roads). This new capability handles nearly 90% of the power events, and has reduced the need to install a separate power generator at the site.

Currently, Mimir's science capabilities are being enhanced through acqusition of a new bandpass filter and a new half-wave plate for polarimetry. These have been purchased either through a joint BU-GSU initiative (bandpass filter), or as a visitor contribution (half-wave plate: Professor Terry Jones, University of Minnesota). The new bandpass filter will add a new set of wavelength bands to Mimir's spectroscopic capabilities, enabling a new host of science programs, especially for very low mass stars (Professor Andrew West, BU) and very high mass stars (Professor Doug Gies, GSU). The new half-wave plate will double the number of wavebands for Mimir polarimetry, giving us the most sensitive K-band imaging polarimeter of any observatory. Professor Jones will use this new capability to study solar system comet scattered light to infer the physical properties of the dust in comet tails. The IAR's blazar group will use this new K-band polarization capability to study blazar variability and the structure of jets from galactic black holes.

The Mimir website is http://people.bu.edu/clemens/mimir.

Flexi: Increasing the Science Return from Mimir

One of the most exciting science prospects for GPIPS is to reveal, for the first time, the 3D details of the galactic magnetic field. In order to do so, however, it is necessary to determine distances to at least 100,000 of the stars that are expected to be measured polarimetrically. The stars are too faint and too extincted by galactic dust to be seen by most optical wavelength surveys or even future space missions, making observations in the infrared necessary. Mimir by itself can conduct spectroscopy of the stars, but Mimir can only do this for only one star at a time; i.e., much too slowly to make 3D mapping of the galactic magnetic field feasible with Mimir alone.

What is needed is a way to collect the spectra for many stars simultaneously. "Flexi" will be a telescope enhancement unit that positions many fiber optic cables across the telescope focal plane and routes those fibers to Mimir, thereby boosting spectroscopic throughput by a large factor. A notional plan to put an 81-fiber automatic positioner onto the Perkins, as a "front end" for Mimir spectroscopy, would represent a huge increase in the science impact of the telescope. An NSF proposal for Flexi is being prepared for submission to the NSF on November 1, 2010. While it is true that multi-object spectrographs are in use on many large telescopes, none of the existing systems operate at wavelengths as long as Flexi+Mimir. The unique combination of Flexi and Mimir will again make our systems unique on the planet, gaining for us capabilities that are simply not available anywhere else. In addition to boosting the science that can be done with GPIPS, the Flexi+Mimir combination will enable a great number of additional exciting investigations to be carried out. IAR astronomers, as well as our colleagues at Lowell Observatory and Georgia State University, have multiple projects in mind that are ideally suited to Flexi+Mimir. These include studies of exoplanet transits, star clusters, galactic structure, and small satellite galaxy companions of larger external galaxies. In addition, this instrumental combination could play a role in helping to increase the scientific harvest of the Discovery Channel Telescope, something Mimir alone could not easily do on that telescope.

HIPO

HIPO, the High Speed Imaging Photometer for Occultation, is an instrument that was built by Lowell Observatory personnel and the IAR's Telescope Support Scientist, Brian Taylor. HIPO will be used on SOFIA, NASA's Stratospheric Observatory for Infrared Astronomy. SOFIA is a Boeing 747sp airplane equipped with a 2.5-m telescope that will take infrared observations at 41,000 to 45,000 feet above sea level. Operation at such a high altitude allows instruments to get above much of the water vapor that absorbs large bands of the infrared spectrum at lower altitudes.

HIPO is a special PI instrument and is the only optical instrument that will fly on SOFIA. HIPO was designed and built with the goals of testing and evaluating the optical components of the SOFIA telescope, as well as to observe astronomical occultations. In HIPO has been mounted on the telescope, and it has been used for initial evaluation and alignment of the optical systems, door alignment, secondary mirror operations testing, and pointing stability. It is expected that HIPO will fly in the coming years for additional testing of the telescope and, ultimately, will be used for science flights that involve occultations of Kuiper-belt objects, high-speed stellar oscillation measurements, and other programs that will be proposed by guest investigators.

MIRSI

MIRSI, the Mid-Infrared Spectrometer and Imager, has been a facility instrument at NASA's Infrared Telescope Facility (IRTF) in Hawaii since late 2002 and continues to be a highly-sought after instrument. MIRSI was built by the late Professor Lynne Deutsch and is primarily used by the general astronomical community to study asteroids and planets. IAR members have used MIRSI to image infrared dark clouds in order to obtain constraints on the sizes of the central cores that harbor massive star formation. Narrow-band imaging of other, known star forming regions has also been carried out in order to determine the composition of gas and dust toward star-forming regions.

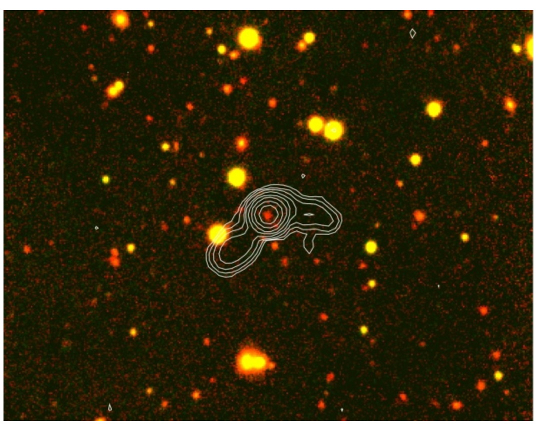
MIRSI provides both imaging and spectroscopy across the mid-infrared band, from 7 to 25 microns. A number of different combinations of filters and grisms are available to users, allowing them to quickly and efficiently switch between imaging and spectroscopic mode. This is advantageous because it allows users to maximize the time spent studying astronomical sources instead of dealing with complex instrument changes. On a per semester basis (approximately 180 nights), MIRSI continues to be regularly scheduled for 20-25% of the available observing nights. The community interest in MIRSI is driven by its high-quality wide-field imaging capabilities. This makes MIRSI and the smaller aperture NASA IRTF competitive with mid-infrared instruments on most of the world's largest telescopes such as Keck, Gemini, and the VLT for mapping large regions of star formation and solar system phenomena such as comets. Unlike the mid-infrared instruments on larger aperture telescopes, MIRSI can capture variations in spectral line, dust, and PAH emission throughout a star forming region, providing valuable diagnostic tools. Furthermore, MIRSI provides images with high contrast between bright and dim emission, enabling MIRSI users to detect very faint sources.

In return for contributing MIRSI to the IRTF, Boston University astronomers are guaranteed observing time on the telescope. MIRSI is currently unsupported financially by Boston University.

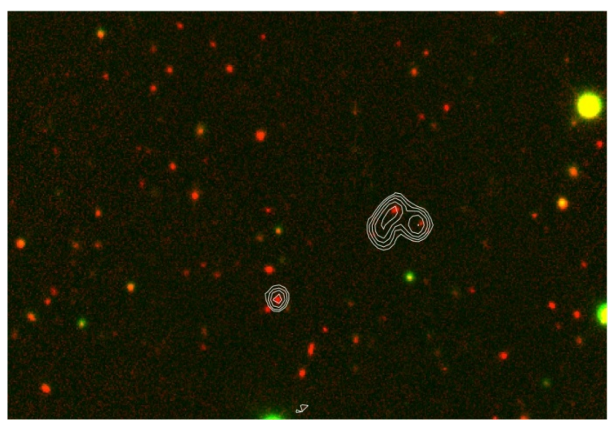
Science Programs

The IAR hosts many different science programs. Some of the particularly noteworthy results from the past year are outlined in the Science Highlights section, and below are updates on other ongoing investigations.

BU graduate student Joshua Wing has been working with Professor Blanton to correlate different morphologies of radio sources with objects detected via optical light in the Sloan Digital Sky Survey (SDSS). Hundreds of clusters associated with the radio sources have been located in the SDSS, and the correlations between cluster properties and radio source properties have been studied. Mr.Wing and Professor Blanton have found that bent, double-lobed radio sources are more often found in clusters of galaxies (about 70% of the time) than straight, extended radio sources or compact radio sources. In addition, FR I sources (sources with edge-darkened lobes) are more often found in clusters than are FR II sources (those with edge-brightened lobes). The bent, double-lobed sources that do not have optical identifications in the SDSS are likely not found because their host galaxies are very distant and are, therefore, also very faint. These objects are good candidates for high-redshift clusters. Mr. Wing and Professor Blanton are undertaking a program to follow up these candidates with deep observations in the optical and near-infrared using the Perkins telescope and the 4-m telescope at KPNO. Hundreds of clusters associated with radio sources at redshifts $z > 0.8$ are expected to be found from the full sample using these follow up observations. Mr. Wing performed observations in November 2009 and April 2010 in the near-infrared at the KPNO 4-m, and he has additional observations scheduled for December 2010. He also observed with the Perkins telescope in April 2010.



Overlay of FIRST 20 cm radio contours onto a two-color image of J- and K-band data from NEWFIRM on the KPNO 4-m telescope of the high-redshift cluster candidate 0734+2933. The image size is 2.5 arcmin by 1.5 arcmin, corresponding to 1.2 Mpc by 0.7 Mpc, assuming the redshift of the cluster is z = 1. Stars and nearby (low redshift) galaxies appear yellow/green (J-band), while distant (high redshift) galaxies appear red (K-band).

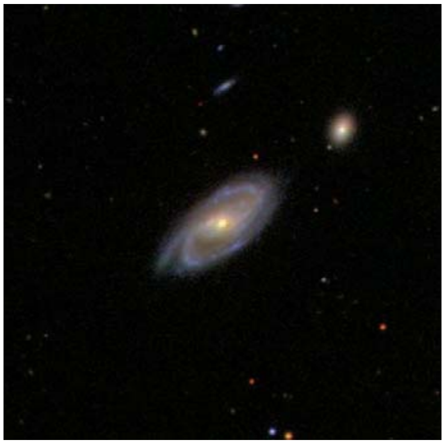


Overlay of the FISRT 20 cm radio contours onto a two-color image of R-band data (from PRISM on the Perkins Telescope) and K-band data (from NEWFIRM on the KPNO 4-m telescope) of the high-redshift cluster candidate 0844+2538. The image size is 3 arcmin by 2 arcmin, corresponding to 1.4 Mpc by 1 Mpc, assuming the redshift of the cluster is z = 1. Stars and nearby (low redshift) galaxies appear

BU graduate student Edmund Douglass, together with Professor Blanton, has been examining the X-ray cluster environments of bent, double-lobed ("wide-angle tail" or "WAT") radio sources using data from the Chandra X-ray Observatory. It is important to understand the conditions found in these types of clusters if we are to use similar objects at high redshifts for studies of galaxy evolution and cosmology. A detailed study of the cluster Abell 562 has revealed that it is likely the site of a merger which has set the intracluster gas in motion, providing the ram pressure to bend the radio lobes. A rise in temperature, associated with a merger shock, is detected and the upper limit on the shock Mach number is 1.6. Mr. Douglass is also completing a Chandra archival study of a sample of clusters with WAT radio sources, and using optical data from the SDSS to examine the velocity structure in these systems.

Professor Brainerd’s research focuses primarily on the dark matter component of galaxies, specifically the amount and distribution of dark matter in the halos. By definition, the dark matter is not visible so it is not possible to “see” the dark matter at any wavelength of light. However, by using luminous tracers of the gravitational potentials generated by the dark matter halos, Professor Brainerd and her students are able to study the dark matter halos directly. Two of the ways in which Professor Brainerd and her students carry out these studies are the locations and motions of small satellite galaxies, as well as gravitational lensing of extremely distant galaxies by the dark matter halos of relatively nearby galaxies.

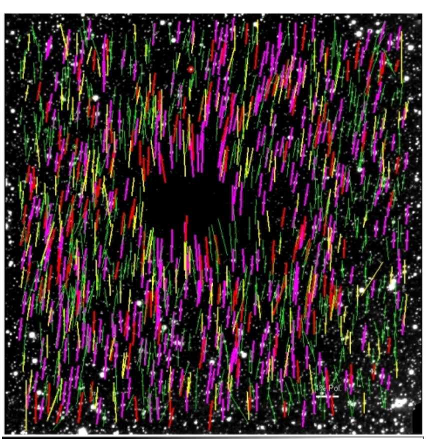
BU graduate student Ingolfur Agustsson, working with Professor Brainerd, has obtained a very interesting result regarding the ways in which luminous galaxies are embedded within their dark matter halos. By studying the locations of the satellites of large, bright galaxies in the Sloan Digital Sky Survey and comparing them to the locations of satellites of large, bright galaxies in the Millennium Run simulation, they were able to determine that spiral galaxies and elliptical galaxies are embedded within their dark matter halos in fundamentally different ways. Specifically, the angular momentum vectors of spiral galaxies must be aligned with the net angular momenta of their halos, while elliptical galaxies simply share the shapes of their dark matter halos. In practice, what this means is that the dark matter mass and the luminous stellar distribution are almost perfectly aligned in elliptical galaxies. In the case of spirals, however, there is a substantial misalignment of the projected dark matter mass (i.e., the major axis of the mass) and the luminous disk of the galaxy due to the fact that the net angular momentum vector of the dark matter halo is typically not aligned with one of its principle moments of inertia.



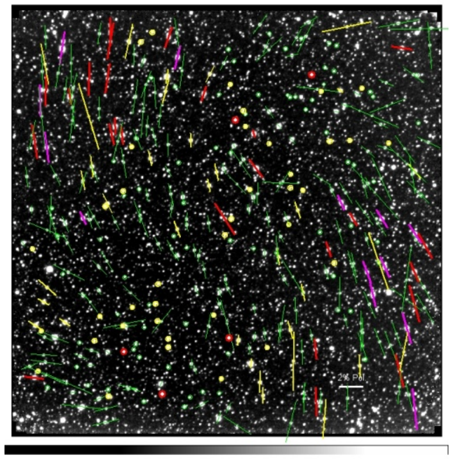
Spiral host galaxy and its satellites from the Sloan Digital Sky Survey.

BU graduate student Paul Howell, working with Professor Brainerd, has investigated whether weak gravitational lensing may be used to constrain the shapes of the dark matter halos of galaxies. The most popular theory of dark matter (the so-called Cold Dark Matter model) predicts that the dark matter halos of galaxies are triaxial, not spherical. As a result, in the plane of the sky the dark matter halos will take on elliptical shapes and this should give rise to an anisotropic gravitational lensing signal. Through a combination of deep imaging data and extensive Monte Carlo simulations, they have shown that placing direct constraints on the shapes of the dark matter halos of galaxies with gravitational lensing is extremely tricky. This is due to the fact that most of the foreground "lens" galaxies in a typical sample have, themselves, been weakly lensed. This means that the observed shapes and orientations of the lens galaxies have been slightly altered compared to their intrinsic shapes, which induces a variety of systematic effects on the observed gravitational lensing signal. Mr. Howell and Professor Brainerd have shown that, depending upon the masses of the lens galaxies, the weak lensing signal may be appear to be isotropic (even if the halos are non-spherical) or it may appear to show that mass and light are oriented at right angles to one another (despite the fact that mass and light are, in fact, perfectly aligned within the galaxies). Their most recent analysis of a deep, wide-field data set (approximately 14 square degrees) has, nevertheless, led to the conclusion that the dark matter halos of field galaxies are non-spherical and are consistent with the predictions of the Cold Dark Matter model.

Professor Clemens' research group has continued to make progress on the Galactic Plane Infrared Polarization Survey (GPIPS) using the Mimir instrument on the Perkins telescope. Their team was recently renewed for another 4 years of funding by the NSF in order to bring the observational phase of the Survey to completion and to release the resulting catalogs of polarization and deep photometry to the community. This past year has been one of intense work on the software systems that support reduction and analysis of the huge GPIPS data volume, as well as continued observations to collect data for the Survey. Critical milestones include completion of the Mimir Software System - Photo-POLarimetry (MSP-PPOL) package, which handles all of the final data processing needed to obtain stellar polarizations (and, therefore, reveal the properties of the galactic magnetic field). As part of that effort, BU graduate student April Pinnick completed her program that computes the faint instrumental polarization signature that Mimir adds to the incoming astronomical signals. Because of this characterization, Professor Clemens' group can now remove this unwanted component with high precision and can now recover accurate polarizations to levels not originally thought possible for Mimir.



Mimir image and stellar polarization vectors, centered on a small, dense dark cloud in the Pipe nebula region. The polarization vectors indicate the presence of a remarkably coherent magnetic field.



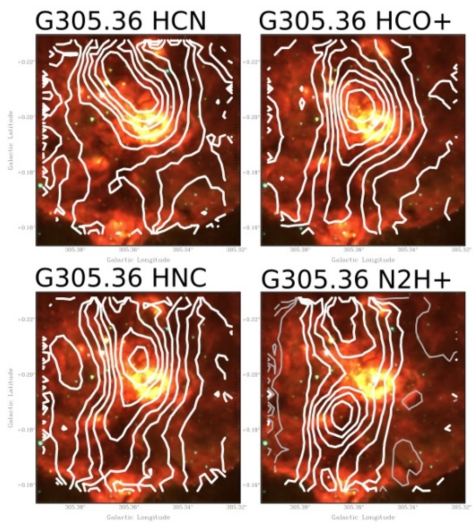
Mimir image and stellar polarization vectors, centered on a field that is located in nearly the same part of the sky as the previous figure. The "swirl" pattern of the vectors may indicate that the line-of-sight component of the magnetic field is undergoing strong changes.

BU Graduate student Mike Pavel, working with Professor Clemens, has advanced his modeling of the large-scale nature of the galactic magnetic field to the point of making detailed predictions based on several competing models. He has already obtained the Mimir polarimetric data necessary to test the models and he will perform final tests this summer to refute or corroborate the models based on his data. BU undergraduate student Julie Moreau, working with Professor Clemens, has designed a project to reveal the 3D nature of the galactic field for one 10x10 arcmin field (of the 3,200 fields making up GPIPS), using Mimir spectroscopy of some 20-25 stars across the field. Ms Moreau is pursuing the new observations and analysis as the core aspects of her Senior Work for Distinction in the 2010/2011 academic year.

With the new MSP-PPOL package finally in working form, Professor Clemens' group has caught up on several delayed collaborative projects. For their JPL collaboration to map the magnetic field across the Taurus dark cloud complex, they completed PPOL processing of some 60 fields and have passed the completed data back to their JPL collaborators for comparison with gas and dust probes along the same lines of sight. In addition, Professor Clemens' group advanced their deep observations of the magnetic field associated with a small, dense dark cloud (a globule) in the Pipe Nebula region, and they have obtained highly significant polarization values for more than 2,000 stars across one 10x10 arcmin field of view. This has revealed an embedded magnetic field with an unprecedented degree of coherence, seemingly at odds with the starless aspect of this globule. In nearly the same part of the sky as the Pipe Nebula, Professor Clemens' group observed another field to show the opposite of uniform magnetic field alignment, instead finding a strong "swirl" of the field vector directions. This may indicate that the magnetic field is strongly changing its line-of-sight component, from roughly tangential in the field edges to nearly pole-on near the field center. Professor Clemens' group re-observed this field with a 2x2 mosaic of positions in May 2010 and they are currently analyzing the new data to try to pin down this unusual magnetic field configuration.

Professor Jackson's research group continued its work on Infrared Dark Clouds (IRDCs). IRDCs are very opaque, cold clouds thought to be the birthplaces of high mass stars and star clusters. They are an important new laboratory for the investigation of the earliest stages of high-mass star formation. One striking aspect of infrared dark clouds is that they tend to have filamentary shapes. This suggests a strong link between filamentary structure and star formation. Professor

Jackson's group has found an extreme example of a filamentary IRDC, the Nessie nebula. Theories suggest that a long, gaseous filament should break up into beads due to a fluid instability called the "sausage instability." The observed clumps of gas in the Nessie nebula conform to the predictions of this theory. Thus, it is possible that star formation may be initiated by the fragmentation of filamentary IRDCs into beads due to the "sausage instability."



Four maps of a star forming core from Australia's Mopra telescope are shown. The colored image is a map of 24 micron emission taken with the Sptizer Space Telescope. The bright bubble in the center is a region of ionized gas powered by a cluster of recently formed stars. The dark regions are dense clouds where new clusters are likely to form. The Mopra maps, shown in the white contours, show the distribution of four different molecules: HCN, HCO+, HNC, and N2H+. Note that the molecules have very different distributions. This shows that the molecular cores that are forming stars have different chemical compositions, which dramatically evolve as the core goes from a cold, pre-stellar stage to a hot post-stellar stage

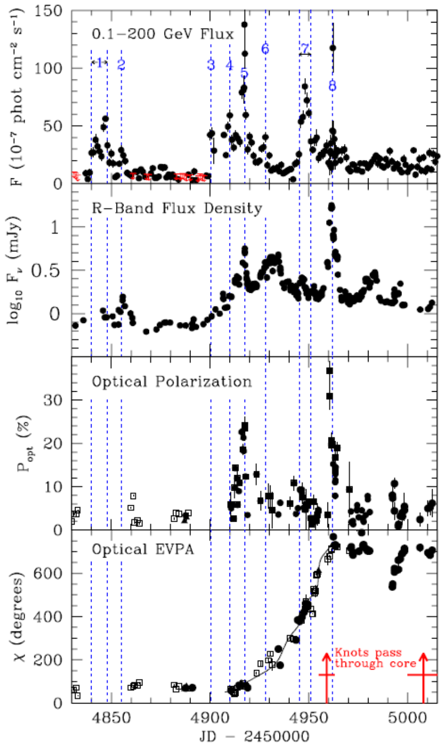
Professor Jackson's group has also begun a massive new project called the MALT 90 survey. Professor Jackson is leading a group of 41 astronomers who will use the 22 meter Mopra radio telescope in Australia to map the molecular gas distribution of 3,000 star cluster-forming cores. The team aims to study how cores evolve from cold cores with no stars to hot cores with multiple stars. The project was awarded 720 hours of telescope time this season. It will take three to four years to complete these observations. A preliminary study showed that the cores are easily detected, and that they show a large range of shapes, sizes, and chemical compositions. This study will find the most important objects for more detailed study with the ALMA telescope, now under construction.

Professor Janes is continuing his analysis of a long series of photometric observations of old open star clusters, searching for evidence of stellar activity cycles that are similar to the solar cycle. He has found that in M67, an old star cluster similar in age to the Sun, most stars do not show evidence for higher levels of activity than our Sun. The only stars with obvious variations were previously found to be X-ray sources. Most or all of those stars are close binary systems, with violent interactions between the components. In addition, BU undergraduate student Sadia Hoq has been working with Professor Janes on two projects. One project was a study of several distant star clusters to determine their distances and ages. These clusters are difficult to observe, partly because they are very faint, but also because they are embedded in rich star fields. Most of the clusters in their list are just barely detectable against the background of stars. As a result, Professor Janes and Ms Hoq had to devise new analytical techniques to extract useful information about the clusters. In addition, Ms Hoq used observations from the Perkins telescope and the 42-inch telescope at Lowell as part of her Senior Work for Distinction. Her distinction project was to study two star clusters located in the field of view of the Kepler spacecraft. The Kepler telescope is currently staring at a region of the sky in the constellation Cygnus, searching for extrasolar planets. There happen to be several star clusters in the Kepler field of view, two of which have never been studied carefully. Ms Hoq's distinction work will become part of a larger study (led by Dr. Soeren Meibom of Harvard University's Center for Astrophysics, and including Dr. Sydney Barnes of Lowell Observatory) to use Kepler data to derive the rotation periods for stars in the clusters. The ultimate goal is to determine how stars spin down over their lifetimes.

BU graduate student JiHyun Kim has been working with Professor Janes on an exciting project to search for evidence of atmospheres surrounding previously discovered extrasolar planets. Their plan is to follow planetary transits with PRISM on the Perkins telescope using a blue filter. The key idea behind their approach is an attempt to detect Rayleigh scattering in the planet's atmosphere (Rayleigh scattering is what makes the sky blue). So far they have acquired some excellent observations of several transits, but their analysis is not yet far enough along to say whether they will be able to detect the planets' atmospheres.

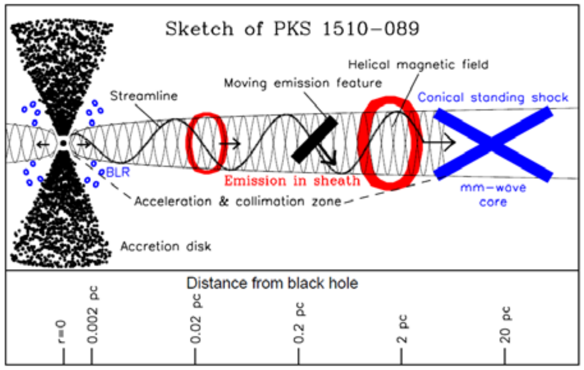
The blazar research group, headed by Professor Marscher and Dr. Jorstad, studies the physics of blazars, the most luminous long-lived objects in the Universe, through comprehensive multi-waveband monitoring. Blazars are quasars or other active galactic nuclei powered by super-massive black holes (often exceeding a billion solar masses) accreting gas from their surroundings. Magnetic fields twisted by orbits around the black hole drive jets of particles along the rotational poles at velocities very close to the speed of light. These jets emit extremely luminous, highly variable radiation all across the electromagnetic spectrum.

The blazar group's main project involves monthly observations at the radio frequency of 43 GHz with the Very Long Baseline Array of a sample of 34 gamma-ray bright blazers, and optical polarimetric and photometric observations with PRISM and MIMIR at the Perkins telescope. The data are combined with observations by collaborators with the St. Petersburg State University telescope, the Crimea Astrophysical telescope, the Liverpool robotic telescope, and with the Calar Alto telescope. The VLBA images, posted on the group's website as the processing of each observation is completed, are used widely by astronomers that study blazars. A continued program of monitoring the X-ray flux of seven bright gamma-ray blazers with NASA's Rossi X-ray Timing Explorer was selected as one of the Core programs for the remainder of the satellite's mission, which has been continued up to at least September 30, 2010. The blazar group was also awarded time for more limited X-ray observations of a number of others with the Swift satellite.

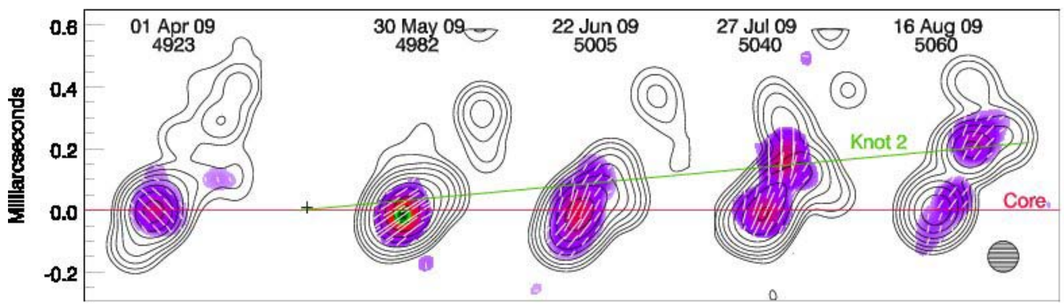


Variation with time of the quasar PKS 1510-089 during the first half of of 2009. Top to bottom, the panels show (1) gamma-ray flux (upper limits in red), (2) optical flux density (note the logarithmic scale), (3) degree of polarization and (4) electric-vector position angle of optical linear polarization. Vertical dotted lines denote major gamma-ray flares.

In addition, NASA's Fermi Gamma-ray Space Telelescope produces publicly available data from which the blazar group derives gamma-ray light curves (brightness vs. time) at photon energies of 0.1 to 300 GeV for all of the blazars in their sample. The group's comprehensive program includes simultaneous observations with Fermi, RXTE, Swift, visible-light and infrared telescopes, and the VLBA. The study is already producing exciting results indicating that gamma-ray emission in blazars is generated by disturbances in the jet. This is inferred from strong correlations between the optical and gamma-ray variability, along with rotation of the optical polarization angle. Most frequently, outbursts of gamma rays occur many light-years away from the black hole as moving disturbances (probably shock waves) pass through standing shocks in the jet, overturning standard theoretical models that had placed them near the black hole. This is brought out vividly when the sequence of radio images and gamma-ray brightness vs. time curve is made into a movie. On the other hand, the group's observations of rotating polarization vectors support current theoretical ideas for how the accreting black holes produce ultra-high speed jets of energetic plasma through winding up a magnetic field. The magnetic field collimates and accelerates the jet flow in a zone upstream of the section of the jet that can be imaged in radio light. In the quasars PKS 1510-089 and 3C 454.3, emission of enhanced visible and gamma-ray light occurs in this zone. The group is working toward understanding the processes responsible for producing bright "blobs" that appear to move faster than light (an illusion) and outbursts in which the brightness can increase by many times.



Sketch of a model for PKS 1510-089. A disturbance ("knot") in the flow of the ject contains ultra-high energy electrons emitting synchrotron radiation at radio to visible wavelengths. A flare of gamma rays is created when the blob passes an intense photon field originating in a sheath surrounding the jet. The disturbance traces a spiral path through a coiled magnetic field, causing the polarization vector to rotate. The black hole (billions of solar masses) is the dot on the left, in the middle of the wedge representing a disk of material falling inward. Note the logarithmic scale, so that various components of the nucleus can be included.



Sequence of 43 GHx VLA images featuring a bright "knot" appearing to move down the jet at a velocity of 21 times the speed of light (an illusion). Contours represent total intensity, while color indicates polarized intensity realtive to the peak (green). The blob passed through the stationary core near the date when a major, but brief, flare of gamma-ray and visible light occurred.

Postdoctoral research associate Mansavita Joshi has developed a numerical code for reproducing the gamma-ray spectral energy distribution from the collision of a pair of shock waves in a blazar jet. She is applying the code to the data obtained by the blazar group. Postdoctoral fellow Ivan Agudo has analyzed the jet of the blazar OJ287, in which the radio jet appears to have suddenly become much broader since 2005, developing a second "core." He is studying the relationship between this event and outbursts of radiation from radio waves to gamma rays. In addition, Dr. Agudo completed a survey of the polarization properties of compact extragalactic radio sources at a wavelength of 3 mm, the first of its kind to include over 100 objects.

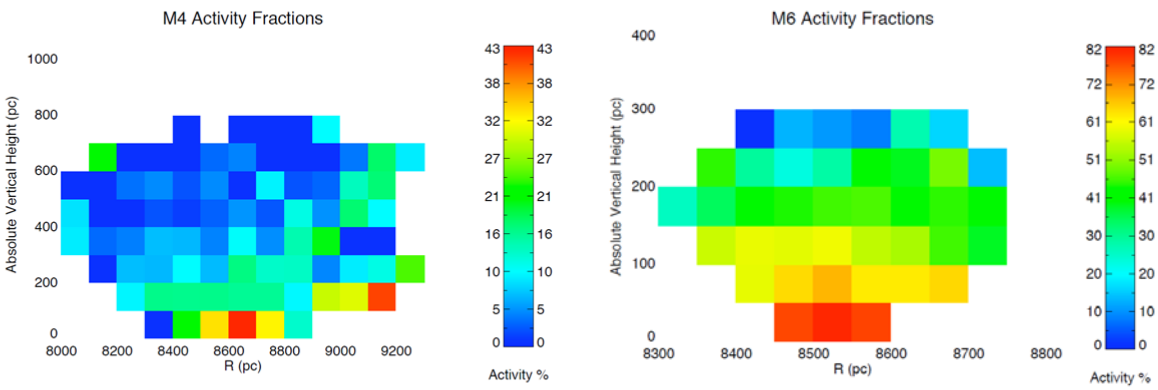
BU graduate student Michael Malmrose, along with Professor Marscher and Dr. Jorstad, has discovered hot dust in a gamma-ray blazar. They constructed the optical-infrared-millimeter-wave spectral energy distribution with data from Lowell Observatory, the Spitzer Space Telescope, and the Submillimeter Array. The spectrum of the quasar 1222+216 includes a power-law component from the relativistic jet plus a strong component with the shape of a modified blackbody spectrum (from a distribution of temperatures) as well as the signature 10-

micron silicate absorption feature. Collaborators at the University of Kentucky fit the spectrum with a model of a clumpy torus of molecular gas and dust in the nucleus of a quasar. The discovery of the dust emission is particularly important to the interpretation of an extremely luminous outburst of gamma rays from this object in April-June 2010: one model of gamma-ray production involves IR photons from hot dust being scattered to gamma-ray energies as the result of collisions with very energetic electrons.

BU graduate student Monica Young, working with Professor Marscher as well as Dr. M. Elvis and Dr. G. Risaliti of the Smithsonian Astrophysical Observatory, completed a major study comparing the X-ray and optical emission properties of a large sample of quasars. In order to do this, she has mined the extensive databases of the Sloan Digital Sky Survey and the XMM-Newton X-ray satellite observatory. She has investigated the relation between optical and X-ray properties such as accretion rate, optical and X-ray luminosity, and X-ray slope. She has compared the observed correlations with population synthesis simulations to determine which correlations are intrinsic to the physics of quasar accretion, and which are simply due to selection effects or the effects of another correlation. A relation between the slope of the X-ray continuum spectrum and X-ray luminosity appears to be real, revealing a relation between the power in X-ray emission and the heating of electrons in the corona.

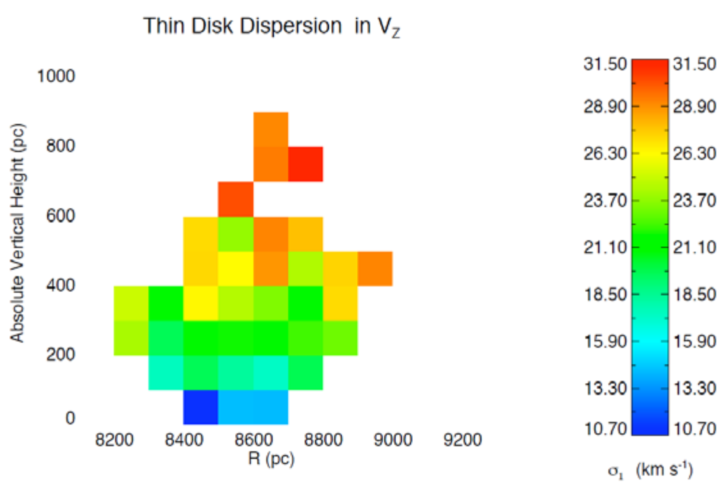
Professor West has recently compiled the largest ever spectroscopic sample of M dwarf stars. Leading a group of students, postdocs, and professors from BU, Cornell, MIT, and the University of Washington, Professor West has analyzed the spectra of more than 70,000 M dwarfs (for which his team had to visually inspect more than 116,000 candidates). This sample will allow Professor West and his collaborators to investigate a number of outstanding problems in stellar and galactic astrophysics. While M dwarfs are the smallest and least luminous hydrogen-burning stars, they are also the most numerous of all stellar constituents in our Galaxy (70% by number), and they have lifetimes that are much longer than the current age of the Universe. Therefore, M dwarfs are ideal candidates for tracing the structure, kinematics and evolution of the local Galaxy. Professor West's new sample will provide the statistical power to uncover many of the remaining mysteries of the local Milky Way.

In addition, Professor West and MIT undergraduate student John Sebastian Pineda have been using the new sample of more than 70,000 M dwarfs to investigate the magnetic activity of these stars as a function of both Galactic height and Galactocentric radius. Previous investigations by Professor West found that magnetic activity in M dwarfs decreased as a function of vertical height in the Galactic disk. Because stars higher up in the Galaxy are on average older, this activity decrease was interpreted as being age dependent. Professor West was able to derive age-activity relations based on dynamical models for stars in the vertical direction. This new investigation in both the vertical and radial directions has confirmed the previous findings but has also provided some striking evidence for an increase in magnetic activity for stars at larger Galactic radii. This is likely due to the fact that stars farther out the Galactic disk are on average younger and are likely more magnetically active. While this complicates some of the previous age-activity relations, it has allowed Professor West and Mr. Pineda to put some important constraints on the age gradient of the Milky Way thin disk.



M4 and M6 activity fractions as functions of Galactocentric radius and absolute distance from the Galactic plane. The color corresponds to the activity fraction, where redder colors indicate bins with greater activity. Each bin has a size of 50 pc X 50 pc. The M4 dwarfs have greater activity fracions at both larger Galactic heights and larger Galactocentric radii. Although the M6 dwarfs show no (or slight) radial variation in activity, they do demonstrate the strong trend that magnetic activity has with Galactic height.

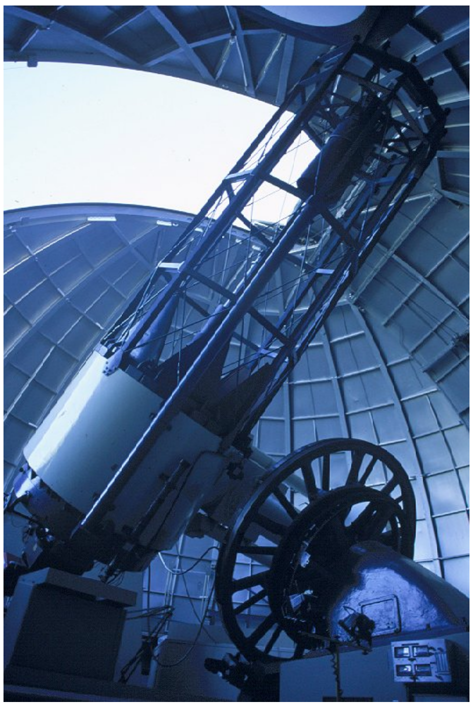
Professor West and Mr. Pineda have also been measuring the kinematics of stars in the local Milky Way. While no significant trends have been found as a function of Galactic radius, there are clear trends in the means and dispersions of velocities with Galactic height. They have created a new Monte Carlo technique for separating the dynamical parameters of the hot and cold dynamical components (thin and thick disks) of the Milky Way disk. Their results are the best measurements of stellar velocities and velocity dispersions that have ever been computed for the Galaxy. In addition to the velocity information, their technique provides detailed information about the relative concentration of thin and thick disk stars as a function of location in the Galaxy. These concentrations put important constraints on models of Galactic structure, which rely on number counts of stars to determine the shape of the Milky Way.



The spatial distribution of the dispersion of the kinematically colder component of the Milky Way disk (the "thin disk") in the vertical direction. Redder colors correspond to bins that have a larger dispersion. Bin sizes are 100 pc X 100 pc.

Lowell Observatory Partnership

For the past 12 years, the IAR has partnered with Lowell Observatory to share the operation of the 1.8-m Perkins Telescope on Anderson Mesa, near Flagstaff, Arizona. A Memorandum of Understanding, signed by BU and Lowell, insures that this partnership will continue through July 2013. As in previous years, IAR astronomers continue to be entitled to 50% of the nights on the telescope, distributed equally over all phases of the moon. In 2009 Lowell entered into an agreement with Georgia State University that entitles the GSU astronomers to 25% of the nights on the Perkins Telescope. Although there is no direct agreement between BU and GSU to operate the Perkins Telescope (i.e., GSU's agreement is solely with Lowell Observatory), the BU astronomers are excited to have this opportunity to work with new colleagues and to build new collaborations.



The Perkins Telescope

A major change took place at Lowell Observatory in June 2010 with the resignation of its Director, Dr. Eileen Friel. Dr. Jeffrey Hall has been appointed as Lowell's acting Director. Via email Dr. Hall has assured the IAR that it is "full speed ahead" at Lowell and that this change of administration will not affect our partnership.

As part of our partnership with Lowell Observatory, the IAR developed two new instruments for the Perkins Telescope: Mimir, which operates at near-IR wavelengths, and PRISM, which operates at optical wavelengths. As detailed in the Instrumentation section, these two instruments are in routine use as the primary science instruments on the telescope. The IAR and Lowell have continued to improve the Perkins Telescope facility over the past several years, an effort that has been primarily funded through the NSF PREST program via grants to BU (PI: Kenneth Janes) and Lowell.

Over the past year Brian Taylor continued to work on our long-term program of improving the Perkins telescope image quality, and making other improvements at the telescope. Most recently, Brian has been working on a system for chilling the primary mirror of the telescope, as well as the air above the mirror, during daytime hours. The goal is to bring the mirror close to the temperature that will be expected during the following night, which will reduce thermal gradients in the optical path. The telescope control room renovations (discussed in last year's report) are now complete and the seeing monitor, a small telescope outside the dome that measures the image quality, is in routine operation. In addition, Brian recently installed a new "PDU" unit, a device that controls electrical power to some of the instruments on the telescope, to replace a unit that has been causing difficulties for some time.

Another event of note was a major failure of the Perkins telescope dome in April 2010. This forced a shutdown of operations for a week, during which the dome problems were resolved. Other than this, the Perkins telescope and its dome have functioned normally, with only minor problems over the past year.

Impact on Education

The use of the Perkins Telescope for professional-quality observations is an important part of our educational mission. To date, approximately 70 undergraduates and 45 graduate students have traveled to Flagstaff to observe with the Perkins Telescope. These include undergraduate honors students (CAS AS102HP and CAS AS203HP), observational astronomy students (CAS AS441 and GRS AS710), senior undergraduate students who use their observations as part of their Senior Work For Distinction (CAS AS491/AS492), and graduate students who use their observations for their oral comprehensive exam projects and PhD dissertations. Of special note is that for the past 6 spring semesters, all of the students enrolled in AS441 have participated in field trips to the Perkins Telescope to use either Mimir or PRISM to collect data for their class projects. Organized into groups of 3-4, AS441 students have each spent 2 to 3 nights operating the Perkins Telescope (weather permitting). This capstone event in the training of our undergraduate astronomy students is extremely popular, and it has been highly effective for aiding the scientific and personal maturation of the students. This unique field trip experience has become a distinguishing high mark for BU and its undergraduate students. In addition to using the Perkins Telescope to acquire data for their course work, AS441 and AS710 students are also encouraged to experience some of the unique features of northern Arizona, including one- or two-day trips to Meteor Crater and/or the Grand Canyon. From 2004 to 2008 the AS441 field trip was sponsored by the National Science Foundation (PREST grant, PI: Kenneth Janes). In 2009 and 2010, the AS441 and AS710 field trips were sponsored by the Department of Astronomy.

AS710 students Michael Malmorse (left), Danielle Pahud (center), and Patricio Sanhueza (right) visiting the Grand Canyon as part of their class field trip to operate the Perkins Telescope in Fall 2009

AS710 students Danielle Pahud (left), Patricio Sanhueza (center), and Michael Malmrose (right) operating the Perkins Telescope.

AS710 students Ewan Douglas (left) and Dylan Morgan (right) visiting Meteor Crater as part of their class field trip to operate the Perkins Telescope in Fall 2009.

Impact on Research and Instrumentation Programs

The IAR's partnership with Lowell Observatory has allowed the IAR to carry out large, long-term projects that would be next to impossible to carry out using shared national facilities. This is because the oversubscription rate for these facilities is simply too high for IAR members to obtain as many observing nights as are necessary to complete these substantial projects. It is the IAR's access to the Perkins Telescope that has placed the blazar research group at the forefront of the study of gamma-ray bright jets in quasars and active galactic nuclei. The blazar group is in the process of carrying out a long-term multi-wavelength study of 33 bright gamma-ray blazars, and completion of the project will take several years (which is the time scale over which a typical blazar changes its brightness, structure, and polarization to a sufficient degree that a careful analysis can be accomplished and firm conclusions can be drawn). **No other similar study is planned by any other blazar groups around the world since they cannot match the scope of program that is being carried out by the IAR's blazar group.** Again, the IAR's partnership with Lowell Observatory and the administrative support that the IAR provides has been crucial to the blazar group in order to secure grant funding, as well as necessary observations on other telescopes at complementary wavelengths (e.g., gamma ray, X-ray, radio/mm wave).

The IAR's partnership with Lowell Observatory has also allowed the GPIPS survey, a unique and comprehensive investigation of the Milky Way's magnetic field, to be carried out. GPIPS (the Galactic Plane Infrared Polarization Survey) represents an increase of 5 orders of magnitude in Galactic magnetic field information over previous studies. The Mimir instrument was specifically designed and developed to conduct the GPIPS project, and Mimir is the premier wide-field infrared imaging polarimeter in the world. The resulting observations from GPIPS will reveal the nature of the magnetic field in star-forming molecular clouds and interstellar voids between the clouds and stars with unprecedented sensitivity and resolution. **No other group in the world can compete effectively with GPIPS because of instrumentation and telescope access.** Again, the IAR's partnership with Lowell Observatory and the administrative support that the IAR provides has been crucial to the funding and execution of this unique, multi-year project.

To remain competitive, the IAR will continue to need full administrative support of our grants and a telescope partnership that is of sufficient scope that it can be used as effective leverage for securing substantial grant funding. In particular, extending our current partnership with Lowell Observatory to include not just the Perkins Telescope, but also other telescopes that are owned by Lowell Observatory (most notably the Discovery Channel Telescope) would be of tremendous benefit to securing the IAR's future as a center of research excellence.

Finally, ongoing instrumentation development projects are made possible by having access to the Perkins Telescope. A new initiative ("Flexi"), discussed in the instrumentation programs section of this report, would vastly increase the science that could be done with the Perkins Telescope by making multi-object spectroscopy possible at near-infrared wavelengths. In addition, adaptive optics (AO) allow much of the distorting effects of the earth's atmosphere to be removed from astronomical images, are becoming a standard capability at many observatories. AO is not currently implemented on the Perkins Telescope, but this would be a natural new direction for our instrument development teams should there be sufficient interest from the BU, Lowell, and GSU astronomers. The Mimir F/17 high-resolution camera is already capable of exploiting the higher angular resolution imaging and spectroscopy that AO would deliver. Science that would be enabled by an AO system includes planetary astronomy, imaging and spectroscopy in dense star fields such as star clusters, as well as starburst galaxies and star-forming regions in our Galaxy.

Funding for Instrumentation and Science at the Perkins Telescope

IAR members have obtained substantial funding from multiple agencies in order to build PRISM and Mimir, as well as to support the science that is being carried out with these instruments. To date, instrument development for the Perkins Telescope accounts for $1.5M, and funding for scientific investigations that include observations with the Perkins Telescope accounts for $3M. In FY2010 IAR members were awarded two new multi-year grants that will further support investigations that include observations with the Perkins Telescope. These grants will fund GPIPS as well as the blazar group's long-term monitoring campaigns. Over their lifetimes, these new Perkins-related grants will generate approximately $1.5M in grant income. Additional grants that will support major scientific projects with the Perkins Telescope are currently pending at the NSF. One of these proposed projects is a study of low-mass wide binary stars in which the binary consists of a white dwarf and an M dwarf. This project will require 40 to 50 nights per year, as well as a new blue grism for the PRISM instrument. In addition, a concentrated campaign to study the activity levels and rotation rates of stars in the star cluster M67 has been proposed. This project will require 50-60 partial nights over a single observing season.

BU-Lowell-GSU Partnership Meeting

On March 12 and 13, 2010, representatives of BU, Lowell, and Georgia State University met at Lowell Observatory to discuss the operation of the Perkins Telescope, including improvements that should be made, new science initiatives/collaborations, and general concerns. During the meeting, a number of "action items" were identified and these will be completed as resources become available. Among the key findings of the meeting are:

- There is exciting science being planned for Anderson Mesa, ranging across the entire field of astronomy, from nearby solar system objects to distant blazars and galaxies.

- There is strong interest within the partnerships for more spectroscopic capability. Two possible instruments were discussed at length: Kiwispec (an initiative being led by Lowell astronomers) and Flexi (an initiative being led by Dan Clemens, and discussed in the instrumentation section)

- Several issues were identified relating to support and operations in a time of increased budgetary and personnel stress at Lowell, primarily because of the DCT development. In addition, BU participants are concerned about the heavy operational burden that Brian Taylor has undertaken, and the Mimir observer training and certification role that falls to Dan Clemens.

- It has become clear that, unlike the recent past, oversubscription of the Perkins Telescope is now an issue. This is in part due to the inclusion of GSU in the partnership, but it is also due to increased interest in use of the Perkins by Lowell astronomers. Ways to improve the scheduling process were discussed, and as of spring 2010 we are experimenting with some new observing modes (including options for split/shared nights) in order to increase telescope efficiency.

- Several maintenance issues, upgrade possibilities, and software improvements were also identified.

Importantly, it was clear from this meeting that the telescopes on Anderson Mesa (of which the Perkins is one) remain very useful, as evidenced by the oversubscription rates, and they are not scheduled to simply close down when the Discovery Channel Telescope comes on line (see the Discovery Channel Telescope section of this report). This is especially good news for many of the IAR astronomers (most notably the blazar group), whose work is actually best suited to the smaller Perkins Telescope than it is to a larger telescope like the DCT. In fact, the Anderson Mesa telescopes are expected to play a complementary role to the DCT if they are instrumented appropriately. Lowell's current financial models and projections keep the Anderson Mesa telescopes in operation beyond 2013 (the end of our current MOU), but with no growth. It was agreed at our meeting that it will be important to plan for more efficient use of these telescopes, and robotic operation of the smallest telescopes on Anderson Mesa (the 31-inch and the 42-inch) is being considered.

Discovery Channel Telescope

Although the IAR has had tremendous scientific success with the Perkins Telescope, it is a small, older telescope. Virtually every Astronomy department in the United States (with the notable exception of Boston University) is involved with a partnership (or *partnerships*) to operate privately owned optical telescopes that are at least twice the diameter of the Perkins, and which are considerably more modern. One of the primary goals of the IAR members over the next few years is to secure a partnership to operate a larger, more modern optical telescope. Without this, IAR members will find it increasingly difficult to carry out their world-class research because real-dollar funding for national astronomical observatories continues to shrink dramatically. In order to guarantee the ability to carry out cutting-edge work, we must obtain access to a private facility that is more modern and has a larger aperture than the Perkins. For astronomers, not having our own state-of-the-art telescope with which to carry out observations is akin to biologists, chemists, or physicists not having their own state-of-the-art laboratories. Simply put, the astronomical laboratory is the observatory, and the experiment is the universe itself.

The Discovery Channel Telescope (DCT), which is being built by Lowell Observatory, presents an ideal opportunity both for the IAR and Boston University. The DCT is expected to make its first engineering observations in spring 2011, with a gradual transition to science observations shortly thereafter. Two major events in conjuction with the DCT have occurred in June 2010: (1) the primary mirror was delivered to the site and (2) the National Science Foundation selected the Large Monolithic Imager (LMI) for funding. LMI will be the primary imaging camera for the DCT, and is being built by Lowell astronomers.

The primary mirror for the DCT being figured at the University of Arizona Mirror Lab.

Becoming involved with the DCT is particularly attractive for the IAR because the telescope is the right size for the majority of our scientific projects (4-m in diameter) and joining the project would allow us to capitalize on our strong existing partnership with Lowell Observatory. The telescope and facility are fully modern and present a great opportunity for the IAR to reinvigorate our program of building astronomical instrumentation. The larger size of the DCT would enable the IAR to carry out high-impact studies that would be impossible with the Perkins. The IAR would use the DCT to carry out multi-object spectroscopy in the near-infrared for: (1) Galactic "decomposition", in which the distances to the 500,000 stars would be obtained, (2) dynamical studies of galaxy host-satellite systems and galaxy clusters, (3) spectral information for sources discovered by the Large Synoptic Survey Telescope (LSST). The LSST is a unique telescope that is currently under construction. Its light gathering power will be amongst the largest of all optical telescopes, and it will map the entire sky twice every single week. This will generate an enormous database of objects and their brightness. However, LSST will not measure the spectra of these objects. IAR astronomers will use the DCT to obtain this highly complimentary data for the LSST sources. The LSST database will eventually be fully available to the public. In addition, however, Professor Andrew West was recently selected as a formal "collaborator" on the LSST team. Muti-object spectroscopy in the infrared is not widely available to astronomers at this time, and to carry out the studies above the IAR will build a new instrument for the DCT (Flexi). Construction of this new instrument will, once again, put the IAR in the position of having truly unique scientific capabilities.

The IAR would also use the DCT to discover Jupiter-like extrasolar planets that orbit their stars at distances similar to Jupiter's distance in our own solar system (note: due to observational selection effects all currently known Jupiter-like extrasolar planets are located in extremely small orbits about their stars). The DCT would also be used by the IAR to discover very distant galaxy clusters (of which only a handful are known at the present time, but which have the potential to place strong constraints on the history of the universe), and to measure the distances to Infrared Dark Clouds in the Milky Way.

The DCT project in the broader sense opens up a wealth of opportunities in which BU faculty and students in the School of Education (SED) and College of Communications (COM) can become involved. John Hendricks (founder and CEO of Discovery Communications, Inc.) has personally invested a substantial amount of his own money in the DCT, and our understanding is that he wants the telescope to be used in part for educational purposes.   As we understand it, Discovery Communications would like Lowell Observatory to partner with a university, and ideally to have professional educators from the university be involved with repackaging television programs for use in school classrooms. (Discovery Channel educational programs are regularly used in the vast majority of science classrooms around the USA.) Not only would joining the DCT project be beneficial to the IAR, it would also present an unparalleled opportunity for Boston University to obtain an extraordinarily high profile in education and outreach to the general public.

The completed dome for the DCT.

We cannot think of a better way for the IAR to foster interdisciplinary activity at Boston University (i.e., cross-college activity with COM and SED) than becoming involved with the DCT. With the encouragement of CAS Dean Virgina Sapiro, Professors James Jackson and Tereasa Brainerd met recently with Professor Thomas Fiedler (Dean, COM) and Professor Hardin Coleman (Dean, SED) to discuss the possibility of COM and SED becoming involved with the DCT project. Both Professor Coleman and Professor Fiedler expressed great enthusiasm for the project, and felt that both students and faculty members of their colleges would welcome the opportunity to participate. Because of this, we are planning to make a trip to the headquarters of Discovery Communications (Silver Spring, MD) in late summer to learn more about ways in which Discovery would like SED and COM to participate in the DCT through such avenues as education, curriculum development, outreach, and programming.

The IAR has already demonstrated through our existing partnership with Lowell Observatory that guaranteed access to a private optical telescope has a tremendous impact on our ability to win grants, carry out long-term projects, and build facility-class astronomical instruments. Extending our partnership with Lowell Observatory will increase our ability to carry out exciting, front-line research as well as reinvigorate our instrumentation program. Professor Dan Clemens has already begun work on the new instrument, Flexi, that would greatly benefit the scientific programs of many of the IAR members, as well as many of the Lowell observers. As discussed above, Flexi would be a fiber-fed, multi-object spectrograph (81 fibers) for near-infrared spectroscopy. Such multi-object capability in the near-infrared is simply not available to the astronomical community at this time, and the construction and deployment of Flexi would gain the IAR scientific capabilities that are not available anywhere else. As envisioned, Flexi is likely to be fielded first on the Perkins Telescope, and could then easily transfer directly to the DCT.

Future Activities

During the upcoming year we will continue the operation of the Perkins telescope in partnership with Lowell Observatory. MIRSI will remain at the Infrared Telescope Facility. The availability of PRISM, Mimir, and MIRSI will continue to improve the quantity, quality, and stature of our scientific publications. Having guaranteed access to these instruments is paying off with successful proposals to federal funding agencies, and we expect this trend will continue in the future. Although the recent hire of Dr. Andrew West, a specialist in stellar astrophysics, will compensate for the imminent retirement of Professor Ken Janes, the IAR still needs to hire an additional new, young faculty member within the next two years. It would be especially helpful to hire a faculty member who specializes in the building of instruments in order to revitalize our instrument program. Such a revitalization could allow us access to new, large telescopes in exchange for providing state-of-the-art, facility-class instruments. The hiring of two young faculty members (one a stellar astrophysics specialist, and the other an instrumentation specialist) was strongly endorsed by the IAR's Advisory Review Board in their March 2008 report.

In order to maximize the science return from our substantial investments in PRISM and Mimir, it is vital that we continue our partnership with Lowell Observatory through at least July 2013 (i.e., the end of the current MOU). Mimir was specifically designed and built to carry out the GPIPS project, which will be about 40% complete by the end of this summer. No other instrument/telescope combination is capable of performing this particular survey, and the completion of the survey will require several more seasons of observing. Further, the blazar group's current large project depends critically on long-term monitoring of blazers with PRISM and Mimir on the Perkins telescope. Without guaranteed access to optical and near-IR observations, their efforts will founder.

In addition to the obvious scientific return arguments, there are other important reasons to continue our partnership with Lowell Observatory. Through our partnership with Lowell, we gain depth and visibility. Lowell has a high visibility in many communities, and this enhances our visibility in those areas. We also gain opportunities for growth and enhanced telescope access via our partnership. Also, it is not merely the faculty members of the IAR who have benefited from our partnership with Lowell over the past 12 years; students of all levels (undergraduate astronomy majors, undergraduate non-science majors, and graduate students) have enjoyed important, practical educational experiences with a telescope that is of sufficient quality for professional astronomical research to be done. This is a far cry from the sorts of very basic amateur astronomy that can be done with the small telescopes in the Coit Observatory (located on the roof of the CAS building). Undergraduate student training in the hands-on use of professional-grade telescopes and modern instruments is hard to come by at most US institutions, and such training gives our students competitive advantages in job searches, career choices, and graduate school applications. We will, therefore, continue to bring BU students to the Perkins Telescope in order to enrich their academic experience.

To remain competitive with funding agencies and to attract the strongest young astronomers to our faculty, it is vital that the IAR have access to high-quality research-grade telescopes. Although the Perkins Telescope has been a tremendous boon to our science effort, it is not a modern telescope. Also, at 1.8m in diameter the aperture of the Perkins is, to say the least, rather modest. Therefore, to maintain the vitality of our research effort, it is critical to look beyond the Perkins Telescope. The majority of US universities have access to large privately owned telescopes, which guarantees the ability of the astronomers to engage in forefront work. The building and operation of such telescopes is often funded through consortia of partners from multiple universities. All of our US peer departments (and even some lower-tiered departments) have guaranteed access to telescope facilities that are far superior to the Perkins. Of order 30 US astronomy departments have regular access to privately owned telescopes that have at least twice the collecting area of the Perkins Telescope. Without guaranteed access to a larger, more modern telescope than the Perkins in the near future, the IAR will not continue to thrive. IAR members will find it increasingly difficult to compete for funding to carry out their research and to build new astronomical instrumentation.

Over the past several months the IAR has been encouraged to form an exploratory committee to investigate ways in which the IAR could become partners with Lowell Observatory in the Discovery Channel Telescope (DCT). Joining the DCT project would not only benefit the IAR astronomers, it also holds great promise for direct involvement of students and faculty in the School of Education and College of Communications. Joining the DCT project would, therefore, foster substantial interdisciplinary work at Boston University. Professors Brainerd and Jackson are in the process of arranging a visit of BU personnel (including the Deans of CAS, SED, and COM) to Discovery Communications in Summer 2010 in order to learn more about the ways in which BU can become involved with this project.

Seminar Series

The IAR Astrophysics Seminar Series on Monday 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-three astrophysicists. Graduate students prepare for upcoming seminars through the Astrophysics Journal Club, which meets on Friday afternoons. The seminar schedule is shown in Appendix B.

Accounts, Funding, Expenditures

Accounts supervised by the IAR during the past year include a total of thirty-two grants and contracts, the Lowell Operations account (20-341), the IDC return account for the IAR (20-351-1648-9), the IAR departmental account (20-351), Professor Blanton's startup account (20 201 1838-9), Professor Jackson's retention account (20 201 1588-9), and Professor West's startup account (020 201 8307-9). Grant and contract accounts supervised by the IAR include seven new sponsored grants and contracts, one existing grant which received further income, and twenty-five other continuing sponsored grants and contracts within the IAR. A total of thirteen of these sponsored grants and contracts were closed out during the past year. Fifteen new funding proposals were submitted to federal and other agencies, totaling over $3.39M.

Lowell Operations (20-341)

The Lowell Operations account is funded through the College of Arts and Sciences and is used to cover the cost of the annual usage fee to Lowell Observatory, the salary for the BU Telescope Support Scientist at Lowell and auto insurance on the BU vehicle kept in Arizona for use by BU personnel when they go there to observe. The expenses to be recorded against this account for FY10 are as indicated in the following table.

Category	Cost
Usage fee paid to Lowell Observatory	$151,151
*Brian Taylor (partial salary)	$35,243
Auto Insurance	$2,235
Total	$188,629

*The remainder of Brian Taylor's salary in FY10 was paid from grants awarded to IAR members.

IAR Dept. Account (020-351)

This year there was no activity on this account.

IAR IDC Return (20-351-1648-9)
This account was used to meet IAR expenses throughout the year. Expenditures, as of this report, totaled $124,962.66 and income totaled $154,159.61. In managing IAR activities utilizing this account, we internally track expenses in nine categories, some of which have Object Code equivalents, but others of which either combine or split Object Codes. These expense categories are broken down in the following table. In addition to the IDC return, the IAR income includes $10,000 of seed money for pre-proposal development of Flexi that was generously provided by Boston University. Expenditures for the pre-proposal development work will be reflected in next year's report.

IAR FY2010 Expenditures

Category	Cost	Percent of FY10 Expenditures
Basic Operations	$58,154	47%
Infrastructure	$44,844*	36%
Seminar Series, Social, Travel	$16,551	13%
Sponsored Project Overrun	$4,013	3%
General Research, Etc	$1400	1%
Total Expended	$124,962	100%

*Includes $31,000 for replacement of PRISM detector

Basic Operations, the largest expense category, covers fixed costs such as the Fiscal Administrator's salary, the director's stipend, and benefits for both. Infrastructure makes up the 2nd largest expense category for the IAR this year due to the replacement of the PRISM detector. The 3rd largest expense category is the Seminar Series, Social, and Travel which includes travel, costs, meals, and accommodations for our guest speakers as well as expenses for PhD receptions. Twelve seminars were held during the Fall 2009 semester, and eleven were held during the Spring 2010 semester. The schedules are shown in appendix B

Sponsored Grants and Contracts

The IAR managed a total of thirty-two grants during this fiscal year. There are six new grants, which have been awarded to the Institute, five existing grants were awarded further funding, and there were twenty-one other continuing grants. This year, the IAR closed out a total of thirteen awards. A summary of the FY2010 sponsored grant income and expenditures are contained in the following tables.

FY2010 Grant Income – Institute for Astrophysical Research (7/2009-6/2010)

P.I.	Agency	Title	FY2010 Award
*Bania	1002 NRAO	GBT Student Observing for Loren Anderson	$12,841
Bania	2157 NSF	Galactic Chemical Evolution: The 3-Helium Project	$110,578
*Blanton	1237 NASA	X-Ray Cluster Environments of Radio Sources	$94,195
Clemens	2903 NSF	Completing The Galactic Plane Infrared Polarization Survey (GPIPS)	$183,292
Jackson	2673 NASA	Galactic Structures Using 2Mass Data	$108,613
Janes	9080 NSF	Old Star Clusters: Stellar Activity and Galactic Structure	$34,216
*Jorstad	1041 NASA	Correlation Between Gamma-Ray Variations and Disturbances in the Jets of Blazars	$99,998
*Marscher	1120 NASA	Snapshots of the Spectral Energy Distribution of Blazars	$20,000
Marscher	2472 NASA	Comprehensive Multiwaveband Monitoring Program of Gamma-Ray Bright Blazars	$233,994
*Marscher	2856 NSF	The Most Compact Regions of Relativistic Jets in Active Galactic Nuclei	$602,138
*West	1410 NSF	Wide Low-Mass Binaries: Coeval Laboratories for Testing the Formation and Evolution of Stars and the Structure and Evolution of the Milky Way	$17,714

***New Awards**

Summary of IAR Grant Income

Origin of Award	Total Current Year Funding (7/09-6/10)
Institute for Astrophysical Research (20-351)	$1,517,579

FY2010 Grant Expenditures – Institute for Astrophysical Research (7/2009– 6/2010)

P.I.	Agency	Title	FY2010 Expense
Bania	1002 NRAO/GBT	GBT Student Observing for Loren Anderson	$7,822.76
Bania	2157 NSF	Galactic Chemical Evolution: The 3-Helium Project	$40,118.21
Bania	2239 JPL	Spitzer Space Telescope: Heating and Cooling in the Translucent Interstellar Medium	$1,872.72
Bania	2640 NSF/GBT	NRAO GBT Student Support	$0
Blanton	1237 NASA	X-Ray Cluster Environments of Radio Sources	$45,193.37
Blanton	2746 SAO	Shocks, Ripples and Bubbles: A Very Deep Observation of Abell 2052	$87,523.22
Blanton	8651 Foundations	Claire Booth Luce Professorship	$0
Brainerd	2088 NSF	Bright Field Galaxies and Their Dark Matter Halos	$65,267.29
Brainerd	2089 NSF	Bright Field Galaxies and Their Dark Matter Halos	$438.09
Clemens	2903 NSF	Completing The Galactic Plane Infrared Polarization Survey (GPIPS)	$152,835.52
Clemens	9378 NSF	The Galactic Plane Infrared Polarization Survey (GPIPS)	$36,426.24
Jackson	2196 NASA	Protostars in Infrared Dark Clouds	$36,748.38
Jackson	2459 NSF	Infrared Dark Clouds	$116,102.38
Jackson	2673 NASA	Galactic Structures Using 2Mass Data	$28,504.18
Jackson	8862 NASA	The Mid-Course Space Experiment Extended Source Catalog	$96,754.81
Jackson	9078 NSF	Release and Analysis of the Galactic Ring Survey	$19,320.97
Jackson	9528 JPL	Spitzer Cycle 3 Funding: Active Star Formation in Infrared Dark Clouds	$11,562.22
Janes	2398 NSF	REU Supplement: Old Star Clusters: Stellar Activity and Galactic Structure	$3,531.25
Janes	9080 NSF	Old Star Clusters: Stellar Activity and Galactic Structure	$32,577.35
Jorstad	1041 NASA	Correlation Between Gamma-Ray	$22,924.41

		Variations and Disturbances in the Jets of Blazars	
Jorstad	2477 NASA	Searching for the Connection between X-ray and Gamma-ray Variability and Jet Activity in Blazars	$4,257.19
Jorstad	2564 NASA	High Resolution Mapping of the Gamma-Ray Emission Regions in Blazar Jets	$4,488.83
Marscher	1120 NASA	Snapshots of the Spectral Energy Distribution of Blazars	$15,274.65
Marscher	2238 NASA	Probing the Relativistic Jets of Active Galactic Nuclei with Multiwaveband Monitoring	$28,608.02
Marscher	2240 JPL	Spitzer Space Telescope: Velocity Gradients in the Jets of BL Lac Objects	$0
Marscher	2259 NASA	Velocity Gradients in the Jets of BL Lac Objects	$0
Marscher	2270 NASA	Velocity Gradients in the Jets of BL Lac Objects	$0
Marscher	2472 NASA	Comprehensive Multiwaveband Monitoring Program of Gamma-Ray Bright Blazars	$257,702.90
Marscher	2529 NASA	PSD Break, Jet Scale and Black-Hole Mass of the FR II radio Galaxy 3C III	$9,659.84
Marscher	2856 NSF	The Most Compact Regions of Relativistic Jets in Active Galactic Nuclei	$211,273.52
Marscher	9508 JPL	Spitzer Cycle 3 funding: Contribution of Dust Emission to the Spectral Energy Distribution of Gamma-Ray Bright Blazars (Subcontract via JPL)	$0
West	1410 NSF	Wide Low-Mass Binaries: Coeval Laboratories for Testing the Formation and Evolution of Stars and the Structure and Evolution of the Milky Way	$0

Summary of IAR Sponsored Funding Expenditures

Origin of Award	**Total Current Year Expenditures (7/09-6/10)**
Institute for Astrophysical Research (20-351)	$1,335,461.57

Appendix A: Publications and Presentations

Articles in Refereed Journals

Abdo, A.A.,...,Jorstad, S.G.,...,Marscher, A.P., et al., “A Change in the Optical Polarization Associated with a Gamma-ray Flare in the Blazar 3C 279,” 2010, Nature, 463, 919

Abdo, A.A.,...,Jorstad, S.G.,...,Marscher, A.P., et al., “The Spectral Energy Distribution of Fermi Bright Blazars,” 2010, ApJ, 716, 30

Agudo, I., Thum, C., Wiesemeyer, H., and Krichbaum, T.P., “A 3.5mm Polarimetric Survey of Radio Loud AGN,” 2010, ApJS, in press

Agustsson, I. & Brainerd, T. G., “Anisotropic Locations of Satellite Galaxies: Clues to the Orientations of Galaxies within their Dark Matter Halos”, 2010, ApJ, 709, 1321

Anderson, L. D. & Bania, T. M., "Resolution of the Distance Ambiguity for Galactic H II Regions", 2009, ApJ, 690, 706

Anderson, L. D., Snowden, S. L., & Bania, T. M., “X-ray Shadowing Experiments Toward Infrared Dark Clouds”, 2010, ApJ in press

Anderson, L.D., Bania, T. M., Jackson, J. M., Clemens, D. P.; Heyer, M., Simon, R., Shah, R. Y., Rathborne, J. M., "The Molecular Properties of Galactic H II Regions", 2009, ApJS, 181, 255

Bania, T. M., Anderson, L. D., Balser, D. S., & Rood, R. T., “The Green Bank Telescope H II Region Discovery Survey”, 2010, ApJL, in press

Blanton, E. L., Clarke, T. E., Sarazin, C. L., Randall, S. W., & McNamara, B. R., “Active Galactic Nucleus Feedback in Clusters of Galaxies”, 2010, Publications of the National Academy of Science, 107, 16

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Brainerd, T. G., “Multiple Weak Deflections in Galaxy-Galaxy Lensing”, 2010, ApJ, 713, 603

Browning, M. K., Basri, G., Marcy, G. W., West, A. A., & Zhang, J., “Rotation and Magetic Activity in a Sample of M-dwarfs”, 2010, AJ, 139,504

Burgasser, A. J., Dhital, S., & West, A. A., “Resolved Spectroscopy of M Dwarf/L Dwarf Binaries. III. The ”Wide” L3.5/L4 Dwarf Binary 2MASS J15500845+1455180AB”, 2009, AJ, 138, 1563

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Chambers, E. T., Jackson, J. M., Rathborne, J. M., & Simon, R., "Star Formation Activity of Cores within Infrared Dark Clouds," 2009, ApJS, 181, 360

Chatterjee, R., Marscher, A. P., Jorstad, S. G. et al., “Disk-Jet Connection in the Radio Galaxy 3C 120,” 2009, ApJ, 704, 1689

Chen, C., Cote, P., West, A. A., Peng, E. W., & Ferrarse, L., “Homogeneous ugriz Photometry for ACS Virgo Cluster Survey Galaxies: Non-Parametric Analysis of the Photometric and Structural Scaling Relations”, 2010, ApJS, submitted

D'Ammando, F., ...Jorstad, S.G.,...Marscher, A.P., et al., “AGILE Detection of a Rapid Gamma-ray Flare from the Blazar PKS 1510-089 during the GASP-WEBT Monitoring,” 2009, AA, 508, 181

Dhital, S., West, A. A., Stassun, K. G., & Bochanski, J. J., “Sloan Low-massWide Pairs of Kinematically Equivalent Stars (SLoWPoKES): A Catalog of Very Wide, Low-mass Pairs”, 2010, AJ, 139, 2566

Douglass, E. M., Blanton, E. L., Clarke, T. E., Randall, S. W., & Wing, J. D., "The Merger Environment of the WAT Hosting Cluster Abell 562", ApJ, submitted

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Howell, P. J. & Brainerd, T. G., “Galaxy-Galaxy Lensing by Non-Spherical Haloes I: Theoretical Considerations”, 2010, MNRAS in press

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Janes, K. A., & Hoq, S., "A Quantitative Analysis of Distant Open Clusters", 2010, AJ, submitted

Jorstad, S.G., Marscher, A.P., et al. , “Flaring Behavior of the Quasar 3C 454.3 across the Electromagnetic Spectrum,” 2010, ApJ, 715, 362

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Kocevski, D., West, A. A., & Modjaz, M., “Modeling the GRB Host Mass Distribution”, 2009, ApJ, 702, 377

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Villata, M.,...,Jorstad, S.G.,...,Marscher, A.P., et al., “The GASP-WEBT Monitoring of 3C 454.3 during the 2008 Optical-to-Radio and Gamma-ray Outburst”, 2009, AA, 504, L9

Villata, M.,...,Jorstad, S.G.,...Marscher, A.P., et al., “The correlated optical and radio variability of BL Lacertae. WEBT data analysis 1994-2005”, 2009, AA, 501, 455

West, A. A., Garcia-Appadoo, D. A., Dalcanton, J. J., Disney, M. J., Rockosi, C. M., Ivezic, Z., Bentz, M. C., & Brinkmann, J., “HI-selected Galaxies in the Sloan Digital Sky Survey I: Optical Data”, 2010, AJ, 139, 315

West, A. A., Garcia-Appadoo, D. A., Dalcanton, J. J., Disney, M. J., Rockosi, C. M., & Ivezic, Z., “HI-selected Galaxies in the Sloan Digital Sky Survey II: The Colors of Gas-Rich Galaxies”, 2009, AJ, 138, 796

Professional Seminars, Colloquia and Conference Talks

Agustsson, I., Washington, DC, January 2010, “Probing Dark Matter Halos using Satellite Galaxies”, dissertation talk, American Astronomical Society Meeting #215

Bania, T. M., Geneva, Switzerland, November 2009, “Measurements of 3-He in Galactic H II Regions and Planetary Nebulae”, invited review, IAU Symposium No. 268, “Light Elements in the Universe”

Blanton, E. L., Boston, MA, September 2009, “AGN Feedback in Clusters of Galaxies”, invited review at "Chandra's First Decade of Discovery"

Blanton, E. L., Ohio University, May 2010, "AGN in Clusters of Galaxies: Cooling Flows, Feedback, and High-z Systems", invited colloquium

Blanton, E. L., Yale University, November 2009, "AGN in Clusters of Galaxies: Cooling Flows, Feedback, and High-z Systems", invited colloquium

Brainerd, T. G., Boston University, December 2009, “Seeing the Unseeable: Clues to the Orientations of Galaxies within their Dark Matter Halos”, invited talk for PHOTON

Brainerd, T. G., Drexel University, June 2010, “Seeing the Unseeable: Clues to the Orientations of Galaxies within their Dark Matter Halos”, invited colloquium

Brainerd, T. G., Waltham, MA, September 2009, “Intrinsic Alignments of Galaxies”, invited colloquium, Brandeis University

Clemens, D., Lowell Observatory, September 2009, "GPIPS - The Galactic Plane Infrared Polarization Survey, invited colloquium

Clemens, D., University of Massachusetts, December 2009, "GPIPS - The Galactic Plane Infrared Polarization Survey, invited colloquium

Clemens, D., University of Minnesota, September 2009, "GPIPS - The Galactic Plane Infrared Polarization Survey, invited colloquium

Jackson, J. M., Amherst, MA, August 2009, "Filamentary Infrared Dark Clouds," , scholarly paper presented at the Science Workshop for the Large Millimeter Telescope, UMass, Amherst

Jackson, J. M., Leeds, England, July 2009, “Infrared Dark Clouds”, invited review at the Workshop on Infrared Dark Clouds, University of Leeds

Jackson, J. M., Newport, RI, October 2009, "Snakes in the Plane: Cluster formation in Filamentary Infrared Dark Clouds," scholarly paper presented at “Star Formation in Dense Cores” meeting to Honor Phil Myer

Jorstad, S. G., Bonn, Germany, June 2010, “Fermi Meets Jansky – AGN at Radio and Gamma-Rays”, invited talk at “Localization of the Gamma-ray Emission Site Using Multi-waveband Data and mm-VLBI”

Jorstad, S. G., March 2010, “Correlation Between Parsec-Scale Jet Behavior and Gamma-Ray Light Curves of Blazars”, 11th AAS High Energy Astrophysics Division Meeting, contributed talk

Jorstad, S. G., Washington, DC, January 2010, “Connection Between Gamma-Ray Variations and Disturbances in the Jets of Blazars”, American Astronomical Society Meeting #215, invited talk at special session

Joshi, M., Washington, DC, January 2010, “Multi-wavelength Spectral Analysis of the Blazar 3C 279”, contributed talk, American Astronomical Society Meeting #215

Malmrose, M., Boston, MA, May 2010, “Spitzer Detection of a Clumpy Dust Torus in the Gamma-ray Blazar PG 1222+216 (4C21.35)”, contributed talk at the 20th New England Regional Quasar Meeting

Marscher, A. P., Bonn, Germany, June 2010, “Fermi Meets Jansky – AGN at Radio and Gamma-rays”, contributed talk at “Rapid Variability of Gamma-ray Emission from Sites near the 43 GHz Cores of Blazar Jets”

Marscher, A. P., Boston, MA, June 2010, “Active Galactic Nuclei”, invited seminar for director and summer students of the Maria Mitchell Observatory

Marscher, A. P., Cork, Ireland, December 2009, “Sites of Gamma-ray and X-ray Emission in the Jets of Blazars”, invited colloquium, University College Cork

Marscher, A. P., Granada, Spain, June 2010, “Gamma-rays from the Relativistic Plasma Jets of Blazars”, invited colloquium at the Instituto de Astrofisica de Aldalucia

Marscher, A. P., Miami, FL, March 2010, “Gamma-rays from the Relativistic Plasma Jets of Blazars”, invited colloquium, Florida International University

Marscher, A. P., Washington, DC, January 2010, “Multiple Gamma-ray Flares from Superluminal Knots in Blazars”, contributed talk, American Astronomical Society Meeting #215

Marscher, A. P., Washington, DC, November 2009, “RXTE Monitoring of Gamma-ray Bursts”, invited talk at the RXTE workshop

Marscher, A. P., Washington, DC, November 2009, “The Inner Jet of the Quasar PKS 1510-089 as Revealed by Multi-waveband Monitoring”, contributed talk, Fermi Symposium

West, A. A., Cambridge, MA, April 2010, “Big Science from Little Stars: What can we learn from the Volkswagens of the Milky Way?”, invited colloquium, MIT Kavli Institute

West, A. A., Cambridge, MA, January 2010, “Creating a Diversity Plan”, invited talk at the MIT Physics Diversity Summit

West, A. A., Flagstaff, AZ, March 2010, “Big Science from Little Stars: What can we learn from the Volkswagens of the Milky Way?”, invited colloquium, Lowell Observatory

West, A. A., Middletown, CT, February 2010, “Big Science from Little Stars: What can we learn from the Volkswagens of the Milky Way?”, invited colloquium, Wesleyan University

West, A. A., San Diego, CA, April 2010, “Big Science from Little Stars: What can we learn from the Volkswagens of the Milky Way?”, UC San Diego Astrophysics Journal Club

West, A. A., Toronto, Canada, October 2009, “Stellar (Low-Mass Star) Activity, Spindown (Age) and the Sloan Digital Sky Survey”, invited review at the CITA Workshop on Magnetic Fields

West, A. A., Washington, DC, April 2010, “Big Science from Little Stars: What ca we learn from the Volkswagens of the Milky Way?”, invited colloquium, Carnegie DTM

Young, M., Washington, DC, January 2010, “The SDSS/XMM-Newton Quasar Survey: Accretion Physics via Trends and Outliers”, dissertation talk, American Astronomical Society Meeting #215

Conference Proceedings, Abstracts and Poster Papers

Agudo, I., Jorstad, S.G., Marscher, A.P., Larionov, V., Gomez, J.L., Wiesemeyer, H., Thum, C., Gurwell, M., Heidt, J., & D'Arcangelo, F.D., “The Multi-Spectral-Range Behavior of OJ287 in 2005-2010,” 2010, in Fermi Meets Jansky - AGN at Radio and Gamma-Rays, ed. T. Savolainen et al. (Max-Planck-Institut fur Radioastronomie), in press

Agustsson, I., “Probing Dark Matter Halos with Satellite Galaxies”, 2010, American Astronomical Society Meeting #215, #375.04, BAAS, 42, 583

Anderson, L. D., Bania, T. M., Balser, D. S., & Rood, R. T., “First Results from the Green Bank Telescope H II Region Discovery Survey”, 2010, AAS Meeting #216, #424.02, BAAS, 42, 836

Balser, D. S., Rood, R. T., & Bania, T. M., “4-He Abundances: Optical vs. Radio Recombination Line Measurements”, 2010, in "Light Elements in the Universe", Proceedings IAU Symposium No. 268, Charbonnel, C., Tosi, M., & Primas, F. eds., (Cambridge: CUP)

Bania, T. M., Anderson, L. D., Balser, D. S., & Rood, R.T., “The Green Bank Telescope Galactic H II Region Discovery Survey”, 2010, AAS Meeting #216, #309.02, BAAS, 42, 871

Bania, T. M., Rood, R. T., & Balser, D. S., "Measurements of 3-He in Galactic H II Regions and Planetary Nebulae", 2010 in "Light Elements in the Universe", Proceedings IAU Symposium No. 268, Charbonnel, C., Tosi, M., & Primas, F. eds., (Cambridge: CUP)

Blanton, E. L., Randall, S. W., Douglass, E. M., Clarke, T. E., Anderson, L. A., Sarazin, C. L., & McNamara, B. R., "Deep Chandra Observations of Feedback in the Cool Cores of A2052 and A262", 2009, at IAU Symposium 267, ``Evolution of Galaxies and Central Black Holes: Feeding and Feedback", Rio De Janeiro, Brazil

Blanton, E. L., Randall, S. W., Sarazin, C. L., McNamara, B. R., & Clarke, T. E., "A Very Deep Chandra Observation of the Cool Core Cluster Abell 2052", 2010, American Astronomical Society HEAD Meeting #11, #34.02, BAAS, 41, 710

Brainerd, T. G., Agustsson, I., Madsen, C. A., & Edmonds, J. A., "Large-Scale Intrinsic Alignments of Galaxies", 2010, AAS Meeting #215, #409.06, BAAS, 42, 234

Chapman, N. L., Goldsmith, P., & Clemens, D., "The Magnetic Field in Taurus", 2010, American Astronomical Society Meeting #215, #2010 January 3-7, Washington, D.C., #332.03, BAAS, 42, 430

Clemens, D. P., Pavel, M., & Pinnick, A., "Automated Analysis Pipelines For The Galactic Plane Infrared Polarization Survey: From Basic Image Processing To Crowded-field, Variable-PSF, Imaging Polarimetry", 2010, American Astronomical Society Meeting #215, #438.01, BAAS, 42, 392

Douglass, E., Blanton, E. L., Clarke, T. E., & Sarazin, C. L., "The Cluster Environments of Wide Angle Tail Radio Sources", 2009, at "Chandra's First Decade of Discovery", Boston, MA

Finn, S. C., Jackson, J. M., Chambers, E. T., Rathborne, J. M., & Simon, R., "Chemical Evolution of Infrared Dark Clouds," 2009, American Astronomical Society Meeting #214, #315.05, BAAS, 41, 692

Finn, S. C., Jackson, J. M., Chambers, E. T., Rathborne, J. M., & Simon, R., "Using CS (2-1) to Determine the Galactic Distribution of Infrared Dark Clouds", 2010, American Astronomical Society Meeting, #215, #414.09, BAAS, 42, 255

Howell, P. J. & Brainerd, T. G., "Properties of Dark Matter Halos from Galaxy-Galaxy Weak Lensing and the Effect of Multiple Deflections", 2010, AAS Meeting #215, #408.04, BAAS, 42, 232

Ingalls, J. G., & Bania, T. M., "Molecular Hydrogen Emission from Translucent Galactic Clouds", at "Reionization to Exoplanets: Spitzer's Growing Legacy", 26-28 Oct. 2009

Jackson, J. M., Finn, S., Chambers, E., Rathborne, J. M., & Simon, R., "The Nessie Nebula: Cluster Formation in a Filamentary Infrared Dark Cloud", 2009, American Astronomical Society Meeting #214, #315.05, BAAS, 41, 760

Jackson, J. M., Finn, S., Rathborne, J. M., & Simon, R., “Periodic Spacing of Protocluster Clumps in a Filamentary Infrared Dark Cloud”, 2010, American Astronomical Society Meeting #216, #309.03

Janes, K., "A Photometric Survey of the Open Clusters NGC 7789 and M67”, 2010, American Astronomical Society Meeting #215, #478.07, BAAS, 42, 566

Jorstad, S., Marscher, A., D'Arcangelo, F., & Harrison, B., “Connection between Gamma-Ray Variations and Disturbances in the Jets of Blazars, 2010, poster paper at the 20th New England Regional Quasar Meeting

Jorstad, S., Marscher, A., D'Arcangelo, F., & Harrison, B., “Connection between Gamma-Ray Variations and Disturbances in the Jets of Blazars,” 2010, in “2009 Fermi Symposium” (eConference C091122), arXiv:0912.5230v2

Jorstad, S., Marscher, A., D'Arcangelo, F., & Harrison,B., “Connection between Gamma-Ray Variations and Disturbances in the Jets of Blazars”, 2009, poster paper at Fermi Symposium

Jorstad, S., Marscher, A., Smith, P., Larionov, V., and Agudo, I., “Localization of the Gamma-ray Emission Site Using Multi-waveband Data and mm-VLBI,” 2010, in Fermi Meets Jansky - AGN at Radio and Gamma-Rays, ed. T. Savolainen et al. (Max-Planck-Institut fur Radioastronomie), in press

Jorstad, S.G. & Marscher, A.P., “Connection between Gamma-Ray Variations and Disturbances in the Jets of Blazars,” 2010, BAAS, #215, #225.02

Jorstad, S.G., & Marscher, A.P., “Correlation between Parsec-Scale Jet Behavior and Gamma-Ray Light Curves of Blazars,” 2010, AAS HEAD meeting, BAAS #11, #30.03

Joshi, M., Marscher, A., Jorstad, S., Larionov, V., Agudo, I., Aller, M., Gurwell, M., & Lahteenmaki, A., “Multi-wavelength Spectral Analysis of the Blazar 3C 279,” 2010, BAAS, #215, #324.06

Marscher, A.P. & Jorstad, S.G., “Rapid Variability of Gamma-ray Emission from Sites near the 43 GHz Cores of Blazar Jets,” 2010, in Fermi Meets Jansky - AGN at Radio and Gamma-Rays, ed. T. Savolainen et al. (Max-Planck-Institut fur Radioastronomie), in press

Marscher, A.P., Jorstad, S.G., D'Arcangelo, F.D., Bhatterai, D., Taylor, B., Olmstead, A.R., Manne-Nicholas, E., Larionov, V.M., Hagen-Thorn, V.A., Konstantinova, T.S., Larionoa, E.G., Larionova, L.V., Melnichuk, D.A., Blinov, D.A., Kopatskaya, E.N., Troitsky, I.S., Agudo, I., G\'omez, J.L., Roca-Sogorb, M., Smith, P.S., Schmidt, G.D., Kurtanidze, O., Nikolashvili, M.G., Kimeridze, G.N., & Sigual, L.A., “The Inner Jet of the Quasar PKS1510-089 as Revealed by Multi-waveband Monitoring,” 2010, in 2009 Fermi Symposium, ed. W.N. Johnson and D.J. Thompson (eConference C091122), arXiv:1002.0806v1

Marscher, A.P., Jorstad, S.G., Larionov, V.M., Agudo, I., Aller, M., Lahteenmaki, A., Smith, P.S., Krichbaum, T., & McHardy, I. M., “Comprehensive Multi-waveband Monitoring of

Gamma-ray Blazars", 2010, poster paper #33.23, 11th AAS High Energy Astrophysics Division Meeting

Marscher, A.P., Jorstad, S.G., Larionov, V.M., Agudo, I., Aller, M., Lahteenmaki, A.,Smith, P.S., Krichbaum, T., & McHardy, I. M., "Comprehensive Multi-waveband Monitoring of Gamma-ray Blazars", 2010, poster paper at the 20th New England Regional Quasar and AGN Meeting

Marscher, A.P., Jorstad, S.G., Larionov, V.M., Agudo, I., Aller, M.F., Gurwell, M., Lahteenmaki, A., & Smith, P.S. 2010, BAAS, #215, #324.07

Marscher, A.P., Jorstad, S.G., Larionov, V.M., Agudo, I., Aller, M., Lahteenmaki, A.,Smith, P.S., Krichbaum, T., & McHardy, I. M. 2010, BAAS, #11, #33.23

Moreau, J. M., Clemens, D., Jameson, K., Pavel, M., & Pinnick, A., "Near Infrared Spectroscopy and Imaging of Star Cluster Mercer 17", 2010, American Astronomical Society Meeting #215, #455.27, BAAS, 42, 477

Pavel, M., "Simulations of Near-IR Polarimetric Observations", 2010, American Astronomical Society Meeting #215, #431.03, BAAS, 42, 362

Pinnick, A., Clemens, D. P., & Pavel, M., "Using Synthetic Polarization Images to Test and Validate the Automated Data Analysis Pipeline for the Galactic Plane Infrared Polarization Survey (GPIPS)", 2010, American Astronomical Society Meeting #215, #438.02, BAAS, 42, 392

Randall, S. W., Forman, C., Markevitch, M., Blanton, E. L., Nulsen, P. E. J., & Forman, W., "Gas Sloshing, AGN Heating, and Bubbles in the Galaxy Group NGC5098", 2009, at IAU Sympoium 267, ``Evolution of Galaxies and Central Black Holes: Feeding and Feedback", Rio De Janeiro, Brazil

Rathborne, J. M., Jackson, J. M., Simon, R., & Zhang, Q., "Infrared Dark Clouds as Precursors to Star Clusters," 2009, Astrophysics and Space Sciences, 324, 155

Schinzel, F., Lobanov, A., Jorstad, S.G., Marscher, A.P., & Taylor, G.B., "Radio Flaring Activity of 3C 345 and its Connection to Gamma-Ray Emission," 2010, in Fermi Meets Jansky - AGN at Radio and Gamma-Rays, ed. T. Savolainen et al. (Max-Planck-Institut fur Radioastronomie), in press

Schwartz, Daniel A.,...Jorstad, S., Marscher, A., et al., "Inverse Compton Analysis of the X-ray Jet in Quasar 4C 19.44," 2009, BAAS, #214, #603.08

Shitanish, J., Balser, D. S., Bania, T. M., Rood, R. T., & Roshi, D. A., "Magnetic Fields in Photo-Dissociation Regions", 2010, AAS Meeting #215, #415.14, BAAS, 42, 263

Touhami, Y., Gies, D. R., Richardson, N. D., Schaefer, G. H., Boyajian, T. S., Williams, S. J., Grundstrom, E. D., McSwain, V. M., Clemens, D. P., &Taylor, B., "Spectral Energy

Distributions of Bright Be Stars and Other Massive Stars", 2010, American Astronomical Society Meeting #215, #428.17, BAAS, 42, 347

Vernazza, P., Carry, B. Emery, J., Hora, J. L., Cruikshank, D., Binzel, R. P., Jackson, J., Helbert, J., & Maturilli, A., "Mid-infrared Spectral Variability For Compositionally Similar Asteroids," 2009, American Astronomical Society, DPS meeting #41, #53.09

Wing, J. & Blanton, E., "Galaxy Cluster Environments Surrounding Radio Sources", 2010, American Astronomical Society Meeting #215, #436.29, BAAS, 42, 389

Young, M., Elvis, M., Marscher, A., & Risaliti, G., "The SDSS/XMM-Newton Quasar Survey: Accretion Physics via Trends and Outliers," 2010, BAAS, #215, #311.02

Young, M., Elvis, M., Risaliti, G., & Marscher, A., "Understanding the Relation between Optical and X-ray Emission in Quasars", poster paper at the 20th New England Regional Quasar and AGN Meeting

Young, M., Elvis, M., Risaliti, G., & Marscher, A., "Understanding the Relation between Optical and X-ray Emission in Quasars," 2010, AAS HEAD meeting, BAAS #11, #7.01

Book

Marscher, A. P., "From Nothing to Everything: The Story of Our Universe", 2010, published electronically at http://www.bu.edu/blazars/textbook.html

Book Chapter

Marscher, A. P., "Jets in Active Galactic Nuclei", 2010, Chapter 7 of "The Jet Paradigm – From Microquasars to Quasars", ed. T. Belloni (Lecture Notes in Physics, vol. 794)

Appendix B: Seminar Series Schedules

Institute for Astrophysical Research Seminar Series
Fall 2009

Sept. 8	Elizabeth Blanton, Boston University “Active Galactic Nuclei in Clusters of Galaxies: Cooling Flows, Feedback, and High-z Systems”
Sept. 15	Martin Elvis, Smithsonian Astrophysical Observatory “The Quasar Continuum: New Connections”
Sept. 29	Edo Berger, Harvard University “Gamma-Ray Bursts: A New Probe of the High-Redshift Universe”
Oct. 6	Eileen Friel, Lowell Observatory “Open Clusters: Their Role in the Galaxy”
Oct. 8	James Green, University of Colorado “Probing the Inter-Galactic Medium with the Cosmic Origins Spectrograph”
Oct. 20	Joshua Winn, MIT “Exoplanets and their Odd Orbital Inclinations”
Oct. 28	John Johnson, University Hawaii “Retired A Stars and their Planets”
Nov. 3	John Bochanski, MIT “Our 15 Million Nearest Neighbors: M Dwarfs & the Local Milky Way”
Nov. 12	Randy Kimble, NASA-Goddard Space Flight Center “A Powerful New Imager for HST: Performance and Early Results of Wide Field Camera 3”
Nov. 17	Aneta Siemiginowska, Smithsonian Astrophysical Observatory “X-ray Jets and Evolution of Extragalactic Radio Sources”
Dec. 1	B.-G. Anderson, NASA-Ames Research Center “The Stratospheric Observatory for Infrared Astronomy ,SOFIA: Status and Science overview”
Dec. 8	David Wilner, Smithsonian Astrophysical Observatory “Planet Forming Disks”

Institute for Astrophysical Research Seminar Series
Spring 2010

Jan. 25	Kenneth Janes, Boston University "Star Clusters: Studies in Stellar and Galactic Evolution"
Feb. 1	Jonathan Foster, Boston University "Scattered, Extinguished and Emitted: Three Views of Star-forming Dust"
Feb. 8	Peter McCullouch, CfA & STScI "Discovery and Characterization of Transiting Extrasolar Planets"
Feb. 16	Crystal Brogan, NRAO “Searching for the Secrets of Massive Star Birth”
Feb. 22	Margaret Meixner, CfA & STScI "The Life Cycle of Matter in the Magellanic Clouds: Insights from the Spitzer SAGE Surveys"
Mar. 1	Don Figer, Rochester Institute of Technology “Massive Young Star Clusters and the Stellar Upper Mass Limit”
Mar. 15	Kim McLeod, Theresa Mall Mullarkey Associate Professor, Wellesley College “Probing the Assembly of Massive Galaxies via Quasar Hosts at z=4”
Mar. 22	Doug Gies, Georgia State University “Transformations in Massive Binary Stars”
Mar. 29	Barry Madore, Carnegie Observatories “The Carnegie Hubble Program (CHP): Determining the Hubble Constant to 2%”
Apr. 5	Henry Roe, Lowell Observatory “ Titan’s Methane Weather”
Apr. 12	Kevin Covey, Hubble Fellow, Cornell University “The Origin & Evolution of Stellar Spins”