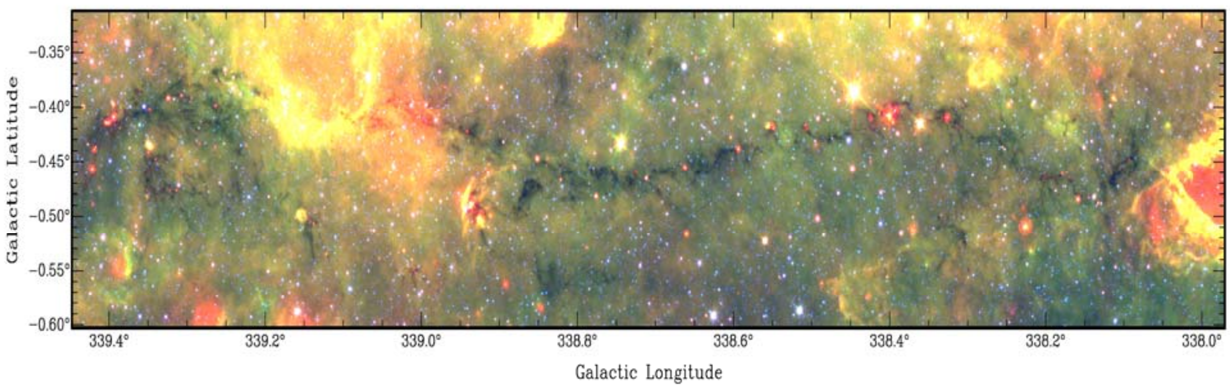
Boston University
Institute for Astrophysical Research
Annual Report
June 2009



GLIMPSE/MIPSGAL image of the "Nessie Nebula," an extremely filamentary infrared dark cloud (IRDC). IRDCs host the earliest stages of high-mass star and cluster formation, and many pre-stellar evolutionary phases can be seen in the Nessie Nebula. The color scale shows 3.6 micron emission (blue), 8 micron emission (green) and 24 micron emission (red).

Tereasa Brainerd, Director
Kimberly Paci, Administrator

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Introduction

Summary

The Institute for Astrophysical Research marked a successful 11th 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 seventeen scientific papers in refereed journals. Among our scientific highlights are: (1) the discovery that Infrared Dark Clouds (IRDCs) tend to be very filamentary in their structure, (2) the establishment of enhanced 4.5 micron emission in IRDCs as an indicator of the earliest stages of high-mass star formation, (3) the discovery that ordinary, bright galaxies are intrinsically aligned with each other over very large distances in the universe, and (4) the discovery of a large number of previously-unknown Galactic HII regions.

In FY2009, total IAR grant expenditures, including new and continuing grants, was $1.36M. IAR members submitted new funding proposals totaling over $3.47M in requests. The IAR received a total of $987,049 in grant income, including ten new awards totaling $907,805.

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, and (4) promoting the design, development, and operation of Boston University instruments and telescopes.

Faculty, Staff and Students

In FY2009, IAR personnel included Professors Thomas Bania, Dan Clemens, James Jackson, Kenneth Janes, and Alan Marscher, Associate Professor Tereasa Brainerd, Assistant Professor Elizabeth Blanton, and Senior Research Associate Dr. Svetlana Jorstad. Other personnel included Research Associate Dr. Irena Stojmirovich, Research Fellow Dr. Kathleen Kraemer, Research Associate Brian Taylor (the IAR's Telescope Support Scientist stationed in Flagstaff, Arizona at Lowell Observatory), Senior Research Associate Dr. Amanda Bosch, and IAR Fiscal Administrator Ms Kimberly Paci.

BU graduate students conducting astrophysical research with IAR members during the past year included Ingolfur Agustsson, Loren Anderson, Dipesh Bhatterai, Edward Chambers, Ritaban Chatterjee, Francesca D'Arcangelo, Edmund Douglass, Susanna Finn, Paul Howell, Ji Hyun Kim, Michael Malmrose, Michael Pavel, April Pinnick, Julia Roman-Duval, Patricio Sanhueza, Joshua Wing, and Monica Young. BU undergraduate students working within the IAR included Brandon Harris, Sadia Hoq, Katherine Jameson, Emily Manne-Nichols, Alice Olmstead, Chad Madsen, and Julie Moreau. Three of these undergraduate students completed Senior Work for Distinction during the 2008/2009 academic year: Katherine Jameson, Alice Olmstead, and Emily Manne-Nichols. In addition, two graduate students at St. Petersburg State University in Russia (Daria Melnik and Ivan Troizkij) were supervised by Dr. Jorstad.

New Faculty Member

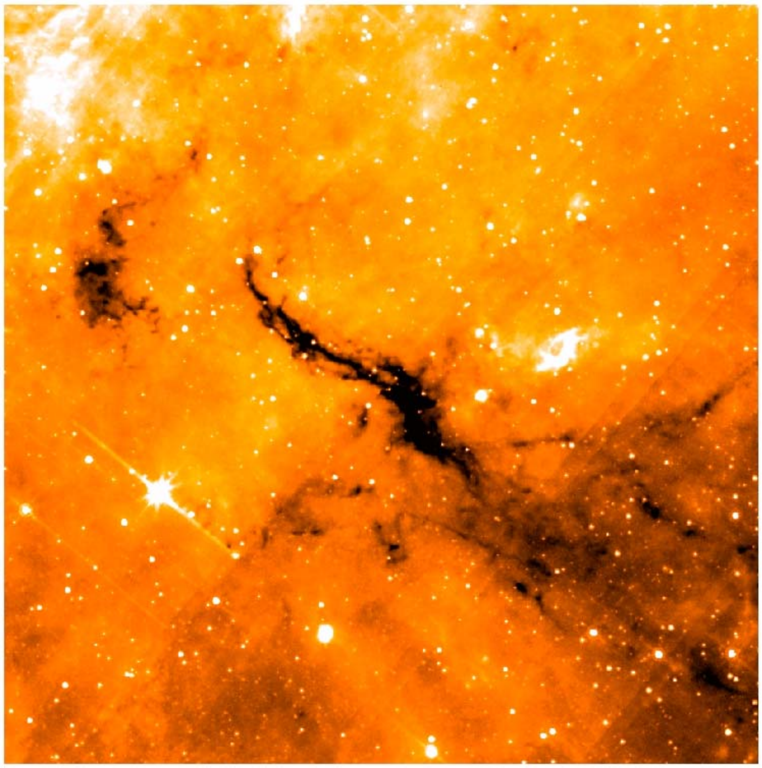
During the spring of 2009, the Department of Astronomy conducted a search for a new faculty member. As a result of this search, Dr. Andrew West (currently a postdoctoral fellow at MIT) was hired and he will join the Department of Astronomy officially in September 2009. We are very excited about the addition of Dr. West to our faculty roster because he brings a great deal of enthusiasm and expertise to the education and research missions of the Department of Astronomy and the IAR.

Dr. West's research focuses on two distinct questions: 1) What can the magnetic activity of low-mass stars tell us about convective dynamos and the structure of the Milky Way galaxy? and 2) How does global star formation proceed in galaxies in response to the physical conditions of the entire system? Recently, Dr. West has used "Galactic Stratigraphy" to assign statistical ages to M dwarf stars. This method draws on the fact that stars that are further from the Galactic Plane have undergone more dynamical heating and are therefore statistically older. As part of this research, Dr. West has created the largest spectroscopic sample of low-mass stars ever assembled (~50,000) and has used this sample to explore the age dependence of magnetic dynamo generation in M dwarfs, as well as the kinematic details of the thin and thick disks of the Milky Way.

In addition to his research, Dr. West has distinguished himself through his commitment to being an advocate for policy change and by playing a large role in increasing the awareness of diversity issues in astronomy. Dr. West, a self-described white male, is a member of the National Society of Black Physicists (NSBP) who regularly attends and presents at the NSBP annual meeting. Dr. West is currently the co-chair of the astronomy/astrophysics section of the NSBP, and hopes to create relationships with students and faculty at Minority Serving Institutions that will allow for collaborations across traditionally un-crossed boundaries. In 2008, the NSBP awarded Dr. West and two colleagues a certificate of distinction for their commitment to diversity in physics and astronomy. As a faculty member at BU, Dr. West plans to continue his efforts to bring diversity to the astronomical academy as well as to the BU campus.

Science Highlights

Infrared Dark Clouds



A GLIMPSE 8 micron image of a typical Infrared Dark Cloud.

Infrared surveys of the Galactic plane performed with the Infrared Space Observatory (ISO), the Midcourse Space Experiment (MSX), and the Spitzer Space Telescope identified an entirely new class of interstellar clouds, the Infrared Dark Clouds (IRDCs; see figure below). These molecular clouds are seen in silhouette against the bright Galactic infrared background. When they were discovered, it was unclear what role, if any, IRDCs played in star formation. Professor Jackson's research group has, however, obtained ample evidence that these IRDC cores host the very earliest phases in the formation of both high-mass stars and star clusters.

Professor Jackson's group has shown that all IRDCs have compact, cold cores superimposed on extended emission. These cold, unresolved cores have characteristic sizes of less than 0.5 pc and masses of ~100 solar masses, exactly as expected for high-mass pre-stellar cores. Therefore, IRDC cores are almost certainly star-forming cores in their earliest phase of evolution. About 1/3 of these IRDC cores are sites of active star formation. The “active” cores typically contain several indicators of star-formation. The high-density tracing molecules CS and HCN show broad line widths, indicating protostellar outflows. The cores also have strong SiO emission. Because SiO forms via the shock destruction of dust grains, strong SiO emission also indicates shocks induced by outflows, and therefore reliably indicates star formation. Spitzer 3—8 micron data from GLIMPSE show slightly extended, diffuse emission, with an apparent enhancement in the 4.5 micron band. In false color, red (8 micron)-green (4.5 micron)-blue (3.6 micron) renderings of the GLIMPSE data, this enhanced 4.5 micron emission reveals itself as a fuzzy patch of green emission. Professor Jackson’s group calls such sources “green fuzzies.” Green fuzzies may arise from a shock-excited H_2 spectral line.

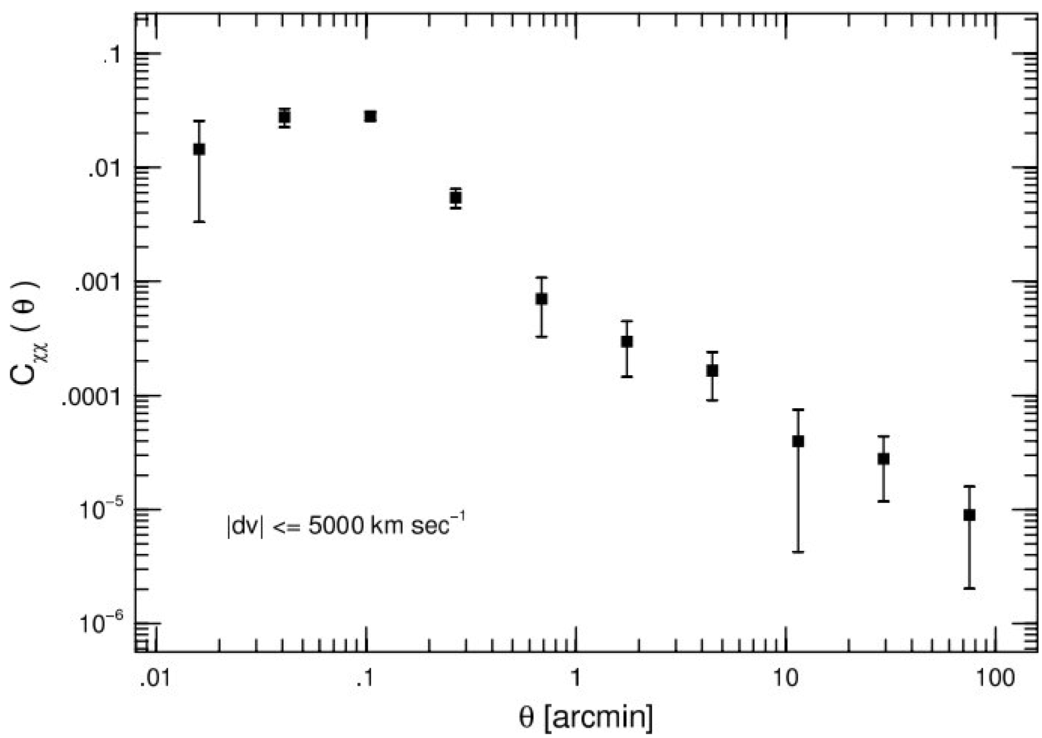
Professor Jackson’s group has shown that IRDC cores containing green fuzzies have all the characteristics expected of an “active” star-forming core. Compared to cores without green fuzzies, the cores with green fuzzies are warmer, smaller, and contain multiple signs that stars are forming inside them, such as bright infrared sources and naturally occurring masers. There is now no doubt that IRDC cores host the earliest stages of high-mass star formation.

Remarkably, many of these IRDCs are quite filamentary in nature. One extreme example is the Nessie nebula, shown on the cover of this report. The nebula stretches over 1.5 degrees along the southern sky (i.e., in size it is 3 times the diameter of the full moon). Nessie contains multiple cores, some of which contain high-mass protostars. The filamentary nature of Nessie and other IRDCs may hold an important clue as to how stars form. Theory suggests that if a gaseous filament is left alone under the influence of its own gravity, it will fragment into “beads” at a characteristic spacing and a characteristic mass. The cores found in Nessie conform amazingly well to these expectations. Thus, star formation may result from the fragmentation into beads of filamentary dark clouds.

Intrinsic Alignments of Galaxies

Professor Brainerd, graduate students Ingolfur Agustsson and Jeffrey Edmonds (BU School of Theology) and undergraduate student Chad Madsen have used the 7th data release of the Sloan Digital Sky Survey (SDSS) to investigate the degree to which ordinary, bright galaxies are aligned with each other. It has long been known that galaxies are not distributed at random in the universe; rather, they form a complicated filamentary network. The most popular model of galaxy formation, known as the Cold Dark Matter (CDM) model, predicts that all large, bright galaxies form within long filaments of dark matter. As a result of non-spherical infall of material along the filaments, as well as tidal torquing during the galaxy formation process, CDM makes a strong prediction that ordinary, bright galaxies (like our own Milky Way) should have a weak tendency to be aligned with each other over vast scales in the universe (of order 10 Mpc).

The image correlation function for ordinary bright galaxies in the SDSS, shown as a function of angular separation on the sky. The function takes on positive values when galaxy images have a tendency to point in the same direction (i.e., they are aligned with each other). The intrinsic alignments extend to very large physical scales (~ 10 Mpc) and are consistent with the predictions of the Cold Dark Matter model.

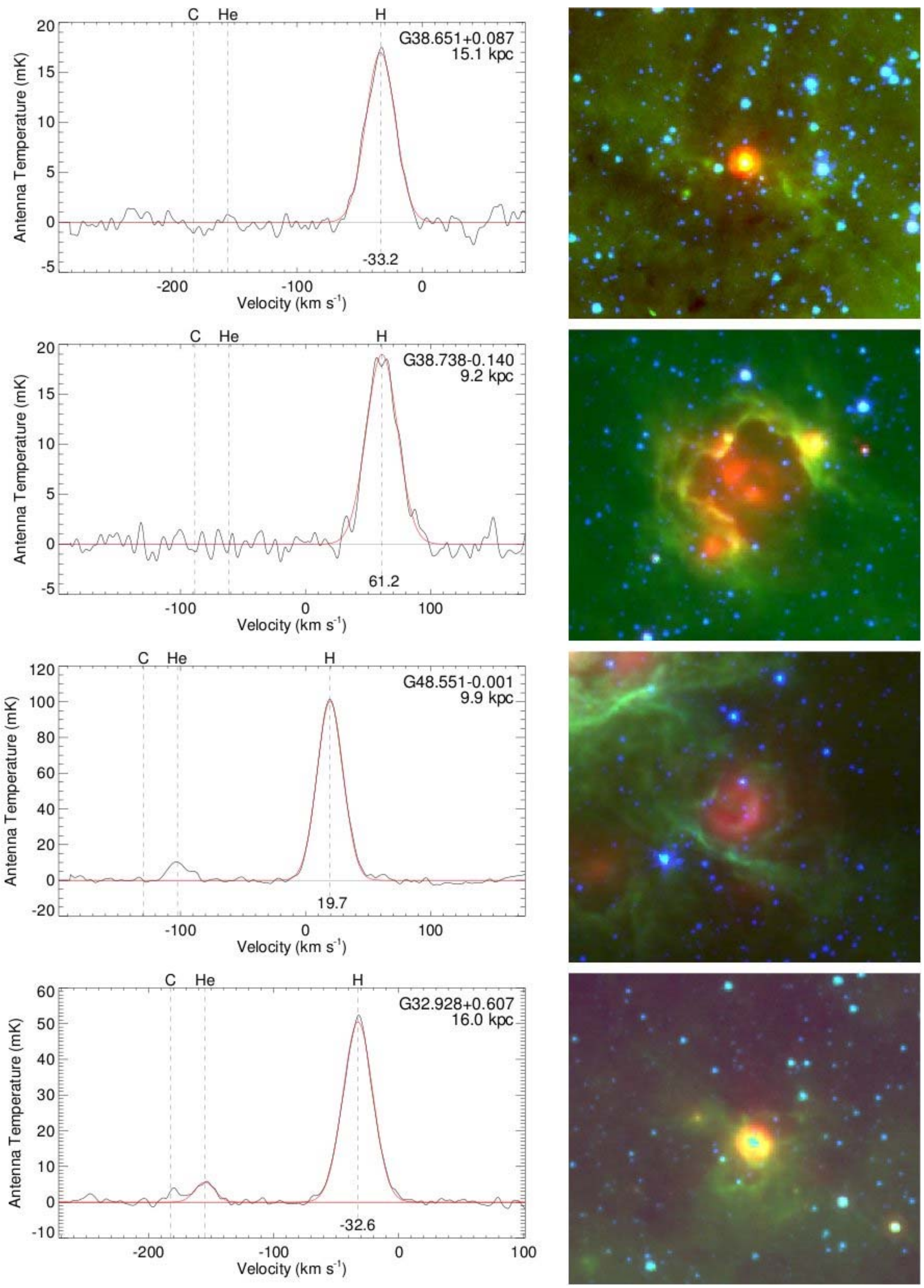


Although it has been known for about a year that the very most luminous elliptical galaxies in the universe (known as the Luminous Red Galaxies) exhibit intrinsic alignment, the work of Professor Brainerd and her students is the first to show that ordinary bright galaxies are intrinsically aligned with each other over large scales in the universe. The galaxies in their study consist of elliptical, spiral, and lenticular galaxies that are at most a few times fainter or a few times brighter than our own Milky Way galaxy. The degree of intrinsic alignment that they detect is completely consistent with the predictions of CDM under a very simple assumption for the way in which luminous galaxies reside within their dark matter halos; elliptical galaxies share the same shapes as their dark matter halos, while disk galaxies (i.e., spirals and lenticulars) share the same net angular momenta as their dark matter halos.

The work of Professor Brainerd and her students constitutes an important test of galaxy formation within the framework of the popular CDM model. In addition, their observations provide a benchmark for the degree of intrinsic galaxy alignment that is likely to contaminate forthcoming large surveys of "cosmic shear". Cosmic shear is a type of weak gravitational lensing of distant galaxies by the large-scale structure of the universe that, in principle, can be used to place strong constraints on the fundamental cosmological parameters (e.g., the expansion rate of the universe, the amount of dark energy in the universe, etc.) as well as the rate at which structure grew in the universe. Central to the theory of cosmic shear, however, is that the images of distant galaxies are not intrinsically correlated with each other. The work of Professor Brainerd and her students shows that this underlying assumption is incorrect, and it will be important for the upcoming cosmic shear studies to carefully account for intrinsic galaxy alignments in their analyses.

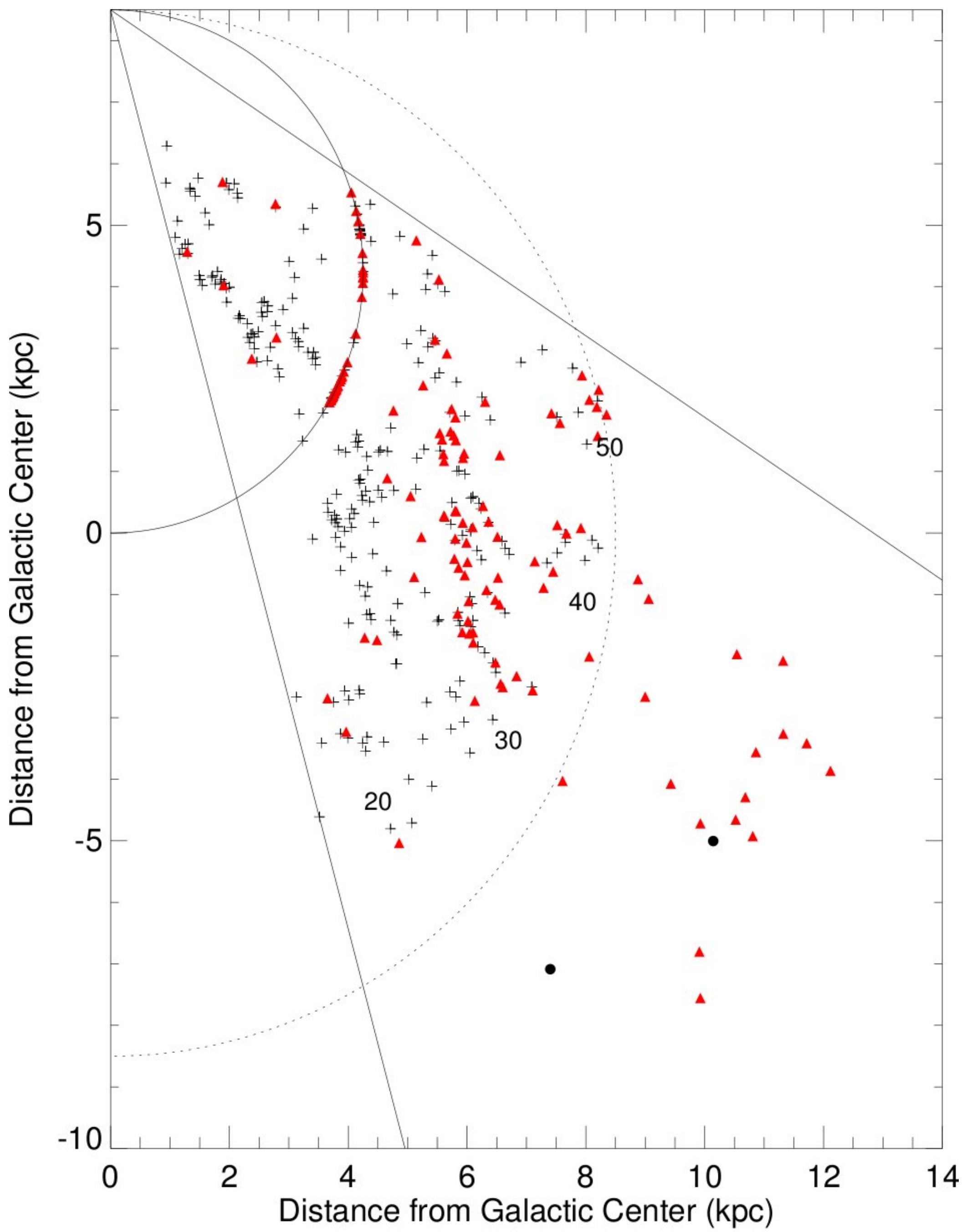
Formation Sites of Massive Stars

Professor Bania and graduate student Loren Anderson are discovering a large population of previously unknown star formation sites in our Milky Way galaxy. These Galactic formation sites of massive, OB-type stars (HII regions) are being found using the NRAO Green Bank Telescope at 3 cm wavelength (X-band) to discover recombination line (RRL) emission from these nebulae. Thus far they have detected RRL emission from 149 of 158 targets, which are defined by morphological matches between 20 cm continuum and mid-infrared images. Since HII region RRLs are optically thin at X-band they can discover HII regions across the entire Galactic disk. For their survey zone Bania and Anderson are doubling the number of known HII regions and making a complete census of all nebulae ionized by single O-type stars within the Solar orbit. For these new nebulae they will determine the nebular kinematic distances, luminosities, metallicities (via the electron temperature, T_e) and helium abundances ($Y={}^4He/H$). 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. They are finding that ~10% of these new nebulae are located in the GCE-critical region beyond the Solar orbit at R_{gal} ~ 9-12kpc. This survey will also give a more accurate census of HII regions and their properties, provide a fair sampling of nebulae at all stages of their evolution, and increase our knowledge of Galactic structure.



Four new HII regions discovered by Professor Bania and graduate student Loren Anderson with the NRAO Green Bank Telescope. The spectra are composite HN-alpha recombination lines; they are the average of 7 alpha transitions at 3 cm wavelength. For the brightest sources the He and C transitions can also be seen. The right panels show Spitzer infrared images of the HII regions, each 5 arcmin on a side (red: MIPSGAL 24 micron emission; green: GLIMPSE 8 micron emission; blue: GLIMPSE 4.5 micron emission). The nebular kinematic distances are quite large. The two negative LSR velocity sources are HII regions located in the GCE-critical region beyond the solar orbit at Rgal ~ 9-12 kpc.

Face-on map of the locations of first Galactic quadrant Milky Way HII regions. Crosses mark the positions of previously known Galactic HII regions. Red triangles mark the positions of the newly discovered HII regions as of March 2009. The dotted line shows the Sun's orbit about the Galactic center. The full drawn line is the locus of tangent points. The wedge locates the zone of the BU-FCRAO Galactic Ring Survey. The discovery survey has increased the populations of GCE-critical HII regions located beyond the Solar Orbit by 800%.



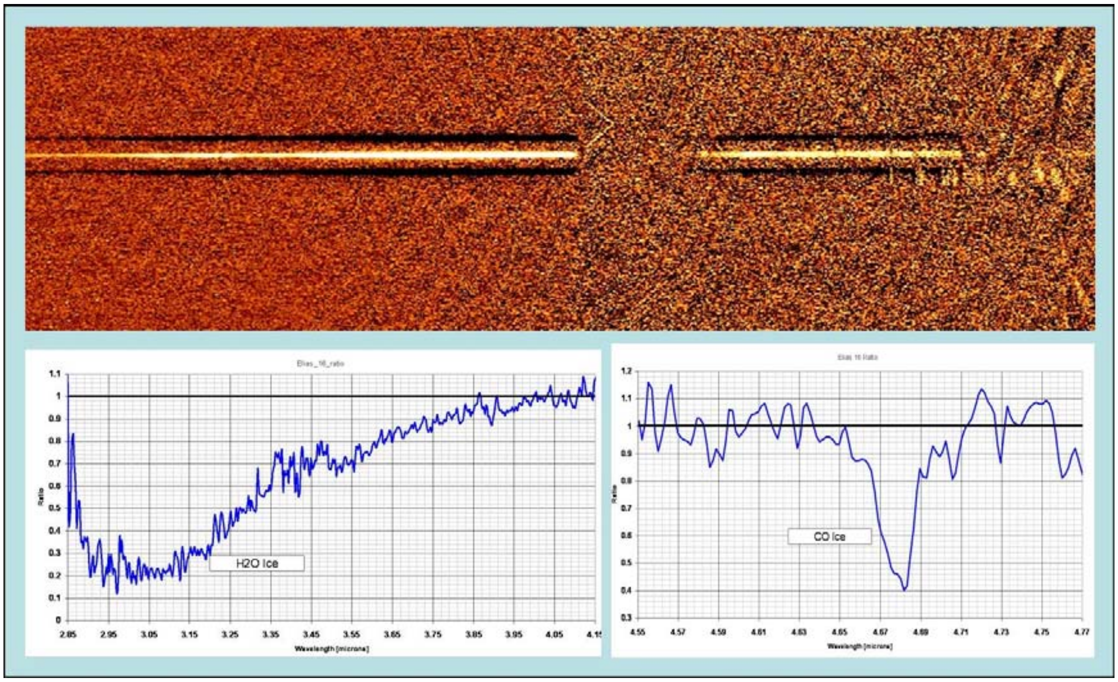
Instrumentation Program

Brian Taylor completing installation of Mimir on the Perkins Telescope. The carrier cart is being wheeled away from the stainless steel cryostat; the electronics box is mounted in the upper left. The two metallic cables leaving the cryostat below the electronics are high-pressure helium lines that are part of the closed-cycle refrigeration system that keeps the optics and detector cold.

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. A new instrument, HIPO, has recently been built by Lowell Observatory personnel and the IAR's Telescope Support Scientist, Brian Taylor. In addition, a new instrument initiative (Flexi) is in development by Professor Clemens in order to capitalize on the science that can be done with Mimir.

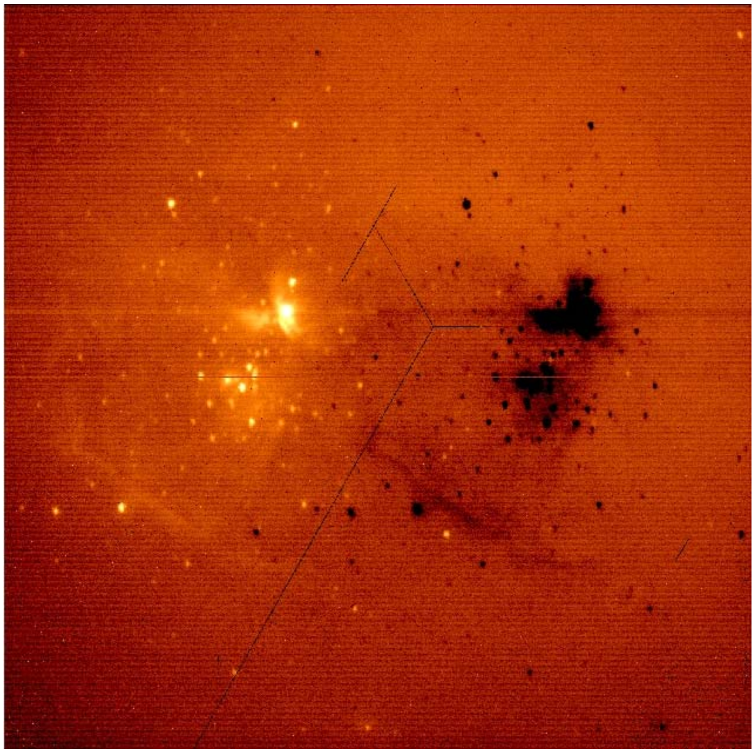
Mimir

Mimir is a facility-class instrument for near infrared imaging, spectroscopy, and polarimetry. As of this time, Mimir has been cold and at vacuum for 293 consecutive days. This is a new record for continuous operations and a sure sign that past problems with the vacuum and refrigerator systems have been eliminated. Mimir is planned to be warmed in July, to permit Brian Taylor to replace the current refrigerator cold-head with its swap-twin. This twin will be used for cooling during the 2009/2010 season while the current cold-head is returned for scheduled refurbishment. Alternating one year usage between the two cold-heads is expected to be a stable operating plan going forward.



On-off spectral image obtained by Mimir of the deeply extincted star Elias 16, located behind the Taurus dark molecular cloud. Wavelength increases from about 2.9 microns on the left to about 5.5 microns on the right. The twin black stripes are artifacts of how these position-switched spectra are obtained and processed; the signal containing portion of the image is the white strip across the middle. Below the image are the spectra extracted from these data. At the lower left, the deep absorption from 2.9 to 3.8 microns wavelength is a solid-state feature produced by water ice, as might be found as mantles surrounding refractory dust grain cores. Similarly, the narrow absorption at the lower right is produced by solid CO ice, which can only exist at temperatures below 17 K. Professor Clemens plans to augment Mimir to be able to use these solid state features to measure magnetic fields localized to the insides of molecular clouds, in order to ascertain the importance of the field in cloud core collapse and star formation.

Anderson Mesa continues to experience a large number of power failures, most recently brought about by heavy construction Lake Mary Road, close to Flagstaff. Additional power outages are caused by severe weather. Such outages put Mimir at grave risk, and at present require Brian Taylor to rush out to the site to manage Mimir. Therefore, Professor Clemens plans to use grant funds to purchase and install a backup power generator. This unit will trigger on power outages and supply power only to critical Mimir systems (helium compressor, health and safety computers and sensors), and hopefully will reduce the work load and stress load on Brian Taylor and the Lowell staff. The generator is expected to be in place before Fall 2009.



L-band (3.6 microns) image toward the Orion molecular cloud and star formation region. This image was produced by subtracting two images, one offset from the other spatially (hence the black and white features). This 10x10 arcminute image is one of, if not the, largest instantaneous L-band images ever obtained and highlights the new L-band imaging mode that was commissioned for Mimir in Winter 2008/2009.

Mimir is being used most extensively in support of Professor Clemens' GPIPS project (discussed in the Science Programs section). It has also been used recently for the BU blazar group's monitoring program, Professor Blanton's distant galaxy cluster discovery program, a study of interstellar bubbles by BU graduate student Mike Pavel, a study of two large molecular clouds by BU undergraduate student Katie Jameson, a study of galactic star clusters by BU graduate student April Pinnick, numerous Lowell science projects, as well as outside user groups' science. In addition, every spring semester undergraduate students enrolled in AS441 (Observational Astronomy) travel to Lowell Observatory to obtain observational data as part of their course work. Although the AS441 students used PRISM in Spring 2009, Mimir was the primary instrument that was used in previous years. Mimir will continue to figure prominently in the course work that is being done by all observational astronomy students (AS441 and AS710) at Boston University.

Recently, studies have revealed that polarimetry conducted within spectral features (absorption bands of water ice) in the longer wavelength L-band (3.1 microns wavelength) offer the unique opportunity to trace magnetic fields deep inside dark molecular clouds, without the confusion generated by surface fields and tracers. Mimir, again, is uniquely suited to conducting studies of magnetic fields in these dense cloud cores using L-band ice polarimetry. Additional wavelength filters and an L-band polarimetric half-wave plate are necessary, and both would be reasonable cost elements in a new Fall 2009 NSF proposal to pursue this intriguing new science area. The unique combination of Mimir on the Perkins Telescope, in infrared imaging polarimetric mode, will both allow this new science to be performed and will do so uniquely - no other instrument can do this, even the instruments that were first used to detect this effect!

This in mind, Professor Clemens conducted test observations with Mimir this winter to demonstrate that L-band and M-band spectroscopy is able to reveal the water and CO ice features. This is a critical demonstration that will greatly strengthen his upcoming NSF proposal.

In addition, Lowell Observatory scientists have expressed an eagerness to exploit Mimir's longer wavelength (L- and M-band) capabilities for studying young stars and binaries. In response, Professor Clemens and Brian Taylor conducted a Mimir engineering run on the Perkins Telescope in February 2009. Devoted primarily to developing and testing the new operations software that would be needed to work at these long wavelengths, the run was a complete success and has launched several new long-wavelength observing modes for Mimir. One of these modes makes Mimir on the Perkins Telescope the widest-angle L-band imaging system on the planet.

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

Flexi – A New Initiative

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 a substantial fraction the nearly 1 million 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 alone 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.

The recently announced MRI-R^2 initiative at NSF may provide an avenue for both revitalizing the use of the Perkins Telescope and for gaining the data that would be needed to make GPIPS analyses truly spectacular. By designing and fabricating a telescope unit that positions many fiber optic cables within the telescope focal plane, and routing those fibers to Mimir, it is possible to boost throughput by a large factor. A notional plan to put an 81-fiber automatic positioner onto the Perkins Telescope as a "front end" for Mimir spectroscopy would represent a nearly one hundred-fold increase in the science impact of the telescope. The internal proposal for this "Flexi" instrument has been prepared and, if selected for BU submission, it will compete in the August 10 MRI-R^2 round. Multi-object spectrographs are in use on many large telescopes, but none operate at wavelengths as long as those at which Flexi+Mimir will operate. Again, this would 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 deal of other tremendously interesting 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.

PRISM

The Perkins Re-Imaging SysteM (PRISM) instrument mounted on the Perkins telescope.

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 operate smoothly, and there have been no significant maintenance issues in the past year. Since July 2008, PRISM observers have obtained some 70,000 images. The image total since the instrument was first installed at the end of 2004 is now over 175,000. The large increase in the number of images in the past year is partly the result of a new capability for sub-framing, which permits a faster readout (but over a smaller field of view). In December 2008 and January 2009, Professor Janes and his colleagues had a campaign to search for possible second planets in the extra-solar planet system XO-2. Using this new capability, they were able to obtain many thousands of images in the short period of their observing run. When they combined the PRISM images with simultaneous images from the 4-meter WIYN telescope at the NOAO, Professor Janes and his colleagues were able to show that it is unlikely that there are any short-period transiting planets in the XO-2 system larger than about twice the size of the Earth.

Image of the famous Horsehead nebula obtained by BU undergraduate student David Jones using PRISM in March 2009 as part of the class work for CAS AS441 (Observational Astronomy).

PRISM is used primarily in support of major long-term observing campaigns, including the study of stellar activity in solar-type stars by Professor Ken Janes, blazar variability programs by the blazar research group and Professor Richard Miller (Georgia State University), as well as tracking of Kuiper-belt objects (the most distant observable objects in our solar system) by Larry Wasserman and Robert Millis at Lowell Observatory, determining the rotation senses of large spiral galaxies by BU graduate student Paul Howell, and searching for distant galaxy clusters by Professor Elizabeth Blanton and BU graduate student Joshua Wing. In addition, a group of six undergraduate students used PRISM for five nights in March 2009 as part of a class project for AS441 (Observational Astronomy).

In April 2009, Professor Janes was awarded a grant of $27,850 from the Mount Cuba Astronomical Foundation to help purchase a new CCD detector for PRISM. Contributions of $5,000 each have also been received from Georgia State University and Lowell Observatory to help support the detector replacement. In addition, Professor Marscher anticipates the receipt of a new grant from the NSF in summer 2009 that includes funding to help with the detector upgrade. All together, Professor Janes and the IAR now have enough funding to purchase the detectors (approx $31,000 plus about $8,000 for some new circuit boards and other hardware). Although the current detector is the best of 2004 technology, in the semiconductor business, that amounts to a full generation. In particular, our current CCD takes almost a minute to read a single full image. The new detector can be read out in a few seconds; since our typical exposure times are about a minute, our overall productivity will be almost doubled. This will be particularly important for time-series projects such as the blazar monitoring and the characterization of extra solar planets.

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

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 an ongoing project that is scheduled to start early science flights in 2010. The observatory 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.

SOFIA, NASA's Stratospheric Observatory for Infrared Astronomy, in the hanger at Edward's Air Force Base.

During the months of October and November 2008, HIPO was taken to NASA Dryden Center at Edward's Air Force base and was used on SOFIA for the first time. 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 Fall 2008 HIPO was mounted on the telescope and was 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

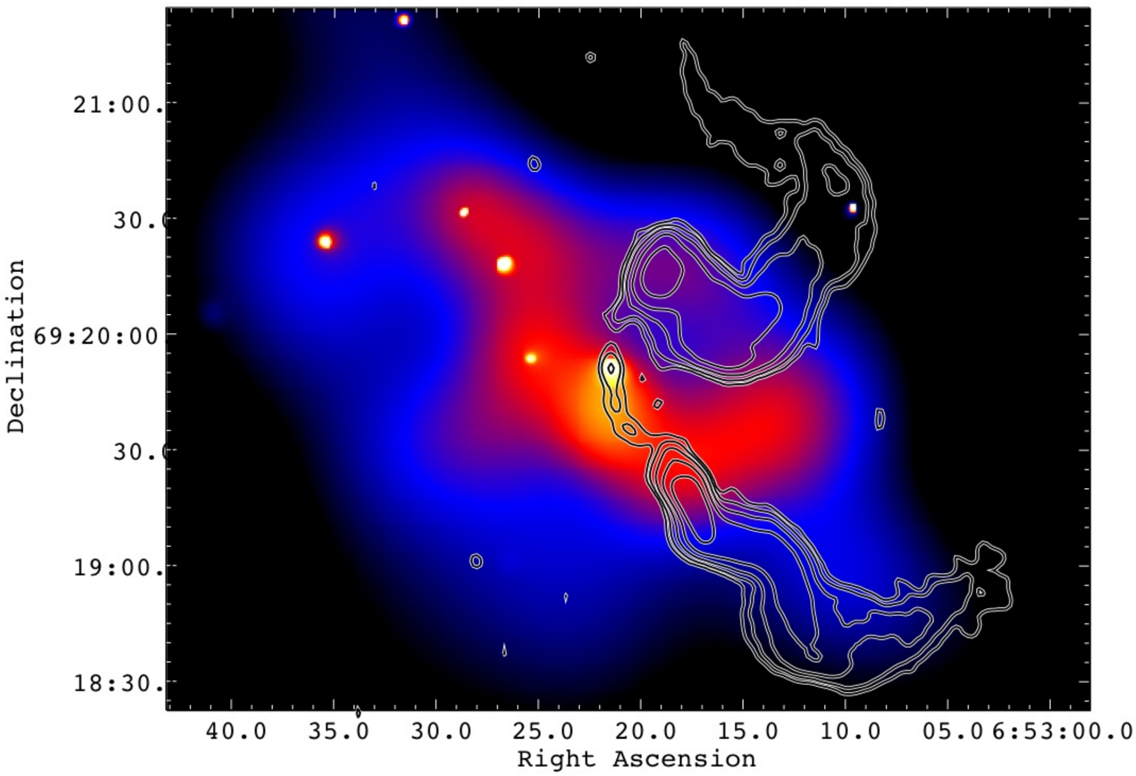
The IAR hosts many different science programs. Some of the particularly noteworthy results from the past year are outlined in the Science Highlights section, and below are updates on other ongoing investigations.

In addition to their work on Galactic HII regions described in the Science Highlights section, Professor Bania and graduate student Loren Anderson have developed three outstanding software tools. First, the TMBIDL package, which is written in IDL, inspired NRAO to develop GBTIDL which is now the main data analysis tool for the Green Bank Telescope (GBT). TMBIDL, however, is much more flexible than GBTIDL. In principle it can analyze data from any single dish radio telescope. TMBIDL is now into its v6.0 release. TMBIDL has already in place functioning interfaces for spectral line and continuum data for the following telescopes: (1) the NRAO GBT; (2) the NAIC Arecibo Observatory; (3) the NRAO 140-foot (archival data); and (3) the MPIfR Effelsberg 100m. TMBIDL can also analyze spectra and make maps and images of the BU-FCRAO ^{13}CO Galactic Ring Survey. GBTIDL has neither these telescope drivers nor the imaging capability. See: http://www.bu.edu/iar/research/dapsdr/index.html. Second, the PLOT_FITS IDL package interfaces with TMBIDL software. It can analyze any sort of FITS data set with the full power of IDL and TMBIDL. This software allows intuitive manipulation of data cubes and 2D images and features spectral line analysis, volume visualization, interactive single channel visualization, region file creation, fast moment map creation, 3-color image creation, contouring, and all the basic functionality of astronomical image display routines such as DS9 or Karma (KVis). Professor Bania and his students find this software to be superior to packages such as DS9 and similar packages because it is within the IDL environment where the user is free to interact with the data using IDL commands. The code can easily be modified to suit the particular needs of any project. See http://people.bu.edu/andersld/. Third, The Boston University Catalog of Galactic HII Regions Website is a flexible, evolving compilation of the properties of the initial first quadrant sample of Galactic HII Regions. It is extremely detailed and builds on the research that Professor Bania and Loren Anderson have published to date. See http://www.bu.edu/iar/hii_regions/.

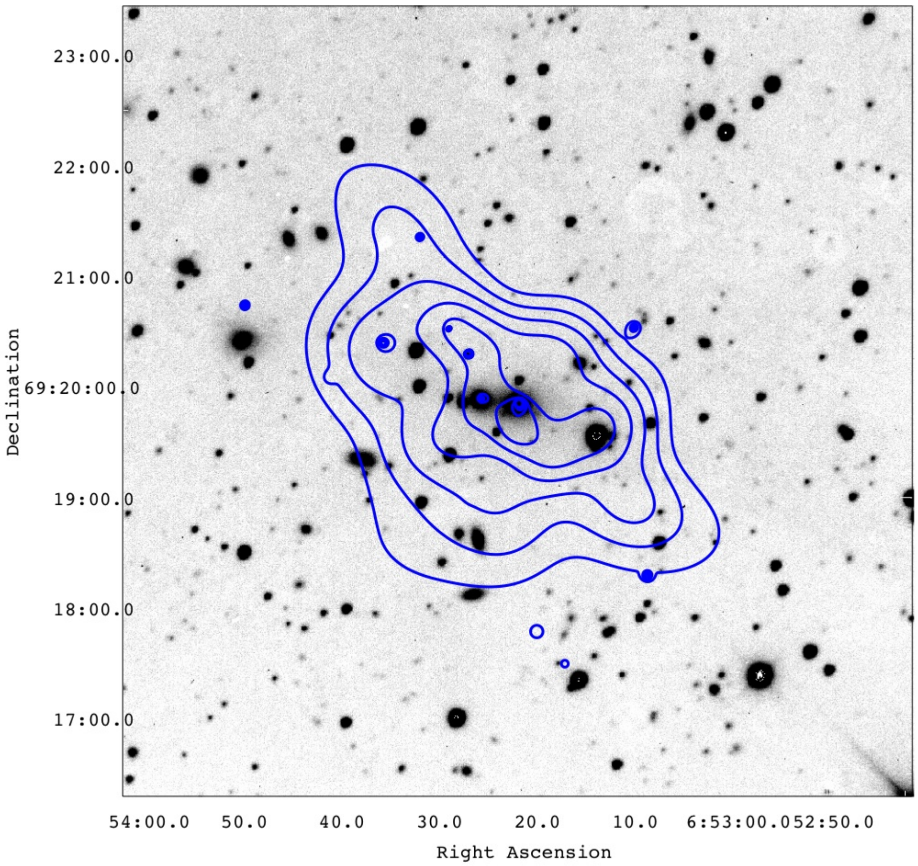
Professor Blanton's research focuses on clusters of galaxies, particularly clusters with large radio sources driven by the accretion of matter onto supermassive black holes in galaxies that reside in the centers of the clusters. Graduate student Joshua Wing has been working with Professor Blanton to correlate different morphologies of radio sources with objects seen at optical wavelengths in the Sloan Digital Sky Survey (SDSS). They have found that bent, double-lobed radio sources are more often found in clusters of galaxies than are straight, extended radio sources or compact radio sources. The bent, double-lobed sources that do not have optical identifications in the SDSS are likely not seen in the SDSS because their host galaxies are very distant and are, therefore, extremely faint. These objects are good candidates for high-redshift clusters. Professor Blanton and Joshua Wing have now observed about 100 of these candidate high-redshift clusters in the R-band using PRISM on the Perkins Telescope. In addition, JoshuaWing and

Professor Blanton were recently awarded time on the KPNO 4-m telescope with the NEWFIRM detector to obtain deep near-infrared images of these objects. The observations will be carried out in November 2009.

Radio contours superposed onto the smoothed Chandra X-ray image of the galaxy cluster Abell 562. The cluster is undergoing a merger and the relative motion of the intracluster medium and the radio source host galaxy provides the ram pressure necessary to bend the radio lobes.

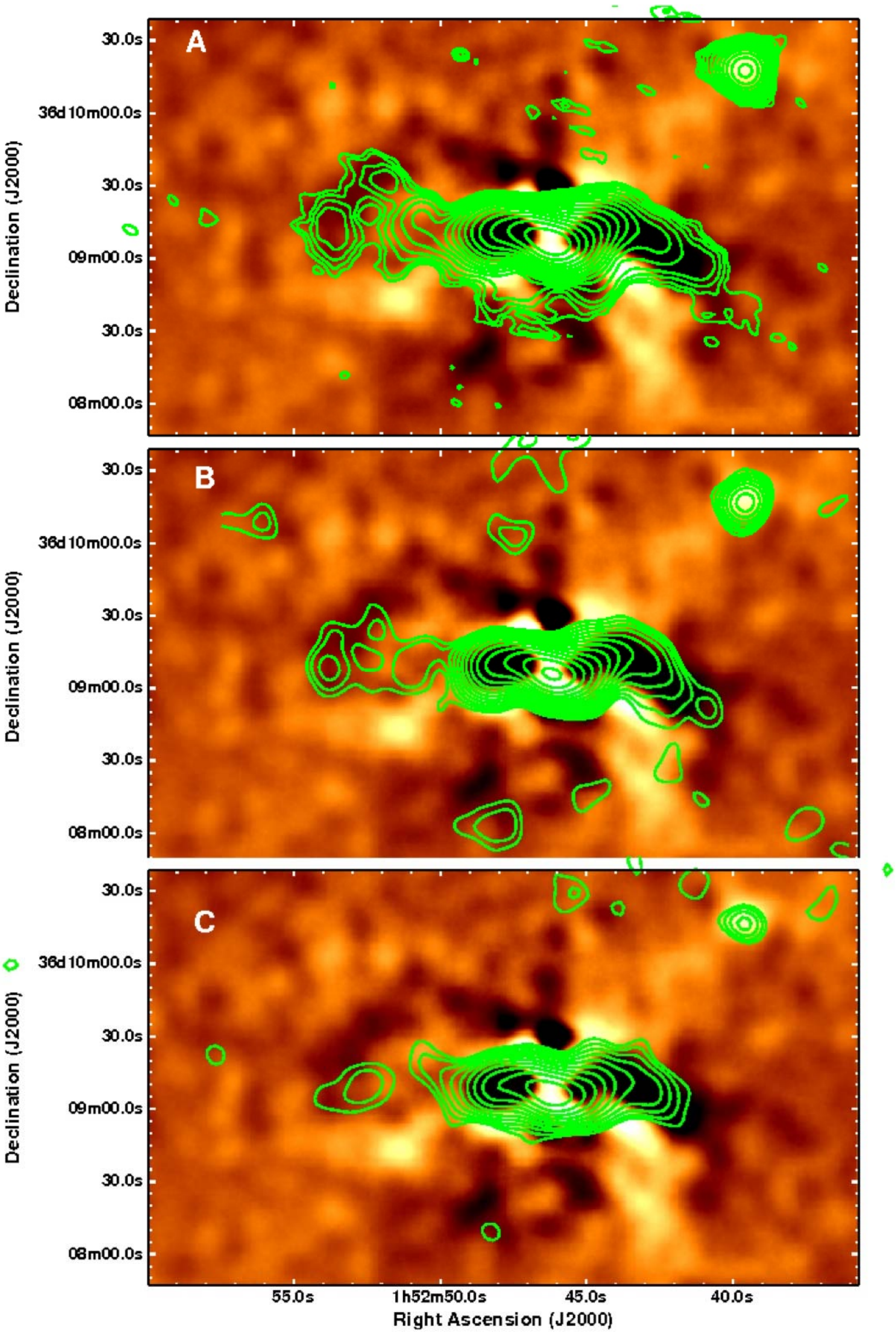


Graduate student Edmund Douglass has been working with Professor Blanton on a study of the X-ray cluster environments of bent, double-lobed ("wide-angle tail" or "WAT") radio sources using data from the Chandra X-ray Observatory. It is important to understand the conditions found in these types of clusters 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 that has set the intracluster gas in motion, providing the ram pressure to bend the radio lobes. In addition, Edmund Douglass is 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.



Contours of Chandra X-ray emission for the galaxy cluster Abell 562 superposed on an optical R-band image taken with PRISM on the Perkins Telescope

Professor Blanton is continuing her work on cooling flow clusters and is examining the feedback from radio sources in their centers. In Abell 2052, two shocks have been found and their separation yields an estimate of the cycle time of the radio source (the rate at which there are outbursts from the active galactic nucleus). Multiple sets of bubbles inflated by the radio lobes also give an estimate of this timescale. Both shocks and buoyantly rising bubbles of relativistic plasma can heat the intracluster medium, and the bubbles dominate in this case. A Chandra LP ("Large Project") was awarded in 2008 to Professor Blanton for this object, and it was recently observed (April - June 2009) for 500 additional kiloseconds. In Abell 262, multiple bubbles are also revealed, and their significance is bolstered by their spatial correspondence with low-frequency radio emission. In this system, Professor Blanton is able to trace four separate outbursts from the AGN, and calculate the cycle time of the radio source and the total energy input rate. Professor Blanton has also determined the radiative efficiency of the radio source and the mass accretion rate onto the black hole. For both A2052 and A262, the energy input from the central AGN can offset the cooling of the cluster gas.



Radio contours superposed on the residual Chandra X-ray image (the emission left after subtracting the average emission, revealing substructure) of the cooling flow galaxy cluster Abell 262. The radio emission corresponds with deficits in the X-ray emission, and four separate outbursts from the AGN are revealed. From top to bottom the observed frequencies are 610 MHz (GMRT), 330 MHz (VLA), and 235 MHz (GMRT).

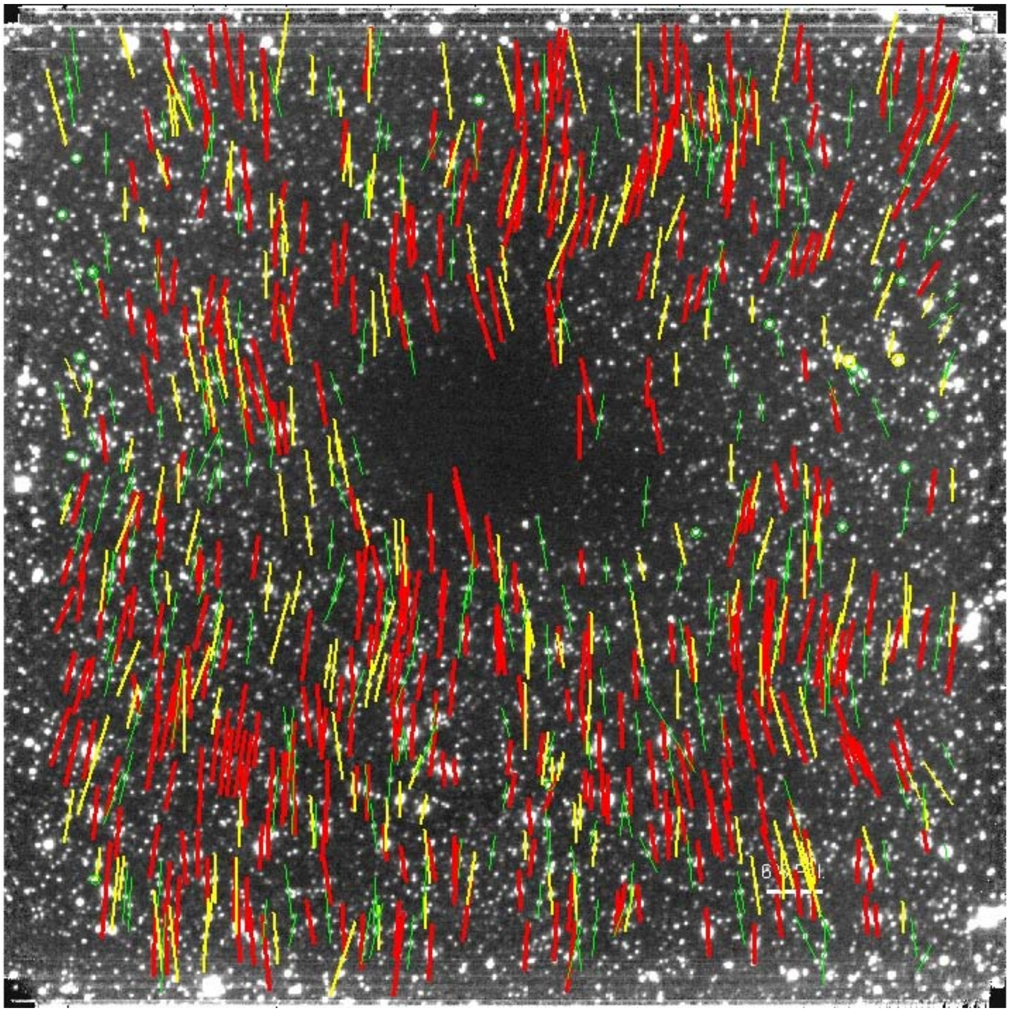
Professor Brainerd has been carrying out research with two graduate students: Paul Howell and Ingolfur Agustsson. Paul Howell's work is focused on the history of accretion of small satellite galaxies by large "host" galaxies. To complete his study, Paul Howell is computing the fraction of satellite galaxies in the Sloan Digital Sky Survey (SDSS) that orbit in a sense that is prograde with respect to the rotation of their "host" galaxy versus the fraction of satellite galaxies that orbit in a sense that is retrograde. To date, observations for about 250 systems have been completed, including multiple nights of observation using PRISM on the Perkins Telescope, as well as two 5-night runs on the KPNO 2-m telescope. Results of Paul Howell's investigation will provide important insight into the degree to which accretion of satellite galaxies may affect the rotation rates of large disk galaxies.

SDSS image of a large, bright spiral "host" galaxy and its satellite galaxy. The satellite is the fuzzy blue object to the right, and slightly lower, than the large galaxy.

Ingolfur Agustsson's work in the past year has focused on the use of small satellite galaxies as dynamical tracers of the mass surrounding large "host" galaxies. In principle, the motions of the satellites should provide a direct measure of the amount of dark matter that surrounds the host galaxies. However, Ingolfur Agustsson's most recent work has uncovered mysterious errors in previous, similar analyses. In particular, he finds that he cannot reproduce some results that have been published in the astronomical literature over the past several years. The source of the errors is not entirely clear, but they appear to be related to the fact that not all objects that one calls "satellites" are, in fact, true satellites. Rather, some fraction of these objects are actually "false" satellites or "interlopers", and the methods by which these false satellites have been accounted for in the past appear to be somewhat questionable.

Lastly, Professor Brainerd has recently begun a collaboration with Professor Barbara Ryden (The Ohio State University) to investigate the degree to which normal, bright elliptical galaxies are aligned with each other versus the degree to which normal, bright spiral galaxies are aligned with each other. They have begun an analysis of the intrinsic alignments of SDSS galaxies with de Vaucouleurs light profiles (representing the elliptical galaxy population) versus those with exponential light profiles (representing the spiral galaxy population). Their initial results suggest that the elliptical galaxies are less strongly aligned with each other on small scales than are the spiral galaxies, but that the intrinsic alignment of elliptical galaxies persists to much larger physical scales than does the intrinsic alignment of spiral galaxies. It is not entirely clear what this result means, but it may reflect differences in the ways in which spirals and ellipticals form. In some theories of galaxy formation, the intrinsic alignment of spirals is caused by tidal torquing due to near neighbor galaxies, and such a signal should not persist to extremely large scales since spirals are known to have a lower clustering amplitude than do ellipticals. In the case of ellipticals, the alignment signal may be more strongly influenced by asymmetric accretion of mass and mergers of small protogalaxies, early in the formation process.

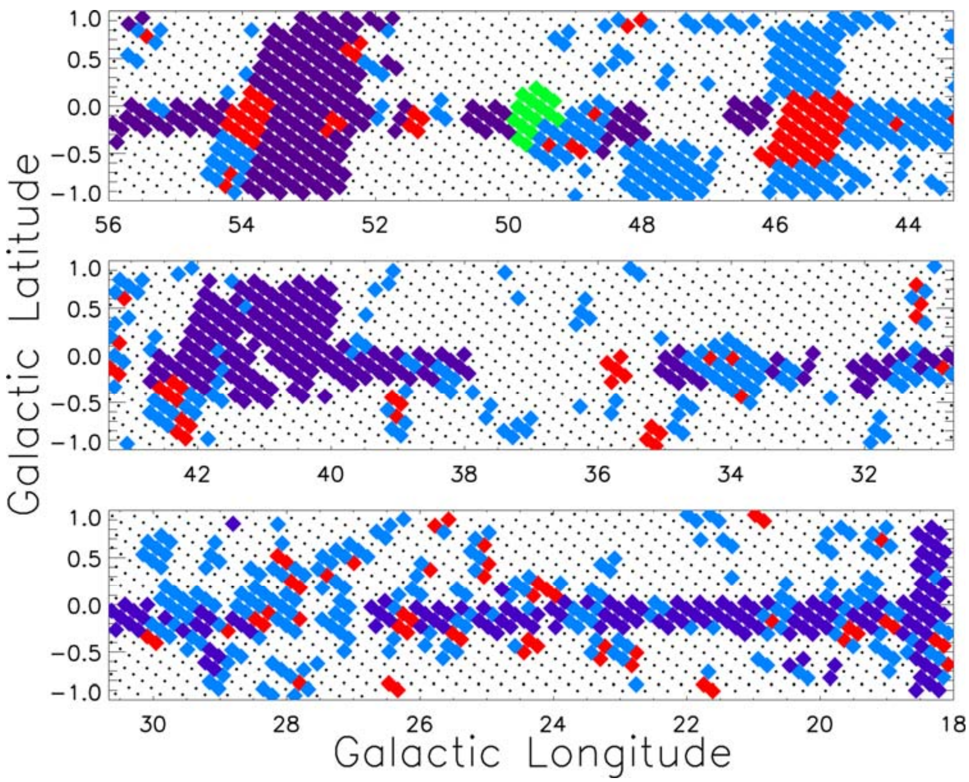
Over the past year Professor Clemens and his research group (graduate students April Pinnick and Mike Pavel, undergraduates Katie Jameson and Julie Moreau, and Telescope Support Scientist Brian Taylor) continued their work on the Galactic Plane Infrared Polarization Survey (GPIPS), an NSF-sponsored large project involving hundreds of nights of observing on the Perkins Telescope with the Mimir instrument. Mimir was specifically designed and developed to conduct the GPIPS project, and Mimir continues to be the premier wide-field infrared imaging polarimeter in the world. The GPIPS project utilized nearly 50 nights on the Perkins over the past year, obtaining infrared polarimetric data on some 500 of the 3,214 "fields" that make up the GPIPS survey sky region.



Mimir deep image and stellar polarizations measured for a single 10x10 arcminute field. There are nearly 700 polarization vectors in this image, and together they reveal a magnetic field which is mostly uniform on the large scale, but highly wavy on smaller scales.

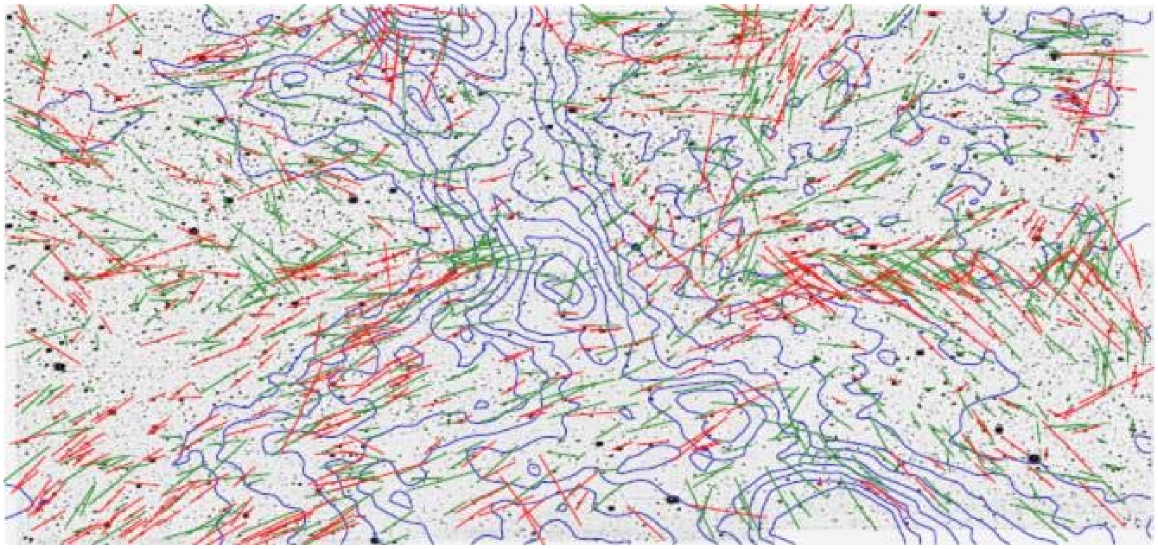
Summer 2009 marks the end of the initial 3-year NSF grant to begin GPIPS data collection. Professor Clemens' group has now obtained data for about 40% of the full 72 square degrees of the sky that GPIPS will eventually cover. More importantly, the data collection rate is now such that completion of GPIPS observing can be accomplished in only 4 more seasons. This is within the time span covered by the current 5-year BU-Lowell Observatory partnership period. GPIPS and the partnership enhance each other, as access to Mimir and the Perkins are necessary for GPIPS to take place, and GPIPS is a major survey that brings high visibility and scientific accomplishment to BU as a result of the partnership.

Stacked grid representing 76 square degrees of the Galactic plane. Black dots are the 3214 zones that Mimir must survey in order to complete GPIPS. Colored boxes show zones observed to date, with colors representing when the data were collected. About 40% of GPIPS is now complete, with the remaining 60% to be completed in the next 4 years.



GPIPS observations have been biased to "skim the cream" scientifically by prioritizing the regions that are being studied. In the first GPIPS season, all galactic star cluster directions were surveyed, and these will form the PhD dissertation research project for April Pinnick. Similarly, all known interstellar bubbles were observed in the second GPIPS season and these will form the PhD dissertation work of Mike Pavel. In past observing, undergraduate student Katie Jameson conducted GPIPS observations of two large molecular clouds and the data formed the basis of her successful Senior Distinction Thesis in May 2009.

Mosaic of 3x2 Mimir fields of view for a small section of the GPIPS survey, showing polarization vectors (color coded for signal-to-noise levels) overlaid on the deep co-added photometric image. Analysis of the magnetic field patterns revealed by the polarization vectors, along with information about the gas and dust along the lines of sight to the stars, will answer key questions regarding the role of the magnetic field in ordering how galactic clouds are assembled and how star formation is regulated.

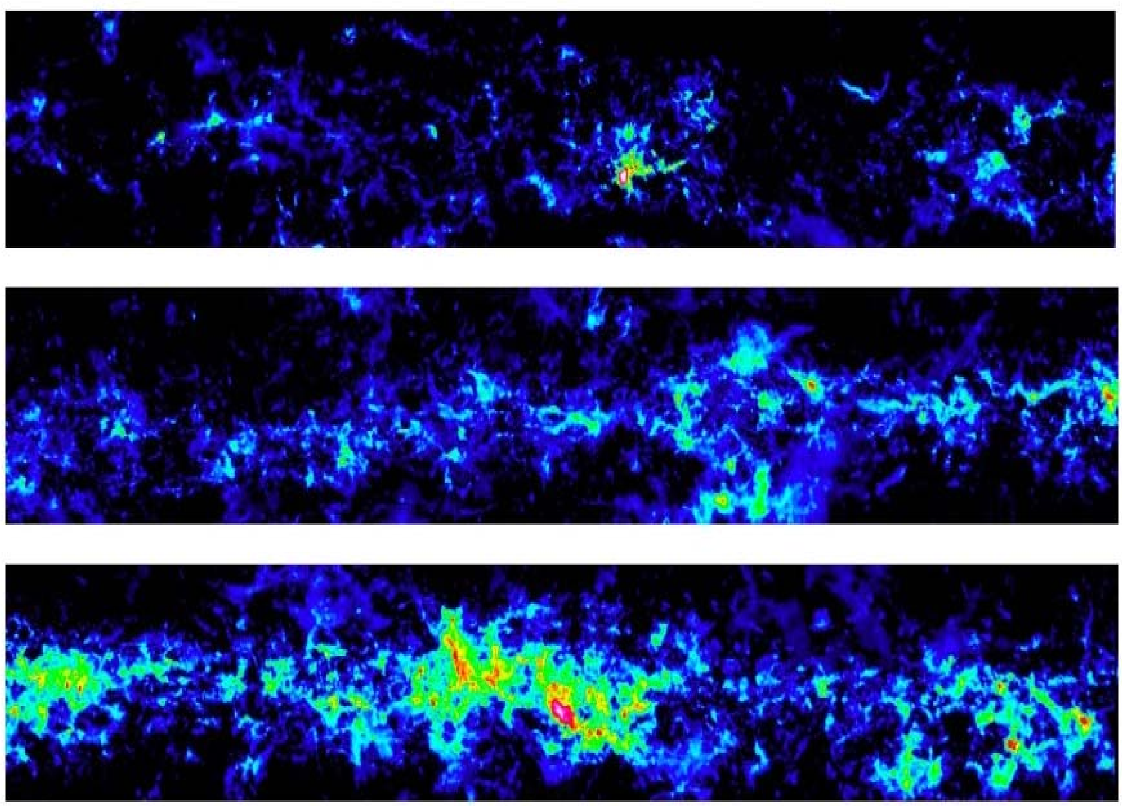


Much of the non-observing effort for Professor Clemens' group over the past year has been in the area of developing the software to perform calibration and analysis of GPIPS (and other Mimir-obtained) data. Last year's releases of two large software packages for Mimir data, the Basic Data Processor (BDP) and the Wavelength Calibration Tool (WCT), continue to be used (at BU, Lowell Observatory, and now Georgia State University) and are supported by Professor Clemens' group. The group is hard at work on the Photo-Polarization (PPOL) package, and will release it later this year after extensive testing. Development of PPOL is important as it is the software tool that extracts GPIPS polarization values and populates the web-based community access data archive. Completion of PPOL will also permit a large number of backlogged science programs to become publications, as Professor Clemens' group has finished all observations on several projects (Orion, M51, Taurus, L183, Pipe Nebula, GPIPS clusters, Outer galaxy latitude survey) but are awaiting calibrated polarization data to come out of the PPOL package.

In November 2008, Professor Clemens submitted a renewal proposal for GPIPS to the NSF, seeking 4 years of funding to allow completion of the survey observations and scientific analysis of key portions of the data. As the time of the writing of this report, Professor Clemens has heard from his NSF program officer that the proposal was positively reviewed and can be expected to receive full funding for the 4 years requested.

Professor Jackson’s research group includes Research Associate Irena Stojimirovic and graduate students Edward Chambers, Susanna Finn, Julia Roman-Duval and Patricio Sanhueza. The group’s primary interest is the formation of stars in our home galaxy, the Milky Way. With the recent completion of the Boston University-Five College Radio Astronomy Observatory Galactic Ring Survey (the GRS), a large molecular line survey of over 72 square degrees of the Galactic plane, Professor Jackson’s group has been analyzing their results in order to study how stars form. The GRS employed a radio telescope near the Quabbin reservoir to map a rare form of carbon monoxide, ^{13}CO, in the Milky Way. Compared with previous molecular line surveys, the GRS offers a considerable improvement in the ability to discern fine details in the molecular clouds. This allows a new, unprecedented view of the molecular interstellar medium.

The complete GRS image of Galactic ^{13}CO emission. The emission has been integrated over all velocities. Top panel: l=43 degrees to l=56 degrees. Middle panel: l=30 degrees to l=43 degrees. Bottom panel: l=18 degrees to l=30 degrees. The brightest emission is yellow and red, the faintest emission is blue and black. Note the complex, filamentary structure of the molecular clouds.



Using GRS data, Professor Jackson's group has identified over 800 molecular clouds. This is the largest set of molecular clouds ever to be identified from a homogenous, well-sampled dataset. The distances to 600 of these clouds have been determined by Professor Jackson's group, and they have found that the distribution of molecular clouds corresponds well with the locations of two known spiral arms in the Milky Way: the "Scutum-Centaurus" arm and the "Saggitarius arm". In addition, Professor Jackson's group finds that the properties of molecular clouds differ significantly according to whether the clouds are located within a spiral arm or are located between spiral arms. In particular, clouds that are within spirals arms have larger sizes, greater masses, and are more tightly gravitationally bound compared to clouds that are located between arms. These differences in the clouds may account for the enhanced star formation rate in spiral arms.

By comparing the GRS data with the earlier ^{12}CO UMass-Stony Brook survey, Professor Jackson's group was able to estimate the temperatures of molecular clouds throughout the Milky Way. They discovered that there is a smooth trend in the cloud temperatures as a function of distance from the center of the Galaxy, with clouds in the inner portion of the Galaxy being slightly warmer than those in the outer Galaxy. The reason for this is unclear, but it may be related to the fact that the inner portion of the Galaxy forms more stars than the outer portion.

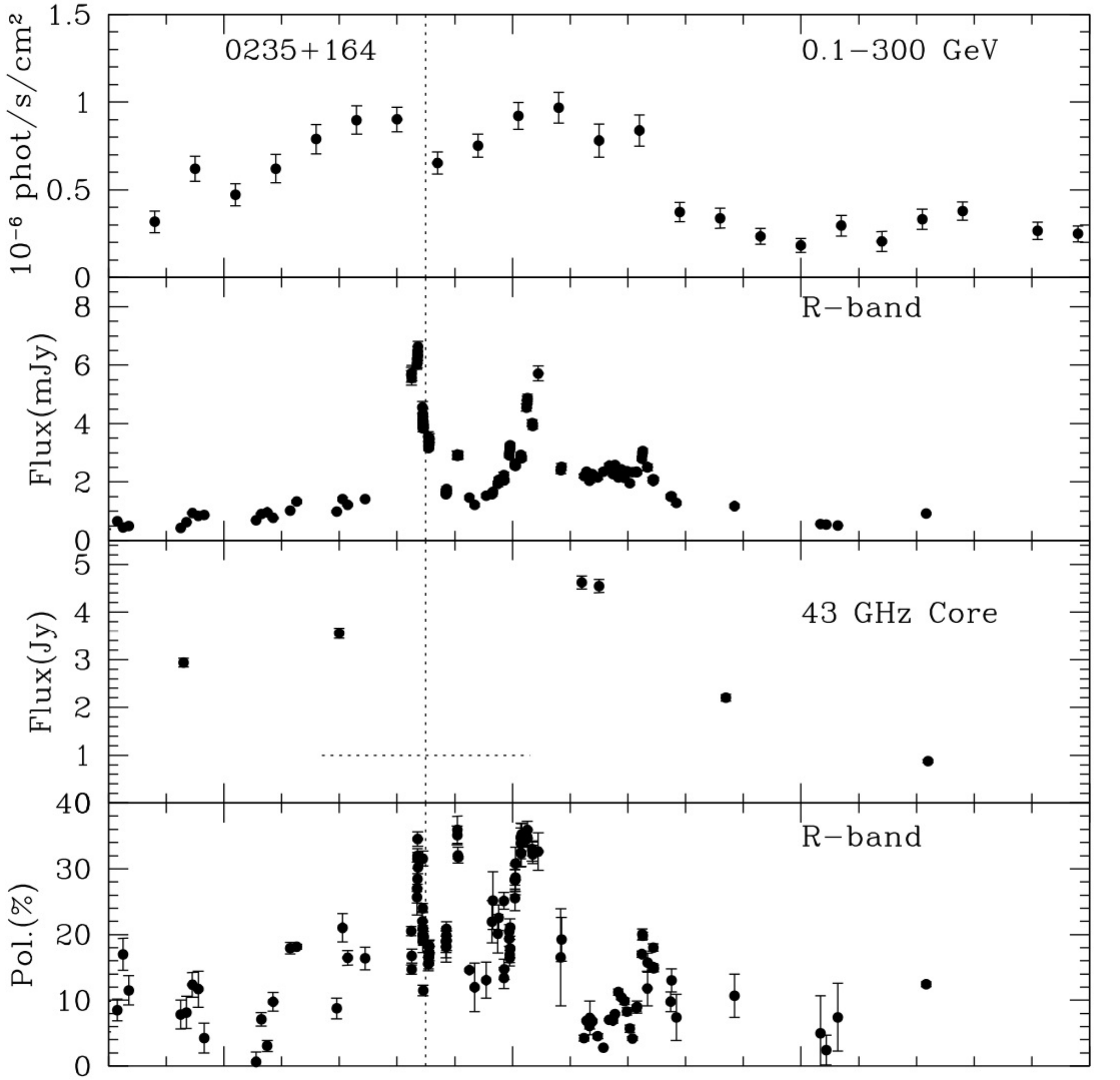
Lastly, Professor Jackson's group has used the GRS to investigate turbulence within molecular clouds. They have used Principal Component Analysis (PCA) to determine the turbulent energy spectrum of roughly 500 GRS clouds, and have found that the turbulent energy spectrum is identical (within the errors) for all molecular clouds. This result was suggested by previous work, but is now definitive based on the GRS analysis. This is an important result that suggests that all clouds contain the same amount of turbulent energy per unit volume, independent of their star formation rates, masses, or galactic location. This, in turn, strongly suggests that turbulent energy is imposed from the outside, perhaps due to Galactic rotation, rather than imposed from the inside (e.g., if it were due to star formation).

Professor Janes and graduate student Ji-Hyun Kim have completed an analysis of the possibility of finding planets transiting in front of stars that are members of star clusters. Although there has been a great deal of interest, and a considerable amount of effort, in finding such planets, none have been found to date. In addition to the work of others, Professor Janes' observations of the cluster NGC 7789 yielded no detections. From their analysis, Professor Janes and Ji-Hyun Kim concluded that although there is a good chance that there are some transiting planets in open star clusters, it would take a truly massive effort to discover them.

Professor Janes continues to participate in the XO project, led by Dr. Peter McCullough (Space Telescope Science Institute) to search for transiting exoplanets. A paper detailing the discovery of their fifth exoplanet, XO-5b, was published this year. For the confirmation of this planet, Professor Janes and his colleagues relied on observations that

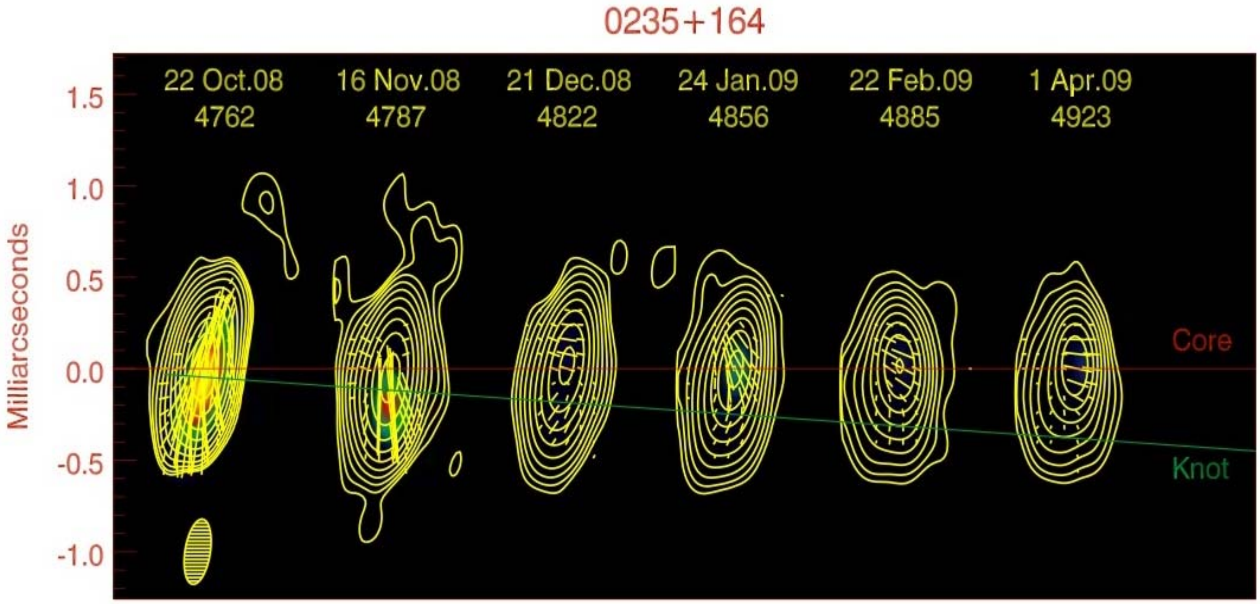
Brian Taylor made at the Perkins Telescope. In addition, Professor Janes and his colleagues undertook a campaign to search for additional planets in the XO-2b system. To accomplish this, Brian Taylor worked at the Perkins Telescope while team member Chris Burke (Center for Astrophysics, Harvard), observed simultaneously with the WIYN 4-meter telescope at the National Optical Astronomy Observatory. As a result of this work, Professor Janes and his colleagues were able to show that it is unlikely for there to be any planets larger than about twice the size of the Earth in the XO-2b system.

Professor Janes is also in the process of wrapping up his long-running program to search for stellar activity (starspots) in open cluster stars. The reason for looking at stars in clusters is that their ages can be determined and, therefore, the activity level as a function of stellar age can be investigated. A difficulty is that the cluster stars are faint, and the fluctuations due to stellar activity are expected to be tiny. Professor Janes has found two groups of stars in several of the clusters that show variability indicative of activity. One group consists of stars that are somewhat hotter and more luminous than the Sun that are just beginning their expansion into red giants. Several of the stars in this group in the cluster M67 are known X-ray sources. They are probably close binary stars undergoing mass transfer from one component to the other as the more massive component begins to expand. The other group of stars is somewhat lower luminosity than the Sun. A number of these stars in the cluster NGC 7789 show evidence for brightness variations right at the limit of detectability, whereas there is little evidence for such fluctuations in stars in the solar-age cluster, M67. These results are consistent with the idea that younger and lower-mass stars show high levels of activity. One conclusion, from this work and other studies, is that our Sun is somewhat less active than other solar-type, solar-age stars.



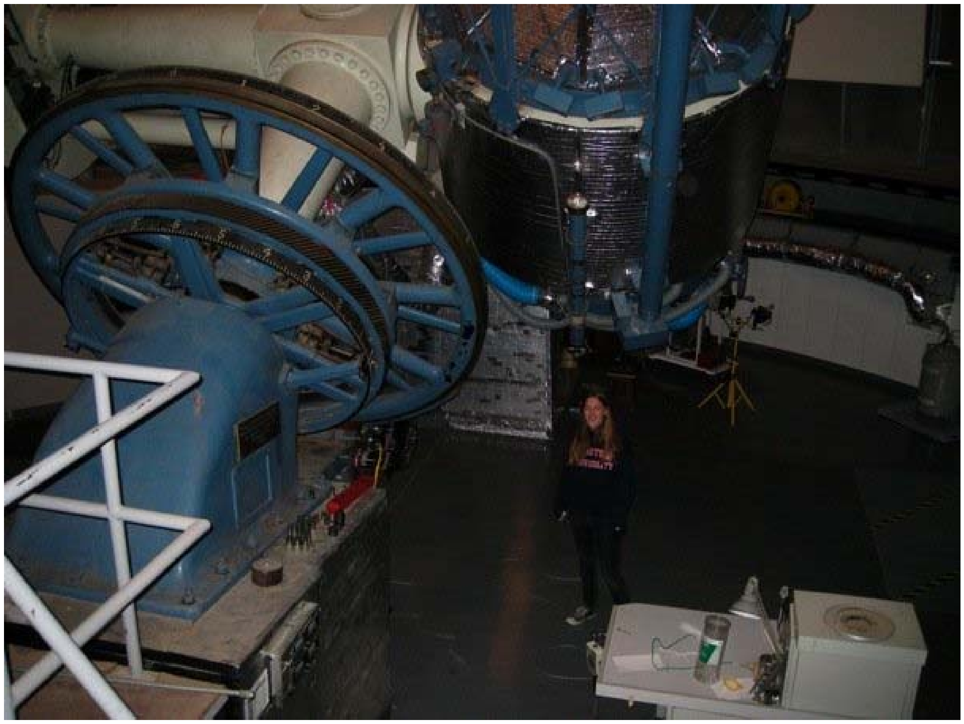
Multifrequency light curves and optical polarization light curve of the blazar AO 0235+164. The dashed line indicates the time of ejection of a bright superluminal knot.

The blazar research group, led by Professor Marscher and Dr. Svetlana Jorstad, studies the physics of blazars, the most luminous long-lived objects in the Universe, through comprehensive multi-waveband monitoring. BU students working in the group over the past year included Francesca D'Arcangelo, Ritaban Chatterjee, Monica Young, Michael Malrose, and Dipesh Bhatterai (graduate level) as well as Alice Olmstead, Emily Manne-Nicholas, and Brandon Harrison (undergraduate level). The blazar group's main project involves monthly observations with the Very Long Baseline Array (VLBA, which produces images of the jets of blazars with angular resolution 1000 times finer than that of the Hubble Space Telescope) of a sample of 33 gamma-ray bright blazars and optical polarimetric and photometric observations with PRISM and Mimir at the Perkins Telescope. The data are combined with observations obtained by collaborators using the St. Petersburg State University telescope (Russia), the Crimea Astrophysical telescope (Ukraine), the Liverpool robotic telescope (Canary Islands), and the Calar Alto telescope (Spain). A continued program of monitoring the X-ray flux of several 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. In total, the blazar group is monitoring the X-ray emission from 11 blazars with RXTE and a number of others with the Swift satellite. With the successful launch of the Fermi Gamma-ray Space Telelescope on June 11, 2008, gamma-ray light curves (brightness vs. time) are now publicly available at photon energies of 0.1 to 300 GeV for dozens of blazars. This allows 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. These results both support and challenge current theoretical ideas for how black holes accreting gas from their environment manage to produce ultra-high speed jets of energetic plasma along their rotational poles. The blazar group's program aims to answer the major outstanding questions in blazar physics concerning the origin of the gamma-ray emission, how the jet is collimated and accelerated, what processes are responsible for bright "blobs" that appear to move faster than light (an illusion), as well as outbursts in which the brightness can increase by many times.



A time sequence of VLBA images of the blazar A0 0235+164 at 43 GHz. The motion of a superluminal knot is shown by the green line; the core of the blazar is shown by the red line. The knot is distinguished from the core by its polarization (yellow line segments showing the E-vector). The color scale shows polarized intensity with a maximum value of 0.165 Jy/beam.

Lowell Observatory Partnership



BU undergraduate student Jessica Donaldson and the Perkins Telescope, AS441 field trip, March 2009.

For the past 11 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 the previous 11 years, IAR astronomers continue to be entitled to 50% of the nights on the telescope, distributed equally over all phases of the moon.

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 discussed below.

BU undergraduate student Alice Olmstead and the Perkins Telescope, AS441 field trip, March 2009.

There are a number of notable changes to the Lowell Partnership this year. First, Lowell Observatory has begun a partnership with the astronomers at Georgia State University that entitles the GSU astronomers to 25% of the nights on the Perkins Telescope, although the details of the Lowell-GSU agreement allow some flexibility and "trade offs" to use Lowell Observatory telescopes other than the Perkins. A number of the GSU astronomers are already well-known to the IAR (particularly Professor Richard Miller, formerly the chair of the IAR Advisory Review Board) and we are excited to have the opportunity to work with new colleagues in the operation of the Perkins Telescope. Note that, at the moment, there is no direct agreement between BU and GSU to operate the Perkins Telescope; GSU's agreement is solely with Lowell Observatory.

The second major change is the retirement of long-time Lowell Observatory Director, Dr. Robert Millis. Dr. Millis began his Directorship in 1989, and he officially stepped down as Director on June 15, 2009. In appreciation for all that Dr. Millis brought to the BU-Lowell partnership, the IAR has commissioned a plaque that will be presented to Dr. Millis in the near future. The wording on the plaque was read aloud by Professor Dan Clemens at Dr. Millis' retirement party on June 14, 2009:

Director Robert L. Millis

In Appreciation

Whereas Bob Millis has provided initiative, leadership, direction, and sound management leading to the scientific, instrumentation, and academic training successes of the Lowell Observatory - Boston University Perkins Telescope Partnership for over a decade, and

Whereas we recognize that this Partnership has been of great benefit to the scientific aspirations of the faculty, staff, and students of the Institute for Astrophysical Research and the Department of Astronomy at Boston University,

We wish to convey our deep gratitude and appreciation to Director Millis and to the scientists and staff of Lowell Observatory.

Signed,

Tereasa G. Brainerd, for the members of the Boston University Institute for Astrophysical Research
James M. Jackson, for the Boston University Department of Astronomy
J. Scott Whitaker, for the Boston University College and Graduate School of Arts and Sciences

Saddened as we are to no longer be working with Dr. Millis as Director of Lowell Observatory, we are delighted that Dr. Eileen Friel has been appointed as the new Director. Dr. Friel is a long-time colleague of the IAR astronomers, whose research interests (galactic evolution, in particular using star clusters as chemical and dynamical probes in the Milky Way, as well as local group galaxies, concentrating on issues of stellar populations, stellar evolution, and nucleosynthesis) overlap the research interests of a number of IAR members. Most recently, Dr. Friel served as the Executive Officer, Division of Astronomical Sciences at the National Science Foundation. Her background includes service as Program Director, Unit Coordinator for the NSF, and Director of the Maria Mitchell Observatory. In addition, Dr. Friel was the Founder and Director of the Cerro Tololo Inter-American Observatory's Research Experiences for Undergraduates (REU) Program. The IAR is looking forward to working with Dr. Friel, and we feel that Dr. Friel's strong interests in education/public outreach, as well as carrying out front-line scientific research, are likely to strengthen the BU-Lowell partnership even more.

PREST

In the fall of 2004, the IAR (PI: Kenneth Janes) and Lowell Observatory (PI: Marc Buie) received a collaborative research grant from a new NSF initiative called "Program for Research and Education with Small Telescopes" (PREST). The grant included funds for upgrades to the Perkins Telescope and dome to improve the image quality, as well as funds for student involvement in the operation of the telescope. Full operation of the program began in early 2005, and the BU portion of the grant expired in December 2008. The Lowell portion of the grant received a no-cost extension, and the remaining funds will be used to continue to improve the telescope over the next year.

In order to improve the image quality it is necessary to remove as many sources of heat as possible from the dome and to ventilate both the dome and the telescope. To date, ventilation fans have been installed to help remove warm air from the dome, ventilation has been added to the primary telescope mirror, and the helium compressor for Mimir has been moved outside of the dome to a separate enclosure. By far the largest source of heat in the dome was the computer room, and this was moved downstairs and away from the telescope about a year and half ago. During the past year, the control room and its ventilation system have been completely renovated. More recently, Brian Taylor has been working on the design of a mirror cooling system, which we hope to install in the coming months using PREST funds.

The PREST grant provided funds for the support of a graduate student in residence in Flagstaff and for travel funds for students to participate in the observational programs at the telescope. During FY06, two BU graduate students, Nina Bonaventura and April Pinnick spent a semester each as "graduate students in residence", living in Flagstaff, helping out at the telescope and beginning work for their own research. These students were fully-funded under the PREST program. During FY07 most of the graduate students who were interested in participating in the residency program were completing course work at BU and were preparing for their written comprehensive exam, so the graduate student residency program was put on hold temporarily.

In FY08 PREST funds were used to support two graduate students (Michael Pavel, who was a graduate student in residence in Flagstaff for the fall semester, and Ji Hyun Kim who was supported for two semesters while attending classes at BU). Mike did a lot of observing during his time at Lowell Observatory, both for himself and for others. In addition, Mike updated the PRISM operating manual and he helped Brian Taylor in a variety of tasks, mostly relating to Mimir maintenance. Mike had rather more interaction with the Lowell staff than most of our previous students students in residence, and the Lowell staff members were very pleased by this.

Ji Hyun used optical imaging data to perform a complete study of the seeing at the Perkins. She used the FWHM image size measurements that come from CCD photometry output files to compile the statistics. Some improvement over the earlier values that we used for the PREST grant were found, but not as much as we had hoped for. However, Ji Hyun completed her study prior to the computer room being moved downstairs, and observers who have used the telescope since have reported a substantial improvement in the seeing following the move. Lastly, Ji Hyun found that in general the seeing at the telescope itself is correlated with, but usually substantially higher than, the seeing recorded by the seeing monitor.

With the end of the BU PREST funding, this program can no longer be used to fund student trips to observe at the Perkins, either for class work (e.g., AS441 or AS710) or for PhD thesis work. In Spring 2009, all but one of the members of AS441 (Observational Astronomy) traveled to Flagstaff to carry out class work with the Perkins. The 2009 trip was funded by the Department of Astronomy.

Impact on Education

The availability of the Perkins Telescope for professional-quality observations has become an important part of our educational mission. In the 11 years of our partnership, approximately 60 undergraduates and 30 graduate students have traveled to Flagstaff to observe. These include undergraduate honors students (AS102 and AS203), observational astronomy students (AS441 and AS710), senior undergraduate students who use their observations as part of their Senior Work for Distinction, and graduate students who use their observations for their oral comprehensive exam projects and PhD theses. Of special note is that for the past 5 spring semesters all but one 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 class projects. Organized into groups of 3 to 4, AS441 students have each spent 2 to 3 nights operating the Perkins Telescope. 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. PREST funds are no longer able to support these trips. However, in Spring 2009 the AS441 field trip was sponsored by the Department of Astronomy.

Impact on Research and Instrumentation Programs

Having guaranteed access to the Perkins Telescope allows IAR members to carry out large, long-term projects that would be difficult or 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 projects. It is the access to the Perkins Telescope that places the BU blazar research group at the very forefront of the study of gamma-ray bright jets in quasars and active galactic nuclei, and has allowed GPIPS, the unique investigation of the Milky Way's magnetic field, to be carried out.

The blazar research group maps the emission from blazar jets across the full electromagnetic spectrum, which is the key to truly understanding the nature of the jets. In particular, the cores of the jets are located within a few light-years of central, supermassive black holes, and the jets emit radiation from microwave wavelengths through gamma-ray wavelengths. Short wavelength (gamma-ray and X-ray) radiation is observed from space observatories, and long wavelength (radio and microwave) radiation is observed with radio telescopes. The blazar research group depends on the Perkins Telescope for observations of the optical and near-IR emission. In order to map the emission at visible wavelengths, the group matches the linear polarization features on radio images with those observed at optical wavelengths, where the angular resolution is too crude to make images of the desired ultra-fine scale. Also, since the emission of the jets is variable at all wavelengths of interest, the group uses cross-wavelength correlations of the variations in brightness to determine the relationship between the optical emission and the X-ray. If the comparison of the polarization angle pinpoints the location of the optical emission on the radio image, then the emission at all wavelengths can be mapped.

The blazar group plans a long-term study of the 40 brightest gamma-ray blazars, and completion 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 the BU blazar group's program.

GPIPS represents an increase of 5 orders of magnitude in Galactic magnetic field information over previous studies. Completing the full GPIPS survey, some 72 square degrees of sky located along the galactic equator in the northern hemisphere, will require about 150-200 clear nights on the Perkins Telescope. Given that the survey region is only visible for a limited time every year (due to the earth's revolution about the sun), and given that not all nights during the visibility time frame will have suitable conditions for observing, completion of GPIPS will take a considerable amount of time. Professor Clemens' research group has invested considerable energy into enhancing the efficiency of data collection, including tracking down and eliminating many unnecessary sources of overhead time. This has greatly improved the efficiency with which data are being collected, and the survey will be completed within the time frame of our current MOU with Lowell Observatory.

Finally, ongoing instrumentation development projects are made possible by having access to the Perkins Telescope. One 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 addtion, adaptive optics (AO), which allow much of the distorting effects of the earth's atmosphere to be removed from astronomical images, are rapidly becoming a standard capability at many observatories. AO is not currently implemented on the Perkins Telescope, and this would be a natural new direction for our instrument development teams. 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, and to support the science that is being carried out with these instruments. To date, instrumentation development for the Perkins Telescope has been funded at a level of $1.5M, and funding for scientific investigations that include observations with the Perkins Telescope totals $2.6M. New funding of order $1M for investigations that include observations with the Perkins Telescope are expected to be received early in FY10 (PIs: Clemens, Marscher, and Jorstad). Major, grant-funded projects that are currently being carried out on Perkins Telescope include a study of old open star clusters (PI: Janes), the Galactic Plane Infrared Polarization Study (PI: Clemens), a study of the rotation senses of the disks of spiral galaxies (PI: Brainerd), and studies of blazar variablitiy (PIs: Marscher and Jorstad).

Future of the Perkins Telescope Beyond 2013

On September 5, 2008, representatives of the IAR (Brainerd, Clemens, Janes, and Marscher) participated in a mini-symposium at Lowell Observatory to discuss the future of the Perkins Telescope beyond 2013. Also present were most of the scientific staff of Lowell Observatory, including Director Robert Millis, as well as Professor Richard Miller of Georgia State University.

The primary purpose of the symposium was to assess the current state of the telescope, what work is immediately necessary to keep the telescope in operation, what sorts of new scientific initiatives could be carried out with modest changes to existing instrumentation, and whether it is feasible to continue the operation of the telescope beyond July 2013 (i.e., the end of the current MOU between BU and Lowell Observatory). By that time, the Discovery Channel Telescope – planned to be the primary telescope that will be used by Lowell astronomers for the next 20 years or so – should be fully operational.

The discussions were frank and open-ended, and although no definite decisions were made, it was clear from the meeting that the Perkins Telescope does indeed have a future beyond 2013. Particularly with the new involvement of Georgia State in the operation of the Perkins, there is now considerably more scientific pressure on the telescope than there has been in past decade. In addition, it was clear that the Perkins could serve as a useful testbed for new instrumentation for the Discovery Channel Telescope.

In terms of new initiatives that could be carried out with modest changes to existing instruments, the Lowell astronomers expressed a keen interest in exploiting Mimir's long wavelength (L- and M-band) capabilities in order to study young stars and binaries. In direct response to this, Professor Clemens and Brian Taylor carried out an engineering run in February 2009. The engineering run was devoted primarily to the development and testing of new operations software, and it was a complete success. This has launched several new long-wavelength modes for Mimir, one of which makes Mimir on the Perkins into the widest-angle L-band imaging system on the planet.

Also, while the concept was not presented at the time of the meeting, the IAR certainly feels that the multi-object spectroscopy capabilities of the proposed "Flexi" instrument (see the Instrumentation Programs section) could easily revitalize science efforts with the Perkins, and might ultimately be transferable to the Discovery Channel Telescope as well.

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 needs to hire an additional new, young faculty member within the next two years. In particular, it would be 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 11 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 large 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.

In order 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. In order to maintain the vitality of our research effort, it is critical that IAR start to look beyond the Perkins Telescope.

The funding for national astronomical observatories continues to shrink at an alarming rate. Therefore, in order to guarantee the ability to carry out cutting-edge astronomy, the majority of US universities have access to large privately-owned telescopes. 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) already 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. 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.

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. At present, a number of new telescopes are being considered by the IAR. As these telescope projects develop and head toward completion, we are weighing the advantages and disadvantages of each.

Seminar Series

The IAR Astrophysics Seminar Series on Tuesday afternoons brings external astrophysicists from the local area as well as from across the nation to Boston University to present their recent work and to consult with IAR faculty and students. During the past year, the IAR sponsored seminars by twenty-four 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-nine 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) and Professor Jackson's retention account (20 201 1588-9). Grant and contract accounts supervised by the IAR include ten new sponsored grants and contracts, two existing grants which received further income, and twenty-seven other continuing sponsored grants and contracts within the IAR. A total of ten of these sponsored grants and contracts were closed out during the past year. Fourteen new funding proposals were submitted to federal and other agencies, totaling over $3.47M.

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 FY09 are as indicated in the following table.

Category	Cost
Usage fee paid to Lowell Observatory	$151,000
*Brian Taylor (partial salary)	$30,766
Auto Insurance	$2,283
Total	$184,049

*The remainder of Brian Taylor's salary in FY09 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 $91,163 and income totaled $104,650. 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 income for FY09, $27,850 was brought in for funding to make improvements to the PRISM instrument located at Lowell Observatory in Flagstaff, AZ. These improvements will be completed in FY10 and will show as expenditures during that fiscal year.

IAR FY2009 Expenditures

Category	Cost	Percent of FY09 Expenditures
Basic Operations	$57,903	64%
Proposal Development	$678	1%
Infrastructure	$7813	9%
Seminar Series	$18,883	20%
Social	$1109	1%
Cost Sharing	$1672	2%
General Research	$1915	2%
Educational Etc.	$1190	1%
Advisory Board	$0	0%
Total Expended	$91,163	100%

Basic Operations, the largest expense category, covers fixed costs such as Fiscal Administrator Paci's salary, the director's stipend, and benefits for both. The seminar series makes up the 2nd largest expense category for the IAR this year. Seminar costs include travel, meals and accommodations for our guest speakers. Ten seminars were held during the Fall 2008 semester, and fourteen were held during the Spring 2009 semester. The schedules are shown in appendix B. Infrastructure expenses make up the 3rd largest expense category. Included in the infrastructure category are costs such as telephone lines and minor computer equipment.

Sponsored Grants and Contracts

The IAR managed a total of thirty-nine grants during this fiscal year. There are ten new grants, which have been awarded to the Institute, two existing grants were awarded further funding, and there were twenty-seven other continuing grants. This year, the IAR closed out a total of ten awards. A summary of the FY2009 sponsored grant income and expenditures are contained in the following tables.

FY2009 Grant Income – Institute for Astrophysical Research (7/2008-6/2009)

P.I.	Agency	Title	FY2009 Award
*Bania	2640 NSF/GBT	NRAO GBT Student Support	$12,820
*Blanton	2746 SAO	Shocks, Ripples and Bubbles: A Very Deep Observation of Abell 2052	$154,209
Brainerd	9578 NASA Subcontract	HIPO: High Speed Imaging Photometer for Occultations (Subcontract from Lowell Obs.)	$41,850
*Jackson	2459 NSF	Infrared Dark Clouds	$209,090
*Jackson	2673 NASA	Galactic Structures Using 2Mass Data	$104,343
*Jackson	2793 SAO	SAO: Long-Term M-W-R Telescope Survey for Dense, Star-Forming Gas Clouds in the Milky Way	$2079
*Janes	2398 NSF	REU Supplement: Old Star Clusters: Stellar Activity and Galactic Structure	$7873
*Jorstad	2477 NASA	Searching for the Connection between X-ray and Gamma-ray Variability and Jet Activity in Blazars	$36,800
*Jorstad	2564 NASA	High Resolution Mapping of the Gamma-Ray Emission Regions in Blazar Jets	$82,997
Marscher	2238 NASA	Probing the Relativistic Jets of Active Galactic Nuclei with Multiwaveband Monitoring	$37,394
*Marscher	2472 NASA	Comprehensive Multiwaveband Monitoring Program of Gamma-Ray Bright Blazars	$233,994
*Marscher	2529 NASA	PSD Break, Jet Scale and Black-Hole Mass of the FR II radio Galaxy 3C III	$63,600

***New Awards**

Summary of IAR Grant Income

Origin of Award	Total Current Year Funding (7/08-6/09)
Institute for Astrophysical Research (20-351)	$987,049

FY2009 Grant Expenditures – Institute for Astrophysical Research (7/2008– 6/2009)

P.I.	Agency	Title	FY2009 Expense
Bania	2157 NSF	Galactic Chemical Evolution: The 3-Helium Project	$65,963
Bania	2640 NSF/GBT	NRAO GBT Student Support	$12,633
Bania	2239 JPL	Spitzer Space Telescope: Heating and Cooling in the Translucent Interstellar Medium	$0
Bania	9963 NASA	Probing Solar Wind Charge Exchange Emission from Earth's Magnetosheath	$0
Blanton	8651 Foundations	Claire Booth Luce Professorship	$125,500
Blanton	2033 NASA	Chandra General Observer Program, Cycle 8-Ripples, Fronts, Bubbles and a Tunnel: A Deep Observation of Abell 262	$0
Blanton	9586 NASA	Chandra General Observer Progam, Cycle 7 – The Formation of WAT Radio Sources: Interaction Between the Radio Lobes and the Intracluster Medium	$0
Blanton	2746 SAO	Shocks, Ripples and Bubbles: A Very Deep Observation of Abell 2052	$24,361
Bosh	8512 NASA	Planetary Ring Studies Using Stellar Occultation	$27,306
Brainerd	2088 NSF	Bright Field Galaxies and Their Dark Matter Halos	$86,681
Brainerd	2089 NSF	Bright Field Galaxies and Their Dark Matter Halos	$2772
Brainerd	9578 NASA	HIPO: High Speed Imaging Photometer for Occultations (Subcontract from Lowell Obs.)	$35,642
Clemens	9378 NSF	The Galactic Plane Infrared Polarization Survey (GPIPS)	$234,569

Jackson	9078 NSF	Release and Analysis of the Galactic Ring Survey	$153,177
Jackson	2459 NSF	Infrared Dark Clouds	$200
Jackson	2673 NASA	Galactic Structures Using 2Mass Data	$1050
Jackson	2793 SAO	SAO: Long-Term M-W-R Telescope Survey for Dense, Star-Forming Gas Clouds in the Milky Way	$2079
Jackson	2035 NRAO	GBT Student Support Program	$0
Jackson	2196 NASA	Protostars in Infrared Dark Clouds	$53,018
Jackson	8862 NASA	The Mid-Course Space Experiment Extended Source Catalog	$14,418
Jackson	9528 JPL	Spitzer Cycle 3 Funding: Active Star Formation in Infrared Dark Clouds	$59,051
Jackson	9529 NASA	Protostars in Infrared Dark Clouds (Subcontract via JPL and Caltech)	$46,594
Janes	8773 NSF	Collaborative Research: Boston University/Lowell Obs. Partnership	$10,889
Janes	2398 NSF	REU Supplement: Old Star Clusters: Stellar Activity and Galactic Structure	$4322
Janes	9080 NSF	Old Star Clusters: Stellar Activity and Galactic Structure	$27,865
Janes	9251 NSF	REU Supplement: Collaborative Research: BU/Lowell Observatory Partnership – Bringing the Perkins Telescope into the 21st Century	$126
Jorstad	2564 NASA	High Resolution Mapping of the Gamma-Ray Emission Regions in Blazar Jets	$66,039
Jorstad	2477 NASA	Searching for the Connection between X-ray and Gamma-ray Variability and Jet Activity in Blazars	$30,149
Marscher	2472 NASA	Comprehensive Multiwaveband Monitoring Program of Gamma-Ray Bright Blazars	$140,241
Marscher	2529 NASA	PSD Break, Jet Scale and Black-Hole Mass of the FR II radio Galaxy 3C III	$43,634

Marscher	2238 NASA	Probing the Relativistic Jets of Active Galactic Nuclei with Multiwaveband Monitoring	$59,363
Marscher	2240 JPL	Spitzer Space Telescope: Velocity Gradients in the Jets of BL Lac Objects	$1314
Marscher	2241 NASA	An Unbiased Deep Census of the Extragalactic 20-100 Kev Sky	$1676
Marscher	2259 NASA	Velocity Gradients in the Jets of BL Lac Objects	$23,559
Marscher	2270 NASA	Velocity Gradients in the Jets of BL Lac Objects	$4676
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
Marscher	9525 NASA	Relation Between High-Energy and Lower-Frequency Emission in Blazars	$0
Marscher	9580 NASA	Events in the Central Engine and Energy Flow into Jets of Radio Galaxies	$0
Marscher	9926 NSF	Probing Blazars Through Multiwaveband Variability of Flux, Polarization, and Structure	$2130

Summary of IAR Sponsored Funding Expenditures

Origin of Award	**Total Current Year Expenditures (7/08-6/09)**
Institute for Astrophysical Research (20-351)	$1,361,267

Appendix A: Publications and Presentations

Articles in Referred Journals

Alexander, M.J.; Kobulnicky, H.A.; Clemens, D.P.; Jameson, K.; Pinnick, A.; Pavel, M.; "The Discovery of a Massive Cluster of Red Supergiants with GLIMPSE," 2009, Astrophysical Journal, 137, p. 4824A

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, Astrophysical Journal Supplement Series, 181, p. 255

Anderson, L.D.; Bania, T.M.; "Resolution Of The Distance Ambiguity For Galactic H II Regions," 2009, Astrophysical Journal, 690, p. 706

Blanton, E. L.; Randall, S. W.; Douglass, E. M.; Sarazin, C. L.; Clarke, T. E.; & McNamara, B. R.; "Shocks and Bubbles in a Deep Chandra Observation of the Cooling Flow Cluster Abell 2052," 2009, Astrophysical Journal, 697, p. L95

Boettcher, M.; Reimer, A.; and Marscher, A. P.; "Implications of the VHE Gamma-Ray Detection of the Quasar 3C 279," 2009, Astrophysical Journal, submitted

Brainerd, T. G.; Agustsson, I.; Madsen, C. A.; and Edmonds, J. A.; "Large-Scale Intrinsic Alignments of Galaxies," 2009, Astrophysical Journal, submitted

Brenneman, L. W.; Weaver, K. A.; Kadler, M.; Tueller, J.; Marscher, A.; Ros, E.; Zensus, A.; Kovalev,Y. Y.; Aller, M.; Aller, H.; Irwin, J.; Kerp, J.; and Kaufmann, S;"Spectral Analysis of the Accretion Flow in NGC 1052 with Suzaku ," 2009, Astrophysical Journal, 698, p. 528-540

Burke, C.J.; McCullough, P.R.; Valenti, J.A.; Long, D.; Johns-Krull, C.M.; Machelek, P.; Janes, K.A.; Taylor, B.; and 5 coauthors; "XO-5b: A transiting Jupiter-sized Planet with a 4-day period," 2008, Astrophysical Journal, 686, p. 1331

Chatterjee, R.; Jorstad, S. G.; Marscher, A. P.; Oh, H.; McHardy, I. M.; Aller, M. F.; Aller, H. D.; Balonek, T. J.; Miller, H. R.; Ryle, W. T.; Tosti, G.; Kurtanidze, O.; Nikolashvili, M.; Larionov, V. M.; and Hagen-Thorn, V. A.; "Correlated Multi-Waveband Variability in the Blazar 3C 279 from 1996 to 2007," 2008, Astrophysical Journal, 689, p. 79-94

Chatterjee, R.; Marscher, A. P.; Jorstad, S. G.; et al; "Disk-Jet Connection in the Radio Galaxy 3C 120," 2009, Astrophysical Journal, submitted

Clarke, T. E.; Blanton, E. L.; Sarazin, C. L.; Anderson, L. D.; Gopal-Krishna, Douglass, E. M.; & Kassim, N. E.; “Tracing Multiple Generations of Active Galactic Nucleus Feedback in the Core of Abell 262,” 2009, Astrophysical Journal, 697, p. 1481

D'Arcangelo, F. D.; Marscher, A. P.; Jorstad, S. G.; et al. “Synchronous Optical and Radio Polarization Variability in the Blazar OJ287,” 2009, Astrophysical Journal, 697, p. 985-995

Gomez, J.L.; Marscher, A.P.; Jorstad, S.G.; Agudo, I.; and Roca-Sogorb, M.; “Faraday Rotation and Polarization Gradients in the Jet of 3C 120: Interaction with the External Medium and a Helical Magnetic Field,” 2008, Astrophysical Journal Letters, 681, L69-L72

Jackson, J.M.; Finn, S. C.; Rathborne, J. M.; Chambers, E. T.; Simon, R.; “The Galactic Distribution of Infrared Dark Clouds” 2008, Astrophysical Journal, 680, p. 349-361

Jones, T. J.; Stark, D.; Woodward, C. E.; Kelley, M. S.; Kolokolova, L.; Clemens, D.; and Pinnick, A.; “Evidence of Fragmenting Dust Particles from Near-Simultaneous Optical and Near-Infrared Photometry and Polarimetry of Comet 73P/SCHWASSMANN WACHMANN 3,” 2008, Astronomical Journal, 135, p. 1318-1327

Larionov, V. M.; Jorstad, S. G.; Marscher, A. P.; Raiteri, C. M.; Villata, M.; et al.; “Results of WEBT, VLBA and RXTE monitoring of 3C 279 during 2006-2007,” 2008, Astronomy & Astrophysics, 492, p. 389-400

Marshall, K.; Ryle, W. T.; Miller, H. Richard; Marscher, A. P.; Jorstad, S. G.; Chicka, B.; and McHardy, I. M.; “Multiwavelength Variability of the Broad Line Radio Galaxy 3C 120,” 2009, Astrophysical Journal, 696, p. 601-607

Raiteri, C. M.; Villata, M.; ... Jorstad S.G,; et al; “A new activity phase of the blazar 3C 454.3. Multifrequency observations by the WEBT and XMM-Newton in 2007-2008,” 2008, Astronomy & Astrophysics, 491, p. 755-766

Raiteri, C. M.; Villata, M.; ... Jorstad S.G.; et al.; “The high activity of 3C 454.3 in autumn 2007. Monitoring by the WEBT during the AGILE detection,” 2008, Astronomy & Astrophysics Letters, 485, L17-L20

Randall, S. W.; Jones, C.; Markevitch, M.; Blanton, E. L.; Nulsen, P. E. J.; & Forman, W. R.; “Gas Sloshing and Bubbles in the Galaxy Group NGC 5098,” 2009, Astrophysical Journal, in press

Rathborne, J.M.; Jackson, J.M.; Zhang, Q.; Simon, R.; “Submillimeter Array Observations of Infrared Dark Clouds: A Tale of Two Cores,” 2008, Astrophysical Journal, 689, p. 1141

Professional Seminars, Colloquia and Conference Talks

Blanton, E. L.; MIT, 2009, invited colloquium: “AGN in Clusters of Galaxies: Cooling Flows, Feedback, and High-z Systems”

Blanton, E. L.; Madison, WI, “The Monster's Fiery Breath: Feedback in galaxies, groups, and clusters,” contributed talk: “Deep Chandra Observations of Feedback in the Cool Cores of A2052 and A262”

Brainerd, T.G.; Kingston, Ontario, June 2009, “Satellite Galaxies as Tracers of their Dark Matter Halos”, contributed talk: “Unveiling the Mass: Extracting and Interpreting Galaxy Masses”

D'Arcangelo, Francesca D.; Marscher, A. P.; Jorstad, S. G.; Smith, P. S.; Larionov, V. M.; et al.; 213th American Astronomical Society meeting, 2009 January 4-8, Long Beach, CA, #326.01, dissertation talk: “Correlated Multiwavelength Polarization in Blazar Cores”

Jackson, J.M.; conference on high-mass star formation, Heidelberg, Germany, 2008 September 10, invited talk: “Infrared Dark Clouds”

Jackson, J.M.; Astrophysics Colloquium, Northwestern University, Evanston, Illinois, 2008 September 30, invited talk: “Snakes in the Plane: High-Mass Star Formation in Filamentary Infrared Dark Clouds”

Jorstad, S. G.; Marscher A. P.; D'Arcangelo, F. D; et al; 213th American Astronomical Society meeting, 2009 January 4-8, Long Beach, CA, #422.01, poster paper: “VLBA Monitoring of the Inner Jet in a Sample of Strong Gamma-ray Blazars”

Marscher, A. P.; Jorstad, S. G.; Larionov, V. M.; Chatterjee, R.; D'Arcangelo, F.; et al.; 213th American Astronomical Society meeting, 2009 January 4-8, Long Beach, CA, #326.03, contributed talk: “Comprehensive Multi-waveband Monitoring of Gamma-ray Bright Blazars”

Olmstead, A. R.; Jorstad, S. G.; Marscher, A. P.; Walker, G.; Strelnitski, V.; and Larionov, V. M.; 213th American Astronomical Society meeting, 2009 January 4-8, Long Beach, CA, #446.07, poster paper: ”Optical Monitoring of a Sample of Gamma-ray Blazars at the Maria Mitchell Observatory”

Conference Proceedings, Abstracts and Poster Papers

Agudo, I.; Bach, U.; Krichbaum, T. P.; Marscher, A. P.; Gonidakis, I.; Diamond, P. J.; Alef, W.; Graham, D.; Witzel, A.; Zensus, J. A.; Bremer, M.; Acosta-Pulido, J. A.; and

Barrena, R.; “NRAO 150: A Recently Identified Quasar Revealing Extreme Non-Ballistic Motion,” 2008, Extragalactic Jets: Theory and Observation from Radio to Gamma Ray, ed. T.A. Rector and D.S. De Young, Astron. Soc. Pacific Conf. Ser., vol. 386, p. 249-255

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Appendix B: Seminar Series Schedules

Institute for Astrophysical Research Seminar Series
Fall 2008

Sept. 9	Alan Marscher, BU/IAR "Probing Deeply Into the Inner Jets of Blazars"
Sept. 23	Soren Meibom, Center for Astrophysics "The Rotational Evolution of Low-Mass Stars"
Oct. 7	Max Tegmark, MIT "New Clues About Inflation, Dark Matter, and Dark Energy"
Oct. 21	Lisa Prato, Lowell Observatory "Young Planets in Visible and Infrared Light: Spots' Tricks"
Oct. 28	Jason Wright, Cornell University "Exoplanet Frontiers: Multiple-Planet Systems, Solar System Analogs, and Planets Around M-Dwarfs"
Nov. 4	Elliot Horch, Southern Connecticut State University "Fainter and Closer: New High-Resolution Imaging Capabilities at the WIYN Telescope"
Nov. 18	Dava Sobel, Author Joint IAR/CSP Seminar: "The Drama of Copernicus: How He Was Convinced to Publish his Crazy Idea"
Nov. 25	Gerritt Verschuur, University of Memphis "Intermediate and High-Velocity "Clouds" A New Look at an Old Problem"
Dec. 2	Ellen Zweibel, University of Wisconsin "The Origin and Evolution of Astrophysical Magnetic Fields"
Dec. 9	Tim Beers, Michigan State University "SEGUE-1, SEGUE-2, and the Future of Large Scale Surveys of the Galaxy"

Institute for Astrophysical Research Seminar Series
Spring 2009

Jan. 20	Warren Brown, CfA "Hypervelocity Stars and Massive Black Holes"
Jan. 27	Dan Clemens, IAR "GPIPS and other fun with the Perkins Telescope"
Feb. 10	Andrew West, MIT "From Foreground Trash to Bountiful Treasure: Galactic Stratigraphy, Magnetic Activity and the Kinematics of M dwarfs in the Sloan Digital Sky Survey"
Feb. 17	Nathan Smith, UC Berkeley "Eruptive Mass Loss in Massive Stars and Precursors to the Most Luminous Supernova Explosions"
Feb. 23	Riccardo Schiavon,Gemini "The History of Star Formation of Early-Type Galaxies"
Feb. 24	Stella Kafka, CalTech "Magnetic Activity on CV Secondaries: Nature or Nurture?"
Mar. 6	Peter Frinchaboy, University of Wisconsin "Stellar Tracers: Probing Physics and Galactic Structure"
Mar. 17	Cornelia Lang, University of Iowa "The Galactic Center"
Mar. 24	Ed Berschinger, MIT "Dark Energy or Modified Gravity?"
Mar. 31	Peter Barnes, University of Florida "The CHAMPS Mopra Molecular Line Survey"
Apr. 7	Peter Schloerb, University of Massachusetts "LMT"
Apr. 14	Gregor Tucker, Brown University "BLAST"

Apr. 21 Richard French, Wellesley University
"Saturn or Pluto"

Apr. 28 Evan Skillman, University of Minnesota
"The Recent Star Formation Histories of Nearby Galaxies"