Boston University
Institute for Astrophysical Research

Architectural rendering of the Discovery Channel Telescope.

Annual Report
June 2011

Overview

Introduction

The mission of the IAR is to promote and facilitate research and education in astrophysics at Boston University. The IAR accomplishes this mission by administering research grants, enhancing the visibility of IAR members with funding agencies, coordinating the use of Boston University astrophysics facilities, promoting the design, development, and operation of Boston University instruments and telescopes, regularly sponsoring seminars and professional meetings, and actively engaging students of all levels in research. The primary research fields in which the IAR astronomers are involved include stars and star formation, the interstellar medium, blazers and other active galaxies, galaxy clusters, extrasolar planets, magnetic fields, dark matter, and the large-scale structure of the universe.

Executive Summary

In FY11 marked a very successful 13th year in the IAR's mission to foster research in astrophysics at Boston University. Without a doubt, the most exciting event for the IAR was a financial commitment from Boston University that will provide a major capital investment in the Discovery Channel Telescope (DCT). The DCT is a new 4.3 meter telescope that is being built by Lowell Observatory, with which the IAR has a long-standing partnership in the operation of the 1.8 Perkins Telescope. Becoming major partners with Lowell Observatory in the DCT will help to insure the ability of BU to continue to carry out cutting-edge astrophysical research, as well as to attract significant federal funding for ground-based studies of the Universe, and to recruit and retain the best observational astronomers. The scientific productivity of the IAR astronomers was truly remarkable this year, and resulted in the publication of 48 manuscripts in the peer-reviewed literature. Amongst our scientific highlights of the year are: the public release of a catalog of more than 600 newly-discovered H II regions in our Galaxy, the first evidence of a "sloshing spiral" resulting from merger activity in a galaxy cluster, the discovery that the outer edge of our solar system is filled with a sea of turbulent magnetic bubbles, and the discovery that the majority of gamma-ray outbursts in blazers originate far from the central black hole, in contradiction with the standard theoretical models. In FY11 the IAR managed 27 active research grants, the total funding for which is \$3.87M to date.

Faculty, Staff and Leadership

Size and Organization

In FY11, the IAR personnel included 5 full professors, 1 associate professor, 3 assistant professors, 2 senior research scientists, 3 postdoctoral associates, 3 visiting researchers, and 1 full-time fiscal administrator. In addition, 21 graduate students and 6 undergraduate students were actively involved in IAR research programs.

Leadership

The IAR has a sole director, and reports to the Dean of the College of Arts and Sciences. FY11 marked the sixth and final year that the IAR Directorship was held by Professor Tereasa Brainerd, who will begin a 3-year term as Chair of the Department of Astronomy in FY12. On July 1, 2011, Professor Alan Marscher will begin a 2-year appointment as IAR Director. Professor Marscher has previously served as the Chair of the Department of Astronomy, an Associate Dean in the College of Arts and Sciences, and the Director of the Center for Teaching Excellence at Boston University.

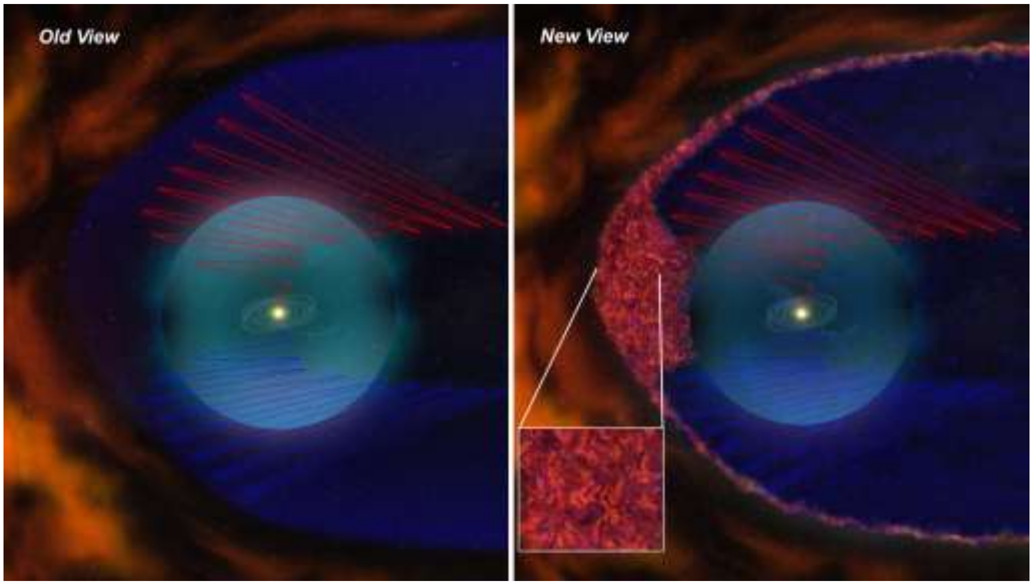
Changes in Appointments and Staffing

On January 1, 2011, Dr. Merav Opher joined the Department of Astronomy and the IAR as an Assistant Professor. Professor Opher comes to us from the Physics Department at George Mason University, where she served as both an Assistant and Associate Professor. We are delighted to have Professor Opher as a member of our faculty because her research interests are a remarkable match to the research interests of the Department of Astronomy as a whole. In many ways, Professor Opher's work bridges the two primary disciplines of the Department: astrophysics and space physics. She is an expert in magnetic processes, including the ways in which magnetic fields affect the interstellar medium, disks around young stars, solar and stellar winds, jets, and the early universe. Professor Opher is also an expert in computer simulations and modeling, and her presence increases our strength in the fields of computational astrophysics and space physics. The IAR is particularly excited that Professor Opher is planning to take her detailed understanding of the physical conditions of our own solar system and apply it to extrasolar planetary systems. The sun is but one of billions of stars in our Galaxy; it just happens to be the star that we can study in the most detail at the present time. Professor Opher's planned work will take what is traditionally thought of as space physics out beyond our own solar system, and will eventually lead to a coherent picture of star-planet interactions in our Galaxy.

Professor Opher is also actively involved with the on-going Voyager mission (now in its 33rd year of operations). On April 28th, she appeared in a NASA TV live broadcast where she addressed a number of the Voyager program's significant findings and contributions to the exploration of space, including Voyager's influence on the rising generation of scientists and the impact Voyager data have had on the scientific community at large. On

June 9th, Professor Opher participated in a NASA media press conference to discuss a new computer model based on the Voyager data that suggests the edge of our solar system is filled with a sea turbulent magnetic bubbles, rather than being smooth as had been expected.

Professor Merav Opher speaking during the April 28th NASA TV live broadcast on the impact and results from the Voyager mission.



The red and blue spirals are the gracefully curving magnetic field lines of the orthodox models. New data from Voyager add a magnetic froth (highlighted by the insert) to the mix. Image credit: NASA (based on a model constructed by Professor Opher and her colleagues).

In Spring 2011, Professor Kenneth Janes was appointed to emeritus status, effective September 1, 2011. Professor Janes taught his last regular lecture course (GRS AS712, *Radiative Processes*) in Fall semester. Professor Janes has served with distinction at Boston University for 38 years, the longest tenure of any member of the Astronomy faculty. He is best known for his work on open star clusters and the structure of the Milky Way, including the fact that the metal content of stars is a function of their location in our Galaxy but, surprisingly, that the metal content of stars is not strongly correlated with their ages. Most recently, Professor Janes has been involved with the XO collaboration in the discovery of a number of extrasolar planets. Professor Janes served as the chair of the IAR's Lowell Liason Committee for over a decade, personally coordinating the efforts of BU and Lowell astronomers in the operation of the Perkins Telescope. Professor Janes also designed and built PRISM, the primary instrument in use on the Perkins telescope for optical imaging, spectroscopy, and polarimetry. A much-beloved teacher and outstanding citizen of the Department, even in retirement Professor Janes will remain a valued scientific colleague whose maturity, perspective, and reliable good humor will always be appreciated.

Professor Emeritus Kenneth Janes.

In Spring semester, Professor Tereasa Brainerd enjoyed a sabbatical leave that enabled her to work extensively on a number of research projects that center upon weak gravitational lensing. The most important discovery that she made during this time was a highly-significant detection of an effect known as "cosmic magnification" by intrinsically red galaxies in the Sloan Digital Sky Survey. While hers is not the first detection of cosmic magnification in the universe, it is the first result that shows the effect is dramatically different for red lens galaxies than it is for blue lens galaxies. The underlying reasons for the dramatic differences are that, on average, red galaxies are 2 to 3 times as massive as blue galaxies, and red galaxies are clustered together more strongly than blue galaxies by a factor of order 6.

Honors, Awards, Prizes, and Related Professional Activities and Accomplishments

In September 2010, Professor Bania chaired the "SETI and the Popular Imagination" panel at the international conference "SETI@50: Celebrating the Search for ET". The conference was held in Green Bank, WV and celebrated the 50^{th} anniversary of Frank Drake's pioneering OZMA SETI search.

Over the past year, Professor Blanton served the final year of a 3-year term as a member of the Chandra X-ray telescope User's Committee. The Committee meets twice per year, and reviews any and all aspects of the Chandra X-ray Center activities, particularly those affecting astronomers who are using the Chandra X-ray telescope in their research. In addition, in Spring 2011 Professor Blanton served as the Chair of one of the proposal review panels for Cycle 13 of the Chandra X-ray telescope. The review panels are charged with selecting the proposals that have the highest scientific priority for execution in the next year of observations. Because the number of requests for observing time vastly exceed the amount of time that is available in any given year, the review panels essentially determine the priority of what science will be carried out with the telescope in any given year.

In April, 2011, Professor Clemens became the Chair-elect of the Board of Directors of the Associated Universities for Research in Astronomy (AURA) at the annual AURA Member-Representatives meeting in Tucson, AZ. Professor Clemens will serve a one-year term as Board Chair beginning July 1, 2011. AURA manages the National Optical Astronomy Observatory (NOAO), the National Solar Observatory (NSO), the Gemini International Observatory, and the Space Telescope Science Institute (STScI) on behalf of the National Science Foundation and NASA. This is an enormous, and highly-visible, service to the entire professional astronomical community in the USA, and the IAR is very proud of Professor Clemens for his willingness to take on this key national leadership role.

During the past year, Dr. Svetlana Jorstad continued her service as a member of the User's Committee for the National Radio Astronomy Observatory (NRAO). The User's Committee consists of users and potential users of NRAO facilities. The Committee advises the Director and the Observatory staff on all aspects of Observatory activities that affect the users of the telescopes. The Committee is appointed by the Director and meets annually.

Over the past year, Professor Marscher continued in his role as Chair of the User's Group for the Fermi Gamma-Ray Space Telescope. Fermi was designed to allow astronomers to explore the most extreme environments in the Universe, where the amount of energy that is involved is far beyond anything that is possible on Earth. The Fermi User's Group was formed in order to represent the broad interests of the user community to the Fermi Project and NASA headquarters.

During Spring semester, Professor Opher was an active member of the National Academy of Sciences' space physics decadal review, "A Decadal Strategy for Solar and Space Physics (Heliophysics)". Professor Opher served on the Solar and Heliospheric Physics panel (where she was Chair of the Outer Heliosphere subpanel), and she was also a member of the Theory & Modeling and Data Exploration Working Group. Although Professor Opher's work on the decadal review began before she arrived at BU, we are nevertheless deeply grateful for her dedication to the profession, and the enthusiasm with which she took on (and completed) this vital role in shaping the future of her field.

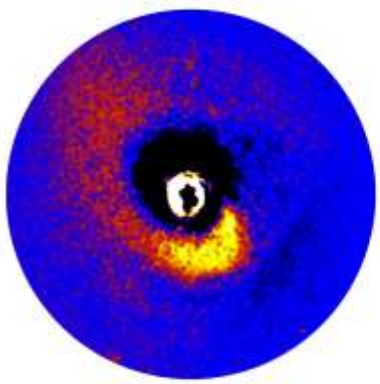
In April 2011, Professor West was awarded the Professor of the Month by the BU Alpha Delta Phi chapter.

Research and Scholarship

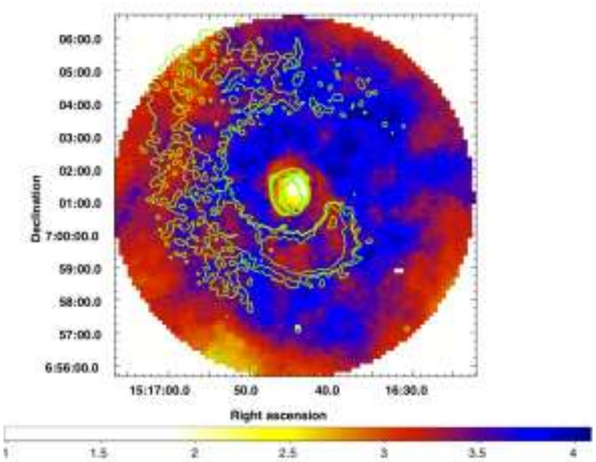
Major Current Research Programs and Projects

Professor Thomas Bania and his research team (which includes his former graduate student Dr. Loren Anderson) have completed a major new survey of star forming regions in our Milky Way Galaxy. The Green Bank Telescope H II Region Discovery Survey (GBT HRDS) found a large population of previously unknown star formation sites. They discovered over 600 new H II regions in the First Quadrant of the Milky Way, which doubled the census of known H II regions. The HRDS has generated a great deal of excitement in the community, with associated press releases from the American Astronomical Society (AAS), NASA, and the National Radio Astronomy Observatory (NRAO), which operates the GBT in Green Bank, WV. There has also been a significant amount of media attention around the HRDS, including several dozen internet and newspaper articles (e.g. Fox News, Wired, Science News, Sciencedaily, Astronomy Now, etc.). In addition, the NRAO management organization, Associated Universities Incorporated (AUI), flagged the HRDS as a major scientific result in its quarterly report to the NSF. The HRDS is featured on the NRAO Green Bank web site, http://www.gb.nrao.edu/ , and NRAO is also hosting the HRDS web site, http://go.nrao.edu , which provides public access to all of the HRDS data.

Professor Blanton and her colleagues presented the first evidence of a "sloshing spiral" in the galaxy cluster known as Abell 2052, which has a cool core. An off-axis cluster or sub-cluster merger in the history of a cluster of galaxies can set the hot, X-ray emitting, intracluster medium in motion, producing a spiral distribution of gas. Such sloshing features can persist for billions of years. Detailed spectral analysis of the feature shows that not only is it a region of excess surface brightness, but it contains gas that is cooler and higher metallicity than its surroundings. Sloshing can redistribute gas from cluster centers to outer cluster regions, carrying cool, high-metallicity gas away from the cluster core. Therefore, sloshing plays an important part in redistributing heavy elements in clusters, and along with AGN feedback, can affect the temperature distribution in cluster centers. As part of the A2052 study, Professor Blanton and her colleagues find a remarkable correlation between X-ray maps of surface brightness and temperature with Hα emission in bright rims surrounding bubbles in the cluster center that have been inflated by the AGN. The Hα represents gas with temperature of order 10^4 K, and X-ray gas with temperature of order 10^7 K is found in these same regions. Therefore, at least some of the X-ray gas is cooling to very low temperatures. In addition to the inner bubbles, Professor Blanton and her colleagues present the first evidence for two new, large, bubbles at larger radii from the cluster center. It is likely that these bubbles are associated with an earlier outburst from the AGN. Each of these bubbles has a radius of about 35 kpc, and can add 10^{60} erg to the intracluster medium, contributing to heating.



Residual X-ray image (0.3-2.0 keV band) of the central 240 kpc radius region of galaxy cluster A2052, after a model has been subtracted. An excess "sloshing spiral" is revealed, and is related to an off-axis cluster or sub-cluster merger likely billions of years in the past.



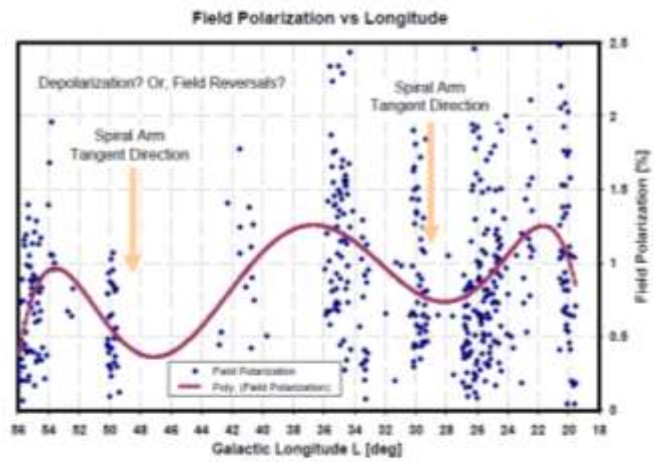
Temperature map of galaxy cluster A2052 with the contours of the sloshing spiral superposed. The scale bar shows T in keV. The spiral feature is significantly cooler than its surroundings.

Professor Blanton and graduate student Josh Wing have also been studying the environments of double-lobed radio sources selected from the VLA FIRST survey. These radio sources are generated by the supermassive black holes in the centers of galaxies, and are sometimes found in galaxy clusters. In a detailed study including bent double-lobed, straight double-lobed, and single-component radio sources, it was found that the bent double-lobed sources were more often associated with clusters of galaxies than the other sources. Based upon this, Professor Blanton has developed a technique to use the bent sources to identify previously-unknown clusters of galaxies that are located at extremely large distances (equivalent to looking back in time by 6 or 7 billion years). This is a critical realm for studies of galaxy formation and evolution, as well as cosmology. Professor Blanton and her collaborators were recently awarded a large Snapshot program to use the Spitzer Space Telescope to observe 655 bent double-lobed radio sources, from which they expect to discover as many as 400 previously unknown distant clusters of galaxies.

Together with Professor Blanton, graduate student Ned Douglass has been analyzing an archival X-ray study of eleven clusters with wide-angle tail (WAT) radio sources. They have also analyzed samples of cool core (CC) and non-cool core (NCC) clusters in a uniform manner, with ten clusters in each of the samples. All ten of CC clusters show at least four out of five of the characteristics of cool cores, while all ten of the NCC clusters show one or fewer of the characteristics of cool cores. The WAT clusters are much more heterogeneous. Seven have two or fewer of the characteristics of cool cores, while four have three or more. Therefore, although many of the WAT clusters seem not to host cool cores and show signs of recent cluster-scale mergers, at least some of the WAT clusters appear relaxed, with cool cores. Correlation of radio properties with X-ray properties reveals that characteristics seen in the radio can be used as predictors of the X-ray cluster environment. For example, the overall extents of WAT radio sources found in clusters with cool cores and high central ICM pressures are smaller than radio sources found in NCC, often merging environments. This is relevant to Professor Blanton's high-redshift cluster search that uses WAT-like radio sources as tracers of galaxy clusters.

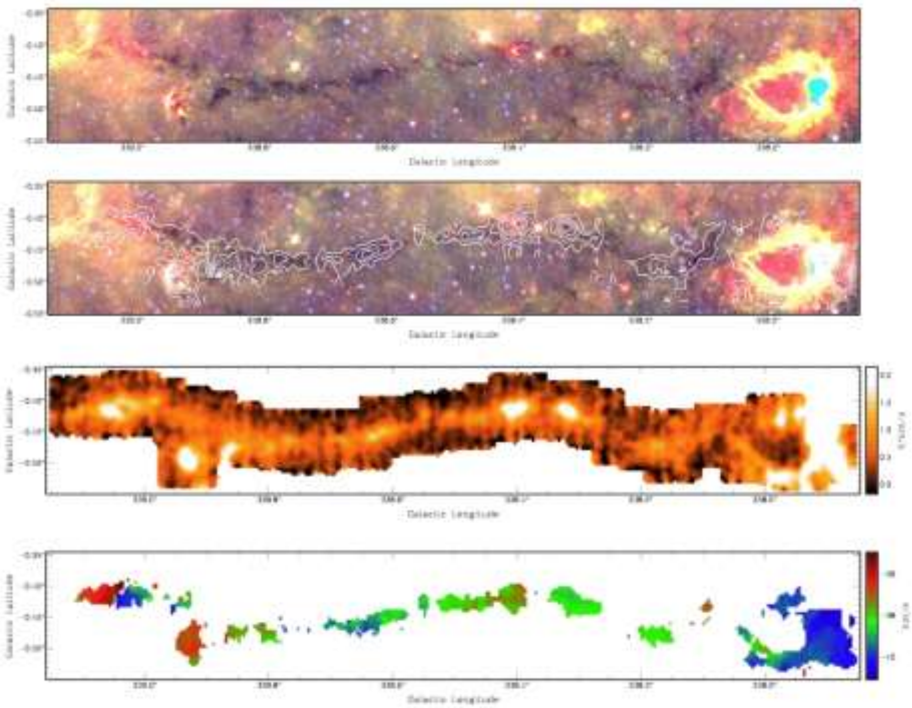
Graduate student Ingolfur Agustsson, working together with Professor Brainerd, has shown that all of the fundamental assumptions that have been used in the past to measure the masses of large galaxies from the motions of the satellite galaxies that orbit them are incorrect. The assumptions are: [1] in 3-dimensions the locations of the satellite galaxies faithfully represent the distribution of dark matter surrounding the large, primary galaxy, [2] the distributions of the velocities of the satellite galaxies with respect to their hosts is well-fitted by a Gaussian distribution, and [3] the distributions of the velocities of "interlopers" (or "false satellites") in the data can be represented by a constant offset. Dr. Agustsson and Professor Brainerd find that the satellite galaxies frequently show a spatial bias with respect to the dark matter distribution (especially in the case of blue primary galaxies and extremely massive red primary galaxies). In addition, they find that the velocity distribution of the genuine satellites is best-fit by a function that is in between a Gaussian and a Lorentzian, and the same is true for the interlopers. The primary conclusions from their work are: [1] all galaxy masses that were previously obtained from the motions of satellite galaxies are incorrect, and [2] previous claims of the observed motions of satellite galaxies being in agreement with the predictions of the Cold Dark Matter model are highly questionable.

Professor Clemens' research group is nearing the end of the data collection phase of the Galactic Plane Infrared Polarization Survey (GPIPS), using the Mimir instrument on the Perkins Telescope. Currently, the observations are about 85% complete and they should be finished in 2012. The GPIPS data analysis is beginning to catch up to the observing, and the first public release of about 15% of the GPIPS data is projected for the end of summer 2011. GPIPS is allowing large-scale magnetic fields in our Galaxy to be probed though a process in which new software is used to mosaic multiple imaging fields together. Using GPIPS, undergraduate student Rob Marchwinski has produced the first resolved magnetic field strength map for a molecular cloud. Graduate student April Pinnick is using GPIPS to study the properties of the magnetic field along the lines of sight to many galactic star clusters. In particular, she will attempt to reveal how the magnetic field properties change on small length scales across the faces of the star clusters. Graduate student Mike Pavel has produced a nearly full-sky map of the way in which the polarimetry of background starlight should reveal the Galactic magnetic field properties. In addition, Professor Clemens' group has active external collaborations that are studying the magnetic fields in the Taurus dark cloud region, the externally illuminated IC63 molecular cloud, and the Hartley-2 comet tail.



Plot of polarization percentage versus galactic longitude. The polarization is averaged across the Mimir field of view for 400+ fields. The data reveal a a modulation that is most likely caused by changing magnetic field properties in, and between, spiral arms in our galactic disk. Mimir's polarimetric sensitivity extends to distances and depths into the galactic dust that no other instrument has been able to see.

Professor Jackson's research group has continued their work on Infrared Dark Clouds (IRDCs). From their studies of the Nessie Nebula, they have proposed that the evenly spaced cores observed in the long filament of the nebula arise from a fluid instability known as the "sausage instability". In addition, graduate student Susanna Finn and Professor Jackson were among the first external users of the new K-band focal place array at the Green Bank Telescope, which they used to make NH_3 maps of a large sample of IRDCs much more quickly than was previously possible. Graduate student Chris Claysmith began a project in which he is using the far-infrared Herschel Hi-GAL survey of the galaxy to identify and characterize IRDCs, including IRDCs on the far side of the galaxy that could not be discovered in previous datasets. Professor Jackson's group also continued to work on the determination of distances to IRDCs, both kinematic distances and extinction distances. The work on extinction distances brought collaborators Robert Benjamin and Joseph Stead to BU in January to work on a paper with post-doc Jonathan Foster that compares different distance estimates to dark clouds. Professor Jackson's group also launched a major new effort to use near-infrared adaptive optics imaging with the Keck and VLT telescopes to find previously invisible low-mass stars in regions of high-mass star formation. Despite the high column densities, the low-mass stars are accessible in the near-infrared and are identifiable from the presence of their outflows. This particular project is also the focus of an ALMA Cycle 0 proposal. ALMA is a new millimeter array telescope that is being constructed in the Atacama desert, and is the first interferometer that will have the dynamic range to see low-mass stars in high-mass star-forming regions.

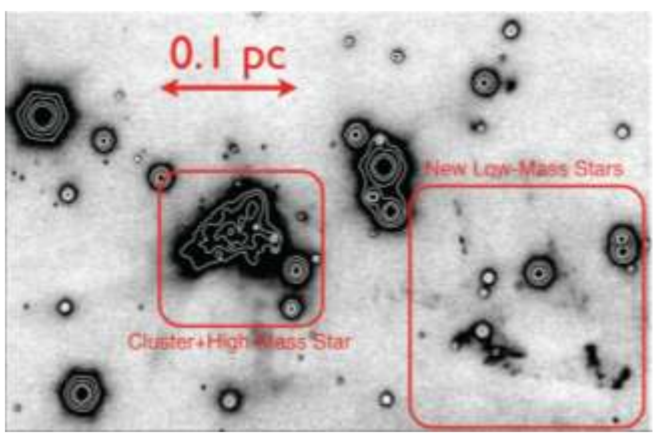


Top panel: Nessie as seen in the infrared at 3.6 microns (blue), 8.0 microns (green), and 24 microns (red).

Second panel: the same with integrated HNC (1-0) contours, showing the excellent correspondence between HNC (1-0) emission and 8 micron extinction.

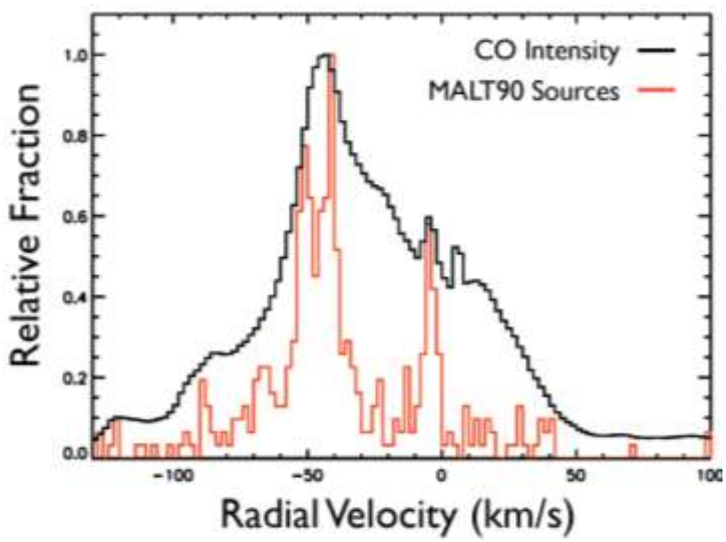
Third panel: cyan crosses showing the positions of cores on the HNC (1-0) integrated intensity map.

Bottom panel: the velocity field (first moment) of HNC (1-0). All the emission is within 4 km/s, demonstrating that the filament is a single coherent object.



Near-infrared (K-band) image of the object known as G034.43+00.24 MM3 taken with the NIRC2 campera on the 10-m Keck telescope using adaptive optics. The image shows high-resolution details of the outflows in the central cluster and a previously undetectable population of distributed low-mass protostars identified by protostellar outflows around very red point sources.

Professor Jackson's group also continued work on the Millimeter Astronomy Legacy Team 90 GHz Survey (MALT90), a large international collaboration that is being led by Professor Jackson. MALT90 is using the 22 meter Mopra radio telescope in Australia over the course of 3 to 4 years to map 3,000 clumps in the Galactic plane in which star clusters are being formed. The first year of observing was completed successfully in 2010, and the data were reduced, verified, and made available to collaborators. The full first year of data will be publicly available by the end of summer 2011. A special session at the meeting "Great Barriers in High-Mass Star Formation" (September 2010) was devoted to MALT90, and attracted a range of astronomers from outside the collaboration. Early science highlights presented at that meeting (and the June 2011 AAS meeting) include: [1] a demonstration that the dense star-forming gas seen in MALT90 is more tightly confined to spiral arms than is CO, [2] evidence that some small number of massive clumps have peculiar chemical variations, and [3] the extragalactic correlation between HCN luminosity and far-infrared luminosity applies to cluster-forming clumps. A total of 840 hours of observing time on the Mopra telescope were awarded for the second MALT90 observing season, which is underway at the time of the writing of this report.



The distribution of MALT90 HNC source velocities from Year 1 (red histogram) overlaid on the 12CO spectrum from the CfA-Columbia CO survey, averaged over the same region (black histogram). The MALT90 sources show a more narrowly-peaked distribution, indicating that the regions of high-mass star formation are tightly confined to spiral arms.

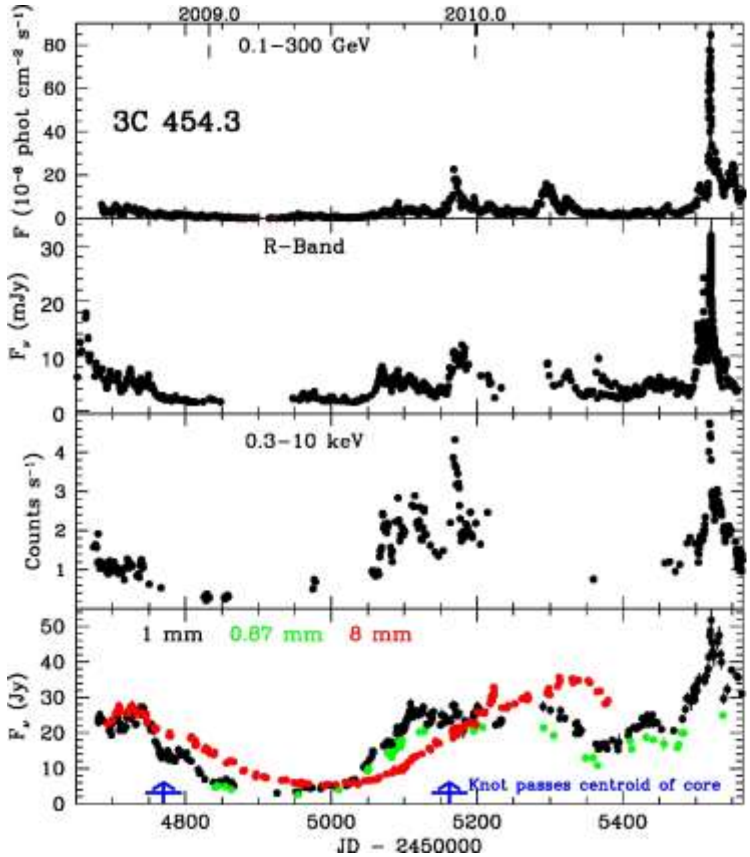
Professor Janes and graduate student Sadia Hoq have recently finished a study of several distant star clusters, the goal of which was to find the distances and ages of the clusters. The clusters in this group are located in the outer part of the disk of the Galaxy, which makes them important for probing the structure and evolution of the Galaxy. In addition, Professor Janes has been working with Dr. Sydney Barnes (Lowell Observatory), Dr. Soeren Meibom (Harvard-Smithsonian Center for Astrophysics) and the Kepler project team on a study of the open star cluster NGC 6811. This particular cluster is located in the field of view of the Kepler spacecraft, and they have been continuously monitoring a selection of stars in the cluster. As stars rotate, starspots come and go, and the stars change very slightly in brightness. This makes it possible to discern the rotation periods of the stars. Since it is also possible to determine the age of a star cluster, this study will allow Professor Janes and his collaborators to learn how stars spin down as they age and, specifically, to develop a calibration of stellar age vs. stellar rotational period. Professor Janes' primary role in the project is to determine the age of NGC 6811 using data from the telescopes at Lowell Observatory.

The blazar research group (led by Professor Marscher and Dr. Jorstad) studies the physics of blazars, the most luminous long-lived objects in the Universe, through comprehensive multi-waveband monitoring. Blazars are quasars or other active galactic nuclei powered by super-massive black holes that are accreting gas from their surroundings. Their main project involves monthly radio frequency observations with the Very Long Baseline Array (which produces images of the jets of blazars in with angular resolution 1000 times finer than that of the Hubble Space Telescope) of a sample of 35 gamma-ray bright blazars, as well as optical polarimetric and photometric observations with PRISM and MIMIR on the Perkins Telescope. These data are then combined with observations by collaborators using 6 other telescopes around the world.

A continued program of monitoring the X-ray flux of six bright gamma-ray blazars with NASA's Rossi X-ray Timing Explorer was selected as one of the Core programs for the remainder of the satellite's mission. The blazar group was also awarded time for more limited X-ray observations of a number of others with the Swift satellite. In addition, the group is using publicly available data from NASA's Fermi Gamma-ray Space Telelescope to derive gamma-ray light curves (brightness vs. time) for all of the blazars in their sample. This project is producing exciting results, indicating that gamma-ray emission in blazars is generated by disturbances in the jet. The majority of outbursts of gamma rays occur many light-years away from the black hole as moving disturbances (probably shock waves) pass through standing shocks in the jet. This finding is overturning standard theoretical models that place the events near the black hole.

On the other hand, the group's observations of rotating polarization vectors support current theoretical ideas for how the accreting black holes produce ultra-high speed jets of energetic plasma through winding up a magnetic field. The magnetic field collimates and accelerates the jet flow in a zone upstream of the section of the jet that can be imaged in radio light. In the quasars PKS 1510-089 and 3C 454.3, emission of enhanced visible and gamma-ray light occurs in this zone. The group is working toward understanding the processes responsible for producing bright "blobs" that appear to move faster than light (an illusion) and outbursts in which the brightness can increase by many times.

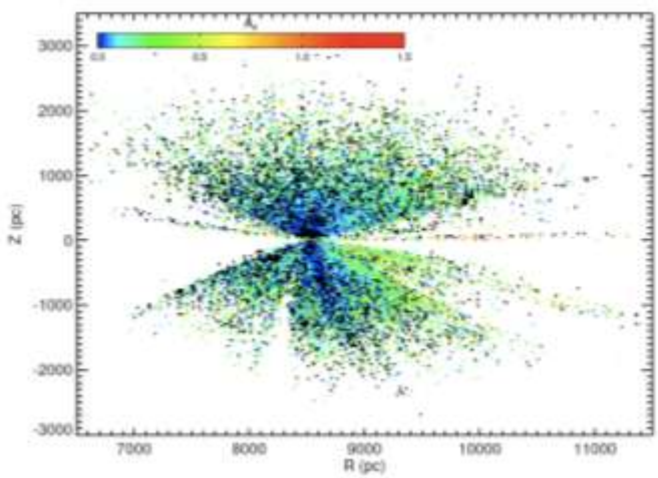
The group observed a "mega-outburst" of radiation across most of the electromagnetic spectrum in the quasar 3C 454.3 in late 2010, during which time the object became the brightest source of gamma rays in the sky. The intensity reached maximum at all wavebands from microwave to gamma ray within the same day, yet the detailed fluctuations in brightness at the different wavebands did not track each other. Professor Marscher is modeling this behavior as turbulent plasma passing through a standing shock wave. He is developing a computer code to simulate the behavior of the emission both in brightness and polarization under this physical scenario, and the early results are promising.



Shown on the left is the brightness of the quasar 3C 454.3 as a function of time at gamma-ray, X-ray, visible red, and microwave (millimeter) wavelengths. The peaks in 2008-09 were considered to be "major" until they were dwarfed by the "mega-outburst" that occured in late 2010. The upward blue arrows at the bottom show the times when a bright "blob" passed through the stationary bright region called the "core," which lies 10-50 light-years from the black hole. Shown on the right is a time sequence of images of the "blob" and "core", where the blob is located to the left of the core. The blazar group interprets these events as the result of turbulent, high-energy, magnetized plasma flowing across one or more standing shocks that compress and heat the plasma.

In addition, graduate student Michael Malmrose, Professor Marscher, and Dr. Jorstad have discovered hot dust in a gamma-ray blazar. The discovery of the dust emission is particularly important to the interpretion of an extremely luminous outburst of gamma rays from this object in April-June 2010. One model of gamma-ray production involves infrared photons from hot dust being scattered to gamma-ray energies as the result of collisions with very energetic electrons. The blazar group will now investigate the possibility that hot dust is generally present in blazers, and will attempt to locate the dust relative to the black hole by observing changes in the luminosity of the infrared emission from the dust.

In the past year Professor West led a team of students and researchers (including three graduate and one undergraduate student from BU) that built and analyzed the largest spectroscopic catalog of low-mass stars ever assembled (over 70,000 spectra). The catalog was published in the Astronomical Journal in 2011, and several additional papers have already been enabled by using this statistically rich sample. One of the papers that made use of these data was written by graduate student David Jones, Professor West, and post-doc Jonathan Foster. Their study investigated the three dimensional distribution of dust in the Galaxy using the smallest of the Milky Way's constituents, M dwarfs. M dwarfs are one of the best tracers of the properties of the nearby Galaxy due to their ubiquity both in the Milky Way and in large, deep astronomical surveys. By comparing the optical spectra of more than 50,000 M dwarfs to similar-type spectra in dust-free lines-of-sight, Jones, West and Foster were able to map the Galactic dust within almost 2 kpc of the Sun. Professor West presented his initial spectroscopic catalog of M dwarfs at the “Cool Stars 16” meeting last summer in Seattle, WA by creating a poster using the images of ~3000 of the M dwarfs from his sample (see image below).



The line of sight visual extinction to more than 50,000 M dwarfs as a function of Galactic height (Z) and Galactocentric radius (R). The azimuthal direction has been compressed in this figure.

Sloan Digital Sky Survey gri composite images of ~3000 images from Professor West's spectroscopic M dwarf sample. The images were put together to mimic the logo of the "Cool Stars 16" conference logo (credit L. Walkowicz) that took place in Seattle, WA in August 2010.

Sponsored Grants and Contracts

In FY11 the IAR managed 27 active research grants. To date, the total funding for these grants is $3.87M (inception through close of FY11). Of the active grants managed by the IAR in FY11, eight were new awards ($0.53M) and six of the continuing awards also received additional funding ($1.34M). The total new IAR grant income for FY11 is therefore $1.87M. IAR grant expenditures in FY11 totaled $1.37M. Over the course of the year, IAR members submitted 19 new funding proposals with requests totaling $6.98M, and the IAR closed out a total of six grants.

New Grants Managed by the IAR in FY2011

Principal Investigator	Title of Project	Agency	Start date	End date	Funding to Date
Clemens, Dan	REU Supplement: Completing the Galactic Plane Infrared Polarization Survey (GPIPS)	NSF	9/1/2009	8/1/2013	$9,500
Goodrich, Charles	NASA IPA Agreement	NASA	2/22/2011	2/21/2012	$181,616
Jackson, James	NRAO GBT Student Observing Program (Susanna Finn)	NRAO	10/1/2010	9/30/2011	$20,000
Jorstad, Svetlana	Searching for the site of Gamma-Ray Emission in Blazar Jets	NASA	11/1/2010	10/31/2011	$99,962
Jorstad, Svetlana	Probing Blazar Physics through Variability across the Electromagnetic Spectrum	NASA	8/1/2010	7/31/2012	$34,990
Jorstad, Svetlana	Location of the High Energy Emission in Blazar Jets (Spring Campaign)	NASA	7/1/2010	6/30/2012	$37,978
Marscher, Alan	Theoretical Study of the Effects of Magnetic Field Geometry on the Gamma-ray Emission of Blazars	NASA	7/21/2010	9/30/2011	$98,000
West, Andrew	Ultraviolet Magnetic Activity of Low-Mass Stars	NASA	9/1/2010	8/31/2011	$45,000

Publications and Scholarly Output

The IAR has continued its vigorous research program. Over the past year, IAR members published 48 scientific papers in refereed journals, along with 12 conference proceedings papers and 51 abstracts.

Undergraduate Education

The use of the Perkins Telescope for professional-quality observations is an important part of our educational mission. To date, approximately 90 undergraduates have traveled to Flagstaff to observe with the Perkins Telescope. These include undergraduate non-science concentrators (CAS AS102HP and CAS AS102), undergraduate science concentrators in the honors program (CAS AS203HP), observational astronomy students (CAS AS441), and senior undergraduate students who use their observations as part of their Senior Work For Distinction (CAS AS491/AS492). The most recent undergraduate senior to use the Perkins telescope as part of her senior work for distinction is Julie Moreau (CAS class of 2011). Julie used the Mimir instrument to obtain new infrared spectra for 20+ stars in one GPIPS field of view in order to determine distances to the stars. This data, combined with the already measured stellar polarizations, enabled the development of a model for the 3D distribution of the magnetic field throughout this region of the galactic disk.

For the past 7 spring semesters, all of the students enrolled in AS441 have participated in field trips to the Perkins Telescope to use either Mimir or PRISM to collect data for their class projects. Organized into groups of 3-4, AS441 students have each spent 2 to 3 nights operating the Perkins Telescope (weather permitting). This capstone event in the training of our undergraduate astronomy students is extremely popular, and it has been highly effective for aiding the scientific and personal maturation of the students. This unique field trip experience has become a distinguishing high mark for BU and its undergraduate students. In addition to using the Perkins Telescope to acquire data for their course work, AS441 students are also encouraged to experience some of the unique features of northern Arizona, including one- or two-day trips to Meteor Crater and/or the Grand Canyon. From 2004 to 2008 the AS441 field trip was sponsored by the National Science Foundation (PREST grant, PI: Kenneth Janes). Since 2009, the AS441 field trip has been sponsored by the Department of Astronomy.

Of special note is that in Fall 2010, 12 students from Professor Clemens' AS102 course (*The Astronomical Universe*) were able to participate in a class field trip to the Perkins telescope to use Mimir to conduct student-initiated research projects for the course. AS102 carries Natural Science Divisional Studies credit, and fulfills the laboratory requirement. Included in all previous AS102 classes was use of the CAS rooftop “teaching” observatory, but this was the first time that the AS102 class as a whole (not just honors students) were able to develop their own observational investigations (not “canned labs”) and use a professional-grade telescope to acquire their observations. The AS102 students operated the Perkins telescope and Mimir instrument, evaluated their data, and presented their findings via formal PowerPoint presentations over the course of two special sessions of the AS102 class. In addition, live Skype 2-way A/V links back to Boston allowed all members of the class to interact with the student observers as they conducted their observations on the Perkins telescope. Students on the field trip were also able to visit the Grand Canyon, Meteor Crater, and/or the Discovery Channel Telescope site. We are particularly pleased and proud that CAS Dean Virgina Sapiro was able to accompany one of the student groups on their field trip, and participated in the telescope observing and side trips with the students.

AS102 students with the Mimir instrument on the Perkins Telescope.

AS 102 students with Dean Sapiro in the Perkins Telescope control room, during observations with the Mimir instrument to conduct the research projects for the class.

AS102 students in the Phoenix Airport. One group of 6 students was headed home to Boston after completing their observations. The other group of 6 students was just arriving and headed up to Flagstaff to conduct their observations.

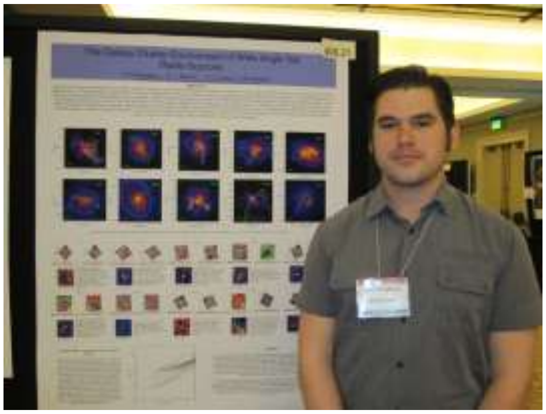
During FY11, 6 undergraduate Astronomy & Physics concentrators were engaged in research under the direction of research supervisors in the IAR.

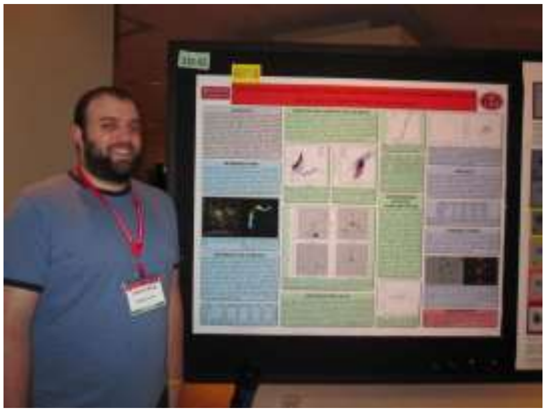
Graduate Education

During FY11, 21 graduate students carried out research in the IAR. Two of the IAR graduate students (Monica Young and Ingolfur Agustsson) successfully defended their PhD thesis in FY11.

The IAR sponsors weekly Astrophysics colloquia during the academic year, and associated with the colloquium series are the 2-credit graduate seminar courses GRS AS850 and AS851. In these seminar courses, the graduate students learn to read and critically evaluate manuscripts that have been published in the peer-reviewed literature. Generally, the manuscripts that are selected for the seminars relate directly to the topic that will be discussed by the speaker in the following week's colloquium (thought the speaker is usually not a co-author on the manuscript). One student is chosen to lead the discussion via a formal PowerPoint presentation, which is then followed by individual group and roundtable discussions of the manuscripts.

As is the case for undergraduate education, the use of the Perkins Telescope figures prominently in our graduate education mission. To date, approximately 45 graduate students have traveled to Flagstaff to observe with the Perkins Telescope. These include students enrolled in GRS AS710 (*Observational Astronomy*), and students who have used the telescope to acquire the data for their oral comprehensive exam projects and PhD dissertations.





Graduate students Josh Wing (left) and Ned Douglass (right) presenting their poster papers at the May 2011 meeting of the American Astronomical Society in Boston, MA.

Community Life

The IAR is a vibrant, collegial community within BU that is engaged in a wide variety of astrophysical research projects. The IAR believes that in order to build the strongest research program, it is extremely important to foster personal interactions, both within the IAR itself and within the broader community of astronomers. The most direct method by which the IAR accomplishes this is through the sponsorship of a colloquium series. During FY11, the IAR hosted 26 professional colloquia, 24 of which were delivered by astronomers from outside Boston University. Graduate students are encouraged to interact directly with the colloquium speakers by hosting lunch with the speaker, having their own private question-and-answer session with the speaker after the colloquium, and joining all members of the IAR at the BU Pub after the colloquium for lively exchanges of ideas. Senior members of the IAR interact directly with the colloquium speakers through private and "group" meetings during the visit, as well as hosting dinners for most of the speakers. Together with the Department of Astronomy, the IAR also sponsors refreshments after the Friday afternoon graduate Journal Club meetings. This provides a good opportunity for all graduate students in the Department (not just IAR students) to interact with each other and with their professors in a casual setting. In addition to the colloquium series and Journal Club, the senior members of the IAR usually gather for lunch once a week during the academic year. During these lunches, we conduct any necessary business discussions, and we also make an active effort to keep each other informed about the research projects that are being conducted in the IAR. The weekly lunches were suspended in Spring 2011 due to Professor Brainerd's sabbatical, but we expect that they will resume in AY11/12.

Outreach Activities

During the academic year, Prof. Marscher directed the senior thesis work of Clifton (C. J.) Masdea, a high-school student enrolled in the Boston University Academy. The study involved comparison of simulated light curves of a blazar with data of the blazar 3C 454.3, which exhibited dramatic changes in brightness across the electromagnetic spectrum in 2010. In Spring 2011, C. J. was highlighted as one of WCVB Boston's "A-Plus" high school students (see also Multimeda Information below).

In Fall 2010, Professor Tereasa Brainerd became a member of the science advisory board for Science for the Public (SftP; http://www.scienceforthepublic.org) and she gave one public lecture on Relativity that was hosted by SftP. SftP is a grass-roots organization in the Boston/Cambridge area that focuses on science literacy specifically for adults, not the usual K-12 audience. Each month, SftP hosts 1 to 2 public lectures by accomplished local experts in the fields of science and technology. The majority of the lectures are videotaped and are available on-line through SftP and WBGH Boston. During its first year of operations, SftP had a difficult time establishing a regular audience because of the need to switch venues every few months (Boston Public Library, Cambridge Public Library, Belmont Community TV facility). Because of its prime location on the Green Line, and because two BU scientists are members of the science advisory board (the other is Research Scientist Sushil Alimchandani, CAS Biology), it was decided that in FY12 the SftP public lectures will be held at BU in CAS Room 522. The next lecture will be held at 7:00pm on July 19 (Professor Andrew West, CAS Astronomy, *Big Science from Little Stars: Volkswagons of the Galaxy*). During FY12, Professor Brainerd will help to host the SftP lectures at BU, including a coffee and cookies social hour after each talk that will allow the public to ask questions of the speaker in an informal situation.

Over the past year Professor West was involved in a number of outreach activities, several of which focused on increasing diversity in astronomy. He was recently named co-chair of the Astronomy & Astrophysics Section of the National Society of Black Physicists (NSBP), served on the AAS Committee for the Status of Minorities in Astronomy, BU's Multicultural Advisory Committee and on the NSBP Astronomy & Astrophysics section's conference committee. Professor West also organized an Upward Bound course for the 2010 BU Upward Bound Math & Science summer program that was taught by a team of BU professors, postdocs and graduate students. In addition to his diversity efforts, Professor West led two "Star Nights" at Waltham Fields Community Farm in July 2010 and February 2011, served on the board of the Somerville Mathematics Fund scholarship organization, and assisted in a visit of a Waltham High School to the BU Astronomy Department.

Facilities and Physical Infrastructure

Lowell Observatory Partnership

For the past 13 years, the IAR has partnered with Lowell Observatory in the operation of the 1.8-m Perkins Telescope on Anderson Mesa, near Flagstaff, Arizona. Of the 262 nights that the Perkins Telescope was used in FY11, 138 were staffed by BU astronomers. As part of our partnership, the IAR developed two new instruments for the Perkins Telescope: Mimir, which operates at near-IR wavelengths, and PRISM, which operates at optical wavelengths. Updates on these instruments and their operation are given below.

A Memorandum of Understanding, signed by BU and Lowell, insures that our partnership in the Perkins Telescope will continue through July 2013. As in previous years, IAR astronomers continue to be entitled to 50% of the nights on the telescope, distributed equally over all phases of the moon. In 2009 Lowell entered into an agreement with Georgia State University that entitles the GSU astronomers to 25% of the nights on the Perkins Telescope. Although there is no direct agreement between BU and GSU to operate the Perkins Telescope (i.e., GSU’s agreement is solely with Lowell Observatory), the BU astronomers are excited to have this opportunity to work with new colleagues and to build new collaborations, some of which have already begun to yield interesting scientific results.

A major development in our partnership with Lowell Observatory occurred in Spring 2011, with Boston University agreeing to make a substantial financial commitment (of order $10M from Central Administration) so that we could become a major partner in the future operation of the Discovery Channel Telescope (DCT). The DCT is a new 4.3 meter telescope being built by Lowell Observatory, and is located 40 miles southeast of Flagstaff, AZ. When completed, the DCT will be the 5th largest telescope in the continental US, and will be a state-of-the-art facility for optical and near-infrared astronomy. The DCT is an excellent match to the science goals of many of the BU astronomers, which include large surveys and time-domain astronomy, amongst other things. Becoming a major partner in the DCT also allows us to capitalize on our strong, long-standing partnership with the astronomers at Lowell Observatory. In addition, the DCT provides excellent opportunities for interdisciplinary, cross-college participation (especially between CAS, SED, COM and ENG). The DCT is now nearing the end of construction, with completion of the telescope expected in late 2011. Very early ("shared risk") science operations are expected in late 2012, with full and stable operations expected in 2013-2014. Negotiations for access to the DCT by BU astronomers are currently in progress. The total number of nights that BU will be granted depends upon the final cost structure of the DCT, as well any facility-class instrumentation that BU astronomers provide for the telescope. However, at this time we expect that BU will ultimately acquire a full capital share of 40 to 60 nights per year on the DCT. This will be a vitally important "game-changer" for the BU astronomers who regularly use ground-based telescopes for their work, and helps to secure the ability of BU to attract significant federal funding for astronomical research, as well as to attract and retain the very best observational astronomers.

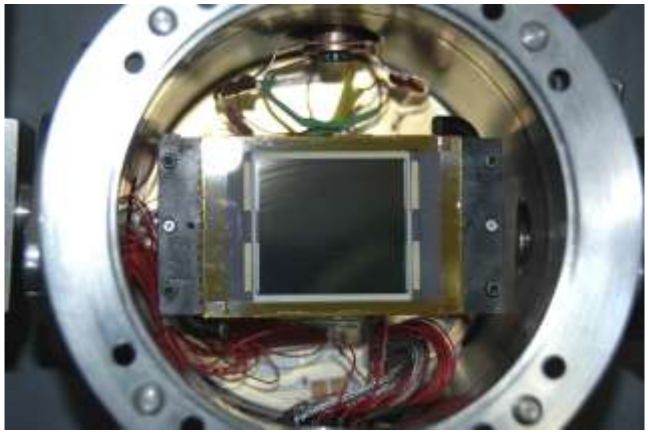
Instrumentation Program

The Perkins Re-Imaging SysteM (PRISM) is the primary instrument in use on the Perkins telescope for optical imaging, spectroscopy, and polarimetry. PRISM continues to work almost flawlessly. In FY11, PRISM was used on 192 nights at the Perkins, more than any other instrument, and over the past year almost 41,000 images were taken with PRISM. In the summer of 2010, a new CCD detector was installed in PRISM. The purchase of the new detector was funded mostly by the Mt. Cuba Astronomical Foundation. Additional funding was provided by the IAR, Georgia State University and Lowell Observatory. The new detector has an extremely smooth response across the field and reads out several times faster than the old detector. These qualities have increased the operational efficiency at the Perkins by a factor of almost 2. The only significant problems with PRISM at the moment are that there is a persistent noise source, and a gradient in the background noise level of the new detector. Also, we have not yet been able to correct the tilt of the detector, relative to the optical axis, so that it is not possible to get a good focus across the entire field. An engineering run has been scheduled for the end of June, 2011 to work on this problem.

The 1.8m Perkins Telescope.

In addition, a new grism ("grating prism") has been installed in PRISM to operate at the blue end of the spectrum. Initial tests indicate that the blue grism will operate very well. The dispersion of the new grism is about 1.2 Angstroms per pixel, giving a roughly uniform coverage from 3500 Angstroms to 6000 Angstroms. In the past year we also purchased a new set of "Sloan" broadband filters (u',g',r',i',z') for use with PRISM. The Sloan filters are becoming more and more standard for use in the community. Among other advantages, they will be used in several of the upcoming wide-field surveys, like that which will be done by the Large Synoptic Survey Telescope.

Mimir, the near-infrared imager, spectrometer, and polarimeter continues to operate well on the Perkins telescope, supporting a wide variety of science programs for BU, Lowell Observatory, Georgia State University, and outside visiting investigators. In FY12, Mimir was used on 116 nights. As of 06/24/2011, Mimir has operated at cold temperatures and deep vacuum pressures for 305 days (since its last warm servicing in summer 2010). Mimir science capabilities were enhanced in summer 2010 through acqusition of a new bandpass filter and a new half-wave plate for polarimetry. These were purchased either through a joint BU-GSU initiative (bandpass filter), or as a visitor contribution (half-wave plate; University of Minnesota - Professor Terry Jones). The new bandpass filter adds a new set of wavelength bands to Mimir's spectroscopic capabilities, enabling a new host of science programs, especially for very low mass and very high mass stars. The new half-wave plate doubles the number of wavebands for Mimir polarimetry, giving us the most sensitive K-band imaging polarimeter on the planet. Professor Terry Jones is using this new capability to study solar system comet scattered light to infer the physical properties of the dust in comet tails. The BU blazar group is using this new K-band polarization capability to study blazar variability and the structure of jets from galactic black holes. In addition to hardware updates, there was a major upgrade to the filter, slit, decker, and half-wave plate software. The new software provides an improved interface to the telescope control software and allows the positions of the various motors in the header to be stored.



The new science array for PRISM installed in the dewar.

In order to reveal the 3D details of the galactic magnetic field over all of the 76 square degrees surveyed by GPIPS, we need to determine distances to approximately 100,000 stars. Mimir can conduct the necessary spectroscopy of the stars, but currently it can only do so one star at a time, which is much too slow to meet the full 3D science goal. A new instrument, "Flexi", was proposed to the NSF in fall 2010 to be the telescope enhancement unit that positions many fiber optic cables across the telescope focal plane and routes those fibers to Mimir, boosting the spectroscopic throughput by a factor of 81. The Flexi+Mimir combination would enable numerous other exciting science projects, including studies of star clusters, galactic structure, and small satellite galaxy companions of larger external galaxies. This instrumental combination will also play a role in helping to boost the scientific harvest of the Discovery Channel Telescope. The initial offering of Flexi to the NSF/ATI program was not selected for funding in FY11, but it will be reproposed in the future.

First light image from PRISM with the new detector installed.

Multimedia Information

In Spring semester, WCVB Boston (Channel 5 news) visited Professor Blanton's AS203 class as part of a piece on C. J. Masdea, a high school student who was enrolled in her class. Footage from the visit that highlighted C. J. as a WCVB "A-Plus" student can be found at: http://www.thebostonchannel.com/video/27666135/detail.html

The public lecture entitled "Einstein's Relativity" that Professor Brainerd gave for Science for the Public in November 2010 can be found at: http://www.scienceforthepublic.org/?page_id=952

Professor Opher's work on the conditions at the outer edge of the solar system from the Voyager mission (NASA Research News, "A Big Surprise from the Edge of the Solar System" can be found at:
http://www.nasa.gov/mission_pages/voyager/heliosphere-surprise.html
http://www.nasa.gov/mission_pages/voyager/multimedia/20110609_briefing_materials.html

Looking to the Future

During the coming year, a major focus for many members of the IAR will be the integration of the DCT into our research programs. Although the DCT is at least 18 months away from its initial science operations, now is the time for the DCT user base to be deciding what the science priorities should be, and what instrumentation will be necessary in order to reach our science goals. Over the course of summer 2011, Professor Clemens will be running a series of instrumentation discussion groups that will enable us to sharpen our focus on the specific instrumentation needs, and to craft a concrete, multi-year plan for instrumentation development. During these sessions we will identify common interests (including scientific overlap as well as "techniques" overlap) that will allow us to make the most efficient plan for going forward with our use of the DCT.

In addition, the coming year is the prime time to establish the framework of the cross-college collaboration that will incorporate a substantial education and public outreach program into our work with the DCT. The IAR has already begun discussions with our colleagues in SED (Professor Donald DeRosa) and COM (Professors Ellen Shell and Douglass Starr) about working with our Lowell Observatory colleagues to expand and deepen Lowell's well-established, highly successful outreach program for middle school children on the local Navajo and Hopi reservations. In addition, we would like to bring a similar program that would include both science and social studies components to the Boston area. Initially, the Boston program is likely to be a summer program, but in the long run we hope to form "sister school" partnerships between the Native American and Boston schools. The central themes of the program as currently envisioned are "The Telescope as a Tool for Social Change" and "How Different Cultures See the Sky".

Professor Andrew West, who already has extensive accomplishments in public outreach and diversification, has expressed a strong interest in taking the lead on this initiative.

Lastly, we are looking forward to an internal science symposium on October 14, 2011 that will be hosted jointly by the Center for Space Physics and the IAR. The symposium will include short, formal talks and poster presentations that highlight all of the major research programs that are currently active in the CSP and IAR. The membership of both units has grown so large that it has been hard for any of us to keep pace with all of the ground-breaking work that is being done. This will be an excellent opportunity for all of us to appreciate both the breadth and depth of our recent accomplishments, as well as to identify potential new and exciting scientific collaborations with our colleagues.