Boston University

Institute for Astrophysical Research

The galaxy cluster Abell 2052 studied by Professor Elizabeth Blanton and collaborators

(Credit: X-ray (blue): NASA/Chandra X-ray Center/Boston U./E. Blanton; background visible image: European Southern Observatory/VLT)

Annual Report

June 2012

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, sponsoring regular seminars and occasional professional meetings, and actively engaging students of all levels in research. The primary research fields in which the IAR astronomers are involved include blazars and other active nuclei of galaxies, clusters of galaxies, the formation of stars, the gaseous and ionized interstellar medium, the evolution and magnetic activity of stars, extrasolar planets, magnetic fields, high-energy phenomena, dark matter, and the large-scale structure of the universe.

Executive Summary

In FY12 marked a very successful 14th year in the IAR's mission to foster research in astrophysics at Boston University. The scientific productivity of the IAR astronomers remained at a high level this year, and resulted in the publication of 44 scientific papers in the peer-reviewed literature and garnered significant interest in the popular media. In FY12 the IAR managed 24 active research grants, the total funding for which was $4.59M awarded to date. This represents an increase of nearly 19% over the previous year.

The IAR manages the use of Boston University's 50% share in observing time at the 1.83-meter-diameter Perkins Telescope of Lowell Observatory in Flagstaff, Arizona. This telescope is vital to the research of a number of IAR faculty, scientific staff, and students. The IAR will also play a key role in instrument development and astronomical research that will be carried out with the Discovery Channel Telescope (DCT) to be operated by Lowell Observatory with Boston University as a permanent partner. Commissioning of the DCT continues on schedule, so that early scientific observations should begin in late 2012.

Faculty, Staff and Leadership

Size and Organization

In FY12, the IAR personnel included 5 full professors (Thomas Bania, Kenneth Brecher, Dan Clemens, James Jackson, and Alan Marscher), 1 associate professor (Tereasa Brainerd), 3 assistant professors (Elizabeth Blanton, Merav Opher, and Andrew West), 1 professor *emeritus* (Kenneth Janes), 2 senior research scientists (Dr. Svetlana Jorstad and Brian Taylor), 3 postdoctoral associates (Dr. Jonathan Foster, Dr. Manasvita Joshi, and Dr. Saurav Dhital), 3 visiting researchers (Iván Agudo, Kevin Covey, and Kathleen Kraemer), and 1 full-time fiscal administrator (Xiomara Forbes followed by Alyson Savoie). In

addition, 21 graduate students and 6 undergraduate students were actively involved in IAR research programs.

Leadership

The IAR has a director, who reports to the Dean of the College of Arts and Sciences. Professor Alan Marscher began a 2-year appointment as IAR Director on July 1, 2011, while the previous director, Professor Tereasa Brainerd, became Chair of the Department of Astronomy.

Changes in Appointments and Staffing

Professor Kenneth Brecher officially joined the IAR in FY12. Professor Brecher is also Director of the Science and Mathematics Education Center at Boston University. Besides his research in high-energy astrophysics, we anticipate that Professor Brecher will participate in educational programs involving the new Discovery Channel Telescope.

Alyson Savoie joined the IAR as Fiscal Administrator in January 2012. She replaces Xiomara Forbes, who left in November 2011. Following discussions with the CAS Dean's office on staffing of the entire Astronomy/Space Physics/Astrophysics operation, the offices of the IAR and Center for Space Physics were consolidated into a single unit. The office manager is Assistant Director Despina Bokios. The team includes Proposal Development Administrator Amanda Rochette, also hired in FY12, as well as a work-study student. The transition to the combined administrative office was quite smooth. The team has done a remarkably good job meeting the needs of both units in the face of the myriad problems caused by the newly implemented BUWorks financial system.

Honors

Professor Marscher was selected as the second annual William H. Nelson Memorial Lecturer in at the Department of Physics and Astronomy, Georgia State University. He delivered the lecture "Black Holes Jets, and Gamma Rays in Active Galactic Nuclei" in Atlanta on April 10.

Related Professional Activities and Accomplishments

Professor Blanton was elected to a three-year term (2012-15) on the Nominating Committee of the American Astronomical Society. This committee selects a slate of candidates for the various officers of the society, which is the primary professional association of astronomers in North America.

Professor Clemens served as the Chair of the Board of Directors of the Associated Universities for Research in Astronomy (AURA) in 2011-12, and was elected to a second one-year term for 2012-13. 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 major commitment of effort by Prof. Clemens represents a key national leadership role serving the entire US professional astronomical community.

During the first half of FY12, Dr. Svetlana Jorstad, Senior Research Scientist, completed the last of her three years of service as a member of the Users' Committee for the National Radio Astronomy

Observatory (NRAO). The User's Committee advises the NRAO director and scientific staff on all aspects of observatory activities that affect the users of the telescopes. The committee meets annually.

Over the past year, Professor Marscher completed a three-year term as Chair of the Users' Group for NASA's Fermi Gamma-Ray Space Telescope. Fermi, launched in 2008, allows astronomers to explore the most enegetic environments in the universe. The Fermi User's Group was formed in order to represent the broad interests of the user community to the Fermi personnel and to NASA Headquarters. In FY12, Prof. Marscher's related duties included helping to compose a proposal to continue the operation of Fermi past its nominal five-year lifetime (i.e., beyond 2014), which he and a NASA scientist presented to the Senior Review panel of NASA's Astrophysics Division. The outcome of the review was favorable for continuation of the mission. Professor Marscher also taught at the Fermi Summer School, which provides training in high-energy astrophysics to graduate students and postdoctoral researchers, in June 2012 at the University of Delaware Marine Campus.

During 2011, 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. The decadal survey plays a vital role in shaping the future of space physics.

IAR members played a number of other important roles in service to the profession. These include reviewing proposals for observing time on telescopes, papers submitted to scientific journals, and funding proposals, serving as members on the scientific organizing committees of, and as session chairs at, scientific conferences, and providing data or training to colleagues and their students at other institutions around the world.

Facilities

The Perkins Telescope at Lowell Observatory

The IAR manages Boston University's 50% share of observing time on the Perkins Telescope, which is a reflecting telescope employing a mirror with a diameter of 1.83 meter (6 feet). The IAR director solicits proposals for observing time from members of the Boston University astronomical community. The

proposals are reviewed, with those that are approved being recommended to Lowell Observatory, where the schedule is drafted. There are often negotiations when multiple observers request overlapping time periods on the telescope.

The Discovery Channel Telescope

The agreement for Boston University to become a permanent partner with Lowell Observatory to operate the new Discovery Channel Telescope (DCT) was signed in October 2012. This will provide Boston University astronomers with guaranteed observing time on this world-class scientific facility. The Department of Astronomy will administer Boston University's role in the DCT. The IAR will be the primary unit for external funding of research projects that use the DCT.

The DCT is a reflecting telescope with a diameter of 4.3 meters, located at Happy Jack, Arizona, on National Forest Service land. This is a very dark site, which, in combination with the large light-collecting area of the telescope, will allow ultra-high-sensitivity observations of faint cosmic objects such as distant stars and galaxies.

The figure below shows the housing and the structure of the telescope, whose construction is finished and commissioning nearly complete.

The Discovery Channel Telescope in northern Arizona

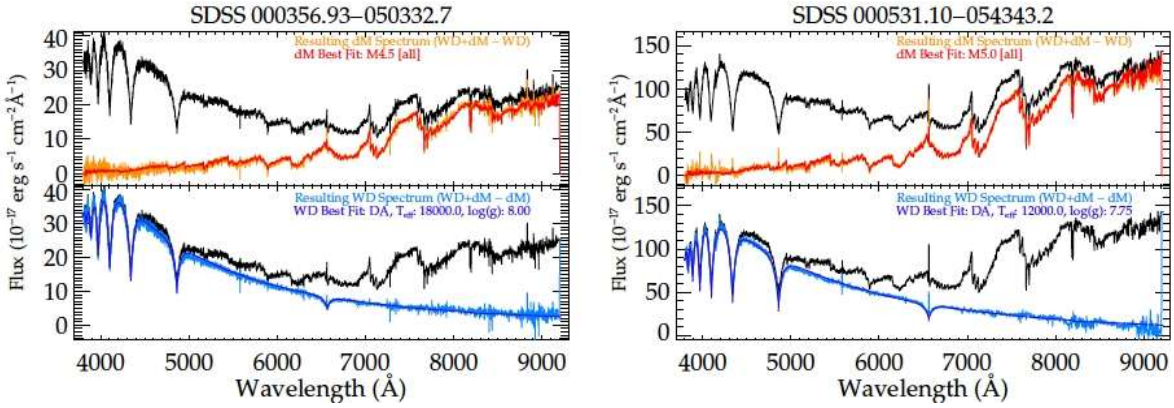
Research & Scholarship: Selected New Results from IAR Research

Observations of Spiral Gaseous Structure by Professor Blanton's Group Reveals "Sloshing" in Clusters of Galaxies

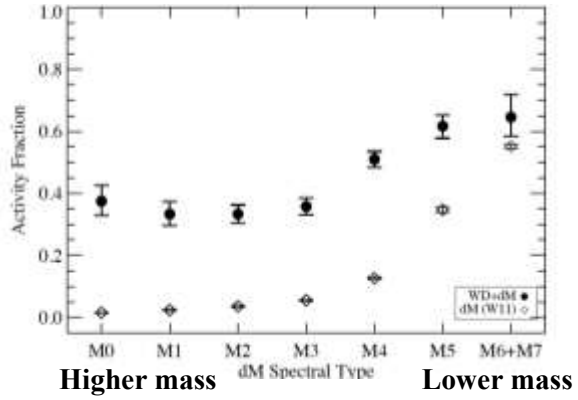
Professor Elizabeth Blanton, students, and collaborators discovered the first evidence of a "sloshing spiral" gaseous structure in the cluster of galaxies Abell 2052 (see the image on the front page of this report). In addition to hundreds or thousands of galaxies, clusters are filled with hot, X-ray-emitting gas. This gas can be set in motion if there is a large-scale merger between clusters or groups of galaxies. In the case of Abell 2052, an off-center merger of a smaller cluster with the main cluster imparted angular momentum to the hot gas, resulting in a spiral distribution. This huge spiral gaseous structure (almost a million light-years across) was discovered using a very long observation (approximately one week) with NASA's orbiting Chandra X-ray Observatory. The sloshing has important implications for the evolution of galaxies in the cluster. It redistributes hot, metal-rich gas to larger radii, and slows down the amount of star formation occurring in the cluster central galaxy. A press release entitled "A Galaxy Cluster Gets Sloshed" appeared in numerous news outlets, and the associated image was selected as a "NASA image of the day" and "National Geographic image of the week." Edmund Douglass, who received his PhD in Astronomy at Boston University in 2011, and is now an assistant professor at American University in Cairo, Egypt, co-authored the study.

Ground-breaking Studies of Stars by Professor West and Graduate Student Dylan Morgan

In the past year Professor Andrew West led a team of students and researchers, featuring the work of graduate student Dylan Morgan, that cataloged and analyzed more than 1700 close pairs of binary stars. These stellar pairs, selected from the Sloan Digital Sky Survey (SDSS), each consistis of an M dwarf (dM – less massive than the Sun) and a white dwarf (WD – the remnant core of a star that used up its hydrogen and helium nuclear "fuel") star. Such systems are important because the vastly different temperatures of the two components (10,000 K vs. 3000 K) allow for individual spectra of these unresolved objects (the stars are so close to each other they look like a single star) to be distinguished from each other. The team created an iterative technique that used spectra of the binaries to separate the WD and dM, and then analyzed the individual components. With the statistical foothold of more than 1000 objects, they were able to show that close companions induce more magnetic activity in the dMs than is typically found in single stars. Although this activity is stronger in binary than in single stars (and gets stronger as the pair separation decreases), it appears to have a finite lifetime that varies as a function of stellar mass. This result has major ramifications for our understanding of magnetic field generation in stars as well as the potential habitability of planets in orbit around low-mass stars.



Each panel displays distinct individual spectra of a dM star and companion white dwarf that are too close to separate in a telescopic image.



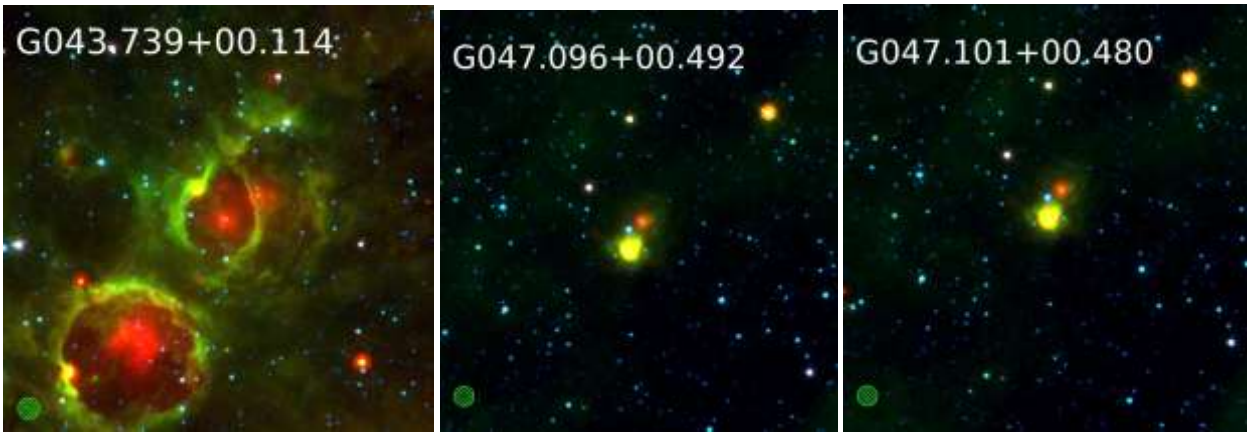
Graph demonstrating that the magnetic activity is higher in stars with lower masses when a white dwarf companion is present.

Finding Distant Ionized Gas Clouds and Using them to Explore our Milky Way Galaxy by Professor Bania and Collaborators

Stars with masses greater than ten times that of our Sun shine for only about 10 million years before they detonate in titanic supernova explosions that spew into space heavy elements forged by nuclear reactions in their cores. During their lives, massive stars ionize the gas that surrounds them, creating an ionized hydrogen (H II) region. Professor Thomas Bania, former BU graduate students Loren Anderson (an assistant professor at West Virginia University) and Dana Balser (a staff scientist at NRAO), and Robert Rood (University of Virginia, deceased) have used the Green Bank Telescope (GBT, operated by the National Radio Astronomy Observatory, NRAO), to discover previously unknown H II regions in distant locations inside our Milky Way Galaxy.

In order to detect fainter H II regions, Prof. Bania's team has migrated their H II Region Discovery Survey (HRDS) to the Arecibo Observatory (operated by the National Astronomy and Ionospheric), the largest radio telescope in the world (1000 feet in diameter). The technique that they employ is to search for hydrogen-recombination lines in the spectra of candidate H II regions that were beyond the reach of the GBT. This has led to the discovery of another 50 H II regions that are among the most distant H II regions found in our Galaxy. The survey, once complete, will allow Bania's team to probe an entirely new zone of the Milky Way for studies of how the chemical evolution of the Galaxy depends on distance from the Galactic Center. The elemental abundances of massive star-forming regions are the result of

billions of years of enrichment caused by the nuclear processing of many stellar generations. The new census of H II regions will provide targets for Galactic chemical evolution studies that will be made by the newly enhanced Jansky Very Large Array and the future Atacama Large Millimeter Array and James Webb Space Telescope.



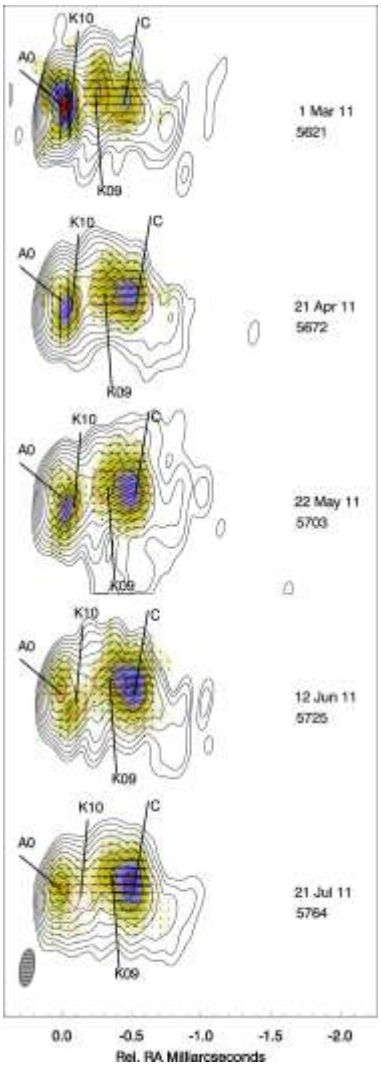
Spitzer Space Telescope images at infrared wavelengths of ionized hydrogen (H II) regions (appearing in red and yellow in these images) recently discovered by the multi-telescope survey carried out by Professor Bania's team. The different colors correspond to three different infrared wavelengths. The right-most two images contain the most distant H II regions observed thus far in our Milky Way Galaxy, lying at distances of more than 30,000 light-years from the Sun.

Probing the Ultra-high-energy Jets of Blazars across the Electromagnetic Spectrum by Professor Marscher, Senior Research Scientist Jorstad, and their Research Group

Blazars – the most extreme class of active nuclei of galaxies – are the most luminous long-lived objects in the universe. They contain supermassive (up to 10 billion times the mass of the Sun) black holes that accrete gas from the central regions of the host galaxy. The accreting hot, ionized gas swirls around the black hole, twisting magnetic fields into tightly wound spirals that form jets of ultra-high-energy charged particles and magnetic fields. The jets stream out of the nucleus at near-light speeds and emit radiation profusely across the entire electromagnetic spectrum, from radio waves to gamma-rays. Blazars are, however, extremely distant, and therefore appear extremely small and faint in the sky. In order to probe the jets, the group led by Professor Alan Marscher and Senior Research Scientist Svetlana Jorstad have developed a comprehensive program to monitor of changes in their brightness and polarization at microwave, infrared, visible, ultraviolet, X-ray, and gamma-ray frequencies. Their project involves monthly radio frequency observations with the Very Long Baseline Array (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 35 blazars, as well as optical polarimetric and photometric observations with PRISM and MIMIR on the Perkins Telescope. Graduate students Michael Malmrose, Nicholas MacDonald, Terri Scott, and Karen Williamson, and undergraduates Kelly Blumenthal and Adi Foord participate in the analysis of the data from these extensive observations. The data collected by the group are combined with observations by collaborators using numerous other telescopes around the world. The team also uses publicly available data from NASA's Fermi Gamma-ray Space Telescope 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 moving disturbances in the jet flow. The majority of outbursts of gamma rays occur many light-years away from the black hole as turbulent "blobs" of high-energy particles and magnetic field pass through stationary shock waves in the jet. This finding has overturned previous theoretical models that placed the events near the black hole.

The group observed a "mega-outburst" of radiation across most of the electromagnetic spectrum in the blazar 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. Prof. Marscher and graduate student Michael Valdez are modeling this behavior as turbulent plasma crossing a standing shock wave. They are developing a computer code to simulate the behavior of the emission both in brightness and polarization under this physical scenario, with promising early results. Postdoctoral associate Manasvita Joshi is developing another computer model that follows a different scenario, in which shells of particles and field collide inside the jet, producing moving shock waves that produce outbursts of light across the spectrum.



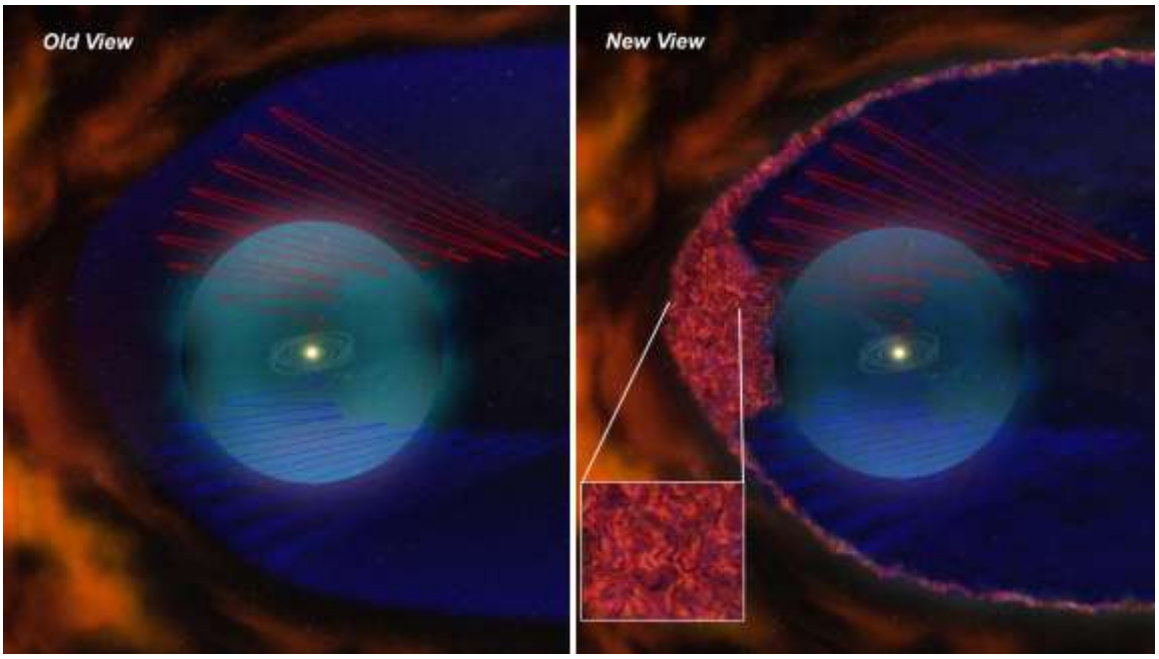
Time sequence of microwave images of the jet of the blazar 3C 454.3 that became the brightest source of gamma-rays in the sky in November 2010. The contours represent brightness (more concentric contours = brighter), while the color represents intensity of polarized emission. The line segments inside the image show the direction of polarization, which is perpendicular to the direction of the magnetic field. The black hole lies slightly to the left of the feature marked "A0," which is called the "core" of the jet and is stationary. Another bright stationary feature is marked "C." In between are two moving "blobs," K9 and K10. The latter was passing through the "core" when the mega-outburst of radiation was seen in November 2010. (K09 passed through the core during a less pronounced outburst in late 2009.) The ability of the Boston University group to locate the gamma-ray outburst in the core, light-years away from the black hole, represents a major breakthrough in the field.

Mapping of the Milky Way's Magnetic Field by Professor Clemens' Group

Professor Dan Clemens' research group is nearing the end of the data collection phase of the Galactic Plane Infrared Polarization Survey (GPIPS), which employs the Mimir instrument (constructed by Prof. Clemens and his group) on the Perkins Telescope. The observations should be finished by autumn 2012. 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. Mimir measures the polarization of starlight in many positions on the sky, which allows the team to infer the direction of the magnetic field in different locations in the Milky Way Galaxy. The GPIPS survey, the first of its kind, operates at infrared wavelengths, at which stars are less obscured by reflection and absorption by dust than at visible wavelengths.

A New Description of the Outer Boundary of the Solar System by Professor Opher's Group

Professor Merav Opher was featured in numerous news media for her group's pioneering work on the interface of the solar wind of charged particles and magnetic field emanating from the Sun with the gaseous medium beyond our solar system. The solar wind passes by the Earth and other planets, eventually reaching the interstellar medium of our Milky Way Galaxy. Prof. Opher's collaboration has found that the old picture of smooth magnetic field structures in the outermost solar system needs to be replaced by a more chaotic, "frothy" model.



Magnetic bubbles at the edge of the solar system: old and a new views. The red and blue spirals are the gracefully curving magnetic field lines of orthodox models. New data from Voyager add a magnetic froth (inset) to the mix. Credit: NASA. In a 2011 paper, Prof. Opher's team predicted that the magnetic field in the heliosheath within the sector is broken into magnetic bubbles. This radically changes how we envision this region of the solar wind and the boundary between the solar system and the interstellar medium of the Milky Way Galaxy.

Sponsored Grants and Contracts

In FY12 the IAR managed 24 active research grants. Nine new grants were awarded through the IAR totaling $736,609 in terms of funds that arrived in FY12. Including the out-year funding committed by the agencies for these grants, the total is $1,756,862. Funds in IAR grants awarded previously and continued into FY12 totaled $3,856,932. The total of new funds that actually were disbursed to Boston University in FY12 plus previous grant funding continuing into FY12 is $4,593,541. This represents an increase of $723,541 (almost 19%) over the same statistic reported in the FY11 IAR Annual Report. That this increase occurred during a year when federal funding was its most stringent in recent years implies that the research programs fostered by the IAR are extremely competitive on the national scale.

Major New Grant Activity

The new grants secured by IAR members include a search for new, very distant clusters of galaxies at infrared wavelengths with the Spitzer Space Telescope by Professor Blanton (sponsored by NASA through the Jet Propulsion Laboratory). Prof. West was awarded a three-year NSF grant to use binary dwarf stars to determine how the magnetic activity and rotation rate of a star depend on its mass. Another is a project by Prof. Jackson to use submillimeter-wave data from the Herschel Space Observatory to determine the temperatures of the dense cores of star-forming clouds of gas in the Milky Way Galaxy. Prof. Marscher and Dr. Jorstad were awarded over $400,000 in NASA grants to expand their program of comprehensive monitoring observations of blazars.

New Grants in FY 2012

Principal Investigator	Title of Project	Agency	Start date	End date	Funding to Date	Total Amount Awarded
Bania, Thomas	Deep GLIMPSE: Exploring the Far Side of the Galaxy	JPL[1]	8/22/2011	9/30/2014	$10,000.00	$10,000
Blanton, Elizabeth	A Targeted, Distant (z>0.7) Cluster Survey, Using Bent, Double-Lobed Radio Sources	JPL[1]	8/19/2011	9/30/2014	$67,060.00	$67,060
Jackson, James	Herschel Dust Temperatures of High-Mass Star Forming Cores	NASA	1/19/2012	1/18/2015	$100,953.00	$315,130
Jorstad, Svetlana	Identifying the Mechanisms of High Energy Photon Production in Gamma-Ray Blazars	NASA	1/27/2012	1/26/2013	$19,000.00	$19,000
Jorstad, Svetlana	Correlation between Gamma-Ray Variations and Disturbances in the Jets of Blazars	NASA	8/1/2011	7/31/2013	$96,962.00	$96,962

Marscher, Alan	Continued Comprehensive Monitoring of Gamma-ray Bright Blazars	NASA	9/1/2011	8/31/2014	$200,000.00	$600,000
Marscher, Alan	Thermal Emission from Hot Dust as a Source of Seed Photons for Producing Gamma-rays in Blazars	NASA	8/1/2011	7/31/2013	$100,000.00	$200,000
Marscher, Alan	Correspondence of X-ray and Submillimeter Variations in Bright Gamma-ray Blazars	NASA	4/25/2012	4/24/2013	$19,000.00	$19,000
West, Andrew	Using White Dwarf-M Pairs to Probe the Magnetic Activity and Angular Momentum Evolution of Low-Mass Stars	NSF	9/1/2011	8/31/2014	$123,634.00	$429,710

[1]JPL = NASA's Jet Propulsion Laboratory

Total funding disbursed in FY12 in new awards: $736,609
Total funding awarded in new awards: $1,756,862

Previous Awards Continuing in FY 2012

Principal Investigator	Title of Project	Agency	Start date	End date	Funding to Date
Bania, Thomas	Galactic Chemical Evolution: The 3-Helium Project	NSF	9/1/2007	8/31/2012	$318,603
Blanton, Elizabeth	Shocks, Ripples, and Bubbles: A Very Deep Observation of Abell 2052	NASA	4/8/2009	4/7/2012	$154,209
Blanton, Elizabeth	X-Ray Cluster Environments of Radio Sources	NASA	1/1/2010	12/31/2012	$328,470
Clemens, Dan	Completing the Galactic Plane Infrared Polarization Survey (GPIPS)	NSF	8/1/2009	7/31/2013	$896,560
Clemens, Dan	REU Supplement: Completing the Galactic Plane Infrared Polarization Survey (GPIPS)	NSF	9/1/2009	8/1/2013	$9,500
Goodrich,	NASA IPA Agreement	NASA	2/22/2011	2/21/2012	$181,616

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Jackson, Jim	NRAO GBT Student Observing Program (Susanna Finn)	NRAO	10/1/2010	9/30/2011	$20,000
Jackson, Jim	Infrared Dark Clouds	NSF	8/1/2008	7/31/2013	$649,151
Jackson, Jim	Determining Galactic Structures From 2Mass Data SED-Fitting Models	NASA	1/1/2009	13/31/2012	$326,002
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
Marscher, Alan	The Most Compact Regions of Relativistic Jets in Active Galactic Nuclei	NSF	7/1/2009	6/30/2013	$602,138
West, Andrew	Ultraviolet Magnetic Activity of Low-Mass Stars	NASA	9/1/2010	8/31/2011	$45,000
West, Andrew	Wide Low-Mass Binaries: Coeval Laboratories For Testing The Formation and Evolution of Stars	NSF	8/5/2009	7/31/2012	$54,753

Total funding in continuing awards: $3,856,932

Undergraduate Education

The use of the Perkins Telescope for professional-quality observations is an important part of our educational mission. To date, approximately 105 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 his senior work for distinction was Robert Marchwinski (CAS class of 2012). Rob's work on resolved mapping of the magnetic field in a galactic molecular cloud will be published in the August 20 issue of *The Astrophysical Journal*.

Prof. Clemens and his AS441 students on a sightseeing trip to the Grand Canyon during their visit to Lowell Observatory in Flagstaff, Arizona in Spring semester 2012.

For the past 8 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 2-4, 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.

AS441 students pose around the Perkins Telescope, equipped with Prof. Clemens' Mimir instrument, in March 2012.

During the 2011/2012 academic year, both the graduate course (AS710) and undergraduate course (AS441) class members were treated to special tours of the Discovery Channel Telescope (DCT), the new 4.3m Lowell Observatory and Boston University facility on Happy Jack. This is the last academic year for which mere tours will take place - beginning this next academic year, the students in these courses will conduct their observations using the new DCT facility, the support of which the Department and the Institute are deeply grateful to the University.

AS441 students in front of the new Discovery Channel Telescope in March 2012.

During FY11, six undergraduate Astronomy & Physics concentrators were engaged in research under the direction of faculty supervisors in the IAR. The IAR faculty consider this to be a very important component to our undergraduate majors program. Experience in world-class research is key to comprehensive preparation of our students for graduate school or post-graduation employment in the field. In return, undergraduate students support the research programs by helping to analyze the voluminous data obtained in the course of our research.

Graduate Education

During FY12, 21 graduate students carried out research in the IAR. Two of the IAR graduate students (Edmund Douglass and Susanna Finn) successfully defended their PhD dissertations in FY12.

The IAR sponsors weekly astrophysics colloquia during the academic year. Associated with the seminar series are a pair of 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 (although the speaker is usually not a co-author on the manuscript). One student is chosen to lead the discussion via a formal PowerPoint presentation before an audience of IAR faculty and students, 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.

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 FY12, the IAR hosted 24 professional colloquia, 21 of which were delivered by astrophysicists from outside Boston University. Graduate students are encouraged to interact directly with the colloquium speakers by attending 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 joining some of the speakers for dinner.

In order to foster greater internal communication of the research programs of the IAR, Center for Space Physics, and Center for Integrated Space Weather Modeling, an internal science symposium was held on October 14, 2011. The event, organized by Professor West and very well attended, featured oral presentations by the faculty and poster presentations by students and postdoctoral research associates. This provided an excellent opportunity for everyone involved 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.

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.

Outreach Activities

Members of the IAR are involved in a variety of activities that enrich the lives of people outside the profession of astronomy. Some of this occurs via press releases and other interactions with the popular media. As mentioned in a previous section, in FY12 Professors Blanton and Opher participated in press releases that garnered substantial national and international attention.

Groups of young members of the Hopi Indian community visit the Perkins Telescope at Lowell Observatory on a regular basis. This often occurs when a Boston University astronomer is observing at the telescope, as occurred multiple times in FY12. The children are provided with an explanation of the observing program and view images being constructed from the current observations with the telescope.

Professor Marscher has written a textbook on cosmology, *From Nothing to Everything: The Story of Our Universe*, an e-book that is available for free download from his research group's website, www.bu.edu/blazars. The website also contains mp3 recordings of his songs with science themes that he sometimes performs for his classes and at public lectures. Prof. Marscher and Dr. Jorstad also mentor an undergraduate student (from another university) participating in the NSF-sponsored Maria Mitchell Observatory summer student program. They provide the student with an observational research project and guide the student through the data analysis, interpretation, and presentation as a paper at the winter meeting of the American Astronomical Society.

Professor Blanton contributed to an on-screen video guide for a science museum exhibit entitled "Black Holes: Space Warps and Time Twists," which is on traveling display at numerous museums across the United States.

Professor West remains active in the Astronomy & Astrophysics Section of the National Society of Black Physicists (NSBP), the American Astronomical Society Committee for the Status of Minorities in Astronomy, and Boston University's Multicultural Advisory Committee.

In addition to the activities listed above, IAR members engage in numerous other forms of outreach. These include, for example, talking to school children, responding to email communications from school students, providing information to the media seeking advice on news items relating to astronomy.

List of Scientific Publications by IAR Members

Papers Published in Peer-Reviewed Scientific Journals
(Current IAR members are listed in bold-face type)

1. Agudo, I., **Marscher, A. P.**, **Jorstad, S. G.**, Gómez, J. L., Perucho, M., Piner, B. G., Rioja, M., Dodson, R., "Erratic Jet Wobbling in the BL Lacertae Object OJ287 Revealed by Sixteen Years of 7 mm VLBA Observations," *The Astrophysical Journal, Vol.* ***747*****, article id. 63** (2012).
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