

# The University of Wisconsin-Madison

## Department of Astronomy

*Madison, WI 53706*

This description covers the Department's activities from October 1, 2003, through September 30, 2004. It only refers to papers that were published within this period. It ignores research that is under way and papers that are in press or submitted.

Gallagher will assume full editorship of the *Astronomical Journal* on 1 January 2005, following his selection in May.

The Southern African Large Telescope (SALT) will undergo engineering tests in 2005. Its Prime Focus Imaging Spectrograph (Nordsieck, PI; Burgh, scientist) will be shipped to South Africa in early 2005. The Spitzer Space Telescope Legacy Science project GLIMPSE, a near-infrared imaging survey of the inner Galactic plane (Churchwell, PI), is producing excellent scientific results. Other major thrusts include studies of star formation, extragalactic structure and evolution, properties of interstellar and intergalactic gas, and studies of magnetized turbulence.

WIYN refers to the Wisconsin-Indiana-Yale-NOAO 3.5-m telescope on Kitt Peak. WHAM refers to the Wisconsin H-Alpha Mapper, a sensitive Fabry-Perot spectrometer operating on Kitt Peak. FUSE denotes the Far-Ultraviolet Spectroscopic Explorer, a satellite that provides spectra from 90 nm to 120 nm. HST is the Hubble Space Telescope.

The description of research that follows emphasizes the contribution of UW personnel, but in almost every case there are several authors from outside that have contributed in various amounts, often taking the lead in the project being described. Space and style do not permit a complete list of colleagues and collaborators for each project. The list of papers at the end of the report lists authors in the correct order in the published paper.

### **1 Personnel**

Dr. Andrew Sheinis accepted a position as Assistant Professor, to begin in Fall, 2005. He

was at Lick Observatory (Santa Cruz) and is interested in instrumentation and the nature of QSOs. Prof. Christopher Anderson retired at the end of the spring semester and was appointed Emeritus Professor. Linda Sparke completed three years' duty as Chair and was replaced in that capacity by John Hoessel. Barger and Lazarian were promoted to Associate Professor. The faculty consist of Professors Cassinelli, Churchwell, Gallagher, Hoessel (Chair), Mathieu, Nordsieck, Reynolds, Savage, Sparke, Zweibel, and Associate Professors Barger, Bershady, Lazarian, and Wilcots. Bless and Mathis are Professors Emeriti residing in Madison. Robert Benjamin is an Assistant Professor of Physics at UW-Whitewater and served in Madison as Program Director of the Summer Research Opportunities Program. Percival is a Scientist; Wakker, an Associate Scientist. Burgh, Haffner, Ignace, and Lehner were Assistant Scientists.

Kelsey Johnson went to the Univ. of Virginia as an Assistant Professor. D. Harbeck went to UC-Berkeley as a Charles Townes Fellow, and R. Indebetouw is at U. Virginia as a postdoctoral researcher. R. Ignace joined the faculty at East Tennessee State University. K. Stassun left for a faculty job at Vanderbilt University. B. Pichardo moved to a postdoctoral research position at U. Kentucky W. Harris left for a faculty job in the Department of Earth and Space Sciences at U. Washington. Orio is a Visiting Associate Scientist. J. Marché served as Lecturer.

Prof. Ron Reynolds received the Beatrice M. Tinsley Award of the American Astronomical Society, given on a worldwide basis every two years for research of and exceptionally creative or innovative character. Amy Barger received the David and Lucile Packard Fellowship for Science and Engineering.

Cassinelli was honored at a workshop entitled "Massive Stars: From Photospheres to V-infinity". Barger edited a book "Supermassive Black Holes in

the Distant Universe”, published by Kluwer Academic Press in its Astrophysics and Space Science Library series.

Bershadsky continues to serve as the Board Director of SALT, with Nordsieck as the Science Working Group representative. Wilcots and Sparke are on the WIYN Board of Directors. Barger is on the WIYN Science Advisory Committee. Mathieu continued as Director of the NSF Center for the Integration of Research, Teaching, and Learning. Reynolds served as Interim Director of the Space Astronomy Lab. Wilcots served as Wisconsin’s representative to the U.S. Square Kilometer Array Consortium and as a member of the International Science Advisory Committee of the SKA radio telescope project.

A. Fox received a University Teaching Assistant award. N. Homeier, now at Johns Hopkins University, presented a PhD thesis, “Behind Closed Curtains: The Hidden Population Of Massive Stars In The Milky Way”, supervised by J. Gallagher. G. Madsen’s PhD thesis (Reynolds, supervisor) was “An Exploration of the Heterogeneous Nature of the Warm Ionized Medium”. He continued at UW-Madison but has accepted a 2-yr NSF Mathematical and Physical Sciences “Distinguished International Postdoctoral Research Fellowship” at the Anglo-Australian Observatory, to begin in January 2005. A. Steffen presented his thesis “A Wide Field *Chandra* Survey of the Lockman Hole” (Barger, supervisor) and is now a postdoctoral fellow at Penn State. C. Watson presented his thesis “Hot Cores and Entrainment in Massive, Bipolar Outflows” (Churchwell, supervisor) and is an Assistant Professor of Physics at Manchester College in Indiana.

## 2 The Solar System

Anderson contributed to a kinetic model of the comae of comets. It examines the chemistry of OH, OI(<sup>3</sup>P) and OI(<sup>1</sup>D) in detail, and the role of these species in the destruction of CO and other molecules.

Reynolds, Madsen, and colleagues determined the kinematics of zodiacal dust by observing Mg I  $\lambda$ 5184 with WHAM. The orbits are eccentric and have a broad distribution of orbital planes. WHAM was used to monitor variations in the solar geocoro-

nal H $\alpha$  during the 1997 - 2001 solar cycle. It is about 45% higher at solar maximum than at minimum.

Gallagher began work on a program with W. Harris (U. Washington) to search for comets around a young star using FUSE to detect UV line absorption associated with cometary gas.

## 3 Stars and Novae

Cassinelli showed that the long-standing problem of supplying enough momentum to the strong winds of Wolf-Rayet stars is not solved by assuming optically thick clumps. The rate of mass loss is reduced, but the amount of momentum extracted by scattering the stellar radiation is reduced. He and others took into account the variations of mass loss rate with latitude for the magnetically torqued disk model for hot star disks. He and Ignace used the infrared free-free continuum of the Wolf-Rayet WR 136, plus the widths of several He II emission lines, to determine that the amount of clumping is small in the outer parts of the wind.

Cassinelli, Reynolds, and colleagues used the *Chandra* X-ray satellite to observe the emission lines in  $\tau$  Sco and Spica ( $\alpha$  Vir) from ions such as Ne IX and O VII. The lines of both are rather narrow rather than being Doppler broadened by the expansion of the stellar wind. The spectra suggest a production by shocks caused by instabilities in the winds.

A team including Gallagher found a linear relation between the equivalent width of the Ca II triplet absorption lines and [Fe/H] in red giants. No age effect is observed. The [Fe/H] = -0.56 for Trumpler 5, lower than about 0.3 dex from the color-magnitude diagram. The method is applicable to red giants in Local Group galaxies.

Ignace, Nordsieck, and Cassinelli studied the Hanle effect that involves the polarization of resonance line radiation scattered by atoms aligned by a circumstellar magnetic field. The effect diagnoses the field in the outer parts of typical hot star winds. For high surface fields, both the Hanle and Zeeman effects can be used.

Lazarian considered the superluminal ejections in microquasars (binary stars with a compact member and a relativistic jet) that might be caused by violent magnetic reconnection events during super-

critical disk mass accretion.

Tidal circularization of binary systems has been a major thrust in Mathieu’s research. He and students determined that the period of spectroscopic binaries below which the orbits are circularized in the old Galactic cluster NGC 188 is longer than in younger clusters. Contrary to theory, tidal circularization is more effective in solar-type main-sequence binaries for times longer than 1 Gyr than currently predicted by tidal models. The team also considered M35 and NGC 6819. Mathieu worked on precision astrometry from old plates of the open cluster NGC 188, using recent CCD Mosaic Imager frames to calibrate the optical distortions for various telescopes and field correctors. The method provided a new catalog of proper motions and positions for stars in the cluster. He used K-band imaging polarimetry to resolve T Tauri binary and multiple system stars and determine the relative orientation of the circumstellar disks. In the binary systems the disks tend to be parallel to each other. In multiple systems, the disk orientations are randomly oriented to the polarization angle of the widest pair. Contamination by interstellar polarization is problematic. AK Sco has been analyzed in some detail, including the structure of its dusty circumstellar disk and variable inflow and outflow.

Sparke and postdoc Pichardo used a new dynamical method to calculate the sizes and shapes of test-particle disks around stars in eccentric binary orbit, where the gravitational potential changes periodically in time. They found that the “observer’s recipe” of using the Roche lobe for a circular orbit at pericenter gives a good approximation to the size of the circumstellar disk. The circumbinary disks are significantly elliptical and off-center such that the inner edge of the disk keeps almost constant distance from the smaller star.

Stasson and Mathieu determined dynamical masses of pre-MS stars in a binary system in the Orion Nebula Cluster, 1.01 and 0.73  $M_{\odot}$ , to  $\sim 1\%$  accuracy. No theoretical models predict both luminosities simultaneously, although the mass-radius relationship is recovered. There seems to be inefficient convection within the stellar interiors.

Using the *Chandra* satellite, Stasson and Mathieu analyzed the X-ray properties of the pre-main-sequence stars in the Orion Nebula cluster. The  $L_X/L_{\text{bol}}$  is anticorrelated with the rotation rates.

Accreting stars show harder x-ray spectra but are not more luminous than the non-accreting objects, possibly because of attenuation by the circumstellar gas. The X-rays arise from the chromospheres, not from accretion.

Zweibel considered magnetic field evolution in neutron star crusts due to the Hall effect (dominant in isolated objects) and ohmic decay (dominant for accreting objects). The team gives expressions for the evolution of the field, both internal and external to the star, with several examples.

Orio used FUSE and HST to observe the spectrum of the dwarf nova EY Cyg during quiescence. The best models have a temperature of 22 kK,  $\log(g) = 9$ , and an accretion belt with  $T = 36$  kK. Photometry of the polar V1062 Tau showed two periods (orbital and spin), plus their beat period. There was an outburst of the object during the observations.

By means of the CN and CH band strengths, Harbeck determined the C and N abundances in the giant stars in three globular clusters. Depletions of C with increasing evolutionary state are evident. There seems to be an extra-mixing process during the later stages of ascent of the Red Giant Branch. He has investigated the C/Fe and N/Fe abundances of main sequence stars in the globular cluster 47 Tuc. The ratios are strongly anticorrelated and are similar to those in the giants. The results rule out simple surface pollution and suggest that substantial fractions of the stars’ masses are mixed.

Whitney and Indebetouw used 3D Monte-Carlo radiative transfer models to explore the effects of stellar temperature on the infrared spectral energy distribution of young stellar objects.

#### 4 The Interstellar Medium

The *Spitzer* Space Telescope’s legacy program GLIMPSE (Churchwell, PI) is very successful. The team includes local members Meade, Indebetouw, Watson, Mathis, B. Whitney (resident scientist), student Devine, and as well as others from several institutions. The project is a survey of the Galactic plane from  $|l| = 10 - 65^\circ$ ,  $|b| \leq 1^\circ$ , in the Infrared Array Camera filters at wavelengths of 3.6, 4.5, 5.8, and 8.0  $\mu\text{m}$ . The filters include emission from interstellar polycyclic aromatic hy-

drocarbon (PAH) features and hydrogen Br $\alpha$ . Papers have been accepted on results describing the massive star formation region RCW49 and showing fascinating images of fine filaments, pillars, knots, and bubbles of diffuse emission, as well as at least 300 stars with infrared excesses, presumably very young stars in the making, within the RCW49 region. Whitney and Indebetouw used 3D Monte-Carlo radiative transfer models to explore the effects of stellar temperature on the infrared spectral energy distribution of young stellar objects. Indebetouw and the team found that interstellar extinction is not very dependent on wavelength in both the field and in the RCW49 region. A tight cluster, probably a globular, was found in the Galactic plane.

Churchwell surveyed 6-cm emission from H<sub>2</sub>CO emission and absorption towards massive young stellar objects. The emission is confined to small regions. The team resolved the distance ambiguities and mapped the Galactic locations of 44 Galactic H II regions by H radio recombination line and H<sub>2</sub>CO measurements. Ignace and Churchwell explained the unusual power-law spectral slope of radio flux from hypercompact H II regions vs. frequency by optically thin clumps with little shadowing. The distribution of the optical depths of the clumps determines the spectrum. Sewilo and Churchwell found broad H radio recombination lines in six massive star formation regions, possibly broadened by several separate mechanisms. Churchwell performed high angular resolution observations on the “hot core” (thermal emission dominated by warm dust) object G29.96-0.02 and found a density and temperature gradients consistent with accretion onto a massive rotating disk.

Lazarian studied the cascade timescale and anisotropy of freely decaying strong MHD turbulence with by means of 3D numerical studies. His team considered stochastic reconnection in a magnetized, partially ionized medium. The speed of reconnection is determined by the ability of the ejected plasma to diffuse away from the current sheet structure. They find the turbulent cascade can extend to well below the viscous cutoff scale. The scalings and anisotropy of compressible magnetohydrodynamic turbulence were investigated by numerical simulations, with applications to cosmic ray acceleration of cosmic rays, gamma ray bursts,

and star formation.

With a 3D photoionization code, Mathis showed that the increase of some nebular line ratios with height above the Galactic midplane results from hardening of the ionizing radiation of the exciting stars by clumped gas, in excess of the increase from smooth gas density distributions.

The WHAM team (Reynolds, Haffner, Madsen, Percival, and others) published its survey of the distribution and kinematics of ionized gas in the Milky Way above declination  $-30^\circ$ . There are 37,565 spectra within 100 km s<sup>-1</sup> of the Local Standard of Rest, with  $3\sigma$  intensities  $\geq 3$  Rayleighs. Many intermediate- and high-velocity clouds are detected. This is a trove of information regarding the Diffuse Ionized Gas.

Savage and Wakker, using FUSE to study O VI in the Milky Way halo, found it in a plane-parallel patchy absorbing layer with an exponential scale height of  $\sim 2.3$  kpc, with an excess in the northern hemisphere. Approximately 60% of the sky is covered with high-velocity O VI, tracing outflowing material, accretion of gas onto the Galaxy, and tidal interactions with the Magellanic Clouds. In another study they find that Complex C, a high-velocity cloud far out of the plane of the Milky Way, has O/H  $\sim 1/6$  solar. Its D/H is consistent with the Wilkinson Microwave Anisotropy Probe measurement of the fluctuations of the cosmic microwave background combined with simple models relating metallicity and D/H. Simple photoionization models of Complex C fail to predict the distribution of its various stages of ionization. Possibly the cloud is interacting with a hot halo medium.

Lehner, Savage, and Wakker investigated the cooling of the diffuse gas using far-UV observations of C II absorption or emission with FUSE and HST in the spectra of 43 objects. On average, 50% of the cooling is in the warm ionized phase. For a cloud at  $\sim 1$  kpc above the galactic plane the cooling is a factor 2 lower than near the plane, and for two clouds  $> 5$  kpc from the plane the rate drops to 10% of that in the plane, similar to those in a sample of damped Ly $\alpha$  absorbers.

Using FUSE, Lehner and Howk (UC San Diego) studied O VI absorption toward four hot stars in the globular cluster NGC 6752. On spatial scales of 2 – 10 pc there are no detectable variations in the O VI column density and velocity distribution. The

hot gas with O VI is quite patchy at larger scales. Lehner and Savage are studying O VI toward white dwarfs 10 – 200 pc from the Sun, relating the amounts of hot gas to cool in order to test model predictions of their mixing.

Watson, with Zweibel and Churchwell, examined the Kelvin-Helmholtz instability in a shear flow of a stellar wind outflowing past partially ionized circumstellar material with an embedded magnetic field. There should be detectably narrower lines in ionized species tracing the outflow as compared to the neutrals. The field is not tangled by turbulence in the boundary layer.

Bethell, Zweibel, Heitsch, and Mathis calculated the radiation field and grain temperature within dark clouds illuminated from outside by interstellar radiation. The cloud is significantly brighter throughout most of its volume than it would be if uniform. Zweibel also determined the instability of a vertical magnetic field in a planar flow on elliptical streamlines, always unstable without a field. There is still instability, although with a slower rate of growth. Heitsch and Zweibel considered turbulent ambipolar diffusion and found that the turbulence rapidly diffuses the magnetic flux to mass ratio.

Indebetouw and others surveyed high stages of ionization (O VI, NV, and CIV) in the Galactic halo with FUSE and HST. These ions are produced by collisions in non-equilibrium gas by processes such as shocks or evaporative interfaces. No single model can explain the observations.

Weitenbeck published interstellar polarization data on stars obtained at the Pine Bluff Observatory during 1995-2003. Several cases are found for which the wavelength dependence is anomalous.

## 5 Extragalactic Astronomy and Cosmology

Barger surveyed the Hubble Deep Field (North) region at 850  $\mu\text{m}$ . The detected submillimeter sources account for 24 – 34% of the far-infrared extragalactic background light. The positions of  $\sim 60\%$  of the submillimeter sources were accurately located using deep radio and X-ray data. In addition, she participated in a deep multicolor survey of the field and measured the density of objects in the range  $3 \leq z \leq 7$ . She also obtained a large sample of spectroscopic redshifts for the

region of the field covered by the Hubble Space Telescope's Great Observatories Origins Deep Survey (GOODS)-North. She and student Steffen participated in a wide-area, deep, synoptic survey at X-ray (using the Chandra X-ray Observatory) and optical (using WIYN and the Japanese telescope Subaru) wavelengths of the "Lockman Hole-Northwest" field, where the Galactic HI emission is at a minimum. Many of the X-ray sources showed variability. They found a definite lack of luminous, high accretion rate sources at  $z < 1$ . She and student Steffen also constructed the hard X-ray luminosity function of AGNs at  $z = 0.1 - 1$  to determine the change of the relative fraction of AGNs with luminosity. Barger participated in a study of the evolution of the ultraluminous infrared galaxy population from nearby space to redshifts of 1.5 and found that the number of objects without clear AGN signatures varies as  $(1 + z)^7$ .

Bershady has been concerned with the Tully-Fisher relation between the masses of galaxies and the spread in velocity of various spectral signatures. He has discussed the scaling relations in barred and unbarred galaxies and how they relate to the virial properties. He and Andersen (MPI-Heidelberg) constructed the first "face-on" Tully-Fisher relation by measuring velocities fitted to the optical spectrum, using the integral-field echelle spectrometer on WIYN. The inclinations are as low as  $4 \sim 15^\circ$ . Asymmetries make an important contribution to the scatter in the T-F relation. Bershady conducted a spectroscopic study of compact blue galaxies with the HST, finding supergiant H II regions. He studied kinematics in the cores of low surface brightness galaxies in order to measure the inner slope of the dark matter distribution. Constant density cores and ones with  $r^{-1}$  profiles are consistent with the data. Noncircular and random motions make the determination of the inner dark matter slope difficult. He compared nearby H II galaxies in the far-UV, using HST, with blue compact galaxies in the near-UV and with  $z \sim 3$  luminous blue galaxies, all at the same rest-frame wavelengths. There are many similarities between the distant and local objects. The asymmetry of the images in the Hubble Deep Field North provides direct evidence for hierarchical galaxy assembly at  $z \sim 3$ .

Gallagher has engaged in programs with many

collaborators to determine the star formation history and age-metallicity relations in galaxies, using color-magnitude diagrams. They applied the method to IC 1613, a dwarf irregular, and found that the rate of star formation has been depressed in the last Gyr. The massive star clusters in NGC 1140 show that most of the star formation activity was induced 35 – 55 Myr ago, consistent with their spectral energy distributions. With WIYN, he performed a photometric survey of carbon stars in M31 and Cetus dwarf spheroidal galaxies. These objects are ancient, without substantial populations of intermediate-age stars. Photometry of bright clusters of stars in nearby starburst galaxies (especially NGC 6240) provides ages and metallicities, and therefore constraints on the star formation histories. With HST, Gallagher and Homeier investigated the small- and intermediate-scale structure and the fraction of mass in the ISM in a sample of local starburst galaxies, including the giant starburst M83. They could obtain a full budget for various ions and the mechanical energy input. The times of ongoing star formation are in the range  $10^7 - 10^8$  yr. The X-ray sources in starburst galaxies are preferentially located near but significantly displaced from the star clusters. Gallagher, Harbeck, and Grebel (MPI-Heidelberg) worked on the chemical evolution of dwarf spheroidal systems. Even the oldest display extended periods of star formation and evolve to gas-free stellar fossil galaxies. Their early period of formation may account for their metals content.

With B. Pritzl, P. Knezek (WIYN), and others Gallagher found that the dwarf galaxy HIPASS J1321-31, with a distinctive plume of red stars in its color-magnitude diagram, probably represents an episode of rapid star formation followed by relative quiescence that is unusual in galactic evolution. Reionization in early phases of the universe seems to have no clear effect on the star formation in nearby dwarf galaxies. NGC 1275, the central galaxy of the Perseus cluster of galaxies, is surrounded by  $H\alpha$  filaments that are also bright in X-rays, possibly due to conduction and mixing of hot and comparatively cool gas. There is a radio bubble seen as a hole in the X-ray emission, and further studies of the ionized gas kinematics are in progress.

Hoessel continued WIYN studies of Cepheids

in NGC 4395, determining a distance of  $4.0 \pm 0.18$  or  $4.3 \pm 0.3$  Mpc, depending on the choice of period-luminosity relationship. Hoessel and Gallagher examined short-period variable stars in the halo of M31. The RR Lyrae stars have lower metallicity than the average of the halo.

Nordsieck determined the wavelength dependence of the interstellar polarization toward globular clusters in M31. The relation was similar to that in the Galaxy, although suggesting somewhat larger grains.

Savage studied the structure of the dust above the plane of the edge-on spiral NGC 4217 with the HST. Some structures extend to 2 kpc and have masses of  $\sim 2 \times 10^5 M_{\odot}$ . The work to lift them is the energy output of several supernovae. Using the FUV satellite FUSE and the HST spectrograph STIS, Savage studied intergalactic absorption towards the QSO PG 1259+593 ( $z_{em} = 0.478$ .) The team achieved high spectral resolution and investigated 78 absorption line components, including heavy ions in four. From the O VI lines they find that a substantial fraction of the baryons in the local universe are in intergalactic gas.

With P. Erwin (IAC Tenerife), Sparke published images from Erwin's 2001 PhD thesis, showing that nuclear bars and disks are common in early-type barred galaxies. This shows that the light of the inner galaxy comes mainly from a flat disklike component, not from a round and dynamically "warm" bulge.

Sparke used near-IR, optical and HI data to study how the kinematics of Polar Ring galaxies fit into the Tully-Fisher relation. They appear not to fit the relation for normal spirals exactly, which may be related to the shape of the dark halos. However, it is surprising that these merger products fall anywhere close to the normal relation! She also used infrared images to show that the apparent bar in ESO 235-G58 is in reality an edge-on disk galaxy, surrounded by a polar ring of low surface brightness.

Wilcots surveyed Magellanic spiral galaxies in HI and found that four of 13 have confirmed neighbors, and only 2 that have their morphology affected by the neighbor. The interactions cannot be responsible for the lopsided morphology, which must be a long-lived characteristic. Wilcots and Wakker used HI emission and FUSE observations

of ionic absorption lines, from both hot and cool gas, to search for the intragroup ISM in two loose groups of galaxies. They detected a small mass of gas of rather loosely constrained extent.

K. Johnson, Indebetouw, Watson, and Kobulnicky investigated the young starburst in the Wolf-Rayet galaxy Haro 3 by radio and infrared imaging. There are very young star clusters. The mass associated with the starburst is  $\sim 10^6 M_{\odot}$ . Johnson mapped the radio spectral energy distribution of very young super-starclusters in Henize 2-10. The masses of ionized gas are relatively low and the pressures  $10^3 - 10^6$  times that in the plane of the Milky Way. Indebetouw and Johnson imaged infrared-selected compact H II regions in the Magellanic Clouds in radio continuum and found properties of star and cluster formation similar to those of compact H II regions in the Galaxy.

## 6 SALT, WIYN, and Instruments

**SALT:** The Southern African Large Telescope (SALT) is an 11-meter optical telescope modified from the Hobby-Eberly Telescope design, located in Sutherland, South Africa. Engineering and integration has proceeded during 2004, with commissioning scheduled to begin in late 2004 into early 2005. The dedication of the telescope is expected in November, 2005. Nordsieck (PI), Burgh, and Percival are completing the Prime Focus Imaging Spectrograph, the primary first-light instrument. It is scheduled to ship to Cape Town in January 2005, with acceptance and commissioning activities to commence directly thereafter. First-science is expected in early 2005.

**The GLIMPSE Legacy Science program** on the *Spitzer* Space Telescope satellite (Churchwell, PI) has completed 3/8 of its survey on both sides of the Galaxy center from  $|b| = 10^{\circ} - 65^{\circ}$ ,  $l = \pm 1^{\circ}$ . Images and photometry of stars are available in four filters centered at 3.6, 4.5, 5.8, and 8.0  $\mu\text{m}$ . A summary of the GLIMPSE Legacy Science program is in Benjamin et al. (2003, PASP, 115, 953), and several papers that have already been produced by the team are on the Web site at [www.astro.wisc.edu/sirtf/glimpsepubs.html](http://www.astro.wisc.edu/sirtf/glimpsepubs.html).

**The WIYN Bench Spectrograph upgrade** (Ber-shady, PI), with gains of factors of 3 in throughput, continues. A successful preliminary design review

has concluded, and optical design is nearing completion. The time scale for project completion is 1-1.5 years from the time of this report. The device employs volume-phase holographic (VPH) high-throughput, holographically produced transmission gratings.

**The halfwave polarimeter (HPOL)**, Nordsieck, PI, resided on the 0.9m telescope at Pine Bluff Observatory. HPOL obtained observations of Be stars, luminous red variables, hot supergiants, interacting binaries, Herbig Ae/Be stars, planets, comets, asteroids, novae, Wolf Rayet stars, symbiotic stars, and other objects. Broadband polarimetric results of HPOL observations are at [www.sal.wisc.edu/HPOL/](http://www.sal.wisc.edu/HPOL/).

**Star Tracker**, Percival, PI. The ST5000 tracker provides pitch, yaw, and roll control for sounding rockets, but can also do a full attitude determination without gyros for both sounding rockets and satellites. The ST5000 has been adopted by NASA's Sounding Rocket program and will replace the current complement of trackers. The ST5000 had a successful commissioning flight in April 2004. Two more commissioning flights are scheduled for late 2004 and early 2005.

**Spatial Heterodyne Spectrometer.** Reynolds and colleagues used their newly built Spatial Heterodyne Spectrometer at the Pine Bluff Observatory to detect for the first time diffuse interstellar [O II] 3726 and 3729 emission from the warm, ionized medium (WIM) extending out 20 degrees from the Galactic plane. These [O II] lines are a principal coolant for the WIM and a potential tracer of temperature variations within the gas.

## 7 Outreach

In conjunction with the African Studies Program and the Wisconsin Teacher Enhancement Program, the Department brought 10 South African science teachers to spend several weeks taking part in teacher enhancement programs on campus.

This summer, UW-Madison hosted another REU (Research Experiences for Undergraduates) program. A diverse group of ten students from around the country joined us for a summer of research. In 2002-4 we hosted 33 students with NSF and UW Graduate School funds; 42The program was directed by R. Benjamin. Pictures of the group and

the results of their research projects are on the REU website:

<http://wisp.physics.wisc.edu/reu>.

The eighth year of the successful Universe in the Park outreach program was directed by Wilcots. There were nearly 50 sessions at 27 state parks and forests throughout Wisconsin, reaching nearly 4000 people.

Mathieu is Co-Director the Center for Integration of Research, Teaching, and Learning (CIRTL), an NSF Center for Learning and Teaching project in collaboration with Michigan State University and Pennsylvania State University. Its mission is to produce a future science, technology, engineering and mathematics (STEM) college faculty that is effective in both research and teaching. The emphasis in the first year was the Delta Program in Teaching and Learning, comprising a suite programs at the University of Wisconsin in which STEM graduate students apply their research skills to the improvement of student learning. More on the CIRTL project can be found at [www.cirtl.net](http://www.cirtl.net) and on Delta at [www.delta.wisc.edu](http://www.delta.wisc.edu).

## 8 Publications

The following are the publications appearing in refereed journals or invited presentations to scientific meetings. Departmental members have their names in bold face.

Alencar, S.H.P., Melo, C.H.F., Dullemond, C.P., Andersen, J., Batalha, C., Vaz, L.P.R., **Mathieu, R.D.** 2003, "The pre-main sequence spectroscopic binary AK Scorpii revisited", *Astronomy and Astrophysics*, 409, 1037-1053.

Andersen, D.R., **Bershady, M.A.** 2003, "A Face-on Tully-Fisher Relation", *Astrophysical Journal*, 599, L79-L82.

**Barger, A.J.** 2003, "High-Redshift Galaxies". *Maps of the Cosmos*. IAU Symposium 216.

**Barger, A.J.** 2003, "The X-Ray Background", *Revisita Mexicana de Astronomia (Serie de Conferencias)*, 17, 226-229.

**Barger, A.J.**, Cowie, L.L., Capak, P., Alexander, D.M., Bauer, F.E., Fernandez, E., Brandt, W.N., Garmire, G.P., Hornschemeier, A.E. 2003, "Optical and Infrared Properties of the 2 Ms Chandra Deep Field North X-Ray Sources", *Astronomical Journal*, 126, 632-665.

Bellamy, M.J., Tadhunter, C.N., Morganti, R., Wills, K.A., Holt, J., Taylor, M.D., **Watson, C.A.** 2003, "Near-infrared spectroscopy of PKS 1549-79: a protoquasar revealed?", *Monthly Notices of the Royal Astronomical Society*, 344, L80-L84.

**Benjamin, R.A.**, and 19 colleagues 2003, "GLIMPSE. I. An SIRTF Legacy Project to Map the Inner Galaxy", *Publications of the Astronomical Society of the Pacific*, 115, 953-964.

**Bershady, M.A.** 2003, "Galaxy Formation and the GTC" (eds. J.M.R. Espinoza, F.G. Lopez, V. Melomartin). *Revista Mexicana de Astronomia y Astrofisica (Serie de Conferencias)*, 16, 203-208.

**Bershady, M.A.**, Andersen, D.R., Harker, J., Ramsey, L.W., Verheijen, M.A.W. 2004, "SparsePak: A Formatted Fiber Field Unit for the WIYN Telescope Bench Spectrograph. I. Design, Construction, and Calibration", *Publications of the Astronomical Society of the Pacific*, 116, 565-590.

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