# The University of Wisconsin-Madison
# Department of Astronomy

*Madison, WI 53706*

As in the past, the Astronomy Department at UW-Madison has been active in a wide range of observational and theoretical research programs. We are playing a major role in the Southern African Large Telescope (SALT) consortium that is constructing a 10-meter optical telescope located at the Southern African Astronomical Observatory site in Sutherland, South Africa. Our efforts are described in §**??** below.

Another major thrust of the department comes from the award of one of the six Legacy Science programs of the Space Infrared Telescope Facility (SIRTF), an 0.85-m telescope in solar orbit, to be launched in early 2003. The UW project, called GLIMPSE (Galactic Legacy Infrared Mid-Plane Survey Extraordinaire), has Churchwell as PI with a team of 15 scientists from 7 institutions. It will be responsible for imaging the inner 2/3 of the Galactic plane, $|b| \leq 1^{o}$, with a spatial resolution of $\sim 2''$, resulting in a catalog of sources ($\sim$99.5% reliable), a database of sources of $\geq$ 98% reliability, and images in the 3 – 8 $\mu$m region. The survey will require 400 hours of telescope time.

## 1 Personnel

The Department was saddened by the death of Emeritus Professor Albert E. Whitford (1905 – March 28, 2002), From 1948 to 1958 he served as Chair of the Department. He was Director of Lick Observatory and Professor (later Professor Emeritus) at UC-Santa Cruz from 1966 to 1996. He then returned to Madison, where he continued his interest and active participation in Astronomy.

Faculty are Professors Cassinelli, Churchwell, Gallagher, Hoessel, Mathieu, Nordsieck, Reynolds, Savage, and Sparke (Chair), Associate Professors Bershady and Wilcots, and Assistant Professors Barger and Lazarian. Bless and Mathis are Professors Emeriti residing in Madison.

Percival is Scientist and Associate Director of the Space Astronomy Laboratory as well as Project Manager for the Prime Focus Imaging Spectrograph on SALT. He continued his participation in the IAU Working Group on Astronomical Standard's initiative "Standards of Fundamental Astronomy" and in the AAS Working Group on Astronomical Software's FITS committee. Harris and Wakker are Associate Scientists. Burgh, Cho, Haffner, and Indebetouw are Assistant Scientists. K. Stassun is a Hubble Fellow and K. Johnson an NSF Postdoctoral Fellow. In September, 2002, Richard Ignace joined the Department as an Assistant Scientist collaborating with Nordsieck, Cassinelli, and Lazarian. Helen Bryce and R. Safako are Research Associates.

Marc Verheijen (McKinney Fellow) accepted a postdoctoral position at the Astrophysikalisches Institut Potsdam. Henry "Chip" Kobulnicky accepted a faculty position at the University of Wyoming. Philipp Richter is at the Arcetri Observatory in Florence. Sydney Barnes left to join the staff at Yale University. M. Orio is Visiting Associate Scientist. Dr. Jordan Marché served as Lecturer during the academic year. Many scientists visited during the year, including Dr. Luis Aguilar (UNAM, Ensenada, Mexico), who is spending his sabbatical year in residence.

J. Hoffman presented a PhD thesis (Nordsieck, supervisor) involving a Monte Carlo radiative transfer model of the polarization signatures arising from binary star-disk systems, developed in collaboration with Nordsieck and Whitney.

N. Miller received the PhD degree with a thesis entitled "Understanding the High Resolution X-Ray Spectra of Early Stars", supervised by Cassinelli. He is now on the faculty of UW-Eau Claire.

Dr. Amy Barger is the recipient of the 2002 Pierce Prize of the AAS for her contributions to extragalactic astronomy and was awarded a Sloan Fellowship in 2002. Churchwell became the Albert E. Whitford Professor of Astronomy in Jan. 2002. He continues to serve on the Visitors Committee of the Arecibo Observatory and to lead the SIRTF GLIMPSE Legacy Science team. Sparke became a Scientific Editor for the Astrophysical Journal in January 2002.

Gallagher continued as Director of the Antarctic Astronomy and Astrophysics Research Institute within the university, which coordinates activities of the Ice Coring and Drilling Service with the AMANDA high energy neutrino observing facility and the developing IceCube project. Bershady continues to serve as the UW SALT Board Director; Nordsieck is the Wisconsin SALT Science Working Group representative; and Wilcots leads the collateral benefits effort.

Mathieu became Principal Investigator of a five-year, $10M grant from the NSF to develop the Center for the Integration of Research, Teaching, and Learning (CIRTL), in partnership with Michigan State and Penn State Universities. The aim is to help graduate students and faculty develop teaching skills that match their research skills, so that all college students may become more scientifically literate.

## 2 Stars, Outflows, and Galactic Structure

Anderson, with Glinski (Tennessee Tech), used the 3.5-m WIYN telescope to observe the features near 5800Å in the nebulosity around HD44179 (the "Red Rectangle"). The observations contradict the hypothesis that the same molecule may be the carrier of these

red bands and the Diffuse Interstellar Bands.

Miller, Cassinelli, Waldron, MacFarlane, and Cohen (Swarthmore) analyzed the high resolution X-ray observations of $\delta$ Ori using the Chandra Satellite. Miller's Ph.D. thesis was an analysis of Chandra observations of six stars that show clearly resolved line profiles of ions ranging from N VII to Fe XVII. Ratios of lines from He-like ions provide the locations of the X-ray sources from the center of the star.

Miller and Cassinelli investigated X-rays from $\tau$ Sco (B0 V), using Chandra made by a team headed by Cohen and XMM observations of Mewe and others at Utrecht. The lines are narrower than expected from prior models of the wind plus shocks in the star. A differential Emission Measure analysis indicates temperatures as high as about $4\times10^7$ K. the results support the Howk, Cassinelli, Bjorkman and Lamers infalling clump model that was published in 2000.

Ignace, Quigley and Cassinelli studied the velocity distribution of the wind of the Wolf Rayet star WR 136 (WN6) using the ISO spectrum of infrared He II recombination lines. In this waveband the radius of continuum location increases with wavelength, so that lines at longer wavelengths tend to be broader in width. No clumpiness is needed to account for the line profile or continuum emission.

Cassinelli, John Brown (Glasgow), Maheswaran (UW-Marathon County), Miller, and Telfer (Glasgow) completed their long study of the formation of Be star disks. They developed the "Magnetically Torqued Disk" (MTD) model in which magnetic fields embedded within the star both add angular momentum to the outflow and direct it to the equator where it forms a shocked compressed disk. This explains how Be stars can have disks that are Keplerian and with minimal radial expansion, which were problems with the Wind Compressed Disk model of Bjorkman and Cassinelli (1993). The MTD model requires unacceptably large fields when applied to early O stars, but needs very reasonable fields ($\sim$300 G) when applied to stars of spectral class B2, the spectral class at the peak of the Be star distribution.

Undergraduate student Moeckel, Cho, and Cassinelli carried out an analysis of the X-rays from bowshocks in stellar winds, particularly for the B0 V star$\tau$ Sco, which shows evidence for infalling clumps. The X-rays show an overabundance of both hard and soft X-rays relative to a planar shock. Undergraduate student Mendygral and Cassinelli used Kurucz stellar atmosphere models to compute the Eddington Limit upper boundary for cool stars in the HR diagram. For hot stars the results agreed with the Ulmer and Fitzpatrick (1998) upper boundary, which lies near the Humphreys Davidson empirical limit. For cool stars the opacity is well below the fully ionized electron scattering value, so the boundary of the Eddington limit (where the radiation pressure equals the inward force of gravity on the atmosphere) is well above the Humphreys Davidson limit. Stars could reach this "Cool Apex Zone" in the HR diagram either in the collapse of the early generation of very massive stars or during outbursts of Luminous Blue Variable stars.

Gallagher, Orio and Harbeck (MPI-A, Munich) observed the outburst of the peculiar variable star V838 Mon. The structure of the variable nebula is consistent with a time-delayed reflection of the brightening of the central star.

M. Halverson completed a master's thesis under Gallagher's direction of the "equatorial" moving wisps around the Crab pulsar using WFPC2 images obtained by J. J. Hester (Arizona State) and collaborators.

Hoffman, with Nordsieck and Whitney (Sp. Sci. Inst.) used Monte Carlo methods to model of the polarization signatures of binary star-disk systems. They used the model to investigate the characteristics of the accretion disk in the interacting binary star $\beta$ Lyr, and found that it must have a small V-band albedo and be geometrically thick, with an optical depth that is large near the disk midplane but decreases toward the polar regions.

Hoffman and Nordsieck continued their study of the PMS binaries BM Ori and MWC 1080. Their analysis of polarimetric observations taken with HPOL at WIYN suggests that the observed polarization variations in such systems may be largely random and not due to binary orbital motion. Their results suggest that that young binary systems do not show repeatable polarization behavior. More concerted efforts to observe complete cycles with more accurate polarimetric measurements are needed.

Hoffman and Whitney are currently modeling the polarization of the luminous blue variable eta Car. Their work tests the polarimetric consequences of popular models for the shape of the homunculus and will be able to constrain the optical depth and the characteristics of the scattering dust grains in the lobes.

Barnes, Hole, Meibom, and Mathieu continued their program acquiring high-precision stellar radial velocities with the WIYN telescope and Multi-Object Spectrograph. As part of the WIYN Open Cluster Study (WOCS), they have obtained 5612 velocity measurements of 511 stars in NGC 188, 4097 measurements of 1116 stars in M35, 2021 measurements of 354 stars in NGC 2264 and 3694 measurements of 940 stars in NGC 6819. The number of spectroscopic binary orbit solutions is steadily increasing in each cluster, with orbital solutions for nearly 70 binaries in NGC 188, the most extensively observed cluster. As a post-doctoral scientist, Dolan developed and commissioned a java-based database allowing flexible access to all WOCS data.

Mathieu, Carr (NRL), and Najita (NOAO) continued a program at the Keck Observatory of high-resolution near-infrared spectroscopy (CO fundamental and overtone transitions) in order to explore the circumstellar gas in both young binaries and single stars. They have shown that the CO transitions are extremely sensitive tracers of disk gas. As such they have expanded their program from binaries to single stars in order to study the history of disk dispersal to later stellar ages than near-infrared continuum emission.

Meibom began his dissertation work with Mathieu studying tidal interactions in close binaries using the extensive WOCS compilation of spectroscopic binary orbit solutions in the open clusters M34, M35, NGC 2264 and NGC 6819. Specifically, he has used the WIYN 0.9m telescope to obtain time-series photometry for the purpose of measuring rotation periods of stars in the open clusters M34 and M35, to be combined with existing rotation periods in NGC 2264. For those stars in spectroscopic binaries he will be able to determine the degree to which the systems are tidally synchronized (or pseudosynchronized) as a function of orbital separation and age. The result will be an empirical calibration of the tidal synchronization timescale, a new approach to constraining tidal evolution theory.

Hubble Fellow Stassun and Mathieu continued an observing program to discover and analyze new low-mass pre-main-sequence (PMS) eclipsing binary (EB) systems in order to test and calibrate PMS stellar evolutionary models. They were awarded the first community program to use the High Resolution Spectrograph on the Hobby Eberly Telescope to determine the component masses of a newly discovered EB system in Orion. With Vaz (UFMG, Brazil), they are comparing the empirically determined positions of these stars on the H-R diagram to those predicted by various PMS stellar evolutionary tracks. They have a large program on the Gemini South telescope to study a newly discovered EB that promises to yield the first empirical masses of PMS stars at the stellar/sub-stellar boundary. With Barsony (JPL) and Ardila (Berkeley), Stassun is analyzing archival Chandra data to characterize the relationship between X-ray emission and stellar rotation among PMS stars in Orion.

## 3 The Interstellar Medium

Churchwell, with Kurtz (UNAM), Araya & Hofner (U Puerto Rico), and students Watson and Sewilo, surveyed UltraCompact (UC) HII regions located in the inner Galaxy in order to resolve the ambiguity in distances arising from combining radial velocities and models of Galactic rotation. They simultaneously observed H110$\alpha$ in emission and the $H_2CO$ (111-110) line in absorption to establish the possible distances (near and far). The plan is to observe as many UC HII regions as possible in the GLIMPSE survey area ($10^o \geq |l| \geq 66^o$ and $|b| \leq 1^o$). The region $l$ = 30–70$^o$ has been completed. Distances were determined, using the Arecibo Telescope, by Araya, Hofner, Churchwell, and Kurtz (2002) for about 20 sources and for an additional 45 by Watson, Araya, Sewilo, Churchwell, Hofner, and Kurtz (2003). Observing time has been scheduled on the Green Bank Telescope to continue this program to complete the northern galactic plane in the GLIMPSE survey area, $l$ =10$^o$ to 30$^o$. A proposal is in preparation to use the Australian Telescope Compact Array to observe sources in the southern half of the GLIMPSE survey. Fish, Reid, Wilner, and Churchwell (2002) have also used H I absorption line measurements to resolve distance ambiguities for 20 sources in the northern galactic plane.

As part of his PhD thesis, Watson obtained CO and $HCO^+$ images for a selection of UC HII regions to determine the physical properties of their outflows. A main thrust of this work will be to determine if magnetohydrodynamic (MHD) entrainment is responsible for the large mass contained in massive protostar bipolar outflows.

Sewilo, Churchwell, Goss, and Kurtz (2003) have begun a study of hypercompact HII regions to determine their nature and evolutionary niche in the formation of massive stars. These intriguing objects are about 10 times smaller and ∼100 times more dense than UC HII regions. They have rising spectral indices from short cm to mm wavelengths, and often have unusually broad radio recombination lines (FWHMs ∼45 km s$^{-1}$). The thrust of the Sewilo et al. study is to localize the positions of the broad lines using the VLA and ultimately to determine what fraction of the line widths are caused by gas dynamics versus pressure, turbulent, and thermal broadening. This study is part of Sewilo's PhD thesis.

Watson, Churchwell, Pankonin, and Bieging (2002) have completed a high spatial resolution study of the W75N massive star formation region using the BIMA Array. Methyl cyanide was imaged at 3 mm both to isolate the source of the molecular emission and to determine physical properties of an apparently emerging massive protostar.

Fox, Savage, Wakker, Richter, Tripp (Princeton) and Sembach (STScI) have studied highly ionized gas in the high velocity cloud (HVC) Complex C. They have been analyzing absorption line profiles from FUSE and STIS to investigate the kinematic relationship between high and low ion absorption in HVCs. Along the PG 1259+593 sight line, the observed high ion column density ratios and coincidence in velocity of high and low ion absorption are consistent with the production of O VI in a conductive interface between the neutral HVC and a hot surrounding medium. They will continue to search for additional examples of directions where conductive interfaces are present. Fox and Savage are investigating highly ionized gas in different environments near the Galaxy, particularly flowing away in the form of positive velocity "wings". Recently discovered in O VI, the nature, origin and location of these wings are all currently unknown.

Fox, Savage, and others have completed their study of the highly ionized gas absorption toward the star HD 116852, an O9 III star lying ∼1.3 kpc from the Galactic plane in the inner galaxy. Using observations from FUSE and STIS of O VI, N V, C IV, and Si IV absorption, they find evidence for three distinct types of highly ionized gas in the ISM. One type of gas traced by Si IV and C IV is photoionized and warm. Another type appears to be associated with highly ionized absorption formed in conductive interfaces between warm gas and hot gas. The third type of gas produces broad collisionally ionized hot components to the absorption seen in C IV, N V, and O VI. This gas type could be explained by radiative cooling.

Gómez (with Cox and Benjamin from Physics) con-

tinues modeling the flow of the ISM into a spiral arm with a 3D MHD model. They are calculating synthetic observations of the Milky Way for comparison with existing and future observations. They expect to find observational signatures of non-circular and large scale vertical motions in observations of the Milky Way and other spiral galaxies. Such vertical motions have already been observed in NGC 5427.

Halverson completed a master's thesis (Gallagher, supervisor) regarding the "equatorial" moving wisps around the Crab pulsar, using WFPC2 images obtained by J. J. Hester (Arizona State) and collaborators.

Lazarian, Cho, and students Yan and Esquivel made substantial progress in obtaining insight into properties and consequences of the ISM turbulence from theoretical, numerical, and observational points of view. They discovered a new regime of MHD turbulence below the scale at which viscosity truncates the ordinary turbulent cascade. Cho, Lazarian & Vishniac (JHU) predicted and numerically confirmed that magnetic turbulence exhibits previously unknown properties and that the ambipolar diffusion does not stop turbulent cascade from propagating to smaller scales. Using these results, they found high magnetic reconnection rates within the CNM (Cold Neutral Medium) and thereby conjectured that reconnection may be an important means of removing magnetic flux from molecular clouds, which would be very important for star formation processes.

Cho & Lazarian investigated compressible turbulence, obtaining the scaling properties of fast, slow and Alfvenic modes through simulations. They, with Yan, applied the new scaling relations to the dynamics of charged interstellar dust grains and cosmic rays. Their results significantly change understanding of the dynamics of both cosmic rays and dust.

Lazarian and colleagues studied turbulent cascade when the sources of turbulence are localized both in time and space, as is the case in the actual ISM, resulting in a description of properties of the so-called imbalanced cascade. Alfvenic turbulence may spread much farther from its sources than previously believed. They are studying the effects of turbulence on heat conduction and the dissipation of beams of MHD waves.

Lazarian continued to consider the Velocity-Channel-Analysis (VCA), proposed earlier with Pogosyan (U Calgary), used to analyze observational data (e.g., H I) to extract the underlying velocity and density statistics. Data cubes from MHD simulations are used to create synthetic observational data. VCA recovered the statistics of the input turbulence in spite of the effects of noise, magnetic field and shear. This result makes earlier results on turbulence in Small Magellanic Clouds obtained by Stanimirovic and Lazarian more trustworthy.

Turbulence determines the statistics of the Galactic emission on small scales, acting as a foreground contaminant for Cosmic Microwave Background (CMB) studies. Assuming that the underlying turbulence has MHD nature, Cho & Lazarian provided predictions for synchrotron emission and polarization as well as the polarization from Galactic dust. Their results are compatible with the available foreground data.

Nordsieck's halfwave polarimeter (HPOL) resided on the 0.9m telescope at Pine Bluff Observatory and observers, including several undergraduates, obtained 243 observations of 108 distinct targets over the course of 100 nights between Oct 1, 2001 and Sept 30, 2002. Specific areas of interest are: interacting binaries, Be stars, ISM probes, AG Dra, AeBe stars, and LRV stars. Broadband polarimetric results of HPOL observations are listed on the HPOL website: www.sal.wisc.edu/HPOL. Anderson & Weitenbeck (UW-Baraboo/Sauk County) and undergraduate Halstead continued making polarimetric observations with HPOL at PBO in the region of NGC1502.

Hausen, Reynolds, and Haffner used the Wisconsin H-Alpha Mapper (WHAM) to measure the [O I] 6300/H$\alpha$ intensity ratios in four O-star H II regions. They found ratios that are approximately a factor of ten lower than the ratios in the fainter, lower density warm ionized medium (WIM), suggesting that the WIM has a significantly lower hydrogen ionization fraction or a higher electron temperature than that in classical H II regions.

De Oliveira-Costa (U. Penn.) et al., Haffner and Reynolds carried out a comparison of the WHAM H$\alpha$ survey with the Tenerife 10 and 15 GHz CMB maps and reported that Galactic free-free emission is not the source of the well known DIRBE (dust) correlated foreground emission in that region. Microwave emission from spinning dust grains is a possible source.

Savage, Wakker, Sembach (STScI) , Richter, Meade, and other members of the Far-Ultraviolet Spectroscopic Explorer (FUSE) science team have completed their survey of O VI absorption in and near the Milky Way. Three major papers are now in press with ApJS: (1) the O VI catalog paper, Wakker et al. "The FUSE Survey of O VI Absorption in and Near the Galaxy." (2) a paper reporting on O VI in the thick disk of the Milky Way, Savage et al. "Distribution and Kinematics of O VI in the Galactic Halo." (3) a paper reporting on high velocity O VI, Sembach et al. "Highly-Ionized High Velocity Gas in the Vicinity of the Galaxy." These papers report on O VI absorption toward 100 extragalactic objects and two distant halo stars. O VI is one of the best tracers of hot gas. The thick disk absorption reveals a widespread but highly irregular distribution of O VI implying the existence of substantial amounts of hot gas with $T \sim \times 10^5$ K in the Milky Way halo. High velocity O VI absorption with $|v| > 100$ km s$^{-1}$ is detected along 65% of the lines of sight. This high velocity O VI traces a variety of phenomena including tidal interactions with the Magellanic Clouds, accretion of gas onto the Milky Way, outflowing material from the Galactic disk, warm/hot gas interactions in a highly extended Galactic corona, and intergalactic gas in the local group.

In a large survey, Richter, Wakker, Savage, and Sembach (STScI) used FUSE to study the distribution and properties of diffuse $H_2$ in intermediate-velocity clouds (IVCs) in the lower Galactic halo. They find that $H_2$

in these clouds is surprisingly widespread, although not very abundant. The $H_2$ probably traces the Cold Neutral Medium in these clouds at volume densities of $\sim$30 $cm^{-3}$. The measurements demonstrate that $H_2$ is an ubiquitous constituent in diffuse interstellar and intergalactic gas, if dust is present and the dissociating UV radiation field is moderate.

In another study of $H_2$ in the Milky Way halo, Richter, Sembach & Howk detect a small ($\sim$34 AU), dense ($\sim 10^3$ $cm^{-3}$) $H_2$ clump in the Galactic halo in direction of two LMC stars. Most likely, this clump is related to Tiny Scale Atomic Structures in the Cold Neutral Medium that have been previously found in H I absorption. This analysis shows that the ISM consists of significant small-scale structure at AU scales.

Tufte and Wilson (Lewis and Clark College) and Madsen, Haffner and Reynolds used WHAM to search for weak H$\alpha$ emission from "compact" high velocity clouds suggested by Blitz et al. and Braun and Burton to be dispersed throughout the Local Group. The detection of H$\alpha$ from four of the five clouds indicated a flux of ionizing radiation that is greater than that of the expected metagalactic flux. This suggests that the clouds are more likely located with the Milky Way's halo rather than in a more distant intergalactic environment.

Mathis, Whitney, & Wood (U. St. Andrews, Scotland) investigated the effects of hierarchical clumping of dust (clumps within clumps) on analyses of observations of reflection nebulae designed to determine the albedo and phase function of dust scattering at optical and ultraviolet wavelengths. They showed that there are very serious ambiguities in such determinations. Mathis is now considering the effects of clumping on the penetration of starlight into dusty clouds.

## 4 Extragalactic/ cosmology

Barger is making a census of the energy-producing galaxies and supermassive black holes in the Universe. Using observations at X-ray, optical, submillimeter, and radio wavelengths, she is studying galaxies and AGN that were previously hidden by dust and gas. Barger and colleagues Cowie (Hawaii), Brandt, Garmire, (Penn State), and Bautz (MIT) conducted a follow-up study with ground-based telescopes of the X-ray sources detected in a 1 million second exposure with the Chandra X-ray Observatory, resulting in an optical imaging and spectroscopic catalog of 370 X-ray sources. Sources at high redshift are more vigorously accreting matter, but the total light production from fainter sources at low redshift is comparable. This AGN "downsizing" is analogous to what is seen for star-forming galaxies. Barger is Co-I on the 2 million second X-ray exposure obtained of the Chandra Deep Field North and on Advanced Camera System (ACS) optical observations of the Chandra North and South fields as part of the GOODS project. Barger and student Steffen, along with Mushotzky (GSFC) and Cowie, have recently obtained a wide-field, moderately deep Lockman Hole X-ray survey to complement the faint source work and learn about the X-ray sources that contribute the most to the X-ray background. Steffen is currently obtaining observations with WIYN of the Lockman Hole field to use with existing deep optical data to estimate photometric redshifts for the X-ray sources. Barger, student Wehner, and Kneib (Toulouse) used gravitational lensing by clusters to determine the submillimeter properties of extremely red objects (EROs) and very red objects (VROs). They found that the ERO and VRO populations mark strong submillimeter emitters. Another conclusion of their study was that the submillimeter extragalactic background light contribution arises primarily from dusty starbursts rather than elliptical galaxies.

Bershady, with Guzman (U. Florida), Koo (UC Santa Cruz), and Lowenthal (U. Mass), has continued ground-based and HST STIS, NICMOS and WFPC surveys of intermediate redshift luminous, compact, blue galaxies (LBGs). Their stellar populations based on optical and infrared photometry yield improved estimates for how much these source may fade over 3-5 Gyr, i.e. what they might look like today. Internal kinematic measurements are forthcoming from STIS spectra; preliminary results indicate chaotic internal velocity structure with little evidence for simple, rotation-dominated motions.

The PhD thesis of D. Andersen (supervisor, Bershady) showed that H$\alpha$ emission-line echelle spectra from DensePak (WIYN) can constrain galactic inclinations down to 10-15°, contrary to the enshrined belief that kinematic measurements are only capable of determining inclinations above 45°. The improvement is due to the higher quality of the optical data now obtainable with integral field units (IFU), as compared to previous H I interferometric maps. It is now possible to study the rotation-speed – luminosity correlation of spiral galaxies (the Tully-Fisher relation) for systems whose geometry is favorable for (a) detailed analysis of their photometric and kinematic structure, and (b) the measurement of the vertical component of the velocity ellipsoid, which in turn can be used to measure the surface mass-density of galaxy disks.

Bershady, Verheijen, Andersen, and R. Swaters (JHU) are involved in a new survey to make direct, kinematic estimates of the masses of galaxy disks. This survey uses the SparsePak IFU on the WIYN 3.5m telescope, the PMAS IFU on the Calar Alto 3.5m telescope, and the CCD imager on the KPNO 0.9m telescope. Their science objectives are to measure the mass of galaxy disks by direct determination of the stellar velocity ellipsoid and to probe the ionized gas velocity fields in late-type and low-surface-brightness systems. Preliminary results indicate lower disks masses than previously estimated based on assumptions of stellar mass-to-light ratios. As part of this effort, Westfall and Bershady have been working on stellar cross-correlation techniques using SparsePak data for Galactic stars and external galaxies.

Crawford and Bershady continue to collaborate with S. Majewski (Virginia) on deep, multi-band optical imaging. These data are being used to explore faint galaxy

counts, the effects of large-scale structure on the counts, the reality of breaks in the counts slopes, and the implications these breaks (or the lack thereof) have for the redshift distribution of the faint galaxy population. This effort has led to the development of new, faint-object photometry and image simulation code for the evaluation of systematic and random errors in source detection and photometry.

Gallagher continued in a collaboration led by T. Smecker-Hane (UC Irvine) and A. Cole (UMass, now Kapteyn Inst.) to measure chemical abundances in LMC red giant stars. New CTIO results for 248 stars in an inner disk field show that the LMC displays a "G-dwarf problem". Additional observations now are in progress with the ESO VLT.

Gallagher completed a collaborative study of stellar populations in the UMi dwarf spheroidal (dSph) as part of a collaborative WFPC2 project led by R. Wyse (JHU). This showed a normal lower main sequence stellar mass function that is similar to that in globular star clusters and indicates a normal fraction of binary stars. Observations to detect ionized gas were carried out by the WHAM group and set new lower limits on the amount of diffuse ionized gas in the UMi and Dra dSphs. A project with E. Grebel (MPIA) and Harbeck is exploring how the dSphs might be shaped by initial conditions at the time of their formation. These results can be compared with stellar populations in star-forming dIrr galaxies, including those of Sextans A and IC 1613 obtained as part of an HST program led by E. Skillman (Minnesota). Imaging photometry with the WIYN telescope in a related program led by Saha and Dolphin (NOAO) revealed large number of variable stars in the Leo A dIrr, including RR Lyrae candidates indicating the presence of very old stars in this mainly younger galaxy.

Research stemming from the Conselice PhD thesis includes a photometric investigation of early-type dwarf galaxies in the center of the Perseus galaxy cluster with the WIYN telescope. Some dE galaxies appear to be old and metal-rich, and thus more likely to be remnants of larger systems than objects born as dwarfs. This view is supported by Arecibo HI 21-cm detections of two dE members of the Virgo cluster, which suggests these also are some type of transformed field galaxy.

New WFPC2 observations of the M83 nucleus by Gallagher, J. Harris and D. Calzetti (STScI) detected another dense assembly of young super star clusters in a circum-nuclear starburst arc. A study with student Homeier (at ESO) and A. Pasquali (ST-ECF) of star clusters in NGC 7673 from WFPC2 images also revealed the presence of large numbers of dense, massive star clusters formed over a short time span in this late interaction phase starburst system. This group now is studying the Markarian 8 interacting pair. Pasquali, R. de Grijs (U. Cambridge) and Gallagher are measuring properties of young stellar complexes and the nucleus of the UltraLuminous Infrared Galaxy, NGC 6240. Despite the huge luminosity of this system, the resolved clusters are normal, while the two nuclei are extremely unusual.

A collaboration between Gallagher and de Grijs, R. O'Connell (Virginia), and L. Smith (UCL) is obtaining optical spectra of M82 super star clusters with STIS to provide better measures of their structures and SEDs. A related program led by A. Lancon (U. Strasbourg) includes Gallagher in studies of the NIR spectra of M82 super star clusters obtained with SpeX on the InfraRed Telescope Facility. Initial results indicate surprising similarity among the IJHK-band spectra of M82 clusters.

Lancon also leads an exploration of the base of the M82 super wind with Gallagher, N. Foester-Schreiber (Leiden), and Smith. Narrow band NICMOS images show locations of dense transition zones from their [Fe II] emission. These suggest the wind becomes collimated on large scales just above the midplane of the disk. Further work on this problem is planned with NIR spectra and optical observations with the WIYN telescope.

With the completion of Otte's (JHU) Ph.D. thesis, new evidence for extra heating in the Diffuse Ionized Gas halos of spiral galaxies was published with Gallagher and Reynolds. A related phenomenon appears to be present in narrow-band WFPC2 images of starburst galaxies obtained by the D. Calzetti et al. collaboration, including Gallagher and Homeier.

Work by Gallagher with L. Matthews (CfA) on low mass disk galaxies included publication of optical rotation curves from CTIO spectra. These show a range of forms, but all imply the disks in these Sd-Sdm systems have normal specific angular momenta. He and Matthews also are studying star formation and the structures of "superthin" disk galaxies with groundbased and HST images.

Gallagher and Matthews also joined in a larger effort including Sparke to analyze WFPC2 images of the polar ring galaxy NGC4650A obtained by the Hubble Heritage program. Gallagher and Sparke joined with M. Arnaboldi (Naples) and E. Iodice (Trieste) in exploring the properties of this galaxy from NIR images. Sparke, A. Watson (UNAM) and Gallagher obtained NIR images for a few northern polar rings with WIYN in an ongoing program to observe the bright nuclear regions in polar rings.

Gallagher and graduate student Wehner worked with W. Brown (CfA) to constrain the mean star formation histories of nearby galaxies. Evolutionary model fits to the V-R color distributions found by Brown for a well defined sample of galaxies imply that current epoch mean star formation rates are only about a factor of 10 below their earlier plateau seen at high redshifts. They estimate that >80% of all stars were formed in the first 5-6 Gyr following the big bang.

Hoessel, Bershady, Saha (NOAO), Majewski (Virginia), and students Glenn and Crawford are continuing their long-term, deep variability survey pointed at intermediate redshift clusters using WIYN and the Mini-Mosaic CCD imager. Third-epoch observations were achieved for 65% of the target fields. Zeropoint calibrations are being acquired with the KPNO 0.9m telescope. Photometric reductions are yielding high-quality color-

magnitude diagrams in the rest-frame vacuum UV, as well as photometric redshifts.

Savage, Richter, Tripp (Princeton), Sembach (STSCI), Howk (JHU), and Jenkins (Princeton) are continuing their program with the Far Ultraviolet Spectroscopic Explorer (FUSE) and the Space Telescope Imaging Spectrograph (STIS) to determine the physical conditions in the recently discovered low redshift intervening O VI absorption line systems seen in the spectra of QSOs. By combining data from FUSE from 905 to 1187 Å and STIS from 1150 to 1800 Å it is possible to determine the number density of low redshift O VI absorbers and to study the physical conditions in individual systems. Five QSOs have so far been observed in this program. The low redshift number density of O VI systems is very large; these highly ionized absorbers contain as much matter as galaxies at low redshift.

K. Johnson is currently studying the earliest stages of extragalactic star formation, spanning the range from individual ultracompact HII regions, to super star clusters.

## 5 SALT, WIYN, and Instruments

**SALT:** The Department is continuing in its international partnership in the Southern African Large Telescope (SALT.) Wisconsin leads the effort to build the Prime Focus Imaging Spectrograph (PFIS; Nordsieck, PI), the primary first-light instrument, described below. SALT is an 11-meter optical telescope modified from the Hobby-Eberly Telescope design, located at the SAAO site in Sutherland, South Africa. Key in the redesign is larger corrected field of view (8′) with better image quality, larger entrance pupil (11m), and an enlarged prime-focus instrument payload. Ground-breaking occurred September 1, 2000, and first light is expected in 2003/2004. At the present time the telescope structure is nearly complete, the overall project is proceeding very well: with over 90% of the contracts let, the project is nearly on schedule and budget.

Significant progress has been made on the PFIS. In October 2001, the Preliminary Design Review was held and PFIS entered the Critical Design phase. The optical design has been streamlined, and design of much of the mechanical system is underway. As of September, 2002, an opto-mechanical engineering consultant has been brought on board, and preparations for the Critical Design Review to be held in March 2003 are commencing. Percival completed the preliminary design of the control system software. The system will use the commercial LabVIEW product, with most of the control electronics being inexpensive, off-the-shelf products from National Instruments.

**WIYN** (the Wisconsin-Indiana-Yale-NOAO 3.5-m telescope on Kitt Peak): Anderson completed the construction of an instrument interface for the f/13.6 modified Cassegrain focus of the Wisconsin-Indiana-Yale-NOAO 3.5-m Telescope. This "CassIAS" will provide acquisition, guiding and calibration functions for a variety of user instruments.

**Star Tracker:** Percival, Jaehnig, Babler, and Harris flew the ST5000 (a low-cost star tracker that provides pitch, yaw, and roll control for sounding rockets, but can also do a full "lost in space" attitude determination without gyros for both sounding rockets and satellites) in December on the Harris sounding rocket flight. The flight was only partially successful. and another flight is scheduled for Summer 2003.

**Wisconsin H-alpha Mapper:** WHAM (Reynolds and Haffner, PIs) has received additional funding from the NSF to probe the temperature, ionization state, and ionizing radiation field associated with warm ionized gas within the disk and halo of the Milky Way. WHAM is a remotely operated observational facility located at Kitt Peak and dedicated to the study of the diffuse ISM through the detection of faint optical emission lines at high spectral resolution.

**The Spatial Heterodyne Spectrometer** was funded by the NSF (Roesler, Physics, PI, with Reynolds, Co-PI) to detect [O II] 3727 emission from warm ionized gas in the Galactic halo, providing information regarding possible variations in the electron temperature.

**The Cosmic Origins Spectrograph:** (COS: J Green (U. Colorado), PI) will be installed in the HST in 2004. Savage is a Co-I on the COS Science Team. COS is a high efficiency UV spectrograph designed to operate between 1150 and 3200 Å with a spectral resolution of ∼20,000. In the far-UV COS is ∼15 times more efficient than the Space Telescope Imaging Spectrograph. COS will be used for a wide range of studies of faint galactic and extragalactic objects. Savage's studies with COS will emphasize the highly ionized gas found in QSO absorption line systems. Highly ionized species of particular interest are O VI, O IV, and Ne VIII. The importance of these studies has increased with the discovery that the intervening O VI absorption line systems found at low redshift contain as much matter as the entire population of galaxies found at low redshift.

## 6 Public Outreach

The Department of Astronomy and Department of Physics jointly hosted its first NSF-supported REU (Research Experiences for Undergraduates) program (Benjamin, Physics, PI) in the summer of 2002. Nine students participated in a directed ten week summer research project as well as attending a weekly lecture series and going on field trips to Yerkes Observatory, Pine Bluff Observatory, and the Synchrotron Radiation Center. At the end of the summer the students presented their research to the departments. These presentation and information on the program is available on http://wisp.physics.wisc.edu/reu. This program will continue at least for two more summers.

As part of a Departmental effort to recruit and train minorities in astronomy, Stassun and Mathieu mentored K. Soto (Ventura Community College) as part of an REU project to discover new PMS EBs in young star-forming regions. Stassun's "Scopes for Schools" outreach program continues, and is being adopted by the National

Science Teachers Association for national dissemination as a model for teacher training in astronomy.

During the summer of 2002 the Universe in the Park program under the direction of Prof. Eric Wilcots held nearly 50 sessions at 30 state parks throughout Wisconsin. It sponsors visits to the parks, mainly by graduate students, including talks and telescopic viewing sessions

The Department of Astronomy, together with the African Studies program and aided by a kind gift from the Evjue Foundation, helped bring five science teachers from South Africa to Madison during the summer of 2002. The teachers participated in a 5 week teacher enhancement program in a broad range of sciences, including astronomy and space science.

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Note: All authors' names associated with UW during the period of the report are in **bold face**.)


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