The University of Wisconsin-Madison

Department of Astronomy

Madison, WI 53706

During the past year, the Astronomy Department at UW-Madison has been active in a wide range of observational and theoretical research program. We initiated instrumentation development for space and ground based programs, and increased the number of faculty and staff. We have joined the Southern African Large Telescope (SALT) consortium that will construct a 10-meter optical telescope located at the Southern African Astronomical Observatory site in Sutherland, South Africa. The design will be modified from the Hobby-Eberly Telescope but will have a larger corrected field of view ($8'$) with better image quality, larger pupil, and an enlarged prime-focus instrument payload. Ground-breaking occurred September 1, 2000. First light is expected in 2003.

We are especially pleased that Dr. Amy Barger has accepted a position as Assistant Professor, to begin her duties in August 2001. She is currently the Hubble Fellow/Chandra Fellow at Large at the Institute of Astronomy, University of Hawaii.

WIYN refers to the Wisconsin-Indiana-Yale-NOAO 3.5-m telescope on Kitt Peak.

1 Personnel

The faculty consists of Professors Anderson (Chair), Cassinelli, Churchwell, Gallagher, Hoessel, Mathieu, Nordsieck, Reynolds, Savage, and Sparke, Associate Professor Bershady (promoted to the rank during the year), and Assistant Professors Barger, Lazarian and Wilcots. Bless, Code, and Mathis are Professors Emeriti who reside in Madison. Percival is Scientist; Harris and Wakker are Associate Scientists. Assistant scientists are Barnes (McKinney Assistant Scientist), Kobulnicky (Hubble Fellow), and Quigley. M. Orio was appointed Visiting Associate Scientist. Dr. Philipp Richter joined the staff as Assistant Scientist, following his graduate work in Bonn, Germany. He will work with Savage on data from the Far Ultraviolet spectrograph (FUSE) satellite relating to gas in the interstellar and intergalactic medium. Dr. Jungyeon Cho arrived from the Johns Hopkins University to work with Lazarian as Assistant Scientist. Dolan, Haffner, and Stasson are Research Associates. W. Harris, M. Quigley, and J. Morgenthaler served as Lecturer for a semester during the academic year. Many scientists visited during the year.

The monograph by H.J.G.L.M. Lamers & J.P. Cassinelli, *Introduction to Stellar Winds*, was published by Cambridge University Press. The advanced-undergraduate textbook "Galaxies in the Universe: An Introduction", by L.S. Sparke and J.S. Gallagher, is ready for publication by the Cambridge University Press in late 2000.

K. Stasson received the PhD for his thesis entitled "A Test of Star Formation Theory: The Connection Between Rotation, Accretion, and Circumstellar Disks Among Low-Mass Pre-Main Sequence Stars." C. Dolan completed his PhD thesis "The Young Population of the λ Orionis Star-Forming Region." Both theses were supervised by Mathieu. P. Erwin received the PhD with a thesis entitled "Barred Galaxies and Orbits in Binary Systems", supervised by Sparke. Erwin in now at the Astrophysical Institute of the Canares in Tenerife, Spain.

Graduate student C. Conselice is spending the 2000-2001 academic year as a visitor at the Space Telescope Science Institute where, in addition to his thesis research, he is investigating the structures of high redshift galaxies. Graduate student J. Hoffman won first place in the Ruth and Helen Dickie Graduate Research Seminar Competition, sponsored by the UW-Madison chapter of Sigma Delta Epsilon, Graduate Women in Science, for her talk entitled "Building a Binary Star: Monte Carlo Modeling of β Lyrae." Hoffman continues as observing coordinator for the Half-wave Polarimeter (HPOL) at Pine Bluff Observatory.

Bless served on two significant committees: Gemini Observatory Site Visit Committee (Divi-

sion of Astronomical Sciences, NSF), and Portfolio Allocation Review Committee (Division of Astronomical Sciences, NSF). Churchwell served as Co-chair of Joint Discussion 3 at the IAU General Assembly in Manchester, England. He continues to serve on the NAIC Visitors Committee for Arecibo Observatory and on the Program Advisory Committee for NRAO, advisory to the NRAO director on long-range programs. Mathieu was Co-Chair of IAU Symposium 200, *The Formation of Binary Stars*, served on the Astronomy and Astrophysics Survey, "Ultraviolet, Optical, and Infrared from Space" Panel, as President of the WIYN Board, as Associate Director of the National Institute of Science Education, and as Director of its College Level 1 Institute. Anderson, Nordsieck, Reynolds, Bershady, and Wilcots have represented Wisconsin on the Interim Board of the Southern African Large Telescope (SALT). Bershady has been appointed as the Wisconsin SALT Board representative and Nordsieck to the SALT Science Working Group. Percival continued his participation in the IAU Working Group on Astronomical Standard's initiative called SOFA: "Standards of Fundamental Astronomy." Its goal is to produce a set of basic software that implement commonly-used formulae and standard models in fundamental astronomy. Savage continued as a member of the Committee for Astronomy and Astrophysics of the National Research Council and of the Space Telescope Institute Council.

2 Stars, Outflows, and Galactic Structure

Barnes continued his work on the rotation rates of late-type stars. His theoretical work with Sofia (Yale) and Pinsonneault (Yale) suggests that the majority of the stars in young open clusters have undergone disk interactions with a time-scale of the order of 1 Myr in their early stages. These models must be compared to observations of stellar rotation periods in clusters that are a few to several hundred Myr old. Some data have already been acquired for NGC 2477 at CTIO; other clusters will be targeted in the winter and spring of 2000-2001. A large dataset for the younger cluster NGC 2516 and a smaller one for the open cluster M 34 is being analyzed in order to investigate the angular momentum distribution and transport in stellar interiors, to learn about its loss through stellar winds, and to understand aspects of star-disk interaction on the pre-main-sequence.

Cassinelli and Miller obtained high-resolution X-ray observations of the early-type stars Zeta Puppis and δ Ori using the High-Energy Transmission Grating Spectrometer on the Chandra spacecraft. The spectra show the line emission from early-type stars in unprecedented detail. Initial results confirm older shock model estimates of the temperature of the emitting gas. The high-resolution capability of the *Chandra* satellite makes density diagnostics of the forbidden, intercombination, and resonance lines of helium-like ions accessible. Initial analysis indicates the densities of the emitting gas are much higher than expected. They plan to analyze the temperature structure of the gas and to search for time variability. Wayne Waldron (Emergent Information Technologies) and Cassinelli carried out a study of the properties of the X-ray sources in Zeta Ori. Cassinelli and John Brown of Glasgow continued investigating the transfer of angular momentum to the disks around Be stars. Richard Ignace (U. Iowa), Quigley, Babler and Cassinelli are analyzing the profiles of recombination and forbidden lines in the *Infrared Space Observatory* spectra of Wolf Rayet stars in order to derive information about the velocity and ionization structure in the winds of the stars. The forbidden lines provide the best information regarding the terminal velocities of the winds; the He II recombination line profiles provide information about their rate of acceleration.

Churchwell has continued a broad collaborative observational program to study the properties of galactic massive star formation regions (MSFRs). A $C^{17}O$ (1-0, 2-1, 3-2) and $C^{18}O$ (2-1) survey towards 16 MSFRs by Hofner, Wyrowski, Walmsley, and Churchwell indicates that the CO emitting clumps have sizes of $\sim$1 pc, averaged densities of $\sim 10^5$ cm^{-3}, temperatures of $\sim$25 K, and clump masses from 10^3 to 4×10^4 M$_\odot$. Most of the clumps are virialized in the sense that their gravitational energy is about the same as the bulk kinetic energy inferred from line widths. The CO temperatures are lower than those inferred from CH_3CN, which is confined to the central cores.

Hunter, Churchwell, Watson, Cox, Benford, and Roelfsema imaged 24 MSFRs at 350 μm with

a resolution of 11″ using the Caltech Submillimeter Observatory, mainly to detect precursors of Ultracompact (UC) HII regions in MSFRs. Of the 28 detected submm components, 10 had luminosities $> 10^{4.3}$ $L_\odot$ but no detected ionized gas. Most of these are maser emitter (either OH, and/or H_2O, or CH_3OH). These are precisely the properties expected during the rapid accretion phase of massive star formation believed to occur prior to the formation of a UC HII region. Analysis of the 350 μm sources indicate average masses of $\sim 10^{3.5}$ $M_\odot$, luminosities of $\sim 10^5$ $L_\odot$, and H column densities of $10^{23.8}$ cm^{-2}.

A program to observe and analyze CH_3CN emission toward MSFRs has been initiated by Churchwell and Watson in collaboration with V. Pankonin (NSF) and John Bieging (U. Ariz). The single dish observations using the Heinrich Hertz telescope of the Submillimeter Observatory have just been submitted for publication (Pankonin et al. 2000, ApJ, submitted). High resolution observations have been obtained with the Berkeley Illinois Millimeter Array toward two regions. Sewilo has analyzed high dynamic range VLA continuum images of G5.89 obtained over a 10 year period; an angular expansion rate of 4±1 mas/y was found, the same as Acord, Churchwell, and Wood (1998) found over a 5 year baseline.

Barnes, Dolan, 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, they have obtained 4776 velocity measurements of 509 stars in NGC 188, 2594 measurements of 936 stars in M35, 1795 measurements of 347 stars in NGC 2264, and 3196 measurements of 861 stars in NGC 6819. Extensive spectroscopic binary populations are being discovered in all four clusters. Nearly 50 binaries have orbital solutions in NGC 188, the most extensively observed cluster. Emphasis this year shifted to careful error analyses in preparation for publication. Raw data for bright stars have measurement precisions of 0.4 km s^{-1}, due to variations among fibers and in night-to-night zero-points. Correction for systematic effects should lower measurement precisions to 0.3 km s^{-1}. Photon errors dominate at the limit of V = 16.5. Using the Mini-Mosaic imager on WIYN, Barnes obtained deep BVI photometry of the central region of the open cluster NGC 6819 in order to generate a color-magnitude diagram for the lower main sequence and to test the Mini-Mosaic.

Dolan completed his thesis study (with Mathieu) on the λ Orionis star-forming region, which presents a snapshot of a moderate-mass giant molecular cloud 1–2 Myr after cloud disruption by OB stars. The OB stars, the low-mass stellar population, remnant molecular clouds, and the dispersed gas are all still present. Dolan used optical photometry and multi-object spectroscopy for lithium absorption to identify 266 PMS stars in an 8 squared degree area. He also obtained new Strömgren photometry for the massive stars, from which he derived a distance of 450 pc and a turnoff age of 6 – 7 Myr. Using these parameters and pre-main-sequence evolutionary models, he mapped the star-formation history of the low-mass stars. He finds that low-mass star formation started throughout the region at about the same time as the birth of the massive stars. Thereafter the birth rate accelerated. Within the last 1–2 Myr star-formation ceased in the center of the star-forming region, near the concentration of OB stars, while it continues in dark clouds 20 pc away. He suggested that a supernova 1–2 Myr ago destroyed the molecular cloud core from which the OB stars formed, but did not terminate star formation in more distant reaches of the giant molecular cloud. He found no secure evidence for triggered or sequential star formation in the outer molecular clouds. The global star formation of the λ Ori region has generated the field IMF, but local star formation in sub-regions shows large deviations from the expected ratio of high- to low-mass stars.

Mathieu, Lattanzi (Torino), and Zinnecker (Potsdam) used relative astrometric observations of the pre-main-sequence single-lined spectroscopic binary 045251+3016 obtained with the Fine Guidance Sensor on the HST. Mathieu and Steffen determined the orbital elements of this system; the semi-major axis is 0.0352″. Optical spectra taken at CfA (with Latham and Torres) provided 58 radial-velocity measurements of the primary star and IR spectra taken at KPNO (with Mazeh (Tel Aviv), Prato (UCLA) and Simon (Stony Brook) provided a mass ratio for the binary system. The derived values for the primary and secondary masses are 1.44

$\pm$ 0.25 $M_\odot$ and 0.78 $\pm$ 0.11 $M_\odot$, respectively, at a distance of 138 $\pm$ 8 pc. The theoretical mass derived from the Baraffe et al. (1998) tracks is closest to the derived mass, deviating by less than one sigma. The Palla and Stahler (1999) tracks deviate further but remain consistent with these data. The D'Antona and Mazzitelli (1997) tracks are more than three sigma away from the derived mass, making them inconsistent with these measurements.

Mathieu, Carr (NRL) and Najita (NOAO) continued a program of high-resolution near-infrared spectroscopy (CO fundamental and overtone transitions) in order to explore the circumstellar gas in several young binaries. They made the first discoveries of CO fundamental ro-vibrational emission from PMS stars. The high-resolution infrared echelle spectra reveal emission lines from both the v=1 and v=2 vibrational levels with line widths of about 70 km s^{-1}. The average CO excitation temperature is about 1200 K. The disk model requires gas with an average surface density of 5 $\times 10^{-4}$ g cm^{-2} that extends outward to 0.5 $\pm$ 0.1 AU and inward to at least 0.1 AU of the center-of-mass. The radial extent for the emitting gas is close to the predicted size of the gap in the DQ Tau accretion disk that is expected to be dynamically cleared by the binary. They interpret these results, and previous modeling of DQ Tau's spectral energy distribution, as evidence for a small amount ($\sim 10^{-10}$ $M_\odot$) of diffuse material residing within the optically-thin disk gap, perhaps connected with accreting material crossing the disk gap.

Hoffman and Nordsieck used the Space Telescope Imaging Spectrograph on the Hubble Space Telescope to search for Doppler signatures of a bipolar outflow in the interacting eclipsing binary star β Lyrae. They seek to confirm their previously-published polarimetric evidence for such an outflow and to investigate its size and composition.

Nordsieck, Hoffman, and Polidan (GSFC) are continuing in their spectropolarimetric investigation of active Algols and W Ser eclipsing interacting binaries. The goal is to obtain spectropolarimetry from 3200 - 10500 Å with a resolution R $\sim$ 800 over the binary phase, with about 20 points per orbit. This is to be analyzed using Hoffman's Monte Carlo code. Observations, obtained with HPOL at Pine Bluff Observatory and WIYN, are now complete for the W Ser stars W Ser, V367 Cyg, RX Cas, and SX Cas, including interstellar polarization measurements at WIYN of the very close companions of SX Cas and V367 Cyg. Observations are also complete for the active Algol systems RY Per, UX Mon, TT Hya and V356 Sgr. The first paper will be for V367 Cyg.

Hoffman and Nordsieck continued their investigation of eclipsing binary Herbig Ae/Be stars by conducting several more polarimetric observations of BM Ori and MWC1080 with HPOL at WIYN in September. They now have nearly complete polarization phase curves for both these young systems, and plan to model them using Hoffman's Monte Carlo code in order to compare their geometrical structures with those of the evolved binary systems previously studied.

Hoffman has completed a Monte Carlo radiative transfer model for binary star-disk systems. She is currently investigating the variations in its observable characteristics throughout parameter space. This model has shown promise in reproducing the observed flux and polarization curves of β Lyrae and should provide insights into the structure of a wide range of other binary systems. B. Whitney (Space Science Institute) continues as a mentor and collaborator in this modeling effort. Hoffman also attended the NASA Summer School for High-Performance Computing at GSFC in July to investigate the possibility of parallelizing the Monte Carlo code in order to construct high-precision wavelength-dependent models.

A new analysis of the visible and ultraviolet continuum polarization in P Cyg, as observed by HPOL and the Wisconsin Ultraviolet PhotoPolarimeter (WUPPE), combined with the wind models of Najarro, has led Nordsieck and collaborators to important new limits on the location, ionization, density, and density contrast of the wind inhomogeneities that cause the intrinsic polarization (Nordsieck and Wisniewski 2000). The lack of a Balmer Jump in polarization indicates that the clumps must be highly ionized. The polarization decrease into the infrared is interpreted as due to competition of free-free absorption with the polarizing electron scattering. The required density indicates that the polarizing clumps must be at the very base of the wind, and the density contrast is a factor of $\sim$10.

Orio has continued to study classical novae,

low mass X-ray binaries, and supersoft X-ray sources, especially the optical identification of X-ray sources. She searched for ionization nebulae around systems with shell hydrogen burning white dwarfs. With the BeppoSAX satellite, she has studied a recent nova (V382 Vel) in X-rays immediately after the outburst. With collaborators, she performed a Target of Opportunity observation of Nova LMC 2000 with the X-ray satellite XMM. She is analyzing archival X-ray observations of novae at any stage after the outburst (even in quiescence). She has participated in an extensive search for other ionization nebulae around novae, cataclysmic variables, and supersoft X-ray sources with the WIYN telescope. She is using it to search for optical counterparts of supersoft X-ray sources in M31 (one has been identified with a nova) and candidate neutron stars (anomalous X-ray pulsars in the Galaxy.)

3 Interstellar Medium

Lazarian worked with D. Pogosyan (CITA) on obtaining the statistics of turbulence from observations. They derived relations between the channel maps and underlying 3D velocity and density statistics. With E. Vishniac (JHU), Lazarian continued to investigate turbulent reconnection. They obtained important results for reconnection in partially ionized gas. Together with De Gouveia Dal Pino (Univ. of Sao Paolo), Lazarian considered the acceleration of ultrahigh energy cosmic rays during reconnection events. With B. Draine (Princeton), Lazarian obtained measures of polarization for dipole radiation from tiny rotating grains (PAHs), important for the Galactic contribution in the range of 10-100 GHz. With M. Efroimsky (Harvard), Lazarian calculated the rate of internal dissipation within asteroids. These results can be used to measure the time from the most recent impact on the asteroid.

Nordsieck and Doane are analyzing data from the fourth flight of the sounding rocket payload Wide-Field Imaging Survey Polarimeter (WISP), launched on 11 April, 1999. WISP is a 20 cm off-axis Schmidt telescope with polarimetric optics, obtaining imaging polarimetry over a 3x4^o field with a resolution of 1$'$ through a broadband filter centered at 1750 Å. The target for this flight was the mid-latitude galactic reflection nebulosity near M81 and M82 (the "Sandage region"), which has strong visible and IR cirrus. It has been detected in the ultraviolet by the JHU and UCB UVX detectors. The goal was to obtain photometry and polarimetry of any scattered UV galactic diffuse light. Surprisingly, no UV cirrus was detected. Using photometry of stars of known brightness in the field, we find that the majority of the detected UV diffuse light cannot be scattered light from galactic cirrus.

Haffner and Reynolds have completed the reduction of the Wisconsin H-alpha Mapper (WHAM) survey. It provides the first view of the large scale distribution and kinematics of the diffuse interstellar H^+ north of declination -30^o. Haffner and Reynolds have begun a collaboration with Tufte (Lewis and Clark College) to study optical emission lines from High Velocity Clouds through remote observing with the WHAM facility. Reynolds, Haffner, Madsen, Mathis, and Wood (CfA) have begun to explore absorption and scattering in the diffuse interstellar medium by comparing radiation transfer models with observed Hα and Hβ intensities and line profiles from WHAM.

Haffner, with Jenkins, Tripp (Princeton), Roesler (Physics Dept), and Reynolds has begun comparing STIS UV observations of the Si II* absorption line with WHAM Hα observations to explore the properties of the warm ionized medium.

Fabian, Savage, Richter, Wakker, Sembach (JHU), Howk (JHU), and Tripp (Princeton) are studying the galactic ISM absorption lines recorded in Space Telescope Imaging Spectrograph (STIS) and FUSE spectra of bright QSOs. The spectra are being used to study the abundances physical conditions, and kinematics of neutral, warm ionized and hot ionized gas extending many kiloparsecs away from the Galactic plane. The first 4 sightlines included the warped outer Galaxy and a high H I column density region of Complex C. Galactic high velocity clouds are found along all four lines of sight.

Savage, Sembach (JHU), Richter, Wakker, Fabian, and members of the FUSE science team are studying the distribution of O VI in the Galactic halo. The first FUSE halo gas paper revealed the existence of an extended but irregularly distributed halo of O VI with an exponential scale height of 2.7$\pm$0.4 kpc. The FUSE observations combined with similar observations of other highly ionized species

from the IUE and HST suggest there is a systematic decrease in the scale heights of Si IV, C IV, N V, to O VI from 5.1 to 2.7 kpc. Such a decrease is difficult to explain with a single model for the origin of the highly ionized gas in the Milky Way halo. Possible hybrid models include hot gas arising in a fountain flow with a augmentation to the amount of Si IV and C IV at high z from turbulent mixing of hot and warm gas or by photoionization by hot halo stars or the extragalactic background. The FUSE halo gas program is being expanded to include measures of O VI absorption toward $\sim$50 AGNs. This larger data set will allow measures of the kinematics of the hot gas and provide clues for the origin(s) of its irregular distribution. These new observations will also make it possible to study the relationships among the gas phases traced by O VI, Fe III, and S III. O VI traces the hot ISM while Fe III and S III trace the warm ionized phase of the ISM.

Richter worked on FUSE FUV absorption line data in order explore the nature of the hot Galactic halo gas, the intermediate- and high-velocity clouds (HVCs/IVCs), and molecular hydrogen in the diffuse ISM.

Wakker, in collaboration with van Woerden (Groningen), Schwarz (Nijmegen), and Kalberla (Bonn), continued investigating the distances and metallicities of HVCs/IVCs. Two large HVCs are distant (d $>$ 4 kpc) and metal poor (Z $<$ 0.1 $Z_\odot$), while most large IVCs are nearby (z$\sim$1 kpc) and metal rich (Z $\sim$ 0.5-1 $Z_\odot$). Combining ion abundances in HVCs and IVCs with those in low velocity gas, Wakker & Mathis found strong correlations between the MgII, CaII, TiII, MnII, FeII abundances and N(HI); the implications of this for the structure of the ISM were discussed.

Mathis continues to investigate the ionization properties of the diffuse ionized gas in the Galaxy by means of photoionization models. He is also interested in the properties of interstellar elemental depletions and, especially, their rather small dispersions about the mean value at a particular value of H I column density. There is considerable unexpected physical content in the column density, and grain destruction must not take place in a few hard shocks, but rather is a continuous function that can be parameterized by the H I column density.

4 Extragalactic Astronomy

Anderson, Weitenbeck (UW-Baraboo) and undergraduate Halstead continued polarimetric observations at the Pine Bluff Observatory in the direction of NGC 1502 in order to investigate the interstellar medium.

Bershady has completed a follow-up imaging survey with WIYN of intermediate redshift spiral galaxies with optical rotation-curves obtained at Palomar and Lick (with Haynes and Giovanelli (Cornell), Mihos (Case Western), and Koo (UC Santa Cruz). The WIYN images suggest that the outlying galaxies in the Tully-Fisher (rotation speed-luminosity) correlation are disturbed systems. Some of the most optically disturbed systems also display evidence for kinematic asymmetry.

Bershady, Gallagher, Sparke, and Wilcots (alphabetical) have continued a collaboration to explore the kinematics and evolution of galaxies. One project bearing results this year is with with D. Andersen (Penn State), namely to determine the intrinsic ellipticity of nearby galaxy disks. Preliminary findings are that disks are non-circular, with a model-dependence measurement of ellipticity of 5% (on average). If correct, then disk ellipticity contributes as much as 50% of the scatter in the Tully-Fisher relation.

Bershady, Conselice, Jangren (Penn State), Koo (UCSC), and Guzman (Yale) completed development of quantitative indices of galaxy morphology, and have applied them to understanding an enigmatic population of luminous, compact narrow emission-line galaxies that appear at intermediate and high redshifts, as well as other distant galaxy populations. The indices include rotational asymmetry, image concentration, size, surface-brightness, and multi-band color. Bershady and Conselice are currently analyzing recent NICMOS observations with the Hubble Deep Field in collaboration with Dickinson (STScI).

Hoessel and Bershady have begun a long-term, deep variability survey pointed at intermediate redshift clusters using the WIYN telescope and the Mini-Mosaic CCD imager. This project is in collaboration with A. Saha (NOAO), and S. Majewski (Virginia). First-epoch observations were achieved for 11 of the 15 targeted fields.

Gallagher and several collaborators continue to

study stellar populations and evolution of galaxies. He, with A. Cole (UMass) and Smecker-Hane (UC-Irvine), used spectroscopic observations of the Large Magellanic Cloud from CTIO to focus on abundance determinations as well as stellar kinematics, while WFPC2 provides quality photometry of the highly resolved field stars. Currently they are completing an analysis of the WFPC2 color-magnitude diagrams. A related project with R. Wyse (Johns Hopkins) and collaborators explores the star formation history of the Ursa Minoris dwarf spheroidal galaxy using combined ground and WFPC2 optical observations.

Gallagher is part of a team led by E. Skillman (U. Minnesota) to obtain deep WFPC2 photometry for the dwarf irregular galaxy IC 1613. An initial analysis of variable stars by A. Dolphin and A. Saha (NOAO) confirm the presence of RR Lyrae variables in a blue horizontal branch. IC 1613 joins the Local Group dwarfs with old metal-poor stars. Gallagher is a member of a group led by E. Tolstoy (UK Gemini office) and Cole (UMass) to derive a star formation history. He also is working with Tolstoy in analyzing deep photometry of isolated Local Group dwarfs obtained under excellent seeing conditions with the ESO VLT/UT1 8-m telescope in 1999.

L. J. Smith (Univ. College London) and Gallagher completed a detailed study of the super star cluster M82-F, for which they measured a stellar velocity dispersion and derived an age and mass. The cluster is overluminous for its 60 Myr age. It possibly lacks low mass stars; it would then dissolve within the next Gyr, despite its 10^6 $M_\odot$ mass. Gallagher participated in a team led by D. Hunter (Lowell) completing a WFPC2 study of the structures and evolutionary status of super star clusters and their surroundings in the starburst region of NGC 1569.

Gallagher joined de Grijs (Virginia, now Cambridge U.) and O'Connell (Virginia) in an HST optical/IR study of star clusters in region B of M82. Large numbers of compact clusters exist covering a range in age of >0.1 Gyr in this post-starburst zone; evidently star formation preferred to make tightly bound objects in this region. He also collaborated with the Virginia group in studying optically visible supernova remnants on WFPC2 images. Gallagher and Homeier are exploring the super star clusters in luminous clumps in the starburst galaxies NGC 2403, NGC 7673, and II Zw 168 with WFPC2 and WIYN optical and UV images. Gallagher initiated discussions with Lancon (U. Strasbourg) to better understand the role of stochastic effects in determining the observed properties of populations of star clusters, and with de Grijs and Hunter to better understand properties of starburst cluster luminosity functions.

Working with A. Ferguson (Cambridge U.) and Wyse (JHU), Gallagher joined a WFPC2 study of And IV that established it is a background dwarf irregular galaxy. They obtained WFPC2 images of HII regions far from the mid-plane of the Magellanic type galaxy NGC 55 to search for high latitude star formation in this edge on Magellanic system and to study stellar populations beyond its main disk. Matthews (NRAO) and Gallagher continued investigating the evolution of pure disk galaxies. An initial analysis of the archetype superthin galaxy UGC 7321 based on WIYN imaging is finished. Results from WFPC2 observations are being prepared for publication. Structural studies by Matthews show that these types of disks experienced slow evolution. They can be used as laboratories for studying self-regulation of star formation processes and its implications for the Tully-Fisher relationship.

Gallagher, Calzetti (STScI), and others (including Conselice) continue to explore the structure of ionized gas in starburst galaxies. Following completion of a study of the extended ionized gas in NGC 5253, new WFPC2 observations have been obtained for the starburst nuclear region of its interacting companion, M83. These reveal a complicated relationship between dense gas and stars, indicating that large local variations in conditions on short timescales within this region. One low-extinction zone contains the usual starburst structure of compact star clusters on a bright background, with ionized gas extending outward from the hole. Gallagher, Conselice, and Homeier are studying the starburst responses of low mass disk galaxies to mild perturbations. These are sometimes very strong. A working hypothesis is that extreme late-type field galaxies that have not been perturbed live on the edge of stability and can respond dramatically to an interaction. This mechanism could produce faint blue field galaxies at

moderate redshifts.

Star formation in starbursts often occurs in large "clumps" that may be the characteristic scales of gravitational instabilities in perturbed, gas-rich disks. Gallagher is exploring the evolution of this type of system through observations of evolutionary sequences of starbursts with guidance from theoretical models. A key question is whether clumps retain their identities and spiral into the centers of galaxies under dynamical friction to form bulges.

Conselice, with Gallagher and Wyse (JHU) as supervisors, is pursuing a PhD thesis on populations of dwarf galaxies in clusters of galaxies. The goal is understanding the origins and astrophysical implications of large numbers of dwarf elliptical (dE) galaxies in clusters. Observations with Levine (USNO- Flagstaff) of Virgo dwarfs yielded photometric and structural information. New radial velocities were measured for 3 dozen Virgo dE candidates. These results in combination with earlier measurements indicate dEs are less dynamically relaxed than galaxies in the cluster cores, suggesting that many of the dEs joined the cluster somewhat later, probably due to infall. Side benefits of this program are excellent optical WIYN images of clusters. These supported a study of ionized filaments around NGC 1275 in Perseus, suggesting the outer filaments originate where relativistic plasma or hot gas disturbs the surrounding, possibly cooling IGM. They also produced a new gravitational lens ring candidate in the galaxy cluster Abell 611; if confirmed, this will join the small set of giant lensed arcs in clusters with low redshifts.

Gallagher, Conselice, and Tolstoy are analyzing properties of faint Local Group dwarf galaxies with VLT B- and R-band images. These data complement deep HST imaging projects in reaching similar limiting magnitudes but with much better surface brightness sensitivity; indeed, most detected objects are resolved. A comparison of the two samples yields insights into the role of selection effects in determining our view of populations of faint galaxies.

As part of her PhD thesis, Otte (working with Gallagher and Reynolds) is obtaining narrow band filter imaging with WIYN and long slit spectroscopy with the 2.1m telescope on Kitt Peak to test the hypothesis of an additional heating mechanism in the diffuse ionized gas of galaxies. With Wilcots, she is using the DensePak on WIYN to measure the Hα velocities and line widths in several galaxies.

Kobulnicky completed a 21-cm and optical emission line kinematic study of local spiral and irregular galaxies with Gebhardt (UCSC). This study provides a calibration of [O II] emission line kinematics with Ca H&K stellar kinematics and 21 cm HI kinematics for assessing the usefulness of these tracers to measure masses of galaxies in the high redshift universe. With Koo (UCSD), Kobulnicky conducted near infrared spectroscopic observations of two high-redshift galaxies near z = 2.9 using the newly-commissioned NIRSPEC spectrograph on the Keck II telescope. The oxygen abundances and masses of these high-redshift galaxies studied to date show 2-3 magnitudes more luminosity for their linewidth and metallicity compared to objects in the local universe. With Woosley and Fryer at UCSC, Kobulnicki is continuing to monitor the radial velocities of 140 O and B stars in Cygnus OB2 association in order to detect companion stars and measure their mass distribution. An initial publication is in preparation and the long-term survey continues at the Lick and Keck Observatories. Kobulnicky and Pisano have described Arecibo 21 cm HI measurements of unusually blue, compact galaxies in the nearby universe. These may be analogs of compact starbursting galaxies observed in the Hubble Deep Field. The goal is to infer the gas properties of these distant galaxies and the potential for future star formation by studying their local counterparts. With K. Johnson (U. Colorado), Kobulnicky presented a press conference at the 2000 Winter AAS meeting on their discovery (ApJ December 1999) of extremely young starburst clusters with ages less than a million years. This discovery received attention from the Discovery Channel Online, the ABC news online, and Sky & Telescope magazine (July 2000).

Madsen and Reynolds have carried out a deep search for Hα emission beyond the outer edge of the H I disk of M 31. No emission was detected down to a limit of 0.03 Rayleighs, corresponding to an emission measure of 0.08 cm^{-6} pc.

To determine the physical conditions in the recently detected intervening O VI systems found at low redshift, Savage, Richter, Tripp (Princeton), Jenkins (Princeton), Sembach (JHU), and Howk (JHU) are studying the intergalactic absorption lines

found in FUSE and STIS spectra of bright low redshift QSOs. These absorption systems may harbor a major fraction of the baryons existing in the low redshift universe (Tripp et al. 2000). The FUSE spectra extend from 905 to 1187 Å; the STIS from 1150 – 1750 Å. The first objects in this program include PG 0953+415 (z = 0.239), H 1821+643 (z =0.297), PG 1116+215 (z = 0.177), and PG 1259+593 (z = 0.472). These UV spectra have been supplemented with WIYN observations of the redshifts of galaxies brighter than B $\sim$ 19 mag.

Howk and Savage are using the HST to image edge-on galaxies to search for dusty interstellar clouds in the disk-halo interface of spiral galaxies. This is a follow-up program to the successful WIYN imaging program that revealed that spiral galaxies like NGC 891 commonly have dust structures extending 0.5 to 1.5 kpc into the halos. These halo dust structures trace 10^5 to 10^6 solar masses of gas and may be the sites of ongoing star formation. The HST program involves obtaining BVI images of five galaxies in the distance range from 17 to 70 Mpc with the WFPC2. The HST results for these galaxies will be compared to those from the closer sample imaged with WIYN under subarcsecond seeing conditions.

The PhD thesis of Erwin (Sparke, advisor) included a survey of early-type barred galaxies with the WIYN telescope, searching for signs of inner bars and other central structures. These turn out to be surprisingly common; about a quarter of the galaxies have secondary bars and about the same fraction have inner disks. One, NGC 2681, may be the clearest example yet of a galaxy with three concentric bars. NGC 3945, previously thought to be triple-barred, is merely double, but it also has a large, extremely bright disk inside its primary bar, with patchy dust lanes, a faint nuclear ring or pseudo-ring within the disk, and an apparent secondary bar crossing the ring. The presence of stellar nuclear rings in these and other galaxies suggests that the centers of these galaxies are dynamically cool and disklike, rather than being dynamically "hot" bulges.

Noordermeer and Sparke investigated the kinematics of a model for lopsided galaxies consisting of a disk lying off-center in a dark halo and orbiting the halo center. They searched for families of stable, closed, non-crossing orbits that the gas should follow. Several models showed strong lopsided gas kinematics, especially those in which the disk spins around its axis in a retrograde sense compared to its orbit around the halo center. The asymmetry was most pronounced when the halo dominated the system. Late-type galaxies, which are dominated by dark matter, show lopsided gas more frequently than early-types.

Sparke, with A. Cox (Beloit College), Watson (UNAM), and van Moorsel (NRAO) discussed optical observations and HI mapping of II Zw 71, a polar ring galaxy, and its close companion II Zw 70. The blue, star-forming, and very gas-rich ring orbits almost over the pole of the small central S0 galaxy, which is almost devoid of HI gas. The ring gas is in orderly rotation, but there is a gas streamer connecting the ring with the companion, a starbursting dwarf. This gaseous bridge, plus the Hα emission in the polar ring and in II Zw 70, are strong evidence for an ongoing interaction between the two galaxies.

Gallagher and Sparke participated in the Hubble Heritage Project's observation of the polar ring galaxy NGC 4650A, chosen by 8,000 Internet voters from a list of candidates. They used the Wide Field and Planetary Camera2 to take multi-color visible waveband images. The unusual disk-ring structure of polar ring systems may be the remnant of a colossal collision between two galaxies, probably at least 1 billion years ago. What is left of one galaxy has become the rotating inner disk of old red stars, while gas from another, smaller, galaxy would have been stripped off and captured to form the polar ring, which we see almost edge-on. Dr. Magda Arnaboldi (Naples Observatory) and her graduate student Enricetta Iodice visited Madison for a month to compare their near-infrared images. Their models indicate that the polar ring has undergone vigorous star formation with the past few hundred million years.

5 Instrumentation and Observatories

5.1 WIYN Instrumentation

Bershady and Andersen (Penn State; CIC exchange student at UW) concluded primary construction of an NSF-funded funded fiber integral field unit ("6-Pak") for WIYN. The cable will be completed and installed on WIYN during the up-

coming year. As part of this instrumentation effort, Bershady is developing a throughput enhancement of the WIYN Bench Spectrograph. A second IFU cable ("Spider") for the Hobby-Eberly Telescope's Medium Resolution Spectrograph is completed and awaits installation. These instruments are unique in their high delivered etendue (7-10 m^2 $arcsec^2$) and spectral resolutions (up to R = 10000). They are designed for study of the dynamics of spiral disks of external galaxies.

5.2 SALT

Wisconsin will lead the effort to contribute the first major SALT facility-class instrument, the Prime Focus Imaging Spectrograph. Nordsieck (PI) is working on its design. It will specialize in very high throughput with low and medium spectral resolution (R = 500 - 13000), plus spectropolarimetry from 3200 to 9000 Å, using an articulated camera and Volume Phase Holographic gratings and a double etalon Fabry-Perot system. With a peak efficiency above 65% and a 3200 Å efficiency above 30%, it will be unique among or superior to existing 8-10m telescopes in the UV, in medium resolution spectroscopy, in Fabry-Perot spectroscopy, and in spectropolarimetry. The instrument will be integrated at the University of Wisconsin - Madison Space Astronomy Lab. The Fabry-Perot system will be supplied by Rutgers and the detector system by South African Astronomical Observatory. Commissioning is currently targeted for late 2003.

5.3 Other instruments

Percival released the new Java-based remote observing package that integrates **Progressive Image Transmission** for large images with a remote engineering data system targeted for low-bandwidth connections to the observatory.

Percival, K. Jaehnig, D. Michalski, and S. Gabelt finished the design of the **advanced star tracker**, the ST5000, that provides pitch, yaw, and roll control for sounding rockets. It can also do a full "lost in space" attitude determination without gyros for both sounding rockets and satellites. The WISP flight of Nordsieck (see §3), its first test, was a complete success. The instrument is being considered as a replacement for the Ball "STRAP" star tracker that has been standard for sounding rockets since the 1970's.

Nordsieck's **halfwave polarimeter (HPOL)** resided on the 0.9m telescope at Pine Bluff Observatory during most of this time period, traveling to the 3.5m WIYN telescope in September 2000. HPOL obtained 415 observations of 134 distinct targets (including 7 nights at WIYN) between Oct 1, 1999 and Sept 30, 2000. Specific areas of interest are: interacting binaries, Be stars, ISM probes, AG Dra, Ae/Be stars, and LRV stars. Broadband polarimetric results of HPOL observations are listed on the HPOL website: www.sal.wisc.edu/HPOL

Nordsieck, Jaehnig, and Harris are continuing development of the **Far-Ultraviolet SpectroPolarimeter (FUSP)**, a sounding rocket payload that will obtain the first high-precision spectropolarimetry from 1050 - 1500 Å, and the first astronomical polarimetry of any kind below 1300 Å. FUSP will provide measurements of polarization produced by electron scattering, resonance line scattering, and hydrogen Rayleigh scattering in the inner circumstellar environment of hot stellar systems, and thereby quantitatively constrain the geometry and dynamics of the system. In addition, the strength and geometry of the magnetic field will be determined from a new diagnostic tool, the Hanle Effect. The telescope is F/2.5 prime-focus with a 50 cm primary. At the telescope focus is the polarimetric optics, a stressed lithium flouride rotating waveplate, followed by a diamond Brewster-angle mirror. The spectrometer uses an aberration-corrected spherical holographic grating and a UV-sensitized CCD detector. The spectral coverage is 1050 - 1500 Å, the spectral resolution is 0.65 Å. The net spatial resolution is about $1'$ perpendicular to the dispersion. The first flight is planned for late 2001, targeting the Be star Zeta Tau and the unpolarized standard β Tau.

Harlander (St Cloud State), Roesler (Physics Dept), and Reynolds have continued the development of a **Spatial Heterodyne Spectrometer** for observations of faint diffuse [O II] 3727 emission from the warm ionized component of the interstellar medium.

Far-Ultraviolet Spectrographic Explorer (FUSE). Savage is a Co-Investigator for the FUSE satellite which was launched in June 1999. FUSE is a dedicated UV spectroscopy mission operating in the 905 to 1187 Å region at a spectral resolution

of ∼20,000. Savage's principal observational program with FUSE involves measurements of O VI absorption produced by the hot interstellar medium of the Milky Way disk and halo. The goal is to study the distribution and kinematics of O VI in order to gain insights about the origin(s) of the hot gas in the interstellar medium. During its first 16 months of operation, FUSE has provided a wealth of information about stars, the ISM, the IGM, and extragalactic sources. The 2000 July 20 issue of ApJ Letters contains 22 papers reporting initial FUSE results. Although FUSE was designed to be a three year mission, NASA has recently agreed to provide the funding that will allow FUSE to be operated for five years.

The **Cosmic Origins Spectrograph (COS)** will be installed on the Hubble Space Telescope in 2003. Savage is a Co-Investigator on the COS science team with J. Green (U. Colorado) serving as the Principal Investigator. COS is a very high efficiency spectrograph designed to operate from 1150 to 3200 Å at a spectral resolution of 22,000. In the Far-UV COS is approximately 15 times more efficient than STIS and will be used for a wide range of spectroscopic studies of faint galactic and extragalactic objects. Savage's observational studies with COS will involve the origin of hot gas associated with galaxy groups and galaxy halos. These studies will be pursued through absorption line observations of highly ionized ions in the UV spectra of QSOs. Species to be studied include O IV, O V, O VI, Ne V, Ne VI, Ne VIII, Mg X and Si XII.

6 Teaching and Outreach

The College Level-1 Institute (Mathieu, Director) within the National Institute of Science Education (Mathieu, Associate Director) completed the Learning Through Technology website. All of the CL-1 products can be found at the website www.wcer.wisc.edu/nise/cl1/.

The "Universe in the Park" program (Wilcots, director), now in its fifth year, is predicated on the idea that the best environment in which to introduce the general public to astronomy is outside, under dark skies. The program takes place in state parks throughout Wisconsin during the summer and fall camping seasons. It consists of talks and slide shows, question sessions, and providing the general public a view astronomical objects through one of the program's telescopes. During the 2000 season there were 43 sessions in 27 state parks from the end of May to the middle of October, as well as Scout camps and Camp MASH, a summer camp for arthritic children. We have involved several members of the faculty, staff, and students, both graduate and undergraduate.

Hoffman was named a Teaching Fellow by the UW-Madison College of Letters and Science, and conducted workshops at a college-wide teaching assistant training session.

7 Publications

Andersen, D.R., Bershady, M.A., Sparke, L.S., Gallagher III, J.S., Wilcots, E.M. 2000, "The Measurement of Disk Elongation in Nearby Disk Galaxies," submitted to ApJ Lett

Barnes, S. A., 2000, "Rotation periods of cluster stars", in "Stellar Clusters and Associations: Convection, Rotation and Dynamos", ed. R. Pallavicini, G. Micela and S. Sciortino, ASP Conf. Series, vol 198 (San Francisco: ASP Press), 319

Barnes, S. A., Sofia, S., & Pinsonneault, M. H., 2001, "Disk-locking and the presence of Slow Rotators among Solar-Type Stars in Young Star Clusters", ApJ, 20 Feb2001 issue

Bershady, M. A., Jangren, A., Conselice, C. J. 2000, "Structural and Photometric Classification of Galaxies – I. Calibration Based on a Nearby Galaxy Sample," AJ, 119, 2645

Bershady, M. A. 2000, "Galaxy Form and Spectral-Type: A Physical Framework for Measuring Evolution," Astrophysics & Space Science, 269-270, 183

Bland-Hawthorn, J. and Reynolds, R. J., "Gas in Galaxies", in *Encyclopedia of Astronomy and astrophysics*, ed. P. G. Murden (IOP Publishing and Macmillan), in press

Bouche, N., Lowenthal, J.D., Charlton, J.C., Bershady, M.A., Churchill, C.W., Steidel, C.C., 2000,"H-alpha Imaging with HST + NICMOS of an Elusive Damped Ly-alpha Cloud at z = 0.6", ApJ, submitted

Brandt, J.C. et al. (incl. B. D. Savage) 2000, "Goddard High Resolution Spectrograph Observations of NGC 4151", AJ, in press

Brandt, W.N., & Gallagher, J.S. 2000, "Observational Similarities and Potential Connections Be-

tween Luminous Ultrasoft NLS1s and BALQSOs", New Astronomy Reviews, in press

Brown, J.C., Ignace, R. and Cassinelli, J.P. 2000, "Hot Star Polarimetric Variability and the Nature of Wind Inhomogeneities", A&A, 356, 619

Callaway, M.B., Savage, B.D., Benjamin, R.A., Haffner, L.M., & Tufte, S. L. 2000, "Observational Evidence of Supershell Blowout in GS 018-04+44", ApJ, 532, 943.

Cassinelli, J. P. & MacGregor, K. B. 2000, "The Dynamics of Flux Tubes in the Radiative Interiors of Hot Stars", in IAU Coll. 175, *The Be Phenomenon in Early Type Stars*, eds. M.A. Smith, H.F. Henrichs, J. Fabregat (San Francisco, ASP), 337

Churchwell, E. 2000, "Massive Star Formation: New Results", in *Proc. IAU General Assembly, Joint Discussion 3*, in press

Cohen, D.H., Cassinelli, J.P., MacFarlane, J.J., & Owocki, S.P. 2000, "EUV/X-ray Emission and the Thermal and Ionization Structure of B star Winds", in *Thermal and Ionization Aspects of Flows from Hot Stars: Observations and Theory*, ASP Conf Ser. 204, ed. H.J.G.L.M. Lamers & A. Sapar (San Francisco, ASP), 65

Cole A.A., Smecker-Hane, T.A., & Gallagher, J.S. 2000, " The Metallicity Distribution Function of Red Giants in the LMC", AJ, 120, 1808

Conselice, C. J., Bershady, M. A., & Jangren, A. 2000, "The Symmetry of Galaxies: Physical Morphology for nearby and High Redshift Galaxies," ApJ, 529, 886

Conselice, C. J., Bershady, M. A., & Gallagher, J. S., III. 2000, "Physical morphology and triggers of starburst galaxies", A&A, 354, L21

Conselice, C.J., Gallagher, J.S., Calzetti, D., Homeier, N., & Kinney, A. 2000, "Panchromatic Study of Nearby Ultraviolet-bright Starburst Galaxies: Implications for Massive Star Formation and High-Redshift Galaxies", AJ, 119, 79

Cox, A.L., Sparke, L.S., Watson, A.M., & van Moorsel, G. 2001, "Stars and Gas in the Galaxy Pair II Zw 70/71", AJ, in press

Dayal, A., et al. (incl. J.S. Gallagher). 2000, AJ, 119, 315

de Grijs, R., O'Connell, R. W., Becker, G.D., Chevalier, R.A., & Gallagher, J.S. 2000, "Supernova Remnants in the Fossil Starburst in M82". AJ, 119, 681

De Gouveia Dal Pino, E. & Lazarian, A. 2000, "Ultra-high-Energy Cosmic-Ray Acceleration by magnetic reconnection in newborn accretion-induced collapse pulsars", ApJ, 536, L31

de Oliveira-Costa, A., Tegmark, M., Devlin, M.J., Haffner, L.M., Herbig, T., Miller, A.D., Page, L.A., Reynolds, R.J., and Tufte, S.L., "Galactic Contamination in the QMAP Experiment", ApJ(Lett), in press

Dickinson, M. plus 9 co-authors, Bershady, M. A., Conselice, C., Ferguson, H., Fruchter, A. 2000, "The Unusual Infrared Object HDF-N J123656.3+621322," ApJ, 531, 624

Dolan, C.J., & Mathieu, R.D. 1999, "A WIYN Lithium Survey for Young Stars in the λ Orionis Star-Forming Region", AJ, 118, 2409

Dolan, C.J., & Mathieu, R.D. 2000, "The Spatial Distribution of the λ Orionis Pre-Main-Sequence Population", AJ, in press

Efroimsky, M., Lazarian, A. 2000, "Inelastic relaxation in tumbling asteroids and comets", *MNRAS*, 311, 269-278

Ferguson, A.M.N., Gallagher, J. S., & Wyse, R.F.G. 2000, "On the Nature of Andromeda IV", AJ, 120, 821

Greiner,J.,Schwarz, R., Zharikov, S., & Orio, M. 2000, "RX J1420+5334 – another tidal disruption event?", A&A (Lett.), in press (astro-ph 0009430)

Greiner, J., Orio, M., & Schwarz, R. 1999, "The shortest-period supersoft X-ray source", A&A, 355, 1041

Haffner, L.M. "The Wisconsin H-Alpha Mapper Northern Sky Survey", ASP Conference Series, in press

Haffner, L.M., Reynolds, R.J., and Tufte, S.L., 2000, "The Wisconsin H-alpha Mapper: A New Look at the Warm Ionized Medium", Rev. Mex. A&A (Conf. Proceedings), 9, 335, 2000.

Harries, T.J., Babler, B.L., & Fox, G. K. 2000, "The polarized spectrum of the dust producing Wolf-Rayet+O-star binary WR137" A&A, 361, 273.

Heiles, C., Haffner, L.M., Reynolds, R.J., and Tufte, S.L. 2000, "Physical Conditions, Grain Temperatures, and Enhanced Very Small Grains in the Barnard Loop", ApJ 536, 335

Hoffman, J.L., Whitney, B.A. & Nordsieck, K.H. 2000, "The Be Phenomenon in Early-Type Stars", in IAU Colloq. 175, ed. M. Smith, H. Hen-

richs & J. Fabregat, ASP Conf 214 (San Francisco: ASP)

Hofner, P., Wyrowski, F., Walmsley, C. M., & Churchwell, E. 2000, "A C17O Survey toward Ultracompact HII Regions", Ap. J., 536, 393

Holtzman, J.A., Gallagher, J.S., et al. 1999, "Observations and Implications of the Star Formation History of the Large Magellanic Cloud", AJ, 118, 2262

Howk, J., Cassinelli, J.P., Bjorkman, J.E., & Lamers, H.J.G.L.M. 2000, "Stagnation and Infall of Dense Clumps in the Stellar Wind of τ Scorpii", ApJ, 534, 348

Howk, J.C., & Savage, B.D. 2000, "The Multiphase Halo of NGC 891: WIYN H-alpha and BVI Imaging", AJ, 119, 644

Howk, J.C., Savage, B.D., & Fabian, D. 1999, "Abundances and Physical Conditions in the Warm Neutral Medium Towards Mu Columbae", ApJ, 525, 253

Howk, J.C., Sembach, K. R., & Savage, B. D. 2000, "The Abundance of Interstellar Boron", ApJ, in press

Hunter, D.A.,O'Connell, R.W., Gallagher, J.S., & Smecker-Hane, T.A. 2000, "The Star Clusters in the Starburst Irregular Galaxy
NGC 1569", AJ, November.

Hunter, T., Churchwell, E., Watson, C., Cox, P., Benford, D.J., & Roelfsema, P.R. 2000, "350 μm Images of Massive Star Formation Regions", AJ, 119, 2711.

Jangren, A., Bershady, M. A., Conselice, C., Koo, D. C., Guzman, R. 1999, "Structural and Photometric Classification of Galaxies – II. Application to Luminous Blue Compact Galaxies at Intermediate Redshift," submitted to AJ

Lagache, G., Haffner, L.M., Reynolds, R.J., & Tufte, S.L. 2000, "Evidence for Dust Emission in the Warm Ionised Medium Using WHAM Data", A&A, 354, 247

Lagache, G., Puget, J.-L., et al. (incl. Reynolds, R.J.) 2000, "The Extragalactic Background and its Fluctuations in the Far-Infrared Wavelengths", in proceedings of the Ringberg Castle Conference *ISO Surveys of a Dusty Universe*, in press

Lazarian, A., & Pogosyan, D. 2000, "Velocity modification of HI power spectrum", ApJ, 537, 720

Lazarian, A. & Draine, B.T. 2000, "Resonance paramagnetic relaxation and alignment of small grains", ApJ, 536, L15

Lazarian, A. 2000, "Physics of Grain Alignment", in *Cosmic Evolution and Galaxy Formation*, ed. J. Franco, ASP, in press

Lazarian, A. & Vishniac, E. 2000, "Fast Reconnection of Magnetic Fields in Turbulent Fluids", Rev. Mex. Astr. Astrofis., 9, 55-62

Lazarian, A. 1999, "Statistics of Turbulence from Spectral-Line Data Cubes", in "Plasma Turbulence and Energetic particles", eds. Michal Ostrowski & Reinhard Schlickeiser, Cracow, p. 28-47

Li, Q., Brown, J.C., Ignace, R., Cassinelli, J.P., & Oskinova, L.M. 2000, "Wolf-Rayet wind structure and optical variability", A&A, 357, 233.

Maciejewski, W., & Sparke, L.S. 2000, " Orbits supporting bars within bars", MNRAS, 313, 745

Magalhães, A.M. & Nordsieck, K.H. 2000, "Asymmetries around Luminous Red Variables", in *The Carbon Star Phenomenon*, ed. R.F.Wing, (Dordrecht:Kluwer), 433

Matheson, T., 4 co-authors, Bershady, M. A., et al. 2000, "Optical Spectroscopy of Supernova 1993J During Its First 2500 Days," AJ, 120, 1487

Mathieu, R.D., 2000, "Assessment Tools to Drive Learning: FLAG, SALG, and Other Proven Assessments Available Online", in *Targeting Curricular Change: Reform in Undergraduate Education in Science, Math, Engineering, and Technology*, Annals Amer. Higher Education, in press

Mathieu, R.D. 2000, "Pre-Main Sequence Binary Stars", in *Encyclopedia of Astronomy and Astrophysics*, ed. Emerson, in press

Mathieu, R.D., 2000, "The WIYN Open Cluster Study", in *Stellar Clusters and Associations: Convection, Rotation and Dynamos*, ed. R. Pallavicini, G. Micela & S. Sciortino (San Francisco: ASP Press), 517

Mathieu, R.D., Ghez, A., Jensen, E.L.N., & Simon, M., 2000, "Pre-Main Sequence Binary Stars", in *Protostars and Planets IV*, ed. V. Mannings, A.P. Boss and S.S. Russell (Tucson: U. of Ariz. Press), 703

Mathis, J. S. 2000, "Properties of interstellar dust", J. Geophys. Res., 105, 10269

Mathis, J. S. 2000, "The Warm Ionized Medium in the Milky Way and Other Galaxies", ApJ, in press

Matthews, L.D., Gallagher, J.S., & van Driel,

W. 1999, "The Extraordinary "Superthin" Spiral Galaxy UGC 7321. I. Disk Color Gradients and Global Properties from Multiwavelength Observations" AJ, 118, 2751

Monkiewicz, J., et al. (incl. J.S. Gallagher) 1999, "The Age of the Sculptor Dwarf Spheroidal Galaxy from Imaging with WFPC2", PASP, 111, 1392

Moos, H.W. et al. (incl. B.D. Savage) 2000, "Overview of the FUSE Mission", ApJ, 538, L1.

Mould, J.R., et al. (incl. J.S. Gallagher). 2000,"Jet-induced Star Formation in Centaurus A", ApJ, 536, 266

Murphy E.M., Sembach K.R., Gibson, B.K., Shull, J.M., Savage, B.D., Roth, K.C., Moos, H.W., Green, J.C., York, D.G., & Wakker, B.P., 2000, "FUSE spectroscopy of high-velocity cloud complex C", ApJ, 538, L35

Noordermeer, E., Sparke, L.S., & Levine, S.E. 2001, "The Kinematics of Lopsided Galaxies", MNRAS, submitted

Nordsieck, K.H. 1999, Proc SPIE, 3764, 124. "Ultraviolet astronomical polarimetry: some results and prospects"

Nordsieck, K.H. & Wisniewski, J. 2000, "Ultraviolet and Visible Spectropolarimetric Variability in P Cygni" in *P Cygni - 2000; 400 years of Progress*, ed. M. de Groot (San Francisco: ASP), in press

Oegerle, W.R. et al. (incl. B.D. Savage) 2000, "FUSE Observations of the Galactic and Intergalactic Medium Towards H 1821+643", ApJ,538, L23

Orio, M., Covington, J., & Ögelman, H. 2000, "The observations of classical and recurrent novae in the ROSAT data base", A&A, submitted

Orio, M., Greiner, J., 1999, "LMC 1995, the third supersoft X-ray nova", A&A, 344, L13

Orio, M., with 9 authors following. 2000, ApJ(Letters), submitted

Pankonin, V., Churchwell, E., Watson, C., & Bieging, J. 2000, "A Search for the Earliest Stages of Massive Protostars", ApJ, in press

Pisano, D.J., & Wilcots, E.M. 2000, "Structure and Star Formation in NGC 925", AJ, 120, 763

Pisano, D.J., & Wilcots, E.M. 2000, "Companions and Interactions in the NGC 6946 System", MNRAS, in press

Pisano, D.J., & Wilcots, E.M. 2000, "Assessing the State of Galaxy Formation", to appear in *Gas and Galaxy Evolution*, ASP conference series, eds. J.E. Hibbard, M.P. Rupen, and J.H. van Gorkom

Reynolds, R.J., Haffner, L.M., and Tufte, S.L. 2000, "Temperature Variations and Non-Photoionization Heating in the Warm Ionized Medium of Galaxies", Rev. Mex. A&A (Conf.), 9, 249, 2000.

Richter, P., Savage, B.D., Wakker B.P., Sembach K.R., Kalberla P.M.W. 2001, "The FUSE spectrum of PG0804+761: a study of atomic and molecular gas in the lower Galactic halo and beyond", ApJ, in press

Savage, B.D. 1999, "Ultraviolet-Optical Space Astronomy - Past, Present, and Future", in *Ultraviolet-Optical Space Astronomy Beyond HST*, eds. J. A. Morse, J. M. Shull, and A. Kinney (ASP Conference Series No. 164), 3

Savage, B.D. et al. 2000, "FUSE Observations of O VI Absorption in the Galactic Halo", ApJ, 538, L27

Savage, B.D. 2000, "Ultraviolet Absorption Line Studies of the Galactic Interstellar Medium with the Goddard High Resolution Spectrograph", in *A Decade of HST Science*, (Cambridge: Cambridge Univ. Press), in press

Savage, B.D. 2001, "Early Ultraviolet Spectroscopy from Space", in *The Century of Space Science*, eds. J. Bleeker, J. Beiss, M.C.E. Huber (Dordrecht: Kluwer Academic Press), in press

Savage, B.D., Sembach, K.R., & Howk, J. C. 2001, "STIS and GHRS Observations of Warm and Hot Gas Overlying the Scutum Supershell", ApJ, Jan. 20

Savage, B.D., Wakker, B.P., et al., 2000, "The Hubble Space Telescope quasar absorption line Key project XV. Milky Way absorption lines", ApJS, in press

Sembach, K.R., Savage, B.D., & Hurwitz, M. 1999, "GHRS and OFREUS-II Observations of the Highly Ionized Interstellar Medium Toward ESO 141-055", ApJ, 524, 98

Sembach, K.R et al. (incl. B.D.Savage). 2000, "FUSE Observations of O VI in High Velocity Clouds", ApJ, 538, L31.

Shull, M.J. et al. (incl. B.D. Savage) 2000, "FUSE Observations of Diffuse Molecular Hydrogen", ApJ, 538, L73.

Shull, M. J. et al. (incl. B.D. Savage) 2000,

"FUSE Observations of the Low-Redshift Ly-Beta Forest", ApJ, 538, L13.

Smith, L.J., & Gallagher, J.S. 2000, "The Properties of Young Clusters in M82", in *Massive Stellar Clusters*, ASP Conf. Ser., eds. A. Lancon and C.M. Boily

Snow, T.P. et al. 2000, "FUSE Observations of H_2 in the Translucent Interstellar Cloud Toward HD 73882", ApJ 538, L65.

Sparke, L.S. 2000, "Warps, Polar Rings and High-Velocity Clouds", to appear as a chapter in *High Velocity Clouds*, ed. H. van Woerden, U. Schwarz, & B. Wakker (Dordrecht: Kluwer), in press

Stassun, K. G. 2000, "A Brief Introduction to DQ Tau", in *The Formation of Binary Stars*, ASP Conference Proceedings, ed. H. Zinnecker & R. Mathieu

Stassun, K. G., Mathieu, R. D., Vrba, F. J., & Mazeh, T. 2000, "A 10 Micron Search for Inner-Truncated Circumstellar Disks Among Pre-Main Sequence Stars With Photometric Rotation Periods", 2000, AJ, in press

Steffen, A., Mathieu, R.D., Lattanzi, M.G., Latham, D.W., Mazeh, T., Prato, L., Simon, M., and Zinnecker, H. 2000, "A Dynamical Mass Constraint for Pre-Main-Sequence Tracks: The Binary NTT 045251+3016", AJ, submitted

Tripp, T. M., & Savage, B.D. 2000, "O VI and Multicomponent HI Absorption Associated with a Galaxy Group in the Direction of
PG 0953+415: Physical Conditions and Baryonic Content", ApJ, 542, 42

Tripp, T. M, Savage, B.D, & Jenkins, E.B. 2000, "Intervening O VI Quasar Absorption Systems at Low Redshift: A Significant Baryon Reservoir", ApJ, 534, L1

van Driel, W., Arnaboldi, M., Combes, F., & Sparke, L. S. 2000, "A neutral hydrogen survey of polar ring galaxies. III. Nançay observations and comparison with published data", A&AS, 141, 385

Vincent,M.B., et al. (incl. J.S. Gallagher & J.G. Hoessel), 2000, "Jupiter's Polar Regions in the Ultraviolet as Imaged by HST/WFPC2: Auroral-Aligned Features and Zonal Motions", Icarus, 143, 205

Vincent,M.B., et al. (incl. J.S. Gallagher & J.G. Hoessel), 2000, "Mapping Jupiter's Latitudinal Bands and Great Red Spot Using HST/ WFPC2 Far-Ultraviolet Imaging", Icarus, 143, 189

Voshchinnikov, N.V., & Mathis, John S. 1999, "Calculating Cross Sections of Composite Interstellar Grains", ApJ, 526, 257

Wakker, B.P., J.C. Howk, B.D. Savage, H. van Woerden, S.L. Tufte, U.J. Schwarz, R. Benjamin, R.J. Reynolds, R.F. Peletier, & P.M.W. Kalberla, 1999, "Identification of Low-Metallicity Gas Accreting onto the Milky Way", Nature 402, 388

Wakker B.P., & Mathis J.S. 2000, "Dependence of gas phase abundances in the ISM on column density", ApJ(Lett), in press

Wood, K. & Reynolds, R.J., 1999, "A Model for the Scattered Light Contribution and Polarization of the Diffuse H-alpha Galactic Background", ApJ 525, 799

Wood, K., Wolk, S., Stanek, K., Leussis, G., Stassun, K. G., Wolff, M., & Whitney, B. 2000, "A Test of Star Formation Theory: The Connection Between Rotation, Accretion, and Circumstellar Disks Among Low-Mass Pre-Main Sequence Stars," ApJ, in press