

The University of Wisconsin-Madison

Department of Astronomy

Madison, WI 53706

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, and Assistant Professors Ber-shady, Lazarian, and Wilcots. Percival served as Scientist. Emeriti Professors who reside in Madison are Bless, Code (mainly based in Tucson), Mathis, and Whitford. Postdoctoral fellows were Harris, Quigley, Haffner, & Wakker. S. Barnes is the “McKinney Assistant Scientist”. He arrived from Lowell Observatory in Flagstaff, Arizona where he held the Lowell Fellowship. Henry Kobulnicky arrived as a Hubble Fellow from UC-Santa Cruz.

Dr. Alex Lazarian joined the staff as Assistant Professor in September, 1999. He had postdoctoral fellowships at the Canadian Institute for Theoretical Astrophysics, Princeton University, and the University of Texas. He is presently considering problems of magnetic reconnection in the interstellar medium, dust-grain alignment, statistics of interstellar turbulence, and cosmic rays.

A. Weitenbeck and J. Lattis were appointed Lecturers for the Fall semester 1998-1999; Weitenbeck and M. Quigley served in that capacity in the spring semester.

A. Cole completed his Ph.D. thesis, “Helium Burning Stars and the Star-Formation Histories of Dwarf Galaxies,” and moved to a postdoctoral position at the University of Massachusetts.

Matthew Haffner received the Ph.D. degree for his work with the Wisconsin H α Mapper (WHAM) project with a thesis entitled “WHAM Observations of H-alpha, [S II], and [N II] toward the Orion and Perseus Arms.” In January he joined the WHAM team in a postdoctoral

position. S. Tufte left his postdoctoral position with the WHAM team in July to begin his duties as Assistant Professor in the Department of Physics at Lewis and Clark College in Portland, OR.

C. Howk received the Ph.D. degree with a thesis “Extraplanar Dust in Nearby Edge-On Galaxies” based on imaging data from WIYN. In April, 1999, he joined the research staff at The Johns Hopkins University pursuing UV studies of the interstellar medium and working with the FUSE (Far Ultraviolet Spectroscopic Explorer) project.

M. Faison (Beloit College) defended his Ph.D. thesis dealing with small scale (a few AU) structure in the Interstellar Medium (ISM). Faison used VLBI techniques to measure small scale structure toward bright background quasars. He was advised by Miller Goss while at NRAO and by Churchwell.

Edo Noordermeer, a final-year student at Utrecht University, visited for the 1998/99 academic year to work with Sparke on lopsided galaxies. Marta Sewilo (Krakow Univ.) worked with Churchwell on VLA and WIYN data reduction. David Andersen is a CIC-exchange graduate student from Penn State.

Cassinelli was on leave in the fall of 1998 for two months at the High Altitude Observatory of NCAR, and for two months at the Physics and Astronomy Department of the University of Glasgow, Scotland. Churchwell continues to serve as the Chair of the Scientific Advisory Committee for the Atacama Large Millimeter Array (ALMA) project. He has joined the Visitors Committee for NAIC (Arecibo Observatory) and a newly established long-range Program Advisory Committee serving the Director of NRAO. Gallagher continued as a member of the International Gemini 8-m Telescopes Project and WIYN Telescope Boards and is in-

volved in MAXAT, studies of extremely large ground-based telescopes. Mathieu served on the Astronomy and Astrophysics Survey - UVOIR from Space Panel, on the WIYN Board. and on the WIYN Scientific Advisory Committee (Chair). He is Associate Director, National Institute of Science Education, and is Director of its College Level 1 Institute. Savage continued as a member of the Committee for Astronomy and Astrophysics of the National Research Council. The AURA Board of directors elected Savage to the Space Telescope Institute Council. Savage was a member of the Public Policy and Education Panel of the Astronomy and Astrophysics Decade Survey and of the NASA UV-Optical Space Astronomy Working Group, which completed the strategy report entitled, "The Emergence of the Modern Universe: The Scientific Case for the Next UV-Optical Space Telescope." Wilcots served on the ALMA Advisory Committee. Percival continued his participation in the IAU Working Group on Astronomical Standard's initiative "Standards of Fundamental Astronomy." The goal of this effort is to produce a set of basic software that implement commonly-used formulae and standard models in fundamental astronomy.

2 Stars, Outflows, and Galactic Structure

2.1 Star formation regions.

Churchwell and collaborators continued their investigations of massive star formation regions. In collaboration with Todd Hunter (CfA), Pierre Cox (Inst. de Astroph, Paris), and Peter Roelfsema (Univ. Groningen, Netherlands), Churchwell and C. Watson have completed a FIR high resolution survey of massive star formation regions. Images of 27 regions were obtained at $350 \mu\text{m}$ with the Caltech Submillimeter Observatory on Mauna Kea, Hawaii. Twenty-three regions showed warm dust emission. The FIR emission distributions were compared with radio free-free and the positions of OH, H₂O, and CH₃OH masers. In most cases the FIR and radio free-free emission are coincident, but the masers tend to be close to, but not usually coincident with, the radio continuum or FIR peaks.

Ten of the observed FIR sources have no radio continuum counterparts and may be emerging massive protostars which have not yet been able to form a detectable UC HII region because of massive infall of ambient material onto the protostar. That is, they may be the long sought precursors to UC HII regions.

Work has continued on the quest to measure the angular expansion rates of UC HII regions. The first 5 years of measurements of G5.89 was published by Acord, Churchwell, and Wood (1998). In the meantime a 4th epoch has been obtained for both G5.89 and G34.26, which gives a 10 year baseline for both objects.

Churchwell and Code have obtained deep V, R, and I images of massive star formation regions to detect very reddened stars which might provide information on the absorbing natal cloud. Spectra were also obtained toward G35.20-1.74 and G80.87+0.42 this past August.

Methyl cyanide (CH₃CN) seems to be strongly enhanced at locations where massive protostars are emerging. C. Watson and Churchwell are collaborating with Pankonin (NSF) and Biegging (Univ. Arizona) in a program to use CH₃CN as a possible tracer of emerging massive protostars by: (a) surveying CH₃CN toward a large number of massive star formation regions using the HHT submillimeter telescope on Mt. Graham in Arizona; and, (b) following the single-dish observations with high spatial resolution observations using the BIMA millimeter array. The single-dish data have been obtained and reduced and the BIMA observations are scheduled. Most of the massive star formation regions observed were detected in CH₃CN line emission.

2.2 Pre-Main-Sequence (PMS) stars.

Stassun, Mathieu, Mazeh (Tel Aviv), and Vrba (USNO) continued their study of disk-regulated rotation among low-mass PMS stars. They had found rotation periods for nearly 250 low-mass PMS stars in the vicinity of the Orion Nebula. Stellar rotation periods do not correlate with the presence of near-IR excess-emission signatures of disks, suggesting that at an age of a million years disks do not play a critical role in regulating stellar angular momentum.

Subsequently, the team has searched for mid-IR (N-band) disk signatures among 32 PMS stars lacking disk signatures in the near-IR. In a conventional picture, the slow rotators among these stars are regulated by disks that have inner holes. However, the lack of mid-IR excess shows definitively that no disks are present. A large fraction of slowly rotating PMS stars lack near-IR excesses, implying that some 40% of all young, low-mass, PMS stars do not have disks capable of regulating stellar rotation. These findings challenge existing PMS rotational evolution models, which typically employ disk-regulated stellar rotation as the primary means for depleting stellar angular momentum early in the PMS phase.

Dolan continued his thesis study (with Mathieu) of the λ Orionis star-forming region. Using WIYN/Hydra they have surveyed lithium absorption in 2400 PMS candidates across a diameter of the region. Previous objective prism surveys had revealed 15 T Tauri stars. Using the lithium diagnostic, Dolan and Mathieu have found 212 PMS stars. These stars fall on a remarkably narrow locus in the H-R diagram with an inferred average age on the order of 1 million years. This age is less than that of the OB stars, suggesting triggered star formation. Remarkably, the ages of the low-mass stars seem independent of the distance from λ Ori, even for stars up to 30 pc away. Additionally, the newly discovered stars are nearly all weak-lined T Tauri stars and, despite their youth, do not show diagnostics of actively accreting disks. The low-mass/high mass ratio for these stars seems higher than for the field star initial mass function, even though only about 10 percent of the star-forming region has been thoroughly surveyed for low-mass young stars.

Stassun and Whitney are combining archival HST NICMOS images of Class I stars in Taurus with 3-D Monte Carlo image-synthesis codes to investigate the disk/envelope structure of very young stars. This work addresses whether the observed scattered-light morphologies are produced by jet-evacuated “cavities” in large circumstellar envelopes, or by bipolar jet-remnant material in the absence of circumstellar envelopes.

Relative astrometric observations of the PMS

single-lined spectroscopic binary 045251+3016 were obtained with the HST Fine Guidance Sensor by Mathieu, Lattanzi (Torino), and Zinnecker (Potsdam). Mathieu and Steffen found the semi-major axis to be $0.0352''$. The spectroscopic orbit provides the total mass of the system as a function of distance; at the Taurus distance of 142 pc, the masses of the primary and secondary are 1.7 and 0.9 M_{\odot} , respectively. Efforts are underway to obtain a spectrum of the secondary and thereby a radial velocity measurement, determining the masses of the individual stars and the distance to the binary directly. The masses of these PMS stars will test current PMS stellar evolution models.

2.3 Cool stars.

Using the WIYN DensePak (a coherent bundle of 91 fibers, each subtending $3''$ on the sky, placed in a grid with $4''$ spacing), Anderson continued his monitoring the Ca II K line monitoring of the stars in various galactic clusters in order to find secular variations in their chromospheric activities.

Barnes has been working on the structure and rotational evolution of G, K and M stars. He generates rotating stellar models and constrains and tests them as a function of age using observations of photometrically determined rotation periods of stars in young open clusters.

2.4 Hot stars.

Cassinelli worked with Keith MacGregor (HAO) to explore the possibility that a magnetic field could be transported to the surface by buoyancy. The field might be generated by a dynamo at the interface between the convective core and radiative envelope. The dynamics and thermodynamics of a flux tube are followed versus time. There is a significant slowing of the rise of the axisymmetric tubes when they achieve a state in which both the density and temperature are only slightly lower than the surrounding medium. The rise can continue at a slow rate and in some cases reach the surface on the order of 10^4 years. For weaker fields the rise rate could be amplified by the effects of circulation currents. This latter topic is being investigated in collaboration with M. Maheswaran

(UW Marathon Center.)

With John Brown and Rico Ignace (Glasgow U.), Cassinelli submitted a paper to A&A on hot star polarimetric variability. If wind material is redistributed, there is significant cancellation of the polarization of the compressed regions by the evacuated regions. Only for processes that redistribute matter over large radial or angular scales is significant net polarization produced. Related projects on spectropolarimetry are being carried out with Li Qingkang (Beijing), a visiting scientist at Glasgow and at UW.

Ignace, Cassinelli and Nordsieck completed a second paper on the Hanle effect as a diagnostic of magnetic fields in hot star envelopes, this time accounting for resolved line profiles.

Howk (now at JHU), Cassinelli, J. Bjorkman (U. Toledo) and Lamers (Utrecht) explained two anomalies associated with τ Sco (B0V): the hard X-ray emission, and also the line profiles obtained with *Copernicus* satellite that suggest infall. The model proposes that clumps form in the wind, and as there is no velocity gradient across a clump the line force is absent. The clump can thus follow a trajectory that eventually infalls toward the star.

Quigley, Cassinelli, and Cohen (U. Delaware) have been interpreting *Infrared Space Observatory* observations of B stars, to see if the anomalously large continuum flux observed by EUVE in the stars ϵ and β Cma are caused by thermal emission, as opposed to non-LTE effects. Quigley, Cassinelli, Ignace and Brian Babler are also studying the IR continuum of Wolf-Rayet stars in an attempt to derive velocity distributions. Both IR lines and continua form in the winds. The change in line widths allows for a determination of the wind velocity at the radius where the local continuum is formed.

Gallagher continued to work with New Mexico State University Ph.D. student Nichole King and advisor R. Walterbos on her thesis studies of luminous blue variables (LBVs) and related stars in M31. Multi-band WIYN imaging was used to study the age distributions in regions containing LBVs, showing that some LBVs appear to be significantly younger than their surroundings. These stars might have formed later than their cohort, or possibly underwent unusu-

ally slow evolutionary development.

Wolff (Space Sci. Inst.), Code and Groth completed a study of the central stars in four high excitation Planetary Nebulae (IC 2165, Me2-1, NGC 2440 and NGC 7027), using data obtained with the Wide Field Camera and Wide Field Planetary Camera 2 (WFPC2) on the HST. The main objective was to obtain improved values of the magnitude and interstellar reddening of these four objects. Each of these central stars has an effective temperature above 10^5 K and therefore is very faint in the visual relative to the strong nebular emission produced by the high ionizing flux of the stars. The higher spatial resolution provided by HST and the use of a narrower band filter than the traditional V filter enhances the contrast between the star and background. The use of ultraviolet filters made it possible to determine interstellar reddening based on the 2200 Å feature.

2.5 Binary Stars.

Hoffman and Nordsieck will have HST time to observe the interacting binary star β Lyrae with the Space Telescope Imaging Spectrograph (STIS), in order to search for Doppler signatures of the bipolar outflow suggested by ground-based observations.

Hoffman continues work on a Monte Carlo radiative transfer model for binary stars. The model can simulate the effects of accretion disks and other extended matter distributions and will allow investigation of the geometrical structure of a wide range of binary systems. Hoffman, working with B. Whitney (Space Science Institute), has modeled fluxes and polarization of β Lyrae in promising agreement with observational data.

As part of their ongoing investigation into the accretion structures of interacting binaries, Nordsieck and Hoffman obtained good-quality polarimetric data on several eclipsing Algol and W Ser binary stars at WIYN. They also observed two eclipsing binary Herbig Ae/Be stars for modeling.

Mathieu, Carr (NRL) and Najita (CfA) 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.

2.6 Star clusters.

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 435 stars in NGC 188, 1904 measurements of 923 stars in M35, 1577 measurements of 343 stars in NGC 2264 and 2063 measurements of 736 stars in NGC 6819. Extensive spectroscopic binary populations are being discovered in all four clusters, with orbital solutions for nearly 50 binaries in NGC 188, the most extensively observed cluster.

3 Interstellar Matter

The Wisconsin H-Alpha Mapper (WHAM) H α survey (Reynolds, Haffner, Tufte, Quigley, and colleagues) has been completed, and the data (spectra and maps) will become available in early 2000.

Reynolds, Haffner, and Tufte have reported (ApJ 523, 223, 1999) the results of a study of H α , [N II], and [S II] emission in the Milky Way using WHAM. Variations in emission line ratios noticed in the diffuse ionized gas of other galaxies are confirmed for the Milky Way and extended to much fainter emission regions. They conclude that increases of [S II]/H α and [N II]/H α with distance from the midplane probably result from an increase in the temperature, rather than a decrease in the ionization parameter as had previously been assumed. They propose that an additional source of heat dominates over photoionization in low density gas within the disk and halos of galaxies. They point to the dissipation of plasma turbulence, photoelectric emission from small grains, magnetic reconnection, and coulomb collisions with cosmic rays as potential candidates for this supplemental heating. Mathis modeled the Warm Ionized Medium in both local gas and in the Perseus Arm at both 500 and 1200 pc. He finds that photoionization models require heating beyond that supplied by photoionization to explain the spectra quantitatively.

Wood (CfA) and Reynolds have begun to

use Monte Carlo simulations to explore the scattering and extinction of H α photons in the diffuse interstellar medium (ApJ, in press). Their initial models reproduce the overall characteristics of the observed H α background and predict that 5% -20% of the observed H α at high latitudes is scattered light from bright H II regions located near the midplane. This is in agreement with observational estimates based on [S II]/H α and [O III]/H α line ratio measurements.

Hausen, Pifer, Reynolds, and Haffner with Tufte (Lewis & Clark College) have completed WHAM observations of a number of optical emission lines for the direction toward the high latitude O star HD 93521, previously investigated in UV absorption lines by Spitzer & Fitzpatrick. The new emission line results will be used to constrain the temperature and ionization state of the diffuse interstellar clouds along the line of sight.

Nordsieck and Wisniewski have significantly improved the upper limits on polarimetric features associated with the diffuse interstellar bands by combining all polarimetric standard data obtained in three years of operation of the HPOL spectropolarimeter. No features are seen at roughly the p/1000 level.

Fabian, Savage, and Tripp (Princeton) are studying the galactic ISM absorption lines recorded in a STIS (Space Telescope Imaging Spectrograph) echelle spectrum of the bright QSO PG 0953+415. The spectrum provides nearly complete wavelength coverage over the region from 1150 to 1750 Å at a spectral resolution of 40,000. The direction to PG 0953+415 ($l = 179.8^\circ$, $b = 51.7^\circ$) allows the study of halo gas absorption at high latitude for gas not affected by differential galactic rotation. The extremely strong and wide lines of C II, Si II and Si III provide information about highly turbulent gas in the halo and reveal absorption by several high velocity clouds not seen in 21 cm emission. This is only the second line of sight through the halo (3C 273 was the first) to be observed at high UV spectral resolution with reasonably complete wavelength coverage. A measure of N(C II*) provides information on the cooling of halo gas through the C II fine structure line at 158 μ m. The broad lines of Si IV

and C IV provide insights about the relationship between the low and high ionization absorption for complete paths through halo gas.

Howk, Savage, and Fabian have used archival ultraviolet data taken by the Goddard High Resolution Spectrograph on board HST to study the gas-phase abundances and physical conditions of the warm neutral gas along the sightline to the low-halo star μ Columbae. They demonstrated that the elements zinc, phosphorus, and sulfur are present with solar system abundances relative to hydrogen along this sightline while the abundances of other elements relative to hydrogen are similar to those found along other warm, disk-like interstellar sightlines. The high-quality abundance measurements are used to infer the composition of interstellar dust grains in the warm neutral medium. The interstellar dust toward μ Columbae is not solely composed of common silicate grains, but likely also includes an oxide or pure iron component.

Savage, Wakker, and the QSO absorption line Key Project team have used the combined results from all three Key Project absorption line catalogs to study the Milky Way absorption toward 83 QSOs in order to determine the nature of UV absorption through the complete galaxy halo for many directions. The Milky Way lines provide important examples of the range of absorption properties of a zero redshift (current epoch) galaxy for comparison with absorption seen at higher redshift in QSO metal line systems. The Milky Way halo gas exhibits “mixed ionization” absorption with the high ionization by Si IV and C IV substantially weaker than the extremely strong intermediate and low-ionization absorption produced from Si III, Si II, C II, Mg II and Fe II. The Galactic Ly α absorption toward 14 QSOs gives values of H I column densities systematically 10 to 40% smaller than those from 21 cm emission. Part of this systematic difference may be produced by radio beam averaging (FWHM = 21') of an irregular distribution of H I. The high velocity cloud phenomena is studied in the sensitive line of Mg II toward most of the QSOs. The sky covering factor of high velocity Mg II is large, with 41 of 71 QSO lines of sight showing either resolved high velocity absorption or principal absorption

so strong that blended low and high velocity Mg II absorption is suggested.

Callaway, Savage, Benjamin, Haffner and Tufte have used 21 cm (NRAO 43 m), H α (WHAM), X-ray (ROSAT), IR (IRAS), and UV (IUE) observations to study the properties of the Scutum Supershell (GS 018-04+44) which is an elongated shell about 5° in diameter extending -7° below the galactic plane centered on the direction $l = 17.5^\circ$ and $b = -4^\circ$. The Scutum Supershell lies at a kinematic distance of ~ 3.3 kpc, implying a shell diameter of ~ 300 pc and a vertical extension away from the Galactic plane of ~ 400 pc. The top of the shell is missing, suggesting blowout may have occurred. In a follow-up investigation, Savage, Sembach (JHU), and Howk (JHU) are studying high quality high resolution (2.7 km s^{-1}) spectra of HD 177989 obtained with the STIS. HD 177989 lies at a distance of ~ 5 kpc in the direction $l = 17.9^\circ, b = -11.9^\circ$. The path passes though gas ~ 700 pc below the galactic plane in the region overlying the Scutum Supershell. Extremely strong absorptions by C IV and Si IV are found at a velocity that associates the gas with the ejecta of the supershell. The spectra are being used to study the ejection of hot gas into the halo by Galactic shells and supershells.

Mathis and Voschinnikov (Sobolev Ap. Inst., St. Petersburg) have determined the cross sections of complex, fluffy interstellar grains composed of a variety of materials by means of layered concentric spheres. Mathis is applying the results to a theory of interstellar grains.

Wakker, in collaboration with Beers (Michigan State), van Woerden (Groningen), Schwarz (Nijmegen), Peletier (Durham, UK), and Kalberla (Bonn), continued the investigating the distances and metallicities of high- and intermediate velocity clouds. Two papers were published in Nature. Complex A was shown to be a 10^5 – $10^6 M_\odot$ cloud 2.5–7 kpc above the Galactic plane, while complex C is at $z > 3$ kpc. A measurement with HST of S⁺ in complex C showed that this cloud has 1/10th solar metallicity. The cloud represents infall of low-metallicity gas at a rate theoretically required to solve the G-dwarf problem.

4 Extragalactic

Extragalactic research is the largest single focus of the UW astronomy faculty, including Bershady, Gallagher, Hoessel, Savage, Sparke, and Wilcots, along with their students Cole, Conselice, Erwin, Homeier, Pisano, and many outside collaborators. They have used the WIYN telescope, among others, extensively.

4.1 Kinematics.

Bershady and collaborators Haynes and Giovanelli (Cornell), Mihos (Case Western), and Koo (UC Santa Cruz) have continued a rotation-curve survey of intermediate redshift spiral galaxies at Palomar, Lick, and WIYN Observatories. A sample of roughly 50 galaxies to $z < 0.4$ shows little change in the Tully-Fisher relation, but a strong color-dependence is seen in the zero-point of the B-band TF relation.

Bershady, Gallagher, Sparke, and Wilcots have developed a collaboration to explore the kinematics and evolution of galaxies. One project underway with Andersen (Penn State) and van Driel (Nançay) is to determine the intrinsic ellipticity of nearby galaxy disks. There have been two successful seasons of observations with WIYN DensePak.

Noordermeer (now at Utrecht) 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. Their velocity fields were very similar to that measured in HI for the lopsided galaxy NGC 4395. The lopsidedness in their models was most pronounced in the models where the halo dominates the system. This is supported by observations that the gas in late-type galaxies, which are dominated by dark matter, shows lopsidedness more frequently.

4.2 Star formation histories.

Bershady, Conselice, Jangren (Penn State), Koo (Santa Cruz), and Guzman (Yale) have continued to develop quantitative indices of galaxy morphology that apply to 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 multiband color. Bershady and Conselice are currently analyzing recent NICMOS observations with the Hubble Deep Field in collaboration with Dickinson (STScI).

Gallagher continued to work on developing quantitative methods for measuring star formation histories of galaxies. For nearby galaxies where individual stars can be resolved, fitting color-magnitude diagrams is a powerful approach. The availability of excellent observations taken with WFPC2 has led to major advances in this area. Work on the Magellanic Clouds with J. Holtzman (NMSU) and other WFPC2 Team members is essentially complete. The WFPC2 Team program results support the idea of an enhancement during the last 2-4 Gyr in the LMC star formation rate and differences in the evolutionary history between the LMC bar and disk. Further progress in assessing the LMC's star formation history will come from a larger WFPC2 census that is nearing completion in a program led by T. Smecker-Hane (UC-Irvine) and also involving A. Cole (UMass).

Cole's Ph.D. thesis, "Helium Burning Stars and the Star-Formation Histories of Dwarf Galaxies" explored the age and chemical abundances of the red clump stars as a tracer of past star formation at ages of 1-10 Gyr. It included a derivation of the metallicity distribution in LMC field red giants from Strömgren photometry and a smaller survey of CaII infrared triplet line strengths, both done from CTIO. Analysis of these will permit the construction of new and improved models of the LMC's stellar populations.

A UW-Madison group (Cole, Gallagher, Hoessel) worked closely with E. Tolstoy (ESO-Garching) in analyzing WFPC2 resolved star

photometry in several Local Group dwarf irregular galaxies. The original relatively shallow data were obtained in a program led by E. Skillman (Minnesota), and the resulting techniques applied this year to deeper WFPC2 Team GTO observations of a central field in IC 1613. This showed IC 1613 has a stellar age structure that is similar to the Pegasus dwarf, with a dominant middle age ($4\approx 5$ Gyr) or older stellar component. A deep WFPC2 exposure has now been taken of an outer IC 1613 field and will be used to make a more detailed study of the old stellar populations. Cole and Gallagher also are working with R. Wyse (Johns Hopkins) in studying the Ursa Minor dwarf spheroidal galaxy stellar populations using a combination of HST and ground-based data.

Gallagher collaborated with J. Mould (Australian National University) and others in using WFPC2 to determine the stellar content of regions close to ionized gas filaments along the outer edges of the Cen A radio lobe. Their data suggest that normal OB associations have formed in this region. Comparisons with narrow-band $H\alpha$ images taken by D. Calzetti (STScI) suggest that stellar photoionization can contribute to some but perhaps not all of the HII emission.

Gallagher and Wyse (Johns Hopkins) are collaborating in a project led by A. Ferguson (Cambridge) that is using WFPC2 to understand the enigmatic And IV dwarf. WFPC2 observations have been combined with ground-based observations, including data from WIYN, to obtain a much better census of stellar populations in and around And IV.

Pisano continued his thesis work with Wilcots on isolated galaxies to assess the state of continuing galaxy formation in the local universe. They have conducted an HI survey of isolated galaxies with the Very Large Array and the Australia Telescope Compact Array to search for the gaseous remnants of galaxy assembly. They found previously unknown companions around roughly 15% of their sample galaxies, and signatures of recent interactions around another 15%. Optical follow-up work with WIYN & the MDM 1.3m in collaboration with C. Liu (Columbia) will determine the stel-

lar properties of the isolated galaxies and their companions.

Wilcots, Pisano, and Elmegreen (IBM Watson Research Center) continued their optical study of NGC 925, a late-type barred spiral galaxy. Using WIYN observations in B,V,R and $H\alpha$, they are examining the global star formation and stellar properties of this galaxy and comparing the stellar distribution to that found in their previous HI studies of the galaxy. Many signs of large-scale asymmetries have been found in this galaxy, which is believed to be typical of its type.

4.3 Ionized H in Galaxies.

Gallagher and Wyse (JHU) are completing a program with A. Ferguson (Cambridge) to measure abundances of HII regions located beyond the R_{25} optical boundaries of spiral galaxies. New observations obtained at the WHT and KPNO will allow better abundance measurements in a few key galaxies and thereby present definitive results on the O abundances in the outer HI disks of nearby galaxies.

B. Otte began a Ph.D. thesis under the direction of Gallagher and Reynolds to test the hypothesis that an extra heating source comes into play in regions containing low density ionized gas. Measurements of optical emission line ratios can constrain this model, and the necessary measurements are now under way, including new spectroscopic observations of NGC 891 in collaboration with A. Ferguson (Cambridge). Otte worked on spectra (taken with DensePak on WIYN) of several galaxies to measure velocities and line widths of ionized hydrogen for comparison with HI velocity fields in these galaxies.

Mathis has modeled the diffuse ionized gas in NGC 891 and other edge-on extragalactic systems. The most difficult observations to interpret are that $[N II]\lambda 6583/H\alpha$ increases to over unity, while there is rather strong $[O I]\lambda 6300$ as well. In addition there is much stronger $[O III]\lambda 5007/H\beta$ at large distances from the plane. Photoionization models explaining these effects are possible if there is heating beyond that furnished by photoionization alone.

4.4 Extragalactic Star Clusters.

Gallagher and L. J. Smith (University College London) are continuing their investigations of dense super star clusters. A successful 1999 observing run on the William Herschel Telescope led to a measurement of the stellar velocity dispersion of 13 km s^{-1} in M82 super star cluster F. This young star cluster therefore has the stellar kinematics of a massive globular star cluster. Work is also continuing to analyze spectra of super star clusters to obtain their stellar population mixes and ages.

Gallagher is a member of a team led by R. W. O’Connell and R. de Grijs (U. Virginia) that is analyzing WFPC2 and NICMOS images of bright clumps in the starburst galaxy M82. These data reveal swarms of compact star clusters in the ‘post-burst’ M82 B region. The HST images allow the first measurements of sizes and luminosities for large numbers of lower luminosity M82 star clusters, as well as an initial exploration of luminous stellar populations. In a related HST program Gallagher is working with D. Hunter’s (Lowell Obs.) group to measure stellar population properties and super star cluster characteristics in the starburst zone of the low mass galaxy NGC 1569. The project also includes narrow band $H\alpha$ images. These imply that this and other starbursts may be in a regime where shells produced by star-forming regions interact; well-defined ionized super shells then are unable to develop.

4.5 Structure of Galaxies.

Gallagher continues his collaboration in L. Matthews’ (NRAO) program to determine the structure and evolution of low mass spiral-like ‘‘extreme late-type’’ galaxies. The emphasis is on understanding the properties of stellar disks in edge-on extreme late-type systems, which are seen as pure, thin-disk ‘‘superthin’’ galaxies. First results show that UGC 7321 is an under-evolved disk that yet has a relatively complex structure implying some degree of secular evolution, e.g. via disk heating. A WFPC2 GTO investigation of small scale structures in the nearby superthin galaxies UGC 711 and UGC 7321 is nearing completion, and shows

the presence of an intriguing population of dark (molecular?) clouds within these dynamically cold disks, as well as typical products of low level galactic star formation processes (sparse OB associations and star clusters). The collaborative component of the project includes further optical work on super thin galaxy structures from multi-color observations made with the WIYN telescope.

Peter Erwin has completed his 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 a triple, is merely double-barred; 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 ‘hot’ bulges.

Witold Maciejewski and Sparke have investigated stellar orbits in galaxies which have small central bars within larger kiloparsec-scale structures. Because dynamical times are shorter in the centers of galaxies, it is likely that the figure of the small bar is rotating faster than that of the large bar, so that the gravitational potential is not steady in any rotating frame. It has previously been thought that orbits in such a time-varying potential were likely to be highly chaotic, and that smooth gas flow would not be possible. We have shown that the potentials allow a set of closed loops that return to themselves after the two bars have made half a rotation relative to each other; gas on these loops can orbit without crossing any other gas streams, so that a stable flow is possible. Comparing these models with observations of dust lanes in doubly-barred galaxies (from WIYN and HST) constrains the speeds at which the two bars rotate.

Cole and Nordsieck completed analysis of

Wide-field Imaging Survey Polarimeter (WISP) UV polarimetric imaging results for the LMC. Significant results are: (1) Diffuse UV light (blue) is seen over most of the WISP image, with a structure very similar to the IRAS diffuse IR light. (2) The light is polarized at the 5–10% level, consistent with starlight scattered by internal dust. (3) One side of the UV image (2 kpc across) is consistent with being illuminated by association B1 (the polarization vectors are centered on B1). The UV diffuse light near B2 does not appear to be illuminated by it. This is explained if B2 is on the near side of the dust disk, so that it can heat the dust, but a forward-throwing phase function suppresses the backscattered light. (4) The UV scattered light is quite strong (> 3000 photons/s-cm²-Å-sr). In fact, the UV scattered light is comparable to the IRAS thermal light, so that the UV must supply the majority of the heating to the diffuse dust in the LMC. Models of the polarized scattered light show that the LMC tilt is 36° and that the dust phase function parameter g is consistent with 0.7.

Sparke is involved in a single-dish survey of polar ring galaxies with the Nançay radio telescope, which will yield average HI masses and linewidths, and provide further candidates for high-resolution mapping. With van Driel and other collaborators, she considered the 21-cm HI line in optically selected polar ring galaxies and polar ring galaxy candidates. They present the HI line data for all 74 galaxies observed, as well as all other published HI line parameters of these objects. Alan Watson (New Mexico State U.), A. Cox (Beloit College) and Sparke are using multicolor optical and H-band images to constrain the ages of stars in the rings.

Wilcots and Marvel (American Astronomical Society) made the first detection of H I associated with the newly discovered Cas 1 dwarf galaxy in the IC 342 group. Wilcots, Armandroff (NOAO), and Caldwell (Smithsonian) also used the VLA to measure the H I content in low surface brightness galaxies in the M81 group. They are following up this detection with higher resolution H I imaging. Wilcots is also collaborating with Hunter (Lowell) on mapping the distribution of CO in the irregular galaxy NGC

4449.

Wilcots is currently working with a number of UW undergraduates. Wilcots and Prescott used the VLA HI observations to show that ongoing interactions actually have very little to do with shaping the asymmetric morphology of lopsided galaxies. Wilcots and Thurow are using WIYN to search for luminous blue variable stars in the nearby starburst galaxy IC 10. Wilcots, Thurow, and McIntyre (ANU) have completed a study of feedback in the star-forming irregular NGC 4214. Using the WIYN integral field unit spectrograph, Densepak, they mapped the kinematics of the ionized gas and found significant deviations from the HI velocity field but no evidence that NGC4214 is losing gas. Work with Thurow on WIYN Densepak observations of IC 1613 and IC 10 continues. Wilcots is also working with Vinson on an undergraduate thesis focusing on interactions between low mass galaxies using both WIYN and VLA data.

Wilcots and Miller (Leiden) are using WIYN imaging to study the massive stellar populations in the Local Group irregulars IC 10 and IC 1613. In work in progress they find that massive star formation in IC 10 has progressed across the entire extent of the galaxy in less than 2 Myr. This work bolsters their VLA study of the HI content of IC 10.

4.6 Starburst Galaxies.

Gallagher and Homeier are completing a WFPC2- and WIYN-based investigation of star clusters in the luminous ‘clumps’ within the starburst galaxy NGC 7673. They find the clumps resemble the bright regions in M82; they are effectively super associations of compact star clusters. The origins of such objects seem to be associated with perturbations in gas-rich systems, and they may therefore have been a major factor in the early evolution of galactic disks.

Gallagher, Conselice and Homeier are collaborating with D. Calzetti’s (STScI) group in detailed studies of nearby starbursts. The program addresses several issues, with an emphasis at STScI on emission line properties and at Wisconsin on the stellar content and structures of nearby examples of UV-bright starbursts. Their objective is to understand the types of galax-

ies involved in the starbursts, the evolution of the starburst, and its ultimate impact on the host galaxy. High quality CCD imaging and DensePak areal spectroscopy with WIYN suggests that many blue starbursts are nearby disk galaxies seen at low inclination. External perturbations have produced large increases in star formation rates without disrupting the disks, implying that the systems will likely return to moderate star-formation rate late-type galaxies after the burst. These results also give a new basis for interpreting moderate redshift compact narrow emission line galaxies as starbursts in low inclination disks.

Progress is also being made on the internal development of the starbursts. The HST archival study of Conselice *et al.* shows that star formation can dominate to the degree that UV and optical structures look similar. These observations also emphasize the importance of kpc-scale star-forming clumps in starbursts involving a significant fraction of the host galaxy.

4.7 Intergalactic gas.

Tripp (Princeton) and Savage are continuing their study of the nature of low redshift Lyman alpha absorbers in the UV spectra of QSOs. Results have been published for H 1821+643 ($z = 0.287$) and PG 1116+215 ($z = 0.177$) by Tripp et al. (1998) using observations from the GHRS and WIYN. The program is being continued for the path to PG 0953+415 ($z = 0.239$) with new UV measurements from STIS at 40,000 resolution. The UV observations provide information on Lyman alpha and metal line systems while the WIYN observations provide galaxy redshift information for one degree fields centered on the QSOs. The combination of the two data sets permits a study of the relationship between the absorbers and the galaxies. The observations are consistent with the hypothesis that many of the low redshift weak Lyman alpha absorption lines trace the overall gas distributions in the large scale structures of galaxies rather than the gaseous halos of individual galaxies (Tripp et al. 1998). Of great interest in this work is the occasional detection of O VI metal line systems such as the system seen toward H 1821+643 by Savage et al. (1998) at $z = 0.225$. The new

observations of PG 0953+415 also reveal a low redshift O VI system associated with a group of Lyman alpha lines near the redshift of a Galaxy group. The spectra are being studied to obtain information on the origin of the ionization and of the gas in the O VI systems and to evaluate the possibility that a significant fraction of the baryons at low redshift may exist in a hot phase of the IGM.

Howk (now at JHU) and Savage have continued to use the superb image quality provided by the WIYN telescope to study dust and ionized gas in the disk-halo interface in nearby edge-on spiral galaxies. They have completed an imaging survey of all truly edge-on, massive spiral galaxies (in the northern hemisphere within 25 Mpc); this survey demonstrates that massive ($> 10^5 M_{\odot}$) dust-bearing clouds are a common constituent of the interstellar thick disks of spiral galaxies. The presence of high- z interstellar dust in spirals is correlated with the presence of diffuse ionized gas far from the planes of these systems.

Howk and Savage (Howk's thesis) have used WIYN to produce deep images of the galaxy NGC 891 in the BVI bandpasses and in the light of $H\alpha$. These images show that the dusty filaments seen in absorption against the background stellar light of this galaxy stretch to 1 – 2 kpc above the midplane, but that there is a paucity of such structures at larger heights from the plane. Their deep, high-resolution $H\alpha$ images show that the diffuse ionized gas and the dusty filaments are not directly related, and likely occupy different physical regions. They conclude that the dusty filaments seen in absorption represent a dense, possibly molecular, phase of the thick disk the multiphase ISM of NGC 891.

4.8 Clusters of Galaxies.

Conselice is working on a Ph.D. thesis project to study small scale stellar objects and features in clusters of galaxies. Initial phases of the program, which involves Wyse (Hopkins), included surveys of Coma and Perseus, as well as several of the AWM poor clusters for dwarf galaxies and other unusual features. The results have been published and add to the growing evidence for

significant levels of interaction-induced distortions in nearby rich clusters. The second step, now in progress, examines the kinematics and structures of lower luminosity cluster members as a means to explore evolutionary processes. For example, ‘harassment’ of infalling galaxies is a possible engine for modifying structures and evolution of cluster galaxies that is suggested theory and by observations of infall candidates, such as those found in CfA cluster studies by Geller and her collaborators. The approach is to measure radial velocity distributions of Virgo cluster dwarfs that are potentially the products of harassment. These can be compared with velocity distributions of giant cluster members to test the degree to which dwarfs and giants are a dynamically uniform mix. They are also measuring evidence for tidal interactions (e.g. from asymmetries) and other abnormal evolutionary features (colors, emission lines) from B and R band WIYN images, especially for the Perseus and Coma clusters. Coma shows obvious evidence for distressed dwarfs while the similar density Perseus cluster does not; this seems consistent with a recent cluster-cluster merger in Coma that is producing major changes in the structure of the cluster. In collaboration with M. Geller’s (CfA) group, they are also imaging candidates for infalling galaxies and finding evidence for unusual structures. Their program joins others in finding increasing evidence for ongoing environmentally-driven processes in galaxy clusters, indicating that these objects cannot be treated as simple systems that are in a steady state.

The cluster observations also include a superb quality narrow-band WIYN image of the NGC 1275 emission line filament system obtained by Conselice. This image, supplemented with Densepak and long slit spectra, is the basis for a reexamination by Conselice, Gallagher, and Wyse of the state and evolution of ionized gas in NGC 1275. A preliminary analysis suggests that the properties of the ionized filaments might be best understood if an outflow exists from NGC 1275, rather than the usual assumption of a pure inflow from the cluster onto this galaxy.

Wilcots is collaborating on two major stud-

ies of the neutral gas content of loose groups of galaxies. A team led by van Driel (Observatoire de Paris) used the Nançay radio telescope to survey the H I content of galaxies in a sample of active, intermediate, and quiescent loose groups taken from Marcum’s (TCU) Ph.D. thesis (Wisconsin 1994). Wilcots is also collaborating with Zabludoff (Arizona) and van Gorkom (Columbia) to completely map the HI distribution in groups of galaxies using the Very Large Array.

5 Teaching and Outreach

UW gives graduate students a limited amount of queue observing on WIYN for their own research programs conducted independently of faculty. Three student projects were completed. Dolan, Haffner, and Hoffman searched for evidence of photoevaporation and forming stars on the face of the B35 cloud using H α and [S II] images. Hot gas seems to be streaming off the cloud. Homeier and Miller investigated the kinematics of three Wolf-Rayet nebulae using DensePak and found evidence for expanding bubbles of ionized gas surrounding these stars. Kearns and Madsen used DensePak to conduct exploratory studies of a new sample of low surface brightness galaxies selected from the Kitt Peak International Spectroscopic Survey database (Salzer et al, 1998).

The College Level-Institute (Mathieu, Director) within the National Institute of Science Education completed the Field-tested Learning Assessment Guide (FLAG). The FLAG is a user-friendly web site which will introduce the user to innovative classroom assessment techniques, determine the tools best suited to the user’s needs, and provide a complete tutorial package for classroom use. The CL-1 Institute also launched the Institute for Learning Technology, which will develop a guide to effective practice of technology in the classroom for release in Summer 2000. All of these products can be found at www.wcer.wisc.edu/nise/cl1/.

Hoffman led workshops for “Explorathon for Girls in Science,” a statewide program for educating middle-school and high-school-aged girls about careers in math and science.

Wilcots once again ran the extremely popu-

lar “Universe in the Park” outreach program (www.astro.wisc.edu/~ewilcots/uitp) in conjunction with the Wisconsin State Parks. This year 34 sessions at 23 different state parks. Each event consists of 20 minute talk and slide show followed by stargazing using one of the programs telescopes. The department’s off-campus outreach center “Space Place” continued hosting monthly public astronomy lectures, school and senior groups, and this year held two week-long workshops for Madison area school teachers.

6 Instrumentation

Integral Field Units (IFUs). Bershadsky has continued an NSF-funded funded instrumentation program to build an IFU “Spider” for the Hobby Eberly Telescope’s Medium Resolution Spectrograph. This project as been expanded to include building a second IFU (“6-Pak”) for the WIYN telescope’s Bench Spectrograph. Andersen (Penn State) is currently at Wisconsin as part of CIC exchange to help build these instruments. These IFUs and their telescopes are unique in their high delivered etendue and capability of achieving spectral resolutions up to $R = 10000$. They are designed for study of the dynamics of spiral disks of external galaxies. As part of this instrumentation effort, Bershadsky is working towards a redesign of some of the WIYN Bench Spectrograph to improve the throughput.

The Wide-Field Imaging Survey Polarimeter (WISP). Nordsieck and Harris continued the flight series of WISP, a suborbital rocket payload which obtains vacuum ultraviolet wide field (3x4 degree) polarimetric images. The fourth flight of the series was launched successfully on 12 April, 1999, targeting the mid-latitude Galactic clouds found by Sandage near M81 and M82. Surprisingly, these clouds were not detected at 1700 Å at a level which would account for the FUV diffuse Galactic Light flux reported for this region by the UVX Shuttle experiments. A new UV polarimetric imager, the Cosmic Ultraviolet Polarimetric Imaging Device (“CUPID”), with a sensitivity 20 times WISP, is being designed to follow up these puzzling results.

Far-Ultraviolet SpectroPolarimeter

(“FUSP”) Nordsieck and Harris continue on the development of FUSP, a suborbital rocket payload that will obtain the first spectropolarimetry from 1050 to 1500 Å with a resolution of $R=1800$. Scientific targets include Be stars, OB stars with dense winds in a test of the Hanle Effect magnetic field diagnostic, interstellar polarization, and interacting binaries. The first flight is scheduled for late 2000. This research was described in an invited paper to the SPIE Denver meeting.

Progressive Image Transmission; star tracker. Percival (with P. Baranowski) developed a 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, Nordsieck, Babler, Harris, and Bonomo flew a prototype low-cost star tracker with embedded support for Progressive Image Transmission on a sounding rocket. The flight test was successful, and an advanced version is now being designed.

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 1185 Å region at a spectral resolution of 30,000. Savage’s 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 will be 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. As of October 1999 FUSE was still in the orbital verification phase and was successfully obtaining Far-UV spectra in the 980 to 1185 Å region.

Cosmic Origins Spectrograph (COS). COS is will be installed on the HST 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 through-put spectrograph operating from 1150 to 3200 Å at a spectral resolution of 22,000. In the Far-UV COS is approximately 20 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.

7 Other Activities

Anderson continued his interests in the Jupiter/Io system by WITN DensePak observations of [S II]. The goal is to determine mass loading of the Jovian magnetosphere by newly formed ions.

There is a program on X-rays in classical novae, both in quiescence and in outburst, by Orío and Ögelman in Physics. They used ROSAT and have started SAX observations. Orío studied supersoft X-ray sources and galactic black hole candidates in optical wavelengths with WIYN, with ESO telescopes, and with the 1m telescopes of the Wise and Turin Observatories. She discovered interesting changes in the light curve of A0620-0 and a low mass supersoft X-ray system, prototype of a new class of objects. Ögelman and collaborators completed a study of the jet of the Vela pulsar and for the first time detected gamma radiation from the pulsar PSR B1055-52.

Fabian, with Sofia (Whitman College) and Howk (JHU), used high signal to noise archival GHRS data to confirm the theoretical branching ratio and oscillator strength for the weak Mg II 3s-4p doublet at 1240Å. Both apparent optical depth analysis and component fitting of the μ Col, γ Ara and ρ Leo sightlines support a revision of the branching ratio f_{1239}/f_{1240} to 1.74 ± 0.06 down from an assumed value of 2.00.

Laboratory measurements of astrophysical interests were carried out in the Physics Department under Prof. J. Lawler. With an active program to measure the resonance absorption oscillator strengths of the Fe-group elements, they have determined 59 UV and VUV oscillator strengths for Ni II. Their measurements indicate that Ni is less depleted in the ISM than previously estimated. They have measured radiative

lifetimes for 39 odd-parity and 42 even-parity levels of Ho I, 37 even-parity levels of Ho II, 22 odd-parity and 4 even-parity levels of Lu I, and 14 odd-parity levels of Lu II, and absolute transition probabilities for 915 transitions in Dy I and Dy II, as well as branching fractions for all upper levels of Lu I and Lu II with measured radiative lifetimes.

There is strong astrophysical activity in other groups of Physics, including the theory of the interstellar medium, X-ray instrumentation, optical instrumentation, neutrino astrophysics, and the physics of turbulence.

8 Publications

The graduate textbook, "Introduction to Stellar Winds" by Lamers (Utrecht) and Cassinelli has now appeared as a book by Cambridge University Press. The advanced undergraduate text on galaxies by

Sparke and Gallagher will be published by CUP in 2000.

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