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[S0002-7537(93)24541-3]

This description covers the Department's activities from October 1, 2000, through September 30, 2001. It is condensed from a longer version at www.astro.wisc.edu that also lists published papers and invited reviews.

The Department was active in the 11-m Southern African Large Telescope (SALT) project. UW has a 17% share and is responsible for the design and construction of the Prime Focus Imaging Spectrograph (Nordsieck, PI), one of the major instruments. First light is planned for 2004. Another highlight was the award of one of six Legacy Science Projects of the Space science Infrared Telescope (SIRTF) to UW (Churchwell, PI), to produce an NIR imaging survey of the inner Galactic Plane. Other major thrusts include studies of star formation, extragalactic structure and evolution, and properties of highly ionized gas and H₂ using far-ultraviolet spectra of QSOs and AGNs.

Dr. Amy Barger, recipient of the 2001 Annie Jump Cannon Award, began her duties as Assistant Professor. She was the Hubble Fellow/Chandra Fellow at Large at the Inst. of Astronomy, University of Hawaii.

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

1. PERSONNEL

In June, Prof. Linda Sparke became Chair, succeeding Prof. Anderson. Other faculty members are Professors Cassinelli, Churchwell, Gallagher, Hoessel, Mathieu, Nordsieck, Reynolds, and Savage, Associate Professors Bershady and Wilcots (promoted from Assistant Professor), and Assistant Professors Barger and Lazarian. Percival is Scientist; Harris and Wakker are Associate Scientists. Drs. Eric Burgh, Marc Verheijen, and Remy Indebetauw joined the staff as Assistant Scientists. Other Assistant Scientists are Barnes, Cho, Haffner, and Kobulnicky. M. Orio is Visiting Associate Scientist. Stassun is a Hubble Fellow. Dr. David James (St. Andrews) spent March-September in Madison. Receiving the PhD were Conselice (now at Caltech), Otte (JHU), Pisano (NSF Fellow at CSIRO Australia Telescope National Facility), and Andersen (exchange student from Penn State, now at Max-Planck-Institut, Heidelberg).

2. STARS, OUTFLOWS, AND GALACTIC STRUCTURE

Cassinelli and colleagues have analyzed the high-resolution Chandra X-ray spectra of ζ Puppis (O4f), δ Orionis (O9.5 & B0.5 III), and ζ Ori (O9.5 Ia) using forbidden, intercombination, and resonance lines of helium-like ions as diagnostics. The Doppler-broadened emission line profiles reveal the temperature structure of the gas. The X-ray line spectra differ in several ways from predictions. Cassinelli, Nordsieck, and R. Ignace (U. Iowa) have continued their work on the UV diagnostics of magnetic fields in hot stars using the Hanle effect. It should be able to reveal $B < 100$ Gauss using high resolution polarization observations of

strong UV lines. Cassinelli and colleagues used Infrared Space Observatory spectra of Wolf Rayet stars to study the velocity laws and the filling factors in the winds. The filling factor of the hot material in the wind is about only 1/50.

Mathieu and colleagues continued acquiring high-precision stellar radial velocities with the WIYN telescope and Multi-Object Spectrograph. As part of the WIYN Open Cluster Study (WOCS), they have obtained multiple velocity measurements of thousands of stars in NGC 188, M35, NGC 2264, and NGC 6819. The number of known spectroscopic binary orbits is steadily increasing in each cluster. Another group including Mathieu continued a program at the Keck Observatory of high-resolution near-infrared spectroscopy (CO fundamental and overtone transitions) in order to explore the circumstellar gas in both young binaries and single stars. The CO transitions are extremely sensitive tracers of disk gas. In order to study the history of disk dispersal to later stellar ages, they have expanded their program from binaries to single stars. Mathieu and colleagues completed a $v \sin i$ study of low-mass Trapezium stars, finding strong evidence that the period light variations of T Tauri stars are caused by spot modulation as the star rotates. Surprisingly, for stars with known period the mean $\sin i$ is significantly lower than expected for a random distribution of stellar rotation axes. Stassun and Mathieu continued their study of pre-main-sequence (PMS) eclipsing binary stars to derive empirical mass measurements of young, low-mass stars as well as their survey of PMS spectroscopic binary stars in Orion. They and colleagues completed their studies of the photometric variability of stars in the old open cluster M67. Photometric variability is strongly correlated with binarity. James, Mathieu, and Barnes worked on the M7 and M34 open clusters, important because of their intermediate ages (about 250 Myr) and differing metallicities. Stassun and colleagues studied the photometric variability of the embedded young star HH30. Magnetically channeled accretion of circumstellar disk material onto the central star is modeled by means of Monte Carlo radiative transfer. Barnes has continued to work on stellar evolution, with an emphasis on the rotational evolution of stars, and investigating the rotational consequences of disk-locking of young stars and the rotation rates of the host stars of extra-solar planets.

Hoffman, Nordsieck, and Whitney continued Monte Carlo radiative transfer modeling of binary star-disk systems, especially of β Lyrae. Hoffman and Nordsieck have estimated the interstellar and intrinsic polarization of two PMS binary stars and have determined the orientation of a circumstellar disk in MWC 349A, supporting its classification as a PMS B[e] star.

Orio, with colleagues, is studying pointed XMM-Newton observations for Nova LMC 1995 (a supersoft X-ray source and a candidate type Ia supernova progenitor) and the behavior of post-outburst novae observed with Chandra. She is investigating the long term variability of X-ray sources, es-

pecially cataclysmic variables and low mass X-ray binaries, the long term behavior of classical novae at quiescence, and the optical identification and monitoring of Low Mass X-Ray Binaries and cataclysmic variables that are X-ray sources.

3. INTERSTELLAR MEDIUM (ISM)

The Northern Sky Survey total H α intensity map from WHAM (Wisconsin H-alpha Mapper; Reynolds, PI) is available to the community at the web site <http://www.astro.wisc.edu/wham/>. The survey provides the first view of the large scale distribution and kinematics of the diffuse H α north of declination -30° .

Churchwell, with several colleagues, has been active in many projects, such as determining the properties of precursors of ultracompact HII regions using CH₄CN line emission as shown in a large fraction of 20 known massive star formation regions. Hollis (GSFC) and Churchwell showed that abundances of complex interstellar molecules are consistent with formation from chemical groups that were initially formed on grain surfaces. Churchwell used the Arecibo telescope to measure the H110 α emission line toward 21 ultracompact H II regions, and the H₂CO line in absorption, so the near/far distance ambiguity was resolved. Student Sewilo is measuring the angular expansion rates of two ultracompact H II regions using VLA continuum images obtained over a 10 year period. She will determine the kinematic distances of others. Student Watson considers outflows associated with massive star formation, especially the origin of the large masses in the outflows.

Lazarian and colleagues Cho, Yan, & Esquivel investigated properties and consequences of the ISM turbulence from theoretical, numerical, and observational points of view. Theoretical studies of MHD turbulence provided new results on turbulence cascade in partially ionized gas, on coupling of different MHD modes, on cosmic ray scattering, and on acceleration of cosmic rays. Lazarian continued work with Pogosyan (Univ. Edmonton) on velocity and density statistics of turbulence from observational data, concentrating on the effects of absorption, with applications to H I, CO and other molecular species. Results were applied to H I in the Small Magellanic Cloud. With De Gouveia Dal Pino (Univ. Sao Paolo), Lazarian obtained constraints on the acceleration of ultra high energy cosmic rays during reconnection events. With French collaborators, he worked on the statistics of starlight polarization, important for Cosmic Microwave Background studies.

Reynolds, Haffner, student Madsen, and several colleagues used WHAM to characterize the kinematics and emission measure of diffuse ionized gas. They detected for the first time the temperature sensitive [NII] λ 5755 in the diffuse ISM, finding that the electron temperature of low density ionized gas is 2000 K higher than that in classical H II regions. The WHAM sky survey data found evidence for an enormous superbubble that appears to have blown out into the halo above the Cas OB6 association in the Perseus arm, supporting the idea that some of the ionizing radiation from O stars is able to travel long distances through large cavities in the Galactic disk. The WHAM sky survey created the first H α map of a high latitude intermediate velocity cloud, the

“K Complex.” The ionized gas traces the H I quite well spatially and kinematically over the 600 square degree complex.

Savage, many colleagues, and members of the Far Ultraviolet Spectroscopic Explorer (FUSE) science team have nearly completed their survey of O VI absorption in the Milky Way halo toward 85 extragalactic objects. High velocity O VI absorption is detected along 65% of the lines of sight, with a widespread but highly irregular distribution in the Milky Way gas. A combination of models involving the radiative cooling of hot gas in a Galactic fountain flow ($\sim 2M_\odot/\text{yr}$ for each side of the disk) and the turbulent mixing of warm and hot gases appears to be required to explain the highly ionized gas found in the halo.

Wakker completed a literature survey on high- and intermediate-velocity clouds that showed the diversity of HVCs. Some are distant ($d > 4$ kpc) and metal poor ($Z < 0.1Z_\odot$), other are nearby (~ 1 kpc from the Galactic plane) and metal rich ($Z \sim 0.5 - 1Z_\odot$), while still others are tidal debris ($d \sim 50$ kpc, $Z \sim 0.25Z_\odot$). Richter focussed on FUSE observations of neutral and molecular gas in Intermediate- and High Velocity Clouds. He detected a widespread diffuse molecular gas phase in the lower Milky Way halo.

4. EXTRAGALACTIC ASTRONOMY

With many colleagues, Barger is obtaining a more complete census of the energy-producing galaxies and supermassive black holes in the Universe. Observations at X-ray, submillimeter, and radio wavelengths reveal galaxies and AGN previously hidden by dust and gas. The Chandra X-ray Observatory has detected obscured supermassive black holes at the centers of galaxies. A population associated with normal galaxies, and another with optically faint galaxies, were discovered by optical Chandra observations. Barger estimated the accretion history of the Universe. To further determine the nature of the X-ray sources, she and student Steffen are analyzing spectroscopic data obtained with HYDRA on WIYN of sources in a wide-area field to be targeted with Chandra. This study will be complementary to forthcoming far-infrared observations of the region with the Space Infrared Telescope Facility. Barger is Co-I on the Chandra Deep Field North survey, expected to resolve fully the X-ray background into its constituent sources. She will be involved in the optical and submillimeter follow-up. Barger and student Hedrick are doing a submillimeter study of extremely red objects that are gravitationally lensed by three rich Abell clusters. Barger is also examining the submillimeter properties of faint radio sources.

Working with various colleagues, Bershadsky has investigated the mass of galaxy disks by direct determination of the stellar velocity ellipsoid and probed the ionized gas velocity fields in late-type and low-surface-brightness systems. He and Hoessel have begun a long-term, deep variability survey of intermediate redshift clusters with WIYN.

Gallagher, with many colleagues, works on defining and understanding physical processes responsible for the evolution of galaxies, with an emphasis on lower mass systems. These are common and include the satellites of the Milky

Way. The LMC bar is younger than the disk, probably appearing as a distinct component 4-6 Gyr ago. Studies of Local Group dwarf galaxy stellar populations continue. VLT spectroscopy of the IR Ca II triplet in three nearby dwarfs provides a glimpse of chemical enrichment patterns. For his Ph.D. thesis, C. Conselice (now Caltech) worked on the nature and origins of ubiquitous spheroidal dwarfs in clusters. This program also yielded spectacular WIYN images of the system of ionized filaments and young stars associated with the central Perseus cluster galaxy NGC 1275. Gallagher continues studies of small field galaxies, including an analysis of major axis kinematics. These are dark matter-dominated systems with normal (i.e., high) specific angular momentum content.

Reynolds, Haffner, and Madsen used WHAM to carry out a deep search for H α emission in the plane of M 31. They detected faint emission out to the edge of the H I disk, which extends to a radius twice that of the stellar disk. They found no evidence for an ionized gaseous disk extending beyond the H I disk. Otte, Gallagher, and Reynolds observed the [O II] 3727/H α line ratio in a number of edge-on spiral galaxies and found evidence that the observed variations in the line ratio are due at least in part to variations in the temperature of the emitting gas. This suggests the existence of an additional heat source within the diffuse ionized gas.

Savage, Richter, Wakker, and colleagues are pursuing a program with FUSE and the Space Telescope Imaging Spectrograph (STIS) to determine the physical conditions and number density of the recently discovered low redshift intervening O VI absorption line systems seen in the spectra of QSOs. At low redshift, this highly ionized gas apparently contains as much matter as galaxies. To understand the origin of the O VI systems, one must determine the association of the absorbers with galaxies, galaxy groups, or other structures along the line of sight to each QSO. Fox and Savage have initiated a program to determine redshifts in the fields of the QSOs being studied by FUSE and STIS. Apparently O VI systems are either associated with the halos of individual galaxies or with gas in the large scale structures traced by galaxies.

Sparke and Erwin (Inst. Canarias) are using WIYN to search early-type barred galaxies 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. Gaseous star-forming nuclear rings are also common, especially among the S0 galaxies in the sample. Cox (Beloit College) and Sparke analyzed radio observations of polar ring galaxies to

show that these are no more likely to contain an active nucleus than are normal elliptical or SO galaxies.

Wilcots and colleagues are seeking to understand the distribution and kinematics of H I in the environment of galaxies and the symbiotic relationship between star formation, the evolution of massive stars, and the evolution of the interstellar medium in galaxies. They have examined ionized gas in various star-forming irregular galaxies, extended H I around nearby irregular galaxies, and the H I content of poor groups of galaxies. Work continues on mapping a number of groups across the evolutionary sequence with both the VLA and the Australia Telescope Compact Array.

Kobulnicky and colleagues published a spectroscopic chemical and dynamical study of high-redshift galaxies, continued investigation of the youngest phases of massive star cluster formation, and completed a study comparing the 21-cm neutral hydrogen and ionized gas kinematics. Verheijen and colleagues are investigating the galaxy cluster Abell 2192 (redshift ~ 0.2) in H I to order to understand the evolution of the cold gas content and stellar populations of gas rich galaxies falling into the gravitational potential well.

5. WIYN, SALT, AND INSTRUMENTS

Nordsieck is PI for the first major SALT facility-class instrument, the Prime Focus Imaging Spectrograph. It will have very high throughput with low and medium spectral resolution ($R = 500 - 13000$) with spectropolarimetric and Fabry-Perot capability, 3200 – 9000 Å, with a field of view of 8'.

Anderson is the Wisconsin PI for the construction of the Cassegrain Instrument Adapter System for the WIYN Telescope, which will provide routine access for integral field devices as well as user instruments to the Cassegrain f/13.5 focus. It provides acquisition and guiding signals as well as calibration source beams.

An NSF-funded fiber integral field unit (“SparsePak”) for WIYN was built at Wisconsin (Bershady, PI). The instrument is currently in commissioning phase.

The WIYN Observatory and partners took over operation of the Kitt Peak 0.9m telescope, to be dedicated to wide-field imaging, with emphasis on time-dependent astrophysics and student projects.

An advanced low-cost star tracker (the ST5000), built by Percival and colleagues, provides pitch, yaw, and roll control. It can also do a full attitude determination for both sounding rockets and satellites, without gyros, from the positions of a few stars.