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This report covers the period from September 1997 through August 1998.

1. PERSONNEL AND EDUCATION

Faculty and staff active during this period were P. N. Appleton, G. H. Bowen (emeritus), D. A. Carter-Lewis, J. J. Eitter (Observatory Manager), S. Kawaler, F. Krennrich, R. Lavery, C. Struck & L. A. Willson.

Graduate students in astronomy included R. Benson, M. A. Bransford, J. Dostal, M. S. O'Brien, M. Reed, A. Remijan, F. Samuelson & G. W. Turner. During this period, the MS degree was awarded to Anthony Remijan, and the Ph.D to Mark Bransford (now at New Mexico State University) and Sean O'Brien (now at Grinnell College). Russ Woodbury (from Electrical Engineering but working on an astronomy related project) was supported by an Iowa Space Grant Consortium fellowship during the end of this period.

Undergraduates involved in astronomical research during this period were Eric Hoversten, Nicole Heide, Agnes Biscoff & Nick Mostek.

Appleton began a term as AURA membership representative for ISU, and is also serving on the AURA Space Telescope Institute Council (STIC). Kawaler continues as Director of the Whole Earth Telescope (WET) collaboration. Willson began a term on the new AURA Board of Directors. She continues to serve on the Council of the AAVSO.

In January 1998, Dr. Scot J. Kleinman joined the group as an assistant research scientist. He is working with Kawaler on the Whole Earth Telescope project, and acts as the Associate Director of WET Operations.

Visitors to the department during this period were Tony Marston (Drake), Ray Norris (Australia), Charlene Heisler (Australia), Evan Skillman (Minnesota), Stefan Dreizler (Germany), Don Winget (Texas), Francois Vuille (South Africa), Judi Provencal (Delaware) & Mike Montgomery (Texas), Chris Clemens (Caltech).

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2. FACILITIES

The observations at Fick Observatory were adversely affected by an unusually cloudy fall and winter, probably influenced by the last *el nino*. CCD observations were made on 36 nights, using the new Newtonian port with funding provided by the Iowa Space Grant Consortium. The new arrangement provides a high throughput and a wider field of view at the f/4 focus (approx. 20 arcminutes) and is working extremely well at present. We are currently adding an automated translation stage to allow for automatic focusing and positioning of the CCD autoguider. WET testing and obser-

vations were made on 3 nights. The stellar radial velocity project obtained about 1150 observations over 26 nights.

ISU continues to be the central site for coordination of WET observing campaigns. WET is a world-wide network of astronomers who observe using multichannel photoelectric photometers, that is used to obtain 24 hour/day coverage of variable stars for the purposes of stellar seismology. WET is affiliated with the International Institute of Theoretical and Applied Physics (IITAP) at ISU.

3. RESEARCH PROGRAMS

3.1 Stars & ISM

Willson and Bowen continue to work on problems associated with mass loss from evolved red giants. Bowen is currently writing a series of papers for submission to the *Astrophysical Journal* detailing his calculations of the past several years, documenting the version of the code used for these models, and presenting the resulting evolutionary pattern for evolved AGB stars. Willson gave two review talks on the subject this year: one on "Mass Loss from Pulsating Stars" at the ESO workshop on Cyclical Variability in Stellar Winds in October, and one on "Mass loss from Cool Stars" at the STScI May Symposium on "Unsolved Problems in Stellar Evolution Theory." In the process of preparing these two talks and the associated papers she made considerable progress in understanding the nature of the differences between the "Bowen" class of models (with density-dependent non-LTE thermal relaxation) and the "Berlin/Vienna" class of models (with very fast or LTE coupling between the thermal energy in the gas and the radiation field). For example, it can be demonstrated quite simply that the common practice of using LTE radiative transfer with a dynamical model $T(r)$, where non-LTE was assumed in computing the dynamics, amounts to a violation of conservation of energy, and this explains the often absurd results of such calculations.

O'Brien, under Kawaler's supervision, completed his Ph.D. thesis on the group properties of the pulsating pre-white dwarf stars. Among many things, he found that the observed trends in the dominant pulsation periods with temperature can be understood in terms of the different masses of the pulsators of different temperatures. Furthermore, these results shed light on the excitation mechanism for these pulsators. Results have been reported in *The Astrophysical Journal*, with more papers to follow in the coming year.

Kawaler, Gough, and T. Sekii (IoA) completed an exploration of the prospect of using the observed rotational splitting in pulsating white dwarfs to constrain their internal rotation rates; results of this investigation will appear in *The Astrophysical Journal*.

In collaboration with W. Dziembowski (Copernicus Astronomical Center, Warsaw) and T. Van Hoolst (Leuven),

Kawaler explored the role of unstable *non*-radial modes in models of RR Lyra stars. Nonlinear coupling between high-degree modes and the radial modes may play a role in observed systematics of RR Lyra period and amplitude correlations. This work has appeared in the Monthly Notices of the Royal Astronomical Society.

Kawaler continues his collaboration with observers from the South African Astronomical Observatory in the exploration of the EC14026 stars, which rapidly pulsating sdB with periods near 100-160 seconds. Kawaler's contribution was in making evolutionary Extreme Horizontal Branch models to try and identify the modes present and the driving mechanism. Global observing campaigns have been completed on three of these stars: PB8783, PG 1047, and PG 1605. Kawaler has made models in an effort to interpret the observed pulsation periods and deduce the evolutionary status of these stars as well as their internal structure. Particular success in matching the observed period has been achieved for PG 1605, the longest-period pulsator. These results, in preparation for publication, indicate that this star has evolved well past the core helium-burning stage.

In April 1998, the Whole Earth Telescope observed the pulsating white dwarf star BPM 37093. This ZZ Ceti star is unusual in that it is by far the most massive of the class. As such, it is likely that its interior is largely crystalline. The WET observations, along with parallel Hubble Space Telescope time-resolved spectroscopy, should reveal the extent of the crystalline core and, for the first time, test the theory of crystallization

Appleton & Eitter continue to explore the molecular properties of the "Eitter's Globule" through a 5 day observing run with the Onsala Space Observatory (with Bergman & Horellou-OSO). This extremely dense dust globule was discovered by Eitter at Fick last year. Observations at OSO were made in May 1998 under extremely good conditions in the 12CO (1-0) and 13CO (1-0) and HCO+ lines. The entire field around the globule, including several smaller globules were mapped with high velocity resolution. The main globule (of implied mass 3 M(sun)) appears to be rotating slowly, and the dust tail also shows a velocity gradient in CO along it. At the center of the cloud a small disk is observed at optical wavelengths with its major axis oriented perpendicular to the rotation axis of the globule as a whole. The globule may represent the early stages in the formation of a dusty planetary disk.

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3.2 Galaxies

Lavery, with graduate students M. Reed and A. Remijan have begun a search for distant collisional ring galaxies in deep HST WFPC2 images obtained from the HST Archives. The goal of this program is to use these collisional rings to investigate the change in the galaxy interaction and merger rate as a function of redshift out to a redshift of 1. With about 45 WFPC2 fields now searched, approximately 10% of the overall program, a total of 10 excellent collisional ring galaxy candidates have been identified. This relatively large number of galaxies already identified suggests an interaction rate that increases very steeply with redshift. The observed number of galaxies rules out a constant galaxy interaction rate ($m = 0$) at greater than the 3 sigma level. These initial results were presented at the 1998 Summer AAS meeting in San Diego.

Lavery and J. P. Henry (IfA/Hawaii) have continued their analysis on the gravitational lens cluster of galaxies A963 at a redshift of 0.2. Deep B and R band images of the cluster

have not revealed any new large magnification images aside from the two original large arcs. Redshifts for 36 red cluster members have been used to determine a velocity dispersion of 1350 km/s for this cluster, a value similar to other known lensing clusters. This velocity dispersion is quite large for the X-ray temperature of 6.8 keV. Deep ROSAT HRI images of this cluster are presently being analyzed. The goal of the program is to combine these data, along with the lensing information, to produce a consistent mass distribution model for this cluster.

Lavery, P. Seitzer (Michigan), G. Da Costa (AAO), N. Suntzeff and A. Walker (CTIO) are completing their photometric reduction of HST observations of the Tucana Dwarf Galaxy, a Local Group galaxy discovered by Lavery while a postdoctoral fellow at Mt. Stromlo Obs. Deep WFPC-2 images in the V and I bands reach a magnitude limit well below the horizontal branch in the CM diagram. A distance modulus of 24.80 is determined for Tucana, which is consistent with previous estimates. In the CM diagram, there appears to be a number of stars with colors bluer than the subgiant branch. Analysis continues with the hope of determining whether these stars are blue stragglers or signs of an episode of ‘‘recent’’ star formation.

Struck continued numerical hydrodynamical (SPH) modeling studies of the early stages of collisions between galaxies with substantial gas disks. A small grid of such models, with detailed descriptions of the hydrodynamical effects, and the effects of radiative cooling and heating from young stars, was published in Struck (1997). In addition, detailed modeling of several specific collisional systems was undertaken with collaborators. For example, Struck, with B. Smith (Caltech/IPAC) and R. Pogge (Ohio State), continued studies of the ring-like Arp 284 system. In the previous year we published high resolution VLA 21 cm. observations and a preliminary model. The radio observations revealed a massive gas bridge, a large gas loop, as well as the optically visible rings and tail. These features, and the general kinematics of the system, have now been successfully matched by a model of a high inclination, prograde collision (for the companion), with an impact point about half-way out in the primary disk. This model was produced with a SPH simulation code with rigid halo potentials and local self-gravity in the disks. It is currently being redone with the fully self-consistent N-body-SPH ‘‘Hydra’’ code made available by H. Couchman.

The Arp 284 study is part of a larger effort of this collaboration to study star formation and gas dynamics in tidal tails and bridges. There is evidence from ring galaxies that splash bridges produced by small impact parameter collisions generate little new star formation, while tidal, M 51 type bridges and tails make new stars in compression waves. Arp 284 appears to be an example of an intermediate case, in which inclined, off-center impacts generate both hydrodynamical splash and tidal torqueing effects. We are obtaining multiwavelength (optical, near-infrared, 21 cm. and CO) observations of a sample of systems including both extreme and intermediate cases.

Struck is also working within a broad collaboration studying a related class of collisional galaxies, the oculars, which

are the result of prograde encounters. The goals of this project include comparing observations of likely examples to models to further our understanding of the development of the transient ocular waveform, and its evolution into a bar component. In the last year an extensive study of the NGC 2535/6 system was published (Kaufman *et al.* 1997, and Brinks *et al.* 1998), and a paper is in preparation on the somewhat more evolved system NGC 5394/5 (Arp 84). To date there is good agreement between models and observations, which confirms the general collisional theory and inspires attempts to construct more detailed models of specific morphological and kinematical structures. In a related example, HST observations of one of our sample systems, NGC 2207, have revealed small scale spiral structures in the central regions of this galaxy, that may be the result of a new acoustic instability discovered by collaborator B. Elmegreen with L. Montenegro and C. Yuan (Elmegreen *et al.* 1998).

Appleton and Bransford have continued their work on collisional galaxies with observations of two Seyfert ring galaxies, Arp 118 (with collaborators K. Freeman and C. McCain at Mt. Stromlo Observatory) and NGC 985 (with Y. Gao at U. of Toronto). Arp 118 was observed at the VLA in the 21cm neutral hydrogen line, and the HI distribution was found to be very peculiar. The system is composed of two galaxies apparently undergoing a very high velocity collision. Most of the neutral hydrogen emission was seen to originate from one side of the galaxy, and most of the colder molecular gas was found to originate on the opposite side, away from the region of maximum compression in the disk. The ionized gas is distributed uniformly over both halves of the galaxy and shows a very large velocity spread. In the center of NGC 1144, there are major perturbations in the nuclear velocity field of the ionized gas. The galaxy is very disturbed, and may provide clues about how collisions may drive activity in Seyfert galaxies. The other Seyfert, NGC 985, was observed by Appleton and collaborators with the Berkeley-Illinois-Maryland Array (BIMA), a millimeter aperture synthesis telescope. Carbon monoxide was detected in large quantities from the two galaxies involved in the interaction. Analysis of these data is still ongoing.

Appleton and collaborators from Europe (V. Charmandaris, I. F. Mirabel, and F. Combes-CEA Saclay, and Observatoire de Paris and C. Horellou, Sweden) continue to probe the ISM in collisional ring galaxies through a variety of different techniques. Following up on the success of HST observations of the Cartwheel (see last years report), we have been successful in showing that the center of the Cartwheel, often believed to be inactive, contains both a substantial reservoir of molecules and a significant quantity of warm dust. The latter observations, as a result of ISO imaging of the galaxy, suggests that the center of the Cartwheel may be the site of ongoing star formation which is heating the dust. In a similar observation of the centrally-smooth ring galaxy VI-I Zw 466, Appleton and collaborators have also detected mid-IR emission, this time exclusively associated with the outer ring. The ‘‘banana’’ shaped distribution of warm dust and radio emitting plasma seems to be the result of a strong compression of the ISM, as predicted by numerical simulations of near-central collisions between two galaxies.

Observations have begun in Australia (R. P. Norris and C. Heisler) and the US (Appleton, Bransford and Marston) of the COLA sample of galaxies (Compact Objects in Low-power AGN). This is an infrared-selected sample of 213 galaxies in a narrow shell of redshift space chosen to try to answer the following questions: Why do some galaxies contain AGNs and other do not? Is a nuclear starburst irrelevant or central to AGN activity, and what, if any, is the role of galaxy interactions? Most previous samples of AGN have been defined using optical or near IR spectra and have been strongly biased by the effects of strong optical extinction in their cores. Our sample uses the existence of a high brightness-temperature radio core (which is unaffected by dust) as evidence of an AGN. Observations have already begun using the VLA and the southern VLBI network to search for radio cores in our redshift shell, and VLBA observations are planned in the near future. Observations at Fick, and with the MSSSO 40" telescope provide optical photometry of the sample, and CO observations have either begun or are planned at the SEST and NRAO 12-meter millimeter telescopes. Once identified, the galaxies containing an AGN will be studied in great detail, especially in their inner regions, and compared with a control sample of coreless galaxies.

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3.3 TeV Gamma-ray Astronomy

The ISU group consists of faculty David Carter-Lewis and Frank Krennrich, post-docs Michael Catanese and Stephane LeBohec and graduate students Frank Samuelson and Ricardo Rodriguez. Recent graduates include Gora Mohanty (Ph. D) who has a post-doc position at Ecole Polytechnique in Paris and Jeff Zweerink (PhD) who has a post-doc position and the University of California at Riverside and Giridhar Nandikotkur (MS) who is working on a PhD at the University of Maryland. The ISU group is a member of the Whipple Observatory Gamma-ray collaboration that operates a Cherenkov imaging telescope on Mt. Hopkins in southern Arizona. Michael Catanese lives in Tucson, near the Observatory. Other members of the collaboration include Harvard-Smithsonian CfA, ISU, University College Dublin, Leeds University, St. Patrick's College - Maynooth, and Purdue University. This collaboration developed the imaging technique which differentiates Cherenkov light images from those from hadronic cosmic-ray background using a nanosecond camera consisting of 109 photomultiplier tubes on the focal plane of a 10m reflector. The telescope operates in a regime where background images are much more numerous and the imaging technique rejects more than 99 percent of these. The technique has been pivotal in our detection of the Crab Nebula (now the standard candle at TeV energies) and AGN Markarian 421 and 501. We have detected strong signals from the Crab Nebula (now the standard candle at these energies) and the AGNs Markarian 421 and Markarian 501 and 1ES 2344+514. Within the last year, at ISU we have concentrated on (1) spectrum determinations (2) development of a "low elevation" method to extend measurements to beyond 10 TeV (3) investigation of possibilities of stereo imaging and (4) campaigns in which TeV observations are coordinated with those at GeV and keV energies.

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