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This report covers the period from September 1995 through August 1996.

1. PERSONNEL AND EDUCATION

Faculty and staff active during this time were P. N. Appleton, G. H. Bowen (emeritus), D. A. Carter–Lewis, J. Eitter, S. Kawaler, R. C. Lamb, R. Lavery, C. Struck, and L. A. Willson. Postdoctoral associates were F. Krennrich, M. Catanese, and Hubble Fellow J. C. Clemens.

Graduate students in astronomy included M. Bransford, M. S. O'Brien, V. Charmandaris, B. T. Dehner, G. W. Turner, M. Sindberg, R. Loper, C.H. Kim, M. Jacobs, G. Nandikotkur, M. Reed, C. Fenlason, F. Samuelson, G. Mohanty, and J. Zweerink. During this reporting period, the Ph.D. degree was awarded to Mohanty, Dehner, and Charmandaris. Fenlason received a Masters degree.

At the end of the reporting period, R. C. Lamb announced his retirement from the faculty, and J. C. Clemens accepted a Fairchild Fellowship at the California Institute of Technology.

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http://www.public.iastate.edu/~astro

2. FACILITIES

During the interval of this report, CCD observations were obtained on 59 nights at the Fick Observatory this year. A wide field camera was developed which can be mounted piggy-back to the 0.6m Mather telescope. This uses the present CCD system and four interchangeable lenses to give fields of view from 1.8 degrees to 13.3 degrees. It was used to obtain images of comet Hyakutake(C/1996 B2) and other extended objects.

The stellar radial velocity project obtained an additional 2,350 observations on 57 nights of observing. This program is now entering its twenty-first year with a total of about 58,000 observations. There is hope of completing a summary paper of all observations to the present time this coming year.

3. RESEARCH PROGRAMS

3.1 Stars

Kawaler was on Faculty Improvement Leave during the Fall 1995 term. He spent 3 months working with Douglas Gough and others at the Institute of Astronomy, Cambridge University. Kawaler, Gough, and T. Sekii (IoA) explored using the observed rotational splittings in pulsating white dwarfs to constrain their internal rotation rates; results of this investigation are currently being prepared for publication. Kawaler also spent one month as a visiting scientist at the Copernicus Astronomical Center in Warsaw, Poland; he was hosted there by W. Dziembowski and P. Moskalik. Kawaler completed his review of white dwarf stars that was originally presented as a series of lectures at the 25th Saas Fee Advanced Course in Les Diablerets, Switzerland. This review be published as one of three chapters in the book ''Stellar Remnants'' that is a result of the course.

Ph.D. student Ben Dehner completed his Ph.D. thesis research involving theoretical computations of white dwarf evolution including time-dependent diffusion. He showed that the very thin helium–rich surface layer of the warm DB white dwarf GD358 is fully consistent with the thicker helium layer of the much hotter PG 1159 stars. Dehner's detailed models directly linking ordinary DB white dwarfs with the PG1159 stars. He also explored the consequences of trace hydrogen on the spectral evolution of these models.

ISU continued its involvement in the Whole Earth Telescope (WET) project. WET is a world-wide network of telescopes outfitted with multichannel photoelectric photometers, that is used to obtain 24 hour/day coverage of pulsating stars for the purposes of stellar seismology. WET is affiliated with the International Institute of Theoretical and Applied Physics (IITAP) at ISU.

O'Brien, Clemens, Kawaler, and Dehner analyzed archival photometry of the pulsating PG1159 star PG0122, and showed that this star shows similar pulsation periods to the star PG2131, previously investigated by Kawaler and the WET team. PG0122 is likely the most massive of the pulsating PG1159 stars. A WET observing run on PG0122 was scheduled for October 1996 with O'Brien as principal investigator. In the third year of his Hubble Fellowship, Clemens obtained 11 orbits of Hubble Space Telescope time to conduct time-resolved spectrophotometry of the pulsating white dwarf PY VUL. Data from the FOS were successfully reduced, and Clemens, O'Brien, and their collaborators are preparing the results for publication. At the end of the reporting period, Clemens accepted a Fairchild Fellowship at the California Institute of Technology.

Kawaler, Bond, and R. Ciardullo (Penn State) completed of analysis of the pulsating central of the planetary nebulae NGC 1501. These data were obtained during a global campaigns of CCD photometry involving sites in the United States, Japan, China, Israel, and Germany. The results will appear in the December, 1996, Astronomical Journal. Kawaler also collaborated with observers from the South African Astronomical Observatory in the exploration of a new class of pulsating star. The EC14026 stars are rapidly pulsating sdB stars found in the Edinburgh-Cape survey; they are multiperiodic variable stars 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. The first papers

describing these stars are to appear soon in MNRAS.

Bowen and Willson continue their in-depth investigation of the mass loss process from pulsating AGB stars. The 1995 Bowen grid of models (discussed in Willson, Bowen and Struck 1996, with a more comprehensive series of papers in preparation) provide a direct fit to disparate observational quantities – luminosities, mass loss rates, and conditions for maser emission (WBS and Humphreys *et al.* 1996). In the process of matching the models to the observations it has become apparent that some widely-used empirical relations have been entirely misunderstood. For example, the Reimers' relation that is often invoked as a rule for mass loss from evolving stars is found to be entirely the result of selection effects with mass loss rates that are extremely sensitive to stellar parameters.

During January-July 1996 Willson was on Faculty Improvement Leave at the University of Minnesota and Uppsala University, where she mainly worked on connecting observational data to theoretical models of Miras, and also initiated some new joint projects. She also continues to collaborate on a variety of projects with G. Wallerstein, University of Washington (cf. Hoard *et al.* 1996) Also during this time she has maintained a major commitment to work for the astronomical community as a member of the AAS Council, the AAVSO Council, the AURA Board of Directors, and as chair of the AURA Observatories Council.

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3.2 Galaxies

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. Lavery, P. Seitzer (Michigan), G. Da Costa (AAO), N. Suntzeff and A. Walker (CTIO) have also looked at the population of background field galaxies in the HST images of Tucana. They identified seven collisional ring galaxy candidates. Due to the very small field of view of the WFPC2 camera, there was only a 1% probability of a single ring galaxy being present in the observed field. The relatively large number observed provides evidence for a galaxy interaction rate that increases steeply with redshift. A more detailed analysis of these results is published in *The Astrophysical Journal Letters*.. Graduate student Chang-Hwan Kim is continuing his thesis research under Lavery. His program is a detailed analysis of the gravitational lensing

cluster GHO 2154+0508. This cluster has a redshift of 0.33 and is associated with a very high surface brightness arclet with a redshift of 0.721. This high surface brightness, low magnification arclet suggests the lensing mass is not very centrally concentrated and that this cluster may be in the early stages of formation. The ROSAT HRI observations reveal a patchy distribution of the x-ray gas. This gas distribution is being compared to the galaxy distribution measured from wide-field imaging done at the Fick Observatory. Deep optical imaging to identify additional lensed galaxy is now in progress in the WIYN queue-mode observing program. Lavery, M. J. Pierce (KPNO/Indiana) and R. D. McClure (DAO) have completed their program of high resolution imaging of distant clusters of galaxies using the Canada-France-Hawaii Telescope of the Mauna Kea Observatory. Two of the last clusters observed were Cl0016+1654 (z =0.54) and Cl0303+1708 (z=0.41). As in previously observed clusters, a high incidence of pairs and interacting systems is apparent for those cluster members having the stellar features indicative of recent star formation in their spectra. A comparison of these CFHT images of the star-forming galaxies with Hubble Space Telescope images of these galaxies, obtained from the archive, is now underway. Lavery, in HST archival images of the distant cluster Cl0016+1609, identified a ''giant arc'' associated with this cluster. Previous attempts at identifying gravitationally lensed images produced by this distant rich cluster in ground-based imaging programs have failed to find any strong lensed image candidates. The ''giant arc'' identified in the HST images is only 3.5 arcsec in length, but is unresolved in the Wide Field Camera images, being less than 0.2 arcsec in width. The source galaxy for the arc is likely to be at very high redshift and similar in its properties to the large number of compact objects present in the Hubble Deep Field. A more detailed description of this arc will presented in the November 1996 Astronomical Journal. Observations of collisional ring galaxies by Appleton and collaborators continues with the publication of the main optical/IR photometric data and atlas of the sample, reduction and investigation of metal content of the rings and their dynamics. A summary of some of this work in found in a major review article on the subject by Appleton and Struck. Work continues to extract the wealth of astrophysics from the HST WFPC2 observations of the Cartwheel ring galaxy. Color gradients, first found from ground based observations, are being explored by looking in detail at the distribution of both star clusters and extended disk emission in the ring. These are being compared with numerical models of stellar evolution in the wake of the ring. This work is funded under a NASA grant. In addition to the publication of papers in the Astrophysical Journal on the neutral hydrogen dynamics of two ring systems (VII Zw 466 and Arp 10), two new systems were observed at the VLA this year (Appleton and Bransford). These were the interesting empty ring galaxy II Zw 28 (also observed with the HST) and the more complicated system Arp 118. II Zw 28 is shown to contain a remarkable undisturbed HI disk somewhat larger than the optical ring, but higher resolution observations are required to resolve internal dynamics. The Arp 118 system (observations were performed in collaboration with K. Freeman and C. McCaine (Mt. Stromlo Observatory, Australia) showed, in addition to a disturbed HI disk, high velocity gas seen in absorption against the nucleus of one of the galaxies. This emission may be related to the extremely high velocity ionized material seen in AAT observations. In all four systems so far observed in HI, significant numbers of dwarf HI-rich companions have been detected in the outer regions of the groups containing the ring galaxies. These galaxies can provide information about the dark matter content of the groups. This work is funded by NSF grant AST-9319596. Appleton, in collaboration with C. Horellou (OSO), F. Mirabel (CEA-Saclay), J. Higdon (ATNF) and S. Lord (IPAC) have obtained pointed ISO observations of the VII Zw 466 group at 5 mid-IR wavelengths. This work is ongoing, but will provide the first direct measurements of warm dust in a classical ring galaxy and will help to resolve the question of the origin of large-scale color gradients seen in this and other systems. The work is funded by a NASA grant. In an ongoing multi-wavelength study of the circumnuclear star-formation properties of AGNs, Bransford & A. P. Marston have obtained 3 nights on the AAT to perform infrared observations using IRIS. They detected bright and extended molecular hydrogen, Brackett gamma, and [FeII] in three out of the five galaxies observed. These observation will help us to quantify more precisely the role of star formation in the inner disks of these AGNs. Further radio observations (Bransford, Appleton, and R. Norris) revealed that our sample contains a mixture of radio morphologies: four linear sources, containing knots of emission which are most likely ionized plasma ejected from an AGN in the form of plasmons, two diffuse sources, one L+D source, and the remaining sources are extended on a scale of 2-3.'' Spectroscopic studies of the sample by Bransford, Appleton, and C. Heisler) of the sample show that significant circumnuclear star formation is occurring, particularly in the diffuse radio sources. The work is supported by an NSF International Collaboration grant. Work continues on the optical follow-up survey of IRAS sources discovered after filtering the Band-4 IRAS Sky Survey database ($\lambda 100\ \mu$m) using the Morphological Filter. The filter, developed in collaboration between J. Basart and L. He (EECPE-ISU) and Appleton has revealed many new IRAS sources near or in the Galactic plane. Many of the sources are found to be real, since our R-band survey performed with the 0.6-m Mather telescope at the E. W. Fick Observatory is finding many optical counterparts. So far most of these are either compact HII regions or other complex galactic sources. Redshift follow-up is being pursued for a small number of possible extragalactic candidates, which may be galaxies obscured by the galactic plane. The filter work was funded by a NASA HPCC grant. Struck has continued work on SPH models of galaxy collisions involving two gas-rich disks, with a mass ratio of typically 1/3. In these simulations the galaxy halos are modeled as rigid gravitational potentials, but with local self-gravity calculated on scales smaller than the shear scale within the gas-plus-star disks. In most cases an adiabatic equation of state is used with additional terms for cooling and heating from young star activity. Twin models with an isothermal equation of state are often run for comparison. A small grid of models of

nearly central collisions have been carried out, sampling a part of the space of collision parameters and relative disk orientations. Depending on these parameters, a wide variety of morphologies can be formed from the combined forces of hydrodynamic splash and tidal torqueing (see Struck 1996a,b). These usually include ring and/or spiral waves, gaseous splash bridges between the two galaxies, and sometimes torqued gas/star plumes and bridges. The old stars and gas can sometimes be partially separated in the latter features. Which galaxy contributes the most to a splash bridge is found to depend strongly on the companion orientation at impact. The companion disks are usually highly disrupted by the collisional impact, but reform via accretion from the bridge. However, the orientation of the new gas disk is generally much different than that of the remaining old star disk in the companion. There is also substantial accretion into the central regions of the primary, which causes a great deal of heating and disruption there until the accretion peaks and declines. Thus, the models suggest that accretion may inhibit star formation in the central regions of some collisional galaxies for a considerable time. This point may be very relevant to the Cartwheel ring galaxy, where there is little star formation within the inner ring, but there is an extended bridge of HI gas. Though most of the gas in the Cartwheel disk is concentrated in the outer parts, broad band HST observations have resolved numerous dust lanes in the inner ring region indicating that cool gas is probably present there. These observations also revealed blue, comet-like objects lying within or across the inner ring. The bow-shock morphology of these objects suggests shock emission, though induced star formation may also be present, especially in the ''comet heads.'' The observations are not yet sufficient to determine whether these objects result from dispersive radial motions in the disk, or are in fact the result of infall out of the bridge. This work is described in a paper in press (Struck *et al.* 1996), and the Cartwheel observations are described in several publications below. New HI maps of both the Cartwheel (Higdon 1996), and the classical ring galaxy VII Zw 466 (mapped by Appleton and Charmandaris, see reference below), show that both have gas bridges. Neither bridge has any significant on-going star formation, nor any visible old star component. This is also true in the models of splash bridges, in contrast to tidal bridges. Struck has been working with B. Smith (Caltech/IPAC) on models of new high resolution observations of the ring-like system Arp 284. In this case, the bridge seems to be a combined effect of splash and sling, with gas and young stars offset from the old stars. Struck is also working with an extensive collaboration on another similar class of collisional galaxies, the oculars (see the reference of Kaufman *et al.* below).

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3.3 Gamma rays

The ISU group consists of faculty member D.A. Carter–Lewis, postdocs F. Krennrich and M. Catanese and graduate students G. Mohanty, J. Zweerink, C. Fenlason and G. Nandikotkur. Mohanty finished his PhD thesis on the energy spectrum of the Crab Nebula last spring. Fenlason finished an MS at about the same time. We are presently searching for a replacement for faculty-member Lamb who retired in August 1996. 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. Both ISU postdocs live 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, University of Michigan, 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. Since these telescopes operate in a regime where background images are much more numerous, this has turned out to be a major advance. We have detected strong signals from the Crab Nebula (now the standard candle at these energies) and the AGNs Markarian 421 and 501. At ISU we have also been heavily involved in developing methods for determining energy spectra of cosmic emitters of TeV gamma rays and are now confident in our spectrum for the Crab Nebula. Highlights from the past year include the following.

Detection of extremely strong and rapidly varying TeV flares from Markarian 421. In one of the outbursts, which lasted about 30 minutes, the flux increased by a factor of about 25 suggesting that the emission region is very small. The TeV emission from Markarian 421 was known to variable on time scales of days and multi-wavelength observations have demonstrated a correlation with emission at lower energies. The TeV emission is also consistent with zero steady emission.

We have taken several steps forward in the measurement of TeV spectra and now workers at ISU and the University of Leeds get the same result for the Crab Nebula spectrum. The techniques are being applied to other spectra, especially the Markarian flares.

Shell-type supernova remnants are the usually assumed to be the birthplace of cosmic rays up to energies of about 100 TeV. Recently, it has been pointed out that, if this is the case, gamma-rays from pion decay should be observable with our telescope. We have observed several shell-type SNR (Tycho, Cass-A, γ-Cygni, W44, W63 W51 and IC443) and seen no observable flux, only upper limits.

The US Department of Energy has funded a major upgrade of the telescope from 109 to 541 pixels over a period of three years.

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