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This report covers the period from September 1996 through August 1997.

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, R. Lavery, C. Struck & L. A. Willson.

Graduate students in astronomy included R. Benson, M. A. Bransford, J. Dostal, M. Jacobs, C. H. Kim, M. S. O'Brien, M. Reed, A. Remijan, F. Samuelson, G. W. Turner. During this period, the MS degree was awarded to M. Jacobs.

Undergraduates involved in astronomical research during this period were Andrew Beaty, funded under the Iowa Space Grant Consortium.

In July Willson concluded a 3-year term as chair of AURA's Observatories Council, and began a term on the new AURA Board of Directors. She continues to serve on the Council of the AAVSO.

In July 1997, Kawaler became director of the Whole Earth Telescope (WET) collaboration.

Appleton spent May-June 1997 as a visitor to the Service D'Astrophysique, CEA-CEN Saclay, France, and August 1997 at Mt. Stromlo Observatory and the ATNF, Sydney, Australia.

Visitors to the department during this period were I. Iben (Illinois), R. Norris (ATNF), C. Heisler (MSSSO), Michael Hillas (Leeds), Roseanne Di Steffano (Cfa), Bev Smith (IPAC-Caltech), Jim Buckley (Cfa), Reshmi Mukherjee, Lucy Fortson (Chicago), Robert Stobie & Darragh Donoghue (SAAO).

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2. FACILITIES

During this period, CCD observations were made on 55 nights at the Fick Observatory. Observations of comet Hale-Bopp (C/1995 O1) with the CCD wide-field camera were the highlight of the year. The stellar radial velocity project obtained an additional 1250 observations on 33 nights.

The 0.6m Mather telescope is being upgraded with the addition of a Newtonian focus. This upgrade will allow rapid switching between several output ports. The first port to be completed is the feed to the CCD camera which will operate at f/3.6 and have a field of view of 20 arc-minutes with the present detector. A 2 x 2 K chip is planned to take full advantage of the new optics, significantly flatter field, and higher throughput of the new system. A second port will be added next year with the highest priority being that of an optical fiber feed to the radial–velocity spectrometer. Eventually we plan to incoporate a third port for the next–generation of WET photometer. This upgrade was supported by a grant from the Iowa Space Grant Consortium.

With Kawaler assuming directorship of the Whole Earth Telescope, ISU became 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

Kawaler, Gough, and T. Sekii (IoA, Cambridge, UK) completed an exploration of the prospect of using the observed rotational splittings in pulsating white dwarfs to constrain their internal rotation rates; results of this investigation are soon to be submitted for publication.

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 been submitted for publication, and was presented at the Los Alamos Pulsation workshop in June 1997.

While at ISU in 1996, J.C. Clemens (now at Caltech) obtained 11 orbits of Hubble Space Telescope time to conduct time–resolved spectrophotometry of the pulsating white dwarf PY Vul. Clemens, O'Brien, and their collaborators completed reduction and analysis of this large data set, and are preparing the results for publication.

Kawaler, Bond, and R. Ciardullo (Penn State) completed of analysis of the pulsating central star 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 were published in the December, 1996, Astronomical Journal.

Kawaler continues his collaboration with observers from the South African Astronomical Observatory in the exploration of the EC14026 stars, which are rapidly pulsating 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 two of these stars: PB8783 and PG1047; 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.

In September 1996, the Whole Earth Telescope observed the pulsating pre-white dwarf star PG0122. As PI for this observation, O'Brien was faced with data from the WET run with the poorest weather in the history of the collaboration. Still, data were of sufficient quality to allow new insights into the pulsation spectrum of this star. O'Brien concludes that this star is the coolest and most massive of the pulsating pre-white dwarfs. As such, theoretical models predict that this star is cooling principally by neutrino emission. In the paper describing this work, O'Brien and the WET collaboration suggest that measurement of the rate of period change of PG0122 can lead to important constraints on the process of neutrino production in dense plasma. In addition to the paper that has been accepted for the *Astrophysical Journal*, these results will be expanded upon in a paper in preparation as well as in O'Brien's Ph.D. dissertation.

In collaboration with J.C. Clemens, I.N. Reid, and J.E. Gizis of Caltech, O'Brien analyzed data on the masses and radii of low–mass main sequence stars. Their conclusion is that a change in the parameters of the mass–radius relation of M dwarfs may be responsible for the observed peculiar distribution of orbital periods of cataclysmic variable stars. A paper describing these results has been submitted for publication in *The Astrophysical Journal*.

Bowen has continued dynamical modeling calculations for pulsating AGB stars, with the goal of understanding their dynamical structure and behavior, and especially their evolution with mass loss. Calculations are now complete for a large grid of models having parameters consistent with the Iben (1984) RLMZ relationship (masses 0.7 to 4.0 solar mass, metallicities 1 to 0.01 solar, and luminosities giving mass loss rates from 1E-10 to 1E-5 Msun/yr for each M, Z combination), plus extensive testing of the results' sensitivity to variations of the parameters and approximations involved—a total of around 400 models. The results, which confirm and extend those described in Bowen and Willson (1991), have been used to derive analytic relations for evolutionary tracks in this parameter range. Several papers describing this and related work are in preparation. Work is continuing in such areas as time-dependent chemistry, improved radiative transfer, silicate grain formation and properties, etc.

Of crucial importance in these models are (a) the evolutionary ''path'' in parameter space (e.g. the relationship during evolution between the stellar parameters R and T_{eff}, here given by the Iben relation, which matters a very great deal; it must be realistic, or the results will be very wrong indeed.); (b) the complex nonlinear interactions among various processes in the model, which change in their relative importance greatly during the evolution of a given star, and can be quite different from one stellar type to another; and (c) the strong density dependence of various rates, which makes disequilibrium quite common in all but the relatively dense inner atmosphere, and introduces several key phenomena.

Willson, who is studying the implications of these results for evolving stellar populations, is finding promising, often impressive agreement with various published observational results. For example, reports on progress comparing the Bowen calculations with observational constraints were included in review talks given in a special session on Miras at the fall meeting of the AAVSO, in the spring meeting of the AAVSO in Sion, Switzerland, and at an ESO sponsored meeting on cyclic variability in winds. Also a talk on Miras with more historical flavor was given at the symposium in honor of Dorrit Hoffleit's 90th Birthday at Yale.

Willson is collaborating with J. A. Mattei of the AAVSO on a long-term project concerning classificaton of red variables based on lightcurves and other fundamental data. A preliminary report was given at the Venice Hipparcos symposium. In conjunction with this work they have noted a striking lack of correlation between parallaxes - including Hipparcos values - and angular diameters for Miras, suggesting strongly that either or both of these quantities is at present very poorly known.

Eitter, discovered a collection of peculiar Bok globules in the HII region LBN-249 using a wide-field lens attached to the TI 800 x 800 CCD at the Fick Observatory. Follow up observations with the 0.6-m Mather telescope (with Appleton) show what appears to be long trails of dust behind the globules which all seem to be entering the HII region from the same direction. Additional observations with the 20-m Onsala Space Observatory (with P. Bergman, OSO) show strong detections of ^{12}CO(1-0), ^{13}CO(1-0) and HCO+(1-0) molecular line transitions. Assuming that the main globule is at the same distance as the HII region (it has the correct velocity) the mass of molecular hydrogen is approximately 3 $[D/1.5kpc]^2$ M$\odot$. If the globule has just entered the HII region, it is likely that it will experience a significant external pressure which might induce collapse. The study of such regions may provide a laboratory for the study of the ''cloud-crushing'' theory of massive star formation in starburst nuclei (Jog & Das 1997, ApJ, 473, 797), where molecular material from galaxy interactions is funnelled into a high-pressure nuclear region and converted to stars. Further molecular line observations are proposed to investigate the dynamical state of the globules.

PUBLICATIONS

Bond, H.E., **Kawaler**, S.D., Ciardullo, R., *et al.* 1996, ''Asteroseismological Observations of the Central Star of the Planetary Nebula NGC 1501,'' AJ, 112, 2699

Breger, M., *et al.* (including **M.S. O'Brien**) 1996, ''The δ Scuti star FG Virginis. II. A search for high pulsation frequencies,'' A&A, 309, 197

Kawaler, S.D. 1996, ''White Dwarf Stars,'' in *The 1995 Saas Fee Course in Astrophysics: Stellar Remnants*, ed. G. Meynet (Berlin, Springer-Verlag)

Stobie, R.S., **Kawaler**, S.D., Kilkenny, D., O'Donoghue, D. & Koen, C. 1997, ''A New Class of Rapidly Pulsating Star - III. Oscillations in EC10228-0905 and Pulsation Analysis,'' MNRAS, 285, 651

Clemens, J.C., Reid, I.N., Gizis, J., & **O'Brien, M.S.** 1997, ''The Lower Main Sequence and the Cataclysmic Variable Orbital Period Distribution,'' ApJ, (In Press)

Handler, G. *et al.* (including **M.S. O'Brien**) 1997, ''New Whole Earth Telescope Observations of CD -24 7599: steps towards δ Scuti star seismology,'' MNRAS, 286, 303

O'Brien, M.S., Vauclair, G., **Kawaler, S.D.**, *et al.* (the WET Collaboration) 1997, ''Asteroseismology of a Star Cooled by Neutrino Emission: the Pulsating Pre-White Dwarf PG0122+200,'' ApJ, (In Press)

O'Brien, M.S, & **Kawaler, S.D.** 1997, ''Measurement of Neutrino Cooling Rates in Pre-White Dwarfs,'' BAAS, 189, 78.10

O'Donoghue, D. *et al.* (including **M.S. O'Brien** & **S. Kawaler**) 1997, ''The EC14026 Stars V: the pulsation periods of PB 8783,'' MNRAS, (In Press)

Mattei, J. A., Foster, G. Hurwitz, L. A. Malatesta, K. H., **Willson, L. A.**, Mennessier, M. O. 1997, ''Classification of Red Variables'' in Proceedings of HIPPARCOS Symposium Venice'97, Perryman *et al.* eds, ESA-SP, (In Press)

Appleton, P. N., **Eitter, J. J.** & Bergman, P. 1997, ''Infalling Dust Globules in Cygnus: A Laboratory for Testing Cloud-Crushing Models of Star Formation,'' ApJ, (in preparation)

3.2 Galaxies

Struck completed work on a small grid of SPH models of galaxy collisions involving two gas-rich disks, with a mass ratio of typically 1/3. In these models the galaxy halos are represented as rigid gravitational potentials, but with local self-gravity calculated on scales smaller than the shear scale within the gas-plus-star disks. Radiative cooling and heating from young stars were included, and multiple thermal phases allowed in the gas. Twin models with an isothermal equation of state were generally run for comparison (see Struck 1997a-d).

These models show that a clear star-forming ring wave can form even when a substantial segment of the primary disk is disrupted and splashed out by the impact of the gas disk of the companion. Which galaxy contributes the most to a splash bridge is found to depend strongly on the companion orientation at impact. In face-on impacts the bridge consists almost entirely of gas knocked out of the primary disk, while most of the companion disk is captured into the primary. In more inclined impacts, the companion contributes more to the bridge gas, and its contribution dominates when its disk lies in the orbital plane and rotates in the prograde sense.

The companion gas 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 very different from that of the pre-collision companion disk (i.e., it is usually perpendicular to the bridge). Ring galaxy companions often appear very disturbed, but have been little studied.

There is also substantial accretion into the central regions of the primary, which causes a great deal of heating and disruption, until the accretion declines. Accretion inhibits star formation in the central regions of both 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, broadband HST observations have resolved numerous dust lanes in the inner ring region suggesting the presence of cool gas. These observations also reveal 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 Struck *et al.* (1996).

The ring galaxy bridges that have been discovered and mapped at 21 cm. do not show significant on-going star formation. This is also true in the models of splash bridges, which contrasts with the situation of M51-type, tidally torqued bridges. Struck has been working with B. Smith (Caltech/IPAC) and R. Pogge (Ohio State) on studies of intermediate cases, involving inclined, off-center impacts between gas bridges where we expect both hydrodynamical splash and tidal torqueing effects to play a role in bridge structure and evolution. In particular, we have focussed on models of the ring-like system Arp 284 as a first case. High resolution optical and radio observations have revealed a massive gas bridge, and shown that the gas and young stars in this system are offset from the old stars. A massive gas loop was also revealed by the VLA HI map. These features, as well as rings and tails within the primary disk have been modeled quite successfully by a prograde collision (for the companion), with an impact point about half-way out in the primary disk. This work is descrbed in the paper of Smith *et al.* (1997). Struck is also working within a collaboration studying a similar class of collisional galaxies, the oculars (see the references of Kaufman *et al.* below).

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 (see reference below). Reconstruction of the source galaxy is being done by L. Rimoldini (Pavia, Italy) as part of his undergraduate thesis (B. Bertotti, Advisor), with Lavery as an external advisor.

Lavery, Q. D. Wang and M. Ulmer (Northwestern) have completed their analysis of the X-ray and optical structure of the rich cluster of galaxies A2111 at a redshift of 0.23. Both the X-ray images (ROSAT PSPC and HRI) and the optical galaxy distribution reveal the cluster to be elongated along the same direction. These X-ray images also reveal a subclump of X-ray gas of somewhat higher temperature compared with the majority of the cluster gas. These properties suggest A2111 has undergone a merger event with a subcluster of substantial mass. This recent merger event may also be responsible for the large population of blue galaxies in this cluster.

Graduate student Chang-Hwan Kim is continuing his thesis 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, and deep optical imaging obtained through the WIYN queue-mode observing program at the Kitt Peak National Observatory.

Lavery and graduate student Michael Reed are in the reduction stages of a redshift survey of Abell richness–3 clusters based on data obtained with the 2.3-meter telescope of the Siding Spring Observatory. While most of the clusters are from the Southern Abell catalog, the sample also includes a number of overlap clusters from both catalogs, as well as some centrally concentrated richness–2 clusters from the southern catalog. This program will significantly increase the number of nearby rich clusters with measured redshifts.

Appleton, with M. Jacobs (Graduate Student), C. Struck and collaborators K. Borne (NASA/STX) and R. Lucas (STScI) have made a detailed study of the photometry of the many hundreds of star forming knots and star clusters in the Cartwheel ring galaxy based on their HST data. The work investigates the evolution of massive star clusters and associations as the expanding density wave moves radially outwards. The results confirm that the outer ring is populated with massive young associations with a broad spread of colors quite consistent with a very young stellar population. The B-I color index is used to investigate color variations in both the clusters and the underlying light. The results for segments of the disk free from spokes are consistent with models of an aging stellar population with radius, superimposed on an underlying centrally concentrated disk component. Star clusters and associations inside the ring (between the outer and inner rings) have luminosities and colors consistent with being aged remnants of the brightest outer ring clusters if it is assumed they were formed when the ring passed over that part of the disk some 200 million years ago. Some of these clusters may also be the result of secondary star formation as gas is compressed in the spokes.

M. Bransford and Appleton, with Marston (Drake) have completed their spectroscopic study of bright northern ring galaxies. They find that the oxygen abundances of the rings are uniformly around half-solar and do not show a decreasing trend with radius, contrary to the naive picture of a ring propagating down a metallicity gradient. A comparison has also been made of the colors of the star clusters with numerical models of stellar evolution to determine the star formation history of the rings. It is found that in most cases the colors are consistent with young clusters with ages in the range 10-80 million years, which is significantly less than the dynamical timescale for the ring propagation. This work is funded by an NSF grant.

Bransford and Appleton, in collaboration with C. Heilser (MSSSO), R. Norris (ATNF) & A. Marston (Drake) have completed an observations pilot study of 12 radio bright southern Seyfert galaxies to investigate the possible relationship between arcsec radio morphology, and nuclear or circumnuclear emission line properties. The radio stuctures, which were mapped at three frequencies at the Australia Telescope National Facility show a range of morphology from Linear (L), Diffuse (D) and Compact (C). The D class sources are found to exhibit signs of starburst activity in the inner few kpc's of the galaxies, whereas the (L) type sources often show signs of shocked (or LINER) activity, especially associated with the ends of linear radio structures. A dramatic example is IC 5063, which shows a linear–triple structure in the radio with strong IR [FeII] and molecular hydrogen line emission from the ends of the triple suggesting an interaction between outwardly propagating ''blobs'' and the ISM. Future scheduled AAT observations with the ''3D'' IR spectro-imaging scanner may confirm this picture. It is found that the radio morphology of the sample is correlated with the FIR color temperature of the dust, with ''C-type'' sources having hotter FIR colors than the ''D-type'' sources. Significant free-free absorption is seen in a number of Seyfert galaxies at radio wavelengths, suggesting high column densities of plasma probably associated with star formation. An Astrophysical Journal article on this work has just been accepted for publication. This work is funded by an NSF U.S.-Australia international cooperative grant.

The AGN collaboration above has now begun a new large-scale project to investigate the properties of lower-power AGN's (called COLA-Compact Objects in Low-powered AGN's). A sample of over 200 galaxies in a constant redshift shell has been defined. The sample will initially be searched for compact radio cores using both the VLBA and the PTI (southern) VLBI network. This will form the basis for the selection of the AGN subset. A second sample, sharing the same global properties as the radio-core sample will be drawn from the larger sample using gas content ($HI+H_2$) and I-band imaging (performed at Fick and MSSSO). Once these small subsets are defined, a full-scale study will be made of the nuclear properties of these galaxies to search for differences between the cored and un-cored galaxies.

PUBLICATIONS

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Kaufman, M., Brinks, E., Elmegreen, D. M., Thomasson, M., Elmegreen, B. G., **Struck, C.** & Klaric, M. 1997, ''Observations of the Ocular Galaxy NGC 2535 and its starburst companion NGC 2536,'' AJ (In Press)

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Struck, C. 1997, ''Star Formation in Collisions Between Two Gas-Rich Galaxy Disks,'' in ''Proceedings of I.A.U. Symp. 186, Galaxy Interactions at Low and High Redshift,'' ed. D. Sanders (San Francisco: ASP),(Submitted)

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Smith, B. J., **Struck, C.**, & Pogge, R. W. 1997, ''Atomic Hydrogen and Star Formation in the Bridge/Ring Interacting Galaxy Pair NGC 7714/15 (Arp 284),'' ApJ, 483, 754

Appleton, P. N. & Marston, A. P. 1997, ''Multiwavelength Observations of Collisional Ring Galaxies: I Broad-band Images, Global Properties and Radial Color of the Sample Galaxies,'' AJ, 113, 201

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3.3 TeV Gamma-ray Astronomy

The ISU group consists of David Carter-Lewis, Frank Krennrich, faculty, Michael Catanese, a post-doc and Frank Samuelson, a graduate student. Within the last year Gora Mohanty finished his PhD and accepted a post-doc position; Jeff Zweerink finished his PhD and accepted a teaching position; Giridhar Nandikotkur finished his MS and is now working on a PhD at the University of Maryland and Richard Lamb retired but is still active in research via Cal. Tech. 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 that 99 percent of these. The techique has been pivotal in our detection of the Crab Nebula (now the standard candle at TeV energies) and AGN Markarian 421 and 501. 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. Details are in the publications listed below.

PUBLICATIONS

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Catanese, M., *et al.* 1997, ''Multiwavelength Correlations of Mrk 501,'' ApJL, 487, L143

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Hillas, M.A. *et al.* 1997, ''The Spectrum of TeV gamma-rays from the Crab Nebula,'' ApJ, (submitted)

Krennrich, F. *et al.* 1997, ''Multi-TeV γ-Ray Emission from Markarian 421,'' ApJ, 481, 758

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P. N. Appleton