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I. PERSONNEL

This report covers the period from August 1985 to August 1986. Within the Department of Physics and Astronomy, those currently involved in astronomical research are Dr. J.P. Davidson and R. Desko (IUE Data Analysis), Drs. David Beard and Thomas P. Armstrong (Solar System Studies), and Drs. Barbara J. Anthony-Twarog, Stephen J. Shawl, and Bruce A. Twarog (Stellar and Galactic Studies). New additions to the faculty include Dr. Scott Baird of Benedictine College (Stellar and Galactic Studies) who became an adjunct assistant professor in Sept. 1985, and Dr. Adrian Melott (Cosmology and the Early Universe) who became an assistant professor within the department in July 1986.

II. INSTRUMENTATION AND DATA ANALYSIS

Installation of the Mid-American Astronomical Image Processing Laboratory (MAIPL) is essentially complete, with the acquisition of an image processor display from International Imaging Systems. Programs to reduce two-dimensional photometric data and one-dimensional spectra are available for general use and include DAOPHOT for stellar CCD photometry, R2D2 for image operations, and RETICENT for spectrum analysis. Programs to extract spectra from two-dimensional arrays are being installed. In addition, the plotting package MONGO is now available on the Department of Physics and Astronomy VAX 11/750. Interested users are urged to inquire.

Student Dan Long has begun an upgrade of the Mann two-coordinate measuring engine on loan from the University of Texas to permit direct recording of positions via an interface of the engine with a Zenith 148 personal computer. The data will then be transferred for analysis to the VAX 11/750.

III. RESEARCH

a. Stellar and Galactic Studies

Shawl, and Don Bord (University of Michigan at Dearborn), as a part of their search for companions to long period variables, have determined new periods for 11 southern stars based on photographic and new photoelectric observations made within the past decade. For 7 stars for which mean periods were previously known, differences between the newly derived period and the published values is <17 days. Four stars had no published period: FU Hya (190 days), EI TrA (274 days), V1161 Sgr (175 days), and RX Mic (239 days). Finding charts and light curves for some of the less well-studied of these variables are also available. The times of maximum brightness derived from the new data differ by more than a quarter period when compared with the dates predicted using the published numbers. Photometric analysis of additional stars is continuing. This work has received partial support from the University of Kansas General Research Fund.

Shawl, in collaboration with J. E. Hesser (DAO) and Cameron Reed (St. Mary's), are nearing completion of their study of the reddening of the galactic globular clusters. The *preliminary* results are as follows: (1) observed Hesser–Shawl spectral types (1985, *P.A.S.P.* **97**, 465) and homogenized colors from Reed (1985, *P.A.S.P.*, **97**, 120) are used to calibrate the color–spectral type relation for 50 clusters. Color excesses are then derived for 93 clusters on the HS spectral type system. The results are thus based on the most homogeneous data base available; (2) a large scatter among F9/G0-G2 clusters may reflect the onset of a discontinuity with cluster population as discussed by Zinn (1985, *Ap. J.*, **293**, 424.) and other papers by Hesser and Shawl; (3) trends with integrated spectral type are clear in the $(U-B)_0$, $(B-V)_0$ diagram, but not in the $(V-R)_0$, $(R-I)_0$ diagram; (4) the $(U-V)_0$, $(V-I)_0$ diagram is sensitive to integrated spectral type (metallicity).

Shawl and J. Brodie (University of California) have obtained long–slit spectra of the globular clusters M3, M13, and M15 with the slit aligned through both the cluster center and the dark "patches" seen on the cluster, for the purpose of trying to determine if the "patches" are dust and, if so, what the properties are. The observations were obtained with the Lick 40-inch Neckel telescope and CCD spectrograph.

The program of photographic photometry in open clusters involving Anthony-Twarog, N. Caldwell (N. O. A. O.), and Twarog continues. Results are now available for several clusters, and measurements of the clusters NGC 3680 by student Erich Heim and NGC 2360 by student Ray Murray are now underway.

For NGC 6259, student Don Payne has completed reductions of 10 plates of the cluster taken with the Yale 1m at Cerro Tololo. The exposures reached $V \geq 17.5$. Using the iris astrophotometer at the University of Kansas (on loan from Yale University), and standard stars from an earlier study by Hawarden (*M.N.R.A.S.*,**169**, 539), we were able to show that: (1) the standard errors of a single measurement were below 0.025 mag for both colors; (2) the width of the main sequence is approximately three times larger than expected from photometric errors alone; (3) the cluster reddening is $E(B-V) = 0.64 \pm 0.03$, and the apparent modulus is the same as that of M11. Further analysis showed that the spread in color is unlikely to be the result of variable reddening and is probably due to an age spread within the cluster. Though the cluster *cm* (color-magnitude) diagram is similar, it is not identical to that of M11, especially in that it lacks an extended main sequence composed of significantly younger stars. A paper detailing these results is in preparation.

For NGC 2354, student David Bishir completed reduction of 21 plates taken with the Yale 1m. Using the iris astrophotometer at the University of Kansas and calibrations based upon a set of short 4m CCD exposures of the cluster, a surprising result emerged. Contrary to expectations based upon earlier photographic work by Dürbeck using lower quality data, a cluster does not exist as a coherent entity. From the *cm* diagram, the "cluster" appears to be a slight stellar density enhancement in the overall distribution in this area of the sky. No coherent distribution of stars in the *cm* diagram is apparent other than what one would expect for a random field near the galactic plane, a result confirmed by a star count analysis of the area surrounding the cluster. Whether the enhancement is the result of a hole in the reddening distribution or simply a small fluctation in the number of stars cannot be decided without additional information.

Anthony-Twarog and Twarog have completed a photoelectric and CCD *uvby*Hβ survey of the open cluster IC 4651. From the Hβ photometry, it is concluded that the cluster reddening is $E(B-V) = 0.089$, significantly lower than that found from broad band and *DDO* photometry. With the lower reddening, the cluster metallicity becomes [Fe/H] $= 0.21 \pm 0.03$ relative to the sun, higher than the Hyades by 0.09 dex, and the true modulus is approximately 9.9. It should be noted that adoption of the higher reddening value leads to an anomalously higher metallicity and a modulus inconsistent with clusters of an age similar to that of IC 4651 or 2.4×10^9 years. More importantly, the photometry confirms a result found in the recently completed photographic sur-

vey by Anthony-Twarog, Twarog, N. Caldwell (N. O. A. O.) and student K. Mukherjee. The main sequence of the cluster shows an intrinsic spread of 0.03 to 0.04 in $B-V$, similar to the result found for a slightly more metal-poor cluster of comparable age, NGC 752. Though the cluster *cm* diagram morphology is different for these two objects due to the metallicity difference, it is apparent that the broadening of the main sequence is restricted to stars in the early to mid F range, and is probably linked to the existence of the Böhm-Vitense gap in the main sequence. Since this is caused by a change in the convective layers of the stars, it could have an important impact upon our understanding of low mass stellar evolution. The CCD observations of the cluster clearly demonstrate the value of this instrument for observations on photometric systems of intermediate bandwidth, providing comparable accuracy for a large sample of stars to fainter magnitudes in integration times of considerably shorter length, *e.g.*, one night of observation compared to one or two weeks. Two papers detailing these results are in preparation.

Twarog, in collaboration with P. Nissen (Aarhus Univ.) and D. Crawford (N. O. A. O.), has completed the merger and analysis of a large sample of photoelectric *uvby*Hβ photometry of the cluster. The definitive values for the cluster parameters are found to be $E(B-V) = 0.032$, [Fe/H] $= -0.06 \pm 0.07$, and a true distance modulus of 9.71. The age of the cluster on the system of VandenBerg is found to be 5.0×10^9 years. It was demonstrated that the binaries in the cluster tend to have higher reddening, that the cool F stars require inclusion of a luminosity correction in the metallicity calibration, and that a strong temperature dependence exists in the slope of the luminosity calibration, reaching values as large as 17 for the early G stars. The *cm* diagram above the main sequence gap is dominated by binaries, while an apparent paucity exists below it. The turnoff shows clear evidence of a blueward hook which is not accurately predicted by the isochrones of VandenBerg, either because of convective overshoot or adoption of too blue a solar color, or both. Unlike the younger open clusters NGC 752 and IC 4651, no evidence is found for an intrinsic spread in color on the main sequence below the gap.

In a companion study, Anthony-Twarog has completed some of the first CCD observations with the *uvby* photoelectric system in M67. The photoelectric observations of Nissen, Twarog and Crawford have been used to calibrate the instrumental indices derived from the CCD observations and to demonstrate that fundamental parameters of comparable precision can be obtained for large numbers of stars in this way.

In an additional initial application of CCD–*uvby* photometry, Anthony-Twarog is completing preparation of a paper discussing observations of the upper main sequence of the globular cluster NGC 6397. The precision of the *cm* diagram greatly exceeds previous studies in the cluster, and with the additional information afforded by the $c_1, b-y$ diagram enables a determination of the age as $16 \pm 1 \times 10^9$ years when compared to the isochrones of Vandenberg(1985). There are too few observations of extremely metal-poor dwarfs of this temperature range to directly compare to in order to determine the metallicity of the cluster in this manner, although the recent models of Lester, Gray and Kurucz (1986) will be employed. The luminosity sensitivity of the metallicity index δm_1 indicated in the two studies of M67 is confirmed in this study as well. Perhaps most exciting is the isolation of several binary candidates above the main sequence following exclusion of probably non-members on photometric grounds. This work and the photographic cluster studies have been supported by the National Science Foundation through AST 8420209.

Anthony-Twarog, J. Laird (University of North Carolina), and Twarog have continued their program of extension and expansion of the *uvby* system to five filters with the addition of a *Ca* filter and observation of stars as cool as K5. Preliminary reductions of data obtained at KPNO in Dec. 1985 reveal that the *Ca* filter is three times more sensitive to metallicity changes than δm_1, and more importantly, provides convincing evidence for a luminosity effect in the transformation of δm_1 to [Fe/H]. The *Ca* index is also sensitive to such effects, but apparently to a lesser degree, allowing use of a *Ca*, δm_1 color-color diagram to derive evolutionary effects for cooler stars, independent of c_1. Observations of F, G and early K stars from the Bright Star Catalog are continuing using the 24 in. and 1m. telescopes at CTIO. Over the summer, student Don Payne obtained standard star observations on the *Ca* system at Braeside Observatory in Arizona under a grant from Research Corporation. These data are being compiled to provide an equatorial network of standards around the sky.

Students Don Payne and Dan Long, under the direction of Twarog, have begun an analysis of the theoretical reddening slopes for cool stars under a variety of photometric systems, including the four color *uvby* system. With the possibility of CCD observations of globular clusters and galaxies on intermediate band systems becoming a reality, the need for preliminary estimates of the effects of reddening on the color indices for cool stars, independent of the currently nonexistent empirical calibrations, is increasingly important. Additionally, these results will be used as a test of a possible technique for deconvolving the effects of reddening and metallicity on the integrated light of clusters, for use in analysis of proposed extragalactic cluster observations by ST involving Twarog, Anthony-Twarog, and others under the direction of K. Janes (Boston Univ.).

Graduate student Tamara Whitacre, under the direction of Anthony-Twarog and Twarog, has begun her Master's Thesis project, a comprehensive *UBVRI* CCD survey of the young open cluster NGC 3293. The intention is to study the faint end of the main sequence to determine its extent as a test of the possible discrepancy found between the turnoff age and pre-main sequence collapse age of the lower mass stars found by Herbst *et al.*. Additionally, the luminosity function will be estimated, and any variation in its makeup as a function of position within the cluster will be analyzed. The multicolor data will allow differentiation of potential cluster non-members, while providing a handle on reddening variation across the cluster.

Work by Davidson, Desko and Bord (Univ. of Michigan at Dearborn) is continuing in the analysis of the ultraviolet spectra of various stellar objects. An article is in press describing the complete package for the reduction of spectra from *IUE* tapes provided by the Astronomical Data Center at NASA Goddard Space Flight Center. Desko and Bord have completed analysis of the ultraviolet spectrum of HD 101065 (Przybylski's star) in which a definite presence of common iron-peak elements in addition to numerous doubly-ionized rare-earth elements has been confirmed. Radial velocity sweeps yield no strong evidence of segregation between the iron-peak and lanthanide rare-earth elements in this star. New evidence to support the identification of Co I and Co II was also presented in a paper on this work given by Bord at the 8th annual meeting of *IUE* observers in Paris. The similarity of HD 101065 to several hot magnetic Ap stars which also exhibit unusually strong presence of [Co/Fe] was noted. Work by Davidson and Desko is continuing on the southern binary system χ Lupi (HR 5883).

Baird continued work on Superluminous Giant (SLG) candidate stars in the Large Magellanic Cloud with Phillip Flower of Clemson Univ. Baird and Flower published a study of SLG candidates in 10 young LMC clusters based on both blue and red spectra of roughly 120 Å/mm dispersion taken with the 1m Yale telescope at CTIO. Of six stars with reliable radial velocities, four were clearly found to be galactic objects; while the other two could be in the LMC, they might also be halo stars. To answer the question of whether all SLG candidates might be foreground objects, Baird measured radial velocities of 8 SLG candidates in the cluster NGC 1866

using 25 Å/mm blue spectra obtained in 1982 with the CTIO 4m. Four of the 8 had velocity systems compatible with LMC membership. The exceptions were in the outer regions of the cluster where contamination is more likely. This work has been submitted by Baird and Flower to the Astronomical Journal.

With Horace Smith of Michigan State Univ., Baird has begun a study of short period variables and general stellar populations in the region of the Small Magellanic Cloud near NGC 362. A series of second-epoch plates will be obtained with the CTIO 1.5m this December to compare with identical plates taken by J. Graham in 1971. The two plate series will allow removal of many foreground stars and determination of light and color curves for variables with periods less than 1 day. CCD frames in *B* and *V* for several fields in the study regions will allow a detailed study of the stellar populations of the SMC in a field that runs from the SMC halo to the northeast arm of the SMC. Baird is continuing to process and analyze the huge amount of data obtained with D. Dawson in their 1984-85 survey of southern RV Tauri stars. With the use of the University of Kansas MAIPL software systems, Baird has begun reduction of the SIT vidicon spectra obtained at CTIO. *UBVRI* light and color curves for over 40 stars are now almost complete.

b. Solar and Space Physics

Beard has discussed a mechanism whereby electrons in cometary comae may ionize molecules in copious amounts, up to 300 ions/cc. In the process of escaping along the magnetic field, the electrons electrostatically accelerate the ions to kinetic energies of hundreds ev, while the ion energies perpendicular to the field remain a few ev. Such a dense concentration of energetic electrons has been observed by probes sent through P. Halley and P. Giacobini-Zinner this past year. An article on this work will appear in Planetary and Space Science this fall.

Beard with student M. Gast is analyzing observations of long-period comet orbits to determine the evaporative force on the heated comet nuclei. This will yield the cometary mass, dimensions, density, mass loss rate and life expectancy. This work is supported by the Solar Terrestrial and Planetary Atmospheres programs of NASA.

Beard, with students M. Gast, K. Predmore, and C. Teaford, is fitting magnetospheric field calculations, intrinsic multipole magnetic moments, magnetotail and trapped plasma current fields to observations of Mercury, Saturn and Jupiter to obtain precise models of their magnetospheric fields. This work is supported by the Solar Terrestrial branch of NASA.

Beard's student, D. Hirschi, has nearly completed his Ph.D. thesis on the use of Doppler shifts in zodiacal light observations to determine the distributions of orbital parameters of interplanetary dust.

The most noteworthy activities of Armstrong and his students during the 1985-86 academic year center on the Voyager 2 Uranus encounter of January 24, 1986. The Low Energy Charged Particle experiment team, of which Armstrong is a member, reported on the complicated structure of the trapped energetic charged particle radiation in the Uranian magnetic field. Analytical and interpretative work on the proton and electron sources is continuing.

Susan M. Tholen completed a study of the terrestrial magnetic and energetic particle response to the impact of interplanetary shock waves on the magnetosphere. She was able to show that shock impact produces particle acceleration in the magnetotail. This undergraduate research project was carried out in part at the A.T.& T. Bell Laboratories, Murray Hill, New Jersey.

Ramona Kessel, working under Armstrong's direction, completed a PhD dissertation on the accceleration and modulation of energetic protons by propagating interplanetary shock waves from solar flares. Her work succeeded in reproducing the particle angular distributions emerging from these shocks into the unshocked, upstream region of the solar wind. She compared detailed and specific numerical simulations of the expected responses with observations taken with the IMP 8 spacecraft.

Ed V. Bell II, also working under the direction of Armstrong, completed and published a manuscript on the loss of trapped charged particle radiation by impact on the larger natural satellites of Jupiter and Saturn. By taking account of orbital tilt, eccentricity, and the finite sizes of the particle gyroradii and satellite bodies, he was able to explain the location and energy dependence of absorption signatures found in the measurements made with Voyager 1 at Jupiter. A futher refinement of this work is in progress and will found the basis of Mr. Bell's PhD dissertation.

Michael Holmes, Ali Rezvani and Mark Phillips have been refining a numerical description of the structure and characteristics of electrostatic plasma sheaths which form around objects in low Earth orbit. This work emphasizes the nature of complicated spacecraft surfaces which have both electrically insulating and conducting parts. The detailed structure of the surfaces, especially where insulators and conducted join, controls the structure and spatial extent of the sheath.

As an extension of the work on spacecraft in the plasma environment described above, Mike Holmes has developed a simulation approach to describe the electrical state of small solid particles in contact with a plasma. This work is aimed at determining which characteristics of the environment and material determine the electrical state and to illuminate the conditions which may enhance or modulate the accretion processes in dusty astrophysical plasmas.

Yue Wu and Colleen McKee have completed a numerical simulation of the charged particle optics of the focussing magnetic spectrometer in the Low Energy Magnetospheric Measurement subsystem of the Galileo Energetic Particle Detector Experiment. The simulation is fully three-dimensional and describes the detector geometry in great detail. This work will form the basis for the evaluation of EPD responses in particle beam calibrations as well as in (eventual) orbit at Jupiter.

Bernard Yu has developed a numerical simulation of energetic electron and proton motions in the Earth's magnetotail using the earlier work of Beard and his students, Dean Hirschi and Keith Propp of the magnetic field structure as a starting point. Specific magnetospheric energetic particle bursts have been modelled and tentative source regions have been identified.

IV. TEACHING AND PUBLIC SERVICE

Twarog presented public talks to the astronomy clubs of Tulsa, and Kansas City, the Lawrence Kiwanis, the Kansas City alumni association of the University of Chicago, the meeting of the AOK Association of Physics Teachers, and the Benedictine College summer workshop for high school teachers. Anthony-Twarog coordinated public information services on Comet Halley, and gave several public talks.

The Astronomy Associates of Lawrence continued to serve the astronomy program and the Lawrence and University of Kansas communities by continuing the regular weekly schedule of public viewing sessions at the Clyde Tombaugh Observatory. More than 500 visitors were able to see Comet Halley, among other things, this past year with their help. The A.A.L. also has assisted in the celebration of the centennial of astronomy at the University of Kansas, concluded in this past academic year. Dr. Frank Drake was a featured guest honoring this celebration, as were visitors Craig Wheeler, Steve Shore, and alumni Ed Barker, Harold Corwin, Humberto Campins, Ed Sion and Ron Snell.

The Midwest Astronomy Camp was held at the University of Kansas for the tenth year, drawing over 15 students from Kansas and regional high schools to study and observe at the Tombaugh Observatory under the direction of Davidson with the assistance of T. Whitacre and E. Heim.

V. MISCELLANEOUS

Bachelor of Science degrees in Astronomy were granted to Don Payne, who has entered the new Masters program in Computational Physics and Astronomy at the University of Kansas, and to David Bishir who accepted a government service posting for one year in Africa.

Shawl spent the year on sabbatical leave at the Astronomy Department at the University of California at Berkeley.

The AAS has accepted an invitation from The University of Kansas and other universities in our region to host the 1988 summer meeting in Kansas City.

Beard gave talks on comets and the magnetospheres of Mercury, Saturn and Jupiter at a workshop at the University of Michigan, at the A. G. U. meetings in San Francisco and Baltimore, the Mercury Conference at in Tucson, and at the Universities of Arkansas and Iowa. B. Twarog presented colloquia and an invited review paper on small telescope research in photometry at Benedictine College and I.A.U. Symposium No. 118 in New Zealand, respectively. B. Twarog attended the Midamerican Astronomers Regional Astrophysics Conference and the American Astronomical Society Meeting in Ames where he presented the results of his work with students Don Payne and Dave Bishir on the open clusters NGC 6259 and NGC 2354 as discussed above.

Twarog, Anthony-Twarog, Davidson and Mukherjee attended the summer meeting of the A.A.S. in Ames, where three poster papers were presented.

Student Scott Randle spent the summer at the Lake Afton Observatory in Wichita obtaining photometric observations of anomalous Cepheids under the direction of Dr. David Alexander and the financial support of a University of Kansas undergraduate research award.

VI. PUBLICATIONS

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White, R. E. and Shawl, S. J. "Axial Ratios and Orientations for 100 Galactic Globular Clusters", *A. J.*, submitted.