Clyde W. Tombaugh Observatory
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I. PERSONNEL

This report covers the period from mid-August 1983 to mid-August 1984. Within the Department of Physics and Astronomy, those currently involved in astronomical research are Dr. J. P. Davidson (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). Dr. Donald J. Bord (IUE Data Analysis) of Benedictine College continued as an adjunct assistant professor until August of 1984 when he left for a position at the University of Michigan-Dearborn.

II. INSTRUMENTATION AND DATA REDUCTION

Major changes in the departmental data reduction capabilities have resulted from a significant upgrade of the departmental VAX 11/750 under the direction of Dr. Tom Armstrong. The memory has been expanded from 1 to 2 megabytes, an additional four 470 megabyte disks, two 6250 bpi tape drives, five monochromatic and two color graphics terminals have been installed. In addition to improved capabilities for space physics research, the upgrade has lead to the establishment of the Midamerican Astronomical Image Processing Lab (MAIPL), a regional facility for the reduction and analysis of data from two dimensional detectors and digitized photographic plates. Software routines currently available on the system include DAOPHOT by P.B. Stetson, a stellar photometry reduction routine, and R2D2 from the University of Victoria. Plans for the coming year include the installation of an I^2S Model 75 Image Display Processor with the IRAF system under development at N.O.A.O. for the analysis of surface photometry and stellar spectroscopy. This center has been developed with the cooperation of the Universities of Arkansas, Missouri, Nebraska, Iowa State, and Wichita State, and the financial support of the University of Kansas. In addition to the above equipment, the recently obtained SRC survey will be stored in the MAIPL for general use by area astronomers.

For educational and research needs, the department has acquired a Grant Spectrum Comparator on permanent loan from Yale University, joining the iris astrophotometer already in continuous operation as part of undergraduate research programs.

The 6-inch Clark refractor has been completely refurbished by the Astronomy Associates of Lawrence and installed in a new Ash dome on the roof of Lindley Hall.

The 27-inch Pitt telescope has been realuminized for the first time in seven years, improvements have been made in the dome structure, and the guide controls on the camera have been automated. Tests of cluster plates obtained with the 27-inch show it to be capable of providing photometric quality data under good conditions.

III. RESEARCH

A. Stellar and Galactic Studies

J.P. Davidson and a number of students continued to work on the analysis of IUE data using the method of wavelength coincidence statistics (WCS). The method was applied to the southern sky binary object Chi Lupi as well as 73 Draconis and α^2 CVn. In each case, a global search was carried out with the help of summer student Elizabeth Armstrong using the VAX 11/750 routines developed by graduate student Richard Desko. Preliminary results confirm most of the spectral features found by previous well-known optical studies. However, preliminary analysis of Chi Lupi suggests there is good statistical evidence to support the existence of gold (Au) in one of the components of this binary. The analysis has made use of all the IUE data available, which consisted of only five images near phases 0.46 and 0.92.

Working in collaboration with Donald J. Bord (now at the University of Michigan-Dearborn), J.P. Davidson has exploited the radial velocity degree of freedom in the WCS method to determine the radial velocities from this IUE data for several sharp-lined chemically peculiar stars. The velocity scanning technique is accurate to within 5 km/s. This work has been accepted for publication in Astronomy and Astrophysics.

J.P. Davidson, in collaboration with undergraduate Michael Hart, has initiated a theoretical investigation of the physics of very massive stars.

B.J. Anthony-Twarog and B.A. Twarog have completed a study of the old open cluster NGC 6791 and the globular cluster NGC 6535 employing B and V frames obtained with the KPNO Video Camera on the 2.1 m. The status of NGC 6791 as a uniquely rich and valuable member of the old disk is confirmed by a color-magnitude diagram similar to, but older than, that of NGC 188, using a rederived value of E(B-V) = 0.20 for the reddening. Based upon the shape of the cluster turnoff, the metallicity of the NGC 6791 must be approximately solar, in aggrement with recent photometric estimates based upon DDO and Washington photometry. The cluster is approximately 2.2 magnitudes more distant than NGC 188. More importantly, the true distance modulus for the cluster based upon main sequence fitting to theoretical isochrones produces a red giant clump magnitude which is indicative of a significant metallicity and age dependence for the luminosity of the horizontal branch, in agreement with the recent work of Sandage. As part of the analysis, the authors developed a new technique for age determination, independent of reddening and metallicity, based upon the color-magnitude diagram morphology which is calibrated for clusters between 1 and 7 billion years old on the scale of Ciardullo and Demarque.

As a followup to the above investigation, B.J. Anthony-Twarog has begun a proper motion membership study of NGC 6791 in collaboration with Dr. Kyle Cudworth of Yerkes Observatory.

The study will make use of first epoch Lick 36" and 120" plates and second epoch 4m plates from KPNO.

B.J. Anthony-Twarog and B.A. Twarog, in collaboration with Dr. E. Schmidt of Nebraska and Dr. John Laird of the University of Michigan-Ann Arbor, have begun preliminary observations of G and early K dwarfs using the Stromgren uvby system, augmented for the hotter stars by a 100 A filter which straddles the H and K CaII lines in the ultraviolet. The goal of this program is to extend the system calibration to cool stars for use in stellar population studies, particularly, a reanalysis of the G-dwarf metallicity distribution in the solar neighborhood, a crucial datum in constraining chemical evolution models of the Galaxy. Preliminary results of observations with the Ca filter on the Hyades and a sample of nearby subdwarfs indicates that the index has a metallicity sensitivity which extends to approximately [Fe/H] = -1.8, or about 0.5 dex further than the weak line index, m1. This program has received initial funding from the General Research Funds of the University of Kansas.

B.J. Anthony-Twarog and B.A. Twarog, with Dr. C.N. Caldwell of CTIO, have begun a long term program of photographic photometry in several intermediate age open clusters. Approximately 70 B and V plates have been obtained with the 1m telescope of CTIO of the clusters NGC 3114, NGC 2354, IC 4651, and NGC 3680. Plates have also been taken with proper motion studies in mind, first epoch plates for IC 4651 and NGC 2354, second epoch plates for NGC 3114 and NGC 3680. BV calibration frames have been obtained in all the clusters using the CCD camera on the 4m at CTIO. Preliminary measurements of the plates of NGC 2354 by undergraduate David Bishir are underway at the University of Kansas using the departmental iris astrophotometer. Reduction of the CCD frames will be done with the recently installed DAOPHOT in MAIPL.

The reinvestigation of the galactic globular cluster radial velocities by Stephen J. Shawl and Dr. James Hesser (DAO) has continued and is nearing the point of producing final radial velocities. A portion of this work has consisted of the classification of some 260 spectra of 90 clusters. These new spectral types have been compared in detail with all previous spectral types, as well as with photometric and metallicity data. The main results at this time include: the new data show good agreement with previous classifications; spectral types have been derived for the first time for 23 previously unclassified clusters; the classifications show tight correlations with Harris and Canterna's QCMT indices and with Zinn's Q39 indices; the spectra show the onset of ultraviolet CN at spectral type F8.

As part of the above radial velocity project, a detailed radial velocity analysis of the CTIO Yale 1m Boller and Chivens image-tube spectrograph using gratings number 26 and 35 in first order has been carried out by Shawl and Hesser. The instrument is found to be stable from night to night although non-zero corrections have been determined. There are no systematic effects with either hour angle or zenith distance. The possible systematic effect with declination reported in Shawl, Hesser, and Meyer (IAU Colloquium N. 68) can be explained adequately as a result of differential atmospheric refraction; this can be corrected as discussed in Bassino and Muzzio (1984 preprint). This project has received generous support from the NSF through grant AST 8000001.

S.J. Shawl and Dr. D. Bord (University of Michigan-Dearborn) have made photometric observations of some 65 Miras chosen for having a magnitude range of less than 4 magnitudes and a brightness at minimum brighter than 13.5, as part of a search for duplicity among Mira variables. These photometric data will be used to choose stars for further spectroscopic examination. This work has received partial support from the University of Kansas General Research Fund.

B.A. Twarog is in the second year of a three year program to study the structure of the disk of the Galaxy at large distances from the plane using Stromgren photometry of F and early G dwarfs at the South Galactic Pole. To date, a complete set of four observations each have been obtained for approximately 150 stars. Partial data are available for an additional 50 stars. The final sample will include over 300 stars with V less than 14.5. Preliminary reductions indicate that the photometry is of sufficient accuracy to provide reliable relative age estimates and that a possible systematic error exists in the BV colors of the survey sample of Bok and Basinska. This research is supported under the NSF grant AST-8302091.

In addition to the above data, Twarog has obtained multiple (4-6) observations each of over 40 stars in the intermediate age disk cluster IC 4651. Two observations each on the H Beta system have been taken of a dozen stars in the cluster. The data will be used in an analysis of the cluster age, reddening, distance, and metallicity, and, more importantly, to search for evidence of main sequence structure in the cm diagram comparable to that found in NGC 752, a cluster of similar age, but only half the metallicity of IC 4651. Partial observations have also been taken in NGC 2360 and M67.

Work continues on the project by Twarog and undergraduates Troy Mellon and Ray Murray to survey the South Galactic Pole for carbon stars. To date, each of the twenty fields has been surveyed on the short exposures (V less than 14.0) by at least one of the above persons and a number of possible candidates have been found. In those areas for which the survey has been completed by all three participants, cross-identifications are in progress. A list of candidates is being prepared for followup by photometry to check the classification.

B.A. Twarog and summer student Cheryl Smith have completed a photometric search for variable stars in the old disk cluster NGC 752 and NGC 7789 using plates obtained with the Yale 1m telescope. No significant variation has been found in NGC 7789, but the well-known eclipsing binary DS And was rediscovered in NGC 752. More importantly, conclusive evidence was found for variability of E235 in the cluster, a star for which no evidence of variability has been noted since a footnote was published by Johnson (1952) explaining that two discordant observations had been obtained of the star. Of the six stars in NGC 752 classed as binaries on the basis of Stromgren photometry, three have now been confirmed through spectroscopic and/or photometric techniques. None of the stars classed as single

have been found to be binaries with either method.

B. Solar System Studies

D. Beard is continuing his collaboration with the Imperial College of London astronomers in the study of doppler shifts in zodiacal light and with the I.C. Space Plasma group on plasma transport in the magneto-tail. This program is supported through a grant from NASA.

Beard, in collaboration with Armstrong, has begun a NASA funded program to do a numerical and observational study of charged particle motion in the mid and inner Jovian atmosphere. This project complements another NASA supported program involving a number of graduate and undergraduate students to model and analyze shocks, type I tail rays, and atmospheres of comets.

Gul Tariq has completed his Ph.D. thesis investigating the interaction of Ganymede with a hot, co-rotating Jovian plasma. The goal has been the explanation of the large fluctuations in the energetic ion spectra which Voyager 2 observed as it passed near the downstream corotation wake of Ganymede. Magnetic and electric processes have been successfully modelled, and several mechanicsms of charged particle energization have been characterized.

Mark Paonessa (now at Applied Physics Lab) completed his Ph.D. work on analysis of Voyager 2 data to evaluate quantitatively particle sources, losses, and transport. Other graduate research programs with Armstrong include a numerical simulation of multiple encounters of charged particles with solar and interplanetary shocks by Mona Kessel and a continued program by Ed Bell to develop a computer program to simulate charged particle motion in the vicinity of the natural planetary satellites and to estimate the lifetimes of such particles against impact on satellite surfaces.

Armstrong has completed his work with postdoc M. Ahmadian on the electrostatics of interplanetary dust. The numerical simulations have included photoelectrons and secondary electron emission from the solid material. Studies have also been made of the characteristics of solar and interplanetary charged particles over a solar cycle by undergraduate student J. Shields and graduate student S. Eckes. The results show that significant differences in the composition of the particles occurs between solar maximum and solar minimum.

Armstrong is continuing his active involvement in current and future solar system satellite studies. He has contributed further developments to the calibration and characterization of the energetic charged particle detector for the Galileo orbiter to be launched in 1986. Development of software for flight data reduction and analysis has begun at KU. Voyager data reduction and analysis continues, including cruise data leading up to the Uranus encounter in 1986. Plans are being developed for participation in the observations of a possible Uranian magnetosphere with the Low Energy Charged Particle experiment. Armstrong has also been heavily involved in the development of the international solar polar satellite (Ulysses) mission to be launched in 1986. Software production for data analysis of the mission results is underway at KU.

IV. TEACHING AND PUBLIC SERVICE

The Clyde Tombaugh Observatory has continued its regular Friday night open house with the support of the Astronomy Associates of Lawrence. The members of the Astronomy Associates have continued to provide valuable service in the form of lectures and demonstrations at schools, community organizations, and the Museum of Natural History throughout the year. Their help has led to the continued success of the monthly lecture series "Eyes on the Universe" which drew over 400 people during the year. Speakers included Drs. Charles Peterson of the University of Missouri, Columbia, Sumner Starrfield of Arizona State, and Stanley Lombardo of the University of Kansas. Because of their efforts, over 500 people showed up to view the partial solar eclipse from the roof of Lindley Hall.

The Astronomy Camp of the Midwestern Music and Art Camp was held for the eighth year, drawing over 30 students to the two sessions run by J.P. Davidson with the help of Erich Heim and Mara Whitacre.

B. Anthony-Twarog and B. Twarog both presented public talks to the Astronomical Society of Topeka and the Astronomical Society of Kansas City. S. Shawl presented talks to the Topeka group and to the Regional Junior Science and Humanities Symposium. Shawl continued his participation in the Shapley Lecture Program of the AAS, giving a talk at Abilene Christian University in Texas.

V. MISCELLANEOUS

Ph.D. degrees in Physics with an emphasis in Space Physics were granted to Scott Brandon (Numerical Simulation of Positively Biased Probes and Dielectric Disks in a Plasma), Mark Paonessa (Analysis of Voyager Observations of Ion and Electron Phase Space Densities in the Magnetospheres of Jupiter and Saturn), and Keith Propp (The Geomagneto System: Charged Particle Trajectories in the Geomagnetic Tail).

Armstrong was one of four recipients of the Higuchi Achievement Award given by the University of Kansas.

Anthony-Twarog presented a colloquium at the University of Missouri, Columbia; Shawl gave a colloquium at Kansas State University; and Twarog gave colloquia at Iowa State University and Yale University. Additionally, Twarog presented a graduate seminar series at Yale University on Chemical Evolution of the Galaxy.

At the Kansas Academy of Sciences, J.P. Davidson and E. Armstrong detailed their results from IUE data analysis, T. Mellon and R. Murray discussed their carbon star study with Twarog, and J. Shields discussed his work with Armstrong on solar flare analysis.

Anthony-Twarog, Shawl, Twarog, and undergraduate Shields all gave talks at the Mid American Regional Astronomy Conference in Columbia, Missouri.

Beard gave colloquia on his work with comets at the University of Iowa, Imperial College, and the University of Michigan Comet Workshop, and presented papers at the December and May meetings of the American Geophysical Union. Armstrong presented colloquia at the University of Arkansas, Fayetteville and the local SPS banquet.

Shawl published an instructor's manual to accompany the introductory Astronomy text "The

Essentials of the Dynamic Universe" by Ted Snow (West: St. Paul 1984).

Undergraduate J. Shields spent the summer as a research assistant at Kitt Peak National Observatory working under the direction of Roger Davies.

Armstrong and graduate students Scott Brandon and Ramona Rusk attended the Spacecraft Environmental Interactions Technology Conference in Colorado Springs and presented their results of a study with Dr. J. Enoch on the self-consistent simulation of plasma interactions with secondary-emitting insulators. Armstrong also attended the Fall Meeting of the American Geophysical Union with graduate students Steve Eckes, Claude Laird, and Gul Tariq, and undergraduate J. Shields. Armstrong presented two invited papers on energetic ions and electrons in planetary and interplanetary magnetospheres, coauthored by Eckes, Shields, and S.M. Krimigis (APL). Laird discussed his work on solar particle fluxes and nitrate levels in south pole snow, and Tariq discussed his thesis results on expansion of the jovian plasma in Ganymede's wake. Armstrong and Dr. M. Paonessa also presented their work on Voyager I observations of Jovian ion and electron phase space densities and longitudinal asymmetry in the Io plasma torus. Finally, Eckes and Dr. P. Briggs discussed high energy interplanetary electrons and protons over the years 1972-1982.

VI. VISITORS

We were pleased to be visited during the time of this report by the following researchers in astronomy and space physics for discussions of their research: Dr. Keith Propp, Dr. Mike Schultz (Aerospace Corp.), Dr. Frank Kutchko (Fort Hays State), Dr. Lee Ann Willson (Iowa State University), Dr. Steve Shore (CWRU), Dr. Phyllis Lugger (University of Missouri, Columbia), Dr. William Fowler, Nobel Laureate in Physics (CalTech), Dr. Sumner Starrfield (Arizona State University), and Dr. Tom Chester (JPL).

VII. PUBLICATIONS

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Anthony-Twarog, B.J. 1984. "uvby Photometry in M39 and Lyrae", A.J. 89, 655.

Anthony-Twarog, B.J. 1984. "Video Camera Photometry in the Old Clusters NGC 6791 and NGC 6535", B.A.A.S. 16, 504. (Abstract).

Anthony-Twarog, B.J., and Twarog, B.A. 1984. "Faint Stellar Photometry in Clusters. II. NGC 6791 and NGC 6535", Ap. J. in press.

Armstrong, T.P., and Paonessa, M.T. 1983. "Energetic Ion Losses near Io's Orbit", J. Geophys. Res. 88, 3936.

Armstrong, T.P., and Paonessa, M.T. 1984. "Longitudinal Asymmetry in the Io Plasma Torus", J. Geophys. Res. 89, 3005.

Beard, D.B. 1984. "Infrared Coronal Polarization and the Size of Interplanetary Dust Particles," Astr. Ap. 132, 317.

Beard, D.B., Whelan, T.A., and Gast, M.A. 1984. "Solar Pressure and Molecular Decay for Cometary Atmospheres", Ap. J. in press.

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Twarog, B.A. 1984. "uvby Photometry of Secondary Standards Near the South Galactic Pole", A.J. 89, 523.

Twarog, B.A. 1984. "uvby Photometry of Blue Stragglers in NGC 7789", B.A.A.S. 16, 504. (Abstract).

White, R.E., Shawl, S.J., and Coyne, G.V. 1984. "Discovery of Intrinsic Polarization in the Apparent Light of Globular Cluster Red Giant Stars". A.J. 89, 480.