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I. PERSONNEL

This report covers the period from August 1988 to August 1989. Within the Department of Physics and Astronomy, those currently involved in astronomical research are Dr. J.P. Davidson (IUE Data Analysis), Drs. Doug McKay, Adrian Melott, John Ralston (Cosmology and Theoretical Particle Astrophysics), Dr. Thomas P. Armstrong (on leave at NASA headquarters) and Dr. Thomas E. Cravens (Solar System Studies), Drs. Barbara J. Anthony-Twarog, Stephen J. Shawl, Bruce A. Twarog and adjunct professor Dr. Scott Baird of Benedictine College (Stellar and Galactic Studies). Dr. William Schuster from the National Astronomical Observatory of Mexico was a visiting scientist in the Fall.

II. RESEARCH

a. Stellar and Galactic Studies

Baird has continued working on a project to determine whether RV Tauri stars compose a homogeneous evolutionary group. Vidicon spectra of 40 RV Tauri stars are being processed with the Reticon software package and compared with synthetic spectra to determine the basic atmospheric parameters of these stars. SZ Aqr, which was observed during rising light between a deep minimum and maximum light, was discovered to have hydrogen emission lines which varied 10% or more in intensity over a 30 minute interval. With Dennis Dawson, of Western Connecticut State University, Baird has collaborated on a photoelectric survey of the same stars. The photoelectric survey is now in preprint form. Some of the photoelectric work was used in a study of the light variations of V564 Ophiuchi; this study (see the list of publications below) contains color and light curves for V564 Oph over a four year interval. Although light minimum would always fall near the predicted time it could arrive several days late or early, a characteristic behavior of RV Tauri stars.

With Horace Smith (Michigan State University), Baird is examining the populations and possible population gradients in a region stretching from the halo of the Small Magellanic Cloud to its northeast arm. A set of second epoch plates were obtained at the Cerro Tololo 4 meter prime focus. CCD frames of subareas in the field are being processed using the image processing facilities of the MidAmerica Image Processing Laboratory (MAIPL).

Davidson continues to pursue the study of the unusual isotopic abundances of some very heavy elements in early-type stars — in particular the curious abundance anomalies found for ^{198}Pt , ^{202}Hg and ^{204}Hg in the star χ Lupi. Programs to repeat and extend the earlier calculations of Michaud on radiation diffusion are being developed. There are plans to do a general search for anomalous platinum strength in the available IUE data of such stars. This work is currently funded by a grant from the University of Kansas General Research Fund.

Anthony-Twarog, Twarog and student Sheela Shodhan completed an analysis of CCD data obtained in the Strömgren photometric system for stars in the open cluster NGC 3680, a cluster with an apparently bifurcated main sequence. Building on results of a photoelectric study in the cluster by Poul Nissen, the results confirm a true distance modulus for the cluster of 9.74 ± 0.20 , and a metallicity $[\text{Fe}/\text{H}]$ of 0.10 ± 0.09 based on 18 probable non-binary members of the cluster. One possible explanation for the apparently bimodal main sequence was discussed, a combination of binaries on the upper main sequence and a sharply curved turnoff similar to the predictions of models by Bertelli *et al.* employing convective overshoot mixing.

Anthony-Twarog, Twarog, and former student Erich

Heim have analyzed BV photographic material in the same cluster, NGC 3680, and are now preparing the results for publication. The photographic survey covers a considerably larger area than the CCD survey, and is complete to $V = 16$. Like IC 4651, NGC 3680 has a rather poorly populated lower main sequence ($M_V > 4.5$).

Following the detection of main sequence binary candidates in the globular cluster NGC 6397 using *uvby* CCD photometry, Anthony-Twarog with Twarog and N. Suntzeff of CTIO began photometric surveys in additional cluster fields to isolate binary candidates while attempting to confirm the binary nature of existing candidates directly with radial velocity measurements. The latter task has proved to be just beyond the reach of current instrumental capability. Photometry in four additional fields was obtained in 1988 and has been reduced and analyzed. Stars with colors and metallicity indices similar to other main sequence stars, yet with substantially brighter apparent magnitudes, are being examined as potential photometric candidates.

Anthony-Twarog is continuing observations to develop and calibrate fields suitable for use as *uvby* standards for CCD observations. CCD images and calibrating photoelectric photometry have been obtained for several dozen candidate fields, mostly near the celestial equator and containing 2 to 5 stars of varying color. Observations will continue at CTIO.

Anthony-Twarog, Twarog, and J. Kaluzny and M. Shara, both of S.T.S.I., completed analysis of color-magnitude diagram of the old open cluster NGC 2420; the data were based upon CCD frames obtained with the 0.9 meter telescope at K.P.N.O. Originally observed for the purpose of identifying contact binary systems, 5 CCD frames in each color were combined for 4 overlapping fields at the cluster core. The resulting colors produced the tightest CMD for any open cluster yet studied. Because of the unusual degree of accuracy, fine structure analysis of the CMD was possible. The cluster revealed a well-defined binary sequence which implied a cluster population of binaries at a minimum level of 50% of the cluster systems. Near the turnoff, the cluster sequence widened, apparently due to crossover by the binary sequence, but in contradiction with a simple extrapolation of binary sequence of normal stars. Comparison to theoretical isochrones reemphasized the inability of standard models without convective overshoot to reproduce the shape of the turnoff. An apparent modulus of 11.95, $E(B - V) = 0.05$, and an age of 3.4 billion years were derived. Comparison with the globular cluster, 47 Tuc, lead to the conclusion that it must have a metallicity significantly lower than that for NGC 2420, and an apparent modulus of 13.4.

Krishna Mukherjee, along with Anthony-Twarog, analyzed data from the Cerro Tololo Inter-American Observatory 4 meter telescope Prime Focus CCD camera system. With eight frames in each Strömgren color, Mukherjee was able to show that the true dispersions in color and in the Strömgren metallicity index m_1 are consistent with an intrinsic and presumably primordial dispersion of ± 0.8 dex in iron-peak elements among the main sequence stars. Partial support for this research by the National Science Foundation through grant AST 8420209 and by the University of Kansas through its General Research Fund is gratefully acknowledged.

W. Schuster, a visiting astronomer from the National Observatory of Mexico obtained a complete set of CCD frames covering most of the open cluster NGC 7789 down to the level of the turnoff. The data are being reduced to produce a reliable CMD for this intermediate age open cluster and to look for structure in the CMD near the turnoff region. Additional data have been collected on the cluster NGC 559.

During his visit to Kansas, W. Schuster was able to complete the writeup of a series of papers detailing the extension of

the uvby system to halo dwarfs of F and G type. Based upon photometry of 711 stars obtained in cooperation with P. Nissen (U. Aarhus), the authors were able to define a reddening and metallicity calibration for metal-poor stars. When applied to the sample it was possible to show that an age spread of almost 3 billion years existed among the field halo dwarfs, in contradiction with the classical picture of a rapid collapse for the halo. Further work is continuing to extend the luminosity calibration of the system to halo stars.

The search for companions to long-period variables, by Shawl and Donald Bord (University of Michigan-Dearborn), continues with the submission of the second of their photometry papers (results were described in last year's report), and with the granting of spectroscopic observing time at CTIO on the 1-meter telescope with the 2D-Fruitti in the Fall observing season.

Shawl, in collaboration with Ray White (Steward Observatory) made new polarimetric observations of red giant stars in globular clusters with the aim of refining the conclusions of their first study a few years ago. Such refining includes study of time variability of the polarization, and better detailing the location of those stars in the clusters' H-R diagram which show intrinsic polarization. Observations made with the Steward Observatory two-hole polarimeter are being rigorously compared with those made with the MINIPOL polarimeter.

Shawl, along with previous undergraduate student Michael Luhman (University of Texas at Austin), examined the infrared CaII triplet in the spectra of 33 late-type variable stars. Approximately half the stars are M-type, with the rest divided between N- and S-type. The spectra were obtained on I-N plates at a dispersion of 86 \AA mm^{-1} . These data, along with some of the H and K lines, support the existence of stratified CaII emission and absorption layers in these stars.

The systematic reinvestigation of the radial velocity of the galactic globular clusters begun by Shawl and Hesser (DAO) many years ago, has been held up by our need to fully understand all sources of possible systematic error. Our current work concentrates on understanding the effects of the order-separating interference filter on the derived cluster velocity.

Twarog and Anthony-Twarog are nearing completion of a project with John B. Laird of Bowling Green State University to extend and expand the capabilities of the Strömrgren photoelectric photometry system to cooler, and especially to more metal-poor stars. A new photometric index analogous to the Strömrgren m_1 index has been constructed utilizing a filter which measures the strength of the Calcium H and K lines. The new index is three times more sensitive to changes in metallicity for metal-poor stars and retains its sensitivity for the most metal-poor stars known. The initial phases of the observational program, that of developing primary standards, of observing a large sample of bright stars and of observing a sizable sample of metal-poor stars, are now complete and the next year should see the completion of the final phase, that of observing stars with well-determined parallaxes in order to define the luminosity effects on the index. Recent results for cool dwarfs indicate that the index is sensitive to age variation for disk stars. This possibility is implied by the fact that the Hyades cool dwarfs form an upper bound in the color-color diagram despite their high metallicity. An upper bound is caused by weaker Ca lines; the Hyades lines may be filled in by flux due to chromospheric activity. Combined use of the m_1 and Ca indices may allow direct age separation at a crude level.

b. Cosmology and Theoretical Astrophysics

McKay and Ralston are pursuing their work on "bright" dark matter, which is a proposal that the so-called dark matter might be detectable by spontaneous decay with emission of a photon. This can occur in several theories of elementary particles, and is especially attractive as an explanation of H-alpha ionizing radiation recently observed in our own galaxy and in intergalactic clouds.

c. Space Physics and Solar System Studies

Armstrong, post-doctoral fellow Gang Ye, and undergraduate H. Choo are analyzing the charged particle data from the Low Energy Charged Particle (LECP) experiment on the Voyager 1 and 2 spacecraft. In particular, they are beginning the analysis of data from the recent encounter of Voyager 2 with Neptune. Preliminary data indicates that energetic electrons are precipitating into the upper atmosphere of Neptune.

Cravens is leading a number of theoretical investigations which seek to improve our understanding of the nature of the interaction of the solar wind with the upper atmospheres and ionospheres of non-magnetic bodies in the solar system, such as Venus, Mars, and comets. The ionospheres of non-magnetic bodies act as obstacles to the charged particles of the solar wind, which are thus deflected around them. One tool developed to study the effects of the solar wind interaction with planetary ionospheres is a magnetohydrodynamics model which includes a variety of ion-neutral interaction processes such as chemistry and ion-neutral frictional drag. Along with graduate student Ned Keller, he is using this model to explain the existence of a magnetic field-free cavity surrounding the nucleus of comet Halley, observed by the magnetometer on the Giotto spacecraft during its encounter. Another theoretical tool which he is using to study the interaction of the solar wind with comets is a test particle computer code which follows thousands of cometary ion trajectories in the solar wind, after they have been created by the ionization of neutrals by solar ultraviolet radiation. Cravens, graduate student L. McKenzie, and Ye are learning that an important part of the assimilation of cometary particles into the solar wind is the scattering of these particles by magnetic irregularities and waves.

Cravens, in collaboration with scientists at other universities and at NASA, is also conducting several theoretical investigations into the physics and chemistry of the upper atmospheres and ionospheres of Jupiter, Saturn, and Uranus. Evidence for auroral particle precipitation into the upper atmosphere of Jupiter was provided by the ultraviolet spectrometers on the Voyager 1 and 2 spacecraft, and by the IUE satellite. Magnetospheric measurements made by particle detection instruments on the Voyager spacecraft have indicated that energetic sulfur and oxygen ions are precipitating from the magnetosphere near the Jovian satellite Io, into the atmosphere of Jupiter. Cravens and University of Michigan graduate student G. Eisenhower are constructing a model to investigate the photochemical effects of thermalized auroral oxygen.

Cravens and graduate student L. Gan are studying the interaction of magnetosheath electrons with the atmospheres of both comets and Venus by solving the Boltzmann equation.

III. MISCELLANEOUS

Bachelor of Science degrees in Astronomy were awarded to Stan Dyck (currently in the Ph.D program at Indiana University) and Jeff Robertson (in the masters' program at San Diego State University). Krishna Mukherjee completed the requirements for the M.S. degree in Computational Physics and Astronomy with a defense of her thesis "*uvby* CCD Photometry of the Main Sequence of Omega Centauri".

Anthony-Twarog presented a public lecture on conservation laws in physics to the Astronomical Society of Kansas City.

Cravens was a convener of the IAGA symposium on "Plasma Interactions with Neutral Gases" in Exeter, England. An invited paper at the Conference on Comets in the Post-Halley Era in Bamberg, W. Germany, both invited and contributed papers at the Spring AGU Meeting, an invited talk at the Chapman Conference at the Univ. of Surrey, and made numerous presentations at the IAGA Scientific Assembly in Exeter, U.K.

McKay gave an invited talk "Current Evidence for Dark Matter Radiative Decay" at the 10th Annual Grand Unification Workshop held at Chapel Hill, North Carolina. It will be published in the meeting proceedings. Melott gave colloquia at Ohio State University, Iowa State University, the University of

Illinois, and Kansas State University. He gave a public lecture at Bethel College, Newton Kansas. He attended the Toronto Workshop on "Computing Cosmologies", the APS meeting in Baltimore, the Users Training Workshop at National Center for Supercomputing Applications, and presented an Invited Lecture at the colloquium on *Megaparsec Cosmology* at the Royal Dutch Academy of Sciences.

Ralston gave an invited talk titled "Signals of Dark Matter Radiative Decay" at the Particle-Astrophysics Workshop held in Berkeley in November. It will be published in the meeting proceedings. An earlier talk on the same subject was published in *Neutrino 88*. He also gave a colloquium at the University of Missouri at Kansas City and a seminar at Penn State University.

Anthony-Twarog, Baird, Cravens, Ralston, and Shawl all gave talks at the the 19th Annual MidAmerica Regional Astrophysics Conference in Kansas City. Student Ned Keller also gave a presentation.

Shawl was the co-chair of the session on astronomy workshops for teachers at the AAS meeting in Boston. He continued at a Shapley lecturer with visits to the University of North Dakota and Arkansas State University. He continued his service on the AAS Education Advisory Committee. Talks were given at the AAS meeting in Boston, and to the Astronomical Society of Kansas City.

IV. PUBLICATIONS

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