The University of Toledo
Ritter Astrophysical Research Center
Toledo, Ohio 43606

This report covers the period 1 July 1994 to 30 June 1995.

1. PERSONNEL

During the report period, W. B. Lee was Visiting Assistant Professor of Astronomy. Federman was on sabbatical leave; otherwise, the permanent staff was unchanged.

Graduate students involved in astronomical research were: Bruce Cantor, Brian Friedmann, Karl Gordon, Rebecca Lindell, Chris Mulliss, Jens Petersohn, Dmitri Ryutov, Jr., Yong Zheng, and Janos Zsargo.

Visiting undergraduate Michelle Beaver (Purdue Univ.) was involved in research during the summer of 1994, with support from an REU grant to the Department of Physics and Astronomy.

Students involved in accelerator-based laboratory astrophysics were: undergraduates Rich Ghrist and Mike Kacher; and graduate students Rick Irving, Murray Henderson, Yushan Lu, Rasa Matulioniene, and Henry Povolny.

2. OBSERVATORY INSTRUMENTATION

The 1200×800-pixel CCD camera system that was received from Wright Instruments Ltd. in November 1992 provided another trouble-free year for the 1-m telescope. During the report period, a total of 784 stellar and planetary spectra were obtained on 93 nights. Most of the stellar observations were made with the échelle spectrograph at the standard H α setting, where the spectral coverage consists of 9 disjoint 70-Å regions in the yellow and red, and with a wide slit that yields a spectral resolving power of about 26,000.

In May, Observatory Technician R. J. Burmeister completed the design, construction, and installation of a remotely-operated cover for the upper end of the 1-m telescope's closed tube. Consisting of overlapping, triangular aluminum plates, the cover opens or closes like a flower when its driving pistons are activated by compressed air. Operation can be commanded manually at the press of a button or from a computer.

Also during the report period, we replaced our aging ISIT television camera, which was used for placing a star image on the input end of the optical fiber that couples the telescope to the spectrograph and keeping it there during an exposure, with an SBIG ST-6 CCD camera. Advantages conferred by the CCD, according to our experience, include more accurate focusing of the telescope optics and more accurate centering of stars on the fiber, both of which cause higher photon throughput down the fiber. At the end of the report period, implementation of the ST-6 as an autoguider was still in progress.

Burmeister enabled computer-controlled operation of the spectrograph calibration lamps. This function is carried out by a PC running under OS/2, which also runs programs that control the ST-6 and remotely adjust the spectrograph grating settings as needed. As the report period ended, Burmeister was engaged in improving the performance of this multitasking system.

3. RESEARCH

3.1 Stellar Astrophysics

Ritter Observatory participated in an internationally coordinated, multiwavelength campaign, led by H. Henrichs (Univ. Amsterdam), to study time variability in the spectra of the O-type stars ξ Per and 68 Cyg. We also collected échelle spectra of λ Eri as part of a campaign organized by R. Hirata (Kyoto Univ.), and we observed selected A-type shell stars and Herbig Ae/Be stars as part of a consortium led by C. Grady (Applied Res. Corp.). The observatory also provided high-resolution spectra at Hα of selected Be and shell stars and symbiotic stars, in support of investigations by K. S. Bjorkman (Univ. Wisconsin) and R. Schulte-Ladbeck (Univ. Pittsburgh) respectively, with the Astro-2/WUPPE mission in 1995 March.

Working with Morrison, Beaver studied variable spectral features in the candidate Herbig Ae/Be star HD 50138. The observational material consisted of CCD échelle spectra obtained from 1993 Nov. to 1995 Mar. with the 1-m telescope, in which the SNR ranges from about 20 to about 100. Hα is a strong, double-peaked emission feature, with the central absorption approximately at rest with respect to the center of mass of the star. The He I and Si II lines have their absorption minima at this same velocity, but they show an inverse P-Cygni profile. The long-wavelength absorption wing is strongly variable, occasionally disappearing completely to leave a symmetrical absorption feature (although the short-wavelength emission persists at these times). These line profile characteristics support the claim that this star is accreting gas.

Mulliss analyzed radial velocities obtained from 58 Ritter échelle spectra of ι Her, a well-studied B3 IV star that exhibits photometric, radial-velocity, and line-profile variability. Discrepant periodicities have been reported in the literature. Since the star exhibits both orbital and pulsational radial-velocity variations that are similar to each other in amplitude, it was necessary to apply an iterative process to determine separate least-squares solutions for the orbital elements and the pulsational velocity variations. The best-fitting least-squares orbit solution was subtracted from the velocity data, periodic functions fitted to the residuals, that fit subtracted from the data, and the process repeated. A previously unreported radial-velocity variation with a period of 0.80 ± 0.02 d dominated the orbit residuals. The stability of this mode of oscillation was investigated with a sliding-window analysis, in which successive 30-point data sets were analyzed with the Lomb periodogram. The 0.80-day oscillation gradually gave way to the two periods observed

by Rogerson (1984). Thus, the mode switching that has previously been suspected in this star is now better documented.

Gordon has been analyzing Ritter échelle spectra of the spectroscopically variable A-type supergiants α Cyg and HR 1040. In HR 1040, the morphology of Hα is highly variable, with emission appearing sometimes on the red side of the absorption, sometimes on the blue side, sometimes on both, and sometimes on neither. In addition, the data show two episodes of greatly increased strength of the blue-shifted absorption component of Hα, which probably indicates enhanced mass loss.

Gordon and J. Aufdenberg (Arizona State) are continuing to monitor the Hα variability of the symbiotic system CH Cyg.

Anderson completed work under a NASA Consortium Agreement with a group of investigators at NASA-Ames led by Edwin Erickson. Model atmospheres of hot stars were computed in order to provide realistic ionizing fluxes for a study of H II regions. The models revealed that seemingly unrelated inconsistencies between standard models and observations are actually connected: *a*) hot stars are brighter in the extreme ultraviolet (He I continuum) than predicted; *b*) they have less Fe III absorption near 155 nm than predicted; and *c*) they have unexplained variable emission in the He I 2.058 μm line. All of these problems are resolved when an outwardly increasing microturbulence *gradient* in the upper atmosphere is included in the models. Anderson is preparing the results for publication.

As an outgrowth of the previous work and its implications for infrared spectra and for the extreme ultraviolet (13-54 eV), Anderson has begun a collaboration with J. Drew of Imperial College London to explore the parameter sensitivity of infrared emission lines in hot main-sequence stars. In addition, Anderson and Drew are collaborating with a group at Wisconsin to model the extreme ultraviolet spectra of the B-type giants ϵ CMa and β CMa. These stars have been observed by the *EUVE* satellite to have higher radiative fluxes in the EUV than any contemporary model predicts.

Iwamoto, in collaboration with a Kyoto group, continued analytic as well as numerical calculations on the physical kinetics problem associated with the phase transitions between the proto-neutron star phase and the meson-condensed phase. They looked into the evolution of the chemical composition, the time dependence of the temperature (which arises from the competition between the neutrino cooling and the heating due to the latent heat release), and any signature in the form of a neutrino burst.

Stimulated by recent measurements of the Hubble parameter that contradict the estimated age of old stars in our galaxy, Iwamoto, with collaborators at Kyoto, Michigan, and Tokyo, began evaluating the uncertainties associated with age estimates of old stars. Specifically, they are introducing such effects as mass segregation, convection, Coulomb solidification, opacity, and other plasma physics uncertainties in the otherwise currently-best evolutionary code in order to see whether the combined uncertainties in the estimated ages of stars could accommodate the age of the universe that is inferred from the observational value of the Hubble parameter.

3.2 Interstellar Matter

Federman and collaborators acquired data on OH absorption at 3078 Å and studied the consequences of the measurements for OH and CH^+ production. With J. Weber and D. Lambert (Univ. of Texas at Austin), he observed *o*, ζ, and ξ Per at McDonald Observatory with a CCD. They confirmed earlier measurements of OH absorption toward *o* and ζ Per and obtained a constraining upper limit toward ξ Per. If cosmic ray ionization controls OH production, these results provide estimates of the cosmic ray ionization rate. Ionization rates of 10^{-17} to 10^{-16} s^{-1} were found; the highest rate was obtained for the sight line to *o* Per. Since this sight line passes near the active star-forming region IC 348, the enhanced rate may be the result of recent Type II supernovae. Once the ionization rate is known, measurements of HD with the *Copernicus* satellite yield values for the cosmologically important D/H ratio. The three directions in Perseus have comparable D/H ratios, and the analysis suggests that D/H = $(1.5 \pm 0.5) \times 10^{-5}$, a value consistent with atomic data from the Lyman series of absorption lines.

The upper limit on OH absorption toward ξ Per led to a better understanding of CH^+ formation. As is now well known, the endothermic reaction $C^+ + H_2 \rightarrow CH^+ + H$ must be included in the scheme for CH^+ synthesis. A similar reaction ($O + H_2 \rightarrow OH + H$) adds to the amount of OH *if* high temperatures are involved in CH^+ production. Although the upper limit on OH toward ξ Per is comparable to the observed amount of OH toward ζ Per, there is a factor of 10 more CH^+ toward ξ Per. The high-temperature scheme does not allow large variations in the CH^+/OH ratio. Instead, Federman with University College, London colleagues J. Rawlings, S. Taylor, and D. Williams suggested a non-thermal source for CH^+ that invoked the passage of Alfvén waves. Since C^+ ions are tied to the magnetic field permeating the cloud, the Alfvén wave causes non-thermal motion of C^+ relative to the cold, neutral background H_2 molecules, thereby allowing the CH^+ reaction to proceed, but hindering enhanced production of OH. More detailed models are now in progress.

For 27 lines in 14 multiplets of S I, Federman and J. Cardelli (Villanova Univ.) analyzed data that were acquired as part of their other programs with the Goddard High Resolution Spectrograph on *HST*. The result was a self-consistent set of oscillator strengths for S I absorption toward ζ Oph. The curve-of-growth analysis included a weak line whose oscillator strength had been determined precisely in recent laboratory experiments. The resulting astronomically derived multiplet oscillator strengths agree well with the results from the Opacity Project for the multiplets with $^3S^o$ and $^3P^o$ upper states, but significant differences occur for transitions involving $^3D^o$ upper states. It appears that mixing among $^3D^o$ states with excited cores has to be included in the large-scale calculations.

Witt and Gordon collaborated with D. Calzetti (STScI) and colleagues on investigating the UV scattering properties of dust in the reflection nebula IC 435. *IUE* observations of this object obtained during the 1980's had indicated that enhanced scattering might occur in the wavelength range coinciding with the 2175 Å extinction feature. New, high S/N

IUE data in two regions of IC 435 showed conclusively that no such enhanced scattering is present and that the 2175 Å feature is produced by a pure absorption process. Furthermore, the scattering throughout the UV is strongly forward directed, with an increasing asymmetry toward shorter wavelengths.

Witt and Gordon launched a new study of radiative transfer in clumpy scattering media. Work is in progress on applying the results to dusty galaxies and clumpy reflection nebulae where models with homogeneous dust distributions may yield inadequate descriptions.

Witt collaborated with T. Snow (Univ. of Colorado) on an investigation of the interstellar carbon budget. New results concerning the abundance of carbon in young stars as well as stars similar to the Sun in age and galactocentric distance suggest that solar abundances are not suitable as cosmic reference abundances. Snow and Witt recommend the use of a reference abundance of 225 ± 50 carbon atoms per 10^6 H for the present interstellar medium. Coupled with recent determinations of the interstellar gas-phase carbon abundance along several lines of sight, this leaves fewer than 100 carbon atoms per 10^6 H available for the formation of large carbon molecules and carbon dust, which represents a severe constraint for many current interstellar dust models.

With T. Sasseen (UC Berkeley), Witt and Friedmann analyzed far-UV surface brightness measurements in fifteen 8^o fields obtained by the FAUST experiment during a March 1992 shuttle mission. A Monte Carlo model, developed by Witt and Petersohn, was used to predict the diffuse galactic light. The model takes into account the cloudy nature of the interstellar medium, and it utilizes a radiation field based on the far-UV fluxes of 58,000 stars observed by the TD-1 satellite. It is anticipated that tight constraints will emerge for the far-UV albedo and the phase function asymmetry of galactic dust grains representative of the diffuse medium at intermediate and high galactic latitudes.

R. Lindell, under Witt's supervision, continued to study the wavelength dependence of attenuation by dust associated with the ''Evil Eye'' galaxy, NGC 4826.

3.3 Planetary Astronomy

James has been the PI of an *HST* project for monitoring Mars with WFPC2 and with FOS. Images of Mars obtained during the past year, when the planet was near aphelion, revealed an extensive equatorial band of water ice clouds encircling the planet. These clouds seem to be the result of a low saturation level for water vapor in the atmosphere; this season is one of relatively high humidity due to water subliming from the north polar cap, and the water condenses into clouds in the sub-equatorial region. This has major implications relative to the global distribution of water on the planet, which have been explored by James, T. Clancy (Space Science Inst., Boulder), M. Wolff (a postdoc on this project), and others in a recently submitted article.

Zheng completed a study of the distribution and properties of martian clouds in 1993 *HST* observations. He used a radiation transfer code to deduce the optical thicknesses of clouds on Mars at various wavelengths.

Wolff and Cantor are using a weak CO_2 band to monitor the global opacity on Mars. Using the échelle spectrograph of the 1-m telescope at $R \simeq 60{,}000$ allows accurate determination of equivalent widths of individual lines in the 8689 Å band. From comparison of these data with models, the global optical depth and the temperature structure in the atmosphere may be deduced.

James collaborated with L. Martin (Lowell) on Earth-based Mars imaging during the 1995 opposition. These CCD observations were made with the 31-in reflecting telescope at Lowell Obs.; the schedule was designed to fill in the gaps between the monthly *HST* sequences. In addition, James is a Participating Scientist on the *Mars Global Surveyor* Camera Team.

3.4 Laboratory Astrophysics

At the Toledo Heavy Ion Accelerator (THIA), development of the Position Sensitive Detection system and associated data collection collection equipment has continued.

Curtis, Irving, and Henderson have completed isoelectronic measurements of lifetimes in Ag II, Cd III, and In IV. These were motivated by recent GHRS/ *HST* observations of the HgMn-type stars κ Cnc and χ Lup, as well as by applications in EUV absorption spectroscopy made possible by, e. g., *EUVE* satellite data.

Curtis, Irving, Henderson, Ghrist, and Kacher have been collaborating with I. Martinson, R. Hellborg, P. Bengtsson, S. Johansson, C. Jupén, and G. Kalus (Univ. of Lund) and E. Träbert, J. Granzow, and J. Doerfert (Bochum Univ.). These collaborations have completed lifetime measurements of the resonance and intercombination lines of Ne I, Na II, Mg III, Al IV, Si V, P VI in the neon sequence, as well as C III, N IV, O V, and F VI in the beryllium sequence. Lifetime studies have also been carried out for N III in the boron sequence and for members of the aluminum sequence.

Curtis, Theodosiou and C. Nicolaides (National Hellenic Research Foundation of Athens) have developed a method by which high-precision measurements of lifetimes can be combined with a comprehensive knowledge of cancellation effects to make high-precision determinations of electrostatic core polarizabilities. They have applied these methods to Mg^+, Ca^+, and Zn^+, and they have achieved precise specification of the wavelengths of transitions between high Rydberg states of neutral Mg, Ca, and Zn.

Jupén and Curtis have made observations in spark and JET tokamak spectra that have led to high-precision specification of energy levels and transition wavelengths in the Al isoelectronic sequence for the ions from P III to Mo XXX.

Curtis, Ellis, and Martinson have developed a data-based parameterization that permits precise isoelectronic determinations of line strengths, and they have applied it to transition probabilities for the resonance transitions of the Li, Na, Cu, and Ag sequences, and both the resonance and intercombination transitions of the Be sequence.

This work profited greatly from extended working visits by Martinson, Hellborg, and Bengtsson (Univ. of Lund) and by A. Hibbert and J. Fleming (Queen's Univ. Belfast).

Under the direction of Kvale, several studies of H^- ions impacting on neutral atoms were recently undertaken. Stud-

ied in particular was the single- and double-electron detachment of H^- in collisions with noble gas atoms at 5- to 50-keV impact energies. In addition, a detachment study of H^- impact on methane was completed.

With Kvale and Ellis, Matulioniene performed a theoretical study of collisional excitation of neutral atoms by H^- impact. In preparation for experimental work, she estimated the expected cross section by means of a coulombic approximation theory of target excitation. The experimental part of the research involved the extraction of cross sections from measured energy-loss spectra. Roughly six months later, Lu obtained the first measurement of the cross section for H^- impact excitation of helium to its $n=2$ states. Current work aims to reduce the experimental errors in this measurement.

Witt and Ryutov collaborated with D. Furton (Rhode Island Coll.) on the characterization of a wide range of hydrogenated amorphous carbon (HAC) samples. These materials are laboratory analogues of interstellar dust components responsible for the extended red emission (ERE) and the interstellar 3.4-μm band absorption. Measurements of Raman scattering spectra and of the photoluminescence efficiency were performed, as well as measurements of the 3.4-μm absorption band strengths and the UV–visible absorption spectrum. A subset of the HAC samples was found to match the mass absorption coefficient at 3.4 μm of the interstellar dust while simultaneously matching the detailed absorption band profile. These HAC materials have a high band gap, near 2 eV, and also a high photoluminescence efficiency.

Lee and Witt collaborated in an experiment to conduct gas-phase spectroscopy of HAC clusters, produced by laser sputtering off HAC films provided by Furton. The aim was to search for absorption features matching diffuse interstellar bands. The column density of the produced species was insufficient to lead to observable features. The experiment is now being redesigned to capture the sputtering products in a frozen argon matrix for subsequent spectroscopic analysis.

In an ongoing experiment, Schectman, Henderson, and Povolny obtained oscillator strengths for transitions in Si II from measurements of mean lives and branching ratios. Their mean life for the line at 1527 Å confirms the theoretical prediction of Hibbert *et al.* (1992) from a large-scale computation.

The A − X $(v',0)$ bands of CO with $v'\geqslant 7$ are among the best transitions for obtaining reliable estimates of column density because they are relatively weak. The available experimental and theoretical information on band oscillator strengths shows differences of 20–30%, a range that is greater than the uncertainties associated with the astronomical measurements. Federman, Lee, and K. Menningen (Univ. of Wisconsin at Whitewater) began an experiment at the Univ. of Wisconsin Synchrotron Radiation Center to help determine the most appropriate set of oscillator strengths for interstellar studies.

4. INSTRUCTION

4.1 Academic

The M. S. degree in physics was awarded to Karl Gordon, Yushan Lu, Rasa Matulioniene, and Yong Zheng.

Undergraduate astronomy enrollments for the four academic quarters covered by the report period were as follows. In our general education courses, the annual total was 935 for the three introductory lecture courses and 120 for the laboratory. The more advanced (300-level) general-education courses had a total enrollment of 44. In graduate courses and advanced undergraduate courses for science majors, the total enrollment was 26.

4.2 Public

Undergraduate Assistants to Mak and Anderson for public education were Elizabeth Schulz, Dawn Carmany, Jeff Potter, and Aletha Tomczac. During the report period, the Ritter Planetarium presented six unique planetarium programs, all of which were written and produced in-house. New programs presented for the public at Ritter Planetarium were (authors in parentheses):

''Shoemaker-Levy 9'' (Mak, McCully, Schulz, and Carmany)

''25 Years After Apollo'' (Mak)

''Is There Anyone Out There'' (Mak, Caplinger, Binder)

Ritter Planetarium continued its sponsorship of the Strongsville High School Planetarium begun last year. To help McCully establish the Schuelle Planetarium in Bay Village, Ohio, the following programs were adapted and presented there by Ritter staff: ''Old Lights of Holiday Nights'' (adapted by McCully and Mak), ''Santa's Secret Star'' (adapted by McCully and Mak), and ''Is There Anyone Out There'' (adapted by McCully).

The total attendance for all programming conducted under the auspices of Ritter Planetarium and Brooks Observatory reached an all-time high of 23,500 for the year, up about 1300 from last year. When weather permitted, we continued our normal program of monthly public observing nights with the Ritter 1-m telescope and weekend evening viewings with the facilities of the Brooks Observatory. Each event usually attracted 50 to 100 people. Approximately 5000 attended during the year.

We conducted our Five Part Amateur Astronomy Workshop Series, and Mak taught several internet workshops for teachers. Carmany developed an interactive planetarium program and observing session to meet the requirements for the Astronomy Merit Badge program in the Boy Scouts of America. To date we have conducted twenty such programs leading to nearly 300 Astronomy Merit Badges. We continued our telescope loan program, in which teachers must attend a three hour workshop to become certified to borrow a Celestron-8. The telescope has been continuously on loan since the program began two years ago. Mak continued working with John Grafton (Bryan High School, UT-SPICA-91) to provide students with observing opportunities in Bryan.

On 11 May 1995 the Planetarium was closed for asbestos removal and for renovation of the lobby ceiling, offices, and reading room on the first floor of the Ritter building. As part of the renovation, a room is being converted into a resource area where a continually growing collection of materials will be available for teachers and the public to review, including books, magazines, videotapes, and software.

Planetarium staff delivered papers at six conferences.

5. MISCELLANEOUS

5.1 Participation in meetings

Federman presented an invited talk at the International Conference on High Resolution Astronomical and Laboratory Spectroscopy which was held in Brussels.

Witt gave invited lectures at the STScI Workshop ''Dust Survival in Galactic/Intergalactic Media'' and at the NATO Advanced Research Workshop ''Opacity of Spiral Disks'' in Cardiff, Wales. He also presented papers at the COBE Workshop ''Uncovering the Far-Infrared Background'' at the University of Maryland and at the ESO/MPA workshop ''Spiral Galaxies in the Near-IR''in Garching, Germany.

Iwamoto presented papers at the Fall Meeting of the Ohio Section of the APS at the Univ. of Toledo, Toledo, Ohio and the Joint April Meeting of the APS and the AAPT in Washington, D. C.

Witt served on the scientific organizing committee for the Cold Dust/Galaxy Morphology conference scheduled for Jan. 1996 in Johannesburg, South Africa.

K. Gordon attended the AAS meetings in Tucson and Pittsburgh and presented papers on radiative transfer in clumpy media jointly with Witt. Also attending the Pittsburgh AAS meeting were Cantor, Friedmann, and Lindell; presenting contributed posters were Beaver, Morrison, Mulliss, and Zsargo.

5.2 Visiting Lectureships

Federman gave colloquia/seminars at the Univ. of Wisconsin-Madison, Yerkes Observatory, Univ. of Waterloo, Univ. of Texas at Austin, University College, London, and Queens Univ., Belfast. Witt presented colloquia at Cornell University and at ESO Headquarters in Garching, Germany.

Witt presented an invited lecture ''Carbon in Interstellar Space'' at the Spring Meeting of the Ohio Section of the American Physical Society in Youngstown, OH.

Iwamoto gave an invited colloquium at Bowling Green State Univ., Bowling Green, Ohio.

5.3 Awards and Research Support

We gratefully acknowledge NASA grants to Federman and Schectman and to Dempsey (STScI) and Bopp and grants from STScI to Federman and James. Witt, Gordon, and Friedmann acknowledge support from the NASA LTSA program. Anderson gratefully acknowledges support from NASA-Ames for publication and computation. James is a *Mars Global Surveyor* Participating Scientist and a Co-I on a Lowell Observatory Mars observing grant.

Iwamoto wishes to acknowledge the Yukawa Institute for Theoretical Physics and the Department of Physics, Kyoto Univ. for support during his visits. Curtis acknowledges support from the US DOE.

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