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This report covers the period 1 July 1995 to 30 June 1996.

1. PERSONNEL

During the report period, W. B. Lee was Visiting Assistant Professor of Astronomy. Otherwise, the permanent staff was unchanged.

Graduate students involved in astronomical research were: Bruce Cantor, Brian Friedmann, Karl Gordon, David Knauth, Rebecca Lindell, Christopher Mulliss, Jens Petersohn, Tracy Smith, ZhongYuan Xue, and Janos Zsargo.

Visiting undergraduates Michelle Beaver (Mich. St. Univ.) and Eric Higgs (Xavier Univ.) were involved in research during the summer of 1995, with support from an REU grant to the Department of Physics and Astronomy.

Students involved in accelerator-based laboratory astrophysics were: undergraduate Nilkath Smrdelj and graduate students Don George, Rick Irving, Murray Henderson, Yushan Lu, Rasa Matulioniene, Henry Povolny, and Wenge Zhang.

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 échelle spectrograph with the 1-m telescope. During the report period, a total of 416 stellar and planetary spectra were obtained on 67 nights. Most of the stellar observations were made with the standard Hα grating 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. Information on the stars observed with the 1-m telescope since the fall of 1993 and on the number and quality of spectra of each one can be found in Gordon (1996).

Since 1992, the closed tube of the 1-m telescope has been a climate-controlled environment when the telescope is not in use. A dehumidification system operates inside it, and filtered, dehumidified air is pumped into the telescope in order to maintain positive pressure. During the report period, we visually assessed the effects of this arrangement on the reflectivity of the unprotected Al coating of the CerVit primary mirror. Over the three years since the last re-aluminization of the mirror, the coating has undergone, if anything, less deterioration than normally used to take place in six months before the installation of the climate control system. As a result, we now need to re-aluminize less frequently than before, and we have a more reflective primary as well.

3. RESEARCH

3.1 Stellar Astrophysics

Anderson, with the help of Xue, extended his calculation of non-LTE atmospheres from the early B range into the mid- and late-B range of temperatures. These atmospheres have new and extended model ions for the single, double, and triple ions of C, N, O, Ne, Al, and Si, with representations for all allowed transitions between states with principal quantum numbers less than 7 built on the first two or three parent excitations. The models also include distribution function representations for the transitions in double and triple ions of Sc–Ni. Xue has written a program that maps all transitions in various databases onto the model atoms, including transitions between states that are not directly represented in the models (e.g., states with principal quantum number 7 and above, which are assumed to be in LTE with the parent ion). Thus, Anderson and Xue are finally able to produce highly structured, high-resolution emergent spectra for direct comparison with observations. These new spectra should allow the analysis of the possible influence of turbulence gradients, which have been discussed in past reports.

With Beaver, Morrison continued to study time variability in the Hα and He I λ 5875 lines in the candidate Herbig Ae/Be star HD 50138. Beaver and Morrison also studied profiles of these lines acquired with the 1-m telescope in the candidate Herbig Ae/Be star HD 163296. Although this star is known to have a highly time-variable Hα profile, these data indicate a level of activity not previously reported. The line showed not only the previously observed P Cygni and double-peaked profile shapes, but also a single-peaked morphology, which has not previously been observed in this star. The overall morphology changed from one form to another on time scales as short as 10 days. Morrison began a collaboration with C. Grady (Applied Res. Corp.) to search for signatures of accreting gas in Hα and Na D line profiles in A-type shell stars such as 131 Tau.

Mulliss continued to collaborate with J. Grigsby (Wittenberg Univ.) on a study of the iron abundance in ι Her (B3 IV), based on comparison of the LTE models by Kurucz with ultraviolet Fe II and Fe III lines. The results indicate that this star has an iron abundance of only 0.25 times that of the Sun.

Using the 1-m telescope, Mulliss obtained Hα spectra as ground-based support for an *IUE* observing campaign on the Be star ω Ori. The *IUE* observations were taken by G. Peters (USC) on February 2–5, and the campaign caught this star just after one of its quasi-periodic outbursts.

Gordon and J. Aufdenberg (Arizona State) continued to monitor the symbiotic system CH Cyg. High-resolution profiles of Hα and He I λ 5875 have been collected frequently since Fall 1993 and sporadically since 1989.

Gordon and Morrison continued to accumulate spectra of late B- and early A-type supergiants. The Hα profiles of all of the Ia stars are variable, with one of them (HR 1040) in particular having a highly variable profile and occasional dramatic increases in the absorption equivalent width at high velocity.

Gordon and Mulliss have been analyzing spectra of ζ^2 CrB, a known double-lined spectroscopic binary. They have

found it to be a triple system, with periods of 1.72 days for the inner binary and 250 days for the unseen third star. The 1.72-day period is much shorter than the previously determined period of 12.5842 d (Abhyankar and Sarma 1966). The components of the inner binary have significantly different $v \sin i$ values, a result suggesting that this close binary is not tidally synchronized.

Gordon has been collecting spectra of the slowly pulsating B star 53 Per. With C. Aerts (Univ. Leuven), he plans to study the long-term evolution of this star's pulsational periods and amplitudes.

3.2 Interstellar Matter

Federman and collaborators D. Lambert and Y. Sheffer (Univ. of Texas at Austin) and J. Cardelli (Villanova Univ.) used the Goddard High Resolution Spectrograph on the *Hubble Space Telescope* to obtain the first determination of the $^{11}B/^{10}B$ ratio beyond the solar system. For the sight line toward δ Sco, they obtained a boron isotope ratio of ~ 4, which is similar to the ratio for solar system material. The implied near constancy of the $^{11}B/^{10}B$ ratio over the past 5 Gyr is consistent with models of Galactic nucleosynthesis for light elements. The main sources of boron are spallation reactions involving cosmic ray protons on interstellar CNO nuclei, enhanced fluxes of low-energy CNO cosmic rays on interstellar protons, and neutrinos on ^{12}C during supernova explosions. Follow-up studies include the sight lines to κ Ori and ζ Oph.

Federman and Zsargo analyzed other data from the *HST* in order to extract self-consistent sets of oscillator strengths for neutral carbon and singly-ionized nickel; Cardelli participated in the analysis of C I. For C, lines with precise laboratory oscillator strengths formed the basis for a curve-of-growth analysis. The results on weak intercombination (spin-flip) lines are especially useful in deriving the abundance of neutral carbon, as are the results for permitted lines below 1200 Å. Since no laboratory data exist for the UV lines of Ni^+, our set of oscillator strengths for this ion cannot be placed on an absolute scale as was the case for C. Experiments in collaboration with D. Gibson (Denison Univ.) are planned to remedy this situation.

Witt, Friedmann, and T. Sasseen (UC Berkeley) completed their analysis of far-UV background observations obtained with the FAUST experiment during a March 1992 shuttle mission. They confirmed that a major contribution to the far-UV background originates in scattering of galactic starlight by dust. The derived far-UV (157 nm) scattering properties are an albedo $a = 0.45 \pm 0.05$ and a phase function asymmetry $g = 0.68 \pm 0.10$. The albedo associated with the low-density diffuse interstellar medium investigated in this study is about 50% lower than that commonly encountered in reflection nebulae and star forming regions. The difference is attributed to a difference in the dust size distributions, with smaller grains prevailing in the diffuse ISM.

Witt and Gordon continued their investigation of the radiative transfer in clumpy, scattering media by extending their studies to galaxies and to the reflection nebula NGC 7023. They produced a two-phase clumpy model for NGC 7023, which successfully reproduced the existing observations from the far UV to the near IR for this object. In galaxies, clumpiness of the ISM greatly reduces the effective opacity of a given mass of dust, substantially reducing the reddening of the integrated light.

Witt and Madsen investigated the question of the dust albedo in the near IR by analyzing *V*- and *K*-band images of the galaxies NGC 1546, NGC 1947, and NGC 3521. Comparison of the attenuation in *V* and the associated color excesses in $V-K$ across the disks of these galaxies with radiative transfer models revealed that the dust albedo in the *K* band is essentially identical to that in the *V* band, substantially higher than suggested by current dust models.

Witt and Madsen also derived dust masses for a number of late-type galaxies for which *V*- and *K*-band images had been obtained by P. Grosbol. They utilized relations between the $V-K$ color excess of the integrated light and the column density of dust derived from radiative transfer models. The work is now being extended to include the clumpiness of the ISM, which is expected to increase the inferred dust masses.

T. Snow (Univ. of Colorado) and Witt continued their investigations of the abundance constraints for models of interstellar dust. As in the case of carbon (Snow and Witt 1995), they found that depletions of other important grain constituents, such as O, Si, and Fe, may be substantially less than currently assumed, if compositional data from young stars are used for reference abundances instead of solar system abundances. This result places severe constraints on most current grain models, and it suggests that the most likely candidates for interstellar dust are grains with maximal extinction cross section per unit mass, such as porous or fluffy particles.

3.3 Planetary System Astrophysics

James continued as PI of a *Hubble Space Telescope* program to monitor Mars with WFPC2 and with FOS. The program has been active whenever Mars has been observable since 1990. No new data were acquired during the report period because the elongation of Mars was less than 50deg, but observations have resumed for Cycle 6. Analyses of images and spectra acquired in earlier years have shown that the atmosphere of Mars has recently been significantly more cloudy near aphelion than previously believed. Coupled with microwave CO spectra obtained by Clancy (SSI), these data suggest that this process may play an important role in the global water cycle. M. Wolff and other team members have analyzed images of Mars acquired during 1995, finding significant dust activity in the north polar region of the planet. FOS spectra have been used to study the distribution and temporal dependence of ozone on Mars.

Wolff and Cantor are using a weak CO_2 band to monitor the global aerosol opacity and atmospheric temperature on Mars. Use of the échelle spectrograph with $R \simeq 60{,}000$ allows determination of equivalent widths of individual lines in the 8689 Å band. Only a few observations were made during this time period, because of the position of Mars relative to Earth, but the project will resume near the end of 1996.

Cantor, with the help of Higgs, has been analyzing extensive observations, made with both WFPC1 and WFPC2, of

the north polar cap of Mars. Cantor is comparing the cap regressions seen during the four spring seasons observed by *HST* to each other and to the historical data base.

James is a Participating Scientist and member of the MOC (Mars Observer Camera) Team on the Mars Global Surveyor Mission. Preliminary planning for the mapping phases of the mission took place during the past year. In addition, James has been involved in the design of the MARCI (Mars Color Imager) camera for the 1998 Mars Surveyor Orbiter.

In late March, Morrison obtained two 2-hour integrations with the échelle spectrograph of the head of Comet C/1996 B2 (Hyakutake). One of the spectra was taken with the usual Hα grating settings (ß 2) and the other covered a slightly different region of the spectrum. Mulliss, Knauth, and Lee carried out reductions and preliminary line identifications. The main goal of the research is to improve the precision and resolution of currently available observations of unidentified lines in cometary spectra.

3.4 Laboratory Astrophysics

Federman, Lee, and K. Menningen (Univ. of Wisconsin Whitewater) studied absorption from the $A - X\ (v',0)$ bands of CO with $v' \geqslant 7$ at the Synchrotron Radiation Center of the Univ. of Wisconsin. Previous results on the band oscillator strengths differed by 20-30%. The goal was to obtain precise relative oscillator strengths for several bands for use in analyses of interstellar ^{12}CO and ^{13}CO. The results are consistent with previous experiments based on electron energy-loss spectroscopy and with astronomical observations, and thus they provide a more secure foundation for future interstellar work.

In collaboration with G.M. Wahlgren (Univ. of Lund), Henderson, Curtis, Ellis and Irving made lifetime measurements, empirical branching ratio determinations, and theoretical calculations for the $6p7s\ ^3P_0$ and $^3P_1$ levels in Bi II. These results were combined to obtain absorption oscillator strengths between these levels and those of the $6p^2$ ground configuration.

Since Bi is the last element in the chain of neutron capture nucleosynthesis that is radioactively stable, the quantitative analysis of its abundance in stellar atmospheres puts a constraint on the theories of nucleosynthesis for the very heavy elements. Although observations of Bi in astronomical spectra have been limited to a few chemically peculiar stars, our measurements provide a test of earlier abundance estimates, which were based on theoretical oscillator strengths (Jacobs and Dworetsky 1982, Wahlgren *et al.* 1994). The measured oscillator strengths are consistent with the theoretical values used by Wahlgren, require only small revisions to those by Jacobs and Dworetsky, and do not alter the conclusions of these abundance determinations.

Henderson and Curtis have made lifetime measurements of the $6s6p\ ^1P_1$, $6s6p\ ^3P_1$, $6s6d\ ^1D_2$, and $6s7s\ ^1S_0$ levels in singly ionized thallium. Spectral lines from Tl II have been identified in GHRS observations of Hg-Mn stars, and this eighty-electron system presents a severe challenge to existing calculational methods, which can be tested only by acquiring a base of reliable measurements. In collaboration with E. Pinnington and J. Kernahan (Univ. of Alberta), Henderson and Curtis have also made new measurements of the $6s^2\ ^1S_0$ - $6s6p\ ^3P_1$ intercombination lifetimes. By exploiting semiempirical regularities, the team has been able to extrapolate measured strengths of the resonance and intercombination lines at the low charge end of the sequence to the asymptotic high-Z limit.

Henderson and Curtis undertook measurements of the lifetimes of the resonance and intercombination transitions $3p^6\ ^1S_0$ - $3p^5 4s\ ^{1,3}P_1$ for K II in the Ar isoelectronic sequence. These nominally allowed and forbidden channels are affected both by singlet-triplet mixing and by configuration interaction with the plunging $3p^5 3d\ ^3P_1$ level.

Irving, Martinson and Curtis have measured lifetimes for doubly excited levels in B II. The levels studied were the $2p3p\ ^3S_1$, $^3P_2$, $^3D_3$, $^1P_1$, and $^1D_2$ and the $2p3d\ ^3D_3$ and $^3D_1$, with transitions in the region $\lambda\lambda 600-1050$ Å. In B II, these levels undergo radiative decay, so that the measurements can be used as a test of theoretical calculations of the radiative portion of the decay rate for their isoelectronic counterparts in which autoionization channels become significant.

Ryutov completed an investigation of the optical properties of a series of HAC samples prepared by D. Furton (Rhode Island Coll.). The samples consisted of thin films deposited on quartz substrates in a d-c glow-discharge reactor. The feed gas was methane. By varying the deposition conditions, Furton produced samples with a wide range of band gaps. A tight correlation between the photoluminescence efficiency and the band gap was observed. Pure HAC is able to match the photoluminescence efficiency of the interstellar solids that are responsible for extended red emission (ERE), but it luminesces at shorter wavelengths than observed in the ISM.

Witt, Furton, and Smith began experiments on carbonaceous solids with silicon impurities. These materials luminesce at longer wavelengths than HAC, providing an improved match to the ERE.

A laser ablation chamber with a 45deg side arm for the UV laser entrance was designed by Lee. This glass vessel was constructed for laboratory absorption spectroscopy on cryogenic matrix-isolated species—carbon clusters and carbon-bearing radicals—generated from HAC film via excimer laser ablation. Carbon species produced in the plume are to be carried by argon gas and codeposited onto a 10 K sapphire disk. Smith and Witt plan to carry out such an experiment in order to investigate the possibility that HAC is a precursor of reactive species in the ISM.

3.5 High-Energy Astrophysics

Iwamoto collaborated with a Kyoto group on the physical kinetics processes associated with the phase transitions between the proto-neutron star phase and the meson-condensed phase. As a first step, they followed the time evolution of the chemical composition for a given, fixed temperature and found that it depends quite sensitively on this temperature. They plan to investigate the time dependence of the tempera-

ture itself, taking into account the neutrino cooling and the heating due to the latent heat release. The goal is to find observable features.

With collaborators in Kyoto, Michigan, and Tokyo, Iwamoto continued to study the evolution of white dwarfs in order to assess the accuracy of current age estimates of the galactic disk. The study is also expected to be applicable to the evolution of brown dwarfs, as well as placing constraints on the properties of the light particles that are potentially important for cooling.

3.6 Science Education

Mulliss reported on an implication of the stellar main sequence that can be taught in an introductory astronomy course. Mulliss and Lee investigated the origin and accuracy of the standard rounding rule for multiplication and division. They found that the standard rule is apt to cause a loss in precision when applied to simple problems. Their work also proved that no a priori rounding rule always works, but they demonstrated the existence of a simple alternative rounding rule that is more accurate than the standard rule and can never lead to a loss in precision.

Under the auspices of the Reserach Apprenticeships in Science Program, Lee and two local-area high school students completed a study in which, using the temperature variation of a parked car in the sun, they repeatably derived a surface temperature of the Sun within 6% of the accepted value.

4. INSTRUCTION

4.1 Academic

The M. S. degree in physics was awarded to Dmitri Ryutov, Jr., and to Christopher Mulliss. The Ph. D. degree in physics was awarded to Rick Irving.

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 1084 for the three introductory lecture courses and 135 for the laboratory. The more advanced (300-level) general-education courses had a total enrollment of 52. The junior/senior level course entitled, ''Astronomy in the Planetarium,'' had an enrollment of 13. In graduate courses and advanced undergraduate courses for science majors, the total enrollment was 31.

4.2 Public

Undergraduate assistants to Anderson and Mak for public education were Elizabeth Schulz, Dawn Carmany, Jeff Potter, Aletha Tomczac, Michelle Gennarro, Suzanne Bradford, and Brian Nelson. During the report period, the Ritter Planetarium presented the following original planetarium programs (authors in parentheses):

''Internet: Your Information Superhighway to the Stars'' (Mak)

''Cosmic Disasters and Dinosaurs'' (Mak, McCully, and Schulz)

''Star Factory'' (Carmany, Potter, Mak)

The total attendance for all programming conducted under the auspices of Ritter Planetarium and Brooks Observatory reached an all-time high of 25,500 for the year, up about 2000 from last year. Approximately 8000 attended public observing sessions during the year, including nearly 2500 for our six-night Comet Hyakutake observing program.

During the report period, we conducted over 30 Astronomy Merit Badge programs for Boy Scouts, allowing over 400 Scouts to receive their badges. During the report period, Carmany developed a similar program for Girl Scouts, which has been given 20 times to date.

Ritter Planetarium co-hosted (with Bowling Green State University) a meeting of CRAP (Cleveland Regional Association of Planetariums). Planetarium Staff attended seven meetings, delivering four papers.

5. MISCELLANEOUS

5.1 Participation in meetings

Beaver and Morrison each presented a contributed poster at the San Antonio AAS meeting in January. Federman, Zsargo, and Morrison were first authors of contributed posters at the Madison AAS meeting in June.

Federman presented invited talks at the 5th International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas (Meudon, France) and at Nuclei in the Cosmos IV (Univ. of Notre Dame).

Iwamoto presented papers at the Joint April Meeting of the APS and the AAPT (Indianapolis, IN).

James attended the Mars Telescopic Observations Workshop (Ithaca, NY), the DPS meeting (Kona, HI), and the Workshop on Evolution of Martian Volatiles (Houston, TX).

5.2 Visiting lectureships

Federman gave colloquia at the Univ. of Western Ontario and the Univ. of Kentucky. Witt presented colloquia at NRAO (Socorro, NM), at the Univ. of Chicago, and at Friedrich Schiller Univ. (Jena). Gordon presented a talk at Lick Observatory.

5.3 Service

Federman chaired the White Dwarf/Interstellar Matter Panel for EUVE proposals. Morrison continued to serve on the V. M. Slipher Committee on Public Education in Astronomy.

5.4 Awards and Research Support

We gratefully acknowledge a NASA grant to Federman and Schectman and STScI grants to Federman and James. James received suppport from JPL as Participating Scientist on the MOC team of MGS and as Co-I on the MARCI camera on Mars Surveyor ’98. Kvale acknowledges support from the Department of Energy. Witt, Gordon, and Friedmann acknowledge support from NASA.

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

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