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

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This report covers the period 1 July 2001 to 30 June 2002.

1. PERSONNEL

During the report period, Alex Carciofi and Yaron Sheffer joined the Center as postdoctoral research associates working with J. Bjorkman and Federman, respectively. J. Bjorkman was appointed to a tenure-track position as Assistant Professor. Bopp accepted an appointment as Director of the UT Center for Teaching and Learning.

Students involved in astronomical research were: undergraduates Amanda Gault, Jacquelyn Must, Pat Sadowski, Lori Schmetzer, and Josh Thomas; and graduate students Jennifer Benson, Boncho Bonev, David Horne, David Knauth, Don Koglin, Ivaylo Mihaylov, Kaike Pan, Uma Vijh, and John Wisniewski.

Visiting NSF-REU undergraduate students were, for summer 2001: Gregory Mack (Ohio Wesleyan), Althea Moorhead (U. of Arizona), Tom Crenny (Wheeling Jesuit U.), and Kevin Croxall (Brigham Young U.); and for summer 2002: Chandra Jacobs (Duke U.) and Marleen Martinez (U. of Washington).

V. Klochkova and V. Panchuk (Special Astrophysical Obs., Russia) visited for three weeks in November 2001 as part of a collaboration with K. Bjorkman and Miroshnichenko.

2. OBSERVATORY

The 1-m telescope was out of service for mirror recoating from 1 through 24 April, 2002. During this period, Burmeister developed an economical method for re-collimating the secondary mirror with respect to the primary, by means of a precisely mounted pencil-sized laser. The result was better light concentration in the stellar image, as evidenced by a factor-of-two improvement in the throughput of the fiber-fed spectrograph system.

During the report period, 1063 stellar spectra were obtained with the échelle spectrograph on a total of 130 nights used. The échelle observations were made with our 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 $R \simeq 26{,}000$. The Ritter observing team consisted of K. Bjorkman, Knauth, Miroshnichenko, Morrison, Thomas, and Wisniewski.

3. RESEARCH

3.1 Stellar Astrophysics

Ritter Obs. continued its long-term spectroscopic monitoring programs on hot supergiant stars, Herbig Ae/Be stars, and classical Be and shell stars. Working with Morrison and K. Bjorkman, Croxall studied the accumulated Ritter archival spectra and archival spectropolarimetry from Pine Bluff Obs. (U. Wisconsin) of the Be star 60 Cyg. In the spring of 2002, the observing team collected spectra of the peculiar eruptive object V838 Mon near maximum light.

Wisniewski and K. Bjorkman, together with A. Magalhães (U. of São Paulo, Brazil), began a study of circumstellar disks around B stars in clusters in the LMC and SMC. The first observations were completed in November 2001. The initial phase of the study uses imaging polarimetry from CTIO to detect disk-like systems among known emission-line stars. Preliminary data reduction shows the technique is promising, and further observations are scheduled for October 2002.

Wisniewski and K. Bjorkman are applying techniques developed for determining disk temperatures from spectropolarimetry to the analysis of intrinsic changes in the Be star π Aqr. K. Bjorkman, Gault, and J. Bjorkman are developing a technique for estimating the inclination angle of the disks of Be stars from infrared photometry and optical polarimetry measurements. From a simplified disk model, a preliminary grid of predictions for infrared flux vs. polarization was developed. The effects of different disk models on the results are being investigated.

K. Bjorkman and M. Meade (U. Wisconsin) continued to analyze spectropolarimetry of massive stars and to develop the ''Spectropolarimetric Atlas of Northern Be Stars'' (`http://www.sal.wisc.edu/HPOL/atlases/bes/`).

K. Bjorkman and Miroshnichenko carried out observations of circumstellar environments in massive stars at different evolutionary states using the MIRLIN instrument on the NASA IRTF. Data reduction is underway.

Miroshnichenko and K. Bjorkman, in collaboration with V. Klochkova and E. Chentsov (SAO, Russia) and several others, completed a high-resolution optical and infrared study of the emission-line star V669 Cep. While the optical spectrum contains mainly emission lines typical for an early-type star, features of a cool star were found in the near IR. It was concluded that V669 Cep is a mass-exchanging binary, a member of a subgroup of B[e] objects.

Miroshnichenko and K. Bjorkman, with Klochkova and V. Panchuk (SAO, Russia), studied a high-resolution optical spectrum of the B[e]/black hole binary candidate CI Cam. The profiles of most of the emission lines show a triple-peaked structure, not observed previously. The Na I D-lines with 2 interstellar absorption components suggest that the system is located within the Perseus arm at a distance of $\leqslant 3$ kpc, closer than was concluded in other recent studies.

The same group with M. Yushkin (SAO, Russia) completed the analysis of high-resolution spectra of the protoplanetary nebula candidate IRAS 01005+7910. Spectral line identification was done for the first time, and significant spectral variability was detected. The star was found to be metal deficient and carbon enriched (C/O $\geqslant 1$).

Miroshnichenko, with R. Hynes and co-authors from several institutions, presented a study of spectroscopic data on CI Cam obtained since its all-wavelength outburst in 1998.

Parameters of the visible star and circumstellar disk, interstellar extinction, distance toward the object, and spectral variations were discussed.

Miroshnichenko completed a study of V1137 Aql. This object was found to be an early M-type giant with an optically thick, dusty envelope, and it may be a low-amplitude Mira.

J. Bjorkman, Mihaylov, Carciofi, K. Wood (U. St. Andrews), and B. Whitney (Space Sciences Inst.) continued developing 3-D radiative transfer techniques that use Monte Carlo simulation. As part of his Ph.D. thesis, Mihaylov is investigating the momentum transfer arising from multiple resonance-line scattering in stellar winds with complex velocity structures. Using Monte Carlo techniques, he samples the line absorption/scattering to determine the wind acceleration. This technique is similar to that developed by Lucy and Abbott for determining stellar mass-loss rates, except that a velocity law for the wind is not assumed. Instead, a newly developed technique is used to determine self-consistently both the mass-loss rate and the wind velocity as a function of position in the wind.

Another application of Bjorkman's Monte Carlo radiation transfer models is self-consistent calculation of the structure of protostellar disks. Initial work (in collaboration with Wood, Whitney, and M. Wolff) found evidence for dust grain growth (the first step in planet formation) in the young protoplanetary disk of HH30 IRS. In collaboration with C. Lada, the group also investigated how to use the emergent SED to determine the disk clearing time and the location where the clearing occurs.

At the opposite end of the evolutionary sequence, Carciofi is studying the proto-planetary nebula Hen 3-1475 in collaboration with C. Rodrigues. This object shows a well-defined bipolar structure and jets in process of collimation. The central ~ 2 arcsec consists of an equatorially enhanced dusty envelope that is a source of molecular and dust emission and of optical polarization. Simultaneously being modeled are the 0.3 to 160 μm spectral energy distribution, *UBVRI* polarimetry, and *HST* archive images at many wavelengths. The simultaneous fit rules out many possible circumstellar geometries (cylindrical and wedge-shaped) and favors a disk-like geometry with some material in the polar region. The wind is found to be composed of two components: a very extended and dense outer region, with dust temperatures around 150 K, and an optically thin inner region with grain temperatures around 800 K.

Since dust grains of different sizes have different absorption and emission efficiencies, they will have different equilibrium temperatures. To study this effect, Carciofi extended the radiative equilibrium models to allow different temperatures for grains with different sizes and chemical compositions. Applying this model to dust in the winds from both cool and hot stars, he found that the IR portion of the SED is insensitive to grain size, despite the different equilibrium temperatures. Isotropic scattering can be a poor approximation when calculating the SED of dusty circumstellar envelopes. In particular, the forward throwing nature of dust grains can significantly increase the UV continuum when it is dominated by the scattered light.

Carciofi and J. Bjorkman are developing a 3-D Monte Carlo ionization equilibrium code for use in studying the circumstellar envelopes of hot stars, such as classical Be star disks. The code includes electron scattering, bound-free and free-free absorption and emission and line absorption and emission. A NLTE rate solver is being developed, which will provide level populations and ionization fractions throughout the wind. Currently, the code is restricted to pure hydrogen winds, but this restriction will be removed in the future.

To make these codes more efficient, Carciofi and J. Bjorkman are developing parallelization techniques (using MPI) for use on Beowulf-class machines. Although trivial in many cases (e.g., electron scattering codes), the parallelization is much more difficult for radiative equilibrium codes. Because quantities like the number of absorbed photons in a given cell must be available to all processors, each processor must communicate its photon absorptions to all the other processors. This communication can dominate the total execution time, making the parallelized version of the code very inefficient. Solutions to this problem are being sought.

J. Bjorkman has begun developing methods to use gravitational microlensing as a tool for exploring the structure of extended circumstellar envelopes. In collaboration with R. Ignace (U. Iowa) and J. Simmons (U. Glasgow), he is investigating the polarization signal produced by a microlensing event. They find that simultaneous observations of the polarization and flux amplification can be used to determine the lens proper motion, impact parameter, and Einstein radius, which is especially important for studies of dark matter in the Galaxy.

3.2 Interstellar Matter

Pan, under the supervision of Federman, completed his Ph.D. thesis research. He is studying the structure of diffuse molecular gas toward the star-forming regions associated with Cep OB2, Cep OB3, and ρ Oph. In about 30 stars, he observed the lines of CN, CH, CH^+, Ca II, Ca I, and K I with high-resolution spectrographs at McDonald Obs. and KPNO. The resulting large data set allows comprehensive statistical analyses to be performed. For instance, the Doppler-broadening parameter, a measure of the amount of turbulence, is found to differ from one species to another. CN has the narrowest lines, while Ca II has the broadest. It is inferred that CN is restricted to the innermost, densest portions of the cloud while Ca II is more widespread along the line of sight than other species. Absorption from CH shows two distinct behaviors, CN-like and CH^+-like. CN-like CH is a precursor to the synthesis of CN, and CH^+-like CH is the result of CH^+ production. This dichotomy is the clearest indication yet of the presence of distinct chemical networks in diffuse molecular gas along a given line of sight, most likely in different portions of the same cloud (based on radial velocity). The inverse relationship between the columns of CN and CH^+ found in these data is further evidence.

Sheffer, working with Federman and D. Lambert (U. Texas), analyzed the rich CO spectrum seen toward X Per in high-resolution spectra acquired with *HST*. The data revealed the first detection via UV absorption of $^{12}C^{17}O$ and indi-

vidual rotational lines of $^{12}C^{18}O$. These measurements, along with those on $^{12}C^{16}O$ and $^{13}C^{16}O$, allowed study of the processes affecting the isotopomeric ratios.

In a joint effort with D.-H. Lee, K.-W. Min (Korea Advanced Inst. of Science and Tech.), W. Van Dyke Dixon (Johns Hopkins), and M. Hurwitz (UC Berkeley), Federman interpreted interstellar absorption from CO and H_2 in the spectrum of HD 37903. The data were acquired during the Shuttle-based mission *ORFEUS*. A self-consistent picture is emerging for the foreground photodissociation region. Absorption from high-lying rotational levels in H_2, as well as excited vibrational levels seen in *HST* spectra, comes from the region nearest the star where the temperatures, densities, and flux of UV radiation are highest. The CO and the $J=0$ and 1 levels of H_2 probe more distant material.

Witt and Vijh are studying extended red emission in Galactic and extragalactic interstellar dust. Vijh completed an extensive study of the internal dust attenuation in 906 Lyman break galaxies, with data provided by C. Steidel (Caltech). She demonstrated that UV attenuation depends strongly on the luminosity of the system involved and concluded that the uncorrected star formation rate during the epoch $2<z<4$ needs to be increased by a factor between 6 and 18 to account properly for dust attenuation.

In collaboration with K.D. Gordon (U. Arizona), Pierini and Witt started to analyze model results on radiative transfer through a bulge/disk galactic system with a doubly-exponential, two-phase clumpy dust distribution. For each bulge/disk model realization, the parameter space consists of 25 wavelengths from 0.1 to 3 μm, 6 values of the dust mass, and 10 values of the inclination, while the dust type, two-phase density ratio, and filling factor of the clumps are fixed. Bulge and disk are assumed to have different attenuation functions for a given set of parameters. In general, the attenuation function changes dramatically in shape and normalization as a function of dust mass and inclination. The initial application of this model to statistical data sets on nearby bulge + disk galaxies like the Milky Way is encouraging. Extension of the model to galaxies of different Hubble types at different redshifts is in progress.

3.3 Planetary System Astrophysics

James is a Participating Scientist for *Mars Global Surveyor* and is a member of the MOC (Mars Orbiter Camera) Team. He has been selected as a co-I for the 2005 *Mars Reconnaissance* payload. His principal interest during the report period was the seasonal behaviors of the Martian caps; he used data acquired by the MOC wide- and narrow-angle cameras. He is also analyzing MOC observations of Martian clouds in the Polar Regions and is using them in a collaborative study of polar meteorology with J. Hollingsworth (NASA Ames).

The large interannual variability of the amount of dust activity on Mars presumably influences the seasonal condensate cycles on the planet. The backwarming effects of atmospheric dust on the sublimation rate of the CO_2 polar caps is the subject of a theoretical study being undertaken by Bonev, in collaboration with J. Bjorkman, using Bjorkman's radiative equilibrium models. The fact that one MOC year included a major dust storm while the other did not provides an unusual opportunity to compare theory with observations.

Benson completed an analysis of the MOC data on condensate clouds in the Tharsis/Valles Marineris region of the planet. Horne is studying dust and condensate clouds in the Hellas region.

HST has monitored Mars during all periods since 1990 in which Mars has been observable, including the report period. The observations consisted of STIS UV spectra and WFPC2 images; they will be used to determine the amounts of ozone, dust, and condensate clouds in the Martian atmosphere. Because of the STIS down time during 2001, some of these observations were moved into Cycle 10 and occurred during the recent dust storm. The data are being analyzed to extract the UV scattering properties of the dust. A continuation of this project has been approved for Cycles 11 and 12.

3.4 Laboratory Astrophysics

In another study of interstellar CO in the *HST* spectrum of X Per, Sheffer, Lambert, and Federman detected new intersystem bands and extracted their oscillator strengths. These results will be useful in interpreting data for sight lines where the singlet-singlet bands (usually $A-X$) have large optical depths and are not reliable measures of abundance.

Curtis collaborated with H. Nilsson, S. Ivarsson, H. Sabel and C.M. Sikström (U. of Lund) on a review of recent studies combining lifetime measurements (using laser induced fluorescence) and branching fraction measurements (using Fourier transform spectroscopy). From these two types of measurements together with a detailed analysis of the sources of uncertainty, oscillator strengths of typical accuracies 5-10% were obtained.

4. INSTRUCTION

4.1 Academic

Knauth received the Ph.D. in physics and is now a Postdoctoral Fellow at JHU. K. Bjorkman was named a 2001–2003 Master Teacher of the UT College of Arts and Sciences.

In 1997 September, The U. of Toledo changed from a quarter to a semester academic calendar. Therefore, for comparison with earlier enrollment figures, the following numbers should be multiplied by 1.5. Undergraduate astronomy enrollments for the summer 2001 and academic year 2001-2002 were as follows. In our general education courses, the total was 1322 for the three introductory lecture courses and 93 for the laboratory. The more advanced general-education courses had a total enrollment of 53. In graduate courses and advanced undergraduate courses for science majors, the total enrollment was 22.

4.2 Public

K. Bjorkman gave the invited Keynote Address at the Ohio Junior Science and Humanities Symposium in April 2002. K. and J. Bjorkman participated as Scientist Content Specialists in the UT TAPESTRIES program for K-6 teachers in July 2001.

Mak was one of three recipients of the university's annual Outstanding Professional Staff award. Undergraduate Assistants for public education to Anderson, Mak and Potter at the Ritter Planetarium-Brooks Obs. were Erin Durant and Heather Moritz. Lori Schmetzer began the report period as an undergraduate and continued as a graduate student. Kathy Czechowski was a weekend volunteer. D. Mulliss continued to maintain the Planetarium's web pages (http://www.rpbo.utoledo.edu).

The planetarium received funding from the Toledo Rotary Foundation, the College of Arts & Sciences, and the Friends of Ritter Planetarium for renovation of the Spitz A3P projector. Work will be performed by Ash Enterprises.

During the report period, Ritter Planetarium presented a record 21 different public planetarium programs. Fifteen of these were from our library, four were new in-house productions, one was co-produced with the Staerkel Planetarium in Champaign IL, and one was purchased from Joe Hopkins Engineering.

Shows newly presented to the public during the report period were (author/producer in parentheses): ''The Old Lights of Holiday Nights,'' version 2001 (Mak, Potter); ''Santa's Secret Star'' (Mak and W. McCully of Staerkel); ''Bear Tales and other Grizzly Stories'' (Joe Hopkins Engineering); ''Native American Skylore'' (Potter); ''To Pluto and Beyond'' (Potter); ''Is There Anyone Out There?'' (Potter).

We continued our normal program of monthly public observing nights with the Ritter 1-m telescope and weekly evening viewings with the facilities of the Brooks Observatory. Approximately 5,000 people viewed or toured one or both of our observatories.

The Boy Scouts' Astronomy Merit Badge program and the Girl Scouts' Space Exploration Ribbon program were completed during the report period by approximately 400 Boy Scouts and 200 Girl Scouts. Approximately 250 attended the newly developed Cub Scout and Brownie programs.

Approximately 40 children, accompanied by their parents, attended the newly developed Parent-Child Space Academy workshops. These three- to four-hour workshops, offered quarterly, feature planetarium programs, hands-on activities, and observing sessions.

The planetarium staff collaborated on special events with other area organizations: COSI-Toledo, the Stranahan Arboretum, The University of Toledo SciMaTEC program, TAPESTRIES, and the Toledo-Lucas County Public Library Jason Project. As usual, the staff attended various local, state, and regional conferences. Mak served as a mentor to several junior and senior high school students.

The total attendance for all programming conducted under the auspices of Ritter Planetarium and Brooks Observatory was 29,500. This figure represents an increase of nearly 5% from last year and marks the busiest year in our history.

5. MISCELLANEOUS

5.1 Participation in Meetings

Federman gave an invited paper at a Symposium of the 85th Canadian Society for Chemistry in honor of Chris Brion (UBC). He presented posters at the *FUSE* Science and Data Workshop and the 3rd International Conference on Atomic and Molecular Data and Their Applications (ICAMDATA).

Posters were presented at the 199th Meeting of the American Astronomical Society in Washington, DC, by Croxall, Knauth, Pan, and Carciofi. Posters at the 200th AAS meeting in Albuquerque were presented by Miroshnichenko, by J. Bjorkman, by Carciofi, and by Wisniewski and K. Bjorkman. Bonev presented a talk at the November, 2001 DPS meeting.

Miroshnichenko presented an oral talk at IAU Colloquium 187, ''Exotic Stars as Challenges to Evolution,'' Miami, FL. In collaboration with Gordon and Witt, Pierini presented a poster at the conference ''Galaxy Evolution: Theory and Observations'' held in Cozumel, Mexico.

5.2 Visiting Lectureships

Federman gave colloquia at Valparaiso U., Denison U., and the U. of Western Ontario. K. Bjorkman presented a colloquium at Wayne State U., and she also presented the Sigma Xi/Dion D. Raftopolous Award Lecture at the U. of Toledo. J. and K. Bjorkman each presented a colloquium at the U. of St. Andrews (Scotland). Witt presented colloquia at the U. of Chicago and the U. of Colorado.

Miroshnichenko spent a month at Max-Planck-Institut für Radioastronomie (Bonn, Germany) as a visiting scientist and presented colloquia at this Institute as well as at the Inst. d'Astrophysique de Paris, the U. of Amsterdam, and the U. of Utrecht.

5.3 Service

Morrison continued to serve on the V. M. Slipher Committee on Public Education in Astronomy until that committee was dissolved by the National Academy of Sciences in the summer of 2001. J. Bjorkman continued to serve on the Organizing Committee of the IAU Working Group on Active B stars. Federman continued as chair of the *FUSE* Observers' Advisory Committee and served on the Executive Committee for Commission 14 (Atomic and Molecular Data) of the IAU.

5.4 Awards and Research Support

K. Bjorkman continued as a Cottrell Scholar of the Research Corporation and gratefully acknowledges this support. Morrison and Wisniewski received support from the Fund for Astrophysical Research. K. Bjorkman and Miroshnichenko acknowledge support from the U.S. Civilian Research and Development Foundation (CRDF) Cooperative Grants Program.

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