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

This report covers the period 1 July 2002 to 30 June 2003.

1. PERSONNEL

During the report period, Pierini left to take up a position at the Max-Planck-Inst. für Extraterrestrische Physik (Garching, Germany). Lerothodi Leeuw joined the Center as a postdoctoral research associate working with Witt. Miroshnichenko was promoted to Research Assistant Professor. K. Bjorkman was promoted to Professor and was on sabbatical leave during academic year 2002–2003.

Students involved in astronomical research were: undergraduates Amanda Gault, Erin Hardy, Jacquelyn Must, Joshua Thomas, and Sarah Tonon (EECS); and graduate students Jennifer Benson, Boncho Bonev, David Horne, Douglas Long, Ivaylo Mihaylov, Kaike Pan, Uma Vijh, and John Wisniewski.

Visiting NSF-REU undergraduate students were, for summer 2002: Chandra Jacobs (Duke U.) and Marleen Martinez (U. of Washington); and for summer 2003: Benjamin Johnson (U. of Dayton).

2. OBSERVATORY

The 1-m telescope was out of service for mirror recoating from 8 July to 22 September 2002. During the report period, 592 stellar spectra were obtained with the échelle spectrograph on a total of 94 nights used. The observations were made with the Hα grating setting, where the spectral coverage consists of 9 separate 70-Å regions in the yellow and red, and with a wide slit that yields a spectral resolving power $R \simeq 26{,}000$. The observing team consisted of Gault, Long, Miroshnichenko, Morrison, Thomas, and Wisniewski.

Jacobs and Tonon worked on upgrades to the telescope control system. Burmeister installed a new interface card in the IBM-compatible computer that controls calibration lamps and other apparatus connected to the telescope, and he rewrote the control program in *LabView*, which turned out to provide a very friendly user interface.

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. With Jacobs, Morrison began a radial-velocity study of the A-type supergiant star 9 Per. Morrison resumed a collaboration with S. Adelman (Citadel) to collect concurrent spectroscopic and photometric observations of the A-type supergiant stars α Cyg and HR 1040. Ritter spectra were employed by J. Aufdenberg (CfA) and P. Hauschildt (U. Georgia) in a model-atmosphere study (2003) of cool giant stars with interferometrically measured angular diameters.

K. Bjorkman and Wisniewski, together with A. Magalhães (Univ. of São Paulo, Brazil), continued a study of circumstellar disks around B stars in clusters in the LMC and SMC. The second set of CTIO observations was completed in October 2002. Data reduction of the cluster photometry and imaging polarimetry shows that a number of disk-like systems have been detected among the known emission-line stars in selected clusters. Calibration and analysis of the data continued.

The same group used CTIO observations to investigate the polarimetric characteristics of the unusual outburst of V838 Mon. The interstellar polarization along the line of sight to the star was determined, and evidence for changes in the intrinsic polarization due to the stellar ejecta was found. The CTIO observations are also being used to study the polarimetric characteristics of B[e] stars in the LMC/SMC.

K. Bjorkman, with M. Meade (U. Wisconsin-Madison), continued development of the spectropolarimetric atlas of Be stars, as well as monitoring for spectropolarimetric variability from the UW Pine Bluff Obs. (PBO). During the report period, additional observations were obtained and added to the database. For individual stars, spectropolarimetric data from the PBO are being combined with spectroscopy from Ritter Observatory to study changes in the circumstellar disks. Wisniewski, K. Bjorkman, and Meade are studying the variations in π Aqr in particular detail.

Miroshnichenko, in collaboration with K.-H. Hofmann, N.R. Ikhsanov, and G. Weigelt (Max-Planck-Institut für Radioastronomie, Germany), and Yu. Balega (Special Astrophys. Obs., Russia) completed a study of the B[e] star MWC 349A by means of bispectrum speckle interferometry obtained at the 6-m telescope of the Russian Academy of Sciences. The diffraction-limited *J*-, *H*-, and *K*-band images suggest the star is surrounded by an almost edge-on circumstellar disk. It is concluded that MWC 349A is a B[e] supergiant, possibly in a binary system. Miroshnichenko and K. Bjorkman in collaboration with V. Klochkova, E. Chentsov, V. Panchuk, and S. Yermakov (Special Astrophys. Observ.) compiled an atlas of spectra of five emission-line stars. Miroshnichenko and K. Bjorkman with V. Klochkova (Special Astrophys. Observ., Russia) analyzed photometry and spectroscopy of a poorly investigated B[e] star, AS 160. The presence of a double-peaked profile in Hα indicates that the gaseous envelope of the star is nonspherical. Previously unstudied photometric data suggest the presence of a compact dust envelope. Miroshnichenko and K. Bjorkman with H. Levato and M. Grosso (Complejo Astronómico El Leoncito, Argentina) undertook a study of an early-type emission-line star, HDE 327083, which has long been considered to be one of the most luminous stars in the Milky Way. High-resolution optical spectroscopy revealed the presence of photospheric lines of a cool luminous companion. It was concluded that HDE 327083 represents an advanced evolutionary stage of a β Lyr-type binary.

The same group with N.D. Morrison and J.P. Wisniewski, N. Manset (CFHT Corp.), D.C. Knauth (John Hopkins U.), and amateur astronomers E. Pollmann (Germany) and C. Buil (France) continued a spectroscopic monitoring program of the binary system δ Sco, whose primary became a Be star after the last periastron encounter in the summer of 2000.

Miroshnichenko, D. Vinković, and M. Elitzur (U. of Kentucky) and Ž. Ivezić (Princeton U.) continued their efforts to develop a two-component model for the dusty envelopes of pre-main-sequence intermediate-mass stars. Two different geometries have been proposed to explain the dust emission from pre-main-sequence stars: flared disks; and ''classical'' geometrically-thin optically-thick disks embedded in optically thin halos. It was shown that imaging is required to distinguish between these two morphologies. Flux measurements can never be sufficient, because, for every model constructed with one geometry, there exists a model constructed with the other that produces identical flux at all IR wavelengths.

Miroshnichenko and K. Bjorkman with A. Kusakin (Sternberg Astronomical Inst., Russia), N. Drake (Obs. Nacional, Brazil), R. Rudy, D. Lynch, S. Mazuk, and C. Venturini (Aerospace Corp.), R. Puetter (U. of California at San Diego), and R.B. Perry (NASA Langley) discovered Hα emission in two 8th-magnitude A-type stars, HD 19993 and HD 29035, and studied them in detail. The analysis shows that HD 19993 is an A7/8 II star ($T_{\rm eff}=7500\pm200$ K, $\log g=2.7\pm0.2$, $v\sin i=35\pm2$ km s^{-1}, $M=4.8\pm0.8M_{\odot}$) with a mild metal deficiency ([Fe/H] $=-0.3\pm0.1$). HD 29035 is a B9/A0 V star ($T_{\rm eff}\simeq10000$ K, $\log g\simeq4$, $v\sin i\simeq150$ km s^{-1}). The presence of an IR excess and Hα emission in combination with very different locations in the H-R diagram suggest different natures and evolutionary stages for the objects. It is concluded that HD 29035 is a candidate Herbig Ae-type star, while HD 19993 is a post-main-sequence object.

With Anderson-Huang, Johnson developed and tested a computer program that creates a three-dimensional model of a gray stellar atmosphere with radiation-driven velocities. With further additions, the code will be used to model microturbulence.

J. Bjorkman, Mihaylov, and Carciofi, in collaboration with K. Wood (U. St. Andrews) and B. Whitney (Space Sciences Inst.) continued developing 3-D radiative transfer techniques that employ Monte Carlo simulation. As part of his Ph.D. thesis, Mihaylov continued to investigate 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 the mass-loss rate and the velocity law are determined self-consistently. The results indicate that, for the relatively low mass-loss rates of B stars, the wind does not accelerate monotonically because the wind solution fails at a distance of 2–5 stellar radii (typically), and the wind switches to the decelerating branch of the wind momentum equation.

Another application of Bjorkman's Monte Carlo radiation transfer models is the self-consistent calculation of the physical conditions in protostellar disks. The latest results (obtained in collaboration with K. Wood, B. Whitney, and K. Rice) include evidence for a gap in the disk of GM Aur, consistent with the presence of a Jupiter-sized planet orbiting GM Aur at a distance of a few AU.

At the opposite end of the evolutionary sequence, Carciofi is carrying out a study of the proto-planetary nebula Hen 3-1475 in collaboration with C. Rodrigues (INPE/Brazil). This object shows a well-defined bipolar structure and collimated jets. The central region ($\sim$2 arcsec) consists of an equatorially enhanced dusty envelope where molecular and far-infrared emission and polarized optical radiation are produced. In this study, many different observations are modeled simultaneously, including the spectral energy distribution in the 0.3 to 160 μm range, *UBVRI* polarimetry, and *HST* archival images in many wavelengths. One of the main findings is that a two-shell model, composed of an optically thin hot dusty disk close to the star and an optically thick cold disk far away, is required to explain the two peaks observed in the IR SED. Because the object is O-rich, silicate was adopted as the main constituent of the dust. However, these models fail to reproduce the lack of observed silicate emission in the 9.7-μm band. Very large (up to 50 μm) grains in the dusty envelope may need to be introduced in order to suppress this band.

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. Another result is that isotropic scattering can be a poor approximation in models 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.

In addition to radiative equilibrium calculations, 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 continuum processes (electron scattering, bound-free and free-free absorption and emission), as well as line absorption and emission. A NLTE rate solver has been developed, which provides the 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.

J. Bjorkman continued to develop methods of exploring the structure of extended circumstellar envelopes by means of gravitational microlensing. In collaboration with R. Ignace and H. Bryce (U. Wisconsin-Madison) and J. Simmons (U. Glasgow), he investigated the polarization signal produced by the microlensing event. They found that simultaneous observations of the polarization and flux amplification can be

used to determine the lens proper motion, impact parameter, and Einstein radius. The latter is especially important for studies of the dark matter component of the Galaxy.

3.2 Interstellar Matter

Federman's group studied the chemistry of diffuse interstellar clouds. As an aid to understanding the results of Pan's Ph.D. research, Sheffer extracted the column density of H_2 along the line of sight toward about a dozen stars in Cep OB2 and OB3 from spectra acquired with *FUSE*. From these results, he derived the distribution of rotational level populations and hence the kinetic temperature and the flux of ultraviolet radiation permeating the gas clouds. Of particular note is the result that the CH/H_2 ratio toward Cep OB3 is smaller than that toward Cep OB2. This difference arises because the gas densities in the sight lines toward Cep OB3 are lower, as inferred from chemical analyses on CH and CN.

Federman and Pan, in collaboration with E. Rollinde and P. Boissé (IAP), furthered their studies of structure in diffuse molecular material. Multi-epoch observations of the runaway star AE Aur revealed: a 20% increase in the amount of CH between 1997 and 1998, with no change in the amount of CH^+; an increase in the CN excitation temperature between 1993 and 1998; and weakly correlated variations in CH and CH^+ columns over periods of 6 to 12 months (or about 10 AU). The best explanation for the phenomena is CH^+ production and then synthesis of CH in a photodissociation region.

T. Crenny (Wheeling Jesuit U.) and Federman reanalyzed CO spectra from the *Copernicus* satellite in about 20 sight lines containing modest molecular abundances. The CO column densities are small enough that self-shielding from photodissociation is not occurring. Other studies, whose focus was on molecular-gas-rich sight lines, found that the CO column density correlates with H_2 column density. Since CH and H_2 track each other in diffuse molecular clouds, a corresponding trend between CO and CH is expected, but is not seen in the present sample. These sight lines have relatively low gas densities, as inferred from the distribution of fine structure level populations in neutral carbon and from the lack of CN and C_2 absorption. CH arises from reactions associated with CH^+ synthesis under non-equilibrium conditions according to the chemical modeling by Zsargó and Federman (2003). The observed amount of CO, however, can be reproduced via CH^+ chemistry only in the densest sight lines in the sample. Crenny and Federman conclude that CO absorption arises in dense clumps along the line of sight.

Witt and Vijh, in collaboration with K. Gordon (U. Arizona) initiated an extensive observing program to study optical and near-IR luminescence from interstellar nanoparticles. Successful observing runs at KPNO, Steward Obs., and CTIO provided optical spectrographic data on extended red emission (ERE) and blue fluorescence in various nebulae. These interstellar environments are known for production of the unidentified infrared bands, which are often attributed to unspecified aromatic hydrocarbon structures. Detection of near-UV/blue fluorescence, which is characteristic of neutral small PAH molecules such as pyrene and anthracene, has led to the first identification of specific molecules in these environments.

Witt, Leeuw, Gordon, and Must undertook a study designed to determine the characteristics of the clumpy structure of reflection nebulae. One approach examined the statistics of the reddening data for large samples of illuminating stars and compared them with radiative transfer models for clumpy reflection nebulae viewed from random directions. Another approach led to the development of a technique for analyzing the spatial surface brightness fluctuations in reflection nebulae in terms of characteristic sizes and filling factors of clumps within the nebulae. Plans are underway to apply this technique to wide-field images of nebulae, to be obtained with the new prime-focus CCD camera on the 2.3-m Bok telescope of Steward Obs.

Witt collaborated with Pierini, C. Maraston, and R. Bender (MPIEP Garching) on a study of dust attenuation in extremely red galaxies. Leeuw analyzed new mm-to-far-IR observations of seven nearby elliptical galaxies to derive dust temperatures and masses. The emissivity index was found to be consistent with standard amorphous silicate and carbonaceous grain models.

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 behavior of the Martian polar caps; he used data acquired by the MOC wide- and narrow-angle cameras.

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.

In December 2002, Bonev took up residence at NASA/GSFC to pursue the second part of his thesis with M. Mumma on cometary near-IR OH prompt emission. Bonev is developing a method of using this emission as a proxy for water production in comets. He is a member of the team that is acquiring high-resolution near-IR observations of comets and Mars with CSHELL (NASA IRTF) and NIRSPEC (W.M. Keck Obs.).

Benson completed an analysis of the MOC data on condensate clouds in the Tharsis/Valles Marineris region of Mars. In addition to continuing work on clouds, she began a study of the interannual variations of the Martian seasonal and residual polar caps using MOC wide-angle images. 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 ACS/

HRC images; they will be used to determine the concentrations of ozone, dust, and condensate clouds in the Martian atmosphere and to study the wavelength dependence of the polar albedo. The UV scattering properties of the dust are also being obtained from the data. Hardy is studying cloud motions in the HRC images in order to constrain winds on Mars.

3.4 Laboratory Astrophysics

Sheffer and Federman, collaborating with Andersson (Johns Hopkins), detected eleven CO Rydberg bands in the *FUSE* spectrum of HD 203374A, eight of which have never before been observed outside the laboratory. They derived oscillator strengths for the transitions, based on a CO abundance from bands with well-determined oscillator strengths. For the bands involving the upper states *B*, *C*, and *E*, the astronomical determinations are consistent with oscillator strengths obtained from the group's laboratory measurements. The new detections include transitions below 1000 Å between the ground (X) state and the K, L', W, and I' states; these bands play an important role in CO photochemistry. The astronomically derived oscillator strengths for bands at the shortest wavelengths, where predissociation dominates radiative decay, agree with earlier laboratory measurements.

Working with Kvale, Thomas developed a design for a Faraday cup detector that yields more reliable measurements of the beam current in an accelerator than conventional designs.

4. INSTRUCTION

4.1 Academic

Pan received the Ph.D. in physics and is now a Postdoctoral Fellow at Bowling Green State U.

Curtis published a graduate-level textbook, *Atomic Structure and Lifetimes: A Conceptual Approach*. It emphasizes semiclassical and semiempirical modeling, with worked examples that are directly applicable to research areas outside the atomic physics specialty, including many specific to astronomy.

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 summer 2002 and academic year 2002-2003 were as follows. In our general education courses, the total was 1310 for the three introductory lecture courses and 99 for the laboratory. The more advanced general-education courses had a total enrollment of 35. In graduate courses and advanced undergraduate courses for science majors, the total enrollment was 27.

4.2 Public

Undergraduate assistants for public education at the Ritter Planetarium-Brooks Observatory were Amanda Popovich and Samantha McAfee. Schmetzer continued as a graduate student assisting in operations while pursuing a customized Masters program in Planetarium Science. Czechowski continued as a weekend volunteer. D. Mulliss continued to maintain the Planetarium's web pages.[1]

During the report period, Ritter Planetarium presented twenty-one different programs during the one hundred regularly scheduled weekend public events. Of these, five were new productions: ''So You Want to be an Astronomer?'' (Mak and Potter); ''Women in Astronomy'' (Schmetzer); ''Street Smart Astronomy'' (Mulliss and Mak); ''Our Planet'' (Potter); and ''Navigating with Lewis and Clark'' (U. of North Dakota).

The planetarium presented approximately three hundred programs to visiting school groups, many coming from over fifty miles away. Formal program evaluations remained very positive. As part of routine program maintenance, many of the thirty programs in its library were updated or reproduced. A comprehensive follow-up packet was developed for many of the more popular K-12 programs.

Monthly public observing with the Ritter 1-m telescope and weekend evening viewings with the facilities of the Brooks Observatory continued. Approximately four thousand people visited one observatory or the other. During the report period, approximately 400 Boy Scouts and 275 Girl Scouts completed the Boy Scouts' Astronomy Merit Badge program and the Girl Scouts' Space Exploration Ribbon program, respectively. Attendance at the newly implemented Cub Scout/Brownie program, offered monthly, was about 350.

During the report period, the Ritter Planetarium implemented a monthly Senior Citizen Day program for area nursing homes. Attendance at these events has been modest so far. The planetarium staff also presented several workshops, including the popular Parent-Child Space Academy workshop developed during the previous report period. The planetarium staff collaborated on special events with other area organizations such as COSI-Toledo and the Stranahan Arboretum.

Schmetzer received a NASA/PLATO grant to purchase ''Skywatchers of Ancient Africa'' to expand our Black History Month programming. The central star projector, a Spitz A3P-Prime, was renovated in September 2002 by Ash Enterprises. This project was paid for in part by The Friends of Ritter, the College of Arts and Sciences, and a grant from the Toledo Rotary Foundation. The U. of Toledo also funded the installation of a new lighting and control system to replace the previous lumaline system.

Total attendance for the year was 28,500, down slightly from last year's record high attendance of 29,500.

5. MISCELLANEOUS

5.1 Participation in Meetings

Witt, Vijh, and Leeuw participated in the international symposium ''Astrophysics of Dust'' in Estes Park, CO, in May 2003, where they presented or co-presented six posters. Carciofi also presented a poster there. Witt presented an invited paper on extended red emission, and he was the orga-

[1]www.rpbo.utoledo.edu

nizer and overall chairman of the symposium. The meeting had over 250 participants from 22 countries, 44 invited lectures, and nearly 200 poster presentations. Witt, B. Draine, (Princeton U.) and G. Clayton (Louisiana State U.) are editing the proceedings volume.

K. Bjorkman is a member of the Scientific Organizing Committee for a meeting, ''The Nature and Evolution of Disks around Hot Stars,'' to be held in Johnson City, TN, in July 2004.

Miroshnichenko presented an oral talk and a poster at the International Colloquium ''Open Issues in Local Star Formation,'' Ouro Preto, Brazil (April, 2003).

J. Bjorkman, Mihaylov, K. Bjorkman, Wisniewski, and Gault each presented a poster paper at the 201st AAS meeting in Seattle. Federman, Pan, and Sheffer each presented a poster at the 202nd AAS meeting in Nashville, TN.

Federman gave an invited paper at the workshop ''Frontiers in Laboratory Astrophysics'' at the U. of Georgia and presented a paper at the 58th Ohio State U. International Symposium on Molecular Spectroscopy, at which he also chaired a session. Kvale presented an invited talk at the Seventeenth International Conference on the Application of Accelerators in Research and Industry (CAARI 2002), U. of North Texas, Denton, TX.

Bonev presented a poster at the annual meeting of the Solar Physics Division of the AAS in Laurel, MD, and an invited talk at the September meeting of Northwest Ohio planetaria. Benson and Bonev presented posters at the DPS meeting in Birmingham, AL.

5.2 Visiting Lectureships

K. Bjorkman was a Brittingham Visiting Scholar at the U. of Wisconsin-Madison, Dept. of Astronomy, in April 2003. She presented several lectures and talks during this visit. She also gave an invited colloquium to the Dept. of Astronomy, Case Western Reserve U. and an invited seminar to the Dept. of Physics & Astronomy, Michigan State U. She gave an invited public lecture at the Cleveland Museum of Natural History, as part of their Frontiers of Astronomy series.

Witt presented colloquia at the U. of Arizona and at Princeton U.; J. Bjorkman gave colloquia at the U. of São Paulo and the U. of Toledo.

5.3 Service

K. Bjorkman was appointed in June 2003 to a 3-year term on the AAS Committee on Employment.

Federman continued as a member of the *FUSE* Observers' Advisory Committee and of the Scientific Organizing Committee for Commission 14 (Atomic and Molecular Data) of the IAU. J. Bjorkman continues serving on the Organizing Committee of the IAU Working Group on Active B stars. Morrison began a three-year term on the Annie J. Cannon Award Advisory Committee of the AAS.

5.4 Awards and Research Support

Federman was elected a Fellow of the American Physical Society.

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K. Bjorkman completed a 2-year term as Master Teacher in the College of Arts and Sciences. Wisniewski (with K. Bjorkman) was awarded a three-year NASA GSRP Fellowship. K. Bjorkman continued as a Cottrell Scholar of the Research Corporation and gratefully acknowledges this support. K. Bjorkman and Wisniewski, and likewise Witt and Vijh, acknowledge significant observing time awards from NOAO/CTIO, accompanied by travel support for Wisniewski and Vijh, respectively. Gault was supported on an Ohio Space Grant Consortium Scholarship. K. Bjorkman thanks the U. of Wisconsin-Madison and the U. of São Paulo, Brazil, for support and hospitality during the respective visits.

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