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

[S0002-7537(90)00801-0]

This report covers the period 1 July 1998 to 30 June 1999.

## 1. PERSONNEL

During the report period, Anatoly Miroshnichenko rejoined the department as a postdoctoral research associate working with K. Bjorkman. Min Yan was a postdoctoral research associate with Federman. Aziz Majeed, an astrophysics placement student from the Univ. of Hertfordshire, spent 10 months in the Center. Mulliss accepted a position at Ball Aerospace. The permanent staff was unchanged.

Students involved in astronomical research were: undergraduates Will Fischer, Darren Hojnacki, and Goldie Summers; and graduate students Brian Abbott, Bruce Cantor, Brian Friedmann, David Knauth, Ivaylo Mihaylov, Christopher Mulliss, Kaike Pan, Kathy Shan, Tracy Smith, Larissa Spiker, and Janos Zsargó. Visiting NSF REU undergraduate students were, during the summer of 1998, Jennifer Benson (Buena Vista Univ. Iowa) and Eric Higgs (Xavier Univ.), and, during the summer of 1999, Nikole Howard (Worcester Poly.), and Kyle Westfall (U. Virginia).

## 2. OBSERVATORY

Ritter Obs. is now employing both the échelle and the Low-Dispersion Spectrograph (LDS) concurrently. A new optical fiber feed from the Cassegrain focus of the 1-m telescope to each spectrograph has been installed, and the Wright Instruments cameras are daisy-chained on the signal line to the data acquisition PC. Switching cameras is quickly accomplished with a few commands to the Wright Instruments software.

With the two spectrographs, which are operated over a broad range of the spectrum, four different wavelength calibration lamps must be available at the input ends of the fiber feeds. To enable selection of the needed lamp, Burmeister designed a housing with sockets for six lamps arrayed around a rotatable central turret. A 45° mirror atop the turret selects the desired lamp when the observer commands it into position, either manually or by computer control.

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, and the older 400 × 600-pixel camera was used with the LDS. During the report period, 716 stellar spectra were obtained on 90 nights. Most of the observations were made with the standard H$\alpha$ grating setting of the échelle spectrograph, 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 $R \simeq 26{,}000$. In dual operation mode, some test exposures were made with the LDS in the H$\alpha$ region with a resolution of about 1 Å.

## 3. RESEARCH

### 3.1 Stellar Astrophysics

Continuing spectroscopic monitoring programs at Ritter Obs. that are not described below concern: binary stars, Herbig Ae/Be stars, A-type shell stars, and UU Herculis-type stars. In support of the XMEGA collaboration, led by M. F. Corcoran (NASA/Goddard), Ritter Obs. obtained high-resolution spectra of $\iota$ Ori concurrently with ASCA observations of the system at both periastron and apastron. S. Marchenko (U. Montréal) is leading the effort of preparing the collaboration's optical observations for publication.

J. Bjorkman and K. Wood (Harvard CfA) continued to develop 3-D continuum radiative transfer techniques using Monte Carlo simulation. Not only is the team now able to determine the radiative equilibrium temperatures of complex circumstellar environments, they are also beginning to include ionization equilibrium in their calculations. This will enable studies of the ionization structure of the Galaxy and investigations of the re-ionization of the early universe.

In addition, J. Bjorkman continues to work on calculating line profiles in aspherical circumstellar envelopes, with the aim of refining current determinations of the mass-loss rates from hot stars (in collaboration with K. Bjorkman). As part of this program, Mihailov has developed a Monte Carlo line synthesis code for calculating resonance-line profiles in complex aspherical, non-monotonic velocity fields in the outflows from hot stars. In order to compute accurate line profiles, it is also necessary to determine the ionization distribution within the stellar wind. For his M.S. thesis project, Abbott modified J. MacFarlane's (Prism Computational Sciences) spherically symmetric NLTE ionization code to use the density and velocity of the Wind Compressed Disk model of a rotating stellar wind. These 2-D ionization fractions were used by the Monte Carlo line profile code to calculate the line profiles for rotating winds.

J. Bjorkman is working with R. Ignace, M. Hendry, and J. Simmons (Univ. Glasgow) on determining the effects of gravitational microlensing of extended sources. Preliminary work indicates that microlensing an AGB star would produce observable spectroscopic line profile and linear polarization signatures that would aid in diagnosing the properties of both the lensing object and the extended circumstellar envelope.

K. Bjorkman, in collaboration with Miroshnichenko, continued the analysis of ultraviolet spectropolarimetric observations of Oe/Be, B[e], and Herbig Ae/Be stars obtained with the WUPPE instrument aboard the Astro-2 space shuttle mission. The UV observations are combined with contemporaneous optical observations for complete spectropolarimetric coverage from 1450 Å to 1.05 $\mu$m.

With Wood, Bjorkman and Bjorkman have developed techniques for analyzing the structure of circumstellar disks around classical Be stars using continuum spectropolarimetry. From optical observations obtained with the Halfwave

Polarimeter (HPOL) at the Pine Bluff Obs. (PBO), they showed that the disk structure can be well constrained by the polarization data. Recent work includes refinement of a method for estimating the average disk temperatures of Oe/Be stars from the polarization line blanketing in the UV. Preliminary studies by Summers and K. Bjorkman indicate that such temperatures may also be derived from the optical data, provided that the data are of high enough resolution and signal-to-noise ratio.

K. Bjorkman continued a spectropolarimetric survey of Herbig Ae/Be and T Tauri stars using the HPOL instrument at PBO and at the WIYN observatory at Kitt Peak. Additional observations were obtained in March 1999. Other work on the Herbig Ae/Be stars by K. Bjorkman includes an ongoing collaboration with C. Grady (GSFC) and M. Sitko (U. Cincinnati) to investigate the nature of the circumstellar envelopes around these stars using ultraviolet, optical, and infrared spectroscopy, and UV and optical spectropolarimetry.

K. Bjorkman, in collaboration with M. Meade (U. Wisconsin), continues to work on an atlas of spectropolarimetric observations of Be stars based on 1989–1994 observations from PBO. A preliminary version of the Web-based portion of the atlas was presented at IAU Colloquium 198 in June 1999. Analysis of the database will be used to investigate the nature of variability in Be star polarization and its implications for disk models.

D. McDavid (Limber Obs.) is working with K. Bjorkman, J. Bjorkman, and A.T. Okazaki (Hokkai-Gakuen Univ.) to investigate whether contemporaneous observations of H$\alpha$ $V/R$ spectral variations and polarization levels in classical Be stars can be used as a test of models for disk structure. In particular, predictions of the one-armed spiral density wave model are being tested for the stars $\zeta$ Tau and 48 Lib, using data from Ritter, Limber Obs., PBO, and the literature. Benson contributed to this effort in July 1998, and Summers in June 1999.

Spiker and K. Bjorkman continued their research on the mass-loss rates of B stars. Spiker's M.S. thesis will discuss efforts to account properly for the underlying photospheric line blanketing in estimating mass loss from UV wind lines; preliminary indications are that photospheric line blanketing can be responsible for a number of significant features in the wind-line profiles, and so should be considered when measuring wind velocities and estimating mass-loss rates.

K. Bjorkman, in collaboration with J. Hoffman and K. Nordsieck (U. Wisconsin), is investigating the circumstellar envelope of the interacting binary system $\beta$ Lyr using spectropolarimetric data from PBO along with high-resolution spectroscopic data from Ritter Obs. Both the H$\alpha$ profile and the level of the broadband polarization show clear dependences on orbital phase. Monitoring of the star is continuing at both observatories, and analysis of the combined data is underway.

In other new collaborations, K. Bjorkman is part of a team, led by Wood and including B. Whitney (Space Sciences Inst.) and S. Kenyon (CfA), that is planning to use the adaptive optics system at Mt. Wilson observatory to image the circumstellar envelopes of pre-main-sequence stars. Also, Bjorkman and Bjorkman are beginning a new collaboration with Whitney to model *HST* observations of the luminous blue variable star $\eta$ Car.

Miroshnichenko, Mulliss, K. Bjorkman, and Morrison, in collaboration with Yu. Glagolevskij and G. Chuntonov (Special Astrophys. Observ., Russia) obtained nearly 20 high-resolution spectra of the bright Herbig Be star HD 200775. Analyzing long-term data on its H$\alpha$ line equivalent width, they found that the variations have a period of 1345 days.

With R. Gray (Appalachian State Univ.), S. Vieira (Univ. Belo Horizonte, Brazil), K. Kuratov (Fesenkov Astroph. Inst., Kazakhstan) and Yu. Bergner (Pulkovo Obs.), Miroshnichenko completed the first accurate spectral classifications of nine recently recognized Herbig Ae/Be candidate stars. Near-IR excesses were discovered in AS 116 and BD $+11°829$. Algol-type variability, which is not common in Herbig Ae/Be stars, was detected in MQ Cas and V1012 Ori.

Miroshnichenko's studies of the dusty envelopes of Herbig Ae/Be stars continued. In collaboration with Ž. Ivezić (Princeton Univ.) and D. Vinković and M. Elitzur (Univ. of Kentucky), he proposed a model for envelope-embedded disks that seems to reconcile conflicting conclusions regarding the dust geometry in these objects. Detailed radiative transfer calculations based on this model successfully fit the data from UV to mm wavelengths and show that the disks have central holes. The model also provides a natural resolution of some puzzling results of IR imaging.

In collaboration with P. Corporon (Univ. Montréal), Miroshnichenko obtained and analyzed photometric variations and high-resolution spectra of the B[e] star MWC 342 and suggested that this object is likely a binary system with a compact companion. Together with T. Sheikina (Fesenkov Astrophys. Inst., Kazakhstan), they presented a poster at the 194th AAS Meeting suggesting that properties of a group of 11 galactic B[e] and related stars may be explained by this hypothesis.

With K. Kuratov, T. Sheikina and D. Mukanov (Fesenkov Astrophys. Inst., Kazakhstan), Miroshnichenko carried out a photometric and spectroscopic study of a suspected luminous star, LS II $+22°8$, and concluded that it is a classical Be star. Miroshnichenko and K. Bjorkman, with D. McDavid (Limber Obs.) and T. Pogrosheva (Sternberg Astron. Inst.), studied the behavior of the classical Be star $\pi$ Aqr during a recent episode of disk loss and re-determined its fundamental parameters: $\log(L_{\rm bol}/L_\odot) = 4.1 \pm 0.3$, $T_{\rm eff} = 24000 \pm 1000$ K, $\log g = 3.9 \pm 0.1$, $M_* = 11 \pm 1.5 M_\odot$.

Miroshnichenko and K. Bjorkman cross-correlated the Be star catalog with the IRAS Point Source and Faint Source catalogs, selected 24 objects with IR fluxes not consistent with those expected from free-free or photospheric radiation, and analyzed IRAS high-resolution images of these objects. Nine of them either are very extended or show no concentration on the star's position, and their excesses are probably due to infrared cirrus emission. The remaining objects were found to have point-like or marginally extended images at least in 3 of 4 IRAS bands, which may be due to radiation from circumstellar dust formed early in the evolution of the star. It is proposed that some intermediate-mass stars retain protostellar dust through the classical Be star stage.

Morrison continued to work with Fischer on a study of variability in the H$\alpha$ profile and in the radial velocities and equivalent widths of photospheric lines in 6 Cas (A3 Ia$^+$). Analysis of the approximately 25 spectra shows definite variability in all these quantities but no clear periodicity. In general, the absorption and emission strength and velocity in H$\alpha$ remain roughly constant during one observing season but change dramatically from season to season. The data set includes several episodes in which H$\alpha$ showed a a more rapidly varying discrete absorption component superimposed on the usual P Cygni profile. With E. Chentsov (Spec. Astr. Obs.), Fischer and Morrison plan to combine existing observations in order to construct a more densely spaced time series of spectra.

Fischer also studied seven Ritter échelle spectra of HD 223960 (A0 Ia$^+$), which is very unusual among A-type supergiants in that all available spectra show a double-peaked H$\alpha$ emission profile. Since our spectra show no radial-velocity variability in the photospheric lines at the $\pm$ 2 kms$^{-1}$ level, a binary model for this star is not indicated.

Hojnacki began to study the H$\alpha$ variability of 9 Per (A2 Ia) in 21 spectra taken during the years 1993–1998. Like some other late B- and early A-type supergiants, this star occasionally shows enhanced absorption in the blue wing of H$\alpha$. The interval between episodes varies from star to star; in this star, it appears to be about one year, since an episode occurred on about the same date in each of the five observing seasons included in the data set. Current interpretations favor a density or an ionization structure in the stellar wind that is carried in and out of view by the star's rotation. Longer and more densely spaced series of observations are needed in order to determine whether the phenomenon is truly periodic.

Morrison collaborated on a study of the long-term spectroscopic and photometric variability of P Cygni (B1 Ia$^+$) with N. Markova (NAO Bulgaria), M. de Groot (Armagh Obs.), and I. Kolka (Tartu Obs.). Data obtained at several observatories from 1989 to 1999 were analyzed in a uniform way. Both the H$\alpha$ equivalent width and the *UBV* photometric material show cyclical variability on time scales of years, but the cycles have different lengths. This result is in keeping with a growing body of evidence that photospheric and wind phenomena in many hot supergiant stars vary on different time scales and, therefore, likely have different causes.

### 3.2 Interstellar Matter

Witt studied interstellar dust in a variety of environments, ranging from the solar system to remote galaxies. With P. Frisch (U. Chicago) *et al.*, he examined the consequences of direct observations by dust detectors aboard *Ulysses* and *Galileo* of interstellar grains within the solar system. These observations suggest that the size distribution of grains extends to larger values than generally assumed for interstellar grains, and the inferred dust-to-gas ratio for the inflowing interstellar material is higher than the canonical average Galactic value.

In collaboration with V. Zubko (Technion, Haifa) and Smith, Witt studied the impact of a proposed population of silicon nanoparticles on interstellar extinction. Of major importance is the dependence of the dielectric functions of materials upon particle size when in the nanoparticle regime. It was found that the quantum efficiency for Extended Red Emission (ERE) generation by these particles must be near 100%, if existing abundance constraints for Si are to be met. No structures due to silicon nanoparticles are to be expected in the UV extinction curve.

With Majeed and T. Boroson (KPNO-Gemini), Witt analyzed long-slit spectra of the Evil Eye galaxy (NGC 4826), covering the spectral range 500–950 nm. Evidence for ERE was found in the light emanating from the prominent dust lane across the bright bulge of this galaxy.

In collaboration with K. Gordon (LSU), Witt completed the second paper in a series on multiple scattering in clumpy media, this one dealing with radiative transfer in galactic environments. In addition to providing very extensive and detailed numerical model data, this paper discusses in particular the effects of internal dust on the UV spectral energy distribution of starburst and Lyman-break galaxies. Witt also completed an invited review paper on small and very small interstellar grains, to be published in J. G. R.—Space Science.

In collaboration with Smith and Gordon, Witt investigated observational constraints on the efficiency of the ERE and the related issue of the origin of the ERE. Observationally derived minimum quantum efficiencies vary widely with radiation environment, being highest in locations with very low photon densities and moderately hard radiation fields. This and other observed characteristics of the ERE point toward an origin in small clusters that need UV photons for ERE excitation but are subject to destruction through multiphoton absorptions taking place during a single cooling time scale. Silicon nanoparticles in the 1–5 nm diameter range are excellent candidates.

In collaboration with Gordon and M. Cohen (UC-Berkeley), Witt continued an effort to map the ERE and the diffuse galactic light (DGL) over the sky at intermediate and high galactic latitudes. The aims are to extend the demonstration that ERE is present in the diffuse ISM of the Galaxy and to explore correlations between the ERE agent and different populations of interstellar grains that are detectable by their extinction and IR emission characteristics.

Federman and Zsargó, in collaboration with D. Lambert, Y. Sheffer (U. Texas), J. Cardelli (Villanova), B-G Andersson (JHU), and E. van Dishoeck (Leiden), studied ultraviolet absorption from interstellar $^{12}$CO and $^{13}$CO toward $\rho$ Oph A and $\chi$ Oph. The measurements were obtained at medium resolution with the Goddard High Resolution Spectrograph on the *Hubble Space Telescope*. Column density ratios, $N(^{12}\mathrm{CO})/N(^{13}\mathrm{CO})$, of 125 $\pm$ 23 and 117 $\pm$ 35 were derived for the sight lines toward $\rho$ Oph A and $\chi$ Oph, respectively. A value of 1000 $\pm$ 500 for the ratio $N(^{12}\mathrm{C}^{16}\mathrm{O})/N(^{12}\mathrm{C}^{18}\mathrm{O})$ toward $\rho$ Oph A was also obtained. These ratios are larger than the isotopic ratios for carbon and oxygen appropriate for the ambient material. Since for both carbon and oxygen the more abundant isotopomer is enhanced, selective isotope photodissociation plays the key role in the fractionation process. The enhancement arises because the more abundant isotopomer has lines that are more optically thick, resulting in more self shielding from dissociating radiation. A simple

argument involving the amount of self shielding (from $N(^{12}CO)$) and the strength of the UV field permeating the gas (from the amount of vibrationally excited $H_2$ seen in our spectra) shows that selective isotope photodissociation controls the fractionation seen in these two sight lines, as well as the sight line to $\zeta$ Oph.

Knauth, Federman, and Lambert inferred the physical conditions in the photodissociation regions (PDRs) of two reflection nebulae, NGC 2023 and vdB 102, through high-resolution optical spectra of the illuminating stars HD 37903 and HD 147009, respectively. These observations probe the PDRs in front of the stars. Measurements of Na I, K I, CH, $C_2$, and CN were analyzed. Estimates of the gas density and the flux of ultraviolet radiation were derived and compared with the results from infrared and radio studies, which sampled the PDR in the molecular cloud behind the star. In the foreground material, the gas density and the ultraviolet flux are lower than in the molecular material. It appears that the foreground gas is farther from the source of illumination. Finally, the columns of Na I and K I were reproduced when the extinction curve for the sight line was adopted. As in our earlier study of the PDR toward HD 200775, the illuminating star of the nebula NGC 7023, we conclude that future modeling efforts of PDRs should be based on the extinction curve for the sight line being studied.

Pan, Yan, and Federman analyzed *IUE* NEWSIPS spectra of HD 37903, 20 Aql, and HD 200775. Compared with earlier versions of these spectra, the NEWSIPS data yield more accurate and mutually consistent equivalent widths. The column density ratio, $N(^{12}CO)/N(^{13}CO)$, was found to be $\geq$ 10, 43 $\pm$ 4, and 23 $\pm$ 5 toward HD 37903, 20 Aql, and HD 200775, respectively. The value for the sight line to 20 Aql is consistent with earlier determinations. $N(^{13}CO)$ is enhanced in the foreground PDR of NGC 7023. Enhanced levels of $^{13}CO$ arise when the gas is cold (T $\leqslant$ 30 K) and the abundance of $C^+$ is high because an intense UV radiation field is present; such physical conditions were suggested by us for this PDR in an earlier study.

### 3.3 Planetary System Astrophysics

*HST* has monitored Mars during all periods since 1990 in which Mars has been observable. During the most recent year, STIS spectra were acquired in visible and near IR wavelengths in order to study the reflectance spectrum of the Martian surface. Analyses of images and spectra acquired in 1997 continue to confirm the significant aphelion cloud belt first observed in 1993–1997 *HST* images. Shan is currently assembling an atlas of cloud observations based upon all years of *HST* observations.

Cantor compared regressions of the Martian North Polar Cap during the four spring seasons observed by *HST* to each other and to the historical database. This work has led to new insights concerning the interannual variability of the cap recession and to new measures of the albedo of the north polar frost deposits. Cantor has also recently completed a detailed analysis of the photometry of Phobos based on Cycle 4–7 *HST* images.

James is a Participating Scientist for Mars Global Surveyor and is a member of the MOC (Mars Observer Camera) Team. He determined the behavior of the Martian South Polar Cap using the aerobraking images acquired during the fall of 1997 and is currently using the MOC data to study the behaviors of the polar caps. Cantor is using MOC data to study the behavior of dust on Mars. James was also Deputy PI of the MARCI camera experiment on the Mars Climate Orbiter.

### 3.4 Laboratory Astrophysics

Graduate students involved in theoretical and accelerator-based atomic physics research included Murray Henderson, Rasa Matulioniene, and Henry Povolny.

Irving, Henderson, Curtis, and Martinson made precision lifetime measurements of the $2s^2\ ^1S - 2s2p^1P$ resonance lines in Be I and B II. B II $\lambda$1362 has been used extensively to determine stellar boron abundances, and the $^{11}B/^{10}B$ abundance ratio is crucial for testing models for light element nucleosynthesis. This line is also important because it masks lines in Hg II and Hg III that have been observed in chemically peculiar stars. The measurements utilized the ANDC method to eliminate the effects of cascade repopulation, are of higher precision than earlier measurements, and are in excellent agreement with recent theoretical predictions.

Henderson, Irving, Curtis, and Martinson measured the lifetimes of all twelve levels of the $5d^96p$ configuration in Hg III. The three $J = 1$ levels decay to the ground state, $5d^{10}$, whereas the $J = 0,2,3,4$ levels decay to the metastable level $5d^96s$. These results were compared to lifetimes obtained previously in our laboratory for the isoelectronic ion Au II and the homologous ions Ag II, Cd III, and In IV to reveal systematic patterns. These lifetimes were also calculated with the Dirac-Fock code GRASP. For the $J = 0,2$ level lifetimes, the agreement between theory and experiment was very good, but the shortest-lived $J = 1$ transition was 2 times slower than predicted by theory. For the $J = 3,4$ levels, the experimental lifetimes were approximately 30% longer than the theoretical predictions.

Henderson, Irving, Matulioniene, Curtis, and Ellis collaborated with Wahlgren and Brage at the Univ. of Lund on measuring lifetimes for the radiation emitted in the ground term transitions of the nominal form $5s^25p^65d^x6s$ - $5s^25p^65d^x6p$ in Ta II ($x = 3$), W II ($x = 4$) and Re II ($x = 5$). The absorption spectra of these ions in the region 2000–3000 Å are potentially useful for astrophysical abundance determinations and spectrum synthesis. Supporting theoretical calculations were also performed to characterize configuration interaction and to estimate the degree of decay branching of the upper levels. The lifetime measurements were combined with these theoretical considerations and with branching fractions deduced from available emission measurements to specify the oscillator strengths of these transitions. The results were applied to *HST* spectra to estimate the tungsten abundance in Sirius.

Witt, in collaboration with Furton (Rhode Island Coll.), Deng (UT), Smith, and Friedmann, continued laboratory studies of candidate grain mantle and nanoparticle materials, with the principal aim of finding likely sources of the ERE, which is observed in many dusty astronomical environments. Considerable effort went into the design and construction of

a photoluminescence spectrophotometer for measuring the absolute photoluminescence quantum efficiency of candidate materials. Studied were materials including hydrogenated amorphous carbon (HAC), hydrogenated amorphous carbon-silicon alloys, diamond-like carbons, nanodiamonds, silicon carbide nanoparticles, carbon nanoparticles, and silicon nanoparticles.

Jointly with Furton and Rhode Island student J.W. Laiho, Witt completed an investigation of the amount of interstellar carbon locked in solid hydrogenated amorphous carbon, based on observations of the strength and detailed profile of the interstellar 3.4-$\mu$m C–H stretch absorption band. It was concluded that interstellar amorphous carbon needs to be highly hydrogenated in order to provide the required mass absorption coefficient for the 3.4$\mu$m transition, and that most likely about 80 carbon atoms in the form of HAC per million H atoms are needed to satisfy the observational constraints.

Theodosiou and Federman determined theoretical oscillator strengths and branching ratios for ultraviolet transitions in Mg II. The focus was on the weak doublet at 1240 Å because it is the best means to obtain accurate interstellar abundances. The multiplet oscillator strength is in excellent agreement with a recent astronomical analysis and in good agreement with other recent computations. A key result of the calculation is that the branching ratio differs from the *LS* coupling value: 1.78 $\pm$ 0.03 vs. 2. Very recent astronomical studies confirm our predicted branching ratio.

### 3.5 High-Energy Astrophysics

Iwamoto calculated the thermal resistivity of metals due to electron-electron scattering by using the static screening potential, with the screening length determined by the compressibility, which is in turn derived from the Monte-Carlo values for the correlation energy. The agreement of the result with experiment is competitive with that of other, more sophisticated theories. This simple model at one atmosphere pressure should serve as a good reference point for studying the transport properties of matter at high densities, which pertain to the interiors of large planets, white dwarfs, and neutron stars.

The axion has been one of the candidates for dark matter for over two decades. Astrophysical arguments still give the most stringent constraints on its properties, such as mass and coupling to matter. Iwamoto calculated the axion bremsstrahlung rate due to nucleon-nucleon collisions for degenerate neutron-star matter in the general case of different neutron and proton Fermi momenta. Within the two-DFSZ and KSVZ (hadronic)-axion models, the latest parameters were used and the model dependence of the rate was examined. The analytic expressions for the energy-loss rates that were obtained may be used to study the long-term cooling of neutron stars. In collaboration with the groups in Tokyo and Montana State, Iwamoto obtained limits on axion parameters by comparing the evolutionary calculation with observational data from *ROSAT*. It was found that, if the correct neutron-star matter equation of state is soft, then the axion limits thus obtained are of the same order of magnitude as the limits from SN 1987a. The latter have become less stringent over the last several years but are still considered to be the best limits.

A possible route to the formation of a black hole of relatively low mass in the gravitational collapse of a highly-evolved star, associated with a supernova, is the formation of a neutron star, briefly metastable due to the trapped neutrinos and high temperature. Then the equation of state may soften, leading to the final collapse. The softening of the equation of state may be caused by meson condensation. In order to examine the viability of such a mechanism, first proposed by G. E. Brown and H. Bethe, it is necessary to compare different time scales: the hydrodynamic, the weak interaction, and the cooling and deleptonization. Iwamoto, in collaboration with researchers in Kyoto and Chiba Inst. Tech., studied the dynamical weak processes associated with meson condensation inside neutron stars. They calculated the reaction rates for the thermal kaon process, in which kaons are produced thermally via nucleon-nucleon collisions, and solved the rate equations numerically to follow the kinetics of condensation. They also discussed the similarities and differences between the meson condensation inside neutron stars and the Bose condensation in gaseous atomic systems.

## 4. INSTRUCTION

### 4.1 Academic

The M.S. degree in physics was awarded to Abbott, who has accepted a position at the Hayden Planetarium, and to Knauth.

In 1997 September, The University 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 quarter and the two semesters covered by the report period were as follows. In our general education courses, the annual total was 1088 for the three introductory lecture courses and 93 for the laboratory. The more advanced general-education courses had a total enrollment of 22. In graduate courses and advanced undergraduate courses for science majors, the total enrollment was 26.

### 4.2 Public

K. Bjorkman participated in outreach programs to local schools and served as a mentor to several high school students interested in astronomy. She also presented a session on ‘‘Physics FUN-damentals’’ to girl scouts at the Maumee Valley Girl Scout Council’s Quantum Leap program, which is designed to interest junior high school girls in math and science.

Undergraduate assistants to Anderson-Huang and Mak for public education at the Ritter Planetarium-Brooks Observatory were Dawn Mulliss, Will Fischer, Meredith Gray, and Bethany Stelneki.

During the report period, the Ritter Planetarium presented a record sixteen unique public planetarium programs, including the following shows written in-house (authors in parentheses):

Planet Quest: The Search Continues (D. Mulliss)
The Fall Skies over Toledo (Mak and D. Mulliss)
Fire from the Sky (D. Mulliss and Mak)
Winter Skies over Toledo (Mak)
Women in Astronomy (D. Mulliss)
Lightyears Away (Mak)
The Spring Skies over Toledo (Mak)
The Outer Limits (Mak).

We continued our normal program of monthly public observing nights with the Ritter 1-meter telescope and weekend evening viewings with the facilities of the Brooks Observatory. Approximately five thousand people visited one observatory or the other, including about one thousand who attended Mars Watch 1999 during opposition.

Our offerings to the local K-12 community continued to expand. Visiting school groups may now choose from over twenty programs, some live, some taped. While these programs cover all aspects of astronomy, each begins with a live tour of the night sky and ends with a question and answer session. We are developing follow-up packets geared to specific school programs; packets for the six most popular programs are ready.

During the report period, approximately 250 Boy Scouts and 200 Girl Scouts completed the Boy Scouts' Astronomy Merit Badge program and the Girl Scouts' Space Exploration Ribbon program, respectively. Mak conducted the annual ''How to Buy a Telescope'' workshop.

The total attendance for all programming conducted under the auspices of Ritter Planetarium and Brooks Obs. was approximately 26,750. This figure is the same as last year and represents an all-time high. The planetarium staff attended local, state, and regional conferences. The planetarium cohosted (with Bowling Green State University Planetarium) a meeting of the Cleveland Regional Association of Planetarians.

## 5. MISCELLANEOUS

### 5.1 Participation in Meetings

J. Bjorkman, K. Bjorkman, Federman, Fischer and Morrison, Knauth, Miroshnichenko, Smith, and Witt presented posters at the 194th AAS meeting in Chicago. At IAU Colloquium 175 in Alicante, Spain, J. Bjorkman gave an invited review talk and presented a poster; K. Bjorkman presented an invited review talk and three posters; and Miroshnichenko presented three posters. Bjorkman and Bjorkman participated in the workshop, ''Eta Carinae at the Millenium,'' at Gallatin Gateway, Montana, in July 1998.

Federman presented a poster at the 6th International Colloquium on Atomic Spectra and Oscillator Strengths, which was held in Victoria, BC. Federman and Witt each gave an invited lecture at the American Chemical Society's 31st Central Regional Meeting, ''Chemistry in Space,'' in Columbus, OH. Witt was an invited speaker at the workshop, ''Dust in the Local Interstellar Medium,'' in Bern, Switzerland in October 1998. Iwamoto presented a paper at the 1999 Centennial Meeting of the APS in Atlanta, Georgia, and attended the David N. Schramm Memorial Symposium: Inner Space/Outer Space II at Fermilab, Batavia, IL.

### 5.2 Visiting Lectureships

J. Bjorkman and Federman presented colloquia at the U. of Wisconsin and at Western Michigan U., respectively.

### 5.3 Service

J. Bjorkman continues to serve a three-year term on the IAU Working Group on Active B stars. He was also a member of the scientific organizing committee for IAU Colloquium 175, ''The Be Phenomenon in Early-Type Stars,'' held 28 June – 2 July, 1999 in Alicante, Spain. K. Bjorkman continued as a member of the Publications Board of the AAS, and Morrison continued to serve on the V. M. Slipher Committee on Public Education in Astronomy. Federman is a member of the *FUSE* Observers Advisory Council.

### 5.4 Awards and Research Support

K. Bjorkman was selected as a 1999 Cottrell Scholar by the Research Corporation and gratefully acknowledges this award, which will support both teaching and research. We gratefully acknowledge an NSF grant to Iwamoto; a NASA grant to K. Bjorkman; a NASA grant to Federman, Schectman, and Cheng; NASA LTSA grants to J. Bjorkman, to K. Bjorkman, and to Federman; an STScI grant to Federman; and three NASA grants to Witt.

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

Participation in research by Benson, Fischer, and Summers was supported by an NSF-REU grant to the Department of Physics and Astronomy.

## PUBLICATIONS

External collaborators are listed in parentheses.

### Reports, Theses, and Abstracts

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Nancy D. Morrison