

The University of Georgia
Department of Physics and Astronomy
Athens, Georgia 30602

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The following report covers the Department activities from October 1996 through October 1997.

1. PERSONNEL

Department members participating in astrophysics or astronomy research or instruction were Professors J. Scott Shaw and Jean-Pierre Caillault, Associate Professors Coates Johnson and Loris Magnani, Assistant Professor Peter Hauschildt, graduate students Thomas Hearty, Sangeeta Mysore, Inseok Song, Sharon Holcomb, Travis Barman, and J.D. Myers. Undergraduate students Suzanne Nicol (Northeastern) and Anthony Tong Truong (University of California at Berkeley) spent the summer as NSF REU interns, while University of Georgia undergraduates William Shoemaker and Hannah Curry spent the summer at Cornell and Haystack Observatory, respectively, as NSF REU summer interns.

Two graduate students were granted degrees in 1997. Thomas Hearty received a PhD for a dissertation titled "Star Formation at High Galactic Latitudes," and Sharon Holcomb received an MS for a dissertation titled "A Survey of High-Latitude Molecular Gas in the Southern Galactic Hemisphere." Both dissertations were directed by Magnani.

2. FACILITIES

The University of Georgia is a member of the Southeastern Association for Research in Astronomy (SARA), a consortium of five south-eastern universities (East Tennessee State, Valdosta State, Florida Tech, and Florida International University).

The consortium operates a 0.9-m telescope on Kitt Peak. This telescope is now completely functional with a CCD camera. The capability for robotic and remote operation is expected in the winter of 1997/98.

In addition, the consortium also operates a summer NSF REU program. The NSF has recently extended SARA's REU grant for 4 years.

The astronomy group at the University of Georgia has five SUN Sparcstations, two HP workstations, and numerous smaller machines available for data processing and computation.

In addition, a 24-inch Cassegrain telescope is available on the roof of the Physics Building for teaching and public nights.

3. RESEARCH

Caillault served as the chairman of a discussion session on the nature of the ROSAT field sources at the 10th Cool Stars Workshop in Cambridge. Recent studies using the ROSAT All-Sky Survey towards nearby star-forming regions have identified a widely dispersed population of X-ray active stars and have suggested that these objects are older PMS stars located far from molecular clouds. Another group at the meeting, however, presented a simple model assuming con-

tinuing star formation over the past 10⁸ yrs. The model quantitatively reproduces the number, surface density, X-ray emission, and optical properties of the RASS sources, leading to the argument that these stars are not PMS stars, but young MS stars of ages up to $\sim 10^8$ yrs. A third party noted that the similarity between molecular cloud lifetimes and the ambipolar diffusion timescale implied that star formation does not take place instantaneously, nor at a constant rate. They thus argued that the probability of finding a large population of old stars in a star-forming region is intrinsically very small and that the post-T Tauri problem is by and large nonexistent. A panel consisting of representatives of each of the different camps (Rainer Wichmann [Heidelberg], Cesar Briceño [CfA], Eduardo Martin [IAC/Berkeley], and Francesco Palla [Arcetri]) initiated the discussion in this session by presenting briefly their points of view on this controversial topic. This was followed by numerous comments and questions from the Workshop participants.

Gagné (JILA), Caillault, Stauffer (CfA), and Linsky (JILA) have obtained half of their scheduled ASCA observations of θ^1 Ori C. The only existing ASCA X-ray spectrum of the Trapezium region shows a very strong component of high temperature plasma, with emission measure approximately five times larger than that of the cooler component. Although ASCA cannot spatially resolve θ^1 Ori C from the remainder of the Trapezium, they can use their ROSAT HRI data to limit the contribution of PMS stars to the overall flux. Their observing program is designed to re-observe the Trapezium at θ^1 Ori C's rotational phases 0.0 and 0.5 in order to determine whether the spectrum changes as a function of rotational phase. This will allow them to distinguish between two scenarios for the X-ray emission of θ^1 Ori C: absorption of magnetospheric X-rays in a corotating wind or magnetosphere eclipses.

Myers, Caillault, and Gagné are analyzing ROSAT HRI snapshots of the Trapezium cluster taken over the course of 21 days. The purpose of this study is to determine the nature of the short-term variability of the young, low-mass stars in the cluster. However, they will also be able to characterize the long-term variability, since many high-resolution X-ray observations of the Trapezium have been obtained over the last two decades. They are also interested in the number of short-term flares detected. Since there are so many stars within the field of view, the cluster is an excellent target for flare studies. Determining the extent of variability will enable them to determine whether Montmerle *et al.*'s (1983) suggested "continual flaring" can entirely account for the observed emission. Thus, they also hope to quantify and compare the frequency, strength and timescales of X-ray flares versus optical flares and compare the X-ray flare data from Orion with that obtained from ROSAT and Einstein observations of the stars in other star-forming regions such as ρ Oph, Chamaeleon, Tau-Aur, and older clusters such as the Pleiades, α Per, and the Hyades.

Mysore and Stauffer have obtained V- and I-band photometry of the moderately rich open cluster M35 (NGC2168). Since M35's age (20-40 Myr) is comparable to that of the Pleiades cluster (70 Myr), they expect a similar functional dependence on mass of the fraction of stars that appear to be photometrically variable. Further analysis of the data will allow for a determination of the BY Dra fraction among low-mass stars in M35. The observations were made from Nov. 1995 through Jan. 1996 at the Mt. Hopkins Observatory and the Kitt Peak National Observatory.

Song and Caillault have proposed to use the VLBA to study AS431 (= WR147), a highly-reddened WN8 Wolf-Rayet star which is both a hard, strong X-ray source and a double radio source (separation = 0".58). The radio emission consists of a southern thermal source (coincident with the optical position of the WR-star) and a slightly weaker, non-thermal northern source. Although probably a member of the Cyg OB2 association ($d \sim 2$ kpc), AS431's distance has been estimated to be 630 pc. The X-ray emission is currently best explained by capture of the WR-star's dense, equatorial wind by a neutron star companion. However, the true nature of the companion to AS431 is not known. While non-thermal radio emission is consistent with the source being a neutron star, there is another plausible explanation: an extragalactic source in the line-of-sight. They hope to answer two questions with the astrometric capabilities of the VLBA: (1) Is AS431's distance < 2 kpc? and (2) Is the non-thermal radio source extragalactic?

Song, Caillault, Stauffer, and Barrado (CfA) are attempting to determine the ages of β Pic stars since this knowledge may play an important role in understanding whether planetary system formation is common. If the ages of β Pic stars are all very young, then this suggests that planet formation is common and that the range of dust optical depths is an age indicator; if the ages are spread out over a few hundred Myr, then planetary formation would be determined by random initial conditions. While it is difficult to determine directly the ages of individual A-stars, one can employ indirect methods, such as standard age-dating techniques for low-mass stars if the A-stars have such binary companions. Since young, low-mass stars are strong X-ray emitters, they will analyze all of the archival ROSAT PSPC and HRI images which contain β Pic candidates in order to determine whether there exist any X-ray sources within $\sim 10^4$ AU (roughly equivalent to $\sim 10'$) of the A-stars. If so, then they will obtain follow-up optical photometry and spectra of all possible optical identifications. These data will then allow them to determine whether the star is a physical companion to the A-star and, if so, its age and that of the β Pic candidate.

Hauschildt, Schwarz (Arizona State), Starrfield (Arizona State), Baron (U. Oklahoma), Allard (Wichita St.), and Shore (Indiana, South Bend) present new detailed NLTE calculations for model atmospheres of novae during outburst. This fully self-consistent NLTE treatment for a number of model atoms includes 3922 NLTE levels and 47061 NLTE primary transitions. The new results show that the large set of NLTE lines constitute the majority of the total line blanketing opacity in nova atmospheres. Although LTE background lines are

included, their effect is small on the model structures and on the synthetic spectra. The assumption of LTE leads to incorrect synthetic spectra and the results indicate that NLTE calculations are required for reliably modeling nova spectra. In addition, a detailed NLTE treatment for a number of ionization stages of iron changes the results of previous calculations and improves the fit to observed nova spectra.

LMC 1988 #1 was a slow, CO type, dust forming classical nova. It was the first extragalactic nova to be observed with the IUE satellite. Hauschildt, Schwarz, Starrfield, Baron, Allard, and Shore have successfully fit observed ultraviolet and optical spectra of LMC 1988 #1 taken within the first two months of its outburst (when the atmosphere was still optically thick) with synthetic spectra computed using PHOENIX nova model atmospheres. The synthetic spectra reproduce most of the features seen in the spectra and provide V band magnitudes consistent with the observed light curve. The fits are improved by increasing the CNO abundances to 10 times the solar values.

Hauschildt, Schwarz, Starrfield, Baron, Allard, and Shore have analyzed the early optically thick ultraviolet spectra of Nova OS And 1986 using a grid of spherically symmetric, non-LTE, line-blanketed, expanding model atmospheres and synthetic spectra with the following set of parameters: $5,000 \leq T_{model} \leq 60,000$ K, solar abundances, $\rho \propto r^{-3}$, $v_{max} = 2000$ km s $^{-1}$, $L = 6 \times 10^4 L_{\odot}$, and a statistical or microturbulent velocity of 50 km s $^{-1}$. Synthetic spectra are used to estimate the model parameters corresponding to the observed IUE spectra. The fits to the observations were then iteratively improved by changing the parameters of the model atmospheres, in particular T_{model} and the abundances, to arrive at the best fits to the optically thick pseudo-continuum and the features found in the IUE spectra. The IUE spectra show two different optically thick subphases. The earliest spectra, taken a few days after maximum optical light, show a pseudo-continuum created by overlapping absorption lines. The later observations, taken approximately 3 weeks after maximum light, show the simultaneous presence of allowed, semi-forbidden, and forbidden lines in the observed spectra. Analysis of these phases indicates that OS And 86 had solar metallicities except for Mg which showed evidence of being underabundant by as much as a factor of 10. A distance of 5.1 kpc to OS And 86 was derived along with a peak bolometric luminosity of $\sim 5 \times 10^4 L_{\odot}$. The computed nova parameters provide insights into the physics of the early outburst and explain the spectra seen by IUE. Lastly, evidence in the later observations is found for large non-LTE effects of Fe II which, when included, lead to much better agreement with the observations.

An important addition to the parallel implementation of the generalized stellar atmosphere and NLTE radiative transfer computer program PHOENIX is described by Hauschildt and Baron. Parallel algorithms have been developed for radiative transfer, spectral line opacity, and NLTE opacity and rate calculations. These algorithms divided the work spatially or by spectral lines, that is distributing the radial zones, individual spectral lines, or characteristic rays among different processors. For finite, monotonic velocity fields, the radiative transfer equation is an initial value problem in wave-

length, and hence each wavelength point depends upon the previous one. However, for sophisticated NLTE models of both static and moving atmospheres needed to accurately describe, e.g., novae and supernovae, the number of wavelength points is very large (200,000–300,000) and hence parallelization over wavelength can lead both to considerable speedup in calculation time and the ability to make use of the aggregate memory available on massively parallel supercomputers. Hauschildt and Baron describe an implementation of a pipelined design for the wavelength parallelization of PHOENIX, where the data from the processor working on a previous wavelength point is sent to the processor working on the succeeding wavelength point as soon as it is known. Their implementation uses a MIMD design based on a relatively small number of MPI library calls and is fully portable between serial and parallel computers.

Hauschildt, Aufdenberg (Arizona State), Shore, and Baron successfully reproduce the full multi-wavelength spectrum, including the extreme ultraviolet (EUV) continuum observed by the *Extreme Ultraviolet Explorer*, of the B2 II star ϵ CMa with a non-LTE fully line-blanketed spherical model atmosphere. The available spectrophotometry of ϵ CMa from 350 Å to 25 μm is best fit with model parameters $T_{eff}=21750$ K, $\log(g)=3.2$, and an angular diameter of 0.77 mas. The model predicts a hydrogen ionizing flux, q_0 , of 1.59×10^{21} photons $\text{cm}^{-2} \text{s}^{-1}$ at the star's surface and 5540 photons $\text{cm}^{-2} \text{s}^{-1}$ at the surface of the Local Cloud. The synthetic spectra are in excellent agreement with observed continuum and line fluxes from échelle spectra obtained with the Goddard High Resolution Spectrograph. While agreement between the absolute UV flux of ϵ CMa as measured by *GHR*S and their model atmosphere is found, these fluxes are $\sim 30\%$ higher in the UV than measured by *IUE*, *OAO-2*, and *TD-1*, in excess of the published errors in the absolute calibration of these data. The *IUE* and *TD-1* data appear to have a wavelength independent systematic error in their absolute calibration of 30%. The *OAO-2* data, in agreement with the model's absolute flux between 1200 Å and 2000 Å, lie 30% below the model and *GHR*S fluxes from 2000 Å to 3000 Å, suggesting a relative as well as absolute calibration error in these data. The agreement between the model and the measured EUV flux is a result of the higher temperatures at the formation depths of the H I and He I Lyman continua compared to other models. These higher temperatures increase the level of the EUV continuum and reduce the strength of the 912 Å and 504 Å edges. An important difference between these calculations and previous calculations is the computation of the model atmosphere out to very small optical depths which results in higher temperatures in the EUV continuum forming region.

Supernovae, with their diversity of compositions, velocities, envelope masses, and interactions are good testing grounds for probing the importance of NLTE in expanding atmospheres. In addition to treating H, He, Li I, O I, Ne I, Na I, and Mg II in NLTE, Hauschildt, Baron, Nugent (LBL), and Branch (U. Oklahoma) use a very large model atom of Fe II to test the importance of NLTE processes in both SNe Ia and II. Since the total number of potential line transitions that one has to include is enormous (≈ 40 million), approxi-

mations and simplifications are required to treat the problem accurately and in finite computer time. With a large Fe II model atom (617 levels, 13,675 primary NLTE line transitions) they are able to test several assumptions for treating the background opacity that are needed to obtain correct UV line blanketing which determines the shape of near-maximum light supernova spectra. Due to interactions within the multiplets, treating the background lines as pure scattering (thermalization parameter $\epsilon=0$) is a poor approximation and an overall mean value of $\epsilon \sim 0.05-0.10$ is a far better approximation. This is true even in SNe Ia, where the continuum absorption optical depth at 5000 Å ($\equiv \tau_{std}$) is $\ll 1$. A detailed treatment of NLTE effects is required to properly determine the ionization states of both abundant and trace elements.

Hauschildt, Baron, Nugent, and Branch present NLTE synthetic spectra for the Type Ia supernovae SN 1992A SN 1981B, and SN 1991bg near maximum light. At this epoch both of the normal SNe Ia (SNe 1981b and 1992A) were observed from the UV through the optical. This wide spectral coverage is essential for determining the density structure of a SN Ia. The fits are in good agreement with observation and provide some insight as to the differences between these supernovae. SNe Ia appear to form a spectral sequence which can be understood in terms of their luminosities. They also discuss the application of the spectral fitting expanding atmosphere method (SEAM) to SNe Ia which gives a distance that is independent of those based on the decay of ^{56}Ni and on Cepheid variable stars.

Allard, Hauschildt, Baraffe (CNRS-Lyon), and Chabrier (CNRS-Lyon) present preliminary non-grey model atmospheres and interiors for cool brown dwarfs. The resulting synthetic spectra are compared to available spectroscopic and photometric observations of the coolest brown dwarf yet discovered, Gl229B (Nakajima *et al.* 1995). Despite the grainless nature of the present models, the resulting synthetic spectra provide an excellent fit to most of the spectral features of the brown dwarf. Both the presence of methane absorption and the substellar nature of Gl229B are confirmed. These preliminary models set an upper limit for the effective temperature of 1000 K. The evolution of brown dwarfs with solar composition and masses from 0.02 to 0.065 M_{\odot} was computed. While uncertainties in the age of the system yield some indetermination for the mass of Gl229B, the most likely solution is $m \approx 0.04-0.055 M_{\odot}$. In any case, an upper limit $m = 0.065 M_{\odot}$ can be set for a very unlikely age $t = 10$ Gyr.

Hauschildt, Baraffe, Chabrier, and Allard present new evolutionary calculations for low-mass and very low-mass M-dwarfs, for a metallicity range $-2 \leq [M/H] \leq 0$, down to the hydrogen-burning minimum mass ($0.07 < M/M_{\odot} < 0.6$). The calculations include the best input physics presently available, i.e., equation of state, enhancement of nuclear reaction rates and atmosphere models. The most recent atmosphere models calculated by Allard and Hauschildt (1996) are used, based on *synthetic* spectra at finite metallicity, and grey atmosphere models based on Alexander and Ferguson (1994) Rosseland opacities. Comparisons are made with observational results down to the bottom of the main sequence,

for different metallicities, in a magnitude (M_V) - color ($V-I$) diagram, and in color-color I, J, H, K diagrams. Excellent agreement between theory and observations is found over the whole characteristic temperature/luminosity range. The mass of the faintest objects observed is found to be $m_{lim} \approx 0.085 M_\odot$ for $[M/H]=0$ and -0.5 , and $m_{lim} = 0.09 M_\odot$ for $[M/H]=-1.5$, for an age of 10 Gyrs.

Hauschildt and Serena Viti (UCL) *et al.* compare observations of the binary system CM Draconis with synthetic spectra computed using the stellar atmosphere code PHOENIX. Spectroscopic observations from 0.40 to $2.41 \mu\text{m}$, combined with photometry and the accurately known surface gravity enable them to estimate the temperature and metallicity using detailed spectral synthesis. Discrepancies between the analysis of the infrared and optical spectrum have been found: while the optical spectral energy distribution (SED) yields a metal-rich solution with $T_{\text{eff}}=3000$ K, the infrared SED yields $-0.8 \leq [M/H] \leq -0.6$, compatible with the high space motion of the system. The low-metallicity characteristics of the infrared SED could be real and is partly supported by a detailed analysis of the atomic lines in the optical region. However, the known incompleteness of the TiO and H_2O line lists in the models used as well as problems with the observational data will cause systematic errors.

Hauschildt, Allard, Alexander (Wichita St.), Schweitzer (LSU-Heidelberg), and Baron continue their work on the atmospheres of M dwarfs. The atmospheres of M stars are dominated by a small number of very strong molecular compounds (H_2O , TiO, H_2 , CO, VO). Most of the hydrogen is locked in molecular H_2 , most of the carbon in CO; and H_2O , TiO and VO opacities define a pseudo-continuum covering the entire flux distribution of these stars. The optical "continuum" is due to TiO vibrational bands which are often used as temperature indicators for these stars. These may be the depth of the bands relative to the troughs in between them; or the depth of the VO bands; or of the atomic lines relative to the local "continuum"; or even the strength of the infrared water bands; all of these depend on the strength of the TiO bands and the amount of flux-redistribution to longer wavelengths produced by them. Departures from LTE of the Ti I atom, and thus the concentration of the important TiO molecule, could, therefore, have severe and measurable consequences on the atmospheric structure and spectra of these stars. Hauschildt *et al.* discuss NLTE effects of Ti I in fully self-consistent models for a few representative M/Brown dwarf and M giant model atmospheres and spectra.

Shaw and Nicol have obtained a solution to the eclipsing binary HL Aurigae from observations in the Washington system (CMVT1T2) taken at the University of Georgia observatory. They also have a preliminary solution of XX Leonis.

Shaw, Dittmann (DeKalb) and Mysore observed the open cluster NGC 1342 photometrically at the SARA Observatory in the hopes of finding close binary stars. The data are in the preliminary stages of reduction and an additional run at the SARA 0.9m is scheduled for November 1997.

Magnani, D. Hartmann (CfA), and P. Thaddeus (CfA) continue their study of the "X-factor," the ratio of the molecular hydrogen column density to the velocity-integrated CO($J=1-0$) antenna-temperature, in translucent molecular

clouds. Their current effort focusses on the variation of the X-factor from position to position in particular translucent clouds. The two clouds which have been studied thus far, MBM40 and MBM16, show markedly different behavior: The X-factor tends to vary significantly from position to position in MBM16 but not in MBM40. This variation may be due to the CO(1-0) integrated antenna temperature being a poor tracer of H_2 in low-column density regions.

Magnani, Hartmann, and Thaddeus continue their survey for high-latitude molecular gas. The entire northern Galactic hemisphere has been sampled in a locally-cartesian $1 \text{ deg} \times 1 \text{ deg}$ grid. A total of only 23 detections have been made in the North, underscoring the paucity of molecular gas at $b \geq 30^\circ$. A similar survey of the Southern Galactic hemisphere has recently been completed and analysis is underway.

PUBLICATIONS

- The publication list includes all papers published or submitted between October 1996 and October 1997 by the staff.
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