

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

[S0002-7537(93)04431-2]

The following report covers the Department activities from October 1999 through October 2000.

1. PERSONNEL

Department members participating in astrophysics or astronomy research or instruction were Professors J. Scott Shaw and Jean-Pierre Caillault, Associate Professor Loris Magnani, Assistant Professors Peter Hauschildt and Phillip Stancil, postdoctoral fellows Ian Short and Andreas Schweitzer, and graduate students Inseok Song, Travis Barman, Mariam Dittmann, Ray Chastain, and Larry Solanch. Undergraduate student Martha Boyer from the University of Minnesota spent the summer as an NSF REU intern working with Shaw. Song received the PhD degree for his dissertation titled: "The Ages and Evolution of Vega-like Stars" and moved to a postdoctoral position at UCLA. The dissertation was directed by Caillault. Barman attended the NASA Summer School for High Performance Computing for Earth and Space Sciences at the Goddard Space Flight Center, Maryland. Short moved to a faculty position at Florida Atlantic University in Boca Raton.

2. FACILITIES

The University of Georgia is a member of the Southeastern Association for Research in Astronomy (SARA), a consortium of six south-eastern universities (Clemson, East Tennessee State University, the Florida Institute of Technology, Florida International University, Valdosta State University and the University of Georgia). The consortium operates a 0.9-m telescope on Kitt Peak. This telescope is now completely functional with a CCD camera. Some remote observing programs have commenced and robotic operation is currently underway. In addition, the consortium also operates a summer NSF REU program.

The astronomy group at the University of Georgia has numerous SUNs, Alphas, HPs, and IBM workstations, and numerous smaller machines available for data processing and computation. In addition, a 0.6-m Cassegrain telescope is available on the roof of the Physics Building for teaching and public nights. This telescope has been equipped with UVBRI filters, and an Axiom CCD for student research.

3. RESEARCH

D. R. Schultz (Oak Ridge) and Stancil surveyed the atomic and molecular collision literature for the period 1996-1999 for Commission 14 of the International Astronomical Union. The survey concentrated on advances in the calculation or measurement of those processes most relevant to astrophysical and atmospheric environments including collisions among electrons, atoms, ions, and molecules. The

project was complementary to the primary focus of the authors' efforts in providing accurate atomic and molecular collision calculations for modeling needs.

Stancil, K. Kirby (CfA), J.-P. Gu (Wuppertal), J. Hirsch (Wuppertal), R. J. Buenker (Wuppertal), and Sannigrahi (Kharagpur) performed quantum-mechanical calculations of the formation of molecular ions by the process of radiative association. They investigated the molecular ions SiH^+ , PH^+ , and SH^+ which may be of relevance to the modeling of diffuse and translucent interstellar clouds. The rate coefficient for the formation of SiH^+ was found to be comparable to that for CH^+ and an order of magnitude larger than the rate coefficient for SiH_2^+ . However, the rate coefficients for PH^+ and SH^+ formation were calculated to be at least an order of magnitude smaller than for PH_2^+ and SH_2^+ formation, respectively. The reverse process of photodissociation will be investigated for these molecules and others in the future.

Stancil, Schultz, Kimura (Yamaguchi), Gu, Hirsch, and Buenker using a variety of theoretical approaches computed the cross sections and rate coefficients for total and fine-structure resolved charge transfer in collisions of O^+ with H and H^+ with O. The calculations covered the energy range 0.1 meV/u to 10 MeV/u and the temperature range 10 K to 10^7 K. The rate coefficients were found to be a factor of two larger than earlier estimates at 10,000 K and may have a significant effect on the oxygen ionization balance in photoionized nebulae models. Because of the large abundances of hydrogen, oxygen, and their ions and the efficiencies of their charge transfer reactions, the processes are also important for the oxygen chemistry in interstellar clouds, for neutral interstellar oxygen penetration into the heliosphere, and for energetic oxygen ion precipitation into the Jovian atmosphere. Other ion-atom and ion-molecule charge transfer collisions of astrophysical and atmospheric relevance are currently being investigated.

Stancil, S. Lepp (UNLV), A. Dalgarno (CfA), T. Abel (CfA), and Schultz are extending their work on the chemistry of the early Universe to the study of the formation of the first proto-galaxies. The production of molecules and their effect on the cooling are being studied for various hydrodynamic evolution scenarios. The most accurate chemical, collisional, and cooling data, some computed when lacking in the literature, are being incorporated.

Schweitzer, Hauschildt and E. Baron (Oklahoma) are investigating a technique to treat systems with very many quantum levels, like molecules, in non-LTE. This method is based on a superlevel formalism coupled with rate operator splitting. Superlevels consist of many individual levels that are assumed to be in LTE relative to each other. The usage of superlevels reduces the dimensionality of the rate equations dramatically and thereby makes the problem computationally more tractable. The superlevel formalism retains maximum accuracy by using direct opacity sampling (dOS) when cal-

culating the radiative transitions and the opacities. This method has been developed in order to treat molecules in cool dwarf model calculations in non-LTE. Cool dwarfs have low electron densities and a radiation field that is far from a black body radiation field, so that the conditions for the common LTE approximation may be invalidated. Therefore, the most important opacity sources, the molecules, need to be treated in non-LTE. As a case study their method was applied to carbon monoxide. The technique gives accurate results since the conditions for the superlevel method are very well met for this molecule. Due to very high collisional cross sections with hydrogen and the high densities of H_2 , the population of CO itself shows no significant deviation from LTE.

Schweitzer, J.Krautter (LSW, Heidelberg), S. Wagner (LSW, Heidelberg), I. Appenzeller (LSW, Heidelberg) and the FORS team (ESO) presented deep I band imaging of the globular cluster M4. This object is the closest globular cluster and has the second smallest distance modulus. It is a perfect target to study the lower main sequence. The observations were carried out with FORS1 on the VLT. With half a night on that telescope the team obtained the deepest images ever taken of M4. The images contain the only homogeneous sample of stars reaching the faintest region of the main sequence. These results indicate the end of the main sequence to be at $I=13.1 \pm 1.0$.

W. Brandner (IA Hawaii), H. Zinnecker (AIP Potsdam), J. M. Alcalá (OAC Napoli), F. Allard (CRAL, Lyon), E. Covino (OAC Napoli), S. Frink (UCSD), R. Köhler (AIP Potsdam), M. Kunkel (Würzburg), A. Moneti (ISO-SOC Vilspa) and Schweitzer have made high-spatial resolution HST and ground-based adaptive optics observations, and high-sensitivity ISO (ISOCAM & ISOPHOT) observations of a sample of X-ray selected weak-line (WTTS) and post (PTTS) T Tauri stars located in the nearby Chamaeleon T and Scorpius-Centaurus OB associations. HST/NICMOS and adaptive optics observations aimed at identifying substellar companions (young brown dwarfs) at separations ≥ 30 AU from the primary stars. No such objects were found within 300 AU of any of the target stars, and a number of faint objects at larger separations can very likely be attributed to a population of field (background) stars. ISOCAM observations of 5 to 15 Myr old WTTS and PTTS in ScoCen reveal infrared excesses which are clearly above photospheric levels, and which have a spectral index intermediate between that of younger (1 to 5 Myr) T Tauri stars in Chamaeleon and that of pure stellar photospheres. The difference in the spectral index of the older PTTS in ScoCen compared to the younger classical and weak-line TTS in Cha can be attributed to a deficiency of smaller size (0.1 to 1 μm) dust grains relative to larger size ($\approx 5 \mu\text{m}$) dust grains in the disks of the PTTS. The lack of small dust grains is either due to the environment (effect of OB stars) or due to disk evolution. If the latter is the case, it would hint that circumstellar disks start to get dust depleted at an age between 5 to 15 Myr. Dust depletion is very likely related to the build-up of larger particles (ultimately rocks and planetesimals) and thus an indicator for the onset of the period of planet formation.

Hauschildt, G. Chabrier (CRAL Lyon), I. Baraffe (CRAL

Lyon), and Allard consider the depletion of primordial deuterium in the interior of substellar objects as a function of mass, age, and absolute magnitude in several photometric passbands and characterize potential spectroscopic signatures of deuterium in the lines of deuterated water. These results will serve as a useful, independent diagnostic to characterize the mass and/or the age of young substellar objects and to provide an independent age determination of very young clusters. These results can serve to identify objects at the deuterium-burning limit and to confront the theoretical prediction that D burning is a necessary condition to form star-like objects.

Hauschildt and J.A. Orosz (Penn State) have written a light curve synthesis code that makes direct use of model atmosphere specific intensities, in particular the NextGen model atmosphere grid for cool giants ($T_{eff} \leq 6800$ K and $\log(g) \leq 3.5$). These models (computed using spherical geometry) predict a limb darkening behavior that deviates significantly from a simple linear or two-parameter law (there is less intensity at the limb of the star). The presence of a significantly nonlinear limb darkening law has two main consequences. First, the ellipsoidal light curve computed for a tidally distorted giant using the NextGen intensities is in general different from the lightcurve computed using the same geometry but with the black body approximation and a one- or two-parameter limb darkening law. In most cases the light curves computed with the NextGen intensities have deeper minima than their black body counterparts. Thus, the light curve solutions for binaries with a giant component obtained with models with near linear limb darkening (either black body or plane-parallel model atmosphere intensities) are biased. Observations over a wide wavelength range (i.e., both the optical and infrared) are particularly useful in discriminating between models with nearly linear limb darkening and the NextGen models. Second, rotational broadening kernels for Roche lobe filling (or nearly filling) giants can be significantly different from analytic kernels due to a combination of the nonspherical shape of the star and the radical departure from a simple limb darkening law. As a result, geometrical information inferred from $V_{rot} \sin i$ measurements of cool giants in binary systems are likewise biased.

Hauschildt, S. Leggett (Hawaii), Allard, T. Geballe (Gemini) and Schweitzer have obtained 1.0-2.5 μm spectra at $R \sim 600$ of 14 disk dwarfs with spectral types M6 to L7. For four of the dwarfs they have also obtained infrared spectra at $R \sim 3000$ in several narrow intervals. In addition, new L' photometry for four of the dwarfs in the sample allows improved determinations of their bolometric luminosities. While obtaining the photometry the L-dwarf DBD 0205-1159 was resolved into an identical pair of objects separated by 0.35". The spectra, together with the published energy distribution for one other L5 dwarf, are compared to synthetic spectra generated by upgraded model atmospheres. Good matches are found for $2200 \text{ K} \geq T_{eff} \geq 1900 \text{ K}$ (spectral types around M9 to L3), but discrepancies exist at $T_{eff} \approx 2300 \text{ K}$ (M8) and for $T_{eff} \leq 1800 \text{ K}$ (L5-L7). At the higher temperatures the mismatches are due to incompleteness in the water vapor opacity linelist. At the lower temperatures the disagreement is probably due to dust: a photo-

spheric distribution in equilibrium with the gas phase is assumed and any diffusion mechanisms are neglected. Despite these discrepancies, effective temperatures for the sample to ± 100 K are derived, and diameters to 15%. Agreement with structural models using non-grey atmospheres is reasonable, and agreement with other temperature determinations is also reasonable, except for the coolest objects.

Hauschildt, D.K. Lowenthal (Oklahoma), and Baron present spectral analysis of early observations of the Type II supernova 1998S using the general non-local thermodynamic equilibrium spectral code PHOENIX. They model both the underlying supernova spectrum and the overlying circumstellar interaction region and produce spectra in good agreement with observations. The early spectra are well fit by lines produced primarily in the circumstellar region itself, and later spectra are due primarily to the supernova ejecta. Intermediate spectra are affected by both regions. A mass-loss rate of order $0.0001 - 0.001 M_{\odot} \text{ yr}^{-1}$ is inferred for a wind speed of $100 - 1000 \text{ km s}^{-1}$.

Hauschildt, E.J. Lentz (Oklahoma), Baron, and D. Branch (Oklahoma) have studied SN 1984A which shows unusually large expansion velocities in lines from freshly synthesized material, relative to typical Type Ia Supernovae (SNe Ia). SN 1984A is an example of a group of SNe Ia which have very large blue-shifts of the P-Cygni features, but otherwise normal spectra. They have modeled several early spectra of SN 1984A with the multi-purpose NLTE model atmosphere and spectrum synthesis code, PHOENIX. As input, two delayed detonation models, CS15DD3 (Iwamoto *et al.* 1999) and DD21c (Höflich *et al.* 1998), have been used. These models show line expansion velocities which are larger than that for a typical deflagration model like W7, which fit the spectra of normal SNe Ia quite well. These delayed detonation models are reasonable approximations to large absorption feature blue-shift SNe Ia, like SN 1984A. Higher densities of newly synthesized intermediate mass elements at higher velocities, $v > 15000 \text{ km s}^{-1}$, are found in delayed detonation models than in deflagration models. This increase in density at high velocities is responsible for the larger blue-shifts in the synthetic spectra. Moreover, the variations in line width in observed SNe Ia are likely due to density variations in the outer, high-velocity layers of their atmospheres.

Hauschildt, Chabrier, Baraffe, and Allard present evolutionary calculations for very-low-mass stars and brown dwarfs based on synthetic spectra and non-grey atmosphere models which include dust formation and opacity, i.e., objects with $T_{eff} < 2800$ K. The interior of the most massive brown dwarfs is shown to develop a conductive core after 2 Gyr which slows down their cooling. Comparison is made in optical and infrared color-magnitude diagrams with recent late-M and L-dwarf observations. The saturation in optical colors and the very red near-infrared colors of these objects are well explained by the onset of dust formation in the atmosphere. Comparison of the faintest presently observed L-dwarfs with these dusty evolutionary models suggests that dynamical processes such as turbulent diffusion and gravitational settling are taking place near the photosphere. As the effective temperature decreases below $T_{eff} \approx 1300\text{-}1400$ K,

the colors of these objects move to very blue near-infrared colors, a consequence of the ongoing methane absorption in the infrared. This suggests the possibility of a brown dwarf gap in J; H; K color-magnitude diagrams around this temperature.

Hauschildt and Baron have calculated fast direct spectral model fits to two early-time spectra of SN 1999em, using the SYNOW synthetic spectrum code. The first is an extremely early blue optical spectrum and the second a combined HST and optical spectrum obtained one week later. Spectroscopically, this supernova appears to be a normal Type II and these fits are in excellent agreement with the observed spectra. Direct analysis suggests the presence of enhanced nitrogen. Studies of these spectra with the full NLTE general model atmosphere code PHOENIX cannot confirm enhanced nitrogen (nor rule it out), but they do require enhanced helium. An even more intriguing possible line identification is complicated by Balmer and He I lines, which fall naturally out of the detailed calculations with a shallow density gradient. Very early spectra combined with sophisticated spectral modeling allow an independent estimate of the total reddening to the supernova, since, when the spectrum is very blue, dereddening leads to changes in the blue flux that cannot be reproduced by altering the ‘‘temperature’’ of the emitted radiation. These results are extremely encouraging since they imply that detailed modeling of early spectra can shed light on both the abundances and total extinction of SNe II, the latter improving their utility and reliability as distance indicators.

Hauschildt, Chabrier, Baraffe, and Allard present evolutionary calculations for very-low-mass stars and brown dwarfs based on synthetic spectra and non-grey atmosphere models which include dust formation and opacity, i.e., objects with $T_{eff} \leq 2800$ K. The interior of the most massive brown dwarfs is shown to develop a conductive core after ~ 2 Gyr which slows down their cooling. Comparison is made in optical and infrared color-magnitude diagrams with late-M and L-dwarf recent observations. The saturation in optical colors and the very red near-infrared colors of these objects are well explained by the onset of dust formation in the atmosphere. Comparison of the faintest presently observed L-dwarfs with these dusty evolutionary models suggests that some grains have already started to settle below the photosphere, yielding bluer colors as the effective temperature decreases, a consequence of the ongoing methane absorption in the infrared.

Hauschildt, Allard, and D. Schwenke (Ames) compare the structures of model atmospheres and synthetic spectra calculated using different line lists for TiO and water vapor. The effects of different line list combinations on the model structures and spectra for both dwarf and giant stars are examined. It is shown that recent improvements result in significantly improved spectra, in particular in the optical where TiO bands are important. The water vapor dominated near-IR region remains problematic as the current water line lists do not yet completely reproduce the shapes of the observed spectra. The AMES TiO list provides more opacity in most bands and the new, smaller oscillator strengths lead to systematically cooler temperatures for early type M dwarfs

than previous models. These effects combine and will help to significantly improve the fits of models to observations in the optical as well as result in improved synthetic photometry of M stars.

Hauschildt, A. Hui-Bon-Hoa and F. LeBlanc (Moncton) are investigating the effects of diffusion in the atmospheres of hot horizontal-branch stars using a model atmosphere code which includes diffusion self-consistently. Equilibrium stratifications (i.e., for which the diffusion velocity equals zero in each layer) are computed for models of effective temperatures between 10,000 and 25,000 K. The stratified models provide much better agreement with many observational features (jump in the (u; u-y) color-magnitude diagram, gaps, lower spectroscopic gravities) in comparison with classical horizontal-branch models. The observed abundance anomalies are also consistent with the amounts that can be supported in the atmospheres. Diffusion could then play an important role in the so-called second parameter effect.

Hauschildt, Allard, and Schweitzer have calculated a grid of spherically symmetric model atmospheres for young pre-MS stars. This grid spans the parameter range $2000 \text{ K} \leq T_{\text{eff}} \leq 6800 \text{ K}$ and $2.0 \leq \log(g) \leq 3.5$ for $M=0.1 M_{\odot}$, appropriate for low mass stars and brown dwarfs. A major improvement is the replacement of TiO and H₂O line lists with the newer line list calculated by the NASA-AMES group, for TiO (about 175 million lines of 5 isotopes) and for H₂O (about 350 million lines in 2 isotopes). The model structures, spectra and broad-band colors in standard filters are provided in electronic form.

Hauschildt, Allard, J. Ferguson (Wichita), Baron, and D.R. Alexander (Wichita) have completed the extension of the NextGen model atmosphere grid to the regime of giant stars. The input physics of the models is nearly identical to the NextGen dwarf atmosphere models, however, spherical geometry is used self-consistently in the model calculations (including the radiative transfer). The authors re-visit the discussion of the effects of spherical geometry on the structure of the atmospheres and the emitted spectra and investigate the results of NLTE calculations for a few selected models.

Hauschildt, Barman, Short and Baron calculated a grid of NLTE line-blanketed model atmospheres for white dwarfs in cataclysmic variable (CV) systems using the stellar atmosphere code PHOENIX. The grid covers the temperature range 20,000 K to 500,000 K for solar abundances of 10^{-2} and 10^{-4} for metals. The effective temperature resolution is 10,000 K in the range of 20,000 K to 200,000 K and is 20,000 K in the range of 200,000 K to 500,000 K. The models include a large number of NLTE levels for light metals such as CNO and heavy metals such as Ni and Fe. The necessity of using self-consistent NLTE line-blanketed model atmospheres for the analysis of white dwarfs is well known and re-affirmed. The authors discuss the importance of metal opacity, especially metals heavier than Ca, in the atmospheres of CV primaries. They also compare the grid to previously published models and discuss the general improvements offered by their models. In addition, a specific model from the grid is compared to an HST observation of U Gem and predictions for FUSE observations are made.

Hauschildt, G.J. Schwarz (Arizona State), S. Starrfield (Arizona State), Baron, Allard, S.N. Shore (Indiana, South Bend), and P. Whitelock (SAAO) have studied LMC 1988 #1, a slow, CO type, dust forming classical nova; the first extragalactic nova to be observed with the IUE satellite. They have successfully fitted 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. The bolometric luminosity of LMC 1988 #1 was approximately constant at $2 \times 10^{38} \text{ ergs s}^{-1}$ at a distance of 47.3 kpc for the first 2 months of the outburst until the formation of the dust shell.

Hauschildt, J.P. Aufdenberg (Arizona State), Shore, and Baron successfully reproduce the 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 the star from 350 Å to 25 μm is best fit with model parameters $T_{\text{eff}} = 21750 \text{ K}$, $\log(g) = 3.2$, and an angular diameter of 0.77 mas. Their model predicts a hydrogen ionizing flux, q_0 , of $1.59 \times 10^{21} \text{ photons cm}^{-2} \text{ s}^{-1}$ 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 is found between the absolute UV flux of ϵ CMa as measured by *GHR*S and the model atmosphere, these fluxes are ~30% higher in the UV than measured by *IUE*, *OA*O-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 *OA*O-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 ones is the computation of the model atmosphere out to very small optical depths which results in higher temperatures in the EUV continuum forming region.

Hauschildt, Leggett, and Allard present new infrared JHK photometry for 61 halo and disk stars around the stellar/substellar boundary. In addition, new L' photometry for 21 of these stars and for 40 low-mass stars taken from the Leggett 1992 photometry compilation was obtained. These data are combined with available optical photometry and astrometric data to produce color-color and absolute magnitude-color diagrams — the current sample extends the

similar work presented in the 1992 paper into more metal-poor and lower mass regimes. The disk and halo sequences are compared to the predictions of the latest model atmospheres and structural models. Good agreement between observation and theory is found except for known problems in the V and H passbands probably due to incomplete molecular data for TiO, metal hydrides and H₂O. The metal-poor M subdwarfs are well matched by the models as oxide opacity sources are less important in this case. The known extreme M subdwarfs have metallicities about one-hundredth solar, and the coolest subdwarfs have $T_{eff} \sim 3000$ K with masses $\sim 0.09 M_{\odot}$. The grainless models are not able to reproduce the flux distributions of disk objects with $T_{eff} < 2500$ K. However, a preliminary version of the NextGen-Dusty models which includes homogeneous formation and extinction by dust grains is able to match the colors of these very cool objects. The least luminous objects in this sample are GD165B, three DENIS objects — DBD0205, DBD1058 and DBD1228 — and Kelu-1. These have $T_{eff} \sim 2000$ K and are at or below the stellar limit with masses $\leq 0.075 M_{\odot}$. Photometry alone cannot constrain these parameters further as the age is unknown, but published lithium detections for two of these objects (Kelu-1 and DBD1228) imply that they are young (aged about 1 Gyr) and substellar (mass $\leq 0.06 M_{\odot}$).

Hauschildt, S.L. Pistinner (Bar Sheba), D. Eichler (Bar Sheba), and Baron calculated a grid of spherically symmetric OB stellar atmospheres at low metallicities, including both non-local thermodynamic equilibrium (NLTE) and metal line blanketing effects. This is done to assess the uncertainties in helium abundance determination by nebular codes due to input stellar atmosphere models. The more sophisticated stellar atmosphere models they use can differ from LTE models by as much as 40 percent in the ratio of He- to H-ionizing photons.

Hauschildt, Shahbaz (Oxford), and Naylor (Oxford) obtained high resolution echelle spectroscopy of the recurrent nova T CrB. They compared the surface abundance of Li in T CrB with field M-stars and find it to be somewhat below solar, whereas in the M3III field stars it is non-existent. Possible explanations for this include a delay in the onset of convection in the giant star, enhanced coronal activity due to star-spots or the enhancement of Li resulting from the nova explosion.

Hauschildt, G. Basri (California, Berkeley), S. Mohanty (California, Berkeley), Allard, X. Delfosse (Grenoble), E. Martin (IAC, Tenerife), T. Forveille (Grenoble), and B. Goldman (Saclay) have obtained Keck HIRES spectra of 6 late-M dwarfs and 11 L dwarfs. The goal of the project is to assign effective temperatures to the objects using detailed atmospheric models and fine analysis of the alkali resonance absorption lines of Cs I and Rb I. These yield mutually consistent results when “cleared-dust” models are used, which account for the removal of refractory species from the molecular states but do not include dust opacities. A tendency for the Rb I line to imply a slightly higher temperature is found, and ascribed to an incomplete treatment of the overlying molecular opacities. This work, in combination with results from the infrared, hints that dust in these atmospheres

has settled out of the high atmosphere but is present in the deep photosphere. They also derive radial and rotational velocities for all the objects, finding that the previously discovered trend of rapid rotation for very low mass objects is quite pervasive.

Song, Caillault, D. Barrado y Navascués (MPIfA), J. Stauffer (CfA), and S. Randich (Arcetri Obs.) have determined ages of eight late spectral type Vega-like stars through standard age dating techniques for late-type field stars (location on the color-magnitude diagram with theoretical isochrones, Li 6708Å absorption strength, CaII H&K, X-ray, $v \sin i$, kinematic population, etc.). With the exception of the very unusual pre-main sequence star system HD 98800, all seven Vega-like stars are the same age as the Hyades cluster or older.

Song, Caillault, Barrado y Navascués (MPIfA), and Stauffer (CfA) have estimated the ages of a sample of A-type Vega-like stars by using Stromgren uvby β photometric data and theoretical evolutionary tracks. Thirteen percent of these A-stars have been reported as Vega-like stars in the literature and the ages of this subset run the gamut from very young (50 Myr) to old (1Gyr), with no obvious age difference compared to those of field A-stars. It is clearly shown that the fractional IR luminosity decreases with the ages of Vega-like stars.

Song, Caillault, Barrado y Navascués, Stauffer, P. Arty-mowicz (Stockholm Observatory, Sweden), and D. Backman (Franklin & Marshall College) have shown that Vega-like stars can be divided into two groups, those with a high dust content and those with a low dust content. Stars in the former group contain warm dust and show a mid-IR excess and stars in the latter group have cold dust and show a FIR excess. Two models, the “dust avalanche model” and the “giant gas planet’s gravitational influence model,” are offered as possible explanations of this observed bi-modality.

Magnani and Chastain have begun a project to study the gas-to-dust ratio at high Galactic latitudes. The column density of gas will be determined from the high-latitude CO survey described above and from the Leiden-Dwingeloo 21 cm survey by Hartmann and Burton. The dust content will be derived from IRAS 60 and 100 μ m data.

Magnani and Solanch are studying the possibility that molecular gas may form in the Galaxy at high-z, at the top of the Galactic “worms” or “chimneys” identified in HI.

Shaw and Dittmann continue their work on detection of close binary stars in open clusters.

PUBLICATIONS

The publication list includes all papers published or submitted between October 1999 and October 2000 by the staff. Alibert, Y., Baraffe, I., **Hauschildt, P.**, & Allard, F. 1999, “Period – luminosity – color – radius relationships of Cepheids as a function of metallicity: evolutionary effects, AAp, 344, 551
Allard, F., **Hauschildt, P.** & **Schweitzer, A.** 2000, “Spherically symmetric model atmospheres for low mass pre-Main Sequence stars with effective temperatures between 2000 and 6800 K,” ApJ, 541, 1004

- Allard, F., **Hauschildt, P.**, & Schwenke, D. 2000, "TiO and H₂O absorption lines in cool stellar atmospheres," ApJ, in press
- Aufdenberg, J. P., **Hauschildt, P.**, & Baron, E. 1999, "A Non-LTE Line-Blanketed Stellar Atmosphere Model for the Early B Giant β Cma," MNRAS, 302, 599
- Barman, T.S., Hauschildt, P.H., Short, C.I.**, & Baron, E. 2000, "A Grid of Non-LTE Model Atmospheres for White Dwarfs in Cataclysmic Variables," ApJ, 537, 946
- Baron, E., Branch, D., **Hauschildt, P.**, Filippenko, A. V., & Kirshner, R. P. 1999, "Spectral Models of the Type Ic SN 1994I in M51," ApJ, 527, 739
- Barrado y Navascués, D., Stauffer, J., **Song, I.**, & **Caillault, J.-P.** 1999, "The Age of β Pictoris," ApJ, 520, L123
- Basri, G., Mohanty, S., Allard, F., **Hauschildt, P.**, Delfosse, X., Martin, E.L., Forveille, T., & Goldman, B. 2000, "An Effective Temperature Scale for Late M and L Dwarfs, from Resonance Absorption Lines of Cs I and Rb I," ApJ, in press
- Beuermann, K., Baraffe, I., & **Hauschildt, P.** 1999, "Barnes-Evans relations for late-type giants and dwarfs," AAp, 348, 524
- Brandner, W., Zinnecker, H., Alcalá, J. M., Allard, F., Covino, E. Frink, S., Köhler, R., Kunkel, M., Moneti, A., & **Schweitzer, A.**, 2000, "Timescales of Disk Evolution and Planet Formation: HST, Adaptive Optics, and ISO Observations of Weak-Line and Post-T Tauri Stars," AJ, 120, 950
- Chabrier, G., Baraffe, I., Allard, F., & **Hauschildt, P.** 2000, "Evolutionary models for very-low-mass stars and brown dwarfs with dusty atmospheres," ApJ, in press
- Chabrier, G., Baraffe, I., Allard, F., & **Hauschildt, P.** 2000, "Deuterium burning in sub-stellar objects," ApJL, in press
- Ferguson, J. W., Alexander, D. R., Johnson, H. R., Allard, F., & **Hauschildt, P.** 1999, "PAHs & Grains in Carbon-rich Stellar Atmospheres," ApJ, submitted
- Hauschildt, P.** & Baron, E. 1999, "Numerical Solution of the Expanding Stellar Atmosphere Problem," Journal of Computational and Applied Mathematics, 109, 41
- Hauschildt, P.**, Allard, F., & Baron, E. 1999, "The NextGen Model Atmosphere grid for $3000 \leq T_{\text{eff}} \leq 10000$ K," ApJ, 512, 377
- Hauschildt, P.**, Allard, F., Ferguson, J., Baron, E., & Alexander, D. R. 1999, "The NextGen Model Atmosphere grid: I. Spherically symmetric model atmospheres for giant stars with effective temperatures between 3000 and 6800 K," ApJ, 525, 871
- Hauschildt, P.** 2000, "Cool Stellar Atmospheres," Encyclopedia of Astronomy and Astrophysics," in press
- Hui-Bon-Hoa, A., LeBlanc, F., & **Hauschildt, P.** 2000, "Diffusion in the Atmospheres of Blue Horizontal-Branch Stars," ApJL, 535, L43
- Leinert, C., Allard, F., Richichi, A., & **Hauschildt, P.** 2000, "The multiple system LHS 1070: a case study for the onset of dust formation in the atmospheres of very low mass stars," AAp, 353, 691
- Leggett, S.K., Allard, F., Dahn, C., **Hauschildt, P.**, Kerr, T.H., & Rayner, J. 2000, "Spectral Energy Distributions for Disk and Halo M-Dwarfs," ApJ, 535, 965
- Lenz, E. J., Baron, E., Branch, D., & **Hauschildt, P.**, Nugent, P. E. 1999, "Metallicity Effects in NLTE Model Atmospheres of Type Ia Supernovae," ApJ, 530, 966
- Magnani, L.**, Hartmann, D., S.L. Holcomb, L.E. Smith, & Thaddeus, P. 2000, "A Survey of High-Latitude Molecular Gas in the Southern Galactic Hemisphere," ApJ, 535, 167
- Martini, P., Wagner, R. M., Tomaney, A., Rich, R. M., Della Valle, M., & **Hauschildt, P.** 1999, "Nova Sagittarii 1994 #1 (V4332 Sagittarii): The Discovery and Evolution of an Unusual Luminous Red Variable Star," AJ, 118, 1034
- Micela, G., Sciortino, S., Harnden, F.R., Jr., Kashyap, V., Prosser, C.F., Damiani, F., Stauffer, J., & **Caillault, J.-P.** 1999, "Deep ROSAT HRI Observations of the Pleiades," AAp, 341, 751
- Orosz, J. A. & **Hauschildt, P.** 2000, "The use of the Next-Gen model atmospheres for cool giants in a light curve synthesis code," AAp, in press
- Pistinner, S. L., **Hauschildt, P.**, Eichler, D., & Baron, E. 1999, "Spectroscopy Of Low Metallicity Giant H II Regions: A grid of low Metallicity Stellar atmospheres," MNRAS, 302, 684
- Pistinner, S. L., **Hauschildt, P.**, Eichler, D., & Baron, E. 1999, "On The Primordial Helium Abundance And Spectroscopic Uncertainties," Israel Rev. Phys., in press
- Schultz, D.R. & **Stancil, P.C.** 1999, "International Astronomical Union, Commission 14: Atomic and Molecular Data, Working Group 3: Collision Processes," Reports on Astronomy, XXIVA, 13
- Schwarz, G. J., **Hauschildt, P.**, Starrfield, S., Whitelock, P. A., Baron, E., & Sonneborn, G. 1999, "A multiwavelength study of the early evolution of the classical nova LMC 1988 #1," MNRAS, in press
- Schweitzer, A.**, Scholz, R.-D., Stauffer, J., Irwin, M. & McCaughrean, M.J. 1999, "APMPM J0559-2903: The coolest extreme subdwarf known," AAp, 350, L60
- Schweitzer, A.** Scholz, R.-D., Irwin, I., Ibata, R., Stauffer, J., McCaughrean, M.J. & Zinnecker, H. 1999, "Nearby late type dwarfs discovered by a new high proper motion survey," in *Proceedings of NASA Ames Nearby Stars Workshop*, Backmann, D. & Henry, T. (eds.), in press
- Schweitzer, A., Hauschildt, P.H.**, & Baron, E., 2000, "Non-LTE Treatment of Molecules in the Photospheres of Cool Stars," ApJ, 541, 1004
- Shabaz, T., **Hauschildt, P.**, Naylor, T., & Ringwald, F. 1999, "On the abundance of Lithium in T CrB," MNRAS, 306, 675
- Shaw, J.S.**, Ragona, T., & McCook, G. 1999, "A Preliminary Solution for the Eclipsing Binary RZ Dra," IAPPP Communications, 73, 117
- Short, C.I.**, & Byrne, P.B., 1999, in *Proceedings of Solar and Stellar Activity: Similarities and Differences*, ASP Conference Series 158, C.J. Butler and J.G. Doyle, eds. (San Francisco: ASP), p. 311
- Short, C. I., Hauschildt, P.**, & Baron, E. 1999, "Massive Multi-species, Multi-level NLTE Model Atmospheres for Novae in Outburst," ApJ, 525, 375
- Short, C.I., Hauschildt, P.**, Starrfield, S., & Baron, E. 2001,

- “Non-LTE Modeling of Nova Cygni 1992,” ApJ, in press
- Song, I., Caillault, J.-P.**, Barrado y Navascués, D., Stauffer, J., & Randich, S. 2000, “Ages of Late Spectral Type Vega-Like Stars,” ApJ, 533, L41
- Song, I., Caillault, J.-P.**, Barrado y Navascués, D., & Stauffer, J., “Ages of A-type Vega-like Stars from uvby β Photometry,” ApJ, 546, in press (Jan. issue, 2001).
- Stancil, P.C.**, Kirby, K., Gu, J.-P., Hirsch, G. Buenker, R.J., & Sannigrahi, A.B. 2000, “The Formation of SiH⁺, PH⁺, and SH⁺ by Radiative Association,” AApS, 142, 107
- Stancil, P.C.**, Schultz, D.R., Kimura, M., Gu, J.-P., Hirsch, G., & Buenker, R.J. 1999, “Charge Transfer in Collisions of O⁺ with H and H⁺ with O,” AApS, 140, 225
- Verter, F., **Magnani, L.**, Dwek, E., & Rickard, L.-J. 2000, “Infrared Properties of Molecular Cirrus. II. Cloud-to-Cloud Variations in Graphite and PAH Content,” ApJ, 536, 831
- Wichmann, R., Covino, E., Alcalá, J. M., Krautter, J., Allain, S., & **Hauschildt, P.** 1999, “High-resolution spectroscopy of ROSAT-discovered WTTs near Lupus,” MNRAS, 307, 909

L. Magnani