FUSE Observations of Galactic and LMC Novae in Outburst
Final Report—Summary of Research

P. H. Hauschildt
5/1/00 – 4/30/01
University of Georgia
Dept. of Physics and Astronomy
Athens, GA 30602-2451
NAG5-9396

Analyzing FUSE Observations of Galactic and LMC Novae

We have started to analyze the FUSE data of novae obtained under this program with improved expanding NLTE line-blanketed model atmospheres. The new models are still under construction, however, intial results are very promising. We expect that these models will be useful not only for the analyses of FUSE nova spectra but also for the interpretation of FUSE spectra of stellar winds, hot stars, and other objects.

Detailed NLTE Model Atmospheres for Novae during Outburst: II. Modeling optical and ultraviolet observations of Nova LMC 1988 #1.

with Greg J. Schwarz, S. Starrfield, E. Baron, France Allard, Steven N. Shore, P. Whitelock

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. We 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 2×10^{38} 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.

Numerical Solution of the Expanding Stellar Atmosphere Problem

with E.Baron

In this paper we discuss numerical methods and algorithms for the solution of NLTE stellar atmosphere problems involving expanding atmospheres, e.g., found in novae, supernovae and stellar winds. We show how a scheme of nested iterations can be used to reduce the high dimension of the problem to a number of problems with smaller dimensions. As examples of these sub-problems, we discuss the numerical solution of the radiative transfer equation for relativistically expanding media with spherical symmetry, the solution of the multi-level non-LTE statistical equilibrium problem for extremely large model atoms, and our temperature correction procedure. Although modern iteration schemes are very efficient, parallel algorithms are essential in making large scale calculations feasible, therefore we discuss some parallelization schemes that we have developed.

A Non-LTE line-blanketed expanding atmosphere model for A-supergiant α Cygni *with J. P. Aufdenberg, E. Baron*

We present non-LTE metal line-blanketed expanding atmosphere models and synthetic spectra for comparison with the spectral energy distribution of A-supergiant ff Cyg from the UV to the radio. Our model treats the hydrostatic inner atmosphere and the extended expanding outer atmosphere as a unified structure and the radiative transfer is computed in the co-moving frame. By simultaneously fitting the UV, optical, IR and radio spectrophotometry we constrain $\dot{M}$ Stability of the deep hydrostatic layers against outward acceleration demands that the gravitational potential at the photosphere be $\log g \approx 1.5$ The best fitting model angular diameter is in very good agreem ent with the most recent interferometric measurement. We find a good fit to the photospheric Balmer and Pfund lines. We fit the Mg II resonance lines and find a best fit terminal velocity of $v_\infty = 225$km/s. We present synthetic radio spectra from the partially ionized winds of A-supergiants over a range of mass-loss rates and we find the standard assumptions regarding the radio spectra of warm supergiants break down for A-supergiants.

non-LTE model atmosphere analysis
of the early ultraviolet spectra of nova Andromedae 1986
with Greg J. Schwarz, S. Starrfield,
E. Baron, France Allard, Steven N. Shore, and G. Sonneborn

We 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: $5,000 \leq \mathrm{T}_{model} \leq 60,000$K, solar abundances, $\rho \propto r^{-3}$, $v_{\max} = 2000\,\mathrm{km\,s^{-1}}$, $L = 6 \times 10^4\,\mathrm{L}_\odot$, and a statistical or microturbulent velocity of 50 $\mathrm{km\,s^{-1}}$. We used the synthetic spectra 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 indicate that OS And 86 had solar metallicities except for Mg which showed evidence of being underabundant by as much as a factor of 10. We determine a distance of 5.1 kpc to OS And 86 and derive a peak bolometric luminosity of $\sim 5 \times 10^4$ $\mathrm{L}_\odot$. The computed nova parameters provide insights into the physics of the early outburst and explain the spectra seen by *IUE*. Lastly, we find evidence in the later observations for large non-LTE effects of Fe II which, when included, lead to much better agreement with the observations.

List of Publications in refereed journals (2000–2001)
Peter H. Hauschildt

1. Gibor Basri, Subhanjoy Mohanty, France Allard, Hauschildt, P.H., Xavier Delfosse, Eduardo L. Martin, Thierry Forveille, Bertrand Goldman: 2000, *An Effective Temperature Scale for Late M and L Dwarfs, from Resonance Absorption Lines of Cs I and Rb I*, ApJ, **538**, 363-385.

2. Lenz, E. J., Baron, E., Branch, D., Hauschildt, P.H., Nugent, P. E.: 2000, *Metallicity Effects in NLTE Model Atmospheres of Type Ia Supernovae*, ApJ, **530**, 966–976.

3. Leinert, C., Allard, F., Richichi, A., Hauschildt, P.H.: 2000, *The multiple system LHS 1070: a case study for the onset of dust formation in the atmospheres of very low mass stars*, A&A, **353**, 691–706.

4. Leggett, S. K., Allard, F., Dahn, C., Hauschildt, P.H., Kerr, T. H., Rayner, J.: 2000, *Spectral Energy Distributions for Disk and Halo M-Dwarfs*, ApJ, **535**, 965–974

5. Schweitzer, A., Hauschildt, P.H., Baron, E.: 2000, *Non–LTE treatment of molecules in the photospheres of cool stars*, ApJ, **541**, 1004–1015.

6. Barman, T. S., Hauschildt, P.H., Short, C. I., Baron, E.: 2000, *A Grid of NLTE Model Atmospheres for White Dwarfs in Cataclysmic Variables*, ApJ, **537**, 946-952.

7. Allard, F, Hauschildt, P.H., 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.

8. Allard, F, Hauschildt, P.H., Schwenke, D.: 2000, *TiO and H_2O absorption lines in cool stellar atmospheres*, ApJ, **540**, 1005-1015.

9. Chabrier, G., Baraffe, I, Allard, F., Hauschildt, P.H.: 2000, *Evolutionary models for very-low-mass stars and brown dwarfs with dusty atmospheres*, ApJ, **542**, 464-472.

10. Hui-Bon-Hoa, A, LeBlanc, F, Hauschildt, P.H.: 2000, *Diffusion in the Atmospheres of Blue Horizontal-Branch Stars*, ApJL, **535**, L43–L45

11. Orosz, J. A., Hauschildt, P.H.: 2000, *The use of the NextGen model atmospheres for cool giants in a light curve synthesis code*, A&A, **364**, 265-281.

12. E. Baron, David Branch, Hauschildt, P.H., Alexei V. Filippenko, R. P. Kirshner, P. M. Challis, S. Jha, R. Chevalier, Claes Fransson, Peter Lundqvist, Peter Garnavich, Bruno Leibundgut, R McCray, E. Michael, Nino Panagia, M. M. Phillips, Jason Pun, Brian Schmidt, George Sonneborn, N. B. Suntzeff, L. F. Wang and J. C. Wheeler: 2000, *Preliminary Spectral Analysis of the Type II Supernova 1999em*. ApJ, **545**, 444-448.

13. Short, C.I., Hauschildt, P.H., Starrfield, S., Baron, E.: 2001, *Non-LTE Modeling of Nova Cygni 1992*, ApJ, **547**, 1057-1070.

14. Chabrier, G., Baraffe, I., Allard, F., Hauschildt, P.H.: 2000, *Deuterium burning in sub-stellar objects*, ApJL, **542**, L119-L122.

15. Eric J. Lentz, E. Baron, David Branch, Hauschildt, P.H., Claes Fransson, Peter Lundqvist, Peter Garnavich, Nate Bastian, Alexei V. Filippenko, R. P. Kirshner, P. M. Challis, S. Jha, R. Chevalier, Bruno Leibundgut, R. McCray, E. Michael, Nino Panagia, M. M. Phillips,C. S. J. Pun, Brian Schmidt, George Sonneborn, N. B. Suntzeff, L. Wang, J. C. Wheeler: 2001, *Analysis of the Type IIn Supernova 1998S: Effects of Circumstellar Interaction on Observed Spectra*, ApJ, **547**, 406-411.

16. Lentz, E. J., Baron, E., Branch, D., Hauschildt, P.H.: 2000, *SN 1984A and Delayed Detonation Models of Type Ia Supernovae*, ApJ, **547**, 402-405.

17. Leggett, S. K., Allard, F., Geballe, T. R., Hauschildt, P.H., Schweitzer, A.: 2000, *Infrared Spectra and Spectral Energy Distributions of Late–M– and L–Dwarfs*, ApJ, **548**, 908-918.

18. Hauschildt, P.H., Lowenthal, D. K., and Baron, E.: 2000, *Parallel Implementation of the* PHOENIX *Generalized Stellar Atmosphere Program. III: A parallel algorithm for direct opacity sampling*, ApJ, *in press*

19. Ferguson, J. W., Alexander, D. R., Allard, F, Hauschildt, P.H.: 2001, *Grains in the Atmospheres of Red Giant Stars*, ApJ, *in press.*

20. Allard, F., Hauschildt, P.H., Alexander, D. R., Tamanai, A., Schweitzer, A.: 2000, *The Limiting Effects of Dust in Brown Dwarf Model Atmospheres*, ApJ, *in press.*

21. Albrow, M., An, J., Beaulieu, J.-P., Caldwell, J. A. R., Dominik, M., Greenhill, J., Hill, K., Kane, S., Martin, R., Menzies, J., Pollard, K., Sackett, P. D., Sahu, K. C., Vermaak, P., Watson, R., Williams, A. (The PLANET Collaboration), Hauschildt, P.H.: 2000, *Hα Equivalent Width Variations across the Face of a Microlensed K Giant in the Galactic Bulge*, ApJL, *in press.*

22. Lentz, E. J., Baron, E., Branch, D., Hauschildt, P.H.: 2001, *NLTE Synthetic Spectral Fits to the Type Ia Supernova 1994D in NGC 4525*, ApJ, *in press.*

23. Schwarz, G. J.. Shore, S. N., Starrfield, S., Hauschildt, P.H., Della Valle, M., Baron, E.: 2001, *Multiwavelength Analysis of the Extraordinary Nova LMC 1991*, MNRAS, **320**, 103–123.

24. Schweitzer, A., Gizis, J. E., Hauschildt, P.H., Allard, F., Reid, N.: 2001, *Analysis of Keck HIRES Spectra of Early L-type Dwarfs*, ApJ, *in press.*

25. Doyle, J.G., Jevremovic, D., Short, C. I., Hauschildt, P.H., Livingston, W., Vince, I.: 2001 *The Mn 5432/5392Å Line formation Explained*, A&A, *in press.*

26. Barman, T. S., Hauschildt, P.H., Allard, F.: 2001, *Irradiated Planets*, ApJ, *in press.*

27. Mitchell, R.C., Baron, E., Branch, D., Lundqvist, P., Blinnikov, S., Hauschildt, P.H., and Pun, C. S. J.: 2001, ^{56}*Ni Mixing in the Outer Layers of SN 1987A*, ApJ, *in press.*

28. Steiner, O., Hauschildt, P.H., Bruls, J.: 2001, *Radiative properties of magnetic elements I. Why are G-band bright spots bright?*, A&A, **372**, L13-L16.

29. Lucas, P. W., Roche, P. F., Allard, F, and Hauschildt, P.H.: 2001, *Infrared Spectroscopy of Substellar Objects in Orion*, MNRAS, *in press.*

30. Schweitzer, A., Gizis, J. E., Hauschildt, P.H., Allard, F., Howard, E. M., Kirkpatrick, J. D.: 2001, *Effective Temperatures of late L-dwarfs and the onset of Methane signatures*, ApJ, *submitted.*