# SPECTROSCOPIC DETERMINATION OF THE PHYSICAL CONDITIONS IN HOT OPTICALLY THIN SOURCES

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**Spectroscopic Determination of the Physical Conditions in Hot, Optically Thin Sources**

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Nancy S. Brickhouse (Principal Investigator)

January 3, 2003

This annual report covers the period from Oct 1, 2001 to Sep 30, 2002.

**APEC/APED.** The Astrophysics Plasma Emission Code and Database (APEC/APED), developed in part under this grant, have been upgraded to Version 1.3.0 (see http://asc.harvard.edu/atomdb) and are now beginning to find widespread applications to X-ray spectral data from Chandra and XMM-Newton (17 citations in published work, plus numerous other conference and prepublication papers).

These models represent the best theoretical data currently available and are reasonably complete below about 30 Å. Upgrades to the atomic database since the last reporting period include: the addition of accurate Ni L-shell wavelengths; the replacement of Li-like models from n=5 to n=7 using self-consistent HULLAC calculations; addition of reference wavelengths for Ne, Mg, Si, and S from pre-release NIST data; public versions of density-sensitive emissivities; additional references in the database; Fe K alpha models to complete the collisional equilibrium models below 30 Å.

We are making significant progress in improving the spectral models between 30 and 90 Å, by the addition of HULLAC calculations and NIST wavelengths for L-shell ions of Ne, Mg, Si, S, Ar, and Ca. We have discovered some missing configurations in the preliminary models, and are now waiting for new calculations from our collaborator.

While the output models are now public, the code itself is not ready for a public release. We have made significant progress toward this goal through programming improvements, including optimized error codes, a major (elusive) bug fix, and additions to our testing protocols. Documentation is the most critical remaing code issue for a public release. In order for the community to exploit the massive atomic data compiled under this project for the purpose of non-equilibrium ionization plasmas, these steps are necessary.

Secondarily, we are beginning to investigate limited uses of APEC for X-ray photoionized plasma, as for opacity modeling (e.g. warm absorbers). While the opacities are directly available from APED, the code itself needs to be modified to calculate the emission spectra from photoionized gas. We will

stop short of calculating the ionization balance in photoionization, but can make considerable progress in data analysis of high resolution X-ray spectra.

**The Emission Line Project.** Stellar coronae are being used to benchmark the atomic data in APED as part of the Emission Line Project. The models appear to be in good agreement with the observations for most of the strong lines; however, we have identified significant discrepancies in the 3s/3d line ratios not only for Fe XVII, but also for Fe XVIII and XIX. The Fe XVII problem has been known from solar observations, and is currently being tested under EBIT laboratory conditions by two competing groups. The Fe XVIII problem is substantially worse, but perhaps will shed light on the relevant underlying theoretical issues. These results were presented to the community at the Noordwijk meeting in November 2001 and at the SPIE meeting in August 2002 and are being written for publication now.

The careful analysis of these high quality X-ray spectra has also shown that there are serious problems with some of the analysis techniques in widespread use. There are several manifestations of the problem, but the main problem is that line-to-continuum ratios may be seriously mismeasured. We have developed a rigorous approach to fitting APEC continuum models to line-free spectral regions, identified by the complete line list as well as by visual inspection. Overbinning of spectral data leads to an overestimate of the continuum level; furthermore, use of the Cash statistic for low count bins leads to more consistent (and correct) fits to the continuum level. We have reported at several conferences that the measurement of line ratio diagnostics, such as for electron densities in stellar coronae, is critically dependent on careful continuum modeling.

**Collaborations to improve spectral modeling.** We continue to collaborate widely with atomic physicists in order to find the best atomic data, and to solicit calculations and measurements that are needed. Several visitors to the Institute for Atomic and Molecular Physics here at the CfA are working with us on various projects, e.g. Robin Reid from Queens University Belfast for proton impact excitation data and Verne Jacobs from NRL on dielectronic recombination.

**Management.** Dr. John Raymond, Dr. Duane Liedahl, and Dr. Randall Smith continue to work closely as collaborators on this project. We have added a new member to our team with the hire in February 2002 of Ronnie Hoogerwerf. Dr. Hoogerwerf joined our group with extensive programming and database management experience through his association with the Hip-

parcos project. He has already demonstrated remarkable ability and care in programming and data analysis work. We are also fortunate to have Dr. Yair Krongold-Herrera come to the CfA as a visitor on a Mexican government postdoctoral fellowship to help initiate a new collaboration to take advantage of APED for warm absorption modeling, with application to high resolution X-ray spectra of AGN.

## Publications and Presentations during the Reporting Period


Brickhouse, N. S. 2002, Quantitative Analysis of Coronal X-ray Spectra at High Resolution, in *Proceedings of SPIE Conference on Astronomical Telescopes and Instruments*, X-ray and Gamma-ray Telescopes and Instruments for Astronomy, in press

Brickhouse, N. S. 2002, Accuracy and Limitations of Atomic Data for X-ray Spectroscopy, Workshop on Plasma Processes, Diagnostics & Codes, New Visions of the X-ray Universe in the XMM-Newton and Chandra Era, Noordwijk, the Netherlands, ESA

Brickhouse, N. S., Dupree, A. K., & Young, P. R. 2001, X-ray Doppler Imaging of 44i Boo with Chandra, ApJ, 562, L75

Drake, J. J., Brickhouse, N. S., Kashyap, V., Laming, J. M., Huenemoerder, D. P., Smith, R. K., & Wargelin, B. J. 2001, Enhanced Noble Gases in the Coronae of Active Stars, *Ap. J.*, 548, L81

Johnson, O., Drake, J. J., Kashyap, V., Brickhouse, N. S., Dupree, A. K., Freeman, P., Young, P. R., & Kriss, G. A. 2002, The Capella Giants and Coronal Evolution Across the Hertzsprung Gap, *Ap. J.*, 565, L97

Lepson, J. K., Beiersdorfer, P., Brown, G. V., Liedahl, D. A., Utter, S. B., Brickhouse, N. S., Dupree, A. K., Kaastra, J. S., Mewe, R., & Kahn, S. M. 2002, Emission Lines of Fe VII - Fe X in the Extreme Ultraviolet Region, 60 - 140 Å, *Ap. J.*, in press

Maggio, A., Favata, F., Brickhouse, N. S., & Dupree, A. K. 2002, Coronal Abundances and Thermal Structure of the Super-Metal-Rich Star 30 Ari, in *New Visions of the X-ray Universe in the XMM-Newton and Chandra Era*, ASP Conf. Series, ed. F. Jansen, in press

McLaughlin, B. M., Kirby, K. P., Smith, R. K., Brickhouse, N. S., & Liedahl, D. A. 2001, Electron Collisional Excitation of the $1s^2 2s^2 2p^3$ ($^4S^0_{3/2}$, $^2D^0_{5/2,3/2}$, $^2P^0_{3/2,1/2}$) Fine-Structure Levels in $Fe^{18+}$ Ions, *J. Phys. B*, 34, 4521

Sanz-Forcada, J., Brickhouse, N. S., & Dupree, A. K. 2002, The Structure of Stellar Coronae in Active Binary Systems, ApJ, accepted

Smith, R. K., Brickhouse, N. S., Liedahl, D. A., & Raymond, J. C. 2001, Standard Formats for Atomic Data: the APED, in *Spectroscopic Challenges of Photoionized Plasmas*, ASP Conf. Series Vol. 247, ed. G. Ferland and D. W. Savin, 161

Takacs, E. et al. (15 authors) 2002, Spectroscopy of Trapped Ions with a Microcalorimeter on the NIST Electron Beam Ion Trap, in *Spectroscopy of Trapped Ions with a Microcalorimeter on the NIST Electron Beam Ion Trap*, NASA Laboratory Astrophysics Workshop, ed. F. Salama, in press

## Conferences Attended during the Reporting Period

*Dr. Brickhouse*:

New Visions of the X-ray Universe in the Chandra and XMM-Newton Era, ESA, November 2001, Noordwijk, the Netherlands

Workshop on Data Analysis Challenges in Solar and Stellar Astrophysics, AAS Meeting, January 2002, Washington, D. C.

AAS Meeting, jointly sponsored with the AAS HEAD, April 2002, Albuquerque, NM

X-ray and Gamma-ray Telescopes and Instruments for Astronomy, SPIE Astronomical Telescopes and Instruments, Waikoloa, HI, August 2002