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The Stellar Wind From the Central Star of NGC 7009

G. Sonneborn[1], R. C. Iping[1,2], D. L. Massa[1,3], and Y-H Chu[4]

[1]Lab. for Observational Cosmology, Code 665, NASA/GSFC, Greenbelt, MD 20771 USA
email: george.sonneborn@nasa.gov

[2]Dept. of Physics, Catholic University of America, Washington, DC 20064 USA

[3]SGT, Inc., Greenbelt, MD 20770 USA

[4]Dept. of Astronomy, University of Illinois, Urbana, IL 61801 USA

Abstract. High-resolution 905-1187Å spectra of the central star of NGC 7009 obtained with the FUSE satellite provide new constraints on the mass loss and atmosphere parameters. The most prominent spectral feature is a very strong P-Cygni profile of O VI 1032-1038. The only other wind lines are S VI 933-44 (FUSE) and N V 1238-42 and O V 1371 from IUE spectra. C IV 1548-50 and P V 1118-28 are not present, indicating that the wind is very highly ionized. A lower limit on the mass loss rate ($\dot{M} > 10^{-8} M_{\odot} \mathrm{y}^{-1}, v_{\infty} = 2450$ km s^{-1}) has been derived from an SEI analysis of these wind lines. Preliminary identification of several photospheric spectral features include several strong Fe VII and O VI lines between 1100 and 1170 Å.

Keywords. planetary nebulae: individual (NGC 7009), ultraviolet: stars, techniques: spectroscopic, space vehicles: FUSE , stars: mass loss

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NGC 7009 is a classical elliptical PN with a jet-like structure and low-ionization knots on its major axis. High-excitation emission dominates the inner regions of the nebula, indicating a fast-wind interaction may be important. The current parameters of the hot, H-rich central star ($T_{\rm eff}$ = 82,000 K, log g = 4.80, and $y = N(He)/[N(H) + N(He)] = 0.08$) are from Méndez *et al.* (1988). UV resonance transitions are the best diagnostics of stellar wind parameters.

NGC 7009 was observed by the Far Ultraviolet Spectroscopic Explorer (FUSE) satellite (Moos *et al.* 2000), covering 910–1187 Å at a resolution of ∼15 km s^{-1}. These data, plus archival IUE spectra (1150-2000Å), show that only four stellar wind lines are detected in NGC 7009. These are the resonance doublets O VI 1032-38, S VI 933-44, and N V 1238-42, and the excited state transition O V 1371. The lower level of the O V 1371 line is the upper level of the O V resonance line at 629.73 Å. C IV 1548-50 and P V 1118-28 are not present, indicating that the wind is very highly ionized.

Fig. 1 shows part of the FUSE spectrum of NGC 7009. Preliminary identification of photospheric lines include Fe VII, Fe VI, O VI, and possibly F VI 1139.5 (Werner *et al.* 2005). Some features are not yet identified. The line IDs are consistent with the stellar radial velocity of −46 km s^{-1}. The width of the stellar features indicates $v \sin i$ ∼100 km s^{-1}. Comparison with the sdO star BD +28 4211 ($T_{\rm eff}$ = 82,000 K, log g = 6.2) indicates that Fe VII and O VI, compared with O IV and Fe VI in BD+28 4211, are unexpectedly strong, raising the possibility that $T_{\rm eff}$ may be underestimated in NGC 7009. Non-LTE modelling of the FUV stellar spectrum is in progress.

An SEI analysis of the O VI, O V, N V, and S VI line profiles was made, following the same procedures used by Massa *et al.* (2003). From this analysis the terminal velocity in the wind is $v_{\infty} \sim 2450$ km s^{-1}. The wind law parameter β is 0.8. Model profile fits for these four lines are shown in Fig. 2a. Fig. 2b shows $\dot{M}q$ as a function of $w = v/v_{\infty}$, where

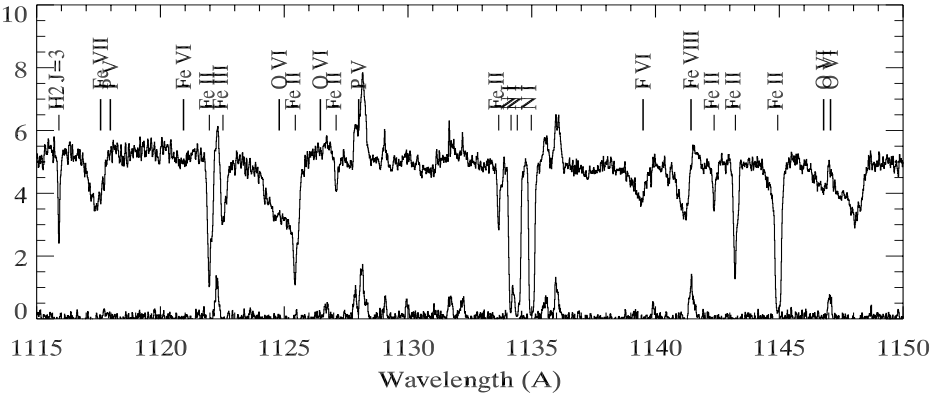

Figure 1. FUSE spectrum of NGC 7009. Line IDs with short tick marks (low ionization) are interstellar; long tick marks (high ionization states) are stellar. A FUSE narrow-slit spectrum of the nebula 3" from the star is at the bottom to show the nebular emission features.

q is the ionization fraction of the ion in question. The O VI line is strongly saturated ($\tau \sim 50$), and so provides only a lower limit to the mass loss rate ($\dot{M} > 10^{-8} M_{\odot} \mathrm{y}^{-1}$). The other wind lines are unsaturated and the low values of $\dot{M}q$ for N V and S VI shows that these ions are trace species in the wind.

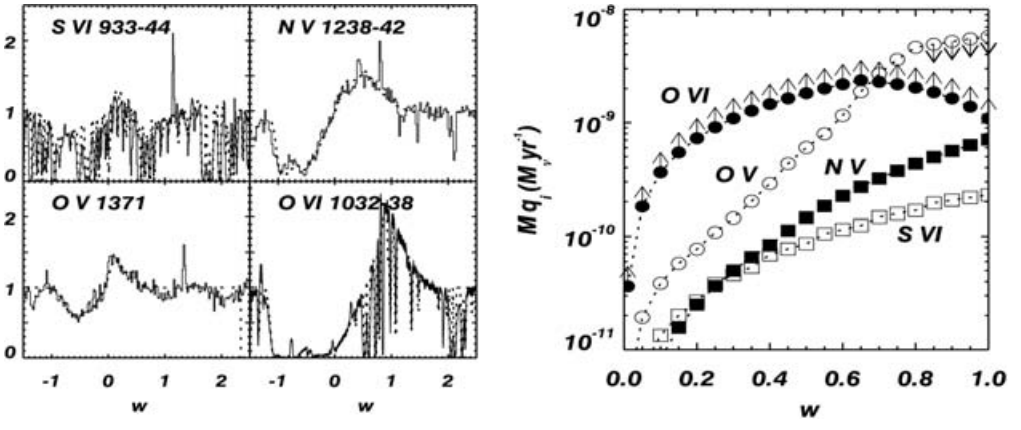

Figure 2. (*left*) SEI model fits to O VI, S VI, N V, and O V lines for $v_\infty = 2450$ km s^{-1} and $\beta = 0.8$. The narrow absorption lines surrounding the S VI and O VI lines are from the Lyman and Werner bands of interstellar H_2. (*right*) Mass-loss parameter $\dot{M}q$ as a function of normalized wind velocity for the O VI, O V, N V, and S VI lines.

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References

Massa, D.L., Fullerton, A.W., Sonneborn, G., & Hutchings, J.B. 2003, *ApJ* 586, 996
Méndez, R.H., Kudritzki, R.P., Herrero, A., Husfeld, D., & Groth, H.G. 1988, *A&A* 190, 113
Moos, H. W., *et al.* 2000, *ApJ* 538, L1
Werner, K., Rauch, T., & Kruk, J.W. 2005, *A&A* 433, 641