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The FUSE Mission: Atomic Data Needs in the 900–1200 Å Spectral Region

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Abstract. The Far Ultraviolet Spectroscopic Explorer (FUSE) is presently producing high resolution (R ~ 20,000) absorption-line spectra of astronomical objects ranging from Solar System planets to quasars. The 900–1200 Å spectral region observed by FUSE is exceedingly rich in atomic and molecular transitions arising out of the ground state. It is already clear from early FUSE observations that the atomic data (e.g., oscillator strengths) for some transitions are considerably different than those predicted by theoretical calculations. I briefly describe the most pressing oscillator strength needs in this wavelength range for studies of the interstellar medium.

1. Introduction

The launch of the FUSE satellite in June 1999 marked the beginning of a new era of high-resolution far-ultraviolet spectroscopy of astronomical objects. FUSE observes light in the rich spectral region between the Lyman limit at 912 Å and the lower wavelength cutoff of the Hubble Space Telescope spectrographs at ~ 1150 Å. The FUSE instruments are at least 10,000 times more sensitive to far-ultraviolet light than previous high-resolution instruments in space (e.g., Copernicus). FUSE produces spectra with a resolution of $\sim 20 - 25$ km s^{-1} (FWHM) and has sufficient sensitivity to observe objects outside the Galaxy. As of 1 October 2000, FUSE had made more than 800 astronomical observations.

Early FUSE science results are reported in the 20 July 2000 issue of the *Astrophysical Journal* and in the proceedings of Joint Discussion 11 at this IAU meeting. An overview of the mission is given by Moos et al. (2000), and the on-orbit performance of the instrumentation is described by Sahnow et al. (2000).

2. Atomic Data Needs

Most of the oscillator strengths used to derive column densities from the atomic absorption line strengths in the far-UV spectral region are based upon theoretical calculations. These calculations are usually quite complex, with various configuration mixings and energy levels to model. It is not uncommon for different calculations to yield similar results, and often these results agree well with laboratory and/or astronomical data. However, there are cases where disagreements exist (see Morton 1991, 2002).

There are numerous lines of abundant elements in various ionization states observable in the FUSE bandpass (e.g., H I; D I; C I-III; N I-III; O I,VI; Si II; Cl I-II; Ar I-II; P II-III; S III,VI; Fe II-III). Some of these are crucial for understanding the nucleosynthetic history of the interstellar gas and the effects of astration on the observed D/H ratio. The O I lines are particularly important since 1) they provide the most robust estimate of the amount of neutral gas present (other than H I) because of charge exchange between O ions and H atoms, and 2) they often have wavelengths similar to those of the D I lines, which means that the O I lines must be modeled accurately to estimate their impact on the observed D I absorption. Important O I lines for which laboratory f-value measurements are desirable are listed in Table 1 along with selected lines of other neutral and ionized gas tracers that have f-value uncertainties of $\gtrsim$ 20%. In some cases, only a single line of a species is observable (e.g., Fe III), making an accurate measurement of the f-value even more important.

Table 1. Lines Needing Oscillator Strength Measurements[a]

Ion	Mult.	λ(Å)	log $f\lambda$	Ion	Mult.	λ(Å)	log $f\lambda$
O I	3	1039.230	0.980	N I	3.04	954.104	0.809
	3.01	1026.476	0.402		3.06	952.303	0.252
	7	976.448	0.509				
	9	972.143	−0.511	Si II	5.01	1020.699	1.225
	10	971.738	1.052				
	11	950.885	0.176	P II	3	1152.818	2.451
	12	948.686	0.778			963.800	3.148
	14	936.630	0.534			961.041	2.525
	15	930.257	−0.301				
	17	925.442	−0.485	S III	2	1012.495	1.651
	18	924.950	0.155				
	21	919.908	−0.786	Fe III	1	1122.524	1.786

[a]These selected resonance lines are important for studying the neutral and ionized interstellar medium. The wavelengths and f-values of the lines are from the extensive Morton (1991, 2002) compilations. Most of the f-values are based on theoretical calculations.

Figure 1 shows a comparison of the observed and expected line strengths for several O I lines toward the subdwarf star BD +28° 4211. The transitions at 972.1 and 1026.5 Å are clearly stronger than the values predicted from a single-component curve of growth fit to the other O I lines in the spectrum. We are currently using FUSE data of this type to constrain the relative f-values of the O I lines, but an absolute calibration will require a laboratory measurement of one or more of the lines listed in Table 1.

Table 1 does not include lines of Fe II. Recent work by Howk et al. (2000) confirms that most of the theoretical (Raassen & Uylings 1998) f-values for the 1050–1150Å ground-state transitions are well-determined. Three of the 11 Fe II transitions studied ($\lambda\lambda$1112.048, 1121.975, 1127.098) have f-values that differ from theory by as much as a factor of two, but this is probably due to difficulty in modeling the strong mixing with nearby energy levels (see Johansson

2001, this volume). The short wavelength Fe II *f*-values are tied into laboratory measurements at long wavelengths (cf., Mullman et al. 1997).

In addition to the interstellar lines identified here, there are numerous fine-structure and excited-level lines in the FUSE bandpass for which little atomic data exist. Better wavelengths and *f*-values for these lines, particularly those of heavy elements such as Fe, Ni, and Cr, would be of considerable help in modeling the atmospheres of hot stars used as continuum sources for ISM studies.

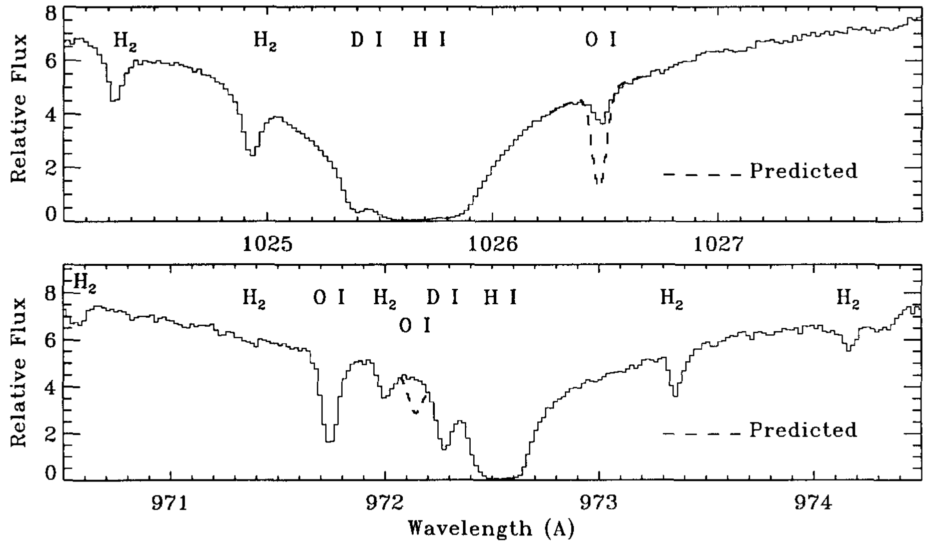

Figure 1: FUSE data for BD +28° 4211 showing the observed and expected strengths of the O I lines near 972.1 and 1026.5 Å. The predicted line strengths are based on a curve of growth fit to the other O I lines seen in the full FUSE spectrum. An analysis of the interstellar lines in this FUSE spectrum is presented by Sonneborn et al. (2001).

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