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ANALYSIS OF THE FUSE SPECTRA OF THE HE-POOR SDO STAR MCT 0019−2441

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Abstract. We present a preliminary analysis of the FUSE spectra of MCT 0019−2441, a relatively He-poor sdO star. Among the handful of absorption features of photospheric origin present in the ultraviolet, we identify the O VI doublet at 1031.9 and 1037.6 Å, the S VI doublet at 933.4 and 944.5 Å, the Si IV triplet at 1122.5 and 1128.3 Å and some N IV lines. While synthetic spectra based on NLTE line blanketed model atmospheres can reproduce most line profiles, they fail to reproduce the O VI line profiles in a satisfactory manner. Possible solutions to this puzzle are considered.

Key words: stars: hot subdwarfs – stars: abundances – stars: individual (MCT 0019−2441)

1. INTRODUCTION

The hot subdwarf MCT 0019−2441 ($V = 14.48$) was observed with the FUSE Observatory as a part of an ongoing effort at mapping the atmospheric chemical composition of a relatively large sample of sdB and sdOB stars (see, e.g., Fontaine et al. 2005). The main objective of this work is to understand better the physical processes that determine the chemical composition of subdwarf atmospheres. However, at $T_{\rm eff} = 58\,350$ K and $\log g = 5.6$, MCT 0019−2441 turned out to be a "cool" sdO star with a low helium abundance ($n_{\rm He}/n_{\rm H} = 0.08$). Since its FUSE spectra do not show the myriad of lines that are present in the spectra of most other hot subdwarf stars, MCT 0019−2441 is well suited for a complete spectral analysis, as the continuum level is clearly defined and most photospheric absorption features can be identified. A first look at the unusual FUSE spectra of this object was provided by Lamontagne et al. (2003), and we present here the first quantitative analysis of its abundance pattern.

2. OBSERVATIONAL MATERIAL AND MODEL ATMOSPHERES

The FUSE data on MCT 0019−2441 (dataset B0541001) are similar to those presented by Lamontagne et al. (2003) and consist of four exposures, for a total of 9.2 ksec. In parallel, a medium-resolution optical spectrum of MCT 0019−2441 was secured by M. Billères at the NTT, while two IUE low-dispersion observations were recovered from the MAST archives (images SWP 26277 and LWP 06290).

To carry out our analysis of the spectra, we use TLUSTY 200 and SYNSPEC 48 (Hubeny 1988; Hubeny & Lanz 1995) respectively for the computation of model atmospheres and synthetic spectra. These codes are used to generate grids of NLTE, homogeneous, plane-parallel models that include blanketing by the hydrogen and helium lines. A first grid, used to derive the atmospheric parameters, is devoid of heavy elements. Our fits to the hydrogen and helium lines yield $T_{\rm eff} = 58\,350$ K, $\log g = 5.6$ and $n_{\rm He}/n_{\rm H} = 0.08$. The corresponding reddening-free energy distribution shows good agreement with the composite energy distribution built from FUSE, IUE and optical data.

With these atmospheric parameters, grids of model atmospheres were generated that include detailed atomic models for O III through O VI and for S IV through S VI. Not only does this allow line blanketing by O and S to be accounted for, but NLTE populations of O and S can also be calculated and used in the computation of synthetic spectra. For other heavy elements (C, N, Si, P and Fe), we currently use a line blanketed model with log(O/H)= −5 and log (S/H) = −7 for the computation of synthetic spectra in which these elements are added as traces and treated in LTE. The atomic data for the lines is taken from the compilations of Kurucz[1].

3. ABUNDANCE ANALYSES

The ultraviolet line spectrum of MCT 0019−2441, although far simpler than that of the vast majority of hot subdwarfs, provides interesting challenges when confronted to detailed abundance analyses. Some features, like the Si IV 1128 Å lines, can be fit with the help of a χ^2 minimizing procedure that simultaneously optimizes the abundance and the level of the continuum. For the O VI lines the procedure does not work well, because the lines appear too strong to be entirely photospheric. In many cases, the absence of absorption features in the FUSE spectra led to upper limits on the abun-

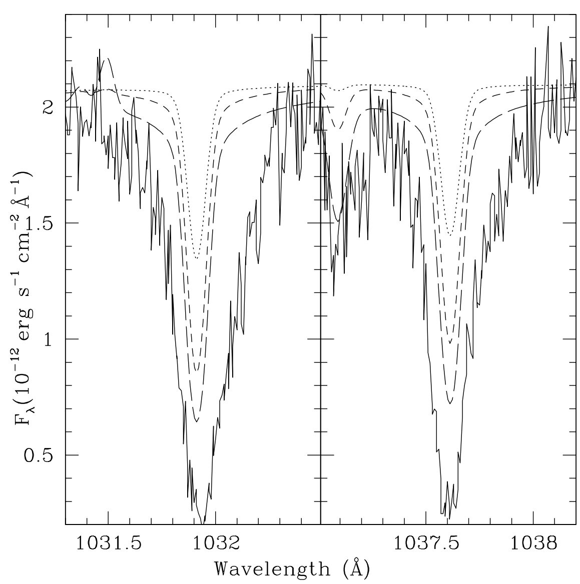

Fig. 1. Synthetic spectra with log (O/H) = −5 (dots), −4 (short dash) and −3 (long dash) compared to the FUSE data.

[1] see http://cfa-www.harvard.edu/amdata/ampdata/kurucz23/sekur.html

dance of the element considered. We now comment on specific elements.

Oxygen. We observe strong O VI resonance lines at 1031.9 and 1037.6 Å, with respective equivalent widths of ~ 275 and ~ 190 mÅ. They have the same velocity as the Lyman lines within the instrumental resolution (about 15 $\mathrm{km\,s^{-1}}$). At the same time, there is negligible absorption from O IV throughout the FUSE spectral range. The only O IV lines detected in the FUSE spectra (1067.768 and 1067.832 Å) indicate $\log(\mathrm{O/H}) < -4.8$, an abundance too low by orders of magnitude to reproduce the O VI equivalent widths, not to mention the line profiles (see Figure 1). This situation is addressed in the next section.

Sulfur. The S VI 933 and 944 Å lines are detected and have equivalent widths of 67.6 and 62.4 mÅ, respectively. The fit to the S VI 933 Å line yields an abundance of $\log(\mathrm{S/H}) = -7.9$, while the 944 Å line is best matched for $\log(\mathrm{S/H}) = -7.6$. In the latter case, the core of the line is still poorly matched.

Carbon. The C III 1175 Å multiplet is absent, while the C III 977 Å resonance line is strong. This indicates that C III absorption occurs in the ISM, as the 1175 Å multiplet arises from an excited state. Unfortunately, there are no additional constraints to be extracted from the IUE spectra, since the C IV resonance lines are absent. From the absence of absorption features near 1175 Å, we derive an upper limit to the photospheric carbon abundance of $\log(\mathrm{C/H}) < -7.0$.

Nitrogen. The N IV lines around 922–955 Å are all compatible with an abundance of $\log(\mathrm{N/H}) = -7.6 \pm 0.3$, but there are minor discrepancies between the shape of the observed continuum and the synthetic spectrum in this spectral interval. This may perhaps be due to small errors in the values of the atmospheric parameters we determined or to problems with the flux calibration of the FUSE data at such short wavelength.

Silicon. The Si IV 1128 Å lines are well matched by our automated χ^2 procedure, yielding $\log(\mathrm{Si/H}) = -7.4$. The 1122 Å line is blended with a Fe III ISM line, but the observed feature is compatible with the derived abundance.

Phosphorus. The absence of the P V resonance lines at 1118.0 and 1128.0 Å yields an upper limit of $\log(\mathrm{P/H}) < -9.6$. The atmosphere of MCT 0019−2441 appears to be completely devoid of phosphorus, an element observed in most hot subdwarfs.

Iron. The FUSE spectra have been inspected for evidence of Fe V or Fe VI lines or both. Their non-detection implies an upper limit of $\log(\mathrm{Fe/H}) < -5.0$ under LTE assumption. We stress that NLTE effects play an important role in the ionization and excitation balance of iron under such atmospheric conditions and are not accounted for in this preliminary analysis.

4. DISCUSSION

Many lines routinely seen in hot subdwarfs are absent from the ultraviolet spectrum of MCT 0019−2441; we nevertheless have some difficulty in accounting for the strongest features, those of O VI, observed in the spectrum. While small errors in the atmospheric parameters (T_{eff} and $\log g$) could play some role in explaining these difficulties, we note that the parameters we derive reproduce satisfactorily both the optical spectrum and the overall energy distribution; the only disagreement appears in the predicted continuum in the 910–950 Å region. We also remark that, while our calculations for the Stark broadening of the O VI and S VI lines make use of the latest semi-classical damping constants of Dimitrijević & Sahal-

Bréchot (1992, 1993), there are still no fully quantum-mechanical calculations of the broadening of these lines.

In addition to these obvious possibilities, other scenarios should perhaps also be considered to account for the strength of the O VI lines. The first possibility is that their strength reflects an inhomogeneous equilibrium distribution of heavy elements. A stratification of this type might be disrupted by a weak stellar wind, however. In MCT 0019−2441, the O VI lines do show asymmetric profiles that may be related to the presence of such a wind. It appears therefore unlikely that stratification can be invoked to solve the puzzle of the O VI lines.

Another possibility is a contribution to the observed profile from diffuse O VI absorption in the local ISM. This is considered unlikely, on the basis of the recent analysis by Oegerle et al. (2005) of 25 lines of sight to nearby ($d < 250$ pc) white dwarfs. They report equivalent widths of O VI lines less than 22 mÅ. Situated ~ 1.7 kpc away, however, MCT 0019−2441 is significantly beyond the distance sampled by Oegerle et al. On a much longer line of sight ($d = 10.2$ kpc), Howk et al. (2003) present an analysis of vZ 1128, a post-AGB star located in the globular cluster M 3, which shows an ultraviolet spectrum similar to that of MCT 0019−2441. They suggest that the O VI absorption, with equivalent widths of 260 mÅ and 150 mÅ respectively, arises at the interfaces between the hot and warm phases of the ISM. While the line strengths are compatible with those observed in MCT 0019−2441, the distance is significantly larger than that to our target.

A final possibility is that circumstellar material might contribute to the observed O VI absorption. In the case of vZ 1128, Howk et al. (2003) argue that this is unlikely given the absence of high-velocity material. The same argument could be made for MCT 0019−2441, but the issue could be settled by a direct observation of the surroundings of that star. For instance, Otte et al. (2004) report the detection of a O VI-emitting nebula around the hot white dwarf KPD 0005+5106 ($T_{\rm eff} = 120\,000$ K, $\log g = 7.0$), a hot PG 1159 star known to show O VI absorption in the optical (Sion et al. 1985).

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