On an ultraviolet spectral atlas of α^2 CVn

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Abstract. We describe the ultraviolet spectra of the Ap star α^2 CVn that have been acquired with the Hubble Space Telescope and the nature of the optical region analyses for its rotational velocity and elemental abundances that have been undertaken in support of the ultraviolet data.

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1. Introduction

The spectrum of the prototypical magnetic star α^2 CVn (= HR 4915, A0p Si, Hg, Eu, Cr) has been recognized as peculiar for one hundred years (Maury 1897). As a result of its brightness it has been an important target for several lines of inquiry into warm chemically peculiar stars. Yet even though α^2 CVn has been a centerpiece for Ap star study, there is still much to learn from its spectrum, particularly at ultraviolet (UV) wavelengths. We have undertaken to study its UV spectrum in order to more fully identify those ions that are present and better quantify the rich line opacity that leads to flux redistribution. The UV atlas consists of 35 wavelength settings of the Goddard High Resolution Spectrograph (GHRS) onboard the Hubble Space Telescope (HST). Three first-order gratings, characterized by spectral resolving powers between R = $\lambda/\Delta\lambda$ = 20000 and 35000, were used to collect high quality (S/N > 100) data over the wavelength interval 1510 to 2640 Å. The data were collected on three separate dates, each corresponding to magnetic phase 0.0 +/- 0.1, the phase of maximum UV opacity and Eu II line strength at optical wavelengths.

However, the nature of the UV spectrum can not be studied independently of the optical region, and it was deemed necessary to acquire optical region spectra to address issues such as rotational velocity and elemental abundances. Optical region spectra were obtained during several observing campaigns with the 2.6-m Nordic Optical Telescope (NOT). The SOFIN echelle spectrograph was used to obtain complete optical coverage at a resolving power of R = 25000 at a single phase, along with limited wavelength coverage observations for many phases at a resolving power of R = 80000.

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2. Optical region analyses

2.1. Rotational velocity

The projected equatorial rotational velocity, $v \sin i$, was determined by synthetic spectrum fitting of unblended Fe II lines found in the red spectral region. The use of Fe II lines essentially minimizes line broadening effects arising from hyperfine structure (hfs) and isotope shifts (IS). No account was made of the possible Zeeman broadening, so the result may be considered an upper limit. Line breadths were first compared for the observed rotational phases for each of several ions (Fe II, Si II, Eu II, Cr II) in order to identify the phase with the narrowest lines. The phase 0.09 observation was determined to have the sharpest lines, thereby representing the spectrum that was least affected by magnetic broadening. The program SYNTHE and atomic line data of Kurucz were then used to generate synthetic spectra. The ATLAS9 model having the atmospheric parameters $T_{\rm eff}$ = 11500 K, log g = 4.0, microturbulent velocity 2.0 km s^{-1}, and a 10 times solar metallicity was chosen. By comparison of the observation with synthetic spectra it was determined that $v \sin i$ = 14 km s^{-1}. This value is smaller than previously published values: 29 (Hoffleit & Jaschek 1982), 24 (Wolff & Preston 1978), 18 (Abt et al. 1972), and 17 km s^{-1} (Khokhlova & Pavlova 1984).

2.2. Elemental abundances

The published literature features a wide range of values for the elemental abundances of α^2 CVn. Perhaps the most worrisome are those for the iron-group elements, for which estimates range from solar values to 100 times solar. Starting the abundance analysis at UV wavelengths is difficult due to the line blending and the uncertainty of continuum placement. Thus, the analysis was begun at red wavelengths, where continuum placement was often a trivial task and line blending is minimal. The same atmospheric model parameters as above were used with opacities of 1, 10, and 100 times the solar opacity. The best fits to the Fe II lines are for an abundance enhancement of [Fe/H] = +0.7 at phase 0.09 and +0.5 at phase 0.91. Other iron-group elements show similar enhancements. The rare-earth elements (REE) dominate the bluer optical wavelengths, and their enhancements were found to be more extreme, typically between 3.5 and 4.5 orders of magnitude greater than the solar values. However, it must be cautioned that these abundance enhancements were derived using a line list that did not account for hfs, IS, or magnetic broadening. The inclusion of these effects is likely to change the abundance enhancements determined for the REE.

3. The UV continuum: Where is it ?

Theoretically, if the line list is complete and the stellar parameters are known, then synthetic spectra can be used to assign the continuum level. However,

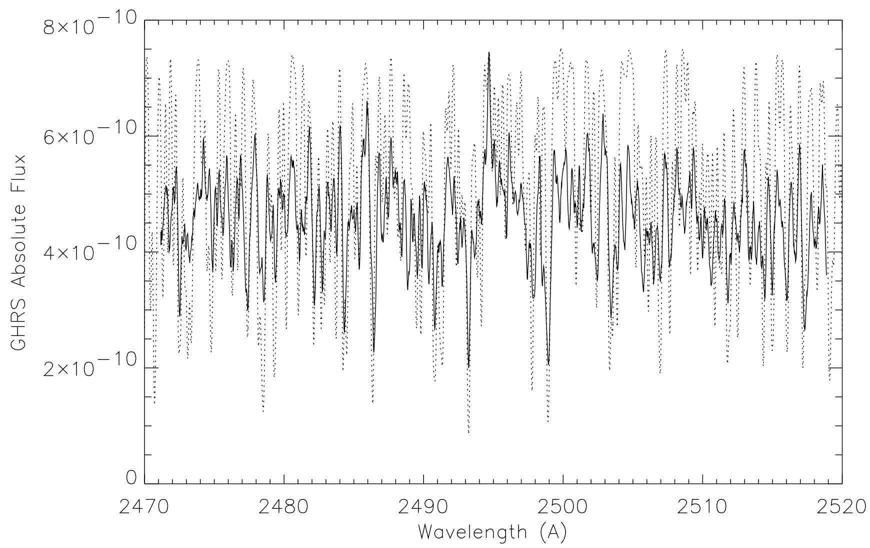

Figure 1. α^2 CVn GHRS observation (solid) and synthetic spectrum (dashed).

the absence of a myriad of REE third spectra lines from the linelists at UV wavelengths renders this problem more difficult than continuum placement at optical wavelengths. This problem is illustrated in Figure 1, which compares an HST/GHRS observation of α^2 CVn with a synthetic spectrum that was calculated using the best fit $v \sin i$ and elemental abundances from the optical region analysis. The two spectra have been arbitrarily normalized to the peak in the observed spectrum. The absence of this peak, due to either a slightly different grating setting or the use of lower spectral resolution would likely lead to choosing a continuum level that is too low. Those lines in the figure that are calculated as too strong relative to the observation most likely reflect either poor oscillator strengths or a residual error in the continuum placement. Careful study of these spectra also reveals missing opacity due to either incorrect model elemental abundances or missing atomic lines in the calculation.

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