VOYAGER EUV AND FUV OBSERVATIONS

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ABSTRACT

The Voyager 1 and 2 ultraviolet spectrometers are sensitive over the wavelength range 500 to 1700 A. In the EUV, at wavelengths shortward of the Lyman limit (912 A), Voyager observations have detected emission from three out of a sample of 11 nearby hot DA white dwarfs. These observations imply very low HI column densities in the directions of the three stars detected. In the FUV, at wavelengths between 912 and 1200 A, Voyager observations of O and B stars can be used to study interstellar reddening at the shortest wavelengths and to provide useful estimates of interstellar H_2 column densities.

INTRODUCTION

The ultraviolet spectrometers aboard the two Voyager spacecraft provide several unique means of exploring the local interstellar medium. Routine access to the 500 to 912 A region of the extreme ultraviolet (EUV) allows the use of nearby hot stellar sources as a probe of local neutral hydrogen column densities. A comprehensive set of observations of luminous O and B stars in the far UV (FUV) between 912 and 1200 A offers the possibility of systematically studying reddening at the shortest observable wavelengths. Because of the strong and characteristic band absorption from the H_2 molecule at these wavelengths, these same observations hold the promise of measuring interstellar H_2 column densities.

EUV OBSERVATIONS.

Observations of hot nearby subluminous stars in the EUV can be used to obtain local HI column densities. Meaningful results however, require the existence of lines of sight having very low HI column densities ($N_{HI} \lesssim 5 \times 10^{18}$ cm^{-2}). In this regard observations of hot white dwarfs have been especially important. Of the four sources initially detected with the Apollo-Soyuz EUV telescope two, HZ 43 (Margon et al. 1976a) and Feige 24 (Margon et al. 1976b), were determined to be hot DA white dwarfs.

The 500 to 912 A EUV capabilities of the Voyager 1 and 2 spacecraft have been used to survey a sample of nearby hot white dwarfs. A list of the DA white dwarfs surveyed along with their temperatures, distances and galactic coordinates is contained in Table 1. Of these eleven objects, three exhibit detectable continua shortward of 912 A (Fig. 1). Voyager 2 EUV observations of HZ 43 (Holberg et al. 1980a) indicate a column density of $N_{HI} = 3.9 \times 10^{17}$ cm^{-2} for this white dwarf. An interesting comparsion of HZ 43 with a nearly identical white dwarf GD 246 is shown in Figure 2. Here the FUV count rate spectra of both stars are virtually indistinguishable while only HZ 43 shows a measurable EUV continuum. Since there is no detectable EUV emission from GD 246 it is only possible to place a lower limit on the HI column density ($N_{HI} > 1.5 \times 10^{18}$). It is interesting to note however that GD 246 was detected as an Einstein soft X-ray source (Petre et al. 1983). The HI column density along its line of sight therefore cannot be much in excess of the above quantity,

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and in fact could be easily determined by simple comparison with the HZ 43 soft X-ray flux.

Voyager observations have yielded two new EUV sources, G191 B2B (Holberg et al. 1980b) and GD 153. For G191 B2B the estimated N_{HI} column density is 10^{18} cm^{-2}. The corresponding preliminary value for GD 153 is 6 x 10^{17} cm^{-2}. Two interesting comments can be made concerning GD 153. First, GD 153 is separated from HZ 43 by only 8°.3 of arc and lies at approximately the same distance so that it almost certainly is within the same low HI window in the ISM. Second, this star has also been identified as an Einstein soft X-ray source (Kahn et al. 1983) so that its entire EUV spectrum is potentially observable with future EUV instrumentation.

A survey of over 50 of the brighter subluminous objects has been conducted with Voyager. These observations include DO white dwarfs (PG 1034+001, HD 149499B, etc.), hot central stars of planetary nebulae (NGC 246, NGC 7293, etc.), and hot O and B subdwarfs (BD +28°4211, Feige 34, etc.). No EUV emission has been detected from any of these objects. Of particular interest are Voyager observations of cataclysmic variables in outburst. On the basis of soft X-ray and UV observations, it has been proposed (Córdova and Mason 1982) that the bulk of the outburst energy from cataclysmic variables such as SS Cyg and U Gem could be emitted in the EUV. This, in conjunction with the Apollo-Soyuz detection of SS Cyg at ~100 A (Margon et al. 1978) has led to the expectation that cataclysmic variables might represent a large class of EUV sources. Voyager has observed three cataclysmic variables in outburst, SS Cyg, U Gem and VW Hyi. No EUV emission (integrated flux $< 2 \times 10^{-11}$ ergs cm^{-2} s^{-1}, between 540 and 740 A) is detected. Descriptions of the SS Cyg and U Gem observations are contained in Polidan and Holberg (1984). In the case of U Gem this EUV upper limit can be translated into a highly model dependent lower limits on the HI column of 10^{17} to 10^{18} cm^{-2} compared with an upper limit of $N_H < 5 \times 10^{18}$ cm^{-2} derived from soft X-ray observations (Córdova et al. 1984). The failure to detect any of the cataclysmic variables in the EUV with Voyager is significant but perhaps even more important are the Voyager FUV observations (Polidan and Holberg 1984) which indicate a substantial flattening of the outburst energy distributions of all three objects below 1200 A. The clear implication of these observations is that little intrinsic EUV flux is actually emitted and that the FUV and soft X-ray fluxes arise from separate regions. Thus while cataclysmic variables may represent significant sources at 100 or 200 A, they have a diminished prospect for detection at longer wavelengths.

FUV OBSERVATIONS.

In addition to the Voyager observations of the subluminous stars discussed in the previous sections there exists a large body of observational data on luminous O and B stars. While none of these objects exhibits any detectable EUV emissions, the ability to observe down to the Lyman limit represents a unique opportunity to explore the effects of interstellar extinction below 1200 A. The only data currently available at these wavelengths is a study involving four, reddened-unreddened, pairs of stars observed with Copernicus (York et al. 1973). In Figure 3 we show an extinction curve derived from Voyager 2 of one pair of the stars observed by Copernicus (ξ Per and 15 Mon). Compared with this observation are the extinction data of York et al. and older OAO-2 data. Over most of the wavelength range agreement is good, as might be expected. Shortward of 1140 A however, the results diverge with Voyager extinctions lying higher than the Copernicus measurements. The simple explanation for this divergence is that at the spectral resolution of Voyager (~25 A) it is not possible to distinguish narrow bands of continuum which are free from absorption due to interstellar H_2 bands. In effect extinction, as measured by Voyager, has two components, absorption due to interstellar dust and interstellar H_2. In spite of the fact that what is being measured is a low resolution convolution of absorption due to both dust and H_2, initial analysis has shown that a separation of these two components is practical through modeling. This separation is aided by the fact that, at Voyager resolution, H_2 absorption has a characteristic wavelength dependence which manifests itself in a broad 'absorption trough' centered on 1000 A.

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TABLE 1

Voyager Observations of DA White Dwarfs

	Object	Type	T_{eff} (K)[1]	V	ℓ^{II}, b^{II}	D (pc)[2]	S/C[3]	EUV[4]	Ref.
1.	CoD-38°10980	DA2	24,700	11.00	342,7	15	2	—	
2.	Sirius B	DA2	27,000	8.30	227,-9	2.7	1,2	<2.6	Holberg, Wesemael, Hubený (1984)
3.	EG 118	DA2	31,400	13.45	359,24	40	2	—	
4.	GD 394	DA2	33,000	13.09	91,1	30	1	—	
5.	GD 71	DA1	34,800	13.06	192,-5	45	1	—	
6.	GD 659	DA1	38,500	13.36	299,-84	40	1,2	—	Holberg and Wesemael 1984
7.	GD 153	DA1	50,000	13.42	317,85	40	1,2	0.8	
8.	HZ 43	DAO	55,000	12.86	54,84	63	1,2	3.8	Holberg et al. 1980a
9.	GD 246	DAO	55,000	13.11	87,-45	40	1,2	<0.3	
10.	G191 B2B	DAO	62,500	11.78	156,7	48	1,2	3.5	Holberg et al. 1980b
11.	Feige 24	DAO	70,000	12.25	166,-50	90	1,2	?	

Notes
1. Temperatures determined from either Koester, Schultz and Weidemann (1979) or Voyager FUV fluxes.
2. Distances are from either measured parallaxes or absolute magnitudes (McCook and Sion, 1984).
3. Voyager 1 or 2.
4. Measured integrated EUV flux in the 540 to 740 Å band in units of 10^{-10} ergs cm^{-2} s^{-1}. No entry implies a preliminary upper limit of 5 x 10^{-11} erg cm^{-2} s^{-1}.

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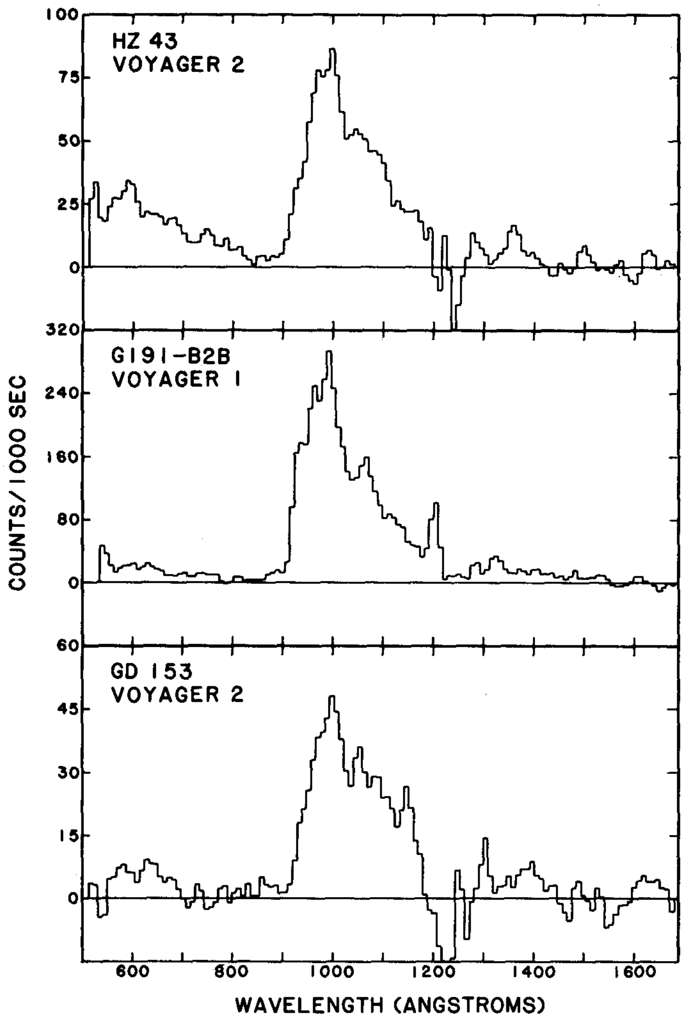

Fig. 1.—A comparison of the count rate spectra for the three hot white dwarfs which have been detected between 500 and 912 A by Voyager.

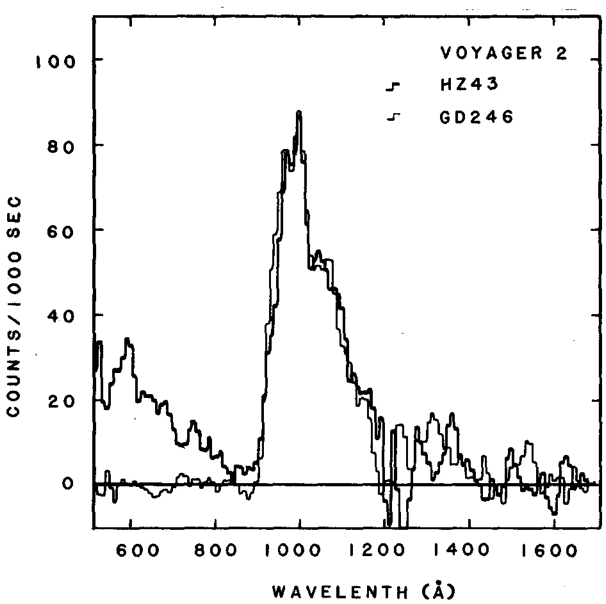

Fig. 2.—A comparison of two very similar hot white dwarfs, HZ 43 and GD 246, as observed with Voyager 2. Longward of 912 A the two stars are virtually identical. Shortward of 912 A HZ 43 shows strong EUV emission, which is due to the low HI column density in the direction of HZ 43 ($N_{HI} = 3.9 \times 10^{17}\ cm^{-2}$). For GD 246 the corresponding HI column must be greater than $2.8 \times 10^{18}\ cm^{-2}$.

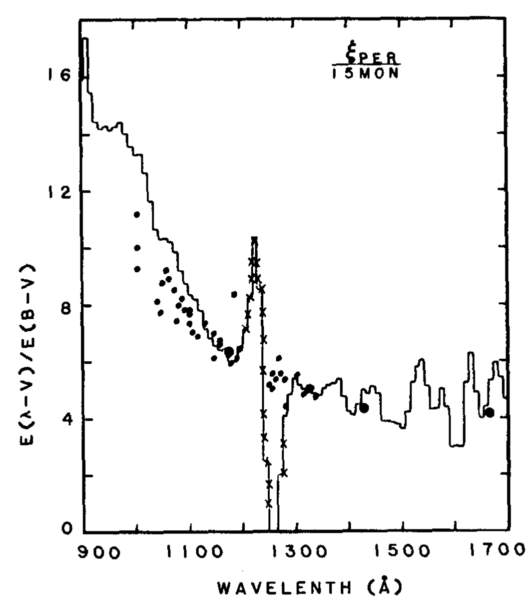

Fig. 3.—The interstellar extinction curve determined for a reddened (ξ Per) and unreddened (15 Mon) pair. Here a Voyager based determination (histogram) is compared with the data of York et al. (1973) (light dots) from Copernicus. The heavy dots correspond to earlier OAO-2 data. The Voyager data is in agreement with that of Copernicus down to ~1140 Å where the effects of absorption of the H_2 bands become significant. The Copernicus reddening determination was derived from high resolution data obtained between the H_2 band features. Voyager data include H_2 absorption blended with the effects of reddening from interstellar dust. Through modeling these two components can be separated in Voyager data and the interstellar reddening curve extended out to the Lyman limit and useful measurements of H_2 columns obtained.