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# FAR-ULTRAVIOLET BACKGROUND OBSERVATIONS AT HIGH GALACTIC LATITUDE. II. DIFFUSE EMISSION

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## ABSTRACT

A single spectrum, of extremely long integration time, is used to place stringent new limits on the diffuse far-UV background in the 500–1200 Å region. This spectrum, obtained in the vicinity of the North Galactic Pole with the *Voyager 2* ultraviolet spectrometer, can be explained solely on the basis of resonant scattering from interplanetary H I and He I. Limits on any additional sources of sky background radiation corresponding to 100–200 photons $cm^{-2}$ $s^{-1}$ $sr^{-1}$ $Å^{-1}$ for continuum emission and 6000 photons $cm^{-2}$ $s^{-1}$ $sr^{-1}$ for line emission are demonstrated. Comparisons of these upper limits with existing measurements and various potential source mechanisms are discussed. The first detection of resonantly scattered interplanetary H I Lyman-$\gamma$ (973 Å) emission is reported.

*Subject headings:* cosmic background radiation — galaxies: Milky Way — ultraviolet: general

## I. INTRODUCTION

Measurements of the far-ultraviolet diffuse background below 1200 Å are of considerable interest. The far-ultraviolet radiation field, in particular for energies above 13.6 eV, may control the ionization balance of the interstellar medium. At high Galactic latitudes the principal sources of this emission are expected to be continuum starlight scattered from interstellar dust, and molecular Lyman and Werner band emission from fluorescing $H_2$. In addition, there may also be observable line emission from ionized species in a hot component of the interstellar medium. Emission lines from such a hot plasma may already have been detected at longer wavelengths (Feldman, Brune, and Henry 1981).

Relatively few background observations have been reported in the wavelength range from 500 to 1200 Å, and those which have been reported are for the most part broad-band photometric measurements. This is in contrast to the region longward of 1200 Å, where a considerable number of photometric and spectrophotometric measurements have been reported (see Paresce and Jakobsen 1980 for a recent review). The earliest background observations below 1200 Å were those of Belyaev *et al.* (1971) from *Venera 5* and *6*. These experiments, which employed Geiger counters having large fields of view (FOVs), sensitive in the 1050–1180 Å band, reported intensities between $3.6 \times 10^4$ and $1.7 \times 10^3$ photons $cm^{-2}$ $s^{-1}$ $sr^{-1}$ $Å^{-1}$. (All continuum intensities hereafter are expressed in units of photons $cm^{-2}$ $s^{-1}$ $sr^{-1}$ $Å^{-1}$, called "CU.") More recently, Bixler, Bowyer, and Grewing (1984) obtained observations in the 1040–1080 Å band with a narrow (0.23 $deg^2$) FOV, which yielded an upper limit of 9700 CU at high Galactic latitudes. A similar upper limit in the 912–1050 Å band is also obtained by Opal and Weller (1984).

The only spectrophotometric results at these wavelengths are those of Sandel, Shemansky, and Broadfoot (1979). They discussed a series of early interplanetary cruise spectra made with the *Voyager 1* and *2* ultraviolet spectrometers (UVSs). These observations, obtained at low and mid Galactic latitudes, contained either *no* or only modest diffuse background intensities. At low Galactic latitudes ($|b| < 25°$), typical brightnesses were ~4000 CU, while at mid latitudes ($25° < |b| < 45°$), upper limits of 500 CU were obtained. As we shall see, the *detected* signals in Sandel, Shemansky, and Broadfoot (1979) are characteristic of stellar continua and reflect either an unresolved stellar component or scattered diffuse starlight. The high Galactic latitude results presented here represent substantial improvements to the upper limits reported by Sandel *et al.*

In addition to diffuse continuum emission, potential sources of diffuse molecular band and atomic line emission exist in the interstellar medium. Duley and Williams (1980) have proposed fluorescent emission from $H_2$ as a significant contributor to the observed far-ultraviolet background below 1800 Å. Following this, Jakobsen (1982) showed that the reported correlations between 1500 Å and 1700 Å background measurements (Paresce, McKee, and Bowyer 1980; Maucherat-Joubert, Deharveng, and Cruvellier 1980) could be explained by a combination of starlight scattered by interstellar dust and $H_2$ fluorescence. A background component due to $H_2$ fluorescence would have a characteristic spectral signature, particularly in the 912–1200 Å region.

Line emission from highly ionized species in a hot component of the interstellar medium can also contribute to the diffuse far-UV background. Feldman, Brune, and Henry (1981) have reported the possible detection of such a background component from a rocket observation in several directions near the North Galactic Pole. Identifications were made of diffuse emission lines due to N IV $\lambda$1487, C IV $\lambda$1549, and O III $\lambda$1663 in low-resolution spectra ($\Delta\lambda \approx 60$ Å). An additional feature was also identified as a blend of Si IV $\lambda$1398 and O IV $\lambda$1406. Respective intensities of these lines were 10,000, 8000, 17,000 and 9500 photons $cm^{-2}$ $s^{-1}$ $sr^{-1}$ (hereafter 1 photon $cm^{-2}$ $s^{-1}$ $sr^{-1}$ = 1 "line unit," LU). The authors argue convincingly against a terrestrial source of this emission and suggest it arises from a hot Galactic halo. Paresce, Monsignori Fossi, and Landini (1983) have shown that the observed intensities are compatible with hot plasma emission models, but only for a restricted range of temperature ($1.6 \times 10^5 < T < 2.0 \times 10^5$ K) and emission measure (0.4–0.6 $cm^{-6}$ pc). The emission spectrum from such a plasma will additionally produce strong emission lines in the 912–1200 Å region

(Paresce, Monsignori Fossi, and Landini 1983). Further, if the absorbing column of interstellar H I is interspersed with the emitting material, detectable emission from lines shortward of the Lyman limit (912 Å) may result. Such models have been calculated by Labov, Martin, and Bowyer (1984).

In this paper a very sensitive observation of the far-UV background, near the North Galactic Pole, is presented. This observation was obtained in the outer solar system, near the orbit of Saturn, by the *Voyager 2* UVS and covers the 500–1200 Å wavelength range. It consists of a large number of spectra, recorded over a 44 day period, which have been co-added to produce a single spectrum of extremely long duration. This spectrum can be uniquely decomposed into constituent parts representing instrumental dark counts and a simple emission line spectrum due to resonant scattering from H I and He I in the interplanetary medium. The residual signal, following removal of these components, is a flat, null spectrum showing no evidence of diffuse emission, either line or continuum. In the following section the procedures used to decompose this spectrum are discussed. In § III upper limits are placed on various sources of the far-UV sky background and compared with previous results. Additional *Voyager* sky background observations obtained along other lines of sight exist and will be discussed at a later date. Many of these observations, particularly at lower Galactic latitudes, do contain detectable flux longward of the Lyman limit.

## II. OBSERVATIONS AND ANALYSIS

The observations on which this paper is based have been previously described in Holberg and Barber (1985, hereafter Paper I). In that study four individual high Galactic latitude observations were used to place limits on far-UV emission from the Coma Cluster of galaxies. This was a purely differential measurement which sought an emission enhancement associated with the Coma Cluster. No evidence of any such emission was detected, and all four spectra were found to be virtually identical except for a time-varying Ly$\alpha$ component, of interplanetary origin. The spatial homogeneity demonstrated in Paper I (see Fig. 2 therein) is used here to justify the combination of all four observations into a single spectrum with a total integration time of 1,508,198 s ($\sim$2.5 weeks). The resulting count rate spectrum is shown in Figure 1. As mentioned in Paper I, there are several readily apparent components to this spectrum. They are the H I Ly$\alpha$ (1216 Å), Ly$\beta$ (1026 Å), and He I (584 Å) lines arising from the resonant scattering of solar photons from interplanetary H I and He I. Together with instrumental dark counts, these lines dominate the spectrum in Figure 1.

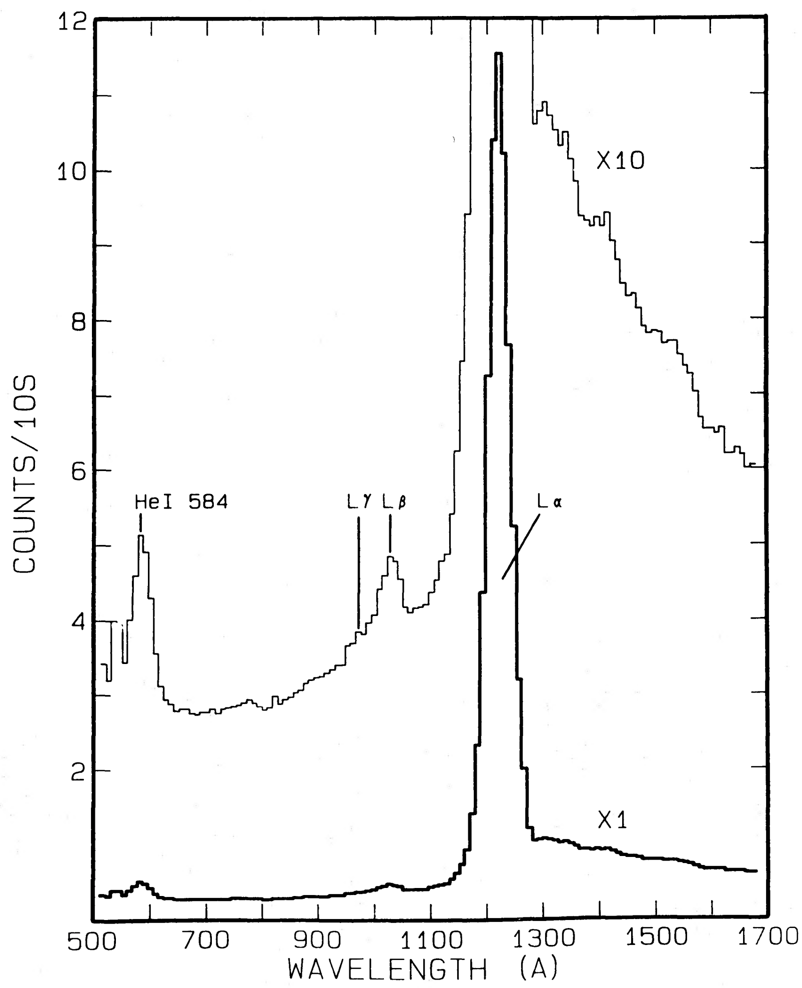


FIG. 1.—*Voyager 2* sky background spectrum representing the average count rate over a period of 1,508,198 s. Upper spectrum multiplied by a factor of 10 to illustrate structure. Emission lines due to H I Ly$\alpha$ (1216 Å), Ly$\beta$ (1026 Å), Ly$\gamma$ (973 Å), and He I $\lambda$584 are indicated.

### *a) Instrumental Dark Counts*

The dark, nonphoton, count rate of the UVS is established by radiation-induced events occurring within the microchannel plate array stage of the detector. The primary source of this radiation is $\gamma$-rays arising from the radioactive decay of the $^{238}$Pu and actinide contaminants within the spacecraft's radioisotope thermoelectric generators (RTGs). The characteristic noise spectrum produced by this radiation is shown in Figure 2. It exhibits the following features. First, to within a few percent, it is constant with time. Measurements made when the UVS was targeted to the shadowed calibration plate on the spacecraft in 1980 April and 1984 August show essentially no change in either the spectral shape or level of this background. These 1980 and 1984 measurements are compared in Figure 2. Second, it exhibits 30% variations in background count rate, *but not spectral shape*, with the articulation attitude of the spacecraft scan platform on which the UVS is located. This property of the background is explained simply by the fact that the RTGs and the UVS are located on separate booms projecting from opposite sides of the spacecraft. The RTGs thus effectively appear as a point source to the UVS. Approximately 14 g $cm^{-2}$ of shielding is provided by the UVS detector housing (as illustrated in Fig. 3 of Broadfoot *et al.* 1977). However, other science instruments sharing the scan platform with the UVS constitute a substantial source of "shadowing" for the detector. Thus, the effective shielding depends on the attitude of the detector with respect to the direction of the RTGs. Due to the complex geometry relating to the RTGs, shadowing from other instruments on the scan platform, and the UVS detector, it is not practical to compute a dark count rate for a given attitude. Rather, it is sufficient to multiply the dark count spectrum by a scalar constant and then to subtract the result from the sky background spectrum. This scalar is regarded as a free parameter to be chosen by fitting individual spectra. In practice, its value is always near unity, and in the sky background spectrum treated here it is 0.8415. The uniqueness of this procedure and its possible effect on the final results are discussed in § III.

### *b) Instrumental Scattering*

Removal of the dark counts yields a spectrum (Fig. 3) comprising only photon events. The principal features of this spectrum are four interplanetary emission lines and their

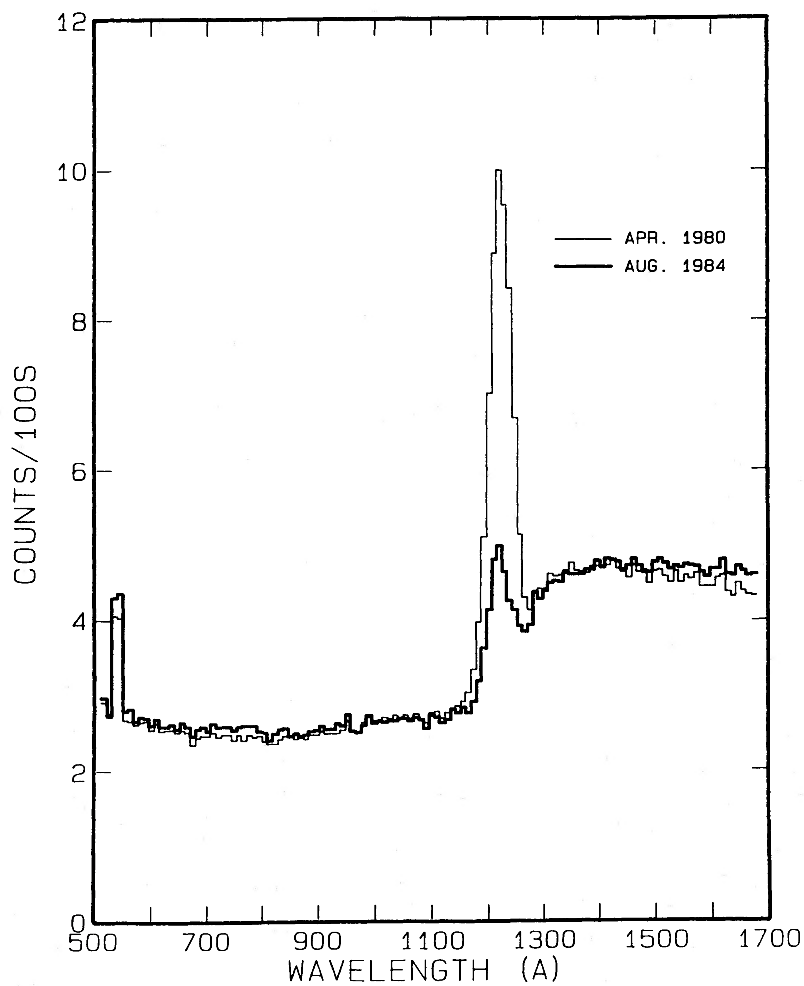


FIG. 2.—Comparison of instrumental dark count spectra from 1980 and 1984, obtained while the UVS airglow port was pointed toward a calibration plate within the solar shadow of the spacecraft. A residual Ly$\alpha$ signal, due to a diffuse reflection of the sky background from the calibration plate, is present at two different intensities. The remainder of the signal is due to $\gamma$-ray–induced counting within the microchannel plate stage of the UVS detector. These $\gamma$-rays originate on board the spacecraft itself. The abrupt increase in count rate longward of $\sim$1300 Å is produced by radiation-induced fluorescence from the $MgF_2$ substrate of the photocathode covering that portion of the detector. The integration times are 813,430 s (1980) and 794,520 s (1984). No significant change has occurred in this background over the 4 yr period.

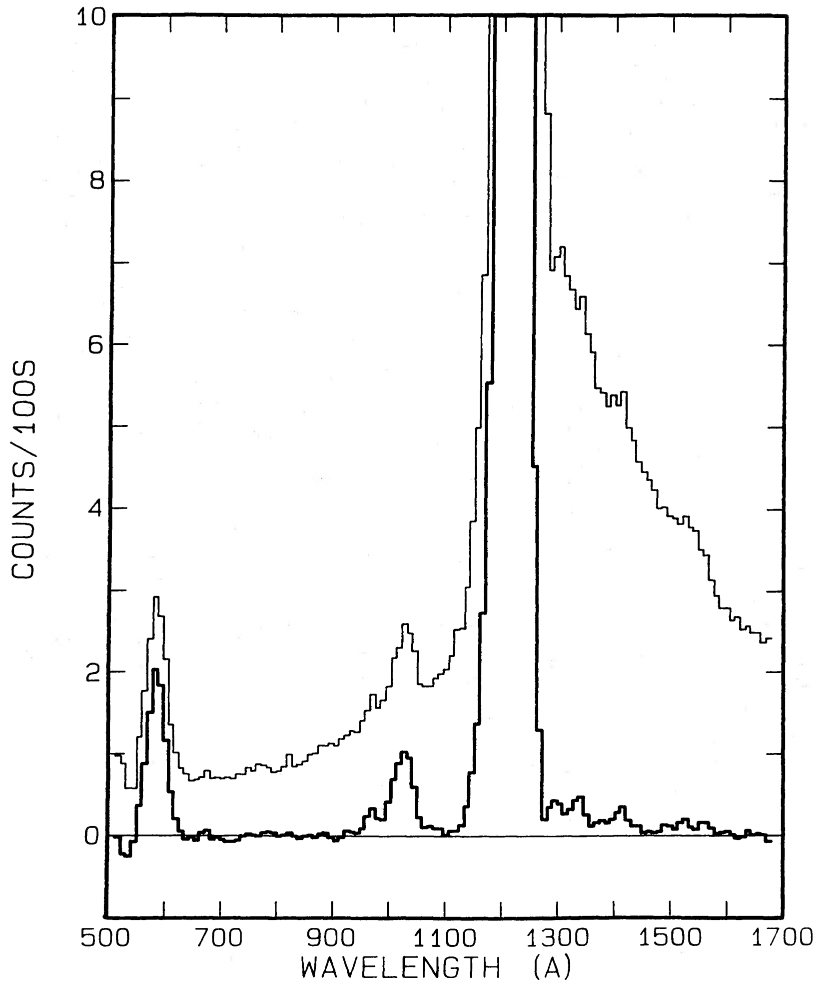


FIG. 3.—Two successive stages in the analysis of the background spectrum from Fig. 1. First (*upper plot*), the result of directly subtracting a scaled ($\times 0.8415$) background spectrum (minus Lyα signal) from Fig. 2. Second (*lower plot*), the result of removing instrumental scattering from the remaining photon signal. Removal of instrumental scattering is accomplished with a $126 \times 126$ element matrix operator developed from laboratory measurements of scattering within the flight instrument. The lower spectrum contains the interplanetary emissions lines due to Lyα, Lyβ, Lyγ, and He I.

associated broad, low-level, scattering wings, predominantly that of Lyα. In practice, the pseudocontinuum produced by scattering from these lines can be removed to a high degree of accuracy. The technique employed in removing scattered light has been previously discussed in detail in Broadfoot *et al.* (1981) as well as in Shemansky, Sandel, and Broadfoot (1979) and Sandel, Shemansky, and Broadfoot (1979). Briefly, the instrumental response to scattering from line or continuum sources is modeled by a $126 \times 126$ element matrix which describes the count rate response at instrumental channel $j$ to an observed signal centered at channel $i$. This matrix operator is completely empirical, having been determined from laboratory scattering measurements of 50 individual emission lines covering the entire band pass of the flight instrument. Eight years of flight experience with this scattering matrix (and a similar one appropriate to *Voyager 1*) yields considerable confidence in its ability to accurately model scattering within the instrument. A wide variety of line and continuum sources have been observed with both *Voyager* instruments, including Jovian torus and Cygnus Loop emission, the rich Lyman and Werner $H_2$ band emissions of Jupiter and Saturn, and a large sample of stars of various types. Under all these circumstances scattering within the instrument has been successfully modeled.

Scattered light is removed from *Voyager* spectra in a self-consistent manner through the use of a "descattering" matrix, which is simply the mathematical inverse of the scattering matrix. Application of this inverse matrix operator is a standard reduction step in the analysis of all *Voyager* spectra. Perhaps one of the most severe reliability tests of the scattering removal process is the ability to remove scattered light from the Lyman continuum region of a hot star. The energy distribution of a hot, unreddened, star is abruptly truncated at the Lyman limit (912 Å) by the opacity of the interstellar medium to the extent that virtually all stars possess *no detectable flux* shortward of 912 Å. The removal of stellar continuum scattered into wavelength channels shortward of 912 Å is illustrated in Figure 4 for the case of the bright B2 III star β Lup, where the inverse scattering matrix has been applied. The transition in the spectrum at 912 Å corresponds to the basic instrumental resolution. Measurement of this, and other stellar observations, shows that 93% of the scattered light has been removed from the Lyman continuum region. It is useful to recall the point made earlier, that the scattering matrix was developed from measurements of *monochromatic emission lines.* Its ability to correctly model the abrupt transition in a strong stellar continuum is good evidence of its accuracy. Finally, it

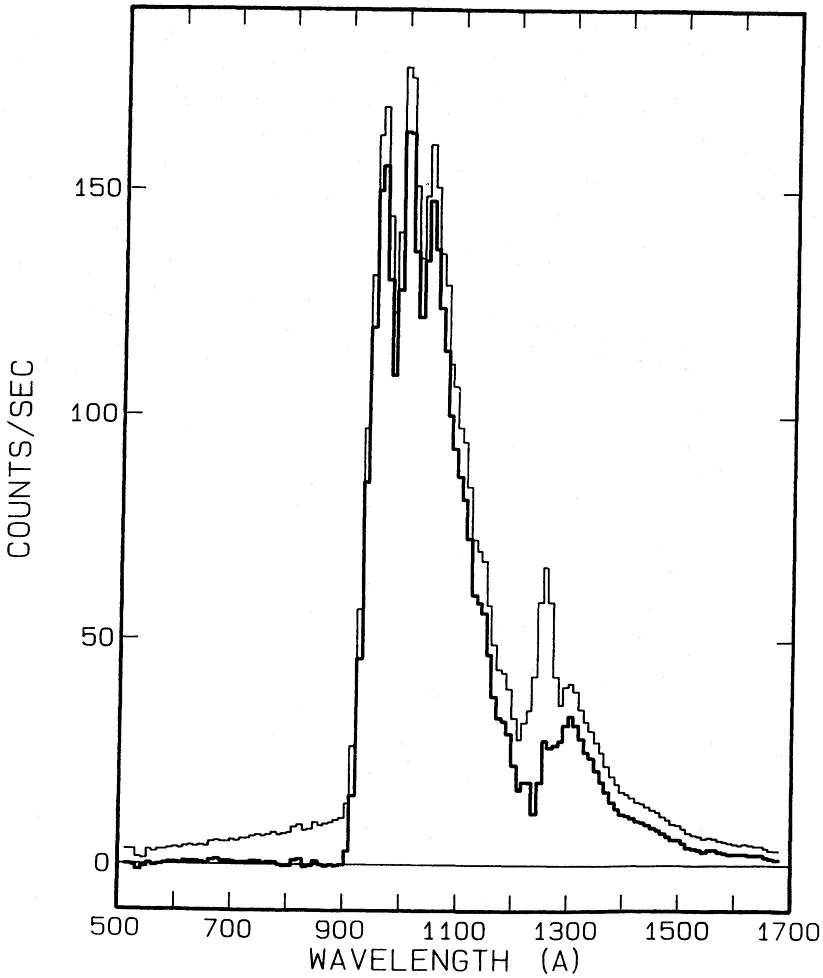


FIG. 4.—Count rate spectrum of $\beta$ Lup, illustrating the removal of instrumental scattering. The light and heavy histograms show results before and after application of the descattering matrix respectively. Consideration of the 600–900 Å region indicates that descattering succeeded in removing over 93% of the light scattered into the Lyman continuum region. Similar results are routinely obtained on other bright stars of differing far-UV energy distributions.

should be pointed out that the *Voyager* instruments employ low-noise, linear, photon-counting detectors and that they contain no moving parts. In addition, the instruments have operated continuously in a stable environment since launch. Under such circumstances it is reasonable to expect that instrumental scattering can be removed from observations to the extent that it can be characterized by laboratory measurement.

The lower plot in Figure 3 shows the result of removing the effects of scattered light. The resulting four interplanetary emission lines are now readily apparent. Also apparent is the lack of any significant continuum.

### *c) Interplanetary Emission Lines*

The four emission lines evident in Figure 3 were earlier identified as arising within the interplanetary medium. The source of these lines is resonance scattering from solar lines by neutral H and He, of interstellar origin, entering the heliosphere due to the motion of the Sun with respect to the local interstellar medium. Diffuse line emission from this material is present in all directions and hence is a component of virtually all *Voyager* spectra. Previous *Voyager* observations of Ly$\alpha$, Ly$\beta$ and He I $\lambda$584 are discussed in Sandel, Shemansky, and Broadfoot (1978, 1979) and Shemansky, Sandel, and Broadfoot (1979). The presence of the faint Ly$\gamma$ line seen in Figure 3 represents the first reported detection of this feature in the interplanetary background.

The intensities of these four lines are observed to vary as a function of both the line of sight and solar activity (Paper I; Shemansky, Judge, and Jessen 1984). The line ratios also exhibit subtle variations in response to solar activity and the differences in the radiative transfer of the lines within the interplanetary medium. For example, the Ly$\alpha$ line is optically thick, while the Ly$\beta$ and Ly$\gamma$ lines are optically thin in the interplanetary medium. Having identified the origin of these four lines, they can be removed from the background spectrum in an effort to detect the presence of any additional components of the far UV background. The removal of these lines is shown in Figure 5. The procedure consists of synthesizing the instrumental response to the four lines and scaling the intensities to match the observed lines. In line units these intensities for Ly$\alpha$, Ly$\beta$, Ly$\gamma$, and He I $\lambda$584 are $8.6 \times 10^7$, $1.9 \times 10^5$, $4.5 \times 10^4$, and $9.6 \times 10^4$ LU. Here the concern is with the residual spectrum following the removal of these lines. As can be seen in Figure 6, this residential spectrum contains no structure except for a feature centered on Ly$\alpha$ and due to the incomplete removal of this extremely intense line. Excluding this feature, the remaining spectrum is fully consistent with count statistics

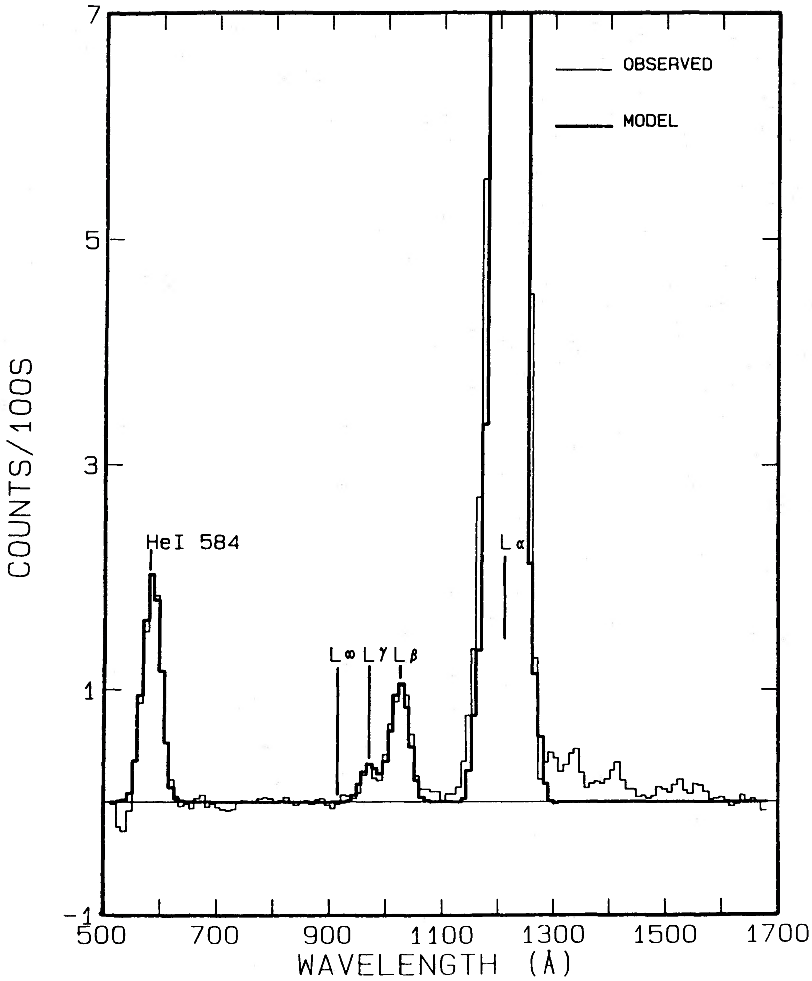


FIG. 5.—Residual spectrum from Fig. 3 (*heavy line*) compared with the instrumental response to the four identified lines (*light line*). Intensities of the synthetic lines are Ly$\alpha$ ($8.6 \times 10^7$ LU), Ly$\beta$ ($1.9 \times 10^5$ LU), Ly$\gamma$ ($4.5 \times 10^4$ LU), and He I $\lambda$584 ($9.6 \times 10^4$ LU). This is the first reported detection of interplanetary Ly$\gamma$.

alone. In fact, the residual spectrum in Figure 6 is approximately the same as those arrived at in Paper I from the direct differencing of the four background spectra which have been combined here.

Having reduced the *Voyager* background spectrum to a dark count contribution and a simple four-line emission spectrum, it is natural to inquire about the uniqueness of this decomposition. One way to answer this question is to perform the same decomposition on different spectra obtained in the same region of the sky but acquired at various times over a period of several years. For such spectra the strength of the interplanetary lines will change (due to solar activity), but, because the same area of the sky is being viewed and therefore the UVS detector has virtually the same orientation with respect to the RTGs, the dark count background will remain unchanged. Such a test has been performed on several background observations acquired within 7° of the North Galactic Pole and spread over the period 1979–1983. These spectra had integration times of between 40,000 and 200,000 s and are characterized by interplanetary line intensities which vary by +20% to −10% with respect to those in the current background spectrum. In each case a successful decomposition was possible using the *same* dark count spectrum and scalar multiplier.

## III. DISCUSSION

### *a) Upper Limits to the Continuum Background*

One significant aspect of the residual count rate spectrum arrived at in the previous section is the complete absence of any stellar signature. The *Voyager* spectrometers are virtually blind to stellar sources having energy distributions corresponding to a spectral type later than about A2. Hotter stars, however, produce an unambiguous spectral signature in UVS data. A good example of the UVS response to a faint stellar source is the count rate spectrum of the DO white dwarf HZ 34 ($V = 15.66$, $T_{\rm eff} = 50{,}000$ K) shown in Figure 7. This spectrum, obtained shortly after the background observations discussed here, consist of 45,620 s of on-axis stellar data from which 93,312 s of adjacent sky background has been subtracted. As can be seen in Figure 7, the stellar continuum rises abruptly from the noise near ~1150 Å, peaks at 970 Å, and cuts off sharply at 912 Å. The lack of observable continuum at longer wavelengths results from the relatively low instrumental sensitivity beyond 1200 Å. On an absolute scale, the HZ 34 continuum in Figure 7 peaks at 0.047 photons cm$^{-2}$ s$^{-1}$ Å$^{-1}$; averaged over the $2.65 \times 10^{-5}$ sr UVS FOV, this corresponds to 1770 CU. Much fainter hot stars have been detected with the UVS. From observed UVS spectra of hot B stars it is

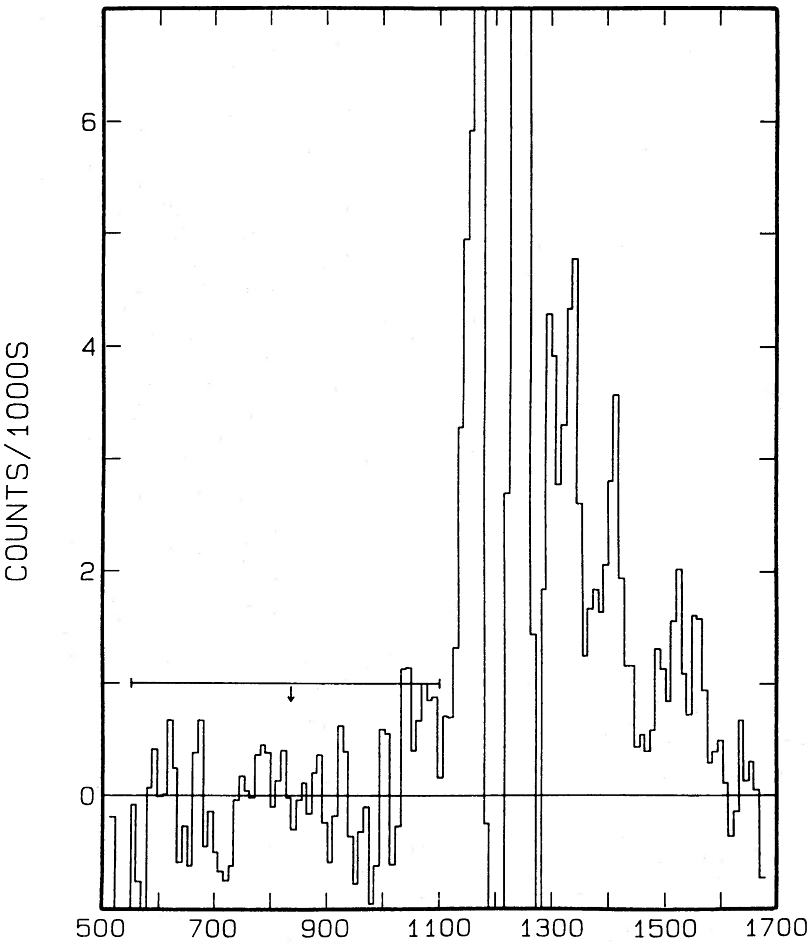


FIG. 6

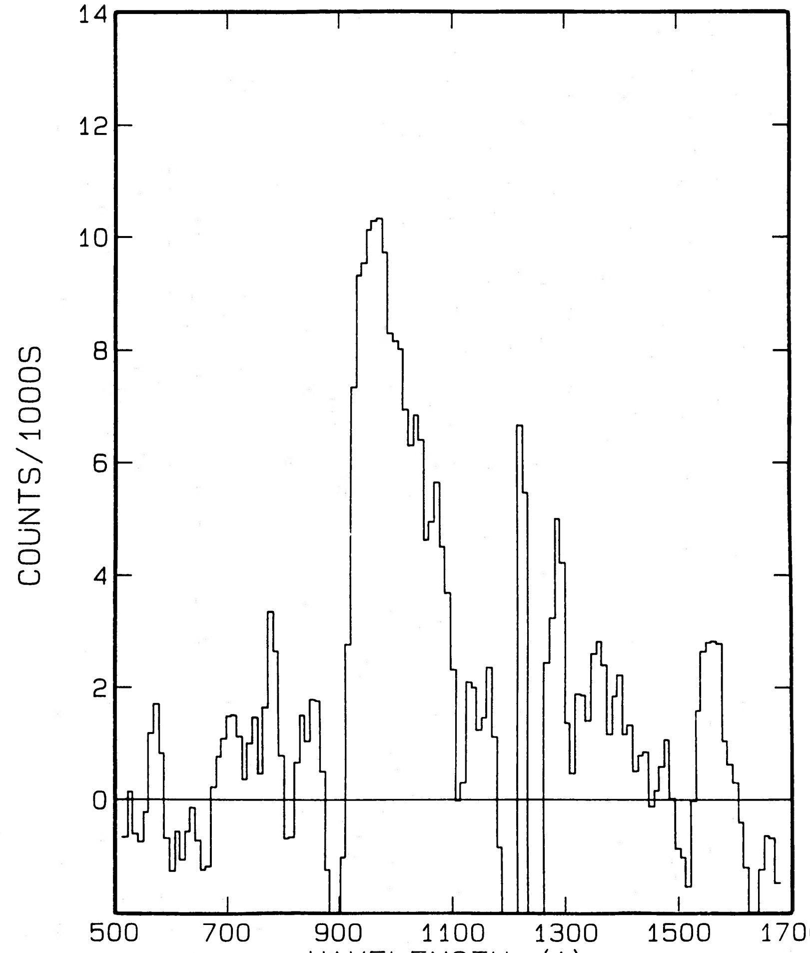


FIG. 7

FIG. 6.—Result of removing the four interplanetary emission lines from the residual spectrum shown in Fig. 5. The centrally reversed feature at $\sim 1200$ Å results from the less than perfect removal of the very strong Ly$\alpha$ line. The final result is consistent with expected count studies. No line or continuum emission is seen. Note the lack of any discontinuity at the Lyman limit (912 Å).

FIG. 7.—Count rate spectrum of the faint DO white dwarf HZ 34. Adjacent sky background has been subtracted and instrumental scattering removed. A similar result can be obtained using the same spectral decomposition techniques employed on the North Galactic Pole background spectrum.

possible to establish an upper limit of 100 CU on any diffuse stellar continuum in the spectrum of Figure 6. Such a level would correspond to the presence of one *unreddended* B0 star of visual magnitude 17 in the UVS FOV.

This lack of any stellar signature is in contrast to some of the previous *Voyager* background observations described by Sandel, Shemansky, and Broadfoot (1979). They discussed early *Voyager 1* and *2* observations made in a number of different directions. One significant characteristic of these observations was the presence of measurable continuum intensities in *several* directions. In particular, one spectrum, analyzed in detail, showed a strong residual continuum in the 900–1200 Å band. This spectrum, obtained in the direction $l = 183°$, $b = 14°$, has occasionally been interpreted as a measure of a general isotropic far-UV background at these wavlengths. In fact, the actual content of this spectrum (and the others reported by the authors as having a measurable continuum) is clearly stellar. It is even possible to be reasonably specific about the types of stars which are contributing the bulk of the flux. Comparisons of this background continuum with direct *Voyager* observations of a variety of early-type starts (See Fig. 1 of Polidan, Stalio, and Peters 1986) indicate that spectral types B1–B3 dominate, if there is no reddening, or alternately types O–B1 if there is significant reddening. The intensity of the signal corresponds to the equivalent of one unreddened B2 star of magnitude $V = 13$ within the UVS FOV. The authors have ruled out the presence of any identifiable discrete stellar sources in the data, and it is not possible at this stage to discriminate between a background composed of direct light from unresolved stars or a truly diffuse component due to the scattering of starlight from interstellar dust. However, the surprisingly early type nature of the observed spectrum, together with the natural expectation of severe reddening of any stars at the observed intensities, strongly argues in favor of the latter interpretation. In any event, it is the mid Galactic latitude upper limit observations obtained by Sandel, Shemansky, and Broadfoot (1979) and Shemansky, Sandel, and Broadfoot (1979) which are most relevant to discussions of the general far-UV background.

For the high galactic latitude results discussed here it is possible to define an upper limit to a possible far-UV background continuum of a more general nature. Such an upper limit covers the wavelength range 500–1200 Å and is defined by the count rate upper limit of $10^{-3}$ counts $s^{-1}$ shown in Figure 6. The corresponding absolute intensities are presented in Figure 8. This limit formally extends across the entire detector (excluding the Ly$\alpha$ region). However, due to low sensitivity longward of Ly$\alpha$, the corresponding upper limits exceed those of other observers.

A striking aspect of the residual spectrum in Figure 6 is its

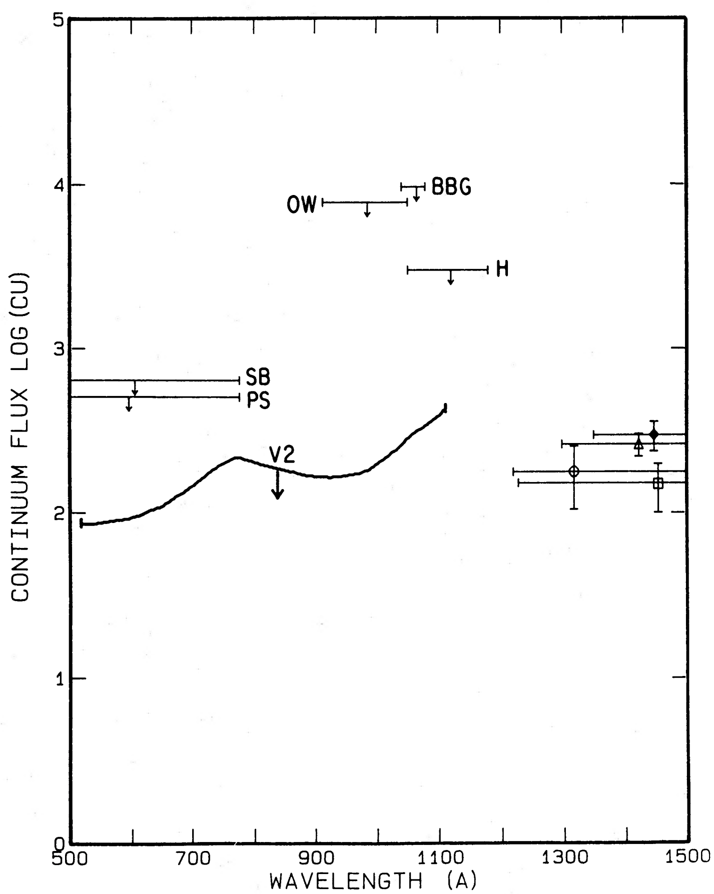


FIG. 8.—Summary of various high-latitude observations of the far-UV sky background. Arrows distinguish upper limits from reported measurements of background flux. Specific upper limits are: V2 (this work), SB (Stern and Bowyer 1979), PS (Paresce and Stern 1981), BBG (Bixler, Bowyer, and Grewing 1984), OW (Opal and Weller 1984), and H (Henry 1973). Measurements of background intensity are Weller 1983 (*circle*), Feldman, Brune, and Henry (1981) (*square*), Henry *et al.* 1978 (*triangle*), and Paresce *et al.* 1979 (*diamond*).

complete flatness and lack of features between 500 and 1150 Å and in particular the total absence of any discontinuity at the Lyman limit (912 Å). It could be argued that the process of removing the scaled dark count spectrum is in some way responsible for this null result and that a true background continuum might have escaped notice. This would however be the case only if such a celestial background had a *count rate* spectrum precisely matching the shape of the removed background spectrum (e.g., essentially flat between 500 and 1150 Å). Such a background spectrum would be highly contrived in that its spectrum in photon units would have to possess a shape matching the inverse of the UVS sensitivity versus $\lambda$ curve. More importantly, it is extremely difficult to imagine a continuum source, or sources, originating any significant distance from the solar system that would not possess a large discontinuity at the Lyman limit.

With the possible exception of Belyaev *et al.* (1971), who report 1050–1180 Å background measurements in several unspecified directions, only upper limits currently exist for components of the high-latitude background in the region between the soft X-ray background and 1200 Å. In Figure 8 the *Voyager* upper limit for the diffuse continuum background is compared with previous upper limits reported from broad-band photometric observations in the range 500–1200 Å. Below the Lyman limit, Stern and Bowyer (1979) obtain an upper limit of 645 CU from the *Apollo-Soyuz* Sn filter (500–775 Å) observations. Paresce and Stern (1981) report a slightly lower (515 CU) revision of the same data. Longward of 912 Å, the most recent result is that of Bixler, Bowyer, and Grewing (1984), who report a limit of 9700 CU obtained with a 1 m rocket-borne telescope in the 1040–1080 Å band. A similar result of 7800 CU is reported by Opal and Weller (1984) for the lowest count rates reported from the *STP 72-1* satellite. This result refers to the 912–1050 Å portion of their pass band. Also shown in Figure 8 is the reported 3010 CU upper limit of Henry (1973) in the 1050–1180 Å band. However, as pointed out by Bixler, Bowyer, and Grewing (1984) on the basis of the reported flux from $\alpha$ Leo, this result should probably be revised upward by at least a factor of 4.

It is also of interest to compare the upper limits presented here, for the wavelength region below 1200 Å, with various far-UV background measurements reported at longer wavelengths. Low-resolution spectrophotometric measurements obtained by Henry *et al.* (1978) and Anderson *et al.* (1979*a*, *b*) concur as to the existence of a diffuse far-UV continuum within the 1200–1700 Å region. The *Apollo 17* measurements of Henry *et al.* (1978) showed a relatively flat continuum with an intensity 263 $\pm$ 40 CU between 1300 and 1525 Å with apparent declines at 1275 and 1625 Å. Using a spectrometer on an *Aries* rocket, Anderson *et al.* (1979*a*, *b*) reported observations on a uniform far-UV background covering the spectral range 1230–1680 Å at an intensity of 285 $\pm$ 32 CU. The *continuum* intensity of this measurement was subsequently revised downward to 150 $\pm$ 50 CU by Feldman, Brune, and Henry (1981), who identified broad spectral features present in the data with diffuse emission lines. The 1275 and 1625 Å declines in the *Apollo 17* spectrum were not present in the *Aries* data. Both experiments had relatively large fields of view (0.044 sr, *Apollo 17*; and 0.0025 sr, *Aries*) and viewed regions of the sky at high Galactic latitude.

Photometric observations from the 1350–1550 Å channel on the *Apollo-Soyuz* EUV telescope (Paresce *et al.* 1979; Paresce, McKee, and Bowyer 1980) have also been reported. The lowest high-latitude count rates reported by these authors correspond to 300 CU. Although such a limit is in apparent agreement with the above results, significant differences remain (Paresce, McKee, and Bowyer 1980). Most significant are the 3–4 times higher intensities measured by *Apollo-Soyuz* in the *particular* directions corresponding to those of Anderson *et al.* and the "patchiness" of the high-latitude background intensity seen by *Apollo-Soyuz*. This latter effect, which corresponds to significant intensity variations on the scale of the $\sim 2\overset{\circ}{.}5$ FOV, is shown to be positively correlated with neutral hydrogen column densities (Paresce, McKee, and Bowyer 1980). Additional broad-band (1220–1500 Å) photometric measurements have been reported by Weller (1983) from the *Solrad 11* satellite. These observations report an intensity of 180 $\pm$ 75 CU near the North Galactic Pole. All three experiments, which viewed adjacent regions within 20° of the North Galactic Pole, are thus in general agreement concerning existence of a diffuse high-latitude background with an intensity between 150 and 300 CU.

A frequently discussed source of the background observed at longer wavelengths is the backscattering of starlight from high-latitude dust. Indeed, significant correlations have been shown to exist between 21 cm H I columns and observed UV background intensities in the 1400–1700 Å region (Paresce, McKee, and Bowyer 1980; Maucherat-Joubert, Deharveng and Cruvellier 1980; Jakobsen 1982; Zvereva *et al.* 1982). In order for backscattering to be a significant component of the high-latitude background, the interstellar dust must scatter UV photons fairly isotropically and have a relatively high albedo (Jura 1979; Jakobsen 1982).

It is apparent from the *Voyager* upper limit in Figure 8 that the high-latitude background intensities observed at longer wavelengths do not extend significantly shortward of 1200 Å, at levels about 100 CU. This result implies that if backscatter is responsible for the observations longward of 1300 Å, then the scattering properties of the dust are substantially different at shorter wavelengths, since the illuminating UV radiation field is not expected to change dramatically between 1500 and 1000 Å (Gondhalekar, Phillips, and Wilson 1980).

### *b*) *Upper Limits to Line Emission*

The measurable presence of interplanetary H I Ly$\gamma$ in the background spectrum in Figure 5 is a good indication of the sensitivity of the present data to diffuse line emission. As mentioned previously, Feldman, Brune, and Henry (1981) reported the detection of a number of relatively intense emission lines in a rocket experiment designed to measure the far-UV background. These emission lines were attributed to a hot component of the interstellar medium. Paresce, Monsignori Fossi, and Landini (1983) have shown that the Feldman *et al.* observation can be consistent with emitting plasma having a limited range of temperature and emission measure. The same emission model proposed by Paresce *et al.* also predicts several prominent emission lines in the 912–1200 Å region. The most intense of these are due to N III $\lambda$991 and close blends of S VI $\lambda\lambda$933.4 and 944.5, O VI $\lambda\lambda$1031.9 and 1037.6, and S IV $\lambda\lambda$1062.7 and 1073.0. Figure 9 shows both the predicted intensities of these lines and the corresponding upper limits which can be derived from the residual spectrum (Fig. 6). The present *Voyager* upper limits are seen to be marginally consistent with the brightest lines predicted by Paresce *et al.* and therefore do not appear to contribute any additional constraints on this particular model of the hot interstellar medium. The Paresce *et*

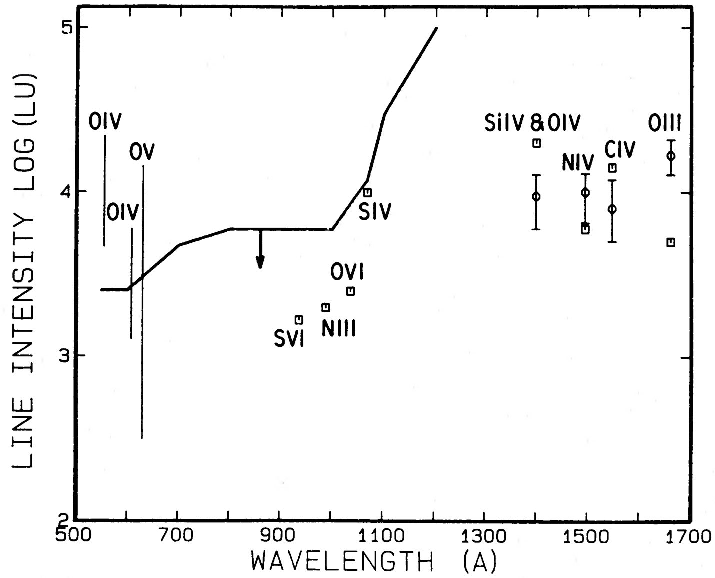


FIG. 9.—Summary of various observations and model predictions of high-latitude diffuse line emission. The observed intensities of the lines reported by Feldman, Brune, and Henry (1981) are indicated by the error bars. The corresponding emission line intensities for the interstellar plasma discussed by Paresce, Monsignori Fossi, and Landini (1983) are indicated by squares. The *Voyager* upper limit in the 500–1200 Å region is shown as a heavy curve. The three lines on the left represent a range of emission line intensities expected from O IV and O V in the particular interstellar medium model discussed by Labov, Martin, and Bowyer (1984).

*al.* model assumes a foreground neutral hydrogen column of $N_{\rm N\,I} = 2 \times 10^{19}$ cm$^{-2}$ and hence predicts no observable emission lines in the 500–912 Å region. If the neutral hydrogen is interspersed with the emitting plasma, absorption in the Lyman continuum region is effectively reduced and EUV emission lines may exist at observable intensities. A range of predicted intensities for one such model is given in Labov, Martin, and Bowyer (1984). Figure 9 compares the Labov *et al.* estimates for three of the more intense lines due to O IV and O V with the present *Voyager* upper limits. Only the O IV $\lambda$554 line appears to be completely ruled out by these results.

In summary, the *Voyager* observations presented here have yielded significant new upper limits on the far-UV background at high Galactic latitude. For diffuse continuum emission, this results in nearly an order of magnitude improvement over previous upper limits. If the high-latitude backgrounds which have been observed longward of 1300 Å are in fact due to backscatter from interstellar dust above the Galactic plane, then the *Voyager* upper limit in the 912–1150 Å region implies the scattering properties of the dust are appreciably different in this wavelength range. The corresponding upper limits for diffuse line emission, while not strongly constraining existing models of a hot diffuse component of the interstellar medium, are nonetheless the lowest yet reported shortward of 1200 Å.

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