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THE COSMIC FAR ULTRAVIOLET BACKGROUND

Stuart Bowyer

Astronomy Department and Center for EUV Astrophysics,
University of California, Berkeley, California 94720

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1. INTRODUCTION

From the beginnings of space research, attempts were made to measure the cosmic far ultraviolet ($\lambda\lambda \approx 1000$ to 2000 Å) background. This work was strongly motivated by the hope that in this waveband a true extragalactic flux could be detected and characterized. Theoretical speculation as to possible sources for this radiation was unconstrained by the available data and included such diverse processes as emission from a lukewarm intergalactic medium, emission from hot gas produced in a protogalaxy collapse phase in the early universe, the summed emission from a star formation burst phase in young galaxies, and photons from the electromagnetic decay of real or hypothetical exotic particles that were produced, or may have been produced, in the early universe.

It was the expectation that all of the problems that had bedeviled attempts to measure the cosmic extragalactic flux in the optical band would be overcome: the zodiacal light would be absent because the Sun's radiation falls rapidly in the ultraviolet, the measurements would be made above the atmospheric airglow, and the difficulty of separating the diffuse background radiation from that produced by stars would be reduced or even eliminated since the ultraviolet-producing early stars would be limited to the Galactic plane.

The first twenty years of measurements, carried out by a number of groups in at least five countries, covered the entire far ultraviolet band, but for a number of technical and astrophysical reasons, these efforts were concentrated on the wavelength band from 1300 to 2000 Å. The results obtained indicated that the flux was uniform across the celestial sphere

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and hence was cosmological in origin. Estimates of the intensity of this flux, however, varied by three orders of magnitude, with no clustering around a mean. For a review of the initial work and a discussion of the reasons for these discrepant results, the reader is referred to the work of Davidsen, Bowyer & Lampton (12) and Paresce & Jakobsen (51). It is clear that a major problem with many of these measurements was the need for an uncertain correction for stellar signals. It is perhaps most useful to state that these initial results provided empirical evidence that measurements of the diffuse far ultraviolet background are intrinsically difficult.

A turning point in the study of this background occurred in 1980, when results were obtained from a far ultraviolet channel of a telescope flown as part of the *Apollo-Soyuz* mission. This instrument had a relatively large throughput and a field of view small enough to make a reasonable attempt at excluding stars from the data set, rather than making a typically large and uncertain correction for their effects. The subset of highest quality data from this experiment exhibited a correlation between intensity and Galactic neutral hydrogen column as derived from 21-cm radio measurements (52). Although these results were criticized on a variety of grounds, they were quickly confirmed by data from a large fraction of the sky obtained with an instrument on the *D2B* satellite. This telescope also had a small field of view and a large throughput (46). These results showed that the vast majority of the far ultraviolet flux was connected with processes in our Milky Way Galaxy and was not, in fact, extragalactic in origin. Although both of these data sets were consistent with a small part of this flux being isotropic, there was no way to determine whether this component was due to residual airglow processes at satellite altitudes, or to processes occurring within the Galaxy, or to extragalactic phenomena.

The realization that much, or even all, of the far ultraviolet background was Galactic in origin fundamentally changed the character of research in this field. Since then substantial progress has been made and the results obtained have had an impact on a wide range of astrophysical problems.

2. THE CORRELATION BETWEEN FAR ULTRAVIOLET BACKGROUND AND GALACTIC PARAMETERS

In the 1980s a number of experiments were carried out to investigate the correlation between the intensity of the far ultraviolet background and parameters associated with the Milky Way Galaxy. The most common association investigated was that with Galactic neutral hydrogen column as derived from 21-cm radio studies. It is important to note, however, that many variables correlate with Galactic neutral hydrogen column, and a correlation of the far ultraviolet intensity with this parameter may only be a consequence of these general relationships. Additional evidence would have to be provided to demonstrate that a correlation between the far ultraviolet intensity and Galactic neutral hydrogen column is, in fact, a direct correlation. This point is addressed later in this section. Despite this caveat, an observed correlation with any Galactic variable would be of profound significance since it would demonstrate that the flux is not extragalactic but is Galactic in origin.

The Berkeley Extreme Ultraviolet Telescope (52) obtained data on this topic with a 37-cm diameter grazing incidence telescope. The telescope had a 2.5° circular field of view and a filter mechanism that was used to select various bandpasses for observation. In addition to the primary extreme ultraviolet bands, the instrument also included a far ultraviolet channel. The bandpass of this channel (1350–1550 Å) was defined by a calcium fluoride filter on the short wavelength side and by the rapid decline in the detector efficiency on the long wavelength side. Because of the rather unusual observing conditions characterizing this joint-nation manned mission, the data obtained were of uneven quality (53). The data set for $|b| > 30°$ (chosen to avoid extensive star contamination) was subjected to an array of screening routines designed to select the subset of the data that had no definable evidence of airglow, zodiacal light, spacecraft glow, or particle contamination. Stellar signals were then removed from these data. In 86% of the data, the stellar correction was less than 20% of the observed count rate. This restricted data set provided clear evidence of a correlation with Galactic hydrogen, though this correlation was not exact. An offset was also found, in that the intensity extrapolated to zero hydrogen column was not zero but ranged (depending on view direction) from about 200 to 600 photons cm^{-2} sec^{-1} str^{-1} $Å^{-1}$ (hereafter continuum units, CU).

Subsequently, Maucherat-Joubert, Deharveng & Cruvellier (46) used data obtained with a far ultraviolet multichannel spectrophotometer flown on the French Astronomical Satellite *D2B-Aura* to search for a correlation with Galactic hydrogen. The bandpass of the spectrophotometric channel employed was 1525–1855 Å. A calcium fluoride filter eliminated the potential contamination of the data with instrumentally scattered hydrogen Lyman alpha radiation. The combination of slit width and satellite rotation gave a $1° \times 2.75°$ field of view per integration period. Data with $|b| > 40°$ were examined in detail. Resolved stars were removed and the signal was corrected for dark current. The resultant data were binned in areas covering 24 to 40 square degrees, depending on the uniformity of the Galactic hydrogen column in the binned area. A correlation of intensity with Galactic hydrogen was found for the overall data set and also for a subset of the data that had a high gradient of hydrogen column. The zero hydrogen column extrapolated to zero intensity was found to be 600 (+0, −250) CU.

Zvereva et al (72) utilized data from a spectrophotometer flown on the Soviet *Prognoz-6* satellite to look for a correlation of this type. The field of view of the instrument was 6°. The bandpass selected for study covered $\lambda\lambda$ 1500 to 1700 Å. Data for $|b| > 15°$ were corrected for a small hydrogen 1216 Å signal and for stellar contributions. A correlation with Galactic hydrogen column was found, with an intensity extrapolated to zero hydrogen column of 470 CU.

Weller (66) obtained data on the far ultraviolet background with a photometer on the *Solrad II* satellite. This photometer had ~0.003 cm^2 effective area and a field of view of 8°. The bandpass of the instrument was ~1230–1500 Å. The observations were made during a relatively brief period between other modes of the experiment. No attempt was made to search for a correlation with Galactic neutral hydrogen column although a large variation with Galactic latitude was noted. A minimum intensity of about 200 CU was found at the North and South Galactic poles.

Joubert et al (36) reanalyzed the far ultraviolet data obtained with the *D2B* satellite using more of the data (all data with $|b| > 30°$) and using improved and extended 21-cm radio data. A strong correlation with neutral Galactic hydrogen was confirmed. It was noted that the distribution of data was not symmetric with respect to the regression line, primarily because of regions with ultraviolet excesses at the higher intensity levels. When these excess flux regions were excluded from the data, the intensity extrapolated to zero hydrogen column was 677 ± 20 CU.

Three photometers sensitive in the far ultraviolet were employed at the focal plane of a one-meter telescope flown on an *Aries* sounding rocket to study this question (34). These photometers covered wavelengths from 1450 to 2400 Å in three bands. The large collecting area of this telescope provided high sensitivity, which permitted the use of a very small field of view ($\frac{1}{2}°$) and virtually eliminated the problem of stellar contamination. The use of three photometers permitted an accurate appraisal of airglow and zodiacal light effects. Data from all three photometers showed a correlation with Galactic hydrogen column. The shortest wavelength photometer spanning the 1450 to 1700 Å range required less than a 10% correction for airglow, and the potential uncorrected stellar signal was less than 10%. Data from this photometer showed a flux extrapolated to zero Galactic hydrogen column of 610 ± 60 CU.

Fix, Craven & Frank (21) used data obtained with an ultraviolet imaging photometer flown on the *Dynamics Explorer I* to study this question. This imager had a bandpass from 1360 to 1800 Å and had a small field of view

(0.32°). A correlation with Galactic hydrogen column was found with an intensity extrapolated to zero hydrogen column of 530 ± 80 CU.

Onaka (48) reported on data obtained with a far ultraviolet imaging detector at the focal plane of a 17-cm Ritchy-Chretien telescope. The instrument was flown on a sounding rocket and a scan of the Virgo cluster was carried out. A correlation of the intensity of the background flux with Galactic hydrogen column was observed, and an extrapolation of this intensity to zero hydrogen column yielded ~ 30 CU. This result was rather uncertain, however, because of the relatively small range of hydrogen column densities scanned.

Lequeux (40) and Perault et al (55) carried out a very detailed reanalysis of the data obtained with the far ultraviolet imager on the French *D2B-Aura* satellite. Great care was taken to account for stellar contributions, and carefully normalized fine-grid 21-cm radio contours were used to generate hydrogen column maps. The resultant data display a close correlation between intensity and Galactic hydrogen with less dispersion than is exhibited in other results.

Murthy et al (47) reported measurements of the far ultraviolet background obtained with the Johns Hopkins far ultraviolet spectrometer that was flown on the Space Shuttle as part of NASA's UVX payload. The Johns Hopkins instrument consisted of two Ebert-Fastie scanning spectrometers fed by off-axis parabolic mirrors. The field of view of these spectrometers was $4° \times 0.3°$. The short wavelength spectrometer covered the spectral range from 1200 to 1700 Å with a resolution of 17 Å. The mirror for this spectrometer was 5.2×7.8 cm. Murthy et al found some, but not conclusive, evidence for a spatially varying background with this instrument.

Hurwitz, Bowyer & Martin (30) obtained data with the Berkeley imaging nebular spectrograph, which was the other instrument in the NASA UVX payload. The Johns Hopkins and Berkeley instruments were co-aligned and operated simultaneously. The Berkeley instrument had a field of view of $0.1° \times 4°$, a resolution of 15 ± 2 Å, and a bandpass from 1400 to 1850 Å. This instrument had a number of advantages for studies of the diffuse ultraviolet background. It employed a photon-counting detector with very low background, and it had a large area–solid angle product that provided high sensitivity and allowed investigation of very low reddening view directions (the instrument was, in fact, some five orders of magnitude more sensitive to extended diffuse radiation than the instrumentation on the *IUE* satellite). The narrow field of view perpendicular to the dispersion direction limited the number of stars that could contribute to the spectra. Those stellar signals that were present could be easily identified and removed from the data because of the imaging capabilities of the instrument. Special care was taken in the design and fabrication of this instrument to assure that stray light from stellar sources and out-of-band scattering would be negligible. Consequently, view directions with relatively high column densities of neutral hydrogen (and with accompanying higher stellar signals) could be investigated. Finally, because the instrument had spectroscopic capabilities, different processes contributing to the background could be identified and treated independently. The intensity of the background obtained with this instrument was strongly correlated with hydrogen column at low hydrogen column densities; at higher column densities, the flux saturated and remained constant thereafter with increasing hydrogen column. The flux extrapolated to zero hydrogen column was 272 ± 13 CU.

One of the key motives for utilizing two co-aligned instruments in NASA's UVX payload was to provide independent measurements of the cosmic far ultraviolet background under identical observing conditions. In Figure 1, I superimpose the data from these two instruments. The solid squares represent the Berkeley data (30) and the hollow triangles the Johns Hopkins results (47). The vertical error bars indicate statistical uncertainties (Berkeley data) or uncertainties in subtracting various backgrounds (Johns Hopkins data). Horizontal errors bars on the Johns Hopkins data, where present, indicate a range of Galactic latitude included in scanned observations. Scanned observations were treated as multiple targets by Berkeley. The Johns Hopkins data span ~1200–1700 Å; the Berkeley data span 1415–1835 Å, excluding high ionization emission lines and H_2 fluorescence concentrated between 1535 and 1655 Å.

In Figure 2, the Berkeley data presented in Figure 1 are plotted against Galactic neutral hydrogen column. The intensity of this flux is seen to be strongly correlated with neutral hydrogen until saturation occurs; thereafter the flux remains constant with increasing hydrogen column.

A summary of all the results discussed above is shown in Table 1. The majority of these data show a correlation of intensity with Galactic latitude and/or neutral hydrogen column indicating the far ultraviolet background is primarily Galactic in origin. Disagreement exists regarding the slope of the correlation, the degree of scatter about the mean, and the intensity of the flux extrapolated to zero hydrogen column. These differences could reflect true astrophysical effects since a variety of mechanisms will produce a diffuse far ultraviolet flux at some level. However, it is unclear whether these observations have reached a level of accuracy that reflects true astrophysical phenomena or if these are simply experimental artifacts.

Finally, I return to the question of the underlying cause of the correlation of far ultraviolet intensity with some Galactic variable. It is clear that the majority of the data summarized in Table 1 are dominated by a cosec *b*

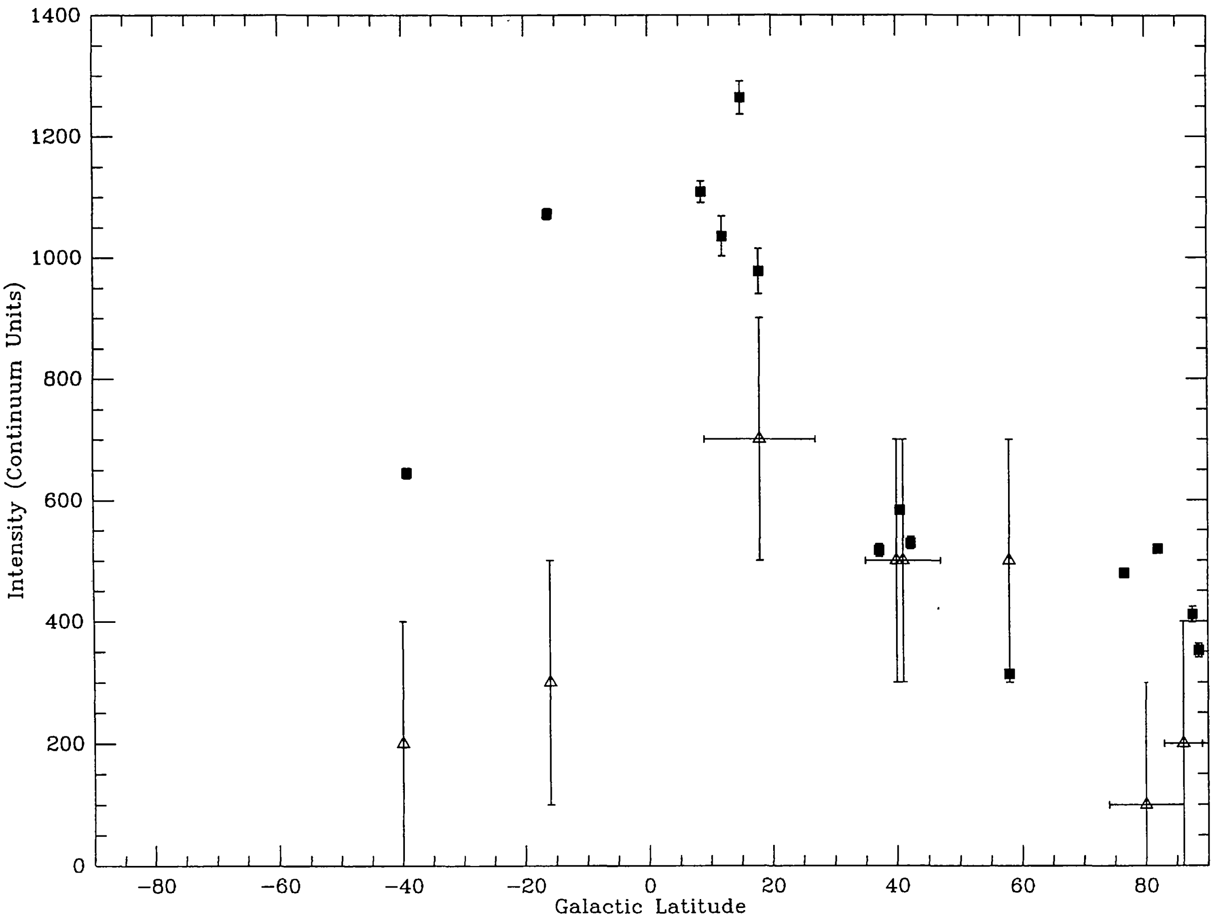

Figure 1 Measurements of the diffuse far ultraviolet background obtained with the co-aligned University of California at Berkeley (UCB) and Johns Hopkins University (JHU) spectrometers flown together as the UVX experiment on the Space Shuttle. The solid squares represent UCB data; the hollow triangles JHU. The vertical error bars indicate statistical uncertainties (UCB) or uncertainties in subtracting various backgrounds (JHU). The horizontal error bars on the JHU data, where present, indicate a range of Galactic latitude included in scanned observations. Scanned observations were treated as multiple targets by UCB.

variation with Galactic latitude, which is expected for any quantity with a plane parallel Galactic distribution. The *D2B* data set as analyzed by Perault et al (55) is of sufficient quality to establish that the far ultraviolet intensities do not correlate with cosec b as well as they correlate with Galactic neutral hydrogen column density. Hurwitz, Bowyer & Martin (30) found the reduced χ^2 of their UVX data was three times better in a dependence with Galactic neutral hydrogen column than with Galactic latitude. As is shown in Figure 2, they also found that their data saturated at a value of $N_{\mathrm{HI}} \approx 10^{21}$ atoms cm^{-2}, which provides an additional clue as to the source of the diffuse far ultraviolet flux.

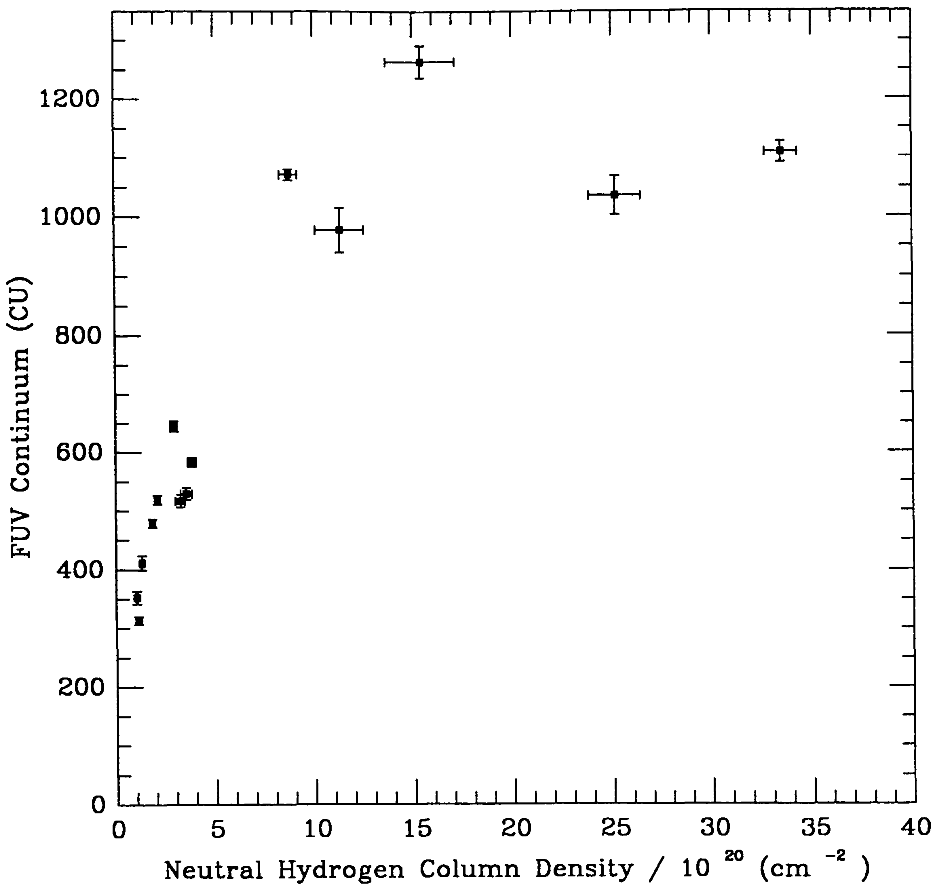

Figure 2 The continuum far ultraviolet intensity as obtained with the UCB spectrograph on the UVX experiment versus neutral Galactic hydrogen column. The vertical error bars are statistical uncertainties only; the horizontal uncertainties indicate the range of hydrogen column covered in the observation. The intensity of the background is strongly correlated with hydrogen column at low hydrogen column densities; at higher column densities the optical depth becomes greater than one and the background intensity remains constant with increasing hydrogen column.

3. DUST-SCATTERED GALACTIC RADIATION AS THE PRIMARY SOURCE OF THE FAR ULTRAVIOLET BACKGROUND

Radiation from early stars scattered by Galactic dust is a candidate for the primary source of the diffuse far ultraviolet background. Indeed, with our present knowledge, it is tempting to employ the term "obvious candidate" but this does not reflect the near consensus outlook of workers in the early 1980s. There were two widely held objections to starlight scattered by dust as the source of this radiation: (*a*) the intensity of the radiation was believed to be uniform across the sky, yet dust was believed to be

Table 1 Correlation of intensity of the far ultraviolet background with Galactic neutral hydrogen column[a]

Investigators	Slope of correlation[b]	Intensity at $N_H = 0$ intercept[c]	Comments
Paresce, McKee & Bowyer (52)	90±10 to 140±20	106±60 to 570±80	*Apollo-Soyuz* Mission. Variation among four view directions
Maucherat-Joubert, Deharveng & Cruvellier (46)	180±80	600^{+0}_{-350}	*D2B* satellite $\|b\| > 40°$
Zvereva et al (72)	150	470	*Prognoz 6* satellite
Weller (66)	Not evaluated (Strong correlation with Galactic latitude)	Not evaluated 180±75 280±88 at North and South Galactic poles	*Solrad 11* satellite
Joubert et al (36)	96±6	677±20	Reanalysis of *D2B* satellite data $\|b\| > 30°$
Jakobsen et al (34)	100±10	450±30	*Aries* rocket
Fix, Craven & Frank (21)	~60	530±80	*Dynamics Explorer 1*
Murthy et al (47)	None found	Not evaluated 100 to 300 at high Galactic latitudes	Johns Hopkins UVX Shuttle experiment
Lequeux (40)	96	Not evaluated	Detailed reanalysis of *D2B* satellite data
Onaka (48)	(30) (see text)	400	Rocket flight scan of Virgo cluster
Hurwitz, Bowyer & Martin (30)	102±6	272±13	Berkeley UVX Shuttle experiment

[a] Data reported since 1980. For earlier results, see reviews by Davidsen, Bowyer & Lampton (12) and Paresce & Jakobsen (51).
[b] Units of photons $(cm^2\ s\ ster\ Å)^{-1}/10^{20}$ HI cm^{-2}.
[c] Units of photons $(cm^2\ s\ ster\ Å)^{-1}$.

sparse to nonexistent at high Galactic latitudes; and (*b*) dust was believed to be strongly forward scattering in the far ultraviolet, and hence even if dust were present at high Galactic latitudes, radiation from hot stars in the plane would not be scattered back to our midplane position.

Although a fair amount of optical work has since been carried out indicating that dust is widely distributed at high Galactic latitudes, results from the *IRAS* satellite have been sufficiently dramatic that this point is no longer contentious (42). However, even now it is not clear if high latitude dust is omnipresent or just widespread. (I return to this point at the end of this section.)

The second factor, the character of the scattering properties of dust in the far ultraviolet, is still a matter of dispute. Substantial work by a number of investigators has been carried out in an effort to determine these parameters. Many of these investigations used the instrumentation on the *OAO-2* or the *IUE* satellite, but a number employed specialized instruments specifically designed for studies of dust. In the analysis of their data, most workers employ the formalism of Henyey & Greenstein (26), in which scattering is characterized by two parameters: the albedo ($\omega = 0$ implies complete absorption; $\omega = 1$ implies complete reflection), and the scattering asymmetry factor of the grains ($g = 0$ implies isotropic scattering; $g = 1$ implies total forward scattering). In Table 2, I list the results obtained by various workers on this topic.

Table 2 Dust properties in the far ultraviolet (FUV)

Workers	Target	Results
Andriesse, Piersma & Witt (3)	NGC1435	$g \approx 0.25$
Jura (37)	NGC1435	$g \approx 0.2$
Carruthers & Opal (11)	Orion	"Albedo is high"
Witt & Lillie (69)	Orion	ω higher in FUV than at 2175 Å bump; scattering more isotropic in FUV than at longer λ
Bohlin et al (8)	Orion	$0.5 < \omega < 0.7$
Tanaka et al (64), Onaka et al (49)	Orion	$0.3 < \omega < 0.6$, $0.2 < g < 0.5$
de Boer & Kuss (13)	Orion	$g \approx 0.6$, ω and g similar across FUV band
Donas et al (16)	M101	g lower in FUV than at visible
Witt et al (71)	NGC7023	$\omega \approx 0.6$; $g \approx 0.25$
Witt, Bohlin & Stecher (68)	CED201, IC435	ω similar in FUV and at 2700 Å if g constant
Lillie & Witt (41)	DGL	$0.4 < \omega < 0.6$, $0.7 < g < 0.9$
Anderson, Henry & Fastie (2)	DGL	Either $g > 0.9$ or $\omega < 0.2$
Joubert et al (36)	DGL	$0.6 < g < 0.7$ (assumed $\omega = 0.5$)
Jakobsen et al (34)	DGL	$\omega \times (1-g) \approx 0.16$
Onaka (48)	DGL	$\omega \times (1-g) \approx 0.07$
Fix, Craven & Frank (21)	DGL	$g > 0.9$
Hurwitz, Bowyer & Martin (30)	DGL	$\omega = 0.16 \pm 0.03$, $g < 0.2$ (80% confidence)

It is readily apparent that there is no systematic agreement in these results. The reasons for these differences are not entirely clear, but some specific problems can be cited. Studies of individual dust clouds are made difficult because of uncertainties in the scattering geometry of the cloud/star system, e.g. is the cloud in front of, or behind, the illuminating star? Large-scale studies of the diffuse Galactic background are difficult because of the problem of separating diffuse scattered light from starlight in view directions at low Galactic latitudes. Measurements at low latitudes are crucial because they fix the albedo, which then allows for a solution for the scattering asymmetry factor. For example, the analysis of the extensive *D2B* data set (36) was limited to $|b| > 30°$. Consequently, the albedo could not be determined but had to be assumed, and the result derived for the asymmetry factor is crucially dependent upon the assumed albedo. Simple errors can lead to incorrect results. Fix, Craven & Frank (21) obtained a large value for the asymmetry factor by fitting their plane-to-pole data set with standard formulae; unfortunately, the formulae used were not appropriate for their case since they neglect an optical depth term; this leads to an incorrect result. Finally, it should be noted that some of the results in Table 2 rely on the relative calibration of several instruments, which introduces a systematic uncertainty in the derived values.

The Berkeley UVX instrument had particular advantages for the investigation of the ultraviolet scattering properties of dust. Because of the specialized characteristics of this instrument, observations of diffuse radiation could be made over a large range of reddening, free of the interfering effects of starlight or instrumentally scattered radiation (Hurwitz et al 30). The resultant data clearly display saturation effects at higher values of hydrogen column density (and hence larger reddening). (See Figure 2 for an example of this effect.) The high Galactic latitude observations of most workers can be reproduced almost equally well with a combination of either a high albedo and high g or a low albedo and low g. However, the observations of Hurwitz et al include low latitude targets, which by necessity include a relatively high density of stars. By exploiting the imaging properties of the Berkeley UVX experiment, these stars were identified and their signals removed from the data. The resultant diffuse background at low Galactic latitudes was surprisingly faint and was only consistent with a low value for the albedo, independent of g. If the albedo of high latitude grains is similar to that found for the low latitude regions, then g must necessarily be low. A detailed analysis of these data gives best-fit results of 0.16 for the albedo and zero for the scattering asymmetry factor; the range of allowed values is listed in Table 2. These results are quite surprising and suggest that the grains scattering the ultraviolet radiation are of different size and character than those producing scattering in the visible and emission in the infrared. Although these results are unexpected, they appear to be well founded (though it can be reasonably argued that this author is not the most objective judge of this statement, and it must be emphasized again that this field is acknowledged to be fraught with difficulties and uncertainties). In any case, these results are the product of a single investigation and were obtained from a limited, and perhaps atypical, region of sky.

The extent of Galactic dust at high latitudes is of intrinsic interest and will affect a variety of observational programs. It might be expected that data from *IRAS* and *COBE* could resolve this issue but such is not the case, at least at present (e.g. 62). The *IRAS* data are inconclusive because of uncertainties in the zero-point offset of the instrument; data from *COBE* do not suffer this problem but both instruments are subject to uncertain contamination from zodiacal dust at the Galactic poles.

To examine this question Martin, Hurwitz & Bowyer (45) compared two far ultraviolet spectra obtained with the Berkeley UVX instrument at high Galactic latitudes. Studies in the far ultraviolet have the advantage that zodiacal light is not present shortward of ~2000 Å. [The exact wavelength cutoff depends upon the detailed observational parameters, but for view directions well off the plane of the ecliptic the zodiacal light cannot be detected below 1900 Å (65).] The continuum from the view direction which includes a small but measurable dust component has the same shape but a higher intensity than that obtained from the lowest intensity view direction. The authors therefore conclude that dust is also the source of the continuum emission in the lowest intensity view direction. Since this region seems typical of the lowest hydrogen column density view directions in the Galaxy, Martin et al conclude that at least some far ultraviolet scattering dust is likely to be present everywhere.

The far ultraviolet intensity-to-$N_{\rm HI}$ ratio is different in the direction of lowest $N_{\rm HI}$ from its value at higher $N_{\rm HI}$. Martin et al prefer the explanation that it is the dust associated with ionized gas that contributes to the excess far ultraviolet intensity in the low $N_{\rm HI}$ target, but they cannot rule out alternative, but somewhat forced, scenarios.

Hurwitz, Bowyer & Martin (30) also suggest that dust is present in all view directions in the Galaxy. In their derivation of the far ultraviolet dust scattering properties, one of their independent variables is the residual dust scattering at the poles. They are able to rule out the hypothesis that there is no dust at the poles at the 68% confidence level; unfortunately the data are not sufficiently definitive to rule out this hypothesis at a higher level of significance.

4. THE SPECTRUM OF THE FAR ULTRAVIOLET BACKGROUND

4.1 *Theoretical Suggestions*

A wide-ranging set of processes have been suggested as sources of the spectral features in the far ultraviolet background. Early on, when data were limited and the flux was thought to be extragalactic, speculation centered on processes that might be associated with galaxy formation in the early universe, or processes in a possible intergalactic medium. For a discussion of these early suggestions, the reader is referred to the reviews by Davidsen, Bowyer & Lampton (12) and Paresce & Jakobsen (51).

With the realization that the far ultraviolet background might well be dominated by Galactic radiation, entirely different classes of source mechanisms were advanced. Duley & Williams (17) suggested H_2 fluorescence as a contributor to this background. The ratio of molecular to atomic hydrogen is primarily determined by the balance of the formation of molecules on dust grains and their destruction by photoabsorption of ultraviolet light in the interstellar radiation field. Duley & Williams noted that a byproduct of the destruction process that was observable, in principle, was emission in the far ultraviolet, which consists of two components. The first is due to transitions between various rotational and vibrational levels within different electronic states of the H_2 molecule. During these transitions, incident photons in the 845 to 1108 Å range are absorbed in the Lyman and Werner bands from the ground state and then reemitted in far ultraviolet bands with $\lambda \leq 1845$ Å through decays to excited vibrational levels of the ground electronic state. The second process involves continuum emission that arises during decays to unbound levels of the ground state. This process leads to dissociation of the molecule, with a probability per absorption of $\sim 10\%$. Jakobsen (33) computed a detailed spectrum of this radiation and showed that, in reasonable conditions this process could contribute up to 30% of the observed diffuse background.

Jakobsen & Paresce (35) suggested that a hot ($\sim 10^5$ K) Galactic corona would produce emission lines in the far ultraviolet. Multiply ionized carbon, nitrogen, oxygen, and silicon were predicted to produce the strongest lines in this gas. Although the intensities derived by these authors were below the sensitivity of instrumentation available at the time, they showed this flux might be detectable with future instrumentation. Edgar & Chevalier (18) refined these calculations to account for the fact that interstellar gas at $\sim 10^5$ K is at the peak of its cooling curve, and hence a more realistic emission spectrum would result from time-dependent ionization calculations in a gas cooling from a higher temperature. The intensities they obtained were substantially different from those obtained by Jakobsen & Paresce for some lines because of the persistence of highly ionized species as cooling occurs. They also showed that by measurement of an appropriate set of lines, one could, in principle, determine both the character of the cooling and the mass inflow rate of the cooling material.

Deharveng, Joubert & Barge (15) investigated the possible contribution of a warm ($\sim 10^4$ K) intercloud medium to the far ultraviolet background. They concluded that for $\lambda < 2000$ Å, an intercombination line of CIII is a potential emission line. They also showed a potential source of continuum emission is hydrogen two-photon emission. Recombination of ionized hydrogen populates the 2^2S level both by direct recombination and by cascades following recombination to higher levels. This emission becomes stronger than the decreasing HI free-bound and free-free continua below 2700 Å; it reaches a peak at about 1400 Å, where it exceeds these continua by more than two orders of magnitude.

4.2 *Observational Results*

Given the difficulty of measuring weak diffuse radiation intermixed with stellar signals, it is not surprising that there have been relatively few attempts to obtain spectra of the far ultraviolet background, nor is it surprising that the results obtained have been disparate. Spectral measurements made by Henry et al (25) using a spectrometer flown on *Apollo 17* during Moon-Earth coast are shown in Figure 3. These data are from four view directions at high Galactic latitudes. Two sets of error bars are shown based on two different analyses of the data. A broad hump in the spectrum is apparent.

The results of Henry et al (25) were initially supported by the observations by Hua et al (29), who obtained data on the diffuse far ultraviolet background with a spectrometer flown on a Soviet spacecraft in a highly elongated, high apogee (200,000 km) orbit. These results are shown in Figure 4; the upper curve shows the sky background uncorrected for stars, and the lower curve shows the background after subtraction of a computed stellar contribution.

Anderson et al (1) reported data obtained with a compliment of instruments flown on an *Aries* sounding rocket that observed three regions at high Galactic latitude. The data from the spectrographic instrument are shown as solid circles in Figure 5 (the remaining points refer to previous results). The spectrum obtained is essentially flat over most of the band, with an increase longward of ~ 1700 Å.

Following the suggestion of Jakobsen & Paresce (35) that a hot Galactic corona will produce emission lines in the far ultraviolet, Feldman, Brune & Henry (19) reanalyzed the data from two of the three view directions

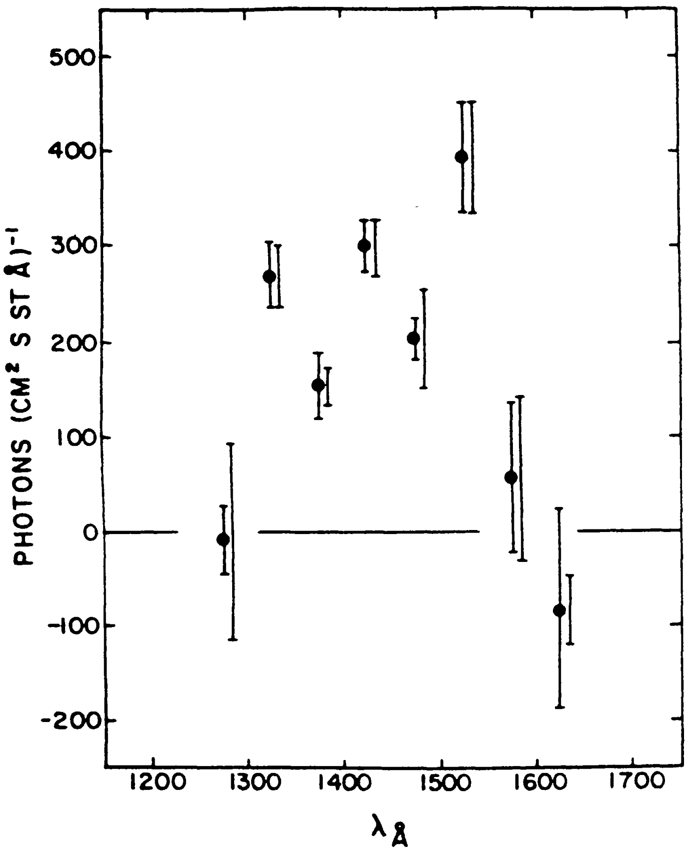

Figure 3 Spectral measurements reported by Henry et al (25) obtained with a spectrometer flown on *Apollo 17* during Moon-Earth coast. These data are from four view directions at high Galactic latitudes. Two sets of error bars are shown based on two different analyses of the data.

observed by Anderson et al (1) using a different method of analysis. Their results are shown in Figure 6. The two peaks show the response of the spectrometer to terrestrial oxygen line emission at 1304 and 1356 Å. The dashed, dotted and solid lines are estimates of various contributions to the background not made by diffuse radiation. Intensity enhancements in the data after subtraction of these components were considered by Feldman et al as possible emission from forbidden NIV at 1490 Å, CIV at 1550 Å, and forbidden O III at 1660 Å. However, the intensities obtained were approximately two orders of magnitude larger than that predicted by Jakobsen & Paresce (35); Edgar & Chevalier (18) concluded these intensities were at least a factor of five larger than could be present without violating other observational constraints. In the light of these analyses and in consideration of further experimental work discussed below, we conclude these results were spurious.

Murthy et al (47) reported ~17 Å spectra from the Johns Hopkins UVX experiment flown on the Space Shuttle covering wavelengths from 1200 to 1700 Å. They found a spectrally flat background over this band, with no evidence for the lines suggested by Feldman, Brune & Henry (19); however because of the sensitivity of their measurement they could not formally rule out lines of this intensity.

Martin & Bowyer (43) reported the discovery of emission lines of CIV and O III in several high Galactic latitude view directions with the Berkeley UVX far ultraviolet spectrometer and OIV/SiIV and NIII line detections in a summed high latitude spectrum. In Figure 7, I show data obtained in one of several high latitude view directions. The dashed line shows the best-fit solution; the dotted line shows the assumed continuum. CIV emission is clearly evident in the data (formally, it is present at 8σ). The intensities observed were roughly those predicted by Jakobsen & Paresce (35) and Edgar & Chevalier (18) and are about two orders of magnitude below those reported by Feldman, Brune & Henry (19). These flux levels were sufficiently low that they would not have been detected by the Johns Hopkins instrument, which was taking data in the same view direction simultaneously (47).

Martin & Bowyer combined their emission results with absorption data obtained with the *IUE* instrument and showed the flux emanated from 2

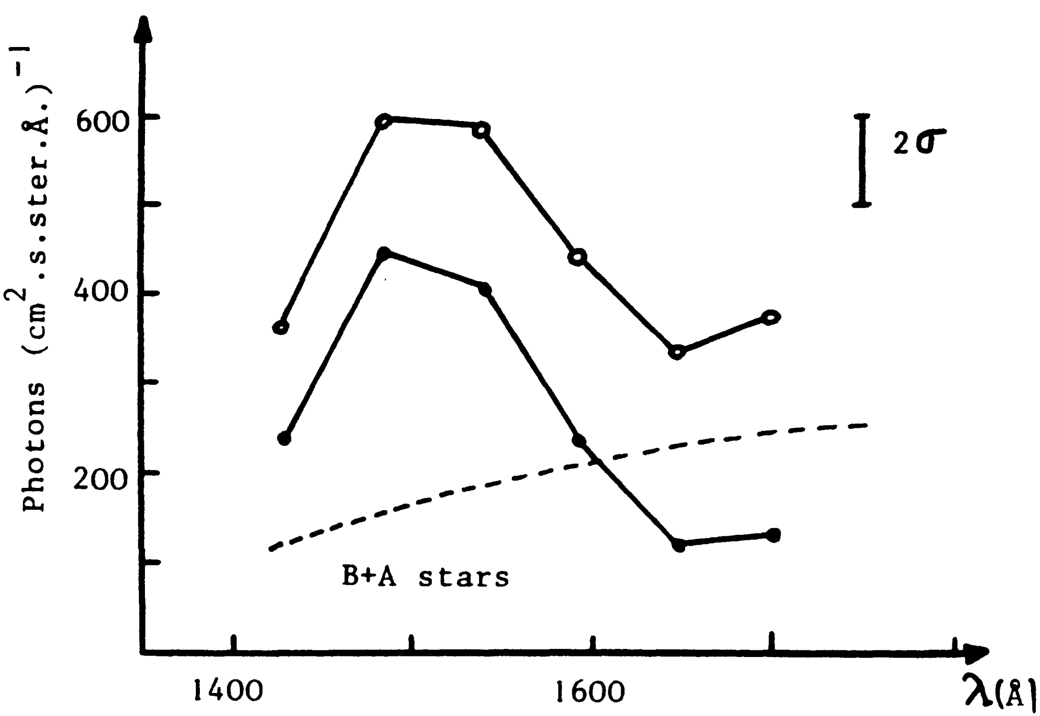

Figure 4 Observations by Hua et al (29) who obtained data on the diffuse far ultraviolet background with a spectrometer flown on a Soviet spacecraft in a highly elongated, high apogee (200,000 km) orbit. The upper solid curve shows the sky background uncorrected for stars, and the lower solid curve shows the background after subtraction of the computed stellar contribution, which is shown as a dashed line.

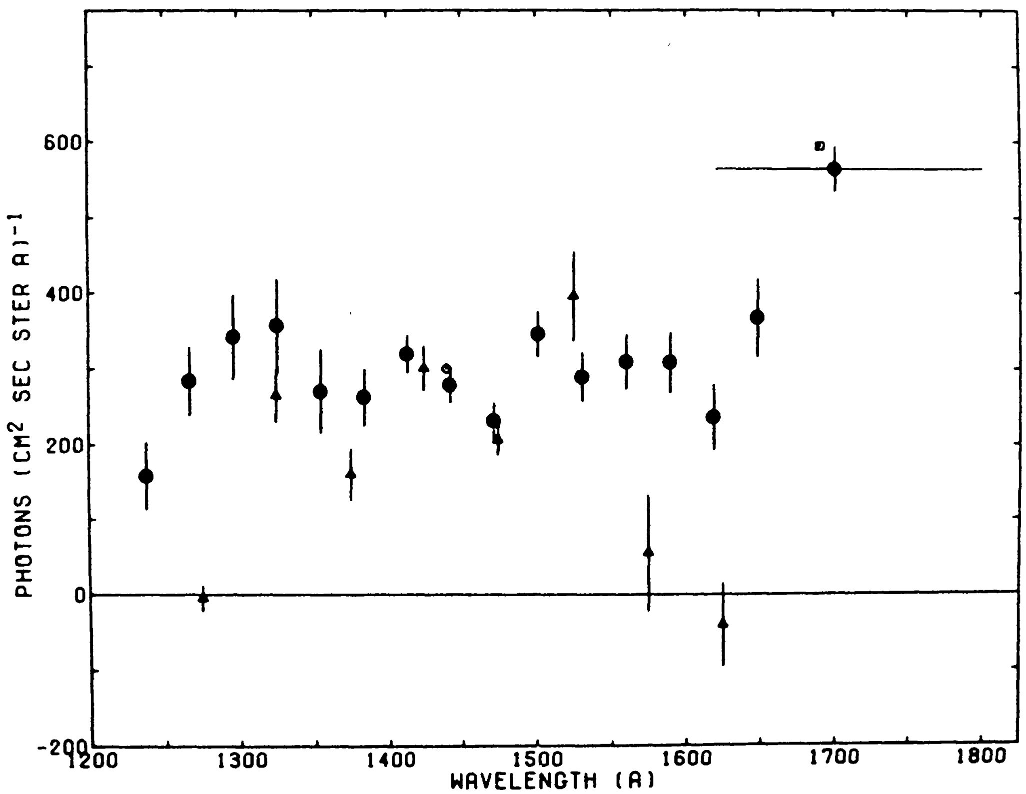

Figure 5 Data obtained by Anderson et al (1) with instruments flown on an *Aries* sounding rocket that observed three regions at high Galactic latitude. The data from the spectrographic instrument are shown as solid circles in this figure. (The remaining points refer to previously reported results.)

to 3 kpc above the Galactic plane. The data are not compatible with photoionized Galactic halo models, but are consistent with the Galactic fountain model of Shapiro & Field (59). The mass infall rate derived from these data is 6–25 $M_\odot$ yr^{-1}, confirming that the halo must be continuously replenished.

Martin, Hurwitz & Bowyer (44) found molecular hydrogen emission in four view directions with the Berkeley UVX experiment. Molecular hydrogen had previously been detected in two very high density cloud complexes with nearby OB stars (10, 70) but had not been observed in the diffuse interstellar medium. All of the four detections were in view directions with only modest neutral hydrogen column densities ($\sim 10^{21}$ HI cm^{-2}), but three of the four view directions included molecular clouds as indicated by the presence of CO emission. Analysis of these data indicated the molecular hydrogen was clumped with a filling factor of <0.2. Evidence was presented that in one case the cloud appeared to be in the process of being destroyed by the radiation field.

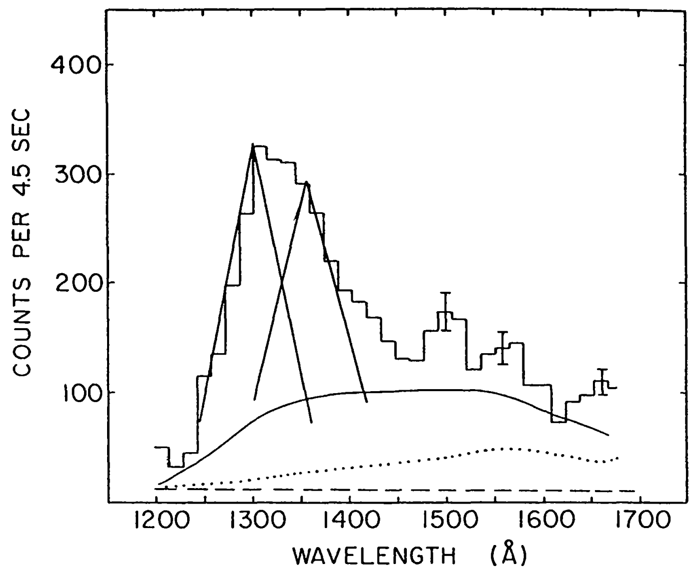

Figure 6 Data from two of the three view directions observed by Anderson et al (1) and reanalyzed by Feldman et al (19) using a different method of analysis in order to search for line emission. The two peaks show the response of the spectrometer to terrestrial oxygen line emission at 1304 and 1356 Å. The dashed, dotted and solid lines are estimates of various contributions to the background not due to diffuse radiation. Intensity enhancements in the data after subtraction of these components were considered by Feldman et al as possible emission from forbidden NIV at 1490 Å, CIV at 1550 Å, and OIII] at 1660 Å.

5. THE COSMIC BACKGROUND FROM 912 TO 1200 Å

The 910 to 1200 Å band has many transitions which, if present as spectral features, will be useful as diagnostics of astronomical phenomena, including CIII 977, NIII 990, H Lyman β 1027, OVI 1032/1038, SiIV 1020, NII 1085, and the H_2 Lyman and Werner bands. Despite the obvious promise of studies of diffuse radiation in this bandpass, very few measurements have been made. The primary reason for this is technical; the (comparatively) intense geocoronal/interplanetary hydrogen Lyman α line at 1216 Å is a ubiquitous source of instrumentally scattered radiation since it is $\sim 10^6$ times more intense than other sources of astronomical flux. Scattered H Lyman α radiation can be eliminated in instruments carrying out measurements longward of 1250 Å through the use of filters with appropriate short wavelength cutoffs, but no simple mechanisms exist for eliminating instrumentally scattered H Lyman α radiation at shorter wavelengths.

Bixler, Bowyer & Grewing (6) measured the cosmic background from 1040 to 1080 Å with a photometer with a very small field of view (0.23

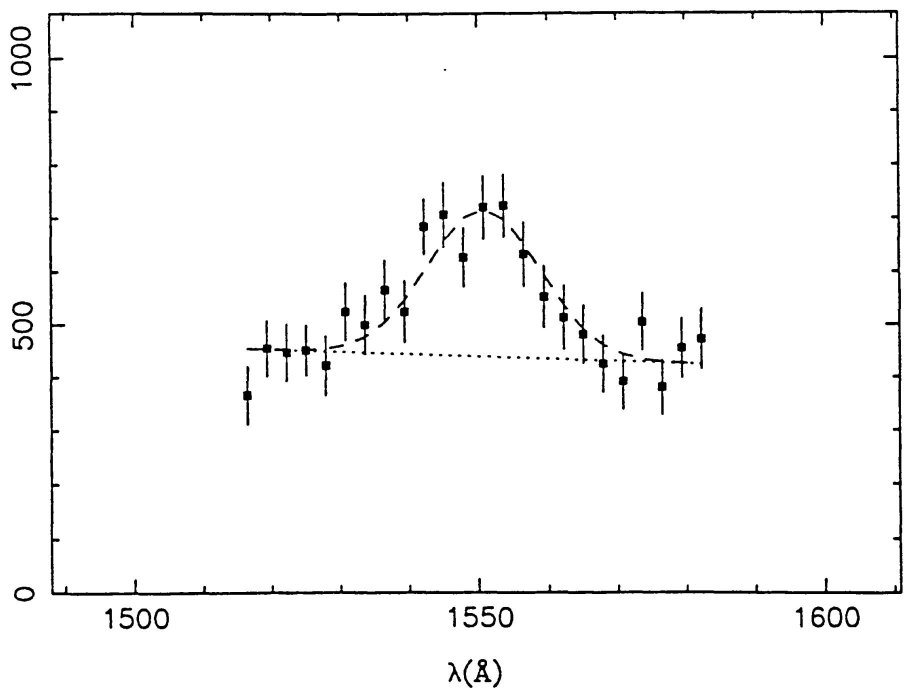

Figure 7 A subset of the data obtained by Martin & Bowyer (43) with the Berkeley UVX spectrometer from a high Galactic latitude view direction. The dashed line shows the best fit solution to the data; the dotted line shows the assumed continuum. These authors attribute the emission to CIV 1550 Å. Statistically significant detections of the CIV line were obtained in several high latitude view directions.

square degree). The photometer was used in combination with a lithium fluoride/indium filter placed at the focal plane of a one-meter rocket-borne telescope. Although the effects of starlight were easily accessed and the filter combination was successful in reducing the H Lyman α flux to a negligible level, the overall sensitivity of the measurement was low and yielded only an upper limit of $\sim 10^4$ CU for this band. Opal & Weller (50) employed an indium filter to define a bandpass from 700 to 1100 Å combined with a photometer with a field of view of ~ 50 square degrees. The instrument was flown on a satellite that provided substantial integration time, but because of stellar contamination only an upper limit of $\sim 10^4$ CU was obtained for the diffuse background.

A number of studies of the cosmic background from 910 to 1200 Å have been carried out with the *Voyager 2* spectrometer (9). This instrument had ~ 30 Å resolution for diffuse radiation and suffered from several sources of background, including an onboard radioactive power generator, and substantial instrumental scattering. A variety of approaches were employed to correct for these effects. The astronomical flux derived (or the upper limits to an astronomical flux) is typically $\lesssim 40$ times smaller than the raw counting rate. While the corrections applied appear to be well thought out, a reduction of this scale does admit to some uncertainty.

Shemansky, Sandel & Broadfoot (60) obtained data from three regions in the Cygnus loop with the *Voyager* instrument. They detected emission centered at 980 and 1035 Å but the 30 Å resolution complicated their analysis. These authors concluded that the 980 Å feature was CIII 977 and the 1035 Å feature was CII 1037. This interpretation of the 1035 Å feature is not consistent with any reasonable theoretical picture, however, and is most assuredly wrong since it is contradicted by data at longer wavelengths obtained with IUE.

Blair et al (7) carried out a detailed analysis of substantial regions of the Cygnus loop using extensive *Voyager* data. Two features were detected, one at 980 Å and one at 1035 Å. These authors conclude that the 980 Å feature is CIII 977 (but NIII 990 is also expected to be present in the *Voyager* spectrum and would be blended with the CIII line given the instrument resolution) and the 1035 Å feature is primarily OVI 1032, 1038. They provide evidence that these lines produce the majority of the cooling in the Cygnus loop. They conclude the OIV emission emanates from directly behind the main blast wave as defined by the X-ray emission, while the CIII 977 is associated with cooler material that also produces optical emission.

Chris Martin (1990, private communication) has recently observed the Cygnus loop in a sounding rocket flight; he detected and resolved the OVI 1032/1038 emission at almost 10σ.

Holberg (27) used the *Voyager 2* spectrometer with a very long integration time ($\sim 1.5 \times 10^6$ sec) in an attempt to detect the cosmic far ultraviolet background in a view direction near the Galactic pole. He obtained upper limits on an astronomical flux of $\sim 4 \times 10^2$ to 10^4 CU over the 912 to 1200 Å band.

Edelstein and Bowyer (1990, private communication) flew a double dispersion nebular spectrometer on a sounding rocket to search for emission in the 970 to 1100 Å band from the Galactic corona. The theoretical work of Edgar & Chevalier (18) indicates that, given the intensity of the CIV 1550 line reported by Martin & Bowyer (43), the OVI 1032 Å line will be predominant in this band. A preliminary analysis of the data obtained by Edelstein and Bowyer indicates that this line is at least a factor of two to four less than that predicted by Edgar & Chevalier.

6. THE EXTRAGALACTIC BACKGROUND AND RELATED EXOTICA

The most commonly cited argument that the diffuse far ultraviolet background is in part, or entirely, extragalactic is that this flux is uniform over the celestial sphere, at least at high Galactic latitudes. While it is now clear that the data supporting this argument are deficient and most of the flux is due to processes in the Galaxy, it is also clear that some minimum flux (typically a few hundred CUs) is present in all view directions at high Galactic latitudes. Further, as summarized in Table 1, the intensity of this flux is still finite when extrapolated to zero neutral Galactic hydrogen column. It may well be that this flux is uniform across the sky and the scatter in the data reported in Table 1 only represents experimental uncertainty. Even if this is true, however, it is by no means established that this flux is extragalactic since it could be the product of geocoronal, solar system, or Galatic effects. Indeed, Hurwitz, Bowyer & Martin (30) and Martin, Hurwitz & Bowyer (45) provided evidence discussed earlier in this review that the majority of this "uniform" flux is Galactic in origin.

Despite these uncertainties, it has been established that the far ultraviolet background does convey information on a variety of topics that might be classified as "cosmological" in character. I review some of these topics in the following.

6.1 *The Radiative Decay of Massive Neutrinos and Other Particles*

Stecker (63) and Kimble, Bowyer & Jakobsen (38) used the intensity of the far ultraviolet background to derive constraints on the radiative lifetime of massive neutrinos assuming these particles form a uniform cosmic sea of material. Although these (and later) authors framed their discussion in terms of massive neutrinos, their arguments are valid for any particles conforming to the underlying assumptions. These authors assumed that radiative decay dominates the decay routes available (this is the favored route in many of the relevant particle physics models), and the secondary particle is very light compared to the parent (as would be expected for neutrinos, given the limited number of neutrino families). Neutrinos with masses of 10–100 ev/c^2 were considered, which covered the range of mass suggested by the available experimental data. Stecker interpreted a possible step in the spectrum of the far ultraviolet background as the product of neutrino decay and derived a lifetime for this decay. Given subsequent data, this result is surely incorrect. Kimble et al examined the range of lifetimes for which the far ultraviolet data were relevant; they included the effects of attenuation of the decay radiation through a clumpy intergalactic medium. These authors were able to obtain upper limits to the radiative decay of the neutrino for lifetimes between 10^{13} and 10^{22} sec. Martin, Hurwitz & Bowyer (45) searched for an edge, or step, in their lowest intensity, high Galactic latitude spectrum obtained with the Berkeley UVX experiment and were able to improve upon the results of Kimble et al by a factor of about three.

Shipman & Cowsik (61) pointed out that observations of assemblages of matter (such as clusters of galaxies) would provide more stringent limits (though for a narrower range of potential masses) with the assumption that these local potential wells can capture the particles. Shipman & Cowsik (61) and Holberg & Barber (28) used *Voyager* far ultraviolet data from the Coma cluster to set limits of $\sim 10^{24}$ to 10^{26} sec on the radiative lifetimes of neutrinos with masses from ~ 5 to 15 ev/c^2. Martin, Hurwitz & Bowyer (45) considered effects of massive neutrinos trapped in, or forming the core of, gravitational potential wells associated with large-scale structure in the universe. In this case, large-scale fluctuations in the spatial distribution of the particles comparable to those observed in the Center for Astrophysics (CfA) redshift survey (14) would produce neutrino radiative decay emission smeared by the velocity dispersions present in the most concentrated regions. This structure will have a characteristic scale of $\gtrsim 2500$ km sec^{-1} and will produce continuum fluctuations in ~ 15 to 30 Å bins. In a search of the Berkeley UVX experimental data, Martin et al found no evidence for these fluctuations. The results of these investigations are shown in Figure 8.

6.2 *The Far Ultraviolet Background from Galaxies*

Spatial information on very weak far ultraviolet sources was obtained by Martin & Bowyer (43) with an imaging detector sensitive over the band 1350 to 1900 Å. This detector was flown at the focal plane of a one-meter extreme ultraviolet/far ultraviolet telescope developed as a collaborative effort between Berkeley & Tübingen (23). Data from this imager were subjected to a radial power spectrum analysis in a search for a component of the far ultraviolet background flux that would correlate with angular separation. This search was motivated by the fact that field stars are essentially randomly distributed in angular separation on the sky, while galaxies are known to cluster, and the scale of this clustering is well characterized by a two-point correlation function derived from optical data (54). The results obtained by Martin & Bowyer are shown in Figure 9. Here the observed radial power spectrum of the flux is plotted against angular frequency. The best-fit line to the data is a power law with index -1.6, but given the limited dynamic range of the measurement this result is not well constrained. The solid line shows a power law with an index of -1.2 that is consistent with the data and is expected from the integrated light of galaxies. Any alternate processes producing this power would not only have to be the result of a spurious unknown effect, but would also have to produce, purely by chance, a power spectrum consistent with that

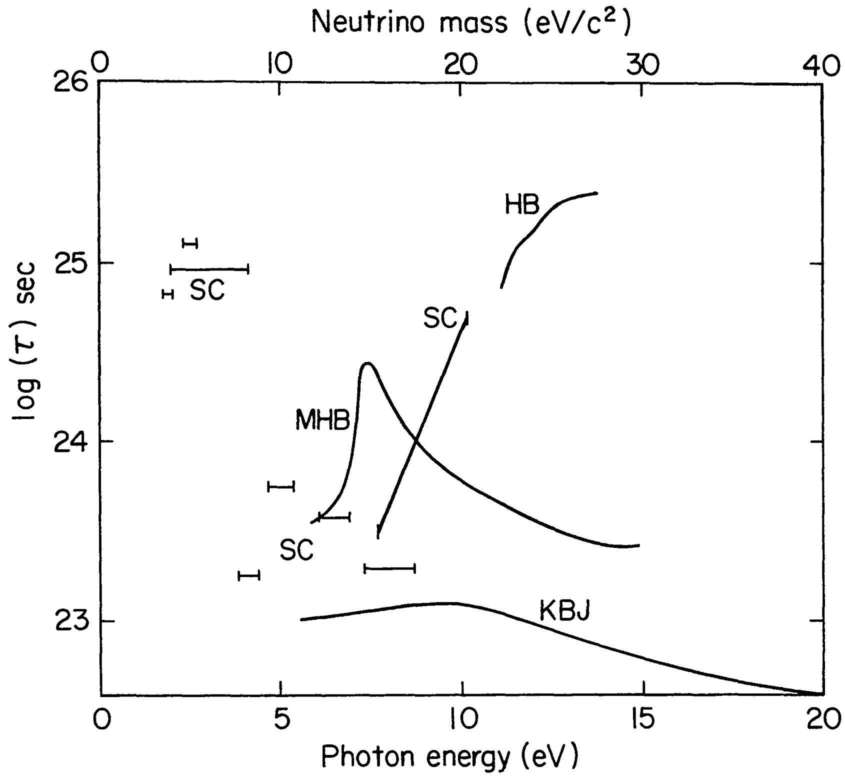

Figure 8 Lower limits to the radiative lifetime of neutrinos as derived from studies of the far ultraviolet background. Different lines reflect different types of data and/or different effects based on different underlying assumptions. KBJ is from Kimble, Bowyer & Jakobsen (38), HB is from Holberg & Barber (28), MHB is from Martin, Hurwitz & Bowyer (45), and SC is from Shipman & Cowsik (61). The results of Shipman & Cowsik include various other data in addition to far ultraviolet observations.

produced by galaxies. One may thus conclude that this component of the far ultraviolet background ($\sim$50 CU in intensity) is indeed the summed flux of galaxies. The far ultraviolet flux emitted by galaxies contributing to this component of the background is emitted by galaxies in the redshift range from 0.1 to 0.6. The flux is shifted out of the observed far ultraviolet band at distances corresponding to times earlier than the most recent one third of a Hubble time.

Hurwitz, Bowyer & Martin (30) obtained indirect evidence for an extragalactic component of the far ultraviolet background from an analysis of the data obtained with the Berkeley UVX spectrometer. In their analysis of the continuum emission, they folded a model of the Galactic stellar radiation field with the observational data and solved for four independent variables: (*a*) the albedo of the dust, (*b*) the scattering phase function of the dust, (*c*) residual dust at $N_{HI} = 0$, and (*d*) an "external" flux assumed to be independent of the Galactic radiation field and to be isotropic except

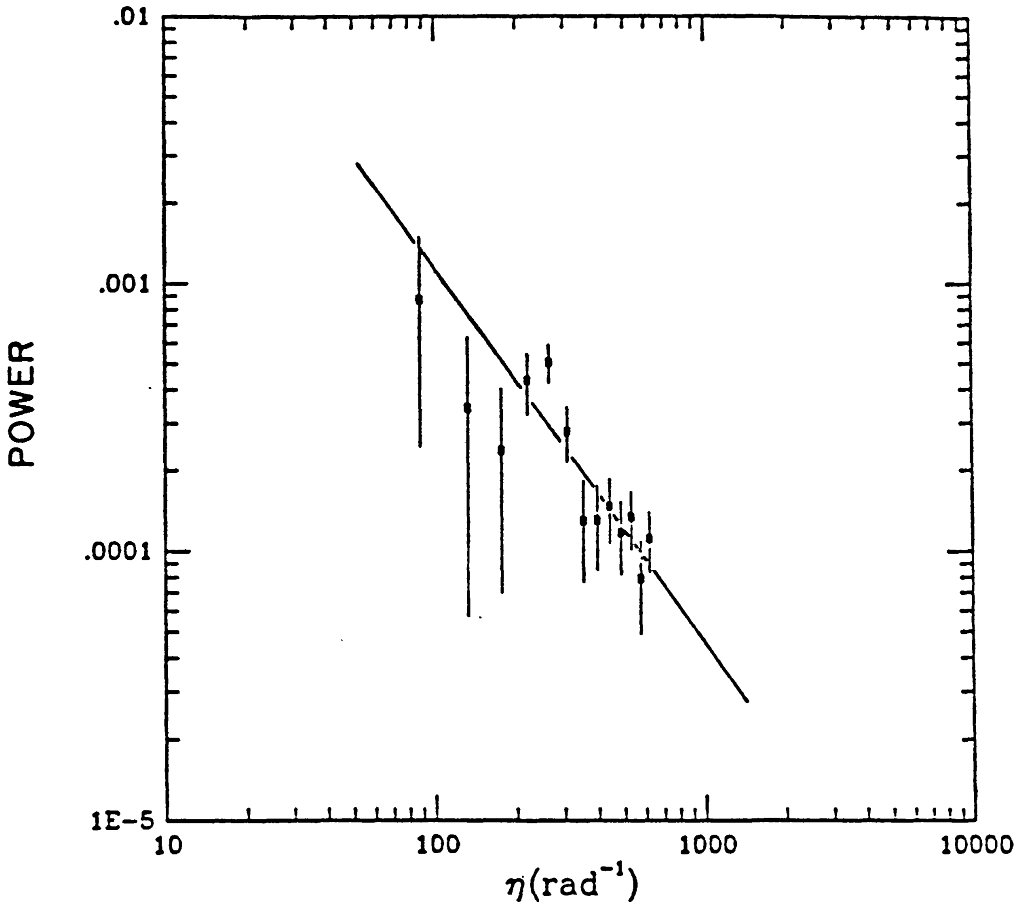

Figure 9 Results obtained by Martin & Bowyer (43) on the spatial distribution of weak far ultraviolet sources. Here the radial power spectrum of the sources is plotted angular frequency. Stars contribute a noncorrelated, white noise component to this data. The best-fit line is a power law with index -1.6, but, given the limited dynamic range of the measurement, this result is not well constrained. The solid line shows a power law with an index of -1.2, which is consistent with the data and is what is expected from the integrated light of galaxies.

for attenuation by foreground dust. The results of this analysis for the albedo and scattering phase function of the dust were discussed earlier in this review. The "external" flux in this analysis has at least three components. One component is emission at 1550 Å and 1660 Å, with an intensity consistent with that reported by Martin & Bowyer (43) for CIV and OIII] produced in the Galactic halo. Since the flux is produced well above the plane, this result provides a consistency check on the analysis. The second component of "external" flux is emission of ~120 CU over the entire wavelength band. Diffuse Hα emission line studies (56) indicate that two-photon emission from a warm ionized medium with a large-scale height will contribute a continuum of about 50 CU in the far ultraviolet at high Galactic latitudes, a contribution that will appear in this analysis as an "external" flux. The remaining flux is consistent with the value obtained directly by Martin & Bowyer (43) as the summed flux of external galaxies.

The intensity of the summed ultraviolet radiation from galaxies has an important astrophysical consequence. The observed intensity is consistent only with a relatively low and constant star formation rate in galaxies corresponding to $\leq 0.033\ M_{\odot}\ \mathrm{yr}^{-1}\ \mathrm{Mpc}^{-3}\ \mathrm{h}^{-2}$ for the redshift range $0.1 < z < 0.6$. It also limits so-called star burst galaxies to less than 10% of the total population of galaxies in this period.

6.3 *Active Galactic Nuclei*

The integrated light from active galactic nuclei (AGN) (primarily QSOs) will contribute at some level to the diffuse far ultraviolet background. The intensity of this flux is of considerable interest because it is generally thought to be the factor that determines the ionization of intergalactic Lyman α clouds and it may photoionize the Galactic halo. A number of authors have estimated the intensity of this flux (5, 31, 32, 43, 57); the range of estimates is between 0.1 and 10 CU.

It is clear that the far ultraviolet flux produced by AGN will be too small to be directly disentangled from existing measurements. Future specialized searches may be capable of providing information on this topic.

6.4 *Emission from an Intergalactic Medium*

Early interest in the cosmic far ultraviolet background was motivated at least in part by its relevance to the existence of a cosmologically significant intergalactic medium (IGM). A high temperature ($>10^6$ K) IGM would produce X-ray emission, and a lower temperature ($<10^4$ K) medium would produce absorption effects in QSO spectra; observational constraints on these parameters were interpreted as ruling out these two scenarios, but the possibility of an intermediate temperature IGM remained. An intermediate temperature IGM would most likely be detected by its far ultraviolet emission; the most likely far ultraviolet radiation would be redshifted Lyman α transitions of HI 1216 Å and HeII 304 Å from an ionized primordial gas (20, 39). In the early stages of galaxy formation this gas might be reionized collisionally by the passage of shocks or by interactions with energetic particles (22, 67) or by photoionization (4). The emission spectrum depends upon the details and timescales of the reionization; in particular, collisional ionization of the gas produces much more far ultraviolet radiation than does photoionization. Motivated by these suggestions, a variety of data were searched for indications of radiation from an intermediate temperature IGM (1, 25, 32).

In the 1980s several groups developed more detailed models of far ultraviolet emission from a lukewarm IGM. Jakobsen (32) showed that special conditions would be required if emission from this source were to contribute substantially (~ 300 CU) to the far ultraviolet background. In particular, collisional ionization and substantial clumping of the IGM would be required, and the thermal input must be carefully proscribed or direct observational constraints would be violated.

Paresce, McKee & Bowyer (52) suggested that fast shocks and photoionization would be the most likely ionization mechanisms and these would produce prompt ionization with substantially less radiation. They examined the case in which the gas is sufficiently highly ionized that the dominant emission lines are produced primarily by recombination. In this scenario, the far ultraviolet emission from the IGM is ~ 10 CU.

Martin, Hurwitz & Bowyer (45) considered emission from an IGM for a variety of scenarios and compared their results with improved observational constraints provided by the X-ray background (58), the lack of absorption troughs shortward of H Lyman α continuum in the spectra of QSOs (24), limits on emission in the far ultraviolet background as discussed in this article, and limits on spatial fluctuations in the far ultraviolet background (43). They found that even their most optimistic scenarios including collisional ionization and clumping of the IGM violated observational constraints for an IGM with even a relatively low density (15% of the critical density of the universe). This result is to some extent model dependent, but the models employed were sufficiently broad that either very special and unexpected conditions occurred in the early universe, or the far ultraviolet background has at most a component < 10 CU from the IGM. A component this small will be difficult to identify.

7. CONCLUSIONS

In the past ten years, remarkable progress has been made in our understanding of the diffuse far ultraviolet background. In the beginning of the 1980s, the consensus was that this background was primarily extragalactic in origin. Estimates of its intensity ranged over three orders of magnitude. Its spectrum was unknown. We now know that this flux is primarily Galactic in origin, but a small extragalactic component has probably been detected.

A number of processes contributing to this background have been identified. The primary source of the background is scattering by dust. This dust appears to have a low albedo and scatter isotropically and hence is different from the dust that produces scattering in the visible spectrum. There is preliminary evidence that this dust is present in all view directions in the Galaxy.

Emission from hot ($\sim 10^5$ K) gas has been detected. An analysis of this radiation establishes that the emitting gas is well above the Galactic plane and thus resolves a long-standing controversy regarding the origin of the interstellar high ionization lines seen in absorption in studies carried out with the *IUE* satellite. The so-called Galactic fountain model for the origin of this gas is consistent with the data.

Two-photon emission from recombining ionized hydrogen has been recognized as a component of the far ultraviolet background. Molecular

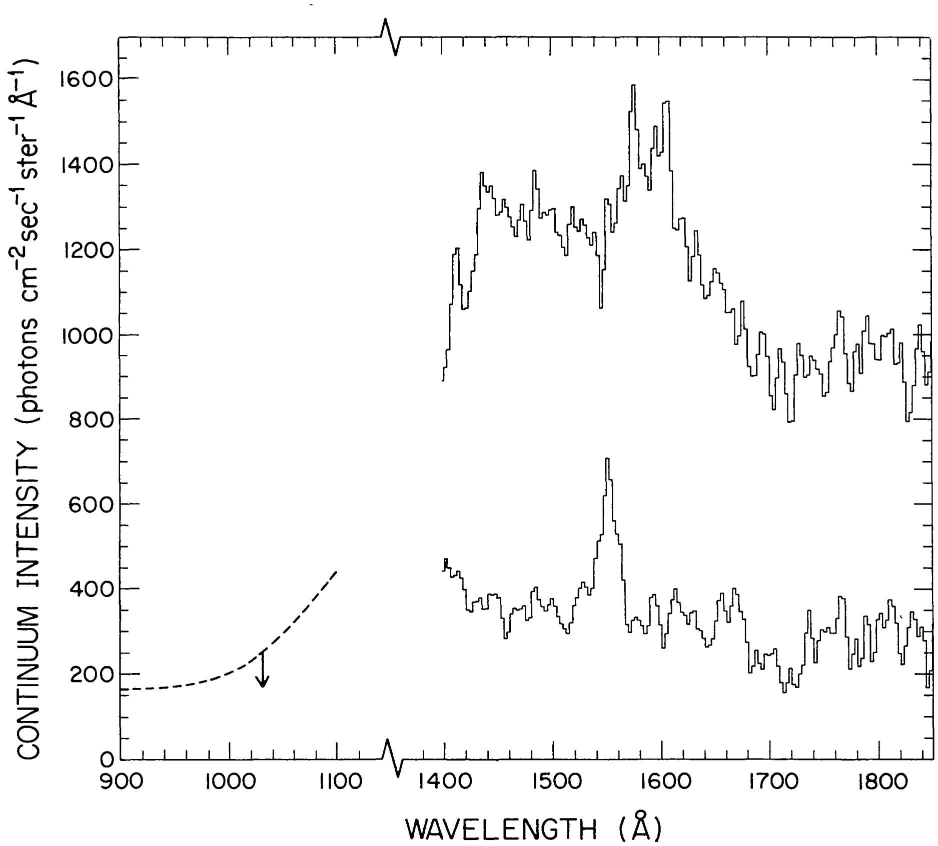

Figure 10 Summary data on the cosmic far ultraviolet background. The data from 912 to ~ 1200 Å are from Holberg (27) and are upper limits to the flux from a high Galactic latitude view direction. Two data sets are shown for the 1400 to 1850 Å band. The upper line is from Hurwitz, Bowyer & Martin (30) and shows typical data obtained in view directions with $\tau_{dust} \geq 1$. The lower line is from Martin & Bowyer (43) and shows data obtained at a high Galactic latitude; the CIV 1550 Å line is clearly evident in emission and the 1663 Å line of OIII] is also apparent, though at lower signal-to-noise ratio.

hydrogen fluorescence was found to be present in low density molecular clouds. The data indicate that this emission is primarily produced from clumped portions within the clouds.

In Figure 10, I provide examples of the best available data on the diffuse far ultraviolet background. The data from 912 to ~1200 Å are from Holberg (27) and are upper limits to the background from a high Galactic latitude view direction. Two data sets are shown for the 1400 to 1850 Å band. The upper line is from Hurwitz, Bowyer & Martin (30) and shows data obtained at a low Galactic latitude. These data are typical of what is observed in view directions with an optical depth of $\tau_{\rm dust} \geq 1$. Molecular hydrogen fluorescence is evident as an additional component at wavelengths from 1550 to 1650 Å. The lower line is from Martin & Bowyer (43) and shows data obtained at a high Galactic latitude and low total neutral hydrogen column. The CIV 1550 Å line is clearly evident in emission, and the 1663 Å line of forbidden O III is also apparent though at lower signal-to-noise ratios.

The only extragalactic component that appears to have been detected is the summed far ultraviolet emission of all galaxies. If the reported flux is taken only as an upper limit to the true flux from galaxies, significant limits can be placed on the star formation rate in the universe for the past one third of a Hubble time.

The major components of the cosmic far ultraviolet background are summarized in Table 3. It is clear that studies of the diffuse ultraviolet background have at long last begun to bear fruit. The results obtained

Table 3 Components of the diffuse cosmic far ultraviolet background with approximate intensities[a]

Total intensity	300–1500
Galactic components	
Scattering by dust	200–1500
HII two-photon emission	50
H_2 fluorescence	100 (in molecular clouds)
Components of the "uniform" high-latitude background	
Dust (?)	200
Summed from all galaxies	50
HII two-photon emission	50
Hot gas line emission	10
QSOs/AGNs	<10
Intergalactic medium	<10
Unexplained	none to <200

[a] Intensities dependent upon view direction. Intensities of processes producing discrete features are averaged over the 1400–1850 Å band. Units are photon $cm^{-2}\ s^{-1}\ ster^{-1}\ Å^{-1}$.

have not only delineated the origins of this flux, they have also enriched our understanding of diverse areas of astrophysical interest.

ACKNOWLEDGMENTS

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