THE GALACTIC FAR ULTRAVIOLET BACKGROUND

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ABSTRACT. Measurements of the far ultraviolet background are reviewed. A major turning point occurred in the study of this field in the early 1980s, when evidence was first presented that this flux was primarily galactic in origin rather than extragalactic, as had been generally believed. A number of experiments have confirmed this result, and it has been established that the flux is the result of scattering of starlight by dust. However, the detailed scattering properties of dust in the far ultraviolet are uncertain; a wide range of albedos and scattering phase functions have been reported. Very recent evidence indicates that ultraviolet scattering grains are different from grains that scatter in the visible in that they have a low albedo and scatter isotropically. There is evidence that this dust is present at some level in all view directions in the galaxy. Spectral emission features have been detected recently in the diffuse background. Lines of C IV and O III] have been observed and lines of O IV/Si IV and N III have probably been observed. It has been established that the 10^5 K gas producing these lines is 2–3 kpc above the galactic plane. Overall mass flux rates of 5 to 25 $M_\odot$ yr^{-1} for this gas are indicated, which provides strong support for the galactic fountain model for this material. Emission from molecular hydrogen has been detected in directions of high and low neutral hydrogen column density. This emission emanates from low density molecular clouds and indicates clumping of the emitting material in the clouds. Our knowledge of the sources of the far ultraviolet background has increased dramatically in the past 10 years. The results obtained have yielded surprising new insights on a variety of astrophysical topics.

1. INTRODUCTION

From the beginnings of space research, attempts were made to measure the cosmic far ultraviolet ($\lambda\lambda \sim$ 1000–2000 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 which 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

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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 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 this initial work and for a discussion of the reasons for these discrepant results, the reader is referred to Davidsen, Bowyer, and Lampton (1974) and Paresce and Jakobsen (1980). 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 with results obtained with 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 which was sufficiently small that stars could be excluded from the data set. 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 (Paresce, McKee, and Bowyer 1980). 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 (Maucherat-Joubert, Deharveng, and Cruvellier 1980). 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. Subsequently, substantial progress has been made, and the results obtained have had an impact on a wide range of astrophysical problems.

2. THE CORRELATION BETWEEN INTENSITY OF THE FAR ULTRAVIOLET BACKGROUND AND NEUTRAL GALACTIC HYDROGEN

A number of experiments have been carried out to investigate the correlation between the intensity of the far ultraviolet background and the neutral galactic hydrogen. The Berkeley Extreme Ultraviolet Telescope (Paresce, McKee, and Bowyer 1980) 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 (λλ 1350–1550 Å) was defined by a calcium fluoride filter on the short-wavelength side and by the rapid decline in the detector efficiency at the long-wavelength side. Because of the rather unusual observing conditions which accompanied this joint-nation manned mission, the data obtained were of uneven quality (Paresce et al. 1979). The data set for $|b| > 30°$ (chosen to avoid extensive star contamination) was subjected to an array of screening routines which selected that subset of the data which 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 showed a correlation with galactic hydrogen as derived from 21 cm radio measurements, 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} s^{-1} sr^{-1} Å^{-1} (hereafter continuum units ≡ cu).

Subsequently, Maucherat-Joubert, Deharveng, and Cruvellier (1980) 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 λλ 1525–1855 Å. A calcium fluoride filter eliminated potential scattered hydrogen 1216 Å radiation. The combination of slit width and satellite rotation gave a 1° × 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 24–40 $\deg^2$, 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. (1982) 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 λλ 1500–1700 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 (1983) 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° FWHM. The bandpass of the instrument was ~ 1230 to 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. (1983) reanalyzed the far ultraviolet data obtained with the D2B satellite using a larger amount 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 symmetrical 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 (Jakobsen et al. 1984). These photometers covered wavelengths from λλ 1450–2400 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 (0.5°), virtually eliminating the problem of stellar contamination. The use of three photometers permitted an accurate appraisal of possible airglow and zodiacal light effects. Data from all three photometers showed a correlation with galactic hydrogen column. The shortest wavelength photometer which spanned the 1450–1700 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, and Frank (1989*a*; 1989*b*, both this volume) 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 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 (1989, this volume) 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. It was recognized, however, that this result was rather uncertain because of the relatively small range of hydrogen column densities scanned.

Lequeux (1989, this volume) and Lequeux, Hanus, and Perault (1990) have 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.

Hurwitz, Bowyer, and Martin (1989, this volume; 1990, in preparation) report on their data obtained by the Berkeley imaging nebular spectrograph which was flown on the Space Shuttle as part of NASA's UVX (Ultraviolet Experiment) payload. This instrument had a field of view of 0.1° × 4°, a resolution of 15 ± 2 Å, and a bandpass from 1400 to 1850 Å. Special care was taken in the design and fabrication of this instrument to assure that scattering from stellar sources would be negligible.

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 had a large area-solid angle product, which 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 which were present could be easily identified and removed from the data because of the imaging capabilities of the instrument. Consequently, view directions with relatively high column densities of neutral hydrogen (and generally higher densities of stars) could also be investigated. Finally, because the instrument had spectroscopic capabilities, different processes contributing to the background could be identified and treated independently. The detector background was determined throughout the observation period through the use of an automatically interposed opaque shutter. The instrument was calibrated before and after flight, and the results agreed to within 10%.

In Figure 1, the continuum far ultraviolet intensity measured with this instrument is shown as a function of neutral hydrogen column density (Hurwitz, Bowyer, and Martin 1990). The spectra were integrated over the total bandpass of the instrument excluding wavelengths where other processes contribute significantly to the continuum. 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 remains constant thereafter with increasing hydrogen column. The flux extrapolated to zero hydrogen column is 272 ± 13 cu.

Henry, Feldman, and Murthy (1989, this volume) and Murthy et al. (1989) reported measurements of the far ultraviolet background obtained with the Johns Hopkins far ultraviolet

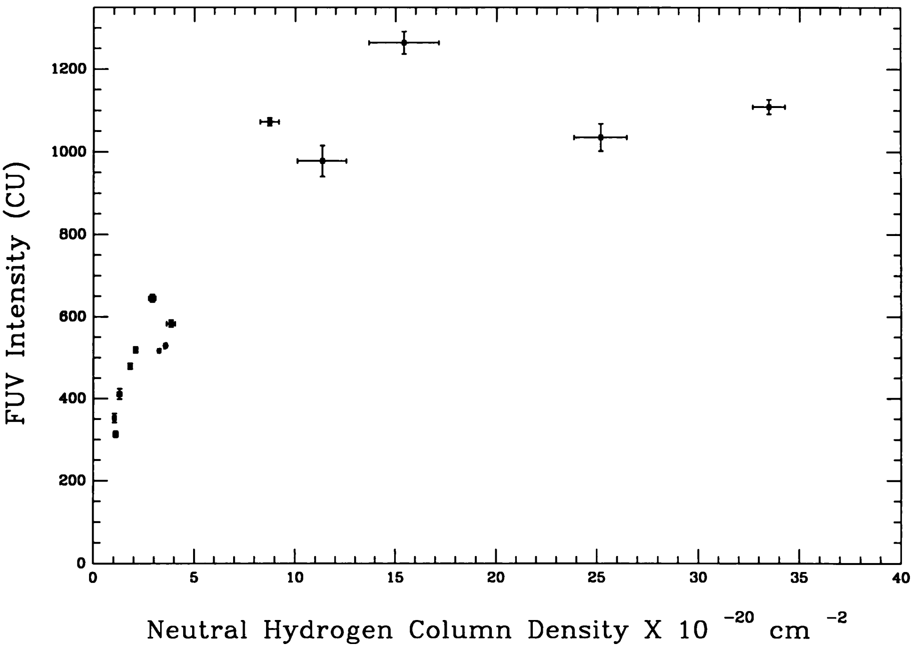

Figure 1. The continuum far ultraviolet intensity versus neutral galactic hydrogen column as obtained with the Berkeley nebular spectrograph. For this display, the spectra were integrated over the total bandpass of the instrument excluding wavelengths where high-ionization or molecular hydrogen emission contribute significantly to the continuum. 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.

spectrometer, the other instrument in the NASA UVX payload. The Johns Hopkins and Berkeley instruments were coaligned and operated simultaneously. The Johns Hopkins instrument consisted of two Ebert-Fastie scanning spectrometers which were fed by off-axis parabolic mirrors. 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. The data obtained with this instrument "were plagued by a very high electrical noise level, which both introduced a number of spikes and added a constant DC level to the 'true' instrumental dark count" (Murthy et al. 1989). The authors carried out a variety of procedures to establish the true count rate and background level. The results obtained yielded an intensity which was similar to that obtained by Hurwitz, Bowyer, and Martin (1989, this volume; 1990). The Johns Hopkins observations found "some, but not conclusive, evidence for a spatially varying background" (Murthy et al. 1989), in contradiction with the Berkeley results, which found clear evidence for a spatially varying background from the same view directions. The reason for this difference is not known.

TABLE 1. Correlation of Intensity of the Far Ultraviolet Background with Galactic Neutral Hydrogen Column[1]

Investigation	Slope of Correlation[2]	Intensity at $N_H = 0$ Intercept[3]	Comments
Paresce, McKee, and Bowyer 1980	90 ± 10 to 140 ± 20	106 ± 60 to 570 ± 80	Apollo-Soyuz Mission Variation among 4 view directions
Maucherat-Joubert, Deharveng, and Cruvellier 1980	180 ± 80	$600 {+0 \atop -250}$	D2B Satellite $\vert b \vert > 40°$
Zvereva et al. 1982	150	150	Prognoz 6 Satellite
Weller 1983	Not evaluated	Not evaluated 180 ± 75 280 ± 88 at North and South Galactic Poles	Solrad 11 Satellite
Joubert et al. 1983	96 ± 6	677 ± 20	Reanalysis of D2B Satellite data $\vert b \vert > 30°$
Jakobsen et al. 1984	210 ± 20	450 ± 30	Aries Rocket
Fix, Craven, and Frank 1989*a*	~ 60	530 ± 80	Dynamics Explorer 1
Murthy et al. 1989	Not evaluated	Not evaluated 100 to 300 at high galactic latitudes	Johns Hopkins UVX Shuttle Experiment
Hurwitz, Bowyer, and Martin 1989, this volume	102 ± 6	272 ± 13	Berkeley UVX Shuttle Experiment
Lequeux 1989, this volume	96	Not evaluated	Detailed reanalysis of D2B Satellite data
Onaka 1989, this volume	(30) (see text)	400	Rocket Flight Scan of Virgo Cluster

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[1] Data reported since 1980. For earlier results, see Davidsen, Bowyer, and Lampton (1974) and Paresce and Jakobsen (1980).

[2] Units of photons $(\mathrm{cm}^2\ \mathrm{s\ sr\ Å})^{-1}/10^{20}$ H I cm^{-2}

[3] Units of photons $(\mathrm{cm}^2\ \mathrm{s\ sr\ Å})^{-1}$

The results discussed here are summarized in Table 1. The majority of the data reported in the 1980s show a correlation of intensity with neutral hydrogen column, indicating that 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 extrapolated to zero hydrogen column. These differences could reflect astrophysical effects that add to the primary source of the background radiation. Certainly a variety of mechanisms will produce a diffuse far ultraviolet flux at some level. The question is whether the experimental results have yet reached a level of accuracy which reflects true astrophysical phenomena or if these differences are simply experimental artifacts. In this regard, it is interesting to note that two of the more extensive data sets that have been treated in some detail agree as to the slope of the correlation (Lequeux 1989, this volume; Lequeux, Hanus, and Perault 1990; Hurwitz, Bowyer, and Martin 1989, this volume; 1990).

The intensity of the flux extrapolated to zero hydrogen column is highly dependent upon experimental uncertainties, and since it is typically within a factor of a few of the lowest flux measured, it is most likely to reflect true astrophysical effects. Consequently this number is most likely to vary with specific view direction.

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 consensus outlook of workers in the field when the mechanism was first advanced by Paresce, McKee, and Bowyer (1980). There were two widely held objections to starlight scattered by dust as the source of this radiation: (1) dust was believed to be sparse to non-existent at high galactic latitudes, and (2) dust was believed to be strongly forward-scattering in the far ultraviolet, and hence even if dust was present at high galactic latitudes, radiation from hot stars in the plane would not be scattered back to our mid-plane position.

Although a fair amount of optical work has since been carried out which indicates 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 (Low et al. 1984). However, because of uncertainties in the zero point level of the IRAS detectors, it is not clear if high-latitude dust is omnipresent or just widespread.

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 OAO-2 or the IUE satellite, but a number employed specialized instruments specifically intended for studies of dust. In the analysis of their data, most workers employ the formalism of Henyey and Greenstein (1941), who showed that dust could be well characterized by two parameters: the albedo (ω=0.0 implies complete absorption; ω=1 implies complete reflection) and the scattering asymmetry factor of the grains (g = 0.0 implies isotropic scattering; g = 1 implies total forward scattering). In Table 2, I list the results obtained by various workers on this topic.

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-

TABLE 2. Dust Properties in the Far Ultraviolet

Workers	Target	Results
Andriesse, Piersma, and Witt (1977)	NGC1435	$g \sim 0.25$
Jura (1979)	NGC1435	$g \sim 0.2$
Carruthers and Opal (1977)	Orion	"Albedo is high"
Witt and Lillie (1978)	Orion	ω higher in FUV than at 2175 Å bump scattering more isotropic in FUV than at longer λ
Bohlin et al. (1982)	Orion	$0.5 < \omega < 0.7$
Tanaka et al., Onaka et al. (1984)	Orion	$0.3 < \omega < 0.6$, $0.2 < g < 0.5$
de Boer and Kuss (1988)	Orion	$g \sim 0.6$, ω and g similar across FUV band
Witt et al. (1982)	NGC7023	$\omega \sim 0.6$; $g \sim 0.25$
Witt, Bohlin, and Stecher (1986)	CED201, IC435	ω similar in FUV and at 2700 Å if g constant
Donas et al. (1981)	M101	g lower in FUV than at visible λ
Lillie and Witt (1976)	DGL	$0.4 < \omega < 0.6$, $0.7 < g < 0.9$
Anderson, Henry, Fastie (1982)	DGL	either $g > 0.9$ or $\omega < 0.2$
Joubert et al. (1983)	DGL	$0.6 < g < 0.7$ (assumed $\omega = 0.5$)
Jakobsen et al. (1984)	DGL	$\omega \times (1-g) \sim 0.16$
Onaka (1989, this volume)	DGL	$\omega \times (1-g) \sim 0.07$
Fix, Craven, and Frank (1989*a*)	DGL	$g > 0.9$
Hurwitz, Bowyer, and Martin (1990)	DGL	$\omega = 0.16 \pm 0.03$ $g < 0.2$ (80% confidence)

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 since 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 (Joubert et al. 1983) 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. Finally, simple omissions can lead to incorrect results. Fix, Craven, and Frank (1989*a*) obtained a large value for the asymmetry factor by fitting their plane-to-pole data set with standard formula; unfortunately, the formulae used were not appropriate since they neglected an optical depth term; this led to an incorrect result.

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 starlight. The resultant data clearly display saturation effects at higher values of hydrogen column density (and hence larger reddening). (See Figure 1 for one example of this effect.) Detailed analysis of these data (Hurwitz, Bowyer, and Martin 1990) 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. The high galactic latitude observations of Hurwitz, Bowyer, and Martin (1990), and those of most other 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 data of Hurwitz, Bowyer, and Martin (1990) include low-latitude targets with relatively faint background intensities; these are consistent only 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. 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, and the field is acknowledged to be fraught with difficulties and uncertainties, they appear to be well founded (though it can be reasonably argued that this author is not the best judge of this statement). In any case, these results are the product of a single investigation and certainly need independent confirmation.

Martin, Hurwitz, and Bowyer (1990*a*) have compared the continuum spectrum obtained with the Berkeley UVX instrument in the direction of their lowest intensity flux measurement with a view direction which includes a small, but measurable, dust component. The continua of the two spectra are essentially identical except for intensity; the authors therefore conclude that dust is the source of the continuum emission in both directions. The intensity in the direction with lowest neutral hydrogen column density is ~ 300 cu, and since this is similar to the lowest levels of flux measured by other investigators in a variety of view directions, these authors conclude that at least some far ultraviolet scattering dust is present essentially in every view direction in the galaxy. This type of measurement is fraught with difficulties, and hence this result should be viewed with caution. If true, however, this finding will have substantial consequences for all of ultraviolet astronomy.

4. THE SPECTRUM OF THE FAR ULTRAVIOLET BACKGROUND

4.1. Theoretical Suggestions

A wide-ranging set of processes has been suggested that would produce 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 on processes in a possible intergalactic medium. For a discussion of these early suggestions, the reader is referred to the reviews by Davidsen, Bowyer, and Lampton (1974) and Paresce and Jakobsen (1980).

With the realization that the far ultraviolet background might well be dominated by galactic radiation, an entirely different class of suggestions was advanced. Duley and Williams (1980) 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 and Williams noted that a byproduct of the destruction process that was observable, in principle, was emission in the far ultraviolet. This emission consists of two components. The first is due to fluorescence in the vibrational-electronic transitions of the H_2 molecule when incident photons in the 845–1108 Å range are absorbed in the Lyman and Werner bands from the ground state, which are 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 emitted during decays to unbound levels of the ground state. This process leads to dissociation of the molecule with a probability per absorption of ~10%.

Jakobsen (1983) computed a detailed spectrum of this radiation and showed that in reasonable conditions in the Galaxy, this process could contribute up to 30% of the observed diffuse background (Jakobsen 1982).

Jakobsen and Paresce (1981) suggested that a hot (~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 and Chevalier (1986) refined these calculations to account for the fact that interstellar gas at ~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 and 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, and Barge (1982) investigated the possible contribution of a warm (~10^4 K) intercloud medium to the far ultraviolet background. They concluded that for $\lambda <$ 2000 Å, an intercombination line of carbon III is a potential emission line. They also showed that 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 H I freebound and free-free continua below 2700 Å.

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. Early spectral measurements made by Henry et al. (1978) and Hua et al. (1978) indicated the presence of a broad spectral feature in the background, but this result was negated by a higher quality spectrum obtained by Anderson et al. (1979), who found a flat spectrum.

Following the suggestion of Jakobsen and Paresce (1981) that emission lines from a hot galactic corona might be present in the far ultraviolet background, Feldman, Brune, and Henry (1981) reexamined the flat spectrum reported by Anderson et al. "to the limits of the instrumental resolution" ($\Delta\lambda$ ~ 60 Å) and found evidence to "suggest the presence of an emission line component to the radiation field." However, the intensities of these lines were two orders of magnitude larger than that predicted by Jakobsen and Paresce. Edgar and Chevalier (1986) 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. (1989) reported ~17 Å spectra from the Johns Hopkins UVX experiment flown on the Space Shuttle covering the wavelength range from 1200 to 1700 Å. They found a spectrally flat background over this band with no evidence for the lines suggested by Feldman, Brune, and Henry (1981); however, due to the sensitivity of their measurement, they could not formally rule out lines of this intensity.

Martin and Bowyer (1989) have reported the discovery of emission lines of C IV and O III] in several high galactic latitude view directions with the Berkeley UVX far ultraviolet nebular spectrometer and O IV/Si IV and N III line detections in a summed high latitude spectrum. The intensities observed were roughly those predicted by Jakobsen and Paresce (1981) and Edgar and Chevalier (1986) and were about two orders of magnitude below those reported by Feldman, Brune, and Henry (1981). These flux levels were sufficiently low that they would not have been detected by the Johns Hopkins instrument that was taking data in the same view direction simultaneously (Murthy et al., 1989).

Martin and Bowyer combined their emission results with absorption data obtained with the IUE instrument and showed that the flux emanated from high above the galactic plane. This proved the existence of the long postulated, but unproven, hot galactic halo. The mass infall rate derived from these data showed that the source for this halo must be continuously replenished, which provided experimental confirmation of the ''galactic fountain'' model of the galactic halo gas (Shapiro and Field 1976).

Martin, Hurwitz, and Bowyer (1990*b*) found molecular hydrogen emission in four view directions with the Berkeley nebular spectrograph flown on the Space Shuttle as part of the UVX experiment. Molecular hydrogen had previously been detected in two very high density cloud complexes (Brown et al. 1981; Witt et al. 1989) but had not been observed elsewhere. All of the four detections were in view directions with only modest neutral hydrogen column densities ($\sim 10^{21}$ H I 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.

5. 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 view was that this background was primarily extragalactic in origin. Estimates of its intensity ranged over 3 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 that contribute 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 to scatter isotropically and hence is different from dust that produces scattering in the visible. 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 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 gas seems to be the appropriate description of the overall phenomenon.

Two-photon emission from recombining ionized hydrogen has been recognized as a component of the far ultraviolet background. Molecular hydrogen fluorescence was found to be present in low density molecular clouds. The data indicate that the emission is produced primarily from clumped portions within the clouds.

The only extragalactic component to the background that appears to have been detected (for a review of the extragalactic far ultraviolet background, see Paresce 1989, this volume) is the summed far ultraviolet emission of all galaxies. If the reported flux (Martin and Bowyer 1989) 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.

A summary of the major components of the cosmic far ultraviolet background is presented in Table 3. It is clear that studies of the diffuse ultraviolet background have at long last begun to bear fruit. The results obtained have not only delineated the origins of this flux, they have also enriched our understanding of diverse areas of astrophysical interest.

TABLE 3. Components of the Diffuse Cosmic Far Ultraviolet Background with Estimated Intensities[1]

Total Intensity	250–1500
Galactic Components	
Scattering by Dust	0–1500
H II Two Photon Emission	50
H_2 Fluorescence	100 (in molecular clouds)
Hot Gas Line Emission	10
Uniform Component	
Summed from All Galaxies	50
Dust in the Milky Way	0–200
QSOs / AGNs	< 10
Unexplained	0–200

[1] Intensities dependent upon view direction. Units are photon cm^{-2} s^{-1} sr^{-1} $Å^{-1}$.

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A.W. Harris: *You say that your observations establish that the* 10^5 *K gas is situated well above the galactic plane. Does this mean you can rule out the possibility that a significant amount is situated within the galactic disk?*

S. Bowyer: Yes. Given the emission measure we find, if the gas were located primarily in the disk it would be vastly over-pressured and hence would rapidly dissipate into the halo.

J.B. Holberg: *Do the emission lines seen in the Berkeley UVX experiment and the emission lines seen in the Labov-Bowyer Rocket spectrum come from the same plasma?*

S. Bowyer: If we interpret the emission seen in our rocket flight as lines and line complexes from a hot thermal plasma, three different temperatures are indicated: one consistent with that inferred from broad-band soft X-ray measurements; one consistent with the Berkeley UVX and IUE measurements; and one at a temperature of $\sim 8 \times 10^5$ K, which is consistent with the temperature derived from O VI absorption studies made with the Copernicus Satellite.