FAINT OPTICAL LINE EMISSION FROM THE DIFFUSE INTERSTELLAR MEDIUM: OBSERVATIONS AND IMPLICATIONS

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ABSTRACT. Diffuse galactic Hα emission appears to cover the entire sky with an intensity that ranges from 3–12 R near the galactic equator to 0.25–0.8 R near the galactic poles. Observations of this H-recombination line and the forbidden lines, [S II] 6716 Å, [N II] 6583 Å, and [O III] 5007 Å, indicate that the emission originates from a low-density, 2–3 kpc thick layer of warm (~10^4 K), ionized interstellar gas that has an emission-line spectrum significantly different from that of the traditional, more localized H II regions. Along a line perpendicular to the galactic disk, the mean emission measure of this layer is 4.5 cm^{-6} pc, and the column density of the H^+ is 2×10^{20} cm^{-2}. The origin of this diffuse ionization is not yet clear; however, its existence requires the equivalent of about 14% of the total ionizing photon flux from O stars or nearly all of the power injected into the ISM by supernova. This optically emitting gas also may be a nonnegligible source of diffuse emission in the far ultraviolet (FUV) and infrared (IR).

1. INTRODUCTION

In 1938 Struve and Elvey found extended regions of nebular line emission in Cygnus and Cepheus, which differed from "Hubble's nebulae" in that they showed "little or no tendency to concentrate toward a bright star." They attributed the emission to ionized gas "excited by the general stellar radiation coming from O and B stars in the Milky Way star clouds." These particular regions have angular extents ~10° and Hα intensities ~10^2 R (1 R = $10^6/4\pi$ photons cm^{-2} s^{-1} sr^{-1} or 2.41×10^{-7} ergs cm^{-2} s^{-1} sr^{-1} at Hα), which by today's standards are neither very faint nor extended. However, with the techniques available at the time, such regions of diffuse interstellar emission apparently were too faint for further exploration. It was not until approximately three decades later that diffuse optical line emission from the Galaxy became a serious topic for study, initially among aeronomers, who worried about possible galactic contamination of their spectroscopic observations of aurorae (Montbriand, Tinsley, and Vallance Jones 1965), zodiacal light (Daehler, Mack, and Stoner 1968), and airglow emission (Hindle, Reay, and Ring 1968). For example, during a study of terrestrial Hβ emission in the night sky using low-resolution Fabry-Perot spectroscopy, Reay and Ring (1969) found evidence for faint, diffuse Hβ emission associated with the galactic plane. Their results were soon supported by Hβ photometric measurements of the night sky by Johnson (1971), who reported the detection of faint Hβ emission in directions near ($|b| < 30°$) the galactic plane but outside the mapped H II regions. In addition, improved Hα photography of the sky revealed both filamentary and diffuse emission from areas between the bright H II regions and sometimes far from the galactic plane (e.g., Morgan, Strömgren, and Johnson 1955; Meaburn 1967; Cruvellier 1967; Georgelin and Georgelin 1970; Courtès and Sivan 1972; Sivan 1974; Parker, Gull, and Kirshner 1979). Photometric observations from Earth orbit (Levasseur 1976) also revealed a band of diffuse Hα emission extending along the entire Milky Way.

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A serious limitation of these broad-band observations of faint galactic Balmer line emission is contamination by background starlight and the presence of terrestrial (geocoronal) Hα and Hβ emission lines, which generally overwhelm the galactic emission at $|b| > 15°$ (e.g., Reay and Ring 1969; Johnson 1971). Fortunately, since the galactic hydrogen often has radial velocities of ± 25 km s^{-1} (±0.5 Å) or more with respect to the Earth, it has been possible with high-resolution Fabry-Perot spectroscopy to resolve the unshifted, geocoronal emission line from the usually much fainter galactic lines and thus unambiguously measure the intensities, radial velocities, and widths of the diffuse galactic emission lines (Reynolds 1971; Reynolds, Roesler, and Scherb 1973); high spectral resolution also suppresses the night sky continuum. This technique led to the detection and study of a very faint (~1–10 R) source of galactic line emission that seems to be present over the entire sky (e.g., Reynolds, Roesler, and Scherb 1974; Reynolds 1977, 1980, 1983, 1984, 1987*a*). The following is a summary of the most recent observations of this diffuse emission plus a discussion of its possible origin and its implications for the galactic radiation field in the extreme ultraviolet (EUV), FUV, visible, and IR.

2. OBSERVATIONS OF THE DIFFUSE OPTICAL LINE EMISSION

2.1 Hα

Sivan's (1974) wide-field (60°), 10 Å passband Hα photographs show the distribution of galactic Hα emission down to a sensitivity limit of about 15 R (Reynolds 1983) with an angular resolution of ~0.5°. His survey reveals a complex pattern of Hα emission near the galactic equator consisting of many discrete H II regions, at least two enormous bubblelike structures (the Gum nebula and the Orion-Eridanus shell), and regions of extended, diffuse emission, including, for example, the Struve and Elvey region in Cygnus at $70° \leq l \leq 90°$ and a large portion of the southern Milky Way at $285° \leq l \leq 30°$. Some of the brighter patches of diffuse emission in the southern Milky Way have been investigated with a grating nebular spectrograph (Sivan, Stasinska, and Lequeux 1986). Almost all of the Hα emission detected by this survey is located at $|b| < 15°$.

High spectral resolution (0.26 Å; 12 km s^{-1}) Fabry-Perot scans have sampled the Hα emission in a few hundred directions on the sky with 0°.1 and 0°.8 fields of view (beam diameters). Although the Fabry-Perot observations have not yet provided the high angular resolution of the photographic surveys, they have detected (and provided kinematic information for) galactic Hα emission down to intensity limits of 0.5 R or less. This is about a factor of 30 more sensitive than photographic techniques and about a factor of 1000 more sensitive than radio recombination line observations. Virtually all of the observations have been carried out with University of Wisconsin 0.15 m, dual etalon Fabry-Perot spectrometers operated at various times at the 0.9 m telescope at Goddard Space Flight Center in Maryland, at the McMath 1.5 m telescope on Kitt Peak, and at observing facilities near Madison, Wisconsin (Roesler et al. 1978). The observations have clearly revealed the existence of a ubiquitous galactic Hα background, which has an intensity that ranges from approximately 3–12 R, with a mean value of 6 R, along the galactic equator to 0.25–0.8 R near the galactic poles (e.g., Reynolds, Roesler, and Scherb 1974; Reynolds 1983, 1984).

Four sample scans are shown in Figure 1. The data points represent photomultiplier counts accumulated within 2.1 km s^{-1} velocity bins plotted versus radial velocity with respect to the Earth. In each scan the geocoronal Hα line is centered near 0 km s^{-1}, while the galactic

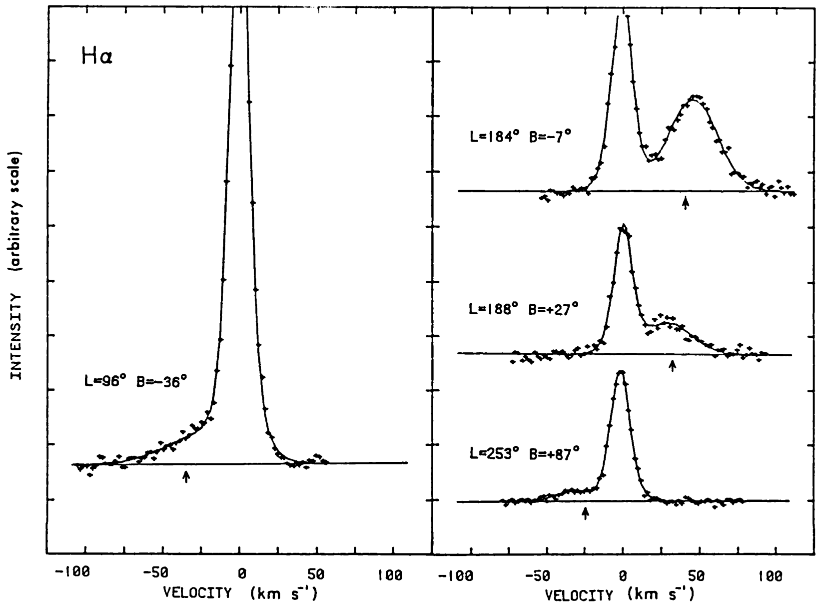

Figure 1. Fabry-Perot scans of Hα emission in four directions. The radial velocity scale is with respect to the Earth, and the LSR velocity for each scan is indicated by an arrow. The three scans on the right were obtained in February and March, when the geocoronal line (at 0 km s^{-1}) is faint to moderate; the scan on the left was obtained in June, when the geocoronal line is relatively bright throughout the night. The integration time for the scan at b = +87° was 37 min, while the integration time for each of the other three scans was about 13 min.

Hα emission is detected as a broader feature centered near the local standard of rest (LSR) velocity (denoted by an arrow). In order to minimize confusion between the galactic and geocoronal emission, the scans are obtained during times of the the year when the LSR velocity for the observation direction is well separated from the Earth's velocity. The scans are fitted with Gaussian emission components to facilitate the derivation of an intensity, radial velocity, and width for each galactic and geocoronal Hα emission component. The solid curve drawn through the data points for each scan in Figure 1 is the sum of the best-fit Gaussian components (in these cases one galactic and one geocoronal) convolved with the instrumental spectral response function. The scatter of individual data points about this line is due to Poisson fluctuations of the accumulated counts; off the lines the counts are dominated by continuum from the night sky. The derived galactic Hα intensities in Figure 1 range from 7.0 ± 0.4 R at l = 184°, b = −7°, to 0.8 ± 0.4 R at l = 253°, b = +87°. Absolute intensities are based upon calibrations that use planetary nebulae, bright emission nebulae, and standard stars (Scherb 1981); the systematic error is probably less than 15%. The integration time for a scan is typically about 15 min, which provides a signal-to-noise ratio of about 10σ within a 12 km s^{-1} spectral element at the peak of a 1 R galactic emission line (FWHM ≈ 25 km s^{-1}). This is sufficient for the intensity, radial velocity, and line width to be measured with reasonable (±10%) accuracy.

Figure 2 is a map of galactic Hα intensities synthesized from the Fabry-Perot data presented in Reynolds, Roesler, and Scherb (1974), Reynolds and Ogden (1979, 1982),

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Reynolds (1983, 1984, 1985*a*) for the LSR radial velocity interval –20 km s^{-1} to +60 km s^{-1}; this excludes Hα emission from the Perseus spiral arm at l = 90° to 150°. The observations are scattered over the sky at declinations greater than –20°, with the angular separations between the observation directions typically ranging from 5°–10° at $|b| < 20°$ to 10°–20° at higher latitudes. This extreme undersampling of the sky obviously restricts the information that can be obtained from this map primarily to the very large scale features of the diffuse emission. Unfortunately, the required integration times imply that, until more efficient instrumentation is developed, higher angular resolution surveys of this emission will have to be limited to only a few, small regions of the sky (see below).

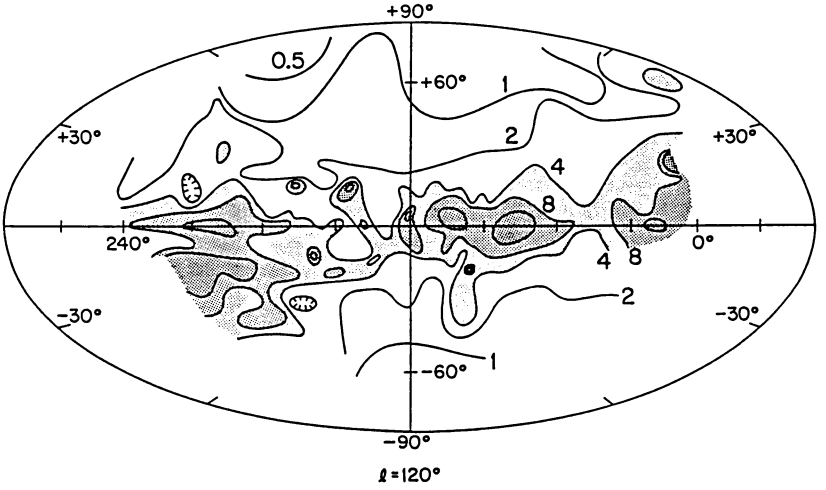

Figure 2. A contour map of diffuse galactic Hα emission constructed from over 500 Fabry-Perot scans at declinations $\delta > -20°$. The contours represent galactic Hα within the radial velocity interval –20 km s^{-1} ≤ V_{LSR} < +60 km s^{-1}, which excludes emission from the outer Perseus arm at $90° < l < 150°$. The contour levels are 0.5, 1, 2, 4, 8, and 20 R, where 1 R = $10^6/4\pi$ photons cm^{-2} s^{-1} sr^{-1}. The center of the Aitoff projection is at l = 120°, b = 0°.

While some of the small "bright spots" in Figure 2 are associated with H II regions surrounding O and B stars (e.g., α Cam at l = 144°, b = +14°; ξ Per at 163°, –13°; 10 Lac at 117°, –11°; α Vir at 316°, +51°), most of this map consists of truly diffuse Hα emission that shows no tendency to concentrate toward a luminous star. Within about 10° of the galactic equator, local spiral structure (Becker and Fenkart 1970) is apparent in the pattern of Hα intensities. There is enhanced emission at $l < 30°$, which is associated with the Sagittarius arm, and at l = 60° to 240°, which is associated with the local Orion arm; the intensities are lowest in the interarm directions, l = 30°–60°, and in directions perpendicular to the Orion arm, l = 140°–170°. This structure is also apparent in the radial velocities of the Hα emission (Reynolds 1983). At $|b| > 5°$, the Hα intensities I_α generally decrease with increasing $|b|$ in a manner consistent with $I_\alpha \sin|b|$ = 1 R (Reynolds 1984). At a given latitude there appear to be real intensity variations from direction to direction of about a factor of 3 (peak to trough); there is also some evidence that at $|b| > 60°$ the mean value of I_α may be approximately a factor of 2 below that predicted by the $\csc|b|$ distribution at lower latitudes (see Reynolds 1984).

In order to investigate the Hα intensity distribution on smaller angular scales, two $11° \times 11°$ regions of the sky were mapped on an approximately $1° \times 1°$ grid with a 0°8 diameter beam. One of these maps was centered at $l = 144°$, $b = -20°$ (Reynolds 1980), and the other at $l = 213°$, $b = +3°$ (Reynolds 1987*a*). The resulting 1° angular resolution velocity-interval "images" of the Hα background reveal a complex morphology consisting of filaments and diffuse patches of enhanced emission ($\gtrsim$ 1 R) superposed on a fainter, more uniform Hα background. An examination of the structure of the background emission at even higher angular resolution (~1–2′) has been started recently by directly imaging the sky onto a low-noise charge-coupled device (Milster et al. 1989; Brinkmann 1987).

2.2 Other Emission Lines

In addition to Hα the nebular lines, [N II] 6583 Å, [S II] 6716 Å, and [O III] 5007 Å, have been identified in the galactic background. They have intensities approximately 0.3, 0.3, and 0.06 that of Hα, respectively (e.g., Reynolds 1985*c*; Sivan, Stasinska, and Lequeux 1986). Searched for but not found are [N I] 5201 Å and [O I] 6300 Å, which have intensities less than 9×10^{-3} and less than 2×10^{2} that of Hα, respectively (Reynolds, Roesler, and Scherb 1977; Reynolds 1989*b*). The [N II]/Hα intensity ratio is similar to that found in traditional H II regions surrounding O stars, while the [S II]/Hα ratio is much larger and the [O III]/Hα, Hβ ratios smaller than those observed in H II regions.

High [S II]/Hα ratios appear to be a general characteristic of the background emission that clearly distinguishes it from H II regions associated with O and B stars. Accurate comparisons of the [S II]/Hα ratios between the H II regions and the galactic background (Reynolds 1985*b*, 1988) reveal that the [S II] intensities in the background are systematically larger than those in the H II regions by about a factor of 4. A systematic difference remains even when the Hα surface brightness of the H II region is comparable with that of the galactic background. However, the H II regions do show some evidence for a gradual increase in the [S II]/Hα ratio with decreasing Hα surface brightness, which suggests the ratios may be comparable with those in the background when the H II region surface brightness is less than 1 R (Reynolds 1988).

The range of [S II]/Hα ratios (from 0.23–0.53) in the background is larger than the estimated errors, indicating that there is a real variation within the galactic background. All of the forbidden line data have been obtained at moderate to low galactic latitudes ($-36° \leq b \leq +12°$); within this range there is no evidence for a correlation with latitude.

3. THE ORIGIN OF THE EMISSION

3.1 Properties of the Emitting Gas

The diffuse galactic line emission appears to originate from warm, ionized interstellar gas located outside the traditional H II regions (see Kulkarni and Heiles 1987, 1988 for thorough reviews of the atomic components of the interstellar medium [ISM]). While the nature of this ionized gas is not well understood, the optical emission-line observations do place many constraints on its properties, including the temperature, kinematics, emission measure, distribution within the galactic disk, and ionization state.

The high [S II]/Hα and low [O III]/Hα, Hβ intensity ratios found in the background imply that the diffuse Hα emission is not primarily light from bright H II regions scattered by interstellar dust. For example, the [O III] 5007 Å/Hα intensity ratio, which has a value in the background that is approximately one-tenth that typically found in bright emission nebulae (see, e.g., Table 3 in Reynolds 1985*c* and Table 2 in Sivan, Stasinska, and Lequeux 1986), places an upper limit of about 10% on the contribution of scattered light from such bright H II regions to the diffuse Hα emission near the galactic equator. A scattered component of the background Hα that was as high as this upper limit would account for only about 3% and 8% of the background [S II] and [N II], respectively. Scattered light from bright H II regions also appears to be relatively small at higher ($b \approx 40°$) galactic latitudes (Reynolds, Scherb, and Roesler 1973).

3.1.1. Temperature and nonthermal motions. Accurate, direct measurements of the temperature of the emitting gas from observations of [O III] 4363 Å and [N II] 5755 Å do not exist because these lines are expected to be extremely faint, and a search for them has not yet been attempted. However, an analysis of the line widths of Hα and [S II] provides an upper limit of 20,000 K and a most probable gas temperature of about 8000 K (Reynolds 1985*b*). This line width analysis also indicates that the random, nonthermal motions within the gas have speeds typically 10–30 km s^{-1}. The existence of the thermally excited forbidden line emission also provides a lower limit on the electron temperature of about 5500 K (Reynolds 1989*b*). Hereafter a temperature of 8000 K is adopted for the emitting gas.

3.1.2. Emission measure. The emission measure ($\mathrm{EM} = \int n_e^2\, ds$) of the gas along a line of sight not affected significantly by interstellar extinction is determined from the relation

$$\mathrm{EM} = 2.75\ T_4^{0.9}\ I_\alpha\ \mathrm{cm^{-6}\ pc}, \tag{1}$$

where I_α is in rayleighs (R) and T_4 is the electron temperature in units of 10^4 K. Since at high latitudes $< I_\alpha \sin|b| > \approx 1$ R, the mean emission measure along a line perpendicular to the galactic disk is approximately 4.5 $\mathrm{cm^{-6}}$ pc.

3.1.3. Distribution: scale height, density, and filling fraction. The $\csc|b|$ intensity distribution of the diffuse Hα at $|b| \gtrsim 5°$ suggests that the emitting gas has a disklike distribution about the galactic plane. Although it is concentrated within the spiral arms (see section 2.1), the gas seems to be present along every line of sight, even through interarm directions and toward the galactic poles (Figure 2). The ubiquitous nature of the emission and the relatively smooth decrease in the average intensity with increasing $|b|$ (Reynolds 1987*a*) indicate that the emitting gas is very widespread.

Significant deviations from a $\csc|b|$ distribution at $|b| \lesssim 5°$ appear to be due to the dominance of interstellar extinction for long path lengths through the galactic disk. The effective path length for absorption (as opposed to scattering) of the diffuse Hα photons has been estimated to be ~2 kpc (Reynolds 1985*d*). Therefore, the average intensity of the diffuse Hα along the galactic equator of 6 R implies a mean square electron density $<n_e^2>_0 \approx 0.007\ \mathrm{cm^{-6}}$ at $z = 0$ (from equation [1]), and the pole-to-plane intensity ratio of approximately one-sixth indicates a scale height $H \approx 600$ pc, for the gas. This scale height is consistent with $H = 600$–1200 pc obtained from an examination of the latitude extent of diffuse Hα emission from the Perseus spiral arm (Reynolds 1985*d*; also new data, in preparation). The presence of Hα emitting gas at $|z| \geq 1$ kpc is also implied by the kinematic distances derived for emission features in the 1° angular resolution map centered at $l = 144°$, $b = -20°$. The inferred local densities within these emission features are $n_e \approx 0.2\ \mathrm{cm^{-3}}$ (Reynolds 1980), which suggests that the emitting gas is clumped into regions that occupy a

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fraction $f = <n_e^2>_o/n_e^2 = 0.2$ of the total volume. Therefore, the H^+ column density is $N_{H^+}\sin|b| \approx 10^{20}$ cm^{-2}, and near the midplane the space averaged electron density is $<n_e>_o \approx 0.04$ cm^{-3}.

3.1.4. Ionization state. The ionization/excitation conditions within the emitting gas apparently differ significantly from conditions within traditional H II regions. The very low intensity of [O III] and the relatively strong [S II] (and [N II]) indicate a low state of excitation, with few ions present that require ionization energies greater than 23–35 eV. On the other hand, the absence of [N I] and especially [O I], which is tightly coupled by charge exchange to the ionization state of hydrogen, implies that hydrogen is nearly fully ionized, with an ionization ratio $n_{H^+}/n_{H^o} > 2$ within the emitting gas (e.g., Reynolds 1989*b*).

3.2. Other Evidence for Diffuse Ionized Gas

Many other diverse observations indicate substantial ionization of the interstellar gas outside bright, localized H II regions. These observations include pulsar dispersion measures, radio scintillations, and rotation measures (e.g., Guelin 1974; Hewish et al. 1968); the free-free absorption of galactic synchrotron emission at low frequencies (Hoyle and Ellis 1963); and UV interstellar absorption lines (Gry, York, and Vidal-Madjar 1985). Some of these observations preceded the detection of the diffuse Balmer emission.

As a result of their analysis of the unique data obtained with the Tasmanian very low frequency radio array, Hoyle and Ellis (1963) were the first to propose the existence of an extensive layer of warm ($T \approx 10^4$ K), ionized gas about the galactic plane. They derived a mean emission measure of 5 cm^{-6} pc and a free electron column density ~10^{20} cm^{-2} through this ionized layer, values that are nearly identical to those derived years later from diffuse Hα observations (3.1.3) and pulsar dispersion measures. The pulsar data directly confirmed the existence of such a layer and have shown that it has a total thickness of about 3 kpc and a space-averaged electron density $<n_e>_o \approx 0.03$ cm^{-3} near the midplane (Weisberg, Rankin, and Boriakoff 1980; Reynolds 1989*a*). This diffuse H^+ accounts for about one-quarter of the total column density of atomic hydrogen near the solar circle and appears to be the dominant state of the interstellar gas at $|z| > 1$ kpc, where the density is equal to or greater than that of the high $|z|$ neutral hydrogen found by Lockman (1984) and Lockman, Hobbs, and Shull (1986).

Since the space-averaged electron density, column density, and thickness of this extended layer of ionized gas are very similar to those derived for the optically emitting gas, it appears that this ionized layer is the source of the diffuse optical line emission. Kulkarni and Heiles (1987) have shown that any difference between the scale heights derived for the dispersion measure–producing gas ($H \approx 1500$ pc) and for the Hα-producing gas ($H \approx 800$ pc) may be an indication that the filling fraction f is a function of $|z|$; for example, with the above values, consistency is achieved if f increases from about 0.1 at $z = 0$ to 0.6 at 1 kpc.

3.3 The Source of the Ionization

The source of this diffuse ionization is not yet established. It has been suggested that the high [S II]/Hα ratios in the galactic background are the result of either an extremely dilute ionizing radiation field (Mathis 1986; Reynolds 1988) or a combination of photoionization and weak shocks (Sivan, Stasinska, and Lequeux 1986; Brand and Mathis 1978). Whatever the mechanism, the intensity of the Hα background at high $|b|$ implies an average of 4×10^6 H-ionizations s^{-1} per cm^2 column perpendicular to the galactic disk at 0.46 Hα photons per subsequent recombination (Martin 1988); this corresponds to a minimum power input of 9×10^{-5} ergs s^{-1} cm^{-2} at 13.6 eV per ionization. Of the known sources of ionization and heating within the galactic disk, only luminous stars (essentially the O stars), which produce 3×10^7 ionizing photons s^{-1} cm^{-2} (Abbott 1982), and supernovae, which inject $\sim 1 \times 10^{-4}$ ergs s^{-1} cm^{-2} (e.g., Abbott 1982), meet or surpass this minimum requirement. Hot evolved stars (Panagia and Terzian 1984), cosmic rays (van Dishoeck and Black 1986), and the diffuse X-ray background (McCammon et al. 1983) fail to produce the required ionization by factors ranging from 20 to 2000. Moreover, Hα observations of an intergalactic H I cloud (Reynolds et al. 1986) and of high velocity clouds (Kutyrev and Reynolds 1989; Reynolds 1987*b*), which probe the ionizing radiation field within and outside the galactic halo, imply that at most 8–14% of the observed Hα is produced by ionizing radiation coming from outside the Galaxy.

Davidson and Terzian (1969) were the first to propose that the pulsar dispersion measures are produced by very faint, extended H II regions surrounding early-type stars. More recently it has been suggested that the diffuse, ionized gas is located in transition regions between the H I clouds and the hot, very low density "coronal" gas, and that it is photoionized by ambient Lyman continuum (LC) photons originating from the luminous stars and supernova remnants (McKee and Ostriker 1977). However, the scale height of the ionized gas is much larger than that of both the H I clouds and the known sources of ionization; about 70% of the gas appears to be located at $|z| > 500$ pc (Reynolds 1990). Thus the presence of substantial amounts of warm H^+ at high $|z|$ and along lines of sight far from ionizing stars (Reynolds 1989*c*) seems to require either the existence of some as yet unidentified source of ionization or a special morphology of the H I in the galactic disk that allows LC photons originating near the galactic plane to travel hundreds of pc from their source and reach the lower halo (see Cox 1989; and Bregman and Harrington 1986).

4. IMPLICATIONS FOR THE GALACTIC RADIATION FIELD AT OTHER WAVELENGTHS

4.1. A Diffuse EUV Flux

If the interstellar ionization responsible for the emission-line background is produced by Lyman continuum radiation, then one LC photon per H-ionization implies a production rate of 4×10^6 "diffuse" LC photons s^{-1} per cm^2 of galactic disk. This places an upper limit of $F_{LC} < 4 \times 10^6$ s^{-1} cm^{-2} on the local flux of LC photons within the diffuse ISM. A lower limit on F_{LC} can be derived from the ionization balance of hydrogen within the optically emitting gas. Specifically,

$$F_{LC} = \frac{\alpha_H}{\langle\sigma_H\rangle} \frac{n_{H^+}}{n_{H^\circ}} n_e, \qquad (2)$$

where α_H is the effective (case B) hydrogen recombination coefficient ($\alpha_H = 2.58 \times 10^{-13}\, T_4^{-0.806}$ cm^3 s^{-1}; Martin 1988) and $\langle\sigma_H\rangle$ is the photoionization cross section weighted by the spectrum of the ionizing radiation. The emission line data imply $n_{H^+}/n_{H^\circ} > 2$, $T_4 \approx 1$, and $n_e \approx 0.2$ cm^{-3}; also, $\langle\sigma_H\rangle < 6 \times 10^{-18}$ cm^{-2}, the cross section at the Lyman edge. Therefore, $F_{LC} > 2 \times 10^4$ cm^{-2} s^{-1}. These limits on F_{LC} are shown in Figure 3 for the case in which the radiation is confined between the H and He I ionization edges (13.6–24.6 eV). This range is suggested by the strong emission from S^+ and the weak emission from O^{+2}. Included in Figure 3 for comparison are various space-based observations of the local radiation field between UV and soft X-ray energies. Since neutral hydrogen in the Local Cloud (e.g., McClintock et al. 1978) will probably prevent a direct measurement of the diffuse galactic ionizing radiation field near the Lyman edge, the optical background observations appear to fill in an important spectral region on this plot.

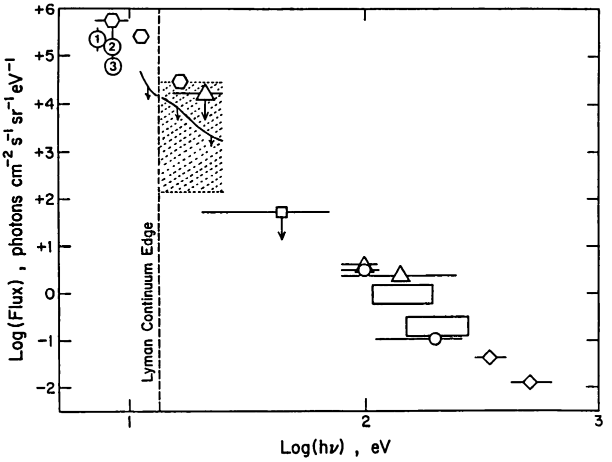

Figure 3. The diffuse galactic EUV flux (shaded region) between 13.6 eV and 24.6 eV predicted by the optical emission-line background (see text). For comparison, direct observations of (and upper limits for) the local, FUV, EUV, and X-ray fluxes are also indicated: Hayakawa et al. 1975 (*diamonds*); Williamson et al. 1974 and Sanders et al. 1977 (*rectangles*); Cash et al. 1976 (*empty circles*); Stern and Bowyer 1979 (*triangles*); Paresce and Stern 1981 (*square*); Sandel et al. 1979 (*hexagons*); Maucherat-Joubert et al. 1979, 1980 (*circled 1*); Paresce et al. 1979, 1980 (*circled 2*); Martin and Bowyer 1989*a* (*circled 3*); Holberg 1986 (*wavy line*).

4.2 FUV Radiation and the Visible Continuum

Joubert et al. (1983) have pointed out that in some high galactic latitude directions, two-photon (plus free-free and bound-free) continuum emission from the diffuse ionized gas could be a significant fraction of the observed galactic background emission near 1500 Å. The continuum emission spectrum that accompanies a 1 R Hα line is shown in Figure 4. The average FUV continuum intensity I_c at high $|b|$ related to the optical emission-line background is then $\langle I_c \sin|b|\rangle \approx 60$ photons cm^{-2} s^{-1} sr^{-1} Å^{-1}, which is about 10–25% of the observed FUV background (e.g., Murthy et al. 1989; Martin and Bowyer 1989*a*; Jakobsen et al. 1984). Where the Hα intensity is significantly higher than average, for example, in the Eridanus region ($l \approx 190°$, $b \approx -40°$; Figure 2), the diffuse, ionized gas may be the dominant source of the continuum. On the other hand, in the visible (i.e., 4400 Å) the continuum intensity is 6.4×10^{-2} S_{10} units per R of Hα, which is only about 3% of the diffuse galactic light (Toller 1983). Within the 2200 Å wide R band, where most of the observed lines are located, 1 R of Hα plus the accompanying forbidden lines and the continuum emission is equivalent to about +28.7 mag arcsec^{-2}, or 0.22 S_{10} units.

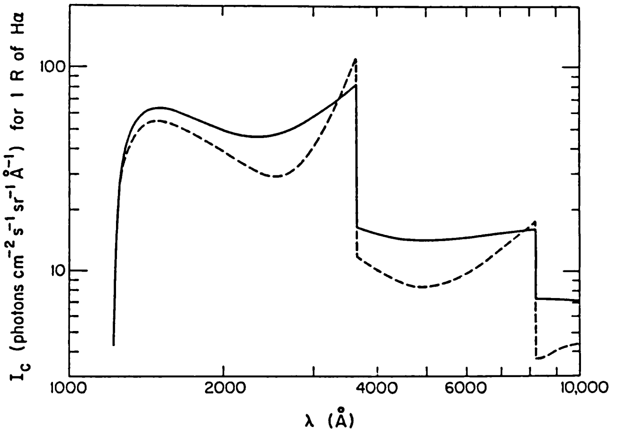

Figure 4. The sum of the two photon, bound-free, and free-free continuum intensities that accompany one R of Hα emission from ionized interstellar hydrogen (neutral helium). The total continuum intensity is shown for two temperatures: 10,000 K, solid line; 5000 K, broken line (from Aller 1987 and references therein; Martin 1988).

An interesting and potentially important aspect of the faint galactic [O III] 5007 Å emission is that a portion (or even most) of the emission may originate from a higher-temperature, "coronal" component of the ISM. Shuttle-borne observations by Martin and Bowyer (1989*b*) suggest that diffuse O III] 1663 Å line emission (and C IV 1550 Å) has been detected at high latitudes with an intensity of $\sim 2 \times 10^{-2}$ R. At a temperature of 10^5 K, where C^{+3} and O^{+2} are produced in collisional equilibrium, the predicted [O III] 5007 Å intensity is 0.05 R (Shields et al. 1981), which is comparable to that expected (~0.06 R) at high $|b|$ on the basis of the observed [O III] 5007 Å/Hα intensity ratio in the plane (Reynolds 1985*c*).

4.3 IR Emission

Since the diffuse H^+ accounts for ~25% of the atomic hydrogen in the galactic disk, it may account for a comparable fraction of the galactic IR background continuum (cirrus) originating from warm dust. The relative contributions from these two sources will also depend upon differences in the radiation field and grain properties within the neutral and ionized regions. Harwit, Houck, and Stacey (1986) have proposed that [N III] 57 μm and [O III] 52 μm and 88 μm fine-structure line emission from diffuse, ionized gas may be another source of IR background. Because of the low excitation state of the gas (3.1.4), other lines, such as [N II] 122 μm and 204 μm, may be a source of diffuse IR.

5. SUMMARY AND CONCLUSIONS

Faint optical line emission from the Galaxy appears to extend over the entire sky. It originates primarily from a warm (~10^4 K), ionized component of the ISM that is associated with pulsar dispersion measures and the very low frequency f-f absorption. This ionized gas has a scale height of ~1500 pc, it occupies ~20% of the volume with a density ~0.2 cm^{-3} near the midplane, and it has a total column density through the disk of about 2.3×10^{20} cm^{-2} (2.6 $M_\odot$ pc^{-2}), which is 37% of the H I. The maintenance of this ionization requires a large fraction of the total power budget of the ISM and suggests that a substantial flux (~10^4–10^6 cm^{-2} s^{-1}) of diffuse Lyman continuum photons is present within the galactic disk and lower halo.

The three strongest lines to be identified in the galactic background are Hα (6563 Å), [N II] 6583 Å, and [S II] 6716 Å, which, together with the weaker lines in the doublets and the associated continuum emission, produce an average surface brightness in the broad R band that ranges from about +27 mag arcsec^{-2} (for 6 R of Hα) near the galactic equator to +29 mag arcsec^{-2} (for 0.5–1 R of Hα) at $|b| > 50°$. Associated emissions in the FUV and the IR may account on average for about 10–25% of the observed background emission in these wavelength regions. Therefore, this source of emission probably should be taken into consideration in the analysis of the galactic FUV and IR background data, especially in directions with higher than average optical line emission. Unfortunately, except for a few small areas, the sky is extremely undersampled by the Fabry-Perot observations, and detailed maps of the emission do not exist. This situation should be remedied in the near future, because the technology is now available to build spectrometers with throughputs one to two orders of magnitude larger than that of the current devices.

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F. Boulanger: *Did you compare the distribution of the diffuse ionized gas with that of the HI gas?*

R. Reynolds: No systematic comparison has yet been made. There is some evidence for a correlation on large scales; namely, at galactic latitudes |b| > 50 both the HI column densities and the H_α intensities are about a factor of two lower than what is predicted by assuming a cosec |b| distributions at lower latitudes. On smaller angular scales there are indications that some diffuse H_α emission features may be related to HI features, while others are not (see Reynolds 1980, *Ap.J.*, **236**, 153).

B. Wang: *Is there any information about extinction within the HII regions and is there observational evidence for the properties of such dust?*

R. Reynolds: I have no information about the properties of the dust within the diffuse HII gas. Presumably it is not much different from that in the diffuse neutral gas; however, since the origin of the HII is still quite uncertain, systematic difference between the HII- and HI-regions cannot be ruled out.

K. Mattila: *Would the Hα-absorption in starlight influence your data?*

R. Reynolds: Regarding the importance of the Fraunhofer Hα absorption feature in the background starlight, all I can say now is that I have seen no evidence for it in any of our spectra, even where the intensity of the galactic Hα lines is as low as 0.25 R. Therefore, the existence of this spectral feature in the continuum starlight apparently does not significantly affect the diffuse Hα data.

G. Münch: The contribution of scattering to the Hα-spectrum of the interstellar medium at high latitudes cannot be large. The continuum we measure (12-16 counts/sec) is accounted for by dark current (2 cps), unresolved stars (at |b| ≈ 60°, 2 cps), zodiacal light (4 cps at β > 30), scattered starlight and artificial illumination in the atmosphere (the rest). The last component may have Hα in absorption, but our measurements (at high shifts from the local standard of rest) show that one cannot have a depth greater than about 10%.