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INVESTIGATION OF THE DIFFUSE ULTRAVIOLET BACKGROUND WITH DE DATA
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Final Technical Report

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1 SUMMARY

I have used the imaging instrumentation on the Dymanics Explorer 1 satellite to measure the intensity of the diffuse ultraviolet radiation on two great circles about the sky. I find that the extragalactic component of the diffuse ultraviolet radiation has an intensity of 530±15 units (a unit is one photon/(cm^2 s A sr) at a wavelength of 150 nm. The galactic component of the diffuse ultraviolet radiation has a dependence on galactic latitude which requires strongly forward scattering particles if it is produced by dust above the galactic plane.

2 INTRODUCTION

The diffuse ultraviolet background is the cosmic ultraviolet radiation which is not attributable directly to stars in the galaxy. The nature of the diffuse ultraviolet background is of interest in both galactic and extragalactic contexts. The extragalactic component of the diffuse ultraviolet background may include contributions from quasars, galaxies, and the intergalactic medium (Paresce and Jakobsen 1980). However, there is a considerable uncertainty about the magnitude of the contributions of these sources. The extragalactic component is presumed to be isotropic, but detectable only in directions in which the galactic component is very small.

The galactic component of the diffuse ultraviolet background is thought to be primarily starlight from the galactic plane which has beens scattered by interstellar dust particles. If so, then the intensity of the galactic component at a given wavelength and in a particular direction should depend on the amount of dust in that direction, the albedo and phase function of the particles, and the amount of ultraviolet light emerging from the galactic plane. The galactic component should show a dependence on galactic latitude and may, moreover, be patchy. Certainly the interstellar gas with which the dust is believed to be mixed varies considerably in column density with direction (e.g., Heiles 1975). Also, there are faint, filamentary reflection nebulae at moderate to high galactic latitudes (Sandage 1976). The presence of high latitude dust is manifest in the wispy infrared cirrus observed by the IRAS satellite (Low et al. 1986). If the diffuse ultraviolet background is radiation scattered by the same particles which produce the filamentary reflection nebulae, then the ultraviolet background is spatially varible able on a scale of a degree or less. General models of the galactic component of the diffuse ultraviolet radiation have been made by several investigators (e.g., Jura 1979a, 1979b, Anderson et al. 1982).

There have already been a number of measurements of the diffuse ultraviolet background. The extent to which the measurements disagree about both the magnitude and isotropy of the background is remarkable. Lillie and Witt (1976) investigated the diffuse ultraviolet background by studying 71 widely distributed fields with the Wisconsin Experimental Package on OAO-2. They found a typical intensity at 150 nm of 1000 photons/ cm^2 s A sr (or units, following Anderson et al. 1982) with a strong dependence on galactic latitude. Henry et al. (1977) observed about half the sky during a rocket flight. After correcting for the contribution of stars they found, at high galactic latitudes, an intensity of about 1000 to 2000 units at 150 nm. However, they attributed the radiation to airglow. Pitz et al. (1979) measured the ultraviolet background on a rocket flight and found an intensity of about 2500 units at 180 nm with little or no spatial variability. Observations with the D2B satellite were used (Moucherat-Joubert et al. 1979, Joubert et al. 1983) to find an average intensity sity of about 1000 units at 170 nm at high galactic latitude and a correlation with neutral hydrogen column density. Anderson et al. (1982) found the spectrum of the diffuse ultraviolet background between 118 nm and 168 nm using data from the Apollo 17 mission. They found, after correction for internally scattered light and starlight, that there was no significant residual intensity to a level of about 300 units. Voyager ultraviolet spectrometer data were used by Sandel et al. (1979) to measure an average intensity of about 5000 units at 150 nm. Paresce et al. (1980) used data from the Apollo-Soyuz mission and found that the diffuse ultraviolet background between 135 nm and 155 nm has a typical value of 800 to 1000 units with definite spatial variability. They found that intensity correlates well with neutral hydrogen column density except near the galactic poles. They also found that the minimum measured intensity was 300 units, which they suggested was attributable to the isotropic extragalactic component of the diffuse ultraviolet background.

Recently, Tennyson et al. (1988) have reported the first spectroscopic measurement of the diffuse ultraviolet radiation in the 170 to 285 nm wavelength range, obtained during a rocket flight. They found a typical intensity at high galactic latitudes of 300±100 units at 180 nm. Henry et al. (1986) have discussed measurements from the UVX experiment carried on the space shuttle. For eight regions at various galactic latitudes, they found a range of intensities at 180 nm. The lowest reported intensity was 150 units.

Many of the published measurements have been criticized for instrumental problems, calibration deficiencies, or contamination by local sources of ultraviolet radiation. The measurements span a factor of at least ten in the average intensity of the diffuse ultraviolet background. There is also considerable disagreement about its spatial variability. I have used the ultraviolet imaging instrumentation on the Dynamics Explorer 1 spacecraft to contribute to the resolution of these problems.

3 OBSERVATIONS

The Dynamics Explorer 1 spacecraft (DE) was placed in polar orbit in August 1981. The DE orbit has a period of about 6.8 hours and an apogee of about 4.6 earth radii. The imaging instrumentation for the Dynamics Explorer Mission (Frank et al. 1981) was designed primarily to obtain global auroral images. The instrument, however, has also been used successfully to study marine bioluminescence, the geocorona, and the global distribution of atmospheric ozone. The DE ultraviolet imaging photometer consists of a baffled collimator, a flat stepping mirror, an off-axis parabolic mirror, a pinhole, a collimating lens, one of several transmission filters, and a photomultiplier tube. The effective collecting area of the photometer is 20.3 cm^2 and the field of view is 0.32°. The imager scans a strip of sky 0.32°wide during each spacecraft rotation (6 seconds), obtaining data for about 1550 pixels at intervals of 0.23°. Each pixel is accumulated for 3.4 ms. Normally, the field of view is rotated 0.25°by means of the stepping mirror after each spacecraft rotation in order to produce an image. In order to develop adequate counting statistics, however, I have used repeated measurements of the same scan line in investigating the diffuse ultraviolet background.

The observations which are described in this paper were obtained on four days during July 1984 and on four days during July 1987. During those times the DE apogee was nearly above the earth's north pole. The 1984 observations were carried out using filter 136W, for which the photometric response peaks at 145 nm and has a FWHM of 41 nm. The 1987 measurements were made using filter 136W and 140N, for which the photometric response peaks at 156 nm and has a FWHM of 34 nm. The photometric response functions using filters 136W and 140N are shown in Figure 1. For both filters, the response to (geocoronal and heliospheric) Lyman alpha radiation is essentially zero. After the elimination of data for which the imager was pointed at earth, data dropouts occurred, or DE began to enter the trapped particle zones, 9.5 hours of usable data (22 seconds per pixel) remained for 1984 and 14.4 hours (33 seconds per pixel) for 1987. For each year, the scan line was nearly a great circle and nearly perpendicular to the celestial equator. The 1984 scan line crossed the celestial equator at 10.64^h, while in 1987 the crossing was at 10.37^h. A portion of the 1984 data, showing the strip of sky at 10.64^h from the north celestial pole to the equator is shown in Figure 2. The relatively bright stars in the scan line appear as sharp peaks about 3 pixels in width.

Stars in the scan line were identified using the SAO catalog. For the brighter identified stars, flux distributions from the IUE Ultraviolet Spectral Atlas and the normalized instrumental sensitivity were used to calibrate the photometric system. For filter 136W, the instrumental sensitivity was 4.88 x 10^{-6} and 2.65 x 10^{-6} count-pixel/unit for 1984 and 1987, respectively. For filter 140N, the instrumental sensitivity was 1.69 x 10^{-6} count-pixel/unit in 1987. The calibration has a standard error of about 10%. The significant decline in sensitivity between 1984 and 1987 resulted in lower count rates. Thus the 1987 measurements of the diffuse ultraviolet radiation have a lower signal to noise ratio despite than the 1984 measurements despite longer integration times

Pixels containing identifiable stars were removed from the data. This procedure eliminated contamination of the data by stars with spectral type later than A0. O and B stars fainter than the limiting magnitude of the SAO catalog may still contribute to the data. These, however, are strongly confined to the plane of the galaxy and are a possible problem only for small galactic latitudes. After eliminating pixels contaminated by identified stars, 1325 pixels for 1984 and 1342 pixels for 1987 remained for further analysis.

Before I could determine the properties of the diffuse ultraviolet radiation, it was necessary to investigate the extent to which the measurements were contaminated by other contributions to the count rate of the photometer. I am confident that there is no zodiacal contribution, first because the measured intensity shows no correlation with ecliptic latitude and also because the zodiacal brightness declines nearly to zero below about 200 nm (Tennyson et al. 1988). No measureable contribution from trapped energetic particles is present, since the data show no dependence on invariant latitude for the range of latitudes over which data were retained for analysis. The count rates for times when DE was well within the trapped particle zones show that the expected rates for the greatly reduced particle fluxes at high latitudes should be negliglble. Contamination by geocoronal Lyman α or auroral radiation is not present, as the intensity shows no dependence on zenith angle. The design of the DE imager ensures that scattered light is not significant.

The photometry, however, does include a dark count rate (zero-point offset). This may be due to Cherenkov radiation produced by galactic cosmic rays in various optical elements of the photometer as well as direct cosmic ray impacts on the photomultiplier tube. I was able to determine the level at which cosmic rays contributed to the 1987 count rates by comparing the measurements made with filter 136W to those made with filter 140N. The two filters are similar in their wavelengths of maximum transmission and FWHM, but the photometric sensitivity (determined measurements of stars in the scan line) with filter 140N is only 0.639 ± 0.004 as great as that with filter 136W. Thus, the count rate due to diffuse ultraviolet radiation is smaller with filter 140N than with filter 136W while the dark count rate is presumed to be the same for both filters. The wide and narrow count rates are shown in Figure 3. The dark count rate which best fits the data is 0.00706 ± 0.00013 count-pixel, or about 2670 ± 50 units (for filter 136W). I have subtracted this from the count rates using both filters, divided by the instrumental sensitivity, and combined the data from both filters to determine the intensity for each pixel in the 1987 scan line.

The zero point of the 1984 data was determined by comparing the average intensities for 1984 and 1987 for all pixels which were located more than 30°from the galactic plane. The mean difference (I_{1984} - I_{1987}) was 706 ± 17 units. I have used this as the value of the zero-point for 1984 and subtracted it from the intensity of each pixel. For the 1984 measurements, 706 pixels was equivalent to a count rate of 0.00344 count-pixel. This is about half the dark count rate rate found for 1987. The increase in dark count rate between 1984 and 1987 is consistent with an increase in cosmic ray intensities during that period (Van Allen 1988).

The intensity along the scan line, corrected for dark count rate and with stars removed,is shown for the 1984 data in Figure 4. At no point along the scan line does the smoothed intensity decrease to zero.

4 DISCUSSION

The intensity of the ultraviolet background shows a definite dependence on galactic latitude. However, the precise nature of the relationship between intensity and latitude varies with galactic longitude. Ultraviolet intensity is shown against galactic latitude for the sgements of the 1984 data containing galactic plane crossings at 106° and 286° galactic longitude, respectively, in Figures 5 and 6. At galactic latitudes above 50°, the ultraviolet intensity has a typical value of about 500 units. Although there appear to be real differences in the dependence of intensity on latitude for the four cuts through the galactic plane, I have explored the general relationship by averaging all data in 2° intervals of absolute value of galactic latitude, b. The average intensities are shown in Figure 7. For $|b|$ greater than 10°, intensity can be reasonably well fit by a linear function of $\csc|b|$. For latitudes nearer the galactic plane, the density of bright ultraviolet stars is too great to permit them to be individually identified and removed from the data. Thus measurements within about 10° of the plane are too badly contaminated by stars to yield any meaningful information about the diffuse radiation. Extrapolation of the linear function of $\csc|b|$ relationship results in an estimate of 550±50 units for the intensity of diffuse ultraviolet radiation at the galactic pole.

I have used the neutral hydrogen column densities of Heiles (1975) (and the zero-point correction of Heiles, Stark, and Kulkarni 1981) to investigate the relationship between ultraviolet intensity and hydrogen column density. Estimates of the mean column density in 2° intervals along the scan line are shown against intensity for regions with $|b| > 30°$ in Figure 8. Although there is an obvious increase in intensity with increasing hydrogen column density, most of the relationship is probably due to the general latitude dependences of both intensity and column density It was not generally possible to relate localized minima or maxima in hydrogen column density with those in intensity. An exception was the region near 135° longitude and 40° latitude (Figure 9), in which local maxima can be seen in both hydrogen column density and intensity. A linear least squares fit to the data shown in Figure 8 has a slope about 50% smaller than that found by Joubert et al. (1983), who used averages over $30(°)^2$ regions, and two times smaller than the average slope found by Paresce et al. (1980) for averages over regions of about $6(°)^2$. However, Paresce et al. found a considerable range of slopes for the four regions which they investigated. For out measurements, the dispersion of points about the least squares line is about the same as those of previous studies. The intercept of the least squares line is 531±15 units, which I take to be the extragalactic component of the diffuse cosmic radiation. My result is in general agreement most recent determinations of the high latitude ultraviolet intensity, which are generally less than 1000 units in the spectral region below 250 nm. I am in clear disagreement with the results of Pitz et al. (1979), Sandel et al. (1979), and Henry et al. (1977), who report much larger intensities. A background intensity at the level of a few hundred units can be accounted for as the integrated light of galaxies for some models of galactic evolution and some mixture of galaxy types (Code and Welch 1982). However, more speculative mechanisms for producing a measureable extragalactic component of the diffuse ultraviolet radiation have also been proposed. These are discussed in Paresce (1983).

When the extragalactic component is subtracted from the intensity, the galactic component remains. The galactic component is generally thought to be attributable the scattering of starlight by dust which lies at some distance from the galactic plane. The latitude dependence of the galactic component of the diffuse radiation, then depends on the distribution and optical properties of the dust. Jura (1979a, 1979b) has shown that if the galaxy is an infinite plane of uniform source function and optical thickness, the intensity of light scattered to the observer by a cloud of particles at latitude b is

$$I \propto 1 - 1.1g(sin(b))^{0.5}$$

where g is the asymmetry factor in the Henyey-Greenstein phase function (Henyey and Greenstein 1941). Jura's relationship holds for latitudes greater than 10° so long as g≤0.8. I have found that a fit of (1) to the galactic component of the diffuse radiation requires a value of g > 0.9 (i.e. strongly forward scattering particles), which makes the use of Jura's relationship doubtful. I also tried to match the latitude dependence of the galactic component using numerical calculations based on a model of Anderson et al. (1982). The model resembles that proposed by Jura except that a thin absorbing layer between the galactic plane and the scattering particles is assumed in order to prevent a significant contribution to the scattered radiation from extremely distant parts of the galactic plane. I have performed numerical integration over the galactic plane to calculate the intensity versus latitude for values of g between 0.1 and 0.98. None of the calculations produced a latitude dependence which was steep enough to match the measured intensity. We conclude that either the model for the galaxy (including absorbing layer) or the Henyey-Greenstein phase function is inappropriate, but that the measurements require strongly forward scattering particles in any case.

5 CONCLUSION

I have measured the intensity of cosmic radiation at 150 nm for about 3000 directions covering about $230(°)^2$. After removing a stellar component, I find that the data show a strong dependence on galactic latitude. My measurements extend to galactic latitudes of about ±60°. Extrapolation of the galactic latitude dependence to b=90° suggests an intensity at the pole of 550±50 units. The measured intensity is also correlated with neutral hydrogen column density. A linear fit to the relationship between intensity and hydrogen column density has an intercept of 530±15 units. I identify this with the (isotropic) extragalactic component of the diffuse radiation.

The intensity of the galactic component of the diffuse radiation falls nearly to zero at high galactic latitude. If the galactic component is produced by the scattering of galactic plane radiation, then the scattering particles must be strongly forward scattering (g > 0.9 if they obey the Henyey-Greenstein phase function).

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6 FIGURE CAPTIONS

Fig 1.—The pre-launch absolute sensitivities of the DE ultraviolet imaging photometer as functions of wavelength for filters 136W and 140N.

Fig 2.—Count rate for part of the scan line for 1984 observations. Right ascension is 10.64^h for all pixels. The north celestial pole is at the left and the celestial equator at the right.

Fig 3.—Count rates for filters 136W and 140N. Pixels containing identifiable stars have been excluded.

Fig 4.—Intensity on the scan line for 1984 observations. Intensity has been set to zero for pixels containing identifiable stars. A unit is one photon/(cm^2 s A sr).

Fig 5.—Intensity versus galactic latitude for the half of the 1984 scan line centered on the galatic plane crossing at 106°.

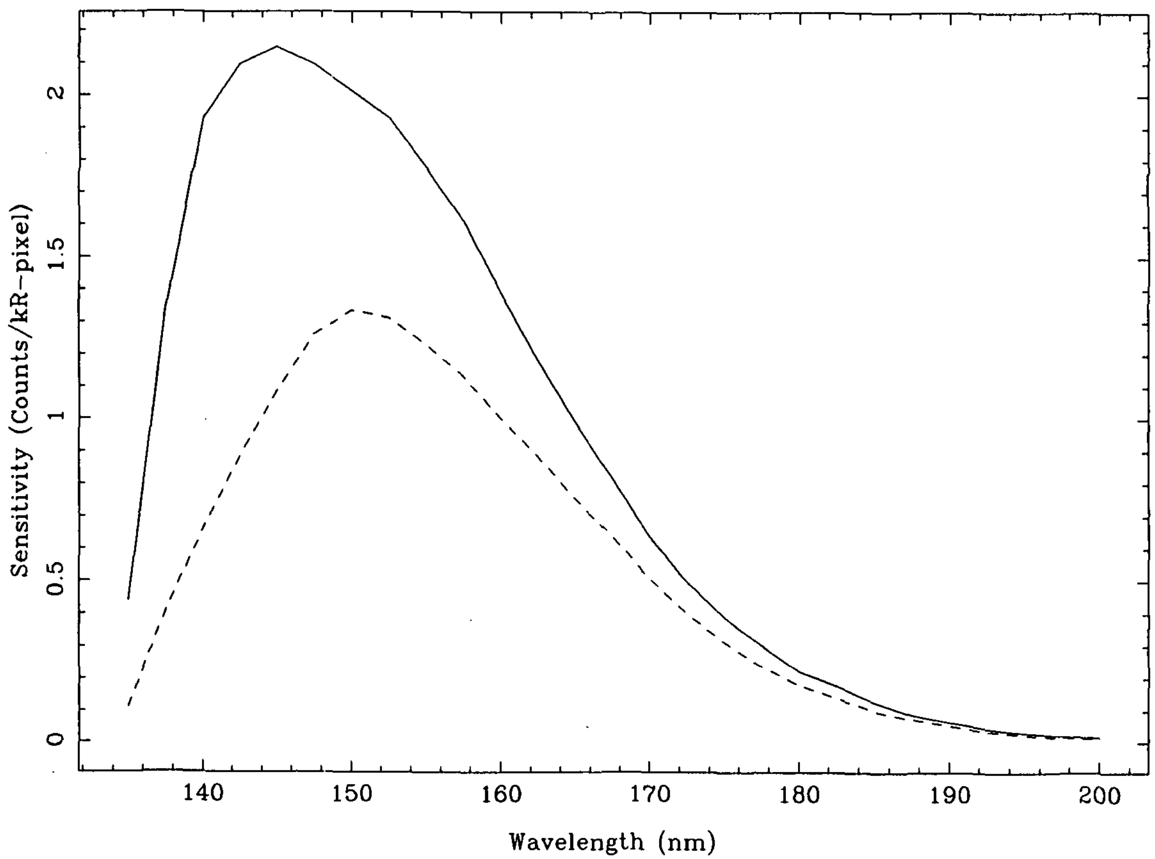
Fig 6.—Intensity versus galactic latitude for the half of the 1984 scan line centered on the galatic plane crossing at 286°.

Fig 7.—Intensity and versus the absolute value of galactic latitude. Each point represents the weighted mean of all measurements in a 2° interval of latitude. Error bars correspond to $\pm$ 1 σ.

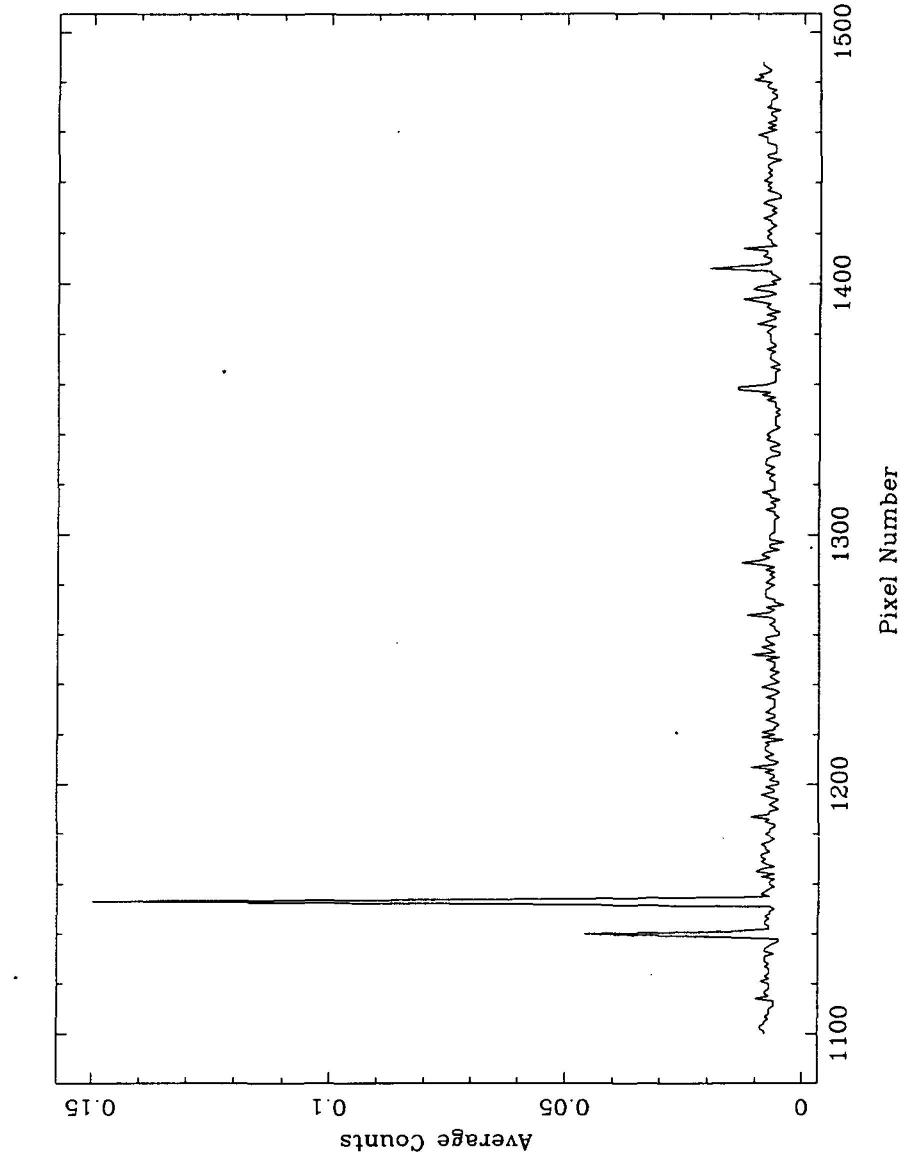
Fig 8.—Intensity versus column density of neutral hydrogen. Each point represents the weighted mean of measurements within 2° intervals of galactic latitude for either the 1984 or 1987 scan line. Neutral hydrogen column density is given in units of 2.23×10^{18} cm^{-2}.

Fig 9.—Intensity versus neutral hydrogen column density for the part of the 1984 scan line near 135° longitude, 40° latitude. Neutral hydrogen column density is given in units of 2.23×10^{18} cm^{-2}.

Fig 10.—The intensity of the galactic component of the diffuse ultraviolet radiation versus the absolute value of galactic latitude.



Sensitivity (Counts/kR−pixel)
0
0.5
1
1.5
2
140
150
160
170
180
190
200
Wavelength (nm)


Average Counts
0.15
0.1
0.05
0
Pixel Number
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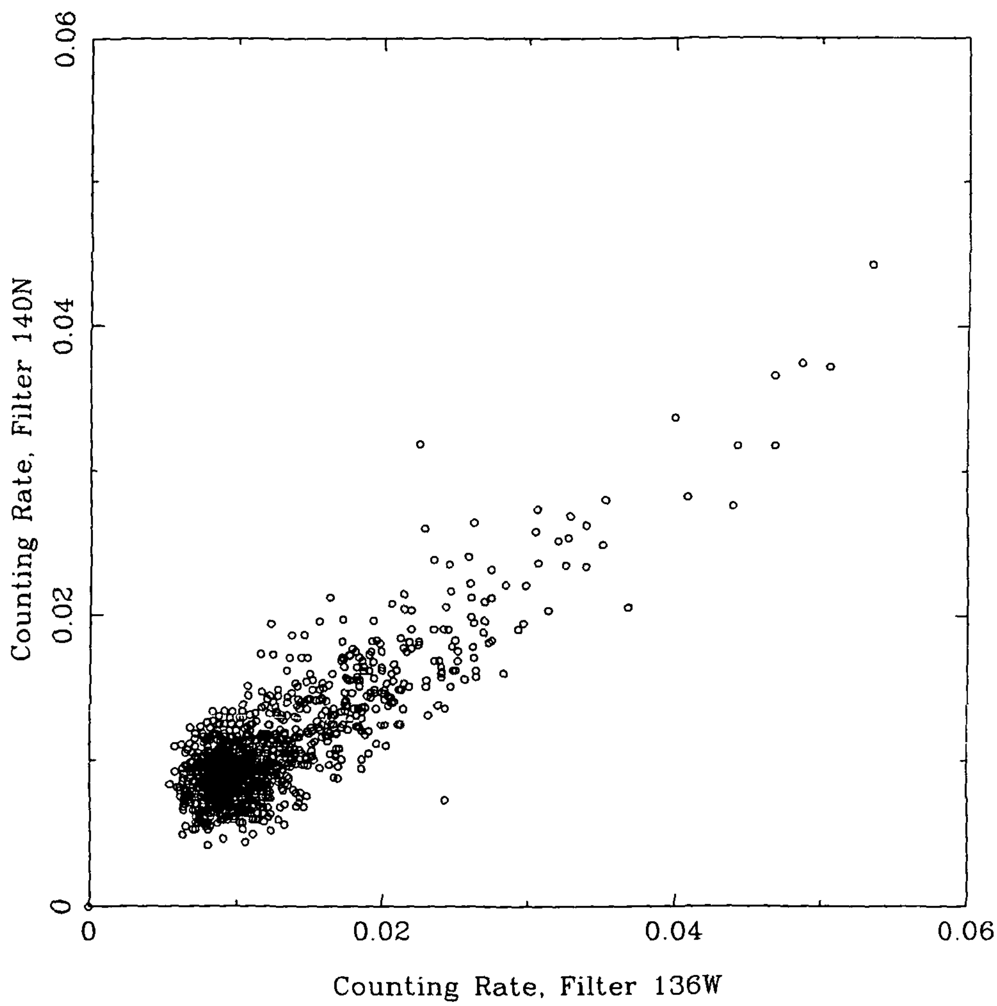
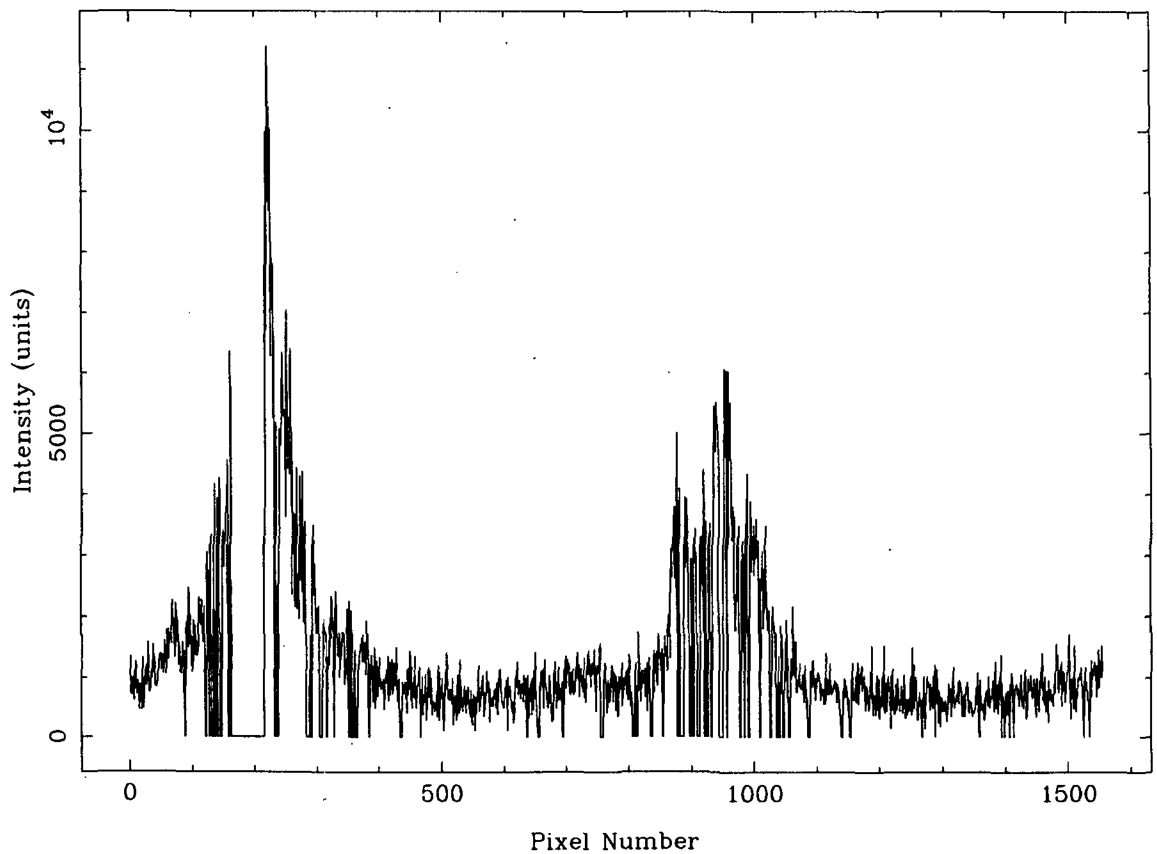
1200
1300
1400
1500


0.06
0.04
0.02
0
Counting Rate, Filter 140N
0
0.02
0.04
0.06
Counting Rate, Filter 136W


Intensity (units)
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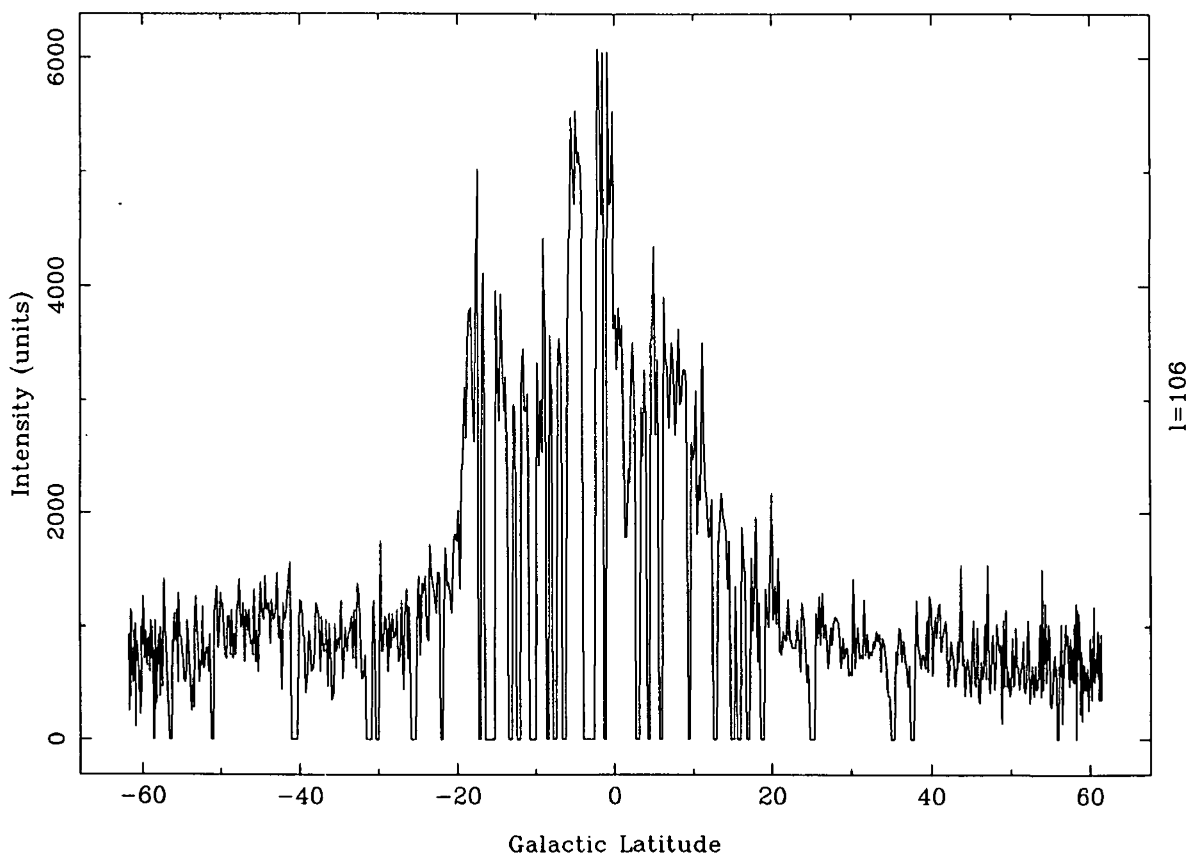
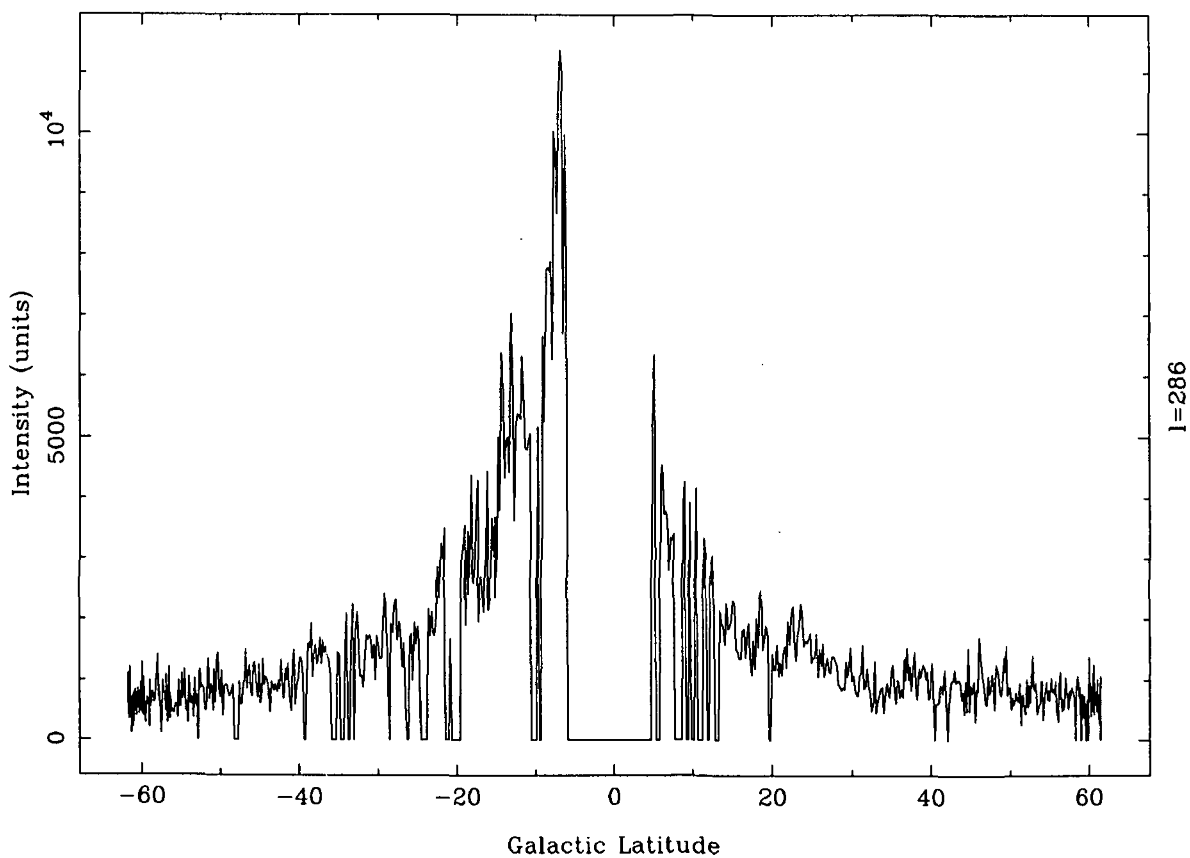
5000
0
0
500
1000
1500
Pixel Number



6000
4000
2000
0
Intensity (units)
−60
−40
−20
0
20
40
60
Galactic Latitude
l=106


l=286
Intensity (units)
10^4
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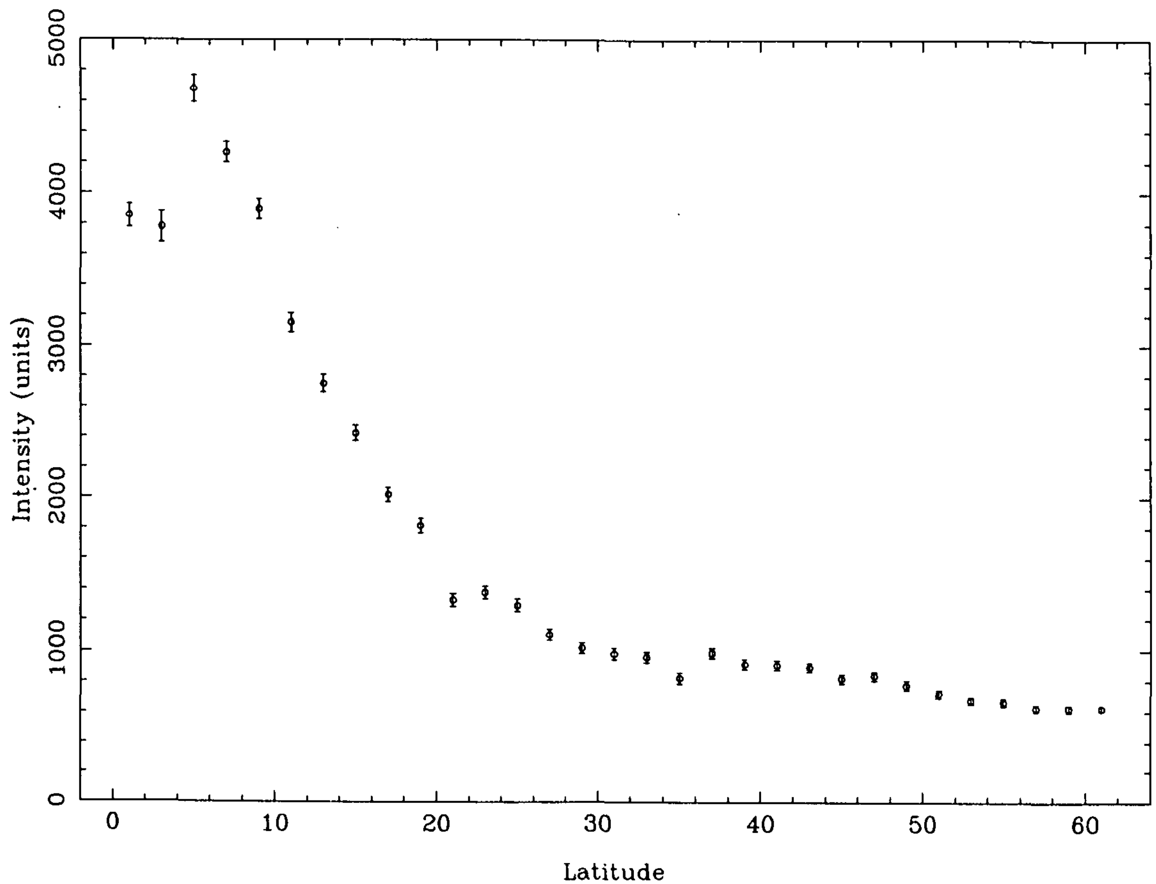
0
−60
−40
−20
0
20
40
60
Galactic Latitude


Intensity (units)
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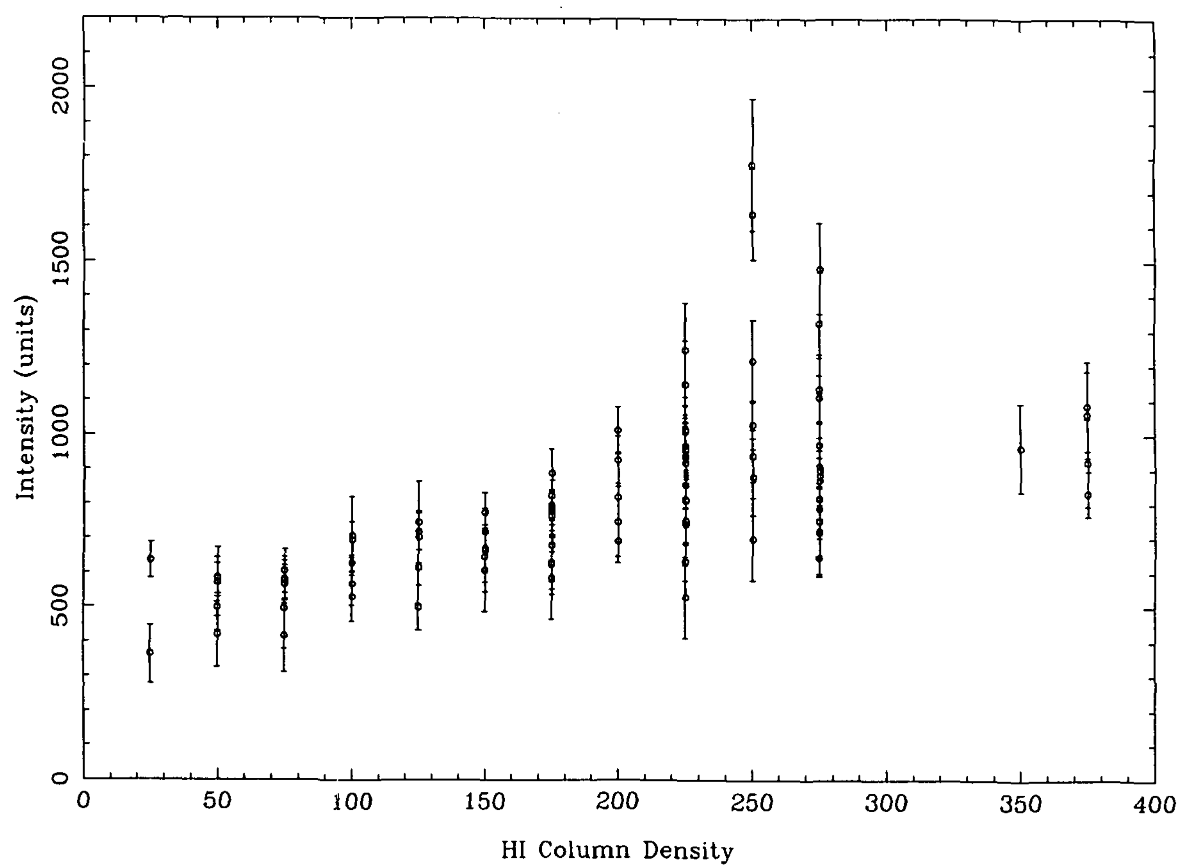
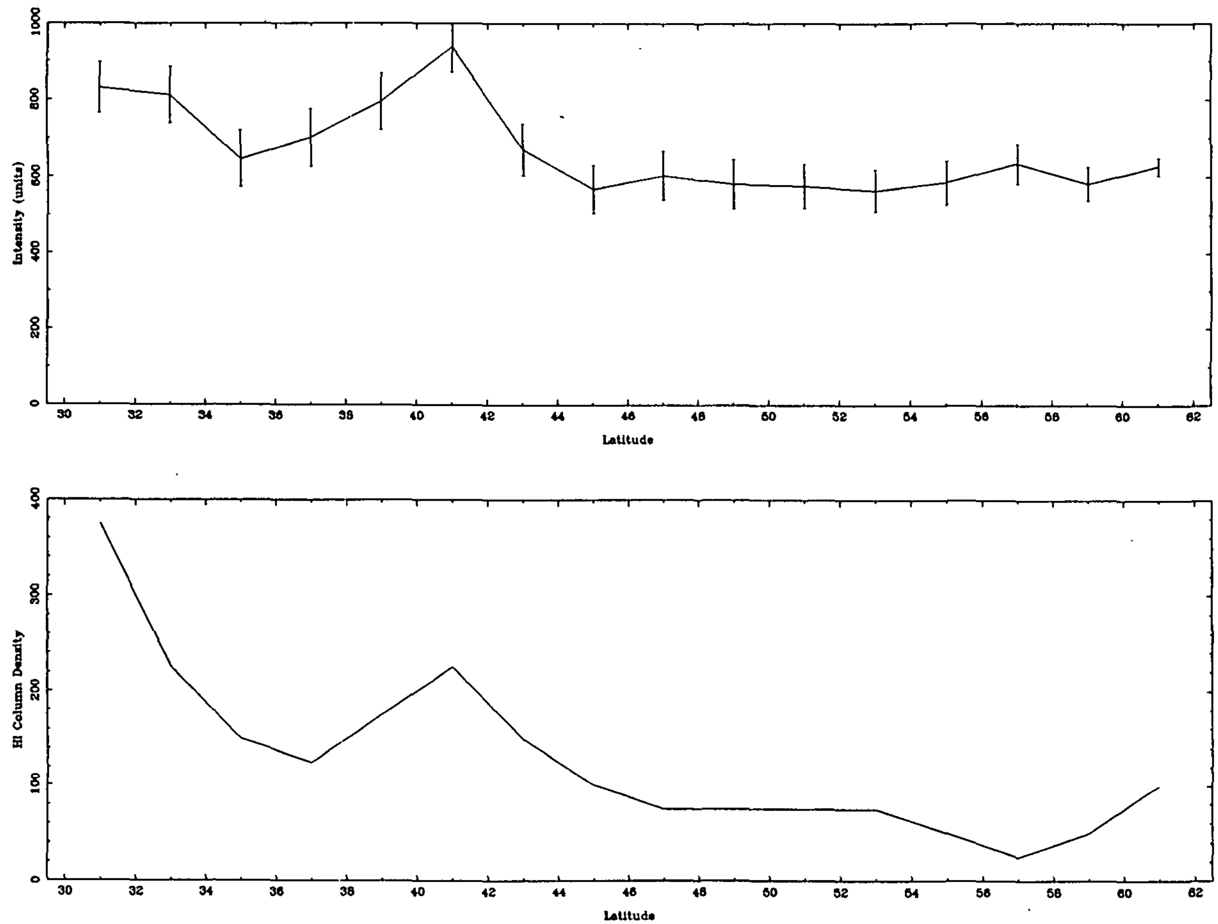
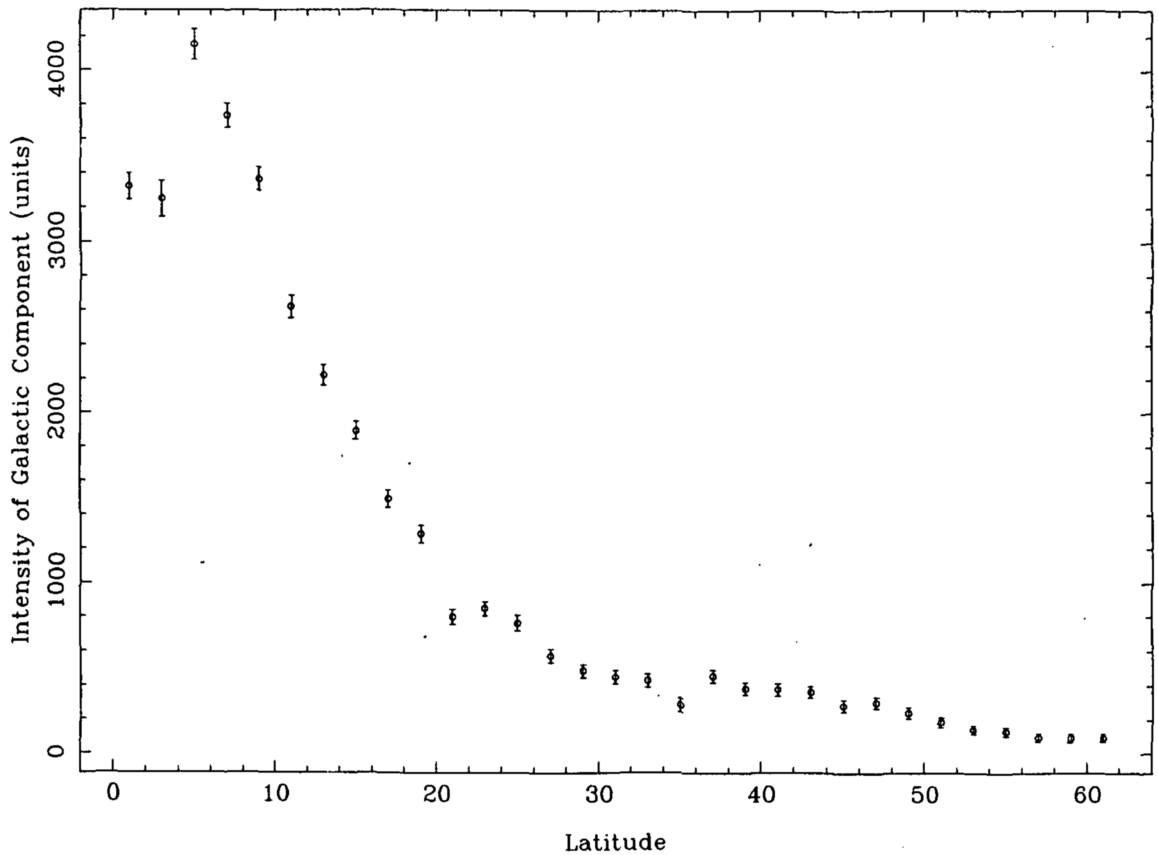
1000
2000
3000
4000
5000
0
10
20
30
40
50
60
Latitude



Intensity (units)
0
500
1000
1500
2000
0
50
100
150
200
250
300
350
400
HI Column Density



Intensity (units)
HI Column Density
Latitude


Intensity of Galactic Component (units)
0
1000
2000
3000
4000
0
10
20
30
40
50
60
Latitude

10