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PIONEER 10 AND VOYAGER OBSERVATIONS OF THE INTERSTELLAR MEDIUM IN SCATTERED EMISSION OF THE He 584 A AND H Lyα 1216 A LINES

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ABSTRACT

The combination of Pioneer photometric and Voyager spectrometric observations of EUV interstellar—interplanetary emissions in the region beyond 5 AU have been applied to a determination of atomic hydrogen and helium densities. These density estimates obtained from direct measurement of scattered radiation depend on absolute calibration of the instruments, in the same way as other earlier determinations based on the same method. However, we have combined the spacecraft data with daily full sun averages of the H Lyα 1216 A line obtained by the Solar Mesospheric Explorer (SME) satellite, to obtain a measure of atomic hydrogen density independent of instrument absolute calibration. The method depends on observations of long and short term temporal variability of the solar line over a 1 year period, and the fact that the ISM is optically thick. The density estimates from preliminary work on these observations are [H] = 0.12 cm^{-3} and [He] = .016 cm^{-3}, giving a density ratio close to the cosmic abundance value, in contrast to some earlier results indicating a depletion of atomic hydrogen. We have obtained estimates of galactic background emissions in the signals of both spacecraft.

Introduction

The estimation of neutral densities in the LISM through observations of resonance scattered solar radiation is simplified somewhat if the observations are made beyond 5 AU, where local perturbation by the sun is not a serious consideration in the analysis. We have combined the data obtained by Pioneer 10 (P10), Voyager 2 (V2) and SME to produce estimates of hydrogen and helium densities using two basically different methods. The first method is the conventional one in which the H and He densities are estimated using instrument calibration and solar emission intensities to calculate densities from the scattered He 584 A and H 1216 A and 1025 A lines. The second method depends on comparing the daily average variation of the 1216 A line as measured by P10 and V2 with the directly measured solar emission line from the SME satellite. The time variations measured by the three instruments during the year 1982 are interpreted in terms of optical thickness of the LSIM to the solar 1216 A line. The measure of optical thickness then reduces to an estimate of H density through multiple scattering calculations. The present work obtains a rough density estimate on the basis of multiple scattering characteristics calculated by Keller, Richter and Thomas (1981). The results are preliminary in nature because we require more specific multiple scattering calculations. We suggest that the data is of sufficient quality that further detailed multiple scattering calculations specific to the observational data be pursued. In addition to ISM densities we have obtained estimates of galactic background emissions in the signals of the two spacecraft.

SUMMARY

Pioneer 10 and Voyager 2 observations of the ISM in the >5 AU region have been used to estimate hydrogen and helium densities. The spacecraft data has also been combined with SME 1216 A solar observations to obtain an H density independent of absolute instrument calibration, and to set a limit on galactic background at 1216 A in the upstream direction.

1) The helium density based on the calibrations of both the P10 and V2 instruments is estimated to be [He] = 0.016 cm^{-3}. This density is based on a benchmark He 584 A flux of 1.3 x 10^9 Ph cm^{-2} s^{-1} measured by Heroux and Higgins (1977) in 1973. The P10 data for this estimate is taken from DOY 104/73 and DOY 163/74. The line width is assumed constant at 29.3 cm^{-1}. Using this benchmark at solar minimum the P10 data on DOY 278/79 imply a solar flux of 4. x 10^9 Ph cm^{-2} s^{-1} at 1 AU. With this value of F0 and the V2 data obtained on the same day, we obtain the same density [He] = 0.016 cm^{-3}. The two instruments are thus on the same calibration scale at 584 A.

2) Comparison of the two instruments at 1216 A on DOY 278/79 indicates a calibration difference of a factor of 4.4, where

$$I_{V2}(1216) = 4.4 I_{P10}(1216). \qquad (1)$$

Using P10 data and an SME reference in 1982, we estimate F_0 = 4.3 x 10^{11} Ph cm^{-2} s^{-1} on DOY 278/79. This yields [H] = 0.14 cm^{-3}, based on optically thin model and the V2 calibration. With equation 1, the two instruments give the same implied solar fluxes from 1979 to the present, within esimated temporal-spatial uncertainties. Correction for optical thickness using Keller Richter and Thomas (1981), gives [H] = 0.12 cm^{-3}. The most recent estimate of solar flux predicted by the two instruments on DOY 35-37/84 are F_0 = 4.0 x 10^{11} Ph cm^{-2} s^{-1}, for V2 and F_0 = 3.5 x 10^{11} Ph cm^{-2} s^{-1} for P10. Line shapes are based on Lemaire et al. (1978)

3) The I(1216)/I(1025) ratio measured by V2 in the ISM is constant over time and spacecraft position from 1977-1981, 1.5 AU - 10 AU. Assuming that relative line shapes do not change, this result is in accord with multiple scattering theory. The measured mean ratio is I(1216)/I(1025) = 485 ± 37. The mean solar source ratio using Heroux and Higgins (1977) and Hinteregger (1979) data is $I_0(1216)/I_0(1025)$ = 79.7 and 63.7 respectively. Using Lemaire et al line shapes we then have $I_0n(1216)/I_0n(1025)$ = 84.1 and 67.2 The predicted ratio from solar line intensities is then I(1216)/I(1025) = 503 and 402, for the optically thin model. For the optically thick model of Keller et al. (1981) we correct to obtain I(1216)/I(1025) = 600 and 480, which is to be compared to the measured value above of 485. On this basis the V2 1025 A measurement gives [H] = 0.10 and 0.12 cm^{-3} for the two cases.

4) Another method for calculating the H density independent of instrument calibration has been applied through comparing daily averages of the 1216 A signal of P10 and V2 with the solar emission line flux measured by SME, during 1982. During the last half of 1982 a strong 26 day cycle shows good stability for 7 cycles. Although the long term variation of V2 and SME during 1982 is the same, the 26 day period variation is depressed in the V2 data. This is also the case for P10, but the 26 day modulation is depressed still further. We interpret this to be caused primarily by multiple scattering, and using Keller et al. (1981) we obtain, [H] = 0.16 cm^{-3}, from the modulation of V2 observations at 10 AU and, [H] = 0.11 cm^{-3}, from observation by P10 at 30 AU. This calculation assumes there is no additional contribution caused by line center intensity amplification relative to the integrated line. If there is line center amplification according to the formula obtained here, we have [H] = 0.17 cm^{-3} and [H] = 0.12 cm^{-3}, in the two cases. According to these calculations only 20% of the P10 signal is zero order scattering. For V2, 50% of the observed signal is zero order scattering.We emphasize that spacecraft background signals have been carefully assessed using three independent means, in applying this method.

5) According to Keller et al. (1981), observations made at different radial distance should follow a 1/r curve whether the line is optically thick or not. This is borne out by the V2 I(1216)/I(1025) ratio measurements. On this basis we can use the continuous data of P10 to establish long term variation of solar flux line center. If we use the integrated 1216 A line full sun plot for solar cycle 21 estimated by Lean and Skumanich (1983), we obtain a slightly lower variation over the 1973-1982 period. If this is attributed to line center variation we obtain the relation $f_0 = C\,(F_0)^n$ Ph $cm^{-2}\ s^{-1}\ A^{-1}$ where $C = 4.18 \times 10^{-6}$ and $n = 1.46$, following the relation developed by Vidal-Madjar. However, it is not clear this relation would improve the fit of the variations, F_0 from the above formula and P10 data vs. F_0 from Lean and Skumanich, over the whole 1973-1982 period.

6) Galactic background
Cross-correlation of the V2 and SME data at 1216 A in the first half of 1982 where there is a slow variation in solar intensity, indicates that there is no measureable galactic component. That is, <10 R of the 800 R total intensity can be attributed to a galactic 1216 A component. V2 is looking upstream and falling off proportional to 1/r from 1979 onward and there is no detectable bow shock component. P10 contains a galactic component in its field, detected by V2 in 1977. This emission accounts for the clock angle variation of the P10 1216 A signal at 30 AU.

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FIGURES

Figures 1 and 2 show the daily average data of P10 and V2 plotted against the phase shifted SME direct observations of the solar 1216 A line in 1982. Although both sets of ISM data follow the long term trend in solar line intensity during 1982, the 26 day cycle modulation is depressed progressively in each spacecraft; V2 is at ~12 AU and P10 is near 30 AU observing approximately radially outward. The spacecraft data are shown as heavy lines.

Figure 3 shows the inferred solar flux at 1216 A from 1973 to 1983 using P10 data, compared to Lean and Skumanich (1983) calculations. We assume a constant line shape in the calculation. The P10 data is shown as a heavy line.

Figure 4 shows Voyager 2 spectrum in the direction of the galactic pole (RA 194°.8, Dec 28°.18) compared to the spectrum in the direction of the P10 line of sight (RA 73°.64, Dec 18°.12). The latter spectrum (light plotted line) shows a relatively strong spatially diffuse galactic emission longward of 912 A, and a substantially weaker 1216 A line due both to a lower solar source emission rate and observation across the downstream depletion cavity.

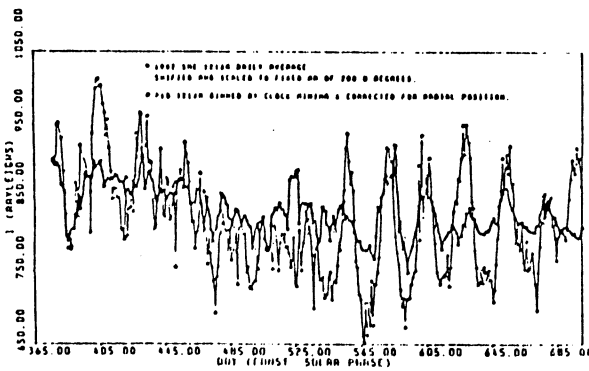

Figure 1

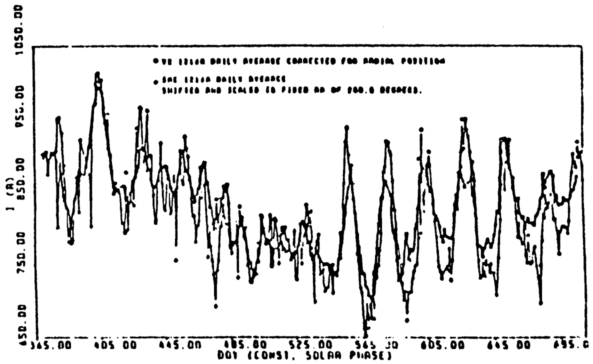

Figure 2

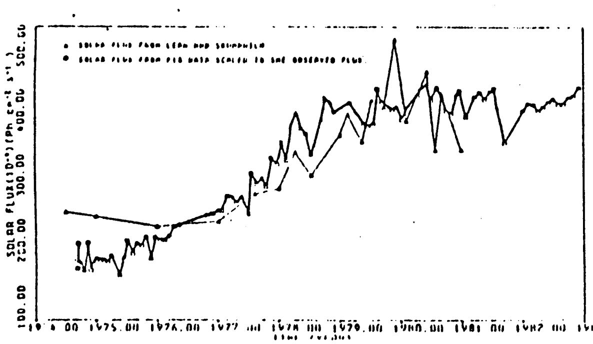

Figure 3

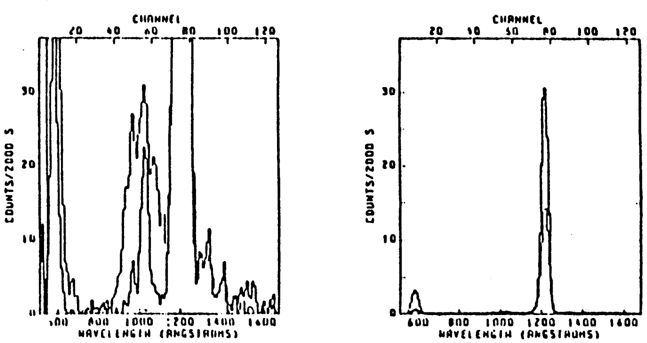

Figure 4