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COMPARISON OF 10.7 CM RADIO FLUX WITH SME SOLAR LYMAN ALPHA FLUX

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Abstract. Measurements of the solar Lyman alpha flux that were made over a seven-and-one-half-year period between October 11, 1981 and April 13, 1989 have been compared with ground-based measurements of the solar 10.7 cm radio flux made over the same time period. There is a long-term correlation between these two measures of solar flux during the declining part of the solar cycle. During the solar minimum period, there is only a poor correlation between the two solar fluxes because the 10.7 cm radio flux reaches a minimum of 65×10^{-22} W m^{-2} Hz^{-1} and does not vary below this value while the Lyman alpha flux continues to decline and show long-term and short-term variations. During the early ascending phase of the new solar cycle, there is again a correlation between the two fluxes, although the constant of proportionality between the two is different from the constant during the declining phase of the previous solar cycle. Somewhat later, during the period November 25, 1988 — April 13, 1989 (last period when observations of Lyman alpha were made) a medium-term correlation exists and the proportionality of the two indices is once again similar to what it was during the declining phase of the previous solar cycle. A study of the correlation of the 10.7 cm flux with the Lyman alpha for a 999-day period during the declining phase showed that for the short-term (27-day) variation there is a correlation between the two fluxes but the proportionality between them varies from one solar rotation to the next. The conclusion is that the solar 10.7 cm radio flux is not a useful index for the prediction of solar Lyman alpha flux for the short-term, 27-day variations.

Introduction

One method of determining the density of atomic hydrogen in the earth's upper atmosphere, in the atmospheres of the other planets, and in interplanetary space is the technique of measuring the intensity of the solar Lyman alpha radiation that is scattered by hydrogen atoms. A precise determination of the atomic hydrogen density requires a precise determination of the flux of the solar radiation that is illuminating the hydrogen atoms. Since the solar Lyman alpha radiation varies with a long-term period of 11 years, with intermediate-term periods of hundreds of days, and with a short-term period of twenty-seven days due to the rotation of the sun, a continuous determination of the solar Lyman alpha flux is required. It is particularly important to have precise knowledge of the solar Lyman alpha flux when studying variations in atomic hydrogen density (in planetary atmospheres or the interplanetary medium) when the atomic hydrogen density itself may be varying in response to changes in the solar output that have the same period and phase as the changes in the solar Lyman alpha flux.

There have been a number of orbiting planetary spacecraft that have measured the variation of Lyman alpha radiation scattered by hydrogen in the planets' upper atmospheres; for example, the Mariner 9 observations of Mars (Barth *et al.*, 1972) and the Pioneer-Venus observations of Venus (Paxton *et al.*, 1988). Planetary spacecraft have also measured the Lyman alpha sky background produced by the scattering of solar Lyman alpha radiation by interplanetary atomic hydrogen that enters the solar system from the interstellar medium. Voyager 2 observations of the Lyman alpha sky background over a period of 313 days in 1982 showed that the sky background did vary in response to variations in the solar Lyman alpha flux (Shemansky *et al.*, 1984). Prognoz 5 and 6 employed hydrogen absorption cells to determine atomic hydrogen density and dynamics within the local interstellar medium (Bertaux *et al.* 1985). Pioneer-Venus observations of the Lyman alpha sky background from 1979 until the present have covered a time period that is a substantial part of a solar cycle (Ajello *et al.*, 1987). Table 1 of this paper summarizes earlier interplanetary Lyman alpha observations. The Galileo spacecraft will make measurements of the Lyman alpha sky background during the six-year flight from Earth to Venus, back to Earth and then from Earth to Jupiter. The Lyman alpha sky background varies as a function of heliocentric distance and look direction as well as time. Knowledge of the intrinsic solar variation is necessary to determine correctly the radial distance and spatial variations.

There have been earlier measurements of solar Lyman alpha

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radiation (AE E: Hinteregger *et al.*, 1981; OSO-5: Vidal-Madjar *et al.*, 1975). However, the Solar Mesosphere Explorer has made the longest continuous set of well-calibrated measurements during the seven and one-half years of its operation.

Observations

The flux of solar Lyman alpha radiation was measured daily during the seven-and-one-half-year period from October 11, 1981 to April 13, 1989. A description of the instrument is given in Rottman *et al.* (1982) and a summary of the measurements of the solar ultraviolet irradiance in Rottman (1988). The instrument was designed and operated with special attention paid to the long-term stability. Alternate scattering screens were used with a strategy to determine long-term drift in instrumental sensitivity. In addition, a series of coordinated rocket experiments were conducted. In this paper, daily measurements of the Lyman alpha flux are compared with the 10.7 cm radio flux measured from the ground over the same time period. The objective of this study is to determine under what circumstances it is possible to predict the Lyman alpha flux from the knowledge of ground-based measurements of the 10.7 cm radio flux. There have been earlier studies of the correlation of solar Lyman alpha flux with the solar 10.7 cm radio flux (see, for example, Vidal-Madjar and Phissamay, 1980; Bossy and Nicolet, 1981; Bossy, 1983; Hedin, 1984; and Donnelly *et al.*, 1986). The SME solar ultraviolet spectrometer measured the total flux in the solar Lyman alpha line. Earlier satellites have measured the relationship between the Lyman alpha flux at line center and the total line flux (Vidal-Madjar and Phissamay, 1980; see also, Ajello *et al.*, 1987).

A linear least-squares fit was performed on the data for the time period 11 October, 1981 to 26 July, 1984 using the 10.7 cm data as the independent variable x and the Lyman alpha data as the dependent variable $y = s \bullet x + b$, where s is the slope and b is the intercept. The analysis also yields the linear correlation coefficient, r. This analysis gave a slope of 6.7×10^8, an intercept of 2.5×10^{11}, and a correlation coefficient of 0.84, where the units of the Lyman alpha flux are photons $cm^{-2}\ sec^{-1}$ and of the radio flux, $10^{-22}\ W\ m^{-2}\ Hz^{-1}$. The 10.7 cm radio flux data were multiplied by these coefficients and plotted in Figure 1 together with the Lyman alpha solar flux. An inspection of the figure shows the following. During the declining part of the solar cycle, October 11, 1981 — July 26, 1984, there is a long-term correlation between the 10.7 cm radio flux and the Lyman alpha flux. During the solar minimum period, July 26, 1984 — April 11, 1987, the 10.7 cm radio flux reaches a minimum value of $65 \times 10^{-22}\ W\ m^{-2}\ Hz^{-1}$. There are excursions above this value, but none below. In contrast, the Lyman alpha solar flux continues to decrease during this period, reaching a minimum in August 1986 and continues to clearly show a 27-day variation due to solar rotation. During the period April 11, 1987 — November 25, 1988, both solar fluxes begin to increase, with the 10.7 cm radio flux leading the increase and the Lyman alpha flux catching up during the latter part of this period. During the last 139 days of SME operations, November 25, 1988 — April 13, 1989, the 10.7 cm radio flux and the Lyman alpha flux again overlap indicating a behavior similar to that during the declining portion of solar cycle 21, October 11, 1981 — July 26, 1984.

A quantitative description of this behavior is given in Table 1. The declining phase of solar activity, October 11, 1981 — July 26, 1984, is divided into four periods: period 1 is 209 days long, periods 2, 3, and 4 are each 270 days long. The table shows the results of performing a least squares fit on these four data sets. For all four sets, the correlation coefficients are greater than 0.6 and the slopes, namely, the ratio of the Lyman alpha flux to the 10.7 cm flux, are all within 20% of the mean value. This result implies that for periods of 200 days or longer there is a correlation between the 10.7 cm flux and the Lyman alpha flux and that the slope and intercept of the proportionality is similar during these four periods. Period 5, July 26, 1984 — April 11, 1987, is the time of solar minimum. Here the correlation coefficient is the lowest of the seven periods, and the slope is much larger than during periods 1, 2, 3, and 4. This result is interpreted to mean that during solar minimum, the 10.7 cm flux is not a useful indicator of the Lyman alpha flux. During period 6, the time of rising solar activity, the correlation coefficient is high, but the slope is a different value than the slope during the time of decreasing solar activity. An inspection of Figure 1 shows the 10.7 cm flux to be leading the Lyman alpha flux as they both increase in amplitude. The analysis of the data for the final period when SME observations were available, period 7, shows a high correlation coefficient and value of the slope that is similar to the value obtained during the decreasing part of the solar cycle.

TABLE 1

Period	Date	Slope	Intercept	Coefficient
1	11 Oct 81	5.4 E8	2.8 E11	0.72
2	8 May 82	5.0 E8	2.8 E11	0.68
3	2 Feb 83	6.5 E8	2.5 E11	0.65
4	30 Oct 83	4.5 E8	2.6 E11	0.63
5	26 Jul 84	9.8 E8	1.9 E11	0.55
6	11 Apr 87	8.7 E8	1.9 E11	0.89
7	25 Nov 88	5.0 E8	2.6 E11	0.76

Results of least-squares-fit of solar 10.7 cm radio flux to solar Lyman alpha flux. The date is the beginning of each time period. The date of the end of the last period is April 13, 1989. The units of the 10.7 cm radio flux are 10^{-22} $W\ m^{-2}\ Hz^{-1}$ and of the Lyman alpha flux, photons $cm^{-2}\ sec^{-1}$.

In order to determine if the 10.7 cm flux may be used as an indicator of Lyman alpha flux on the time scale of the 27-day rotation of the sun, the period May 1982 through November 1982 was studied. Table 2 shows the results of least-squares fit analyses of seven 27-day periods beginning May 8, 1982, and ending November 13, 1982. The Lyman alpha flux and the scaled 10.7 cm flux for this period are plotted in Figure 2. The scaling used in Figure 2 is the same as that in Figure 1; namely, a slope of 6.7×10^8 and an intercept of 2.5×10^{11}. An inspection of Figure 2 and Table 2 for these seven solar

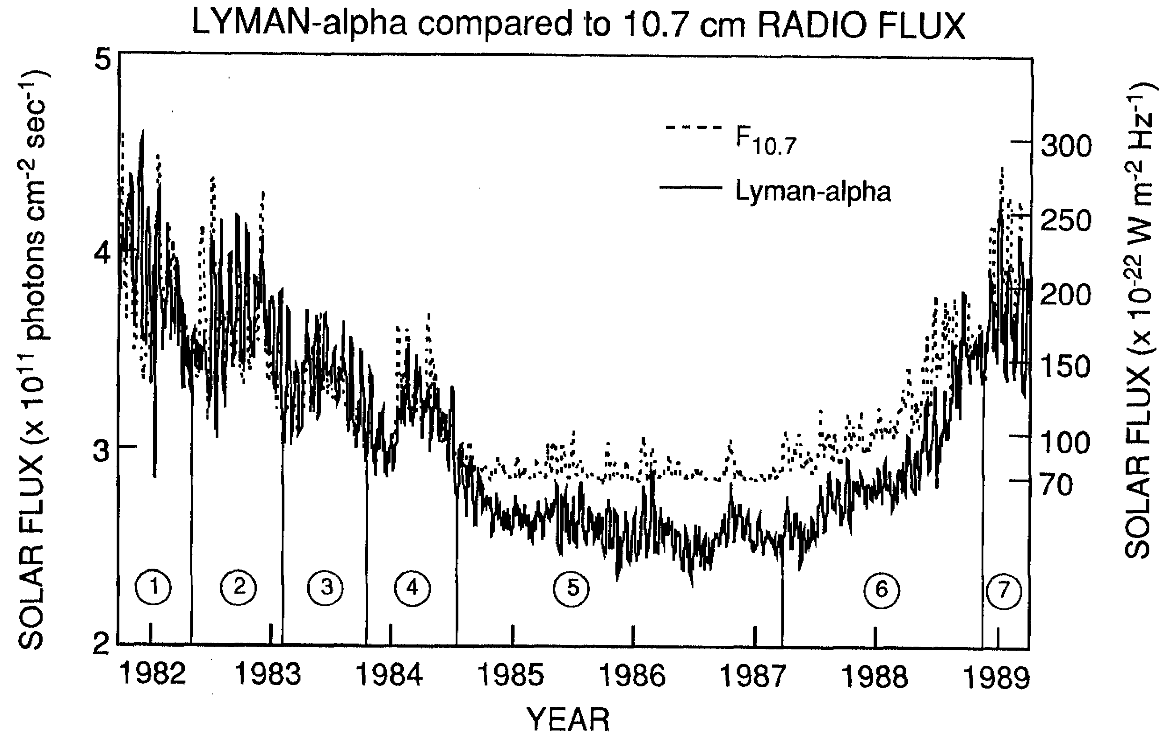

Fig. 1. Comparison of solar Lyman alpha flux to solar 10.7 cm radio flux for the period October 11, 1981 — April 13, 1989. Periods 1, 2, 3, and 4 correspond to the declining phase of solar activity. Period 5 is the solar minimum period. Periods 6 and 7 are part of the rising phase of solar activity. See Table 1 for the dates of each period.

rotation periods shows the following. For the May period, there is not much variation in either the Lyman alpha flux or the 10.7 cm flux. In June, there is a large variation in the 10.7 cm flux and only a small variation in the Lyman alpha flux. In July 1982, both Lyman alpha and 10.7 cm fluxes show large variations. The correlation coefficient for this 27-day period is high. The value of the slope, rotation period 3 in Table 2, is similar to the slope for the 270-day period, period 2 in Table 1. For the next four solar rotation periods, August — November, the amplitude of Lyman alpha flux variation is greater than the amplitude of the 10.7 cm flux variation. This behavior is shown by the calculated slopes for rotations 4-7 in Table 2.

TABLE 2

Rotation	Date	Slope	Intercept	Coefficient
1	8 May 82	6.1 E8	2.6 E11	0.61
2	4 Jun 82	1.3 E8	3.2 E11	0.50
3	1 Jul 82	4.8 E8	2.7 E11	0.92
4	28 Jul 82	9.5 E8	2.0 E11	0.89
5	24 Aug 82	9.9 E8	2.0 E11	0.61
6	20 Sep 82	9.5 E8	2.2 E11	0.94
7	17 Oct 82	1.0 E9	2.1 E11	0.81

Results of least-squares-fit of solar 10.7 cm radio flux to solar Lyman alpha flux for seven 27-day periods in 1982. The date is the beginning of each time period. The end of the last time period is November 13, 1982.

This same analysis was applied to 37 27-day periods between October 31, 1981, and July 26, 1984. In eleven of these periods the Lyman alpha flux and the 10.7 cm flux varied with the same slope (±20%); in eleven periods, the Lyman alpha flux varied with greater amplitude than the 10.7 cm flux; and, in eleven periods, the Lyman alpha flux varied with a smaller amplitude than the 10.7 cm flux. In the remaining four periods, the correlation was extremely poor. The relationship

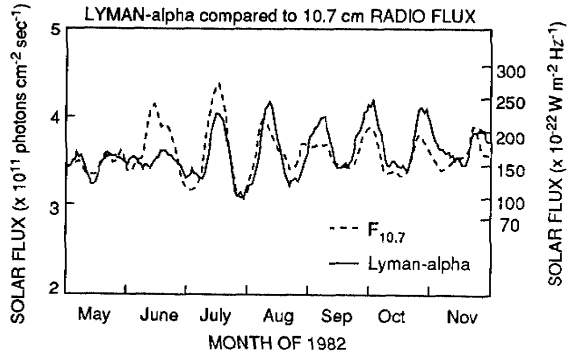

Fig. 2. Comparison of solar Lyman alpha flux to solar 10.7 cm radio flux for the period May — November 1982. The dates of the 27-day periods are given in Table 2.

between the Lyman alpha flux and the 10.7 cm flux is irregular and does not exhibit a systematic, predictable behavior.

Conclusions

There is a long-term correlation between the solar Lyman alpha flux and the solar 10.7 cm radio flux for periods of 200 days or longer during the decreasing and increasing phases of the solar activity cycle. During the period of solar minimum of almost three years there is not a useful correlation because the 10.7 cm flux reaches a minimum value and does not vary below that value while, in fact, the Lyman alpha flux continues to show long-term and numerous 27-day variations. The long-term relationship between the Lyman alpha flux and the 10.7 cm flux is different between the descending and rising portions of the solar cycle. There is not a predictable correlation between the 27-day variations of the Lyman alpha flux and 10.7 cm radio flux. The 10.7 cm radio flux is not a reliable indicator of solar Lyman alpha flux for applications such as the determining of atomic hydrogen density from the scattering of solar Lyman alpha radiation. For experiments, such as measuring interplanetary atomic hydrogen and atomic hydrogen in planetary atmospheres, some other method of determining the solar Lyman alpha flux needs to be made. The best method, of course, is a direct measurement of the solar Lyman alpha flux from the same spacecraft that is making the measurements of the scattered Lyman alpha radiation.

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