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SOLAR FLARE EFFECTS ON NEUTRAL GAS GLOW IN INTERPLANETARY SPACE

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Abstract—Solar flares in hydrogen and helium resonance lines (1216 and 584 Å) must be expected to result in temporal variations of neutral gas glow inside the heliosphere. Simultaneous measurements of glow variation and solar emission bursts proposed in this work would provide principally new experimental opportunities to derive the neutral atom number density distribution along the line-of-sight. Such a remote probing technique, similar in idea to radar, may be of great importance for the study of local interstellar medium–solar system interaction. The magnitude and occurrence frequency of solar flares in e.u.v. were assessed on the basis of the relation between e.u.v. flare emission enhancement and apparent solar flare area in *Hα*, for which data of solar patrol are available. The analytical expressions for glow temporal variations were obtained for a few model number density distributions similar to those expected for interstellar hydrogen and helium inside the heliosphere. The discussion of relevant instrumentation shows that a space experiment, based on the exploitation of the solar flare effect, seems to be marginally feasible for hydrogen atoms and could be successful for helium atoms.

INTRODUCTION

The heliosphere is filled with dilute neutral gas. The neutral atoms—mostly hydrogen and helium—are of interstellar origin and penetrate the solar system from the local interstellar medium (LISM). These atoms are glowing under solar illumination and, until now, the measurement of the glow radiation was the only way to study the flow of neutral interstellar gas (ISG) in the solar system. The ISG glow was studied extensively both theoretically and experimentally [see reviews of Axford (1973), Fahr (1974), Holzer (1977) and more recently Bertaux (1984)] and, as a result, a qualitative understanding of the interaction between the LISM and the solar system was achieved.

In experiments which are performed either from spacecraft or sounding rockets, the distribution of the background radiation in resonance lines (1216 Å for hydrogen and 584 Å for helium) over the sky is measured. This glow is the solar radiation scattered by neutral atoms inside the heliosphere. The radiation intensity depends on resonant solar photon flux, number density distribution and dynamical properties of the neutral gas. The neutral gas characteristics depend on that of the LISM, the heliopause structure and the interaction of neutral atoms with solar gravitational and radiation fields as well as with solar wind plasma inside the heliosphere. The measurements of radiation intensity distribution over the sky, performed at the vicinity of the Earth orbit, give, in principle, the opportunity to derive the characteristics of unperturbed ISG in the LISM. Such an approach is valid only if the theoretical models treating the LISM–solar system interaction are adequate.

However, the conventional theoretical models are challenged nowadays by certain physical incompatibilities with the results of optical experiments (Ripken and Fahr, 1983; Bertaux, 1984). In particular, the derived temperatures and bulk velocities of interstellar hydrogen and helium in the LISM are somewhat different.

To cope with this unsatisfactory situation, both new theoretical approaches (Baranov *et al.*, 1979; Baranov and Ruderman, 1979; Gruntman, 1982; Ripken and Fahr, 1983; Fahr *et al.*, 1986) and new space experiments are pushed forward. The proposed experiments are of a principally new type. They are based on neutral atom direct *in situ* detection and include interstellar helium detection (Rosenbauer *et al.*, 1983; Rosenbauer *et al.*, 1984) and solar wind neutral component measurements (Gruntman, 1980; Gruntman and Leonas, 1983; Gruntman and Leonas, 1985).

However, the continuation of indirect, remote optical measurements seems to be important, since a lot of effort has already been devoted to the elaboration of the instrumentation and techniques and extensive data and experience have been gathered. New approaches to optical measurements may provide a lot of valuable data. It should be noted here that the radiation intensity (measured in optical experiments) depends on the neutral atom distribution over both space and velocity in the heliosphere (derived from the measurements) in a rather complicated manner. The radiation intensity is a double integral of the neutral atom distribution: one integration over the line-of-sight and, in each point, the convolution of the local radial velocity distribution with the solar line shape allowing for the Doppler shifts of individual atoms. It is obvious that ambiguity is inherent to the derivation of ISG characteristics from such measurements.

DIFFERENTIAL MEASUREMENTS AND REMOTE SENSING OF THE ISG

Progress in optical experiments is connected with the replacement of the integral measurements by differential ones (i.e. by decreasing the number of integrations in the relation between the distribution function and the measured values). One opportunity is to measure accurately the spectral characteristics of scattered radiation. This approach in its most straightforward and powerful manner, despite rather serious experimental difficulties, was realized successfully by Adams and Frisch (1977). A less powerful technique, that of absorption cells, which provides some information on the spectral characteristics of registered radiation, was used by a number of groups (e.g. Crifo *et al.*, 1979; Bertaux, 1984) and is planned for future experiments.

It was a consensus earlier that the only way to perform real differential measurement of atom number density is the *in situ* direct atom detection. We believe that this is the first time that differential measurements are proposed to be performed remotely from the fixed observation point by registration of temporal variations of the scattered radiation due to solar flares. The idea is similar to that of radar and the several minutes enhancement of the solar radiation in the resonance line during the solar flare would provide the probing "radar" pulse. Similarly to radar, a new acronyn SODAR (SOlar Detection And Ranging) could be coined for the proposed technique.

The temporal variations of the background radiation have, to our knowledge, never been treated for time scales less than a few hours, though, for far greater time scales, temporal variations were considered by Blum and Fahr (1970) (for a 27 day cycle) and by Ruciński (1985) and Bzowski *et al.* (1985) (for 11 y solar cycle).

The aim of this work is to consider the effect of solar flares on neutral atom glow in resonance spectral lines of helium and hydrogen and to assess the experimental feasibility. Further, the expected frequency and magnitude of solar flares in spectral lines of interest will be discussed and then the temporal variations of the background radiation will be calculated. In the last part of the paper, some comments on experiment feasibility as well as on some problems of relevant instrumentation will be made.

SOLAR FLARES IN E.U.V.

The direct data on the expected magnitude and occurrence frequency of solar flares in e.u.v. are lacking since there is no permanent solar patrol in this spectral range. The only feasible way to assess expected solar flare characteristics is to use available data of solar patrol in larger wavelengths, for instance in $H\alpha$, providing the required characteristics and available data are interdependent.

Solar e.u.v. radiation during flares was measured by a number of satellite experiments on *OSO*-1, *OSO*-3 (Hinteregger and Hall, 1969; Hall, 1973), *OSO*-5 (Kelly and Rense, 1972), *OSO*-4 and *OSO*-6 (Wood *et al.*, 1972), *SOLRAD*-11 (Horan *et al.*, 1983) as well as by ground-based observations of sudden frequency deviations (SFD), a type of sudden ionospheric disturbance (SID) (Donnelly, 1971). The latter type of observations can provide information on a very broad bandwidth (10–1030 Å) radiation only. Among satellite experiments, some also provide data only on very broad bandwidths (e.g. *OSO*-5 and *SOLRAD*-11). Therefore, the measurements of emission at specific wavelengths (especially as far as 1216 and 584 Å are concerned) could not be considered as abundant.

All e.u.v. emissions are a combination of slow component and impulsive bursts, depending on the region where emitting atoms and ions are located. The typical emission time structures are shown in Fig. 1 (Fig. 6 from Donnelly *et al.*, 1973). A slow or gradual component, emitted mainly from the solar corona regions, would cause small gradual enhancement of background radiation and would be detrimental to a SODAR-like experiment. Fortunately, both 1216 and 584 Å lines are emitted from the solar chromosphere and/or chromosphere–corona transition regions which results in a burst-like behaviour of the radiation (Hall, 1971; Donnelly *et al.*, 1973). The typical rise- and decay-time of emission enhancement in hydrogen Lyman-α are 2.4 ± 1.6 and 4.4 ± 3.0 min, respectively (Hall, 1971). It is important that these characteristic times are not constants in the usual sense of e-fold of rise and decay, but are the total time intervals measured from the pre-flare level to the maximum, and from the maximum back to the initial level. One may safely assume that the helium 584 Å line temporal characteristics are rather similar to that of hydrogen Lyman-α as it is excited by the same process and emitted from the same spatial region.

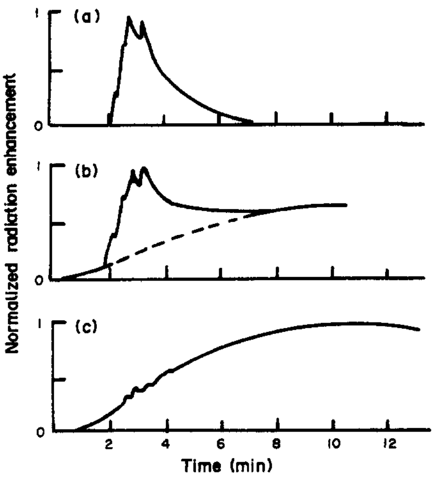

FIG. 1. EMPIRICAL MODEL OF e.u.v. EMISSION TIME STRUCTURE: (a) O VI 1032 Å, CHROMOSPHERIC AND CHROMOSPHERIC–CORONA TRANSITION REGION EMISSIONS; (b) Mg X 625 Å; (c) Fe XVI 335 Å, CORONA EMISSIONS (FROM DONNELLY *et al.*, 1973; Fig. 6).

Solar flares are monitored by a number of ground-based stations worldwide and a solar patrol surveys the Sun almost continuously. The most widely used way to assess solar flares is by their area visible in the $H\alpha$ line. An appropriate class number (from S to 1, 2, 3 and 4) is assigned to each registered flare according to its area (Svestka, 1976). The areas used for flare assessment are apparent areas corrected for foreshortening due to different positions on the solar disk (Sawyer, 1967). It was found (Hall, 1971) that the magnitude of the impulsive enhancement in e.u.v. lines correlates with the measured corrected flare area in $H\alpha$. Some sort of average or typical behavior was inferred from the sample of data in which the dispersion of measurements was uncomfortably large. The emission enhancements due to flares in e.u.v. are related to the flare area in $H\alpha$ by the expression:

$$E = kA^{3/2} \quad (1)$$

where E is the enhancement in the percentage of the undisturbed photon flux, A is the corrected area in heliospheric square degrees, and k is a factor depending on the wavelength of the line. For hydrogen Lyman-α Hall (1971) found that $k = 0.3 \pm 0.1$. The value of k was derived from the measurements of only two flares. For three observed flares in the helium 584 Å line no emission enhancement was measured at all. It was emphasized however, that these flares were probably not typical, since quite often 584 Å line emission enhancements were observed at another mode of instrument operation, its magnitudes being similar to those of the nearly 630 Å line (OV). The value of k for this oxygen line was derived to be 1.2 ± 0.4 and it was based solidly on 26 flare observations. The emission enhancements in the 584 Å line were also observed by Wood *et al.* (1972). Therefore, one may safely assume that the relative enhancement of the helium 584 Å line is at least similar to that of Lyman-α and may be even greater.

The expected occurrence frequency and magnitude of emission enhancement were estimated by using the data on solar flare corrected areas published regularly in Solar–Geophysical Data. Obviously, the solar activity, including flares, depends strongly on the phase of the solar 11 y cycle. For instance, the total number of registered flares (all classes) for 1980 (solar maximum) and 1986 (solar minimum) were 10,132 and 730, respectively. The monthly variations of the number of flares during these years are presented in Fig. 2. The difference in the average occurrence frequency of solar flares during 1980 and 1986 is almost as high as a factor of 14.

In the following, the expected radiation enhancements E were calculated by the expression $E = 0.3A^{3/2}$, where values of A are taken from Solar–Geophysical Data. Only the flares of the importance of the class 1 and higher were counted (656 and 36 for 1980 and 1986, respectively). If the average corrected area for a group of observations was not given, it was calculated by averaging presented values of corrected areas of individual observations. For a number of

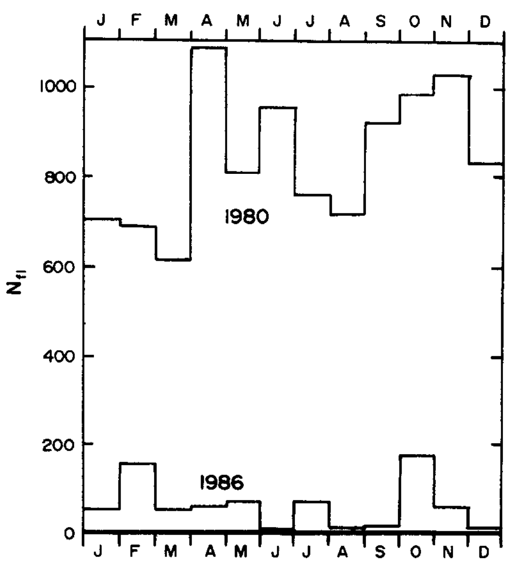

FIG. 2. MONTHLY NUMBERS OF REGISTERED SOLAR FLARES (ALL CLASSES) N_{fl} DURING 1980 (SOLAR MAXIMUM) AND 1986 (SOLAR MINIMUM).

registered flares, no data on the corrected area were available. These flares, being observed near the edge of solar disk, were not counted at all. Therefore, the presented occurrence frequency is the lower limit. The expected radiation enhancements for 1980 and 1986 are shown in Fig. 3. Only enhancements greater than or equal to 2% are presented (corresponding to $A = 3.5$ heliocentric square degree): 198 for 1980 and 17 for 1986. The distribution of the number $N(E)$ of enhancements (number of enhancements between E and $E+1\%$) is presented in Fig. 4 by solid bars. The line in the upper part of the figure shows the number of enhancements, N_E equal to or greater than E. Figures 3 and 4 do not represent the real history of the e.u.v. radiation enhancements during 1980 and 1986, but rather that such occurrence frequency and magnitudes are typical for these periods of time. Actually, the frequency may be somewhat higher, since not each e.u.v. flare is accompanied by a flare in the $H\alpha$ line. The expected magnitudes of presented enhancements correspond to that of hydrogen Lyman-α line. As far as the helium 584 Å line is concerned, the magnitudes of enhancements might be similar or even greater.

One may see that the expected hydrogen 1216 Å line emission enhancements greater than 8% occur on average every month during the solar maximum and every 3 months during the solar minimum time. For the solar maximum year, the enhancements of 5% and greater could be expected on average three times per month.

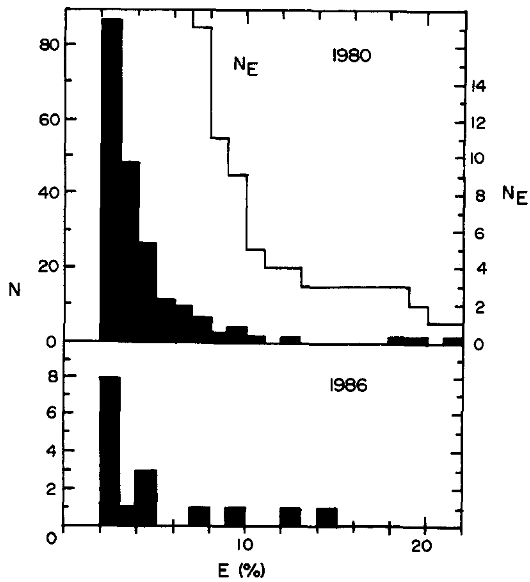

FIG. 4. THE DISTRIBUTION OF THE NUMBER OF ENHANCEMENTS N OF THE MAGNITUDE E (BETWEEN E AND $E+1\%$). The solid line in upper part is the number N_E of enhancements equal to or greater than E.

TEMPORAL VARIATIONS OF NEUTRAL ATOM GLOW

Consider now temporal variations of neutral gas glow due to solar flares. Let us express the solar radiation flux F_s (photons per square centimeter per second) in the spectral line of interest in the form

$$F_s(R, t) = F_s^0(R)(1+f_s(t)) \quad (2)$$

where F_s^0 is the constant level of radiation flux and $f_s(t)$ is the relative flux enhancement (but contrary to E not expressed in percentages) during the solar flare, R is the distance from the Sun and

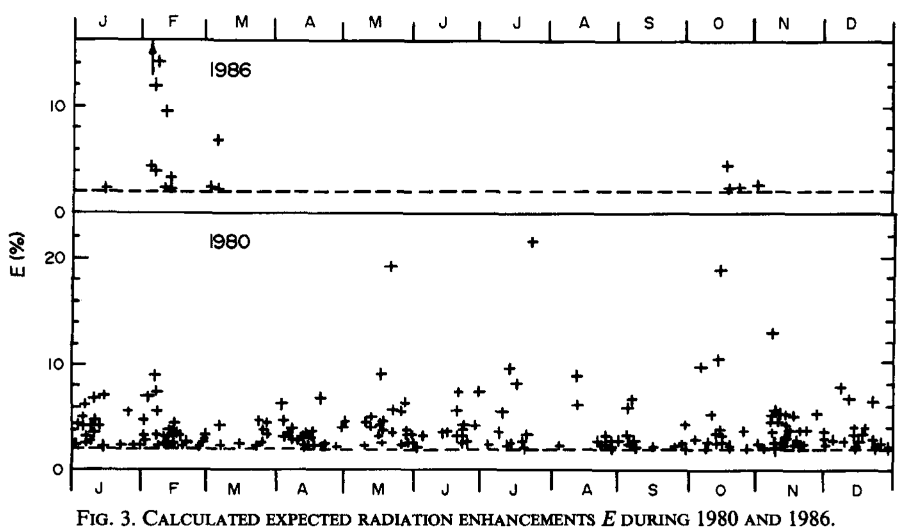

FIG. 3. CALCULATED EXPECTED RADIATION ENHANCEMENTS E DURING 1980 AND 1986. By the arrow, February 1986, the flare is marked with the expected enhancement $E = 44\%$. Time axes are not identical since 1980 was a leap year.

$$F_s^0(R) = F_s^0(R_0)(R_0/R)^2 \tag{3}$$

where R_0 is the Earth's orbit radius, i.e. 1 a.u. The formula (3) presumes that neutral gas in the interplanetary space is optically thin. Obviously, $f_s(t)$ equals zero except during the several minutes interval of e.u.v. radiation bursts. For the given point and the direction of observation, the scattered background radiation flux intensity $F_b(t)$ (photons per square centimeter per second per steradian) can be presented in a similar form, that is

$$F_b(t) = F_b^0(1+f_b(t)) \tag{4}$$

where F_b^0 is the constant level of the background radiation flux from a selected direction and $f_b(t)$ is the relative background radiation flux enhancement due to the solar flare.

We will consider the scattered background radiation flux reaching a given point at Earth orbit from the antisunward direction only, which is of the most interest also from the experimental point of view. The background radiation flux enhancement depends on that of the solar e.u.v. flux illuminating the neutral atoms situated along the line-of-sight. Solar e.u.v. enhancements are obviously not isotropic. The most pronounced manifestation of the effect is, for instance, a solar flare which is located at the "other", invisible side of the Sun, and therefore could not be seen from the observation point. However, this "invisible" flare would affect background radiation reaching the given point from certain directions. The problems related to the anisotropy of the solar radiation could be eliminated by conducting observations in the antisunward direction only. In this case, the primary solar radiation flux $F_s(t)$, which is responsible for the background radiation (providing solar photon multiple scattering is negligible), could be monitored at the same point.

The background radiation flux at Earth orbit at the moment of time t can be expressed as

$$F_b(t) = B\int_{R_0}^{\infty} F_s\left(R, t-\frac{2(R-R_0)}{c}\right) n(R)\xi(R)\,\mathrm{d}R \tag{5}$$

where B is a constant, c is the velocity of light, and $n(R)$ is the neutral atom number density along a line-of-sight. The function $\xi(R)$ comprises the probability of a neutral atom scattering a light photon in a given direction and the convolution of the solar line profile with the neutral atom velocity distribution function to allow for the effect of individual atom Doppler shifts. We assume here that the solar line profile does not change during the flare, which may not be the case. The experimental evidences are extremely poor and further study is needed to clarify the problem. The properties of $\xi(R)$ are different for hydrogen and helium atoms. For hydrogen 1216 Å photons, the scattering is almost isotropic (e.g. Brandt and Chamberlain, 1959) and the solar emission line profile could be considered as being flat since the line width is ~ 1 Å (e.g. Vidal-Madjar, 1977). This line width corresponds to Doppler velocities ± 150 km s^{-1}. This velocity range is far greater than the expected velocity spread of interstellar hydrogen atoms inside the heliosphere. Therefore, for hydrogen, $\xi(R)$ can be assumed constant. For the helium 584 Å line, the scattering is anisotropic (Carlson and Judge, 1976) and the solar line full width at half of the maximum is only 120–140 mÅ (Carlson and Judge, 1976) which corresponds to Doppler velocities ± 34 km s^{-1}. The expected helium atom velocities are comparable with or greater than this velocity range and the function $\xi(R)$ would depend strongly on the point and the direction of the observation. Further, we will assume that $\xi(R)$ is included either in constant B for hydrogen or in a number density $n(R)$ for helium (i.e. the helium number density is substituted by an "effective" number density). In that case, substituting equations (2), (3) and (4) into equation (5), results in

$$f_b(t) = \frac{1}{I_0}\int_{R_0}^{\infty} f_s\left(t-\frac{2(R-R_0)}{c}\right) n(R)(R_0/R)^2\,\mathrm{d}R \tag{6}$$

where

$$I_0 = \int_{R_0}^{\infty} n(R)(R_0/R)^2\,\mathrm{d}R. \tag{7}$$

The value of I_0 is the integral over the "source function" along the line-of-sight and has the sense of an effective number of scattering centers in a given direction. If the flare in e.u.v. starts at the moment t_1 and ends at the moment t_2, then the intensity enhancement $f_b(t_0)$ observed at moment t_0 would be determined by the integral (6) with the integral limits

$$\left(R_0 + \frac{t_0-t_1}{2}c\right) \quad \text{and} \quad \left(R_0 + \frac{t_0-t_2}{2}c\right).$$

Only those neutral atoms which are contained along the line of length $\Delta L = c(t_2-t_1)/2$ would contribute to $f_b(t_0)$, the column length of these contributing atoms shifting from the Sun with the increase of time interval elapsed after the flare.

In order to assess qualitatively (and analytically) the temporal behavior of $f_b(t)$, a simplified model of a solar flare will be used. Let us assume that the solar flare emission enhancement in the spectral line of interest starts at moment $t = 0$, its duration is τ and its intensity during the flare is constant, i.e.

$$f_s(t) = \begin{cases} 0, & t < 0 \\ f_0, & 0 < t < \tau \\ 0, & \tau < t. \end{cases} \qquad (8)$$

In that case, the integral (6) can be calculated analytically for certain number density distribution functions $n(R)$, which are similar to those expected inside the heliosphere. We will consider two such distribution functions resembling helium and hydrogen neutral atom properties.

(1) The uniform distribution is similar qualitatively to that of helium atoms (within a factor ~ 2) except in the solar wake region. For the wake region, an enhancement of atom number density is expected, therefore the effect of solar flare induced temporal variations of the glow would be even more pronounced than for the uniform distribution. For the uniform number density distribution function $n(R) = n_0$ the integral (7) equals $I_0 = n_0 R_0$. The background radiation enhancement then would be

$$f_b(t) = \begin{cases} f_0 \dfrac{\kappa t}{1+\kappa t}, & 0 < t < \tau \\ f_0 \dfrac{\kappa \tau}{(1+\kappa(t-\tau))(1+\kappa t)}, & \tau < t \end{cases} \qquad (9)$$

where $\kappa = c/2R_0$. The value of $f_b(t)$ increases while $t < \tau$, then begins to decrease, and finally for large values of t, decreases approximately as $\sim 1/t^2$. One may also see that the relative background radiation enhancement is proportional to the product $(f_0 \tau)$, i.e. is proportional to the total number of photons produced during the flare. This fact can be used for the scaling of the presented calculation results.

For the typical value of $\tau = 5$ min the dependence of f_b on t is presented in Fig. 5. The main radiation enhancement is confined to the time interval of 20 min after the flare with a rather sharp maximum at moment $t = \tau$.

(2) Let us consider now the number density distribution which is similar to that expected for hydrogen atoms. The realistic number density distribution for hydrogen atoms can be easily obtained if one assumes that solar gravitation attraction is precisely counterbalanced by radiational pressure, i.e. $\mu = 1$, where μ is the ratio of solar radiation pressure to gravitational force. The condition $\mu = 1$ seems to be realistic for the solar maximum period, and for solar minimum, $\mu = 0.75$ can be assumed (Bertaux, 1984). That means that assuming $\mu = 1$, one considers the lower limit of the number density corresponding to the worst conditions for a SODAR-like experiment.

Let us assume that the temperature T_0 of incoming interstellar hydrogen gas equals zero. This assumption results in a decreased number density in the solar wake region in comparison with a more realistic value of $T_0 \cong 10^4$ K. For an ISG with the number density and velocity n_0 and V_0 at "infinity" in the LISM, the number density n_H at a point with coordinates (R, Θ) would be

$$n_H(R, \Theta) = n_0 \exp\left(-\frac{\beta_0 R_0}{V_0} \frac{\Theta}{\sin(\Theta)} \frac{R_0}{R}\right) \qquad (10)$$

where β_0 is the hydrogen atom loss rate at Earth orbit, and the angle Θ is counted from the direction antiparallel to the velocity vector V_0. If we introduce the function

$$g(\Theta) = \frac{\beta_0 R_0}{V_0} \frac{\Theta}{\sin(\Theta)} \qquad (11)$$

then the integral I_0 (7) for the number density distribution (10) may be expressed as a function of angle Θ in the following way

$$I_0(\Theta) = n_0 R_0 \frac{1-\exp(-g(\Theta))}{g(\Theta)}. \qquad (12)$$

The dependence of radiation enhancement $f_b(t)$ on the direction of the observation Θ at Earth orbit would be

$$f_b(t, \Theta) = \frac{f_0}{1-\exp(-g(\Theta))} X$$

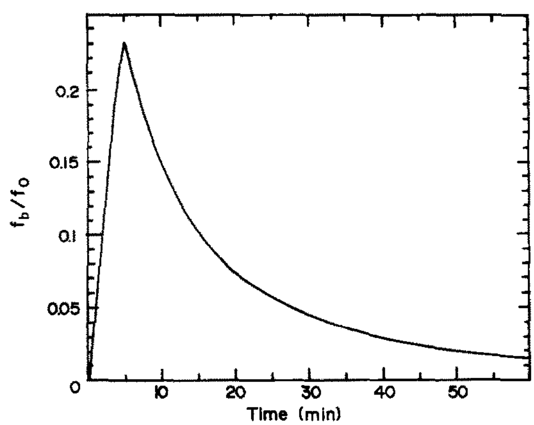

FIG. 5. THE DEPENDENCE ON TIME OF THE RELATIVE BACKGROUND RADIATION ENHANCEMENT f_b NORMALIZED TO THE RELATIVE FLARE RADIATION ENHANCEMENT f_0 FOR UNIFORM NEUTRAL ATOM NUMBER DENSITY DISTRIBUTION AND FLARE DURATION $\tau = 5$ min.

$$X\begin{cases}\exp\left(-\dfrac{g(\Theta)}{1+\kappa t}\right)-\exp(-g(\Theta)), & 0<t<\tau\\ \exp\left(-\dfrac{g(\Theta)}{1+\kappa t}\right)-\exp\left(-\dfrac{g(\Theta)}{1+\kappa(t-\tau)}\right), & \tau<t.\end{cases} \quad (13)$$

For commonly accepted values $V_0 = 20\ \mathrm{km\ s^{-1}}$ and $\beta_0 = 5.5\times10^{-7}\ \mathrm{s^{-1}}$, the dependences $f_b(t)$ for a set of different directions of observation Θ (resulting from the Earth being at different orbital positions), are shown in Fig. 6 for a solar flare duration $\tau = 5$ min. Obviously, the relative radiation enhancement is less pronounced than for the uniform distribution case.

EXPERIMENTAL OPPORTUNITIES

Let us assess now requirements for, and conditions of the SODAR experiment. One may consider the experiment as follows. The spacecraft, being preferably beyond the geocorona, moves around the Sun. Two sensors incorporated in the instrument look at the sunward and antisunward directions, respectively. Both sensors measure the radiation intensity in the helium 584 Å and hydrogen 1216 Å spectral lines. Measurements are performed during the period of time when the spacecraft sweeps at least one full rotation around the Sun. Though the phenomena of interest, solar flares of high importance, are rare, the instrument is to operate all the time.

It is important to emphasize that, providing the absolute values of both solar and scattered photon fluxes (F_s and F_b) are measured and photon scattering cross-section is known, the neutral atom number density along the line-of-sight can be deduced directly (5). If only relative photon flux changes (f_s and f_b) are measured, then a model of number density distribution in the heliosphere is to be assumed (and its parameters adjusted). It follows from the fact that the relation between f_s and f_b (6) includes, besides the local value, also the integral I_0 over the number density distribution along the line-of-sight.

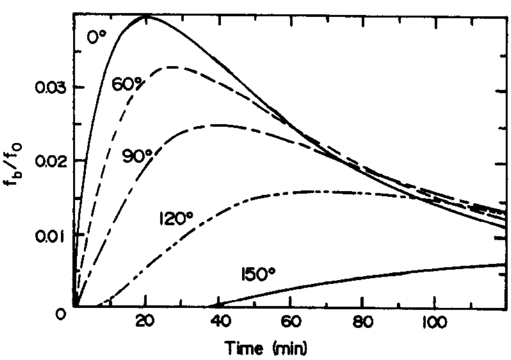

FIG. 6. FOR A HYDROGEN-LIKE NEUTRAL ATOM NUMBER DENSITY DISTRIBUTION ($\mu = 1$ AND $T_0 = 0$), THE TIME DEPENDENCE OF f_b/f_0 IS SHOWN FOR A NUMBER OF DIFFERENT LOOK-DIRECTIONS; SOLAR FLARE DURATION $\tau = 5$ min.

The most reliable and accurate radiation intensity measurements require the counting of the individual photons. Secondary electron multipliers, for instance channel electron multipliers and detectors on the basis of microchannel plates, can be used for this purpose. The most important factor affecting the accuracy of measurements seems to be statistics. To improve the accuracy, the number of registered photons is to be maximized. The restriction on the maximum count rate I_{max} is inherent for secondary electron multipliers and usually $I_{max} = (1-5)\times10^5\ \mathrm{s^{-1}}$ could be accepted as a safe and realistic limit. The typical flare duration is 300 s and the corresponding "spatial resolution" of SODAR experiment is $\Delta = \tau c/2 = 0.3$ a.u. Obviously, the accumulation time (exposure time), during which photon counts are summed, is not to be less than $\tau_a = 100$ s. The maximum number of photons, to be counted during this time interval, is $N_{ph} = I_{max}\tau_a = 10^7$. The relative error r to measure N_{ph}, and radiation intensity respectively, would consequently be $r = 10^{-3}$ (3 S.D.). The statistical error of the measurement of the relative radiation enhancement f is approximately r/f, since the preflare initial value of intensity could be measured by accumulating counts during the longer time interval.

One of the physical values, which is to be determined in the experiment, is the ratio f_b/f_0, and the relative error of this value would be

$$(r/f_0)\left(1+\frac{1}{f_b/f_0}\right). \quad (14)$$

This relative error is nearly 100% for the f_b/f_0 ratio equal to 0.01 and 0.02 for solar flare radiation enhancements f_0 of 10% and 5%, respectively. For hydrogen Lyman-α, 5% enhancement flares occur three times per month during solar maximum period. For the helium 584 Å line, the enhancements of the same magnitude may be expected more often. Comparing the values of the ratio f_b/f_0 corresponding to $\approx$100% relative error with the magnitudes of expected background radiation enhancements presented in Figs 5 and 6, one may conclude that the SODAR experiment to probe hydrogen atoms in heliosphere is marginally feasible. As far as helium is concerned, the successful probing seems to be definitely feasible.

Some comments on the problems of relevant instrumentation are to be made. The main question is whether maximum permissible (by detectors) count rate I_{max} is achievable. The solar emission in the required spectral lines is very strong (Vidal-Madjar, 1977; Timothy, 1977). Therefore, despite the photon loss in the spectrometer, there are no problems in achieving the required count rate of the sensors monitoring direct solar radiation.

As far as background radiation is concerned, it should be noted, that the 1216 and 584 Å lines are expected to be dominant features in the interplanetary emission spectrum. These lines could be separated efficiently by filtering (e.g. Carlson and Judge, 1974). The background radiation detector count rate would be

$$I_b = S_d \Omega_d \varepsilon \Phi_b \eta \quad (15)$$

where S_d and Ω_d are the detector sensitive area and the field-of-view solid angle, respectively, ε is the photon detection efficiency, η is the instrument transmission in the particular spectral line, and Φ_b is the photon flux number density (per square centimeter per steradian). The detector sensitive area of $S_d = 10\ cm^2$ is typical for detectors based on microchannel plates and the detection efficiency ε could be as high as 0.4 (Martin and Bowyer, 1982). For the detector field-of-view solid angle $\Omega_d = 15° \times 15° = 7 \times 10^{-2}$ Sr and $\Phi_b = 1$ R

$$I_b = 2 \times 10^4 \eta\ s^{-1}. \quad (16)$$

For hydrogen 1216 Å, for which background radiation intensity $\Phi_b = 300\text{–}600$ R is typical, the maximum count rate is easily achievable. For helium 584 Å with a typical intensity of $\Phi_b = 1\text{–}20$ R (e.g. Ajello, 1978), the count rate may vary from I_{max} down to values of one order of magnitude lower. This may result in the decrease (by a factor of 3) of accuracy, however for helium the expected variations of f_b are significant and the expected accuracy of the measurements remain reasonably high. Statistical accuracy can obviously be improved by the use of an array of identical independent detectors. Putting together counts from all detectors improves the statistical accuracy by a factor $(N_d)^{1/2}$, where N_d is the number of detectors. The use of a number of independent detectors is also favorable since they provide redundancy.

CONCLUSION

Solar flares in e.u.v. would result in temporal variations of neutral gas glow in interplanetary space. Simultaneous measurements of glow variation and solar emission burst provide an opportunity to derive neutral atom number density distribution along the line-of-sight. A new acronym, to name the new radar-like remote probing technique based on this effect, was coined—SODAR.

The magnitude and occurrence frequency of solar flares in e.u.v. were assessed on the basis of the relation between e.u.v. flare emission enhancement and apparent solar flare area in *Hα*. For the latter, the data of solar patrol, performed on a regular basis, are available.

The analytical expressions for glow temporal variations were obtained for a few model number density distributions inside the heliosphere. The discussion of relevant instrumentation showed that the SODAR experiment to probe interplanetary hydrogen might be marginally feasible. As far as interplanetary helium is concerned, the situation is much more promising.

To make experiment feasibility assessment more reliable, measurements of solar radiation flux (including line shapes) in 1216 and 584 Å spectral lines during flares, and a more accurate relationship with apparent flare areas in *Hα* as a consequence, are needed. The existing experimental data on background radiation may also contain experimental evidence of the solar flare induced glow variations. The search for such evidence is of great importance, and already existing data can provide a solid basis for the feasibility assessment of SODAR experiments and may give new information on neutral gas characteristics inside the heliosphere.

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