Calculation of RF emission brightness temperature of high density plasmas clouds in Sun-terrestrial interplanetary space

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Abstract. In this paper, bremsstrahlung, the dominating RF emission mechanism of high density plasmas clouds in sun-terrestrial interplanetary space, is studied. The bremsstrahlung brightness temperature of the plasmas clouds from 0.47 AU to 1 AU are calculated according to the data that recorded by Mariner l0. The calculating results show that the RF emission brightness temperature of high density clouds can be identified as compared to those plasmas clouds in times of quiet sun by radiometer with 2 K temperature resolution. Therefore, forecast of disastrous space weather can be obtained in time according to the variation of emission brightness temperature of the plasmas clouds.

Index Terms. Brightness temperature, radio emission, interplanetary space, plasmas clouds.

1. Introduction

The Sun is a fixed star which is proximate to Earth of about 1 AU. As a consequence, a wealth of phenomena such as CMEs which occurring through the Sun's atmosphere are the principal drivers of the space weather and the near-Earth conditions (Raulin and Pacini, 2005; Munro, et al., 1979; Webb and Hundhaunsen, 1987; Cyr and Webb, 1991). For examples, they often drive interplanetary shocks and cause geomagnetic storms. Therefore, space operations and satellite communication and surveillance systems will be disturbed. (Jadav et al., 2005). High density plasmas clouds are the basic nature of CMEs as they propagating into interplanetary space. In Fig. 1, the LASCO C3 solar observatory satellite recorded a major, long duration, proton ejection event from the sun. We can see that high density plasmas cloud is generated as the ejection entered the interplanetary space. Therefore, bremsstrahlung as the mainly radio emission mechanism of the plasmas cloud will be intensified undoubtedly.

In this paper, we calculate the RF emission brightness temperature of high density plasmas cloud that induced by ICMEs by use of the scientific data which recorded by Mariner l0. The calculating results show that the emission brightness temperatures of the plasmas clouds are approximately a few decuple of those plasmas clouds in times of quiet sun. The variation of emission brightness temperatures can be identified by radiometer with 2 K temperature resolution. We can predict how serious the CMEs will be by analyzing the variation of the brightness temperature.

2. Bremsstrahlung theory

The basis for incoherent radio emission in low density medium like the solar corona is the emission from free accelerated particles. The dominating RF emission mechanism of high density plasmas clouds, which are induced by the propagation of CMEs in the interplanetary space, is bremsstrahlung. Moreover, cyclotron emission and recombination emission do a little contribution to RF emission (Sun and Wu, 2005). In this paper, we focus on the calculation of bremsstrahlung brightness temperature.

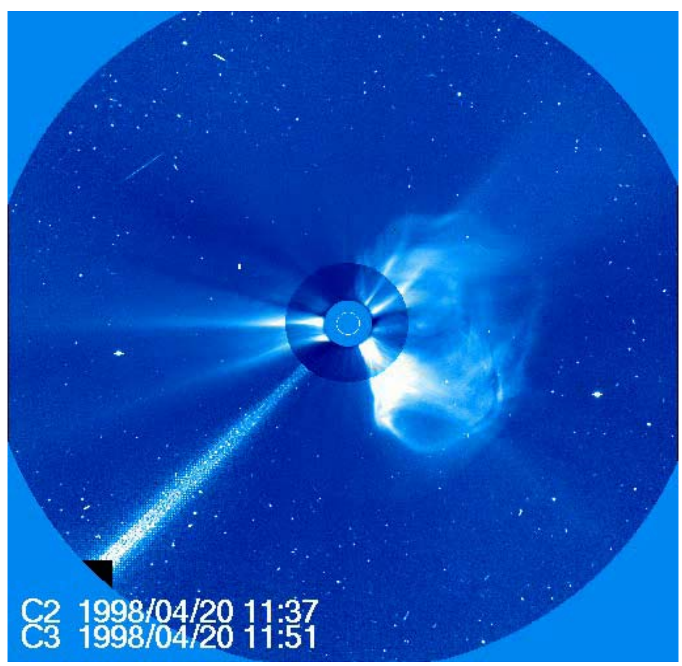

Fig. 1. CME recorded by LASCO.

Bremsstrahlung is caused by Coulomb collisions between charged particles in plasmas. In Fig. 2, an example of a binary collision between an electron with velocity v and an ion with charge Zi is shown. b is impact parameter.

Consider a cloud of plasmas with electrons temperature T, number density of the electrons N, number density of the ions N_i and electrons thermal velocity *v*. The velocity distribution of the electrons in this cloud is given by the Maxwell distribution:

$$f(v) = N_e \left(\frac{m_e}{2\pi\kappa T}\right)^{\frac{3}{2}} e^{-\frac{m_e v^2}{2\kappa T}} . \tag{1}$$

The emission coefficient of bremsstrahlung is:

$$j_f = 1.501\times10^{-39} \frac{N N_i Z^2}{T^{\frac{1}{2}}}[17.72 + \ln \frac{T^{\frac{3}{2}}}{fZ}] . \tag{2}$$

where *f* is the emission frequency and *Z* is the serial number of atomic nucleus. The unit of it is erg cm^{-3} sr^{-1} sec^{-1} Hz^{-1}. The corresponding absorption coefficient is:

$$\alpha_f = 9.78\times10^{-3} \frac{N N_i Z^2}{T^{\frac{3}{2}} f^2}[17.72 + \ln \frac{T^{\frac{3}{2}}}{fZ}] . \tag{3}$$

The unit of absorption coefficient is cm^{-1}. The source function of bremsstrahlung is:

$$S_f = \frac{j_f}{n_r^2 \alpha_f} . \tag{4}$$

Where $n_r = [1-(\frac{f_{pe}}{f})^2]^{-1}$ is refractive index of the plasmas cloud. The plasma frequency f_{pe} is approximately equal to $10^4\sqrt{N}$ (Rybicki and Lightman, 1979). When Eqs. (2) and (3) are substituted into Eq. (4), we also obtain:

$$S_f = 1.534\times10^{-37} \frac{Tf^2}{1-(\frac{f_p}{f})^2} . \tag{5}$$

If there is no initially outer emission, the emission intensity is (G. Bekefi, 1966):

$$I_f = S_f[1-e^{-\int_0^L \alpha_f ds}] . \tag{6}$$

Where $\int_0^L \alpha_f ds$ is optical depth, L is the thickness of the medium. τ_f is equal to $\alpha_f L$ if the plasmas is homogeneous. The unit of it is erg sec^{-1} cm^{-2} sr^{-1}. Thus, the emission intensity is

$$I_f = S_f[1-e^{-\alpha_f L}] .$$
(7)

When Eqs. (3) and (5) are substituted into Eq. (7), the following equation for I_f is obtained:

$$I_f = 1.53\times 10^{-37} \frac{T f^2[1-e^{-\alpha_f L}]}{1-(\frac{f_p}{f})^2} . \tag{8}$$

The low-frequency portion of the radiation spectrum is well approximated by the relation (Bekefi, 1966):

$$I_f \approx \frac{2kT_B f^2}{c^2} . \tag{9}$$

Therefore, the brightness temperature T_B is:

$$T_B = \frac{c^2 I_f}{2\kappa f^2} . \tag{10}$$

When Eq. (8) and the value of c, κ are substituted into Eq. (10), the following equation for T_B is obtained:

$$T_B = 0.5\times \frac{[1-e^{-\alpha_f L}]T}{1-(\frac{f_p}{f})^2} . \tag{11}$$

The unit of T_B is K:

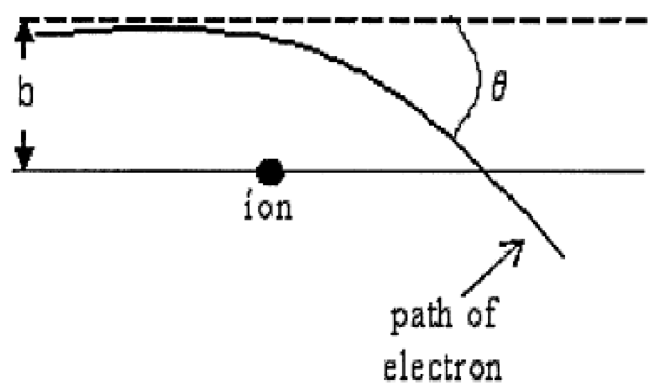

Fig. 2. Binary Coulomb collision.

3. Calculating results

The bremsstrahlung brightness temperature of high density plasma clouds between 0.47 AU and 1 AU are calculated by using the data that recorded by Mariner l0. The electrons temperature of plasmas clouds have relation to their density, which is shown in the empirical equation (Sittler, Jr. and Scudder, 1980):

$$T_e \approx 5.5\times10^4 \times n_e^{0.175} . \tag{12}$$

Correspondingly, we obtain the expression of electron density n_e:

$$n_e \approx \sqrt[0.175]{T_e \times 10^{-4} / 5.5} . \tag{13}$$

The electrons density n_e = 7.1 when the heliocentric distance is approximately equal to 1 AU (M. G. Kivelson and C. T. Russell, 1995). Therefore, the corresponding electrons temperature T_e =0.775×10^5. By use of the data (Feldman et al., 1979) recorded by Mariner l0 and according to equation (13), we obtain the corresponding electrons density, which is shown in Table 1.

Table 1. The Electrons Temperature and Density of Plasmas Clouds in Times of Quiet Sun

R (AU)	T_e (10^5K)	n_e (cm^{-1})
1	0.775	7.1
0.75	0.79±0.04	7.92
0.69	0.80±0.03	8.51
0.62	0.85±0.03	12.03
0.53	0.98±0.07	27.13
0.47	1.04±0.04	38.10

It can be seen in Fig. 1 that high density plasmas clouds emerge after CMEs ejected into interplanetary space. The densities of them decrease sharply as heliocentric distance increasing. The fluctuation range of electrons density is from 0.3 cm^{-3} to 33.6 cm^{-3} near 1 AU (Sun and Wu, 2005). Moreover, the fluctuation range of electrons temperature T_e is from 6201K to 402019 K near 1 AU (Sun and Wu, 2005). Namely, the electrons density and temperature can reach 4.73 multiple of those in times of quiet sun. In this paper, we conservatively estimate electrons density of the high plasmas cloud by multiply the initial values in Table 1 by $2^{n/2}$×4.73, n=1, 2, 3, 4, 5. The corresponding electrons temperatures of them are calculated according to equation (12). The calculating results are shown in Table 2.

Table 2. The Electrons Density and Temperature of High Density Plasmas Clouds

R (AU)	T_e (10^5K)	n_e (cm^{-1})
1	1.02	33.6
0.75	1.10	52.98
0.69	1.18	80.50
0.62	1.34	160.94
0.53	1.64	513.30
0.47	1.85	1019.43

From equation (3), (11), Z = 1, L = 3×10^{10} *cm* and the value of N_e, T_e that in Table 2, we thus obtain the calculating results: brightness temperature of the high density plasmas clouds near 1 AU, 0.75 AU, 0.69 AU, 0.53 AU and 0.47 AU as emission frequency are equal to 10^5 KHz approach 1.2 K, 3.0 K, 6.5 K, 25 K, 230 K, 850 K, respectively. Moreover, the brightness temperature decreases about two magnitudes if emission frequency increases one magnitude with identical heliocentric distance. We give the detailed results in Fig. 3.

It can be seen in Fig. 3 that: (a) the brightness temperature curves take on the look of semi-parabolic waveform; (b) the brightness temperature with identical emission frequency decrease sharply as heliocentric distance increase.

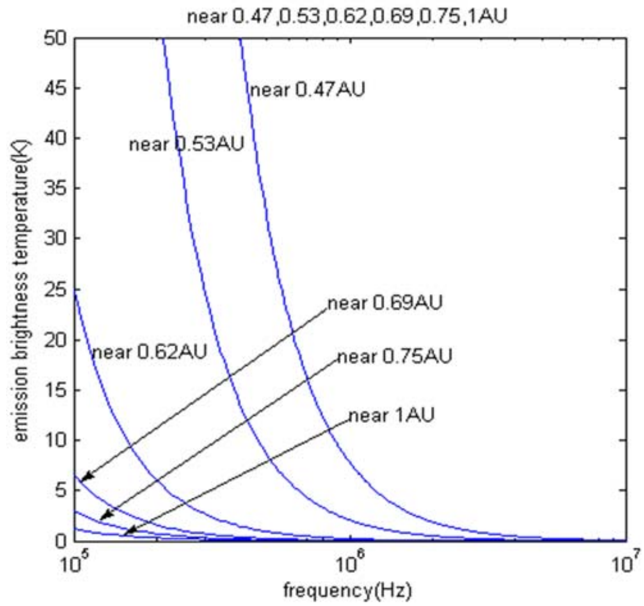

Fig. 3. The comparison of brightness temperature with various heliocentric distances.

4. Summary

In this paper, brightness temperatures of mainly RF emission mechanism of the high density plasmas clouds in interplanetary space are calculated. The calculating results presents in this paper are approximately a few decuple of those in times of quiet sun period. Namely, the variation of RF emission brightness temperature of plasmas clouds in times of quiet sun and of the high density clouds can be identified by radiometer with 2 K temperature resolution and appropriate detective frequency. Therefore, according to the variation of emission brightness temperature of the plasmas clouds, forecast of disastrous space weather can be obtained in time by use of radiometer.

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