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

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Abstract. In this paper, bremsstrahlung, the dominating RF emission mechanism of high density plasmas clouds in sun-earth interplanetary space, is studied. The bremsstrahlung brightness temperature of the plasmas clouds from 0.47AU to 1AU are calculated based on the data that recorded by Mariner l0. The calculating results show that the RF emission brightness temperature of high density clouds can be differentiated as compared to those plasmas clouds in times of quiet sun by radiometer with 2K 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, calculation, emission, interplanetary space, plasmas clouds.

1. Introduction

The Sun 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 (J. P. Raulin and A. A. Pacini, 2005, R. H. Munro, et al., 1979, D. F. Webb and A. J. Hundhaunsen, 1987, O. C. S. Cyr and D .F. Webb, 1991). For examples, they often drive interplanetary shocks, cause geomagnetic storms, pose hazards to space operations and interference with satellite communication and surveillance systems (R. M. Jadav, K .N. Iyer, H. P. Joshi and H. O. Vats, 2005). High density plasmas clouds are a significant characteristic as the propagation of CMEs in interplanetary space, which is shown in Fig.1.

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 differentiated by radiometer with 2K temperature resolution. According to this, a majority of space disaster weather events can be forecasted.

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 interplanetary space, is bremsstrahlung. Moreover, cyclotron emission and recombination emission do a little contribution to RF emission (Sun Weiying and Wu Ji, 2005). In this paper, we focus on the calculation of bremsstrahlung brightness temperature.

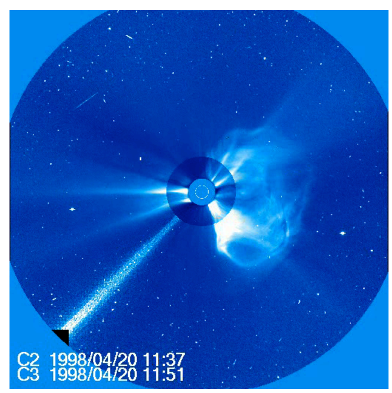

Fig. 1. CME recorded by LASCO

Bremsstrahlung is due to Coulomb collisions between charged particles in plasmas. In Fig. 2, an example of a binary collision between an electron of velocity v and an ion of 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, electrons thermal velocity v. The velocity distribution of the electrons in this cloud is given by the Maxwell distribution:

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

The emission coefficient of bremsstrahlung is:

$$j_f = 1.501\times10^{-39}\frac{NN_iZ^2}{T^{\frac{1}{2}}}[17.72+\ln\frac{T^{\frac{3}{2}}}{fZ}]. \quad (2)$$

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

$$\alpha_f = 9.78\times10^{-3}\times\frac{NN_iZ^2}{T^{\frac{3}{2}}f^2}[17.72+\ln\frac{T^{\frac{3}{2}}}{fZ}]\cdot \quad (3)$$

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

$$S_f = \frac{1}{n_r^2}\frac{j_f}{\alpha_f}. \quad (4)$$

Where is refractive index of the plasmas cloud. The plasma frequency is approximately equal to (G. B. Rybicki and A. P. Lightman, 1979). Substitution of (2) and (3) in (4), we also obtain:

. (5)

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

$$I_f = S_f(1-e^{-\int_0^L\alpha_f ds}). \quad (6)$$

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

. (7)

Substitution of (3) and (5) in (7) leads to the following equation for :

. (8)

The low-frequency portion of the radiation spectrum is well approximated by the relation that applies to $hf << \kappa T$. (G. Bekefi, 1966):

$$I_f \approx 2kT_Bf^2/c^2. \quad (9)$$

Therefore, the brightness temperature T_B is:

. (10)

Substitution of (8) and the value of , in (10) leads to the following equation for which unit is K:

. (1)

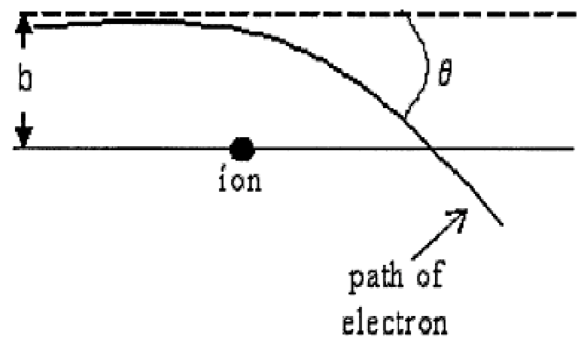

Fig. 2. Binary Coulomb collision

3. Calculating results

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

$$T \approx 5.5\times10^4\times n_e^{0.175}. \quad (12)$$

Correspondingly, we obtain the expression of electron density n_e:

$$n_e \approx \sqrt[0.175]{T\times10^{-4}/5.5}. \quad (13)$$

The electrons density n_e=7.1 when the heliocentric distance is approximately equal to 1 (M. G. Kivelson and C. T. Russell, 1995). The corresponding electrons temperature T =0.775_10^5 by use of equation (12). According to the data (W. C. Feldman, J. R. Asbridge, S. J. Bame, J. T. Gosling and D .S. Lemons, 1979) recorded by Mariner l0 and equation (13), we obtain the corresponding electrons density, which is shown in Table1.

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

R (AU)	T_e (10^{5}K)	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 eject into interplanetary space. The densities of them decrease as heliocentric distance increasing. The fluctuation range of electrons density is 0.3-33.6 cm^{-3}and that of electrons temperature T is 6201-402019K near 1AU (Sun Weiying and Wu Ji, 2005). Namely, the electrons density and temperature can reach 4.73 and 5.19 multiple of those in times of quiet sun, respectively. In this paper, we conservatively estimate electrons density of the high plasmas cloud by multiply the initial values in Table1 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 Table2.

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

Substitution of equation (3), Z=1, L=3_$10^{10}$$cm$ and the value of N_e, T that in Table2 in equation (11) leads to the calculating results: brightness temperature of the high density plasmas clouds as emission frequency are equal to 10^5KHz approach 1.2K, 3.0K, 6.5K, 25K, 230K, 850K near 1AU, 0.75AU, 0.69AU, 0.53AU and 0.47AU, respectively; the brightness temperature decreases about two magnitudes if emission frequency increases one magnitude as heliocentric distance is constant. We give the detailed results in Fig. 3.

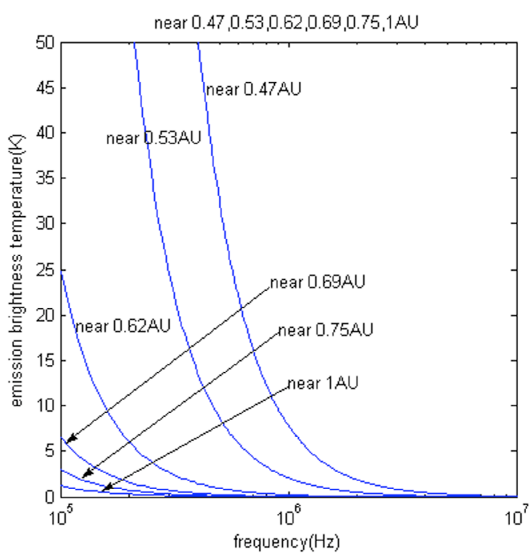

Fig. 3. The comparison of brightness temperature with various heliocentric distances

It can be seen in Fig. 3 that: (a) the brightness temperature curve decreases with half of parabolic waveform; (b) the brightness temperature with identical emission frequency decrease sharply as heliocentric distance increase.

4. Summary

In this paper, brightness temperatures of mainly RF emission mechanism of the high density plasmas cloud in interplanetary space are calculated. The correspondingly 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 differentiated by radiometer with 2K temperature resolution and appropriate detective frequency. Therefore, high density plasmas clouds which have tremendously effects on space weather can be forecast with radiometer.

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