Dusty Comets as Possible X-Ray Multi-Mirror Mission Targets

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High-velocity collisions between cometary and interplanetary dust particles as possible X-ray generating process in dusty comets is considered. Unique information about generation of high-temperature plasma due to collisions of dust particles may be obtained from observations of dusty comets in the inner heliosphere with the X-ray multi-mirror telescope at high angular/ spatial resolution.

1. Introduction

The passage of dusty comets through the Zodiacal dust cloud at small heliocentric distances, R≤1AU, is accompanied by collisions of cometary and interplanetary dust particles with high relative velocities, V=70-700 km/sec, corresponding to impact specific powers of the order of 10^{12}-10^{15} W/cm^2 and initial temperatures of plasma blobs T_o=10^5-10^7 K. Acceleration of dust particles to such velocities under laboratory conditions is a problem being solved so far, so that experimental data on the generation of hot plasma and X-ray radiation due to dust grains collisions are absent.

The expected X-ray luminosity of comets due to collisions of cometary and interplanetary dust grains was calculated, but only for the collisionally-thick zone of the cometary comae (Ibadov 1980, 1985, 1990, 1995). A strong cometary X-ray radiation was discovered by the ROSAT (Lusse et al. 1996; Dennerl et al. 1997) and different theoretical models were proposed: small current sheets in the solar wind (Brandt et al., 1996); generation of keV electrons in the cometary coma via wave particle interaction as the source mechanism of collisional excitation of the X-ray emission (Bingham et al., 1996); charge transfer interaction between the highly charged solar wind heavy ions (C^{6+},C^{5+},O^{7+},O^{6+} etc.) and cometary molecules (Cravens, 1996); scattering of the solar X-ray radiation by very small dust particles (Wickramasinghe and Hoyle, 1996); collisional self-generation of high-velocity dust particles of very small sizes (10-100 A) in the cometary comas (Ip and Chow, 1997). Production of X-rays by collisions between cometary and interplanetary dust grains was discussed as well (Krasnopolsky 1997), however the presence of an attogram cometary dust cloud (see Utterback and Kissel 1990; Sagdeev et al. 1990) and fragmentation of interplanetary dust particles in the comae of comets were not taken into account.

In the present paper main characteristics of photons produced in dusty comets due to generation of high-temperature plasma blobs from cometary and interplanetary dust grains collisions are considered.

2. Production of high-energy photons in dusty comets

Dusty comets like comet Halley 1986 III are characterized by the dust to gas production rate ratio $\mu \equiv M_d / M_g \geq 0.1$ (Sagdeev et al. 1986; Reinhard 1986). In such comets the main interaction mechanism between the cometary gas-dust coma and interplanetary dust is an explosion-type mechanism resulting production of high-temperature plasma blobs and high-energy photons (Ibadov 1987).

2.1. Energy of photons. The most probable energy of photons emitted from the plasma blobs, E_m, is determined by the initial temperature of the blobs T_o (Ibadov 1990), namely

$$E_m = 3kT_o = \frac{Am_H V^2}{4(1+z+2x_1/3)} = \frac{12.6\times10^{11} erg}{R} = \frac{80}{R} eV. \quad (1)$$

Here A is the mean mass number of atoms in colliding particles; m_H is the mass of a hydrogen atom; $V=V_o R^{-1/2}$, V_o is the value of V at R=1AU; z is the most probable multiplicity of charge of the plasma ions; $x_1 \equiv I_z/kT_o$, I_z is the ionization potential of the z-ions; the numerical calculation in (1) corresponds to A=30, V_o=70 km/sec, z=3, x_1=3, so that for A=10, z=1, V_o=50 km/sec we get E_m=14/R eV. Thus, dusty comets at R≤1AU are sources of EUV and X-rays.

2.2. Proper EUV and X-ray luminosity. The proper short-wavelength luminosity of dusty comets connected with generation of hot plasma by the way considered, $L_x \equiv L(E \geq E_m)$, may be expressed as the sum of the luminosities of the collisionally thick and collisionally thin zones of the cometary dust coma, L_s and L_v . Using the efficiency of conversion of the kinetic energy of colliding dust grains into electromagnetic radiation, $k_x=E_x/E_{in}$ (Ibadov 1990), we have

$$L_s = k_x\left(\pi r_x^2\right)\frac{\rho V^3}{4} = \frac{L_{so}}{R^7}. \quad (2)$$

Here $r_x \equiv \pi n_o \sigma_c r_o^2 = r_{xo} R^{-2}$ is the radius of the collisionally thick zone of the cometary dust coma, i.e. the cometocentric distance within which the flux of interplanetary dust grains penetrating into the cometary coma fully transforms into plasma blobs due to collisions with cometary dust particles; ρ is the spatial mass density of interplanetary dust; the mean number density of cometary dust particles in the coma, $n_c=n_{oc}(r_o /r)^2$, is used; n_{oc} is the value of n_c at $r=r_o$; r_o is the radius of the cometary nucleus; σ is the effective cross section for collisions between cometary and interplanetary dust grains: $\sigma=4\pi<a^2>$, $<a^2>$ is the mean value of a^2 determined using the law for a number density of comeary dust particles $n(a)\sim a^{-p}$, a is the radius of a cometary dust particles; the formula for σ is chosen to reproduce the idea that the mean size of interplanetary dust particles within the cometary dust coma will be close to the mean size of cometary dust particles due to intense fragmentation of interplanetary dust particles at the boundary of the cometary dust coma; the mean value of $\rho=\rho_o R^{-1.3}$ (Grun et al. 1985) and $k_x=k_{xo}R^{-1/2}$ are used for obtaining $L_s=L_s(R)$; L_{so}, r_{xo}, ρ_o and k_{xo} are the values of L_s, r_x, ρ and k_x at R=1AU.

The luminosity of the collisionally thin zone of the cometary dust coma may be expressed, after integration over the volume of cylindrical column along the direction of the relative velocity V, as

$$L_V = k_x \frac{\rho V^3}{2} r_x (r_c - r_x) = \frac{2}{\pi} \frac{r_c - r_x}{r_x} L_s, \qquad (3)$$

where r_c is the radius of the cometary dust coma.

The radius of the collisionally thick zone of the cometary dust coma, r_x, depends on the value of size distribution parameter of cometary dust particles p :

$$r_{x1} = \frac{3\dot{M}_d}{4\delta V_{d2}} \frac{4-p}{(3-p)a_2}, \quad for \quad 1 < p < 3, \qquad (4)$$

$$r_{x2} = \frac{3\dot{M}_d}{4\delta V_{d1}} \frac{p-4}{(p-3)a_1}, \quad for \quad p > 4, \qquad (5)$$

where $\dot{M}_d$ is the dust production rate of the cometary nucleus, δ is the density of the dust particles, V_{d1} and V_{d2} are the outflowing velocities of dust particles with sizes a_1 and a_2, respectively; a_1 and a_2 are the minimal and maximal radii of dust particles emitted from the cometary nucleus (Ibadov 1996).

According to (2), (3) and (4) with p=2, $\dot{M}_d$ =10^7 g/sec, δ=0.5 g/cm^3, V_{d2} =5x10^2 cm/sec, a_2 =1 mm, k_{xo} = 0.01, ρ_o = 5x10^{-22} g/cm^3, V= 5x10^6 cm/sec and r_c =1.5x10^{10} cm we have r_{x1}=6x10^5 cm, L_{s1}=1.6x$10^8$$R^{-7}$ erg/sec and L_{v1}=2.4x$10^{12}$$R^{-5}$ erg/sec. For p=5, a_1=10^{-4} cm, V_{d1}=5x10^4 cm/sec and other parameters above indicated using (2), (3) and (5) we get r_{x2}=1.5x10^6 cm, L_{s2}=8x$10^8$$R^{-7}$ erg/sec, L_{v2}=4x$10^{12}$$R^{-5}$ erg/sec.

Assuming that for attogram dust particles p=5, a_1=10^{-6} cm, V_{d1}=5·10^4 cm/sec, $\dot{M}_d$ =10^8 g/sec we obtain r_{x2}(AT)=1.5x10^9 cm, L_{s2}(AT)=8x$10^{14}$$R^{-7}$ erg/sec, L_{v2}(AT)=4x$10^{15}$$R^{-5}$ erg/sec.

3. Conclusion

Observations of dusty comets at small heliocentric distances, R≤1AU, with XMM are highly desirable to get data on production of hot plasma due to high velocity collisions of dust grains.

The problem of identification of different mechanisms of X-ray generation in comets is actual. It is reasonable to get X-ray spectra of comets with high spatial resolution as well as the dependence of the X-ray spectra and luminosity of comets on heliocentric distance.

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