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# Plasma astrophysics implication in discovery and interpretation of X-ray radiation from comets

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**Abstract.** Discovery of soft X-ray radiation from comet Hyakutake C/1996 B2 by space telescope ROSAT in March 1996 as well as establishing the regularity of the phenomenon for comets in general opened a new area of research for the plasma astrophysics. The first soft X-ray observations have been motivated by the results of a theoretical investigation on the efficiency of production of energetic photons, in the energy range 0.1-1 keV, by hot plasma clumps generated in dusty comets via high velocity collision with interplanetary dust at small heliocentric distances. Moreover, the soft X-ray luminosities measured significantly exceeded the value predicted. A short review of proposed theoretical models and mechanisms for explaining X-ray emission from comets as well as some prospects for the future X ray observations of comets are presented.

**Keywords.** plasma astrophysics general, comets, cosmic dust, high velocity collisions, high-temperature plasma, multicharge ions, X-ray radiation

## 1. Introduction

Development of the plasma astrophysics has accompanied formation of the physics of comets during more than hundred years. The origin and dynamics of comet plasma tails as well as mechanisms of ionization of cometary molecules in the coma were the basic subjects of plasma astrophysics and physics of comets. The study of comets up to 1970 years carried out mainly using ground based observations, i.e. in the optical range of the spectrum (see, e.g., Dobrovolsky 1966; Brandt & Hodge 1967).

Space UV observations of comets, including HI Lyman alpha 1216 A, discovered the presence of giant atomic hydrogen coma (Donn *et al.* (1976) and references therein). Space missions to comet Halley 1986 III and other comets presented new data on the structure of comets, including comet nucleus, gas, dust and plasma (Reinhard 1986; Sagdeev *et al.* 1986, and references therein).

Comet X-ray radiation in the 0.09 to 2.0 keV band was discovered by space telescope ROSAT during observations of comet Hyakutake C/1996 B2 in 27 March 1996 (Lisse *et al.* 1996). These soft X-ray observations have been motivated by results of a theoretical investigation on the efficiency of generation of energetic photons, within the energy range 0.1–1 keV, by hot plasma blobs/clumps produced in dusty comets via high velocity collision, $V > 70$ km/s, with interplanetary dust at small heliocentric distances, $R < 1$ AU (Ibadov 1990).

At the same time the cometary soft X-ray luminosity measured, of the order of $10^{15}$ erg/s with considerable variations, significantly exceeded the value predicted.

In the present paper a short review of proposed theoretical models and basic mechanisms for explaining X-ray emission from comets as well as some prospects in the field are presented.

## 2. Generation of X-rays in comets

Classical mechanism of comet radiation due to scattering of solar radiation by cometary dust and resonance fluorescence of solar photons on cometary atmosphere molecules is unable to produce detectable comet X-rays, at least this mechanism is weaker than that connected with collision between cometary and interplanetary dust at R < 1 AU (Ibadov 1985).

High-temperature intensively radiating plasma clumps in comets may be generated via high-velocity collisions between cometary and interplanetary dust particles (Ibadov 1980, 1983, 1987, 1990, 1996a). Expanding plasma clumps, "compound particles", produced in such process consist of heavy multicharge ions of elements like Fe, Si, O etc. (Ibadov 1986). For this reason the intensity of recombination radiation from clumps, i.e. due to bound-bound transitions of electrons in the plasma clump, tens times greater than that for bremsstrahlung, i.e. free-free transitions. Moreover, plasma clumps may radiate as a black body. In this case the efficiency of X-ray radiation $k_x$ reaches 0.1, i.e. around tenth time larger than that for hot expanding plasma produced by ultrashort/picosecond laser pulses on light/ fusion elements (Basov *et al.* 1971).

The comet X-ray luminosity due to high-velocity collisions between cometary and interplanetary dust particles is determined as a sum of emissions from collisionally thick and collisionally thin volumes of the comet dust coma, namely

$$L_x(dd) = k_x \frac{\rho V^3}{4} \left[(\pi r_x^2) + 4 r_c r_x \ln(r_c/r_x)\right]. \tag{2.1}$$

Here $\rho = \rho(R) = 5x10^{-22} R_*^{-1.3}$ g/cm$^3$ is the mean spatial mass density of interplanetary dust (has mainly prograde orbit near the ecliptic, see, e.g., Grun *et al.* 1985), and this value can rise up to thousands times within interplanetary dust clouds/trails (e.g., Lebedinets 1984), V=V(R) is the relative velocity of colliding comet and IPD particles, $r_x$ is the radius of the collisionally thick zone of the comet dust coma relative IPD, $r_c$ is the effective radius for comet X-rays: $r_c = \min(r_a, r_c), r_a$ is the aperture radius of the photon detector/telescope, $r_c$ is the radius of a comet dust coma, depends on the dust production rate of the nucleus and size distribution of dust particles (Reinhard 1986, Sagdeev *et al.* 1986, Utterback & Kissel 1990, Lisse *et al.* 1996), $R_*$ is the heliocentric distance in AU (Ibadov 1990, 1996a, 1998, 2000, 2001; Ibadov & Dennerl 2000a, b).

The most probable energy of photons from plasma clumps is

$$h\nu_m = 2.8kT = \frac{0.7 A m_p V^2}{3(1 + z + 2x_1/3)} = T_* \left(\frac{V}{V_*}\right)^2 \approx \frac{h\nu_{m*}}{R_*} \text{ eV}, \tag{2.2}$$

where $T$ is the initial temperature of the expanding plasma clump, A is the mean atomic number for colliding dust particles, $m_p$is the proton's mass, $z$ is the mean multiplicity of charge of ions, $x_1$ is the mean relative ionization potential, $T_* = 10^6 K, V_* = 70$ km/s, $h\nu_{m*} = 70$ eV for comets like 1P/Halley with retrograde orbits and $T_* = 7x10^5 K, V_* =$ 50 km/s, $h\nu_{m*} = 50$ eV for Hyakutake C/1996 B2 type comets with polar/quasipolar orbits (Ibadov 1990, 1996b).

Using (2.1) and (2.2) for $R = 1$ AU with realistic values of parameters of the radiation process $k_x = 0.1, \rho_* = 5 \times 10^{-22}$ g/cm$^3$, $V = 50$ km/s, $r_x = 10^2$ km, $r_c = r_a = 10^5$ km we have $L_x(dd) = 3 \times 10^{15}$ erg/s, $h\nu_m = 50$ eV.

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Gas and dust flows from comet nuclei are ejected mainly to the Sun direction, according to results of space missions to comet 1P/Halley in March 1986 as well as ground-based observations of comet Mrkos 1957d with 5-meter Palomar telescope at high angular resolution (Greenstein 1958, Greenstein & Arpigny 1962, Reinhard 1986, Sagdeev *et al.* 1986, and references therein). In addition, the cometocentric velocities of ejected dust particles are negligibly small than comet orbital one. Therefore maximum X-ray brightness due to dust-dust collisions should be shifted in the Sun direction, independently of the position/direction of a comet relative to its perihelion. The ROSAT observations in March 1996 showed similar picture. So, rapid variability of the detected flux of X-rays on a time scale around 1 hour may be caused by considerable IPD nonhomogeneity.

The further searches, followed the discovery of comet X-rays, revealed other possible plasma processes resulting in generation of soft X-rays in comets (Brandt *et al.* 1996, Ip & Chow 1997, Uchida *et al.* 1998, and references therein). In particular, soft X-rays may be generated due to recombination, charge exchange, of the solar wind multicharge ions like $C^{6+}$, $O^{6+}$, $N^{6+}$ etc., escaping from the solar corona plasma with temperature around 100 eV, on cometary coma molecules. The corresponding X-ray luminosity is determined as

$$L_x(SW) = \sum A_i E_i n_i V_i S_{i*}, \tag{2.3}$$

where $A_i, E_i, n_i, V_i$ are the abundance of multicharge ions of kind i in the solar wind relative to protons, recombination energy of these ions, protons number density and velocity in the solar wind, respectively, $S_{i*}$ is the cross section of the cometapause in the comet coma where charge exchange process between solar wind multicharge ions and cometary molecules intensively occurs (Cravens 1997).

From (2.3) with $A_i = 10^{-3}$, $E_i = 300$ eV, $n_i = 5$ cm$^{-3}$, $V_i = 400$ km/s, $S_{i*} = 10^{19}$ cm$^2$ we have $L_x(SW) = 10^{15}$ erg/s. This value is four times less than the mean value obtained from ROSAT observations of comet Hyakutake in March 1996. Hence, contribution of other possible mechanisms for comet X-ray emission should be taken into account.

## 3. Conclusions

High velocity collisions between cometary and interplanetary dust particles at small heliocentric distances, $R \leqslant 1$ AU, are possible generators of high-temperature plasma and soft X-rays as well as multicharge ions in dusty comets, especially in comets like 1P/Halley (retrograde orbits) and Hyakutake C/1996 B2 (polar and quasipolar orbits).

Searches for soft, 0.09–2 keV, and ultrasoft, 30–90 eV, X-ray radiation from dusty comets with retrograde and polar/quasi-polar orbits around R $\leqslant$1 AU by space telescopes like ROSAT and XMM are of interest for plasma astrophysics, physics of comets as well as for studying cosmic dust in the inner heliosphere.

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