Generation of Hot Plasma and X-Rays in Comets

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Generation of hot plasma and X-rays in comets due to high-velocity collisions between cometary and interplanetary dust particles is analytically considered. The results are presented as a brief summary of our researches carried out in the field during the last three decades. It is found that in the inner heliosphere, i.e., at relative velocities of colliding dust particles more than 50–70 km/s (for retrograde and quasi-retrograde comets), initial temperatures of short-living dense plasma clumps produced by these collisions will be more than 10^5 K. Observable indicators of the phenomenon are multicharge ions as well as X-ray radiation of the hot clumps. The study of comets like Halley 1986 III and Hyakutake 1996 B2, having dust to gas production rates ratio more than 0.1, perihelion distances less than 1 AU and almost retrograde orbital motion, providing the dominant role of high-velocity (d-d) collisions in the gas-dust comet comas, is especially important to reveal peculiarities of the new radiation process/mechanisms in the Solar System objects using soft X-ray observatories like ROSAT and XMM. Such researches can expand the role of comets as natural space probes.

1 Introduction

The passage of bright dusty comets through circumsolar region is accompanied by intense collisions between cometary and interplanetary dust particles. Indeed, comet nuclei approaching the Sun become intense sources of gas-dust matter. According to the data of in situ measurements by VEGA 1/2 and GIOTTO missions, carried out at the comet heliocentric distance $R = 0.8$–0.9 AU, the gas and dust production rates of the nucleus of comet Halley 1986 III are $Q_g = 4 \times 10^7$ and $Q_d = 10^7$ g/s, respectively. These data lead to the dust to gas production rate ratio around 0.25 [1, 2].

Calculations show that for the Halley type dusty comets the dominant interaction mechanism of the gas-dust coma of the comet with interplanetary dust particles, IPD, will be no meteor-like phenomenon (i.e., intense gradual thermal evaporation of IPD due to irradiation by the cometary coma gas molecules), but collisions between comet dust and IPD, (d-d) process, that can lead to high-temperature phenomena: impulse generation of hot plasma, multicharge ions and soft, 0.1–1 keV, X-rays [3, 4, 5].

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Meantime, discovery of soft cometary X-rays was made on 27 March 1996 by orbital telescope ROSAT during observations of bright and dusty comet Hyakutake 1996 B2 having quasi-retrograde orbit [6]. To carry out these observations results of a theoretical consideration [7] was used, as a motivation (Dennerl, Lisse, Truemper, 1998, 1999, private communications).

We present here a brief review of basic results of theoretical investigations on the generation of hot plasma and X-rays in comets due to high-velocity collisions between dust particles as well as some prospects for further X-ray observations of dusty comets.

2 Generation of hot plasma and X-rays in comets by (d-d) process

Collisions between dusty coma of comets and interplanetary/zodiacal dust cloud, (d-d) process, in the inner heliosphere have high-velocity character for comets with retrograde and quasi-retrograde orbits. This phenomenon will lead to production of hot quickly expanding/short-living dense plasma clumps. The initial temperature of the plasma and the mean charge of ions can be analytically presented as $T = T_*(V/V_*)^2$ and $z = z_*(V/V_*)^{(2/s_i)}$ ($s_i = 1.3$ is the parameter of the curve of ionization potentials, $I(z)$, of dust particle atoms), so that at $R_* = 1$ AU we have $V = V_* = 7 \times 10^6$ cm/s and $T_* = 3 \times 10^5$ K, $z_* = 4$ for the Halley 1986 III type comets.

Calculations show that radiation mechanism of hot dense/quickly expanding plasma clumps with the initial radii around and more than 10^{-5} cm will be like the black-body one, due to suffice large "optical/photon thickness" of the plasma clots consisting of multicharge ions of heavy/multielectron atoms of elements like Fe, Si, O, etc. Such plasma blobs during their expansion become optically thin and hence can give line emission too.

The efficiency of conversion of the kinetic energy of colliding dust particles into the energy of X-ray photons, k_x, was calculated for the both cases taking into account both bremsstrahlung and recombination radiation mechanisms. It is found that the maximum value of the efficiency will be around $k_x = 0.1$. The most probable energy of photons from the cometary coma hot plasma clumps will raise at decreasing the comet heliocentric distance and change in the range 0.1–1 keV at the range of $R = 1$–0.1 AU, respectively [7, 8, 9].

X-ray luminosity of dusty comets like comet Hyakutake 1996 B2 due to (d-d) process will be more than 10^{15} erg/s at $R < 1$ AU [10]. This value is close to the measured soft X-ray luminosity of comet Hyakutake 1996 B2 by ROSAT as $L_x(0.09{-}2\,\mathrm{keV}, R = 1\,\mathrm{AU}) = 4 \times 10^{15}$ erg/s, with strong temporal variations [6].

It should be noted that an essential contribution to the X-ray luminosity of comets can also give line emission due to recombination of multicharge ions of the solar wind plasma via charge exchange process with cometary coma atoms and molecules that occurs effectively near the cometopause [11].

The maximum brightness of the X-ray emission of the cometary gas-dust coma, produced by these radiation mechanisms, should be located/shifted in the direction to the Sun because gas-dust matter from the comet nucleus always is being ejected, basically, towards the Sun. It is compatible with observations of such bright comet as Mrkos 1957d/1957 V showed emissions of Na-atoms with anomalous distribution at high angular resolution, as well as with data of the Vega 1/2 and Giotto in situ television observations of comet Halley 1986 III (cf. [1, 2, 12, 13, 14]).

3 Conclusions

It is analytically shown that high-velocity collisions between cometary and interplanetary dust particles in the comas of dusty comets with retrograde and quasi-retrograde orbital motion, (d-d) process, will lead to generation of hot short-living dense plasma clumps in the inner heliosphere. Such component of the cometary atmospheres plasma is able to emit 0.1–1 keV photons, i.e., soft X-rays.

Modern soft X-ray space telescopes like ROSAT and XMM have carried out X-ray observations of comets only at heliocentric distances close and more than 1 AU. For revealing and identification of X-ray generation mechanisms of comets as well as using comets as natural space probes it is important appropriate observations of bright dusty comets in the inner heliosphere and determining the dependence of X-ray luminosity and spectra of comets on the heliocentric distance.

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