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Movement of CaII ions in the inner solar system

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The present paper is devoted to interpretation of the first observations of cold gas in the outer solar corona. The author attempts to construct a numerical model of the movement of Ca ions after they leave the parent body: sungrazing comets, dust particles or meteoroids. The preliminary model takes into account the results of observations (Gulyaev and Shcheglov 1999): the radial velocity of about 230–300 km/sec is observed at elongations from 5 up to 20 solar radii. The action of radiation pressure, gravity and magnetic drift in a radial magnetic field of the Sun is taken into account. Radiation pressure by the resonance lines H and K CaII of the solar spectrum on calcium ions is the principal one in the dynamics of ions, which move with an acceleration away from the Sun. Despite the roughness of the model, the good fit to the observations is marked. The dynamical model will allow us to evaluate an interval of distances at which a disintegration of parent bodies and a formation of gas clouds can take place and to estimate the conformity of the proposed mechanism of acceleration to observed velocities.

Keywords: Interplanetary medium; Sun; Solar corona; Eclipses; Meteors; Meteoroids; Comets

1 Introduction

It is known that interplanetary dust is spiraling slowly to the Sun under the Poynting–Robertson effect. All dust particles evaporate at some distance from the Sun and transform into gas. As it was shown in a review by Leinert (1975), some dust sublimation zones for particles of different chemical composition can exist between 4 and 9 $r_{\rm sol}$ from the centre of the Sun. A more detailed determination of the border of a zone free of dust has represented a great problem until now because of the complexity of experiments connected with the study of a dusty F-corona.

What happens to cold gas formed after dust evaporation in conditions of the external solar corona?

According to calculations carried out some years ego (Shestakova 1990), the lifetimes of atoms and most of the first ions with low ionization potentials are limited by the rate of their ionization by ultra-violet radiation of the Sun. When an atom loses two or three electrons, its further ionization is caused as a rule by collisions with

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corona particles, because due to high potentials of each following stage of ionization the probability of radiative ionization becomes less.

It is possible to consider a process of transformation of a cold gas into a hot coronal one to be completed after approaching an ionization balance, which in conditions of solar corona occurs at high stages of ionization.

Thus, evidence that there is a low-ionization gas not typical of a solar corona in the solar vicinity can be considered to be the result of injection of interplanetary (interstellar) matter such as a flow of meteoroids, comets or Zodiacal dust. An appearance of interplanetary matter in the solar corona was testified by the SOHO mission, registering many sungrazing comets every year.

It is not our goal to study this complex process of transition of a cold gas into coronal one, which can occur in the case of penetration of interplanetary matter inside a dense region of the corona. We shall be limited by the consideration of the dynamics of first Ca ions; their resonance luminescence was recently discovered by Gulyaev and Shcheglov (1999) in the outer solar corona during the total solar eclipse on February 26, 1998.

The first prediction of the possibility to detect emission of some atoms and low ionization ions formed after sublimation of Zodiacal dust has been done by Shestakova (1990). Soon after that, search for the presence of cold substance in the external solar corona has begun.

Some attempts to detect a resonance emission of Ca ions using the device of Shcheglov were made during total solar eclipses. The sensitivity of the device increased from one eclipse to another, and at last the success was achieved. The first attempt of interferometric observations was made on 1991, July 11 in Mexico, La Paz (A.K. Aimanov, L.I. Shestakova and P.V. Shcheglov). Emission rings covering the entire field of view, reaching about 30 degrees, appeared at a photo with the longest exposition. As it was found after the analysis, the rings of emission belonged to mercury $\lambda =$ 3906.4 Å.

Further interferometric observations of 1997, March 9 in the Chita Region of Russia (Gulyaev, Shcheglov) have shown that the instrument has a good sensitivity, as all eclipsed sky was covered by rings of H- and K-CaII absorption lines. However, no emission was found.

Only during the eclipse of 1998, February 26 in Guadalupe wide-field interferometric observations of the F-corona in lines H- and K-CaII (Gulyaev and Shcheglov 1999) have shown the presence of CaII emission in several parts of the interferogram to the west from the Sun. The intensity of observed emission at the centre of an absorption line has appeared to be equal approximately to the intensity of a continuous spectrum between lines.

According to Koutchmy (1998) eclipsed sky brightness at a place of observations was $2{\cdot}10^{-9}$ times lower than the brightness of the solar disk centre. According to Allen (1963), an intensity of continuum near $\lambda = 3900$ Å was approximately equal to $4.4{\cdot}10^{6}$ ergs/(cm^2·sec·sr·Å). Thus, the observed value of continuous spectrum intensity near the K CaII line is equal to about $B_0 = 8.8{\cdot}10^{-3}$ ergs/(cm^2·sec·sr·Å). It has a good agreement with estimations of K CaII intensity carried out by Shestakova (1990). According to the cited paper, estimation of intensity of resonance emission in K CaII line at a distance of 6 $r_{\rm sol}$ is the following: $1.6{\cdot}(10^{-2}$–$10^{-3})$ ergs/(cm^2·sec·sr).

In this paper the author makes an attempt to construct a model of the movement

of Ca ions after coming off from a parent body. Since the results of observations give radial velocities and elongation instead of real velocities and distances from the Sun, the examination of exact geometry of movement is rather problematic.

Our preliminary model takes into account only the fact that at elongations from 5 up to 20 $r_{\rm sol}$ the red shifts 3–4 Å are observed and they correspond to radial velocity 230–300 km/sec (Gulyaev and Shcheglov 1999). A dynamical model will allow us to evaluate distances from the Sun at which a disintegration of parent bodies and a formation of gas clouds can take place and to estimate the conformity of the proposed mechanism of acceleration by radiation pressure in resonance lines of H- and K-CaII to observed velocities of Ca ions.

2 Model

By estimations of Shestakova (1990) the lifetime of a neutral atom of calcium is insignificant. At a distance of 6 $r_{\rm sol}$ it will be ionized approximately within 160 seconds. The lifetime of the first ion of calcium before the following ionization at the same distance is 3 orders of magnitude higher and approximately equal to $1.5{\cdot}10^5$ seconds.

Because of the small lifetime of Ca-atom in the field of solar radiation, we do not assume formation of Ca ions by any other way, besides ionization by solar radiation. A charge excharge process with protons of a solar wind is not important for our consideration because in this case high-speed Ca ions are not formed.

Thus, the movement of a neutral atom can be excluded from our consideration, and we shall model an ion just after its estrangement from a parent body. We base the construction of a dynamical model of CaII ion movement in the observed circumsolar region on the following assumptions:

1. Atoms of calcium are formed as a result of disintegration of small bodies of the Solar system driven along Keplerian orbits with eccentricity $e \leq 1$.

The interstellar or interplanetary origin of a parent body, from which a cloud of observed cold gas was formed, is not important now, because the velocities of interstellar dust and gas do not exceed 20–30 km/sec in the vicinity of the Sun (Grun et al. 1993; Lalleman et al. 1994; Yamamoto and Mukai 1998), in other words they are less than an order of magnitude as compared with values observed by Gulyaev and Shcheglov (1999).

So, velocities of interstellar gas do not surpass typical orbital velocities of Solar system objects inside the orbit of the Earth and we do not make differences between interstellar and interplanetary origin of parent bodies.

2. The influence of a corona and mixing with it are neglected, as the relaxation time of the first Ca ion with a corona at a distance of 6 $r_{\rm sol}$ according to theory (Alfven and Feltkhammar 1967) and due to our estimations is approximately equal to $2.1{\cdot}10^6$ seconds. This value is as high as an order of magnitude in comparison with the above mentioned lifetime of the ion before its following ionization by ultraviolet radiation of the Sun.

We used here the slowing-down time of Ca ions at protons as a relaxation time, which, according to theory (Shestakova 1990), is defined from the ratio

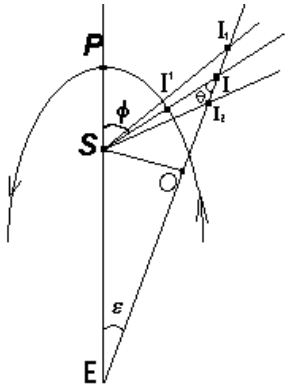


Figure 1 Geometry. E – the Earth, S – the Sun, φ – true anomaly, P – perihelion of an orbit, I^1 – the start position of an ion at an orbit of a parent body, I – an observed position of an ion, ε – elongation, θ – angle between directions to the Sun and to the Earth from point I.

$$t_s(i,p) = \frac{m_i^2\,\nu_i\,\nu_{_T}^2}{4p\cdot e_i^2\,e_p^2(1+m_i/m_p)\,n_p\,\ln L\cdot f(\nu/\nu_{_T})}, \tag{1}$$

where $\nu_{_T} = (2kT_p/m_p)^{0.5}$ and for $\nu = \nu_{_T}$, $f(\nu/\nu_{_T}) = 0.43$. Λ is the Debye shielding distance. Estimation of $t_s(i,e)$ slowing-down time of Ca ions at electrons gives a value equal to $1.45{\cdot}10^7$ seconds, i.e., it is much greater than that mentioned above ($t_s(i,p)$ in (1)).

Thus, consideration of any process of interaction between Ca ions and particles of corona is useful only after their transition into the following stage of ionization, but just then, emission in a line K CaII disappears.

3. The possible contribution of cyclotron rotation into observed velocities is not taken into account yet. This contribution can be significant near the start position and decreases with removal of an ion from the Sun.

The trajectory of a parent body is assumed to follow a heliocentric elliptical orbit:

$$r = \frac{p}{1+e\cos\varphi}, \tag{2}$$

for which the momentum conservation equation is given by: $r^2\dot{\varphi} = \sqrt{\mu\cdot p}$, where r is the distance from the Sun, $\mu = \gamma\cdot M_{\rm sol}$ – reduced mass of the Sun, γ – gravitational constant, $M_{\rm sol}$ - the Sun's mass, $p = q(1+e)$ – parameter of an orbit, q and e – perihelion distance and eccentricity of an orbit, φ – true anomaly or angle between directions to perihelion and current point of an orbit, $\dot{\varphi}$ – time derivative of φ.

When ions are ejected from a parent body, their radial and tangential velocities after differentiation of (2) are equal to:

$$\dot{r} = \sqrt{\frac{m}{p}}\,e\sin\varphi, \qquad r\dot{\varphi} = \sqrt{\frac{m}{p}}\,(1+e\cos\varphi). \tag{3}$$

Let an ion come off a parent body at any point I^1 at a line SI (Fig. 1). The force acting on the ion along the radius-vector can be summarized as follows:

$$m\ddot{r} = F_{\rm K} + F_{\rm H} + F_{\rm g} + F_{\rm M}, \tag{4}$$

where $\ddot{r}$ – radial acceleration, m – mass of a Ca ion, $F_{\rm K}$ and $F_{\rm H}$ – radiation pressure in K- and H-CaII resonance lines, $F_{\rm g}$ – gravity. $F_{\rm M}$ is a force caused by the action of a magnetic field considered (in the first order approach) to be averaged for one period of gyration. In a radial field of the Sun the action of this force will appear as "magnetic mirror acceleration" or gradient drift of the guiding centre of a particle to the region of the weaker field away from the Sun. In this case, eq. (4) will be the equation of movement of the guiding centre, around which cyclotron rotation of a particle occurs.

2.1 Radiation pressure

Following Allen (1963), the absorption coefficient in a line looks like:

$$\alpha_i = f_i\, \pi e^2 \lambda_i^2 / m_e\, c^2\,,$$

where e and m_e – charge and mass of an electron, λ_i and f_i – central wavelength and oscillator strength of i-transition, c – speed of light.

The radiation pressure on an ion consists of the total action for all transitions. When an atom (ion) is at the ground level, the force of radiation pressure is defined by the sum of pressure in resonance lines. As a rule, the radiation pressure in this case is the highest. For a Ca ion we obtain:

$$F_{\rm K} + F_{\rm H} = (\pi/c) \cdot (\alpha_{\rm K} I_{\rm K} \eta_{\rm K} + \alpha_{\rm H} I_{\rm H} \eta_{\rm H})/(r/r_{\rm sol})^2,$$

where the subscripts K and H are related to lines K and H, respectively; $I_{\rm K}, I_{\rm H}$ – intensity of a continuous spectrum near the lines K and H for a solar disk as a whole; $\eta_{\rm K}, \eta_{\rm H}$ – residual intensity in units of a continuum for a certain point inside an absorption line corresponding to the Doppler shift of an ion:

$$\Delta\lambda_k = \lambda_k(\dot{r}/c), \qquad \Delta\lambda_{\rm H} = \lambda_{\rm H}(\dot{r}/c),$$

where $\lambda_k = 3933.68$ Å, $\lambda_{\rm H} = 3968.49$ Å – central wavelengths of absorption lines.

Acceleration of an ion as the result of the action of radiation pressure is directed away from the Sun. After substitution of numerical values of constants it will be equal to:

$$\ddot{r} = (F_{\rm K} + F_{\rm H})/m = (0.14782 I_{\rm K} \eta_{\rm K} + 0.078506 I_{\rm H} \eta_{\rm H})/(r/r_{\rm sol})^2 \ {\rm cm/sec}^2.$$

2.2 Magnetic mirror acceleration

Drift of an ion to the region of a weak magnetic field can be determined in the assumption, which the magnetic induction decreases according to the law (Rossi and Olbert 1970): $B = A/r^2$.

The acceleration of an ion directed away from the Sun in this case will be equal to:

$$\ddot{r} = F_{\rm M}/m = -(M/m)\cdot(\partial B/\partial l) = (M/m)\cdot(2A/r^3),$$

where $M = (m\nu^2\cdot\sin^2\alpha)/2B = const$ – magnetic momentum of a current created by spiral movement of a particle around the guiding centre; α – pitch angle formed by the direction of movement of a particle with magnetic field B; l – length of an arch of a magnetic field line which is tracking through the guiding centre, around which the particle rotates, l coincides with r in a radial field; m, ν – mass and full speed of a particle.

In our case the direction of a magnetic field coincides with the direction of radius-vector: $\nu\cdot\sin\alpha = r\dot{\varphi}$. It means that the tangential component of a particle orbital velocity at the moment of detachment from a parent body coincides with the velocity of cyclotron rotation of a particle around the guiding centre drifting from the Sun together with the particle. As a result we obtain an acceleration of the guiding centre, which coincides with the acceleration of a particle averaged for one cyclotron period:

$$\ddot{r} = (r\dot{\varphi})^2\, r_{\rm st}^2/\, r^3,$$

where $r_{\rm st}$ is the starting distance from the Sun at the moment of particle estrangement from a body, $(r\dot{\varphi})$ – starting value of tangential velocity at the same moment.

For the circular orbital movement of a parent body $(r\dot{\varphi})_0 = \sqrt{\mu/r_{\rm st}}$ from here we obtain:

$$\ddot{r} = \mu\, r_{\rm st}/\, r^3 = 0.27394\ \cdot 10^5\,(r_{\rm st}/r)\,/(r\,/r_{\rm sol})^2\,{\rm cm/sec}^2.$$

From the expression written above it is seen that at $r = r_{\rm st}$ the acceleration of an ion caused by magnetic mirror acceleration coincides with gravitational one. It may be interesting in the case of ions, for which the radiation pressure is practically absent. Such ions keep moving by inertia. The radial magnetic field considered here is not the only possible assumption. The flux of ions leaving a parent body can take place also in a field of another configuration, for example, close to axial (near the Sun). The drift beyond the plane of the initial orbit with the tendency to Polar Regions is possible in this case.

2.3 General view of the equation of movement

Acceleration of an ion by gravity may be written as follows:

$$\ddot{r}\ =\ F_{\rm g}\,/m =\ \mu/r^2\ =\ 0.27394\ \cdot 10^5/(r\,/r_{\rm sol})^2\,{\rm cm/sec}^2.$$

As a result the equation of movement (4) will be transformed to a form convenient for numerical calculations:

$$\ddot{r} = (0.14782\, I_{\rm K}\eta_{\rm K}\ +\ 0.078506\, I_{\rm H}\eta_{\rm H}\ +\ 0.27394\cdot 10^5\,(J\cdot r_{\rm st}/r - 1))\,/(r\,/r_{\rm sol})^2\,{\rm cm/sec}^2, \tag{5}$$

where $J = (r\,\dot{\varphi})^2/(r\,\dot{\varphi})_0^2$ is the parameter, which takes into account the deviation of the tangential velocity of a particle at the starting position from the circular keplerian

one. In all examined cases at $e \leq 1$ the value $0 < J \leq 2$. The obtained equation (5) is used to calculate the movement of an ion, averaged for the cyclotron period, after its extraction from the parent body.

2.4 Choice of starting distance

We pay special attention to the choice of the starting distance of ions, as this value is not a simple modeling parameter, it can be just a border of a dust free zone or an arbitrary point of the orbit of the parent body.

Tentative estimation of the acceleration of Ca ions according to equations (5) shows that the ions will leave the Sun in a radial direction mainly under the action of radiation pressure.

As it follows from observations, extraction of atoms (ions) from a parent body took place in the southwest sector behind a picture plane at a distance which did not exceed the observed elongation $20\, r_{\rm sol}$. It is necessary to take into account also that we observe a projection to a line of sight. In the case of an ion estrangement before a picture plane, the projection of radial velocity (relative to the Sun) on a line of sight would have an opposite sign and would be observed not as a red shift but as a blue shift.

The angle between the true direction of movement of an ion SI and the direction the Earth – the Sun (ES in Fig. 1) cannot be too small, since the observed elongation is great enough, it means that the velocity across a line of sight has a significant value. The angle between the direction of movement of ions and the picture plane cannot be too small because of the high value of observed radial velocity.

Let us note also that there is no restriction for the direction of movement. The direction of movement of a parent body can be both prograde and retrograde. Figure 1 presents an orbit of prograde movement (counter-clockwise if looking from the North Pole of the ecliptic). I is the probable position of an ion on line I_1I_2 at the moment of observation. The probable range of starting positions I^1 is inside a cone with the top in S and is limited by I_1I_2 on the surface of the cone.

According to the statistics of disintegration of comets (Kresak 1981; Sekanina 1997), the destruction of a parent body occurs, as a rule, at a descending branch of an orbit, during the movement to the perihelion. It is natural if the disintegration of a body is caused by solar radiation heating at its approach to the Sun (Shestakova and Tambovtseva 1997–1998).

It seems natural to choose such a starting distance, where the substance of chondrite composition begins to melt. The complexity appears as the substance represents a mixture of various minerals: olivine (about 50% of mass), pyroxene (30%) and plagioclase (10%), all the rest (10%) – other impurities (Krinov 1955). Olivine and pyroxene form 3/4 of the mass of meteoric substance. Olivine consists of a mix of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Pyroxene is also chemically divided into 2 species: $MgSiO_3$ and $FeSiO_3$, they are Mg pyroxene and Fe pyroxene. Plagioclase contains high concentrations of Al, Ca, Na impurities.

The temperature profile derived from the F-corona brightness for dust particles at solar distances smaller than 0.3 AU from the Sun in the ecliptic has a radial slope proportional to $r^{-1/2}$, similar to the blackbody, but the absolute value is about 10% below that of a blackbody (Mann 1996). Fe olivine and Fe pyroxene are the most

easy melting substances of all mentioned above. They have approximately identical melting temperatures equal to about 1370 K (Krinov 1955). The bodies at a distance of 9 $r_{\rm sol}$ from the centre of the Sun will have such temperatures in the blackbody approximation: $T = T_{\rm eff}/\sqrt{2r/r_{\rm sol}}$, where $T_{\rm eff}$ is effective temperature of the solar photosphere.

The most refractory mineral Mg olivine melts at 2160 K (Krinov 1955), which coincides with the blackbody temperature at a distance of 3.6 $r_{\rm sol}$. Particles of low abundant oxides: (Al_2O_3) and orthosilicate, with melting temperatures about 2300 K and 2400 K correspondingly, and also graphite, the melting temperature of which is much higher (Campbell 1956), can be found even closer to the Sun. Particles of Al silicate and plagioclase are evaporated close to 4 $r_{\rm sol}$, because their melting begins at 2100 K (Krinov 1955; Campbell 1956). Silica glass (SiO_2), the melting temperature of which by Campbell (1956) is equal to about 2000 K, is evaporated just after 4 $r_{\rm sol}$. Mg pyroxene and pure iron melt at 5 $r_{\rm sol}$.

In our calculations, we accept as a basis the distance equal to 9 $r_{\rm sol}$, where about 40% of meteoric substance melts. Also, we should not forget that Ca ions can reach the inner regions of the corona up to (3–4) $r_{\rm sol}$ together with refractory particles of Mg olivine and plagioclase, together they can make up to 35% of meteoric substance. By our estimations, at a distance of 3 $r_{\rm sol}$, the relaxation time of Ca ions with a corona is equal to the lifetime, which is determined by the following ionization of ions by ultraviolet radiation of the Sun. Thus, the ions penetrating into inner region of the F-corona would mix up with a substance of the corona.

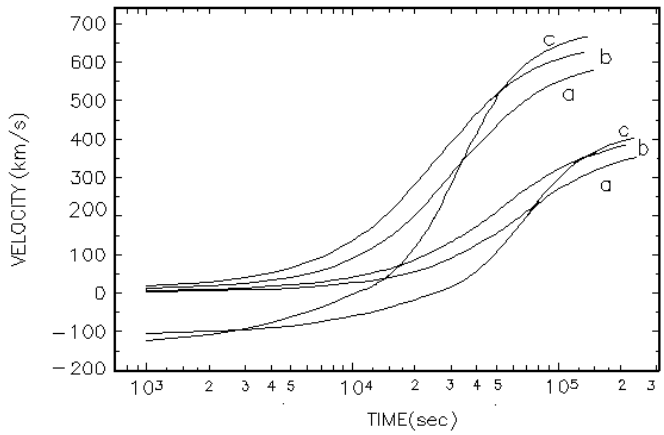


Figure 2 Velocity of Ca ions versus time after leaving the parent body. Initial orbits of parent bodies: a) Start from a circular orbit; b) start from a parabolic orbit in perihelion; c) start from a parabolic orbit in quadrature. The upper three curves – start from 9 $r_{\rm sol}$, the lower ones – start from 15 $r_{\rm sol}$.

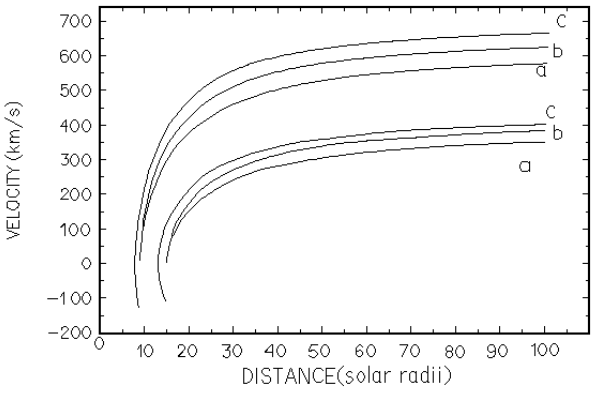


Figure 3 The same as Fig. 2 versus the distance from the Sun.

3 Results and discussion

The numerical calculations are carried out using equation (5) for various starting conditions.

a) Start from a circular orbit, $J = 1$, $\dot{r} = 0$, $r_{\rm st} = 9\ r_{\rm sol}$.

b) Start from a parabolic orbit in perihelion, $\varphi = 0$, $\dot{r} = 0$, $r\dot{\varphi} = 2\sqrt{\mu\,/p}$, where $p = 2\ r_{\rm st}$, $J = 2$, $r_{\rm st} = 9\ r_{\rm sol}$.

c) Start from a parabolic orbit in quadrature, $\varphi = -90°$, $\dot{r} = -\sqrt{\mu\,/p}$, $r\dot{\varphi} = \sqrt{\mu\,/p}$, where $p = r_{\rm st}$ and $\dot{r}$ is the radial velocity directed to the Sun, because a parent body approaches the Sun, $J = 1$, $r_{\rm st} = 9\ r_{\rm sol}$.

In all three cases the variants with other starting distances were also calculated. The results of calculations for starting distances of 9 and 15 solar radii are shown in Figs. 2 and 3.

For accounts of radiation pressure at a given Doppler shift the intensity of H- and K- CaII solar spectrum features, according to the atlas Minnaert et al. (1940) is used. The level of a continuous spectrum near the lines is accepted according to Allen (1963): $I_{\rm K} = 3.15{\cdot}10^6$ ergs/(cm^2·sec·sr·Å) and $I_{\rm H} = 3.20{\cdot}10^6$ ergs/(cm^2·sec·sr·Å).

Let us consider Fig. 1 in detail. An ion goes with acceleration from the Sun along radius-vector SI. Here $SO\ \perp EI$, where I is the position of an ion at the moment of observation. I^1 is the position of an ion on the same radius-vector SI at the moment of extraction from a parent body. The point I^1 lies at an orbit of a parent body and is at a starting distance of $r_{\rm st}$ from the centre of the Sun. At position I the angle SIE between directions to the Sun (S) and the Earth (E) is equal to θ. The observed elongation is equal to $SO = R\sin\varepsilon = 20\ r_{\rm sol}$, where $R = ES = 1$ AU. An observable projection of a particle's velocity on a line of sight is equal to

$$\dot{r}\cos\theta = \dot{r}\sqrt{1 - \left(\frac{20\ r_{\rm sol}}{r}\right)^2} = 230\text{–}300\,\mathrm{km/sec}\,. \qquad (6)$$

Using criterion (6), it is possible to compare results of calculations according to equation (5) with observations. The results of this comparison are summarized in Table 1.

For example, particles emitted from a circular orbit at 9 $r_{\rm sol}$, after acceleration at a distance of 24 $r_{\rm sol}$ would have a projection of velocity to a line of sight 230 km/sec, and at 28 $r_{\rm sol}$ the projection will be equal to 300 km/sec, according to the first line of Table 1. Thus, the observed elongation is always equal to 20 $r_{\rm sol}$.

Table 1 The distances where the calculated radial velocity of ions coincides with observed velocities equal to 230–300 km/sec at an elongation of 20 $r_{\rm sol}$.

Start distance	Circ. orbit[a]	Parab. orbit[b], $\varphi = -90^\circ$	Parab. orbit[c], $\varphi = 0^\circ$
9 $r_{\rm sol}$	(24–28) $r_{\rm sol}$	(22–25) $r_{\rm sol}$	(23–26) $r_{\rm sol}$
12 $r_{\rm sol}$	(29–38) $r_{\rm sol}$	(26–31) $r_{\rm sol}$	(27–34) $r_{\rm sol}$
13 $r_{\rm sol}$	(31–43) $r_{\rm sol}$	(27–34) $r_{\rm sol}$	(29–37) $r_{\rm sol}$
15 $r_{\rm sol}$	(37–59) $r_{\rm sol}$	(31–42) $r_{\rm sol}$	(33–47) $r_{\rm sol}$

[a]An ion comes off from a parent body at an arbitrary point of a circular orbit;
[b]An ion comes off at a quadrature position of a parabolic orbit when approaches the Sun;
[c]Estrangement of ion at perihelion of a parabolic orbit.

The space asymmetry of observed emission makes circular orbits of parent bodies improbable. The most probable scenario: flows of meteoroids or comet's debris driven along extended orbits penetrate into the circumsolar region. The closer to the Sun extraction of particles from a parent body occurs, the higher the terminal velocity of ions be achieved (Figs. 2 and 3) and the closer the "modeled" distance of Table 1 be to the observed elongation equal to 20 $r_{\rm sol}$.

On the whole, dynamic analysis shows that ions leaving an orbit of a parent body, penetrating into the solar vicinity up to distances smaller than 15 $r_{\rm sol}$, can be accelerated up to observed velocities under the action of the considered forces, and the scenario proposed here does not contradict the results of observations. Our research into the processes of transformation of dust and small bodies into gas in the circumsolar region can be continued in the future. Probably, the problem discussed here is not limited by the framework of the Solar system but it is important for studies of the physics of stars. For example, it is possible that similar processes take place near β-Pictoris, where disk debris and giant planet was discovered (Lagrange et al. 2010). Observations out of atmosphere, which allow expanding spectral study in the ultraviolet spectral region, would be the best development of such research.

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