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SEARCH FOR GAS OF COMET-METEOR ORIGIN IN THE INNER SOLAR SYSTEM: CAII ION EMISSION

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Abstract. Interplanetary dust of asteroidal and cometary origin gradually drifts toward the Sun under the drag produced by solar radiation and the solar wind. Upon reaching the sublimation zone, the dust evaporates and breaks down into atoms, which are then ionized and may subsequently be carried away by the solar wind. Some atoms and singly charged ions experience resonant-line radiation pressure that significantly exceeds the gravitational pull of the Sun. Elements of this kind can be accelerated by radiation pressure to high velocities, provided that their lifetime before the next ionization event is sufficiently long. Gas clouds formed by the disintegration of compact objects such as comets or meteoroid streams in the vicinity of the Sun may be separated by radiation pressure into several clouds with homogeneous chemical composition and travel outward as far as Earth's orbit. Previous calculations have shown that a number of atoms and singly charged ions can attain high velocities within their lifetime before further ionization. Solar radiation acts most efficiently on the singly ionized species of magnesium and calcium. Earlier studies demonstrated that emission in the H and K lines of CaII can be detected during solar eclipses using highly sensitive, high spectral resolution instruments. Such unique observations have been accomplished only twice, in the works of Gulyaev and Shcheglov during the solar eclipses of 26 February 1998 and 11 August 1999. The difficulty of these observations is compounded by the short duration of eclipses and the presence of atmospheric disturbances. Observations made outside Earth's atmosphere using orbital instruments are free from such limitations.

Given the presence of inhomogeneities and density enhancements in the form of meteoroid streams within the inner Solar System, the likelihood of detecting clouds containing distinct groups of atoms or ions increases.

Keywords: dust, gas, meteoroid streams, resonance emission, calcium atoms and ions

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КҮН ЖҮЙЕСІНІҢ ІШКІ АЙМАҒЫНДАҒЫ КОМЕТА-МЕТЕОРЛЫҚ ТЕКТЕГІ ГАЗДЫ ІЗДЕУ: САІІ ИОНДАРЫНЫҢ ЖАРҚЫРАУЫ

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Аннотация. Астероидтық және кометалық шығу тектi планетааралық шаң Күн сәулеленуі мен күн желі әсерінен болатын тежелулердің ықпалымен біртіндеп Күнге жақындайды. Сублимация аймағына жеткен кезде шаң буланып, атомдарға ыдырайды, олар кейін иондалып, әрі қарай күн желімен ілесіп әкетілуі мүмкін. Кейбір атомдар мен алғашқы иондар резонанстық сызықтардағы сәулелік қысымды сезінеді, ол Күннің тартылыс күшінен едәуір асып түседі. Мұндай элементтер, егер келесі иондалуға дейінгі өмір сүру уақыты жеткілікті ұзақ болса, сәулелік қысым әсерінен жоғары жылдамдықтарға дейін үдетілуі мүмкін. Күнге жақын маңда ықшам нысандардың кометалардың немесе метеор ағындарының

ыдырауы нәтижесінде түзілген газ бұлттары сәулелік қысым әсерінен химиялық құрамы біртекті бірнеше бұлтқа бөлініп, Жер орбитасына дейін жете алады. Бұрын жүргізілген есептеулер келесі иондалуға дейінгі өмір сүру уақыты ішінде жоғары жылдамдықтарға жете алатын бірқатар атомдар мен алғашқы иондардың бар екенін көрсетті. Күн радиациясының әсері Mg және Ca элементтерінің бірінші иондарына ең тиімді түрде әсер етеді. Бұрын жасалған зерттеулер CaII-дің H және K сызықтарының сәуле шығаруын жоғары сезімталдыққа және жоғары спектралдық айырымдылыққа ие аспаптарды пайдалана отырып, күн тұтылулары кезінде тіркеуге болатынын көрсетті. Мұндай бірегей зерттеулер бар болғаны екі рет Гуляев пен Щегловтың еңбектерінде 1998 жылғы 26 ақпандағы және 1999 жылғы 11 тамыздағы күн тұтылулары кезінде жүзеге асырылды. Мұндай зерттеулердің күрделілігі тұтылулардың қысқа мерзімділігімен және атмосфералық кедергілердің болуымен күшейе түседі. Жер атмосферасынан тыс, орбиталық аппараттардың көмегімен жүргізілетін бақылауларда мұндай шектеулер жоқ. Ішкі Күн жүйесінде метеор ағындары түріндегі біртектес еместіктер мен тығыздалулардың болуын ескерсек, жекелеген атомдар немесе иондар топтарын қамтитын бұлттарды анықтау ықтималдығы арта түседі.

Түйін сөздер: шаң, газ, метеорлық ағындар, резонанстық жарқырау, Ca атомдары мен иондары

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ПОИСК ГАЗА КОМЕТНО-МЕТЕОРНОГО ПРОИСХОЖДЕНИЯ ВО ВНУТРЕННЕЙ ОБЛАСТИ СОЛНЕЧНОЙ СИСТЕМЫ: СВЕЧЕНИЕ ИОНОВ CAII

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Аннотация. Межпланетная пыль астероидного и кометного происхождения постепенно приближается к Солнцу под действием торможения солнечным излучением и солнечным ветром. При достижении области сублимации пылевые частицы испаряются и распадаются на атомы, которые затем ионизуются и далее могут увлекаться солнечным ветром. Некоторые атомы и однократно ионизованные ионы испытывают действие светового давления в резонансных линиях, значительно превышающего силу солнечного тяготения. Такие элементы могут разгоняться световым давлением до больших скоростей, если время их жизни до следующей ионизации достаточно велико. Облака газа, образовавшиеся в результате распада вблизи Солнца компактных объектов - комет или метеорных потоков, — могут под действием светового давления разделяться на несколько облаков с однородным химическим составом и достигать орбиты Земли. Выполненные ранее расчеты показали, что существует ряд атомов и однократно ионизованных ионов, способных достичь высоких скоростей за время своего существования до следующей ионизации. Наиболее эффективно солнечная радиация воздействует на однократно ионизованные ионы Mg и Ca. Ранее проведенные исследования показали, что регистрация свечения линий H и K Ca II возможна во время солнечных затмений с использованием высокочувствительных приборов, обладающих высоким спектральным разрешением. Такие уникальные исследования были реализованы лишь дважды - в работах Гуляева и Щеглова во время солнечных затмений 26 февраля 1998 года и 11 августа 1999 года. Трудность подобных исследований усугубляется кратковременностью затмений и наличием атмосферных помех. Наблюдения за пределами земной атмосферы с помощью орбитальных аппаратов таких ограничений не имеют. С учетом наличия во внутренней Солнечной системе неоднородностей и уплотнений в виде метеорных потоков возрастает вероятность обнаружения облаков, содержащих отдельные группы атомов или ионов.

Ключевые слова: пыль, газ, метеорные потоки, резонансное свечение, атомы и ионы Ca

Introduction. The behavior of interplanetary dust is governed by the Poynting-Robertson drag effect, whose action leads to the fact that dust particles initially moving on circular orbits begin to approach the Sun along a spiral. It is obvious that the dust reaches the sublimation region, where it is heated to high temperatures and evaporates. For a long time, experimental investigation of this region was not carried out, since the near-solar region is a rather difficult object for observations. Attention was first drawn to the dust sublimation region near the Sun after the reports by (Peterson et al., 1967; MacQueen et al., 1968) on the detection of local maxima of dust thermal emission at a wavelength of 2.2 at heliocentric distances of 3.5, 4.0, 8.7, and 9.2 $R_{\odot}$ near the ecliptic plane, symmetrically with respect to the Sun.

In the review by (Mann et al., 2004), an extensive list of infrared (IR) observations of the F-corona is presented, including both indications of the presence of thermal emission and its absence. IR observations revealed no signs of thermal radiation at distances up to 15 $R_{\odot}$ during the solar eclipses of 1980 and 1991. At the same time, during the eclipse of 11 June 1983 an intense maximum of IR emission was detected to the west of the Sun, with a complete absence of thermal emission on the eastern side. Apparently, we are dealing with non-stationary dust formations clouds in the near-solar region.

It is obvious that dust in the sublimation region evaporates and is converted into a gas whose temperature is several orders of magnitude lower than the temperature of the surrounding gas of the solar corona. The atoms of the resulting gas will actively interact with solar radiation and coronal particles. The relaxation time of atoms and primary ions with the coronal gas due to collisions is sufficiently large at distances from $4R_{\odot}$ to $10R_{\odot}$ compared with their lifetime, which is determined by ionization under the action of the Sun's ultraviolet (UV) radiation.

As for secondary ions, their lifetime until the next ionization may exceed the relaxation time with the coronal gas, and if these ions have not left the near-solar region, then they mix with the corona. Further ionization then proceeds mainly due to collisions with coronal particles, since the potential of each subsequent ionization increases to such an extent that the probability of ionization by radiation becomes much smaller because of the lack of high-energy quanta in the solar emission spectrum.

The process of transformation of cold gas into typically coronal gas can be considered complete after the onset of ionization equilibrium, which, under solar coronal conditions, occurs at high stages of ionization. Evidence for the presence in the near-solar region of gas with low degrees of ionization, not typical of the solar corona, can be regarded as consequences of the injection into the near-solar region of interplanetary material in the form of a flux of meteoroids, comets, or zodiacal dust.

What are the specific characteristics of the interaction between neutral atoms (and primary ions) and solar radiation prior to further ionization? Firstly, many neutral atoms possess resonance lines corresponding to transitions from the ground state in spectral regions near the peak of solar radiation. Certain atomic transitions may have significant oscillator strengths, experiencing radiation pressure in resonance lines that exceeds the Sun's gravitational pull. This allows specific atoms to exit the circumsolar region and accelerate to high velocities, potentially reaching solar escape velocity. Since the lifetime of primary ions significantly exceeds that of neutral atoms, the highest velocities are attained by elements that exhibit high radiation pressure in both their neutral and singly ionized states.

The first estimates of the intensity of resonance emission of some atoms and primary ions near the dust sublimation region were made in (Shestakova et al., 1990). That work concluded that Mg and Ca ions can reach the highest velocities, whose lifetimes allow them to accelerate to high speeds. It is precisely these elements that, after the first ionization, can exhibit the maximum intensity of resonance emission, which can be detected in observations during total solar eclipses or by means of space experiments.

The best candidates for such experiments are the resonance emissions of MgII. The cosmic abundance of Mg exceeds that of Ca by approximately an order of magnitude, and the estimated emission intensity also exceeds the intensity of the CaII K line by roughly an order of magnitude. Unfortunately, the resonance lines of MgI and MgII lie in the near-ultraviolet region, with vacuum wavelengths of about 2853Å and 2796Å, respectively. Such observations require more complex instrumentation than observations of lines in the optical range.

Of all atoms and ions having spectral emission lines in the optical range, the most effective may be the detection of the emission of calcium ions. The lifetime of these ions until the next ionization exceeds the lifetime of neutral calcium atoms by three orders of magnitude and is almost four orders of magnitude greater than the lifetime of sodium atoms.

(Gulyaev and Shcheglov, 1999) were the first to confidently register the resonance emission of CaII during the eclipse of 26 February 1998 in Guadeloupe using a Fabry-Perot etalon (FPE) at several sections of the interferogram to the west of the Sun in the heliocentric distance interval from $5R_{\odot}$ to $20R_{\odot}$. The emission intensity in the CaII K line observed at the center of the terrestrial-sky absorption line during the eclipse turned out to be approximately equal to the intensity of the continuous spectrum in the interval between the lines. In total, nine emission features were recorded in the spectrum. One emission feature proved to be unshifted; two others showed negative velocities of -160 and -168 km/sec. For the remaining six emission features, the shifts of the K line were in the range 2.2-3.7Å, which corresponds to a radial velocity from 170 to 280 km/sec with a probable error of ±20 km/sec. The derived velocities for these emission features turned out to be higher than the Keplerian velocities of circular orbital motion for the distances of the region considered, despite the fact that radial velocities were observed, i.e., projections of the spatial velocities onto the line of sight. Naturally, the true spatial velocities may be much larger.

In (Shestakova et al., 2004), an attempt was made to model the orbit of the parent body using emission details (features) of Ca-ion emission obtained from the observations of (Gulyaev and Shcheglov et al., 2001) during the eclipse of 26 February 1998. The simultaneously observed extended emission region cannot be interpreted as the passage of a single parent body. The most probable source of the appearance of cold gas in the outer solar corona may be explained by a scenario in which streams of meteoroids or remnants of comets, moving on elongated orbits, penetrate into the near-solar region. Ca ion particles leaving the parent orbit at each moment of time form an isochrone. All the observed emission is contained within an isochrone of $25 \cdot 10^3$ seconds. During this time, near perihelion the meteor stream (parent bodies) manages to traverse more than 180° in the plane of the sky. Applying the model to the observed results, taking into account the emission configuration and the observed radial velocities, made it possible to estimate the parameters of a parabolic orbit of the parent bodies with a perihelion distance of about $2R_{\odot}$. The stream of bodies crossed the ecliptic almost at a right angle from south to north, extending along the orbit near perihelion by almost 180°. The total mass of the dispersed material, assuming a chemical composition of CI-type chondrites, is $M_{CI} = 1\times10^{11}$ g. For a porous comet-type body with an average abundance for the Solar System, the mass estimate is $M_{com} = 2.6\times10^{13}$ g, which is equivalent to a body of radius 0.22 km at a density of 0.6 g/cm^3.

In (Shestakova et al., 2004; 2013), calculations were performed of the acceleration of calcium ions by radiation pressure upon detachment from different points along the orbit from a parent body moving on a parabolic orbit with a perihelion distance $q = 2R_{\odot}$. It was shown that atoms attain the highest velocities when they detach from the parent body at perihelion. The farther from the Sun the detachment of an atom occurs, the lower its terminal velocity.

Detailed calculations of the acceleration of CaII ions were carried out in (Shestakova et al., 2013), where an attempt was made to construct a numerical model of the motion of calcium ions after detachment from parent bodies comets, dust grains, or meteoroids following their approach to the Sun.

In the present work, an attempt is made to construct a model of the motion of Ca ions after detachment from the parent body at various distances from the Sun. The influence of radiation pressure, gravity, and magnetic drift in the Sun's radial magnetic field is taken into account. Radiation pressure on calcium ions in the H and K resonance lines of CaII in the solar spectrum is the dominant factor in the dynamics of the ions, which accelerate as they move away from the Sun. The dynamical model makes it possible to estimate the range of distances at which the disintegration of parent bodies and the formation of gas clouds may occur, and to assess the consistency of the proposed acceleration mechanism with the observed velocities (Gulyaev and Shcheglov 1999). Despite the crudeness of the model, one can note its good agreement with the observations.

Method and model. According to the estimates of (Shestakova et al., 1990), the lifetime of a neutral calcium atom is short. At a distance of 6R□ from the center of the Sun, it will be ionized within 160 s. The lifetime of the first calcium ion before the next ionization at the same distance from the Sun is already three orders of magnitude larger: 1.5×10^5 s. Owing to the short lifetime of the calcium atom in the solar radiation field, we do not assume the formation of calcium ions by any other mechanisms, but take into account only ionization by solar radiation. Thus, the motion of the neutral atom is excluded from consideration, and we will immediately calculate the motion of the ion after detachment from the parent body. To construct a dynamical model of the motion of CaII ions in the observed region near the Sun, we will rely on the following assumptions:

- 1) Ca atoms are produced as a result of the disintegration of small bodies of the Solar System or of interstellar bodies moving along Keplerian orbits. The origin (interstellar or interplanetary) of the parent body from which the cloud of the observed cold gas formed is of no fundamental importance; therefore, we do not distinguish between interstellar and interplanetary origins of the parent bodies.
- 2) We neglect the influence of the corona and mixing with it, since the relaxation time of the first Ca ion with the corona at a distance of $6R_\odot$, according to the theory (Alfven and Feltkhammar, 1967), exceeds by more than an order of magnitude the lifetime of this ion until the next ionization by the Sun's UV radiation. As the relaxation time, we adopt the slowing-down time of calcium ions on protons, which, according to (Alfven and Feltkhammar, 1967), is determined from the relation:

$$\frac{m_i^2 v_i v_T^2}{4\pi \cdot e_i^2 e_p^2 (1+m_i/m_p) n_p \ln\Lambda \cdot f(v/v_T)} \qquad (1)$$

where $v_T = (2kT_p/m_p)^{0.5}$ and for $v = v_T$, $f(v/v_T) = 0.43$. Λ - Debye shielding radius. This quantity , according to (1), is, by our estimates, 1.5×10^5 s, by more than an order of magnitude. Thus, consideration of the processes of interaction of calcium ions with the coronal material is meaningful only after their transition to the next ionization stage, in which emission in the CaII K line is absent.

- 3) The possible contribution of cyclotron rotation to the observed velocities is not yet taken into account. This contribution may be significant near the starting positions and decreases as the ion moves away from the Sun.

We represent the trajectory of the parent body by the classical equation of elliptical motion:

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

for which the conservation-of-angular-momentum equation, or the areal law $r^2\dot{\varphi} = \sqrt{\mu \cdot p}$, is also valid. At the moment of detachment of the ion from the parent body, its radial and tangential velocities will be equal to:

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

Let an ion be separated from its parent body at some location I[1] on the line SI (see Figure 1). The force acting within the ionic radius the vector can be represented as several forces:

$$m\ddot{r} = F_K + F_H + F_g + F_M \tag{4}$$

Where $\ddot{r}$ is the radial acceleration, m is the mass of the Ca, F_K. F_H are the radiation-pressure forces in the CaII K and H resonance lines, F_g is the gravitational force. F_M is the force due to the action of the magnetic field, considered in the first-order approximation, i.e., averaged over one Larmor period. In the Sun's radial field, the action of this force will manifest as a gradient drift toward a weaker field (magnetic mirror acceleration), i.e., away from the Sun. In this case, the entire Equation (3) will be the equation of motion of the guiding center about which the particle undergoes cyclotron rotation. A complete derivation of the general equation of motion is presented in (Shestakova et al., 2013) and the Equation (4) of motion is transformed to a form convenient for numerical solution:

$$\ddot{r} = (0.14782 I_K h_K + 0.078506 I_H h_H + 0.27394 \cdot 10^5 (J \cdot r_{st}/r - 1))/(r/r_{sol})^2 \text{ cm/sec}^2, \tag{5}$$

where $J = (r\dot{\varphi})^2/(r\dot{\varphi})_o^2$ accounts for the difference between the velocity of the parent body and circular Keplerian motion, and is specified by the initial conditions. In all cases considered, for $e \leq 1$, the quantity satisfies $0 < J \leq 2$. The resulting Equation (5) is used futher for calculations of the ion motion, averaged over the Larmor period, after detachment from the parent body.

Many attempts have been made to explain the spatial distribution of dust in the vicinity of the Sun, the orbital distribution of dust particles, the temperature profile, and the boundary of the dust-free zone, where dust completely sublimates and turns into gas (Mann et al., 1996). However, most of these attempts do not have a solid observational basis, because successful observations of the dust corona, which are carried out under conditions of total solar eclipses, are very rare. The question of the location of the boundary of the dust-free zone still remains open.

We pay special attention to the choice of the starting distance of the ions, since the starting distance is not merely a model parameter, but precisely the distance at which the boundary of the dust-free zone or the orbit of the parent body may be located.

The starting distance at which melting of chondritic material begins appears natural. The difficulty is that this material is a mixture of various minerals: olivine, pyroxene, plagioclase, and various impurities. Olivine and pyroxene together constitute three quarters of the mass of meteoritic material (Krinov et al., 1955). Olivine consists of a mixture of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Pyroxene consists of a mixture of $MgSiO_3$ and $FeSiO_3$ (Mg-pyroxene and Fe-pyroxene). Plagioclase contains high concentrations of impurities of Al, Ca, and Na.

The most fusible substance among those listed above is Fe-bearing olivine and pyroxene, whose melting temperatures are approximately the same and amount to about 1370 K (Krinov et al., 1955). In the blackbody approximation, bodies at a distance of $9R_\odot$ from the center of the Sun will have such a temperature. The refractory mineral forsterite (Mg_2SiO_4) melts at 2160 K (Krinov et al., 1955), which coincides with the blackbody temperature at a distance of $3.6R_\odot$. Even closer to the Sun, particles of oxides may approach: alumina (Al_2O_3) and a variety of calcium silicate orthosilicate whose melting temperatures are close to 2300 K and 2400 K, respectively, as well as graphite, whose melting temperature is significantly higher. Near $6R_\odot$ particles of the aluminosilicate mullite and plagioclase, which melt at 2100 K (Krinov et al., 1955), and siliceous glass (SiO_2), whose melting temperature is close to 2000 K, also evaporate. Mg-pyroxene and pure iron melt at $5R_\odot$.

The distance deserves $9R_\odot$ special attention, since about 40% of meteoritic material melts there. This distance we will take as the basis in our calculations. One should also not forget that Ca ions can reach inner regions of the corona down to $(3\text{-}4)R_\odot$ together with refractory particles of Mg-olivine and plagioclase, which together can constitute up to 35% of meteoritic material. According to our estimates, at distances smaller than $3R_\odot$ the relaxation time of a Ca ion with the corona is shorter than the lifetime of the ion until the next ionization by the Sun's UV radiation; therefore, ions penetrating into the inner regions of the corona remain in the corona.

Results. Numerical calculations were carried out using equation (5) for various initial conditions.

a) Start from a circular orbit, J = 1, $\dot{r} = 0$, $R_{start} = 5R_\odot$

b) Start from a parabolic orbit at perihelion, $\phi = 0$, $\dot{r} = 0$, $r\dot{\varphi} = 2\sqrt{\mu / p}$, где p= 2r, J = 2, $R_{start} = 9R_{\odot}$

c) Start from a parabolic orbit at quadrature, $\phi = -90^0$, $\dot{r} = -\sqrt{\mu / p}$, $r\dot{\varphi} = \sqrt{\mu / p}$, $p = r$

In all three cases, variants with other starting distances were also computed. The results of the calculations for ion starts at distances of 9 and 15 solar radii are presented in Figures 1 and 2.

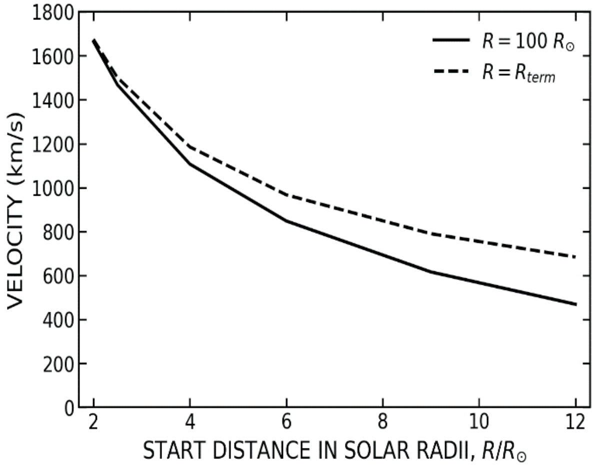

Figure 1. Radial velocities of calcium ions calculated for various initial distances at a heliocentric distance of $100R_{\odot}$, and the terminal velocity at infinity - R_{term}.

Figure 2 presents the results of calculations of the radial velocities at a distance of 100 solar radii and the terminal velocities at infinity.

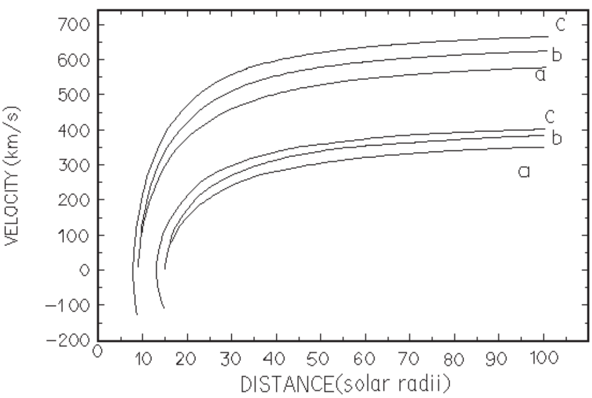

Figure 2. Velocity of Ca-ions versus distance from the Sun after leaving the parent body. Initial orbits of parent bodies: a) Start from a circular orbit; b) start from a parabolic orbit in perihelion; c) start from a parabolic orbit in quadrature. The upper three curves - start from 9 $R_{\odot}$ the lower ones- start from 15 $R_{\odot}$.

Figure 3 shows the radial velocities developed by Ca ions when they start from different points of the orbits at distances of 9 $R_\odot$ and 15$R_\odot$. The dynamical analysis shows that ions leaving the orbit of a parent body that penetrates into the near-solar region to distances smaller than 15$R_\odot$ can be accelerated to the observed velocities under the action of the forces considered. Thus, the scenario we propose does not contradict the observational results.

In (Gulyaev and Shcheglov, 2001), a second attempt at similar observations with a Fabry-Perot etalon in inclined beams, carried out during the total solar eclipse of 11 August 1999 in Bulgaria, is also described. The results of this observation differ in that strong emission was detected at the centers of the lines with zero Doppler shift. This phenomenon is explained by its temporal coincidence with the maximum of the Perseid meteor stream, which in itself may be of interest as a method for estimating the influx of meteoric material to Earth. Against such a background of powerful emissions, it was difficult to isolate fragments formed in the sublimation region. Nevertheless, three such fragments were identified near an elongation of 20$R_\odot$ exhibiting very high radial velocities of about 500 km/sec. The registered fragments were more compact than in the first experiment, and the corresponding radial velocities had different signs: -420 km/sec (19$R_\odot$), +490 km/sec (21$R_\odot$) and 830 km/sec (24$R_\odot$). Thus, in the vicinity of the Sun one can observe the motion of low-ionization Ca ions with radial velocities of different signs and magnitudes close to 1000 km/sec, which does not contradict the model calculations presented in Figures 2 and 3.

The most probable scenario can be considered one in which streams of meteoroids or remnants of comets, moving on elongated orbits, penetrate into the near-solar region. The closer to the Sun the detachment of particles from the parent body occurs, the higher the velocities to which the ions can be accelerated (Figs. 1 and 2).

The best option for extending such studies would be observations outside Earth's atmosphere, which would allow the spectral investigations to be extended into the ultraviolet region.

Possibilities of space observations of resonant luminescence in the H and K lines of CaII.

1) History of the Search. Prior to the successful interferometric observations by Gulyaev and Shcheglov, several attempts were made to detect Ca ion resonance emission in the solar F-corona. In July 1990, Aimanova and Shestakova utilized the Nikolsky coronagraph (Almaty) in an attempt to detect CaII H and K line emissions using a spectrograph with a dispersion of approximately 0.3 Å/mm. A series of consecutive images of the daytime sky at distances from 3 to 9 $R_\odot$ west of the Sun along the diurnal parallel (at 0.5 $R_\odot$ intervals) evealed a faint emission band in the CaII K line at 6 $R_\odot$. Due to time constraints related to an expedition for the total solar eclipse of July 22, 1990, these results could not be verified and remained unpublished.

Subsequently, several more attempts were made to detect the resonance emission of the Ca ion during total solar eclipses. Observations on 22 July 1990 were carried out by A. M. Sredinin according to the program of L. I. Shestakova in Siberia, the settlement of Markovo. An interference filter placed in front of the camera was centered on the CaII

K line and had a width $\delta\lambda_{0.5}$ Å 100 Å. The structural features of the outer corona were best seen in the image obtained with an exposure of 30 s, in which the sky background already had a significant density. The central part of the frame out to 6 $R_\odot$ was strongly overexposed and was burdened by distortions associated with the displacement of the Sun during the exposure, which was made without clock drive. Outside this near-Sun region, after contact copying onto Mikrat-200 film, the sky background was practically eliminated and unusual structures were revealed in the region of the Sun's southern pole: two quasi-radial streams resembling in shape dipole field lines symmetrically curved in opposite directions from the pole. The width of the structures was 3-4 $R_\odot$ and their extent reached 15 $R_\odot$ from the Sun. Owing to the unreliability of the photometry of the original negative, the results also remained unpublished.

The first attempt at interferometric observations without feeding optics, using the setup of P.V. Shcheglov containing a Fabry-Perot etalon in inclined beams, was made on 11 July 1991 in Mexico by A.K. Aimanov, L.I. Shestakova. It turned out that the image with the longest exposure contained emission rings covering the entire field of view, about 30 degrees. After analysis, it was found that the emission rings belonged to mercury, which was established with complete certainty, since a mercury lamp was used as the comparison source. Apparently, at the observing site (La Paz, Mexico) advertising lighting automatically switched on as darkness fell during the total phase of the eclipse; therefore, the sky spectrum contained strong mercury lines.

Simultaneous observations in Mexico using a coronagraph (Aimanov et al., 1995) equipped with an FPE in the exit pupil allowed for radial velocity measurements of dust in the inner corona up to 6 $R_\odot$. Velocities were estimated via CaII absorption lines; no emission was detected. The interference filter (IF) used was centered at λ3947Å with a half-width of $\delta\lambda_{1/2}$ = 50Å to encompass both H and K lines. The mercury line at λ3906Å did not interfere as it fell outside the filter's passband.

Subsequently, observations by R.A. Gulyaev were carried out on the wide-angle interferometric setup of P.V. Shcheglov with a Fabry-Pérot etalon in inclined beams, whose sensitivity increased from eclipse to eclipse and whose observations ultimately led to success. Interferometric observations on 9 March 1997 in Chita Oblast, performed by R.A. Gulyaev on Shcheglov's setup, showed a high sensitivity level that made it possible to record the sky background at the time of the eclipse, since the entire image was covered by rings of the CaII H and K absorption lines present in the sky spectrum. However, emission was also not detected.

Only during the eclipse of 26 February 1998 in Guadeloupe did interferometric observations of the corona in the CaII H and K lines (Gulyaev and Shcheglov, 2001) show the presence of Ca-ion emission in several regions of the interferogram to the west of the Sun. Compared with 1997, the instrument sensitivity increased by a factor of 40. In the image, the sky absorption lines at the time of the eclipse were clearly visible across the entire field of view. The emission intensity in the CaII K line, observed at the center of the absorption line, turned out to be approximately equal to the intensity of the continuous spectrum in the interval between the lines. As a result, the estimate of the intensity of the continuous spectrum obtained from the image near the CaII H and K lines is B = 8.8×10^{-3} erg/(cm^2 s sr Å). This means that, for observations with an instrumental profile of width about 1 Å, the intensity of the observed emission falls within the range of the predicted estimates made in (Shestakova et al., 1990). According to that work, the estimated emission intensity for resonance emission in the CaII K line at a distance of 6 $R_\odot$ is $1.6 \times (10^{-2} - 10^{-3})$ erg/(cm^2 s sr).

2) Device selection. Taking into account the results of unsuccessful and successful observational attempts, one can select the following relatively simple instrument configuration: a small-aperture camera with a filter and a wide field of view of 10° - 20°, without feeding optics 10° field of view corresponds to 40 $R_\odot$.

In front of the camera lens with an f-number from 1:1 to 1:1.5 and a diameter of 50 ± 5 mm an interference filter (IF) fully covering the light beam is mounted. In the focal plane of the lens, a detector array sensitive in the wavelength range 3900 - 4000Å is installed.

The maximum transmission of the IF, λ_{max} = 3952Å ± 2Å, is oriented toward the mean position between the CaII H and K lines, whose vacuum wavelengths are 3969.591 Å and 3934.777 Å, respectively. The IF half-width is $\delta\lambda_{1/2}$ = (52-54) Å. The filter transmits both CaII H and K resonance lines, taking into account a Doppler shift of of *±600 km/sec* for $\delta\lambda_{1/2}$ =52Å. A Doppler shift of 1 Å in this region corresponds to a velocity of 76 km/sec. The shape of the filter transmission profile should be close to rectangular.

The main difficulty in conducting observations is shielding the camera from direct sunlight. The localization of the observing region is to the north, east, south, and west of the Sun. The edge of the field of view is oriented at a distance of 4 $R_\odot$ = 1° from the edge of the solar disk (5$R_\odot$ from the center of the Sun). In one observing set, four frames are obtained from all four sides of the Sun. The north-south directions must also be monitored, since outflows from the poles (jets) are also possible.

Testing the camera and selecting the exposure can be carried out under terrestrial conditions at an observatory. The terrestrial sky at full Moon should provide an optimal signal level on the CCD array. The sky glow at full Moon is slightly weaker than the sky during a solar eclipse. The emissions observed in Gulyaev's experiment were comparable in intensity to portions of the continuous sky spectrum during eclipses. According to (Makarova et al., 1994), the brightness of the Sun in the selected spectral interval is about $B_\odot \approx 2.8 \times 10^7$ J/(sec m^2 m sr). An estimate of the sky brightness at the time of an eclipse, according to (Kimura and Mann, 1998) and (Shestakova and Demchenko, 2010), is $(1\text{-}3)\times10^{-9}$ $B_\odot$. As a result, the instrument sensitivity should be no worse than $(2 - 6) \times 10^{-2}$ J/(sec m^2 m sr). The daytime sky at zenith will also make it possible to select the exposure, taking into account that the sky during a solar eclipse is 5000-10000 times fainter than the daytime sky, as was measured during our observations of solar eclipses.

3) Expected Observational Results

Within the field of view, the appearance of emission spots of different sizes is expected, indicating the presence of regions of increased concentration of calcium ions that appeared after the disintegration and dispersion of denser bodies of comet-asteroid composition.

4) Future Research Directions

Possible continuation of the research: scanning the region of the inner Solar System using a telescope with a long-slit spectrograph to measure the radial velocities of emission clouds, in order to investigate the dynamics of these objects and study the sources of their occurrence.

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