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Observations of the resonance glow of atoms in region of solid material sublimation in the near circumsolar space

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1. During the total solar eclipse on 12 December 1871 Pierre Janssen for the first time discovered visually dark Fraunhofer lines in the spectrum of the solar corona. 12 years later, during the solar eclipse in 1883, he successfully photographed the Fraunhofer spectrum of the corona. Having analyzed the spectrograms, Janssen came to the conclusion that in certain domains of the solar corona there is substance in the form of solid particles reflecting the sunlight [1].

In the research of the Fraunhofer spectrum of the solar corona the spectrograms taken by Ludendorff during the solar eclipse on 10 September 1923 were prominent. Using photometric procession of spectrograms, Grotrian [2] divided the coronal spectrum into two components: (1) the continuous spectrum without absorption lines (the K-corona) and (2) the Fraunhofer spectrum, identical to the Sun spectrum (the F-corona). Some years later notation was introduced for one more component of coronal spectrum: a set of coronal emission lines became denoted as the E-corona.

Grotrian proposed serious arguments in favor of the common dusty nature of the F-corona and zodiacal light. But there was doubt in the possibility of existence of solid dust particles at small distances from the Sun. In 1929 Russell showed that due to the evaporation of dust particles in neighboring near-solar space there must exist a dust-free zone of radius of order $4R_{\odot}$ around the Sun. With such a dust-free zone at hand the brightness distribution of the F-corona has to have, obviously, a maximum at some distance from the Sun. Nevertheless, the eclipse observations indicated the monotonic diminishing the F-corona brightness over all interval of heliocentric distances from about 1.1 $R_{\odot}$ to several tens of $R_{\odot}$.

The problem was solved by Allen [3] and Van-de-Hulst [4] who showed that the crucial role in forming the F-corona radiation belongs to diffraction on particles of size 10 – 100 μm, situated in interplanetary space between the Sun and the Earth. The indicatrix of diffractional scattering on such particles is strongly extended in the direction of the incident light. That is why in forming the observable F-corona only dust which is at the distance more than 20 $R_{\odot}$ from the Sun takes part. It follows from this that the most inner part of the interplanetary dust cloud ($r < 20\,R_{\odot}$) is inaccessible for observations using the usual, traditional means, for example, photographing the corona in visible light.

2. But there are other possibilities to research of the inner regions of the interplanetary dust cloud, which do not depend upon the mechanism of radiation scattering. First of all this is recording the thermal radiation of the heated dust in the infrared domain of the spectrum. Peterson [5] theoretically predicted the existence of such radiation in the form of an emission ring at a distance of about 4 $R_{\odot}$ around the Sun. In fact, during the eclipse on 12 November 1966 Peterson [6] and MacQueen [7] found a peak of radiation with $\lambda \approx 2.2$ μm at a distance of about 4 $R_{\odot}$ from the Sun. So one more component of the coronal emission was discovered, called the T-corona.

Later, other observations from both the ground (during the eclipses) and balloons and rockets confirmed the presence of the brightness maximum at a distance of about 4 $R_{\odot}$ at different wavelengths from 2 to 10 μm. Brightness peaks were also pointed out at other heliocentric distances from 3.5 to 10 $R_{\odot}$. On the other hand, there were number of cases, for example, during the solar eclipses in 1980 and 1991, when infrared observations did not point out any signs of the increased thermal radiation at distances up to $15R_{\odot}$ from the Sun. Moreover, during the solar eclipse on 11 June 1983 an intense peak of IR-radiation to the West of the Sun was found in the total absence of increased radiation in the Eastern part of the corona. It became clear that we deal with discrete nonstationary dusty formations in the near-solar space. Koutchmy and Lamy [8] suggested that the F-corona is a superposition of the 'far' corona (in accordance with the theory by Allen and Van-de-Hulst) and a variable 'local' corona. The variability of the 'local corona' could be connected, for example, with comets closely approaching the Sun.

3. The most promising seems method to be the other way of researching the innermost regions of the interplanetary dust cloud, which have not get wide application yet. We mean detecting the resonance radiation of atoms and low-charged ions escaping by sublimation from the dust particles. Resonance lines can be the most reliable indicators of the process of the solid substance sublimation near the Sun. Perhaps for the first time, Shestakova [9] drew attention to this fact. She evaluated the expected intensities for a series of resonance lines of metals at the heliocentric distance of $6R_{\odot}$ and found that the most preferable lines for the first pilot observations are the H and K lines of the ionized calcium.

As early as during the solar eclipse on 17 May 1882 A Schuster pointed out the presence of the H and K emission lines in the corona spectrum. But these lines coincided in λ with the corresponding chromospheric lines, i.e. did not have a Doppler shift. For the most part they were due to the scattering of the chromosphere and prominences radiation in the Earth's atmosphere. As for the lines connected with the dust sublimation, one should expect a considerable Doppler shift, generated by the motion of the dust particles along the line of sight. Really, the Keplerian velocity of circular orbital motion is, for example, about 200 km/s , at the distance of $5R_{\odot}$ from the Sun. At such velocities along the line of sight, the Doppler shifts in the neighbourhood of the H-and K lines is equal to approximately 3 Å.

For the search for resonance emissions of Ca II during solar eclipses a portable interferometric camera on the basis of Fabry – Perot etalon, was developed and constructed in Sternberg Astronomical Institute of Moscow State University. The camera enabled us to photograph the near-solar region of the sky of diameter up to 20° (approximately $80R_{\odot}$) in the neighbourhood of the K line [10]. During the solar eclipse on 26 February 1998, we successfully carried out the first observations using this instrument [11].

Analysis of the interferogram taken during the solar eclipse showed the following. All the field of view of the frame is covered with interference bands corresponding to the interferogram of the day-time sky. In such a picture, due to the scattering of the solar light from the penumbra, one can see emissional details (fragments of the rings) corresponding to the *K*-line with Doppler shift. The emission details are present in the range of heliocentric distances from 5 to $20R_{\odot}$. The location of these details on the celestial sphere (solid short arcs numbered from 1 to 9) is shown in Fig. 1. Dashed arcs, crossing all the field, refer to the nonshifted *K* line on the interferogram of the day sky.

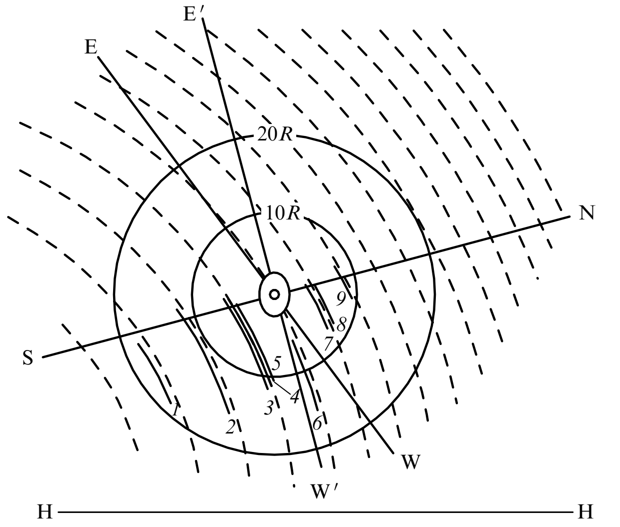

Figure 1. Situation of the emission details on the interferogram of the eclipse sky on 26 February 1998. The central oval corresponds to the image of the solar corona. The dashed arcs refer to the nonshifted *K* line in the scattered sky light. Short solid arcs numbered from *1* to *9* are emission details. NS is the direction of the axis of the Sun's rotation. EW is the diurnal parallel; E′W′ is the direction of the ecliptic, HH is the almucantar (the line parallel to the horizon). The two concentric circles correspond to the heliocentric distances of 10 and 20 solar radii.

The shifts of the *K* line are 2.2 – 3.7 Å, which corresponds to velocity from 170 to 280 km/s with a probable error ±20 km/s (detail No. 4 is not shifted). The obtained velocities are somewhat higher than the Keplerian velocities of circular orbital motion for the distances under consideration; the sign of the Doppler shift of most of the emission details corresponds to the direction of orbital motion of planets in the solar system.

The presence of the great Doppler shifts is a weighty argument in favor of these spectral features being the sought emissions, connected with sublimation of the moving dust. Such a phenomenon seems to have been recorded for the first time. Apparently, in addition to the already known K, E, F and T components one can state the discovery of a new component of the solar corona radiation. We proposed to call it the S-corona (from the word sublimation) [12].

The observations of the next solar eclipse on 11 August 1999 confirmed the results of 1998 [13]. In the photograph of 1999 the domains of sublimation radiation are more compact than in 1998, and the Doppler shifts correspond to far higher velocities. The negative signs of the Doppler shift are pointed out as well. The corresponding diagram is presented in Fig. 2.

4. The results of the observations of solar eclipses in 1998 and 1999 enable us to conclude that the resonance glow of Ca II with considerable Doppler shift (S-corona) is not distributed isotropically around the Sun but is localized in separate more or less compact domains. Apparently at heliocentric distances

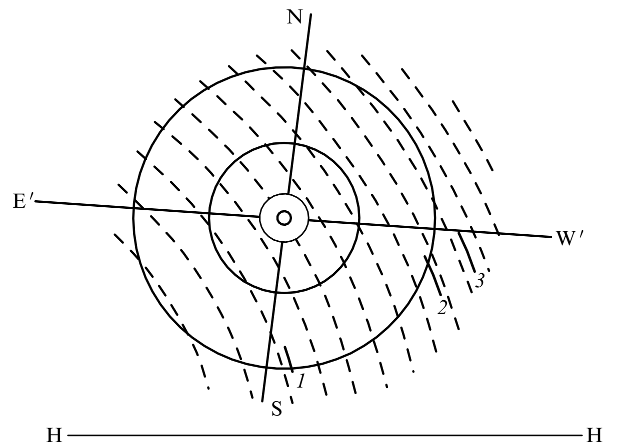

Figure 2. Situation of the details on the interferogram of the eclipse sky on 11 August 1999. The notation is the same as in Fig. 1.

less than $20R_{\odot}$, the uniformly distributed dust (the internal part of the zodiacal dusty cloud) is practically absent. Instead of this one can observe discrete sporadic formations which may be connected with showers of meteoroids and/or sungrazing comets. This conclusion is in concordance with Koutchmy and Lamy's suggestion for the T-corona mentioned above.

Recently Shestakova [14] developed a theoretical model for the motion of Ca II ions after they leave the parent body under sublimation. According to [14] the most probable is the following scenario. Stone and dust showers (meteoroids, minicomets) moving along extended orbits intrude into the near-solar region. In the region of sublimation a gaseous cloud arises which under influence of the light pressure tears off the initial orbits and swiftly departs from the Sun, leaving the sublimation domain far behind. The consequences of this model correlate well with the results of our observations [11, 13].

As for the small sungrazing comets, now it is known that there are many of them. According to observations from the space observatory SOHO, situated at the first Lagrangian point of libration at a distance of 1.4 M km from the Earth and functioning since 1996, up to 50 such comets are discovered annually. But the images of the outer corona, taken from SOHO during the solar eclipses on 26 February 1998 and 11 August 1999, show no comets which could correspond to our emission formations. Apparently, in the Ca line we detect more faint objects than minicomets observable from SOHO in the white light. The number of such objects should be very large.

5. Now the observational data on the S-corona are restricted to only our results obtained by the one *K* line of Ca II. Naturally, the observations should be extended to resonance lines of other elements. These are first of all the lines D_1 and D_2 of Na I, and the lines $\lambda = 3720$ Å and $\lambda = 3860$ Å of Fe I. Because the content of silicon in meteorites usually is very high, one should find Si lines, for example, the known line $\lambda = 3905$ Å of Si I. Then, the fragments of solid substance in the interplanetary space should be saturated with helium due to the capture of α-particles from the solar wind and solar cosmic rays. That is why the observations of helium lines D_3 ($\lambda = 5876$ Å) and $\lambda = 10830$ Å are of great interest. All the lines mentioned above are available to ground-based observations under the conditions of total solar eclipses. It is a great temptation to observe resonance lines of Mg, whose abundance is an order higher than the abundance of Ca; these are the line $\lambda = 2852$ Å of Mg I and the doublet $\lambda_1 = 2795$ Å and $\lambda_2 = 2802$ Å of Mg II. Because the spectral region $\lambda \approx 2800$ Å is inaccessible to ground-based observations, the transport of equipment beyond the terrestrial atmosphere becomes necessary.

Note that, the observation of emission lines of different chemical elements will give the possibility of direct study of the mineralogical composition of interplanetary dust in the immediate proximity of the Sun.

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