Wide-field investigation of the velocity field of the circumsolar dust during the total solar eclipse on July 22, 2009

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Abstract. We describe preliminary results of the wide-field (up to $30 \div 40\ R_\odot$ heliocentric distance) spectro-imaging of the dust grains in the solar F-corona carried out during the total solar eclipse (TSE) of July 22, 2009 at Yuexi, China. The aim of the observations was to measure the radial velocities of the circumsolar dust grains. The field of radial velocities of dust was obtained by Doppler shifts of the Ca II K λ 383.4 nm absorption line. The instrument used was a spectro-imaging camera with a Fabry-Perot (FP) etalon. Thin clouds during the eclipse modulated the intensity of the dust scattered light but the experiment was successful giving the valuable data on the dust radial velocity of the Ca II K line in absorption (no emission in this line was seen in the FP data). The resulting mean radial velocity in the selected strips of the interferogram images is ≈ -100 km/s. The definite conclusions on the radial velocity field will be drawn only when the on-going thorough data reduction and final analysis of the data will be completed.

Key words: Sun: solar eclipse, F-corona, radial velocity, Fabry-Perot etalon

Широко-полево изследване на полето на скоростите на околослънчевия прах по време на пълното слънчево затъмнение на 22 юли 2009 г.

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Приведени са предварителните резултати от широкополево (до $30 \div 40\ R_\odot$ хелиоцентрично отстояние) изследване на праха в слънчевата F-корона, проведено по време на пълното слънчево затъмнение на 22 юли 2009 г. в Китай. Целта на наблюденията беше да се определи полето на лъчевите скорости на околослънчевия прах. Полето на лъчевите скорости бе получено чрез измерване на Доплеровото преместване в абсорбционната линия Ca II K λ 383.4 nm. Използваният инструмент бе 3D-спектрална камера с еталон на Фабри-Перо. Тънките облаци по време на затъмнението модулираха интензитета на разсеяната от праха светлина, което обаче не оказва влияние върху самите лъчеви скорости и експериментът бе успешен, давайки значими данни за полето на скоростите на праха, наблюдавани в абсорбция в линията Ca II K (емисия в тази линия не беше регистрирана). Резултантната средна лъчева скорост в избрани ивици на изображенията на интерферограмите е ≈ -100 km/s. Окончателни изводи за полето на лъчевите скорости ще направим след завършването на цялоатната редукция на данните и финалния им анализ.

1 Introduction

Our vision of the dust properties in the solar vicinity, its spatial distribution, and its origin had to evolve during last 25 years. The initially simple picture of the zodiacal light dust grains of asterodial origin falling onto the Sun due to the Poynting-Robertson effect had to be changed to take into account other phenomena, and in particular the dust contribution from comets. The successful measurements of the radial velocities of the dust grains in the F-corona, thought to be impossible, played a decisive role in this new insight in the circumsolar dust nature (see Shcheglov et al. [1987] for the description of the first measurements). The analysis of the dust grains velocity field made by Shestakova [1987] shows that the dust exists well above the ecliptical disk. Further, if the dominant motion is Keplerian, there is also a part of dust grains which velocities close to zero, which could be produced by comets as well. It was also shown that there is a population of the dust grains with size close to 0.5 mcm, the half of that of the zodiacal light grains. Finally, the data indicated a dust free zone at heliocentric distances $r < 4\ R_{\odot}$. Subsequent intensive studies of the comet P/Halley confirmed these conclusions (see Mann [2000] and Shestakova [2003] for reviews). The first radial velocity measurements done during the total solar eclipse in Kazakhstan on July 31, 1981 were recently followed by two other expeditions, during the TSE in Kazakhstan on March 29, 2006 and in southern Siberia on August 1, 2007 (Shestakova [2007]). The velocity field in 2006 happened to be very different from the Keplerian motion, namely the dust grains motion was perpendicular to the ecliptic. The only solar system bodies with such a motion are comets. The picture changed once again in 2007 showing prograde Keplerian motion. This puzzling behavior of the velocity field appealed for further investigations. The outstanding duration of total solar eclipse on July 22, 2009 gave hopes to carry out observations of exceptional accuracy.

Our collaboration of the Fesenkov Astrophysical Institute of Almaty (Kazakhstan), the Laboratoire d'Astrophysique de Grenoble (France), Department of Astronomy at the Sofia University and Institute of Astronomy of the Bulgarian Academy (Bulgaria) of Sciences prepared an experiment with an interferometric spectro-imaging instrument using a Fabry-Perot etalon to measure the dust grains radial velocity field. The spectral range of the experiment was around Ca II K line $\lambda\,383.4$ nm where the possible emission due to evaporated dust has a strong contrast.

2 Observations and instrumentation

We observed at the city of Yuexi in Anhui state of the China (30°51.0′ N, 116°22.0′ E, 1000 m above the sea level) in the very middle of the TSE band. The duration of the total phase was 5 min 37 s.

The Interferometric Spectro-imaging Instrument (ISI) especially designed for these observations can be seen in fig. 1. To have a light construction, we used a set-up with the FP and a narrow-band filter immediately before the objective and a camera. This time we did not used a collimator, nor coronographic mask as it has been the case in previous observations (Shcheglov et

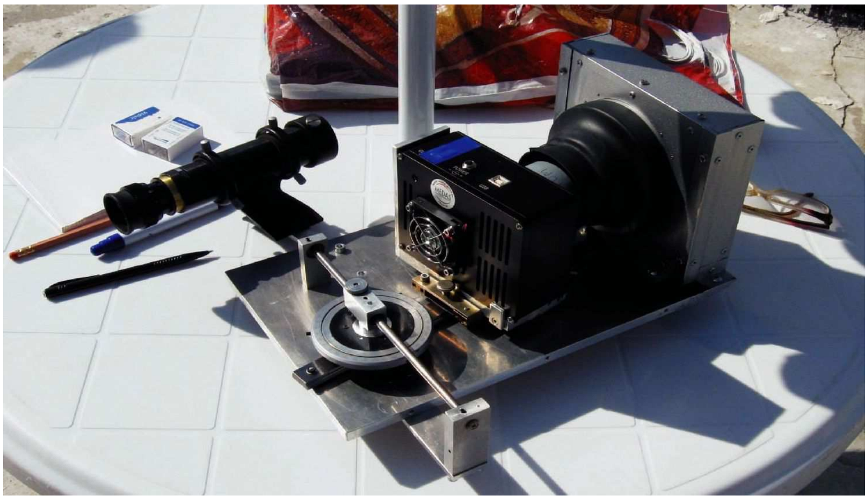

Fig. 1. The Interferometric Spectro-imaging instrument (ISI).

al. [1987]). To obtain a better spatial sampling of the circumsolar region up to 30 $R_\odot$, the FP and the filter were inclined with the respect to the optical axis by $\approx 10°$. The FP plates are spaced by 70 microns, the filter used has a FWHM of 3 nm and was centered at $\lambda = 395.0$ nm. We used an objective Angenieux with $f = 50$ mm opened at $f/0.95$, and a SBIG CCD detector ST-3200 ME. Three frames of different exposures were secured during the eclipse. Additionally, a number of calibration frames were exposed immediately before and after the eclipse at the same position of the instrument (spectral Hg I lamp, tungsten lamp, daylight sky).

During the totality the weather was partly cloudy. Nevertheless, the clouds were thin enough to let a part of light to pass through, so that the radial velocity measurements (which are sensitive to the position of the interference rings and insensitive to the flux variations) were quite successful.

3 Preliminary data reduction

The frames were corrected for the hot, cold, and dead pixels and 2×2 binned. One of the original interferograms secured during the totality and cleaned in such a way is shown in fig. 2.

The determination of wavelengths from FP interferograms is based on the equation

$$m\lambda = 2d\cos\theta + \varepsilon \tag{1}$$

where m is the order of interference, λ is the wavelength, d is the thickness of the FP etalon (in the case considered here this is the air gap between the reflecting plates), θ is the angle of incidence, and ε is the phase change at reflection. From all parameters in eq. 1, before starting the reduction, only

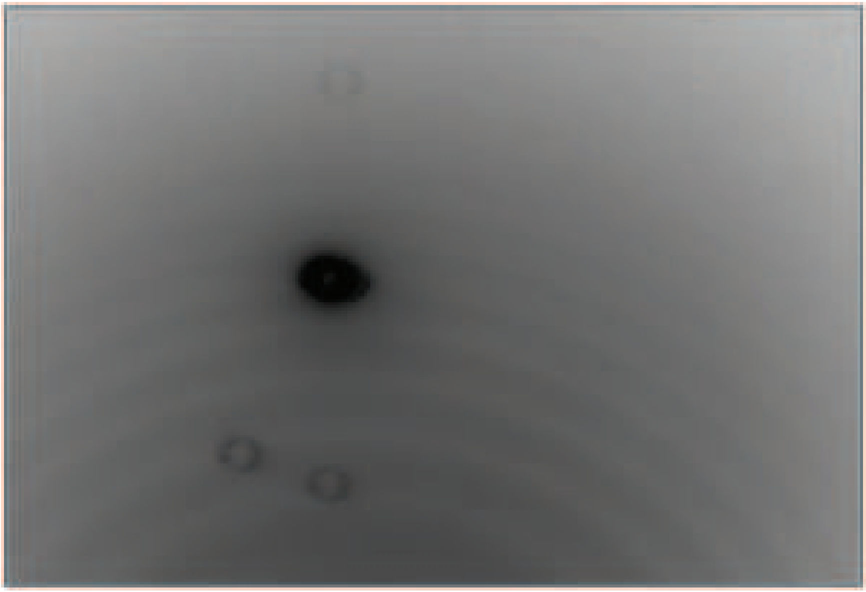

Fig. 2. One of the original interferograms secured during the totality and corrected for the hot, cold, and dead pixels.

the wavelength is known, $\lambda = 393.366$ nm. Also known are the focal length of the camera used (50 mm), the pixel size of the CCD (13.6 mcm after 2×2 binning), and the dimensions of the binned CCD chip (1092×736 px). Thus, the geometrical centre of the CCD is at coordinates (546, 368). Because the FP etalon was inclined against the optical axis, the centre of the fringe system lies outside of the CCD chip.

To obtain the coordinates of the centre of the fringe pattern we measured five of the absorption fringes in the sky interferogram. Three points were measured on each interferogram and fitted with circles. The mean value of the centers of these circles determines the centre of the fringe system at $(424.6, -391.714)$. Using the distance between the centers of both CCD and fringe system, as well the focal length of the optics, we derived the inclination of the FP to be $11.82°$.

In table 1 the radii of the 5 fitted circles are given, together with their angles of incidence θ, which have been used to derive the thickness of the etalon. For this purpose we used all possible pairs of fringes, having orders (m, n). The actual orders are not known at this stage, but this does not matter, as we are interested only on the differences between all possible pairs of orders (10 different pairs are possible in the case of 5 fringes). This is immediately seen from the following relation for the thickness of the FP, which was obtained from the pairwise (for orders m and n) application (subtraction) of eq. 1:

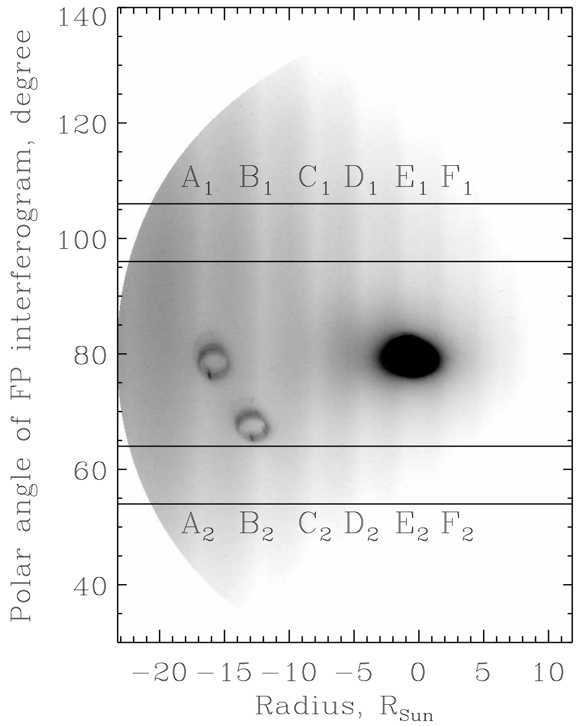

Fig. 3. The interferogram transformed to polar coordinates centered at the FP fringe system.

Table 1. Parameters of the FP fringe system.

Fringe number	Radius, px, px	θ, degrees	Order
1	498.467	7.72125	327.534
2	580.253	8.96894	326.489
3	651.003	10.0414	325.467
4	710.453	10.9372	324.527
5	770.639	11.8386	323.500

$$d = \frac{(m-n) \times \lambda}{2 \times (\cos\theta_m - \cos\theta_n)} \tag{2}$$

The mean thickness of the FP etalon found from the 10 possible combinations is 65.010 ± 0.005 mcm. With thus derived thickness, the measured angles and known wavelength of rest we are able to calculate the actual orders of interference which are listed in the last column of table 1. The derived orders were used to create the lambda scale around each particular absorption minimum. As we can see, the orders are not integer numbers but half of integers. This is because we are using absorptions in this analysis, i.e. we consider destructive interference.

4 Results

In fig. 3 the interferogram transformed to polar coordinates centered at the fringe system of the FP are shown. The polar angle is counted counterclockwise from the positive part of the X axis. The latter is renormalized to give heliocentric distances. The strips indicate the regions used for the wavelength and radial velocity estimates. The letters A, B,C, D and F indicate different FP orders.

In fig. 4 the intensity profiles along the upper and lower strips (averaged over the polar angle) are shown. Solid line corresponds to the eclipse profile, dashed line is the daylight sky. The minima correspond to the Ca II K line absorption at different heliocentric distances.

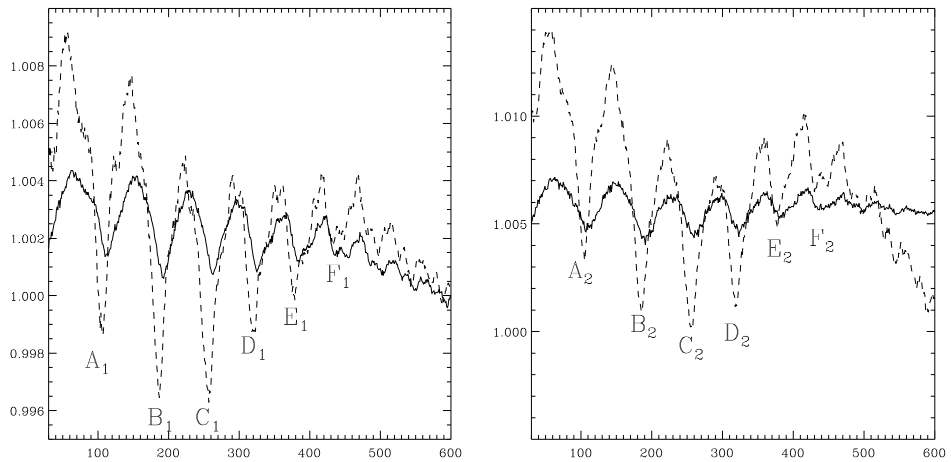

Fig. 4. The intensity profiles along the upper (*left*) and lower (*right*) strips.

In fig. 5 a comparison of the F-corona (solid line) and skylight (dashed line) Ca II K line absorption profiles is shown. The wavelength shift between the profile of the F-corona and that of the skylight is clearly seen and corresponds to the line-of-sight velocity of about -100 km s^{-1}.

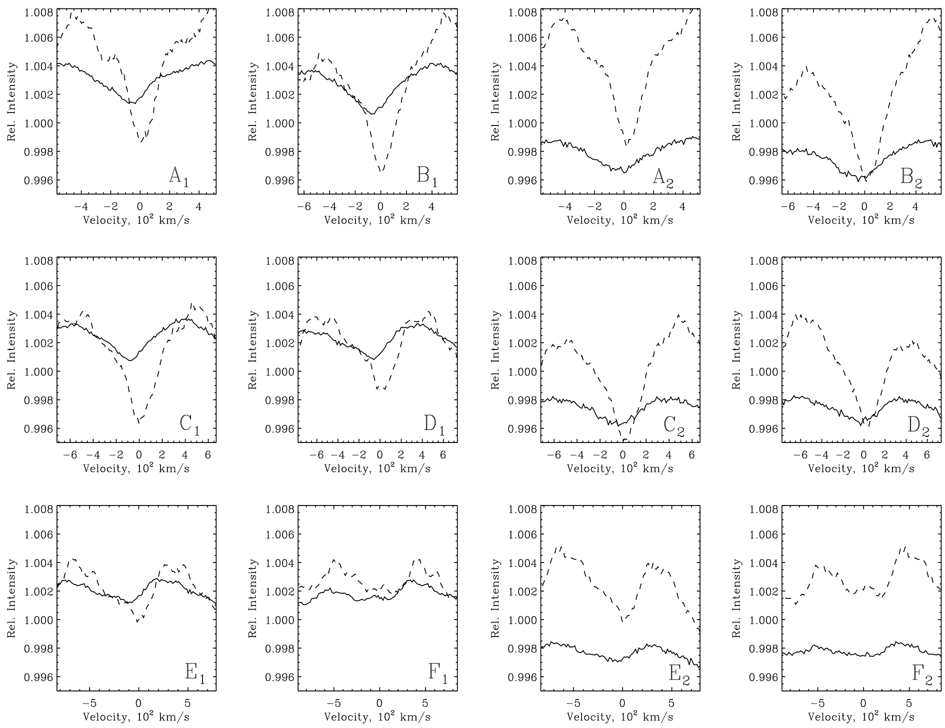

Fig. 5. The velocity profiles along the upper (*left*) and lower (*right*) strips.

5 Conclusions

In spite of a partially cloudy weather during the TSE2009 useful radial velocity data from the interferometric spectro-imaging at Ca II K line λ 383.4 nm line were obtained. The preliminary reduction of the ISI data reported here shows that the radial velocity field of the dust grains in the solar vicinity up to 30 $R_\odot$ can be extracted. The resulting radial velocity in the selected strips, ≈ -100 km s^{-1}, is in general agreement with the values of the previous measurement.

Our measurements confirm the tendency observed during the total eclipses in 1987, 2006 and 2007 that the velocity field of the dust grains in the F-corona can vary from year to year.

The definite conclusions will be drawn when the on-going thorough data reduction and final analysis of the data will be completed.

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References

Aimanov, A. K., Aimanova, G. K., & Shestakova, L. I. 1995, *Astronomy Letters, 21, 196*
Gulyaev, R. A., & Shcheglov, P. V. 1999, *Rep. Acad. Sci. (in russian), 366, 199*
Mann, I., Krivov,A., & Kimura, H. 2000, *Icarus, 146, 568*
Shcheglov, P. V., Shestakova, L. I., & Aimanov, A. K. 1987, *A&A, 173, 383*
Shestakova, L. I. 1987, *A&A, 175, 289*
Shestakova, L. I. 1990, *Pis'ma v Astron. Zh., 16, 550*
Shestakova, L. I. 2003, *Astron. Astrophys. Transactions, 22, 191*
Shestakova, L. I., Rspaev, F. K., Minasyants, G S., Dubovitskiy, A. I., & Chalabaev, A. 2007, *Odessa Astron. Publ., 20, 203*