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ABOUT THE SOLAR EDGE AND SOLAR DIAMETER VARIATION STUDIES

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Abstract. Without spurious effects due to instrumental and/or Earth atmospheric parasitic light, the true solar edge can only be correctly analyzed at the time of solar total eclipses. We discuss the problems occurring when using solar diameter measurements made outside of solar total eclipses, including the possible limb effects related to different sources of solar activity. Effects due to the PSF and to the scattered light should be discussed with reference to coronagraphic methods used to reduce the ultimate sources of parasitic light.

Keywords: sun:corona, sun:fundamental parameters, Eclipses

1 Introduction

The variation of the solar diameter was discussed a long time ago, with also some interrogations on indirect effects on the Earth climate of long time period solar variabilities associated with the Total Solar Irradiance - TSI. This energy can be also evaluated by considering the solar diameter measurements, as described in Nesmes-Ribes and Thuillier 1966. They suggested that the solar diameter could change over centuries, and this could be measured in space, free of Earth atmospheric turbulence, distortion and refraction, thanks to the Picard space mission designed by the French Space Agency CNES. These solar diameter measurements are performed in space but outside of eclipse conditions. The variations of the Total Solar Irradiance (TSI) S can be analyzed assuming a simple model:

$S = \frac{\pi * R^2 * \sigma * T_{eff}^2}{A^2}$

A is the distance Sun-Earth (an average value over 1 Year is evidently considered) equal to the astronomical unit (constant) in average (also called the A.U.) while variations over the solar disk are neglected. The variations of S can then be due to the changes of the solar radius Ro or/and of the effective temperature T of the photosphere (possibly a consequence of global processes occurring deep inside the Sun) assuming A is constant:

$\frac{\delta S}{S} = 2 * \frac{\delta R_0}{R_0} + 4 * \frac{\delta T_{eff}}{T_{eff}}$

The relative variations of the TSI, S, during a solar cycle is less than +/- 0.001. Then the relative variation of the solar radius cannot be more than +/- 0.4 arcsecond and indeed, it is considerably smaller. It could be as small as 10 milli-arcsec, taking into account the variations of the effective temperature of the photosphere, which seems not correlated with the solar cycle and the magnetic activity based on the Kitt Peak 35 Years long series of precise measurements of the equivalent width of selected solar spectral lines (Livingston et al. 2004).

2 Methods for the solar diameter measurements

Several methods have been or are still used to measure the solar diameter (Koutchmy et al 2011). Special heliometers were designed for more than 100 years. They were visually operated instruments and a large (1.55 arcseconds) correction for irradiation effect should be introduced. Also the analysis of Mercury and Venus transits can be used for measuring the solar diameter. Solar Astrolabes working at the same almucantarat for both limbs allow long acquisitions series, without a need of correction for refraction effect. Small apertures were used. Solar transit measurements can be made with stationary ground based telescopes measuring also at the

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same almucantarat. The analysis of solar disk images are actually made in Space with MDI of SoHO, AIA of SDO and the dedicated Picard mission. Finally, Solar Total Eclipses allow an accurate timing of the contact instants determined by the value of the solar diameter and the invariable diameter of the Moon and of the distance Earth- Moon. Eclipses observations seem to be a good way to measure the solar diameter, the Sun is covered by the Moon, our celestial body, at a distance of about 400000 km. The phenomenon allows defining as well and importantly the true solar edge, thanks to the use of slit less flash spectra, separating the continuum at the solar edge and the faint low excitation emission lines, which could indeed be associated with the local magnetic field. The inconveniences are that the solar total eclipses occurs in average at approximately one per two years, in different locations on Earth, and the contact duration is a few seconds and this is very short.

3 Advantages of Eclipse Observations

Solar eclipse observations are performed on the ground with economic, small portable equipment, including new technology fast CCD cameras and light PC computers. Total solar eclipses are free of seeing effects because the occultation occurs in space, this is a fundamental advantage, and there are no spurious effects due to the scattered and parasitic light coming from the disk which is fully occulted in Space. It is a differential method where the immutable lunar disk is used as a reference and magnified by a factor of more than 1:30. Additional advantages come from the use of precise timing and positioning GPS devices and spectrally resolved time series. Precise lunar profiles are available from stellar occultation. The classical Watts profiles and those from the Kaguya space mission are indeed used. The following figure 1 shows how could be defined the true solar edge during the last total solar eclipse of 11th July 2010 in French Polynesia, using slitless flash spectra, by analyzing the true continuum seen between the many faint emission lines.

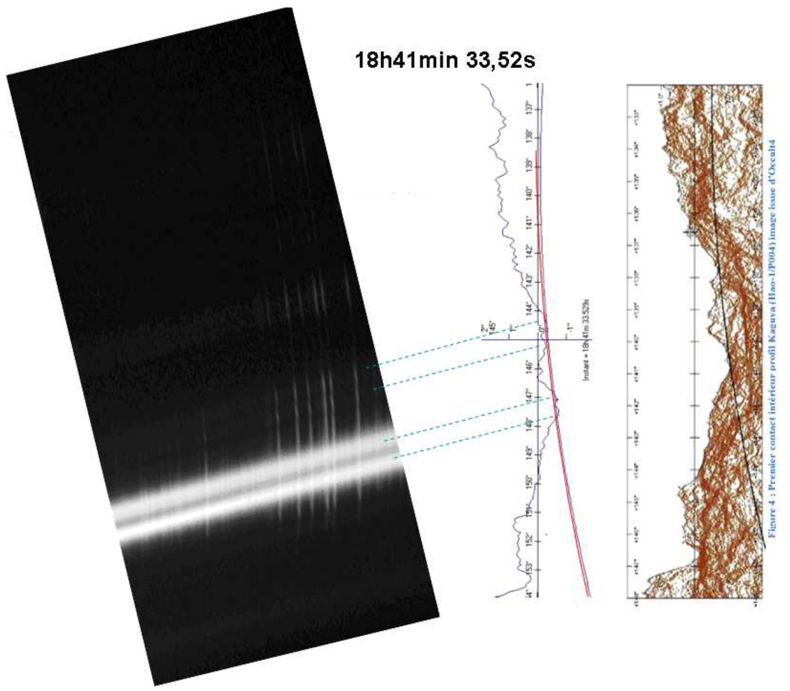

Fig. 1. Extract of 11th July 2010 total eclipse flash spectra, fitting with the Kaguya lunar limb profile. This shows how the lunar mountains and valleys modulate the solar lines, the continuum of the flash spectra, and the modulation of the Baily bead spectra.

The disadvantage of the method is that there are irregularities due to lunar mountains and valleys, which give more difficulties to measure the contacts by the use of a chrono-datation. There is also the question of the optical global Moon shape and geometry, but this point is beyond the scope of this contribution, and further analysis should be performed. To avoid these defects, we also tried to look (first, at ground based) at a diffracted solar limb using the linear edge of a metallic wall situated at a distance of 150 meters to simulate future observations with the proposed space borne mission Aspiics/Proba3 (Vives et al 2005).

4 Outside of eclipse groundbased experiments for studying the solar edge using external occultation coronographic methods

These diffraction experiments were done in the context of the Aspiics/Proba3 space mission, consisting of an artificial occultation to try to reproduce solar total eclipses conditions using two satellites, one with the observing instruments, and the other with an occulting disk of 1.5 m of diameter, separated by a distance of 150 meters. Figure 2 shows the schematic we used for performing the acquisitions of the rising Sun occulted by a vertical wall images. The next figure 3 shows typical results we obtained, by taking four images per second during the

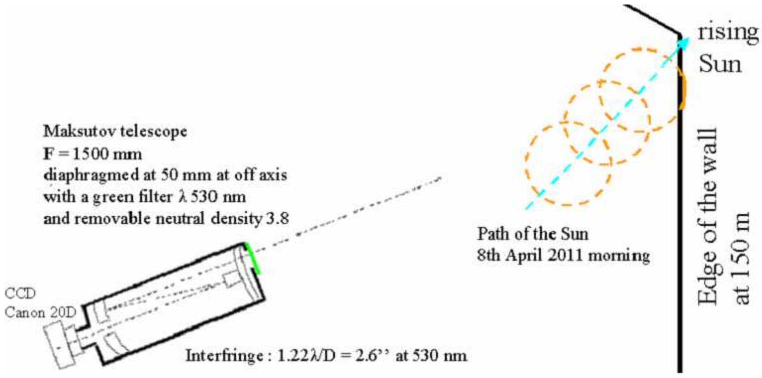

Fig. 2. Schematic of the experiment using a Maksutov imaging telescope, situated at 150 m from the edge of the wall when the rising Sun limb begins to appear

appearance of the solar limb, when it rises in the vicinity of the vertical wall edge situated at 150 m. This method

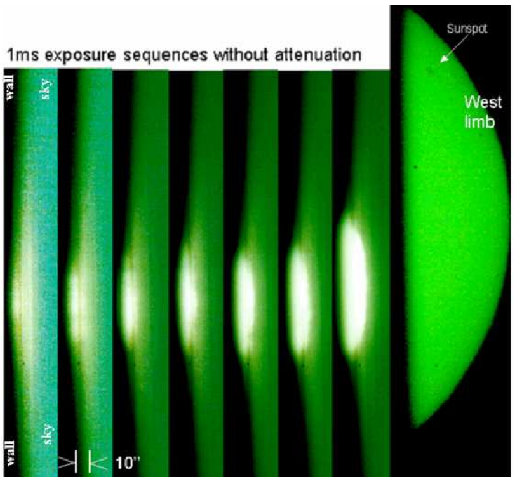

Fig. 3. Time sequences performed the 8th April 2011 at 6h15 UTC, at the time of the rising Sun, taken using a 4 frames/s cadence, 1ms of exposure time at 200 ISO, to show the diffraction patterns from a vertical wall edge. A large band green filter is placed in front of an F = 1500 mm Maksutov telescope, diaphragmed at 50 mm, see Fig. 2. The focusing was put at infinity. The edge of the vertical wall was situated at 150 meters. Image visualizations were adjusted in Log scale. An Astrosolar ND 3.8 neutral density filter was used after for the 5 ms exposure image of the disk shown at right at same scale for orientation and calibration.

supposedly allows evaluating at groundbased the extension of the scattered light, including the instrument PSF, closed to the solar limb, during a grazing occultation. The diffraction of the Sun light by the edge of the wall should be seen at the beginning just before the extreme solar limb appears. It apparently produces a total extension of at least 10 arcseconds. The aperture of the Maksutov telescope produces small diffraction minima and maxima when illuminated by the very small crescent of the solar limb and the measured distance between two maxima was estimated to be 3 +/- 0.5 arcseconds. Because the apparent path of the rising Sun in the sky is not strictly vertical like the wall edge, the contact corresponding to a less than 3 arcseconds crescent is rather short. These sequences allowed evaluating the solar aureola which is more than ten times more extended than the diffraction pattern, and it overlaps the Earth atmosphere scattering and the effect of the PSF. This shows the possibilities, without aureola in space, to observe very near the solar limb with Aspiics/Proba 3. Indeed, there will be much less parasitic scattered light in Space than at ground based, especially with a low Sun. The day of the 8th April 2011 was however very clear, without clouds and the seeing was fair. We also looked at the diffraction of the wall using the rising Sun, without green filter when focussing at 150 m. The following figure 4 shows two images we obtain with the defocused image of the Sun and the extension of the diffracted light by the wall.

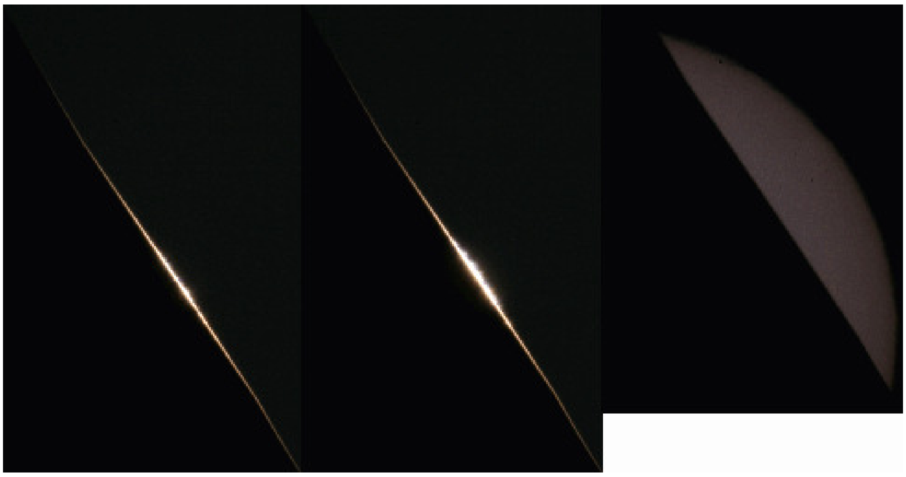

Fig. 4. Fringes with the occulted rising Sun while focusing on the wall at 150 m and a 0.25 ms exposure at 200 iso without ND; the solar disk at the same scale with a ND 3.8 and 5 ms exposure.

5 Conclusion

From the previous solar limb images obtained without an occultation in Space, we deduced that the solar light seen beyond the limb was due to the aureola effect (Earth atmospheric scattering and/or the instrumental PSF including extended wings) and in a lower extend, by diffraction fringes when a 50 mm aperture imaging telescope is used. The total diffraction extension obtained with tests with a linear wall edge had an extension of approximately 10 arcseconds, mainly due to the effect of the Earth atmosphere. We expect very much less parasitic scattered and diffracted light with the Aspiics/Proba 3 space mission. There will be no aureola. It will also be possible to observe close to the limb, for analysing the transition region and the low corona. From the total solar eclipse conditions, the solar edge is much better defined, while using high cadence flash spectra imaging, and this will continue to be the best method to be developed in the near future for studying the solar diameter.

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