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The transit of Venus and the Black Drop Effect

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Abstract. The long awaited transit of Venus on 8th June 2004 was a great opportunity to understand the notorious "Black Drop Effect", the appearance of a band linking the solar limb to the disk of the planet near the point of internal tangency, which heavily limited the accuracy of the calculation of the Astronomical Unit in the 18th and 19th century. CCD images obtained by the telescope of the Physics Department of Lecce, combined with the high resolution ones of the TRACE spacecraft and others taken all over the world in the context of the ESO VT-2004 Program, show that the black drop effect was probably due to a combination of atmospheric *seeing* effects, optical aberrations and a convolution of the systemic PSF with the planetary and limb-darkened solar disks.

1. Introduction

The 8th of June 2004 was the day of the long awaited Venus Transit over the sun. In 1716, E.Halley proposed a geometric method to calculate the distance between the Earth and the Sun starting from the times of the transit measured from observatories placed in different locations of known geographic coordinates. Nevertheless, the numerous scientific expeditions organised by the greatest scientific powers of that period had unexpected difficulties measuring with precision the exact moment of contact between the disk of Venus and the Sun, mainly on account of the Black Drop phenomenon (Van Helden 1989-1995).

The **Black Drop** is a type of link that connects the edges of the planet with the border of the Sun. It has been in various ways by observers throughout the centuries (see Fig.1) and it is also present on the photographic images. Different mechanisms have been proposed to explain its origin, ranging from astigmatism to diffraction phenomena, from the refraction of Venus' atmosphere to smearing caused by bad seeing (Schaefer 2001a, 2001b). Nevertheless Schneider et al. (2004) have demonstrated that this phenomenon also happened during the transit of Mercury as shown by the space images from the TRACE probe. Being a planet devoid of atmosphere, it is possible to exclude any refractive effects that this would cause. Moreover, the TRACE probe works in space and is therefore unaffected by alterations of the optical path due to the earth's atmosphere which would enlarge this phenomenon. This study documents the results of the observations made in this regard.

2. The observations of the transit

The observations were made with an apocromatic refractor with a 75mm opening, part of the equipment at the Physics Department of the University of Lecce, combined with a CCD detector with a fast scanning time (20 fps). The extremely high optical quality of the in-

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Fig. 1. Black Drop Effect as seen by Capitan Cook in 1769 from Tahiti

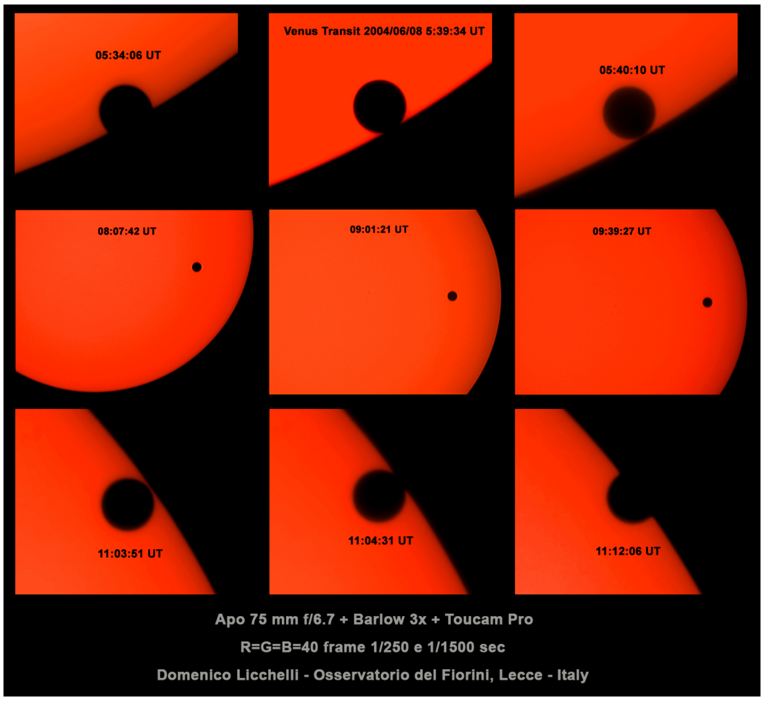

Fig. 2. The sequence of the transit of 8th June 2004. The technical data are on the image

strument should remove a priori effects due to various kinds of optical aberrations. The day of the transit was characterised by good and sunny weather, but with a high atmopheric instability due to the residue of an atlantic disturbance that had been raging in the Salento the previous night. The meteo data provided by the Observatory of Environmental Physics and Chemistry, Material Sciences Department at the University of Lecce, shows that for the en-

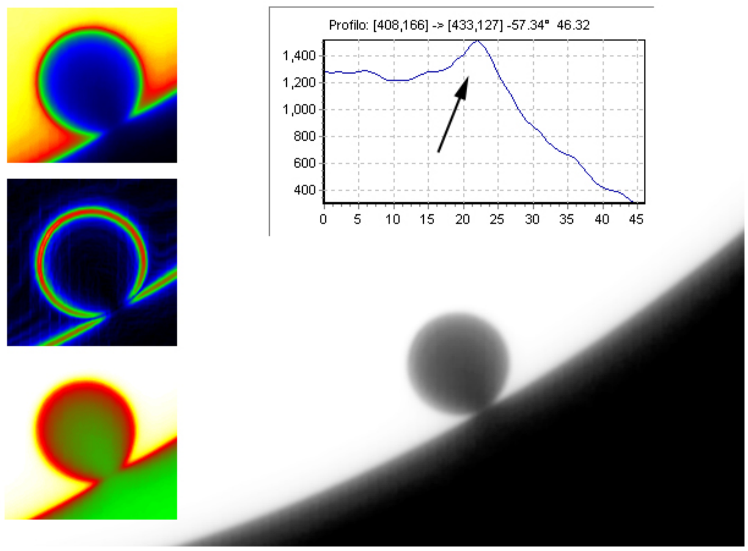

Fig. 3. The formation of Black Drop at the moment of the second contact

tire duration of the transit, the wind remained at a medium strength with gusts of strong wind (over 36 km/h at the moment of the IV contact), with frequent changes in direction and intensity. A convective current further complicated the acquisition of the images, making the focusing extremely problematic even with a modest focal length. Under these working conditions, it was impossible to investigate the evanescent phenomena related to Venus' atmosphere (halos, luminous arches, etc.) reported in observers' chronicles of past centuries. Imaging with a high frame rate (20 fps) and accurate elaborations of the frames focused on Venus' moment of entrance and exit on the solar disk, did however allow us to determine the contact times with a high degree of precision. This was the main aim of the VT-2004 Program, organised by ESO, in order to then calculate the distance between the Earth and the Sun. The value obtained was equal to **149.555.327, with an average error of 0.028%** (the real value of the Astronomical Unit is 149.597.870 km). Fig. 2 shows a collage of some moments of the transit. The central series, obtained through a direct focus allows for a better evaluation of Venus' diameter in relation to the sun's.

Fig. 3 shows the moment of the second contact. The Black Drop is evident both in the grey scale image and in false colour elaboration. In particular, the outline of the radial brightness drawn from the center of the Venus disk shows a sudden rise in corresponding with the thin thickness that was created between the borders of the two disks, as evidence that the tangent point was exceeded. Similar images were obtained from dozens of observers with the most varied instruments.

Fig. 4 shows that the link already begins to form when the two disk are in proximity of the tangent point, and reveals itself as a curve towards the inside border of the solar disk.

3. Conclusions

Instead, Fig. 5, depicts the entry and exit times of Venus, with reference to TRACE probe images (http://nicmosis.as.arizona.edu:8000/ ECLIPSE_WEB/TRANSIT_04/ TRACE/TOV_TRACE.html).

As already seen in the case of Mercury the Black Drop is clearly visible, with characteristics not unlike those in Fig. 6, but instead using images obtained from Earth.

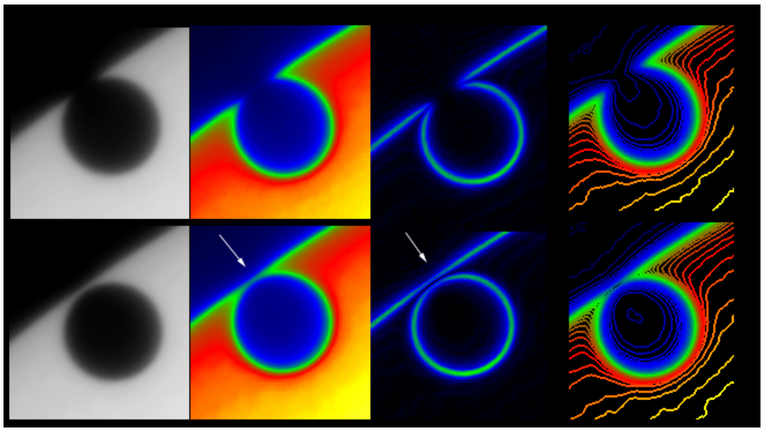

Fig. 4. The formation of the Black Drop at the moment of the third contact

Fig. 5. The Black Drop taken from the space from the TRACE probe in white light.

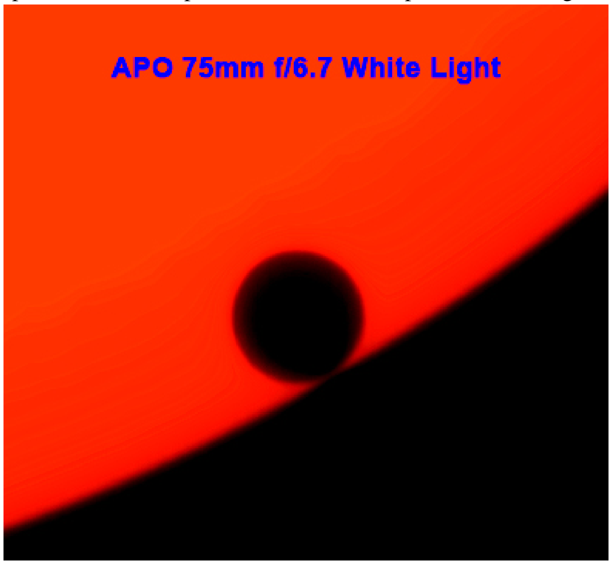

Fig. 6. The Black Drop taken from Earth in white light.

Space images confirm the hypothesis suggested by Schneider et al. (2004) about the formation of the Black Drop. The phenomenon is mainly due to the PSF instrumental convolution with solar limb-darkening. However, the importance of the phenomenon is certainly increased by the bad seeing conditions at the moment of the observations. In this case, a rather pronounced smearing is added to the first effect, obtaining the structures that are well reproduced by the digital simulations suggested by Schaefer (2001). From a quick survey made in the photographic archive of the VT-2004 Program http://www.vt-2004.org/photos/index.html, it is likewise evident that the optical quality of instruments is another factor that works to reveal the Black Drop and, more generally, to accentuate the deformations and distortions characteristic in different regions characterised by a high contrast. The transit of an internal planet over the Sun has lost its scientific importance for the calculation of the Earth-Sun distance. Neverheless, to study the implications in depth could be important in order to better comprehend the transits of the extrasolar planets, the number of which is in constant increase.

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