SF2A 2014
J. Ballet, F. Bournaud, F. Martins, R. Monier and C. Reylé (eds)

THE JUNE 6 2012 TRANSIT OF VENUS: IMAGING AND SPECTROSCOPIC ANALYSIS OF THE UPPER ATMOSPHERE EMISSION

C. Bazin[1], X. Zhi[2], D. Valls-Gabaud[3], S. Koutchmy[1], P. Rocher[4], Z.Y. Zin[2], Y. Fu[2], L. Yang[2], G.Q. Liu[2], Z. Liu[2], K. Ji[5] and H. Goodarzi[6]

Abstract. In the context of transiting exoplanets, the last June 6, 2012 Venus transit was a unique opportunity to address important questions regarding its atmosphere. The transit of Venus is indeed a particular case of an Earth-like planet transit, and the inference one can make about the upper layers of its atmosphere can be applied to other exoplanets. To this aim, we designed a small spectrograph that we placed at the focus of the New Vacuum Solar Telescope of Yunnan Observatory in China (45 m focus and 1 m of aperture), coupled to a 4K×2K 14 bit CCD detector, to measure low-resolution optical spectra of the refracted, scattered and transmitted solar radiation in the upper layers of the planet. It covered the 385-780 nm range when Venus was over the disc, and 540-680 nm (including the O_2 terrestrial bands) during the 18 minutes-long egress. The Hα and He I D3 lines were recorded repeatedly. The atmospheric Lomonossov arc of Venus was simultaneously imaged using Hα and TiO filters, allowing us to check the slit position on the images of Venus and to locate the spectroscopic features on its disc. The spectra show the signature of the Northern Pole horn part; a second part was evidenced on the spectra taken near but outside the limb. We studied the O_2, H_2O and Hα line profiles searching for signatures arising from Venus and we compared the observed spectra with synthetic models. The spectroscopic dataset can now be used by a large community for discussing the properties of the upper atmosphere of Venus and the future detection of Venus-like exoplanets. Finally, the study is completed using a unique very high resolution deconvolved image of the arc and Venus silhouetted at the limb of the Sun, from the SOT of the Hinode space mission.

Keywords: Venus, transit, Lomonossov atmospheric arcs, Venus upper atmosphere, exoplanets

1 Introduction

On the occasion of the last 6 June 2012 Venus transit, we designed a spectrograph that we installed at the focus of the New Vacuum Solar Telescope of 1 meter-diameter and 45 meter of focal length at the Fuxian Lake site of Yunnan Observatory.

The goal of these observations was the study of the Lomonossov arc (L-arc) arising in the Venus atmosphere. In the 18th century, Lomonossov was the first who claimed to have observed the arc that he interpreted as an evidence of the Venus atmosphere), for analysing the transmitted, refracted, and reflected light of the Sun in the Venus upper atmosphere layers, which are badly known (see Russel et al. 2006; Tanga et al. 2011; Ehrenreich et al. 2011; Pasachoff et al. 2011). The Lomonossov arc occur when Venus crosses the solar limb. The context of this experiment is also that Venus can be considerered as a transiting exoplanet across the Sun, hence providing reference (optical) spectra when Venus-like transiting exoplanets will be found. In fact, no visible spectra existed or were obtained in the past Venus transits, and this was a unique opportunity and spectroscopic experiment ever attempted. We covered the full the visible range, from 380 nm to 780 nm, when Venus was transiting the solar disc. The slit of the spectrograph was placed across the Venus shadow, and 4 spectra per

[1] Institut d'Astrophysique de Paris, 98 bis Bd Arago, 75014 Paris, France
[2] Fuxian Solar Observatory, Yunnan Observatory, Chinese Academy of Sciences, Kunming, China
[3] LERMA, Observatoire de Paris, 61 Avenue de l'Observatoire, 75014 Paris, France
[4] IMCCE, Observatoire de Paris, 77 avenue Denfert-Rochereau, 75014 Paris, France
[5] Yunnan Key Laboratory of Computer Technology, Kunming, China
[6] Tabriz University, IR of Iran

second were recorded simultaneously with narrow-band Hα and TiO images. During the transit, we inserted a Rochon Calcite prism, to measure the polarisation in two orthogonal directions (see the optical configuration in Figure 1). We observed a high polarisation ratio and the data are still being analysed. We obtained 200 spectra over 70 nm-wide spectral intervals. In this contribution, we present a subset of our results, dealing with the O_2 line profiles along and outside the Lomonossov arc.

2 The Venus transit spectra and TiO 706 nm and Hα images

2.1 Spectrograph and optical setup

We used a Littrow spectrograph setup with two achromatic lenses for reducing the transverse aberrations. We placed before the spectrograph the usual "solar"-type imaging setup with a beam splitter cube, allowing us to have simultaneously the spectra, plus a channel in Hα (with a narrow-band filter) and channel for imaging in the TiO 706 nm filter to obtain near-IR images, see Figure 1. Further details of the configuration used are provided by Zhi et al. (2014).

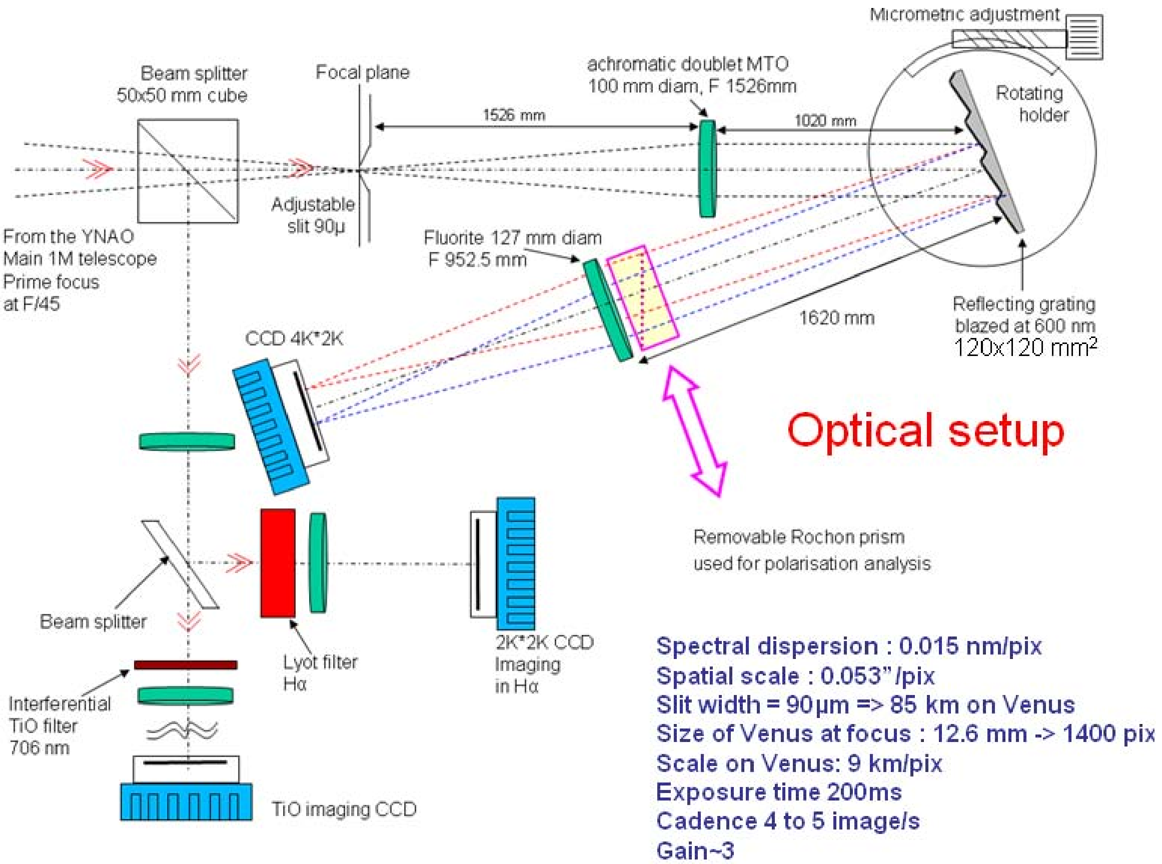

Fig. 1. Diagram of the optical setup after a cube beam splitter, including the Littrov spectrograph as a first channel, and the TiO 706 nm and Hα imaging channels in the reflected beam. We designed this setup for recording images and spectra simultaneously.

2.2 First visible spectra of the Lomonossov arc and O_2 line profiles analysis

Some 200 spectra with a 70 nm spectral range, covering the 380 nm to 780 nm interval, were successfully obtained during the egress phase of the transit of Venus.

As an example, we show a spectrum extracted from the sequence near Hα and the O_2 band. This spectrum (see Figure 2) was obtained when Venus was crossing the solar edge. Figure 2 also shows the Hα and TiO images obtained simultaneously, along with the position of the slit. The dark part of the spectrum is the shadow of Venus, and the bright continuum correspond to the Lomonossov arc.

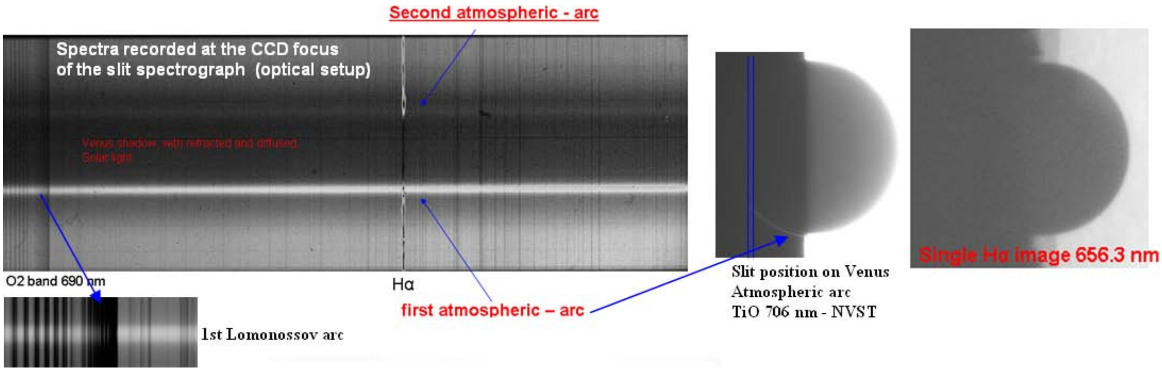

Fig. 2. *Left:* Two-dimensional spectrum in the O_2 bands and Hα region showing for the first time the spectra of the two Lomonossov arcs, (due to Mie scattering, see Ehrenreich et al. 2011). *Right:* the images in the Hα and TiO 706 nm bands and the position of the slit during the egress (when Venus crossed the solar limb at the end of the transit). Note the strong diffused light which makes the Venus disc not to be entirely dark, and the strong contribution of the chromospheric emission near the limb in the Hα image.

3 Discussion and conclusion

The adopted strategy for orienting the slit of the spectrograph was entirely successful. Two atmospheric horns corresponding to the Lomonossov arcs were observed, both photometrically and spectroscopically. The spectral range, exposure time, and the cadence were optimal. We observed the reddenning of the spectra, after analysing the intensity profiles in a more extended spectral domain.

The results presented here allowed us to disentangle the O_2 lines arising from the Earth atmosphere and those coming from the atmosphere of Venus. We note that there is a clear darkening followed by a brightening in the along the Lomonossov arc in the 688.8 to 688.9 nm O_2 line profile (see Figure 3).

The intensity profiles of Figure 3 give a better estimate of the gradients in the core (where the brightening occurs) and in the wings of this O_2 line as seen in absorption.

The collected data will be made publicly available and will be useful for analysis of Venus-type exoplanets, as the next Venus transit will not happen in 105 years (December 11, 2117). The database of level 2 spectra is in preparation and will be made publicly available.

CB and DVG warmly thank the hospitality of Fuxian Lake Observatory during the observations. We thank the entire NVST team from Fuxian Solar Observatory for the help provided to ensure the successful observations of the 2012 transit of Venus.

References

Ehrenreich, D., Vidal-Madjar, A., Widemann, T., Gronoff, G., Tanga, P., Barthélemy, M., Lilensten, J., Lecavelier des Etangs, A. and Arnold, L. 2011, A&A, 527, L2

Pasachoff, J.M., Schneider, G. and Widemann, T. 2011, AJ, 141, 112

Russell, C.T., Strangeway, R.J., Zhang, T.L. 2006, Planet. Space Sci., 54, 1344

Tanga, P., Widemann, T., Sicardy, B., Pasachoff, J., Arnaud, J., Comolli, L., Rondi, A., Rondi, S., and Suetterlin, P. 2011, Icarus, 218, 207

Xu, Z., Bazin, C., Valls-Gabaud, D., Koutchmy, S., Rocher, P., Jin, Z.Y., Fu, Y., Yang, L., Liu, G.Q., Liu, Z. and Ji, K. 2014, A&A Letters, submitted

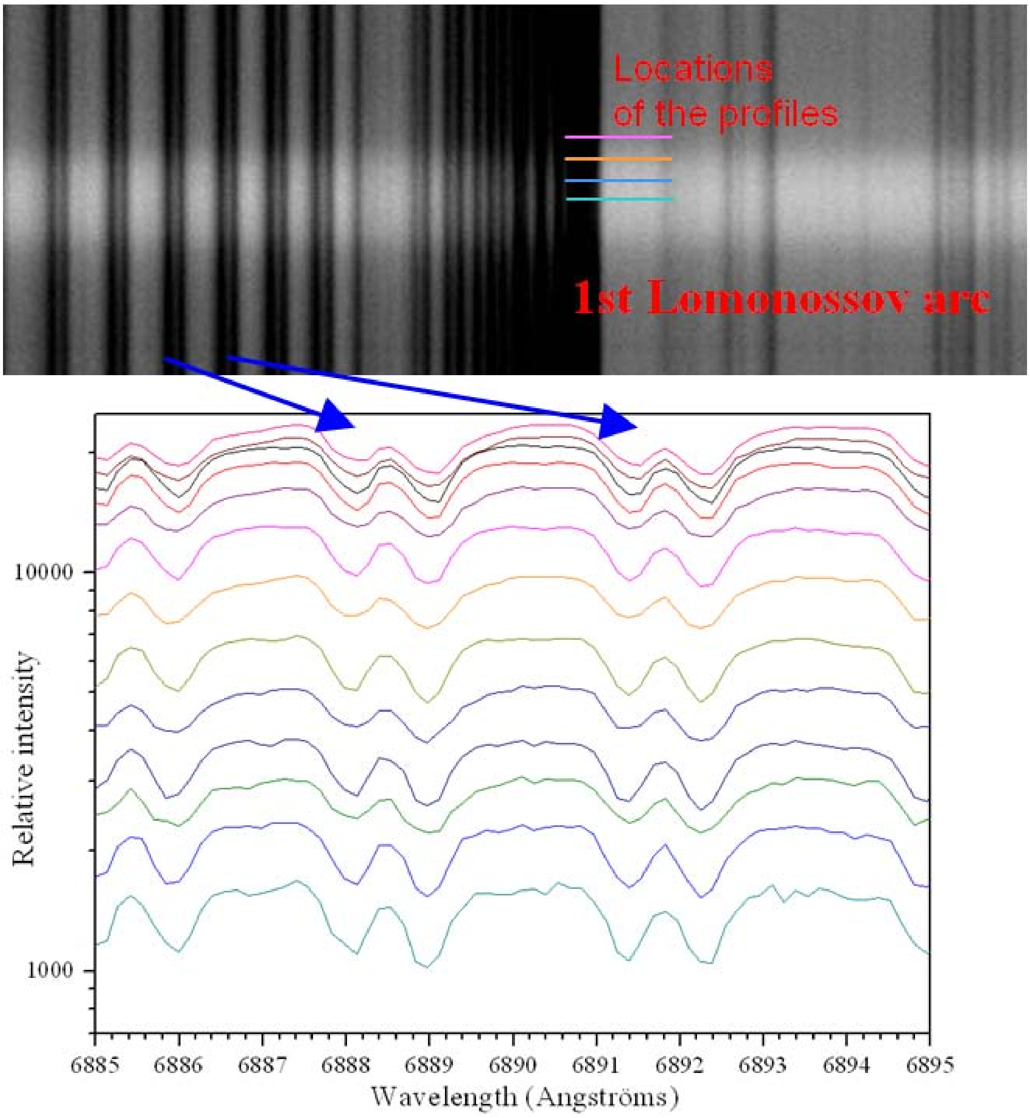

Fig. 3. Intensity profiles as a function of the wavelength in the O_2 terrestrial bands. The profiles are compared along and outside the Lomonossov arc to analyse the effects of the refracted, transmitted, and reflected solar light in the upper layers of the Venus atmosphere, and searching some O_2 line profiles signature. The distance between two consecutive radial cuts corresponds to 100 km on the Venus disc.

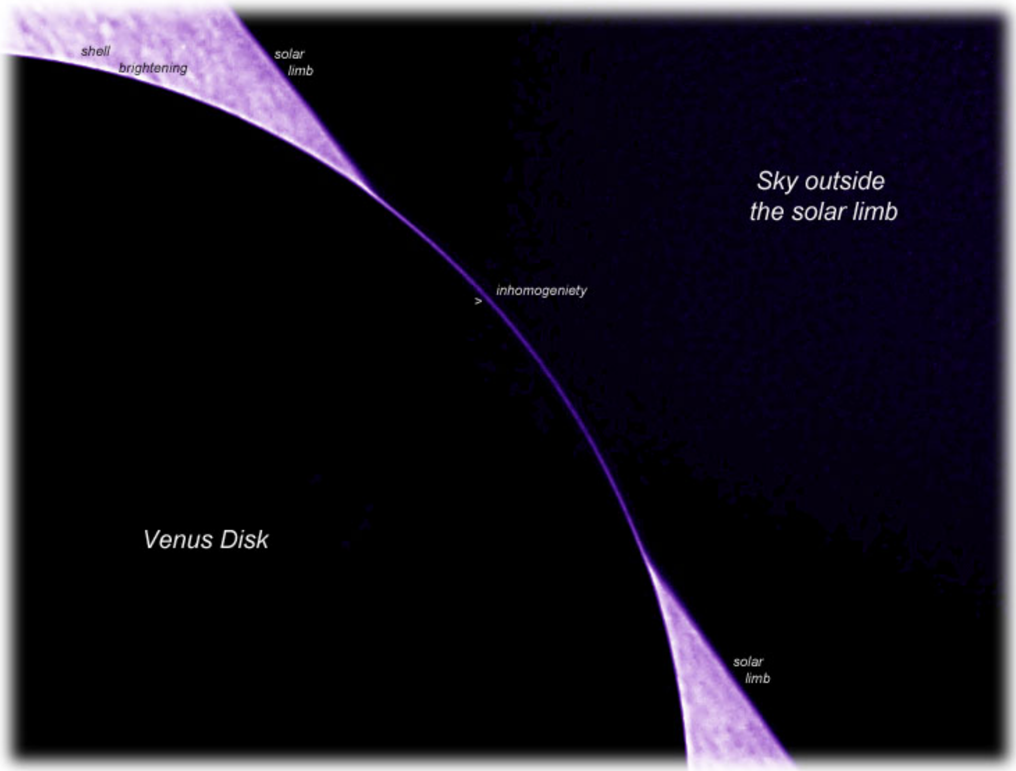

Fig. 4. The egress of Venus as observed by Hinode. The image has been processed and deconvolved, and note that no Gibbs effect is detected on the very narrow OII Lomonossov arc outside the solar disc. A narrow and faint brightening is seen around the disc of Venus, as seen in silhouette over the extreme solar limb.