

Signal-to Noise improvements for observations of 2023 Betelgeuse's Occultation

C. Sigismondi, ICRA/ICRANet and ITIS G. Ferraris, Rome

C. Costa, Specola Vaticana and IOTA/ES

A. Noschese, AstroCampania and IOTA/ES

K. Guhl, IOTA/ES

M. Bisconte, Saracena Library

Corresponding author: sigismondi@icra.it

Abstract: The occultation of Betelgeuse by the asteroid Leona was known since decades, and it has been prepared carefully. The local organizers of AstroCampania association were ready to react in real time to the meteo conditions and move and accomodate many observers from the Thyrrenian to the Ionian coast of Calabria, near the predicted centerline. A IOTA/ES meeting happened at lunch time in Cassano all'Ionio.

The uncertainty on the astrometry and on the diameter of Betelgeuse suggested to stay near the centerline, to obtain the maximum from data.

The battle against the scintillation was finally won by realizing multi-holes masks for large field-telescopes.

The preliminary results have been presented at the IAU meeting in memory of J. M. Pasachoff (1943-2022) who also planned special observations of this event.

Introduction among stellar occultations the one of Betelgeuse presented the opportunity to see a red supergiant, with the largest angular diameter, partially covered by an asteroid recently carefully monitored by a Spanish team.¹ A vaste zone of stellar penumbra was expected by the occultation of a 80x54 mas asteroid over a 48 mas star, and a centerline width of 17 km was ± 10 km uncertain because of the astrometry of Betelgeuse,² too bright for GAIA instruments.

Moreover Betelgeuse is the brightest variable star, classified as SR-C type, which undergone a major dimming in 2019-2020, of more than a magnitude, down to 1.8 visual.^{3,4}

The centerline's uncertainty, and the possible stellar activity, being Betelgeuse's luminosity at maximum phase (visual mag. 0.2), suggested to locate the best instruments on the predicted centerline.

Constraints from Meteo and Geography the field trips of this type of observations imply to set up an observatory in a short time, where the centerline is predicted and the weather is favourable.

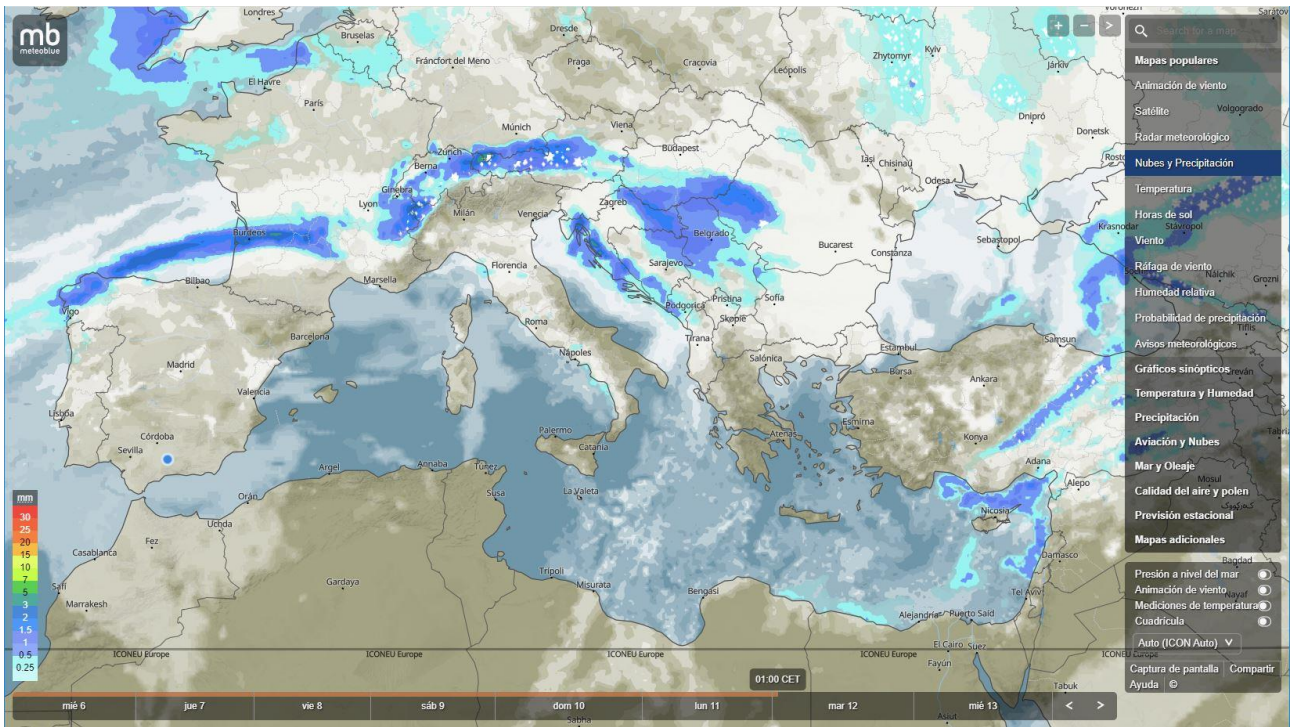
The Jonian coast of Calabria was considered better than the other, because of the clouds on the Thyrrenian basin and near the coast. The block made by the Pollino massif to the clouds guaranteed good observations on that night, excepted for some lenticular and thick clouds.

¹ [2309.12272.pdf \(arxiv.org\)](https://arxiv.org/abs/2309.12272) Ortiz, et al. (2023)

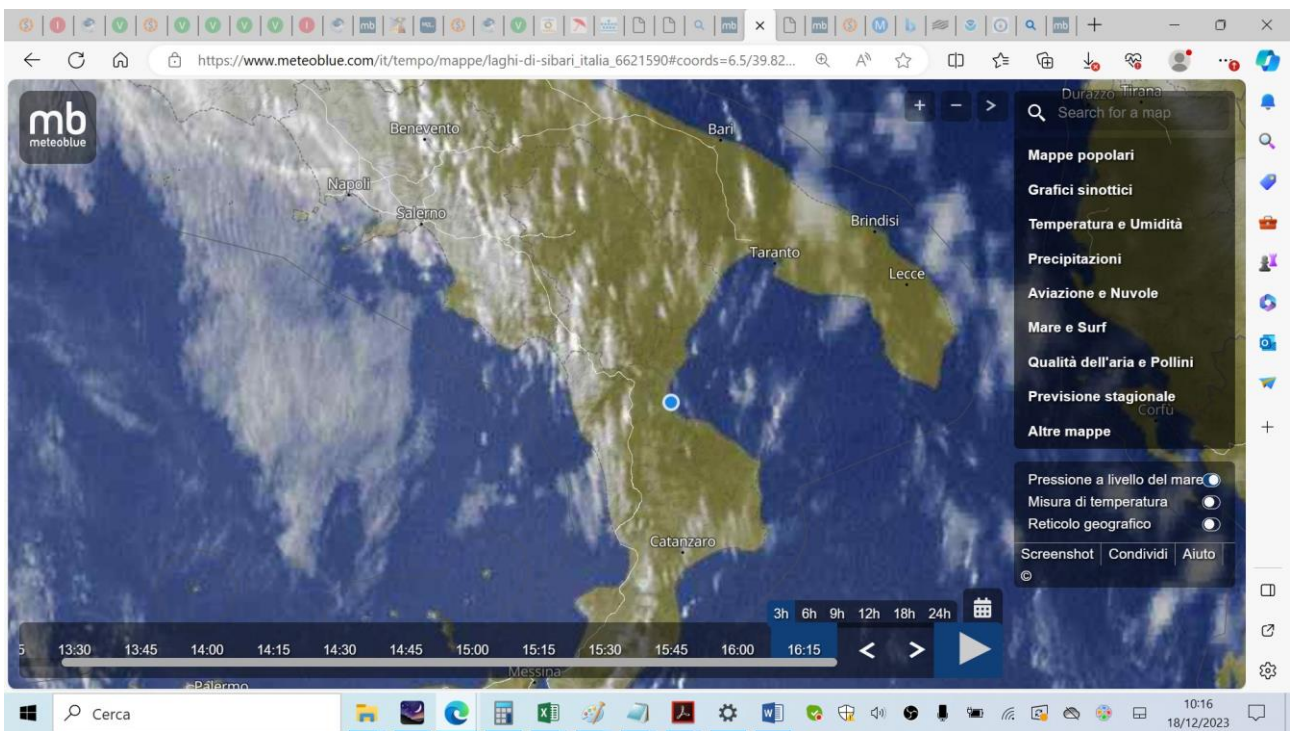
² <http://www.icra.it/gerbertus/2023/Gerb-19-2023-Sigismondi-Beteleguse-361-366.pdf> Sigismondi, et al., Gerbertus 19, 361 (2023)

³ [I.C.R.A. Network - Betelgeuse dimming \(icranet.org\)](https://www.icranet.org/) Jan 17, 2020 meeting

⁴ [16th Marcel Grossmann Meeting :: Virtual Meeting \(icra.it\)](https://www.icra.it/) Parallel Session, *Fall and Rise of Betelgeuse* (2021)



Forecast for the night of 11-12 december 2023 in Europe 6 days before (Meteoblue elaboration).



Real meteo conditions (satellite) in Calabria and Puglia at sunset of 11 december 2023.



Lenticular clouds with the atmospheric circulation in Calabria, as on 30 november 2023 from Saracena.



Lenticular clouds at sunrise of 13 december 2023 from Sibari (Betelgeuse's centerline).

Stellar scintillation with small telescopes it is well known that stellar scintillation is due to the continuous high frequency modifications of the unperturbed wavefronts and to the Poissonian noise, when the photon counts are low. For Betelgeuse the high luminosity saturates almost all astronomical sensors, even with small telescopes. The first approach was to use small apertures telescopes (50-60 mm).

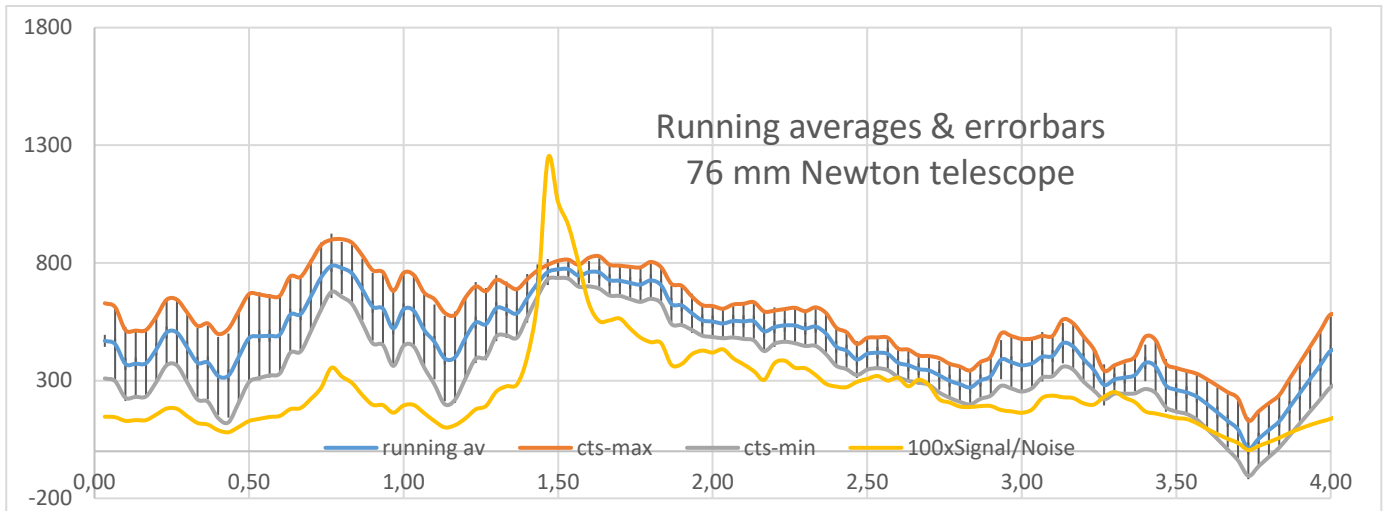
But the scintillation signal was much stronger than the expected signal from the occultation, which was going to be partial, around $\frac{1}{4}$ of the total luminosity of the star, for most of the centerline.

It was clear that a small telescope would have lost the light modulation's details from the progressive stellar covering. The idea of using multi-holes masks⁵ came out of the solution and we made trial video to show the bounty of that choice. The result was immediately spread Worldwide to allow all the observers to get the better data from this unique opportunity.⁶

⁵ Also known as **Hartmann masks** for focusing, but it was not the case here.

http://icranet.org/index.php?option=com_content&task=view&id=1514

⁶ <https://www.astronomerstelegram.org/?read=16374> C. Sigismondi, C. Costa and A. Noschese (2023).



The signal to noise ratio in a **cloud-occultation** of Betelgeuse at 1:08:30 UT (Sigismondi observing station, Sibari, 6 km North of the predicted centerline). The max value of S/N is 12, while the masked Leviatan allowed to reach 30 steadily.



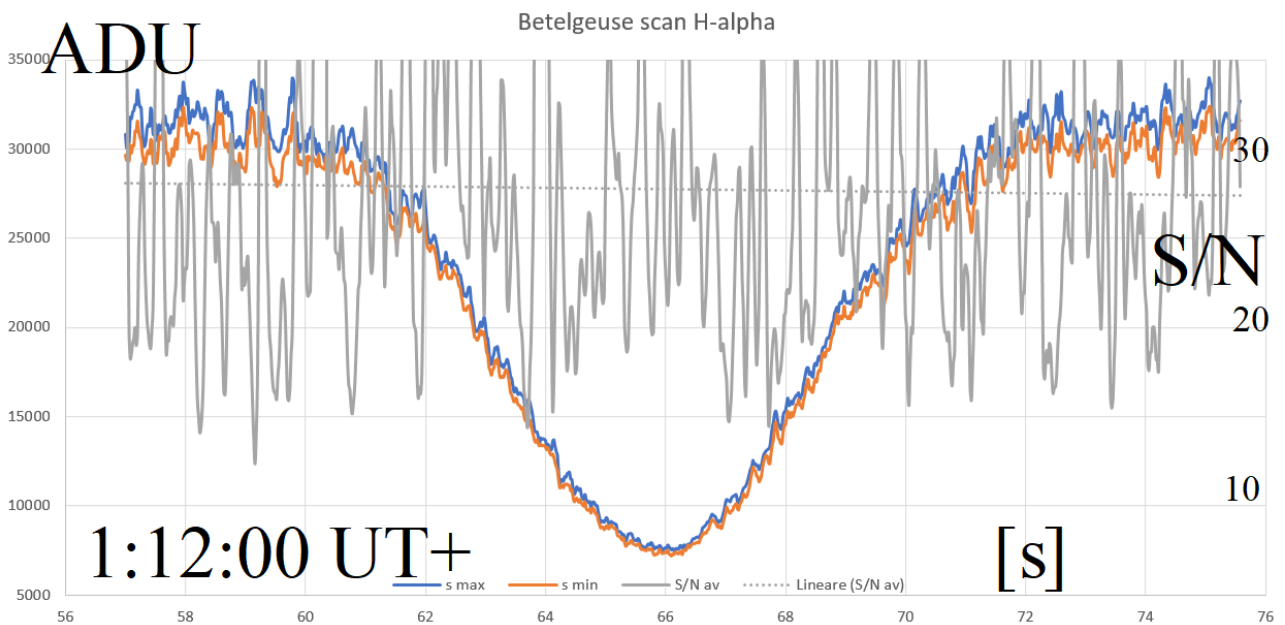
The telescopes' setup at Noschese's observing place: C9, 10 cm refractor.



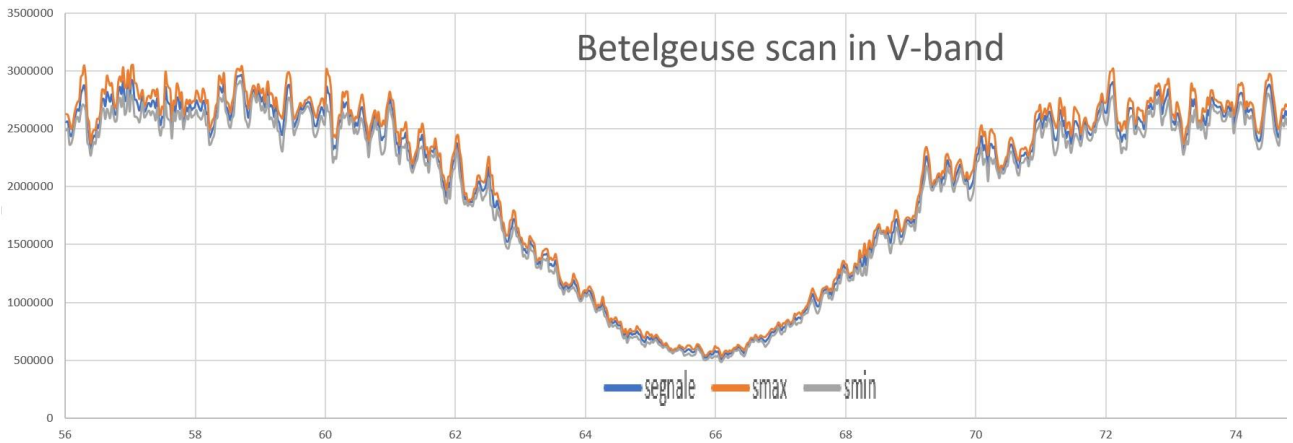
Noschese's masked "Leviatan" 50 cm Newton Dobson-mount telescope, with the mask.

Lightcurves

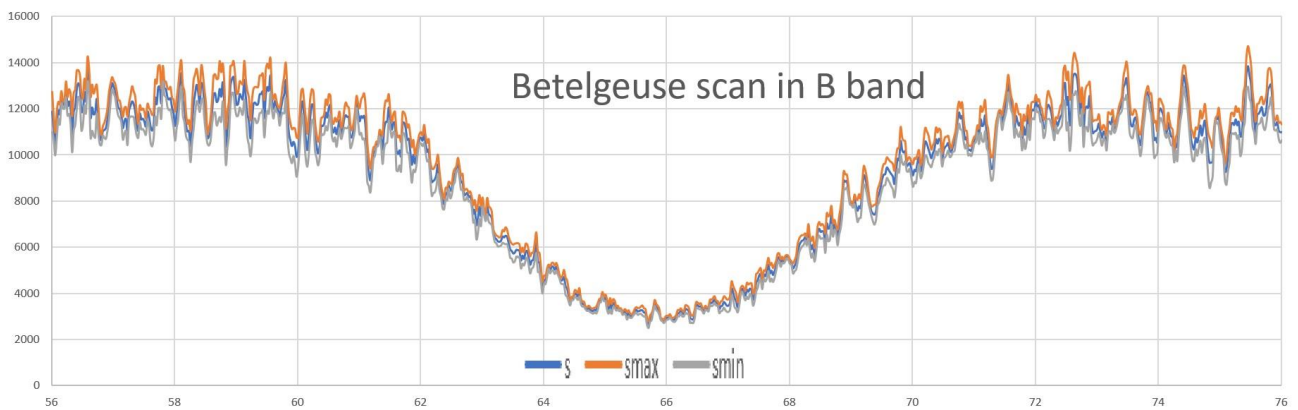
The preliminary analysis is still ongoing on December 18, but this papers wants to show the Signal-to-Noise of the masked Leviatan compared with the 3'' Newton, clouded out at the climax moment.



The H_{α} curve of the occultation of Betelgeuse (50 cm Dobson, the "masked Leviatan"). In red the minimum signal and in blue the maximum. Running averages over a 0.1 s, along with the standard deviations from the same value. The Signal-to-noise ratio is always at level 30.



Betelgeuse scan in V-band (Noschese's station, telescope C9 23.5 cm f/10), V filter Johnson Cousins, 8 holes x 40 mm mask, exposition frames: 25 ms.



Betelgeuse occultation in B band (time from 1:12:00 UTC). Refractor 10 cm f/5 no mask, 25 ms exposition. Noschese's station.

The starting of the occultation is the first bending of the curve, and the total occultation lasted about 12 s.

The angular velocity of the asteroid was 8.22 mas/s.⁷ The duration of the occultation in B band (10 cm telescope), and V band (28 cm) is also clearly visible, and this permitted to do the first estimates⁸ of the stellar diameter.

The start-to-end time of the occultation to the present analysis is transformed into angular chord of the asteroid+star as H-alpha 100±0.7 mas; V-Band 103 mas and 98.6 mas in B-band. A smaller H-alpha size than the V-band is intriguing, but completely preliminary.

Also asymmetries in the light curve have to be confirmed by independent observations, because a cloud veil could have determined them very easily.

Naked eye spectroscopy in Saracena and Kepler's planetary occultation at 11.7 km north of the Preston's centerline⁹ another team was observing the phenomenon with naked eye. Mariangela Bisconte accounted:
¹⁰ *It was not an ON/OFF phenomenon, but rather a dimming. It is like a dark veil was passing on Betelgeuse*

⁷ <https://cloud.occultwatcher.net/event/1075-319-83995-648466-H27989/1246616> Steve Preston, (2023).

⁸ D. Herald on Planocult mailing list, 16 dec 2023. The Star is 58 mas in H-alpha, 59 in V-band and 59 in B-band, the LDF parameter u=0.98.

⁹ <https://cloud.occultwatcher.net/event/1075-319-83995-648466-H27989/1246616> with 1 Dec (update)+ 27 Nov (orbit)

¹⁰ Anche se è improprio utilizzare la terminologia

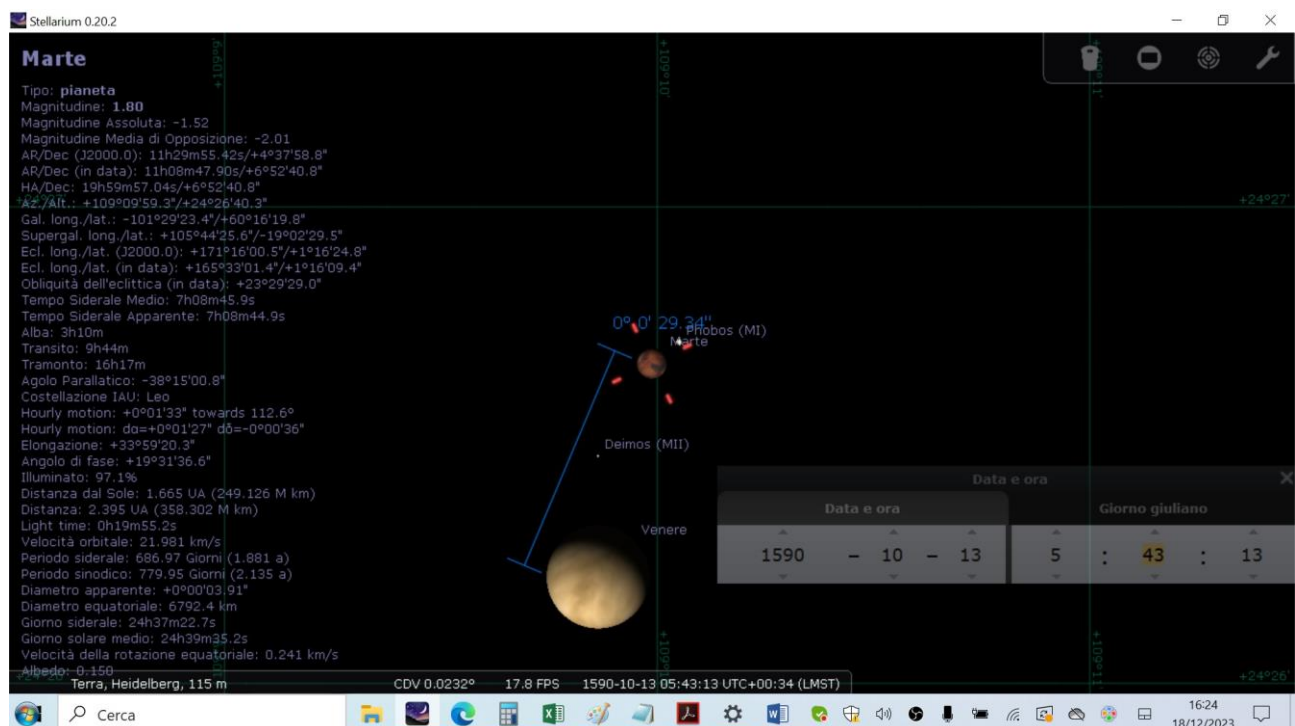
which darkened the colors from red-orange it become opaque and gray. Immediately after this passage the star turned bright and sparkling red again.

The timing of this phenomenon was 2:13:00 local time, as in the ephemerides, and the perceived duration was slightly larger than 1 second. The time to pronounce “Angelo–di” rapidly.

The change in color was perceived, and this can be explained as originated by the asteroid Leona covering the center of Betelgeuse and leaving visible the limb darkened peripheral zones.

The account was original and not changed according to previous astrophysical technical knowledges.

To find a similar account about colors, we have to go back to 1590¹¹ when with his master Michael Maestlin, Kepler observed in Heidelberg the occultation of Mars by Venus in 1590. Kepler accounted of the white color of Venus merging with the red one of Mars. In that phenomenon, during 36 minutes, the two planets were separated by less than 20 arcseconds, the limit for naked eye angular resolution.



Simulation of the Venus-Mars occultation of 1590, observed by Kepler and Maestlin in Heidelberg.

Conclusions The decision to adopt many holes-masks maturated in the discussions before the occultation and it allowed to reach a Signal-to-noise ratio of 30 in each frame of the video, necessary to obtain clear light curves of this unique occultation.

The first occultation curves fit¹² a diameter for Betelgeuse larger than predicted (60 vs 48 mas) with differences in H alpha, V and B bands. A strong limb darkening ($u > 0.5$) is also evident, from fits and from naked eye observations.

“accensione/spengimento”, è stato più come un offuscamento. È come se dinanzi a Betelgeuse passasse un velo indubbiamente scuro che ne ha opacizzato i colori: da rosso-aranciato, mi è parsa di vederla opaca appunto e grigiastrea. Immediatamente dopo il passaggio di questo velo, Betelgeuse è tornata a brillare più intensamente di prima e con un bel colore rosso acceso.

¹¹ https://en.wikipedia.org/wiki/Planetary_transits_and_occultations#cite_note-sat57-3

¹² https://starblink.org/occult_simulator realized by University of Granada, Astrogranada-Sociedad Astronomica Granadina and Instituto de Astrofisica de Andalucia.

The change in color of Betelgeuse during the occultation was also visible to the unaided eye, without previous specific advice. This was possibly the first naked-eye observation of Limb Darkening evidence of another star, beyond the Sun.¹³

Acknowledgments Massimo Corbisiero of AstroCampania association, who chaired the local organizing committee. Maria Dal Pian, Paolo Ochner and Federico Manzini who discussed the preliminary data. Cesare Barbieri and the AQUEYE/IQUEYE team, already active in Occultation projects at Asiago Observatory.

¹³ A spectrum by Sebastian Voltmer at Almodovar del Rio, is available on the web, https://spaceweathergallery2.com/indiv_upload.php?upload_id=202392