Detecting the penumbra of Betelgeuse with a diffuse telescope during the Leona occultation

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Abstract The asteroidal occultation of Leona over Betelgeuse on December 12, 2023 offers the opportunity to study the surface disomogeneities of the closest supergiant star, by combining the data of a "diffuse telescope" displaced on the Calabria's Italian coast. To reduce the scintillation noise, some remarks on the difference with a traditional occultation's scope are here presented. Defocusing this 0.2 magnitude star will spread its signal over a larger area of the detector, avoiding the saturation. The loss of the imaging quality and of reference stars –as in the traditional asteroidal occultations- is compensated with a cleaner signal in the crucial phases of descent-ascent ramps of the light curve of this occultation, where all the information of the stellar surface are present. In case of partial occultations, a few kilometers North or South from the centerline, also the highest signal-to-noise ratio with a reduced scintillation will improve the final result. The comparison with 2005 Regulus total occultation is discussed in view of chosing the correct telescopes for observing this phenomenon

Sommario L'occultazione asteroidale di Leona su Betelgeuse del prossimo 12 dicembre 2023 offre l'opportunità di studiare la superficie della stella supergigante più vicina. L'uso di un "telescopio diffuso" disposto su 100 km di costa calabra a Nord e a Sud della prevista centerline permetterà questo studio. Al fine di ridurre il rumore di scintillazione senza arrivare alla saturazione del segnale si suggeriscono due tecniche: defocus e maschera all'obbiettivo. Betelgeuse è attualmente di magnitudine 0.2 quindi la sua luce può saturare i rivelatori più sensibili se focalizzata, mentre sparpagliarla su un'area più vasta mediante defocus risolve il problema della saturazione, permettendo di usare tutta l'apertura del telescopio che riduce l'effetto della scintillazione. Una maschera in cui sono creati dei fori circolari la cui area sia tale da non far saturare Betelgeuse, ma da cogliere più caustiche del fronte d'onda contemporaneamente, manterrebbe l'imaging ed eviterebbe la saturazione. L'imaging però, oltre il disco di Airy della stella, che dipende dal diametro del telescopio, non fornisce altra informazione di rilevanza astrofisica, mentre una curva di luce con scintillazione inferiore al 100% può essere molto utile per tutte le osservazioni condotte, sia dove l'eclissi è totale, sia dove è parziale.

Keywords: stellar astrometry, stellar diameter, stellar surface, Betelgeuse, asteroidal occultation.

Opportunity of this asteroidal occultation. Normally a total asteroidal occultation is used to measure the position and the

shape of the asteroid, and normally the star is practically point-like. In the case of Regulus' occultations of 2005 and 2014 the stellar diameter was 1.3 mas (milliarcseconds), which produced a very tiny modulation of the signal before and after the onset of the totality, but in general only the Fresnel fringes are expected to occur for such a phenomenon.

For 319 Leona main belt asteroid the shape has been recently monitored in Spain, but the real opportunity is given by the 48 mas angular extension of the target star: one of the seven brightest stars in the sky and possibly the largest in angular diameter, beyond our Sun.

Resolution beyond Rayleigh limit to resolve details on a 48 mas disk it would be necessary at least 5 mas of angular resolution, in order to have at least 10 pixels. It implies a 200-m telescope, with a diameter similar to the VLT interferometric array. With a single telescope, used as a photometer, we can capture the light of Betelgeuse during the occultation while the asteroid covers gradually the stellar surface. The stellar light modulation will locate the limbs of the star as the asteroid covers them, generating an ON/OFF signal, modulated by its Fresnel fringes. As in al the occultations the chords of the asteroidal shadow depend on the position of the observer with respect to the real centerline, but **the penumbral signal of Betelgeuse is the complete novelty** for such type of observations.

Duration of the phenomenon, order of magnitude analysis Leona is a 54x80 km (Ortiz et al., 2023) outer main belt asteroid discovered in Nice Observatory in 1891, and at its distance from Earth, will span 41x60 mas. Betelgeuse is a supergiant star of 48 mas of diameter, corresponding to roughly 1000 times the solar diameter at about 600 light years and to 63 km at the asteroid's distance. The uncertainties on these dimensions are probably well beyond 1 mas, because the star

is an "irregular variable star" and the asteroid is not a perfect sphere indeed. The position of the asteroid is better known with respect to the one of Betelgeuse. α Orionis' position has an uncertainty still around 10 mas, for computing the centerline position. The geometry of that occultation is probably very similar to an annular-total solar eclipse, with a very narrow annularity strip, which will be found...by chance!

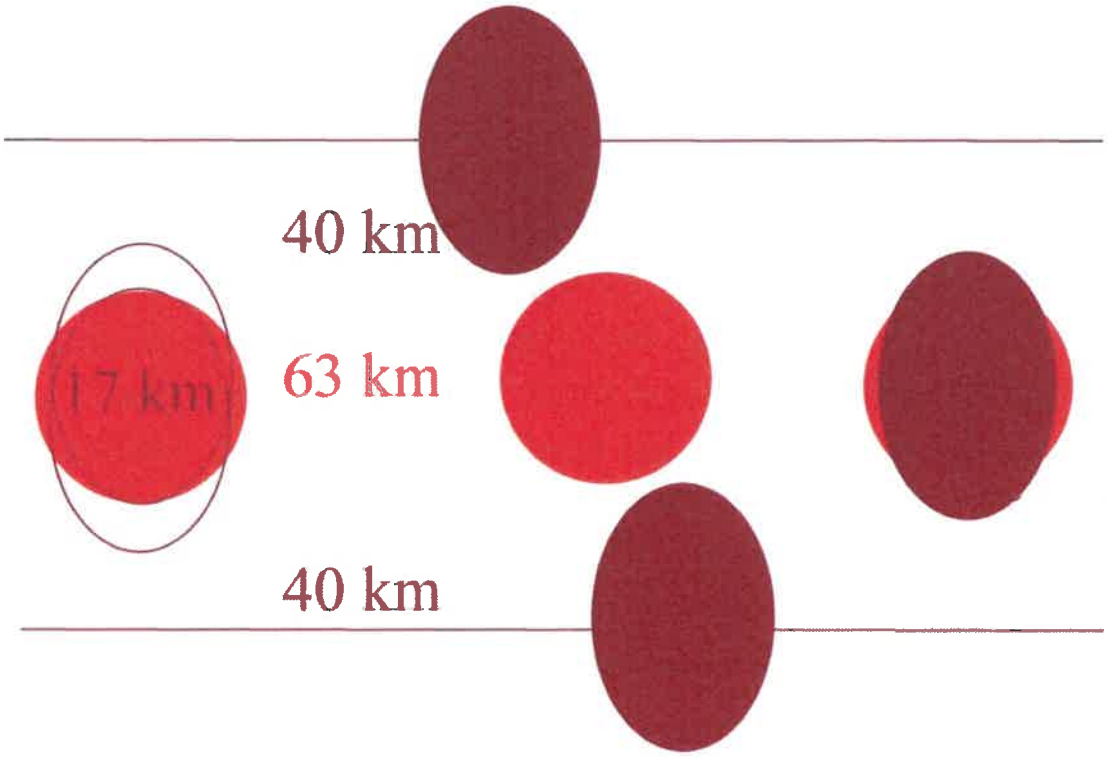

Fig. 1 Total and penumbral eclipse for Betelgeuse under Leona in the sky. Centerline from Steve Preston (2023), Belvedere Marittimo (CS) https://cloud.occultwatcher.net/event/1075-319-83995-648466-H27989/1246616

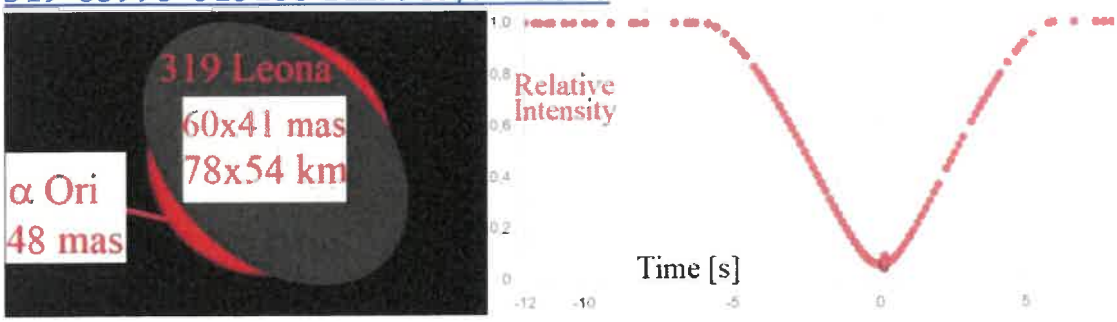

Fig. 2 Eclipse simulation of Granada University (2023) https://starblink.org/occult_simulator_en with Ortiz et al. data.

According to Ortiz et al. (2023) the dimensions of Leona are 78x54 km or 60x41 mas, the orientation unpredictable (45° in the simulation of fig. 2).The velocity of the asteroid is around 8 mas/s, then the partial phase may last 5.8 s, the two ramps of partiality phases other 5.8+5.8 seconds in the centerline (for ideal spherical objects). Also on the penumbral zones an information on the stellar disk is available: in the Northern zone we can collect the integrated luminosity of the exposed Northern hemisphere of the star, and the same for the South.

Scintillation and signal-to-noise ratio in the case of Regulus in 2005 we could record with an old tape-camcorder (50 mm standard objective lens, 25 fps) a video of the occultation during a cloud crossing. The scintillation signal was producing irregular oscillations equal to the 100% of the stellar flux.

Now the astronomers are equipped with better performing cameras, and the problem is only to reduce the scintillation avoiding the saturation. A 20-25 cm diameter telescope offers less scintillation than a 5 cm one, it can be used or with a coded mask on the objective, or with defocusing the star to avoid saturation.

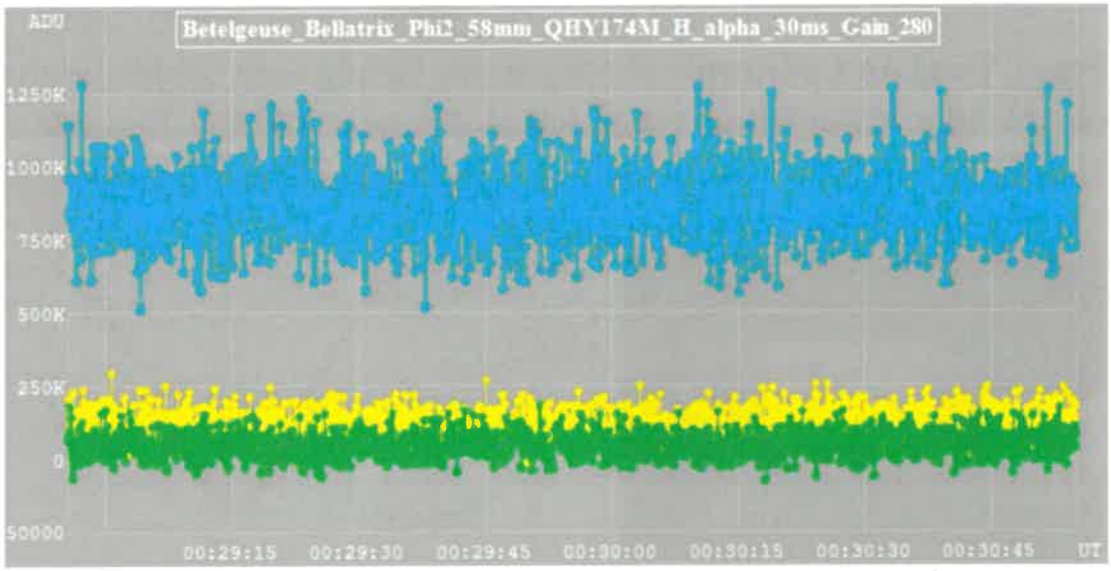

Fig. 3 Light curve, aperture photometry, bkg mode (courtesy of Claudio Costa, IOTA). The scintillation is due to 58 mm lens.

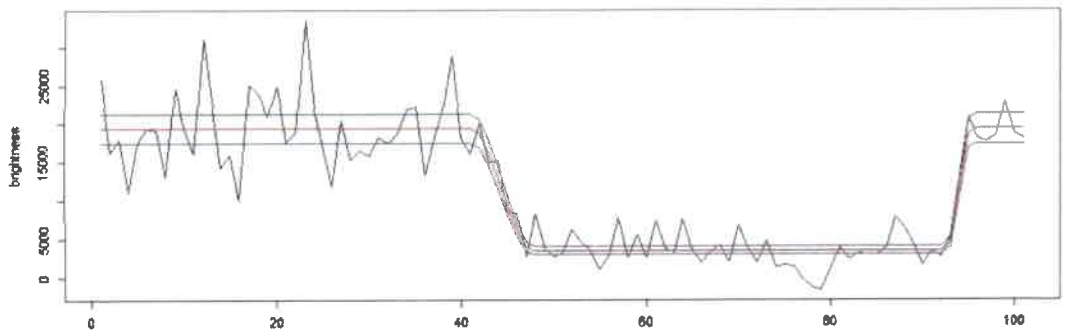

Fig. 4 The occultation of Regulus 19 oct 2005 (fig. 7 ref. 1). The scintillation is strong, from 50 mm lens objective.

Scintillation mask: to record more wavefronts' cusps and maintaining imaging capabilities (not useful for studying the stellar surface) it is possible to cover the objective with a many-holes mask in cardboard.

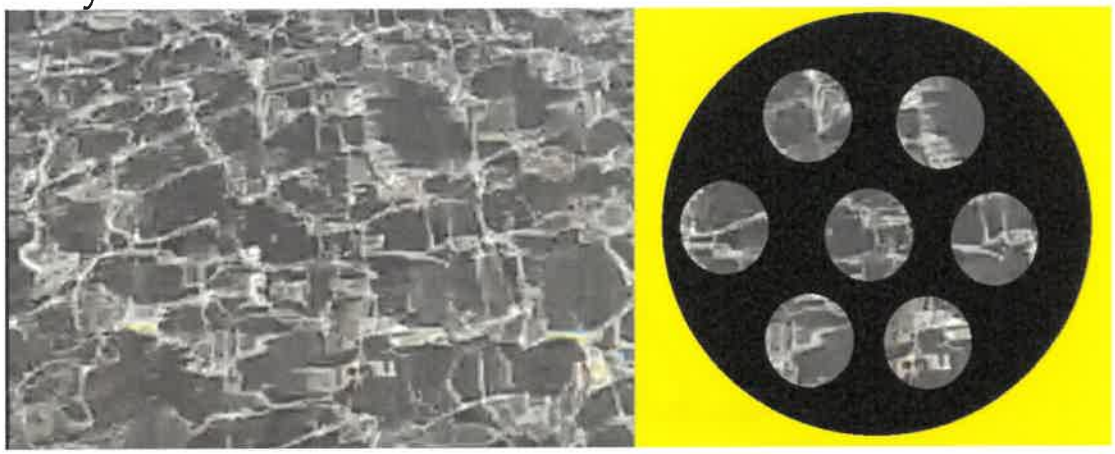

Fig. 5 The perturbed stellar wavefront with the caustics, where is the highest level of scintillation, and the many-holes mask.

My recommendation is to use the main 20 cm telescope with defocus, neglecting the problem of comparison stars.

Betelgeuse itself will provide the calibration for its un-occulted flux, **since the relevant information is available only during the partial phases of penumbral eclipse**, and it will differential in any case. The cloud passed in 2005 over Regulus in the first phase of the occultation shows why the reference star was not useful, while an improved signal-to-noise ratio from the stellar signal is now crucial for the surface details determinations.

Conclusions The relatively large angular diameter of Betelgeuse will determine a 5-6 s of partial occultation, or penumbral occultation both before and after totality, and a similar situation in penumbral (partial) eclipses from about 90 km North or 90 km South of the centerline, making **all the observations worth to be done**. At the present time the Calabrese coast from the Policastro Gulf to Capo Vaticano, is all interested by the relevant total phase of this occultation, but the outher penumbral zones of 72 km expand the area of potential observers.

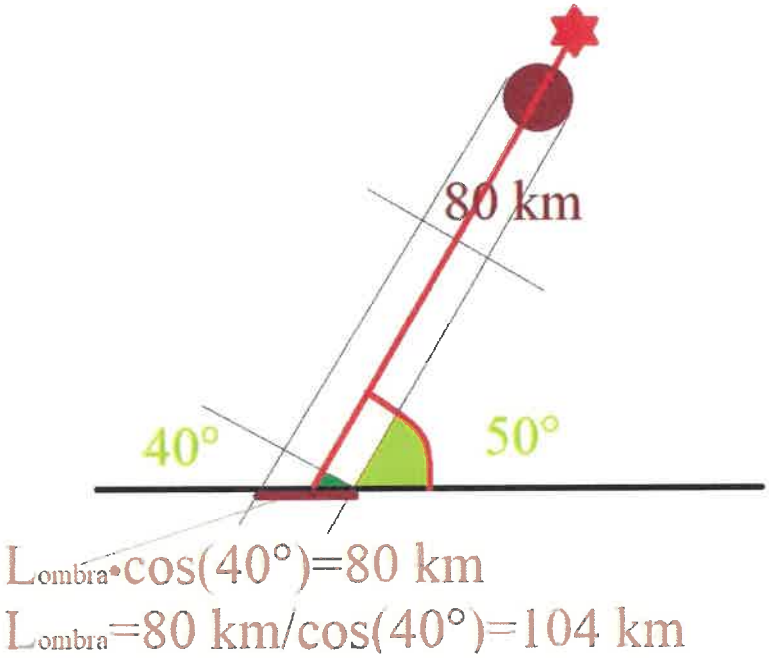

Fig. 6 The projected lenght of the asteroidal shadow at 50° of altitude for Betelgeuse as in Calabria the night of 12 december at 2:12 local time.

Acknowledgments: to Alfonso Noschese and Claudio Costa.

References

Ortiz et al. https://arxiv.org/pdf/2309.12272.pdf (2023)
Sigismondi, C. (2023) https://youtu.be/g4JuwpqLysA
Sigismondi, C. , Flatres, T. and T. George, (2014)
https://arxiv.org/ftp/arxiv/papers/1403/1403.4926.pdf

Betelgeuse Occultation day before: logistic and instruments

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Alfonso Noschese (AstroCampania, Italy)
Udated: December 11th 2023

Abstract The locations for observing the asteroidal occultation of Betelgeuse have been choosen on the Jonian coast of Calabria, for being near the centerline and with a clearer sky, according to the last weather forecasts (meteoblue 16 hours before the occultation). A prevision of the magnitude reached by Betelgeuse at maximum occultation, with respect to the Limb Darkening Function and to the predicted centerline, with the corresponding errorbar of 10 milliarcseconds are presented.

Sommario Le posizioni per l'osservazione del fenomeno sono state scelte nella costa Jonica della Calabria in base alle previsioni meteoblue 16 ore prima. Una simulazione per valutare la curva di luce dell'occultazione, la magnitudine stellare al suo massimo e la variazione con la Limb Darkening Function di Betelgeuse sono presentate, anche considerando l'incertezza di 10 millisecondi d'arco sulla posizione di Betelgeuse.

Keywords: stellar astrometry, stellar diameter, stellar surface, Betelgeuse, asteroidal occultationò, Limb Darkening Function.

Weather forecasts and Ephemerides for Sibari (Jonian sea)

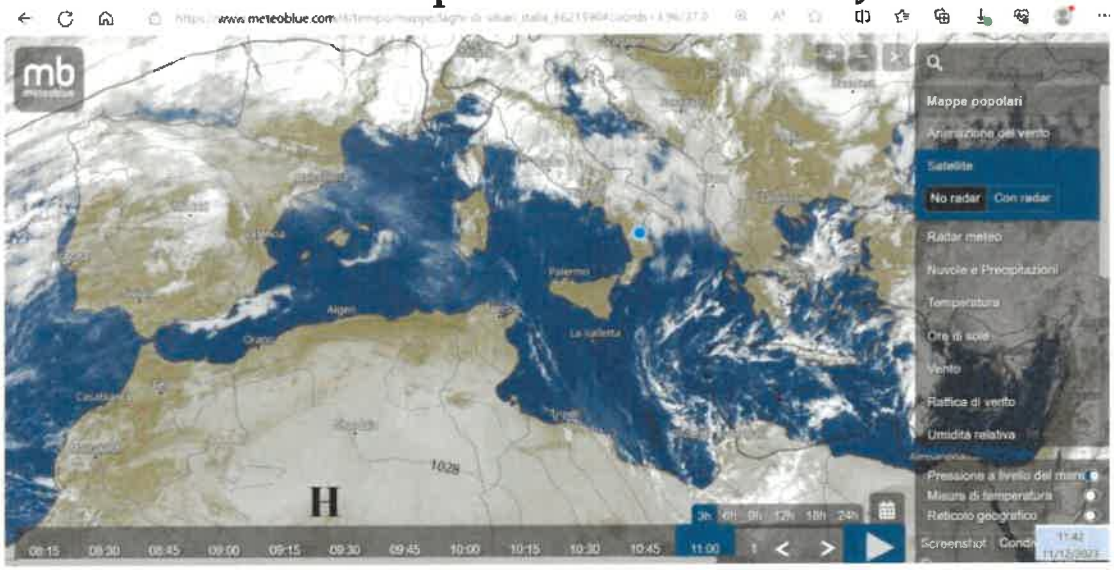

Fig. a The high pressure is established over Algerian Sahara, with a clockwise motion of the clouds at 700 mb (3000 m), coming from North in Calabria, either Jonian or Thyrrenian.
The air circulation is evidenced in the wind animation obtained with meteoblue "Laghi di Sibari".

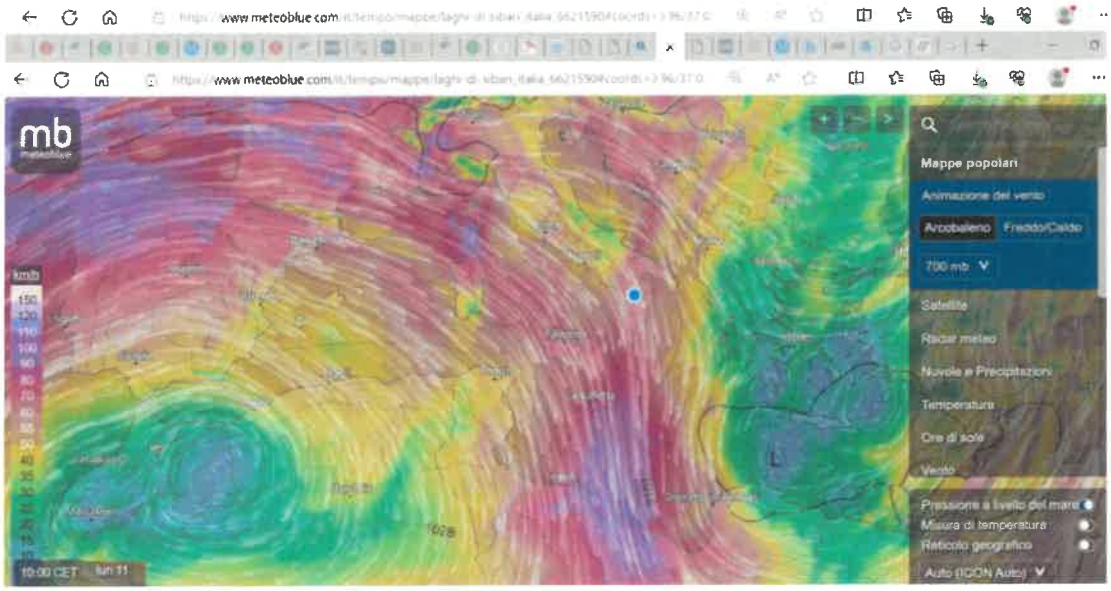

Fig. b Wind animation at quote 3000 m, as on 11 dec 10 UT.

The local forecast for Sibari is represented in the figure below:

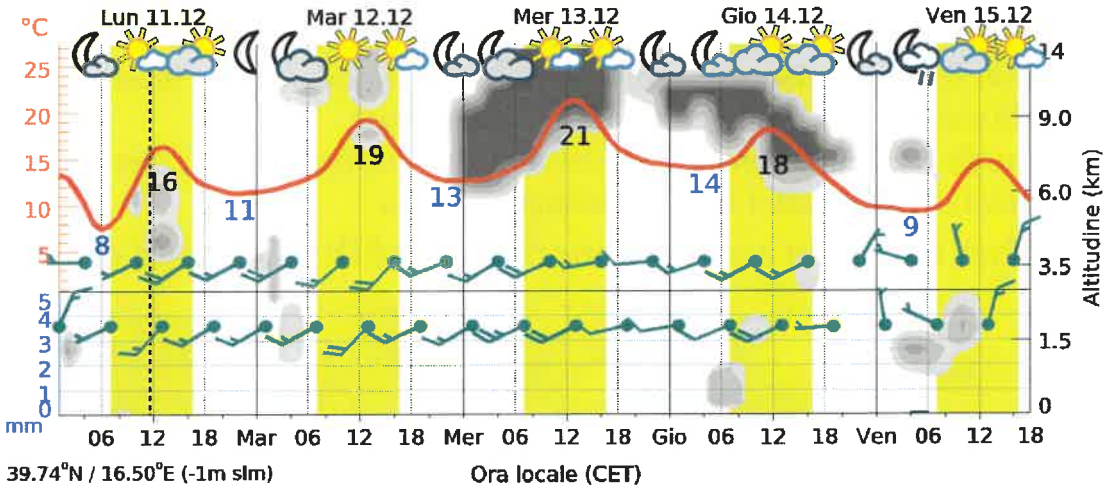

Fig. c Clouds' coverage at 3-4000 m for 12 december at 2 AM. This is the better forecast for the centerline.

Ephemerides of Steve Preston's Occultwatcher site aren updated to 1 dec 2023. Event Prediction (occultwatcher.net)

Sibari is 6.9 km North of the centerline (right, according to the direction of the asteroidal motion). The uncertainty of Betelgeuse's position is ±10 mas, ±20 km on the ground at maximum, then Sibari can be actually from 26.9 km North to 13.1 km South of the real centerline. For the three cases, selecting a 90° rotation of the asteroidal profile, we obtain the curves in fig. d, with the website of the University of Granada.

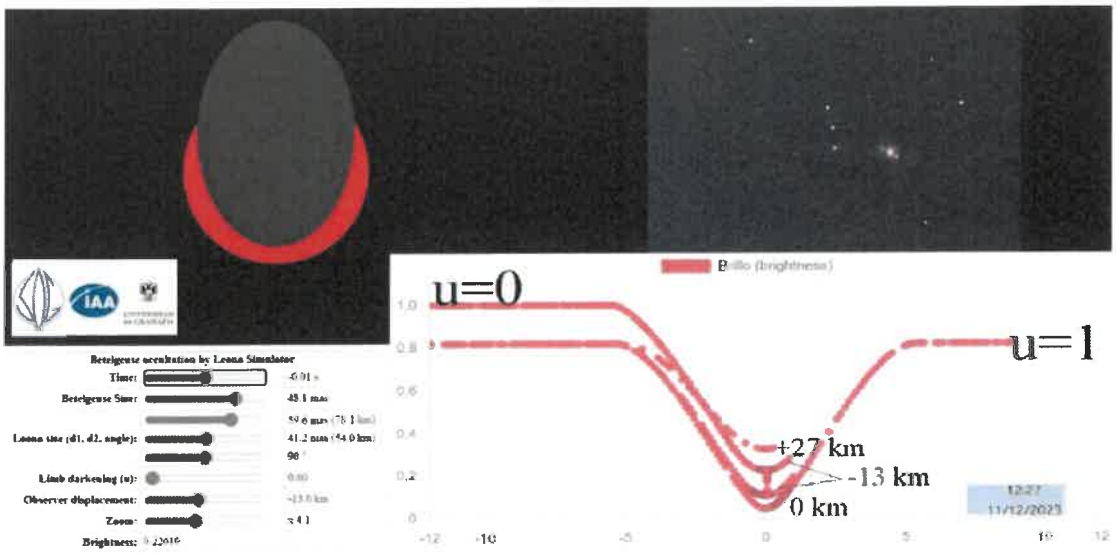

Fig. d Simulations of the light curves with and without LDF, at the real centerline, and +27 km or -13 km as the limiting values for Sibari's distance. The normalization is 1 for u[1]=0, 0.8 if u=1.

Magnitude of the lightcurve: Betelgeuse is presently at visual magnitude 0.25 (from AAVSO database). The photons' flux from the star drops to 0.04 from a 0.8 of total flux with u=1. It corresponds to a 5.75 magnitudes drop in the centerline, and 2.25 mag for -13 km, and only 1.0 mag for +27 km.

In the case of no LDF (uniformly luminous disk, u=0) the computus at -13 km yields a drop of 1.6 mag instead of 2.25, because the limb would be brighter.

The luminosity of Betelgeuse at minimum, could be as faint as 6 magnitude in the centerline, 2.5 mag at 13 km South or 1.25 mag being at 27 km North. In all cases the aspect of Orion willl change significantly for at least 5 seconds centered around the minimum at 2:13:06 for Sibari.

The seeing for Sibari, during the night 11-12 december will be determined by the Jet Stream shear with the lower atmospheric shells. The expected seeing is evaluated as 0.8" and it is minimum right at 2-3 AM, during the occultation. The figure e has been computed 13 hours before (meteoblue site).

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[1] https://www.astro.uvic.ca/~tatum/stellatm/atm6.pdf for u parameter description and equations.


Tue 2023-12-12
sunrise: 07:03 sunset: 16:31 moonrise: 06:39 moonset: 15:45 moonphase: 0%

	Low	Mid	High	Arc Sec.	1	2	Jet Stream	Bot (km)	Top (km)	K/100m	Temp	Rel. Hum.	Celestial Bodies
0	9	39	0	0.89	5	4	50 m/s	00.6	02.0	0.6 K	12 °C	54%	----J-U--
1	12	53	0	0.89	5	4	49 m/s	04.3	05.0	0.5 K	12 °C	62%	----J-U--
2	19	58	5	0.79	5	4	49 m/s	05.0	05.7	0.5 K	12 °C	67%	----J-U--
3	27	57	12	0.77	5	3	51 m/s	05.7	06.5	0.5 K	12 °C	69%	----J-U--
4	30	52	18	0.80	5	4	51 m/s	00.1	02.0	0.7 K	12 °C	70%	--V---U--
5	23	40	24	0.92	4	2	50 m/s	04.3	05.7	0.5 K	13 °C	70%	--V------
6	10	23	30	0.97	4	3	50 m/s	04.3	05.0	0.6 K	13 °C	67%	--V------
7	1	10	30	1.06	4	2	50 m/s	03.7	05.0	0.6 K	13 °C	64%	L-VM-----
8	1	5	20	1.08	5	4	49 m/s	04.3	05.0	0.6 K	14 °C	60%	L-VM-----
9	2	2	4	1.02	5	3	48 m/s	03.7	05.0	0.5 K	15 °C	54%	LMVM-----
10	4	1	0	1.21	5	3	47 m/s	03.7	05.0	0.5 K	17 °C	56%	LMVM-----
11	5	2	20	1.27	5	3	46 m/s	03.7	05.0	0.5 K	18 °C	56%	LMVM----P
12	6	4	51	1.07	5	4	45 m/s	03.7	04.3	0.6 K	19 °C	56%	Tornare su
13	7	6	72	1.12	5	4	44 m/s	03.1	04.3	0.5 K	19 °C	57%	LMVM-S-NP

06:39 07:03 0%

Fig. e The seeing forecasted on 12 dec 2023 at Sibari.

Instruments the telescopes are choosen as big as possible, ref.1

Fig. f a C9 telescope (28 cm) masked with eitght-4cm holes.

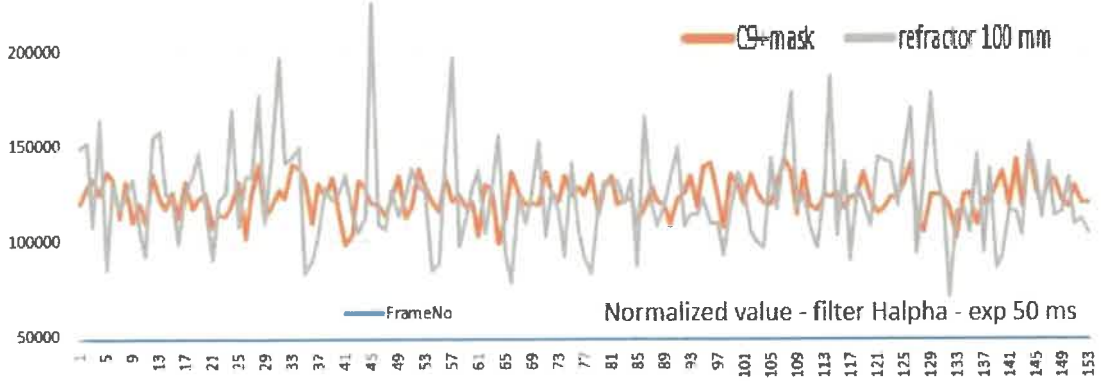


Fig. g Expected scintillation for C9 masked and a 4'' refractor.

This mask reduced drastically the scintillation of the star by averaging the turbulence cells in front of each of the 40 mm holes while keeping the original resolution of the 28 or 20 cm objectives. The 3" below (fig h) is equipped with a 15 mm exit pupil eyepiece, to allow afocal recording with the smartphone.

Fig. h a Newtonian 3" f/4.6 telescope equipped with a long focal eyepiece of f=110 mm, for the afocal recording, with the Observatory of Monte Mario in Rome in background.

The scintillation of Betelgeuse in afocal mode with samsung J5 and different instruments: Newton 3"/700 mm f/9.2 https://youtu.be/Hkt0Nhn8bxY ; monocular 42 mm 10x https://youtu.be/gL7StKV1pgs ; monocular 18 mm 6x https://youtube.com/shorts/aL0uVp1NA5I ; Sirius with 1.85 mm and f=4 mm: https://youtube.com/shorts/BxOGlRnReaI

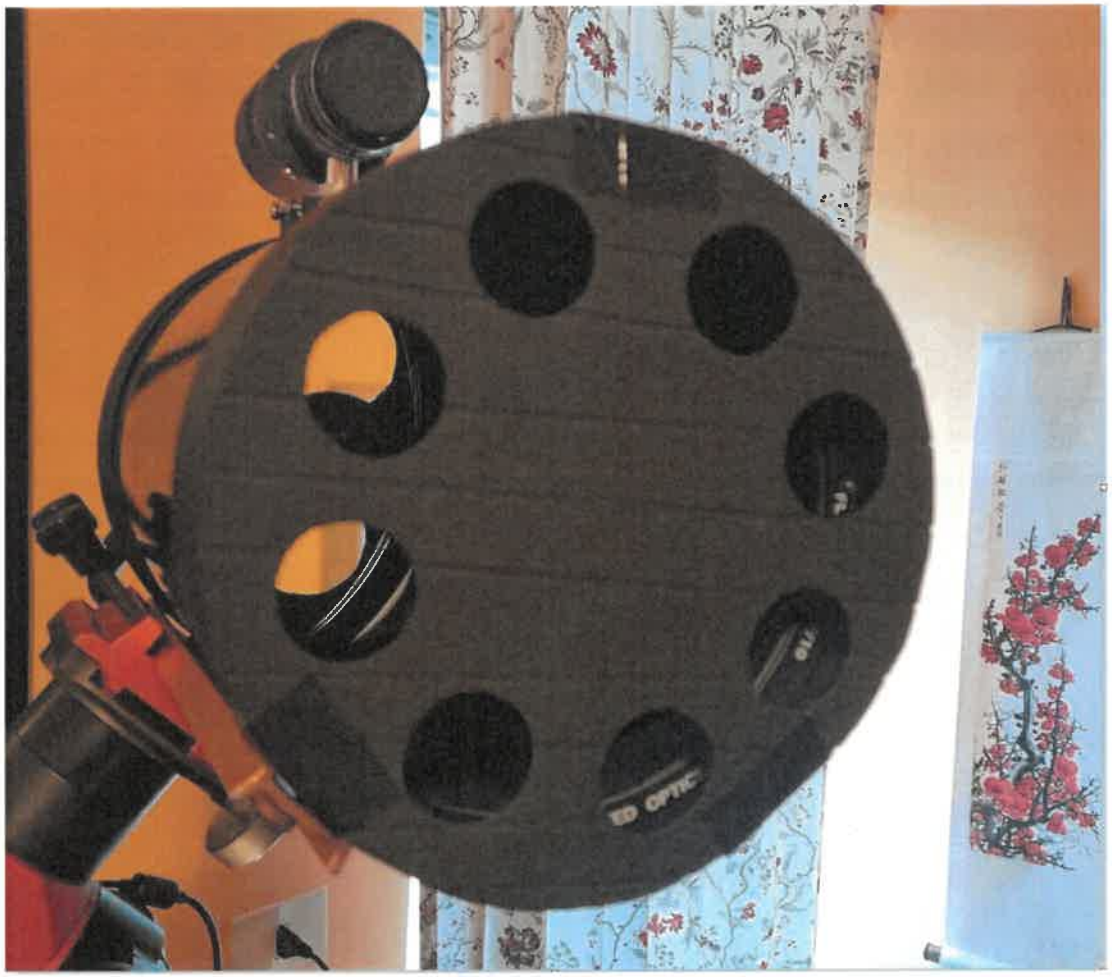


Fig. i The mask at the C8 telescope.

Conclusions 2: masks, de-focusing and large exit pupil for afocal recording will be used in the Jonian coast of Calabria for this unique event, where a 0.25 mag red supergiant is occulted by Leona a 80x54 km asteroid, at which distance from Earth the star would be 63 km wide. On ground dimensions are 1.5x.

Acknowledgments to Irene Sigismondi and to Elisabetta Natale. **Dedication:** The effort in preparing this observation will contribute to commemorate prof. Jay M. Pasachoff 1943-2022, renowned solar astronomer, **see below the program of the 16 December IAU-NASE meeting *Remembering Jay*.**

References 1. Sigismondi, C. , Costa, C. and A. Noschese (2023) ATel #16374: The occultation of Betelgeuse by Leona: recovering the stellar surface brightness of a red supergiant, with a diffuse telescope, on Dec 12 1:12 UT

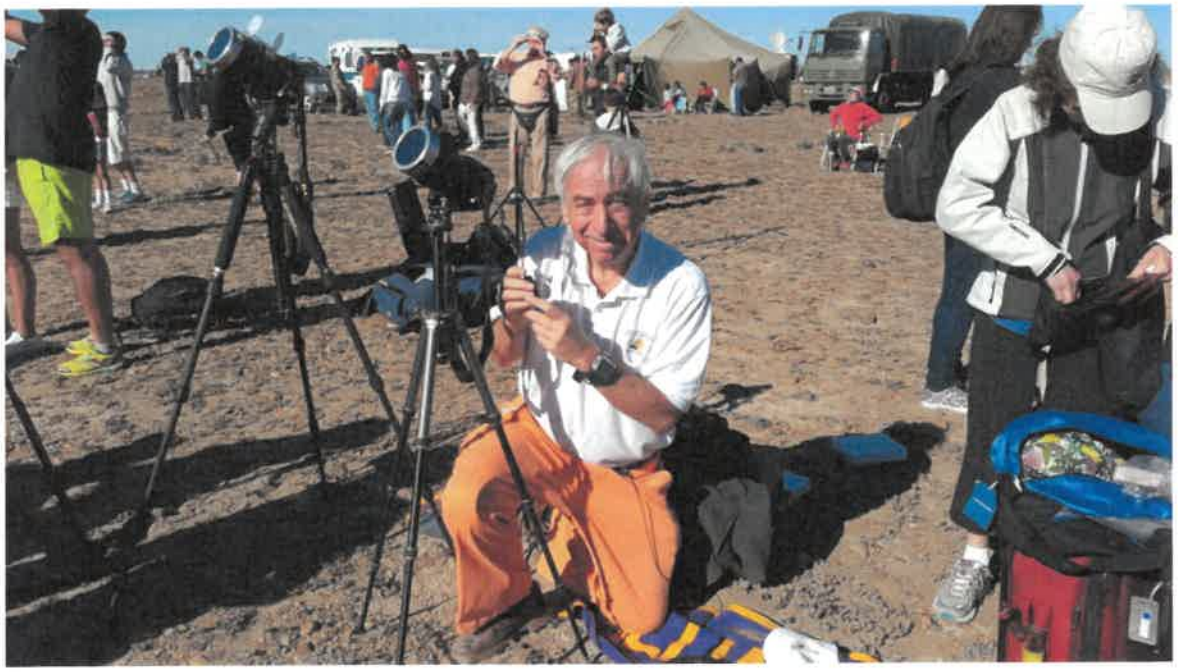
Network for Astronomy School Education

Workshop "Remembering Jay"

December 16, 2023

2001, Kariba lake, Zambia

Joe Kornblum, Jay Pasachoff, Jim Pollack, and the Harvard College Observatory/US Air Force eclipse camera , 1963, Quebeq, Canada (first Jay's eclipse).



2017, Patagonia, Argentina

As an introduction

The Network for Astronomy School Education (IAU-NASE), organized this special workshop in honor of a colleague and a friend, Jay Pasachoff, one of the most famous astronomers on the planet.

Almost all the people devoted to the astronomical observation, professionals and amateurs, know his A Field Guide to the Stars and Planets, and the most part of them, where part of some of his travels as "eclipse hunter".

Jay is not any more between us, but his figure, enthusiasm, charisma is and will be always present

One of his last projects was the observation of the occultation of Betelgeuse by the asteroid 319 Leona, on December 12th, 2023 (Figure 1), this workshop is a tribute to this idea, concreted by colleagues along the road of the visibility of the event and to Jay's figure, presenting different aspect of his work and his life in the voices of this nearest friends an his family.

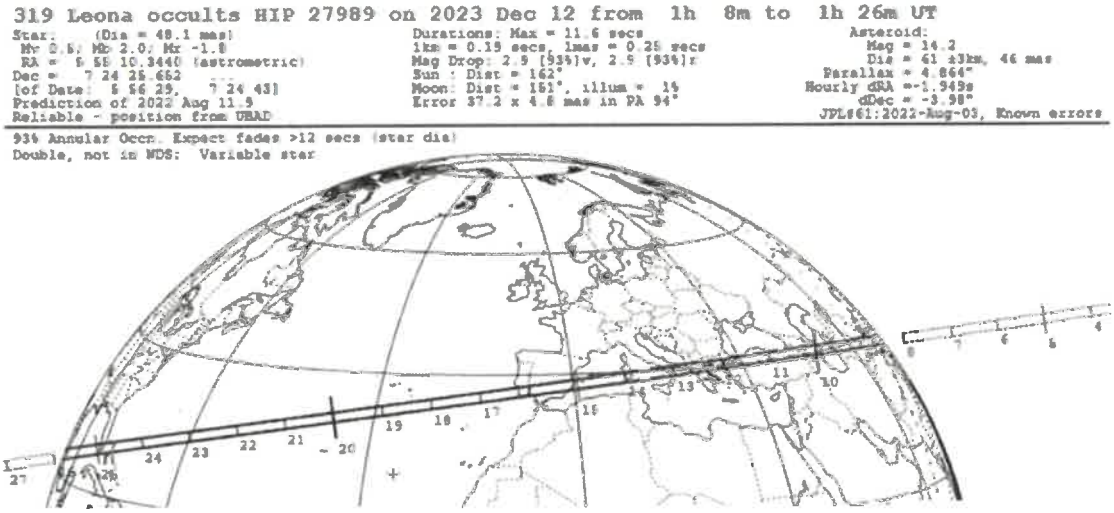


Fig. 1 Path of the occultation of Betelgeuse by Leona

Timeline (CET)

First Part: Occultation of Betelguese: a Jay Pasachoff's invitation

13:30 – 13:45 Opening session Beatriz García & Rosa M. Ros, NASE.

13:45 - 14:15 "Betelgeuse Ocultation" Carles Schnabel, Associació Astronómica de Sabadell, Sabadell, Spain.

14:15 - 14:30 "Observations from Andalucia, Spain" JosÉ M. Díaz, Úbeda, Spain.

14:30 - 14:45 " **Solar and stellar diameters with eclipses and occultations**, Costantino Sigismondi, Roma, Italy.

14:45 - 15:00 "Betelgeuse occultation, Observations from Greece" Margarita Metaxa, Athenes, Greece.

Second Part: Memories of Jay Pasachoff

15:00 - 15:05 "Jay as my friend" Zhongquan.

15:05 - 15:10 "A friend in need", Jagdev Sight.

15:10 - 15:15 "Generosity" Fred Espenak.

15:20 - 15:50 Jay Pasachoff, his general career...his ideas, how he organized his life...", Pasachoff Family, USA.

15:50 - 16:00 Closing session Rosa M. Ros & Beatriz García.