

Refraction at the horizon measured by sunrise and sunset timing

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ESOP

XLI

European Symposium on Occultation Projects

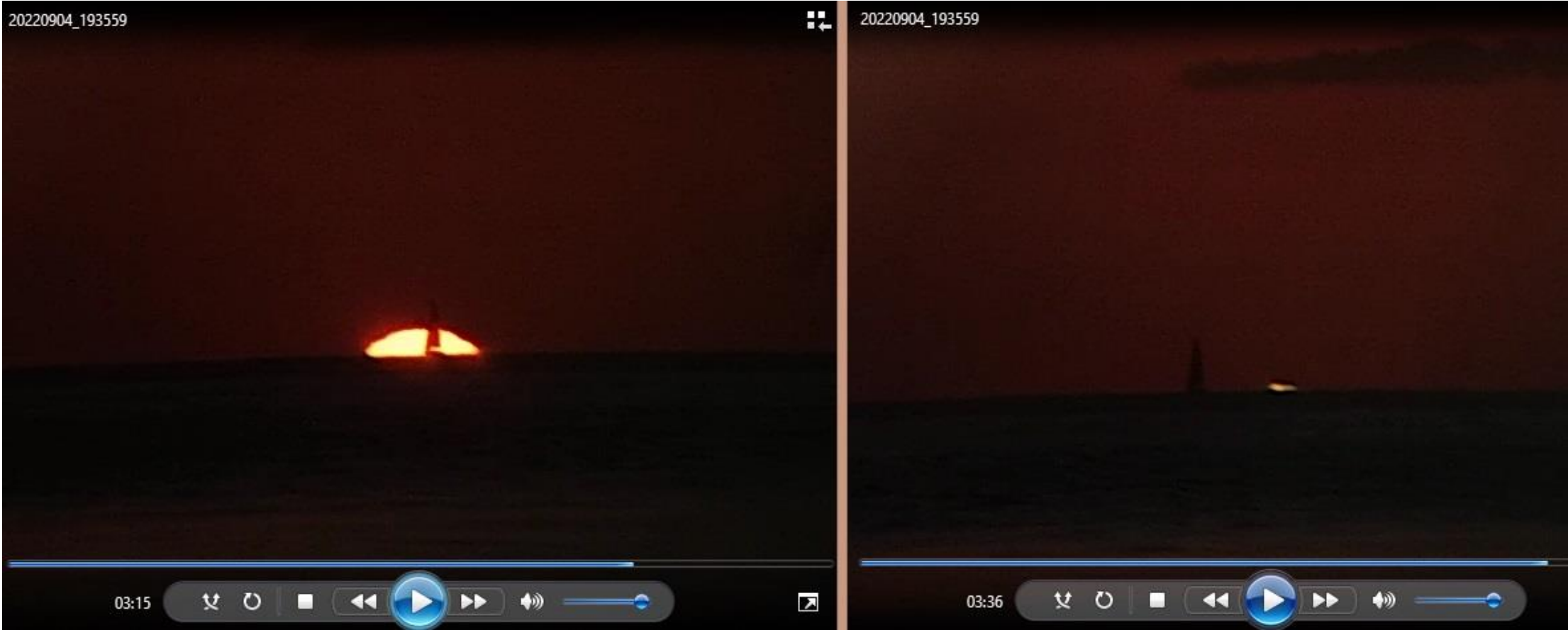
Granada 2022 SPAIN

Why this theme?

- Solar diameter measurements at zero almucantar
- Is it possible to measure the solar diameter by timing a sunset?
- How much is precise?

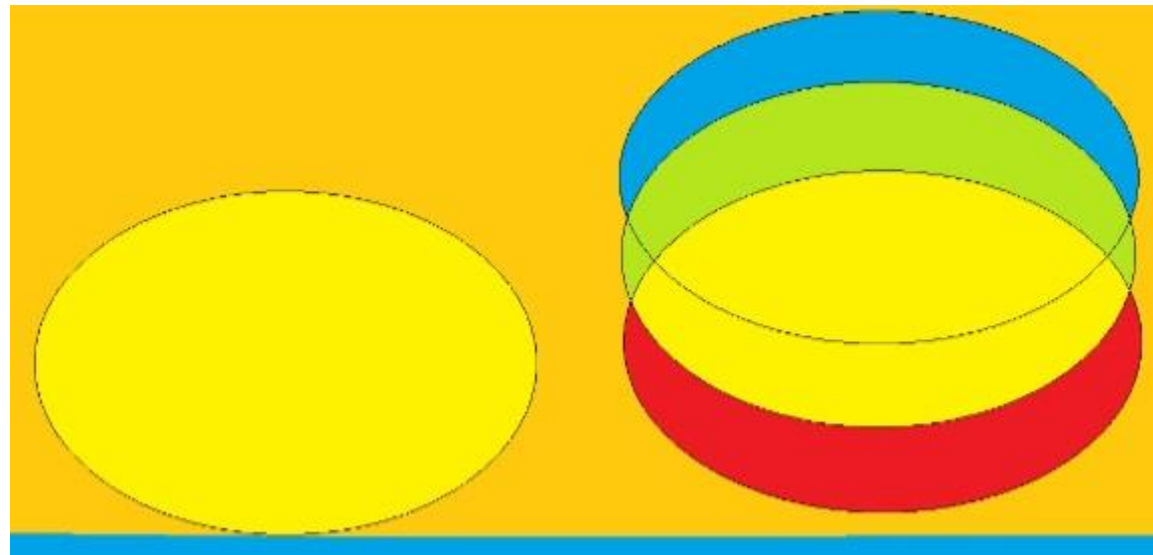
- The role of atmospheric refraction is evidenced
- Also from a chromatic point of view

The elusive blue flash shows the chromatic vertical splitting of the Sun (FCO 4 sept 22)



Prismatic effect of the atmosphere: vertical enlargement of the Sun

- <http://www.icra.it/gerbertus/2021/Gerb-14-2021-Sigismondi-Prismatico-75-78.pdf>
- https://astropix.com/html/observing/atmospheric_prismatic_dispersion.html

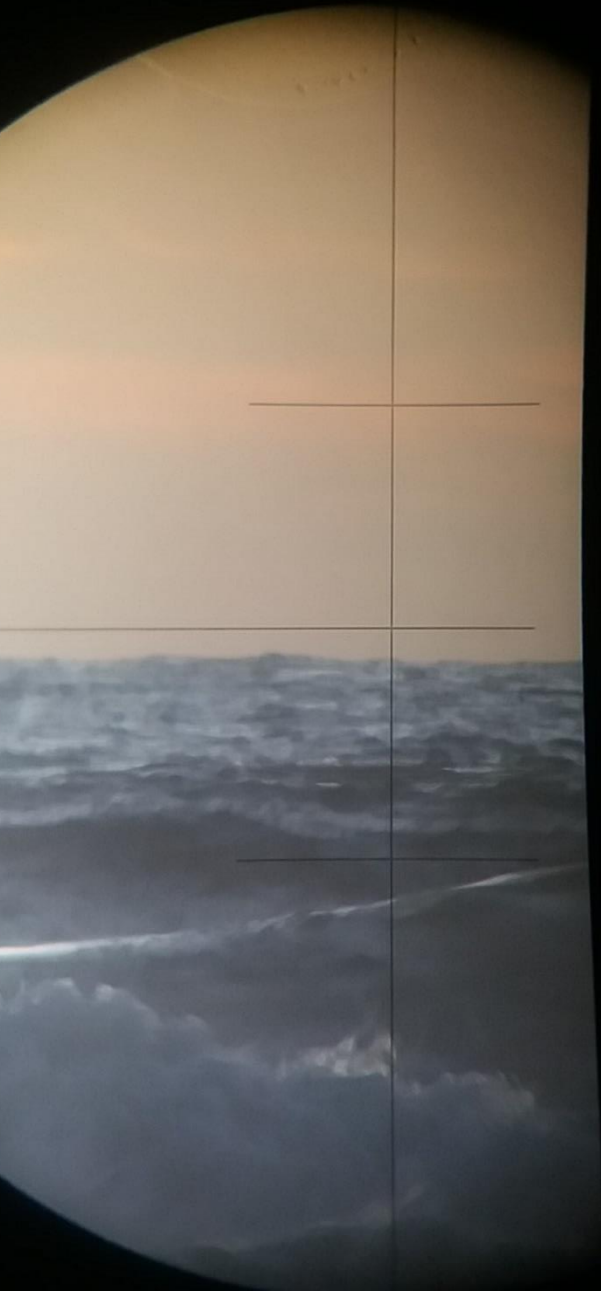


Refraction vs airmass

- Plane parallel approximation
- Airmass $X=1/\sin(h^\circ)$
- Garstang model at sea level and toward horizon $X=5$
- Exponential integral over a chord

Refraction vs vertical gradient on the line of sight

- In a fresh evening 14°C of November 2020, wind from North, sea water still at 18°C level-telescope Officine Galileo
- Pontile 3.4 m above sea level 4' depression (extra 2')
- Regina Pacis 10 m above sea level 6' depression (extra 3')



Ostia:
Pontile vs
Regina
Pacis

geom.
depression
in arc min
 $=\sqrt{h[m]}$

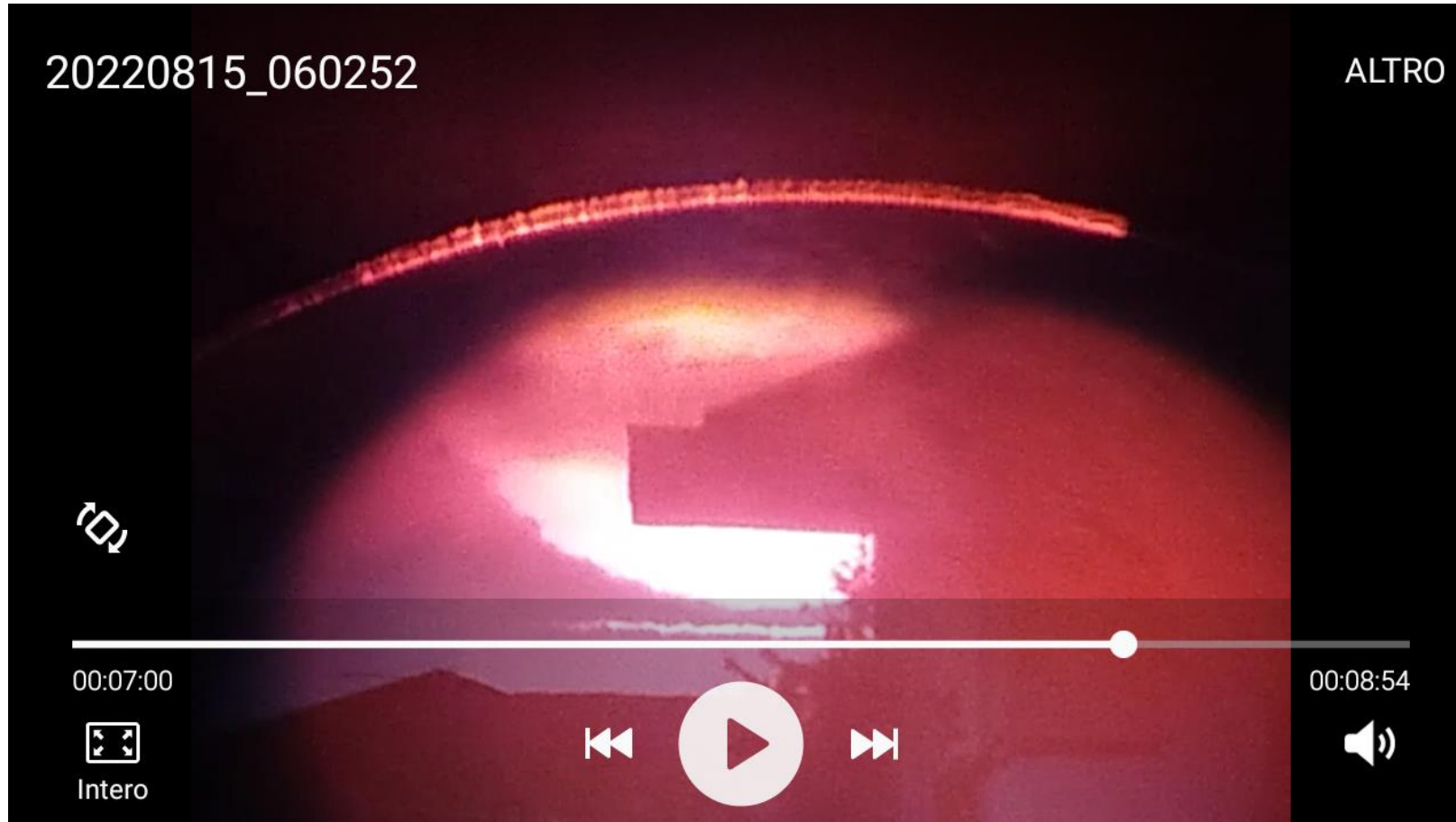


Lanciano (256 m above sea level)

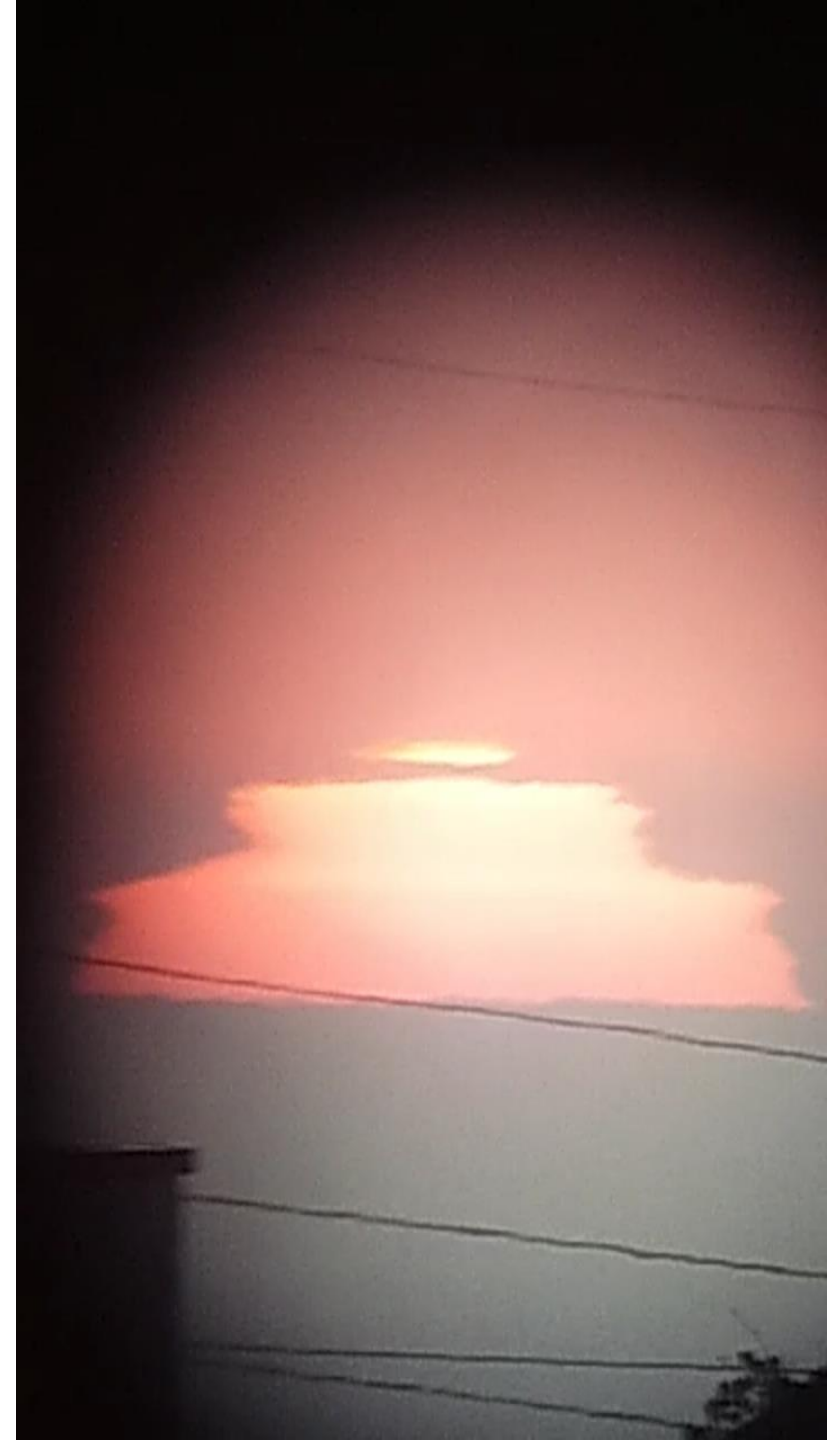
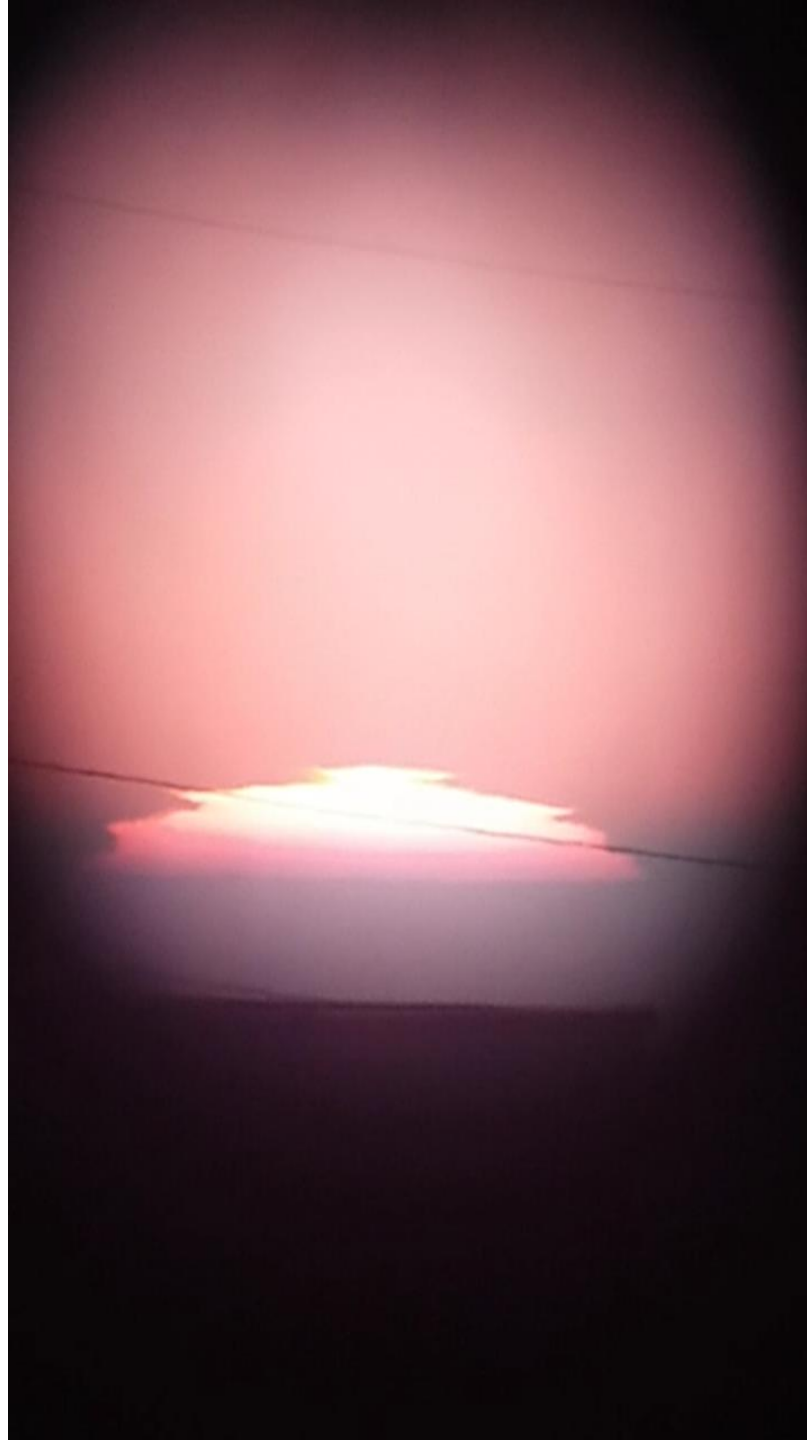
- Fluctuation of the horizon
- «Reference chimney» on the foreground at 600 m
- Sea horizon about 0.6' below 16 may



Ordinary refraction Lanciano 15 August 2022



Extraordinary
refraction
(Novaja Zemlija
effect, May 16)
from Lanciano



16 may vs 15 august (from sea water colder than air to the inverse situation)



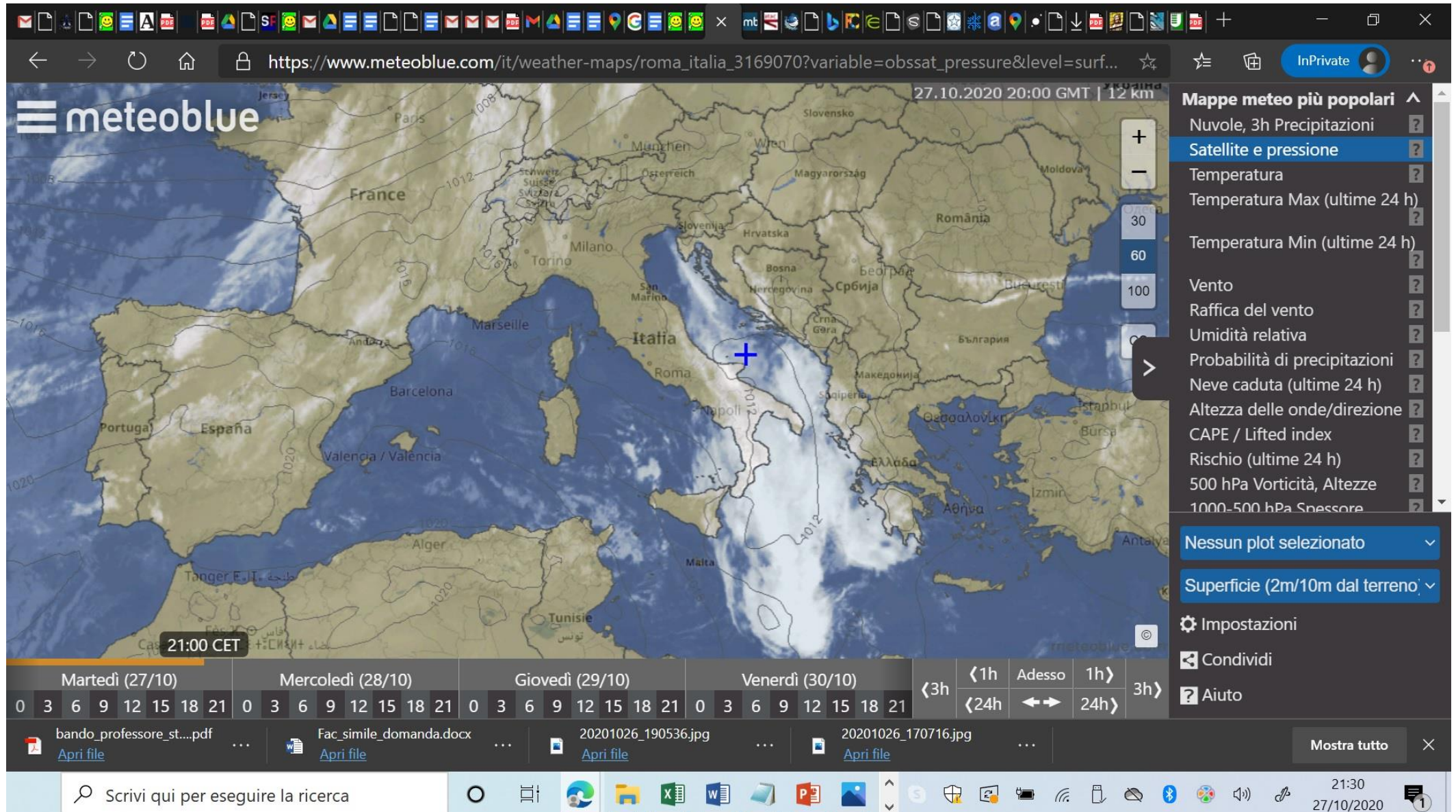
- Colder water:
horizon up
- Hotter water:
horizon down

Note that Lanciano is more than 15 km inland



Refraction vs pressure gradient

- Ostia-Baleares 800 km
- $\Delta P = 0-10$ mbar



Airmass extinction

- Zenith
- Horizon
- Quote above sea level
- $X=1/\text{Sen}(h^\circ)$ «flat atmosphere»



Reflection on the atmosphere



Extinction & Refraction

- Water vapour near the horizon (warning for invisible clouds by night!)
 - Novaja Zemlija effect
 - Tropopause
 - ISS-quote refraction
 - Moon eclipses
- 

Similar conditions from 5 to 10 september '22:
no reflection on the atmosphere, the horizon
cuts the solar disk



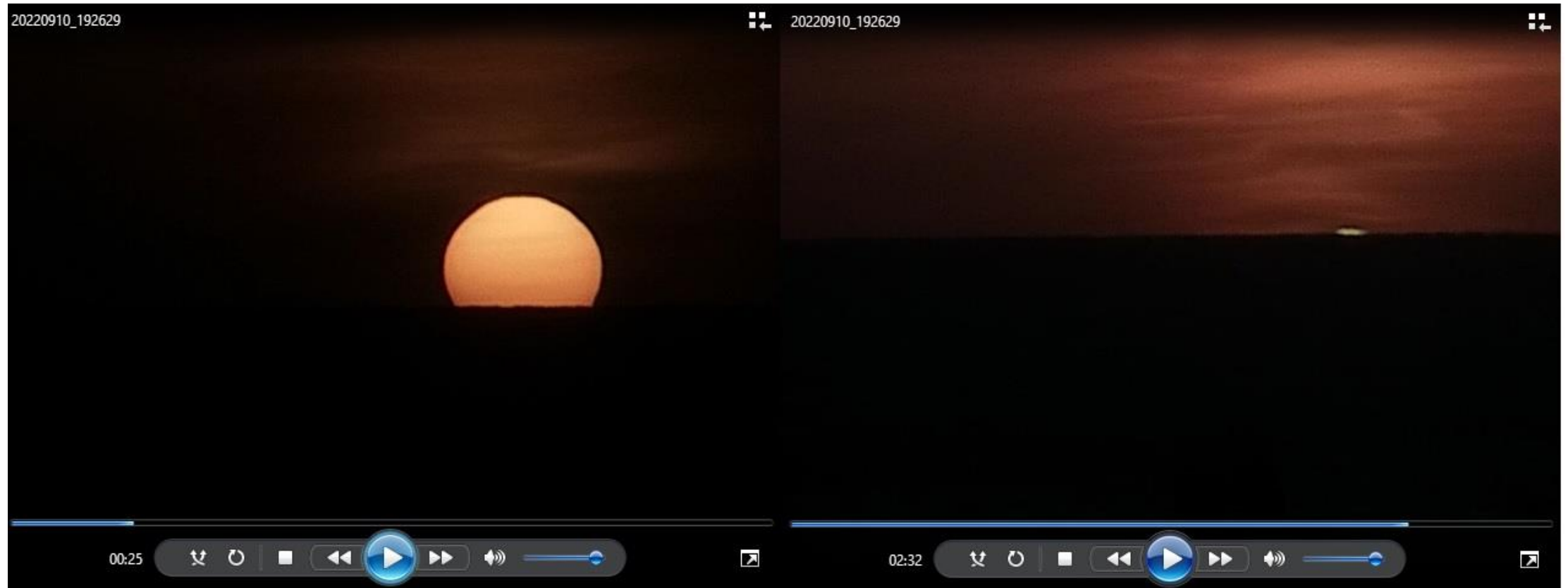
No reflection 5, 6, 7, 9 and 10 September '22



9 sept 22



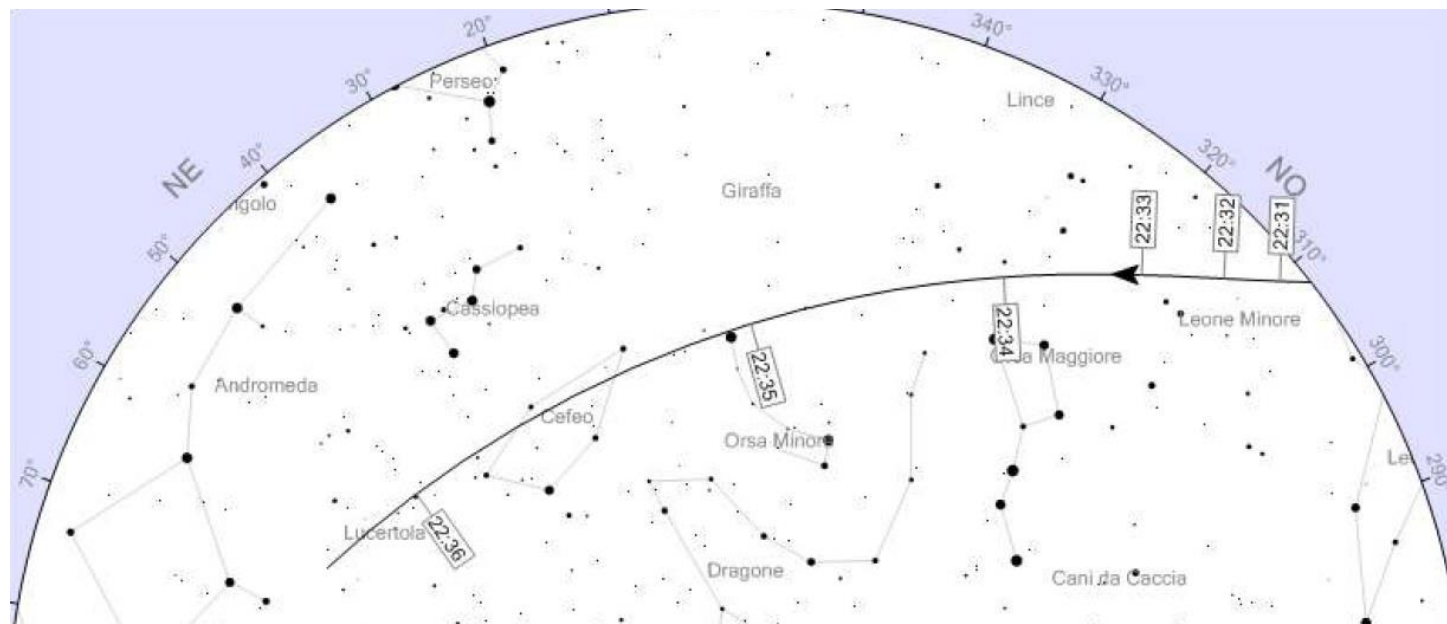
10 sept 2022: with green/blue flash



Antisolar rays at Eastern horizon, 9 Sept 15hr16 before full Moon



ISS last reflected light



Data: martedì 26 luglio 2022

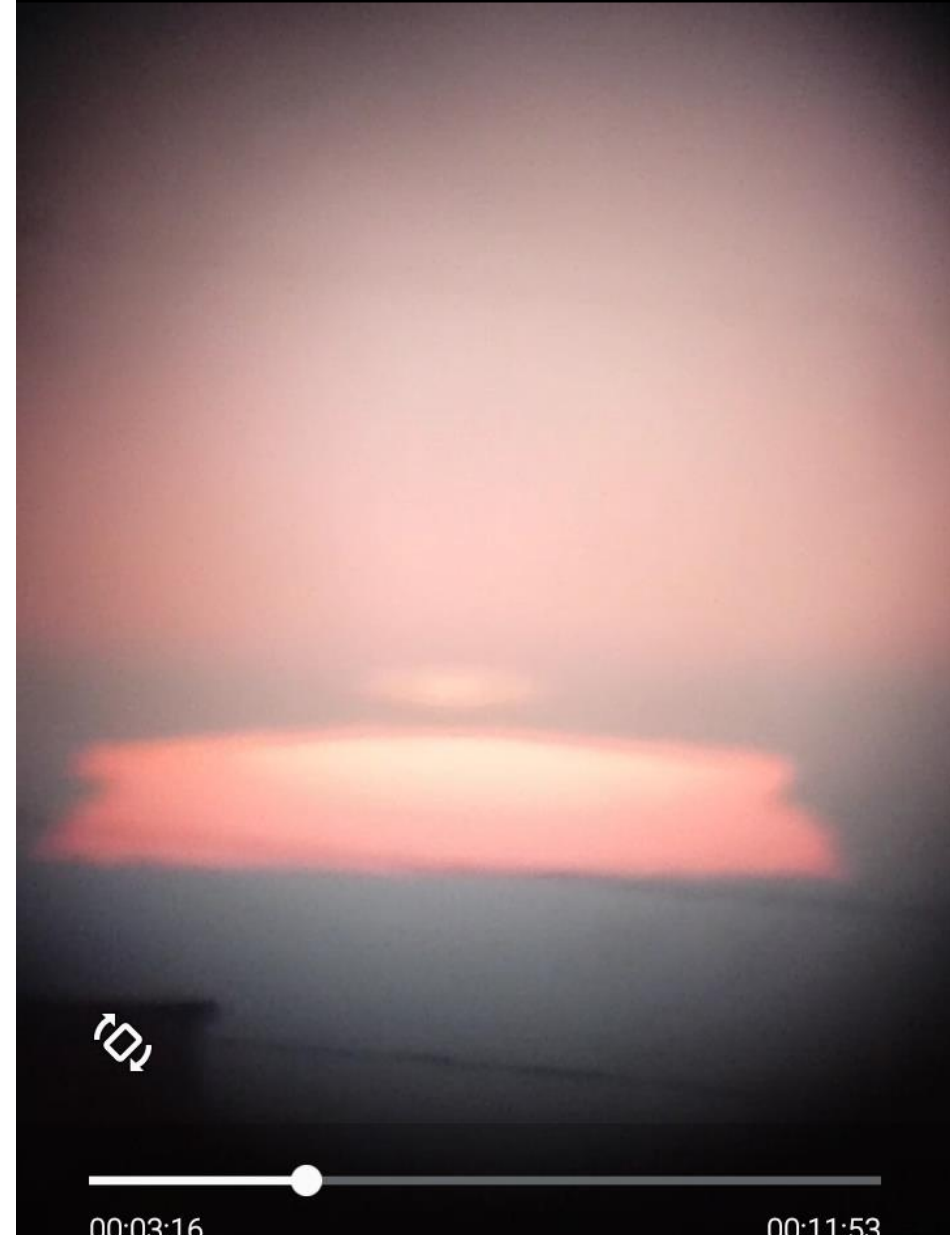
Orbita: 413 x 419 km, 51,6° (Epoca: 26 luglio)

Evento	ora	Altezza	Azimet	Distanza (km)	Magnitudine	Altezza Sole
Sorge	22:30:10	0°	307° (NO)	2.353	1,6	-17,7°
raggiunge l'altezza di 10°	22:32:20	10°	314° (NO)	1.489	0,3	-18,0°
Culmina	22:35:33	44°	29° (NNE)	582	-3,0	-18,4°
Entra nell'Ombra	22:36:20	36°	69° (ENE)	672	-2,9	-18,5°

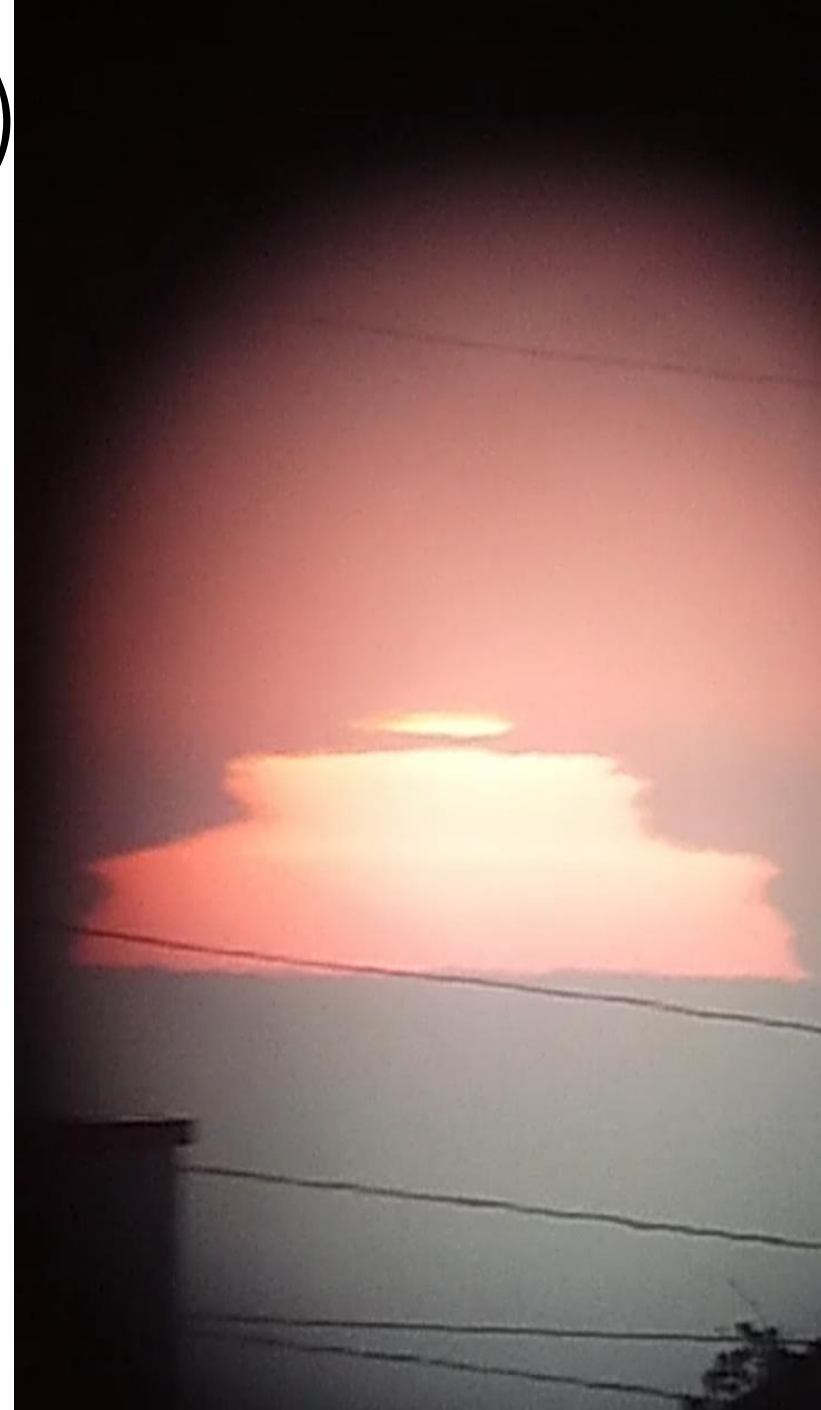
Tropopause (up to 12 km @ 42° N)



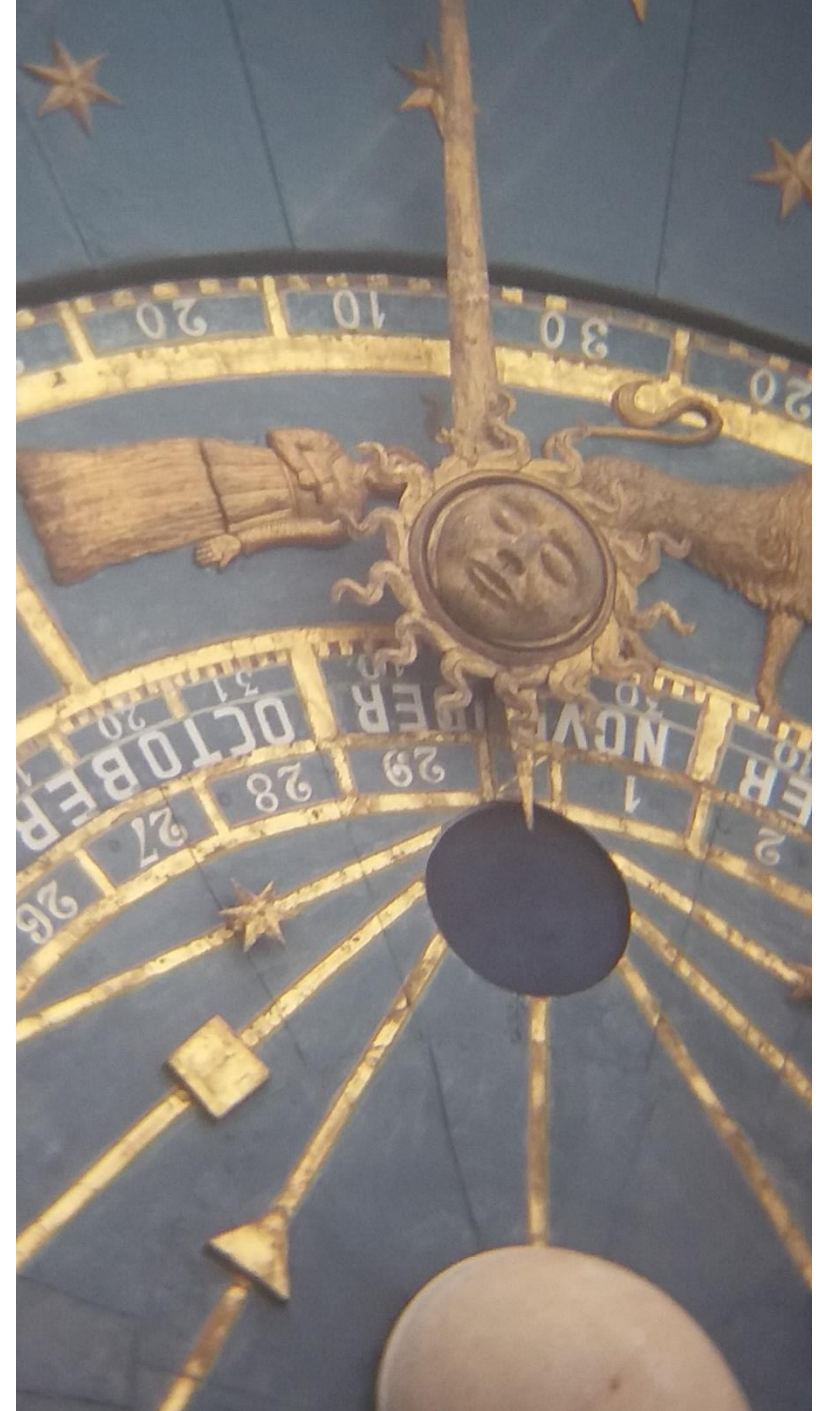
Depressed horizon
 $v_h[m]$



Single ($h=3.3$ m) vs Multiple (256 m) reflections



Moon and refraction

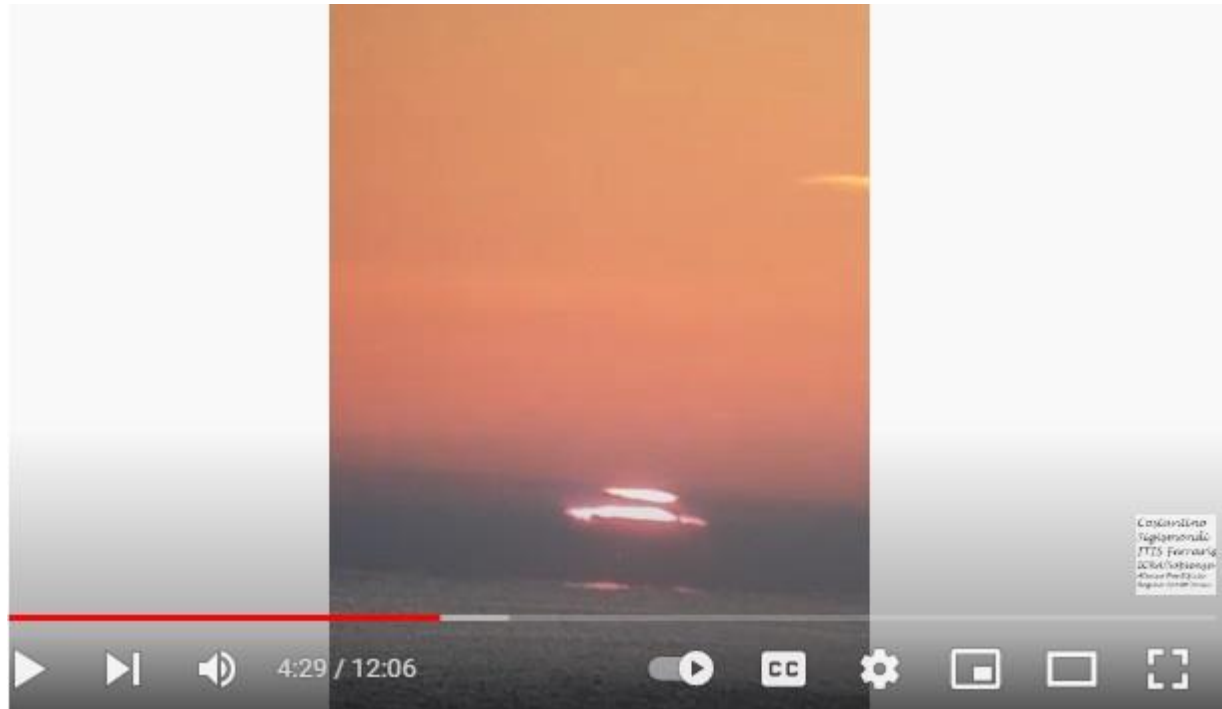


Moonrise 9 sept 2022, -3' at the third floor



Novaja Zemlja effect: Sun limb visible 81' below the horizon at sea level!

- <https://youtu.be/Z4PslHz0Fpk>



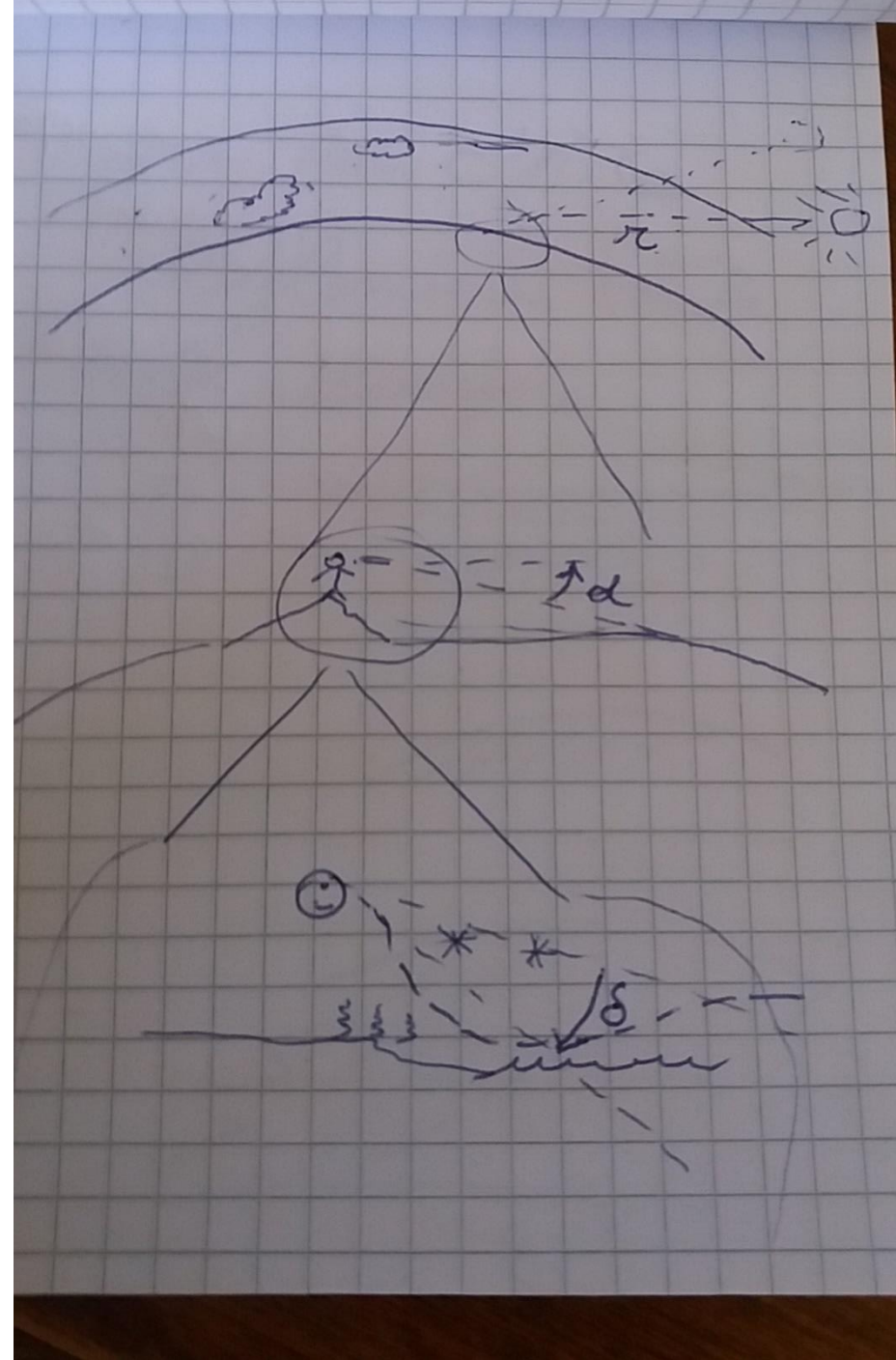
The Arithmetic of Sunsets

$$R = r + d + \delta$$

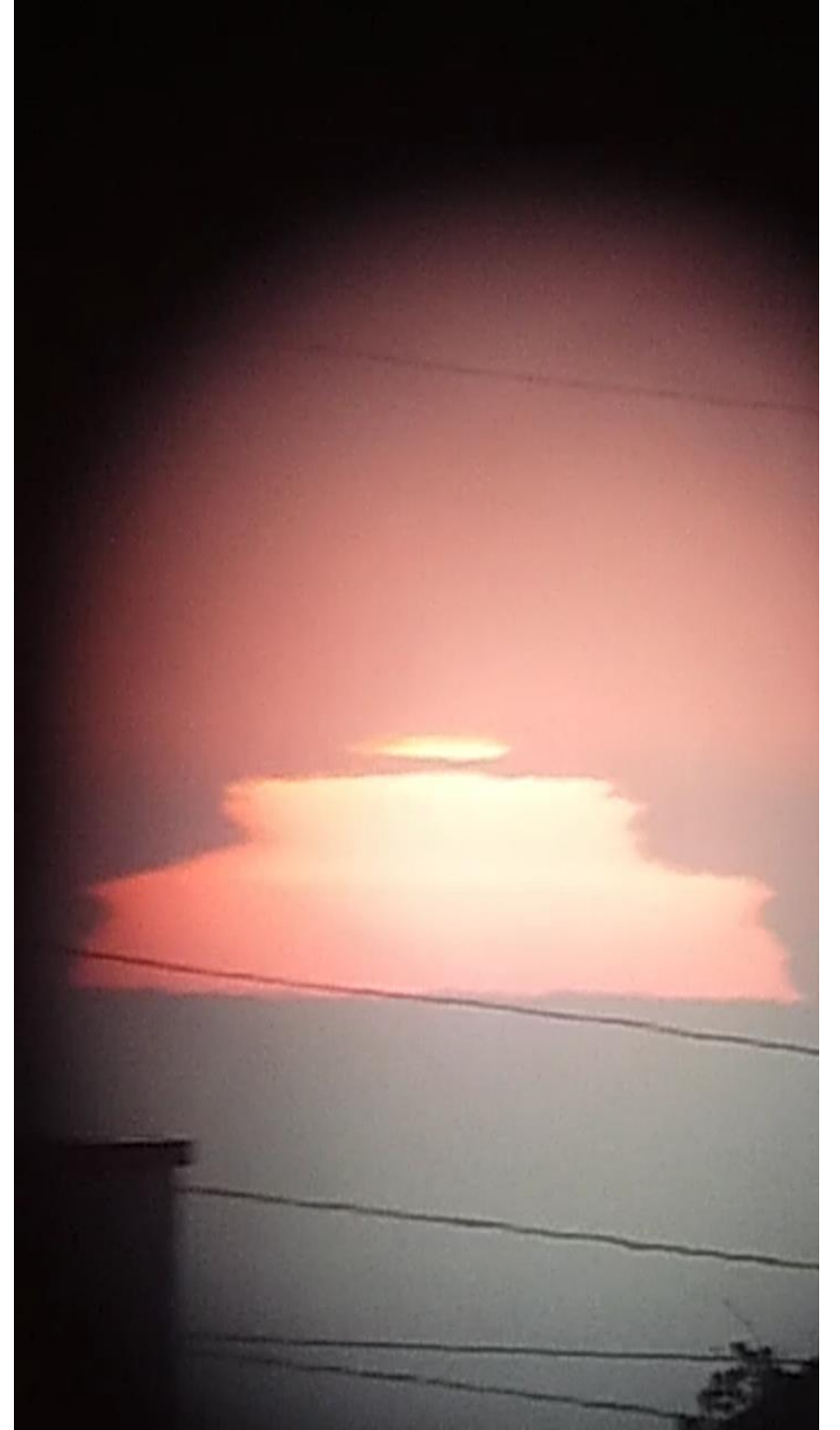
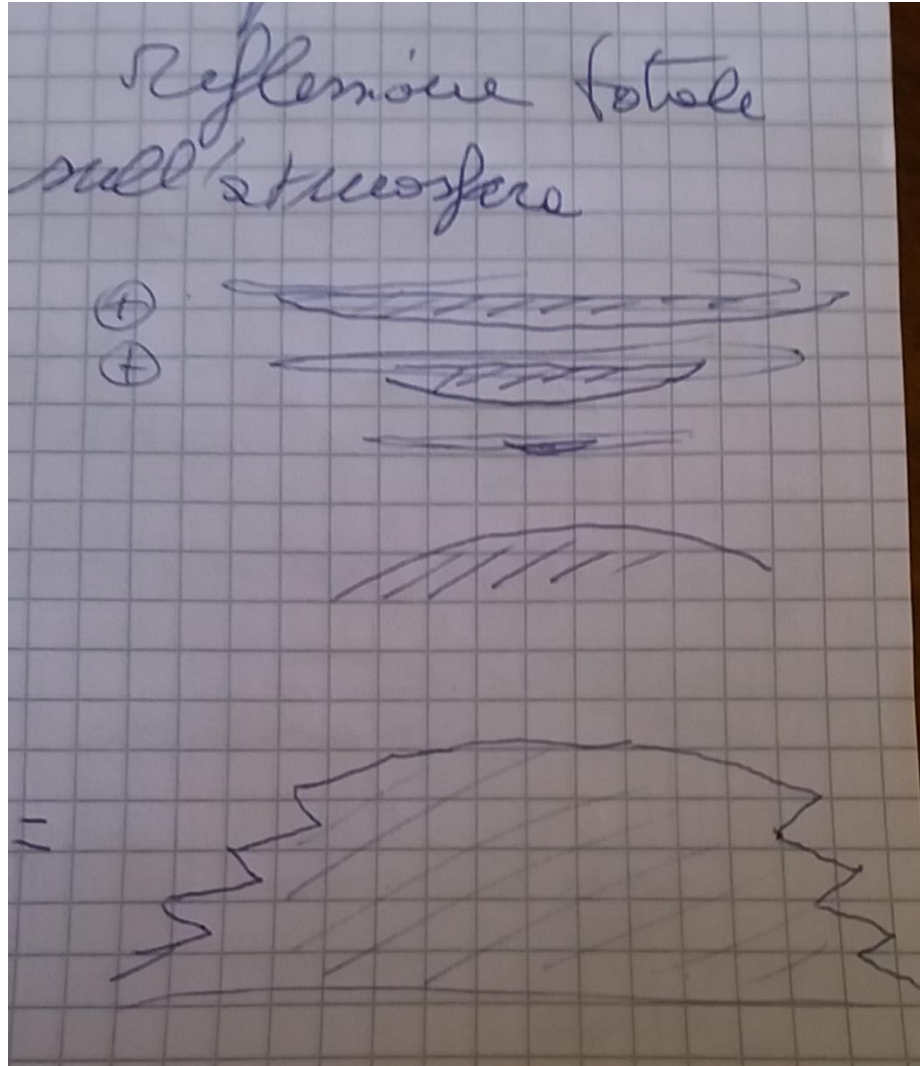
r depends on X (airmass)

d on the quote of the obs.

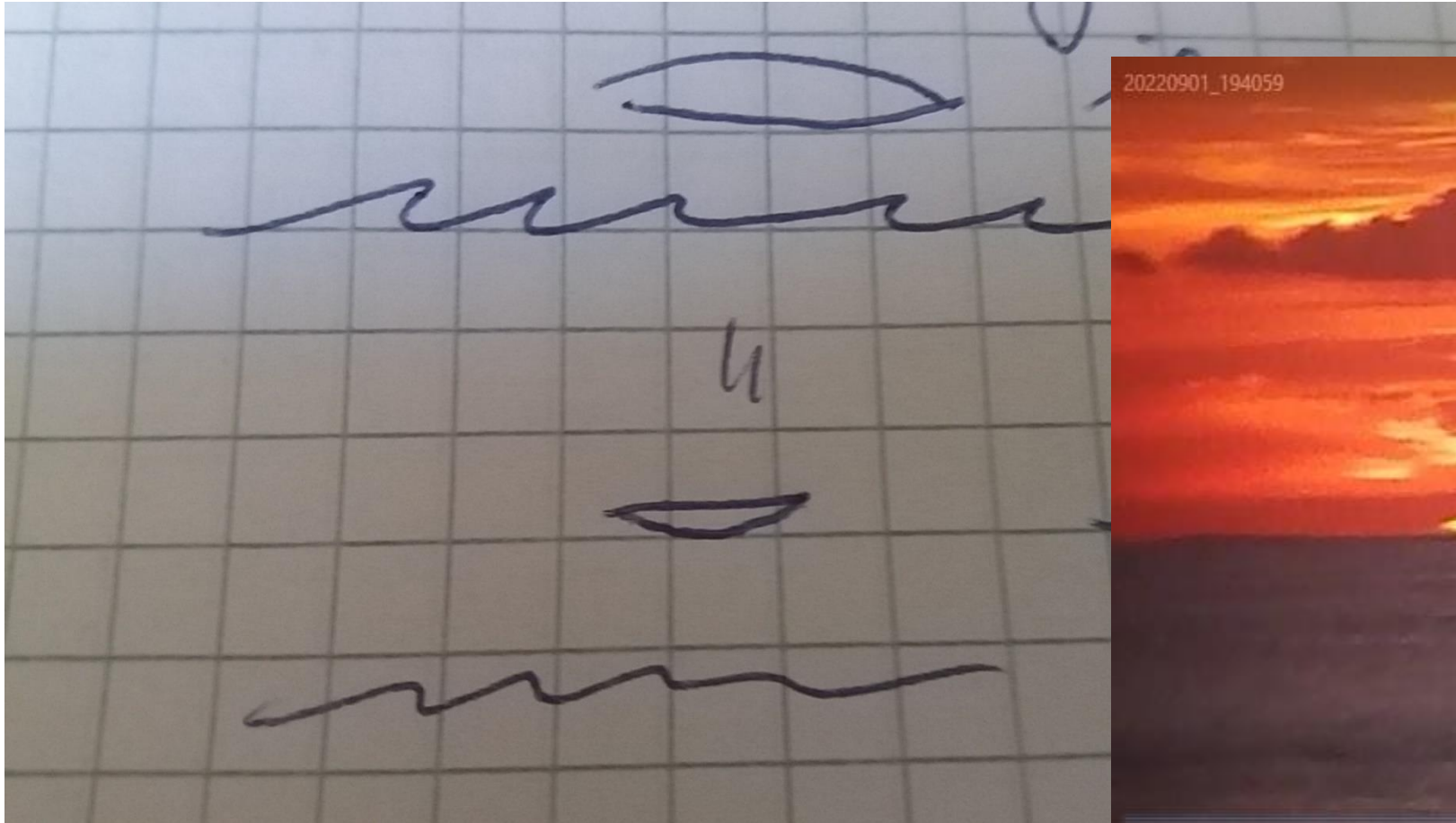
δ on local Temperature gradients



The total reflection on the atmosphere: the “Pagoda” Sun



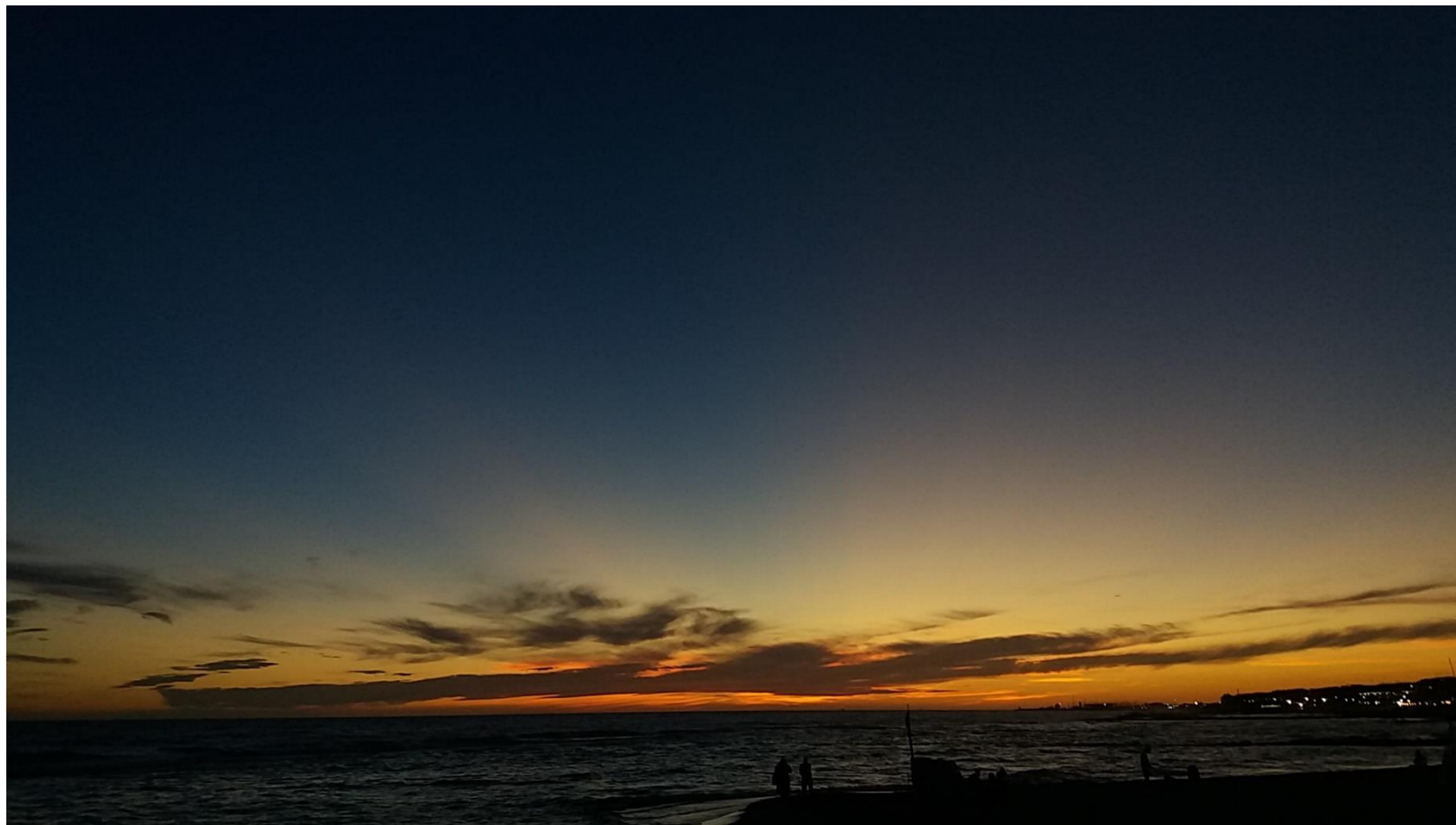
Total reflection at sea level (rather frequent):
upper atmospheric layer less dense than lower one



Numbers: typical values

- Sea level, as the books 😊 35' up to 42'
- 256 m 40'+depression
- 10-12 km 45'+depression
- 400 km: refraction from all the atmosphere
- Moon: idem

After sunset yesterday at Ostia



Sunsets in the history of local art (The extasis of Ostia of St. Monica and his son St. Augustin)



Ostia by night on Sept 9 in syzyzy



Equinoctial tides (central Thyrranian sea) with tidal coefficients for Sept 10, 2022



Variability with meteo conditions

- r is an integral property, whose variation diminish as the airmass go to its maximum
- δ is dependant on vertical and horizontal Temperature gradients, and it can have strong variations (0 to 3'-4')
- The chromatic effect is also dependant on the meteo, even if the green flash can be better visible through a camera with low ISO than by the naked eyes (partially bleached).
- Due to all these conditions the vertical solar diameter at sunset cannot be measured correctly only by timing the transit through the sea horizon.

Conclusions

- The sunsets/sunrises are observed with UTC synchronized video
- The last/first glimpse of the Sun timing is used to determine the total refraction R
- The quote of the observer h determines the horizon's depression d
- and the atmospheric refraction r (in term of airmasses on the line of sight)
- The local conditions (vertical and horizontal Temperature gradients) determine δ
- The (total internal) reflection on the atmospheric layer denser than the lower one produces the mirages
- Multiple mirages produce the Pagoda Sun and the Novaja Zemlja effect
- The chromatic splitting produced by the atmosphere near the horizon enlarges the vertical diameter of the Sun with an upper green rim and a lower red one