RIMO Correction Factor: a correction of a lunar irradiance model to estimate accurate AOD values

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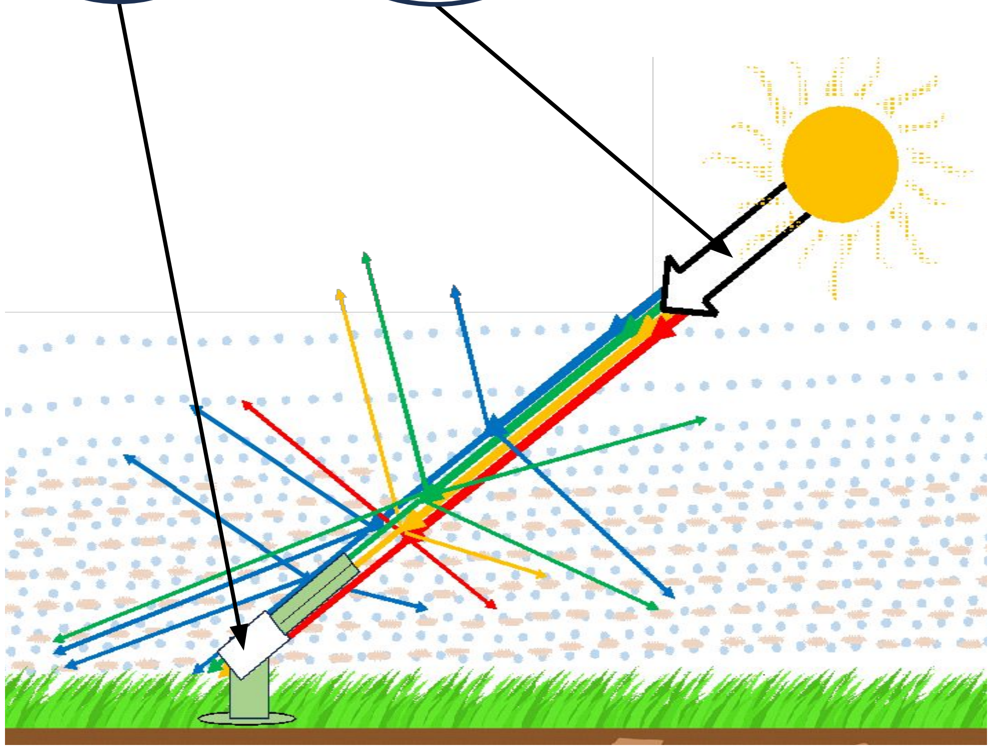
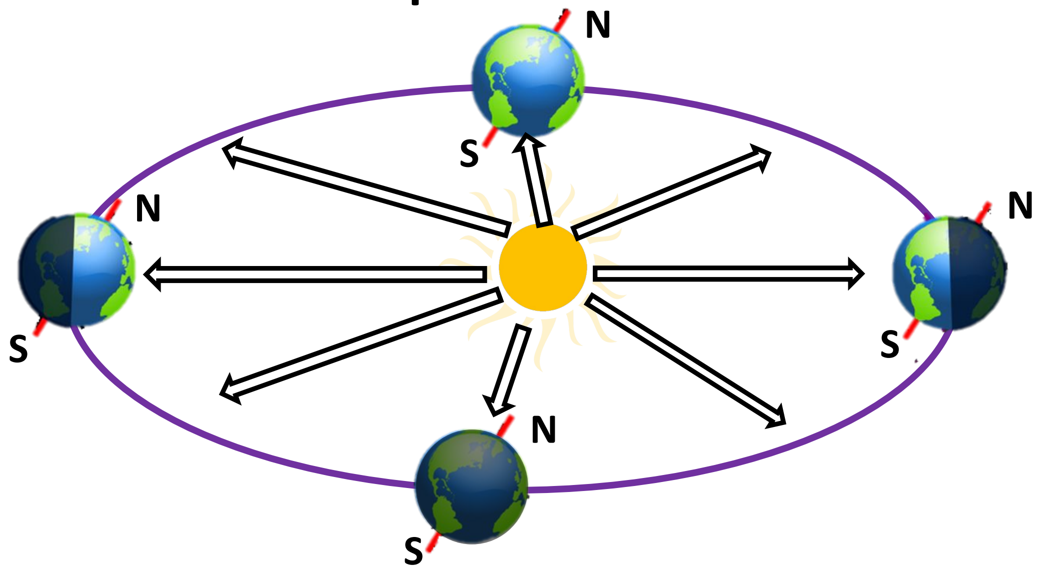
Sun photometry

Beer's law (spectral)

$$E^{sun} = E_0^{sun} \exp(-m\tau)$$



Elliptical orbit



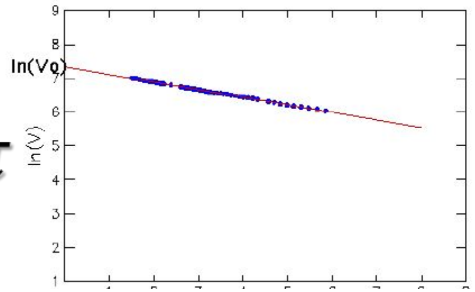
Low eccentricity (0.017):

E_0^{sun} → varies **only ±3%** along the year.

E_0^{sun} → can be easily corrected from Earth-Sun distance.

It allows Langley calibration

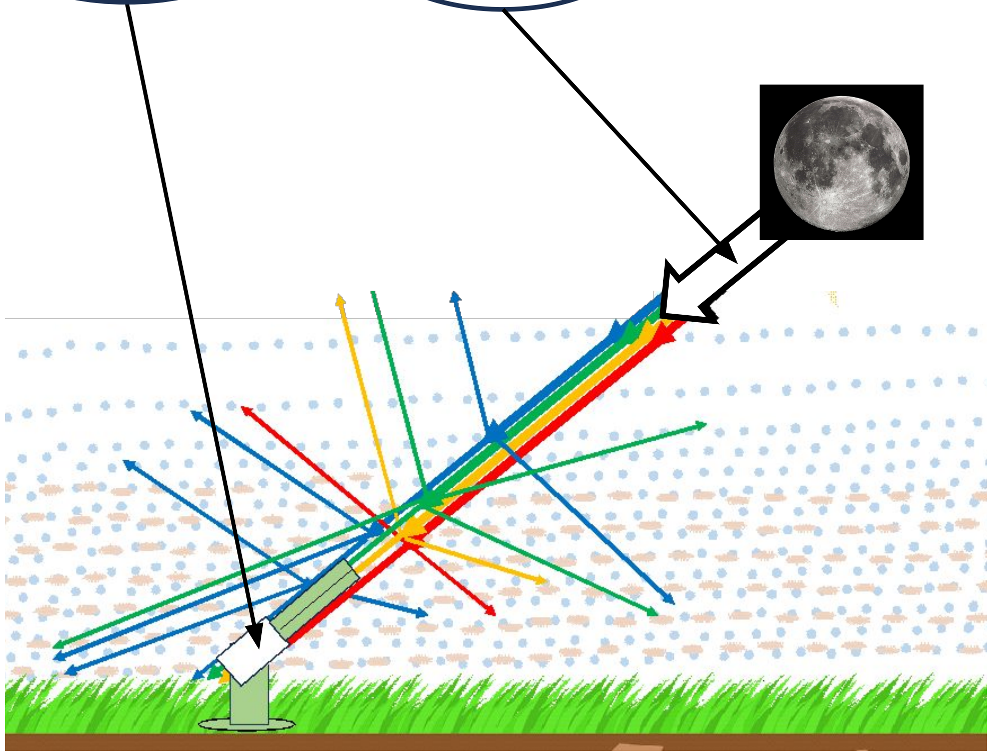
$$\log(E^{sun}) = \log(E_0^{sun}) - m\tau$$



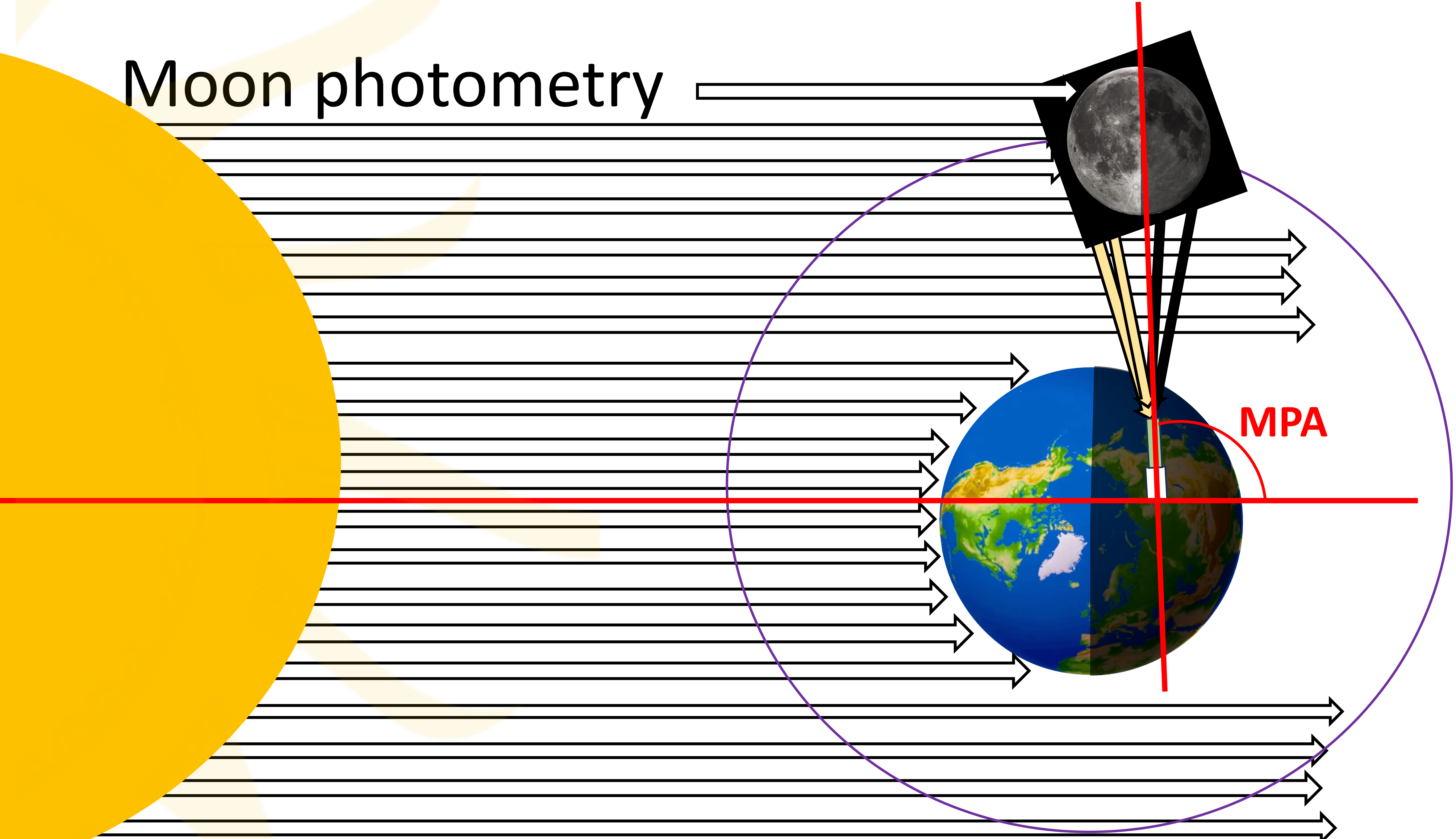
Moon photometry

<u>Beer's law (spectral)</u>

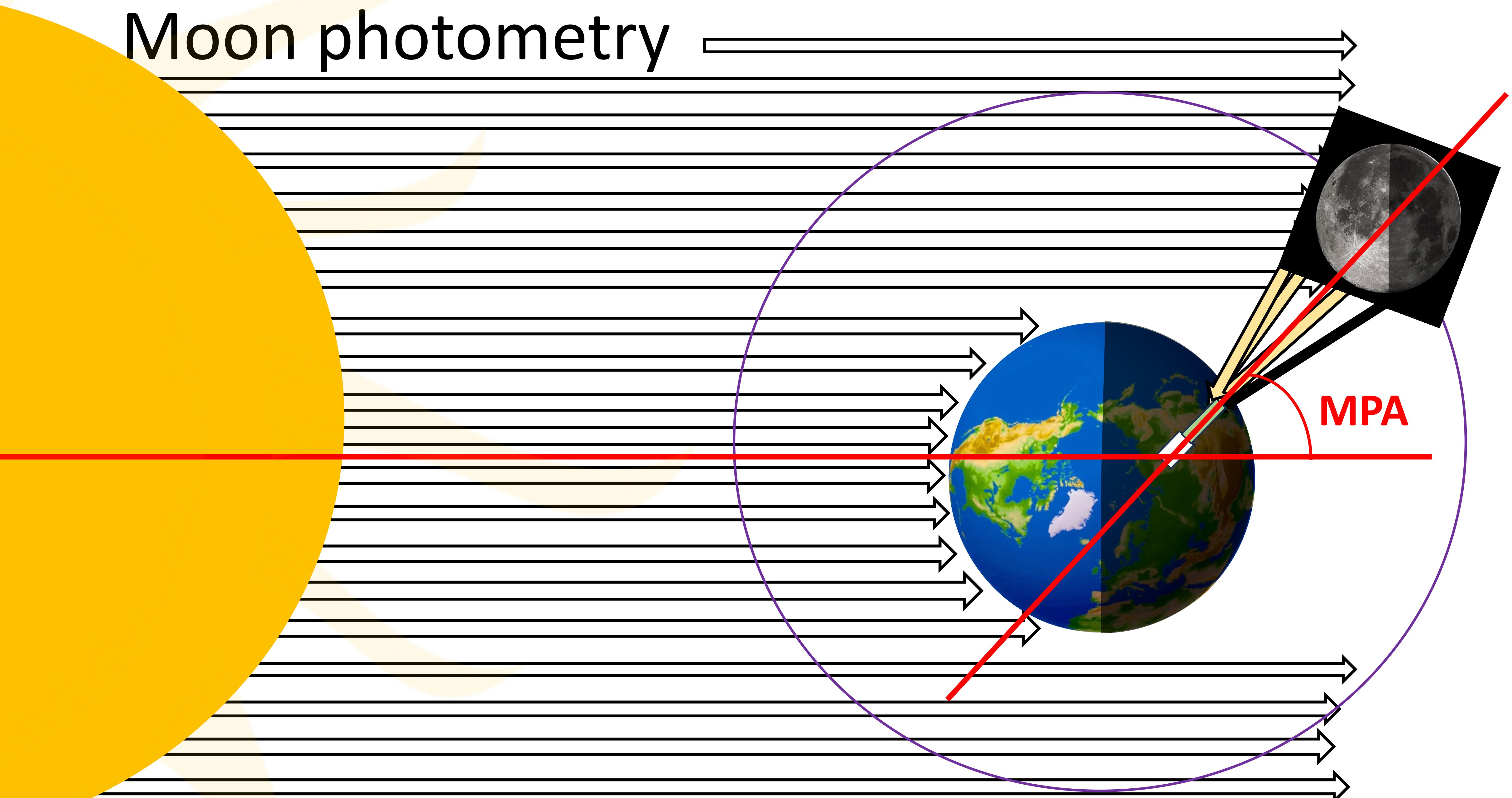
- $E^{moon} = E_0^{moon} \exp(-m\tau)$



Moon photometry



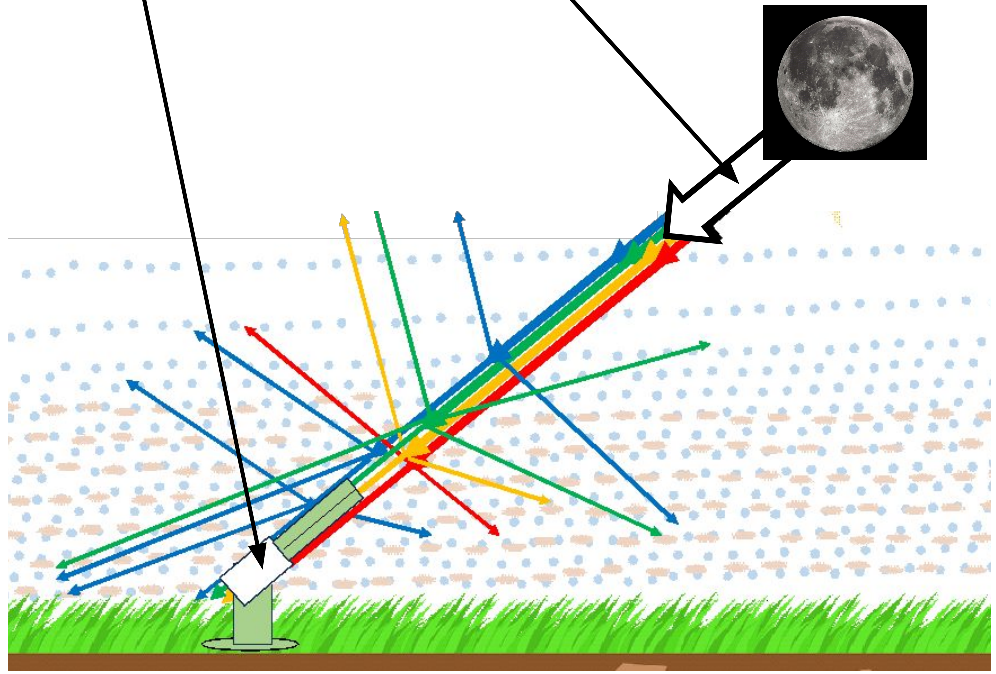
Moon photometry

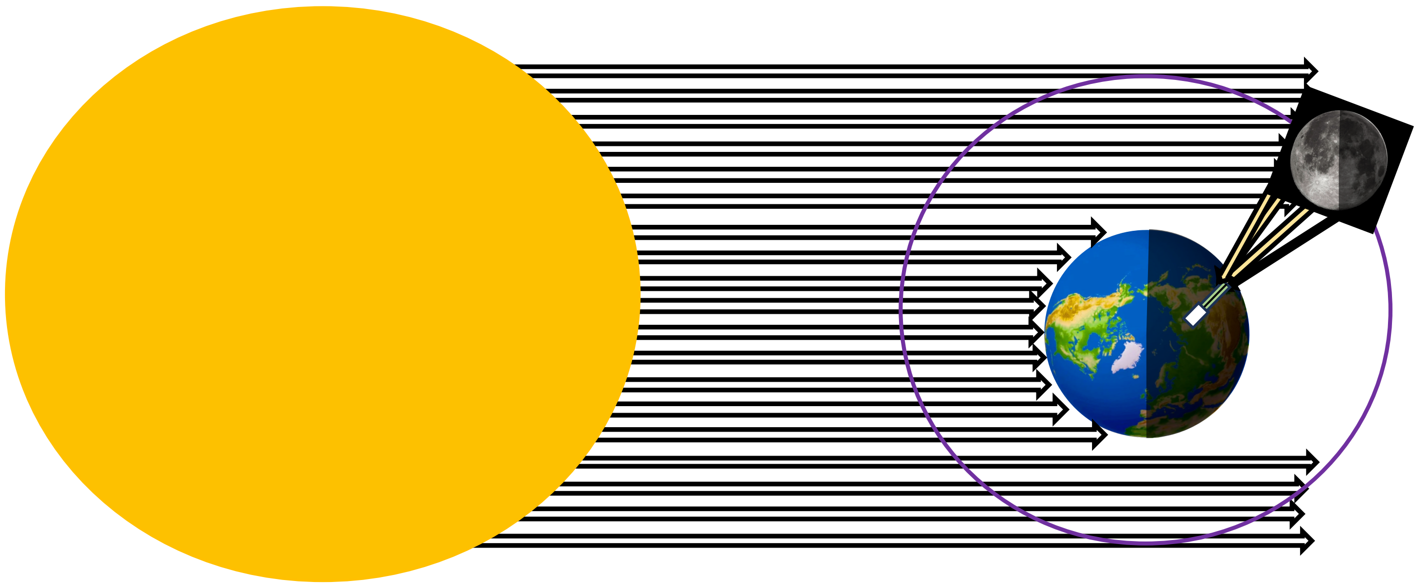


Moon photometry

Beer's law (spectral)

$$E^{moon} = E_0^{moon} \exp(-m\tau)$$





E_0^{moon}
- Varies **A LOT**, specially with Moon Phase.
- Varies significatively **even in one night**.
- Moon **reflectance is not easy** to correct.

It **DOES NOT** allow Langley calibration

We need a model to estimate E_0^{moon} !!!

ROLO/RIMO model

Robotic Lunar Observatory (ROLO)

Kieffer&Stone 2005.

$$E_0^{moon} = A \frac{\Omega\, E_0^{sun}}{\quad} F_{distance}$$

Moon Reflectance

$$\ln[A(k)] = \sum_{i=0}^{3} a_i(k) g_r^i + \sum_{j=1}^{3} b_i(k)\Phi^{2j-1} + c_1\phi + c_2\theta + c_3\Phi\phi + c_4\Phi\theta + d_1(k)\exp\left(-\frac{g_d}{p_1}\right) + d_2(k)\exp\left(-\frac{g_d}{p_2}\right) + d_3(k)\cos\left(\frac{g_d - p_3}{p_4}\right),$$

MPA

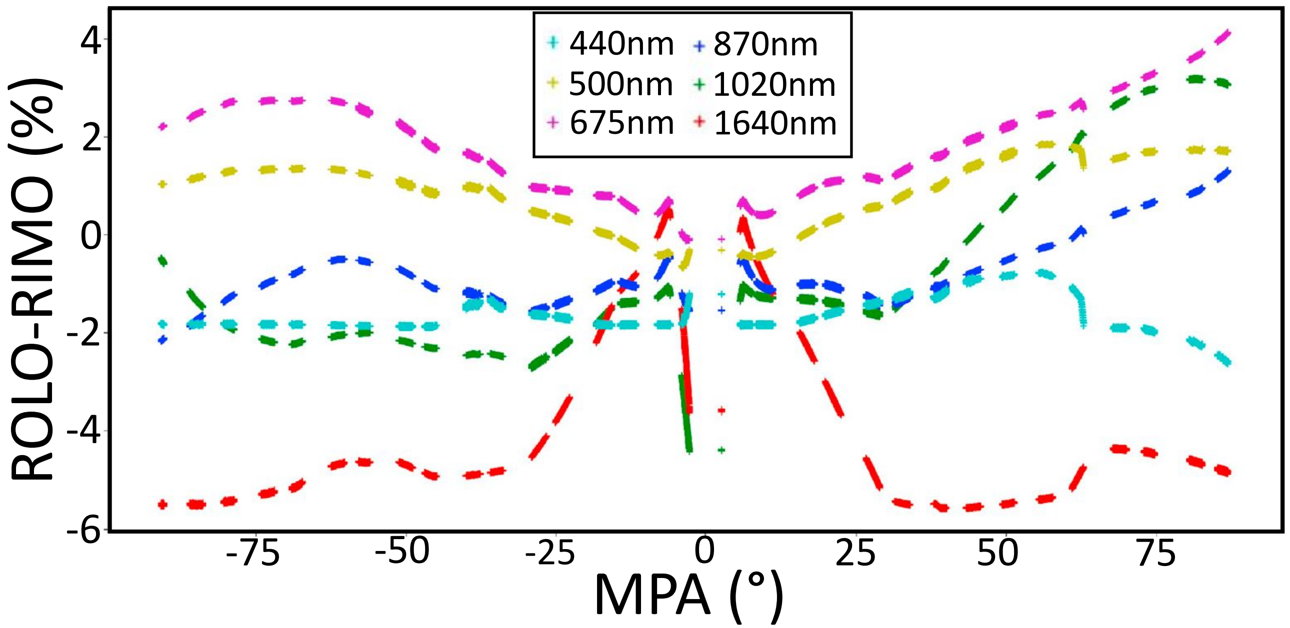
ROLO Implementation for Moon photometry Observation (RIMO)

Barreto et al. 2019.

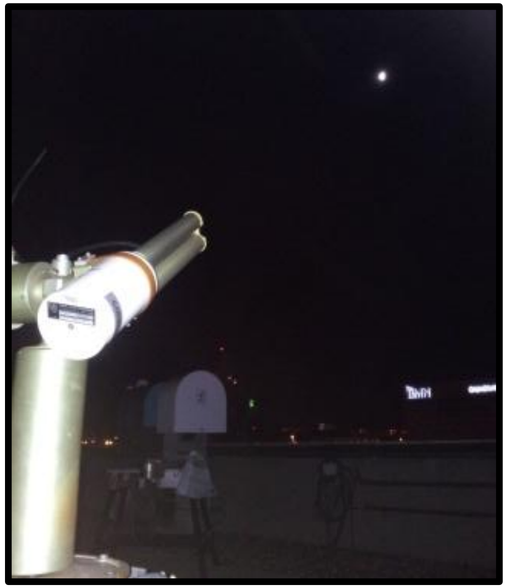
- **Free** and **public** implementation of ROLO.

http://testbed.aemet.es/rimoapp

- **±2%** between RIMO and ROLO.



CIMEL318-T



- SUN/SKY/**LUNAR** TRIPLE photometer (CIMEL CE318-T).
- Sky radiance and **direct Sun and Moon irradiance** at several wavelengths (narrow filters) as 440, 675, 870 and 1020 nm.
- AERONET Sun calibration (Langley or intercomparison against master).

Moon calibration: **Gain method** (transfer sun calibration to lunar; *Barreto et al.* 2016)

E_0^{sun} → **Sun calibration**

E_0^{moon} → **RIMO**

E^{sun} → **Sun calibration**

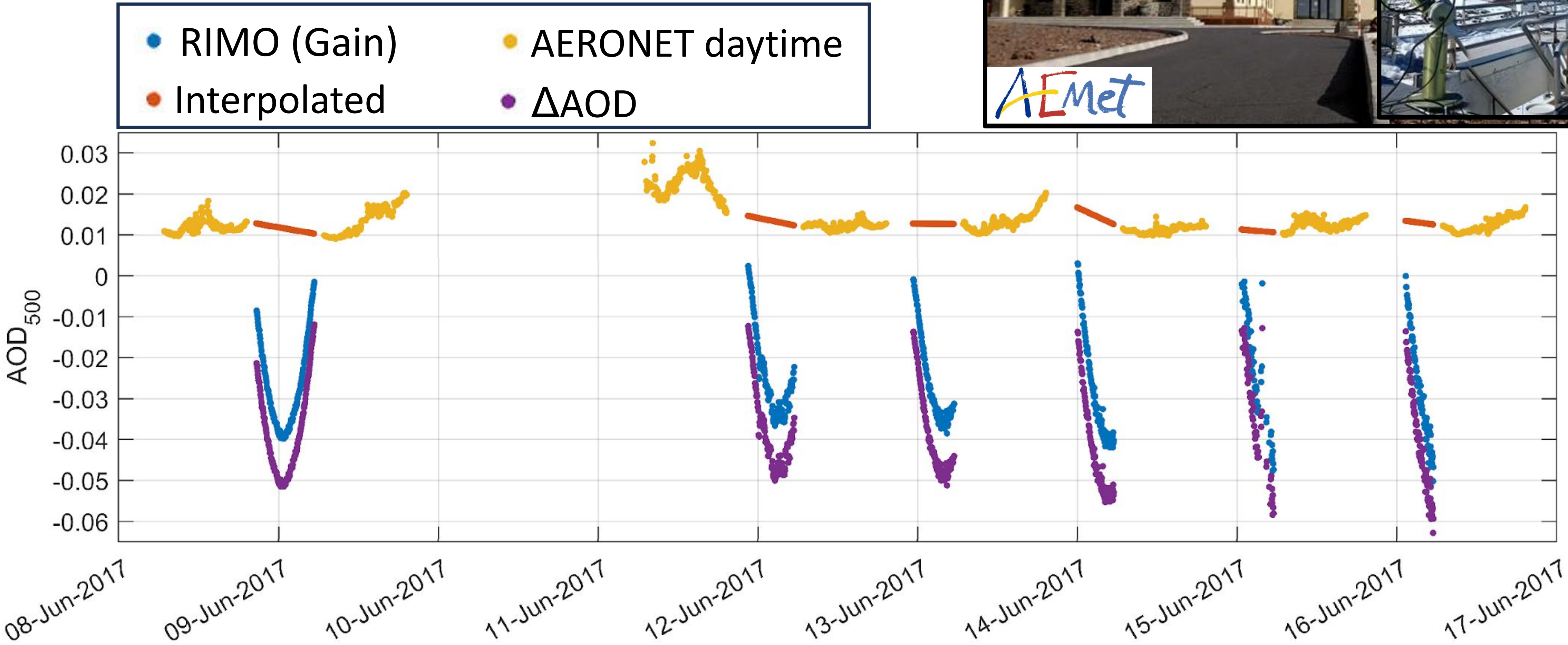
E^{moon} → **Gain (G)**

$$E^{moon} = \frac{E^{sun}}{\;}$$

G= 4096 (amplification)

Aerosol Optical Depth (AOD)

AOD calculated using **RIMO** and **the Gain method** in Izaña with CIMEL **CE318-T**.



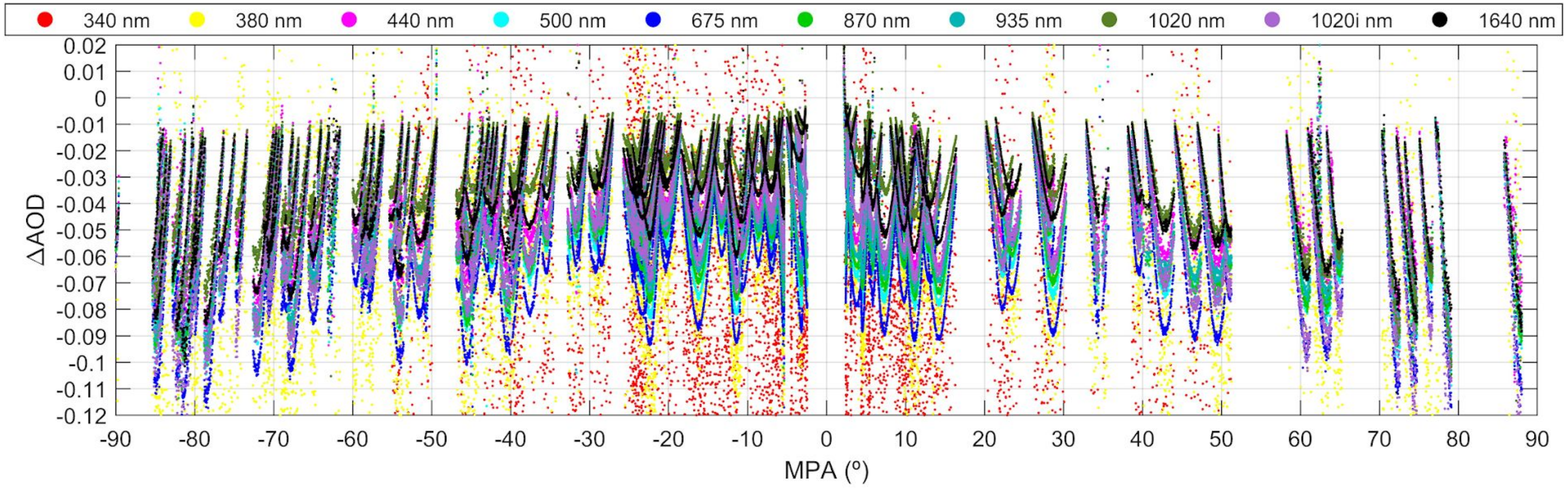
RIMO Correction Factor (RCF)

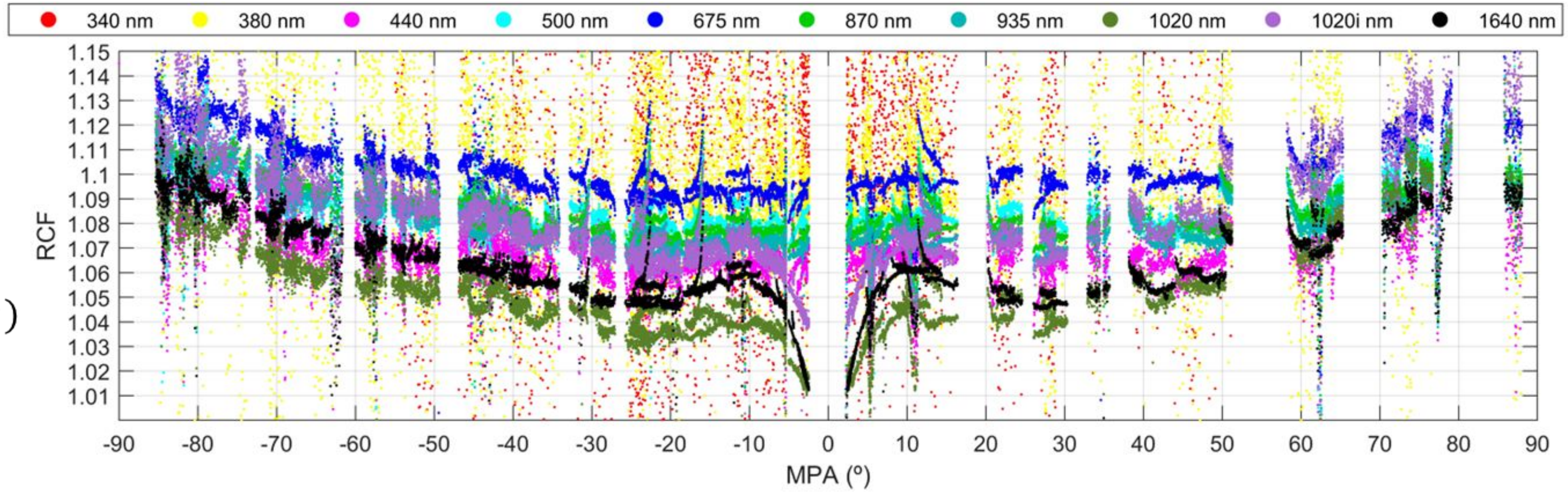
ΔAOD calculated for **98 pristine nights** (2014-2018) at <u>Izaña</u> (~13000 data per λ).

$$\Delta AOD = \frac{1}{m} log \left(\frac{E_{0-ref}^{moon}}{E_{0-RIMO}^{moon}} \right)$$

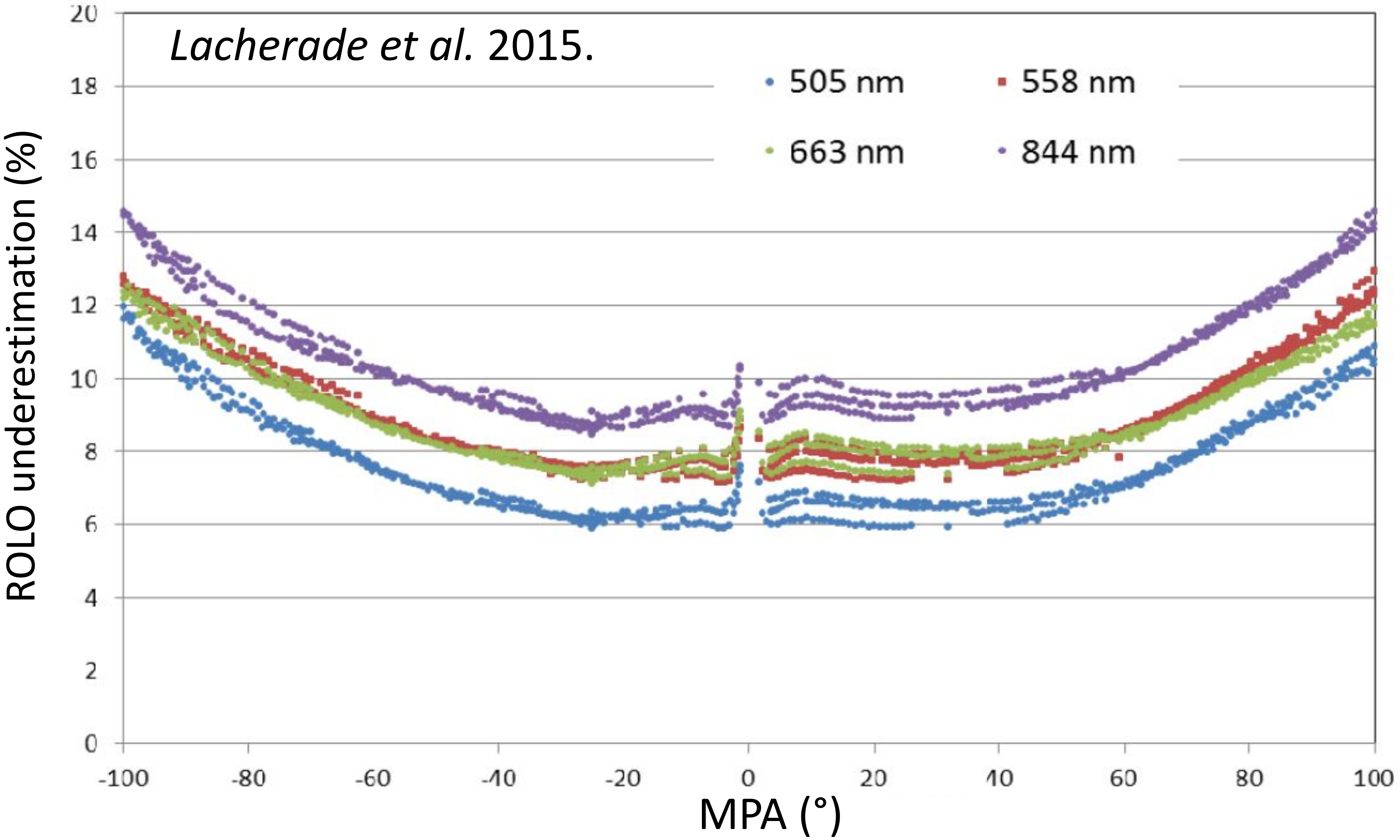
E_0^{moon} value that provides **realistic AOD** values. It is considered now our reference.

$$RCF = \left(\frac{E_{0-ref}^{moon}}{E_{0-RIMO}^{moon}} \right) = \exp(m\ \Delta AOD)$$

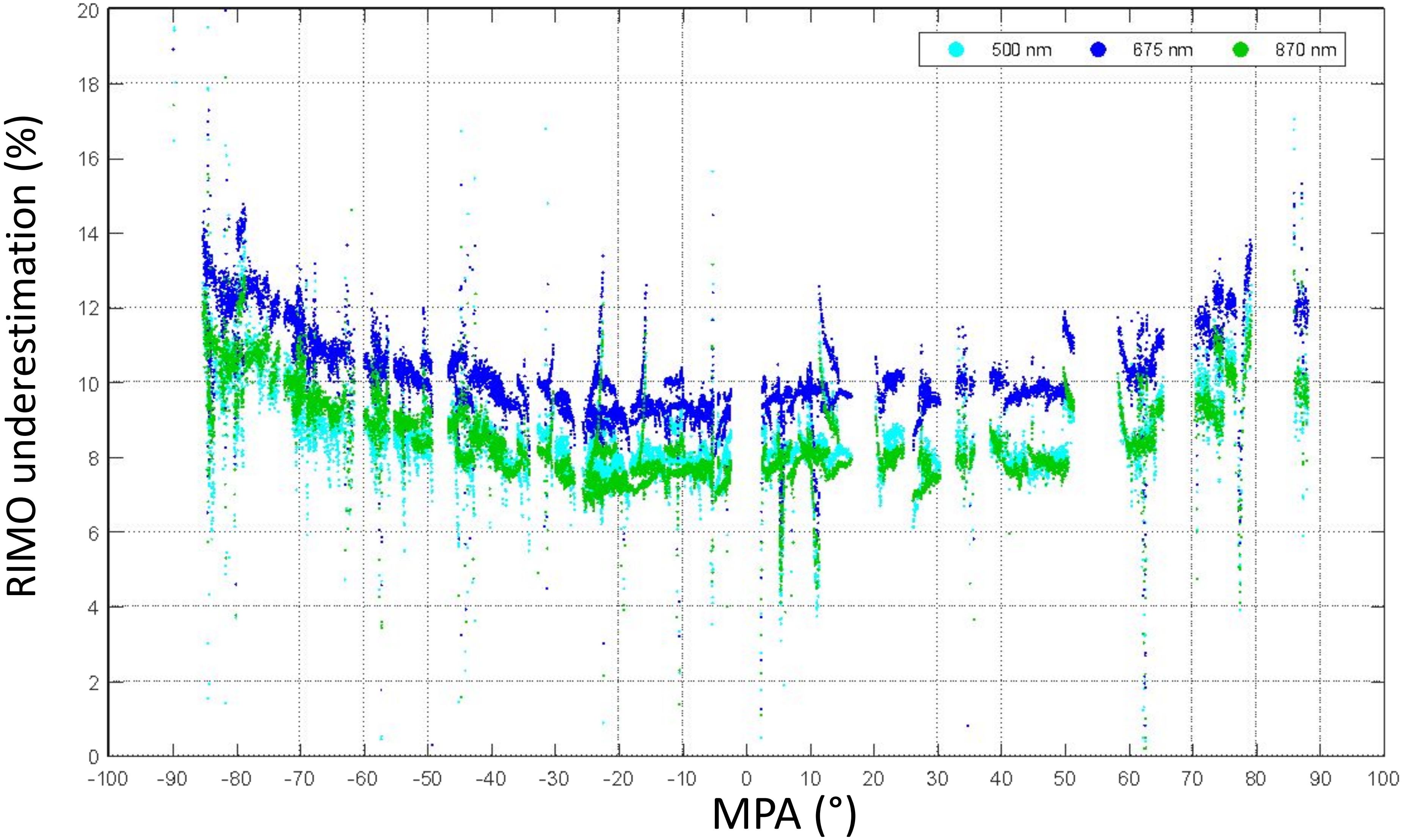




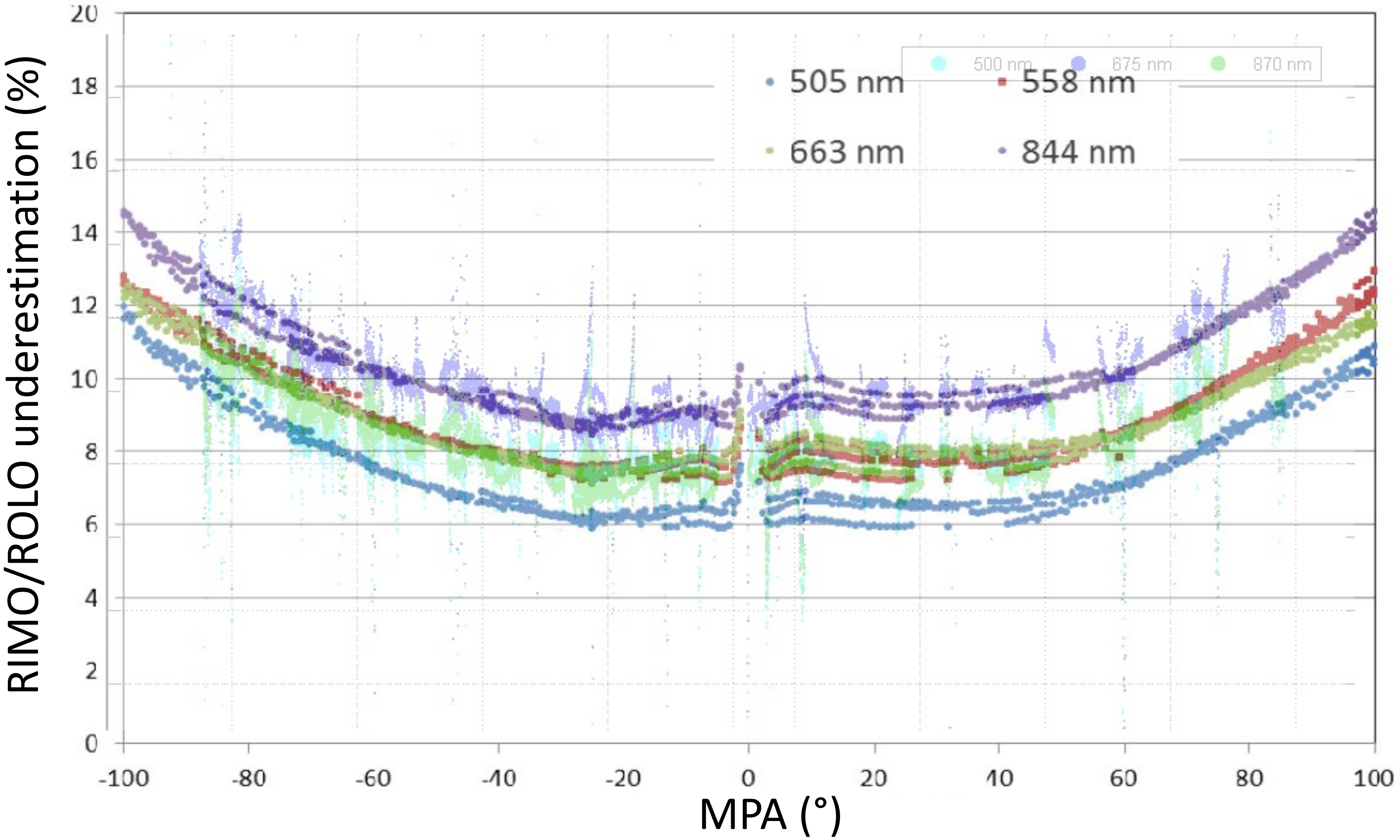
RIMO/ROLO Performance



RIMO/ROLO Performance



RIMO/ROLO Performance

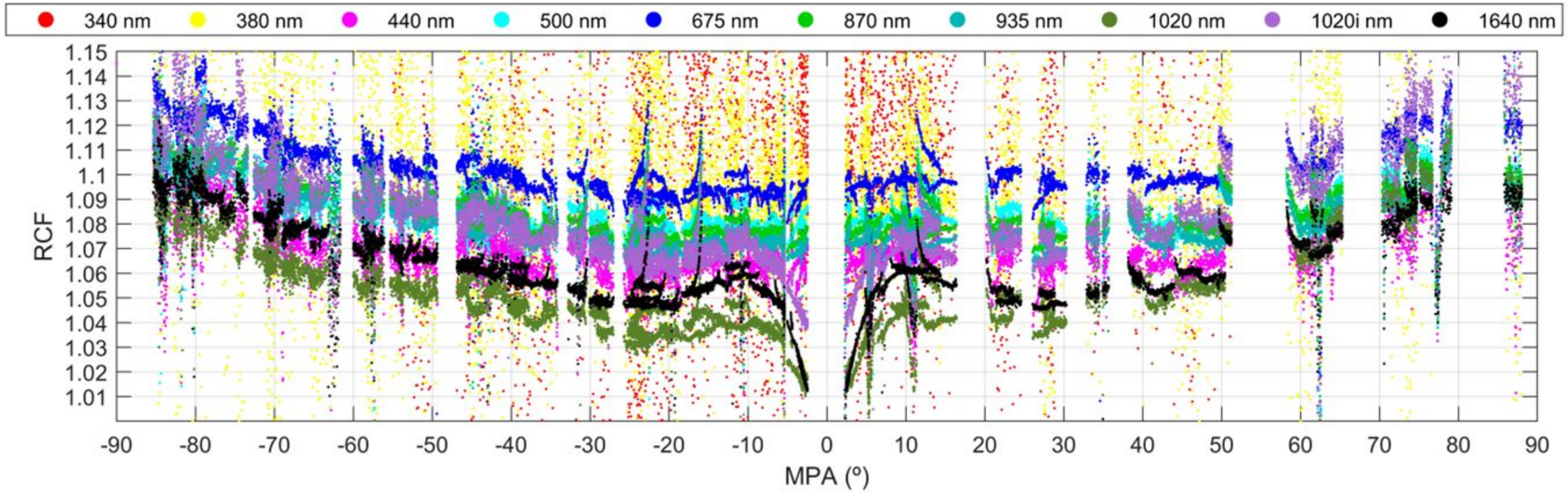


RIMO Correction Factor (RCF)

$$RCF = \left(\frac{E_{0-ref}^{moon}}{E_{0-RIMO}^{moon}}\right)$$

$$RCF = a + bg + cg^2$$

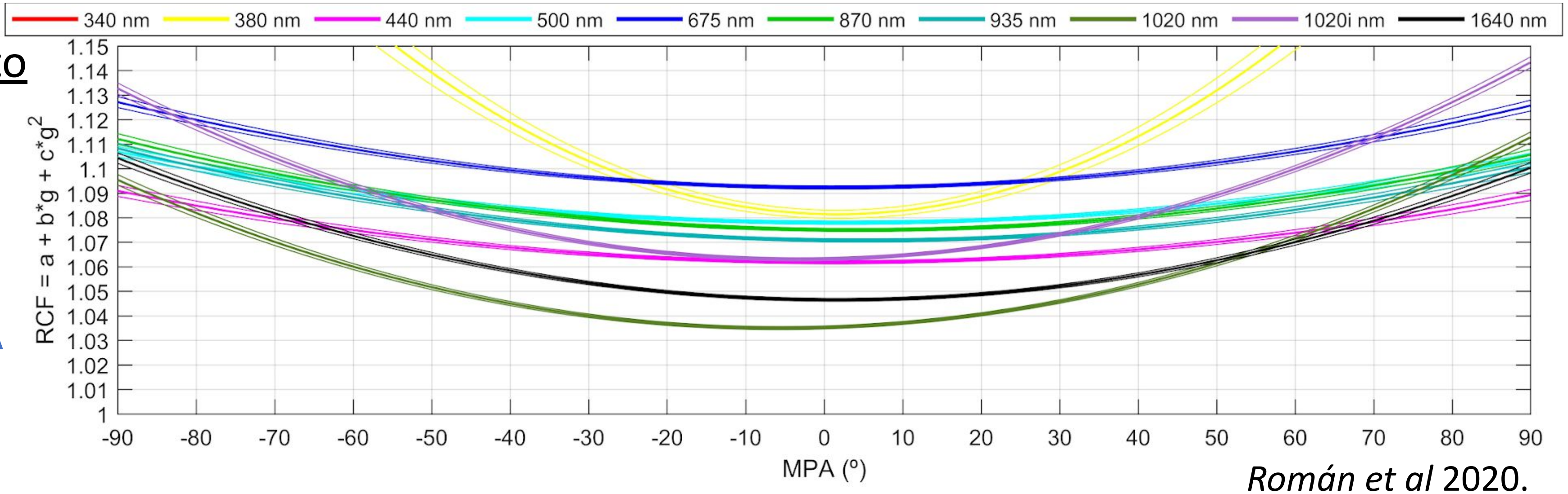
MPA



An **effective** E_0^{moon} value, <u>capable to derive AOD</u>, is obtained multiplying:

$$E_0^{moon} = E_{0-RIMO}^{moon} * RCF$$

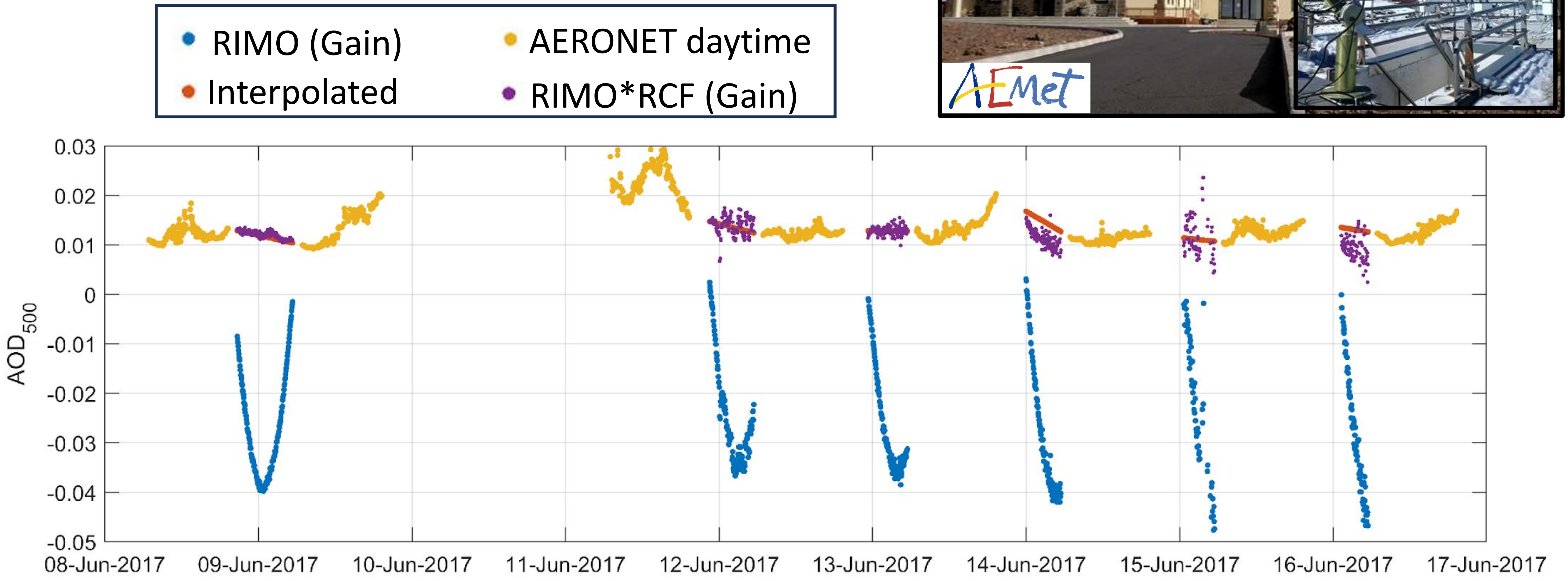
With RCF obtained only with MPA and the *a*, *b* and *c* coefficients.



Román et al 2020.

AOD with RCF

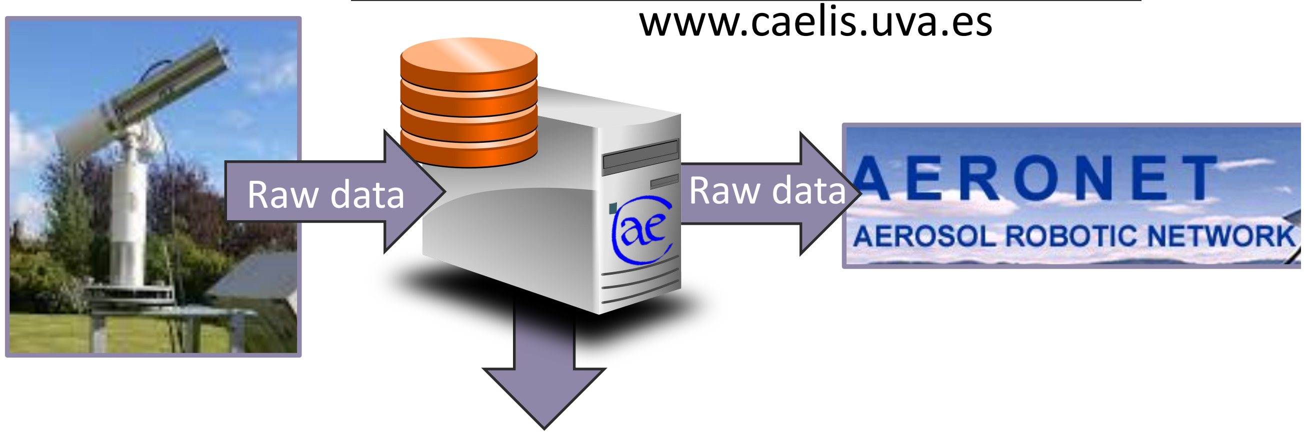
AOD calculated using **RIMO * RCF** and **the Gain method** in Izaña with CIMEL **CE318-T**.



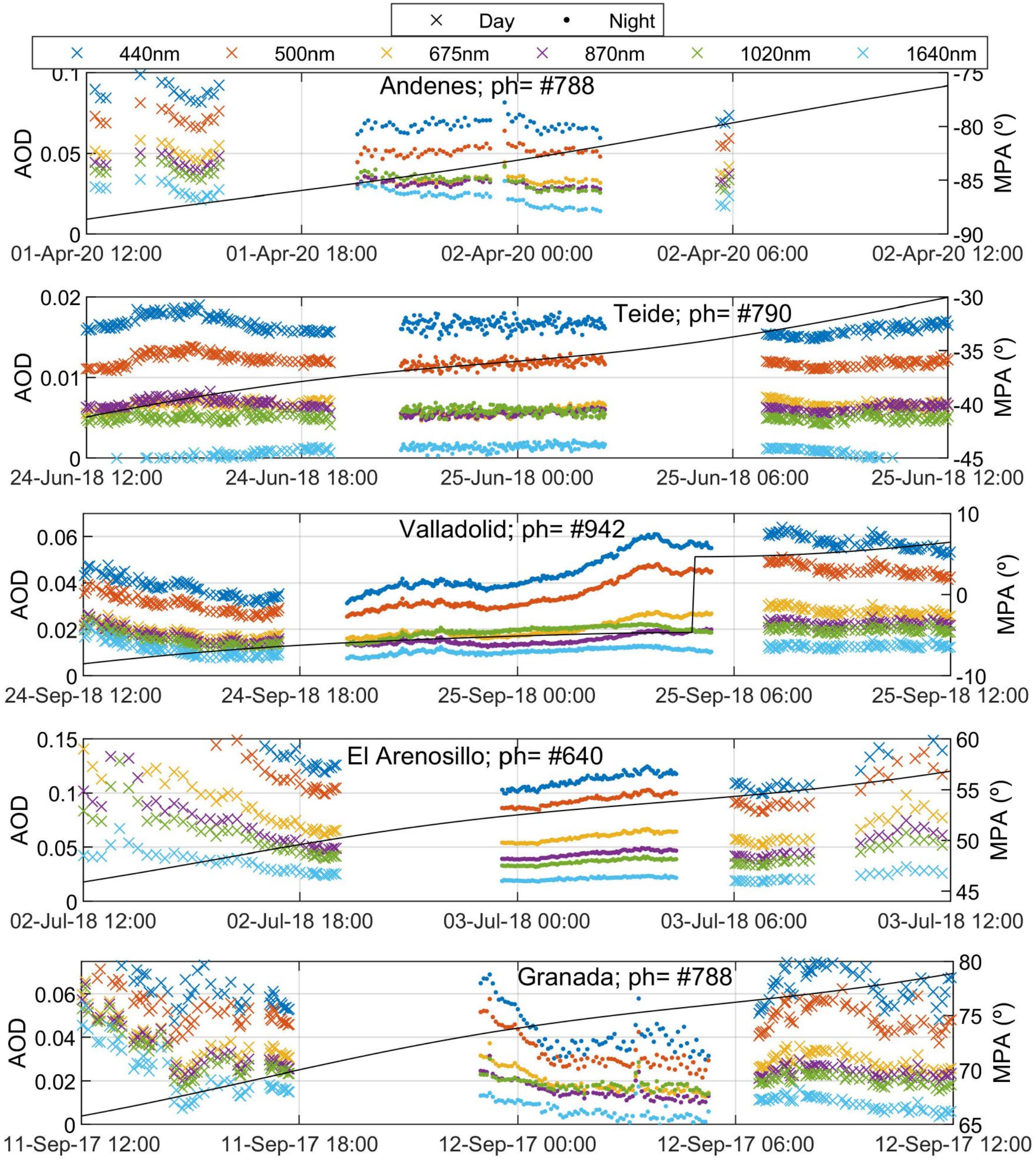
AOD with RCF in CAELIS

CAELIS is a computer tool that manages and process data of GOA CF photometers and helps to visualize the data.

www.caelis.uva.es



- Data Quality check.
- Process AOD.
- **Moon AOD with RCF.**
- ...

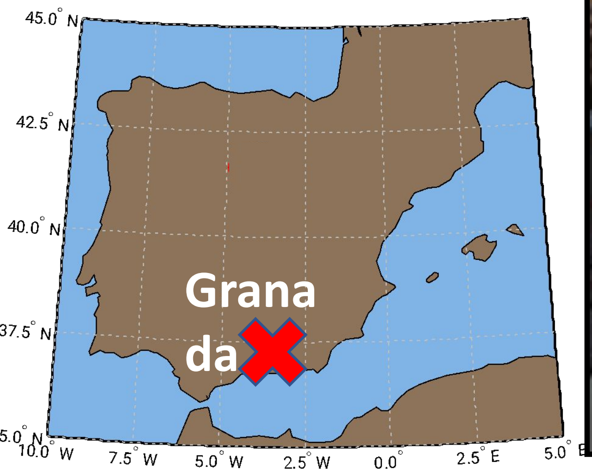


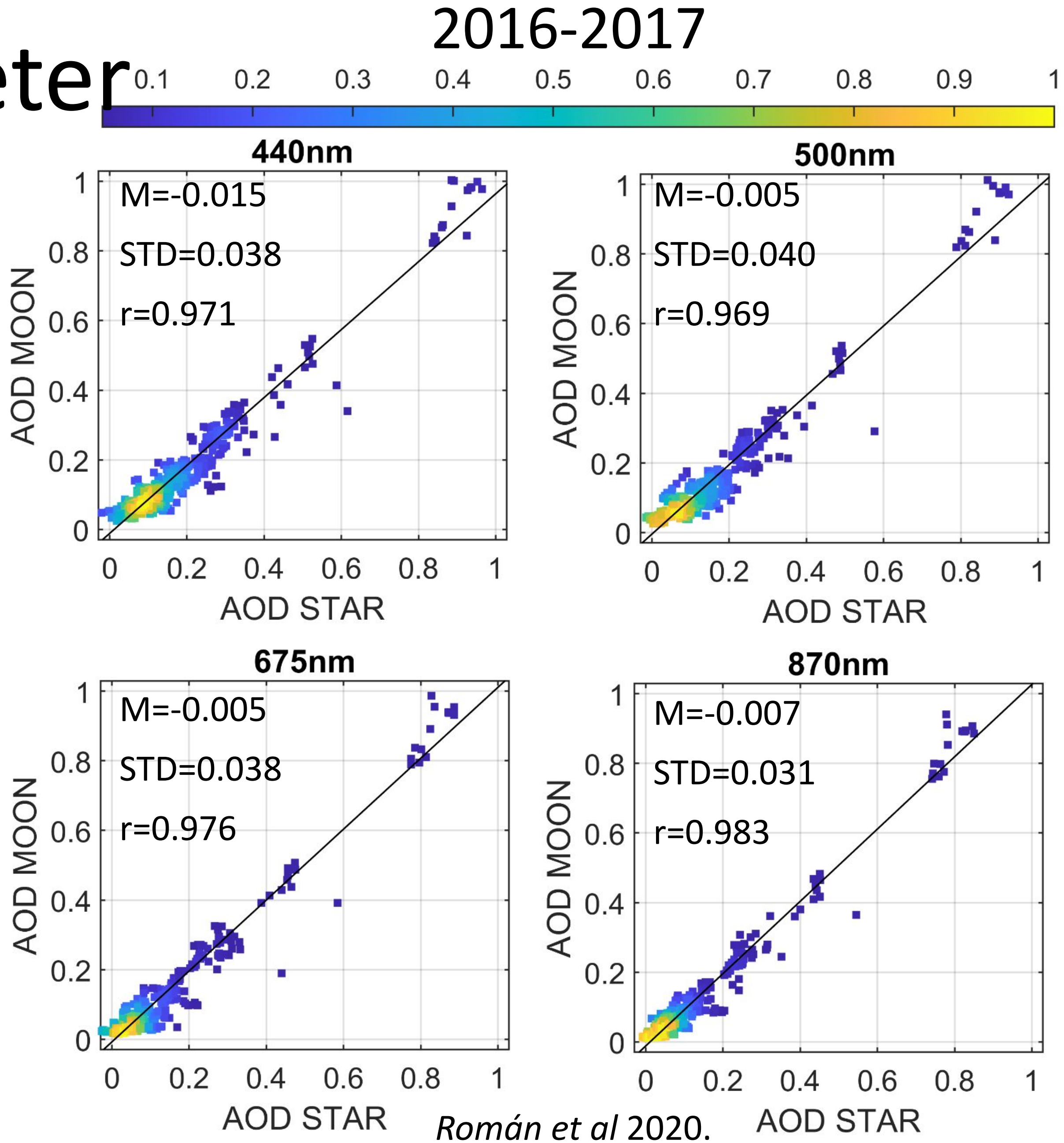
González et al 2020.

Moon VS. Star photometer

Star photometer at **Granada** (Spain).

Basically, a **CCD** camera connected to a **telescope** making photos to different stars in order to provide AOD and water vapour column. *Pérez-Ramírez et al. 2008*.

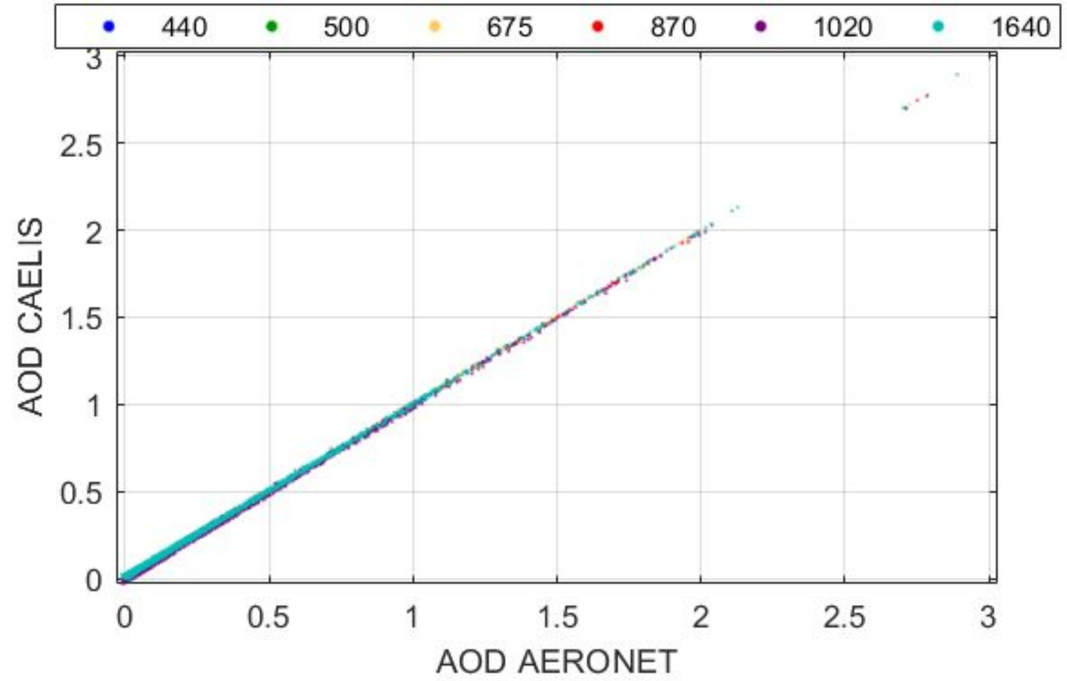


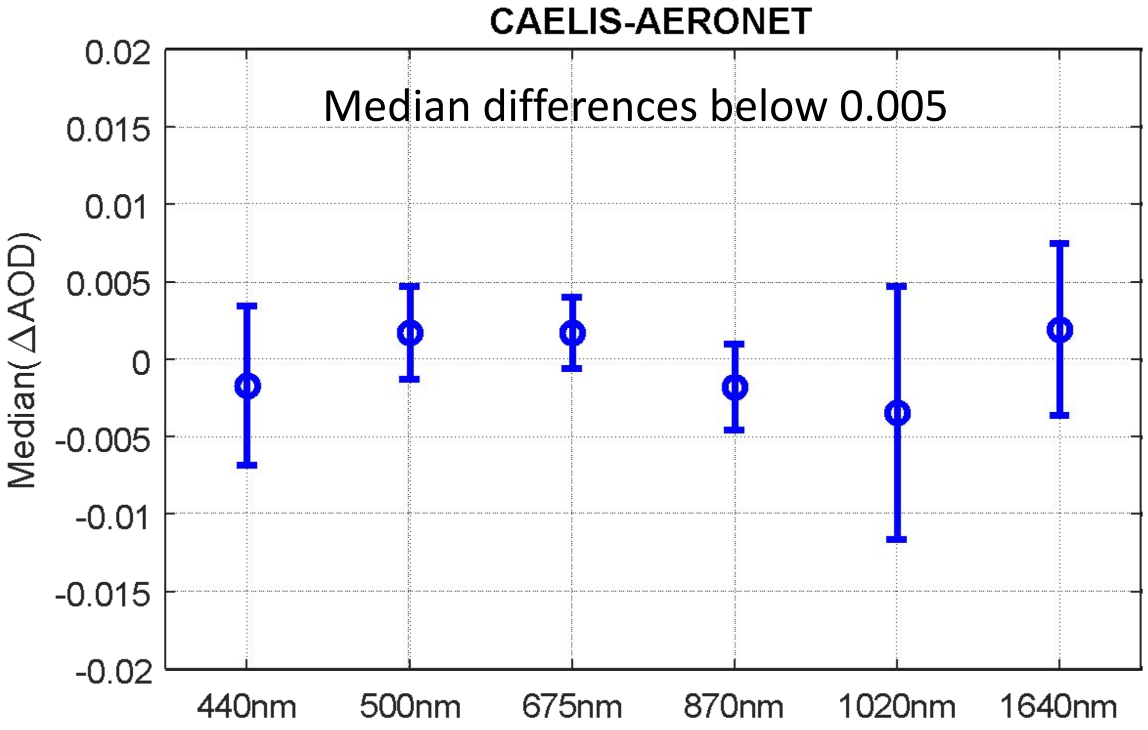


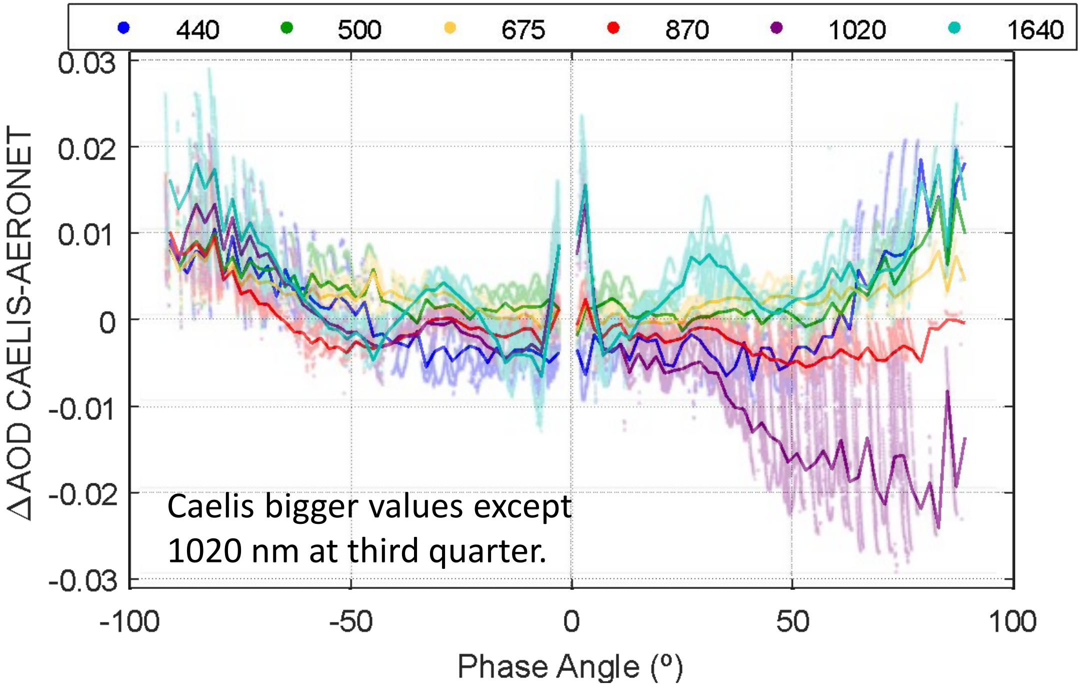
Román et al 2020.

CAELIS VS. AERONET

Due to the availability of star photometer data at **Granada** (Spain), data from March 2016 to October 2017 has been used.
The **Level 1.0** (not cloud-screened) is shown and AERONET product is provisional.







Conclusions

- RIMO/ROLO **underestimates** the real extrarrestrial lunar irradiance about **1-14%,** and this **underestimation depends on MPA** and causes negative and unrealistic AOD values.
- This underestimation **can be corrected** multiplying RIMO **by the RCF**, which can be obtained from the MPA.
- The **AOD** values calculated **using RCF fits well** with the **expected** values, showing **continuity** between <u>sunset-nighttime-sunrise</u>.
- These AOD values **correlates** with **independent star photometer** measurements.
- We **recommend** to use **RCF with RIMO** for AOD calculations at least until a better lunar extraterrestrial irradiance model appears.

THANK YOU!

More detailed info in:

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Correction of a lunar-irradiance model for aerosol optical depth retrieval and comparison with a star photometer

Roberto Román[1], Ramiro González[1], Carlos Toledano[1], África Barreto[2,3,1], Daniel Pérez-Ramírez[4,5], Jose A. Benavent-Oltra[4,5], Francisco J. Olmo[4,5], Victoria E. Cachorro[1], Lucas Alados-Arboledas[4,5], and Ángel M. de Frutos[1]

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Daytime and nighttime aerosol optical depth implementation in CÆLIS

Ramiro González[1], Carlos Toledano[1], Roberto Román[1], David Fuertes[2], Alberto Berjón[1,3,4], David Mateos[1], Carmen Guirado-Fuentes[1,3], Cristian Velasco-Merino[1], Juan Carlos Antuña-Sánchez[1], Abel Calle[1], Victoria E. Cachorro[1], and Ángel M. de Frutos[1]