IPC-XIII/FRC-V Symposium, PMOD
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LUNAR PHOTOMETRY

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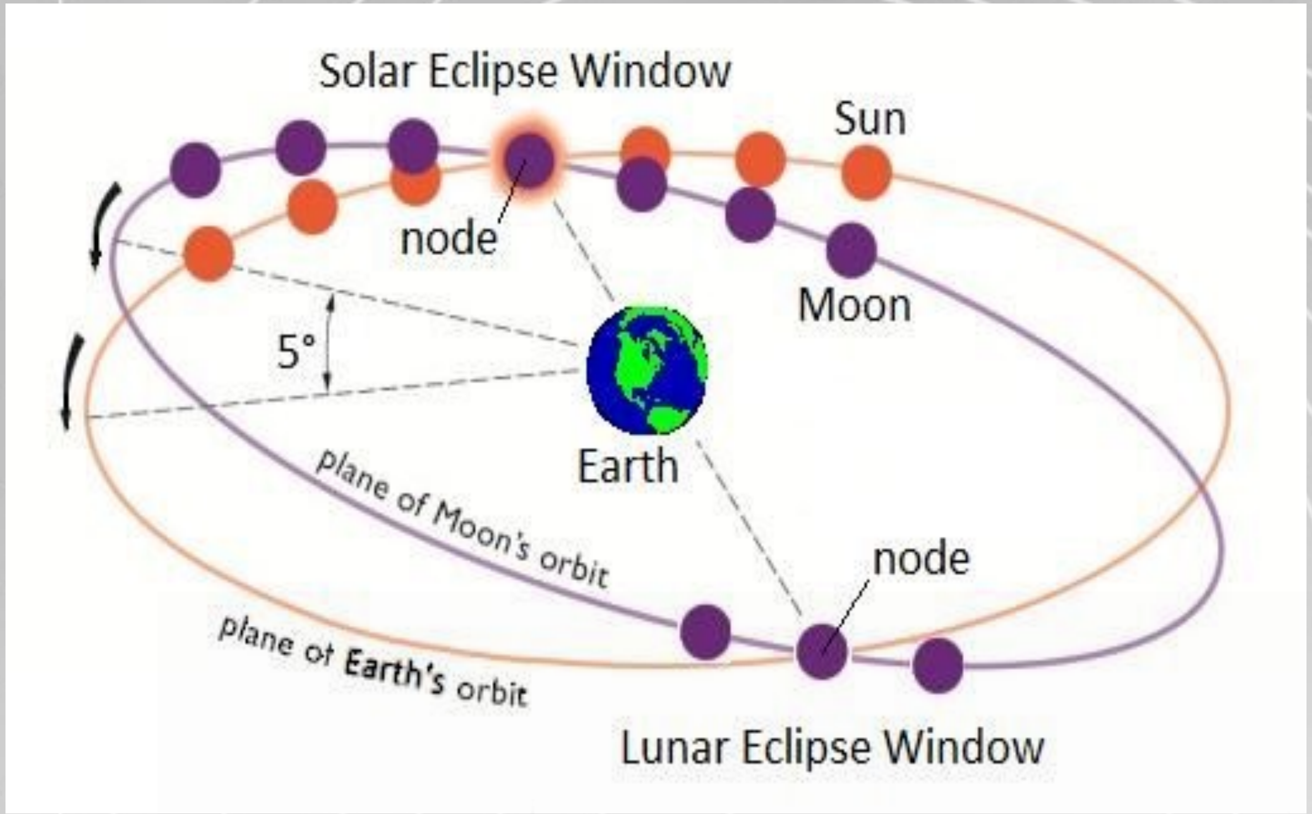
LUNAR PHOTOMETRY - Outline

- Features of the Moon's orbit
- Technical problems
- Motivation. Detect:
  - Diurnal cycles
  - Change in atmospheric composition
  - Polar studies (polar night)
- Commertial instruments: Cimel, Prede, LunarPFR
- Lunar Irradiance Models. Calibration. Recent advances and possible solutions
- Brief summary of the nocturnal (lunar) activities
  - 3 lunar campaigns + MOSAIC

THE SUN

FEATURES OF THE MOON'S ORBIT

Periodic lunar cycles



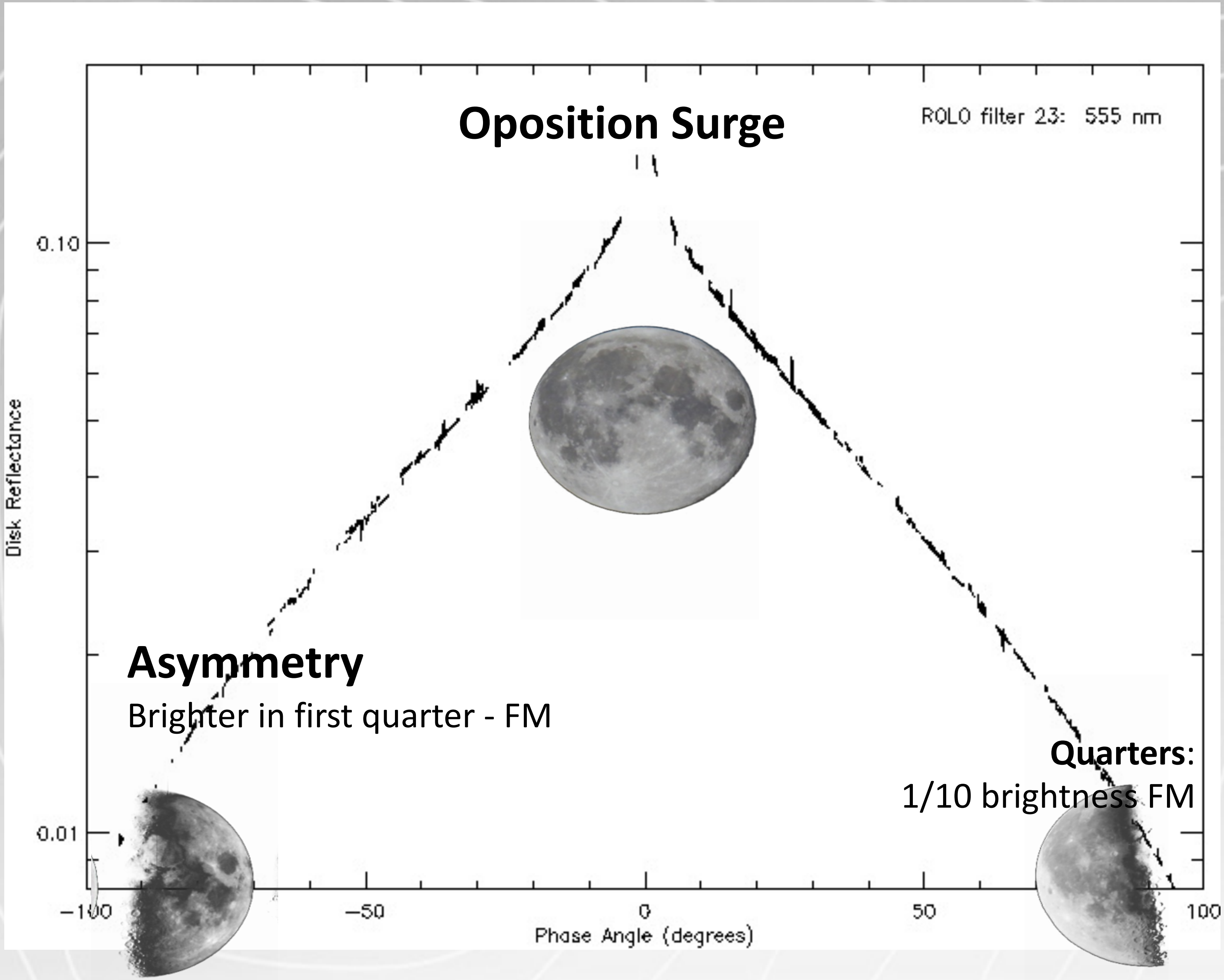
- Diurnal cycle: rise & set
- Orbital cycle: 27,3d
  - $\Delta d_{app} \approx 14\%$
  - $\Delta I \approx 30\%$ (SuperMoon, + 50000km)
  - Lunar nodes
- Saros (18 yr)
- Draconic cycle (18.6 yr) [2025 - 2034]

What the moon has to do with oceanic tides (floodings)+ long-term lunar atmospheric tides

- Lunar Librations


Moon Phases 2020
Including Libration and Position Angle
Peary
Euctemon
Neison
Moigno
Kane
Democritus
Gärtner
Bürg
Plana
Williams
Apollo 15
Posidonius
Chacornac
Le Monnier
Apollo 17
Apollo 12
Apollo 14
Plinius
Maraldi
Lamont
Apollo 11
Apollo 16
Theophilus
Cyrillus
Isidorus
Daguerre
Catharina
Beaumont
Polybius
Fracastorius
Rothmann
Rabbi Levi
Riccius
Nicolai
Pitiscus
Hommel
Schomberger
28
30
32
Time 01 Jan 2020 00:00 UT
Phase 30.0% (5d 18h 47m)
Diameter 1774.5 arcseconds
Distance 403898 km (31.70 Earths)
Position 23h 15m 39s, 10° 04' 57"S
Subsolar 0.045°S 114.557°E
Sub-Earth 6.360°N 0.773°E
Pos. Angle 336.353°

Features of the lunar disk reflectance

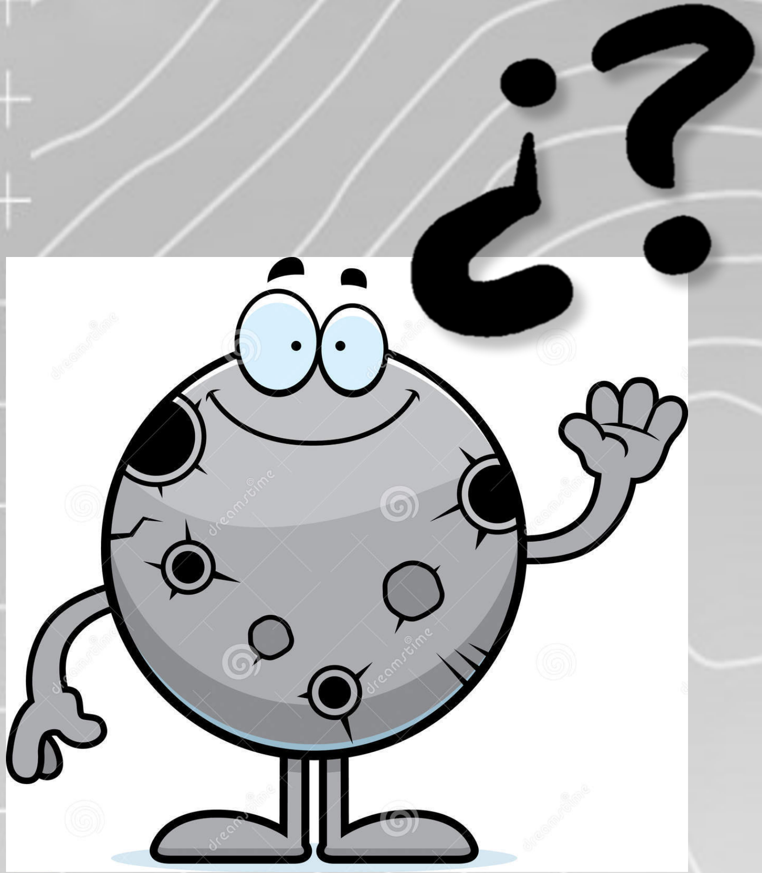


TECHNICAL PROBLEMS, MOTIVATION AND COMMERCIAL INSTRUMENTS

Technical problems

- 6-7 orders of magnitude (detectors with enough sensibility)
- Suitable SNR (quarters)
- Sun-light pollution
- High dynamic range (solar/lunar)
- Tracking: 4Q
- UV

Moon photometry: Motivation

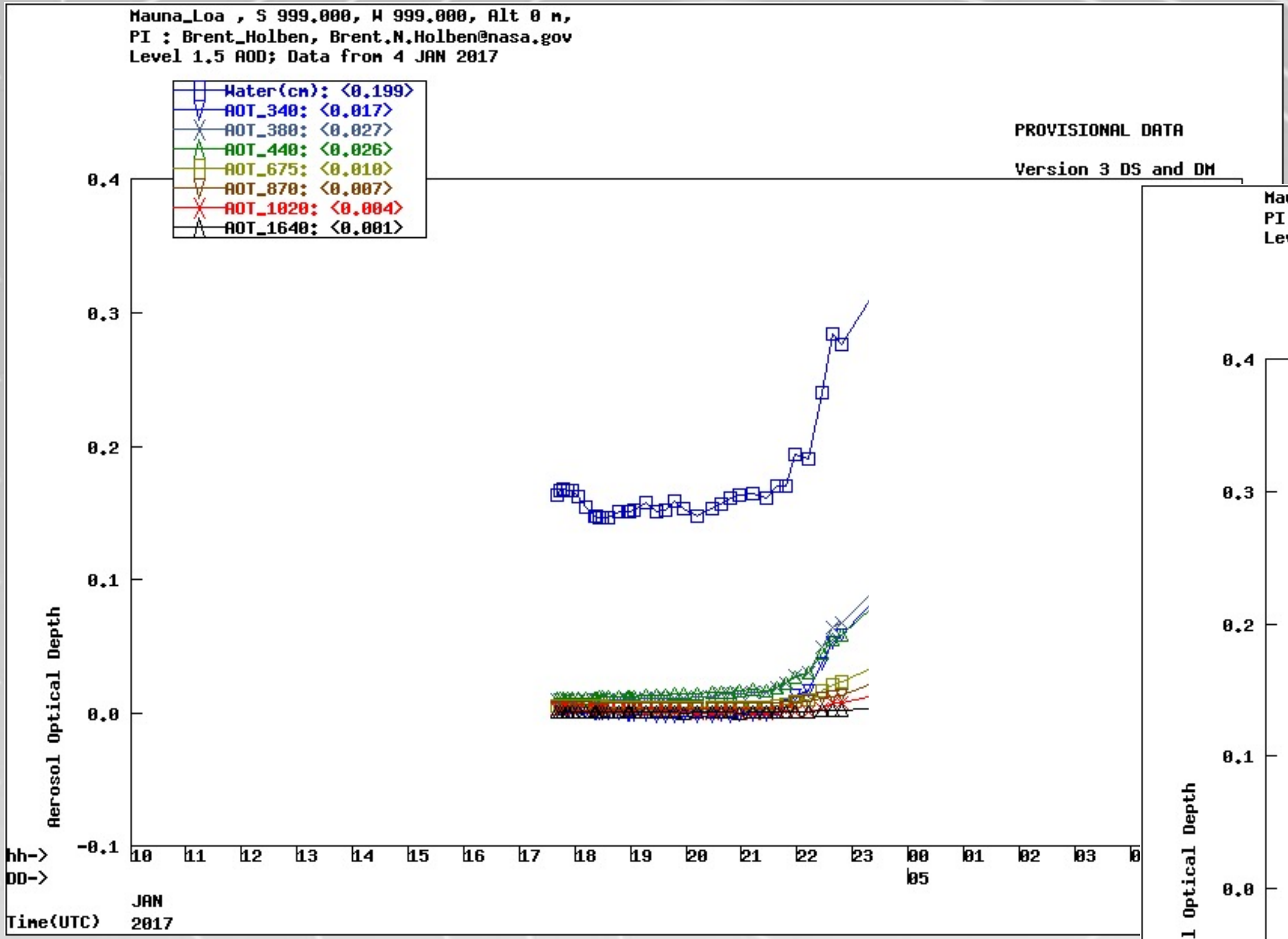


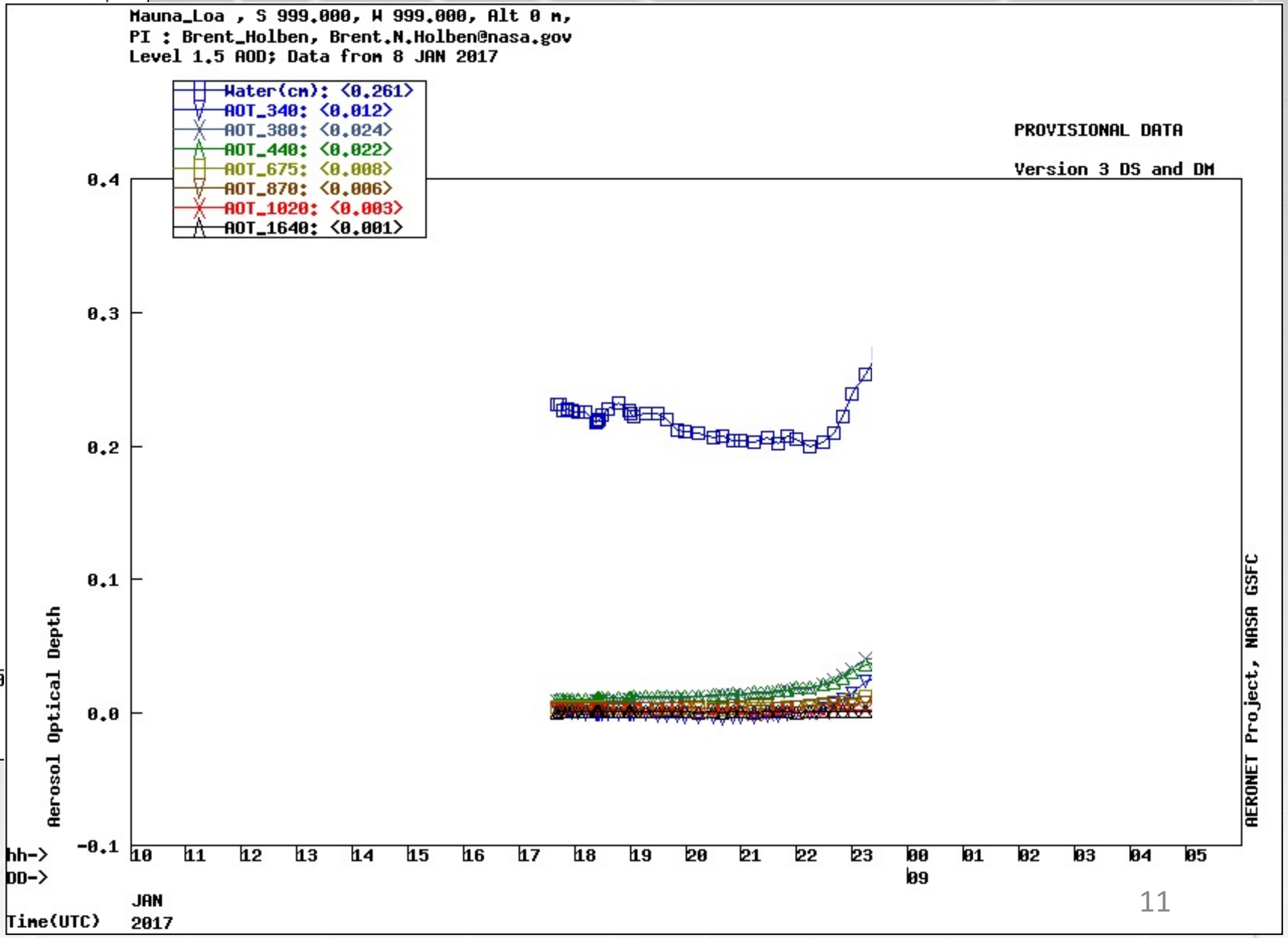
Why is it important to measure aerosols at night?

- Models and satellite data evaluation/assimilation
- Lidar/photometry synergies: active remote sensing techniques also dependent on column-integrated AOD information
- Ensure a continuous monitoring of aerosols for climate studies
  - **Diurnal cycle**
  - Evaluate dynamics, transport and chemistry of atmospheric aerosols
  - High latitude stations (Polar Winter)

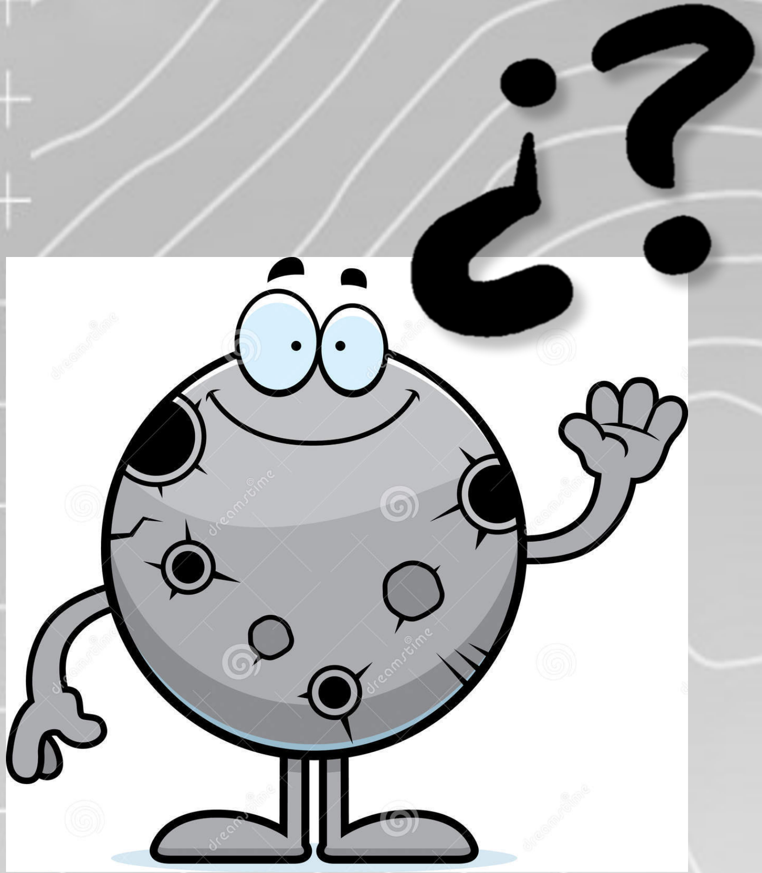
Moon photometry: Motivation – Continuous monitoring

Diurnal cycles





Moon photometry: Motivation



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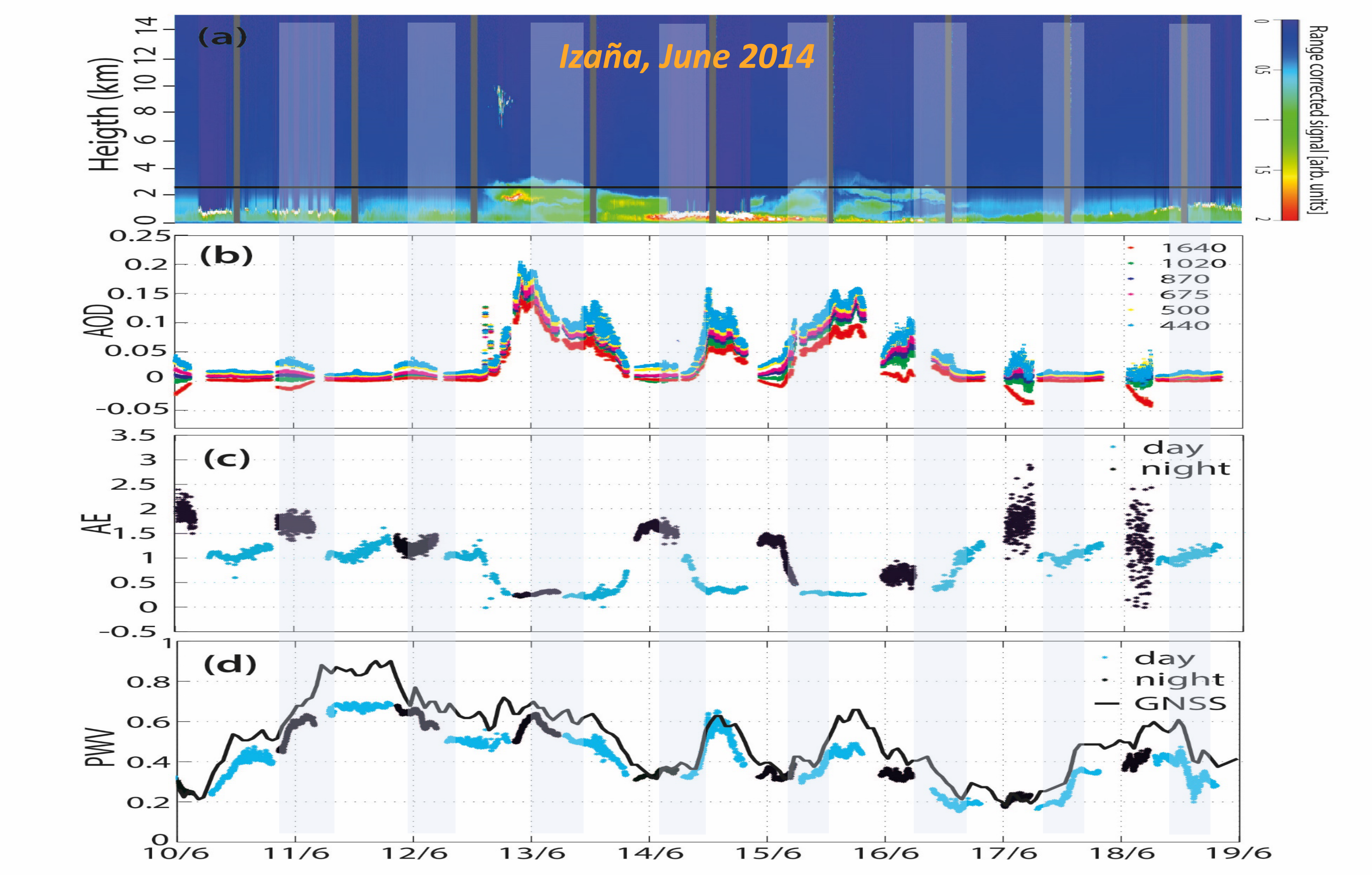
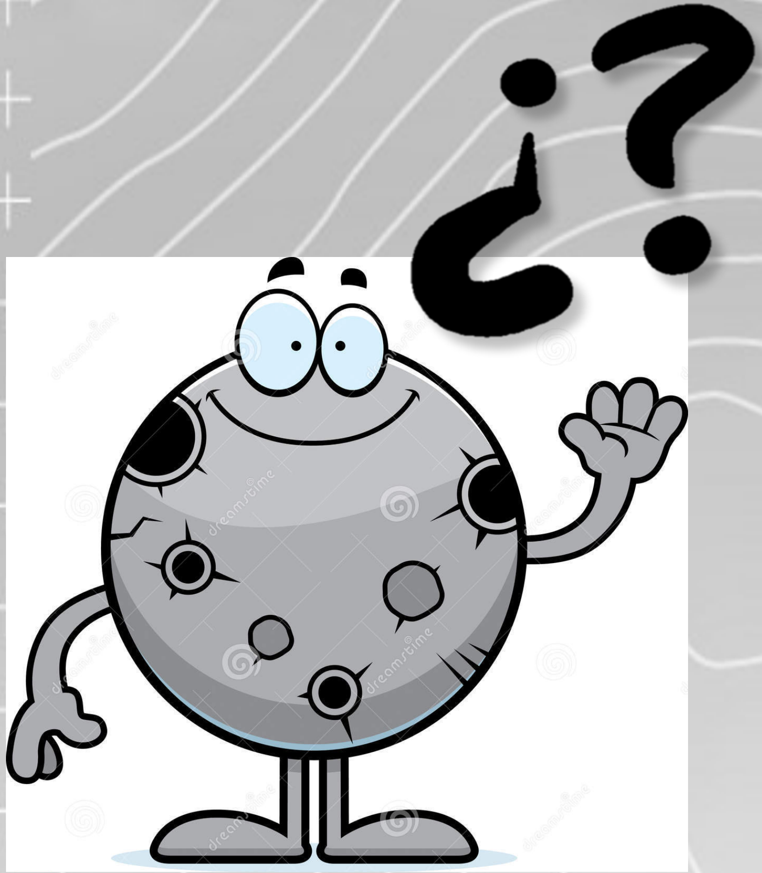
Moon photometry: Motivation – Continuous monitoring

Detect changes atm. composition



Barreto et al. (2016)

Moon photometry: Motivation



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Moon photometry: Motivation – Polar regions

- early indicator of climate change
- challenging environment

Moon photometry: Motivation – Polar regions

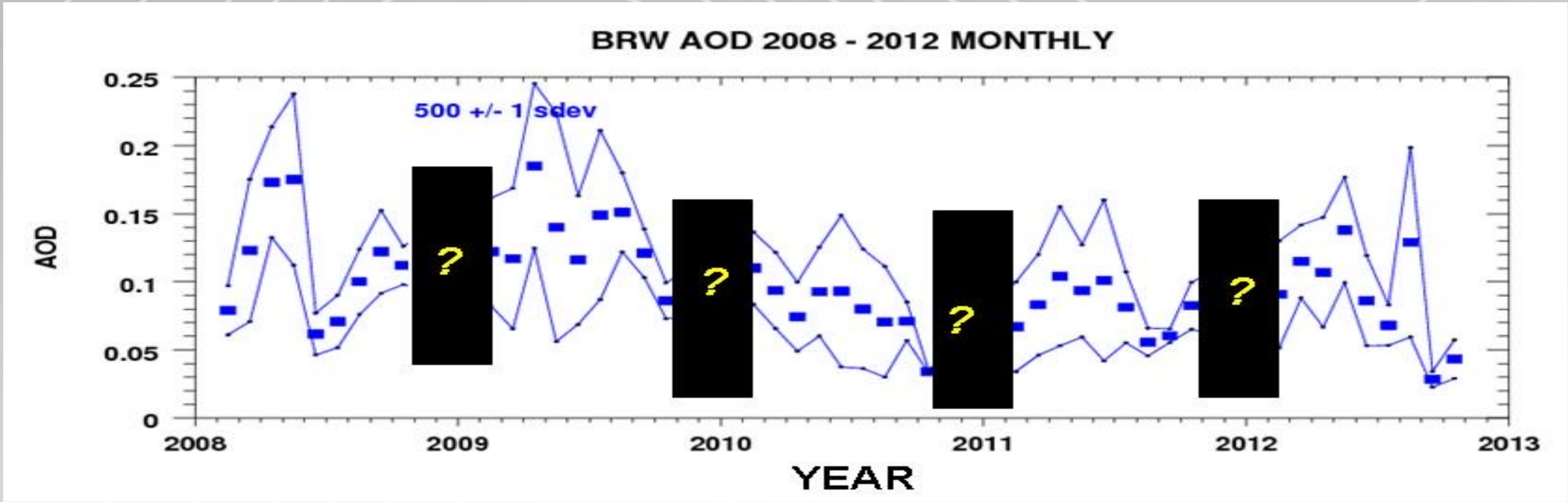
ARCTIC HAZE – “POO-JOK” (1750)

The first indicator of human activity in the Arctic

NASA P3B and the Arctic haze layer 02 (source: https://www.esrl.noaa.gov)

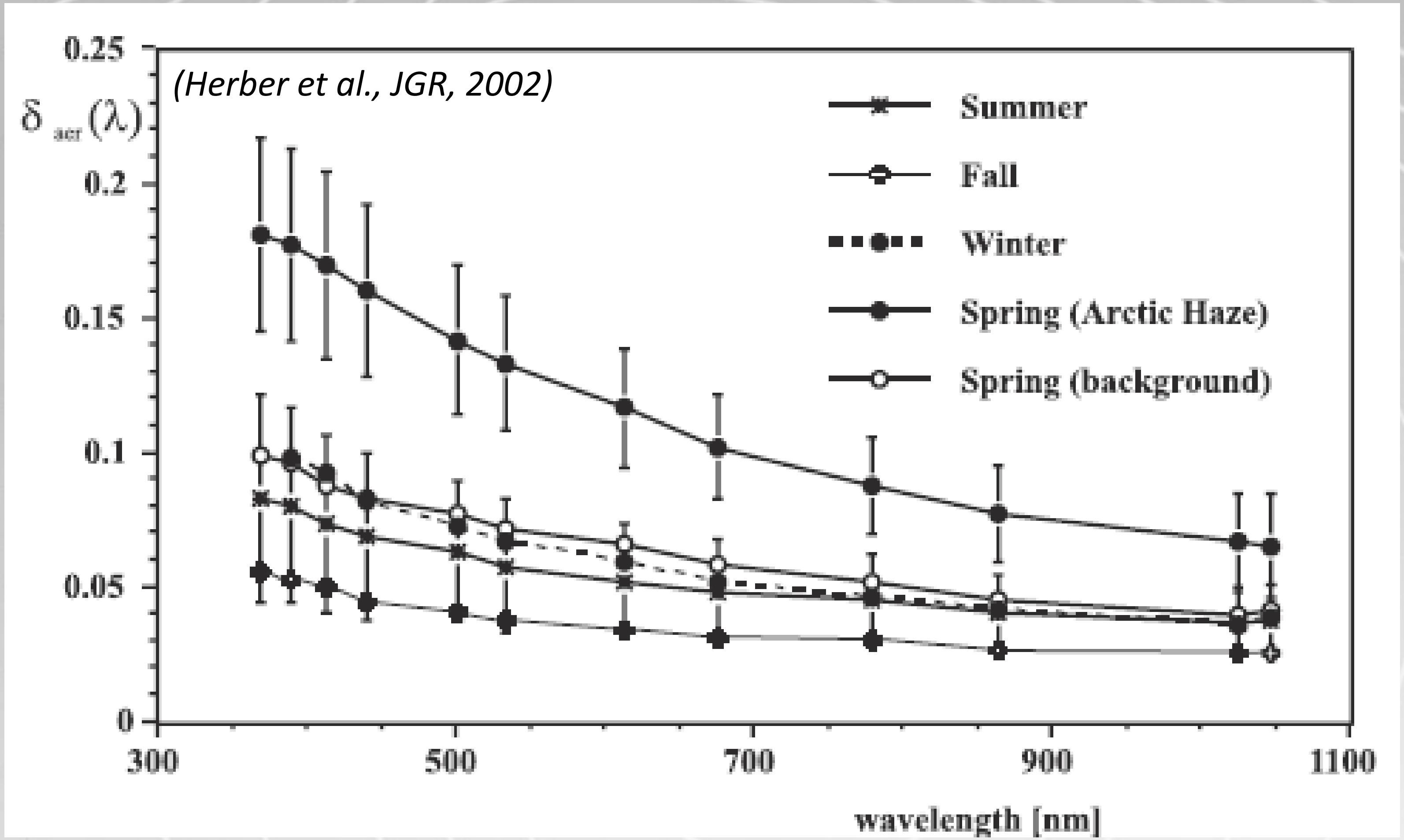
Moon photometry: Motivation – Polar regions

Gaps in the long polar night!



Moon photometry: Motivation – Polar regions

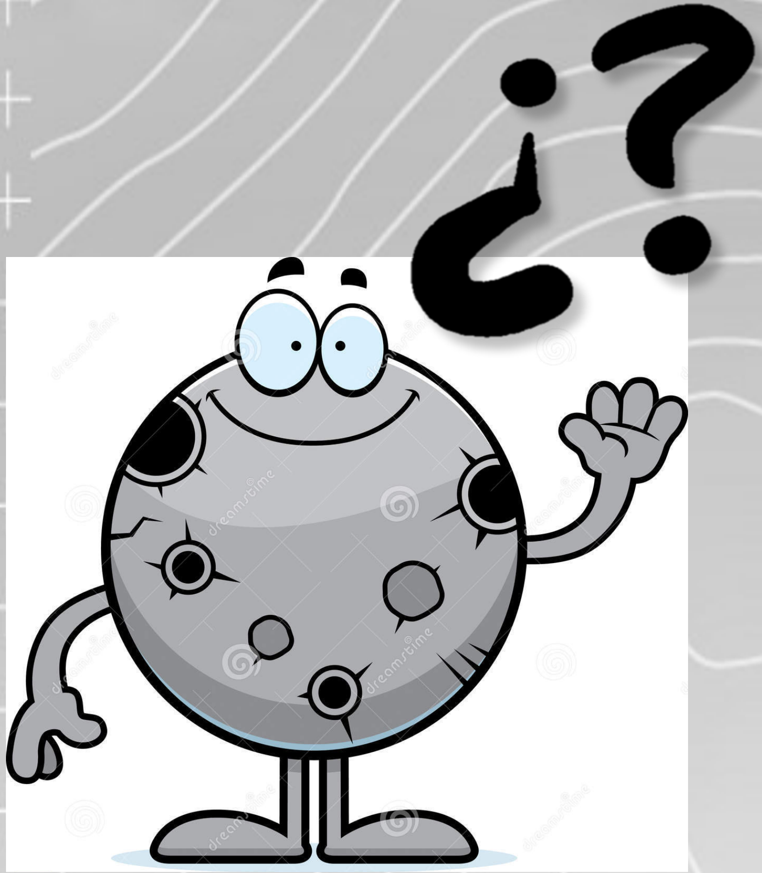
And finally … Data!!!! Thanks to Herber et al. (2002)



Ny-Alesund (Norway)
1991-1999

There are still a lot of things to do in this regard, trying to understand the complex mechanisms of transport to the Arctic.

Moon photometry: Motivation



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Moon + Star photometry

Commercial lunar photometers

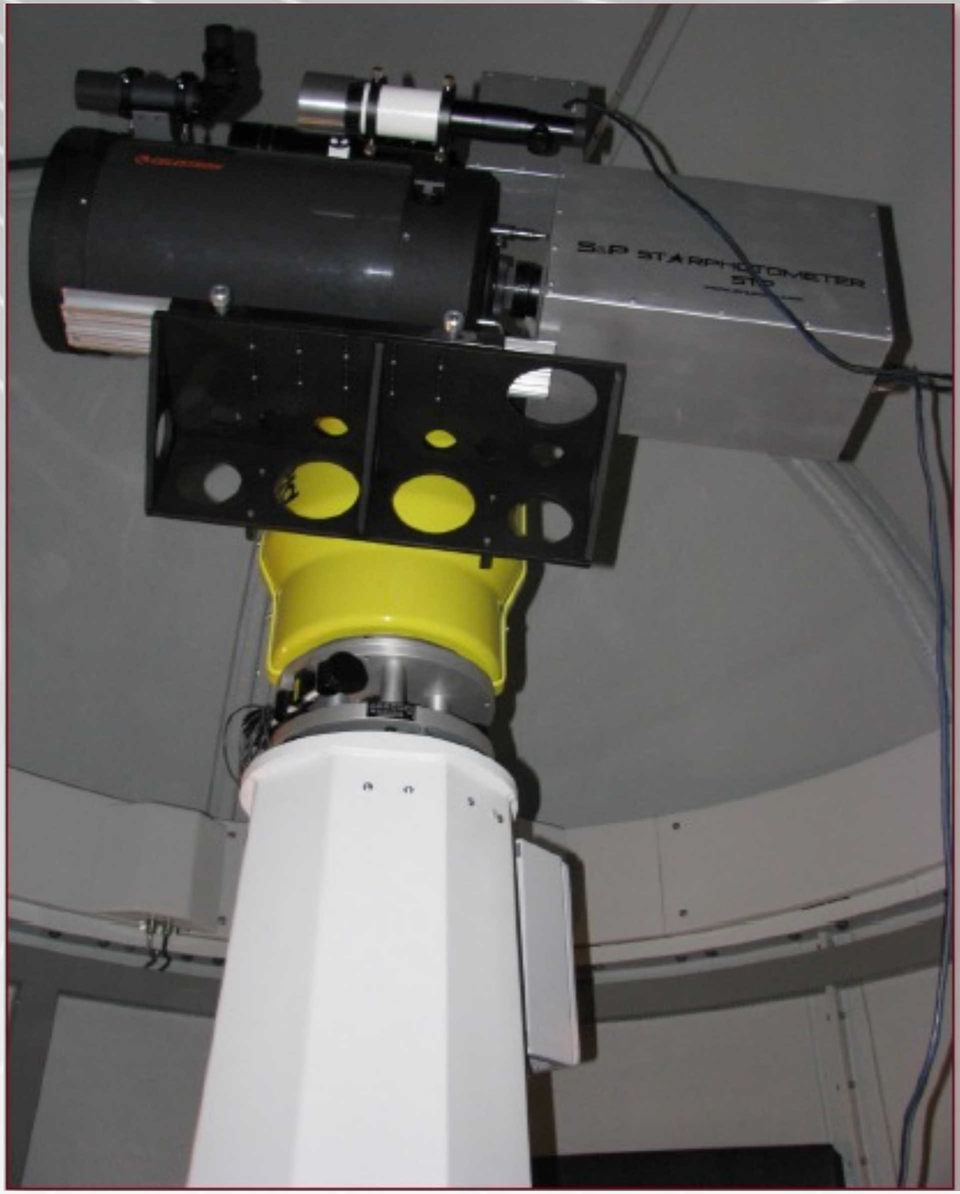
Sun/sky/lunar Cimel

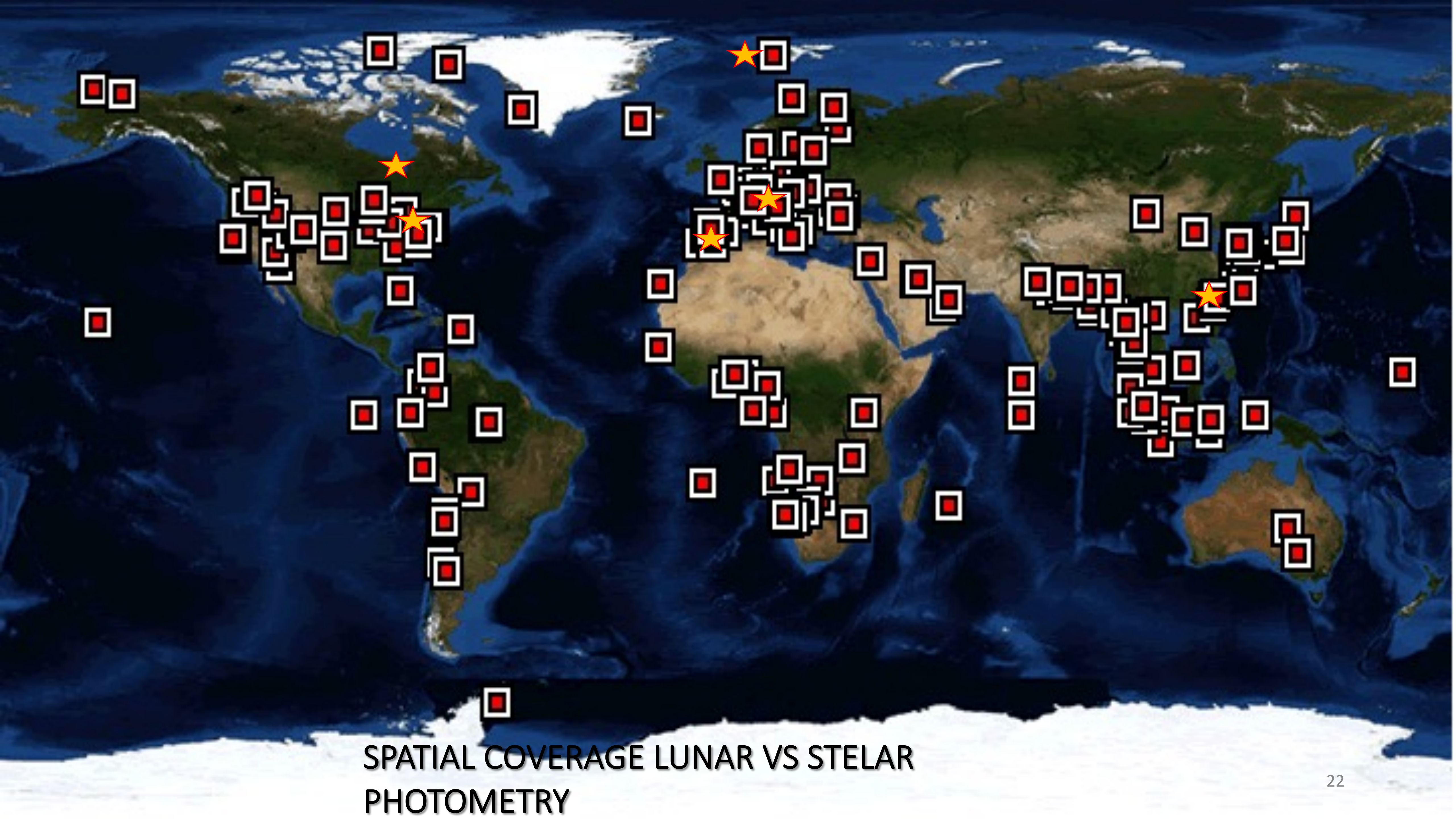
LunarPFR

Solar/Lunar PREDE

Commercial stelar photometers

DR. SCHULTZ & PARTNER GMBH STAR-PHOTOMETER





SPATIAL COVERAGE LUNAR VS STELAR PHOTOMETRY

CALIBRATION & LUNAR EXO-ATMOSPHERIC IRRADIANCE MODELS

Main problem in lunar photometry: calibration!

Moon's illumination is changing at any time

As a consequence (Beer-Lambert-Bougher Law): $V_\lambda = V_{0,\lambda} \cdot e^{-\tau_\lambda \cdot m}$

$V_{0,\lambda}$ → To be calculated at any time!!!!

Lunar Langley Method
Barreto et al. (2016)

$$V_{0,\lambda} = \kappa_\lambda \cdot I_{0,\lambda}$$

$I_{0,\lambda}$ → Lunar exo-atmospheric Irradiance Model

κ_λ → Calibration CONSTANT

A highly accurate exo-atmospheric lunar irradiance model is mandatory for Moon photometry!!

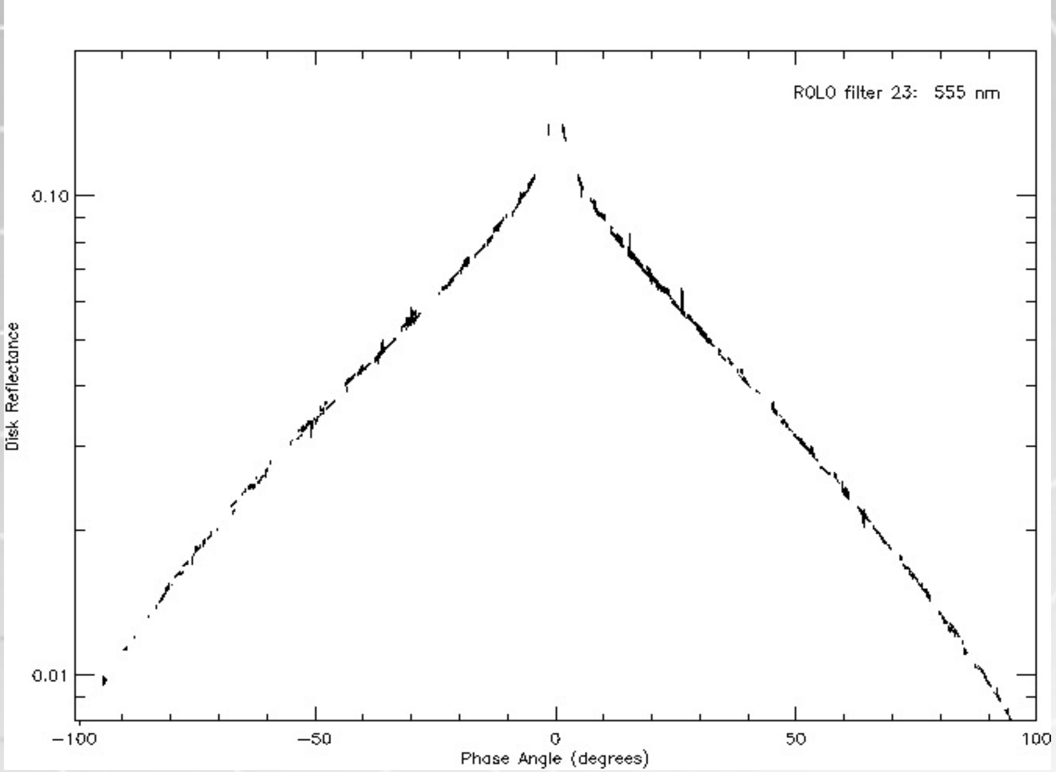
ROLO USGS exo-atmospheric lunar irradiance model

(Kieffer and Stone, 2005)

ROLO USGS exo-atmospheric lunar irradiance model

$$ln(A_j) = \sum_{n=1}^{3} a_{i,j} g^{n} + \sum_{n=1}^{3} b_{n,j}\varphi^{2n-1} + c_1\cdot\theta + c_2\cdot\phi + c_3\cdot\varphi\cdot\theta + c_4\cdot\varphi\cdot\phi + d_{1,j}\cdot e^{\frac{-g}{p_1}} + d_{2,j}\cdot e^{\frac{-g}{p_2}} + d_{3,j}\cdot cos\left(\frac{g-p_3}{p_4}\right)$$

g: moon's phase angle
θ and Φ: selenographic lat/lon observer
φ: selenographic sun's longitude



where:

$$I_j = \frac{A_j \cdot \Omega_M \cdot E_j}{\pi}$$

(ROLO**, USGS Lunar Irradiance empirical model)

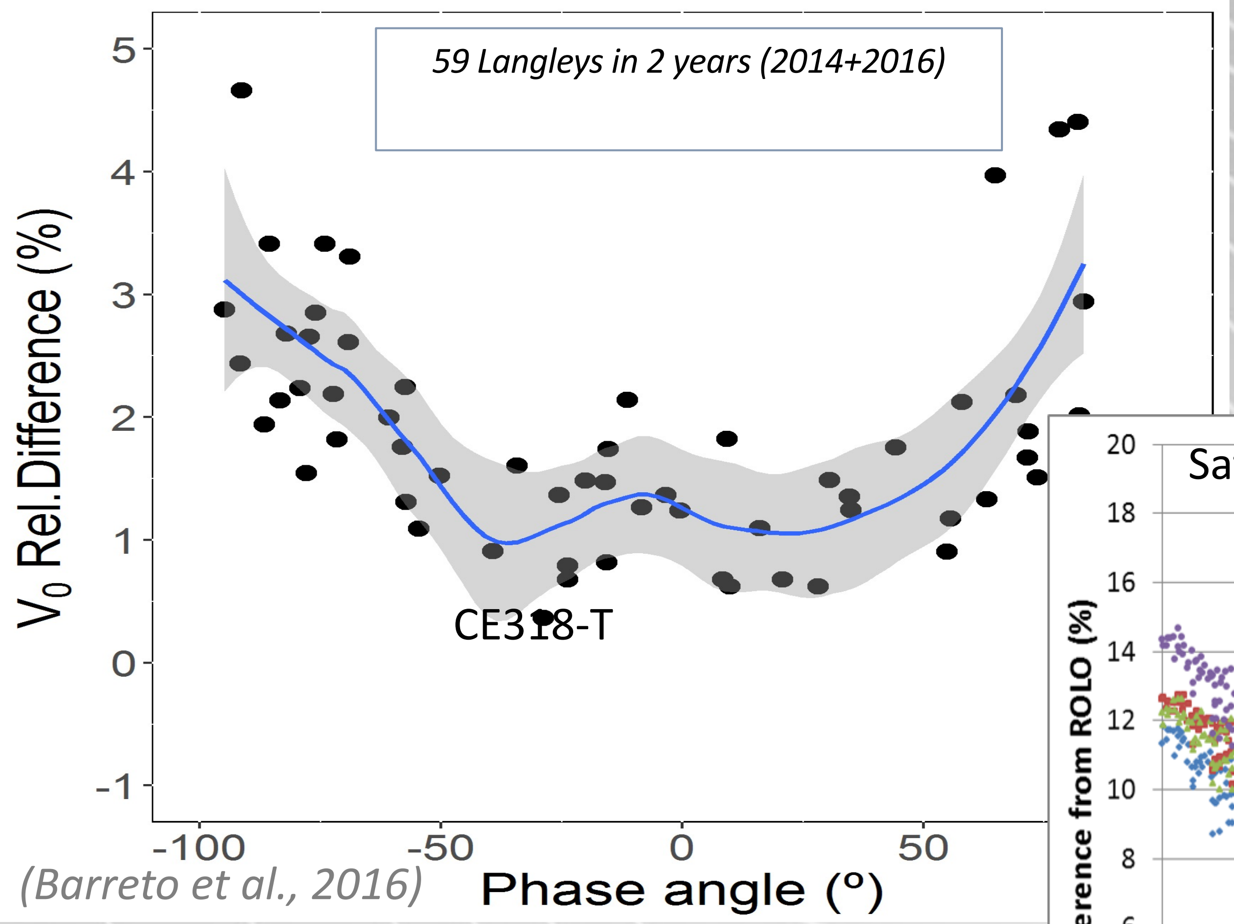
moon's disk-equivalent reflectances

moon's solid angle

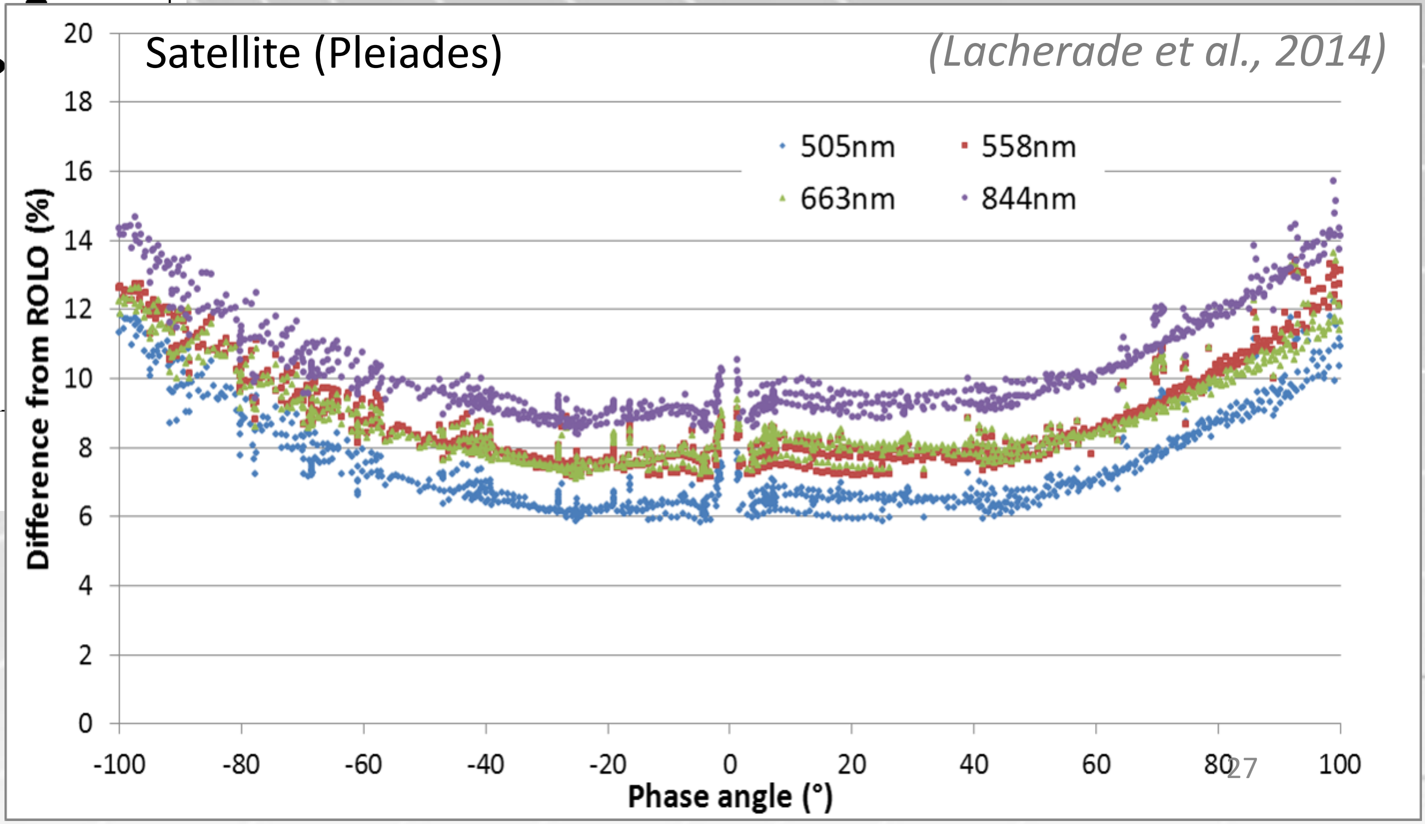
sun's spectral irrad. 1AU (Wehrli)

(Ω_M=6.4177x10^{-5} sr (1 AU))

ROLO USGS exo-atmospheric lunar irradiance model: uncertainty

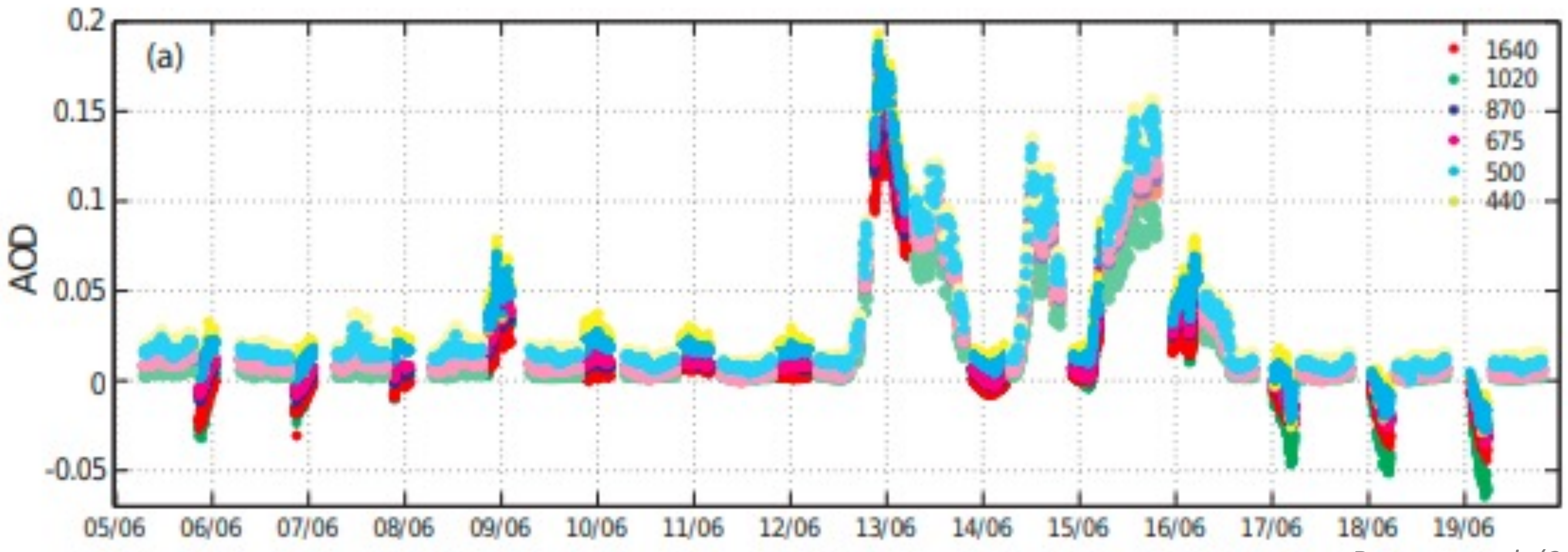


Estimated absolute uncertainty: 5-10%
Goal: 2%



ROLO USGS exo-atmospheric lunar irradiance model: uncertainty

Important dependence of the AOD uncertainty with the Moon's phase



Barreto et al. (2017)

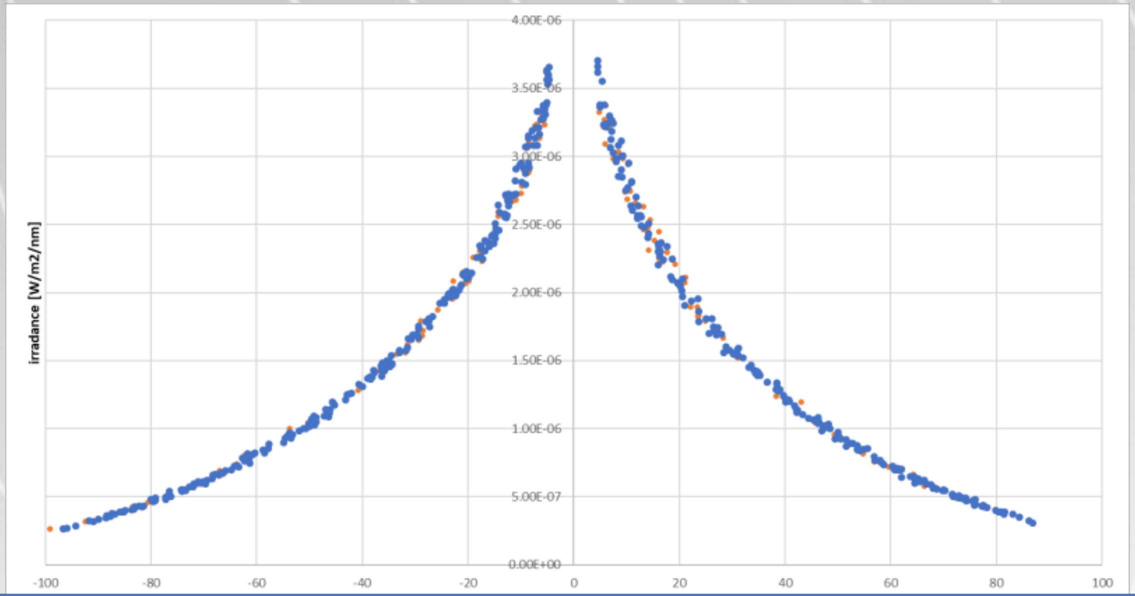
ROLO USGS exo-atmospheric lunar irradiance model: uncertainty

Possible solutions:

1) Improvement of the ROLO model with new lunar measurements
2) Develop a completely new lunar irradiance model with new measurements
3) Develop new calibration approaches: The Gain-Ratio calibration method

Improved exo-atmospheric lunar irradiance model: ESA LIME

Lunar spectral irradiance measurement and modelling for absolute calibration of EO optical sensors (ESA funded project)

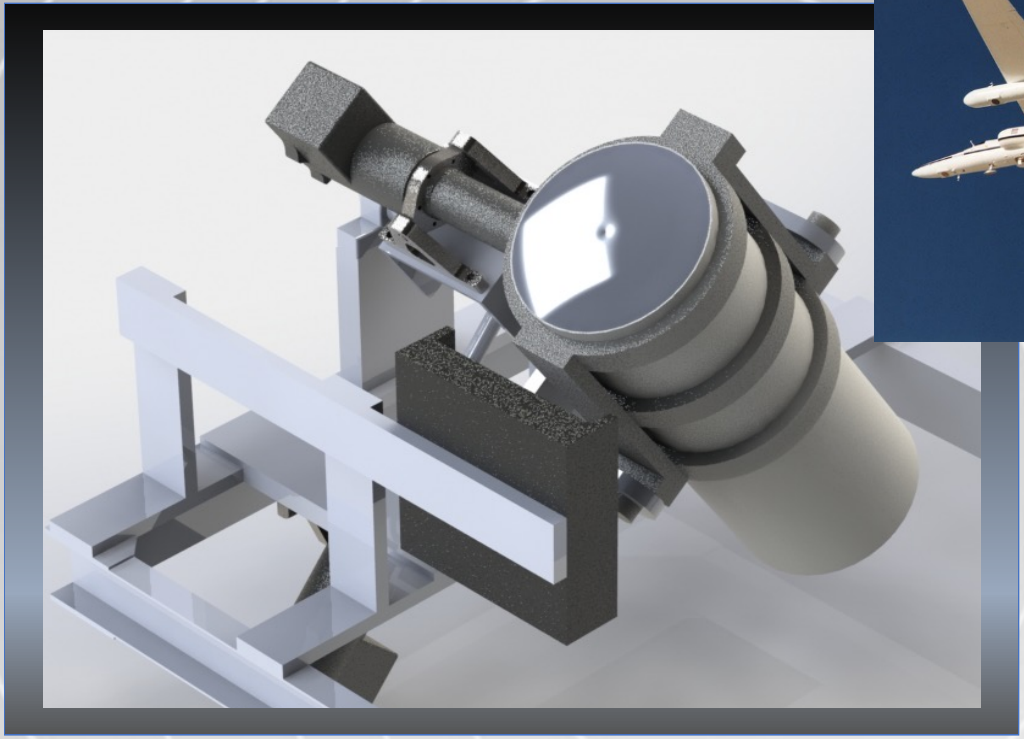


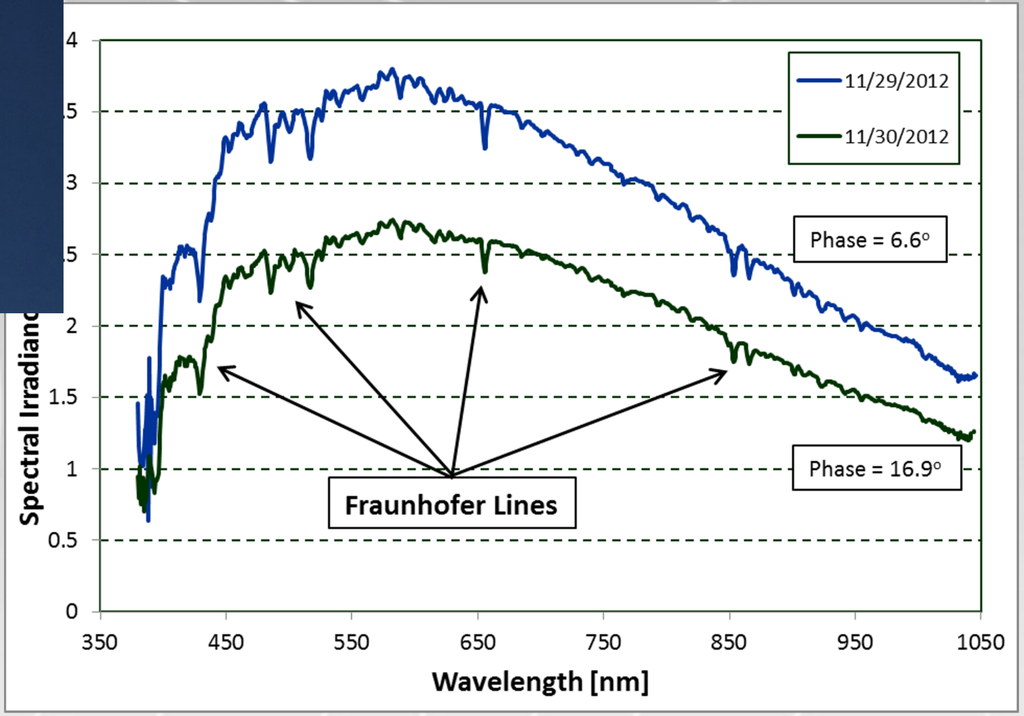
	440 nm	500 nm	675 nm	870 nm	1020 nm	1640 nm
$u(\ln(V_0))$	0.21%	0.16%	0.13%	0.12%	0.12%	0.21%

New exo-atmospheric lunar irradiance models: NASA AIR-LUSI

Airborne LUnar Spectral Irradiance (AIR-LUSI) mission

Earth Sciences Division –
Hydrosphere, Biosphere,
and Geophysics





Air-LUSI telescope and autonomous, robotic mount is designed to acquire unprecedentedly accurate measurements of lunar spectral irradiance from an ER-2 aircraft flying at 21km altitude.

New exo-atmospheric lunar irradiance models: NASA + ESA

2020

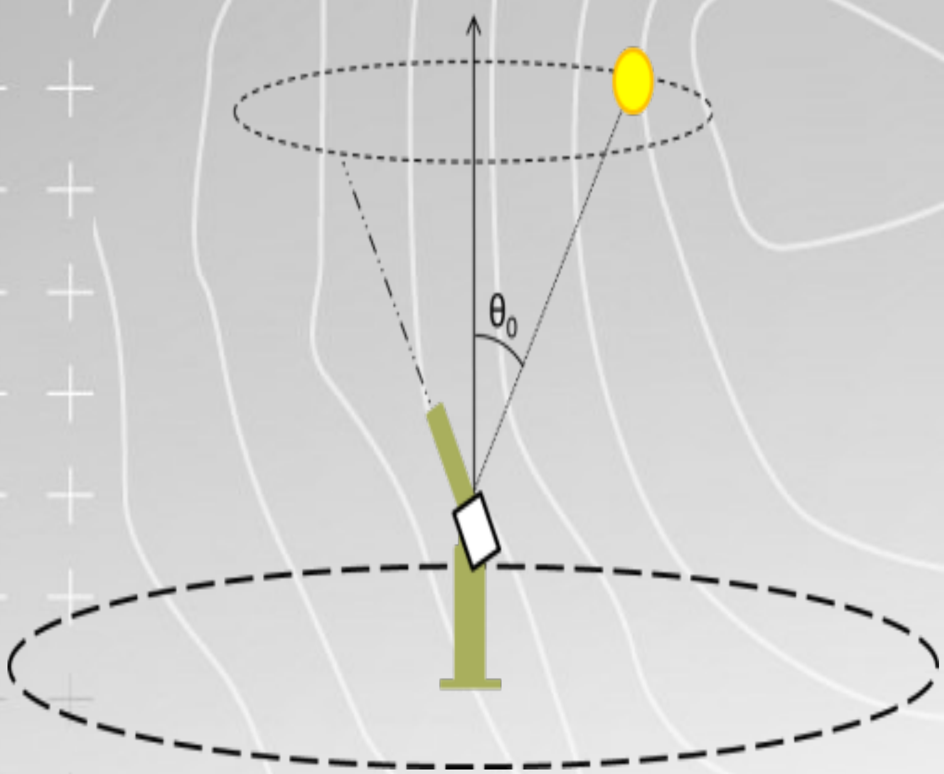
LUNAR IRRADIANCE MODEL OF ESA

air-LUSI
NASA UMBC NIST USGS Guelph Hawk

NASA

New calibration approaches: Gain ratio

- Does not need the ROLO model
- Affected by ROLO absolute uncertainties (AOD calculation)



$$G = \frac{SKY}{AUR} \cdot \frac{AUR}{SUN} = \frac{SKY\ (MOON)}{SUN}$$

≈ 32 ≈ 128

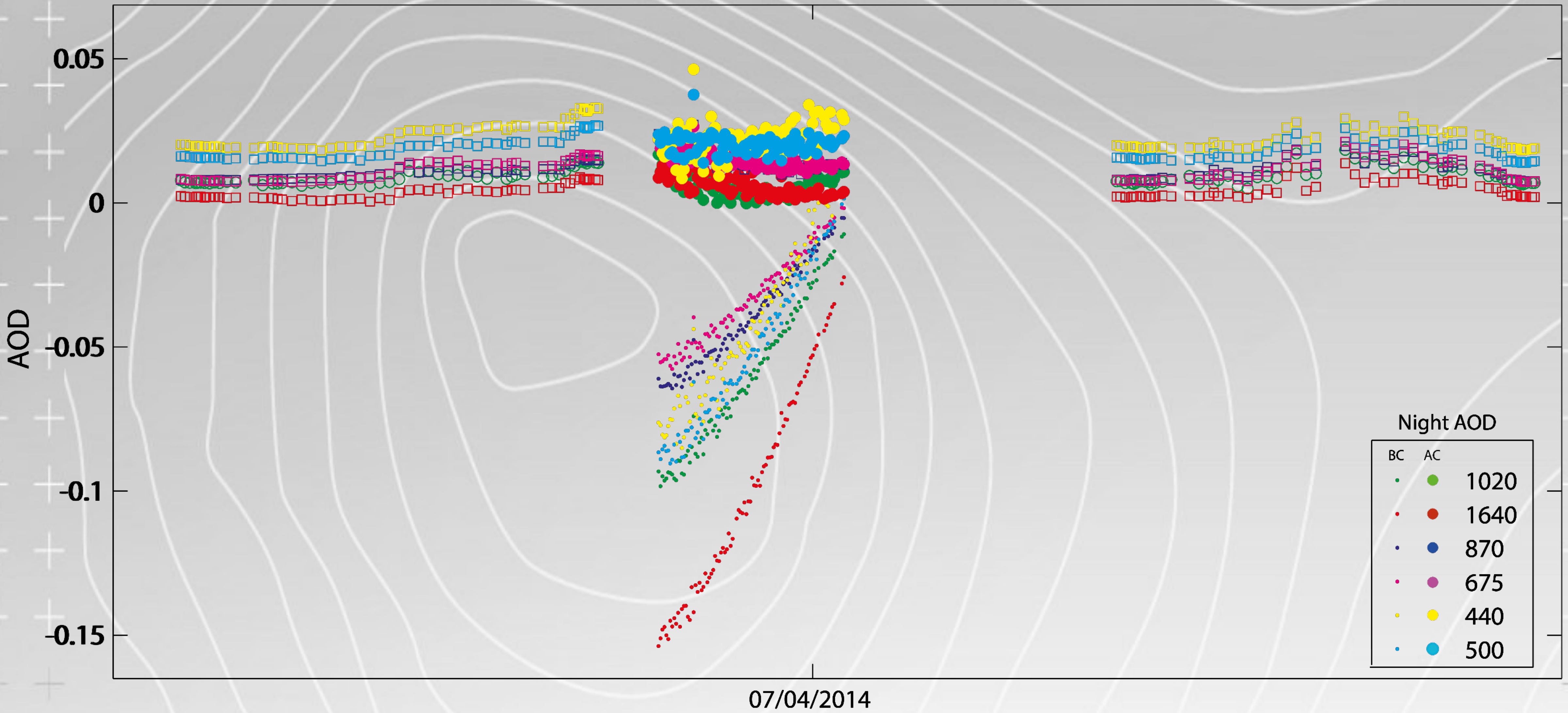
32x128=**4096** Nominal value

(ΔR≤0,1%)

$$k_{moon} = \frac{V_{0,sun}}{E_{0,sun}} \cdot G$$

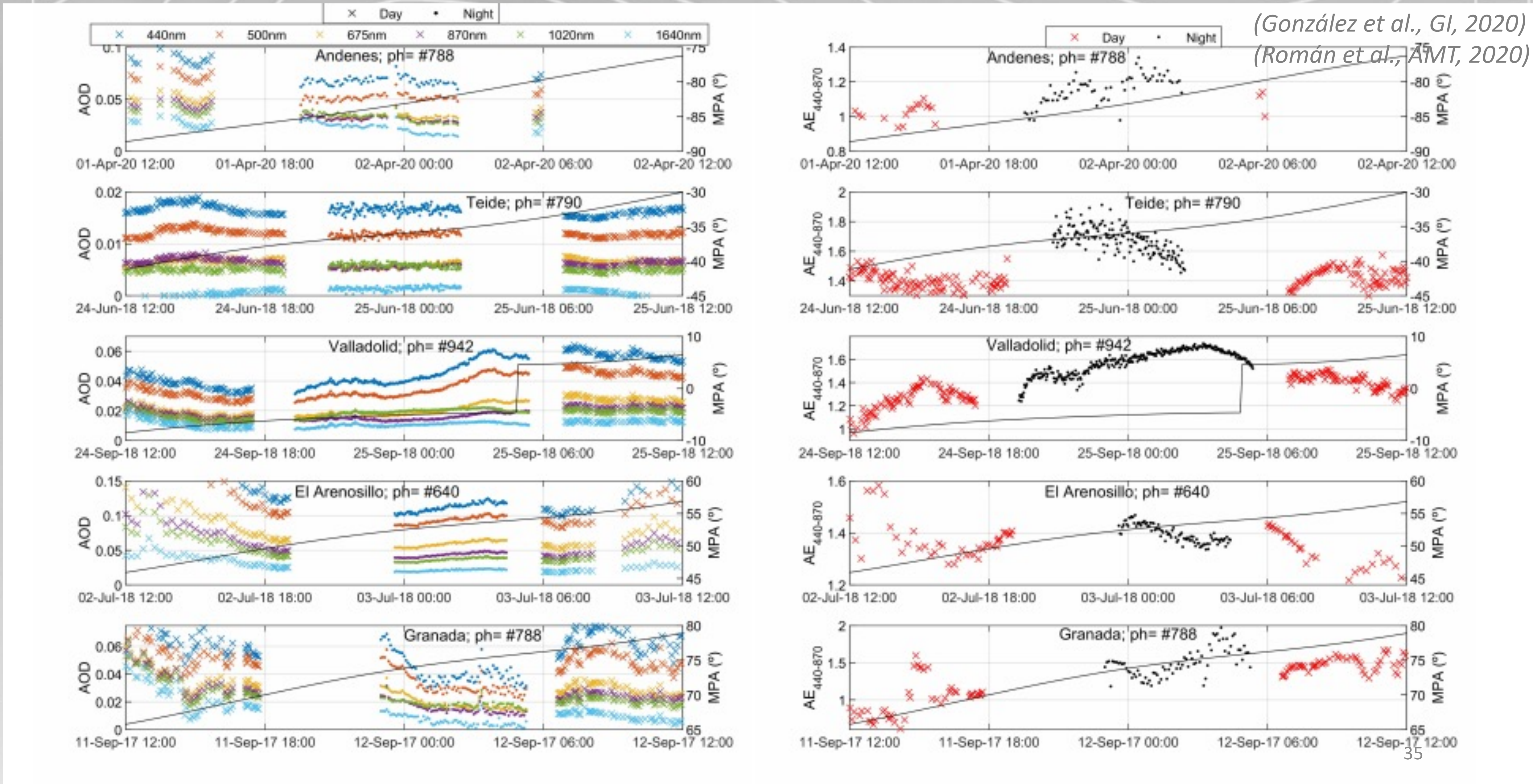
(Barreto et al., 2016)

New calibration approaches: Gain ratio (pros & cons)



New calibration approaches: GAIN-RCF calibration method

(González et al., GI, 2020)
(Román et al., AMT, 2020)



New calibration approaches: AERONET Provisional lunar data

AEROSOL OPTICAL DEPTH (V3)-SOLAR
- + Data Display
- + Download Tool
- + Download All Sites
- + Climatology Tables
- + Web Service

AEROSOL INVERSIONS (V3)
- + Data Display
- + Download Tool
- + Download All Sites
- + Web Service

SOLAR FLUX
- + Data Display

OCEAN COLOR
- + V3 Data Display
- + V3 Web Service

LUNAR AOD (V3) - PROVISIONAL
- + Data Display
- + Download Tool

SELECT CHARTS FOR LARGER IMAGES

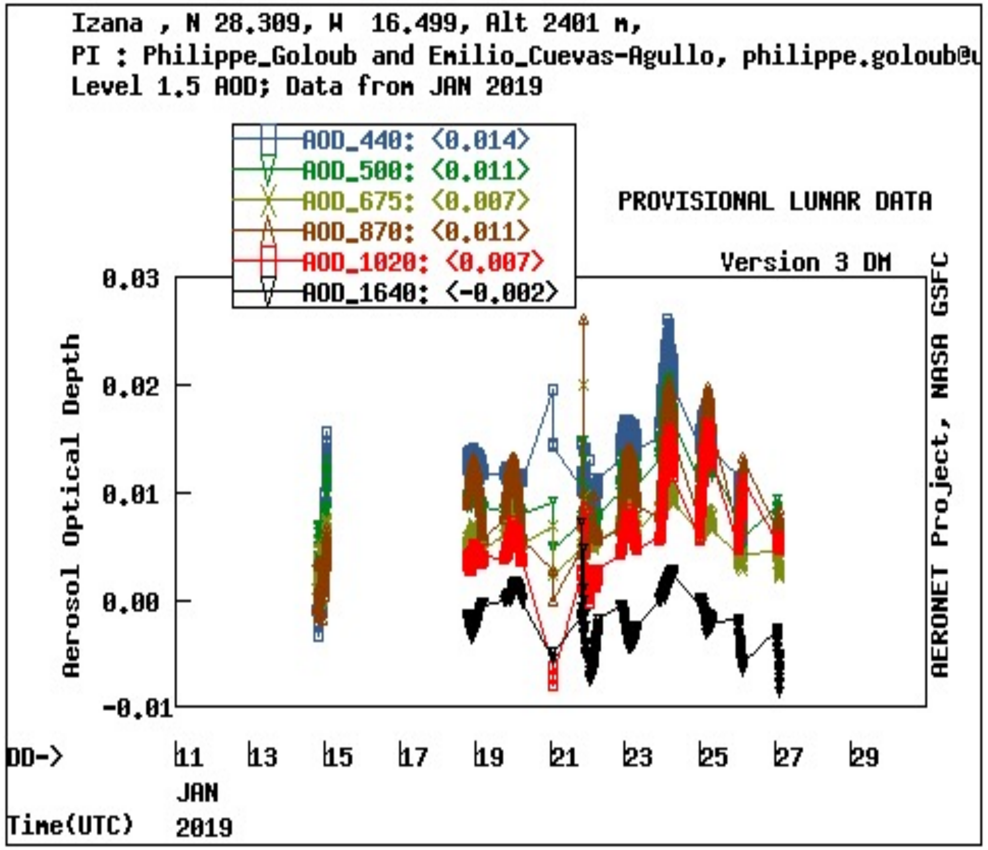
Choose year :	2018	2019	2020
Choose month of 2019 :	JAN	FEB	MAR
	APR	MAY	JUN
	JUL	AUG	SEP
	OCT	NOV	DEC

Choose day MIDNIGHT of JAN 2019

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31					

AOD Level 1.5 data from year of 2019

AOD Level 1.5 data from JAN of 2019



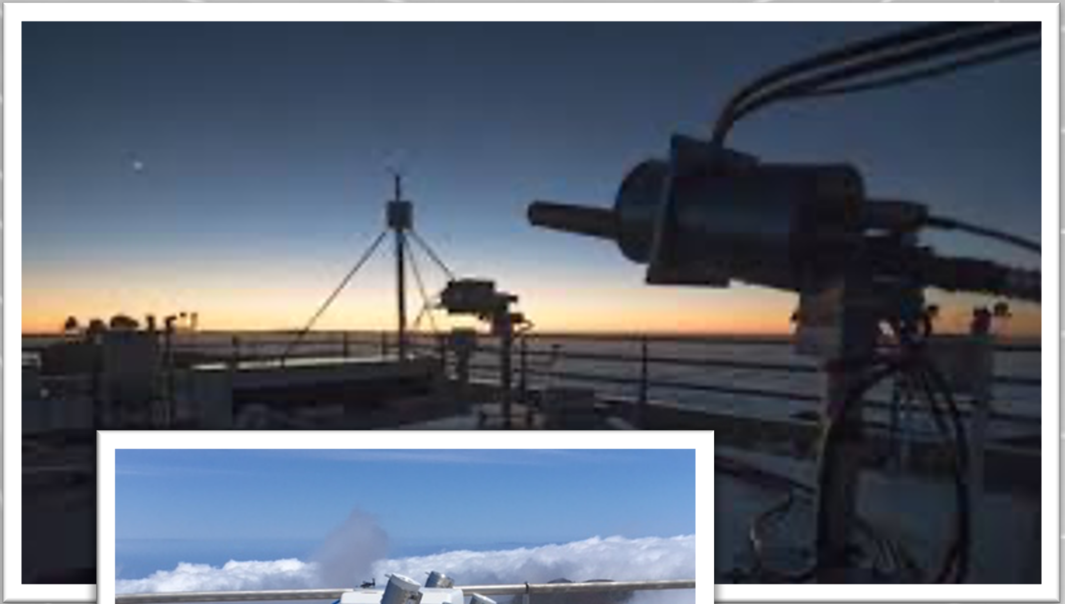
LUNAR PHOTOMETRY CAMPAINGS

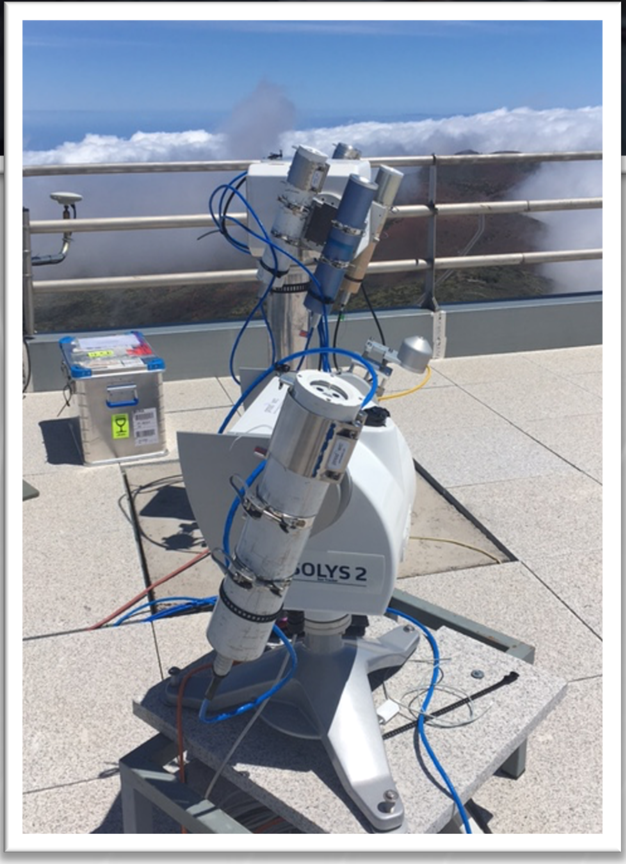
FIRST LUNAR PHOTOMETRY CAMPAIGN: IZAÑA, 2017

Lunar Photometry Campaign and Workshop
Izaña 2017

GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA Y PESCA, ALIMENTACIÓN Y MEDIO AMBIENTE
AEMet Agencia Estatal de Meteorología
Grupo de Óptica Atmosférica GOA-UVA Universidad de Valladolid
ACTRiS

FIRST LUNAR PHOTOMETRY CAMPAIGN: IZAÑA, 2017





SECOND LUNAR PHOTOMETRY CAMPAIGN: NY-ALESUND, 2020

Instruments participant: CE318-TS, PFR, Stellar, All sky camera, MPL, Raman Lidar, Prede prototype, C-Lidar

THIRD LUNAR PHOTOMETRY CAMPAIGN: LINDENBERG, 2020

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

DWD

MOL-RAO:
Meteorological Observatory Lindenberg – Richard Assmann Observatory
52.2 N, 14.1 E, 120 m
At Lindenberg (Germany/Brandenburg)

MOSAiC

Multidisciplinary Drifting Observatory for the Study of Arctic Climate

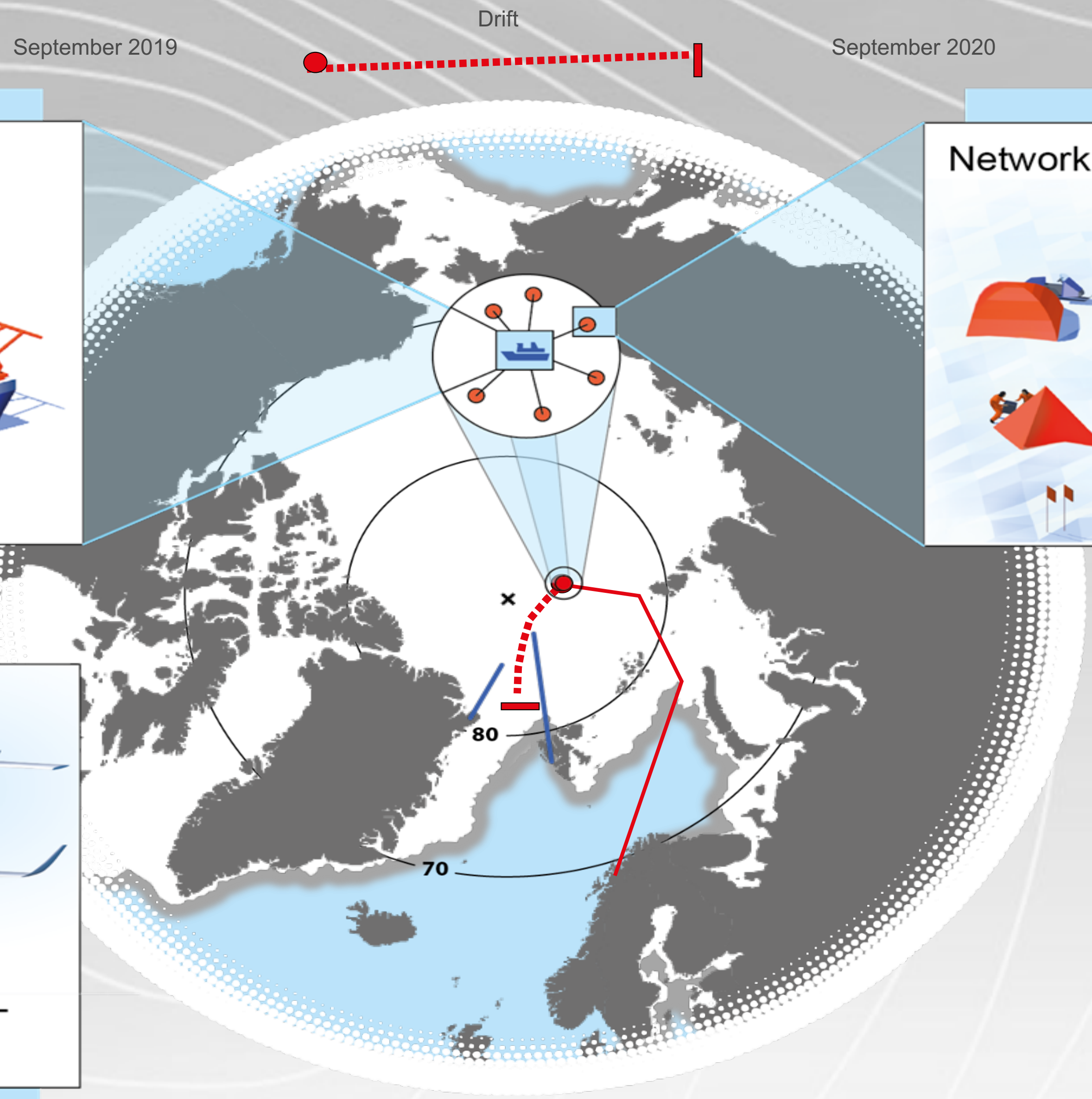
Sep 2019 – Sep. 2020
5 icebreakers, flights
300 scientists from 60 institutions (17 nationalities)

An entire year trapped in the Arctic ice

The largest Central Arctic expedition ever

MOSAiC
International Arctic Drift Expedition

The MOSAiC Expedition



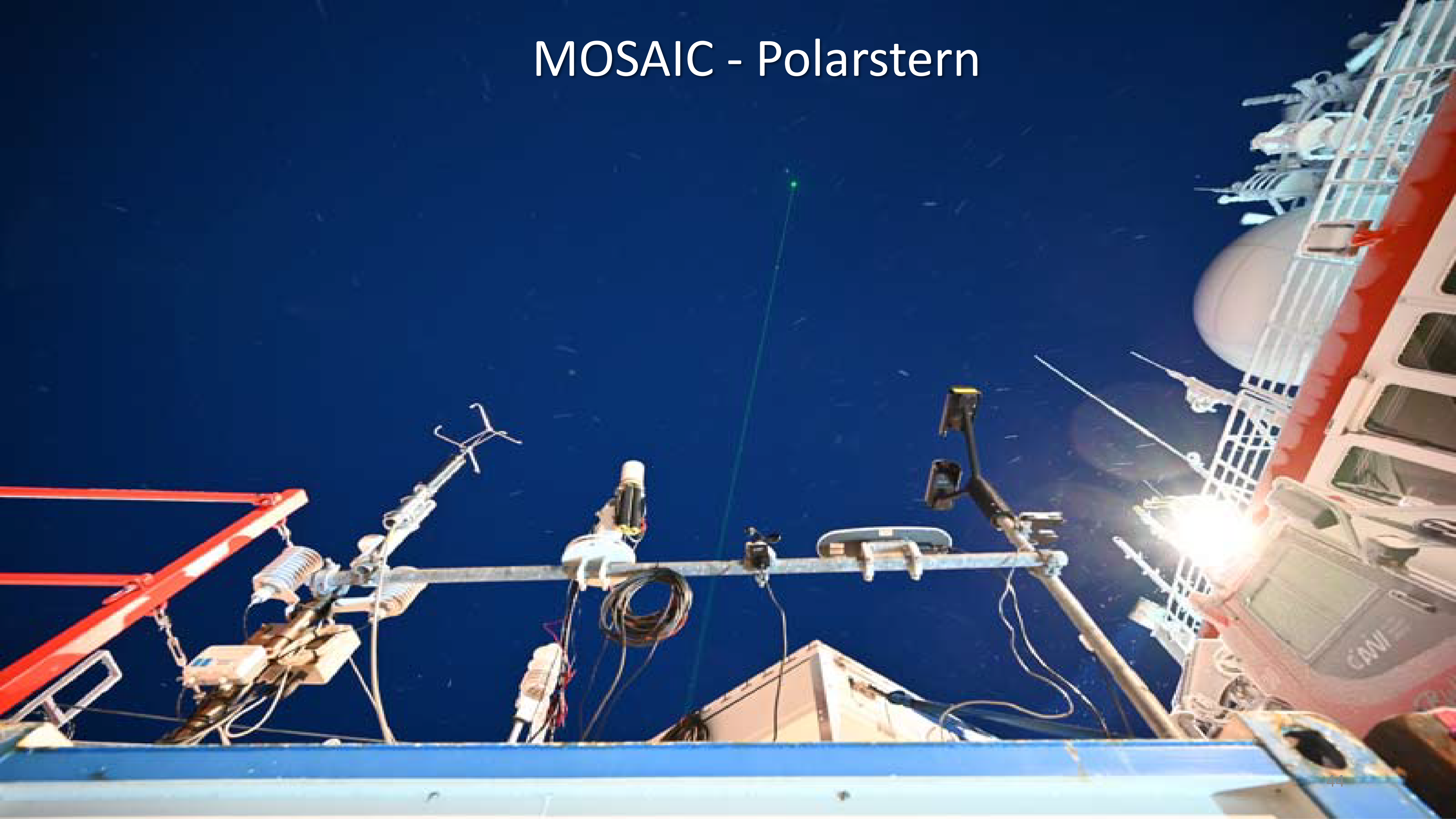
Central observatory:
RV Polarstern

Network of camps on the ice

Operations of research aircrafts and helicopters

Extended vertical and geo-graphical coverage

MOSAIC - Polarstern



Thanks for your attention!