Lunar irradiance measurement and modelling for absolute radiometric calibration of EO sensors

Lunar Calibration Update

Stefan Adriaensen (VITO), Marc Bouvet (ESA), Emma Woolliams (NPL), Sarah Taylor (NPL), Maria Garcia Miranda(NPL), Carlos Toledano (Univ. Valladolid), Alberto Berjón (Univ. Valladolid), África Barreto (Univ. Valladolid)

NPL National Physical Laboratory UVa vito vision on tec esa

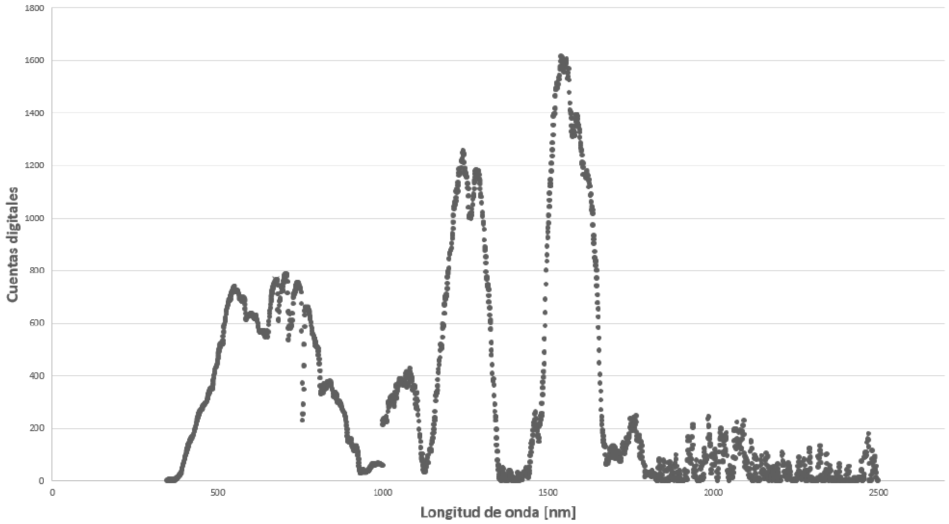
ESA – ESRIN- GSICS – 04/03/2019

Project Overview : goal

- Define a strategy for lunar irradiance measurements
- Acquire and calibrate a capable instrument
- Install at a location with optimal atmospheric conditions and make operational
- Store the irradiance measurements in a database system
- Model the irradiance based upon knowledge, target sub 2% absolute radiometric accuracy
- Compare the model irradiance with space based lunar irradiance measurements

Instruments

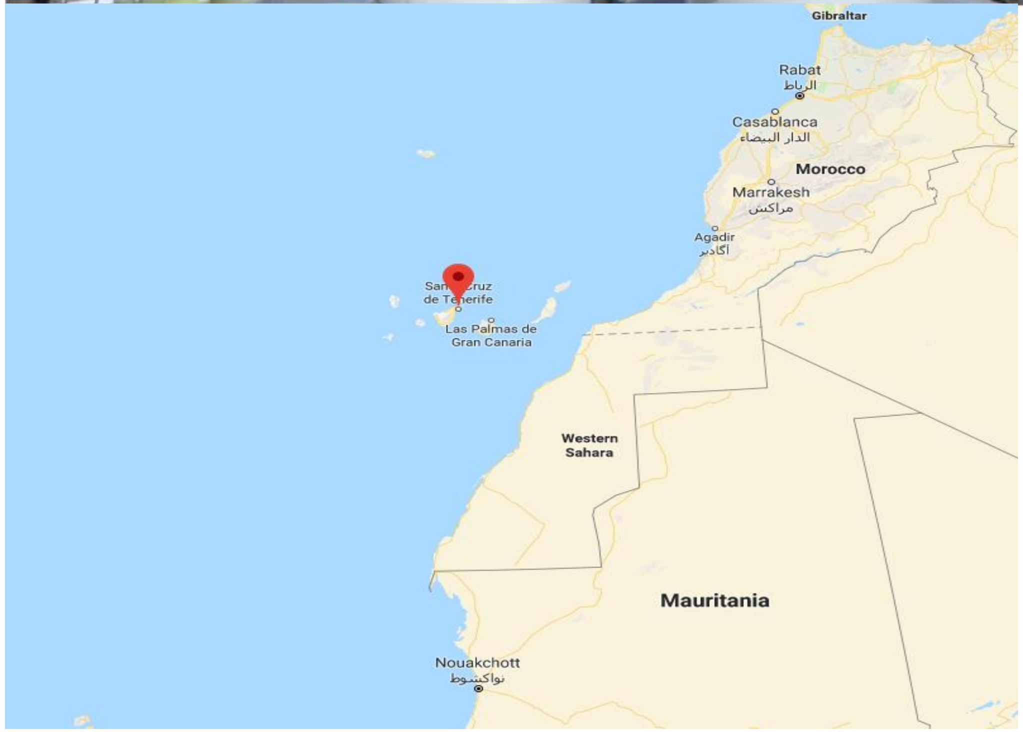
- Irradiance measurements
  - the Sun-Sky-Lunar photometer CE318 from CIMEL designed for night aerosol retrieval and adapted specifically for this project:
  - Spectral channels: 340, 380, 440, 500, 670 870, 936, 1020, 1640 nm
  - Double filter wheel for polarimetric measurements
  - Modification of firmware for polarimetric capabilities in direct lunar observation configuration
  - Installed and operational since April 2018
- Spectral Measurements (for spectal smoothing the model output)
  - ASD field spectrometer (>1800nm)
  - Pandora 2S



NPL National Physical Laboratory
UVa
vito vision on tec
esa

Location

- On Island Tenerife (Spain) in the North Atlantic Ocean
- Pico Teide (3555 m)
- Izaña : Atmospheric Research Center (2391 m)
- Very stable and 'clean' atmosphere
- +100 measurements per year
    - Sahara dust events
    - Weather conditions on the Peak Teide
- Aerosol Optical Loading (500nm) between 0.007 and 0.1



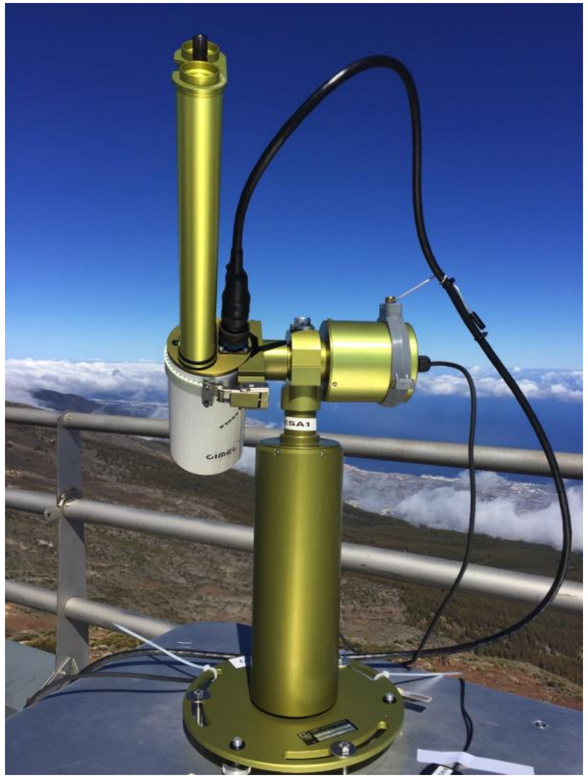
NPL National Physical Laboratory

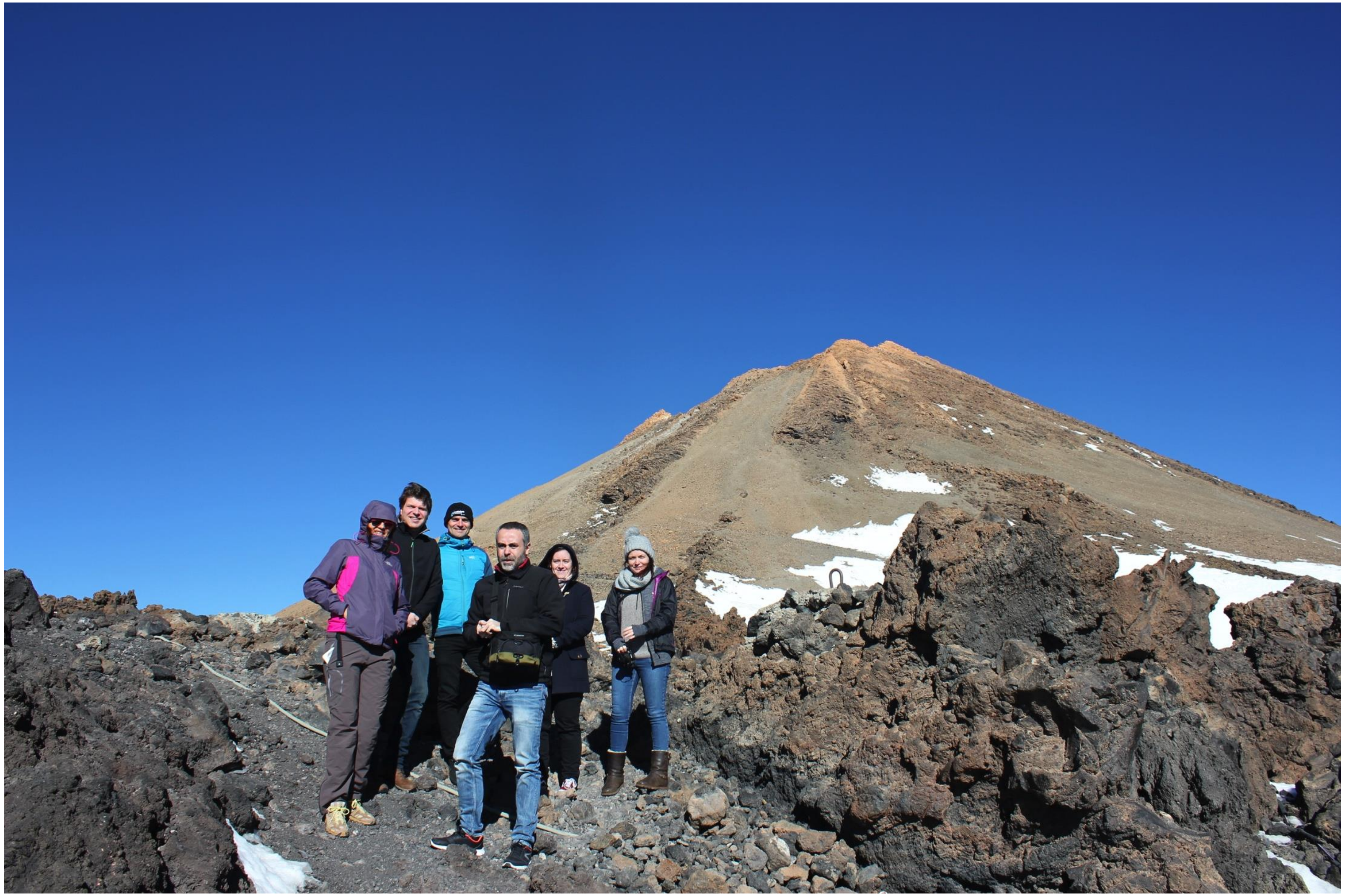
UVa

vito vision on tec

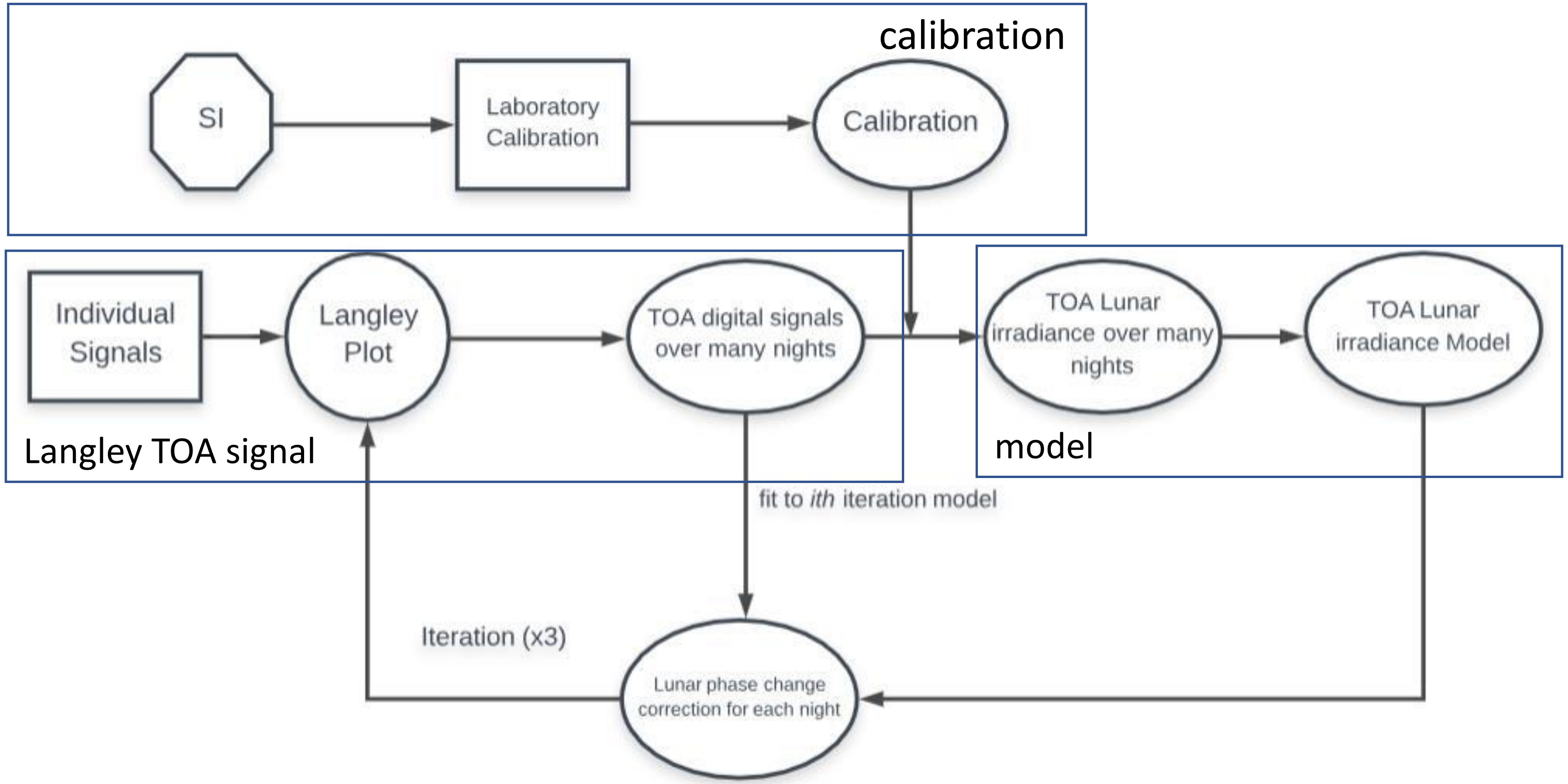
esa

Location





Process

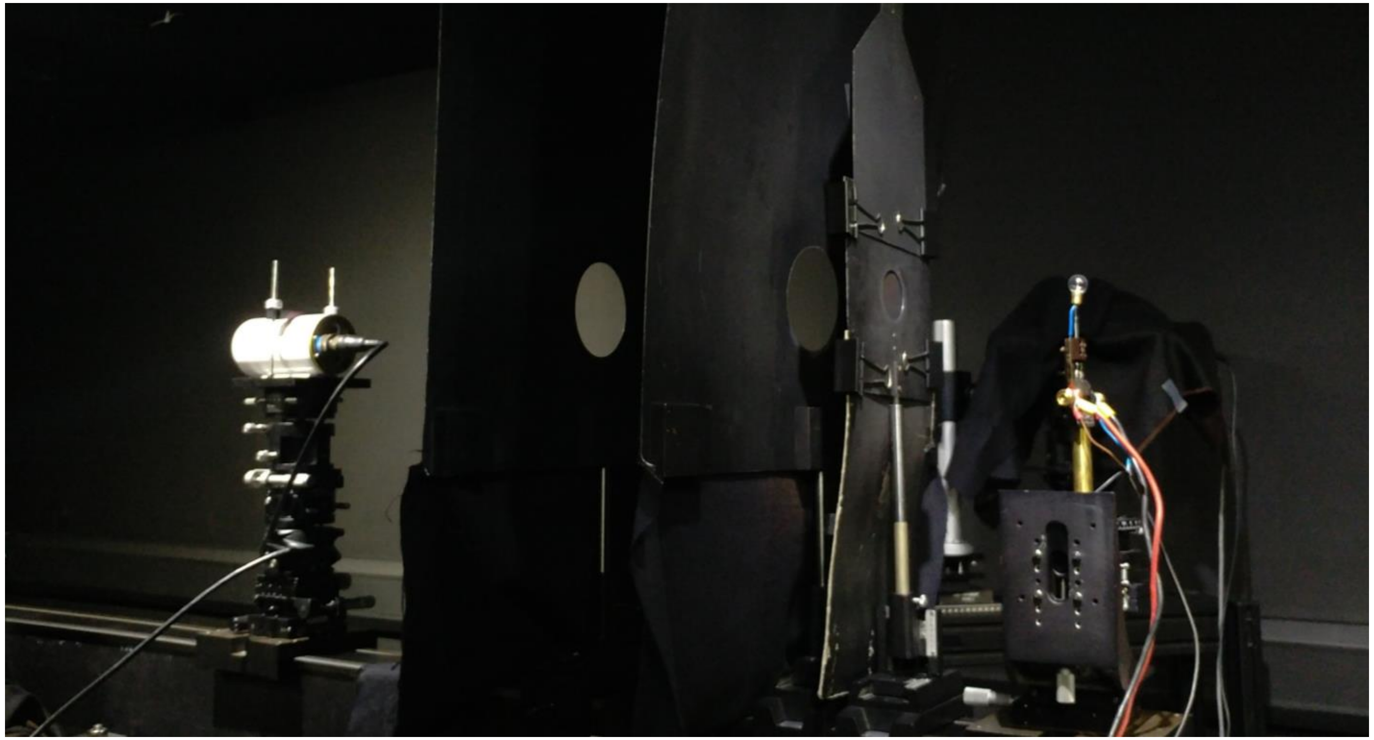


NPL National Physical Laboratory UVa vito vision on tec esa

Instrument Calibration

- Full instrument calibration conducted at NPL, in cooperation with UVa
  - Linearity
  - Irradiance & Radiance Responsivity
  - Temperature characterization
  - Reference plane
- NPL SI traceability

Miners lamp



Calibration Setup : irradiance responsivity measurement

NPL National Physical Laboratory UVa vito vision on tec esa

Calibration uncertainty

$$C_{\bar{E},\mathrm{CIMEL}}(\lambda_i) = \frac{\left(\sum_j E_{\mathrm{lamp},x}(\lambda_j)\xi_i(\lambda_j)\delta\lambda\right)F_T}{G_{\mathrm{ratio}}\left[D_{\mathrm{CIMEL,lamp},x}(\lambda_i) - D_{\mathrm{CIMEL,dark}}(\lambda_i)\right]} + 0$$

Spectral Channel	MOON calibration Coefficient	Standard uncertainty	Expanded uncertainty $k = 2$
340 nm Si	5.306 × 10^{-09}	1.72%	3.44%
380 nm Si	2.227 × 10^{-09}	1.20%	2.41%
440 nm Si	5.759 × 10^{-10}	0.97%	1.94%
500 nm Si	4.481 × 10^{-10}	0.96%	1.91%
675 nm Si	3.205 × 10^{-10}	0.93%	1.86%
870 nm Si	2.547 × 10^{-10}	0.91%	1.82%
937 nm Si	2.431 × 10^{-10}	0.97%	1.95%
1020 nm Si	2.735 × 10^{-10}	1.05%	2.11%
1020 nm InGaAs	2.119 × 10^{-10}	1.01%	2.03%
1640 nm InGaAs	4.893 x 10^{-11}	1.06%	2.11%

Operations

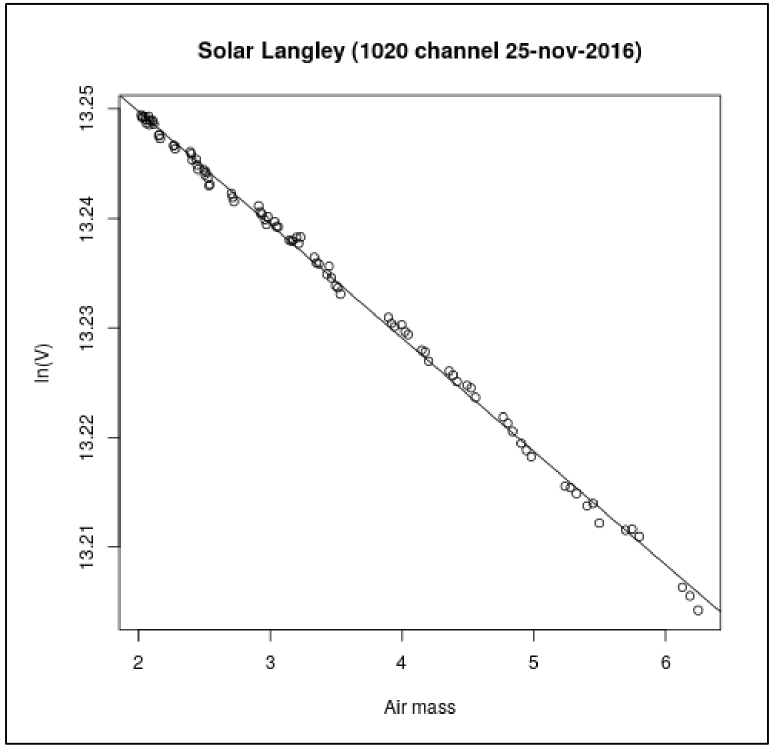
- Develop an automated processing scheme for deriving lunar spectral irradiance measurements
- Archive the raw data
- Process the raw data into lunar spectral irradiance measurements
- Build a database of lunar spectral irradiance measurements

National Physical Laboratory

Measurements

- Nighttime irradiance measurement of the Moon
- Iterative Langley plot

- TOA irradiance can be determined from a set of 2 (or more) measurements
- Atmosphere condition is assumed constant : linear regression for relationship between instrument and TOA signal
  - Dominant source of uncertainty is in this assumption
- Changes in atmosphere are minimized due to high altitude
- Correction for change in phase, sun – earth - moon distances



$$ln(V^s(\lambda,t)) = ln(V_0^s(\lambda)) - m(\theta)\tau_\lambda$$

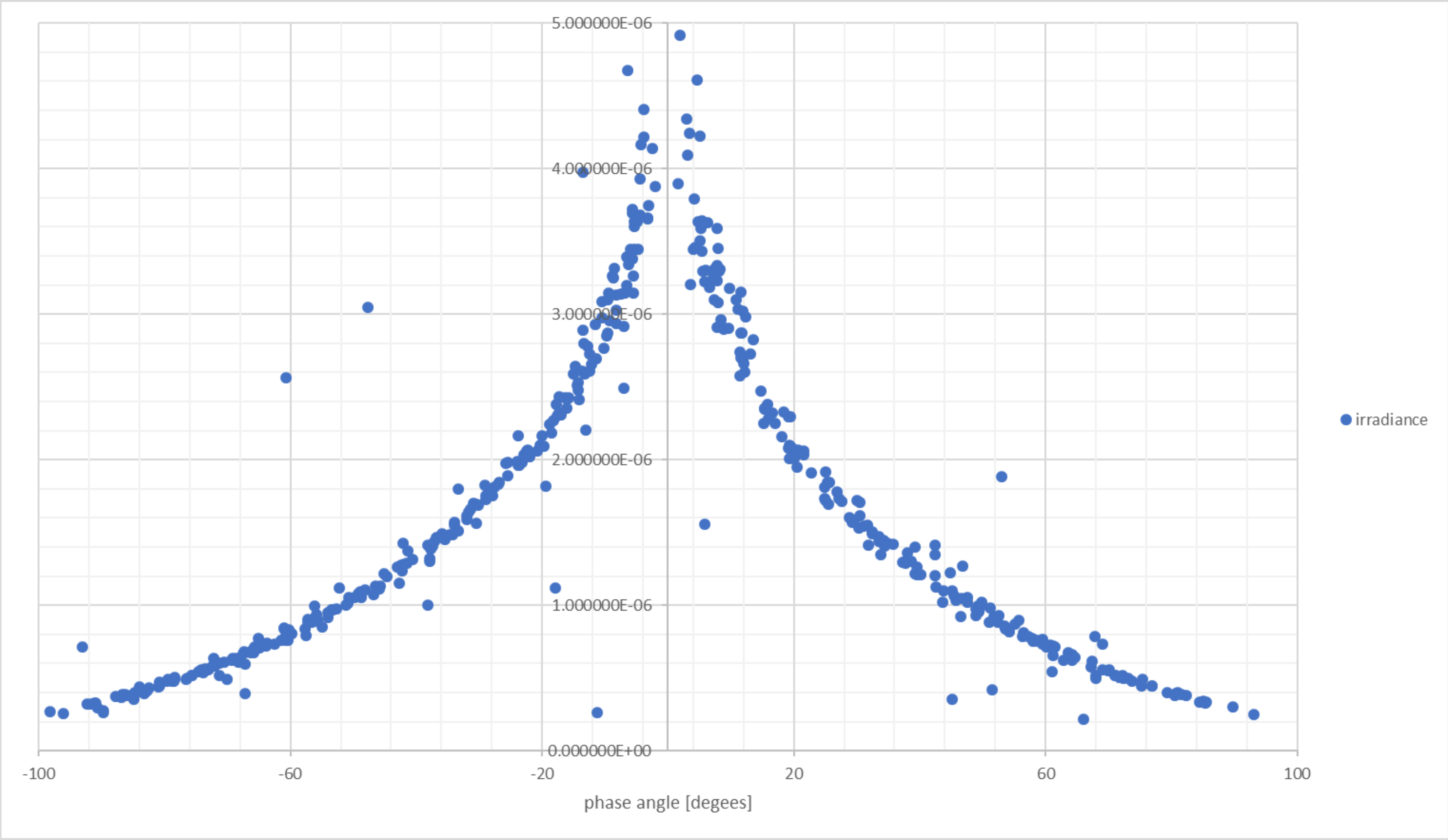
	Uncertainty in Vo [%]							
	1640nm	1020nm	870nm	675nm	500nm	440nm	380nm	340nm
Aerosol	0.2	0.2	0.3	0.3	0.5	0.5	0.5	0.7
Other	0.17	0.25	0.01	0.12	0.17	0.19	0.31	0.5
Total	0.37	0.45	0.31	0.42	0.67	0.69	0.81	1.2

NPL National Physical Laboratory UVa vito vision on tec esa

Measurements

- About 400 irradiance measurements
- Combination
  - 2 datasets of 2 instruments
- Clean but outliers
- Plot : irradiance against phase angle
- Increased uncertainty in low phase angles

440nm



National Physical Laboratory

UVa

vito
vision on tec

esa

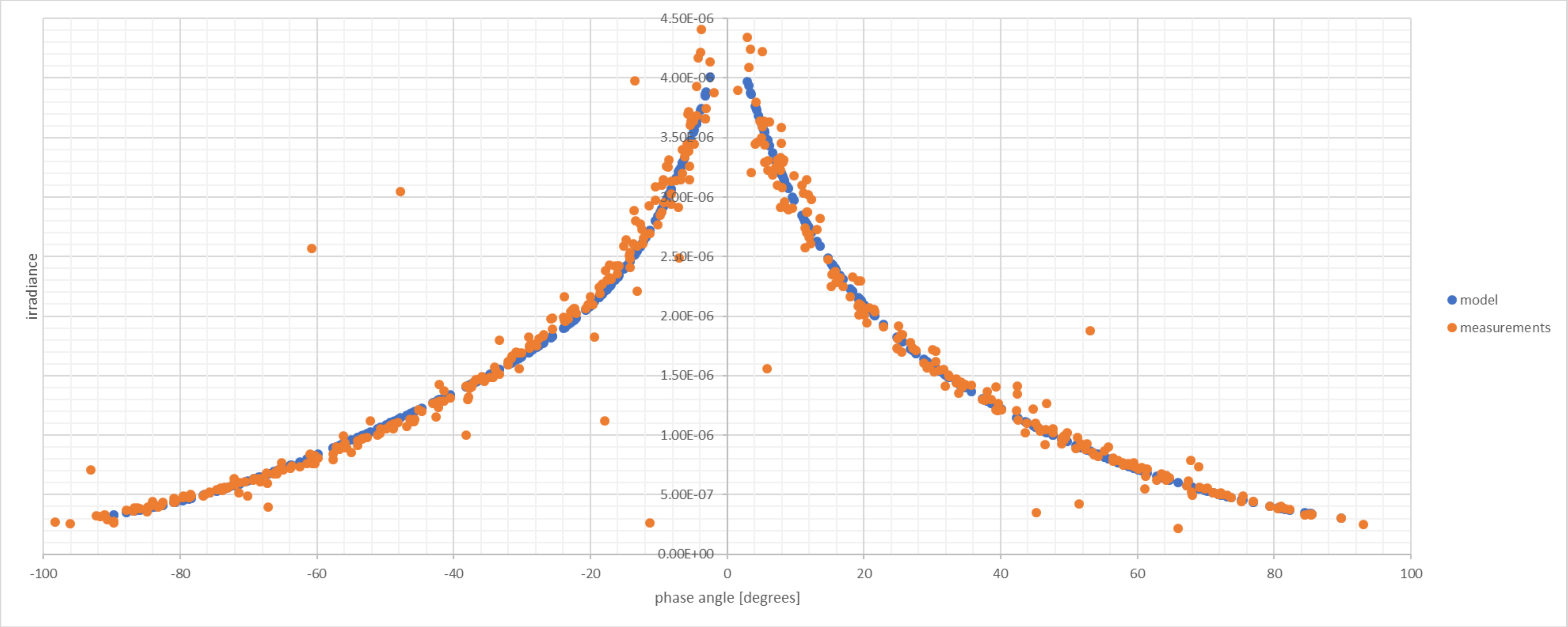
Modelling

- Based upon the work done by USGS : Kiefer and Stone 2005
  - Phase angle
  - Solar selenographic lon, observer selenographic lat and lon
- Linear and non-linear part in the equation
  - Specific regression methods for both parts
  - First linear part, non-linear part based upon residuals
- Outliers need filtering, big influence on regression result
- Iterative procedure : removal of the outliers, then refit
- Conversion of reflectance to irradiance using solar irradiance

$$ln(A_k) = \sum_{i=0}^{3} a_{ik} g^i + \sum_{i=1}^{3} b_{ik} \Phi^{2i-1} + c_1\theta + c_2\phi + c_3\Phi\theta + c_4\Phi\phi + d_{1k} e^{-\frac{g}{p_1}} + d_{2k} e^{-\frac{g}{p_2}} + d_{3k} \cos\left(\frac{g - p_3}{p_4}\right) \quad (1)$$

NPL National Physical Laboratory UVa vito vision on tec esa

Model vs measurements



NPL National Physical Laboratory

UVa

vito vision on tec

esa

Comparison with EO sensors and model

- Currently under development
- Similar approach as Kieffer and Stone but less spectral bands in the model
- Spectral smoothing based upon EO instrument spectral response
- ASD measurements to asses Apollo sand spectra and possibly replace
- PROBA-V and PLEIADES lunar acquisitions are currently baseline
    - Candidates from GLOD
    - GIRO

Lunar irradiance image PROBA-V 06/09/2017

NPL National Physical Laboratory UVa vito vision on tec esa

Thank you !