A collaborative effort toward validating a lunar irradiance model for using the Moon as an SI-traceable radiometric reference standard

Marc Bouvet[1], Kevin Turpie[2], Africa Barreto[3,4], Agnieszka Bialek[5], Steven Brown[6], Pieter De Vis[5], Jacob Fahy[5], Javier Gaton[4], Ramiro Gonzalez[4], Stephen E. Maxwell[6], Carlos Toledano[4], Joseph P. Rice[6], Adriaensen Stefan[7], Thomas C. Stone[8], John T. Woodward[6], Emma Woolliams[5]

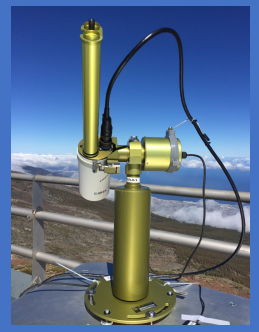
[1] European Space Agency (ESA-ESTEC), Netherlands; [2] University of Maryland, Goddard Space Flight Center, USA; [3] State Meteorological Agency (AEMET), Spain; [4] University of Valladolid (UVa), Spain; [5] National Physical Laboratory, UK; [6] National Institute of Standards and Technology (NIST), USA; [7] Flemish Research Institute of Technology (VITO), Belgium; [8] U.S. Geological Survey (USGS), USA;

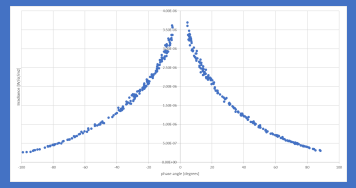
The Lunar Irradiance Model of ESA (LIME) and the airborne Lunar Spectral Irradiance Project (air-LUSI) of NASA, have both measured lunar irradiance. The very stable Moon is useful for consistent climate monitoring by EO sensors.

Both teams involve metrology institutes providing traceability and supporting uncertainty analysis. Recent collaborations have allowed for comparisons between the observations and models derived from them.

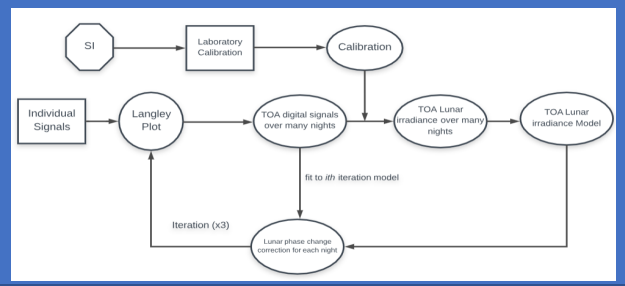
The LIME model:

- Outputs lunar disk integrated spectral irradiance
- Based on measurements carried out with a multispectral lunar photometer at Teide Peak
- Model based on the ROLO model of Kieffer and Stone [2005]
- Uncertainty analysis propagated from instrument to model with Monte Carlo methods. U = ~3% (k=2)
- Calibration traceable to SI via NPL



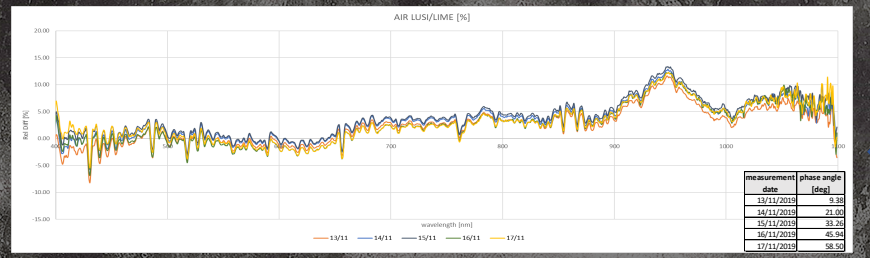


Lunar irradiance measurements at 440 nm based on more than 3+ years of measurements (about 400 lunar irradiance measurements)



Comparison

- Comparisons so far between 5 air-LUSI demonstration measurements and LIME model (plot below). Future work will consider comparisons for different phases, with different solar models and at different parts of the processing chain.



<u>Preliminary</u> comparison of LIME predictions against air-LUSI measurements

Next Steps:

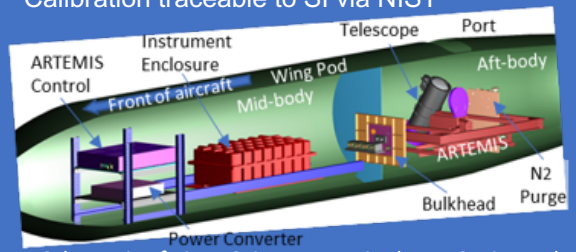
- Following a successful preliminary comparison further work is planned to make better quality comparison using updated air-LUSI measurements and improved LIME modelling using hyperspectral measurements
- Complete and publish comparisons with rigorous uncertainty for different angles and conditions.
- Research on how to combine multiple comparisons to get comparison uncertainty considering error covariance

Community recommendations

- Benefit in collaboration between teams on different continents, involving metrology institutes– encourage other cal/val methods to do similar
- The moon is a valuable calibration source. Satellite operators are encouraged to include lunar views for calibration purposes

The air-LUSI measurements:

- air-LUSI measures disk-integrated lunar spectral irradiance from a NASA ER-2 aircraft at 21 km altitude
- Spectral range is 350 nm to 1050 nm at less than 4 nm resolution
- A transfer spectrograph is used to calibrate air-LUSI while loaded in aircraft before each flight
- air-LUSI is monitored in flight against onboard reference LED
- Demonstration flights achieved U = 2% (k=2) from 450 nm to 900 nm on Demonstration Flights. U < 1.2% is anticipated for Science Flights, starting in March 2022.
- Calibration traceable to SI via NIST



Schematic of air-LUSI instrument in the ER-2 wingpod (above). Calibration chain from primary standards to top-of-atmosphere lunar irradiance (below).