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EnMAP Moon observations

Miguel Pato^{1,*} on behalf of the EnMAP Consortium

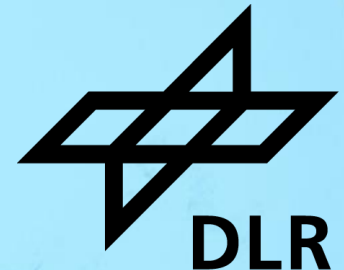
GSICS Lunar Calibration Subgroup
Web meeting, 13.11.2025

¹ German Aerospace Center (DLR), Remote Sensing
Technology Institute, Oberpfaffenhofen, Germany

* Miguel.FigueiredoVazPato@dlr.de

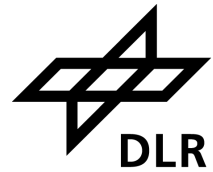
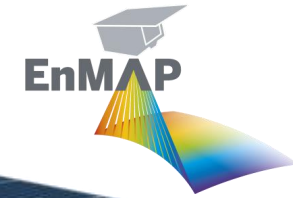


GFZ



EnMAP mission: requirements and fact sheet

<https://www.enmap.org/>



EnMAP specification	VNIR	SWIR
Spectral range	420 – 1000 nm	900 – 2445 nm
Number of spectral bands	91	133
Spectral sampling distance	6.5 nm	10 nm
Spectral full width at half maximum	6 – 11 nm	7 – 11 nm
Spectral accuracy	0.5 nm	1 nm
Spectral stability	0.5 nm	
Spectral smile	<0.2 pix	
Signal-to-noise ratio	>500 (at 495 nm)	>150 (at 2200 nm)
Radiometric accuracy	<5%	
Radiometric stability	<2.5%	
Geometric accuracy	1 pix (30 m) with GCPs, otherwise 100 m	
VNIR/SWIR co-registration	0.2 pix	
L2A AOT, WV, BOA (land, water)	see Storch et al 2023	
Orbit type, altitude and inclination	Sun-synchronous, 653 km, 97.96°	
Orbit period and repeat cycle	1.6 h, 398 revolutions in 27 days	
Local time descending node	11:00 h ± 18 min	
Revisit time	4 days (±30° off-nadir tilt) 21 days (±5° off-nadir tilt)	
Ground sampling distance	30 m (at nadir; sea level)	
Swath width	30 km (2.63° across track)	
Swath length	1000 km / orbit; 5000 km / day	
Product size	30 km x 30 km	



Source: DLR

Mission Management

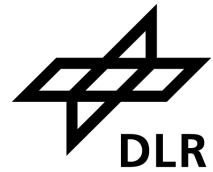
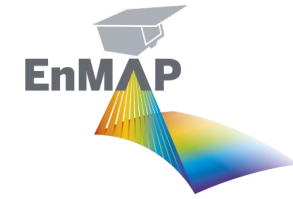
Science PI

Platform | Instrument

MOS | PGS | PCV

In-orbit calibration type	Mechanism	Frequency
Relative radiometric (lamp)	white spectralon	1x / week
Absolute radiometric (Sun)	Sun diffuser	1x / 2 months
Spectral	doped spectralon	1x / fortnight
Linearity	focal plane LEDs	1x / month
Deep space	dark sky	1x / month
Dark frames	closed shutter	before/after imaging

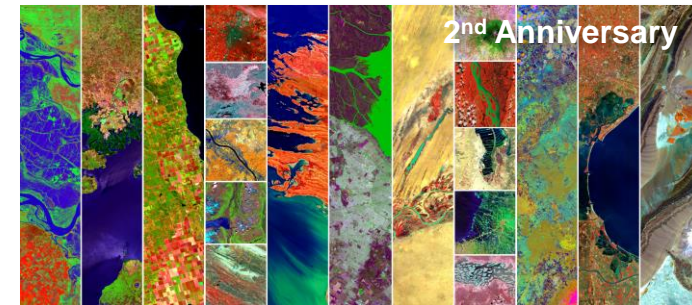
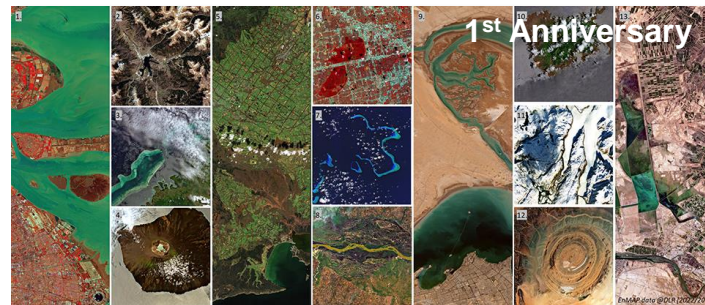
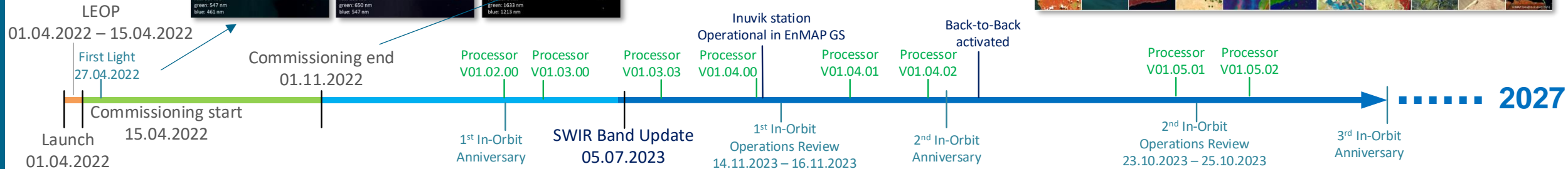
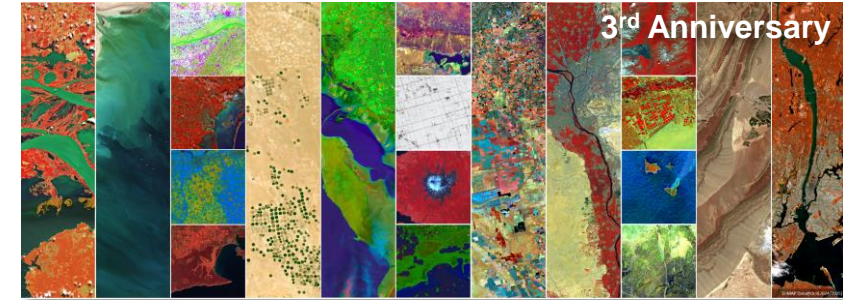
EnMAP mission: timeline



First EnMAP image 27.04.2022



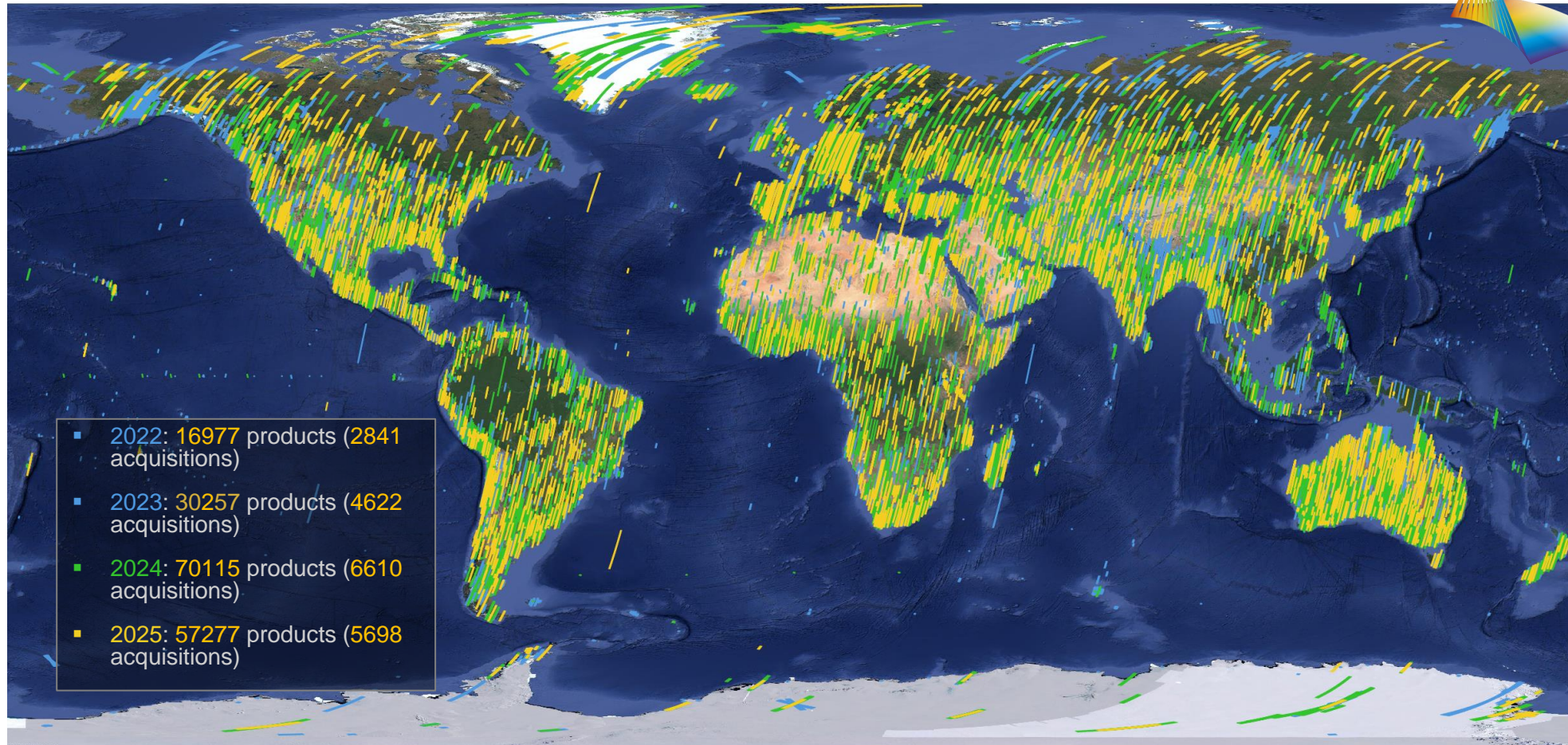
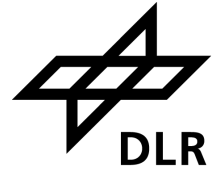
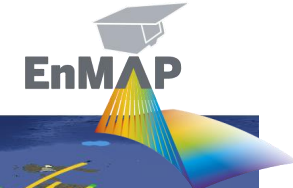
Results at the end of commissioning phase published in *Remote Sensing of Environment* 294 (2023) 113632



- Nominal mission is planned for 5.5 years (until Sep 2027).
- Preparations are currently underway to request a 5-yr extension of the mission (Oct 2027 – Sep 2032). Instrument and ground systems assessments indicate no obstacles to continue operations.

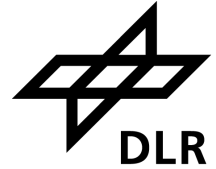
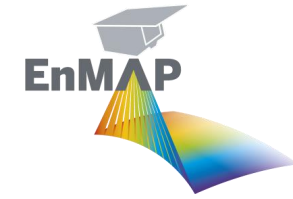
EnMAP mission: data catalog

until Q3 2025



- 19 768 Earth acquisitions
- 174 481 Earth products archived and available for ordering
- 327 Calibrations (Sun, Deep Space, Lamp, Spectral, Linearity) and 10 Moon Observations

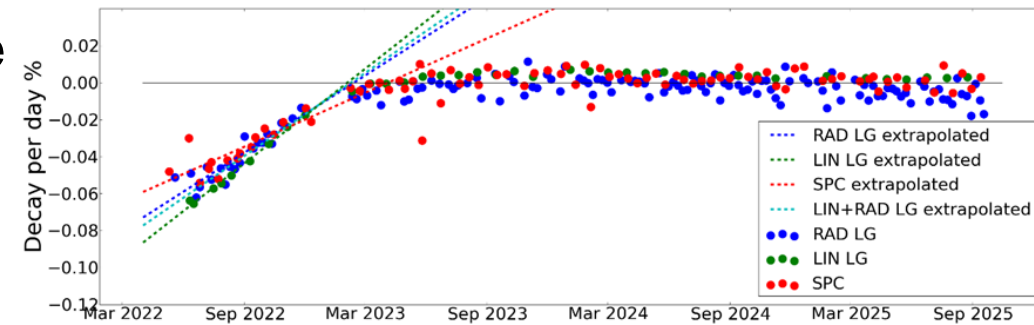
Radiometric performance



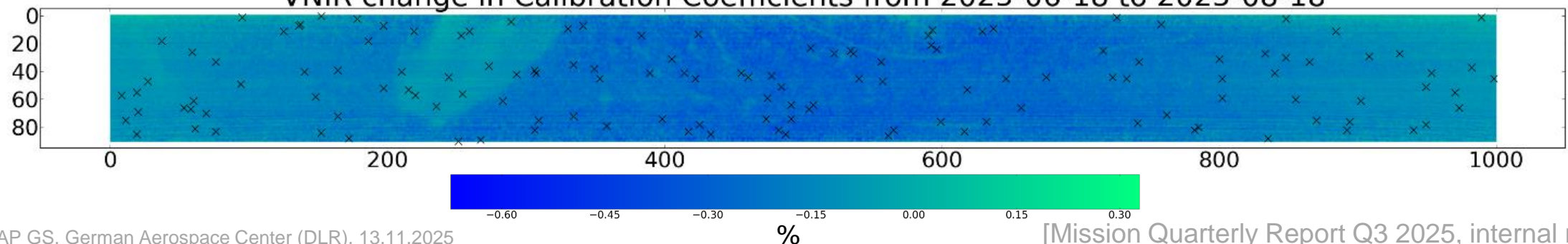
Highlight: Continuous monitoring of sensor performance with regular in-orbit calibration

Actions / results:

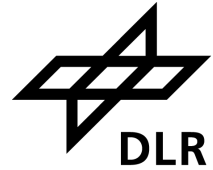
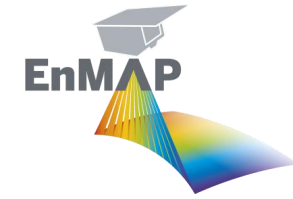
- Fast VNIR degradation observed during first year slowed down by Mar 2023 but with differences across focal plane.
- VNIR changes are offset by regular absolute calibrations (as per design).
- SWIR sensor is very stable since launch.
- Dark signal is remarkably stable since launch.



VNIR change in Calibration Coefficients from 2025-06-18 to 2025-08-18



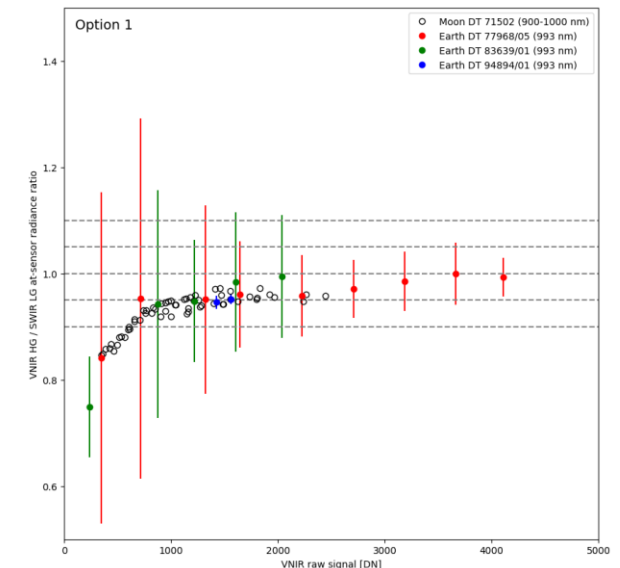
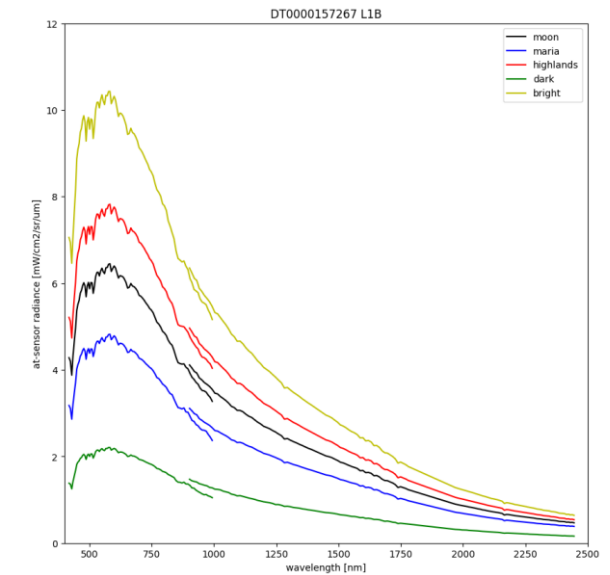
Radiometric performance



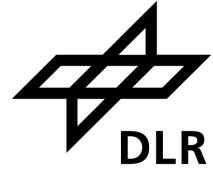
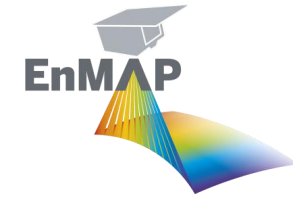
Highlight: Continuous monitoring of sensor performance with regular in-orbit calibration

Actions / results:

- VNIR/SWIR mismatch at 900–1000 nm is especially strong at low signals, but also present at large signals.
- Root cause not identified, but likely related to imperfect VNIR non-linearity correction and unidentified inconsistency between Sun calibration and Earth scenes.
- Intensive effort dedicated to solve issue, but all calibration-based solutions are only partially successful.
- Correction proposal being consolidated based on Earth and Moon validation results. Calibration update is expected in the coming quarters.



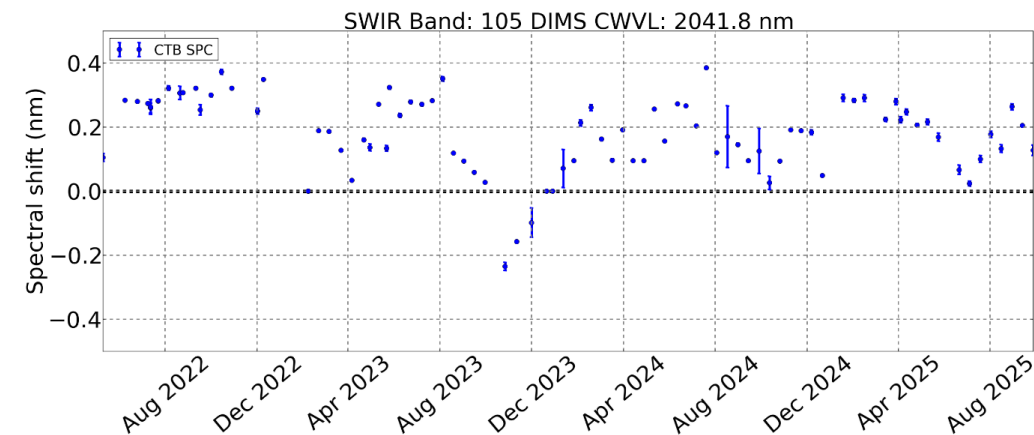
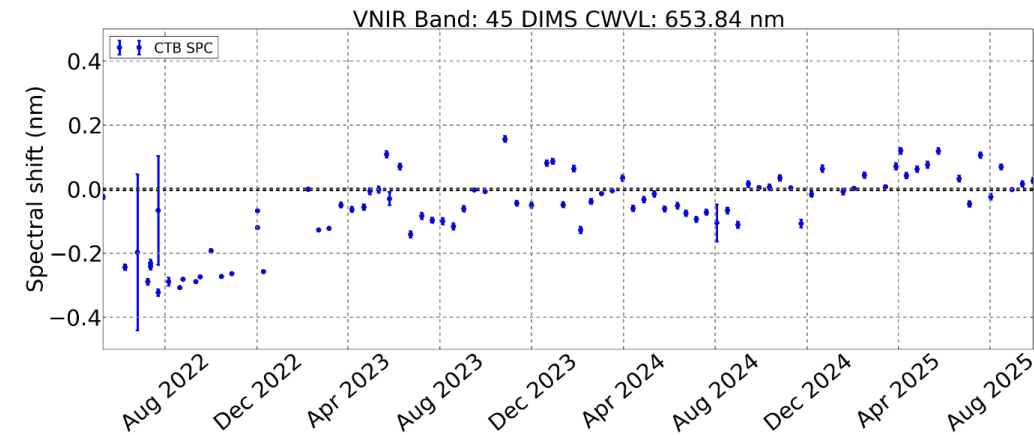
Spectral performance



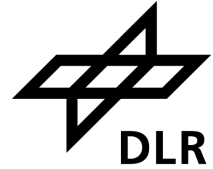
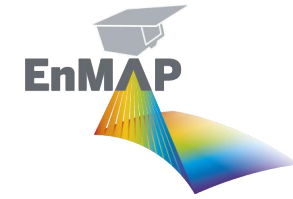
Highlight: Good spectral stability since beginning of mission

Actions / results:

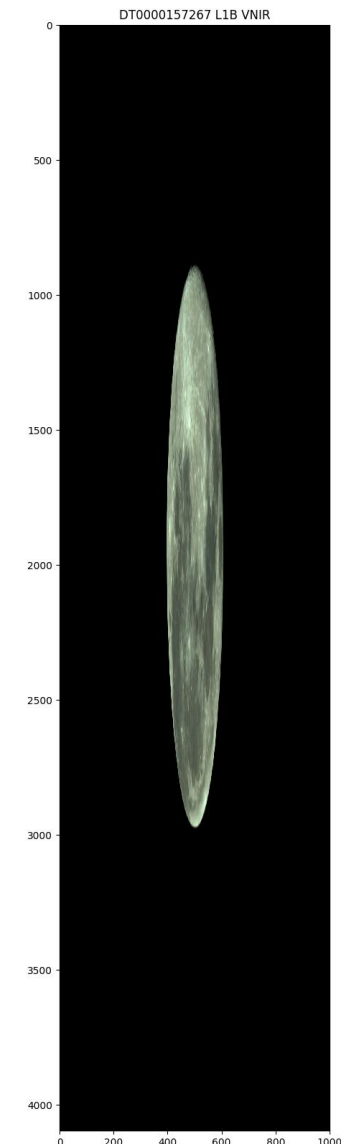
- Spectral updates are performed whenever shifts above 0.5 nm are detected in spectral calibration.
- After a few updates during commissioning, the last spectral update is from Feb 2023.
- Spectral stability since last update is better than 0.2 nm for VNIR and 0.4 nm for SWIR.
- Vicarious spectral checks at 760 nm and 2050 nm performed quarterly.



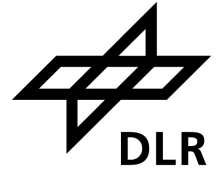
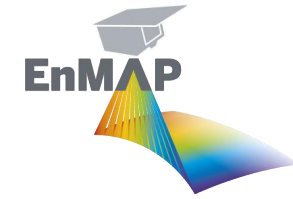
EnMAP Moon observations



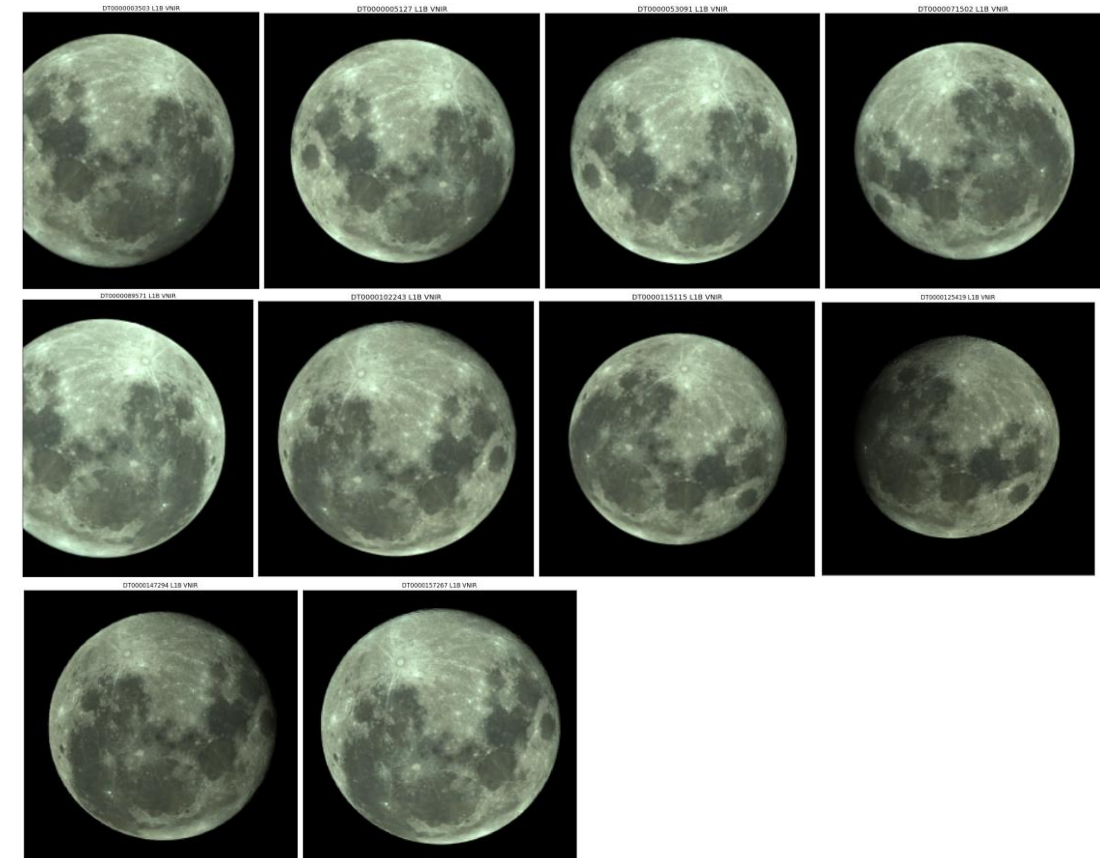
- Moon observations are not part of EnMAP routine operations, but they are useful for calibration and dedicated Cal/Val studies.
- Ten Moon observations acquired and commitment to observe every two months. Next: early Dec 2025.
- Imaging strategy:
 - along-track scan of Moon with 10x oversampling
 - Earth observation mode used (not all SWIR bands transmitted, see below)
- Spectral data:
 - VNIR: 418–993 nm, 91 bands, SSD 5–8 nm, FWHM 6–11 nm
 - SWIR: 902–2445 nm, 133 bands, SSD 7.5–12 nm, FWHM 7–11 nmspectral gaps: 1391–1461 nm, 1760–1939 nm (<05.07.2023)
1391–1449 nm, 1780–1968 nm (>=05.07.2023)



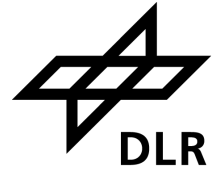
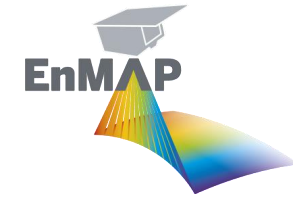
EnMAP Moon observations



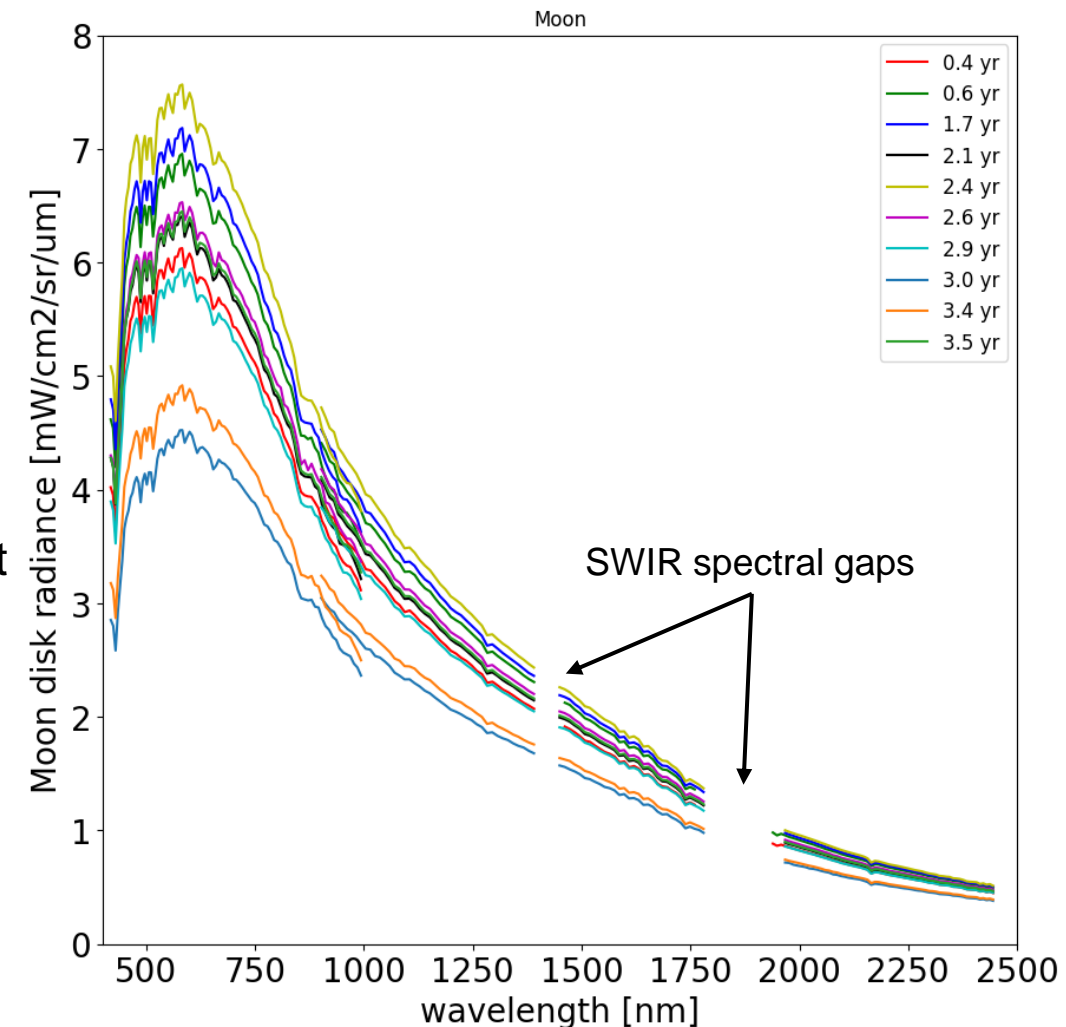
Datatake ID	Date	Number of tiles*	Approximate lunar phase [°]
3503	09.09.2022	3	-8.2
5127	07.11.2022	4	-6.2
53091	27.11.2023	12	5.6
71502	24.04.2024	4	6.8
89571	19.08.2024	4	3.4
102243	16.11.2024	4	7.7
115115	13.02.2025	4	10.7
125419	10.04.2025	4	-23.0
147294	10.08.2025	4	15.4
157267	07.10.2025	4	7.4



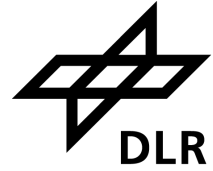
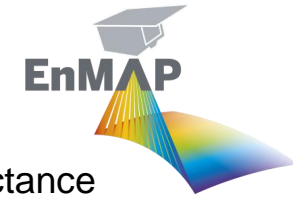
EnMAP Moon observations



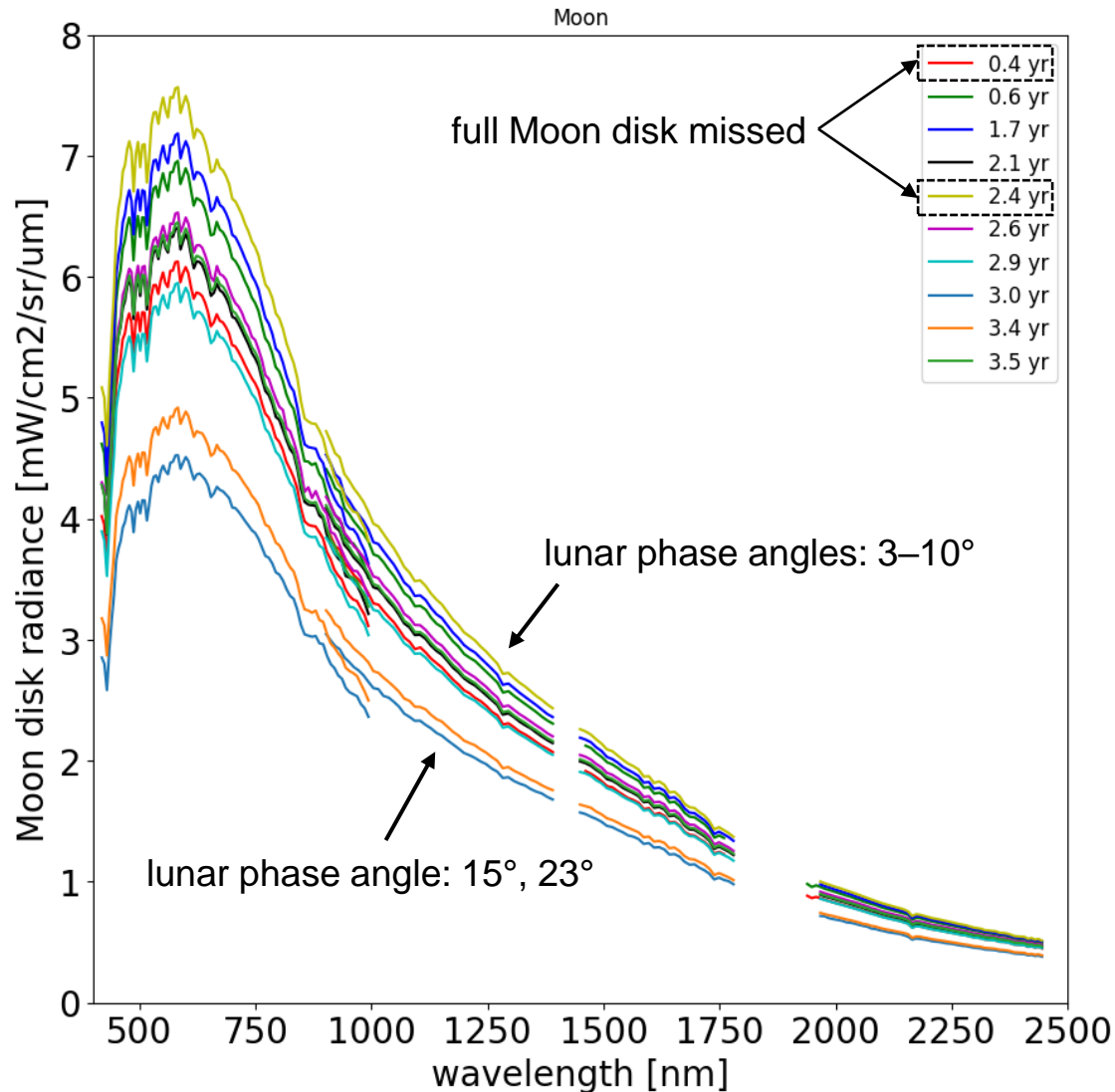
- Moon data are not currently part of EnMAP calibration procedures, but are used for dedicated calibration checks (e.g., dark signal, straylight) not possible with other measurements.
- Mid-term goal is to use Moon data for alternative radiometric validation and Sun diffuser monitoring (especially for mission extension).
- Comparison to lunar models is needed to achieve this goal and EnMAP team is currently collaborating with lunar expert teams (USGS, CNES, ESS).
- Moon products are not official EnMAP products, not delivered to external users and with limited documentation and support provided on a best-effort basis.



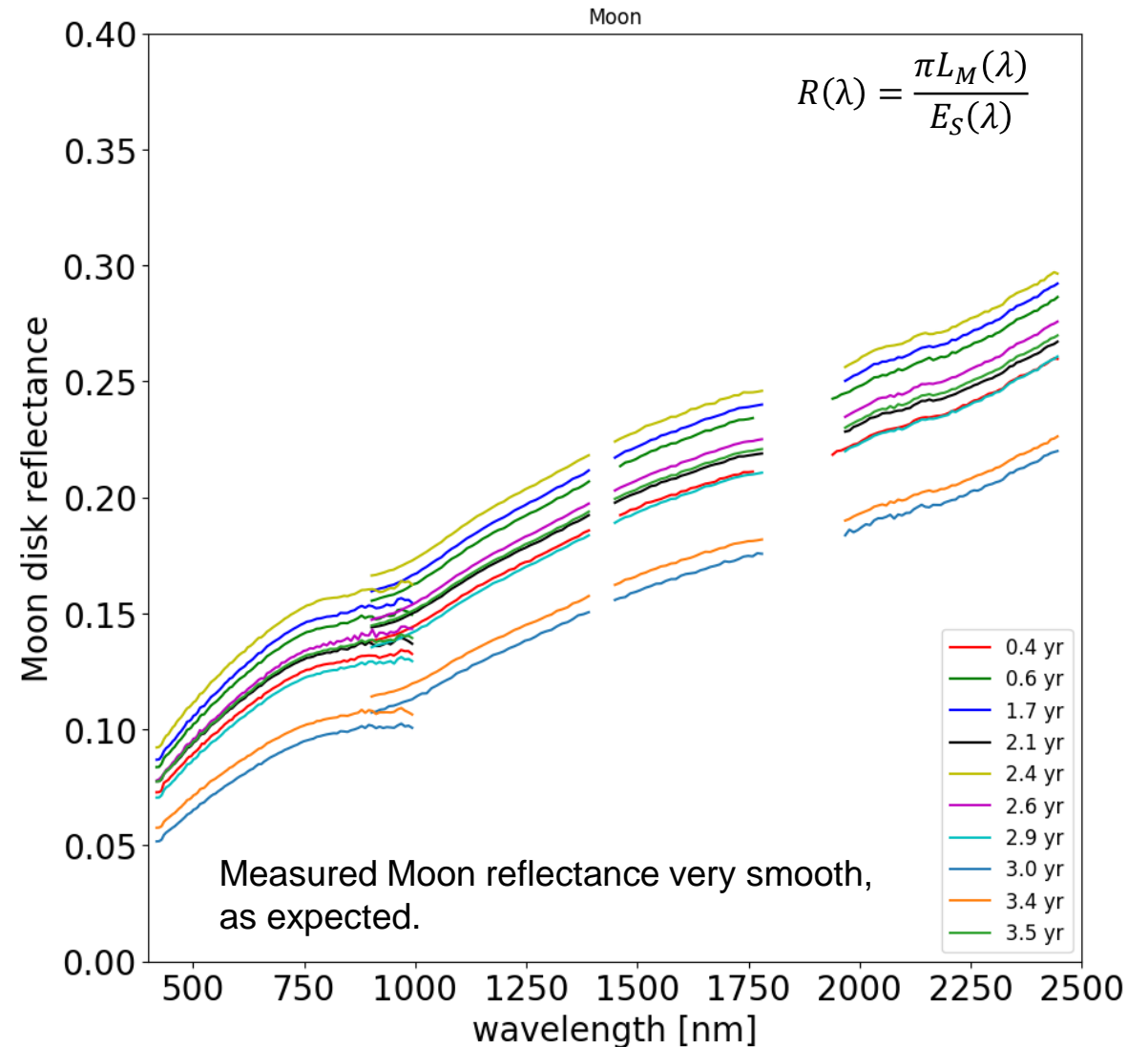
EnMAP Moon data and models



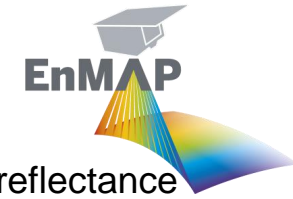
At-sensor radiance averaged over Moon



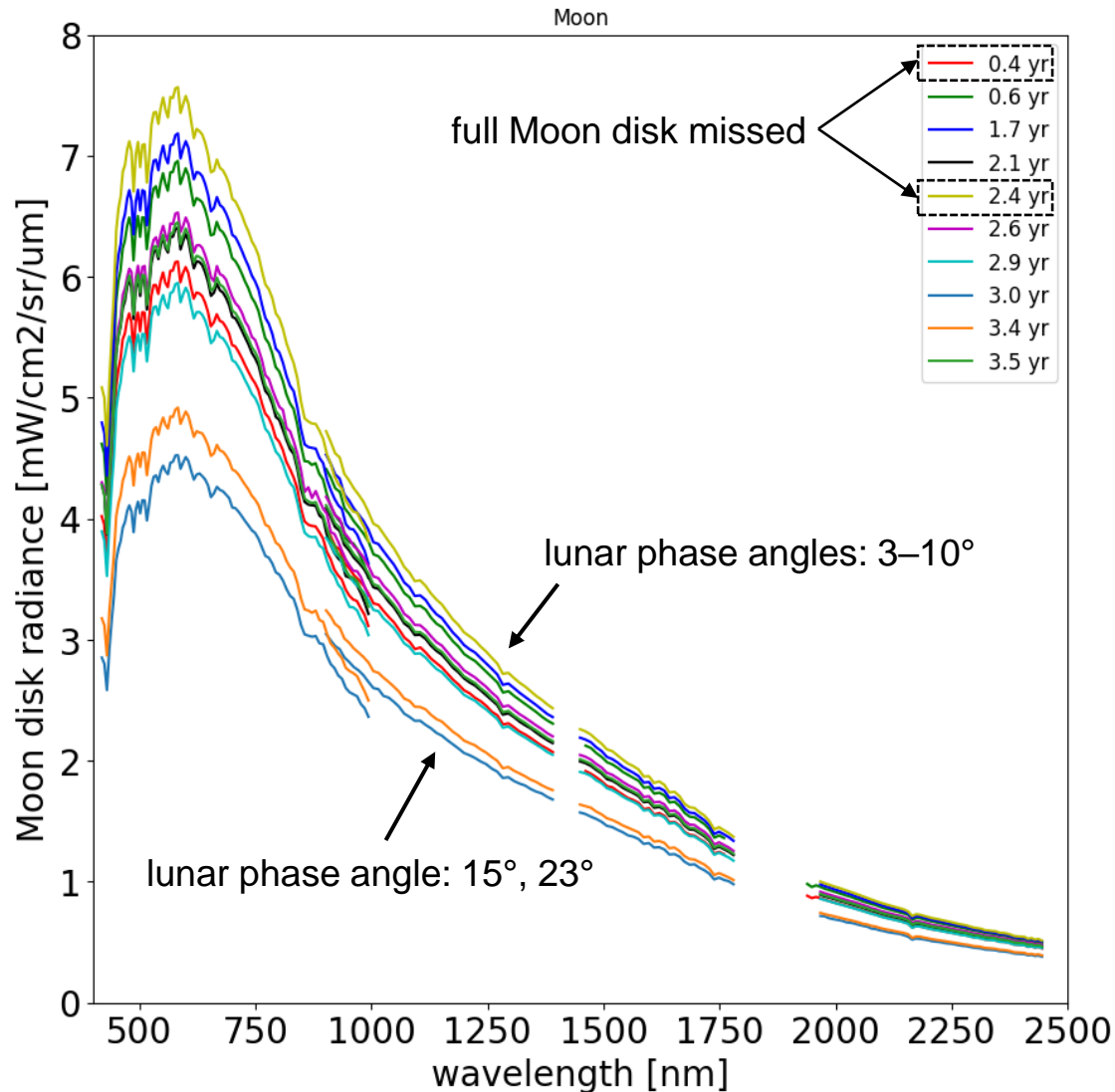
Moon disk reflectance



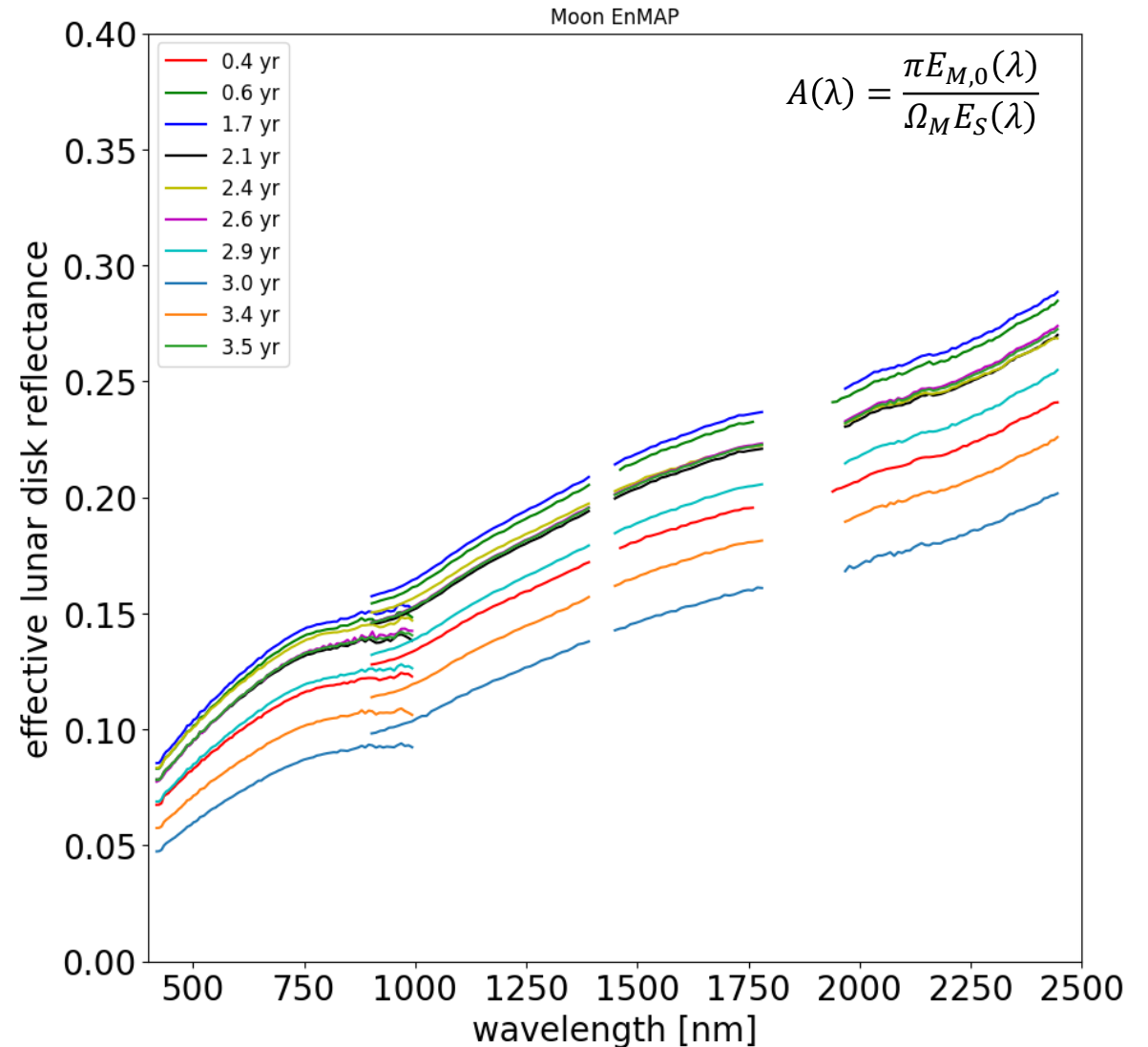
EnMAP Moon data and models



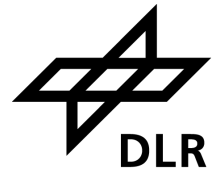
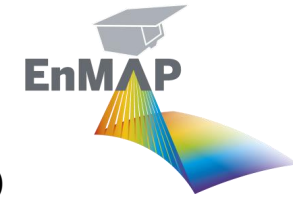
At-sensor radiance averaged over Moon



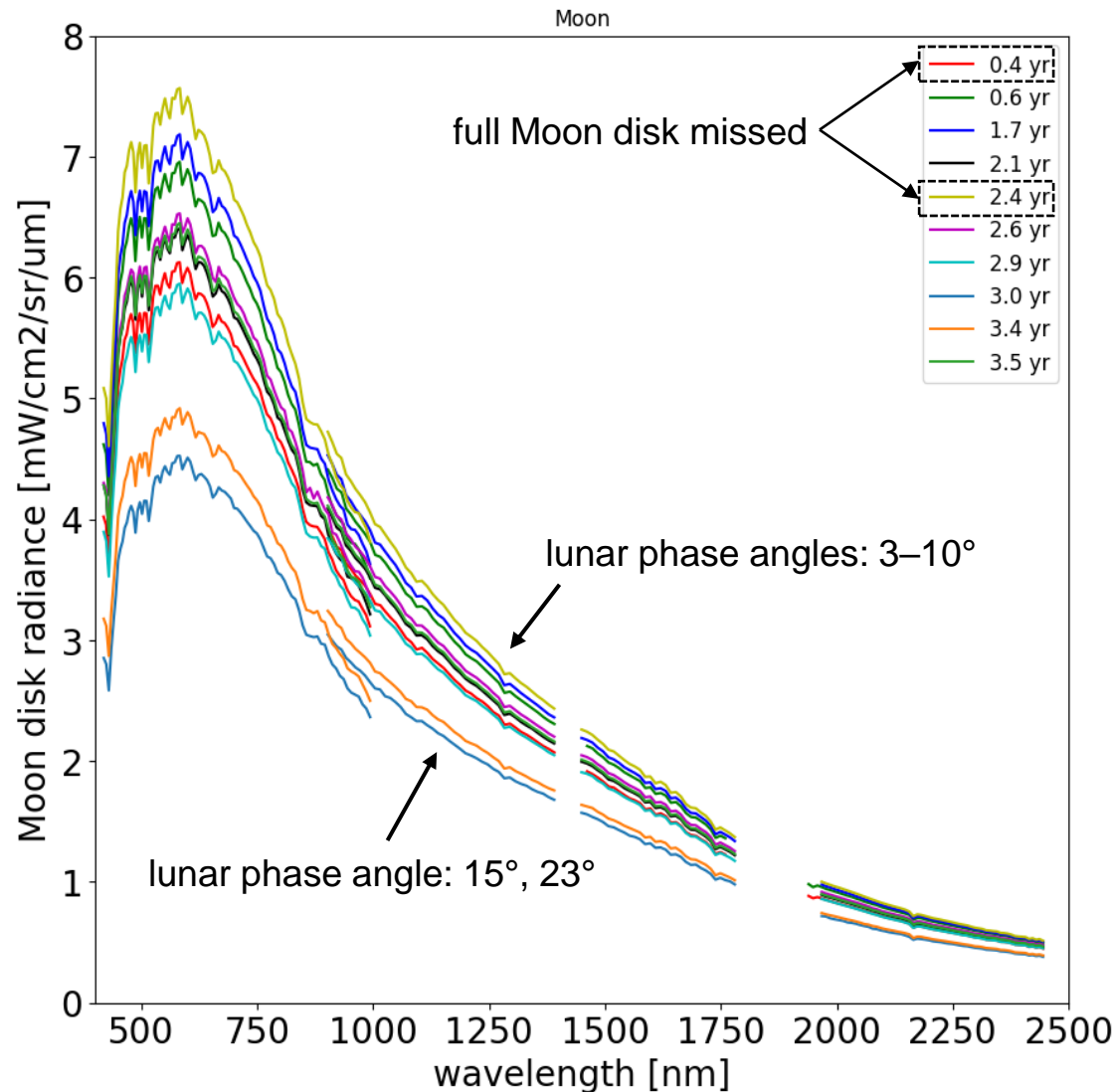
Effective Moon disk reflectance



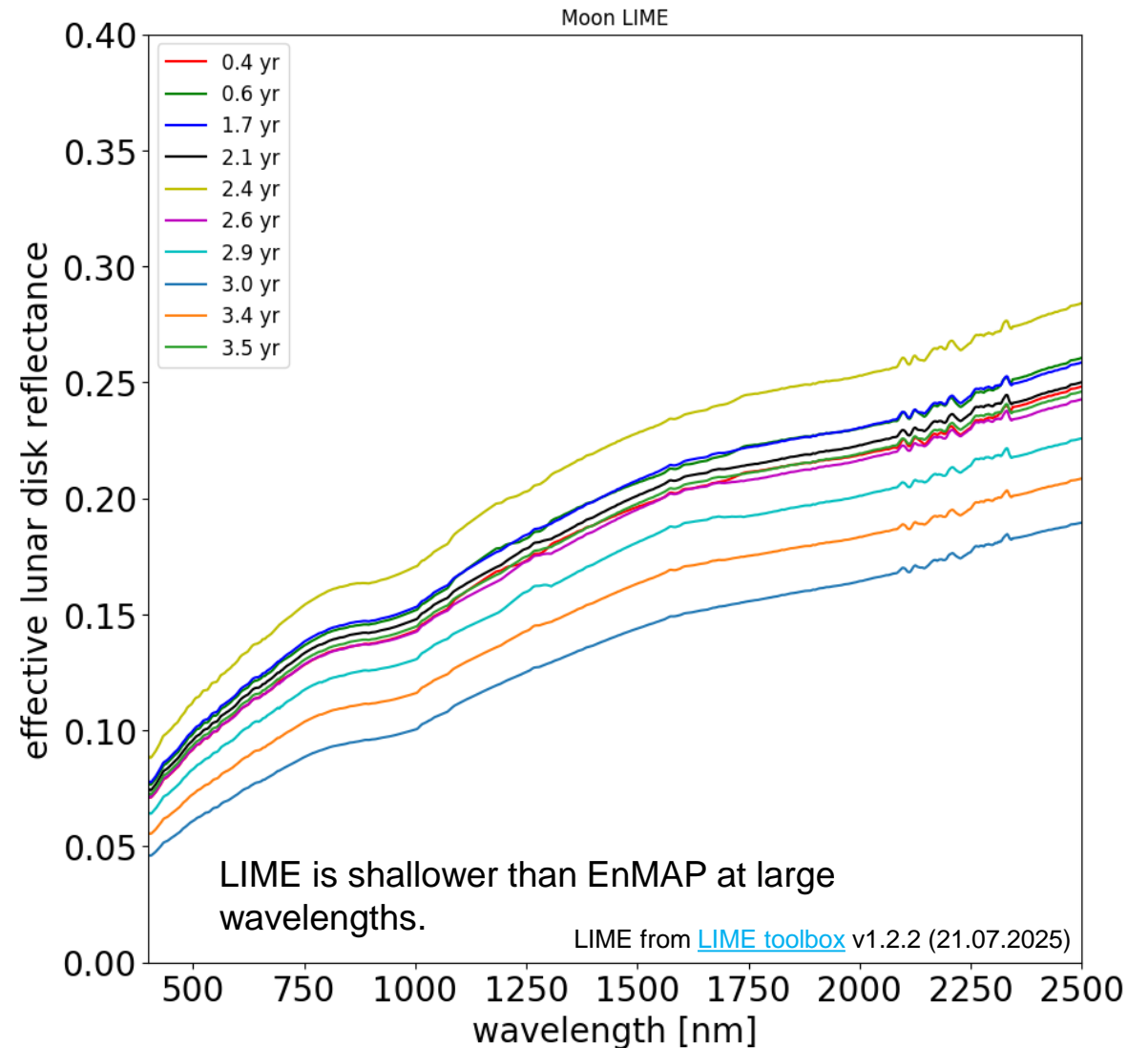
EnMAP Moon data and models



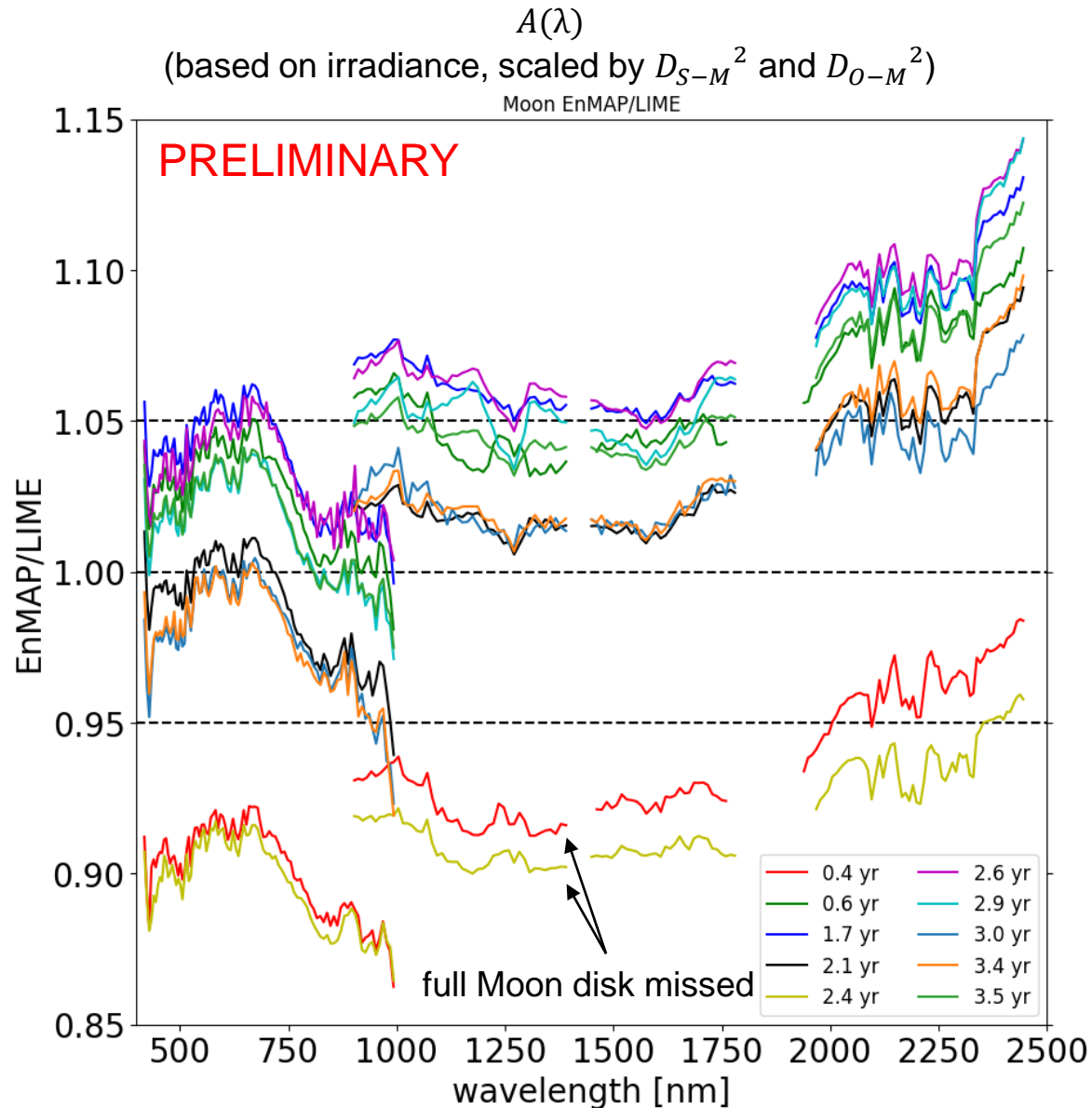
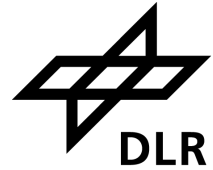
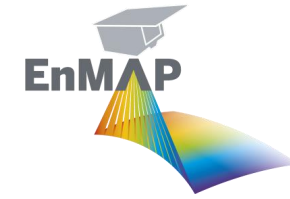
At-sensor radiance averaged over Moon



LIME $A(\lambda)$

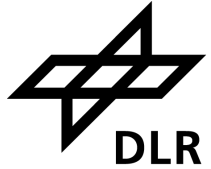
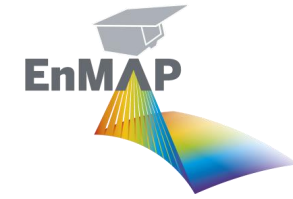


EnMAP Moon data and models



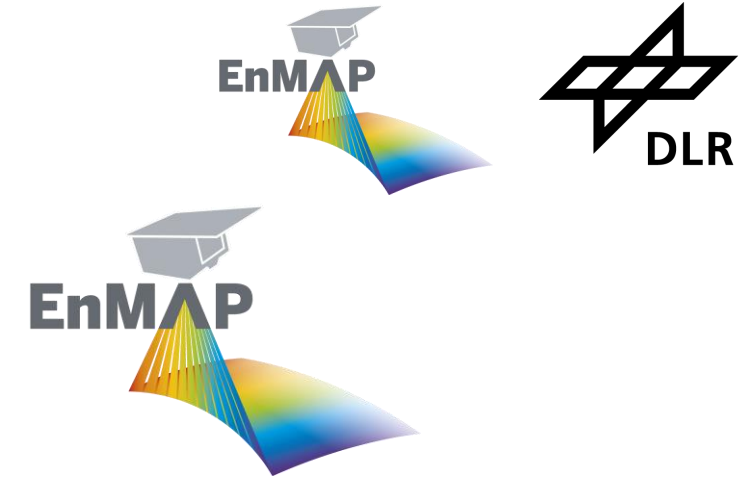
- Observations where full Moon disk was missed clearly not suited for model comparison.
- VNIR/SWIR mismatch at 900–1000 nm visible and under investigation by calibration team.
- Overall VNIR is roughly in line with LIME, while SWIR is about 5% above.
- Unclear reason for bump at 600–700 nm. Under investigation.
- Unclear reason for rise above 2000 nm. EnMAP reflectance look reasonable. Possible cause is spectral extrapolation in the lunar model in this range.

Outlook



- After more than 3.5 years in space, EnMAP is in a mature phase with deep knowledge of instrument performance.
- All in-orbit calibration facilities and both VNIR and SWIR instruments working nominally and stable.
- Five-year mission extension (Oct 2027 – Sep 2032) currently being considered.
- Moon observations routinely performed every two months and analysed offline in a best-effort basis.
- There are no plans to make EnMAP Moon data public.

Acknowledgements



This research was supported by the DLR Space Agency with funds of the German Federal Ministry of Economic Affairs and Climate Action on the basis of a decision by the German Bundestag (50 EE 0850, 50 EE 1923 and 50 EE 2108).

Useful links:

- Tasking orders and catalog browsing:
<https://planning.enmap.org/>
- Mission quarterly reports:
<https://www.enmap.org/mission/>
- ICDs, ATBDs, FAQ, change log:
https://www.enmap.org/data_access/

<https://www.enmap.org/>

