In-Orbit Performance of the ALADIN Instrument

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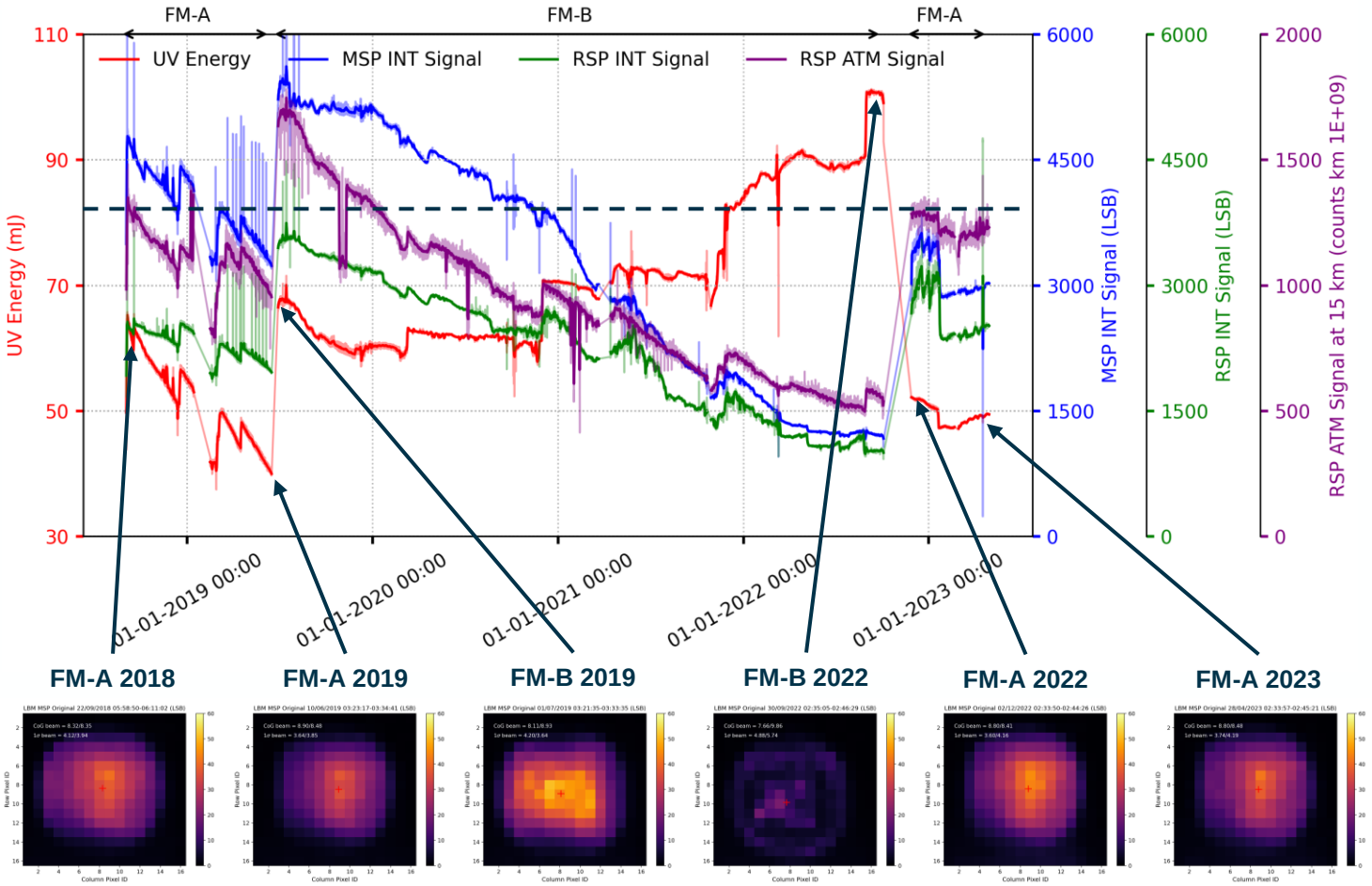
Outline

1. Long term evolutions
2. Main events on ALADIN since last year
3. Root cause assessment for atmospheric signal loss during FM-B operations
4. Impacts of the switch-back to FM-A on the signal and wind data quality
5. End-of-Life (EOL) Activities
6. Conclusions and outlook

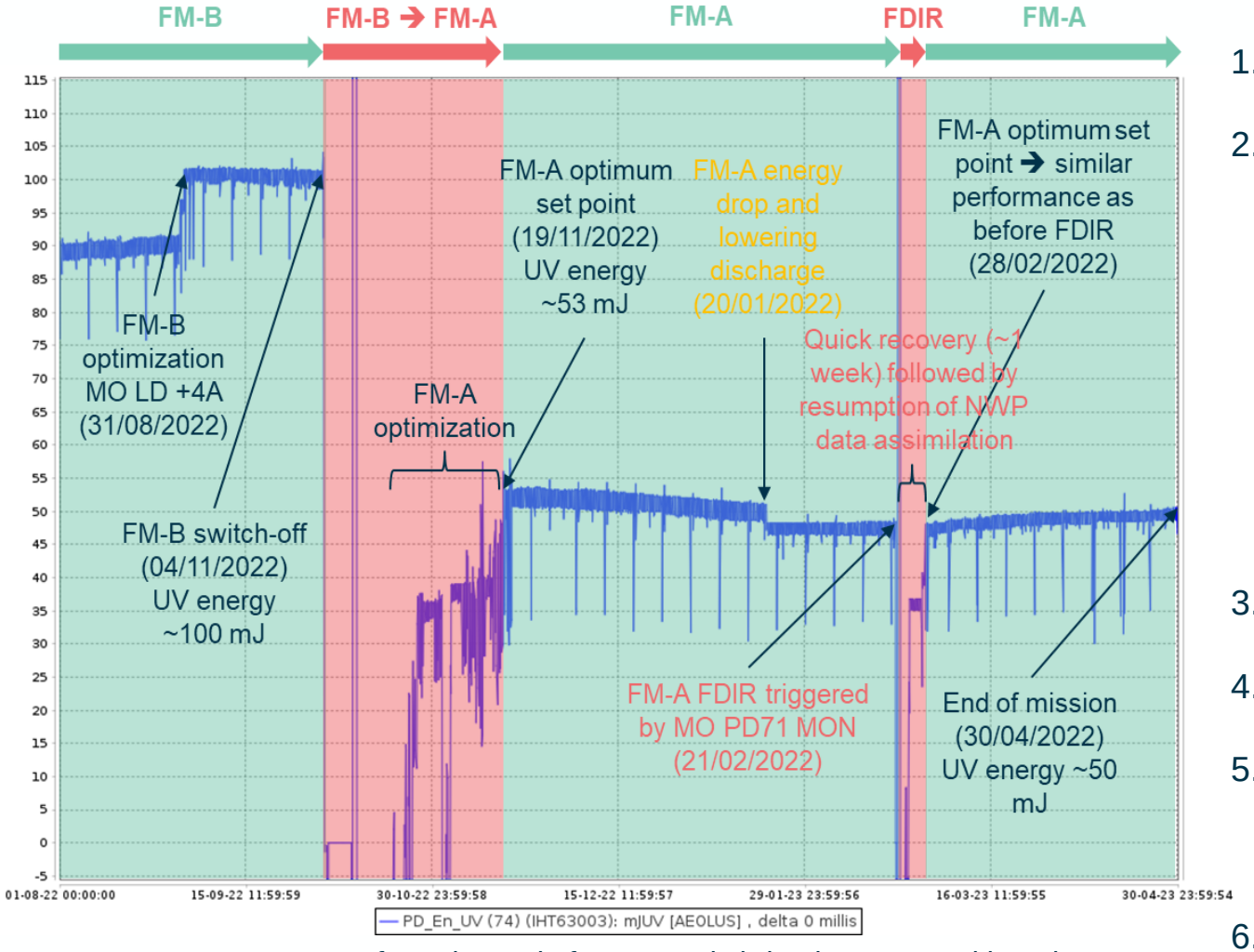
(1) Long term evolutions



Long term evolution of several ALADIN signal levels (PD74 UV energy, INT path signals, and the Rayleigh ATM path signal at 15 km) over the Aeolus operational mission and the NF beam profiles.

- The FM-A (nominal transmitter) was operated from Sept-2018 – Jun-2019 (~9 months). Decreases in the internal (INT) path and the atmospheric (ATM) path signals are in line with the degradation on UV energy due to the misalignment on the Master Oscillator (MO).
- Early switch to the FM-B (redundant transmitter) in June-2019 and operated up to Oct-2022 (~3.3 years). The FM-B showed good and more stable performance.
- A long term degradation with similar magnitude in both the INT path and the ATM path signals were observed during FM-B operations (-70%), independent of the UV energy.
- The degradation is reasonably consistent with independent measurements of the emit energy by the Pierre Auger Observatory (PAO) in Argentina.
- Finally, it was decided to switch-back to FM-A in Oct-Nov 2022. The NF beam profiles (INT path) indicate that the beam is similar to the FM-A beam profiles in 2019 (i.e. no evidence of significant beam motion or clipping)
- It is remarkable that the INT and ATM path signals have also recovered to the original levels in 2019 at the start of operations (optimized instrument setting + P/N settings).
- **On 30/04/2022, Aeolus completed the operational mission.**

(2) Main events on ALADIN since last year

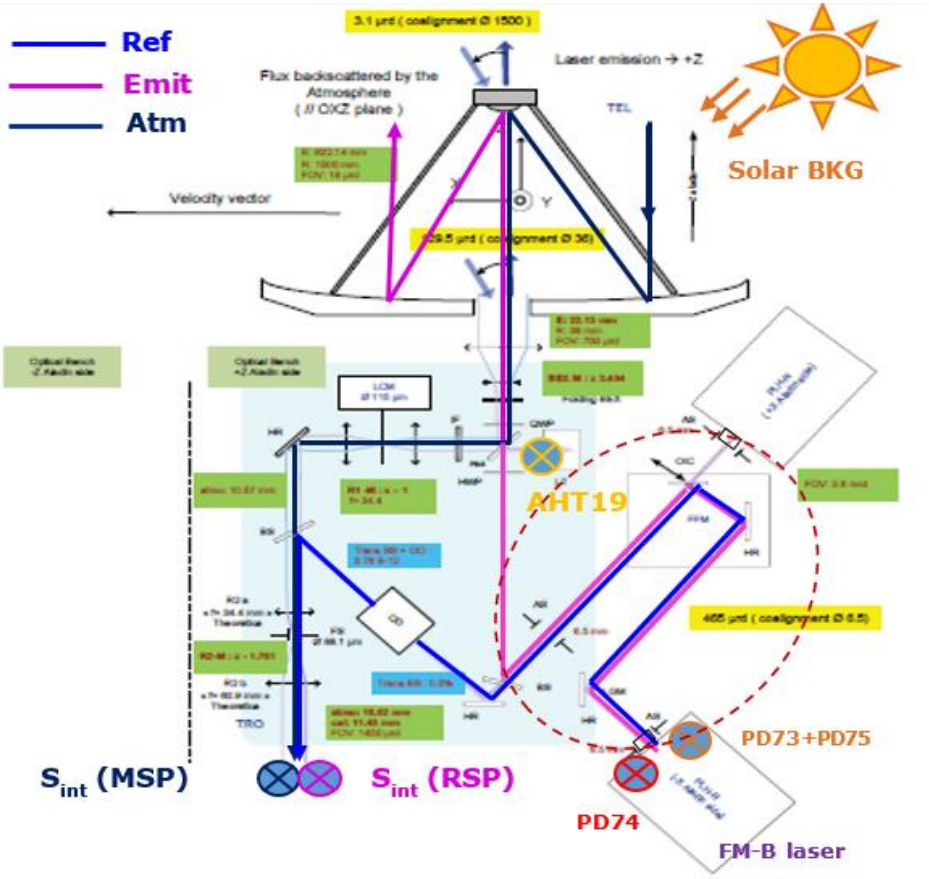


Laser UV output energy from the end of FM-B, switch-back to FM-A with main events towards the end of the operational mission lifetime.

1. Increase of the FM-B UV energy to support the JATAC in Sept-2022. It became the nominal setting for ~1 month until the switch-over.
2. Switch-back to the FM-A with the following reasons:
   - The severe degradation on the atmospheric signal returns during FM-B operations. Most likely it is due to the Laser Induced Contamination (LIC).
   - Increases of the STRO pressure (3x during FM-B) could slow down the decrease rate of the signals (not solve the whole issue). Moreover, the STRO pressure itself was ”leaking”.
   - Necessity to have operational mission with decent signal levels, therefore good wind quality, as well as for the EOL tests.
   - Potential additional information towards the investigations of the ALADIN signal losses (e.g.,, during FM-B operations).
3. FM-A optimizations during the commissioning resulted in the UV energy output around 53 mJ on 19/11/2022 (+30% c.f. FM-A 2019).
4. FM-A energy drop by ~3 mJ on 20/01/2023 due to changes in the Q-switch discharge conditions.
5. FDIR triggered transition to STBY on 21/02/2023 caused by out of range value on MO PD71. The recovery took 1 week (the UV energy went back to the level before the FDIR) followed by the resumption of nominal operations on 28/02/2023.
6. End of operational mission on 30/04/2023, followed by EOL tests.

(3) Assessment for ATM signal loss during FM-B

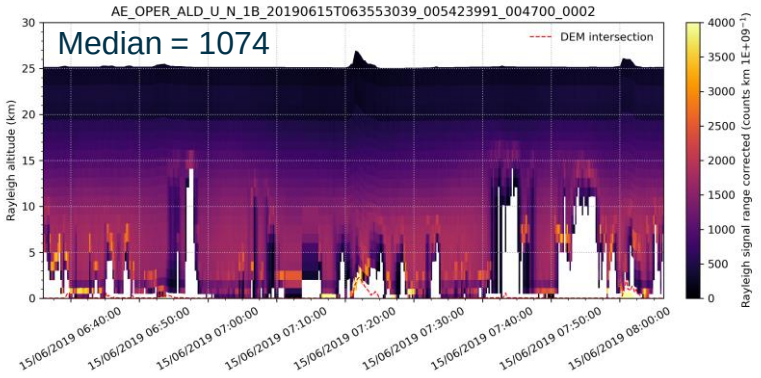
- With the switch-back to the FM-A, we observed an increase in the ATM path signal of x2.2 despite operating around half of the UV energy at the end of FM-B.
- The switch-back has also recovered both the emit path and the INT signal levels back to those that were observed at the end of the FM-A in 2019 (similar efficiency and beam profiles) means that there is insignificant degradation in these optical paths.
- This allows us to conclude that the atmospheric return signal degradation observed during FM-B operations is restricted to those optics which guide the FM-B laser beam on to the nominal optical axis.
- The NF beam profile at the end of FM-B has a “doughnut” structure which is similar to LIC deposits which have been analyzed during the FM-C life-test. It also showed a constant degradation rate, similar to that observed during FM-B operations.
- For Laser-Induced Damage (LID) and Laser-Induced Absorption (LIA) we would expect the maximum attenuation to be related to the central high fluence region of the laser beam.
- There was an obvious increase of pressure in the STRO (outgassing) when the Flip-Flop Mechanism (FFM) was actuated in 2019 (FM-A => FM-B).
- **It is therefore concluded that the most probable cause of the degradation during the FM-B operations is localized LIC on the optics used to steer the FM-B laser on to the instrument emit path, possibly due to the activation of the FFM during the swap from FM-A to FM-B.**



Schematic of the ALADIN instrument indicating the optics impacted by optical attenuation (red ellipse)

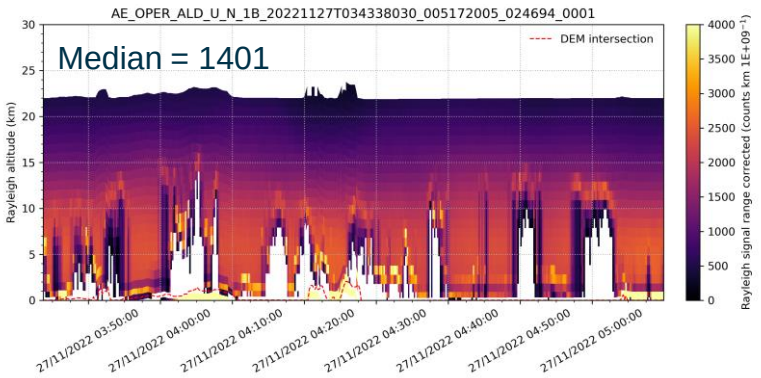
(4) Impacts of the switch-back to FM-A

End of FM-A 2019

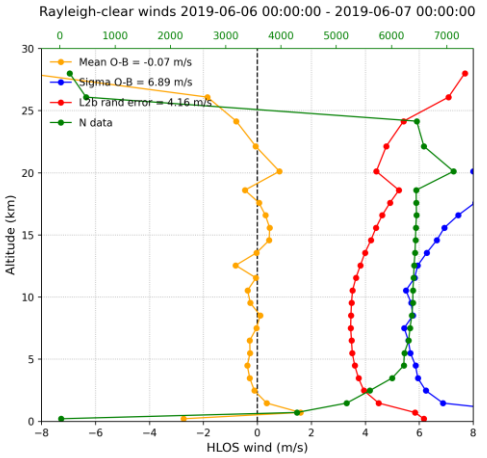


End of FM-B 2022

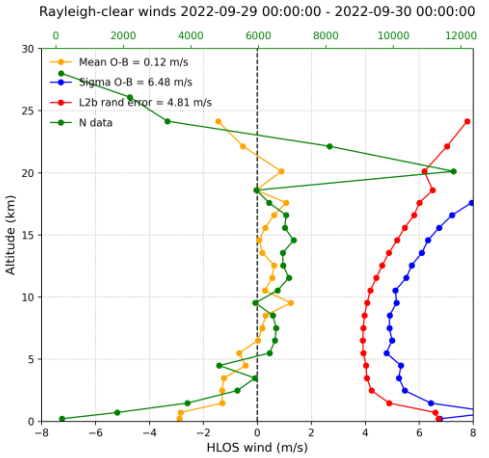
Start of FM-A 2022



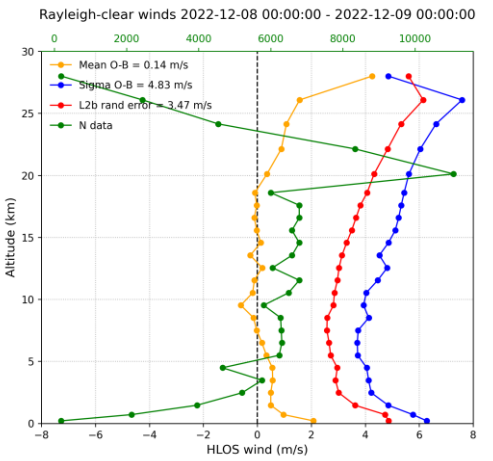
End of FM-A 2019



End of FM-B 2022



Start of FM-A 2022



- Significant improvement on the ATM signal of **+123%** compared with the end of FM-B operations in October 2022 and **+30%** compared with FM-A operations in June 2019.
- The random error (estimated via sigma O-B) over the vertical profile has reduced by **-25%** compared to the end of FM-B operations (from 6.48 m/s to 4.83 m/s).
- Compared to earlier FM-A and FM-B operations, there is also a significant contribution to the improvement in the random error as a consequence of the increase in the number of laser shots accumulated (P) from 19 to 114, that has been applied since 01-March-2022.
- **<u>The switch-back to FM-A was a very good decision and well paid off.</u>**

(5) End-of-Life Activities

What are we doing after the end of operational mission before the re-entry?
We received many interesting proposals for the EOL tests from DISC, Industry, and internal ESA. 18 tests agreed to be performed (very high, high, medium, and low priority)

Main purposes:

1. To investigate issues during in-orbit operations (e.g., initial loss, clipping, hot-pixel in memory and imaging zones, freq. stability, etc.)
2. Knowledge and technological transfers to the future missions (EarthCARE and EPS-Aeolus)

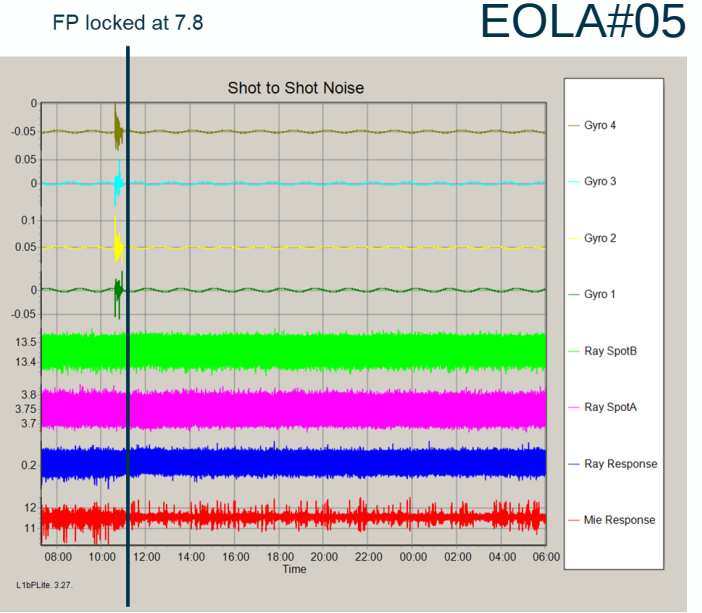
Timeline:

- The EOL tests started officially on 01-May-2023 with a max duration of 6 weeks:
  - 4 weeks for tests
  - 1 week for contingency (e.g., FDIR, to repeat those which are not optimum) ➔ **FDIR on 03-May-2023**
  - 1 week for laser swap (FM-A to FM-B) ➔ **succeed (11-17 May 2023)**
- 4 tests already performed in April-2023, during the nominal mission by replacing the IRC slots.
- The EOL activities will finish before the start of the decay (latest update from FD => 19-June-2023)

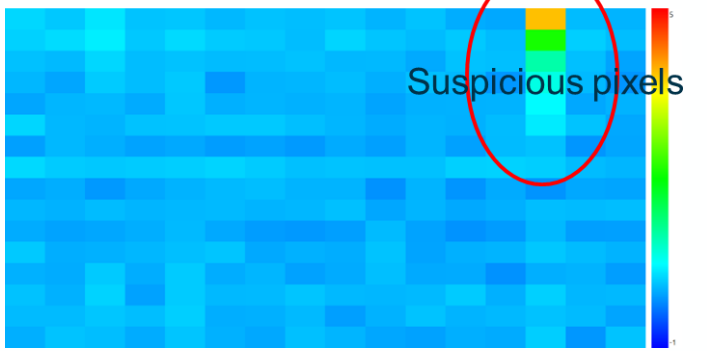
Latest updates:

- We have performed **10/18 (55%)** EOLAs #17, #18, #24, #05, #10, #12, #20 (will be repeated), #03, #16, and #23. EOLAs #04 and #13 (telescope tests) are on-going during the conference.
- An FDIR was triggered on 03-May-2023 due to a commanding issue while preparing EOLA#03. Several failed attempts to switch on the FM-A led to the decision to carry on the remaining tests with the FM-B.

EOLA#05



EOLA#16



(6) Conclusions and outlook

- The ALADIN instrument has been operating for 4.6 years (~7 billion shots) and has concluded the operational mission on 30-April-2023.
- The FM-A was operated for 9 months (Sept-2018 to June-2018) and suffered from the MO misalignment. This led to the decision to switch to the redundant laser FM-B.
- The FM-B accumulated 3.3 years of operational lifetime (more than the original mission lifetime). A record level of 100 mJ UV energy was successfully demonstrated at the end of FM-B operations.
- A successful switch-back to the FM-A and optimization of the laser output energy to 53 mJ October-November 2022.
- The switch-back to the FM-A has significantly improved the ATM signal level (123%) as well as the random error (23-30%) to the lowest level of the entire mission (partly due to the P/N setting).
- It also shed a better understanding of the root cause(s) of the degradation of the atmospheric return signals which can be localized to the few optics which steer the FM-B on to the nominal optical axis where no significant degradation is evident. The most probable root cause is due to the LIC from the FFM activation in 2019.
- Apart from the UV energy drop on 21-Jan-2023 (Q-cwitch discharge), the FM-A UV energy since the switch-back looks very stable (optimized TxA setting). The FM-A has operated for 6 months since the October-2022.
- The remaining time before the re-entry is dedicated for the EOL tests to investigate issues during in-orbit operations and to transfer knowledge and technology to the future missions.

Finally, we would like to take the opportunity to sincerely thank all the people who have been involved in the activities on Aeolus and the scientists here for their continued patience and supports!!