EarthCARE 2026 Science and Validation workshop

8–12 June 2026 | Rhodes House | Oxford, UK

# EarthCARE ATmospheric LIDar (ATLID) performance status after nearly 3 billion shots of successful in-flight operation, comparison and impact on other ESA LiDAR Missions.

**De Sanctis V** [1], Bravetti P [2], Marnas F [2], Schaube A [3], Ciapponi A [2], Sapia A [4], D'Ottavi A [4], Candra Krisna T [2], Abis B [1], Piro A [1], Russo A [1], Di Ciolo L [1], de Villele G [3], Lochard J [3], Haas C [5], Wernahm D [2], Hummel T [1], Porciani M [2], Parrinello T [1], Frommknecht B [1].

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**5** Airbus Defence And Space GmbH, Immenstaad, Germany

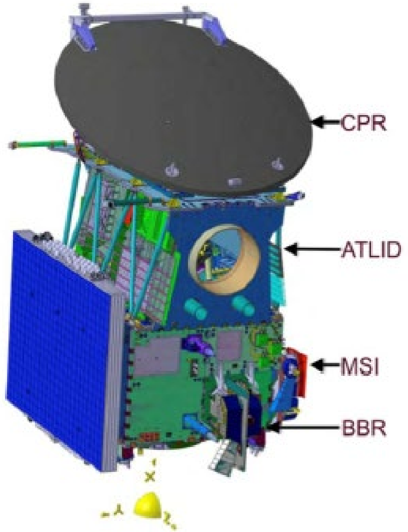
# EarthCARE mission

- **EarthCARE** satellite is the 6th ESA explorer mission

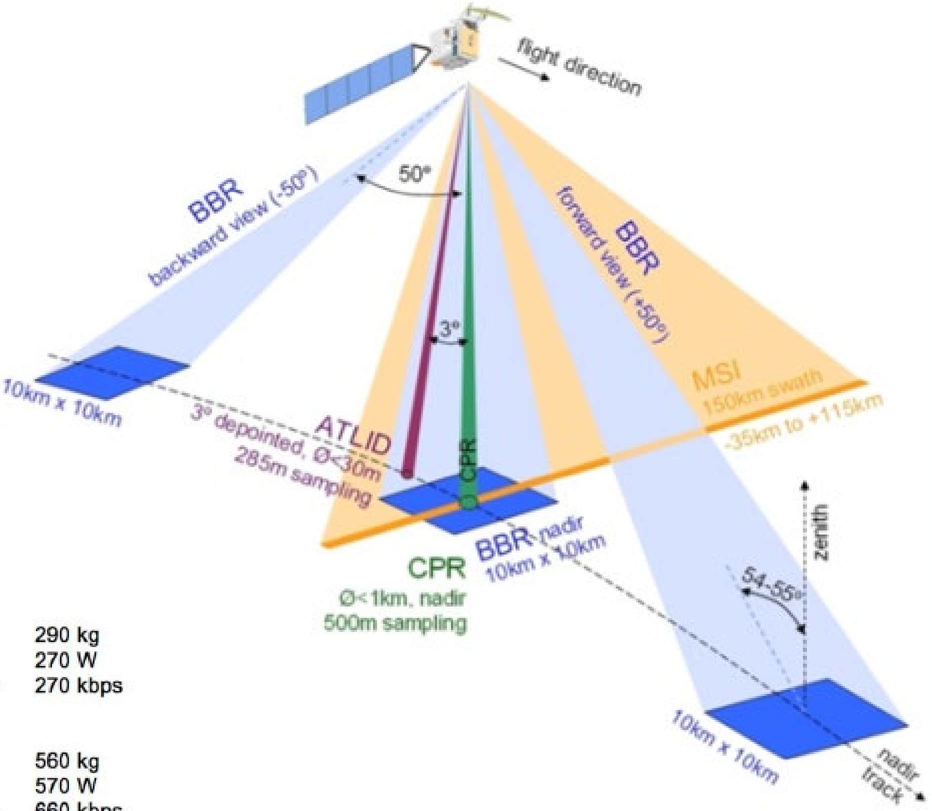
- Quantify aerosol and cloud radiation interactions to improve numerical modelling for climate and weather forecast

- **4 instruments work in synergy :**
  - CPR: 94GHz cloud profiling radar
  - ATLID: UV atmospheric Lidar
  - MSI : multispectral imager
  - BBR: broadband radiometer

- **Satellite requirements**
  - Sun synchronous orbit (14:00 desc.mode)
  - Low average altitude 405km
  - Repeat cycle of 25 days
  - Design lifetime of 3 years




| | | |
|---|---|---|
| CPR | Mass | 290 kg |
| | Power | 270 W |
| | Data Rate | 270 kbps |
| ATLID | Mass | 560 kg |
| | Power | 570 W |
| | Data Rate | 660 kbps |
| MSI | Mass | 57 kg |
| | Power | 60 W |
| | Data Rate | 611 kbps |
| BBR | Mass | 48 kg |
| | Power | 45 W |
| | Data Rate | 145 kbps |



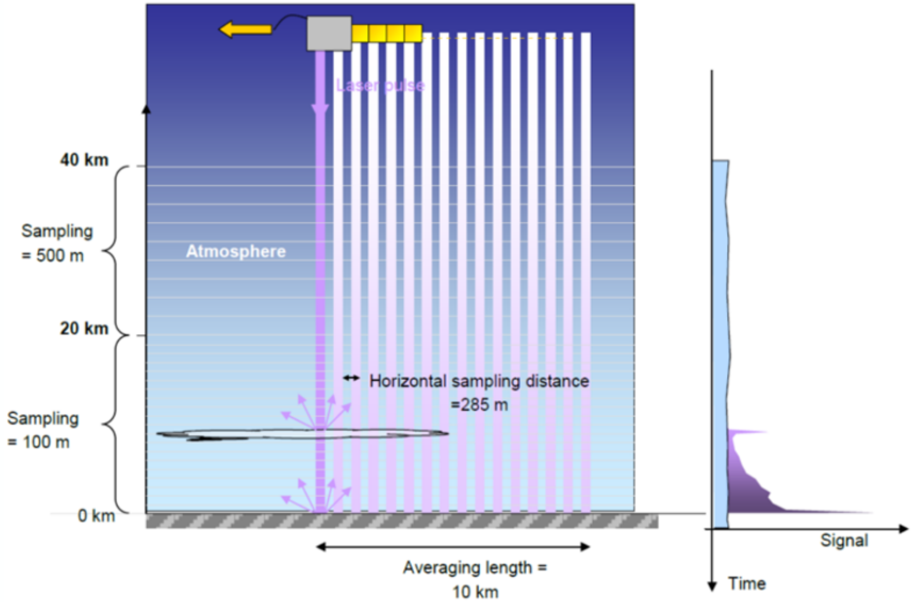
# ATLID measurement

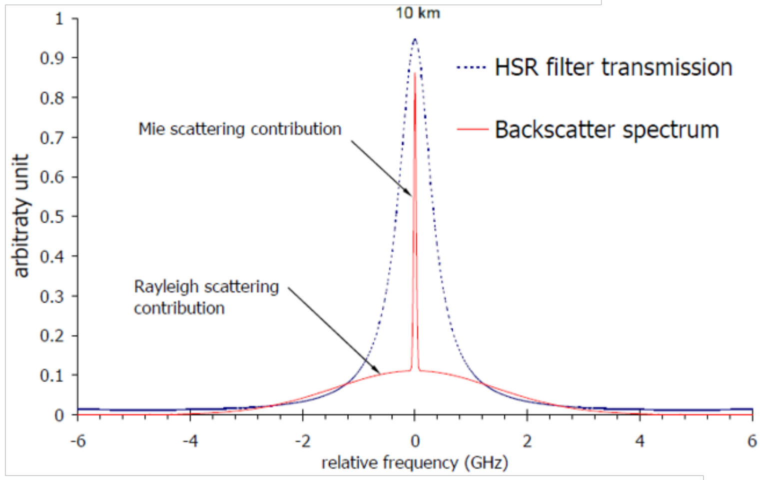
- **Atmospheric LIDAR with 355nm source**

- Measurement of vertical profile of optically thin clouds and aerosol layers:
  - Vertical profile from 0 to 40km, resolution from 100 to 500m
  - 14 m diameter laser footprint, with horizontal ground sample every 280 m
  - Performance derived over 10 km horizontal averaging of laser accumulations

- **Detection with High Spectral Resolution Etalon technique**
- A Fabry Perot Etalon separates the narrow bandwidth backscattered Mie signal from the broadband Rayleigh signal
- Co- and Cross-polarisation signal separation.

- 3 science channels
  - Mie Co-polarisation-> aerosol and thin clouds backscattering
  - Rayleigh Co-polarisation -> molecular backscattering
  - Cross polarisation -> polarisation ratio of backscattering



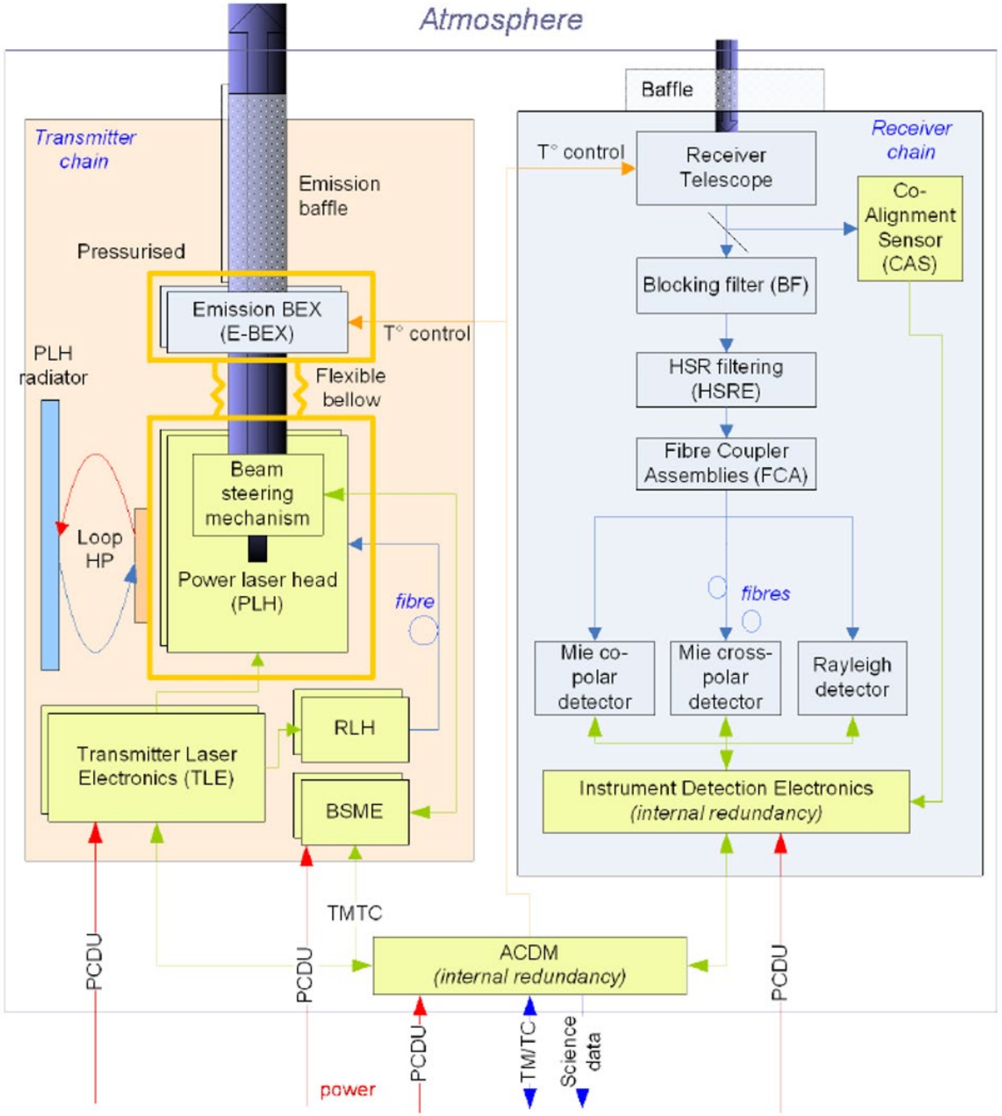



# ATLID design

- **Bistatic architecture:** separate transmitter and receiver, with active co-alignment loop.

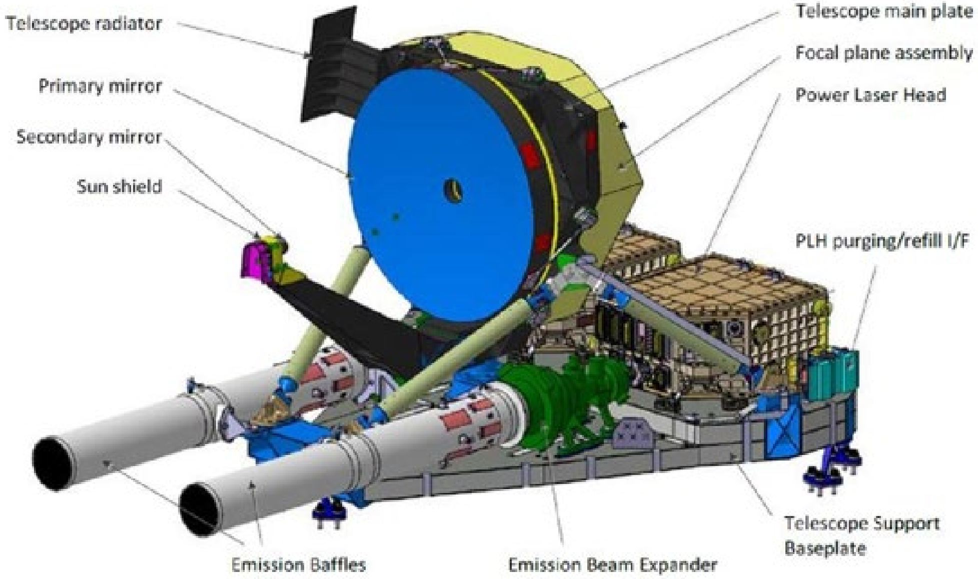
- **Transmitter**:
  - Pressurized power laser head 37.5mJ (reduced from 40mJ for LIDT) @50.5Hz, seeded by frequency adjustable reference laser
  - Beam steering mechanism
  - Beam expander and external baffle to protect from contamination
  - Fully redundant equipment.

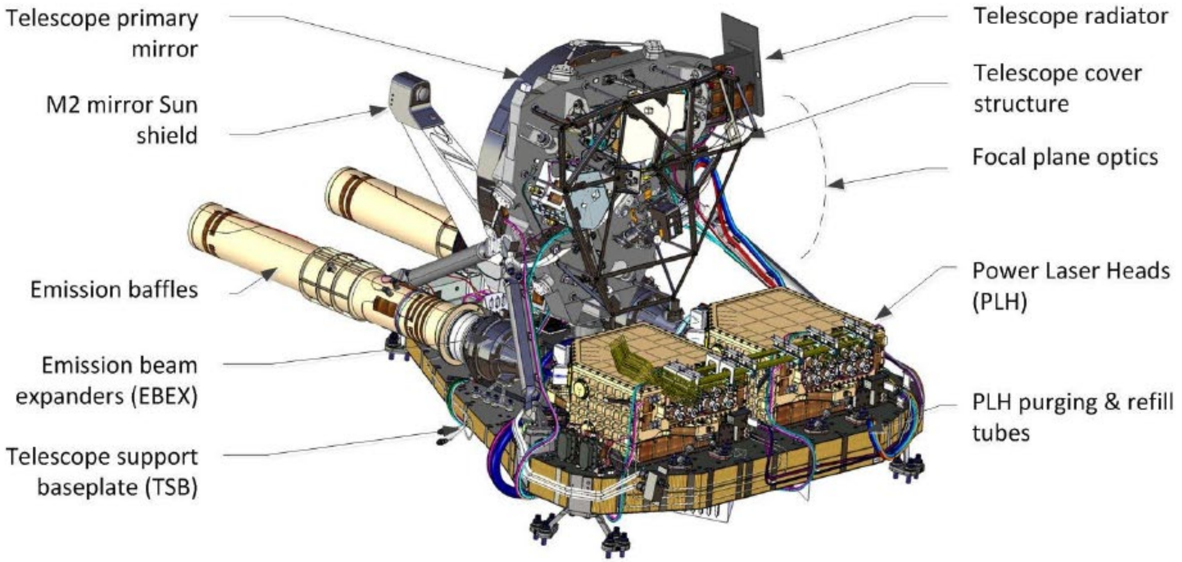
- **Receiver**
  - 620mm diameter telescope with co- alignment sensor, spectral and spatial filtering before final High Spectral Resolution Etalon and polariser stage.



# ATLID design

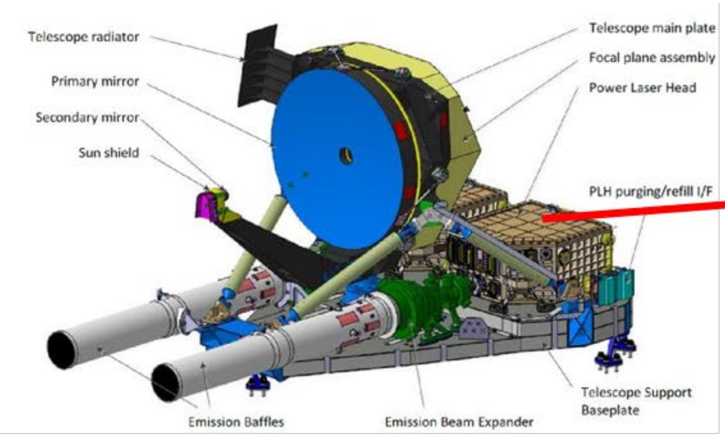
- **Bistatic architecture:** separate transmitter and receiver, with active co-alignment loop.
  - **Advantage of bi-static architecture:**
  - ATLID RxA FoV oversized compared to TxA and, with the beam steering capability, no expected issue with alignment to capture the returned beam.
  - LIC issues easier to deal with, the TxA being pressurised up to the EBEX exit.
  - EBEX thermal focussing capability

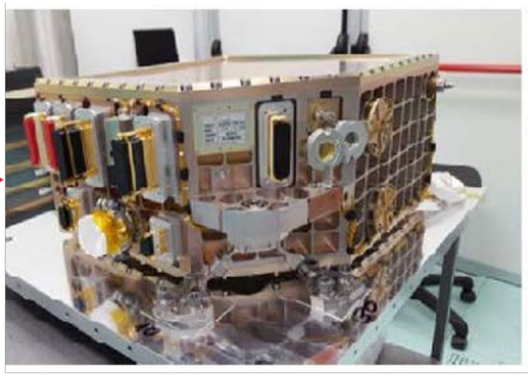


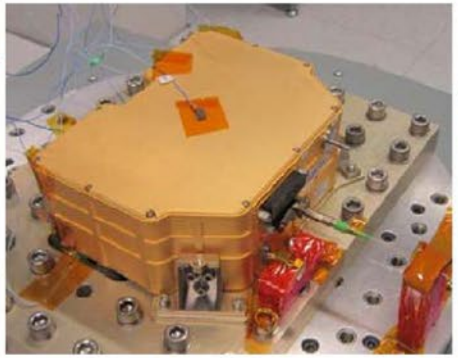
# ATLID – TXA

- **Transmitter:** composed by TxA, EBEX and baffle.

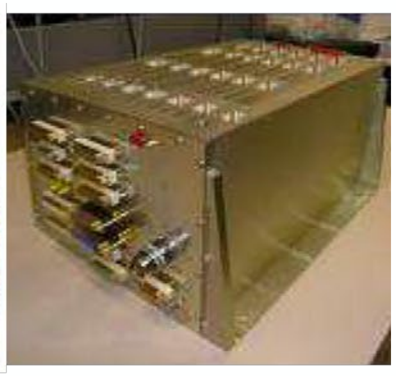


PLH

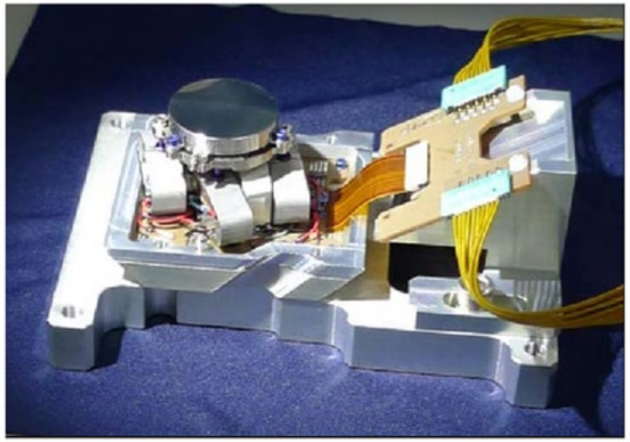


RLH



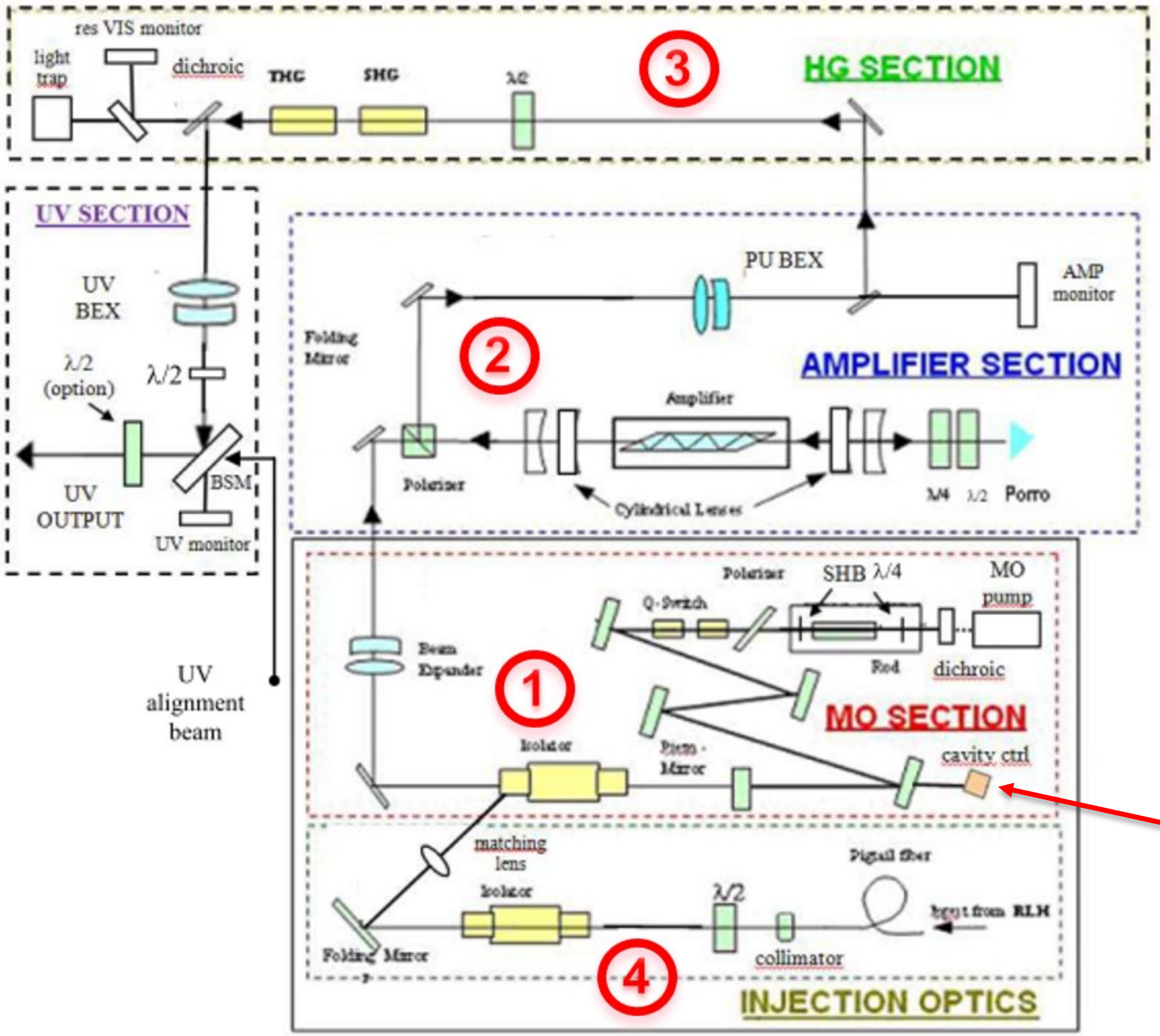
TLE

- **TxA (Transmitter Assembly) :**
- Power Laser Head (PLH, including a Beam Steering Mechanism, BSM)
- Reference Laser Head (RLH)
- Transmitter Laser Electronics (TLE)



BSM

# ATLID – TxA architecture




## MOPA DPSS Laser:

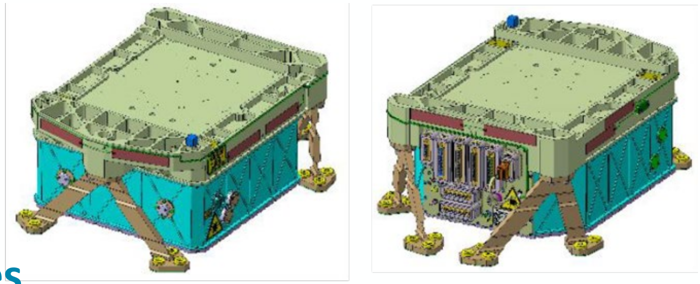
- The Transmitter is a diode-pumped, Q-switched, Nd:YAG Laser frequency tripled

- **Sections:**
  - Master Oscillator 1
  - Amplification 2
  - Wavelength conversion 3

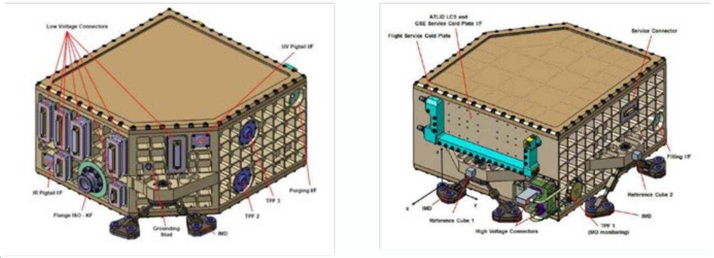
- **Features:**
  - Seeder injection locking 4
  - Oscillator cavity control loop

# ATLID – PLH evolution of AEOLUS Aladin PLH

- **ATLID laser improvements with respect to ALADIN laser**
  - ATLID transmitter is very similar to Aladin one. It is composed of the same optical sections but with only 1 Amplifier due to lower energy requested by the mission (40mJ by design wrt 80mJ of UV emitted energy)
  - basing on Aladin TxA heritage, efforts have been put in ATLID PLH design in order to improve:
    - **robustness against Laser Induced Contamination (LIC) and Laser Induced Damages (LID)**: ATLID TxA design includes **dry air pressurization** whose reliability has been verified through the execution of leak tests
    - **improvement of thermo-mechanical stability:**
      - **The ATLID H model Optical Bench is designed to *minimize pressurization impact*** on the amplifier and optical components stability.
      - **ATLID PLH design focuses on *thermal and mechanical interface separation to minimize distortions***: the ATLID single Pump Unit (PU) is mounted on the Optical Bench wall to guarantee a single thermal interface for the PLH separated from the MO invar plate.
      - ***The decoupling the MO (Master Oscillator) alignment from thermal perturbations, reducing the dependence on external thermal disturbances***



Aladin PLH

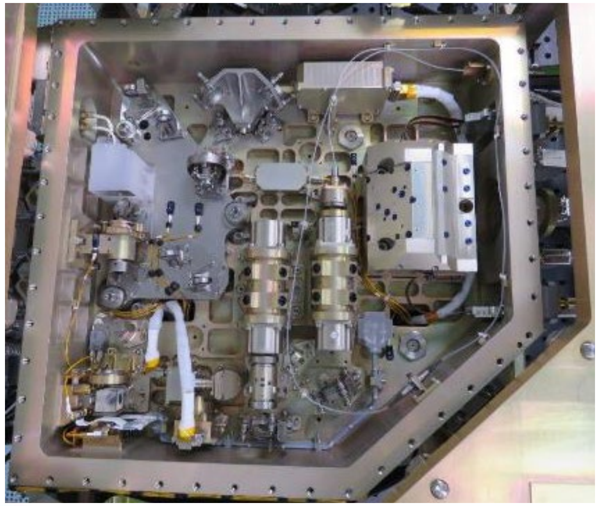


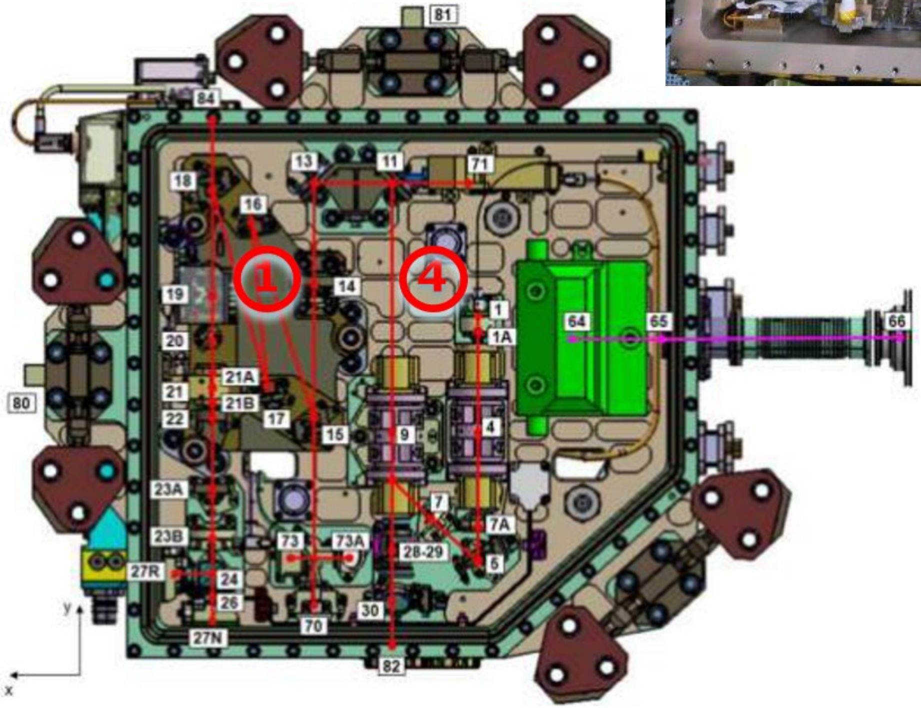
ATLID PLH

# ATLID – TxA optical layout

## Lower optical bench:

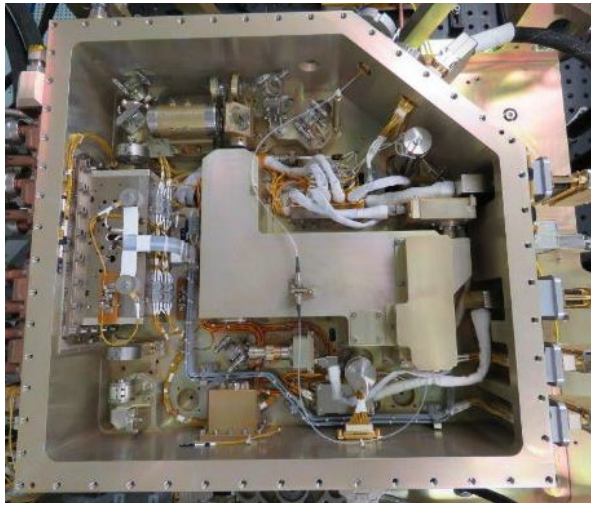
1. **Master Oscillator** with Oscillator cavity control loop
4. Seeder injection locking
- **BSM** (green box)

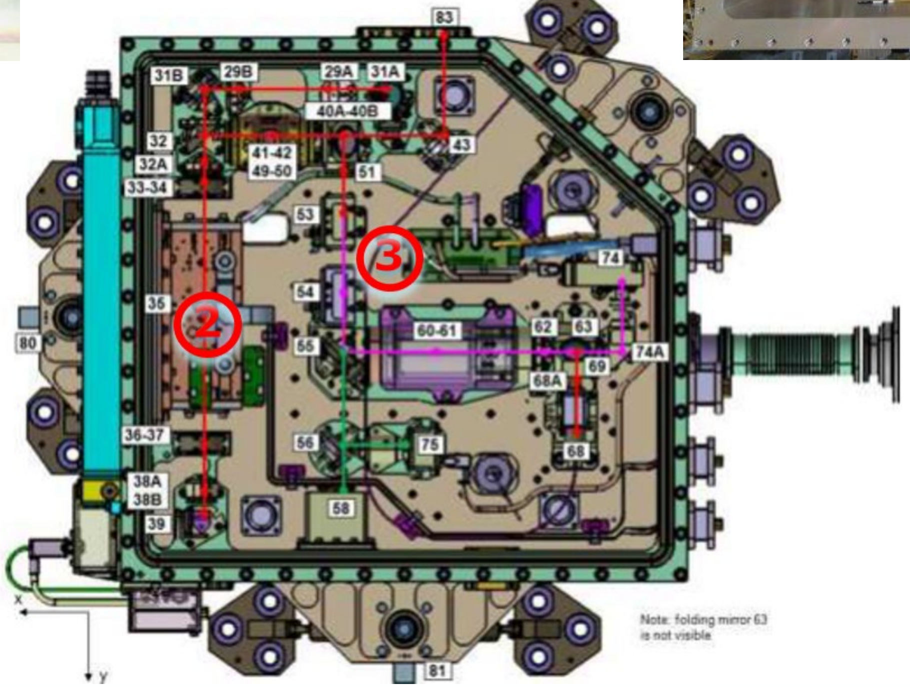




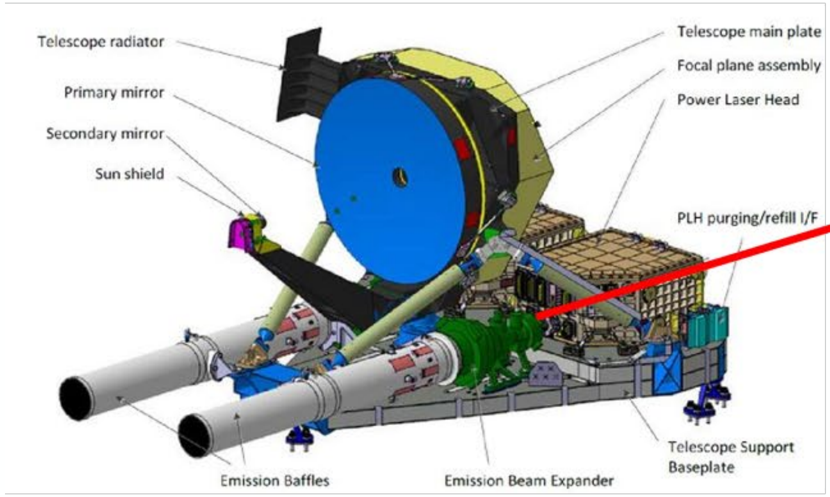

## Upper optical bench:

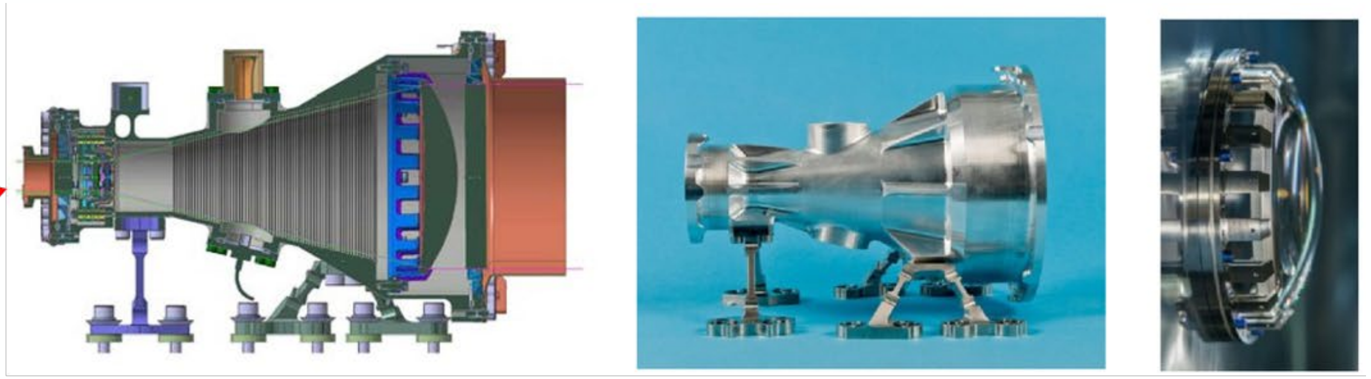
2. **Amplification Section**
3. **UV section** (protected by a carter)



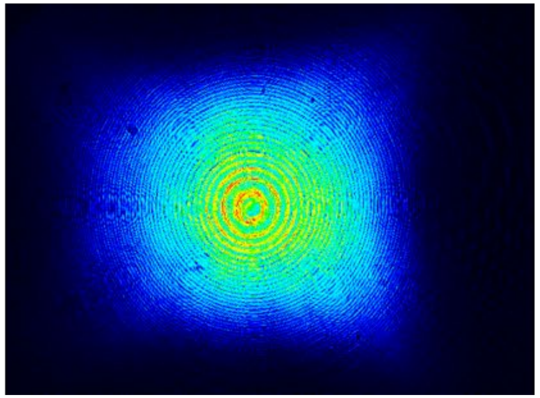


# ATLID – EBEX



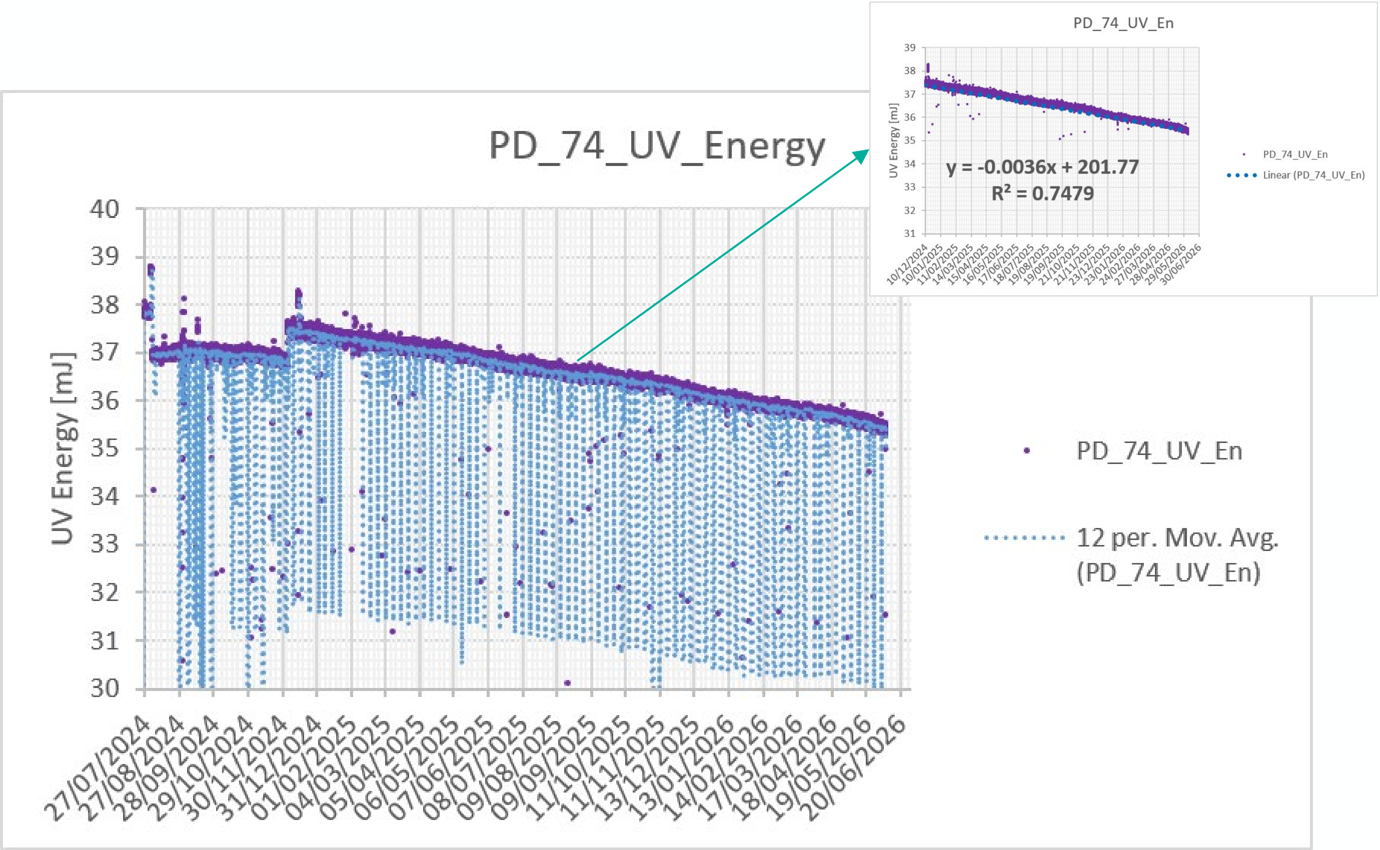
- **E-BEX (external beam expander):**
  - Optical magnification: 6.7x
  - Output beam size: 60 mm x 60 mm @ $1/e^2$
  - Pressurized
  - Low WFE



# EarthCARE – ATLID UV energy after 3 billion shots and almost 2 years of continuously and successfully in-flight operations

- **After almost 2 years of operation the ATLID laser confirms the enhanced performance stability demonstrated during on-ground tests**

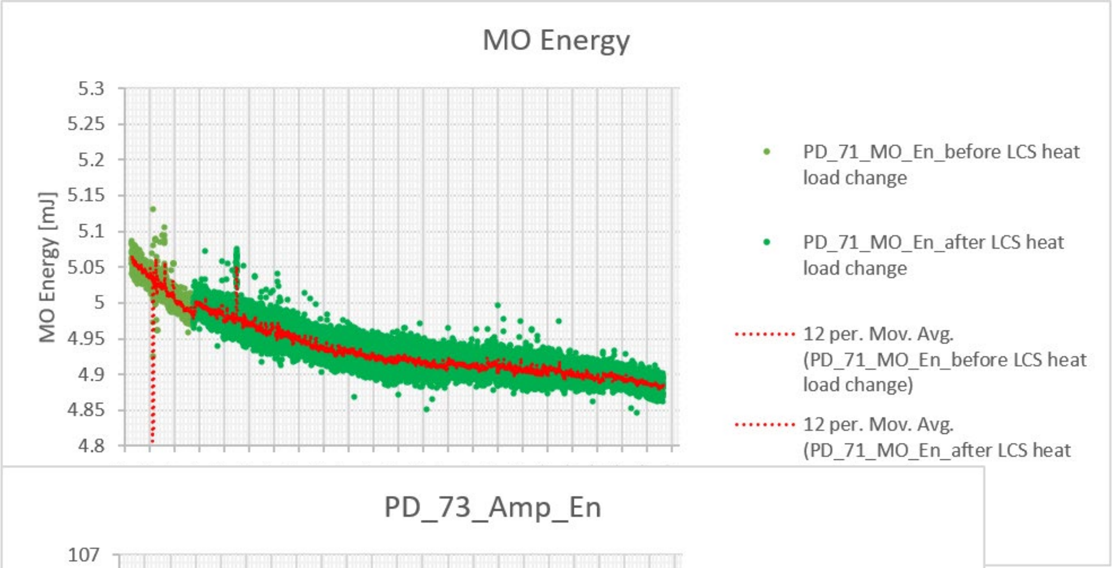
- EarthCARE was launched on May 24th, 2024. The ATLID laser was switched on for the first time in flight on July 25th, 2024, only 1 month after the launch date.
- After some setting optimizations, like Harmonic Chrystal temperature, the **final UV emitted energy of 37.8mJ** was reached, well in line with the requirements for the instrument.
- Until now **no TxA parameter** (Diods currents in therms of amplitude, duration and phases) **has been used** to increase the UV energy.
- There are several TxA parameters that could be adjusted to **increase the UV energy again and to extend the lifetime of the instrument** well beyond the nominal mission duration.

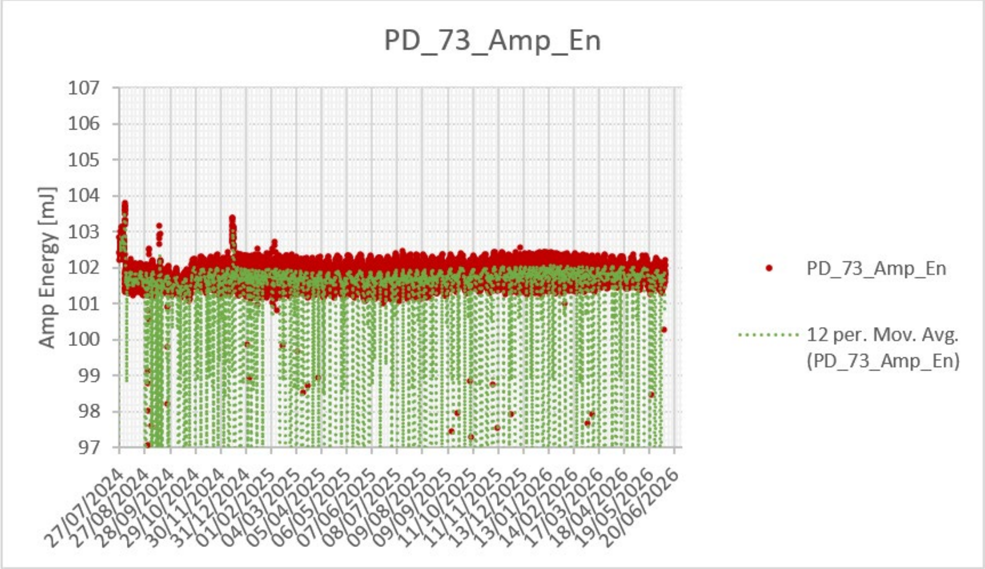


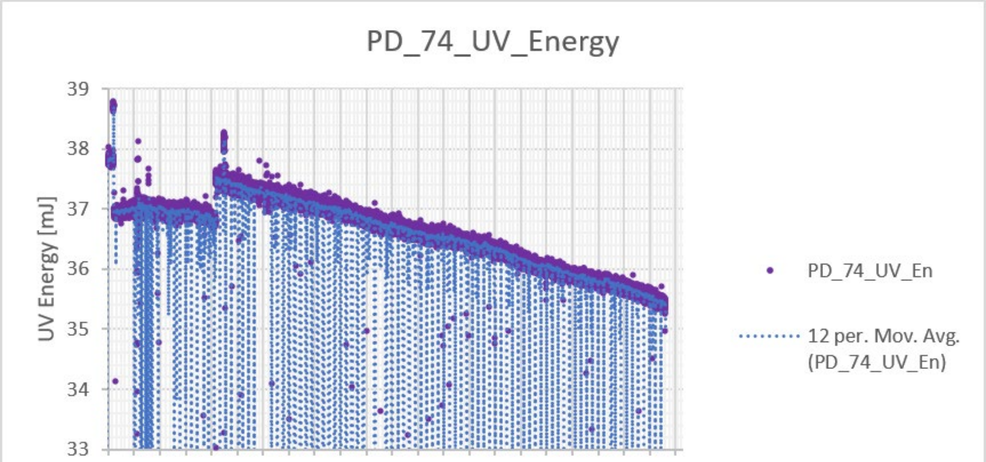

- A continuous linear decay of **- 4µJ/day of the UV energy (loss of almost - 4% per year)** has remained constant since December 2024.
- In line with best EOL prevision, lower than Aladin one of 7% per year

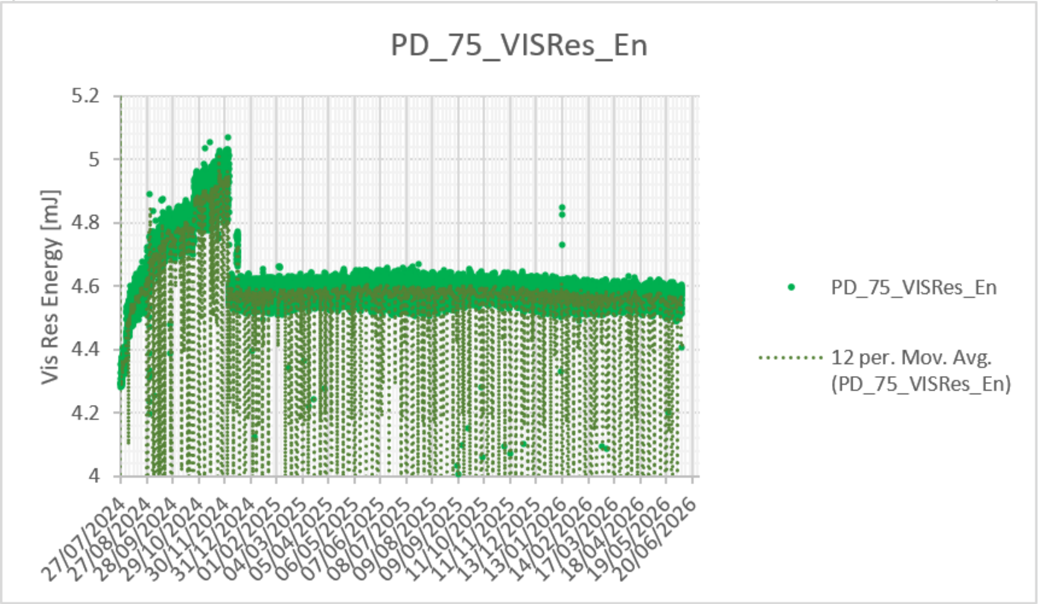
# EarthCARE – ATLID UV energies after 3 billion shots successfully in-flight operations

- **After 3 billion shots (reached today) ATLID laser confirms the enhanced performance stability proved during on-ground tests**



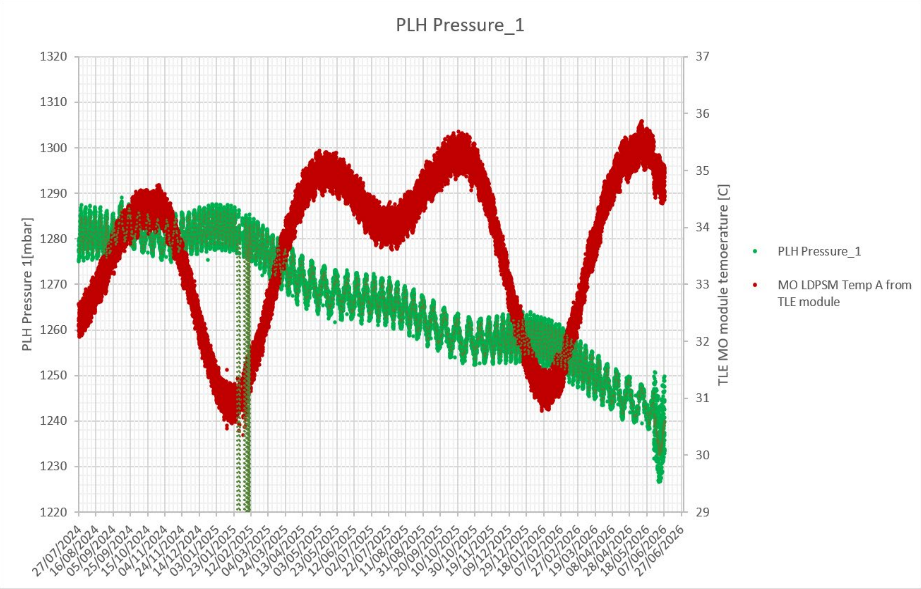




- MO energy show a different evolution compared to UV
- Amplifier energy is stable
- Visible residual energy is flat after crystal temperature tuning

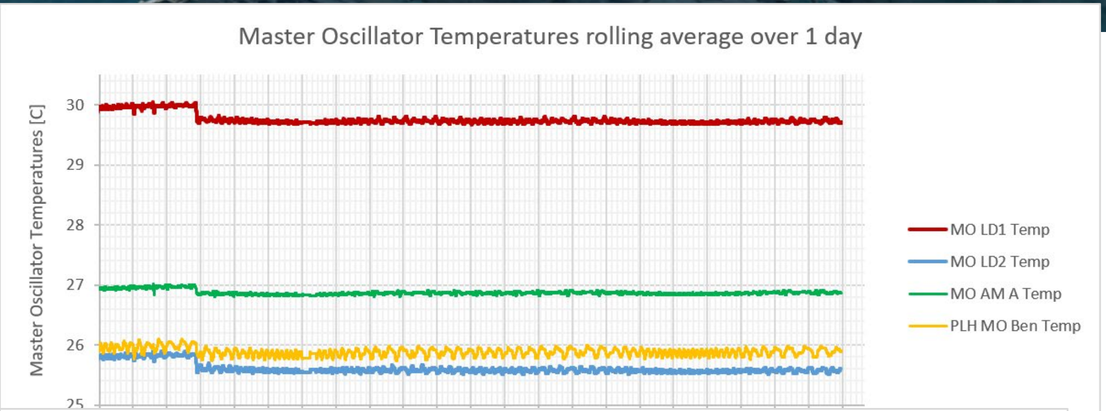
# ATLID laser other main HKs: PLH pressure

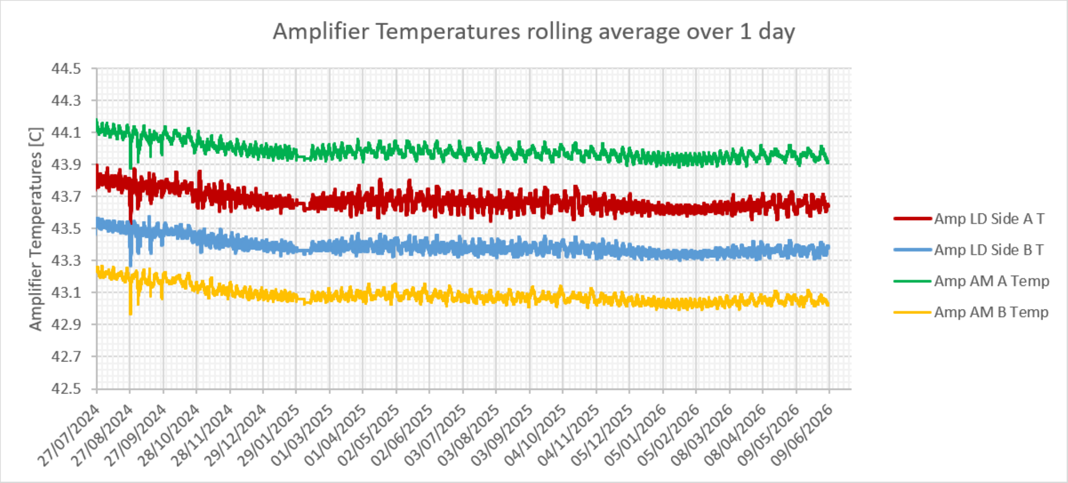
- **Pressure in the PLH is critical for the laser lifetime (due to LIC):now it was demonstrated that the improvement in the mechanical stability of the PLH design has guarantee the lifetime of ATLID for the mission .**
  - Pressure is measured in both PLH, even in non-used one raw measurements are corrected with the TLE temperature before the analysis of the data by Airbus Touluse every 6 months. TLE temperature is not controlled so there is an impact on the raw values.
  - **The Pressure decay trend is still in line with the expectation.**
  - **At this time, PLH Pressure seems not to be a limitation for the extension of the mission .**
  - The pressure decrease rate has seasonal dependence for example due to eclipse season: over 2 years similar decay trends have been detected in the same year period.
  - The average pressure decrease rate over last 6 months:
    - -0.116 mbar/day for the end of this period vs
      - 0.056 mbar/day over previous period (PLH B, active)
    - -0,089 mbar/day for this period vs
      -0.069 mbar/day over previous period (PLH A, redundant)
  - The absolute pressure in April 2026:
    - about 117 mbar (PLH B, active)
    - about 1060 mbar (PLH A, redundant, important uncertainty)

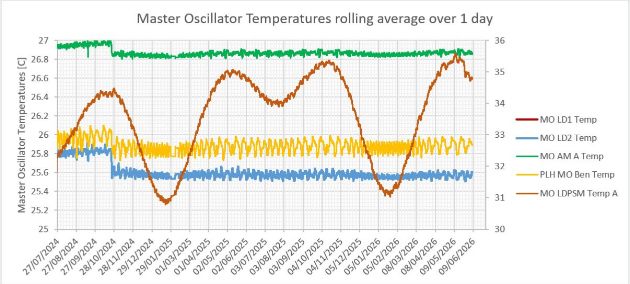


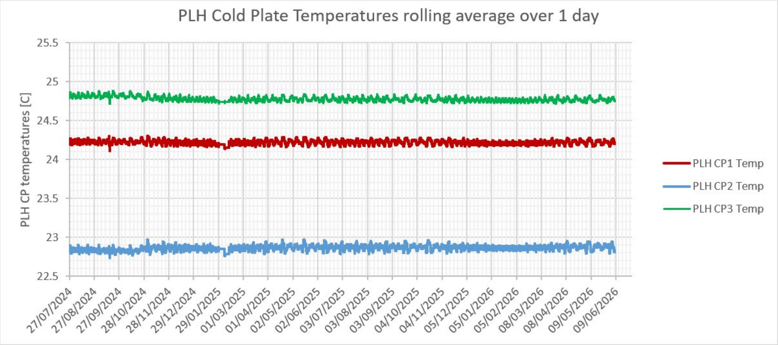
# ATLID PLH other main HKs: Internal Temperatures

- **ATLID PLH Internal Temperatures are stabilized by the Laser Cooling System (LCS) of ATLID: an in-flight Cold Plate, based on mini loops heat pipes technique, applied on the lateral wall of the PLH optical bench to control the temperature of the MO Pump Diode and of the Amplifier**
  - After an initial period of thermal assessment with a decay trend, already seen in Aeolus mission and in ATLID laser Lifetime Test on-ground, all internal temperatures (MO Diodes, MO Active Material and MO bench, Cold Plate and Amplifier Diodes and Active Materials) have demonstrated a high stability
  - Situation was improved after the change of the heat load of the LCD in October 2024 in order to improve the efficiency of the mini loop heat pipes. This is well visible on the MO temperatures. From this optimization the MO temperature have been better controlled and also the MO energy decrease trend change asymptotically.
  - Noise on the temperatures change on seasonal basis well correlated with TLE external temp.

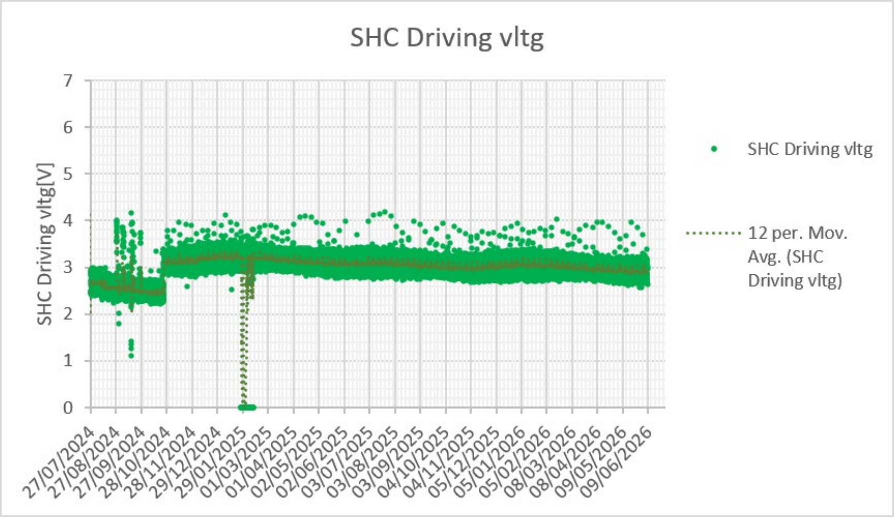


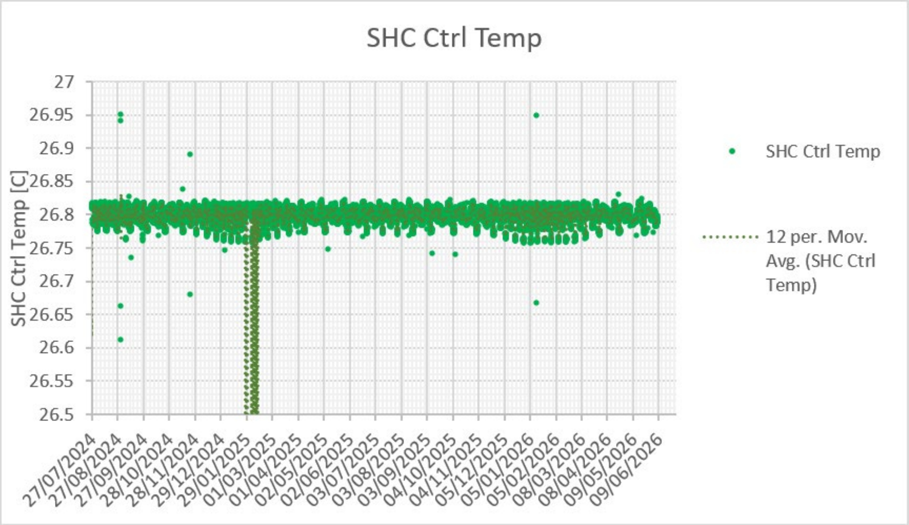



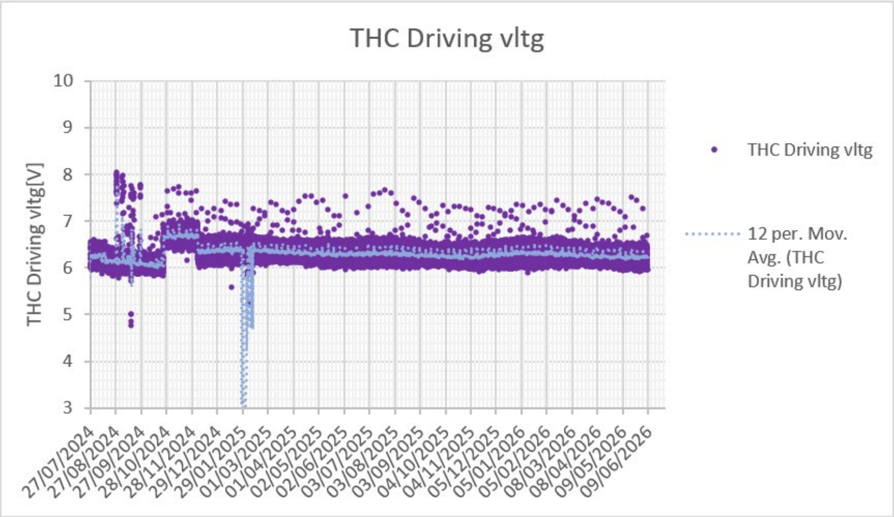



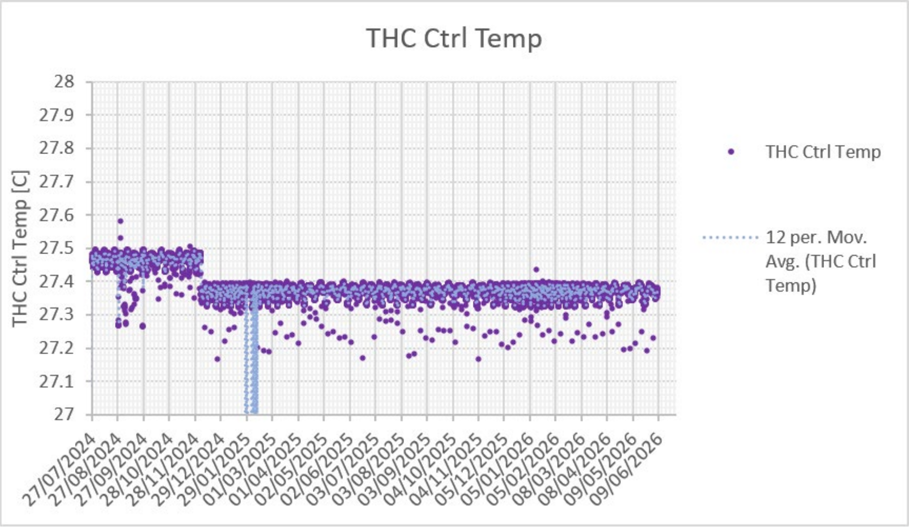



# ATLID Harmonic Section temperature and Driving Voltages



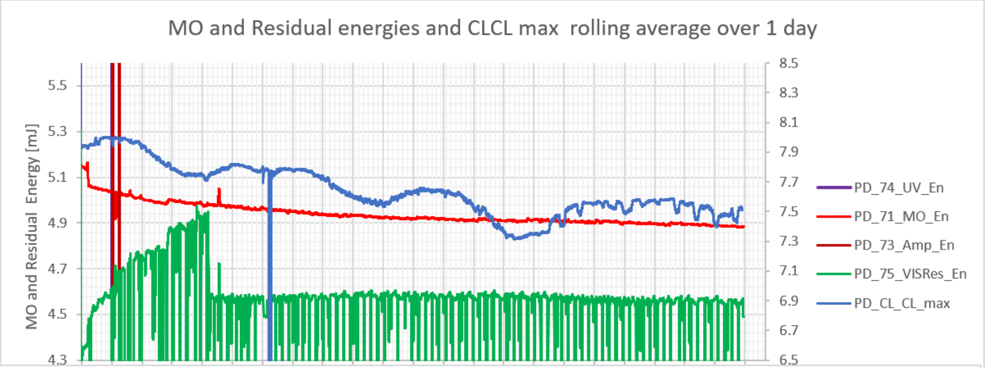



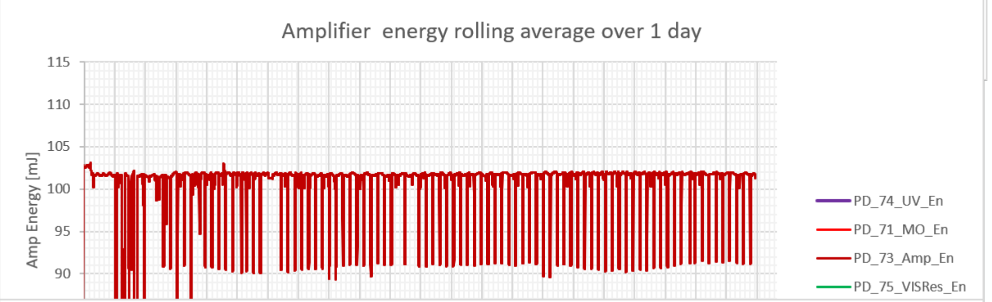



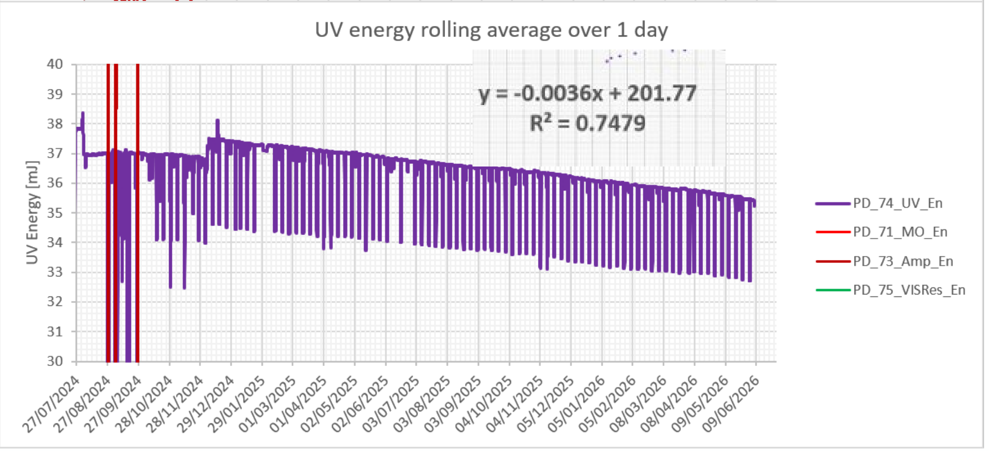
# ATLID UV energy trend

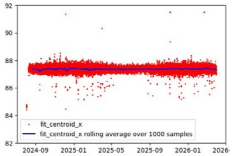
- A continuous linear decay of **- 4µJ/day of the UV energy (loss of almost - 4% per year)** has remained constant since December 2024.
- In line with best EOL prevision, lower than Aladin one of 7% per year
- The energy loss trend is in line with the best expectation based on the on-ground test before launch (BIT, LTT and so on) and based on the test on ATLID Laser Diode lifetime performed in ESTEC.

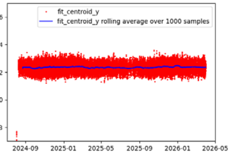
- **Possible UV energy loss causes:**
  - Diode Ageing (confirmed by LFT on Diodes) but no big evidence on Amp photodiode, MO photodiode,
  - NO evidence of LIC at least to HS crystals: HS Driving voltages are very stable and very stable Residual energy signal
  - very small LIDT or LIC or other phenomena on the UV optics after UV dichroic and before the UV photodiode (from Energy trend)→ to be analysed more
  - Beam movement or tilt: from Coalignment System meas, from the trend of MO energy and from HS sensitivity no evidence of any tilt in any direction
  - before the heat load optimization of the LCS tilt in the horizontal direction was present for sure: confirmed by HS temp adjustment, change of CLCL max and Multimode Ratio, MO and energy residual energy and CAS tilt meas



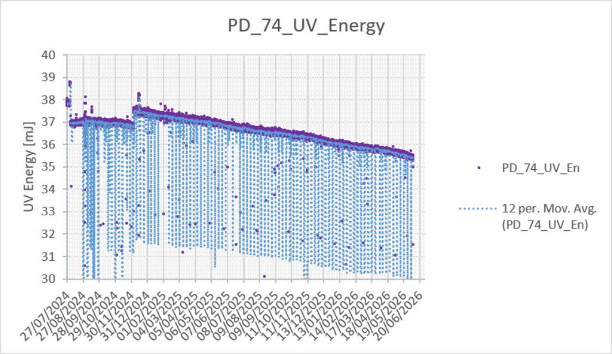



# ATLID UV UV energy recovery

- Nominally the energy recovery should follow the rules of the ATLID TxA Command Flow
- It suggest some steps based on the changes along time visible in the TxA HKs like energies, temperatures etc.
- The first step is optimization of the HS conversion efficiency, but a test was already performed in January 2026 without any big sign of need of optimization. An HS sensitivity test could be repeated but for sure a complete Sensitivity Test could give the idea of the status and health of the laser and of the amount of change that is necessary on the parameter selected.
- It is worth to mention that, even if the Command Flow gives the most reasonable indications on how to increase the energy, could be very important to take into account also the possible causes of the losses of UV energy. In fact, it could be very useful to select, despite the command flow indications, the parameters that do not increase the cause of the energy losses like:
    - Increase Diode Ageing (confirmed by LFT on Diodes)
    - Avoid LIDT or LIC on UV optcts
    - Induce Beam movement or tilt
- The AMP phases (delay between MO diode pulse and AMP diodes pulses) is the easier way to increase the energy without impact on power balance and diodes ageing and with low increase of fluence for UV optics



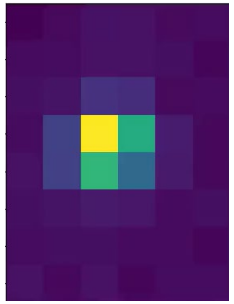

| tep | Section | Description | Tele-Command | Tele-Measurement | Criterion on TM |
|---|---|---|---|---|---|
| | HC conversion efficiency | Find the optimum SHC and THC temperature set point using the parabola-like energy evolution vs $T_{HC}$. | SHC_Temp (IHC01027)<br>THC_Temp (IHC01030) | PD_En_UV (IHT01003)<br>(also check minimization of PD_Residual value) | Maximum value |
| | Check of HC voltage margin | If the margin on the SHC or THC voltage is too low, then the variation of Cold Plate set point could be considered to increase the margin. In case the CP temperature is modified:<br>- The TxA shall be set to WU mode.<br>- The TRP shall be modified.<br>- The 2 next points shall be executed before coming back to Emission mode. | T_CP setpoint (TRP) - | SHC Driving vltg (IHT01037)<br>THC Driving vltg (IHT01038) | > 0.5V and < 13.5V for stationary TRP<br><br>> 1V and < 13V including +/-1°C variation of TRP |
| 3 | MO thermal configuration | To compensate the MO diode temperature, MO heating current is used. | MO_Heat_I_Setting (IHC01024) | MO LD1 Temperature IHT01051 (or MO LD2 Temperature - IHT01052 in case of use of redundancy) | Restore reference value |
| 4 | Amplifier thermal configuration, A bench | To compensate the Amplifier temperature – bench A, amplifier heating current is used. | Amp_LDPSM_1_Heat_I_EMIS_Setting (IHC01036) | Amp LD Side A Temperature (IHT01059) | Restore reference value |
| 5 | Amplifier thermal configuration, B bench | To compensate the Amplifier temperature, amplifier heating current is used. | Amp_LDPSM_2_Heat_I_EMIS_Setting (IHC01065) | Amp LD Side B Temperature (IHT01060) | Restore reference value |
| 6 | MO energy | In case a variation is observed, restore MO energy | T_WDT_Q/S_ON (IHC01020)<br><br>(T_PH_Amp_LDPSM_1 - IHC01015 and T_PH_Amp_LDPSM_2 - IHC01019 shall be moved rigidly with it, in order to avoid any variation of the amplification factor) | PD_En_MO (IHT01006) | Restore reference value |
| 7 | IR energy | In case a variation is observed, restore Amplifier energy. AMP1 and AMP2 TCs shall be modified together, always assuming the same value. | T_PH_Amp_LDPSM_1 (IHC01015)<br>T_PH_Amp_LDPSM_2 (IHC01019) | PD_En_Amp (IHT01008) | Restore reference value |

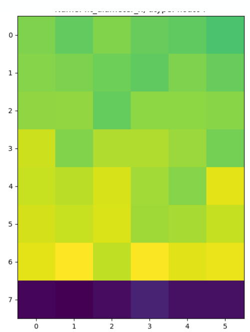
*Table 10-1 – Procedure step list for performance recovery*

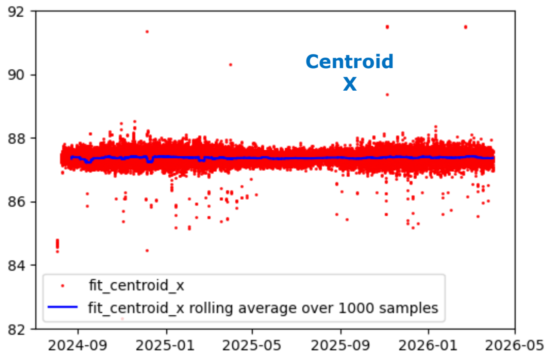
# Beam pointing and divergence evolution

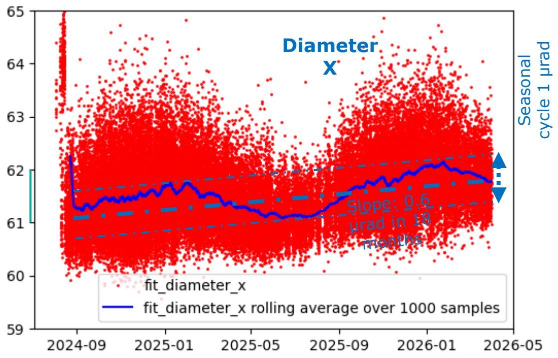
Courtesy of Aeolus 2 team Paolo Bravetti e Trismono Kandra Krisna

- Laser beam properties can be derived from CAS image analysis

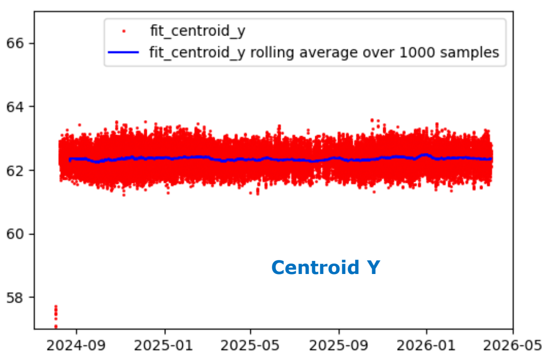


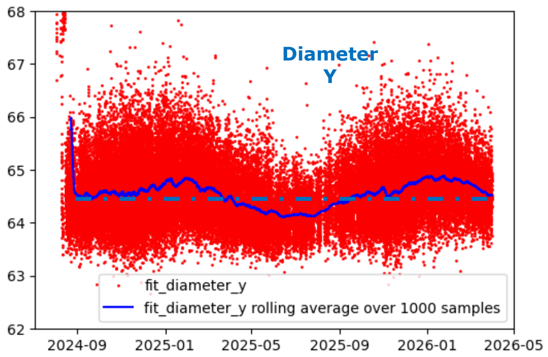




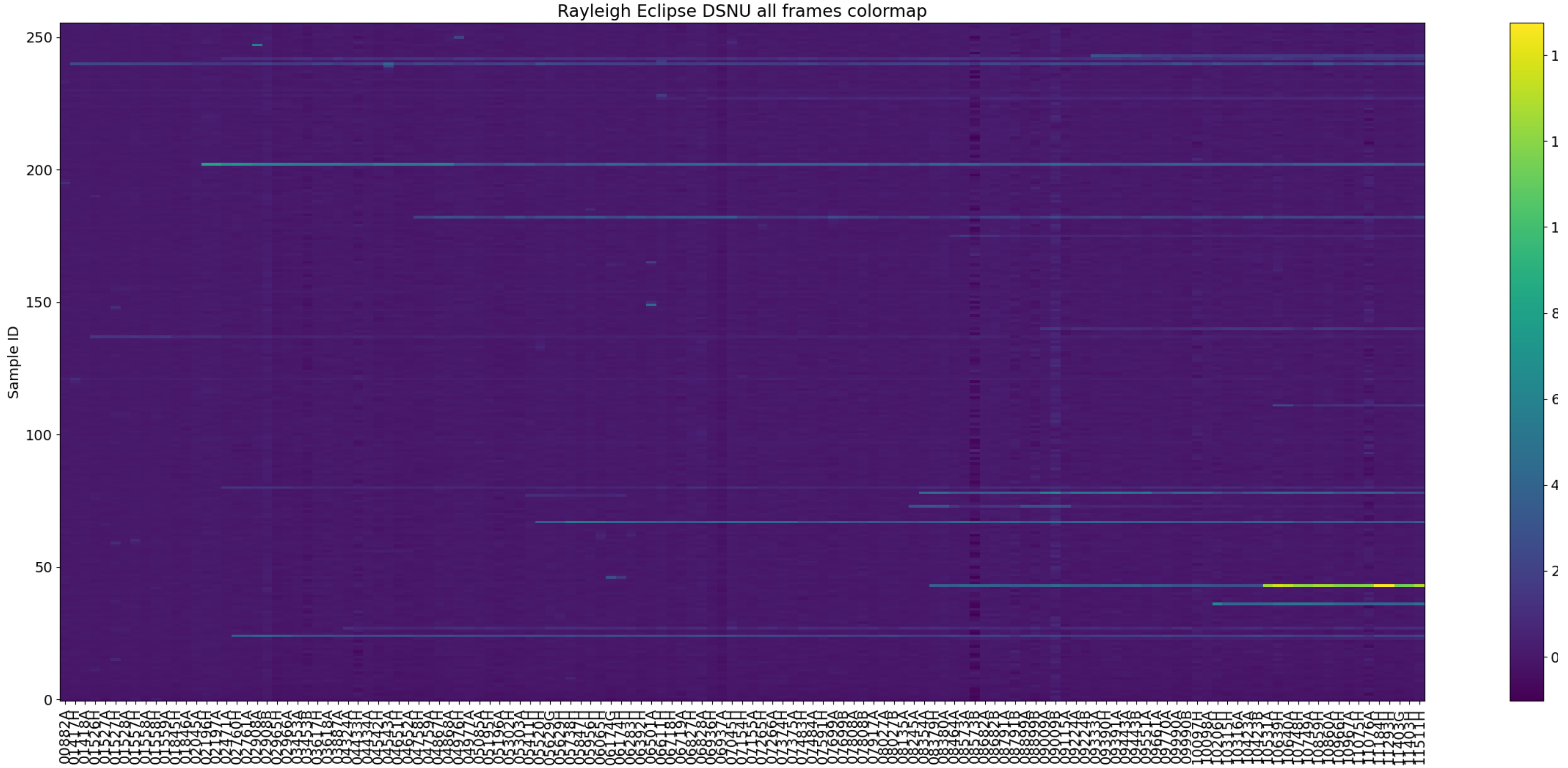

- The images are strongly impacted by solar background
- Filtering only images without strong solar background impact, the evolution of beam pointing and divergence can be derived over the whole >17 months period
- No significant variation of the beam centroid is observed
- Slight divergence increase of the horizontal divergence with time and small seasonal (orbital?) oscillation
- A characterization of background in daylight conditions would help, just TUBA in different moment of the day:
  - To investigate the effective Solar Background (SBKG) integration time – overcorrection of SBKG
  - To investigate reduced Charge Storage Ratio (CSR) on Rayleigh cold pixel

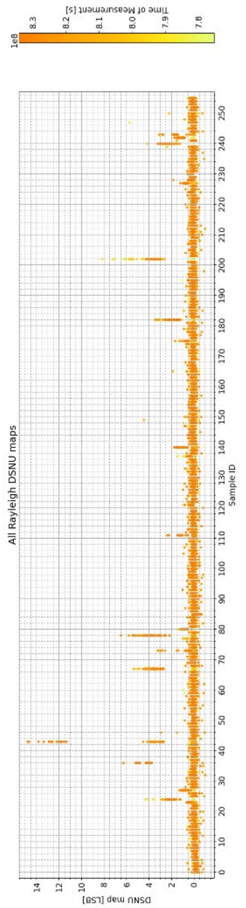


# ATLID Hot pixels - Dark Current Calibrations since the beginning of the mission

- Every week a Dark Current Calibration (DCC) is executed, as for requirement, and **Hot and Cold pixels has been identified since the instrument switch-on on all receiver channels (Rayleigh, Mie and Crosspolar)**
  - ATLID Rayleigh channel Hot pixels, DCC from the first switch-on to 7/06/2026




**Courtesy of Annabel Chantry (DISC KNMI)**

# ATLID Hot pixels - Dark Current Calibrations since the beginning of the mission

- The table provides the **ATLID LIDAR Hot and Cold pixels since the switch-on on all channels to last Sunday, almost 2 years.**

**Rayleigh**

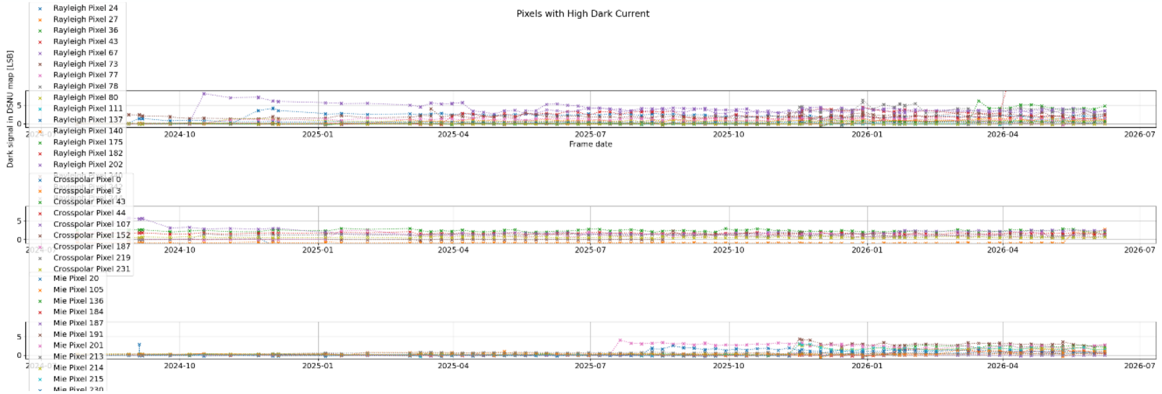
| Pixel Index* | Approx height [km] | First Frame |
|---|---|---|
| 240 | -0.17 | 01293F |
| 137 | 10.43 | 01450H |
| 202 | 3.74 | 02090C |
| 80 | 16.29 | 02262D |
| 242 | -0.38 | 02398H |
| 24 | 28.93 | 02742H |
| 27 | 27.44 | 03921C |
| 182 | 5.76 | 04666F |
| 77 | 16.62 | 05409H? |
| 67 | 17.65 | 05424G |
| 73 | | 08245A |
| 78 | | 08354A |
| 43 | | 08379H |
| 175 | | 08573A |
| 140 | | 09009B |
| 244 | | 09390H |
| 245 | | 09390H |
| 36 | | 10206H |

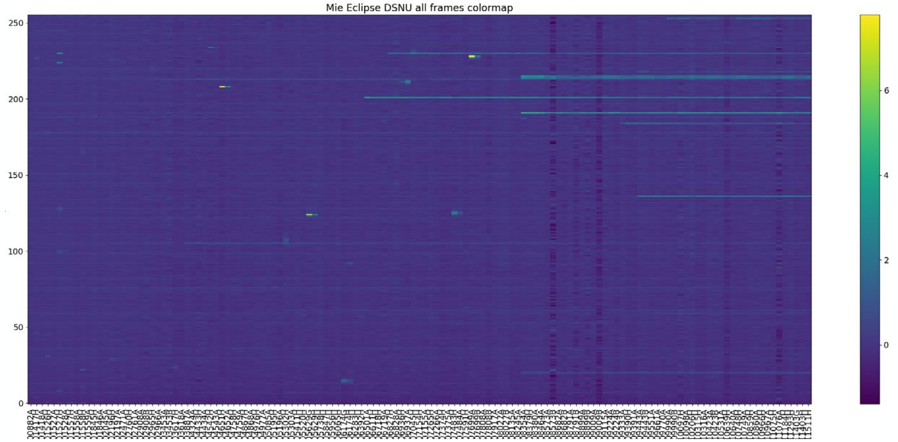
**Mie**

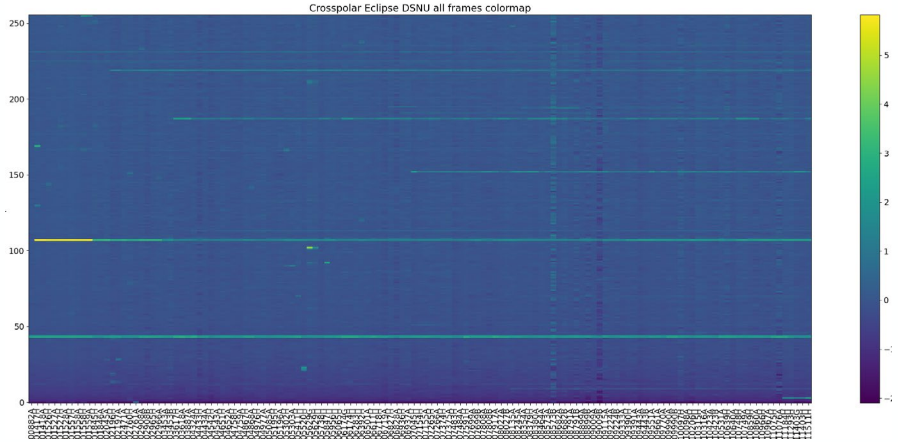
| Pixel Index* | Approx height [km] | First Frame |
|---|---|---|
| 105 | 13.72 | 03676H |
| 201 | 3.83 | 06445H |
| 230 | 0.85 | 06793H |
| 20 | | 08354A |
| 187 | | 08354A |
| 191 | | 08354A |
| 213 | | 08354A |
| 214 | | 08354A |
| 215 | | 08354A |
| 184 | | 09333A |
| 136 | | 09391A |
| 253 | | 09990B |

**Crosspolar**

| Pixel Index* | Approx height [km] | First Frame |
|---|---|---|
| 231 | | unknown** |
| 43 | 20.1 | unknown** |
| 44 | 20 | unknown** |
| 107 | 13.51 | 01355D |
| 219 | 1.99 | 02167C |
| 187 | 5.28 | 03508G |
| 152 | 8.88 | 07037H |
| 3 | | 11184H |




**Courtesy of Annabel Chantry (DISC KNMI)**