The Wind Lidar Mission ADM-Aeolus

Recent Science Activities and Status of Instrument Development

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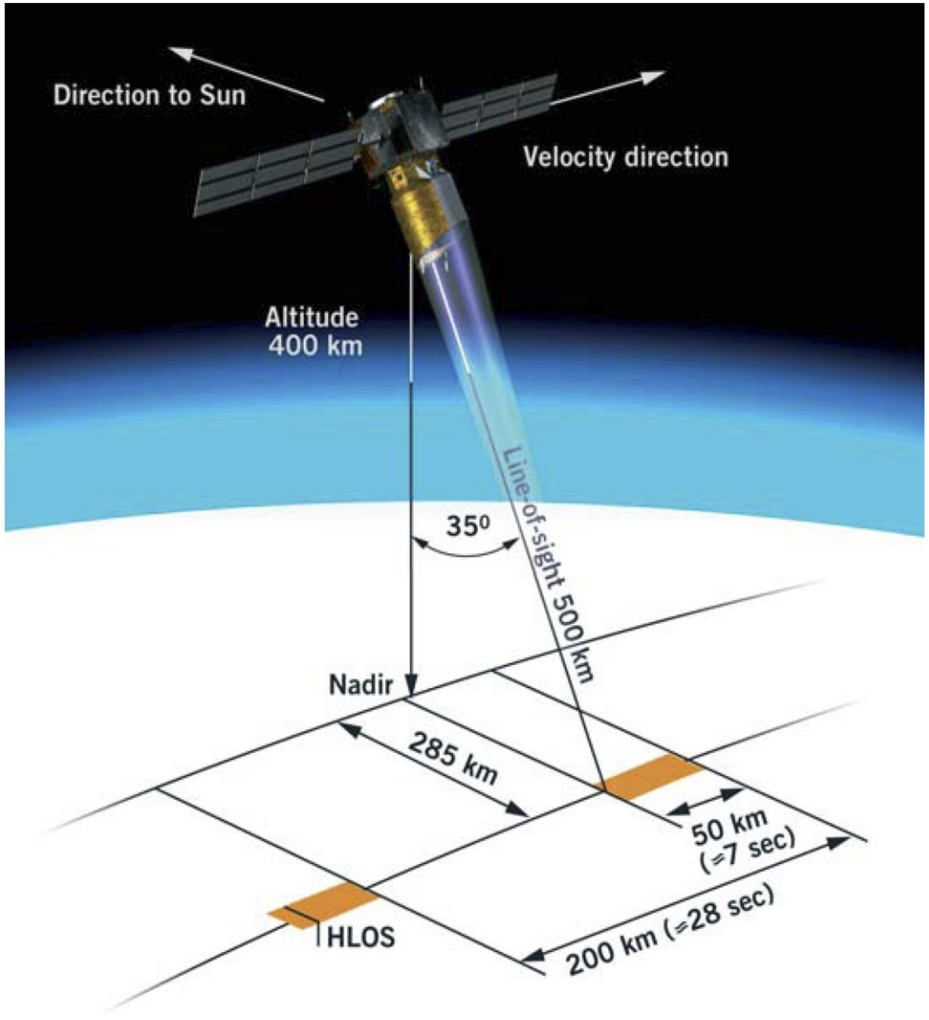
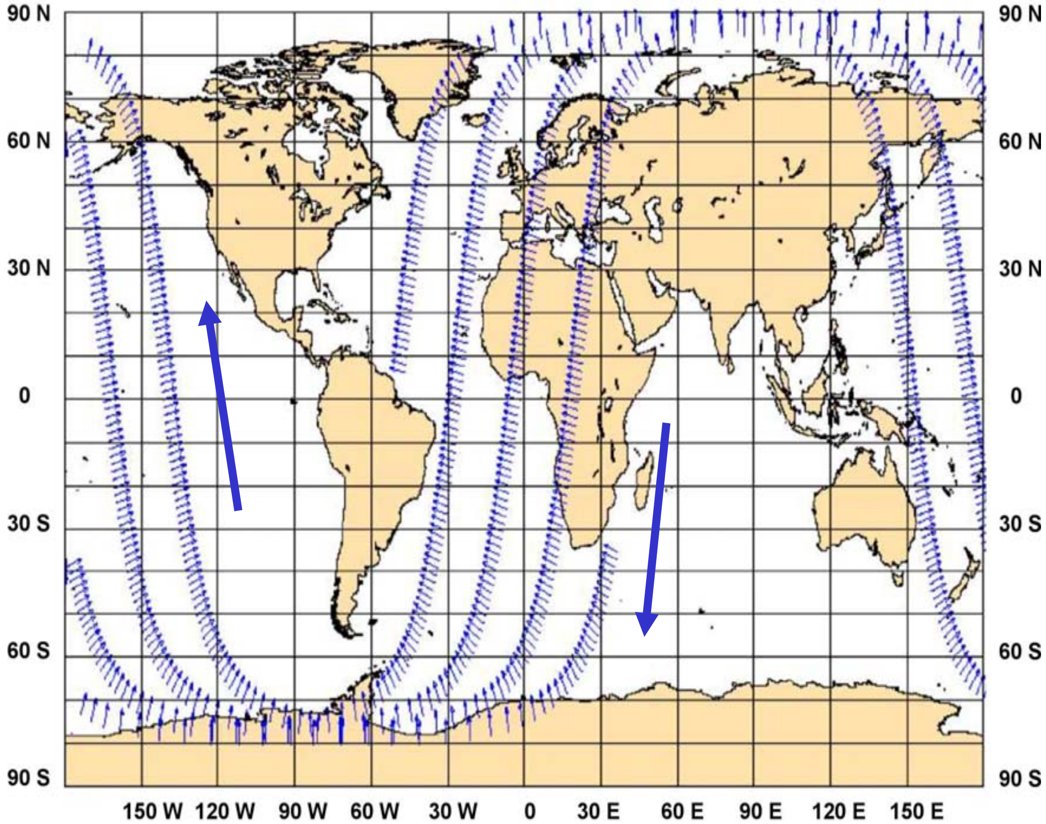
Atmospheric Dynamics Mission ADM-Aeolus



ADM-Aeolus with single payload
Atmospheric LAser Doppler INstrument
ALADIN

- Observations of Line-of-Sight LOS wind profiles in **troposphere to lower stratosphere up to 30 km** with **vertical resolution from 250 m - 2 km** horizontally averaged over **50 km every 200 km**
- Vertical sampling with **25 range gates** can be varied up to 8 times during one orbit
- High requirement on **random error** of HLOS
  <1 m/s (z=0-2 km, for Δz=0.5 km)
  <2 m/s (z=2-16 km, for Δz= 1 km),
  unknown bias <0.4 m/s and linearity error <0.7 % of actual wind speed; HLOS: projection on horizontal of LOS => LOS accuracy = 0.6*HLOS
- Operating @ **355 nm** with spectrometers for molecular Rayleigh and aerosol/cloud Mie backscatter
- First **wind lidar** and first High Spectral Resolution Lidar **HSRL** in space to obtain aerosol/cloud optical properties (backscatter and extinction coefficients)

ADM-Aeolus Coverage and Data Availability



50 km observations during 6 hour period

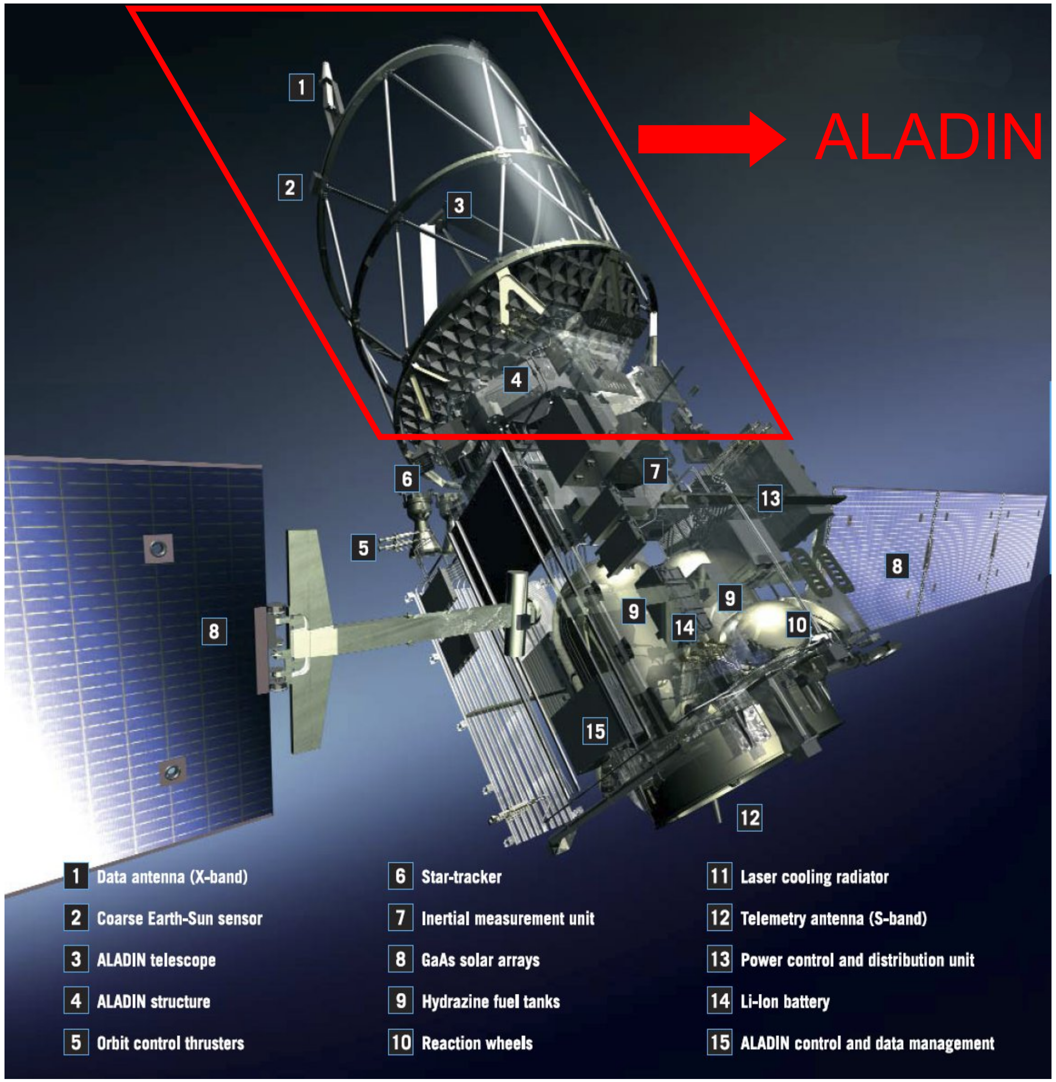
- **3200 wind profiles per day**: about factor 3 more than radiosondes
- **3 hour data availability** after observation (NRT-Service) => 1 data-downlink per orbit; 30 minutes data availability for parts of orbit (QRT-Service with late start of downlink)
- **launch date late 2009** (consolidated launch date prediction in some months expected)
- **mission lifetime 39 months**: observations from 2010-2012

Overview paper about ADM-Aeolus Stoffelen et al. 2005, Bull. Am. Met. Soc.

and soon **ADM-Aeolus Science Report** (ESA publication SP-1311)

and soon **TELLUS special edition** about ADM-Aeolus workshop 2006

Satellit und Instrument ALADIN



Mass and Power Budgets

mass: 1100 kg dry +116-266 kg fuel
power: 1.4 kW avg. (solar array 2.4 kW peak)
mass instrument: 470 kg
power instrument: avg. 840 W (laser 510 W)
Volume: 4.3 m x 2.0 m x 1.9 m

Doppler Lidar Instrument ALADIN

Nd:YAG laser in burst mode operation
(120 mJ @ 355 nm, 100 Hz)
1.5 m Cassegrain telescope
Dual-Channel-Receiver with ACCD detector
(Accumulation Charge Coupled Device)

Orbit

polar, sun-synchronous, dawn-dusk (6 pm LTAN),
97° inclination; height 410 km (395-425 km),
7 days orbit repeat cycle (109 orbits);
92.5 min orbit duration

Pointing and Orbit Control

GPS, Star-Tracker, Inertial Measurement Unit,
Yaw steering to compensate for earth rotation

Launcher

Rockot (Russia), Dnepr (Russia) or Vega (ESA):
tbd in 2008

Comparison of Power-Aperture Products of Space Lidars

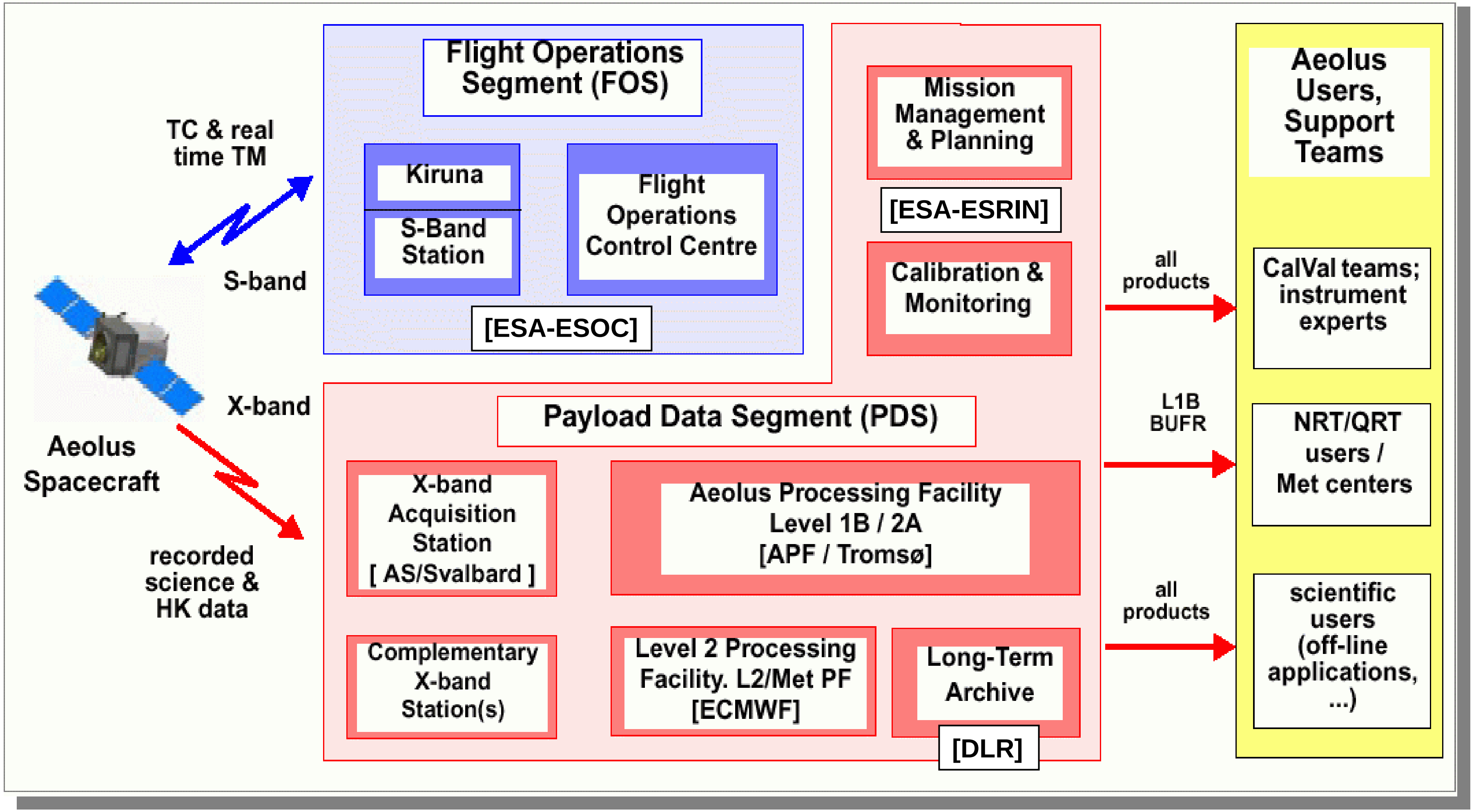
Lidar	Lidar altitude	Pulse energy	Pulse rep. rate	Mirror diameter	Power-aperture product PAP, range-cor.
LITE (532 nm)	250 km	560 mJ	10 Hz	1.0 m	$7.0\ 10^{-11}$ W
GLAS (532 nm)	600 km	35 mJ	40 Hz	0.9 m	$0.25\ 10^{-11}$ W
CALIOP (532 nm)	700 km	110 mJ	20 Hz	1.0 m	$0.35\ 10^{-11}$ W
ALADIN (355 nm)	410 km	150 mJ	100 Hz	1.5 m	$15.8\ 10^{-11}$ W
ATLID (355 nm)	450 km	20 mJ	100 Hz	0.6 m	$0.28\ 10^{-11}$ W

Factor 45

Factor 56

adapted from A. Ansmann 2006

ADM-Aeolus Ground Segment



Ground Segment - Svalbard Satellite Reception Station

Data-downlink with 5 Mbit/s with X-Band to 2.4 m antenna to Svalbard, Norway (78°15'N)

ADM-Aeolus Data Products

Product	Contents	Processor developer and location	Size in MByte/orbit
Level 0	Time ordered source packets with ALADIN measurement & housekeeping data	MDA (Canada) Tromsø (Norway)	47
Level 1b	*Geo-located, calibrated observational data* ▪ preliminary HLOS velocity profiles (standard atmosphere used in Rayleigh processing) ▪ viewing geometry & scene geo-location data	MDA (Canada) Tromsø (Norway)	10-15 (BUFR) + 22 (EE XML Format)
Level 2a	*Supplementary product* ▪ Cloud profiles, coverage, cloud top heights ▪ Aerosol extinction and backscatter profiles, ground reflectance, optical depth	DLR-IMF Tromsø (Norway)	12
Level 2b	*Consolidated HLOS wind observations* Consolidated HLOS wind profiles; temperature T and pressure p (Rayleigh-Brillouin) correction applied with ECMWF model T and p	ECMWF Reading	18
Level 2c	*Aeolus assisted wind vector product* Vertical wind profiles (u and v component); NWP model output after assimilation of Aeolus wind	ECMWF Reading	22

Ongoing ADM-Aeolus Scientific Studies

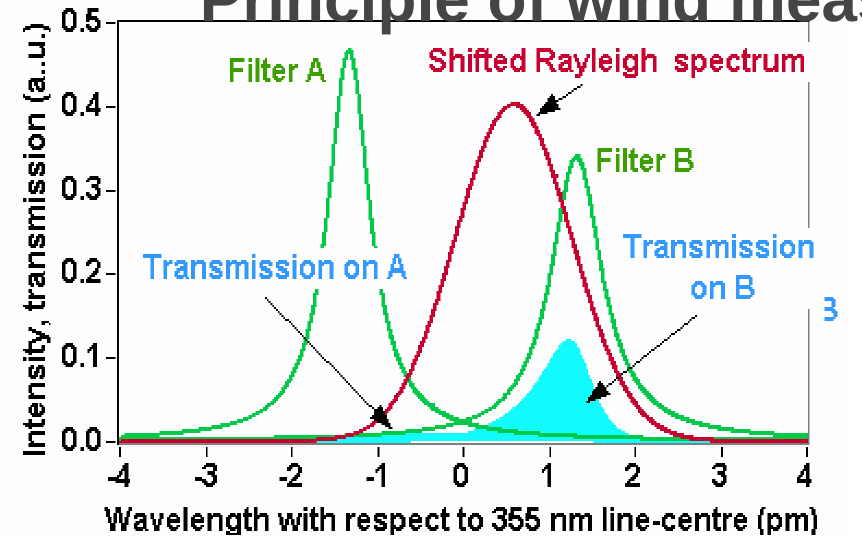
Title	Team
Consolidation of ADM-Aeolus Ground Processing including L2A Products	**DLR** Germany Météo-France, KNMI, IPSL, PSol
Development and Production of Aeolus Wind Data Products	**ECMWF** UK Météo-France, KNMI, IPSL, DLR
ADM-Aeolus Campaigns	**DLR** Germany Météo-France, KNMI, IPSL, DWD, MIM
Optimisation of spatial and temporal sampling	**KNMI** Netherlands
Tropical dynamics and equatorial waves	**MISU** Sweden
Rayleigh-Brillouin Scattering Experiment	**tbd**

ESA plans an Announcement of Opportunity AO for ADM-Aeolus scientific use of data for late 2008 in addition to the AO for Cal/Val

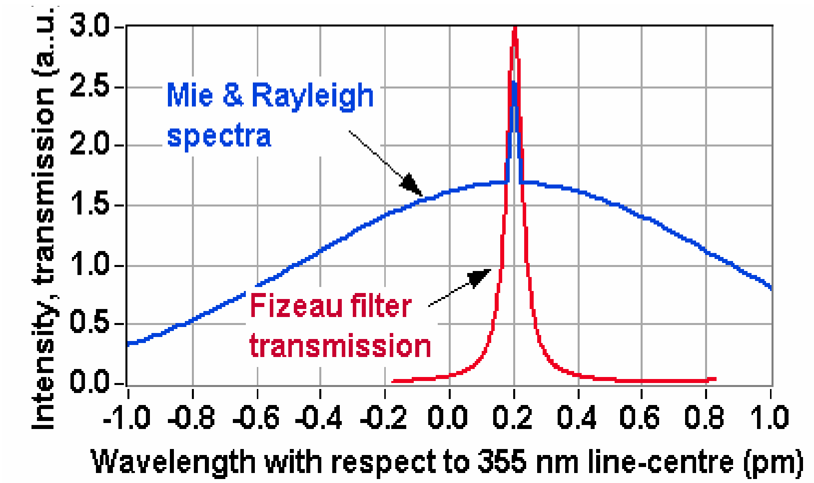
ADM-Aeolus Calibration/Validation AO

- Announcement of Opportunity AO issued by ESA for Cal/Val on October 1, 2007
- Open to PI worldwide in order to get access to ADM-Aeolus data; but no funds provided by ESA (BYOF)
- AO was open until December 15, 2007
- 15 proposals received with PI´s from Canada, China, France, Germany, Japan, Netherlands, Norway, and USA
- Review by ESA and external experts until end March 2008
- Notification of PI´s until end March 2008
- ESA plans to organize an AO user workshop in late 2008

Principle of wind measurement with ALADIN



Principle of spectrometer für molecular signal



principle of spectrometer für aerosol signal

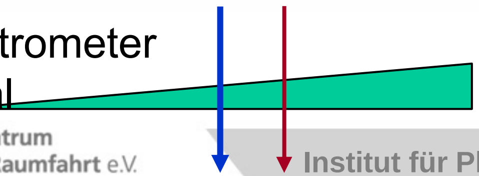


Fig. U. Paffrath

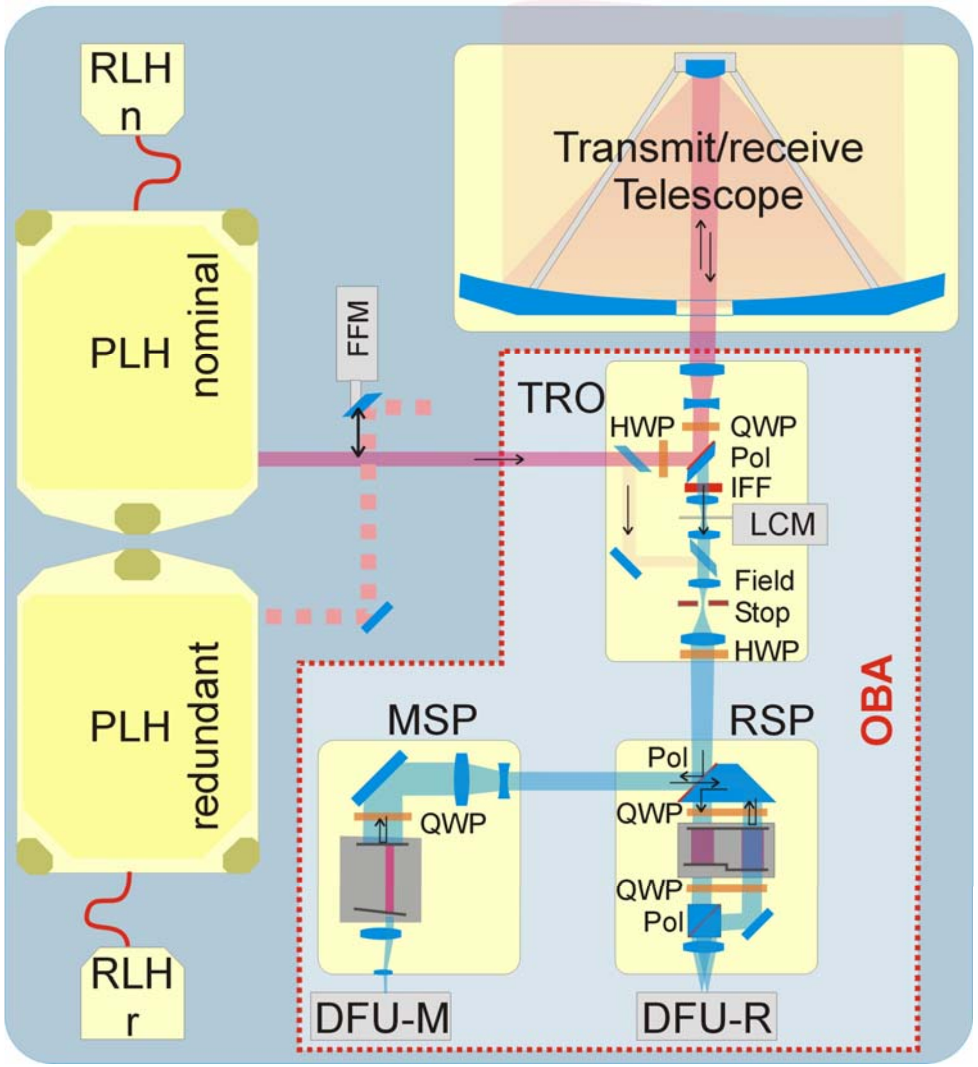
Atmospheric LAser Doppler INstrument ALADIN

- Direct-Detection Doppler Lidar at 355 nm with 2 spectrometers to analyse backscatter signal from molecules (Rayleigh) and aerosol/clouds (Mie)
- Double edge technique for spectrally broad molecular return, e.g. NASA GLOW instrument (Gentry et al. 2000), but sequential implementation
- Fizeau spectrometer for spectrally small aerosol/cloud return
- Uses Accumulation CCD as detector => high quantum efficiency >0.8 and quasi-photon counting mode
- ALADIN is a High-Spectral Resolution Lidar HSRL with 3 channels: 2 for molecular signal, 1 for aerosol/cloud signal => retrieval of profiles of aerosol/cloud optical properties possible

ALADIN Optical Layout

Transmitter laser assembly:
Reference Laser Head with stabilized tunable MISER lasers seeding the Power Laser Head with low power oscillator, two amplifiers and tripling stage two redundant laser assemblies in ALADIN

Mie receiver:
Fizeau interferometer, thermally stable, fringe imaged on single accumulation CCD

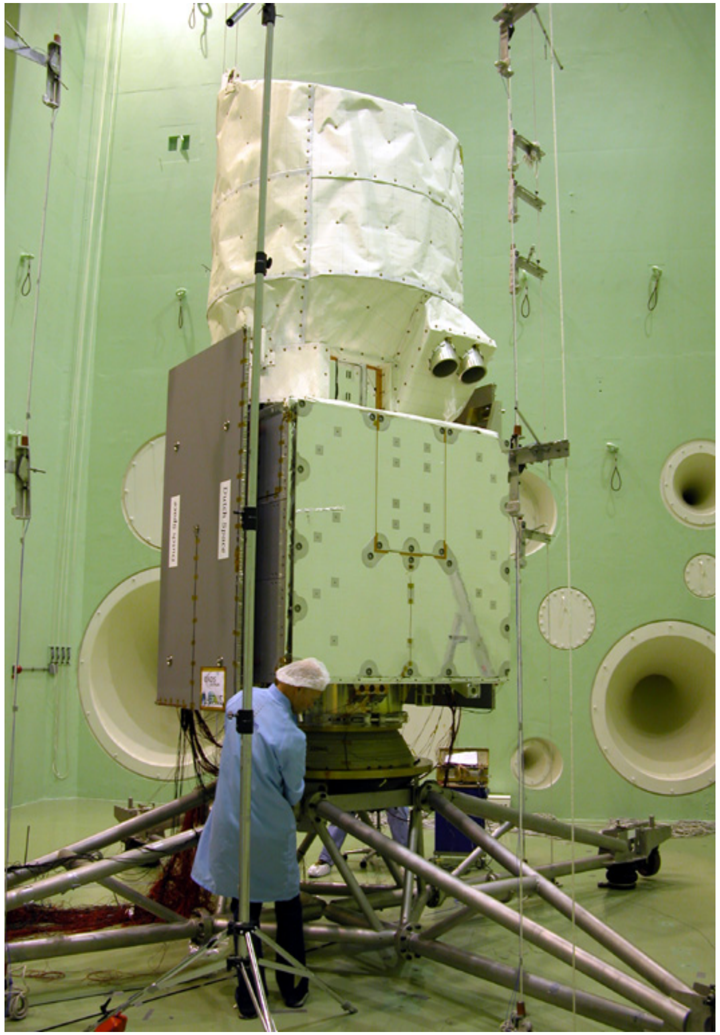


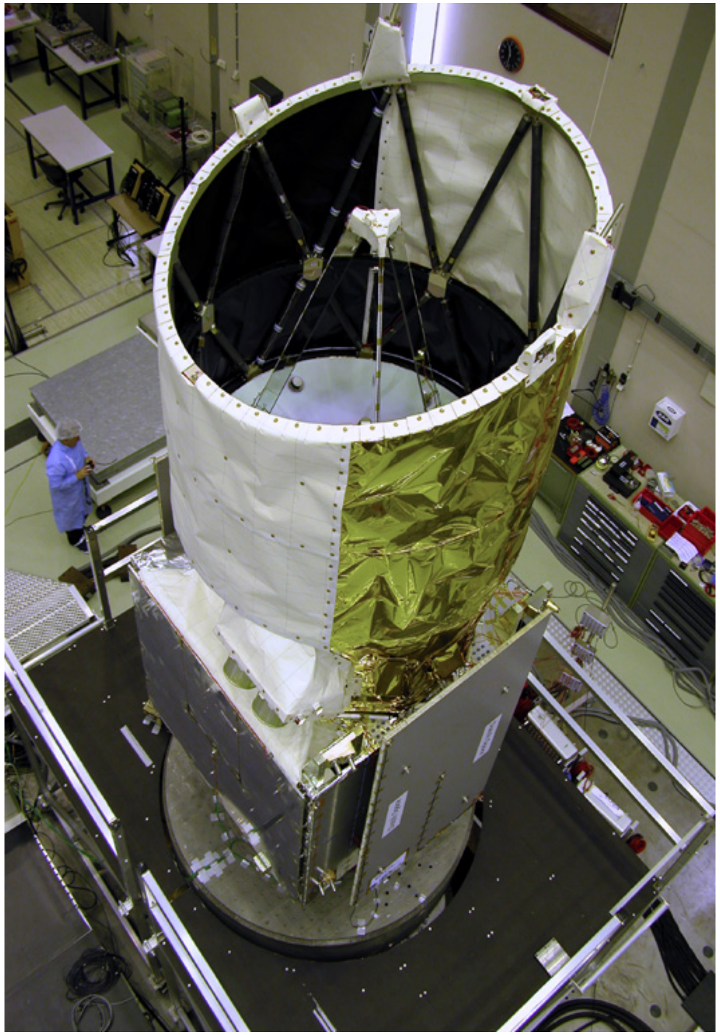
Telescope:
1.5 m diameter, Cassegrain, SiC lightweight structure, afocal, thermally focused

Transmit/receive optics:
polarizer as T/R switch, Laser Chopper mechanism, 1 focus as field stop, interference filter and prism for broad-band rejection of solar background

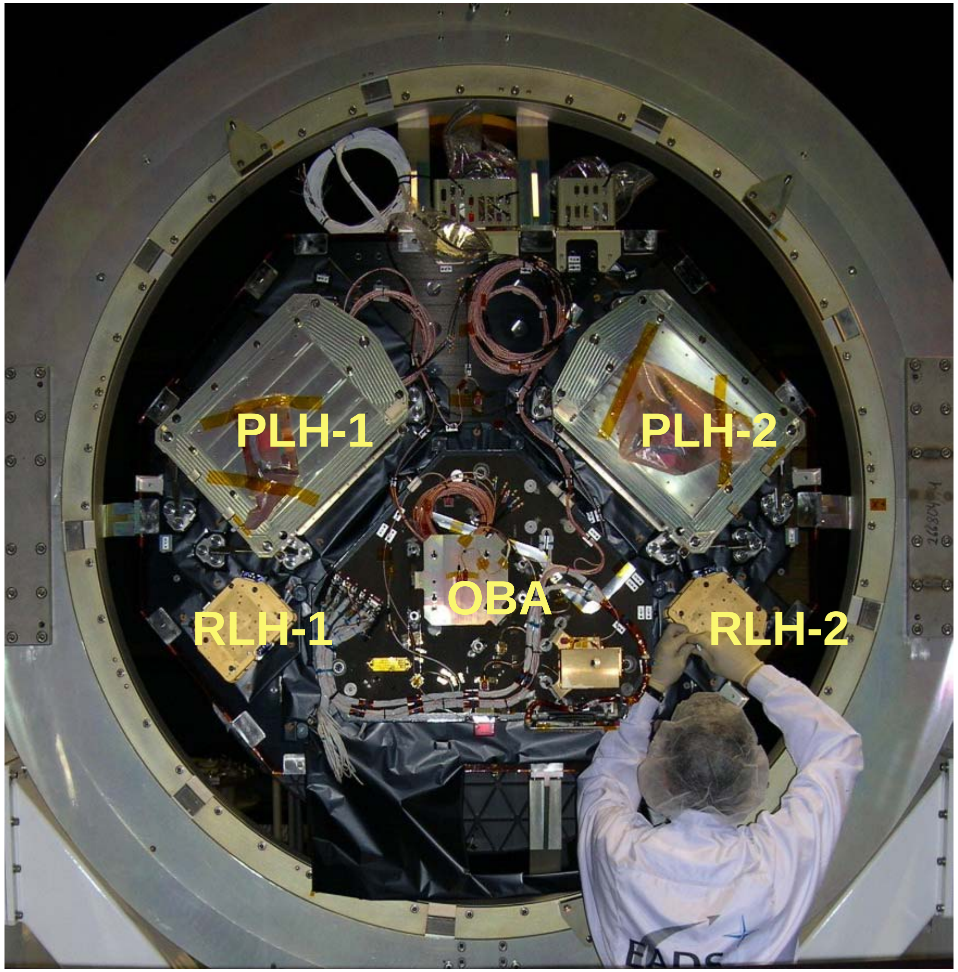
Rayleigh receiver:
Double edge Fabry-Perot interferometer, sequentially illuminated, temperature tunable Outputs focused on single accumulation CCD

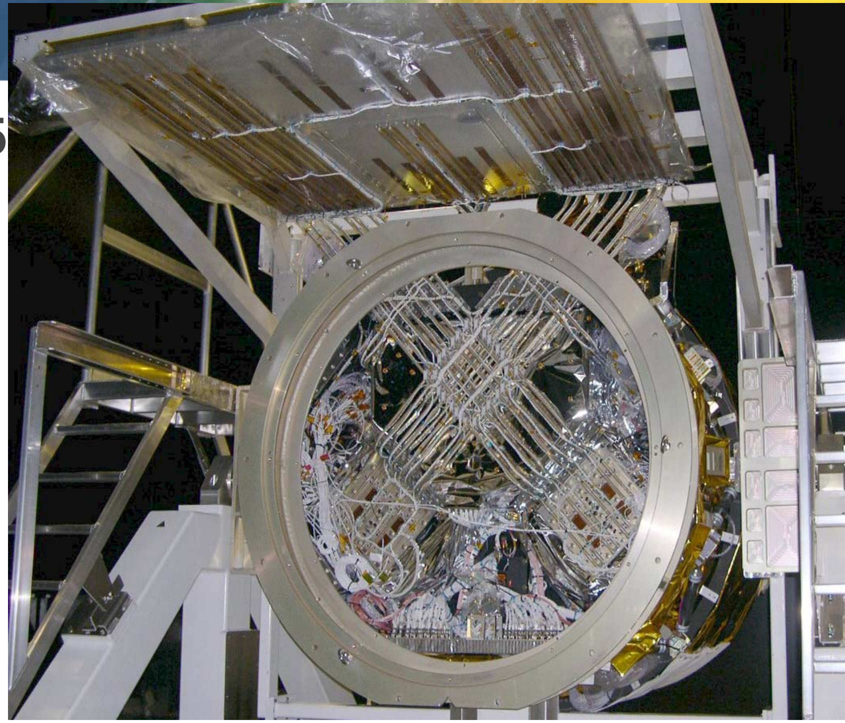
Aeolus Structure Model Acoustic and Shaker Test 2005

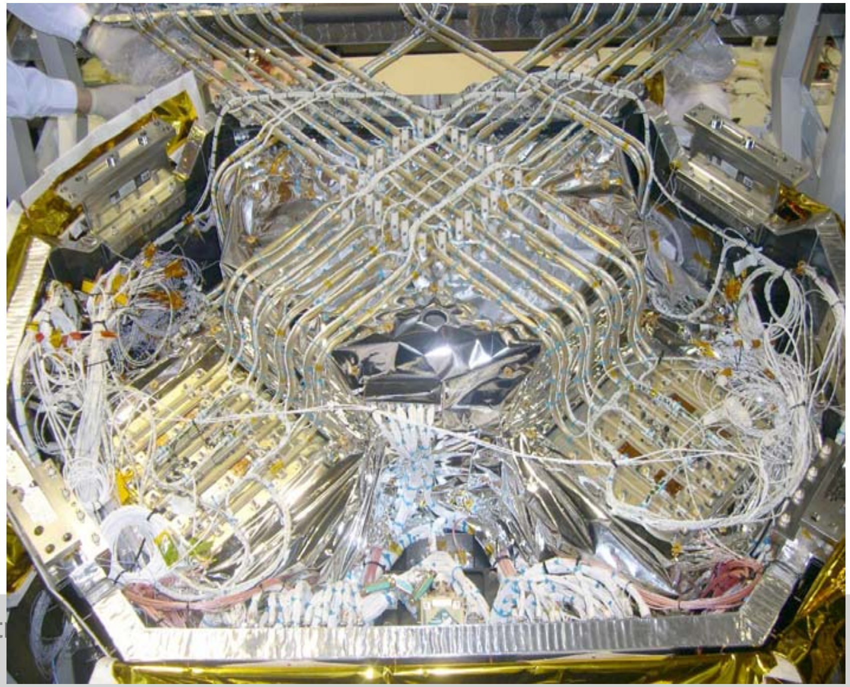




ALADIN OSTM and Laser Radiator 2005

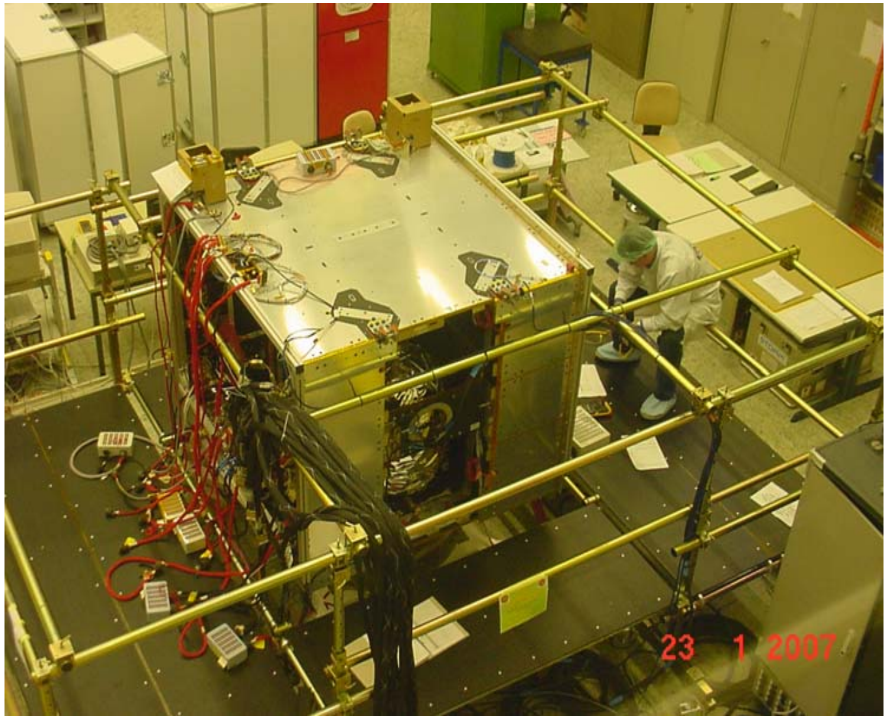






Optical Structure Thermal Model (OSTM), Power Laser Head (PLH), Reference Laser Head (RLH) Optical Bench Assembly (OBA)

Satellite Bus

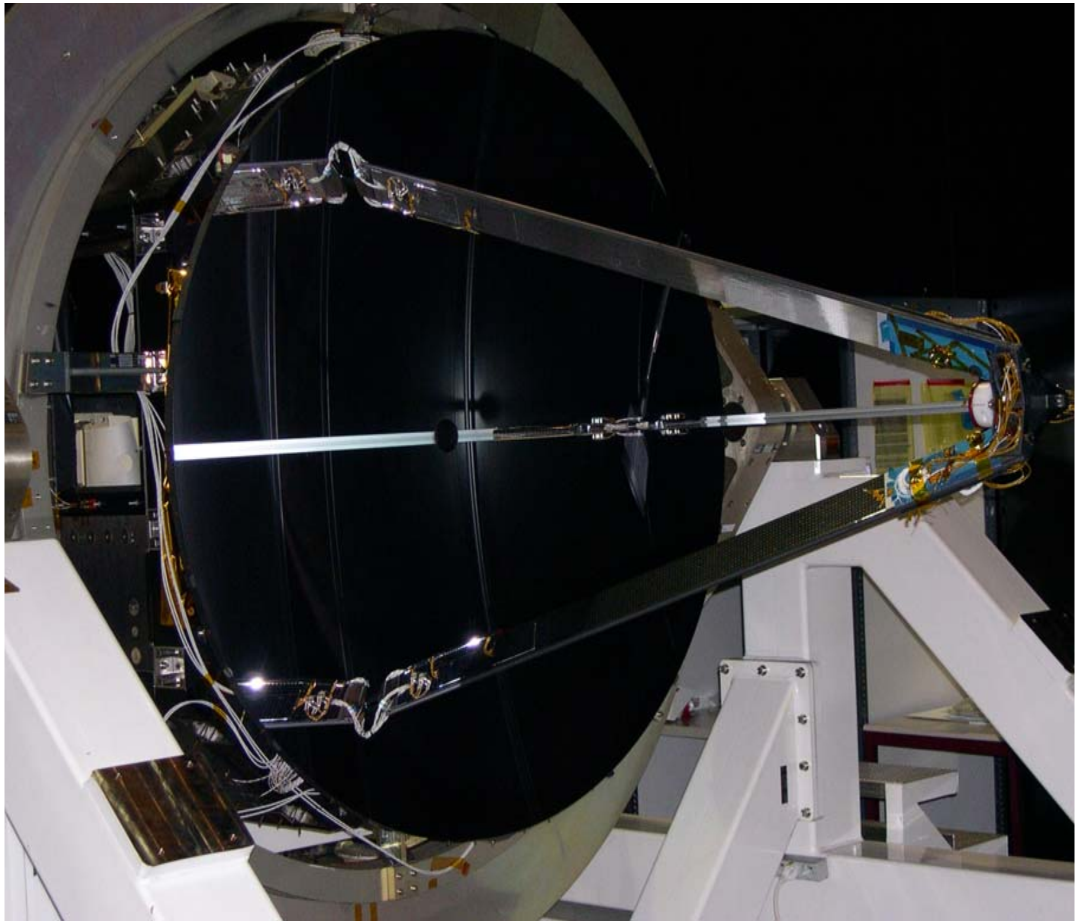


Satellite bus during integration at Astrium, Germany and was finalised at Astrium Stevenage, UK

Mechanical and electrical integration is complete, including AOCS, CESS, GPS, IMU

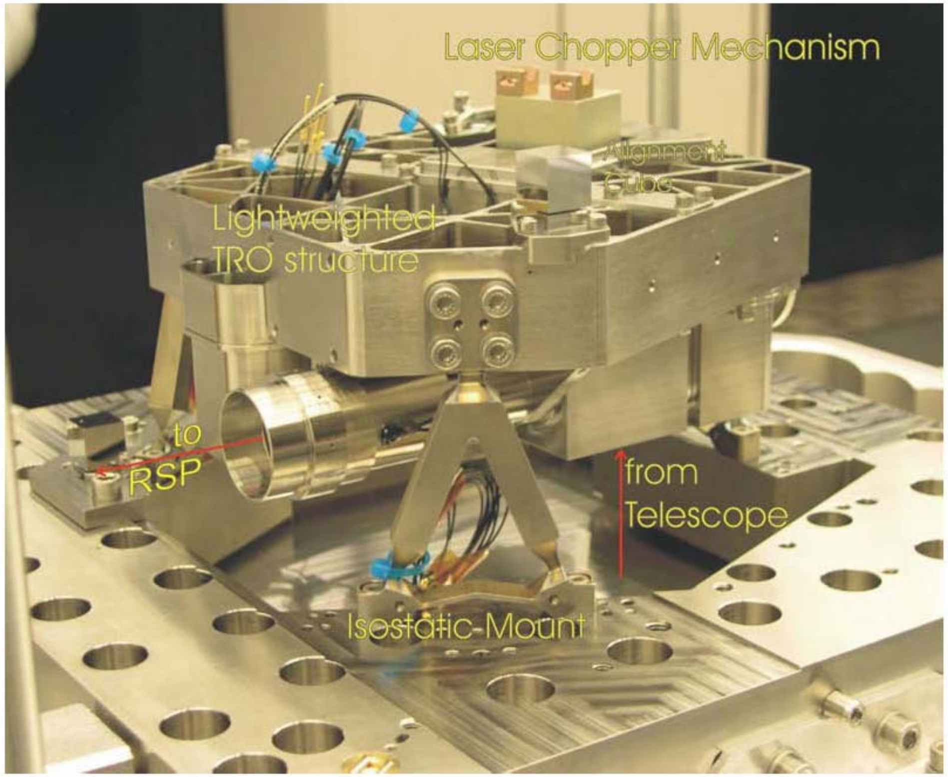
Intermediate On-Board Software Version delivered in December 2007

Telescope



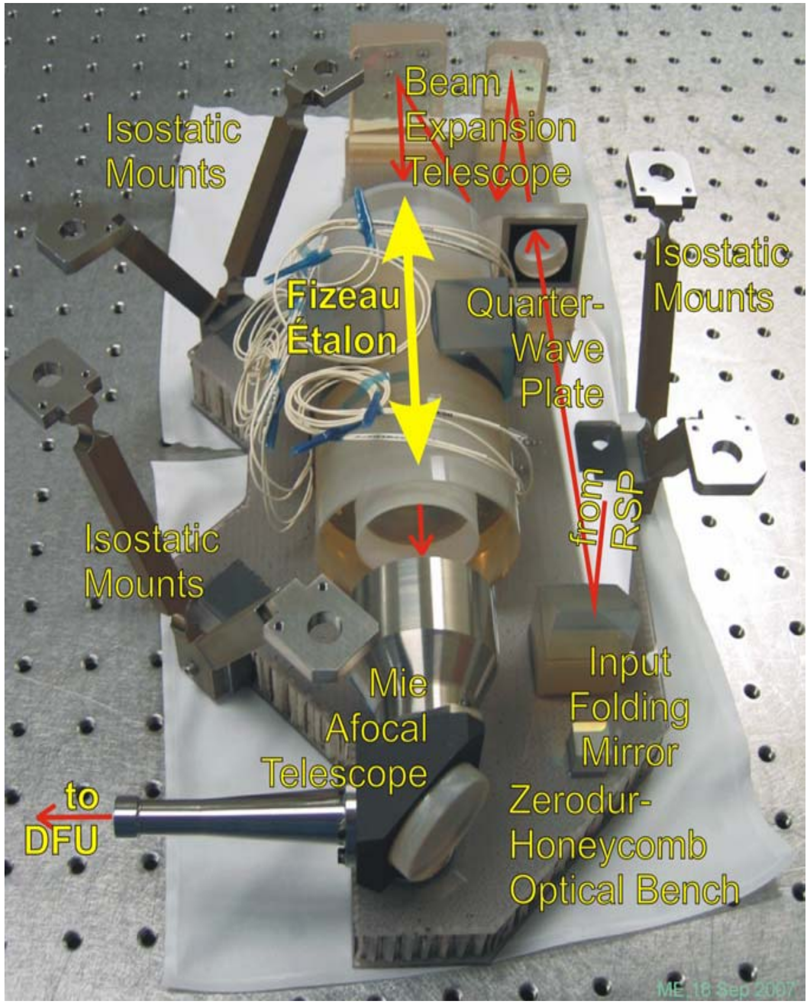
1.5 m afocal Cassegrain SiC Telescope at Astrium Toulouse, France
mass 75 kg, thermal refocusing, total wavefront error is below 300 nm,
magnification 41.67, secondary mirror Ø 46 mm

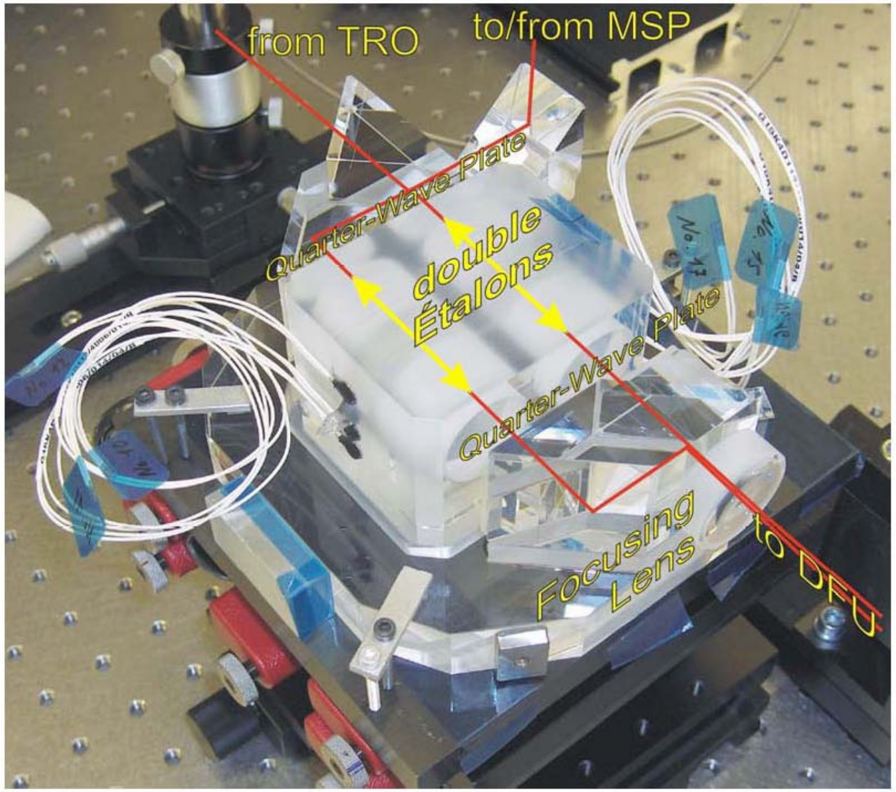
Transmit-Receive Optic



Transmit-Receive Optics from Kayser-Threde, Germany
including transmit-path optic, calibration path optic, receive path optic with background filter (equivalent bandwidth 1nm, T=0.8), Laser Chopper Mechanism, Field Stop and polarizing optics

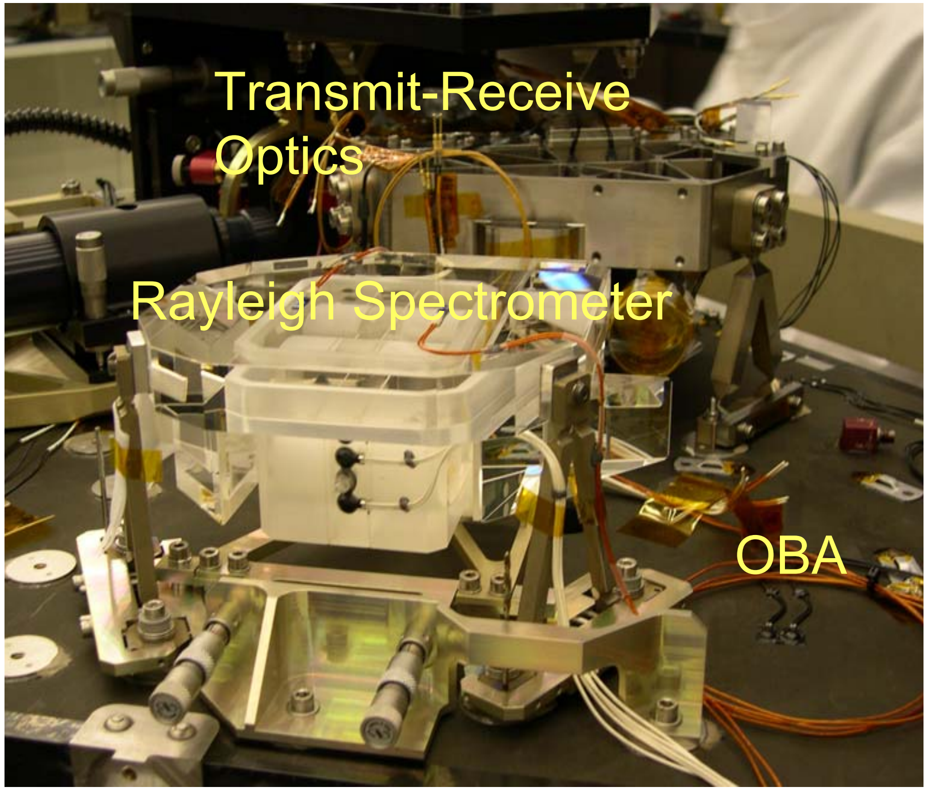
Optical Receiver - Mie and Rayleigh Spectrometer

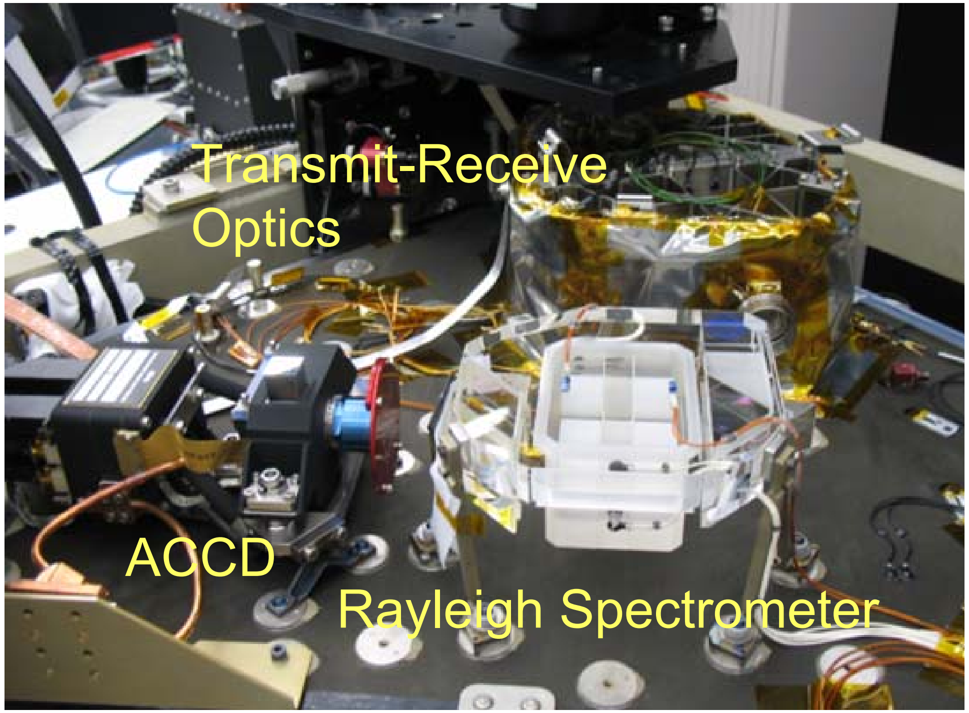




Mie and Rayleigh-Spectrometer from Contraves (Switzerland), now Oerlikon Space

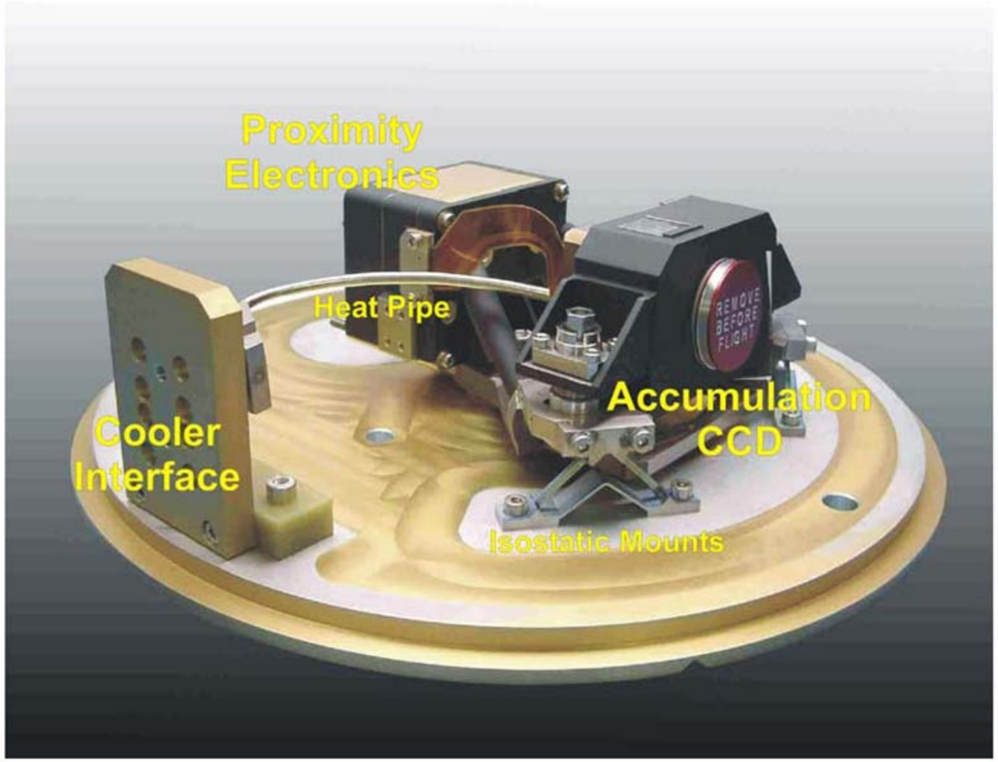
Optical Receiver - Integration

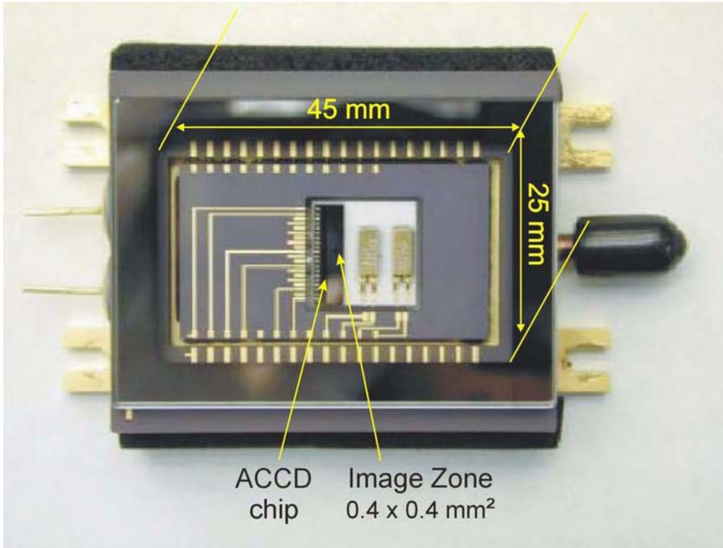




Integration of the Optical Bench Assembly OBA at Astrium-Toulouse finalized
Optical, electrical and performance characterisation will be performed

Accumulation CCD Detector

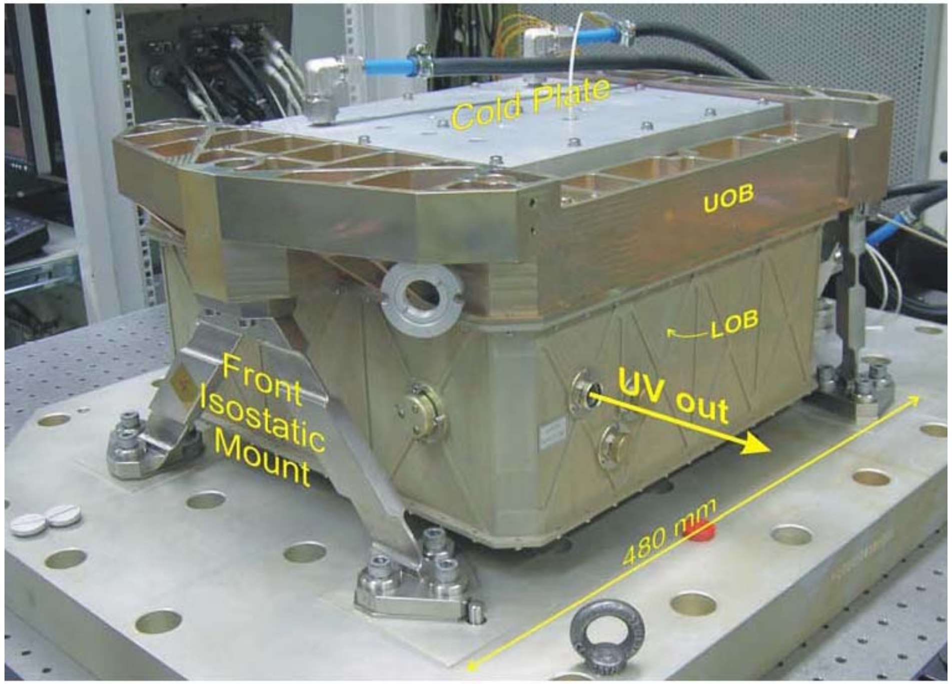


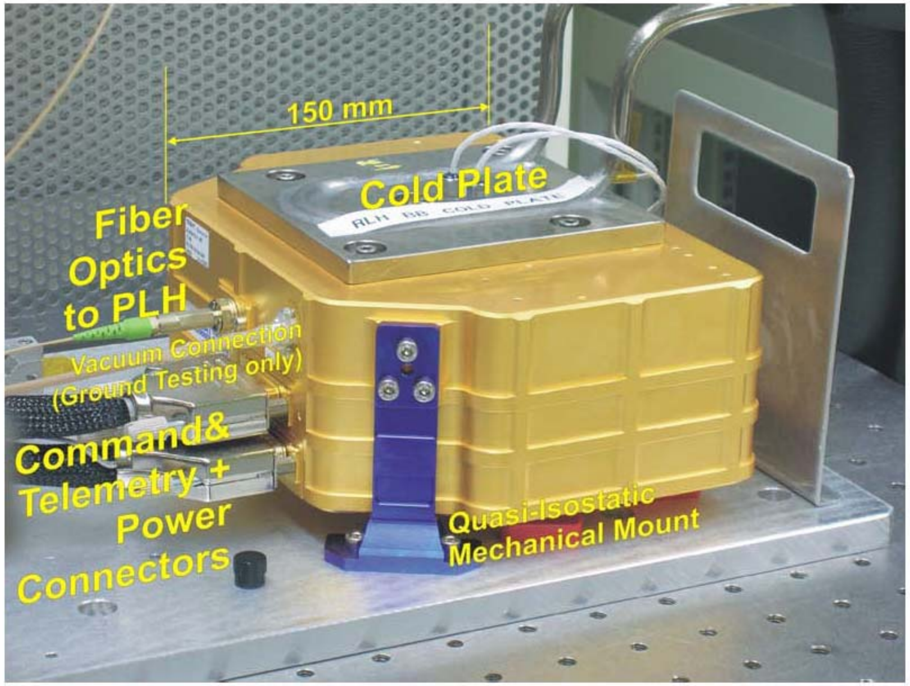


Detector Unit with Accumulation CCD from e2V (UK)

ACCD Image Zone is 16*16 pixels; memory zone has 25 rows => thus 25 range gates
quantum efficiency 0.85, quasi-photon counting due to low read-out noise
because of on-chip accumulation of charges
ACCD cooled to -30°C via thermo-electric coolers

Power and Reference Laser Head

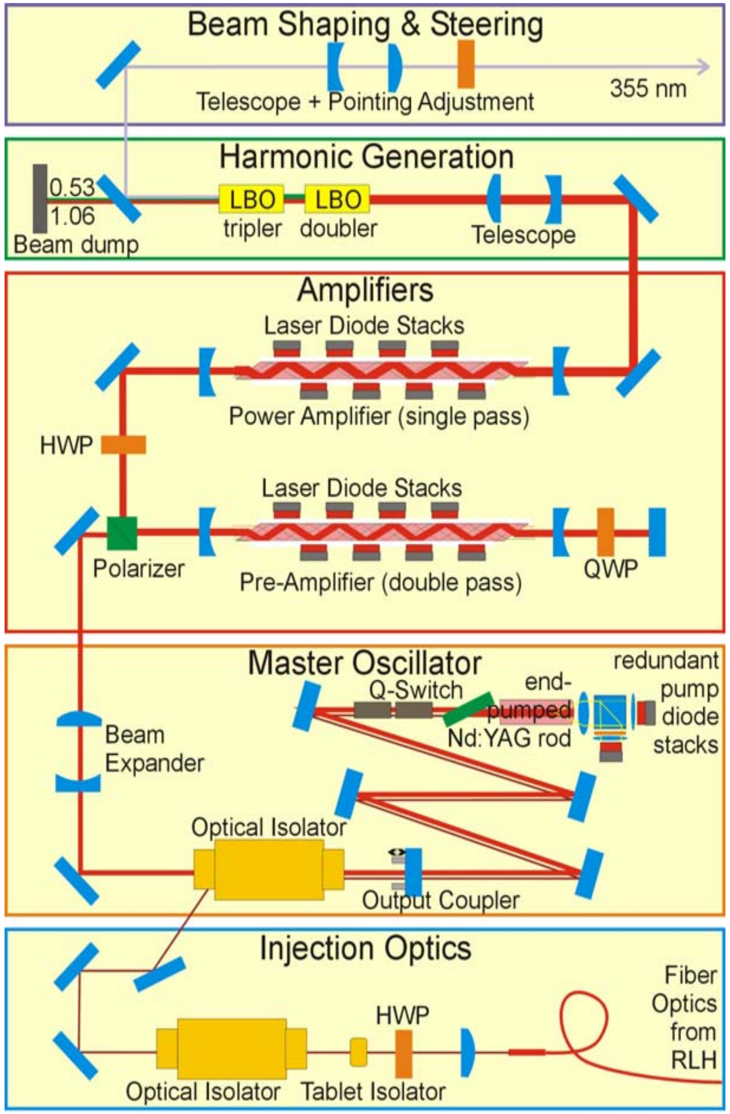




Power Laser Head from Galileo Avionica, Italy
1 Engineering Qualification Model built; 1 Flight Model built, a total of 3 Flight Models will be built
480 x 350 x 180 mm, 27 kg
total laser mass including electronics is 51.5 kg (without harness)

Reference Laser Head from TESAT, Germany
3 Flight Models built, tested and delivered
150 mm length, 2.1 kg

Laser Transmitter - Optical Layout and Specifications



Specifications

- 120 mJ at 355 nm with 100 Hz, 30 ns pulse length
- burst mode operation (5 s warm-up, 7 s on, 12 s off for power amplifiers, not master oscillator)
- 4 MHz (UV) rms frequency jitter
- tunability over 11 GHz for calibration
- output beam: Ø 7.5 mm with 400 µrad
- conductively cooled via a cold plate

Laser Diodes

- Flight models from Quantel Laser Diodes all manufactered (108 stacks total, 48 stacks needed), tested and qualified (6 month test):
- Life-testing of diodes continuous up to 2 years

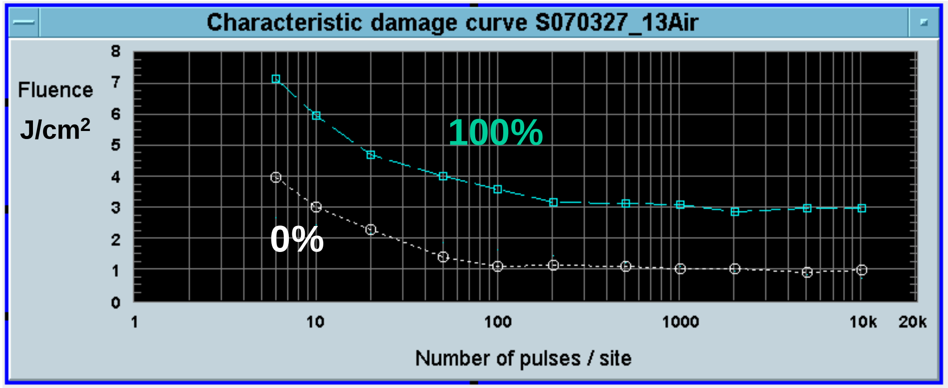
Laser Induced Damage LID

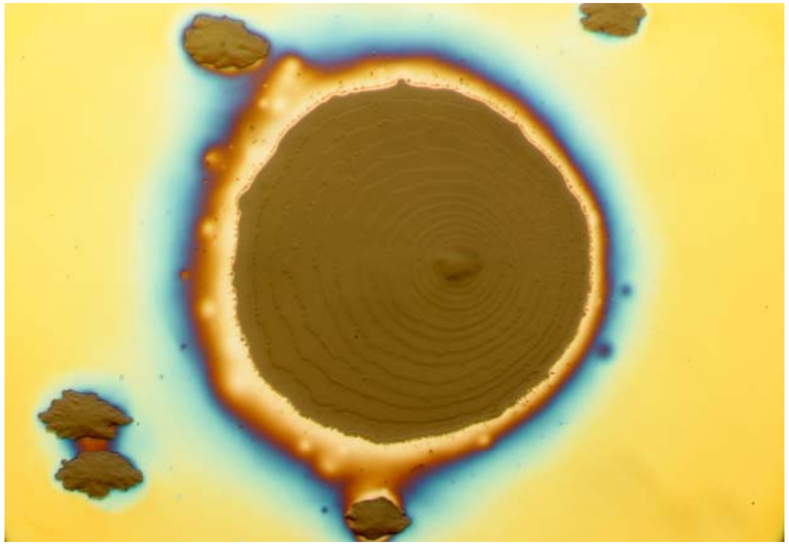
- All optics qualified for LID; tests up to 10^4 shots and then extrapolation up to $2\text{-}3 \cdot 10^9$ pulses (39 months)

Laser Induced Contamination LIC

- LIC due to outgassing of organic components
- bake-out and purging with air until launch
- 6 month life test of 3rd laser in vacuum planned

Laser Optic Qualification at DLR Stuttgart





Microscopic image of damage on laser optic

photo and material courtesy
Wolfgang Riede, DLR Stuttgart

ALADIN Power laser head

- more than 70 optical components and about 20-30 unique combinations of substrate and coating
- very compact design => high fluences up to 25 J/cm^2, most IR optics 5-15 J/cm^2, most UV optics 2-6 J/cm^2
- wavelengths 1064 nm, 532 nm, and 355 nm (UV); long pulse lengths of 20-30 ns
- vacuum operation

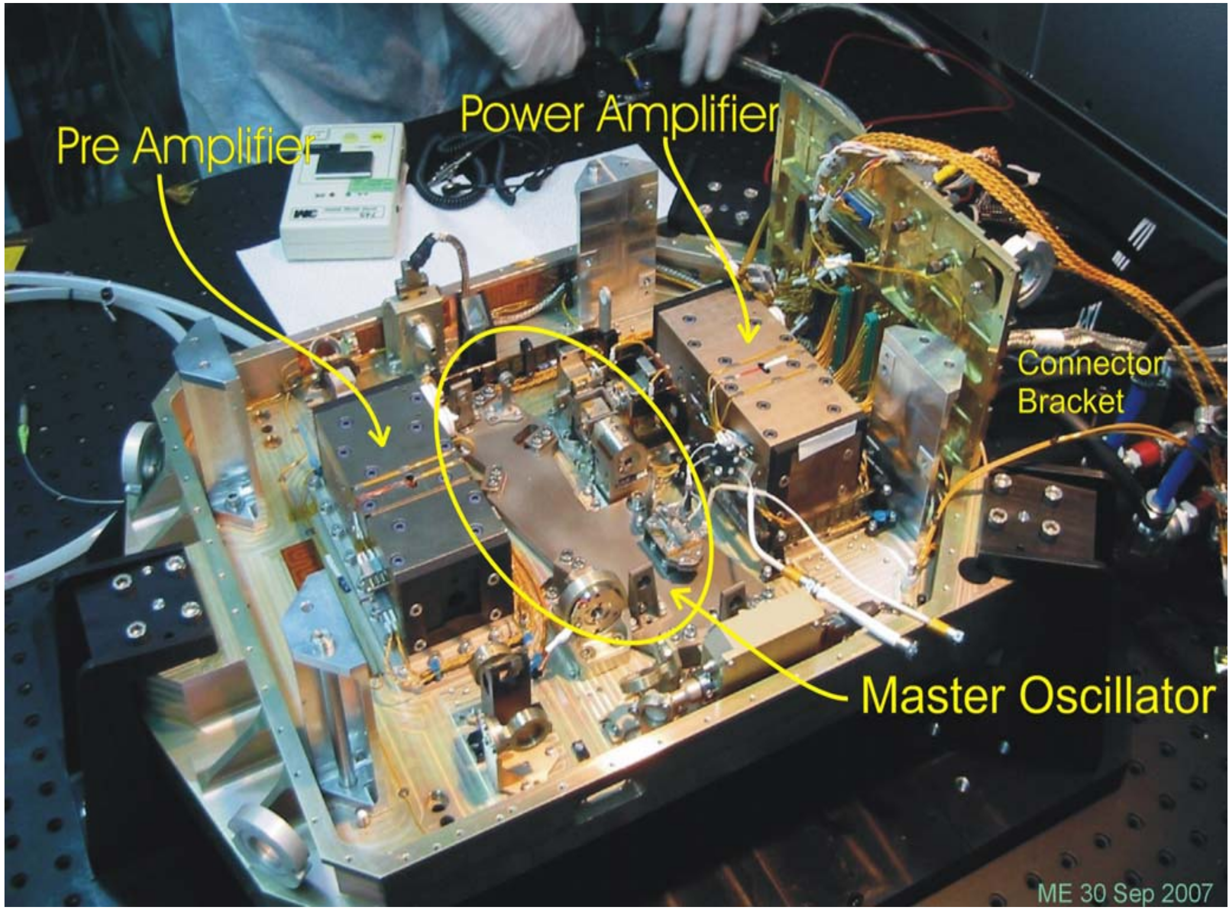
Laser Induced Damage Threshold LIDT

- LIDT in air with S-on-1 Test with S = 10^4 shots; tests done with shorter pulse lengths of 3-4 ns => scaling law
- Tests of degradation of LIDT in vacuum => lower LIDT
- Identification of coatings with high vacuum LIDT
- Testing of all coatings used in ALADIN
- Extended LIDT test over Million shots at ESA-ESTEC

Laser Induced Contamination LIC

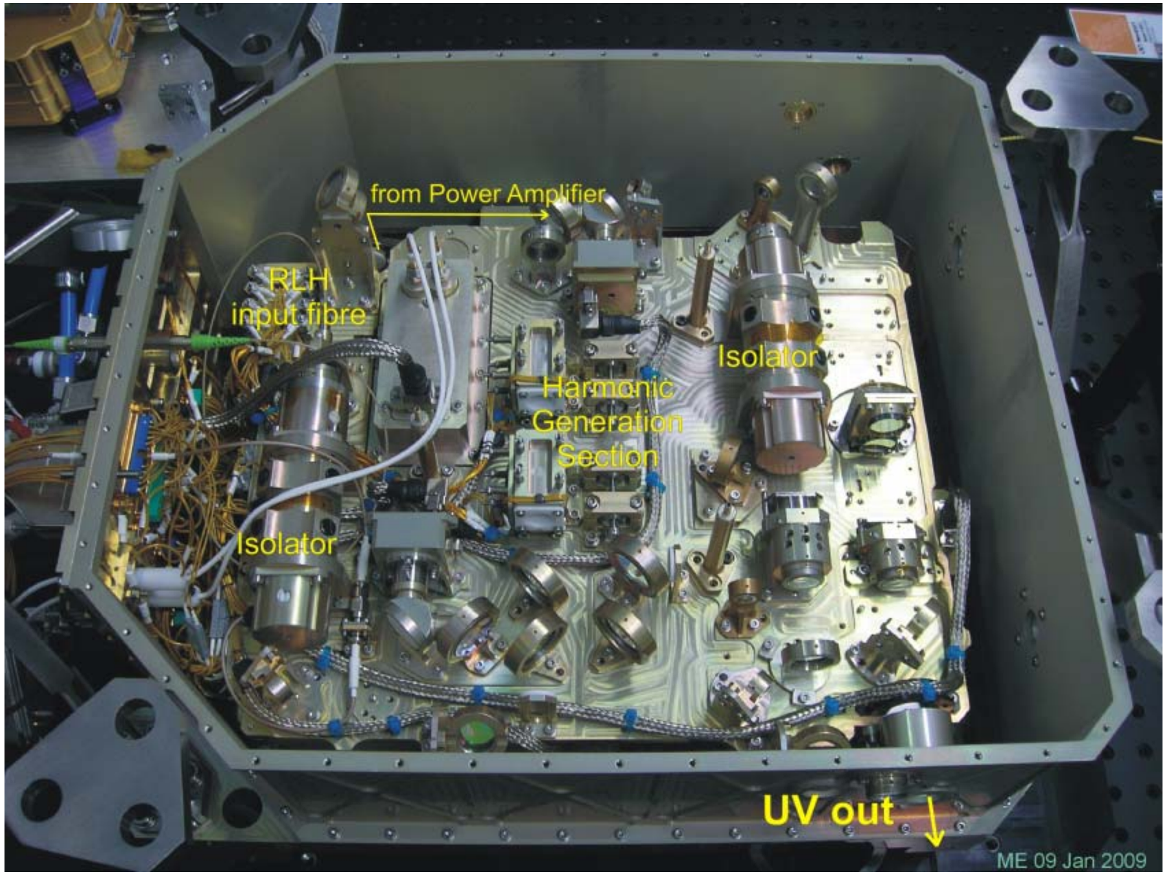
- LIC due to outgassing of organic components and molecular contamination
- Contaminants accumulate on laser-irradiated optics
- Test campaign in vacuum with 1064 nm and 355 nm, different temperatures and up to 10^7 shots; on-line monitoring of deposit built-up with fluorescence imaging
- Further tests of LIC at ESA-ESTEC

Laser Transmitter - Flight Model 1



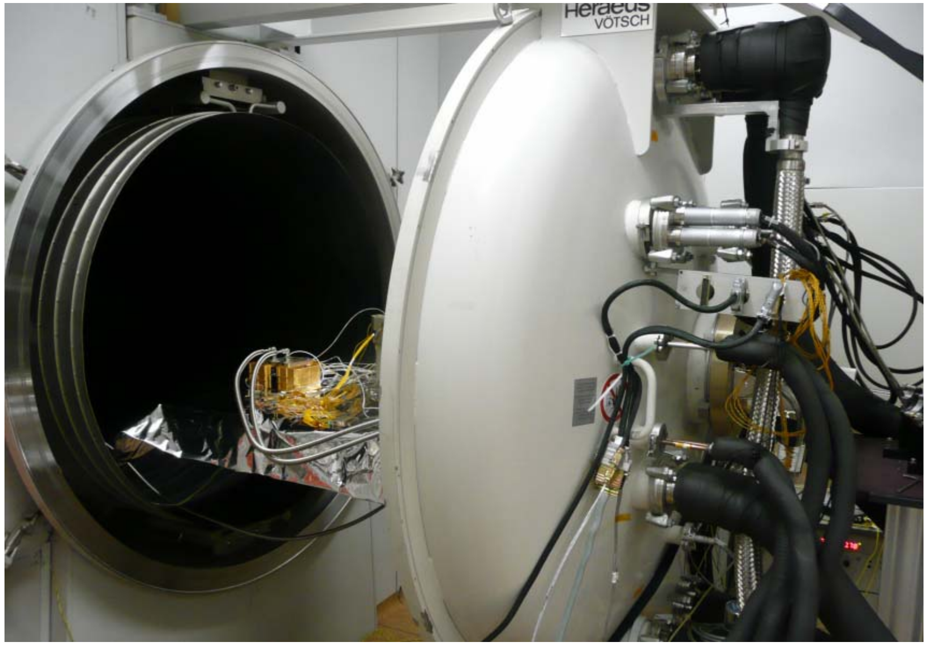
Power Laser Head PLH upper optical bench (without lower optical bench mounted) with Master Oscillator, Pre-Amplifier and Power Amplifier

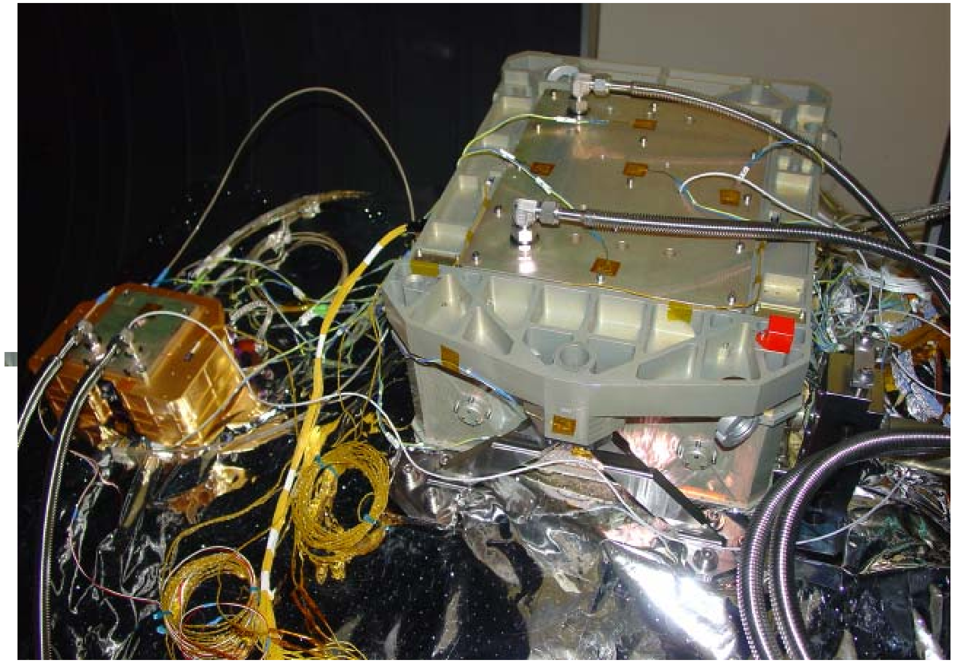
Laser Transmitter - Flight Model 1



Power Laser Head Lower Optical Bench with Isolators and
Higher Harmonic Generation Section (LBO crystals)

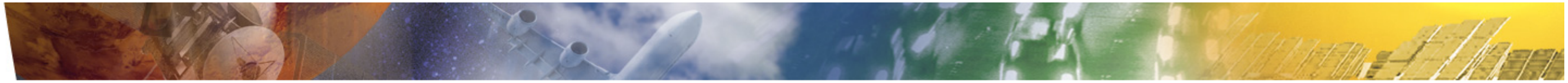
Thermal-Vacuum Test of FM1 laser





Flight Model FM1 Laser entering Thermal-Vacuum
Test at Galileo Avionica Florence in January 2008

6 month life-testing in vacuum of laser FM3 is planned

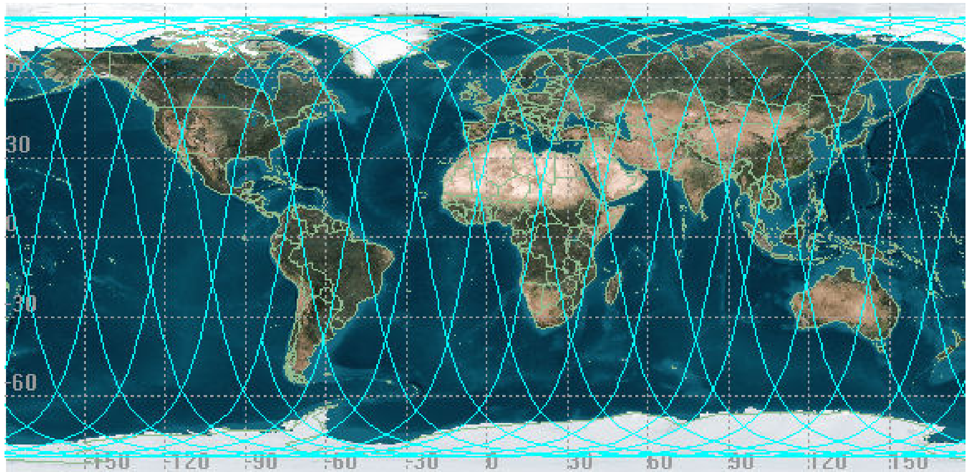


Atmospheric Dynamics Mission ADM-Aeolus

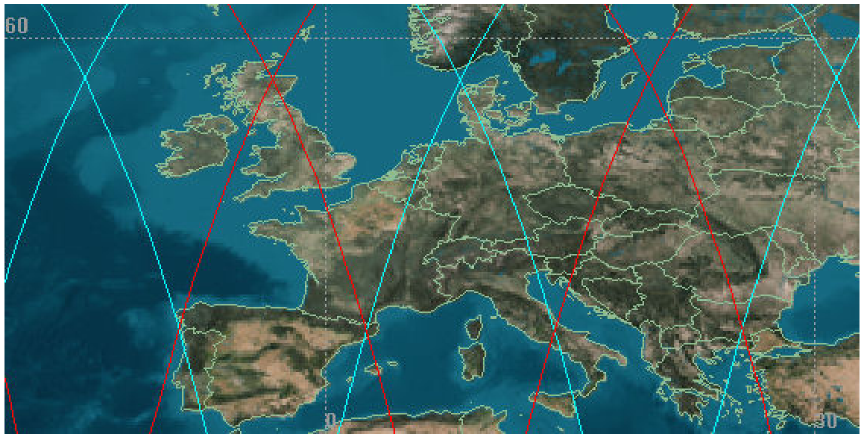
Summary and Conclusions

- Satellite bus mechanical and electrical integration completed
- Optical receiver manufactured and integrated including telescope, spectrometers, and ACCD detectors
- Laser Transmitter Flight Model 1 manufactured and thermal-vacuum testing ongoing
- All laser diodes manufactured and qualified
- ESA call for cal/val proposals closed and proposals under review
- Next major milestone will be the thermal-vacuum test of the laser => consolidated launch date in some months expected
- ESA call for science use of ADM-Aeolus data planned for late 2008

ADM-Aeolus
Considerations for Operational Follow-on Missions



1 day global coverage for 1 spacecraft



1 day European Coverage for 2 spacecrafts

- Objective of ADM-Aeolus follow-on missions is to achieve denser horizontal coverage and/or sensing of 2 wind components by 2 to 3 operational satellites in space (PIEW study from KNMI)
- EUMETSAT SWG/AEG have recognized potential of wind lidar within post-EPS
- Temporal gap between end of ADM-Aeolus (around 2012) and post-EPS (after 2018)
- Recommendation of ADM-Aeolus Mission Advisory Group during its October 2007 meeting: *"We urge these two agencies to explore the possibility of collaborating also toward developing their joint observing capabilities to include the critical missing vertically resolved wind observations."*
- November 2007: Kick-off for (small) study on ADM-Follow-on Missions with focus on new laser concepts by Astrium Germany funded by DLR

LIDAR Instruments for Earth Observation Missions