Space Frequency-Comb for In-Orbit-Demonstration in Low-Earth-Orbit

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About Menlo Systems

Prof. Dr. Theodor W. Hänsch

Dr. Michael Mei, CEO

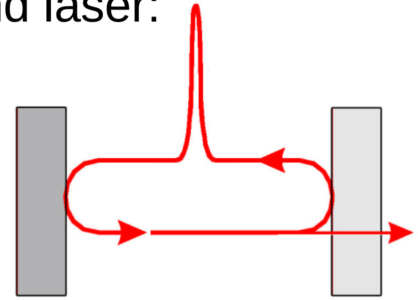
Dr. Ronald Holzwarth, CTO

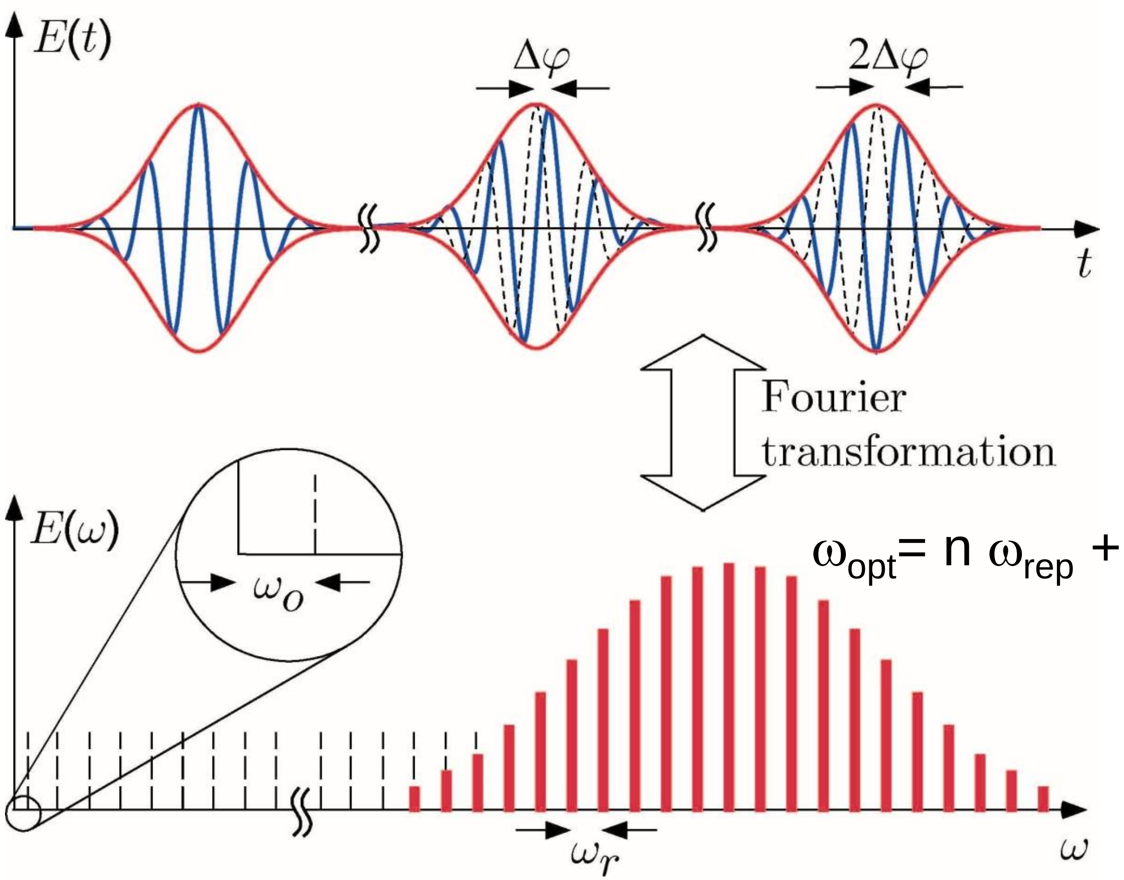
Precision in photonics. Together we shape light.

- For 20 years leading developer and global supplier for precision metrology instrumentation
- Known for its Nobel Prize winning optical frequency comb technology
- Headquarters in Martinsried, Germany, subsidiaries in US, Japan and China
- International customers from science and industry

The Optical Frequency Comb

Modelocked femtosecond laser:





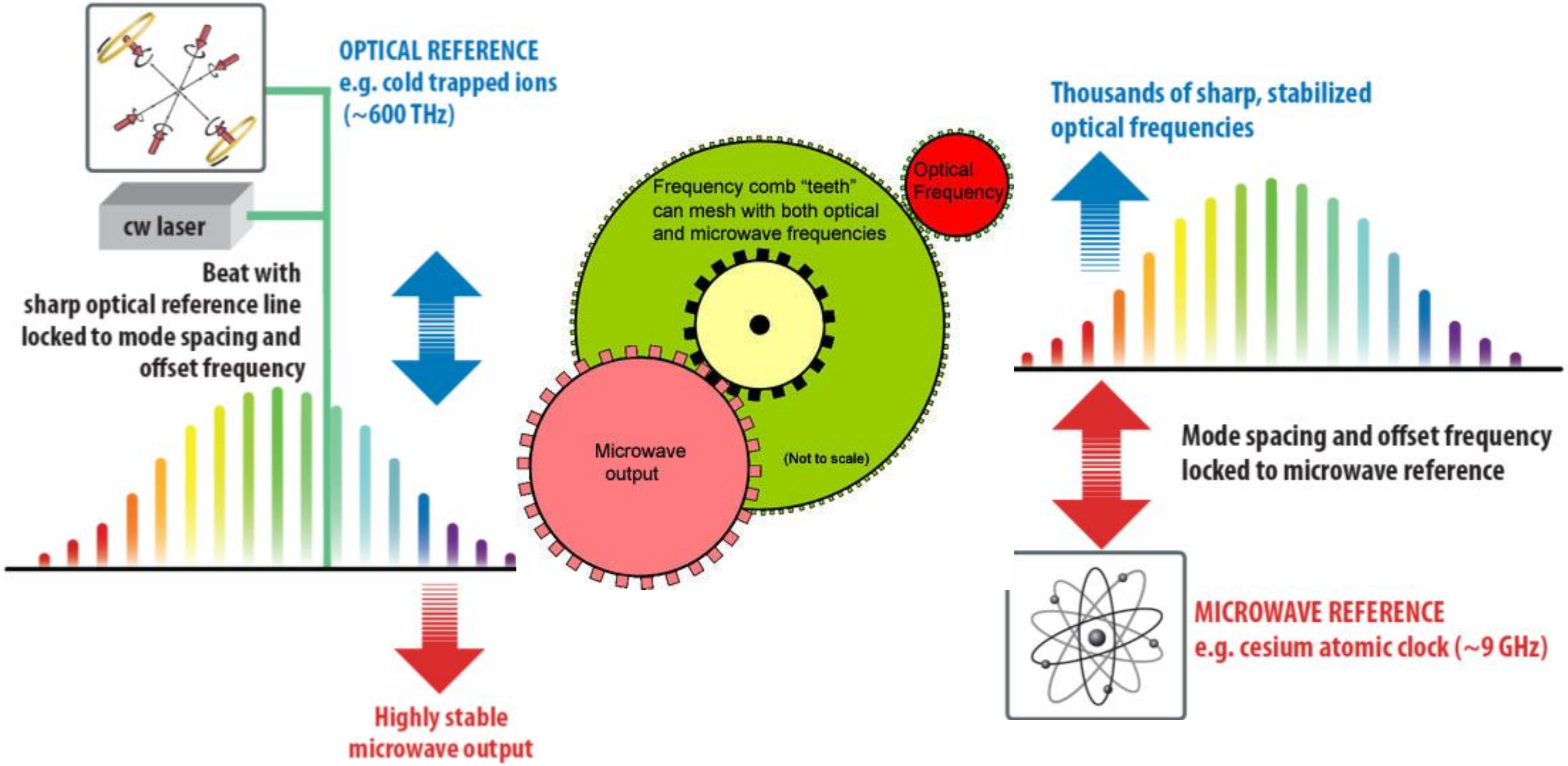
$\omega_{opt} = n\,\omega_{rep} + \omega_0$

Theodor W. Hänsch
2005

Application of the Frequency Comb

Optical reference → stable radio frequency

Radio reference → stable optical comblines



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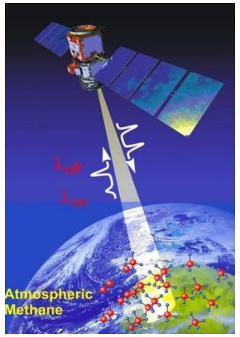
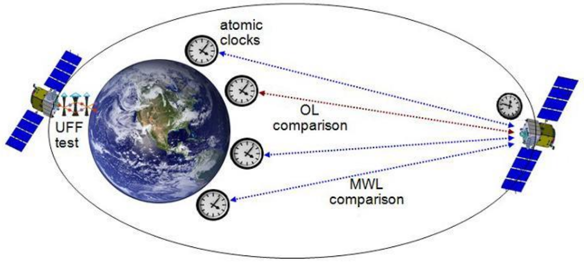
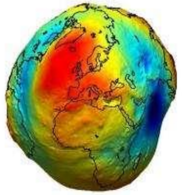
Space Applications



Einstein's Equivalence Principle



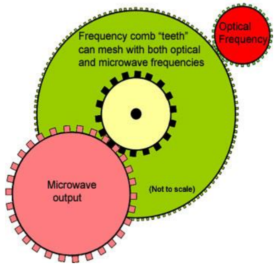
Gravitational Potential
GRACE



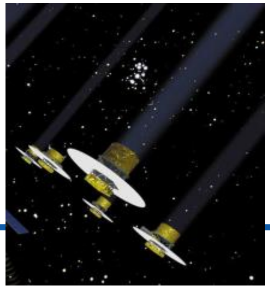
Atmospheric
Trace Gas Detection
MERLIN, A-SCOPE

Optical Clocks & MW
GNSS, RADAR

Reference & Time
Distribution
GNSS



Ranging for formation
flying satellites
GRACE, NGO, DARWIN



Why are there no combs in space, yet?

Because they are not qualified for space environment!

Environmental Sensitivity of Lasers:

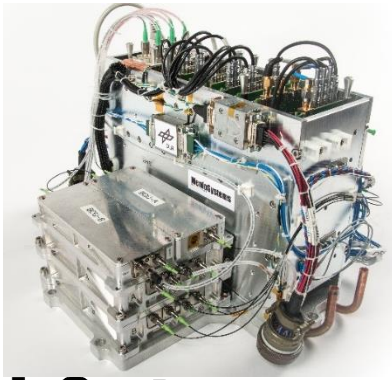
- Vacuum → no fundamental problem
- Thermal → advanced thermal stabilization
- Vibrations → could be damped or feedback stabilized
- Lifetime → **optics bonding**, pump diodes, **qualified fiber-optics components**
- Radiation → **electronics**, **radiation tolerant fibers**

SWaP, Systemsintegration

In the past years Menlo Systems has demonstrated robust comb systems flying in experimental payloads on sounding rockets up to 280 km height

Single Comb

Dual Comb



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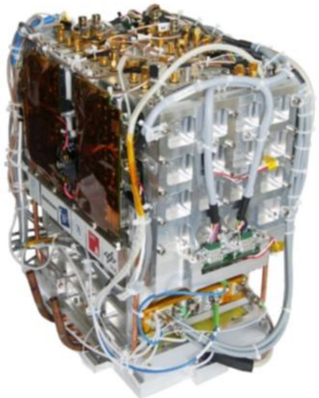
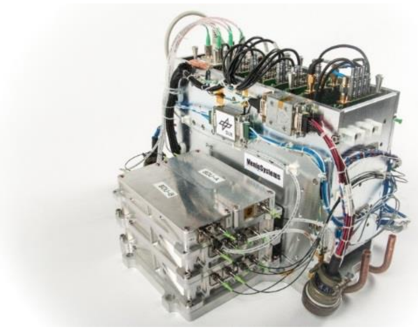
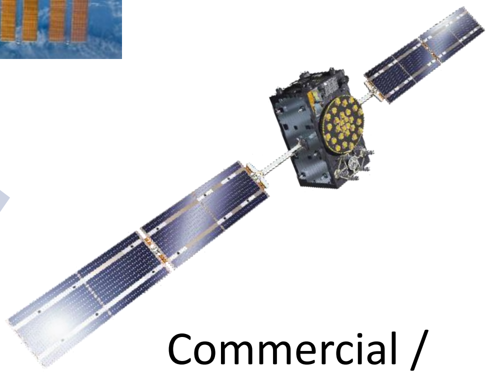
Roadmap to Spacecombs







Laboratory Comb
2010

- Greatest Flexibility
- Highest Performance

FOKUS I
2014

- 24 kg / 21 L / 90 W
- Robust & compact
- **Texus 51&53 flight 2015/16**

FOKUS II
2018

- 10 kg / 7 L / 50 W
- Dual Comb
- Vacuum compatible
- Ultra-Low-Noise actuator
- **Texus 54 flight 2018**

OPUS / ROSC
2018 - 2022

- Robust and compact systemintegration
- 7 kg / 6 L / 40 W
- Space suitable optics module
- Electronics prepared for qualification

COMPASSO IOV
2024+

- In-Orbit-Demonstration of an Iodine Clock

Commercial / Science Mission
2028+

- COMPASSO targets Galileo 2nd Generation

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COMPASSO

Mission Goals

- **in orbit verification of optical key technologies** relevant for GNSS evolutions in terms of feasibility and performance
- testing onboard the **Bartolomeo Platform** of the **International Space Station (ISS)**

Compact and highly stable laser optical clocks

- optical Iodine references (IR)
- optical frequency comb (FC)

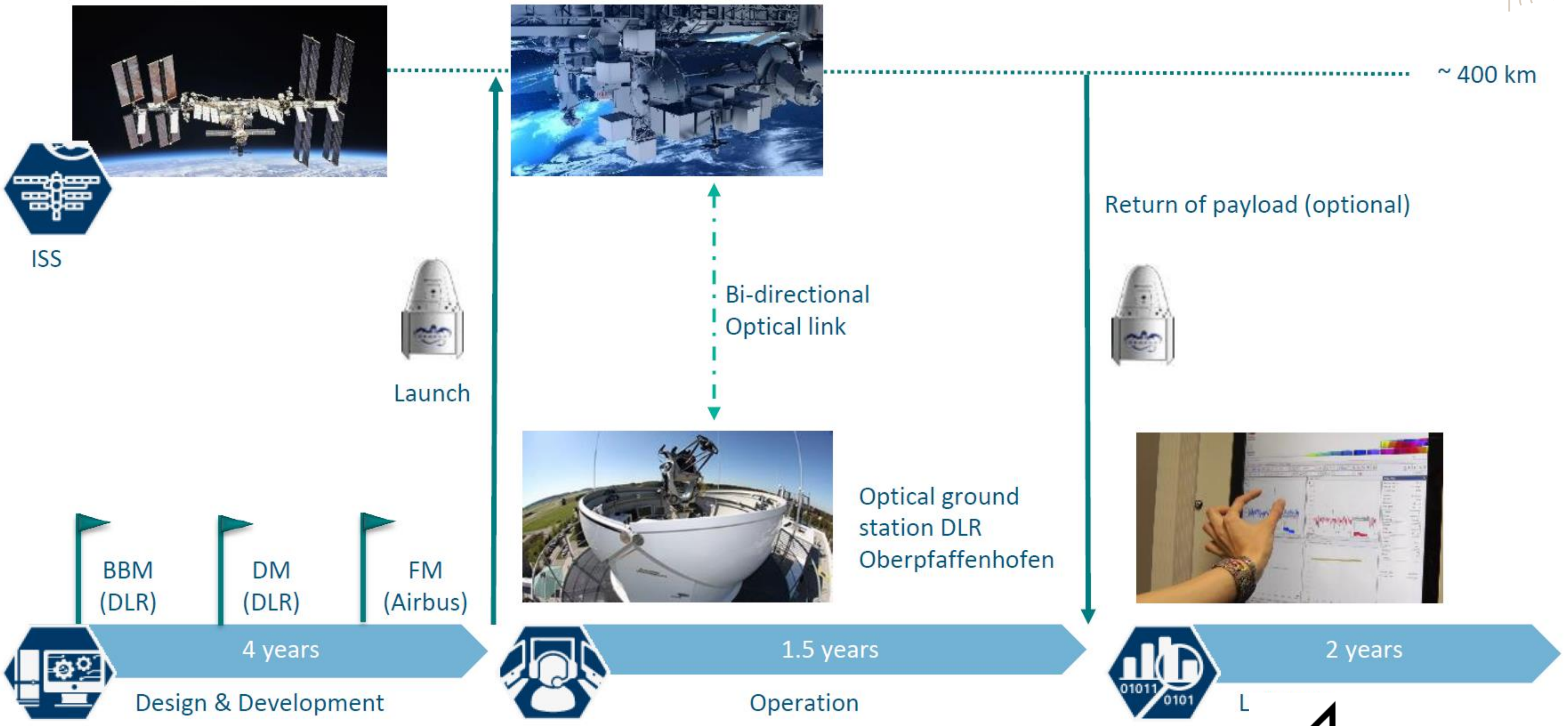
Laser communication and ranging terminals (LCRT):

- Time, frequency transfer between ISS and ground

Envisaged launch: 2025

Mission duration: 1.5 years

Mission Scenario



BBM: Breadboard Model; DM: Development Model; FM: Flight Model

Deutsches Zentrum für Luft- und Raumfahrt

Frequency Comb for COMPASSO

Highly integrated optical frequency comb with minimal external connections
- Data
- Power
- RF in/out
- Optical in/out

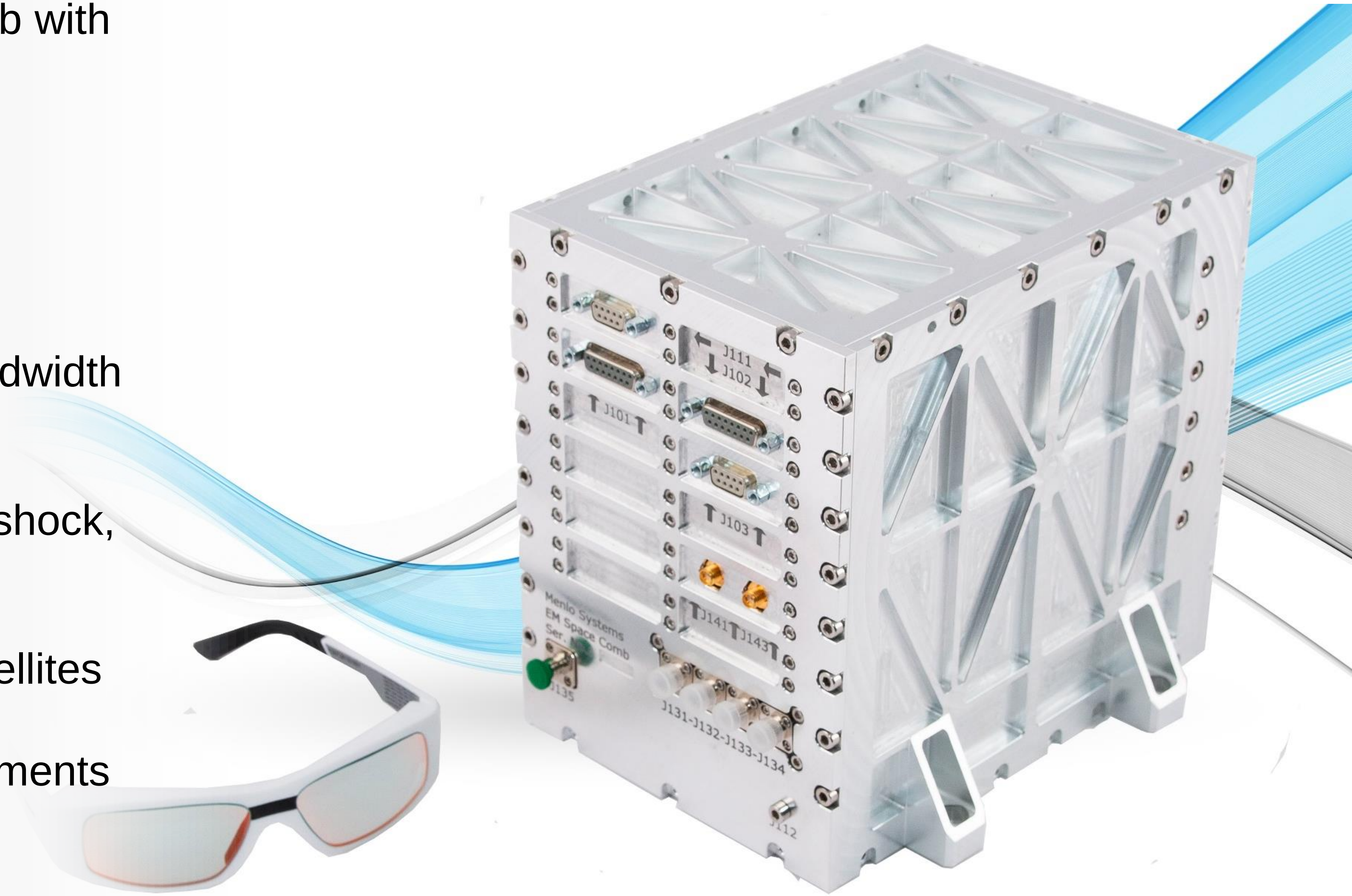
Autonomous system operation, low bandwidth control by GSE

Robust against environment: vibration, shock, temperature, radiation

Low SWAP, suitable for rockets and satellites

Ultra-stable optic mounting, no readjustments necessary

Vacuum and 0-g compatible thermal management



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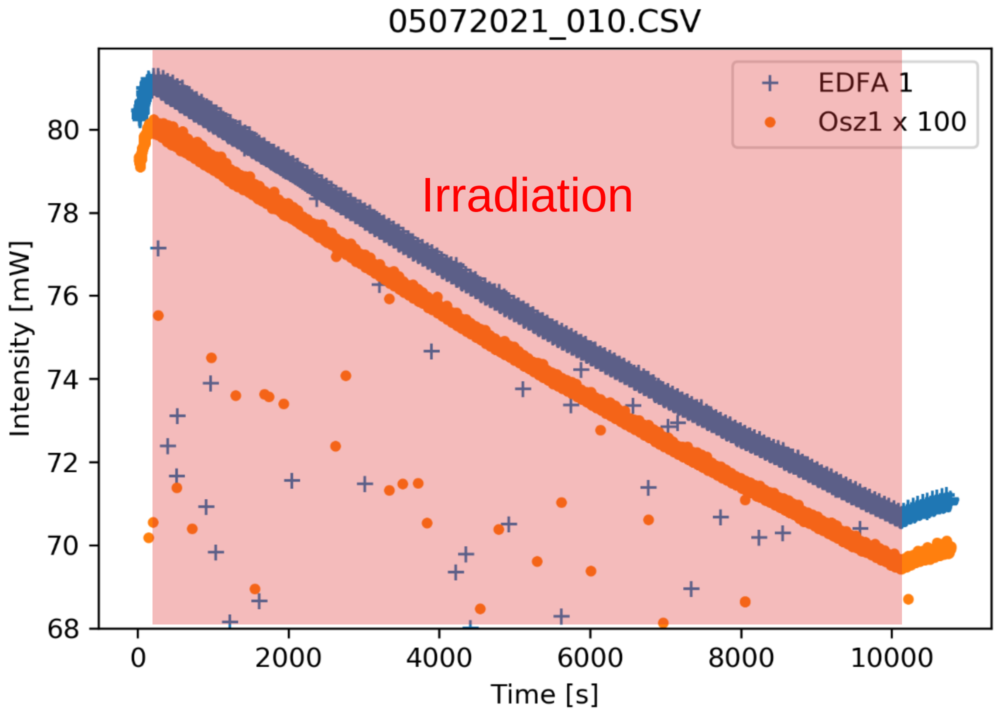
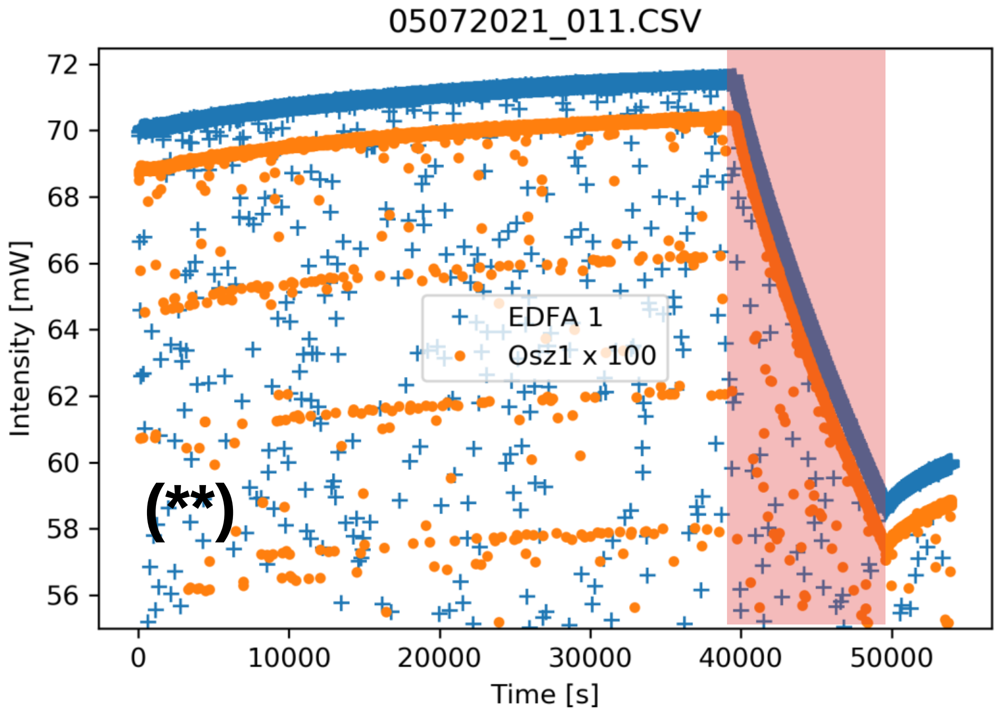
Standard fiber laser under irradiation

Laser power degradation is 0.6 dB at 100 Gy (1 year MEO),
but significant recovery is possible



Irradiation at 10 mGy/s, 90% DC (duty cycle)



10 hr recovery, then irradiation at 10 mGy/s, 10% DC

(**) Outlier dots are caused by laser on/off switching

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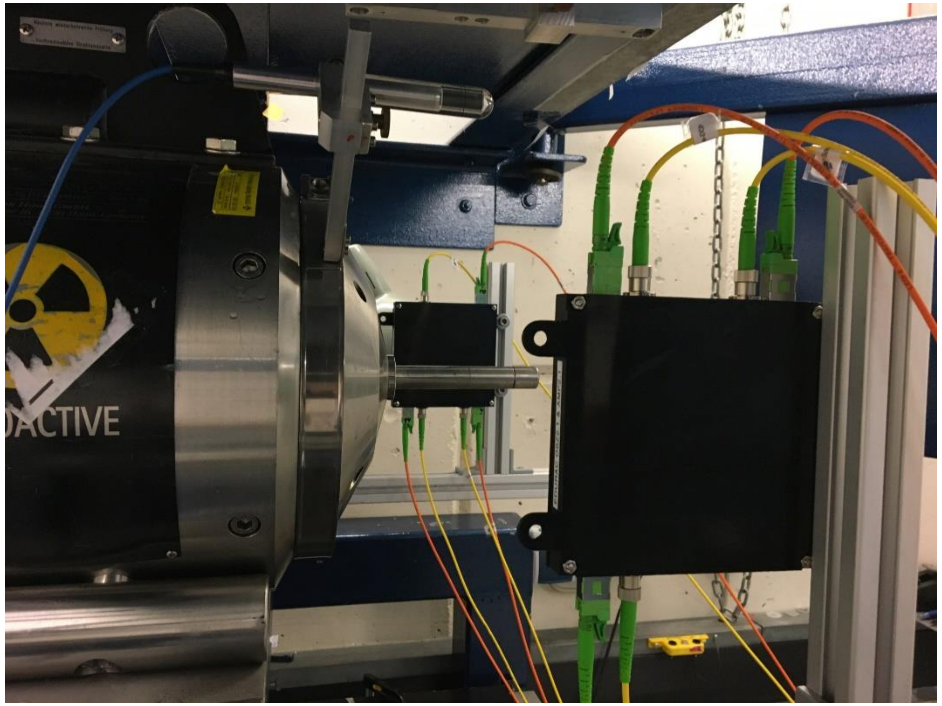
Solution

iXblue designed pm-fiber with improved radiation hardness

- iXblue fiber design takes into account high fiber gain and low fiber dispersion
- Fiber is irradiated under regular laser operation, which can affect fiber degradation rate

Two NALM fiber oscillator and EDFA have been placed simultaneously into irradiated area

Lasers are switched on/off with selectable duty cycle (DC)



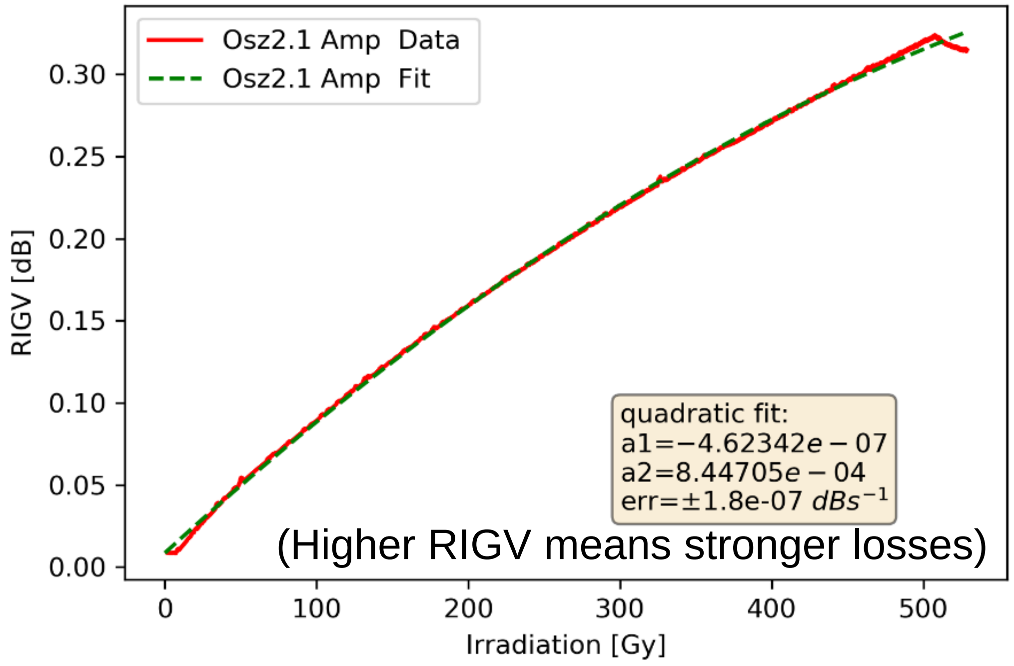
Laser Co_{60} irradiation geometry

RIGV of Radhard Fiber Laser

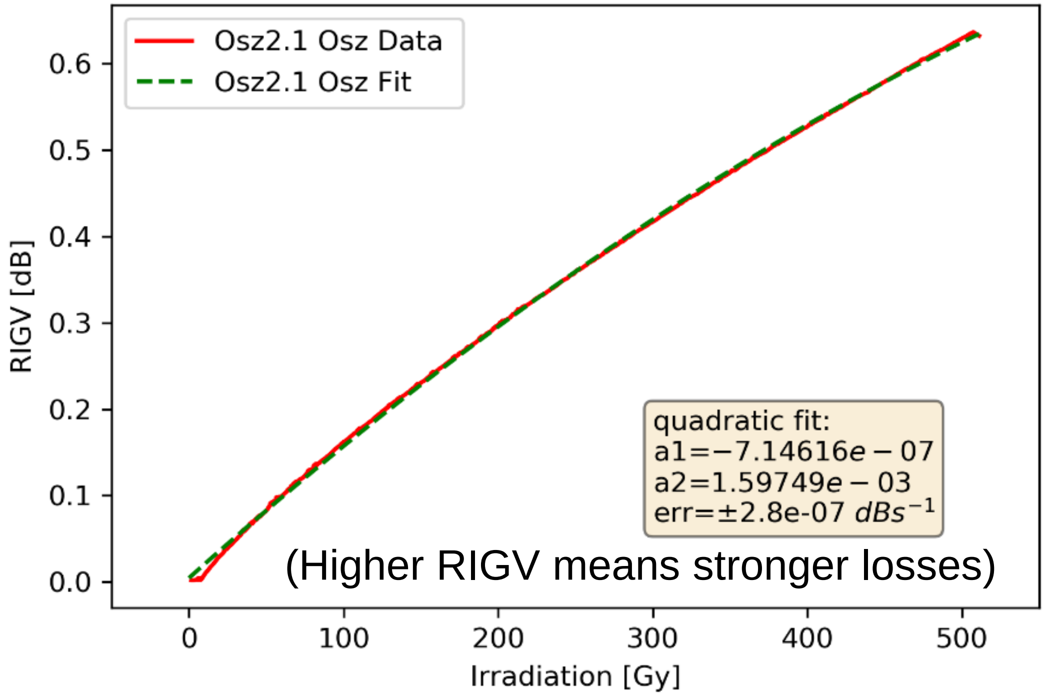
Irradiation with 1 kGy (10 years MEO) operated at 90% DC

- radiation induced gain variation (RIGV) measured
- Amplifier output loss is about 1/10 compared to standard fiber
- Oscillator looses about 13% of output power

Amplifier RIGV



Oscillator RIGV



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Thank you for your attention!