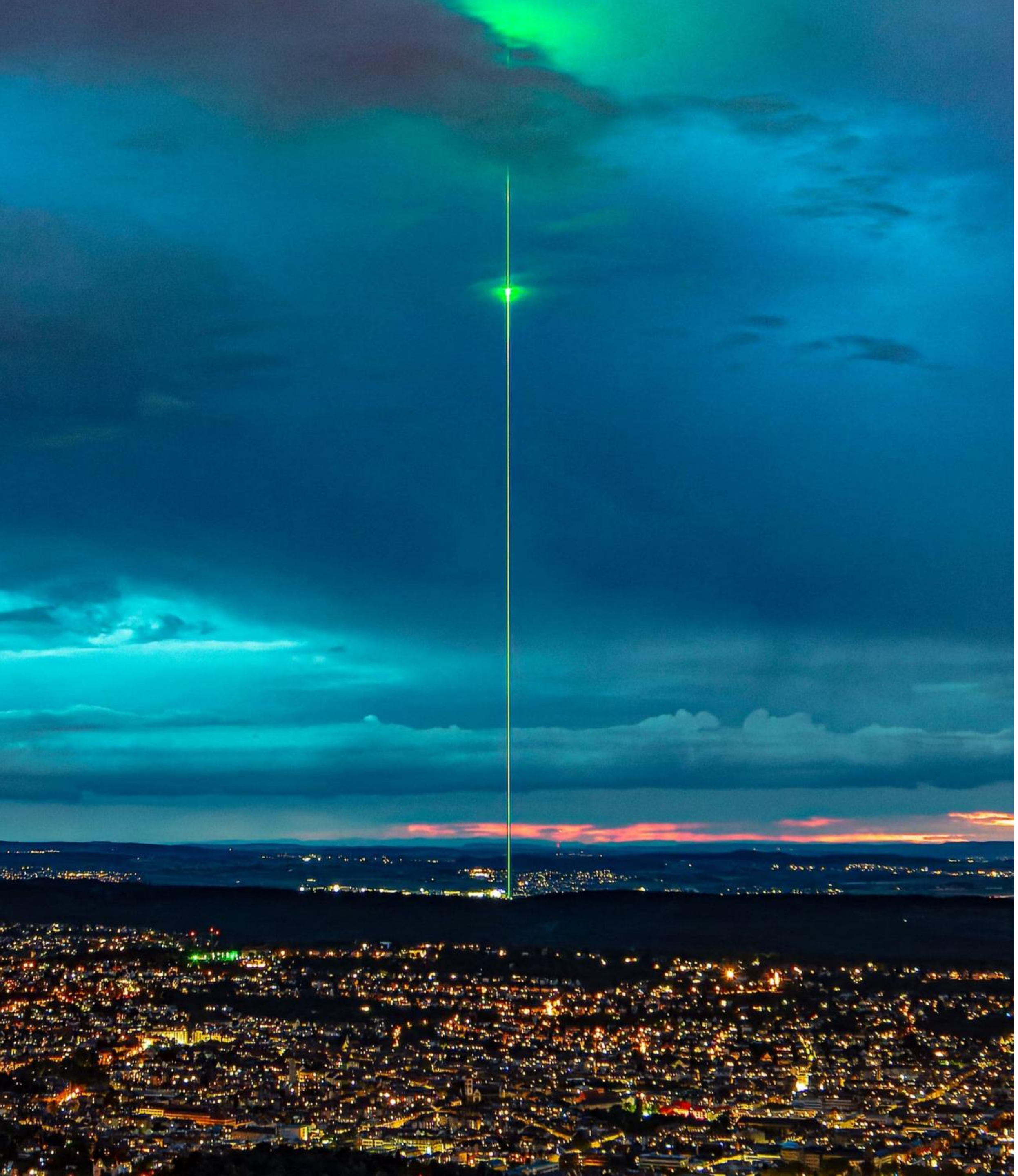


Fachhochschule Nordwestschweiz FHNW – Dec. 4, 2023

TRUMPF's step into space

From laser-based 3D metal printing to quantum sensors

Dr. Berthold Schmidt | CTO TRUMPF

TRUMPF 100 1923–2023

AI-Response to: “A Swiss cheese with holes made of silver shiny metal in outer space” (Dall-E3)

Motivation

- Cooperation with new partners (private space industry)
- Exploring innovative, composite materials
- Realization of new structures
- New technologies for stringent applications
- AI assisted design approaches

TRUMPF 100 1923–2023

Agenda

01 Introduction to TRUMPF

02 3D metal printing for space applications

03 Quantum Gyroscope (QYRO) for position control of satellites

TRUMPF 100 1923–2023

Agenda

At a glance – key corporate figures

Fiscal Year 22/23

Sales revenue (bn. EUR)
5.4
+27 %

Order intake (bn. EUR)
5.1
–8.8 %

Employees as of June 30, 2023
18,352
+10.9 %

Earnings before interest and taxes (EBIT) (m. EUR)
615
+31.4 %

EBIT margin
11.5 %

R+D costs (m. EUR)
476
+6.3 %

R+D quota
8.9 %

Investments (m. EUR)
316
+44.7 %

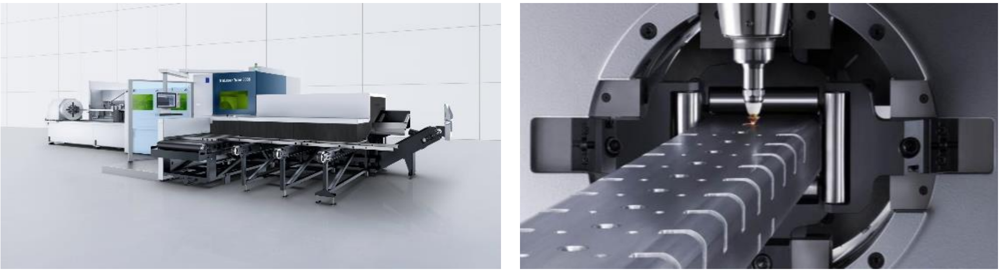
Business Unit Machine Tools (MT)

Machines for laser cutting

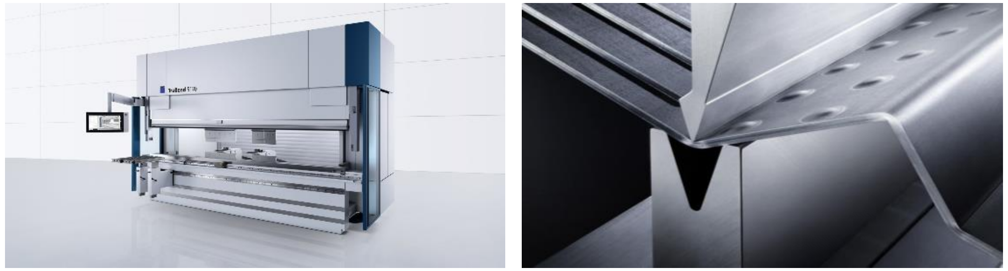
Machines for laser welding

Machines for punching and punch laser processing

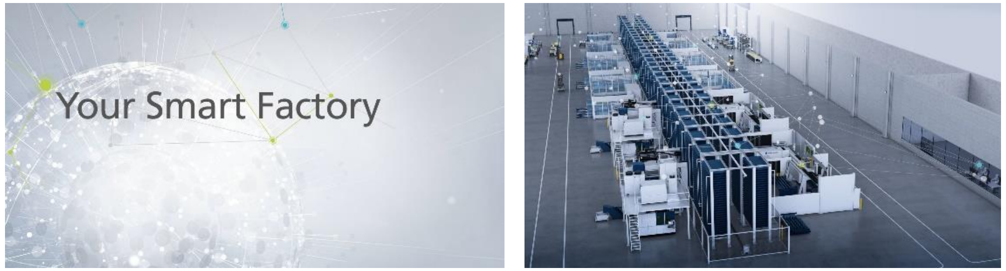
Machines for tube processing



Machines for bending

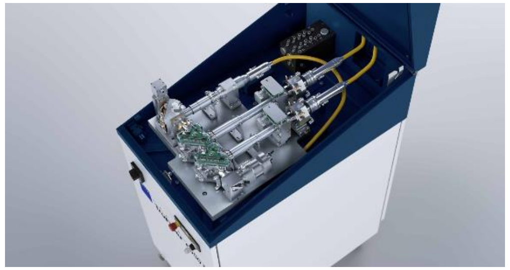


Solutions for networked production



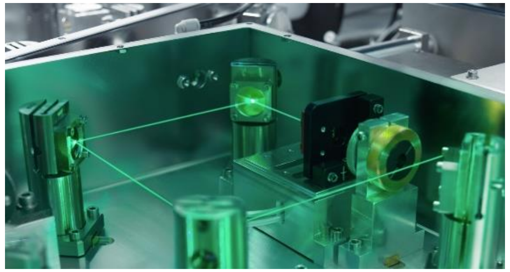
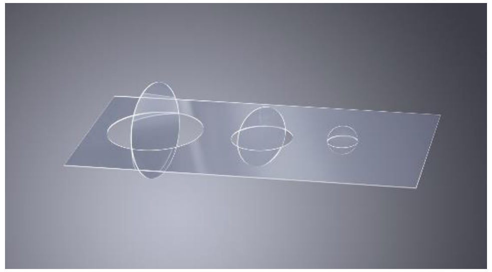
Business Unit Laser Technology (LT)

CW High-power Lasers



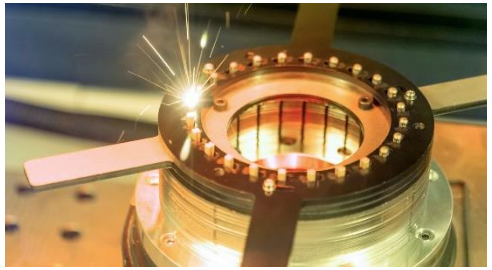

Laser Systems


Short/Ultrashort Pulse Lasers

Machines for Additive Manufacturing


Processing Optics and Sensors

Marking Lasers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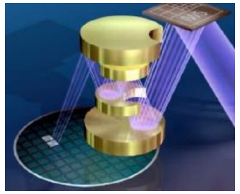
Business Fields: EUV, Electronics, Photonic Components

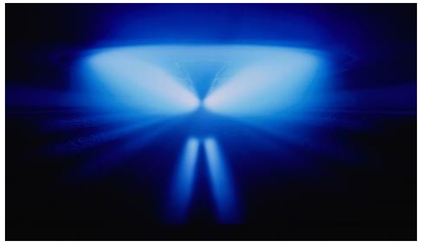
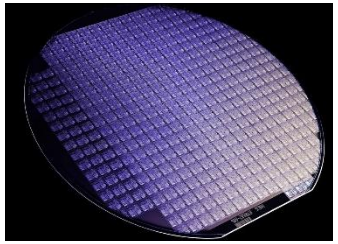
EUV

Drive laser systems for EUV lithography

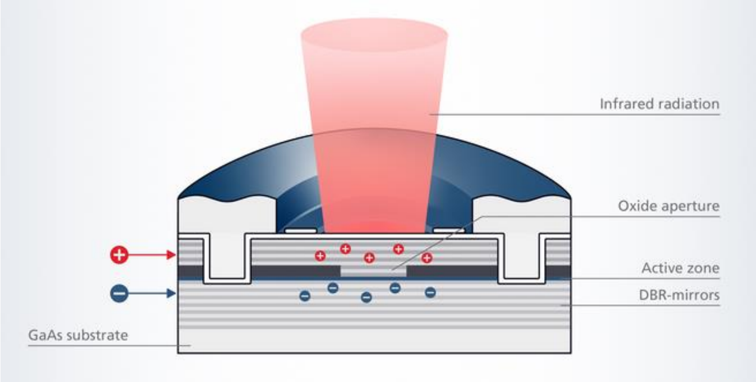

Electronics (E)

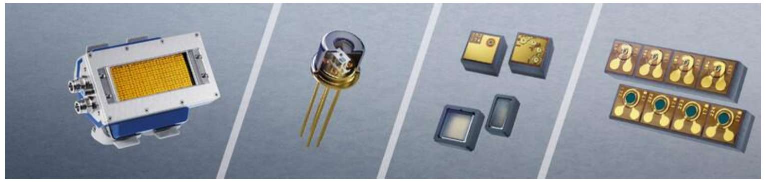
Power electronics, especially plasma generators for the semiconductor industry


Photonic Components (PC)

Semiconductor lasers (VCSELs) for sensing and datacom applications





Agenda

01 Introduction to TRUMPF

02 3D metal printing for space applications

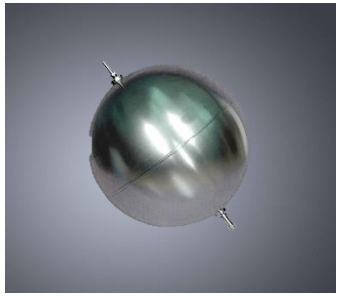
03 Quantum Gyroscope (QYRO) for position control of satellites

Space – Laser Applications Examples & Overview

Supporting more efficient manufacture of launch vehicles and components

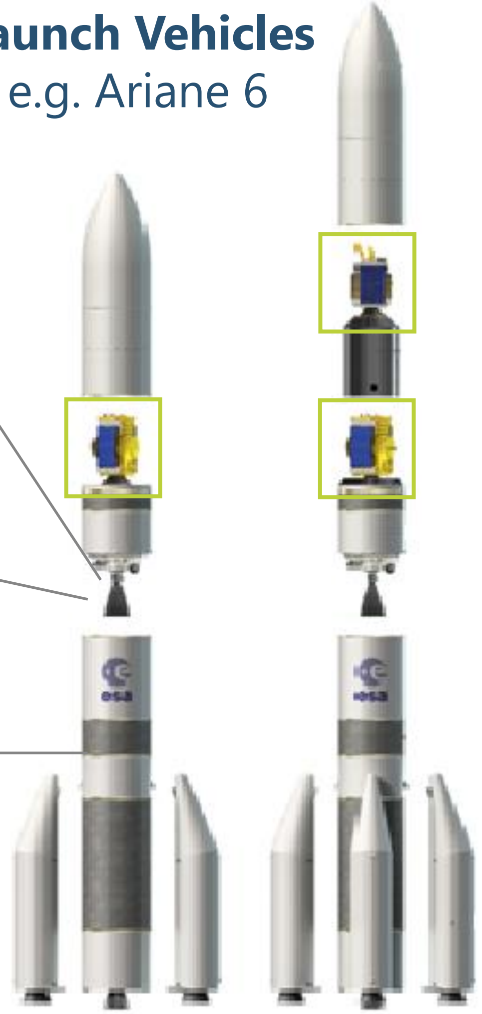
AM – Ignition Chambers
Material: Ni/Cu-Alloys
Courtesy of Hyperganic

AM by DED – Thrusters with cooling channels
Material: Cu-Alloys
Courtesy of RPM Innovations



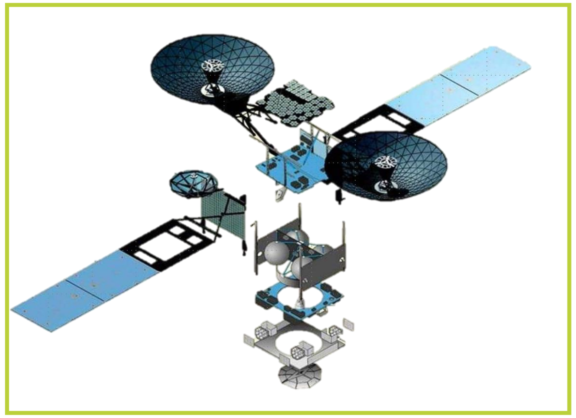
Joining/AM by DED – Structures
Material: Titanium, Aluminum

Launch Vehicles
e.g. Ariane 6



Source: DLR German Space Agency; Credit: Arianespace

Payload / Satellites
e.g. Data/Relay Satellites



Source: NASA illustration of TDRS (Tracking & Data Relay Satellite)

Depending on mission type a broad range of laser applications are of interest for satellites

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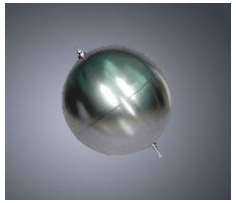
Space: Satellites – Laser Applications Examples & Overview

Many powder bed AM applications are already used in satellites

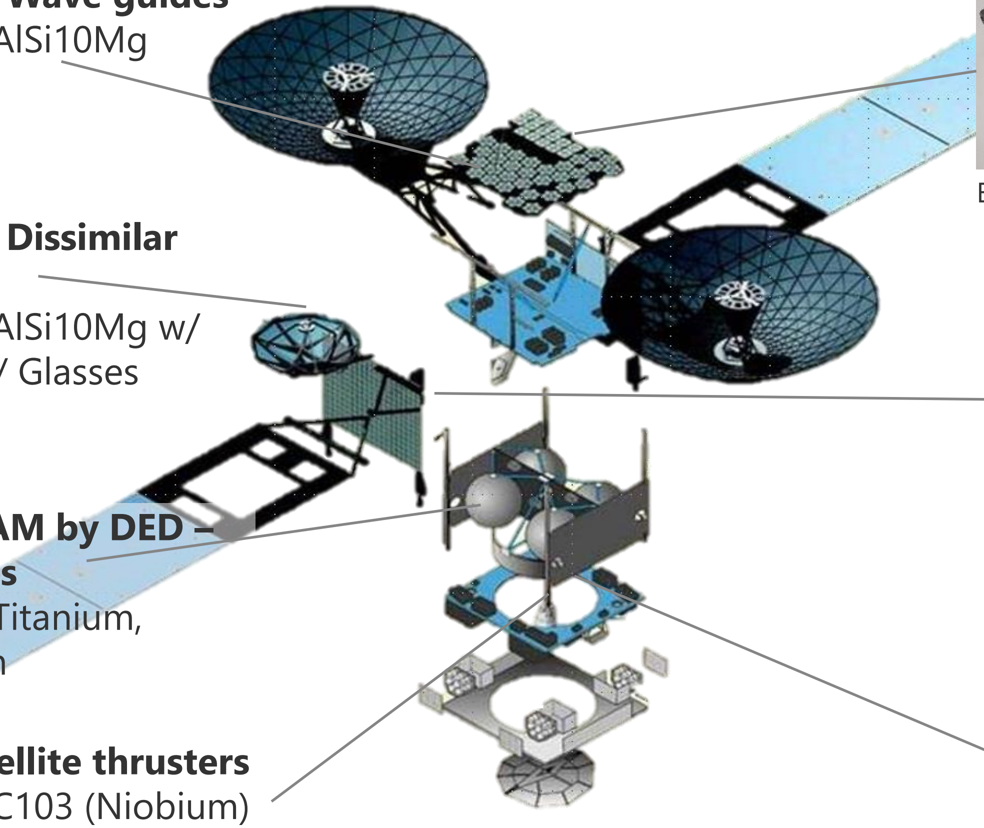
Joining – Wave guides
Material: AlSi10Mg

Joining – Dissimilar materials
Material: AlSi10Mg w/ Sapphire / Glasses



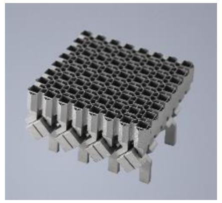
Joining/AM by DED – Structures
Material: Titanium, Aluminum

AM – Satellite thrusters
Material: C103 (Niobium)
EXHIBITION SAMPLE



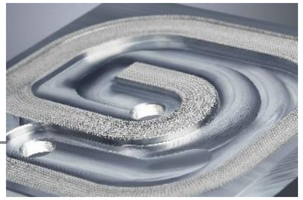
Source: NASA illustration of TDRS (Tracking & Data Relay Satellite)

Brackets

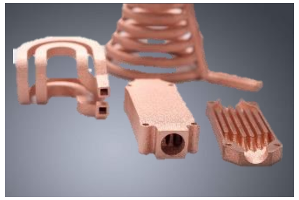


RF Antennas

AM – Sub payloads components
Material: AlSi10Mg
EXHIBITION SAMPLE



Cleaning & Structuring – Heat exchanger
Material: Different materials



AM – Coils & Heat Exchangers
Material: Pure copper

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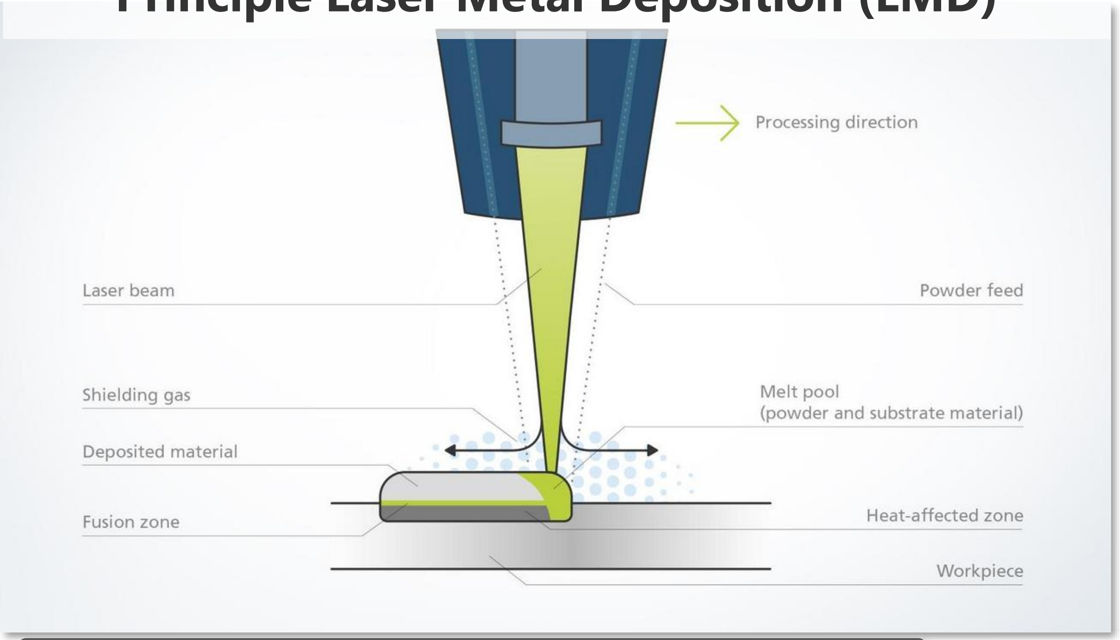
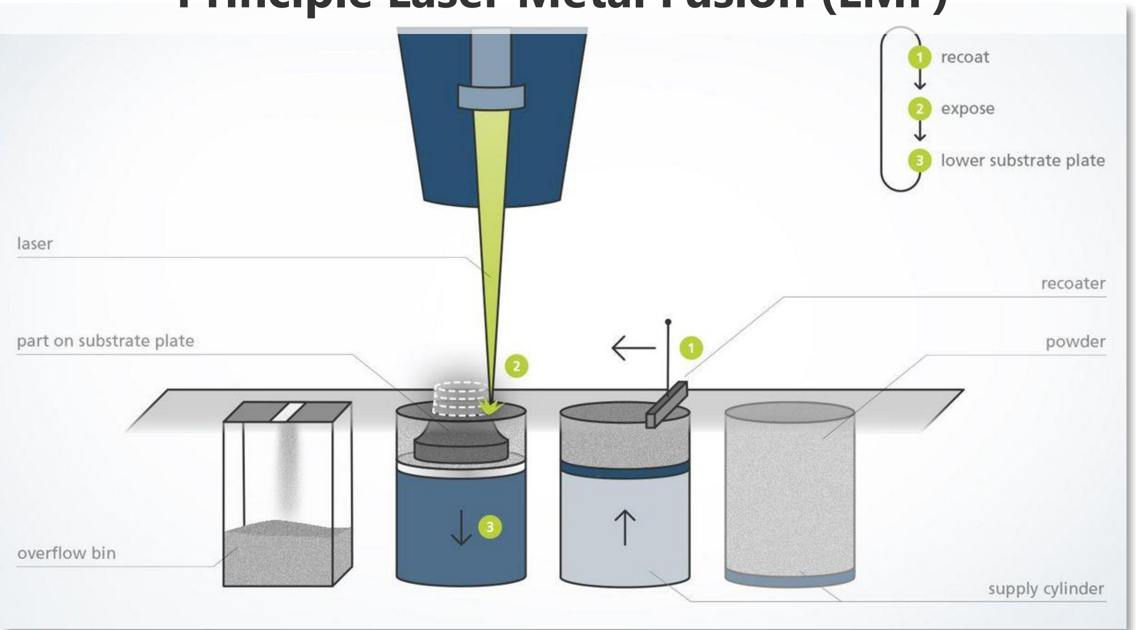
Laser Additive Technologies LMD & LMF – Working Principles

Complementary technologies with individual benefits

Principle Laser Metal Deposition (LMD)

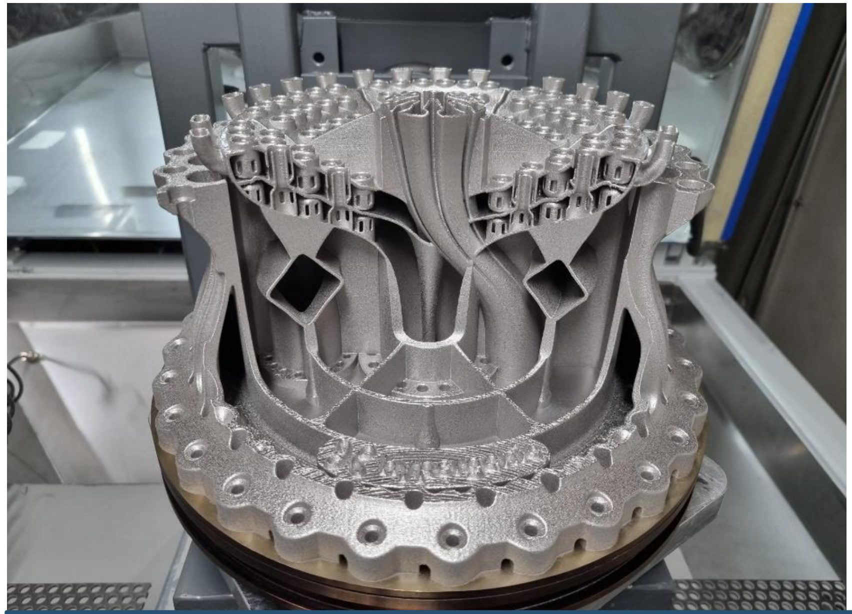


Principle Laser Metal Fusion (LMF)



Ti-6-2-4-2 Applications

AI assisted design: Injector Head by Hyperganic



Hyperganic Group GmbH “Injector Head”

- Material: Ti-6Al-2Sn-4Zr-2Mo
- Machine: TruPrint 5000 with 500°C preheat option
- Number of layers: 2410 at 60mm
- Build Time (multilaser): 27 hours, 51 min
- Cost: approx. €2,905 without heat treat & post processing

Rocket Injector Ring by GERG

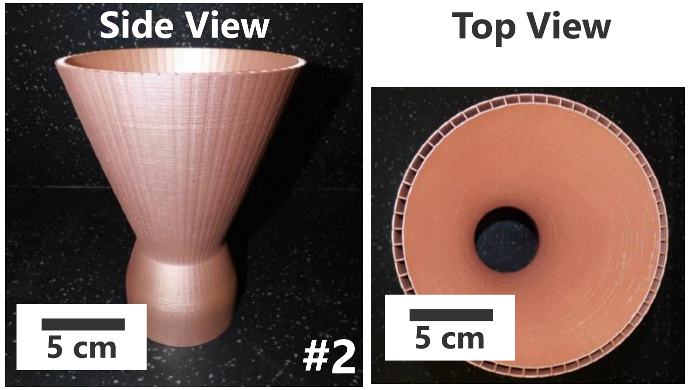
GERG “Rocket Injector Ring”

- Material: Ti-6Al-2Sn-4Zr-2Mo
- Machine: TruPrint 5000 with 500°C preheat option
- Number of layers: 3953 at 60mm
- Build Time (multilaser): 28 hours
- Cost: approx. €2600 without heat treat & post processing

a) Modell-&Formenbau Blasius GERG GmbH

Additive Manufacturing of Metal Structures – Rocket Nozzles

Cost efficient AM for very big structural parts using LMD-Technology



Benefits
- Lowest material costs & highest part properties by AM[1]
- Use of green laser for e.g. copper (#2)

Relevant Features
- Part size only limited by size of gantry or robot system (#1)

Application Details
- Build-up of features with surface resolution of approx. <0.5mm (#3)
- Build-up of Cu-alloys with internal cooling channels (#2)
- Build-up rates can be much higher than powder bed process
- No "support material" needed → much lower powder consumption
- Often used materials for AM purposes:
  Inconel 625, Inconel 718 (#3). Potentially copper alloys.

[1] AM Additive Manufacturing

Results – Nozzle Thruster Mock-Up

By use of high-power green laser sources high build-up rates are achievable

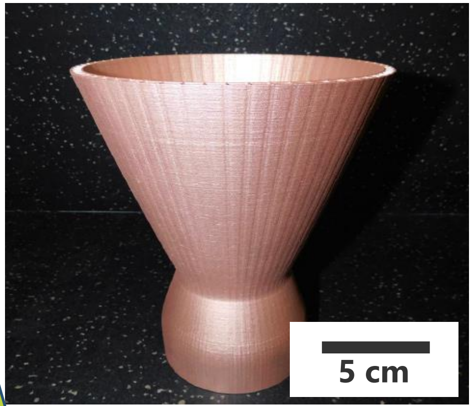
Build-up of volumes with green feasible

- Using a 1 – 3kW laser source to proof higher build-up rates
- Scaling of existing process parameters to higher laser powers feasible
- Process optimization depending on application & design needed

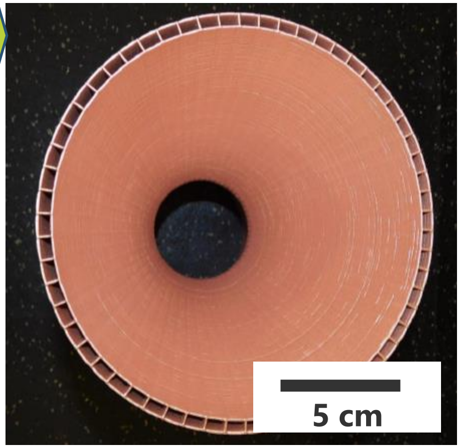
→ Wall thickness of approx. 1mm

→ Layer height of approx. 300-500 µm

→ Using LMD up-to factor 10 less powder consumption in comparison to PBF-processes



Side View



Top View

Courtesy of RPM Innovations

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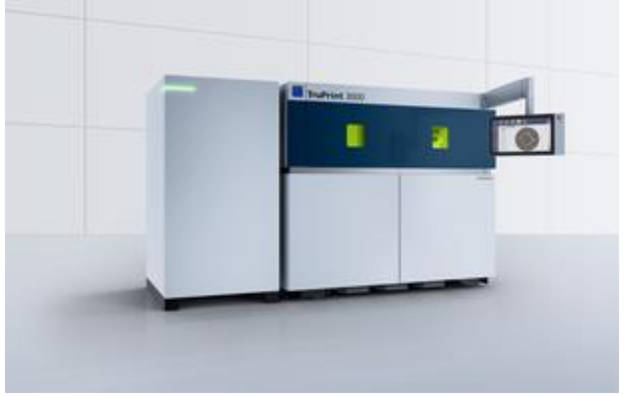
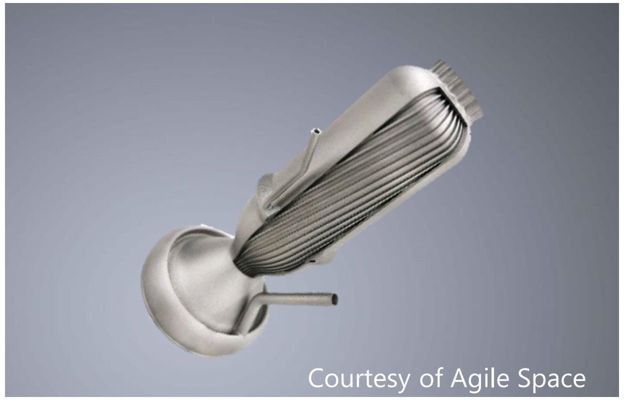
Laser Metal Fusion – Propulsion Applications

From rocket engines to small satellite thrusters



Courtesy of *1



Courtesy of Agile Space

Benefits

- Weight and cost reduction
- Suitable for relevant batch sizes
- General feasibility

Relevant Features

- Advanced cooling designs
- Reduction of parts per assembly

Application Details

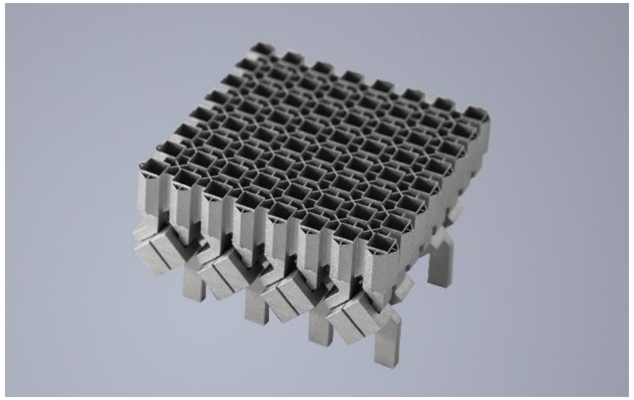
- Used materials: Inc 718, Inc 625, Ti6Al4V
- C103 material for use in cryogenic environment
- Printing of other refractory metals possible
- Reduction of support structures to maintain geometry & allow sustainable business case

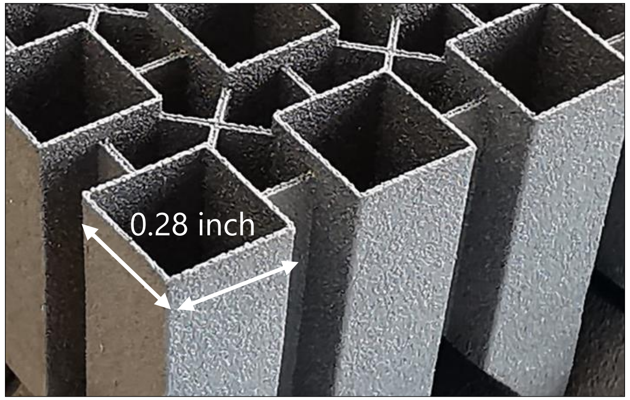
TRUMPF 100 1923–2023

Laser Metal Fusion – Waveguide & Antenna Applications

Complex and monolithic geometries addressable

EXHIBITION SAMPLE





Benefits
- Weight and cost reduction
- Advanced designs possible

Relevant Features
- Ra surface “as printed” between 3-5 µm
- Monolithic (integral) design approach

Application Details
- Excellent printing resolution to even address K_u & K_a band frequencies
- AlSi10Mg alloy
- 20 µm layer thickness
- Printing time for 4 antennas of 18 hours
- Low geometrical deviation e.g. Ka band filter below 50 µm

Agenda

Quantenbasierte Gyroskope

Die Zukunft der hochpräzisen Lagebestimmung im Weltall

Nuclear Spin-Based **Q**uantum G**yro**scopes for New Space Applications

QANT

Galileo Kompetenzzentrum

Leibniz Ferdinand Braun Institut

BOSCH

TRUMPF

DLR

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

QYRO targets to bring a NMR gyro sensor into space

Bundesministerium für Bildung und Forschung

quanten technologien

Project Goal:

- Develop, launch and validate a **quantum-based gyroscope** as an efficient and low-cost alternative technology compared to commercial classical gyros for space navigation.
- A highly sensitive atomic NMR gyroscope will sense rotation and **provide accurate position control** of CubeSats for communication.
- **First satellite controlled by quantum technology!**

Funding:

- Joint project funded by the Federal Government of Germany (BMBF) under *"Lighthouse projects in quantum-based measurement technology to address society challenges"*
- Duration: 5 years (2022 to 2027)

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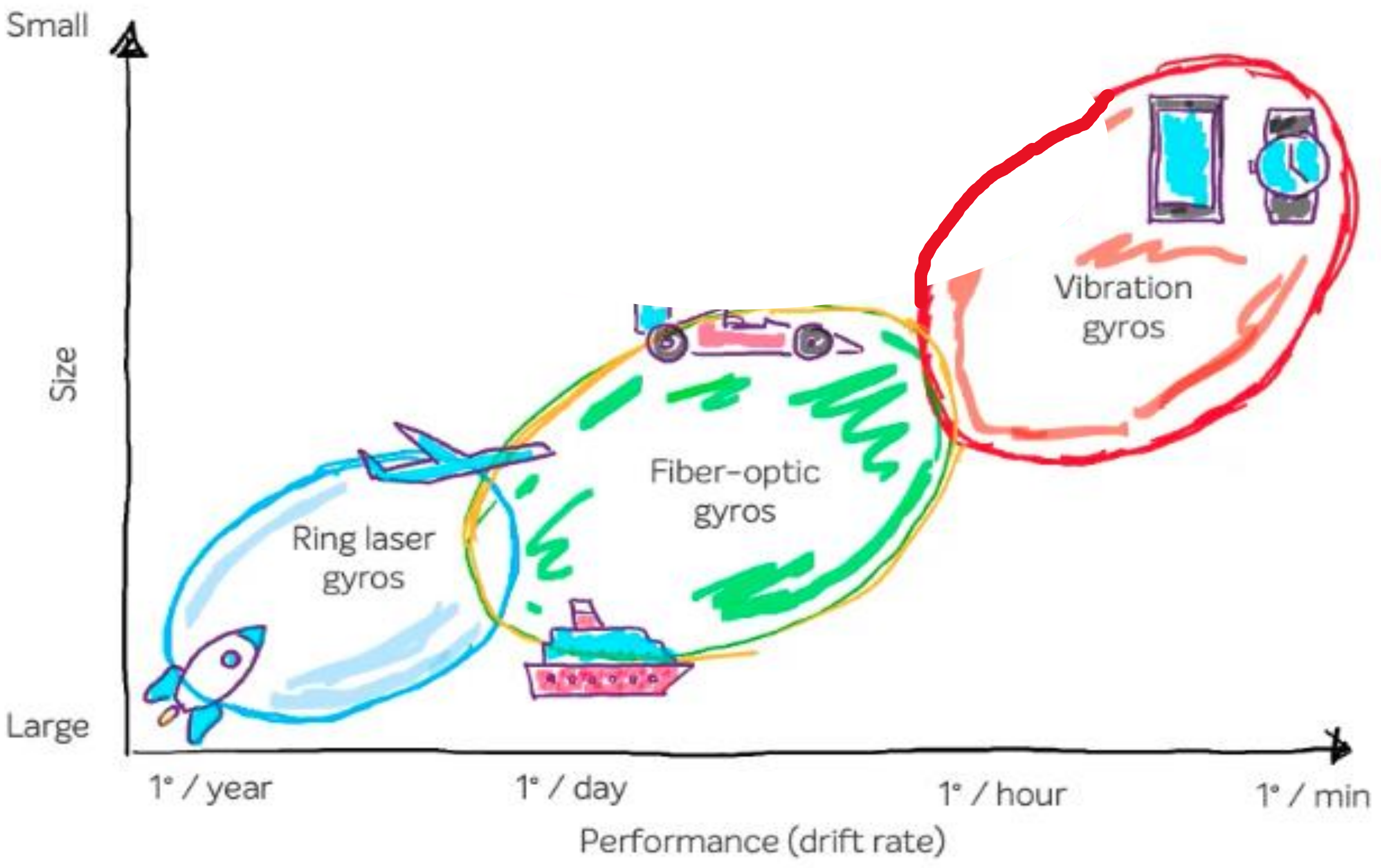
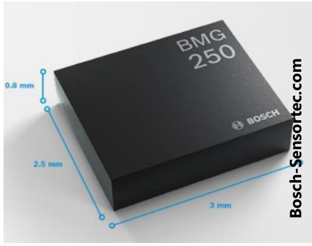
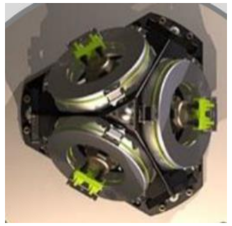
There are at least four conventional inertial sensor technologies for gyroscopes





MEMS / vibration Gyro
Coriolis force

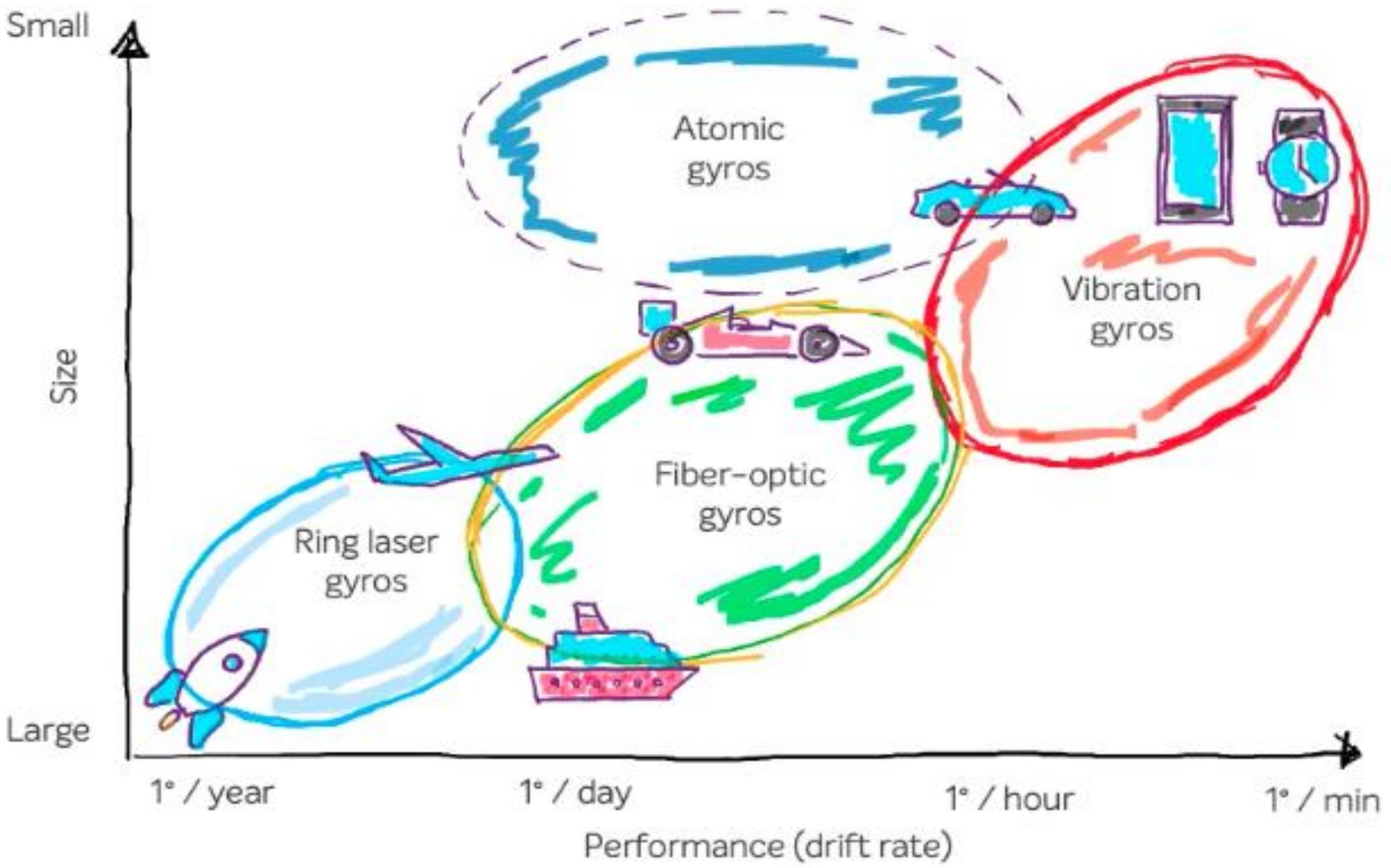
Fiber-optic Gyro (FOG)
Sagnac interference

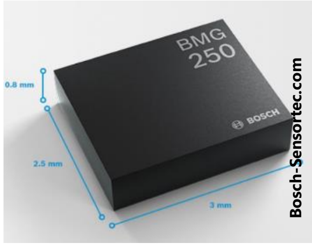


Ring Laser Gyro
Sagnac interference

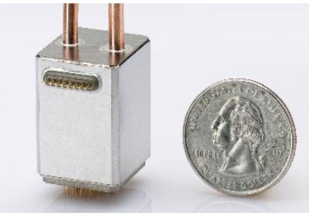
TRUMPF 100 1923–2023

There are at least four conventional inertial sensor technologies for gyroscopes



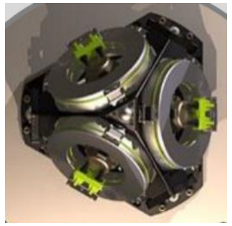


MEMS / vibration Gyro
Coriolis force



NMR (atomic) Gyro
Nuclear Magnetic Resonance
Northrop Grumman Corporation (NGC)

Fiber-optic Gyro (FOG)
Sagnac interference



Ring Laser Gyro
Sagnac interference

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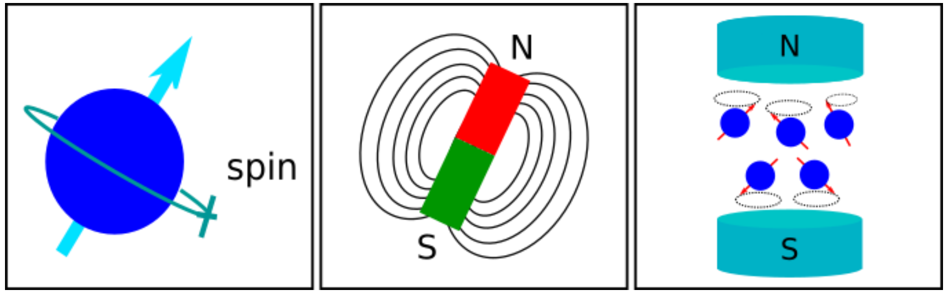
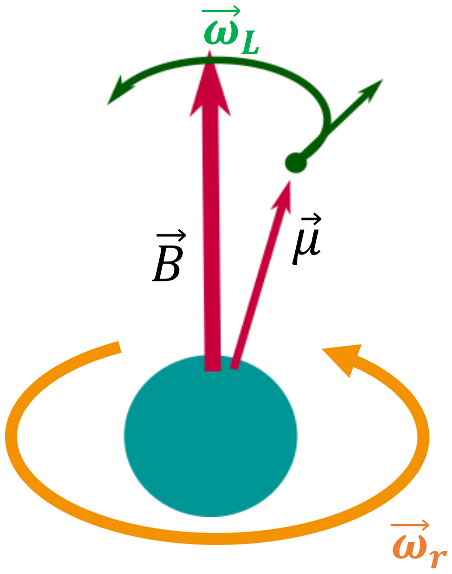
We sense the nuclear spins to determine angular rotation



Rotating charges exhibit a magnetic moment $\vec{\mu}$

Magnetic moments in external B-field



What: Measuring the Nuclear Magnetic Resonance (NMR) of noble gases.

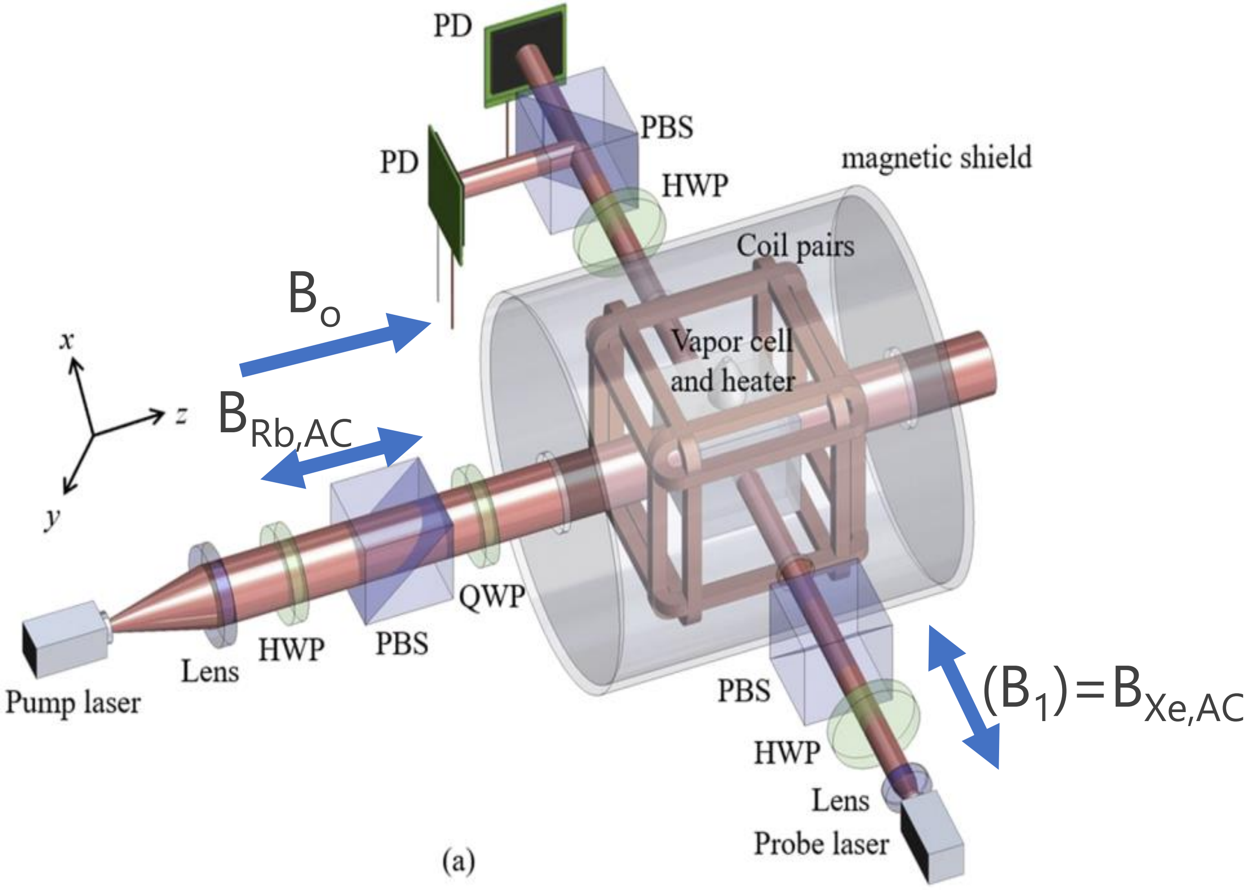
Where: Enclosed in a miniaturized atomic vapor cell, magnetically isolated from the outside world.

How: The nuclear spins of atoms are precessing in an applied and constant magnetic field at the *Larmor frequency* $\vec{\omega}_L$ defined by a natural constant.

If there is an external mechanical rotation $\vec{\omega}_r$ the Larmor frequency of the nuclear spins will shift proportional to the external rotation.

Why? determining changes in the orientation around its sensitive axis (defined by B-field) to measure angular rotation with high sensitivity.

A hot vapor cell is the sensor core of a NMRG



AIP Advances **10**, 075209 (2020)

Component	Function	Partner
Laser diodes	795 nm Pump and Probe (VCSEL)	FBH,TPC, TLB
MEMs vapor cell	Rb, Xe hermetically sealed, heated	BOSCH
Magnetic fields and shielding	3-axis magnetic coils (B_o, B_{Rb} and B_{xe}) 3-layer magnetic shielding	BOSCH
Detector	Polarization filtering probe beam detection (balanced detector)	Q.ANT
Laser driver	Low noise current and temperature driver	Q.ANT

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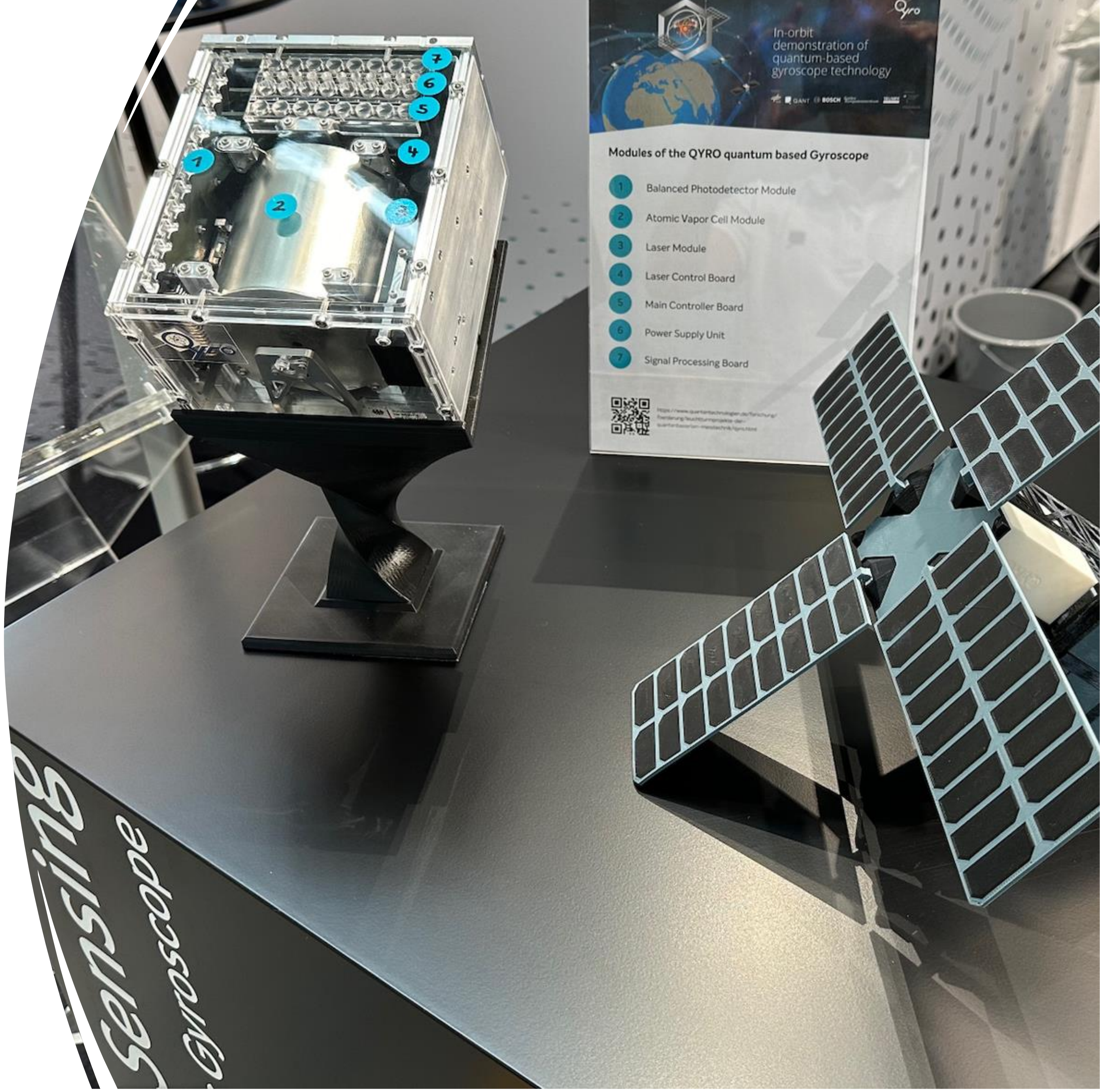
FlatSat model (non-functional) was presented at Quantum Effects fair in Stuttgart (October 2023)

- QYRO FlatSat in real scale
- PETER CubeSat model on the right (white box in satellite is the QYRO unit)
- Launch is planned in 2027



Thank You.

Contact Person

Dr. Berthold Schmidt | CTO