The RVS3000 rendezvous and docking sensor technology

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RVS3000 Rendezvous & Docking Sensor Technology

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The city of Jena.

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German Optical Valley: Tradition and Future

Our partners:

Ernst-Abbe-Fachhochschule Jena
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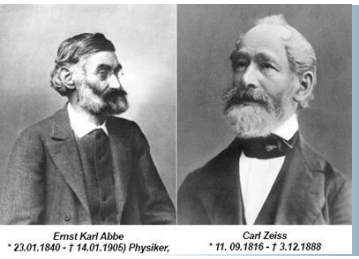
Tradition and future



inspired by the pioneers of the optics industry

visionary technology & innovative solutions for modern space systems

Jena-Optronik is world´s leading supplier for

- **AOCS Sensors (Star Sensors and LIDAR Sensors)**
- **Instruments and components for optical Earth observation**

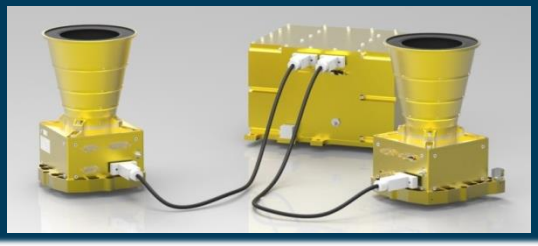
- **Location:** Jena, Germany
- **Core business:** AOCS sensors & optical instruments for Earth observation
- **President & CEO:** Dietmar Ratzsch
- **Employees:** 248 (as per Oct 2018)
- **Revenue 2017:** 55 Mio €
- **Equipment capacity:** up to 100 star sensors per year

Cutting edge technology

Products and solutions from Jena

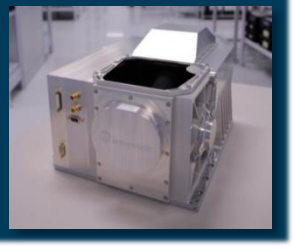
Star sensors (ASTRO product family)

- Market leader #1 for telecom and earth observation missions
- System solutions for primes
- 1st tier supplier



LIDAR sensors (RVS product family)

- World leader: the most successful LIDAR sensor for Rendezvous and Docking to supply the ISS
- New generation RVS 3000 sensor
- New market of in-orbit servicing and future lander missions/applications



Optical instruments and subsystems

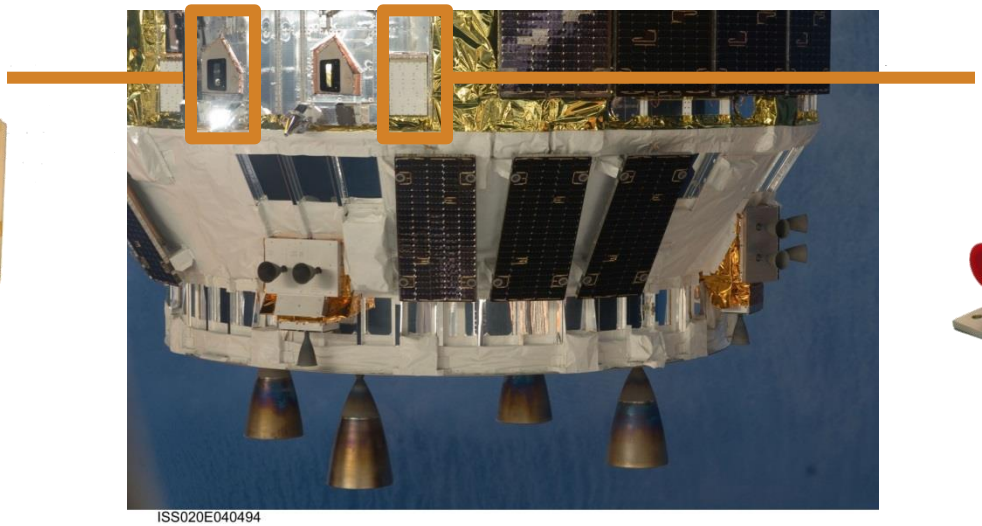
- Solid multi-spectral imager, efficient radiometer, electronic as well as opto-mechanical subsystems and components for operational Earth observation
- Instruments and components for space exploration; Software & data processing

- Boeing "Supplier of the year 2006" & nominee 2018
- Space Systems Loral „Supplier Excellence Award“ 2016
- Mitsubishi Electric Corporation “Best Supplier Award” 2014
- Mitsubishi Electric Corporation “Best Supplier Award” 2011
- Mitsubishi Electric Corporation “Certificate of Appreciation“ 2009
- Astrium "Master supplier 2007“

RVS Heritage

RVS® - the world's most proven rendezvous & docking sensor

- **43 Flight Units already delivered**
- **36 Units Flight Heritage**



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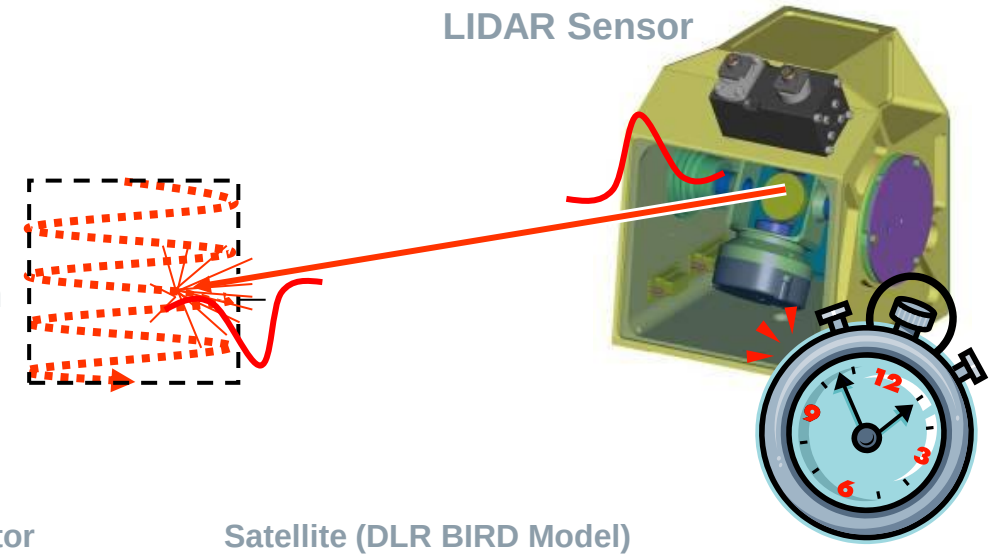
LIDAR sensors for Rendezvous & Docking

RVS, RVS3000, RVS3000-3D

- **Leading sensor for vehicles approaching ISS**
- **ISS re-supply vehicles using JOP LIDAR sensors:**
  - Space Shuttle (two qualification flights for RVS)
  - ATV (RVS as operative sensor on all missions & RVS3000 family optical block on-orbit demonstration flight on ATV5)
  - HTV (RVS)
  - Cygnus (RVS)
  - Dream Chaser (RVS3000 primary sensor & RVS3000-3D secondary sensor)

Time-of-Flight (Scanning) LIDAR Working Principle

LIDAR Sensor



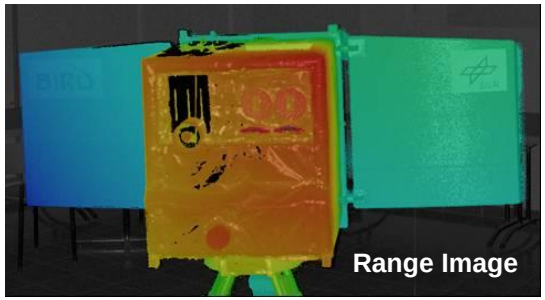
Scan Pattern

Scanning of a target object with a moving scan mirror

Range measurement with time-of-flight of a laser pulse

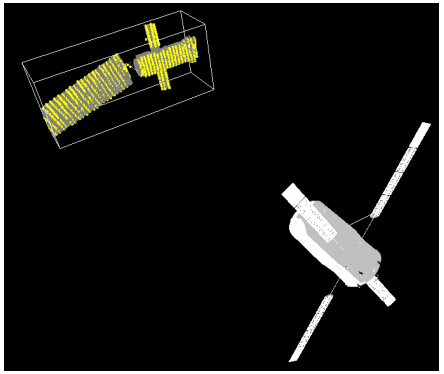
Retro Reflector

Satellite (DLR BIRD Model)



2.9 m 3.8 m

LIDAR scanning of Envisat



Astrium / JOP

Features of a Scanning LIDAR

Scanning LIDAR uses a movable mirror system to steer the laser beam

- Completely flexible FoV (1° x 1° … 40° x 40°) and scan parameters (low speed – high resolution „megapixel image“ vs. high speed – low resolution for pose estimation of fast-moving objects)
- High LOS resolution possible

Single detection channel

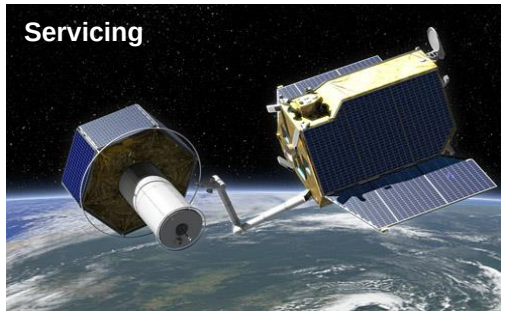
- High dynamic range – from non-cooperative targets at long distance to reflective elements at short distance
- High range resolution

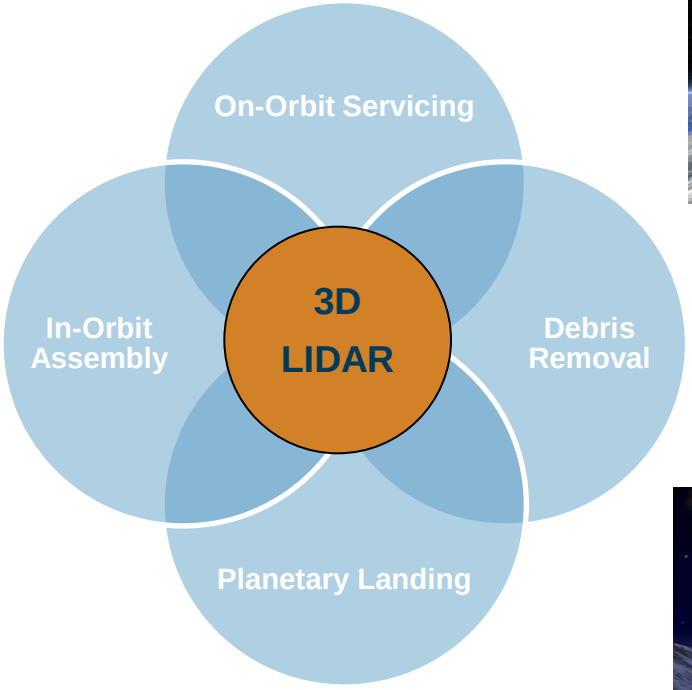
Detection channel as standalone Laser Range Finder

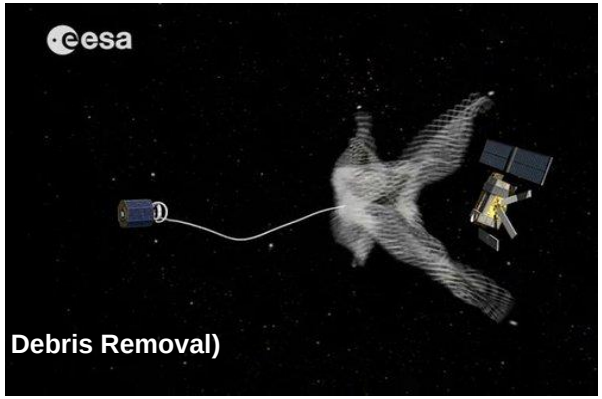
- The detection channel can be used as a high-accuracy non-scanning Laser Range Finder for distance measurements („Laser Altimeter“)
- Options:
  - Compact Laser Altimeter using stand-alone detection channel
  - Scanning LIDAR system with Laser Altimeter mode for extended operating range

Optical Relative Navigation Sensor Applications

New challenges







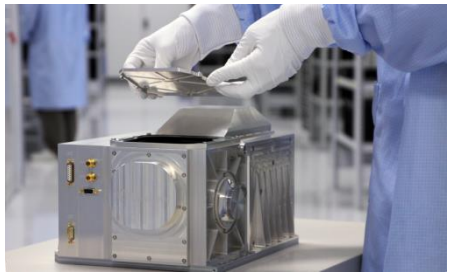
Jena-Optronik LIDAR Sensors for Rendezvous and Docking




RVS-ARP

RVS for ATV / HTV / Cygnus
43 Flight Models delivered (2 more under contract), flawless flight heritage



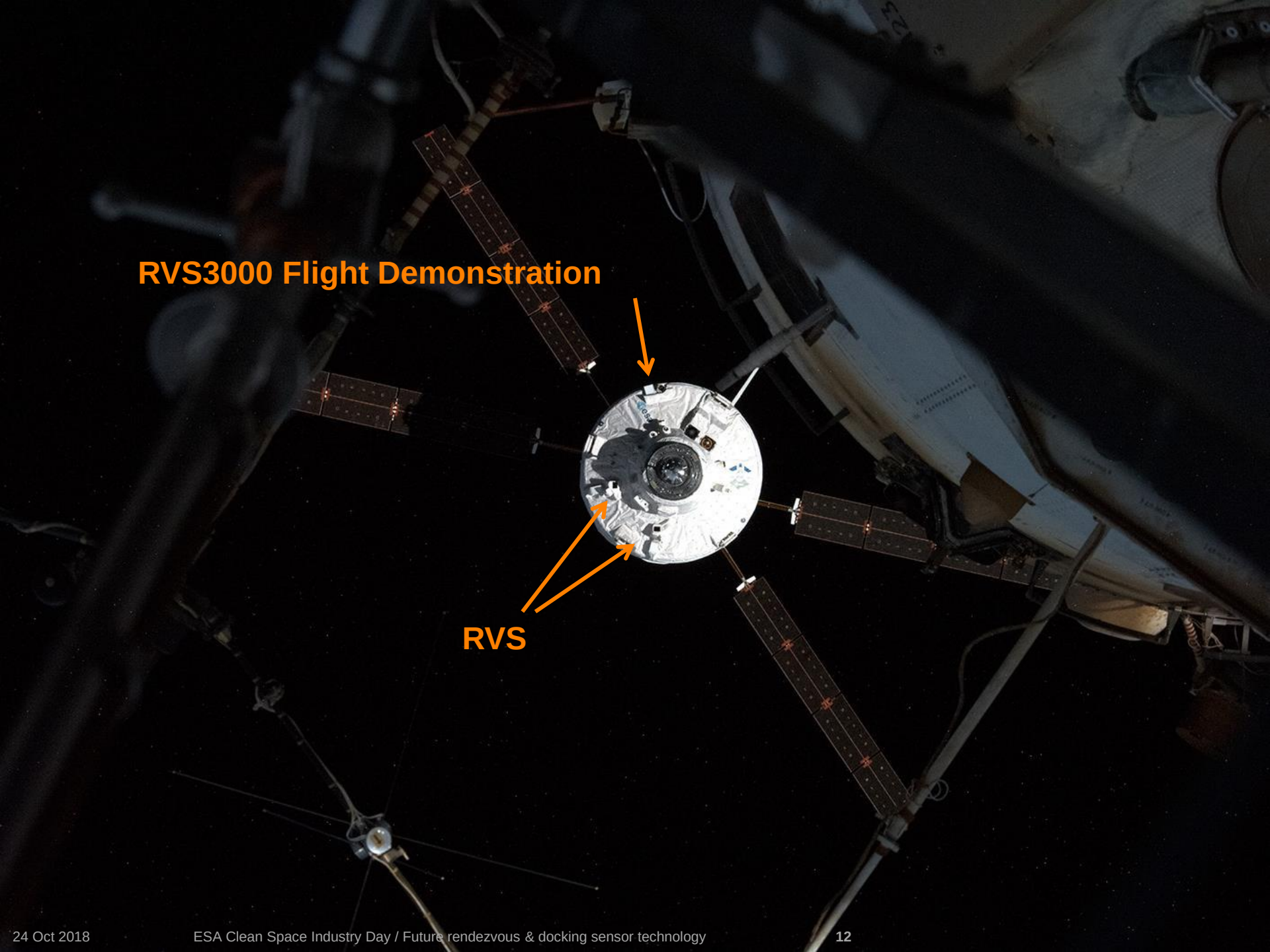


LiQuaRD*

LIRIS-2 on ATV-5

RVS3000

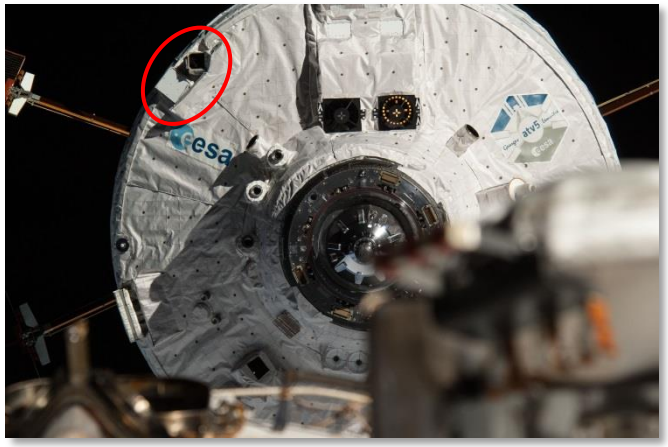
*** LIDAR Qualification for Rendezvous and Docking (DLR)**


RVS3000 Flight Demonstration
RVS

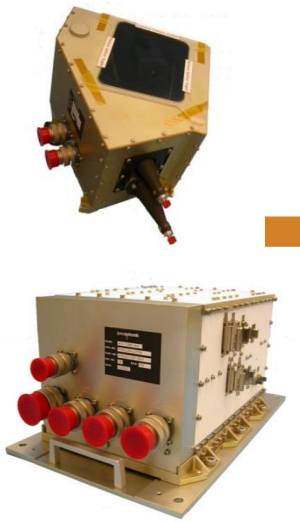
LIRIS-2: RVS3000 Flight Demonstration on ATV-5

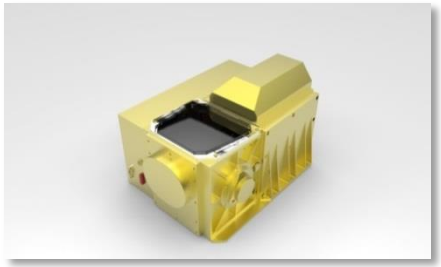
LIRIS (Laser Infrared Imaging Sensor) Technology Demonstration on ATV-5 „Georges Lemaître“

- RVS3000 flight demonstration model designed, built and qualified for first space flight within about 1 year
- Acquisition of 3D image data during ATV-5 approach to ISS
- Switch-on at ca. 3500m to collect retroreflector data
- 3D image data from ISS (operating range limited by laser eye-safety regulations for ISS)
- 3D data from sensor is time-correlated with the approach data of the operational RVS (TGM) / VDM sensors on ATV-5
- 1.3 GB of 3D data and housekeeping data collected
- Additional switch-on after undocking
  – nominal performance after 6 months in orbit



LIDAR Sensors
RVS3000 and RVS3000-3D





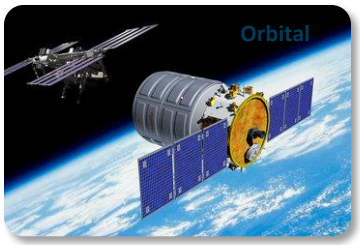
3D Imaging LIDAR in One-Box-Design

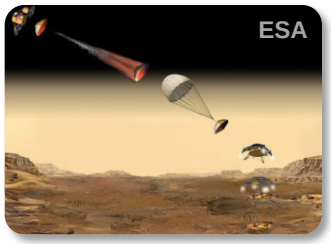
RVS3000 (Imaging LIDAR)

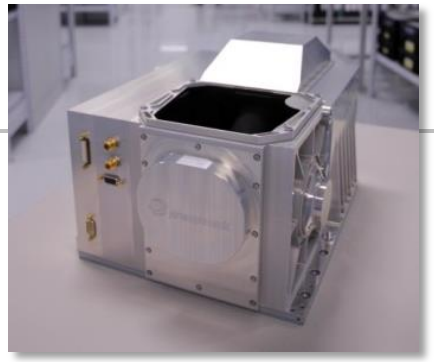
- intended for cooperative targets (retroreflectors), e.g. ISS supply → short-duration LEO missions
- internal data processing for retroreflector targets
- reduced laser power for eye safety

RVS3000-3D (3D Imaging LIDAR)

- intended for non-cooperative targets, e.g. space robotics, on-orbit-servicing → long-duration LEO/GEO missions
- more powerful internal processing than RVS3000 → pose estimation
- high laser power for large operating range against non-cooperative target







LIDAR Sensors
RVS3000 and RVS3000-3D

RVS3000
cooperative targets

3D-LIDAR in One-Box-Design

- intended for cooperative targets (retroreflectors), e.g. ISS supply → short-duration Low-Earth-Orbit missions
- internal data processing for retroreflector targets
- reduced laser power for eye safety
- One-box-design for simplified test, handling and installation

RVS3000-3D
non-cooperative targets

3D Imaging LIDAR in One-Box-Design

- intended for non-cooperative targets, e.g. space robotics, on-orbit-servicing → long-duration Low-Earth-Orbit / Geostationary Orbit missions
- more powerful internal processing than RVS3000
- high laser power for large operating range against non-cooperative targets
- One-box-design for simplified test, handling and installation

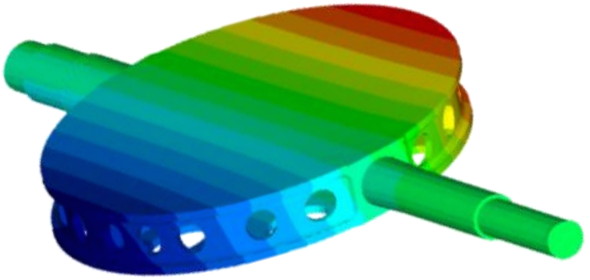
LIDAR Sensors
RVS3000 and RVS3000-3D

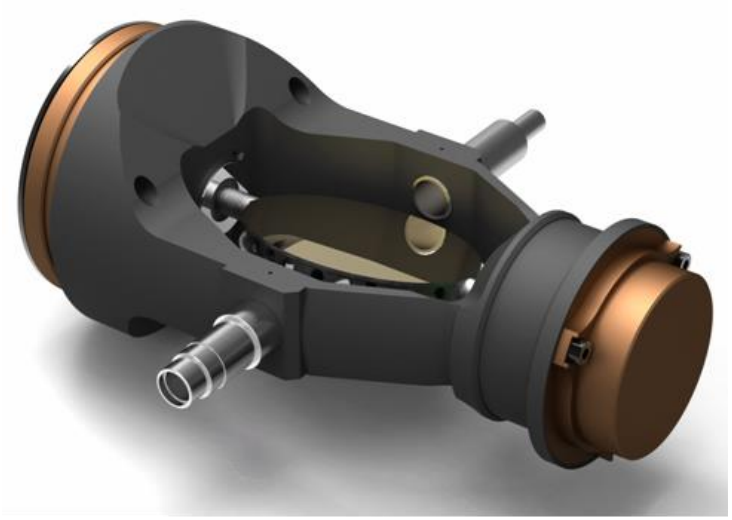
Specification Summary

Parameter	Heritage RVS	RVS3000	RVS3000-3D
Mirror system	2 separate scan mirrors	1 gimbal-mounted scan mirror	
Field-of-View	1° x 1° … 40° x 40°	1° x 1° … 40° x 40°	
Laser system	Laser diode 912nm, class 1 eye-safe	Fiber laser 1550nm, class 1 eye-safe	Fiber laser 1550nm, class 3B, three power levels
Max. operating range retroreflectors	1300 m	Up to 3000 m (customer-specific)	
Max. operating range non-cooperative targets	n/a	(ca. 200m)	ca. 1400 m for reflectivity = 0.17
Range noise (3sigma)	better 0.1% of range	better 0.1% of range	
Max. frame rate	(1 Hz)	2 Hz (max. scan speed 0.25s / frame)	
Size	E-Box (270 x 278 x 196) mm Optical Head (315 x 224 x 176) mm	Integrated Box (340 x 265 x 213) mm	
Mass	14.7 kg	ca. 12 kg	ca. 13 kg
Interface	MIL1553B	MIL1553B	SpaceWire

New Technologies: High Performance Optical Head

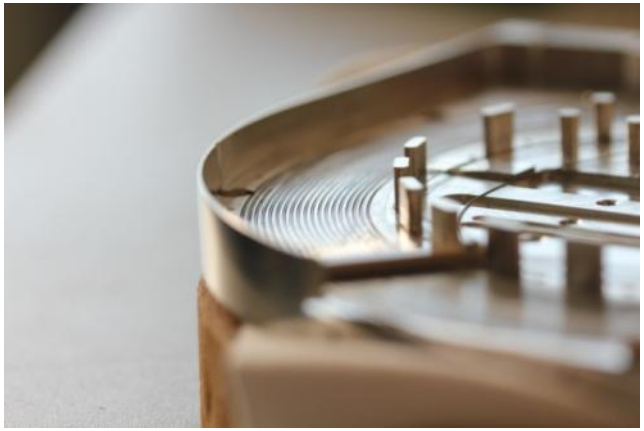
- **Highly optimized scan mirror made from Beryllium alloy**
  - Minimal weight (14 g) & moment of inertia
  - High stiffness at scan frequencies up to 100 Hz
- **Optimized scan motors:**
  - High torque
  - low weight
  - low power consumption
- **Optics design: Coaxial optical frontend for measuring range against retroreflectors and satellite materials**



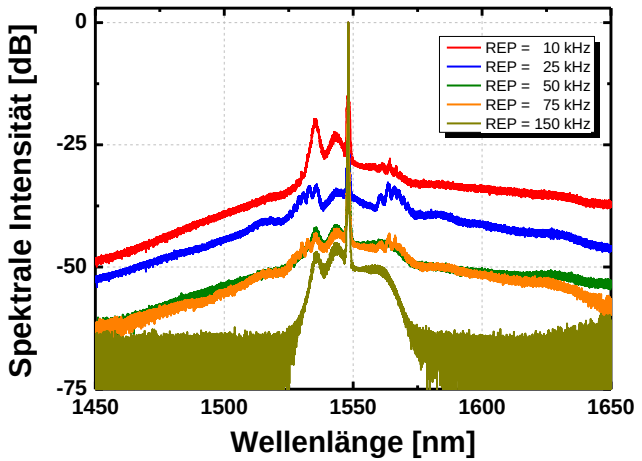


LIDAR Sensors
RVS3000 and RVS3000-3D

New Technologies: Fiber Laser



- Development of a qualified fiber laser for space applications
- Wavelength: 1550 nm (Erbium-doped fiber)
- Pulse duration: 3…10 ns (LIRIS-2: 10 ns)
- Pulse peak power: >4 kW (LIRIS-2: 7,5 W)
- Rep. rate: 20…150 kHz (LIRIS-2: 35…40 kHz)
- Switchable power levels with same beam characteristics



LIDAR Sensors
RVS3000 and RVS3000-3D

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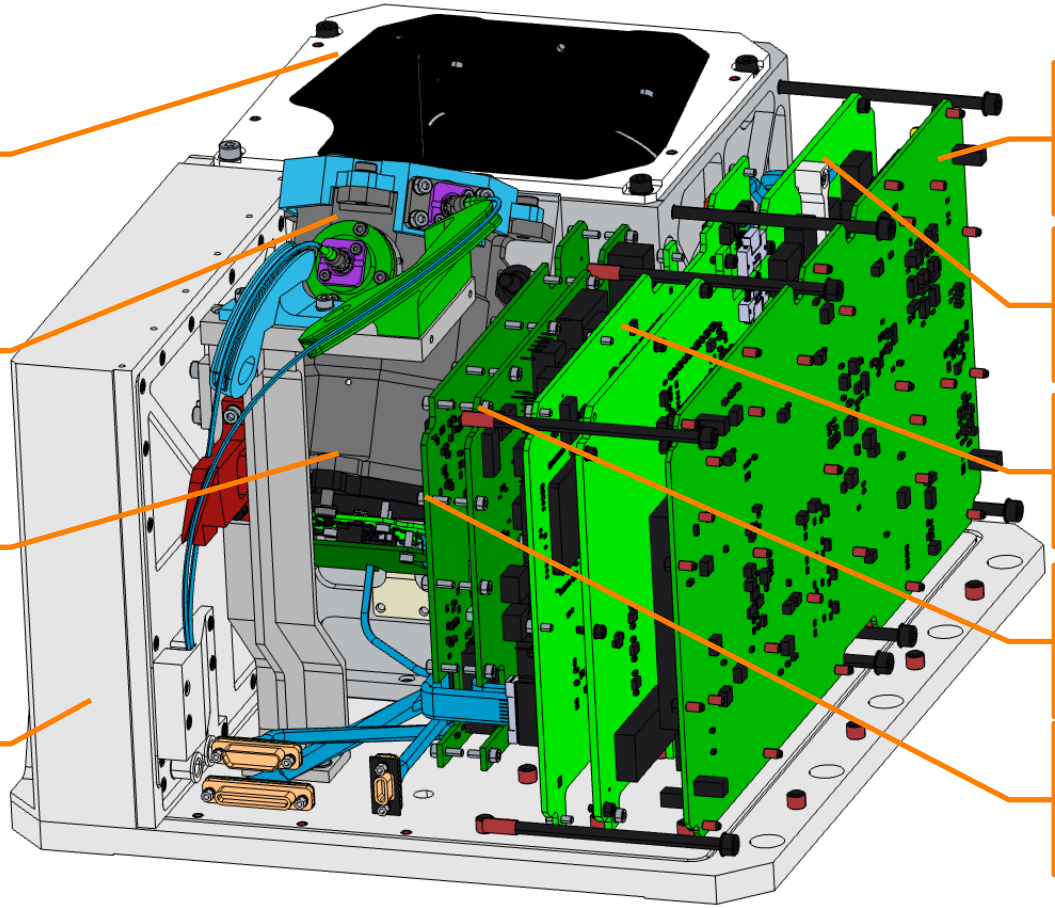
New technology: Single box design

- Accomodation of optical & electrical components together
- Development of optional Image Processing Board for 3D capabilities (also accomodated within the same envelope)



LIDAR optical head
- scan mirror
- motors, encoders

Optical Front End
- lenses, filter
- mirror, prism

RX-PB
- receiver electronics
- APD

FL / TX
- fiber laser
- transmitter electronics

Power PCB
- provides power to LIDAR electronics

SCE PCB
- scanner control electronics

RFC - PCB
- range finder control
- interface to S/C

optional: IPB PCB
- 3D image processing

RX PCB
- for signal evaluation of RX-PB

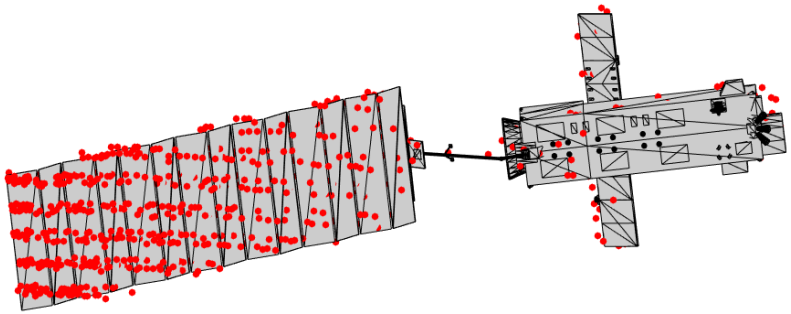
LIDAR Sensors
RVS3000 and RVS3000-3D

New technology: LIDAR + 6-DOF Image processing

- Real-time calculation of 6DOF information from LIDAR 3D Pointclouds
- Application of Iterative Closest Point Algorithm
- Matching between LIDAR scans and target CAD model

Non-Cooperative Target Scenario (e.g. Envisat)

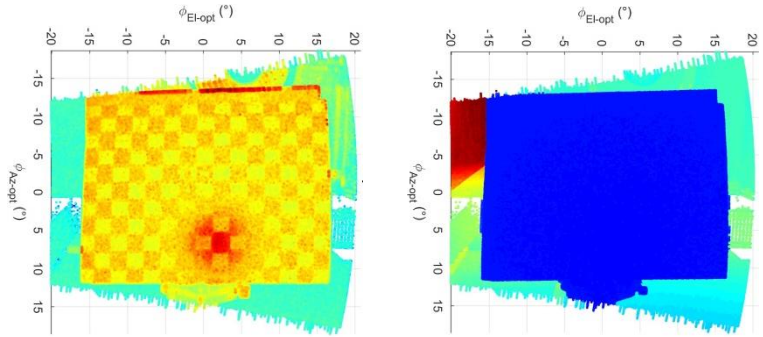
Match of Scan Data with CAD Model



RVS3000 Test Campaigns

DLR Robotics Test Facility EPOS (12/2017)

- **RVS3000 model form-fit-function equivalent to flight hardware**
- **Functionality of sensor system confirmed**
  - Sensor control
  - Scanner performance
  - Range finder operation
- **Several GB of 3D point cloud data recorded**



amplitude range

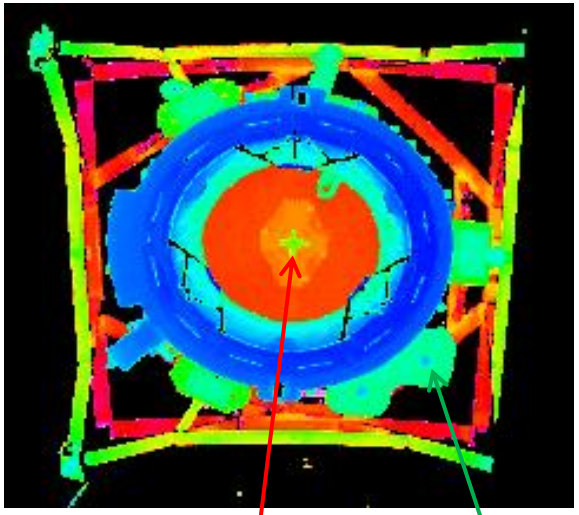

EPOS press photo, source: DLR

RVS3000 Test Campaigns

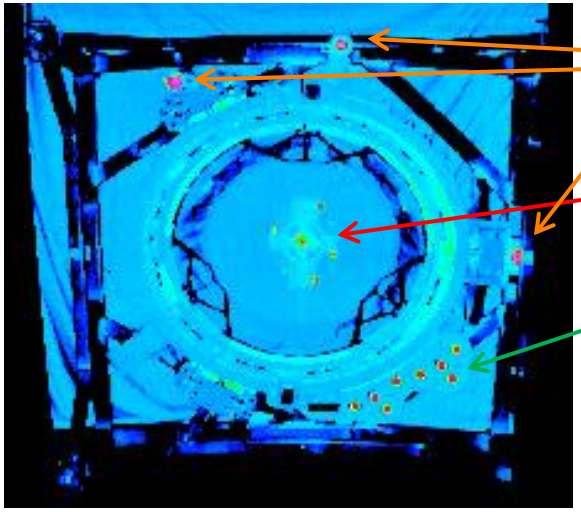
NASA Kennedy Space Flight Center (06/2018)

- Functional verification of SW enhancements based on EPOS testing
- Docking capability verification against IDA3 (images below taken at 10m distance)
- Successful demonstration of capability to work through a glass window

Range Image



Amplitude Image



Planar / Hemi Retroreflectors

Centerline Docking Target (CDT) with STORRM reflectors

Peripheral Docking Target (PDT)

CDT standoff clearly visible

PDT standoff clearly visible

RVS3000 status

Status overview

- **First qualification campaign for one customer program completed in May 2018 (TRL8 achieved)**
- **At least one further qualification campaigns for another customer programs planned throughout 2019**
- **Total of 19 flight models contracted, thereof**
  - 13 ea. RVS3000 for cooperative target approach applications
  - 6 ea. RVS3000-3D for non-cooperative target approach applications
- **Marketing campaigns running, currently with three additional customers**
- **First two launches (RVS3000 + RVS3000-3D) planned in 2019 (=TRL9)**

Planned flight model deliveries

Quarter	Planned Deliveries [Units]
Q4/2018	3
Q1/2019	2
Q2/2019	3
Q3/2019	4
Q4/2019	1
Q1/2020	2
Q2/2020	2
Q3/2020	2

Rendezvous & Docking Sensor Outlook

Future path of development

- Customers requirements:
  - Smaller (-50%)
  - Lighter (-50%)
  - More competitive pricing (<<50%)
- First discussions started by JOP to assess technologies for next generation sensors
- Includes potential technology exchange with automotive industry
- In parallel: further expansion of RVS3000 family (e.g. automatic docking missions, planetary landing missions)

Thank you very much!

Questions?

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