JOP experience and lessons learned with integration of LIDARS in GNC/avionics processing chains

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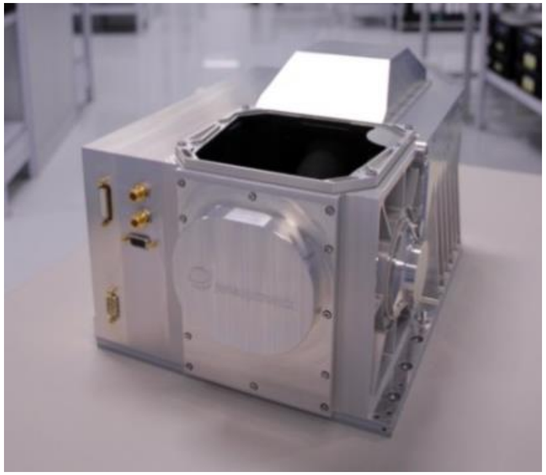
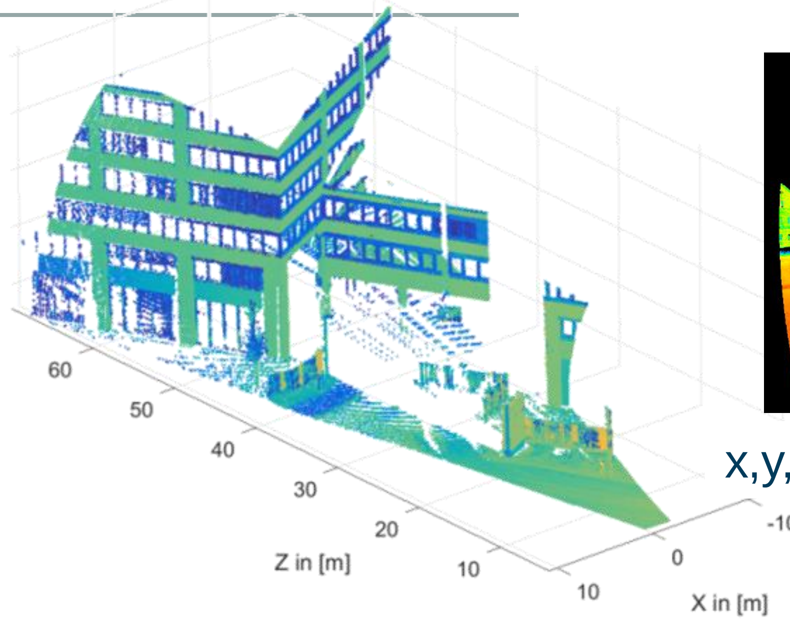
18.11.2021

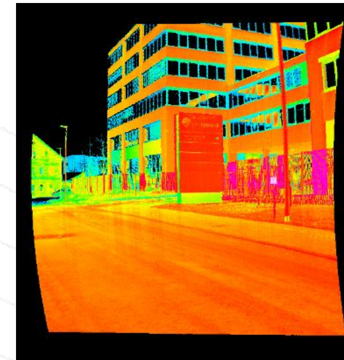
RVS3000(-3D) LIDAR Product Family



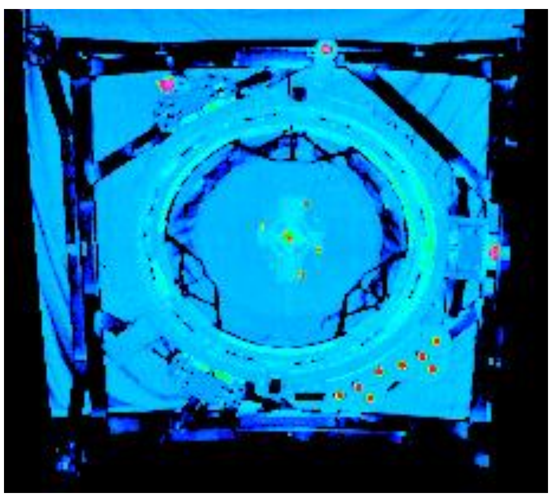
RVS3000-3D



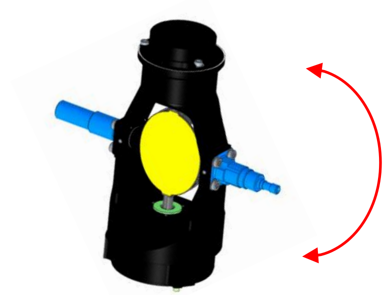
RVS3000-3D Scan

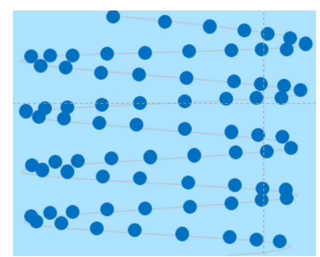


x,y,z, amplitude



RVS3000-3D Scan of IDA3 FM





Laser frequency: 40 kHz (nominal)

Berthing, Docking, Servicing, Sample Return **Landing**

1 2 3 4 5

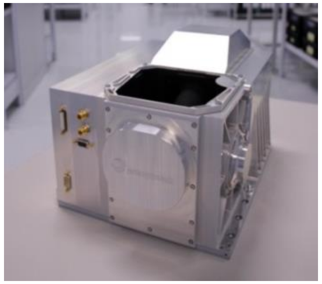
Jena-Optronik LIDARs for Rendezvous and Docking




RVS-ARP

RVS for ATV / HTV / Cygnus
48 Flight Models delivered, 48 under contract, flawless flight heritage





LiQuaRD*

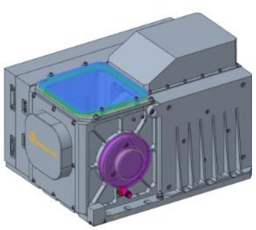
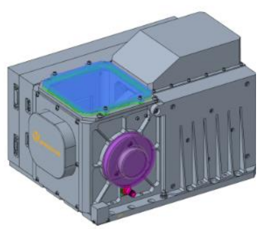
LIRIS-2 on ATV-5

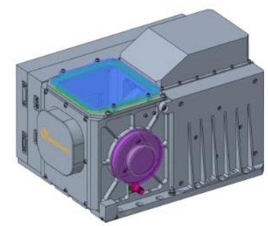
RVS3000(-3D) 15/13/25+ FMs delivered/flown/contract

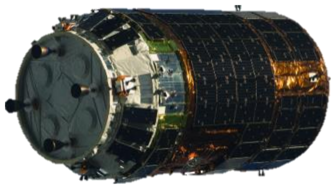
* LIDAR Qualification for Rendezvous and Docking (DLR)

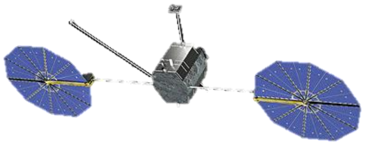
RVS3000(-3D) at a glance

NORTHROP GRUMMAN	MITSUBISHI ELECTRIC	SNC SIERRA NEVADA CORPORATION	NORTHROP GRUMMAN	LOCKHEED MARTIN
NASA CRS2	JAXA ISS Resupply	NASA CRS2	NORTHROP GRUMMAN MEV	NASA Artemis
Cygnus	HTV	DreamChaser	MEV	ORION
EEE Part Class 2 Mission Duration 0,5year LEO	EEE Part Class 2 Mission Duration 0,5year LEO	EEE Part Class 1 Mission Duration 10 Starts LEO Crew handling design	EEE Part Class 1 Mission Duration 15y GEO	EEE Part Class 1 Mission Duration 1-2y Lunar Crew handling design



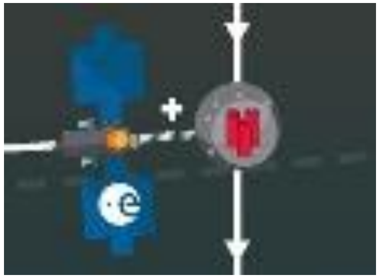



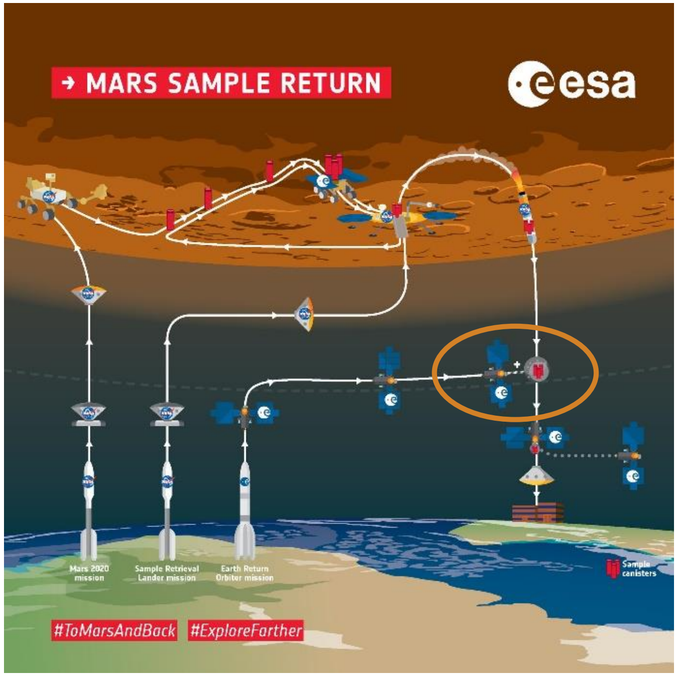



RVS3000(-3D) at a glance

AIRBUS

esa MSR



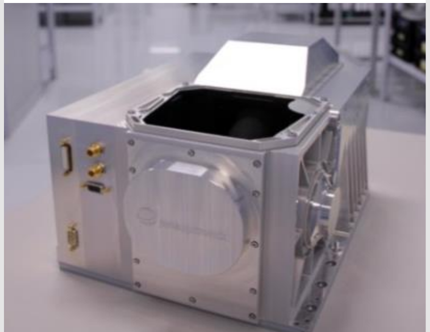


RVS3000:
cooperative targets

Scanning LIDAR

Time-of-flight ranging

Retro Tracking



RVS3000(-3D)

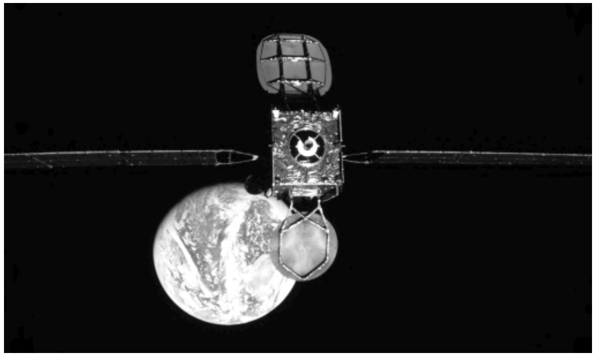
RVS3000-3D:
non-cooperative targets

Scanning LIDAR

Time-of-flight ranging

3D Pose Estimation

TRL 9



TRL 9

Overview

- RVS3000(-3D) Product Line – System Overview
- LIDAR Sensors by JOP – History & Heritage
- **LIDAR System Aspects**
- **Retro Tracking – System, Experiences, Observations, Lessons Learned**
- **Pose Estimation – System, Experiences, Observations, Lessons Learned**
- **Summary**

System Aspects

RVS 3000(-3D) Work Flow

A Smart 3D Sensor for various Space Applications in a Single Box

Point Cloud Measurement
cooperative/
non-cooperative targets

- Scanning LIDAR
- Time-of-flight ranging

3D Point Cloud
low-level

- Calibration & Correction
- Filtering, ROI

3D Point Cloud
high-level

- Retro Tracking
- 3D Pose Estimation
- *Hazard Detection*

Processed & Reduced Information to S/C GNC

jenaoptronik

Requested information is decisive for the project
- requirements, verification & responsibilities, interfaces -

3D Point Cloud
low-level

Calibration & Correction

Filtering, ROI

point cloud - x,y,z amplitude

command, control, monitor

e.g. laser power, scanner settings, …

S/C GNC System

3D Point Cloud
high-level

Retro Tracking

3D Pose Estimation

Hazard Detection

Processed & Reduced Information to S/C GNC

„obj. level“ information

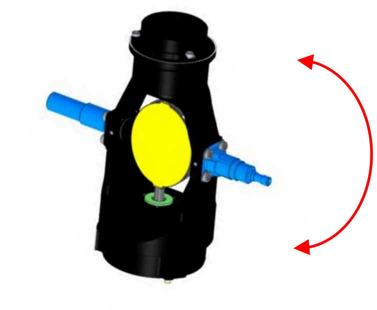
„command modes“ e.g. „look for retros“

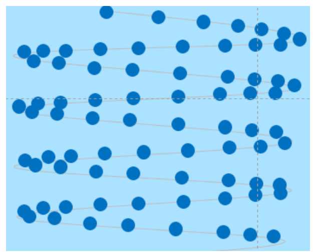
S/C GNC System

Address this aspect early!

System Aspects
– Scanning LIDAR vs. FLASH LIDAR

Scanning LIDAR





Laser frequency: 40 kHz (nominal)

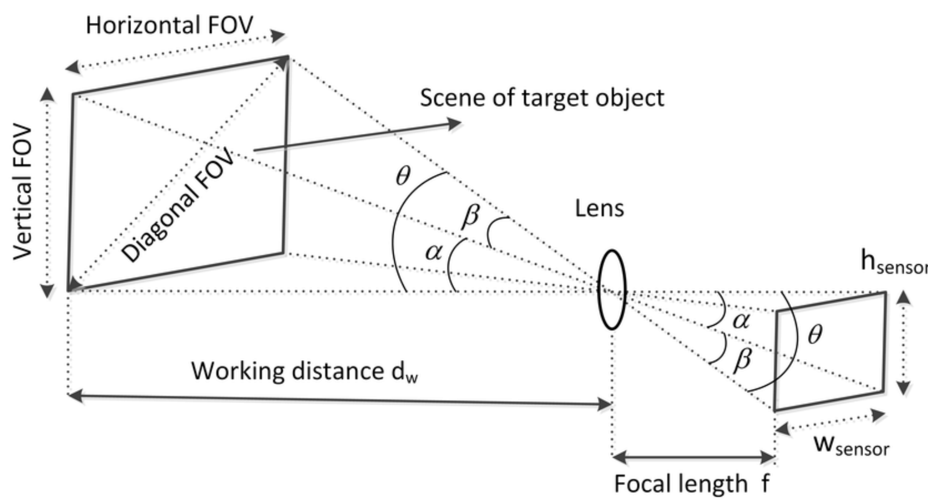
scan frequencies,
laser frequency, … adjustable!
→ very flexible

typ. update rate 2 Hz (full scan)

FLASH LIDAR – like a camera fixed angular field of view & angular resolution

focal length + pixel size
→ fixed angular resolution

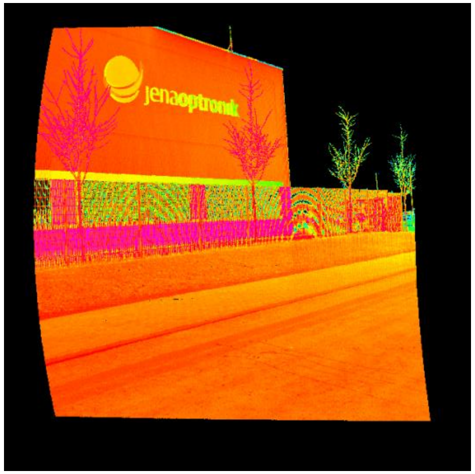
typ. higher update rate



System Aspects
RVS 3000(-3D) Key Feature, Scanning LIDAR

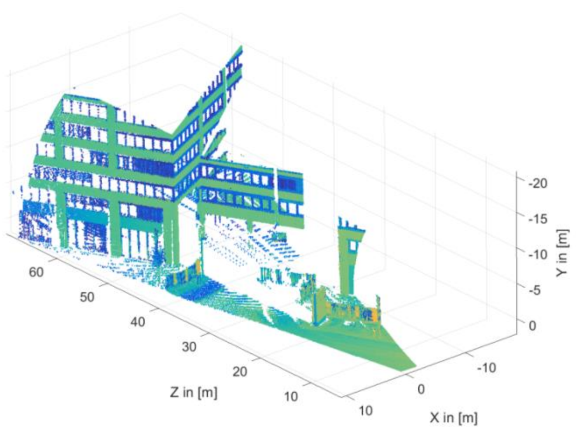
Scanning Time-of-Flight Ranging

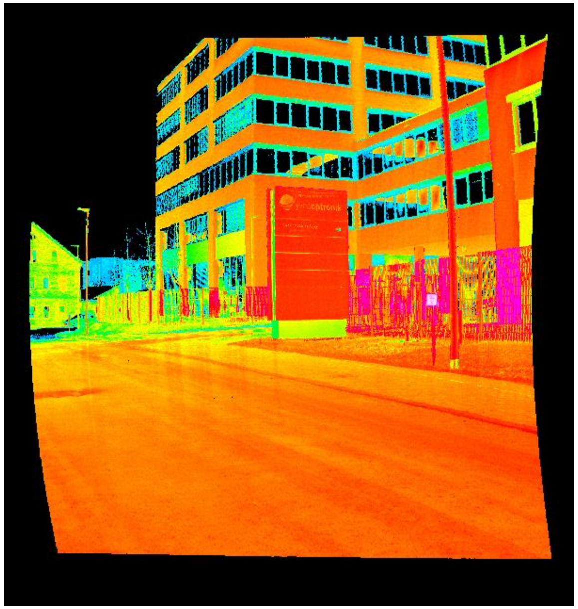
- Laser and range finder provide range and amplitude
- Constantly high performance within the total LIDAR FOV
- <u>No</u> “dead pixel” (!)
- Single Shot Range 3σ Noise*: < 1–2 cm
- Single Shot Range Bias: < 1 cm



RVS3000-3D Scan

JOP Building



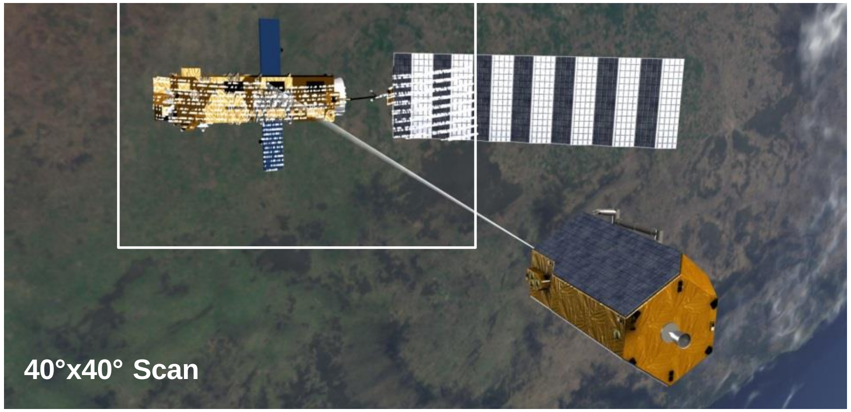


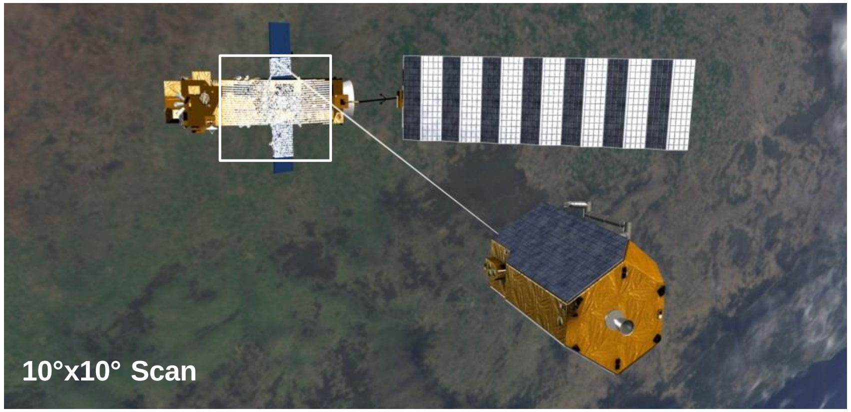
RVS3000-3D Scan

Note: depending on target properties*

Scanning LIDAR

- Large degree of flexibility with respect to Field-of-View (<1x1…40x40 deg)
- High performance angular measurement (noise < 0.001 deg, bias < 0.05 deg)
- Variable scan speed leading to adjustable point cloud resolution
  - Slow high-resolution scans with "megapixel" images
  - Fast scans for proximity operations with moving/rotating objects
- Range, Az, El, and amplitude Information





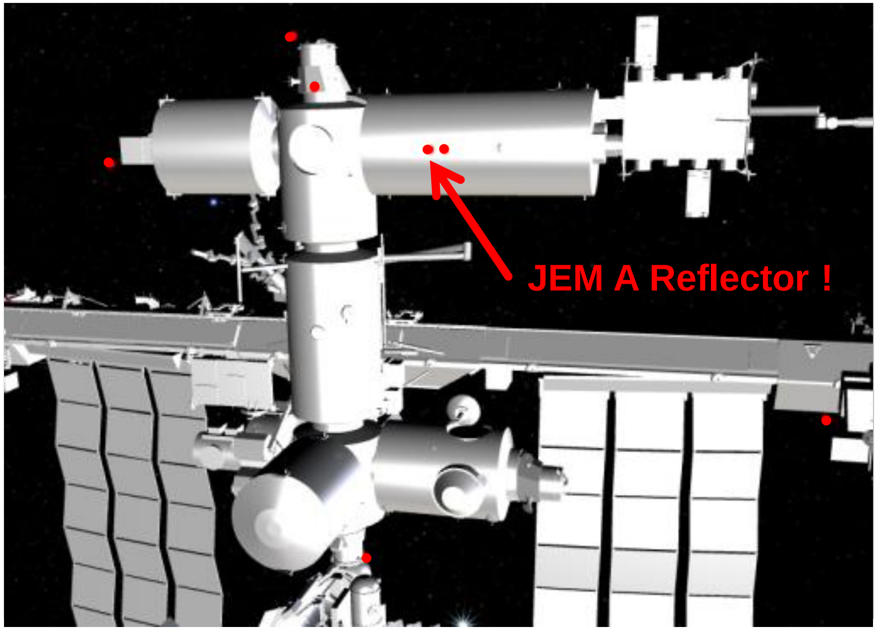
Scanning LIDAR in Debris Removal Scenario

RVS3000 – Retro Tracking

System, Experiences, Observations, Lessons Learned

RVS 3000 – Retro Reflector Tracking

- Identification & Tracking of Retro reflector objects
- JOP heritage retro identification algorithms
  - 2 Hz Update Rate
  - Validated during 45 flights to ISS (without any target loss!)



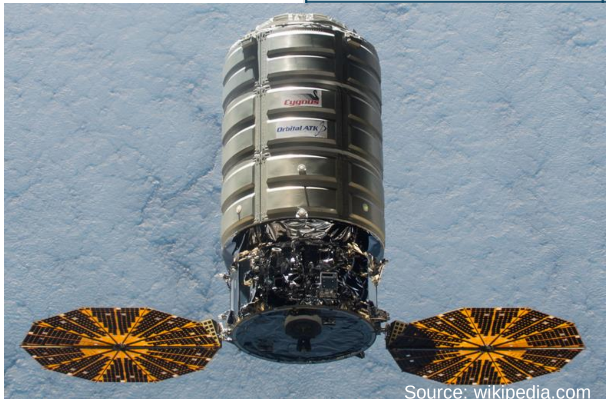
RVS3000 Flights

- 11 FMs flown to ISS

NORTHROP GRUMMAN

CRS2

Cygnus

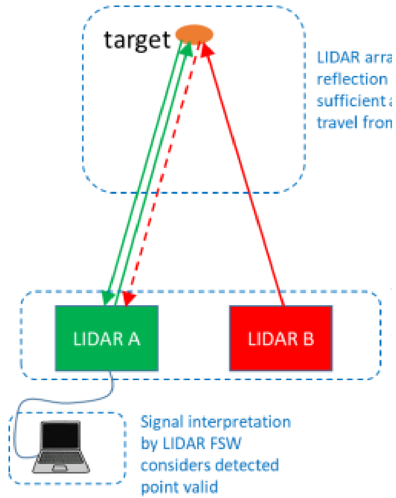


- **Orbit:** LEO
- **Spacecraft :** Cygnus
- **Target client:** Space Station
- **Approach:** R-BAR
- **Target:** cooperative; final target JEMA hemispherical reflector

RVS 3000 – Retro Reflector Tracking, Cross Talk

	TRs per RR object		
Range [m]	Retro #1	Retro #2	Retro #3
688,972	195	289	1
688,455	162	258	6
687,9605	207	245	1
687,45	186	256	5
685,4515	205	272	3
120,177	2	258	43
111,946	15	231	1
111,1935	3	267	13
108,9245	39	218	2
107,4565	57	196	1
107,3935	1	266	108
107,32	86	213	2
107,1685	65	201	1
107,1075	1	259	114
107,0365	96	214	3
106,75	68	184	1
106,643	41	199	2
105,7725	99	182	3
105,364	61	176	1
104,953	106	192	3
104,5415	80	191	2
102,478	71	185	4
98,862	1	109	135
94,1515	1	165	113
88,515	152	116	1
83,3905	1	119	126
81,389	6	123	115
81,2775	8	111	110
81,161	1	116	116
79,6025	6	117	116
79,5505	125	3	121
78,128	1	120	119
77,969	3	118	118
77,8635	2	121	115
74,4425	1	126	124
73,3435	203	101	4
68,5845	116	9	120
65,7365	1	126	128
62,6955	149	123	1
55,298	1	114	119
55,048	1	122	125

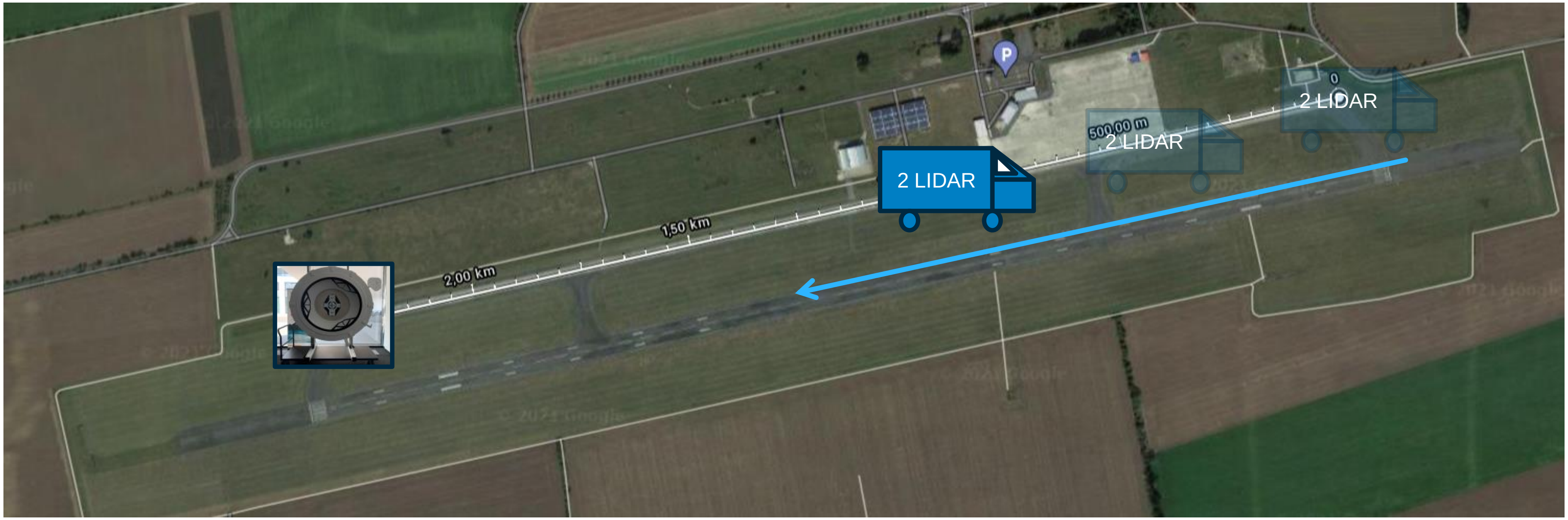
- Configuration
  - RVS3000 wavelength=1550nm
  - other LIDAR, wavelength~1550nm
- Observation of „wrong“ retro reflectors „here and there“ due to cross talk between units
- Solution: software adaption for retro identification



Lessons learned:

- perform LIDAR tests in spacecraft configuration (test as you fly & fly as you test!)
- emphasize relevance of cross talk

Cross Talk Tests

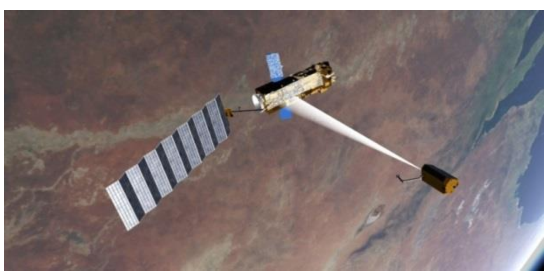


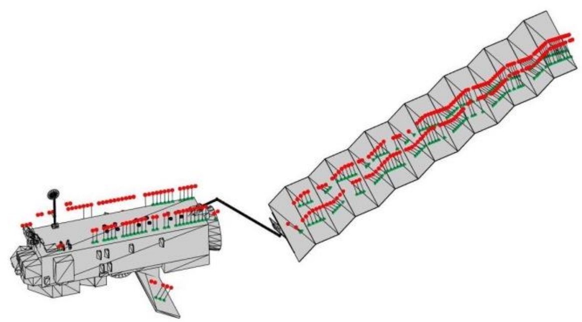
RVS3000-3D – Pose Estimation

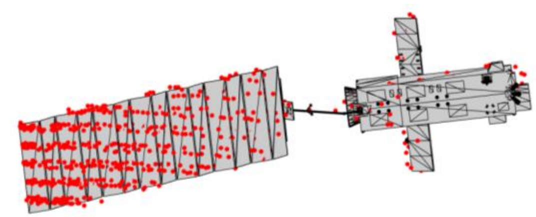
System, Experiences, Observations, Lessons Learned

RVS 3000-3D – Pose Estimation

- Pose calculated based on matching between RVS scan and target reference model
- Real-time algorithm application on dedicated image processing board
  - 2 Hz Pose Update Rate
  - 1s Latency
- Algorithm Flow:





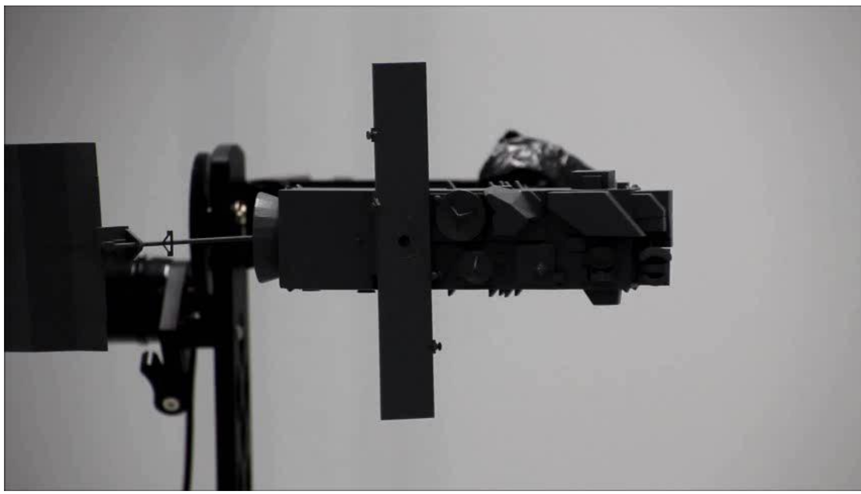


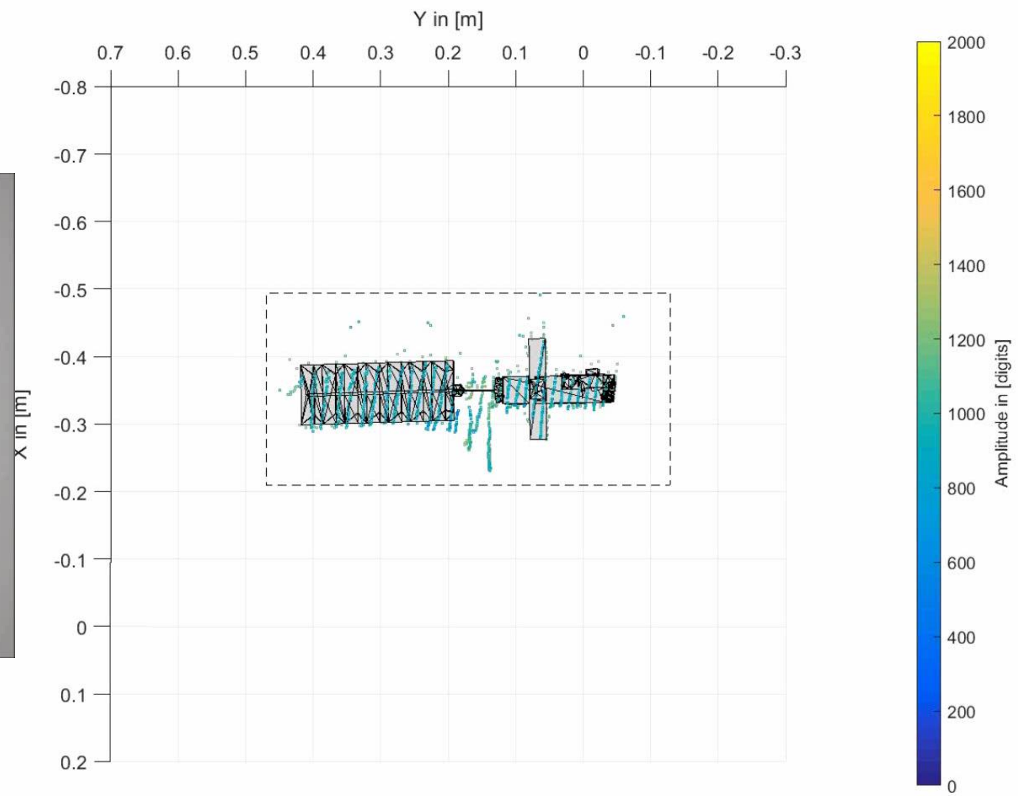
1 – Acquisition of LIDAR Scan

2 – Matching LIDAR Scan vs. Model

3 – Pose

Pose Estimation Demo

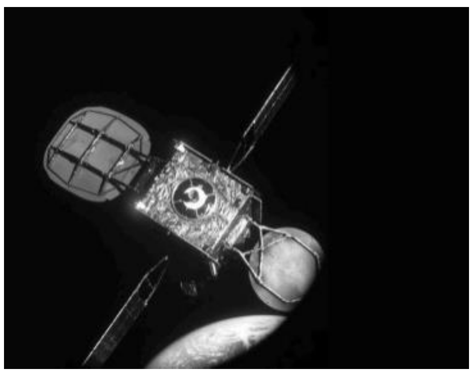




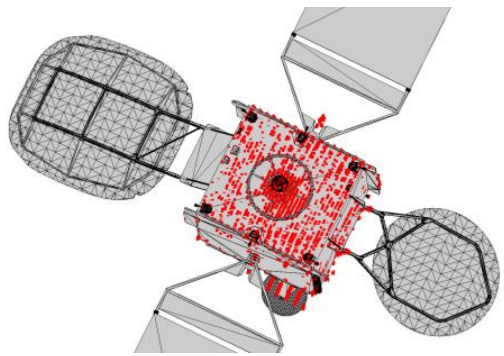
LIDAR iFOV

RVS3000-3D Flights

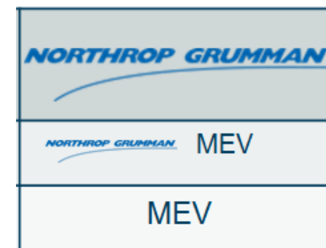
RVS3000-3D	Launch Date	MEV S/C	Docking Date #1	Docking Target #1
SN17	April 2019	MEV1	2020-02-24	IS901
SN18	November 2019	MEV2	2021-04-12	IS1002



® NG/SpaceLogistics - VSS JOP Camera



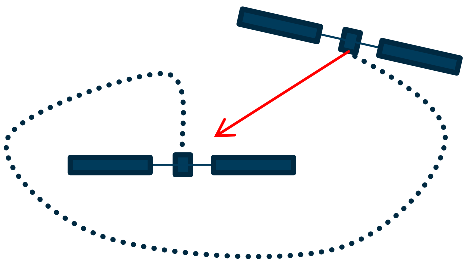
SN17 In-Orbit Scan and Pose Estimation



- **Orbit:** GEO
- **Spacecraft :** Mission Extension Vehicle
- **Target client:** GEO Com Sat
- **Approach:** ellipse
- **Target:** diffuse; Autonomous 6DOF Pose Estimation by LIDAR

POSE Estimation Performance

	RVS3000-3D - Pose 3σ Noise vs. Intelsat IS901 (In Orbit Performance)					
Range [m]	**X [m]**	**Y [m]**	**Z [m]**	**Roll [°]**	**Pitch [°]**	**Yaw [°]**
940	0.165	0.166	0.477	3.89	4.69	4.16
630	0.063	0.079	0.047	1.23	1.24	1.56
440	0.104	0.148	0.066	3.21	3.73	2.02
250	0.107	0.176	0.153	2.97	1.52	2.68
100	0.018	0.083	0.017	1.51	2.56	0.91
82	0.034	0.078	0.036	1.93	1.84	1.08
65	0.015	0.024	0.030	0.61	1.35	0.37
35	0.011	0.012	0.032	1.14	0.93	0.41
15	0.009	0.015	0.006	0.67	0.32	0.22
1.5	0.014	0.009	0.006	0.96	0.38	0.49



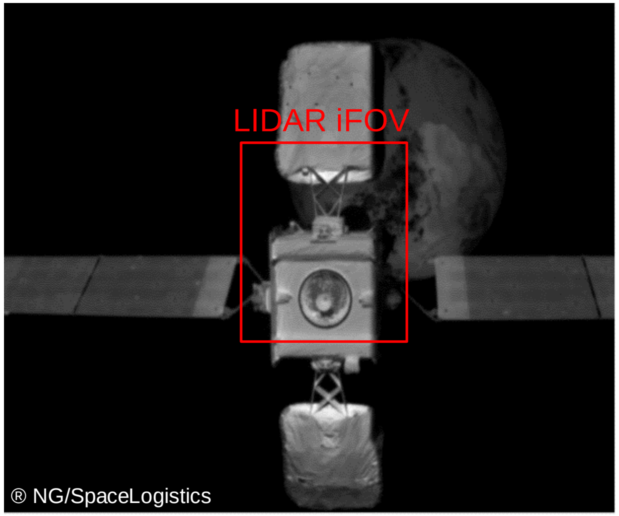
Observation: 6DOF Performance depends on
visible features, viewing angles & approach trajectory

Root cause:

reflectivity of satellite materials vary strongly (return signal – weak/strong)
→strong variation of point density on objects → impact on performance

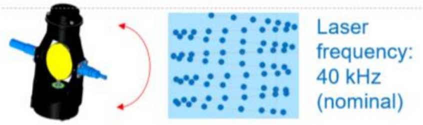
Client Properties

IR Image of IS1002

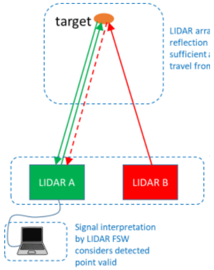


- Observation:
  - risk of partially unknown/unclear geometry/optical properties of clients
  - high degree of flexibility needed for servicing/clean space missions
  - be prepared to work with a set of configurations for conops & algorithms
    → solar arrays visible yes/no, MLI yes/no, …
  - download link of point cloud data is recommemnded

RVS 3000-3D – LIDAR for satellite servicing, Lessons Learned & Potentials

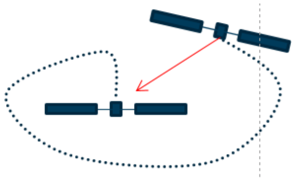


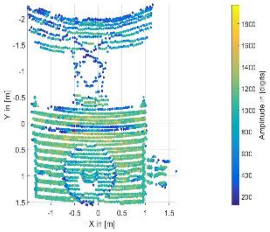
- System Aspects
  - Interface point cloud vs. object level → address this early!
  - Scanning LIDAR vs. FLASH LIDAR → scanning LIDARs are very flexible!



- Cross Talk
  - → Emphasize topic to customers & the community!
  - → Test as you fly! Fly as you test!

- Enable Flexibility for the Mission (e.g. servicing, clean space)
  (optical properties/geometry of the client partially unknown, algorithms sensitive)
  - → LIDAR Design e.g. high granularity of laser levels
  - → Mission/CONOPS e.g. be prepared with a set of configurations for CONOPS/algorithms; download link for point cloud data is needed





Thank you for your attention! Questions?

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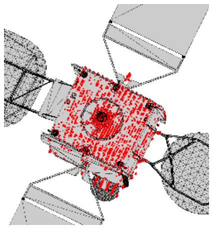
Delivery of 1st RVS 3000-3D FM in 2018

RVS3000 Family Evolution – Smart 3D Sensor Berthing, Docking, Servicing & Landing



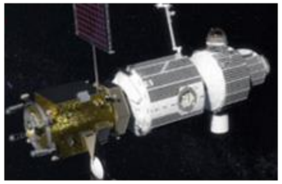
RVS3000-3D ✓

- Docking non-cooperative targets
  6D Pose Estimation
- **Heritage on MEV**

RVS3000-X

Development on going

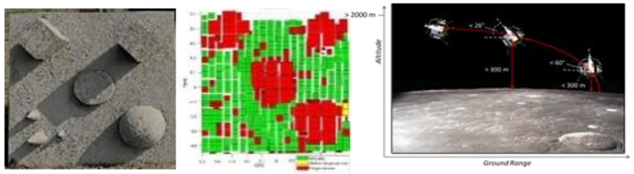
- non-cooperative & cooperative targets
  Retro Tracking & 6D Pose Estimation
- **Crew-handling design**
- **Product line harmonization**



RVS3000-L

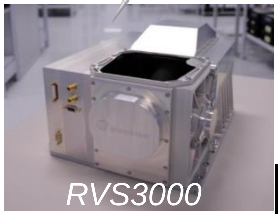
Development kicked-off

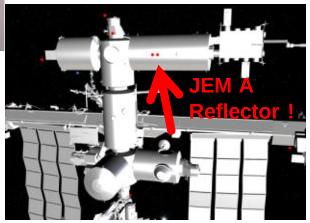
- non-cooperative & cooperative targets
  Landing Application
- **Motion Correction & Hazard Detection**



RVS3000 ✓

- ISS/cooperative targets
  Retro Tracking
- **Heritage on Cygnus**





μRVS – the next step

Technology development

- Single-photon avalanche diode array
- Powerful pulse diode laser (~905 nm)
- Miniaturized scan mirror