GNC Sensors for in Orbit Servicing Missions

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Agenda

GNC Sensors for in Orbit Servicing Missions

- Visual Sensor Suite – Flight Experience on MEV
- RVS3000-3D LIDAR
- Future Development: ASTROtir

jenaoptronik

ASTRO Cam(Sys)

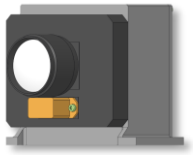
ASTRO CL Cam ✓

- smart, tough, radiation hard

ASTRO Cam

- **Ordered for HERA-Mission**
- NFOV for asteroid approach
- Deep space

ASTRO*tir* Cam

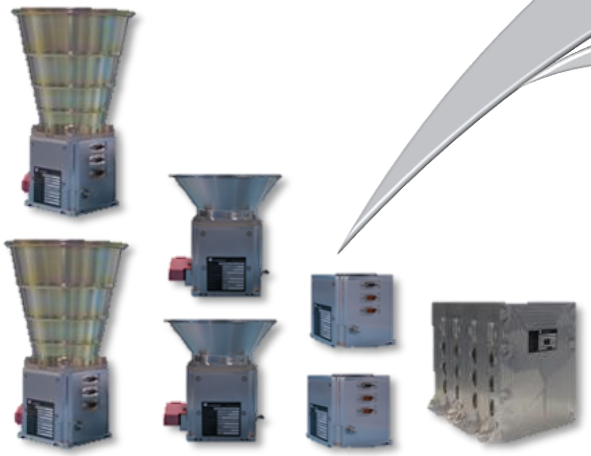


- Infrared spectrum

Building block strategy including *ASTROcontrol* software solution

ASTRO*head* CamSys ✓

- **Heritage with MEV, flies on MEV 1&2**
- Combination of multiple heads with e-box
- Optional full redundant



ASTRO XP Cam

- Extreme NFOV, high precisicion
- inspection and navigation, surveillance

ASTRO APS3 Cam

- true real time snap shot images and image series

Introduction

- In Mar. 2018 Northrop Grumman Innovation System contracted the development and manufacturing of the Visual Sensor Suite – VSS
- Target was to provide a sensor suite for the visual spectral range for the Mission Extension Vehicle – MEV
- VSS is based on the new visual range multi-mission camera system **ASTRO*head***
- In a historic achievement, Northrop Grumman's MEV1 docked successfully on a non-cooperative satellite in space on February 25th, 2020 – in less than three years after contracting the development of the VSS
- ASTRO*head* is the first product world-wide that flies with the FaintStar image sensor

Timeline

Feb. 2017: Kick-off

Sep. 2018: Shipment VSS1

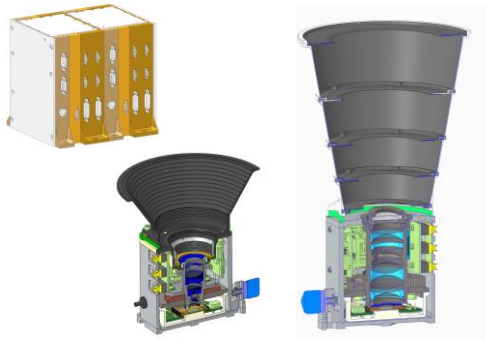
Apr. 2019: Shipment VSS2

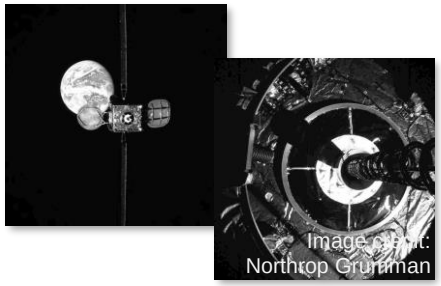
Oct. 2019: Launch MEV1

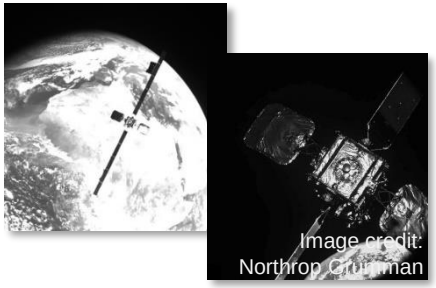
Feb. 2020: Docking with IS901

Aug. 2020: Launch MEV2

Apr. 2021: Docking with IS10-02



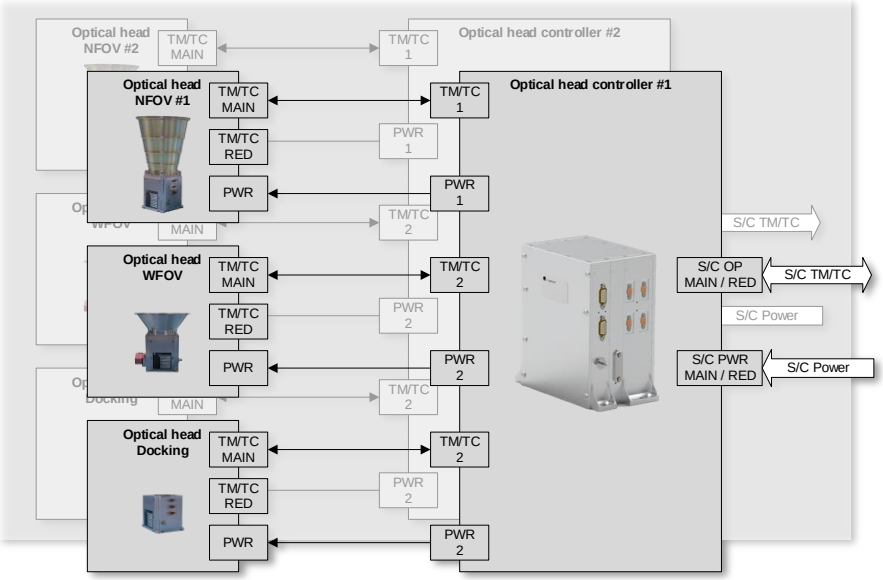




Architecture (VSS configuration)

ASTRO*head* consist of:

- Six **optical heads**
  - 2x narrow field of view (NFOV)
  - 2x wide field of view (WFOV)
  - 2x docking camera (WFOV)



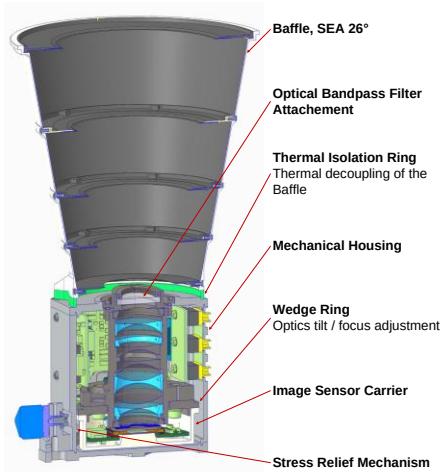
- Two **optical head controller**:
  - Power distribution
  - Command and configuration
  - Synchronization
  - Adaption to customer interface protocols
  - Image processing, if applicable

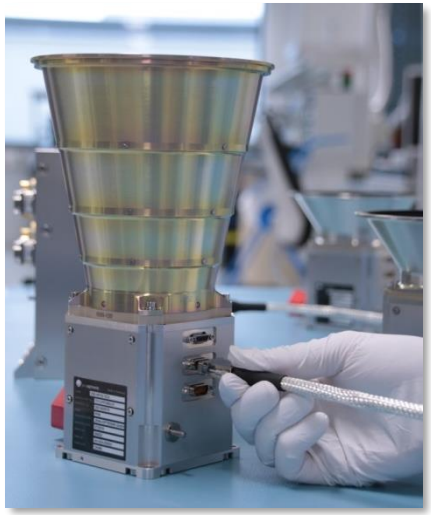
Key Figures

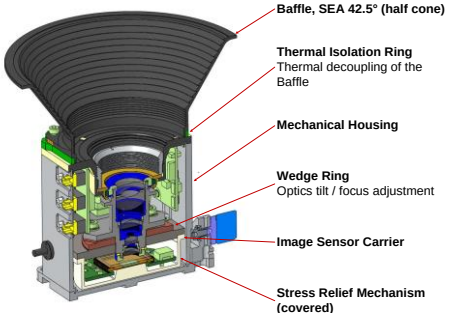
Image sensor:	FaintStar
System output:	Raw images, JPEG compresed images
Update rate:	Up to 4Hz for full frame images
Operational interface:	SpaceWire
Optical head mass:	≤ 1.2kg (baffle included)
Optical head envelope	80 x 80 x 95 / 234mm^3 (with / without baffle)
Optical head power consumption:	≤ 1W
Controller mass:	≤ 4.3kg (VSS configuration)
Controller envelope:	193 x 172 x 180.5mm^3 (VSS configuration)
Controller power consumption:	≤ 25W (VSS configuration)
Temperature range (op. / non-op.):	-10 to +50°C / -40 to +70°C
Total ionizing dose (TID)	50krad
Life time:	≥ 18years in GEO environment
EEE-parts quality	Class I

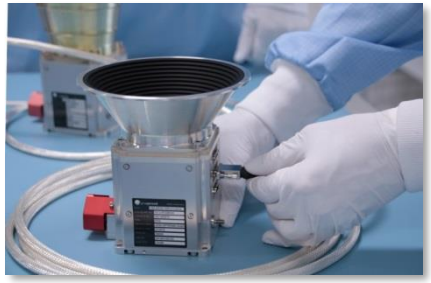
Optical Head Mechanics and Baffle

- Lightweight and compact
- Passive athermalized design to ensure maximum alignment stability over temperature range
- FPA adjustment via wedge ring
- 4mm overall shielding to sustain high radiative environments
- Baffle for SEA of 26deg (NFOV) resp. 42.5deg (WFOV)









Optical Head Optics and Electronics

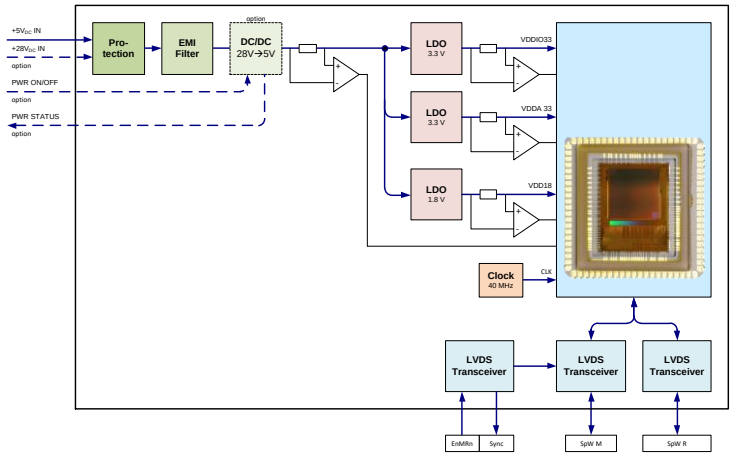
Optics:

- NFOV: FOV 19deg, aperture 23.5mm
- WFOV: FOV 68deg, aperture 1.05mm
- Refractive
- Radiation hard glasses

Optical head electronics:

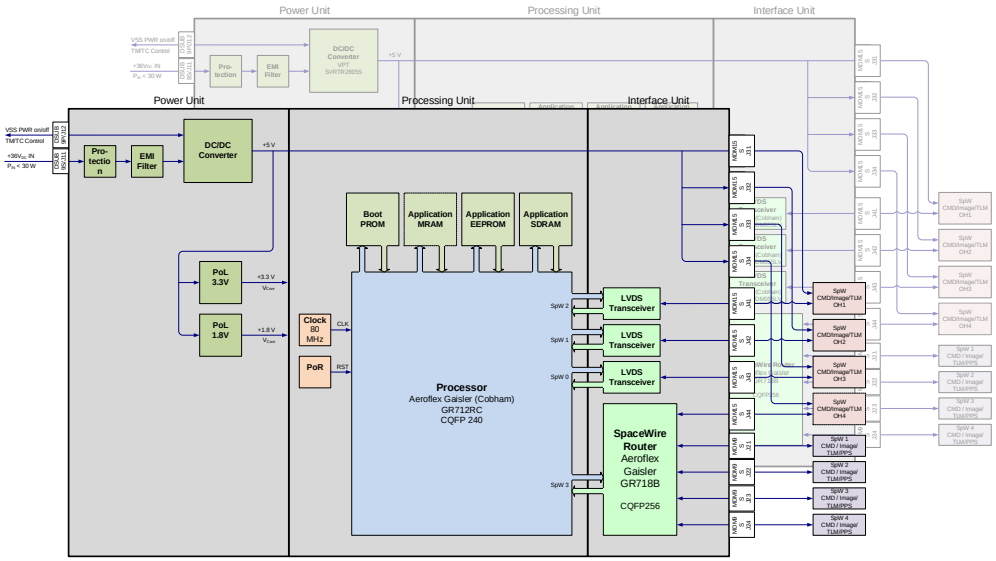
- Image sensor: FaintStar
- Operational interface: SpaceWire
- Power interface: 5V / 28V (option)
- Power consumption: ≤ 1W

- Redundant operational interface (option)
- Power status interface (option)
- Power command interface (option)



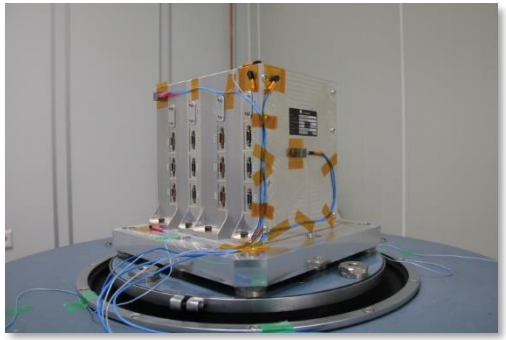
Optical Head Controller

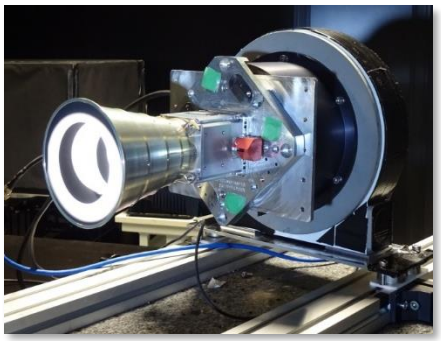
- Dedicated PCBs for power, processing, interface
- One tailored metal frame for each PCB
- Processor: LEON3
- SpaceWire router supports up to 8 interfaces per processor



Qualification

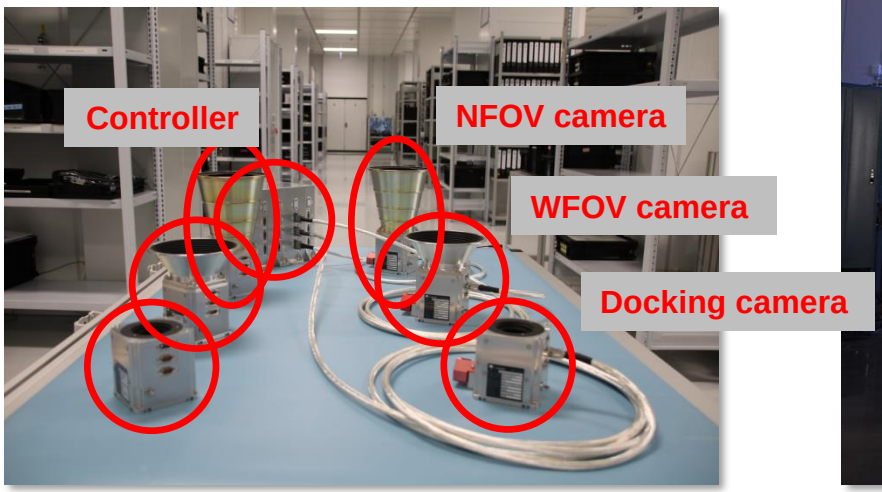
- Full qualifcation performed
- All relevant environmental tests included:
  - Sine vibration
  - Random vibration
  - Shock
  - EMC/ESD
  - Thermal-vacuum cycling
  - Straylight testing

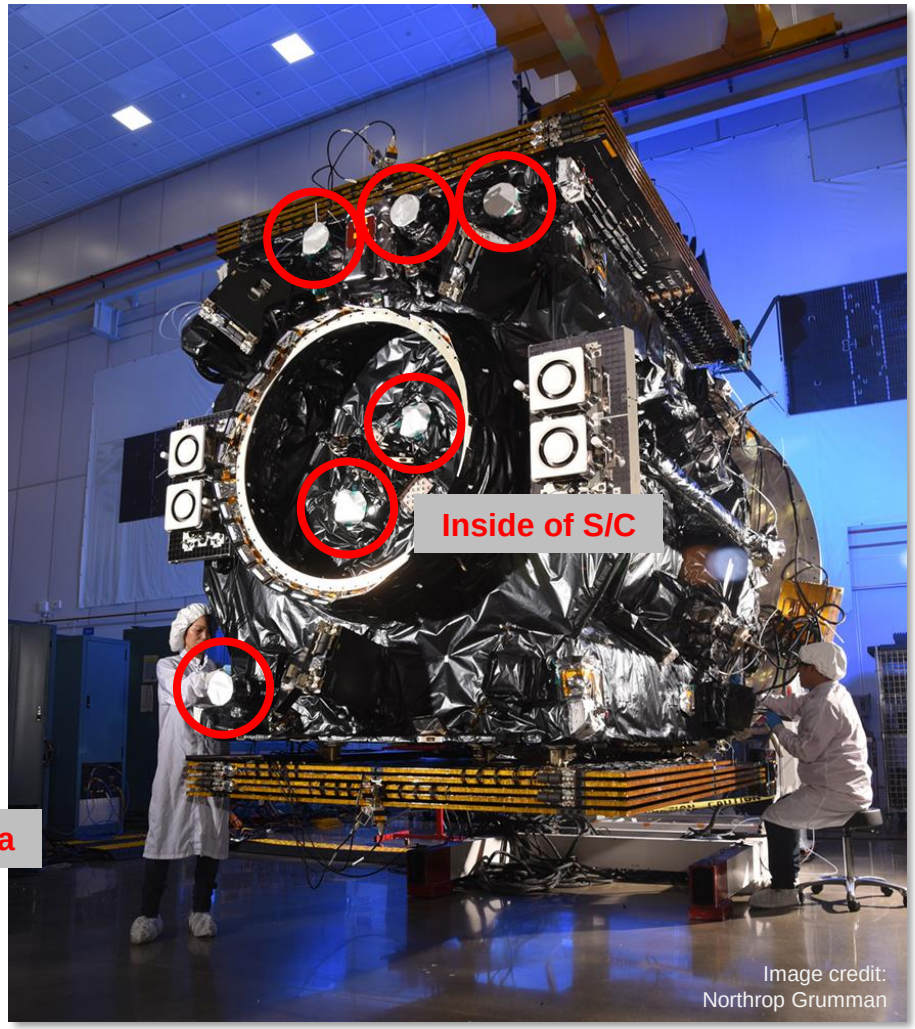




VSS S/C Accommodation

- Task was to deliver raw images and compressed images for proximity operations and docking
- This involves the detection of the client satellite from a distance of 45.000m
- As well as guidance until docking

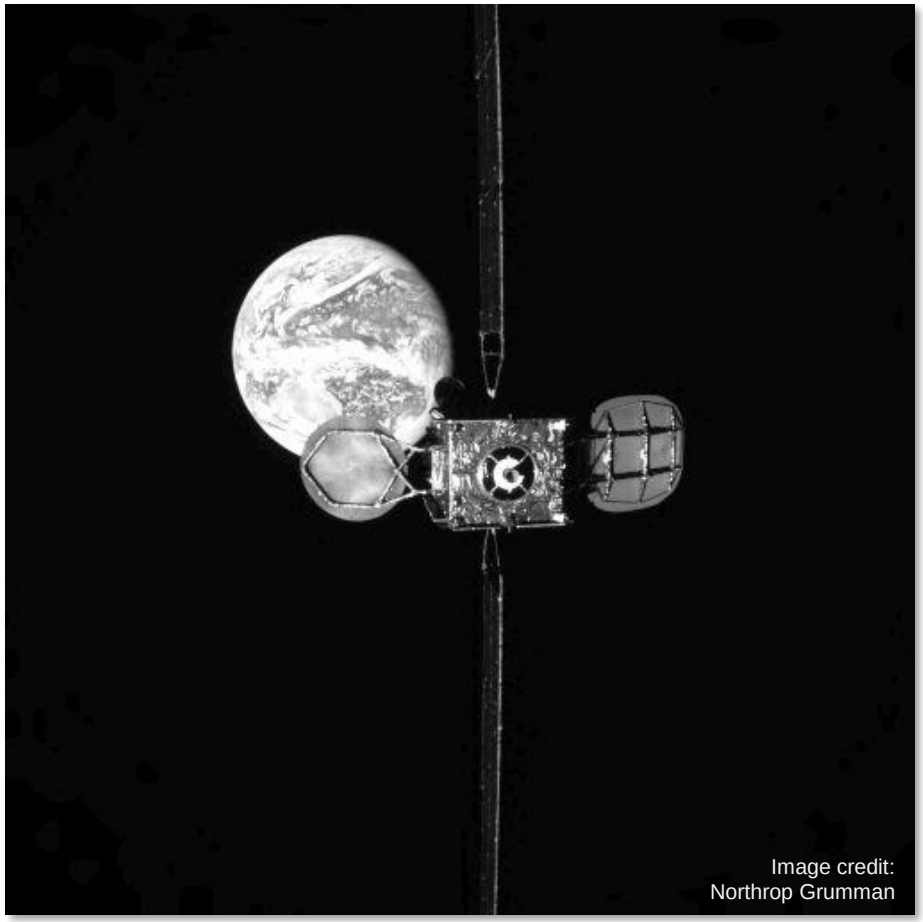




In-Flight Heritage

- **Historic achievement by Northrop Grumman**: First docking to a non-cooperative satellite in space on February 25th, 2020
- **ASTROhead** provided image data for attitude and position measurement (in parallel to the Jena-Optronik RVS3000 3D) as well as surveillance
- **ASTROhead** provided first public images of a deployed satellite in GEO with Earth in background

Image provided by Northrop Grumman



Mission Phases

Top - detection:

- Far distances
- provided by VSS NFOV camera

Middle/left – navigation at mid range:

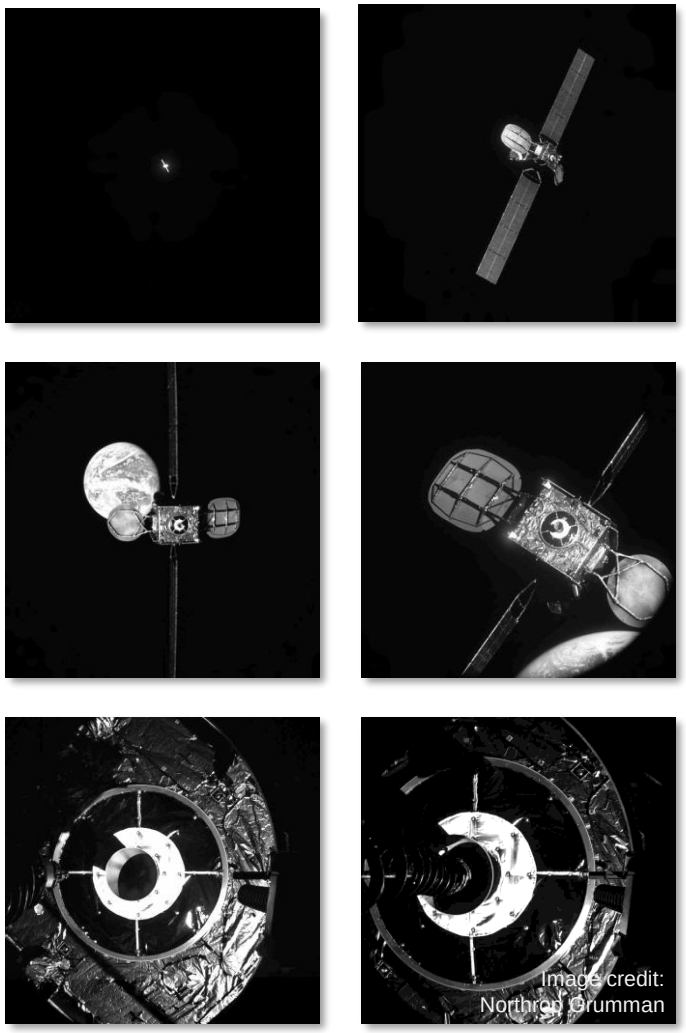
- Far hold position at approx. 80 meters
- Provided by VSS WFOV camera

Middle/right – navigation at close range:

- Near hold position at approx. 20 meters
- Provided by VSS NFOV camera

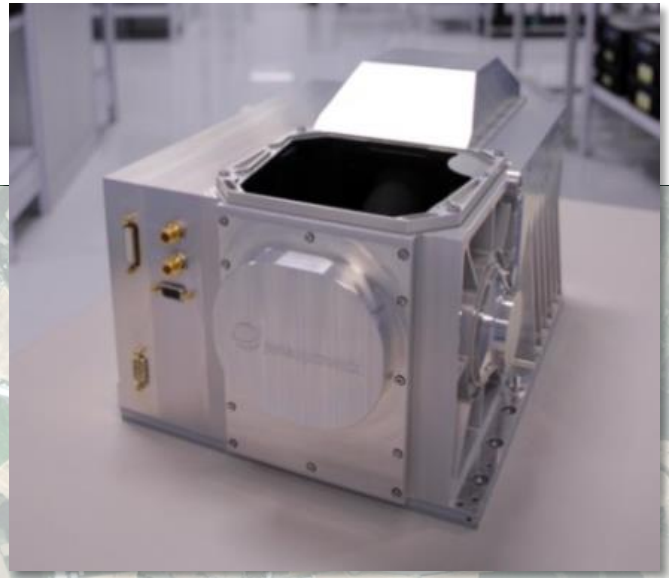
Bottom - docking:

- Prior and after Docking
- Provided by VSS docking camera

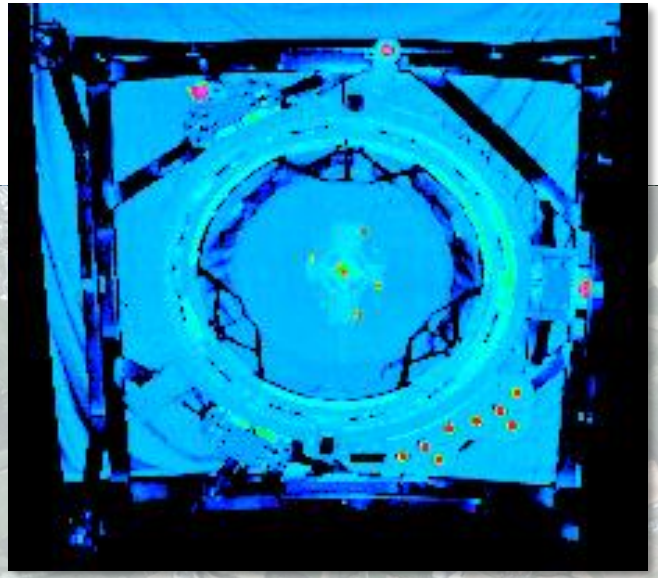


JOP LIDAR Missions

Overview



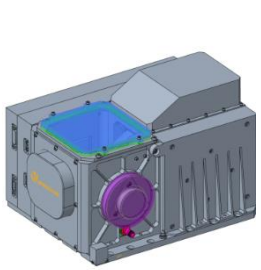
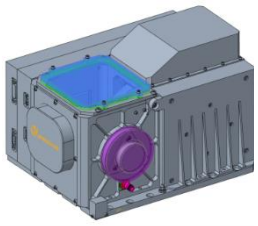
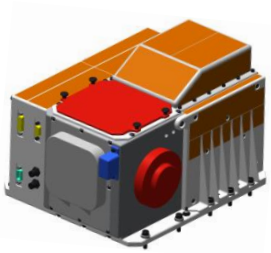
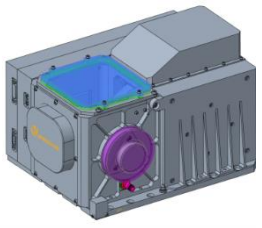
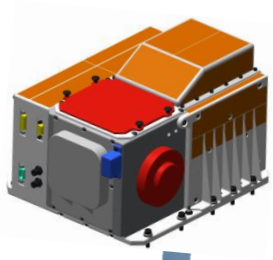
RVS3000-3D

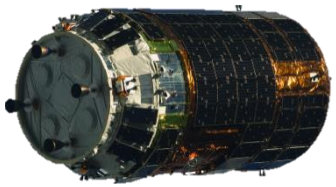


RVS3000-3D Scan of IDA3 FM

RVS3000 at a glance

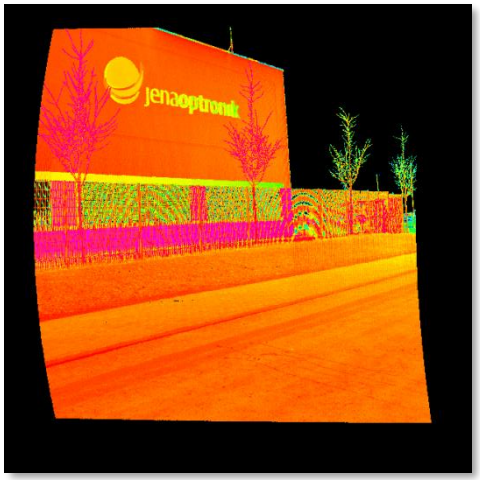
NORTHROP GRUMMAN	MITSUBISHI ELECTRIC	SIERRA NEVADA CORPORATION	NORTHROP GRUMMAN	LOCKHEED MARTIN
NASA CRS2	JAXA ISS Resupply	NASA CRS2	NORTHROP GRUMMAN MEV	NASA Artemis
Cygnus	HTV	DreamChaser	MEV	ORION
EEE Part Class 2 Mission Duration 0,5year LEO	EEE Part Class 2 Mission Duration 0,5year LEO	EEE Part 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

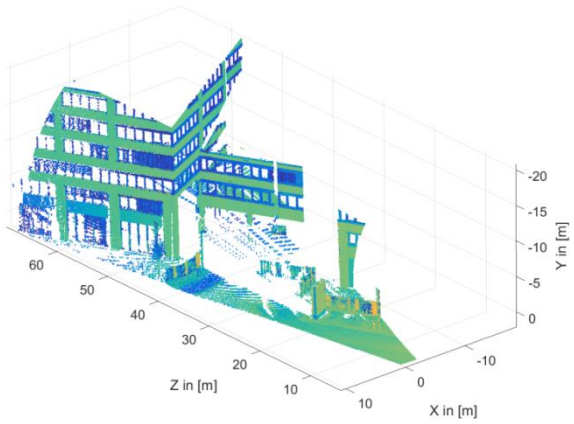


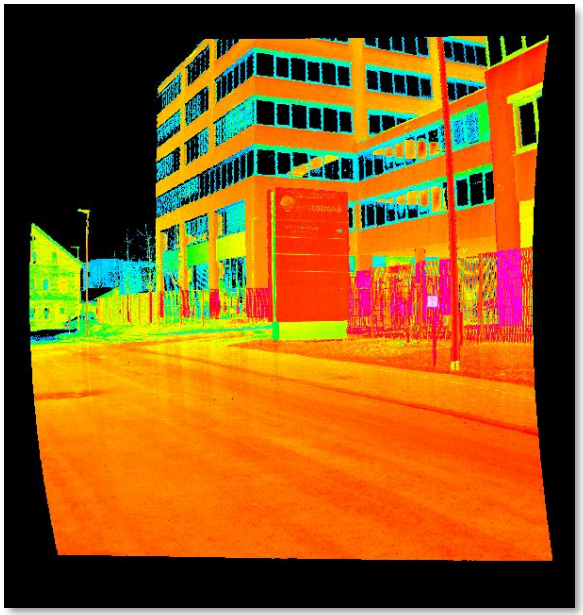

Time-of-Flight Ranging

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



RVS3000-3D Scan





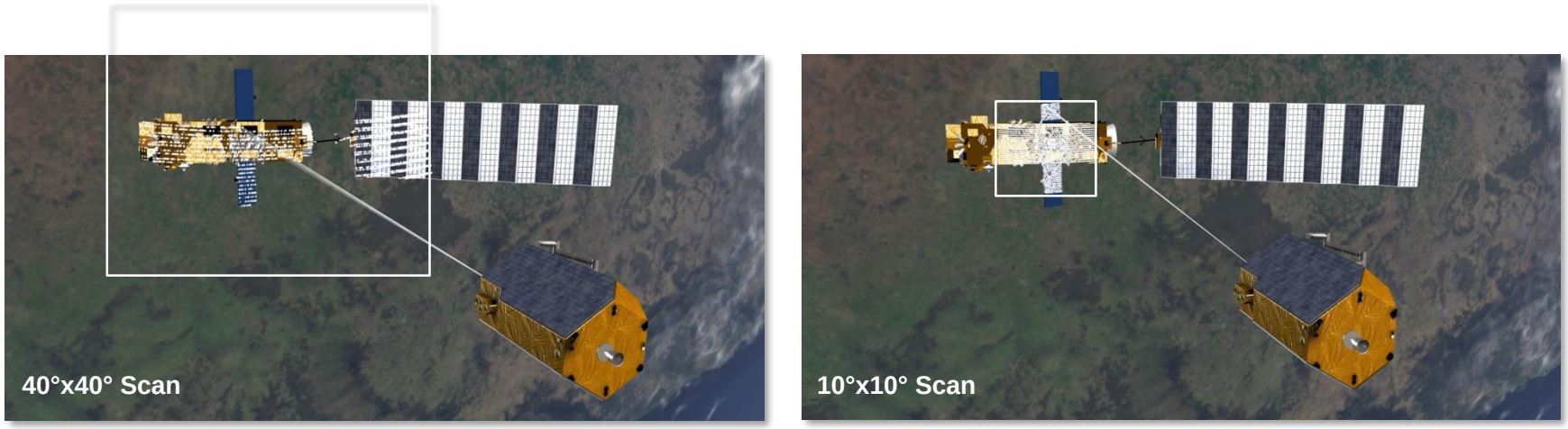
RVS3000-3D Scan

JOP Building

Note: depending on target properties*

Scanning LIDAR

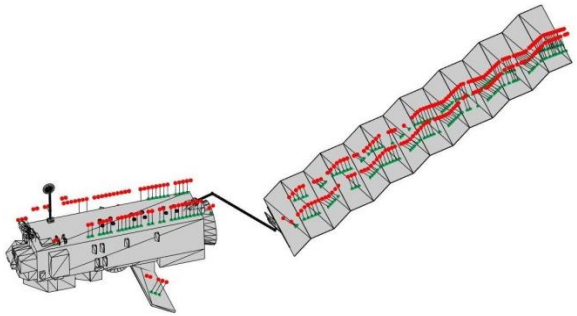
- Large degree of flexibility with respect to Field-of-View (<1x1…40x40 deg)
- High performance angular measurement (noise < 0.001 deg, bias < 0.05 deg)
- Variable scan speed leading to adjustable point cloud resolution
  - Slow high-resolution scans with “megapixel” images
  - Fast scans for proximity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

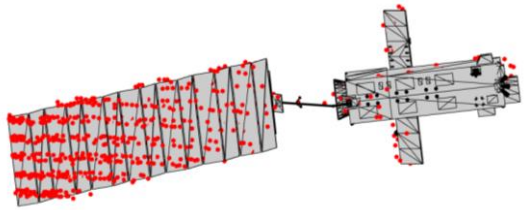


Scanning LIDAR in Debris Removal Scenario

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:



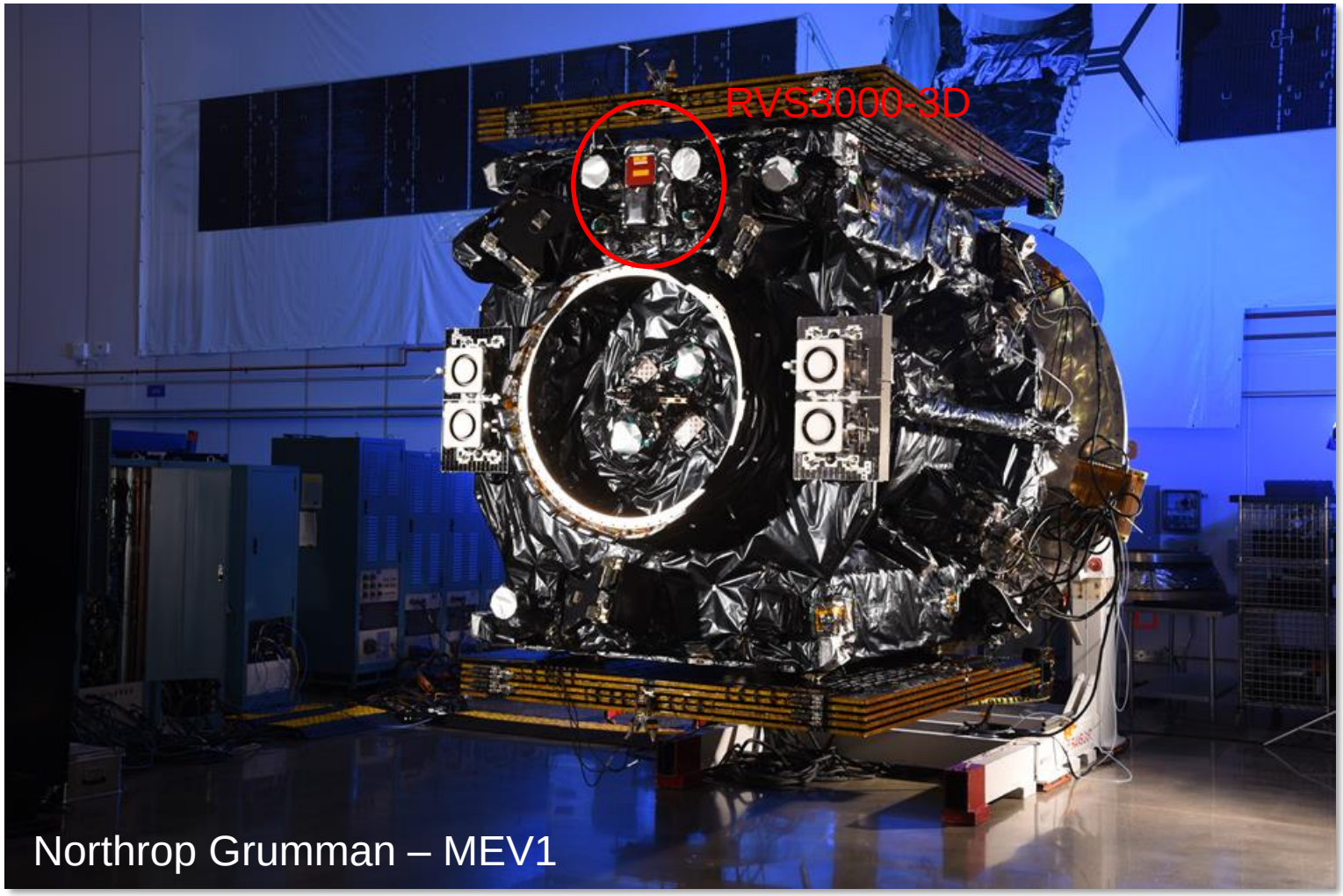


1 Acquisition of LIDAR Scan

2 Matching LIDAR Scan vs. Model

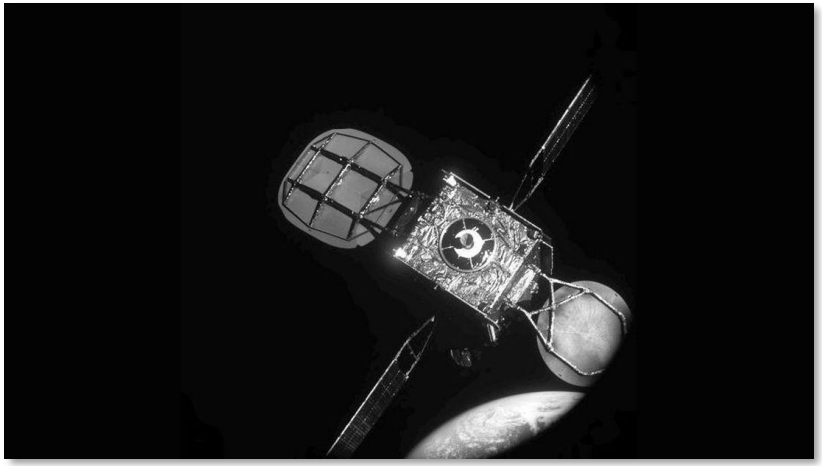
3 Pose

RVS3000-3D – In Orbit Experience

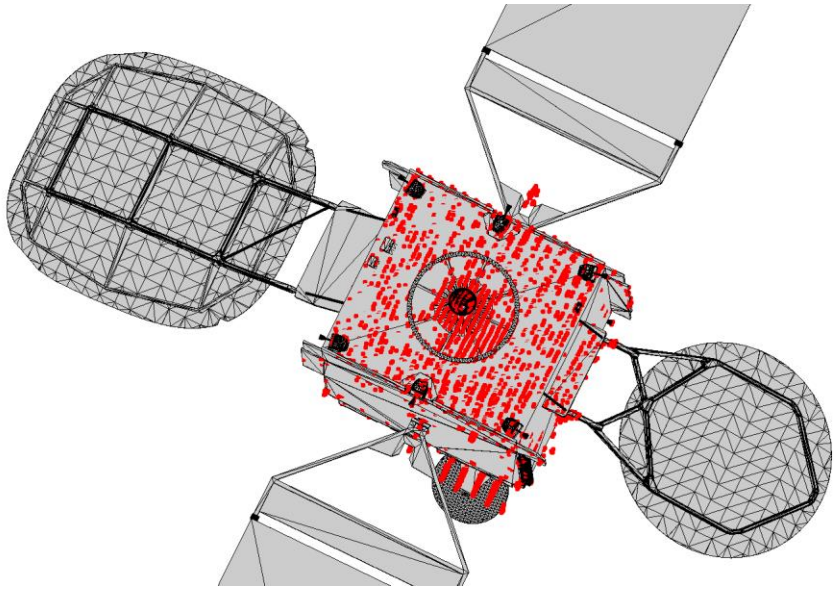


Delivery of 1st RVS 3000-3D FM in 2018

RVS3000-3D – In Orbit Experience



JOP AstroHead Camera - Image of IS901 in Orbit



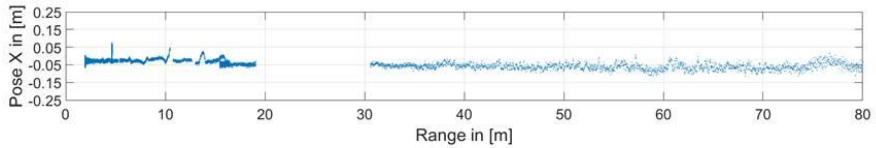
JOP RVS3000-3D - Scan & Pose of IS901 in Orbit

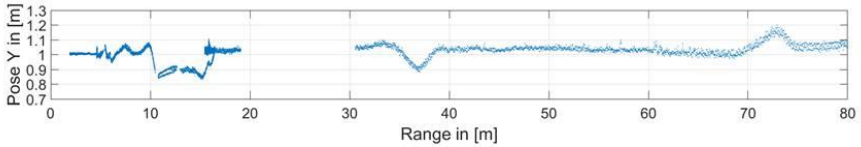
Successful Docking in GEO in Februar 2020 !

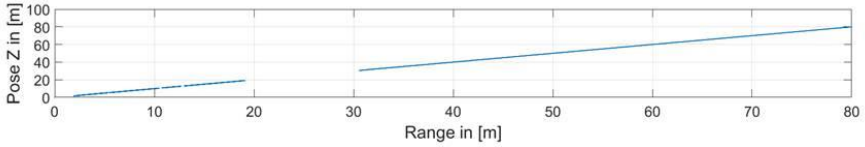
RVS 3000-3D – LIDAR for satellite servicing

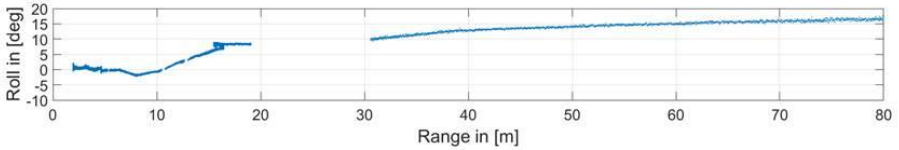
- Pose Estimation LIDAR developed for Satellite Servicing Mission
- Qualified for 15 years GEO mission
- 2 FMs delivered in 2018
- Pose Performance vs. GEOs in close range:
  - Position better than 1-3 cm
  - Attitude better than 0.5-1 deg
- Pose Estimation algorithms developed and qualified within 2 years (!)
- Successful Docking of MEV1 in GEO February 2020 **(TRL 9)**
- Successful Docking of MEV2 in GEO April 2021 **(LIDAR primary for docking)**

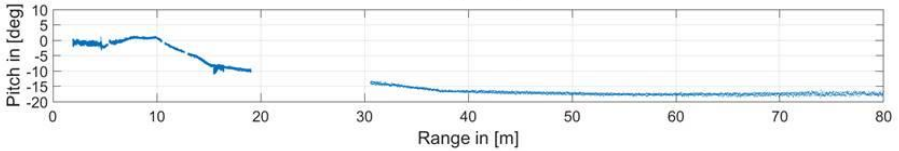
RVS 3000-3D – Pose Estimation In-Orbit Performance vs. IS1002

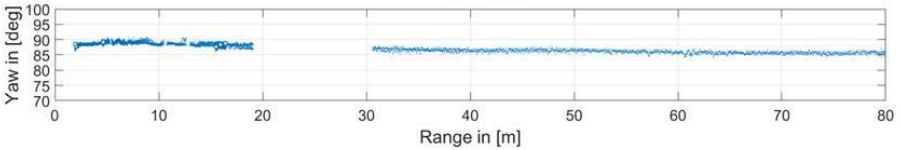


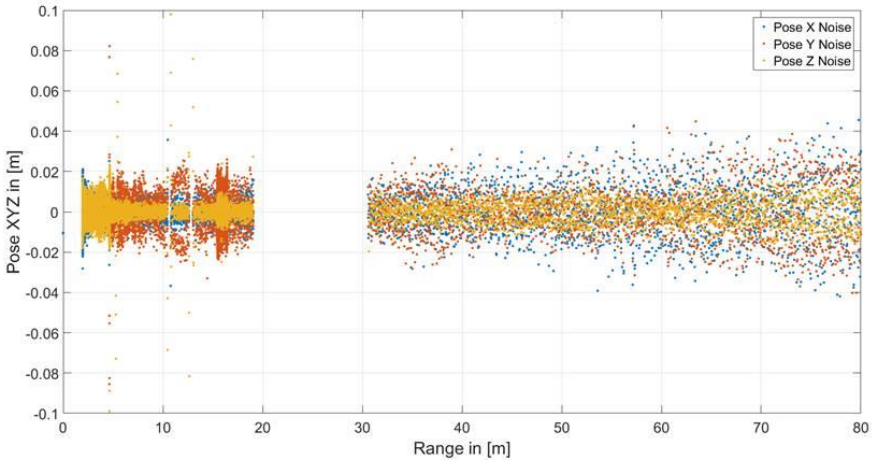


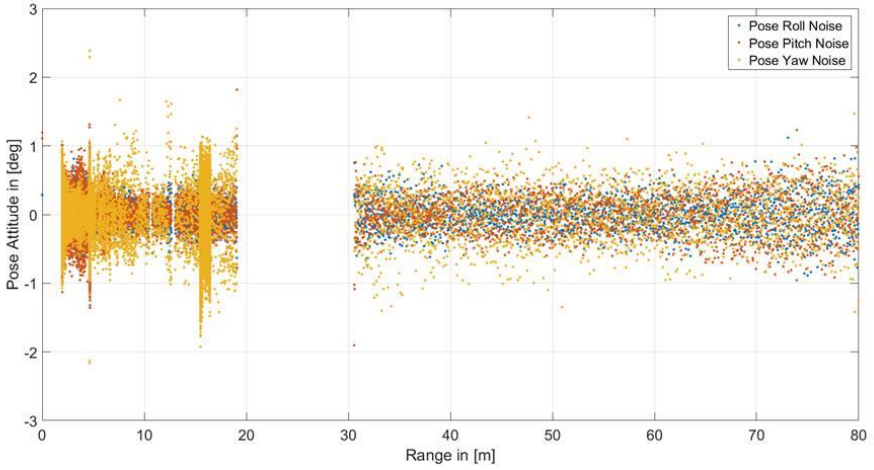








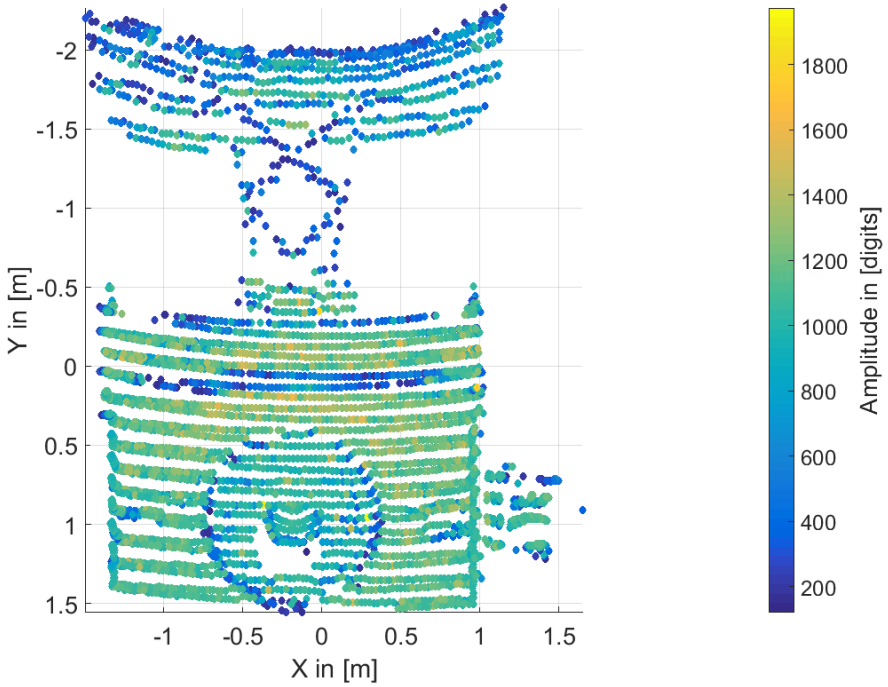


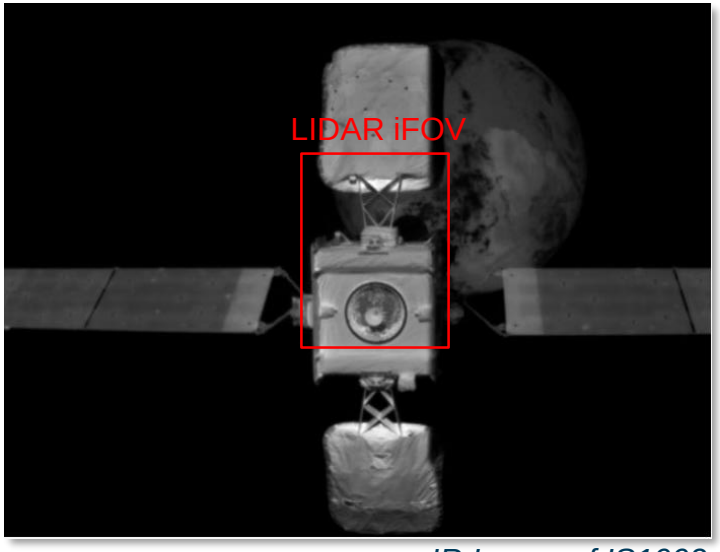


*Bias estimated based on moving average over 10 consecutive pose results

RVS 3000-3D – Pose Estimation In-Orbit Performance vs. IS1002

LIDAR Scan of IS1002 – 2Hz





IR Image of IS1002

iFOV…instantaneous Scan FOV

RVS 3000-3D – LIDAR for satellite servicing

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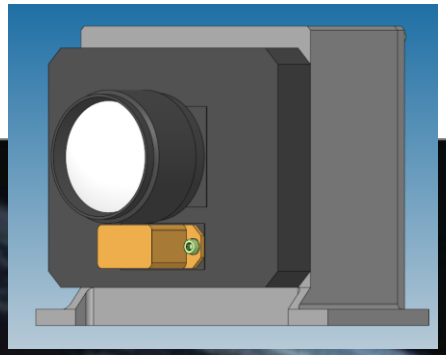
- Qualified for 15 years GEO mission
- 2 FMs delivered in 2018
- Pose Performance vs. GEOs in close range:
  - Position better than 1-3 cm
  - Attitude better than 0.5-1 deg
- Pose Estimation algorithms developed and qualified within 2 years (!)
- Successful Docking of MEV1 in GEO February 2020 **(TRL 9)**
- Successful Docking of MEV2 in GEO April 2021 **(LIDAR primary for docking)**

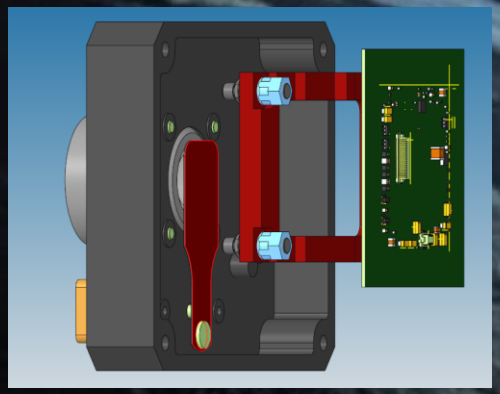
Outlook, Future Developments

ASTRO thermal infrared - ASTROtir – Thermal Infrared Camera for Space Applications

Applications:

- Formation flying / relative navigation
- Approach and Docking at a space object
- Image generation of near satellite objects



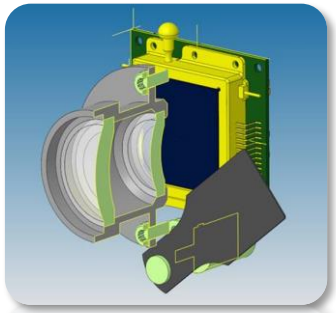


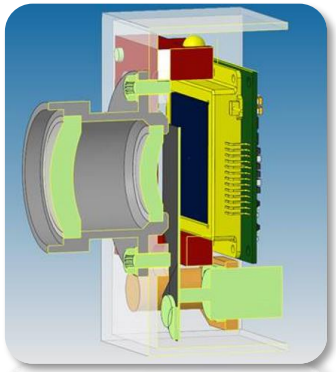
Key Characteristics:

- State of the Art Microbolometer – PICO1024GEN2 (1024x768, 17 µm, <50 mK @f#1, 300K, 25°C FPA)
- Flexibility by interchangeable lenses with common sensor IF
- Internal shutter for sun protection, correction & calibration.
- Analog PCB & digital PCB with FPGA-based camera controller.
- Regulated power & SpW Interface
- Optional Image Processing Board

ASTROtir programatics

- De-risking activities are currently running, external funding secured
- Development is scheduled to start in 03/2022
- JOP aims at a production capability of initially 12 units, ramping up to 36 units in the fourth production year
- Product qualification completed in 11/2024
- Batch production of FMs can be started after product qualification is completed
  - Accelerated options evaluated and single FM production can be advanced to realize an early delivery schedule for 1st FM.
- Manufacturing time for a unit of 12 FM batches is 12 months, lead time is higher as necessary parts need to be procured in advance of the begin of the production





Many Thanks for Your Attention!
Questions?

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