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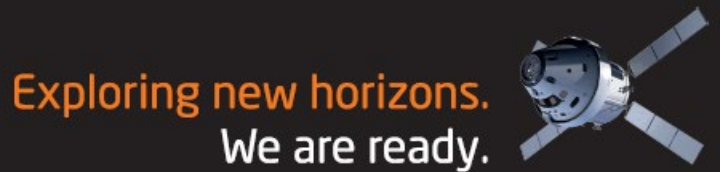
Towards a Sensors Suite for Close Proximity Operations and Object Detection in the Vicinity of Spacecrafts

Max Möller, Simon Chelkowski
Jena-Optronik GmbH, Germany
https://www.jena-optronik.de/

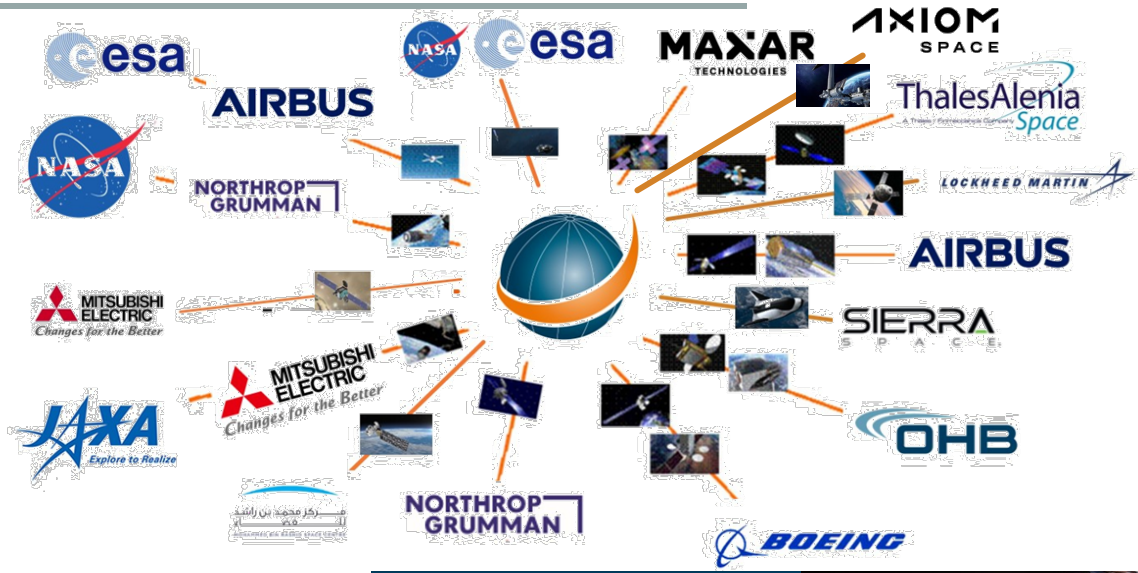


Subsidiary of **Airbus Defence and Space**

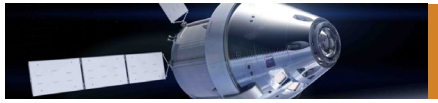
Location: **Jena, Germany**

Employees: **238 (end of 2022)**

Revenues: **56 m€ (2022)**

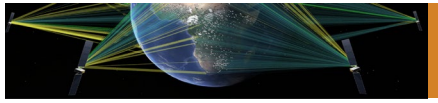


Space exploration



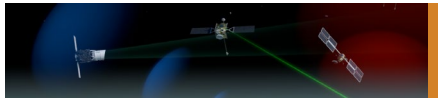
Human spaceflight

Earth observation



Telecommunications & Navigation

Space logistics & Debris removal



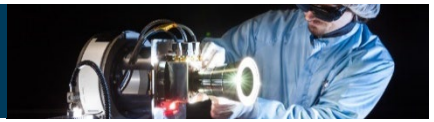
Space Situational Awareness

your mission

our solution

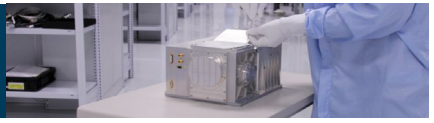
Dedicated department @JOP since 2022

Star Sensors ASTRO© family

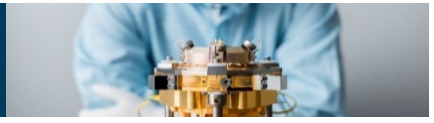


Cameras

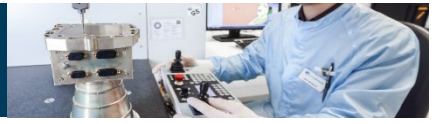
LiDAR RVS© family



Space optics & Electronics



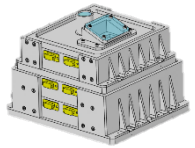
Services



RVS ® successful space LiDARs for rendezvous and docking

- 100 units contracted
- >60 units flawless flight heritage on ATV, HTV, Cygnus, MEV
- Application for Dream Chaser, ORION, Mars Sample Return, Astroscale ELSA-M, AXIOM
- LEO – GEO – Lunar Orbit – Lander Applications

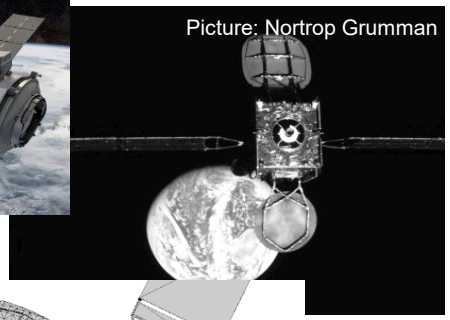
RVS3000, RVS3000-X



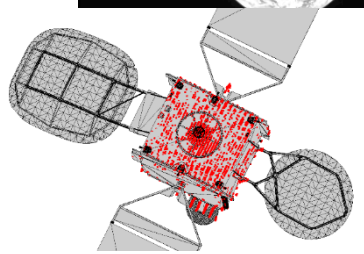
µRVS

ISS Resupply

In Orbit Service



Exploration

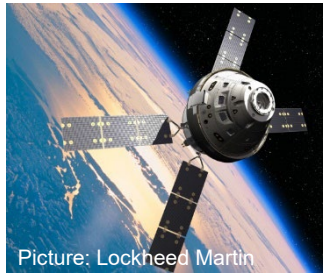


ASTRO ® series - worlds most successful Star Sensors

Earth Observation

Telecom

Human Space Flight



ASTRO APS

ASTROgyro

ASTRO CL

- Worlds 1st autonomous star sensor ASTRO1 was developed in Jena
- >750 star sensors contracted since 2000
- >450 star sensors with flawless in orbit operation (>2000 years)
- LEO – MEO – GEO – HEO – Lunar Orbit – Deep Space
- Radiation hard solution for large constellations

Overview of JOP space situational awareness

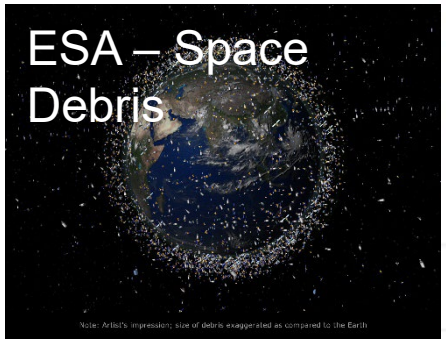
Monitoring of Satellite Surrounding – from Space

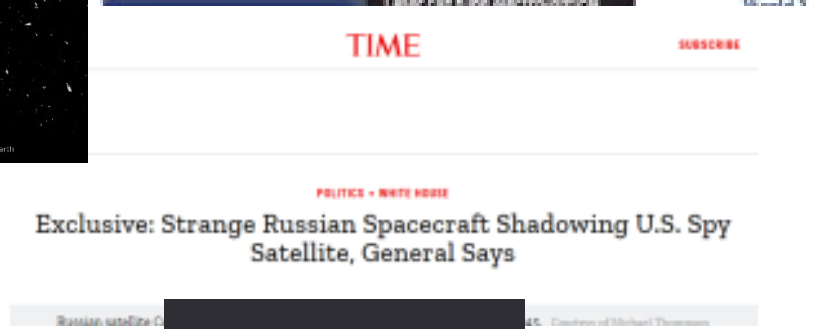
There are three areas within the Space Situational Awareness (SSA) sector:

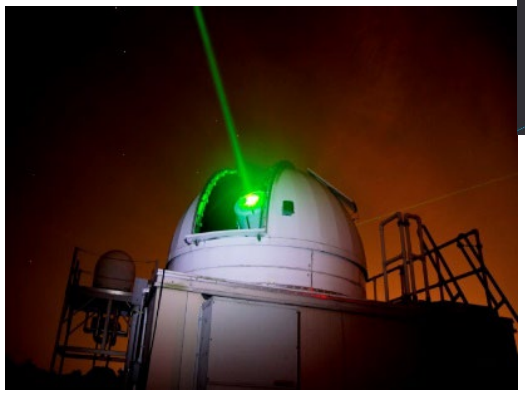
- Space Weather → Monitoring of the sun and its influence on earth
- **Natural objects and debris → Example: *Clean Space***
- **Actively initiated threats and disturbances (covers RPO)**
  - Threat by approach and docking
  - Threat by Laser
  - Threat by disturbance of any kind

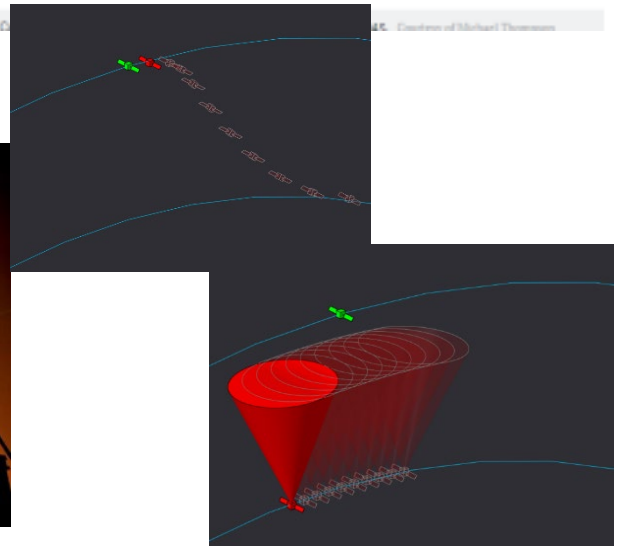
Application cases for a SSA – Sensor Suite:

- **Detection** of an object in the *keep-out-zone* or *of a laser tracker*
- **Tracking** of an object to evaluate its orbit and intention
- **Identification** of an object by generation of high resolution images which are evaluated on ground.

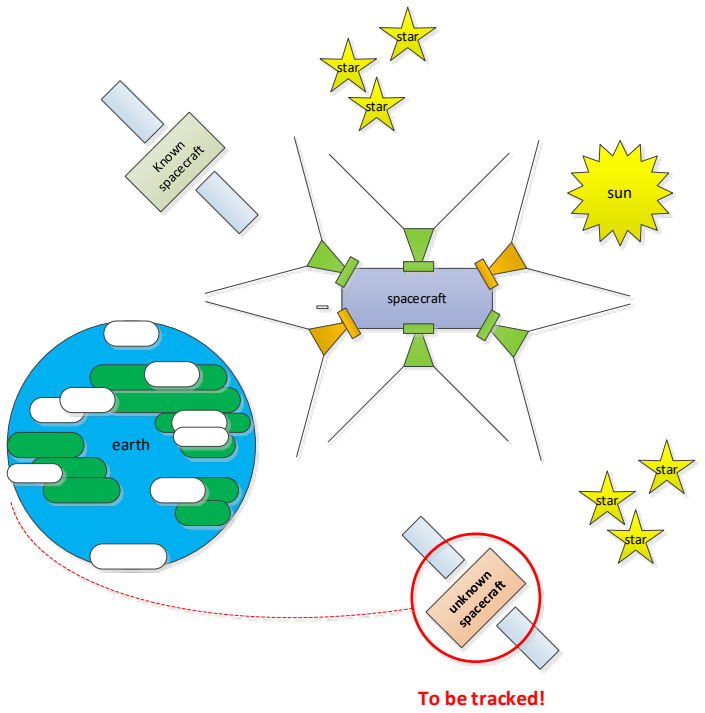








Motivation Sensor Suite for Space Situational Awareness

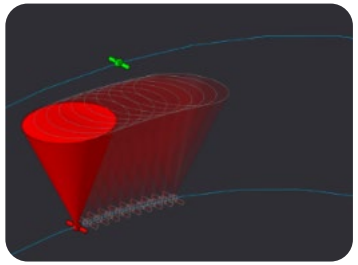


- **Tasks:**
  - Civil: **detect and track** potentially dangerous objects for the spacecraft (e.g. other space crafts, space debris, other uncontrolled objects in potentially intercepting orbits)
  - Civil: **Obtain in-situ data on currently unknown objects** (not observable from ground, statistically in orbit debris models)
  - Military: **protect own space based assets, requires identification** (e.g. hinder surveillance from space by other parties spacecrafts, decision makers need identification)
- **Common Interests/Needs:**
  - **Detection and characterization of object parameters** (size, orbit, distance, speed, controlled?, owner etc.)
  - Coverage of **satellite surrounding/relevant directions**
  - **Sensing range shall be large** to maximise warning time
  - Perform operation **independent of light conditions**
  - **Reject known harmless objects** to minimize date rate and computational power

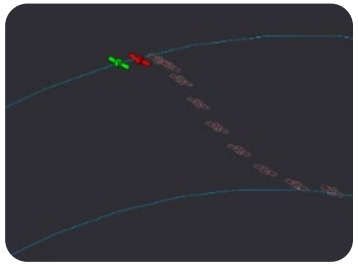
Useful sensors: VIS and IR cameras, LiDARs, Laser Rangefinder, optionally laser threat detection sensors

Motivation Sensor Suite for Space Situational Awareness

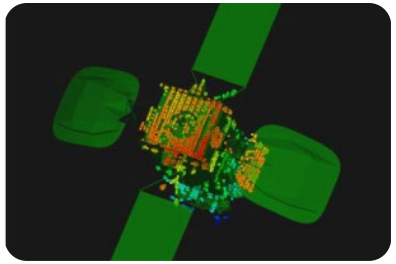
Possible Approach and fly-by Scenarios



Fly-by in lower-orbit and optical observation

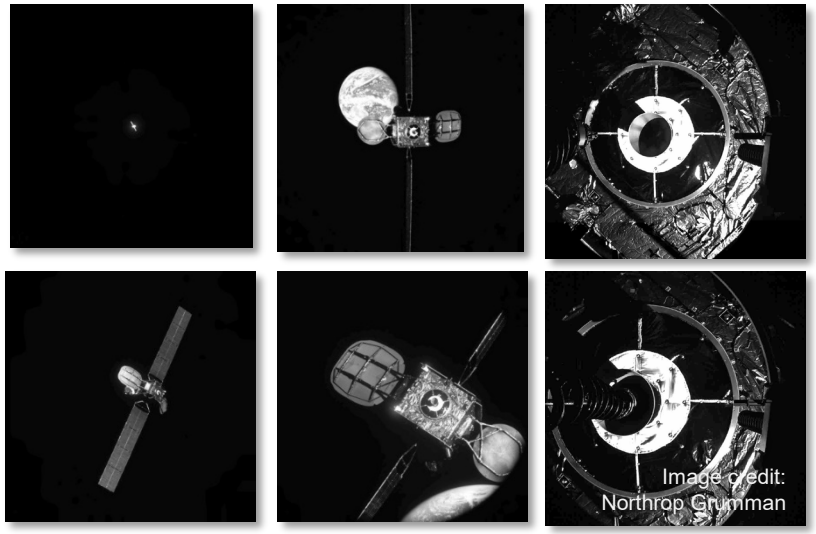


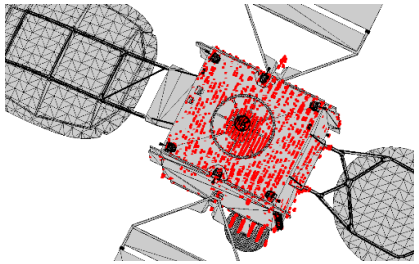
Change of orbit, follow and observe / investigate

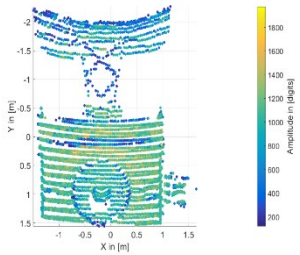


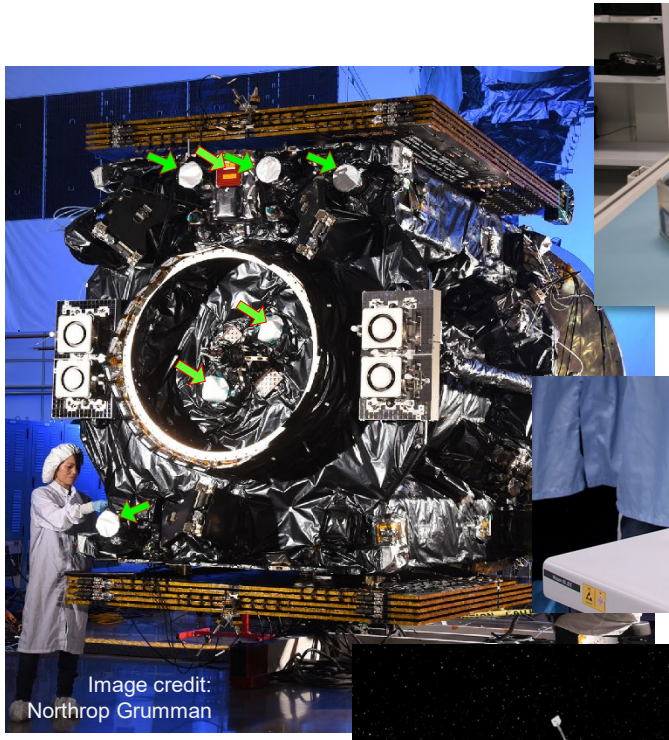
Approach and scan via LiDAR

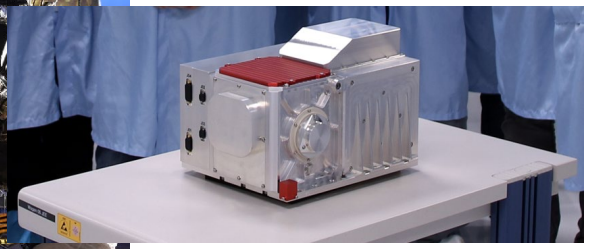
Example, intended docking in GEO orbit

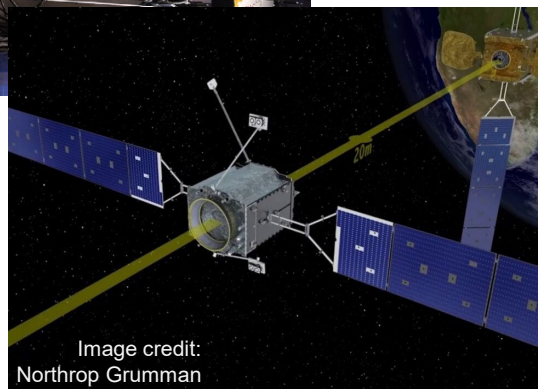












Achievement with MEV: First commercial docking to a non-cooperative satellite in space (geo orbit, both controlled) on February 25th, 2020 – JOP VIS Cameras, and LIDAR

JOP's SSA & SDA Sensor Suite

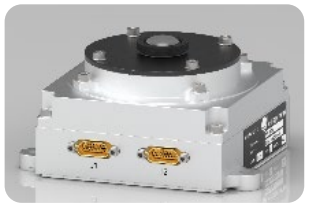
An optical sensor suite for SSA & SDA purposes is ideal to protect a spacecraft by **detecting, tracking and identification of incoming threats.**

Many of the essential components of a SSA sensor suite are already existing in the portfolio of Jena Optronik, further are currently being developed.

- Sensors for such a suite are:
  - **Cameras with different field of views** To detect illuminated objects
  - **Laser Threat detection** To detect incoming laser radiation
  - **IR Camera** To detect unilluminated objects
  - **LIDAR/Laser range finder** To actively detect & track of objects
  - **Central Processing** Unit Fusion of sensor data and control
  - **Gimbal mount** For cameras with identification purposes

- The sensor suite can be configured in modular setup to match specific customer needs.

Optical cameras (various lenses and FOV)

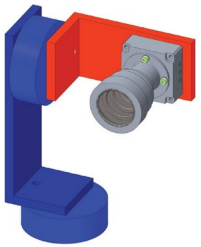


ASTROtir (IR Camera)

ASTRO*las* *(Laser Warner)*

RVS 3000 & RVS 3000-3D

µRVS



Gimbal Mount

Central Processing Unit

Demonstration on ASTRO CL

- **Possible Working principle for a camera/star tracker based sensor**

Scenario Image
Detected by sensor suite

↓

Removal of known objects (stars, plantes, moons, etc)

↓

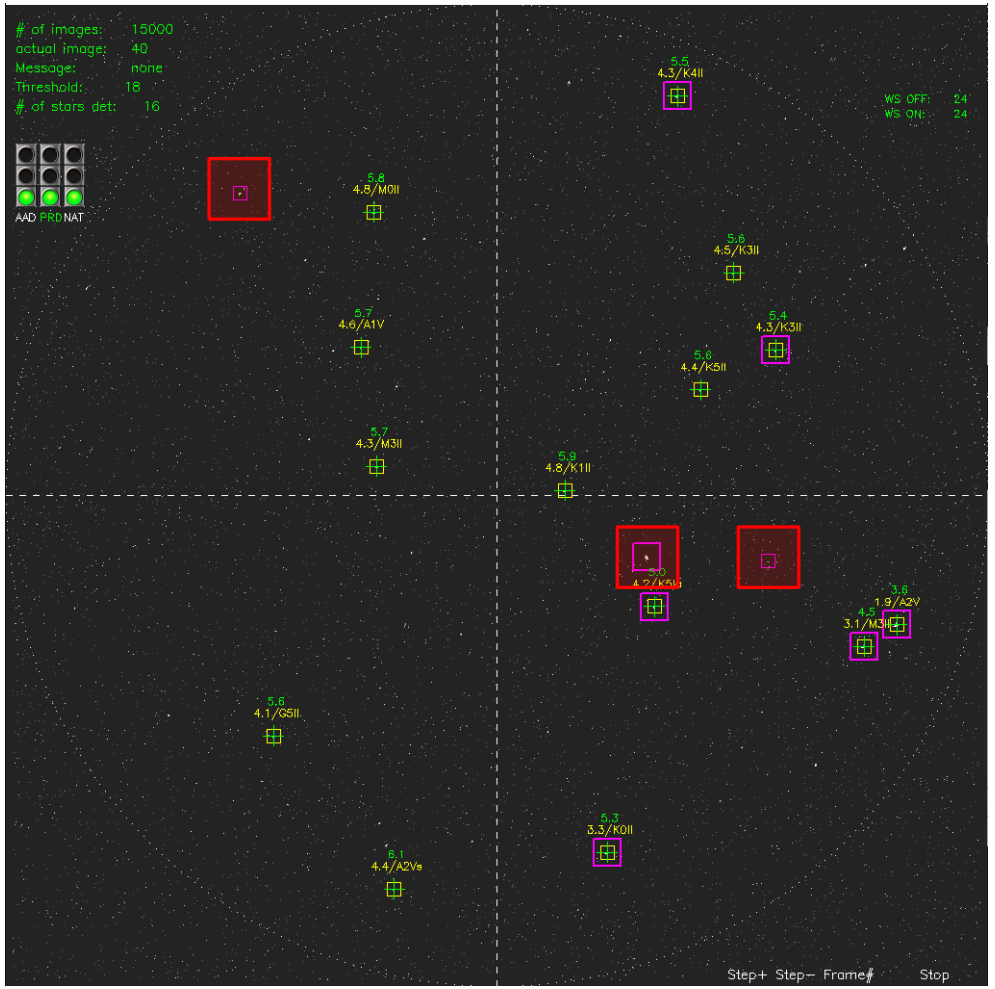
Optional: Removal of artificial objects

↓

Sensor output
Angular coordinates w.r.t. satellite coordinate system
Tracking of an identified object in FoV

== “Inverse” Star Tracker

Star Tracker FoV



FoV:	25deg circular
Limit:	5.8mi
Update Rate:	4.6Hz

The classical star tracker operates in the nominal attitude tracking mode with:

- 14 verified guide stars,
- 2 rejected guide stars and
- 1 non-star object

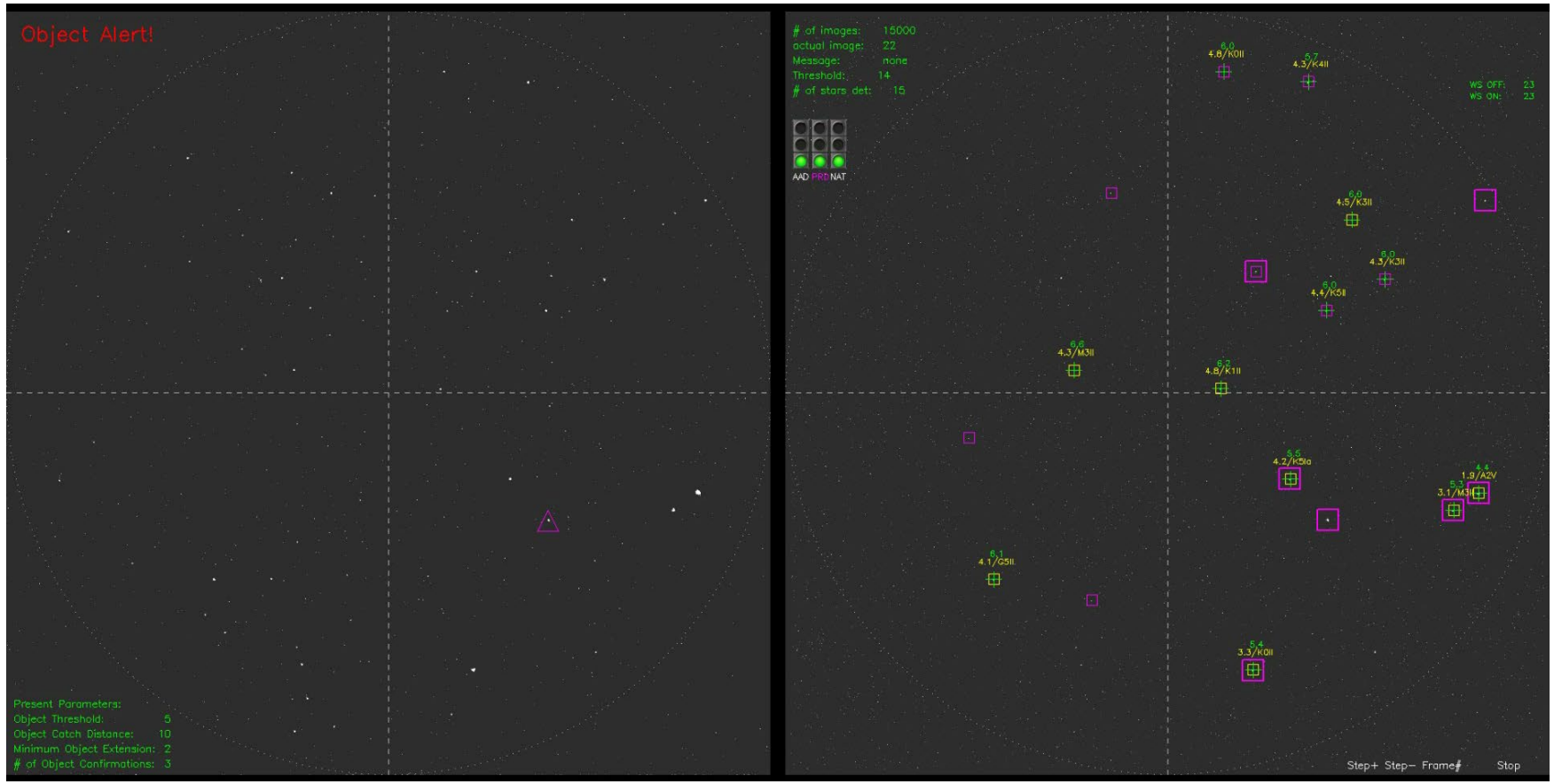
ASTRO CL, star tracker head with SW running in OBC for e.g. constellations

Demonstration on ASTRO CL

- Ground based concept demonstration performed in 2023 using ASTRO CL with adapted inverse star tracker software running on laptop.

Inverse Star Tracker FoV

Star Tracker FoV

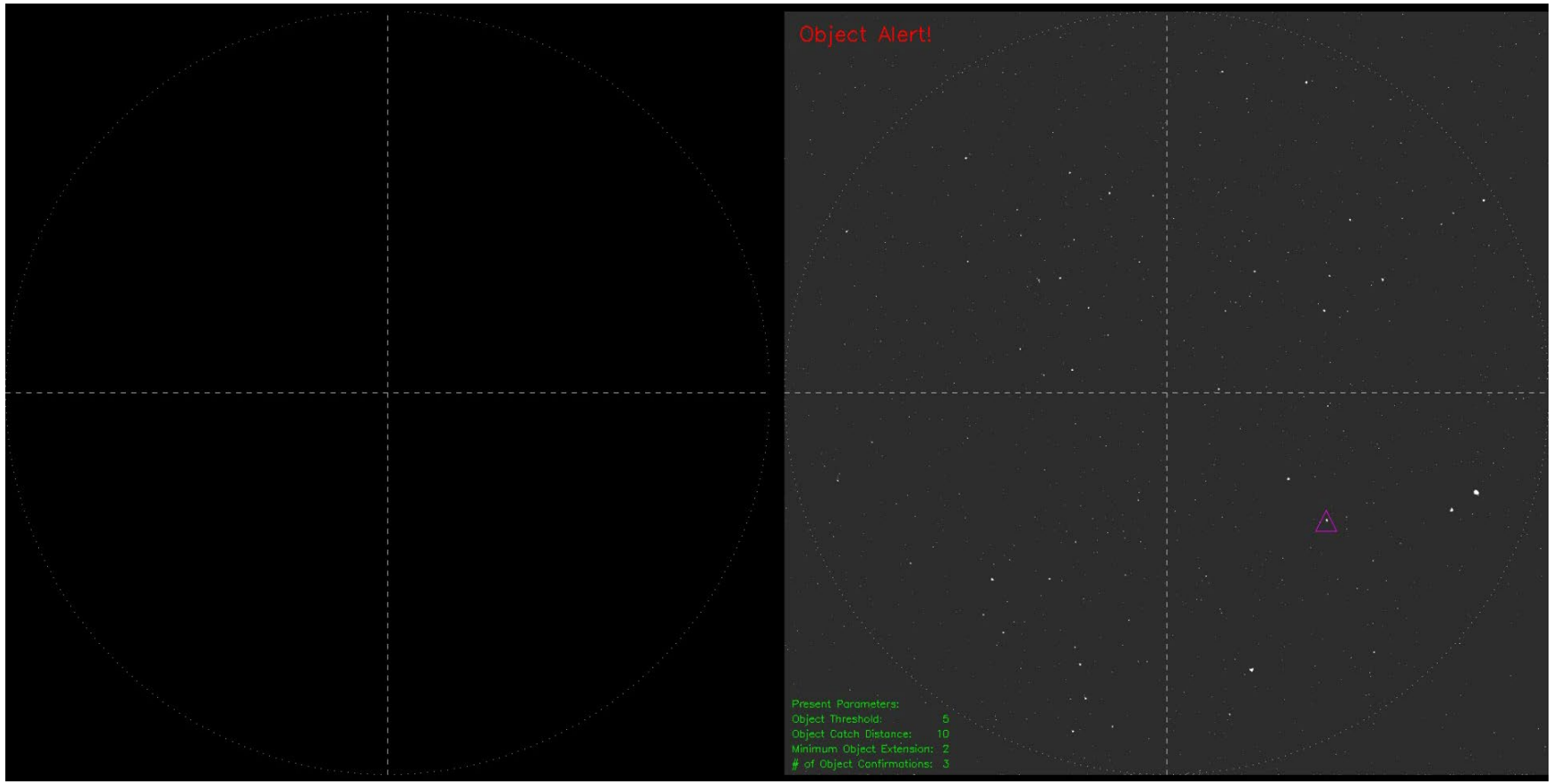


Demonstration on ASTRO CL

- Ground based concept demonstration performed in 2023 using ASTRO CL with adapted inverse star tracker software running on laptop.

Objects accumulated during 1 hour survey

Inverse Star Tracker FoV



Overview of JOP visual cameras

Overview VIS cameras

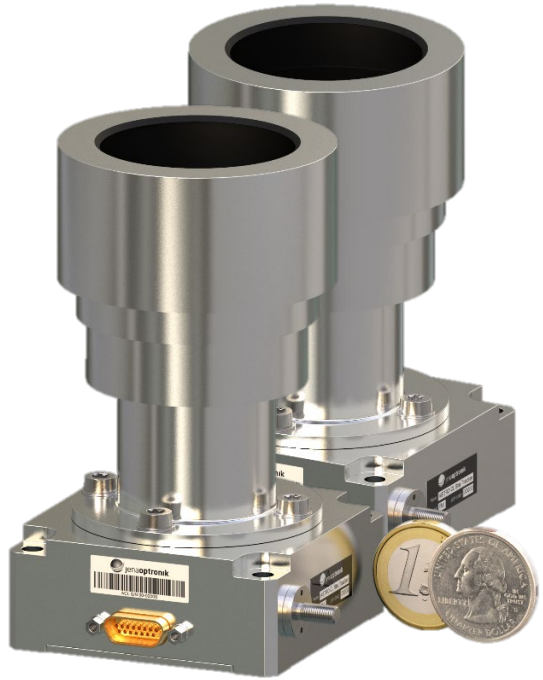
Generic Hardware + Application driven Software = Desired Functionality

- **Building blocks:**
  - Faintstar2 based
  - JOP designed high-rel optics
  - LEON-4 based processing
  - Highly configurable
  - Multiple power and operational interfaces
  - Software

- **Applications:**
  - Star tracking
  - Navigation
  - Robust rate measurement
  - **Space-Situational-Awareness**

Best candidate VIS camera for SSA purposes

- Technical data
  - OH Interface: SpW Link, 5V
  - OH Power: < 1W
  - Mass: 300g
- Main application: star tracking
- For SSA Purposes a the software needs to be adapted.

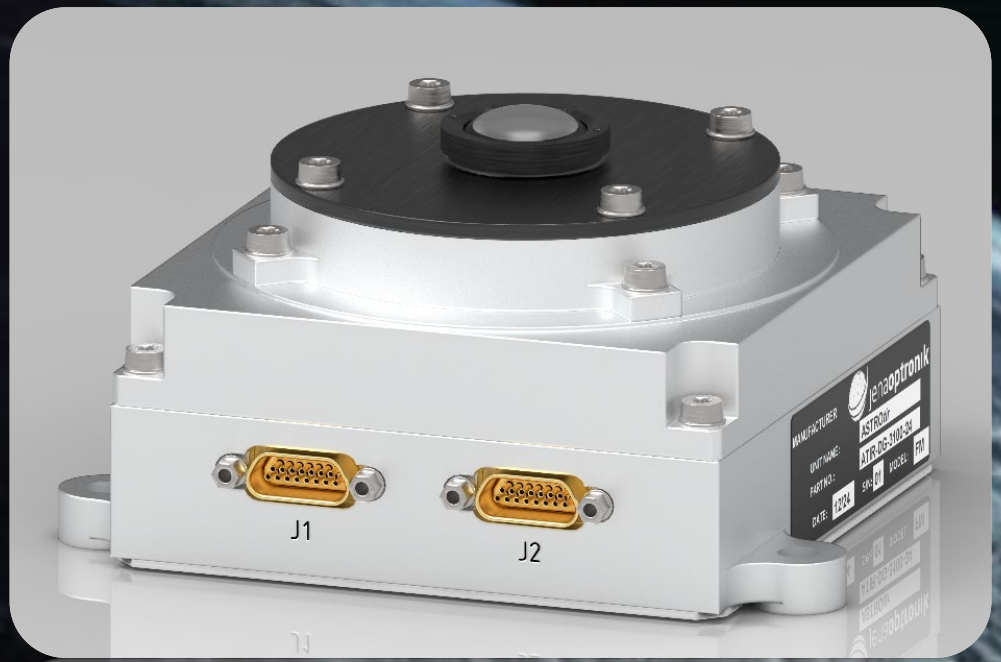


- ASTRO CL star tracker is **fully qualified since 2020**.
- Space-borne CMOS APS design with FaintStar2.
  All EEE-parts are **radiation-hard and latch-up free**. No sudden OH resets!!!
- The image detector qualification **radiation loads fully cover** critical
  EoL loads of the **LEO and GEO-Orbits**.

ASTRO CL is the most robust and compact Constellation Star Tracker available at the market.

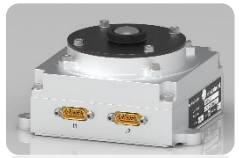
And is easily adapted to SSA use cases via a software update

ASTRO*tir* – A compact, lightweight and multi purpose thermal infrared camera for space applications



Key Characteristics:

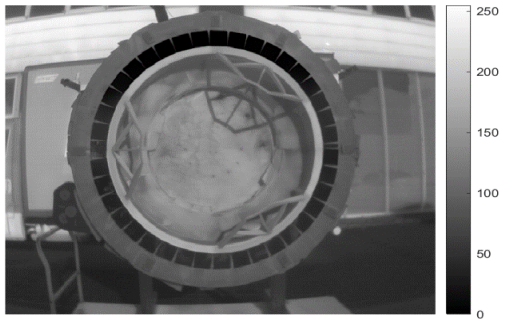
- State of the Art digital Microbolometer
  (1280x1024, 12 µm, <50 mK @f#1, 300K, 25°C FPA)
- Camera Resolution : 640 x 480 pixel, optionally increasable with dedicated optics
- Optional Internal shutter for sun protection, correction & calibration
- Advanced PCB technology allowing small and light weight sensor
- FPGA-based camera controller.
- Regulated power & SpW Interface
- Optional Image Processing implementable



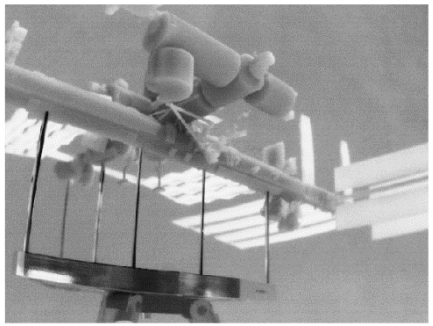
Conceptual Design

- Target is a “new space” high-rel product similar to our latest very compact ASTRO CL star tracker product.

ASTRO CL ASTRO*tir WFoV* ASTRO*tir NFoV*



IR Image with ATTO640D detector Breadboard



Thermal image of a 3D-printed model of the International Space Station taken with our ASTROtir Breadboard

Preliminary Data Sheet

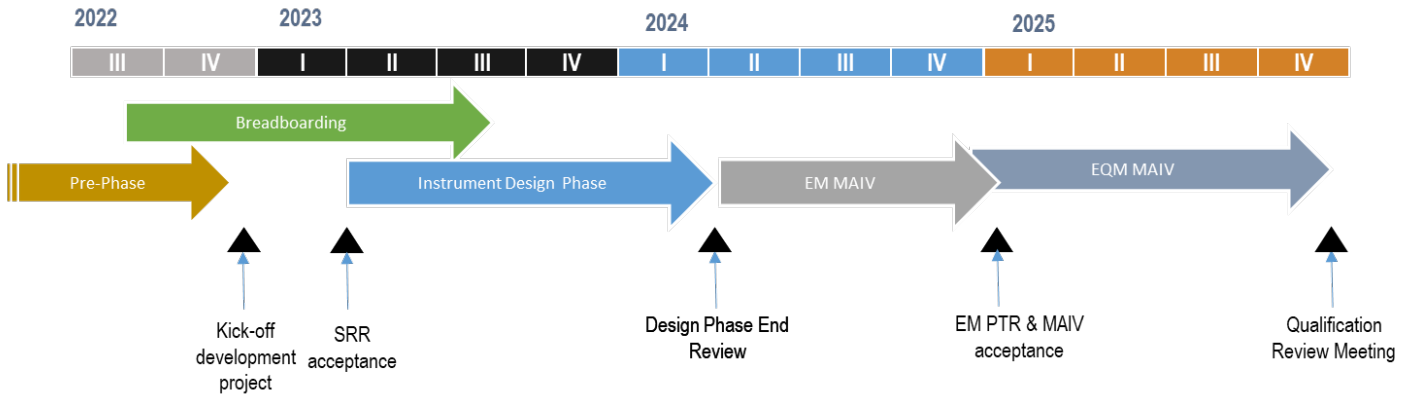
Product information and data sheet available online under https://www.jena-optronik.de/products/cameras-and-camera-systems/astrotir.html

Topic	ASTRO*tir*
Dimensions	83mm x 80mm x 52mm
Mass	570g for wide FoV 615g for narrow FoV
Frame Rate	12Hz for 640x480
FOV	Wide: 60° Narrow: 20° further FOV optional
Resolution	VGA 640x480, optional 1280x1024[1)]
Bit depth	>14bit
I/F	SpaceWire
Configuration	FPGA for Camera Control will have capabilities for NUC correction and other features too
Shutter	Optional: Modular Shutter
Lifetime	6y / (10y)
Power	≤7W (TBC)

1): *requires specific lens development, consequently the system mass will be increasing*

Ongoing Development

- Model Philosophy for the development:
  - Camera Breadboard with desired detector and commercial optics and electronics in a 3D-printed housing with a breadboard shutter
  - Engineering Model
  - Engineering Qualification Model
- Specialties of the individual Models:
  - EM and EQM share the same design (goal), EM MAIV is starting after final design review
  - EQM is used to perform qualification campaign and reach TRL8



- Development was kicked-off in 2022 with co-funding by ESA.
- PDR has been passed.
- Detailed Design Review planned in first half of 2024 and completion of qualification end of 2025.

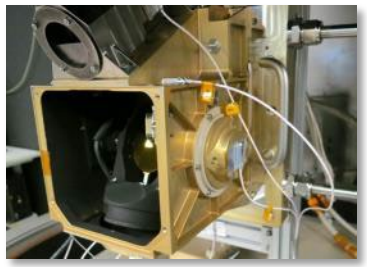
RVS Product Family Extract

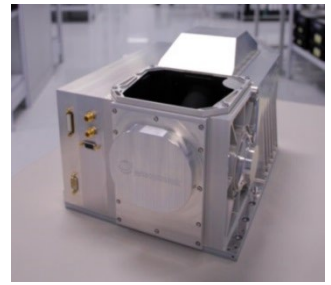
RVS Family Heritage




RVS-ARP

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





LiQuaRD*

LIRIS-2 on ATV-5

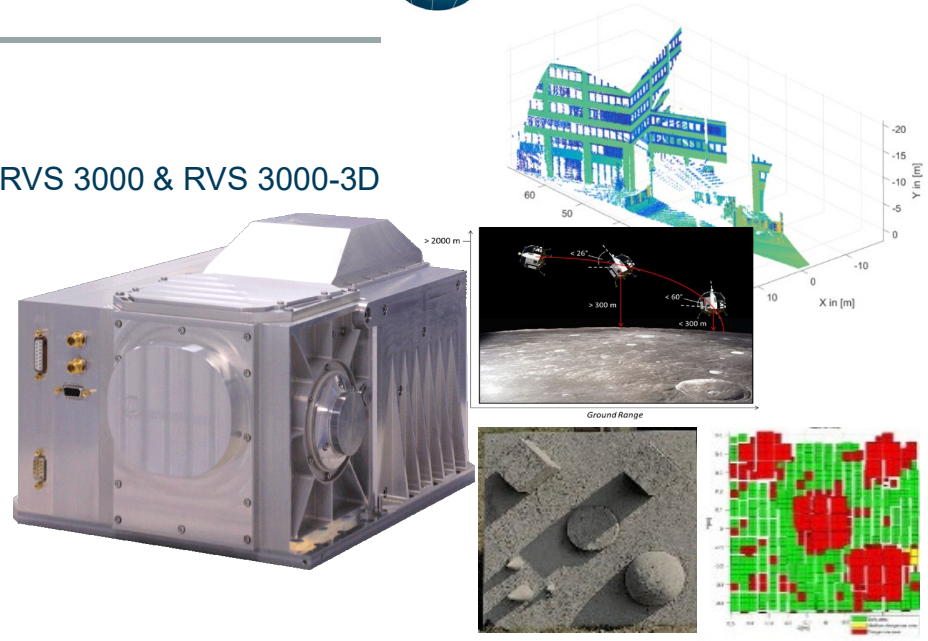
RVS3000 Product Family
70+/32/21 FMs
contracted/delivered/flown

* LIDAR Qualification for Rendezvous and Docking (DLR)

Successful space lidars for rendezvous and docking

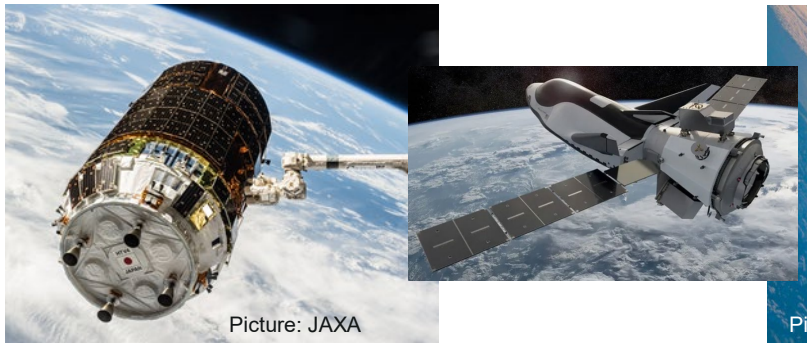
- >60 units flawless flight heritage to ISS
  as primary sensor on ATV, HTV, Cygnus, MEV (in-orbit servicing)
- Application for Dream Chaser, ORION, Mars Sample Return, Astroscale ELSA-M, AXIOM
- LEO – GEO – Lunar Orbit – Lander Applications
- Activities for Landing Applications – Hazard Detection and Avoidance, e.g. with ESA

RVS 3000 & RVS 3000-3D

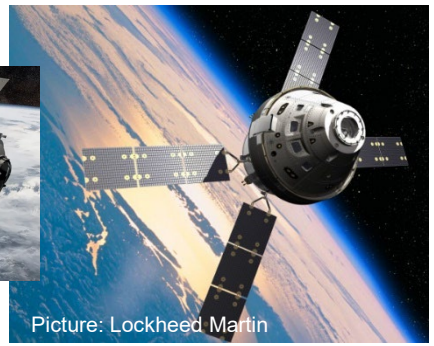


ISS Resupply

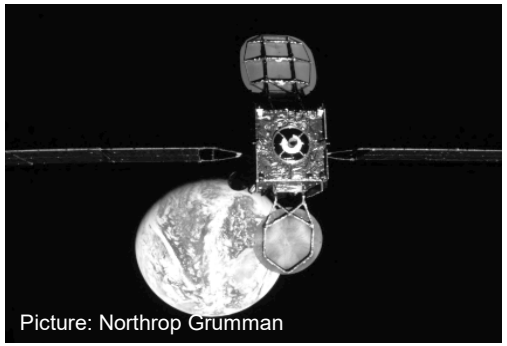

Picture: Nortrop Grumman


Picture: JAXA

Exploration

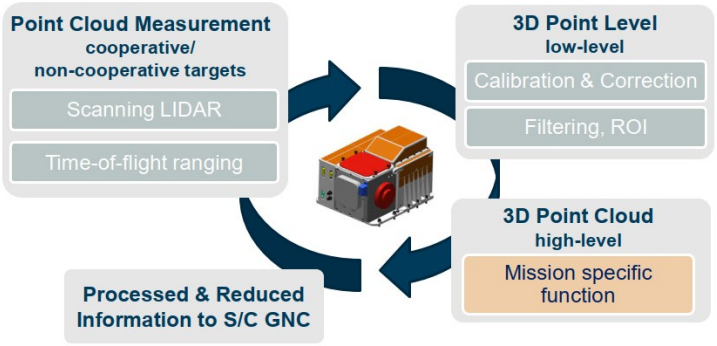

Picture: Lockheed Martin

In Orbit Service

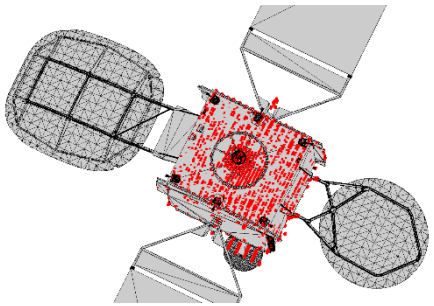

Picture: Northrop Grumman

RVS3000, RVS3000-X LiDAR

- Imaging LiDAR create 3D point clouds of objects
- Mission specific processing of point cloud to extract needed information for proximity operations
- Applications:
  - Close proximity guidance and navigation for rendezvous and docking
  - On-orbit satellite servicing and assembly
  - Landing Application under consideration



Mission specific LiDAR processing Flow

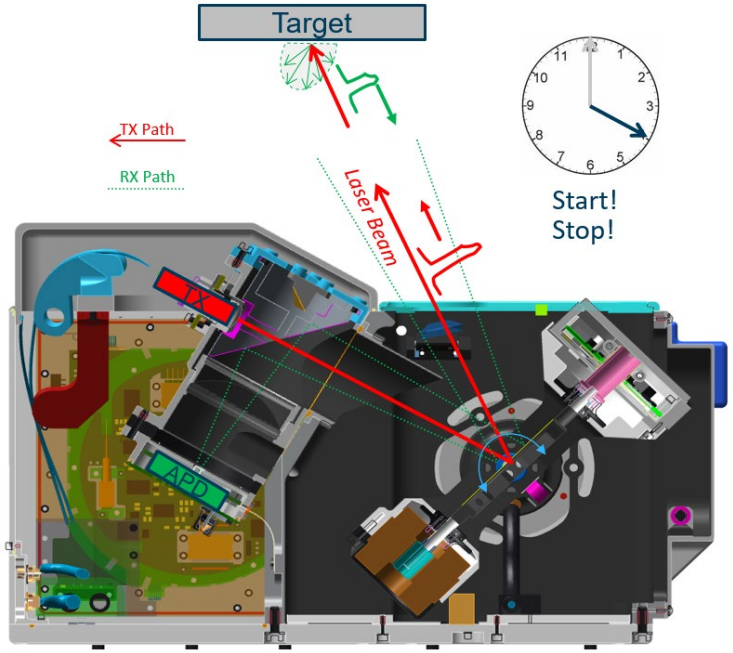


RVS 3000-3D Scan of IS901 in Orbit Image Credit: Northrop Grumman from MEV Mission

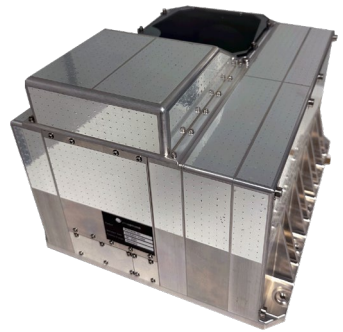
Scanning LiDAR in SSA Applications

- Measurement of Direction and Distance to Objects in the Vicinity of a Spacecraft
- Independent on scene illumination
- RVS 3000 product has reached TRL9
  - ISS resupply missions (Cygnus)
  - In Orbit servicing (MEV Mission)

More Detailed Information on JOP LiDAR products



RVS 3000-3D schematic setup

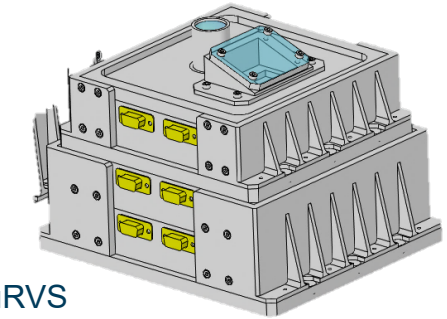


RVS 3000 & RVS 3000-3D

µRVS – Miniaturized Space Lidar Sensor

- µRVS is a miniaturized space lidar.
- It will be complementary to RVS 3000 family in the Jena-Optronik product portfolio.
- Miniaturization will be achieved through introduction of a manifold of new technological features.

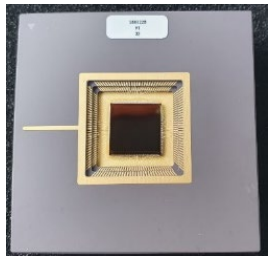
RVS 3000



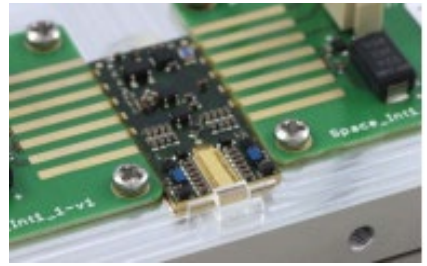
µRVS

Maximum sensing distance for a non cooperative target	100	m
Field of view	± 20	deg
Angular resolution of the transmitter	0,2	deg
Full frame frequency	3	Hz
Minimal mass	<3	kg
Minimal power consumption	<15	W

µMirror (MEMS)



SPAD Detector



Diode Laser

Sensor concept – requirement of components

Laser source – Laser diode

- Wavelength: 905 nm
- Pulse repetition: 20 kHz – 100 kHz
- Pulse power: 60 W

Scanner – µ-mirror:

- FoV (optical): > 40 - 0.1 deg (variable)
- Frame rate: 3 Hz
- Angle resolution: < 0.2 deg

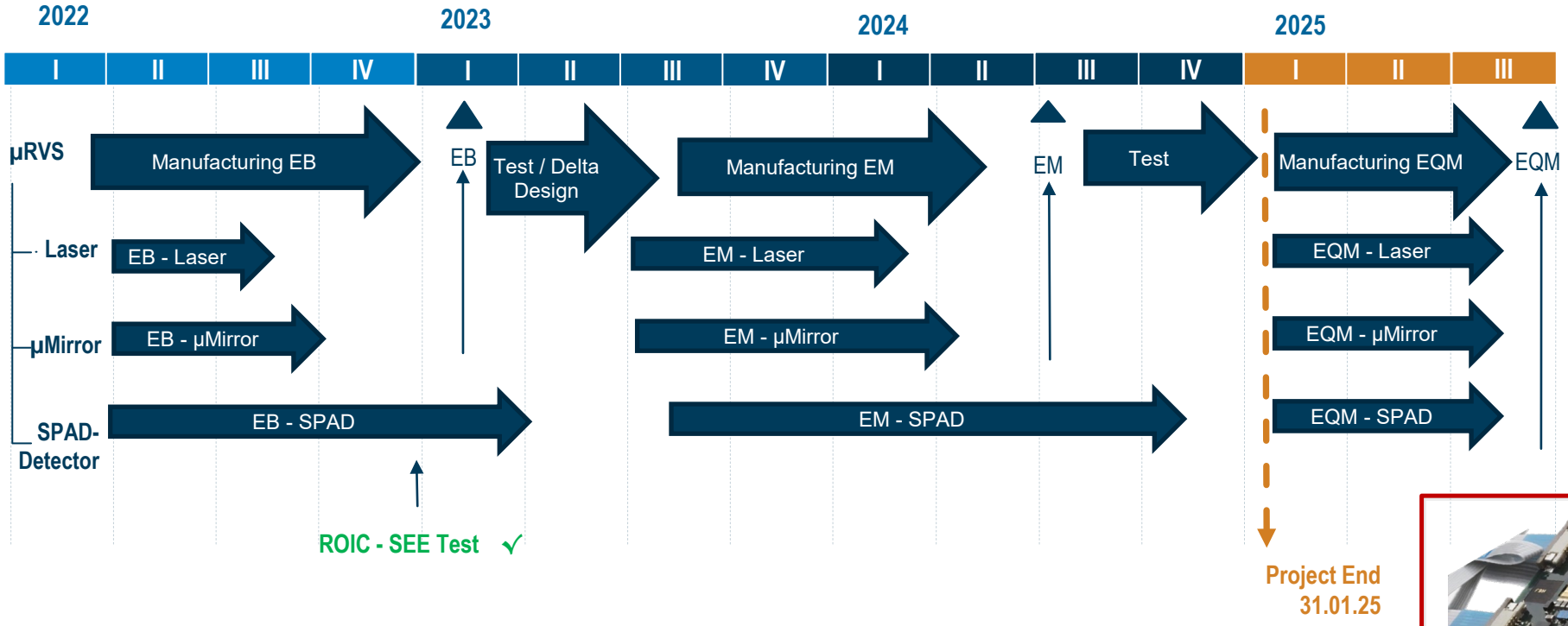
Detector – SPAD array :

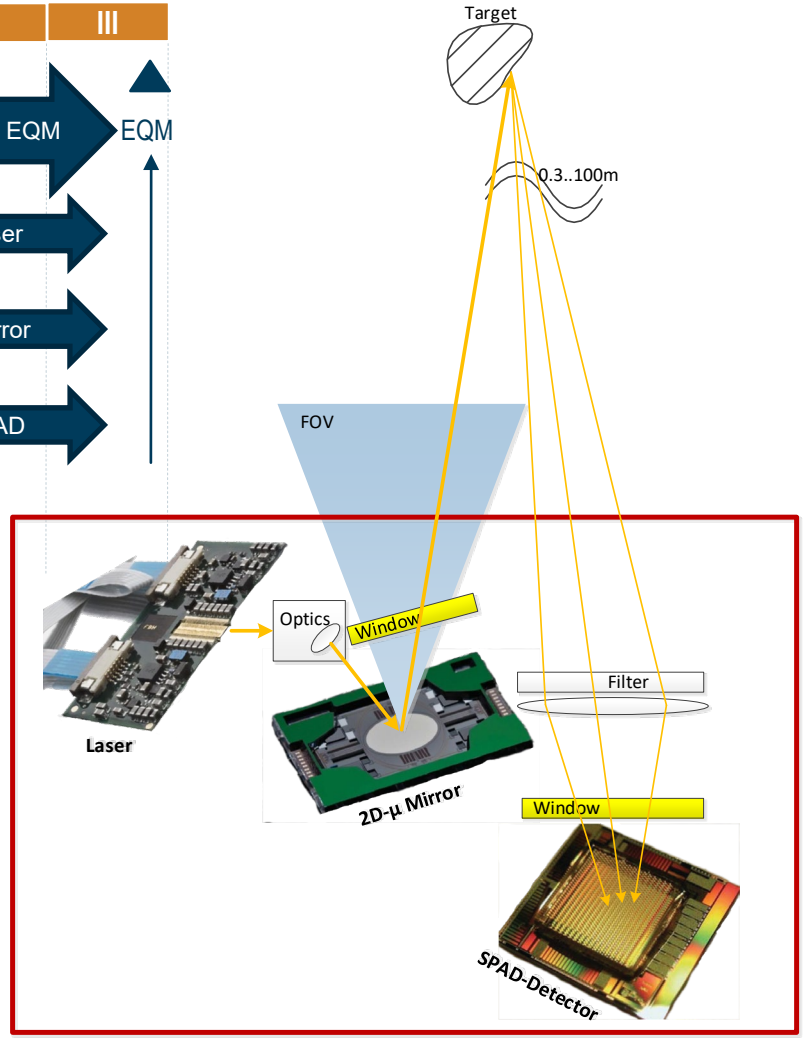
- Detector matrix: 112 x 112 pixel
- Range resolution: < 5 cm
- Range (non cooperative): 0.2 m - 100 m

µRVS – Sensor:

- Size (L x W x H): (15 x 15 x 12) cm
- Mass: < 2.5kg
- Power consumption < 15W

µRVS – Development Planning





- Current µRVS development phase aims to demonstrate TRL 5+ with Engineering Model beginning of 2025
- Radiation test on detector as critical innovation has been recently performed successfully.
- Industrialization of new technologies will be prepared within the EQM phase.

Conclusion

- Jena-Optronik GmbH has **a wide variety of sensors** that are capable of being used in a **SSA / SDA sensor suite** right now. Such a sensor suite is able to detect, track and ideally identify incoming threats to any spacecraft that is equipped with it.

- The **sensor suite** can be adapted **to work autonomously** and independently of the primary mission of the host spacecraft. Data processing from the different sensors is done autonomously. In case of a detection, the suite will provide key information to the spacecraft, track the threat and enabling the spacecraft operator to decide on how to react on basis of factual data.

- This capability will be key in the future operation of spacecrafts where the number of civil and military actors in the space domain increases.

- Jena-Optronik GmbH is ready to support you in securing your valuable space assets.

… let's discuss and exchange on needs, and software and data-handling concepts with and for the sensors!

Thank you

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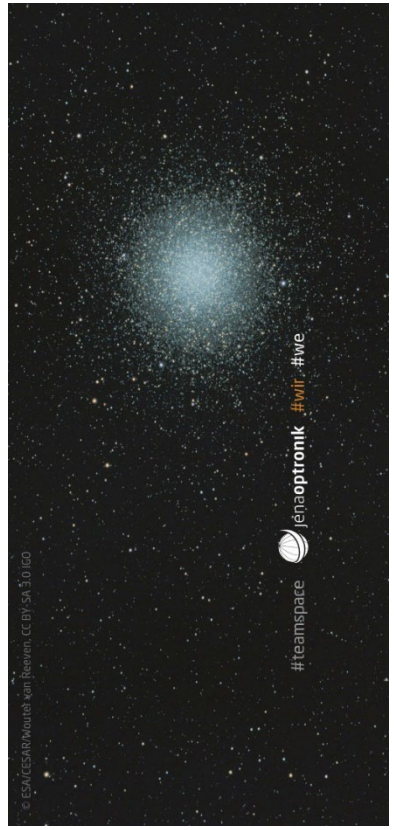
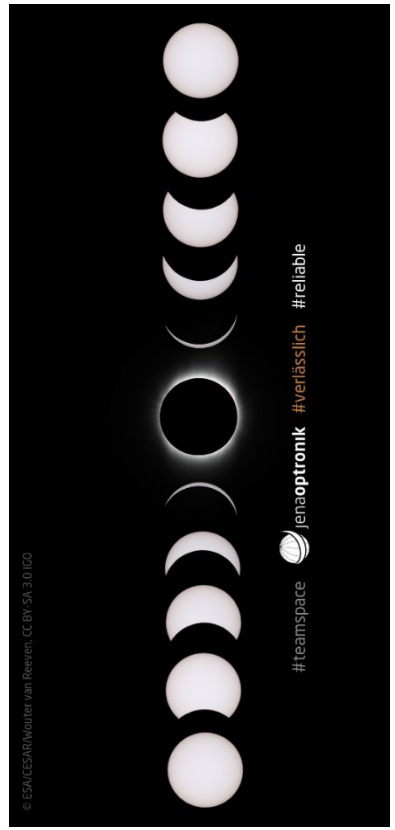
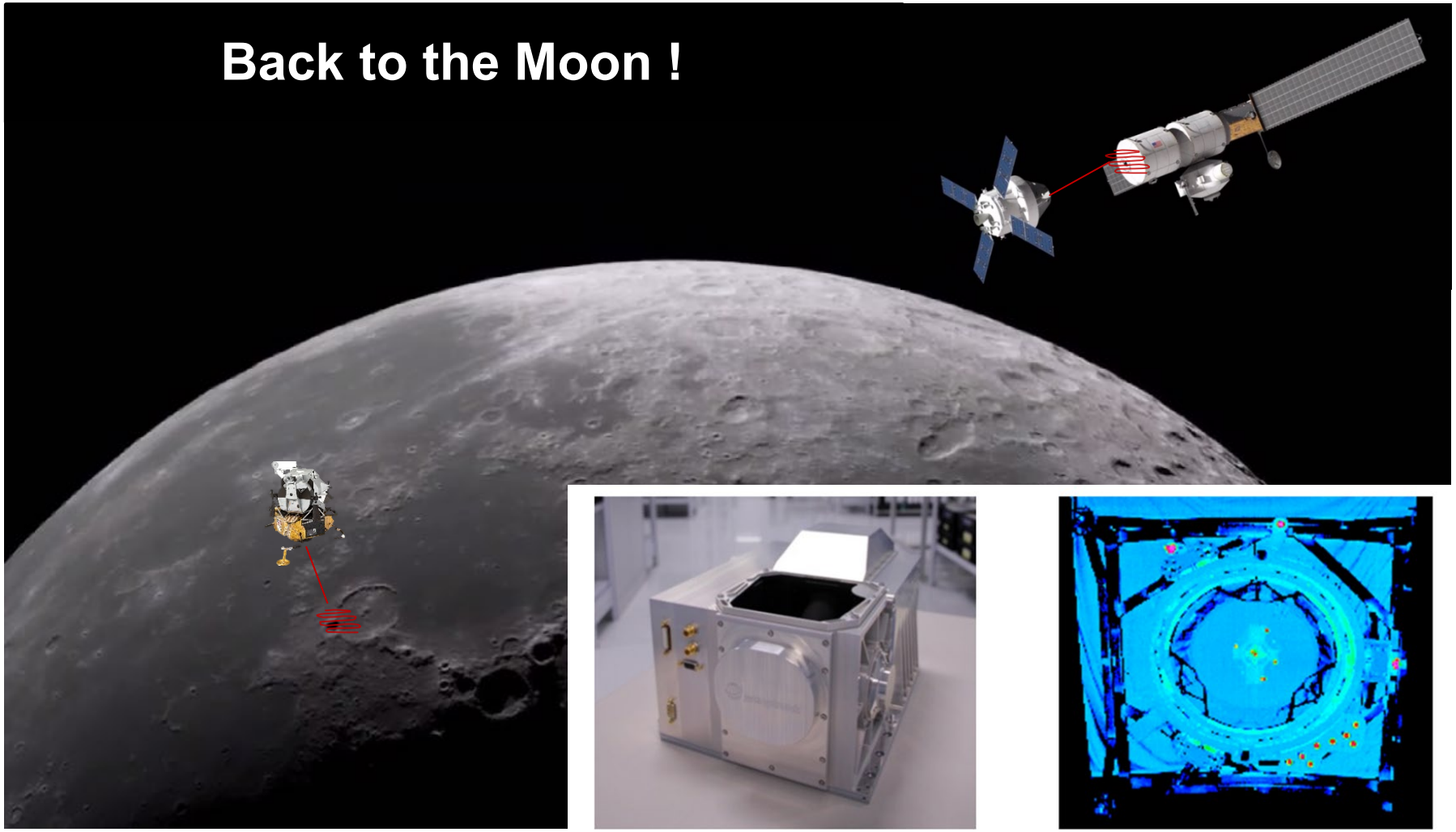
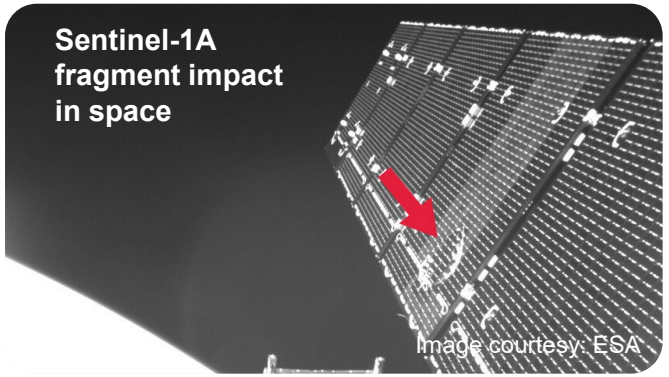


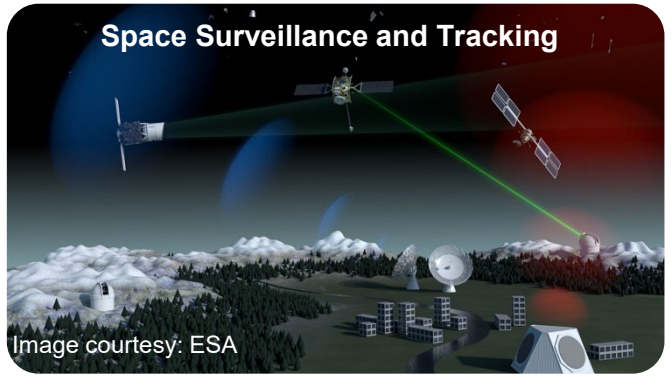



Back to the Moon !

Education: Terminology

- SST – Space Surveillance and Tracking
  - **Detect, Track, Catalogue**
  - Follows the interest of the general public
  - EU activities joint within EU SST, https://www.eusst.eu/





- SSA – Space Situational Awareness
  - Perform SST and analyse SST data to identify risks and hazards associated for space operations
  - Obtain object data: Recognize object types, missions, etc. → **Identification**
  - SSA covers domain congestion to enable safe and effective space operations
  - Follows the interest of the general public and satellite providers / launch providers

- SDA – Space Domain Awareness
  - Term originates back to a Memo from John Shaw from USSF from 4th of Oct. 2019[1)]
  - Shaw defines SDA as ***identification, characterization and understanding of any factor, passive or active, associated with the space domain that could affect space operations and thereby impact the security, safety, economy or environment of our nation.***

SDA and SSA can be considered as two sides of the same coin; the former is mainly focused on military and operational aspects, the latter on civil/dual uses.

Captain Alessio Di Mare, Italian Airforce

1): https://spacenews.com/air-force-ssa-is-no-more-its-space-domain-awareness/