D. Cerutti-Maori

Support of IADC WG1 activities with the TIRA system - ESA delegation

Tracking and Imaging Radar (TIRA)

Specifications

- Located near Bonn (Germany)
- 34 m parabolic dish in Cassegrain configuration
  - High angular velocity (24°/s in az., 6°/s in el.)
  - Very high mechanical pointing accuracy: 0.6" (ca. 3 m at a range of 1000 km)
- L-band tracking radar
  - Center frequency: 1.3 GHz
  - Auto-tracking (monopulse)
  - Beamwidth: 0.5° (9 km at R = 1000 km)
- Ku-band imaging radar
  - Center frequency: 16.7 GHz
  - Beamwidth: 0.031° (540 m at R = 1000 km)

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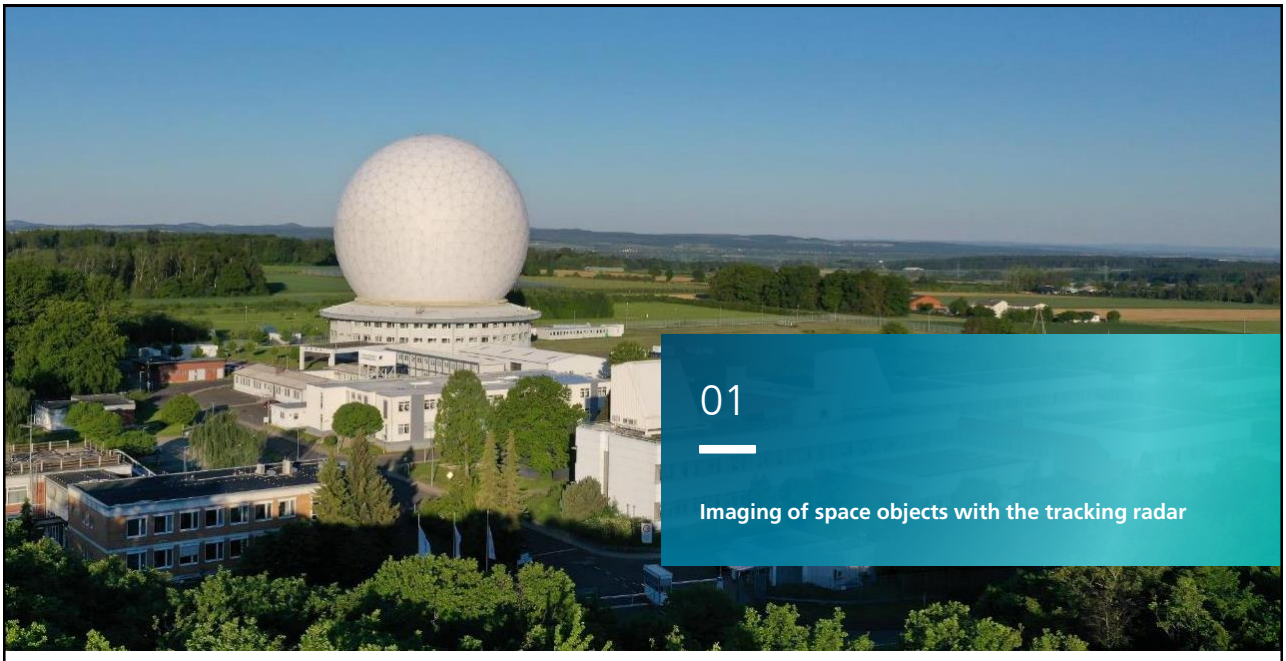
Outline

- **AI38.2: "Attitude motion characterization of LEO upper stages using different observation techniques"**
  - New imaging technique with the tracking radar
  - Update on the methods available for assessing the attitude motion
- **IT 34.1: "Feasible options to study Molniya population of space debris"**
  - Observation of GEO objects
  - Investigation of the possibility to observe the Molniya population with the TIRA system
- **IT 39.2: "Permanent IT on fragmentations"**
  - Update on COSMOS-1408, Observation of the largest debris



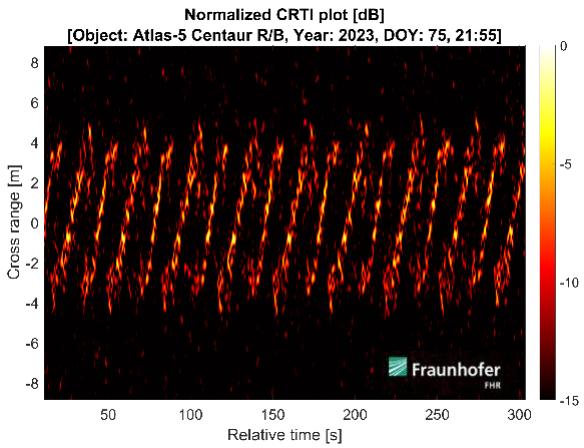
01

Imaging of space objects with the tracking radar

Atlas 5 Centaur R/B (40731)

Cross Range / Time / Intensity plot

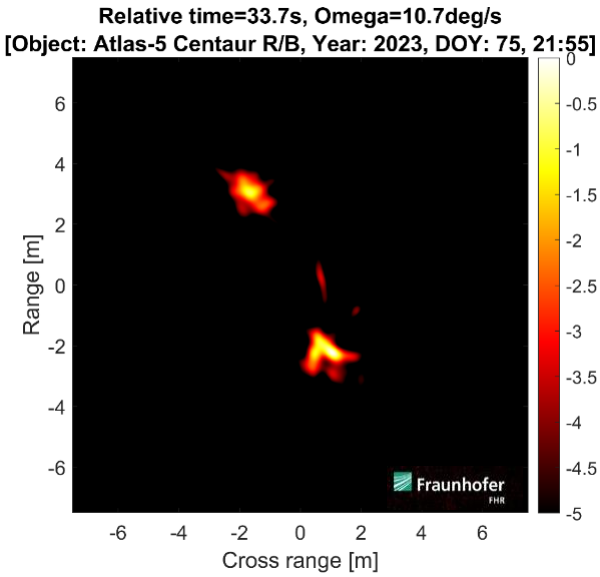
- R/B dimension
  - Total length: 12.7 m
  - Diameter 3.0 m
- **Range: 23 000 km**
- **L-band observation**
- Cross range profiles after compensation of the translational motion
  - The R/B rotates with an apparent angular velocity of 10.7 deg/s
  - The corresponding period is about 34 s



Atlas 5 Centaur R/B (40731)

Doppler tomographic reconstruction

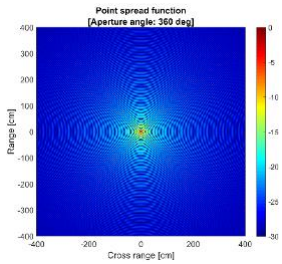
- Partially coherent reconstruction method
- **Range: 23 000 km**
- **L-band observation**

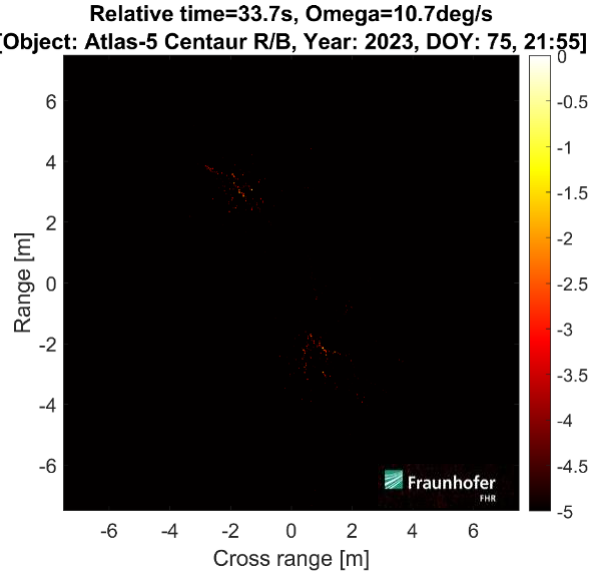


Atlas 5 Centaur R/B (40731)

Backprojection

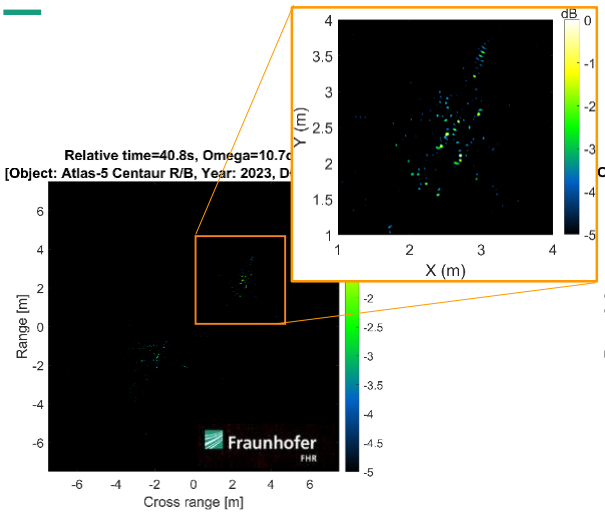
- Fully coherent reconstruction method
- **Range: 23 000 km**
- **L-band observation**

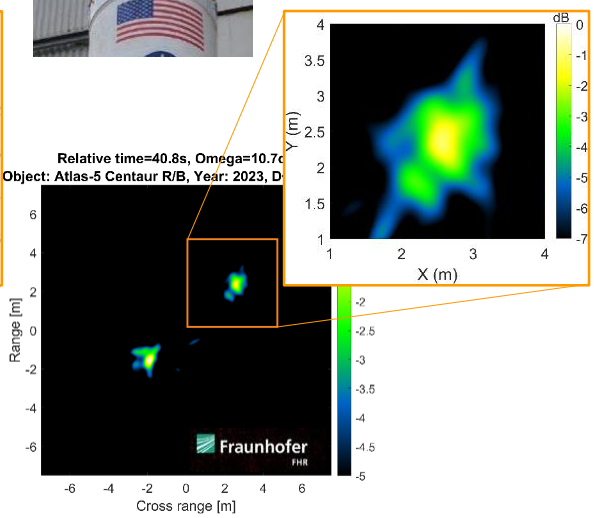




Atlas 5 Centaur R/B (40731)

Backprojection vs. tomography





02

Estimation of the attitude motion of space objects

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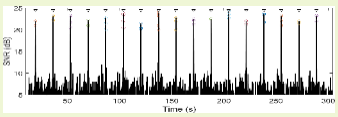
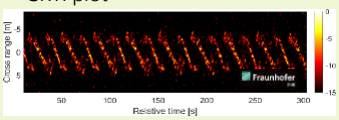
Tracking and Imaging Radar (TIRA)

Different kinds of measurements for attitude motion estimation

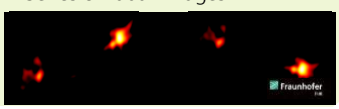
- **L-band tracking radar**
  - RCS curve



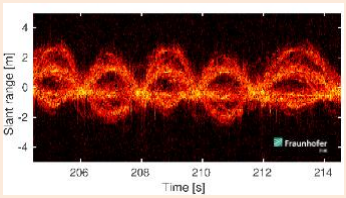
  - CRTI plot



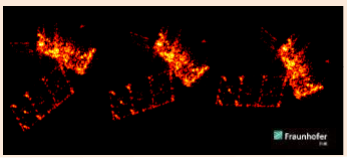
  - Series of radar images



- **Ku-band imaging radar**
  - RTI plot



  - Series of radar images



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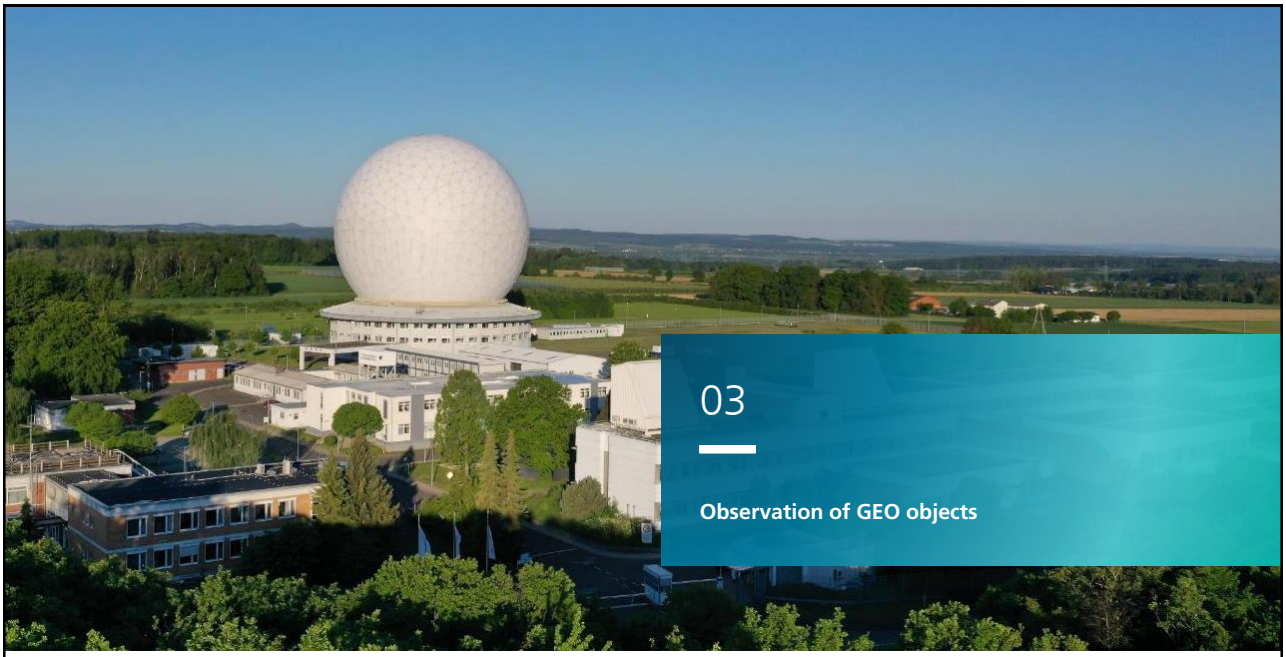


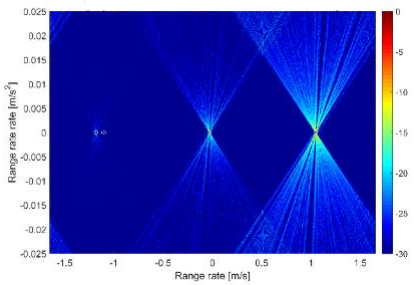
03

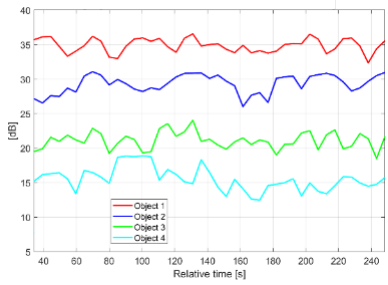
Observation of GEO objects

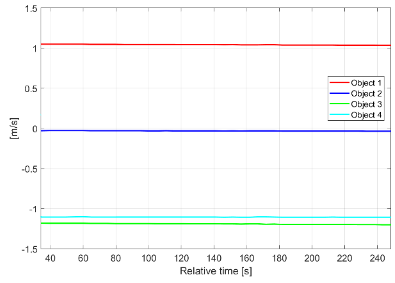
GEO satellite cluster

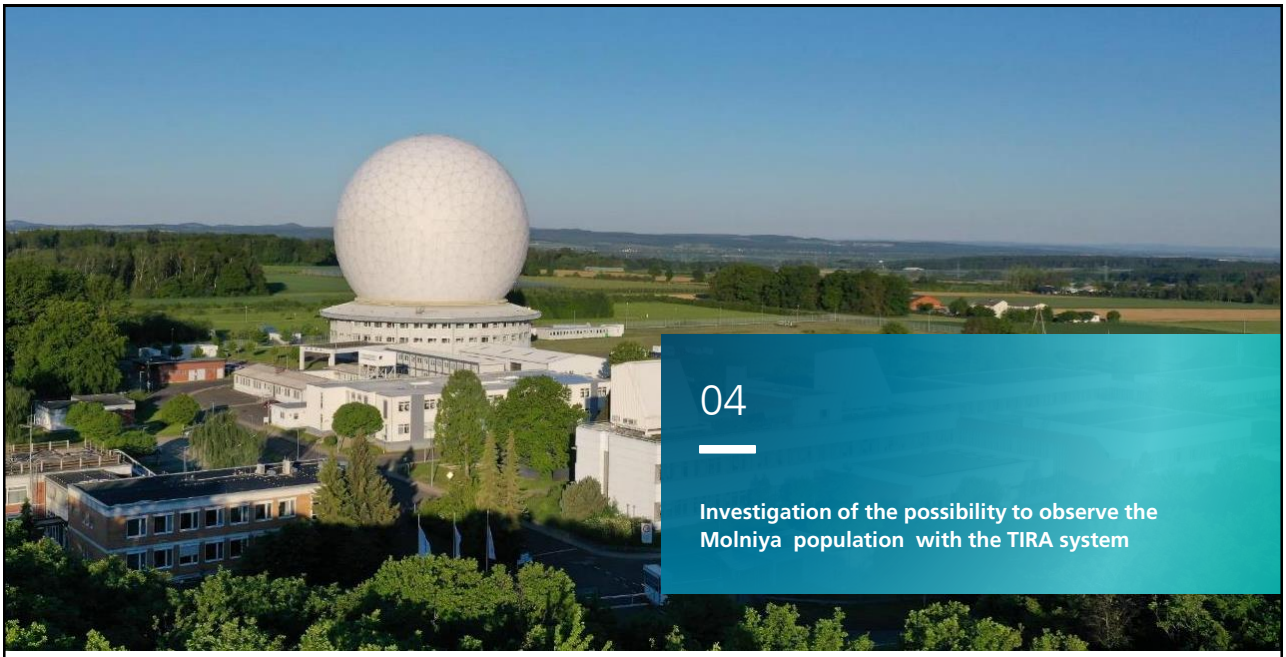
Target detection

- Discrimination of a GEO satellite cluster after integration over ~ 1 min
  - 4 objects could be detected
- Precise estimation of the range rate and range rate rate of the objects
  - Range rate is unambiguous for GEO objects









04

Investigation of the possibility to observe the Molniya population with the TIRA system

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Can Molniya objects be detected with TIRA?

Input population and methodology

- Input population
  - Molnyia objects of the SpaceTrack catalogue
    - Only 37 objects
- Two simulations were conducted
  - E-BPE and S-BPE
- Methodology
  - TLE propagated with SGP4 for the whole time span of the BPE
  - Geometrical filter to check the object visibility
  - Beam crossing list as output
- Goal
  - Investigation of the radar parameter subspace
  - Assessment of the possibility to observe the Molniya population with the TIRA system

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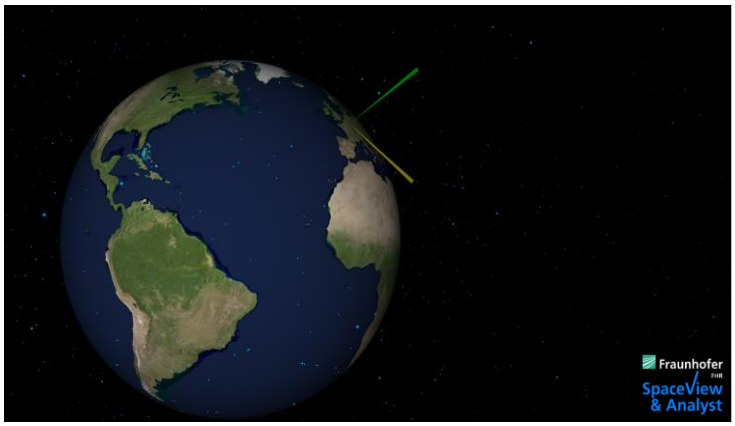
Can Molniya objects be detected with TIRA?

Simulation environment and BPE configuration

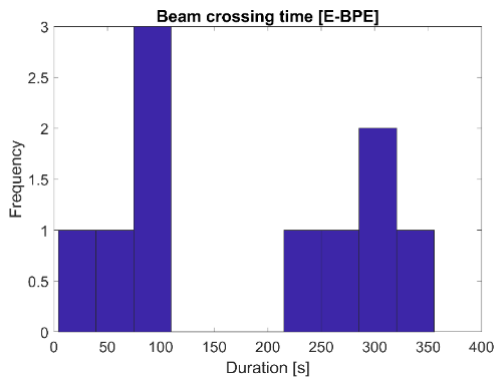


Simulation parameters		
System	TIRA	
Configuration	East	South
Elevation	75°	10°
Azimuth	90°	165°
Beamwidth	1.2°	1.2°
PRF	30 Hz	30 Hz
Crossings	10	10
Objects	7	7
Duration	30 days	30 days

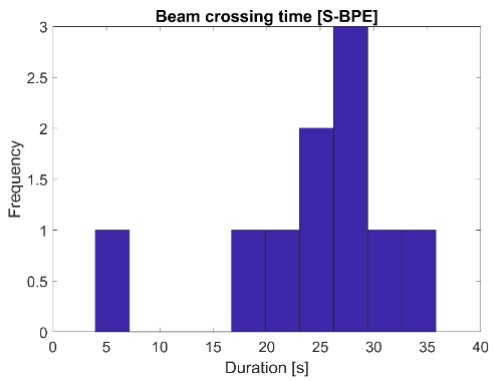
Beam crossing Molniya objects

Beam crossing time (E-BPE / S-BPE)

- Beam crossing time around 200 s



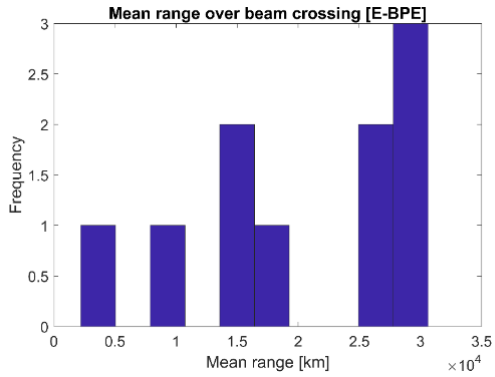
- Beam crossing time around 25 s



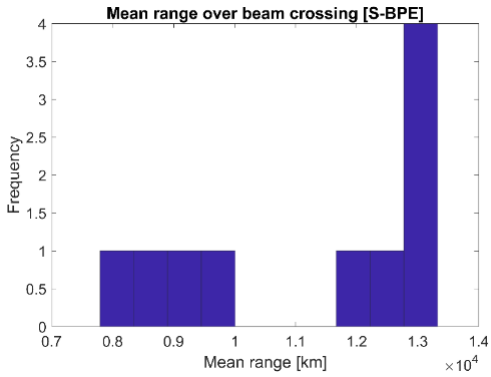
Beam crossing Molniya objects

Mean range (E-BPE / S-BPE)

- Range is between 5000 km and 30 000 km



- Range is around 10 000 km



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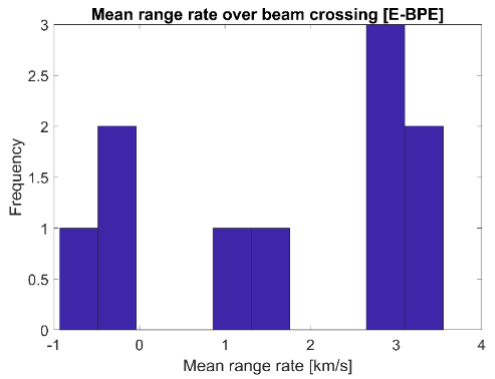
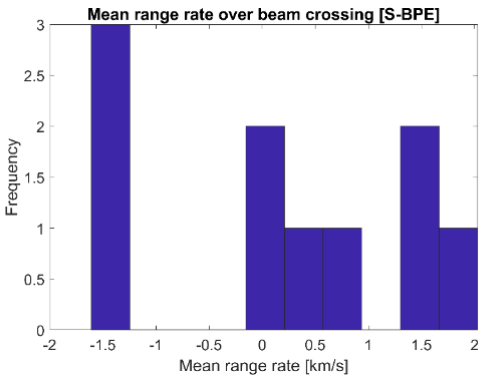
Beam crossing Molniya objects

Mean range rate (E-BPE / S-BPE)

- Range rate is widely distributed



- Range rate is widely distributed



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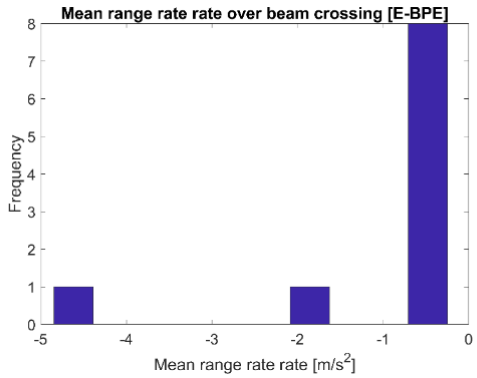
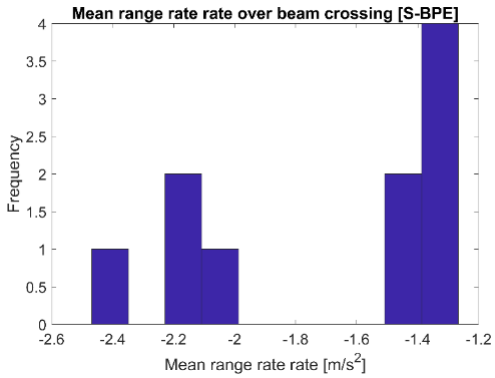
Beam crossing Molniya objects

Mean range rate rate (E-BPE / S-BPE)

- Small range rate rate and small range rate rate variation



- Small range rate rate and small range rate rate variation



Can Molniya objects be detected with TIRA?

Conclusion

- The investigation of the radar parameter subspace has shown that Molniya objects can be detected with the TIRA system
  - Coherent integration is possible
  - Detection performance depends on the size of the objects
    - ~50 cm (NASA SEM) at 10 000 km
- From the parameter distribution, a S-BPE seems to be preferable
  - Similar number of detected objects
  - The mean range is around 10 000 km for all the beam crossing objects
- The signal processing should be tailored to the characteristics of the Molniya population
  - The problem of range ambiguities has to be solved
  - Discrimination of objects in different orbital regimes
- The main question is raised by the very few beam crossings during both BPE simulations of 30 days each
  - True number of Molniya objects?
  - How many crossing objects are expected during a time-limited BPE?

05

Update on COSMOS-1408
Observation of the largest debris

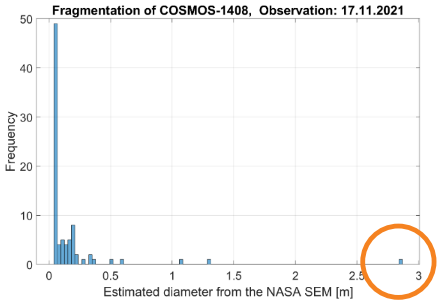
Fraunhofer FHR

COSMOS-1408

Tselina-D

- ELINT satellite providing detailed observation of radio sources
  - Large SIGINT detectors were attached at the lower part of the satellite bus
- Right picture
  - Tselina-R, Tselina-D probably similar
- Dimension
  - From https://brushbeater.org/wp-content/uploads/2018/11/radars.pdf : "*Tselina-2 basically is an enlarged version of Tselina-D. Its pressurized bus is **4.46 m** high with a diameter ranging from **1.2 to 1.4 m**.* "

Credit:
https://space.skyrocket.de/doc_sdat/tselina-d.htm



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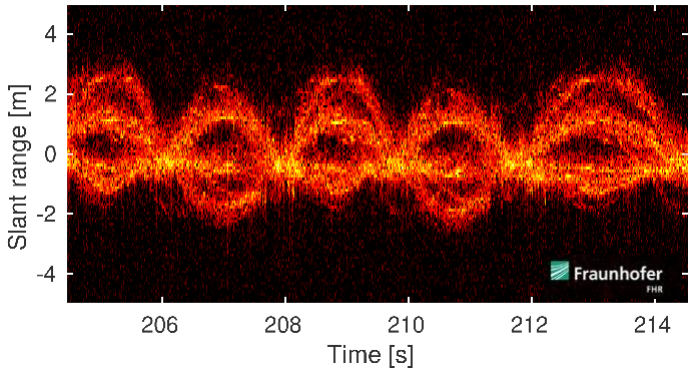
COSMOS-1408

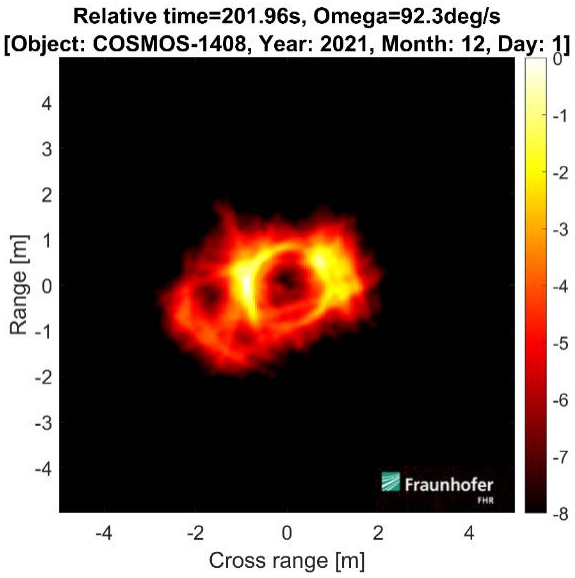
Observation of the largest debris with the imaging radar (1.12.2021)

- Measured range profiles over time
  - Large object with a minimum length of about 4.5m
  - No specular return, nonsymmetrical pattern
- Extremely fast tumbling object
  - Angular velocity about 90 deg/s
- Due to the fast angular velocity, the data are strongly undersampled
  - Radar images cannot be computed using the ISAR technique



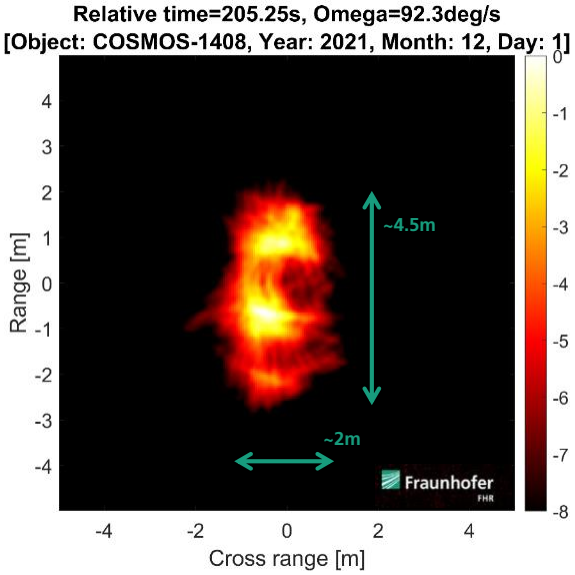
COSMOS-1408

Tomographic reconstruction



COSMOS-1408

Tomographic reconstruction



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Contact

Dr. Delphine Cerutti-Maori
Delphine.Cerutti-Maori@fhr.fraunhofer.de