Space Debris Attitude Motion Measurements and Modelling, ENVISAT case

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Outline

Introduction

- ESA GSTP activity dedicated to attitude determination of defunct satellites and upper stages

- Motivation:
  - Contingency scenarios – in case spacecraft is damage due to the collision with small particle or contact is lost due to technical problems necessary to get as much as possible information about its current status, including attitude stage
  - Active Debris Removal (ADR), preparation 1-10 years:
    - Low Earth Orbit (LEO) region dense due to the large space debris population
    - Large compact objects like spacecraft or upper stages a large source of debris in case of fragmentation events
    - Necessary remediation measures in order to stabilize LEO population

Motivation – ENVISAT case

- ENVISAT (ENVIronmental SATellite) (Cospar ID 2002-009A, NORAD 27386) is a former European Space Agency (ESA) mission dedicated to the Precise Orbit Determination (PDO) and radar altimeter instrument range bias calibration
- Satellite on Sun-Synchronous Orbit (SSO) with orbital period ~ 100 min (mean altitude ~ 800 km)
- Lost contact with satellite at 8th of April 2012, mission declared over in May 2012
- After failure ESA organized a campaign to investigate the integrity of the satellite, used direct space-based imaging and ground-based imaging showed no noticeable damage
- Since 2013 International Laser Ranging Service (ILRS) network regular observe ENVISAT for orbit improvement
- ENVISAT in the most dense region, more than 7,000 kg mass, size 2.5 x 2.5 x 10 m³ (main body)

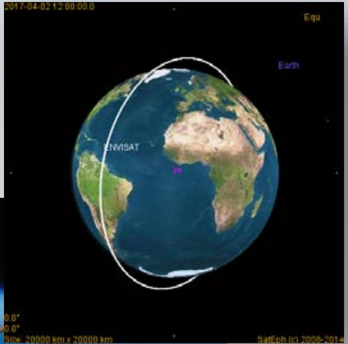

Fig. – ENVISAT in real colors. Credit: ESA

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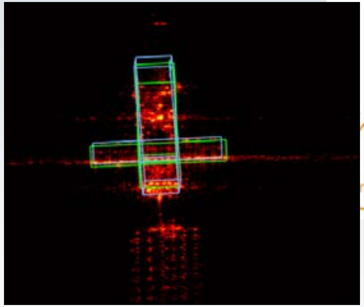
Observation techniques

- To determine and monitor object behaviour several different techniques observation can be used , within the study focus on:
  - ISAR images acquired by radar
  - Light curves acquired by optical telescope
  - SLR residuals acquired by SLR systems

- ISAR images acquisition and their processing:
  - Acquired by radar system
  - Possible to extract the full rotation vector
  - Any target can be acquired which is within the range
  - Can be used during any weather, day/night
  - Target range/size dependency



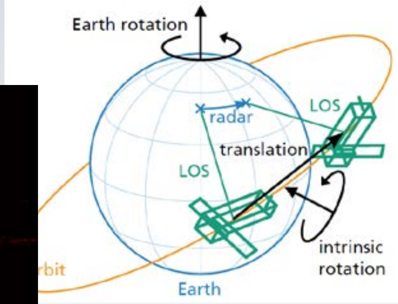
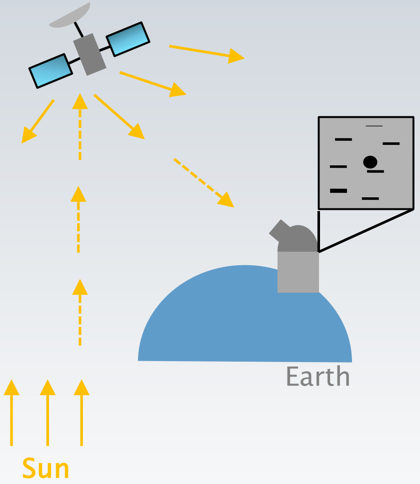


Fig. – ISAR image of ENVISAT with superposed WGMs (green: manual projection, grey:automatic projection). Credit: Sommer et al. (2017)

Observation techniques

- Light curves acquisition and processing:
  - Acquired by optical passive systems (telescopes), largely used in astronomy field
  - Possible to extract apparent rotation velocity
  - Any target can be acquired which is illuminated by the sun
  - Only limited information for rotation vector
  - Applicable only for by sun illuminated objects
  - Can not be used during bed weather conditions and daylight (not always)



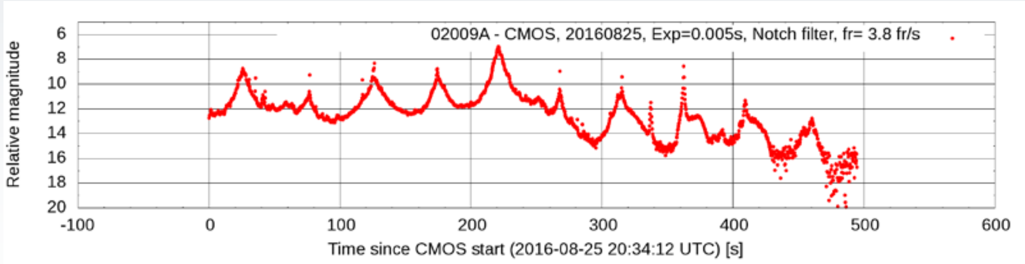
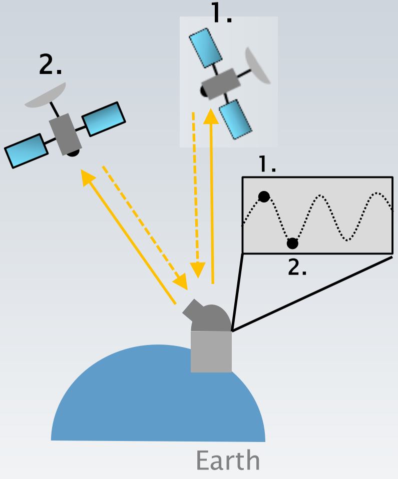


Fig. – sCMOS light curve acquired by ZIMLAT telescope at 2016-08-25, starting at 20:34 UTC. Credit: AIUB

Observation techniques

- SLR residuals acquisition and processing:
  - Acquired by optical active systems, SLR systems
  - Possible to extract apparent rotation vector if conditions are fovorable
  - Any target can be acquired which is equipped with RRA and RRA visible
  - Applicable only for objects equipped with RRA (not always)
  - RRA not always visible from sensor
  - Can not be used during bad weather conditions



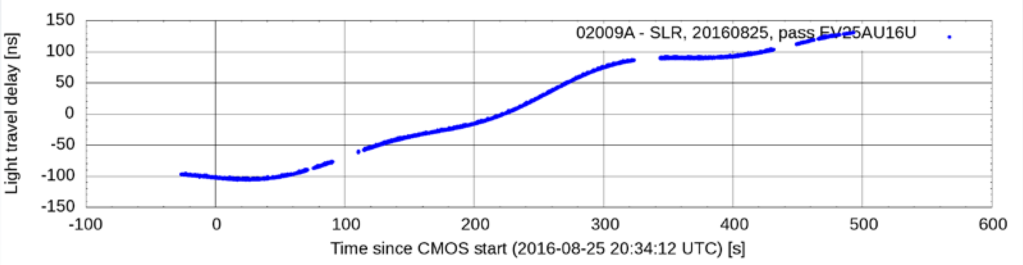


Fig. – SLR residuals acquired by ZIMLAT telescope at 2016-08-25, starting at 20:34 UTC. Credit: AIUB

Sensors

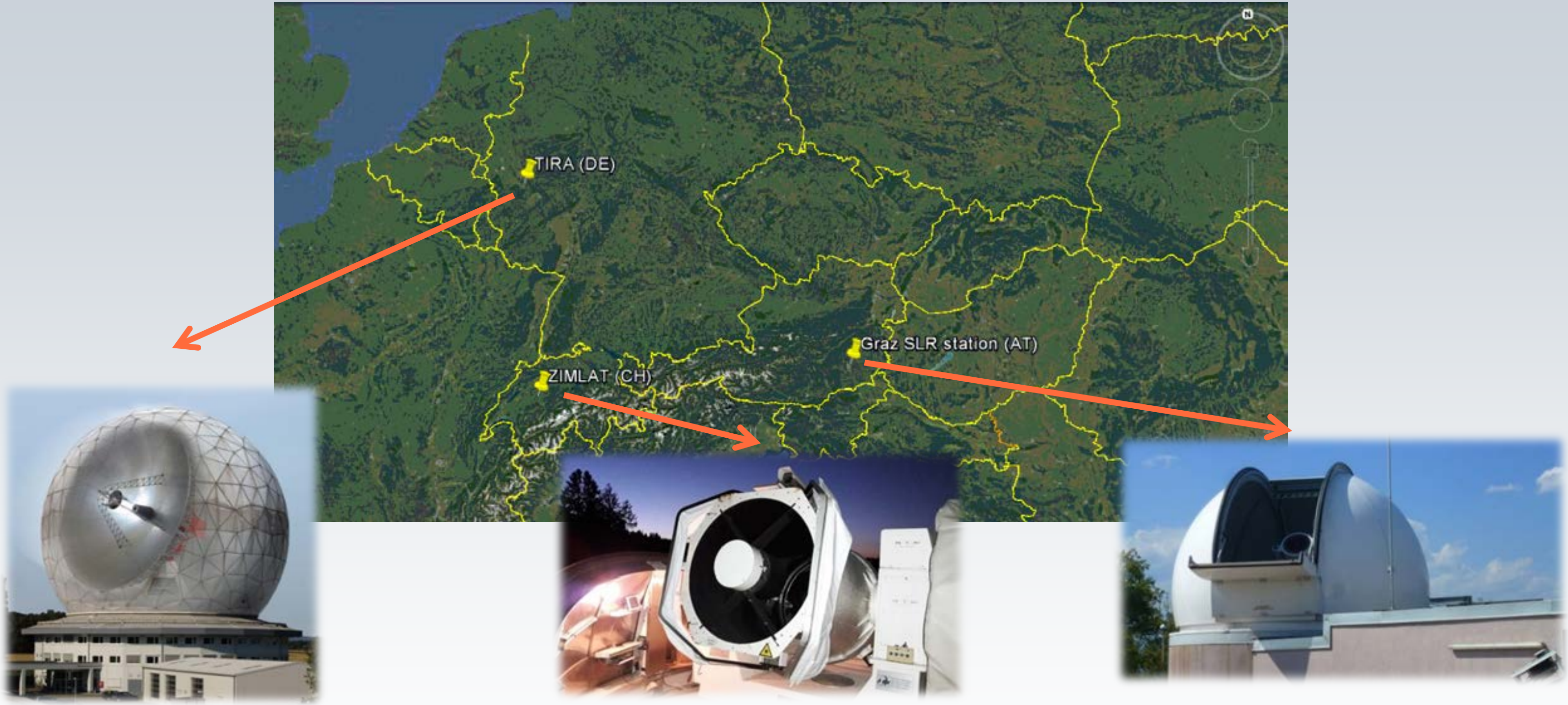


Fig. – Geographical distribution of sensors participating during the activity showed (upper panel).
TIRA (left panel), ZIMLAT (middle panel) and Graz SLR station (right panel). Credit: Google, FHR, AIUB, IWF

Sensors

- Three different systems available for the activity to acquire measurement data:

- FHR's Tracking and Imaging Radar (TIRA) (Germany) –
  - Narrowband high power tracking radar, transmission frequency in L-band (1,333 GHz)
  - Wideband imaging radar has a transmission frequency in Ku-band (16.7 GHz)
  - ISAR and RCS acquisition

- AIUB 's Zimmerwald Laser and Astrometry Telescope (ZIMLAT) (Switzerland) –
  - 70cm diameter, CCD/sCMOS cameras available
  - SLR laser, Sapphire, 100 mJ, 10 Hz
  - Light curves and SLR residuals acquisition

- IWF's SLR station Graz (Austria)–
  - SLR acquisition to cooperative
  - SLR acquisition to non-cooperative
  - Single photon light curve acquisition

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ιOTA – In-Orbit Tumbling Analysis tool

- ιOTA – In-Orbit Tumbling Analysis tool

- Main functions:
  - Short-term attitude prediction along with the orbit prediction
  - Long-term attitude prediction
  - Synthetic data generation

- All relevant torques and forces assumed:
  - Aerodynamics forces and torque
  - Eddy current damping
  - Gravitational acceleration and torque (Earth)
  - Solar radiation pressure
  - Third-body acceleration (Sun and Moon)

ιOTA – In-Orbit Tumbling Analysis tool

- Simulation modules for optional spacecraft related influences are:
  - AOCS behaviour: Magnetic torquer activation
  - AOCS behaviour: Reaction wheel behaviour
  - AOCS behaviour: Thruster firing
  - Moving parts (tank sloshing)
  - Impact effects
  - Outgassing or leakage

- The post-processing modules comprise:
  - History module: Output and storage of all relevant (selected) simulation data
  - Light curve modelling
  - Optical image generation in the GUI
  - Radar image generation
  - Radar Cross Section estimation data
  - Satellite laser ranging measurement simulation, range and residuals

ιOTA – In-Orbit Tumbling Analysis tool

- ιOTA – Inputs:
  - the attitude state assumption based on real observations, e.g. initial values for spin rate and spin axis direction determined from SLR data, from direct imaging or from SAR images,
  - environmental conditions,
  - the 3D surface geometry/shape of the target,
  - the CoM determined from International Laser Ranging Service (ILRS) network data or Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) measurements or from models,
  - the MoI obtained from the manufacturer data or models,
  - the surface properties, diffuse and specular reflection,
  - the retro-reflector positions according to the CoM and to the surface geometry

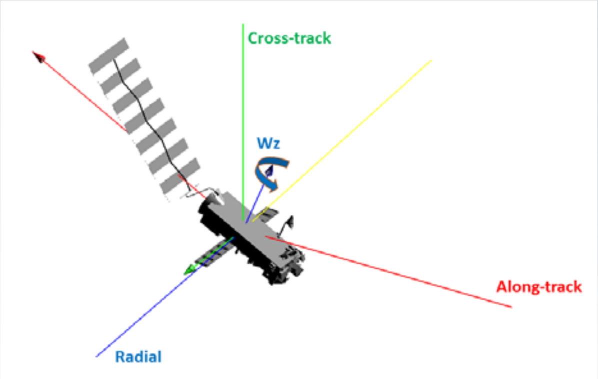


Fig. – ENVISAT 3D model used in ιOTA. Credit: ιOTA /HTG

Collaborative campaign

- Planning for simultaneous observations fulfilling following criteria:
  - all sensors available, TIRA, ZIMLAT, Graz SLR station
  - all spacecraft priority targets visible from all sites following defined limits for the minimum elevation above the horizon and pass duration
  - The weather predictions need to be favorable 24 hours a priori to the observation night either for Zimmerwald site or Graz SLR station

- Selected two most ranked nights in September 2016, 2016-09-06 and 2016-09-21:
  - Used only TIRA (ISAR and RCS) and ZIMLAT (light curves and SLR residuals), Graz SLR station with clouds
  - Goal to have simultaneous observations to all passes to all fours targets during given night

- All targets acquired by TIRA and ZIMLAT light curves, and only ENVISAT acquired by ZIMLAT SLR

Collaborative campaign

- Only ENVISAT observed simultaneously by all three techniques (ISAR+light curve+SLR residuals) (green rows)
- For all other targets at least ISAR + light curve (blue rows)

Night 2016-09-06

Pass	ZIMLAT SLR	Remark	ZIMLAT LC	Remark	TIRA	Remark
ENVISAT 2016-09-06 18:10 UTC	N/A	-	N/A	-	YES	L-band + Ku-band
ENVISAT 2016-09-06 19:47 UTC	YES	~400 Interrupted signal	YES	CMOS ~400s	YES	L-band + Ku-band
ERS-1 2016-09-07 01:43 UTC	NO	-	YES	CMOS ~250s	YES	L-band + Ku-band
ERS-2 2016-09-07 01:51 UTC	NO	-	YES	CMOS ~120s	-	-
Adeos-2 2016-09-07 03:09 UTC	NO	-	YES	CMOS ~450s	YES	L-band + Ku-band
ERS-2 2016-09-07 03:23 UTC	N/A	-	YES	CCD ~130s	YES	L-band + Ku-band

Night 2016-09-21

Pass	ZIMLAT SLR	Remark	ZIMLAT LC	Remark	TIRA	Remark
ENVISAT 2016-09-21 18:57 UTC	NO	-	YES	CMOS ~200s	YES	L-band + Ku-band
ENVISAT 2016-09-21 20:37 UTC	YES	~500s Full signal	YES	CMOS ~120s	YES	L-band + Ku-band
ERS-1 2016-09-22 00:57 UTC	N/A	-	N/A	-	YES	L-band + Ku-band
ERS-2 2016-09-22 02:13 UTC	NO	-	YES	CMOS ~50s	YES	L-band + Ku-band
ERS-1 2016-09-22 02:39 UTC	NO	-	YES	CMOS ~100s Interrupted	YES	L-band + Ku-band
Adeos-2 2016-09-22 03:25 UTC	NO	-	YES	CMOS ~450s	YES	L-band + Ku-band

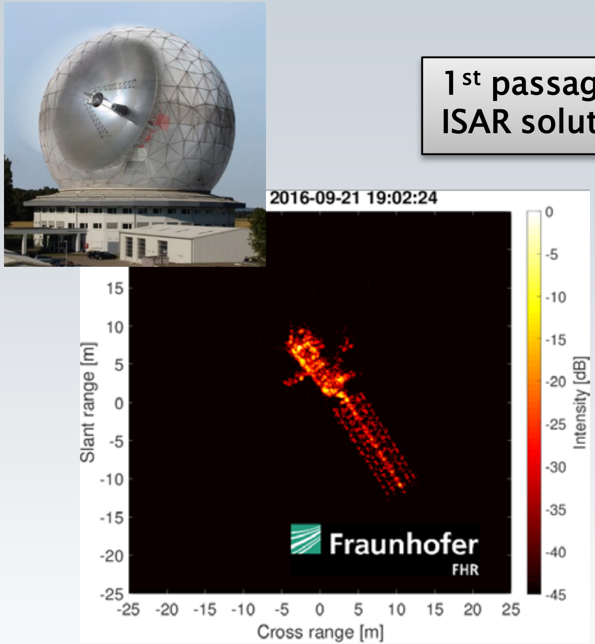
FHR's ISAR solution

AIUB's SLR solution

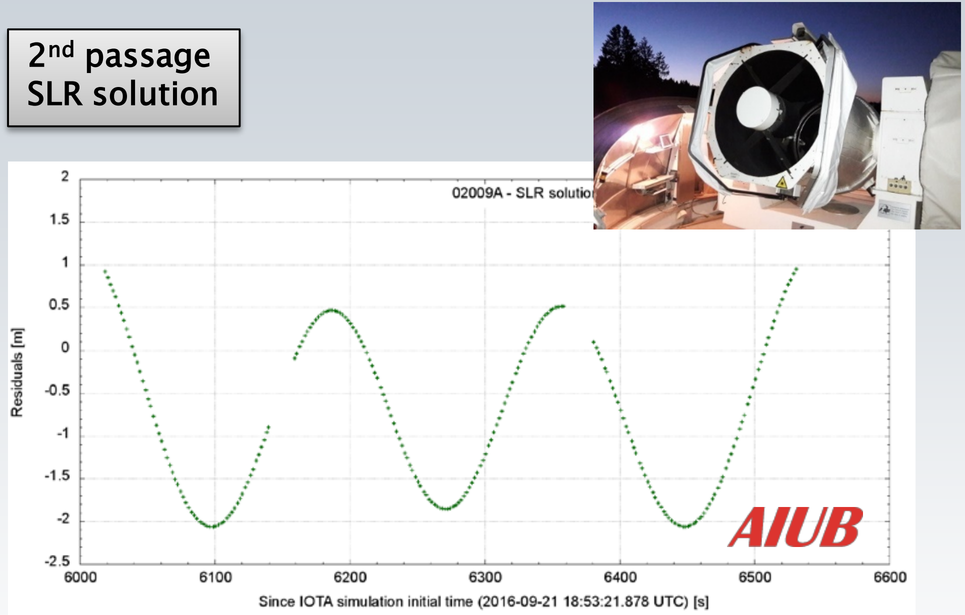
Collaborative campaign, ENVISAT

1st passage
ISAR solution

2nd passage
SLR solution



For ISAR solution determination see Sommer et al. (2017)



For SLR solution determination see Pittet et al. (2017)

Fig. – SLR residuals acquired by ZIMLAT system (left panel) and ISAR image acquired by TIRA during collaborative observation night 2016-09-21, pass started at 20:33 UTC.

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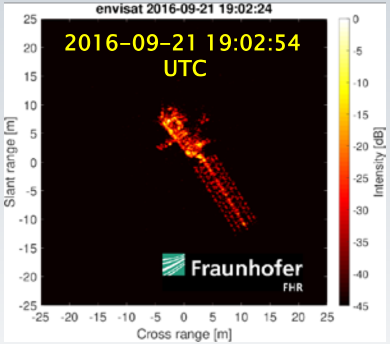
Collaborative campaign, ISAR solution

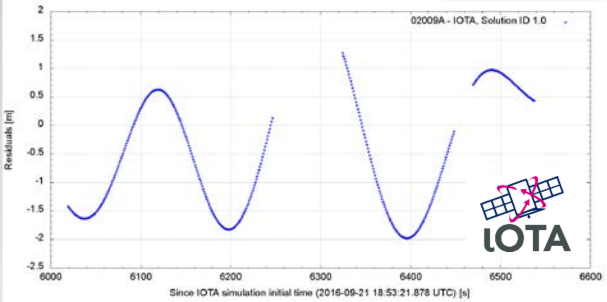


1st passage
ISAR solution:
RPY, WxWyWz,
ref. epoch

ιOTA

FHR ISAR solution
+
ιOTA integration
+
Generated synthetic data

2nd passage



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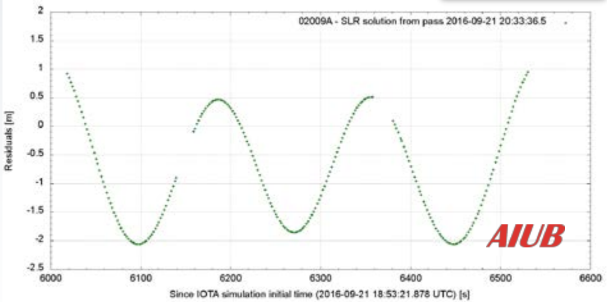
2nd passage



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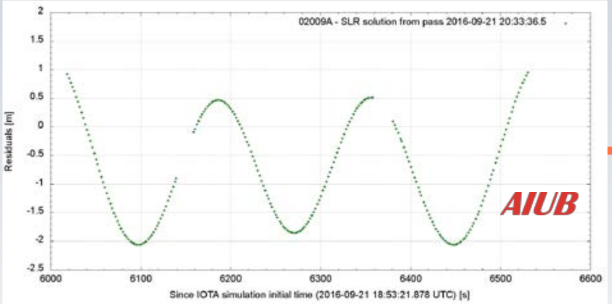
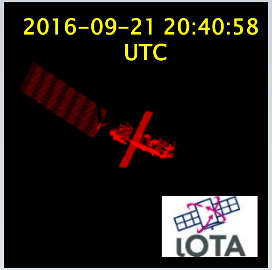
Collaborative campaign, SLR solution



2nd passage
SLR solution:
RPY, WxWyWz ,
ref. epoch

AIUB SLR solution
+
ιOTA integration
+
Generated synthetic data



2nd passage

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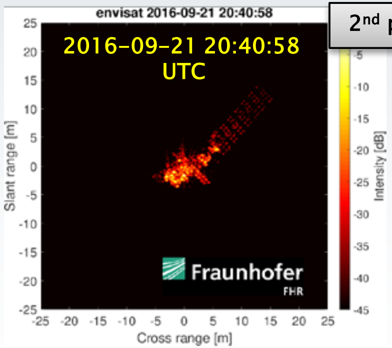
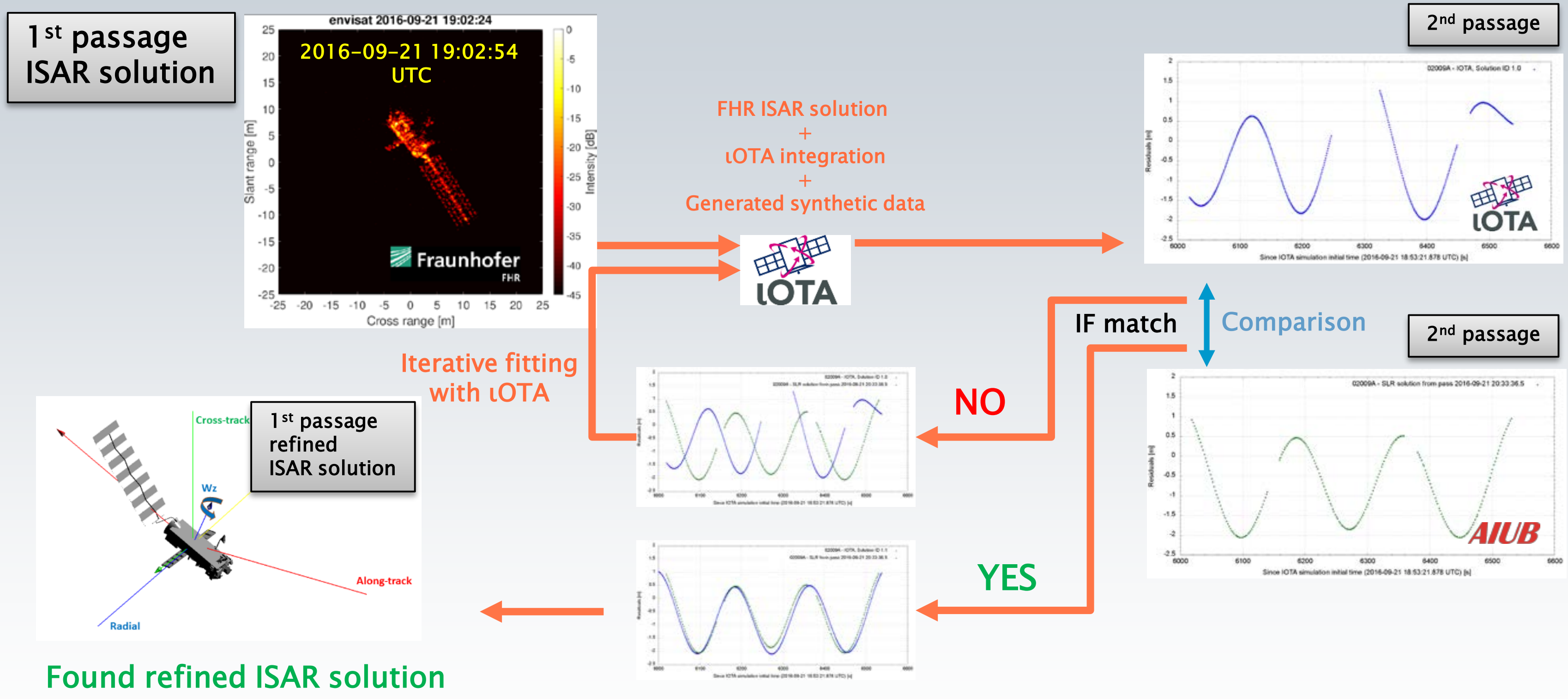


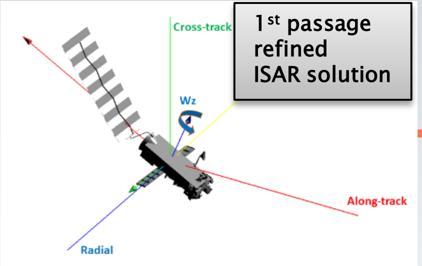
2nd passage

Collaborative campaign, solution refinement



J. Silha et al. – Space Debris Attitude Motion Measurements and Modelling, ENVISAT case,
Clean Space industrial days, 24–27 October 2017

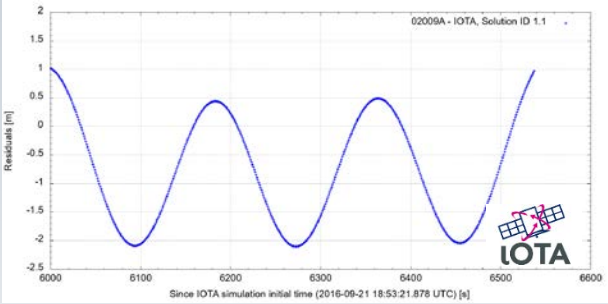
Collaborative campaign, solution validation



1st passage
refined
ISAR solution

FHR ISAR solution
+
ιOTA integration
+
Generated synthetic data

2nd passage



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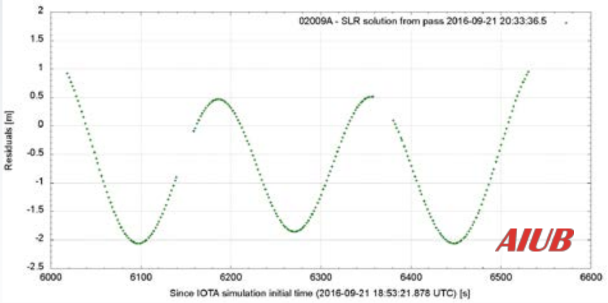
2nd passage



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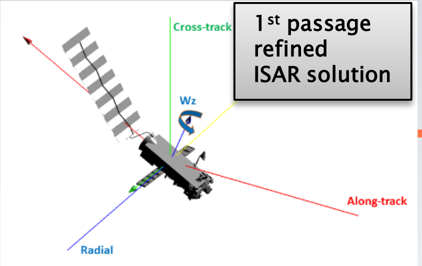
Collaborative campaign, solution validation



FHR ISAR solution
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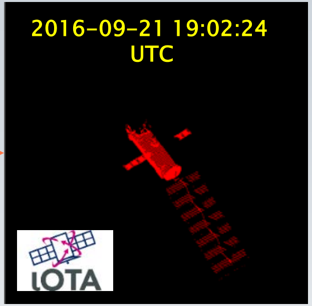
1st passage



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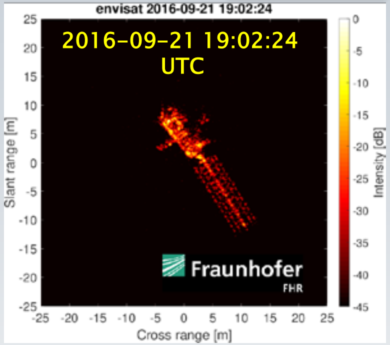
1st passage



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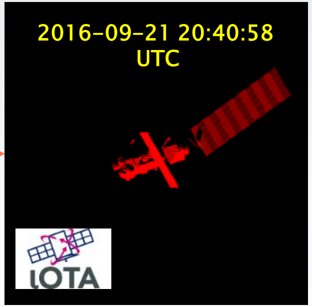

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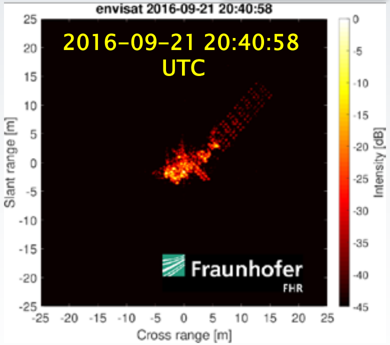

Summary

- Presented ESA study dedicated to the attitude determination techniques and observations, study already finished
- Developed tool ιOTA to generate synthetic measurements for direct comparison with real measurements, namely ISAR image, SLR residuals, light curve and direct image
- ιOTA predicts also future attitude states, short- (hours, days) and long-term (months, years) for contingency and ADR missions
- Performed collaborative campaign when radar, SLR station and telescope have been used to acquire data for ENVISAT for the same time
- Attitude state determination/refinement for ENVISAT by using ιOTA case by using ISAR solution refined with SLR measurements
- iOTA functions validated via ENVISAT case

Thank you for your attention!