Space Debris Orbit Predictions using Bi-static Laser Observations. Case Study: ENVISAT

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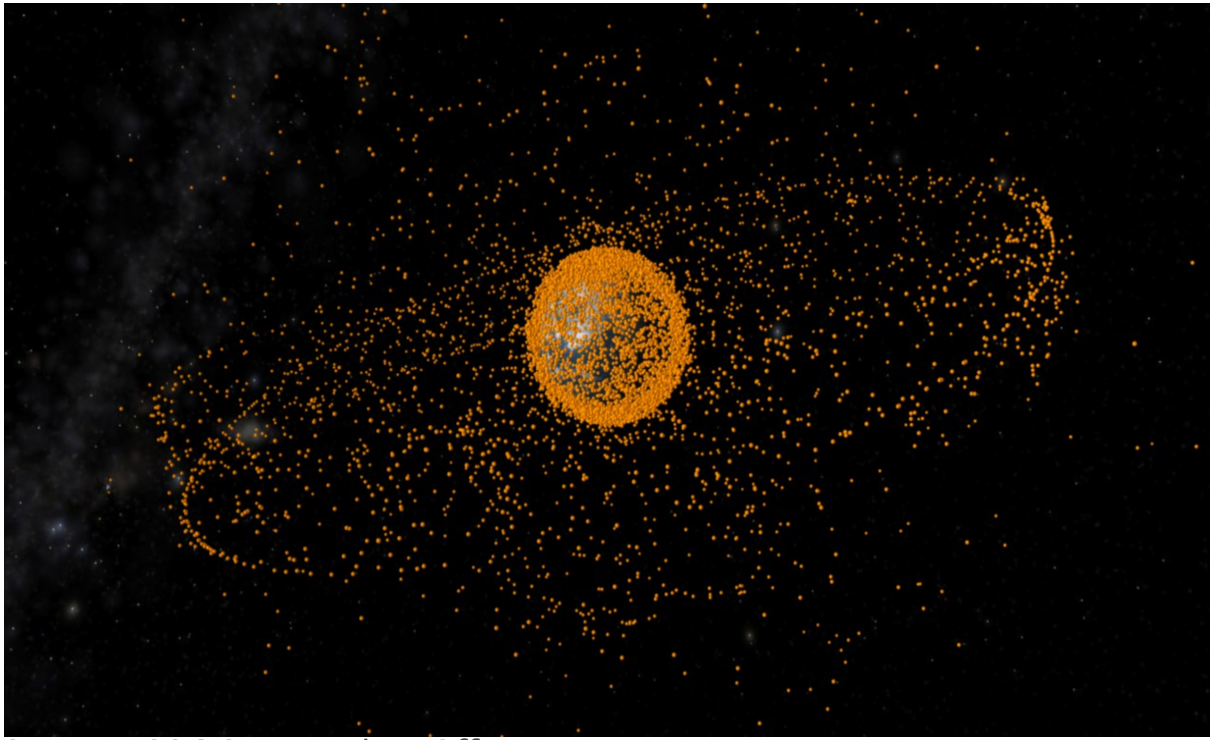
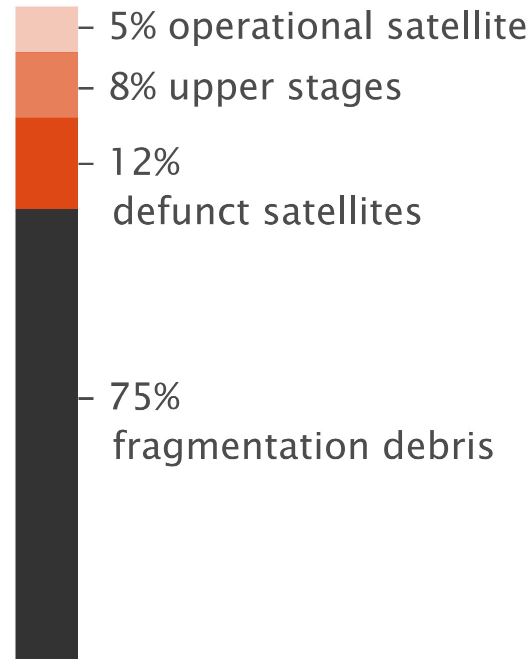
Space Debris

- man made objects which no longer serve any useful purpose



Source: ESOC Space Debris Office



around 24.000 monitored objects
(larger RCS than 10 cm)

- high collision risk in Low Earth Orbit @ inclinations between 80°– 100°
- tracking usually performed with RADAR and OPTICAL methods
  alternatively Laser Ranging to Space Debris has been demonstrated

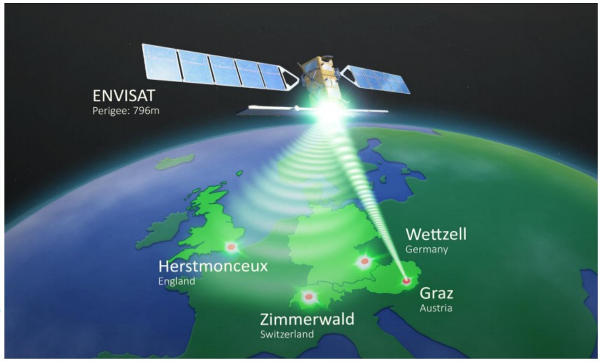
Why ENVISAT?

- "ideal" Space Debris object
  - defunct spacecraft (since April 2012) equipped with LRRs
  - one of the largest abondoned intact satellites (mass 8 t), collision risk
  - orbital altitude 770 km, inclination 98°, eccentricity 0.001
  - 25 SLR stations tracked ENVISAT in 2014 – THANK YOU!

→ allows to study orbit prediction errors against the background of sparse tracking data

→ realistic Space Debris tracking data scenario (e.g. 3 passes from one single station)

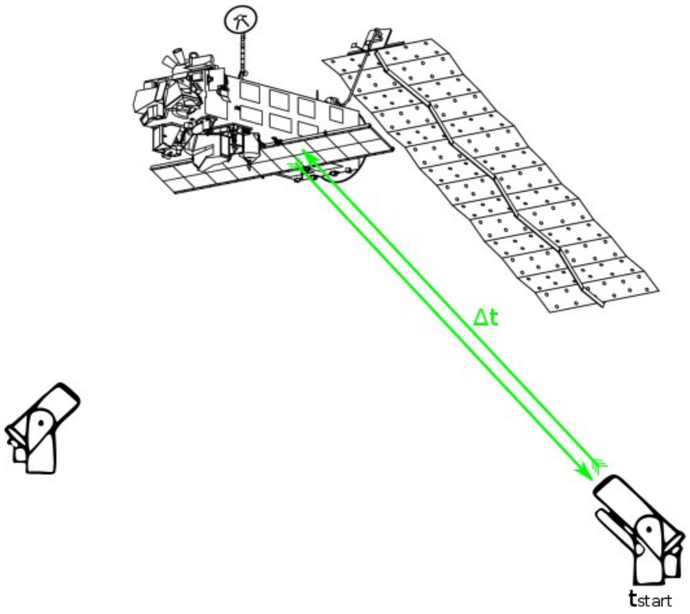
- bi-static experiment (campaign in 2013)
  - ENVISAT one of the targets
  - 1 active station (Graz)
  - 3 passive stations



Graphics: © Peter Ruzek / AIUB

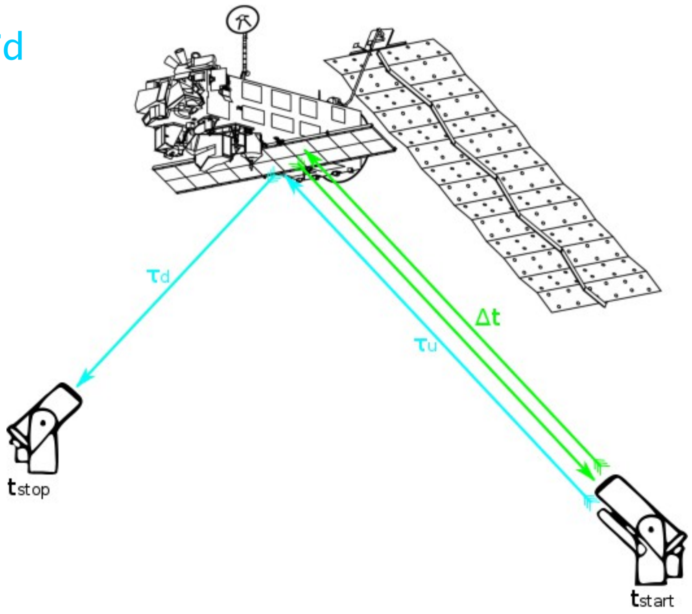
Bi-static Laser Observations

- active SLR-station fires laser pulses at times t_{start} (sampling @ 80 Hz) and detects reflected photons measuring Δt



Bi-static Laser Observations

- active SLR-station fires laser pulses at times t_{start} (sampling @ 80 Hz) and detects reflected photons measuring Δt
- passive station measures arrival time t_{stop} of diffusely reflected photons
- a (first) approach in 2 steps
  - selection of the appropriate transmit time
  - separation of uplink τ_u and downlink τ_d
- → considered as separate observations in dynamic orbit determination
- → synchronization of stations is essential
- → diffuse reflection from large object (solar panel, satellite body, etc.)



Orbit Determination and Prediction

- computed with GEODYN II – many thanks to GSFC for support!
- equally weighted batch least squares estimation (rejection level 3.5 σ)
- elevation cut-off 10°
- estimated parameters per arc
  - initial state vector
  - drag coefficient
  - SRP coefficient
  - empirical accelerations (along-track, constant, and 1/rev)
  - measurement bias per pass

conservative force model	
central body	EIGEN5s up to d/o 150
third body	JPL DE-403
solid earth tides	IERS conventions 2003
ocean tides	GOT 4.8
pole tides	IERS conventions 2003
non-conservative force model	
atmospheric density model	MSIS-86
solar radiation	Cannonball, cylindrical shadow model
reference frames	
inertial reference frame	J 2000.0
terrestrial reference frame	SLRF2008
tidal loading displacement	no atmospheric pressure loading
measurement correction	
tropospheric refraction model	Mendes-Pavlis
center-of-mass correction	not applied

Realistic Tracking Scenarios

- realistic laser tracking data scenario for Space Debris
  - orbit determination using tracking data during a period of 3 days
  - investigation of 3 different observation subsets

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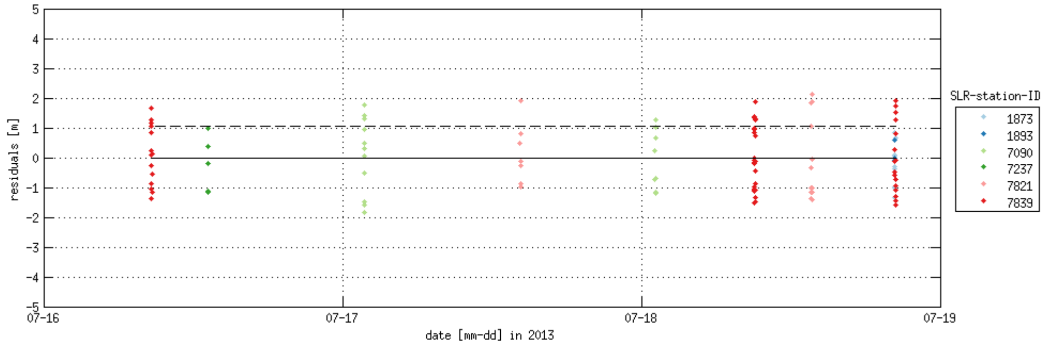
    (a) all available two-way laser ranges
    (10 passes collected by 6 stations, 115 NPs)

    (b) two-way laser ranges from a single station
    (3 passes collected by Graz, 57 NPs)

    (c) observation set (b) and additional 3 passes of bi-static observations
    (bi-static measurements between Graz and Wettzell, 155 NPs)

Post-fit observation residual
RMS 1.04 m (5 iterations)



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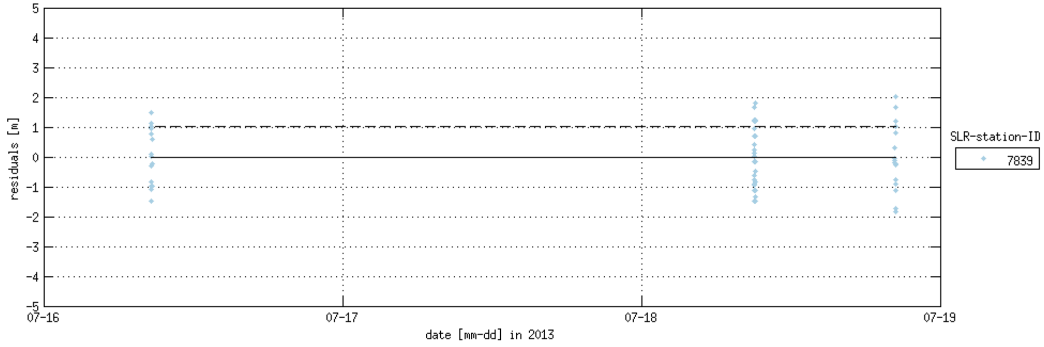
Post-fit observation residual RMS 1.01 m (6 iterations)

less constrained OD!



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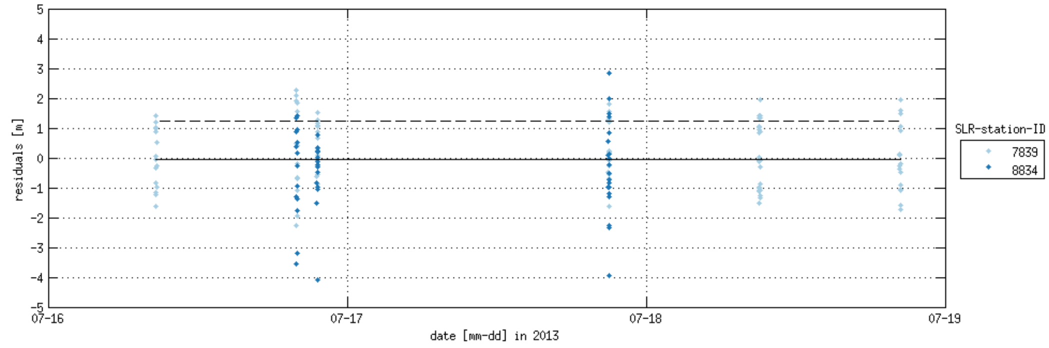
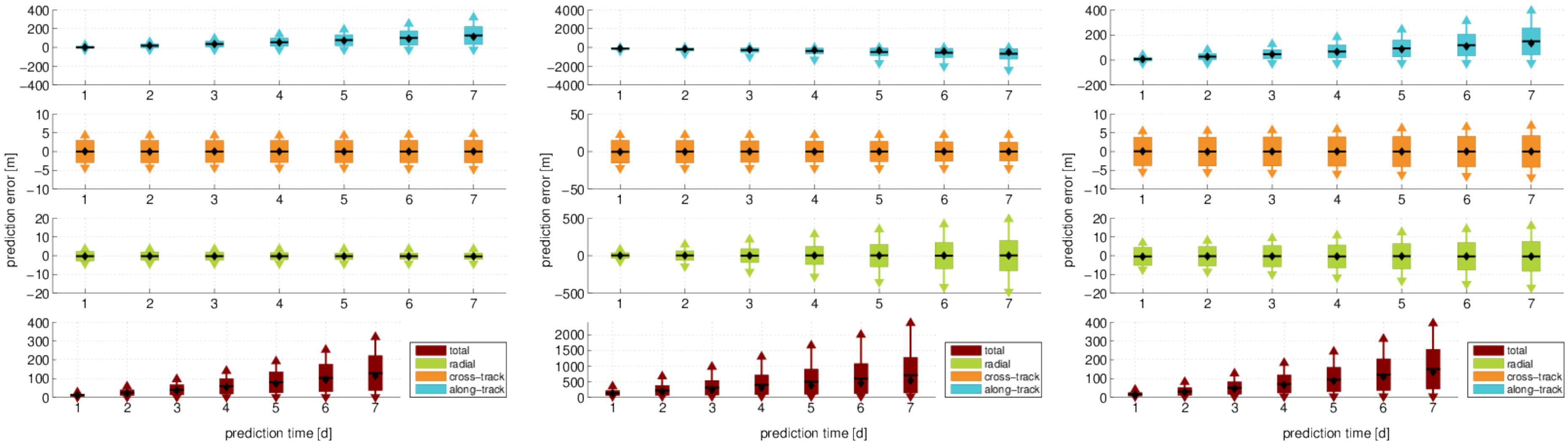
Post-fit observation residual
RMS 1.23 m (6 iterations)



Validation with Reference Orbit

- reference orbit derived from “convential” two–way laser ranges collected by 12 SLR stations during 10 days (452 NPs)
    - post–fit observation residual RMS 1.1 m
- along–track error dominating, error dependent on prediction time



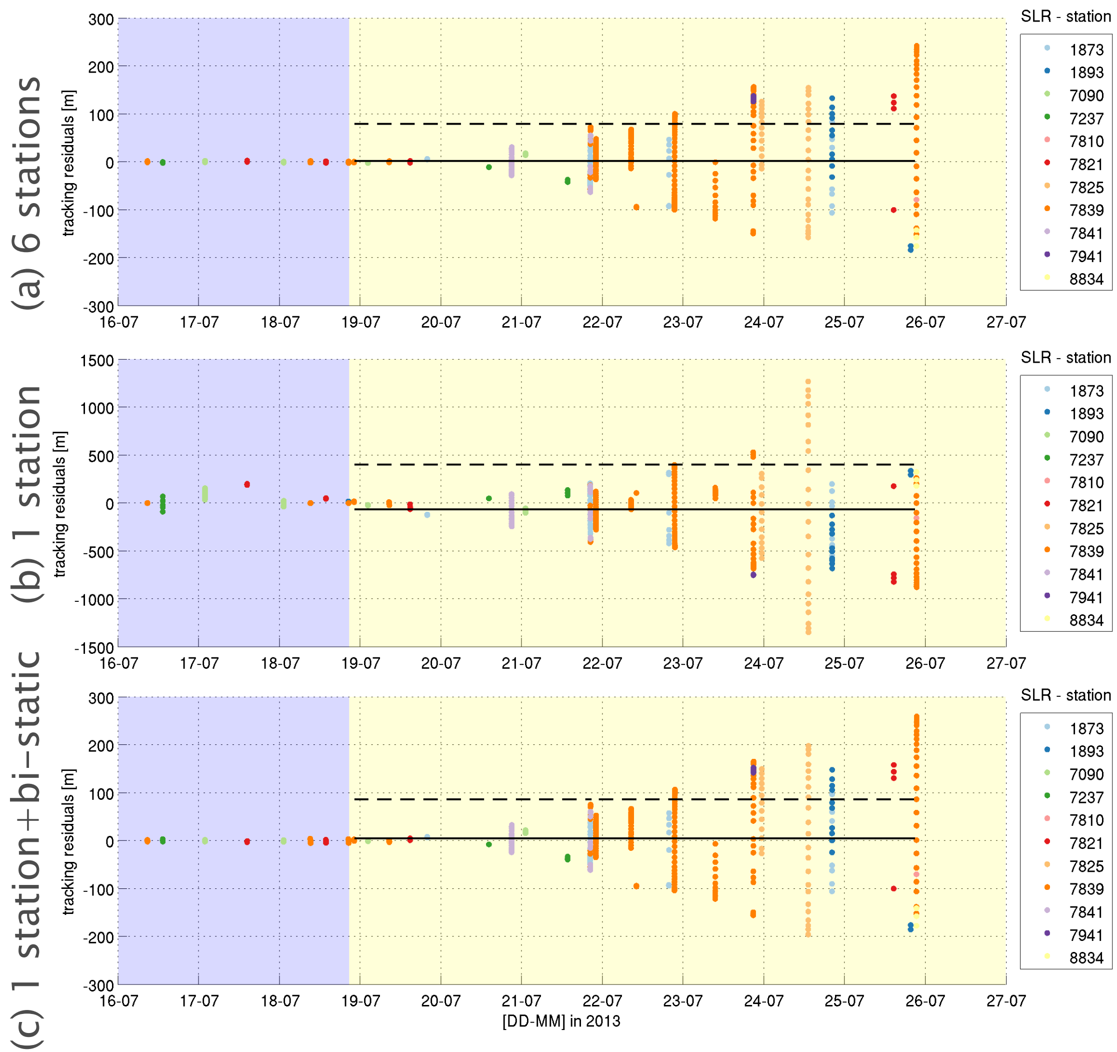
(a) 6 stations (b) 1 station (c) 1 station + bi–static

- observation set (c) outperforms single–station results by one order of magnitude
- including bi–static observations yields comparable prediction errors w.r.t. (a)

Validation with Laser Tracking Data

- all available two-way laser ranges are used for validation (no bi-static observations)

  - comparable results to validation with reference orbit
  - (b) large residuals for un-considered tracking data in OD
  - (c) slightly larger residuals in OD compared to (a)
  - (a) max. residual 240 m
  - (c) max. residual 260 m
  - equivalent residual patterns of (a) and (c) in OP



Conclusion and Outlook

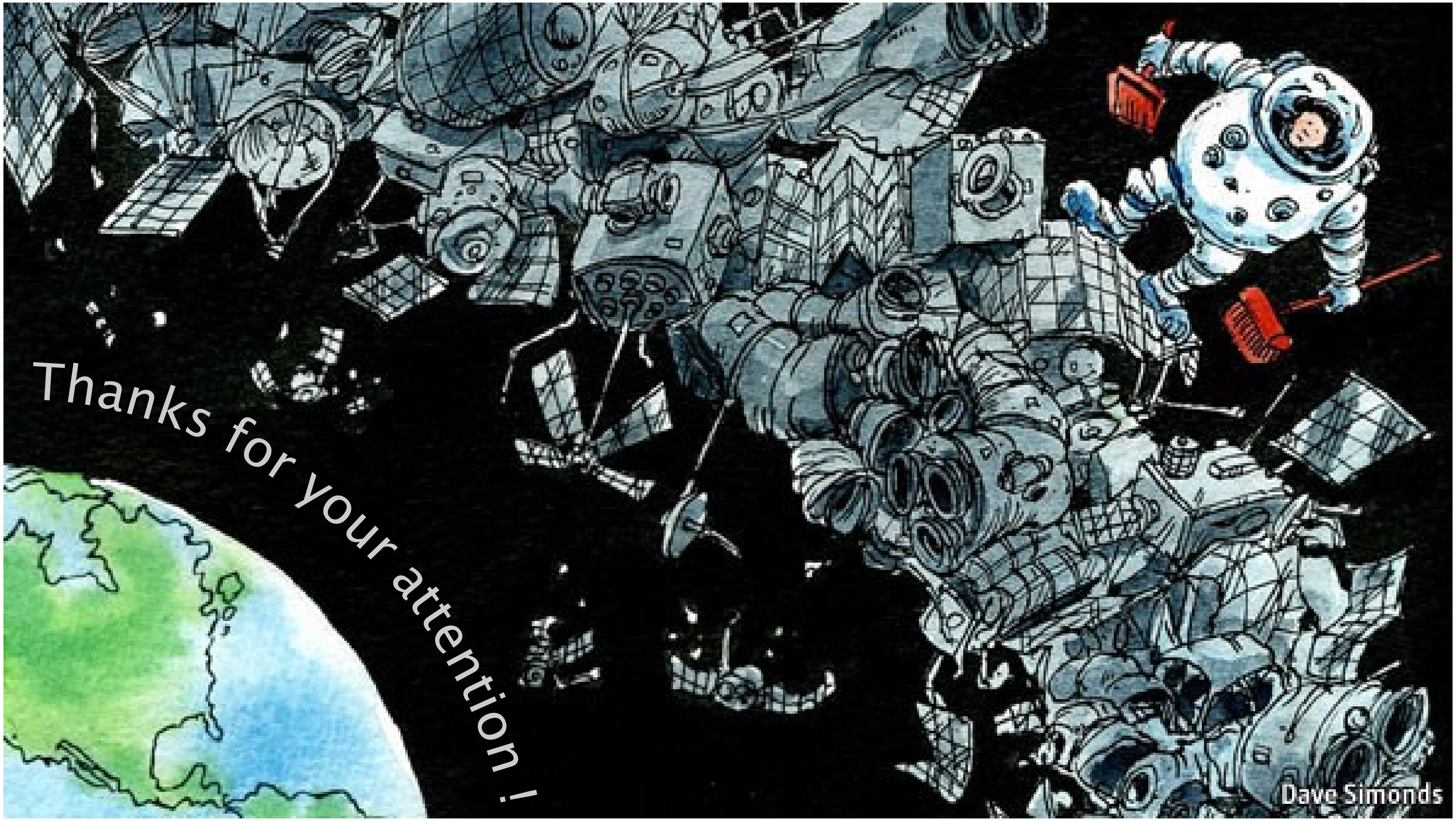
- incorporation of 3 bi-static passes improves the quality of orbit predictions by one order of magnitude w.r.t. single-station results
- prediction errors are comparable to using 10 passes collected by 6 stations
- using a subset of laser tracking data collected during 3 days result in orbit prediction errors of around 300 m after 7 days of prediction
- laser observations can improve the reliability and accuracy of orbit predictions of selected objects

➔ extension to a wider range of (uncooperative) Space Debris objects (e.g. upper stages)

➔ investigation of possibilities to improve atmospheric drag modeling (e.g. attitude and spin*)

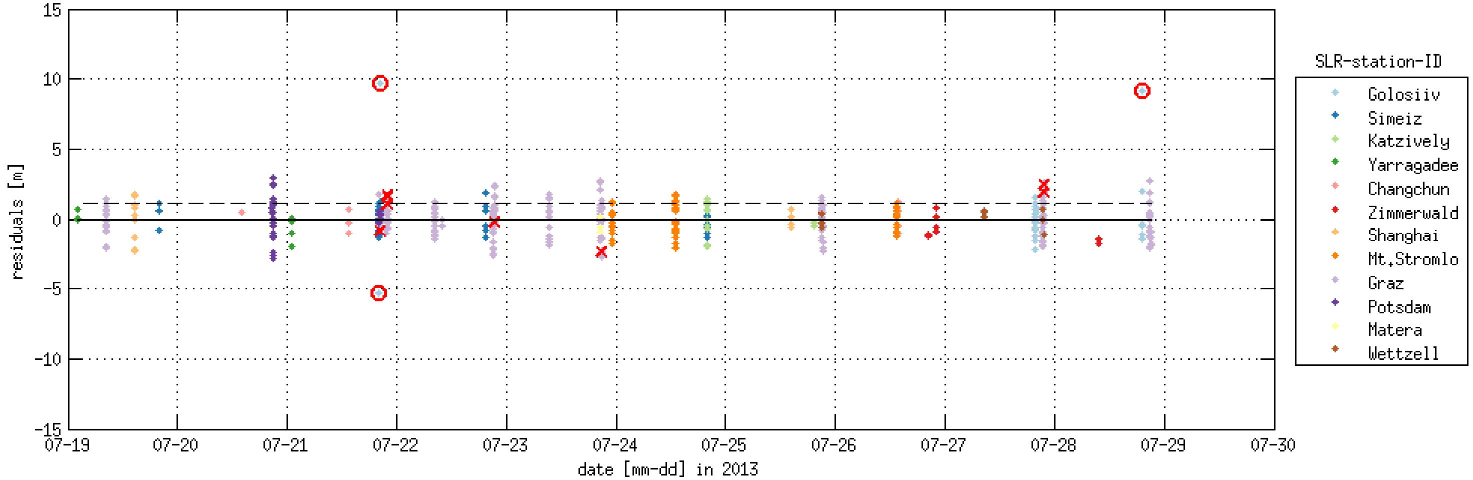
* see Kucharksi, D. et al. (2014): Attitude and Spin Period of Space Debris Envisat Measured by Satellite Laser Ranging, Geoscience and Remote Sensing, IEEE Transactions, Volume 52, Issue 12


Dave Simonds


Thanks for your attention !
Dave Simonds

Validation with Reference Orbit

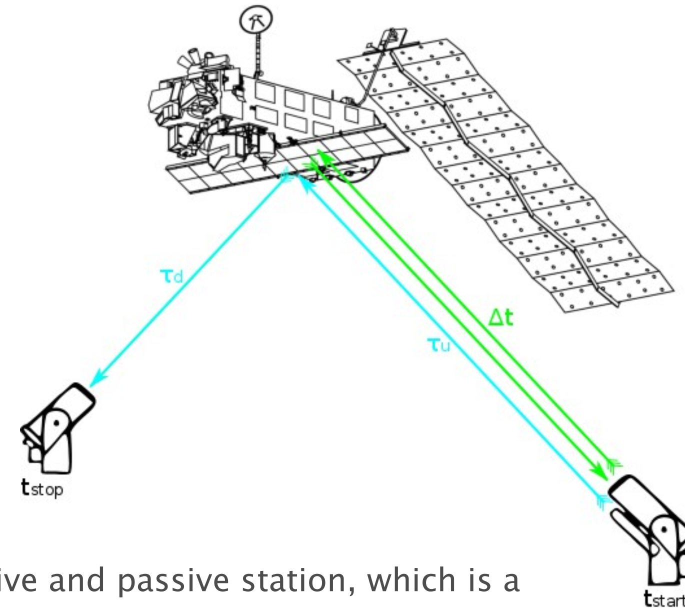
- determined reference orbit using “convential” two-way laser ranges
- tracking data collected from 12 SLR stations during a period of 10 days
- post-fit observational residual RMS is 1.1 m



Bi-static Laser Observations

- selection of the appropriate transmit time t_{start}
  - based on the assumption that $\Delta t \sim \tau_u + \tau_d$ *
  - compute approximate transmit time via fixed-point iteration from t_{stop} and interpolation of Δt
  - select t_{start} from known firing times (80 Hz) constrained by $|\tau_u + \tau_d| < (2 \cdot 80\ \text{Hz})^{-1}$

- separation of uplink τ_u and downlink τ_d
  - uplink $\tau_u = \Delta t(t_{start})/2$ (cubic interpolation)
  - $\tau_d = t_{stop} - t_{start} - \tau_u$



* assumption is justified, because of the small distance between active and passive station, which is a requirement to detect diffusely reflected photons.