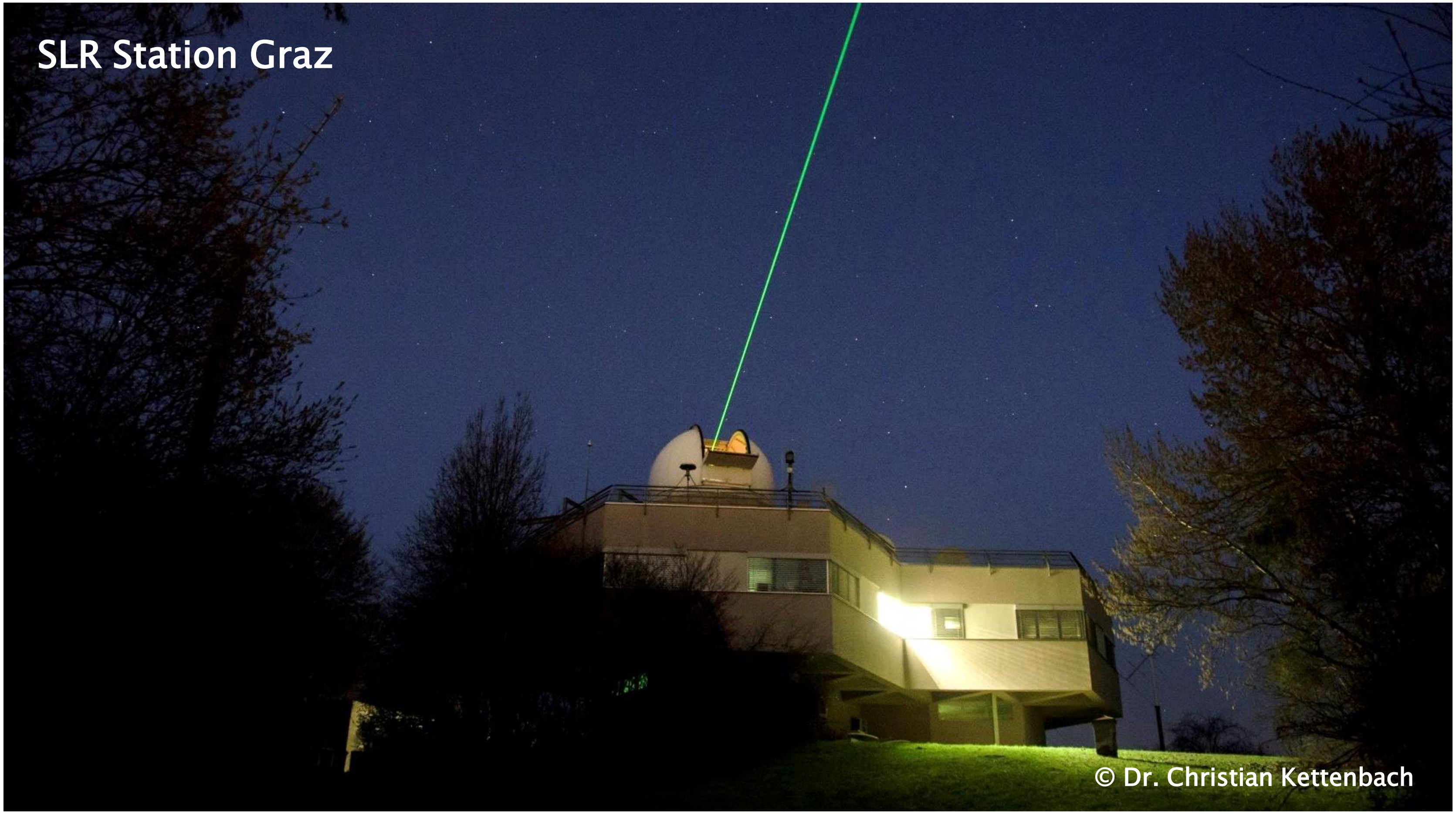
SIMULTANEOUS SPACE DEBRIS LASER RANGING AND LIGHT CURVE MEASUREMENTS OF A LARGE RE-ENTERING UPPER STAGE



Michael Steindorfer, Georg Kirchner, Franz Koidl, Peiyuan Wang
Space Research Institute, Austrian Academy of Sciences

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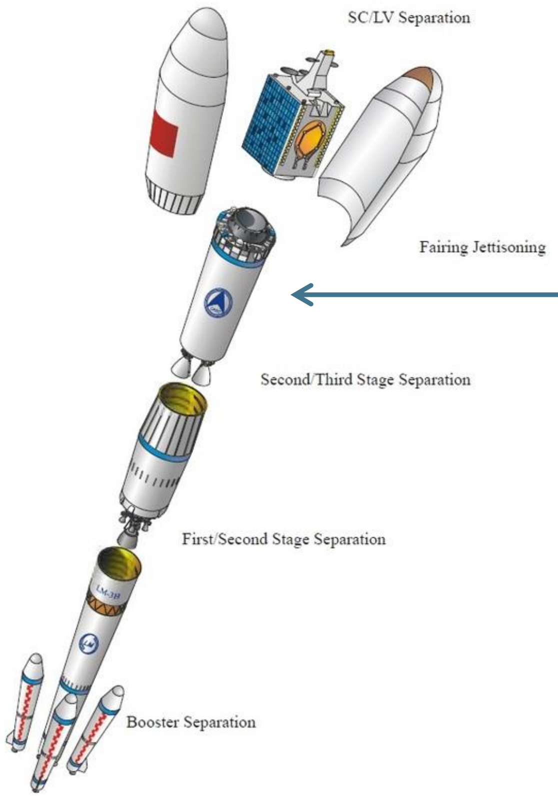
DETAILS: RE-ENTRY OBJECT

- CZ-3B R/B, Norad ID 38253, Third stage of Long March 3B rocket
- Source: http://www.spaceflight101.net/long-march-3b.html



Third Stage

Type	CZ-3B Third Stage
Length	12.38m
Diameter	3.0m
Launch Mass	20,933kg
Empty Mass	2,740kg
Fuel	Liquid Hydrogen
Oxidizer	Liquid Oxygen
Propellant Mass	18,193kg
Propulsion	YF-75
Thrust	156.9kN
Specific Impulse	4,312Ns/kg
Chamber Pressure	37.6bar
Area Ratio	80
Restart Capability	Yes
Prop Utilization	Yes
Burn Time	469s
Control	Engine Gimbaling (Pitch & Yaw)
Attitude Control Sys	4x70N, 8x40N (Roll, Pitch & Yaw)
Prop Management	2x300N, 2x45N

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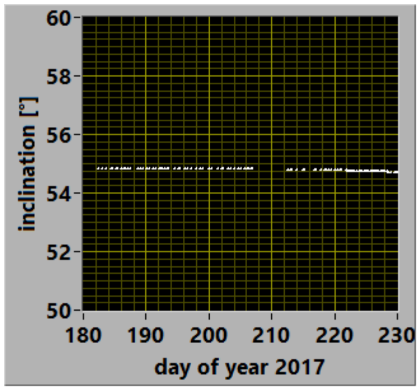
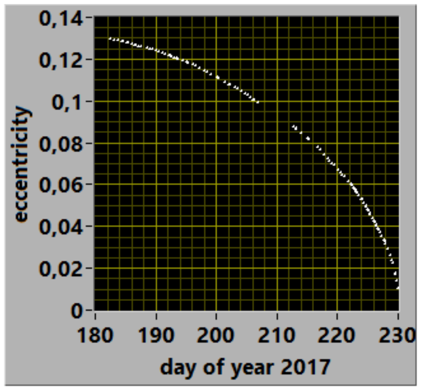
ORBITAL PARAMETERS UNTIL RE-ENTRY

2017-07-01 - 2017-08-19 (reentry: 2017-08-18), TLE source: space-track.org

inclination



eccentricity



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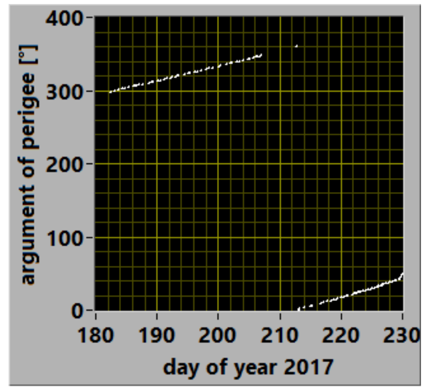
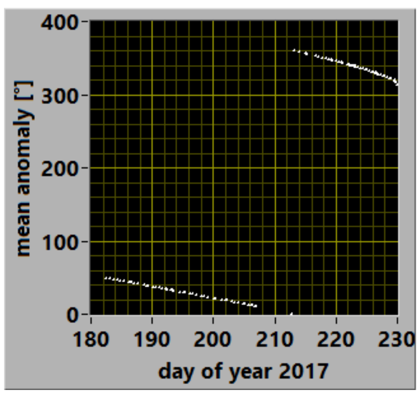
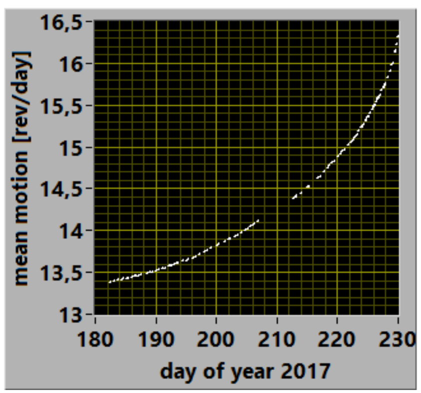
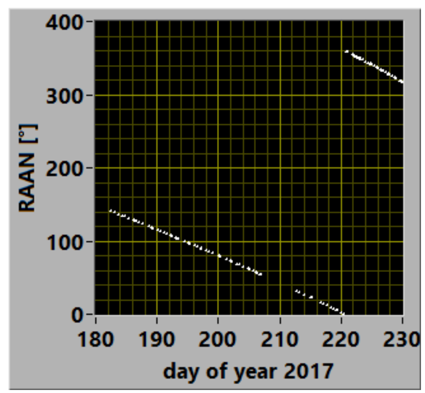




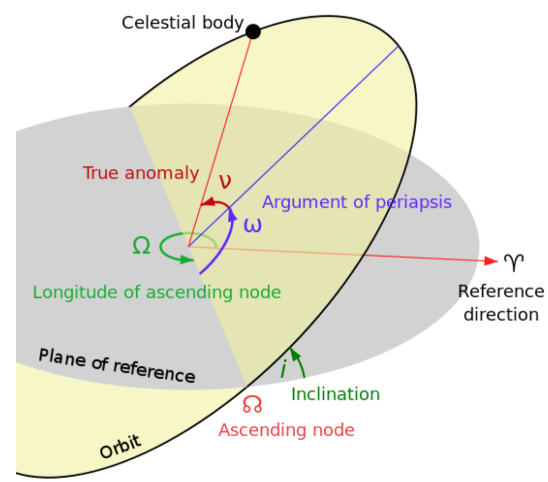
Mean anom



mean motion



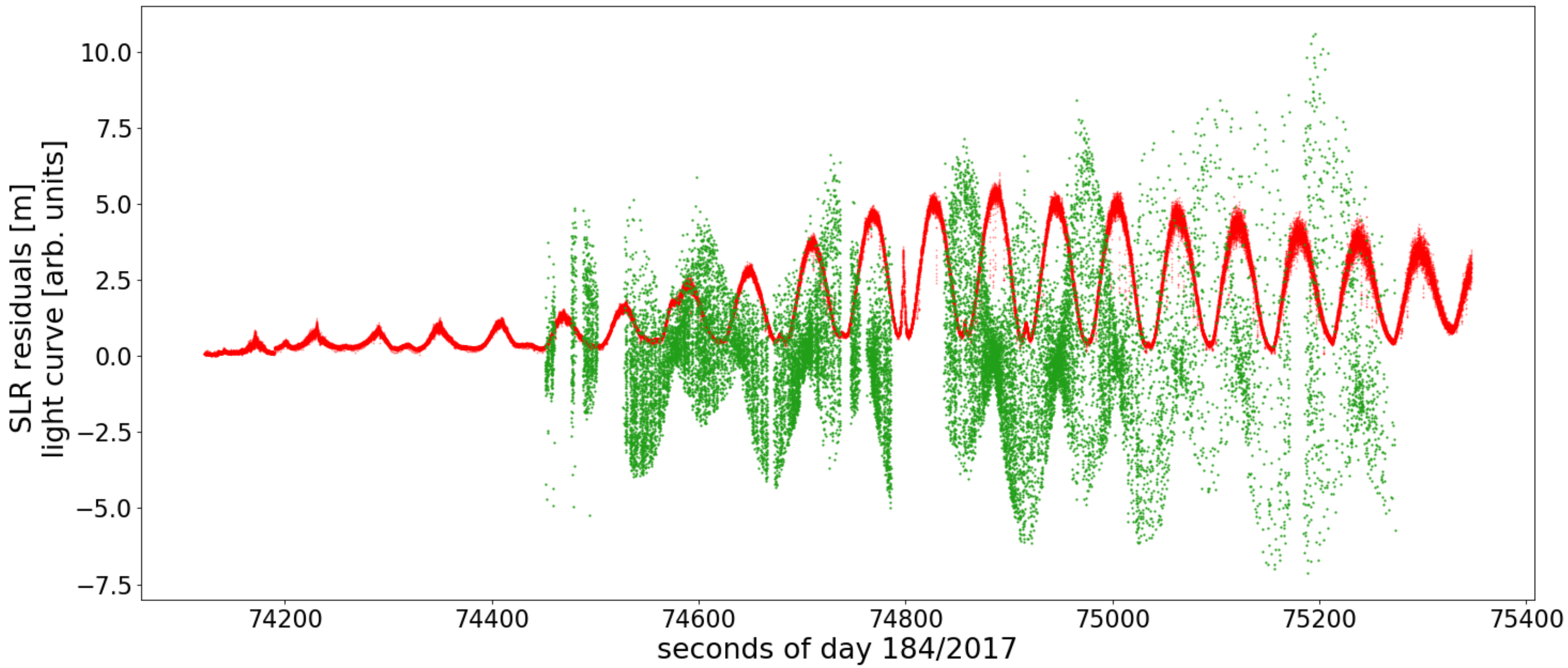
RAAN



MEASURED SLR & LIGHT CURVES

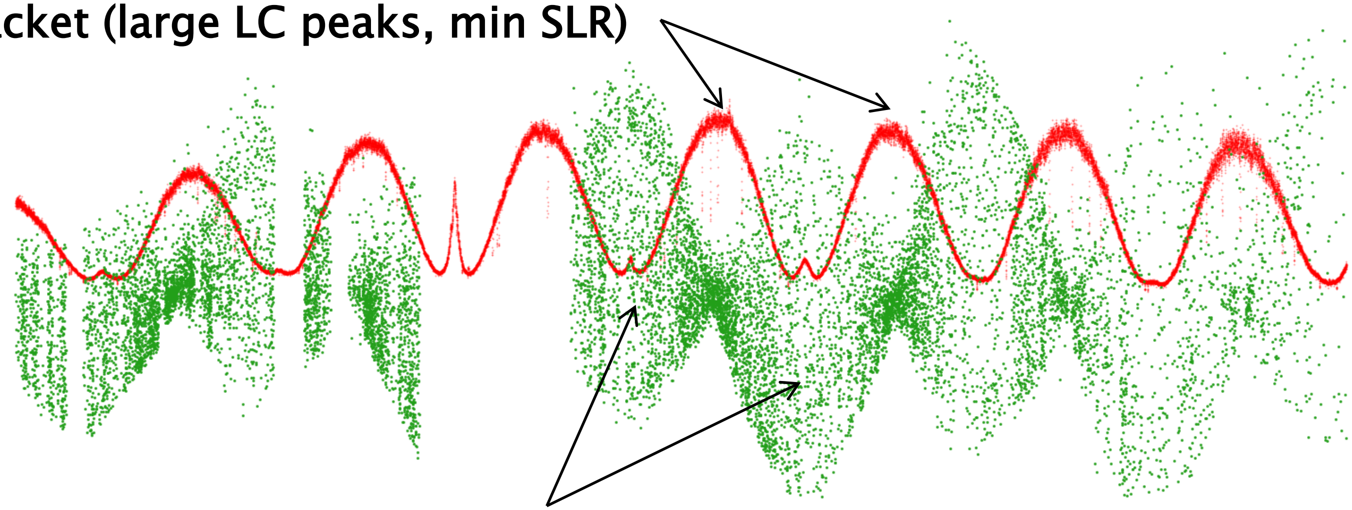
Simultaneous space debris laser ranging and light curve measurements:

- SLR: 100 Hz, 3 ns, 20 W, 200 mJ // LC: wavelength ≠ 532 nm used (SPAD)
- x-axis: seconds of day 184 (2017-07-03)
- y-axis: SLR range residuals [m] (green), max. slant ranges ~3000 km
- y-axis: Light curve (red), scaled to fit within the SLR plot range



SPACE DEBRIS LASER RANGING / LIGHT CURVES

- Maximum SLR offset: approx. 13 meters
  - Cylinder axis roughly parallel to line of sight
- Maximum SLR residuals <-> Small light curve peaks
- Minimum SLR residuals <-> Large light curve peaks
- Large LC peaks: Sunlight reflection from cylinder jacket (SLR Minimum)
- Small LC peaks: Sunlight reflection from top/bottom surface
- Periodical offset of SLR residuals -> center of mass ≠ geometrical center ?



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SIMULATIONS

Main goals of simulations

- Choose a model representing the rocket body shape
  - Cylinder with height = 12.4 m, diameter = 3.0 m
- Define parameter set for different starting positions of cylinder
  - Rotation axis orientation
  - Phase angle of rotation
- Simulate light curves and SLR residuals
- Compare simulation results to measurements
- Find a potential candidate for the rotation axis

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LIGHT CURVE SIMULATIONS

$$I = \frac{I_{sun} A_{eff}}{4\pi R^2 (earth - object)}$$

$$A_{eff} = \sum_{j=1}^{N} A_j \, a_j (\vec{n}_j \vec{\imath})_+ (\vec{n}_j \vec{o})_+$$

a_j … surface albedo

A_j … surface area

$\vec{n}_j$ … surface normal vector, object

$\vec{\imath}$ … vector object – sun

$\vec{o}$ … vector object – observer

Reference: ANALYSIS OF OBSERVED AND SIMULATED LIGHT CURVES OF SPACE DEBRIS

Carolin Früh, Thomas Schildknecht, Astronomical Institute, University of Bern, Switzerland

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SIMULATION DETAILS LIGHT CURVE / SLR

Light curves

1) Define set of cylinder surface: Grid of normal vectors in ECI system
2) Rotate cylinder (normal vectors) to starting position / starting phase
3) Propagate & rotate **normal vectors** along SGP4 path
4) Set surfaces areas of normal vectors according to rocket body dimensions
5) Enter in formula (sun/satellite/observer position) -> Light curves

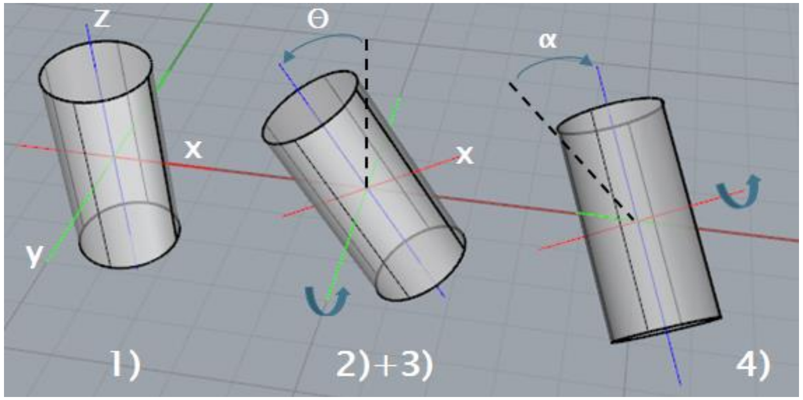
SLR resiudals

1) Calculate surface vectors: Cylinder center (SGP4) - Cylinder surface
2) Rotate surface vectors to starting position / starting phase
3) Propagate & rotate surface vectors along SGP4 path
4) Calculate absolute values (distance from SGP4 path) -> SLR residuals

PARAMETER SPACE OF SIMULATION

Assumption: Rotation around body fixed x-axis (no precession)

1) Cylinder initially defined along z-axis (ECI, GCRS)
2) Cylinder rotated around y-axis: initial angle: Θ_y
3) Cylinder rotated around x-axis: initial angle: Θ_x
4) Cylinder rotated around body fixed axis: phase angle: α
5) Cylinder rotated around body fixed axis while SPG4 propagated along orbit



Parameter space: Θ_y, Θ_y, α : [0°, 5°, 10°, 15°, ... , 360°]

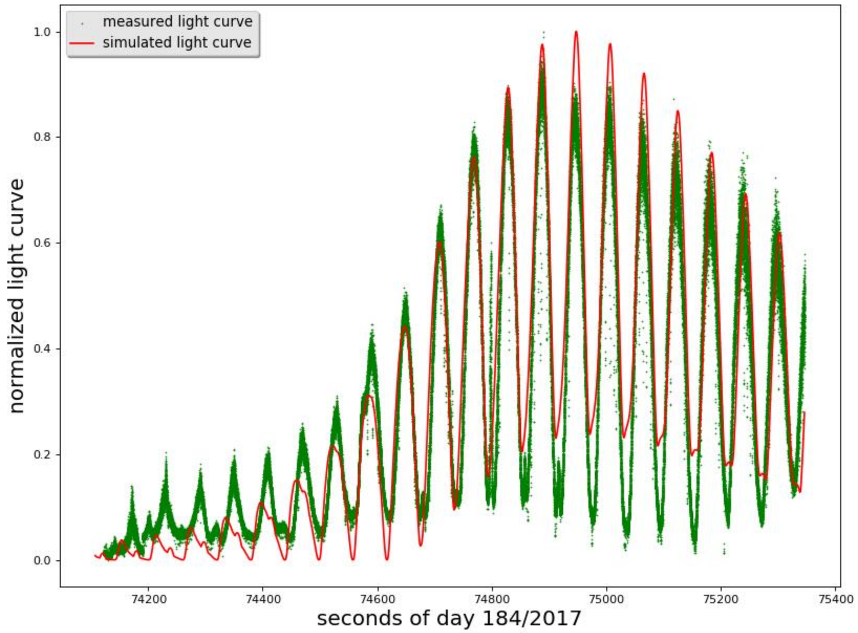
Rotation of cylinder to starting position (72*72*72 simulations, ~1200s each)

OPTIMIZATION RESULTS

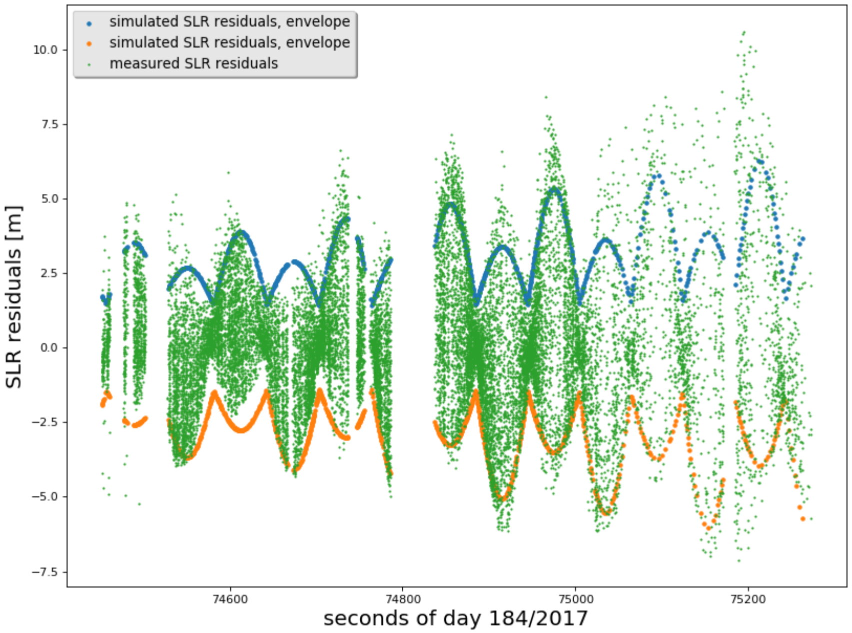
Optimization criteria: Matching peaks LC and SLR // LC and SLR residuals minimum

- Optimization: $\Theta_{y\_init} = 105^\circ$, $\Theta_{y\_init} = 195^\circ$, $phase_{init} = 345^\circ$
- Candidate for rotation axis = [-0.26, -0.25, 0.93], dec = 69°, ra = 224°

Light curve



SLR



green: experimental results

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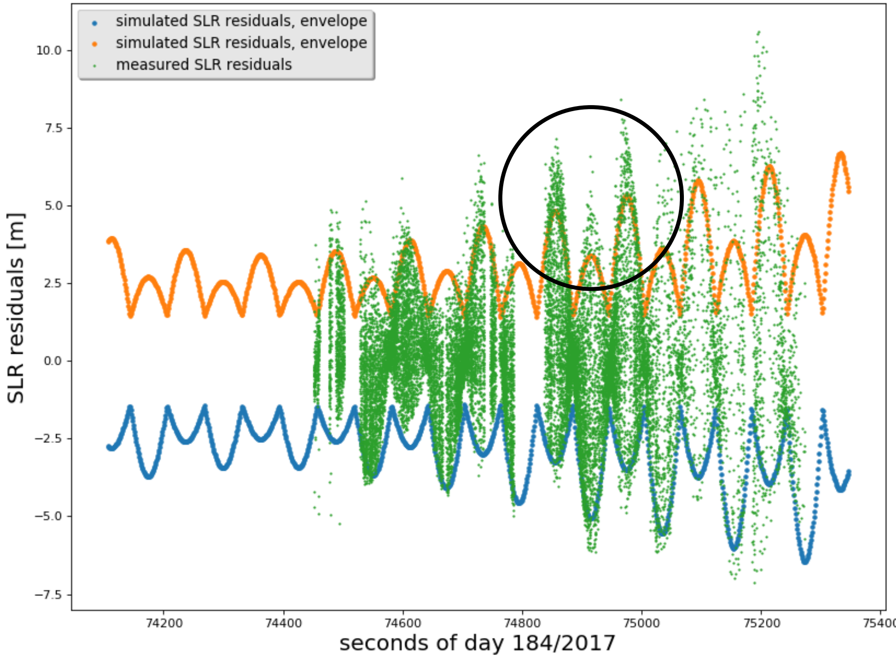
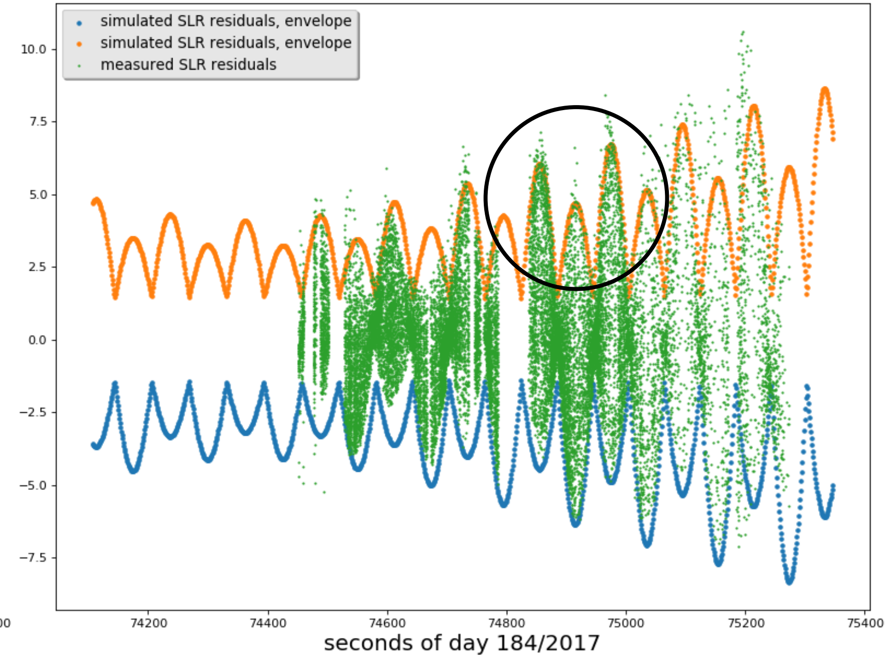
CYLINDER HEIGHT 18 METERS

- SLR results height: 12.4 m, SLR results height: 18 m (estimation: nozzels)
- Better match of SLR residuals in comparison with simulation

height = 12.4 m



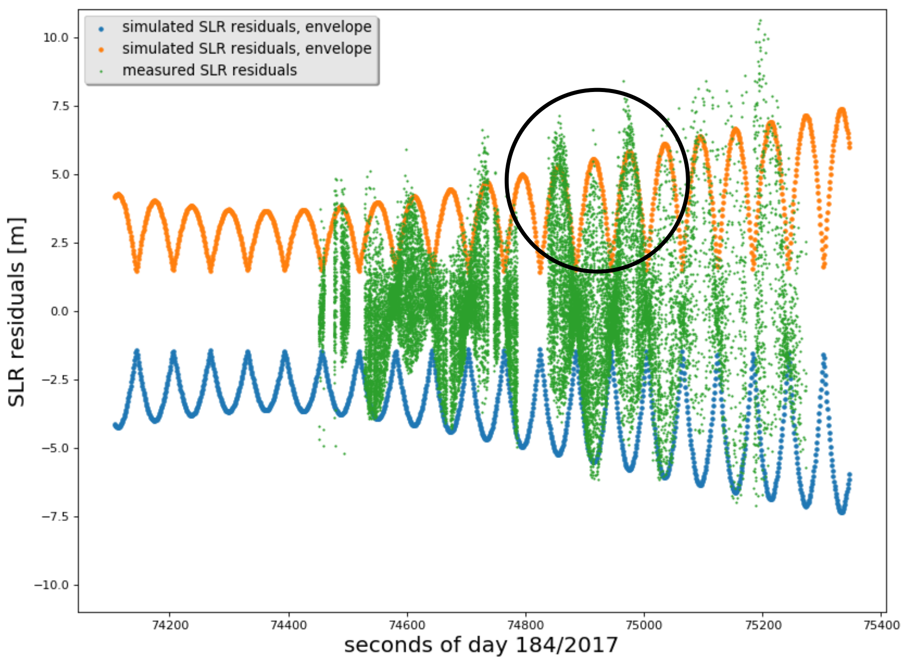
height = 18 m



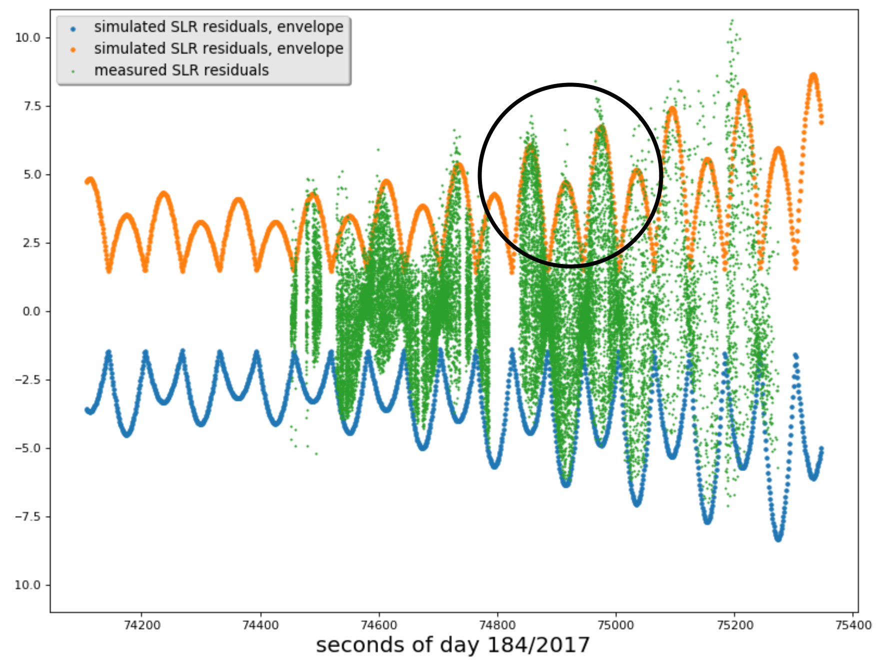
ROTATION: CENTER OF MASS OFFSET

- SLR residuals: Rotation around center of mass (not geometrical center)
- Periodic height variations in SLR residuals can be explained

z_off = 0 m



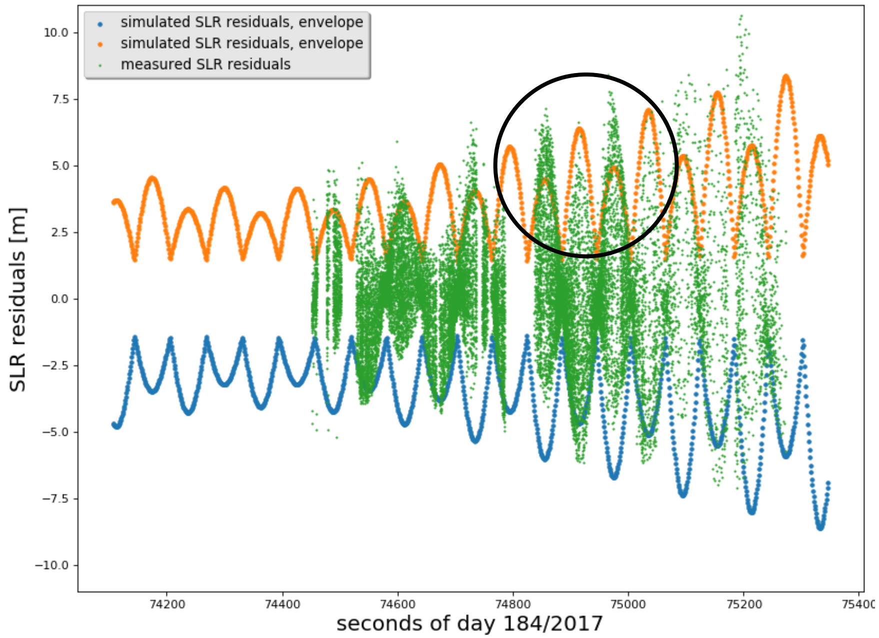
z_off = −1.8 m



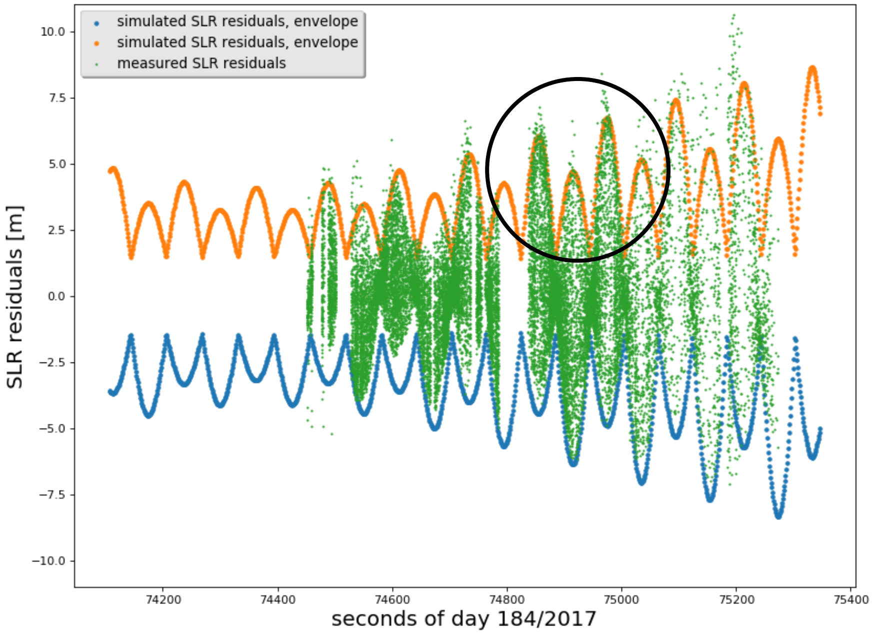
ADVANTAGES OF SLR

- SLR residuals: Different phase angles: variation of 180°
- Due to center of mass offset -> with SLR possible to identify phase

phase offset = 180°



phase offset = 0°



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SUMMARY

Summary

- Simultaneous light curve and SLR measurements
- Target: large upper stage rocket body
- Comparison experiments with simulations
- Analysis based on only one set of measurements each
- Draw conclusions on rocket body orientation along path, including phase

Outlook

- Refine rocket body model
  - Simulate nozzels & top / bottom surface in greater detail (not flat)
  - Include BRDF: bidirectional reflectance distribution function

! Use the light gathered by your telescope which is not needed for SLR !

THANK YOU