IGS INTERNATIONAL GNSS SERVICE

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WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

Assessment of IGS Repro3 orbits using SLR observations

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Study

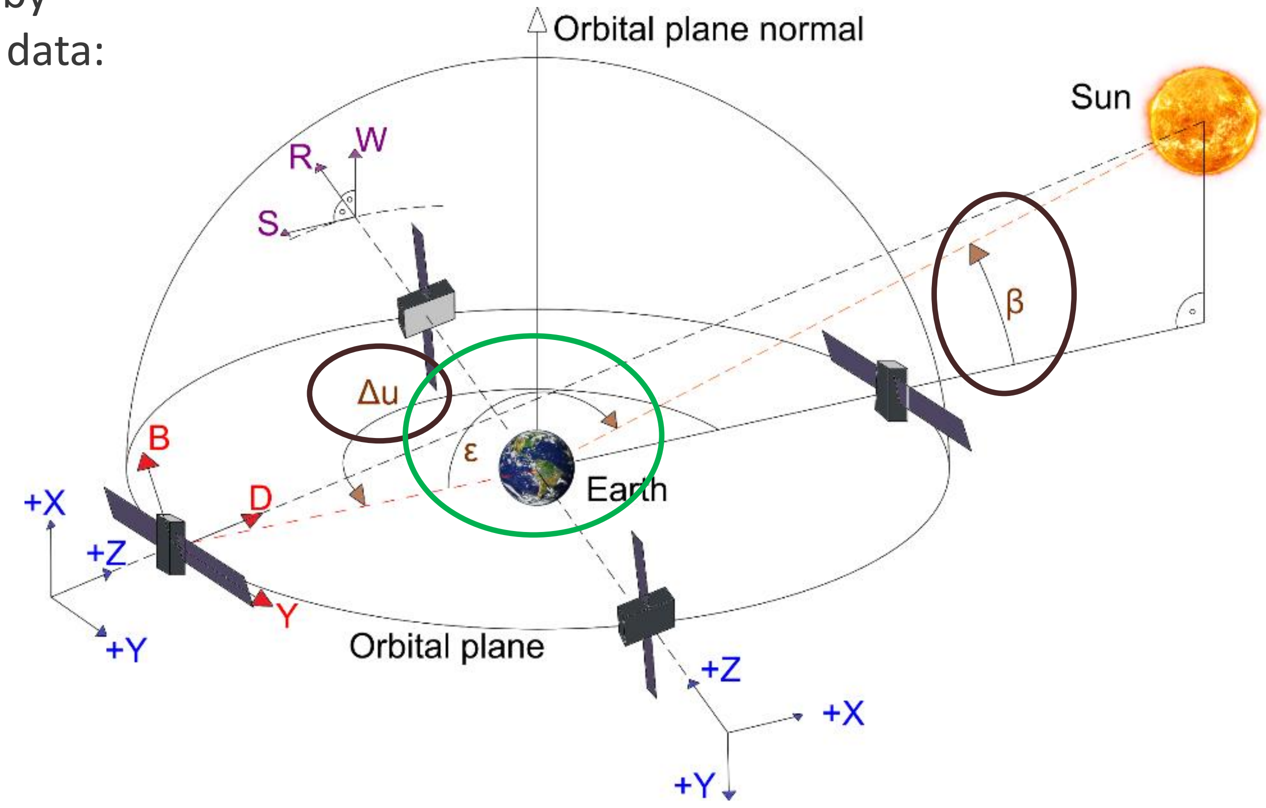
- Validation of the combined IGS Repro3 orbits delivered by Geoscience Australia using Satellite Laser Ranging (SLR) data:
  - Traditional global AC weighting algorithm
  - Satellite-specific AC weighting algorithm

- Dataset 2013-2020 (main interest in Galileo)

- SLR validation of different satellite types: Galileo FOC, FOC eccentric orbit, IOV, GLONASS-M, -M+, -K1A, -K1B, GPS

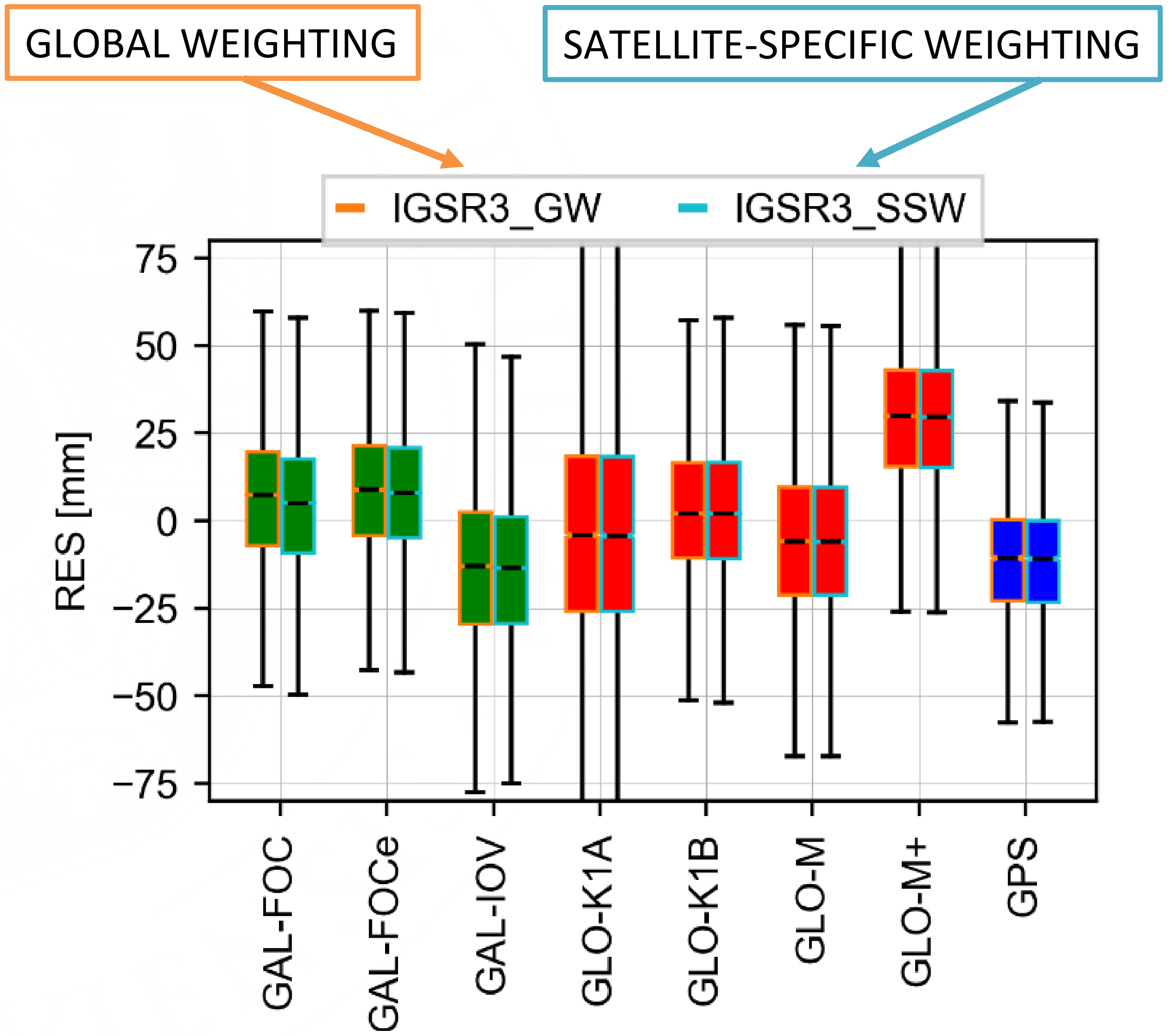
- Searching for patterns in SLR residuals in different satellite-Sun-Earth geometry
  - SLR residuals as a function of β and argument of latitude of the satellite with respect to the argument of the latitude of the Sun (Δu),
  - SLR residuals as a function of elongation angle (ε)

- Possibilities to study SLR-related issues - Satellite signature effect



satellite-Sun-Earth geometry

Results for different satellite types

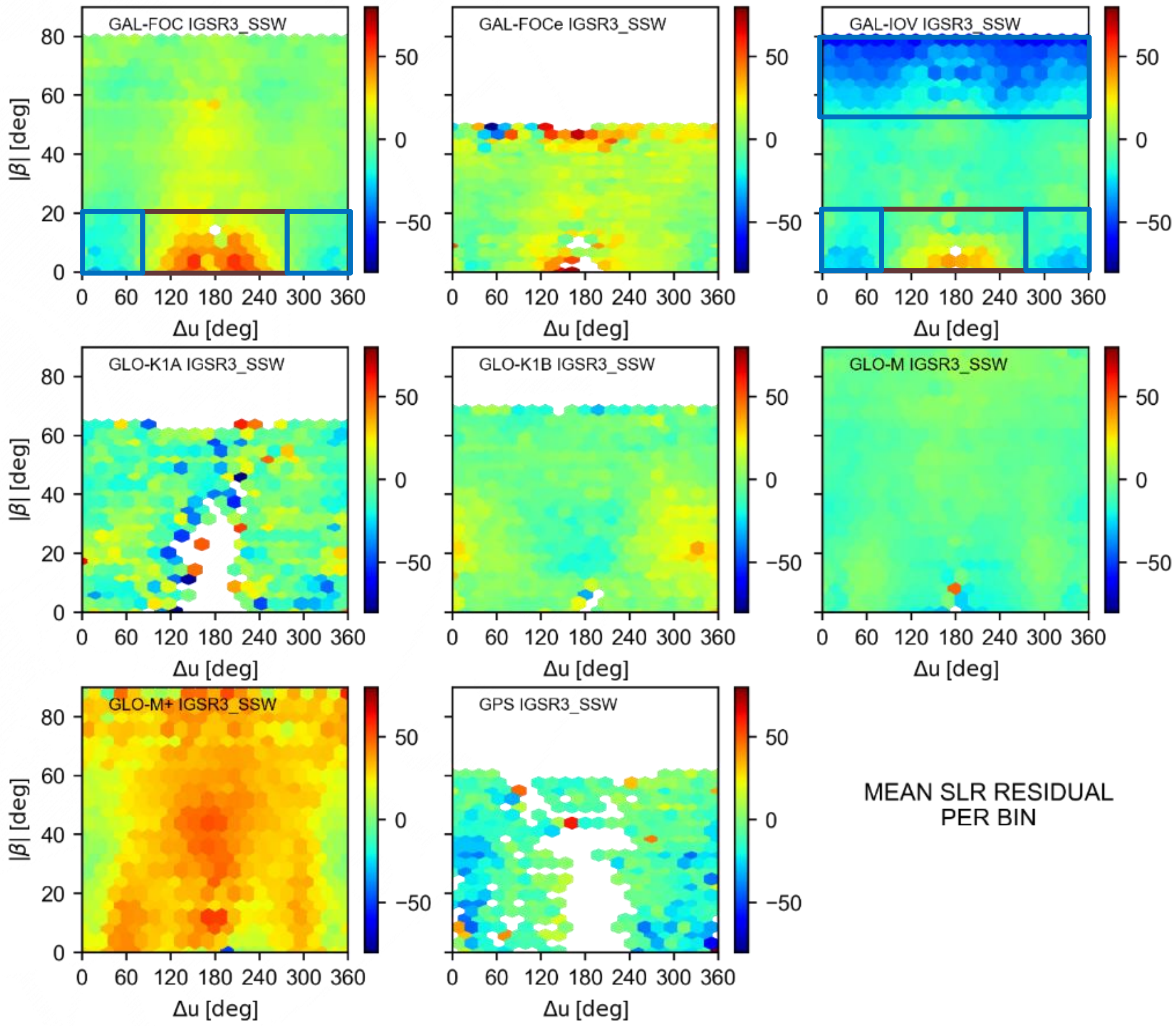


[mm]	MEAN		STD		RMS0	
type	GW	SSW	GW	SSW	GW	SSW
GAL-FOC	5.2	3.1	24.1	24.1	24.7	24.3
GAL-FOCe	7.7	7.1	25.2	24.7	26.3	25.7
GAL-IOV	-14.1	-14.6	31.1	28.9	34.2	32.4
GLO-K1A	-2.9	-3.0	37.7	37.7	37.8	37.8
GLO-K1B	3.8	3.7	23.8	23.8	24.1	24.1
GLO-M	-5.5	-5.5	29.2	29.3	29.7	29.9
GLO-M+	28.7	28.4	25.8	25.8	38.6	38.4
GPS	-11.2	-11.6	23.2	23.2	25.8	25.9

- Improvement of SSW compared to GGW

	MEAN [%]	STD [%]	RMS [%]
GAL-FOC	-39.2	0.0	-1.4
GAL-FOCe	-8.9	-1.8	-2.4
GAL-IOV	3.8	-7.2	-5.3
GLO-K1A	2.3	0.0	0.0
GLO-K1B	-0.2	0.1	0.1
GLO-M	0.3	0.6	0.6
GLO-M+	-1.0	0.1	-0.6
GPS	2.9	0.2	0.8

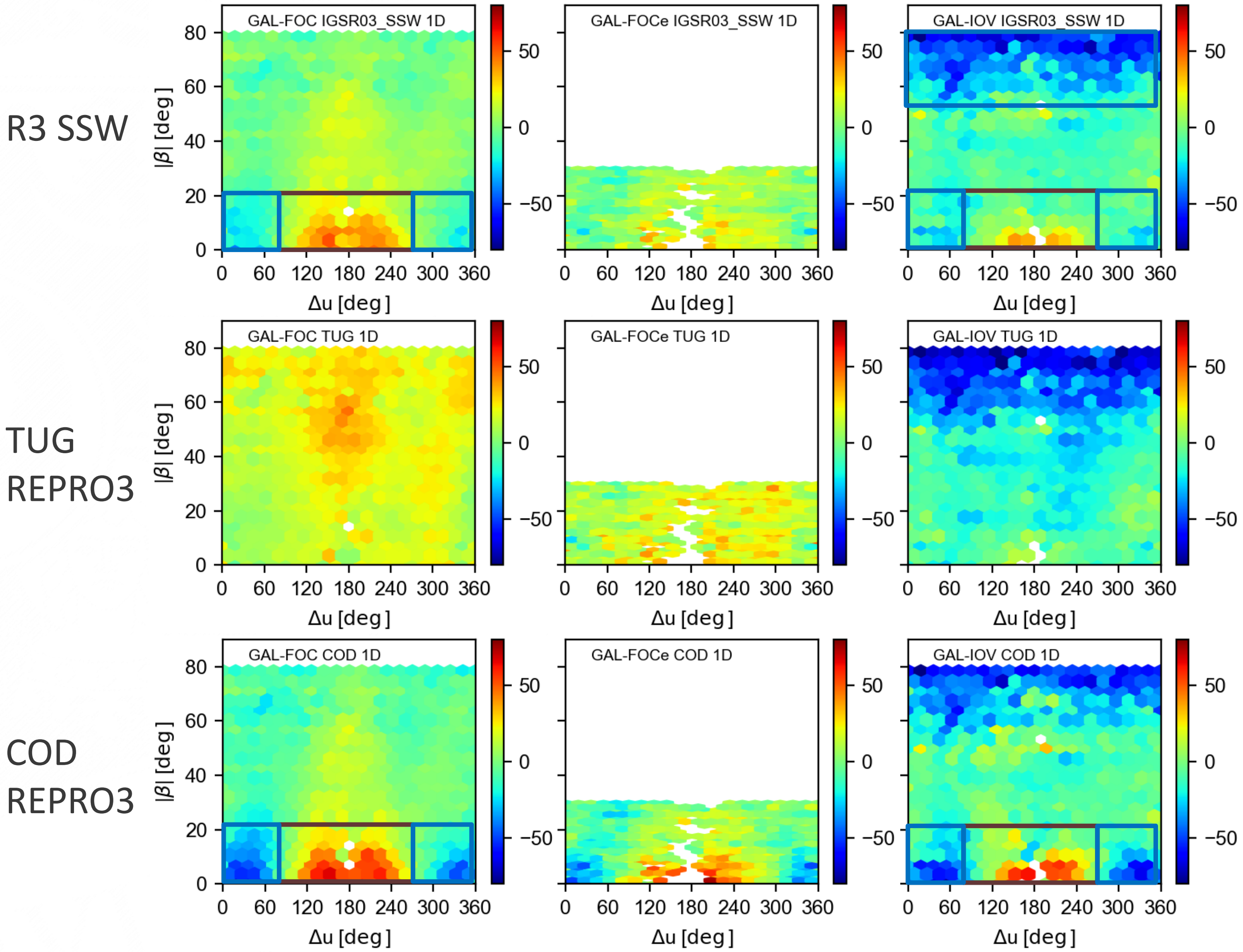
Orbit modeling issues - searching for patterns in SLR residuals



SLR residuals as a function of <u>absolute β</u> and argument of latitude of the satellite with respect to the argument of latitude of the Sun (Δu)

- Characteristic patterns for Galileo FOC (eclipsing seasons) and IOV satellites (eclipsing seasons and high β angles)
- Excellent quality for GLONASS-M and K1B

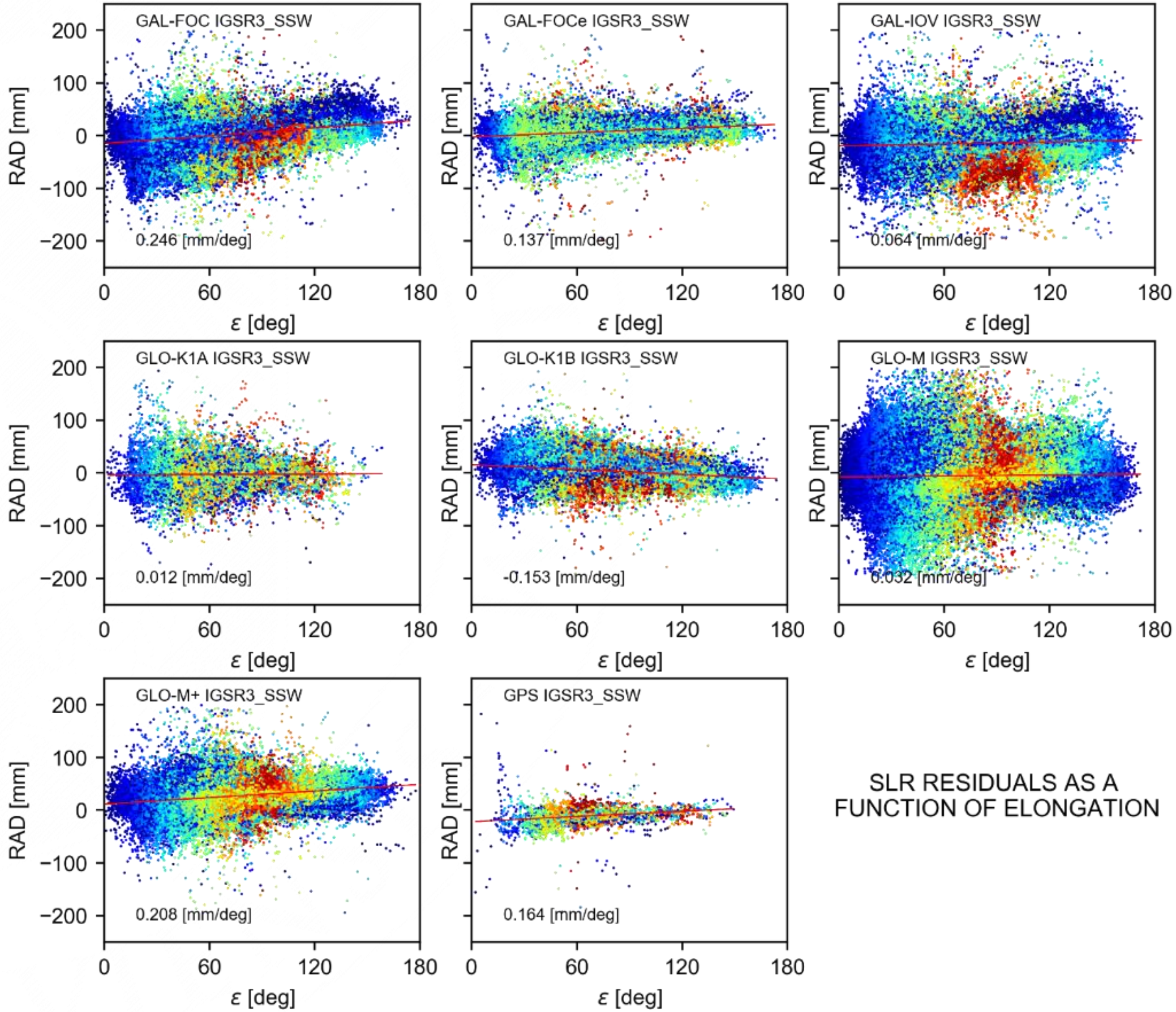
Galileo – Comparison with TUG and COD contributions (2019-2021)



SLR residuals as a function of absolute β and argument of latitude of the satellite with respect to the argument of latitude of the Sun (Δu)

- R3 SSW solutions show similar patterns to those we know from ECOM2 solutions.
- These are, for example, amplified in the CODE solutions and not visible in the TUG solutions
- Validation of the remaining ACs in progress

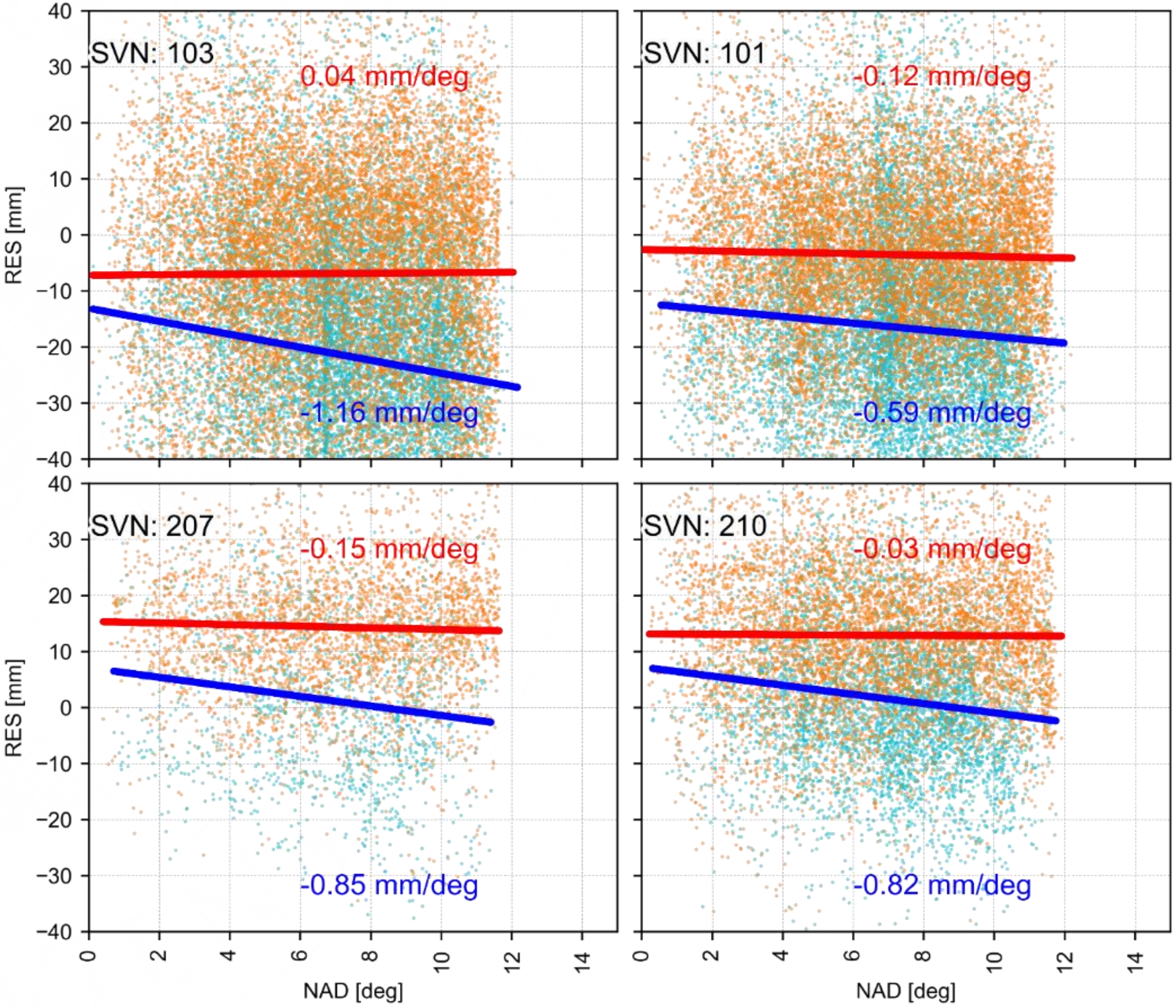
Orbit modeling issues - searching for patterns in SLR residuals



SLR residuals as a function of elongation angle (ε). Dots are colored with the absolute height of the Sun above the orbital plane (β)

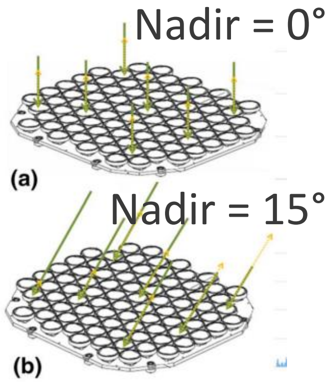
- Linear dependency between the elongation angle (ε) and SLR residuals for Galileo FOC satellites with a slope of 0.25 (FOC), 0.14 (FOCe), -0.15 (K1B), and 0.21 mm/deg (M+).
- Excellent quality for GLONASS-M and K1A satellites

Possibilities to study SLR-related issues - satellite signature effect

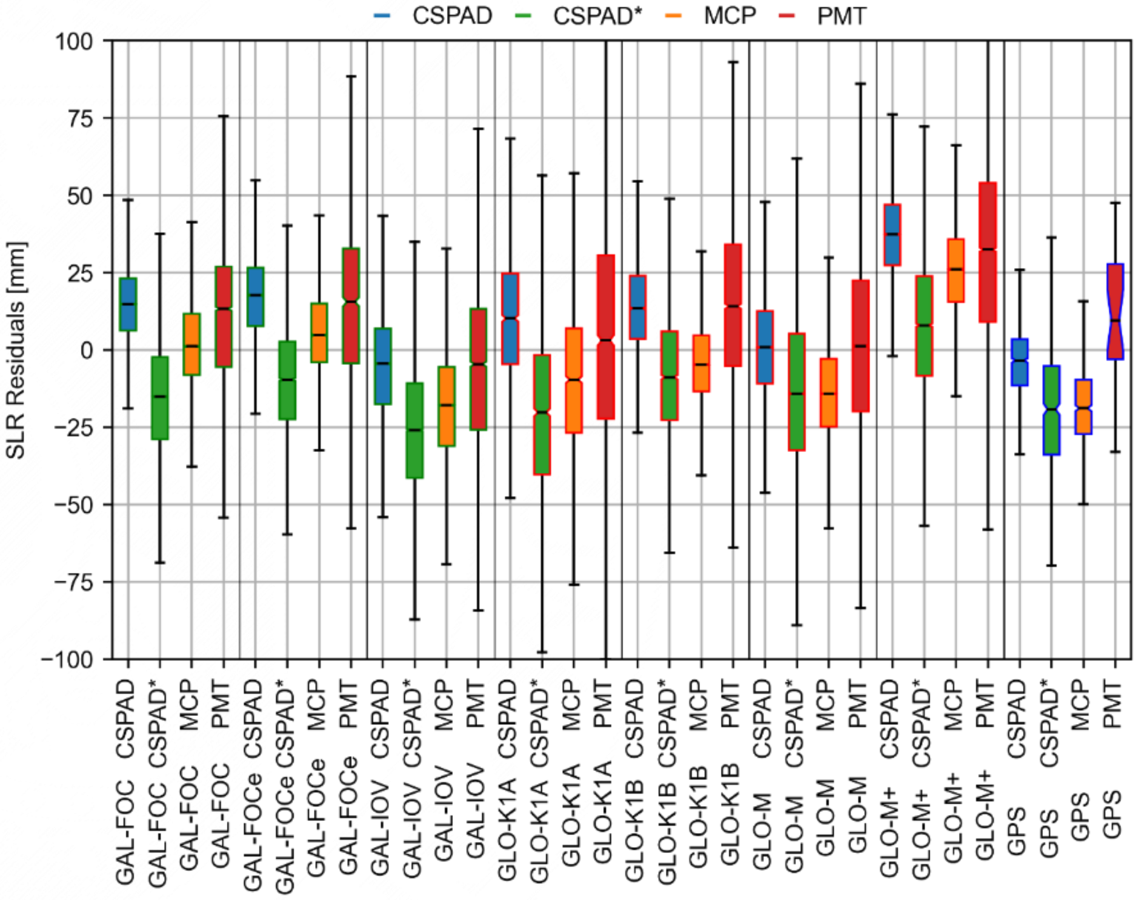


SLR residuals as a function of nadir angle for multi-photon MCP and single-photon CSPAD

When taking SLR observations from the stations equipped with MCP detectors a linear dependency between the SLR residuals and nadir angle („satellite signature effect") is visible **(Mostly for Galileo IOV – large LRA)**



Possibilities to study SLR-related issues



CSPAD: European stations

CSPAD*: Chinese stations

MCP: NASA stations

PMT: Russian stations

Type	Detector	Mean [mm]	Number of normal points [mm]
GAL-FOC	CSPAD	14.8	67835
	CSPAD*	-16.7	42940
	MCP	2.1	43968
	PMT	10.7	6729
GAL-FOCe	CSPAD	16.9	10621
	CSPAD*	-10.9	6034
	MCP	5.3	10198
	PMT	15.5	1604
GAL-IOV	CSPAD	-5.5	39480
	CSPAD*	-25.9	14629
	MCP	-18.2	42815
	PMT	-5.9	5423

There are some substantial differences (2 cm) in the mean offset of SLR residuals when considering SLR observations from different stations.

Long time-series of the uniform in quality GNSS orbits allow for the study of detector-specific issues in Satellite Laser Ranging to the GNSS satellites.

Conclusions

- Analysis of SLR residuals indicate that there are only minor differences between the two delivered sets of combined solutions, which differ in terms of weighting strategy
  - Weighting strategy affects the mean and standard deviation of the individual satellite types, i.e., Galileo FOC and IOV
  - **In general, the standard deviation of SLR residuals is at the level of 2.5 cm**
  - Analysis of SLR residuals in Sun-Earth-satellite frame indicate some issue in the orbit modeling for the individual types of the GNSS satellites
  - Some of these issues have been already mitigated by IGS ACs (Galileo FOC in the case of TUG); thus, there is still ground for the improvement in the combination strategy

- Next steps:
  - SLR validation of all the AC contributions covering the full time frame (1994 – 2020)
    <u>More insight in the orbit modeling issues and valuable information for the combination improvement</u>
  - Long time-series of uniform in quality GNSS orbits allow for the study of detector-specific issues in Satellite Laser Ranging to the GNSS satellites

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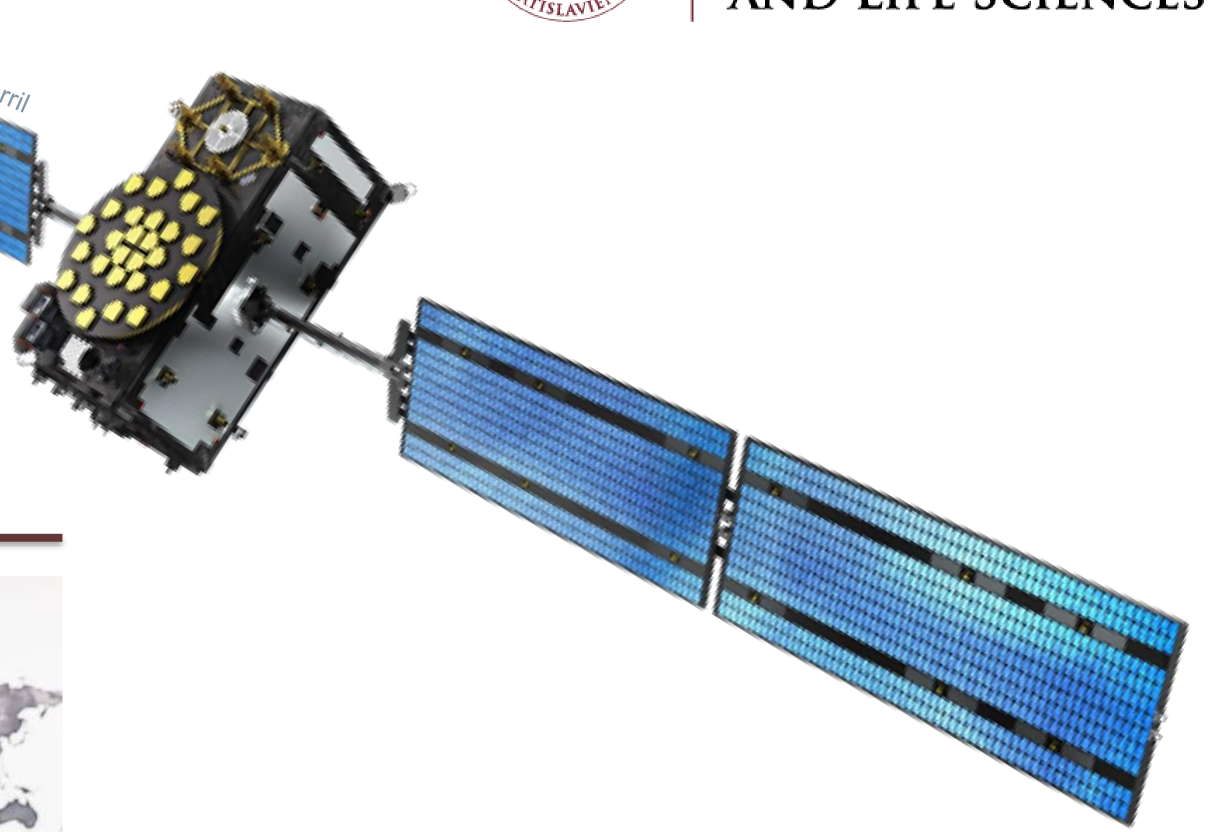

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