GPS Back under the Laser: SLR-Based Orbit Validation of GPS III SV09 and SV10

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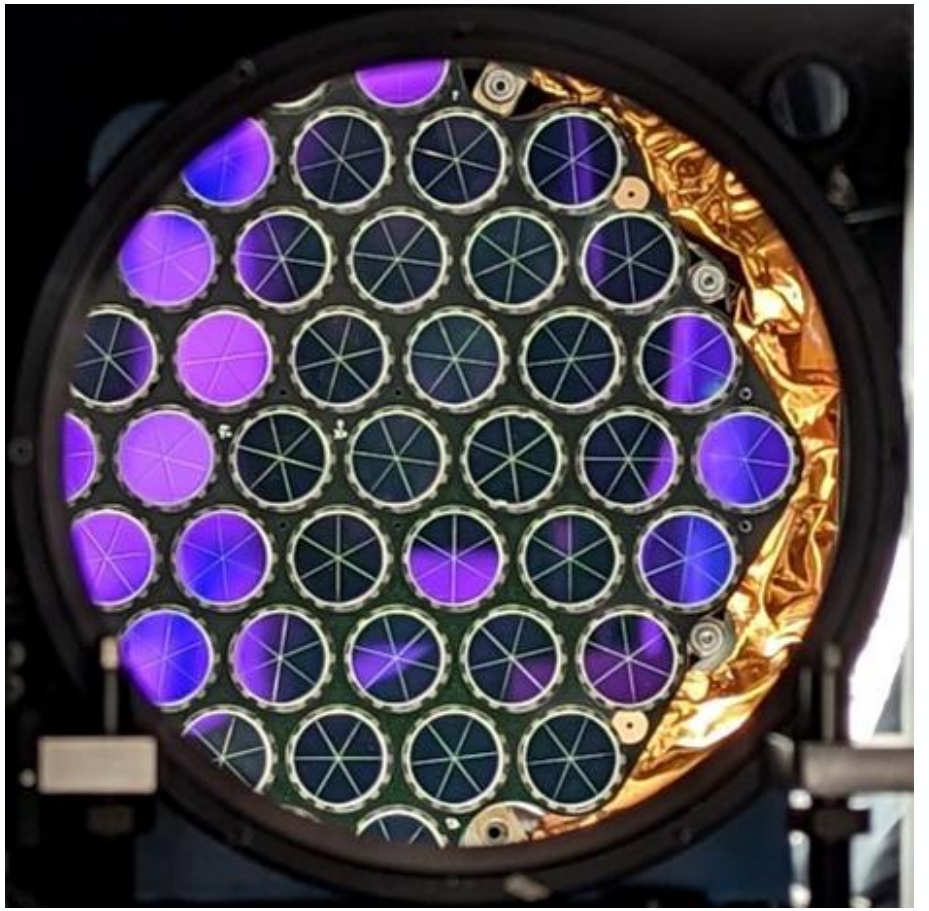
05/06/2026

Introduction

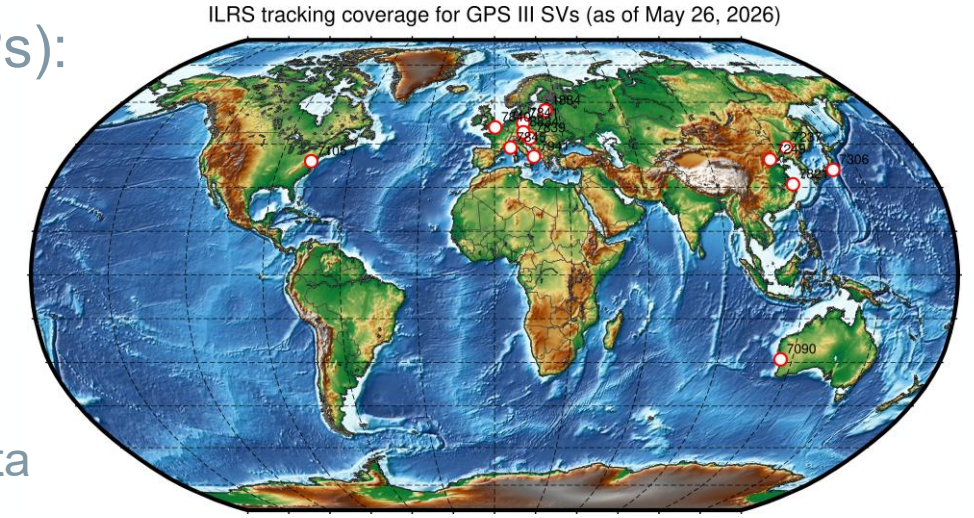
- GPS SLR returns after ~30 years
  - Last GPS SVs carrying Laser Retroreflector Arrays (LRAs) were GPS IIA (SVN 35/36), launched in 1993/94
- LRAs now reintroduced on latest Block III satellites:
  - SV09 (SVN 82) – launched January 27, 2026
  - SV10 (SVN 83) – launched April 21, 2026
- Scientifically valuable in multiple ways:
  - Independent orbit validation at millimeter level
  - Improvement of radiation force models
  - Re-establishment of the GPS–SLR space tie
  - Determination of eclipse yaw attitude
- Key facts:
  - 40.6 cm diameter planar array with 48 fused-silica CCRs
  - Corner cube size: 40.6 mm (diameter) x 29.7 mm (height)
  - Refractive index at 532 nm: n = 1.46071
  - Developed jointly by Goddard Space Flight Center (GSFC) and Naval Research Laboratory (NRL)



Credits: NASA

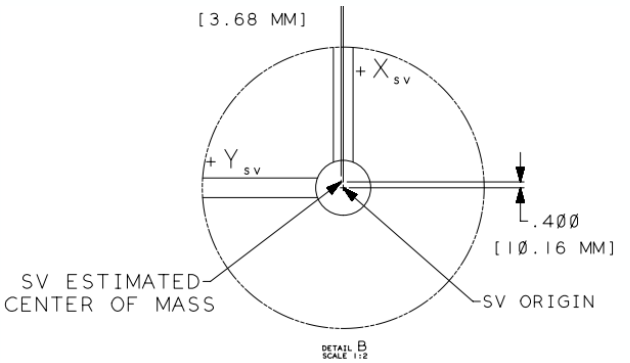
SLR Analysis

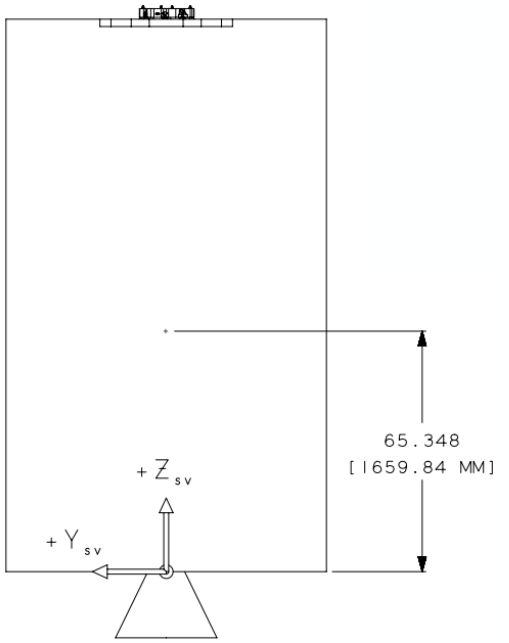
- Generation of 24-hour GPS orbit solutions using different radiation force models:
  - ECOM1 + RnR25
  - ECOM1 + Box-Wing
  - ECOM2
- SLR analysis based on sparse set of normal points (NPs):
  - SV09: 1013 NPs from 13 stations between March 4 and May 26
  - SV10: 33 NPs from 3 stations between May 15 and 26
- LRA offsets:
  - Daily estimation followed by combination at the NEQ level
  - One common X/Y offset and two satellite-specific Z offsets
  - Comparison against offset derived from May 2026 ILRS metadata (https://ilrs.gsfc.nasa.gov/docs/2026/GP-IC-0214.pdf)
- SLR residuals compared with satellite clock residuals (≙ clock estimates after removal of daily 2nd-order best-fit polynomials)



LRA Offset Computation (1/2)

- Input:
  - Center-of-Mass (CoM) position, see drawing (right)
  - CCR front-surface center coordinates
  - Prism diameter and refractive index
- Coordinate transformation into IGS frame:
  - Sign inversion of X and Y
  - Removal of CoM vector
- Computation of CCR mean position
- Determination of reflection point (Fitzmaurice et al. 1977):
  - Range correction: $\Delta R = L\sqrt{n^2 - \sin^2\theta}$
  - Vertex distance derived from elementary geometry: $L = D/\sqrt{6}$
  - Final range correction obtained by averaging over incidence angles θ:



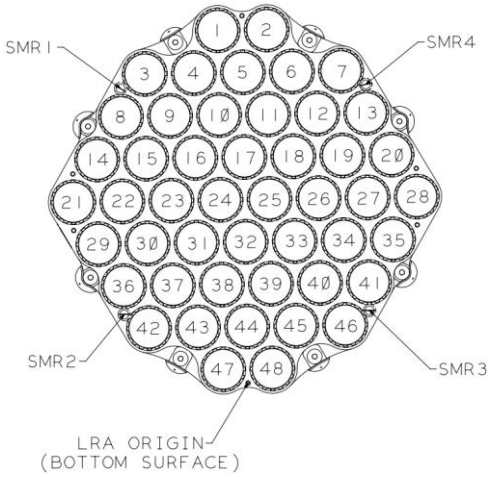


Source: https://ilrs.gsfc.nasa.gov/docs/2026/GP-IC-0214.pdf

θ [deg]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	Mean
ΔR [mm]	24.2	24.2	24.2	24.2	24.2	24.2	24.1	24.1	24.1	24.1	24.0	24.0	24.0	23.9	24.1

LRA Offset Computation (2/2)

	X_{IGS} [mm]	Y_{IGS} [mm]	Z_{IGS} [mm]
#1	1037.46	-155.64	2216.0
#2	994.14	-130.58	2216.0
#3	1124.13	-155.73	2216.0
#4	1080.82	-130.66	2216.0
#5	1037.50	-105.60	2216.0
⋮	⋮	⋮	⋮
CCR mean	1102.6	6.9	2216.0
Range correction			24.1
LRA offset	**1102.6**	**6.9**	**2191.9**



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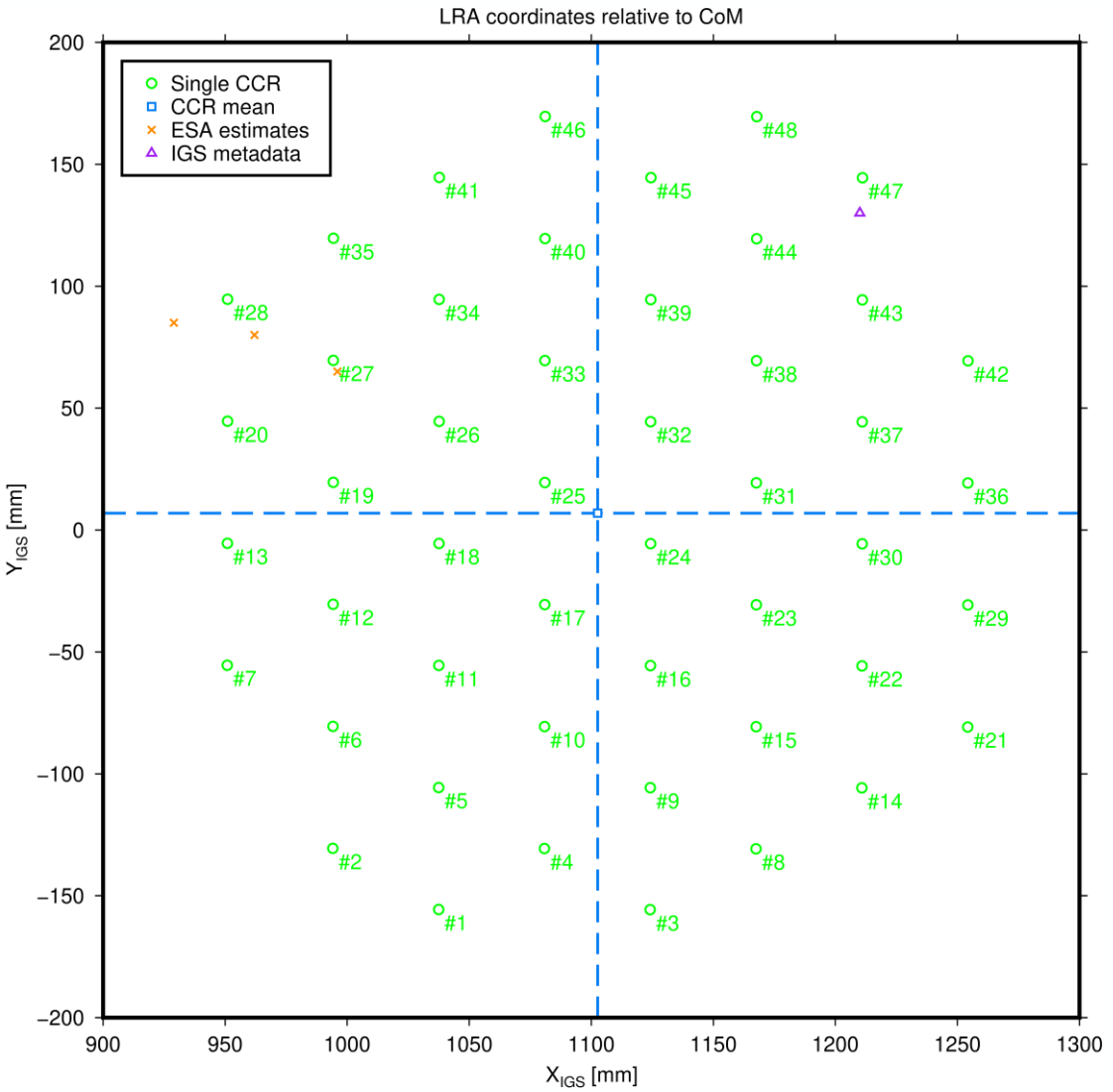
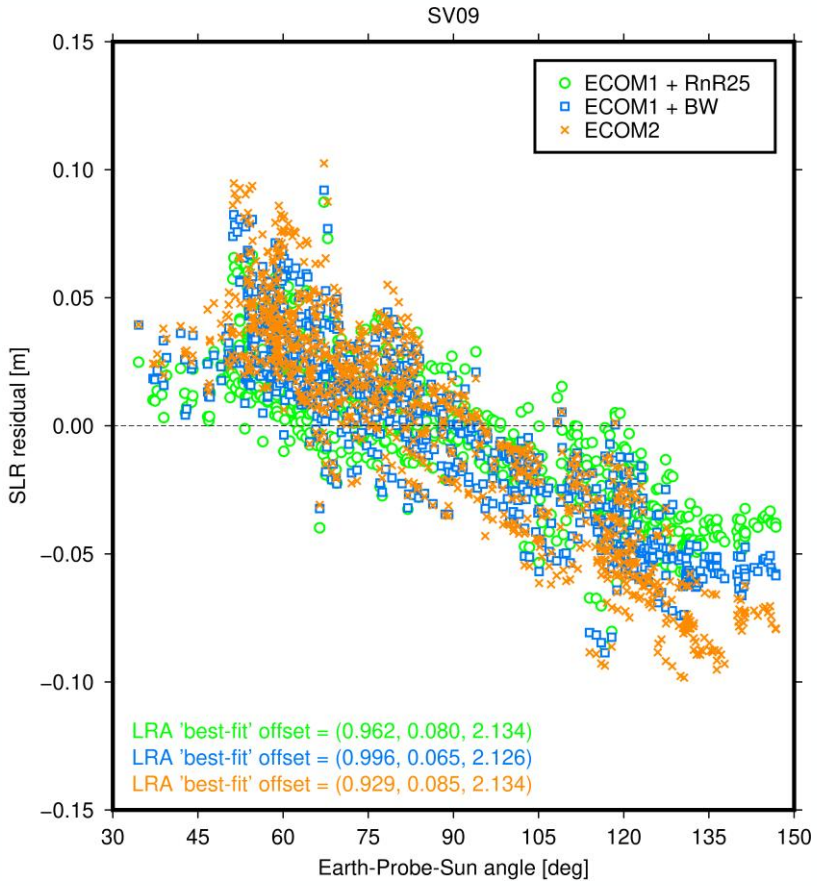
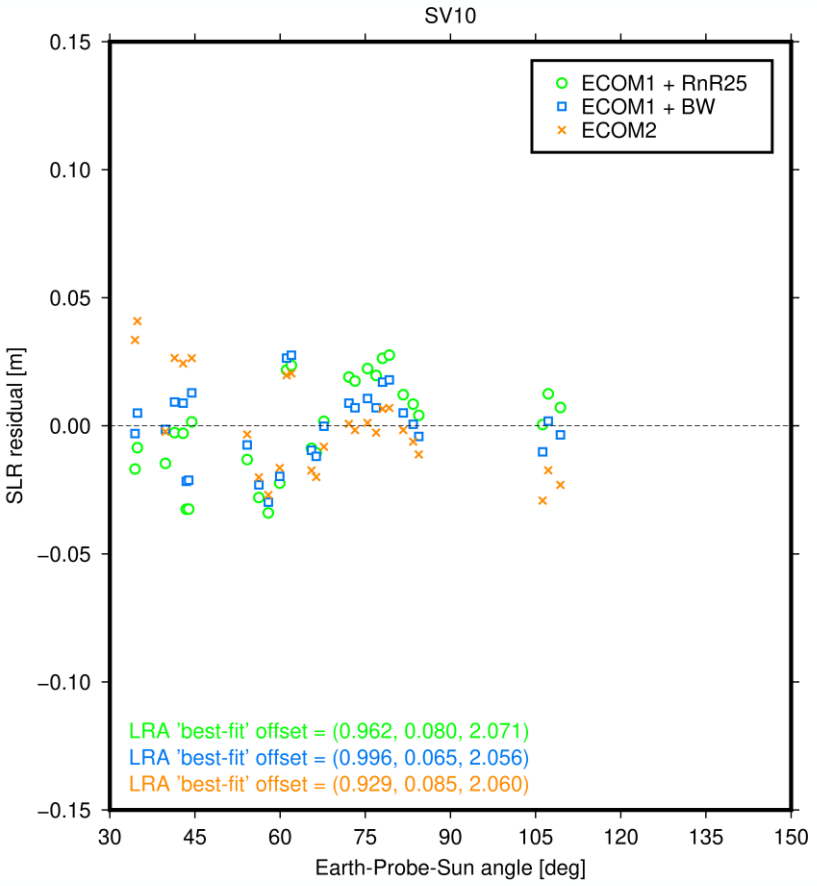
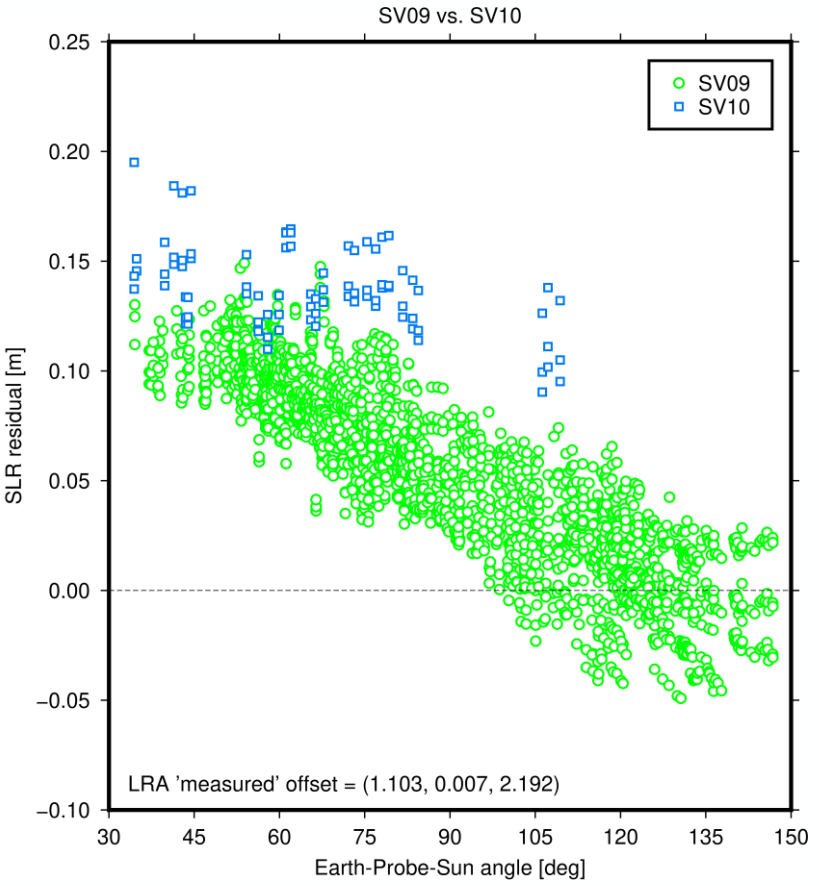


SLR Residuals

- Analysis of SLR range residuals relative to “best-fit” and “measured” LRA offsets:
  - Strong once-per-rev signature visible for SV09, regardless of the underlying force model
  - Mean biases of +6 cm (SV09) and +14 cm (SV10) when applying the measured offset

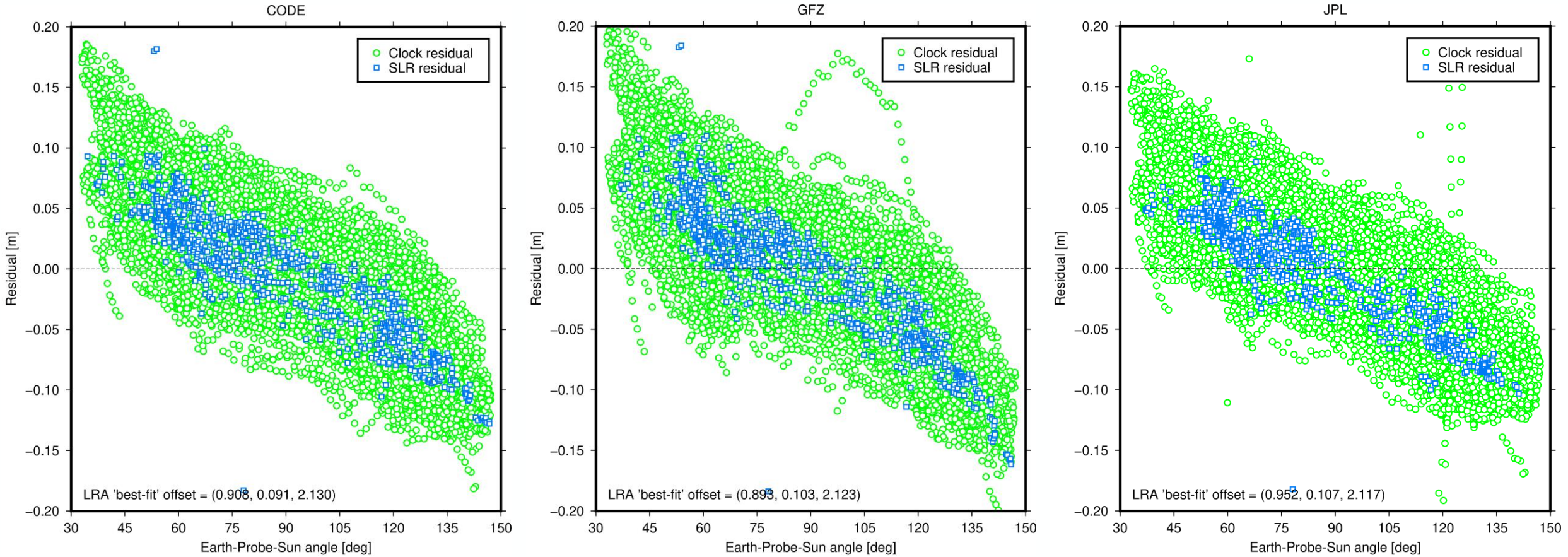






IGS AC Rapids: SLR vs. Clock residuals

- Rapid orbit and clock products for SV09 from 10 ACs analyzed
  - CODE, NRCan, ESA, GFZ, GRGS, JPL, NGS, SIO, USNO and Wuhan University
- Similar SLR residuals across all ACs, strongly correlated with de-trended clock estimates



Conclusions

- SLR once again proves to be a powerful tool for independent orbit validation
- GPS III SV09:
  - SLR range residuals reveal radial orbit errors of up to approximately ±0.1 m
  - Consistent across all tested force models and IGS AC submissions
  - One-to-one correlation between SLR and satellite clock residuals
- GPS III SV10:
  - Flatter SLR residuals, with scatter at the few-centimeter level
  - Additional SLR tracking from more stations required for a more thorough analysis
- Results indicate need for satellite-specific force models for SV09 and SV10
  - Additional evidence provided by unusually large ECOM B-cosine estimates
- Preliminary LRA offsets derived from ILRS metadata to be treated with caution ⚠
  - Further clarification required, particularly for Z component
- Ultimate geodetic value of SLR stands or falls with accurate knowledge of the “true” LRA reflection center