

CODE's multi-GNSS orbit solution

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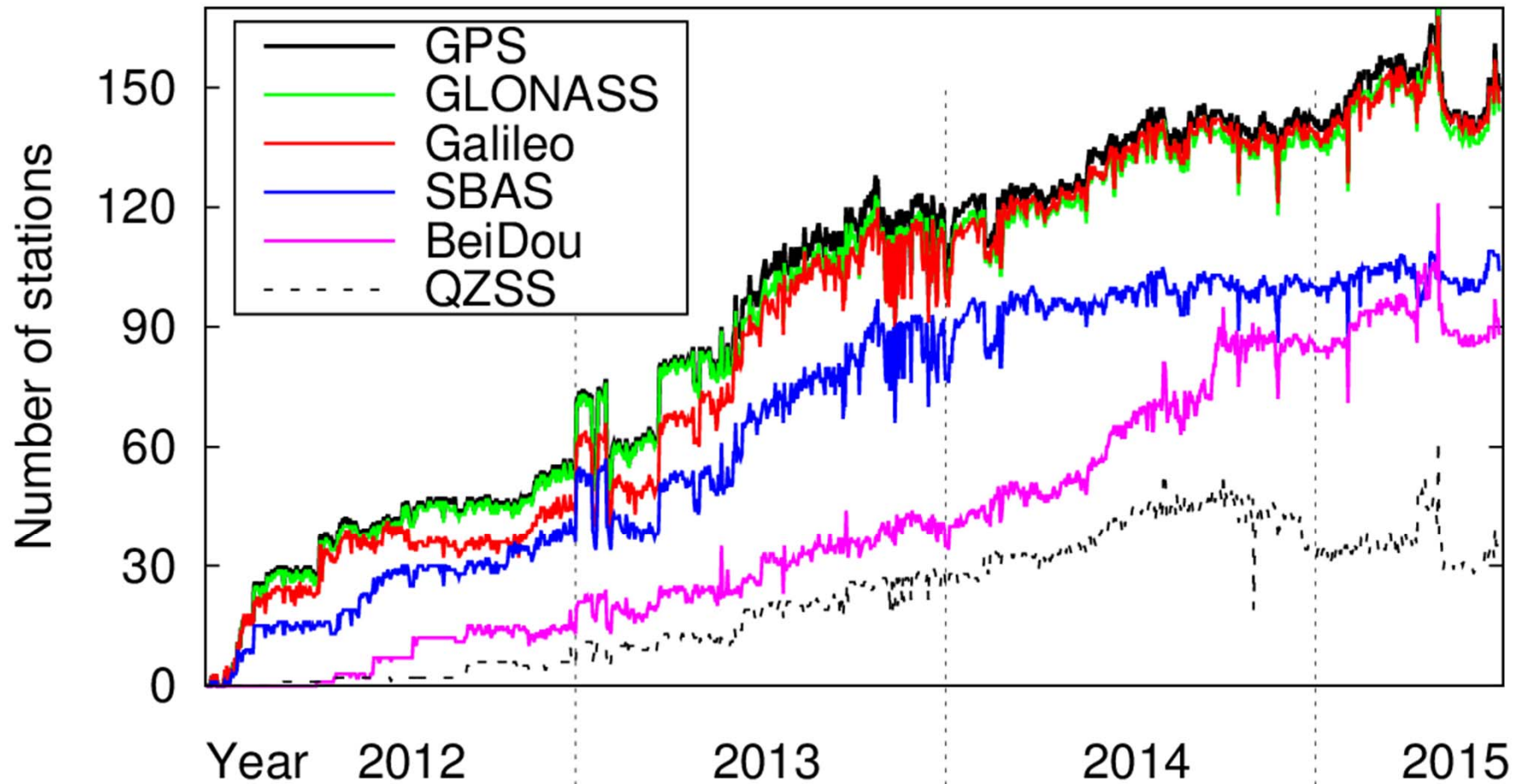
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Braunschweig, Germany

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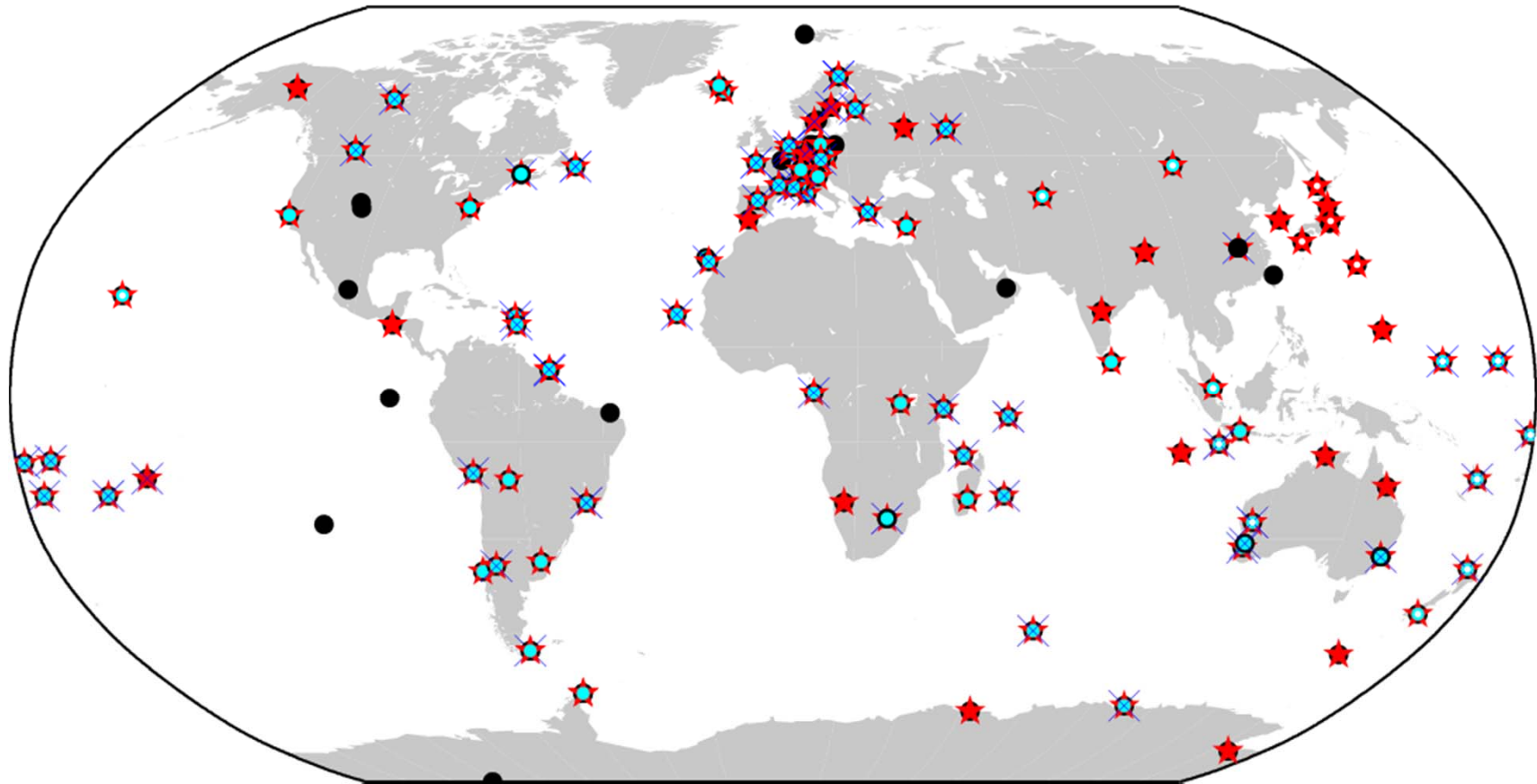
MGEX data monitoring

Number of stations providing daily RINEX3 files included in CODE's raw data monitoring (data sources IGS-MGEX and EPN)



Tracking network

Station distribution for orbit solution (DOY 15/030)



● GPS ★ GLONASS ● Galileo X BeiDou ○ QZSS

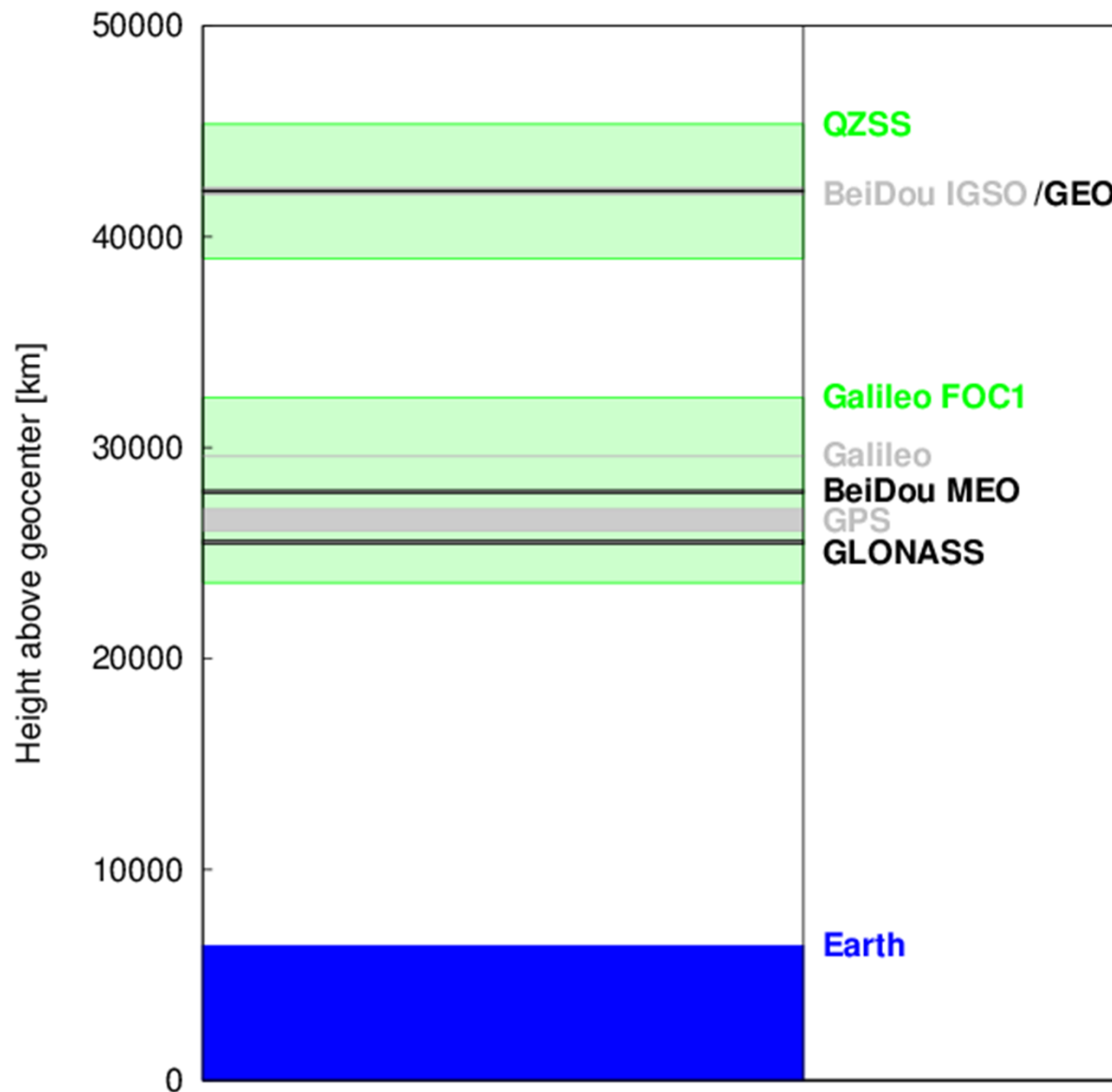
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CODE MGEX orbit solution

GNSS considered:	GPS + GLONASS + Galileo + BeiDou (MEO+IGSO) + QZSS (70 SV)
Processing mode:	post-processing / 2 weeks delay (since 2015)
Timespan covered:	GPS-weeks 1689 - today
Number of stations:	130 (GPS), 110 (GLONASS), 85 (Galileo); 55 (BeiDou); 20 (QZSS)
Processing scheme:	double-difference network processing (observable: phase double differences)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) GAL; B1 (L1) + B2 (L7) BeiDou
Orbit characteristic:	3-day long arcs; RPR: ECOM / ECOM2 (since 2015)
Reference frame:	IGS08 (until week 1708); IGb08 (since week 1709)
IERS conventions:	IERS2003 (until 1705); IERS2010 (since 1706)
Product list:	daily orbits (SP3) and ERPs
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

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Involved satellite systems



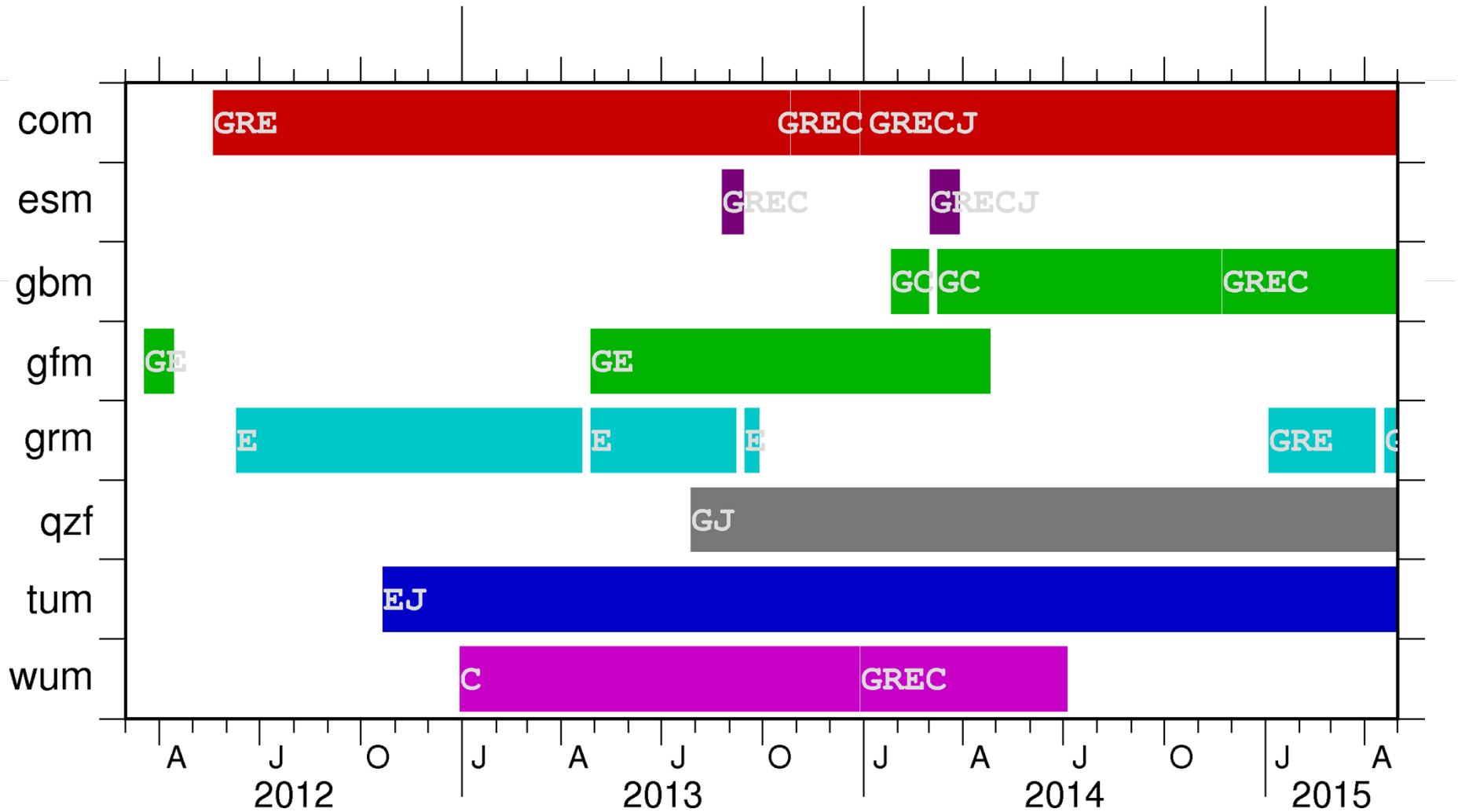
>70 GNSS and RNSS satellites with different orbit characteristics (orbit height, eccentricity, inclination), signals, tracking modes

CODE MGEX clock solution

GNSS considered:	GPS + GLONASS + Galileo + BeiDou + QZSS (70 SV)
Processing mode:	post-processing / 2 weeks delay (since 2015)
Timespan covered:	GPS-weeks 1710 - today
Number of stations:	130 (GPS), 35 (GLO), 45 (Galileo); 50 (BeiDou); 20 (QZSS)
Processing scheme:	zero-difference network processing (observable: code+phase undifferenced)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) GAL; B1 (L1) + B2 (L7) BeiDou
A priori information:	orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08
IERS conventions:	IERS2010
Product list:	epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily inter-system biases for mixed stations in Bernese DCB and BIAS-SINEX (BIA) format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

MGEX products availability

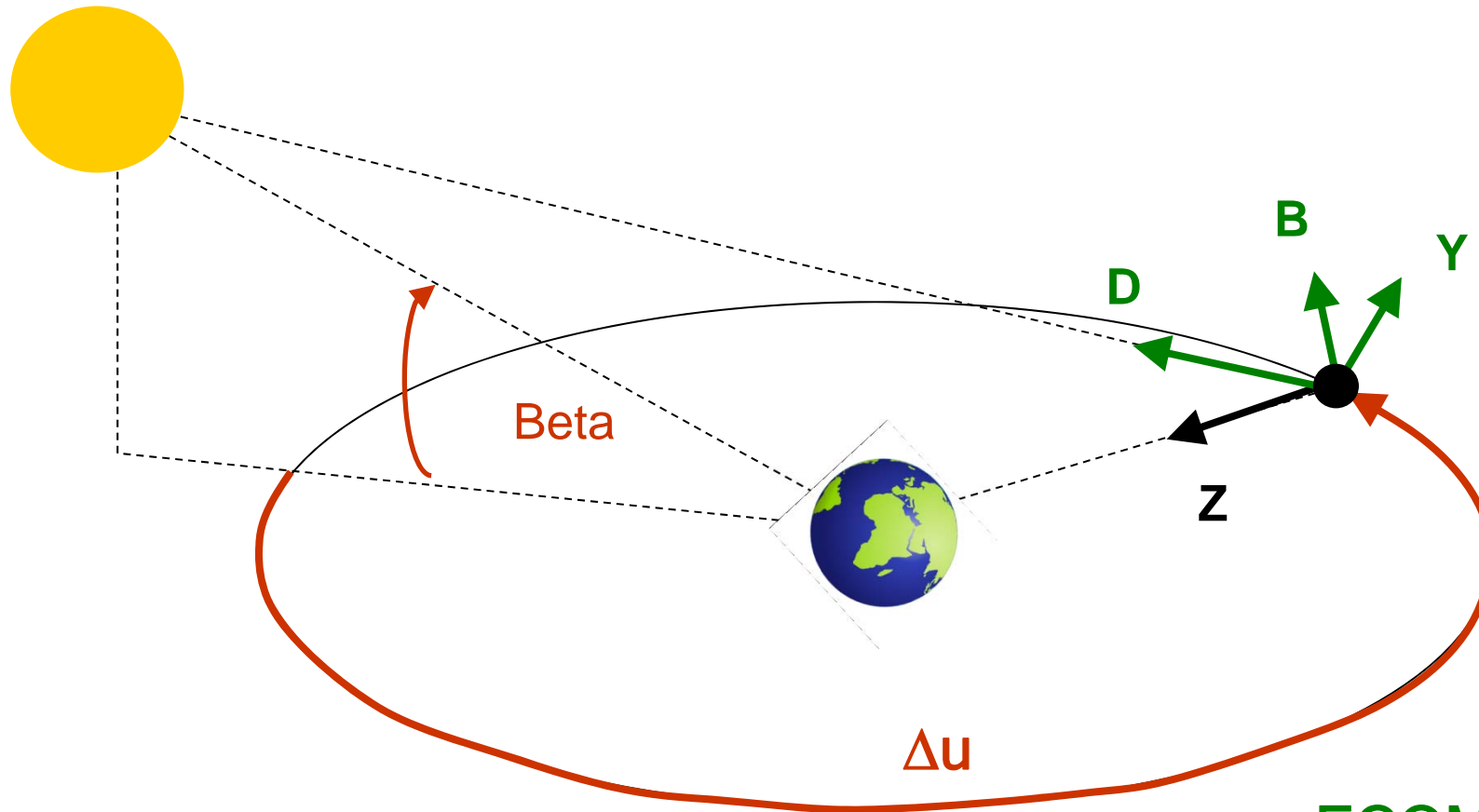
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Status: 01-May-2015

Satellite system IDs according to the content of the precise orbit files at <ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/>

Orbit description and Yaw attitude



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Angles and directions:

Beta: Elevation of Sun above orbital plane

Δu : Argument of latitude

Z: Direction satellite \rightarrow Earth (antenna direction)

ECOM axes:

D: Direction satellite \rightarrow Sun

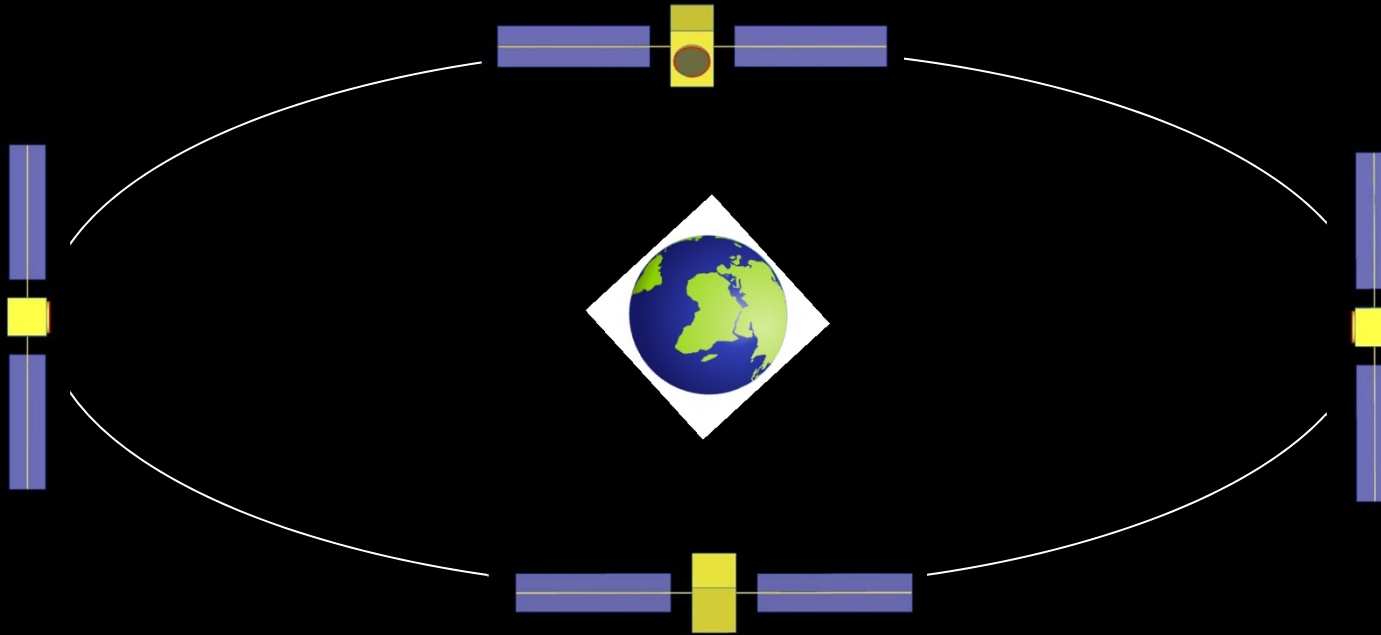
Y: Solar panel axis

B: Third ECOM axis

Solar radiation pressure

Satellite cross-section as seen from the Sun (Beta $\approx 30^\circ$) during one orbital revolution:

=> solar panel area does not change



=> but: cross-section of long satellite bodies w.r.t. the Sun varies

New Empirical CODE radiation pressure Model

- MGEX-reprocessing for 2014 using ECOM (5 RPR par.; Springer et al., 1999) vs. ECOM2 (9 RPR par., Arnold et al., 2015)
 - Validation with SLR residuals and satellite clock corrections
 - The new ECOM takes into account the periodically changing cross section of the satellite body wrt. the Sun
- => Improvements expected for Galileo, GLONASS, QZSS

ECOM1 (old):

$$D(u) = D_0$$

$$Y(u) = Y_0$$

$$B(u) = B_0 + B_C \cos(u) + B_S \sin(u)$$

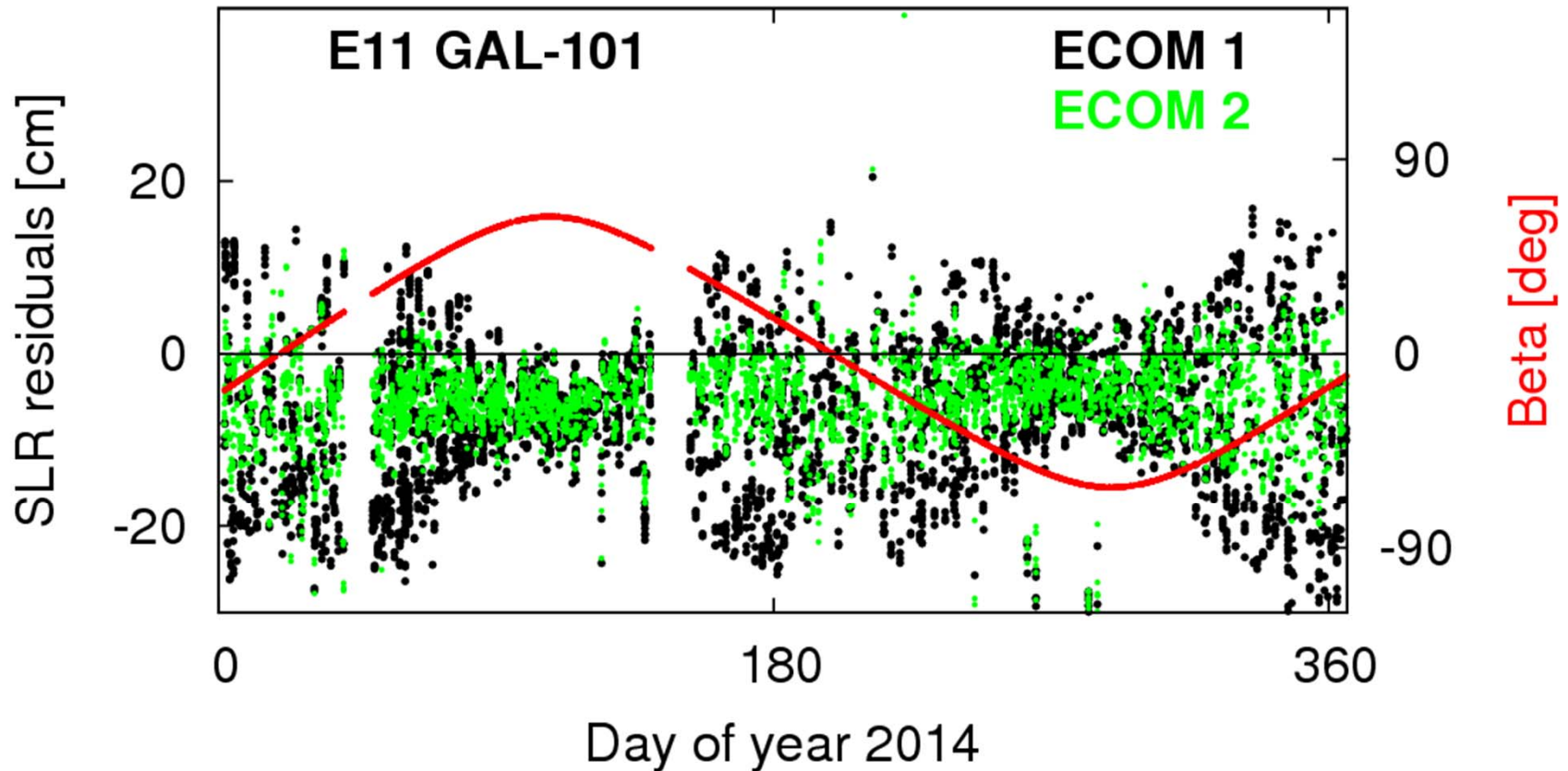
ECOM2 (new):

$$D(u) = D_0 + D_{2C} \cos(2\Delta u) + D_{2S} \sin(2\Delta u) \\ + D_{4C} \cos(4\Delta u) + D_{4S} \sin(4\Delta u)$$

$$Y(u) = Y_0$$

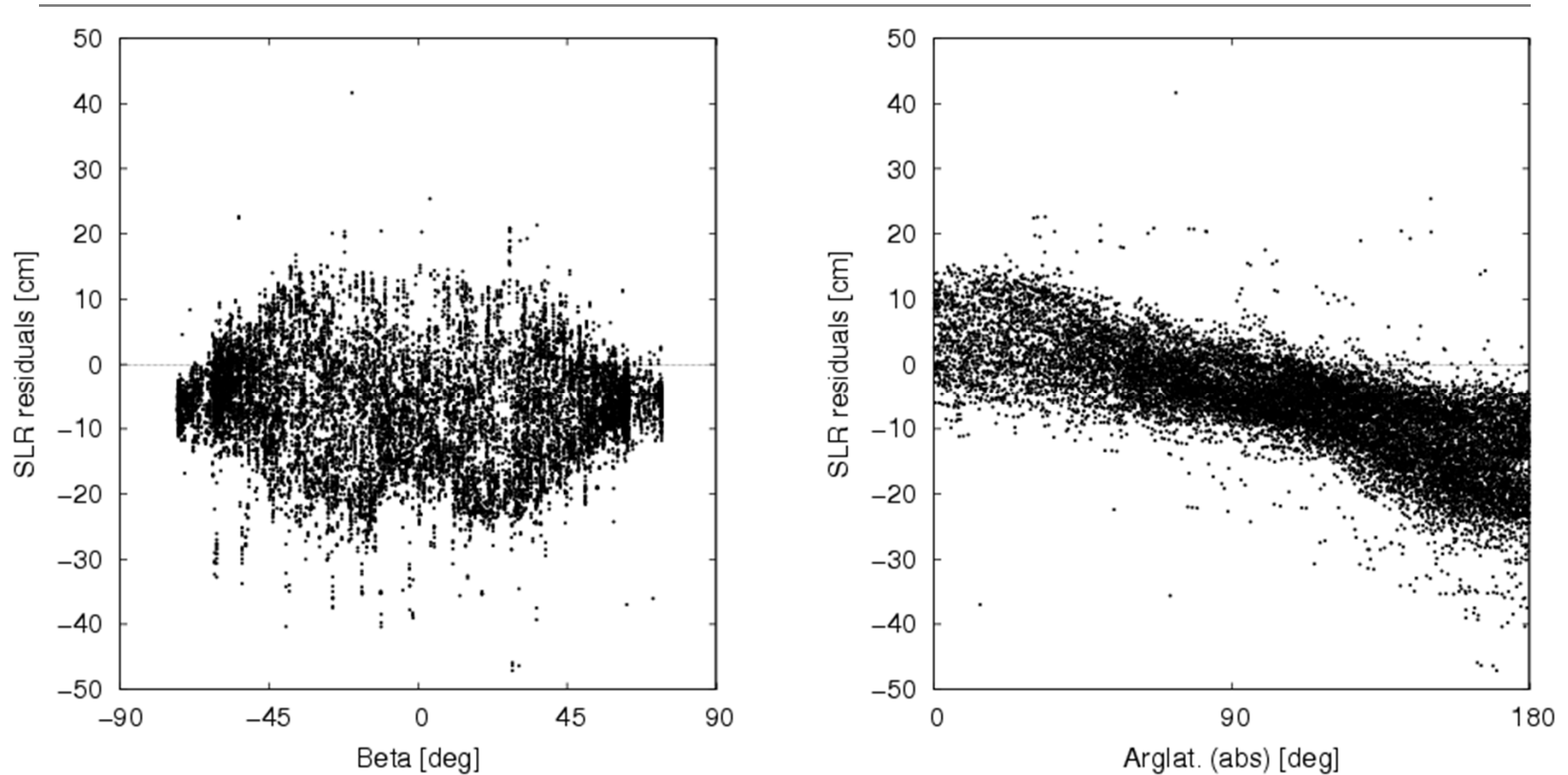
$$B(u) = B_0 + B_C \cos(\Delta u) + B_S \sin(\Delta u)$$

Impact of new ECOM on Galileo orbits



⇒ Significant reduction of size and dependency of SLR residuals on the Beta-angle (elevation of the Sun above the orbital plane)

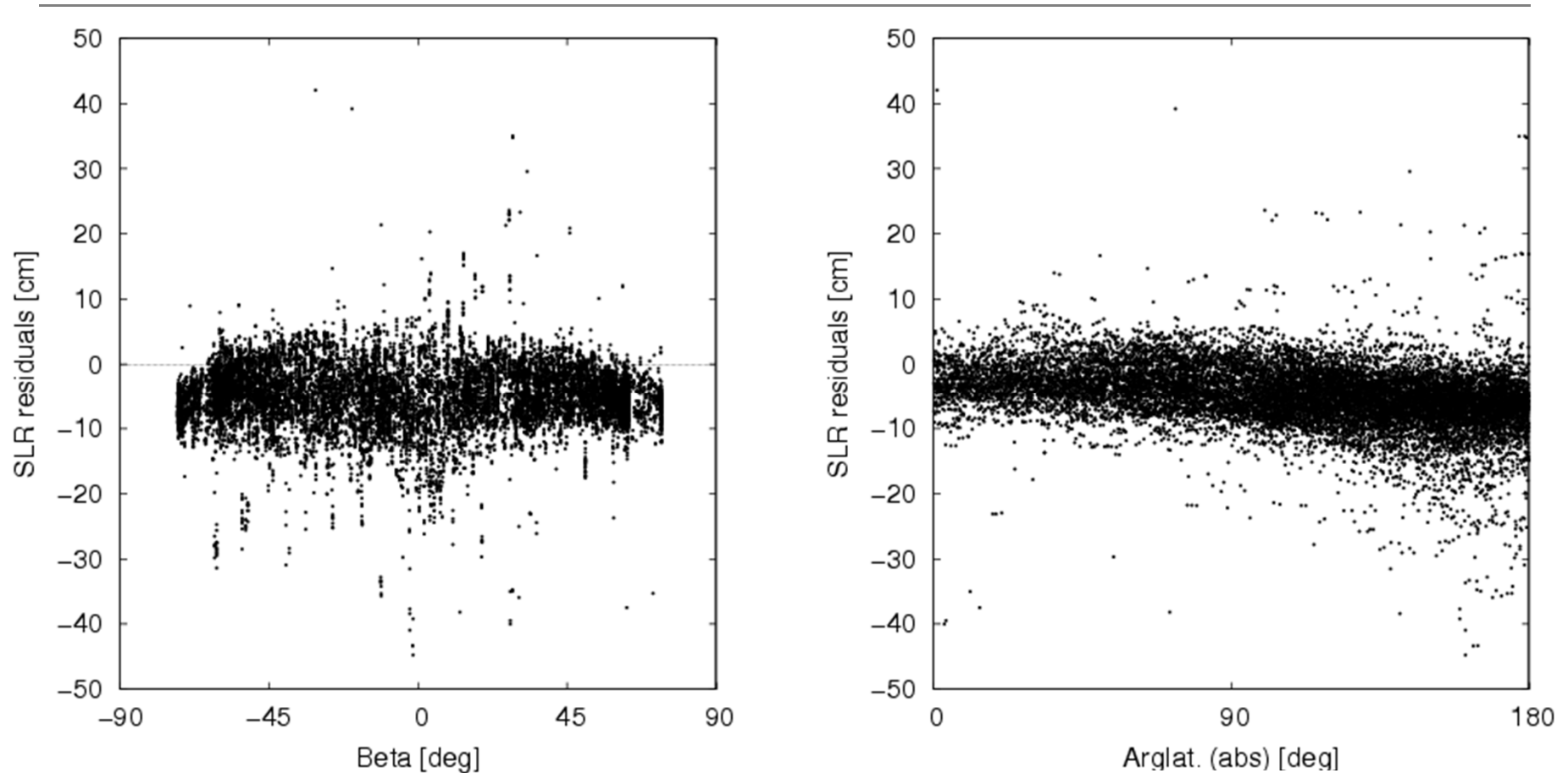
Impact of new ECOM on Galileo orbits



ECOM1 (all Galileo satellites):

=> Large SLR residuals for low and medium Beta angles and for argument of latitude around 0 and +-180 degrees

Impact of new ECOM on Galileo orbits

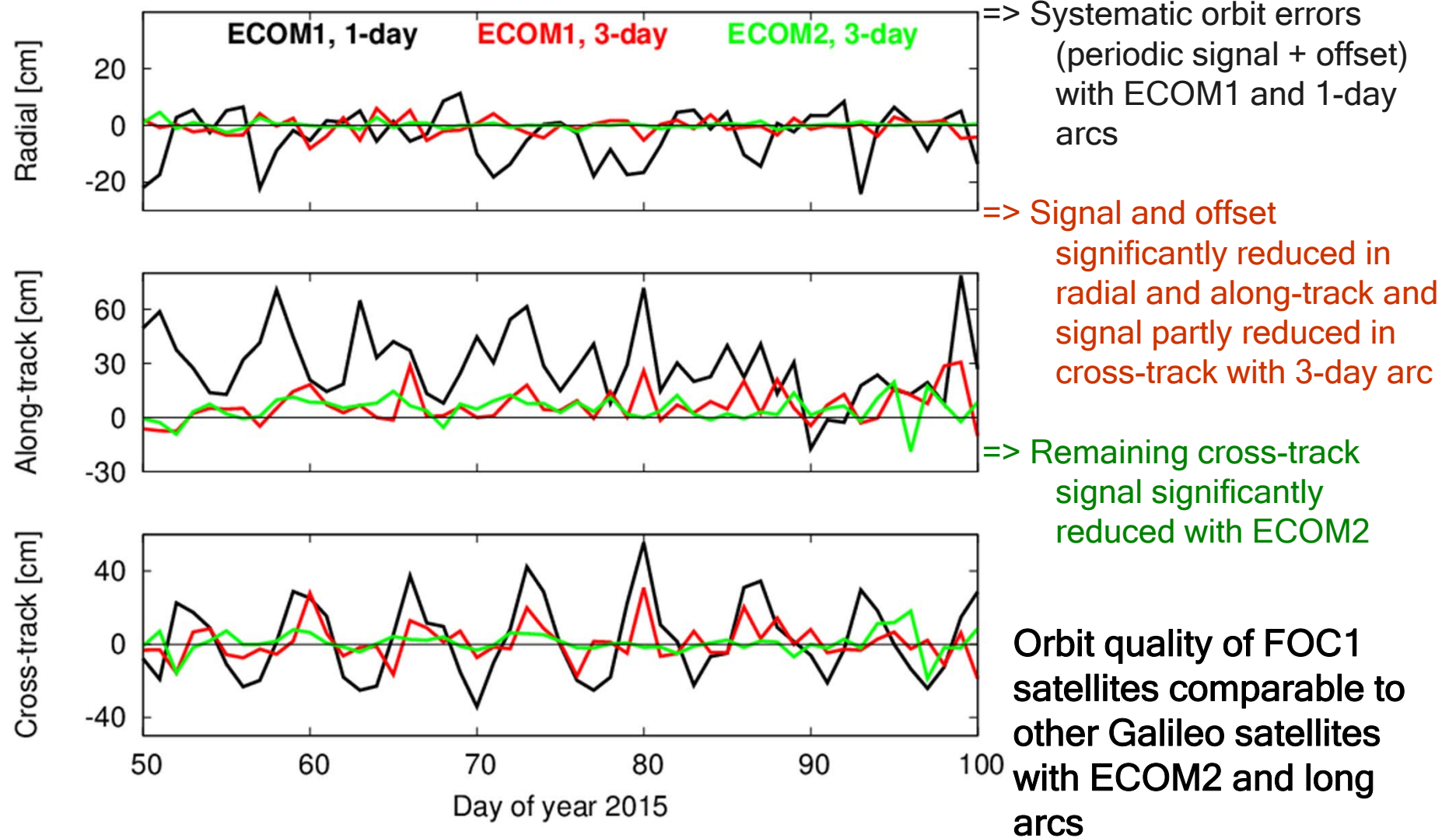


ECOM2 (all Galileo satellites):

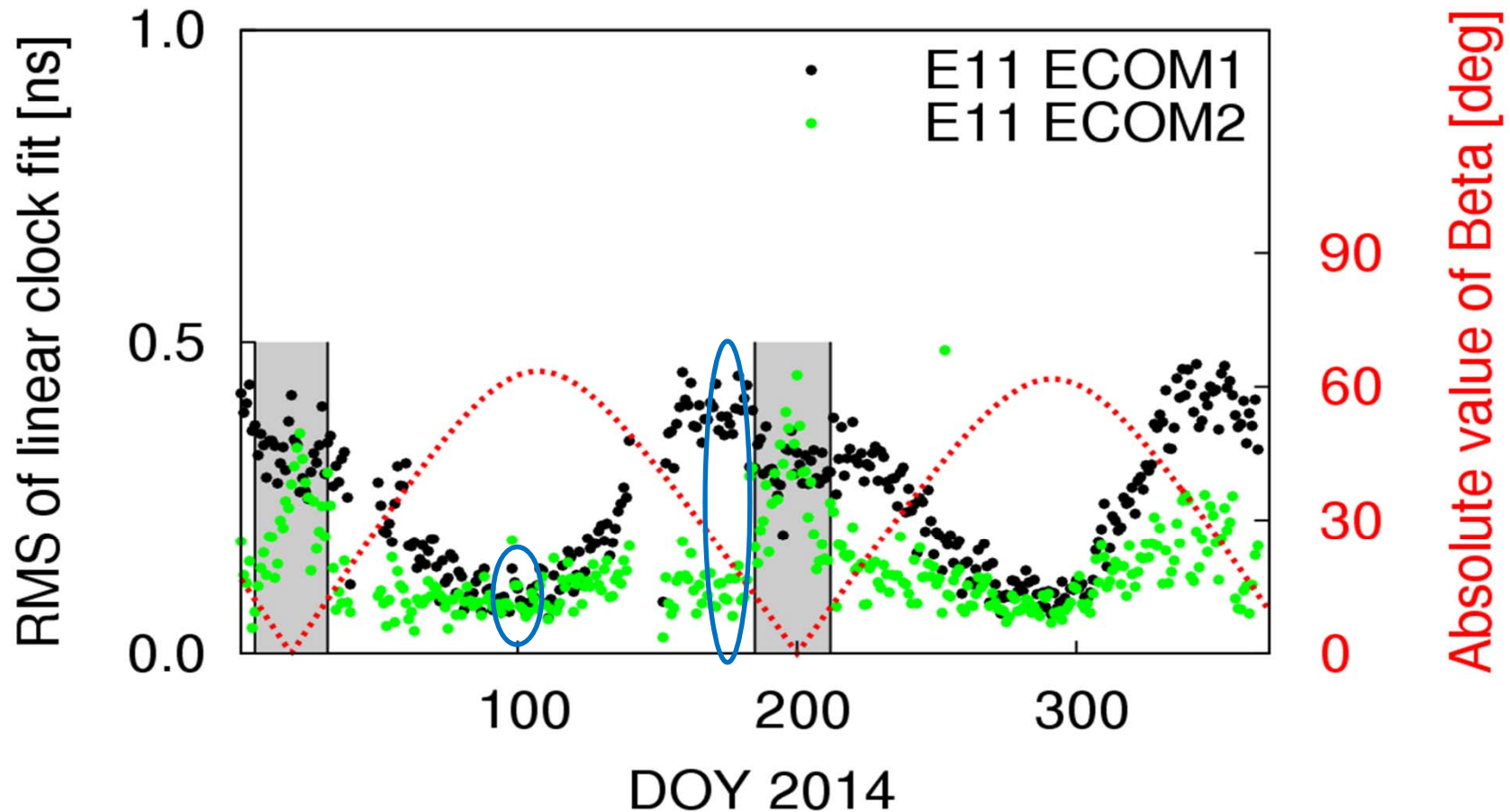
- => Systematics in the SLR residuals are significantly reduced
- => SLR offset of about 5 cm (less for FOC) remains

Orbits of Galileo FOC1 satellites

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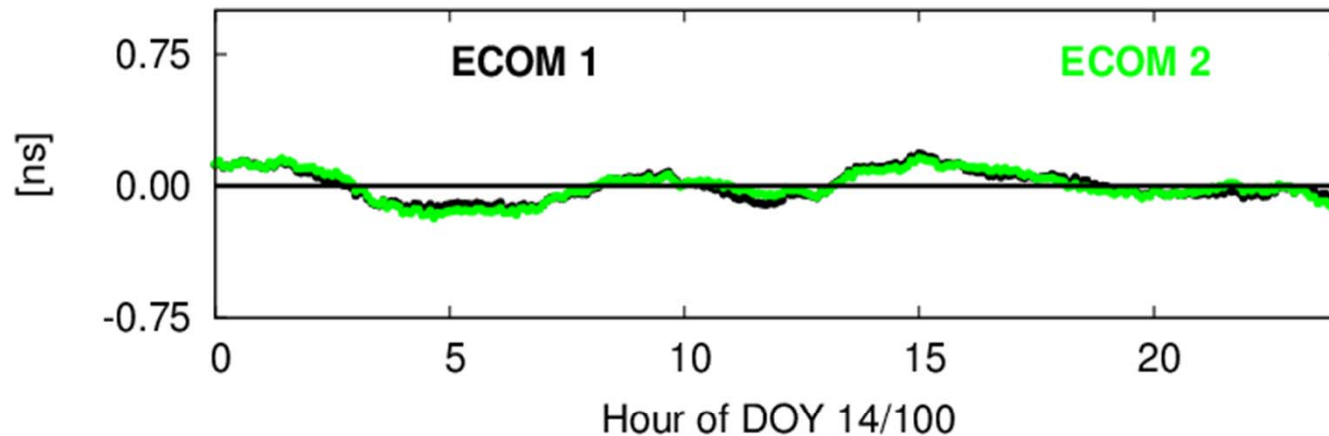
Impact of new ECOM on Galileo clock corrections



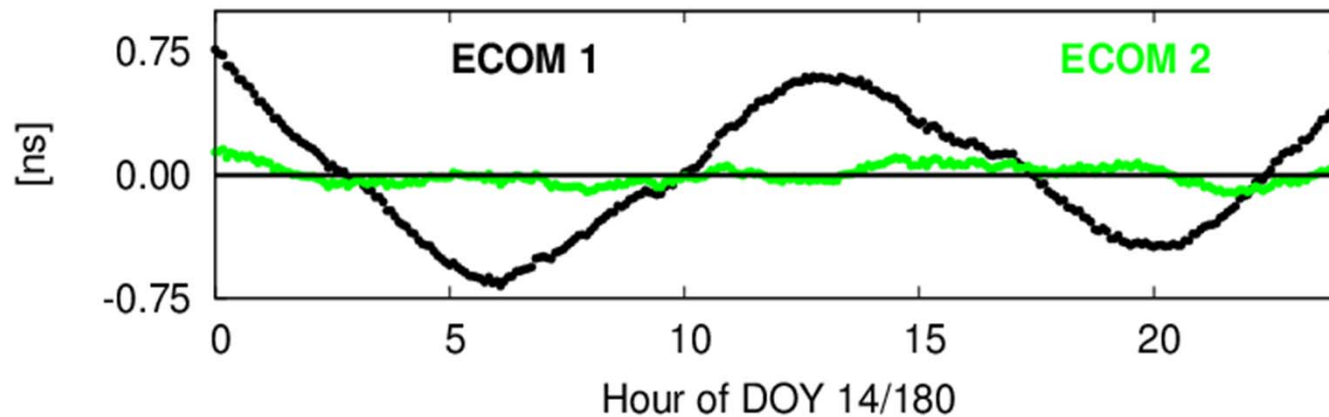
- => Significant reduction of Beta angle dependency
- => Pronounced signal remains during eclipse season or close-by (=> impact of mis-modelled attitude?)

Impact of new ECOM on Galileo clock corrections

Clock corrections of Galileo PRN E11, SVN E101

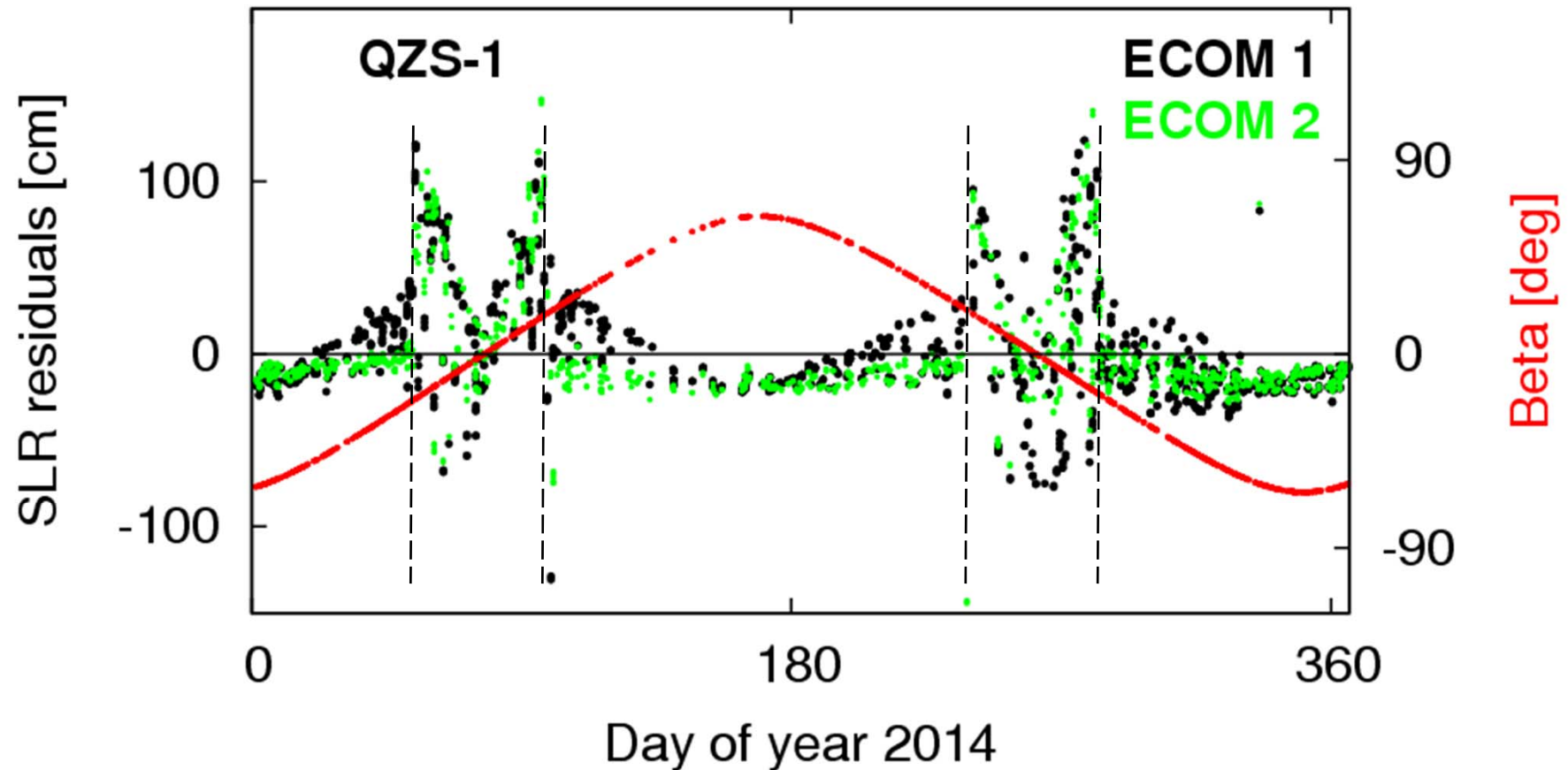


Large beta-angle:
=> Small clock signal
(about ± 0.15 ns)



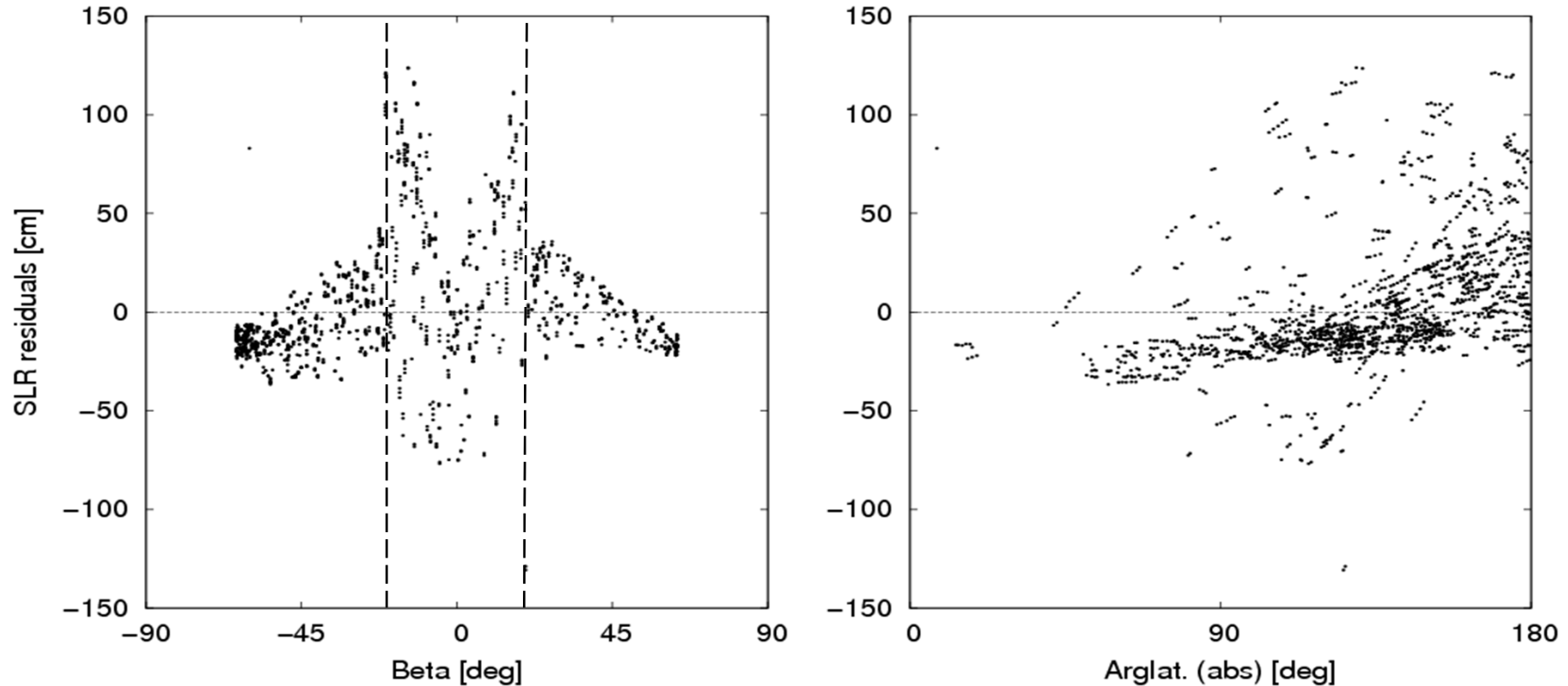
Low beta-angle:
=> Periodic signal caused
by mis-modelled orbit
=> significantly reduction
(± 0.75 ns \rightarrow ± 0.15
ns)

Impact of new ECOM on QZSS orbits



- ⇒ Improvement (dependency on Beta angle is reduced)
- ⇒ Unconsidered normal attitude mode dominates orbit errors at low Beta angles (< 20 degrees)

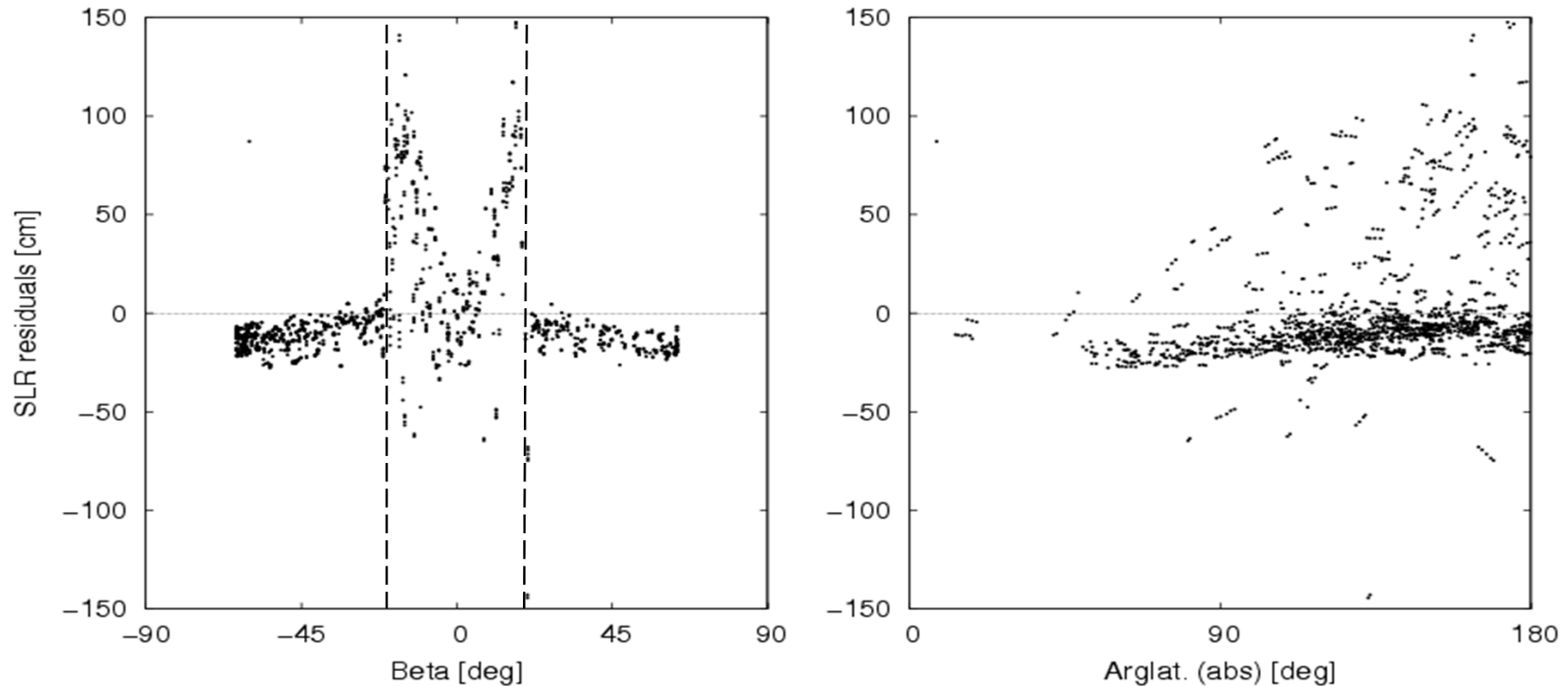
Impact of new ECOM on QZSS orbits



ECOM1:

- => $\text{abs}(\text{Beta}) < 20$ degrees: SLR residuals dominated by unconsidered orbit normal attitude mode
- => $\text{abs}(\text{Beta}) > 20$ degrees: correlation with Beta angle and argument of latitude

Impact of new ECOM on QZSS orbits

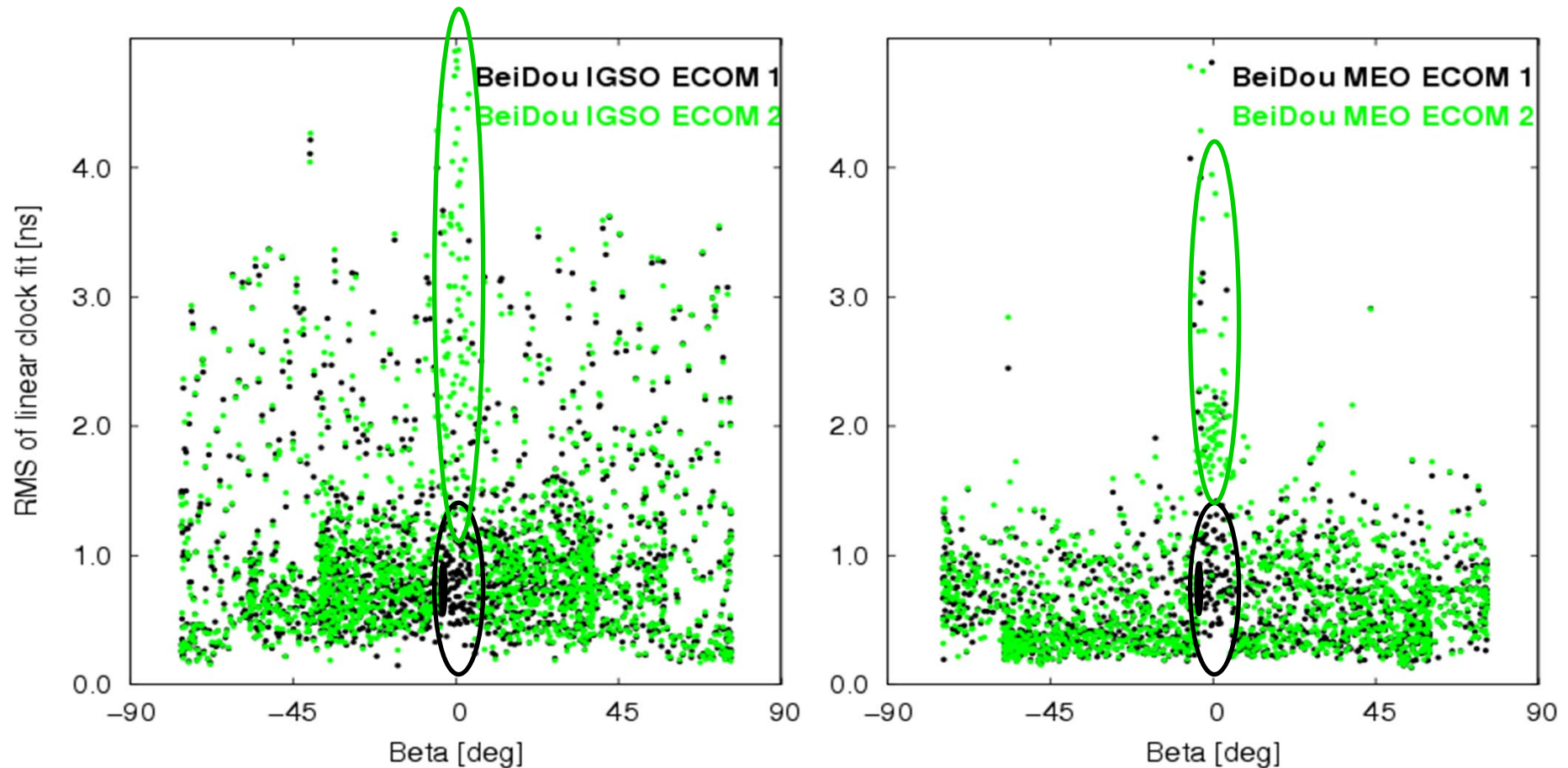


ECOM2:

- => $\text{abs}(\text{Beta}) < 20$ degrees: no big change
- => $\text{abs}(\text{Beta}) > 20$ degrees: systematics in the SLR residuals are reduced

— => SLR offset remains

Impact of new ECOM on BeiDou clock corrections

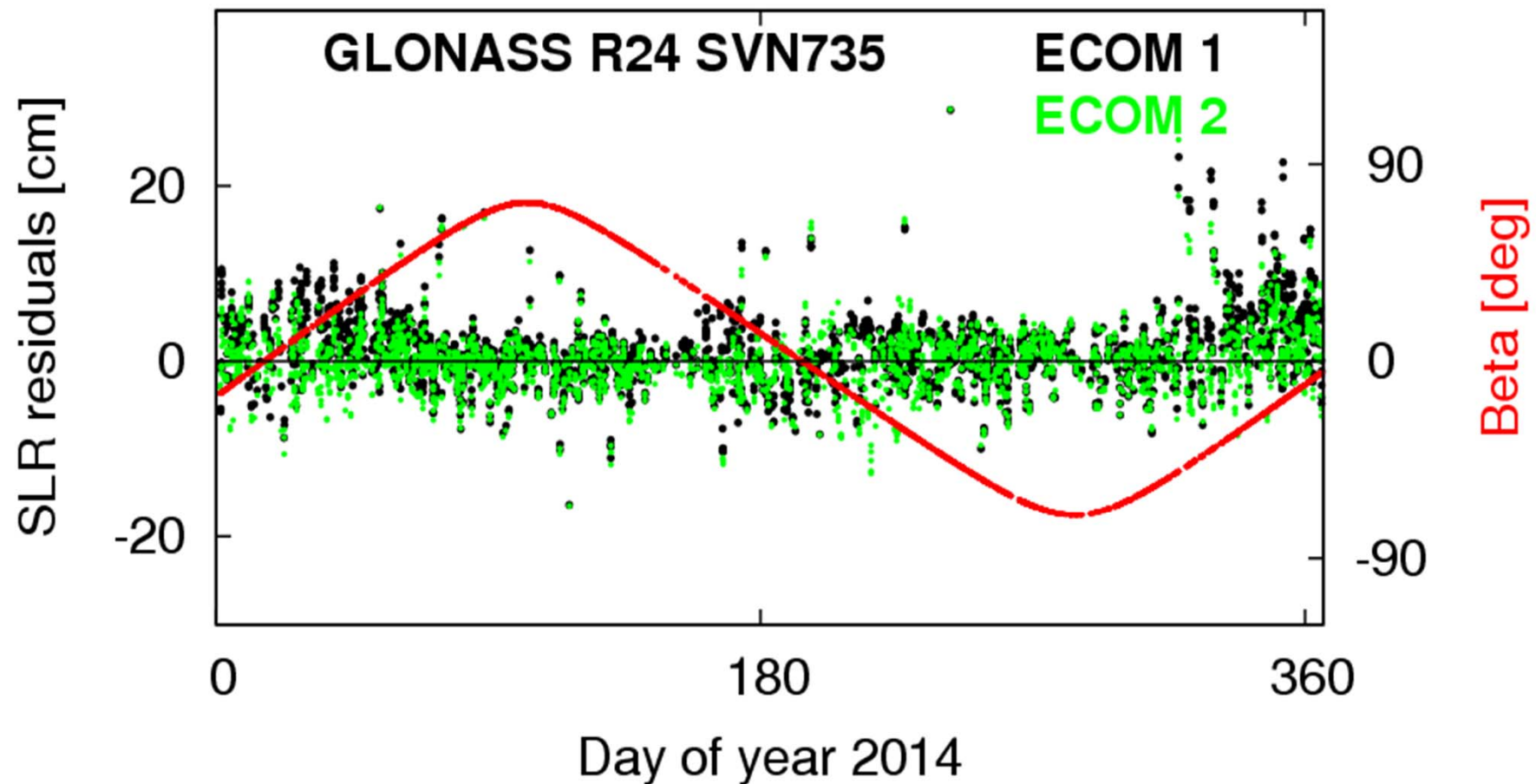


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=> No significant impact of new ECOM on BeiDou satellite clock corrections, but

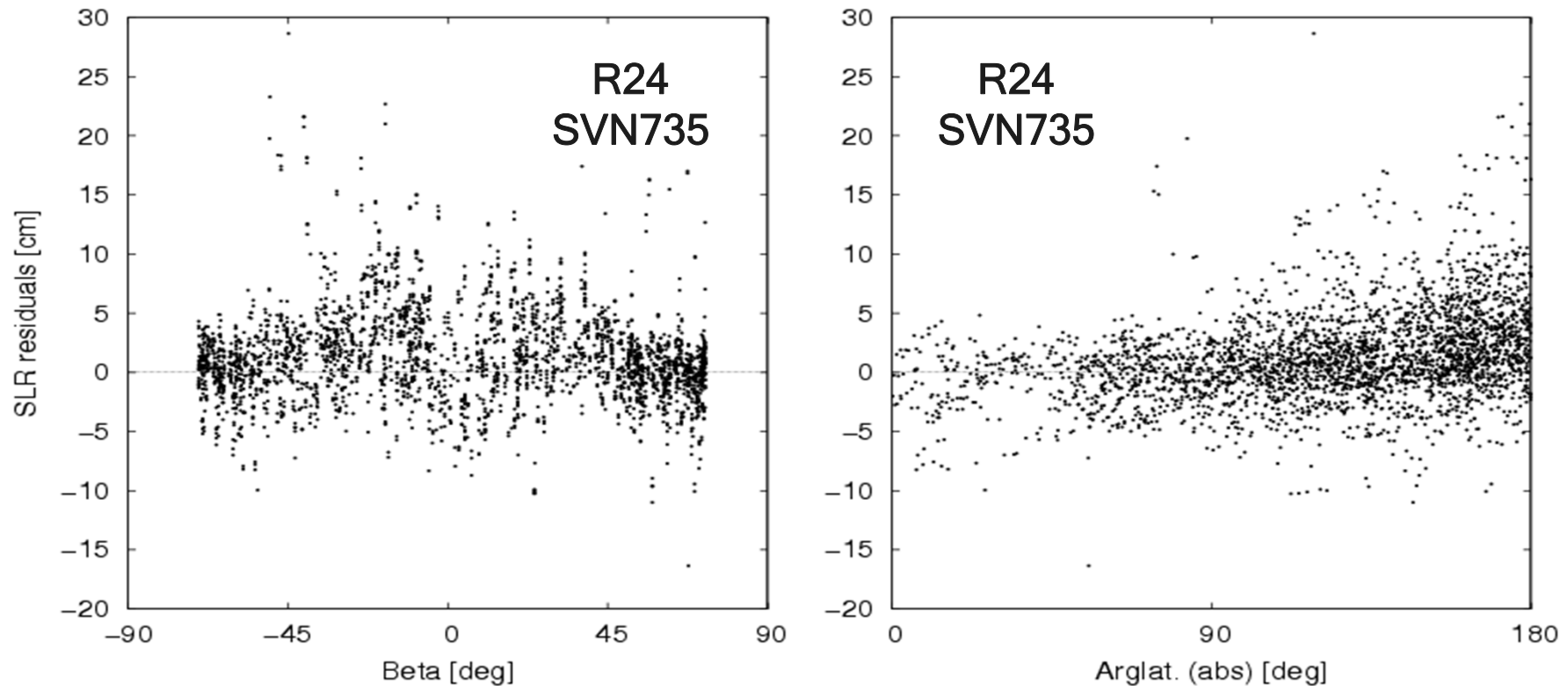
— => Increased RMS of clock fit for very small Beta angles (confirming changed attitude mode at $\text{abs}(\text{Beta}) < 4$ degrees)

Impact of new ECOM on GLONASS orbits



⇒ Moderate reduction of SLR residuals at low Beta angles for majority of satellites

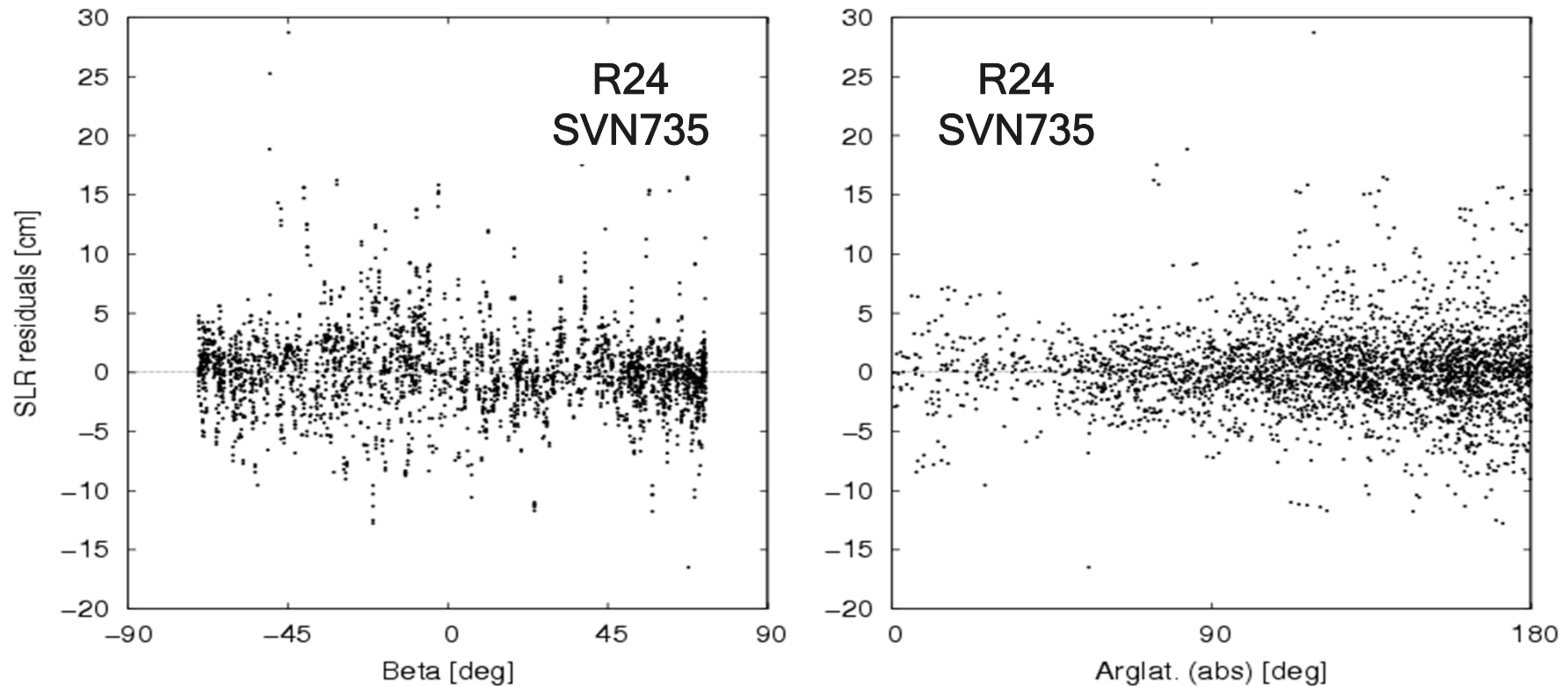
Impact of new ECOM on GLONASS orbits



ECOM1:

=> Moderate correlation of SLR residuals with Beta angle and argument of latitude

Impact of new ECOM on GLONASS orbits

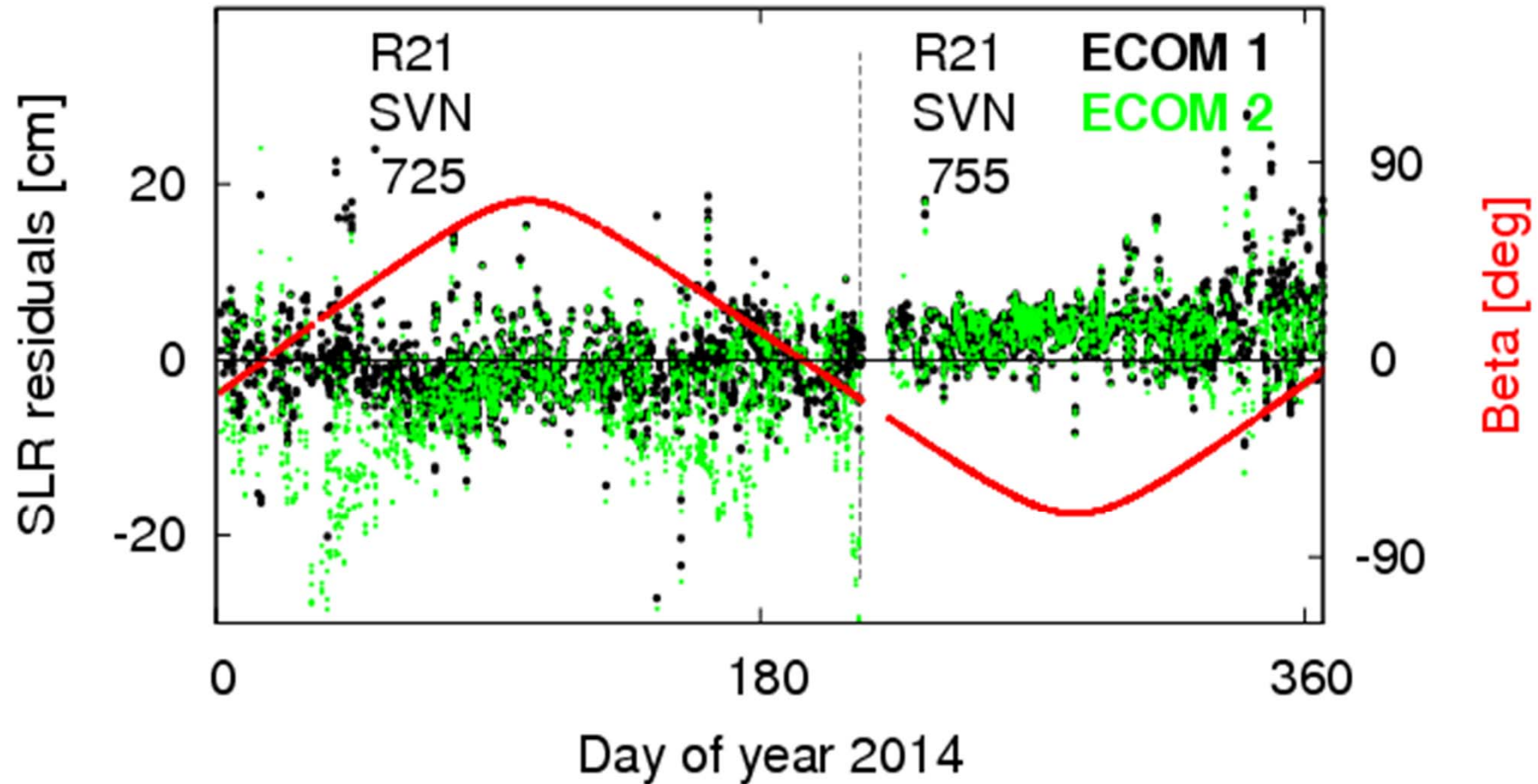


ECOM2:

=> Systematics in the SLR residuals are reduced

Impact of new ECOM on GLONASS - exceptions

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⇒ ECOM2 does not work well for all GLONASS satellites

Orbit modeling: Summary

- Galileo: clear benefit from ECOM2
- QZSS: significant benefit from ECOM2 when in yaw attitude mode
- GLONASS: moderate benefit from ECOM2 for the majority of satellites; degradation for some satellites
- ECOM2 seems to be more sensitive to attitude mis-modellings
- Normal attitude steering mode at low beta-angles causes very large orbit errors if not correctly considered
- Stable satellite clocks (GPS IIF, Galileo, QZSS) are suited for orbit validation

Thank you
for
your interest!