Orbit modelling in CODE's MGEX solution

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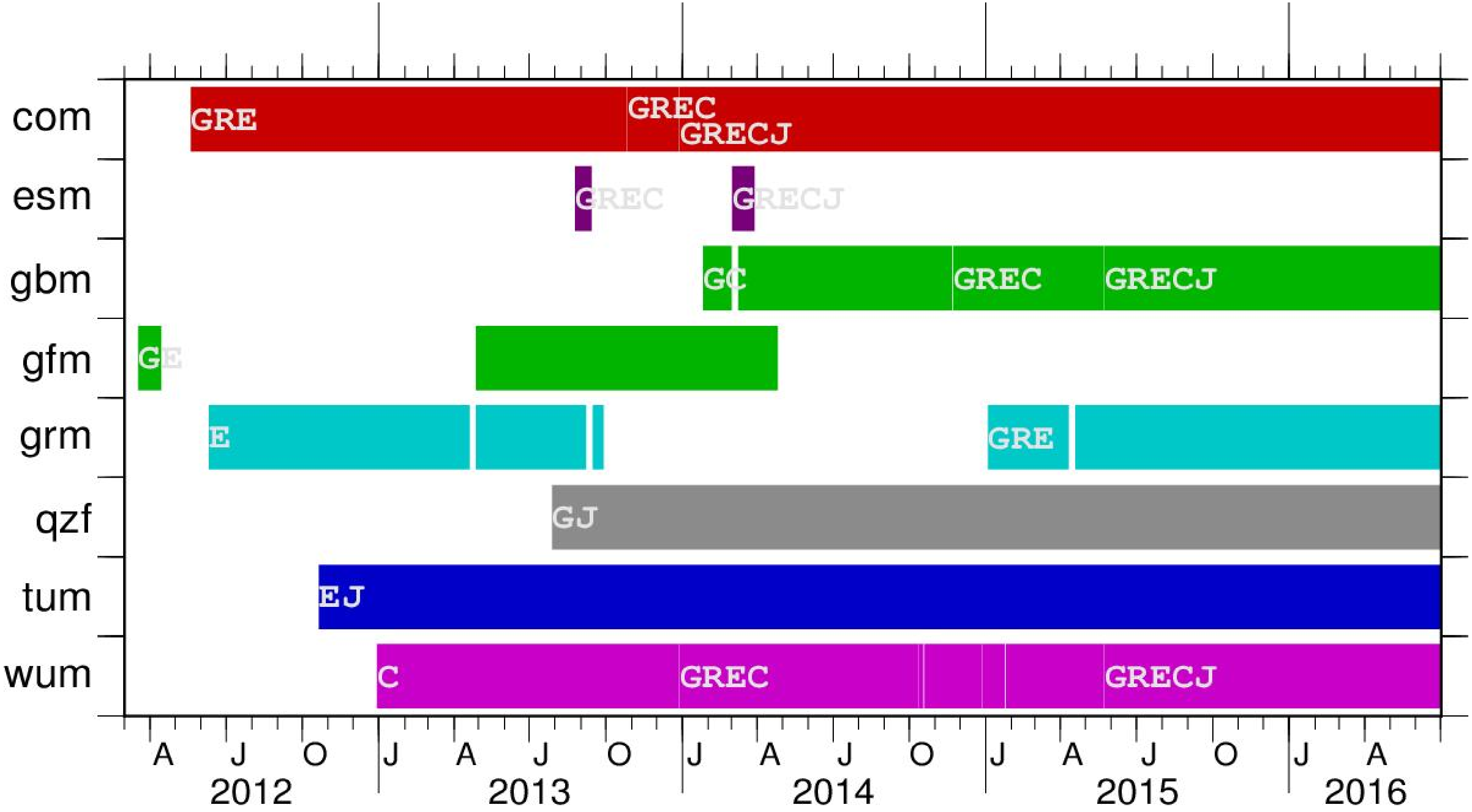
Contents

- Data base and network
- CODE MGEX orbit solution
- CODE MGEX clock solution
- Model changes and implementations
- Validation of satellite orbits and clock corrections
- Summary and outlook

MGEX products availability

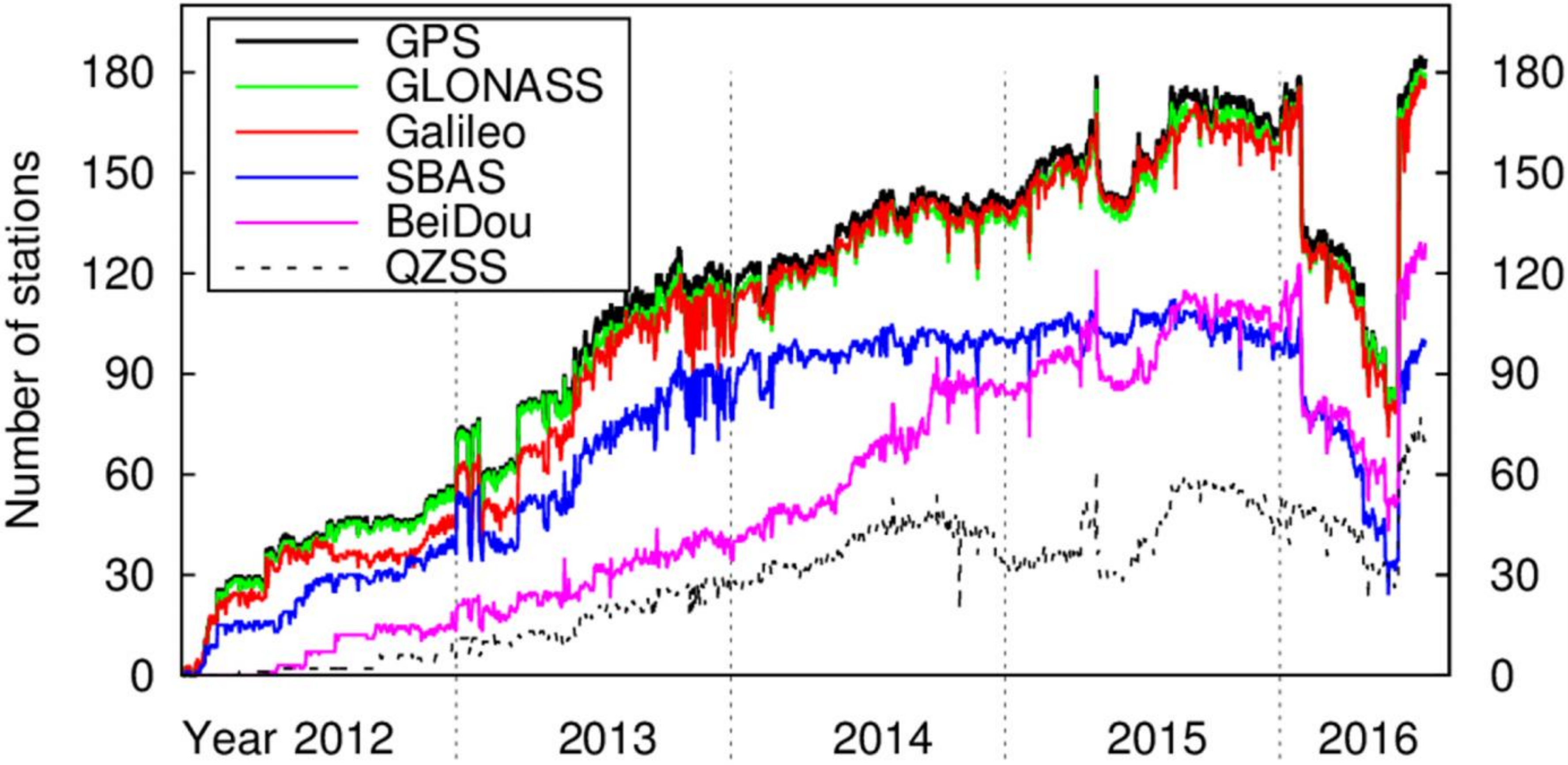


Status: July 2016

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

MGEX data monitoring

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



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ICG+2016, Shanghai, China, 27–30 July 2016

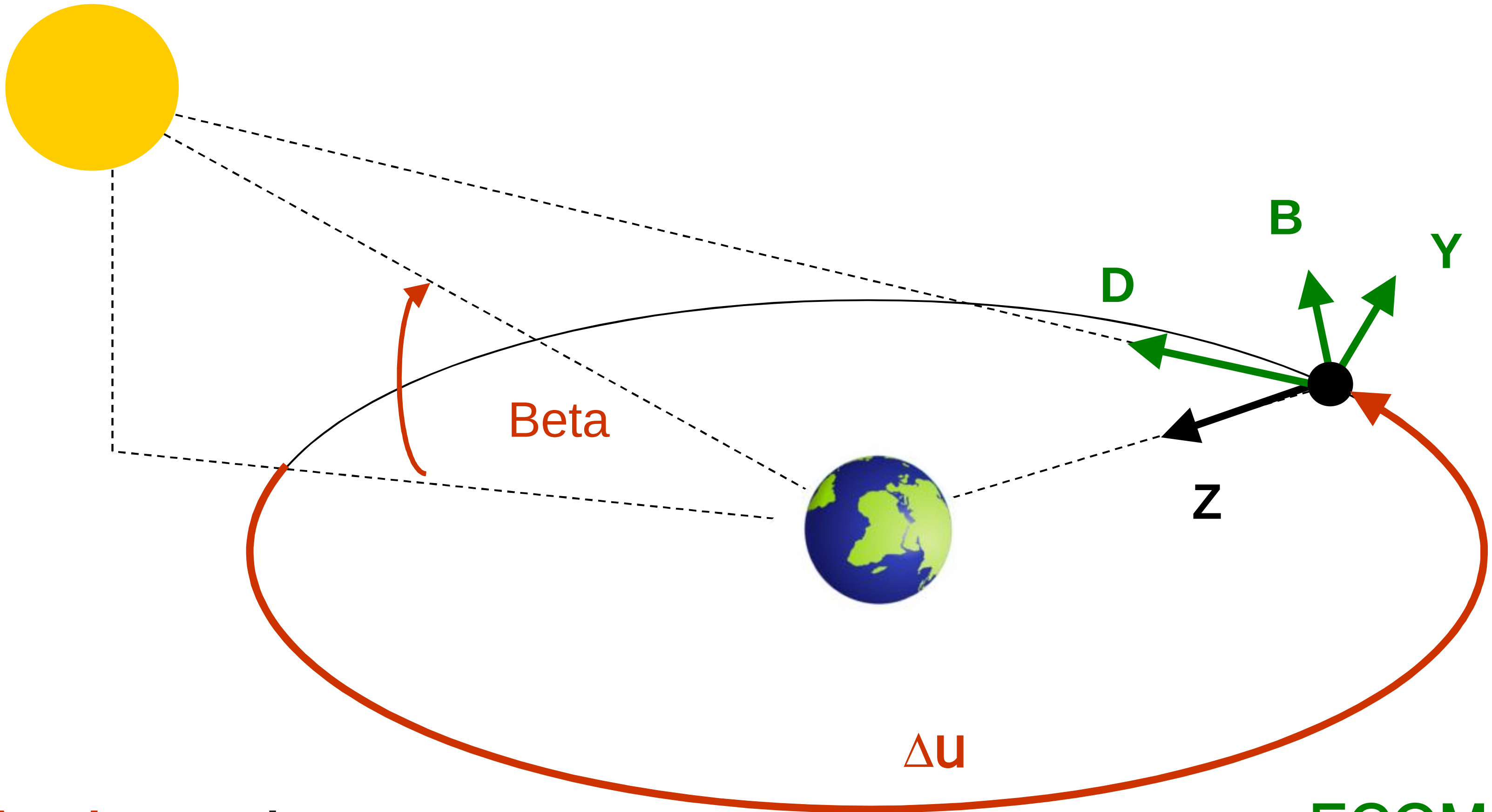
CODE MGEX orbit solution

GNSS considered:	**GPS + GLONASS + Galileo + BeiDou** (MEO+IGSO) + **QZSS** (≈70 SV)
Processing mode:	Post-processing (≈2 weeks latency)
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) Galileo; B1 (L1) + B2 (L7) BeiDou
Orbit characteristic:	3-day long arcs; SRP: 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/ and **ftp://ftp.unibe.ch/aiub/CODE_MGEX/**
Designator:	comwwwwd.???.Z

CODE MGEX clock solution

GNSS considered:	**GPS + GLONASS + Galileo + BeiDou + QZSS** (≈70 SV)
Processing mode:	Post-processing (≈2 weeks latency)
Timespan covered:	GPS-weeks 1710 - today
Number of stations:	130 (GPS), 45 (GLO), 45 (Galileo); 50 (BeiDou); 20 (QZSS)
Processing scheme:	**Zero-difference** processing (observable: code+phase undifferenced)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) Galileo; 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 format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/ and ftp://ftp.unibe.ch/aiub/CODE_MGEX/

Orbit description and Yaw attitude



Angles and vectors:

Beta: Elevation of Sun above orbital plane

Δu: Argument of latitude

Z: Direction satellite -> Earth (antenna direction)

ECOM axes:

D: Direction satellite -> Sun

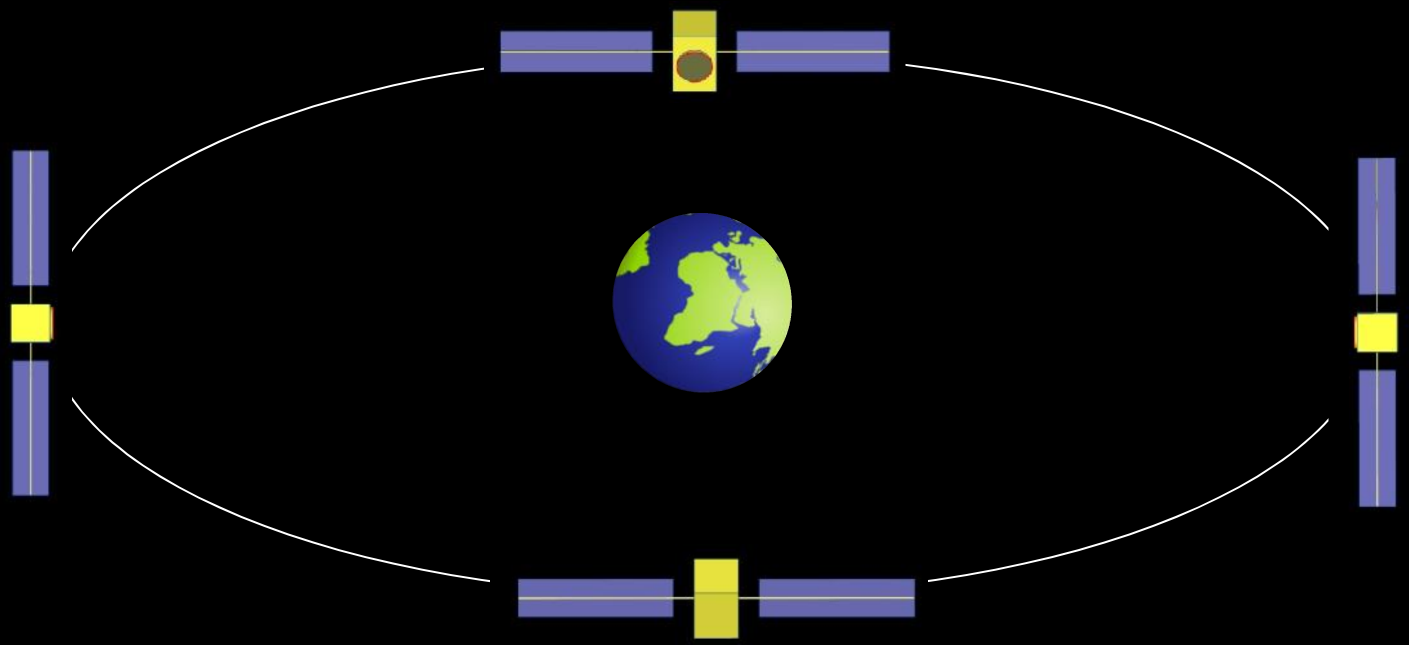
Y: Solar panel axis

B: Third ECOM axis

Solar radiation pressure

Satellite cross-section as seen from the Sun (Beta ù 30°) 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.; Beutler et al., 1994, 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 elongated satellite bodies 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):

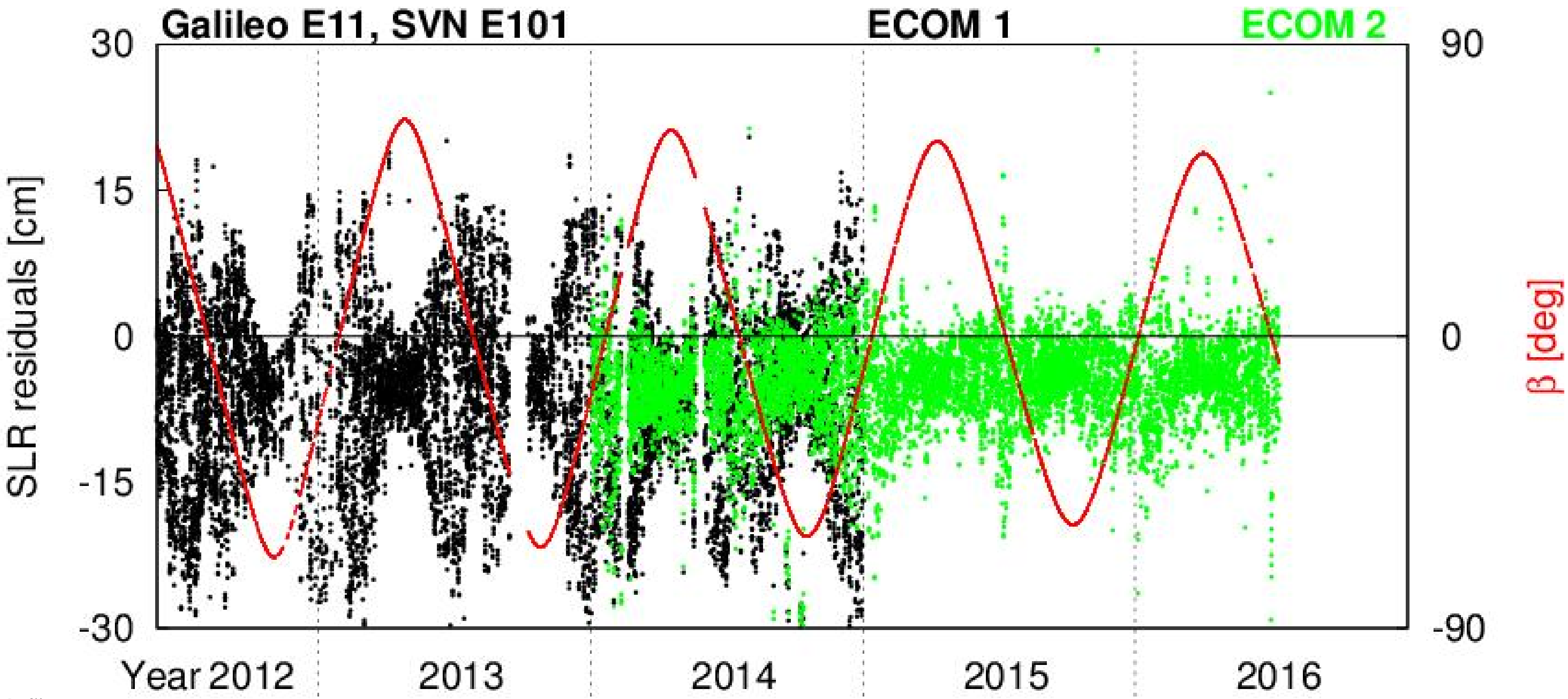
$D(u) = D_0 + D_{2C} \cos(2\Delta u) + D_{2S} \sin(2\Delta u)$

$+ D_{4C} \cos(4\Delta u) + D_{4S} \sin(4\Delta u)$

$Y(u) = Y_0$

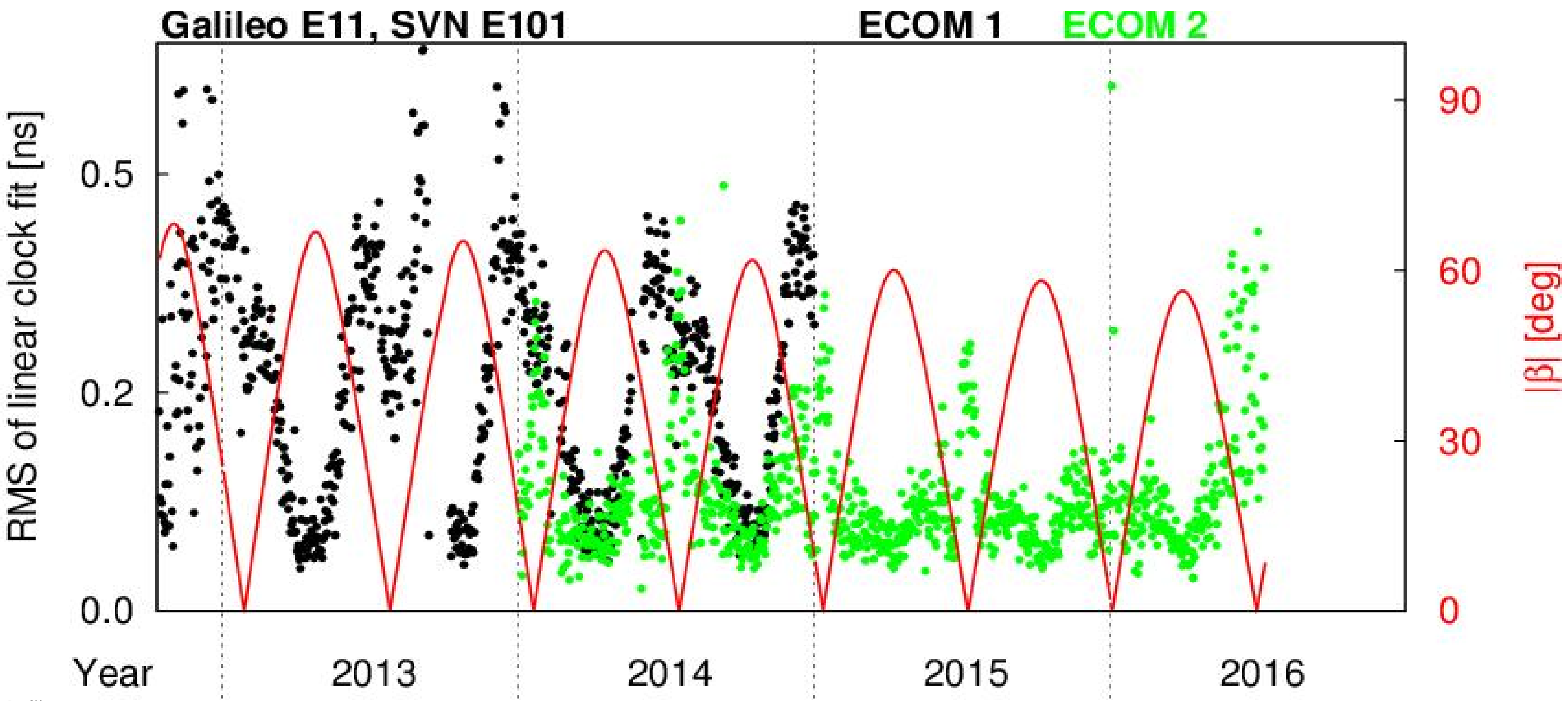
$B(u) = B_0 + B_C \cos(\Delta u) + B_S \sin(\Delta u)$

Galileo orbit validation



⇒ Significant reduction of dependency on beta-angle, when changing to the ECOM2

Galileo clock validation



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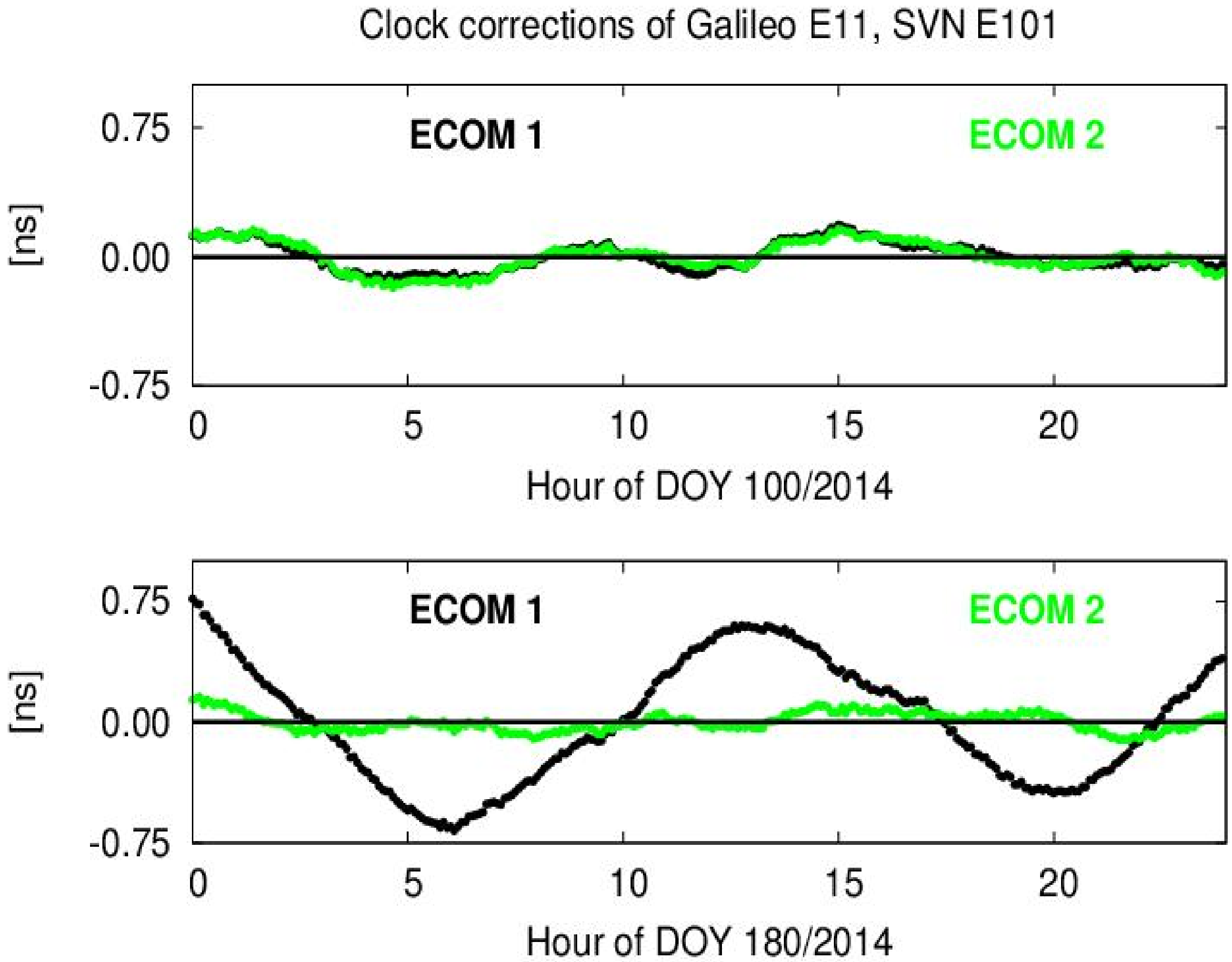
⇒ Significant reduction of dependency on beta angle

⇒ Pronounced signal remains during eclipse season or close-by

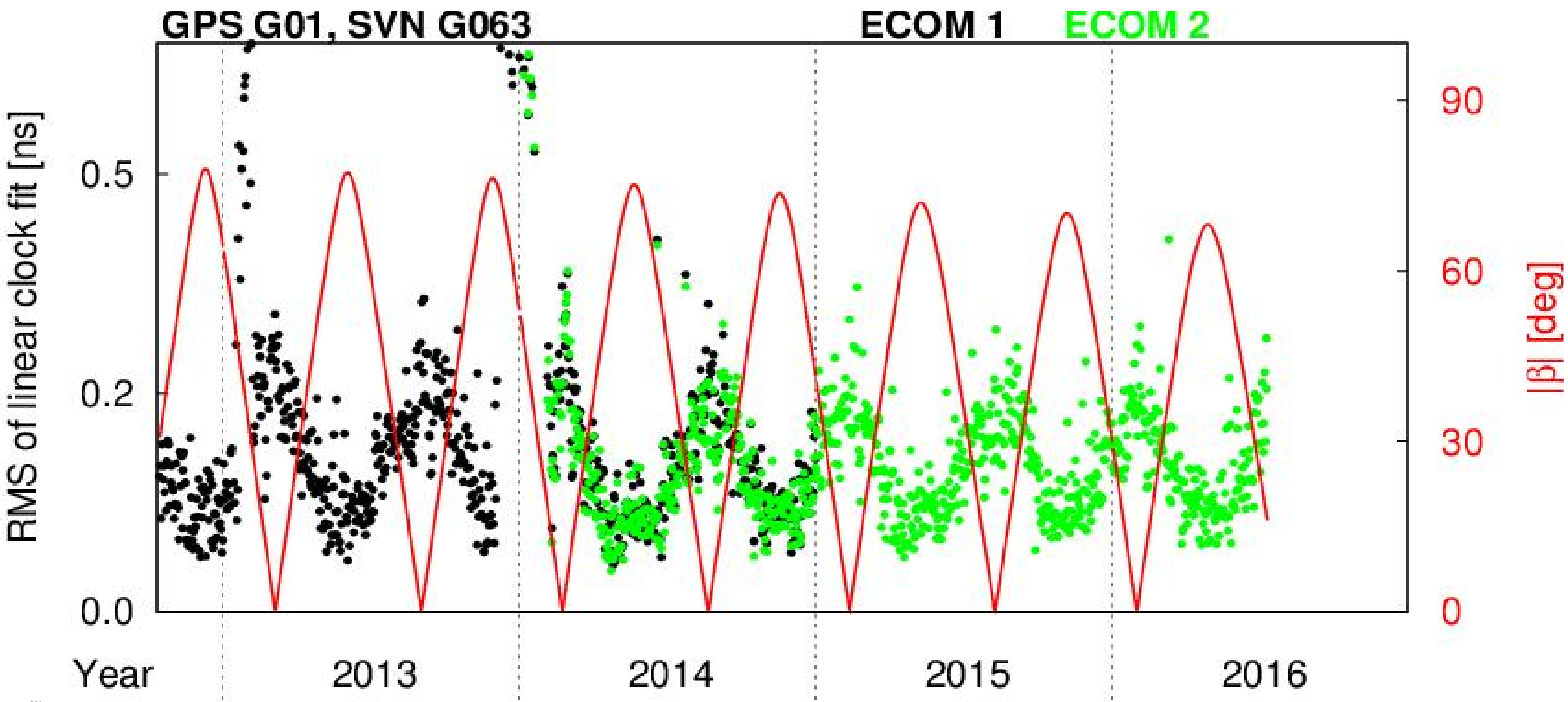
Galileo clock validation



Large beta-angle:
=> Clock signal has small amplitude (about ±0.15 ns)

Small beta-angle:
=> Periodic signal caused by mis-modelled orbit (**ECOM1**)
=> Significant reduction of signal amplitude from ±0.75 ns to ±0.15 ns when switching to ECOM2

GPS clock validation

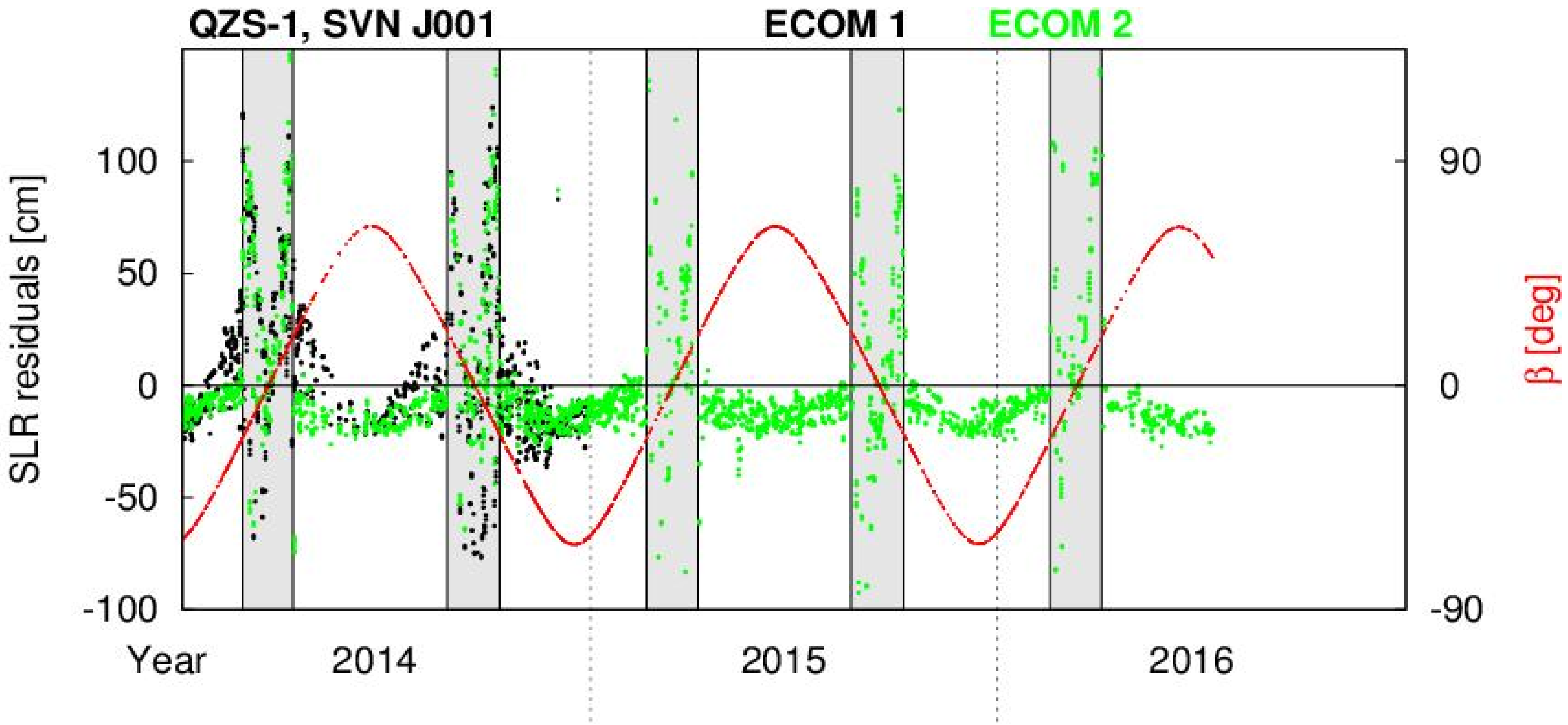


⇒ Moderate dependency on beta angle

⇒ No impact of new ECOM

⇒ Different possible reasons for signal (e.g., thermal issues)

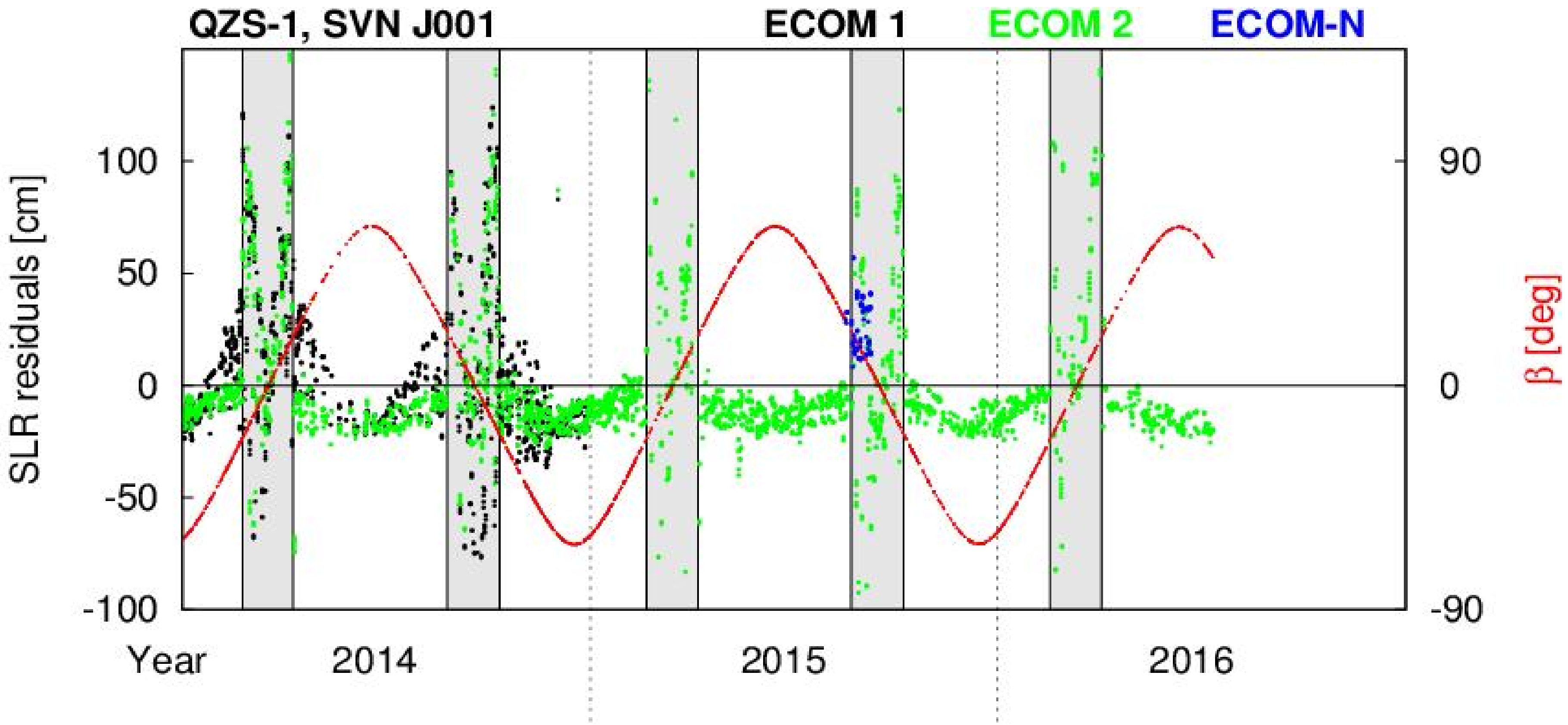
QZSS orbit validation



⇒ Yaw-steering: ECOM2 reduces dependency on beta angle

⇒ Significant SLR offset remains

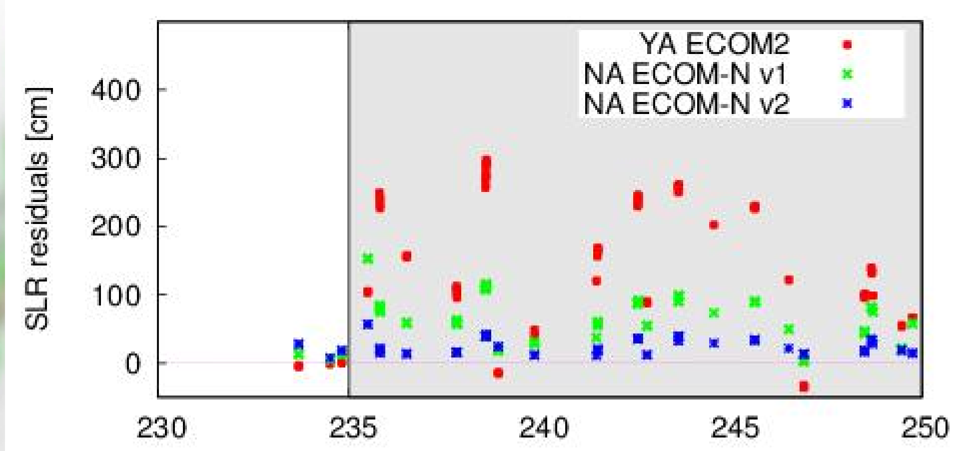
QZSS orbit validation



⇒ Normal attitude mode (|ß| < 20°; marked grey): large orbit errors

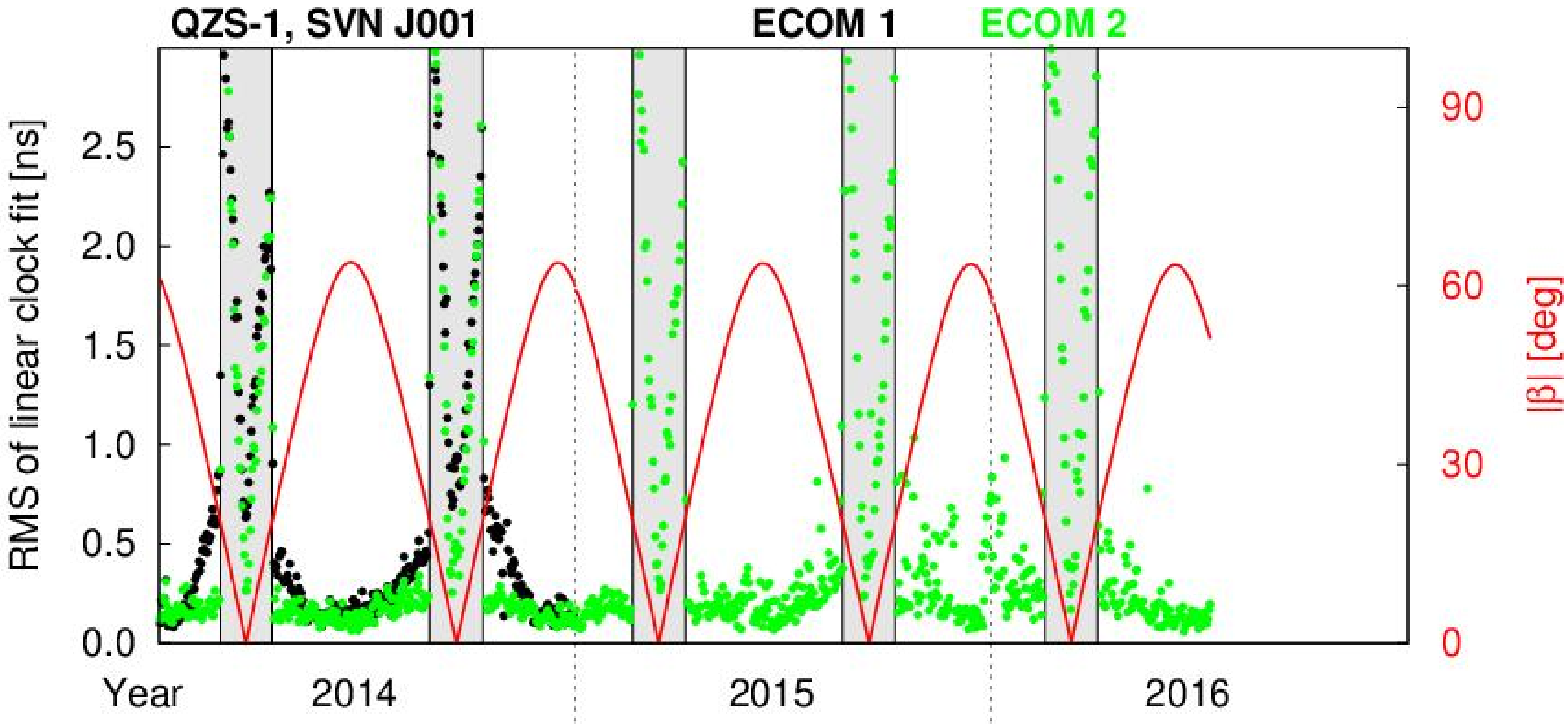
⇒ Test of new ECOM versions better suited for orbit normal attitude mode

QZSS orbit validation



⇒ Test of new ECOM versions better suited for orbit normal attitude mode

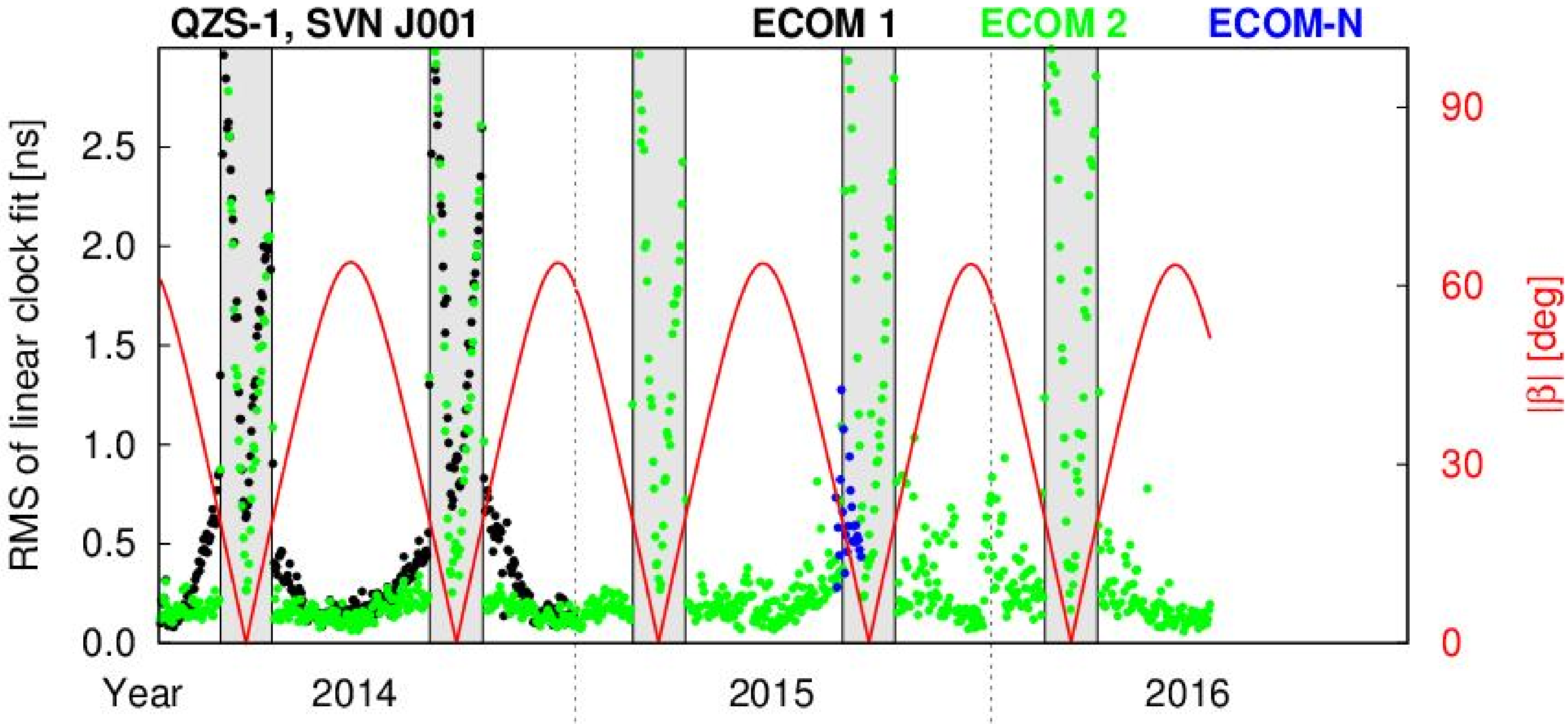
QZSS clock validation



⇒ Yaw-steering: significant reduction of dependency on beta angle thanks to ECOM2

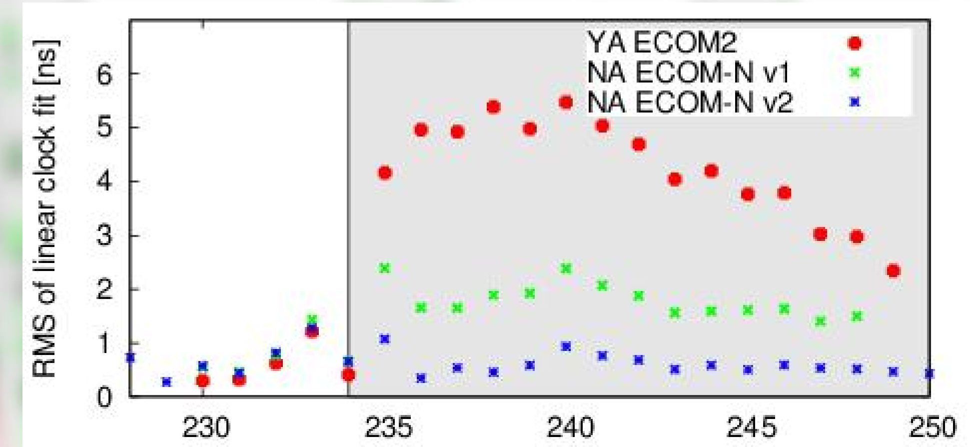
⇒ Orbit normal attitude mode (grey): large errors remain

QZSS clock validation



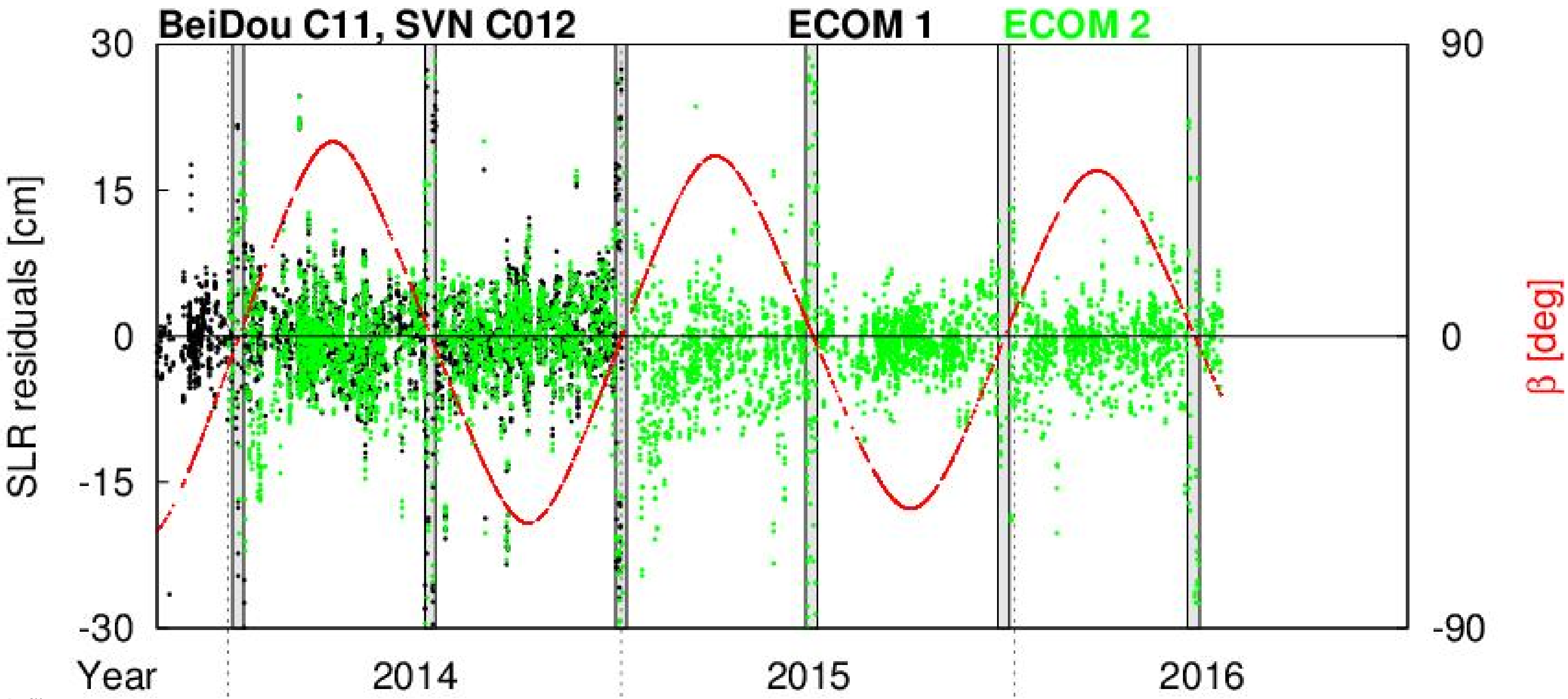
⇒ Experiments with ECOM versions better suited for orbit normal attitude mode

QZSS clock validation



⇒ Experiments with ECOM versions better suited for orbit normal attitude mode

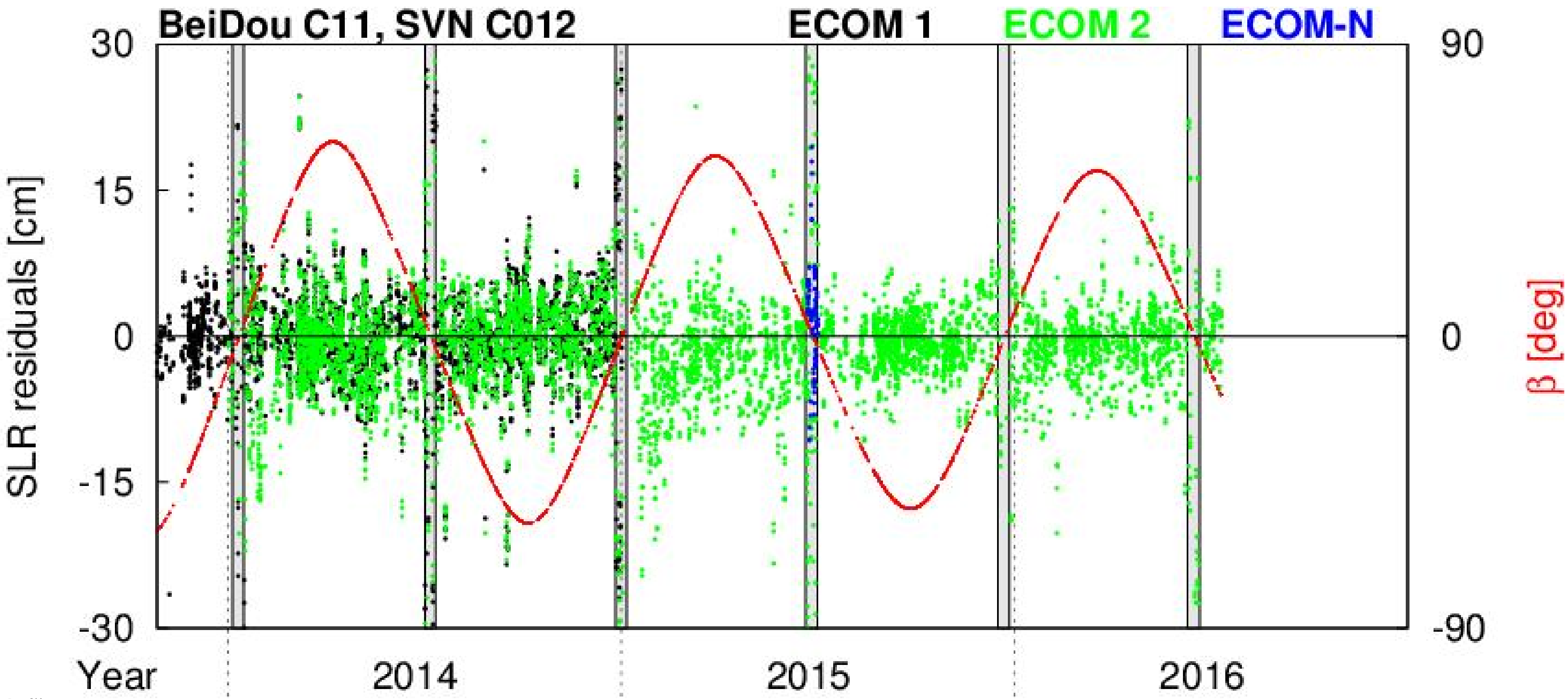
BeiDou orbit validation



⇒ Yaw-steering: no significant impact of ECOM version

⇒ Orbit normal attitude mode (|ß| < 4°; grey boxes; not correctly considered): large residuals

BeiDou orbit validation



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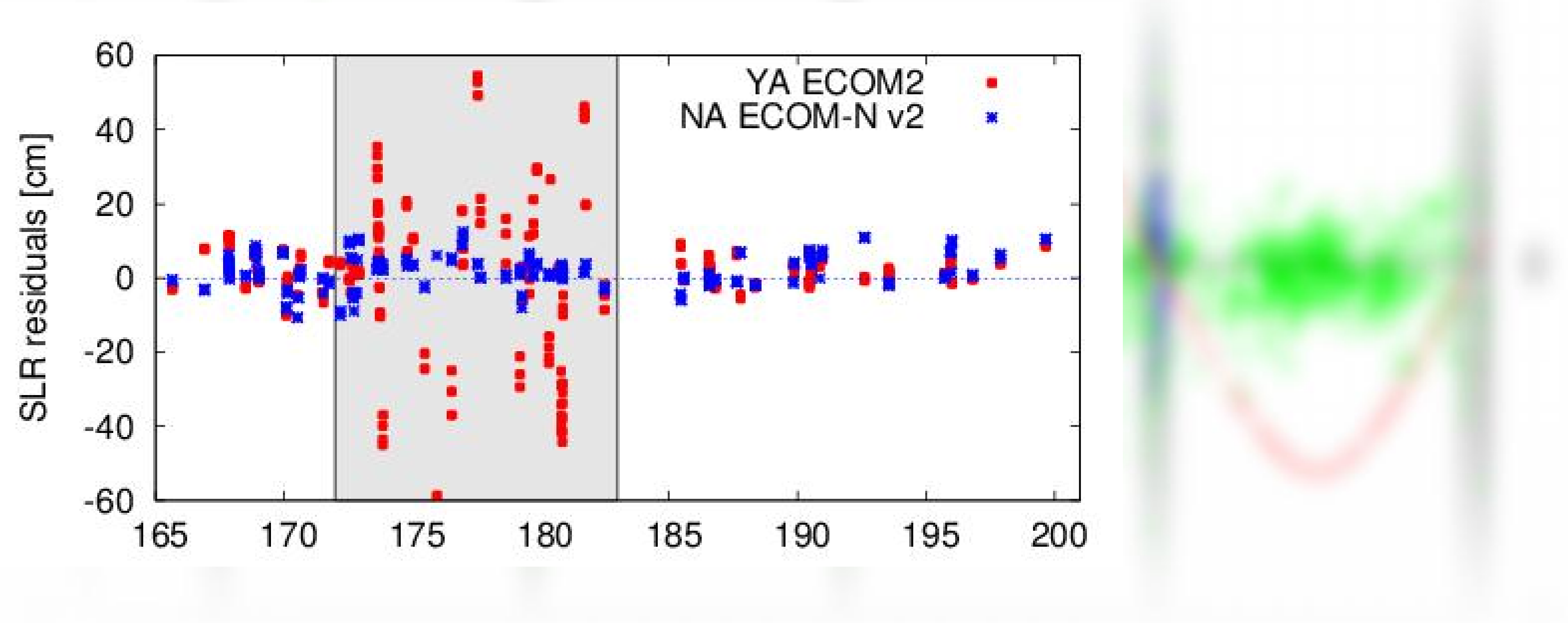
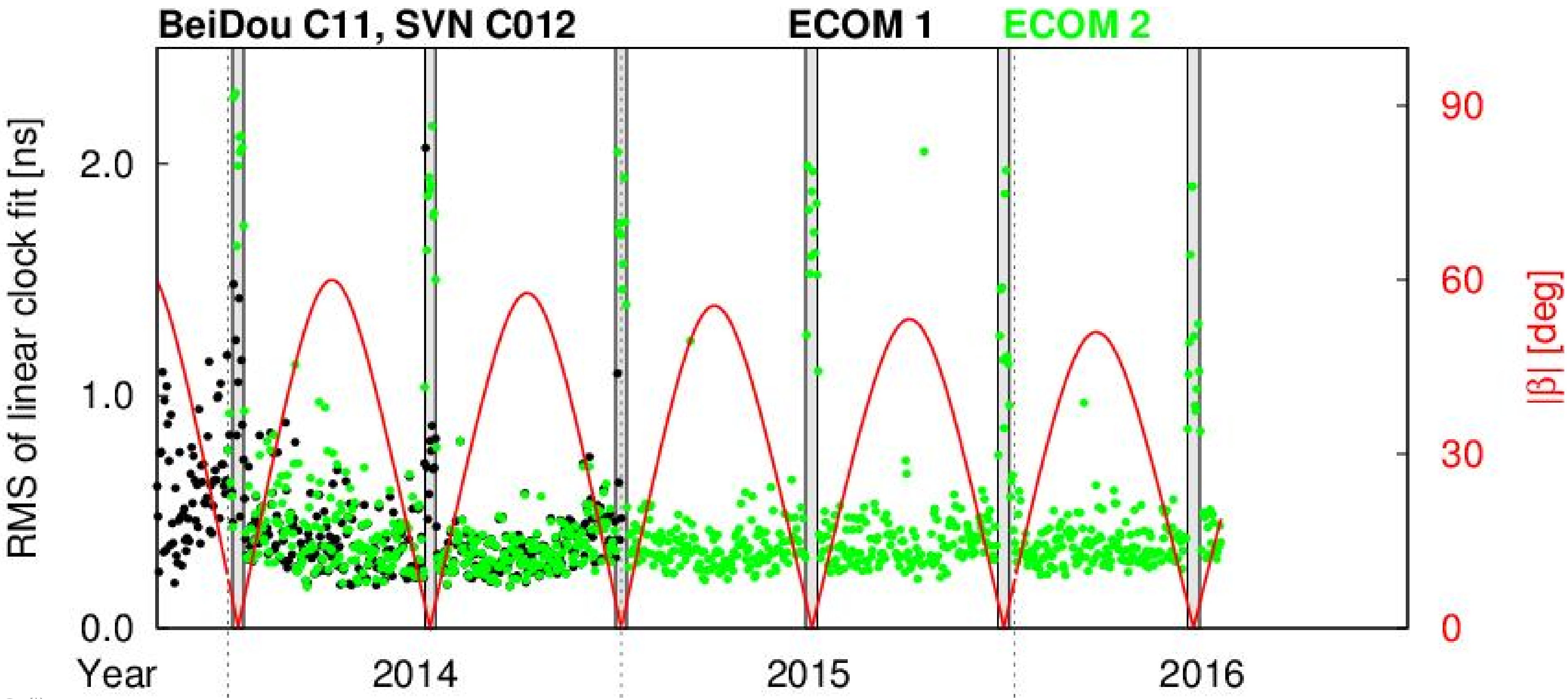
⇒ Test of new ECOM versions better suited for orbit normal attitude mode

BeiDou orbit validation



⇒ Test of new ECOM versions better suited for orbit normal attitude mode

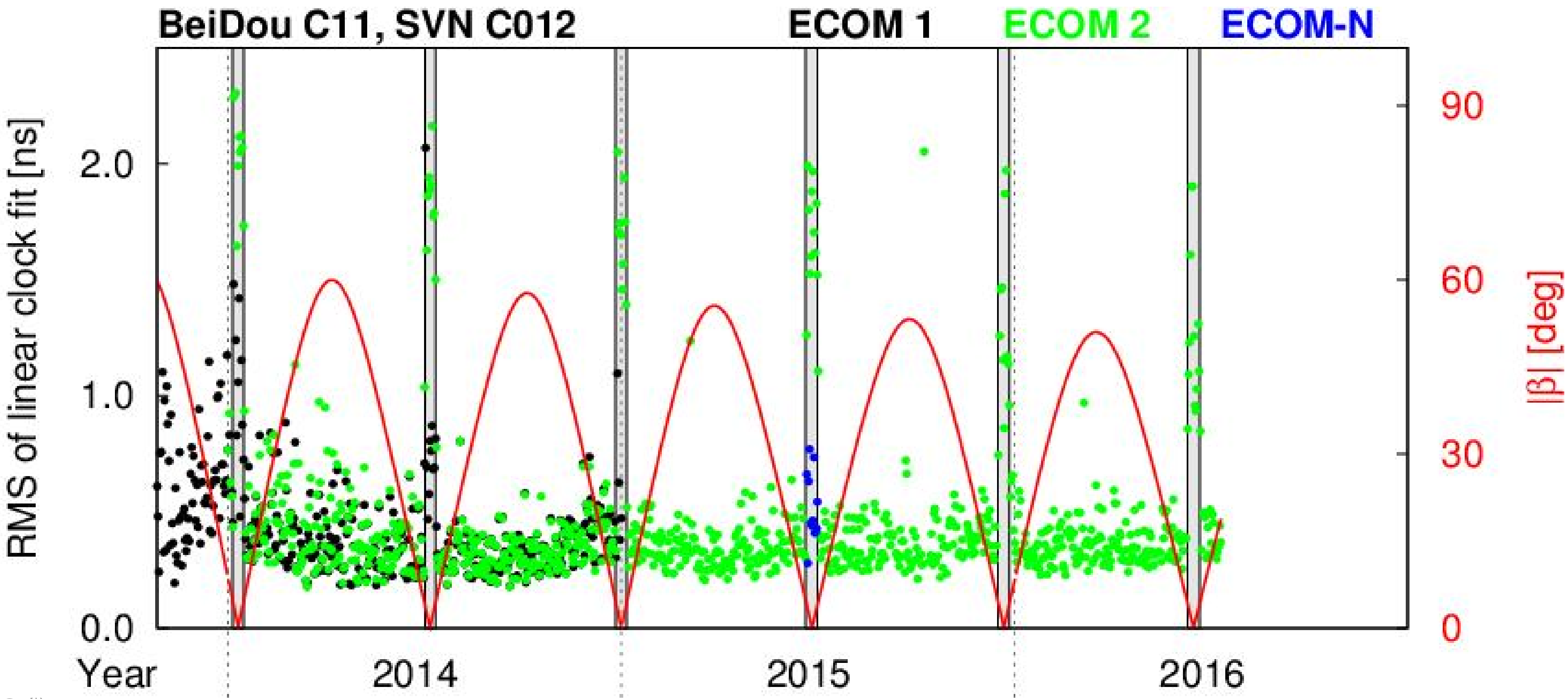
BeiDou clock validation



⇒ Yaw-steering: no significant difference between ECOM versions

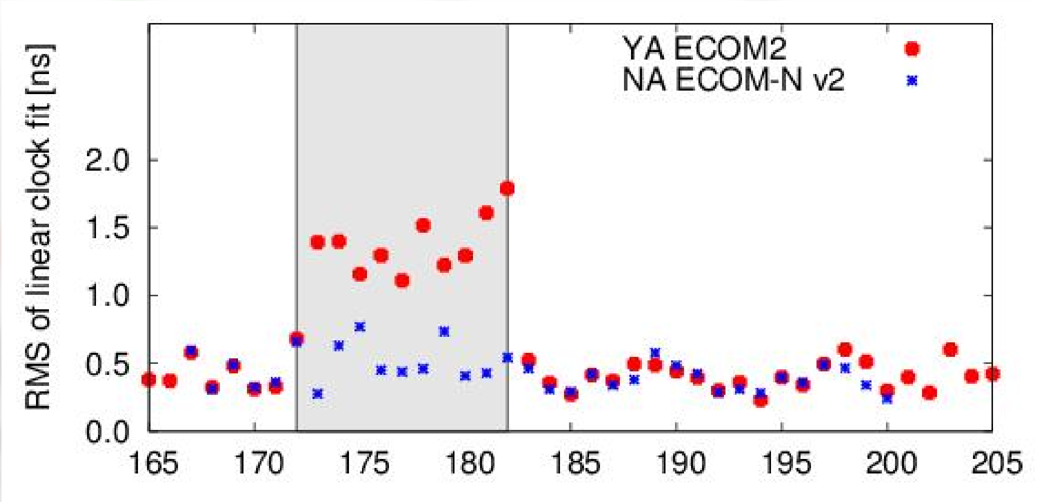
⇒ Orbit normal attitude mode (|ß| < 4°, marked grey; wrong attitude considered): ECOM2 may even degrade solution

BeiDou clock validation



⇒ Experiments with ECOM versions better suited for orbit normal attitude mode

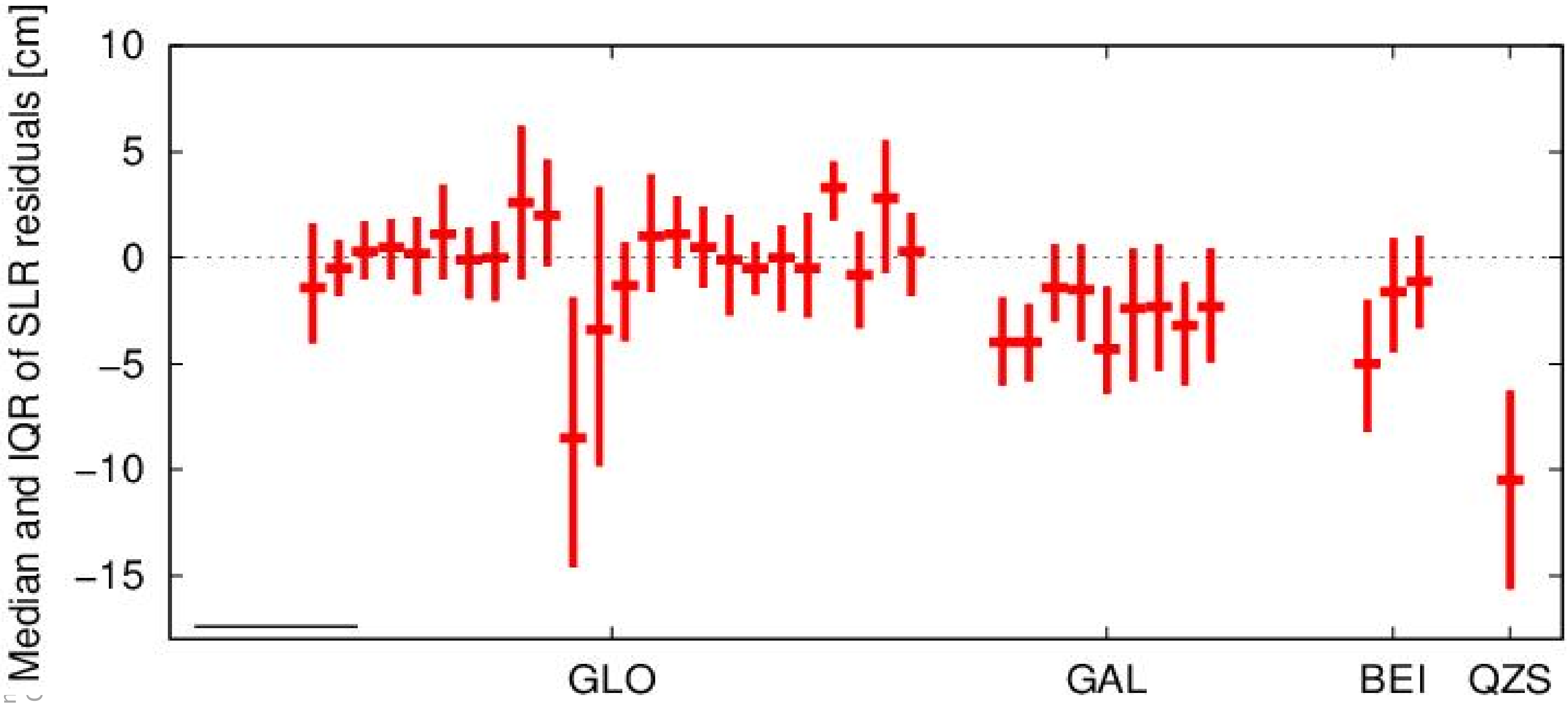
BeiDou clock validation



⇒ Experiments with ECOM versions better suited for orbit normal attitude mode

Orbit validation 2015: SLR

(Median and IQR; satellites in eclipse or normal mode are not considered)

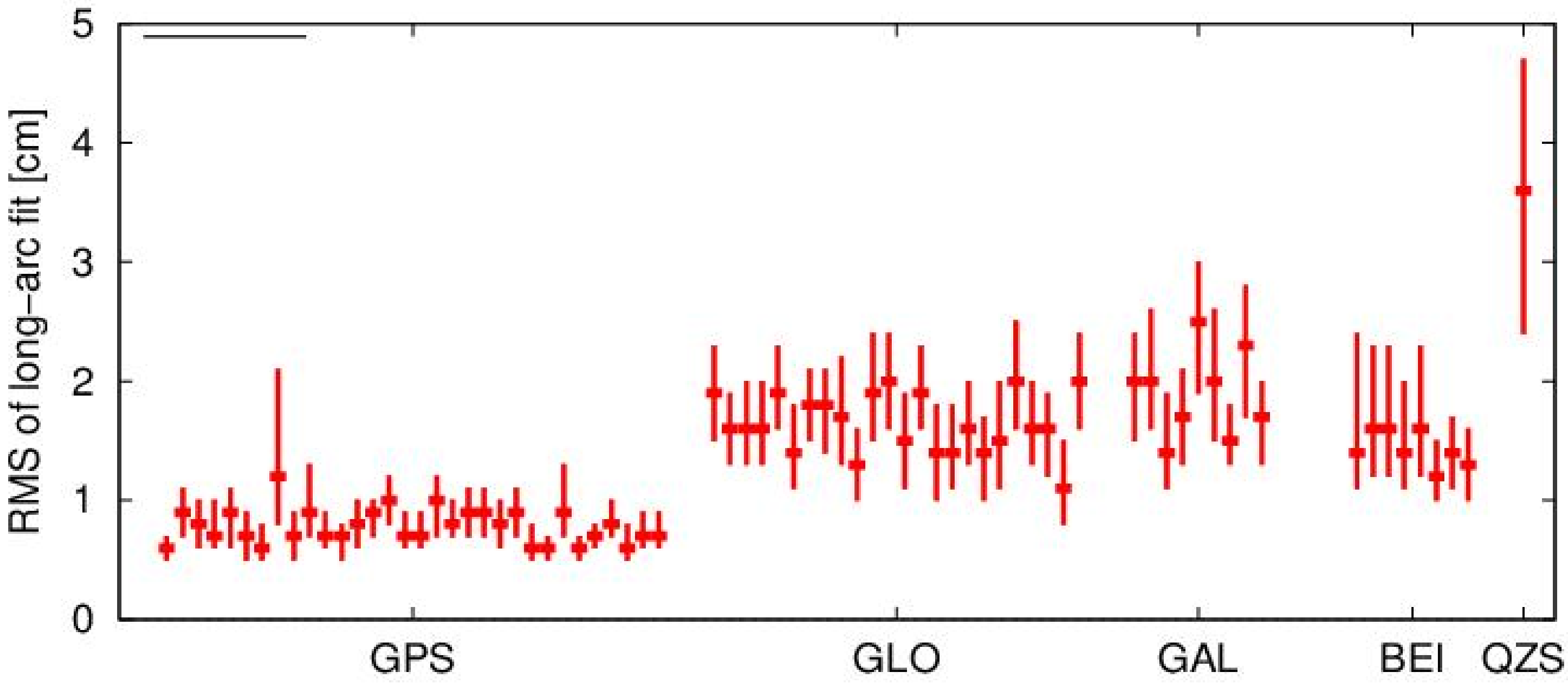


⇒ GLONASS: inhomogeneous (unknown issues with some SCs)

⇒ New systems: significant offsets due to modelling deficiencies (e.g., ANTEX, albedo, antenna thrust)

Orbit validation 2015: 3-day long-arc fit

(Median and IQR; satellites in eclipse or normal mode are not considered)



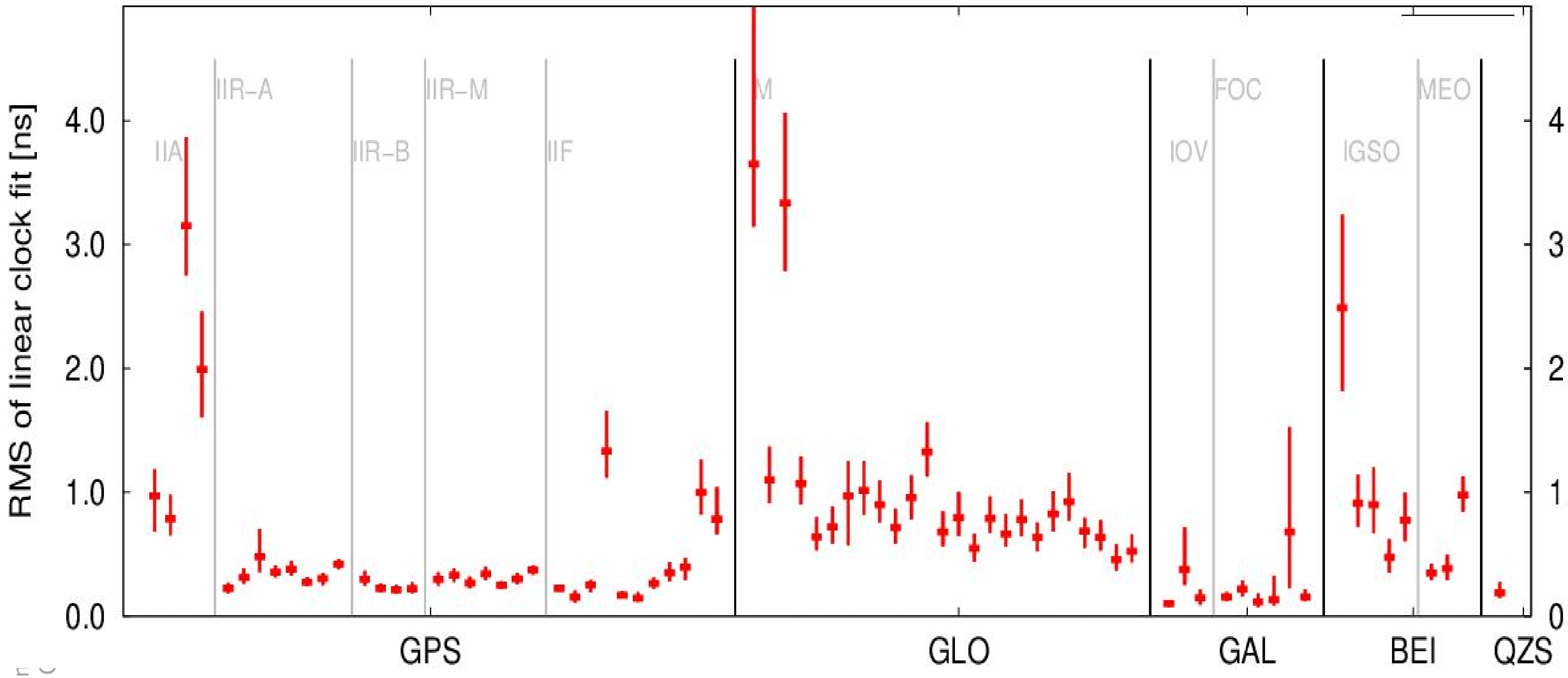
⇒ Galileo and BeiDou: almost comparable to GLONASS

⇒ QZSS performs worst

⇒ BeiDou MEOs better than IGSOs

Clock validation 2015: median RMS of daily linear fit

(Median and IQR; satellites in eclipse or normal mode are not considered)



⇒ Galileo PHM, QZS-1, most GPS IIR and IIF: excellent performance

⇒ GPS IIA, some IIF, GLONASS, Galileo RAFS: less good (RMS: 0.5 ns or bigger)

⇒ BeiDou: mixed performance

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COM to-do list

- [x] Implementation of Galileo, QZSS, BeiDou (except GEOs)
- [x] Use of RINEX3 files from IGS and EPN - now also with long file names; selection of observation types
- [x] Improved SRP model for yaw-steering attitude (ECOM2, Arnold et al., 2015)
- [...] Normal attitude and related SRP models for QZSS and BeiDou
- [...] Attitude laws for GPS, GLONASS, (Galileo?) eclipses
- [...] ANTEX (PCO+PCV) for Galileo, QZSS, BeiDou
- [...] Proper handling of observation biases; new BIAS-SINEX version
- [ ] Ambiguity resolution for Galileo, BeiDou, QZSS; improvement for GLONASS
- [ ] Albedo radiation modelling for Galileo, QZSS, BeiDou
- [ ] Antenna thrust for (GLONASS), Galileo, QZSS, BeiDou

Summary

- Still a some way to go until the new GNSS can contribute to CODE's IGS solutions to the same extent as GPS
- Our current focus: orbit normal attitude (challenges are, e.g., SRP modelling, detection and consideration of mode-transitions, …), correct handling of observation biases, PCO+PCV estimation for new systems
- Reprocessing of data from 2015 or 2016 planned after implementation of further improvements

Thank you

for

your interest!