Orbit and Clock Determination - Galileo

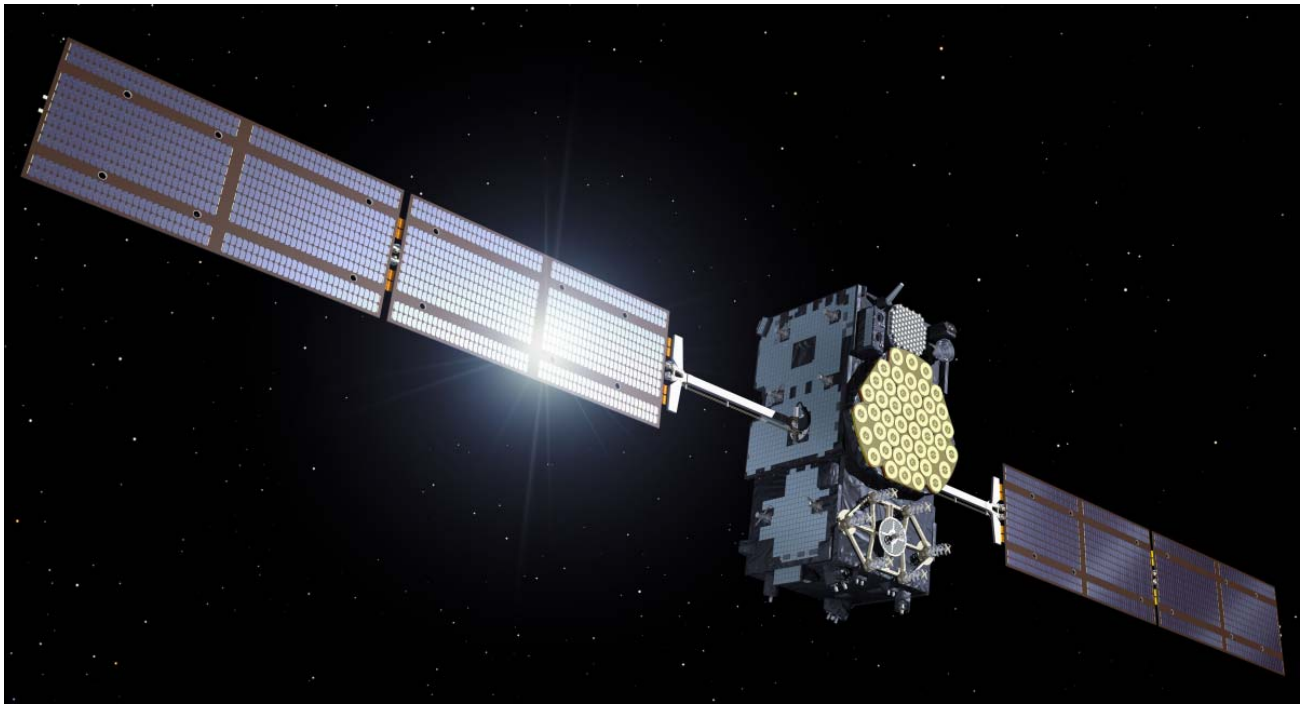
L. Prange[1], P. Steigenberger[2], M. Uhlemann[3], S. Loyer[4], T. Springer[5]

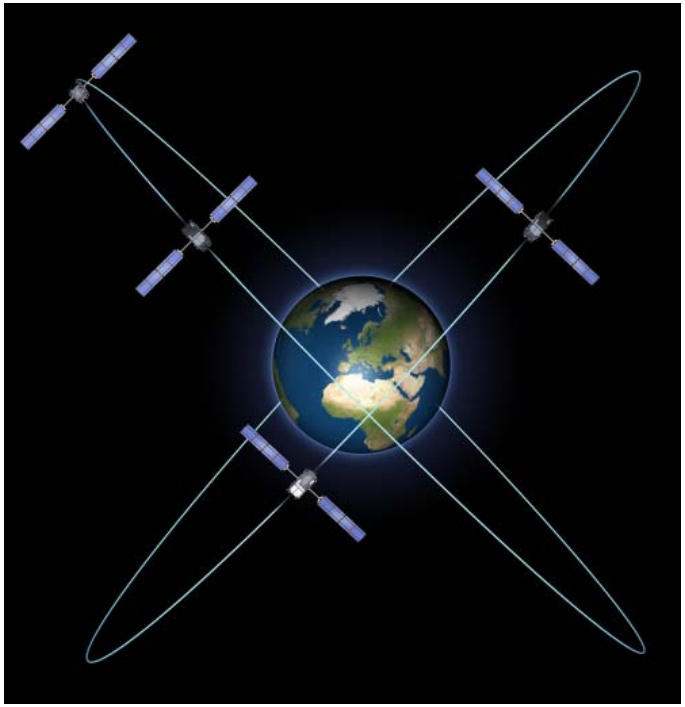
[1] Astronomical Institute, University of Bern, Switzerland
[2] Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany
[3] GeoForschungsZentrum Potsdam, Germany
[4] Collecte Localisation Satellites, Toulouse, France
[5] European Space Operations Centre, Darmstadt, Germany

Contents

- Galileo mission status
- The IGS MGEX network
- MGEX Galileo products
  - Products availability
  - AC processing strategies
- MGEX Galileo product validation
  - Orbit validation
  - Clock validation
- Summary and outlook

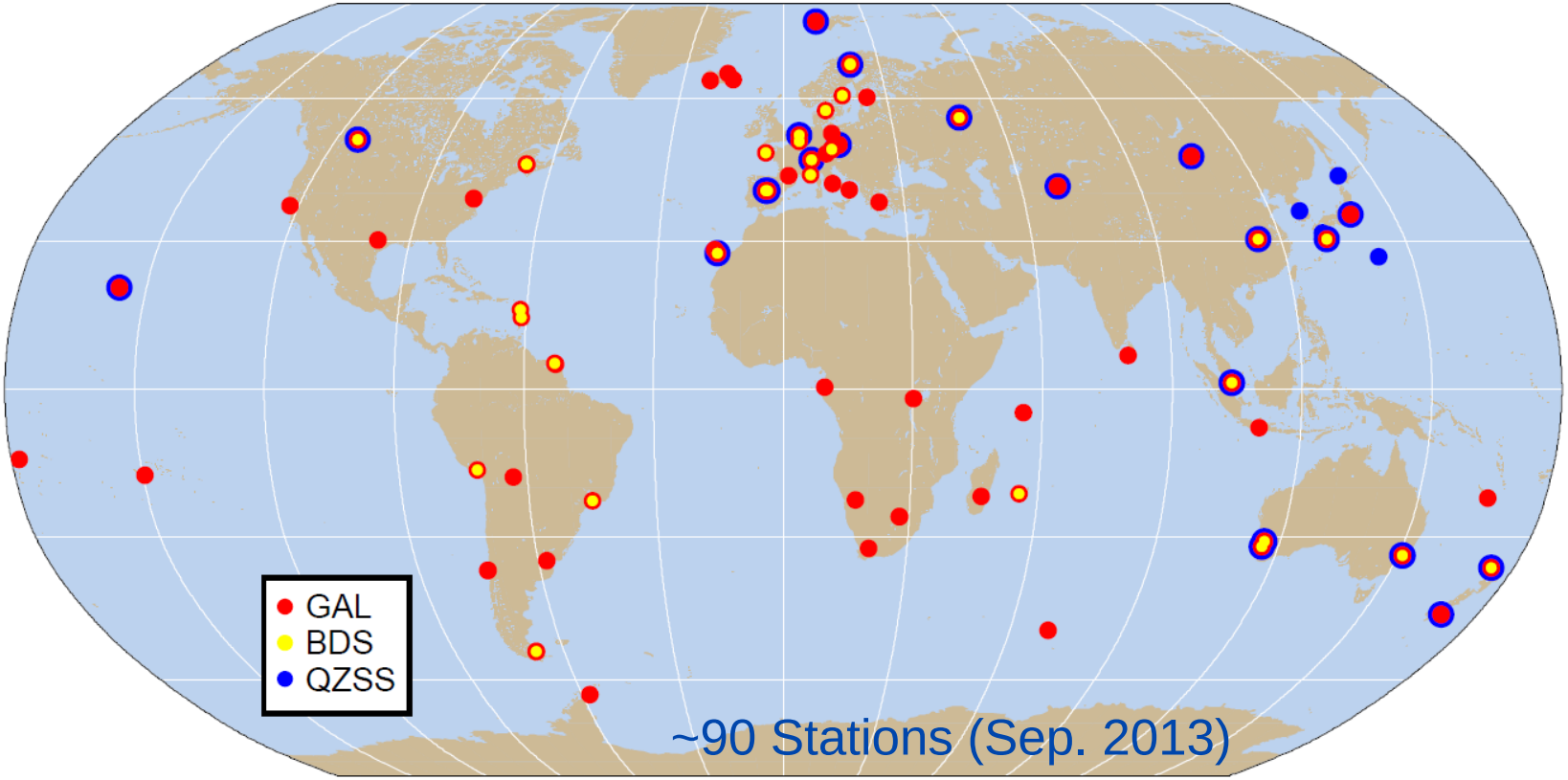
Galileo Status





- Four Galileo In-Orbit Validation (IOV) satellites in orbit
  - E11 and E12 launched in October 2011
  - E19 and E20 launched in October 2012
- First FOC satellite dual launch planned for August 2014

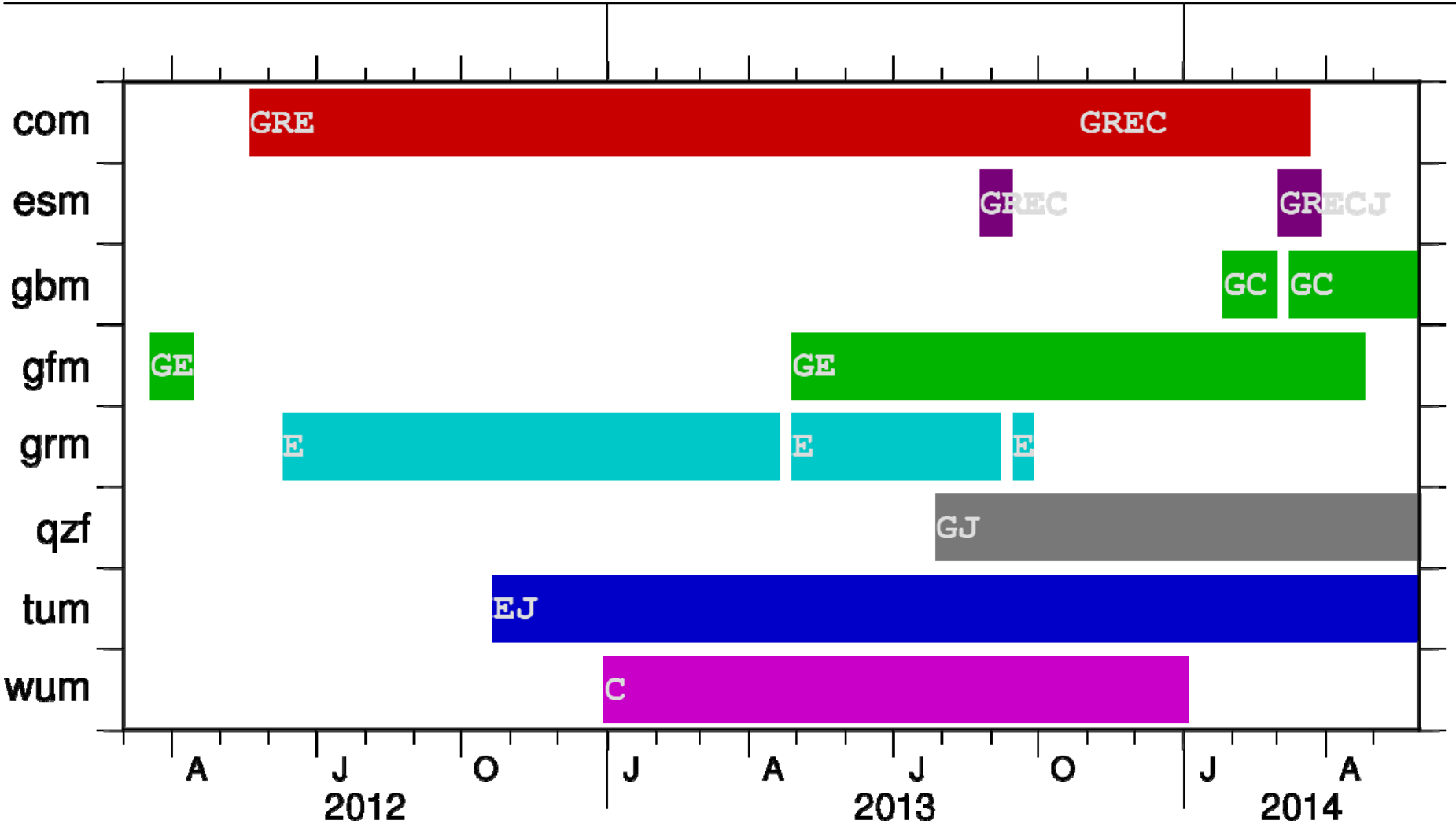
The IGS MGEX Network



ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/
http://mgex.igs-ip.net/

- Nearly all MGEX stations are tracking Galileo

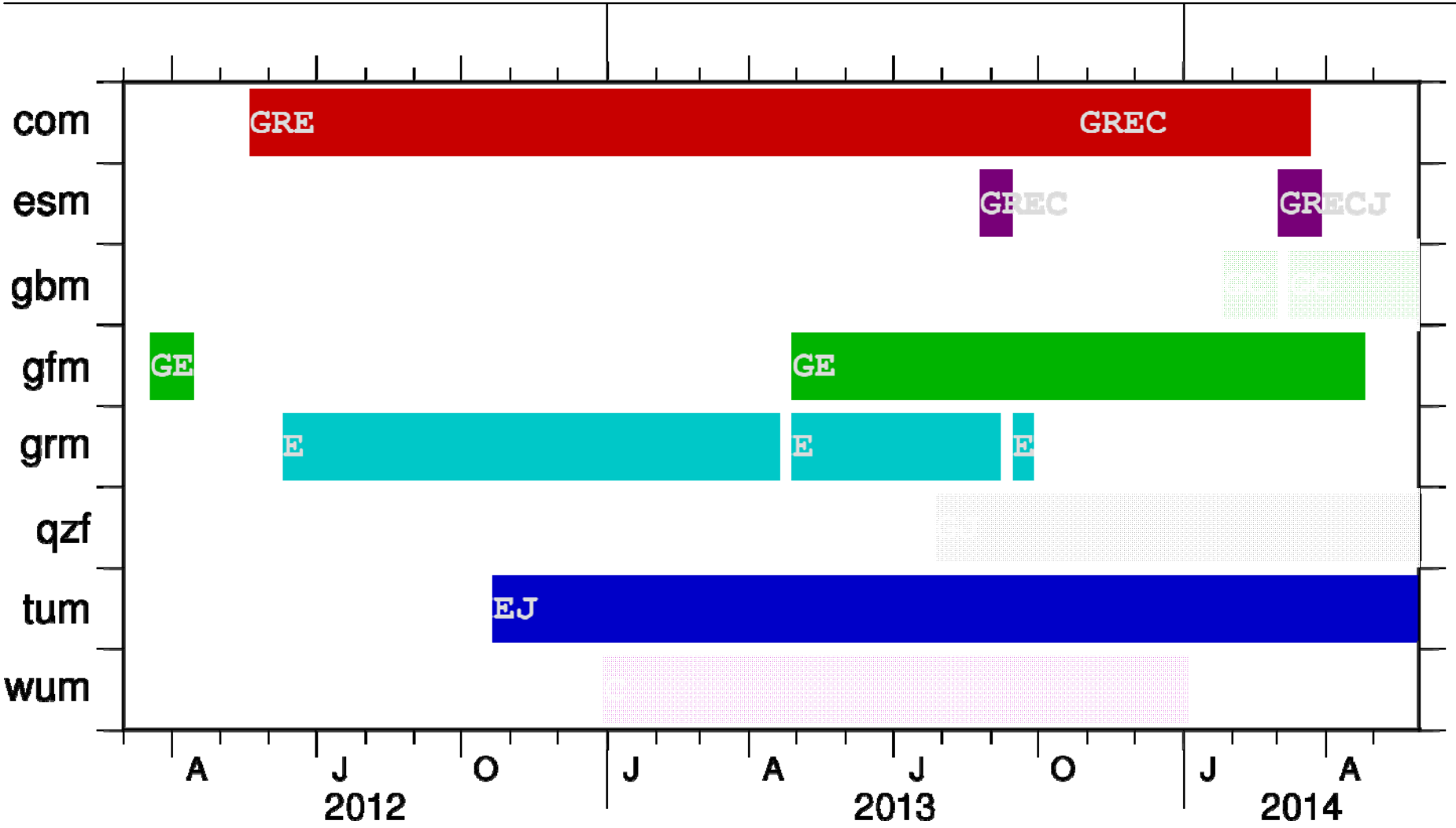
MGEX products availability



Status: 15-June-2014

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

MGEX Galileo products availability



Status: 15-June-2014

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

MGEX Galileo analysis centers

Institution	Software	Diff. LVL	Phase center	Arc-length	CLK sampling
CNES/CLS (GRM)	CNES POD GINS	zero	MGEX	30 h	15 min
CODE (COM)	Bernese 5.3	double (orbit) zero (clock)	ESA	3 d	5 min
ESOC (ESM)	NAPEOS	zero	ESA	1 d	5 min
GFZ (GFM)	EPOS.P8	zero	ESA	3 d	5 min
TUM (TUM)	Bernese 5.0	zero	MGEX	3 d	15 min

MGEX Galileo product validation

„MGEX data analysis at CODE – current status“, Prange et al., presented at the EGU 2013, Vienna:

- Validation of COM, TUM, GRM orbits for different time intervals in 2012 (long arc fit and SLR residuals)

„Quality assessment of Galileo Orbit and Clock Products of the IGS Multi-GNSS Experiment (MGEX)“, Steigenberger et al., presented at the AGU 2013, San Francisco

and

„Galileo Orbit and Clock Quality of the IGS Multi-GNSS Experiment“, Steigenberger et al. (2014), accepted for publication in Advances in Space Research:

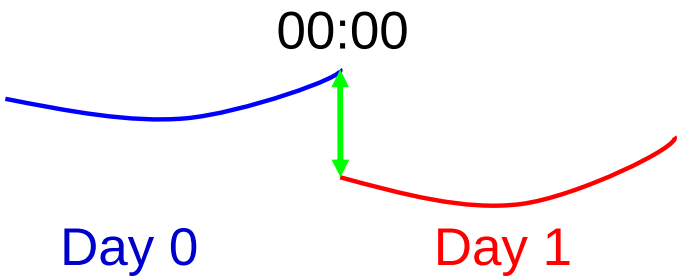
- Overview, description, validation of MGEX Galileo orbit and clock products
- Validation time interval: 20 weeks from 28 April till 14 September 2013 (day of year 118 – 257/2013, GPS week 1738 – 1757)

=> validation results presented here again (see following slides)

Orbit validation

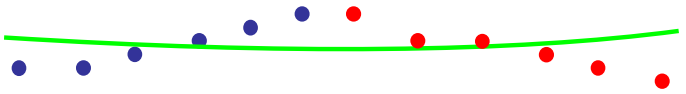
Day boundary discontinuities

- 3D position difference between consecutive days at midnight



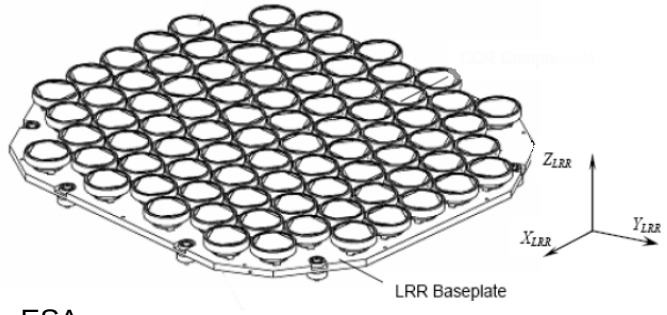
2-day orbit fit RMS

- 2-day orbit fitted through positions of 2 consecutive days
- 3D RMS of 2-day arc w.r.t. original orbits



Satellite Laser Ranging residuals

- Independent optic technique



ESA

Orbit comparisons

- Differences between two ACs in radial, along-track, cross-track direction

Orbit validation

Common time period considered, median values given in **cm**

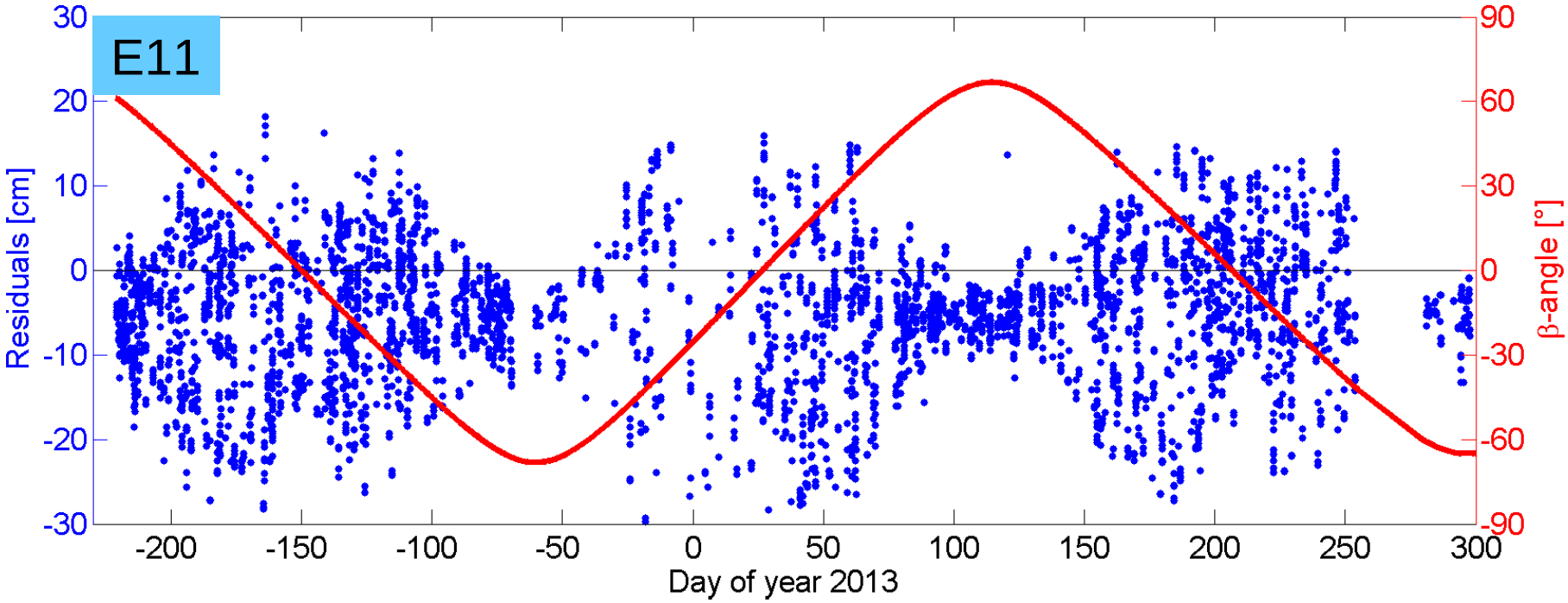
Day Boundary Discontinuities

Satellite	COM	GFM	GRM	TUM
E11	4.4	8.1	20.9	5.8
E12	4.7	8.0	20.7	6.7
E19	4.8	8.9	28.0	6.3
E20	4.7	8.5	22.1	6.1

2-day Orbit Fit RMS

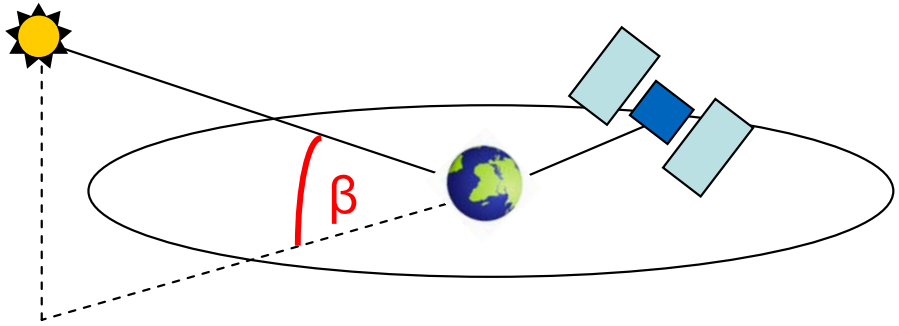
Satellite	COM	GFM	GRM	TUM
E11	1.4	2.7	6.6	1.3
E12	1.4	2.7	6.4	1.5
E19	1.5	2.9	6.4	1.5
E20	1.5	3.0	6.7	1.6

Orbit validation with SLR

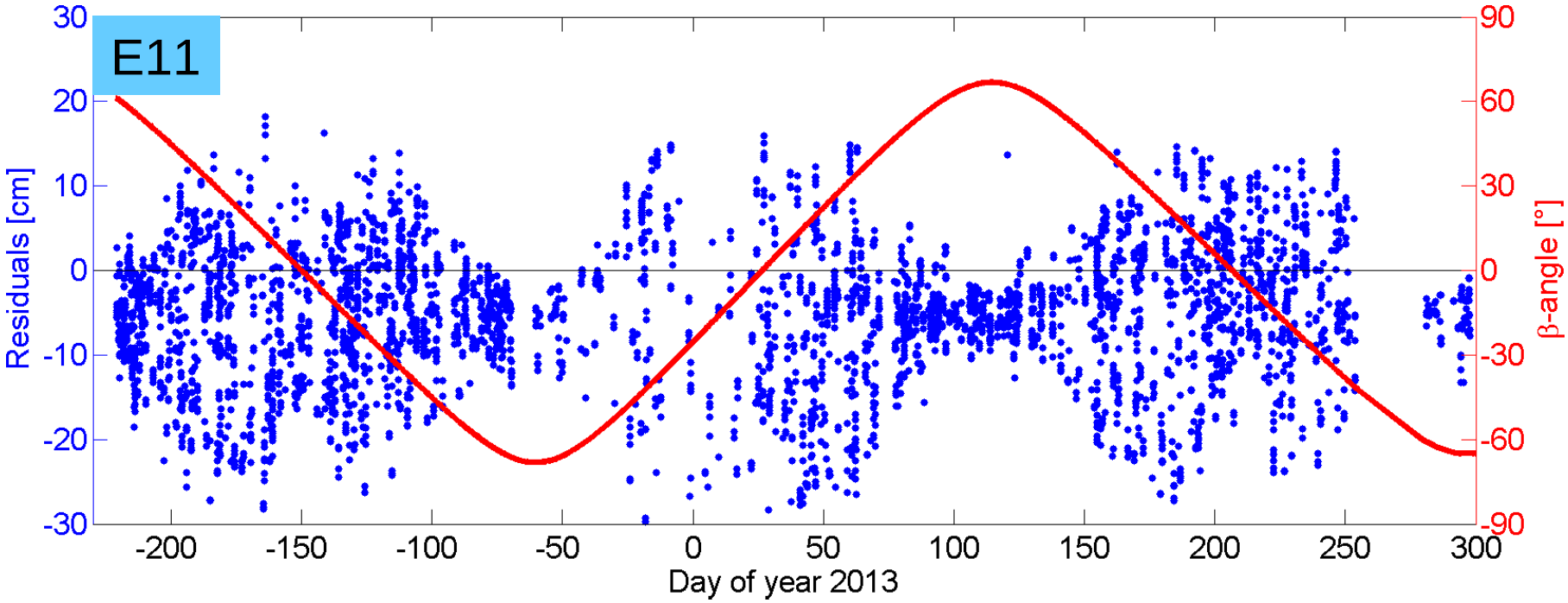


Elevation of the Sun above the orbital plane

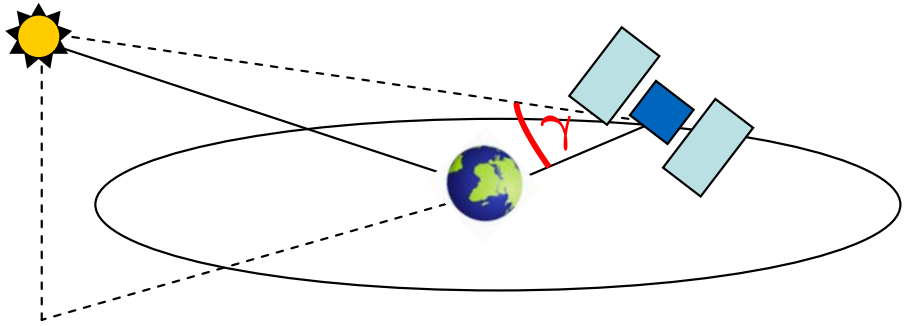
Satellite	Bias [cm]	STD [cm]
E11	-5.2	8.4
E12	-5.9	8.1



Orbit validation with SLR

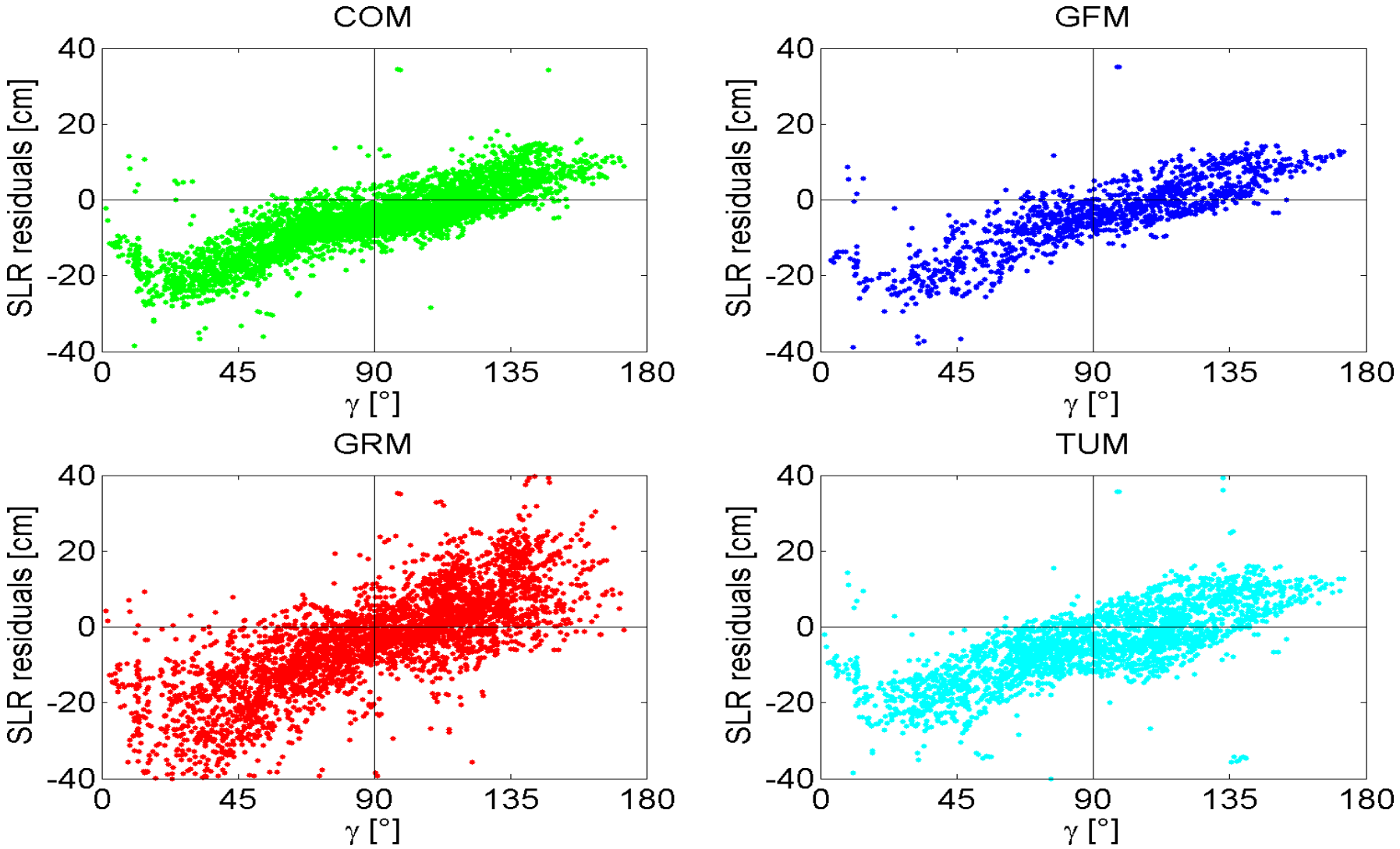


Elevation of the Sun above the orbital plane



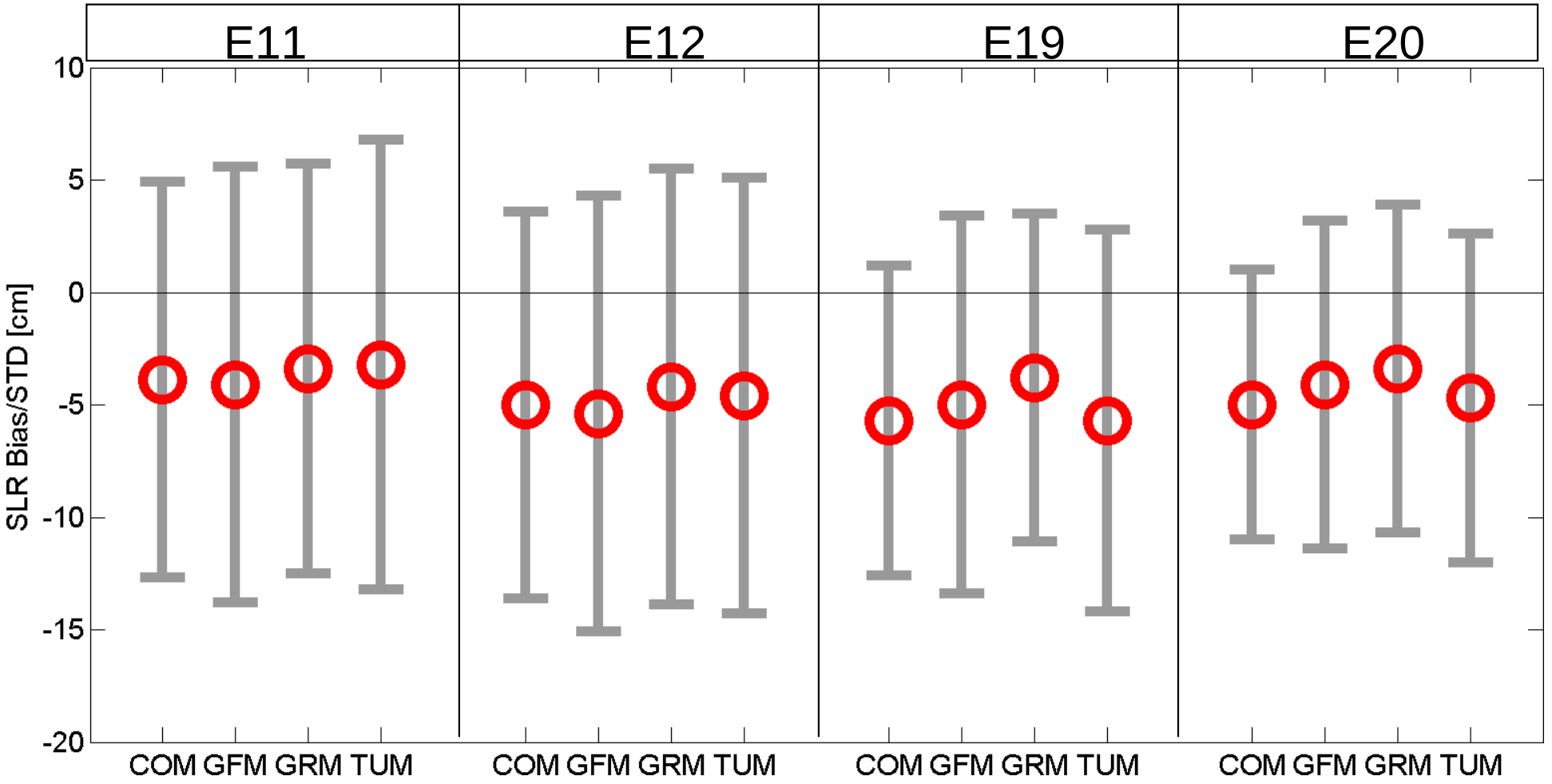
Orbit validation with SLR

SLR Residuals vs. Earth-Satellite-Sun Angle: E11



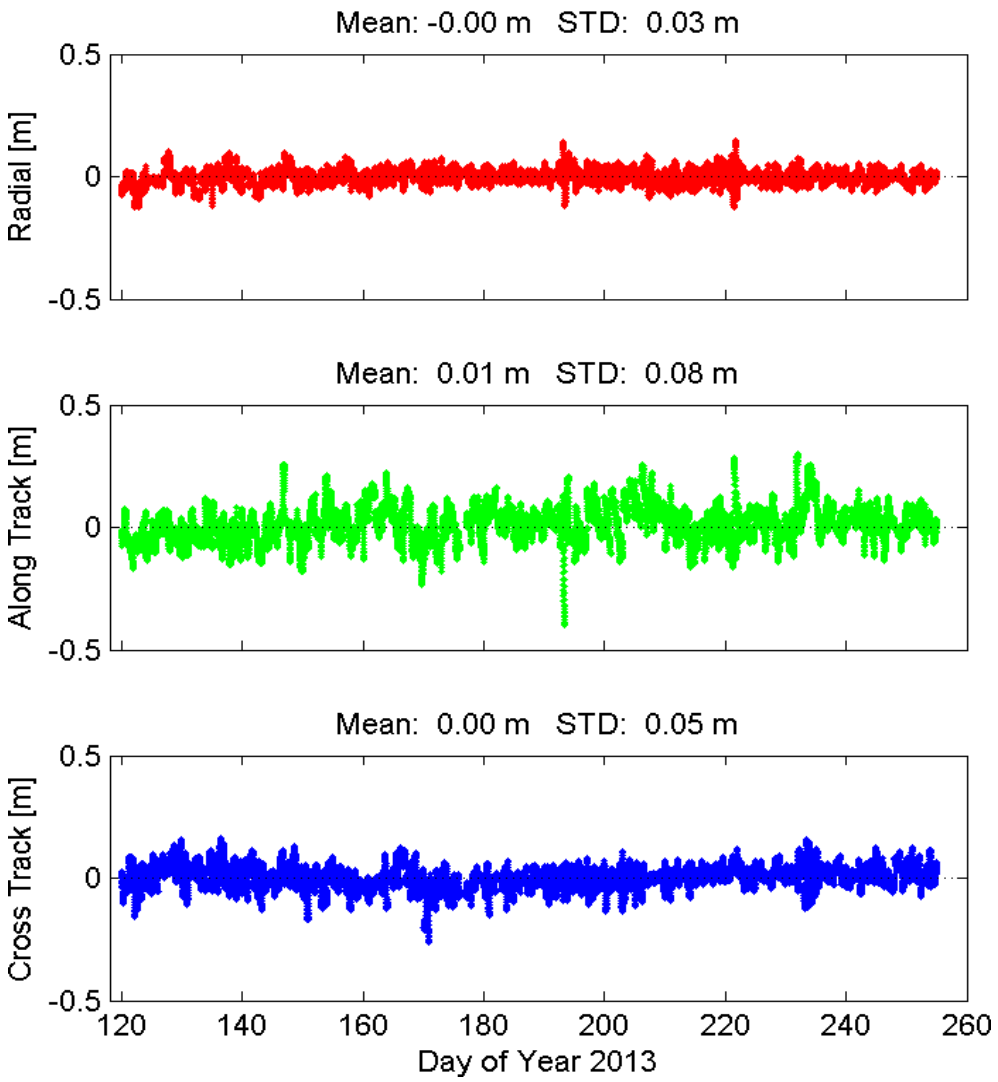
Orbit validation with SLR

Mean bias and standard deviation (STD) of SLR residuals

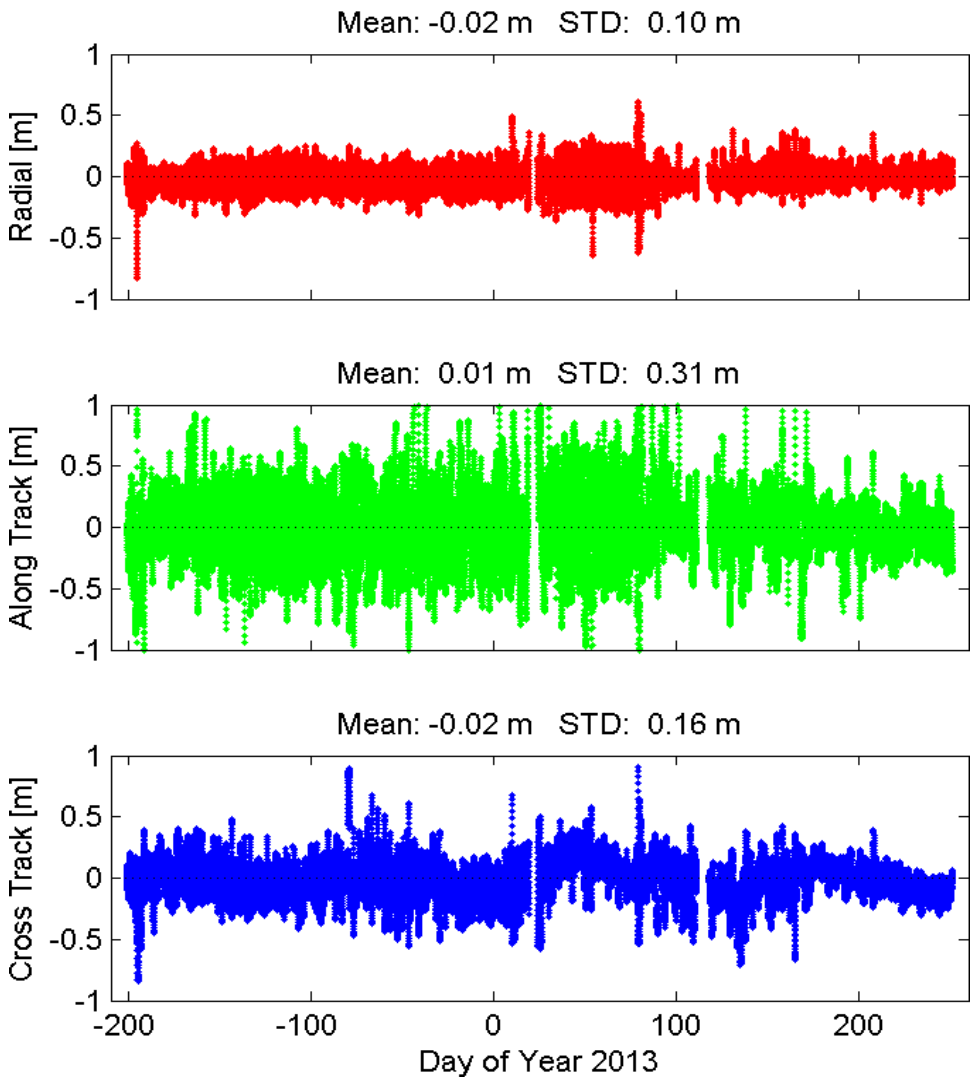


Orbit differences between ACs for E11

COM vs. GFM

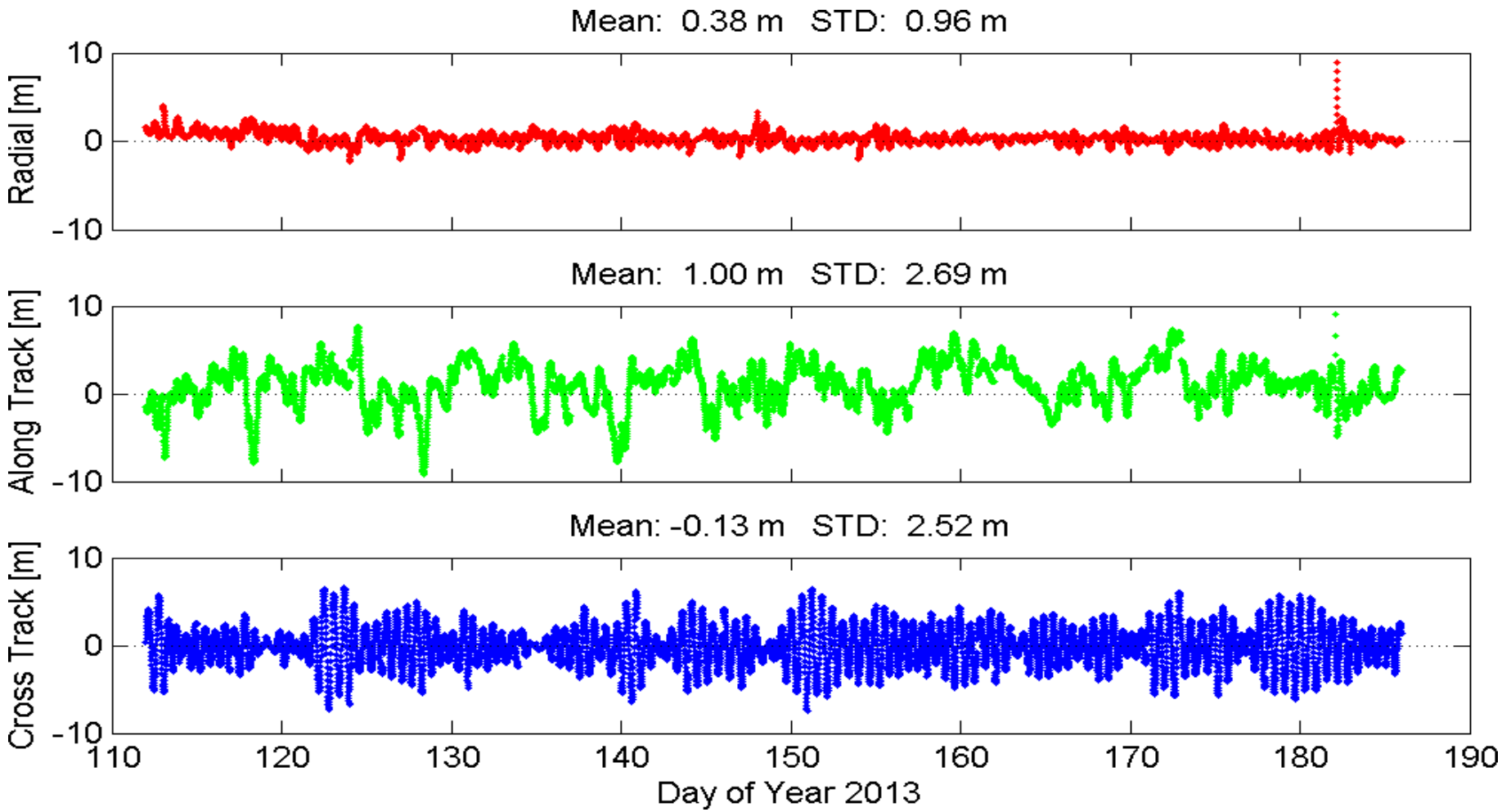


COM vs. GRM

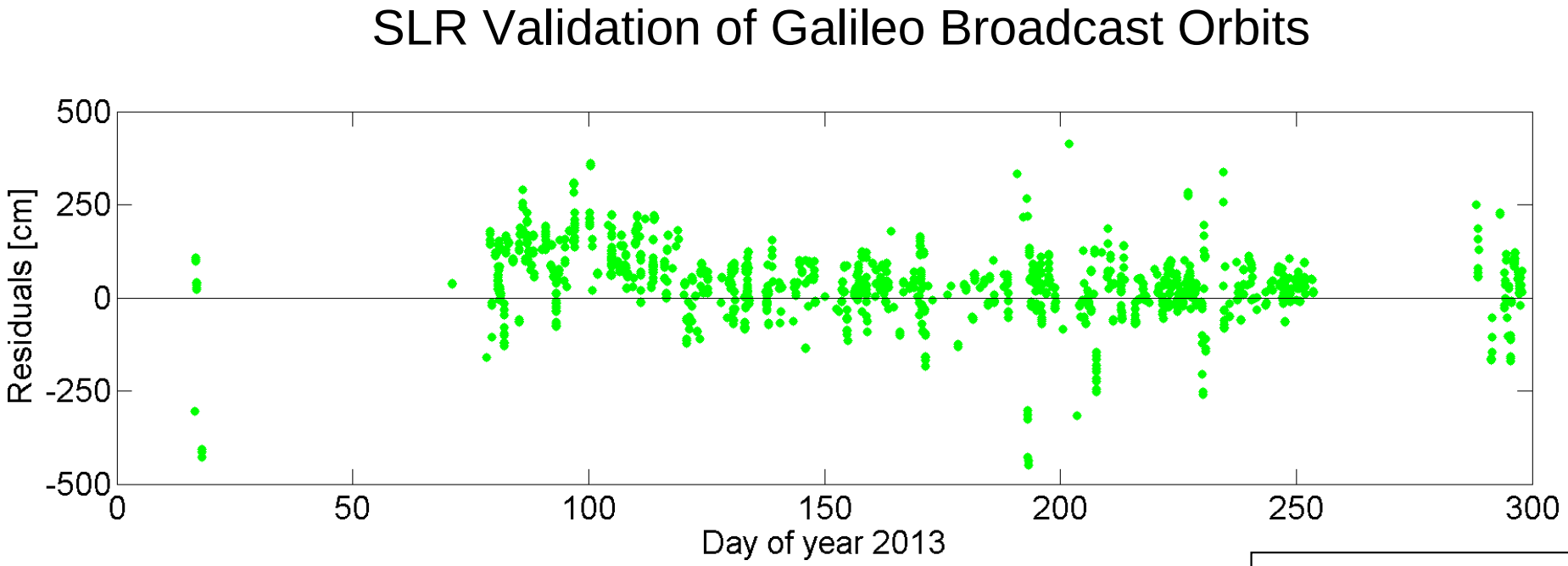


Broadcast orbit validation

Orbit Comparison E11: Broadcast vs. TUM



Broadcast orbit validation



	E11	E12	E19	E20
Offset [cm]	36.8	39.4	32.1	25.8
STD [cm]	94.0	88.2	101.6	113.2
RMS [cm]	100.9	96.5	106.5	116.0

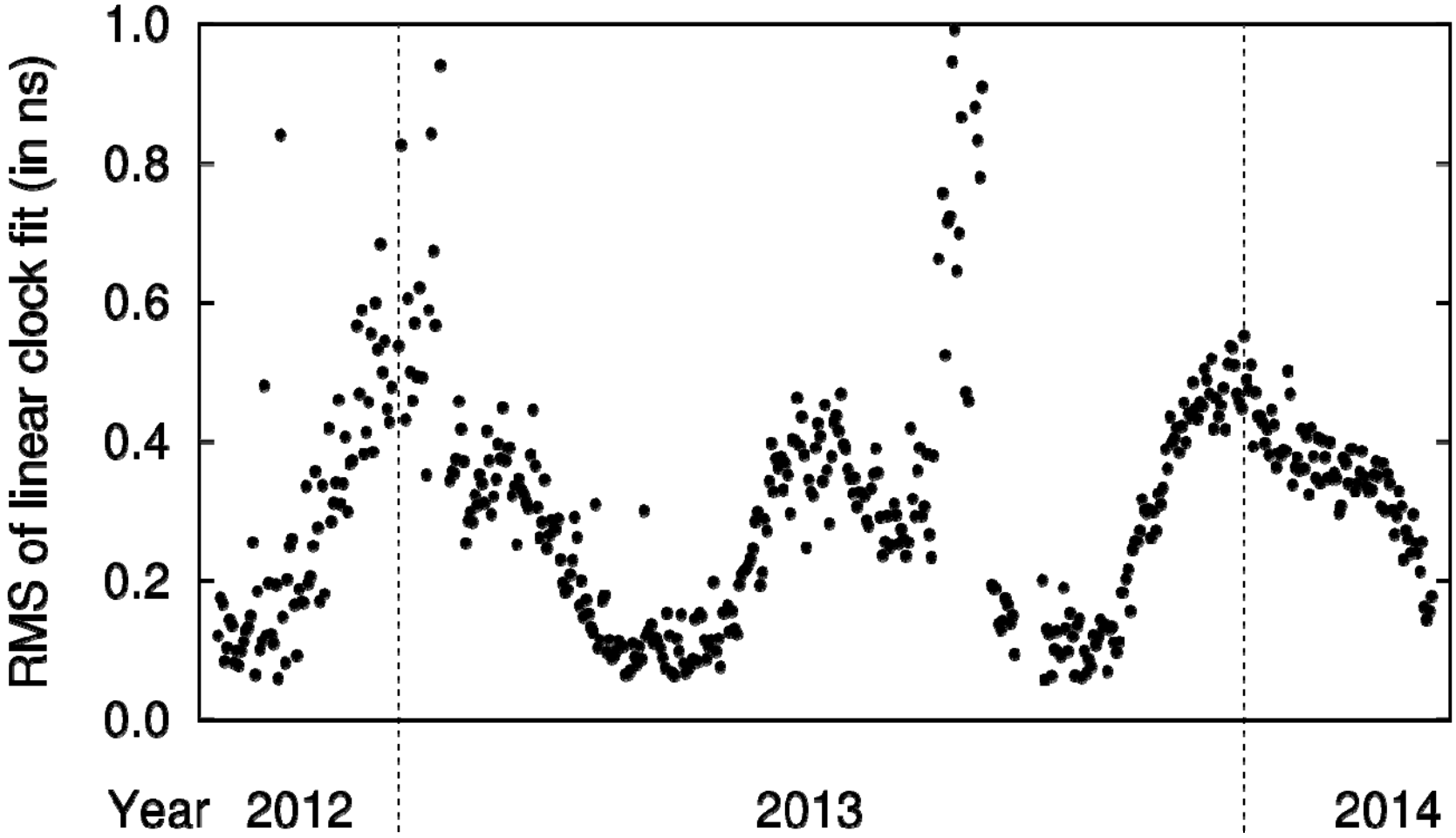
Time period:
DOY 1 - 300/2013

Outlier limit: 5 m

Nominal satellite antenna offsets

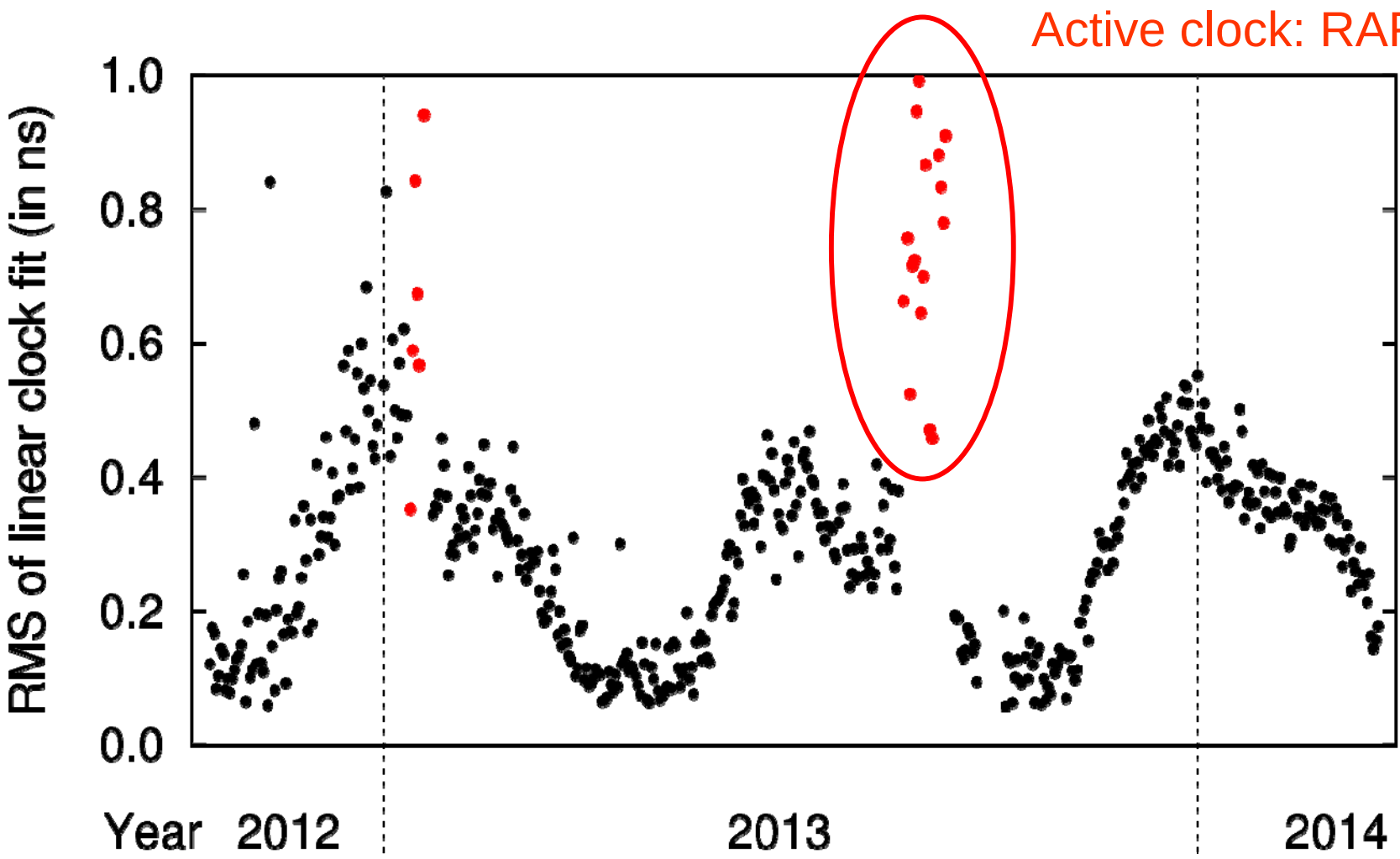
Clock validation

Linear fit of COM clock estimates for E12



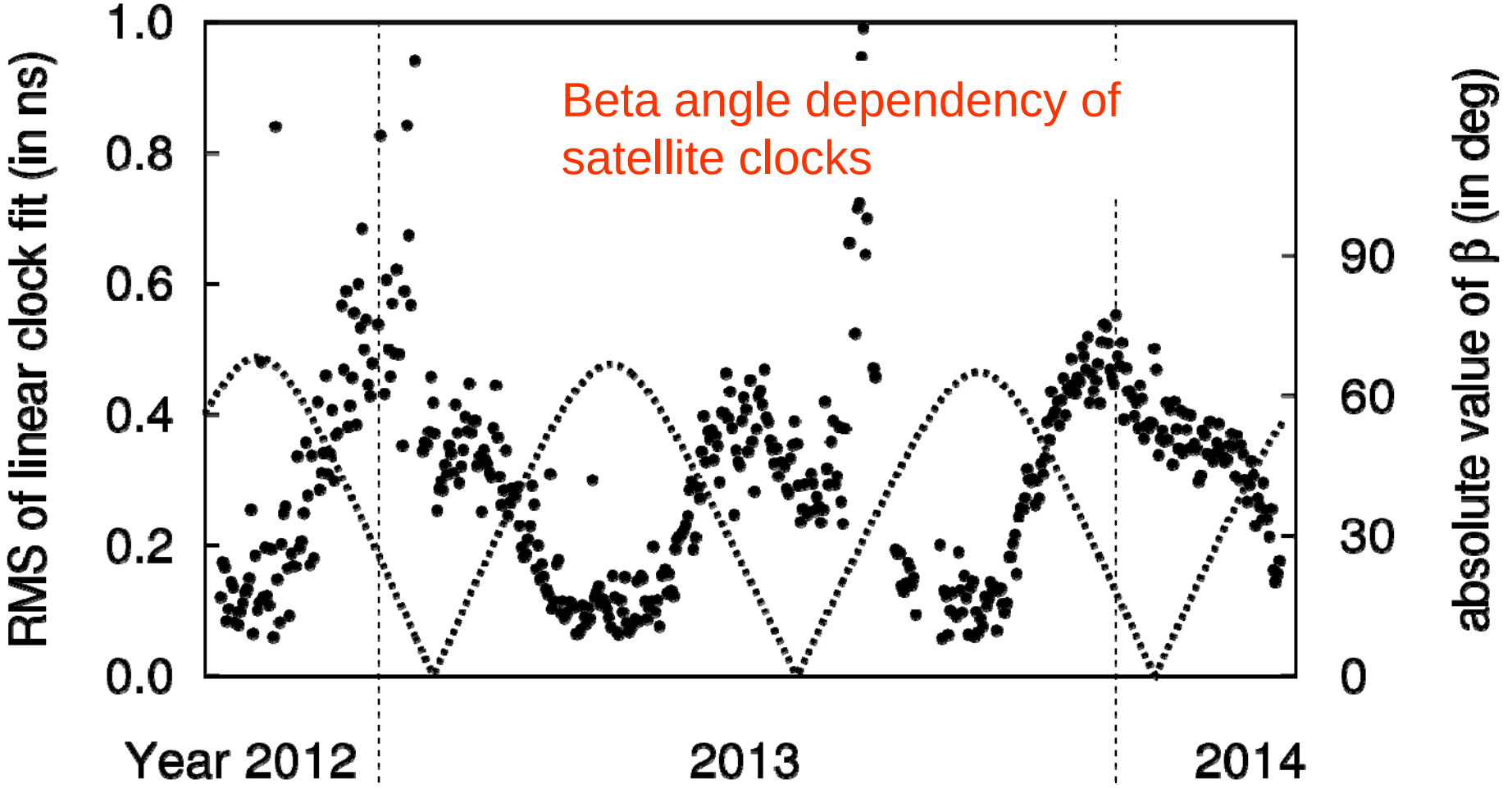
Clock validation

Linear fit of COM clock estimates for E12



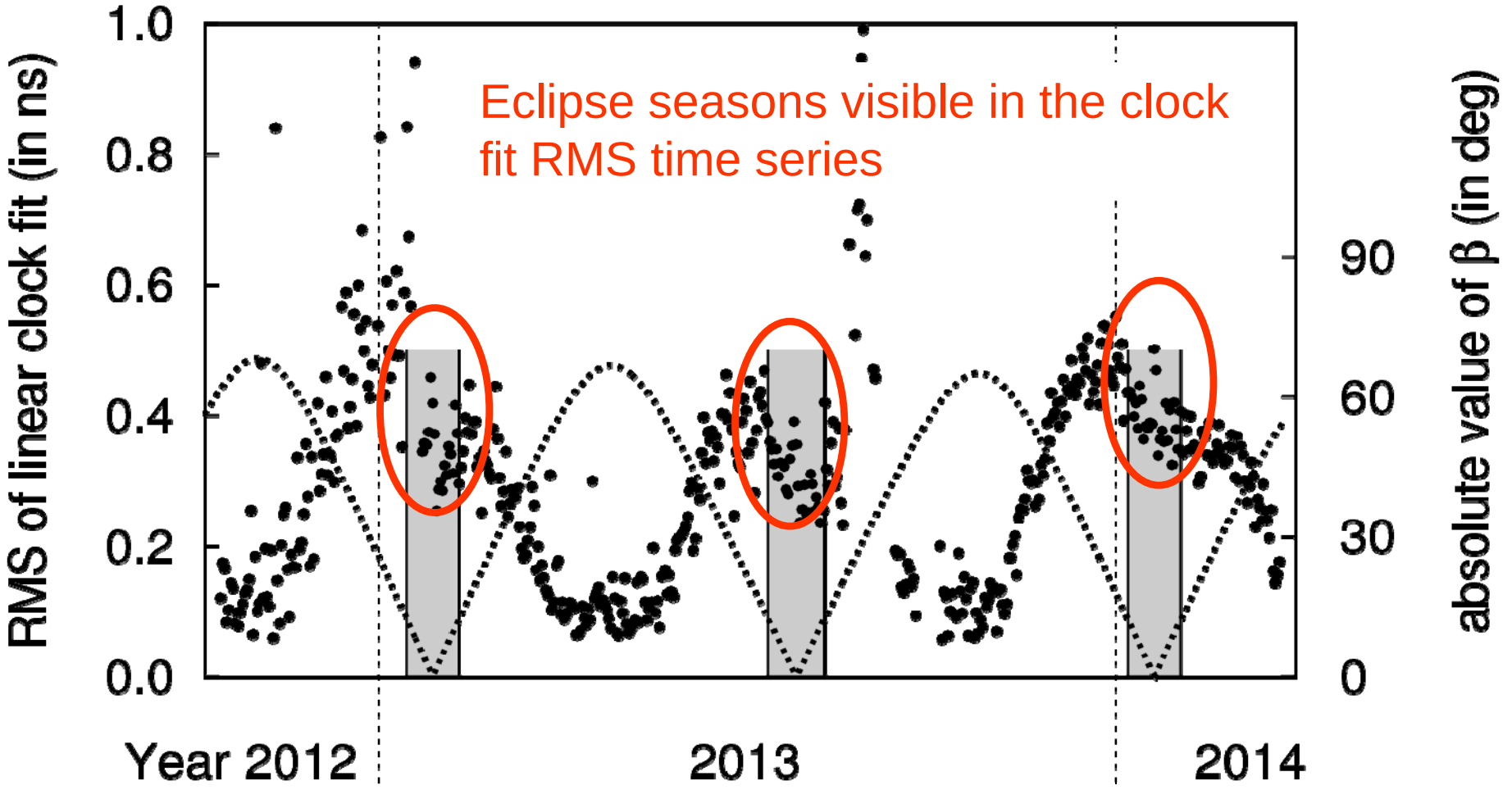
Clock validation

Linear fit of COM clock estimates, elevation of the Sun above the orbital plane for E12

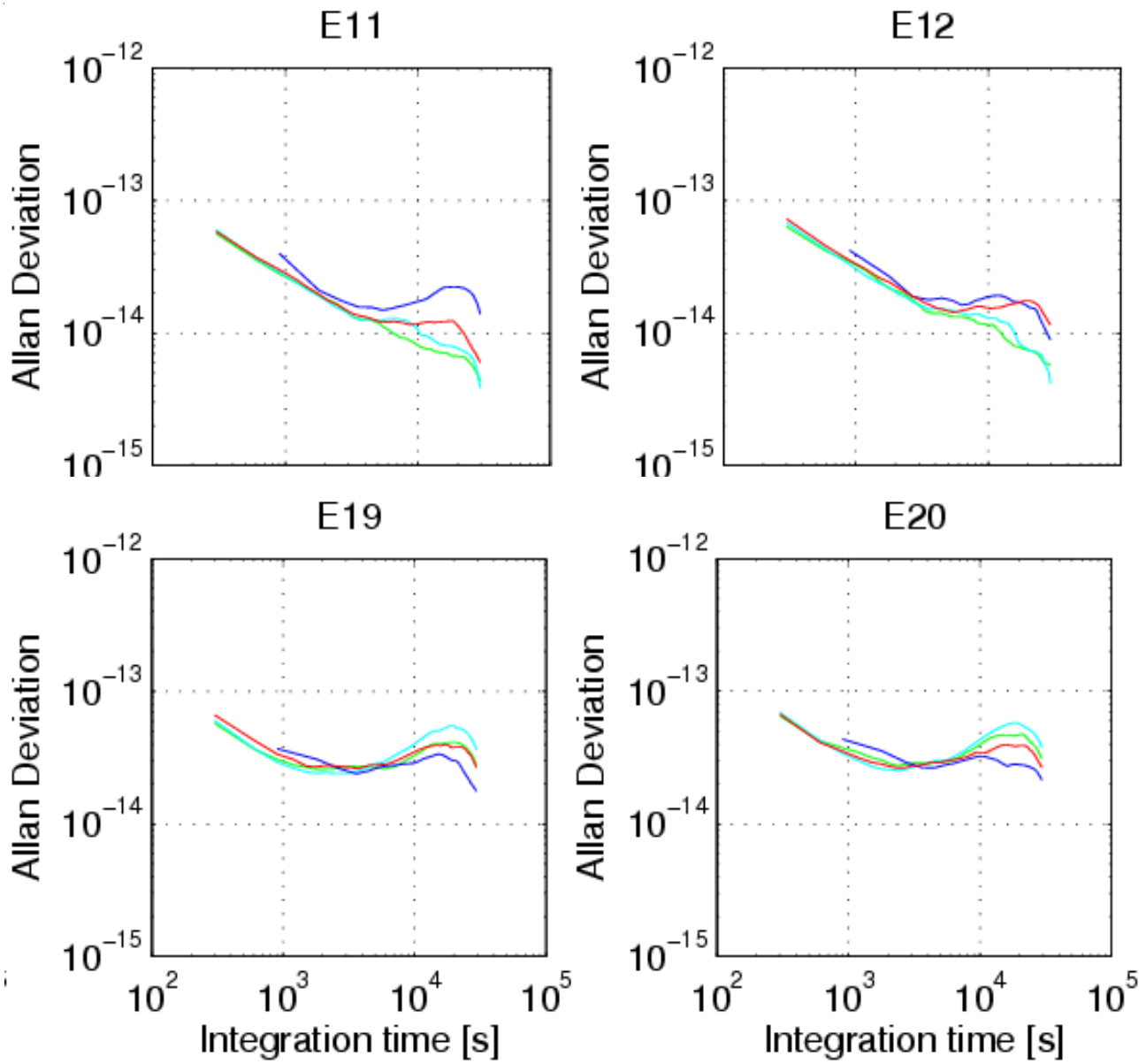


Clock validation

Linear fit of COM clock estimates, elevation of the Sun above the orbital plane, and eclipse seasons for E12



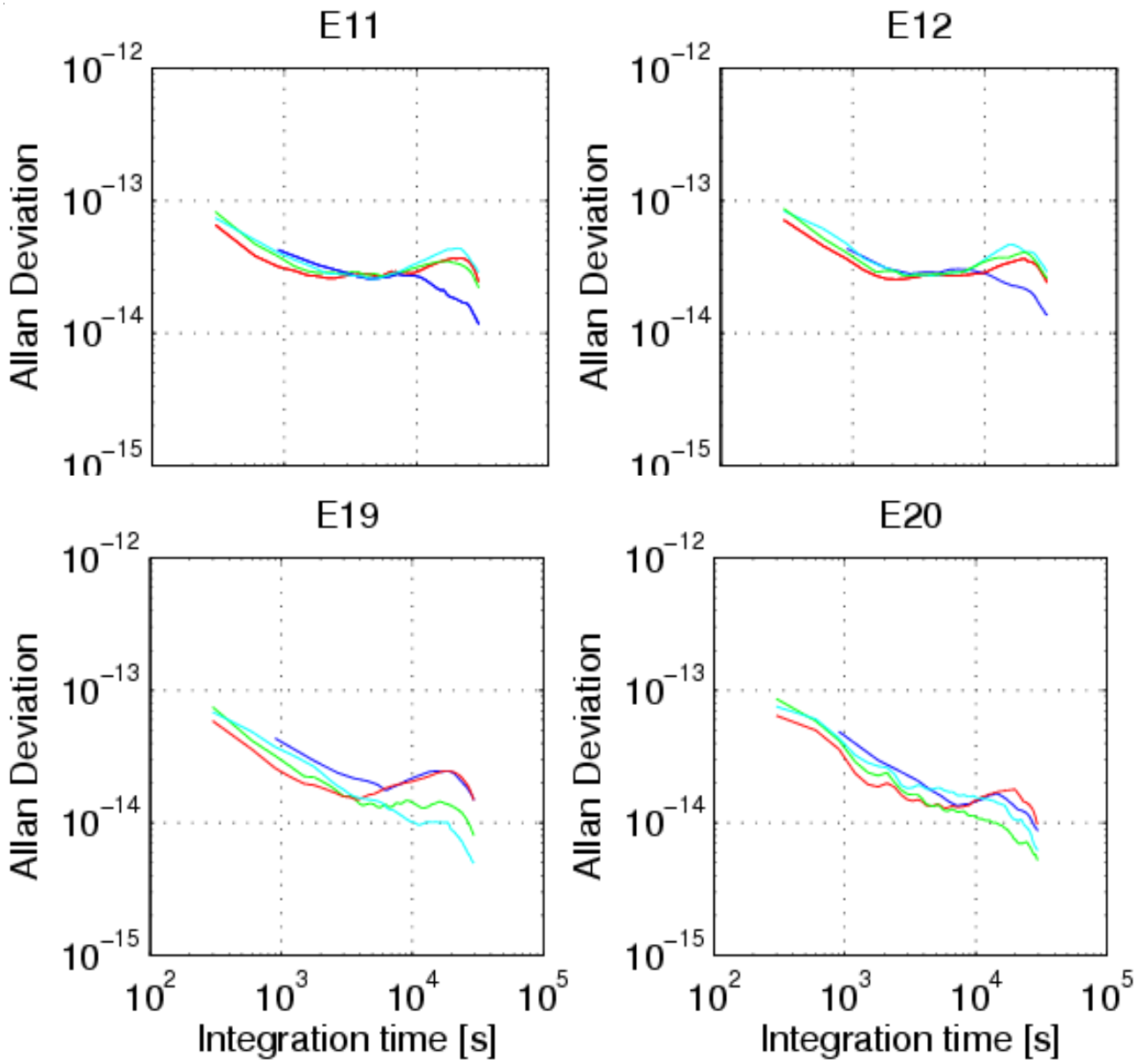
Clock validation



Median
Allan deviations of
Galileo PHM clocks
from 7 days of data
(GPS week 1738;
DOY 13/118 - 124)

COM
GFM
GRM
TUM

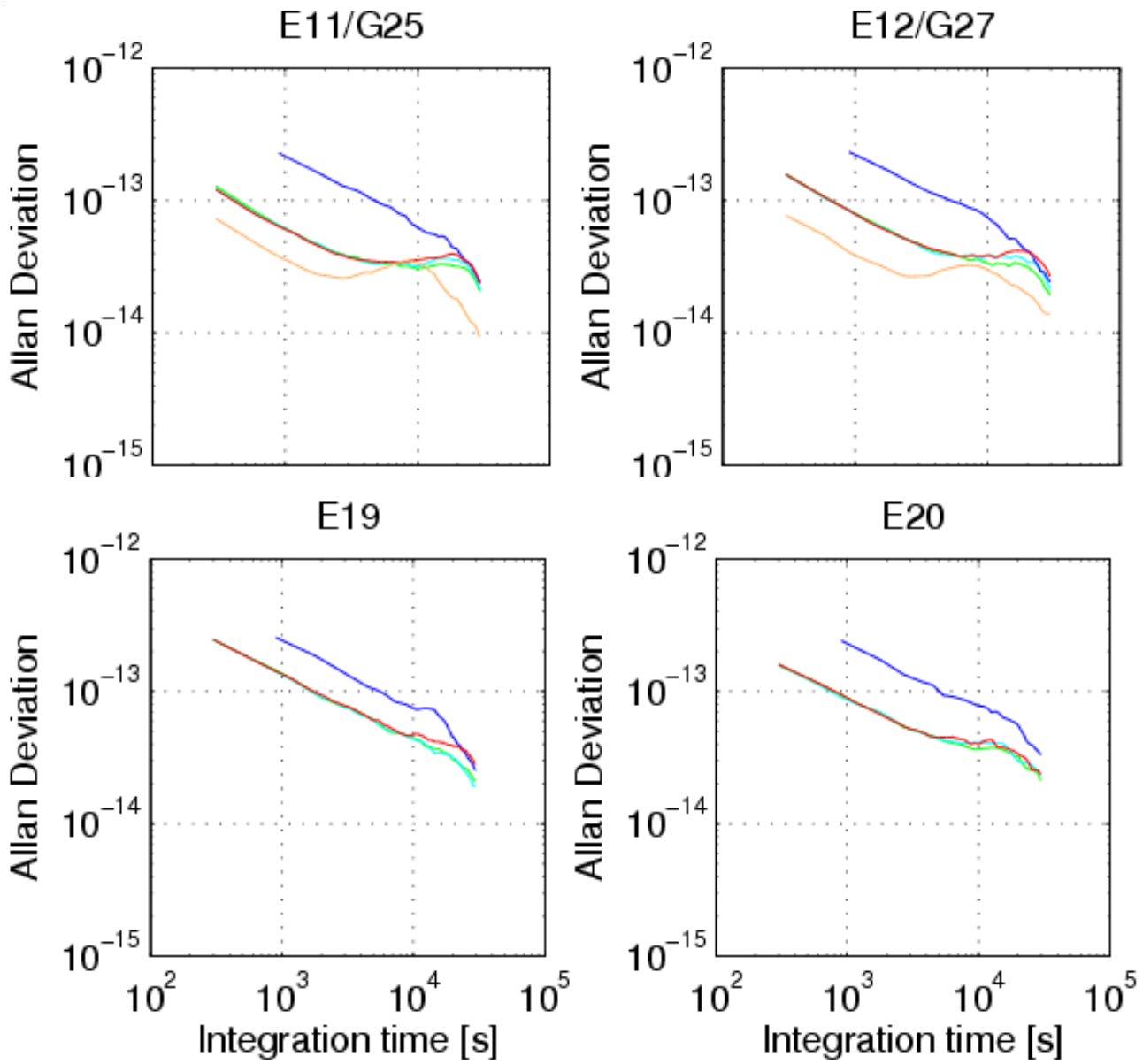
Clock validation



Median
Allan deviations of
Galileo PHM clocks
from 7 days of data
(GPS week 1750;
DOY 13/202 - 208)

COM
GFM
GRM
TUM

Clock validation



Median
Allan deviations of
Galileo RAFS clocks
from 3 weeks of data
(GPS weeks
1754 – 1757;
DOYs 13/234 - 254)

COM

GFM

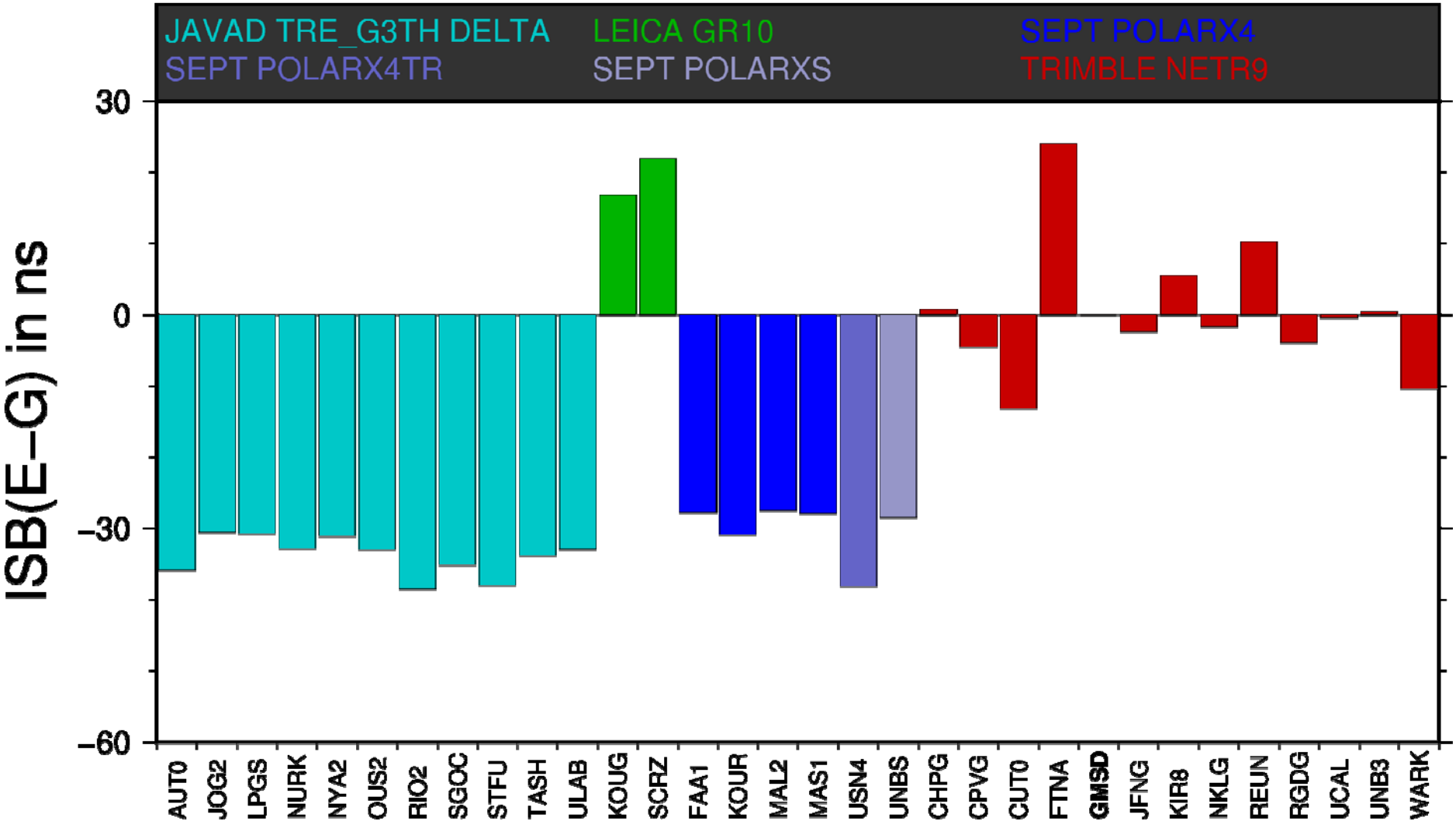
GRM

TUM

GPS IIF

Biases

Galileo–GPS ISB for COM solution (frequencies: L1+L2 GPS, L1+L5 GAL)



Summary and outlook

- MGEX Galileo products with different features available (**short latency**: TUM; **all GNSS** included: ESM; **long time series**: COM, GFM, TUM, GRM)
- **Precision** of Galileo MGEX products is generally **below the one decimeter level**
- **Radial accuracy** as evaluated by SLR is at the **one decimeter level** with a systematic **bias of about 5 cm**
- Galileo **Broadcast orbits** have a **meter level accuracy**
- **Systematic effects** visible in orbits and clocks of **all ACs** due to orbit modeling problems (radiation pressure)
- **Modeling deficiencies** due to lack of knowledge about the satellites:
  - Satellite antenna phase center offsets and variations
  - Attitude behavior, satellite dimensions, and surface properties