Advancing the orbit model for Galileo satellites during eclipse seasons

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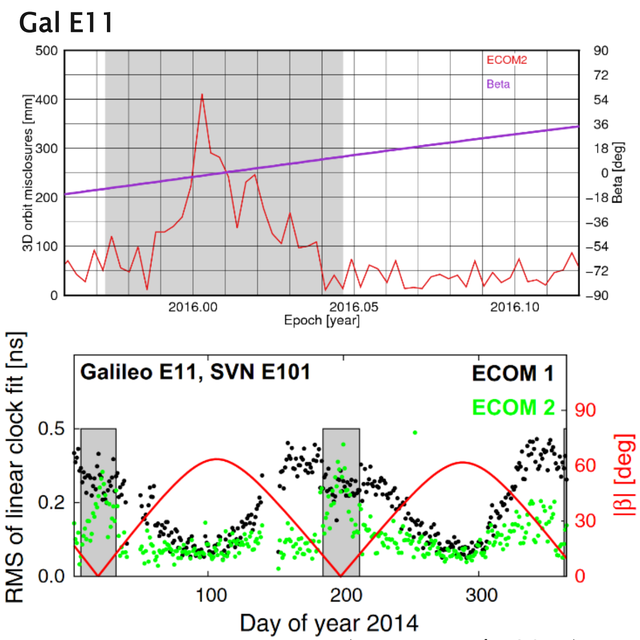
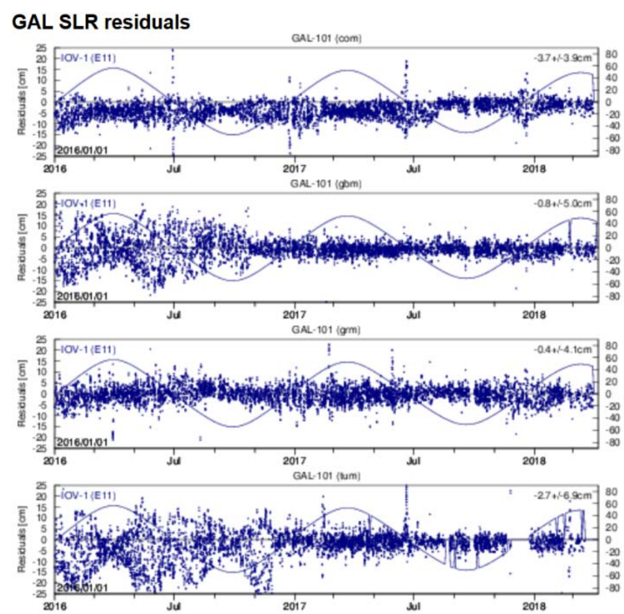
Motivation

- Poor (Galileo) orbit modelling during eclipse seasons using Empirical CODE Orbit Model (ECOM2; Arnold et. al., 2015):
  - elevated orbit misclosures at day boundaries;
  - artifacts in SLR residuals at low β angles;
  - elevated RMS of linear clock fits during eclipses.



(Prange et al., 2017)



(http://mgex.igs.org/analysis/slrres_GAL.php)

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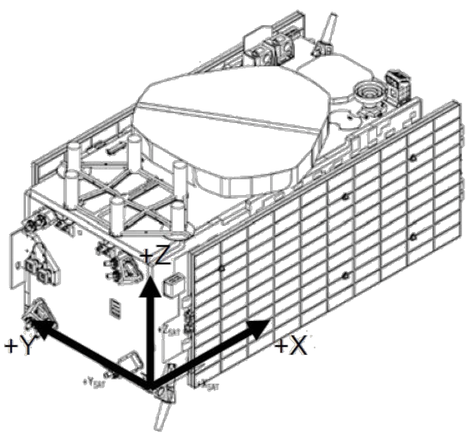
Possible reasons

- Incorrect modelling of satellite attitude (nominal instead of the “true”).
  - Corrected thanks to the metadata of Galileo IOV and FOC satellites published by GSA.
- Insufficient SRP model parameterization.
  - More demanding to the modelling due to low satellite weight, but reasonably solved by ECOM2.
- Thermal effects are not fully absorbed (e.g., during eclipse seasons).
  - All empirical (SRP) parameters are switched off in eclipses.

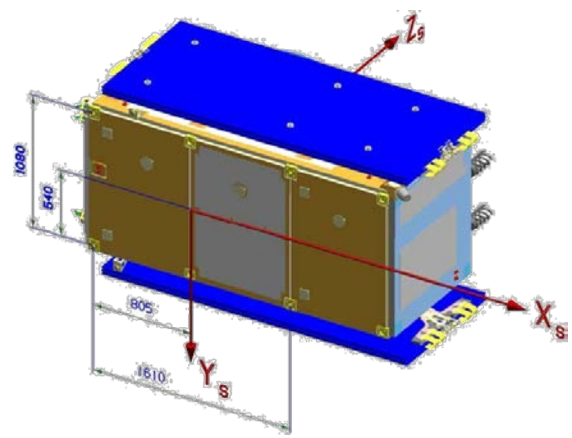
Galileo Satellites

- From the metadata* published by GSA:
  - thermal radiators on +X, +Y, -Y, -Z (FOC only) faces of the satellite body;
  - Galileo satellite mass ~700 kg.

IOV



FOC



(*) https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata

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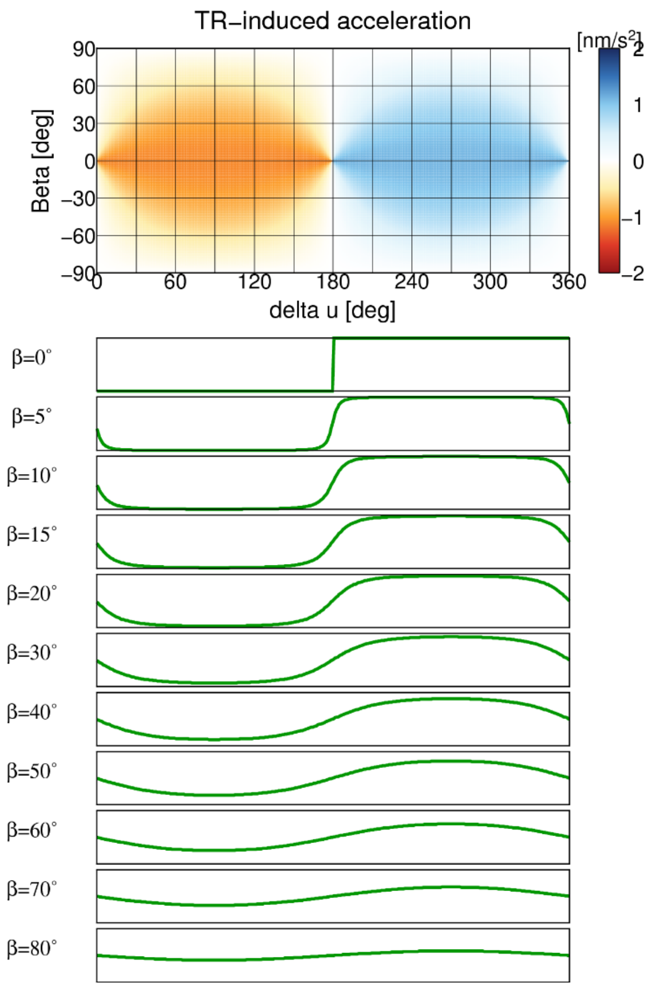
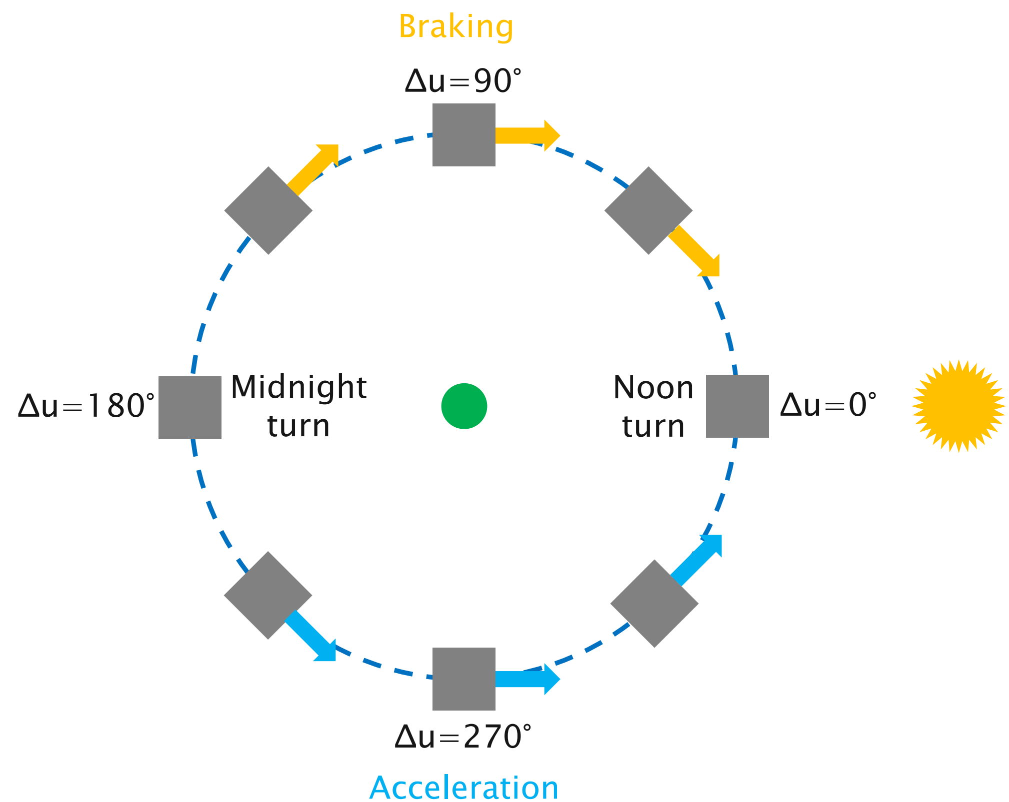
Simulations of +X radiator effects

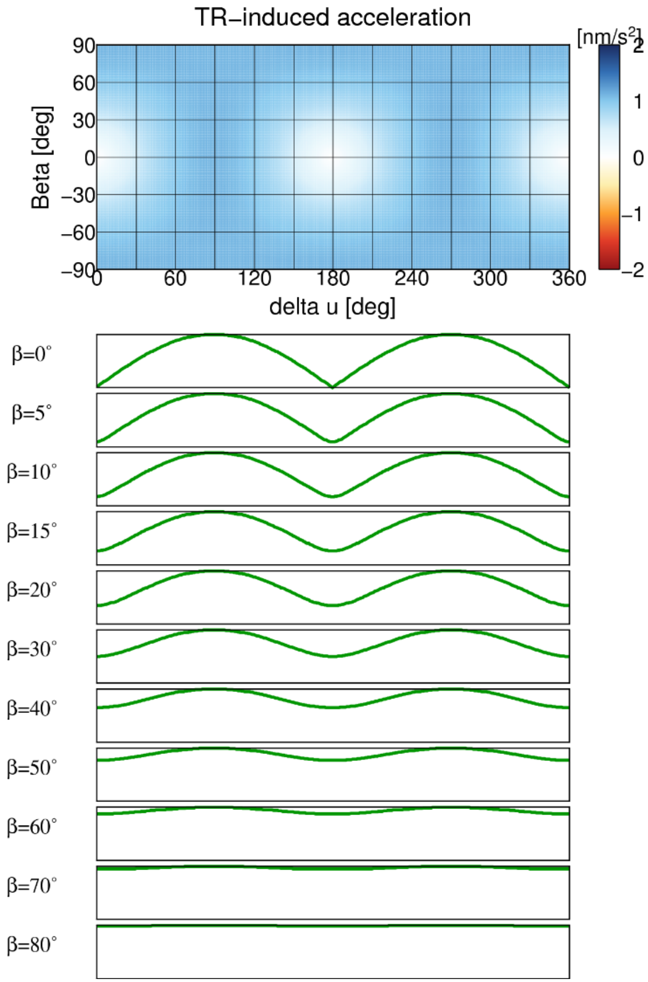
Along-track component





Additional terms in ECOM2 (D1S)

Projection on ECOM2 *D* axis (satellite–Sun)



To be accounted by ECOM2:

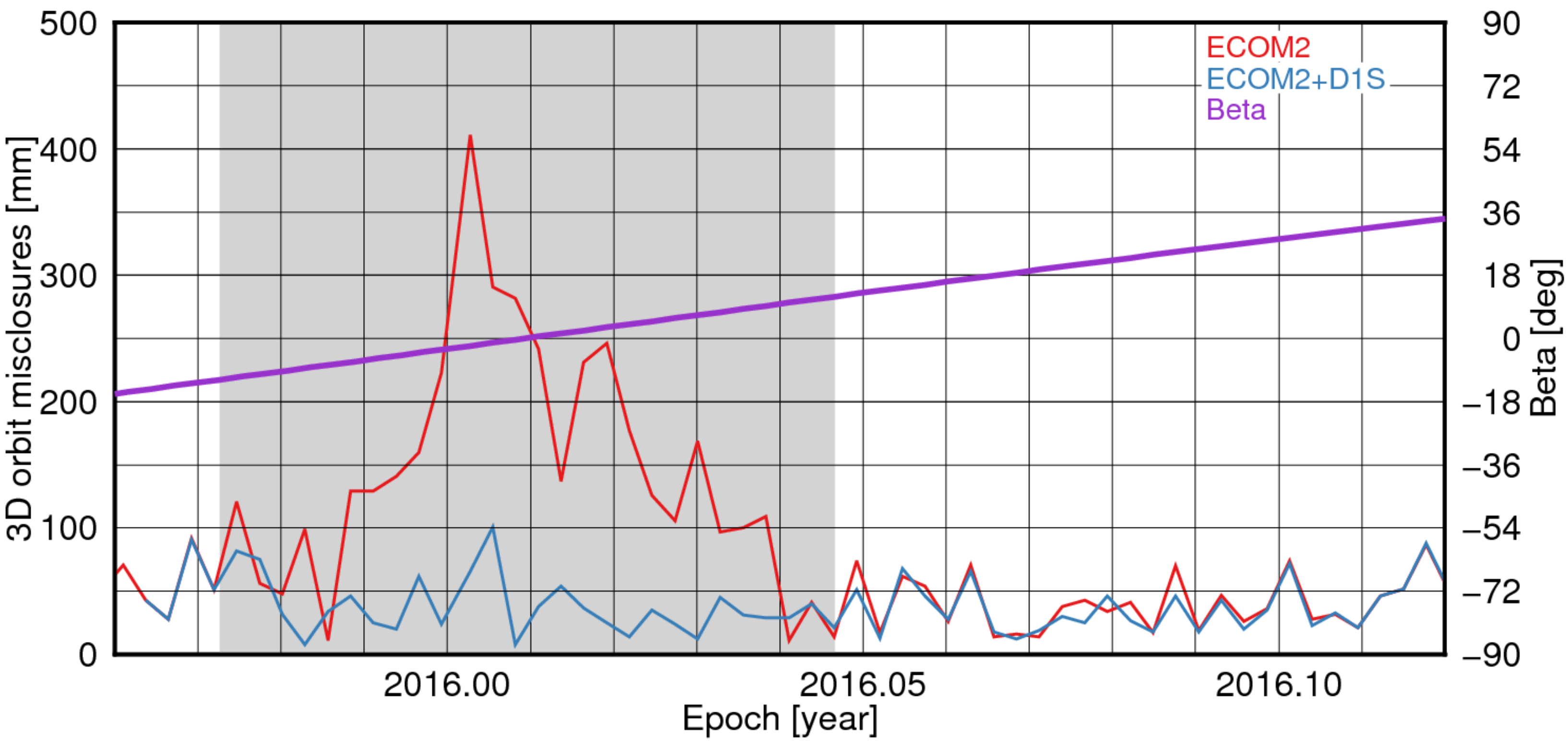
- for low β angles requires a once–per–rev sine term in *D*,
- for high β angles a constant term in *D* is sufficient.

Actions taken:

- introduced D1S for $|\beta|<12°$ for Galileo satellites,
- reprocessed the data from one eclipse season for Galileo.

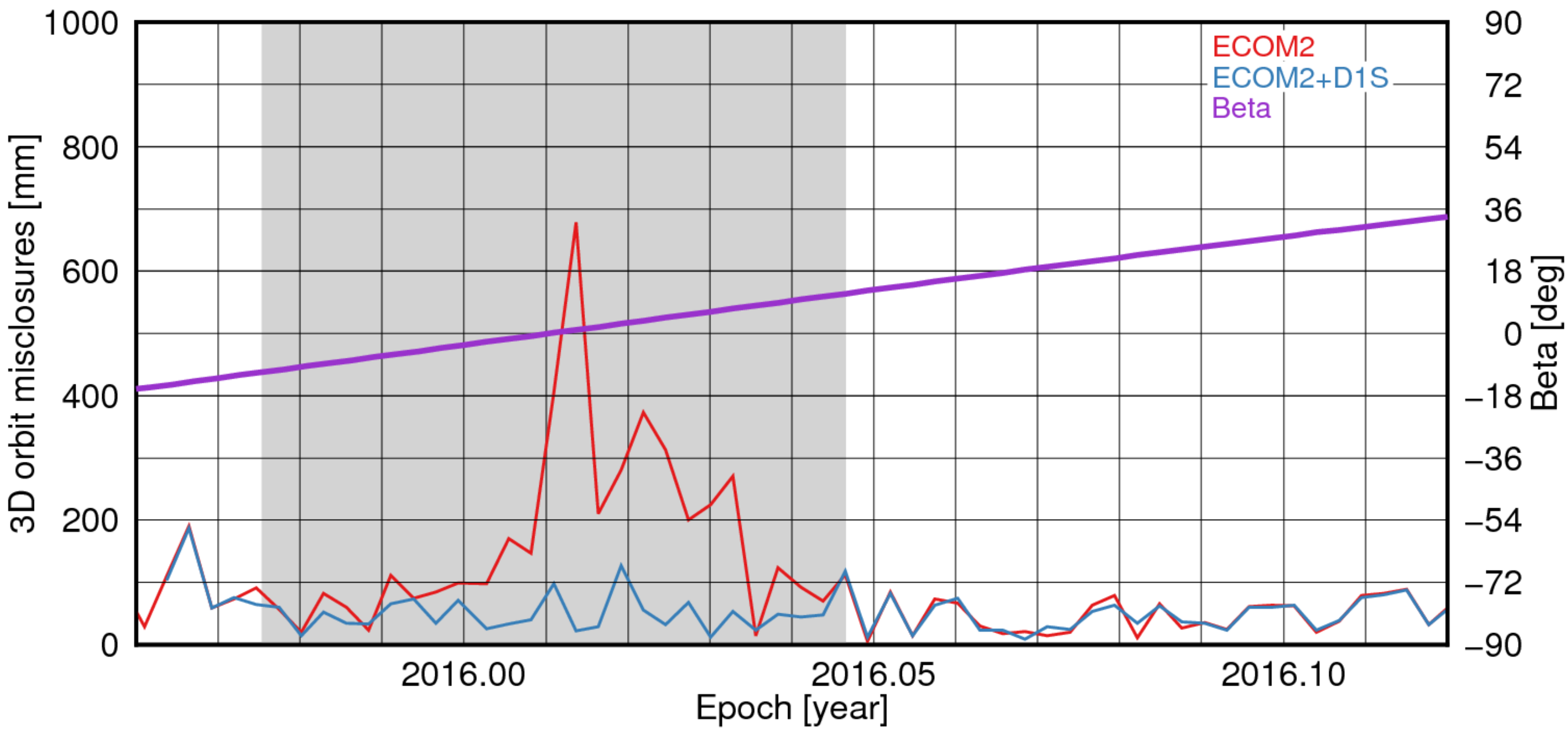
Results: Orbit Misclosures

- **Orbit misclosures for E11 during eclipse phase in Dec 2015 – Jan 2016:**



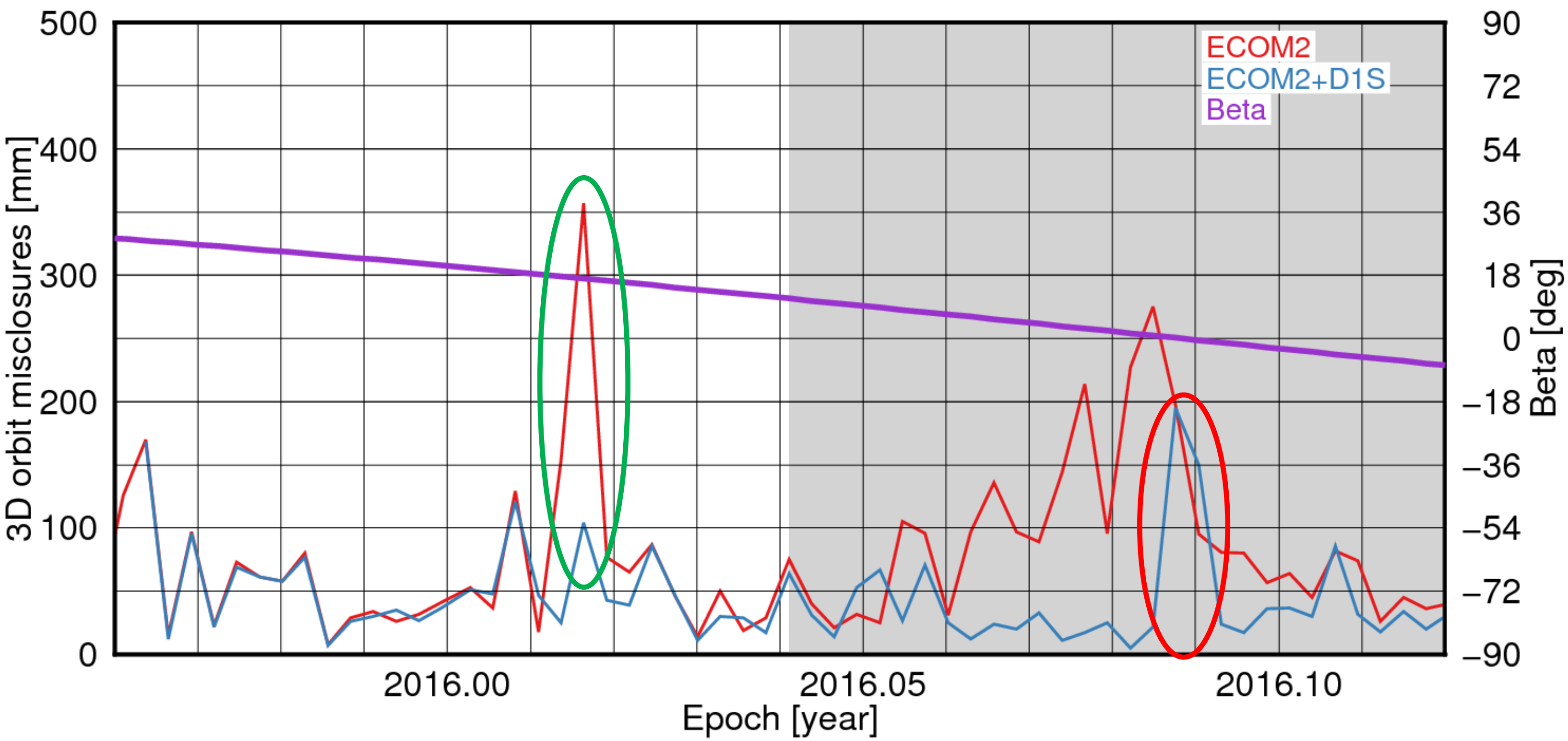
Results: Orbit Misclosures

- **Orbit misclosures for E26 during eclipse phase in Dec 2015 – Jan 2016:**



Results: Orbit Misclosures

- **Orbit misclosures for E30 during eclipse phase in Jan – Feb 2016:**



Results: SLR Residuals

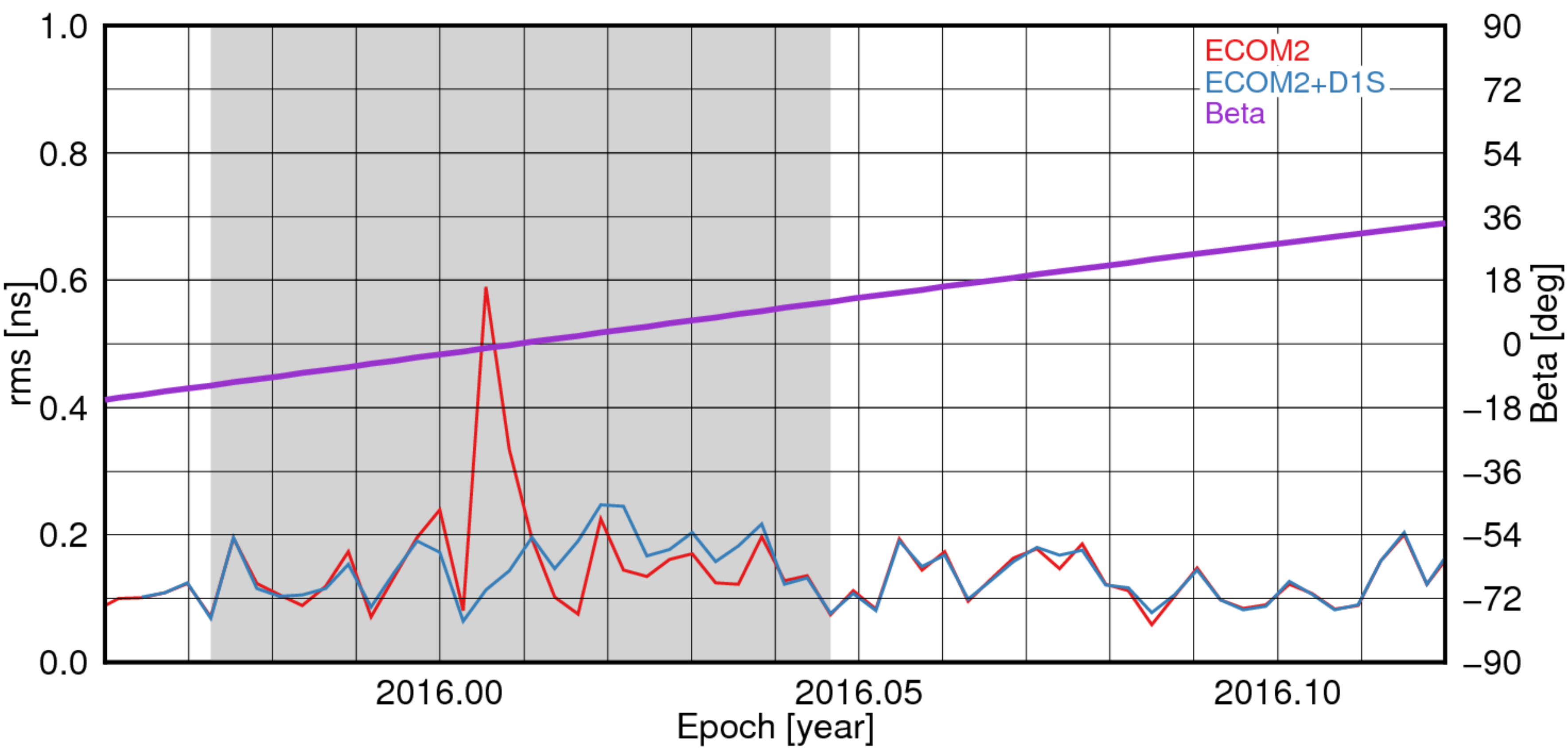
Summary on the SLR residuals:

- **the pattern is left unchanged (shrinking at orbit noon and expansion at orbit midnight);**
- **the scatter of the SLR residuals is reduced during eclipse phases in Dec 2015 – Feb 2016:**

	ECOM2	ECOM2+D1S
IOV	−12.7 ± 57.3	−16.7 ± 53.8
FOC	−9.7 ± 49.0	−11.5 ± 46.7
IOV+FOC	−10.6 ± 52.3	−13.4 ± 49.6

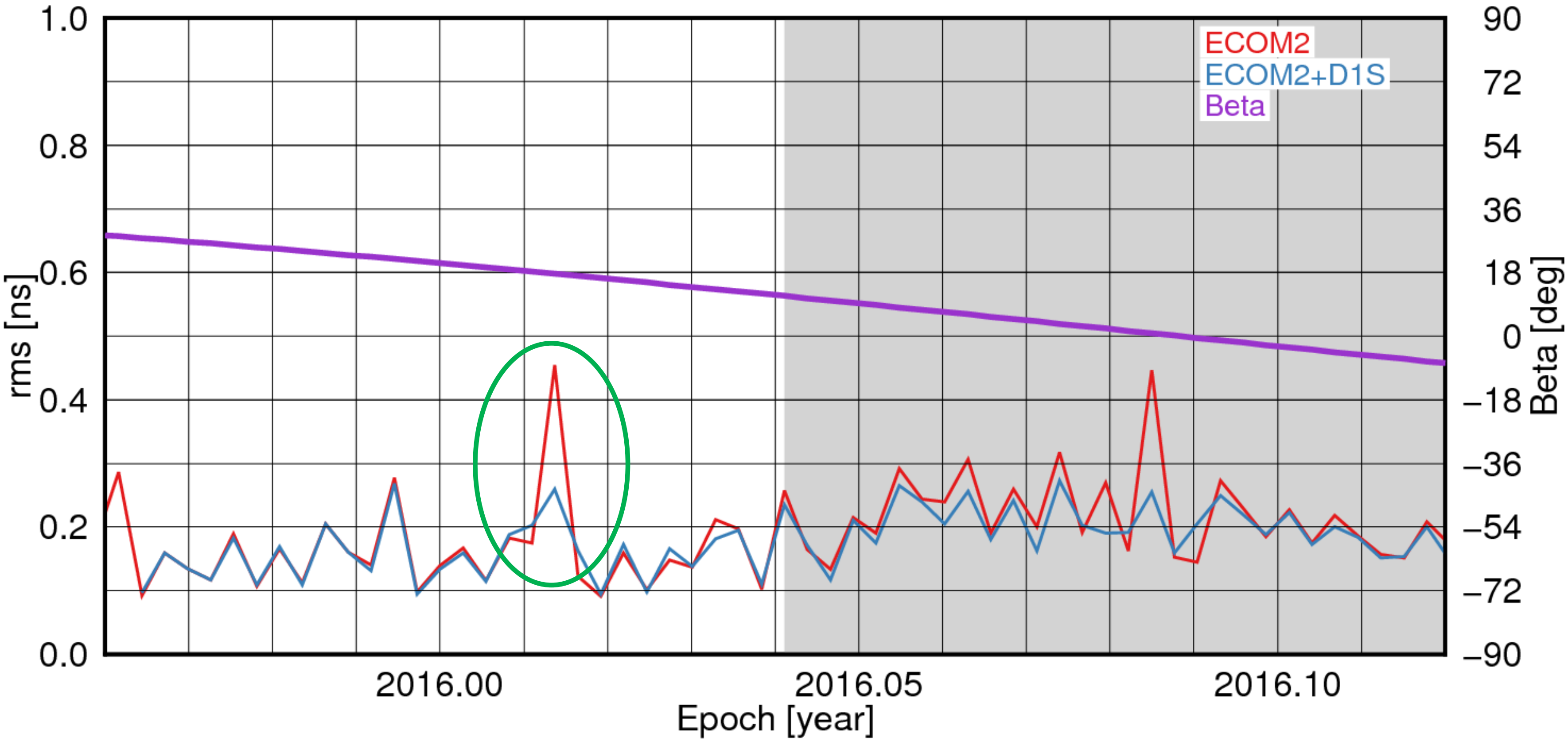
Results: Satellite Clocks

- RMS of the linear clock fit for E11 in Dec 2015 – Feb 2016:



Results: Satellite Clocks

- RMS of the linear clock fit for E30 in Dec 2015 – Feb 2016:



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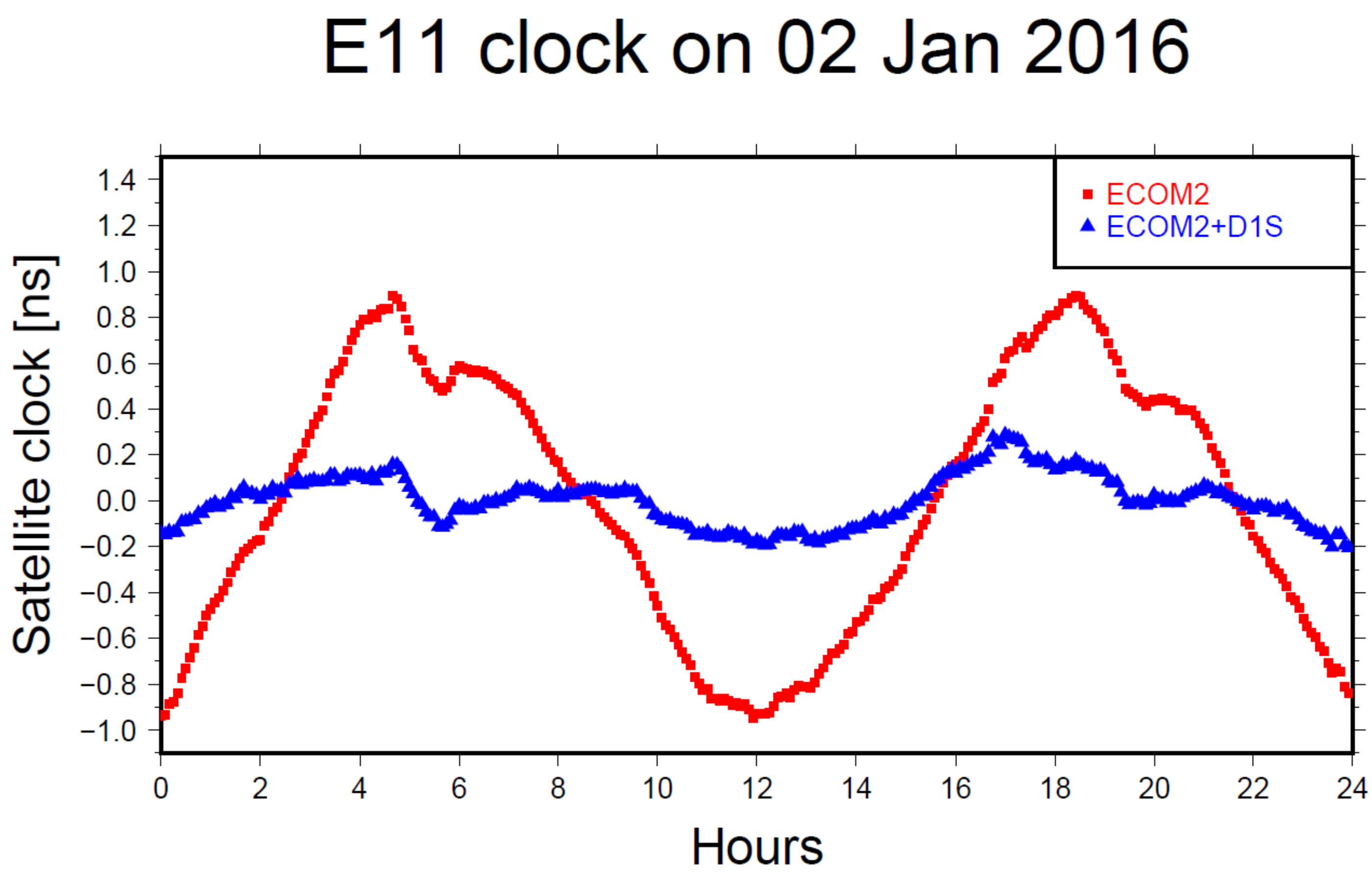
Results: Satellite Clocks

- **Estimated satellite clocks (extreme case):**



Conclusion

- The recently published Galileo metadata shed light on how to model shadow crossings of the satellites, e.g.,
  - attitude control,
  - complete antenna correction models,
  - surface properties.
- Details on the internal temperature management of the satellites are appreciated.
- The unaccounted thermal effects may significantly deteriorate the estimated orbit.
- Addition of once-per-rev sine term in D to ECOM2 during eclipses significantly improves orbit modelling of Galileo satellites (should be added only for small β angles).