SLR measurements and their importance for Galileo

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Issue/Revision: 1.0
Reference:
Status:

Outline

1. ESA/Galileo support to ILRS
2. SLR tracking of Galileo satellites
3. Galileo benefits from SLR
4. Galileo, next steps
5. Discussion

ESA support to ILRS

ESA agreed to provide:

- Orbit predictions to ILRS:
  - ESOC as prediction centre
  - GCC (Oberpfaffenhofen) as backup and for initial tracking
- Galileo satellite information to ILRS
  - Reflector shape
  - Cube geometry and material
  - Reflector centre of phase position
  - Satellite centre of mass position

ESA support to ILRS
ESA sends predictions for all active Galileo satellites
Galileo (gal), ESA (esa)

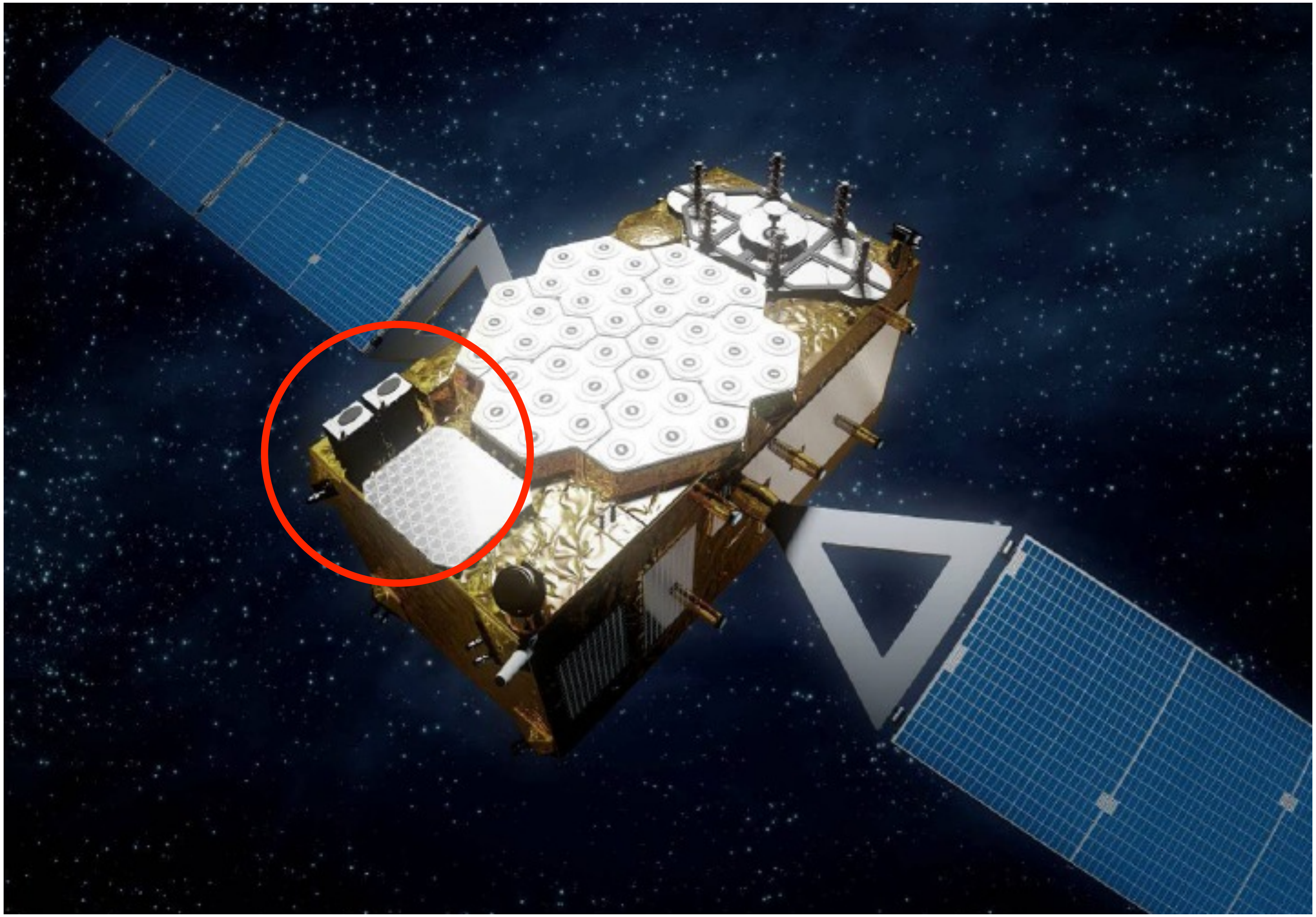
galileo101_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM
galileo101_cpf_151012_7851.gal	39.2 kB	10/12/15, 8:41:00 AM
galileo102_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM
galileo102_cpf_151012_7851.gal	39.2 kB	10/12/15, 8:41:00 AM
galileo103_cpf_151011_7841.gal	39.2 kB	10/11/15, 5:41:00 AM
galileo103_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM
galileo104_cpf_151011_7841.gal	39.2 kB	10/11/15, 5:41:00 AM
galileo104_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM
galileo201_cpf_151011_7841.gal	39.2 kB	10/11/15, 5:51:00 AM
galileo201_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM
galileo202_cpf_151011_7841.gal	39.2 kB	10/11/15, 6:01:00 AM
galileo202_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM
galileo203_cpf_151011_7841.gal	39.2 kB	10/11/15, 6:01:00 AM
galileo204_cpf_151010_7831.gal	39.2 kB	10/10/15, 6:01:00 AM
galileo204_cpf_151012_7851.esa	38.7 kB	10/12/15, 5:51:00 AM

ESA support to ILRS
Post manoeuvre CoM offsets provided to ILRS

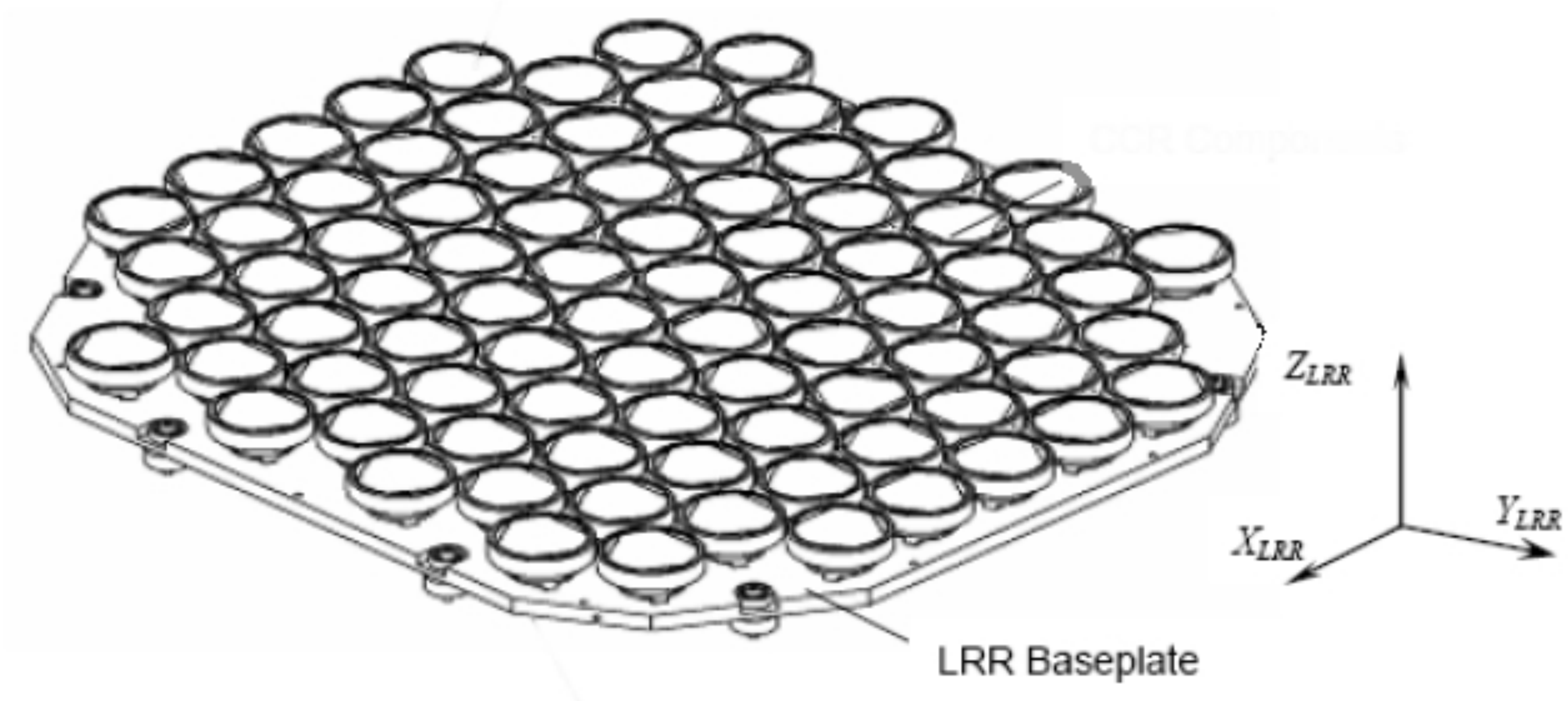
Galileo-101	Galileo-102
Issue Date: 2014-11-20T17:34:07.239	Issue Date: 2014-11-20T17:34:07.239
Satellite Mass: 696.815 kg	Satellite Mass: 694.778 kg
CoM X: 1.205844 m	CoM X: 1.205333 m
CoM Y: 0.628967 m	CoM Y: 0.628807 m
CoM Z: 0.553436 m	CoM Z: 0.551409 m
Galileo-103	**Galileo-104**
Issue Date: 2014-12-01T15:24:04.447	Issue Date:2014-11-20T17:34:07.239
Satellite Mass: 697.632000000000 kg	Satellite Mass: 695.652 kg
CoM X: 1.20529100000000 m	CoM X: 1.20532 m
CoM Y: 0.629577000000000 m	CoM Y: 0.628956 m
CoM Z: 0.552809000000000 m	CoM Z: 0.551509 m

Galileo-201	Galileo-202
Issue Date: 2015-05-11T12:25:45.141	Issue Date: 2015-05-11T12:25:45.141
Satellite Mass: 660.977000000000 kg	Satellite Mass: 662.646000000000 kg
CoM X: 0.331700000000000 m	CoM X: 0.314043000000000 m
CoM Y: -1.350000000000000E-002 m	CoM Y: -1.259100000000000E-002 m
CoM Z: 0.561900000000000 m	CoM Z: 0.562313000000000 m
Galileo-203	**Galileo-204**
Issue Date: 2015-05-11T12:25:45.141	Issue Date: 2015-05-11T12:25:45.141
Satellite Mass: 706.162000000000 kg	Satellite Mass: 706.619000000000 kg
CoM X: 0.259110000000000 m	CoM X: 0.260607000000000 m
CoM Y: -9.211000000000000E-003 m	CoM Y: -9.296000000000000E-003 m
CoM Z: 0.561133000000000 m	CoM Z: 0.561128000000000 m

Galileo IOV LRA

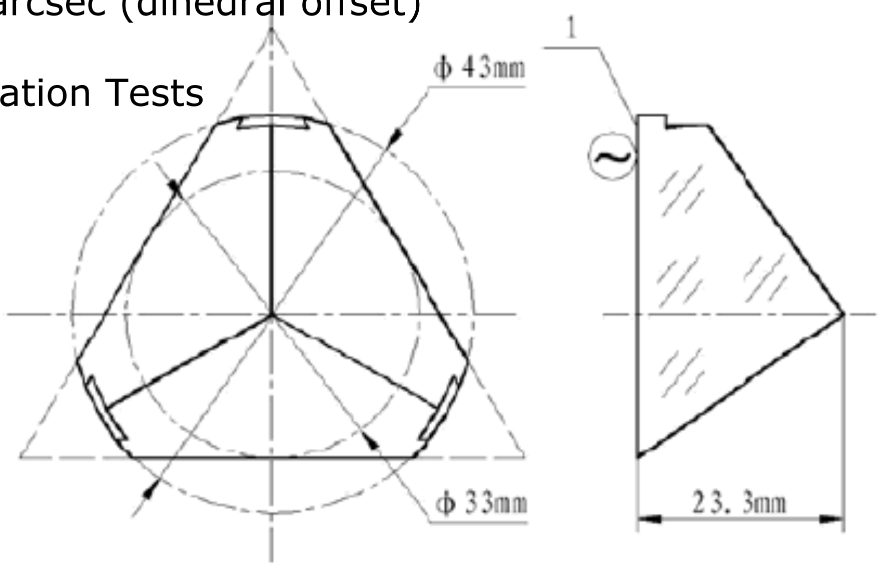


IOV LRA



IOV LRA, as reported on SLR Mission Request

1. 84 Corner Cube Reflectors (CCR)
    a. doped fused silica (Suprasil 311) glass tetrahedron
    b. no metallic coating on reflective surfaces
    c. front surface coated with ITO
    d. aperture face is included in a circle of 43 mm diameter
    e. Minimum aperture 33 mm diameter
    f. height of the tetrahedron is 23.3 mm
    g. Iso-static mounting to plate
    h. N = 1.46, critical angle16.9 deg
        - which covers the entire LRR operating range (Earth radius of 12.44°)
        - no coating, total reflection is obtained without any loss
    i. Velocity aberration compensation 0.8 arcsec (dihedral offset)
    j. CCR are randomly oriented
    k. LRA Centre of Phase TBD after Qualification Tests



IOV LRA, as reported on SLR Mission Request

4 IOV S/C, manufactured by Astrium (G)

Array type: Planar, 84 Corner Cube Reflectors (CCR).

Array manufacturer: North China Research Institute of Electro Optics

Phase centre of the LRA relative to a satellite-based origin:

X = 2298 mm, Y = 595 mm, Z = 1174 mm

Cube:

Parallel to the LRA plate, random rotation perpendicular to plate.

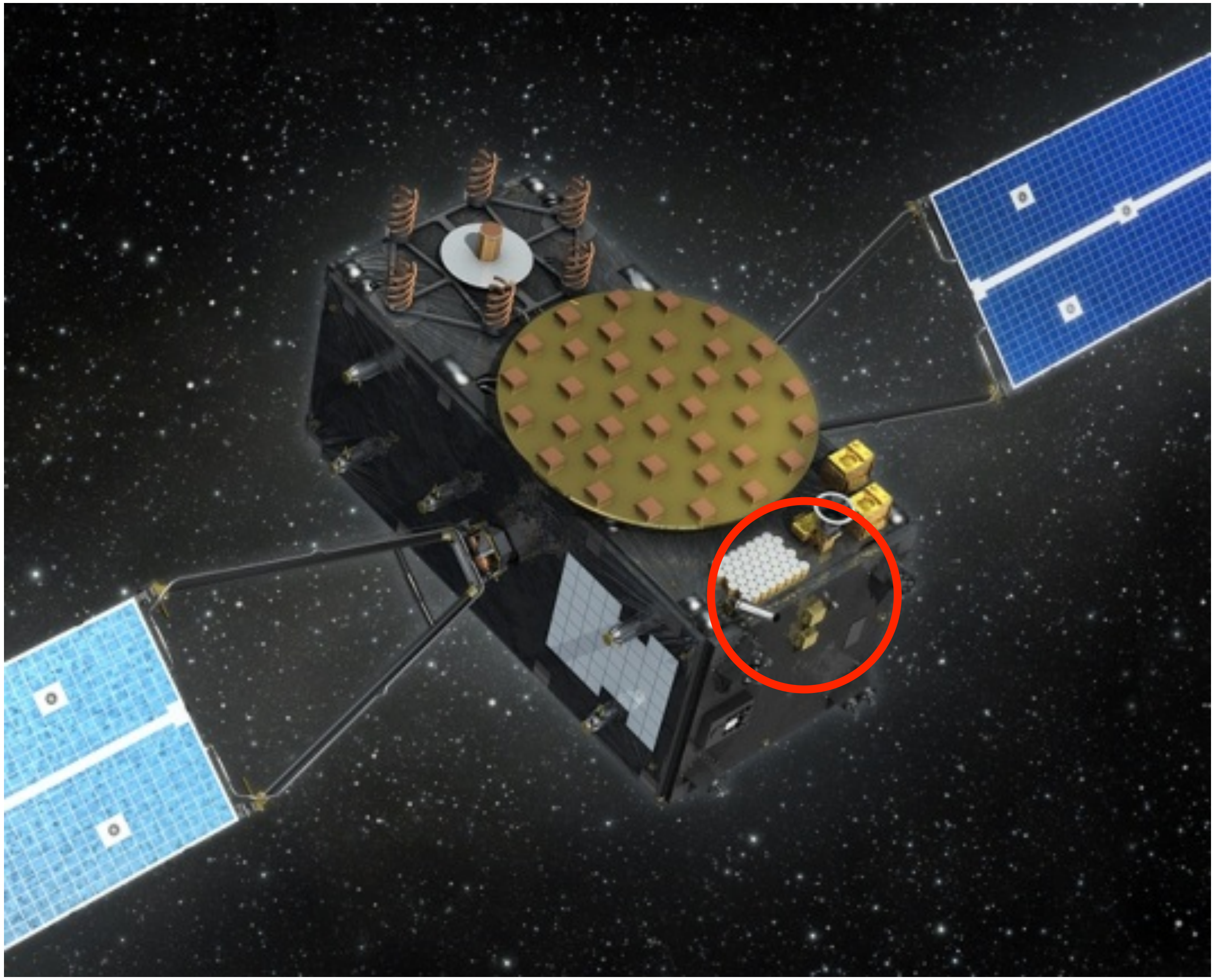
Height 23.3 mm, diameter 43 mm (aperture)

N = 1.46, critical angle 16.9 deg

Dihedral angle offset(s) and manufacturing tolerance: 0.80 arcsec

Reflective surface uncoated, incident surface coated with ITO

FOC LRA location on S/C



FOC LRA, as will be reported on SLR Mission Request

14 FOC1 + 8 FOC2 S/C, manufactured by OHB, Payload by SSTL

Array type: Planar, 60 CCR.

Array manufacturer: Institute for Precision Instrument Engineering (PSI)

Previously used on the following missions:

- Glonass-729 (launched on 25 December 2008)
- Glonass-736, Glonass-737, Glonass-738

Phase centre of the LRA relative to a satellite-based origin:

- X = -703mm, Y = -27.5mm, Z = 1117.45mm

Cube

- Parallel to the LRA plate, random rotation perpendicular to plate.
- Height 19.1 mm, diameter 28.2 mm (aperture)
- Fused silica КУ1 n=1.46 for 532 nm
- Dihedral angle offset(s) and manufacturing tolerance: 0.50 arcsec
- Reflective surface uncoated, no anti-reflection coating on front

ILRS Mission Priorities

23	GLONASS-123	glonass123	1004102	9123	Russia	19,100	65	
24	GLONASS-125	glonass125	1100901	9125	Russia	19,100	65	
25	GLONASS-128	glonass128	1106401	9128	Russia	19,100	65	
26	GLONASS-129	glonass129	1106402	9129	Russia	19,100	65	
27	GLONASS-133	glonass133	1403201	9133	Russia	19,100	65	
28	GLONASS-134	glonass134	1407501	9134	Russia	19,100	65	
29	COMPASS-M3	compassm3	1201801	2004	China	21,528	55.0	
30	Galileo-101	galileo101	1106001	7101	ESA	23,220	56	
31	Galileo-102	galileo102	1106002	7102	ESA	23,220	56	
32	Galileo-103	galileo103	1205501	7103	ESA	23,220	56	
33	Galileo-104	galileo104	1205502	7104	ESA	23,220	56	
34	GPS-36	gps36	9401601	3636	U. S. DOD	20,030	64.8	
35	Galileo-201	galileo201	1405001	7201	ESA	23,220	56	
36	Galileo-202	galileo202	1405002	7202	ESA	23,220	56	
37	Galileo-203	galileo203	1501701	7203	ESA	23,220	56	
38	Galileo-204	galileo204	1501702	7204	ESA	23,220	56	

SLR measurements
Glonass (1 January – 11 October)

	NPT / day[1)]	% days with measurements
GLO-714	5	83.44
GLO-715	9	87.55
GLO-716	12	95.60
GLO-717	9	86.81
GLO-719	7	87.91
GLO-720	8	92.31
GLO-721	10	89.74
GLO-723	10	90.84
GLO-725	6	56.78
GLO-730	7	88.28
GLO-731	8	89.01

[1)] Days without observations are not considered

SLR measurements
Glonass (1 January – 11 October)

	NPT / day[1)]	% days with measurements
GLO-732	9	92.31
GLO-733	7	89.01
GLO-734	10	94.87
GLO-735	10	92.67
GLO-736	13	96.34
GLO-737	23	99.63
GLO-738	16	98.53
GLO-742	17	98.53
GLO-743	14	97.44
GLO-744	19	98.53
GLO-745	26	99.27
GLO-801	12	91.94

[1)] Days without observations are not considered

SLR measurements
Galileo IOV/FOC (1 January – 11 October)

		NPT / day[1]	% days with measurements
IOV	GAL-101	16	96.34
	GAL-102	15	95.97
	GAL-103	17	95.97
	GAL-104	17	97.07
FOC	GAL-201	9	90.73
	GAL-202	9	83.80
	GAL-203	10	72.93
	GAL-204	9	80.70

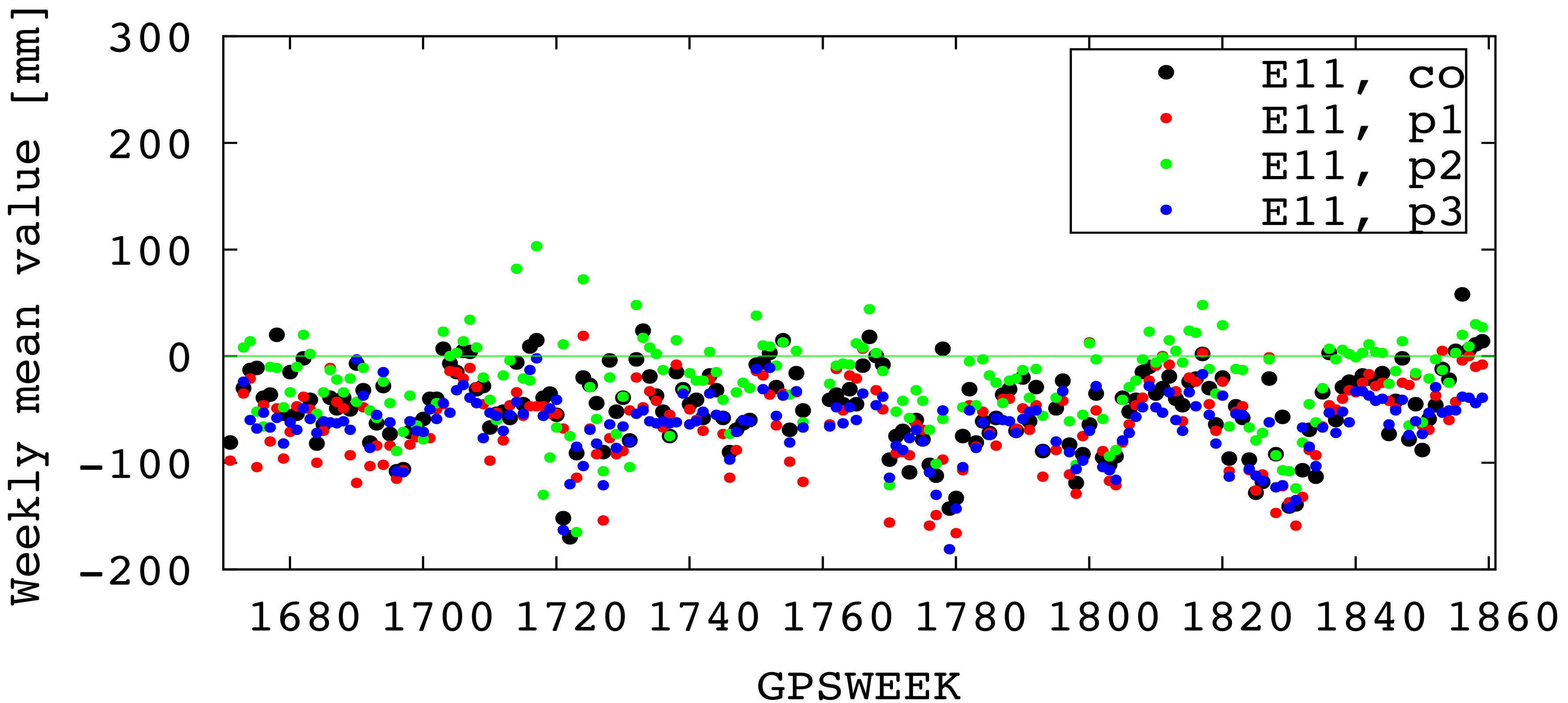
[1] Days without observations are not considered

SLR measurements
Galileo IOV/FOC vs. Glonass (1 January – 11 October)

	NPT / day[1)]	% days with measurements
Galileo IOV	16	96.34
Galileo FOC	9	82.04
Glonass	12	91.24

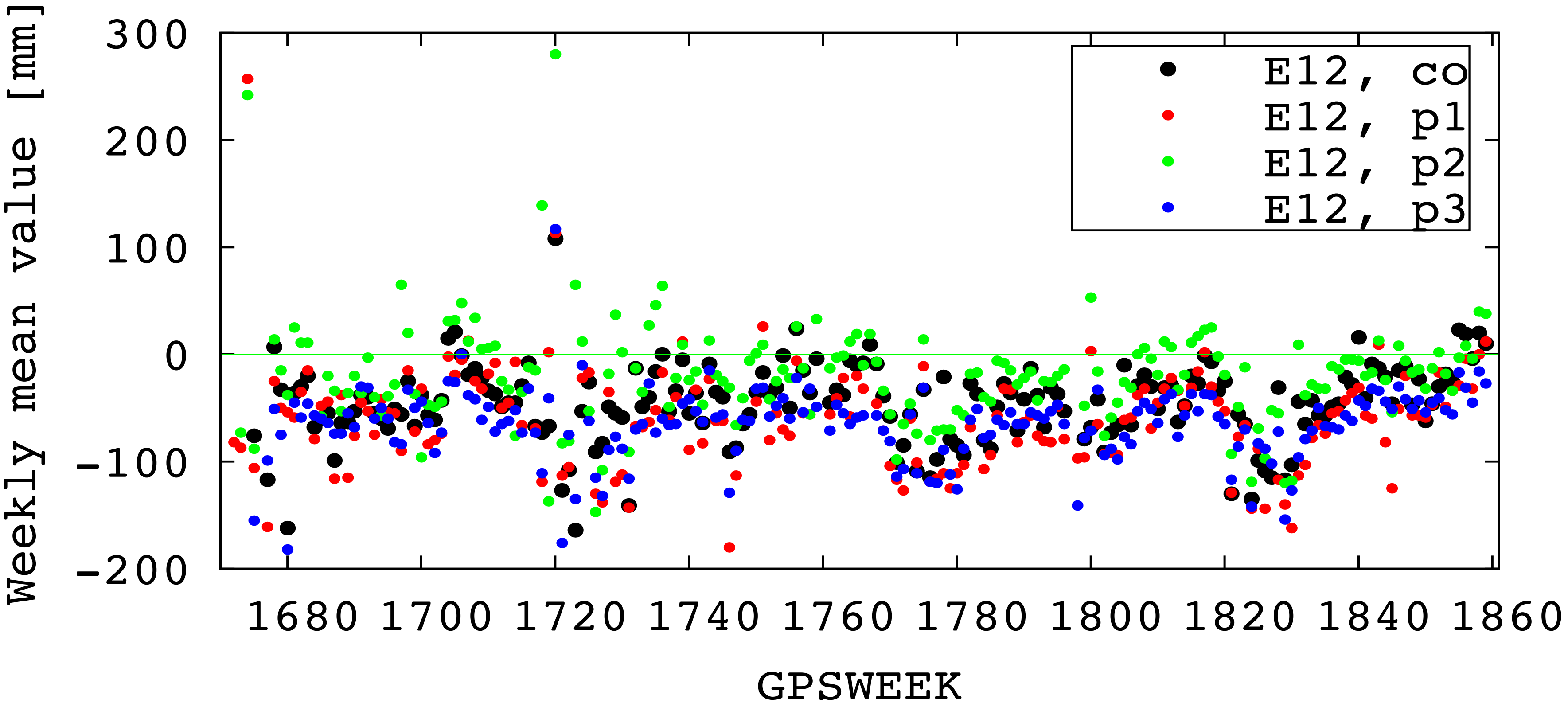
[1)] Days without observations are not considered

Galileo benefits from ILRS
Validation of operational Galileo orbit products



OVF weekly report 26 September 2015

Galileo benefits from ILRS
Validation of operational Galileo orbit products



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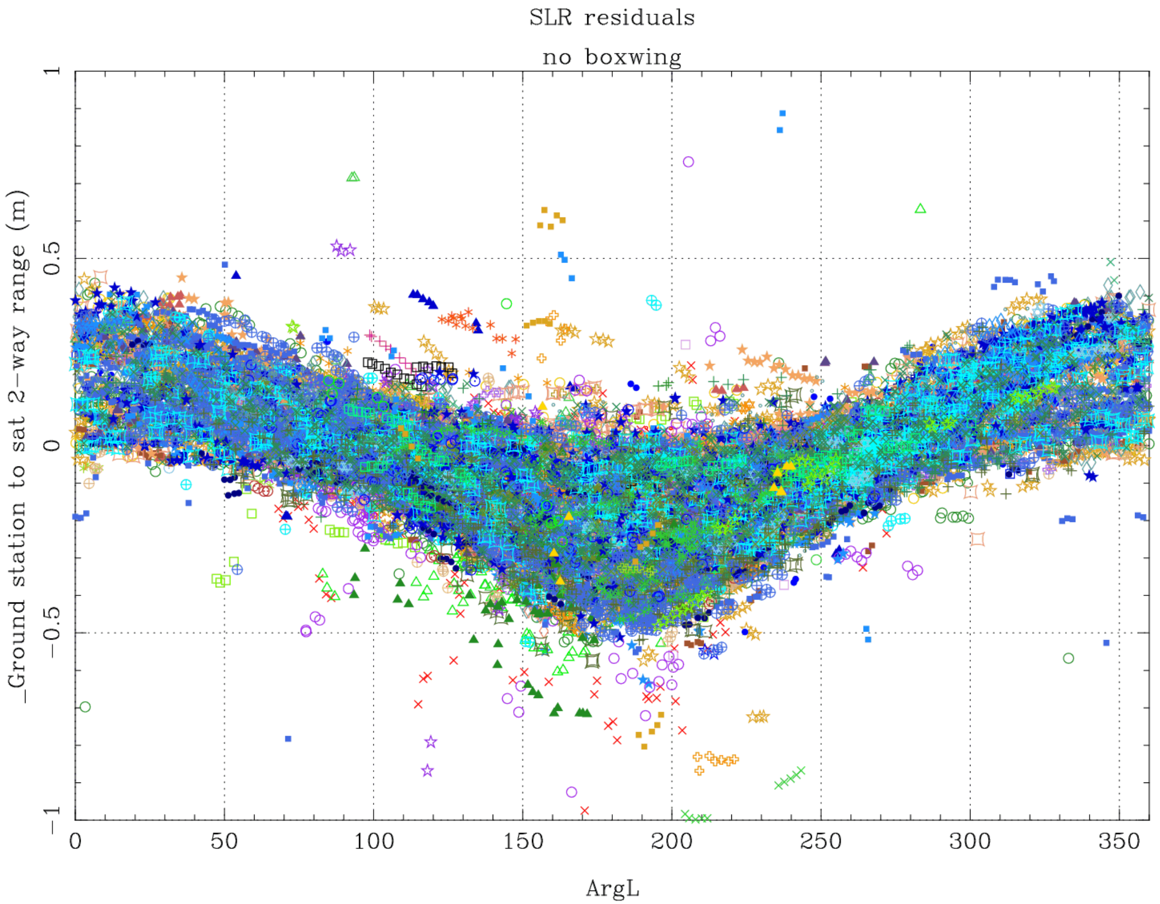
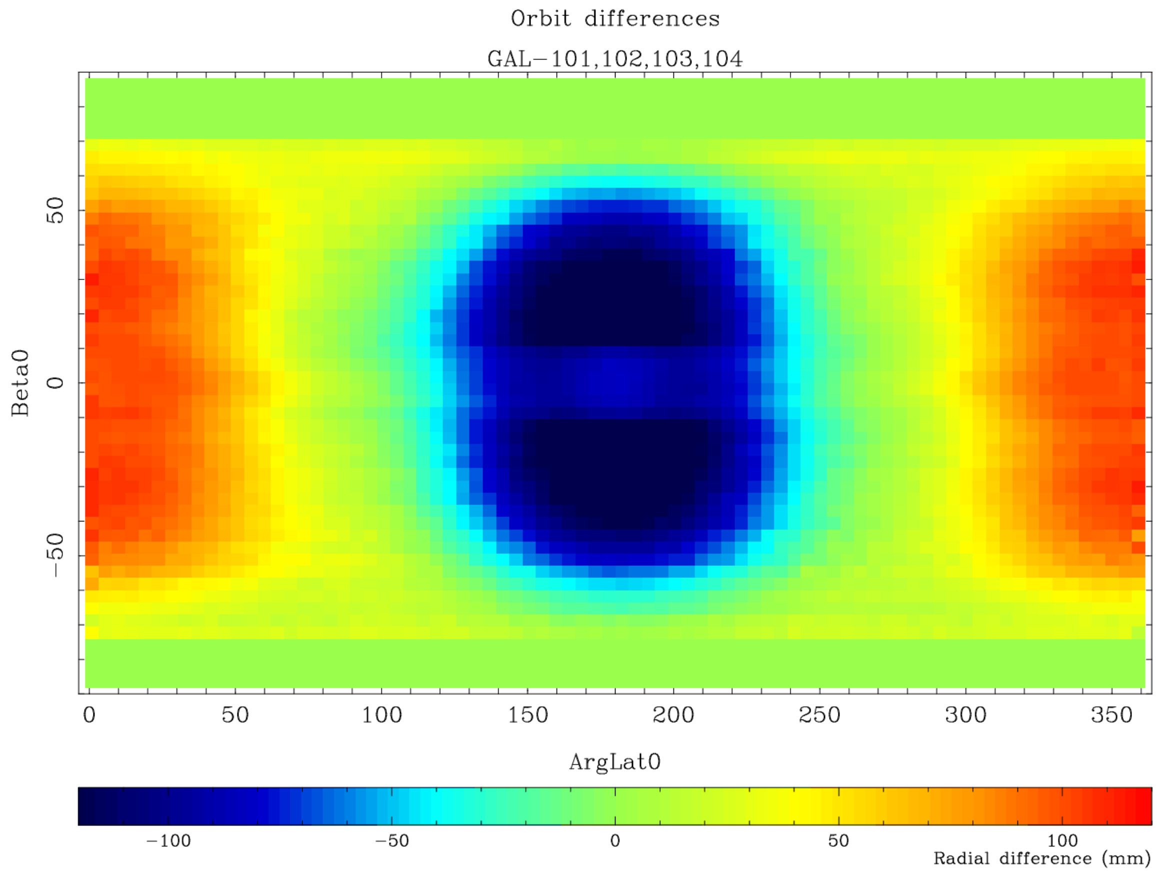
Galileo benefits from ILRS
Validation of operational Galileo orbit products

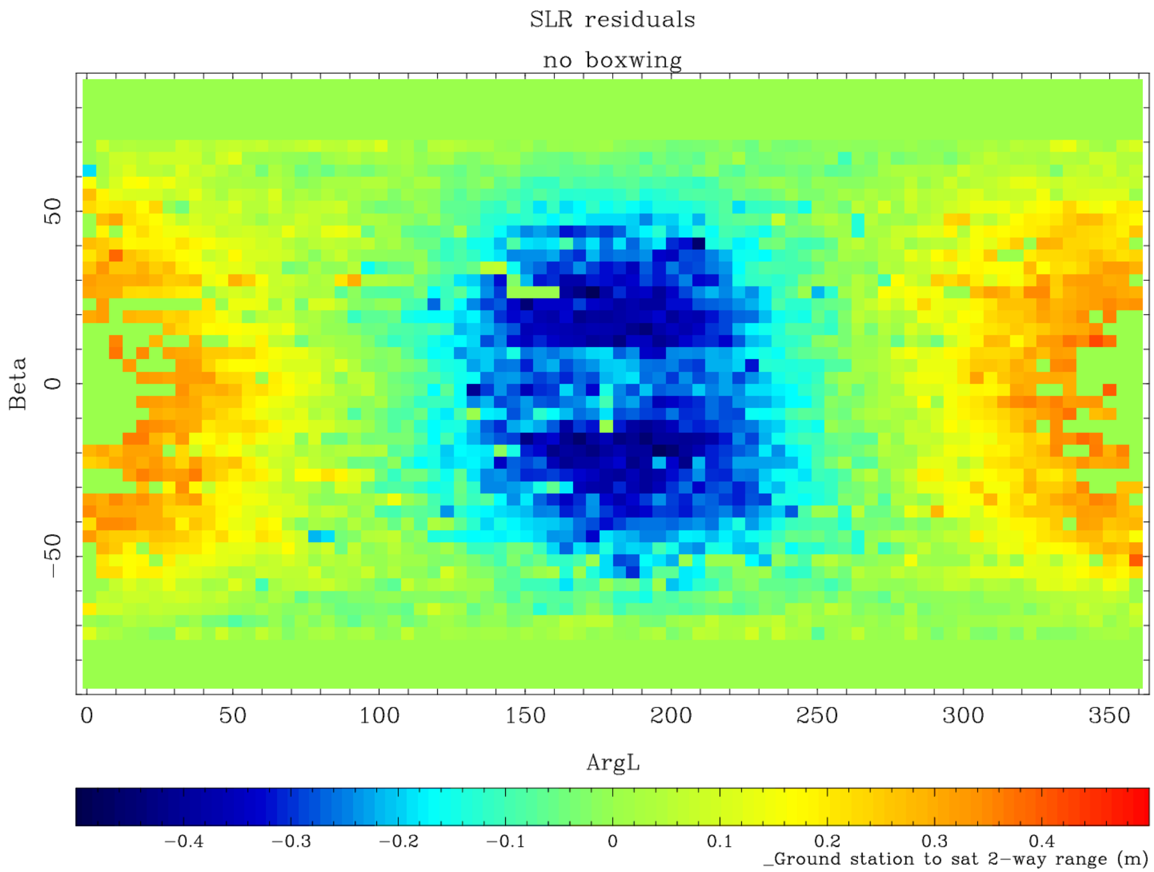


Galileo benefits from ILRS
Model validation
Orbit difference CODE vs. box-wing

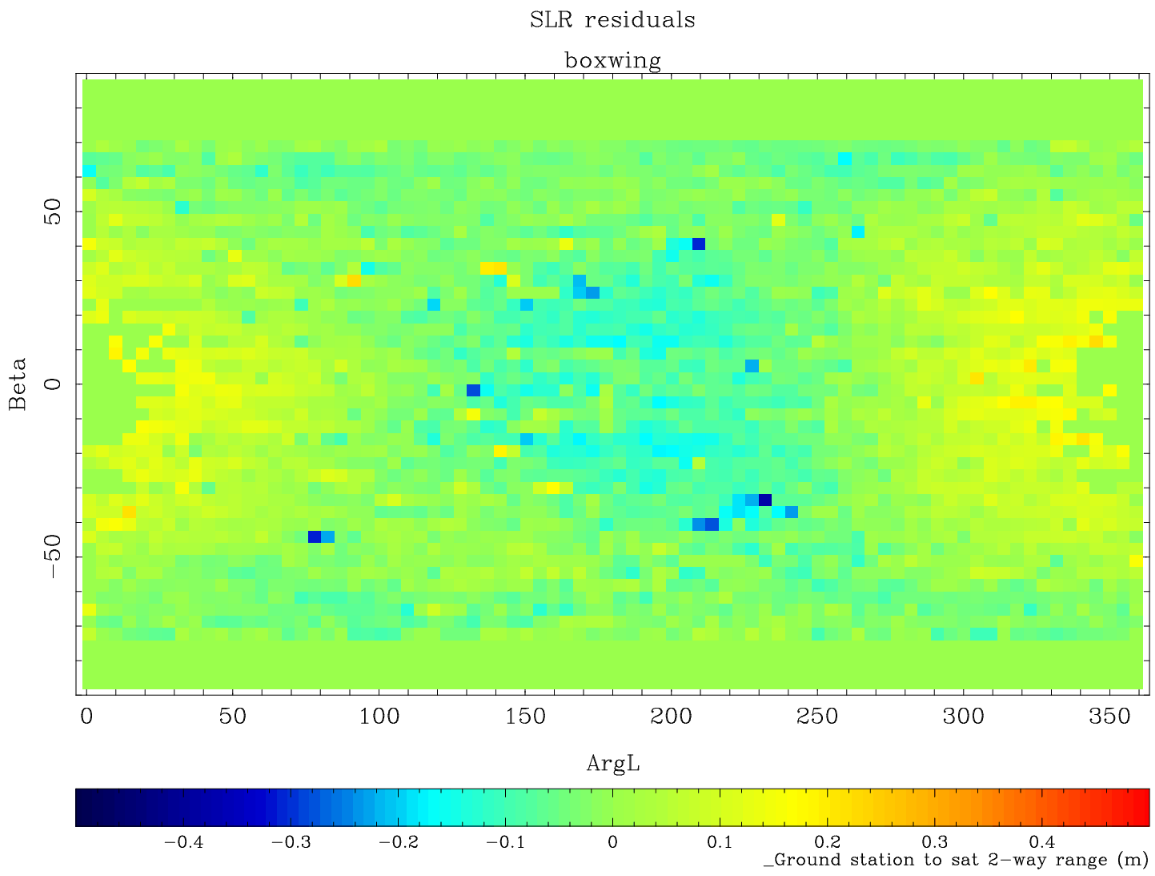


Question: Which is the correct model?

Galileo benefits from ILRS
Model validation
2-way SLR residuals (without box-wing)



Galileo benefits from ILRS
Model validation
2-way SLR residuals (with box-wing)



SLR residuals answer the question of the correct model!

On-going ESA studies/experiments

Studies:

- Improved GNSS – Based precise orbit determination by using highly accurate clocks

  Idea: Study impact of clock modelling POD and global parameters

- Orbit/SRP Modelling for Long Term Prediction

  Idea: Study advanced SRP models to improve long term orbit predictions

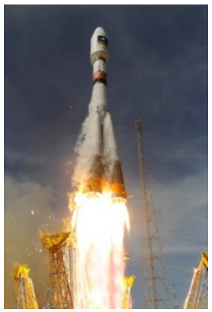
Experiments:

- Fundamental Physics with Galileo: General Relativity Experiment (GREAT)

  Idea: Testing the laws of Relativity

  Unique opportunity PHM in an elliptical orbit

Galileo next steps



FOC-M4 (Launch on Soyuz)

GSAT0208 in storage at ESTEC, waiting for delivery to CSG

GSAT0209 in storage at ESTEC, waiting for delivery to CSG

FOC-M5 (Launch on Ariane-5)

GSAT0210 at ESTEC. TVAC completed

GSAT0211 at ESTEC. Starting environmental test campaign

GSAT0212 at OHB Bremen, completing integration activities

GSAT0207 at OHB Bremen, completing integration activities

FOC-M6 (Launch on Soyuz)

GSAT0213-14 at OHB Bremen, under integration

FOC-M7 (Launch on Ariane-5)

GSAT0215-18 at OHB Bremen, under integration

FOC-M8 (Launch on Ariane-5)

GSAT0219-22 at OHB Bremen, under integration

Conclusions

ESA supports the ILRS by providing

- Galileo orbit predictions
- Selected Galileo satellite information (e.g. Reflector shape, CoM, etc.)

SLR measurements are of great benefit for:

- Galileo orbit validation
- Galileo force model development and validation

Points for improvement:

- It would be very much appreciated if the position of the Galileo satellites in the ILRS mission priority list could be increased and therefore be tracked more often.

ESA would like to thank the entire ILRS community for its very much appreciated support and good cooperation.