ETRUSCO-GMES @ SCF_LAB:

R&D on laser-based Geometrodynamics applied to Galileo, IRNSS & GMES

SCF_LAB

Satellite/Lunar/GNSS laser ranging and altimetry Characterization Facilities' LABoratory

Simone Dell'Agnello for the SCF_LAB Team

Italian National Institute for Nuclear Physics, Laboratori Nazionali di Frascati (INFN-LNF), Via Enrico Fermi 40, Frascati (Rome), 00044, Italy

Preventivi 2013 Rome, September 2012

SCF_LAB Team: Anagrafica

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A. Boni	100%
C. Lops	100%
M. Maiello	100%
S. Berardi	100%
G. Patrizi	100%
M. Martini	100%
G. Bellettini (Uni Roma2)	100%
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R. March (CNR)	100%
N. Intaglietta	70%
M. Tibuzzi	100%
E. Ciocci	100%
L. Salvatori	100%
M. Lobello	100%
A. Stecchi	20%
E. Bernieri	20%

RICERCATORI		TECNOLOGI		TOT. PERS.	FTE	FTE / PERS.
7.59 fte	10 pers.	5.7 fte	7 pers.	17	13.3	0.782
7.59 FTE	10 PERS.	5.7 FTE	7 PERS.	17	13.29	0.782

- 17 people
- 13.3 FTE
- 3 group technicians
- 0.782 FTE / person

- Interest by other INFN Sections to join ETRUSCO-GMES
  - Roma 3 (W. Plastino)
  - Bologna (S. Zerbini et al, Geofisica)

Judgment of the 44th Meeting of the LNF SC

http://www.lnf.infn.it/committee/pdf/FindRec44.pdf

44th MEETING OF THE LNF SCIENTIFIC COMMITTEE
FINDINGS AND RECOMMENDATIONS

7. Space Research at the SCF_LAB

The **S**atellite/Lunar/GNSS laser ranging **C**haracterization **F**acility **LAB**oratory operates in clean room at LNF two unique and unprecedented Optical Ground Support Equipments to characterize the space segments for these programs. They simulate in laboratory the conditions in space and they deliver the integrated thermal behavior and optical response of Laser Retroreflector Arrays (LRAs) in that environment. The group is involved in the analysis of the data providing important tests of General Relativity. Large part of the funding of the SCF_LAB is from external agencies.

7.1 Recommendations

The SC takes note that the group is making good use of existing infrastructures (eg. clean rooms) giving added value to the Laboratory also with external contracts.

Acronyms and definitions

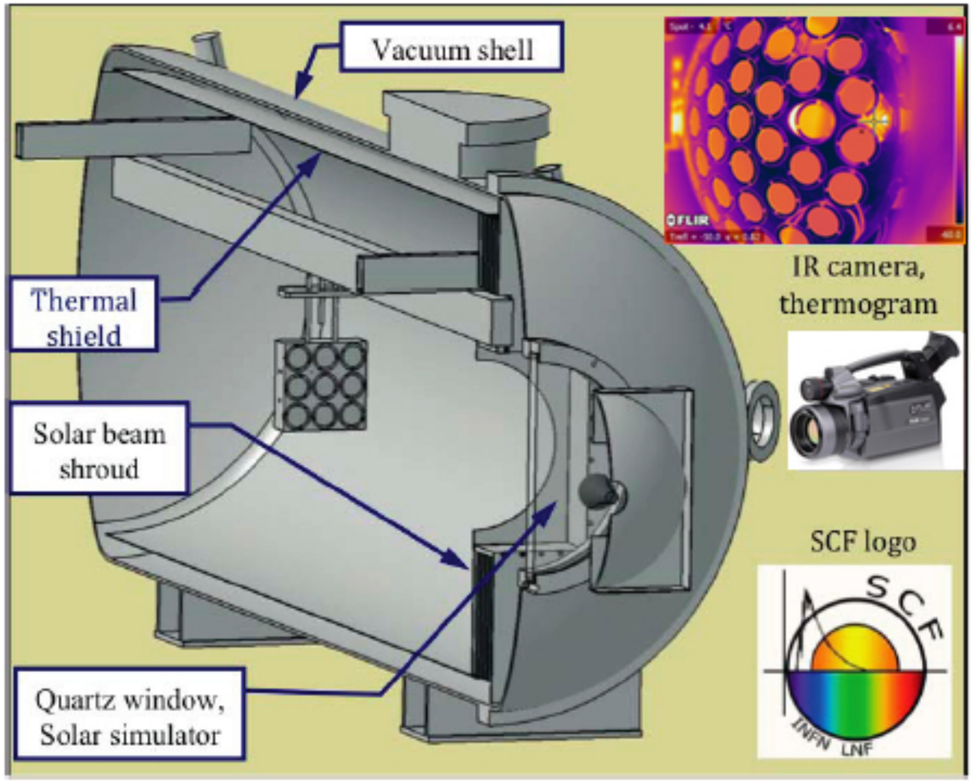
1. AM0: Air Mass Zero
2. ASI: Agenzia Spaziale Italiana
3. BT: Break Through
4. CCR: Cube Corner Retroreflector
5. ESA: European Space Agency
6. ETRUSCO: Extra Terrestrial Ranging to Unified Satellite Constellation
7. FFDP: Far Field Diffraction Pattern
8. FOC: Full Orbit Capability
9. GCO: GNSS Critical half Orbit
10. GNSS : Global Navigation Satellite System
11. GPS: Global Positioning System
12. GRA: GNSS Retroreflector Arrays
13. GTRF: Galileo Terrestrial Reference Frame
14. ILRS: International Laser Ranging Service
15. IOV: In Orbit Validation
16. IP: Intellectual Property
17. ITRF: International Terrestrial Reference Frame
18. ITRS: International Terrestrial Reference System
19. KPI: Key Performance Indicator
20. OCS: Optical Cross Section
21. LAGEOS: LAser GEOdynamics Satellite
22. SCF: Satellite/lunar laser ranging Characterization Facility
23. SLR: Satellite Laser Ranging
24. TIR: Total Internal Reflection
25. WI: Wavefront Interferogram

Galileo and GMES

- **Galileo**, ETRUSCO R&D started in CSN5 in 2006
  - EU Flagship Space Program n. 1
- **GMES**, Global Monitoring for Environment & Security
  - EU Flagship Space Program n. 2
- ETRUSCO-GMES
  - **ETRUSCO-IOV:** SCF-Test for Galileo IOV
  - **ETRUSCO-IRNSS** : SCF-Test for 'Indian Galileo' (GNSS)
  - **G-CALIMES**: Unification of Galileo and Italian constellations for radar mapping of Earth surface

SCF_LAB @INFN-LNF

Two unique OGSE (Optical Ground Support Equipment) facilities in a clean room to characterize the space segment of laser ranging altimetry



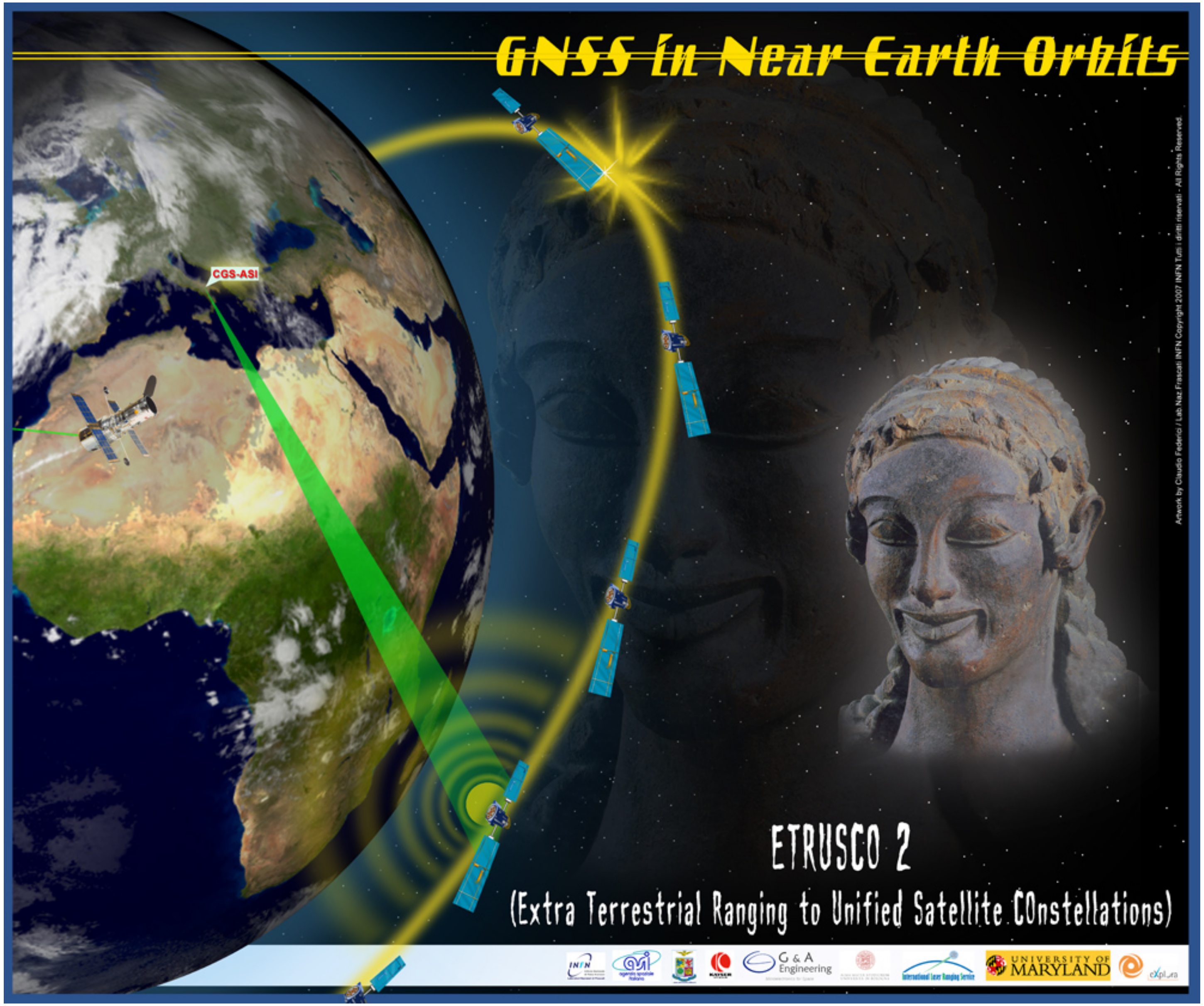
SCF for SLR/LLR/ Altimetry (RD-1, RD-2)

SCF-G for GNSS (RD-10)

ETRUSCO-2: ASI-INFN Program for GNSS (May 2010 April 2013)

[RD-10]

Optimized for Galileo and GPS-3

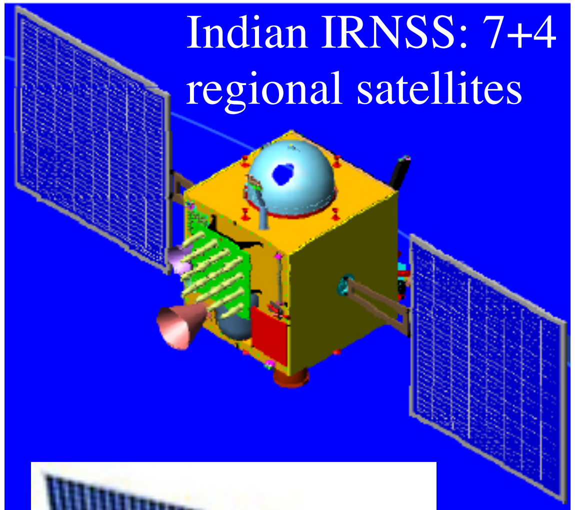


PI:
S. Dell'Agnello

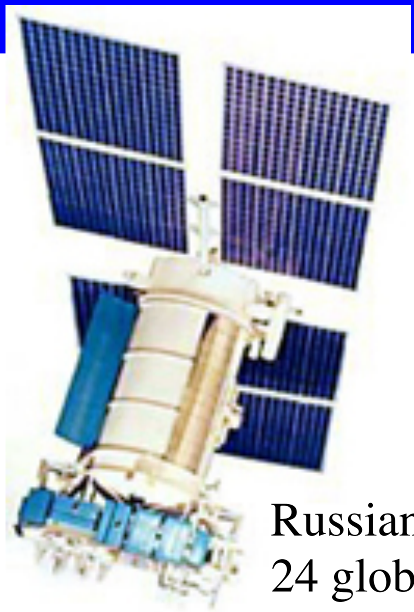
Co-PIs:
R. Vittori, ESA
G. Bianco, ASI

Global Navigation Satellite System (GNSS):

~100 satellites with laser retroreflectors (CCRs)

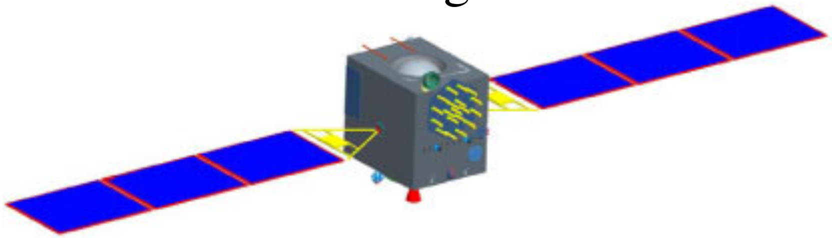


European Galileo:
30 satellites



Russian GLONASS:
24 global satellites

Chinese COMPASS:
20 global and 5
regional satellites



Galileo IOV (In-Orbit validation)

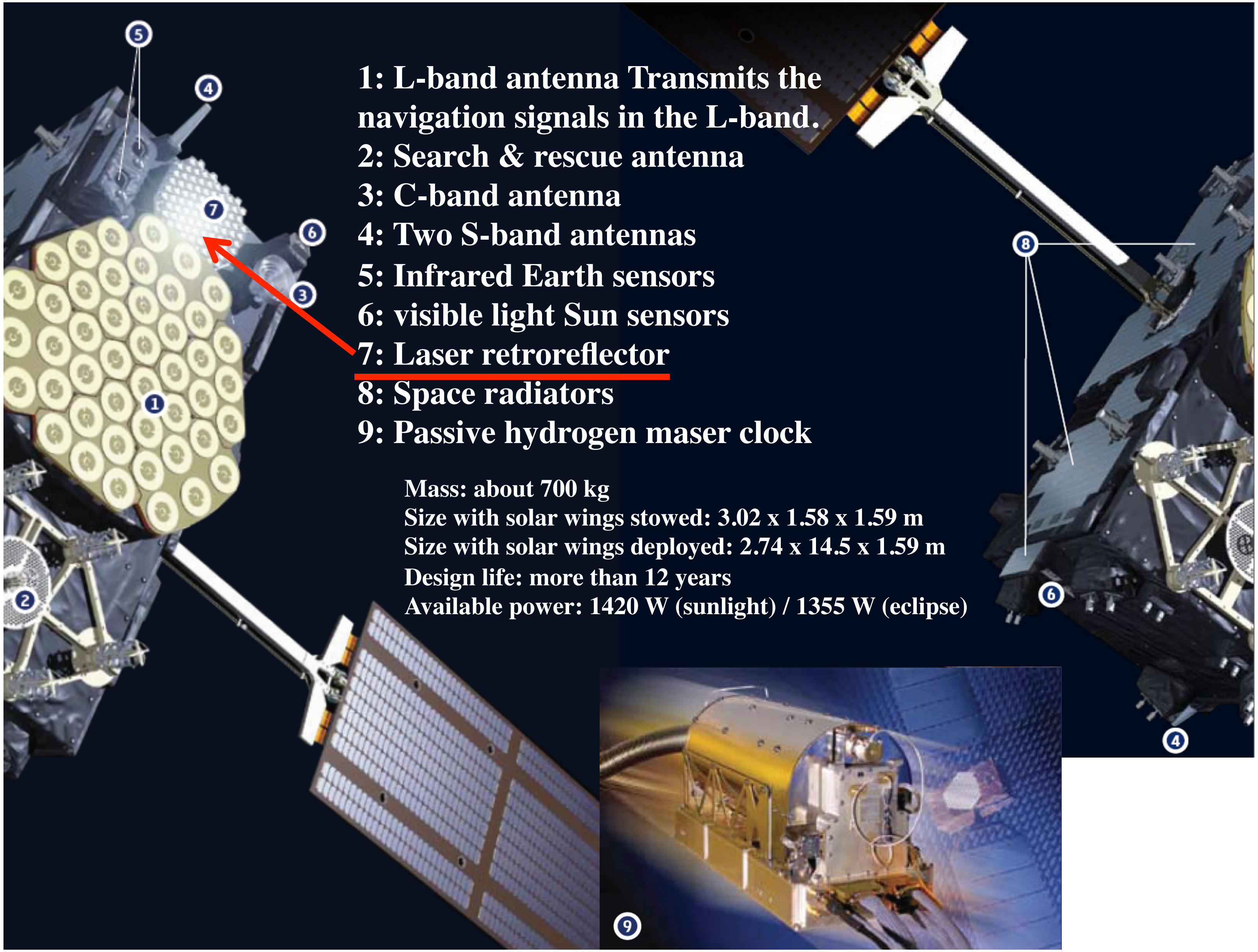
IOV1, IOV2 launched on Oct. 2011

IOV3, IOV4 launched on Oct. 2012

Galileo implementation plan

4 IOV satellites launched

First 4 Galileo IOV satellites

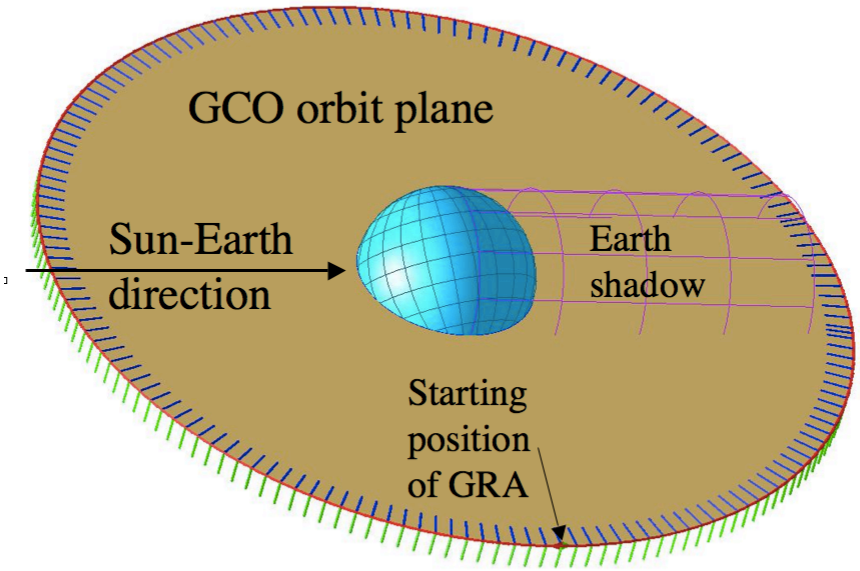


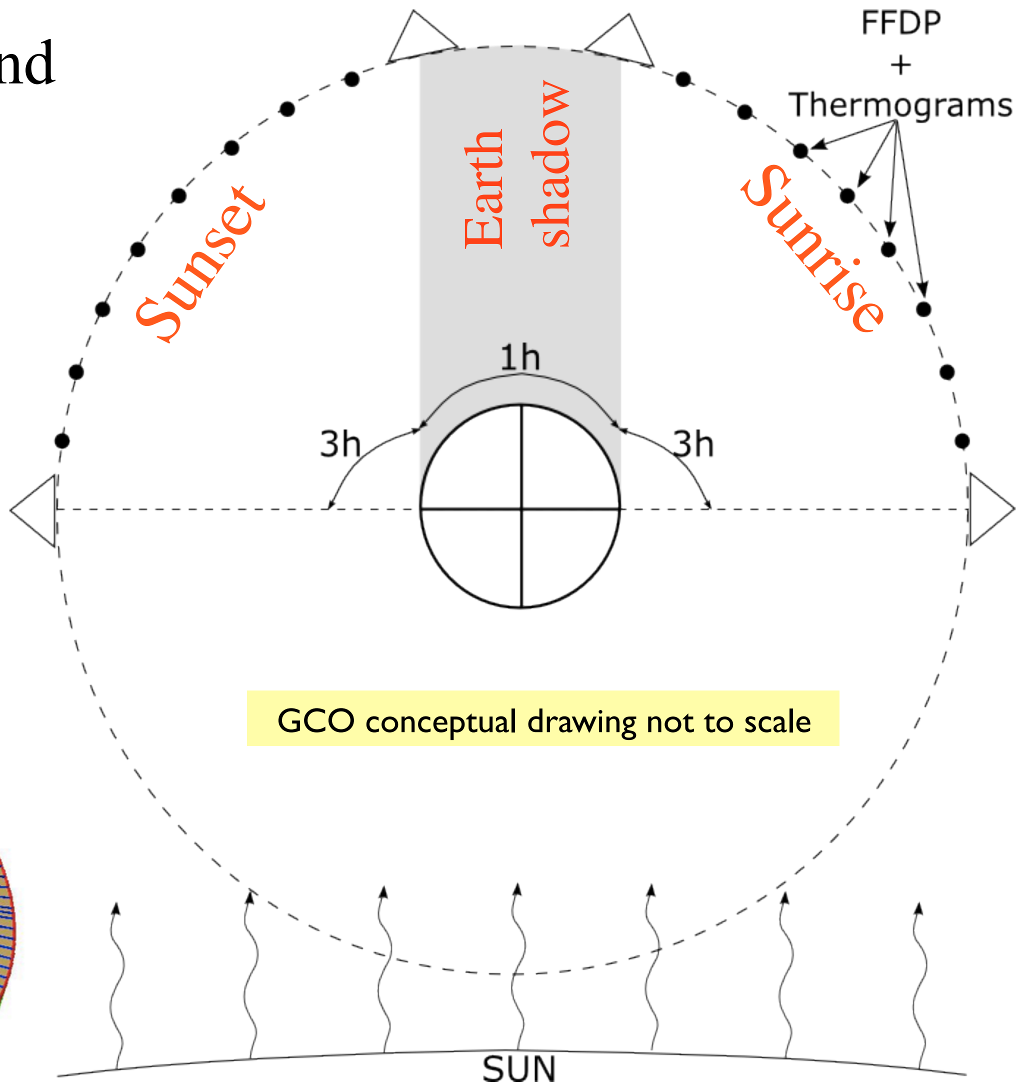
SCF-Test of Galileo Critical half-Orbit

Sunrise-Eclipse-Sunset probes critical features of the thermal and optical behavior of the CCR

Galileo orbit:

- Altitude = 23222 km
- Period ~ 14 hr, shadow ~ 1hr



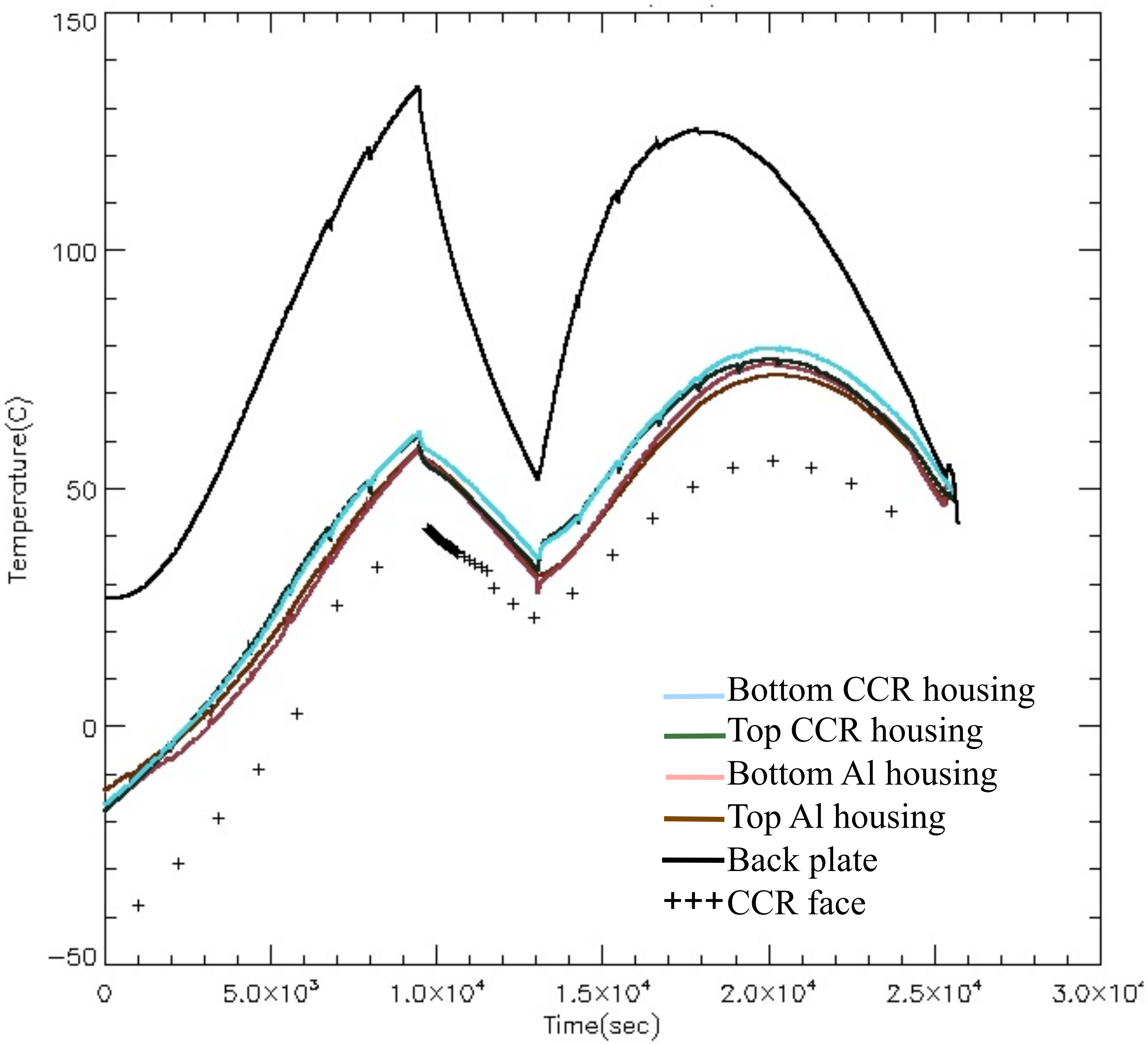


Galileo reflector temperature measurements

Measured temperatures vs. time (& sun inclination):

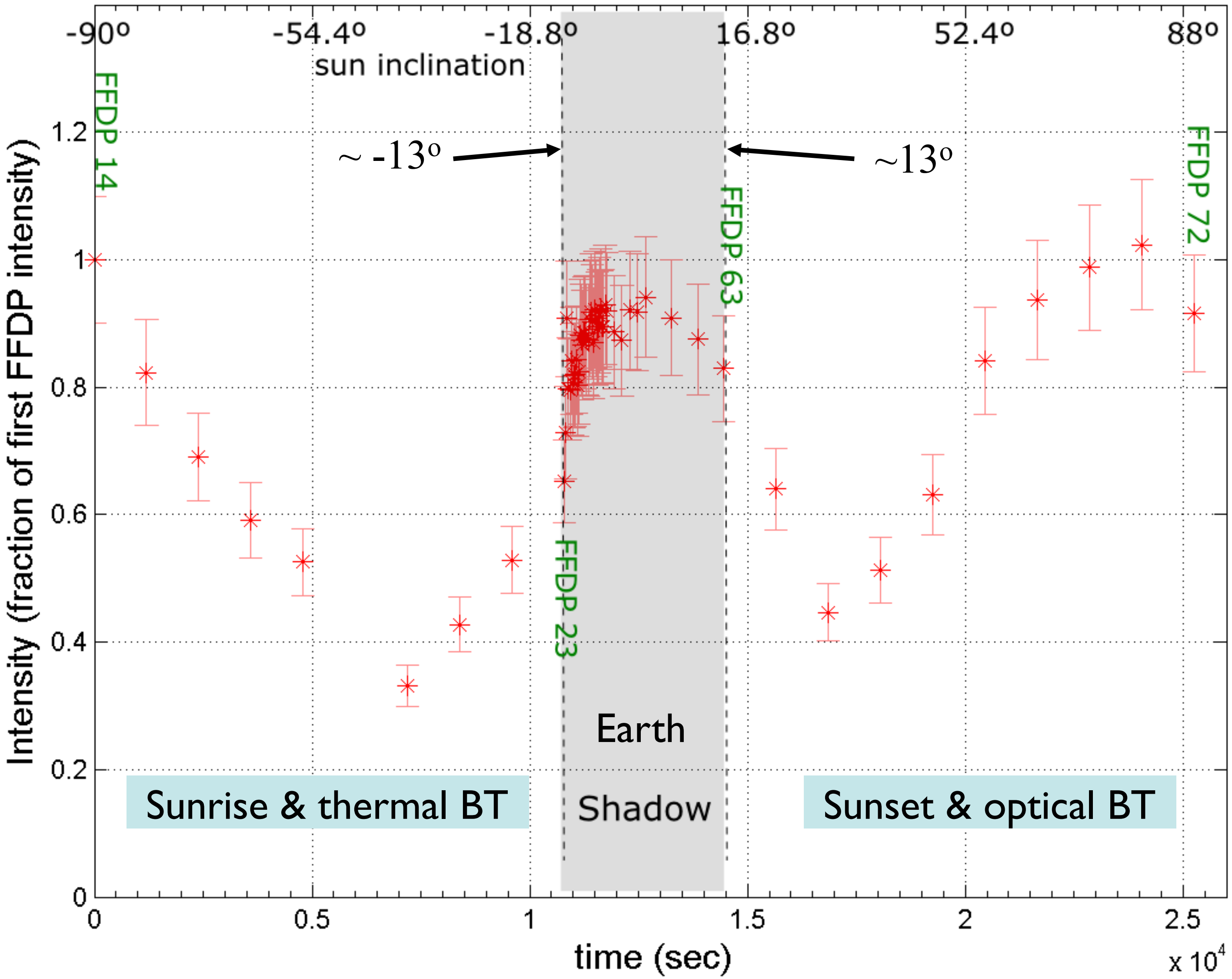
- 2 probes on CCR housing
- 2 probes on Al housing
- 1 probe on the back-plate
- IR camera thermograms of the outer CCR face

Note the very large temperature excursion, >100 K



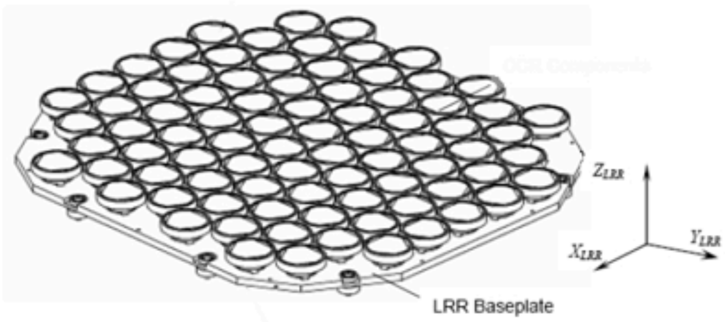
Galileo laser return intensity measurement

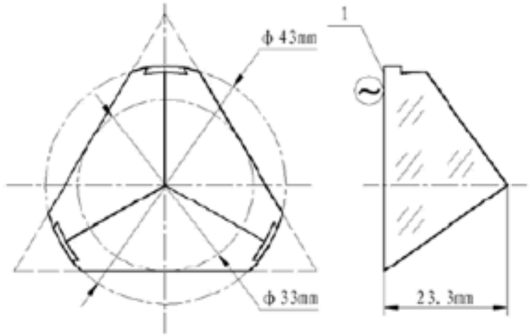
at 24 μrad "velocity aberration"



Public recognition of INFN work for Galileo by ESA on web site of Intern. Laser Ranging Service

Galileo retroreflector array location





Galileo retroreflector array

Galileo corner cube configuration

Retroreflector information courtesy of ESA

RetroReflector Array (RRA) Characteristics:

Additional information about the Galileo retroreflector array can be found in the Galileo-101 and -102 ILRS SLR Mission Support Request Form. Specifications for the Galileo extracted from this support request form:

- Number of CCRs: 84
- CCR size: 33 mm diameter, 23.3 mm height
- Material: Doped fused silica (Suprasil 311)
- Coating: Reflective surface uncoaded, incident surface coated with indium tin oxide

Additional information:

- ESA presentation on Galileo retroreflector design
- "ETRUSCO-2: An ASI-INFN Project of Technological Development and SCF-TEST of GNSS LASER Retroreflector Arrays"

INFN press release: IOV launch & LNF work

GENERALE

- CHI SIAMO
- ORGANIZZAZIONE
- PRESIDENZA
- UFFICIO COMUNICAZIONE
- AMMINISTRAZIONE CENTRALE
- ELENCO TELEFONICO
- OPPORTUNITÀ DI LAVORO

ATTIVITÀ

- FISICA PARTICELLARE
- ASTROPARTICELLARE
- FISICA NUCLEARE
- FISICA TEORICA
- RICERCA TECNOLOGICA
- ESPERIMENTI
- PUBBLICAZIONI INFN
- TESI INFN

SERVIZI

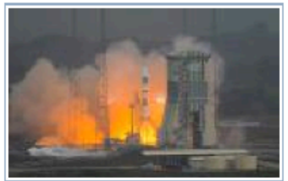
- PORTALE INFN
- AGENDA INFN
- EDUCATIONAL
- WEBCAST
- MULTIMEDIA
- EU FP7

Privacy Policy

Trasparenza valutazione e merito

27-10-2011: LANCIO DEI PRIMI DUE SATELLITI DI GALILEO

ELENCO COMPLETO



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Galileo, la costellazione europea di navigazione satellitare, e' un programma di bandiera dell'Unione Europea. Il lancio dei primi due satelliti Galileo In-Orbit Validation (IOV) il 21 ottobre 2011 (http://www.esa.int/SPECIALS/Galileo_IOV/) ha segnato formalmente la nascita della costellazione. Il lancio rimarra' nella storia anche come il primo in cui il lanciatore Russo Soyuz e' partito da una base fuori della Russia. Altri due satelliti Galileo IOV saranno lanciati nel 2012. Assieme ai due satelliti sperimentali GIOVE (Galileo In-Orbit Validation Elements) gia' in orbita, i satelliti IOV costituiranno il primo nucleo operativo della costellazione completa di 30 satelliti. Sviluppato in collaborazione tra la European Space Agency (ESA) e la Commissione Europea, Galileo fornira' un posizionamento di alta precisione e servizi di navigazione e sincronizzazione temporale per utenti di tutto il mondo, come servizio civile con copertura continua. Ogni satellite combina il miglior orologio atomico mai mandato in orbita per la navigazione ? dotato di un? accuratezza di un secondo su tre milioni di anni ? con un potente sistema di trasmissione dei dati di navigazione. I satelliti IOV convalideranno il progetto dell?intero sistema prima del completamento e del lancio del resto della costellazione.
I satelliti GIOVE e IOV di Galileo hanno a bordo matrici di retroriflettori laser necessarie per la calibrazione assoluta della posizione dei satelliti con precisione centimetrica, grazie alla misura del tempo di volo di impulsi laser corti "sparati" dalle stazioni dello International Laser Ranging Service (http://ilrs.gsfc.nasa.gov/). Questo inseguimento laser dei satelliti (satellite laser ranging, in inglese) fornira' a Galileo un posizionamento accurato e assoluto, cioe' relativo al sistema di riferimento internazionale terrestre (http://www.iers.org/IERS/EN/DataProducts/ITRS/itrs.html). Quest?ultimo ? una terna di assi cartesiani co-rotante col nostro pianeta, la cui origine (centro di massa della Terra o geocentro) e la cui unit? di misura (metro orbitale) sono definiti con un contributo predominante dell?inseguimento laser, assieme ad altre tecniche geodetiche (inclusa la very long baseline interferometry e la stessa navigazione satellitare).

I Laboratori Nazionali di Frascati (LNF) dell?Istituto Nazionale di Fisica Nucleare (INFN) hanno compiuto la caratterizzazione spaziale delle prestazioni dei retroriflettori laser usati su due dei 24 satelliti dell?attuale costellazione GPS americana e sui due satelliti europei GIOVE, in collaborazione con la NASA e l?Universit? del Maryland (College Park, MD, USA). In collaborazione con l?ESA e l?Agenzia Spaziale Italiana (ASI), i LNF hanno iniziato nel 2010 a lavorare alla caratterizzazione di prototipi di retroriflettori laser impiegati sui satelliti Galileo IOV. I test di laboratorio sono stati effettuati presso un apparato sperimentale dedicato dei LNF, costruito principalmente per Galileo e altre costellazioni satellitari, denominato SCF (dal suo acronimo inglese Satellite/lunar laser ranging Characterization Facility). Questo lavoro e' inserito nell?ambito delle attivita' della Commissione Scientifica Nazionale di Gruppo 5 (CSN5) e del progetto ASI-INFN di sviluppo tecnologico, ETRUSCO-2.

Factsheet di Galileo e brochure dei satelliti IOV a cura dell?ESA possono essere consultati agli indirizzi web:
? http://download.esa.int/docs/Galileo_IOV_Launch/Galileo_factsheet_20110801.pdf.
? http://download.esa.int/docs/Galileo_IOV_Launch/BR-297_Galileo_web.pdf.

Lo 'SCF-Test' e i risultati derivati sono di propriet? intellettuale dell?INFN riconosciuta da NASA, ESA e ASI, come riportato in:
? Advances in Space Research 47 (2011) 822?842.
? 3rd Int. Colloquium - Galileo Science (2011), http://www.congrex.nl/11a12/

SITI COLLEGATI ALLA NOTIZIA

CONFERENZE

- 02-11-2011 THIRD INTERNATIONAL WORKSHOP MELODI
- 23-09-2012 CHANNELING 2012 - 5TH INTERNATIONAL CONFERENCE "CHARGED AND NEUTRAL PARTICLES CHANNELING PHENOMENA" SEPTEMBER 23-28, 2012 ALGHERO, ITALY
- 16-10-2012 DARK FORCES SEARCHES AT COLLIDERS

RASSEGNA

- STAMPA
- VIDEO

COMUNICATI STAMPA

- 28-10-2011 ANTONIO MASIERO ELETTO NUOVO MEMBRO DELLA GIUNTA INFN
- 27-10-2011 LANCIO DEI PRIMI DUE SATELLITI DI GALILEO
- 26-10-2011 SI INSEDIA IL NUOVO PRESIDENTE DELL'INFN

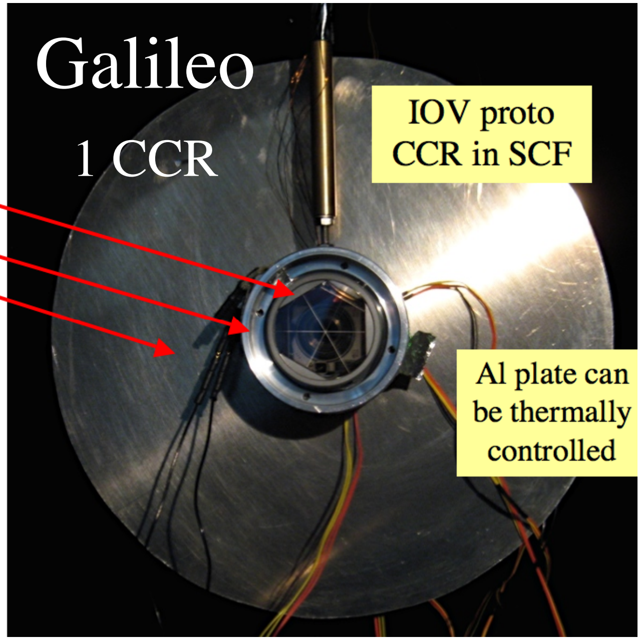
LHC ITALIA

asimmetrie.it

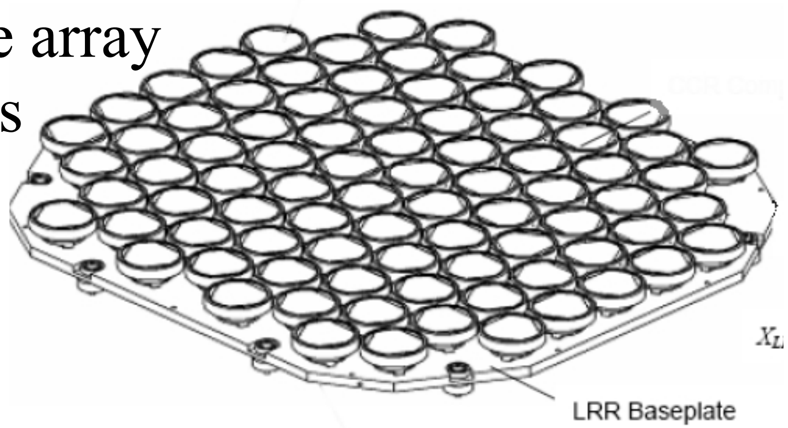
ETRUSCO-IOV Contract (**ESA-INFN**):

SCF-Test of IOV reflectors (CCRs)

CCR housing
Al housing
Al back-plate
inside the SCF



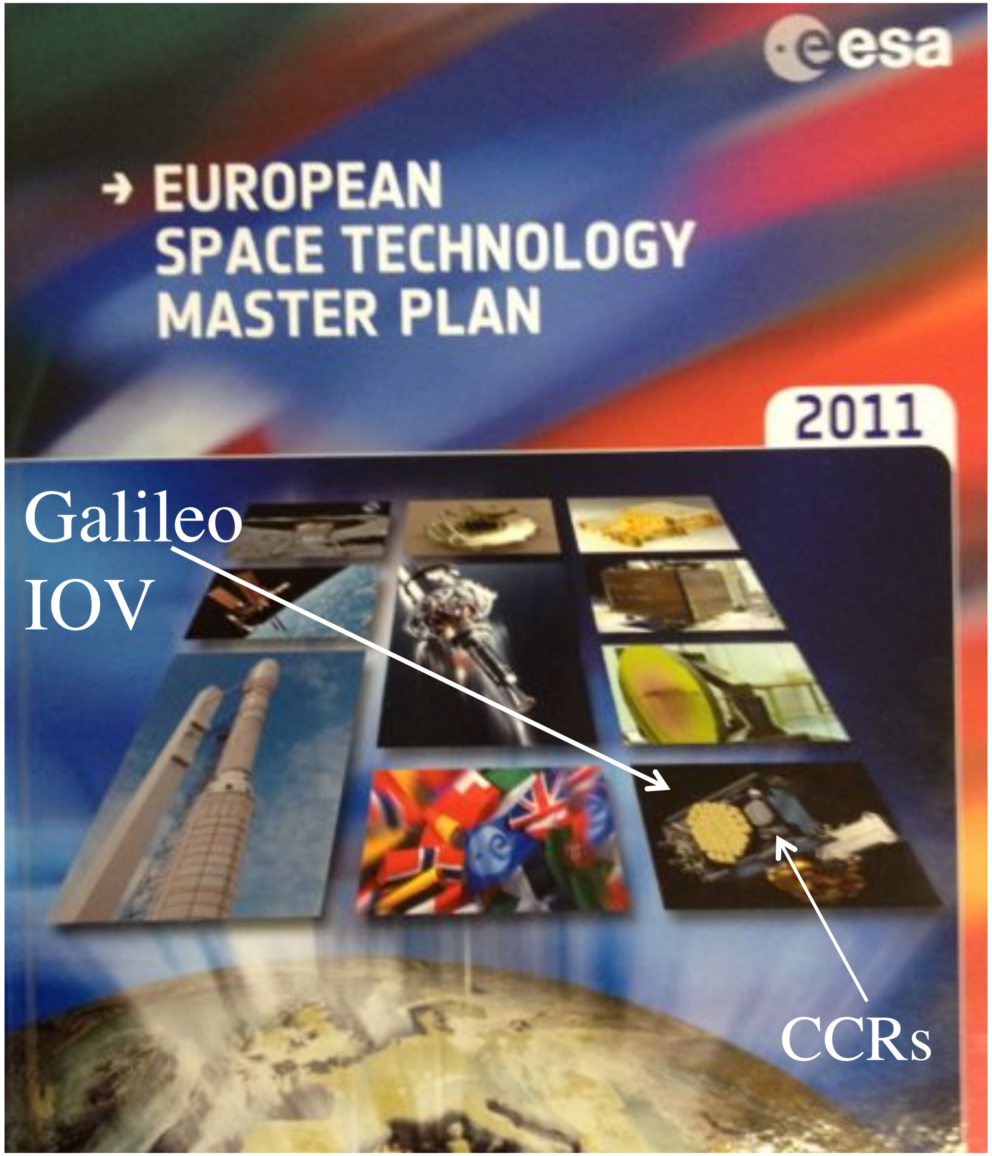
Full-size array
84 CCRs



European Space Technology Master Plan (ESTMP)

- **With 50-50 co-funding** INFN keeps IPR
  - Potential patents: 50-50 property INFN-Agencies

- **Ultimate goal**: publish SCF/SCF-Test in ESTMP, as INFN-CSN5 technology
  - ESTMP analogous of the Particle Data Book (PDG) in fundamental and particle physics
- SCF/SCF-Test proposed for VQR as INFN technological product



G-CALIMES

- Continuation, enhancement and major extension of ETRUSCO program with development of fundamental geometrodynamics networks **Galileo**, and other **GNSS** and for **GMES** (Global Monitoring for Environment and Security)

GMES: from ESA Bulletin Feb. 2012

→ GLOBAL MONITORING FOR ENVIRONMENT AND SECURITY

GMES Space Component getting ready for operations

Monitoring of Environment with Galileo ("SatNav") and
Synthetic Aperture Radar (SAR)
SAR: Italy's CosmoSkyMed (CSK) and ESA's Sentinel-1

Next to Galileo, Global Monitoring for Environment and Security (GMES) is one of the two European Union flagship programmes in space, and another example of how space policy can contribute to improving European citizens' lives.

While the future of Galileo is secured through the EC's proposal to provide sufficient operational funding within the general budget of the EU, the long-term future of GMES has yet to be secured. Unexpectedly, last year the EC proposed to finance GMES outside the EU Multi-Annual Financial Framework (MFF), which covers the period 2014–20, suggesting instead to organise the required funding through a new intergovernmental mechanism.

In the GMES Space Component, the Sentinels and ground segment are currently in the final stages of their development and are getting ready for launch from 2013 onwards. Pre-operational data delivery from existing national and third party missions is well under way. What is most urgently needed now is securing the operational funds and consolidating the governance including Sentinel ownership and data policy.

GMES: from ESA Bulletin Feb. 2012

Who are the users of GMES?

Based on global observations, GMES services, developed in close collaboration with users, will provide essential information in three Earth-system domains (atmosphere, marine and land) and three cross-cutting domains (emergency management, security and climate change).

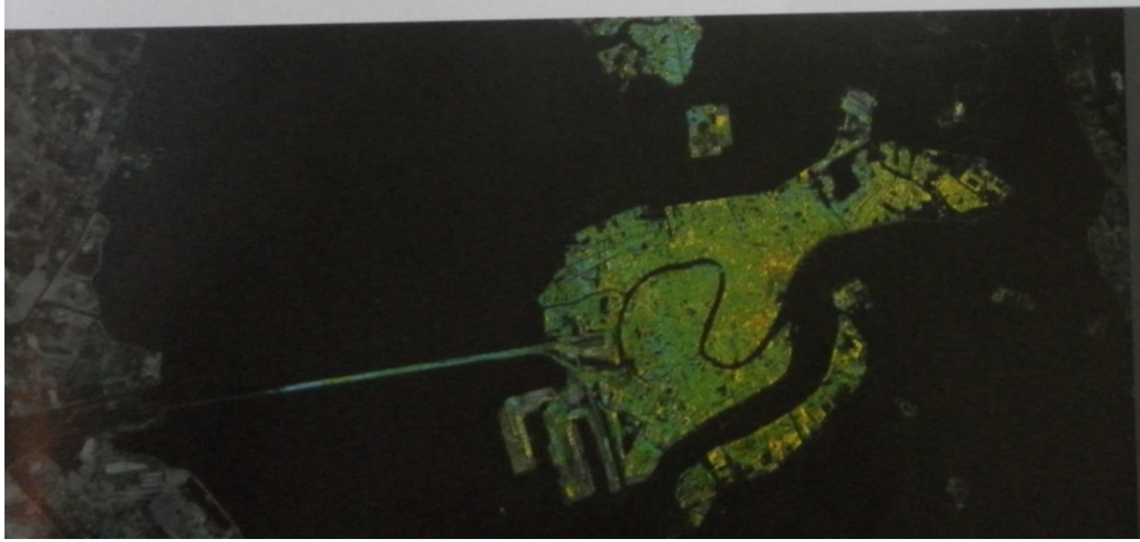
These services, once operational, will provide standardised multi-purpose information common to a broad range of EU policy-relevant application areas:

- GMES Marine Monitoring Service: focused on areas such as marine safety and transport, oil spill monitoring, water quality, weather forecasting and the polar environment.

for Medium-Range Weather Forecasts, Eumetsat and the European Union Satellite Centre), private business and individual citizens. A large variety of commercial industry segments will also benefit through the development and provision of operational geo-services.

At a regional level, GMES is already used to monitor air quality, map coastlines, regional areas and urban expansion and to manage marine and agricultural resources. GMES also plays a key role in disaster management and prevention.

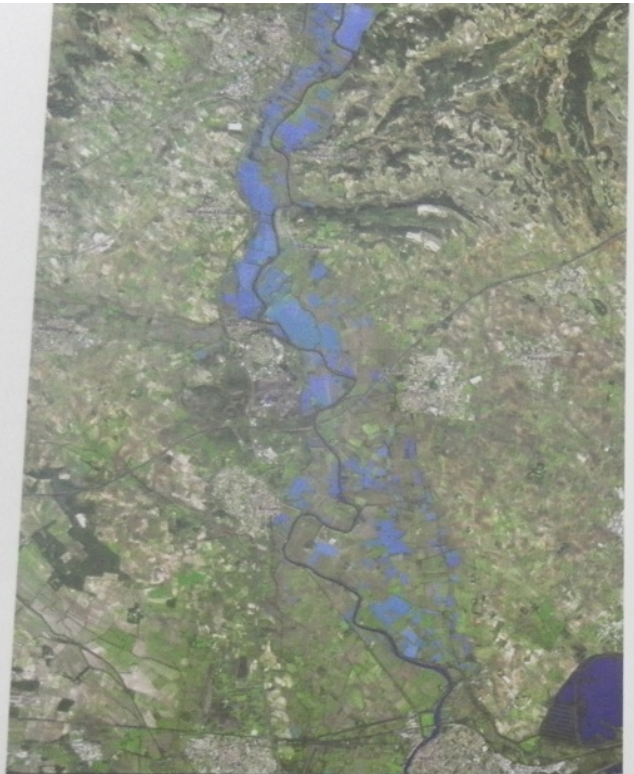
On air quality, for instance, GMES currently provides daily (three-day) air quality forecasts and historical records of key industrial pollutants such as ozone, nitrogen dioxide, sulphur dioxide and aerosols for the major cities and regions of Europe. The forecasts form the basis for the management of health risks of citizens suffering from asthma or other symptoms. The



← Very high resolution map of land subsidence in Venice (mm/year), with data collected from May 2008 to April 2010 showing over 1.5 million point measurements (ESA/DLR)

2012/07/16

GMES: from ESA Bulletin Feb. 2012



↑ Floods of the Hérault in south-eastern France in November 2011 monitored with GMES Contributing Missions (COSMO-SkyMed and SPOT-5, SAFER)

Socio-economic benefits of GMES

According to the EC staff working paper Memo/11/469, *'Money where it matters – how the EU budget delivers value to you'*, published in conjunction with the EU MFF proposal, GMES could provide economic benefits

... analysis of studies that have been carried out.

The ESPI Report 39, *'The Socio-Economic Benefits of GMES'* published in November 2011 follows this line by comparing a study by PricewaterhouseCoopers (PwC) and another one by Booz&Co. An important result is that both studies, although employing different approaches, reach similar conclusions regarding the order of magnitude of potential socio-economic benefits of GMES.

> **€1 invested in GMES brings a macro-economic return of €10**

The PwC study establishes three categories of potential GMES benefits: efficiency benefits, European policy formulation benefits and global action benefits, and assesses them separately. The Booz&Co study, based on a literature review, looks at different funding levels and performs an impact analysis in the areas of climate change, environment and security and industrial development.

Moreover, it differentiates between static and dynamic scenarios. A dynamic scenario, unlike a static one, allows for interaction between relevant ecosystems in the realm of GMES. From both studies, a benefit–cost ratio of about 10 can be derived. This means that for every €1 spent by the European taxpayer on GMES, a public return of €10 can be expected.

2012/07/16

Another application and EU flagship programme: GMES - Observing our planet for a safer world

Managing natural resources and biodiversity, observing the state of the oceans, monitoring the chemical composition of our atmosphere: all depend on accurate information delivered in time to make a difference. The European initiative for the **G**lobal **M**onitoring for **E**nvironment and **S**ecurity (GMES) will provide data to help deal with a range of disparate issues including climate change and border surveillance. Land, sea and atmosphere - each will be observed through GMES, helping to make our lives safer.

The purpose of GMES is to deliver information on environment and security which correspond to identified **user needs**

Goal of ETRUSCO-GMES

Unify observations of Galileo & Cosmo constellations

> GMES will provide us with crucial imagery and data on the environment, which will enable us to understand better and mitigate climate change. It will also make our agriculture and fishery more efficient. This in turn will guarantee better food quality and food security. It will also be of great help in crisis response in emergency situations during natural or manmade disasters.
>
> J.M. Barroso, President of the European Commission, November 2011

Who are the users of GMES?

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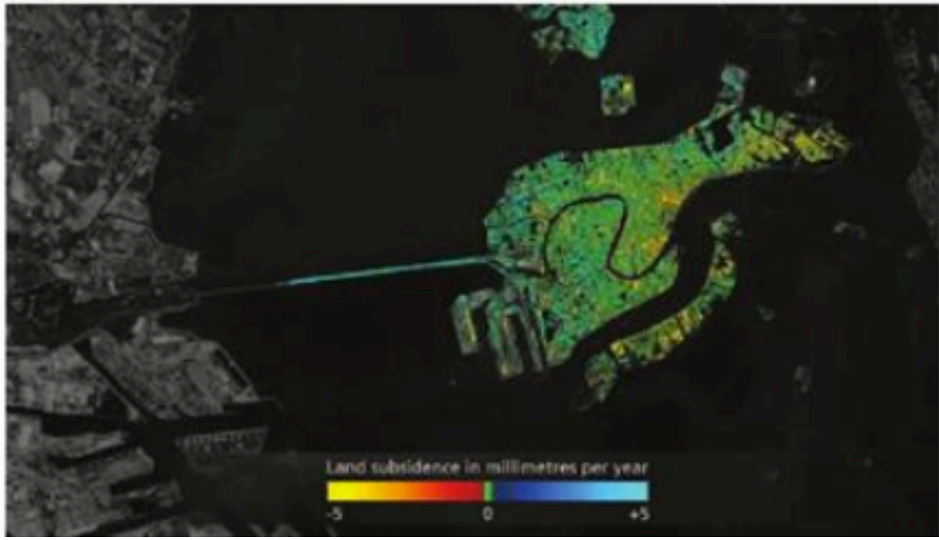
From ESA Bulletin Feb. 2012



← Very high resolution map of land subsidence in Venice (mm/year), with data collected from May 2008 to April 2010 showing over 1.5 million point measurements (ESA/DLR)

Main Reference Documents

- [RD-1] Dell'Agnello, S., et al, **Creation of the new industry-standard space test of laser retroreflectors for the GNSS and LAGEOS**, J. Adv. Space Res. **47** (2011) 822–842.
- [RD-2] P. Willis, Preface, Scientific applications of Galileo and other Global Navigation Satellite Systems (II), J. Adv. Space Res., **47** (2011) 769.
- [RD-3] D. Currie, S. Dell'Agnello, G. Delle Monache, **A Lunar Laser Ranging Array for the 21st Century**, Acta Astron. **68** (2011) 667-680.
- [RD-4] Dell'Agnello, S., et al, Fundamental physics and absolute positioning metrology with the MAGIA lunar orbiter, Exp Astron, October 2011, Volume 32, Issue 1, pp 19-35 ASI Phase A study.
- [RD-5] Dell'Agnello, S. et al, **A Lunar Laser Ranging Retro-Reflector Array for NASA's Manned Landings, the International Lunar Network and the Proposed ASI Lunar Mission MAGIA**, Proceedings of the 16th International Workshop on Laser Ranging, Space Research Centre, Polish Academy of Sciences Warsaw, Poland, 2008.
- [RD-6] International Lunar Network (http://iln.arc.nasa.gov/), Core Instrument and Communications Working Group Final Reports.
- [RD-7] Yi Mao, Max Tegmark, Alan H. Guth, and Serkan Cabi, Constraining torsion with Gravity Probe B, Physical Review D **76,** 104029 (2007).
- [RD-8] March, R., Bellettini, G., Tauraso, R., Dell'Agnello, S., **Constraining spacetime torsion with the Moon and Mercury**, Physical Review D **83**, 104008 (2011).
- [RD-9] March, R., Bellettini, G., Tauraso, R., Dell'Agnello, S., **Constraining spacetime torsion with LAGEOS**, Gen Relativ Gravit (2011) 43:3099–3126.
- [RD-10] **ETRUSCO-2: An ASI-INFN project of technological development and "SCF-Test" of GNSS LASER Retroreflector Arrays**, S, Dell'Agnello, 3rd International Colloquium on on Scientific and Fundamental Aspects of the Galileo Programme, Copenhagen, Denmark, August 2011

Why Europe needs Galileo?

Galileo is a strategic program:

- The European Commission (EC) estimates that 6-7% of European GDP, around 800 billion by value, is dependent on satellite navigation.
- The EC and European Space Agency (ESA) joined forces to build Galileo: Europe's independence is the chief reason.
- By being inter-operable with GPS and GLONASS, Galileo will allow positions to be determined accurately for most places on Earth, even in high rise cities where buildings obscure signals from satellites low on the horizon.
- Galileo will achieve better coverage at high latitudes.
- Europe will be able to exploit the opportunities provided by satellite navigation to the full extent.

Galileo Services

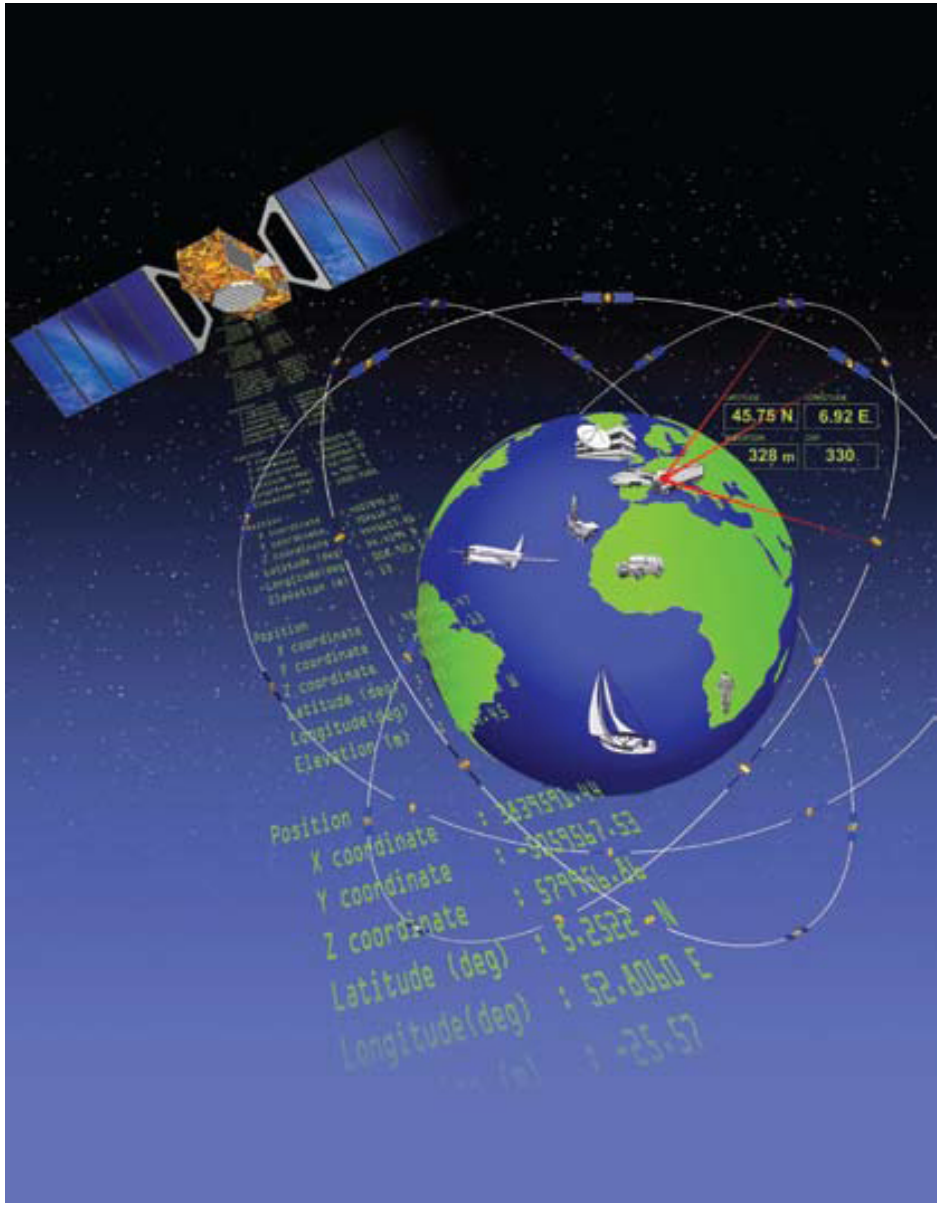
• **Open Service:** the Galileo navigational signal will be accessible by the general public free of charge, providing improved global positioning. It's the only open GNSS

• **Public Regulated Service:** two encrypted signals with controlled access for specific users such as governmental bodies.

• **Search and Rescue Service:** Galileo will contribute to the international Cospas–Sarsat system for search and rescue. A distress signal will be relayed to the Rescue Coordination Centre and Galileo will inform the user that their situation has been detected.

• **Safety-of-Life Service:** standard already available for aviation (ICAO standard) thanks to EGNOS, Galileo will further improve the service performance.

• **Commercial Service:** Galileo will provide a signal for high data throughput and highly accurate authenticated data (time synchronization), particularly interesting for professional users.



Internal anatomy of the Galileo IOV satellite

- **Rubidium clock:** an atomic clock based on a different technology, ensuring redundancy to the masers. It is accurate to within 1.8 nanoseconds over 12 hours.
- **Clock monitoring and control unit:** provides the interface between the four clocks and the navigation signal generator unit. It also ensures that the frequencies produced by the master clock and active spare are in phase, so that the spare can take over instantly should the master clock fail.
- **Navigation signal generator unit:** generates the navigation signals using input from the clock monitoring and control unit and the uplinked navigation and integrity data from the C-band antenna. The navigation signals are converted to L-band for broadcast to users.
- **Gyroscopes:** measure the rotation of the satellite.
- **Reaction wheels:** control the rotation of the satellite. When they spin, so does the satellite, in the opposite direction. The satellite rotates twice per orbit to allow the solar wings to face the Sun's rays.
- **Magneto-torquer:** modifies the speed of rotation of the reaction wheels by introducing a magnetism-based torque (turning force) in the opposite direction.
- **Power conditioning and distribution unit:** regulates and controls power from the solar array and batteries for distribution to all the satellite's subsystems and payload.
- **Onboard computer:** controls the satellite platform and payload.