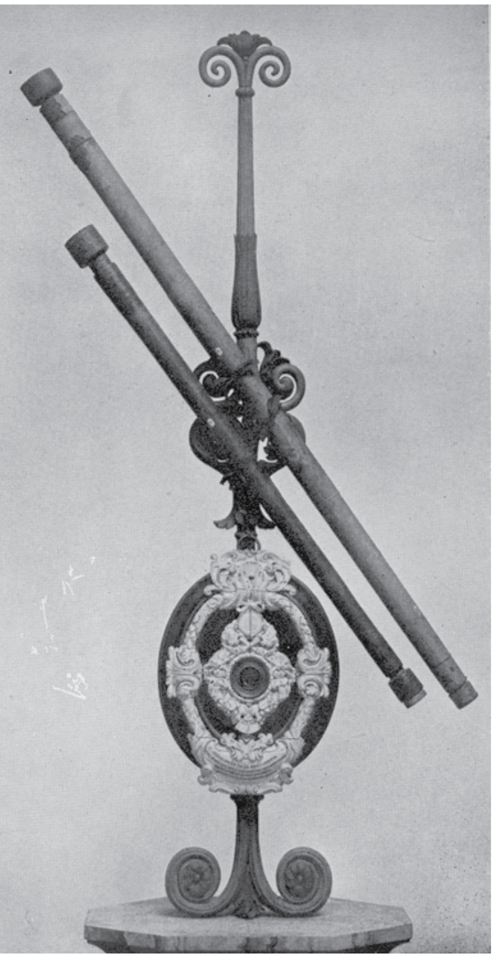
→ BIRTH OF THE EUROPEAN SATELLITE NAVIGATION CONSTELLATION

Galileo In-Orbit Validation

What's in a name?

The development phase of Europe's satellite navigation system was named after Italian astronomer Galileo Galilei (1564–1642), famous as the first to turn a telescope to the heavens. His discovery of Jupiter's largest four moons proved invaluable for early navigation: their orbital motion could be used as a celestial clock, visible from all over Earth.



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→ EUROPEAN SATELLITE NAVIGATION TAKING SHAPE

The first element of Europe's global satellite navigation system is on its way. Two Soyuz rockets will launch two satellites each: the four Galileo In-Orbit Validation (IOV) satellites that form the operational nucleus of the full constellation. Developed in collaboration between ESA and the European Commission (EC), Galileo will provide high-quality positioning, navigation and timing services to users across the whole world as a civil-controlled service with guaranteed continuity of coverage.

Each satellite combines the best atomic clock ever flown for navigation – accurate to one second in three million years – with a powerful transmitter to broadcast precise navigation data. ESA has built a supporting ground network around the globe.

The first satellites will prove that the space and ground segments meet many of Galileo's requirements and will validate the system's design in advance of completing and launching the rest of the constellation.

These first satellites are fully representative of the others that will follow them into orbit. Fourteen more will combine with these four to provide the 'Initial Operational Capability' by mid-decade, which will then lead into the next phase, the final 30-satellite 'Full Operational Capability' (FOC).

First Galileo satellites undergoing testing in Thales Alenia Space's Rome facility

Soyuz at CSG: delivering the first satellites

The first pair of satellites are the first payloads to fly on Russia's Soyuz rocket from its new launch site at Europe's Spaceport in French Guiana (CSG: Centre Spatial Guyanais).

This three-stage rocket is assembled horizontally in the traditional Russian approach, then moved to the vertical so that its payload can be mated from above in the standard European way. A new mobile launch gantry helps this process, while protecting the satellites and the launcher from the environment.

A European dispenser holds the satellites in place during launch and then releases them into their final orbit.

A special version of the launcher is being used: a more powerful Soyuz ST-B variant plus a Fregat-MT upper stage to deliver the satellites into their final circular 23 222 km orbit.

The reignitable Fregat was previously used in its baseline version to deliver ESA's GIOVE-A and -B experimental satellites. Fregat-MT carries an additional 900 kg of propellant.

Soyuz at CSG

→ GUIDED BY THE SKY

The underlying idea behind Galileo and other satnav systems is simple: many ultra-precise clocks are placed in orbit, and their times are broadcast together with their exact positions. Anyone with a receiver can combine these signals to find their three-dimensional location on the planet. In addition, the signals' time stamps serve to synchronise global electronic transactions, such as inter-banking exchanges, telecommunications and energy networks.

Satellite navigation is a hi-tech replication of an ancient tradition. Just like us, our ancestors looked to the sky to navigate and to mark out time. The Phoenicians relied on the few thousand stars visible to the naked eye to traverse the Mediterranean and strike out around Africa. On the other side of the globe, Polynesians navigated by those same celestial markers across thousands of kilometres of open Pacific.

Astronomy itself was born as Egypt, Babylonia and other agricultural societies tracked the motion of the Sun, Moon and stars in order to record the most auspicious times for planting crops.

Astronomical clock, Prague

Finding our way

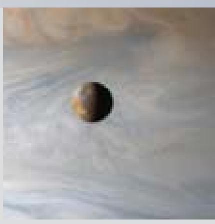
1119 AD

First reference to a compass being used for navigation at sea, by Chinese writer Zhu Yu.

1460

The quadrant, a tool subsequently developed into the sextant, first employed in marine navigation to measure latitude.

1610



Galileo Galilei discovers the first four moons of Jupiter. He realises their motion makes them a kind of clock that can be observed anywhere on Earth, and uses them to help establish longitude more accurately.

1773

John Harrison's marine chronometer solves the problem of measuring longitude at sea.

1817

First gyroscope constructed by Johann von Bohenberger.

1908

Steel ships make traditional compasses less reliable; first gyrocompass developed.

1942

Radio navigation systems developed for aerial warfare during World War II, including the Long-Range Navigation (LORAN) system.

The very first clocks were built as aids to astronomy – first relying on the constant drips of water, before moving to clockwork mechanisms that reproduced the motion of the Solar System in miniature. Europe's first purely mechanical clocks appeared in the 13th century, although they lost hours per day and had to be regularly reset with the aid of sundials.

Around the same time, navigators became less dependent on the sky. The compass allowed sailors to find their direction even when the heavens were cloudy. Before that, maritime trade would largely come to a halt during winter.

Meanwhile, the old astrolabe astronomy instrument evolved into the practical sextant for navigation. A ship's latitude could be faithfully reckoned by measuring the angle of prominent stars. But while north/south latitude could be fixed by the stars, west/east longitude proved more elusive, which rendered long-distance navigation a hit-and-miss affair. This was because Earth's rotation keeps the stars moving sideways at a rate of 15 degrees per hour: any timing drift caused large positioning errors. It was only in the 18th century that self-taught inventor John Harrison crafted the first reliable 'marine chronometer'. Losing less than five seconds every ten days, Harrison's invention was sufficiently reliable for ships to traverse the oceans safely, winning him a fortune from the British Admiralty.

By the 20th century, mechanical clocks had become ever more precise, only to be rendered obsolete by quartz clocks in both accuracy and price. Quartz clocks came to sit at the heart of new radio ranging systems developed during the Second World War to serve long-distance aircraft. Atomic clocks proved far more accurate, drifting only a matter of seconds per million years.

Equally significantly, inertial navigation based on gyroscopes supplemented the long-serving compass. Gyrocompasses proved effective, first on ironclad ships, then planes and eventually the rockets that opened up flight beyond the atmosphere. All the technological ingredients – spaceflight and satellites, radio navigation and atomic clocks – came into place to enable a new era of precision navigation. It only remained to put them together.

1957

Sputnik launched; study of its signal shows that Doppler shift can be used to derive ground position.

1960

US Transit satellite launched, first in a series delivering Doppler-based ranging.

1978

Navstar 1, the first GPS satellite, is launched.

1993

GPS becomes fully operational, with 24 satellites.

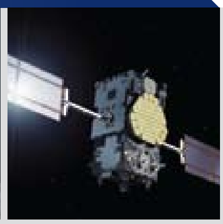
2005

Launch of ESA's GIOVE-A satellite, securing radio frequencies for the upcoming constellation.

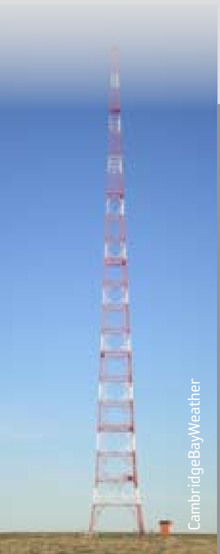
2008

Launch of ESA's GIOVE-B satellite, carrying the most accurate atomic clock ever used for satellite navigation.

2011



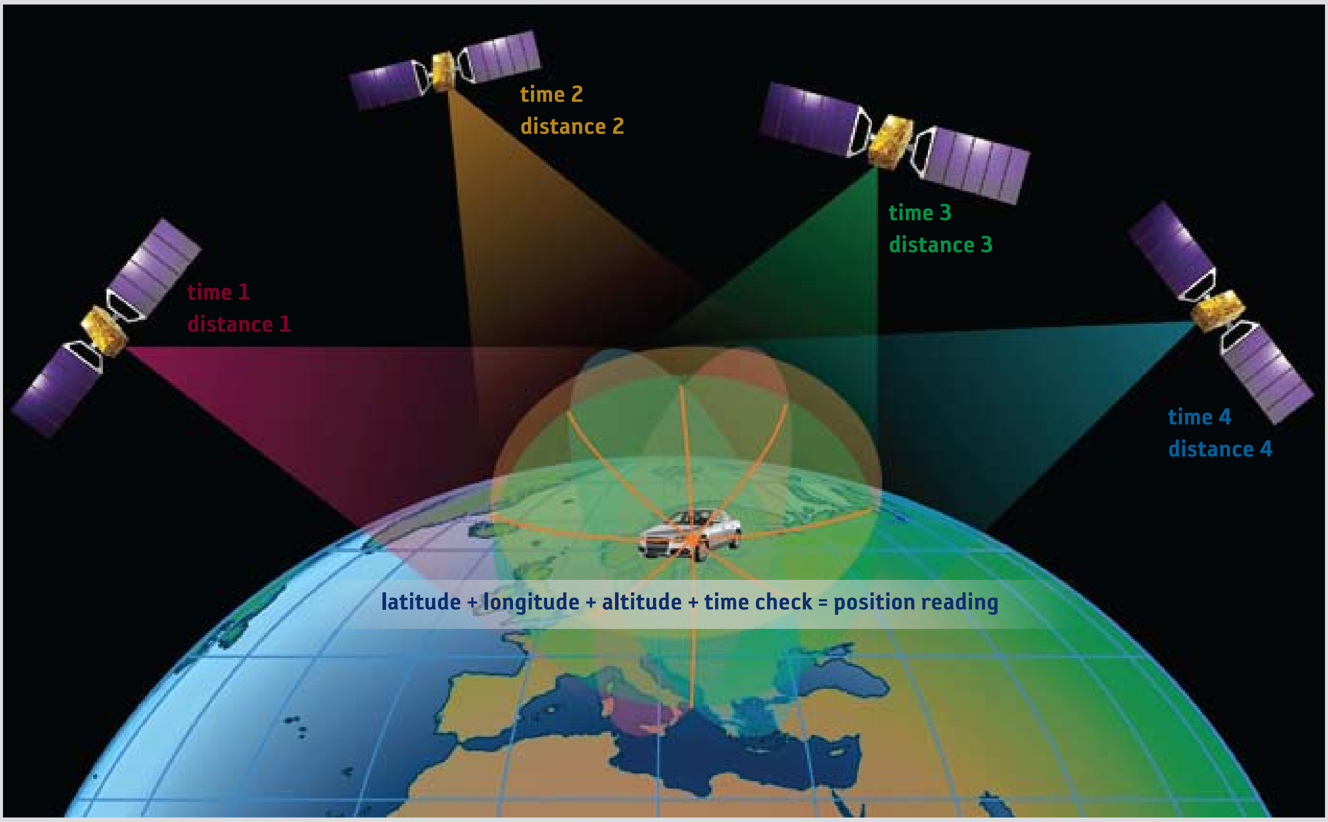
Launch of the first IOV satellites.



Radio-ranging, from Earth to space

The underlying radio-ranging principle behind Galileo is not new. It has been used for decades on a terrestrial, two-dimensional basis: long-distance aircraft measure their position against a global network of radio beacons. Systems like the US LORAN and Russian Chayka incorporate time measurements so that receivers can measure the differing arrival times of signals from separate beacons to fix an aircraft's position over Earth's surface. But with satnav systems delivering heightened precision, terrestrial radio navigation systems are now in sharp decline: LORAN was switched off across the US and Canada in 2010.

→ HOW SATELLITE NAVIGATION WORKS



Navigation beacons have to be as visible as possible. So 20th-century LORAN radio navigation towers guiding air traffic stood hundreds of metres tall, while the lighthouses warning mariners of treacherous waters reach dozens of metres or are built on high ground. In essence, navigation satellites are the same except they are located on the ultimate high ground of space, making them visible anywhere on Earth.

The signal emitted from each satellite is a microwave radio wave containing the time it was transmitted and the satellite's orbital position. Because the speed of light is known, the time it takes for the signal to reach a receiver can be used to calculate the distance from the satellite. Galileo's timing is accurate to the nanosecond*, so this distance can be derived to a very high degree of certainty. Combine inputs from multiple satellite signals simultaneously – like viewing several lighthouses at once – and your place in the world is pinpointed; the stated aim of Galileo is to deliver accuracy in the metre range once the full system is completed.

A broad spread of navigation satellites is needed to ensure that multiple signals can be received at any point on Earth. Locking on to more signals yields greater accuracy, but four is the absolute minimum required. Three are used to 'trilateralise' (the three-dimensional equivalent of triangulation) the user's longitude, latitude and altitude on Earth's surface, and a fourth to determine the time offset between the (precise) satellite clock and the (less precise) clock in the user's receiver.

Design trade-offs dictate a medium-Earth orbit as the optimal altitude for navigation satellite constellations, beginning with the US GPS and Russian Glonass. After 20 years of development, the completed GPS became operational in December 1993. Made available to civil users, GPS pioneered a host of novel applications; satellite navigation has since become part of all our lives. Yet GPS, like Glonass, remains a dual-use, foreign-military-controlled system.

* there are 1000 million nanoseconds in one second

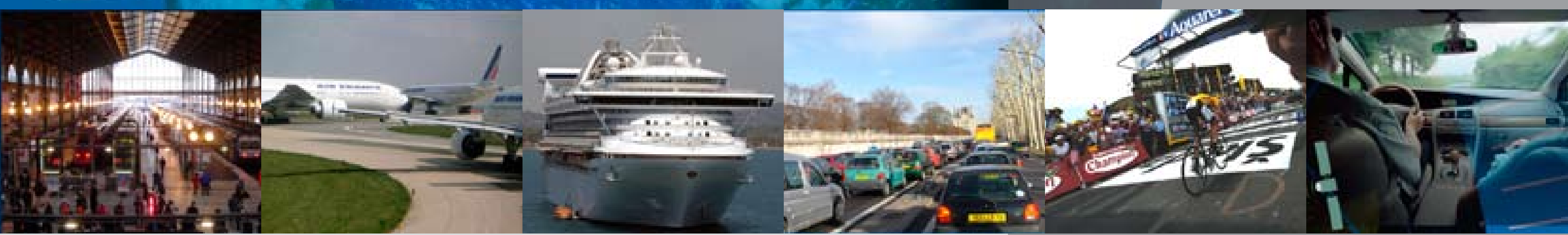
Receiving the signals

Modern satnav receivers are sufficiently miniaturised to fit within car dashboards, tracking sensors or mobile phones. It takes a lot of embedded intelligence for them to do their job: finding their place in the world.

To begin with, using antennas just a few centimetres across, they have to lock onto the minimum four satellites. Each signal is surprisingly faint, equivalent in energy to the beam of a car headlight shining from one side of Europe to the other. So the receivers incorporate detailed almanacs of the satellite orbits. By knowing where the various satellites are meant to be at any time, the receivers can reduce the time it takes to achieve signal lock from minutes to just a few seconds.

Each satellite in space has its own code to identify it, so complex that it comes close to random electrical noise. The receiver stores these complex codes in its memory, and uses them to generate full-power replica signals of the faint signals received. This approach does not need full-size antennas, so user receivers are small and satnav can be widely used.

The stronger versions of the signals are used for the calculations that derive the final navigational data displayed to the user. At the same time, the receivers also keep their internal clocks synchronised with the satellite's onboard atomic clock, by instantly determining the clock offset between them.



→ EUROPE'S FIRST STEPS

The enormous potential benefits of satellite navigation brought ESA and the EC together in collaboration. In the early 1990s the two organisations defined a European Satellite Navigation Strategy so that Europe could be autonomous in this increasingly important strategic and commercial sector.

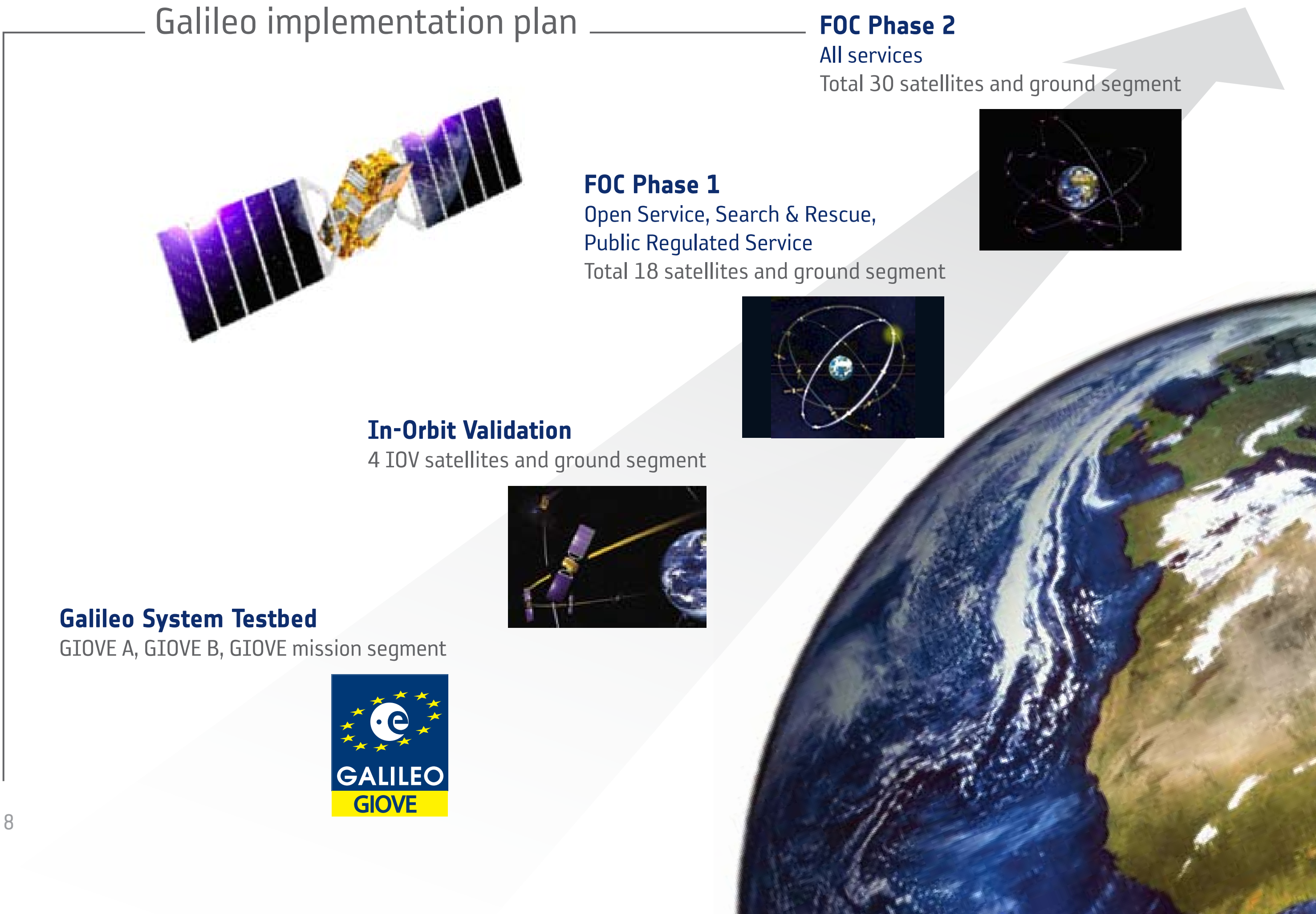
ESA began research and development in cooperation with the EC and the civil aviation community. The development strategy was conceived with two major pillars:

- **EGNOS (European Geostationary Navigation Overlay Service)** A pan-European 'augmentation system', complementing GPS to deliver reliability information to users (it uses GPS signals, improving the service by adding correction and additional information). It will also complement Galileo when deployed.

- **Galileo** A fully autonomous and interoperable worldwide satellite navigation system, broadcasting global navigation signals for high-performance services.

Today, EGNOS is operational and certified, forming the basis of a wide range of general and safety-critical applications across our continent (see page 14).

For Galileo, ESA and the EC agreed a staggered approach. ESA launched two GIOVE satellites in 2005 and 2008, with a representative ground segment. These satellites secured the frequencies provisionally set aside for Galileo by the International Telecommunications Union as well as evaluating the performance of key technologies. Remaining in good health to this day, the GIOVE satellites are being moved to higher altitudes to make room for the Galileo satellites.



Launched into history

The historic first step in the in-orbit validation of the Galileo system was the construction of the two GIOVE satellites, built in parallel with complementary capabilities to provide redundancy. Their name stands for Galileo In-Orbit Validation Element, additionally commemorating Galilei Galileo's discovery of the first, largest moons of planet Jupiter – 'Giove' in Italian.

GIOVE-A Flown on a Soyuz launcher (pictured) from Baikonur Cosmodrome in Kazakhstan on 28 December 2005, GIOVE-A was constructed by Surrey Satellite Technology Ltd in the UK. Carrying the first Galileo signal generator ever flown into orbit, GIOVE-A was equipped with a phased-array antenna of individual L-band (1200–1600 MHz frequency range) elements to illuminate the entire visible Earth beneath it, as well as two very stable rubidium atomic clocks. Two types of radiation detectors monitor its orbital environment.

GIOVE-B Flown on a Soyuz launcher from Baikonur Cosmodrome on 27 April 2008, GIOVE-B was built by a consortium headed by Astrium and Thales. It features an improved phased-array antenna of individual L-band elements illuminating the visible Earth, a signal-generation unit able to produce new types of signals with features agreed between the EU and the USA, an exceptionally stable passive hydrogen maser clock along with a rubidium clock, and a new radiation sensor to monitor its orbital surroundings.

Lessons learnt

Results from GIOVE-A and -B helped to steer the design of the Galileo IOV satellites. GIOVE-A, Europe's first navigation satellite, helped to prove:

- **Satellite design** Europe's first satellite to operate from medium-Earth orbit, where the radiation is extremely severe.
- **Orbit models navigation loop** Confirmed the orbit models used to generate the navigation signal, with the required accuracy of orbit and clock estimates.
- **Rubidium clock** High stability demonstrated in the harsh radiation environment.
- **Ionosphere effects** Assessed using a global network of ground stations.
- **Sensor stations** Data from the 15 GIOVE experimental data stations showed the basic design assumptions of the operational ground segment are sound.
- **GPS to Galileo time offset** GPS and Galileo run on different time systems, so the difference between their timings must be known exactly for the two systems to work together. GIOVE signals incorporate a measurement of the current separation on an experimental basis, demonstrating that interoperability of the two systems is indeed feasible.

In addition, GIOVE-B has also proved:

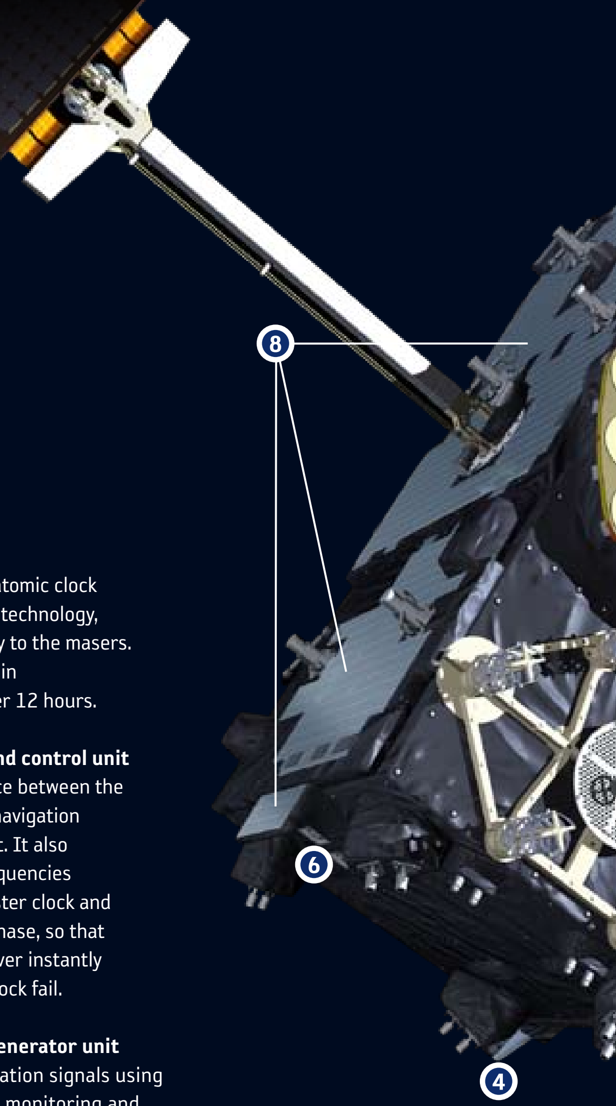
- **Passive hydrogen maser clock** Proven to be the most stable clock ever flown for navigation applications.
- **Multiplexed BOC** The high-performing 'multiplexed binary offset carrier' (BOC) in one of the two GIOVE-B channels is an advanced modulation technique that offers robust protection against signal interference and the misleading signal reflection known as 'multipath'.

GIOVE-A

GIOVE-B

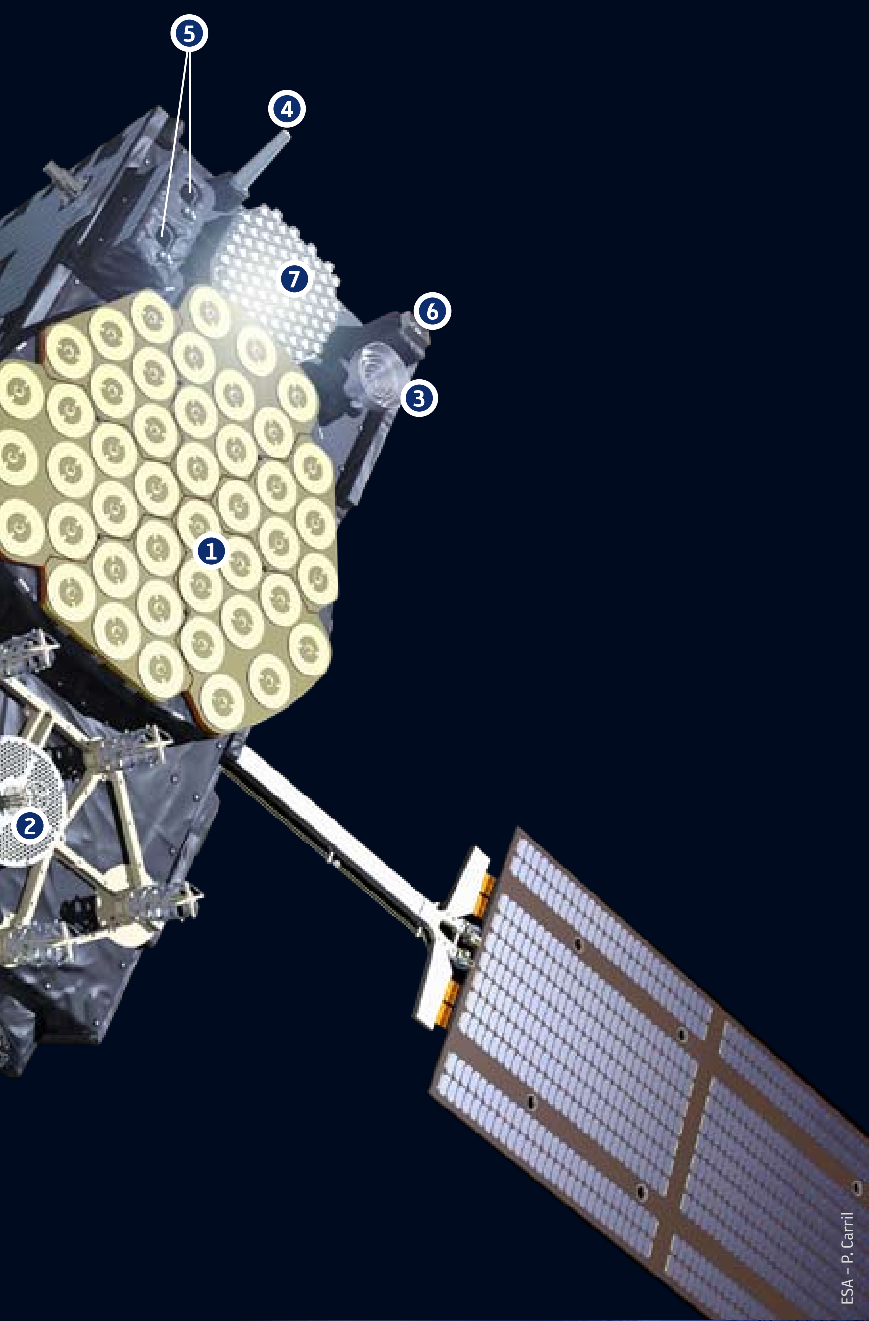
→ ANATOMY OF A NAVIGATION SATELLITE

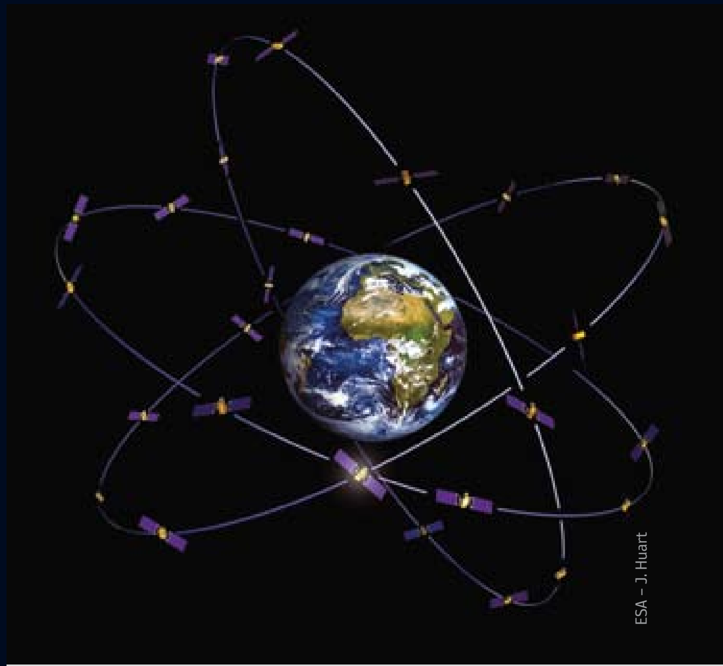
Satellites are high-performance machines, designed to work perfectly for years. The Galileo satellites and especially their navigation payloads incorporate numerous innovations to perform their job over their 12-year design life:



1. **L-band antenna** Transmits the navigation signals in the L-band.
2. **Search & rescue antenna** Picks up distress signals from beacons on Earth and transmits them to a ground station for forwarding to local rescue services.
3. **C-band antenna** Receives signals containing mission data from uplink stations. These include data to synchronise the onboard clocks with a ground-based reference clock and integrity data that contain information about how well each satellite is functioning. This integrity information is incorporated into the navigation signal for transmission to users.
4. **Two S-band antennas** Part of the telemetry, tracking and command subsystem. They transmit housekeeping data about the satellite platform and payload to Galileo's ground control segment and, in turn, receive commands to control the satellite and operate the payload. The S-band antennas also receive, process and transmit ranging signals that measure the satellite's altitude to a few metres.
5. **Infrared Earth sensors and** 6. **visible light Sun sensors** These keep the satellite pointed at Earth. The infrared Earth sensors detect the contrast between the cold of deep space and the heat of Earth's atmosphere. The Sun sensors are visible-light detectors that measure the angle to the Sun.
7. **Laser retroreflector** Allows the measurement of the satellite's distance to within a few centimetres by reflecting a laser beam shone from a ground station. The reflector will be used only about once a year, because altitude measurements via S-band antenna are otherwise accurate enough.
8. **Space radiators** Radiate excess heat to deep space, maintaining onboard electronics within their operational temperature range.
9. **Passive hydrogen maser clock** The master clock on the satellite. Two are flown for redundancy. This atomic clock uses the ultra-stable energy oscillations of a hydrogen atom to measure time to within 0.45 nanoseconds over 12 hours.

- **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.
- **Magnetotorquer** 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.





Orbital FOC architecture

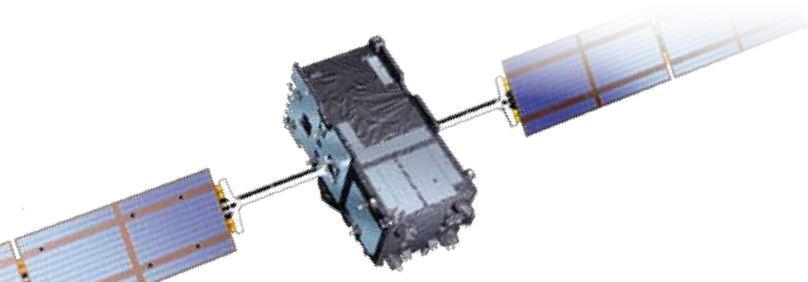
The full operational capability (FOC) constellation will consist of 27 operational satellites plus three spares, circling Earth in three circular medium orbits, at an altitude of 23 222 km with an orbital inclination of 56º to the equator, in planes separated by 120º longitude.

Atomic clock technology

Atomic clocks placed in orbit are the underlying technology behind satellite navigation. All clocks are based on regular oscillations – traditionally the swing of a pendulum, tick of clockwork or pulse of quartz crystal. Highly accurate atomic clocks rely on switches between energy states of an atom's electron shell, induced by light, laser or maser energy.

The first atomic clock, developed in England in 1955, was the size of a room. For satellite navigation, the challenge was to come up with a design that was compact and robust enough to fly in space. Thanks to long-term ESA research and development, two separate atomic clock technologies have been developed and qualified in Europe, then proved suitable for the harsh environment of space by the GIOVE missions.

Galileo carries both types of atomic clock: a smaller rubidium atomic clock, accumulating three seconds' error every million years, and a bulkier hydrogen maser clock, accumulating one second's error every three million years.



→ GALILEO ON THE GROUND

Galileo Control Centre, Oberpfaffenhofen, Germany

Galileo Control Centre, Fucino, Italy

Galileo in-orbit testing facilities, Redu, Belgium

Galileo ground station, Kourou, French Guiana

TTC antenna, Kiruna, Sweden

Sensor station, Svalbard, Norway

New Caledonia, South Pacific, site of a Galileo uplink and sensor station

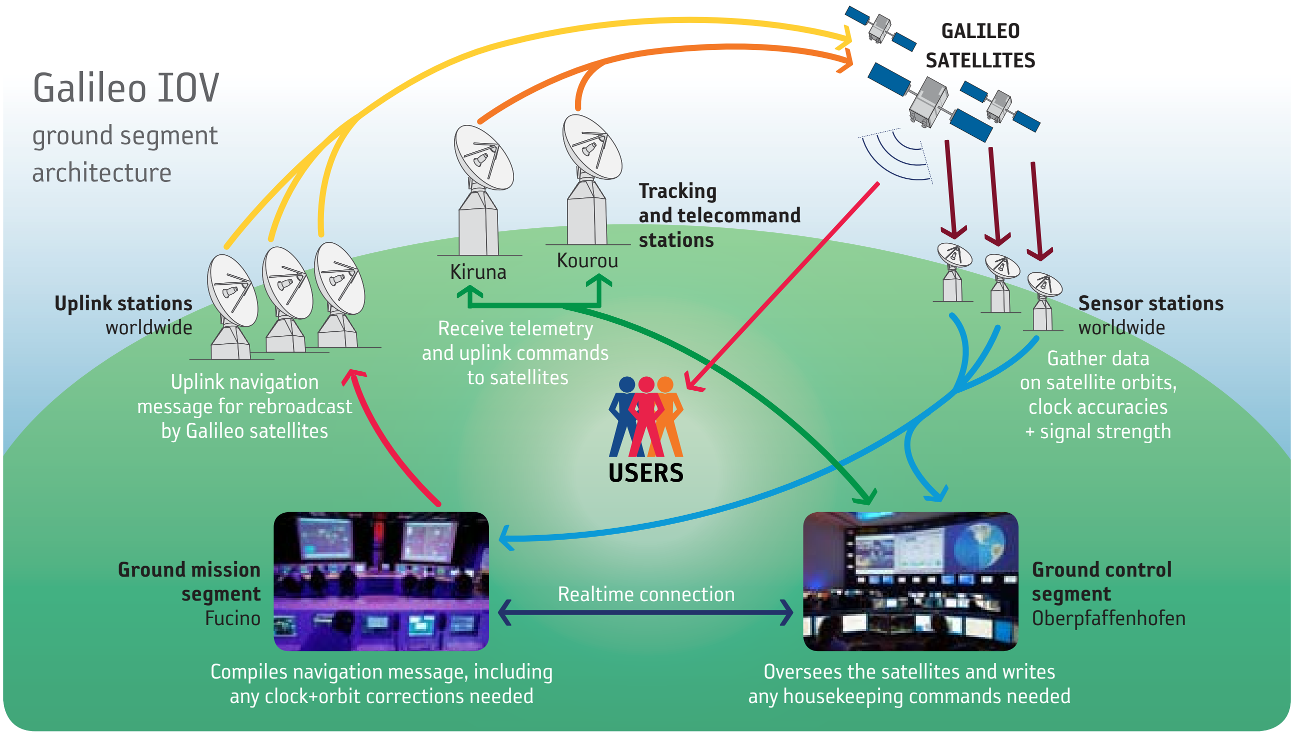
There is a lot more to Galileo than just its satellites in space. The worldwide ground network is essential to ensure the continued reliability of the time and positioning information embedded within the signals from space.

Satellite navigation relies on the receiver to derive the time and point in space that the signal was emitted, with an extremely high level of accuracy. This information is embedded within the signal itself. But onboard atomic clocks can still drift – and just a billionth of a second clock error corresponds to a 30 cm range error.

So a network of ground stations continuously checks each satellite's clock against Galileo System Time, which is generated by the Precise Timing Facility at the Galileo Control Centre in Fucino, Italy, which is in turn cross-checked for alignment to the international Coordinated Universal Time by a group of European timing laboratories.

Satellite orbits drift as well, nudged by the gravitational tug of Earth's slight equatorial bulge and by the Moon and Sun. Even the slight but continuous push of sunlight itself can affect satellites in their orbital paths. So the global network of ground stations picking up the Galileo signals perform radio-ranging in reverse on the satellites emitting them, to pinpoint their current position and identify any orbital drift.

This information on the satellites' clock performances and positions is gathered so that a correcting message can be uplinked to the satellites for rebroadcast to users in the satellite signals themselves. Completing the loop in this way means that optimal system performance can be maintained over time. The quality and reliability of each individual Galileo signal is also checked.

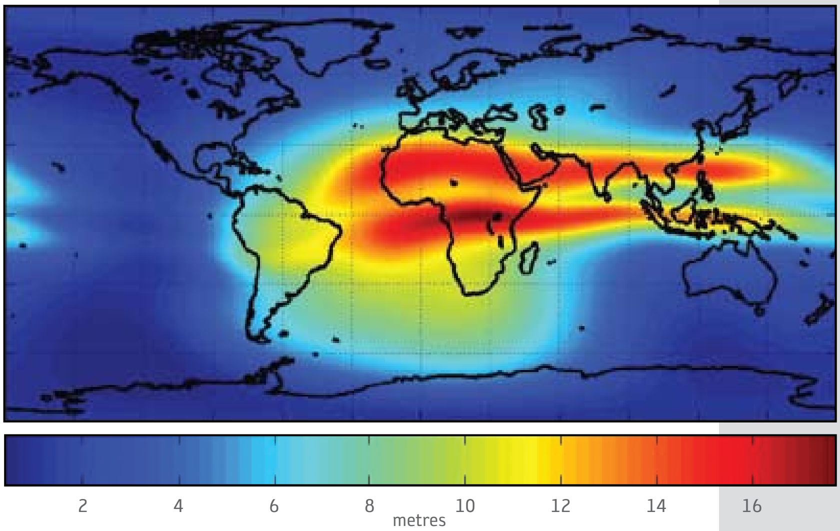


The Galileo ground segment is one of the most complicated developments ever undertaken by ESA, having to fulfil strict levels of performance, security and safety.

- **Ground mission segment (GMS)** In the Fucino Control Centre in Italy, it must provide cutting-edge navigation performance at high speed around the clock, processing data collected from a worldwide network of stations. GMS has two million lines of software code, 500 internal functions, 400 messages and 600 signals circulating through 14 different elements.
- **Ground control segment (GCS)** In the Oberpfaffenhofen Control Centre in Germany, it monitors and controls the constellation with a high degree of automation.

  During the IOV phase, these two centres will have distinct roles; in future, they will work together as hot backups with realtime data synchronisation. In the event of the catastrophic loss of one centre, the other will be able to continue operations.

- **Tracking and telecommand stations** Two, at Kiruna in Sweden and Kourou in French Guiana.
- **Uplink stations** A network of stations to uplink the navigation and integrity data.
- **Sensor stations** A global network providing coverage for clock synchronisation and orbit measurements.
- **Data dissemination network** Interconnecting all Galileo ground facilities.



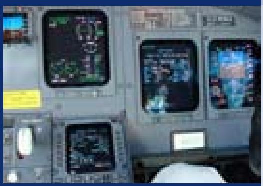
The ionosphere at around noon GMT, showing ionospheric scintillations due to incoming solar energy, in terms of the positioning errors that could result

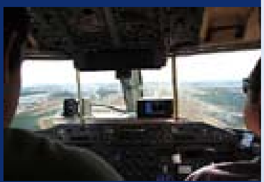
Coping with the ionosphere

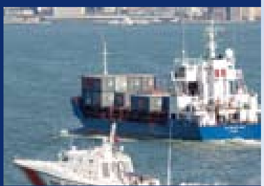
Incoming solar radiation splits apart air molecules at the top of the atmosphere to form an electrically-charged layer known as the 'ionosphere'. Radio pioneers used the ionosphere to reflect their signals beyond Earth's horizon, but for satellite navigation it is more of a hindrance than a help.

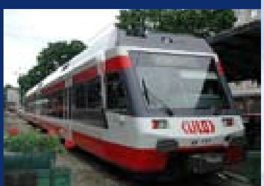
Ionospheric interference can cause satnav receivers to lose signal lock or add significant signal delays, in the worst case causing positioning errors of dozens of metres. Dual-frequency receivers that receive two satnav frequencies simultaneously can overcome this kind of error. Single-frequency receivers of the type used in cars or mobile phones rely on ionospheric error estimates that are generated by the Galileo ground segment and included in the signal message. Galileo incorporates an advanced ionosphere-modelling system to make its error calculations.

→ SERVICES TODAY AND TOMORROW









Today: EGNOS

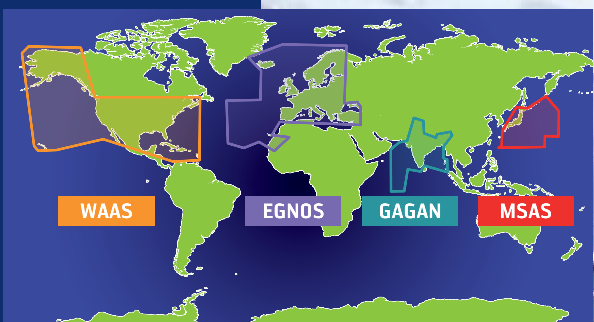
The first pillar of Europe's navigation programme, EGNOS, is already operational, sharpening the accuracy of GPS signals across Europe. In addition, it informs users about the current integrity (level of reliability) of the system based on the GPS satellites' orbits, atomic clock accuracy and ionospheric delay. If the accuracy of the signal falls below a given threshold, users are warned within six seconds.

The **Open Service**, for applications where human life is not at stake, such as personal navigation, goods tracking and precision farming, has been available since October 2009.

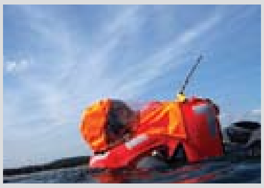
The **Safety-of-Life Service**, where human lives depend on the accuracy and integrity of the signals, became available for its primary purpose of aircraft navigation (beginning with vertical guidance for landing approaches) in March 2011.

The system is based on a network of ground stations, control centres and three geostationary satellites. The ground stations gather data on the current accuracy of GPS signals and embed it in the EGNOS signal, which is uplinked to the satellites to be transmitted to users.

EGNOS is designed against international standards set by the International Civil Aviation Organisation (ICAO) and its development was coordinated with other satellite-based augmentation systems around the world: MSAS in Japan, WAAS in the US, and GAGAN in India.



B. Suhr / Governor of Svalbard



Tomorrow: EGNOS plus Galileo

Once Galileo becomes operational, a portfolio of navigation services will be offered by Galileo and EGNOS, based on varying user needs:

- **Open Service** The Galileo navigational signal will be accessible by the general public free of charge, providing improved global positioning.
- **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 international 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** Already available for aviation to the 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, particularly interesting for professional users.

The potential applications of satellite navigation are virtually limitless. Beyond the safety, efficiency and comfort that satnav brings to the transport sector, it will become a valuable tool for nearly all economic sectors. Keeping track of where you are will be as important as knowing the time of day. Integration of satnav services with other technologies such as mobile communications or traditional navigation aids will multiply their usefulness.

ESA – J. Huart

Evolution of European satnav

EGNOS and Galileo are here to stay. ESA's satnav evolution programme is looking into how the two systems will evolve. Research is under way into future improvements such as expanded augmentation coverage, including how best to support increased navigation in the Arctic region as ice cover recedes, even more precise atomic clocks, and intersatellite links to reduce Galileo's dependence on its ground segment for clock correction.

Improved ionospheric modelling is another innovation that would increase Galileo and EGNOS accuracy while also being of scientific interest. Navigation satellite 'reflectometry' is another field of research: intercepting reflected satnav signals with special receivers to gather scientific and environmental information on Earth's sea and land, including sea-surface height and roughness, wind fields, ice extent, soil moisture and biomass density.

→ GALILEO IOV OVERVIEW

Making the future: Galileo's partners

The definition, development and in-orbit validation phases of the Galileo programme are being carried out by ESA and co-funded with the EC. The Full Operational Capability phase is managed and funded by the EC. The Commission and ESA have a delegation agreement through which ESA acts as design and procurement agent on behalf of the EC.

Galileo IOV satellite

Mass	about 700 kg
Size with solar wings stowed	3.02 x 1.58 x 1.59 m
Size with solar wings deployed	2.74 x 14.5 x 1.59 m
Design life	more than 12 years
Available power	1420 W (sunlight) / 1355 W (eclipse)

Orbit

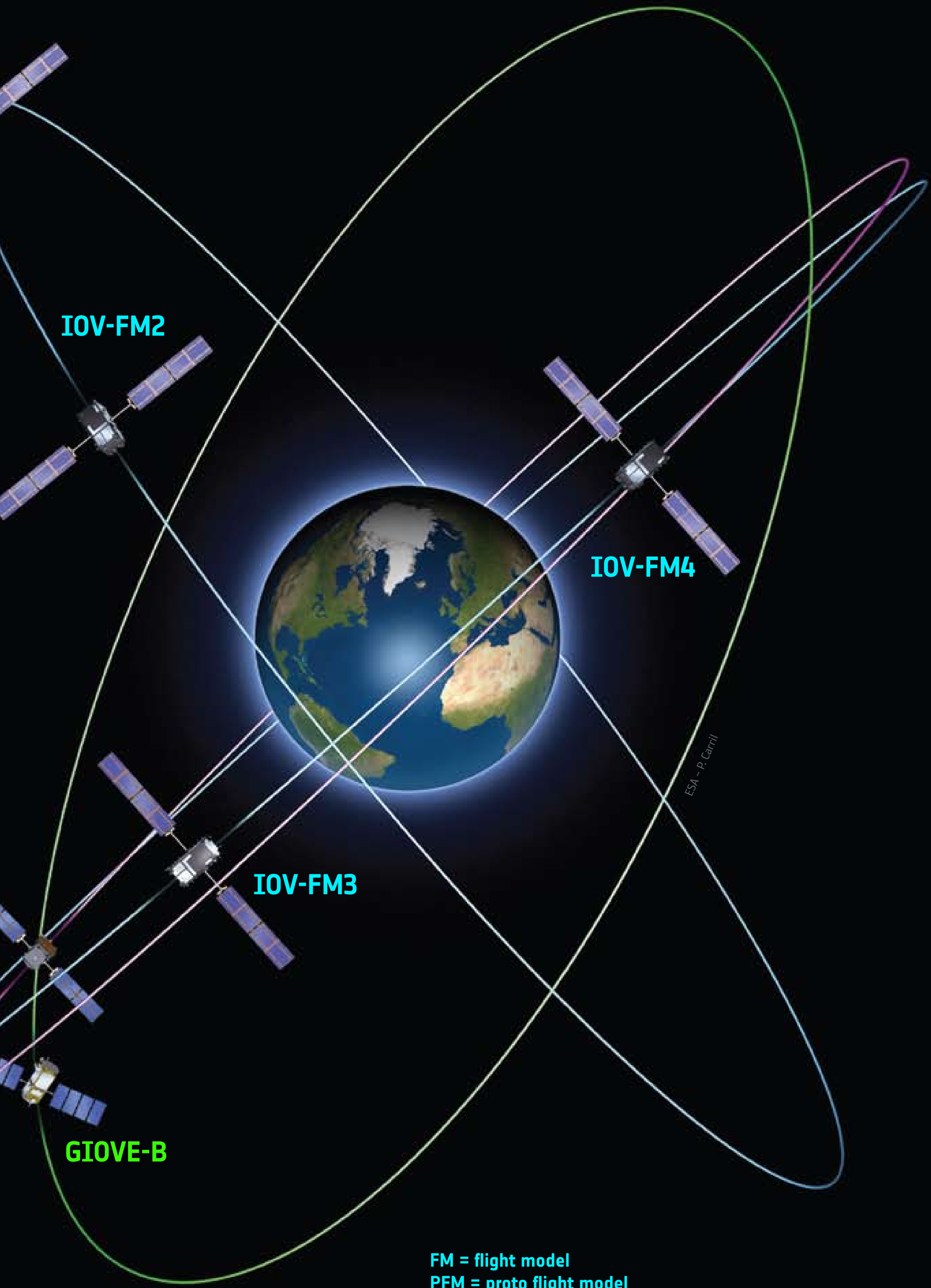
Altitude	23 222 km
Inclination	56°

Galileo IOV main contractors

Space segment	EADS Astrium GmbH (DE) as satellite prime, with Thales Alenia Space (IT) as subcontractor for satellite integration
Operations segment	SpaceOpal, a consortium created by DLR (DE) and Telespazio (IT)
System support activities	Thales Alenia Space (IT)
Ground mission segment	Thales Alenia Space (FR)
Ground control segment	EADS Astrium UK
Test user segment	Thales Avionics (FR), Septentrio (BE)
Global data network	British Telecom (GB)

Further information

www.esa.int/navigation
www.esa.int/egnos
www.esa.int/galileo
http://ec.europa.eu/galileo
www.satellite-navigation.eu
www.egnos-portal.eu
www.gsa.europa.eu



FM = flight model
PFM = proto flight model

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