→ A JOURNEY TO EARTH'S CORE

Swarm: ESA's magnetic field mission

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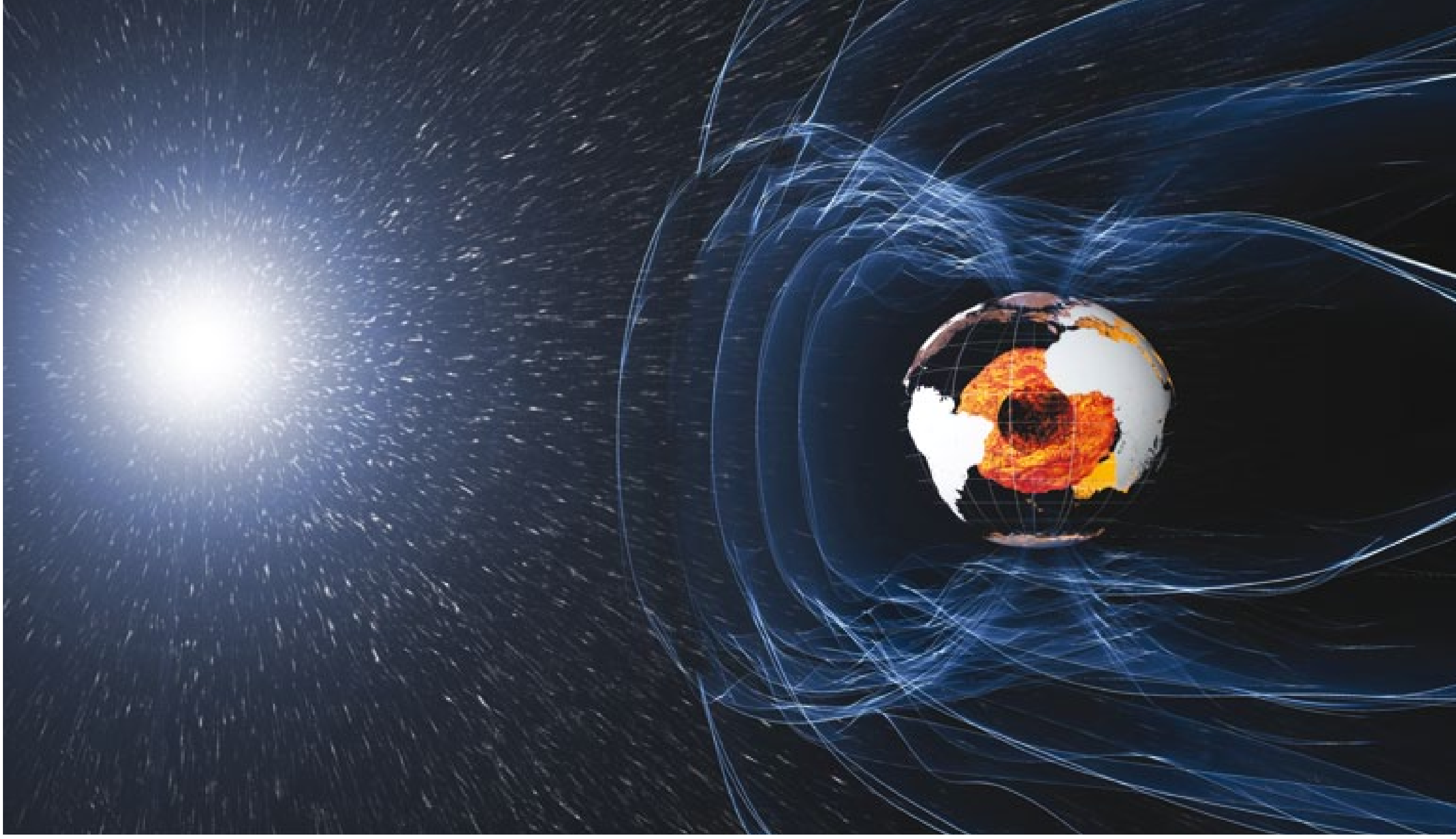
Essential for life on Earth, our planet's protective magnetic shield is weakening. ESA's Swarm mission, a constellation of three state-of-the-art satellites to be launched later this year, will help us understand what is happening to this vital shield.

ESA's Earth Explorer missions are developed in direct response to pressing Earth-science issues raised by the scientific community. They are designed to improve our understanding of how Earth works as a system and the impact human activity is having on natural processes.

Swarm will be the fourth Earth Explorer mission in orbit, following GOCE, SMOS and CryoSat. The mission was proposed by a consortium led by Eigil Friis-Christensen (DTU Space, Denmark), Hermann Lühr (GFZ Potsdam, Germany) and Gauthier Hulot (IPGP, France).

Carrying novel technologies, Swarm sets out to identify and measure precisely the different magnetic signals that stem from our world's core, mantle, crust, oceans, ionosphere and magnetosphere.

By unravelling the mysteries of Earth's magnetic field, Swarm will provide new insights into many natural processes, from those occurring deep inside the planet to the near-Earth electromagnetic environment and the influences of the solar wind.



The force that protects our planet

Although invisible, the magnetic field and electric currents near Earth are responsible for generating complex forces that have an immeasurable impact on our everyday lives. Earth's magnetic field is largely generated deep inside our planet's liquid outer core. This is a huge 'ocean' of swirling molten iron, driven by convection currents. Acting like the spinning conductor in a bicycle dynamo, it generates electrical currents and thus, the continuously changing electromagnetic field. This magnetic field can be likened to that of a powerful bar magnet at the planet's core, which is currently tilted about 11° to Earth's axis of rotation.

The field acts as a shield, protecting the planet from charged particles that stream towards Earth in solar winds. This complex force, however, is in a constant state of flux. Magnetic north wanders and occasionally reverses direction, so that a compass would point south instead of north. Moreover, the magnetic field varies in strength, and it is currently showing signs of significant weakening.

Although the field has been sustained over billions of years, exactly how this happens and its irregular behaviour are still poorly understood.

The continuous changes in the core field that result in motion of the magnetic poles and reversals are important for the study of Earth's lithosphere field (also known as the 'crustal' field), which has induced and remnant magnetised parts. The latter depend on the magnetic properties of the sub-surface rock and the history of Earth's core field. For example, most oceanic crust is generated as a result of volcanic activity.

When the magma hardens, it locks in the direction of the prevailing magnetic field at the time. The seafloor actually acts as a geological 'tape recorder' so that pole reversals are visible in magnetised rock as the seafloor spreads over time. Analysing the magnetic imprints of the ocean floor allows the past core field changes to be reconstructed, and also helps investigate tectonic plate motion.

→ A history of magnetic discovery

1st century AD

Earliest known magnetic compass invented by the Chinese.

11th century

Chinese author Zhu Yu first reports a compass being used for navigation at sea.

12th century

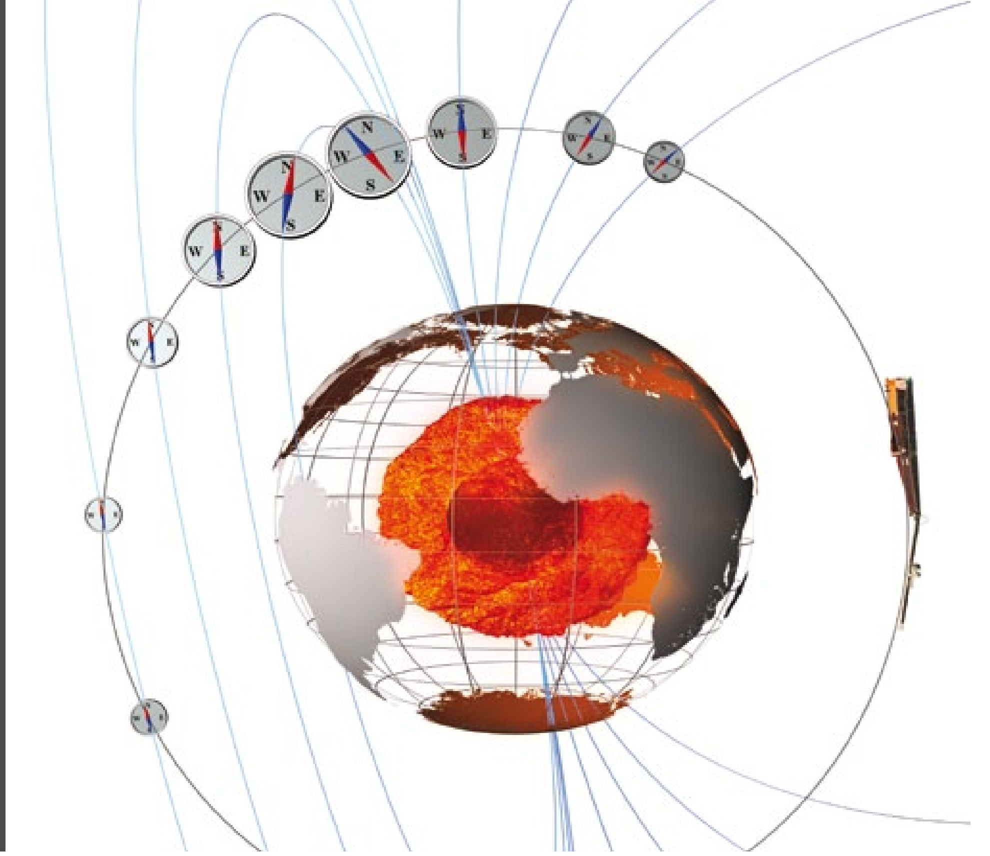
Compass probably introduced into Europe by the Arabs.

1187

English scholar Alexander Neckam reports use of magnetic compass for crossing English Channel.

← Swarm's measurements will further our understanding of space weather and radiation hazards caused by particles from the Sun interacting with our magnetic field (ESA/AOES Medialab)

→ Earth's magnetic field is largely generated deep inside our planet's liquid outer core, and it is continuously changing. Each Swarm satellite aims to measure the strength and direction of the magnetic field (ESA/AOES Medialab)



Other induced sources of magnetism can be found between the thin crust and the outer core and in the ocean. Electrical conductivity variations in the silicate mantle generate minute signals that can be detected in space when electrical currents in the magnetosphere vary in time. These variations can be related to mantle composition, such as temperature, water content and melt processes.

There is also thought to be a weak contribution to the electromagnetic field from oceans. Because seawater is conductive, it generates electrical currents in response to changing electric currents off Earth.

The magnetosphere is the region in space about 10–20 Earth radii from Earth. This region comprises complicated current systems, similar to the ring current around the magnetic equator relative to the magnetic poles on Earth. The magnetosphere protects us from charged particles streaming from the Sun in solar winds. In general, these particles cannot penetrate the magnetosphere.

The ionosphere, a region in the upper atmosphere 50–600 km from Earth, contains ionised atoms resulting from the effect of ultraviolet light from the Sun. Strong electric currents flow in the sunlit hemisphere, which is much more conductive than the night side. The magnetic field of these currents can be detected in magnetic field measurements. Irregular solar activity, known as magnetic storms, results in energetic processes on top of diurnal variations. For example, the aurora borealis and aurora australis are formed when charged particles in solar wind are channelled by Earth's magnetic field into the atmosphere near the poles.

When these particles collide with atoms and molecules (mainly oxygen and nitrogen) in the upper atmosphere, some of the energy in these collisions is transformed into visible light, the green–blue patterns that characterise these auroras.

Swarm will contribute to a better scientific understanding of many of these processes, also in relation to global change and improve our knowledge of how Earth works as a system.

1269

Petrus Peregrinus of Maricourt described a floating compass and writes about the polarity of magnets.

1600

'On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth' published by William Gilbert (who concluded that Earth itself was magnetic and this was why compasses point north, he was also the first to argue that the centre of Earth was iron).

1634

Henry Gellibrand was the first to document that Earth's magnetic field changes with time.

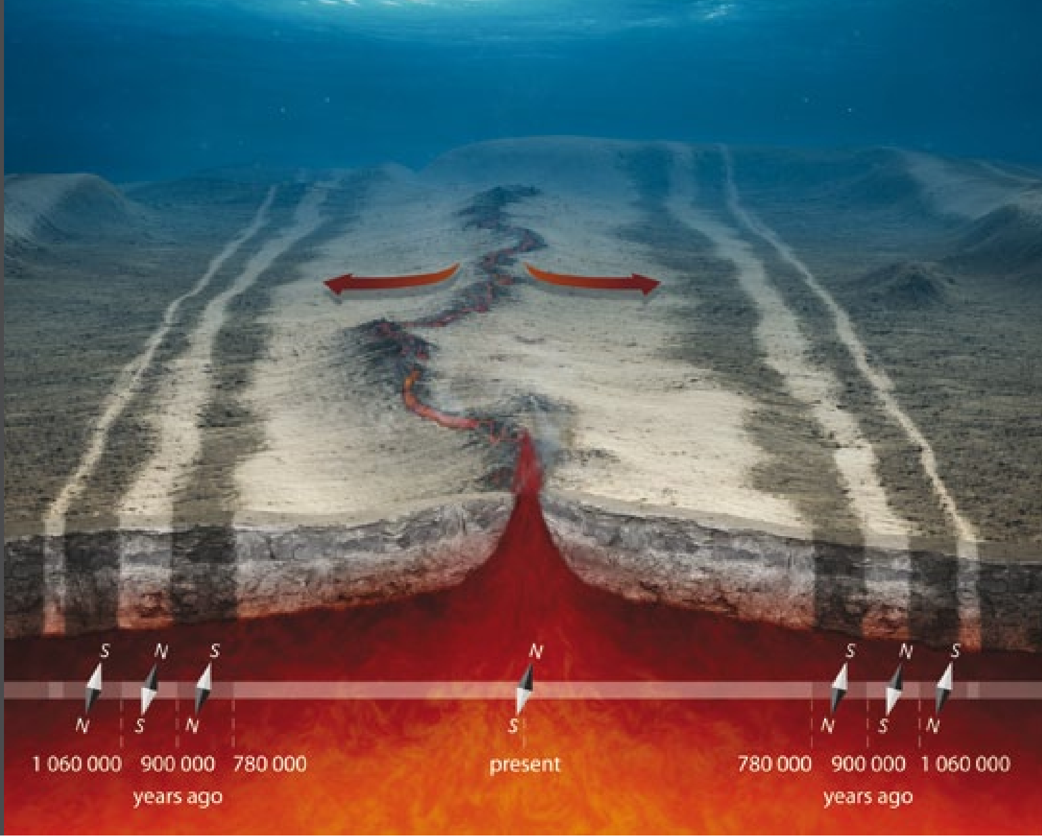
1700

Edmund Halley carried out magnetic surveys over the Atlantic Ocean and publishes the first map showing lines of equal declinations of the magnetic field in the Atlantic.

1798

German explorer Alexander von Humboldt makes magnetic measurements on his voyages through Europe, Latin America and Russia.

→ The direction of magnetic grains laid down successively in Earth's crust, particularly the sea floor, are primary evidence for magnetic field reversal. When the rock is new and molten, its grains are free to align themselves with the prevailing magnetic field. As the rock cools, the grains are frozen in time. As the sea floor expands (in the Atlantic), it is striped with rock oriented in different directions, indicating that the magnetic poles have reversed many times throughout Earth's history (ESA/AOES Medialab)



Space compasses and their bearing on Earth

The three Swarm satellites will provide precise and detailed measurements of the strength and direction of the magnetic field. Magnetic sensors measure a combination of the core field tangled with others from magnetised rocks in the crust, electrical currents flowing in the ionosphere, magnetosphere and oceans, and currents induced by external fields inside Earth. The challenge is to separate the individual magnetic field sources, each with their own characteristics in space and time. GPS receivers, an accelerometer and an electric field instrument will deliver supplementary information to study the interaction of Earth's magnetic field with the solar wind.

The main areas of focus are:

The core

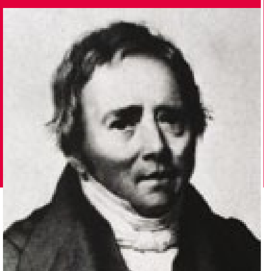
Measuring the core field and, in particular, how it changes over time are two of the very few means of probing the Earth's liquid core. Variations with time directly reflect the fluid flows in the outermost core and provide a unique experimental constraint on geodynamic theory. Progress in geomagnetic research calls for moving beyond simple extrapolation of the field with time to forecasting that field through a better understanding of the underlying physics. A serious limitation on investigating internal processes over months to years is the effect of external magnetic sources that contribute on timescales up to the 11-year solar cycle. All this clearly shows the need for a comprehensive separation and understanding of external and internal processes which Swarm addresses.

The crust

Magnetism of the lithosphere tells us about the history of the global field and geological activity. This needs to be determined from space with much higher resolution than currently exists. By complementing the spatial scales observed from Swarm with aeromagnetic surveys, the gap in our knowledge about Earth's crust will be filled. The crust also holds information on how the changing field may have affected the climate historically, through the escape of atmospheric gases to space.

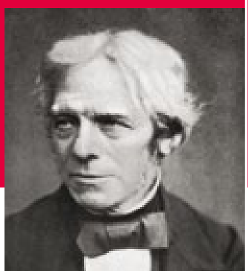
1819

Danish physicist Hans Christian Ørsted discovers relationship between electricity and magnetism when he sees that an electric current can influence a compass needle.



1821

Michael Faraday establishes first basis for the magnetic field concept in physics.



1832

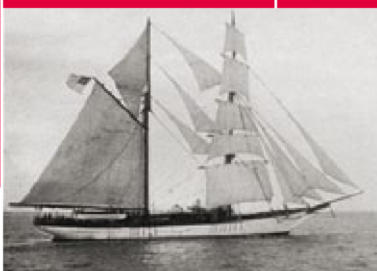
Carl Friedrich Gauss and Wilhelm Weber begin investigating the theory of terrestrial magnetism.

1840

Carl Friedrich Gauss publishes the first geomagnetic field model demonstrating the dipolar nature of Earth's magnetic field.

1909

The *Carnegie*, a yacht made almost entirely of wood and other non-magnetic materials, starts voyages to gather oceanic magnetic data.



The mantle

The constellation of satellites makes it possible, for the first time, to image the mantle's electrical conductivity globally in three dimensions. This will yield clues to its chemical composition and temperature, which are fundamental to understanding mantle properties and dynamics. This will complement seismic analysis and gravity observations made, for example, by GOCE.

The ocean

The conductive ocean produces a relatively weak magnetic signature, which contains independent data on tides and ocean circulation, i.e. the total effect from the ocean. This information is unique and complementary to other satellite techniques. However, it is also very challenging to isolate this signal from all the other contributing sources of the magnetic field.

Two Swarm satellites will orbit close together at the same altitude - initially about 460 km - while the third will be higher at about 530 km. These different near-polar orbits, along with the various Swarm instruments, improve the measurement sampling in space and time (ESA/AOES Medialab)

1919

Irish physicist Joseph Larmor suggests that dynamos could naturally sustain themselves in conducting fluids (this theory explains how the geomagnetic field originates deep inside Earth).

1979

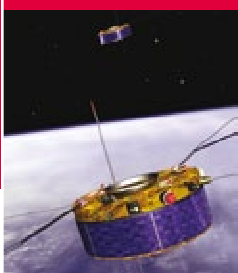
NASA launches Magsat satellite to map Earth's magnetic field.

1999

Denmark launches Ørsted satellite to measure Earth's magnetic field (based on data from this mission, scientists confirmed that the magnetic poles are moving).

2000

ESA launches Cluster mission to study the interaction of solar wind with the magnetosphere.



2000

Germany launches CHAMP satellite to study variations in magnetic and gravity fields.

↑ One of the Swarm satellites, with boom deployed, undergoing tests at IABG's Magnetic Field Simulation Facility in Ottobrunn, Germany. The tests are carried out in a magnetically clean environment – hence the wooden floor (ESA/IABG)

The upper atmosphere

The magnetic field is also of primary importance for Earth's external environment, providing information about the Sun–Earth connected system, which can be studied in detail through Swarm. While there are indications that air density in the thermosphere is related to geomagnetic activity, this is still not well understood. Furthermore, the magnetic field acts as a shield against high-energy particles from the Sun and deep space. It controls the location of radiation belts, and also the path of incoming cosmic ray particles, which reflect the physical state of the heliosphere.

Swarm complements ESA's Cluster mission, which has been in orbit since 2000. Cluster observes the interaction of solar wind with the magnetosphere while Swarm's observations are made closer to Earth. The interplanetary medium controls the energy input into the Earth's magnetosphere and the development of magnetic storms, or 'space weather'. A deeper understanding of the weather in space from Swarm is relevant to satellite technologies, radio communications, navigation systems and power infrastructures. Widely reported, but still largely unknown, are possible correlations between solar activity and climate variations.

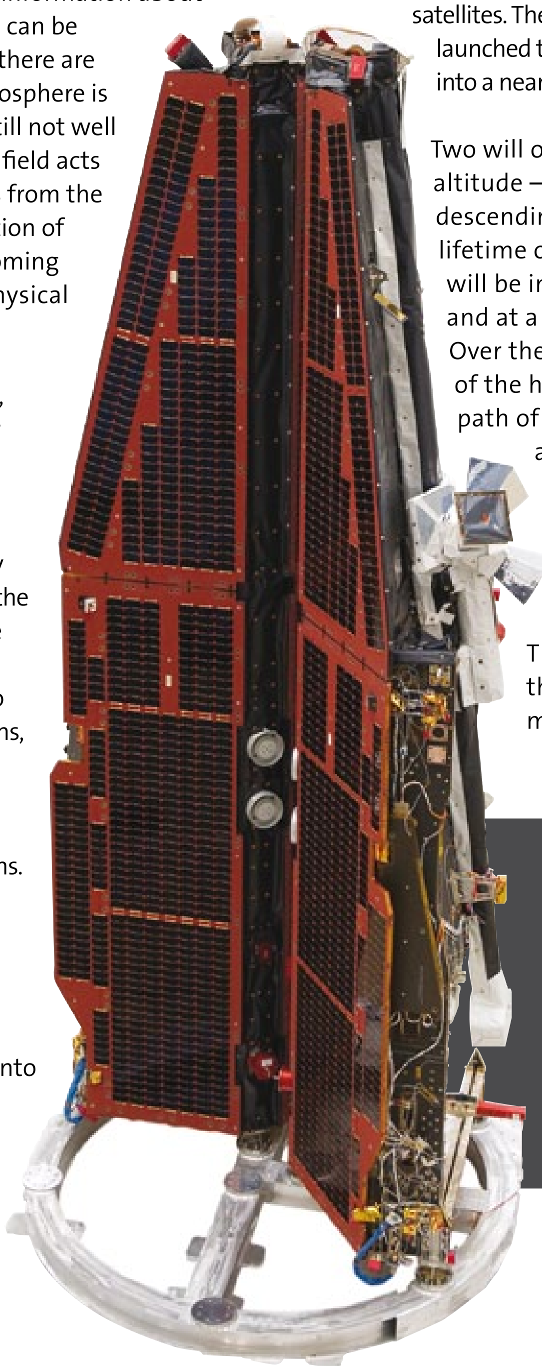
No other single physical quantity can be used for such a variety of studies related to our planet. Highly accurate and frequent measurements of the magnetic field will provide new insight into our planet's formation, dynamics and environment, stretching from Earth's core to the Sun.

The first Earth Explorer constellation

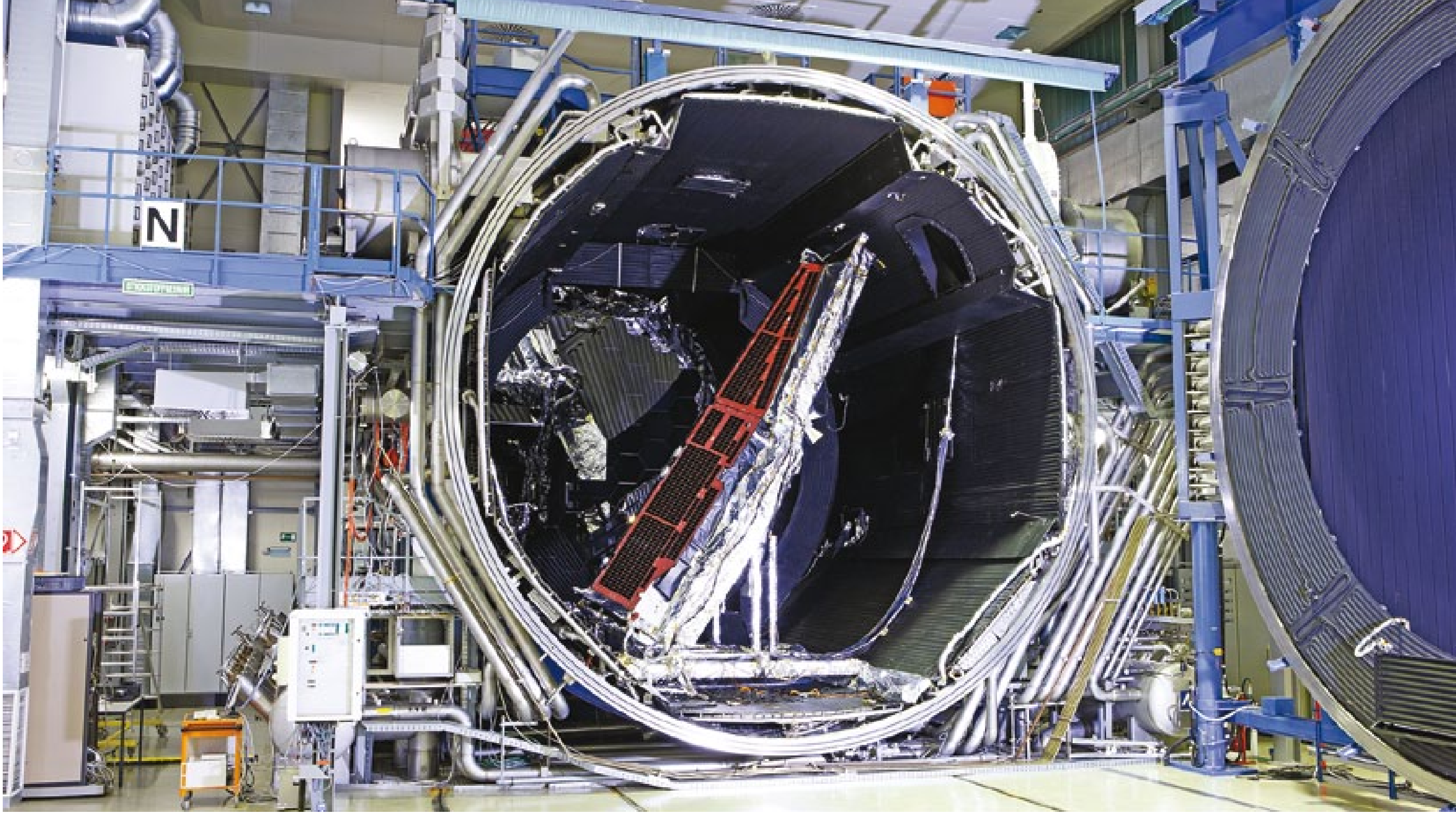
Swarm will be ESA's first constellation of Earth observation satellites. The three identical satellites will be launched together on one rocket from Russia into a near-polar, low-Earth orbit.

Two will orbit in tandem at the same altitude – initially at about 460 km, descending to around 300 km over the lifetime of the mission. The third satellite will be in a higher orbit, initially 530 km, and at a slightly different inclination. Over the course of the mission, the orbit of the higher satellite drifts to cross the path of the two lower satellites at an angle of 90°.

Essentially, the two different orbits, along with the various Swarm instruments, optimise the sampling in space and time. This helps to distinguish between the effects of different sources of magnetism.

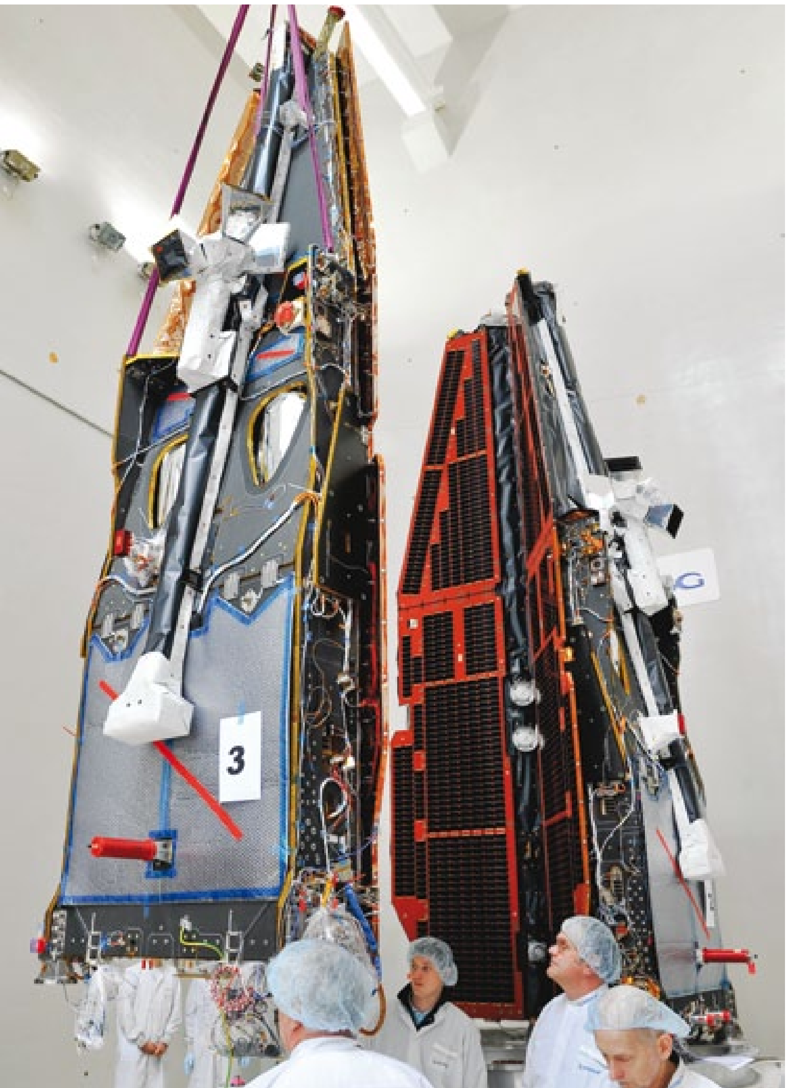


← Two of the trapezoidal Swarm satellites mounted together vertically as they would be under their launcher fairing, with space on the left for the third (ESA/IABG)



↑ A Swarm satellite in the Space Simulation Chamber at IABG, Ottobrun (ESA/IABG)

↓ IABG's centre in Ottobrunn opened its gates on 17 February, when international media representatives were granted access to see the three Swarm satellites (ESA/IABG)



Technological excellence

Swarm had to be designed to cope with a number of highly demanding constraints: a non-Sun-synchronous low Earth orbit, fitting three satellites within one rocket fairing, accommodation of instruments, a small and defined cross-section for reducing air drag (fuel is limited for orbit maintenance), provision of sufficient solar array area, accommodation of units including propellant tanks, 'magnetic cleanliness' near the magnetometers, and avoidance of micro-vibrations to ensure a quiet environment for the accelerometers.

These requirements led to a set of particular design features: a long deployable magnetometer boom, an ultra-stable optical bench, a high ballistic coefficient and body-mounted solar arrays to cover the range of solar aspect angles expected.

To get good magnetic measurements from the magnetometers, the satellites have to be as magnetically clean as possible. Therefore, the magnetometers are placed at the ends of long booms away from the satellite body because their own magnetic fields reduce in proportion with the cube of the distance from the satellite.

Magnetic disturbance is minimised by using appropriate materials, a well-proven electrical grounding concept, self-compensating wiring for power harnesses, batteries and solar arrays, and careful calibration and assembly/integration processes.

Specific focus has been placed on the design of the optical bench carrying the Startracker assembly and Vector →