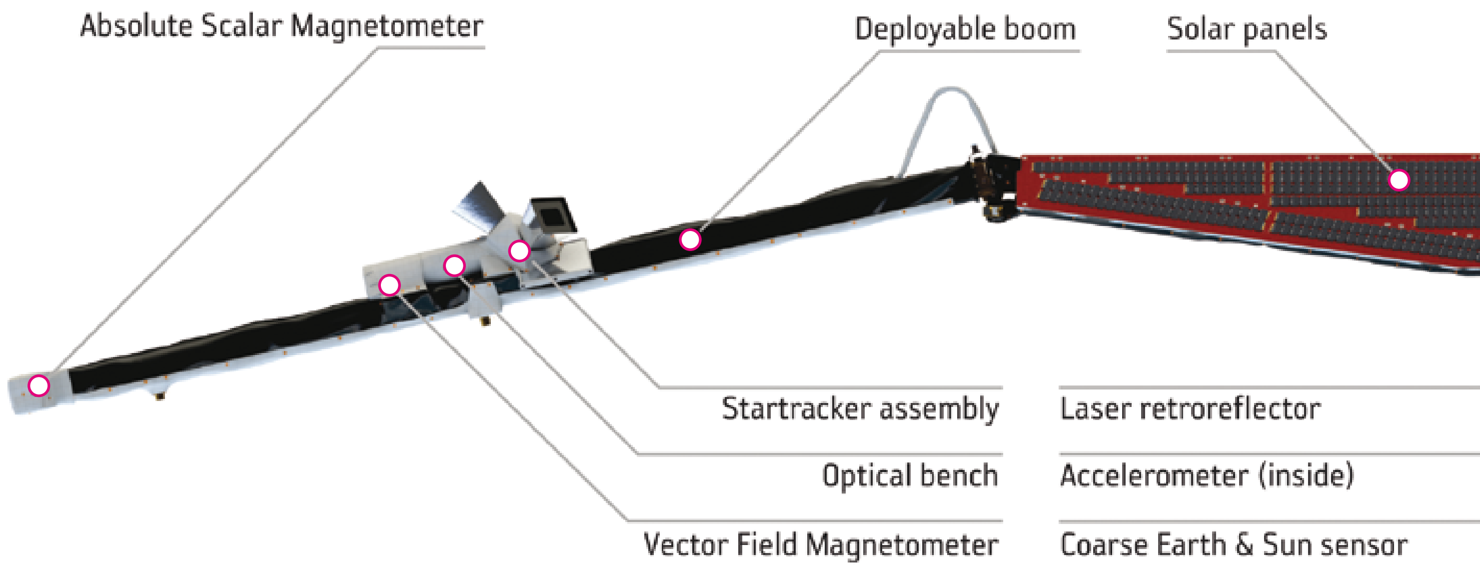
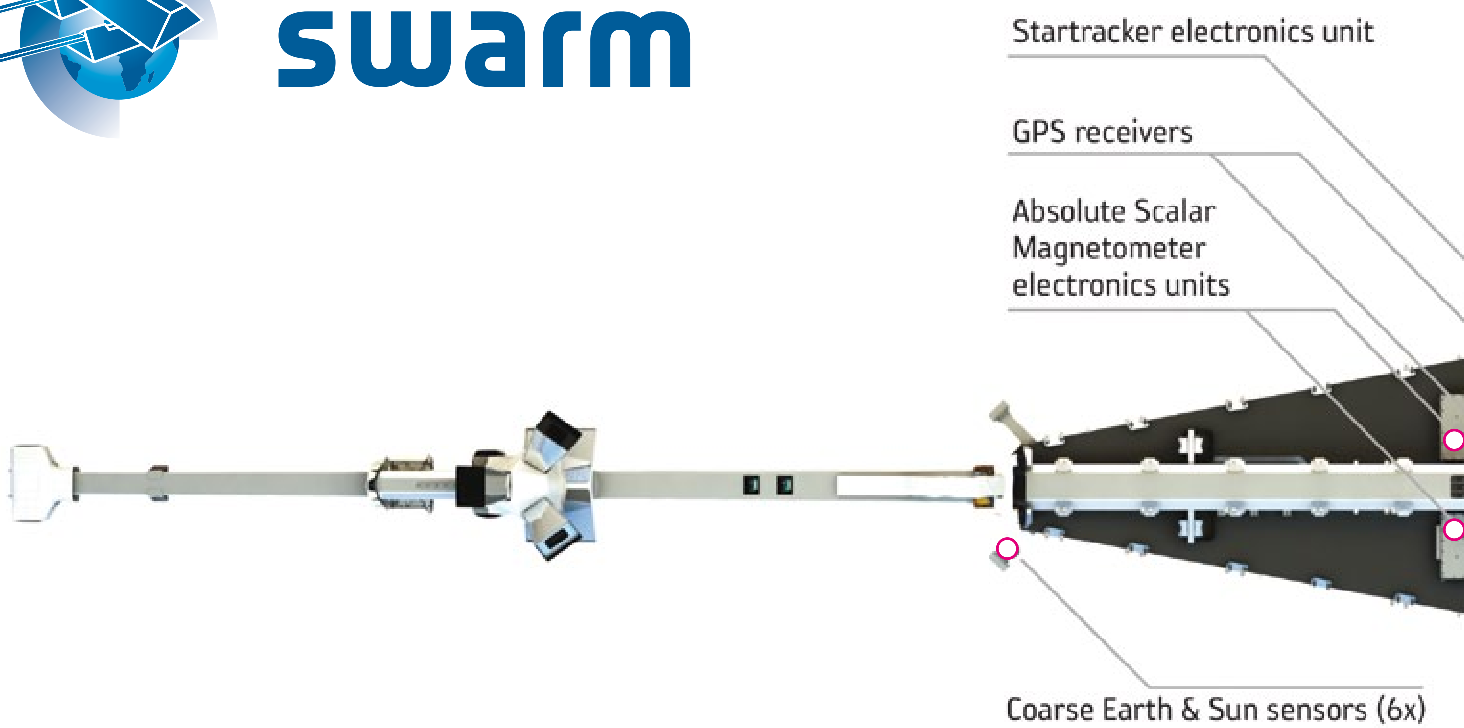
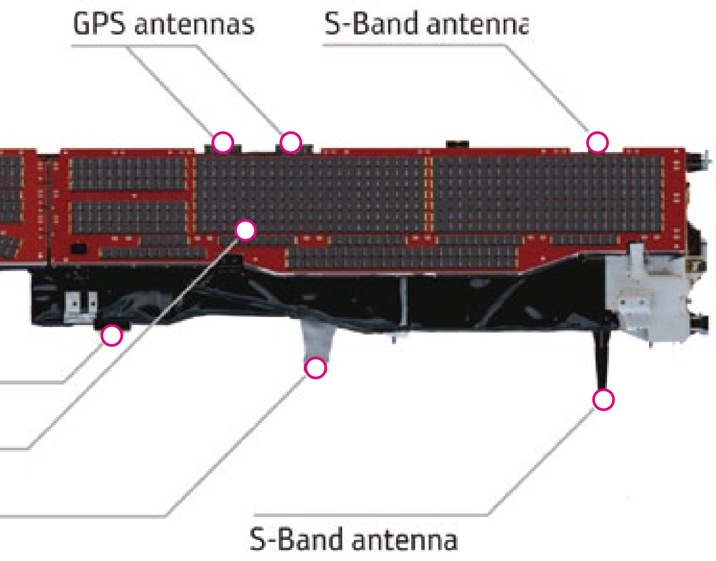
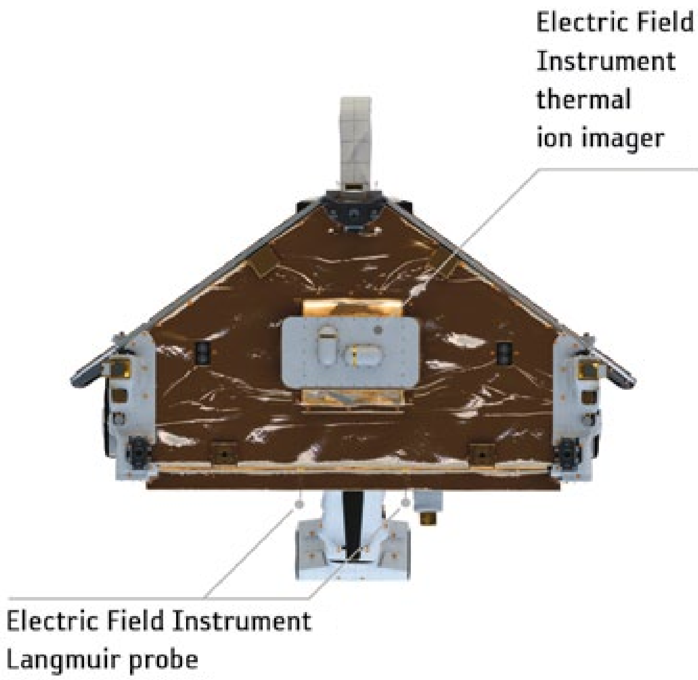
→ ESA'S MAGNETIC FIELD MISSION

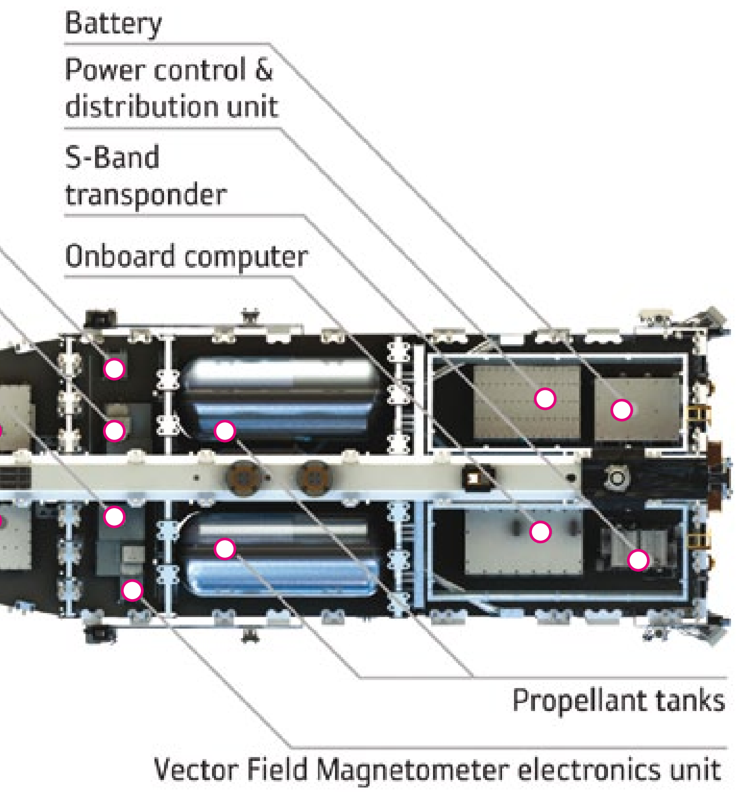


swarm









→ Facts and figures

Dimensions: length (boom deployed) 9.26 m, (boom stowed) 5.04 m, width 1.5 m, height 0.85 m

Mass: 473 kg

Power: two body-mounted solar arrays (two panels per array), gallium arsenide cells in series delivering 608 W; a set of 48 Ah lithium ion batteries

Onboard computer: 6 MB memory, allowing autonomy of satellite for more than three days

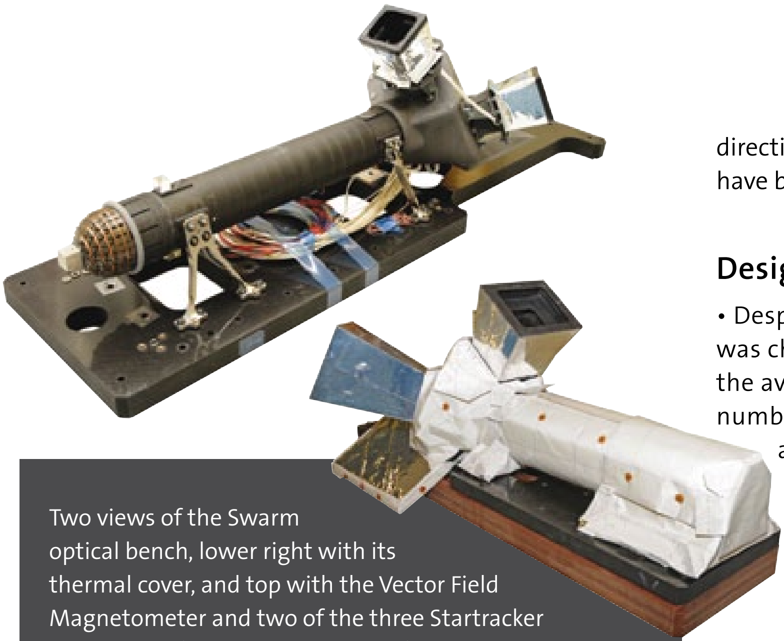
Attitude and orbit control:
magneto-torquers (10 Am^2 moment) and cold-gas thrusters (20 and 50 mN) actively control and maintain attitude on all three axes

Science data downlink:
6 Mbit/s (to Kiruna ground station)

Data processing, distribution and archiving: ESRIN

Mission life: four years (plus three-month commissioning period)

Prime contractor: EADS/Astrium GmbH



Two views of the Swarm optical bench, lower right with its thermal cover, and top with the Vector Field Magnetometer and two of the three Startracker units visible (EADS/Astrium GmbH)

→ Field Magnetometer. The stability of the bench greatly influences the quality of the magnetic data product. The proposed design is based on best technology available.

To receive optimum ionospheric and magnetic signals, Swarm has been designed to fly in a particularly low orbit, between 530 km and 300 km above Earth. The shape of the satellite minimises aerodynamic drag effects and torque, and therefore propellant gas consumption. The mass and volume of the satellites were also limited by the capacity of the small low-cost launchers such as Vega, Rockot or Dnepr.

In turn, this compatibility limited the length of the boom, and meant coming up with a new design of lightweight structure. Orbit definition for the constellation was also a factor in the design, because the three spacecraft need to reach different orbits. Only indirect orbit injection was possible with this class of launcher, which justifies the large quantities of propellant gas carried by each satellite.

The result is three slim, trapezoidal satellites, each about 9 m in length (with boom deployed) and weighing 473 kg, using the maximum available volume under the Rockot fairing. The satellites are symmetrical about their flight direction. The sides of the satellites that face the Sun each have body-mounted solar panels.

Design features

• Despite its low specific impulse, cold-gas propulsion was chosen for the reaction control system because of the availability of low-force thrusters qualified for the number of times they would be fired. 'Freon' was chosen as the propellant gas over the standard nitrogen to reduce the volume of the tank in order that fitted inside the spacecraft and launcher fairing. Reaction wheels were not an option because of magnetic and vibration effects.

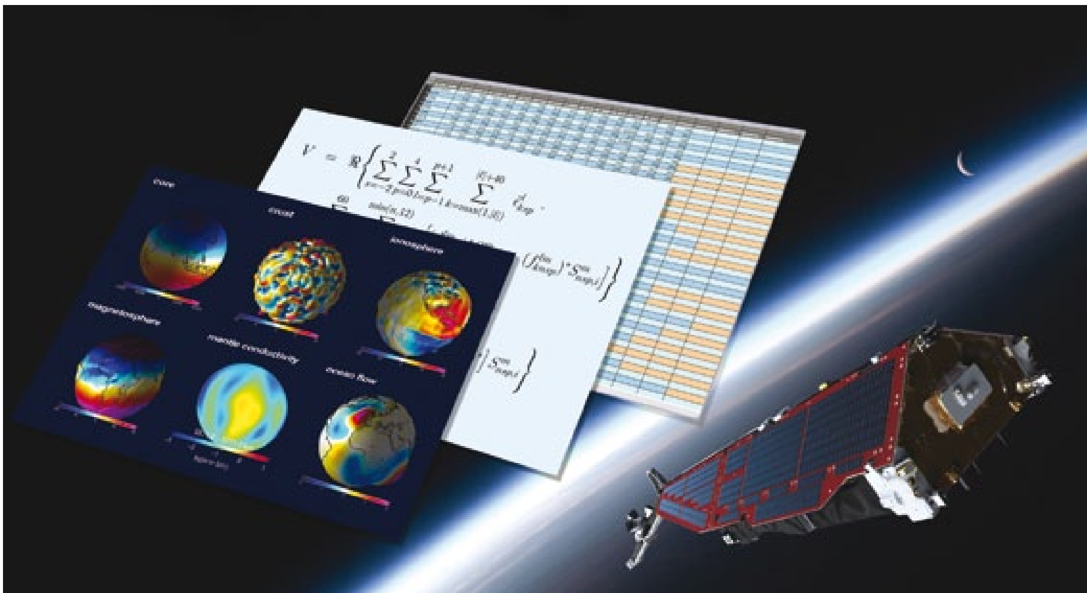
• The micro-accelerometer has to be within 5 mm of the centre of mass of the satellite. For this, the two tanks full of propellant gas are positioned on each side of the micro-accelerometer connected by a pipe. As gas is consumed after a satellite manoeuvre, the level of gas in each tank is the same and the centre of mass remains in the same position. This design allows the measurement of non-gravitational forces.

• The main structure of the satellite is made of carbon-fibre reinforced plastic. This material offers thermal stability, savings on mass and the avoidance of eddy current effects that can be encountered with large aluminium sheets.

• The power system is optimal for electromagnetic compatibility and magnetic cleanliness. The configuration of the solar arrays was optimised to take into account the single launch requirement of limited fairing space.

The launcher

The launcher selected for placing Swarm into orbit with a single launch is the Rockot-KM, procured by ESA through a dedicated contract with Eurockot GmbH based on the experience gained through other ESA missions. The three Swarm satellites will be installed on a Breeze-KM upper



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Swarm will deliver products to study Earth's magnetic field and its interaction with the Sun, which will benefit a broad range of applications in Earth sciences and space weather (ESA/AOES Medialab) stage using an adapter/dispenser system specifically designed for this mission by Khrunichev Space Centre and Salyut Design Bureau of Moscow.

Constellation operations

The Flight Operations Segment is responsible for operating Swarm in orbit. It is in charge of communications with the satellites, ensuring their good health, maintaining orbits, executing payload activities requested from mission management and delivering the science data and housekeeping telemetry to the processing centre.

This segment comprises the mission control centre at ESOC (Darmstadt, Germany), the primary ground station at Kiruna (Sweden), and reinforcement stations for critical mission phases at Svalbard (Norway), Troll (Antarctica) and Perth (Australia). The most critical mission phase is the launch and early orbit phase. Lasting about three days, this phase will be handled by the large mission control team. During this period, an exciting moment will be the first acquisition of signal following the separation of the satellites from the launcher, and checking the successful activation of all essential units. Several hours after launch, the 4 m booms are deployed on each of the satellites.

Next comes a three-month orbit acquisition and commissioning phase, in which a complex sequence of manoeuvres and drifting periods are carried out to gradually reach the correct orbits for operations. The payloads of each satellite are activated, checked and characterised.

In the routine mission orbits, operations will be largely automated, with a reduced number of contacts and a relatively simple planning of science-related activities. During the operational phase of four years, the orbits of the satellites are left in free decay, except for manoeuvres on the lower pair of satellites to avoid collision when satellites cross each other at the poles or for constellation maintenance. This ensures adequate space and local time sampling of the magnetic field to support the separation of the different magnetic field contributions to advance science.

→ 'A Journey to the Centre of the Earth'

Classic science-fiction writer Jules Verne imagined an exciting expedition to the centre of Earth, but the reality is less romantic. The heart of our planet remains inaccessible to direct observation. While Verne's story describes a passage to the Earth's core through an extinct volcano in Iceland, in fact the deepest hole ever drilled by humans is located on the Kola Peninsula in Russia.

Called the 'Kola Superdeep Borehole', this dig was started in 1970 with the aim of reaching the 'Mohorovičić discontinuity', or 'moho', which is where the crust and mantle intermingle. This was never completed and the hole is currently 12 km deep, a mere scratch in thin surface of our planet. But even if it was possible to dig a hole to Earth's centre, 6350 km deep, we would not be able to survive the high temperatures and pressures that exist there: 6000˚C and 360 gigapascals!

So the core is inaccessible, but not completely invisible – because it is possible to explore the centre of Earth virtually, using seismology. Data captured by seismographs all over the world allow us to map the structure of Earth. Scientists now believe Earth has a liquid iron external core and a central solid iron nucleus.

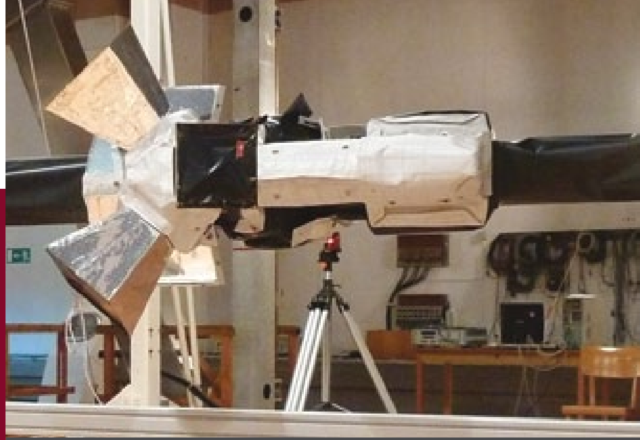
There are other ways to penetrate the depths of our planet, to explore this ultimate 'terra incognita' despite the impossibility of venturing there. Scientists have a number of solutions, such as studying Earth's 'polar wander' (the small wobbles in its axis of rotation) or the variations of acceleration due to gravity for example. All these phenomena offer a lot of information on deep Earth dynamics and especially on the convection movements in the iron ocean around the core, confirmed after over 400 years by magnetic observatories or more recently by Ørsted and CHAMP satellites.

But no other single physical quantity can be used for such a variety of studies related to our planet as the variation of its magnetic field. Highly accurate and frequent measurements of the magnetic field will provide a unique map of mantle conductivity and a new view of the core field.

This virtual picture of Earth can be compared to the rich imagination of Jules Verne, more than a century ago. Swarm will contribute to this virtual picture by providing new insights into our planet's formation, dynamics and environment, from the Sun to the centre of the Earth.

→ Instruments

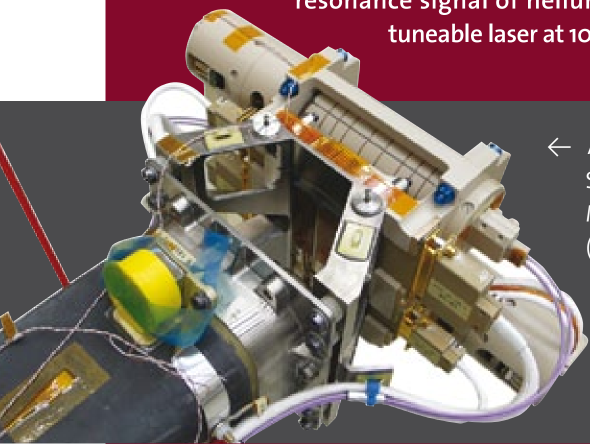
Swarm takes advantage of a new generation of magnetometers. An electric field instrument, an accelerometer and GPS receivers will deliver supplementary information to study the interaction of Earth's magnetic field with solar winds, electric currents and radiation, and their effects on the Earth system.



↑ Startracker assembly (at left of VFM) (ESA/IABG)

Absolute Scalar Magnetometer (ASM)

This novel instrument will measure the magnetic field to an accuracy greater than any other magnetometer. The ASM is an 'optically pumped metastable helium-4 magnetometer', developed and manufactured by CEA-LETI in Grenoble (France) under contract with CNES Toulouse. It provides scalar measurements of the magnetic field for the calibration of the vector field magnetometer using a technique based on enhancing the magnetic resonance signal of helium atoms with a tuneable laser at 1083 nm.

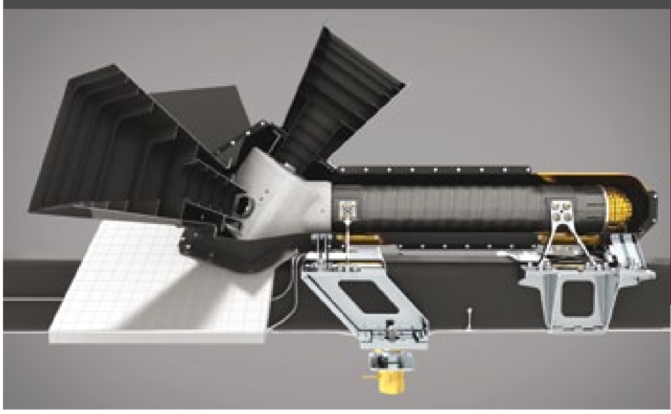


← Absolute Scalar Magnetometer (EADS/Astrium)

Vector Field Magnetometer (VFM)

This core instrument will make high-precision measurements of Earth's magnetic field vector components. It was developed and manufactured at the Technical University of Denmark based on heritage from many previous satellite missions as well as sounding rockets and stratospheric balloons.

↓ Vector Field Magnetometer on the right (ESA/AOES Medialab)

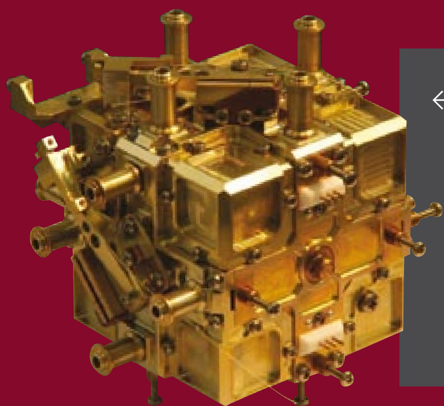


Startracker assembly

This unit provides high-precision attitude data, primarily needed to determine the orientation of the magnetic field vector measured by the Vector Field Magnetometer. The attitude information is also used by the satellite's attitude and orbital control system to establish a fine-pointing mode during normal operations and the orientation of other instruments. This latest generation of startracker was developed and manufactured at the Technical University of Denmark, based on heritage from many previous satellite missions.

Micro-accelerometer

These units will measure the satellites' non-gravitational accelerations in their respective orbits, which in turn will provide information about air drag and solar wind forces. Air density models will be derived from these products and will be used together with magnetic data to obtain new insights on the geomagnetic forcing of the upper atmosphere. The instrument was designed and manufactured by VZLU (Czech Republic) supported by Czech subcontractors – the first time that ESA has contracted an instrument of this complexity to Czech industry.



← Accelerometer sensor (VZLU)

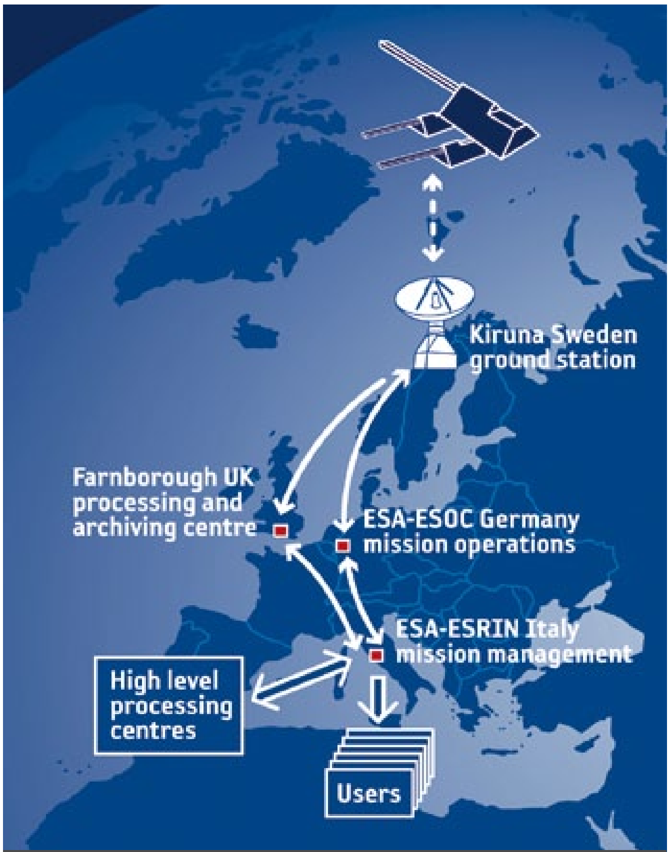
Electrical Field Instrument (EFI)

To characterise the electric field around Earth, this instrument will measure plasma density, drift and acceleration at high resolution. It is the first ever three-dimensional ionospheric imager in orbit, with an ingenious thermal ion imager design from the University of Calgary (Canada) and a unique concept for the sensors of the Langmuir probe from IRFU, Uppsala (Sweden). The instrument was developed by ComDev (Canada) with scientific support of the University of Calgary for the thermal ion imager sensors. The power supplies were developed by CAEN SpA (Italy). A Langmuir probe assembly is included with the instrument to provide measurement of electron density, electron temperature and spacecraft potential.

↑ Electrical Field Instrument thermal ion imagers (EADS/Astrium)

GPS and laser retroreflector

The precise orbit determination of the Swarm satellites will rely on the data of the GPS receiver. Each satellite is equipped with a laser retroreflector to validate the GPS system. Swarm is supported by the International Laser Ranging Service that provides satellite laser-ranging observation data from a network of stations around the world. The GPS receiver (RUAG, Austria) is used firstly as the orbit sensor to provide a real-time navigation solution (position, velocity and time) to the attitude and orbit control system and secondly as a sensor generating raw measurements data (code and carrier phases) as required for precise orbit determination and total electron content measurements. The laser retroreflector for Swarm was procured as a rebuild of existing ones from the GeoForschungs Zentrum Potsdam, that have been used on previous satellite missions such as CHAMP, GRACE and TerraSAR-X.



↑ Swarm's ground segment (ESA/AOES Medialab)

Products and user community

The Swarm Product Data Ground Segment at ESRIN (Frascati, Italy) is the point of access for the scientific community to collect the scientific data from all the instruments on each satellite (Level-1b) and advanced products either per satellite or from a constellation analysis (Level-2).

Typically, for studies of Earth's interior, global models of the core and crust and conductivity maps of the mantle (Level-2) are made available. These are produced for ESA by a consortium of specialists from six European academic institutes with support from consultants in the USA and Czech Republic. For example, for studies of the upper atmosphere, which are usually of a more local nature, magnetic field measurements are provided, and also products per each satellite that contain information about the atmospheric conditions such as ion velocity and direction, ion and electron temperature (all Level-1b), neutral density and winds (Level-2).

The unique combination of local and global products will allow users to address today's scientific open questions. Swarm will deliver products to study Earth's magnetic field and its interaction with the Sun, which will benefit a broad range of applications in Earth sciences and space weather. ■