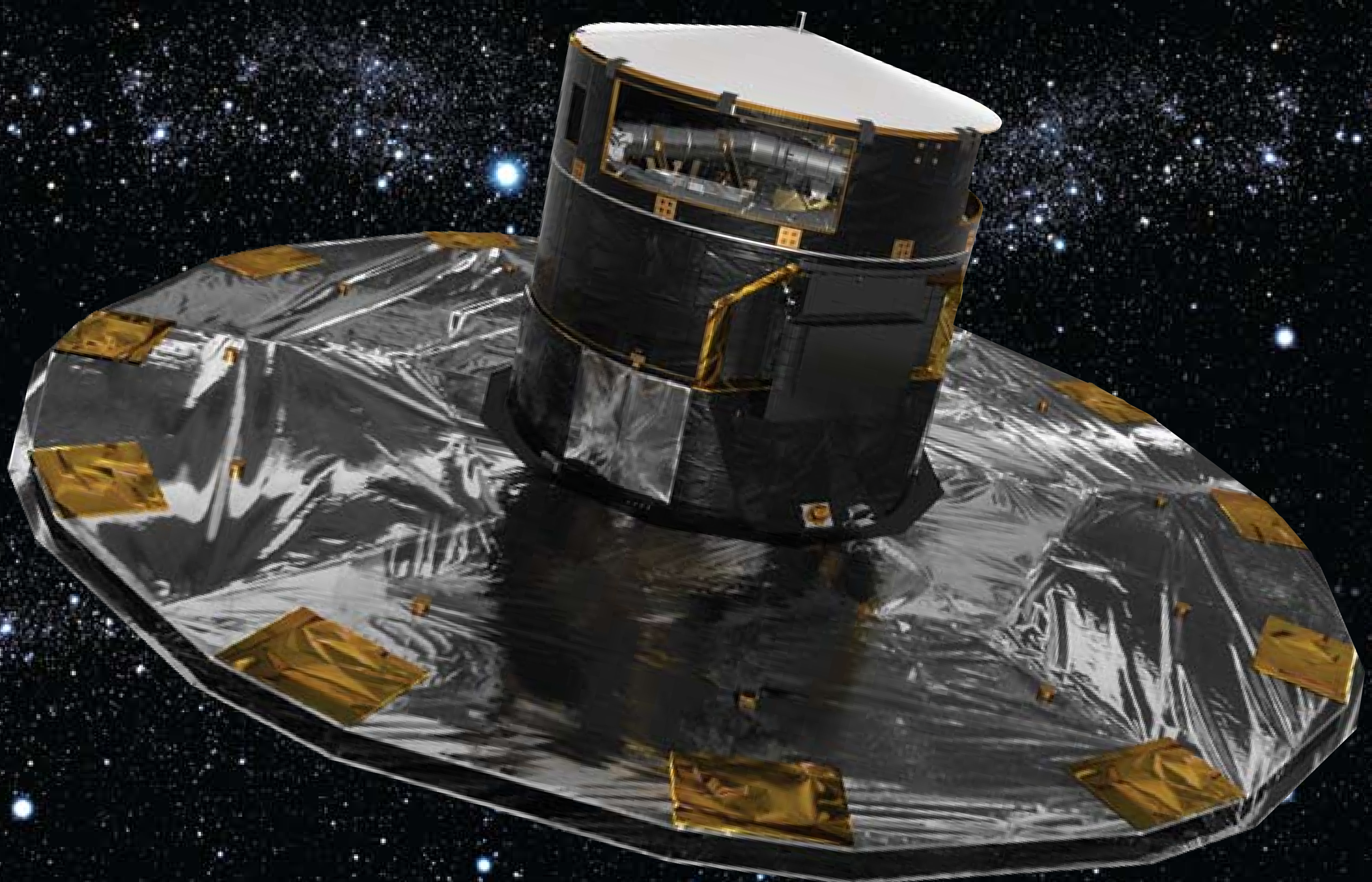
gaia

→ ESA'S GALACTIC CENSUS



European Space Agency

ESA'S SPACE SCIENCE MISSIONS

solar system

bepicolombo

Exploring the smallest, densest and least-understood terrestrial planet in the Solar System to unveil its mysterious origins.

cassini-huygens

A seven-year journey, then NASA's Cassini orbiter began studying the Saturn system from orbit and ESA's Huygens probe descended onto Saturn's giant moon Titan.

cluster

A four-satellite mission to investigate in unprecedented detail the interaction between the Sun and Earth's magnetosphere.

mars express

Europe's first mission to Mars, providing a global picture of the Red Planet's atmosphere, surface and subsurface.

rosetta

Europe's comet chaser, on its way to becoming the first mission to fly alongside and land on a comet, probing the building blocks of the Solar System.

soho

Providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.

venus express

Probing the mysteries of Venus's atmosphere with a precision never achieved before.

astronomy

gaia

Cataloguing the night sky and finding clues to the origin, structure and evolution of our Milky Way.

herschel

Searching in the infrared to unlock the secrets of starbirth and galaxy formation and evolution.

hubble space telescope

A collaboration with NASA on the world's most successful orbital observatory.

integral

The first space observatory to observe celestial objects simultaneously in gamma rays, X-rays and visible light.

jwst

Observing the first galaxies, revealing the birth of stars and planets, and looking for planets with the potential for life.

lisa pathfinder

Opening up a completely new way to understand time and space: seeing the Universe through gravitational waves.

planck

Detecting the first light of the Universe and looking back to the dawn of time.

xmm-newton

Using powerful mirrors to help solve mysteries of the violent X-ray Universe, from enigmatic black holes to the formation of galaxies.

Cover image: ESA/Medialab

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GAIA
ESA'S GALACTIC CENSUS

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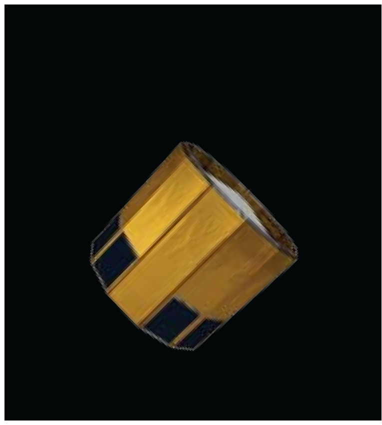
→ THE DISCOVERY MACHINE

The Milky Way and the Southern Cross



Gaia's deployment sequence

Cataloguing the night sky is an essential part of astronomy. Before astronomers can investigate a celestial object, they must know where to find it. Without this knowledge, astronomers would wander helplessly in what Galileo once termed a 'dark labyrinth'.

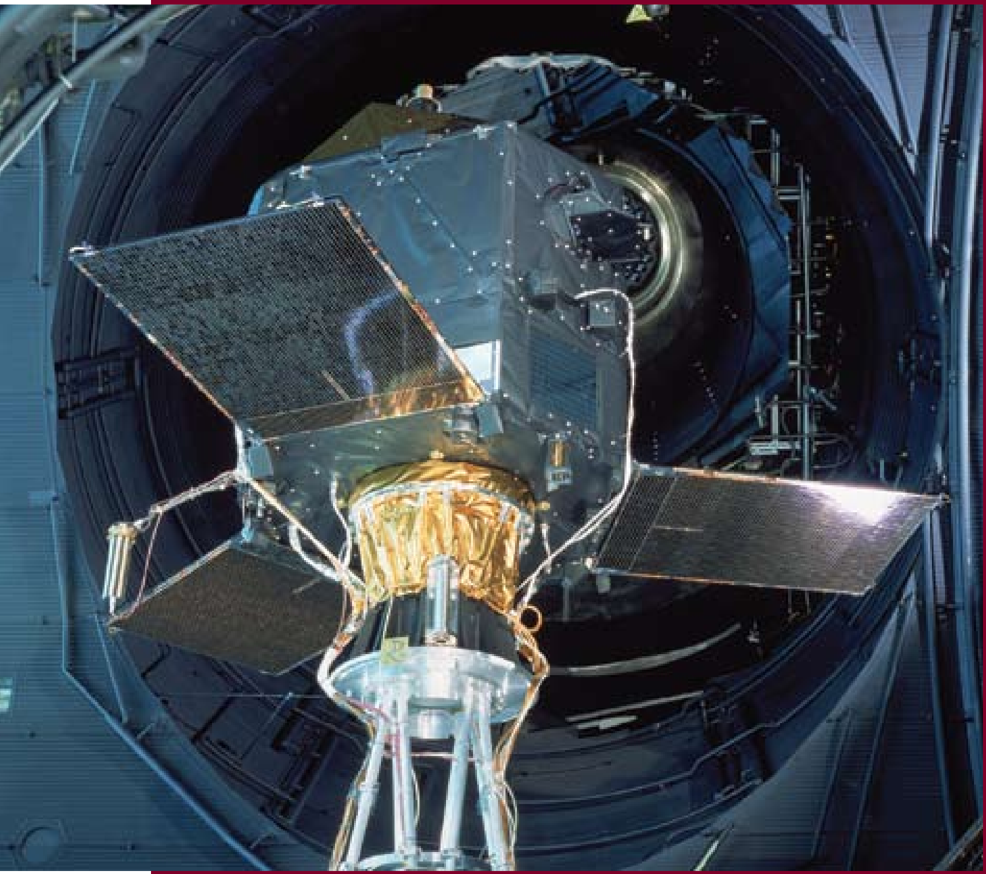
ESA's Gaia mission will create a detailed map of this labyrinth, finding clues to the origin, structure and evolution of our home galaxy, the Milky Way.

Gaia will take a census of one thousand million stars, roughly 1% of all of the stars in our Galaxy. During the satellite's expected lifetime of five years, Gaia will observe each star about 70 times, each time recording its brightness, colour and, most importantly, its position. The precise measurement of a celestial object's position is known as astrometry, and since humans first started studying the sky, astronomers have devoted much of their time to this art. However, Gaia will do so with extraordinary precision, far beyond the dreams of those ancient astronomers.

By comparing Gaia's series of precise observations, today's astronomers will soon be able to make precise measurements of the apparent movement of a star across the heavens, enabling them to determine its distance and motion through space. The resulting database will allow astronomers to trace the history of the Milky Way.

In the course of charting the sky, Gaia's highly superior instruments are expected to uncover vast numbers of previously unknown celestial objects, as well as studying normal stars. Its expected haul includes asteroids in our Solar System, icy bodies in the outer Solar System, failed stars, infant stars, planets around other stars, far-distant stellar explosions, black holes in the process of feeding and giant black holes at the centres of other galaxies.

Gaia will be a discovery machine.



Testing ESA's Hipparcos satellite

Noble tradition

Gaia continues a noble European legacy of star charting that dates all the way back to the Greek astronomer Hipparchus, who lived around 190 BC to 120 BC.

In August 1989, more than 2000 years after Hipparchus, ESA launched Hipparcos, the HIgh Precision PARallax COllecting Satellite and the first satellite devoted to astrometry. Data were collected between 1989 and 1993, and the resulting Hipparcos Catalogue was published in 1997. It contains the positions, distances and movements, 200 times more accurate than any previous measurement, for almost 120 000 stars.

In addition, a second, larger, catalogue derived from the satellite's data is available, containing 2.5 million stars at a somewhat lower precision. The Tycho Catalogue is named after the great 16th-century Danish astronomer Tycho Brahe.

→ STARS AS INDIVIDUALS AND COLLECTIVES

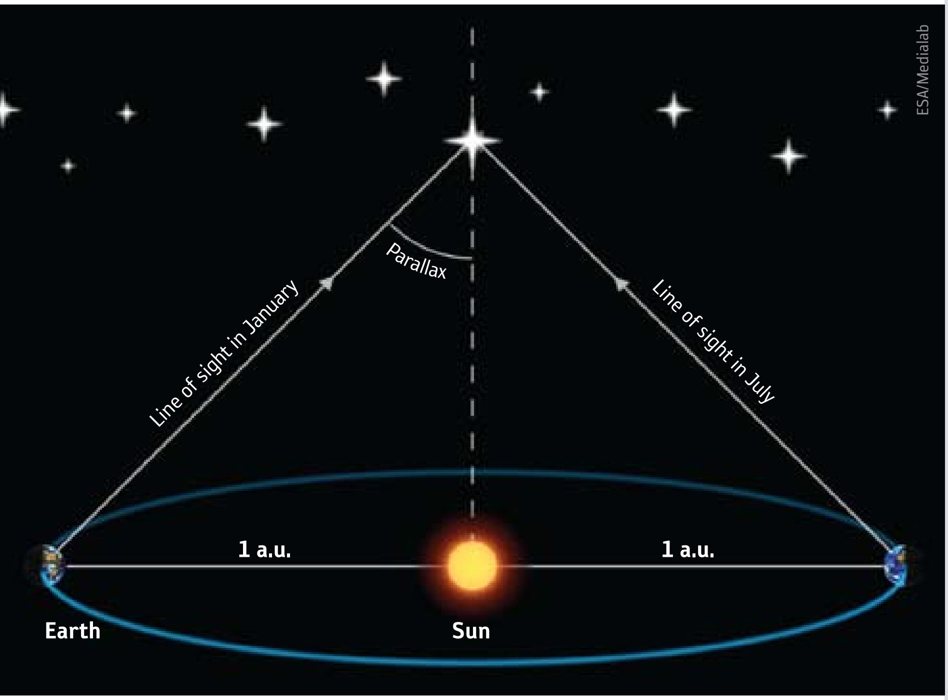
The Milky Way and Orion

To understand the physics of a star fully, its distance from Earth must be known. This is more difficult than it sounds because stars are so remote. Even the closest one is 40 trillion kilometres away, and thus we cannot presently send spacecraft to them to measure as they go. Nor can we bounce radar signals off them, the method used to measure distances within the Solar System. Instead, astronomers have developed other techniques for measuring and estimating distances. The most reliable and only direct way to measure the distance of a star is by determining its parallax (see box). By obtaining extremely precise measurements of the positions of stars, Gaia will yield the parallax for one billion stars; more than 99% of these have never had their distances measured accurately. Gaia will also deliver accurate measurements of other important stellar parameters, including the brightness, temperature, composition and mass. The observations will cover many different types of stars and many different stages of stellar evolution.

Space warps

In the Solar System, space itself is not 'flat'. Instead it contains numerous warps and dips that deflect starlight. These deformations are caused by the gravity of the individual Solar System objects, including the planets and moons, and, as the most massive object, the Sun causes the biggest effect. Unlike most spacecraft, Gaia will be such a precise measuring machine that it will see the deflection of starlight due to these gravitational fields.

Albert Einstein's General Theory of Relativity describes these warps and how they must be taken in account when interpreting data such as from Gaia. In turn, Gaia's precise measurements will offer scientists the chance to test some key parts of Einstein's equations to unprecedented levels.



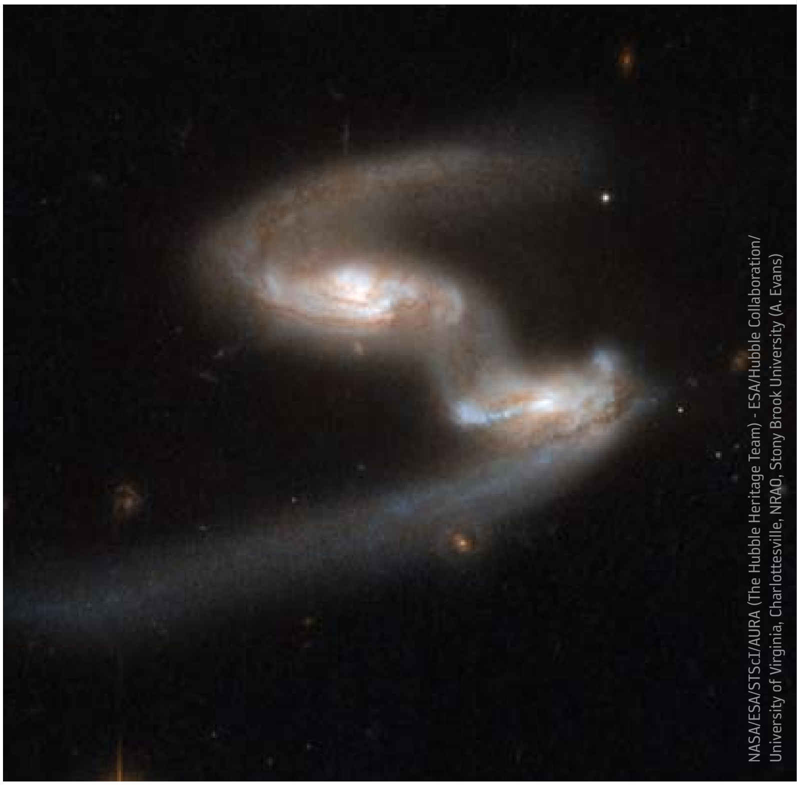
The parallax method of measuring a star's distance

What is parallax?

Hold a finger in front of your face and close one eye. Notice where it is against more distant objects you can see in the background; now open the other eye, closing the first. Your finger appears to move against the more distant objects. This is parallax. If you experiment by moving your finger to different distances in front of your face, you will see that when blinking from one eye to the other, the displacement is greater when your finger is closer than it is when it is far away. Thus, the parallax angle can be used to measure distance.

In astronomy, we can take advantage of the fact that Earth orbits the Sun. Every six months, Earth moves halfway round its orbit and presents a different vantage point for observations, equivalent to blinking between two eyes. The result is that stars apparently move side to side during the year. The nearer a star is to Earth, the larger the movement. However, even for the nearest stars, it is tiny: less than 1 arcsecond, or just 0.05% of the diameter of the full Moon.

Parallax is the only direct way to measure the distances of stars. Other methods can be used out to large distances, but they all rely on models and prior calibration. Parallax is the first crucial step on the cosmological distance ladder, the series of methods used by astronomers to measure ever-more distant objects.



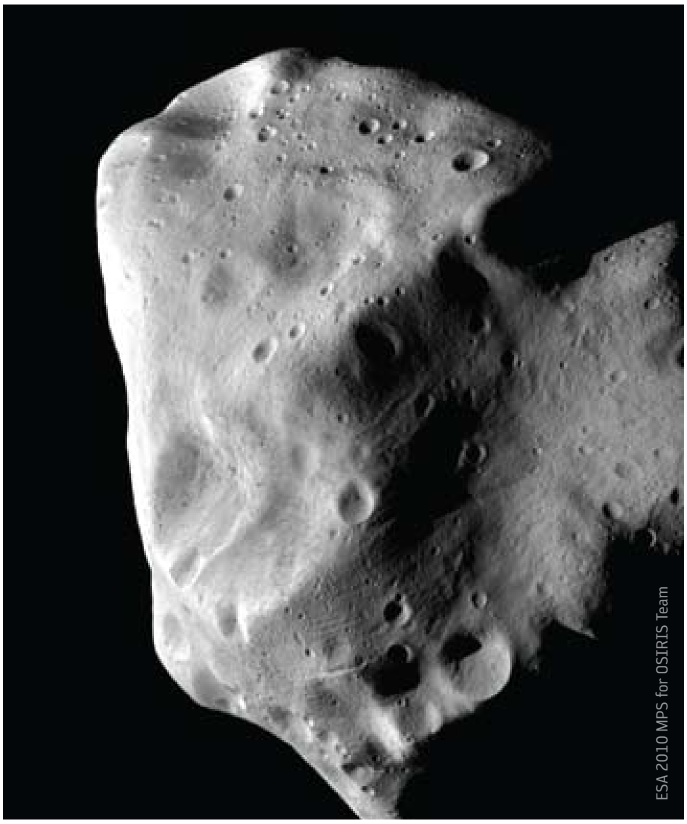
Galaxies grow by merging

Origin of the Milky Way

Our Galaxy is a disc of some one hundred billion stars in a spiral structure surrounding a central bulge. While many of the stars were born in our Milky Way, many others originated in small external galaxies that have subsequently merged with ours. Gaia will make it possible to discover families of stars that share peculiar motions around the Galaxy or anomalous compositions. Each family could be the remnants of a once-separate galaxy that the Milky Way has consumed.

Understanding the history of our Galaxy requires the measurement of stellar distances and motions for large samples of stars of different masses, ages and compositions. Gaia's survey of stars across the entire sky, down to extremely faint limits with a level of precision never accomplished before, will provide such a sample. By revealing the structure and motions of stars in our Galaxy, Gaia will revolutionise our understanding of the history of the Milky Way.

→ OUR SOLAR SYSTEM AND OTHERS



Asteroid Lutetia, as seen by ESA's Rosetta in 2010

Asteroids are remnants left over from the formation of the inner planets in our Solar System. As such, they provide clues about how those planets, including Earth, came to be.

Gaia will accurately measure the positions and velocities of more than 200 000 asteroids, allowing their orbits to be determined with unprecedented precision. The tiny movement created by the gravitational pull experienced as asteroids pass close to one another will also be registered for a few hundred individuals, allowing their combined masses to be determined.

Gaia will be ideally situated to search for asteroids close to the Sun, a blind spot where ground-based telescopes cannot easily see because they would have to look into the daytime sky. Gaia's data will reveal the surface properties of asteroids by measuring how much light is reflected in a particular colour, and its brightness data will allow astronomers to deduce the rotation rates and surface shapes of large numbers of asteroids. Because Gaia is surveying the whole sky, it is likely to discover asteroids in exotic orbits that take them high above and below the plane of the planets.

Trojan asteroids

Noteworthy among the asteroids are the 'Trojans' that 'hide' in the orbit of a planet. The best known are those trapped by the gravity of Jupiter. They are found in two reservoirs, both in Jupiter's orbit: one precedes the planet, the other trails it. The roughly 5000 Jupiter Trojans currently known are probably only a sample of a much larger population.

Gaia will determine whether these asteroids were snatched from all parts of the Solar System or whether they formed from dust grains trapped in Jupiter's orbit. Equally importantly, Gaia will search for Trojan asteroids at similar special locations around Venus, Mars and Earth. These are typically smaller than the Trojans at Jupiter since the planets are smaller, and only a handful have been discovered to date. These include the first Trojan to be found in Earth's orbit, a tiny space rock just 300 m across that was announced on 27 July 2011.

Jupiter is attended by Trojan asteroids. In this image, Jupiter's moon Europa casts its shadow on the planet

Comet showers

Far beyond the outer planets, the Solar System is thought to be enveloped by a large cloud of icy bodies, the comets. Over the aeons, passing stars may have perturbed some of these, making them fall into the inner Solar System in great showers, peppering Earth and other planets in destructive impacts.

Gaia will make a complete survey of all stars within about 150 light years of the Sun, precisely measuring their motions. Rewinding those motions in time will reveal those that have passed close to the Solar System and so could have caused such comet showers. Equally, Gaia's data will allow astronomers to predict future close encounters.

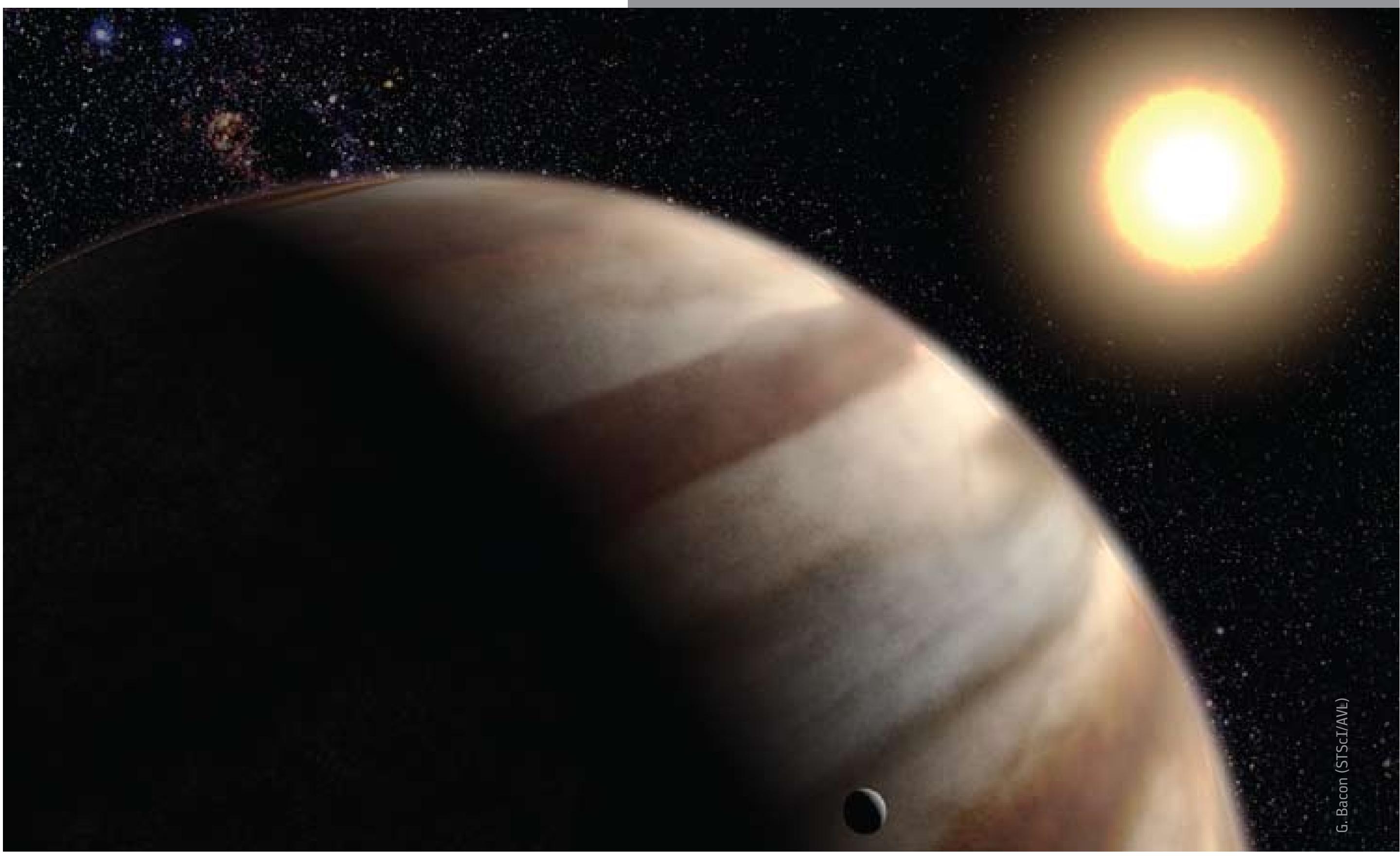
Comet Halley, as seen by ESA's Giotto in 1986

Alien worlds

Beyond our own Solar System, Gaia will be looking carefully at hundreds of thousands of stars within about 500 light years of Earth, searching for evidence of planets around them.

Gaia will watch for stars that are wobbling as they are pulled from side to side by the gravity of orbiting companions. The way a star wobbles reveals the period and orientation of that shared orbit, and, most importantly, the mass of the companion. If this is small enough, it must be a planet. Complex movements indicate that there is more than a single planet in the system.

Currently some 700 planets orbiting other stars are known, and Gaia is expected to identify around 2000 more. This information will significantly improve the statistics on the orbital properties and masses of such planets and will lead to a greater understanding of how planetary systems are formed.



Gaia will reveal planets around other stars

→ HOW DOES GAIA WORK?

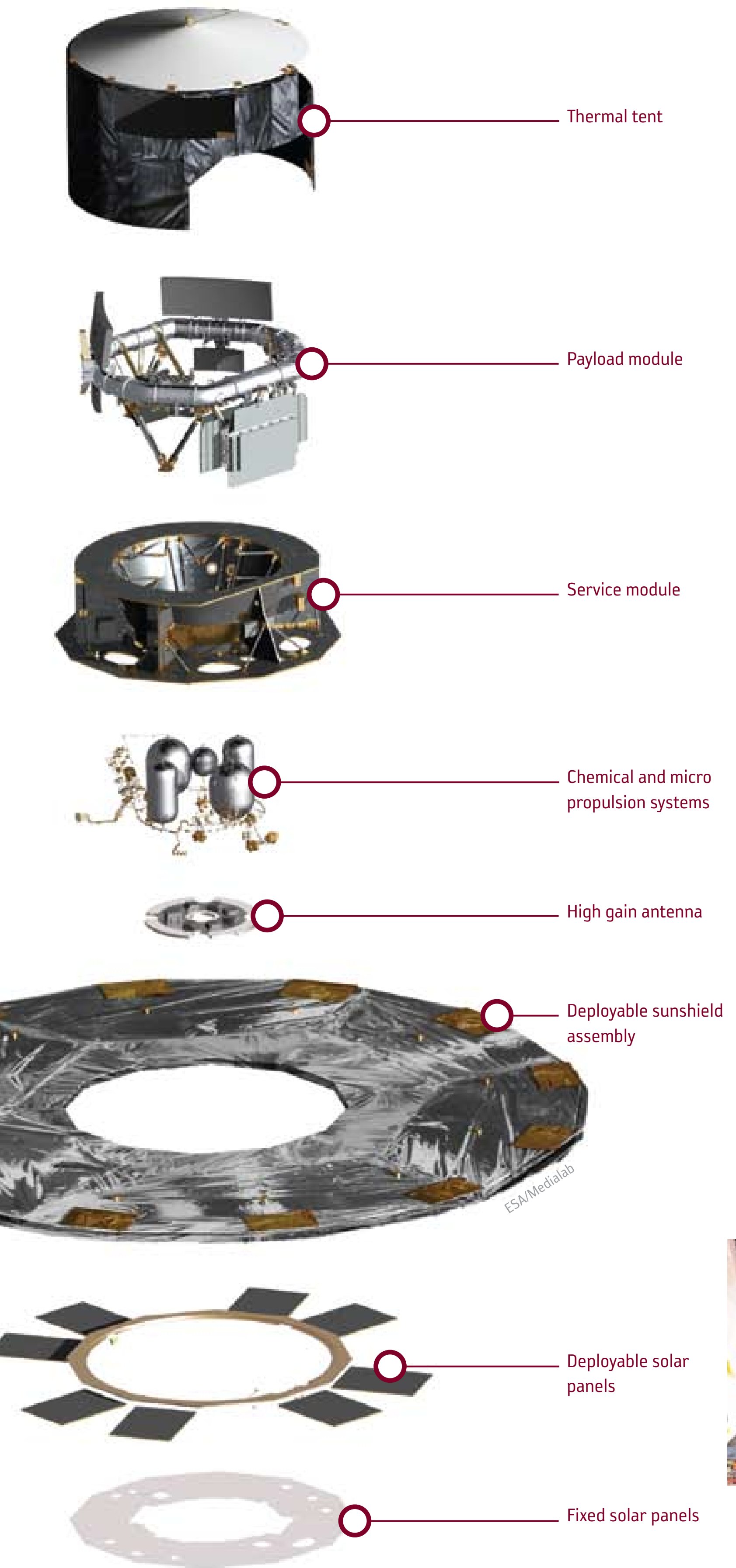
At its heart, Gaia is a space telescope – or rather, two space telescopes that work as one. These two telescopes involve a total of ten mirrors of various sizes and surface shapes to collect, focus and direct light to Gaia's instruments for detection. The main instrument, an astrometer, precisely determines the positions of stars in the sky, while the photometer and spectrometer spread their light out into spectra for analysis.

Gaia's telescopes point at two different portions of the sky, separated by a constant 106.5°. Each has a large primary mirror with a collecting area of about 0.7 m^2. On Earth we are used to round telescope mirrors, but Gaia's will be rectangular to make the most efficient use of the limited space within the spacecraft. These are not large mirrors by modern astronomical standards, but Gaia's great advantage is that it will be observing from space, where there is no atmospheric disturbance to blur the images. A smaller telescope in space can yield more accurate results than a large telescope on Earth.

Gaia is just 3.5 m across, so three curved mirrors and three flat ones are used to focus and repeatedly fold the light beam over a total path of 35 m before the light hits the sensitive, custom-made detectors. Together, Gaia's telescopes and detectors will be powerful enough to detect stars up to 400 000 times fainter than those visible to the naked eye.

To cover the whole sky, Gaia spins slowly, making four full rotations per day and sweeping swathes across the celestial sphere. As it moves around the Sun, different parts of the sky are covered. Over the five-year mission, each star will be observed and measured an average of 70 times.

Final check of one of Gaia's primary mirrors



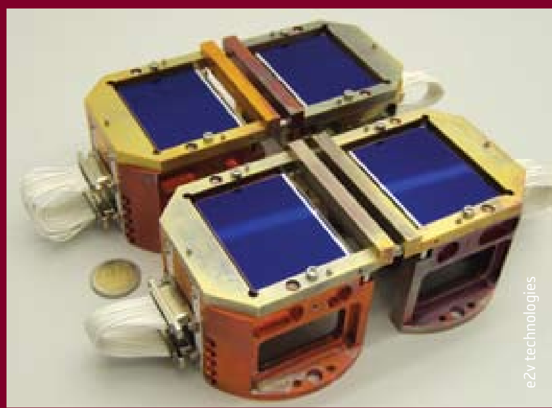
Gaia's instruments

Three instruments will detect the light collected by Gaia's telescopes. Each one uses a set of digital detectors known as charge coupled devices (CCDs) to record the starlight falling onto them. Added together, the Gaia CCDs make the largest focal plane ever flown in space, a total of almost one billion pixels covering an area of about 0.38 m^2:

– The astrometric instrument is devoted to measuring stellar positions on the sky. By combining all measurements of a given star over the five-year mission, it will be possible to deduce its parallax and thus its distance, as well as the velocity of the star as it moves across the plane of the sky.

– The third dimension is provided by the Radial Velocity Spectrometer, which reveals the velocity of the star along the line of sight by measuring the Doppler shift of absorption lines in a high-resolution spectrum covering a narrow wavelength range.

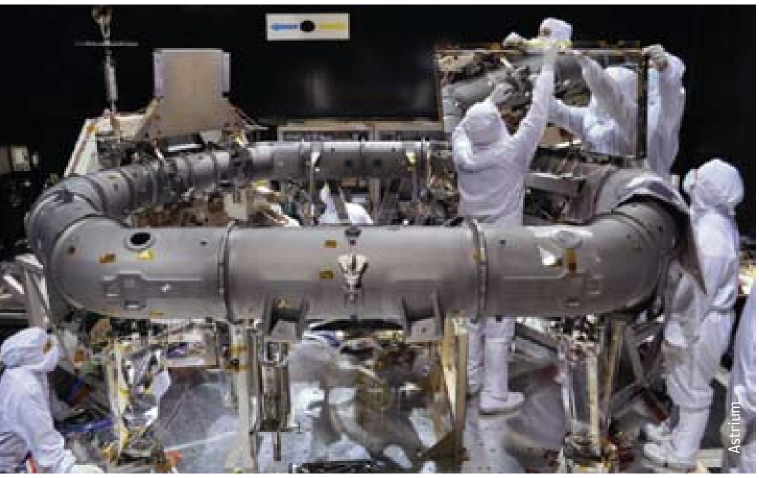
– The photometric instrument provides colour information for celestial objects by generating two low-resolution spectra, one in the blue and one in the red range of the optical spectrum. These data help to determine key stellar properties such as temperature, mass and chemical composition.



Four of the 106 CCDs that are part of Gaia's large focal plane

The Gaia focal plane

→ BUILDING GAIA



Integration of the first primary mirror on the Payload Module

Gaia is composed of two main sections: the payload module and the service module. The payload module is housed inside a protective dome and contains the two telescopes and the three science instruments. They are all mounted on a torus made of a ceramic material called silicon carbide. The extraordinary measurement accuracy required from Gaia calls for an extremely stable payload module that will barely move or deform once in space; this is achieved thanks to the extensive use of silicon carbide.

Underneath the payload module, the service module contains electronic units to run the instruments, as well as the propulsion system, communications units and other essential components. These components are mounted on carbon-fibre-reinforced plastic panels in a conical framework.

Finally, beneath the service module, a large sunshield keeps the spacecraft in shadow, maintaining the payload module at an almost constant temperature of around –110°C, to allow the instruments to take their precise and sensitive readings. The sunshield measures about 10 m across, too large for the launch vehicle fairing, so it comprises a dozen folding panels that will be deployed after launch. Some of the solar array panels that are needed to generate power are fixed on the sunshield, with the rest on the bottom of the spacecraft.

Integration of the Service Module

The spacecraft after deployment of the sunshield in the cleanroom

Gaia involves industry across Europe

United Kingdom
- ABSL
- e2v Technologies
- EADS Astrium
- MSSL
- Selex Systems

Ireland
- Mc Ginley

France
- Boostec
- EADS Astrium
- Intespace
- Latelec
- Onera
- Sagem
- SESO

Spain
- Crisa
- EADS Casa
- Mier
- Rymsa
- Sener
- Thales Alenia Space

Portugal
- Deimos
- Ineti
- Lusospace
- Skysoft

Italy
- Selex Galileo
- SILO
- Thales Alenia Space

USA
- Arde
- Barr
- Maxwell

Netherlands
- Dutch Space
- SSBV
- TNO

Norway
- Kongsberg
- Prototech

Finland
- Patria
- SSF

Sweden
- RUAG Space

Denmark
- Rovsing
- Terma

Germany
- EADS Astrium
- IOF
- Schunk GmbH
- Zeiss

Belgium
- AMOS
- CSL
- SpaceBel
- Thales Alenia Space

Switzerland
- APCO
- RUAG Space
- SpectraTime
- Syderal

Austria
- RUAG Space
- Siemens

Industrial involvement

Gaia is an exceptionally complex space observatory. ESA awarded Astrium SAS (Toulouse, France) the prime contract in May 2006 to develop and build the spacecraft. Together with the German and British branches of Astrium, more than 50 industrial subcontractor companies from across Europe are involved in building this discovery machine.

→ LAUNCH

Gaia will be carried into space at the earliest in 2013 by a Soyuz-STB launch vehicle with a Fregat-MT upper stage, from Europe's Spaceport in French Guiana.

This Soyuz is the most recent of a long line of vehicles that have proved their reliability with more than 1700 launches since launching the first satellite (Sputnik, in 1957) and the first man (Yuri Gagarin, in 1961). The three-stage version that will be used for Gaia was introduced 45 years ago and has been launched more than 850 times. It is by far the world's most-used launch vehicle.

In 2005, ESA and Arianespace started working with their Russian counterparts to build a Soyuz launch facility at CSG (Centre Spatial Guyanais), similar to the other active sites at Baikonur in Kazakhstan and Plesetsk in Russia. By autumn 2011 this facility was ready for the first 'Soyuz at CSG' launch, which took place on 21 October 2011.

The Soyuz launch pad at CSG in French Guiana

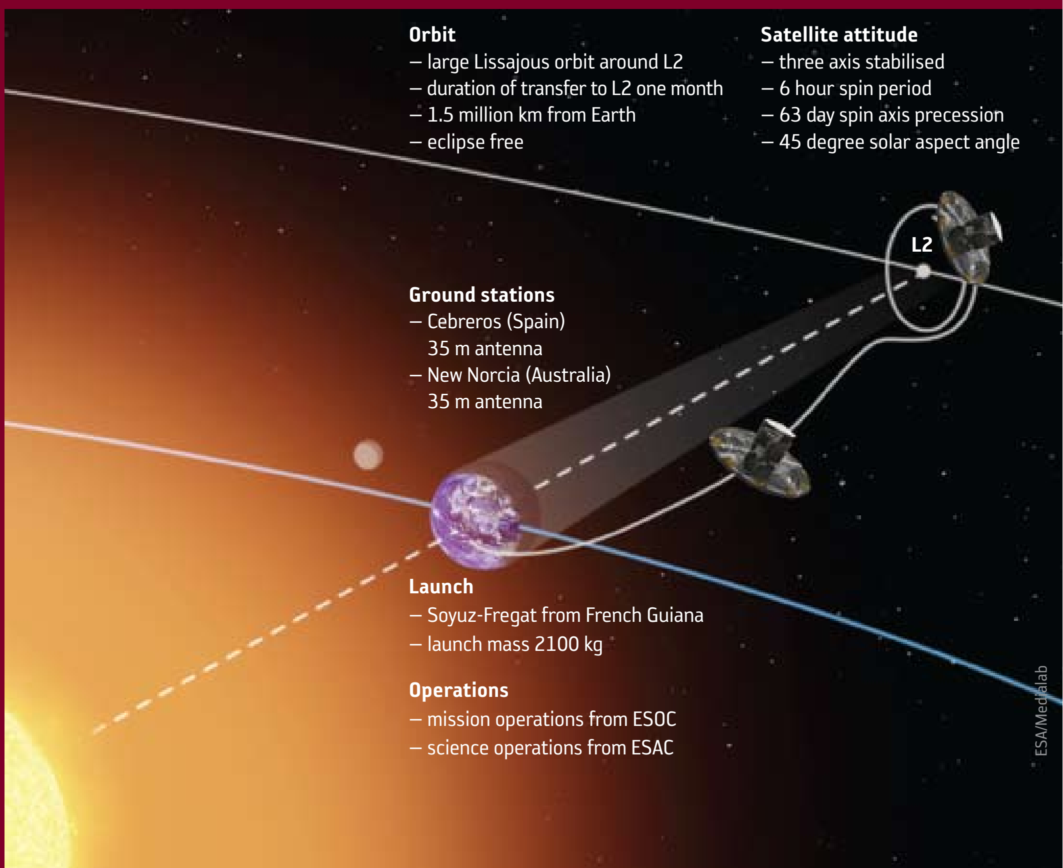
The first Soyuz rocket launch from CSG

Gaia's home in space

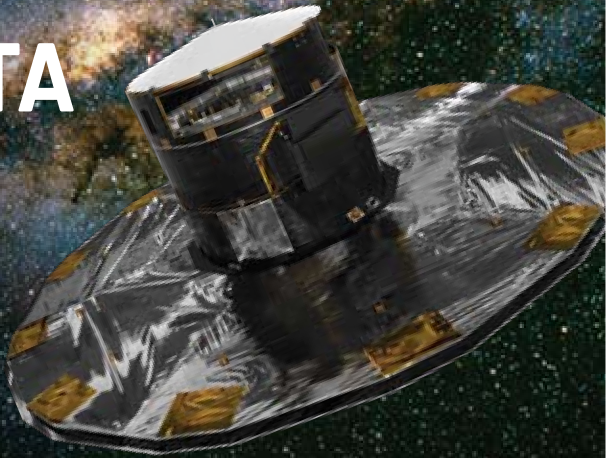
Gaia will map the stars from a vantage point about 1.5 million km away from Earth, orbiting around a special location known as L2. It is one of five 'Lagrangian points', where the gravitational forces of the Sun, Earth and Moon are in balance. With only minimal use of thrusters, a spacecraft placed here will keep pace with Earth as both orbit the Sun.

L2 offers a stable thermal environment because the sunshield will protect Gaia from the Sun, Earth and Moon simultaneously, allowing the satellite to keep cool and enjoy a clear view of the Universe from the other side. In addition, L2 provides a moderate radiation environment, which benefits the longevity of the instrument detectors. Several other satellites are already taking advantage of this location, including ESA's Herschel and Planck.

Gaia's journey to its operational orbit



→ THE FLOOD OF DATA



To achieve its scientific goals, Gaia will have to detect, select and measure hundreds of stars per second almost non-stop for five years, producing a prodigious volume of data. Each day, some 50 Gbytes of data will be generated and these must be sent to Earth.

This extraordinary feat will only be achievable thanks to onboard data processing and compression, combined with a fast downlink speed. Gaia's transmitter can maintain a rate of around 5 Mbit/s, comparable to many home broadband download speeds, although Gaia does it from a distance of 1.5 million km. However, collecting the faint signal requires the use of ESA's most powerful ground stations, the 35 m-diameter radio dishes in Cebreros, Spain, and New Norcia, Australia.

Gaia will communicate with Earth for an average of eight hours every day. During this time, it will transmit not only its compressed science data, but also 'housekeeping' data that allow operators to track the status of the spacecraft and keep it in the best condition possible. At other times, it will record its observations onto a 1000 Gbit solid-state recorder for downlinking later.

ESA's European Space Operations Centre (ESOC), in Darmstadt, Germany, will carry out mission operations. These will include mission planning, spacecraft monitoring and control, and orbit and attitude determination and control. ESA's Space Astronomy Centre (ESAC), Villanueva de la Cañada, Spain, will prioritise, schedule and archive the scientific observations.

The New Norcia deep space antenna, Australia

From raw data to publishable measurements

The Data Processing and Analysis Consortium (DPAC) will process all the raw data received from the satellite, turning it into scientifically-useful quantities. Given the complex, interconnected nature of the Gaia data, these computations will be shared between six different centres across Europe. These centres will base their work on software code and algorithms received from nine topically-organised scientific coordination units. More than 450 people across Europe are already contributing to the development of the huge Gaia data processing effort as part of DPAC. By the end of the mission, the data archive will exceed 1 Petabyte, which is 1 million Gbytes or about 200 000 DVDs' worth.

The final Gaia results will be made freely available worldwide. Although they will not be delivered before 2020, science alerts will be issued early on and intermediate catalogues will be released about two years after launch.

gaia

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