gaia

→ **THE BILLION STAR SURVEYOR**
GAIA DATA RELEASE 1

Media kit

Background image: ESO/S. Brunier

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Gaia - the Billion Star Surveyor

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Gaia's mission is to create the most accurate map of the Galaxy to date.

To do this, Gaia is observing about one billion stars, roughly one per cent of the total stellar content of the Milky Way. Eventually, this detailed inventory will include the positions and motions of stars to unprecedented precision, as well as the brightness and colour of each of them. In the process of discovering more about the Milky Way Gaia will also detect new asteroids in our Solar System, discover planets around other stars, pinpoint extragalactic sources such as quasars, and even provide some tests of Einstein's theory of general relativity.

When we gaze up at stars in the night sky, we see them projected against the celestial tapestry. These stars appear equally far from us, and motionless with respect to one another. But, in reality, stars are located at a huge variety of distances from us, and each of them traces its own path around the centre of our Galaxy, the Milky Way.

There are an estimated one hundred billion galaxies in the Universe, of various sizes and shapes. The Milky Way is a barred spiral galaxy, about 13 billion years old, and home to a few hundred billion stars, including our local star, the Sun.

The Milky Way's structure can be described as a flattened disc where the majority of stars, interspersed with a diffuse mixture of gas and cosmic dust, are located, and a central bulge, where some of the Galaxy's oldest stars can be found. The Galactic Disc is about 100 000 light-years across, and the Sun is located about half way between the centre and periphery.

Beyond the disc and bulge is the stellar halo, a roughly spherical structure with a radius of about 100 000 light-years, containing isolated stars as well as many globular clusters - large, compact conglomerations of some of the most ancient stars in the Galaxy. On a grander scale, the Milky Way is embedded in an even larger halo of invisible dark matter.

Catalogues of stellar positions based on ground-based observations are limited in precision by the turbulence of Earth's atmosphere. Another limitation is that they can probe at most some thousands of stars.

ESA's Hipparcos satellite, the first space mission dedicated to charting the sky, yielded a greatly improved catalogue with nearly 120 000 stars. Gaia will extend this effort by cataloguing 10 000 times more stars and other celestial objects, while measuring additional parameters for each of these, too. With these data, astronomers will be able to investigate in extraordinary detail the past history, current status, and future evolution of our home galaxy.

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Fast Facts

Fast Facts

Launch: 19 December 2013 at 09:12 UTC on a Soyuz rocket from Europe's spaceport in Kourou, French Guiana.

Launch mass: 2030 kg, including 710 kg of payload, a 920 kg service module, and 400 kg of propellant.

Spacecraft dimensions: The spacecraft body (payload and service module) is 4.3 m wide and 2.3 m high; the spacecraft is 10 m across when the sunshield/solar array assembly is deployed.

Payload: The payload comprises two identical optical telescopes/imaging systems, a radial velocity spectrometer, and blue and red photometers. The payload features a 106 CCD focal plane array (0.5 m x 1 m) with nearly 1 billion pixels making it the largest digital camera ever used in space.

Orbit: Gaia circles the Sun in a Lissajous-type orbit at the L2 Lagrangian point, 1.5 million km from Earth in the opposite direction with respect to the Sun.

Ground communications: ESA's ESTRACK stations at Cebreros (Spain), New Norcia (Australia), and Malargüe (Argentina) are used to communicate with the spacecraft.

Mission Operations: The mission is controlled from the European Space Operations Centre (ESOC) in Darmstadt, Germany. Science operations are conducted from the European Space Astronomy Centre (ESAC) in Villafranca del Castillo, Spain.

Data Processing and Analysis Consortium: The Gaia Data Processing and Analysis Consortium (DPAC) is formed by about 450 scientists and software experts, who have been entrusted with the task of converting the telemetry data into scientifically meaningful information and preparing the data releases, including the final Gaia Catalogue. Members of the DPAC come from twenty European countries (Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Slovenia, Spain, Switzerland, Sweden, and the United Kingdom) as well as from further afield (Algeria, Brazil, Israel, and the United States). In addition, ESA makes a significant contribution to DPAC in the form of the Data Processing Centre at the European Space Astronomy Centre (ESAC) in Spain, which amongst other tasks and responsibilities, acts as the central hub for all Gaia data processing.

Industrial contributions: Gaia was designed and built by Astrium (now Airbus Defence and Space), with a core team composed of Astrium France, Germany and UK. The industrial team included 50 companies from 15 European states, along with firms from the US. Some 80 contracts were placed with European companies and three with those in the US. The spacecraft was launched by Arianespace on an STB/Fregat MT Soyuz rocket. Between 2500 and 3000 people in all are involved in the mission.

Cost: The total cost of the mission, from the beginning of preliminary studies to the end of operations, is 740 M€. This does not include expenditures related to the DPAC consortium, currently estimated at around 250 M€, which are covered by the contributing countries participating in the consortium, not ESA. The price tag for the spacecraft itself is 450 M€.

Mission name: Gaia was the acronym for Global Astrometric Interferometer for Astrophysics, the original name of the mission. This reflected the technique of optical interferometry that was first planned for use on the spacecraft. Although the acronym (written GAIA) is no longer applicable, the name (Gaia) remains to provide project continuity.

First Data Release:

Date: Gaia's first data release is published on 14 September 2016

Contents: Positions and Gaia 'G' magnitudes for 1.1 billion stars using only Gaia data;

Positions, parallaxes (distances) and proper motions for more than 2 million stars using the Tycho-Gaia Astrometric Solution (TGAS);

Light curves and characteristics for about 3000 variable stars;

Positions and G magnitudes for more than 2000 quasars - extragalactic sources used to define the celestial reference frame.

Access: All the data will be available from the ESA Gaia Archive:
http://archives.esac.esa.int/gaia
and from the main partner data centres:
Centre de Données astronomiques de Strasbourg (CDS):
http://cds.unistra.fr/gaia
ASI Science Data Center (ASDC):
http://gaiaportal.asdc.asi.it
Astronomisches Rechen-Institut (ARI):
http://gaia.ari.uni-heidelberg.de
Leibniz-Institut für Astrophysik Potsdam (AIP):
http://gaia.aip.de

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Mapping the Galaxy with Gaia

Mapping the Galaxy with Gaia

Based on the extraordinary data collected by Gaia throughout its mission, astronomers will eventually build the most accurate three-dimensional map of the positions, motions, and chemical composition of stars in our Galaxy. By reconstructing the properties and past trajectories of all the stars probed by Gaia, it will be possible to delve deep into the history of our Galaxy's formation and evolution.

The field of astronomy that deals with measuring the positions of celestial bodies in the sky is known as astrometry. Over the course of many centuries astronomers have relied on astrometry to compile ever more detailed maps of the heavens. By monitoring how the positions of stars and other astronomical objects vary over time, it is possible to infer their distances from us and their motions through space - both of these are essential for investigating the physical nature of these distant bodies.

Tiny changes in the position of stars contain information about their distance - this is encoded in the parallax, an apparent annual shift of stars on the sky caused by Earth's motion around the Sun. Over time, stellar positions also slowly change due to the stars' real movement through the Galaxy. The motion perceived across the plane of the sky is termed the proper motion. This provides two of the three components of a star's velocity through the Galaxy; the third component - the radial velocity - can be inferred from the red- or blue-shift of the light in its spectrum.

Gaia will perform its unique census of stars in the Galaxy using the billion-pixel camera at its heart, which collects the light focused by the satellite's dual telescope system. As the satellite spins, the two telescopes scan great circles on the sky. They feed three instruments: one for astrometry (to determine the positions and motions),

one for photometry (to measure the colours of the stars) and one for spectroscopy (to measure their radial velocity and see what the stars are made of).

The astrometric instrument is the core element in the focal plane, providing input to determine the position of stars and other astronomical sources to unprecedented precision; in turn, the positions are used to derive stellar parallaxes and proper motions. This instrument also measures the brightness of all stars in the Gaia G-band, using a bandpass that covers the visible portion of the spectrum, between 330 and 1050 nm. This band was chosen to optimise the collection of starlight, which in turn maximises the precision of the measurements. It also matches the overall sensitivity of the Gaia astrometric instrument thus providing a measure of the brightness as seen by that instrument.

The photometric instrument separates the light from the stars into their constituent colours and does this over a shorter (from 330 nm to 680 nm) and longer (from 640 to 1050 nm) wavelength range. These measurements will in turn be used to determine the colour of each star - the portion of the spectrum where it emits most of its light - which is key to determine its temperature, age, and other properties.

Finally, the radial velocity spectrometer provides spectra for a subset containing the brightest stars observed by Gaia; these spectra are used to estimate the radial velocity of stars - their velocity along the line of sight with respect to Gaia.

For each celestial object, all the information recorded by the instruments is compressed into data packets and stored on board. The data packets are transmitted to ESA's ground stations in Spain, Australia, and Argentina, and are then processed by the Data Processing and Analysis Consortium (DPAC), who are responsible for turning them into scientifically useful data.

At the core of this process is a mathematical procedure called AGIS - the Astrometric Global Iterative Solution. Put simply, this is the way to collate the billions of pieces of information that come from the satellite and convert these into the Gaia map of the Galaxy.

It can be thought of like a giant jigsaw puzzle with hundreds of billions of pieces

that have to be combined, very accurately, before the complete picture emerges. For Gaia, the assembly of this gigantic picture is a complex process that needs to be performed over a number of years in order to reach the expected measurement goal of 20 microarcsecond accuracy for a magnitude 15 star. (A magnitude 15 star is about 4 million times fainter than Sirius, the brightest star in the sky.)

In practice, Gaia's focal plane tracks the position where light from each star falls as it passes across the CCDs and records the time of each transit. To transform this information into astronomically useful quantities, namely measurements of stellar positions on the sky, scientists need to know where Gaia was pointing at each time, as well as its relative position with respect to the Sun and other planets in the Solar System. In addition, they also need to take into account the light bending caused by the Sun and the major planets as well as the exact position of each element in Gaia's optical system and focal plane.

This calibration process is carried out in an iterative fashion. In the data processing, the images of stars recorded on the CCDs are compared to models of how such an image should look. As more data are collected and fed to the algorithms, the models are constantly improved and, in turn, this improves the estimates of the stellar positions on the sky. Other information can also be added in later steps of this process, such as the colour of stars measured by the photometric instrument, since stars of different colours will give rise to slightly different images on the CCDs.

For future data releases, the process will be repeated for more and more data until the estimated position, brightness, colour and other parameters of each source are locked into a consistent and coherent framework. However, in the first data release, based on less than a quarter of the total amount of data that will be collected by Gaia over its entire mission, this iterative loop was performed using only a small subset of the stars - those in common with the earlier Hipparcos and Tycho-2 catalogues for which the position was already known to good accuracy. In the following releases, the subset of stars used for the calibration will be increasingly larger, allowing scientists to estimate more and more parameters to even greater accuracy for all surveyed sources.
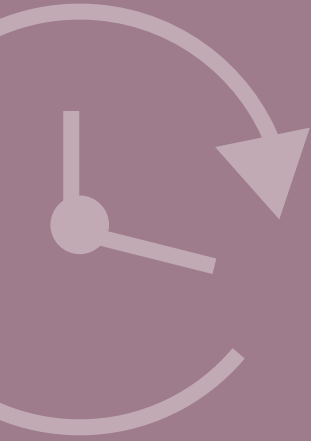
Gaia's first data release - the Galactic Census begins

For the field of astrometry - the discipline of measuring the positions of celestial objects - a new era is on the horizon. The first hints of the data bounty that await us will be revealed when ESA's Gaia mission publishes the first data release based on observations taken by the satellite between 25 July 2014 and 16 September 2015.

This first public release of data includes the positions on the sky for more than one billion stars, as well as their 'G' magnitudes - a measure of their brightness.

As an additional bonus, a smaller dataset provides positions, proper motions (the motion of objects across the plane of the sky) and parallaxes (a measure of the distance) for about 2 million stars in common with the earlier Hipparcos and Tycho-2 Catalogues, based on data from ESA's Hipparcos mission.

Measurements of the brightness of more than 3000 variable stars, about 10% of them newly discovered by Gaia, are also made public.

Finally, the positions and brightness of more than 2000 quasars are published; these extragalactic objects are used to fix the coordinate system for celestial objects.

The enormous and challenging task of processing the data and preparing the release has been entrusted to the Gaia Data Processing and Analysis Consortium (DPAC), a European consortium of scientists and software experts.

The purpose of this first release is to prove that the observing strategy and the data processing 'pipeline' are working well. It will demonstrate the high quality of the scientific data derived from the raw satellite observations.

The validation checks include verifying that the estimates of the stellar parameters are scientifically robust and that all effects related to the satellite and instruments are correctly taken into account. Comparisons with the results from previous astrometric catalogues have also been performed.

ESA has a rich history of producing stellar catalogues. The Hipparcos Catalogue was created from data obtained with the science instrument on ESA's Hipparcos satellite, the first space mission dedicated to astrometry, which operated from 1989 to 1993.

The catalogue, published in 1997, contains the positions and parallax of more than 100 000 stars with a precision of 0.001 arcseconds, and proper motions with a precision of 0.001 arcseconds per year. At the time of publication these values were unprecedented. Even now, more precise measurements have only been achieved for a few dozen objects.

A few years later, the Tycho-2 Catalogue was produced, based on measurements from the star mapper on the Hipparcos satellite and on previous ground-based astrometric catalogues that relied on photographic observations made since the late nineteenth century. This catalogue is less accurate but much larger than the Hipparcos Catalogue, listing positions and proper motions of 2.5 million stars. The average accuracy in the Tycho-2 Catalogue is 0.06 arcseconds for positions - improving to 0.007 arcseconds for the brightest stars - and 0.0025 arcseconds per year for proper motions. (One arcsecond is equivalent to a face of a euro coin from a distance of about 4 kilometres.)

From the first year of Gaia's observations alone, it is not possible to separate two concurrent effects in the changes of stellar positions recorded by the satellite: the apparent annual shift caused by Earth's motion around the Sun, or parallax, which is inversely proportional to a star's distance, and the continuous motion across the sky as stars drift through the Galaxy.

In fact, the two effects are combined and can be only be disentangled by monitoring the tiny changes in stellar positions over timescales longer than one year. DPAC devised a means to overcome this nuisance for at least a small subset of the stars observed by Gaia: they looked for the stars in common between Gaia's first year of

observations and earlier measurements from the Hipparcos and Tycho-2 Catalogues and combined data from all three datasets.

Like every previous stellar catalogue, the Hipparcos and Tycho-2 Catalogues are unique datasets, representing the configuration of stars at specific moments in the history of the Milky Way. For this reason, even though they are less accurate than Gaia's data, they are a valuable complement to Gaia's first dataset. With the additional information recorded over two decades ago, it was possible to separate the contributions of parallaxes and proper motions for the stars in common between the catalogues.

The result is the Tycho-Gaia Astrometric Solution, or TGAS, an additional stellar inventory that is published as part of the first Gaia data release. It provides five parameters - positions, parallaxes, and proper motions - for about 2 million stars.

While the precision of TGAS is better than that of the Hipparcos Catalogue by a factor of about two, the new dataset contains 20 times more stars than the Hipparcos Catalogue, providing a brand new chart of stars in the solar neighbourhood.

The first Gaia data release represents a major advance in terms of the availability of high precision parallaxes and proper motions for the two million stars in the TGAS astrometric dataset and in terms of accurate positions and homogeneous all-sky photometry for the more than one billion stars observed by Gaia.

All data from the first Gaia data release are accessible from the Gaia Archive (archives.esac.esa.int/gaia), which also provides visualisation tools as well as comprehensive documentation to explore the data sets. In addition, the data are also made available through a number of partner and affiliated data centres located in Europe, the United States, South Africa and Japan.
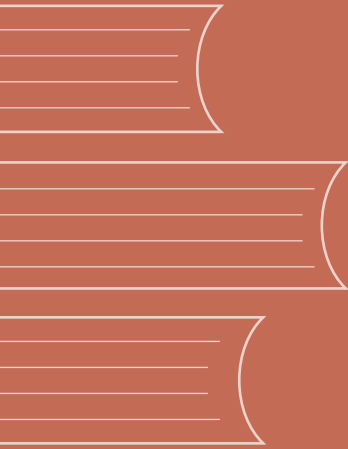
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Towards the final Gaia catalogue

In the early 2020s, the final Gaia catalogue will be published. This will be the definitive stellar catalogue for the foreseeable future, playing a central role in many and varied fields of astronomy.

Producing this final catalogue is a complicated endeavour that requires the entire mission dataset and a complex processing chain devised and tested by hundreds of scientists and software experts in the Gaia Data Processing and Analysis Consortium (DPAC).

Special subsets of Gaia data are being made public to facilitate timely follow-up observations by the wider astronomical community. For example, Science Alerts - announcements to the scientific community about detected transient events such as supernovae and outbursting stars - are regularly issued. The Gaia coordinates for a star were made available, in advance of the data release, to astronomers studying a rare occurrence of Pluto passing in front of this star.

Following the first data release in September 2016, the release of new datasets, based on longer time intervals and with additional data products, are planned to take place with a cadence of about one per year. These will be characterised by increasingly improving precision and additional parameters for the surveyed stars, as well as for other celestial objects - from Solar System bodies to galaxies beyond our Milky Way.

Eventually, the final catalogue will contain full astrometric and photometric parameters for over one billion stars as well as extensive additional information including a classification of the sources and lists of variable stars, multiple stellar

systems and exoplanet-hosting stars. For more than 150 million stars there will be measurements of the radial-velocity - the speed at which the star is travelling towards or away from us.

The final Gaia catalogue will be a census of our Galaxy of such superb precision and detail that it will redefine the fundamental reference frame used for all astronomical coordinate systems. This will truly mark a new era of astrometry.

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Making sense of it all

Making sense of it all - the role of the Gaia Data Processing and Analysis Consortium

During the course of the nominal five-year mission, Gaia sweeps across the sky producing a continuous stream of data that is unintelligible in its raw format to the scientists who want to use it. The task of converting the raw data into scientifically useful products is entrusted to the 450 scientists and software experts who form the Gaia Data Processing and Analysis Consortium (DPAC).

The transformation of the raw measurements takes place within the DPAC Coordination Units, or CUs. Each unit is responsible for developing the scientific algorithms and software corresponding to particular, well-defined aspects of the data processing and analysis.

Two units provide development support for technical aspects such as defining the software architecture and strategy (CU1), and for the data simulations (CU2) that have been essential for preparing for the real mission data by allowing DPAC to test their software and rehearse the science operations.

Three units are responsible for basic data processing. The CU3 unit takes care of processing astrometric data, which provides the positions and motions of celestial bodies in the sky. Photometric data processing, which results in a measure of how much light is emitted by the objects, is the task of CU5. The spectroscopic data processing, carried out by CU6, produces a measure of the velocity with which an object is moving towards or away from us, and what the star is made of.

Three units examine particular aspects of the processed data, looking at Solar

System objects, double stars, orbital binaries, exoplanets,and extragalactic objects (CU4); variable stars (CU7); and classification and characterization of all of the celestial objects observed by Gaia (CU8).

One unit (CU9) is responsible for the preparation, validation and distribution of the intermediate data releases and final Gaia catalogue.

The software developed by each of the CUs is run in one of the six data processing centres located in France (Toulouse), Italy (Turin), Spain (ESAC, near Madrid; Barcelona), Switzerland (Geneva), and the United Kingdom (Cambridge). These centres host the computing hardware and provide software engineering expertise to support the CU software development work.

The DPAC is funded through national funding agencies of the participating ESA member states. These funding agencies have signed a multilateral agreement with ESA that commits all parties to fund the DPAC effort up to the completion of the final Gaia catalogue, expected in the early 2020s. In addition, ESA makes a significant contribution to DPAC in the form of the Data Processing Centre at the European Space Astronomy Centre (ESAC) in Spain, which amongst other tasks and responsibilities, acts as the central hub for all Gaia data processing.

The final Gaia catalogue, to be produced by DPAC and ESA, will contain positions, distances, and motions for more than one billion celestial objects. For each of these objects Gaia will tell us the temperature, where it is in its lifecycle, the composition, and what lies between us and that object. There will be stars from every phase of the stellar lifecycle, as well as asteroids in our Solar System and planets around other stars. There will also be objects located beyond the Milky Way, such as other galaxies and quasars - distant sources that are used to construct the reference frame used for celestial coordinates.

Where is Gaia and why do we need to know?

Where is Gaia and why do we need to know?

Gaia is one of the most demanding of the 14 spacecraft operated by the European Space Operations Centre (ESOC) at Darmstadt in Germany. Situated 1.5 million km from us, the location of the spacecraft must be known to within 150 m every day of the nominal five-year mission, and the time on the spacecraft must be known to within 2 microseconds. At times the amount of data that needs to be downloaded even exceeds the capacity of all three ESA ground stations.

The location of the spacecraft feeds into the data analysis and the accuracy with which this position is measured has a direct impact on the precision with which the positions, motions and distances to the stars can be known.

To determine the distance to a spacecraft, ESOC performs two-way ranging measurements, which are accurate to 5 m. The speed at which the spacecraft is moving towards or away from us is obtained from Doppler measurements, which are accurate to 0.1 mm/s. These measurements are routinely carried out to check that Gaia is in the correct orbit and if not, to calculate and monitor the manoeuvres that are made to place the spacecraft back on track.

The location of Gaia on the plane of the sky is obtained using two widely separated antennas to simultaneously track the location of a transmitter on the spacecraft - this is the delta-differential one-way ranging (DDOR) method. DDOR can provide measurements accurate to about 22 m for Gaia, but since it requires regular use of two of the three ground stations that are shared by all science missions another method is also used.

Daily tracking of the spacecraft is carried out by the Gaia Ground-Based Optical

Tracking (GBOT) programme, organised by the Gaia Data Processing and Analysis Consortium (DPAC), using a network of small robotic telescopes across the world, as well as the European Southern Observatory's VLT Survey Telescope. These measurements will be able to provide the location of Gaia to within 150 m, which is sufficient for the science needs. Initially only DDOR positions are used to determine the actual orbit of Gaia to high accuracy but with the Gaia data available GBOT will routinely produce daily measurements of the location of the spacecraft to the accuracy needed.

Some of Gaia's other operational requirements have meant it was necessary to enhance some operational practices.

At the ground stations, ESA upgraded the infrastructure to support a high data rate, up to 7.62 Mbit/s (about half of a good domestic broadband rate), which allows more data to be downloaded during each period of contact.

Even with this high data rate (the highest of any science mission to date), Gaia is still the biggest user of ESA's large 35 m network. To optimise this use as much as possible, operators came up with a scheme that predicts precisely how much time is needed. The sky is not uniformly dense with stars and this is reflected in the amount of data that is recorded by Gaia. Since Gaia is scanning the sky many times this can be modelled so that the amount of time needed per day can be predicted. Most of the time all the data can be downloaded to ground using the three ground stations, at Cebreros (Spain), New Norcia (Australia), and Malargüe (Argentina). However, when scanning the densest regions of the sky, such as the Galactic Centre, even the high rate and all three stations are not sufficient, and an intelligent onboard scheme selects the least important data types to be deleted.

The communication protocols that are used to transmit data from the ground stations to the space operations centre also had to be adapted to cater to the demands imposed on time accuracy: ESOC must time stamp the data received on ground to an accuracy of better than 2 microseconds. This accuracy is needed to be able to reconstruct the orbits of near-Earth asteroids.

From ancient star maps to precision astrometry

Astrometry, the science of charting the sky, is one of the oldest branches of astronomy.

The first documented records of systematic astronomical observations date back to the Assyro-Babylonians around 1000 BCE, and the oldest known stellar catalogue was compiled in the second century BCE by the Greek astronomer Hipparchus of Nicaea.

Hipparchus's catalogue lists the positions of 850 stars with a precision of one degree - twice the angular size of the full Moon - determined using only naked-eye observations and the few instruments available at the time: gnomons, astrolabes, and armillary spheres. More than 1700 years would pass before any significant improvement would be made.

In the late sixteenth century, Danish astronomer Tycho Brahe measured the positions of about 1000 stars with a precision of about one arcminute, using large quadrants and sextants at the Uraniborg observatory on the island of Hven (in present-day Sweden). His catalogue was completed in 1598 and published in 1627.

Not long before, in 1543, Polish astronomer Nicolaus Copernicus had proposed the revolutionary heliocentric system, in which Earth revolves around the Sun.

This revived the debate about measuring the distance to the stars using parallax - the apparent movement of a foreground object with respect to its background owing to a change in the observer's position. Astronomers had tried to apply this method, also known as triangulation, to determine stellar distances, but no baseline on Earth

was big enough to detect parallaxes because of the immense distances involved. In a heliocentric system, however, they could exploit the much larger baseline offered by Earth's annual motion around the Sun.

Tycho Brahe himself tried to measure the parallax of stars but without success. It would take the invention of the telescope, in the early seventeenth century, and some two hundred years of diligent astronomy before the first distance to a star could be measured.

Meanwhile, in 1718, English astronomer Edmond Halley was the first to discover that stars are not fixed but actually move through space. When comparing contemporary catalogues with those from almost 2000 years earlier, he noticed a displacement in the position of many stars. This displacement corresponds to the projection of the star's velocity in the plane of the sky and is known as proper motion.

In 1725, English astronomer John Flamsteed published the first stellar catalogue compiled with the aid of a telescope, listing the positions of almost 3000 stars with a precision of 10-20 arcseconds. French astronomer Jérome Lalande published an even greater catalogue with the position of 50 000 stars and a precision of around three arcseconds, in 1801.

Shortly after that, in 1838, German astronomer Friedrich Bessel was the first to publish a reliable measurement of parallax, for the star 61 Cygni. Amounting to 0.314 arcseconds, this placed the star at a distance of about 10 light-years. Two more astronomers, the German Wilhelm Struve and Englishman Thomas Henderson, also successfully measured parallaxes in the late 1830s.

Knowledge of astronomical distances finally allowed astronomers to calibrate their observations and to estimate physical parameters of stars, such as their luminosity and size.

From the 1850s onwards, the application of photography to astronomical observations transformed the practice of charting the sky. With this method, Dutch astronomer Jacobus Kapteyn started measuring the parallax of hundreds of stars in the early 1900s.

In 1924, American astronomer Frank Schlesinger published a catalogue with the parallaxes of almost 2000 stars, probing stellar distances out to a few dozen light-years from Earth. His catalogue was extended to over 8000 stars by 1995, but the flickering effect caused by Earth's atmosphere prevented astronomers from reaching a precision better than about 0.01 arcseconds.

The onset of the space age brought astrometry firmly back to centre stage in astronomy. ESA's Hipparcos mission, operating from 1989 to 1993, was the first space telescope devoted to measuring stellar positions.

The Hipparcos catalogue, released in 1997, contains the position, parallax and proper motion of 117 955 stars with a precision of 0.001 arcseconds, allowing astronomers to probe stellar distances out to over 300 light-years.

The larger but less precise Tycho-2 catalogue, published in 2000, lists positions and proper motions of 2.5 million stars, combining data from the star mapper instrument Hipparcos with previous ground-based astrometric catalogues.

The Hipparcos mission has had a profound influence on most fields in astronomy, from studies of stellar interiors and evolution to the dynamics of stars; beyond the Milky Way, stellar distances based on Hipparcos data have allowed cosmologists to refine the calibration of the cosmic distance ladder.

ESA's Gaia mission is astrometry for the twenty-first century, building on the legacy of Hipparcos to chart one billion stars - about one per cent of the content of our Galaxy - measuring their position and parallax with astrometric precisions of down to 0.00001 arcseconds and possibly even better for the brightest stars observed.

Read more in the History of Astrometry series: sci.esa.int/gaia/history-of-astrometry

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Appendix 1: Resources

Gaia online

Gaia is on social media channels:

- @ESAGaia
- www.facebook.com/ESAGaiaMission/

Information about the mission can be found on the following websites:

www.esa.int/gaia - mission summaries and news for the general public

sci.esa.int/gaia - detailed information for interested readers

cosmos.esa.int/gaia - web pages for the Gaia science community

archives.esac.esa.int/gaia - the Gaia mission data archive

A listing of other Gaia websites can be found here:
www.cosmos.esa.int/web/gaia/links

Pictures, illustrations and animations

A variety of photographs, illustrations and animations are available for non-commercial use.

All Gaia images and videos:
sci.esa.int/gaia-gallery

Artist's impressions of the mission and related science:
sci.esa.int/gaia-mission-illustrations

Illustrations of Gaia science:
sci.esa.int/gaia-science

Photographs from the construction and testing phase:
sci.esa.int/gaia-construction-and-testing-photos

Photographs from launch:
sci.esa.int/gaia-launch-campaign-photos

Photographs of the focal plane array and CCDs:
sci.esa.int/gaia-focal-plane-and-ccds-photos

Photographs of the mirrors:
sci.esa.int/gaia-mirrors-photos

Photographs of the Basic Angle Monitor:
sci.esa.int/gaia-basic-angle-monitor-photos

Photographs of the sunshield:
sci.esa.int/gaia-sunshield-photos

Photographs of the payload module:
sci.esa.int/gaia-payload-module-photos

Photographs of the service module:
sci.esa.int/gaia-service-module-photos

Photographs of people:
sci.esa.int/gaia-people

Selected images and videos

Gaia's first map of the Galaxy
http://sci.esa.int/gaia/58209

Gaia by numbers
http://sci.esa.int/gaia/58210

Parallax concept
http://sci.esa.int/gaia/53278

Stellar motion concept
http://sci.esa.int/gaia/53279
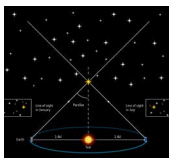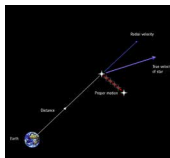
Anatomy of the Milky Way
http://sci.esa.int/gaia/58206

A journey through the Galaxy
http://sci.esa.int/gaia/58215

Gaia spacecraft
(artist's impression)
http://sci.esa.int/gaia/55638

Mapping the Galaxy
http://sci.esa.int/gaia/58214
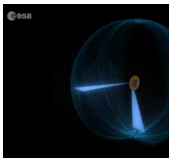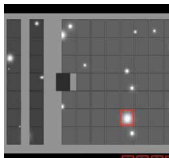
Inside Gaia's
billion pixel camera
http://sci.esa.int/gaia/53560

From launch to orbit
http://sci.esa.int/gaia/53280

Gaia launch - time-lapse of
preparation and launch
http://sci.esa.int/gaia/58063
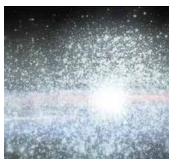
Gaia launch
19 December 2013
http://sci.esa.int/gaia/53539

Guide to our Galaxy
http://sci.esa.int/gaia/53147

Gaia – building on the
legacy of Hipparcos
http://sci.esa.int/gaia/53273

Participation in DPAC
http://sci.esa.int/gaia/56839
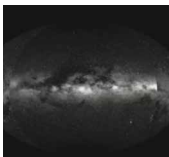
Gaia mission – overview
(pre-launch)
http://sci.esa.int/gaia/58060

Gaia science – overview
(pre-launch)
http://sci.esa.int/gaia/58061
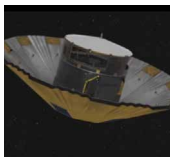
Sunshield deployment
(artist's impression)
http://sci.esa.int/gaia/53375
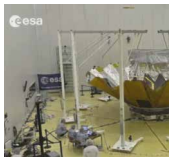
Sunshield deployment (time-lapse, during integration)
http://sci.esa.int/gaia/53113

The Gaia torus during installation of one large mirror
http://sci.esa.int/gaia/58208
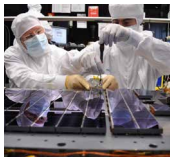
Gaia's CCDs
http://sci.esa.int/gaia/48887

Gaia primary mirror
http://sci.esa.int/gaia/47690

Basic Angle Monitor
http://sci.esa.int/gaia/58139

Phased array antenna
http://sci.esa.int/gaia/50529
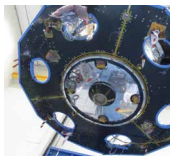
Appendix 2: Speakers at the press event

Photographs, names and titles of the speakers at the press event on 14 September

Alvaro Giménez
Director of Science
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Fred Jansen
Gaia Mission Manager
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Timo Prusti
Gaia Project Scientist
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