Introducing: Gaia

An introduction to Europe's billion star surveyor

Mission Objective:	To produce both the largest and most precise **3D map** of a billion stars within our Milky Way Galaxy.
Primary Goals:	To measure the 3D **positions** and **velocities** of one billion stars. To determine the **brightness** and **motion** of stars throughout the Galaxy, and the **temperature** and **composition** of the brighter ones.
Mission Duration:	Nominally 5 years (2013 – 2018)
Cost:	€960 million
Partners:	Gaia is a **European** mission, run by the European Space Agency (ESA) with contributions from **20 countries**.

What?

Gaia was a goddess in Greek mythology who was seen to be the goddess of Earth and the mother of everything. It also provided an acronym for the original mission proposal in the 1990's, the Global Astrometric Interferometer for Astrophysics. The mission design ended up using an alternative technique, but the name stuck.

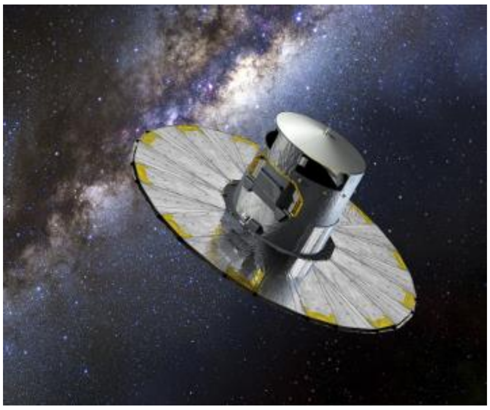

Image Credit: Source (WP:NFCC#4)

Gaia has the mission of producing a three-dimensional map of our Galaxy, the Milky Way. It will do this by monitoring **1 billion stars** over its mission lifetime.

The stars that make up the Galaxy are like **fossils**. Studying them helps us to understand the history of the Milky Way and how it has evolved into its present-day state. We can determine when and where a star formed by studying its chemical make-up. The various stellar orbits around a galaxy indicate the various stages in the formation of the galaxy and how **dark matter,** (the stuff holding everything together), is distributed.

How?

On-board Gaia is the largest camera ever to be launched into space. It is 104 x 42 cm in size and contains **1 billion pixels**. These pixels are divided among 106 CCDs and enable Gaia to detect objects up to **400,000 times fainter** than what we can see with our naked eye. So with Gaia's help, we will be able to observe 1 billion stars, as opposed to the ~6,000 we see with our eyes alone.

Each star that Gaia detects will be observed and measured approximately **70 times**. This is so that Gaia can produce extremely precise measurements of their **positions**, **distances**, **motion** and **luminosity**. This is done using **2 telescopes** on-board Gaia. Each telescope comprises of ten mirrors that focus and direct incoming light onto Gaia's **3 scientific instruments**. These 3 instruments are:

The Astrometric Instrument (ASTRO):	Determines the positions and brightness of stars.
The Radial Velocity Spectrometer (RVS):	Measures the velocity of stars along Gaia's line of sight by calculating the Doppler Shift of calcium lines in the spectrum of the star. (This might seem strange but although stars are predominantly made of hydrogen and helium, calcium is also present in most stars and can be clearly identified in spectra).
The Photometric Instrument (BP/RP):	Looks at low-resolution spectra within a wavelength band of 330-1050 nm. The light is dispersed into separate wavelengths using a prism. This allows scientists to determine properties such as temperature, mass, colour and broad compositions of the stars.

Where is Gaia?

Gaia was launched on a Soyuz-ST rocket from Europe's Spaceport in French Guiana. This sent Gaia to its orbit location where it is today at the **second Lagrangian point** orbit as illustrated in Figure 1. This is located **1.5 million km** away from Earth, where due to gravitational influences from the Sun and Earth, Gaia orbits the Sun with the pace of Earth's orbit.

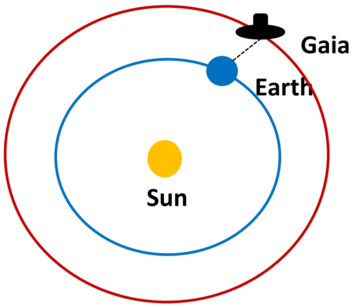

Figure 1 – Gaia's orbital location at Lagrange point 2.

Gaia's Challenge

Previously, we have only had accurate distance measurements to around **100,000 stars** in the Milky Way, this was thanks to Gaia's predecessor, Hipparcos. This satellite was named after the Greek astronomer, Hipparchus. The slight alteration in the spelling provides an acronym for High Precision Parallax Collecting Satellite.

Gaia is set to make several significant improvements on Hipparcos. is able to collect 30 times more light, this means we will be able to measure 10,000 times more stars and calculate their positions **200 times more accurately**.

To get a sense of scale of this difference, Hipparcos' capability was equivalent to measuring the height of an astronaut standing on the Moon, Gaia will be able to measure the astronaut's fingernail. For some stars, Gaia will measure their positions with accuracies equivalent to measuring the width of a human hair from 1,000 km away. That's about the distance between **London and Milan!**

Gaia measures the position of stars using a method known as **parallax**. You may have noticed that the stars in the night sky, do not remain in fixed positions. The direction in which we can see stars depends on where **Earth is in its orbit** (as illustrated by the blue ellipse in Figure 2), and the direction of the star in relation to the Sun (indicated by the dotted line in Figure 2). Therefore the appearance of the night sky changes depending on what time of year it is.

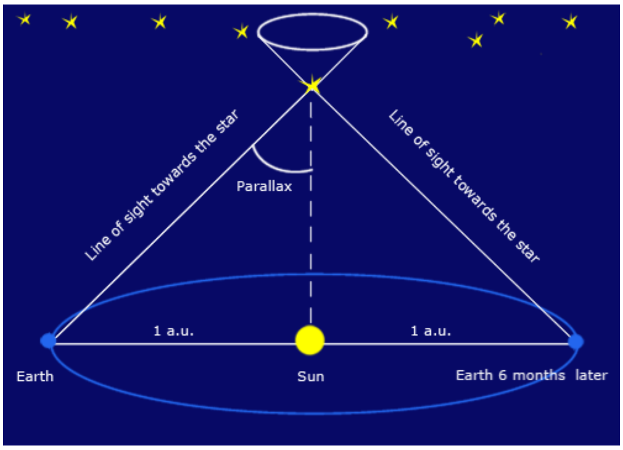

Figure 2 – An illustration of distance measurements to stars using parallax. Image Credit: IoA

The white ellipse in Figure 2 shows how the apparent location of that particular star will change throughout the year. Stars that are closer to us will show greater changes in their positions (bigger ellipses), whereas stars that are further away will vary less (smaller ellipses). We call this stellar parallax. The **distance to a nearby star is inversely proportional to the parallax angle.**

Gaia uses this same technique in relation to its **own orbit.**

But we can see stars from Earth, so why have we sent a big satellite into space?

We wouldn't be able to do all this if Gaia was on Earth. Ground-based telescopes suffer from effects of seeing, this is caused by our atmosphere distorting incoming light from star. This is much like when you open your eyes underwater and everything looks blurry. By placing a satellite outside of our atmosphere it's like lifting our head above the water - we have a much clearer view and can measure the positions of stars more accurately.

A Giddy Gaia

As the Earth orbits the Sun it also spins on its own axis, completing a full rotation each day. Gaia is doing the same but completes a full rotation in **6 hours**, this allows the 2 telescopes to cover the entire celestial sphere 4 times each day.

2 telescopes means 2 fields of view (FoV). These are separated by 106.5^{o} (see Figure 3) and due to Gaia's rotation, each object that appears in the first FoV will appear in the second FoV, 106.5 minutes later. This allows us to compare stellar parallax **displacements in different directions** in order to obtain absolute parallaxes; something that cannot be done on the ground.

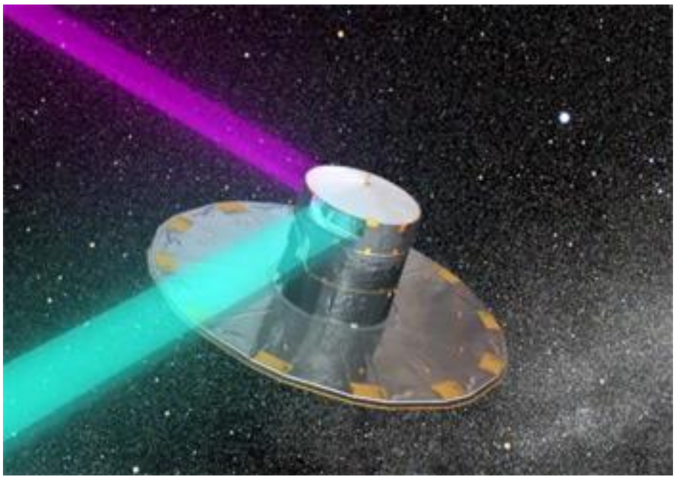

Figure 3 – Gaia's two fields of view separated by 106.5^{o}. Image Credit: ESA

Follow the link below to see how Gaia scans the celestial sky:

https://www.youtube.com/watch?v=bbfb8VhH7L0

Great Britain, Great Gaia.

The UK stands very much in the frontline of contributors in Gaia, with important roles in both the **industrial** and **scientific** aspects of the mission. In terms of industry, the UK led in building Gaia's 106 CCDs and some of the scientific instruments on board.

The Astrium team in Stevenage were responsible for Gaia's electrical service module (ESVM). This module enables the functioning of the spacecraft, including on-board computer, power and control systems. The primary objective of ESVM is to make sure Gaia can record data and communicate its observations back to Earth in order to carry out its mission.

Upon completing its mission, Gaia will have gathered **1 petabyte of data**, that's 1 million gigabytes. 1 gigabyte can store nearly 250 songs; this means Gaia will have gathered the equivalent of **250 million songs,** an impressive playlist!

So, processing this large amount of data requires a lot of people and resources. That's why it is being processed for publication by an organisation of scientists and software developers from over **20 European countries**. This is the **Data Processing and Analysis Consortium** (DPAC), where the UK is host to the Cambridge Data Processing Centre. Here, imaging and spectral data from the BP/RP instrument is processed in order to provide information about the brightness, position and colour of objects. This enables derivation of stellar distances, motions and physical properties.

Details of the main UK participants involved in Gaia are given below:

Science Involvement in Data Processing

University of Cambridge
Mullard Space Science Laboratory
Edinburgh University
Rutherford Appleton Laboratory
University of Leicester
The Open University

Industrial Involvement in On-board Systems and Image Sensors

Astrium
E2v

Gaia by Numbers

Let's break Gaia down into some numbers…

Telescopes:	2
Scientific Instruments:	3
Number of Stars:	1,000,000,000
Average Observations of each Star:	70
Countries Involved:	20
Magnitude:	As low as 20
Orbital Distance from Earth:	1.5 million km
Data:	1 petabyte (1 million gigabytes)
Cost of Mission (Euros):	~960 million
Camera Pixels:	1 billion

https://gaia.ac.uk/alerts

Hours to prepare for Gaia:	3.5 million
Number of CCDs:	106
Gaia's spin period:	6 hours

Why bother?

Not only is Gaia producing the most **accurate and precise map** of our Galaxy to date, it is also foreseen to make many **new discoveries**. Among its observations it will detect around 1,000,000 galaxies, 500,000

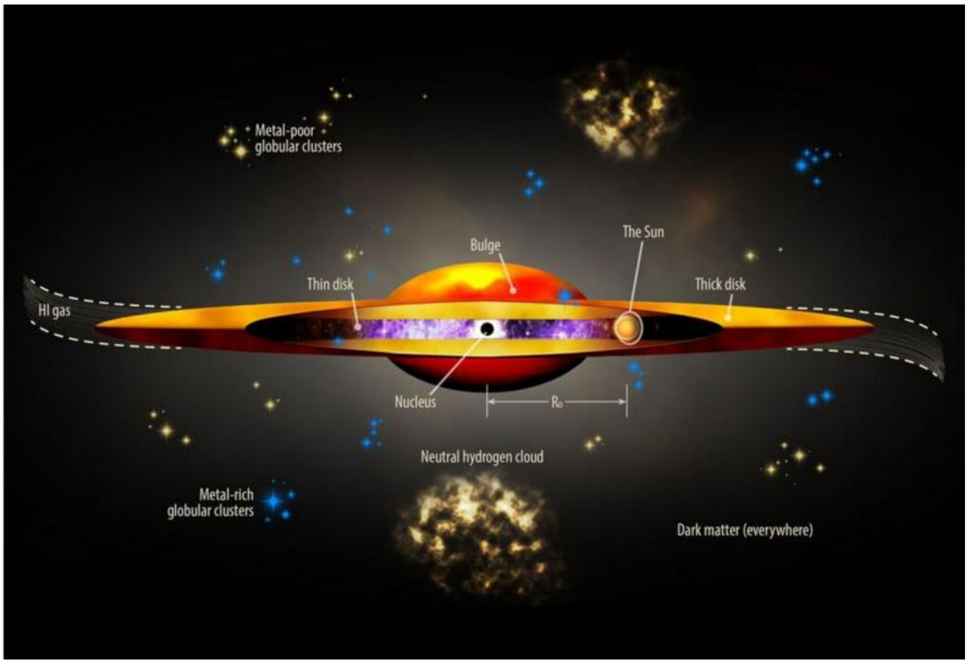

Figure 4 – Our current understanding of the structure of the Milky Way. Image credit: Amanda Smith/IoA

quasars, 10,000 supernovae, 250,000 asteroids, 15,000 exoplanets, 200,000 white dwarfs and 50,000 brown dwarfs.

These vast amounts of data that Gaia is collecting will help us to answer many unanswered questions about the Milky Way and beyond. We will uncover a great deal of information relating to the **origin and evolution of the Milky Way,** and gain greater understanding of its current **structure.**

The Milky Way is the big picture of where we live. You live in a house in a town, in a country on Earth. But further out into space, the Earth lies in our Solar System, within the Milky Way galaxy. Gaia will provide us with the bigger picture of where we live; how big, how old, what shape and how it came to be how it is today.