The Little Books of Gaia

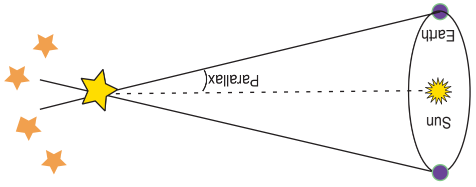
HISTORY OF ASTROMETRY

From Hipparchus to Gaia

June 2009

[Astrometry](#) is the oldest branch of astronomy. It studies the geometrical relationships between objects in the sky and their apparent and true motions.

To find the distance to a star we use a concept called the parallax. If we observe a star from the Earth and record its position with respect to the background stars and then repeat this measurement 6 months later, when the Earth is on the opposite side of its orbit around the Sun, we see that the position of the star appears to shift with respect to the background. This apparent angular displacement of a star is what is called the stellar parallax. By measuring the parallax, we can deduce the distance to a nearby star using simple geometry. But stellar parallax is a difficult quantity to measure as it is extremely small for all but the nearest few hundred stars.



Astrometry also determines how celestial objects are moving in space relative to each other. For this purpose it is necessary to measure two components of motion: the radial velocity which is the velocity of the star away or toward us, and the proper motion which is the motion of an object across the sky.

The radial velocity is easily found by observing the spectrum of a star, but finding the proper motion is tougher and requires careful observation of the movement of the star with respect to others over a number of years.

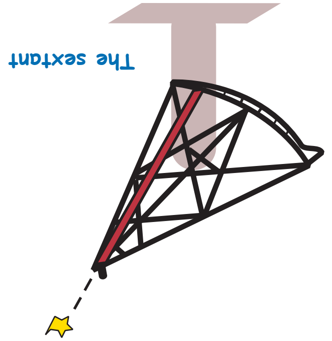
Measuring distances and motions of stars is fundamental to our understanding of the nature of the Universe. Knowing the distance to a star, we can deduce its true luminosity and size and so we can derive essential information about its nature and age. On the other hand, knowing the motion of stars we can deduce not only where they were millions of years ago but also what their positions will be in the future.

Ancient civilizations already realised that objects in the sky appear to move in a regular manner which can be useful for determining directions and time on the Earth. The need to solve problems originating from early communities (e.g. establishing accurately the optimum moment for planting and harvesting) constituted a starting point for precision astrometry.

Making accurate angular measurements and cataloguing celestial positions has been the fundamental task of astronomy until the 19th century and still constitutes a basic element of astronomical research. The angles involved are extremely small and improving the accuracy of astrometric measurements has been a constant goal of astronomers. Improved accuracy has come from the development of new and more precise observing instruments and has led to a series of very fundamental changes in scientific belief.

In 129 B.C. and only with the help of the naked eye, the Greek astronomer Hipparchus was the first to complete a catalogue of a thousand stars, specifying their relative brightness and position with an accuracy of about one degree, i.e. the angle equivalent to the apparent height of a person at a distance of 100 metres. This is considered to represent the birth of the science of astrometry.

After Hipparchus, progress in the accuracy of angular measurements was slight until the 16th century. A revolution came with Tycho Brahe (1546-1601), a Danish astronomer, who fixed star positions to about a minute of arc, i.e. one sixtieth of a degree. He designed, built and calibrated a wide variety of viewing instruments like the sextant or the mural quadrant and changed observational practice profoundly.



The sextant

Tycho's observations of the planets throughout their orbit with unprecedented accuracy allowed Kepler to discover that planets move in elliptical orbits.

In 1609, the telescope was invented, opening new worlds to human scrutiny. But the telescope alone wasn't of much use for measuring angles. It took some time to devise an instrument which would make use of the improved sight available with the telescope, but which would also permit a high angular accuracy.

In the 17th century the filar micrometer was invented, consisting of two wires mounted in the field of view of a telescope which moved towards and away from each other with a screw. The number of turns of the screw indicated the angle subtended by the object in the sky. This allowed breaking the barrier of accuracy imposed by the limited resolution of the human eye, which cannot distinguish angles below 1 minute of arc.

In the 18th century, knowledge of materials and workshop techniques improved significantly allowing instrument makers to engrave angular scales like the astronomical circle with high precision. Accuracies improved to the order of arcseconds, which allowed the detection of stellar aberration in 1725, the first direct proof that the Earth was moving through space. This finally confirmed the controversial Copernican theory which stated that the Earth goes around the Sun, and not vice versa. Another important discovery of this century was Edmund Halley's detection of the motion of stars through space.

In the 19th century, engraving techniques advanced further and measurements were possible with accuracies of fractions of a second of arc. This increase in precision was fundamental for measuring the first stellar parallaxes in the 1830s. The confirmation that stars lay at very large but still finite distances was a turning point in our understanding of stars and of our place in the Universe.

In the 20th century, astronomy focused its research on learning more about the nature of celestial objects instead of only measuring their position. New techniques like spectroscopy (which studies the light emitted by objects to determine their chemical composition, temperature and nature) and the use of photographic plates in astronomy enabled this change to occur. Progress in astrometry meanwhile became very difficult, because it had reached the best precision obtainable from Earth, of approximately 0.1 arcsecond, limited mostly by atmospheric effects.

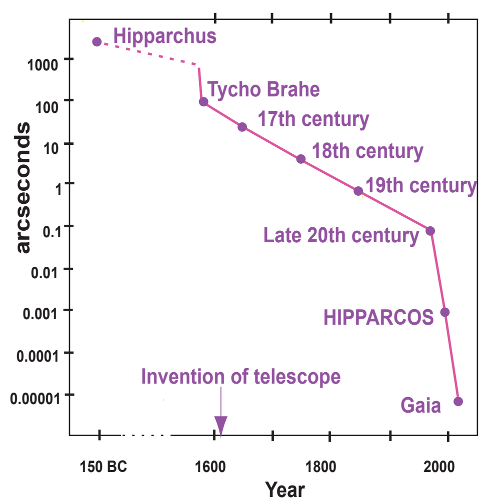
But things changed for astrometry in 1989, as the European Space Agency (ESA) launched the first astrometric satellite, Hipparcos, which has revolutionised our knowledge of star positions. From its orbit, the Hipparcos satellite observed the whole sky, achieving an improvement of about 100 compared to accuracies obtained from the ground. A catalogue was created with the positions, distances and motions of 118218 stars to a precision of around 1 milliarcsecond. The results from Hipparcos are being analysed by scientists all over the world, and important conclusions are emerging about the nature of our Galaxy.

Following the success of Hipparcos, ESA is planning to launch a much more powerful astrometric satellite called Gaia. Gaia will use the most advanced technology to create an extremely precise dynamic three-dimensional map of our Galaxy with positions, distances and also velocities about 1 billion stars. Its accuracy will be about 20 microarcseconds (equivalent to measuring the diameter of a human hair at a distance of 1000 km!) and even better for brighter stars.

The science case for Gaia is extremely broad and ambitious and its ultimate aim is to solve one of the most challenging yet fundamental questions of modern science: understanding the origin and evolution of our own Galaxy, the Milky Way. It will also revolutionise the search for extrasolar planets by detecting thousands of them in the solar neighbourhood.

Gaia represents the dream of many generations as it will bring light to questions that astronomers have been trying to answer for many centuries. It is the expression of a widespread curiosity about the nature of the Universe combined with the most cutting-edge technologies developed by creative engineers.

Positional accuracy through History



More detailed information can be found on the Gaia web site: http://sci.esa.int/Gaia