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Extract of Gaia section

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4.5 Gaia

Introduction

After a detailed concept and technology study during 1998–2000, Gaia was selected as a confirmed mission within ESA's scientific programme in October 2000, with a launch date of 'not later than 2012'. It was confirmed by ESA's SPC following a reevaluation of the science programme in June 2002, and reconfirmed following another reevaluation of the programme in November 2003. The project entered Phase-B2/C/D in February 2006. A launch date of December 2011 is currently targeted.

Scientific goals

Gaia will rely on the proven principles of ESA's Hipparcos mission to solve one of the most difficult yet deeply fundamental challenges in modern astronomy: to create an extraordinarily precise 3-D map of about a billion stars throughout our Galaxy and beyond. In the process, it will map their motions, which encode the origin and subsequent evolution of the Galaxy. Through comprehensive photometric classification, it will provide the detailed physical properties of each star observed: characterising their luminosity, temperature, gravity and elemental composition. This massive stellar census will provide the basic observational data to tackle an enormous range of important problems related to the origin, structure and evolutionary history of our Galaxy – a kind of 'humane genome project' for astronomy.

Gaia will achieve this by repeatedly measuring the positions of all objects down to V = 20 mag. Onboard object detection will ensure that variable stars, supernovae, burst sources, micro-lensed events and minor planets will all be detected and catalogued to this faint limit. Final accuracies of 12–25 μarcsec at 15 mag will provide distances accurate to 10% as far as the Galactic Centre, 30 000 light years away. Stellar motions will be measured even in the Andromeda Galaxy.

Gaia's expected scientific harvest is of almost inconceivable extent and implication. Its main goal is to clarify the origin and history of our Galaxy, by providing tests of the various formation theories, and of star formation and evolution. This is possible because low-mass stars live for much longer than the present age of the Universe, and therefore retain in their atmospheres a fossil record of their detailed origin. The Gaia results will precisely identify relics of tidally-disrupted accretion debris, probe the distribution of dark matter, establish the luminosity function for pre-main-sequence

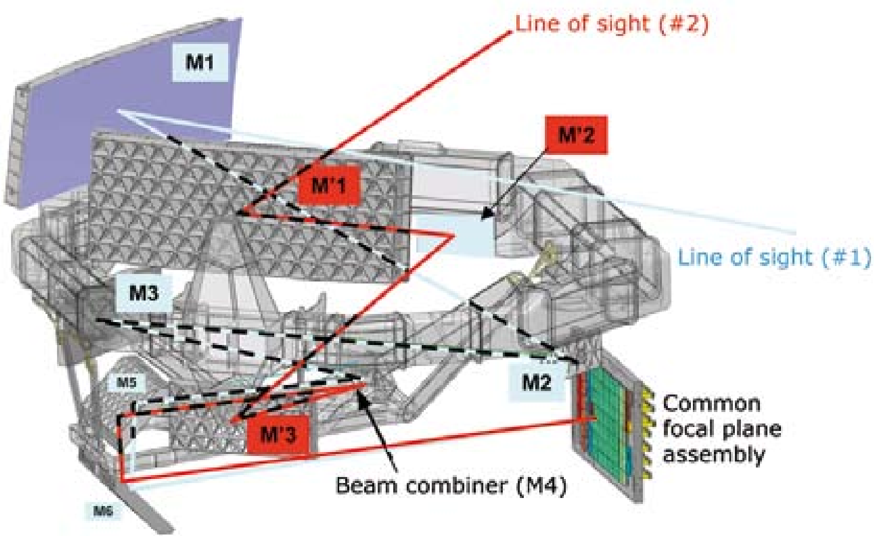

Figure 4.5.1. The Gaia payload features two telescopes, each with an entrance pupil of 1.45m x 0.5 m² and a focal length of 35m, with viewing directions (lines-of-sight) separated by a highly-stable basic angle of 106.5°. The optical path of both telescopes is composed of six reflectors (M1-M6), two of which are common (M5-M6). The telescopes share a common focal plane, with separate regions dedicated to astrometry, photometry and radial velocity measurements. As the spacecraft spins and precesses it scans the sky, eventually covering the entire celestial sphere. All objects down to Gaia's limiting magnitude of 20 (in its own white-light band) will be measured approximately 70 times during the 5-year operational phase of the mission.

For further information, see http://www.rssd.esa.int/Gaia

Table 4.5.1. Gaia vs. Hipparcos capabilities.

	Hipparcos	*GAIA*
Magnitude limit	12	20 mag
Completeness	7.3 - 9.0	20 mag
Bright limit	~ 0	6 mag
Number of objects	120 000	26 million to V = 15
		250 million to V = 18
		1000 million to V = 20
Effective distance limit	1 kpc	1 Mpc
Quasars	none	500 000
Galaxies	none	10^6 - 10^7
Accuracy	1 milliarcsec	7 μarcsec at V = 10
		12-25 μarcsec at V = 15
		100-300 μarcsec at V = 20
Photometry	2-colour	Low-res. spectra to V = 20
Radial velocity	none	15 km/s to V = 16-17
Observing programme	pre-selected	complete and unbiased

stars, detect and categorise rapid evolutionary stellar phases, place unprecedented constraints on the age, internal structure and evolution of all stellar types, establish a rigorous distance-scale framework throughout the Galaxy and beyond, and classify star-formation and kinematical and dynamical behaviour within the local group of galaxies.

Gaia will pinpoint exotic objects in colossal and almost unimaginable numbers: many thousands of extrasolar planets will be discovered, and their detailed orbits and masses determined; tens of thousands of brown dwarfs and white dwarfs will be identified; some 100 000 extragalactic supernovae will be discovered and details passed to ground-based observers for follow-up observations; Solar System studies will receive a massive impetus through the detection of many tens of thousands of new minor planets; inner Trojans and even new trans-Neptunian objects, including Plutinos, may be discovered. Gaia will follow the bending of starlight by the Sun and major planets, over the entire celestial sphere, and therefore directly observe the structure of space–time (the accuracy of its measurement of General Relativistic light bending may reveal the long-sought scalar correction to its tensor form). The PPN parameters gamma and beta will be determined with unprecedented precision.

The spacecraft

Gaia will carry the demonstrated Hipparcos principles into orders of magnitude improvement in terms of accuracy, number of objects, and limiting magnitude, by combining them with state-of-the-art technology. It will be a continuously-scanning spacecraft, accurately measuring 1-D coordinates along great circles and in two simultaneous fields of view, separated by a well-defined and well-known angle. These 1-D coordinates are then converted into the astrometric parameters in a global data analysis, in which distances and proper motions 'fall out' of the processing, as does information on double- and multiple-systems, photometry, variability, metrics,

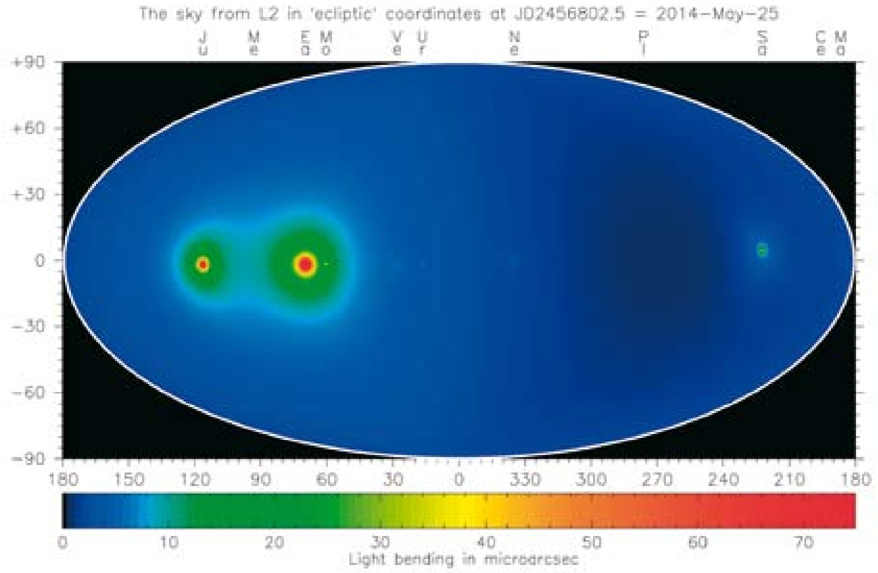

Figure 4.5.2. The amplitude of the relativistic light bending terms due to the presence of the various Solar System objects, as seen by Gaia from its L2 orbit. The sky is shown in ecliptic coordinates, and the dominant effect of the Sun's gravitational field has been suppressed. At the epoch simulated (May 2014), the effects of Jupiter, the Earth, Moon and Saturn can clearly be seen. All planets, as well as other Solar System objects including the four Galilean moons of Jupiter and the most massive minor planets, will have a measurable effect on the Gaia observations. (Courtesy J. de Bruijne)

planetary systems, etc. The payload is based on a large CCD focal plane assembly, with passive thermal control, and natural short-term instrument stability arising from the sunshield, selected orbit and robust payload design.

The telescopes are of moderate size (1.45x0.5 m) manufactured from SiC, with no specific design or manufacturing complexity. The system fits within a Soyuz-Fregat launch configuration, without deployment of any payload elements (moving from an Ariane to a Soyuz launch was one of the results of the 2002 redesign effort). A Lissajous orbit at L2 is the adopted operational orbit, from where about 1 Mbit/s of data is returned to ground station throughout the 5-year mission. The final astrometric accuracies are evaluated through a comprehensive accuracy assessment programme; μarcsec accuracies are possible partly by virtue of the (unusual) instrumental self-calibration achieved through the data analysis on-ground. This ensures that final accuracies essentially reflect the photon noise limit for localisation accuracy, exactly as achieved with Hipparcos.

The preliminary design review was successfully completed by June 2007. The development is progressing toward the critical design review (CDR) currently scheduled for summer 2009. The main technological challenges with direct science impact include the SiC torus, which supports the mirrors and payload unit and the radial velocity spectrometer. The CCD development was started early on and is progressing well, although the treatment of radiation effects on data quality is not yet fully determined. An extensive CCD testing programme is underway to outline the mitigation approach for the CDR. The strategy encompasses a procedure to minimise the effects on board, and calibration of the remaining effect by ground processing.

Scientific organisation and progress

The participation of the wider European astronomical community in the Gaia data processing challenge has been formalised through the Gaia Data Processing and Analysis Consortium (DPAC). The DPAC was selected in 2007 after a call for proposals to perform the data processing for Gaia. DPAC is divided into nine coordination units, responsible for software development, and six data processing centres to run the software. The overall management of the consortium is carried out by the DPAC Executive (DPACE).

The DPAC coordination units (CUs) cover the overall needs of the scientific ground segment data processing. CU1 (System Architecture) covers many issues common across the whole DPAC and is responsible for the overall architecture. CU2 (Data Simulations) is already operational, as simulated Gaia data is needed across DPAC for testing the data processing software. CU3 (Core Processing) is entrusted with the handling of raw data and first look, in addition to the core task of providing the software for astrometric processing. CU4 (Object Processing) will deal with more complicated sources, with a main emphasis on binaries and solar system targets. CU5 (Photometric Processing) is responsible for photometric data from the low-resolution spectrometer, and CU6 (Spectroscopic Processing) will deal with data from the radial velocity spectrometer. CU7 (Variability Processing) is responsible for the software for variability analysis, and CU8 (Astrophysical Parameters) will provide fundamental physical quantities to parameterise the objects in the final Gaia Catalogue. CU9 (Catalogue Access) will be initiated at a later stage.

DPAC passed the System Requirements Review in 2007, ensuring that the ongoing development is based on a correct and complete set of requirements. The DPAC review was part of an overall Ground Segment System Requirements Review which was completed January 2008. The Gaia Ground Segment passed the review successfully and the elements are being implemented in order to have the ground segment ready in time.

2007 saw the spacecraft passing the preliminary design review and the Gaia data-processing consortium being selected, bringing the project into a new phase. This phase included the selection of a new Gaia Science Team (GST). The GST is made up of seven selected scientists from the community and two ex-officio members, the DPAC Chair and the ESA Project Scientist, who also chairs the GST. The new GST took up duty in October 2007 and will continue advising ESA on all scientific aspects of Gaia.