OVERVIEW OF THE GAIA MISSION

M.A.C. Perryman

European Space Agency, Astrophysics Missions Division, ESA-ESTEC, 2200AG Noordwijk, The Netherlands

ABSTRACT

This contribution outlines the overall goals and organisation of the Gaia mission: the role of the scientific community in the project; the organisation, structure, and goals of the scientific working groups; their interaction and influence on the satellite and payload design; the overall project schedule; the organisation and overall approach to the challenges of the data analysis; and the mission data products and their estimated release dates.

Key words: ESA; Gaia; space astrometry.

1. INTRODUCTION

Gaia was originally submitted to the ESA Horizon 2000+ Survey Committee in 1994 and, following a detailed industrial concept and technology study during 1997–8, was approved by ESA's Science Programme Committee in 2000. Following a cost-reduction exercise in 2002, during which a redesign for a Soyuz rather than an Ariane 5 launch was undertaken, Gaia was reconfirmed within the ESA 'Cosmic Vision 2020' science programme in June 2002, with a target launch date of mid-2011. The overall schedule of the project, out to the availability of the final catalogues, is shown in Figure 1.

Gaia will build on the observational principles of Hipparcos to measure detailed properties of the brightest 1 billion stars in the sky. Astrometric accuracies of around 10 microarcsec at 15 mag should lead to 20 million stars measured with distance accuracies of better than 1 per cent, and more than 100 million better than 5 per cent. Tangential velocities will be measured astrometrically at better than 1 km s^{-1} for about 100 million stars, while the dedicated radial velocity spectrometer will gather radial velocities to 1–10 km s^{-1} to 16–17 mag, depending on spectral type. Gaia will provide multi-colour (in 11 medium and 5 broad bands), multi-epoch (of order 100 epochs over 5 years) photometry for each object to 20 mag, with great care being invested in devising the photometric bands to maximise their astrophysical diagnostic power. Scientific preparations for the mission involve the participation of some 14 working groups, taking responsibility for (amongst other aspects) the accuracy modelling, the radial velocity instrument optimisation, preparation of simulated data, and the development of a data processing framework to handle the complex and large (of order 1 Petabyte) Gaia data set.

Gaia will extend the system of high accuracy positional measurements to a very large number of stars throughout our Galaxy. Its contribution to the understanding of the structure and evolution of our Galaxy is based on three complementary observational approaches: (i) a census of the contents of a large, representative, part of the Galaxy; (ii) quantification of the present spatial structure, from distances; (iii) knowledge of the three-dimensional space motions, to determine the gravitational field and the stellar orbits. Astrometric measurements provide model-independent distances and transverse kinematics, the basis of the cosmic distance scale.

Complementary radial velocity and photometric information are required to complete the kinematic and astrophysical information. Photometry, with appropriate astrometric and astrophysical calibration, gives a knowledge of extinction, and hence, combined with astrometry, provides intrinsic luminosities, spatial distribution functions, and stellar chemical abundance and age information. Radial velocities complete the kinematic triad, allowing determination of dynamical motions, gravitational forces, and the distribution of invisible mass.

Gaia will be a continuously scanning spacecraft, accurately measuring one-dimensional coordinates along great circles in two simultaneous fields of view, separated by a well-known angle. The payload utilises a large CCD focal plane assembly, passive thermal control, natural short-term instrument stability due to the sun shield and the selected orbit, and a robust payload design. A 'Lissajous' orbit at the L2 Lagrange point of the Sun-Earth system is the proposed operational orbit, from where about 1 Mbit of data per second is returned to the single ground station throughout the 5-year mission.

By way of introduction to the science goals, it may be noted that Gaia is expected to observe, or discover, very large numbers of specific objects, for example: 10^5–10^6 Solar System objects; 10–30 000 extra-solar planets; 200 000 disc white dwarfs; 10^7 resolved binaries within 250 pc; 10^5 extragalactic supernovae; and 500 000 quasars. Further details of the science goals are given in the accompanying introduction by Mignard.

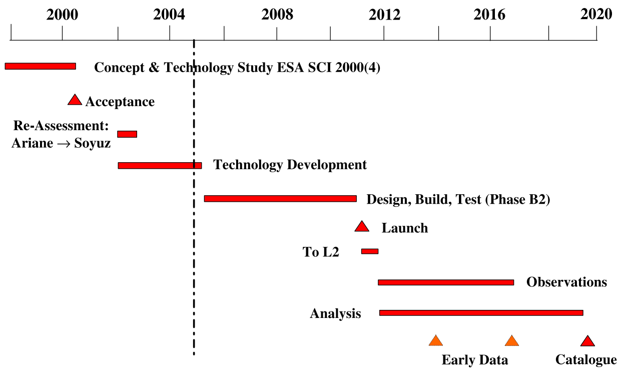

Figure 1. Overall schedule of the Gaia mission.

2. OVERALL DESIGN CONSIDERATIONS

The proposed Gaia design has arisen from requirements on astrometric precision (10 μas at 15 mag), completeness to $V = 20$ mag, the acquisition of radial velocities, the provision of accurate multi-colour photometry for astrophysical diagnostics, and the need for on-board object detection.

2.1. Astrometry

A space astrometry mission has a unique capability to perform global measurements, such that positions, and changes in positions caused by proper motion and parallax, are determined in a reference system consistently defined over the whole sky, for very large numbers of objects. Hipparcos demonstrated that this can be achieved with milliarcsecond accuracy by means of a continuously scanning satellite which observes two directions simultaneously. With current technology this same principle can be applied with a gain of a factor of more than 100 improvement in accuracy, a factor 1000 improvement in limiting magnitude, and a factor of 10 000 in the numbers of stars observed.

Measurements conducted by a continuously scanning satellite are optimally efficient, with each photon acquired during a scan contributing to the precision of the resulting astrometric parameters. The over-riding benefit of global astrometry using a scanning satellite is however not efficiency but reliability: an accurate instrument calibration is performed naturally, while the interconnection of observations over the celestial sphere provides the rigidity and reference system, immediately connected to an extragalactic reference system, and a realistic determination of the standard errors of the astrometric parameters. Two individual viewing directions with a wide separation is the fundamental pre-requisite of the payload, since this leads to the determination of absolute trigonometric parallaxes, and absolute distances, exploiting the method implemented for the first time in the Hipparcos mission. In the Gaia design, these two viewing directions are combined into a single focal plane. Estimated final astrometric accuracies are summarised in Table 1.

2.2. Radial Velocity Measurements

There is one dominant scientific requirement, as well as other additional scientific motivations, for the acquisition of radial velocities with Gaia: (i) astrometric measurements supply only two components of the space motion of the target stars: the third component, radial velocity, is directed along the line of sight, but is nevertheless essential for dynamical studies; (ii) measurement of the radial velocity at a number of epochs is a powerful method for detecting and characterising binary systems; (iii) at the Gaia accuracy levels, ‘perspective acceleration’ is at the same time both a complication and an important observable quantity. If the distance between an object and observer changes with time due to a radial component of motion, a constant transverse velocity is observed as a varying transverse angular motion. Although the effect is generally small, some hundreds of thousands of high-velocity stars will have systematic distance errors if the radial velocities are unknown.

On-board acquisition of radial velocities with Gaia is not only feasible, but is relatively simple (at least in principle), is scientifically necessary, and cannot be readily provided in any other way. In terms of accuracy requirements, faint and bright magnitude regimes can be distinguished. The faint targets will mostly be distant stars, which will be of interest as tracers of Galactic dynamics. The uncertainty in the tangential component of their space motion will be dominated by the error in the parallax. Hence a radial velocity accuracy of $\simeq 5$ km s^{-1} is sufficient for statistical purposes. Stars with $V < 15$ mag will be of individual interest, and the radial velocity will be useful also as an indicator of multiplicity and for the determination of perspective acceleration. The radial velocities will be determined by digital cross-correlation between an observed spectrum and an appropriate template.

Most stars are intrinsically red, and made even redder by interstellar absorption. Thus, a red spectral region is to be preferred for the Gaia spectrograph. To maximize the radial velocity signal even for metal-poor stars, strong, saturated lines are desirable. Specific studies, and ground-based experience, show that the Ca II triplet near 860 nm is optimal for radial velocity determination in the greatest number of stellar types.

Ground-based radial velocity surveys are approaching the one million-object level. That experience shows the cost and complexity of determining some hundreds of millions of radial velocities is daunting. There is also a substantial additional scientific return in acquiring a large number of measurements, and doing so not only well spaced in time but also, preferably, simultaneously with the astrometric measurements (e.g. variables and multiple systems).

Table 1. Target accuracies in parallax (σ_π), position (at mid-epoch, σ_0) and proper motion (σ_μ), versus G magnitude. The values are sky averages.

G (mag)	10	11	12	13	14	15	16	17	18	19	20	21
σ_π (μas)	4	4	4	5	7	11	17	27	45	80	160	500
σ_0 (μas)	3	3	3	4	6	9	15	23	39	70	140	440
σ_μ (μas yr^{-1})	3	3	3	4	5	8	13	20	34	60	120	380

2.3. Derivation of Astrophysical Parameters

The Gaia core science case requires measurement of luminosity, effective temperature, mass, age and composition, in addition to distance and velocity, to optimise understanding of the stellar populations in the Galaxy and its nearest neighbours. The quantities complementary to the kinematics can be derived from the spectral energy distribution of the stars by multi-band photometry and spectroscopy. Acquisition of this astrophysical information is an essential part of the Gaia payload. A broad-band magnitude, and its time dependence, will be obtained from the primary mission data, allowing both astrophysical analyses and the critical corrections for residual system chromaticity. For the brighter stars, the radial velocity spectra will complement the photometric data.

For essentially every application of the Gaia astrometric data, high-quality photometric data will be crucial, in providing the basic tools for classifying stars across the entire HR diagram, as well as in identifying specific and peculiar objects. Photometry must determine (i) temperature and reddening at least for OBA stars and (ii) effective temperatures and abundances for late-type giants and dwarfs. To be able to reconstruct Galactic formation history the distribution function of stellar abundances must be determined to $\sim$ 0.2 dex, while effective temperatures must be determined to $\sim$ 200 K. Separate determination of the abundance of Fe and α-elements (at the same accuracy level) will be desirable for mapping Galactic chemical evolution. These requirements translate into a magnitude accuracy of $\simeq$ 0.02 mag for each colour index.

Considerable effort has been devoted to the design of an optimum filter system for Gaia. The result of this effort is a baseline system, with 4–5 broad and 11 medium passbands, covering the near ultraviolet to the CCD red limit. The broad-band filters are implemented within the astrometric fields, and therefore yield photometry at the same angular resolution (also relevant for chromatic correction), while the 11 medium-band filters are implemented within the spectrometric telescope. Both target magnitude limits of 20 mag, as for the astrometric measurements.

2.4. Summary of Measurement Capabilities

In summary, Gaia's measurement capabilities can be summarised as follows:

Catalogue: $\sim$ 1 billion stars; 0.34 $\times$ 10^6 to $V = 10$ mag; 26 $\times$ 10^6 to $V = 15$ mag; 250 $\times$ 10^6 to $V = 18$ mag; 1000 $\times$ 10^6 to $V = 20$ mag; completeness to about 20 mag.

Sky density: mean density $\sim$25 000 stars deg^{-2}; maximum density $\sim$3 $\times$ 10^6 stars deg^{-2}.

Median parallax errors: 4 μas at 10 mag; 11 μas at 15 mag; 160 μas at 20 mag.

Distance accuracies: 2 million better than 1 per cent; 50 million better than 2 per cent; 110 million better than 5 per cent; 220 million better than 10 per cent.

Tangential velocity accuracies: 40 million better than 0.5 km s^{-1}; 80 million better than 1 km s^{-1}; 200 million better than 3 km s^{-1}; 300 million better than 5 km s^{-1}; 440 million better than 10 km s^{-1}.

Radial velocity accuracies: 1–10 km s^{-1} to $V = 16 -$ 17 mag.

Photometry: to $V = 20$ mag in 4 broad and 11 medium bands.

2.5. On-Board Detection

Clear definition and understanding of the selection function used to decide which targets to observe is a crucial scientific issue, strongly driving the final scientific output of the mission. The optimum selection function, and that adopted, is to detect every target above some practical signal level on-board as it enters the focal plane. This has the advantage that the detection will be carried out in the same waveband, and at the same angular resolution, as the final observations. The focal plane data on all objects down to about 20 mag can then be read out and telemetered to ground within system capabilities. All objects, including Solar System objects, variable objects, supernovae, and microlensed sources, are detected using this 'astrometric sky mapper'.

2.6. Payload Design Principles

The overall design constraints have been investigated in detail in order to optimise the number and optical design of each viewing direction, the choice of wavelength bands, detection systems, detector sampling strategies, basic angle, metrology system, satellite layout, and orbit.

The resulting proposed payload design consists of:

(a) two astrometric viewing directions. Each of these astrometric instruments comprises an all-reflective three-mirror telescope with an aperture of 1.4×0.5 m^2, the two fields separated by a basic angle of 99.4°. Each astrometric field comprises an astrometric sky mapper, the astrometric field proper, and a broad-band photometer. Each sky mapper system provides an on-board capability for star detection and selection, and for the star position and satellite scan-speed measurement. The main focal plane assembly employs CCD technology, with about 170 CCDs and accompanying video chains per focal plane, a pixel size 10 μm along scan, TDI (time-delayed integration) operation, and an integration time of ~ 3.3 s per CCD;

(b) an integrated radial velocity spectrometer and photometric instrument, comprising an all-reflective three-mirror telescope of aperture 0.5×0.5 m^2. The field of view is separated into a dedicated sky mapper, the radial velocity spectrometer, and a medium-band photometer. Both instrument focal planes are also based on CCD technology operating in TDI mode;

(c) the opto-mechanical-thermal assembly comprising: (i) a single structural torus supporting all mirrors and focal planes, employing SiC for both mirrors and structure. There is a symmetrical configuration for the two astrometric viewing directions, with the spectrometric telescope accommodated within the same structure, between the two astrometric viewing directions; (ii) a deployable sun shield to avoid direct sun illumination and rotating shadows on the payload module, combined with the solar array assembly; (iii) control of the heat injection from the service module into the payload module, and control of the focal plane assembly power dissipation in order to provide an ultra-stable internal thermal environment; (iv) an alignment mechanism on the secondary mirror for each astrometric instrument, with micron-level positional accuracy and 200 μm range, to correct for telescope aberration and mirror misalignment at the beginning of life; (v) a permanent monitoring of the basic angle, but without active control on board.

Gaia will operate through continuous sky scanning, this mode being optimally suited for a global, survey-type mission with very many targets, and being of proven validity from Hipparcos. The satellite scans the sky according to a pre-defined pattern in which the axis of rotation (perpendicular to the three viewing directions) is kept at a nominally fixed angle ξ from the Sun, describing a precessional motion about the solar direction at constant speed with respect to the stars. This angle is optimised against satellite sun shield demands, parallax accuracy, and scanning law. Resulting satellite pointing performances are determined from operational and scientific processing requirements on ground.

A mission length of 5 years is adopted for the satellite design lifetime, which starts at launcher separation and includes the transfer phase and all provisions related to system, satellite or ground segment dead time or outage. A lifetime of 6 years has been used for the sizing of all consumables.

3. SPACECRAFT SYSTEM

The spacecraft and orbit are characterised as follows:

- orbit: Lissajous-type, eclipse-free, around L2 point of Sun-Earth system; 220–240 day transfer orbit
- sky scanning: revolving scanning with scan rate = 60 arcsec s^{-1}, precession period = 70 days
- spacecraft: 3-axis stabilized; autonomous propulsion system for transfer orbit; electrical (FEEP) or cold-gas thrusters for operational attitude control; 6 deployable solar panels, integrated with multi-layer insulation to form the sun shield
- science data rate: 1 Mbps sustained, 3 Mbps on down-link, using electronically steerable high-gain phased array antenna
- launch mass: 2030 kg (payload = 900 kg)
- launcher: Soyuz-Fregat, launched from Kourou
- lifetime: 5 years design lifetime, 6 years extended lifetime

4. SCIENTIFIC ORGANISATION

There are three key partners in the Gaia mission: (a) the ESA scientific community, which provides the scientific momentum for the mission, formulates the scientific objectives, provides inputs to technical solutions, monitors the accuracy, and undertakes the development of the data analysis system; (b) ESA, which formulates the system requirements, provides the project management and industrial technical coordination, and provides funding for the satellite, payload, launch and operations; (c) the European industrial consortia, which provide the technical studies and solutions, and the detailed design, construction, integration and tests.

The Gaia Science Team is chaired by the ESA project scientist, and takes responsibility for advising ESA on all aspects related to the scientific performance and conduct of the Gaia mission. For example, the science team supervises and takes responsibility for the studies that need to be undertaken in a timely manner to ensure proper preparation of the satellite and ground segment (data analysis) efforts.

So far, some 250 European scientists have indicated and demonstrated their interest in the prepatory aspects of Gaia. To facilitate this work, the effort is divided into 14 'working groups', organised around a task leader and co-leader. Typically, task leaders of the major tasks with impacts on the satellite design are also members of the Science Team. The present structure of these working groups includes 'core members' (those who expect to devote significant effort to the proposed tasks) and a looser network of 'associate members' (those who will want to make occasional contributions, or who want to be informed from time to time in view of impacts on other tasks). The structure is intended to provide an environment in which specific activities are completed in a timely manner, essential for the project's success, but at the same time where more informal exchanges are encouraged.

The Gaia scientific working groups are loosely organised into three main categories: (a) those related to the development of the satellite or payload: accuracy/error budget, on-board detection, photometry, radial velocity, and calibration; (b) those related to specific objects which necessitate specific attention in the mission preparations and/or data analysis: multiple stars, planetary systems, variable stars, and Solar System objects; and (c) those related to the data processing: processing prototype development, simulations, classification, relativity and reference frame, and science alerts. Members of the Gaia Science Team, and the leaders of the various scientific working groups, can be found via the Gaia www page.

5. DATA ANALYSIS

The total amount of (compressed) science data generated in the course of the five-year mission is about 2×10^{13} bytes (20 TB). Most of this consists of CCD raw or binned pixel values with associated identification tags. The data analysis aims to 'explain' these values in terms of astronomical objects and their characteristics. In principle the astrometric analysis is done by adjusting the object, attitude and instrument models until a satisfactory agreement is found between predicted and observed data. Successful implementation of the data analysis task will require expert knowledge from several different fields of astronomy, mathematics and computer science to be merged in a single, highly efficient system.

The computational complexity of the data analysis arises not just from the amount of data to be processed, but even more from the intricate relationships between the different pieces of information gathered by the various instruments throughout the mission. It is difficult to assess the magnitude of the data analysis problem in terms of processing requirements. Certain basic algorithms that have to be applied to large data sets can be translated into a minimum required number of floating-point operations. Various estimates suggest of order 10^{21} floating-point operations, indicating that very serious attention must be given to the implementation of the data analysis (an effort which is now under way). Observations of each object are distributed throughout the mission, so that calibrations and analysis must be feasible both in the time domain and in the object domain. Flexibility and interaction is needed to cope with special objects, while calibrations must be protected from unintentional modification. Object Oriented (OO) methodologies for data modelling, storage and processing are ideal for meeting the challenges faced by Gaia.

The global astrometric reductions must be formulated in a fully general relativistic framework, including post-post-Newtonian effects of the spherical Sun at the 1 μas level, as well as including corrections due to oblateness and angular momentum of Solar System bodies.

Processing these vast amounts of data will require highly automated and efficient numerical methods. This is particularly critical for the image centroiding of the elementary astrometric and photometric observations, and the corresponding analysis of spectral data in the spectrometric instrument.

Accurate and efficient estimation of the centroid coordinate based on the noisy CCD samples is central for the astrometric performance. Simulations indicate that 12 samples approximately centred on the peak can be read out from the CCD. The centroiding, as well as the magnitude estimation, must be based on these transmitted values. Results of a large number of Monte Carlo experiments, using a maximum-likelihood estimator as the centroiding algorithm, indicate that a rather simple maximum-likelihood algorithm performs extremely well under these idealized conditions.

A preliminary photometric analysis, for discovery of variables, supernovae, etc, can be carried out using standard photometric techniques immediately after data delivery to the ground. In addition, more detailed modelling of the local background and structure in the vicinity of each target using all the mission data in all the passbands will be required. A final end-of-mission re-analysis may benefit from the astrometric determination of the image centroids, locating a well-calibrated point spread function for photometric analysis. Studies of these photometric reductions have begun.

The high-resolution (radial velocity) spectrometer will produce spectra for about a hundred million stars, and multi-epoch, multi-band photometry will be obtained for about one billion stars. The analysis of such large numbers of spectra and photometric measurements needs to be performed in a fully automated fashion, with no manual intervention. Automatic determination of (at least) the surface temperature $T_{\rm eff}$, the metallicity [M/H], and $\log g$ is expected. A fully automated system for the derivation of astrophysical parameters from the large number of spectra and magnitudes collected by Gaia, using all the available information for each star, has been studied, showing the feasibility of an approach based on the use of neural networks. In the classification system foreseen, spectra and photometric measurements will be sent to an 'initial classifier', to sort objects into stellar and non-stellar. Specialist networks then treat each class. For example, stellar data sets are passed to an 'automated stellar parameterization' sub-package.

It is the physical parameters of stars which are really of interest; therefore the proposed system aims to derive physical parameters directly from a stellar spectrum and photometry. Detailed simulations of the automated stellar parameterization system have been completed using a feed-forward neural network operating on the entire set of spectral and photometric measurements. In such a system, the derived values for the stellar parameters are naturally linked to the models used to train the network. Given the extreme rapidity of neural networks, when stellar atmosphere models are improved, reclassification of the entire data set can be done extremely quickly: an archive of 10^8 spectra or photometric measurements could be reclassified in about a day with the present-day computing power of a scientific workstation.

Figure 2 shows the overall data flow foreseen for Gaia. The steps labeled 'pre-processing' ingest the satellite data stream, and apply certain basic operations to the raw CCD data (flat-fielding, bias correction, CR rejection, CTE calibration, etc). The focal plane data streams (ASM, AF1–11, BBP) yield the first approximation to the satellite attitude, as well as the image centroids along-scan. Satellite and Solar System ephemerides are used for the aberration and light-bending positional corrections due to all Solar System objects. An initial source catalogue can be input to assist convergence of the first phase of the object matching. The 'core processing' tasks access the relevant data in the data base, and compute an iterative adjustment to the source positions (along with updated satellite attitude, geometric calibration terms, and global calibration terms). These are the central steps of the global iterative solution, which will be run for some 100 million (bright, well-behaved) sources. Fainter objects or other sources not selected for the adjustment are interpolated into the resulting solution. First-look analysis, running on some 24 hours of satellite data, are considered part of the core processing. Iterated results are passed back immediately to the central Gaia data base.

The 'grid processing' (or shell processing) tasks are steps in the data processing which extract specific data sets from the data base (for example, all photometric observations for a specific source for the light curve analysis, or all astrometric residuals for binary star orbital analysis) subject these data to a specific algorithm or set of algorithms, and return the results to the data base. Updated values may be used for subsequent iterations of the global iterative adjustment. The complex interdependency of the processes is shown only at a very schematic level. To take a specific example, radial velocity determination will use spectral masks based on the stellar physical parameters estimated from the photometric and astrometric analyses. Results of the radial velocity determination will affect the binary star data treatment, and also the global iterative adjustment for nearby, high proper motion stars (perspective acceleration). The astrometric positions will be used as inputs for the photometric data analysis, yielding light curves themselves used for variability analysis, determination of planetary transits, etc. All algorithms must therefore interact in a controlled but highly efficient manner with the centralised data base.

The core processing tasks are considered to run on a dedicated centralised machine, and must yield results in close to real time. The grid processing tasks will be scheduled to run on a wide cluster of grid-type nodes, distributing the computationally intensive tasks for (possibly) remote execution, whilst returning the results to the data base for access and use by other tasks. Algorithms in light font (see Figure 2) have been delivered and are operating in a simplified form in the context of the processing prototype. All other algorithms remain to be written, tested, and included within the overall data model.

In the current baseline processing approach, all pre-processing and core processing tasks will be executed on dedicated hardware at a central location. Prototype algorithms are being procured from the Gaia scientific community and integrated into the common processing environment in Barcelona. The Grid processing tasks (also referred to as shell tasks) will access the common Gaia data base, and subject subsets of the data to numerical analysis using Grid resources. These algorithms will again be procured from the Gaia community, and validated by a single group, before being implemented on the operational machine which will control their execution.

6. FINAL DATA PRODUCTS

It is too early to attempt to consider the physical or logical format in which the final mission data products will be available (in the year 2018 or so). The www, CDs and DVDs, are recent products which may exist in some form in 15 years or may have been superseded by more advanced technology, and interrogation tools may have been revolutionised. Nevertheless, one can anticipate 'final' data products being available in some form around 2018, with inter-related subsets of astrometry (including radial velocity data), photometry (including variability), double and multiple stars and planets, with information on physical classification and characterisation.

But it is equally clear that the scientific community will not wish to wait for the final data products, and some early release catalogues, perhaps as early as 1–2 years into the mission, will probably be foreseen (photometric catalogues, low accuracy astrometric catalogues, scientific alerts, etc). The Gaia scientific teams are not foreseeing 'data rights' in the traditional sense, although evidently groups working on the data analysis will be best positioned to exploit the final data once it appears. There will also be many issues of catalogue use which must be addressed in the coming years: the front-end machine providing access, search and interrogation tools for such a large data base, and visualisation techniques which will be mandatory for such an extensive and complex data set.

7. THE GAIA WWW PAGES

ESA provides a centralised information system through its Gaia www pages[1]. Primarily a tool for scientists working on the Gaia project, it also provides outreach and educational material, and information for the wider scientific and general community interested in learning more about Gaia. For the Gaia scientific community, the www pages provide (sometimes under password protection): up-to-date news features tracking the progress of the mission; a 'Picture of the Week' and a feature on one of the Gaia 'People of the Week'; an extensive series of 'Information Sheets' providing details of the various aspects of the mission (including science, instruments, and data analysis); presentation material; details of forthcoming meetings; links to working group www sites; an image and multimedia 'gallery', and items related to public outreach including the 'Little Books' and 'Interactive Books' of Gaia.

More crucial to the working practices of the Gaia scientific community, the www pages provide links to the Gaia

[1] http://www.rssd.esa.int/Gaia

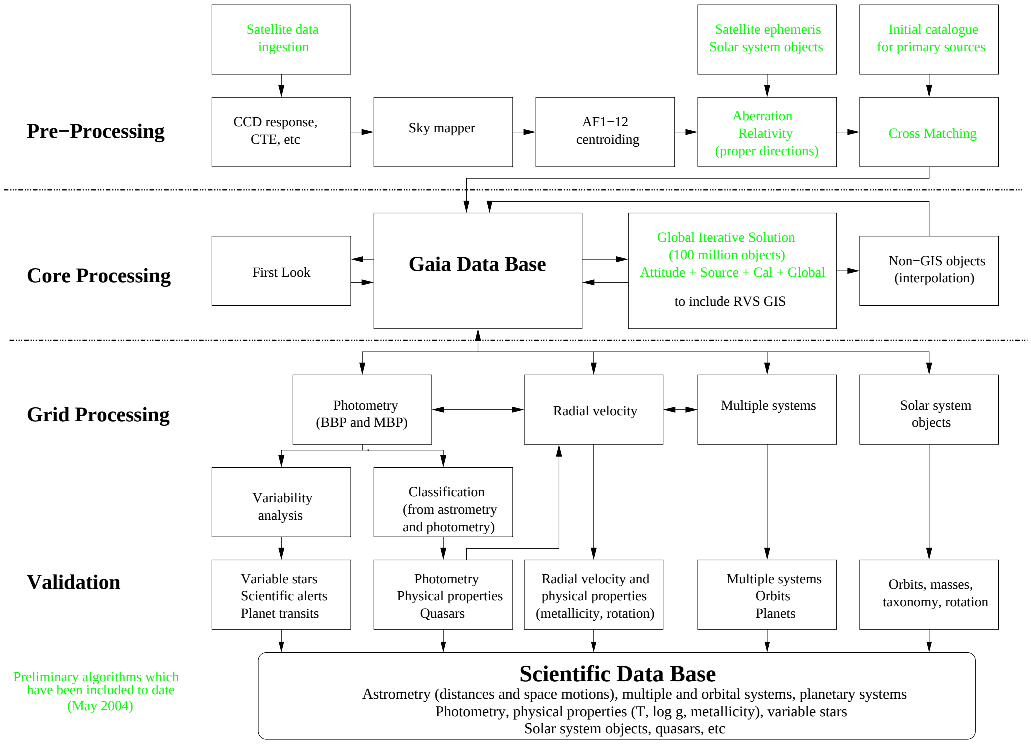

Figure 2. Overview of the data flow foreseen in the Gaia data analysis.

document management system (all scientific documents tracking the development of the data analysis, working groups, etc); to the Gaia parameter data base — an extensive compilation of central numerical parameters of the Gaia mission, in one centralised location, and accessible as html, plain text, or Fortran/C/Java structures, thus ensuring that computer programs related to the simulations, data analysis, etc are all based on the same numerical values, a crucial consideration for a mission whose development is geographically widespread, and so critically dependent on numerical accuracy. Also included are links to research opportunities related to Gaia.

8. EDUCATION AND OUTREACH

Space science missions, and in particular astronomical studies of the visible Universe, have an extraordinary interest for the public at all levels. In addition to the primary ESA goals of basic research and applied technological developments, this means that related educational goals, such as helping to ensure that a continuing supply of scientists, engineers, and technologists will be available to meet the needs of the twenty-first century, can build on Gaia. The images, scientific discoveries and new appreciation of the scale and diversity of nature provided by astronomy captivate people's imaginations, inform teachers, and excite students and the public about science and exploration. To realize and enhance this educational and public outreach capability, the ESA countries are increasingly working to make education at all levels, and the enhanced public understanding of science, integral parts of the space science missions and research programmes.

Gaia is exceptionally well-suited for this educational, awareness and technical training requirement. Gaia will provide opportunities and challenges at all levels, from the evolution of the Galaxy and the search for extra-solar planets, through applied gravitation, to the technical challenges in accessing large data sets. Every one of these is of direct and topical interest, and produces knowledge of very wide and continuing general applicability.

Among many examples of Gaia science which are directly appropriate for general educational opportunities, Gaia will provide the first detailed knowledge of the content and evolution of our own Milky Way, an aspect of astronomy with immediate resonance for all people at all levels. Thus the basic level of interest will be high. Building on this, Gaia will provide detailed knowledge of kinematics, allowing a natural forum for explanation of Newtonian and General Relativity gravitational theory, chaos theory, and orbits. This can be provided naturally at the pictorial level – a movie of the sky – through to the highly technical – metric mapping, gravitational distortions of space-time – appropriate to all ages and interests, and all levels of educational requirements. At a wider level, by providing a precise measure of the distribution of dark matter near the Sun, and throughout the Galaxy, Gaia will set the boundaries of our understanding of the nature of matter, luminous and dark. The direct links with particle physics and fundamental physics are well known, and of wide general appeal.

ESA projects now include a specific budget line to be dedicated to public relations and outreach programmes,

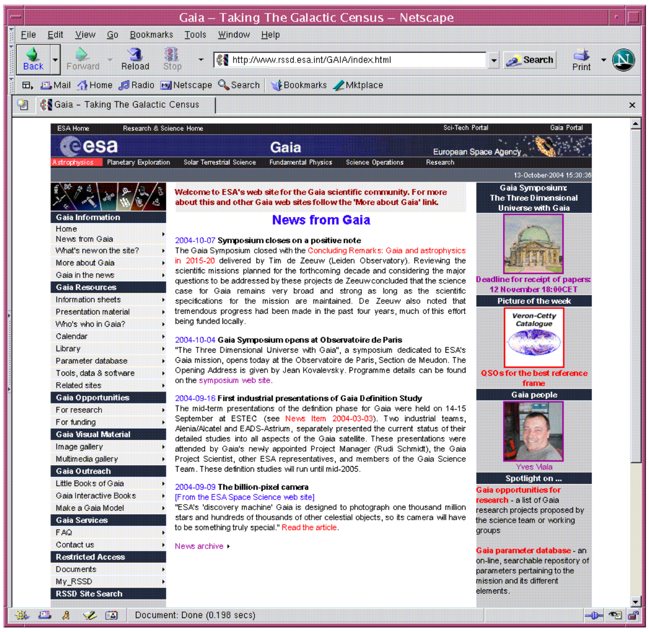

Figure 3. The Gaia www page is an up-to-date centralised information point for the mission: http://www.rssd.esa.int/Gaia.

and appropriate structures must be put in place to ensure an effective use of such resources not available to previous ESA space science missions. Examples could include educational modules (at a variety of levels) related to basic principles of angular measurements, Earth motion, and stellar distances and motions; planetarium programmes focusing on stellar distances and motions; and observational astronomy programmes for amateur and classroom groups related to the monitoring of variable stars. The effectiveness of these programmes has already been demonstrated by the interest of variable star astronomers in the Hipparcos measurements (see, for example, '*Mining Hipparcos's Buried Treasure*' by R.W. Sinnott in the June 1999 issue of Sky & Telescope, and '*The Educational Potential of the Hipparcos Data Base*' by the President of the IAU Commission for the Teaching of Astronomy, J.R. Percy, in ESA SP-402, 739, 1997). And the Hipparcos www site, which includes stereo images, 3-d simulations, access to the Hipparcos and Tycho Catalogues, a series of other animations, as well as links to published scientific papers, has already featured in David Ratledge's book '*Software and Data for Practical Astronomers: the Best of the Internet*'. The Haydn Planetarium in New York, for example, now includes the 'Digital Sky Project', comprising a space travel to Orion at several thousands km s^{-1}, entirely constructed from the Hipparcos Catalogue.

Complementary to these formal educational capabilities, Gaia addresses science of vast general appeal. The general public is genuinely fascinated by astronomical discoveries, and their important general implications for people's understanding of their place in the Universe. Thus activities ranging from the motivation of the creative arts, through galleries and the public media, to informed political debate, will naturally follow from public understanding of the Gaia mission goals, and the Gaia scientific return.

To take one specific example, the discovery of Near Earth Asteroids has enormous potential in terms of public outreach and communication. Gaia's contribution would represent an important opportunity for educational and outreach purposes, and would respond to the repeated invitations of the United Nations and the Council of Europe for a better assessment of the impact risk.

ACKNOWLEDGMENTS

This overview of the Gaia project borrows freely from the content of the Concept and Technology Report on Gaia published in 2000, and modified following the subsequent technology assessment studies. The efforts of the many people involved in the Gaia project is implicit in this synthesis.