Gaia in 2004

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Abstract. This note summarises the status of the Gaia project at the end of 2004, describing the progress achieved in 2004, and summarising the major ongoing and planned activities. An important development was the appointment of the Gaia Project Team within the Projects Department of the ESA Directorate of Science, signifying the transition from study to project phase.The target launch date is 1 December 2011. Compared to the target 1 year ago, this represents a delay of more than 1 year. On the positive side, this corresponds to a technical feasibility assessment of the new Project Team, and may still be compared with the 'not later than 2012' launch target mandated by the Science Programme Committee when the project was accepted by ESA in 2000.

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1 Technical and Programmatic Status

1.1 Background

Approval of a 'Concept and Technology Study' for Gaia was given in 1996. A one-year industrial and scientific study between mid-1997 and mid-1998 (by Matra Marconi Space, subsequently Astrium-SAS, now EADS-Astrium Toulouse) led to the selection of Gaia by the ESA Science Programme Committee in September 2000. The design included two separate astrometric telescopes (viewing directions) each with their own focal plane, and a dedicated telescope for radial velocity and medium-band photometry. Launch was foreseen by Ariane 5, with operation at the L2 Lagrange point, and an estimated industrial cost-at-completion of around 550 MEuro. Technical considerations suggested that a launch in 2010 should be feasible.

At the end of 2001, the revised ESA science programme funding suggested that the high costs of cornerstone missions could not be supported, and a major review of the overall ESA science programme was undertaken by the agency's advisory bodies. The Gaia project initiated a rapid technical re-assessment study, starting in December 2001 and with a duration of 6 months. The constraints on the launch vehicle were relaxed, and the detailed industrial re-assessment study identified a payload design compatible with the (smaller and cheaper) Soyuz launch vehicle, but otherwise maintaining all of the primary scientific goals. The accuracy goal of 10 μarcsec at 15 mag, was relaxed to between 15–20 μarcsec at 15 mag, primarily driven by the necessary reduction in the primary mirror collection area caused by the move from the Ariane 5 to the Soyuz launcher. Gaia was subsequently confirmed within the ESA programme by the SPC in June 2002, with a revised cost-at-completion of about 460 MEuro, and with a 'technical' target launch date in mid-2010, and a statement from the SPC calling for a launch 'not later than 2012'.

During 2003 further financial difficulties within the ESA scientific programme required a re-assessment at the ESA advisory committee level of all science mission not yet in Phase B. After presentations of Gaia to a plenary session of all advisory committees (AWG, SSWG, FPAG, SSAC, and SPC in ESTEC on 7–8 October 2003) and a further presentation to the Astronomy Working Group on 8 October, all relevant missions were subsequently discussed by the SSAC, leading again to the re-confirmation of Gaia, without further modification, by the SPC on 5–6 November 2003.

1.2 Developments in 2004

During 2004, and with the appointment of an ESA Project Team within the Projects Department of the Science Directorate (under Project Manager Rudi Schmidt), the tightening financial situation of the science programme led to renewed efforts to maintain the costs of of the future major missions Gaia and BepiColombo to the 2002 targets of around 460 MEuro. This has led the new project team to a detailed assessment of ESA and industrial costs, mass, power, and schedule margins, and a corresponding effort by industry to identify more cost effective implementations of the Gaia requirements. The outcome of all of these extensive efforts will be known after ESA issues the Invitation to Tender in mid-2005, and when the industrial teams respond with their detailed technical, cost and management proposals in late 2005. At that point, the single prime contractor for the development and launch of the satellite will be selected by ESA. Phase B2 is then due to start in early 2006, with a target satellite launch of 1 December 2011.

Gaia is based on two distinct viewing directions (Astro-1 and Astro-2), brought together in a single focal plane, and complemented by a spectrometer instrument (Spectro). The single Astro focal plane is split into three parts dedicated to the sky mapper, a large astrometric field, and a broad-band photometric field. The focal plane of Spectro is split into two fields: a medium-band photometer, and a radial velocity spectrometer. The main parameters of this system remain unchanged with respect to that presented previously, thus: two viewing directions, separated by a basic angle of 99.4°, superimposed in a single focal plane, and separate spectroscopic telescope including the medium-band photometer and the radial velocity spectrometer. Also unchanged are the principles of operation and observation, the scanning law (including the 50° sun aspect angle and the spin rate of 60 arcsec/s), the on-board detection, and the limiting magnitude. The baseline is still to operate the satellite at the L2 position, from a single ground station, with coverage roughly 8 hours out of every 24, and with data being stored on board and telemetered during the visibility periods. No significant changes in concept were made during 2004, but detailed industrial studies have led to consolidated designs, for example, the AOCS, solar array, power subsystem, etc.

Gaia retains its properties as an ESA-only mission, with a launch date now targetted for December 2011, and an observation period of 5 years. All scientific aspects of the mission are under the responsibility of ESA member state scientists, funded nationally, and interfacing to ESA through the project scientist. Final mission results might be expected some 2–3 years after the end of operations, i.e. around 2018 at the earliest, but with a prolific quantity of intermediate results available throughout the mission. No specific data rights, or scientific proposal submissions, are foreseen for the Gaia mission.

1.3 Technical Highlights of 2004

Technical highlights of 2004, reported on the Gaia www pages throughout the year, included:

2004-02-04 Ground Verification study completed: The final presentation of the Gaia technology Ground Verification contract took place in ESTEC on 3 February. Along with the final report, this successfully and satisfactorily brought to an end a one-year industrial study by EADS-Astrium. It studied the objectives and requirements of the ground verification activities which need to be undertaken before launch, including measurement of the optical behaviour at the operational temperature. This is an essential exercise in concluding whether the stringent payload goals can be guaranteed in orbit, and identifying the associated costs and facilities needed. Central to the plans are the projected use of the Focal thermal vacuum facility in Liege, Belgium.

2004-02-04 High Stability Optical Bench study completed: The final presentation of the Gaia technology High Stability Optical Bench contract took place in ESTEC on 3 February. This successfully concluded a two-year study of the basic angle monitoring device (see Picture of the Week, 2003-11-10). The contract proved the principles and processes using a laboratory prototype of a device which should ultimately have a 1 microarcsec monitoring capability in orbit. The prototype demonstrated the mounting, alignment, and thermal/vibrational stability of the prototype system manufactured from silicon carbide. The contract was undertaken by EADS-Astrium Toulouse, supported by TNO-TPD Delft for the laboratory set-up, and Boostec for the silicon carbide structure and mirrors (see Picture of the Week, 2003-07-07).

2004-03-03 Gaia proceeds to Phase B1: On 2–3 March, separate presentations were made by Alcatel/Alenia and EADS-Astrium to ESA representatives (from the Gaia project and outside) and the Gaia Science Team. Extensive presentations summarised the activities which have been carried out under the parallel System Level Technical Assistance Contracts which have been running with these industrial teams for the past two years. As a result, authorisation was given for Gaia to enter Phase B1, the detailed definition phase, which started in April 2004, and which will extend for 1 year.

2004-03-31 Final presentation of the RVS instrument study: The first phase of the RVS instrument design came to an end with the final presentation of the work performed to date by the RVS Consortium. This scientific consortium comprising Mullard Space Science Laboratory, Observatoire de Paris-Meudon, Brunel University, University of Leicester, Osservatorio di Asiago, and University of Ljubljana, and led by Professor Mark Cropper (MSSL), worked with ESA and the industrial System Level Technical Assistance contractors under the direction of ESA Study Manager Oscar Pace. The consortium has refined all aspects of the instrument design (optics, detector, mechanical, thermal, and on-board processing) providing a baseline design for Gaia's radial velocity spectrograph. This will be refined further during the Definition Study phase, extending to mid-2005.

2004-05-17 Gaia M1 demonstrator successfully sintered: The demonstrator model for the Gaia primary mirror (M1) was successfully sintered at Boostec facilities, France. The Gaia Large Size SiC Mirror study, led by EADS-Astrium, aims to demonstrate the feasibility of the current M1 design by building and testing a replica of the mirror. The study is expected to be completed by mid-2005 (see Picture of the Week, 2004-05-17).

2004-06-17 FPA and CCD demonstrators - critical design review successful: Under contract to ESA, EADS-Astrium (Toulouse) are designing, building and testing two engineering models of the Gaia Astrometric focal plane. The Thermal Mechanical Demonstrator Model (TMDM) is a mock-up of the focal plane structure which will be used for integration and alignment verification, and thermal vacuum testing. The Electro-Optical Demonstrator Model (EODM) is designed to be electronically representative of the flight focal plane. It contains 4 fully-functional CCDs and will be used to assess their performance under nominal operating conditions in the various Gaia TDI modes and for a variety of simulated star magnitudes. The Critical Design Review (CDR) marks the end of the design phase for both of these demonstrator units. EADS-Astrium now have formal approval of their designs from ESA and will proceed to integrate the focal plane demonstrators.

2004-09-16 First industrial presentations of Gaia Definition Study: The mid-term presentations of the definition phase for Gaia were held on 14–15 September at ESTEC (see News Item 2004-03-03). Two industrial teams, Alenia/Alcatel and EADS-Astrium, separately presented the current status of their detailed studies into all aspects of the Gaia satellite. These presentations were attended by Gaia's newly appointed Project Manager (Rudi Schmidt), the Gaia Project Scientist, other ESA representatives, and members of the Gaia Science Team.

2004-12-14 Focal Plane EODM review successful: A successful Test Readiness Review for the Electro-Optical Demonstrator Model (EODM) was held at EADS-Astrium (Toulouse) in early December, paving the way for a series of tests to be carried out over the next few months. The EODM, containing 4 back-illuminated prototype CCDs, is designed to be electronically representative of a portion of the astrometric focal plane. The planned testing will demonstrate the feasibility of driving a number of CCDs synchronously in the various Gaia astrometric TDI modes (ASM, AF normal, AF bright star). A custom test facility has been developed by EADS-Astrium in order to operate the EODM at 165 K in a vacuum chamber whilst providing a moving optical source. The optics are configured to provide a pattern of 'stars', each having a Point Spread Function similar to that of the Gaia astrometric telescope. In addition to characterizing key parameters such as electronic noise and centroiding accuracy, CCD features such as TDI length selection and anti-blooming will be evaluated in the most flight representative configuration to-date.

1.4 Scientific Highlights of 2004

On the scientific side, working groups devoted to the satellite design (accuracy, on-board detection, calibration, etc), to the treatment of specific objects (double stars, variable stars, solar system objects, etc), and to the data analysis activities have continued to make considerable progress, as reported here. Scientific highlights of 2004 included the following milestones reported on the Gaia www pages:

2004-01-26 Science First Look study starts at Heidelberg: A small team at Astronomische Rechen-Institut (ARI), Heidelberg, started work on a 12-month study investigating the feasibility of using basic science data obtained by the instruments on Gaia as a high-precision indicator of the health of the satellite. This Science First Look could provide the possibility of quickly identifying sub-optimal performance in the satellite and of the early correction of mission- critical problems.

2004-05-24 Gaia photometric filters enter final design phase: The Photometry Working Group circulated three documents of relevance to the choice of the photometric system design for Gaia, which will be finalised over the next few months: (a) procedures for the photometric system recommendation (Anthony Brown et al, 11 May, PWG-AB-003); (b) scientific targets for the photometric system design (Carme Jordi et al, 14 May, UB-PWG-009); (c) quantification of the target priorities (Carme Jordi et al, 14 May, UB-PWG-015).

2004-10-07 Gaia Symposium in Paris: A major symposium devoted to Gaia took place between 4–7 October in Paris, and is reported in Section 7.

2004-11-17 GaiaGrid coordinates binary star simulations: A GASS simulation of Gaia telemetry, corresponding to five years of observations of 1000 astrometric binary stars, was successfully completed using the newly-established GaiaGrid environment. 183 independent jobs were distributed through 23 computing nodes distributed in 8 institutes located in 5 countries. A total of 3.8 million CPU seconds were used for the tasks. 16.5 Gb of data were produced and have been used to populate the GDAAS database in order to test the Astrometric Binary Star Analysis shell algorithm.

2004-12-15 Data Processing tests 1-3 completed: The first meeting of the recently-formed Steering Committee of the ongoing Gaia Data Access and Analysis Study (GDAAS) concluded that the first major phase of testing has been completed successfully. Large-scale mission simulations and data analysis runs have been executed over the last three years, under the responsibility of software engineers at GMV Madrid led by Pedro Perez, astronomers at the University of Barcelona led by Jordi Torra, and using the CESCA (Supercomputing Centre of Catalonia) facilities. A mission duration of 18 months, and simulated data for 200 000 stars distributed over the sky, has been used. Results demonstrate that the 'global iterative solution', at the heart of the Gaia data processing challenge, can be implemented as anticipated. The various steps of object matching; source, attitude and calibration updating; and relativistic geometry solution are all included. The system is now being upgraded to a larger-scale run using a more detailed instrument model, and more realistic numerical algorithms. Results for this next phase, GDAAS-2, are expected by June 2005. Naturally, many complications and challenges still lie ahead.

2005-01-10 PWG recommendations for Gaia filter systems: Following extensive studies the Photometry Working Group recommended baseline filter systems for Gaia's Broad-Band and Medium-Band Photometry systems. The C1B system (5 filters, two of which share a CCD strip) has been adopted for BBP; the C1M system (8 blue bands, 6 red bands) has been adopted for MBP. Further details are available from the Photometry Working Group web site under PS optimization.

2 Technical Activities

2.1 Overall Progress — Giovanni Colangelo

Following the strategy approved by IPC (Industrial Policy Committee) in 2002 (ESA/IPC(2002)1, add. 19) and taking into account the specifics of the Science Programme, a definition phase for the Gaia mission started in the first quarter of 2004, in competition with two previously-selected potential prime contractors: Alenia, Italy (with Alcatel, France) and EADS-Astrium, France.

The main objective of the definition phase is the establishment of the technical baseline and its associated cost and the implementation schedule. The mission definition has taken into account the technology development activities underway, in particular the Gaia specific activities in the Science Core Technology Programme (CTP) and the Technology Research Programme (TRP).

Throughout 2004, activities have been mainly focussed on spacecraft design consolidation through dedicated analyses. Gaia will be a three-axes stabilised spacecraft but will exhibit a very slow spin (one revolution per six hours) for accurately measuring one-dimensional coordinates along great circles in two simultaneous fields of view, separated by a well-known angle. The payload utilizes a large CCD focal plane assembly, passive thermal control, natural short-term instrument thermal stability due to the sunshield and the selected orbit, and a robust payload design. The telescopes are of moderate size, and the system fits within a Soyuz-Fregat launch configuration, without deployment of any payload elements. The spacecraft will transmit a steady data stream of 5 Mbit per second during the daily ground contact period of 8 hours to a single ground station during the nominal 5-year mission.

The spacecraft will be placed around the second Lagragian point L2, the selected launcher is the Soyuz-Fregat (version 2-1b) and the launch site is Kourou. There is no launch window constraint applicable to the Gaia launch, with the exception of a few days each month to avoid close approaches to the Moon.

During the execution of the definition phase (second half of 2004), the identification of mass and cost increases led to a further need to initiate spacecraft redesign efforts. The main spacecraft areas impacted by this activity are the payload (particularly the size of the FPAs) and the service module (propulsion and structure). As well as potential mass-saving exercise, alternatives injection strategies into L2 (e.g. lunar fly-by, injection in high eccentric orbit) with respect to the baseline (direct injection in L2 using Fregat) have been studied. The process will continue throughout 2005 (until the conclusion of the ITT process), although positive results have already been achieved without any significant change on the mission concept.

The mission requires several key technologies to be available. There are currently about 20 Gaia-specific technology activities either ongoing or already successfully completed. For some specific areas a brief overview is here reported, with more details on the CCD and FPA in the following section.

CCD/PEM: The most critical activities for the payload concern the focal plane assembly. In particular, the Gaia-specific large-size CCDs and the Proximity Electronic Modules (PEM) connected to each of the CCDs. In view of the large number of CCDs, during the second half of 2004 an early procurement process, important to ensure a timely production of the flight models, was successfully initiated. Furthermore, in order to consolidate the PEM industrialisation process, an additional technology activity started at the end of 2004.

PDHE: The large amount of data gathered from the focal plane requires a massive pre-processing onboard. The second phase of the PDHE contract was started in July 2004. A breadboad of the processing unit based on a Maxwell PPC (Power PC) board is being evaluated and manufactured. However, due to ITAR restrictions associated with such a board, during 2004 a survey for potential processors (belonging to the Power PC family) for Gaia was carried out by both potential prime contractors (Alenia/Alcatel and EADS-Astrium).

Micro-Propulsion: The readiness status of the FEEP technology is still unclear, and a backup solution based on another micro-propulsion system has been investigated. This alternative solution is based on a cold gas system and most of the components are already qualified in the context of other ESA missions. However, toward the end of 2004, in order to demonstrate the concept validity, a technology activity aimed at characterizing the cold gas behaviour through dedicated test campaigns has been initiated.

The complete list of Gaia technology developments, either managed as part of the Core Technology Programme (CTP) or Technology Research Programme (TRP), activities is summarised in Table 1.

Table 1: The ongoing Gaia technology development contracts.

Task	Industrial lead	ESA technical officer	Status
Technical assistance & definition 1	EADS-Astrium (F)	Rudi Scmidt	ongoing
Technical assistance & definition 2	Alenia/Alcatel	Rudi Schmidt	ongoing
Payload data handling electronics	EADS-Astrium (D)	Raffaele Vitulli	ongoing
CCD/FPA development	EADS-Astrium (F)	Igor Zayer	ongoing
Large SiC mirrors	EADS-Astrium/Boostec	Bernd Harnisch	ongoing
Laser metrology/active optics	Alenia	Bernhard Furch	ongoing
PEM industrialisation	–	Torgeir Paulsen	ITT released
RVS optimisation	MSSL	Torgeir Paulsen	ongoing
High-stability optical bench (BAM)	EADS-Astrium/TNO–TPD	Bernd Harnisch	completed 2004
High-stability optical bench	Alcatel	Giuseppe Sarri	ongoing
Payload data handling support	Obs. de Meudon	Torgeir Paulsen	ongoing
AF CCD FM definition	e2v	Philippe Gare	ongoing
Deployable sunshield	Sener	Gerard Migliorero	ongoing
Secondary mirror mechanism	Sener	Pierre Coste	ongoing
Thruster characterisation: FEEP	Alta	David Nicolini	ongoing
Thruster characterisation: cold gas	–	David Nicolini	open
Thruster characterisation: cold gas	Bradford Engineering	Giovanni Colangelo	ongoing
Ground verification	EADS-Astrium (F)	Giovanni Colangelo	completed 2004
Phased array antenna	Alcatel	Arturo Martin Polegre	completed 2003
Data base (GDAAS Phase 2)	GMV/UB	Salim Ansari	completed 2004

A Project Manager leading the project team and responsible for the implementation of the Gaia mission within the agreed schedule and financial resources during the definition and implementation phase, the launch and early orbit phase and the on-station commissioning activities, has been officially nominated in July 2004 (R. Schmidt). After his nomination, the Project Manager started setting up the Gaia project team for the definition and implementation phase (the full deployment of the team will occur before the start of the implementation phase). The Project Manager is at present supported by G. Colangelo, P. Gare, G. Kreiner, O. Pace, T. Paulsen, G. Sarri, R. Tosellini, and M. Witting.

2.2 CCD and Focal Plane Assembly — Alex Short

2.2.1 Industrial Activities

The CCD/FPA demonstrator contract is one of the largest and most critical of the payload technology development activities. The main study contract is with EADS-Astrium (Toulouse). Key sub-contracts are with e2v technologies (CCDs), DLR (PEMs) and Sira Electro-Optics (radiation testing). The activity comprises three elements:

(1) The CCDs themselves: culminating in the manufacture and characterization of Astrometric Field (AF) CCDs, red-enhanced MBP CCD modules and a small Electro-Optical Demonstrator Model (EODM) focal plane. This activity includes a programme of radiation testing and analysis.

(2) The front-end electronics: leading to the manufacture and characterization of a number of Proximity Electronics Modules (PEMs), as well as to the architectural design of the Astro and Spectro focal planes (including sequencers, interconnection modules and interfaces to the Payload Data Handling Electronics).

(3) The FPA thermo-mechanical design: leading to the manufacture and testing of an 80% scale

Thermo-Mechanical Demonstrator Model (TMDM) of Gaia's Astrometric focal plane, as well as the detailed design and modelling of the proposed flight focal plane.

In each of these areas, the study comprises four phases: (a) specification and architecture consolidation leading to a Specification and Architecture Review (SAR); (b) detailed design phase leading to a Preliminary Design Review (PDR), in practice having the significance of a Critical Design Review; (c) bread-boarding phase (demonstrator manufacture) leading to a Test Readiness Review (TRR); (d) characterization phase, leading to a Final Review.

By the end of 2004, demonstrator manufacture was well advanced and Test Readiness Reviews had been held in most areas as follows.

CCDs Two CCD types are being manufactured during the technology demonstration phase.

The Astrometric Field CCD: a large-area, back-illuminated 4-phase CCD with 4500 lines and 1966 columns of 10μm $\times$ 30μm pixels. The 4-phase design allows charge to be confined under at least half of the pixel area, yielding higher pixel full well capacity than a 3-phase device. The device also includes anti-blooming drains, a charge-injection structure, a parallel summing register and a transfer gate. The amplifier is an e2v high-performance two-stage design for scientific applications optimizing read noise and sensitivity. 12 TDI gates are incorporated, allowing charge to be integrated over a selectable number of lines to avoid saturation of bright stars. A broad-band anti-reflection coating is implemented.

The red-enhanced MBP CCD module: comprising 8 CCDs on the same monolithic thinned die. Each CCD within the module has 400 lines and 3930 columns of 15μm $\times$ 10μm pixels. The design has evolved to include both parallel and serial charge injection structures. The blue-enhanced MBP CCD architecture is almost identical. However, the red-enhanced devices are thicker and are fabricated on high-resistivity silicon. The red-enhanced CCDs are therefore considered to be a higher risk which is why red-enhanced CCDs are being produced in the demonstration phase. A red-enhanced anti-reflection coating is implemented.

Test Readiness Reviews for the Development Model AF and MBP CCDs were held on 16–17 August 2004 when fabrication of the first devices was nearing completion. Production, packaging and testing at e2v has continued since then. By the 15 February 2005, 15 AF devices had been accepted by ESA/EADS-Astrium for Electro-Optical and radiation testing.

The first Electro-Optical testing of a single CCD in TDI mode demonstrated performance very much in-line with predictions. In particular, centroiding performance was shown to be very close to the theoretical Cramer-Rao limits and Gaia requirements. Similar tests are now being conducted (until May 2005) using the Electro-Optical Demonstrator Model (EODM) to demonstrate the performance achieved when four CCDs are operated in parallel.

The first radiation testing of Gaia CCDs demonstrated that up to 50% of signal electrons may be lost from the PSF after a 10MeV equivalent proton fluence of 2e10 cm^{-2} (even with charge injection). Work is underway to quantify this properly and to evaluate distortion of the PSF in detail. In the meantime, it is clear that this radiation dose would be unacceptable and a new mission requirement of 2e9 protons (10MeV equivalent) has been defined. A radiation testing final review is planned for June 2005.

An additional activity is underway to demonstrate the technical feasibility of a new CCD structure: the orthogonal transfer, 2D or sideways clocking CCD capable of moving charge across columns in either direction (orthogonal to the regular clocking along columns). If successful, this device may be considered for the RVS instrument since it could compensate for across-scan motion allowing a smaller window to be implemented giving better signal to noise. Alternatively, signal to noise may be boosted using L3CCD technology which includes amplification stages in the readout register.

This technology is already in commercial production but has not been qualified for space use. A programme of radiation testing is being conducted by MSSL/Brunel University.

Front-end electronics: Trade-offs to define the overall front-end electronics architecture including the functionality and design of the PEMs had to take into account the noise performance of the signal chain, proper sequencing and synchronization, minimal power dissipation, and proper interfacing to the PDHE whilst complying with the very tight mechanical accommodation constraints given by the mosaic of CCDs. Each PEM is paired with one CCD, all 18 PEMs in one FPA row interface with one interconnection module which, in turn, interfaces to the PDHE. The latter therefore has 10 Space-Wire connections to the 10 interconnection modules. This row-wise parallel architecture, where the interconnection modules also incorporate their own DC/DC converter and an interface ASIC, keeps harness complexity to an acceptable level while minimizing cross-strapping and single-point failures. It also provides a degree of graceful degradation. In the event of any one interface failure, only one of the 10 rows is lost. The PEM incorporates all functions requiring close proximity to the detector for performance reasons. These comprise the signal chain up to and including a 16-bit ADC, and the lower-level sequencing functions (local high-frequency master clock generator, CCD bias and clock drivers, window and TDI gate control).

Demonstrator PEM unit level testing is well advanced and the PEM final review is scheduled for February 2005.

FPA thermo-mechanical design: 2003 saw the completion of a detailed computer model of the flight FPA mechanical and thermal behaviour using parameters derived from past experience. In 2004, activities were geared towards building the Thermo Mechanical Demonstrator unit. This will be used for thermal-vacuum testing to verify and refine parameters in the computer model of the flight FPA.

By the end of 2004, the TMDM hardware was complete and demonstrator CCDs were being integrated (along with demonstrator PEMs). The TMDM Test Readiness Review is scheduled for March 2005.

Selected papers and reports related to the industrial activities:

- Video chain bandwidth sizing for Gaia (23-MAR-04) Gaia-AS-003 Short, A.
- Gaia MBP FPA Design Report 270.RP.09 issue 02 (20/12/2004) Sira
- FPA EO DM Test Readiness Review GaiaFPA.MN.00571.T.ASTR (03/12/2004) EADS-Astrium
- AF CCD BBM BIL Characterization - Tests Review Board (TRB) GaiaFPA.MN.00527.T.ASTR (02/12/2004) EADS-Astrium
- Progress Report #21 GaiaFPA.RP.00572.T.ASTR (02/12/2004) EADS-Astrium
- MBP Focal Plane Design Requirements Specification GaiaFPA.SP.00150 issue 05 revision 00 (30/11/2004) EADS-Astrium
- AF CCD - Front-Illuminated CCD Test Report GaiaFPA.RP.00355.T.ASTR issue 01 revision 00 (11/10/2004) EADS-Astrium
- Preliminary Testing of the ASTRO AF CCD in AF nominal mode Gaia-E2V-TN-037 issue 1 (11/10/2004) e2v technologies
- Preliminary Testing of the Front-Illuminated ASTRO AF CCD Gaia-E2V-TN-035 issue 1 (11/10/2004) e2v technologies
- SPECTRO MBP CCD Test Plan - Gaia-E2V-PL-040 issue 1 (11/10/2004) e2v technologies
- ASTRO AF CCD Test Plan - Gaia-E2V-PL-010 issue 2 (11/10/2004) e2v technologies
- SPECTRO MBP CCD Interface Control Document Gaia-E2V-TN-017 issue 2 (11/10/2004) e2v technologies
- ASTRO AF CCD Interface Control Document - Gaia-E2V-TN-012 issue 4 (11/10/2004) e2v technologies
- MBP CCD Requirements Specification GaiaFPA.SP.00121.T.ASTR issue 02 revision 00 (11/10/2004) EADS-Astrium
- ASTRO Proximity Electronics Module Demonstrator - PEM DM Test Plan Gaia-PEMD-TP-017-DDR issue 02 revision 01 (11/10/2004) DLR
- ASTRO Interconnection Module Demonstrator - IM DM Test Plan Gaia-IMD-TP-018 issue 01 revision 02 (11/10/2004) DLR
- Proximity Electronics Module (PEM) Performance Assessment Report Gaia-PEMD-AN-012-DDR issue 01 revision 03 (11/10/2004) DLR

- Progress Report #18 GaiaFPA.RP.00447.T.ASTR (05/08/2004) EADS-Astrium
- ASTRO/AF & SPECTRO/MBP CCDs Performance Assessment Report Gaia-E2V-RP-006 issue 05 (25/06/2004) e2v technologies
- Progress Report #17 GaiaFPA.RP.00413.T.ASTR (17/06/2004) EADS-Astrium
- ASTRO Interconnection Module Demonstrator (IMDM) Requirements Specification GaiaFPA.SP.00138.T.ASTR issue 03 revision 00 (15/06/2004) EADS-Astrium
- ASTRO Proximity Electronics Module (PEM) Applicability matrix for the PEM PDM GaiaFPA.SP.00142.T.ASTR issue 03 revision 00 (15/06/2004) EADS-Astrium
- MBP Focal Plane Design Requirements Specification GaiaFPA.SP.00150.T.ASTR issue 04 revision 00 (15/06/2004) EADS-Astrium
- ASTRO FPA TMDM EMC Test Plan GaiaFPA.PLT.00384.T.ASTR issue 01 revision 00 (02/06/2004) EADS-Astrium
- ASTRO FPA Mechanical & Thermal & Optical Interface Control Document (MTOICD) GaiaFPA.AD.00125.T.ASTR issue 02 revision 01 (02/06/2004) EADS-Astrium
- ASTRO FPA Electrical Interface Control Document GaiaFPA.ICD.00135.T.ASTR issue 02 revision 01 (28/05/2004) EADS-Astrium
- ASTRO FPA Electrical Architecture GaiaFPA.ADD.00134.T.ASTR issue 02 revision 01 (28/05/2004) EADS-Astrium
- ASTRO FPA TMDM Electrical Interface Control Document (ICD) GaiaFPA.ICD.00278.T.ASTR issue 01 revision 00 (11/05/2004) EADS-Astrium
- ASTRO FPA TMDM Mechanical & Thermal Interface Control Document (ICD) GaiaFPA.ADD.00364.T.ASTR issue 01 revision 00 (11/05/2004) EADS-Astrium
- FPA TMDM Integration & Test Plan GaiaFPA.PLT.00243.T.ASTR issue 02 revision 00 (11/05/2004) EADS-Astrium
- FPA TMDM - Test Thermal Hardware Definition GaiaFPA.NT.00331.T.ASTR issue 01 revision 00 (11/05/2004) EADS-Astrium
- Description of FPA TMDM & Test Facilities - EXTRACT GaiaFPA.NT.00242.T.ASTR issue 02 revision 00 (11/05/2004) EADS-Astrium
- FPA EODM Test Plan GaiaFPA.PLT.00237.T.ASTR issue 02 revision 00 (11/05/2004) EADS-Astrium
- Description of FPA EODM & Test Facilities - EXTRACT GaiaFPA.NT.00236.T.ASTR issue 02 revision 00 (11/05/2004) EADS-Astrium
- Progress Report #16 GaiaFPA.RP.00304.T.ASTR (08/04/2004) EADS-Astrium
- ASTRO FPA Flight Model Thermal Analyses Report GaiaFPA.RP.00207.T.ASTR issue 01 revision 01 (26/03/2004) EADS-Astrium
- Progress Report #15 GaiaFPA.RP.00280.T.ASTR (03/02/2004) EADS-Astrium
- ASTRO FPA Requirements Specification & Compliance Matrix & Verification Matrix GaiaFPA.SP.00147.T.ASTR issue 03 revision 01 (20/01/2004) EADS-Astrium
- ASTRO FPA General Design Description GaiaFPA.NT.00120.T.ASTR issue 03 revision 01 (16/01/2004) EADS-Astrium

2.2.2 Radiation Issues

Relevant activities are as follows:

(a) Modelling the damage inducing particle fluence at L2 during the course of the mission (solar event dominated): Predictions of the radiation environment at L2 during the Gaia mission have been provided by ESA (TEC) using tools such as SPENVIS (JPL models). These predictions were not updated during 2004. Some slight modification of the particle fluence may be required because the launch date has moved by one year, but this is unlikely to be significant.

(b) Modelling the instantaneous background particle flux and energy spectrum at L2 during solar quiet periods (Galactic Cosmic Ray dominated): Predictions obtained using CREME at ESTEC and EADS-Astrium indicate a GCR rate close to 4 $cm^{-2}s^{-1}$. This is also the value obtained by analyzing XMM data from periods when XMM was outside the Earth's radiation belts. An independent study at Leicester University using XMM radiation monitor data indicated that the background GCR rate could be as high as 8 $cm^{-2}s^{-1}$ and that there may be (in addition) a contribution of about 5 solar particles $cm^{-2}s^{-1}$ even during solar quiet periods. The reason for this discrepancy will be investigated but sufficient operational margins should be assumed to accommodate a significantly higher number in any case.

(c) Modelling particle transport through the spacecraft to give the total damage dose at the CCDs and its evolution through the mission: Spacecraft and instrument designs have changed considerably during 2004. In addition, a new requirement on the maximum mission 10MeV equivalent proton fluence has been defined (2e9 cm^{-2}). Previous sectoral analysis of particle transport through the spacecraft to the CCDs is therefore no longer applicable and the prime contractors are required to present updated modelling at the final presentations in April 2005.

(d) Evaluating the effects of ionizing and non-ionizing damage on Gaia CCDs through irradiation and testing: This activity is currently covered by an EADS-Astrium sub-contract with Sira to perform radiation testing of demonstrator CCDs. In 2004, the first results demonstrated that up to 50% of signal electrons may be lost from the PSF after a 10MeV equivalent proton fluence of 2e10 cm^{-2} (even with charge injection). Work is underway to quantify this properly and to evaluate distortion of the PSF in detail. A second round of proton irradiation and testing is now underway. These tests will capitalize upon numerous lessons learned during the first tests to provide a definitive set of radiation test data for Gaia. In addition, an extra CCD will be irradiated and tested at EADS-Astrium to provide a direct comparison with the un-irradiated TDI data obtained in 2004.

(e) Developing Monte-Carlo simulations to model Gaia CCD behaviour including radiation induced charge trapping: This activity is presently covered by members of the Simulation Working Group at Brunel and in ESA (RSSD). Both groups are currently analyzing Sira data in order to characterize radiation damage induced trapping effects. These will then be applied through Monte-Carlo models to quantify the impact of radiation damage on astrometric accuracy. It is hoped that a detailed understanding of trapping effects in Gaia CCD data will lead to an improvement in astrometric accuracy through modification of the calibrating LSF fitting function.

(f) Developing Monte-Carlo simulations to model background particle event energy and morphology in Gaia CCDs: Particle events in Gaia CCDs (in particular GCRs) are simulated using the Monte-Carlo CCD model developed at ESTEC. In 2004, the first catalogues of simulated AF and MBP particle event morphology and energy were supplied for inclusion in the GIBIS modelling tool. This is now being used to assess the effects of particles on centroiding and the effectiveness of particle rejection.

(g) Predicting Gaia astrometric performance as a function of radiation damage: The task of predicting astrometric performance is being assessed by the system scientist and members of the GST (through use of the Gaia accuracy tool) and independently to the prime system teams. Until now, these predictions have not included the effects of radiation damage to the CCDs. This is currently being addressed by combining the astrometric accuracy tools with the Monte-Carlo modelling described above.

(h) Optimizing CCD operation (especially charge injection) to minimize the effects of radiation damage: In 2004 a new work package was defined for Sira Electro-Optics (diverting funds from RVS thermo-mechanical design effort which is no longer required). The new work package is an extension of the radiation testing to fully characterize charge injection operation for new and radiation damaged Gaia CCDs. The test programme will include operation of the structure in a high level (saturation) mode and a low level (fat zero) mode, a study of injection uniformity, and recommendations for optimum operating conditions (e.g. voltages, frequency and temperature). Interpretation of test results will be made in terms of final astrometric accuracy after five years. This will require the Sira to work closely with the Project Scientist Team.

Selected papers and reports related to Radiation Issues:

- Charge injection strategies for Gaia (22-NOV-04) Brunel-Gaia-TN-012 Holland, A., Smith, D.
- Gaia radiation effects and CCD modelling (12-OCT-04) Gaia-AS-004 Short, A.
- TDI model - initial predictions for AF CCDs (09-OCT-04) Gaia-BU-TN-013 Holland, A., Hutchinson, I., Smith, D.
- Modelling the effects of radiation damage in Gaia (22-JUN-04) Gaia-BU-TN11 Hutchinson, I., Holland, A.,

Smith, D., Castelli, C.

- Gaia CCD Radiation Testing, Test results for First AF CCDs (28/10/2004) SIRA

2.2.3 Theoretical Modelling of CCDs

In order to better predict Gaia performance, a number of Monte-Carlo simulation tools have been development. In 2003 work began at Brunel University and independently at ESTEC, on simulations of the detailed behaviour of the Gaia CCDs, including a detailed treatment of radiation induced charge trapping. By the end of 2004 both of these models were being used to fit radiation test data from Sira. In addition, the ESTEC model is used to provide simulated cosmic ray events (GCR) in Gaia CCDs for use in GIBIS and for PDHE testing.

One of the most important scientific activities at the beginning of 2005 is to combine the this Monte-Carlo modelling with Gaia astrometric accuracy tools in order to make predictions of Gaia astrometric performance based on the analysis of radiation test data.

The physics contained in the ESTEC and Brunel models is similar. The implementation developed at ESTEC comprises two arrays, 4500 pixels long (AF CCDs) by 1 window wide. The first array represents the immobile CCD, containing traps and trapped electrons. The second represents the conveyor-belt of mobile electron packets. Each model cycle corresponds to a CCD line transfer (736 s). During this period, the model carries out three distinct processes:

1. generate mobile electrons due to signal (PSF photons) and noise (background events and stray light). This encompasses not only the interactions of photons and particles within the CCD, but also the spreading of resultant electron clouds (due to diffusion) and mapping to pixels. At this stage, the CCD is modelled as a pixelated slab of silicon with the thickness divided between depletion, field free and substrate (or dead) regions according to the material resistivity and applied electrode bias. Inputs to the model include the star spectrum and PSF, background particle spectra and the reflectivity of the selected anti-reflection coating.
2. transfer electrons between the mobile and trapped arrays according to trap density, occupancy, release time constants etc. This is subdivided into four steps corresponding to the four phases of the CCD. The model currently allows for up to five different trap species, but this is arbitrary and could readily be increased.
3. translate the mobile charge by one pixel along scan and read out one serial register with appropriate binning, noise etc. One of the most major additions to the model in 2004 was the inclusion of charge trapping in the readout register (across scan) as the pixels are read out.

This cycle of steps is repeated for the required number of line transfers (e.g. 2×4500) in order to read an input star image entirely into and out of an AF CCD.

The combined action of steps 2 and 3 (trapping and release combined with charge transfer) leads to charge trailing and charge loss effects (or charge transfer inefficiency). This has a fundamental effect on centroiding performance. By making the model dynamic and as flexible as possible, the effect of many operational factors on the centroiding accuracy may be investigated. The main factors are likely to be temperature, charge injection, stray light, star density and background particles. With so many variables, it is essential that the model be consistently verified against laboratory data prior to extrapolating and making performance predictions for Gaia.

Selected papers and reports related to CCD Modelling:

- Modelling the effects of radiation damage in Gaia (Hutchinson et al., 2004)

- TDI model - initial predictions for AF CCDs (Holland et al., 2004e)
- Gaia radiation effects and CCD modelling (Short, 2004a)
- Charge injection strategies for Gaia (Holland & Smith, 2004)
- Radiation modelling support (Holland et al., 2004d)
- The effect of radiation damage on optical CCDs operating in TDI mode (Ambrosi & Denby, 2004)

3 Operations and ESOC Activities

José-Luis Pellon-Bailon

During 2004 ESOC, the Mission Operations Centre for Gaia, has continued with the preparation work. Tasks have been developed in the areas of mission analysis, ground segment and operations concept preparation, and telecommunications. Part of the mission analysis effort was dedicated to the study of the Gaia launch on-board Soyuz from Kourou. Three different launch scenarios and their corresponding transfer trajectories to L2 have been analysed, namely direct transfer, transfer via Lunar fly-by, and the use of highly eccentric orbits. Discussion with the launch authorities (STARSEM) have been also supported. Mission analysis has also studied the improvement achievable on the orbit determination accuracy including the use of astrometric measurements. Mission Analysis has issued working papers and technical notes on the topics above. From the point of view of ground segment preparation and operations concept, a first issue of the Space to Ground Interface Control Document has been released. Also a new issue of the Mission Assumptions Document has been prepared including the latest changes in the mission design and the assumptions for the computation of the corresponding Cost at Completion for the ground segment. There are still several open points on the ground segment design related to the duration of the daily telecommunications period, which will be closed as soon as the design of the Phased Array Antenna on-board becomes more mature. Due to the amount of science data to be transmitted to ground by Gaia, and the constraints on the ground station coverage time, investigations have been performed in different fields in order to achieve the required performance. In particular a new coding scheme, namely punctured convolutional encoding ($r = 3/4$) concatenated with Reed Solomon, is recommended for implementation. ESOC has dealt also with the absolute time datation accuracy achievable for Gaia and a technical note has been issued on this matter. During 2004 ESOC has supported the revision of the work performed by the industrial contractors on the Gaia spacecraft design. ESOC has prepared also documentation to be delivered to the Gaia Project as support to the ITT release.

Papers or reports issued during the year:

- Gaia space/ground interface control document (Pellon Bailon, 2004)
- Improving Gaia's orbit with Gaia's astrometry? (Bastian, 2004b)
- Orbit determination with astrometric measurements
- Transfer to L2 with and without lunar flyby (Yanez & Hechler, 2004)
- Orbit determination - could ground-based observations help? (Bastian, 2004c)

4 Gaia Scientific Working Groups

At the end of 2004, 270 European scientists were registered as members of one of the 16 'working groups' involved in the scientific preparations for the mission. Each of these has a leader and co-leader, and members are classified into 'core' or 'associate' according to their own estimation of level of involvement in the relevant work (details and membership can be found under the Gaia www page). Core members contribute to the tasks adopted by the working groups, while associate members may expect to provide only occasional inputs, or to be kept informed of progress. The Gaia Science Team is the ESA-appointed advisory group which both advises ESA on all scientific aspects of the mission, and also coordinates and through its wider contacts with the interested community undertakes the necessary scientific preparatory aspects of the mission. There are no data rights associated with involvement in the scientific working groups, apart from the advantages that will accrue from working with and preparing for the analysis of the mission data. The development of the data processing prototype GDAAS (Sections 4.14 and 5) is expected to provide a natural focus for the convergence of the scientific activities over the coming years. Members of most of the working groups listed in the following sections refer to the situation as of the end of 2003.

4.1 Astrometry and Astrometric Error Budget — Jos de Bruijne

Objective: To maintain the astrometric accuracy model for Gaia, accounting for all identified effects impacting on the final mission accuracies. To include all hardware and modelling effects as they become known. To monitor the accuracy model of industry.

Core Members: Frédéric Arenou; Uli Bastian; Jos de Bruijne; Beatrice Bucciarelli; Christine Ducourant; Misha Haywood; Jean Kovalevsky; Lennart Lindegren [leader]; François Mignard [co-leader]; Dimitri Pourbaix; Noel Robichon; Ralf Scholz; Ricky Smart

Associate Members: Carine Babusiaux; Romylos Korakitis; Vladas Vansevičius

The accuracy assessment of Gaia is a task at the very centre of the system design as numerous different effects impact on the expected final astrometric accuracy. The approach adopted for Gaia is a 'top-down' approach, where the final accuracy targets are defined (specifically, 10 μarcsec in the astrometric parameters at $V = 15$ mag), and then an apportioning and modeling of all possible error sources are undertaken. One part of this exercise is carried out, in a somewhat simplified setting, as part of the industrial system design; a more significant part is the development of a detailed error model within the Accuracy Working Group.

A detailed astrometric accuracy tool is indispensable for assessing the quantitative impact of various design alternatives and technical trade-offs on the scientific value of the mission product, for optimising instrument parameters such as the mirror coating reflectivity, and for safeguarding the mission objectives in general. Through these processes, the scientific community will guide the development of the Gaia project through the detailed design and development phase.

Many basic elements of the Gaia astrometric model have been developed over the years, originally as part of the Hipparcos project, primarily by Lindegren (scanning law, PSF calculation, LSF centroiding, etc.). In accordance with Lindegren's proposal, stressing completeness, flexibility, transparency, and integrity, an astrometric accuracy pipeline tool, named GAAT for Gaia Accuracy Analysis Tool, has been developed from these basic elements within the Accuracy Working Group.

The model currently in place provides a simplified yet realistic end-to-end simulation of the Gaia observation process, ranging from photon emission at the astronomical source at the one end, through the effects introduced by, e.g., the revolving scanning law and CCD TDI operation, to single-transit centroiding measurements of the line spread function (LSF), and the averaging of these results over the operational mission lifetime, at the other end. The model also includes, among others, wave-front errors (WFEs) due to aberrations, image smearing due to transverse motion of sources in the focal plane, and charge diffusion in the CCD detectors.

During 2004, GAAT was kept up-to-date and new modules dealing with a G-magnitude-dependent sampling and windowing scheme, TDI gating, and WAP sampling were introduced. In support of ongoing discussions on the astrometric accuracy dependence on certain technical design parameters and to further substantiate the baseline Gaia-2 parameters, a detailed study was made investigating how Gaia's end-of-mission astrometric accuracy depends on the Astro CCD thickness, the solar aspect angle, the Astro mirror coating, the FPA AF CCD mosaic size, and the Astro telescope focal length.

Both the EADS-Astrium and the Alcatel/Alenia industrial system-level astrometric performance methodologies were reviewed. For both, shortcomings were identified, action points were defined, and a list of points of concern was communicated. At the same time, a common performance assessment methodology to be followed by both industrial system-level teams was proposed, subsequently endorsed by the ESA Gaia Project Team. Adherence of both industrial system-level teams to these guidelines will facilitate the verification of all performance assessment software and will enable a meaningful comparison of performance estimates.

The longer-term goal of the modeling effort within the Accuracy Working Group is twofold: (1) to extend the model to include photometric and radial velocity accuracy assessments as well; and (2) to include all effects affecting the final mission accuracies. The latter goal implies a significant development effort will be needed to model error sources that have not been considered in detail so far – for example, attitude modeling (including radiation pressure, solar wind, and micrometeorite impacts filtered through the spacecraft dynamics and attitude control loop), CCD imperfections beyond simple photon and read-out noise (photometric non-linearity, charge-transfer inefficiency, degradation in orbit, etc.), geometric calibration, data processing, etc. During the first half of 2005, emphasis will be given to the quantification of the effects of radiation damage on astrometric accuracy.

Papers or reports issued during the year:

- Combining Gaia windows II - SNR calculations of secondary sources using different numerical binnings and samplings in AF11 (Nurmi, 2004)
- The practical scanning law - an update (Mignard, 2004a)
- The practical scanning law - an update (Fortran code) (Mignard, 2004b)
- Chromaticity versus aberrations for the Gaia astrometric telescope (Gai et al., 2004)
- Geometrical parallax factor (de Bruijne, 2004c)
- Basic angle stability specification (Lindegren, 2004a)
- Chromaticity specification (Lindegren, 2004b)
- Comments to ESA note on ADC ENOB (Pouny, 2004)
- Clocks in Gaia - design and implementation of a clock simulator (Castaneda et al., 2004)
- Effective number of bits (ENOB) for realistic ADCs operated at high frequency (de Bruijne, 2004b)
- The speed of a star image in the Gaia field of view from general attitude motion or scanning law (Lindegren, 2004e)
- Astrometric accuracy - methodology to be used by the industrial system-level teams (de Bruijne, 2004a)
- Scientific requirements for basic angle stability monitoring (Lindegren, 2004d)

4.2 Parameter Data Base

Jos de Bruijne

The parallel development of many aspects of a complex mission like Gaia, which includes many participants in ESA, industrial companies, and a large and active scientific collaboration throughout Europe, makes keeping track of the many design changes, instrument and operational complexities, and numerical values for the data analysis, a challenging problem. A comprehensive, easily-accessible, up-to-date, and definitive compilation of a large range of numerical quantities is required, and discussions were held at GST7 in March 2003 about how to achieve this.

During 2004, the Gaia parameter data base was established to satisfy these needs. The first official release of the data base was made on 1 March 2004, after an extensive contents review coordinated by the GST, and version 1.1 was released on 17 January 2005. Set up in ESTEC by Jos de Bruijne (data content, naming conventions, etc.) and Uwe Lammers (data base structure, interrogation, and output formats) the data base is a centralised repository of Gaia-related parameters. It contains, besides mathematical, physical, and astronomical constants, many satellite and subsystem design parameters. Examples are the size of the astrometric field of view, the read-out noise of the MBP pixels, the adopted mass of Jupiter, the coefficient of thermal expansion of silicon carbide at various temperatures, the QE and MTF of the Astro CCDs as a function of wavelength, etc. At the end of 2004, more than 1500 parameters had been included.

The data base employs a hierarchical parameter naming scheme, reflecting the design of the satellite. All data base entries have self-explanatory names, unambiguous descriptions, and full literature references. For derived parameters, relevant dependencies are provided and implemented in the form of formulae. Multi-dimensional data files are formated in FITS. The data base can be queried or browsed using a regular Web browser such as Internet Explorer or Netscape (http://www.rssd.esa.int/Gaia/paramdb). The search form represents the hierarchical structure of the data base, and contains several selection options (e.g., free-search in the 'description' field, selection of all 'basic parameters', selection of 'scalar parameters', etc.). Multi-dimensional data files can either be downloaded to the user's local disk or be displayed on the user's screen by means of a dedicated Java applet. By default, queries return up-to-date parameter values, although provision is made for retrieval of ('obsolete') reference versions of the data base. Query outputs are formated by default in HTML (other 'human-oriented outputs' are LaTeX and PDF). Data can also be retrieved as Fortran-77, Fortran-90, CSV, Java, ANSI-C, C++, or XML structures for direct inclusion into software codes in these languages. The idea is that all collaborating scientists can use the data base parameters and values directly linked to computational routines. An off-line access mode is also available, enabling users to automatically download the contents of the data base at regular intervals. Further details, including a user manual, are available on Livelink.

During 2004, the data base was maintained actively, following developments in, e.g., the photometric filter design, CCD QE and total detection noise estimates, and the Astro and Spectro windowing/sampling strategy. A short-naming scheme for Fortran-90 output was developed and vector-support was introduced. Significant extensions of the contents are planned in 2005. Consistent use in the future of the data base by the Gaia community at large, including all industrial teams, will ensure correct numerical values throughout the complex software systems being built up as details of the Gaia design develop. The data base is currently being used for the telemetry simulation chain in ESTEC, in the data simulations for GDAAS2, and in the payload data handling electronics software Pyxis.

Documents related to the parameter data base (and reference documents) are:

- Proposal for notations on filters, spectral bands, magnitudes (Bastian & Bailer-Jones, 2004)
- Notations for BBP and MBP (Høg & Jordi, 2004g)
- Gaia System Requirements Document - for technical assistance and definition phase (Colangelo, 2004)
- The Gaia parameter data base - technical users manual (Lammers, 2004a)
- Reference systems, conventions and notations for Gaia (Bastian, 2004d)

4.3 On-board Detection

Frédéric Arenou & Carine Babusiaux

Objective: To provide the prescription of the on-board detection algorithm, and the layout of the astrometric sky mapper and the spectroscopic sky mapper.

Core Members: Frédéric Arenou [leader]; Carine Babusiaux [co-leader]; Bertrand de Batz; Erik Høg; Mike Irwin; Xavier Luri; Gary Mamon (galaxies); Shan Mignot; Jordi Portell; Staffan Söderhjelm (binaries)

Associate Members: Coryn Bailer-Jones (classification); Albert Bijaoui; Jos de Bruijne; Gerry Gilmore; Carme Jordi; David Katz (RVS); Romylos Korakitis; Ralf Scholz; Dimitris Sinachopoulos (crowding, on-board processing); Ricky Smart; Alain Smette (galaxies); Vladas Vansevičius

The Gaia mission provides a real challenge, not only for the data reduction, but also for on board detection. The complexity of the sky, added to the numerous instrumental constraints, requires a dedicated and complex on-board Payload Data Handling (PDH) system. A summary of the 2004 activities is given here and the reader is referred to the 2003 status report to Working Groups, or the dedicated paper written for the Gaia 2004 conference for more details.

The various functions needed on-board are the following: pre-calibration, background estimation, object detection, centroiding, classification, sampling, windowing, selection, window positioning, confirmation, attitude determination and propagation of the positions between all successive CCDs, some of these operations being repeated at different instances. All these functions represent algorithms which should be designed to fulfill the scientific objectives.

Accordingly, the work done by the Working Group for the data handling concerns the scientific and technical requirement specification for these algorithms, the software development and the tests, with an incremental cycle. The reason for this iterative procedure is due to the constant adaptation of the scientific requirements to the actual mission constraints, as well as to the feedback from the PDH System contractor prototyping the electronic architecture. The iterations with the PDHS contractor thus represent a part of the Working Group activity.

Starting with the scientific specification, the windowing and sampling scheme has been studied in the Spectro instrument, and more specifically for the RVF CCD. The general study of sampling and windowing of each CCD is still improving. The various industrial designs have also been analysed in several documents. Besides, a discussion about the various on-board selection schemes has also been introduced, though not solving the challenge to be able to process the data within the available time constraints in the highest density regions.

Regarding this main optimisation issue, the rewriting of some software parts has been pursued this year, and new parts have been added, for instance the cross-matching in Spectro or, provisionally, concerning the pre-calibration. The software implementation of the scientific algorithm, Pyxis version 2 has been delivered in March, and time has also been devoted to documenting its architecture, mostly concerning the interface, to allow a successful industrial breadboard implementation. To check the implementation, test data sets are being defined.

The software development of the scientific algorithms has now reached an encouraging maturity seven years before Gaia launch, thanks to the more than 8 (wo)man-years devoted up to now. Most of the functionalities needed for the scientific data handling have now been studied, and should be fully coded by early 2005, in time for the industrial implementation.

Papers or reports issued during the year:

- GDA implementation requirements (Schaefer, 2004)
- A hardware-oriented connected-component labeling algorithm (Mignot, 2004b)
- Flowcharts of the SWA 2.5 and GD 2.0 detection algorithms (Mignot, 2004a)
- Pyxis V2 (Arenou et al., 2004a)
- Windowing and sampling in RVF (Chereau et al., 2004)
- Telemetry rate simulations - a first look at the complete picture (Lammers, 2004b)
- About selection and priorities on-board Gaia (Arenou et al., 2004b)
- Definition of a telemetry CODEC (Portell et al., 2004b)

4.4 Photometry

Erik Høg & Carme Jordi

Objective: to design the photometric system(s) to be implemented, taking into account astrophysical diagnostics across the broadest range of sources, chromatic effects, sampling strategy, background determination, and compression possibilities, and to develop photometric calibration and standardization procedures.

Core Members: Coryn Bailer-Jones (classification, interstellar extinction); Henri Boffin; Anthony Brown; Jos de Bruijne; Josep Manel Carrasco (filter definition); Norbert Christlieb (classification); Ronald Drimmel; Bengt Edvardsson; Dafydd Evans; Laurent Eyer; Claus Fabricius (PSF); Francesca Figueras; Massimo Fiorucci (filter definition, existing systems); Chris Flynn; Michel Grenon, Ulrike Heiter (filter definition); Erik Høg [leader]; Mike Irwin; Carme Jordi [co-leader] (filter definition); Torsten Kaempf; Jens Knude (interstellar extinction); Indrek Kolka;

Arunas Kucinskas; Floor van Leeuwen; Thibault Lejeune; Oleg Malkov; Valeri Malyuto; Ulisse Munari (filter definition, existing systems); Pasi Nurmi; Nikolai Piskunov (filter definition); Celine Reylé (interstellar extinction); Staffan Söderhjelm (double stars); Chris Sterken; Vytas Straizys; Jokubas Sudzius (interstellar extinction); Grazina Tautvaišienė; Frédéric Thevenin; Yves Viala (interstellar extinction); Tomaž Zwitter

Associate Members: Gianpaolo Bertelli; Albert Bijaoui; Fiorella Castelli; Claire Dollet; N. Wyn Evans; Josef Hron; Algirdas Kazlauskas; Franz Kerschbaum; Evangelos Kontizas; Maria Kontizas; Romylos Korakitis (classification); Claes-Ingvar Lagerkvist; Patrick de Laverny; Yveline Lebreton; Kalevi Mattila; Shan Mignot; Panagiotis Niarchos; Edouard Oblak; Alain Omont (interstellar extinction); Caroline Soubiran (classification); Jordi Torra; Enric Trullols; Mattia Vaccari; Werner Weiss

The design of the photometric systems is a large and complex activity, which has been the subject of considerable effort within the Gaia scientific community over the last 4 years and which resulted in an approved system in December 2004. The task was aimed at defining the detailed choice of the broad-band and medium-band filter systems, taking into consideration the on-board sampling characteristics, the photometric data reductions, and the accuracy on the physical parameters which can be recovered from the ground data processing, and classification tasks.

The approved baseline foresees 5 broad-band filters implemented in 4 strips of CCDs available in the main (Astro) telescope field, and 14 medium-band filters implemented in 16 CCDs available in the Spectro telescope field.

The photometric observations are designed to satisfy a number of different requirements: primarily to provide classification of the observed star through multi-colour photometry, and thereby to provide estimates of luminosity, effective temperature, gravity, chemical abundances, and reddening; and to further characterize the variability of the star or system through multi-epoch photometry. In addition, the broad-band photometric system in the main (Astro) field is primarily designed to provide information to correct for chromatic aberrations in the astrometric positions (these chromatic displacements can amount to several hundreds of μarcsec). The broad-band photometry (BBP) and medium-band photometry (MBP) occupy different telescopes, and have different angular scales and sampling schemes. The overall objective has been to optimize the filter choice through careful design and evaluation of the resulting classification possibilities, and to design a data reduction system allowing background subtraction and therefore highest photometric accuracy down to the most crowded regions feasible. Both BBP and MBP have designed sensitivity limits allowing measurements of all objects down to 20 mag, i.e. matched to the limit of the astrometric observations. Thus each star will have a large quantity of multi-band, multi-epoch photometry available for diagnostic purposes.

Many filter systems exist, according to the purpose for which they were designed. Gaia will be yet another photometric system. Its optimization has been done by a careful prioritization of the stars across the whole HR diagram and according to the main scientific objective: the study of the structure, formation and evolution of our Galaxy. It is clearly impossible to satisfy all possible objectives. The present approach has been to try to design a photometric system for single stars, and then to assess the system diagnostic performance for multiple systems, quasars, solar system objects, etc.

A great activity took place during this year involving the Uppsala, Vilnius, Heidelberg, Lund, Copenhagen and Barcelona teams in optimizing earlier proposals for photometric systems and submitting new ones. The proposals were made to test systematically the impact of specific bands with respect to spectral features and astrophysical parameters determination. The choice of the baseline photometric system was based on an objective performance evaluation of all proposed photometric systems, following and established procedure by Brown et al. (PWG-AB-003). This evaluation is done for an agreed-upon set of scientific priority targets (STs) and consists of: (a) calculating the posterior errors that can be achieved with a PS and comparing those to the error goals; the results are summarized by a figure of merit (FoM); (b) evaluating the global degeneracies of the PS; (c) considering additional criteria such as, for example, the technical feasibility.

The definition of the set of scientific targets, astrophysical parameters, priorities, error goals and the assumed a priori information were finalized during 2004 and are detailed in Jordi et al. (UB-PWG-009; UB-PWG-015). The scientific targets are single stars belonging to the four main stellar populations of the Galaxy (halo, thin and thick discs and bulge) as observed in several locations of the Galaxy. The posterior errors of the astrophysical parameters ($T_{\rm eff}$, $\log g$, [M/H], [α/Fe] and A_v) and the figure of merit were calculated according to the methods outlined in Lindegren (Gaia-LL-047). The value of the parallax and its uncertainty have been included as a priori information according to the prescriptions in Lindegren (Gaia-LL-054). The results of the evaluation and the description of the baseline photometric systems can be found in Jordi et al (UB-PWG-028; UB-PWG-29).

Knowledge of the true stellar densities is one of the major points because of its impact on the on-board data processing and telemetry budget evaluation. Huge effort is devoted by the Besançon and Torino teams to provide realistic star counts and Galaxy stellar simulations based on the Gaia G band and to identify 'problematic' areas for medium-band photometry. Due to the intrinsic interest of characterizing the bulge stars for the understanding of Galaxy structure and history, estimations of the stellar density have been performed assuming different extinction maps (Gaia-BES-001). The bulge visibility strongly depends on the assumed extinction map. In the dense dust lanes, bulge stars are too faint to be observed even at G=20. In few fields close to $b = 0°$ in windows of low extinction, bulge giants may be reached with BBP and MBP.

The ISM, extinction and star-forming regions were discussed by J. Knude and C. Fabricius (Gaia-CUO-159).

Studies on the detection and observation of faint stars with MBP in crowded regions were carried out by J. de Bruijne, E. Høg and D. Evans. It is concluded that 85 per cent of the transits of the stars in areas of average star density of 25000 stars/deg^2 will be observed and that even 30 per cent of the transits when the density is of 250 000 stars/deg^2 will be observed. Therefore, MBP is very useful also in crowded regions. D. Evans has carried out an estimation of the precisions attainable with PSF fitting in crowded areas (PWG-DWE-001).

Optimization of the MBP faint-star sampling and windowing scheme, taking crowding and window overlap into account was performed by J. de Bruijne (Gaia-JdB-014). Two approaches were devised: a) maximization of the end-of-mission total flux and b) maximization of the end-of-mission photometry precision. Advantages and disadvantages of small and large windows and of one and two windowing/sampling schemes for red and blue bands are evaluated. The main conclusion is the need for windows of 10 samples each of 4 pixels AC.

The sampling schemes for Astro and Spectro and the calibration of PSF in MBP have been studied by E. Høg and C. Fabricius (Gaia-CUO-139, -143, -149, -150, -151, -160, -162, -163, and -151v2). The sampling schemes have been approved by the GST.

Manufacturing of photometric filters has been discussed by E. Høg, C. Jordi, J. Knude (Gaia-CUO-146).

The photometric data analysis was studied and a working packages structure was outlined by Brown (PWG-AB-001), considering the inter-relationship with the activities of other WGs. An algorithm for the photometric calibration in terms of large and small calibration units and for the determination of the standard fluxes of the sources was provided by C. Fabricius. This algorithm is implemented in the Gaia Data Access and Analysis System (GDAAS) for the Global Iterative Solution. Activities on the LSF and chromaticity characterization and calibration for GDAAS also took place.

Many studies took place in order to characterize the spectral energy distribution of the stars by doing observations (Kolka, Kucinskas, Tautvaišienė and others), by improving theoretical models (Uppsala team, Hauschildt and others) or by comparing synthetic photometry with observations (Uppsala team, Lejeune and others). The team in Torino established transformations among Gaia and GSC-II photometries for the evaluation of stellar densities as seen by Gaia as a function of the galactic coordinates. All these activities and others carried out by the PWG members were presented at the Gaia Symposium in Paris.

Several large meetings have taken place during 2004: Torino, 21 January; (see Gaia-CUO-135 for the summary); Copenhagen, 20 April (Gaia-CUO-142v.2); Copenhagen, 28–29 June (Gaia-CUO-144); Paris, 8 October (Gaia-CUO-156), and Athens, 25–26 November (Gaia-CUO-161v.2).

The web site of the Photometry Working Group is http://gaia.am.ub.es/PWG/

Papers or reports issued during the year:

- Gaia Photometry News, January 2004 (Høg, 2004b)
- Summary of the PWG-workshop held on 21 January 2004 in Torino (Høg & Jordi, 2004j)
- Gaia photometric system 2003 (Vansevicius & Bridzius, 2004)
- The photometric system 2X (Vansevicius, 2004)
- Basic assumptions for comparing and optimizing Gaia's photometric system (Lindegren et al., 2004)
- Reports from CUO related to Gaia, September 2002 - Feb. 2004 (Høg, 2004c)
- Evolutionary design of photometric systems and its application to Gaia (Bailer-Jones, 2004a)
- The 3F Geneva-Barcelona medium band photometric system for Gaia (Jordi et al., 2004e)
- Gaia photometry news, February 2004 (Høg & Jordi, 2004c)
- Implementation proposal for the HFD-B1 and HFD-M1 photometric systems (Bailer-Jones, 2004e)
- MBP PSFs
- Optimising the orthogonality of the AP gradients for the photometric systems (Brown, 2004b)
- Photometric data analysis for Gaia - definition of work packages (Brown, 2004c)
- Minimum distance and perturbation methods in classification for Gaia (Malyuto & Shvelidze, 2004)
- Gaia photometry news, March 2004 (Høg & Jordi, 2004d)
- Use of parallax information in the photometric system design (Lindegren, 2004f)
- Procedure for photometric systems recommendation (Brown et al., 2004)
- Summary of the PWG meeting in Copenhagen, 30-April-2004 (Høg & Jordi, 2004i)
- Scientific targets for photometric system design (Jordi et al., 2004c)
- Scientific targets for photometric system design - quantification of priorities (Jordi et al., 2004g)
- Scientific targets for PS optimization (Jordi & Carrasco, 2004n)
- MBP profile fitting in crowded regions (Evans, 2004)
- Execution time and speed scaling estimates for stellar parametrization algorithms (Bailer-Jones, 2004b)
- Identification and parametrization of spectroscopic binaries by MBP (Willemsen et al., 2004b)
- HFD filter system design for Gaia - design of the H2B, H3B, H2M and H3M systems and general insights concerning MBO (Bailer-Jones, 2004c)
- Figure of Merit computation (Jordi & Carrasco, 2004d)
- ICAP status report 8 (Bailer-Jones, 2004d)
- Windowing and sampling for faint stars in MBP (de Bruijne et al., 2004)
- Gaia filters - technical status
- Summary of the PWG meeting held on 28-29 June 2004 in Copenhagen (Høg, 2004g)
- Cool stars in the Gaia photometric system (Heiter et al., 2004)
- Figure of Merit computation (PWG-19) (Jordi & Carrasco, 2004j)
- Sampling scheme D for Astro and MBP (Høg, 2004e)
- First Gaia photometry (Høg, 2004a)
- The Galactic Bulge as seen by the Gaia photometers (Reyle & Robin, 2004)
- Figure of Merit computation (assuming interstellar absoprtion known) (Jordi & Carrasco, 2004f)
- Gaia photometry news - August 2004 (Høg & Jordi, 2004b)
- Manufacturing of filters (Høg et al., 2004)
- A new MBP system - K1M (Knude & Høg, 2004)
- A new version of the MBP system for Gaia - V2M (Straizys et al., 2004)
- Sampling and calibration of MBP (Høg & Fabricius, 2004a)
- Figure of Merit computation (K1M and V2M systems) (Jordi & Carrasco, 2004g)
- Stellar parameter uncertainty estimates from bootstrapping neural networks (Willemsen et al., 2004a)
- On Gaia photometric system optimisation and photometric data analysis (Brown, 2004a)
- Figure of Merit computation (MARCS models SEDs) (Jordi & Carrasco, 2004i)

- Two new MBP systems - K2M and K3M (Høg & Knude, 2004c)
- Notes on alpha-elements (Høg & Knude, 2004b)
- A revised version of the BBP system for Gaia - V1B (Straizys, 2004b)
- Figure of Merit computation (K1M and V2M systems) (PWG-024) (Jordi & Carrasco, 2004h)
- MBP systems - F4M, F5M and F6M proposals and their evaluation (Jordi & Carrasco, 2004l)
- Gaia Photometry News, September 2004 (Høg & Jordi, 2004f)
- Sampling Scheme E for Astro and MBP (Høg, 2004f)
- Minutes of the joint classification, variable stars and scientific alerts working groups
- Summary of the PWG meeting held on 8 October 2004 in Paris (Høg & Jordi, 2004h)
- Figure of Merit computation (V1B, K2M, K3M and others) (Jordi & Carrasco, 2004k)
- Four new MBP systems - K4M, K5M, K6M, K7M (Høg & Knude, 2004a)
- A BBP system - P1B (Heiter, 2004)
- One more version of the MBP system for Gaia - V3M (Straizys, 2004a)
- BBP systems - F2B, F3B, F4B, F5B and F6B proposals (Jordi & Carrasco, 2004a)
- MBP systems - F7M - F12M proposals (Jordi & Carrasco, 2004m)
- Gaia photometry news, November 2004 (Høg & Jordi, 2004e)
- Photometric systems evaluation of global degeneracies - results from self-organised maps (Brown, 2004d)
- Figure of merit - minimum photometric error (Jordi & Carrasco, 2004b)
- Figure of merit - weighting schemes (Jordi & Carrasco, 2004c)
- Figure of merit computation - October 2004 PS proposals (Jordi & Carrasco, 2004e)
- Summary of the ICAP And PWG joint meeting in Athens 25-26 November 2004 (Jordi et al., 2004f)
- BBP photometric systems evaluation (Jordi et al., 2004a)
- MBP photometric systems evaluation (Jordi et al., 2004b)

4.5 Radial Velocity Spectrometer

David Katz & Ulisee Munari

Objective: to simulate the data stream generated by the Radial Velocity Spectrometer, to support investigations of design, accuracy, sampling strategy, data compression, data analysis, scientific performance, etc.

Core Members: Coryn Bailer-Jones; Marie-Odile Baylac; Federico Boschi; Veronique Cayatte (data analysis s/w and simulations); Fanny Chemla (optics); Norbert Christlieb; Françoise Crifo; Mark Cropper; Marc David; Ralf Donner; Enrique García-Berro; Ana Gomez; Misha Haywood; Amina Helmi; David Horville (optics); David Katz [leader]; Thomas Lebzelter; Paola Marrese; Keith Mason; Danielle Morin; Ulisse Munari [co-leader]; Francesca Primas; Andrej Prsa; Alejandra Recio-Blanco; Frédéric Royer; Frédéric Sayede (opto-mechanics); Annie Sellier; Rosanna Sordo; Caroline Soubiran (libraries of spectra); Frédéric Thevenin; Catherine Turon; Yves Viala; Glen Wahlgren; Mark Wilkinson; Hong Shen Zao; Tomaž Zwitter

Associate Members: Frédéric Arenou; Gianpaolo Bertelli; James Binney; Corrado Boeche; Giuseppe Bono; Andrej Cadez; Fiorella Castelli; Roger Cayrel; Cesare Chiosi; Elvira Covino; Claus Fabricius; Nicole Feautrier; Massimo Fiorucci; Mario Gai; Gerry Gilmore; Leo Girardi; Andreja Gomboc; Erik Høg; Mike Irwin; Gerard Jasniewicz; Urtzi Jauregi; Carme Jordi; Uffe Jorgensen; Alain Jorissen (cross-correlation masks); Franz Kerschbaum; Arunas Kučinskas; Mario Lattanzi; Patrick de Laverny; Yveline Lebreton; Thibault Lejeune; Mireille Louys; Xavier Luri; Andre Maeder; Paola Marigo; Giuseppe Massone; Eugene Milone; Panos Niarchos; Isabella Pagano; Ignazio Porceddu; Jordi Portell; Peter Reegen; Roberto Silvotti; Alessandro Spagna; Annie Spielfiedel; Rosaria Tantalo; Gilles Theureau; Toma Tomov; Lina Tomasella; Antonella Vallenari (galactic structure); Vladas Vansevičius; Simon Vidrih; Pascal Vola (opto-mechanics)

From mid-2001 to end 2002, the RVS working group worked mainly on the definition of the scientific and technical requirements of the spectrograph. The 18 months of studies led to the selection of the RVS general characteristics, in particular the spectral resolving power: $R = \lambda/\Delta\lambda = 11\ 500$. In 2003, the RVS WG focused on: (a) refining the RVS scientific case, (b) defining and testing the on-board processing algorithms (work mainly performed by the OBD WG) and on refining the assessment of the RVS telemetry budget, (c) improving the RVS simulation tools and observing and modelling stellar spectra, (d) refining the assessment of the RVS performance and (e) defining and prototyping the on-ground RVS data calibration and analysis algorithms. In 2003, the RVS WG has also supported the RVS consortium in the definition of the spectrograph design. In 2004, the RVS WG has continued working on the same 5 broad topics (a–e above) as in 2003. The studies conducted in 2004 are presented below. In 2004, the RVS WG has also assisted the industry teams and the RVS consortium in the revision of the spectrograph design (revision resulting from the evolution of the interfaces with the satellite and from the will to maximise the commonalities between the MBP and RVS instruments). The main changes of the spectrograph design are: (a) the replacement of the dioptric optical design by an all reflective Offner relay-type design and (b) the revision of the focal plane assembly, now made of 10 × 2 (smaller) CCDs instead of 6 × 1.

RVS scientific case:

• a detailed review of the RVS expected scientific harvest in the fields of Galactic structure, binary stars and stellar physics has been performed. It emphasises the important role that the RVS will play in, for example, identifying relics of halo merging events, tracing the Galactic potential, deciphering the chemical history of the Galaxy, characterising SB2 eclipsing binaries or studying variable stars.

• Marrese et al. have continued the assessment of Gaia's performance in the characterisation of eclipsing binaries. The orbits and physical parameters of UW LMi, V432 Aur, and CN Lyn were derived using Hipparcos Hp light curves, Tycho mean B_T and V_T colours and multi-epochs Asiago spectra (with a configuration close to the RVS one). Milone et al. have characterized the peculiar binaries HP Dra, BS Dra and SV Cam.

On-board data-handling and telemetry:

• one of the MBP filters (hereafter referred to as RVF) is the same as the RVS filter. One of the aims of the RVF band is to help with the on-ground calibration and analysis of the RVS data. The merits and drawbacks of different RVF windowing and sampling strategies were assessed and compared, and led to the decision to adopt the same windowing and sampling modes for the RVF as for the other MBP bands.

• prototypes of the on-board RVS data processing algorithms (bias subtraction, gain correction, cosmic rays and defective pixels removal, correction for along and across scan distortions and transverse motion, CCD frame co-addition) have been implemented.

• M. David has defined a numerical model describing the wavelength and AC position of the photons received from a source as a function of the time of detection, the FoV AC position, the photons' position within the spectrum and the integration time. The aim of the model is to allow for a fast wavelength calibration which, in turn, should allow for an optimal co-addition of the spectra from different CCDs.

• Y. Viala and U. Lammers have refined their respective assessments of the RVS and Gaia telemetry streams. Their conclusions are similar. If the daily ground station visibility (11h mean) can be optimally used and the antenna can transmit ∼5 Mbits s^{-1}, then most of the observations can be downloaded to the Earth. Otherwise (e.g. ground station operated only 8h per day) a significant fraction of the data collected will be lost. In case of significant loss of data, a selection strategy should be defined to select and download the scientifically most interesting data/sources.

• A. Vallenari, G. Bertelli, E. Nasi, S. Ragaini and S. Pasetto have proposed and studied a possible selection strategy: i.e. to adapt the RVS limiting magnitude as a function of the field density, taking into account the reduction of the RVS performance with increasing crowding rate and the scientific yield of the observations as a function of magnitude interval and Galactic coordinates.

Observation and modelling of stellar spectra and simulation of the RVS:

• P. Marrese has studied the molecular content of cool star spectra (M, S, C-types), in the Gaia wavelength range, using observations from the Asiago echelle spectrograph as well as synthetic spectra.

• the grid of 183 588 Kurucz spectra covering the RVS wavelength range has been made available through the ESA SpectraLib facility (see below), the Asiago web page, DVDs and via the CDS. A second grid, covering the spectral range 250–1050 nm at several resolving powers (including the RVS one: $R = 11\ 500$), has been computed.

• U. Jauregi has started to port the Kurucz software packages, ATLAS9 and SYNTHE, from Fortran77 to Fortran90. On the longer term, he plans to adapt the code to non-spherical geometry so as to handle fast rotators and to include dust for cool stars.

• F. Thévenin, L. Bigot, P. de Laverny and A. Recio-Blanco have continued their collaboration with the Marcs team, with the aim to produce, by Gaia launch (2011), a grid of synthetic spectra based on revised atomic parameters, 3D hydrodynamics modelling of the atmosphere and taking into account NLTE effects. L. Bigot and A. Nordlünd have simulated hydrodynamical snapshots for the Sun and an A-type star.

• P. Morel, F. Thévenin, L. Piau, Y. Lebreton, M.J. Goupil, and B. Pichon have started optimising the CESAM code to produce, by Gaia launch, stellar evolutionary tracks that could be used for the analysis of Gaia data. L. Piau has optimised the modelling of the red giant branch.

• a spectra database has been implemented at ESTEC: the SpectraLib database (S. Ansari, Y. Balague and U. Lammers). It is accessible on-line: http://gaia.esa.int/spectralib/. In addition to the storage, search and download facilities, it offers several data manipulation tools (e.g. display, zoom, unit conversion, spectral lines fitting).

• R. Sordo has continued updating the 'Asiago database of spectroscopic databases' which contains (as of mid-2004) 285 catalogues (see http://ulisse.pd.astro.it/ADSD/index.html)

• a prototype of the RVS TDI PSF simulator has been developed (D. Katz). It uses ZEMAX optical software output (D. Horville) and integrates a simulator of the CCD/pixels properties developed by A. Short, J. de Bruijne and F. Chéreau.

• the MSSL RVS field of view simulator (M. Cropper) has been made available on-line (see http://www.mssl .ucl.ac.uk/gaia-rvs/).

RVS performance and (on-ground) data analysis algorithms:

• the radial velocity performance of (a) the RVS nominal configuration (i.e. revised baseline), (b) the nominal configuration in case of failure of half of the CCDs and of (c) three backup configurations have been assessed. The simulations predict for the nominal configuration an end of mission 1σ precision of $\sigma V_R \simeq 13$ km s^{-1} for a $V = 17.5$ metal-poor ([Fe/H] $= -1.5$) K1 III star.

• M. Fiorucci and U. Munari have carried out a large set of simulations aimed to test individually as well as together all the main perturbing effects that enter the error budget in cross-correlation radial velocity determinations.

• T. Zwitter and D. Katz have started a double blind test to evaluate the impact of crowding on the RVS RV performance. The first results are consistent with earlier works by T. Zwitter. The study will continue in 2005 with more realistic simulations and with the aim of assessing the performance at higher stellar densities (i.e. $> 40\ 000$ stars deg^{-2} with $V < 17$).

• A. Gomboc and D. Katz have continued evaluating the performance of the RVS in determining the rotational velocities. In the absence of spectral type mismatch, the estimated end of mission 1σ precision is, e.g. $\sigma_{v \sin i} \simeq 15 - 20$ km s^{-1} for a $V = 11$ B5V star. The first assessment of the effect of mismatch seems to show that its impact goes from negligible (i.e. mismatch in $\log g$ for late type stars) to very strong (i.e. mismatch in $\log g$ for early type stars).

• F. Boschi has continued investigating the potential of line ratios to perform fast determinations of the stellar effective temperature and the surface gravity. He has identified 22, 14 and 9 line ratios, in the RVS wavelength range, to constrain the effective temperatures of, respectively, supergiant, giant and dwarf stars.

• A. Recio-Blanco, F. Thévenin, P. de Laverny, A. Bijaoui and D. Katz have developed an automatic program for the determination of the stellar atmospheric parameters. The program relies on a minimum distance technique combined with objective analysis. First tests yield average performance (over a wide range of atmospheric parameters) of $\Delta T_{\rm eff} \sim 95$ K, $\Delta \log g \sim 0.26$ dex and Δ[M/H] ~ 0.13 dex for S/N = 50. T. Zwitter, U. Munari and A. Siebert have investigated a similar technique for the analysis of RAVE and Gaia data.

• A. Siviero has started studying the potential of emission line ratios, in the Gaia wavelength range, to derive the physical conditions in Planetary Nebulae. The ratios CaII/Paschen14 and FeII(861.9nm)/Paschen14 appear as promising indicators of the temperature of the central source.

• S. Vidrih has started assessing the RVS performance in probing the Galactic reddening with the 862 nm Diffuse Interstellar Band (DIB). First results seem to indicate that the DIB should allow to probe the interstellar medium up to ~4 kpc in the Galactic plane and up to ~10–15 kpc away from the plane.

• A. Prša has started reviewing methods and algorithms for performing (a) unconstrained minimisation of multi-dimensional functions without derivative and (b) classification.

On-ground data processing (data model and calibration):

Many studies that are preparing for the on-ground analysis of the data have already been presented in the previous section. This section presents the work devoted to the RVS data model and to the RVS calibration.

• Hui-bon-Hoa & Katz have proposed a data model to represent the RVS telemetry stream and the RVS data within the GDAAS database.

• the RVS will observe about 100–150$\times 10^6$ stars, each on average ~93 times. The satellite and the spectrograph will be optically and mechanically extremely stable. All these factors should allow the RVS to auto-calibrate itself using a subset of well-behaved stars (process referred to as Spectroscopic Global Iterative Solution - SGIS): iteratively characterising the well-behaved stars (e.g. deriving their radial velocity) and using them to calibrate the instrument (e.g. derive the spectral dispersion law). Hui-bon-Hoa & Katz have extrapolated the work of L. Lindegren on the Astrometric Global Iterative Solution to define the SGIS architecture: sequence of operations, modules, input data, output data. The development of an SGIS prototype has started (A. Hui-Bon-Hoa, A. Guerrier and D. Katz).

• a first assessment of the RVS wavelength calibration precision, using well-behaved reference stars, has been performed. For 100 late-type stars brighter than $V = 10$ per calibration unit, the simulations predict wavelength calibration precisions of a few hundreds of meters per second.

• G. Jasniewicz and F. Crifo have started to review existing spectroscopic and radial velocity data bases in order to identify (potential) ground radial velocity standard stars. The aim is to build a list of ground standards with a radial velocity stability, over the 5 years of the Gaia mission, better than a few hundreds of meters per second. This list will be used by the Spectroscopic Global Iterative Solution to: (a) help the convergence of the process and (b) fix the radial velocity zero point.

One meeting of the RVS WG was held in 2004: RVS 8 organised by Vallenari, Katz and Munari, 3-4 June 2004, in Observatory of Padova, Italy. The presentations are available on the RVS web site: http://wwwhip.obspm.fr/gaia/rvs/workshop8Science.html

Papers or reports issued during the year:

- The 860 nm band in SSM - task description (Høg & Jordi, 2004a)
- RVS consortium - progress report 2003 November/December (Cropper, 2004a)
- Gaia-RVS CCD quantum efficiency and MTF (Walton, 2004b)
- L3Vision CCD radiation testing - initial results on 20 devices (Smith & Holland, 2004)
- CCD development plan for Gaia RVS (Cropper et al., 2004a)
- On the feasibility of a quasi-instantaneous wavelength map for the RVS (David, 2004)
- RVS consortium - progress report 2004 April/May (Cropper, 2004b)
- L3CCD radiation results - implications for RVS (Cropper et al., 2004b)
- Telemetric flows for the RVS from GSC-2.2 star counts taking into account overlap of spectra in crowded FoVs (Viala et al., 2004)
- Requirements specification for Gaia RVS (Cropper & Katz, 2004)
- Early results from CCD65 L3CCD using modified MSSL CCD facility (Walton, 2004a)
- RVS CDD requirements specification (Holland et al., 2004a)
- RVS data processing tasks (Hancock et al., 2004)
- Spectroscopic survey of the Galaxy with Gaia I. Design and performance of the Radial Velocity Spectrometer (Katz et al., 2004)
- GDAAS telemetry and data model for the RVS (Hui-Bon-Hoa & Katz, 2004a)
- Proposal for the Spectroscopic Global Iterative solution (Hui-Bon-Hoa & Katz, 2004b)
- Wavelength calibration using reference stars (Crifo & Katz, 2004)
- RVS performance capability (Cropper et al., 2004c)

4.6 RVS – Hardware Consortium

Mark Cropper & David Katz

The RVS Consortium has continued the work begun in 2003 to develop the RVS instrument, identify technical and schedule risks and support the two system-level teams (Alenia/Alcatel and EADS-Astrium) in respect of RVS matters. The Consortium supported both system-level teams in their SLTA&DS contract mid-term reviews, and provided all-up ROM (approximate) cost information for the provision of RVS. As the two payloads have developed, it has proved impossible to have a common design, so the Consortium is developing two similar instruments, with the main differences being opto-mechanical, while the detection chain and electronics are essentially common. This has also had the implication that the previously open information policy of the Consortium with a public website has had to be modified, with some documents requiring different versions for the two system-level teams. The competitive nature of the system-level study prevents some details being discussed in this report.

The year has been split into three parts: the first ran until the end of March, when the Technical Assistance phase contract with ESA ended, and the final report was produced. In October, a Development Phase contract with ESA commenced, and will last for a year. In the months between, RVS Consortium activities continued normally, funded with internal funds, especially after July when additional support in the UK was made available by PPARC. The Consortium structure has remained unchanged, except that the detector work packages transferred from Leicester University to Brunel University with the move of Prof Andrew Holland, and the optics work packages were transferred from Observatoire de Paris (Meudon) to MSSL/UCL. The other institutes are the University of Ljubljana and Asiago Observatory.

The TA Phase contract emphasised the optical design, the focal plane and the on-board data processing. The Definition Phase contract emphasises the detector technology, the on-board data processing and the development plan. In both cases, however the brief encompassed the entire design and development of the instrument. The TA phase final review identified three main priority areas: the adaptation of the Offner design to the two payloads, development of the on-board data handling algorithms and containment of the L3CCD technology risks, so these priorities guided the work between the two contracts.

The year began with a major change to the instrument baseline from a lens-based design to an Offner-spectrometer design. This uses two mirrors and a convex grating to achieve the required spectral dispersion ($\lambda/\Delta\lambda = 11\,500$) and optical performance. The advantages include greater throughput, the possibility of using materials and techniques which are similar to those used elsewhere in Gaia, and a less thermally-sensitive design. The Offner-spectrometer requires large path lengths, so there are also two flat fold mirrors, and with these the instrument is relatively compact and can be accommodated within both payloads (Astrium and Alenia/Alcatel).

A second major change occurred at that time with a revision to the MBP focal plane layout and MBP focal plane arrays by one of the system teams, and later adopted by both. The commonality of the Spectro telescope, and the drive to use similar FPA layouts for both MBP and RVS resulted in an increase in the field of view of the RVS significantly to approximately $2.5^\circ \times 1.6^\circ$. At the same time the focal length of the Spectro telescope was increased from 2.1 to 2.3 m. Both of these forced significant changes to the RVS optical design, but were accommodated within the Offner-spectrometer concept.

The L3CCD technology baselined for the RVS focal plane continued to be a priority, since it has no space heritage. Initial efforts concentrated on the tolerance to non-ionising radiation, with increasing confidence in the non-susceptibility of the L3 avalanche register to failure. A second issue arose at the end of Q1, in which the absence of any data proving the avalanche capability in the high-resistivity L3 devices was highlighted. Ten devices were therefore purchased from e2v from Consortium funds with a high priority in order to examine the voltages required. From Q3 onwards, the specification of the RVS L3CCDs was developed in consultation with ESA and e2v.

In more detail, starting with the optical work, the changes to field of view and Spectro telescope incorporated and the details of the Offner-spectrometer performance were explored in more detail. A number of tradeoffs were performed and particular attention was paid to the balance between wavefront errors and spatial distortion. Some time was lost in Q2 with the transfer of optical work packages to MSSL. There has been a significant effort involved in supporting the mechanical layout of RVS, and ensuring that the interfaces are correct. Initial specifications have been drafted for the grating, which was identified as a high risk item at the TA Phase final report, and vendors approached to comment on manufacturability, testing, schedules and costs. At least one vendor can produce the grating required for RVS.

A significant amount of effort has occurred on mechanical design, which first needed to be migrated to the Offner layout. The designs for the two payloads have now passed through several major iterations, with improvements at each stage. It was decided that it would be necessary to at least consider the inclusion of a focus mechanism on one of the flat mirror. Towards Q4, more detailed design commenced, especially of the mirror mounting strategies, but also of each structural item to support finite element analysis (FEA) and to facilitate obtaining durations and quotations for manufacture. The FEA has been carried out on the structure and on individual mirrors. Initial analysis showed that the first structure frequency was low, but this has now been increased to meet the requirement with relatively minor modifications.

The RVS FPA development was a major part of the work this year as noted above. Very detailed analyses were carried out into the performance of the instrument for different FPA configurations, detector resistivities, and L3, 2-d clocking or classical CCD. These concluded that the current

L3CCD baseline remained the optimal solution (L3+2d clocking was slightly better but introduced significantly higher technology risk). The 2-d clocking option was dropped from consideration in RVS although the e2v contract to develop test structures will be completed. The MBP-type focal plane was adopted, with the RVS L3CCDs being as similar as possible to the red MBP devices with only the addition of the L3 register and consequent changes (for example in the flexi connector). The L3CCDs will be part of the main ESA Gaia CCD procurement from e2v, with the option of withdrawing at particular milestones if the technology is found not to be suitable as it is better understood. During the year, more intensive radiation testing showed that even at 10× the Gaia proton dose, the L3 register performed successfully. More tests are planned of larger samples. e2v reported no unexpected effects of ionising radiation dose. Within the Consortium, tests at the Gaia operating temperature showed that reduced avalanche clock voltages were required, and proved 2.5 electron total video chain noise, even with low gain output stages in the engineering grade L3CCD65s being characterised. The high resistivity L3CCDs purchased from e2v are expected to be delivered shortly, and the avalanche voltages for this material will be characterised for the first time.

The electrical architecture continued to evolve and develop. The search for suitable ADCs and other proximity electronics has continued. Much of this work has been carried out in parallel with an Eddington/Gaia FPA electronics contract from ESA at MSSL/UCL and commonality with the Gaia Astro Proximity Electronics Module has been pursued where this is feasible.

The on-board algorithms were developed through two further iterations, with prototype software developed and a detailed report written for use by the PDHS contract. A requirements specification was also produced. This work allowed the scale of the processing task to be identified, and the prototyping in particular brought to light several secondary issues from earlier concepts which were refined during the course of the work.

At system level, work has begun on the development plan for the instrument, including the model and test philosophy, calibration and ground support equipment. The RVS Requirements Specification was developed from the ESA Gaia Systems Requirements Document, and subsidiary electronics, data algorithm and CCD requirements documents were issued. The ICD was updated in Q4 to reflect the Offner design. As the study progressed through Q4 more project management was incorporated in order to support the higher level of activity, and additional manpower was added both for technical and contractual tasks.

In summary, the RVS has developed significantly during 2004, and much progress has been made. The instrument should meet its performance targets, and is within mass and power allocations. There are currently no show-stoppers regarding technology or manufacturability. Much work remains to be done and details to be addressed through 2005, in particular as regards the optical procurement, L3CCD development and the support for the prime teams. Close working relationships have continued with the RVS Working Group.

Papers or reports issued during the year appear under the listing for the Radial Velocity Working group, with a more comprehensive listing at http://www.mssl.ucl.ac.uk/gaia-rvs.

4.7 Science Telemetry Definition and Simulation — Uwe Lammers

Telemetry Definition: the definition of science telemetry data models for Astro and MBP has been advanced to a point where they can be regarded as flight-representative in terms of completeness and complexity. Drafted data structures are in-line with proposed CCD sampling schemes, include all relevant object attributes determined by the onboard detection chain and honor CCSDS/ESA telemetry standards. Regarding RVS, a simple, robust telemetry model has been defined which, does not reflect the expected complications in view of spectral overlap and crowding yet but is sufficient for the sake of telemetry rate simulations (see below). A proposal for the time tagging of observational data onboard and their proper encoding and inclusion into the science telemetry data stream has existed for a number of years. This scheme has been re-visited in the light of its importance for attainable astrometric accuracies. It was found not not optimally suited for subsequent mission phases and a corresponding counter-proposal has been formulated. This now needs to be incorporated into the data simulations and GDAAS efforts. The telemetry definition work shall continue and should lead to a consolidated and coherent proposal considering all instruments in 2005. It is envisaged that models and structures are formulated in a novel XML-based framework proposed (to CCSDS) by ESOC and other groups.

Simulation Software: A simulation software for studying in detail Gaia science telemetry data rates and volumes has been designed and implemented. The tool allows to emulate as a function of time the complete science data flow starting from instrument-generated data for each observed object onboard down to the reception of telemetry data frames by the ground station on the Earth during daily communication periods. In this chain the presence of all relevant onboard elements such as the Solid-State-Mass-Memory (SSMM) is taken into account as well. For each of the three instrument modules (Astro, RVS, MBP) actual telemetry data models and current best-knowledge of design and performance parameters are utilised. As source for the latter the Gaia Parameter Database (PDB) is used by default. All other key parameters for the simulation are likewise taken from the PDB but can also be passed explicitly as input overriding the database defaults. Example are the downlink data rate through the Medium Gain Antenna (MGA), the size of the SSMM, limiting object magnitudes per instrument, performance of onboard compression algorithm, etc.

The software has been used to carry out a first large round of simulation runs for an assumed 5-year mission duration. A number of key results were obtained that provided a basic understanding in a number of areas where merely uncertain estimates existed before. As an example, the paramount importance of the SSMM in its function as data buffering device was clearly demonstrated. Owing to the extreme inhomogeneities of stellar densities across the sky the amount of data to be downlinked will likewise vary significantly. During phases of scanning in or at shallow angles to the galactic plane acquired data volumes will by far exceed the daily downlink capabilities. Excess data will have to be buffered in the SSMM for a subsequent gradual downlink over a number of consecutive ground station contact periods when lesser dense sky areas are scanned.

The simulation results are expected to aid well in forecasting an optimal size for the SSMM. A first attempt has been made to arrive at a concrete recommendation given the current mission profile and baselined satellite design. This analysis will have to be repeated as fundamental parameters evolve in subsequent phases.

A number of future developments are being envisaged in the interest of further improving the simulation tool and substantiating the results that have been obtained so far: (a) At present only a simple analytical galaxy model is used for predicting observed object densities. A better approach has been identified that is based on static object counts maps derived from the Besançon galaxy model. Present simulation results need to be verified/refined once these maps are available from the SWG; (b) the concept of data stream prioritisation shall be introduced in the simulations. The data from all three modules are now treated with equal weights in the downlink chain which does not correctly reflect their scientific significance. In the light of inevitable data loss with finite SSMM sizes and the concept of science alerts, Astro data should take precedence over MBP and RVS in cases of downlink resource conflicts; (c) a few improvements of the tool's diagnostic capabilities are envisaged to aid in understanding under which circumstances data loss occurs and how this can be optimised.

Papers or reports issued during the year:

- Telemetry rate simulations - a first look at the complete picture (Lammers, 2004b)

4.8 On-Ground and In-Orbit Calibration

Mario Gai & Uli Bastian

Objective: To monitor the industrial on-ground and in-orbit calibration plan, to assess feasibility of the proposed methods, requirements for a priori astronomical data, and provide inputs to the global iterative solution algorithms.

Core Members: Ulrich Bastian (in-flight and post-flight calibration); Fabrizio Bertinetto (metrology); Deborah Busonero; Rossella Cancelliere (mathematical modelling); Enrico Canuto (structural stability, attitude reconstruction); Daniela Carollo; Leonardo Corcione (technology); Rosario Cosentino (CCD, FPA); Mario Gai [leader]; Daniele Gardiol (instrument modelling); Davide Loreggia; M. Biermann; S. Hirte; H. Lenhardt; S. Jordan; Mike Denby; Richard Ambrosi (CCD)

Associate Members: Vladas Vansevičius

The goal of the On-Ground and In-Orbit Calibration Working Group is to implement and maintain a detailed model of the astrometric payload of Gaia, to be used during the manufacturing and integration, operation, and data reduction phases. The critical aspects are: optical quality of individual components and of the overall telescope, including the realignment capability; detector performance (initial and projected along the mission lifetime); instrument stability. The first two sets of parameters affect directly the random noise of individual measurements, whereas the latter impacts on the accuracy of the reference system and of the overall catalogue. Since many aspects of the hardware and of operation provide effects which are difficult to disentangle from each other, the instrument response is described by means of a global function, the Focal Plane to Sky Mapping (FPSM), providing the deviation of the measured position from the geometric conjugated position (gnomonic projection) on the sky. The FPSM is directly monitored on the science data by the transit time of each object on subsequent CCDs. The diagnostics is strengthened also by monitoring other image description parameters (e.g. moments) together with the individual positions.

Throughout integration, CWG monitors the instrument parameters critical with respect to the astrometric performance, supporting the verification of the hardware with respect to the design specifications.

During operations, the calibration task aims at verifying the instrument parameters through an appropriate subset of the science data (most likely the bright star measurements). Operations are ensured within a comparably wide range of the instrument parameters, corresponding to a few milliarcsecond projected on the focal plane; conversely, the targeted astrometric precision requires knowledge of the current parameter values to the order of the microarcsecond. It is thus fundamental to provide a verification of the instrument stability over a time scale shorter than the spin period, and possibly within the thermal time constant of few minutes. Preliminary analysis shows that bright star data may be able to support the diagnostics with an acceptable trade-off between precision and timing resolution.

During data reduction, astrometric, photometric and instrument parameters are derived iteratively on the whole science data set. A specialised version of the calibration procedures developed for in-flight monitoring may provide a cross-check of the proper behaviour of the data reduction, putting in evidence peculiar conditions, e.g. perturbation events or the detector performance variation due to progressive radiation damages. The case of Hipparcos has shown how important the availability of independent evaluation and verification is: in that case, the two data reduction consortia uncovered, by comparison of the results, several problems or errors which could be removed from the final catalogue.

An important contribution to calibration cross-check will be the First Look task currently investigated by the Heidelberg group and described in the following section.

During 2004, the activity of the Calibration Working Group was focused on definition of the measurement sequence and of the overall instrument parameters description in terms of Focal Plane to Sky Mapping (FPSM). The representative optical configuration for the astrometric payload of Gaia, developed in 2003, was used to derive the distribution of optical performance over the field, in terms of elementary measurement precision, and the elementary systematic error associated with chromaticity. The model, validated by cross-check with the results of the CodeV ray tracing code, can be used to derive the realistic measured signal of Gaia at the elementary exposure level, useful for an estimate of the astrometric noise (photon driven random errors) in each region of the field, and for derivation of the systematic errors associated with the source spectral type or with a number of external perturbation to the instrument (e.g. thermo-elastics), both by direct ray tracing or by application of the complete sensitivity matrix. A similar assessment has been performed on the alternative design of Gaia. The results have been presented in the GST 10 meeting on 23 January 2004, in a joint meeting of the CWG, Simulation, and On-Board Detection Working Groups (8-9 July 2004), and in the Gaia Symposium 'The Three-Dimensional Universe with Gaia' (October 2004). Specific issues on operations have been discussed with the OBDWG. Several aspects of the calibration methods under investigation, applicable to both baseline and alternative designs, have been preliminarily analysed in the CWG notes CWG003 and CWG004. Some of the results are included in papers in preparation for the open literature.

Future work in 2005 will include improvements on detector and operation modelling, and definition of procedures for maintenance of the FPSM.

4.9 First Look

Uli Bastian

The purpose of the First Look (FL) task is to provide a quick verification of the health and proper functioning of the spacecraft and scientific instruments during Gaia's operational phase, and in particular to provide a quick in-depth assessment of the inherent measurement precision. The goal is to derive such information on a timescale of one day, in order to be able to quickly recognize any loss of scientific data quality, and to be able to take timely countermeasures to regain the best possible measurement precision.

Spacecraft and instrument health will be assessed at several different levels: The ground segment will do the daily Quick Look (QL), based mainly on housekeeping and ACS data. The so-called Science Quick Look(ScQL), involving a science group in addition to the ground segment, will extend this by investigating a significant subset of the raw scientific data from the instruments. However, the data quality cannot be checked on the μarcsec and millimagnitude level without an extensive scientific data analysis including a high-precision auto-calibration. This will be achieved by the First-Look Preprocessing (FLP) task. The results of this task will subsequently be analysed in the so-called Detailed First Look (DFL). The latter two tasks will be in the hands of a science group, which will routinely feed back its results to the ground segment.

The main science data reduction processes of Gaia (GIS, SGIS) are not suited to satisfy the needs of Detailed First Look. They are computationally very big, and by construction they need many months of data to work. Special methods are therefore necessary to quickly reach (at least some) information on the measurement precision and instrument/spacecraft behaviour at the mission's target precision levels. In the case of Hipparcos this purpose had been served by the Great-Circle reduction as part of the main data reduction. But that procedure does not work in the case of Gaia.

Starting end of 2003, a working group centered on ARI (Heidelberg) has been active in developing the overall First Look concept. For ScQL, specifications of the necessary input data, of the relevant diagnostics and statistics to be derived from them, of the criteria to judge their values, and of the consequences of various possible outcomes are being collected. For the astrometric FLP, two alternative mathematical approaches (called 'one-day iterative solution' and 'ring solution') are being developed and tested. Prototypes for both were essentially completed by the end of the year. During this work it became apparent that First Look will provide the first high-precision calibrations of Gaia and that First Look can significantly contribute to Gaia's commissioning phase.

Two dedicated meetings with ESOC were held to establish contact and to start developing a common understanding of the tasks and goals. Discussions with the on-board data handling group and with the relevant working groups for photometry and RVS were started up on various meetings. A first-stage concept study for First Look, including demonstration software for FLP, is planned to be completed by May 2006.

4.10 Double and Multiple Stars

Frédéric Arenou & Staffan Söderhjelm

Objective: To assess the impacts and requirements on Gaia implied by the existence of double and multiple stars, from the on-board requirements (e.g. samples and patches), the interaction with the photometric and radial velocity data, implications for the data processing (implications for core processing, and detection and analysis algorithms), and exploitation (orbital reconstruction) for all mass ranges down to brown dwarfs.

Core Members: Frédéric Arenou [leader]; Carine Babusiaux; Coryn Bailer-Jones; Henri Boffin; Johann Dischler; Claus Fabricius; Paul Groot (close binaries); Jean-Louis Halbwachs; Sylvie Jancart; Patricia Lampens; Oleg Malkov; François Mignard; Pasi Nurmi; Dimitri Pourbaix; Noel Robichon; Dimitris Sinachopoulos; Staffan Söderhjelm [co-leader]

Associate Members: Hans-Heinrich Bernstein; Melvyn Davies; Claire Dollet; Misha Haywood (brown dwarfs); Erik Høg; Carme Jordi; Roberto Morbidelli; Panagiotis Niarchos; Edouard Oblak; Julienne Palasi; Renato Pannunzio; Ignasi Ribas; Alessandro Spagna; Toma Tomov; Christopher Tout; Vladas Vansevičius; Hans Zinnecker

The analysis of the Double and Multiple Stars (DMS) has been pursued in 2004 with respect to the science case, the simulations and the data analysis, and the Gaia 2004 conference has been the occasion to illustrate these various studies, some of which are mentioned here.

The simulation of DMS has been improved with a description of the 'effective' double-star distribution functions in a form sufficiently simple to allow it to be used for adding binaries to a single-star Galaxy model. Besides their use in refining the science case, the simulations also allow to test the efficiency of the on-board as well as of the on-ground reduction algorithms.

DMS can take benefit from the imaging analysis, which consists of stacking the images obtained at several transits of the same field. The S/N of secondary sources has been studied as a function of different numerical binnings and samplings in AF11, and this has allowed to refine the sampling scheme for this CCD.

The identification and parametrisation of binaries in MBP is another useful study of the duplicity, seen here from a photometric point of view. The detection rate and precision on the various physical parameters which can be determined have been computed as a function of S/N and luminosity ratio.

Progress has been made for the orbit determination aspect, in particular concerning the spectroscopic binaries, taking into account the Gaia scanning law. The astrometric binaries have however not been forgotten: the orbit recovery performances have been evaluated using the Ninth Catalogue of Spectroscopic Binary Orbits, and the GDAAS2 algorithm determining the orbit has successfully served as a test-bed for Grid computing using binary systems simulated with the GASS simulator.

Another study has been initiated, concerning the astrometric binaries with a variable component, giving access to the position angle for a 'fixed' system, or the orbit of the variable component for orbital VIMs.

Eclipsing binaries which are also double-lined spectroscopic binaries continue to be the object of studies in order to evaluate the expected scientific performances while determining orbital and stellar parameters for some systems poorly studied in the literature, using Hipparcos data as an approximation of the future Gaia photometry. A study for a full automated analysis is also ongoing.

Because the overall data analysis of Double and Multiple Stars will be complex, an overall view of the needed resources and interactions between algorithms is needed. For example, an estimation of the (rough) CPU needs of several DMS algorithms has been computed, thanks to the input of algorithm providers.

The Working Group has had one meeting during 2004, on October 7 in Paris, in common with the Planetary Systems Working Group. The contributions may be found on the updated web site http://wwwhip.obspm.fr/gaia/dms, which also contains all the other documents relevant to the Gaia DMS activities (texts, tasks, members).

Papers or reports issued during the year:

- Observing binaries with Gaia - the global picture (Söderhjelm, 2004a)
- Orbits from Hipparcos (Pourbaix, 2004)
- SB2 and eclipsing binaries with Gaia and RAVE (Munari et al., 2004)
- Evaluating Gaia performances on eclipsing binaries III (Marrese et al., 2004)
- DMS (Double and Multiple Stars) work packages (Arenou & Söderhjelm, 2004a)
- Theoretical modelling of observational double-star distribution functions (Söderhjelm, 2004b)
- Double and multiple stars report, Sep 04 (Arenou & Söderhjelm, 2004b)

4.11 Planetary Systems

Mario Lattanzi

Objective: To evaluate the detection capabilities of planetary systems with Gaia (astrometric, photometric, etc.). To refine models of the expected number of systems which may be discovered, and to assess the physical diagnostics that may be expected (orbital elements, co-planarity, etc.) in connection with payload developments. To develop the analysis tools necessary for the data analysis. To consider ground-based facilities and networks that will eventually be required for their follow-up observations.

Core Members: Frédéric Arenou; Stefano Casertano; Claus Fabricius; Sylvie Jancart; Mario Lattanzi [leader]; Bruno Lopez; Karri Muinonen; Petri Muinonen; Renato Pannunzio; Dimitri Pourbaix [co-leader]; Noel Robichon; Alessandro Sozzetti; Alessandro Spagna; Paolo Tanga

Associate Members: Coryn Bailer-Jones; Hans-Heinrich Bernstein; Henri Boffin; Melvyn Davies; Erik Høg; Roberto Morbidelli; Antonino del Popolo

The Planetary Systems Working Group held one meeting on 8 October 2004 at the Paris Observatory. This was hosted by Arenou and Lattanzi. Among the highlights: 23 participants; strong representation from the European planetary transit community (colleagues from the Institut d'Astrophysique, Observatoire Paris-Meudon, and Geneva University Observatory). Several new members joined the group at this meeting.

The following milestones were achieved this year:

June 2004: Test T1 of the Double Blind Test campaign completed and full report circulated (PSWG-OAT-003). The T1 and T1b tests aimed at estimating the completeness and reliability of the planet detections based on fits to simulated time series, either single-star or with orbits. Data simulating a 5-year mission were generated for a total of 100 000 stars, approximately half of which had a planetary companion with signature ranging between 2 and 80 μarcsec and period between 0.2 and 12 years. About 5 per cent of the stars had two planets, and about 1 per cent had three planets. The distribution of planetary signatures was unknown to the two Solvers. On this data set, Solvers were asked to carry out two tests. Test T1 consisted of identifying the likely planet detections, based on a single-star analysis and criteria of the Solvers' own choosing. Test T1b gave the opportunity to the Solvers to improve on their planet detection on the basis of an orbital fit, i.e. using the knowledge that the deviations from a single-star were in fact expected to have the signature of a star-planet system. Unlike for Phase 0, no information was provided to the Solver regarding the actual orbital parameters of the planets; in this sense, Phase 1 was the first truly double-blind test.

The results have shown that, at least for the cases under consideration, detection tests based on deviations from the single-star astrometric solution perform as well as can be expected. Planets down to astrometric signature of 20 μarcsec, corresponding to 2.5 times the assumed single-measurement error, can be detected reliably and consistently, with a very small number of false positives. Even better, the choice of the detection threshold is an effective way to distinguish between highly reliable and marginal candidates. Under the assumptions of this test, which is based on an idealized, perfectly known noise model, potential planet-bearing stars can be identified and screened reliably. Refinements of the detection criterion based on additional considerations, e.g. the quality of the orbital fit, can potentially make an improvement in the fitting procedure. However, the performance of a straight Chi-square or F2 test is already extremely good; such tests, if properly applied, can yield candidates with the expected range of sensitivity and with a powerful discrimination against false positives.

October 2004: The Invited talk 'Detection and Characterization of Extra-Solar Planets with Gaia' delivered at the Gaia Symposium 'The Three-Dimensional Universe with Gaia'. The talk detailed the most recent simulation activities and considered whether or not, based on our results, there is an impact on the Gaia potential contribution to extra-solar planetary science.

Results for the T2 experiment of the DBL test campaign were presented at this meeting for the first time. This experiment was dedicated to determine how well the orbital parameters of a single planet can be measured for a variety of signature significance, period, inclination, and other parameters. The simulations consisted of 50 000 stars, each with a single planet with significance ranging from 2 (barely detected) to 200. Solvers derived the best-fit orbital parameters, together with an error estimate for each and covariances if appropriate. Evaluators first assessed the quality of the solutions and of their error estimates. Evaluators then studied the distribution of orbital parameter errors versus the stellar and orbital parameters themselves, with the goal of deriving simple expressions that can predict the accuracy of the orbital solution for various types of planets as a function of the Gaia error model.

The solvers ran their respective pipelines (detection+orbital reconstruction)on the 50 000 simulated stars, each with one planet, without knowing anything about their orbital properties. The evaluator compared the derived orbital parameters to the simulated ones and his plots showed remarkable agreement. The increasing difficulty of correctly estimating the periods beyond 6-yr is striking in both results. Expectations from our earlier results were that periods up to approximately twice the mission duration (about 9 yr) should have been reliably recovered. However, this was when the scanning law was such that the average number of observations (epochs) available for orbit reconstruction was around 80, twice what is provided by the current scanning law. Therefore, we believe that the 6-yr limit represent the new limit given the adopted scanning law.

On the other hand, we are investigating how we could discriminate between 'bad' (underestimated) and 'good' periods beyond the 6-yr limit in an objective way through the correlations of the orbital solutions with quantities like the number of observation epochs (or ecliptic latitude), error estimates, and other relevant information that might be available during data reduction. The Solvers used fully automated detection and measurement procedures implementing different algorithms.

The methods do not need any a priori knowledge of the orbital characteristics of the simulated planets. In short, the PSWG code is already capable of handling real data.

With the test campaign still on-going we had only started looking at the results in the same way as our earlier investigations, i.e. by analyzing detection probabilities and quality of orbital solutions as function of distance from the Sun and the intrinsic orbital properties (period, inclination, eccentricity, longitude of the ascending node). Preliminary indications are that most of our earlier conclusions remain valid with the noticeable exception of the reduced sensitivity to longer orbital periods caused by the adoption of the current scanning law. Nevertheless, with most of its potential intact, the Gaia contribution to the science case remains as strong as ever. Gaia's main strength continues to be the ability to measure actual masses and orbital parameters for possibly thousands of extra-solar planetary systems. The Gaia data have the potential to: (1) significantly refine our understanding of the statistical properties of extra-solar planets; (2) help crucially test theoretical models of gas giant planet formation; (3) improve our comprehension of the role of dynamical interactions in the early as well as long-term evolution of planetary systems; (4) provide fundamental information to optimize the selection of targets for Darwin/TPF.

Impact of bright star measuring strategies on planet search: this is a critical issue in connection with the current payload developments and Gaia's intrinsic ability of actually delivering its potential to the field of extra-solar planet science. At the PSWG meeting on 8 October Gai reported on the on-going activity to accurately gauge the error at transit level and possibilities offered by the current hardware (full resolution, gates, etc) and different measuring schemes to improve on saturations effects. Saturation sets at $G < 13$ mag (function of Sp) under normal operations (across-scan integration). Full 2D pixel resolution sets saturation at 12.1 mag (again function of Sp). Gai presented a plot showing first results on bright star measurements (1 CCD transit) based on a simple rejection strategy of saturated pixels. The plot reproduces the well-known saw-tooth behaviour of the error as function of magnitude and shows an error of 42 μarcsec at G=12. It is encouraging to know that this number, after considering two consecutive transits of the focal plane, translates to 8.5 μarcsec. This is quite consistent with the great-circle level error considered in the simulations for the double blind test campaign.

Transits: discussion on photometric error budget for searching planets utilizing transits followed (initiated by Vidal-Madjara). Estimates were provided by Robichon who showed curves of photometric error vs magnitude: at G = 15–16, corresponding to the estimated peak of planetary transit discoveries with Gaia, $\sigma_G = 0.002$ mag per transit (for AF and MBP field). A floor of 0.001 mag must be added as one moves toward brighter magnitudes.

Status (conclusion) of the double blind test campaign (expectations, schedule): a summary of the double-blind test campaign was presented (Lattanzi). Discussion concentrated on planning the last, and most difficult step, i.e. the detection of and orbital fit to multiple planets to test the potential of Gaia in establishing co-planarity (see minutes_pswg_no5_last.doc, available on request from Lattanzi).

Papers or reports issued during the year:

- Double-blind tests program for astrometric planet detection with Gaia - progress report II - results for tests T1 and T1b (Casertano et al., 2004)

4.12 Variable Stars

Laurent Eyer & Dafydd Wyn Evans

Objective: To consider the implications of variable stars on the Gaia mission, from the perspective of astrometric requirements (accuracy and multiple star detection) and photometric requirements (choice of filter system); data analysis (impacts on the global iterative solution algorithms); variable star detection, requirements, and analysis; science alerts requirements.

Core Members: Vasily Belokurov; Peter de Cat; Dafydd Evans [co-leader]; Laurent Eyer [leader]; Juan Fabregat (variable X-ray and high-energy sources); Francesca Figueras; Martin Groenewegen; Mike Irwin; Alain Jorissen (Miras and long-period variables); Patrick de Laverny; Philippe Mathias; Ignasi Ribas (eclipsing binaries); Glenn Wahlgren; Werner Weiss; Robert E. Wilson

Associate Members: Coryn Bailer-Jones; Massimo Fiorucci; Margarida Hernanz; Carme Jordi; Franz Kerschbaum; Peter Kroll; Arunas Kučinskas; Thomas Lebzelter; Coralie Neiner; Panagiotis Niarchos; Piotr Popowski; Dimitri Pourbaix; Peter Reegen; Laszlo Szabados; Vladas Vansevičius; Stefan Wagner (extragalactic variability); Filippo Zerbi; Tomaž Zwitter

There have been some organisational changes, a co-task leader was proposed and chosen: Dafydd Wyn Evans from Cambridge University. Several people joined the group enlarging it to 40 people. During 2004, there have been two VSWG meetings in collaboration with the SA and ICAP working groups, they took place in Cambridge and Paris. Participation in SWG and PWG meetings occurred in Torino, and Copenhagen. Furthermore small workshops/meetings took place in Leuven, Torun, Barcelona, Besançon and in Princeton. Decisions and tasks have been completed and actions were engaged, which are now described below.

A general path for the variability analysis has been laid out by Eyer (2005) at the Gaia Symposium in Paris.

There are four steps: variability detection, definition of variability characteristics, classification (probably the need of trained/untrained methods, as well as selection of specific types), finally fitting variable type models.

Work directly related to GDAAS: (1) In order to include variable star analysis in GDAAS, there is a need to introduce variable stars to the Galactic model. The group members who participated in the variable star characteristics are completing the descriptions. It is now the third iteration of the variable star characteristic description. We have at the end of 2004 about 15 variable star characteristics homogeneously described, covering most of the pulsating star types. (2) It has been decided to perform variability tests in the G band for all stars as the G band produces very accurate photometric measurements. It has also been proposed to chose a set of variability tests which can be formulated in a cumulative way. Some code in Fortran has been written for variability tests. They were delivered in September 2004. Since then they have been reviewed by Dafydd Evans.

It has been decided to perform a benchmark of period search algorithms. As pointed out by V. Belokurov, there are some optimised methods even with classical code, which can significantly reduce the computation time. Certain period search methods, are able to detect periods that some others detect only with a poor efficiency. So there is a need to compare period search methods. An action has been set on this topic. Furthermore work has been done on a new method of period search by S. Paltani. There is also a new method from F. Mignard.

A study by L. Eyer and F. Mignard has been completed (submitted to MNRAS): it shows that for strictly periodic signals low signal-to-noise ratios can be detected.

On the question of classification, several studies have been made. It is not yet comparative and we are more in method exploration. The different methods investigated are Self-Organising Maps by V. Belokurov and by A. Naud, Bayesian classifier on ASAS data by L. Eyer, C. Blake (accepted for publication in MNRAS, astro-ph/0406333), and a study has been started by P. Willemsen on the Support Vector Machine method.

The web site has been updated regularly, a list of data mining methods has been added by A. Naud, a list of tools was added. As suggested by V. Belokurov online data were added to the variable star characteristics.

Papers or reports issued during the year:

- Variability of Beta Cephei and SPB stars (Neiner & de Cat, 2004)
- Variability of Gamma Doradus stars (Mathias & Chapellier, 2004)

4.13 Solar System Objects

François Mignard & Vincenzo Zappalà

Objective: to assess the Solar System observations that are feasible with Gaia, to assess any implications for the on-board design (detection, photometry), to assess on-ground processing aspects including orbit determination, and links with subsequent on-ground observations required.

Core Members: Mario Carpino (orbits, masses); Alberto Cellino (size, IRAS calibration); Marco Delbo; Aldo dell'Oro; Elisabetta Dotto (asteroid taxonomy); Daniel Hestroffer; Erik Høg (NEO); Sergei Klioner (relativity); François Mignard [leader]; Karri Muinonen (orbits); Michel Rapaport; Paolo Tanga (surface properties of asteroids); William Thuillot (ground-based follow-up); Stefan Wolff; Vincenzo Zappalà [co-leader]

Associate Members: Coryn Bailer-Jones; Philippe Bendjoya; Jerome Berthier; François Colas (comets); Alain Doressoudiram (KBO); Wyn Evans (Trojans, science alerts); Claus Fabricius (NEO); Poul Hjorth (NEO); Uffe Jorgensen; Claes-Ingvar Lagerkvist; Rene Michelsen (asteroids, NEO); Alessandro Morbidelli; Jean-Marc Petit; Vladas Vansevičius; Jenni Virtanen

The objective of this working group is the assessment of the solar system observations that are feasible with Gaia, the implications for the on-board design (detection, quick alert, moving sources) and the preparation of the ground-based data processing to maximise the science return. The major tasks identified, which determine the overall structure of the WG, are the simulation and detection, the photometric processing, the taxonomic classification, the orbit, mass and physical properties determination from the Gaia data, together with the preparation of a ground-based follow-up.

Very significant advances have been made in 2004 in several of the tasks and key-decisions were made regarding the future activities of the working group. P. Tanga and F. Mignard have continued the development of the simulation by adding a realistic photometry with ellipsoidal sources in rotation and refining almost every aspect of the calculation of the observing sequence and of the error model. The latter is primarily worked out by D. Hestroffer with GIBIS and later adapted to the simulation in the astro fields. The main output of the simulation (observation sequences) has been also customised to meet the needs of the GDAAS prototype, allowing to introduce solar system objects, without restarting from the orbital elements.

The simulation can now produce epoch photometry with enough sophistication to test the inversion aiming to retrieve the shape and rotation parameters of the source. The tools are essentially developed by K. Muinonen, M. Kaasalainen, A. Cellino. Although we have now a reliable assessment of the capabilities of Gaia in this area, much work is still needed in software development, both in simulation and inversion to cope with the complexity of the actual shapes and to evolve toward a robust solution. This study has also permitted to derive practical expressions for the photocentric shift, not too much dependent on the precise knowledge of the surface scattering properties, as was shown by P. Tanga. As for the shape and size an alternative method is currently investigated by A. Dell'Oro and M. Delbo based on the CCD signature, using the departure of the PSF of an extended objects from that of a point source. This method appears promising, especially when the epoch observations can be brought together.

The detection of moving objects on the Astro-fields has been investigated in detail by S. Wolff. In brief he found that for one field crossing of a standard main-belt asteroid, the along-scan velocity will be known with a standard deviation of 0.08 mas/s and 0.2 mas/s for the NEOs. This indicates (i) that the system will be very efficient to recognise moving objects and (ii) that this velocity will be a very useful parameters to predict the position for the next few weeks, a very desirable feature to cross-match the observations. F. Mignard has presented and tested a first version of a chaining algorithm based on the velocity determined at each field crossing, which should allow to bring together all the observation of most of the moving sources.

For the orbit determination K. Muinonen, J. Virtanen and M. Granvik are working out a major piece of software to determine the orbits of minor planets using Gaia-only data. Several methods are tested and the current application has been recoded in F90/95 and comprises about 20 000 lines. From experiments they have shown that given the extreme accuracy of the Gaia measurements, the short arc technique should be efficient to bracket the orbital elements in a box small enough to recover the new objects. The same group, and also D. Hestroffer and J. Berthier have also investigated the orbit improvement for minor planets with a preliminary orbit and shown that the relative accuracy in the orbital elements should be close to 10^{-10}, allowing to see the perihelion precession for the most eccentric ones. M. Rapaport has improved the mathematical model to be used in the determination of the masses with the goal of obtaining an evaluation of the covariance matrix. The standard deviations (formal) show that the masses can be obtained for most of the objects with a formal accuracy below 0.2×10^{-12} solar mass. Due to the retirement of M. Rapaport this work is taken over by S. Mouret in the framework of his PhD work with D. Hestroffer and F. Mignard. A temporary position is funded (from the French Ministry of Higher Education) for the coming three years to carry out this work.

Thanks to the arrival of two new members, S. Lainey from IMCCE in Paris and H. Rauer from the German Institute of Planetary Research in Berlin, we have also looked at the possible impact of Gaia in the dynamics of natural satellites and in cometary science. P. Tanga and F. Mignard are now introducing a new functionality in the SSWG simulation to include planetary satellites, and more generally binary sources. A first version will be presented at the next meeting in May 2005.

The semi-annual advancement meetings of the working group have taken place in May 2004 at the Observatory of Helsinki and in November 2004 at the Lohrmann Observatory in Dresden and both were attended by nearly 20 people. During each meeting the on-going tasks have been reviewed and discussed and guidelines are fixed for the next six months. The next meeting is scheduled at the Observatoire de la Côte d'Azur, Nice, in May 2005. In addition to the tasks reports, one should also discuss on a more detailed task breakdown for the actual data processing and the testing of the algorithms mentioned in this report in a more systematic way on a significant number of cases. Several members of the group made noted presentations during the Gaia symposium in Paris which helped raise the awareness of the scientific community on the impact of Gaia in Solar System Science.

Papers or reports issued during the year:

- Fourth meeting of the Solar System Working Group
- Minutes of the fifth meeting of the solar system working group
- Minutes of the sixth meeting of the solar system working group

4.14 Data Processing Prototype — Lennart Lindegren & Jordi Torra

Objective: To supervise the development of the Gaia data processing prototype, to establish priorities for the core and parallel processing tasks, and define parameters for the simulation runs. To evaluate data base capabilities for protoype processing, mission data processing, and final catalogue access.

Core Members: Frédéric Arenou; Coryn Bailer-Jones; Francesca Figueras; Jean-Louis Halbwachs (recognition); Carme Jordi; Peter Kroll (general data processing scheme/hardware); Floor van Leeuwen; Lennart Lindegren [leader]; Xavier Luri; François Mignard; William O'Mullane; Dimitris Sinachopoulos (object matching, data base, science alerts); Jordi Torra [co-leader];

Associate Members: Hans-Heinrich Bernstein; Olivier Bienaymé (data base); Henri Boffin; Anthony Brown (data base); Daniel Egret (data base); Claus Fabricius; Danielle Morin (data base); Dimitri Pourbaix; John Pye; Noel Robichon; Elena Schilbach; Vladas Vansevičius; Andreas Wicenec (links to ESO)

As in 2003, the work of this grouphas been tied very closely to the industrial data base effort, and results are described under Section 5.

4.15 Simulations of Data Stream

Xavier Luri & Carine Babusiaux

Objective: to simulate the data stream generated by the astrometric (ASM, AF, BBP) and photometric (SSM, MBP) fields, to support investigations of accuracy, sampling strategy, data compression, data analysis, scientific performance, etc. The simulation tool will be modular, allowing progressive enhancement of the simulated data quality towards representative flight data.

Core Members: Frédéric Arenou; Carine Babusiaux [co-leader]; Anthony Brown; Claire Dollet; Ronald Drimmel (extinction); Wyn Evans; Francesca Figueras; Daniel Hestroffer; Carme Jordi; David Katz; Xavier Luri [leader]; Eduard Masana; François Mignard; Dimitri Pourbaix; Noel Robichon; Annie Robin; Dimitris Sinachopoulos; Erik Slezak; Staffan Söderhjelm (binaries); Jordi Torra; Alberto Vecchiato

Associate Members: Guillem Anglada; Coryn Bailer-Jones; Vasily Belokurov; Albert Bijaoui (compression); Jos de Bruijne; Beatrice Bucciarelli; Véronique Cayatte; Dafydd Wyn Evans; Mario Gai; Enrique García-Berro (white dwarfs, microlensing); Gerry Gilmore; Misha Haywood; Sonja Hirte; Erik Høg; Andrew Holland; Mike Irwin; Jordi Isern; Alain Jorissen (Mira variables); Sergei Klioner (relativity); Romylos Korakitis; Mario Lattanzi; Floor van Leeuwen; Lennart Lindegren; Pere Llimona; Gary Mamon; Marie-Odile Mennessier; Manolo Moreno; Danielle Morin; Jordi Portell; Celine Reyle; Elena Schilbach; Ralf Scholz; Alexander Short; Alessandro Spagna; Gilles Theureau; Enric Trullols; Vladas Vansevičius; Simon Vidrih

The structure of the Gaia Simulator, as well as the organization of the SWG, are already well consolidated. Thus, the activities in 2004 have been mainly orientated towards reaching a higher level of realism and complexity in the simulator. Notwithstanding this, the development of the two data generators, GIBIS and GASS, has continued at good pace, with new versions being regularly released; at the same time, the basis for a new data generator, GOG (Gaia Object Generator) has been laid out during this year.

The SWG is now composed of 21 core members and 39 associate members. Its management resources include the web pages (http://gaia.am.ub.es/SWG/) and a CVS repository where the Gaia Simulator code is maintained. In addition, the GIBIS simulator can be accessed via the web pages (see http://gibispc.obspm.fr/ gibis/index.html).

During 2004 three SWG meeting were held:

Cosmic radiation simulation meeting, Bruxelles, 27 April 2004: This meeting was devoted to the definition of a road map for the simulation of cosmic rays. As a result a first implementation has been made available.

Galaxy Model meeting, Barcelona, 27 May 2004: This meeting was devoted to the discussion of the Galaxy Model to be adopted for Gaia simulation. The options were reviewed and the java implementation of the Besançon Galaxy Model was started.

Joint SWG-CWG meeting, Torino, 8-9 July 2004: In this meeting the implementation of the Besançon Galaxy Model was reviewed and discussed. At the same time, count predictions for Gaia from the data of the GSC-II were presented, to be used as a reality check for the simulations. Also, the implementation of elements of the Universe Model beyond the Galaxy Model was discussed.

During 2004 the different parts of the Gaia simulator have grown in complexity and realism and a new data generator, GOG, has been added.

GIBIS: early 2004 GIBIS version 1.5 was released, including the simulation of minor solar system objects. End of 2004 GIBIS version 2.0 was released, containing many improvements, among others a new Astro and Spectro design, a full implementation of Pyxis 2.0, a new Astro and Spectro PSFs and realistic simulation of cosmic rays.

GASS: mid-2004 GASS version 2.0 was released, implementing the latest design of the Astro instrument and a more complete model of the windowing system. GASS was deployed in GaiaGrid, allowing the generation of more massive simulations.

GOG: this new data generator, the Gaia Object Generator, was defined during 2004 and the basis for its development was laid out. Its main purpose will be to generate predicted object counts as well as simulated intermediate and final Gaia data, as a complement GIBIS and GASS for providing simulations for the preparation of the Gaia data processing.

GaiaSimu: the structure of GaiaSimu was revised and updated. The java implementation of the Besançon Galaxy Model was integrated in GaiaSimu and is now fully available in the Gaia Simulator environment. The Besançon Galaxy model is now adopted as the standard Galaxy Model for Gaia.

Papers or reports issued during the year:

- Simulation of Astro LSFs and chromaticity for GDAAS-II (Fabricius, 2004)
- Solar system simulation for GDAAS (Mignard, 2004c)
- Requirements for a Gaia star-count Galaxy model (de Bruijne, 2004d)
- Simulation of the Gaia point spread functions for GIBIS (Babusiaux et al., 2004)

4.16 Classification

Coryn Bailer-Jones

Objective: To address the problem of identification, classification and physical parametrization of objects observed by Gaia, using the extracted data after the on-board object detection and data reduction have been performed. The key goal is the determination of the physical parameters of stars, but in the process segregating solar system and extragalactic objects.

Core Members: Coryn Bailer-Jones [leader]; Anthony Brown (ground-based spectra); Norbert Christlieb; Jean-François Claeskens (QSOs); Carme Jordi; Torsten Kaempf; David Katz (RVS); Oleg Malkov (extinction, binaries); Valeri Malyuto (MDM, new parametrization methods); Dimitris Sinachopoulos (binaries, QSOs, new parametrization methods); Alain Smette (QSOs); Grazina Tautvaišienė (evolved stars, CNO and alpha elements); Vladas Vansevičius; Philip Willemsen

Associate Members: Hans-Martin Adorf; Frédéric Arenou (multiple stars, brown dwarfs, exoplanets); Henri Boffin; Federico Boschi (RVS); Roland Buser (galaxies); Laurent Eyer; Massimo Fiorucci; Eva Grebel; Christian Hennig; Erik Høg; Alain Jorissen (red giants); Algirdas Kazlauskas (Stromvil filters, MDM); Jens Knude; Indrek Kolka; Romylos Korakitis (algorithms, identification, classification); Arunas Kučinskas; Thomas Lebzelter; Ulisse Munari; Michael Odenkirchen; Dimitri Pourbaix (binaries); Celine Reylé; Annie Robin; Pierre Royer (QSOs); Caroline Soubiran (MDM, spectral libraries, standards); Vytas Straizys; Jean Surdej (QSOs); Frédéric Thevenin (parametrization, binaries, specific objects); Catherine Turon; Tomaž Zwitter

The classification group, ICAP ('Identification, Classification and Astrophysical Parametrization') continued working on a number of topics in 2004. Some of this was presented at the Gaia symposium held in Paris in October 2004 and reported in the proceedings.

Christian Hennig studied a number of different statistical methods for performing a discrete classification of Gaia objects (single stars, binary stars, QSOs) and for efficiently identifying outliers (ICAP-CH-001).

Bailer-Jones continued to develop and apply his ‘Heuristic Filter Design’ method for designing the Gaia photometric systems. This contributed to the overall photometric system design effort coordinated by the PWG, which led to a baseline system being selected during the joint ICAP-PWG meeting in Athens in November (Gaia-CBJ-016, -015). Tautvaišienė studied the effects of the alpha-process element abundance on stellar spectra, with the aim of seeing how well alpha-process elements can be determined from Gaia photometry (ICAP-GT-002).

Claeskens, Smette & Surdej continued to work on the identification of QSOs in the Gaia photometry, and how well they can be distinguished from stars. This is necessary for constructing the quasi-inertial reference frame for the astrometry, but a million or so QSOs with multi-band photometry are scientifically interesting in their own right; Claeskens et al. have shown that photometric redshifts and spectral properties can be determined (ICAP-JCF-001).

As part of a wider Gaia effort, Bailer-Jones made initial estimates of the data processing requirements for the classification tasks. This estimate depends heavily on whether global regression methods or local estimation methods are used. In the former case, the processing load as measured in FLOPs is small compared to other tasks, but the latter could be prohibitive (Gaia-CBJ-017).

Willemsen, Kaempf & Bailer-Jones have studied estimating confidence intervals on stellar parameter determinations. They implemented the bootstrap method using neural network classifiers and studied how random and systematic errors vary with magnitude (ICAP-PW-003). This same group also looked at the identification and parametrization of unresolved binary stars, i.e. ones with composite spectral energy distributions. Long-period, distant binary systems will not be revealed by astrometry, yet detecting them is necessary not only for studies of stellar binarity but also for determining mass functions. Using Support Vector Machines, they investigated the reliability with which binaries could be identified as a function of mass ratio and other parameters (ICAP-PW-004).

Malyuto & Myakutin continued to develop a tool for determining stellar radii for stars of given T_{eff}, log g and [Fe/H] based on evolutionary tracks. This tool can be used to estimate the total intrinsic luminosity of a given star in a synthetic template grid (i.e. those used for training classification models). This enables us to model the apparent luminosity of a star of given parallax, and thus allow us to introduce the Gaia parallax into estimating stellar astrophysical parameters. Where the parallaxes are accurate, this should improve the determination of, in particular, surface gravity and effective temperature (ICAP-OM-001).

Additional classification work has been carried out in other working groups. Brown has used self-organizing maps (SOMs) to identify the astrophysical parameter degeneracies in the Gaia photometry (PWG-AB-005), and Eyer (Variable Stars WG) and Belokurov (Alerts WG) have also used SOMs for identifying new or unusual types of objects based on their light curves. Thevenin & Recio-Blanco have worked on determining stellar parameters from the radial velocity spectra. For more information, see the reports from the Photometry and the Radial Velocity working groups.

Three ICAP meetings were held during 2004, all jointly with other working groups: Joint ICAP-VSWG-Alerts working group meeting, 15–16 April, Cambridge; Joint ICAP-VSWG-Alerts working group meeting, 8 October, Paris; Joint ICAP-PWG working group meeting, 25–26 November, Athens.

Details, minutes and copies of the presentations can be obtained via the Classification Working Group web site (http://www.mpia.de/Gaia/).

Papers or reports issued during the year are included within the Photometry Working Group section.

4.17 Relativity and Reference Frame

François Mignard & Mario Lattanzi

Objective: to formulate a data reduction model for the celestial sphere fully consistent with the precepts of General Relativity and including all relevant space-time effects; to establish the procedures for the implementation of such a model; to make provision for the ancillary data (e.g. solar system data) necessary to the mission and the reduction model; to establish the appropriate framework for the links to a quasi-inertial reference system.

Core Members: Beatrice Bucciarelli; Maria Teresa Crosta; Fernando de Felice; Daniel Hestroffer (solar system); Sergei Klioner; Mario Lattanzi [co-leader]; Lennart Lindegren; François Mignard [leader]; Jean-Louis Simon; Alain Smette (quasar detection); Michael Soffel; Alberto Vecchiato

Associate Members: A. Andrei; Guillem Anglada; Luc Blanchet; Jos de Bruijne; Jean-François Claeskens (quasars); Wyn Evans; Agnes Fienga; Eva Grebel; Jean Kovalevsky; Christophe Leponcin-Lafitte; Sophie Pireaux (alternative theories of gravitation); Ian Roxburgh; Pierre Royer (quasars); Erik Slezak; Jean Souchay (solar system); Jean Surdej (quasars); Pierre Teyssandier; Jordi Torra

The activities of the working group cover three more or less connected areas with:

- the development of a relativistic modelling of astrometric observations at the microarcsecond level, required to analyse the Gaia data. The main groups involved in this tasks are the Padova/Torino team (F. de Felice, B. Bucciarelli, M.T. Crosta, M. Lattanzi, A. Vecchiato), and the Dresden group with S. Klioner and M. Soffel and G. Anglada and J. Torra for GDAAS;
- the preparation of the solar system ephemeris at the precision required for Gaia data analysis and the investigation of the timescale transformations between the on-board time and the coordinate-time used in the modeling. The main contributors here are A. Fienga, S. Klioner, F. Mignard, M.T. Crosta and J.L. Simon;
- realisation of the extragalactic reference frame from the observations of QSOs. This includes an automatic recognition of the sources from multicolour photometry. The main group working in this area is at the University of Liège with J.K. Claeskens, P. Royer, A. Smette, J. Surdej and L. Vandenbulck and F. Mignard for the astrometry part.

The second version of the relativistic model based on S. Klioner approach has been implemented in GDAAS and the remaining differences between the predicting and correcting modes have been identified and corrected. Further comparisons were carried out by the Barcelona group giving satisfying results with differences nearly everywhere below 0.1 μarcsec. The prototype of solar system ephemeris is in place in a form in principle rather close to the final, but not yet with the required external accuracy and the agreed timescale. The group at the IMCCE in Paris is now developing a numerical version of their ephemerides which will be used in due time for the Gaia data processing.

In Spring 2004 S. Klioner and F. Mignard arranged a meeting with ESOC to discuss the mission requirements for the Gaia orbit tracking. This resulted into a very positive exchange whose results are reported in the Minutes of the 5th meeting of the RRFWG. Following this meeting S. Klioner has investigated the magnitude of the relativistic effect in the motion of Gaia on its Lissajous orbit in which it shows that according to the level of modelling differences between prediction can be larger than the 10 mm/s in velocity, well above the Gaia requirement.

The current version of the alternative Relativistic Astrometric Model, (RAMOD4) accurate to $(v/c)^3$, is now completed as far the formalism is concerned, although several problem remain with the best way of solving the master equation. Tests are under way at Torino, primarily conducted by A. Vecchiato and M. Lattanzi.

Significant work is done by C. Leponcin-Lafitte and P. Teyssandier to formulate and compute in a very general way the relativistic light deflection brought about by a non spherical distribution of matter in the non static case. In parallel M.T. Crosta and F. Mignard have worked out a practical formula for Jupiter monopole and quadrupole, accurate enough to investigate the possibility of detection with Gaia within small field astrometry, and this has been presented on a poster during the Gaia Symposium in Paris in October 2004.

A major action has been brought to completion this year regarding the relationship between the TCB and the Gaia proper time (time that would be read on an ideal on-board clock) from an investigation by F. Mignard, M.T. Crosta and S. Klioner. A practical representation meeting the Gaia need is provided in the relevant technical note. The inverse relationship and a software to be implemented in GDAAS should follow in 2005.

In relation with the astrometric modelling J. Kovalevsky has continued his work on the spurious proper motion resulting from the motion of the observer and the source around the galactic centre. This is a serious matter which will impact either on the way proper motions are published, or at least on their use for subsequent studies on galactic kinematics and dynamics.

Several members of the group have contributed significantly to the verification process of the Gaia Parameter Data base in the field of the solar system constants and the physical constants. This work stirred very interesting discussions about relativistic units fully relevant in the framework of Gaia.

As for the preparation of the realisation of the primary frame in the visible there have been significant steps toward an efficient photometric selection of a clean subset of QSOs, large enough for this purpose. The Liege group with J.F. Claeskens, A. Smette and J. Surdej has completed the building up of a data base containing any kind of QSO spectra, tested and supplemented with the recent release of the SDSS data. A success rate of 99.92% has been obtained for the clean set with the nice feature that the loss of efficiency is located in specific regions of the colour space where most contaminants come from. In the more standard regions of the colour space, the success rate is higher and the subset should meet the required cleanliness. In a recent and very preliminary investigation F. Mignard has shown how much of the remaining contaminants will be rid of by adding astrometric testing on the proper motion, rather than on the parallax, the latter test being much lest powerful than the former.

The semi-annual advancement meetings of the working group have taken place in June 2004 in ESTEC and in January 2005 in Paris and were attended respectively by 15 and 20 people. During each meeting the on-going tasks have been reviewed and discussed and all the presentations are made available on the WG website within two weeks after the meeting. The next meeting is scheduled in September 2005 in Dresden. The major milestones for 2005 should be a better assessment of the relativistic experiments achievable with Gaia (with the stars, the minor planets and Jupiter), the organisation of the group closer to an operational mode for the data processing and new runs of the QSO testing based on the new photometric filters.

Papers or reports issued during the year:

- Minutes of the fourth meeting of the Relativity and Reference Frame Working group
- A general relativistic model of light propagation in the gravitational field of the solar system - the static case (de Felice et al., 2004)
- Physically adequate proper reference system of a test observer and relativistic description of the Gaia attitude (Klioner, 2004)
- Minutes of the fifth meeting of the relativity and reference frame working group
- Light deflection in Weyl gravity - constraints on the linear parameter (Pireaux, 2004)

- Relation between the Gaia proper time and TCB (Mignard et al., 2004)
- Proper frames and time scan for Gaia-like satellites

4.18 Science Alerts

N. Wyn Evans

Objective: to evaluate the sources which could be detected in a quick look processing on ground and the algorithms for detection, to assess the scientific importance of any proposed reaction time, and the requirements for follow-up observations on ground.

Core Members: Vasily Belokurov; Michel Crézé (supernovae, microlensing); Martin Dominik (astrometric microlensing); Wyn Evans [leader] (supernovae, gamma-ray bursts); Laurent Eyer (variable stars); Alain Milsztajn (microlensing); Piotr Popowski; Annie Robin (alerts versus Galactic model); Dimitris Sinachopoulos (lensing)

Associate Members: Michel Boer; Jos de Bruijne; Françoise Crifo; Christine Ducourant; Bruno Leibundgut; Catherine Turon (high proper motion stars); Werner Weiss (photometry)

The Working Group met in Cambridge in April and in Paris in October, jointly with the closely allied Variable Stars Working Group. Its activities and members are detailed on the web page: http://www.ast.cam.ac.uk/ vasily/sawg/index.php

Many of the science goals of the Gaia mission, especially for bursting or time-varying phenomena, require an early identification, analysis and release of preliminary data. In modern signal processing, such novelty detection is routinely performed with self-organising maps (SOMs), which are an unsupervised clustering algorithm invented by Kohonen. The main activity of the Science Alerts Working Group has been the development of automated machine learning for application to the Gaia data set.

There are a number of topics requiring investigation – such as the optimum input vectors for the maps, the size of the maps, the learning rates and neighbourhoods. Many of these experiments have been carried out using publically available catalogues similar in scope to that expected from the Gaia mission. The tests have demonstrated that SOMs can carry out clustering very quickly, identifying candidates for classical and dwarf novae, eclipsing binaries and small-amplitude red giant variables in test data sets. In general, very large data sets can be processed extremely rapidly with SOMs and the broad features of the data readily extracted. As we have illustrated here, their ideal role is to conduct a 'quick look' through the data set, identifying the most prominent features.

An unusual pattern (such as a supernova-like lightcurve) has the property that it is distant from the node onto which it is mapped, and distant from all nodes. For each data pattern, suppose the 10 closest nodes are found and sorted in the order of increasing distance. Then a linear fit of the distance (scaled by the smallest one) versus node number is produced. Let us call the slope the 'pattern rate'. A rare pattern is well away from all the nodes of the lattice and so the slope is very small. Hence, novelty detection can be implemented by looking for a small pattern rate, as well as a large error at the node onto which it is mapped. Much of this work is detailed in the contribution to 'The Three-Dimensional Universe with Gaia' and is reported more fully in a forthcoming paper by Belokurov & Evans.

The working group has begun to consider two further topics – namely, the construction and maintenance of a data base which records variable stars as they are identified, and the need for ground-based follow-ups. It is expected that partners skilled in the running of data bases and with expertise with robotic telescopes will join the Working Group in the forthcoming year.

4.19 Science Goals

Objective: To assess what major observational, theoretical, or other preparatory developments are required in order to prepare for the large-scale astrophysical interpretation of the data. To consider the requirements for due acquisition of ground-based data in the context of the Gaia mission, for preparatory, on-board, operational, data reduction, scientific exploitation, and follow-up aspects. It is not the goal of this group to attempt to foresee all preparations for detailed use of the data – in general it is the task of the users to make sure that they have all the elements for a correct use of the Gaia data. The objective is, however, to ensure that adequate preparatory data is available to properly calibrate the satellite data, and to ensure that the Gaia data is not delivered to the community with some major interpretative framework missing.

Core Members: Olivier Bienaymé (galactic dynamics); Cesare Chiosi (star formation and stellar populations); Michel Crézé (galactic dynamics); Ronald Drimmel; Daniel Egret; Wyn Evans (galactic dynamics); Laurent Eyer (variability); Gerry Gilmore; Amina Helmi; Rodrigo Ibata; Mike Irwin; Jordi Isern (white dwarfs); Jens Knude (interstellar extinction); Arunas Kučinskas; Yveline Lebreton (stellar evolution); François Mignard; Simon Portegies Zwart (N-body simulations) Staffan Söderhjelm; Caroline Soubiran (reference stars for atmospheric parameters); Alessandro Spagna; Vladas Vansevičius; Tim de Zeeuw (galactic structure)

Associate Members (and persons not in specific Working Groups): Francesca d'Antona; Coryn Bailer-Jones; Martin Barstow; Joss Bland Hawthorn; Jos de Bruijne; Daniela Carollo; Sophie van Eck; Benoit Famaey; Francesca Figueras; Henny Lamers; Marie-Odile Mennessier; Roberto Morbidelli; Luca Pasquini; Siegfried Röser; Maria Sarasso; Tom Shanks; Hans Schrijver; Jordi Torra; Liam Tuohey; Werner Verscheuren; Alan Wells

No specific coordination effort has started.

Papers or reports issued during the year:

- The bulge as seen by the Gaia mission
- Microarcsecond astrometry with Gaia - the solar system, the Galaxy and beyond (Bailer-Jones, 2004f)
- The visibility of the Galactic bulge in optical surveys. Application to the Gaia mission (Robin et al., 2004)

5 Data Analysis

Salim Ansari

5.1 GDAAS

All scientific activities related to Gaia are undertaken and funded by national institutes. However, during the Concept and Technology Study, the hardware and software environment for the Gaia data processing was seen as a particularly critical activity, partly due to its central role in the success of the mission, and partly because many aspects are more industrial in terms of software engineering requirements. A first contract was issued for the Gaia Data Access and Analysis Study (GDAAS), and undertaken by GMV (Madrid) supported by the University of Barcelona, between mid-2000 and June 2002. A follow-on contract started in June 2002 (GMV and UB, with Copenhagen University Observatory), which will extend until early 2005 (GDAAS Phase 2). The work relates closely to the activities of the corresponding scientific working group (Section 4.14). Details of this contract are covered under the description of the overall status of the data analysis (Section 5).

In December 2003, a set of tests of the Global Iterative Solution (GIS) was recommended by the GDAAS Review Committee. In January 2004, during the Progress Review meeting in Copenhagen, a plan was presented by UB/GMV to run these tests to verify the validity of GIS. In summary these tests were:

Test 0 Preliminary Test to check the revised implementation. These tests would verify if systematic trends had disappeared when using newly simulated data. Few amounts of data and small time intervals would be processed. Nominal values in the GIS initialisation.

Test1 A global 6-month GIS would be processed in an ideal case (no additional noise and nominal values for the initialisation) to verify both, that each individual step (attitude, calibration, global and source) are converging when processing them sequentially, and that after 2–3 iterations of a global GIS, the nominal astrometric values from the simulator would be well recovered.

Test2 A global 6-month GIS will be run to prove that GIS is feasible. It would demonstrate that starting with departures from the nominal model for attitude, global, calibration and source data, it is possible to recover the model used to generate telemetry data.

Test 3 A global 6-month GIS will be processed imposing some scattering in the observations and an initial departure from the model used to generate telemetry data. This test would provide a more realistic estimate of the GIS capabilities. Established guidelines for this test are: Additional scatter in the observed field angles. No nominal values at the GIS initialisation

In addition, a rescheduling of all other algorithms foreseen to be implemented during GDAAS2 was presented and the resources accordingly allocated.

The initial tests on GIS have proven that the concept is valid. Many issues on the speed with which the individual iteration steps converge has yet to be resolved, as well as the high scatter in the residuals remains. Larger tests involving 1 million stars over five years have to be deferred to 2005. By the end of 2004, the GIS tests had been finalised only with the original Gaia Data Model and about 200 000 stars.

The GDAAS 2 Data Model was completed in September 2004.

Papers or reports issued during the year:

- GDAAS hardware platform review (Llimona et al., 2004)
- Progress report PR-014 (Serraller & Lopez, 2004b)
- GDAAS Telemetry Model (Masana et al., 2004c)
- Second campaign of GIS testing - Test-0 progress report (Figueras et al., 2004h)
- Cross-matching algorithm description (Chareau, 2004)
- Data base initialization (Jordi et al., 2004d)
- Progress report PR-015 (Serraller & Perez, 2004a)
- IMproved channel coding for longer contact times with Gaia (Martin et al., 2004)
- Timing and transmission schemes for Gaia (Portell et al., 2004a)
- GDAAS CCB Meeting 4
- Telemetry data formats in simulations (Portell et al., 2004c)
- Evaluation of GridAssist and GridSystems
- Assumptions for GDAAS-II simulations (first algorithm implementation campaign) (Masana et al., 2004b)
- Concerning the iteration of the Gaia GIS using simulated data (Lenhardt, 2004)
- Quaternion programs (Hirte, 2004)
- Implementation of fundamental algorithms - 1.03-C, 1.03-2-C, 1.03-3-C (Anglada et al., 2004)
- Second campaign of GIS testing - Test-1 report, 50 percent of primary sources (Figueras et al., 2004c)
- Progress report PR-016 (Serraller & Lopez, 2004c)
- Progress report PR-017 (Serraller & Lopez, 2004a)
- Testing GIS - 10 months of mission data (Figueras et al., 2004d)
- Second campaign of GIS testing - Test-1 report - 100 percent of primary stars (Figueras et al., 2004b)
- Plan for the second campaign of GIS testing II (Figueras et al., 2004i)
- Numerical experiment for a block-iterative solution (Jordan & Bastian, 2004)
- Progress report PR-018 (Serraller & Perez, 2004b)

- Rough estimation of the floating point operations required for GIS processing (Luri et al., 2004)
- Second campaign of GIS testing - Preliminary proofs for Test-2 (Figueras et al., 2004g)
- GIS core processing - implementation of the field angles computation (Torra et al., 2004)
- Second campaign of GIS testing - Test-2 report (Figueras et al., 2004a)
- First look - description of the ring solution (Bernstein et al., 2004)
- First-look preprocessing (mid-term work package report for WP3) (Bastian et al., 2004)
- Estimation of Gaia data processing FLOPs (Perryman, 2004a)
- Progress report PR-019 (Serraller & Perez, 2004c)
- Using quaternions in the RGCS for the ODIS (Jordan et al., 2004)
- A proposed new algorithm for source updating (Lindegren, 2004c)
- First Look - status report to GST13 (Bastian, 2004a)
- Third GIS test campaign on GDAAS-1 data - recommendations
- Harware platform review statistics report (LLimona et al., 2004)
- Progress report PR-020 (Serraller & Perez, 2004d)
- Astrometric binary stars - data generation and derivation of field angles (Masana et al., 2004a)
- Second campaign of GIS testing - Test-2 report (Part B) (Figueras et al., 2004e)
- Third campaign of GIS testing - Test-3 report (Figueras et al., 2004f)
- Task description - Gaia First Look (Biermann & Bastian, 2004)

5.2 GaiaGrid

Having considered that the core tasks involving the Global Iterative Solution had turned out to be far more complex to verify than originally anticipated other alternative means were considered to augment computational power as an alternative source to the central nodes at CESCA for the simulation of data for the GDAAS project, and to allow more active involvement by the algorithm providers to validate the data generated against the implemented shell algorithms. In collaboration with DutchSpace, ESA embarked on an experiment to implement a Grid testbed. Based on a distributed/sharing concept, the Grid allows the possibility of deploying large jobs on geographically distributed authorized computational infrastructures.

For this purpose, several algorithms were identified as being potential candidates for implementation: Astrometric Binary Star analysis, Planetary Detection and Variability Analysis. This, however, also depended on the availability of simulated data and the algorithm readiness. By November 2004, the Astrometric Binary Star Analysis code was running on GaiaGrid. This involved accessing the GDAAS database on CESCA machines in Barcelona, analysing them on a machine at the University of Brussels and storing them on a server at ESTEC. By then, GaiaGrid had grown to a 30-machine infrastructure located in five countries, including: Spain, Italy, Germany, Belgium and the Netherlands.

The Gaia simulator was also successfully run on seven parallel infrastructures.

6 ESA Interfaces

The project scientist makes regular reports to the ESA advisory bodies through the management structure of the Directorate of Science. Monthly reporting meetings are held with the Head of the Research and Scientific Support Department (Alvaro Gimenez) and (separately) with the Director of Science (David Southwood). Regular and efficient contact was maintained with the Gaia study manager (Oscar Pace) and subsequently with the Gaia project manager (Rudi Schmidt), and as necessary, with the Head of the Astrophysics Mission Division (Jean Clavel), the Head of the Data Analysis and Archiving Division (Martin Kessler) and the Head of the Advanced Technology Studies Office (Tone Peacock).

Interfaces between ESA and the Gaia Science Team are maintained through regular science team meetings (five in 2004), and regular e-mail and telephone contact as required. Open invitations to all interested parties to all working group progress meetings, and to the e-mail distribution lists of each working group ensure a reasonably effective form of communication flow for those who wish to remain informed of Gaia activities. The project scientist also issues occasional status reports to all scientists registered in the scientific working groups. Communications within the working groups is through *ad hoc* meetings, and e-mail communications.

Papers or reports issued during the year:

- Gaia - status report to working groups, wg-status-013 (Perryman, 2004b)
- Minutes - Gaia Science Team 10, 22-23 January 2004 (Perryman, 2004c)
- Minutes - Gaia Science Team 11, 2-3 March 2004 (Perryman, 2004d)
- Minutes - Gaia Science Team 12, 30 June-1 July 2004 (Perryman, 2004e)
- Minutes - Gaia Science Team 13, 13-15 Sep 2004 (Perryman, 2004f)
- Minutes - Gaia Science Team 14, 16-17 Dec 2004 (Perryman, 2004g)

7 Scientific Highlights, Education & Outreach

7.1 Scientific Highlights

Between 4–7 October 2004, a major symposium, 'The Three-Dimensional Universe with Gaia', dedicated to the scientific aspects of the Gaia mission was held at the Observatoire de Paris, Meudon, France. Attended by 240 delegates, the four-day meeting was an opportunity to present the current status of the Gaia mission to the interested scientific community, and to hear about the results of investigations carried out in the various areas of the mission over the last four years.

The Symposium was opened by the Director of the Paris Observatory, Daniel Egret, and Jean Kovalevsky, who stressed the great challenges and scientific rewards of Gaia. ESA's Director of Science, David Southwood, presented Gaia in the context of the current ESA science programme. These were followed by technical and scientific presentations.

Activities and overall progress of the 14 scientific working groups (from relativistic aspects of the data analysis to the quasar reference frame) formed a major part of the symposium. Various reports on the massive data analysis preparations gave a detailed perspective on the complexities and challenges facing the on-ground data treatment: the overall simulation chain, the current prototype data analysis system, Grid-related studies, and the photometric data analysis.

Five participants accepted the delicate challenge of summarising the poster presentations in the various categories. This effort contributed significantly to the coverage of a large variety of topics in a limited period of time, and was greatly appreciated by the participants. A highlight of the Symposium was the award by the Paris Observatory of the degree of Doctor Honoris Causa to the Honorary Chair of the Scientific Organising Committee, Adriaan Blaauw, who celebrated his 90th birthday earlier in the year.

The chairs of the SOC, Catherine Turon (Paris-Meudon) and Michael Perryman (ESA) were supported in the organisation of the meeting by the Gaia Science Team, an International Advisory Committee including at least one representative from each ESA member state, and an efficient Local Organising Committee, led by Yves Viala (Meudon) and supported by Karen O'Flaherty (ESA). Generous financial support by various organisations (Paris Observatory, CNES, CNRS, ESA and the Gaia industrial leading groups - EADS-Astrium and Alcatel/Alenia), permitted attendance at the symposium by an unusually large representation of younger scientists (PhDs and post-docs) many of whom are already playing a key role in the preparation of the ambitious Gaia mission. Attendees also included collaborators in Greece (recently members of ESA), and some non-member countries (Slovenia, Lithuania, Estonia, Australia). The proceedings of the symposium will be published by ESA in early 2005.

7.2 Education

Karen O'Flaherty

The ESA Science Education Officer invited Ansari and O'Flaherty to give Gaia presentations to a visiting group of education and science specialists from the Victorian Space Science Education Centre in Australian. Further correspondance and video conferences have led to the creation of three postgraduate research positions at the Virtual Reality Centre at RMIT University, Australia. The purpose of these positions is to develop the technology required to create a virtual reality 3d model of the Gaia Galaxy.

7.3 Outreach

Many members of the Gaia scientific community are active in giving conference talks and seminars on various aspects of Gaia. From ESA, Perryman addressed an audience of 800 young adults at The Hague International Model United Nations on the topic of 'Our Galaxy in 3D'. Ansari also addressed this conference on space and information technology using Gaia to illustrate many of the challenges posed by modern space missions.

Several Gaia articles for the general public were published on ESA's web sites this year:

5 July 2004: Mapping the Galaxy and watching our backyard (translated into all ESA Member State languages and carried by the ESA country desk web sites)

17 July 2004: Nederland investeert in Gaia-missie

9 September 2004: The Billion Pixel Camera (taken by several other web sites including Spiegal online and by La Libre Belgique)

21 September 2004: Keeping ESA's 'lady of space' cool

4 October 2004: L'Univers en 3D: symposium Gaia, Paris (coverage of the Gaia Symposium by the ESA Country Desk for France)

The Little Book of Gaia 'Tales of the Universe' was used to form a pull-out special supplement for 'galaxy - te korurangi', a space and astronomy magazine produced by the Royal Astronomical Society of New Zealand.

8 Other Space Astrometry Missions

In the US, developments continue with the interferometer SIM, and with studies for a scanning astrometric instrument, OBSS led by USNO, which follows the previous concepts of FAME (cancelled by NASA in January 2002) and AMEX (terminated in November 2003). A Japanese astrometry mission, JASMINE (Japanese Astrometry Satellite Mission for Infrared Exploration), continues to be discussed at a lower level.

9 Main Scientific Meetings in 2004

These are summarised in Table 2.

Table 2: The main Gaia scientific meetings in 2004.

Meeting	Organiser	Date (2004)	Location
GDAAS II Core Implementation	Ansari	15 Jan	Copenhagen
Photometry	Høg/Jordi, Drimmel	21 Jan	Turin
GST10	Perryman, Lattanzi	22-23 Jan	Turin
GDAAS II Progress Review	Ansari	16 Feb	Madrid
GST11	Perryman	2-3 Mar	ESTEC
GDAAS II Progress Review	Ansari	15 Mar	Barcelona
Classification, Science Alerts, Variables	Bailer-Jones/W.+D.Evans/Eyer	15-16 Apr	Cambridge
GDAAS II Shell Task Readiness	Ansari	28-29 April	Barcelona
Photometry	Høg/Jordi	30 Apr	Copenhagen
Solar System 5	Mignard/Muinonen, Virtanen	27-28 May	Helsinki
Radial Velocity 8	Cropper/Katz, Vallenari	3-4 Jun	Padova
GDAAS II Progress Review	Ansari	14 Jun	Madrid
Relativity & Reference Frame 5	Mignard/de Bruijne	17-18 Jun	ESTEC
Photometry	Høg/Jordi	28-29 Jun	Copenhagen
GST12	Perryman/ Høg	30 Jun - 1 Jul	Copenhagen
Simulations, ground/orbit calibration	Luri/Gai	8-9 Jul	Turin
GDAAS II Shell Testing Readiness	Ansari	26 Jul	Barcelona
GDAAS II Shell Testing Readiness	Ansari	2 Aug	Barcelona
GST13	Perryman	13 Sep	ESTEC
Gaia Symposium	Turon & Peryrman	4–7 Oct	Paris
Photometry	Høg/Jordi	8 Oct	Paris
Classification, Science Alerts, Variables	Bailer-Jones/W.+D.Evans/Eyer	8 Oct	Paris
Planetary Systems, Double/Multiple Stars	Lattanzi/Arenou	8 Oct	Paris
Photometry, Classification	Høg/Jordi/Bailer-Jones/Kontizas	25-26 Nov	Athens
Solar System 6	Mignard/Klioner	25-26 Nov	Dresden
GST 14	Perryman/Luri	16-17 Dec	Barcelona

10 People

10.1 ESA

ESA–ESTEC Research & Scientific Support Department: Michael Perryman (Project Scientist, SCI-SA) supported by Salim Ansari (SCI-CI); Jos de Bruijne (SCI-SA); Karen O'Flaherty (SCI-SA); Uwe Lammers (SCI-SD); Alexander Short (SCI-A)

ESA–ESTEC Project Team: Rudi Schmidt (Project Manager, SCI-PP); Giovanni Colangelo (System Engineering Section, SCI-PP); Gerhard Kreiner (Software Section, SCI-CI); Giuseppe Sarri (Payload Section, SCI-PTE); Michael Witting (Spacecraft Section, SCI-PE); Raffaele Tosellini (Project Controller, SCI-CM); Jean-Pierre Balley (Product Assurance, TEC-QQM); Oscar Pace (SCI-PF); Torgeir Paulsen (SCI-PF); Philippe Garé (SCI-PTE); Helma Glasbergen (SCI-PP)

ESOC: John Dodsworth (OPS-OSA); Robert Furnell (OPS-OFM) Martin Hechler (OPS-GA); José-Luis Pellon-Bailon (OPS-OSF)

Technical Officers: Pierre Coste (mechanism, TEC-MMM); Hugh Evans (radiation environment, TEC-EMA); Bernhard Furch (laser metrology, TEC-MMO); Bernd Harnisch (SiC optics, high stability optical bench, TEC-MMO); Arturo Martin Polegre (phased-array antenna, TEC-EEA); Gerard Migliorero (sun shield, TEC-MMM); David Nicolini (mN FEEPs, TEC-MPE); Raffaele Vitulli (PDHE, TEC-EDP); Igor Zayer (CCD/FPA, TEC-MME)

Contract Officers: Jonas Amneus (RES-PTE); Pieter de Boer (RES-PT); Fabio Mazzaglia (RES-PTE); Michael Smith (RES-PSS)

10.2 Scientific Community

Gaia Science Team: F. Arenou, C. Bailer-Jones, U. Bastian, E. Høg, A. Holland, C. Jordi, D. Katz, M. Lattanzi, F. van Leeuwen, L. Lindegren, X. Luri, F. Mignard

The scientific working groups (and the leaders, core and associate members) are described in Section 4.

10.3 Industry

Key personnel of the industries in charge of the Gaia industrial contracts:

- **Alcatel (F-Cannes)**: X. Leyre, B. Napierala et al.
- **Alenia (I)**: F. Ravera, G. Secchi, M. Montagne et al.
- **EADS-Astrium (F-Toulouse)**: P. Charvet, F. Safa, F. Chassat, A. Laborie, P. Pouny, C. Vetel, P. Coste, B. Calvel, B. Laviron et al.
- **EADS-Astrium (D)**: R. Best, M. Schelkle et al.

10.4 PhD Students

This section is likely to be incomplete (with provisional titles), but includes specific PhDs efforts (ongoing or completed within the year), kwhich have already contributed to the design or definition of Gaia:

- Altamirano, Pablo (Barcelona-Meudon): *Spectro instrument: simulated data*
- Anglada, Guillem (Barcelona): *Gaia, microarcsecond astrometry. Relativistic model implementation and data reduction*
- Busonero, Deborah (Siena): *Analysis of detailed optical performance over the Astro field*
- Carrasco, Jose M. (Barcelona): Gaia photometry
- Dischler, Johann (Lund): *Population synthesis predictions of the eclipsing binaries observable with Gaia*
- Dollet, Claire (OCA, Nice) *Sky surveys with an imaging satellite*, completed October 2004
- Eriksson, Urban (Lund): *The limits of optical astrometry*
- Guerrier, Antoine (Meudon): *Spectroscopic Global Iterative Solution for the Radial Velocity Spectrometer*
- Jørgensen, Bjarne R. (Lund): *Determination of stellar ages and star formation histories – a Bayesian approach*
- Marrese, Paola (Asiago): *Eclipsing binaries in Gaia as tracers of basic stellar parameters*
- Mignot, Shan (Meudon): *Traitement scientifique à bord du satellite Gaia*
- Mouret, Serge (Paris and Nice): *Asteroid mass determination with Gaia*
- O'Mullane, William (Barcelona): *Large scientific database technologies and their applicability to Gaia*
- Portell i de Mora, Jordi (Barcelona, Institut d'Estudis Espacials de Catalunya): *Ground and user segment for Gaia*
- Sordo, Rosanna (Asiago): *Synthetic spectroscopy and the analysis of Gaia and RAVE spectra*
- Willemsen, Philip (Bonn): *Stellar parameters from standard and novel optical data, using neural networks*, completed end of 2004.
- Wolff, Stefan (Copenhagen): *Detection of Solar System objects*

11 Gaia Web Pages at ESA

Karen O'Flaherty

11.1 The ESA Space Science web site: http://www.esa.int/science

This corporate-level web site is targetted at the general public and the media. The production of content for this web site is the responsibility of the Science Programme Communication Service (SPCS). Each science mission in the Science Programme is represented by an overview and factsheet produced for a general audience (see http://www.esa.int/science/gaia), and by a factsheet and press-kit produced for the media (see http://www.esa.int/science/media and follow the link for Press Kits). The Gaia project keeps the SPCS informed of newsworthy events relevant to Gaia. The SPCS is reponsible for converting this information into material appropriate for its target audiences.

11.2 The ESA Scientific and Technical web site: http://sci.esa.int

This directorate-level web site is targetted at a broad scientific community, including school leavers, undergraduates, postgraduates and those working in scientific establishments. The site aims to provide more in-depth information explaining the 'how and why' of ESA's science missions. Technical aspects of the Scientific and Technical web site are managed by the Science Coordination Office. Responsibility for the content of the Gaia pages on this site resides with the Gaia Project Scientist and Study Manager.

11.3 The Gaia RSSD web site: http://www.rssd.esa.int/gaia

This web site aims to be an information distribution centre for the Gaia scientific community. The primary purpose of the site is to aid the flow of information between individuals and groups working on the project and to provide access to material needed in order to keep up-to-date with developments in the project. Highlights on the web site include:

Latest Gaia news: on the front page of the web site. This is in the form of a short news item, sometimes linked to more detail on an external web site, which refers to some activity relevant to the Gaia project. Some examples are: the delivery of some hardware item, the start or completion of a research task, decisions at ESA affecting the schedule of the project, a milestone reached in a development contract, advertising new research positions available for working on Gaia.

Information Sheets: these are A4 page summaries of different aspects of the Gaia project. There are now approximately 60 information sheets covering a wide range of topics which can be broadly grouped as follows: organisation, spacecraft and payload, operations, accuracy, working groups, and science topics. At this phase of the project while the design of the payload is evolving it is not feasible to maintain the most up-to-date parameters in each Information Sheet. Users are directed to use the Gaia Parameter Data Base if they need accurate data.

Opportunities for Research: this section is intended to act as a notice board for working groups where they can post tasks that need further work but where no person has been identified to carry out the work.

Opportunities for funding: in addition to advertising research positions on the front page, these positions are also listed under Opportunities for Funding. In 2004 seven positions were advertised in this manner.

Meetings: a comprehensive list of meetings relevant to the Gaia science community is maintained online. These are primarily meetings of the working groups and of the Gaia Science Team, but industrial and technical meetings that are considered of wider interest are also included.

Library: the library section contains links to the Gaia LiveLink (scientific) and DMS (technical) documentation repositories, in addition to lists of key papers, and links to ADS and Sissa article and preprint services.

Special Features: The purpose of the 'Picture of the week' feature is to highlight the range of activities underway (either in the area of hardware development, or of scientific research) and at the same time to add to the image gallery, thus improving the range of presentation material available to the Gaia community. The Gaia people feature introduces people from different areas who are contributing to Gaia. In 2004 this included representatives from industry, ESA, the working groups and the Gaia Science Team.

Responsibility for the content of this web site lies with the Gaia Project Scientist. Technical aspects are supported by the RSSD webmaster. Any suggestions for the content, contributions to the 'Gaia picture of the week' or 'Gaia people', images, links, etc, are welcomed, and the Gaia science community is encouraged to actively contribute to the web site content.

11.4 LiveLink

An important medium for the development of Gaia scientific activities is a project-specific document archive (LiveLink, http://www.rssd.esa.int/livelink), maintained under the responsibility of the Project Scientist. 'Working notes' are encouraged on all scientific topics, presenting results, ideas, or concerns at a reasonably informed level. All members of the scientific working groups are encouraged to submit such notes (directly to the Project Scientist), and to subscribe to the alert system, which e-mails a weekly update of all documents posted during the previous week. About 220 such documents have been included in 2004. All members of the working groups and industry have access to this data base. A more restricted documentation system, DMS, contains the industrial and technical technical notes from the industrial system levels teams and contractors.

Acknowledgments

This report is a synthesis of the work undertaken in ESA, within the Gaia industrial teams, and within the Gaia scientific community (the Gaia Science Team and the scientific working groups). I thank all colleagues (notably the Working Group leaders, and all ESA colleagues, as credited in the text) for the reports on their work on which this summary is based.

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