Taking up the Gaia Challenge: DPAC Operations

S. Els
(DPAC Project Office, University of Heidelberg)

W. O’Mullane (ESA, DPACE)
A. Brown (University of Leiden, DPACE)
Outline

- Summary of the Gaia mission and goals
- The Gaia satellite and its scientific instrumentation
- The Gaia science ground segment: layout and operations
- Lessons learned from the development phase
Hipparcos:
position accuracies of 1 milli arcsec
for 118.218 stars down to $V \sim 12.4 \text{mag}$
+ photometry
see M. Perryman (1997) and F. v. Leeuwen (2007)

Measurement principle:
A 29cm telescope, observed simultaneously two FOVs separated by a ‘basic angle’ of 58°.
Rotation of the apparatus allowed to measure the timing of the transiting stars in both FOVs.
<table>
<thead>
<tr>
<th></th>
<th>Hipparcos</th>
<th>Gaia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude limit</td>
<td>12</td>
<td>20 mag</td>
</tr>
<tr>
<td>Completeness</td>
<td>7.3 – 9.0</td>
<td>20 mag</td>
</tr>
<tr>
<td>Bright limit</td>
<td>0</td>
<td>6 mag</td>
</tr>
<tr>
<td>Number of objects</td>
<td>120 000</td>
<td>26 million to V = 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250 million to V = 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000 million to V = 20</td>
</tr>
<tr>
<td>Effective distance</td>
<td>1 kpc</td>
<td>1 Mpc</td>
</tr>
<tr>
<td>Quasars</td>
<td>None</td>
<td>5 x 10^5</td>
</tr>
<tr>
<td>Galaxies</td>
<td>None</td>
<td>10^6 – 10^7</td>
</tr>
<tr>
<td>Accuracy</td>
<td>1 milliarcsec</td>
<td>7 µarcsec at V = 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-25 µarcsec at V = 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300 µarcsec at V = 20</td>
</tr>
<tr>
<td>Photometry</td>
<td>2-colour (B and V)</td>
<td>Low-res. spectra to V = 20</td>
</tr>
<tr>
<td>Radial velocity</td>
<td>None</td>
<td>15 km/s to V = 16-17</td>
</tr>
<tr>
<td>Observing</td>
<td>Pre-selected</td>
<td>Complete and unbiased</td>
</tr>
</tbody>
</table>
The leap: Gaia’s mission goals - II -
Gaia’s optical layout and instrumentation

- 2 telescopes with 1.4m x 0.5m aperture each, f=35m
- Total of 10 mirrors comprising folding mirrors and beam combiner
- A single focal plane on which both FOVs are projected
- Further instrumentation:
  - Photometer prisms
  - RV spectrometer
  - Basic angle monitor
  - Wavefront sensor (commissioning only)
- The entire space craft was designed and built by European industry (no “instrument teams”)
Gaia will scan the sky from L2
Gaia’s focal plane

106 CCDs, each 4500px AL x 1966 AC, read in TDI mode

- Star mapper
- Identification and classification
- Astrometric field imaging
- Photometer
- Low res. spectra
- RVS Spectrometer
- R~10,000

Gaia's focal plane components:
- Sky Mapper CCDs
- Image motion
- WFS
- BAM
- 104.26 cm
- 42.35 cm
DPAC organization and tasks

- Gaia Data Processing and Analysis Consortium (DPAC) is the scientific consortium which will
  - Conduct the processing of the Gaia data
  - Perform the scientific analysis of the Gaia data
  - Compile the Gaia catalogue which will deliver the Gaia promise to the scientific community

- DPAC is structured in
  - Coordination Units (CU) whose members are scientists and engineers developing the analysis methods, algorithms and software
  - Data Processing Centres (DPC) which operate the hardware to process the Gaia data, using the CU provided software products

- Overall, DPAC has more than 450 members, mostly in Europe and some also worldwide
The DPAC CUs and DPCs

- **DPCB University of Barcelona**
  - CU2: Simulations and CU3: Core processing

- **DPCE ESAC and DPCB University of Barcelona:**
  - CU3: Core processing

- **DPCT Altec Torino:**
  - CU3: Astrometric verification unit

- **DPCC: CNES Toulouse**
  - CU2: Simulations
  - CU4: Non-single stars, solar system objects, extended objects
  - CU6: Spectroscopic processing
  - CU8: Astrophysical parameters

- **DPCI: Institute of Astronomy at Cambridge**
  - CU5: Photometric processing

- **DPCG: ISDC/Geneva University**
  - CU7: Variability
Gaia’s main science operations groups

- Gaia is a survey mission, thus there should not be too much interaction with the user
  - Mission operations centre (ESOC): S/C control
  - SOC/DPCE (ESAC): S/C science control, central DPAC hub
  - DPCs: DPAC data processing centres
  - Payload Experts:
    - DPAC (CU) experts covering all scientific and instrumental aspects
    - Conduct performance assessment and verification
    - Support spacecraft configuration decisions during the mission

- DPAC Executive: board of directors
- Gaia Science Team: science advisory group to PS and MM
DPAC’s “daily” operations branch -I-

■ **Goals:**
  - Scientific performance + health monitoring of Gaia
  - Obtaining short term instrument calibrations
    - Trigger setup changes on-board, if necessary to improve science performance
  - Detection of certain transient phenomena

■ **How:**
  - Data are processed asap after reception on-ground
  - Most of this processing works on data covering only few (~1-20) days
Who:

- **DPCE/SOC:**
  - First Look (CU3, SCIs): ODCs, AF, BP/RB, RVS, BAM
  - GBOT (CU3) interface

- **DPCC:**
  - RVS monitoring (CU6)
  - Solar System Object Short Term (CU4)
  - SSO alerts (CU4) <-> IMCCE

- **DPCI:**
  - BP/RP processing and calibration (CU5)
  - Science alerts interface (CU5)

- **DPCT:**
  - BAM+AIM monitoring (CU3-AVU)
Daily data transfers during the Gaia mission
DPAC’s cyclic operations branch

- Goals
  - Produce high fidelity calibrations
  - Generate science data products, ultimately for catalogue releases

- How
  - All data collected since the begin of the mission are processed at certain intervals: the data reduction cycles (DRC)
  - Highly iterative process (iterations are the DRCs)
    - MDB is the central data base
    - MDB is maintained at DPCE/SOC
  - Cycle lengths range from few months up to 1 yr
Conceptual data flow from one cycle to the next

This process is complex, and the involvement of the individual DPCs depends on the data processing progress and availability of data.
A view of the data processing progress

Time of collected data

Days of D

Time covered by processed data

Launch  L2  First Data IOCR

End of Segment 00

End of Segment 01

Daily processing

Cyclic processing

Time of collected data
The Gaia catalogue intermediate catalogue release scenario, note that this is a best case scenario (full details can be found on http://www.rssd.esa.int/index.php?project=GAIA&page=Data_Releases)

- L+22 mo: positions and G magnitudes for single stars
- L+28 mo: five parameter astrometric solution for single stars, integrated BP/RP photometry, sources with verified astrophys. parameters, RVs which show no variability.
- L+40 mo: orbital solutions, system RV, five parameter astrom. solution for binaries, object classification and astrophys. parameters, BP/RP spectra, and/or RVS spectra and mean RV for non variables and for which atmosph. parameters are available.
- L+65 mo: variable star classification and epoch photometry; preliminary SSO orbital solutions, and epoch observations; non-single stars catalog
- EOM+36mo: Final catalog release
DPAC operations in a single picture
Lessons learned from the DPAC development, impacting operations -I-

- **Availability of simulations is crucial**
  - DPAC knew that and CU2 did an excellent job in providing data
  - But: scope the simulation development and data generation carefully
    - There is not too much point in simulating all detection effects in all physical detail, if there are not yet the means to get the most basic sources/effects processed. Make sure that the upstream processes get realistic data first!
    - Having an almost perfect universe model is good, but take care that the development effort to simulate a particular class of objects, of which there are maybe only 10000, does not affect the operationally relevant simulations (previous bullet)
    - Having a system engineering overview of the project is crucial to scope the simulations (which might result in scientifically ‘boring’ simulations).
It is good to have close link between the simulations development team and the team developing the most upstream software

- DPAC had those links (either planned or by coincidence) and they turned out to be useful
- However: make sure that you separate both from a certain point onwards
  - It is within human nature to aim for passing tests
  - Having too close ties between the most upstream sw and simulations developments will result in mostly passed tests, which will ultimately be misleading
  - For operational tests, that link must be broken: yes, it’s painful but unavoidable
Testing, testing, testing – and then there is “integration testing”

DPAC follows the ECSS guidelines and testing is built into its development

- Several years long and several stage E2E has, and still is, being conducted
- Very difficult and time consuming as you go from the daily into the cyclic processing branch: this requires lots of data

But only the testing of the integrated system will allow to assess the status of the system

- Start integration at the DPCs early, best more than one year earlier than you initially think
- Integration of sw by various teams at a DPC can not be done by email exchanges only (communicate, communicate, communicate….)
Conduct “simulation of operations” campaigns in addition to the regular testing campaigns

- DPAC started to conduct “rehearsal” campaigns in mid-2012 and by now 4 of those have been conducted.
- Those are not only about processing (testing) – they must also cover/assess decision hierarchies, communication lines, system engineering, and they must raise operational awareness of the teams.
- But keep the goals and conduct within reason.
  - By making the first few of such exercises (you should have many!) too aggressive you might mislead people in their view on operations.

There are many more lessons we have learned.
Conclusions:
DPAC is preparing itself for November 20, 2013
Stay tuned for the first Gaia results

Images courtesy: ESA and Astrium