Gaia
et
l’exploration des objets variables

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A. La mission
B. Status
C. Quelques résultats
D. Participations à la mission
A. La mission
The Gaia mission

• Cornerstone mission of the European Space Agency

• Observations of ~1.5 billion objects
  2 mag < V < 20.7 mag,

• Astrometry, photometry, spectrophotometry, and spectroscopy (radial velocities)

• Launched 19/12/2013 (Soyuz rocket, French Guyana)

• Duration: 5 (+1) years (~70 times all sky)

• Final Catalog: 2021-2022
The Gaia mission - Astrometric performance

- Hipparchus - 1000 stars
- The Landgrave of Hessen - 1000
- Tycho Brahe - 1000
- Flamsteed - 4000
- Argelander - 26000
- PPM - 400 000
- FK5 - 1500
- UCAC2 - 58 million
- Tycho - 1 million
- USNO - 100
- Hipparcos - 120 000
- Gaia - 1000 million

Errors of best star positions and parallaxes

Year

150 BC  1600  1800  2000
Parallax horizon for G0V stars

$A_V = 0$  $A_V = 5 \text{ mag}$

Figure courtesy Lennart Lindegren
Parallax horizon for K5III stars

$A_V = 0$  $A_V = 5$ mag

Figure courtesy Lennart Lindegren

10 kpc

$10^5$ $10^{10}$
Parallax horizon for classical Cepheids (P = 10 d)

$A_V = 0 \quad A_V = 5 \text{ mag}$
The instruments

Two fields of view

1.45x0.5 m²

106.5°

Focal Plane
The instruments

Primary mirror
The instruments

- Red & blue photometer detectors
- RVS detectors
- Photometer prisms
- RVS grating and afocal field corrector
- Astrometric field
- Sky mapper
- BAM & WFS
- M4/M'4 beam combiner
- M5 & M6 fold mirrors

Image courtesy ESA
The instruments

Focal plane
The instruments - the focal plane

106 CCDs (4500 x 1966 pixels each; pixel size = 10 µm x 30 µm = 59 mas x 177 mas)

- **Sky Mapper CCDs**
- **Astrometric Field CCDs** 0.7° x 0.7°
- **Wave Front Sensor**
- **Basic Angle Monitor**
- **Blue Photometer CCDs**
- **Red Photometer CCDs**
- **Radial-Velocity Spectrometer CCDs**

**Astrometry**
- G band photometry
- Time Delay Integration
- 4.4 sec to cross a CCD

**Spectro-photometry**
- Low-resolution spectra
  - BP: 320 - 660 nm
  - RP: 650 - 1000 nm

**Spectroscopy**
- 847 - 874 nm
  - \( \lambda/\Delta\lambda = 11500 \)

Image courtesy ESA - A. Short
Transit observations

FoV: 0.7 deg x 0.7 deg
pixel: 0.059”(AL) x 0.177”(AC)
Transit observations

50 GB / day

Windows observed:
Faint stars windows transmitted:

star \(<20.7\) mag detected!
Place window.

transmitted: ~4.4 sec
~100 sec

Faint stars

Alternative ESA video: http://sci.esa.int/gaia/53281-inside-gaias-billion-pixel-camera/

Courtesy B. Holl
Transit observations

Image parameter estimation

'centroiding' gives:

\[ t_i \rightarrow t_1, t_2, t_3, \ldots \]

windows transmitted:
The instruments - spectral coverage

Jordi et al. (2010)
The scanning law

Satellite spin axis in 6 hours

Precession of the spin axis in 63 days

45°

106.5°

Basic angle

Consecutive great circles

Line of sight 1

Line of sight 2

J. de Bruijne / ESA
The scanning law

1. Sun motion
The scanning law

1. Sun motion
2. Gaia rotation axis
   *precession in 63 days*

Constant angle to the Sun: 45°
The scanning law

1. Sun motion
2. Gaia rotation axis
   *precession in 63 days*
3. One astrometric FOV
   *rotation in 6 hours*
The scanning law

Mean of 70 measurements (40 - 250)

Courtesy B. Holl

On youtube: https://www.youtube.com/watch?v=lRhe2grA9wE
The scanning law

+ Ecliptic Pole Scanning Law during 1 month commissioning
Data processing

The Data Processing and Analysis Consortium (DPAC)

Two main concepts: 1. Coordination Units (CU)
2. Data Processing Centers (DPC)

~500 people (scientists + software engineers)
The Data Processing and Analysis Consortium (DPAC)

Two main concepts: 1. Coordination Units (CU)
2. Data Processing Centers (DPC)

Variability processing

Transients handling → Alerts

Variability charact. → Gaia catalogues
Variability processing

Fraction of variables (Hipparcos precision)

β Cep \((p\ mode)\)
Be stars
SPB \((g\ mode)\)
δScy \((p\ mode)\)
γDor \((g\ mode)\)
ZZ Ceti
DAV \((g\ mode)\)

Gaia: Extremely good statistical description
Variability movie!

Limited to “good” parallaxes

ESA SP-1200 (1997)
Variability processing

~50-150 million variable objects for Gaia

- 0.5 or 4 or 7 million Eclipsing Binaries

- few 100s to few 1000s or 5,000-30,000 Planetary transits
  (Dzigan & Zucker 2012, Robichon 2002)

- 60,000-240,000 δ Scuti stars (Eyer & Cuypers 2000)

- 70,000 RR Lyrae stars (Eyer & Cuypers 2000)

- 2,000-8000 or 9,000 Cepheids (Eyer & Cuypers 2000, Windmark et al. 2011)

- 6,000 SuperNovae to G=19 for alert system (Gilmore, Belokurov 2009)

- 1,000 Microlensing events

- 500,000 Quasars
The case of binaries

Estimations (Eyer et al. 2013)

→ 30 million astrometric non-single stars

→ 8 million spectroscopic binaries (with 59% SB2)

→ 4 million eclipsing binaries (with 12% spectroscopic binaries)
B. Statut
Current status

19/12/2013 Launch
Current status

• 19/12/2013
  Launch

• 08/01/2014
  @ L2

http://sci.esa.int/gaia/53280-gaia-from-launch-to-orbit/
Current status

- 19/12/2013
  Launch

- 08/01/2014
  @ L2

- 06/02/2014
  Comes into focus

http://www.esa.int/spaceinimages/Images/2014/02/Gaia_calibration_image

NGC 1818

212” x 212”
<1% of Gaia Field Of View
NGC 1818

OGLE-IV 150s

Credit L. Wyrzykowski
NGC 1818

OGLE-IV 150s

Gaia 2.8s

Credit L. Wyrzykowski
Gaia (not with best focus)
Current status

- **19/12/2013**
  Launch

- **08/01/2014**
  @ L2

- **06/02/2014**
  Comes into focus

- **05/06/2014**
  Gaia spectra

http://sci.esa.int/gaia

Gaia-RVS spectrum of HIP 86564

![Gaia-RVS spectrum of HIP 86564](image)

V=6.64 cool red star (K5 spectral type)

Narval spectrum of HIP 86564

![Narval spectrum of HIP 86564](image)
Current status

• 19/12/2013
  Launch

• 08/01/2014
  @ L2

• 06/02/2014
  Comes into focus

• 05/06/2014
  Gaia spectra

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http://sci.esa.int/gaia
Unexpected issues detected during commissioning

• Gaia seen from Earth is fainter than thought  ✔
Unexpected issues detected during commissioning

- Gaia seen from Earth is fainter than thought ✔
- There is a varying stray-light on the focal plane  ~✔

Slide courtesy L. Eyer
Unexpected issues detected during commissioning

- Gaia seen from Earth is fainter than thought ✔
- There is a varying stray-light on the focal plane ~✔
- The Basic Angle Monitor measures larger variations than expected

Slide courtesy L. Eyer
Unexpected issues detected during commissioning

- Gaia seen from Earth is fainter than thought ✔
- There is a varying stray-light on the focal plane ~✓
- The Basic Angle Monitor measures larger variations than expected
- Some evaporation escapes from the service module and contaminate the mirrors ✔

Slide courtesy L. Eyer
Unexpected issues detected during commissioning

- Gaia seen from Earth is fainter than thought
- There is a varying stray-light on the focal plane
- The Basic Angle Monitor measures larger variations than expected
- Some evaporation escapes from the service module and contaminate the mirrors
- There are clanks and micrometeoroid hits

Micro-meteoroid hit example. Figure by F. van Leeuwen

Slide courtesy L. Eyer
The instruments - accuracies

- Astrometric accuracy (G2V): 5-16 μas
- RV accuracy (G2V): 1 km/s, 15 km/s
- Number of stars: 26 million stars
- 250 $10^6$ stars
- 1,000 $10^6$ stars

http://www.cosmos.esa.int/web/gaia/fov
C. Les premiers résultats

http://www.cosmos.esa.int/web/gaia/image-of-the-week
Map of the Galaxy (with Sky Mapper)

http://www.esa.int/spaceinimages/Images/2015/07/Stellar_density_map
Cat’s Eye Nebula (on-board detection algorithm)
Gaia’s detections of asteroids in eight months’ worth of data, compared with the positions on the sky of a sample of 50 000 known asteroids. The colour of the data points is an indication of the accuracy of the detections, showing the separation on the sky between the observed position of Gaia’s detection and the expected position of each asteroid: blue indicates higher accuracy, whereas green and red indicate lower accuracy.
Luminosity & color : Hipparcos + ground-based observations

First HR diagram

http://www.esa.int/spaceinimages/Images/2015/08/Gaia_s_first_Hertzsprung-Russell_diagram
To get the data “flavour”
Comparison with OGLE

Results: Classification of RR Lyrae and Cepheid stars

Classical overtone Cepheid
3 candidate anomalous Cepheids
Type 2 Cepheid

Credits: ESA/Gaia/DPAC/CU5/DPCI/CU7/INAF-OAB/INAF-OACn Gisella Clementini, Vincenzo Ripepi, Silvio Leccia, Laurent Eyer, Lorenzo Rimoldini, Isabelle Lecoeur-Taibi, Nami Mowlavi, Dafydd Evans, Geneva CU7/DPCG and the whole CU7 team. The photometric data reduction was done with the PhotPipe pipeline at DPCI; processing data were received from the IDT pipeline at DPCE.
Results: Classification of Eclipsing binaries

Eclipsing binaries go to a dedicate treatment (Université Libre de Bruxelles) for a full modelling. Here, a simple modelling is performed. The solutions enable a ranking.

Highest rank

Credits: Geneva CU7/DPCG team.
D. Participations à la mission
D1. Gaia Science Alerts (Cambridge University)

http://gaia.ac.uk/alerts

Scan coverage on 11 Nov 2015

As of 9 June 15: 274 alerts of which 80 SN (confirmed or candidate)
AM CVn star discovered!
Fourth only known such eclipsing systems (only one with total eclipse)
Based on additional observations made by amateur astronomers

Campbell et al. 2015, MNRAS 452, 1060
D1. Gaia Science Alerts (Cambridge University)

Gaia14aae

Time

Brightness

Eclipse

Credit: Fraser/Hodgkin/Campbell/BINSIM

http://www.cosmos.esa.int/web/gaia/iow_20150717
# D1. Gaia Science Alerts (Cambridge University)

[http://gaia.ac.uk/alerts](http://gaia.ac.uk/alerts)

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<tr>
<th>Name</th>
<th>UTC timestamp</th>
<th>RA</th>
<th>Dec</th>
<th>AlertMag</th>
<th>HistMag</th>
<th>HistStdDev</th>
<th>Class</th>
<th>Comment</th>
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<tr>
<td>D1a</td>
<td>2015-06-01 15:51:25</td>
<td>358.98623</td>
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<td>17.35</td>
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<td>candidate SN</td>
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<td>D1e</td>
<td>2015-01-24 09:32:33</td>
<td>43.08181</td>
<td>60.57638</td>
<td>18.97</td>
<td>Not known</td>
<td>Not known</td>
<td>unknown</td>
<td>Galactic plane red transient, brightened from 20 to 18 mag in 100 days</td>
<td>3 Jun 2015, 16:16</td>
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<tr>
<td>D1f</td>
<td>2015-05-25 02:24:24</td>
<td>181.02133</td>
<td>14.06805</td>
<td>17.58</td>
<td>Not known</td>
<td>Not known</td>
<td>SN Ia</td>
<td>candidate SN in spiral starforming SDSS galaxy (z=0.043)</td>
<td>2 Jun 2015, 16:06</td>
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<td>D1g</td>
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<td>unknown</td>
<td>Candidate SN on edge of DSS galaxy</td>
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<td>Not known</td>
<td>SN Ia</td>
<td>Candidate young and blue SN on the edge of a DSS galaxy</td>
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</table>
D2. Gaia Follow-Up Network for Solar System Objects
(Gaia FUN-SSO)

React on alerts of moving objects (e.g. asteroids)

→ Coordinate ground-based observations for:
  - confirmation
  - orbit determination/refinement

[Hyperlink to Gaia Follow-Up Network for Solar System Objects]

https://gaiafunsso.imcce.fr

Institut de Mécanique Céleste de Calcul des Ephémérides - Paris Obs.
D2. Gaia Follow-Up Network for Solar System Objects

https://gaiafunsso.imcce.fr
Example: asteroid confirmed on 8/11/2015

Credit Sergi Blanco-Cuaresma, Geneva Observatory with the Mercator telescope, La Palma, Spain
D3. GBOG: ground-based observations for Gaia

• Une douzaine de télescopes (1-2 m) disponibles dans le GBOG
  - Initialement pour préparer la mission
  - Durant la mission pour valider / confirmer des observations

• Données non publiques $\rightarrow$ activités coordonnées au sein du Gaia DPAC (Data Processing and Analysis Consortium)

• Acquisition et réduction des données (courbes de lumière, ...)

• Ouverture pour des amateurs chevronnés:
  - Signature d’une ‘Non-Disclosure Agreement’
### Release scenario

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<tbody>
<tr>
<td><strong>spacecraft operations start</strong></td>
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<td><strong>nominal mission end</strong></td>
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<td><strong>extended mission end?</strong></td>
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#### Release 1:
- α and δ, mean G-magnitude
- Commissioning data
- 100K proper motion stars (Hipparcos + Gaia)
- + (?) TGAS: Tycho+Gaia astrometric solution (2 million stars)

#### Release 2:
- 5-parameter astrometric solutions for single star (parallax)
- Integrated BP/RP + Astrophysical parameters
- Mean $V_{\text{rad}}$ (for non variable)
- + (?) Groups of variables: RR Lyrae stars + Cepheids + Short times scales

#### Release 3:
- Mean $V_{\text{rad}}$
- 5-par astrometry
- Object classifications and Astrophysical Parameters
- Orbital solution of binaries
- Mean RVS spectra

#### Release 4:
- Variable stars classification
- Non-single star catalogue
- Solar system objects

#### Final release:
- everything!

Courtesy of B.Holl
Conclusions

- Gaia : mission unique, en très bonne voie
- Milliard d’étoiles
- Contributions d’amateurs chevronnés bienvenus