The Gaia Galactic Survey Mission

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2nd Heidelberg Astronomy Summer School
September 2007
Gaia in a nutshell

- High accuracy astrometry:
  - parallaxes, proper motions
  - radial velocities, photometry

Entire sky to $G=20$, 100 times over 5 years

- Extinction, astrophysical parameters

- ESA mission for 2011 launch
Major science topics

- How and when did the Galaxy form?
  - substructure in disk and halo (mergers)
  - star formation history
- What is the Galaxy made of?
  - chemical evolution
  - distribution of dark matter
- Stellar structure and evolution: improving models across the whole HRD
What is astrometry?

6D phase space: 3D spatial, 3D velocity
A brief history of astrometry

125 B.C.:  Precession of the equinoxes (Hipparchus)

1717:  First proper motions (Halley)

1725:  Stellar aberration (Bradley), confirming:
- Earth’s motion through space
- finite velocity of light
- immensity of stellar distances

1761/9: Transits of Venus across the Sun (various)
- solar parallax

1783:  Sun’s motion through space (Herschel)

1838-9: First parallaxes (Bessel/Henderson/Struve)
<table>
<thead>
<tr>
<th></th>
<th>Hipparcos</th>
<th>Gaia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Magnitude Limit</strong></td>
<td>12.4</td>
<td>20</td>
</tr>
<tr>
<td><strong>No. sources</strong></td>
<td>120 000</td>
<td>1000 000 000</td>
</tr>
<tr>
<td><strong>No. quasars</strong></td>
<td>none</td>
<td>0.5-1 million</td>
</tr>
<tr>
<td><strong>No. galaxies</strong></td>
<td>none</td>
<td>1-10 million</td>
</tr>
<tr>
<td><strong>Astrometric accuracy</strong></td>
<td>~1000 μas</td>
<td>7 μas at G&lt;10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12-25 μas at G=15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-300 μas at G=20</td>
</tr>
<tr>
<td><strong>Photometry</strong></td>
<td>2 bands</td>
<td>low resolution spectra</td>
</tr>
<tr>
<td><strong>Radial velocities</strong></td>
<td>none</td>
<td>1-10 km/s to G=17-18</td>
</tr>
<tr>
<td><strong>Target selection</strong></td>
<td>input catalogue</td>
<td>real-time onboard selection</td>
</tr>
</tbody>
</table>
Distances

• corresponds to 1–2% distance accuracy at 1kpc for G=15
  – 100,000 stars with distance accuracy better than 0.1%
  – 11 million stars 1%
  – 150 million stars 10%

• important in every area of astronomy
  – angular scales → length scales
  – 3D spatial structure
  – proper motions → velocities
  – intrinsic stellar luminosities

• strength of Gaia is accuracy and statistics
Many science areas

- Galaxy structure (*dark matter potential, abundances*)
- Galaxy evolution (*substructure, star formation history*)
- Stellar populations (*ages, open clusters, SFRs*)
- Stellar structure (*He abundances, luminosities, diffusion*)
- Binary stars (*M-L relation*)
- Exoplanets (*orbits, masses, transits*)
- Solar system (*taxonomy, Near-Earth asteroids*)
- Extragalactic (*local group galaxies, supernovae*)
- Cosmic distance scale (*Cepheids, RR Lyr*)
- Reference frame (*quasars*)
- Fundamental physics (*light bending, γ to 5x10^{-7}*).
Global astrometry

- Space platform required
  - wide field
  - rapid sky coverge
- Scanning principle
  - observe simultaneously in two widely separated fields separated by a fixed *basic angle*
  - measure relative positions along great circle
  - repeat for many orientations over whole sky (for 5 years)
The satellite

• very high thermal and mechanical stability demanded
  – L2 Lissajous orbit
  – no moving parts (phased array antenna)
  – passively cooled

• Soyuz-Fregat launch from Kourou

Sunshield diameter = 10m
Total mass = 2000kg
Solar array power = 12 kW
Two fields-of-view superimposed on a common focal plane
Spectrophotometry

$T_{\text{eff}} = 8500\,\text{K}, \, [\text{M/H}] = 0.0, \, \text{varying log}\, g, \, V = 15$

Dispersion: 7-15 nm/pixel (red), 4-32 nm/pixel (blue)
Purpose: object classification and estimation of stellar parameters

Brown (2006)
Radial velocity spectrograph

- slitless spectrograph
- $R = 11\,500$
- around CaII triplet (848–874 nm)
- for determining radial velocities
- $V_{\text{rad}}$ to 1–10 km/s for $V < 17.5$
- high SNR spectra for millions of stars with $V < 14$
  - physical stellar parameters, e.g. $[\alpha/\text{Fe}]$
Detecting substructure

- spatial overdensities or streams found
  - Sagittarius dSph
  - Canis Major
- but limited discovery space
  - low contrast
  - projection effects
  - streams well-mixed spatially
- can improve with
  - radial velocities
  - better identification of tracers
- ultimately need astrometry
Accretion fossils in phase space

- evolution of accreting systems
- invariant phase space
- large numbers: statistical significance for low density structures
- improve identification further via astrophysical parameters
  - luminosity, age, metallicity
  - tracers: HB, RGB, MS
Summary

Formation and evolution of the Galaxy
Stellar structure and formation
Exoplanets
Solar system
Fundamental physics

All sky survey to G=20 \((10^9 \text{ stars})\)
5D phase space (6D to \(V\sim 17\))
spectrophotometry and RVs

Accuracy = 20 \(\mu\text{as}\) @ G =15:
⇒ distances to <1% for 20 million stars
⇒ transverse velocities to 1 km/s at 1 kpc at G=20

Launch 2011; 5 year mission
http://www.rssd.esa.int/Gaia
Global astrometry from space

- **Ground-based astrometry**
  - narrow (single) field
  - common parallax effect: only *relative* astrometry
  - limited to a few milliarcseconds precision

- **Space-based astrometry**
  - observe simultaneously in two widely separated fields separated by a fixed *basic angle*
  - measure relative positions along great circle
  - repeat for many orientations over whole sky
Focal plane

- 106 CCDs
- 4500 x 1966 Pixels
- 10mm x 30mm
- 59mas x 177mas

• CCDs clocked in TDI mode
• Real-time source detection

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106 CCDs. 4500 x 1966. Pixels: 10mm x 30mm 59mas x 177mas
Timeline

- fully approved by SPC in 2006
- PDR ongoing
  - some significant issues (RVS, radiation damage)
- launch December 2011
- observations 2012-2017 (+1 year possible extension)
- final data processing 2017-2019
- final catalogue release 2019-2020
  - early releases from 2013/2014
Data Processing and Analysis Consortium

- development and operation of entire data processing pipeline
  - from telemetry stream to final catalogue
  - analysis tools and value-added products
  - simulations, science alerts, ground-based calibration data
- geographically distributed, nationally-funded partners
  - currently ~250 members in 15 countries
- no data rights: all data go public after validation
- lifetime
  - formed June 2006 following five years of working groups
  - approved by ESA SPC May 2007 (following AO)
  - operates until catalogue publication
Main Database
ESAC

CU2
Simulations
Barcelona +

CU3
Core Processing
ARI, Heidelberg +

CU4
Object Processing
Brussels +

CU5
Photometric Processing
Cambridge +

CU6
Spectroscopic Processing
Paris +

CU7
Variability Analysis
Geneva +

CU8
Astrophysical Parameters
MPIA, Heidelberg +

CU9
Catalogue Access
N.N.

Ground Station
ESOC

Also Torino, Nice, CNES, Lund, Leiden, Dresden, London, Liege, Uppsala, Athens, plus others

location of CU coordinator
Data processing overview

- **Photometry**
  - IDT, object matching, calibration
  - object classification and astrophysical parameter determination
  - variability

- **Astrometry**
  - global iterative astrometric solution over 100 million sources
  - special solutions (asteroids, binaries, perspective acceleration)
  - self-calibrating: absolute parallaxes (ICRS reference frame tie)
  - GR effects

- **Spectroscopy**
  - extraction, RV determination, calibration
  - stellar atmospheres
Data products

- position, parallax, proper motions (5 parameters)
- radial velocity for brighter sources (6\textsuperscript{th} phase space coordinate)
- G-band magnitude
- RP/BP spectrum
- RVS spectrum for brighter sources
- astrophysical parameters for stars, galaxies and QSOs
- (spectro)photometric variability information
- binary system parameters, orbital solutions (inc. exoplanets)
- solar system object (asteroid) orbits and taxonomy
- alerts of transient events (e.g. supernovae)