Gaia Variability Analysis and Processing

Laurent Eyer on behalf of Coordination Unit 7

Barcelona, Catalonia, Spain

Tuesday December 2, 2014
CU7/DPCCGeneva: variability processing and analysis
CU7/DPCGeneva: variability processing and analysis

- Active members: 72 people
ESA + large collaboration
ESA + large collaboration = MANY documents
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CU7/DPCG level
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CU7/DPCG level

266 documents
ESA + large collaboration = MANY documents

CU7/DPCG level

> 10,000 pages?

266 documents
Gaia can be seen under many facets
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at the heart of Gaia:
a multi-epoch survey
Gaia can be seen under many facets at the heart of Gaia: a multi-epoch survey. Gaia “case” is about variability.
Gaia can be seen under many facets

at the heart of Gaia:

a multi-epoch survey

Gaia “case” is about variability

Gaia is performing Time-Domain Astronomy
Estimation of G magnitude error as function of magnitude (stay-light included)

G magnitude error

G magnitude

Courtesy of Dafydd Evans
Gaia will detect most variable types on this tree
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Variability tree

Asteroids

Stars

Extrinsic

Rotation

Eclipse

Eclipsing binary

Planetary transits

Microlensing

Eclipse occultation

Rotation periods

Determine rotation periods

Stars

Intrinsic

Eclipse

Eruptive

Cataclysmic

AGN

Probe real-time stellar evolution

Find targets & give constraints for asteroseismology

Calibrate Standard Candles

Gaia will detect most variable types on this tree

Credit: L. Eyer & N. Mowlavi (03/2009)
Variability tree

Variability Tree

Asteroids
- Rotation
- Eclipse
- Microlensing
- Asteroid occultation
- Eclipsing binary
- Planetary transits

Stars
- Extrinsic
- Eclipse
- Rotation
- Eclipses
- Eruptive
- Cataclysmic

Intrinsic
- SN
- Supernovae
- Symbiotic
- Dwarf novae
- Long period sdB
- V1093 Her
- W Vir
- Type II Ceph.
- δ Cepheids
- RR Lyrae

Extrinsic
- RCB
- BY Dra
- UV Ceti
- FKCOM
- Single red giants
- ECL
- ELL
- Red dwarf (K-M stars)

Intrinsic
- δ Scuti
- γ Doradus
- Slowly pulsating B stars
- α Cygni
- β Cephei
- λ Eri
- SX Phoenicis
- ACV
- BY Dra
- Single red giants

AGN
- Probe real-time stellar evolution
- Find targets & give constraints for asteroseismology
- Calibrate Standard Candles

- Determine stellar parameters
- May find very short time scale variables
- Determine rotation periods

Gaia will detect most variable types on this tree

Credit: L. Eyer & N. Mowlavi (03/2009)
Variability tree

- Gaia will detect 50 million - 150 million variable objects
- Determine rotation periods
- May find very short time scale variables
- Probes real-time stellar evolution
- Determine rotation periods
- Find targets & give constraints for asteroseismology
- Calibrate Standard Candles
- Gaia will detect most variable types on this tree

Credit: L. Eyer & N. Mowlavi (03/2009)
CU7 / DPCG Variability Analysis: a systematic and comprehensive approach
CU7 / DPCG Variability Analysis: a systematic and comprehensive approach

Berry Holl diagram (2013):
CU7 / DPCG Variability Analysis: a systematic and comprehensive approach

Berry Holl diagram (2013):

- General Variability Detection (GVD)
- Special Variability Detection (SVD)
- Calibrated photometry (CU5)
- Radial velocities (CU6)
- Variables catalogue (CU7)
- Global Variability Studies (GVS)
- Specific Object Studies (SOS)

- Astrometric char (CU3+CU4)
- Spectroscopic char (CU6)
- Astrophysical param (CU8)

- Unexpected Features Analyses
- Supplementary Observations
CU7 / DPCG Variability Analysis: a systematic and comprehensive approach

Berry Holl diagram (2013):

- **General Variability Detection (GVD)**
- **Specific Object Studies (SOS)**
- **Characterization**
- **Classification**
- **Special Variability Detection (SVD)**
- **Variables catalogue (CU7)**
- **Calibrated photometry (CU5)**
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3. Characterization
4. Classification
5. Specific Object Studies (SOS)
6. Variables catalogue (CU7)
7. Global Variability Studies (GVS)

Astrometric char (CU3+CU4)
Spectroscopic char (CU6)
Astrophysical param (CU8)
Calibrated photometry (CU5)
Radial velocities (CU6)

Unsupervised observations (black)
Supervised observations (white)

task 0: re-order the data
The variability analysis is also a validation of calibrations.
Detailed Berry Holl’s diagram:

- **Calibrated photometry (CU5) [ and CU3, CU6, CU8]**
  - **Statistical parameters**
    - **General Variability Detection (GVD)**
      - **Filter (p-value) threshold**
    - **Special Variability Detection (SVD)**
      - **Filter**
        - **Short-time**
        - **Solar-like**
        - **Planets**
  - **Characterization**
    - **Extractor**
      - **Filter**
        - **Transient**
        - **μ-lens**
        - **EB**
    - **(Additional) attribute calculation**
      - **(Un/semi-) supervised classification**
  - **Specific Object Studies (SOS)**
    - **Filter**
      - **μ-lens**
      - **Be**
      - **CV**
      - **EB**
      - **Cep/RRL**
      - **PMS**
      - **LPV**
      - **Flaring**
      - **RotationMod**
      - **AGN**
      - **Rapid-phases**
      - **Short-time**
      - **Planets**
  - **Variables MDB catalogue (CU7)**
  - **Global Variability Studies (GVS)**
Detailed Berry Holl’s diagram:

Calibrated photometry (CU5) [ and CU3, CU6, CU8] → Statistical parameters

- General Variability Detection (GVD)
  - filter (p-value) threshold

- Special Variability Detection (SVD)
  - filter short-time
  - filter solar-like
  - filter planets

Characterization

- Specific Object Studies (SOS)
  - filter μ-lens
  - filter Be
  - filter CV
  - filter EB
  - filter Cep/RRL
  - filter PMS
  - filter LPV
  - filter Flaring
  - filter RotationMod
  - filter short-time
  - filter planets

- (additional) attribute calculation
- (un/semi-) supervised classification

Variables MDB catalogue (CU7) → Global Variability Studies (GVS)
Detailed Berry Holl’s diagram:

Calibrated photometry (CU5) [ and CU3, CU6, CU8]

Statistical parameters

General Variability Detection (GVD)

- Filter (p-value) threshold

Special Variability Detection (SVD)

- Short-time
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- Flaring
- RotationMod

Variables MDB catalogue (CU7)

Global Variability Studies (GVS)
Yes we are ready!
Special Variability Detection: Short time scales, ad-hoc simulation

Simulated data of Gaia Per-CCD photometry

~30 are known, 200 AM CVn stars may be detected by Gaia (Nelemans 2013)
Special Variability Detection:
Short time scales, ad-hoc simulation

Simulated data of Gaia Per-CCD photometry

Gaia is probing the sky at the few seconds level!

~30 are known, 200 AM CVn stars may be detected by Gaia (Nelemans 2013)
Special Variability Detection: Exo-planetary transits ad-hoc simulation (by D.W. Evans)

Brandon Tingley/Shay Zucker

![Graph showing Folded Raw Time Series with G Magnitude on the y-axis and Phase on the x-axis. The graph includes observations and a mean magnitude line.]

Courtesy of L. Guy
Special Variability Detection: Exo-planetary transits ad-hoc simulation (by D.W. Evans)

Brandon Tingley/Shay Zucker

Estimations 100s-1000s detected exoplanet transits (Dzigan & Zucker 2012)

Courtesy of L.Guy
Classification:
Transient extractor: test on EROS data

Mowlavi 2014
### Classification of variables: example on GOG simulations

#### Two fundamental quantities

**Completeness**

<table>
<thead>
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<th>CEP</th>
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<th>DWARFNOVAE</th>
<th>EB</th>
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<td>0</td>
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</tbody>
</table>

**Contamination**

- courtesy of B.Holl and L.Rimoldini
SOS: microlensing: test on OGLE

Source 101827 (f0=1.00)
f1=12.85, u0=3.06, t0=22.02, tmax=1455.78, chi2=5.24e-01

- Measured fluxes
- Paczynski curve
- Residual fluxes
Cepheids: Test on OGLE-III (mostly)

DCEP mode identification from Fourier parameters

Clementini, CU7-19 meeting, 2014
Variable stars in Colour-Magnitude Diagram

LMC OGLE data

Variable stars
Eclipsing
Be
Cepheids: [Fund] [1st Ov] [2nd Ov]
RRLyr: [rrab] [rrc] [rrd] [rrf]
Ellipsoidal
Lpv (Long Period Variables)

Spano et al 2009
Variable stars in Colour-Magnitude Diagram

LMC OGLE data

Variable stars
- Eclipsing
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- Cepheids: [Fund][1st Ov][2nd Ov]
- RRLyr: [rrab][rrc][rrd][rrre]
- Ellipsoidal
- LpV (Long Period Variables)

Spano et al. 2009
Variable stars in Colour-Magnitude Diagram

Gaia:

1) Full description of HR diagram (parallax)

2) better precision (detection of many additional types)

3) simultaneous data in G, BP, RP (motion!)

4) Radial Velocities
Release scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Release 1</th>
<th>Release 2</th>
<th>Release 3</th>
<th>Release 4</th>
<th>Final release</th>
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<tbody>
<tr>
<td>2014</td>
<td>α and δ, mean G-magnitude</td>
<td>5-parameter astrometric solutions for single star (parallax)</td>
<td>Mean $V_{\text{rad}}$</td>
<td>Variable stars classification</td>
<td>everything !</td>
</tr>
<tr>
<td></td>
<td>Commissioning data</td>
<td>Integrated BP/RP + Astrophysical parameters</td>
<td>5-par astrometry</td>
<td>non-single star catalogue</td>
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<tr>
<td></td>
<td>100K proper motion stars (Hipparcos+Gaia)</td>
<td>Mean $V_{\text{rad}}$ (for non variable)</td>
<td>Object classifications and Astrophysical Parameters</td>
<td>solar system objects</td>
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<tr>
<td></td>
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<td></td>
<td>Orbital solution of binaries</td>
<td>mean RVS spectra</td>
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<td>2019</td>
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<tr>
<td>2020</td>
<td>nominal mission end</td>
<td>extended mission end?</td>
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</tbody>
</table>

Science operations start: 2014

Final release: everything!

Courtesy of B.Holl
Release scenario

Release 1:
- $\alpha$ and $\delta$, mean G-magnitude
- Commissioning data
- 100K proper motion stars (Hipparcos+Gaia)

Release 2:
- 5-parameter astrometric solutions for single star (parallax)
- Integrated BP/RP + Astrophysical parameters
- Mean $V_{\text{rad}}$ (for non variable)

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!

Groups of variability types should be made public in releases 1?, 2, 3

Courtesy of B.Holl
Conclusions

Gaia will reveal the universe in an unprecedented way

“Gaia will be the finest catalog of variable stars ever made” D.Hogg
Conclusions

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- CU7 will provide fundamental properties of the objects and of their variability
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- The large numbers of sources observed by Gaia will allow
  - search for very rare objects
  - describe properties of group of variable stars
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- CU7 will provide fundamental properties of the objects and of their variability
- The large numbers of sources observed by Gaia will allow
  - search for very rare objects
  - describe properties of group of variable stars
- The variability analysis is triggering “new” method
- Variability catalogue results will also be most interesting when used with other data sets
  - Complement other projects (LSST, OGLE, CoRoT, Kepler, TESS, PLATO, CHEOPS, …)
  - Follow-up of Gaia data with ground-based facilities (also with “small telescopes”)
Thank you for your attention!
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