Gaia photometry
Methods, performances and problems

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Gaia: at the frontiers of astrometry – ELSA conference
7-11-June-2010
Why Photometry?

Photometry is necessary to account for the chromatic aberrations in the astrometric focal plane to achieve microarcsec accuracy level.

The scientific goals of Gaia require complementary astrometry, photometry and radial velocity data, being the characterization of the observed objects in terms of astrophysical parameters the main goal of the photometry.
Blue and red spectrophotometers

- **Blue photometer:** 330–680 nm
- **Red photometer:** 640–1000 nm

Figures courtesy EADS-Astrium
Focal plane

106 CCDs, 938 million pixels, 2800 cm²
pixel size = 59 mas, angular resolution = 0.12"

Image motion: Delayed integration

Sky Mapper CCDs
Astrometric Field CCDs

Figure courtesy Alex Short
Photometry

1. Photometry: broad bands
2. Spectrophotometry: BP & RP spectra
Gaia passbands

CJ-041 with updates EADS-Astrium (CDR), RK, AM
Spectrophotometry
Blue and red spectrophotometers

Resolution ~100
BP: 4-35 nm/pixel
RP: 7-15 nm/pixel

Red spectra of a M-dwarf (V=17.3)
Red box: extracted window sent to the Earth

Figures courtesy Anthony Brown
Calibration approach & deliverable products
Data processing has to account for:

<table>
<thead>
<tr>
<th>Pre-processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bias, background, CTI (image+SR), gain</td>
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<tr>
<td>• Contamination and blending</td>
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<table>
<thead>
<tr>
<th>Internal calibration</th>
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<tbody>
<tr>
<td>• Overall sensitivity variation (optics, CCDs)</td>
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<tr>
<td>• Flux out of the window (AC &amp; AL flux loss)</td>
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<tr>
<td>• PSF/LSF variation</td>
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<tr>
<td>• Dispersion variation</td>
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<td>• Geometry variation (AL &amp; AC); tilts</td>
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<th>External calibration</th>
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<tr>
<td>• Absolute flux scale</td>
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<tr>
<td>• Wavelength scale</td>
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</table>
Mean, minimum and maximum QE

Figure courtesy Ralf Kohley & Alcione Mora
Figure 9: Flat field images for CCD 05486-15-2 for 400 nm, 550 nm and 900 nm (upper row, from left to right) and for CCD 06036-11-1 (lower row). CCD columns are aligned vertical (AL scan direction) in this figure. Oval dark patterns are believed to origin from particles in the optical path. Note, that the pixels with 3:1 length scale are displayed at 1:1 scale here.
Flux in the window

AF S5R4T1    V-I=2.0

No AC motion    Nominal AC motion    window +1 pixel

1-2% variation
Dispersion and LSF

Disp effect
D₇ ~0.9D₁ → Δλ₇ ~1.1Δλ₁

LSF effect

joint effect
CTI effect on BP/RP spectra

TDI motion

tree charge redistributed by fast traps

charge loss at leading edge due to slow traps
Telemetry → IDT → Pre-processing → Clean images → Internal calibration “forwarding model”
- Source update
- Instrument update

→ Internal fluxes
→ Internal XP spectra

→ External calibration

→ Absolute fluxes
→ BP/RP spectra

MDB

GOG

PMN-004
Full forwarding model

SED

Dispersion $\lambda_0$, LSF/PSF

"mean" spectra

sensitivity LSF/PSF dispersion geometry flux loss

transit spectra

IA+SR CDM bias, gain non-linearity

predicted image

observed image
Telemetry

Raw images

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MDB
Performances
Simple model for $G$ calibration

\[ f_i = (A_0 + a_0) \cdot g_i + (A_1 + a_1) \cdot (b_p - r_p) + (A_2 + a_2) \cdot (b_p - r_p)^2 / g_i + (A_3 + a_3) \cdot (b_p - r_p)^3 / g_i^2 + (A_4 + a_4) \cdot (b_p - r_p)^4 / g_i^3 + (A_5 + a_5) \cdot (b_p - r_p)^5 / g_i^4 + (B_0 \cdot \Delta x_i + B_1 \cdot \Delta x_i^2 + B_2 \cdot \Delta x_i^3) \cdot g_i + (C_0 \cdot v_i + C_1 \cdot v_i^2) \cdot g_i \]
end-of-mission $\sigma_G$

Aperture photometry
Variability

Light curves of stars in M31

Vilardell et al (2007)
HV-005

GASS: 1 day
13 < G < 17
350,000 transits
Conclusions (I)

**G calibration**

- calibration errors at the level of mmag
- CTI in IA & SR not accounted for
- bias and background uncertainties
- non-linearity & saturation under study
- bright stars performances to be assessed

- limited by performance of extraction image parameters
**Simple model for BP/RP calibration**

$$f_i = \sum_{j=-M}^{+M} a_{ij} \cdot h_{i+j}$$

$$a_{ij} = \sum_{l=0}^{L} c_{jl} \cdot (i - i_{ref})^l$$

$$h_i = \sum_{k=1}^{N_{knots}} b_k \cdot B_{k,i}$$

$$f_i = \sum_{j=-M}^{+M} \sum_{k=1}^{N_{knots}} \sum_{l=0}^{L} c_{jl} \cdot b_k \cdot (i - i_{ref})^l \cdot B_{k,i+j}$$

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**Assumptions when calibrating the instrument:**

- Only performed using calibration sources.
- The equations system consist on all observations of all calibration sources performed using the same instrumental configuration (same CCD, FoV, column, gate, dispersion, LSF, geometry,...) and fitting parameters for a given pixel $i$.
- The unknowns are $c_{jl}$.
- $b_k$ (different for each calibration source) are considered as known.

**Assumptions when producing mean spectrum:**

- To be done for every source, not only calibration sources (but for the iterative loop perhaps only calibration sources are needed).
- The equations system is formed by all observations at the same source, independently of the instrumental configuration used, and using all observed pixels in a single equations system.
- The unknowns are $b_k$.
- $c_{jl}$ (different for each instrumental configuration) are considered as known.
Relative residuals in prediction

T=50000K, logg=5.0, 56 obs, $\lambda_{\text{src}}=\lambda_{\text{CCD3}}$

BP, cubic normalized $a_{ij}$, $a_{ij}^0=\text{real}$, 137 knots, G=13

RP, cubic normalized $a_{ij}$, $a_{ij}^0=\text{real}$, 137 knots, G=13, seed=-25341

Hot star: T=50000K, logg=5
$G = 15$

56 noisy observ
Conclusions (II)

BP/RP spectra calibration
• calibration errors below observational noise
• CTI in IA & SR not accounted for
• bias and background uncertainties
• non-linearity & saturation
• improvement of the simple model by the full forwarding model → to assess feasibility

See poster by G. Busso
Thank you

Photometric processing is a collaborative effort: UK, The Netherlands, Italy, Spain