

Detection of Polarization Effects in Gaia Data

Frederic Raison

ADA7 14-18/05/2012

European Space Agency

Introduction



- Gaia is an astrometry mission using 2 telescopes.
- The idea is to use Gaia as a polarimeter (low precision but unbiased global polarimeter).
- This was not planned: we use an asymmetry of the optics to get more information from measurements.
- After my first study of feasibility, Lund University joined.

Overview



- A. How does Gaia work?
- B. What is the polarization impact?
- c. Which science can be done?



esa

A: Gaia in few words

- Launch scheduled for summer 2013 for a 5-year mission at L2.
- micro-arcsecond (μ as) global astrometry for ~1 billion sources in the magnitude range G=[6, 20].
- One of the most comprehensive stellar catalogs to date when completed.
- Sources range from minor Solar System bodies (~250,000), supernovae and burst sources (~20,000) up to nearby galaxies and distant quasars (~ 500,000).



A: Astrometry

- 5 astrometric parameters: are assigned to all point sources: α_0 , δ_0 , μ_{α} , μ_{δ} , π_0
- Want to determine their value for each source.
- Want to have a reference: ICRS









A: Measurements: time of centroids



RVS1 RVS2 RVS3





SM1 SM2

Gaia CCD Setup

row 7

row 6

row 5

row 4

row 3

row 2

row 1

0,420

angle

field

VF2

F

Along-scan field angle

VF3

AF6

F

Star Transit

AF5

AF4

AF9 AF9 ВЪ

P

"Time of observation" for image centre relative to CCD

. determined to ~200 μ as precision (magnitude 15)

Some 700 such measurements per object in 5 years
 => 10¹² observations



B: Impact of polarization on centroiding

- Mirrors coating sensitive to linear polarization and generate wave front error.
- Wave front error induces centroid displacement independent of magnitude, proportional to polarization.
- Can calculate a standard deviation from the shifts of N transits on random CCD raw on a single FOV:

700 observations/source =>	this	is	within	Gaia'	S
resolving capabilities.					

Spectral	σ [µas]
type	@ 1% polarization
B1V	0.43
G2V	0.70
M6V	5.30







B: Astrometric solution





Database knows the mappings $L \leftrightarrow i$, $L \leftrightarrow j$, $L \leftrightarrow k$

SOLVE
$$J(x) = \sum_{L} \left(t_{L}^{obs} - f_{L}(x, aux) \right)^{2} \frac{W_{L}}{\sigma_{L}^{2} + \varepsilon_{L}^{2}} = \sum_{L} R_{L}(x, aux)^{2} W_{L}$$
sum over observations is traised as (O-C) is statistical weight



> Any small change in the orientation of the celestial reference system ($\varepsilon = [\varepsilon_x, \varepsilon_y, \varepsilon_z]$) ...

Any introduction of a small inertial spin of the system $(\omega = [\omega_x, \omega_y, \omega_z]) \dots$

>... leaves observations invariant (differential measurements, no a priori information on sources).

Need to align system of positions and proper motions with the ICRS.

B: Solving for polarization



• Instrumental response:

• Shift = $S_L (\lambda, \Delta \eta, \Delta \zeta, P_L, \theta, \theta_0)$

Solving now for 7 parameters for each source:

$$\alpha_0, \delta_0, \mu_{\alpha}, \mu_{\delta}, \pi_0, Pq, Pu$$

$$P_L = \sqrt{P_Q^2 + P_U^2}$$
$$P_Q = P_L \cos(2\theta)$$
$$P_U = P_L \sin(2\theta)$$

Stokes parameters describing linear polarization of light



 $\Delta \zeta$ = Across-scan field angle $\Delta \eta$ = Along-scan field angle $\Delta \delta$ = Declination $\Delta \alpha$ = Right ascension

B: First results (M6V type @ G=13)



- Astrometric simulations were made by C.Skoog, Lund University, with AGISLab.
- Stockes parameter P_Q and P_U absolute error parameters converge to ~ 0.01 for both 1% and 10% polarized (constant) sources.
- This means the observations will be sensitive to sources with greater than 1% linear polarization for sources for M6V type @ G=13.
- > 2 regimes:
 - bright stars for which accuracy on calibration is $\sigma = 0.01$ on P_{Q} and P_{U} whatever magnitude
 - faint stars for which accuracy depends on magnitude.



Randomly distributed M6V generated sources



C: Which Objects can be calibrated?



> stars:

- from Heiles compilation for about 9300 stars
- Intrinsic polarization.
- ISM (depending on Galactic magnetic field)

➢ QSO:

- Non Variable : 0.5-3%
- Variables: 5-+10%
- Polarization angle turns with z

Potential limitations:

- Knowledge of the instrumental response.
- (auto-)Calibrable? Observations from ground?
- Variability (especially for high polarization). Model?

P(%)	Fraction(%)
≥ 10	0.04
≥ 7	0.27
≥ 5	2.0
≥ 4	5.4
≥ 3	10.5
≥ 2	19.7
≥ 1	36.3
≥ 0.5	50.5

P(%)	Fraction(%)
≥ 1	62.9
≥ 2	34.3
\geq 3	23.9
≥ 4	19.9
≥ 5	15.8
≥ 6	13.4
≥ 7	11.9
≥ 10	8.6

Sources:

"Polarisation of the Gaia Sky" (GAIA-CA-TN-NBI-JK-001, 26 October 2006)

Heiles, C. 2000 AJ 119, 923
Hutsemékers, D., Cabanac, R., Lamy, H., and Sluse, D. 2005 A&A 441, 915

European Space Agency

C: Directions of research



- Salactic magnetic field reconstruction: C. Skoog, D. Hobbs, L. Lindegren, Lund University.
- Impact of QSO errors on Gaia catalog alignment onto ICRF: F. Raison in collaboration with G. Bourdat (Obs.Bordeaux).

Galactic magnetic field reconstruction (c. Seg, E. Hobbs, L. Lindegren, Lund University)

- The calculated all sky Healpix maps for the DIRBE/IRAS dust maps with the angle of minimum polarization located along the plane of I = 77:4.
- (a) E(B-V) colour excess values from dust maps.
- (b) Polarization magnitude values calculated (1% threshold limit to emphasis the structure outside the galactic plane).
- (c) angle calculation
- (d) Polarization magnitude values (full threshold range).



Alignment on the ICRF: principle



- > Parameters ε (orientation) and ω (rotation) are determined by a weighted least-squares solution, using as input the differences in positions and proper motions for a subset of sources, between the AGIS results and a priori data.
- Subset S_{NR} of primary sources to define a kinematically non-rotating celestial frame (10⁸ to 10⁶ QSOs and point-like galactic nuclei). This subset effectively determines ω .
- > Subset S_p of S_{NR} with positions accurately determined % ICRS independently of Gaia: optical counterparts of extragalactic objects from radio interferometry (VLBI). This subset effectively determines ε .
- Subset S_{PM} of sources not belonging to non-rotating subset but with accurate position and proper-motion independently of Gaia. For consistency check.

Does polarization shift impact the estimation of ε ?



- Started from 201 QSOs from ICRF2 provided by G. Bourdat, obs. Bordeaux, for Subset S_P.
- > A polarization shift is calculated for each source of the list: Pshift = S_L (λ , $\Delta \eta$, $\Delta \zeta$, P_L , θ , θ_0)
- > Should calculate the error for each source depending on scanning law.
- But can get a representative typical error by summing shifts for all CCDs and for a limited set of values covering the range of orientations.

Model for QSO



Available QSO spectra are limited: generic spectrum and use redshift (1rst order).



 Generate missing polarization information according to (Hutsemekers+, 2005)

Impact on the ICRF



>
$$\sigma_{tot} = 37.1$$
 uas, $\sigma_{loc} = 36.6$ uas

- Out of the 70 sources, only 5 (blazars) have a polarization error > location error
- No impact on the precision of the estimation of the parameters for the alignment onto the ICRF.
- Accuracy: ongoing work.





- Can do a quick extrapolation to the observable set of the number of calibrable QSOs:
- > ~500,000 expected QSOs for G<20
- Between 17,000 (error pol>2x loc) and 32,000 (error pol>1x loc) calibrated QSOs.
- > = very small part of the QSOs population
- > But would be still the largest catalog up to now.

Potential study



Orientation of QSO polarization vector:

Hutsemékers, D.; Cabanac, R.; Lamy, H.; Sluse, D., "Mapping extreme-scale alignments of quasar polarization vectors", 2005.

Conclusion



- Polarization has a negligible impact on Astrometry.
- Because of the accuracy of the astrometric solution determination, it can be calibrated for a few percent of the sources, which is still an unprecedent set.

Some science can be done.

Acknowledgment



- Jos De Bruijne (ESA/ESTEC) whose presentation sparked off this project.
- ESA/ESAC/SRE-OD for funding this project.
- William O'Mullane (ESA/ESAC) for the initial funding.
- S. Els, R. Kohley and A. Mora (ESA/ESAC) for discussions, comments and reviews.