The Gaia reference frame and the acceleration of the solar system barycentre in the presence of quasar variability

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Introduction

Gaia is an astrometric space mission due for launch in late 2013. It will measure the positions, parallaxes and proper motions of more than 1 billion objects in our Galaxy and beyond. The very accurate astrometric measurements will allow the International Celestial Reference Frame (ICRF) to be improved by one to two orders of magnitude in the optical. To achieve this several sets of quasars will be used. This will allow to define a kinematically stable non-rotating reference frame with the barycentre of the Solar system as its origin. Clearly, the stability of the optical quasar counterparts is critical for achieving the expected accuracy. This poster presents simulation results which show how accurately the reference frame can be recovered in the presence of quasar variability.

The Gaia reference frame

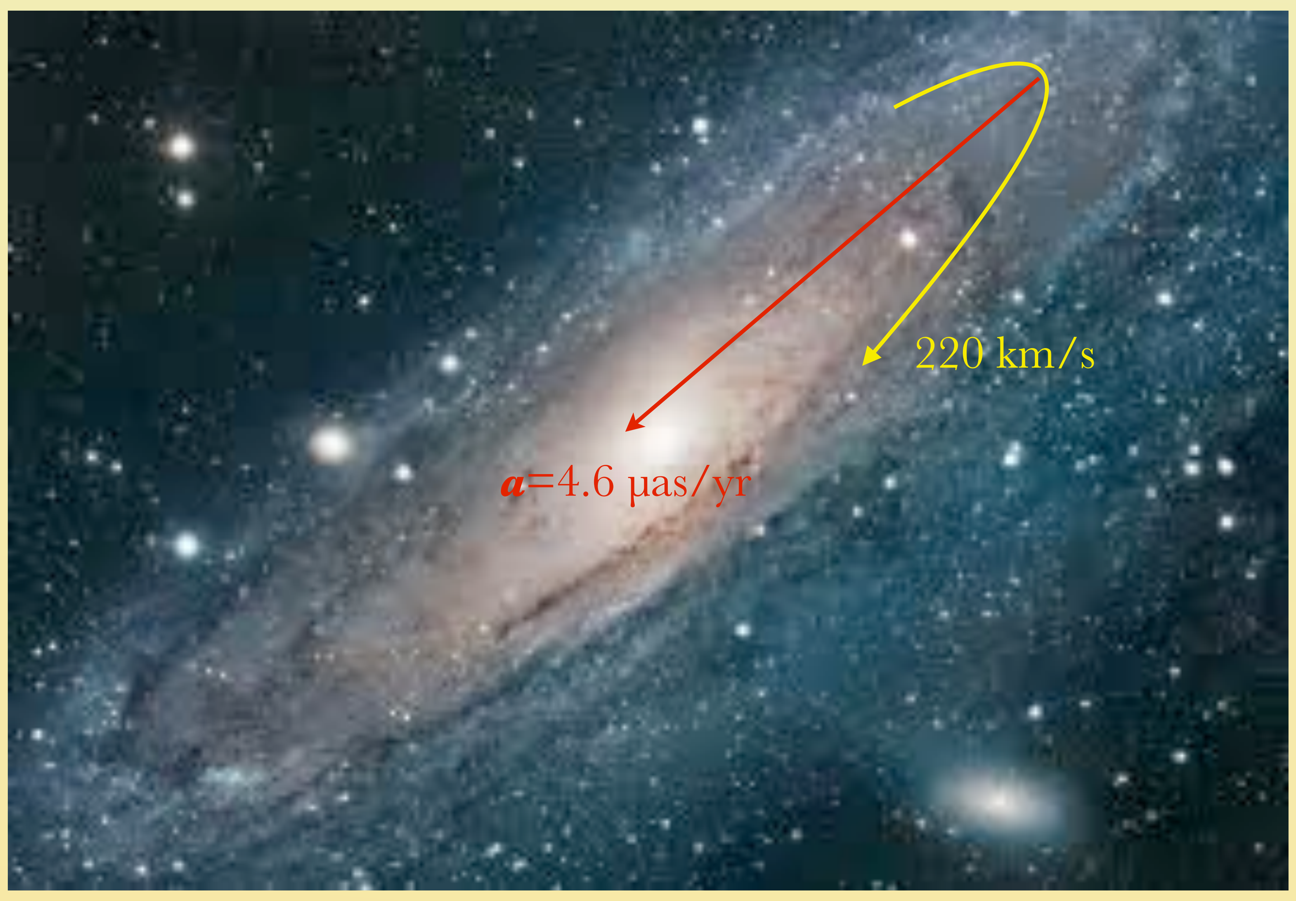
The relative measurement principle of Gaia results in astrometric parameters (positions and proper motions) which are undetermined with respect to six degrees of freedom in the orientation (ε) and spin ($\boldsymbol{\omega}$) of the reference frame. In order to express the final astrometric results in a celestial reference frame which closely matches the ICRS, the orientation and rotation parameters will be estimated from two sets of optical quasars, assumed to have zero proper motion. The two sets are:

- S1 quasars - consisting of the optical counterparts of a few thousand radio VLBI objects with known positions in the ICRS, which help to constrain the orientation (ε).
- S2 quasars - consisting of hundreds of thousands of quasar-like objects taken from ground based and photometric surveys which help to constrain the spin ($\boldsymbol{\omega}$).

Recent observations of AGNs and theoretical studies indicate that variability in the accretion disk and dusty torus surrounding the central black hole can cause photocenter shifts of up to the milliarcsec level. We investigate the statistical impact of expected photocenter variability on the Gaia reference frame based on simulated observations.

Acceleration of Solar system barycentre

The Solar systems orbital velocity is about 220 km/s about the Galactic centre and this causes an aberration effect of approximately 2.5 arcminutes which in itself is unobservable. However, the acceleration of the solar system towards the galactic center causes this aberration to change slowly with time, giving an apparent proper motion of quasars of up to 4.6 µas/yr. This pattern of proper motions must be solved for while determining the reference frame orientation and rotation parameters. We present an estimate of how well the acceleration vector can be determined based on realistic Gaia simulations which also assess the impact of quasar variability.



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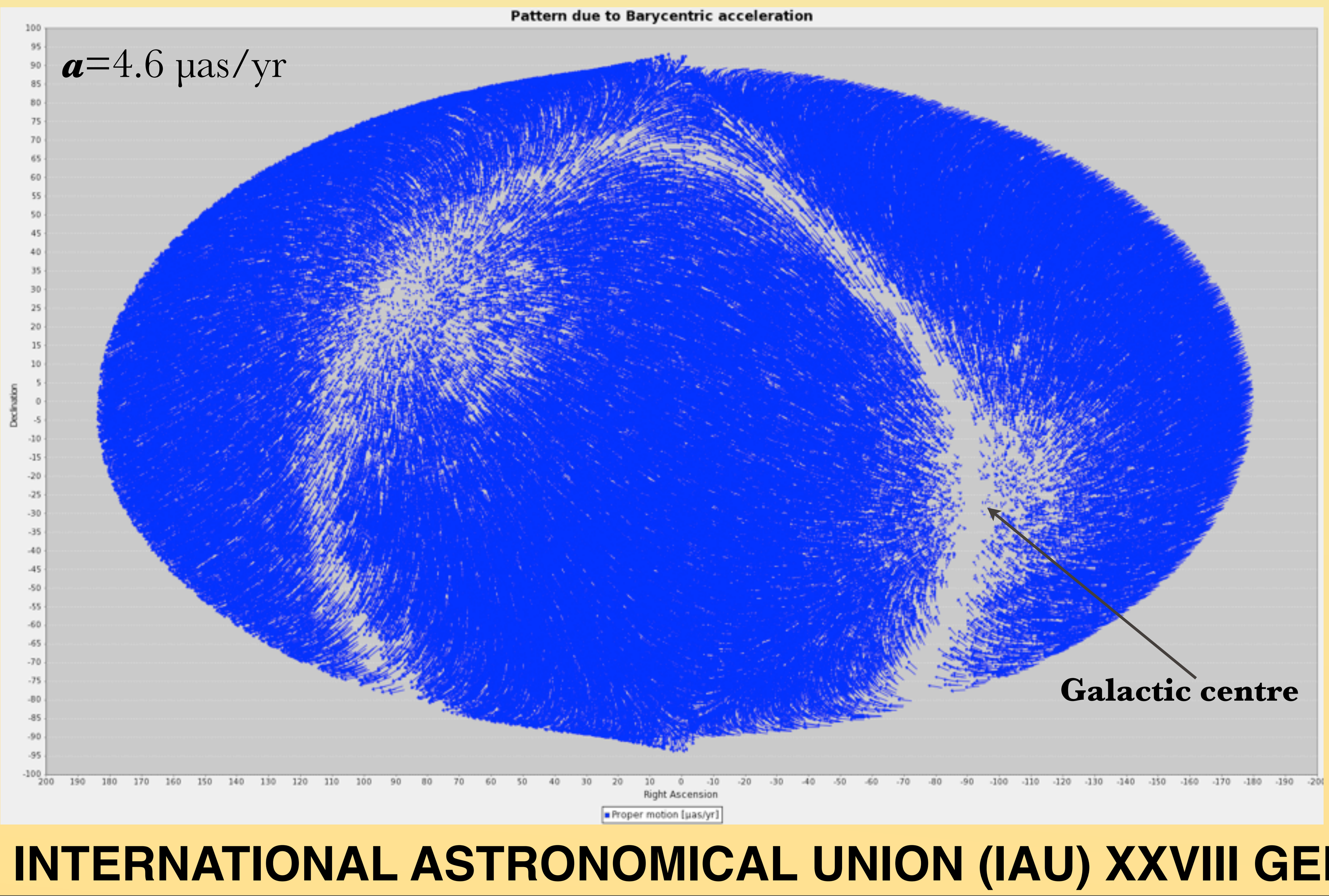
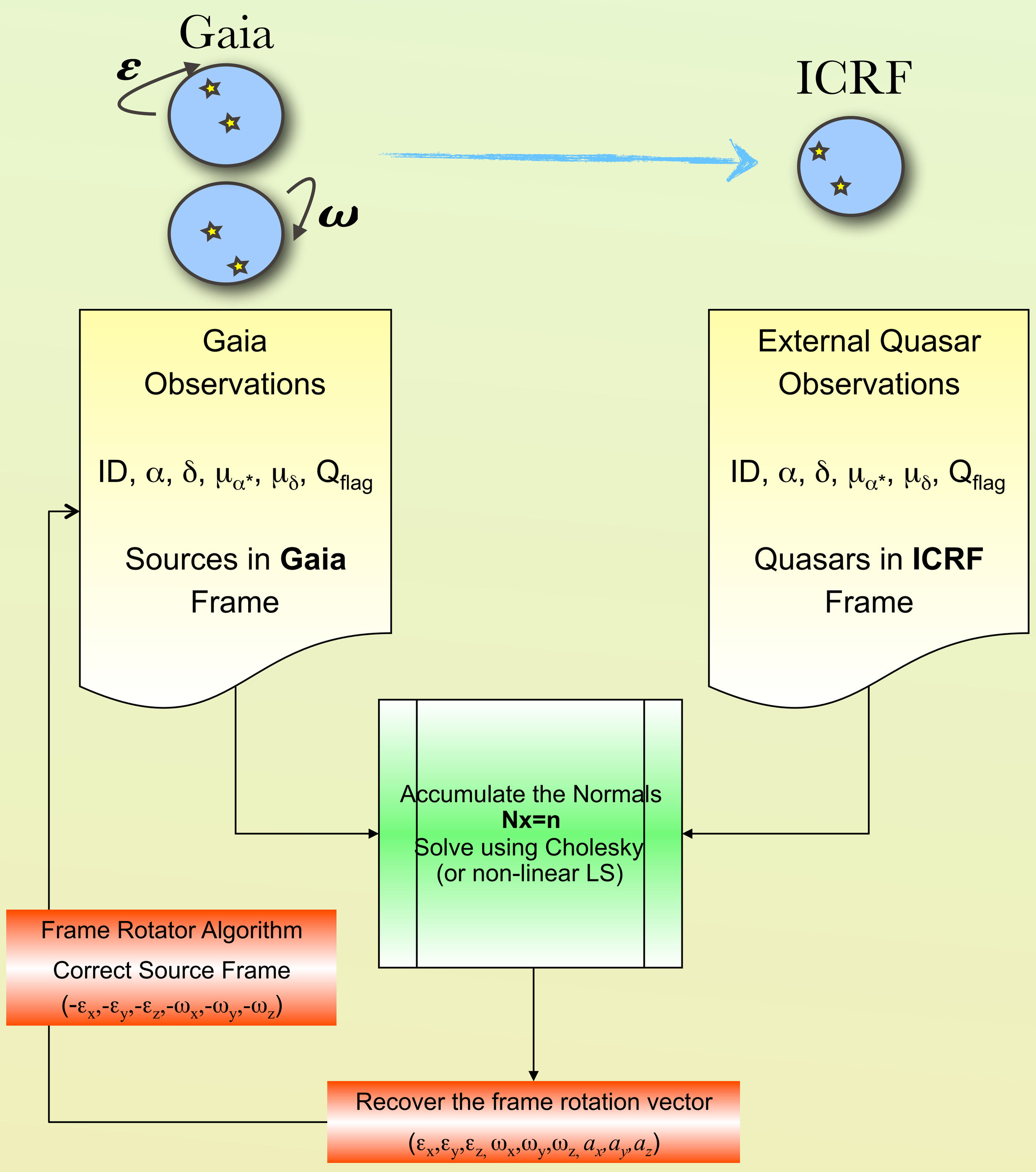
Pattern of proper motions observed in the quasars. A single vector is plotted at each quasar position indicating the magnitude and direction of the proper motion which points towards the galactic centre.



Numerical approach

The core astrometric solution for the Gaia mission uses an iterative least squares approach to determine the astrometric parameters with an accuracy of ~10 µas(/yr). However, Gaia only determines the relative position of sources. The reference frame is therefore arbitrary but must coincide with the extragalactic reference frame (ICRS). There are 6 degrees of freedom in the Gaia solution corresponding to a solid body rotation due to orientation (ε) and spin ($\boldsymbol{\omega}$) between the two frames.

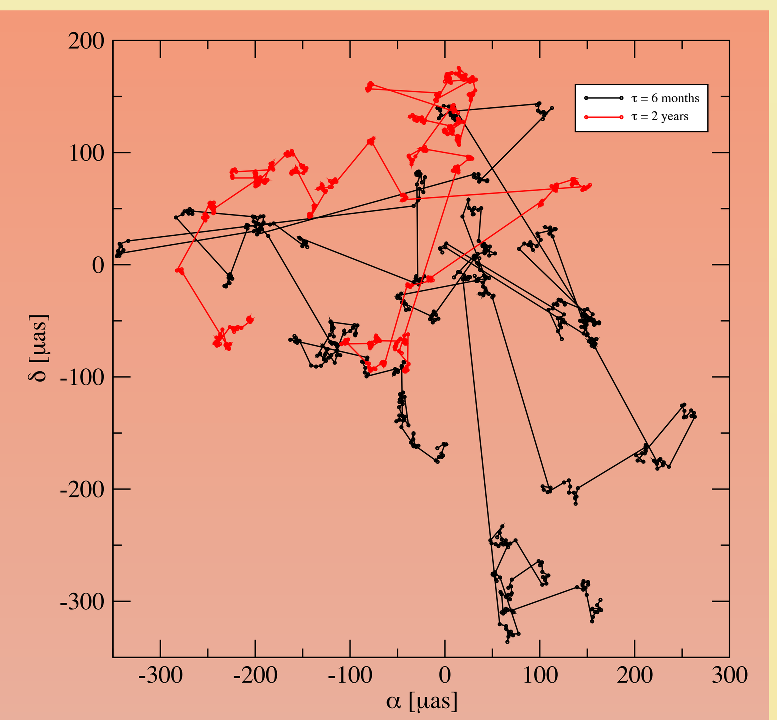


To determine the 6 degrees of freedom, we compare the quasars measured in the Gaia frame with the same quasars measured independently in the VLBI and other ground based surveys. We then perform an iterative solution for the orientation (ε) and spin ($\boldsymbol{\omega}$) parameters and use them to correct the Gaia reference frame. At the same time we can also solve for the acceleration of the Solar system barycentre which we expect to be towards the Galactic centre.

To simulate quasar variability, we use a Markov chain with a characteristic correlation time scale (τ) of six months and two years to generate random photocentre variations. We simulate ~2400 optical counterparts of radio VLBI objects with photocentre variations of 100 µas (set S1) and ~100 thousand quasar-like objects from ground based and photometric surveys with photocentre variations of 120 µas (set S2). Additionally, we use 100 thousand bright random stars to constrain the Gaia attitude solution.

Results

To determine how well we recover the reference frame we run ten different realizations of each simulation using Markov chains and take the RMS values of these results. For the accuracy of the reference frame we compare the final star positions and proper motions with their true values using the same reference frame determination algorithm. The result of this comparison gives the errors from which the RMS values are found. Two examples of the Markov chain are shown in the right figure while the table below shows that quasar variability with various time scales (τ) only increases the errors marginally (9-12%). Scaling these results to the full size mission of half a million quasars should improve them by a factor $\sqrt{5}$.



Two examples of Markov chain photocentre variability for an S2 quasar

RMS difference between true and final values for 100K random sources	Orientation (ε) error [µas]			Spin ($\boldsymbol{\omega}$) error [µas/year]		
	x	y	z	x	y	z
Recovered unperturbed	6.842	6.978	6.535	0.290	0.300	0.322
Recovered perturbed (τ = 6 month)	7.522	7.762	6.818	0.353	0.280	0.380
Recovered perturbed (τ = 2 years)	7.546	8.212	6.940	0.335	0.330	0.337

The apparent proper motion due to the barycentric acceleration of the Solar system towards the galactic centre with and without photocentre variations and a few different correlation times scales is determined simultaneously with the reference frame. The results show that the acceleration term can be recovered reasonably well even in the presence of quasar variability, the magnitude of the vector varies by less than 2%.

Galactocentric acceleration of the solar-system barycentre gives a proper motion pattern with an amplitude of $\|\boldsymbol{a}\|$	RMS acceleration ($\boldsymbol{a}$) [µas/year]		
	x	y	z
Simulated input ($\boldsymbol{a}$)	4.600	0.000	0.000
Recovered unperturbed ($\boldsymbol{a}$)	4.655	0.205	0.321
Recovered perturbed (τ = 6 month) ($\boldsymbol{a}$)	4.638	0.316	0.266
Recovered perturbed (τ = 2 years) ($\boldsymbol{a}$)	4.649	0.239	0.233

In conclusion, photocentric variability at the level of ~100 µas does not appear to significantly perturb the results for either the reference frame determination or the galactocentric acceleration.

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