Pulkovo Observatory

Impact of the Galactic aberration on astrometric observations: Much ado about nothing?

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Galactic aberration in proper motions* (GA)

GA is caused by the Galactocentric acceleration of the Solar System due to rotation of the Galaxy.

Impact on source motion in Galactic coordinate system is given by Kovalevsky (2003), Malkin (2011)

$$\mu_l \cos b = -A \sin l,$$
$$\mu_b = -A \cos l \sin b,$$

where $A = R_0 \Omega_0^2 / c$ is the galactocentric acceleration called hereafter the GA constant.

The amplitude of the motion is minimum (zero) at the Galactic Center and anti-Center (l = 0, 180°, b = 0), and maximum (A) at l = 90, 270° independent of b.

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*) Nomenclature is not settled yet.

GA impact on astronomy and geodesy

1. Celestial reference frame distortion and rotation
   (Titov 2010, Liu et al. 2012, Xu et al. 2013)

2. Earth rotation parameters
   (Malkin 2011, Liu et al. 2012)

Proposed conclusions and actions:

Titov (2010):

... theoretical discussion on the ICRS definition

... modification of the conventional metric tensor

Xu et al. (2013)

... a new ICRF concept

- despite terminology, partly close to the solution discussed here

What to do?

I argue that no new ICRS/ICRF concepts is needed due to the GA effect!

We just have to return to the traditional many-centuries-old astrometric practice of modelling the position of a celestial object as a linear trend with two parameters: the position at the initial (conventional) epoch and the apparent (proper) motion.

GA should be treated as just an astrometric reduction, along with others.

The key question is whether we can build a GA model with sufficient accuracy?

GA modeling

Two step procedure:

1. Compute μ_l *and* μ_b in Galactic coordinate system.
2. Transform μ_l *and* μ_b to μ_α *and* μ_δ in equatorial coordinate system.

The accuracy of step 1 depends on the accuracy of the Galactic aberration constant *A*.

The accuracy of step 2 depends in the accuracy of the rotation matrix between Galactic coordinate system and ICRS.

GA constant from VLBI

Methods:

- compute the coefficients of spherical harmonics as global parameters;
- estimate source position and velocities from a global solution, and then fit spherical harmonics to the velocities;
- compute velocities from position time series, and then fit spherical harmonics to the velocities;
- compute solar velocity variation time series , and then find the GA from these series.

GA constant from VLBI

Latest results for each group:

Author	Software	A, μas/yr
Titov (2009)	Occam	15-24 ± (1-2)
Kurdubov (2011)	QUASAR	10.2 ± 1.1
Xu et al. (2012)	Calc/Solve	5.1 ± 0.3; 6.3 ± 1.2
Titov & Lambert (2013)	Calc/Solve	6.4 ± 0.8; 7.8 ± 0.8
Mean (all)		6.9 ± 1.4
Mean (Calc/Solve)		6.0 ± 0.6

The results obtained from VLBI observations are still not very consistent. This problem has also been discussed by Malkin & Popova (2009), Kurdubov (2011), Malkin (2011), and Titov et al. (2011).

GA constant from stellar astronomy

A is derived from R_0 and Ω_0 estimates

Author	Data	A, µas/yr
Malkin (2011)	Several latest estimates	5.02 ± ?
Malkin (2014)	All available estimates for last 5 years	5.0 ± 0.3
Reid (2014)	100+ parallaxes and proper motions	4.9 ± 0.4

Using the Galactic rotation parameters derived by the methods of stellar astronomy provides more robust and precise results. Thus, we suggest the current best estimate of the GA constant $A = 5.0 \pm 0.3$ µas/yr for modelling the GA effect on the source positions.

Transformation to equatorial system

The rigorous algorithm for transformation of the source motion from the Galactic to the equatorial coordinate system is given by (Murray 1983)

$$\boldsymbol{p}_1 = \begin{bmatrix} -\sin l \\ \cos l \\ 0 \end{bmatrix}, \qquad \boldsymbol{q}_1 = \begin{bmatrix} -\sin b \cos l \\ -\sin b \sin l \\ \cos b \end{bmatrix},$$

$$\boldsymbol{p}_2 = \begin{bmatrix} -\sin \alpha \\ \cos \alpha \\ 0 \end{bmatrix}, \qquad \boldsymbol{p}_G = \boldsymbol{G}\boldsymbol{p}_2,$$

$$\begin{bmatrix} \mu_\alpha \cos \delta \\ \mu_\delta \end{bmatrix} = \begin{bmatrix} \boldsymbol{p}_G \boldsymbol{p}_1 & \boldsymbol{p}_G \boldsymbol{q}_1 \\ -\boldsymbol{p}_G \boldsymbol{q}_1 & \boldsymbol{p}_G \boldsymbol{p}_1 \end{bmatrix} \begin{bmatrix} \mu_l \cos b \\ \mu_b \end{bmatrix},$$

where $\boldsymbol{G}$ is the rotation matrix between the Galactic and equatorial coordinate systems.

Transformation to equatorial system

Currently, an unofficial standard of the transformation between the Galactic and ICRS (equatorial) systems is defined by Perryman & ESA (1997). This matrix was used in HIPPARCOS.

Alternative approaches to the construction of the transformation matrix, based on the latest observations, have been proposed by Liu et al. (2011a, 2011b).

Test computations have shown that the differences in proper motions obtained with different matrices ***G*** is less than 0.04 µas/yr.

Therefore, either matrix can be used to convert the GA-induced motions from the Galactic to the equatorial system.

Modelling source position at a given epoch

All the catalogs should be given at conventional epoch t_0, preferably J2000.0 corresponding the general astrometric conventions.

The source position at epoch of observation t is computed from the position at the catalogue epoch t_0 and the source proper (apparent) motion μ by

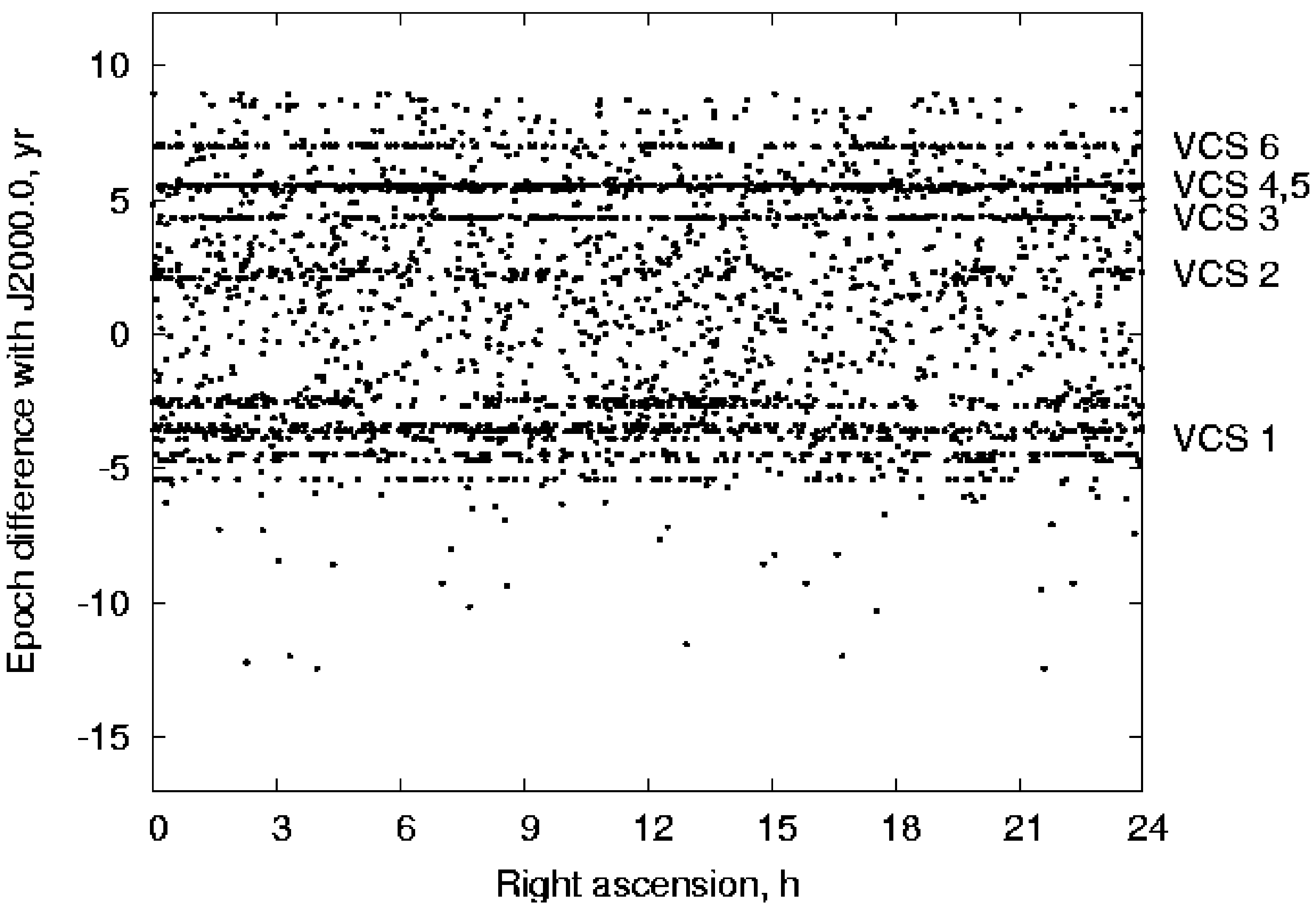
$$\alpha(t) = \alpha(t_0) + \mu_\alpha(t - t_0),$$

$$\delta(t) = \delta(t_0) + \mu_\delta(t - t_0).$$

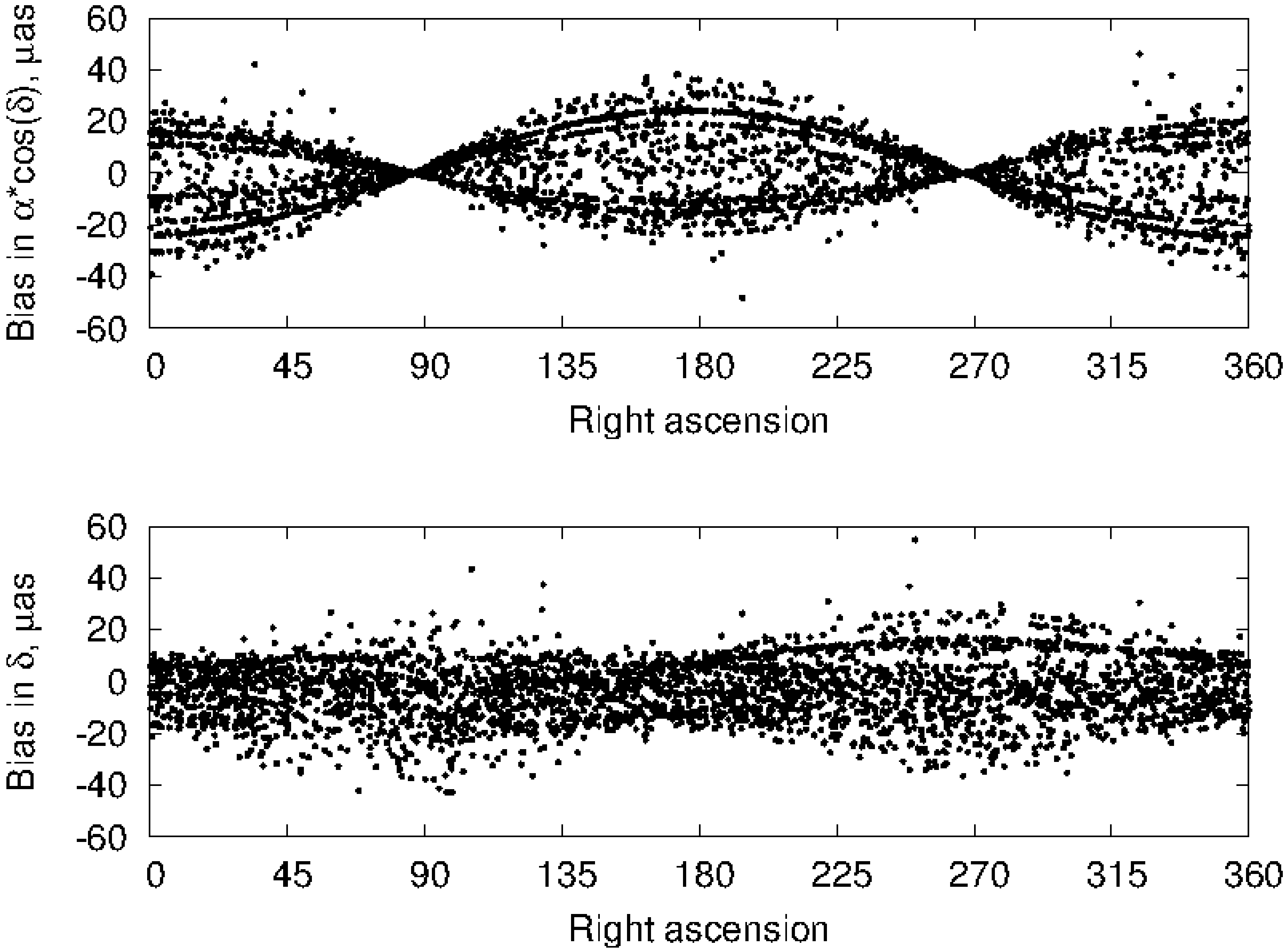
Consequence:

Moving to this classical and more rigorous convention will cause a jump in the source position between new and old catalogues.

ICRF2 position epochs w.r.t. J2000.0



ICRF2 position bias w.r.t. J2000.0



Conclusions

1. The effect of the GA is important for µas astrometry. However, its implications should not be exaggerated. GA should be considered and treated as just an astrometric reduction, along with others like precession, nutation, or annual aberration.

2. The value of GA constant A = 5 ± 0.3 µas/yr, based on the latest measurement of the Galactic rotation parameters, allows us to account for at least 90% of the full GA effect, which is sufficient for modern astrometry. Indeed, the value of A will improve over time from new VLBI and space observations, as is the case with all other astronomical constants.

3. GA modeling should be implemented in the routine VLBI data processing at the stage of computation of apparent source coordinates.

Proposed actions

1. **Include GA modeling in the IERS Conventions.**
2. **Include GA modeling in the VLBI processing software, if not done yet, and use this option in routine data processing.**
3. **Compute and publish radio source position catalogs, including ICRF3, at the standard epoch J2000.0.**
4. **All the VLBI ACs must use the same constant *A!***

Thank you for your attention!