Pulkovo Observatory

Systematic effect of the Galactic aberration on the ICRS realization and EOP

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Outline

Galactic aberration

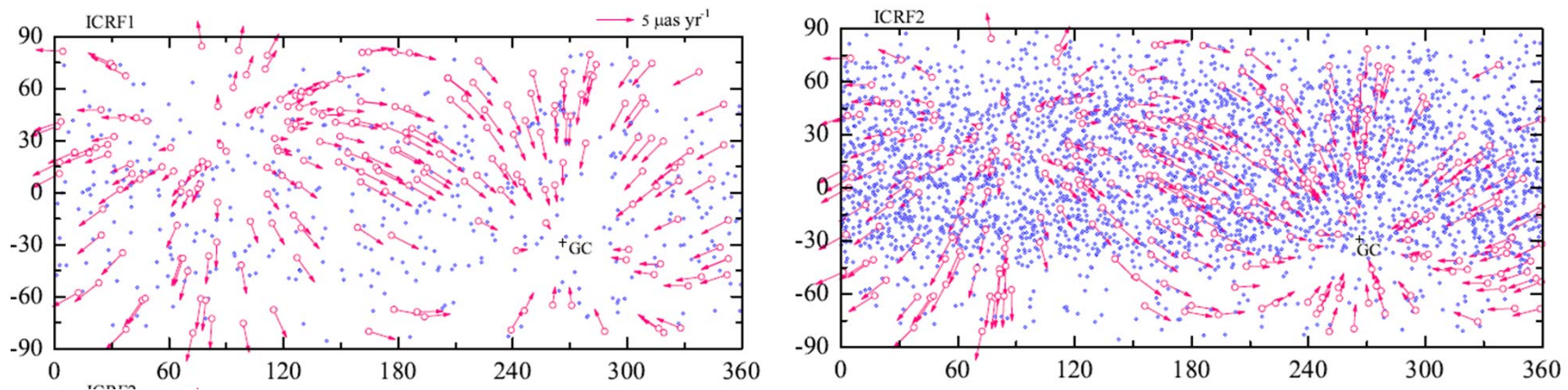The origin of the effect under consideration: acceleration of the SSB around the Galactic center (simplification: circular orbit, Kovalevsky 2003; Kopeikin & Makarov 2006; Titov 2010; Titov 2011)

Figure: The apparent proper motions of ICRF sources.

First order: dipole pattern; the magnitude is

$$A = \frac{\omega_0 V_0}{c} \simeq 5\,\mu\mathrm{as}\,\mathrm{yr}^{-1}$$

which can be called the "Galactic aberration constant" (Malkin 2011).

Global rotation of the ICRS

- What is the systematic effect of the GA effect on the ICRS realization?

- Is the realization of the ICRS rotating due to the dipole proper motion?

Proper motions due to the GA can be written as:

In the Galactic coordinate system

$$\Delta\mu_\ell \cos b = -A \sin \ell,$$
$$\Delta\mu_b = -A \cos \ell \sin b.$$

$$\boxed{A \simeq 5\,\mu\text{as yr}^{-1}}$$

In the Equatorial coordinate system:

$$\Delta\mu_\alpha \cos \delta = -d_1 \sin \alpha + d_2 \cos \alpha,$$
$$\Delta\mu_\delta = -d_1 \cos \alpha \sin \delta - d_2 \sin \alpha \sin \delta + d_3 \cos \delta,$$

where $d_1 = A \cos\alpha_0 \cos\delta_0$, $d_2 = A \sin\alpha_0 \cos\delta_0$, and $d_3 = A \sin\delta_0$

This effect has been measured by VLBI by Titov et al. (2011)

Fit to theoretical proper motions due to the Galactic aberration based on the sources of the ICRF1 and ICRF2 catalogs using the following equations (no weights were used):

$$\Delta\mu_\alpha \cos\delta = -\omega_x \cos\alpha \sin\delta - \omega_y \sin\alpha \sin\delta + \omega_z \cos\delta$$
$$\Delta\mu_\delta = +\omega_x \sin\alpha - \omega_y \cos\alpha,$$

Catalog	No.	ω_x	ω_y	ω_z	ω_{tot}
ICRF1 def	212	$+1.07 \pm 0.08$	-0.20 ± 0.08	$+0.18 \pm 0.09$	1.10 ± 0.14
ICRF1	608	$+0.22 \pm 0.05$	-0.03 ± 0.05	$+0.04 \pm 0.05$	0.22 ± 0.09
ICRF2 def	295	$+0.01 \pm 0.07$	-0.14 ± 0.07	$+0.28 \pm 0.07$	0.31 ± 0.12
ICRF2	3414	$+0.89 \pm 0.02$	-0.08 ± 0.02	$+0.04 \pm 0.02$	0.89 ± 0.03

Conclusion 1: The effect depends on the distribution of sources.

Compare with ICRF axes stabilities $(0.1\,\mu\text{as yr}^{-1} < \omega_{x\,y\,z} < 1\,\mu\text{as yr}^{-1})$

ICRF1 : $20\,\mu\text{as}$ ICRF2 : $10\,\mu\text{as}$

Conclusion 2: The effect is not negligible after a few tens of years.

Geometrical feature of the GA effect

Use the Galactic coordinate system [X_G, Y_G, Z_G] help us to best characterize the geometry of the global rotation resulting from GA effect.

Transform the results in the Equatorial coordinate system, or fit directly the proper motions in the Galactic coordinate system, we have:

The direction of the total rotation can be described in the highlighted plane by the angle:

$$\theta = \arctan \frac{\omega_{Z_G}}{\omega_{Y_G}}$$

unit: μas yr^{-1}
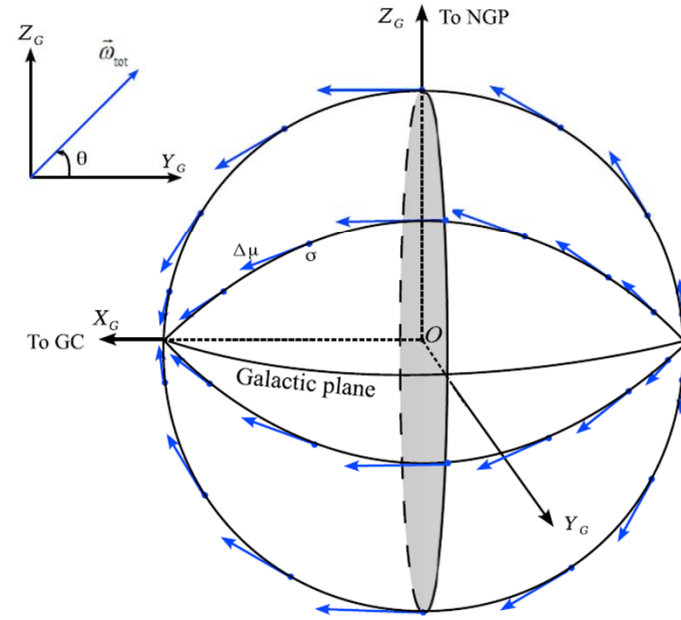
Catalog	No.	ω_{X_G}	ω_{Y_G}	ω_{Z_G}	ω_{tot}	θ
ICRF1 def	212	$+0.03 \pm 0.08$	$+0.73 \pm 0.08$	-0.82 ± 0.09	1.09 ± 0.14	$-48°.3$
ICRF1	608	-0.01 ± 0.05	$+0.15 \pm 0.05$	-0.18 ± 0.05	0.23 ± 0.09	$-50°.2$
ICRF2 def	295	-0.01 ± 0.07	$+0.26 \pm 0.07$	$+0.15 \pm 0.07$	0.30 ± 0.12	$+30°.0$
ICRF2	3414	-0.00 ± 0.02	$+0.51 \pm 0.02$	-0.74 ± 0.02	0.90 ± 0.03	$-55°.4$
uniform	2500	$+0.00 \pm 0.02$	$+0.00 \pm 0.02$	$+0.00 \pm 0.02$	0.00 ± 0.03	$- - -$

Conclusion 3: There is almost no rotation around the X_G axis.
Conclusion 4: With uniform distribution, there is no global rotation.

For the Galactic coordinate system, please see the poster by Zhu & Liu (No. JD7-3-1363).

The revised ICRS

To keep the orthogonality of the ICRS, only global rotation can be applied.

The revised ICRS, denoted ICRS' is such that

$$[\text{ICRS}'] = \mathcal{M}_{\text{rot}}(\psi_x, \psi_y, \psi_z) \cdot [\text{ICRS}]$$

where the rotation angles:

$$\psi_x = \omega_x(t - t_0), \ \psi_y = \omega_y(t - t_0), \ \psi_z = \omega_z(t - t_0)$$

are small quantities over several thousand centuries.

The rotation matrix can be written as:

$$\mathcal{M}_{\text{rot}}(\psi_x, \psi_y, \psi_z) = \begin{pmatrix} 1 & +\psi_z & -\psi_y \\ -\psi_z & 1 & +\psi_x \\ +\psi_y & -\psi_x & 1 \end{pmatrix}$$

Effect of GA on the EOP

ICRS   *ICRS'*

$$(X, Y, \mathrm{ERA}) \xrightarrow[\text{on the radio sources}]{\text{GA effect}} (X + \Delta X, Y + \Delta Y, \mathrm{ERA} + \Delta \mathrm{ERA})$$

Terrestrial−to−Celestial reference system transformation:

$$[\mathrm{ITRS}] = \mathcal{W}(x_p, y_p) \cdot \mathcal{R}_3(\mathrm{ERA} - s) \cdot \mathcal{M}_\Sigma(X, Y) \cdot [\mathrm{ICRS}]$$

in the *ICRS'*

$$\mathcal{M}_\Sigma(X, Y) = \begin{pmatrix} 1 - aX^2 & -aXY & -X \\ -aXY & 1 - aY^2 & -Y \\ X & Y & 1 - a(X^2 + Y^2) \end{pmatrix}$$

$$[\mathrm{ITRS}] = \mathcal{W}(x_p, y_p) \cdot \mathcal{R}_3(\mathrm{ERA} - s + \Delta(\mathrm{ERA} - s)) \cdot \mathcal{M}_\Sigma(X + \Delta X, Y + \Delta Y) \cdot [\mathrm{ICRS}']$$

Note: there is no effect on the ITRS and polar motion

and apply $[\mathrm{ICRS}'] = \mathcal{M}_{\mathrm{rot}}(\psi_x, \psi_y, \psi_z) \cdot [\mathrm{ICRS}]$

$$\mathcal{M}_\Sigma(X, Y) = \mathcal{R}_3(\Delta(\mathrm{ERA} - s)) \cdot \mathcal{M}_\Sigma(X + \Delta X, Y + \Delta Y) \cdot \mathcal{M}_{\mathrm{rot}}(\psi_x, \psi_y, \psi_z)$$

solution ΔX, ΔY, and $\Delta(\mathrm{ERA} - s)$

Theoretical solution:

$$\Delta X = +\psi_z Y - \psi_y Z,$$
$$\Delta Y = -\psi_z X + \psi_x Z$$
$$\Delta(\text{ERA} - s) = -\psi_z - \psi_x X - \psi_y Y.$$

Catalog	values after one century unit: μas			mean rates between J1500 and J2500 unit: μas yr^{-1}		
	ΔX	ΔY	$\Delta(\text{ERA} - s)$	$d\Delta X/dt$	$d\Delta Y/dt$	$d\Delta(\text{ERA} - s)/dt$
ICRF1 def	20.0 ± 8.0	107.1 ± 8.1	-19.0 ± 9.6	0.20 ± 0.08	1.07 ± 0.08	-0.18 ± 0.09
ICRF1	3.3 ± 4.9	22.1 ± 5.0	-4.1 ± 5.3	0.03 ± 0.05	0.22 ± 0.05	-0.04 ± 0.05
ICRF2 def	14.4 ± 7.1	0.7 ± 5.2	-28.0 ± 7.3	0.14 ± 0.07	0.01 ± 0.05	-0.28 ± 0.07
ICRF2	7.8 ± 2.1	88.9 ± 2.2	-5.1 ± 2.4	0.08 ± 0.02	0.89 ± 0.02	-0.04 ± 0.02

The Galactic aberration effect is very different from precession, however the spurious global rotation of the ICRS (realized by these sources) contributes to the linear trend of the celestial pole offsets; this slightly distorts the precession rate estimated from VLBI observations.

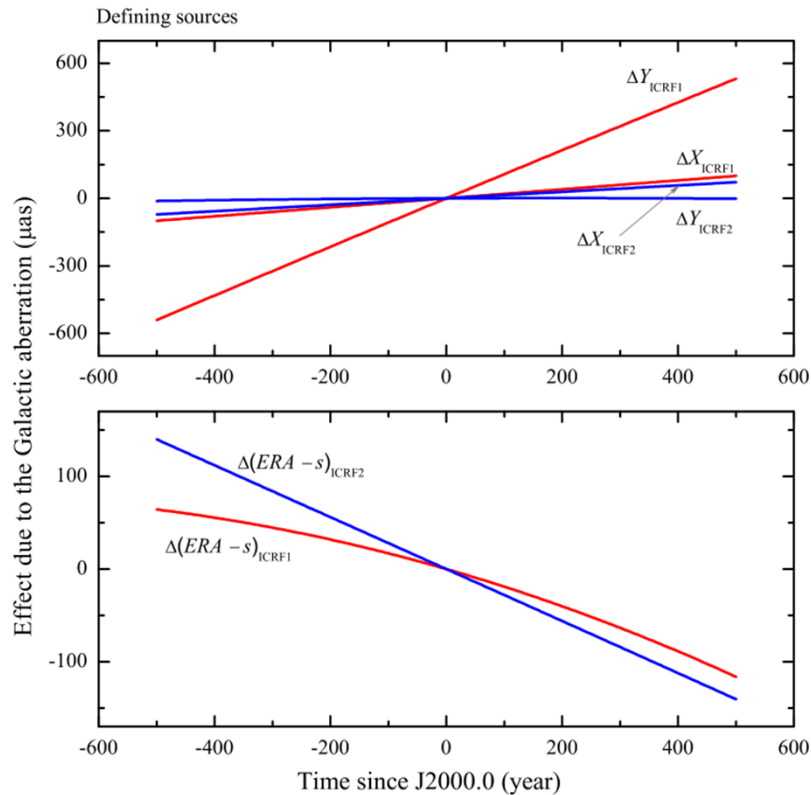1   Compare with Malkin (2011) results based on VLBI EOP series

$$(d\Delta X/dt)_{\text{Malkin}} = +0.1 \pm 0.5 \, \mu\text{as yr}^{-1}$$
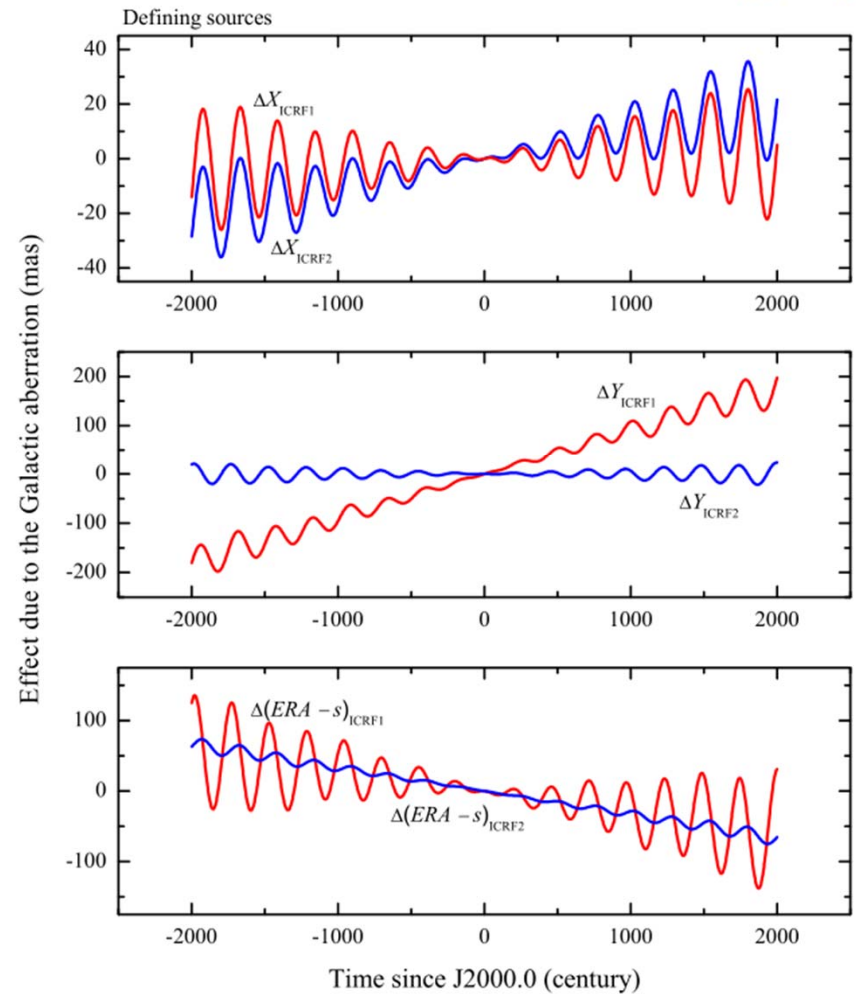$$(d\Delta Y/dt)_{\text{Malkin}} = +0.2 \pm 0.6 \, \mu\text{as yr}^{-1}$$

2   Compare with the accuracy of the precession−nutation model

The accuracy for predicting the CIP location is expected to be better than 100 μas after one century in the near future.

$$\Delta X = +\psi_z Y - \psi_y Z.$$
$$\Delta Y = -\psi_z X + \psi_x Z$$
$$\Delta(ERA - s) = -\psi_z - \psi_x X - \psi_y Y.$$

Time interval: 1000 years
IAU 2006/2000 precession-nutation model

Time interval: 4000 centuries
Vondrak et al. (2011) precession
expressions valid for long time intervals

4. Conclusion and discussion

- ➢ GA effect is responsible for slow rotation of the ICRS realization.

- ➢ The systematic effect depends on the distribution of sources and there is no effect in case of uniform distribution.

- ➢ The use of Galactic coordinate system can best characterize the global rotation.

- ➢ The effect is not negligible after about 30 years (in the next ICRF)

1. Other methods to derive the global rotation of the ICRS realization?

2. How to deal with the deformation effect?

3. Considered as a contribution in the precession−nutation model?
   - *No, because it is not known with sufficient precision.*
- Is a Galactocentric Celestial Reference System (GalCRS) possible?
   - *No, because the corresponding transformation between the GalCRS and the BCRS is not available.*

Nomenclature issue

Secular aberration   Kopeikin & Makarov (2006)

Secular aberration drift   Tivov (2010); Titov et al. (2011)

Aberration in proper motion   Kovalevsky (2003)

Galactic aberration   Malkin (2011); This study

Galactocentric aberration drift   ? ?

A convention should be adopted.