

ALIGNMENT AND DISTORTIONS OF THE GAIA CELESTIAL REFERENCE FRAME AND THE THREE COMPONENTS OF ICRF3

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Abstract

The International Celestial Reference Frame, version 3, provides the best available realization of an inertial, non-rotating, system of celestial coordinates. This presentation describes in-depth analysis of the three components of ICRF3 (observed in the S/X, K, and X/Ka wave bands) relative to the optical counterparts in the Gaia EDR3 catalog. The three vector fields of position differences Gaia - ICRF3 are fitted with uniform sets of 48 vector spherical harmonics up to degree 4. Significant differences are found between these decompositions. The smallest Euler rotation angles, represented by the magnetic harmonic terms of first degree, are found for the S/X catalog, where the largest estimate has a $S/N = 1.3$. The only statistically significant harmonic with a $S/N > 3$ is an electric (poloidal) zonal pattern of degree 2 with vectors in both hemispheres directed toward the equator. The fit for the K catalog also includes only one term with a $S/N > 3$, which is EVSH_211. The X/Ka band catalog, however, has a much greater and radically different distortion pattern dominated by several low-degree harmonics, the most significant one with a $S/N > 9$ being the zonal EVSH_010, which is a streaming field from the south pole to the north pole. This part of ICRF3 cannot be used as intended without appropriate corrections. The overall rates of significant radio-optical position offsets also widely differs between the components. Above the 3 sigma level of confidence, the rates are 25%, 19%, and 35% for the S/X, K, and X/Ka bands, respectively. The detected distortions are dissimilar between the three components of ICRF3; therefore, likely to come from ICRF3 rather than from the optical Gaia CRF.

Methods

The best way to represent large- and medium-scale systematic and sky-correlated patterns in celestial vector-valued data is with the vector spherical harmonic (VSH) functions. The complete expansion of a vector field is infinite, but we limit it to a number of lowest degrees of VSHs. For this study, the limiting degree is 4, and the number of VSH terms is 48.

- The first three magnetic VSHs represent the rigid rotation of the coordinate system
- The sought coefficients of the expansion are determined in a least-squares solution with weights, which are derived from the formal covariances of celestial coordinates
- Significance of fitted terms is evaluated using χ -value (S/N)

Data

- Gaia DR3 source catalog
- ICRF3 S/X, K, and X/Ka catalogs

Each of the ICRF3 components was separately cross-matched with Gaia DR3 using a 11" cone search to check for near neighbors. Some radio-sources have multiple optical counterparts (up to 52). Large fractions of all three samples have excessive positional offsets (i.e., "dislodged" AGNs) above 2.5σ : 32% for S/X, 25% for K, and 45% for X/Ka – a nasty problem for CRF maintenance! After vetting outliers and galaxies, remaining precious sets count 2136, 492, and 307 sources, respectively.

Results

- Within $S/N=3$, the DR3-S/X field has only one statistically significant term, EVSH_020, which is a symmetric meridional flow toward the equator
- Within $S/N=3$, the DR3-K field has only one statistically significant term, EVSH_211, which is a dipole flow toward the positive Y direction
- The the DR3-X/Ka field includes 4 significant low-degree terms, including rotation around the X axis

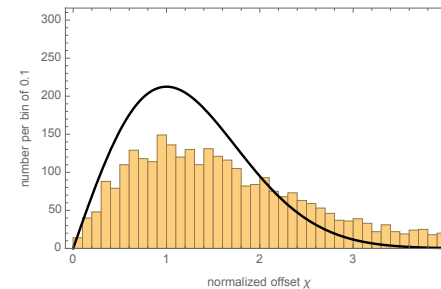


Fig. 1. Histogram of normalized position offsets Gaia DR3 - ICRF3 S/X, and the expected $\chi(2)$ -distribution

Conclusions

- The three components of ICRF3 have sky-correlated distortions with respect to Gaia DR3 with median values ~ 33 , 61, and 175 μas respectively
- The X/Ka catalog is the most misaligned and distorted part
- The different patterns of distortion indicate that their main source is in the VLBI part of the CRF

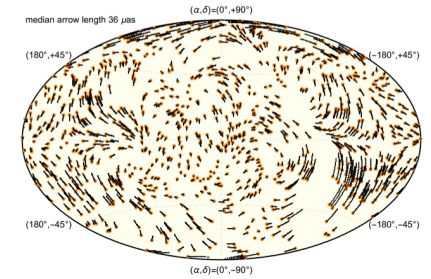


Fig. 1. Gaia DR3 - ICRF3 S/X position difference fitted with 48 VSHs up to $L=4$

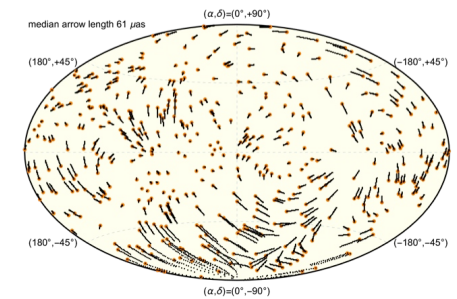


Fig. 2. Gaia DR3 - ICRF3 K position difference fitted with 48 VSHs up to $L=4$

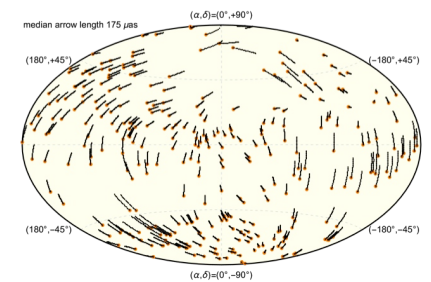


Fig. 3. Gaia DR3 - ICRF3 X/Ka position difference fitted with 48 VSHs up to $L=4$