Service and Research at Paris Observatory Analysis Center (OPAR)

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Abstract We report on the VLBI-related service and research activities at the Paris Observatory (OPAR) Analysis Center during the years 2023 and 2024. Featured items include the opa2023 and opa2024 diurnal and Intensive solutions and research on the relation between source astrometric stability and photometric variability, offering a means of selecting the most appropriate sources for reference frame realization.

1 General information

The service activities relating to the IVS, including the processing of VLBI data and the maintenance of the website, are ensured by one person (S. Lambert). This does not include the maintenance of the Data Center (see the report on the Data Center in this volume) that is ensured by C. Barache, helped by our IT manager T. Carlucci. The rest of the authors mentioned in this report are involved in the valorization of VLBI data through their scientific exploitation and research. They are involved in other services including the IERS ICRS Center and do not participate directly in IVS activities.

2 Service

In 2023, OPAR continued the processing of IVS data, both diurnal and Intensive sessions, in the opa2023a and opa2023i solutions with Calc/Solve. SINEX files were produced routinely for opa2023a so that OPAR could contribute to the IVS combination. Solution opa2023a used the ICRF3 as its a priori radio source catalog and includes a model for the Galactic aberration, i.e., a dipolar displacement field of the quasars toward the Galactic center of amplitude 5.8 µas per year, as recommended by the IVS Working Group 8 (MacMillan et al., 2019) and as used for the production of the ICRF3 catalog (Charlot et al., 2020). The reference epoch of the Galactic aberration modeling is 2015.0, consistent with the ICRF3. As a consequence, the opa2023a quasar coordinate catalog should be read as follows: coordinates listed in the catalog correspond to the apparent position of the sources at 2015.0; at another epoch, the position of the sources should be corrected by the Galactic aberration effect using the above amplitude. In 2024, we produced a set of opa2024 solutions in a similar fashion.

As non-official products, OPAR continued to update radio source coordinate time series, station coordinate time series, and baseline length time series. The radio source coordinate time series are proposed in two versions. A first version is obtained with independent session processing of the opa2023a (and opa2024a) rapid solution, allowing updates as new observations arrive. More accurate time series are obtained by four global solutions in which one fourth of the defining sources are downgraded as local parameters; these series exhibit a substantially lower scatter of the data and allow monitoring of more subtle variations of the position of the radio centroid than with the first version, but they are not updated until the processing of new global solutions.

OPAR also proposes a monitoring of the free core nutation (FCN) by fitting its amplitude and phase over

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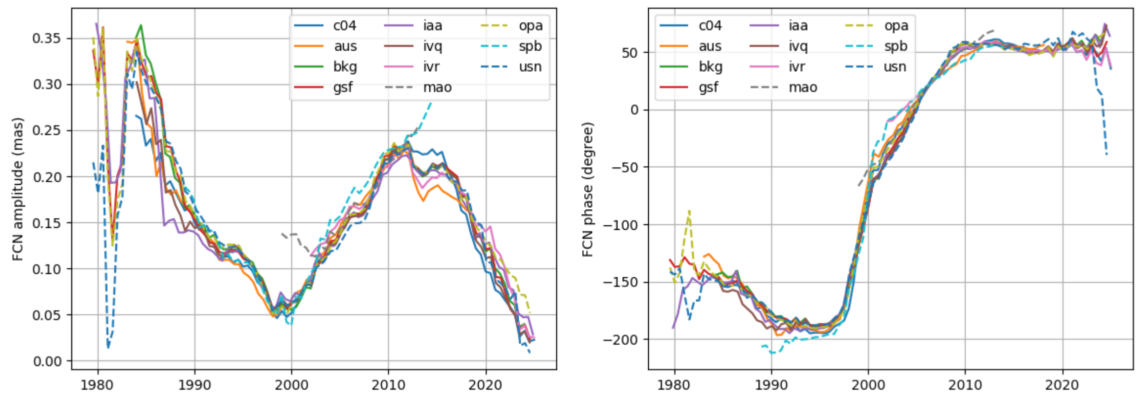

Fig. 1 Amplitude and phase of the free core nutation fitted to several IVS and IERS nutation time series.

a seven-year sliding window to the available nutation time series provided by IVS Analysis Centers and the IERS (Figure 1). For each series, we make available a table of yearly amplitudes (that can be used within a routine to model and predict the evolution of the oscillation) and a time series of the FCN values at the epochs of the data.

All these products are made available at the OPAR website (https://ivsopar.obspm.fr).

3 Research

The scientific exploitation of astrometry data in 2023–2024 is a continuation of our work of Lambert et al. (2024) with the goal of understanding and separating the various causes entering in the astrophotometric signature of the ICRF sources. The final—and ideal—goal of this past work and of the ongoing studies is to be able to qualify the astrometric quality of a source based on non-astrometric characteristics and, conversely, predict astrophysical characteristics based on astrometric signature. Our recent studies included the analysis of coordinate time series under several aspects.

One aspect was finding periodicities. As the VLBI reference point is influenced by the flux distribution around the most compact radio feature, several phenomena in the inner jet can result in apparent periodic motions of the radio ‘centroid’: quasi-regular ejection of new components at the base of the jet, apparent motion of a component of constant flux, etc. Periodicities could also be linked to the existence of a system of black holes whose observational signatures can show up in various observational domains from the optical flux measurements to VLBI imaging (see, e.g., Roland et al., 2013; Britzen et al., 2018; D’Orazio and Charisi, 2023; Valtonen et al., 2024, and references therein). In Makarov et al. (2024), we investigated the use of the L1-norm to estimate the amplitude of periodic signal in irregular and noisy coordinate time series. The advantage of the L1-norm is to be less sensitive to the high number of outliers. We found a number of significant periodicities in several of the IVS sources deserving more thorough studies.

Extending the work by Secrest (2022), we confirmed the anticorrelation between the optical-radio offsets and the optical long-term variability (fractional variability in *Gaia G* band) and found additionally an anticorrelation between the latter and the spatial extension of the astrometric variability ellipse (Lambert and Secrest, 2024). This important result is interpreted as resulting from jets pointing almost directly at the observer: in such cases, the projection on the sky will reduce the optical-radio offset and the astrometric variability of the VLBI reference point. Conversely, the Doppler boosting, strongly enhanced by the weak angle on the line-of-sight, amplifies considerably the optical variability.

In Lambert et al. (2025) we further exploited the *Gaia* DR3 photometric time series at G_{BP} (BP), G_{RP} (RP), and G bands and compared them with optical-radio offsets and positional variability derived from VLBI coordinate time series. Most astrometrically stable sources and sources with smaller optical-radio shifts have lower values of BP/RP correlation and low color-magnitude correlations, corresponding to the Undefined-When-Brighter classes of optical variability. These preferred astrometric objects often belong to the spectral class FSRQ with z of about 1 and higher. A significant correlation is found of both astrometric stability measures with the jet viewing angle. The shorter optical-radio offsets occur in AGNs that contain more massive black holes and more luminous accretion discs, which may be caused by the tendency of smaller viewing angles to be associated with higher redshifts.

The two latter cited works strengthen the hypothesis that the Doppler boosting is the driving physical mechanism at the origin of the observed optical-radio position offsets and the astrometric variability. Our works define several predictors of absolute astrometric performance of reference frame candidates and demonstrate that astrometry with geodetic VLBI is a valuable tool for gaining new inference in the physical processes responsible for quasar activity in the inner parts of the relativistic engines.

Souchay et al. (2024) published a sixth version of the large quasar astrometric catalog (LQAC) with more than two million quasars, of which more than 1.7 million are in common with *Gaia* DR3. The main additional contribution with respect to the previous LQAC version is the cross-matching with the SDSS DR16Q catalog.

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