Service and Research at Paris Observatory Analysis Center (OPAR)

Sébastien Lambert, Christophe Barache, Teddy Carlucci

Abstract We report on the VLBI-related service and research activity at the Paris Observatory Analysis Center (OPAR) during the years 2019 and 2020. Featured items include the use of VLBI to assess the frequency dependence of the polar motion resonance (also known as the Chandler frequency), the check of systematic errors in the existing VLBI and Gaia realizations of the ICRS, and the modeling of 4C31.61 by a triple system of supermassive black holes.

1 Service

In 2019–2020, OPAR continued the processing of IVS data, both diurnal and Intensive sessions, in the opa2019a and opa2019i solutions with Calc/Solve. SINEX files were produced routinely for opa2019a so that OPAR could contribute to the IVS combination. Solution opa2019a uses the ICRF3 as an 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 opa2019a 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. As non-official products, OPAR continued to update radio source coordinate time series, station coordinate time series, and baseline length time series. All of these products are made available at the OPAR website.

OPAR also contributed to the preparation of ITRF2020 by processing the list of observing sessions asked by the Analysis Coordinator.

The Analysis Center made a complete transition to the new VGOS database format (thereby not using anymore the old format).

SYRTE, Observatoire de Paris - Université PSL, CNRS, Sorbonne Université, LNE

OPAR Analysis Center

IVS 2019+2020 Biennial Report

2 Research

Several research items in the space geodesy team of Paris Observatory/SYRTE involved VLBI measurements at the product or data level. Ibnu Nurul Huda defended his PhD Thesis at the end of 2019 on the topic of the analysis of Earth rotation series to determine the resonance frequencies and some rheological properties of the Earth. This problem is generally well-known when one thinks about the free core nutation (FCN) whose resonance affects the amplitude of nutation when the period is close to 430 days in the space-fixed frame of reference. Ibnu extended the research into two directions. First, he developed an approach of fitting the nutation amplitudes directly to the VLBI delay, as opposed to the traditional approach in which the nutation amplitudes are fitted to time series of celestial pole offsets. Second, he looked for the free inner core nutation resonance (FICN, see Nurul-Huda 2019; Nurul-Huda et al. 2020; Ziegler et

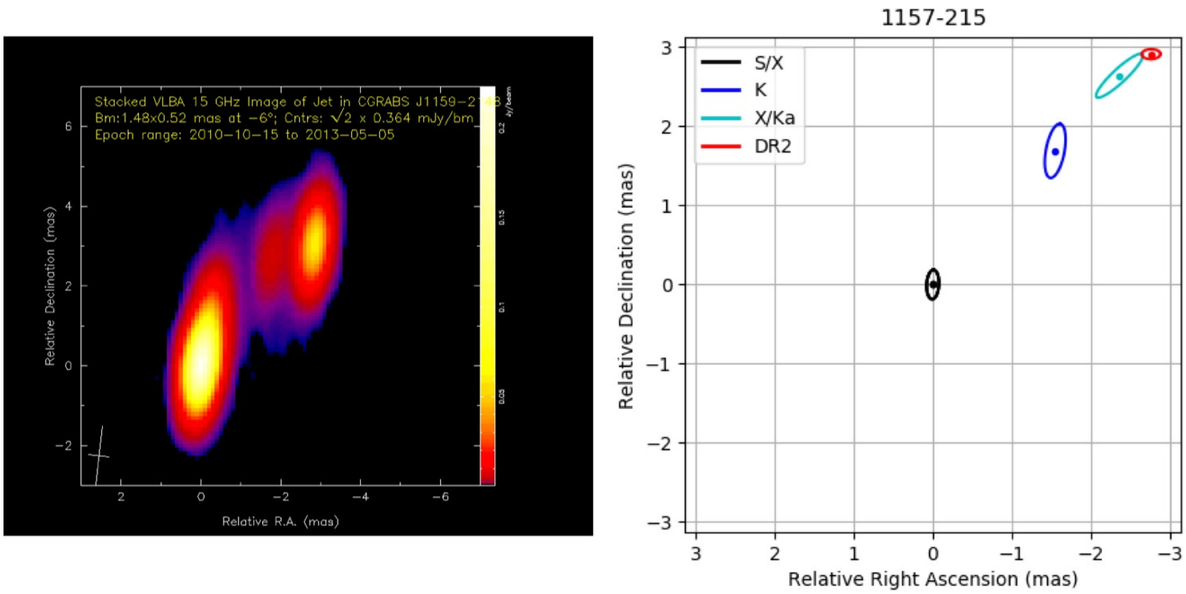

Fig. 1 An example of matching between the structure of an AGN (here from the 15 GHz VLBA MOJAVE database of Lister et al. (2019) and the absolute astrometry positions from Gaia and VLBI.

al. 2020) as well as for the polar motion resonance (PMR). The latter is actually known as the Chandler wobble when observed in the seasonal band in the Earth-fixed frame. Its period is close to 433 days. Nevertheless, because it acts as a resonant frequency in the geophysical transfer function expressing the modification of the amplitude of the oscillations of a rigid Earth under the lunisolar tidal potential by the rheological properties of the real Earth and the ocean, the Chandler frequency can be fitted to observed amplitudes of these oscillations. In the retrograde diurnal band in the terrestrial frame (equivalent to nutations in the space-fixed frame), one finds that the Chandler period is close to 380 days. In the prograde semi-diurnal band, where polar motion is mainly composed of periodic terms caused by the diurnal oceanic tide, the resonant period is about 401 days. In the former case, two complementary factors account for the observed values: the non-equilibrium response of the ocean to the pole-tide potential in the diurnal band, and the resonance of the solid Earth tide at the free core nutation period (Bizouard et al. 2020; Nurul-Huda et al. 2021).

An important activity of the team was devoted to analyzing the recent AGN observations by VLBI and Gaia in view of understanding the radio–optical link in terms of astrophysical processes. An independent assessment of systematic errors in VLBI and Gaia astrometry was achieved by Liu et al. (2020). In this work, we compared the ICRF3 catalogs of three generations (Charlot et al. 2020) with the Gaia DR2 (Prusti et al. 2016; Brown et al. 2018) counterparts. The ICRF3 at X-band closely agrees with Gaia DR2 in terms of global systematics and is nearly free of zonal errors, contrasting notably with previous ICRF realizations. With the improved accuracy of the X-band positions, we can see clearly the radio-to-optical offsets at sub-mas level. Including K-band and Ka-band astrometry will soon benefit studies of the core-shift effect as well as optical signatures of accretion disks and host galaxies (Fig. 1). Nevertheless, a possible zonal error in the Ka-band catalog should not be omitted when considering a physical interpretation of the radio–radio and radio–optical positions.

VLBI imaging followed by a careful follow-up of the various ejected components is one basis of investigating the physical characteristics of a radio source and whether it is made up of a single black hole or a multiple black hole system. A study of 2203+315 (4C31.61) was led by Roland et al. (2020), who modeled trajectories of radio components observed by the MOJAVE survey (Lister et al. 2019). The study suggested that

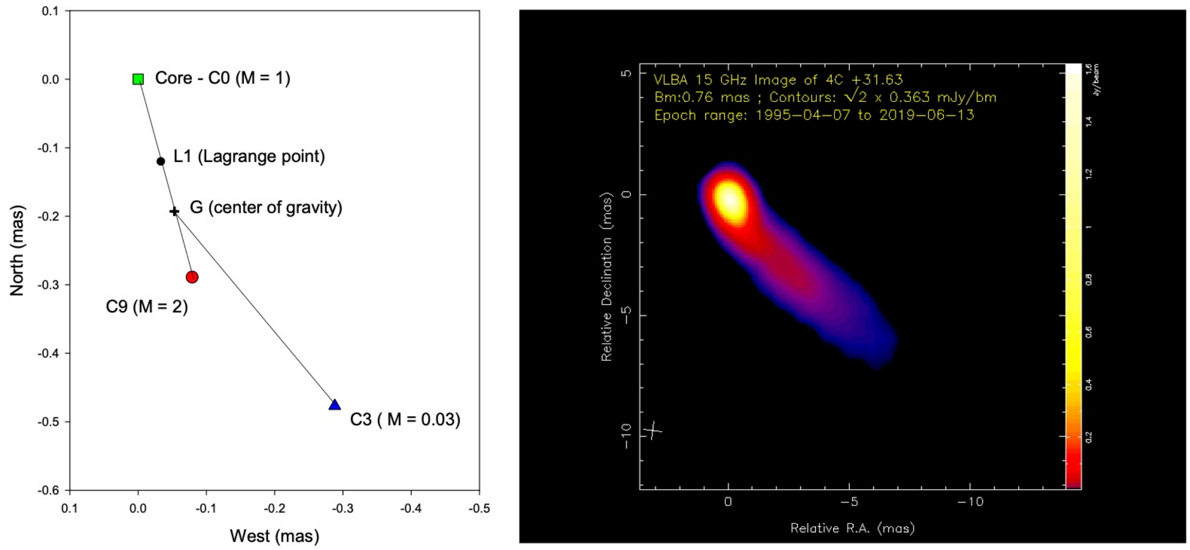

Fig. 2 Left: the system of black holes as modeled by Roland et al. (2020). Right: the MOJAVE stacked epoch 15 GHz VLBA image of Lister et al. (2019).

VLBI components are ejected from three different origins corresponding to three stationary components, one of which is the VLBI core. Most of the mass of the nucleus is associated with a supermassive binary black hole system whose separation is about 0.3 mas (i.e., 1.3 pc), and the mass ratio is 2. This model accounts for the variations detected in the astrometric coordinate time series obtained from geodetic VLBI and shows that it is possible to exploit large MOJAVE-like VLBI databases to propose more insights into the structure of the extragalactic radio sources that are targeted by VLBI in geodesy and astrometry programs. More generally, an ambitious exploitation (e.g., model-fitting of components) of the existing VLBI image database should be undertaken to address more systematically the physical characteristics and the inner structure of the radio sources.

References

1. Bizouard C, Nurul Huda I, Ziegler Y, Lambert S 2019, Frequency dependence of the polar motion resonance, Geophys. J. Int. International 220(2):753
2. Brown AGA, Vallenari A, Prusti T et al. 2021, Gaia Data Release 2 - Summary of the contents and survey properties, A&A 626:A1
3. Charlot P, Jacobs CS, Gordon D et al. 2020, The third realization of the International Celestial Reference Frame by very long baseline interferometry, A&A 644:A159
4. MacMillan DS, Fey AL, Gipson JM et al. 2019, Galactocentric acceleration in VLBI analysis. Findings of IVS WG, A&A 630:A93
5. Nurul-Huda I 2019, Etude des propriétés rhéologiques globale de la Terre à l'aune des observations VLBI, PhD thesis, Université PSL
6. Nurul Huda I, Lambert S, Bizouard C, Ziegler Y 2020, Nutation terms adjustment to VLBI and implication for the Earth rotation resonance parameters, Geophys. J. Int. 220(2):759
7. Nurul Huda I, Bizouard C, Allain D, Lambert S 2021, Polar motion resonance in the prograde diurnal band, Geophys. J. Int., in revision
8. Prusti T, de Bruijne JHJ, Brown AGA et al. 2016, The Gaia mission, A&A 595:A1
9. Ziegler Y, Lambert S, Nurul-Huda I et al. 2020, Contribution of a joint Bayesian inversion of VLBI and gravimetric data to the estimation of the free inner core nutation and free core nutation resonance parameters, Geophys. J. Int. 222(2):845