Source structure correction in geodetic VLBI

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Contents

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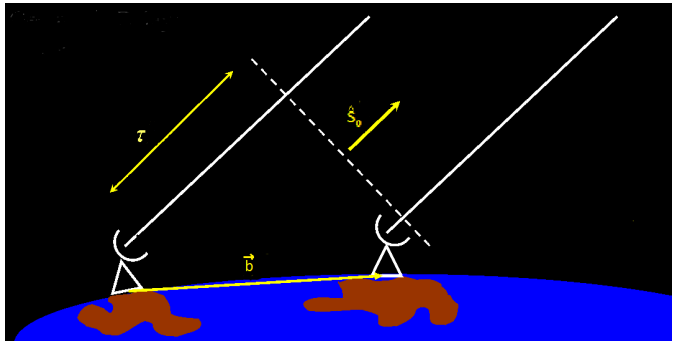
Motivation

- VLBI estimates of the positions of extragalactic radio sources led to the most precise quasi-inertial celestial reference frame known as International Celestial Reference frame (ICRF2), the realization of the Celestial reference system (ICRS).
- The majority of the extragalactic radio sources are AGNs (Active Galactic Nuclei), mostly stable compact core objects.
- Several studies have revealed that some of them are unstable sources meaning a variation of their position over time due to the physics of their AGN.

Introduction: VLBI Model



The Newtonian VLBI model:

$$\tau_g = -\vec{b} \cdot \frac{\hat{s_0}}{c} \tag{1}$$

where $\vec{b} = \vec{r_2}(t_2) - \vec{r_1}(t_1)$ and $\vec{r_2}(t_2)$, $\vec{r_1}(t_1)$ are vectors from the geocenter to each station and the epochs of signal arrival time for each station are t_1, t_2; $\hat{s_0}$ is the unit vector to the intensity maximum of the extragalactic source which is already oriented with regards to the surface of the Earth.

Mathematical representation of radio sources

According to many authors, almost all the extragalactic radio sources in ICRF show a constant behavior in their cores. Therefore, the linear models have to deal with the astrophysics of the objects, for instance:

- Using physical explanations to refine the mathematical model.
- Using Tschebyscheff polynoms to determine the non-constant signal contribution.
- Including galactic rotation to embody velocity fields.

Mathematical representation of radio sources

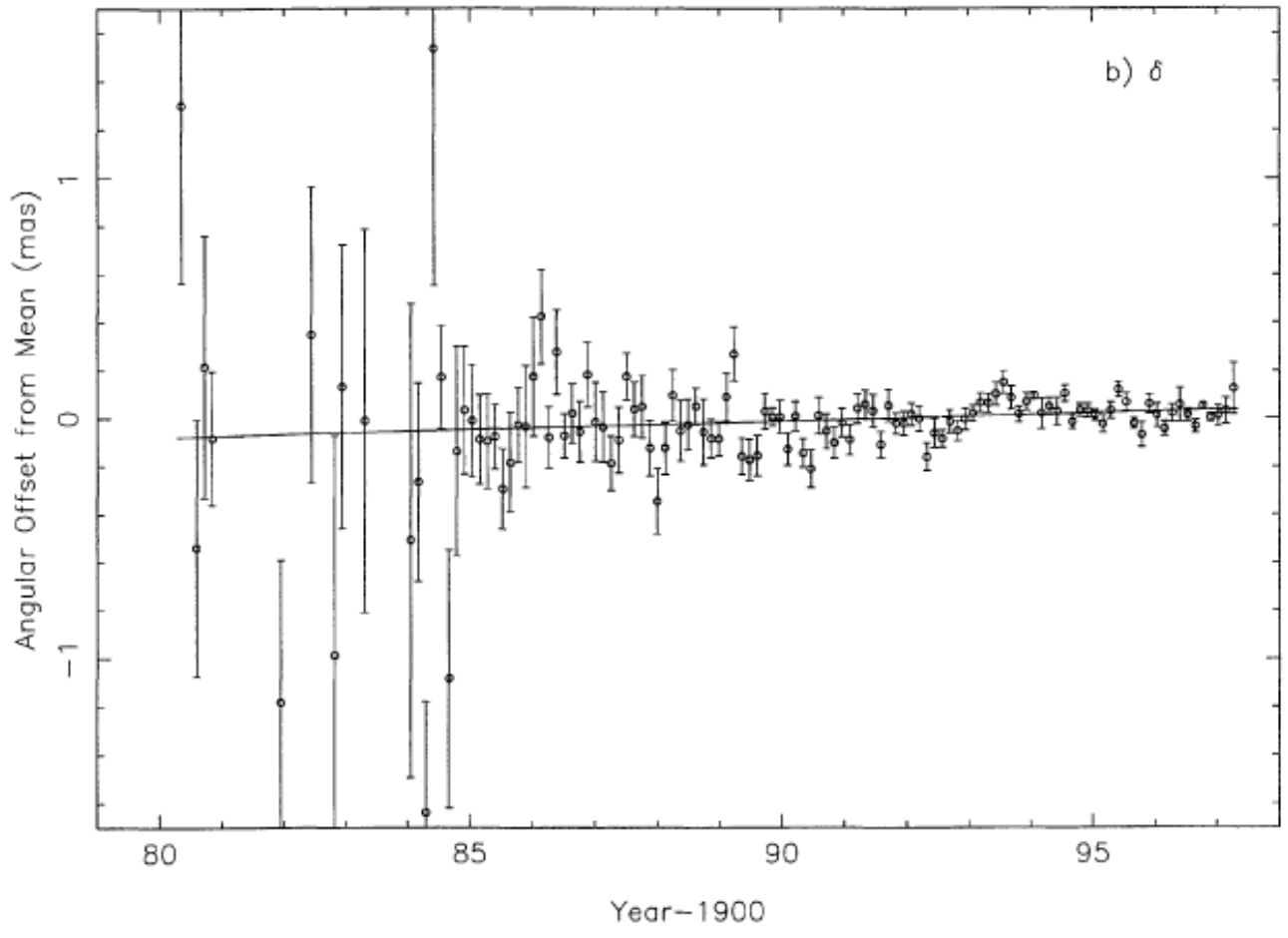


Figure: Taking from Fey et al. 1997. The astrometric position time series for 4C 39.25.

Towards an alternative datum definition

To derive a better datum definition, we should include all the sources (also unstable sources) and their coordinate accuracies. From a statistical point of view, the most points the most reliable datum we have.

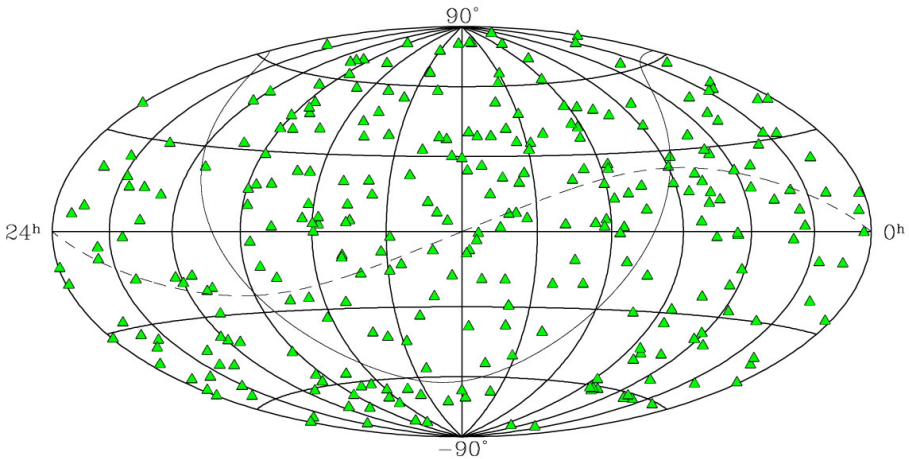


Figure: Taken from http://www.nasa.gov/centers/goddard. A map of the 295 sources of ICRF2.

Completeness

Using all available observations including those obtained by mobile antennas, guest sites/arrays etc. will significantly increase the number of sites in our solution and the number of radio sources at the same time allowing us to increase the number of celestial sources beyond ICRF2.

Figure: left: Taken from ivs.nict.go.jp, IVS annual report 2005 mobile antenna at Yellowknife Observatory. Right: Taken from atnf.csiro.au, very large interferometry array in Australia.

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Physical and mathematical stability criteria

We have estimated the time series of the source positions. This information can be used to match the astrophysical structure of sources into the model, instead of neglect those which are unstable.

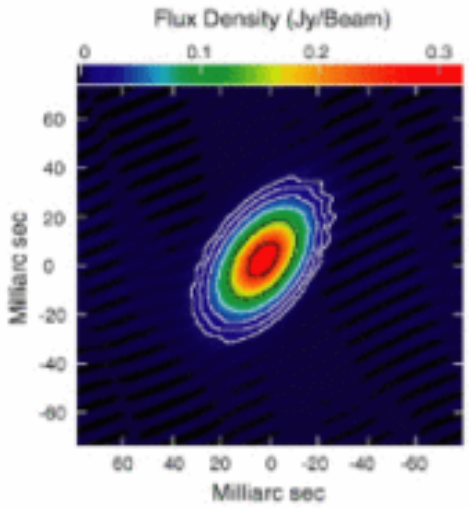

Figure: Taken from dante.net. A contour plot of quasar and its flux density in units of Jansky/beam.

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Aligning Gaia and VLBI observations

The mission Gaia (ESA) will provide a compact celestial reference frame using numerous QSO optical observations. For consistency between optical and radio positions, it will be fundamental to align Gaia and VLBI frames with the highest accuracy (P. Charlot Journeés, Vienna, 2011) . Besides, there are some questions to come up under the alignment:

- What are all the measurement principles and accuracies of Gaia to take into account?
- What are the main problems to align bright optical objects with complex structure sources or at least detectable cores at VLBI scales?

Definition of the reference system

We know so far that the realization of the ICRS is the ICRF. The ICRS is a mathematical model that allows to describe points in the celestial sphere based on celestial coordinates.

- Is the definition of the ICRS correct and unique (also in view of the upcoming GAIA mission)?
- Do models or constants have to be updated?
- Is there a discrepancy between IAU and IAG conventions for transformations within the VLBI model?

Conclusions

- There is a lot of work to be done for the improvement of future radio reference frames!
- it is essential to include source structure corrections to achieve the VLBI2010 and GGOS goals for terrestrial positions (1mm) and velocities (0.1 mm/yr).
- the mathematical source model could be extended, e.g. using piecewise linear functions.
- the celestial datum could be reworked following the statistical theory of reliability.
- the number of sources in the radio catalogue can be extended.

Conclusions

- there have to be principle considerations on how to align VLBI with GAIA.
- including effects like galactic aberration into the model should be considered (O. Titov, Journeés, Vienna, 2011). Despite the small error induced by this in geodetic VLBI, for future reference frames this effect is significant.
- for astrophysics, to align the Gaia and VLBI frames will provide information to study adequately the properties of extragalactic jets of AGNs.

Thank for you attention!