Final project report FWF T 697

Earth-based VLBI in the Galactic Frame (Galactic VLBI)

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PI: Dr. Hana Krásná

1. Report on research work

1.1 Information on the development of the research project

In 2014 (time of project proposal submission) the vivid topic in the scientific geodetic community was the discussion of the next generation international celestial reference frame (ICRF3). In August 2012 the International Astronomical Union (IAU) established the ICRF3 Working Group with the goal to produce the ICRF3 with a planned precision of 0.1 mas for several hundreds of radio sources until the IAU General Assembly in 2018. The focus of the proposed project Galactic VLBI was therefore on the apparent proper motion on the celestial reference frame which was not accounted for in the previous celestial radio catalogues and which reduction was essential for achievement of the highest possible accuracy of the new celestial reference frame. In 2016 Working Group on Galactic Aberration of the International VLBI Service for Geodesy and Astrometry (IVS WG8) was established where I served as a member. The primary objective of the group was to develop a recommended aberration correction to be applied in the ICRF3 solution. After a successful cooperation with Oleg Titov (Geosciences Australia) on the estimation of the solar system acceleration using the Earth scale factor (Titov and Krásná, 2018a) we continued our cooperation with testing the special relativity with geodetic VLBI (Titov and Krásná, 2018b).

With ICRF3, two new features were introduced in the realization of the frame. The first one was the afore mentioned modeling of Galactic acceleration, the second one was the determination of source positions in three radio bands (8 GHz, 24 GHz and 32 GHz). ICRF3 is therefore the first multi-band celestial reference frame ever generated. I was a member of the K-Band Team, analysing the VLBI measurements at the 24 GHz. Our findings, crucial for the ICRF3 generation, were presented at several conferences (see section 4.1).

To be able to estimate the subtle effects from the geodetic VLBI data (such as the apparent proper motion of the radio sources) it is necessary to have a solid foundation of the VLBI data analysis. Therefore, I concentrated during the project also on the analysis strategies with the focus on the celestial reference frame (Krásná et al., 2016; Mayer et al., 2017). Furthermore, the estimation of the global geodetic parameters requires a permanent maintenance of the analysis software. Therefore, some working hours of the project were spent with a further development and updates of the analysis software package VieVS (Böhm et al., 2018; Krásná et al., 2021).

Since the acceleration of the Solar System barycentre causes a dipole systematic effect in the proper motion, its removal in the analysis allows for a more accurate research in the field of the intrinsic motions of the radio sources themselves, known as radio source structure. Therefore, in the final part of my project, I started to focus on the topic of source structure, which will allow a further improvement of the celestial reference frame in the future.

1.2 Most important results and a brief description of their significance

In Titov and Krásná (2018a) a new method to detect the secular aberration drift induced by the solar system acceleration due to the attraction to the Galaxy centre was proposed. We developed a procedure to estimate the scale factor directly from the VLBI data analysis in a source-wise mode within a global solution. The scale factor was estimated for each reference radio source individually as a function of astrometric coordinates (right ascension and declination). With this method we obtained a Galactocentric acceleration vector with an amplitude of 5.2 +/- 0.2 uas/yr from the VLBI observations from 1979.7 until 2016.5. We successfully contributed to the findings of the IVS WG8 (MacMillan et al., 2019) and its recommendations to the ICRF3 working group.

In Titov and Krásná (2018b) we focused on testing of special relativity with geodetic VLBI. As the Earth is orbiting around the Solar system barycentre with the velocity V of 30 km/s, VLBI proves to be a handy tool to detect the subtle effects of the special and general relativity theory with a magnitude of $(V/c)^2$. The theoretical correction for the second order terms reaches up to 300 ps, and it is implemented in the geodetic VLBI group delay model. The total contribution of the second order terms splits into two effects – the variation of the Earth scale, and the deflection of the apparent position of the radio source. The Robertson-Mansouri-Sexl (RMS) generalization of the Lorenz transformation is used for many modern tests of the special relativity theory. We developed an alteration of the RMS formalism to probe the Lorenz invariance with the geodetic VLBI data. Though, since the modern laboratory Michelson-Morley and Kennedy-Thorndike experiments are more accurate than VLBI technique, the presented equations may be used to test the VLBI group delay model itself.

In Krásná et al. (2016) we investigated the impact of Earth orientation parameters (EOP) estimation on source positions in Very Long Baseline Array Calibrator Survey (VCS) sessions which were carried out with ten radio telescopes located on U.S. territory. The aim of those astrometric sessions was to estimate source positions and to make snapshot images of compact radio sources. We showed that if EOP are estimated within the VCS sessions, systematic effects up to 1 mas in the estimated source coordinates occur. Therefore, we recommended fixing the EOP in the VLBI analysis of the regional networks to the IERS C04 values or to the values provided by the global navigation satellite system techniques.

In Krásná and Petrov (2021) we showed that an astronomical VLBI observing program MOJAVE-5 is feasible as a testbed for studying source structure contribution to the path delay in detail. In this paper we answered following questions: 1) What are the metrics of geodetic parameters derived from the MOJAVE-5 dataset? 2) How do these metrics compare to similar geodetic programs? 3) What is the main cause of these differences? The estimated baseline length repeatability which was below 1~ppb gives a good estimate of the impact of remaining systematic errors that are specific for MOJAVE-5. With this finding we prepared a basis for a follow-up research of the effect of source structure on astrometry and geodesy in full detail.

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