WORK RELATED WITH IAU C52: RIFA

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ABSTRACT. Work within IAU Commission 52 RIFA (Relativity in Fundamental Astronomy) and work indirectly related with that commission is reported. The main work concentrated upon two issues: the role of an ecliptic in a relativistic framework, i.e., BCRS and GCRS, and work towards an improved and fully documented relativistic VLBI model. Related work concerned progress in the derivation of the post-linear metric for a system of bodies, body models with exterior gravitational fields with higher spin multipoles and physics in such fields.

1. MAIN WORK

The main work within IAU Commission 52 (RIFA) focussed on two issues. The first one being the role of the ecliptic within a relativistic framework and the second one is related with an improved and completely documented relativistic VLBI theory.

According to IAU2000-Resolution B1.3 (Soffel et al., 2003) the Barycentric Celestial Reference System (BCRS) with coordinates $(t, \mathbf{x})$, where t = TCB is determined by a specific form of the metric tensor, constructed under the assumption that the solar-system is isolated and space-time is asymptotically flat. Effects from cosmology or matter outside the solar system are not taken into account. Clearly an ecliptic might be defined as some t = const. Euclidean plane in barycentric spatial coordinates. IAU2000-Resolution B1.3 also specifies the Geocentric Celestial Reference System (GCRS) with coordinates $(T, \mathbf{X})$, where T = TCG by a corresponding geocentric metric tensor, where gravitational effects from external bodies are described as tidal forces. The GCRS is the basic reference system for a description of physical processes that take place in the immediate neighborhood of the Earth, especially for Earth's rotation. Considering precession-nutation in the past usually angles were used whose definitions require two spatial coordinate planes: some Earth's equator and some kind of ecliptic. The definition of an equinox or some obliquity of ecliptic are examples for that. It is without doubts that such concepts are of great value, e.g., for their relations with the seasons and the tropical year. In Capitaine & Soffel (2015) the definition and use of the ecliptic in modern astronomy is recalled.

However, such definitions face serious problems when we consider very high accuracies when effects from relativity are no longer negligible. As mentioned above some BCRS-ecliptic might be introduced and as long as it is independent upon time (i.e., upon TCB) it might be transferred to the GCRS. However, since the coordinate transformation from $(t, \mathbf{x})$ to $(T, \mathbf{X})$ is a 4-dimensional space-time transformation one faces serious problems when one wants to transfer a time dependent BCRS spatial coordinate plane with t = const. into the GCRS (see, e.g., Soffel 2004). For that reason one should avoid the concept of an ecliptic if such high accuracies are considered.

With respect to the accuracies that are presently achieved with VLBI a theoretical VLBI model should have an accuracy of better than 1 ps and it must be based upon Einstein's theory of gravity. The standard model as e.g., described in the IERS Conventions (2010) (Petit & Luzum, 2010) is based upon a consensus model involving publications of Fanselow–Thomas–Treuhaft–Sovers, Shapiro, Hellings–Shadid–Saless, Soffel–Müller–Wu–Xu and Zhu–Groten (see Eubanks, 1991). The paper of Klioner (1991) also had some influence on the material that can be found in the IERS Conventions (2010).

Together with Sergei Kopeikin we have started to work on a new improved and completely documented relativistic VLBI theory. We started with the works by Klioner (1991), Klioner and Kopeikin (1992) and by Sekido & Fukushima (2006). We checked all calculations, tried to find simpler derivations and started with an exhaustive documentation. As usual the theory is based upon the BCRS and GCRS as the two basic reference systems, e.g., for baseline definitions. The gravitational time delay is now entirely derived by means of the Time-Transfer-Function (TTF). In the frame of this work a very elegant derivation of the Shapiro time delay was derived for a body with arbitrary (time independent) mass- and spin-multipoles moving with a small velocity was found; for details see Soffel & Han (2015). Corrections for parallax and proper motion of the radio source have been discussed. For more details the reader is referred to the living document that can be found under http://astro.geo.tu-dresden.de/RIFA/.

2. RELATED WORK

For theoretical astrometric models beyond the μas-level of accuracy work was done towards a rigorous derivation of the post-linear (BCRS) metric for a system of bodies. The metric in harmonic gauge is written in the form

$$\begin{aligned} g_{00} &= -1 + \frac{2}{c^2}w - \frac{2}{c^4}w^2 + O(c^{-6}) \, , \\ g_{0i} &= -\frac{4}{c^3}w^i + \mathcal{O}(c^{-5}) \, , \\ g_{ij} &= \delta_{ij}\left(1 + \frac{2}{c^2}w + \frac{2}{c^4}w^2\right) + \frac{4}{c^4}q_{ij} + \mathcal{O}(c^{-5}) \end{aligned} \tag{1}$$

and the potential q_{ij} satisfies the relation ($T^{\mu\nu}$: energy-momentum tensor)

$$\Delta q_{ij} = -w_{,i}w_{,j} - 4\pi G\left(T^{ij} - T^{ss}\delta_{ij}\right) \, . \tag{2}$$

We started to look into the case of a single spherically symmetric body. During the calculation of the exterior field (the Schwarzschild field) one faces expressions that depend upon the internal structure of the body (e.g., its radius R) and one has to prove that all such 'bad expressions' either cancel in virtue of the local equations of motion or can be removed by means of a (harmonic) gauge transformation. If one requires the metric to be continuous at the body's surface then outside one faces an unusual form of the Schwarzschild metric that depends upon R. For more details the reader is referred to Klioner & Soffel (2014).

Finally work has been done on models for the Sun and planets with higher spin multipole models; realistic estimates for the higher spin-moments of solar system bodies have been derived (Panhans & Soffel, 2015). In another work the physics in gravitational fields with higher spin multipole moments has been studied (Meichsner & Soffel, 2015).

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3. REFERENCES

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