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DIVISION A / WORKING GROUP MULTI-WAVEBAND REALISATIONS OF INTERNATIONAL CELESTIAL REFERENCE SYSTEM

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1. Introduction

The WG on the Future of ICRS (abridged as ICRS-WG) was created at the IAU General Assembly in Hawaii in 2015, in order to anticipate the evolution of the ICRS with the advent of realisations in different wavelength domains. At the moment this concerns primarily the realisations in the radio domain with the VLBI observing technique on one hand, and an optical realisation coming from the European space mission Gaia. The WG is also in charge to evaluate the alignment procedures between the different realisations and investigate the possible systematic differences between the radio and optical positions of the sources contributing to the realisations. This WG stands at the side of the ICRF-WG in charge of producing in 2018 the 3rd release of the radio realisation (referred to as ICRF3). The ICRS-WG comprised 11 members including three representatives from the ICRF-WG and three people with deep involvement in Gaia astrometry.

2. Timeline

Neither Gaia-CRF nor the updated VLBI-CRF (ICRF3 version) were available during the triennium 2015-2018, a circumstance that limited the WG activities during the first two years. Gaia produced in 2016 its first release (Gaia-DR1), but without a full astrometric solution for the quasars. The corresponding reference frame was limited to the 2191 sources common to ICRF2 and aligned to the latter. The position catalogue of 1 billion stars and the TGAS solutions with full astrometry were given in this frame and provided a secondary access. The true first version of a full realisation of an ICRF in the optical domain with Gaia and based on extragalactic sources is planned for release end of April 2018 while the updated radio version will be released during IAU GA in summer 2018 as ICRF3. Contacts between the two WGs, or at least members of these groups, have been regular and useful for either solution.

The main relevant issues are listed below.

• Comparison of ICRF2 and the Gaia solution in 2016 and confirmation of the small declination bias already seen in the post-ICRF2 solutions

• Early availability of a preliminary X/Ka catalogue that has been used to discuss internally the Gaia solution vs this VLBI solution independent of ICRF2

• Use by Gaia after the DR1 of September 2016 of the GSFC VLBI solution for internal validation. This led to the decision to move from ICRF2 to something closer to ICRF3 for the next alignement.

• ICRF-WG made officially available to the Gaia team of an ICRF3-prototype in July 2017, that was used for the alignment in the iterative astrometric solution for the Gaia DR2

• Gaia carried out for the ICRF-WG a comparison of the S/X-, K-, X/Ka-band working solutions to Gaia provisional DR2 solution in October 2017. Results were provided as overall distortions between the VLBI-solutions and Gaia provisional DR2.

• To optimise the Reference Frame activities (VLBI or optical applications for telescope access) Gaia provided lists of sources detected in the visible, that would with high probability appear in the Gaia DR2. These requests for Gaia data were presented to Gaia executive as an action of the ICRS-WG

3. Recommendations

The items below are working recommendations that are not mature enough to be turned into resolutions in 2018. A mandate of the WG for the new triennium would be to sharpen the contents and implications after the radio and optical realisations are published and used by astronomers.

3.1. *Primary realisation*

The availability of several realisations of the ICRS in different wavebands, with currently similar quality, is a totally new situation since the release of the ICRF1 on 1st January 1998 and of its sequel as ICRF2 in 2009. Although the realisations in S/X-band, K-band, X/Ka-band and in the visible are in the same range of astrometric quality, these realisations differ in terms of source distribution and sky density on one hand and on the community of direct users on the other hand. In all the cases, the best stellar densification is today provided by the 1.5 billion stars of the Gaia DR2 Catalogue. Having these multiple realisations is a really good news and one should capitalise on this. The radio and optical frames are for the time being complementary and should have in the future similar status as primary realisations of the ICRS. This impacts on the terminology to refer properly to each realisation as *an ICRF*, and not as *the ICRF*.

3.2. *Alignment*

The WG agree on the need to have various realisations of the ICRS sharing as much as possible the same orientation as a matter of principle. This cannot be achieved from first principles but only through the alignment using sources common to the various techniques. However this applies strictly to the first realisations, and even in this case the resulting alignment depends on so many details of the implementation that it is at the end more conventional than a unique solution to a well posed problem. Now each technique produces updated releases at more or less regular intervals, and will attempt to preserve the continuity of its axes orientation through the releases. This is an essential requirement for the providers of the frames but even more for the users of the frames (e.g. earth orientation, planetary motions) dealing with long time series and expecting continuity in the orientation. Therefore, to maintain internal consistency, future

releases of the radio and optical frames will be most likely aligned to their next-to-last release rather than relying to a cross-technique alignment that would break their internal consistency between successive releases. A compromise must be found to accommodate the need for internal consistency and the requirement that the frame orientations are as close as possible to each other.

3.3. *Comparison*

For the reasons given above the future radio and optical frames might not be formally aligned to each other. And even if an alignment is carried out, this would be the lower order term of systematic differences occurring at different scales. Therefore it remains essential to compare the positions of the common sources to (i) detect possible physical effects that could shift the radio and optical position, (ii) to determine global or local differences between the two frames. At the level of few 10s microarcseconds, the CRF solutions in radio and optics may vary with source selection, weighting scheme. Therefore for the most demanding usages one should agree on the details of the comparison procedure and provide reference transformations between the frames. This transformation must be agreed upon by the groups responsible for the realisation of the frames and made available on-line.

3.4. *Future observations*

The VLBI observations are mandatory for the Earth rotation monitoring and the other geodetic applications, let alone the spacecraft navigation, with no alternative in view on the short term. Whatever the quality and the use of the optical ICRF, the radio frame remains indispensable for many years to come and VLBI observations for this purpose should be continued and supported. As said earlier the radio and optical frames are complementary and largely independent realisations of the ICRS.

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