Dear Colleagues,

Our comments and suggestions concern the document "The New Reference System; some answers" and especially its Annex B which is supposed to be a part of the Resolution. We think also that quite independently of whether the Resolution is accepted or not such a document with the list of terminology would be of much help. We first criticize the document and then formulate clear suggestions how to improve it from our point of view.

- **(the whole document)** The Introduction starts by referring to the ICRS. If we go to the terminology list we read that the ICRS ... is defined by the metric tensor**s** of the IAU 2000 resolutions without reference to quasar positions. In Annex A we learn that the ICRS defines the orientation of axes of the BCRS and the GCRS but that statement is meaningless if the ICRS is defined only by the metric tensor (not tensors as stated in Annex B) without reference to quasar positions.

  Actually the reference to relativity in the definition of the ICRS is fine but so far has not been mentioned in any IAU resolution. Introduced by the IAU 2000 resolutions were the BCRS and the GCRS and their relations to other coordinate systems have not been specified so far.

- **(the whole document)** The manuscript actually refers to a total of seven astronomical reference systems:

  - ICRS
  - BCRS
  - GCRS
  - The Old Equinox based Celestial Reference System (OECRS)
  - The Improved Equinox Based Celestial Reference System (IECRS)
  - Celestial Intermediate Reference System (CIRS)
  - International Terrestrial Reference System (ITRS)

  The relations between them is not always clear from the text. The equinox based celestial systems are left-overs from the Newtonian way of thinking were a Barycentric and a Geocentric Celestial System were not clearly separated. It is not clear if these two systems can be defined in a reasonable way in a relativistic framework.

  Without these two systems the logic is this:

  The IAU 2000 resolutions define first the BCRS by the choice of its metric tensor. The ICRS should be considered a special version of the BCRS with spatial axes defined by positions of certain quasars. The GCRS is obtained from the BCRS by the 4-dimensional space-time transformation of IAU 2000 Resolution B1.3. The spatial axes of the CIRS and the ITRS are defined by time-dependent rotations of the spatial axes of the GCRS (see e.g., IERS Technical Note No. 29, D.McCarthy and N.Capitaine, Figure 1). The transformations of the CIRS and the ITRS to the BCRS or the ICRS, if really necessary, involve the 4-dimensional relativistic BCRS-GCRS transformation given in the IAU 2000 Resolution B1.3.

  One should start the document with a reference to the GCRS as it was done in the recent text by Capitaine et al. (24 Feb. 2003) or one should refer both to the BCRS and the GCRS.

- **(the whole document)** The notions of reference system and reference frame, though clearly and correctly defined in Annex B, are not always clearly distinguished in the text.

- **(paragraph 2.b: 'Celestial Intermediate Origin (CIO)')** According to the discussion above the wording '... the CIO has a zig-zag secular motion across the ICRF sky' should be replaced by '... the CIO has a zig-zag secular motion in the GCRS'.

- **(paragraph 2.f: 'Precession-Nutation')** The formulae in this section where the ITRF is linked to the ICRF by a rotation are misleading. In all the section 'ICRF' should be replace by 'GCRS', and 'ITRF' by 'ITRS'. E.g. instead of

  'ICRF=Q(t) x R(t) x W(t) x ITRF'

  one should write

  'GCRS=Q(t) x R(t) x W(t) x ITRS'

  In the same way instead of

  'ICRF=B x P(t) x N(t) x R(t) x W(t) x ITRF'.

  The word 'space-fixed' should be dropped.

- **(paragraph 3.a: 'pole offset')** 'Celestial Reference System (CRS)' should be replaced by 'Celestial Intermediate Reference System (CIRS)'. And 'The offset reorients the ICRF ...' by 'The offset reorients the GCRS ...'.

- **(paragraph 4.c: 'geodesic precession and nutation')** Although 'geodesic precession and nutation' are correctly defined in the Annex B, there are several misleading statements in the section on geodesic precession and nutation. Below we suggest how to improve this section:

  'Geodesic precession and nutation are the largest components of the relativistic rotation of the GCRS (which is defined to be kinematically non-rotating, i.e. nonrotating with respect to the BCRS) with respect to a dynamically nonrotating geocentric reference system (a reference system where the equations of motion of Earth's satellites have no Coriolis and centrifugal forces). The equations of motion of Earth's satellites written in the GCRS contain additional Coriolis forces which should be taken into account (as also recommended by the latest IERS Conventions). geodesic precession and nutation are purely relativistic effects which are related to the motion of the geocenter as the origin of the GCRS in the gravitational field of the solar system and cannot be understood as the influence of the luni-solar or planetary torques on the Earth's body. Geodesic precession and nutation are included in the new precession-nutation model. The latter provides, therefore, the rotation between the kinematically non-rotating GCRS and the CIRS.'

- **(Annex A)** We read: "Terrestrial Time ... is defined by application to TCG of a conventional scale factor, so that on the geoid TT is equal to proper time". According to IAU 2000 Resolution B1.9 this conventional scale factor was chosen to be a defining constant in order to be independent of the geoid whose precise definition presents a problem by itself. Therefore, this statement is not correct.

- **(Annex A)** Also the statement: 'the JPL Development Ephemerides use an ephemeris time $T_{\rm eph}$ that is similar to TDB in that it has the same rate as TT..' is misleading. JPL is using the EIH-equations of motion and for that reason $T_{\rm eph}$ should be related to TCB by a linear transformation. In the past one talked about a time scale TDB that differed from TT only by periodic terms. But later it became obvious that such a definition is problematic. Actually the $T_{\rm eph}$ for two different ephemerides will not coincide. Indeed,

the coefficient of the linear transformation between $T_{\rm eph}$ for a particular ephemeris should be computed from that ephemeris. For that reason one has to be very careful.

- **(Annex B: BCRF)** The notion of BCRF is completely new. If the 'number of celestial objects' means solar system bodies then the BCRF would be one possible realization of the BCRS by solar system ephemerides. But this obviously is not the only possible realization of it (as implied by the acronym BCRF and its relation to the acronym BCRS). We would prefer that 'D' for dynamics were added to the name, e.g. BDCRF. If the number of celestial objects refer to quasars then what is the difference to the ICRF? Or is it a generic term for any possible realization of BCRS (or ICRS)?

- **(Annex B: BCRS)** The BCRS is defined only by one metric tensor (not tensors).

- **(Annex B: CIP)** In the document we read: "the transformation from the ICRF to the CIRF". We have already noted above that the ICRS is not related to CIRS by a rotation. We should write "the transformation from the GCRS to the CIRS".

- **(Annex B: GCRF)** What is the GCRF? Why should it be a realization of the GCRS in radio wavelength? It is completely unclear.

- **(Annex B: geocentric intermediate right ascensions and declinations)** We read: "they are geocentric apparent positions corrected for deflection of light and annual aberration". We are unable to grasp the meaning of this. Do you want to underline that the effects of light deflection and annual aberration are taken into account when computing the geocentric intermediate right ascensions and declinations from a catalog in ICRS? Then we would agree with this, but why don't you mention also annual parallax? Also: one should explicitly mention that for the calculation of the light deflection one should forget about the influence of the gravitational field of the Earth.

- **(Annex B: ICRS)** Concerning: the ICRS: what is the meaning of "direction fixed"? We believe that the ICRS is the BCRS (as defined by the BCRS metric tensor (not tensors!)) with specific orientations of the spatial axes.

- **Annex B: apparent place** Why aberration is mentioned and parallax is not?

- **(Annex B: TCB)** It is the coordinate time of the BCRS (not just for a coordinate system at the barycenter).

- **(Annex B: TDB)** To our knowledge, TDB was never defined exactly and this should be mentioned explicitly. The relation of TDB to $T_{\rm eph}$ is unclear from the text. According to the IAU 1991 resolutions we should use the SI units of measurements for all the quantities including the distances in any reference system. The text is, therefore, misleading and should be improved (see below).

- **(Annex B: TCG)** It is the coordinate time of GCRS (not just for a coordinate system at the geocenter).

- **(Annex B: TT)** We read "so that the unit of time of TT is equal to the second of the SI as realized on the geoid". This statements is unclear. The unit of measurement for all the astronomical time scales is the SI second. It is true that TT is not a new time scale, but according to IAU 2000 Resolution B1.9 it has been redefined and no longer depends upon the geoid. One could write: 'so that the mean rate of TT is close to the mean rate of proper time of an observer located on the rotating geoid'.

Some concrete SUGGESTIONS FOR IMPROVEMENT of the Resolution and its Annex (Annex B)

- **Resolution**

  We suggest to replace

  '2) That the International Celestial Reference System (ICRS) has been introduced into use'

  by

  '2) That the Barycentric Celestial Reference System (BCRS), the International Celestial Reference System (ICRS) as a representation of the BCRS and the Geocentric Celestial Reference System (GCRS) have been introduced into use'

- **Resolution**

  We suggest to replace

  '3) The advantages of introducing a new moving reference frame for astronomy'

  by

  '3) The advantages of introducing a new moving geocentric reference system for astronomy'.

- **Resolution** We suggest to replace

  '1. That the terminology "intermediate" be used uniformly to designate the moving reference frame with the z-axis toward the CIP and the x-axis toward the CIO'

  by

  '1. That the terminology "intermediate" be used uniformly to designate the moving geocentric reference system with the z-axis toward the CIP and the x-axis toward the CIO'

- **Resolution**

  We suggest to replace

  '3. That the new Celestial Intermediate Pole and Celestial Intermediate Origin based intermediate moving reference frame be introduced into astronomy'

  by

  '3. That the new Celestial Intermediate Pole and Celestial Intermediate Origin based intermediate moving geocentric reference system be introduced into astronomy'

- **Annex: BCRF**

  Either omit this item or replace it by something like

  '**Barycentric Dynamical Celestial Reference Frame (BDCRF)**: a realization of the ICRS centered at the barycenter of the solar system, consisting of the coordinates and motions of a number of solar system objects.'

- **Annex: BCRS**

  Barycentric Celestial Reference System (BCRS): a system of barycentric space-time coordinates for the solar system within the framework of General Relativity. The metric tensor to be used in the system is specified by the IAU 2000 Resolutions.

- **Annex: CIP**

  Celestial Intermediate Pole (CIP): Geocentric equatorial pole determined by the IAU 2000A precession-nutation model which provides the transformation from the GCRS to the CIRS.

- **Annex: CIRF**

  Celestial Intermediate Reference System (CIRS): Geocentric reference system related to the GCRS by time-dependent rotation. Its is defined by the intermediate equator, CIP, and CIO at a specific date.

- **Annex: GCRF** GCRF should be omitted (or explained)

- **Annex: GCRS**

  Geocentric Celestial Reference System (BCRS): a system of geocentric space-time coordinates within the framework of General Relativity. The metric tensor to be used in the system is specified by the IAU 2000 Resolutions. The GCRS is defined such that its spatial coordinates are kinematically non-rotating with respect to those of the BCRS.

- **Annex: geocentric intermediate right ascensions and declinations**

  geocentric intermediate right ascensions and declinations: coordinates measured in the CIRS at a specific time in TCG or TT. They are geocentric positions differing from the ICRS positions by the annual aberration, annual parallax, gravitational light deflection due to the solar system bodies expect the Earth and the time-dependent rotation describing the transformation from the GCRS to the CIRS.

- **Annex: ICRS**

  International Celestial Reference System (ICRS): a special version of the BCRS where the orientation of the spatial axes is fixed.

- **Annex: TCB**

  Barycentric Coordinate Time (TCB): the coordinate time of the BCRS, related to the Geocentric Coordinate Time (TCG) and Terrestrial Time (TT) by the relativistic transformations that include secular terms.

- **Annex: TDB**

  Barycentric Dynamical Time (TDB): A time scale which was supposed to serve as independent argument of barycentric ephemerides and equations of motion. TDB was defined by the IAU 1976 Resolutions to have no secular drift relative to TT (which is equivalent to TDT). Later it became clear that this condition cannot be exactly satisfied. Independent argument of a solar system ephemeris is a linear function of TCB called T_{eph}.

  We propose also to add:

  Barycentric Ephemeris Time (T_{eph}): an independent time argument of barycentric ephemerides. This time scale is a linear function of TCB. Each ephemeris defines its own version of T_{eph}. The linear drift between T_{eph} and TCB is chosen so that the rates of T_{eph} and TT are as close as possible for the time span covered by the particular ephemeris.

- **Annex: TCG**

  Geocentric Coordinate Time (TCG): the coordinate time of the GCRS, related to Terrestrial Time (TT) by a conventional linear transformation.

- **Annex: TT**

  Terrestrial Time (TT) a time scale related to the Geocentric Coordinate Time (TCG) by a conventional linear transformation so that the mean rate of TT is close to the mean rate of proper time of an observer located on the rotating geoid. TT can be used as the independent time argument for the geocentric ephemerides. In the past TT was also called TDT.

Michael Soffel
Sergei Klioner