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COMMISSION 52 — RELATIVITY IN FUNDAMENTAL ASTRONOMY

RELATIVITÉ DANS ASTRONOMIE FONDAMENTALE

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COMMISSION 52 WORKING GROUPS

none

PROCEEDINGS BUSINESS SESSION, 7 August 2009

1. The Commission and its membership

The IAU Commission 52 "Relativity in Fundamental Astronomy" (RIFA) has been established during the 26th General Assembly of the IAU (Prague, 2006) to centralize the efforts in the field of Applied Relativity and to provide an official forum for corresponding discussions. The general scientific goals of the Commission are:

- clarify geometrical and dynamical concepts of Fundamental Astronomy within a relativistic framework,
- provide adequate mathematical and physical formulations to be used in Fundamental Astronomy,
- deepen the understanding of the above results among astronomers and students in astronomy,
- promote research needed to accomplish these tasks.

In the period 2006–2009 the Commission has actively invited people to participate in the activities of the Commission. In July 2009 the Commission had 39 full members from 10 countries (USA and France having more than 60% of the members). A considerable problem for the Commission was the rule that only IAU members can become members of an IAU commission. In the particular case of Commission 52, which shares the research field with gravitational physics, this has led to the situation when many people actively working in the research field were not allowed to officially join the Commission. In several cases the Commission has undertaken certain efforts in order to make certain individuals new members of the IAU. During General Assembly in Rio de Janeiro many new members have joined the Commission so that the total number of members is now about 70.

2. Activities of the Commission

A web page containing all the information concerning the work of the Commission has been created and activated: `http://astro.geo.tu-dresden.de/RIFA`. It has been decided that this web page will be maintained at the same place. The content of the web page will be obviously determined by the President of the Commission and by its Organizing Committee.

Several scientific and educational projects have been initiated in 2007. The educational projects include compilation of a list of open problems in the field of applied relativity as well as a list of frequently asked questions. The Relativistic Glossary for astronomers has been also created and is available on the web page of the Commission. These three tools are intended to serve the broad astronomical community. The corresponding documents are expected to be updated and enriched in the future by the Commission itself and by future Working Groups of the Commission.

The following three scientific topics were identified by the Commission as important to discuss in the years to come:

1. units of measurements for astronomical quantities in the relativistic context,
2. astronomical units in the relativistic framework,
3. time-dependent ecliptic in the GCRS.

2.1. *Task team "Units of measurements"*

During the period 2006–2009 only the first topic has been discussed in detail. The content of this topic can be summarized as follows. In the literature (including very recent papers) one can find different units used in precise work: "TDB units", "TCB units", "TT units" along with "SI units". The co-existence of these units is related to the relativistic scaling of time and space coordinates. On the other hand, the IAU 1991 resolutions clearly state that only SI units without any additional relativistic scaling should be used for all astronomical quantities (astronomical units like AU are not meant here). Besides the non-SI units lead to certain logical contradictions. For example, time scale TAI cannot be considered as being expressed in the units of SI, if TT is considered to be expressed in non-SI units. A balanced approach to this issue had to be suggested and discussed. Such an approach helps also to unify the notations and numerical values of astronomical constants throughout the literature. As a material for discussions (Klioner 2008) has published a concise review of the problem of relativistic scaling of astronomical quantities.

For this discussion a dedicated discussion forum – task team – has been established. The task team was open for any member of the Commission. All members of a task team were expected to participate *actively* in the discussion. A total of 12 members of the Commission have decided to participate in the task team. The discussion was organized in the form of e-mail exchange. Several documents circulated as a basis for the discussion. The task team had also a number of short workshops during scientific meetings in Paris, Dresden, and in Virginia Beach, VA, USA.

Although the topic of the discussion did not seem to be complicated a priori, the discussion had encountered several difficulties which have also substantially slowed down the elaboration of the common point of view and recommendations for the nomenclature. The work of the task team has finally resulted in a joint paper (Klioner *et al.* 2009) containing the summary of the discussion and the recommendation to use the units of SI with any time coordinates – TCG, TCB, TT, and TDB. This should be considered as a crucial step forward in this area.

2.2. *IAU Symposium 261*

A fundamental problem for the field of Commission 52 is its multidisciplinary nature. Experts in general relativity usually have limited experience with real data and often cannot judge if what they suggest is really relevant for practical purposes. Experts in astronomical data processing usually have limited knowledge of relativity and often try to apply Newtonian way of thinking to general-relativistic concepts. One remedy of this situation is to organize dedicated scientific meeting where both kind of researchers come together and try to understand each other.

The Commission has organized IAU Symposium 261 "Relativity in Fundamental Astronomy: Dynamics, Reference Systems and Data Analysis". The Symposium was held in Virginia Beach, VA, USA from 27 April to 1 May 2009 and gathered about 100 participants from 18 countries. The IAU Symposium 261 had the goals 1) to summarize the advances in Applied Relativity in the past quarter of a century, 2) to highlight the astonishing achievements in testing General Relativity and to elucidate the tests to be expected in the near future, 3) to facilitate the communication and collaboration between scientists working with high-accuracy data of different kinds by providing a chance to meet at a common scientific meeting, and 4) to consider the future developments of Applied Relativity.

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3. Main scientific achievements in Applied Relativity

During Business Session an attempt to summarize the most important developments in the field of Applied Relativity in the period from 2006 to 2009 have been undertaken. The following list does not pretend to be exhaustive.

Brumberg (2007) has demonstrated that in accordance to the old idea of Infeld the variational principle of the Einstein field equations may be used to derive the commonly employed Einstein-Infeld-Hoffman equations of motion from the linearized metric.

Recent re-definition of TDB adopted by the 26th General Assembly of the IAU has created the possibility to define the time scales of new solar system ephemerides in full consistency with General Relativity. The ephemeris group in Paris Observatory (Fienga *et al.* 2009) has used this possibility and created the first version of the "4-dimensional ephemeris" which contains not only the spatial positions and velocities of the solar system objects, but also the numerical transformation between the time parameter of the ephemeris (TDB) to the time scale TT which can be easily used to compute the moments of observations in TAI, UTC or similar time scales generally available to an observer on the Earth.

Earth rotation is the only astronomical phenomenon which is observed with very high accuracy, but still modelled in a Newtonian way. Although a number of attempts to estimate and calculate the relativistic effects in Earth rotation have been undertaken, no consistent theory has appeared until now. At least two projects have been recently started to improve the situation. Brumberg & Simon (2007) consider the formally Newtonian equations of rotational motion with all quantities relativistically transformed into dynamically non-rotating version of the GCRS. Klioner, Gerlach & Soffel (2009) have developed the fully post-Newtonian theory of Earth rotation using numerical integration of the post-Newtonian equations of rotational motion.

Subtle effects in the GPS model are important to improve the accuracy of GPS observations and to model future higher-accuracy navigation systems. Recent papers (Kouba 2004; Larson *et al.* 2007) consider such additional relativistic effects in the GPS model. A detailed review on Relativity in geodesy has been published by Müller *et al.* (2007).

Several new results in the models for light propagation have been published (Kopeikin & Makarov 2007; Le Poncin-Lafitte & Teyssandier 2008; Klioner & Zschocke 2009) aimed at improving the consistency and accuracy of the practical models for high-accuracy positional and ranging observations. These refined models will be used e.g., in the space missions like Bepi-Colombo, Gaia and SIM.

Another research area where substantial progress has been reached is planning and verifying astronomical tests of General Relativity and alternative theories of gravity. In particular, the influence of translational motion of the gravitating bodies on experiments involving light propagation has been considered in detail. Several authors (Bertotti, Ashby & Iess 2008; Kopeikin 2009a,b) have discussed the effect of the motion of the Sun on the light travel time in experiments such as Cassini relativity experiment. The authors finally confirm the claimed accuracy of the Cassini experiment (Bertotti, Iess & Tortora 2003). Considering the anticipated accuracy of the future relativistic experiments it is important to provide realistic errors of the achieved estimates of relativistic parameters. A sophisticated statistical analysis of the relativistic experiments with the ESA mission BepiColombo (Milani *et al.* 2002) has been performed by Ashby, Bender & Wahr (2007).

The ESA project ACES has been recently selected and is aimed at having very accurate clock (stable and accurate at the level of $10^{-16} - 10^{-17}$) in space in the near future. Special care must be taken in practical relativistic modelling of such clocks. Duchayne, Mercier & Wolf (2009) have investigated the relativistic modelling of high-accuracy clock on board of an Earth satellite in full detail.

Finally, the work on the improvement of the relativistic formulations and semantics of the IERS Conventions has been continued. As mentioned above substantial progress has been achieved in developing a consistent nomenclature on units of measurements in the relativistic framework (Klioner 2008; Klioner *et al.* 2009).

4. Future work

The subject of astronomical units mentioned at the beginning of Section 2 above will be treated by a special Working Group of Division I. The participants of Business Session considered that it is appropriate for Commission 52 to discuss the definition of an ecliptic in the

GCRS. The future directions of the work of the Commission 52 will be decided by the future President and the Organizing Committee of the Commission.

Sergei A. Klioner
President of the Commission

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