Report of Commission Meetings

During this General Assembly, Commission 31 held 1 business and 5 scientific sessions among which 2 were organized jointly with Commission 19.

Moreover Commission 31 participated to the Joint Discussions on "Reference Frames" and "Hipparcos" which involved Commissions 4, 7, 8, 19, 20, 24, 31, 33, 40 and 4, 8, 19, 24, 31, 33, 40, 44 respectively. The Joint Discussion on Reference Frames led to the adoption by the IAU General Assembly of a set of 9 resolutions which introduce relativistic theory in the definition and realization of time scales and reference frames. Of particular interest for Commission 31, they introduced also more precise definitions of existing time scales and new designations: TT = Terrestrial Time,TCG = Geocentric Coordinate Time, TCB = Barycentric Coordinate Time. The definitions are given in the set of resolutions adopted by IAU; the attached figure will help to clarify the relations between those time scales. In Celestial Mechanics 1991, a paper of V.Brumberg and M.Soffel could also highlights the resolutions mentioned above.

The first session (24 July) was dedicated to the presentation of scientific papers and to the reports of members of Commission 31 who are representatives in different agencies or commissions.

Dr. Winkler gave a full report concerning the 11th session (19-20 April, 1989) of the Comité Consultatif pour la Définition de la Seconde (CCDS) at the BIPM. The meeting discussed progress in time links (GPS, TV, LORAN-C, VLBI) and in frequency standards technology (mercury ion trap frequency standard). A special working group chaired by David Allan is preparing recommendations to be used to improve the uniformity of GPS measurements made in laboratories worldwide. Two declarations have been produced concerning the opportunity for BIPM to establish other working groups to define precise conditions on the operations of various time link systems. Five recommendations are also taken. The first recommendation suggests that the offset of 1 microsecond between UTC(k) and UTC, requested by CCIR, be changed to the "region of a few microseconds". Recommendation (2) aims a general improvement of the performance of the clocks contributed to TAI. Recommendation (3) deals with a possible improvement of the reference coordinates of antennas used in one-way time intercomparison, while Recommendation (4) recommends BIPM to acquire clock and time comparison hardware to provide a more intimate connection of BIPM with the problems of high precision time intercomparison. Recommendation (5) requests the BIPM to study and organize an optimum network of time links among the contributors to TAI in order better to utilize the major time intercomparison methods (GPS, GLONASS, two-way satellite time transfers).

Report of TAI determination carried out at BIPM is given by G. Petit. Since the 1st of January 1988, BIPM is officially in charge of the establishment and dissemination of TAI and UTC. The report deals with the evolutions that have occurred since that time and on the associated researches that have been carried out at BIPM. GPS is now by far the main technique used for time transfer. The fraction of laboratories equipped has grown from 60% at the end of 1987 to 85% at the end of 1990. Conversely the use of LORAN-C and TV is declining. GLONASS has appeared in 1990 to link UTC (SU). Steering was resumed in 1989, after a period of more than 5 years when it was not found necessary. It has been performed 5 times, in steps of 5.10^{-15}, the general rule being that the frequency adjustments should be below the intrinsic instability of the scale. The general trend is still that the frequency of EAL tends to decrease with respect to the frequency standards.

Different studies are being conducted by the BIPM concerning use of Kalman Filter for time scales, and correlations between contributing clocks. It has been shown that the main cause is change in environment, especially humidity, but apparent correlations due to the time links or to TAI may appear.

The coordinates of the GPS antennas of 23 laboratories have been determined in the global reference frame ITRF88, either by compilation of existing data or by processing of the time data themselves.

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A comparative study of two codeless ionospheric calibrators has been carried out. It has been shown that the use of such ionospheric measurements, associated with post processed precise ephemerides, can greatly improve the precision and accuracy of the GPS time transfer. The CCDS has the task to ensure the standardization of hardware, software and procedures, which is essential in case of Selective Availability.

Finally BIPM participated in the coordination of two-way time transfer and started to study GLONASS.

Dr. J. Luck gave a report on the status on Time development in Australia. The National Standard Commission (NCS) which administers the National Measurement Act 1960, has formed a National Time Committee, and has initiated Commonwealth legislation to have UTC (AUS) legally adopted as the national time scale, as close as possible to UTC (BIPM). The legislation will define time zones and daylight saving based on UTC (AUS); they were formerly the responsibility of individual states and territories and based on nineteenth-century concepts adopted in 1983. The standard frequency and time signal service VNG, discontinued by TELECOM Australia in 1987, was re-activated experimentally in 1988. A permanent service was inaugurated on 3 July 1991, broadcasting on 5.0, 8.638, 12.984 and 16.0 MHz.

The National Time Committee is to study the introduction of low frequency time signals for Australia, similar to DCF 77 in Europe. Low cost medium-resolution GPS timing receivers are also being studied. Since 1988, UTC (AUS) has been defined as equal to UTC (USNOMC), the realization being the 1 pps output from a GPS Time Transfer Unit at CSIRO National Measurement Laboratory corrected by GPS Time variations published in USNO Series 4. The free-running time scale, formerly known as UTC (AUS), is now designated TA (AUS) and is based on selections from 20 caesium standards and 2 hydrogen masers using an algorithm unchanged since 1980. Clock comparisons are made by GPS, local TV and AUSSAT TV. An annual term of amplitude 150-200 ns in TA(AUS)-UTC(BIPM) is evident from the connection by GPS during 1983-1991.

On the problem of the introduction of relativistic corrections for new time scales and Reference Frames, Prof. R.O. Vicente expressed some critical considerations, arguing for a more conservative approach to avoid changes which do not appear as fundamental for practical users.

S. Debarbat summarized contributions presented in 1989 at the meeting "Journées Systèmes de référence spatiotemporels", organized yearly at the Paris observatory; they concern the relativistic effects in astrometry and are related with the set of recommendations to be analyzed by the Joint Discussion on "Reference Frame". S. Debarbat mentioned several relevant papers (Th. Damour, M. Soffel, C. Xu,C.Boucher) published in the Proceedings of the meeting above (available on request, at the Observatoire de Paris, Ed. N. Capitaine). They took steps that conducted to an evolution of concepts and considerations, allowing one to reach some consensus between the authors above; in a common paper they studied equations of motion with the integrated ephemeris from JPL.

P. Pâquet presented the procedure used to realize the reference time scale UTC(ORB) in use at the Royal Observatory of Belgium since early 1991. A mathematical clock is deduced from 3 atomic clocks whose long term drift is measured with respect to an external frequency (GPS or TAI); this mathematical clock is realized by frequency adjustment of a Rubidium.

The precision is of the order of 2×10^{-13}.

The second scientific session (24 July) was dedicated to the activities of the Working Group on Time Transfer, chaired by H. Fliegel.

Since D. Allan was not able to attend the General Assembly, H. Fliegel presented the report of the Working Group on Pulsars; he summarized interesting results obtained in Berkeley, Princeton, Arecibo, Meudon. D. Allan is willing to provide copy of the report.

G. Petit, addressed the assessment of GPS time transfer accuracy by the condition of closure around the world. The precision of time transfer by the GPS common view method is routinely at the level of 10 to 20 ns, even over intercontinental distances. When special care is taken to correct the main sources of error (satellite ephemerides, ionospheric delay, station coordinates), 4-5 ns can be achieved.

Using three intercontinental links around the world, it is possible to establish a closure condition by adding the three independent time transfer values, which should add to zero. This provides a direct estimation of the accuracy of the time transfer technique, except for the cancellation of constant or slowly

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varying receiver biases.

W. Lewandowski, G. Petit, C. Thomas computed such a closure condition for more than six months using data recorded at the Paris Observatory in Paris (France), at the Communication Research Laboratory in Tokyo (Japan) and at the National Institute of Standards and Technology in Boulder,Co (USA). They used GPS ionospheric measurements at the three sites and precise ephemerides provided by the US Defense Mapping Agency to correct the GPS time measurements. The closure condition is verified within a few nanoseconds. The remaining bias is significant, and an attempt is made to explain its origin in several remaining sources of error, and to estimate their respective effect.

Mrs. Ye presented a paper on Time Synchronization in China. At the end of the 70s' a special LF station transmitting BPL signals, which is similar to Loran-C, was established at the centre of China for domestic precise time comparison. The transmitting accuracy of BPL is better than 100 ns; meanwhile, the methods of passive and active television via satellites, and portable clock, were used for time comparison at Shaanxi Observatory, Shanghai Observatory, Beijing Observatory, Institute of Geodesy and Geophysics, Institute of Beijing Radio Metrology and Institute of National Metrology. *Significant results were obtained in China in the 1980s'. Starting from 1990, most of laboratories in* China, have GPS receivers made in China and GPS is the main method of synchronization with BIPM and Foreign time and Frequency laboratories. In recent years the precision obtained by different methods is as follows : LF ground wave (500 ns), Laser pulses (few ns), VLBI (few ns), GPS (10 to 20 ns), satellite SIRIO (better than 100 ns), portable clocks (better than 100 ns).

J.Zhang and Wu Bijun estimated the influence of ionosphere in Wuhan region on GPS signal time delay.

Using the TEC and sunspot data, the authors analyzed the GPS signal propagation time delay variation caused by the ionosphere. By using TEC monthly middle data in the Wuhan region to correct additional time delay caused by the ionosphere, they can make GPS single frequency altimetry accuracy and timing measurements match the dual frequency altimetry accuracy and common view time synchronous accuracy. There is a potential for further improving this accuracy.

Two papers were dedicated to time transfer by geostationary satellites. J. Luck indicated that TV signals from the geostationary communications satellite AUSSAT are used routinely for clock comparisons in the South East quadrant of the continent. They are adequate to 100 ns with orbital corrections from radar ranging, and are used, for example, to transfer UTC (AUS) to the NGS VLBI/CIGNET station at Hobart, Tasmania. Portable GPS-TTU visits have confirmed the stability of AUSSAT TV biasses to 50 ns, but reveal microsecond-level anomalies in 1 pps outputs from GPS geodetic receivers. Experiments are under way within AUSLIG to extend coverage over the whole country by receiving PAL transmissions from national beam.

The AUSSAT orbit can be refined by converting the pseudoranges measured by TV to range differences at pairs of stations whose clock differences are known from GPS. Experiments to date, solving for eccentricity, inclination and station biasses, have reduced time transfer errors below 10 ns.

The next generation of AUSSAT spacecraft, to be launched during 1992, will carry an array of 14 retroreflectors, 38 mm diameter each. Auroral Laser Ranging Observatory has been upgraded to provide the laser power, efficiency and reliability to support this operation with 1 cm precision in range and 3 arcsecond precision in pointing. 1 ns time transfer accuracy over much of Australia, independent of GPS, will result from the better orbit determination.

P. Pâquet reviewed the results obtained in 1989-1990 by a European group who performed time comparison by geostationary satellites; it was not possible to reach a better precision than 100 to 200 ns because the error of the satellite position was of the order of one to two kilometers. On the other hand, a European Working Group "COGEOS" aims to locate the geostationary satellites for the study of zonal harmonics of the Earth gravity field. Since photographic results have been disappointing, an experiment to locate the satellites using time comparison technique is proposed. A first experiment is proposed to be conducted by the end of 1991. The analysis will combine both orbit and time differences determination, or orbit only if GPS is used for time comparison.

C. Veillet reports on the LASSO experiment; which is made mainly of a laser pulse detector associated to an event-timer and a stable oscillator. It is flying on a geosynchronous satellite Meteosat 3/P2 since

August 1988. Ground based laser ranging stations at TUG (Graz, Austria) and OCA/CERGA (Grasse, France) succeeded in November 1991 in getting echoes from the satellite retroflectors and arrival times of the laser pulses at the satellite on the on board time scale. The analysis of these data demonstrated that LASSO is capable of linking time scales at two remote sites with a subnanosecond accuracy.

In September 1991 should begin a new phase of LASSO involving OCA/CERGA and two laser stations in the USA (MLRS, Texas, and 48" Goddard, Maryland), as Meteosat 3/P2 is located at 50 deg. W in the geosynchronous belt since the end of July 1991. NASA, USNO and NIST will cooperate with OCA/CERGA for the success of this unique experiment whose results will be compared to other time transfer techniques (GPS and Mitrex two-way).

In conjunction with LASSO, time transfer comparisons have been performed between GPS and Mitrex two-way through a nine months campaign at TUG and Grasse. A preliminary analysis shows an internal precision of 0.7 ns for a typical two-way session. A rough comparison between GPS and two-way for the first three months shows a 2.7 ns rms of the differences. This campaign will be extended by adding sites in the USA in the frame of LASSO.

Together with the members of Commission 19, the second part of the session (2) was devoted to pay homage to Dr.B.Guinot who has recently retired and was past president of the Commission 31. Dr. Pâquet and Dr. Winkler gave to the members of Commissions 19 and 31 a brief but hearty summary of the scientific and organizational activity carried out by Dr. B. Guinot during about 35 years as director of the BIH and after 1985 at the BIPM.

One session has been entirely dedicated to a seminar given by Prof. V. Brumberg who states several points concerning relativistic aspects for the realization of Time scales and references systems.

It is not possible to summarize the Brumberg's bright presentation but the figures 1 to 4 are extremely useful to return to papers which addressed this problem since few years; they concern the comparisons of observations with respect to computed quantities (fig. 1), the dynamical and non-rotating reference systems (fig. 2), the hierarchy of relativistic reference systems (fig. 3), possible evolution of relativistic Time scales (fig. 4).

A session has been dedicated to a general discussion concerning proposals issued from the IAU Executive Committee, and more particularly, concerning the amalgamation of Commissions and format of future General assemblies. The proposal to reduce the number of Commissions is related to the decision to re-organize the format of the General Assemblies. Participants recognize that it is mandatory to change the format of the assemblies, but nevertheless they confirm what has already been expressed two years ago by exchange of correspondence, that Commission 31 has its own specificity and does not require any amalgamation. Moreover since the Field of timing and reference systems is rapidly changing, no reorganization could be valid for long. The existence of Commission 31 must be preserved to prevent miscommunication between physicists and astronomers, and contact must also be maintained with advanced engineering users.

For the format of the General Assemblies, the participants were not in favour of organizing Symposia before or after an Assembly. It is porposed to restrict the scientific sessions to workshop or symposia organized in common by several commissions; one or two business meetings would be held by Commission.

The participants feel that in its preparation for the next General Assembly, the Organizing Committee must address this problem rapidly.

A new IAU working group on "Astronomical Constants" has been initiated by Dr. Fukushima; the Commission will be represented by V. Brumberg and G. Petit.

The two existing working groups continue under the chairmanship of D. Allan "The use of Millisecond Pulsars and Timing of Pulsars" and J. Luck "Modern Techniques of Time Transfer".

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The new organizing Committee of the Commission is as follows :

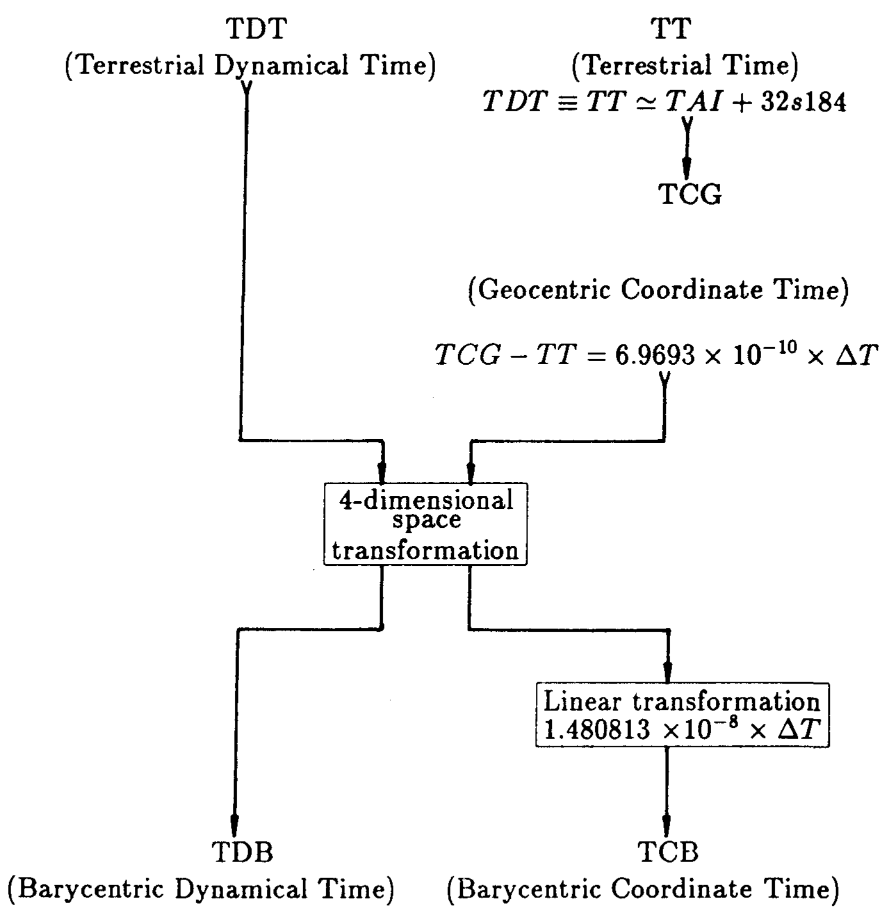
President : E. Proverbio
Vice-President : H. Fliegel
Members : D. Allan, V.A. Brumberg, F. Fujimoto M. Granveaud, B. Guinot, W. Klepezynski, J. Kovalevsky, J. Luck, I. Mueller, P. Pâquet, Ye Shu Hua.

The representatives to international organization are :

- to CCDS and BIPM : W. Winkler
- to FAGS : J. Kovalevsky
- to CCIR : S. Leschiutta

Relations between Time scales

Recommendation 1976 | Recommendation 1991



$$TCB = TDB + 1,550505 \times 10^{-8} \times \Delta T$$
$$\Delta T = (\text{date in days - 1977 January 1, } 0^h)_{TAI} \times 86400 \text{ sec}$$

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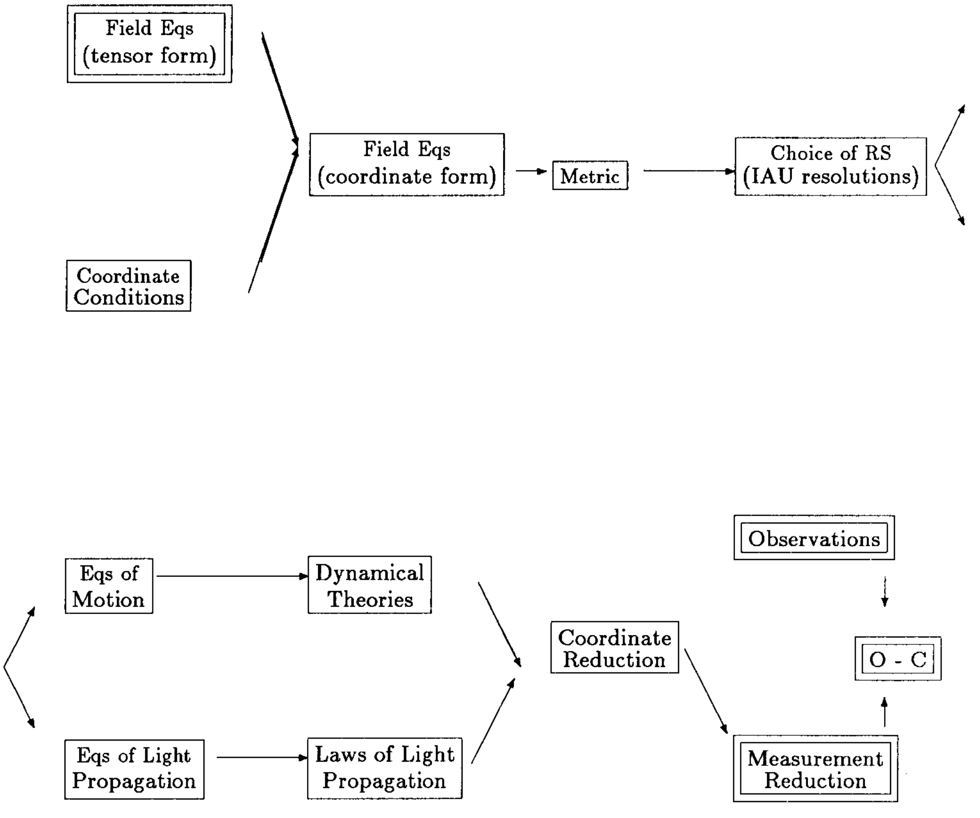
Fig.1 O-C, comparison in relativistic astronomy



In contrast to the inertial coordinates of Newtonian astronomy there exist no global coordinates in relativistic astronomy which may be treated as physically meaningful measurable quantities. Therefore, to perform the physically meaningful O-C analysis one has to convert dynamical effects of motion of the bodies and kinematical effects of light propagation, to be considered in one and the same Reference System (RS), into the measurable quantities (coordinate reduction). The various steps of this process are shown in this figure. The coordinate independent steps are marked by double lines.

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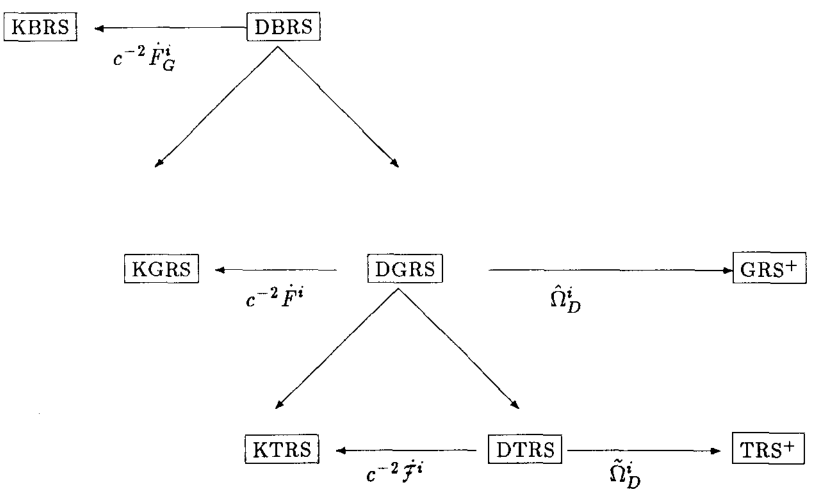
Fig.2. Dynamical (DRS) and Kinematical (KRS) Non-Rotating Reference Systems.



In contrast to Newtonian astronomy one should distinguish in relativistic astronomy between DRS and KRS. Absence of kinematical rotation of any RS means that the transformation between the spatial axes of this RS and generating DRS of more high level contains no rotation terms. With respect to the DRS of the same level such a KRS rotates with the angular velocity of the relativistic order of smallness. KBRS, KGRS and KTRS differ from DBRS, DGRS and DTRS by the amount of galactic ($c^{-2}\dot{F}^i_G$), geodesic ($c^{-2}\dot{F}^i$) and topocentric ($c^{-2}\dot{\mathcal{F}}^i$) precession, respectively. For astrometric purposes one introduces the systems GRS^+ and TRS^+ rotating (at the average) with the Earth with the angular velocities $\hat{\Omega}^i_D$ and $\tilde{\Omega}^i_D$ with respect to DGRS and DTRS, respectively. GRS^+ rotates with respect to KGRS with the angular velocity $\hat{\Omega}^i_K = \hat{\Omega}^i_D - c^{-2}P_{ij}\dot{F}^j$ with P_{ij} being the (Newtonian) orthogonal matrix of spatial transformation from GRS to GRS^+. Similar relation holds for $\tilde{\Omega}^i_D$ and $\tilde{\Omega}^i_K$.

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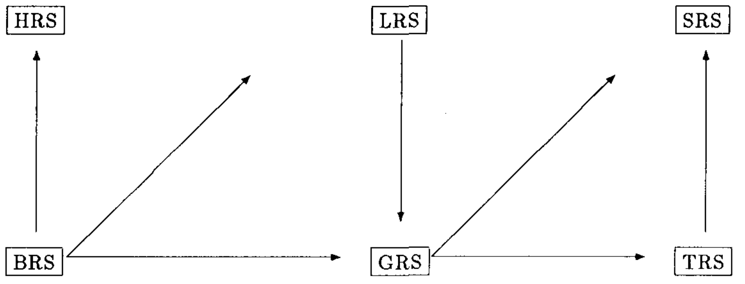
Fig.3. Hierarchy of Relativistic Reference Systems for Solar System Astronomy



This hierarchy includes solar system barycentric RS (BRS), heliocentric RS(HRS), Earth-Moon local RS (LRS), geocentric RS (GRS), topocentric RS (TRS) and satellite RS(SRS). The first four systems are used for the representation of motion of the solar system bodies. The last two systems are suitable for the description of observations made by a ground observer (TRS) or on board of an Earth satellite (SRS). Construction of all systems is based on three main principles: (1) using of one and the same coordinate conditions, (2) compatibility with the principle of equivalence involving the representation of the external mass influence only in the form of tidal terms, and (3) absence of dynamical rotation, i.e. non-existence of Coriolis and inertial terms in the metric of RS

Fig.4. Relativistic Time Scales

	1976	1991	?
	TDT	TCB	TCB
Time	TDT	TCG	TCG
Scales	TAI	TAI	TAIM
	L_c	-	-
Attributes	L_G	L_G	-
	-	TT	-
	geoid	geoid	-

1976 time scales involve two ill-defined constants L_C and L_G and vague defined notion of the geoid. 1991 time scales remove L_C but still retain L_G, the auxiliary time scale $TT(= TDT)$ and the notion of the geoid. It may be possible in future to remove all these attributes introducing TAIM (TAI modified) as the physical realization of TCG (just as TAI represents now the physical realization of TT)

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