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Discussion on time rule out of the Earth

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Abstract

Time is a common metric across boundaries and cultures. To mitigate the influence of relativity effect on time measurement and time unification in wide areas out of the earth, a new time rule is brought about. The deep exploration of the Mars, the Jupiter and other asteroid in the past, employed an independent time system without considering time unification between different subsystems. For the vast space area, the current time rule which applies for the earth ground and the adjacent areas has to be optimized. In this paper, the meaning of time rules is introduced. With Regards to the outer space area, two time concepts depicting the relationship between time and space, and two modes to unify time are brought about. The absolute and relative time viewpoint are discussed here and a proposal to establish a space time keeping system is given.

1. Preface

The collection activity of *Major Cutting-edge Scientific Issues and Engineering Technical Problems in 2021* has been held by China Association for Science and Technology, where the topic *Is there a rule to unify time out of the Earth？*is selected as one of ten major scientific issues. The fundamental importance of time is well recognized in sectors including finance and trade, power regulation, transportation, communication, aerospace, automatic industry and so on. The current time convention applies to the ground earth space and its adjacent area but is not appropriate for the vast universe. During the mission of planetary exploration in solar system or transplanetary travel, the X-ray of pulsar could be used as an intrinsic standard signal for space navigation known as pulsar navigation. So, to build a primary time standard system becomes a premise for pulsar navigation. On the other hand, to build the network connecting the Lunar base, Mars base and spacecrafts, a decentralized time metrology and system is needed. The rule of time is a concept with a greater scope covering primary time standard system, time metrology and its application framework.

In this paper, a conclusion is deducted that time rules out of the Earth is based on the current time convention on the Earth ground，and on this basis, the Space Time Keeping System (STKS) is built.

2. What's the meaning of time rules?

Time rules refer to ways of time measuring and counting for unification, also known as time metrology. Three elements are necessary for time rules: two conventions and a counting scale, as shown in figure1.

The first convention is time unit, which is the basic scale of time intervals, also known as length of second and time scale. At the 13th CGPM in 1967and 26th 2018, the SI unit of measure for time was defined as the duration of 9 192 631 770 cycles of radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom[1]. The new 7 constants in SI system, $\Delta\nu_{Cs}$ is the only conventional constant based on the frequency of caesium atomic clock with the Earth common rotation cycle as a parameter observed around 1950. As long as the SI second is defined as a constant, it is actually a convention of the human society[2]. The SI second is no longer defined by observation, neither it is limited on the Earth ground. Time unit was defined using data in astrological observation and is defined using precise optical frequency standard through representation and dissemination.

The second convention is the beginning of time, known as the reference origin or the initial epoch. It includes the origin of the time axis, the beginning or turning of the calendar cycle, like the beginning of a year and division of day and night. The initial epoch of Gregorian calendar used today is a religious conventional epoch and is used as reference in other time systems.

The counting scale is the calendar, which tells us the specific scale of time calculation. It is also used to describe the rhythm of nature. On the Earth ground, we use day as the basic scale of the Earth self-rotation. And UT is used to describe the change of the Earth's common rotation and self-rotation. And leap second, leap month, and leap year are ways to coordinate the non-integer rhythm of nature in the time axis to get a uniformed cycle. For example, leap year coordinates the difference between cycles of the common rotation and self-rotation of the Earth, leap month coordinates the difference between cycles of the common rotation of the Earth and the observation of the moon shape, leap second coordinates the difference between cycles of the Earth's self-rotation and the transition cycle of quantum energy level of Cs. The calendar unit of "year-month-day" on the Earth ground could describe the motion of the Earth planet but not appropriate for other celestial bodies. The only second unit is a general time unit which is a foundation of time unification between different celestial bodies.

Then, how can we achieve time unification out of the Earth planet? Like on the Earth ground, the rhythm of celestial bodies should be taken into consideration and a new time rule should be established based on the theory of general relativity.

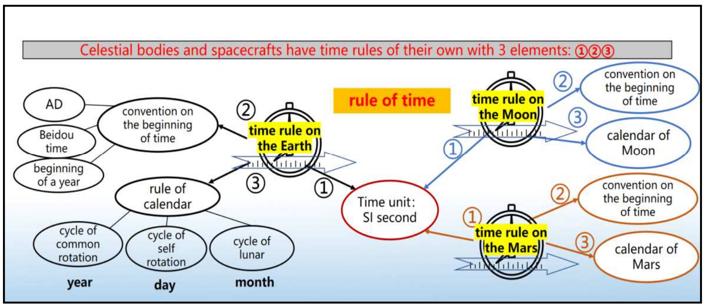

Figure 1. Time's rule has three element: ①time unit ②reference origin ③calendar

3. Time description under GR frame

3.1 Principle of General Relativity

The theory of general relativity (GR) depicts laws and principles of curved time and space in local inertial coordinate systems[3]. And two concepts on time illustrating the relationship between time and space were proposed: proper time and coordinate time.[4] In space, different location has different proper time but a unique coordinate time. [5]

Space and time are indispensable. As is stated in the principle of general relativity said by Einstein: all coordinate system are equivalent with respect to the formulation of the fundamental laws of physics. This underpins our understanding of the theory of general relativity. Assume every individual as an independent coordinate system, one gets his own local coordinate, and fundamental laws of physics applies well right in itself system. However, for observers in different local coordinates, they would find the space and time curved because of the influence of relativity effect. So, synchroneity only makes sense when both of the comparators are in the same coordinate. For comparators in different coordinates, synchroneity does not apply anymore[6].

3.2 Proper time

Proper time in theory of relativity is the time measured at the exact location where the event happens, so called local proper time or inherent time. It is a time measured in SI seconds and is an objective and real physic quantity which could be measured directly.

According to the Schwarzschild metrics, the relationship between the proper time and coordinate time could be expressed as:

$$\Delta t = \int_{\tau_0}^{\tau_0+\Delta\tau}\left(1+\frac{U}{c^2}+\frac{V^2}{2c^2}\right)d\tau \qquad (1).$$

Where: t is coordinate time in seconds; τ is proper time in seconds; Δt is interval on coordinate time axis in seconds; $\Delta\tau$ is interval in seconds on proper time axis; U is the gravitational potential at local; V is the relative speed to the origin of coordinate; c is the speed of light as a constant in m/s.

Time measured in SI seconds on geoid, the proper time on geoid, is TAI. Then, how do we measure the time on other places besides the geoid? Here, two ways are usually used. One is keeping SI second unit to get local proper time τ, and then transformed to coordinate time of t using formula (1), with known parameters of geographic position, latitude, gravitational potential where the clocks located, and the TCG (Geocentric Coordinate Time) which is the coordinate time on the mass centric of the Earth planet could be achieved.

The other way is time service. For clocks out of the geoid surface, or clocks where its geographic location parameters unknown, time unification is achieved by dissemination of time in a way that time-keeping centers send standard time and all the other timing devices keep synchronized to it, abandoning their own local proper time.

3.3 Coordinate time

Coordinate time is the time measured at the origin of the coordinate or at the infinity in inertial coordinate systems in SI seconds, where the gravitational potential is zero and the relative velocity to the origin is zero, thus the influence of relativity effect could be neglected. In formula (1), is U=0, and V=0, then Δt=$\Delta\tau$. And the proper time at the two special points are coordinate time.
The pulsar is so remote from the solar system, so its proper time could be used to represent the coordinate time.

Coordinate time is a variable depending on where the coordinate system located. Different coordinate systems has different coordinate time, and TCG is the coordinate time of Geocentric Coordinate system, and TCB (Barycentre Coordinate Time) is the coordinate time of Barycentre Coordinate system. For some celestial bodies, to build a local time keeping system of its own, they need to define their own coordinate time.

4. Two modes for time unification

4.1 To keep time at centre, and to disseminate time to local

Time unification on the Earth ground and near-earth orbit adopts a mode that is “To keep time at centre, and to disseminate time to local”.[6]There are nearly 80 time keeping centers with more than 400 atomic clocks near the geoid that represent the SI unit second by atomic clocks to measure the local time AT. BIPM produces TAI by averaging and weighting local AT from worldwide. Combining TAI and UT1, and introducing leap seconds, the UTC (Coordinated Universal Time) was officially published. This is to keep time at centre. For other timing devices or atomic clocks not used for time-keeping, they adjusted their time pace to synchronize with the standard time, so called time dissemination to local.

The simple time dissemination method does not work out of the Earth. Firstly, the transmission delay is changing. For example, the distance from the Mars to the Earth is about 55 M km at the nearest and 400M km at the farthest. The delay time is changing approximately between 6min to 22min for just one way. Secondly, Doppler effect makes the time dissemination interval unequal. Thirdly, as theory of Space Metrology[7] illustrates, time simultaneity is a confined concept for clocks in the same coordinate. The time rule on the Earth ground only works in the Geocentric Coordinate system. Only when we abandon the absolute time viewpoint, could we achieve time unification between different local coordinate systems.

4.2 To keep proper time to local , and coordinate time to wide area

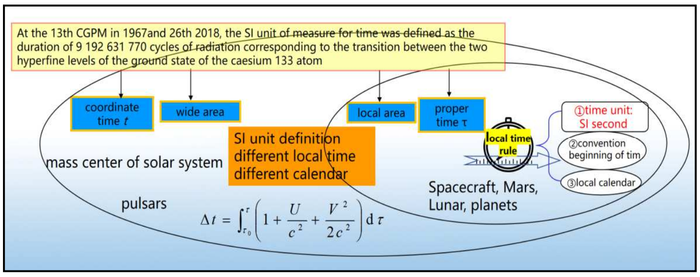

Figure 2. Space time keeping mode of “To keep proper time to local , and coordinate time to wide area”

To achieve time unification between different mass centric coordinates, the equivalence principle based on the theory of general relativity should be adopted. Each local coordinate could have its own time rule, acquire local proper time using cesium atomic clock in SI seconds. Planets and spacecrafts could have their own time epoch and calendar, making their own local time rule. To achieve time unification between local areas, a coordinate works in a larger scale should be adopted, so called wide area.

At the far infinity, the pulsar could be used to replace clocks at the origin of the coordinate. Time unification in wide areas could be achieved by measuring pulsar, so called coordinate time to wide areas. And figure 2 shows us the space time keeping mode of “To keep proper time to local , and coordinate time to wide area”.[8]

5. Two viewpoints of time

5.1 Absolute time viewpoint

Those holding the absolute time viewpoint thinks that the standard time is unique, and time unification could be achieved through dissemination of time, synchronizing to the standard time, and that time is no relevance with coordinates and only clocks on the geoid could represent standard time in SI seconds. Even the effect of relativity is taken into consideration, clocks showing different time should be synchronized to the standard time by adjusting its own pace. Time intervals on axis of standard time is regarded as even. The time lag between standard and the disseminated ones is clock bias model[9]. If its time scale is different from time service signal, the clock should be adjusted its scale. This bias is influenced by the effect of relativity, and with this bias taken into consideration[10], the formula (1) could be changed as:

$$\Delta t = \Delta\tau' + \int_{\tau_0}^{\tau'}\left(\frac{U}{c^2}+\frac{V^2}{2c^2}\right)d\tau' = \Delta\tau'\left[1+o(c^{-2})\right] \quad (2).$$

Here, Δt is the time interval on time axis of standard time, so called standard dissemination time intervals in seconds; $\Delta\tau$’ is time intervals measured of clocks taken the disseminated signals in units different from SI second; U is the gravitational potential where the clocks located; V is the velocity of the clock; c is the constant speed of light in m/s; $o(c^{-2})$ is a variable relative to c^{-2} as the effect of relativity.

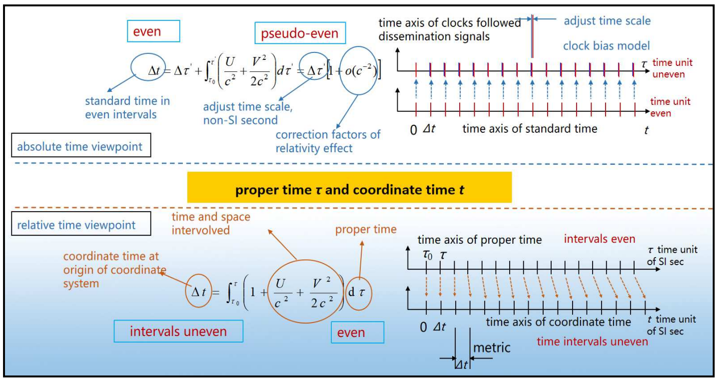

Figure 3. Understanding of time intervals from absolute and relative time viewpoint.

The time mode adopted on the service application layer in Space-based time system GNSS is the traditional time unification mode, the absolute time viewpoint.

5.2 relative time viewpoint

The relative time viewpoint is based on the principle of relativity for space-time.[11] Standard time is not unique. Each local area assume itself time intervals of proper time as even but observers in different local coordinates get uneven measurement results from each others so called standard dissemination or time service. That is how the equivalence principle works. So coordinate time and proper time are not comparable[12].

The essence of relative time viewpoint is based on the equivalence principle of general relativity. The indispensability of time and space is the foundation of understanding this viewpoint. With the three elements of time rule, time unification out of the Earth could be achieved. Firstly, the convention of SI second could be used both in coordinate time in wide areas and proper time in local areas. Secondly, the choice of time epoch and its definition is closely related with the coordinate of space and time. We appoint pulsar's initial epoch as a special epoch when the pulse named number 0 arrives the origin of barycentre of solar system, and then following pulses have sequential number. finally, the relative time viewpoint breaks the limitation of current calendars, and proposes that calendars are ways to depict the rhythm of nature. The traditional mode of "year-month-day-hour" is just appropriate for space on the Earth ground. And each celestial body could have its own calendar. For celestial bodies and spacecrafts in inertial motion, their orbit parameter such as location, velocity and gravitational potential are periodic parameters. And their period should be indexed by their local proper time. By checking the calendar with variables of U and V, the index of the calendar is the time axis of the local proper time. In the future, with the exploration of outer space, the aerospace industry will play a greater role and provide more guide in defining calendars for the universe.

6. Summary

A new time rule is needed for space out of the Earth. The current time rule has been extended to the adjacent space such as GNSS time system. Resolutions since IAU 1991 extend the standard time to the Earth centered coordinate system and further to the barycentric coordinate system, considering the relativity effect[13]. Subscribers could apply the barycentric time on any locations in space and use standard Earth time for the unification of the whole solar system. Resolutions of the IAU provide a theoretic foundation for time unification in outer space based on Earth ground observation. For example, we could get TCB through observation of pulsar.

However, the application and realization of such a method relies on the parameters of geoid and is not appropriate for vast space of solar system. Time dissemination is not convenient and engineering realization becomes impossible. From a more rigorous perspective, it goes against the equivalence principle. For the whole solar system, based on the relative time viewpoint, to build a time unification rule across different local areas, a concept of Space Time-Keeping System (STKS) is proposed by paper[6]. We use cesium atomic clock to measure proper time and pulsar to measure centric coordinate time. By a series of transformation, the coordinate time at the origin of the barycentric coordinate system could be used for time unification. Time rule out of Earth is based on the current time rule on the earth ground , covering a larger area, with higher precision and better stability. And this is the foundation of building STKS. The Earth planet could be seen as a local area or a classic case of a local area connecting with the wide area. Thus it innovates and develops the traditional theory of time rule rather than denying our historic achievements.

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