Report of the IAU Working Group on Coordinated Universal Time (UTC)

Executive Summary

The IAU Working Group on the Redefinition of Coordinated Universal Time (UTC), after considering issues that have the potential to affect the astronomical community, is unable to reach a conclusive recommendation regarding a proposal to eliminate occasional one-second adjustments to UTC. Opinions exist that both support and oppose the proposal, and there is no possibility of reaching an undivided opinion. The Working Group understands that the majority of astronomers lack strong opinions on the subject. Relevant arguments are outlined in this report. Past correspondence between the IAU and the Radiocommunication Sector of the International Telecommunication Union (ITU-R) on this issue, as well as past formal IAU actions regarding Universal Time, are also included.

Consequently, the Working Group recommends that the IAU respond to the ITU-R by stating that the IAU is not in a position to formulate a conclusive opinion regarding any change in the definition of Coordinated Universal Time. Nevertheless, in the event of the deletion of future leap seconds the name of the scale should no longer reference the astronomical time scale “Universal Time” to avoid technical confusion, and a time interval of at least five years between adoption and implementation should be allowed.

Specifically, it recommends that:

1. The IAU express to the ITU-R its gratitude for being asked for its opinion
2. The IAU express to the ITU-R
    a. that, as most astronomers are not affected directly and are accustomed to the current definition of UTC, they lack an opinion on a possible change,
    b. that, considering the diverse interests of a small number of specialized astronomers, consensus concerning a redefinition of UTC among them is unlikely,
    c. that, considering operational astronomical applications primarily, the IAU can neither favor nor oppose the deletion of leap seconds from UTC,
    d. that the word “universal”, and by extension the abbreviation “UT”, is appropriate only for a time scale that is linked to the rotation of the Earth, and would no longer be appropriate if leap seconds were to cease,
    e. that, if a continuous reference timescale is adopted, at least 5 years of lead time is required for re-education and changes to legacy software and data storage formats,
    f. that a different name be considered for a new time scale,
    g. that the IAU continue to be represented in future discussions relating to time scales.
3. The IAU urge its members to develop astronomical software that requires precise Earth orientation information to use Earth orientation data provided by the International Earth Rotation and Reference Systems Service (IERS).
4. The IAU request that the IERS investigate more widely distributed and technologically useful means of providing Earth orientation information.

With the acceptance of this report, the Working Group sees no further need for its continued existence.

Members of the Working Group: Felicitas Arias and Dennis McCarthy (Co-chairs), Daniel Gambis, George Kaplan, Yasuhiro Koyama, Dick Manchester, Robert Nelson (deceased), Masatoshi Ohishi, Arnold Rots, Rob Seaman, Ken Seidelmann, and Shougang Zhang

Background. The Working Group was formed following the XXVIII IAU General Assembly in Beijing in 2012. Its mission is to prepare a proposed response of the IAU to the Radiocommunication Sector of the International Telecommunication Union (ITU-R) in reply to that organization's request to the IAU for comments regarding the possible redefinition of Coordinated Universal Time (UTC). The 2015 World Radiocommunication Conference (WRC-15) agenda item 1.14 is scheduled to "consider the feasibility of achieving a continuous reference time scale, whether by the modification of UTC or some other method."

In 1970 the predecessor organization of the ITU-R (i.e., the International Consultative Committee for Radio (CCIR)), adopted the current definition of UTC which calls for the insertion of leap seconds, beginning in 1972, to maintain UTC within 0.9 seconds of UT1, a quantity that measures the rotation angle of the Earth in the celestial reference system. The modification of this definition has been under discussion in the ITU-R Study Group 7 for well over a decade and has resulted in many reports and commentaries. During that time the IAU also considered the issue. Annex 1 is the Report of the IAU Working Group (2005); Annex 2 is the IAU Letter to ITU-R (2006); Annex 3 is the IAU Commission 31 Report (2010); Annex 4 is the IAU Response to ITU-R Questionnaire (2011); Annex 5 is a statement by the (then) IAU Secretary General, Ian Corbett, on that response to the questionnaire (2011); Annex 6 provides a brief history of past IAU General Assembly statements regarding Universal Time. These documents indicated that establishing a distributed time scale without leap seconds would have little or no negative operational impact on the astronomical community provided that sufficient lead time was provided in order to accommodate changes in software and data storage formats. The IAU statements in Annex 6 are consistent with similar statements made by the International Meridian Conference in 1884 (*Resolution 5*), the Consultative Committee on the Definition of the Second (CCDS) in 1974 (*CCDS Recommendation S-1 (1974)*), the General Conference of Weights and Measures (CGPM) in 1975 (*Resolution 5 of the 15th CGPM*), the International Consultative Committee for Radio (CCIR) in 1975 (*CCIR Recommendation 536*), and the World Administrative Radio Conference (WARC) of the International Telecommunication Union (ITU) in 1979 (*Final Acts of the World Administrative Radio Conference (WARC-79)*). This Working Group has not established the seriousness of negative impacts, but nonetheless acknowledges that substantial lead time would be required regardless of the presumed degree of negative impact.

Discussion. The Working Group has prepared this report to reflect technical concerns of astronomers regarding a change in the definition of UTC under the assumption that the ITU-R will consult responsible experts in other fields for their comments.

The astronomical community has many diverse areas of interest and specialties. The large majority of modern astronomers are generally not concerned, or knowledgeable, about various aspects of fundamental astronomy, including time scales and reference systems. Consequently the majority of the IAU membership is not in a position to formulate a conclusive technical opinion regarding any change in the definition of UTC.

Some IAU members concerned with specialized applications related to navigation, satellite communication, electronic network synchronization and timing standards laboratories, regard leap seconds as an unnecessary expense. These adjustments cannot be predicted with certainty, and they can create confusion for those applications requiring precise time. On the one hand, from an astronomical point of view there appears to be no strong argument for any change to the status quo, which currently provides a means to obtain low-precision Earth orientation information (1 second of time equivalent to 15 arc seconds). On the other hand, since a well-established organization (the International Earth Rotation and Reference Systems Service, IERS) exists within

the IAU reporting Earth orientation information (including predictions) routinely with precision at least five orders of magnitude better than that available through UTC, there is no longer a need to use UTC as a source of Earth orientation information. Some members dealing with the provision of precise time through national institutions and needing long-term stable time scales recognize a need for a uniform time scale and favor a change from the current system that requires occasional expensive adjustments to timing equipment.

Other astronomers concerned with the definition of UTC include space scientists, almanac producers, and those involved in the management and operation of observing instrumentation such as telescopes, antennas, and instruments. They use software and procedures in which the current definition of UTC is embedded. The elimination of leap seconds does not simplify requirements for Earth orientation information in these applications. Some astronomical systems, particularly robotic or automated observatories already fielded or in development, would be adversely affected by the elimination of leap seconds. Observational data archives also make use of UTC time markers. Any change to the current definition will require expensive searches through existing documentation and software to identify and change existing code and data storage formats to accommodate a new definition. The IAU Working Group urges at least five years lead time to allow time to make necessary changes if the definition of UTC is changed. Such lead time is also necessary to inform users of the changes that will be necessary.

Related Issues

Alternate Time Scales No proposed methods for “achieving a continuous reference time scale, whether by the modification of UTC or some other method” have received unanimous support within the Working Group. A suggestion receiving limited support is the potential international distribution of two separate standard time scales, one providing time linked to the Earth’s rotation as is the case now with UTC, and one freed from that constraint (*e.g.* International Atomic Time TAI), as multiple scales are already being employed in some astronomical applications. The working group reached no consensus regarding the desirability of distributing two separate standard time scales.

Nomenclature Another issue is the name of a re-defined scale. The descriptor “Universal” in the term “Universal Time” arose in the later part of the 19th century, when the only source of time was based on the Earth’s rotation, to refer to the definition of a “universal day” that would be independent of location. Following developments in timekeeping in the years since, the term “Universal Time” has been applied to (1) time based on the mean solar day beginning at midnight along the meridian of Greenwich, as recommended by the IAU in 1928, (2) time scales based on the rotation of the Earth with respect to fictitious points defined in adopted celestial reference systems, (3) atomic time scales with internationally adopted adjustments in frequency and epoch aimed to match the Earth’s rotation, and (4) the atomic time scale encoded to provide Earth rotation information. See Annex 6. The word “Coordinated” was first used in 1960 when U. S. and U. K. began to “coordinate” adjustments in their clock time scales. In all these applications the word “universal”, and by extension the abbreviation “UT”, has been preserved to describe a time scale that is linked to the rotation of the Earth. There is no compelling technical reason to maintain the label “Coordinated Universal Time” for a time scale that is not linked to the rotation of the Earth. The nomenclature issue raised by the proposed change in the definition of ‘Coordinated Universal Time’ was also discussed in a statement by the ISO’s Technical Committee 37 to the previous ITU Radio Assembly (January 2012).

Continuous Reference Time Scale. The ITU-R Radiocommunications Sector asked the IAU for input on a "continuous reference time-scale". Although the IAU WG on UTC does not know of a definition for that term, the following properties provide a reasonable concept:

1) time markers with intervals as uniform as current technology allows
2) time markers with values such that the time interval between any two markers is trivially obtained by subtraction without need for a lookup table

The non-uniformity of Universal Time is a long-studied phenomenon. If the two points above are properties of the time scale desired by the ITU-R then no form of Universal Time can satisfy them.

General astronomical software and archival data. The elimination of future leap seconds does simplify the requirements for general astronomical processing and analysis software. However, any tools required to handle archival data must continue to accommodate leap seconds; the only change in this respect is that the leap second table will not change anymore.

Civil Time and Mean Solar Time. A distributed time scale based only on the SI second, without leap second adjustments, would slowly diverge from UT1, which is considered to be nominally equivalent to mean solar time reckoned from midnight on the meridian of Greenwich. Traditionally, mean solar time has been the basis for civil time, and UTC as currently defined has been considered an acceptably accurate surrogate for civil purposes. Considering the current deceleration of the rotational speed of the Earth, we might expect the divergence resulting from the deletion of leap seconds to amount to approximately 2 minutes in 100 years."

Summary. Most astronomers are not affected directly and are accustomed to the current definition of UTC; consequently, they likely lack an informed opinion on changing the status quo. Considering the diverse interests of other specialized astronomers, consensus concerning a redefinition of UTC is unlikely.

Recommendations of the Working Group to the IAU

The Working Group recommends that:

1. The IAU express to the ITU-R its gratitude for being asked for its opinion
2. The IAU express to the ITU-R
    a. that, as most astronomers are not affected directly and are accustomed to the current definition of UTC, they lack an opinion on a possible change,
    b. that, considering the diverse interests of a small number of specialized astronomers, consensus concerning a redefinition of UTC among them is unlikely,
    c. that, considering operational astronomical applications primarily, the IAU can neither favor nor oppose the deletion of leap seconds from UTC,
    d. that the word "universal", and by extension the abbreviation "UT", is appropriate only for a time scale that is linked to the rotation of the Earth, and would no longer be appropriate if leap seconds were to cease,
    e. that, if a continuous reference timescale is adopted, at least 5 years of lead time is required for re-education and changes to legacy software and data storage formats,
    f. that a different name be considered for a new time scale,
    g. that the IAU continue to be represented in future discussions relating to time scales.
3. The IAU urge its members to develop astronomical software that requires precise Earth orientation information to use Earth orientation data provided by the International Earth Rotation and Reference Systems Service (IERS).
4. The IAU request that the IERS investigate more widely distributed and technologically useful means of providing Earth orientation information.

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Annexes

1. **Report of IAU Working Group (2005)**
2. **IAU Letter to ITU-R (2006)**
3. **IAU Commission 31 Report (2010)**
4. **IAU Response to ITU-R Questionnaire (2011)**
5. **Statement by Ian Corbett Regarding the ITU Questionnaire (2011)**
6. **References to Universal Time from Past IAU General Assemblies**

Annex 1: Report of IAU Working Group (2005)

REPORTS ON ASTRONOMY 2002-2005
IAU Transactions XXVIA, 2005
O. Engvold (ed.)

DOI: 00.0000/X000000000000000X

Division I Working Group on "Definition of Coordinated Universal Time"

CHAIR: Dennis, D. McCarthy
MEMBERS: F. Arias, W. Dick, D. Gambis, M. Hosokawa, W. Klepczynski, S. Leschiutta, J. Laverty, Z. Malkin, D. Matsakis, R. Nelson, J. Vondrak, P. Wallace, N. Capitaine (ex officio), T. Fukushima (ex officio)

1. Background

The definition of UTC was implemented in 1972, principally to accommodate celestial navigation and follows recommendation 460 of the International Radio Consultative Committee (CCIR) in 1970. Since 1972 the use of electronic means to navigate has overtaken celestial navigation. This fact along with increasing public dissatisfaction with the possible disruption to modern electronic communications and navigation systems caused by the insertion of a leap second has called into question the current definition of UTC. An extensive review of the background and issues relating to the leap second can be found in Nelson, et al. (2001).

In 2000 the International Telecommunications Union-Radiocommunication Sector (ITU-R), the follow-on organization to the CCIR, adopted Question 236/7 "Future of the UTC Timescale" for discussion and possible future action. The issues addressed in this question were:

1. What are the requirements for globally-accepted time scales for use both in navigation/telecommunication systems, and for civil time keeping?
2. What are the present and future requirements for the tolerance limit between UTC and UT1?
3. Does the current leap second procedure satisfy user needs or should an alternative procedure be developed?

The Question stipulated that results of the above studies should be included in recommendation(s), and that the above studies should be completed by 2006. It further required that this Question should be brought to the attention of the International Earth Rotation Service (IERS), now called the International Earth rotation and Reference system Service, and other international organizations.

The question, which originated with ITU-R Working Party 7A (WP 7A) (Time Signals and Frequency Standard Emissions) of Study Group 7 (Science Services), was referred back to them for action. In response, WP 7A created a Special Rapporteur Group (SRG) to help stimulate studies by Sector Members and gather information for the Working Party on possible recommendations. The SRG met in December 2000, March 2001, May 2001, December 2001, and March 2002. A general lack of interest both within and outside the timing community prompted a special colloquium on the subject hosted by the Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN) in Torino, Italy in 2003. During this time independent surveys on the topic were also conducted by the IERS, The International Union of Radio Sciences (URSI), the Communications Research Laboratory of Japan (CRL), and the National Institute of Standards and Technology of the USA (NIST). The SRG presented a summary overview (primarily conclusions) to the CCTF

Annex 1: Report of IAU Working Group (2005)

meeting in May 2004 and a summary report at the ITU-R WP 7A meeting in September, 2004. At that meeting the U.S. ITU-R Working Party 7A proposed a recommendation to modify the definition of UTC so that, in the future, adjustments would be made to keep the difference between UTC and UT1 within one hour.

The International Astronomical Union (IAU) Working Group on the Definition of Coordinated Universal Time was created in compliance with IAU Resolution B2 of the 24th IAU General Assembly. The members were F. Arias, W. Dick, E. Fedoseev, D. Gambis, W. Klepczynski, S. Leschiutta, J. Luck, Z. Malkin, D. Matsakis, P. Paquet, J. Vondrak, P. Wallace, and S. Ye. D. McCarthy served as Chairman of the Group and as IAU representative to the ITU-R Special Rapporteur Group (SRG) on the Definition of Universal Time.

At the next IAU General Assembly it was decided to extend the lifetime of the Working Group to formulate a draft response to the possible recommendation of the ITU-R. The membership was revised at that time, and its new members are F. Arias, W. Dick, D. Gambis, M. Hosokawa, W. Klepczynski, S. Leschiutta, J. Laverty, Z. Malkin, D. Matsakis, R. Nelson, J. Vondrak, P. Wallace, N. Capitaine (ex officio), and D. McCarthy (chair). Its response to any official action by the ITU is to be submitted through Division 1 to the General Secretary for IAU approval.

2. Options Discussed

Options that have been discussed for the future of UTC include:

1. Maintain the status quo
2. Increase the tolerance between UT1 and UTC
3. Periodic insertion of leap seconds
4. Variable adjustments in frequency
5. Redefine the second
6. Substitute TAI for UTC
7. Discontinue leap seconds in UTC

None of the options beyond (1) has received significant acceptance in discussions and surveys to this point. Also discussed has been the feasibility of establishing a low-cost, low-precision UT1 service for any applications that need approximate mean solar time. The Internet would be a possible way to accomplish this and the IERS is taking steps to implement that service.

3. Issues

In the time since the ITU-R adopted Question 236/7 it is clear that analyses of Earth rotation lead to the conclusion that, at some future point, multiple leap seconds per year will be required to maintain the currently defined tolerance between UT1 and UTC. While advances in telecommunications, navigation and related fields are moving toward the need for a single, internationally recognized uniform time scale, no overwhelming consensus has emerged regarding maintaining the status quo until change is essential or actively seeking an alternative in anticipation of that change.

Continuation of the current definition has also led to concerns regarding the timing sequence to be followed during the actual implementation of a leap second. The convention is to number the leap second with the label "60" in the minute in which it has been inserted. Unfortunately many timing systems do not permit a second to be labeled "60." In the past, this may have resulted in 2 seconds labeled 59 or even a second without a label. A conventional means to resolve this problem has not been adopted.

Annex 1: Report of IAU Working Group (2005)

Yet another concern is that the traditional model of generating internal system time scales for operations could produce multiple de facto time scales. These "pseudo time scales" could lead to confusion and potentially serious consequences.

On the other hand some members of the astronomical community have expressed concerns over any change to the current system. These concerns are based on existing software that takes advantage of the current definition and uses UTC as a substitute for UT1. Their requirements for precision are such that the current 0.9-second tolerance is adequate, and their software has been designed accordingly. Should the definition of UTC be modified in any way that would permit this tolerance to be exceeded, they would anticipate substantial cost to make non-trivial changes in existing software. Similarly, the astrodynamic community has similar concerns regarding legacy software used in the determination of orbital parameters of artificial satellites that again utilizes UTC as a substitute for UT1.

However, although UT1 is expressed as a time, it is not used practically as a time scale. It is used as an angle that is related to the rotation angle of the Earth in the celestial reference frame. Knowledge of UT1 is essential in relating celestial and terrestrial reference systems and is obtained observationally for that purpose. The IERS provides daily values and predictions for up to a year in the future. It is conceivable that the systems served by legacy software based on the current UTC definition could benefit from using more realistic values for UT1 as opposed to the UTC approximation.

The reference of UTC to UT1 does provide a means to keep UTC vaguely in synchronization with the position of the Sun in the sky. It is generally agreed that a change in the definition of UTC that would cause time of day to depart from a solar connection would be unacceptable.

4. Torino Colloquium

Although there was no overall consensus, findings from the official report of the Torino Colloquium, held in 2003, were the following.

1. The definition of UTC is likely to need to be changed from the current UTC standard by the dynamics of the Earth and a means of transitioning to a uniform time scale could be accomplished by the creation of another time scale that might be called Temps International (TI) to clearly distinguish it from solar time.

2. If a change were to be made, a date suggested to inaugurate that change could be 2022, the 50th anniversary of the institution of the UTC timescale. This date was influenced by the anticipated lifetimes of existing systems that would be expensive to change.

3. TI would likely be a continuous atomic time scale, without leap seconds, synchronized with UTC at the time of transition.

4. The responsibility for disseminating UT1 information should remain solely with the IERS.

5. Special Rapporteur Report

Following the Torino Colloquium and after further discussion, the SRG prepared a summary report outlining a possible transition to a new definition of UTC. The final report of the SRG was submitted to ITU-R Working Party 7A. It contained the following recommendations that were presented at the 16th CCTF meeting, May 2004.

1. The creation of a new name was not recommended because it would add significant complications in the process of defining a new time scale. A name change alone could

Annex 1: Report of IAU Working Group (2005)

cause great confusion and complications in the ITU-R process and systems attempting to implement the new standards.

2. The radio broadcast of DUT1 information should be discontinued since UT1 is available via IERS. The general availability of internet data services for both transmission of correction parameters as well as actual timing information may well satisfy the needs of the astronomical and satellite orbit determination communities.

3. The redefinition of a new "UTC" is not necessary

4. Divergence from solar time, a possible issue in "civil" timekeeping is considered to be insignificant as the difference of approximately 1 hour would take until 2600 to accumulate. A step adjustment at that time could maintain approximate agreement for some similar period thereafter. It is very probable that advances in time keeping may lead to other solutions before the first correction is necessary.

5. The recommended date for change is not later than 2010.

6. Recommendation Proposed to ITU-R WP-7A

In order to work toward a final decision on the matter, and because formal proposals must be submitted by sector members, the U. S. submitted a proposed revision to ITU-R TF.460 in September, 2004. In that proposed recommendation the Operational Rules for the formation of UTC after 0000 UTC December 21, 2007 would be modified so that the difference of UT1 from UTC should not exceed 1 hour. It further proposed that adjustments to the UTC time scale should be made as determined by the IERS to ensure that the time scale remains within the specified tolerances and that the IERS should announce the introduction of an adjustment to the UTC time scale at least five years in advance. At the time of that announcement the IERS should provide directions regarding the details of the implementation of the adjustment. The recommended broadcast of DUT1 would be discontinued upon acceptance of the recommendation. Analysis of historical observations of the Earth's rotation currently indicates that such an adjustment would not be required for at least 500 years.

This Recommendation was not adopted by the Working Party largely because of the lack of agreement on any proposed date for implementation. However, it was accepted as a draft ITU document for future discussion, and the Chairman of the SRG was requested to distribute the document for comments.

7. Future

Discussion continues on this subject within the IAU Working Group. The membership has completed an internal survey of their opinions relating to the issues. A compilation will be presented in the final report of the Group at the IAU General Assembly in 2006. The ITU-R will consider the matter again in November 2005. A report on any actions in this matter taken at that meeting along with subsequent recommendations of the Working Group will be presented at the IAU 2006 General Assembly. If a formal recommendation is referred to ITU-R sector members in the future, the IAU will be expected to respond, and this Working Group will prepare a formal response for consideration by the IAU.

References

Nelson, R. A., McCarthy, D. D., Malys, S., Levine, J., Guinot, B., Fliegel, H. F., Beard, R. L., & Bartholomew, T. R. 2001 Metrologia, 38, 509

Annex 2: IAU Letter to ITU-R (2006)

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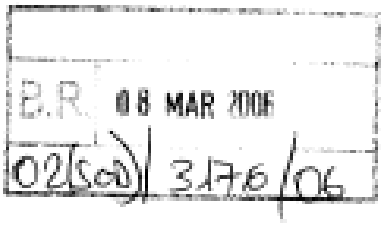

Mr. Alexandre Vassiliev
Counsellor for ITU-R SGD/SG3 & (SGD/SG7)
International Telecommunications Union
Radiocommunication Bureau
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CH-1211 Geneva 20
Switzerland

Paris, March 3rd, 2006

Dear Mr. Vassiliev,

In response to the letter of 7 December 2005 from Valery Timofeev, Director of the International Telecommunication Union Radiocommunication Bureau, regarding issues related to the implementation of the leap second on 31 December 2005, the International Astronomical Union (IAU) offers the following observations. These comments address the issues reported in the areas of navigation, communication, dissemination of precise time, and astronomical services.

The IAU is not aware of any significant problems encountered in navigational systems as a result of the leap second implementation in 2005. Sufficient lead time was provided by the announcement of the International Earth Rotation and Reference Systems Service (IERS) to enable system operators to test equipment prior to the event. The GLONASS navigational system was not available for 2.5 minutes beginning 1 minute after the insertion of the leap second, but at this point it is unclear if that outage was related to the leap second.

The IAU is not aware of any reports of significant outages in communications related to the insertion of a leap second on 31 December 2005. CDMA cell phone systems generally operate on a uniform time (GPS Time) free of leap seconds and need only to know the offset between their internal system time and Coordinated Universal Time (UTC) in order to provide time to their customers. Some cell phone companies failed to update to the new value following the leap second causing the wrong time to be displayed, but no outages were noted.

There were, however, reports of problems related to the transmission of precise time as a result of the leap second event. A low frequency radio station apparently indicated the insertion of the leap second in the wrong minute. A significant percentage of time transfer information provided by Network Time Protocol services was also affected. Some systems properly recorded the sequence of seconds, but others recorded two consecutive seconds labeled "59" or two seconds labeled "0." Some may have failed to indicate any label. This situation clearly calls for efforts toward the international standardization of Network Time

protocols. Some GPS receiving equipment designed to provide precise time apparently failed to record time properly at the time of leap second insertion. These receivers operated properly after they were re-started.

There were some issues reported that were related specifically to astronomical operations. At least one radio telescope engaged in very long baseline interferometry observations for the determination of Earth orientation failed to implement the leap second properly, causing a minor problem. Some other observational Earth rotation information was reported incorrectly and the GPS data reported to the International Global Navigation Satellite System Service (IGS) by a regional network was reported incorrectly by one second. Some software used to correlate VLBI observations experienced minor problems because it had not been tested for leap second compliance previously.

These observations represent only the information that has been made available publicly. There may well have been a variety of minor problems that have not been reported, for example with previously untested software.

In summary, the IAU community was not significantly affected adversely by any problems resulting from the insertion of the leap second on 31 December 2005. However, it should be noted that the testing of software and equipment was facilitated by the six-month lead time provided by the IERS notification. Also, it is important to note that a significant investment in personnel time and effort is required to prepare for the insertion of the leap second and to ensure that the actual event does not adversely affect astronomical observations.

The IAU is concerned with possible changes in the definition of UTC and has had a Working Group devoted to the topic since 2000. The Group is preparing a final report for presentation at the IAU General Assembly in August, 2006. I expect that topic will be discussed in depth at that time. The IAU would be happy to share the reports of those discussions with the International Telecommunications Union when they become available.

Sincerely,

Oddbjorn Engvold
IAU General Secretary

Cc.: Mr. Valery Timofeev
Radiocommunication Bureau (BR) Director

Annex 3: IAU Commission 31 Report (2010)

Dr Ian F Corbett
IAU General Secretary
IAU – UAI Secretariat
Paris

26 September, 2010

Dear Ian

Re: Advice from IAU Commission 31 on the submission to ITU on the issue of Leap Seconds in UTC

Following your request of 21 September for advice on the creation of a new definition of Universal Time Coordinated (UTC) with no leap seconds, I have consulted with the membership of IAU Commission 31 on this matter. In my letter to Commission 31 members, I stated that since the IAU Working Group 2006 report on this matter, opinion appeared to have shifted to favour a continuous UTC timescale with no leap seconds. I specifically requested a response from those who opposed this view. Despite the short time available, I received ten responses, three of which opposed the abolition of leap seconds. The others were in favour of moving to a continuous UTC timescale and this is my personal view as well.

The main arguments for retaining leap seconds were that the current system works well, most users of UTC were happy with it and that some applications where high accuracy was not required used UTC as a proxy for UT1 (which defines the rotational angle of the Earth).

The main arguments for a continuous UTC timescale were that astronomy and space applications require a uniform timescale of high accuracy for interpretation of data, prediction of the motion of celestial bodies and control of observatory facilities including spacecraft guidance. Many of these require an accurate timescale in essentially real time. Introduction of discontinuities in UTC at infrequent intervals has in the past caused some problems. Such discontinuities are generally felt to be more difficult to manage in astronomical applications than a slow continuous change in UT1 – UTC.

Of course, the issue of the divergence of UTC from UT1 is an important one. The IERS currently provides predictions of UT1 – UTC a few days in advance with precision of better than 1 ms in time and measurements within a few days with precision of tens of microseconds. Provided sufficient lead time on implementation of any change is given (five years has been suggested), it is generally felt that computer control systems in astronomy and space applications will have little or no problems coping with the increasing divergence. Current predictions suggest that it will take at least 1000 years for the difference to reach one hour. We feel that it can be safely left to future generations of time keepers to decide how to deal with this issue.

Annex 3: IAU Commission 31 Report (2010)

A number of other time systems provide a uniform scale of time and these are being increasingly used, partly because of the difficulties in handling the discontinuities of UTC. Notable among these is the Global Positioning System (GPS) timescale which is widely available and widely used. However, the precision of these alternative timescales is significantly less than that of UTC, making their use for the most demanding applications problematic. For example, the GPS timescale currently has a stability which is about two orders of magnitude worse than that of UTC.

In summary, although there are some dissenting views, a large majority of Commission 31 members favour the abolition of leap seconds to give a uniform and widely distributed UTC timescale of high accuracy. I therefore recommend that the IAU respond to the ITU supporting the abolition of leap seconds from UTC. A draft response to the ITU questionnaire is attached.

Yours sincerely
Dick

Dr R N Manchester
President, IAU Commission 31
CSIRO Fellow, CSIRO Astronomy and Space Science, Sydney

Annex 4: IAU Response to ITU-R Questionnaire (2011)

Attachment

Questionnaire on a draft revision of Recommendation ITU-R TF.460-6 (leap seconds issue)

Do you support maintaining the current arrangement of linking UT1 and UTC (to provide a celestial time reference)?	NO
Do you have any technical difficulty in introducing leap second today? (If YES could you explain your reasons?) ✓ A continuous timescale is required for in astronomy primarily for the time-tagging of observations, guidance of spacecraft, prediction of the motion of celestial bodies and the control of telescopes. Most facilities base their time keeping on UTC and so discontinuities have to be dealt with, often in real time. While not a major issue, this has caused problems in the past, leading to loss of observation time and faulty data.	YES
Would you support the revision of Recommendation ITU-R TF.460-6? (In any case could you explain your reasons?) ✓ "Time" is intrinsically continuous, thus any discontinuities in broadcast time scales should be avoided. ✓ An IAU Working Group considered this issue in 2006 and found that there was no strong consensus on whether or not the definition of UTC should be changed. Consultations since that time indicate that a majority of astronomers favour the change to a continuous UTC provided that at least five years notice of the change is given.	YES
If it is agreed to eliminate leap second within 5 years after approval of the revision of Recommendation ITU-R TF.460-6, would that create technical difficulties for your administration? (If YES could you explain your reasons?)	NO

Annex 5: Statement by Ian Corbett Regarding ITU Questionnaire (2011)

From: Ian Corbett [mailto:icorbett@eso.org]
Sent: Tuesday, January 11, 2011 1:39 PM
To: P. Kenneth Seidelmann
Cc: 'George Wilkins'; 'Leslie Morrison'; 'George Kaplan'
Subject: Re: IAU Procedures re UTC leap second

Dear Ken,
Here is a short statement from me:

"Following the IAU response to the ITU-R SG7 questionnaire on a new definition of Coordinated Universal Time (UTC) without leap seconds it has become clear that there is a division of opinion with the IAU membership. Given the strength of views expressed it is unlikely that a consensus IAU position could be reached.

When the IAU was invited by ITU-R SG7 to complete its questionnaire I referred the matter to the IAU representative to ITU and then to IAU Commission 31 "Time". I was told that "Many years ago the IAU made a similar survey, and sent its view to the ITU, saying that astronomers do NOT oppose the proposed change." Commission 31, after internal consultation, replied that they did not oppose the proposed change. I replied accordingly to ITU-R.

Subsequently I became aware that members of other IAU Commissions should have been consulted and that had that happened they would probably have opposed the proposed change. An extensive e-mail correspondence ensued which made it clear that there was no consensus within the IAU. The IAU representative to ITU was involved in this exchange of views and can therefore explain the situation to the ITU."

Best wishes

Ian

Annex 6: References to Universal Time from Past IAU General Assemblies

Resolution 1 of IAU Commission 4 at the 7th General Assembly in 1948 found on page 4 of http://iau.org/static/resolutions/IAU1948_French.pdf

> ”La Commission recommande que la désignation 'Temps Universel' (Universal Time; Weltzeit) soit seule utilisée par les astronomes pour désigner le temps solaire moyen, compté à partir de minuit du méridien de Greenwich. Elle exprime le vœu que cette désignation remplace aussitôt que possible les autres expressions encore employées.”
>
> English Translation by the Working Group:
> The commission recommends that the designation 'Universal Time' (Temps Universel; Weltzeit) only be used by astronomers to designate mean solar time, reckoned from midnight of the Greenwich meridian. It hopes that that this designation replaces other expressions still being used as soon as possible.

The proceedings (1964) of the meeting of IAU Commission 31 found on page 16 of http://www.iau.org/static/resolutions/IAU1964_French.pdf

1. L'UAI note qu'il serait utile d'exprimer clairement la distinction entre les deux aspects de la notion de temps, à savoir, l'*époque* (instant) et l'*intervalle de temps*, et l'utilité des diverses échelles de temps.
2. L'époque du T.U. est déterminée par la position angulaire de la Terre autour de son axe; elle est demandée pour divers usages scientifiques et techniques et pour les usages civils, parfois sans délai.
3. Une unité de temps atomique (T.A.), fondée sur une transition quantique, convient comme unité d'intervalle de temps en physique et est entrée dans l'usage pratique depuis 1955. L'adoption d'une transition particulière pour la définition de la second physique est de la compétence de la Conférence Générale des Poids et Mesures.
4. Le T.E. est le temps qui convient à la méchanique céleste dont les travaux immédiats n'exigent la connaissance ni de l'époque, ni de l'unité d'intervalle de temps.
5. L'UAI reconnait que les physiciens ont besoin de la second de temps atomique, mais insist sur la nécessité de fournir aux usagers, d'une façon continue et sans délai, l'époque du T.U.
6. Le besoin existe donc de fournir par des émissions radioélectriques à la fois l'époque du T.U. et l'unité d'intervalle de T.A. C'est ce qui est fait depuis 1959.
7. La méthode pour fournir les deux est possible parce que
    a. l'époque du T.U.2 n'a besoin d'être connue sans correction immédiate qu'avec une tolérance de 0.1 s et
    b. (b) la fréquence peut être maintenue constante par rapport aux étalons atomiques pendant des durées d'une ou plusieurs années au moyen d'un décalage de fréquence connu.

    Dans cette méthode, on maintient la cohérence entre les signaux horaires et la fréquence de l'onde porteuse.
8. On reconnait que d'autres méthodes de compromis sont possibles. Cependant, le système actuel semble le mieux adapté à beaucoup d'exigences courantes.
9. On reconnait qu'il serait désirable de transmettre l'époque de T.U.2 et l'unité d'intervalle de temps sans sauts d'époque ni décalages de fréquence.

English Translation by the Working Group:

Annex 6: References to Universal Time from Past IAU General Assemblies

1. The IAU notes that it would be useful to articulate the distinction between the two aspects of the concept of time, namely, the *epoch* (instant) and the *time interval*, and the utility of various time scales.
2. The epoch of U.T. is determined by the angular position of the Earth about its axis; it is required for various scientific and technical purposes and for civil purposes, sometimes without delay.
3. A unit of atomic time (A.T.), based on a quantum transition, suitable as a physical unit of time interval has come into practical use since 1955. The adoption of a particular transition for the definition of the physical second is the responsibility of the General Conference of Weights and Measures.
4. E.T. is the time that suits celestial mechanics whose immediate work requires neither the knowledge of the epoch, nor the unit of time interval.
5. The IAU recognizes that physicists need the second of atomic time, but insists on the need to provide users, continuously and without delay, the epoch of U.T.
6. Therefore the need exists for radio emissions to provide both the epoch of U.T. and the unit of interval of A.T. This has been done since 1959.
7. The method for providing the two is possible because
    a. the epoch of U.T.2 need not be known without immediate correction to within a tolerance of 0.1 s and
    b. frequency can be kept constant with respect to atomic standards for periods of one or more years by means of a known frequency offset.

   Via this method, coherence is maintained between time signals and the frequency of the carrier wave.
8. We recognize that other methods of compromise are possible. However, the current system seems best suited to many common requirements.
9. We recognize that it would be desirable to transmit the epoch of U.T.2 and the unit of time interval without steps of time nor offsets of frequency.

Resolutions of IAU Commissions 4 and 31 at the 15th General Assembly in 1973 (on page 20 of) http://www.iau.org/static/resolutions/IAU1973_French.pdf

"Resolution No. 1 by Commissions 4 and 31
(Adopted 25 August 1973)

Considering:

(a) that a single worldwide coordinated clock time scale based upon the SI second is desirable,
(b) that the Coordinated Universal Time system (UTC) makes the International Atomic Time (TAI), which is based on the SI second, generally available, and
(c) that the UTC system provides mean solar time to a precision that is needed for navigation and surveying,

Recommend:

The adoption of the UTC system as the basis for the dissemination of standard time (heure normale) in all countries.

Resolution No. 2 by Commissions 4 and 31
(Adopted 29 August 1973)

Considering:

(a) that TAI equalled UT2 (nominally) when UT2 was 1958 January 1d, 0h 0m 0s
(b) the necessity of maintaining all conventional calendarial and time designations,
(c) the desirability of bringing into accordance ET and TAI, which differ by about 32s;

Recommend:

Annex 6: References to Universal Time from Past IAU General Assemblies

(1) that a change be introduced in the TAI as soon as practicable so that TAI (new) equals TAI (old) plus 32 seconds precisely,
(2) that DTA (DAT) be defined by TAI minus UTC, where DTA is an integral number of seconds,
(3) that the CCDS be invited to take the necessary action.

Explanation:
(1) TAI is not affected by leap seconds but UTC is.
(2) The value of DTA is determined and announced by the BIH.
(3) UTC is the basis of standard time, the time in common (civil) use, as disseminated by radio time signals."

Resolution No. 4 by Commissions 4 and 31
(Adopted 29 August 1973)

Considering:
(a) that present procedures governing the insertion of leap seconds have been variously interpreted and,
(b) that if the present trend of the rotation of the earth continues, it will become impossible to maintain UTC within the present limits by the insertion of leap seconds on two preferred dates only and,
(c) that it is important fo many users to have UT1 minus UTC remain within a *fixed* limit;

Recommend:
(1) that the *maximum limit* of UT1 minus UTC be set at +/- 0.950 seconds,
(2) that the maximum deviation of UT1 from UTC plus DUT1 be +/- 0.100 s,
(3) that, when necessary, leap seconds may be introduced at the end of any month, but that first preference be given to the end of June and December, and second preference be given to the end of March and September.