INTERNATIONAL TELECOMMUNICATION UNION
No. 7 September 2013 Special edition

ITU NEWS

itunews.itu.int

The future of time

To abolish or not to abolish the leap second?

Global navigation satellite systems today and tomorrow

Keeping the world's time

ITU leading international cooperation

Dr Hamadoun I. Touré,
ITU Secretary-General

ITU/P.M. Virot

Timekeeping is critical to the functioning of modern society, and international coordination is crucial. Coordinated Universal Time, better known by its acronym UTC, is the legal basis for timekeeping for most countries in the world, and is the *de facto* time-scale in most others. UTC is defined by ITU's Radiocommunication Sector (ITU–R).

The current standard, Recommendation ITU–R TF.460-6, entitled "Standard-frequency and time-signal emissions", recommends the application of leap seconds to maintain UTC close to Universal Time 1 (UT1) — a time proportional to the rotation angle of the Earth on its axis. The leap second came into use in 1972.

A number of years later, some administrations expressed concerns about the implementation of the leap second, and a study question on the future of the UTC time-scale was adopted in 2000. Proposals have been made since 2003 to revise Recommendation ITU–R TF.460-6 in order to achieve a continuous time-scale. Noting that the broader implications of changes to the definition of UTC require additional study with wider participation from ITU Member States and external organizations, the World Radiocommunication Conference in 2012 (WRC-12) called for further studies, postponing the decision to WRC-15. As a result, leap seconds will again be reviewed in 2015.

WRC-12 also asked that its Resolution 653, on the future of the UTC time-scale, be brought to the attention of relevant organizations. In line with this instruction, I have consulted with the International Maritime Organization, the International Civil Aviation Organization, the General Conference of Weights and Measures, the Consultative Committee for Time and Frequency, the International Bureau of Weights and Measures (BIPM), the International Earth Rotation and Reference Systems Service, the International Union of Geodesy and Geophysics, the International Union of Radio Science, the International Organization for Standardization, the World Meteorological Organization and the International Astronomical Union.

I am pleased to report that this consultation resulted in a workshop on the future of the international time-scale, jointly organized by ITU and BIPM, which was held from 19–20 September 2013 in Geneva.

WRC-12 noted that the sporadic insertion of leap seconds may upset systems and applications that depend on accurate timing. Some organizations involved with space activities, global navigation satellite systems, metrology, telecommunications, network synchronization and electric power distribution have requested a continuous time-scale. For other specialized systems and for local time-of-day, however, a time-scale reckoned with respect to the rotation of the Earth is needed. Also, a change in the reference time-scale may have operational and hence economic consequences. ITU–R studies take these considerations into account.

WRC-15 will "consider the feasibility of achieving a continuous reference time-scale, whether by the modification of UTC or some other method, and take appropriate action, taking into account ITU–R studies".

Meanwhile, let me encourage Member States to continue participating in our studies by submitting contributions to ITU–R.

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ISSN 1020–4148
itunews.itu.int
10 issues per year

Editor-in-Chief: Patricia Lusweti
Art Editor: Christine Vanoli
Editorial Assistant: Angela Smith
Circulation Assistant: Albert Sebgarshad

Printed in Geneva by the ITU Printing and Dispatch Division.

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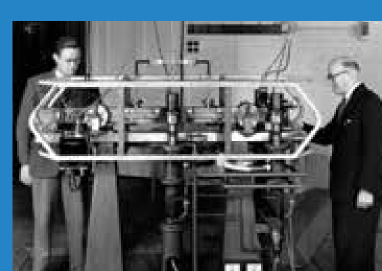
The future of time

To abolish or not to abolish the leap second?



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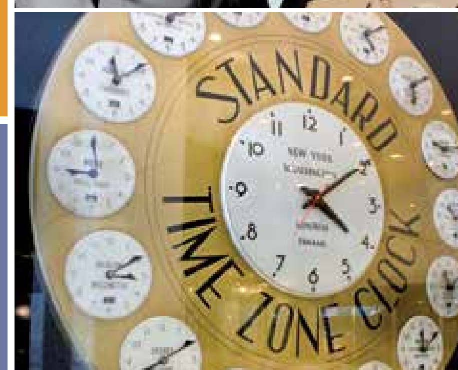


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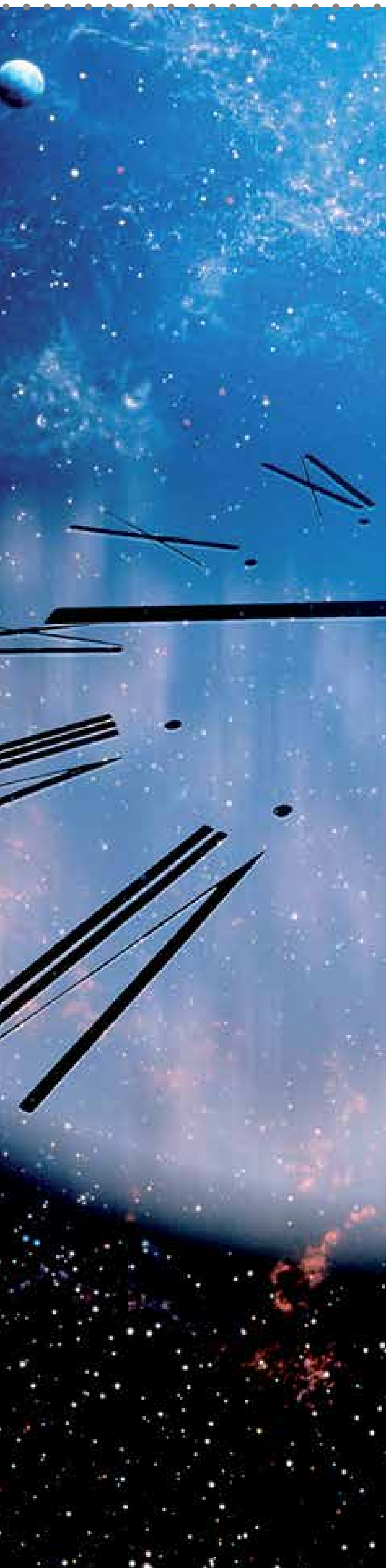
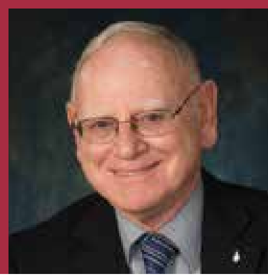
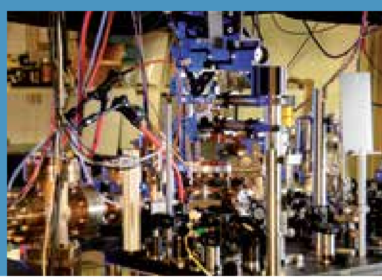
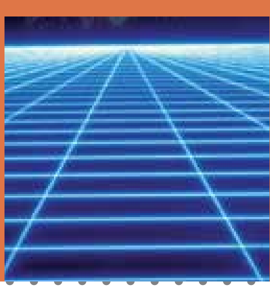
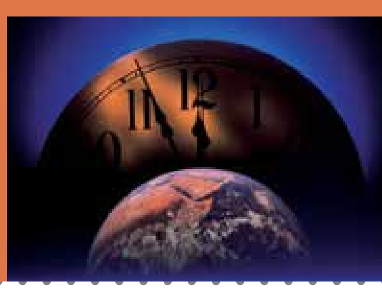




The future of time





AFP

O TEMPORA! O MORES!

Oh the times! Oh the customs!

Cicero

Foreword

Modern times — Is the leap second history?

François Rancy, Director,
ITU Radiocommunication Bureau

François Rancy

The international time-scale, Coordinated Universal Time (UTC), as defined by ITU, is used throughout the world and disseminated by radiocommunication systems. Recommendation ITU–R TF.460-6 on "Standard-frequency and time-signal emissions" is incorporated by reference in the Radio Regulations and provides the official definition of UTC.

Currently, UTC is used for a range of different purposes, from the minutes needed by the general public in adhering to timetables, to the synchronized nanoseconds required in the most demanding applications such as navigation through the global navigation satellite systems — for example the Global Positioning System (GPS), GLONASS and others on the horizon including Europe's Galileo and China's BeiDou.

A variety of systems using UTC have been developed over the past 40 years since the introduction of the leap second (1972), and some of these systems — for example for search and rescue services — are critical to human life. It has, therefore, been argued that the present definition of UTC should be maintained so that these systems can continue to operate as they do now. Another point that has been raised is that, if leap seconds are no longer used, the UTC time-scale will diverge from Earth rotation time. Apart from the affront to the common understanding of time by society at large, this may cause technical difficulties for specific applications including some used in astronomy.

In counterpoint, several arguments have been made for the adoption of a continuous reference time-scale, which would abolish the leap second. One is that the insertion of leap seconds is a costly process and reduces the reliability of systems that depend upon time. Pre-testing of equipment as well as correcting inevitable problems afterwards results in significant expenditure in terms of personnel as well as equipment. Furthermore, stopping all clocks in the world for one second in order to accommodate a leap second creates an ambiguous hiatus, where orderly processes such as precise time-stamping are disrupted. Also, the occasional nature of leap-second insertion is likely to cause significant technological problems to international infrastructure in years to come.

The ITU Radiocommunication Sector (ITU–R) is conducting studies on the feasibility of achieving a continuous reference time-scale for dissemination by radiocommunication systems. As part of the preparatory efforts for the World Radiocommunication Conference in 2015 (WRC-15), a special workshop organized by ITU and the International Bureau of Weights and Measures (BIPM) on 19–20 September 2013 in Geneva provided information to all stakeholders and raised awareness of the key issues and the different perspectives.

We are grateful to the authors of this special edition of *ITU News* for sharing their expertise and perspectives. Their combined knowledge offers a classic resource and reference on the science of timekeeping that will enrich and inform the ongoing debate on the future of time, and on whether or not to abolish the leap second.

Jim Gray, keeper of the American NBS-4 atomic clock. The NBS-4 is the long cylindrical object on the bench. It is a caesium clock, in which atoms of vaporized caesium-133 pass back and forth between magnets at each end. The caesium-133 atoms oscillate between two energy levels as they go. The standard second is based on counting these oscillations. This accurate timekeeping is passed to Paris, where signals from this and other atomic clocks are averaged to produce the worldwide Coordinated Universal Time (UTC)

Alexander Tsiaras/cience Photo Library SPL

The past and future of Coordinated Universal Time

Ronald Beard, Chairman, ITU–R Working Party 7A

Until the mid-1960s, the rotation of the Earth was the basis for determining the length of a day and for defining time-scales. But the rotation of the Earth is irregular leading to increasingly complicated versions of rotational time-scales — including the short-lived Greenwich Mean Sidereal Time — to be created in an attempt to produce a uniform time-scale. Finally, the search for a uniform time-scale led to a change from Earth rotational time to atomic time-scales.

International Atomic Time (TAI) was introduced as a continuous reference time-scale in 1970. It is based on the readings of atomic clocks, and is independent of the irregularities of the Earth's rotation. For the purposes of celestial navigation, however, users needing to determine the rotational angle of the Earth still required access to a time-scale related to rotational time, with an uncertainty of less than a second. This led in 1971 to the adoption of the present Coordinated Universal Time (UTC) system. UTC is a stepped atomic time-scale, defined by ITU's Radiocommunication Sector (ITU–R), formerly the International Radio Consultative Committee (CCIR), in Recommendation ITU–R TF.460.

The steps are known as leap seconds, and were introduced in UTC to reconcile the difference between the uniform atomic reference time, TAI, and rotational time. The maximum difference between UTC and TAI is limited to plus or minus 0.9 second.

Nature's changing course

Apparent solar time, as indicated by a sundial, or more precisely determined by the altitude of the Sun, is the local time defined by the actual diurnal motion of the Sun. However, because of the tilt of the Earth's axis and the elliptical shape of the Earth's orbit, the time interval between successive passages of the Sun over a given meridian is not constant.

The difference between mean and apparent solar time is called the equation of time, and the variation between apparent and mean noon can amount to up to 16.5 minutes. Until the early nineteenth century, voyagers relied on apparent solar time, backed up by astronomical ephemerides (tables giving the calculated positions of celestial objects at regular intervals throughout a period). But as clocks improved — and their use by ships at sea and by railroads grew — apparent solar time was gradually replaced by mean solar time.

Mean solar time is the measure of astronomical time defined by the rotation of the Earth with respect to the Sun, and takes account of the orbital motion of the Earth around the Sun. When referred to the meridian of Greenwich it was called Greenwich Mean Time (GMT) but it is now known as Universal Time (UT) and, when adjusted for the Earth's polar motion, it is known as UT1.

The mean solar day is traditionally described as the time interval between successive transits of the fictitious mean Sun over a given meridian. Historically, the unit of time, the second, was defined as 1/86 400 of a mean solar day. Ephemeris Time (ET) replaced UT1 as the independent variable of astronomical ephemerides in 1960. This was, in turn, replaced by relativistic time-scales in 1984 and resulted in the current Terrestrial Time (TT) as the geocentric time-scale used for astronomical ephemerides.

Overtaking celestial navigation

Since the late 1980s, electronic navigation and communication systems have significantly overtaken celestial navigation. In order to operate, these global systems require a continuous time reference, and several continuous time-scales have been established for internal use for that purpose.

It turns out that these internal continuous time-scales are also ideal for comparisons among precision time centres, as well as for precision time applications and the dissemination of precise time in general. The ease of using these continuous time systems contrasts with the complexity of dealing with a coordinated universal time-scale that involves leap seconds. The application of leap seconds is known to cause difficulties to various networks that use precise time, whether distributed locally or internationally.

These ad hoc system times emanating from continuous internal time-scales are currently being used as a reference in many applications — such as global navigation satellite systems — in order to avoid the use of the discontinuous UTC time-scale. This has unfortunately led to a proliferation of "pseudo" time-scales, calling the current definition of UTC into question.

Standard time and frequency signals

ITU–R Study Group 7 on "Science services" set up its Working Party 7A to deal with "Time signals and frequency standard emissions". ITU–R Working Party 7A is thus responsible for standard time and frequency signal (STFS) services, both terrestrial and satellite. The scope of the working party includes the dissemination, reception and exchange of STFS services, and the coordination of these services, including satellite techniques, on a worldwide basis.

ITU–R Working Party 7A develops and maintains Questions, ITU–R Recommendations in the TF Series, Reports, Opinions and Handbooks relevant to standard time and frequency signal activities, covering the fundamentals of STFS generation, measurements and data processing. The related ITU–R

Astronomical clock in Prague in the Czech Republic, dating back to 1410. This clock displays three different sets of time — central European time, old Bohemian time and Babylonian time — and charts the positions of the Sun and planets around the Earth as medieval astronomers saw it

Keystone/SPL/Victor de Shwanberg

Recommendations are of importance to telecommunication administrations and industry. They also have major consequences for other fields, such as radionavigation, electric power generation, space technology, and scientific and metrological activities. They cover the following topics: terrestrial SFTS transmissions, including high-frequency, very-high frequency and ultra-high frequency broadcasts; television broadcasts; microwave links; coaxial and optical cables; space-based SFTS transmissions, including navigation satellites; communication satellites; meteorological satellites; time and frequency technology, including frequency standards and clocks; measurement systems; performance characterization; time-scales; and time codes.

Defining UTC

A major standard administered by ITU–R Working Party 7A is the definition of UTC in ITU–R Recommendation TF.460. This gives ITU — as one of the international organizations involved in the dissemination and coordination of time and frequency services, and in standards development — a central role in the definition, determination and maintenance of UTC.

The definition of UTC is more than a simple statement. Rather, it is a comprehensive process of incorporating recommendations into myriad standards and applications throughout the telecommunication and navigation communities.

Although the original purpose of UTC was not to be the standard for civil time, it has been adopted as the basis of official or legal time in most of the world, and as the standard reference time and basis of the time zones.

The actual value of UTC is calculated at the International Bureau of Weights and Measures *(Bureau International des Poids et Mesures* — BIPM) from about 420 atomic clocks operated in some 70 time-standards laboratories around the world. UTC is based upon the International System of Units (SI) second, and the inclusion of highly accurate primary clocks in centres around the world as data sources for calculating UTC ensures that there is only about one second of deviation from calculated ideal uniform time in several million years.

UTC is the only time realized by local approximations maintained in timing centres and laboratories designated as UTC*(k)*, with *k* being the timing centre or laboratory's designation. These UTC*(k)* realizations are used in disseminating time signals to users of precise time and those who need to know the current time or real-time values. International Atomic Time is the metrological reference used as the basis for the calculation of UTC, and provides a reference in frequency only.

The future of UTC

In October 2000, a new Question provided the impetus for initiating studies on the possible revision of Recommendation ITU–R TF.460-6. Question ITU–R 236/7 on "The future of the UTC time-scale" originated in response to matters raised by the Consultative Committee for Time and Frequency of the International Committee for Weights and Measures (CIPM).

A Special Rapporteur Group on the future of UTC was established to stimulate studies by ITU Member States and ITU–R Sector Members, and to gather information as a basis for possible modifications to related Recommendations. Creating a Special Rapporteur Group was thought to be necessary because any change to the UTC time-scale — or the identification of an alternative time-scale — would have a significant impact on radiocommunication, telecommunication, satellite navigation and computer systems, and could even affect the social perception of time.

Representatives of BIPM, the International Earth Rotation and Reference Systems Service (IERS), the International Union of Radio Science (URSI) and the International Astronomical Union (IAU) participate in the Special Rapporteur Group as well as in ITU–R Working Party 7A. These organizations have also set up their own working groups to investigate the matter. Reports from these working groups indicate that there is no strong consensus within their organizations either for or against changing the definition of UTC.

Leap seconds and length of day

Leap seconds are currently added to UTC to limit its divergence from UT1 to no more than 0.9 second. In other words, the current practice of using leap seconds to adjust UTC maintains length of day— the difference between the astronomically determined duration of the day and 86 400 SI seconds — at no more than 0.9 second.

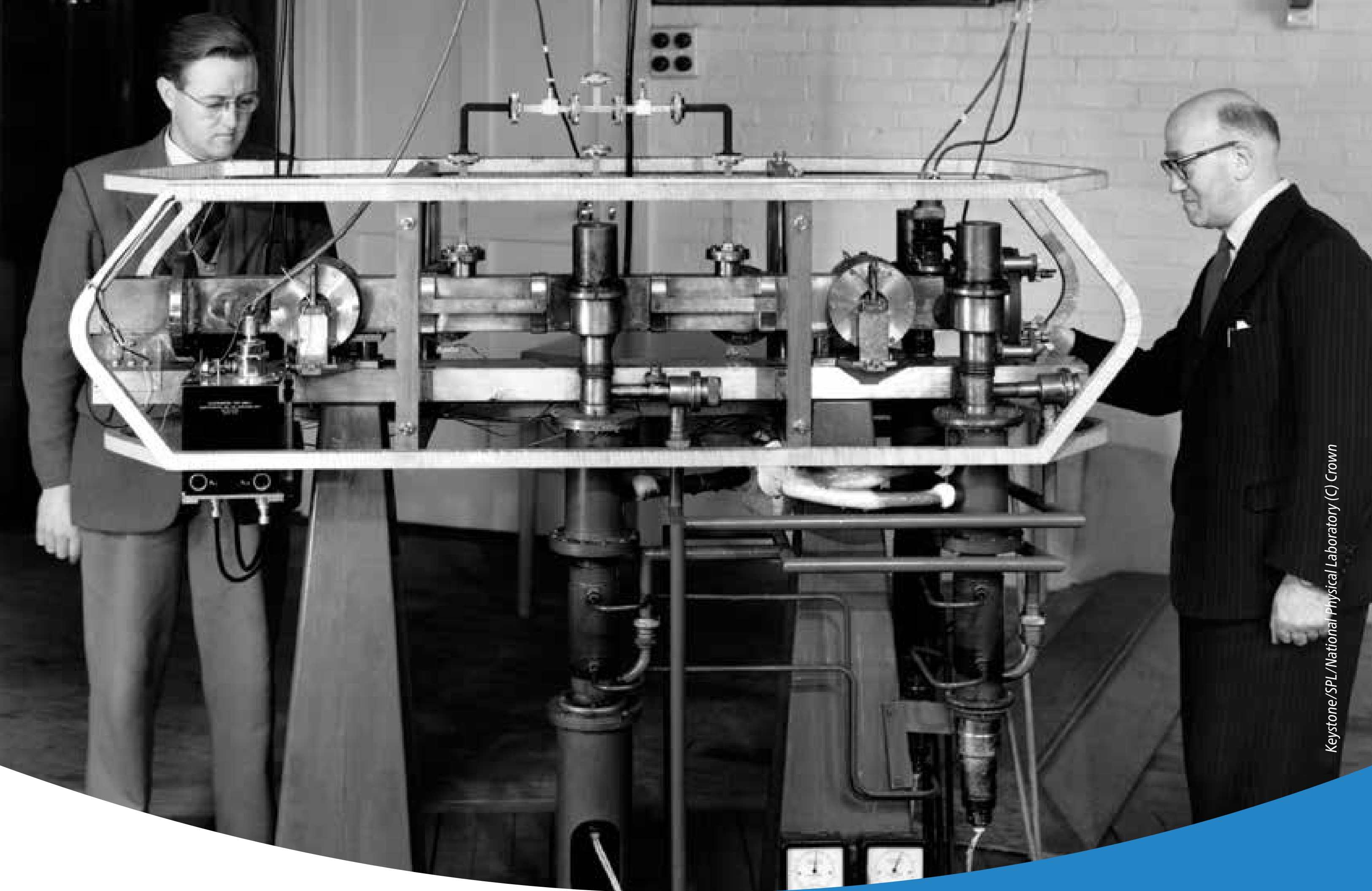
A change to the leap second method is being considered. This would make UTC a continuous atomic time-scale, which would gradually diverge from UT1 (which depends on the Earth's rotation angle). The divergence would result not only from the irregular rate of rotation of the Earth, but also from the fact that the defined duration of the SI second does not perfectly match the duration of the second determined as a fraction of the mean solar day.

Over the past 50 years, the UT1 second has been 2×10^{-8} s longer than the SI second on average, causing about 35 seconds difference between TAI and UT1 today. The rate of the Earth's rotation is also predicted to gradually slow down further, so that in the near future more than one leap second per year would be needed.

Preparing for WRC-15

The various discussions and studies that had been taking place on the question of establishing UTC as a continuous atomic time-scale led to this matter being submitted to the World Radiocommunication Conference (WRC) in 2012 for decision. The topic was discussed at the conference, but many participants felt that more information was needed before a decision could be reached. WRC-12 therefore adopted Resolution 653 (WRC-12), which reflected their agreement to bring the question to the attention of relevant outside organizations, to have ITU–R Working Party 7A carry out further studies, and to include the topic as an agenda item for WRC-15.

As part of the preparatory efforts for WRC-15, a special workshop is being held at ITU headquarters in Geneva on 19–20 September 2013 to provide more information to interested parties and perhaps to stimulate additional studies.



A caesium atomic clock. Physicists Jack Parry (left) and Louis Essen (right) adjusting their caesium resonator, which they developed in 1955. Atoms of vaporized caesium-133 oscillate between two energy levels as they pass back and forth between magnets at each end of the resonator. The standard second is based on counting these oscillations. One standard second is equivalent to about 9193 million oscillations. Essen and Parry's resonator led to the replacement of the astronomical second with the atomic second as a standard of time. This photo was taken in 1956 at the National Physical Laboratory, Teddington, United Kingdom

Time-scales and the International Bureau of Weights and Measures

Elisa Felicitas Arias, Director, Time Department, International Bureau of Weights and Measures (BIPM)

The International Atomic Time (TAI) and Coordinated Universal Time (UTC) are maintained by the International Bureau of Weights and Measures *(Bureau International des Poids et Mesures* —BIPM). TAI constitutes the basis of UTC. Both time-scales are equally stable and accurate, but while TAI is continuous, UTC is adjusted from time to time by the insertion of a leap second to keep it synchronized with the Earth's rotation. The dates for inserting leap seconds in UTC are decided and announced by the International Earth Rotation and Reference Systems Service (IERS).

Time is

The development of the first cæsium frequency standard at the United Kingdom National Physical Laboratory in 1955 marked the beginning of the atomic era in frequency referencing and timekeeping. It was quickly recognized that the cæsium transition could serve as a reference for frequencies.

The unification of time on the basis of the atomic time-scale maintained in the 1960s by the *Bureau International de l'Heure* was recommended by the International Astronomical Union in 1967, by the International Union of Radio Science in 1969, and by ITU in 1970 — through its International Radio Consultative Committee (CCIR) — the forerunner of the Radiocommunication Sector (ITU–R). Finally, in 1971, official recognition was given by the General Conference for Weights and Measures, which introduced the designation International Atomic Time and the universal acronym TAI (as had been used by the *Bureau International de l'Heure* to designate atomic time since 1955).

In those days, however, one obstacle to the universal acceptance of TAI was the need to provide astronomical time (denominated UT1) to those users who — for the purposes of sea navigation and other domestic applications — required a time-scale based on the irregular rotation rate of the Earth. There was discussion about the wisdom of maintaining two different time-scales, and the need to avoid the enormous confusion that this might create. Ultimately, UTC was defined by ITU's CCIR, and its use was endorsed by the General Conference for Weights and Measures in 1975. The definition of UTC was well adapted to the applications and technologies that existed in the early 1970s, and so this unique reference for time dissemination represented a good compromise for all users.

Despite objections, however, atomic time was increasingly used. TAI has never been disseminated directly; in fact it provides a frequency reference but has no practical use for measuring time intervals. It has no physical representation by clocks and in consequence is not disseminated by time signals. UTC is the time reference, calculated from TAI. Both UTC and TAI are calculated in post-processing, and available with a delay of 10 to 40 days. UTC is, however, needed in real time for some specific applications, including astronomical navigation, geodesy, telescope settings, space navigation and satellite tracking. The laboratories contributing to the formation of UTC at BIPM therefore maintain real-time realizations of UTC, indicated by UTC*(k)*, where *k* is the designation of the laboratory concerned. These laboratories provide real-time access to UTC for practical applications and they disseminate UTC by various means.

Time shall unfold

Since 1972, UTC has differed from TAI by an integral number of seconds, changed whenever necessary by the insertion of a leap second to maintain the difference UT1 — UTC within 0.9 second. This system apparently works well. With four decades of experience, the procedures for inserting leap seconds have been refined and secured. However, with the emergence of ever-more sophisticated equipment and services, these procedures are becoming increasingly cumbersome and introduce an ambiguity in dating events when they occur. This has given rise to the creation — for particular applications — of continuous time-scales parallel to TAI but offset by a number of seconds. These alternative time-scales are broadcast, putting at risk the unification of time. Given the progress that has been made in communications, other means of providing UT1 in real time can be envisaged, and the future of UTC is now being discussed.

UTC has many applications in time synchronization at all levels of precision, from the minutes needed by the general public, to the nanoseconds required in the most demanding applications. The case of global navigation satellite systems is typical. The internal system time of the United States Global Positioning System (GPS), known as GPS Time, is closely synchronized with UTC as maintained by the United States Naval Observatory (USNO). GPS disseminates a good approximation to UTC, easily available at all levels of precision from a second to a few nanoseconds. Similar features will be adopted for Galileo, the future European satellite positioning system, and by the upcoming Chinese system BeiDou. The Russian system GLONASS follows UTC with leap seconds, synchronizing GLONASS Time to the realization of UTC in the Russian Federation.

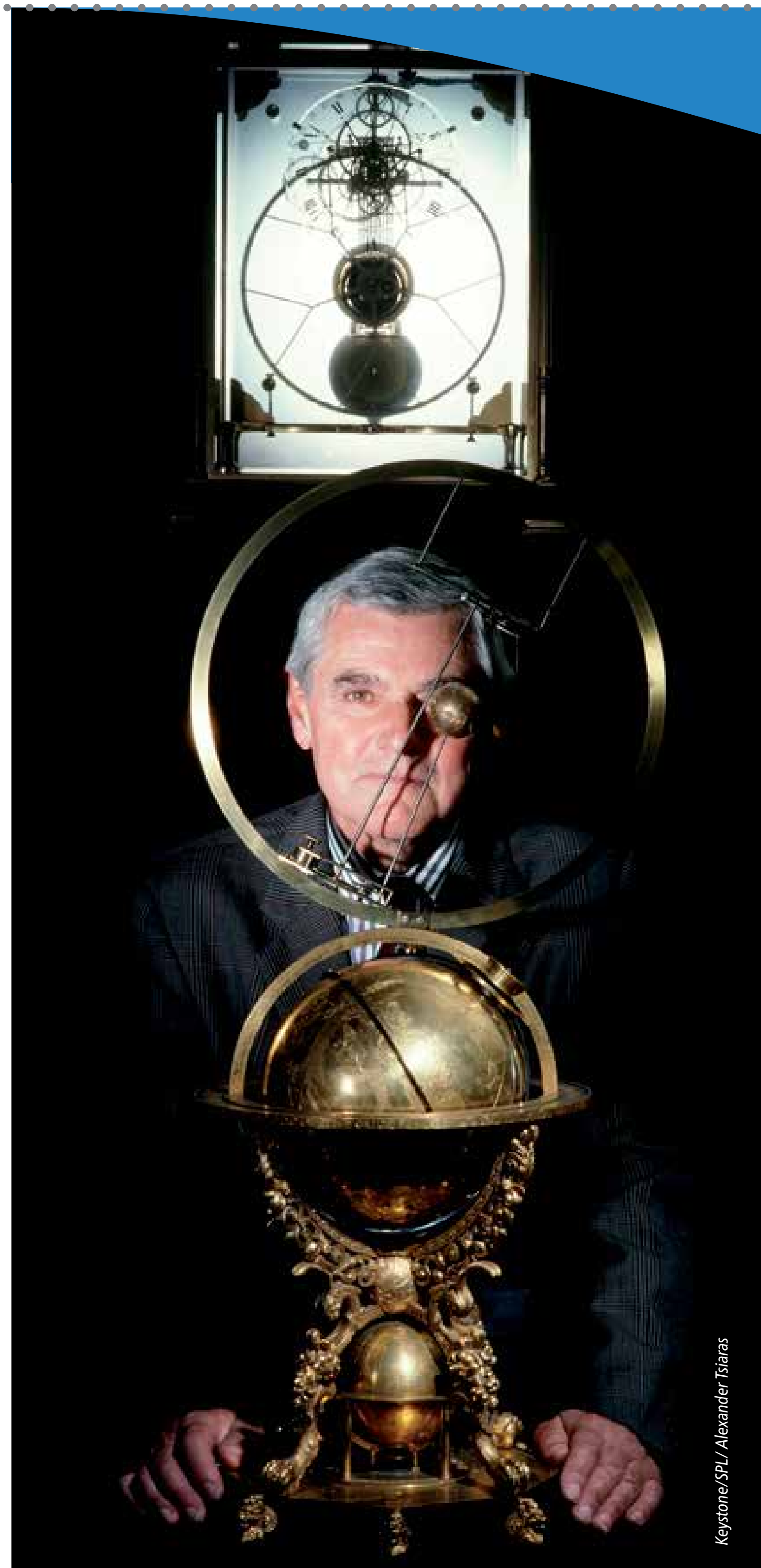
Reliable time for science

TAI is the basis for the realization of time-scales used in dynamics, for modelling the motions of artificial and natural celestial bodies, with applications in the exploration of the solar system, tests of theories, geodesy, geophysics, and studies of the environment. In all these applications, relativistic effects are important. Different algorithms can be established, depending on requirements.

For an international reference such as UTC, the requirement is extreme reliability and long-term frequency stability. UTC therefore relies on the largest possible number of atomic clocks of different types, at present about 420, located in more than 70 institutes worldwide and connected in a network that allows precise time comparisons between remote sites. Each month the differences between the international time-scale UTC and the local approximations UTC*(k)* in contributing laboratories are reported in an official document called *BIPM Circular T.*

International cooperation

Defining, maintaining and realizing the reference time-scale is the result of continuous coordination between a group of organizations. The Metre Convention — a diplomatic treaty —was signed in 1875 and created BIPM, an intergovernmental organization under the authority of the General Conference for Weights and Measures. As at 6 February 2013, BIPM had 55 Member States, and 37 Associate States and Economies of the General Conference. BIPM acts in matters of world metrology, particularly concerning the demand for measurement standards of ever-increasing accuracy, range and diversity, and the need to demonstrate equivalence between national measurement standards. The General Conference for Weights and Measures adopts resolutions on the definition of units, and in particular on the definition of the second; it has adopted TAI and endorsed UTC.



Keystone/SPL/ Alexander Tsiaras

Bernard Guinot, a former Director of the Time Department at the International Bureau of Weights and Measures (BIPM), Paris. Mr Guinot, known affectionately as Father Time, has made two major contributions to accurate timekeeping through atomic clocks

Example of an atomic clock, conceptual computer artwork

Keystone/SPL/Victor de Schwanberg

BIPM is responsible for the provision of UTC and for its calculation, on the basis of international cooperation with national institutes; it gives metrological traceability to UTC to its local realizations.

ITU adopts recommendations relevant to the dissemination of time and frequency signals based on UTC. In particular, Recommendation ITU–R TF.460-6 describes the process for synchronizing UTC to UT1 at the level of 0.9 second.

The International Earth Rotation and Reference Systems Service (IERS) monitors the rotation of the Earth, and fixes and announces the dates of application of leap seconds in UTC. IERS produces and publishes predictions of the values of UT1-UTC, allowing access to UT1 with much higher precision than the coarse approximation of UTC. Finally, the more than 70 institutes that maintain the local realizations UTC*(k)* disseminate time for a variety of national and regional applications, ranging from civil timekeeping to enabling precise time synchronization for space and science activities.

In the event that ITU Member States approve a continuous reference time-scale, then IERS would have the essential role of guaranteeing the provision of the predicted values of UT1-UTC, and ITU would make specific recommendations for the wide dissemination of those values. BIPM would remain responsible for the maintenance of the reference time-scale, as part of a coordinated international effort.

LCD clock displaying an inserted leap second before midnight in the 24-hour time system. The last leap second was added on 30 June 2012

Keystone/SPL/Lawrence Lawry

Leap seconds

Role of the International Earth Rotation and Reference Systems Service

Brian Luzum, Chair, Directing Board, International Earth Rotation and Reference Systems Service

Time

The International Earth Rotation and Reference Systems Service (IERS) has an important role in determining when leap seconds are to be inserted and in announcing the dates for this insertion. In order to understand this role, it is important to know certain features of time.

There are two different kinds of "time", which in today's world are related: first, a uniform time, now based on atomic clocks; and second, "time" based on the variable rotation of the Earth. The difference between uniform time and Earth rotation time only became apparent in the 1930s with improvements in clock technology.

Coordinated Universal Time (UTC) is currently the standard for everyday time usage worldwide. In addition, it plays an important role in such diverse applications as communications, computer network synchronization and navigation through global navigation satellite systems (GNSS), for example, the Global Positioning System (GPS). Because of the accuracy of current

Keystone/SPL/Martin Riedl

A hand-held receiver, based on the Global Positioning System (GPS), being used in the Canadian Arctic. Some 24 GPS satellites trace precision orbits around the Earth. Each satellite transmits radio signals that can be detected by this receiver. Three signals allow calculation of latitude and longitude. A fourth signal allows altitude calculations. Transmission of time data allows the calculation of local time

atomic clocks, UTC is accurate to the scale of several nanoseconds (billionths of a second).

Then and now

Historically, timekeeping was based on the rotation of the Earth. The repetitive passage of astronomical bodies (the Sun, for example) provided a convenient method to mark the passage of time. Time based on observations of the rotation angle of the Earth in a celestial reference system continues to play a role in modern timekeeping.

Today, the measure of the Earth rotation angle is provided by a linear relationship with a time-like quantity called UT1, which is observed using a worldwide network of radio telescopes. Earth rotation data are provided to users in the form of a quantity UT1–UTC.

The rotational speed of the Earth is highly variable as a result of tides, changes in weather, oceans and other geophysical effects. Consequently, the only way to provide this information reliably is to monitor the Earth's rotation on a regular basis. The Earth's rotational speed is measured by fixing devices to the surface of the Earth and observing objects in space. Very long baseline interferometry, using radio telescopes to observe distant radio sources called quasars, can measure UT1 to an accuracy of a few tens of microseconds (millionths of a second).

Leap seconds

Leap seconds were introduced in 1972 as an attempt to ensure synchronization between clock time and Earth rotation. According to Recommendation ITU–R TF.460-6 on standard-frequency and time-signal emissions:

"A positive or negative leap second should be the last second of a UTC month, but first preference should be given to the end of December and June, and second preference to the end of March and September."

"A positive leap second begins at 23h 59m 60s and ends at 0h 0m 0s of the first day of the following month. In the case of a negative leap-second, 23h 59m 58s will be followed one second later by 0h 0m 0s of the first day of the following month."

Because IERS is responsible for monitoring and predicting the quantity UT1–UTC, it provides a vital contribution to the determination of when leap seconds will need to be inserted in order to keep UTC to within 0.9 second of UT1 specified by ITU. In recognition of this, Recommendation ITU–R TF.460-6 stipulates that IERS should decide upon and announce the introduction of a leap second, and that such an announcement should be made at least eight weeks in advance.

Since their inception, there have been 25 leap seconds. Through their implementation as specified in Recommendation ITU–R TF.460-6, leap seconds ensure that the absolute value of the difference between UTC and UT1 never exceeds

Example of an atomic clock, conceptual computer artwork

Keystone/SPL/Victor de Schwanberg

0.9 second. In effect, leap seconds allow users to approximate UT1 with UTC to an accuracy of roughly one second. While in the 1970s this level of approximation may have been considered as only a slight loss of accuracy, nowadays the discrepancy is more glaring because, with today's technology, real-time estimates of the difference between UT1 and UTC can be determined to more than four orders of magnitude better accuracy.

IERS products

Beyond its important role in determining when leap seconds are to be inserted and in disseminating information regarding leap seconds, IERS provides algorithms that enable users to use Earth-orientation parameters in their operations. These algorithms are developed by experts and tested thoroughly in geodetic and geophysical applications to ensure their quality. The algorithms and associated software are available free of charge through IERS websites for Conventions.

As tasked by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG), IERS helps to coordinate the regular measurement of all Earth orientation components, including the Earth's variable rotation. IERS combines these Earth-orientation observations four times per day, providing high-quality predictions for users of parameters of real-time Earth-orientation. All of these data sets are provided to the worldwide community through various computer transfer protocols free of charge.

Announcements of upcoming leap seconds are made through the IERS Bulletin C, which is usually released in January and July, and announces whether it will be necessary to insert a leap second within the next six months. This scheduling meets the "eight weeks in advance" requirement of ITU.

IERS provides the international community with: the International Celestial Reference System and its realization, the International Celestial Reference Frame; the International Terrestrial Reference System and its realization, the International Terrestrial Reference Frame; Earth orientation parameters that are used to transform between the International Celestial Reference Frame and the International Terrestrial Reference Frame; standards, models and constants used in generating

Changing time zones and the jet lag effect

and using reference frames and Earth orientation parameters; and geophysical data to study and understand variations in the reference frames and the Earth's orientation.

In the pipeline

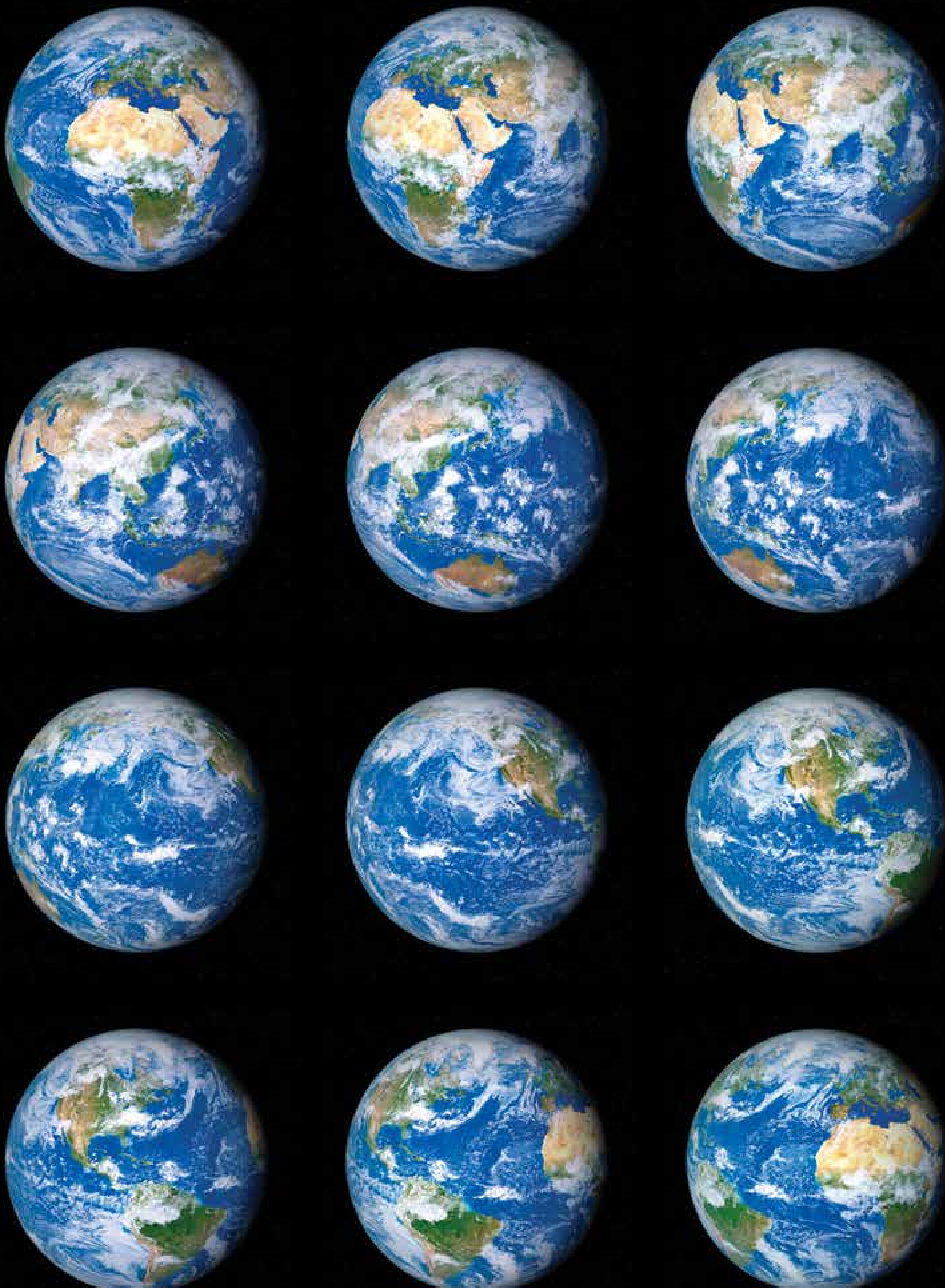
In recognition of rapidly changing technology and in order to meet the emerging needs of its users, IERS plans to create new products, and to move to more modern data file formats to improve the usability of its data. In addition, IERS will investigate the possibility of creating a real-time Earth-orientation parameter transfer protocol. This product would provide UT1 directly to users who currently choose to approximate UT1 using UTC. It would have the advantage of maintaining the same simplicity of implementation that users currently enjoy, while increasing the accuracy of the data by more than four orders of magnitude at no cost to the user.

The IERS commitment

IERS was created in 1987 and began operations on 1 January 1988. It continued much of the work of the *Bureau International de l'Heure,* which had been established early in the twentieth century. IERS is responsible to the International Astronomical Union and the International Union of Geodesy and Geophysics.

IERS has served the international scientific community for more than 25 years. Recently, IERS has positioned itself to more completely serve the needs of its users whether the current definition of Coordinated Universal Time is retained or whether it is redefined to eliminate leap seconds. Either way, ITU can count on IERS to support its users with the data and software needed. IERS is prepared to meet any future requirements of users by the most convenient means.

Twelve views of the Earth as it rotates over a two-hour period. Each photo was taken after 30 degrees of rotation



Keystone/SPL/Detlev Van Ravenswaay

Earth against the glare of the Sun, stars and Milky Way

Keystone/SPL/Detlev Van Ravenswaay

The International Astronomical Union and Coordinated Universal Time

Blue sky thinking

Mizuhiko Hosokawa, President of IAU's Commission 31 on Time, Japan's National Institute of Information and Communications Technology

The International Astronomical Union (IAU) is an organization of researchers in the field of astronomy and has deep and strong relations with the international time-scale. In fact, one of the most important subjects of fundamental astronomy is the construction of reference frames and time-scales. The present Coordinated Universal Time (UTC) is maintained so that the difference between UTC and a measure of the Earth's rotation angle called UT1 is always less than 0.9 second. The precise measurement of UT1 requires astronomical observations.

To determine the value of UT1 with respect to UTC, the angle between the International Celestial Reference System and the International Terrestrial Reference System has to be measured. For this purpose, radio signals from quasars

This article was prepared with the great help of members of IAU's working group on the redefinition of UTC.

which realize the International Celestial Reference Frame are observed by means of very-long-baseline interferometry using radio telescopes whose positions are well determined in the International Terrestrial Reference Frame. Currently, the task of monitoring the value of UT1-UTC is one of the responsibilities of the International Earth Rotation and Reference Systems Service (IERS), established jointly by IAU and the International Union of Geodesy and Geophysics (IUGG). IERS is responsible for decisions on the timing of the leap-second adjustments announced through its *Bulletin C.*

In the astronomical community, there are strong and differing points of view on the insertion of leap seconds. One is academic and the other is practical.

From the academic point of view, the continuity of reference frames and time-scales is important. The link between UTC and astronomical time related to the rotation angle of the Earth (UT1) is considered relevant in that context.

From the practical point of view, many astronomical observatories use UTC as the basis of time for their observations. To track celestial objects with optical and radio telescopes, precise knowledge of the Earth's rotation angle in space is required. The approximation of UTC to UT1 is convenient for this purpose, and some software might have to be modified if UTC were to be redefined in such a way that it could differ from UT1 by more than one second. Thus, some astronomers are concerned about a possible redefinition of UTC.

The discussion about redefining UTC is going on in ITU's Radiocommunication Sector (ITU–R). IAU has provided ITU with opinions and considerations regarding the future of UTC, from the perspective of a scientific organization that is deeply involved in the construction of reference frames and time-scales.

Discussions in IAU from 2000 to 2006

The discussion on the future of UTC and the leap second started at the Special Rapporteur Group, created in 2000 by Working Party 7A (Time Signals and Frequency Standard Emissions) under ITU–R's Study Group 7 (Scientific services). This Special Rapporteur Group was to conduct comprehensive studies in answer to Study Group 7's Question 236/7 on the "Future of the UTC Timescale". The group requested IAU and other international organizations to provide their opinions and suggestions on the matter.

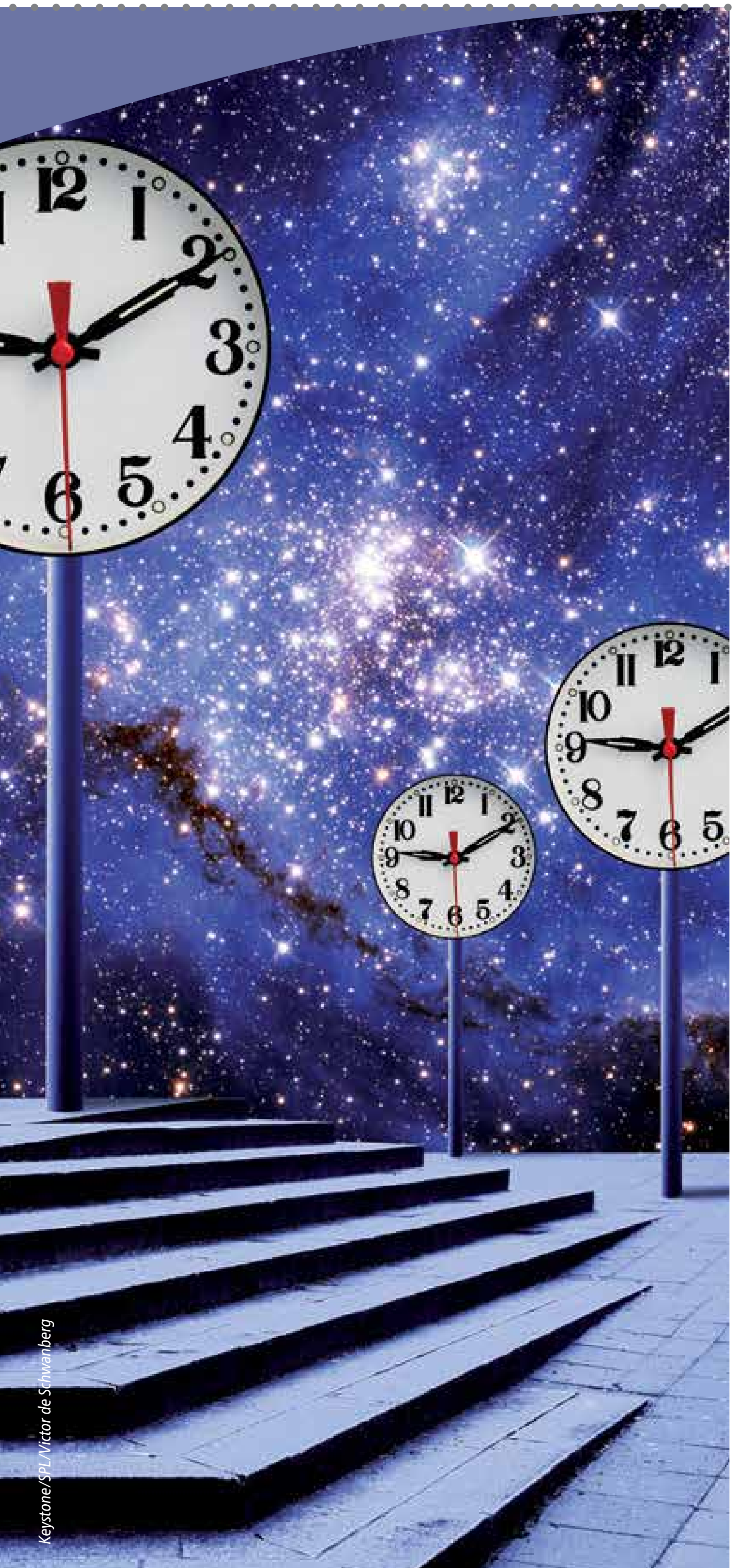
In response to this request, the IAU community carried out extensive studies and discussions on a possible redefinition of UTC. IAU established a working group for this purpose. According to its terms of reference, the working group was to discuss whether there is a requirement for leap seconds, as well as the possibility of inserting leap seconds at pre-determined intervals, and considerations relating to the tolerance limits for UTC-UT1.

After six years of activity, the final report of the working group was produced in 2006. No consensus was reached in the working group on supporting or rejecting a change in the definition of UTC, because of the many pros and cons from the different points of view. There was, however, agreement on one practical request, namely to allow sufficient time before implementing any changes to the definition. A letter from IAU to ITU–R nevertheless stated that the IAU community had not been affected adversely by any problems resulting from the insertion of the leap second on 31 December 2005, although significant investment in personnel time and effort is required to prepare for the insertion of a leap second.

Recent and ongoing IAU activities

The final report of the IAU working group was submitted in 2006 with the expectation that ITU–R and its relevant bodies would find an answer to Question 236/7. However, the Radiocommunication Assembly in 2012 (RA-12) concluded that additional studies were required and that the issue should be discussed at the next Assembly and World Radiocommunication Conference (WRC-15) in 2015.

During discussions in RA-12, it was pointed out that many ITU Member States were not aware of the proposal to suppress



Space and time are unified in a 4-dimensional structure called space-time. This unification was predicted by Einstein's theories of Special and General Relativity

leap-second adjustments. This is why RA-12 decided that all technical options should be fully studied and requested further discussions within the ITU membership and other organizations having an interest in the redefinition of UTC before the next RA-15 and WRC-15.

In response to ITU's request, IAU again established a working group on the redefinition of UTC under its Division on "Fundamental Astronomy". The working group is considering:

- current requirements for civil time-scales;
- options for satisfying the future requirements for civil time-scales;
- retaining UTC as it exists or distributing a purely atomic time-scale;
- the impact of a continuous time-scale on the work of astronomers;
- whether a new continuous time-scale for dissemination worldwide should be adopted and how this should relate to TAI;
- whether the General Conference on Weights and Measures rather than ITU should decide on reference time-scales;
- alternative means of distributing UT1, UTC and/or a new continuous time-scale.

The working group will submit its findings to ITU representing IAU's position on the redefinition of UTC. These findings will be submitted early enough so that they can inform discussions in the various countries and communities before the next Radiocommunication Assembly in 2015. Meanwhile, the latest discussion in the working group will be presented to the workshop on the future of the international time-scale, organized by ITU and the International Bureau of Weights and Measures (BIPM) in Geneva on 19–20 September 2013.

The Earth's time zones in an abstract image of a map set in a clock face

Keystone/SPL/Tony Craddock

Geosciences and international time-scales

Status of the discussions at the International Union of Geodesy and Geophysics

Claude Boucher, International Union of Geodesy and Geophysics representative to the Consultative Committee for Time and Frequency

Discussions thus far

The International Union of Geodesy and Geophysics (IUGG) is concerned with international time-scales, and specifically with Coordinated Universal Time (UTC), both as a user and a provider. On one hand, IUGG uses these time-scales as the time tag for measurements and as the time variable in models. On the other hand, because space geodesy plays a key role in the realization of time-scales, IUGG is a provider of essential data.

The possibility of redefining UTC with the removal of the leap second has been extensively discussed over the past few years. The topic was one of the major items on the agenda of the 19th Consultative Committee for Time and Frequency meeting held in Sèvres, France, in 2012, and IUGG, like the International Astronomical Union and ITU, gave its views. IUGG has also received a formal request from ITU to express its opinion on the subject, and the outcome of discussions in an internal group set up to gather opinions from members of the IUGG community is given below.

UTC as a recommended international time-scale for geoscience

Geoscientists and others are faced with a multiplicity of time-scales — Barycentric Dynamical Time TDB), Terrestrial Dynamical Time (TDT), Geocentric Coordinate Time (TCG), Terrestrial Time (TT), International Atomic Time (TAI), Coordinated Universal Time (UTC), Global Positioning System (GPS) Time and others. The definitions and physical realizations of these time-scales differ, and some effort is required to achieve a clear view of their interrelationships.

IUGG considers that the adoption of a unique preferred international time-scale as a fundamental reference is very important. Like the generally accepted International Terrestrial Reference System, it would be highly desirable for the communities involved to agree on the choice of an international time-scale. At this stage, IUGG considers UTC to be the best choice, in particular because of the decisions already approved by countries through ITU, such as the link between UTC and legal time.

Redefining UTC

The discussion within IUGG concerning the possible redefinition of UTC presupposes the suppression of the leap second. This implies that UTC would be a uniform continuous time-scale strictly derived from International Atomic Time (TAI), and that the constraint on the value of UT1-UTC would be abandoned.

If redefinition is adopted as the way forward, it has several positive aspects that should be underlined. One is that UTC is continuous and uniform. In addition, the difference between UTC and GPS Time is more or less constant.

But there are also counter arguments. One is that if UTC is redefined, it would not provide a good estimate of UT1, although that difficulty could be overcome by making better direct estimates of UT1. Also, some people see the occurrence of a leap second as an opportunity to communicate and coordinate action with related organizations. IUGG will have to adopt a formal position, bearing in mind these points.

Estimating UT1

It is now technically possible to estimate UT1 to an accuracy of 0.001 second, which is a hundred times better than the estimates made using UTC. The International Earth Rotation and Reference Systems Service (IERS) provides the UT1 estimation service at present. IUGG recommends that this IERS service should be supported and provided with the necessary resources to guarantee its quality and continuance.

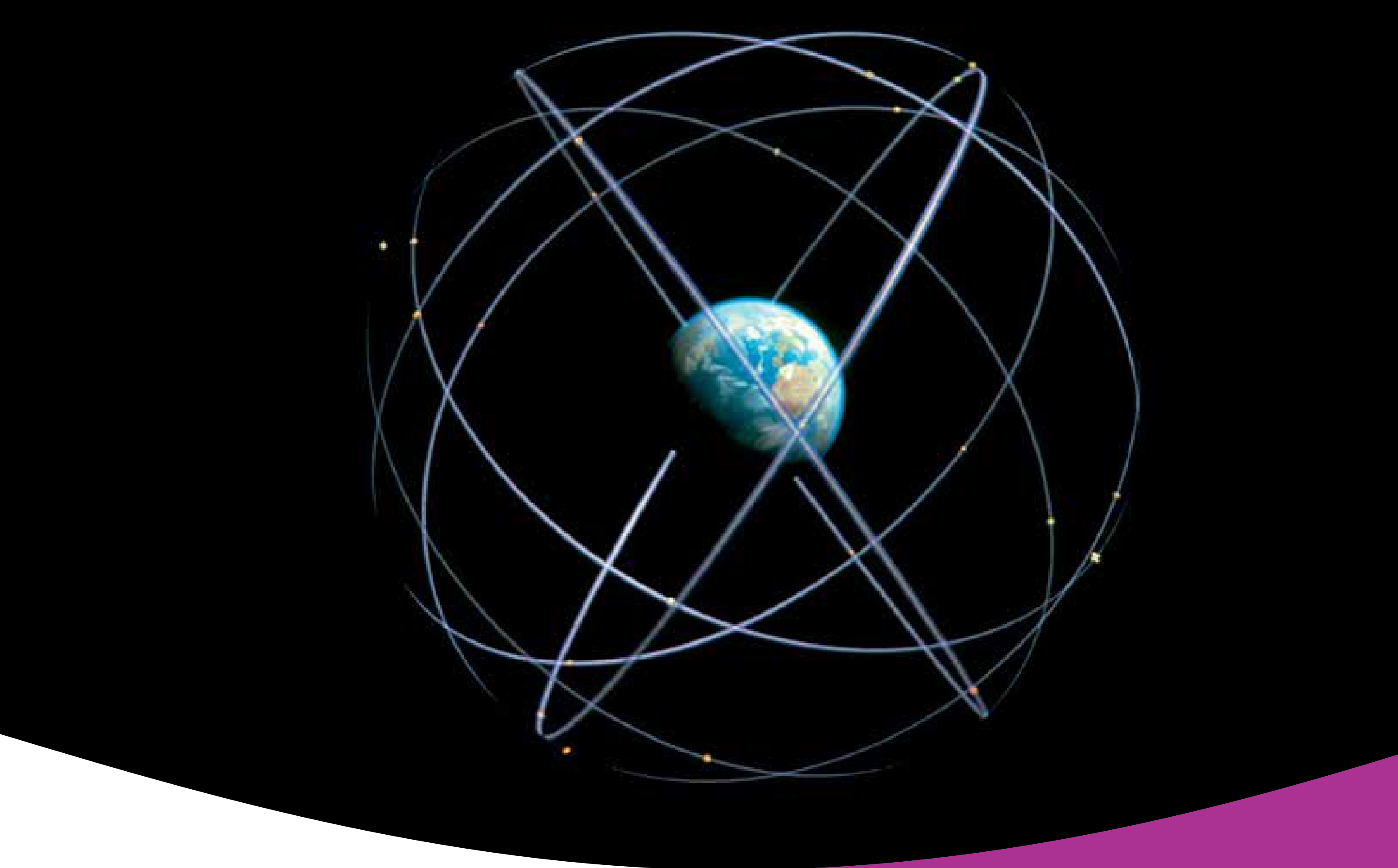
Role of global navigation satellite systems in disseminating Coordinated Universal Time

Global navigation satellite systems — such as GPS, GLONASS, and the upcoming BeiDou and Galileo systems — play a tremendous role in disseminating time-scales. In the opinion of IUGG, it is important to support the services provided by global navigation satellite systems in regard to time-scales. In particular, global navigation satellite systems provide the measurements and information required to achieve instantaneous synchronization at the nanosecond level. Furthermore, these systems broadcast the necessary information to estimate time according to the UTC scale.

The use of the global navigation satellite systems is therefore recommended as an important point to ensure the universal adoption of UTC.

The geoscience world

IUGG is the nongovernmental international organization dedicated to scientific research in all fields of geosciences (geodesy, seismology, volcanology, geomagnetism, the atmospheric sciences, oceanography, hydrology and so on).



Keystone/SPL/ESA/CE/EUROCONTROL

Artist's impression of the orbits of the Navstar satellites used in the Global Positioning System (GPS). The system uses a constellation of 24 satellites. Small ground-based receivers calculate the user's position by measuring the time it takes for signals to arrive from the satellites

IUGG includes various committees, as well as eight associations dealing with specific areas of geoscience: the International Association of Geodesy for geodesy; the International Association of Seismology and Physics of the Earth's Interior for seismology and internal geophysics; the International Association of Volcanology and Chemistry of the Earth's Interior for volcanology and geochemistry; the International Association of Geomagnetism and Aeronomy; the International Association of Meteorology and Atmospheric Sciences; the International Association of Hydrological Sciences; the International Association for the Physical Sciences of the Oceans; and the International Association of Cryospheric Sciences for ice studies.

IUGG and the International Astronomical Union jointly govern the International Earth Rotation and Reference Systems Service (IERS), while IUGG also governs several other international services, such as the International Global Navigation Satellite Systems (GNSS) Service.

IUGG is formally represented in the Consultative Committee for Time and Frequency, one of the consultative committees of the International Committee for Weights and Measurements (CIPM).

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What is in a name?

On the term Coordinated Universal Time

David Finkleman, Senior Scientist, Center for Space Standards and Innovation, Colorado, United States; and Kara Warburton Ph.D. Candidate, City University of Hong Kong

In this article we discuss a current proposal to introduce a new interpretation of the scientific meaning of time; more precisely, we discuss how this new interpretation should be "named" to protect the interests of the scientific and technical community that deal with time measurements.

The definition and use of the term *Coordinated Universal Time* is more than a technical matter. Practical considerations are as important as technical requirements because using and applying accurate and precise time measurements are critical to many fundamental applications — not just knowing "what time it is." Clarity of the meaning of the term is one of the most important practical requirements. We maintain that if the definition of Coordinated Universal Time is changed to remove the essential connection between that time-scale and synodic benchmarks, the term Coordinated Universal Time, abbreviated UTC, cannot be used to refer to the revised time-scale that is disconnected from Earth rotation.

Background of the issue

Coordinated Universal Time was conceived to accommodate a time-scale based on virtually invariant seconds quantified according to frequencies of energy level transitions in stable matter while sustaining the significance of time as a measure of Earth rotation relative to virtually stationary and well characterized inertial references. The leap second is the best known characteristic of UTC as defined in the ITU Radiocommunication Sector's (ITU–R) 460 series of Recommendations to date. The rationale for the leap second and the more precise corrections to UTC available in broadcasts to all in the world is well understood, and the procedures for accommodating leap-second insertions are well codified. Nonetheless, many who do not rely on time synchronized with Earth rotation find the insertion cumbersome and disruptive. Those who feel burdened have petitioned ITU–R to eliminate the leap second from the definition of UTC, most recently in the World Radiocommunication Conference in 2012 (WRC-12). A decision was deferred so that Member States could be better informed. Preparations for reengagement at WRC-15 are ongoing.

Statement of the terminological problem

Noted terminological authorities have examined and judged proposed changes to the definition of UTC. Authoritative rulings were distributed at WRC-12 and submitted through official channels to ITU study groups. The normative terminological position is that the changes proposed, particularly deprecating the connection between UTC and Earth rotation, would create polysemy if the term to designate this changed definition were not also changed. Polysemy can lead to a state of confusion because the same term is used to designate quite different things in the same context. In the case of UTC, if a new term is not introduced to name the new concept, there will be two different interpretations of the concept of time, both designated by UTC: (a) time aligned with Earth rotation embodied with leap seconds and more precise corrections now commonly available and (b) time without any connection to Earth rotation. Proleptic analyses common in astronomy, astrodynamics, religion, and many other fields of endeavour will be confounded. Uncountable reference documents and currently authoritative sources will be ambiguous. Apart from cogent technical objections to deprecating Earth rotation, this lack of terminological clarity alone will have significant practical, societal, and legal consequences. We maintain that a new technical interpretation of the fundamental notion of time must be accompanied by terminological rigour if it is adopted.

How terminology as a discipline can contribute

Terminology is a branch of linguistics that includes work in lexicography, translation, technical writing, knowledge modelling and content management. As a discipline, terminology is concerned with understanding the nature of concepts in specialized fields of activity and their relationships with the terms that denote them. Terminology draws on normative and highly developed principles and methods embodied in the International Organization for Standardization (ISO) Technical Committee 37 (TC37) and its core of professional terminologists. These professionals make all endeavours more effective with transparent and meaningful terms that serve well in almost all languages.

TC37 standards prevail with the same rigour, consensus, and international confirmation as all ISO standards and practices. But in addition, of the 279 technical committees in ISO, TC37 is one of only 11 that have attained the special status of being a "horizontal committee". A horizontal committee helps other technical committees achieve standardization in their respective fields. According to ISO, "Consultation with these committees, or their documents, is advisable if you face difficulties in any of the relevant subject areas." With regard to TC37, ISO further states:

"Terminology plays a vital part in all standardization efforts; it (standardization) can only work if everybody understands what is being talked about. Clear, consistent and coherent standards first of all need clear and consistent terminology. ISO/TC37 develops the principles and methods for developing terminology to facilitate expert communication. If you face difficulty with a particular term and need to define it properly, the rules set by TC37 can help."

A *term* is a linguistic expression that denotes a concept in a *special language* (domain, or subject field). In contrast to words from *general* language, a key property of terms is their single-meaning relationship (called *monosemy*) with the specialized concept that they designate and the stability of the relationship between linguistic form and content in texts dealing with this concept (called lexicalization). Monosemy and lexicalization are fundamental tenets and inviolable principles of normative terminology.

Terminologists discriminate terms precisely from vocabulary in general. The characteristics of a term include the following:

- It is consistently associated with the same concept.
- It is consistently used within a particular subject field.
- It has only one meaning within that subject field.

The terms *Coordinated Universal Time* and *UTC* meet all of these criteria; hence, their meaning and use must be governed by normative terminological rigour. Furthermore, given the highly specialized nature of the field of precise time measurement and the use of measured time across a wide range of applications, these terms are among the most highly "terminological" that one could find in language. In this particular case if any, the application of rigorous terminological principles should not be questioned.

What are the terminological principles that govern the designation and use of a term? Besides being recognized by the same set of semantic features and by its definition, a specialized concept is also recognized by the stability of its association with the term used to designate it. In turn, a term may be recognized as such by virtue of its stable pairing with the same set of semantic features that distinguish the concept from others. This stability is sometimes called "degree of lexicalization" and sometimes "degree of terminologization". The lack of such stability leads to "cognitive fuzziness", as in polysemy and synonymy. Concept-term stability is preserved in the single-concept principle so fundamental for terms in highly specialized scientific and technical fields that depend on absolute clarity.

Retaining the term and abbreviation *Coordinated Universal Time* and *UTC* for a newly introduced concept, a time-scale unrelated to Earth rotation, violates these principles and creates terminologically unarguable polysemy. This was judged authoritatively in documents and evidence presented officially to ITU–R.

Example of a real terminology problem

An example of a real terminology problem may help to demonstrate the importance of applying rigorous terminology management principles to such an important concept as that of time measurement. The term *data type* (sometimes written *datatype*) has been adopted in various technical fields — even very closely related ones — with different meanings. The following is just a small selection of the different definitions that one can find:

1. A set of distinct values, characterized by properties of those values, and by operations on those values (ISO 11179-1 — Information Technology — Metadata Registries).
2. A classification identifying one of various types of data, such as real-valued, integer or Boolean, that determines the possible values for that type (Wikipedia, Computer Science).
3. A classification of individual data points (Statistics).
4. Structural metadata associated with digital data that indicates the digital format or the application used to process the data (M.I.T. Press, Digital Libraries).
5. A string that specifies the format of data that a printing application sends to a printer in a print job (Printing).

Even within the field of computer science, there are different interpretations of the meaning of this term depending on the computing language, for instance:

6. A set of possible values, together with all the operations that know how to deal with those values (Perl programming).
7. A set of rules describing a specific set of information, including the allowed range and operations and how information is stored (Visual Basic programming).
8. A 3-tuple consisting of: a set of distinct values, called its value space; a set of lexical representations, called its lexical space; and a set of facets that characterize properties of the value space, individual values or lexical items (XML).

To complicate matters further, the term *data element type,* that could be perceived as a variant of *data type,* has yet another meaning in computational linguistics — an elementary descriptor used in a linguistic description or annotation scheme (ISO TC37). Yet this concept is also denoted by the term *data category.* To the uninitiated, the term *data category* and *data type* could be misconstrued as synonyms. Even more confusing, the concept of "a range of possible values", corresponding to definitions (1) and (6) above, if not more, is also denoted by yet another term, *value domain* (ISO TC37, ISO TC29, ISO 11179).

This example demonstrates both polysemy (when one term has multiple meanings) and synonymy (when different terms have the same meaning), within a relatively confined subject area or family of related subject areas (computing, information technology, digital libraries, statistics, and so on). As a result of this terminological imprecision, one finds that to avoid ambiguity the terms involved are defined in almost every document where they are used. (Or worse, they are not defined at all and the user is left to guess the meaning.) This results in a proliferation of different definitions, as noted above, meaning that outside of a given context the term *data type* has no identifiable meaning at all.

Keystone/SPL/AJ Photo

Checking laptop performance following the insertion of a leap second in UTC

Proposal

ISO TC37 submitted a proposal to the Radiocommunication Assembly in 2012 aimed at addressing the term Coordinated Universal Time. By edict of ISO, the standards developed by ISO TC37 are "normative" (mandatory) across the 279 ISO technical committees, which govern virtually all scientific and technical domains of human activity. This means that terminological rigour is recognized as essential for effective communication in specialized domains, and this is why ISO designated TC37 as a horizontal committee. The following quote (slightly edited) summarizes TC37's recommendation well:

Rather than changing the meaning of an existing term (…), a new concept (meaning), or a shift in concept, should be designated by a newly coined term.

TC37 presented convincing arguments as to why UTC should *not* be used to refer to a newly introduced concept of time. But it also sanctioned a proposal for a new term already submitted to ITU–R in 2003, namely, *Temps International (TI),* or *International Time* in English. As explained in the proposal, this term transparently conveys the desired meaning of an international standard measurement of time while presenting no conflicts with the terms for the various existing time measurement protocols. Furthermore, it resembles the term *International Atomic Time (TAI),* which is advantageous since the two terms represent almost identical concepts.

Summary

We have described briefly the concepts, principles, and standards of normative and rigorous terminological science. We have further demonstrated that if, alongside the concept long embodied in UTC, a totally different concept divorced from Earth rotation is introduced, the new concept cannot adopt the now ubiquitous UTC term. After demonstrating the authoritative status of ISO TC37 in terminology matters, we presented a proposal from ISO TC37 to coin a new term for the new concept, namely *Temps International*. As authors of this article, we support this proposal, but we also welcome alternatives.

Precision timing. A satellite, train and plane show synchronization with a digital time display accurate to several decimal places. This level of accuracy is needed for global positioning satellite systems to precisely locate fast-moving trains and aircraft

Keystone/SPL/Smetek

Global navigation satellite systems and their system times

W. Lewandowski, International Bureau of Weights and Measures

The International Bureau of Weights and Measures (*Bureau International des Poids et Mesures — BIPM)* is in charge of computing the international reference time-scale known as Coordinated Universal Time (UTC). It is derived from a uniform and continuous time-scale, called International Atomic Time (*Temps Atomic International* — TAI), by applying a correction of an integral number of seconds. UTC is the sole reference time-scale for coordinating the world's time. It serves as the basis of legal time in many countries.

Global navigation satellite systems (GNSS) rely on precise time to enable accurate ranging measurements for positioning, which in turn requires consistent intra-system synchronization. For this purpose GNSS use the following internal reference time-scales, constructed from clock ensembles: GPS Time, GLONASS Time, Galileo System Time (GST) and BeiDou System Time.

These system times are pseudo time-scales and should be regarded as being merely internal GNSS technical parameters and not as time-scales to be used as a reference for other human activities.

Usually, system times are steered to an external stable reference time-scale. For example, GPS Time follows UTC(USNO) modulo one second via its local representation at the United States Naval Observatory. But UTC is a stepped time-scale because of its discontinuity resulting from the use of leap seconds. In particular for the purposes of safety of life services, some providers of global navigation satellite system services have preferred to adopt alternative continuous (unstepped) time-scales. This is causing difficulties for designers of global navigation satellite systems because there is no ideal way of choosing a reference epoch for numbering the seconds of alternative continuous time-scales.

Confusion reigns

The various approaches chosen by providers of global navigation satellite system services, and the relationship between these system times and UTC can be seen in Figure 1.

GPS Time is continuous and is not adjusted for leap seconds. It was set on 6 January 1980, at 00:00 UTC to have zero seconds difference from UTC. GPS Time is 19 seconds behind TAI, and — because of the leap seconds added to UTC — is now (in 2013) 16 seconds ahead of UTC.

GLONASS Time, unlike GPS Time, follows UTC seconds and thus is not a continuous time-scale. Galileo System Time (GST) is continuous and has the same initial epoch as GPS Time. In the early stages of defining the Galileo system, a preliminary decision was taken that GST would use TAI as reference. But bearing in mind that TAI is not intended for general dissemination, the designers of the Galileo system considered that setting the internal time-scale of Galileo to TAI would cause confusion. The final decision was to set to zero the second difference between GST and GPS Time.

BeiDou System Time is continuous and was set on 1 January 2006 at 00:00 UTC to have zero seconds difference from UTC. Thus BeiDou System Time is 33 seconds behind TAI, and is now (in 2013) 2 seconds ahead of UTC.

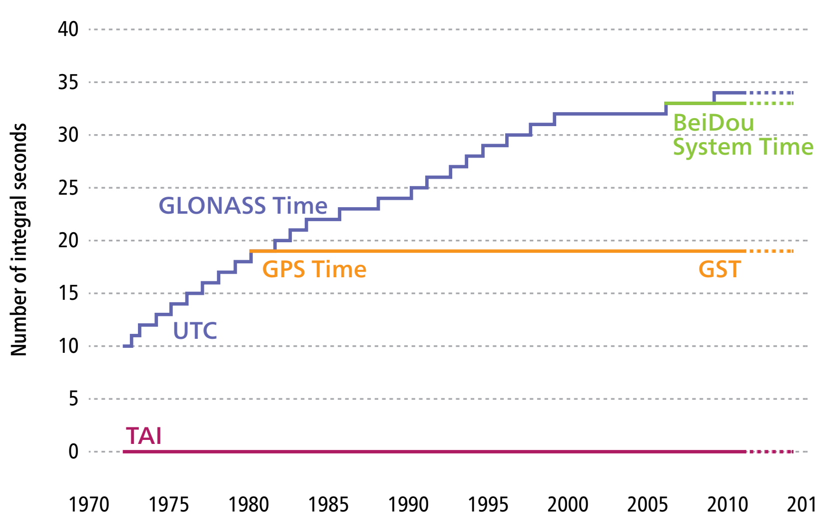
Because UTC is a stepped time-scale, the continuous internal time-scales of global navigation satellite systems become alternative time-scales for some applications. For example, the International GNSS Service (IGS) uses GPS Time for tagging some of its products.

The use of these continuous internal time-scales of global navigation satellite systems is leading to confusion among users, because the various scales differ by tens of seconds. Galileo provides an example of the potential for confusion. Some parts of the Galileo system are tagged to GST, while other parts are tagged to UTC. The greatest difficulty occurs crossing 00:00 (midnight), when for a period of 16 seconds various parts of the system refer to two different days. This may lead to major mistakes.

Pragmatic precision

Although the internal time-scales of global navigation satellite systems do not need to be synchronized to the international standard UTC to meet the needs of navigation, there would be an obvious benefit

Figure 1 — Relationship between different time-scales (differences in an integral number of seconds): International Atomic Time (TAI); Coordinated Universal Time (UTC); GPS Time; Galileo System Time (GST); BeiDou System Time; and GLONASS Time



Checking time on a smartphone following insertion of a leap second in UTC

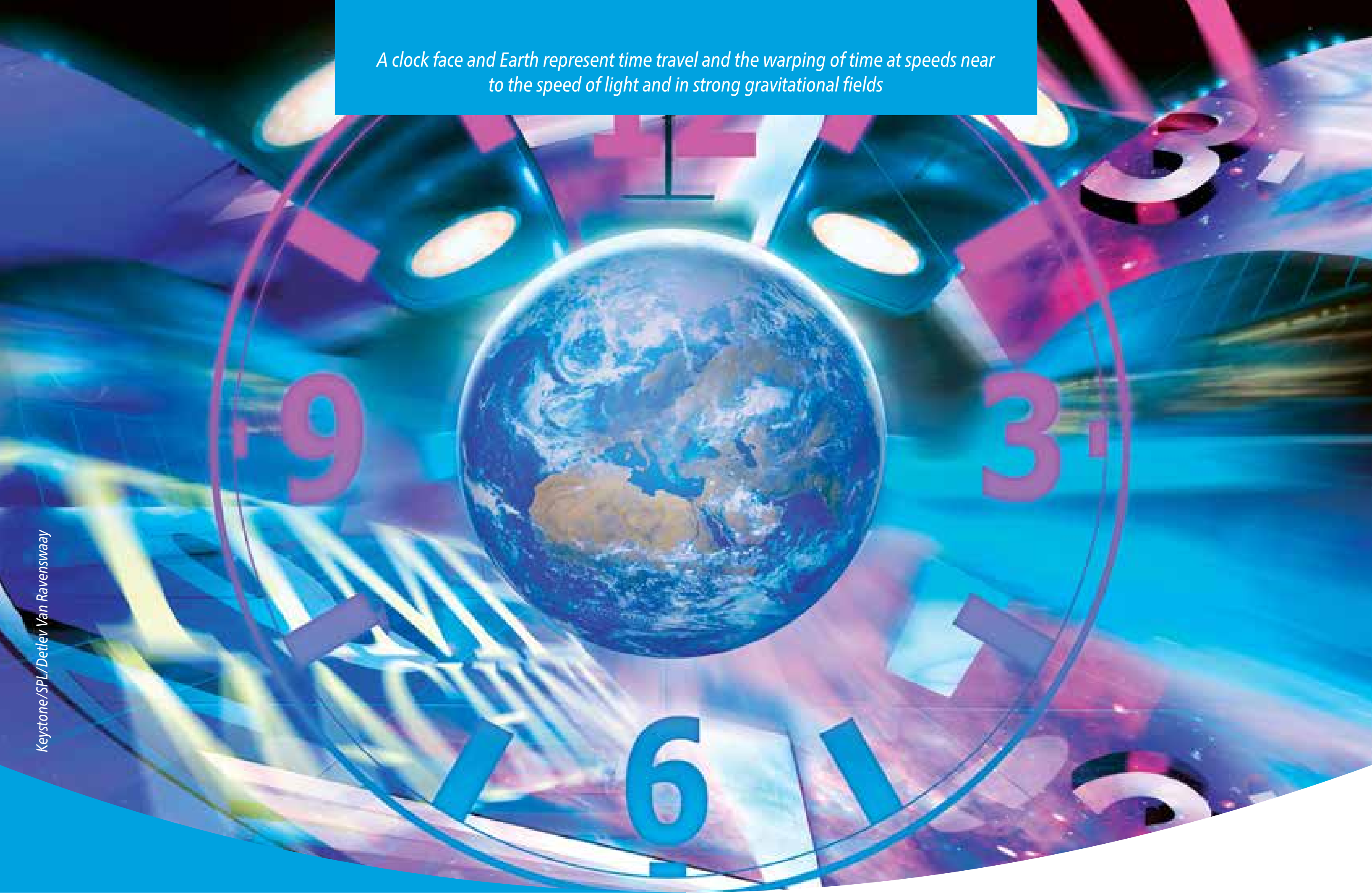
in international coordination to simplify the operation of these systems and allow for their interoperability. This is reflected in the recommendations of the Consultative Committee for Time and Frequency (Recommendation S6-1999) and of the International Committee for Weights and Measures (Recommendation 1 CI -1999). It is also one of the tasks of the International Committee on Global Navigation Satellite Systems.

Today, the global navigation satellite systems represent by far the most common means of obtaining precise UTC. The GPS and GLONASS service providers disseminate corrections to their internal system times to obtain predictions of UTC as maintained at the United States Naval Observatory (UTC(USNO)) and the national time-scale of the Russian Federation (UTC(SU)), respectively. Galileo will also broadcast a physical realization of UTC, as most likely will other systems too. GPS currently broadcasts a prediction of UTC(USNO) which agrees to within a few nanoseconds with actual UTC(USNO), and UTC(USNO) agrees to within a few nanoseconds with actual UTC. This means that GPS broadcasts a prediction of UTC worldwide with an uncertainty of several nanoseconds. At present, GLONASS predictions have an uncertainty of hundreds of nanoseconds, but their accuracy is likely to be improved in the near future through appropriate calibrations.

Time to leave leap seconds behind?

Leap seconds cause difficulties to modern infrastructure, in particular to global navigation satellite systems. Also, celestial maritime navigation can now do without leap seconds, so that argument for keeping leap seconds is no longer valid.

Within ITU's Radiocommunication Sector (ITU–R), consideration is being given to revising the definition of "Coordinated Universal Time". ITU–R is also working on a recommendation that may lead to a new continuous time-scale.



A clock face and Earth represent time travel and the warping of time at speeds near to the speed of light and in strong gravitational fields

Keystone/SPL/Detlev Van Ravenswaay

Space odyssey

Time-scales and global navigation satellite systems

Han Chunhao, Beijing Satellite Navigation Center

In the large-scale space-time continuum around the Earth, a global navigation satellite system is in reality a system for the precise measurement of time.

A global navigation satellite system usually consists of three segments: a space segment (the satellite constellation); a ground control segment (a master station, uplink stations and monitor stations); and a user segment (user receivers). The basic observables are pseudo-ranges, which are defined as the product of the speed of light multiplied by the observed signal travel time (the time difference of the clocks) between the signal source and the observer. All navigation information, such as satellite orbits, clock offsets and ionospheric time delays, are obtained by using these time observables.

Satellite clocks

Given the large scale of space-time involved in satellite trajectories (about 1×10^5 km in space, and several days or even months or years in time) and the precision requirements (accuracy to the 1 metre or even 1 centimetre or 1 millimetre level), the data processing for global navigation satellite systems must be dealt with in the framework of relativity and quantum theory.

There are two kinds of conceptually different time-scales in global navigation satellite systems. These are proper times and coordinate times. Essentially, the observed space interval and time interval between any two events is dependent on the observer. The time readings given directly by ideal clocks located onboard satellites, in stations or by observers are proper times. These are related to the observer — in other words to the space-time environments of the clocks. This means that different observers have different clock times because of their relative velocity and position in the gravitation field.

In order to have a common time reference for all observers, we must choose a special observer and construct a reference system. A reference system contains a three-dimensional space reference frame and a time reference. The former determines the spatial position (with three space coordinates) of an event, the latter gives the happening time, which is called coordinate time.

An engineer in the timekeeping lab poses in front of a clock showing Beijing Time at 07:59:60 next to another clock showing Coordinated Universal Time (UTC) at 23:59:60 at the National Time Service Centre of the Chinese Academy of Sciences in XiAn city, China, on 1 July 2012. An extra second (leap second) was added to the world's atomic clocks on Saturday (30 June 2012) as they underwent an adjustment to keep them in step with the slowing rotation of the Earth. On that night, atomic clocks read 23 hours, 59 minutes and 60 seconds before moving on to midnight UTC

Keystone/SPL/Mark Williamson

Standard time zone clock in the lobby of the News Building in New York

A non-rotating geocentric reference system is used to describe the orbits of Earth satellites, and these are the type of satellites included in global navigation satellite systems. The reference time is usually the geocentric coordinate time or the terrestrial time. Both the geocentric coordinate time and the terrestrial time can be deemed to be the proper time of the observer located at the geocentre, but subject to a different gravitation potential. The geocentric coordinate time supposes that there is no Earth gravitational potential or that the observer is not affected by it. In contrast, the terrestrial time supposes that the observer is subject to a gravitational potential equivalent to that on the geoid (the surface of the ocean as shaped by the influence of the Earth's gravity and rotation alone) or at mean sea level.

Telling the time

The system times of global navigation satellite systems, such as GPS Time, GLONASS Time, Galileo Time and BeiDou Time, are different realizations of terrestrial time. It should be noted that a system time is used only within the system itself, being designed simply for the convenience of system operation. It is impossible to make all the system times the same. However, in order for the system to realize the function of time service, the time offset relative to Coordinated Universal Time (UTC) must be given (with some predetermined uncertainty) in the navigation data broadcast by the global navigation satellite system. Here UTC is the unique choice because it is the standard for civil time all around the world.

Sunrise and sunset

Obviously, having to insert the leap second at irregular periods in UTC is troublesome. For the operation of global navigation satellite systems in particular, the leap second is inconvenient both in regard to timekeeping and time service. Specialists in other technical fields — such as communications and transport — would probably have the same viewpoint.

But we must bear in mind that UTC is used not only in science and technology, but also in every aspect of society. Simply eliminating the leap second means conceptually that UTC has no relation to solar time. Yet sunrise and sunset have always been the natural foundation of civil time.

It should however also be noted that the term "day" as used today is not the real solar day but the mean solar day, as defined at the end of 19th century. We know that the equation of time (the difference between apparent solar time and mean solar time) can reach 16 minutes. In contrast, the current time difference between International Atomic Time (TAI) and Universal Time (UT1, an astronomical time-scale defined by the Earth's rotation used in celestial navigation) is 35 seconds. In the past 40 years, 25 leap seconds have been inserted in UTC. This counters the argument that we could not accept UTC without leap seconds as a civil time, given that even today UTC is not exactly the same as solar time.

The time difference between TAI and UT1 is mainly caused by the deviation of the SI second relative to the mean solar day. All 25 leap seconds are positive; this means that the offset of the SI second is about 1.98×10^{-8} referred to the average solar second. If the definition of SI second could be modified, however, that difference could become even smaller.

In any event, UTC — however defined — should still have some relation conceptually to UT1 as a civil time. The velocity of the Earth's rotation is changing. Maybe in the future the length of a day will change to 86 401 seconds or even longer. What should we do if this happens? This is a good reason for maintaining conceptually some coordinate relationship between UTC and UT1.

New ways of defining Coordinated Universal Time

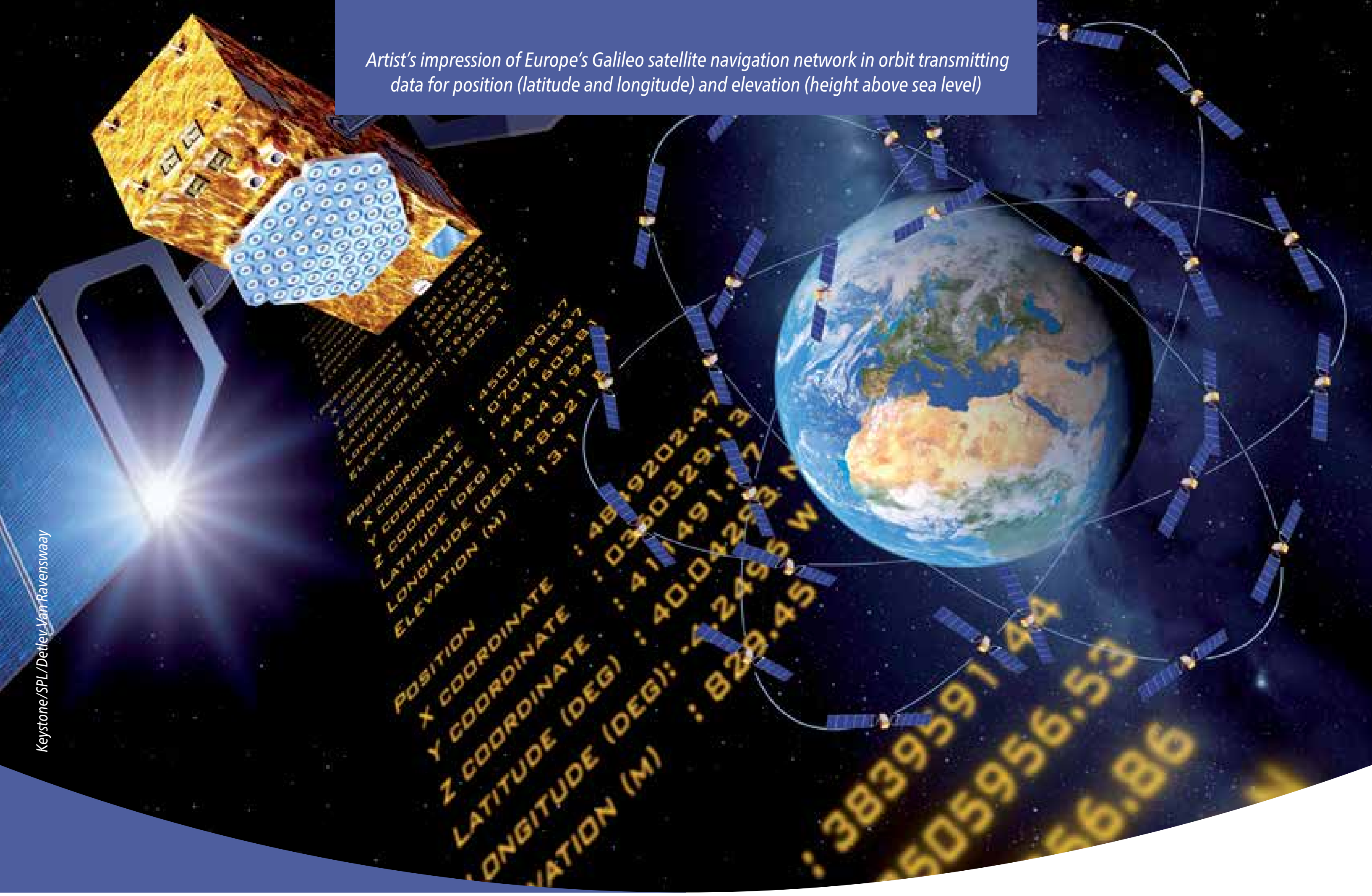
Other than providing the standard for civil time, UTC also plays the role of representing the approximate value of UT1 (the difference between UTC-UT1 is kept within 0.9 second). If the leap second is eliminated, this difference will no longer be limited.

Some people are not in favour of the leap second, arguing that it requires software to be modified. For ground systems, software modification is neither complex nor particularly expensive. But for some space systems, this may not be the case.

The redefinition of Coordinated Universal Time is a matter of great significance. Stopping the leap second would be convenient for most users. But the name of UTC and the related time zones should not be changed, in order to keep some conceptual link with UT1 or solar time. It would be preferable to establish some clear and definite relation between UTC and UT1, for example requiring the phase difference between them to be less than some fixed value (such as 10 minutes), or the relative frequency offset to be less than 1×10^{-7} (about 10 milliseconds in a period of 24 hours).

One option would be to add a leap minute at the end of a century. Indeed, various approaches are possible that would eliminate leap seconds for a sufficiently long period in the foreseeable future.

If UTC were to be redefined in such a way as to stop inserting leap seconds, then global navigation satellite systems should compensate by broadcasting Earth orientation parameters. Indeed, this may be a better way for users to obtain information on the Earth's orientation. In that case, global navigation satellite systems could provide not only a position, navigation and timing service, but also an Earth orientation service.



Artist's impression of Europe's Galileo satellite navigation network in orbit transmitting data for position (latitude and longitude) and elevation (height above sea level)

Keystone/SPL/Detlev Van Ravenswaay

Galileo and Coordinated Universal Time leap seconds

Jörg Hahn, ESA/ESTEC, Galileo System Engineering Manager

Galileo is Europe's own global navigation satellite system designed to provide a highly accurate global positioning service under civilian control. It will be interoperable with the current Global Positioning System (GPS) of the United States and GLONASS of the Russian Federation.

The first two of four operational satellites designed to validate the Galileo concept in both space and on Earth were launched on 21 October 2011. The two others followed on 12 October 2012. This in-orbit validation phase will be followed by additional satellite launches to reach initial operational capability by the middle of this decade.

In the initial stage of Galileo's operation, preliminary versions of the open service, search and rescue service, and public regulated service will be available. Then as the constellation is built up beyond that, new services will be tested and made available until the system reaches full operational capability.

Two Galileo control centres in Europe — one in Fucino (Italy) and the other in Oberpfaffenhofen (Germany) — control the satellites and manage navigation. The data provided by a global network of Galileo sensor stations will be sent to the

Galileo control centres through a redundant communication network. The control centres will use the data from these stations to compute the integrity information and to synchronize the time signal of all satellites with the ground station clocks. The exchange of data between control centres and satellites will be performed through up-link stations.

Galileo System Time

Satellite navigation requires highly accurate measurement of signal travel times. Galileo's own internal reference time system is known as Galileo System Time (GST). It is used for synchronizing all Galileo clocks, including those in the ground segment, on satellites, and in receivers. The broadcast navigation messages are also time-tagged with GST.

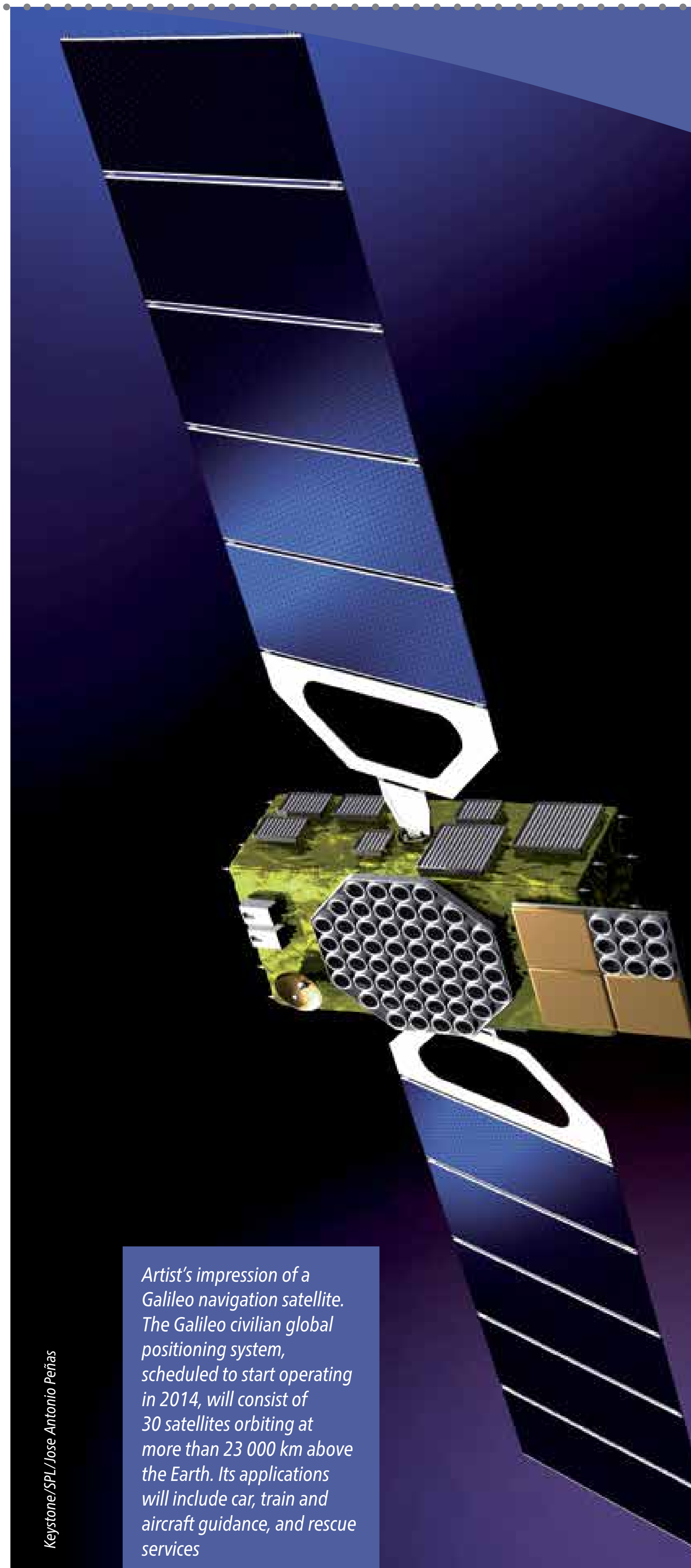
GST is a continuous time-scale steered to Coordinated Universal Time (UTC), modulo 1 second. GST is not subject to leap seconds. The Galileo Time Service Provider links GST to UTC, relying on data from the European timing laboratories.

How Galileo System Time is generated

GST is generated by the Galileo ground mission segment from a set of high-precision atomic clocks in Fucino and Oberpfaffenhofen in the two Precise Time Facilities operating in hot redundancy. Each Precise Time Facility is equipped with two active hydrogen masers and four high-performance caesium clocks.

The Galileo Time Service Provider collaborates with the European timing laboratories to transform GST into UTC for dissemination purposes, and keeps Galileo informed of the difference between the International Atomic Time (TAI) and UTC, as well as of any leap-second announcements.

During the in-orbit validation phase, the Galileo Timing Validation Facility took on the role of time service provider. This facility is located at the National Institute of Metrological Research *(Istituto Nazionale di Ricerca Metrologica),* Turin, Italy, and is supported by the UTC laboratories of Germany, France, the



Keystone/SPL/Jose Antonio Peñas

Artist's impression of a Galileo navigation satellite. The Galileo civilian global positioning system, scheduled to start operating in 2014, will consist of 30 satellites orbiting at more than 23 000 km above the Earth. Its applications will include car, train and aircraft guidance, and rescue services

United Kingdom and Spain. GST is continuously compared with the national realizations of UTC via the two-way satellite time and frequency transfer (TWSTFT), and the GPS Common View service.

The key performance requirements are that the difference between GST and UTC shall be estimated with an accuracy better than 28 nanoseconds (95 per cent of the time), and shall be less than 50 nanoseconds (modulo 1 second) for 95 per cent of the year. Some early performance results show that, between February and March 2013, the difference between GST and UTC was kept within a few nanoseconds.

Dissemination of UTC through Galileo

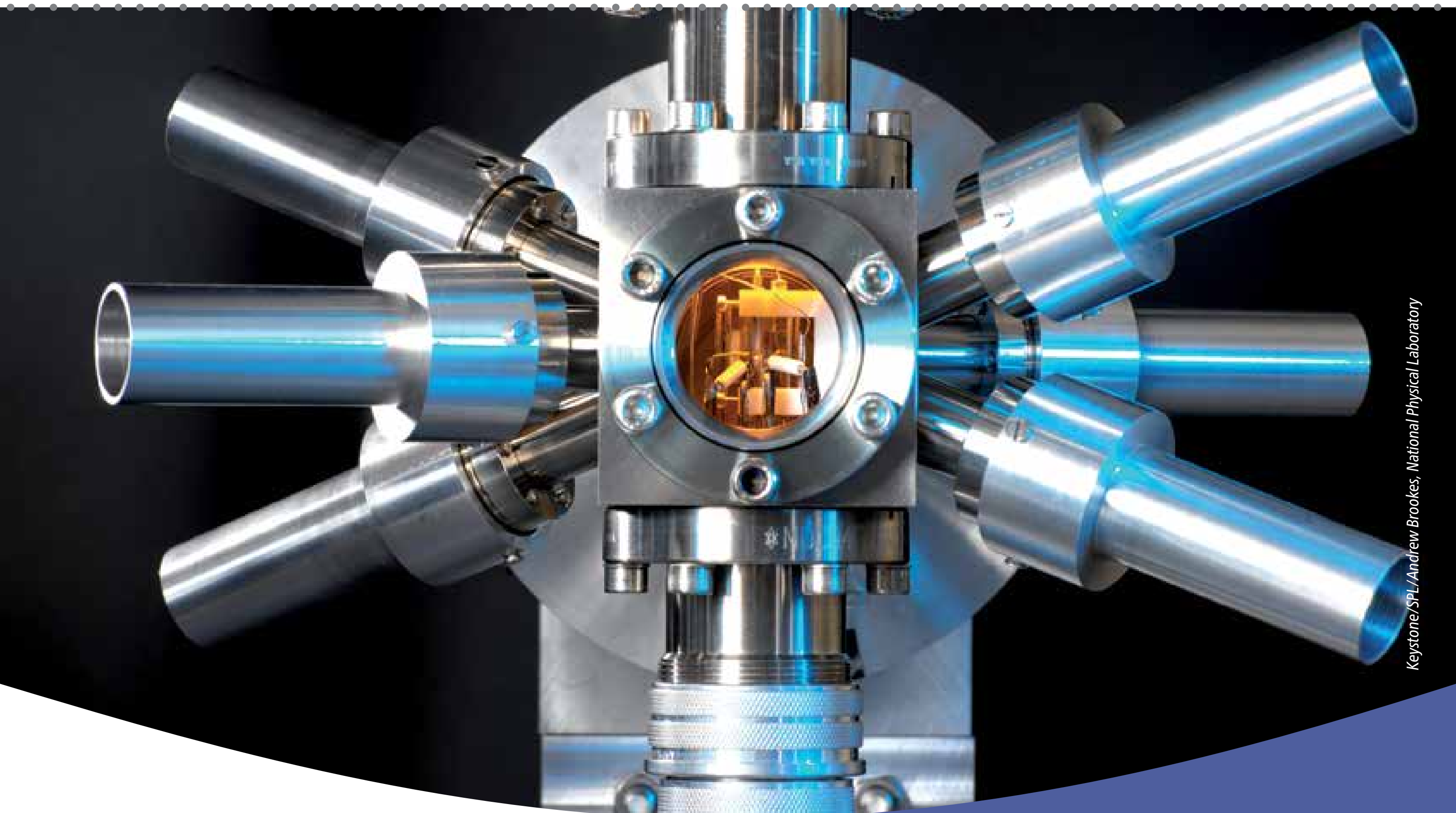
Galileo provides both positioning and timing capability. It disseminates UTC in accordance with Recommendation ITU–R TF.460-6. Thus the Galileo navigation message includes GST-to-UTC conversion parameters, including the total number of leap seconds, an announcement of the introduction of any new leap seconds with the associated date, and the fractional GST-UTC offset. The GST-to-UTC transformation parameters are computed and updated daily by Galileo facilities.

Galileo users will be able to estimate GST from the signal-in-space and, by applying the transformation parameters, obtain UTC for time-tagging their applications. For the vast majority of navigation and timing users, the user position needs to be expressed in Earth-fixed coordinates and the corresponding time tag will be expressed in UTC. Some specialized applications, such as astronomy, may require access to Universal Time.

Galileo Control Centre in Fucino (Italy)

ESA

Galileo Control Centre in Oberpfaffenhofen (Germany)



Keystone/SPL/Andrew Brookes, National Physical Laboratory

Strontium optical clock, with an ion trap (centre) used to provide an optical frequency reference. The strontium optical clock is believed to be three times more accurate than any timekeeping device previously achieved. Optical clocks offer potential advantages for global satellite navigation systems

Impact of leap seconds on Galileo

Galileo facilities are synchronized to GST, which is also used for time tagging most of the Galileo data. However, Galileo still uses UTC in time tagging where required by international formats, for example the GPS Common View data, or the ITU format for TWSTFT data.

Most of the data provided to Galileo by external service facilities — such as the Time Service Provider, the Geodetic Reference Service Provider, and the Return Link Service Provider — are time tagged on UTC. These external service facilities also use UTC for synchronizing their computer networks. Galileo operators use UTC as the reference time for operational planning and event recording.

Galileo is designed to work with leap seconds, and their application is automated. Nevertheless, a new leap second still involves several human actions, for example: updating the default configuration of all elements of the system using the UTC conversion protocol; verifying that the leap second is applied in all elements of the system, including synchronization to UTC of individual pieces of equipment; and verifying that the leap second is applied in the operator's environment.

These actions may involve human errors, jeopardizing the reliability of the system. Abolishing the leap second would simplify system operations and make them more robust. Leap seconds are undesirable in terms of system operations. If leap seconds were discontinued, however, Galileo would have to update the corresponding interfaces.

Whatever the outcome regarding the leap second, however, Galileo would continue to follow international standards and recommendations.

GLONASS and Coordinated Universal Time

Igor V. Zheltonogov, D. Aronov and S. Sorokin, Geyser-Telecom, Russian Federation

The purpose of the Russian Federation's Global Navigation Satellite System (GLONASS) is to provide an unlimited number of air, marine and other users with all-weather three-dimensional positioning, velocity measurement and timing anywhere in the world or in near-Earth space.

GLONASS has three components: a constellation of satellites (space segment); ground-based control facilities (control segment); and user equipment (user segment). The current GLONASS constellation is composed of 29 satellites, of which four are in reserve and one is in testing mode. The most recent launch was on 26 April 2013.

GLONASS Time

Currently, the GLONASS system implements a time-scale with the leap second, in accordance with international standards (Recommendation ITU–R TF.460-6).

The GLONASS time-scale is periodically corrected simultaneously with the Coordinated Universal Time (UTC) leap-second insertions, which are made following announcement by the International Earth Rotation and Reference Systems Service (IERS).

GLONASS users are notified in advance (at least three months before) of these planned leap-second corrections (including their value and sign) through relevant bulletins, notifications and so on. The GLONASS satellite navigation messages themselves do not include any data concerning the UTC leap-second correction.

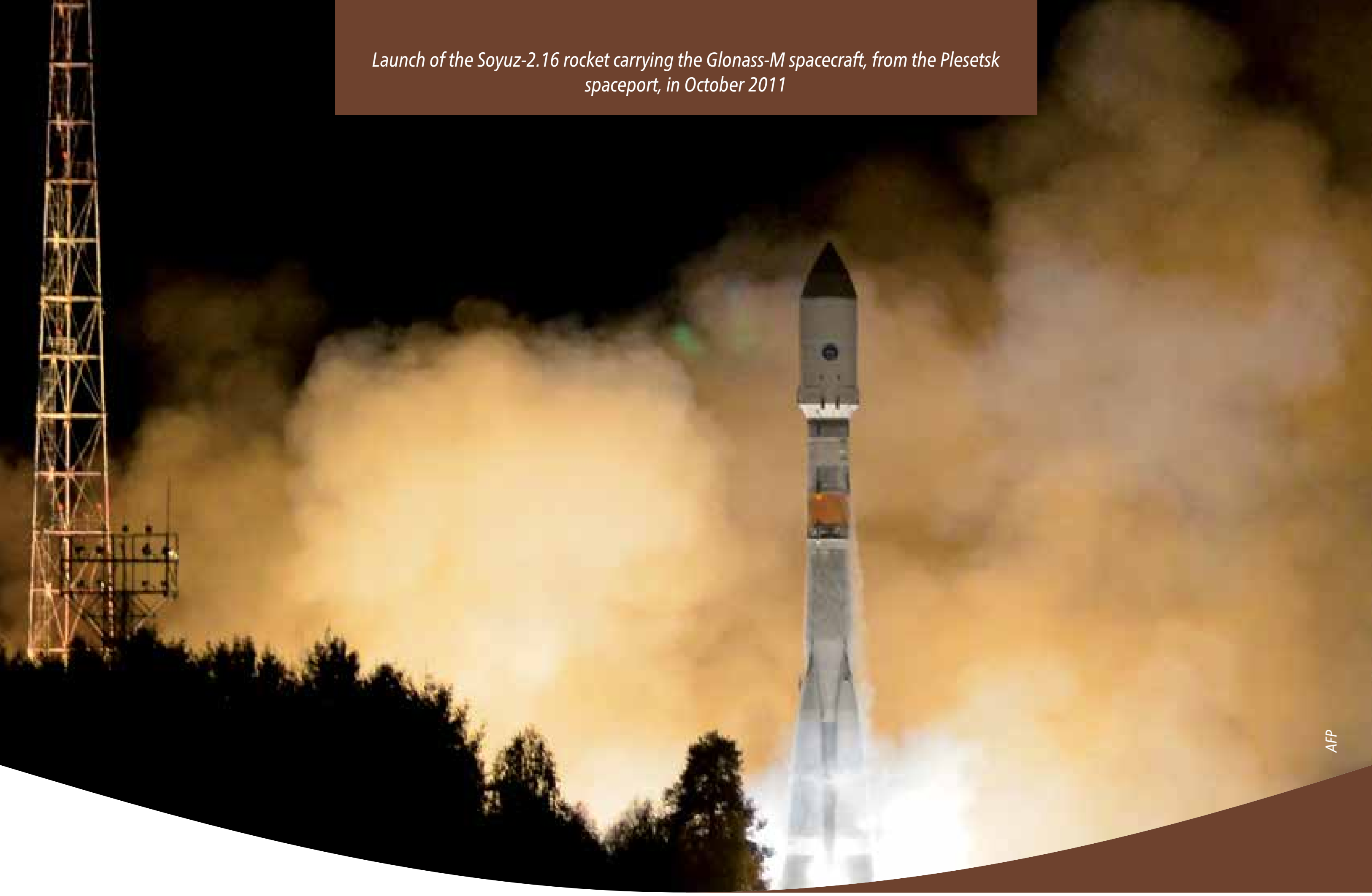
Typically, these corrections (±1 second) are performed once a year (or 1.5 years) at midnight 00 hours 00 minutes 00 seconds UTC from 31 December to 1 January (or from 31 March to 1 April or from 30 June to 1 July or from 30 September to 1 October) simultaneously by all UTC users.

As a result of the periodic leap-second corrections, there is no integer-second difference between GLONASS Time and the UTC (SU) time-scale maintained by the Russian Federation. However, there is a constant three-hour difference between these two time-scales.

The GLONASS view of changing the time-scale

The World Radiocommunication Conference in 2012 (WRC-12) decided that WRC-15 should, under its Agenda item 1.14, consider redefining Coordinated Universal Time (UTC).

Under this agenda item, and in accordance with Resolution 653 (WRC-12), ITU–R is conducting the necessary studies on the feasibility of achieving a continuous reference time-scale for dissemination by radiocommunication systems. ITU–R is also studying issues related to the possible implementation of a continuous reference



Launch of the Soyuz-2.16 rocket carrying the Glonass-M spacecraft, from the Plesetsk spaceport, in October 2011

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time-scale (including technical and operational factors). Based on the studies, WRC-15 is invited "to consider the feasibility of achieving a continuous reference time-scale, whether by the modification of UTC or some other method, and take appropriate action, taking into account ITU–R studies" (emphasis added).

In 30 years of operating the GLONASS system and implementing the time-scale with leap seconds in accordance with international standards, a large amount of existing hardware and software has been adapted for the insertion of leap seconds.

In many cases, for example in that of space-borne receivers, this equipment cannot be updated during its operational life. It should be noted that the guaranteed operational life of spacecraft is more than 10 years, and the GLONASS system will have to maintain its existing time-scale with leap seconds to ensure the continued operation of this hardware.

Navigation receivers are widely used for the safeguarding and rescue of human life, for example the COSPAS-SARSAT International Satellite System for Search and Rescue. The Radio Regulations pay special attention to such applications, and their provision No. 4.10 states: "Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies." This makes it clear that WRC decisions should not create adverse consequences for systems used for the safeguarding and rescue of human life.

If a decision were to be taken to move to a continuous time-scale in the near future and this decision were to be implemented in the GLONASS system without retaining the existing time-scale (with the leap second), then a large amount of existing equipment and the corresponding systems would provide incorrect navigation information or even be totally unable to operate. In some cases (for example in aviation, maritime and satellite systems) this could lead to disaster. To avoid this disastrous outcome, the existing navigation receivers that use the reference time-scale with the leap second would have to be updated or replaced in order to be able to operate with the continuous time-scale. In many cases this would also involve updating all the approved technical documents, and carrying out a complete cycle of

GLONASS equipment in new buses taking part in a pilot project on passenger traffic patterns in Moscow

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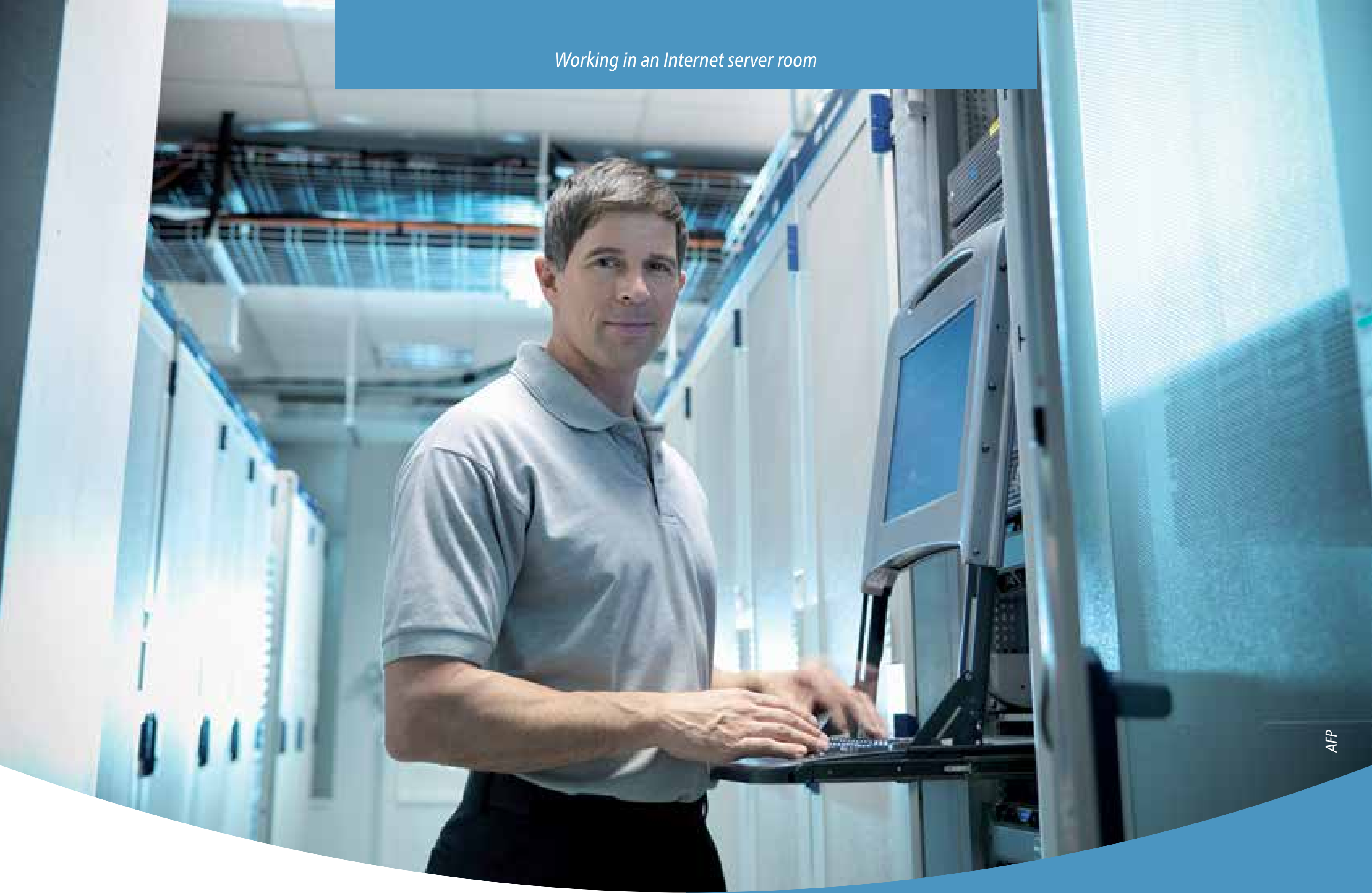
retesting and recertification of the systems and equipment (for example, spacecraft and launch vehicles).

Given the scale of the use of GLONASS system navigation applications in aviation, space and maritime services, there would be significant difficulties for the GLONASS system if the existing time-scale with a leap second is not kept.

The opinion with regard to GLONASS is that WRC-15 should consider solutions that ensure backward compatibility, enabling existing equipment to operate fully without updates and replacements. One possibility would be to keep the current UTC time-scale (with the leap second) without change and bring into use a continuous time-scale on an equal basis. Such a decision would allow systems using the current UTC time-scale to continue to operate without any changes and the associated costs. It would also avoid problems arising from applying corrections to conform to a continuous time-scale.

By maintaining the current UTC time-scale on an equal basis with a new continuous time-scale, it would be possible in each case to apply the more suitable time-scale for any particular system.



Working in an Internet server room

Impact of leap seconds on digital time services

Internet time servers

Judah Levine, Time and Frequency Division, United States National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) operates 45 Internet time servers that are located at sites in the United States. These servers include the computing facilities used by the major stock and commodity exchanges in New York and Chicago. The servers are synchronized to Coordinated Universal Time (UTC), as realized at NIST.

Time formats

The NIST servers respond to requests for time in three different formats: the network time protocol (NTP), the DAYTIME format, and the TIME format.

NIST also operates two servers that provide only authenticated NTP-format time messages to users who have registered with NIST. The authentication is realized by adding a hash value to the response. The hash value is computed on the ordinary message combined with a secret key, which is different for each user. The algorithm guarantees that the message originated from an NIST time server and was not modified in transit. This service is used by foreign and domestic commercial and financial institutions.

The time of an NIST server is represented internally as the number of UTC seconds and fractions of a second since the reference epoch, which is 1970.0.

The NTP and TIME format messages represent the time as the number of UTC seconds (and fractions of a second for NTP) since the corresponding reference epoch, which is 1900.0. The DAYTIME format represents the time as a text string in the form hh:mm:ss, with the seconds fraction as a separate parameter.

Consumer choice

The ensemble of time servers receives approximately 75 000 requests per second (some 6.5 thousand million per day). About 85 per cent of these requests are for time in the NTP format, and the remaining 15 per cent are approximately equally divided between the DAYTIME and TIME formats.

The NTP message exchange includes a measurement of the network delay and is potentially more accurate than either the DAYTIME or TIME formats, but all three formats are still widely used.

Our efforts to encourage users of the TIME format to switch to the more accurate NTP format have met with only limited success.

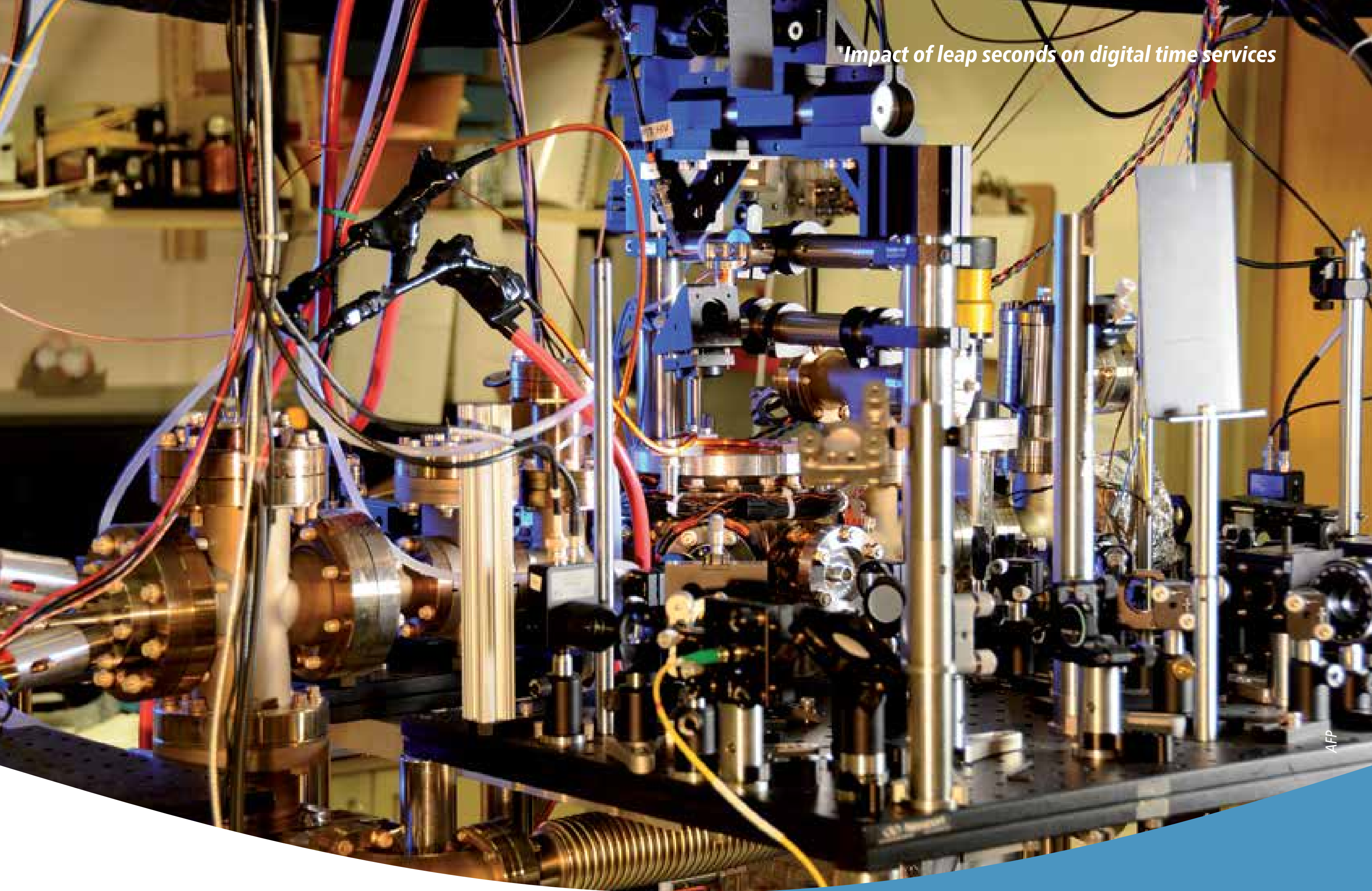
Leap second glitch

The binary format used for the internal system time, and for the NTP and TIME messages, cannot represent the correct time during a positive leap second. Therefore, a positive leap second is represented by repeating the binary value corresponding to 23:59:59 a second time.

The sequence of binary time values during a leap second is equivalent to the UTC time values of 23:59:58, 23:59:59 (first time), 23:59:59 (second time), followed by 00:00:00 of the next day. The internal system software can distinguish between the two identical time values of 23:59:59, but there is no provision in either the NTP or TIME message formats for transmitting this information to a user. The NIST time servers will receive approximately 150 000 requests during the 2-second interval where the integer second corresponds to a UTC time of 23:59:59, so that this is not a negligible problem.

The ambiguity of a time response with an integer second corresponding to 23:59:59 has several important consequences. The first is that the time ordering of events is ambiguous. For example, a time stamp of 23:59:59.1 can occur both before and after a time stamp of 23:59:59.5. Similar ambiguities occur with time intervals measured across a leap second. These short-time intervals play an important role in high-frequency trading and data acquisition.

Another method of implementing a positive (or negative) leap second is to amortize the extra second over some time interval by applying a negative (or positive) frequency offset to the system clock. This method guarantees that the system time will be monotonic, but the time messages transmitted by this type of system will be incorrect during the amortization interval and will differ from the UTC time received from other sources by a varying amount. Time intervals measured during the amortization period will also be incorrect for the same reason. The amortization interval is not specified in any standard. This will lead to different ways of implementing this method, which will result in time values that do not agree with each other during the different amortization intervals. My view is that this method raises more problems than it fixes; it is not used by the NIST servers and is not part of the standard NTP distribution at www.ntp.org.



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Ultra-stable ytterbium lattice atomic clock at the National Institute of Standards and Technology (NIST), United States. Ytterbium atoms are generated in an oven (large metal cylinder on the left) and sent to a vacuum chamber (centre of the photo) to be manipulated and probed by lasers. The tick of the ytterbium clock is said to be more stable than that of any other atomic clock

These effects are much more significant now than they were in 1972 when the leap-second system was introduced. In the first place, automated computer-based financial transactions are no longer limited to the traditional working day, and a leap second near midnight has about the same impact as one during the middle of the day. In the second place, the leap second event, which is defined with respect to UTC, can occur in the middle of a working day in most of Asia and Australia, and these areas have much greater economic activity than they had in 1972. California and other states in the western part of the United States have the same problem.

The NTP and DAYTIME formats provide advance notice of an upcoming leap second. Unfortunately, many common operating systems do not parse the flag. The TIME format has no ability to provide this advance notice. In all of these cases, the clock in the client system will have a time error of 1 second immediately after the leap second has occurred. This time error will persist until the client system requests the time from the server. This "polling interval" varies from one system to another; it may be as short as 64 seconds or as long as several hours. The polling interval is not linked to any specific UTC time, so that an ensemble of systems may have clocks that disagree with each other following a leap second — even if all of the systems have the same nominal polling interval.

In the best case, when the client system detects the one-second error it simply adjusts its clock by the appropriate positive or negative value in a single time step. However, client systems that implement a digital servo loop to control the system clock typically have a more complex response to a large time step, and the time error may oscillate before reaching the correct time. In some cases, the servo loop may crash because the system is not designed to cope with a time error greater than 128 milliseconds. In other implementations, the system treats a one-second error as a network glitch, and tries to remedy the situation by asking for the time again.

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This process obviously will not converge. In some implementations, these problems are so serious that the operators simply shut the system down before a leap second and restart the system after the leap second epoch has passed.

Time is money

The problems of time-ordering, causality and the ambiguity of time intervals in the vicinity of a leap second are not easily remedied because they arise in a fundamental way from the interaction of the binary representation used for time stamps and the occurrence of a positive leap second. During a leap-second correction, the time servers operated by NIST will receive approximately 150 000 time requests when the time transmitted by the server is 23:59:59, and the increasing number of financial transactions that depend on millisecond-level timing are sure to be affected.

The problems associated with the advance notice of a future leap second and how users respond are not fundamental in principle. They could be addressed by abandoning the TIME protocol, which has no advance notice of a leap second, and by ensuring that an application that uses the NTP or DAYTIME protocols parses the leap second flags that are already present and acts on them appropriately.

Despite our efforts over many years, however, a significant number of users have not implemented these suggestions. We know this because the NTP leap second flags are also used to indicate that the server is unsynchronized, and we have a large number of users who do not recognize the unsynchronized message, use the time stamps anyway, and then complain that they have received the wrong time. Our repeated efforts to end support for the TIME protocol have met with widespread resistance from the user community.

In summary, it is my opinion that keeping the difference between Universal Time (UT1) — an astronomical time-scale defined by the Earth's rotation and used in celestial navigation — and UTC smaller than 1 second is not worth the difficulties I have discussed in this article, and I would advocate discontinuing leap seconds in the future.

Big Ben and the Houses of Parliament, London

A British perspective of the future of Coordinated Universal Time

Peter Whibberley, Senior Research Scientist, Time and Frequency Group, National Physical Laboratory, United Kingdom

For more than 40 years, the current international reference time-scale, UTC, has been adjusted in occasional one-second steps known as leap seconds so that it remains closely aligned with time based on the Earth's rotation. For the past 14 years, arguments have surged back and forth in international committees, particularly within the ITU Radiocommunication Sector (ITU–R) Working Party 7A, about the desirability of ending these leap-second adjustments. Despite lengthy debate, no consensus has been found, and an attempt to reach a decision at the World Radiocommunication Conference in 2012 (WRC-12) led instead to a call for further studies.

In this article, Mr Whibberley summarizes the reasons why the United Kingdom has consistently maintained the position that the present definition of Coordinated Universal Time (UTC) with leap seconds is satisfactory, and that the known difficulties caused by leap seconds do not justify breaking the close link between civil timekeeping and the Earth's rotation. All the comments and statements made in the article are Mr Whibberley's interpretation of the debate, and not necessarily either his own personal opinions or those of the UK Government.

Civil timekeeping

The importance of UTC is that it forms the basis of civil timekeeping in the large majority of countries worldwide. It is a compromise, combining the stability obtained from averaging large numbers of atomic clocks in timing institutes around the world with a realization of mean solar time maintained by those leap-second adjustments. At the core of the debate is disagreement about the continuing need to maintain the close linkage between civil timekeeping and Earth time.

The UK Government has considered the arguments for and against ending leap seconds on several occasions. Every time, it has concluded that the present definition of UTC with leap seconds is satisfactory and that the known difficulties caused by leap seconds do not justify breaking the close link between civil timekeeping and the Earth's rotation.

Debate in the United Kingdom about the future of UTC

The first formal proposal to end the insertion of leap seconds in UTC was submitted to ITU–R Working Party 7A in 2004.

To inform its decision-making, the responsible UK Government department consulted official bodies and agencies with an interest in precision timekeeping. None of these authorities reported significant problems arising from leap seconds, while some scientific institutions reported strong support among their memberships for retaining leap seconds. The results of this consultation process, together with the evidence collected by ITU–R Working Party 7A, were put to the Minister for Science at that time, who decided that the United Kingdom should oppose the proposed change. He considered that the reported problems caused by the application of leap seconds in UTC were insufficient to justify what was perceived to be a fundamental change to civil timekeeping.

The discussions within ITU–R on the future of leap seconds have continued to be monitored closely by the UK Government. On two further occasions, in 2008 and in 2011, the government minister responsible for scientific matters (a different person on each occasion) has been presented with an updated account of the debate and the evidence put forward by both sides. On both occasions, the minister was unconvinced by the arguments for ending leap seconds in UTC and decided to continue the policy of his predecessor.

It would be a mistake to assume that the UK Government's dominant consideration is a desire to retain the name Greenwich Mean Time (GMT), which is often, inaccurately, applied to standard time in the United Kingdom rather than the correct term UTC. If leap seconds are ended and UTC is allowed to diverge from Earth rotation time, then the United Kingdom's laws would have to be amended to refer explicitly to UTC rather than GMT. This change would require legislation, but would not be difficult to implement, and any adverse publicity arising from it would most likely be short-term. The lack of concern in the UK Government over the potential loss of GMT is illustrated by its support for proposals that would have moved the United Kingdom into the same time zone as the central European countries; one hour ahead of UTC in winter, and two hours ahead in summer. The resulting loss of the name GMT for United Kingdom's civil time was not a significant factor in the debate.

There is particular concern in the United Kingdom over the lack of public awareness of the divorce between civil timekeeping and astronomical time that will occur if leap seconds are ended. A perception that time-of-day is intimately related to the Earth's rotation is widespread, and the level of public opposition to ending that link is unknown. The proposed change might be viewed as an attempt by technocrats to impose an unnecessary and unpopular change, and studies of public attitudes to the proposal would be highly desirable.

Technical arguments for ending leap seconds

Although the detailed deliberations that underpin government decision-making are not made public, it is probably fair to say that the UK Government's opposition to ending leap seconds arises in large part from its assessment that the evidence collected by ITU–R Working Party 7A of problems caused by leap seconds is insufficient to justify what is viewed as a fundamental change to civil timekeeping.

There is no doubt that when a leap-second adjustment is applied to UTC, costs are incurred in programming the leap second and some systems and equipment have difficulty in handling it. On each occasion when the UK Government has reviewed the available evidence, it concluded that the reported effects are relatively minor, and in many cases could be reduced or eliminated by improved procedures for handling leap seconds and increased automation to reduce the likelihood of human error. It was also concerned that ending leap seconds would itself create difficulties that have not yet been fully assessed.

A second argument put forward for ending leap seconds is that their presence in UTC has resulted in the undesirable proliferation of alternative unstepped time-scales, such as Global Positioning System (GPS) time. The UK Government is not convinced that this development is a cause for serious concern. These additional time-scales are only used internally within their respective systems, they are based on UTC, and they provide time outputs that are converted to UTC before being made available to general users.

If leap seconds are retained, they will tend to become more frequent over time. However, it would probably take well over a thousand years for the interval between leap seconds to decrease to one month, and the UK Government considers that there is plenty of time for further investigation of the long-term implications before a decision has to be reached.

A new name for Coordinated Universal Time without leap seconds

One of the most heated aspects of the debate concerns the retention of the name Coordinated Universal Time if leap-second adjustments are ended.

There are several arguments in favour of a new name. UTC without leap seconds would be a purely atomic time-scale, identical in nature to the existing International Atomic Time (TAI)

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and fundamentally different from a time-scale maintained within one second of astronomical time. For the past 80 years the term Universal Time has designated mean solar time, and a change of name would avoid confusion and ambiguity if the link is ended.

The argument that the name Coordinated Universal Time is now so deeply embedded in laws and regulations around the world that the effort needed to change the name could not be justified has little weight in the United Kingdom, where laws relating to civil time would have to be amended if leap seconds are stopped, regardless of the choice of name.

Alternatives to ending leap seconds

The development of the debate within ITU–R Working Party 7A has led to a polarization between only two options: eliminating leap seconds to change UTC into an unstepped time-scale; or retaining UTC in its present form. At various times other proposals have been put forward, and the current broadening of the debate may allow these alternatives to be considered more thoroughly.

One group of proposals involves retaining steps of some form in UTC, but modifying their size, frequency or scheduling to reduce their impact. Suggestions include leap hours and leap minutes, or accumulating leap seconds over a century. All of these ideas would achieve the aim of retaining a link between UTC and astronomical time. However, they all have the considerable disadvantage that all equipment and software in use worldwide that require precise time would have to be upgraded or replaced, and the cost and effort involved would be considerable. A larger, less frequent step might also cause greater disruption and have more severe consequences, and there is a widespread view in the United Kingdom that it would in practice prove impossible to implement any step larger than one second in UTC.

Other proposed solutions involve modifications to the present system. For example, an unstepped time-scale broadcast alongside UTC could be used in applications that cannot handle leap-second steps, and might be feasible if sufficiently robust methods can be developed to distinguish between the two time-scales. Improved protocols for handling leap seconds and clearer guidance for developers of timing systems would also be beneficial. The UK Government is keen to see such alternative approaches evaluated more thoroughly.

What's the rush?

The existing scheme for leap-second adjustments of UTC has been in use for 40 years, with 25 leap seconds implemented, so a considerable body of experience in handling leap seconds has built up. Since the current procedures for inserting leap seconds could remain viable for many decades, there is no need to amend the present system in haste. Any misjudged change implemented now would be very difficult to reverse.

The UK Government has conducted high-level reviews of the arguments for ending leap seconds on three occasions, and each time has concluded that there is no compelling need to change the present system. UTC with leap seconds remains closely linked to the Earth's rotation, which in the United Kingdom is widely considered to be an important requirement of the civil time-scale. Further studies and broader debate are essential for achieving the necessary level of support worldwide before any change is made to UTC.

Impact of the leap second

Japan's time-stamp system

Koichi Shibata, Time Business Forum, Japan

The integrity of time is a vital part of the modern world. It would be no exaggeration to say that it is the clock that keeps society ticking.

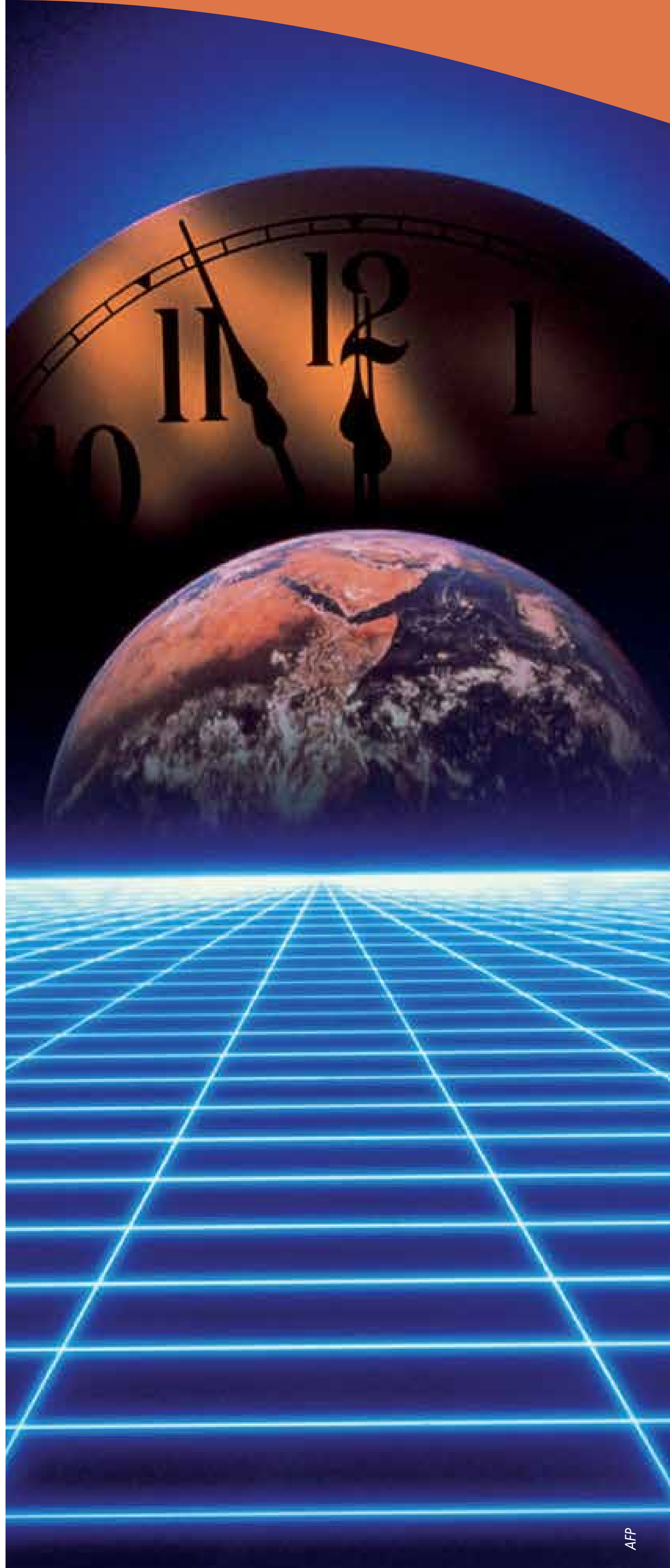
Computer systems such as personal computers or mobile phones support the information communication network that forms the underlying fabric of our everyday lives. All these systems operate in synch with their built-in clocks.

In recent years, increasingly sophisticated network technologies have dramatically speeded up the spread of information, and digital storage for such information has also become widespread because of its convenience.

Unlike paper documents, however, digital information can be copied and modified with great ease, making it difficult to distinguish the original document from a tampered copy.

As a countermeasure, and taking advantage of the fact that time is universal and cannot be reversed, a system that embeds a traceable time stamp in the digital document has been developed, making it possible to accurately identify the original and distinguish it from later copies. Needless to say, the time stamp must be affixed by a trusted third party.

Such a system has been standardized in Japan. Criteria were set in 2005 for Japan's Time Business Accreditation Programme, which has subsequently been adopted by many Japanese businesses. Time stamps prove the integrity of digital documents



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Neon grid with the Earth and clock in shadow and are used to safely share and store information throughout networks.

Japan's accreditation programme has involved the creation of two bodies, authorized to carry out distinct services for the system and operational framework. These bodies are the Time Stamping Authority, which is responsible for distributing time stamps, and the Time Assessment Authority, which verifies the time label in the time stamps for accuracy and traceability.

With time stamps, documents such as intellectual property rights, medical records, electronic signatures, permits and inspection records can be safely stored electronically. This is highly convenient, as litigation prevention, denial measures and accountability can be achieved without the need for physical papers. As such, time stamps are becoming a valuable tool for our society.

Unfortunately, Japan's time-stamp system has been halted three times in the past. Each of these stoppages was caused when adjustments were made to Coordinated Universal Time to include a leap second.

Under Japan's Time Business Accreditation Programme, a time stamp must be accurate to within 1 second of its storage time. This requirement is thrown off by the leap second, forcing the system to refuse the distribution of time stamps.

The Time Stamping Authority and the Time Assessment Authority use many synchronized servers and atomic clocks to perform their time monitoring services with great accuracy. With sporadic, instantaneous events like the leap second, operators must adjust every clock. No mistake is acceptable, as this could result in issuing an inaccurately labelled time stamp.

Of the last three leap-second adjustments, two fell on New Year's day (Japan time), and so did not cause any great problems. The third — and most recent — leap second occurred on 30 June 2012, which luckily was a Sunday in Japan, and the damage it caused was minimal. Nevertheless, each time, the operators have to suspend the service for several hours before the leap-second adjustment occurs to make sure that the whole system is synchronized when resuming the service.

In Japan, systems are adjusted for the leap second at 9 a.m., right when firms open for business. Because more and more firms have started to use the time stamping system, the damage a large-scale halt would cause on a regular workday would be catastrophic.