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.

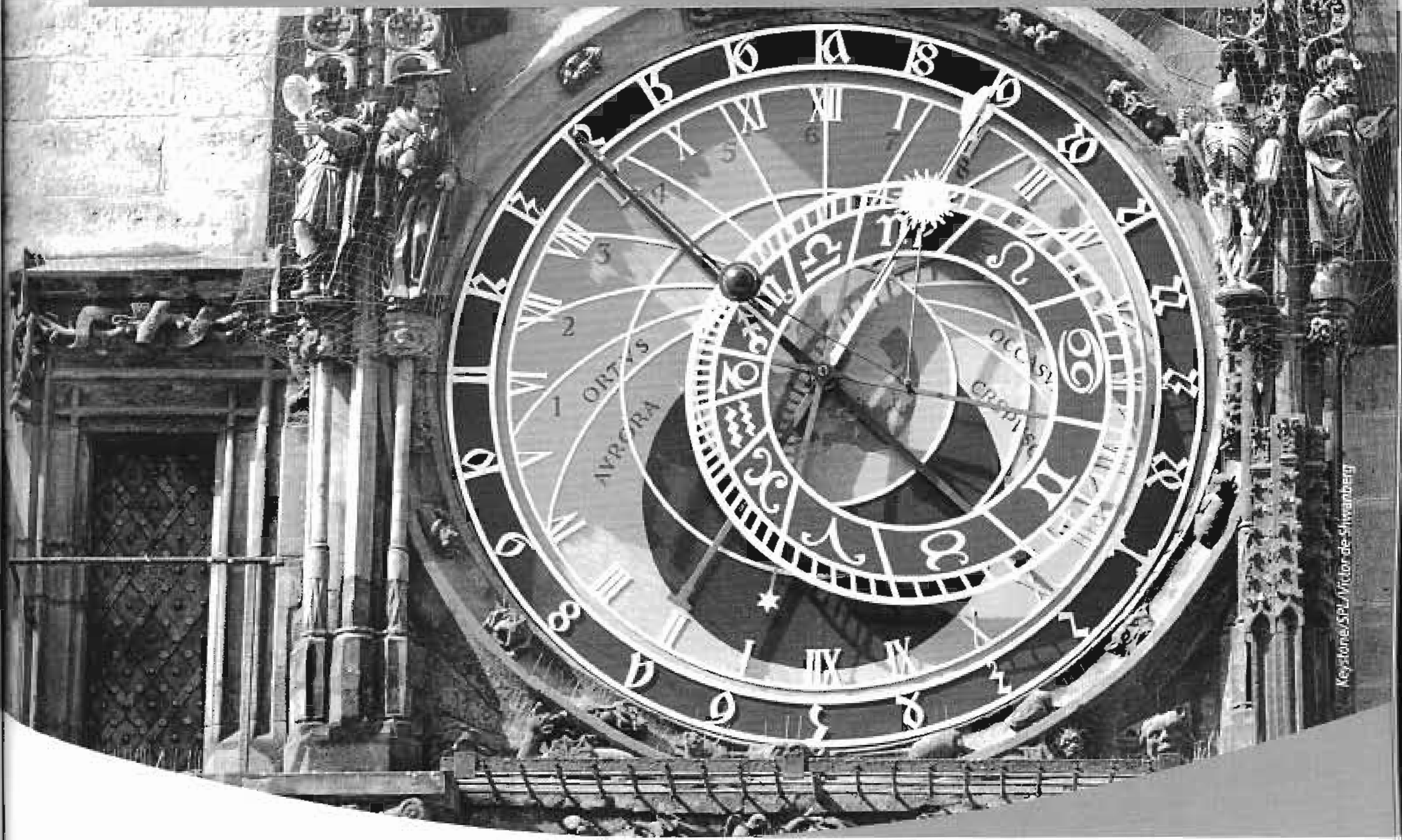
These ad hoc system times emanating from continuous internal time-scales are currently being used as a reference in many applications — such as global navigation satellite systems — in order to avoid the use of the discontinuous UTC time-scale. This has unfortunately led to a proliferation of "pseudo"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

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.

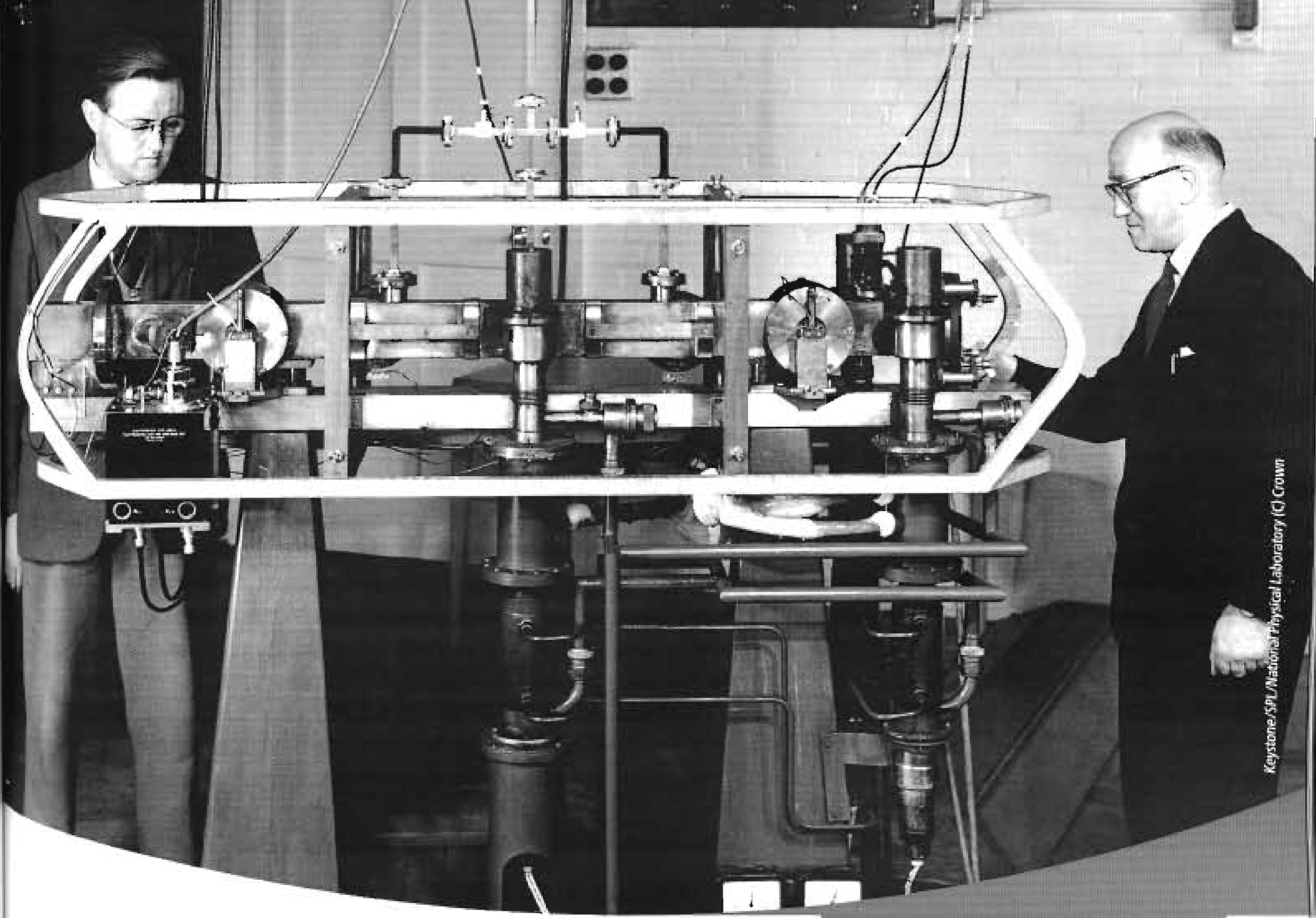
A change to the leap second method is being considered. This would make UTC a continuous atomic time-scale, which would gradually diverge from UT1 (which depends on the Earth's rotation angle). The divergence would result not only from the irregular rate of rotation of the Earth, but also from the fact 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 $2{\times}10^{-8}$ 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).

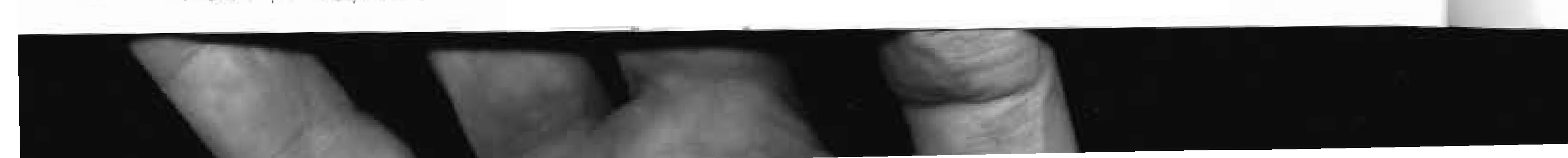
In those days, however, one obstacle to the universal acceptance of TAI was the need to provide astronomical time (denominated UT1) to those users who — for the purposes of sea navigation and other domestic applications — required a time-scale based on the irregular rotation rate of the Earth. There 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.

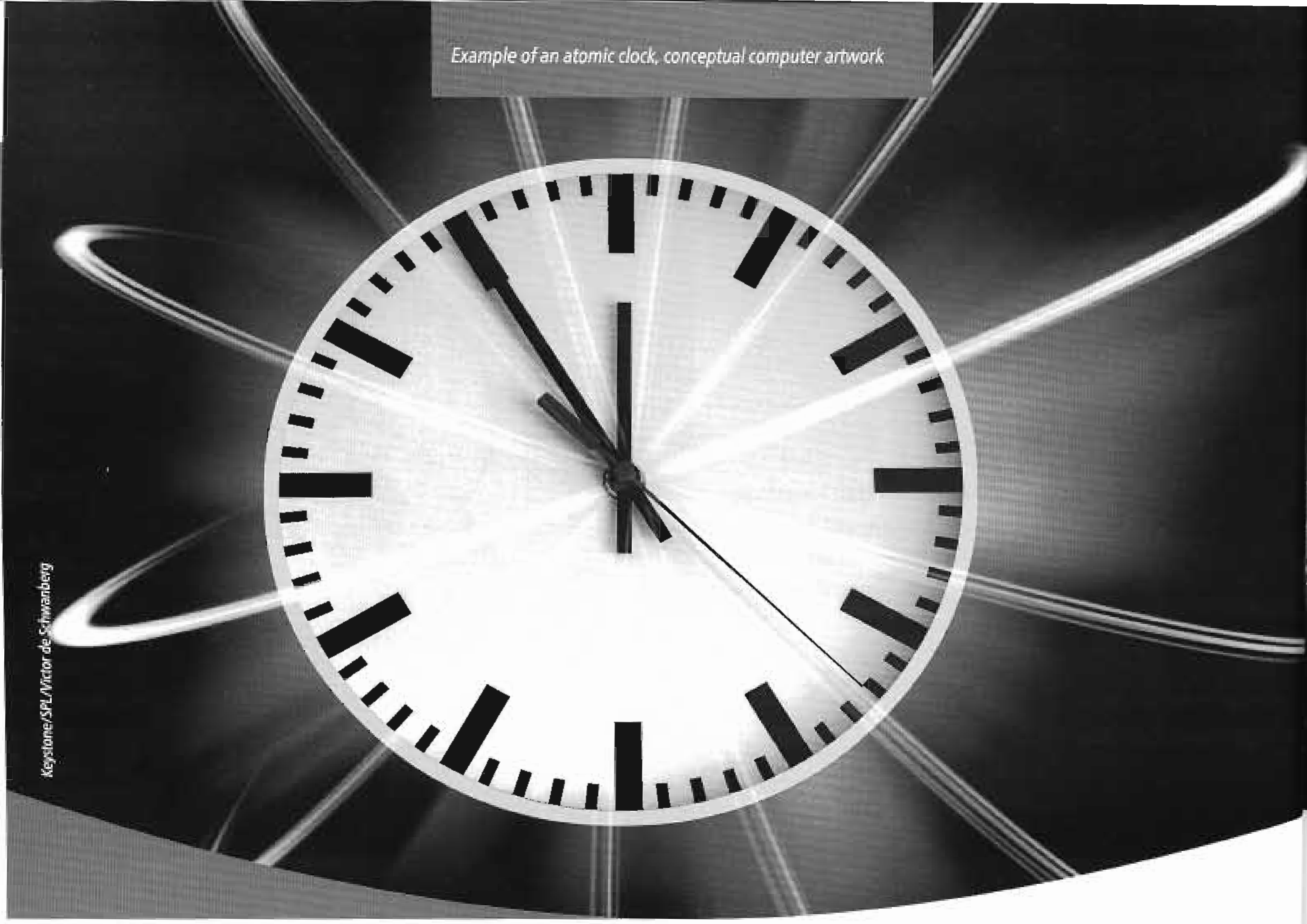
For an international reference such as UTC, the requirement is extreme reliability and long-term frequency stability. UTC therefore relies on the largest possible number of atomic clocks of different types, at present about 420, located in more than 70 institutes worldwide and connected in a network 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



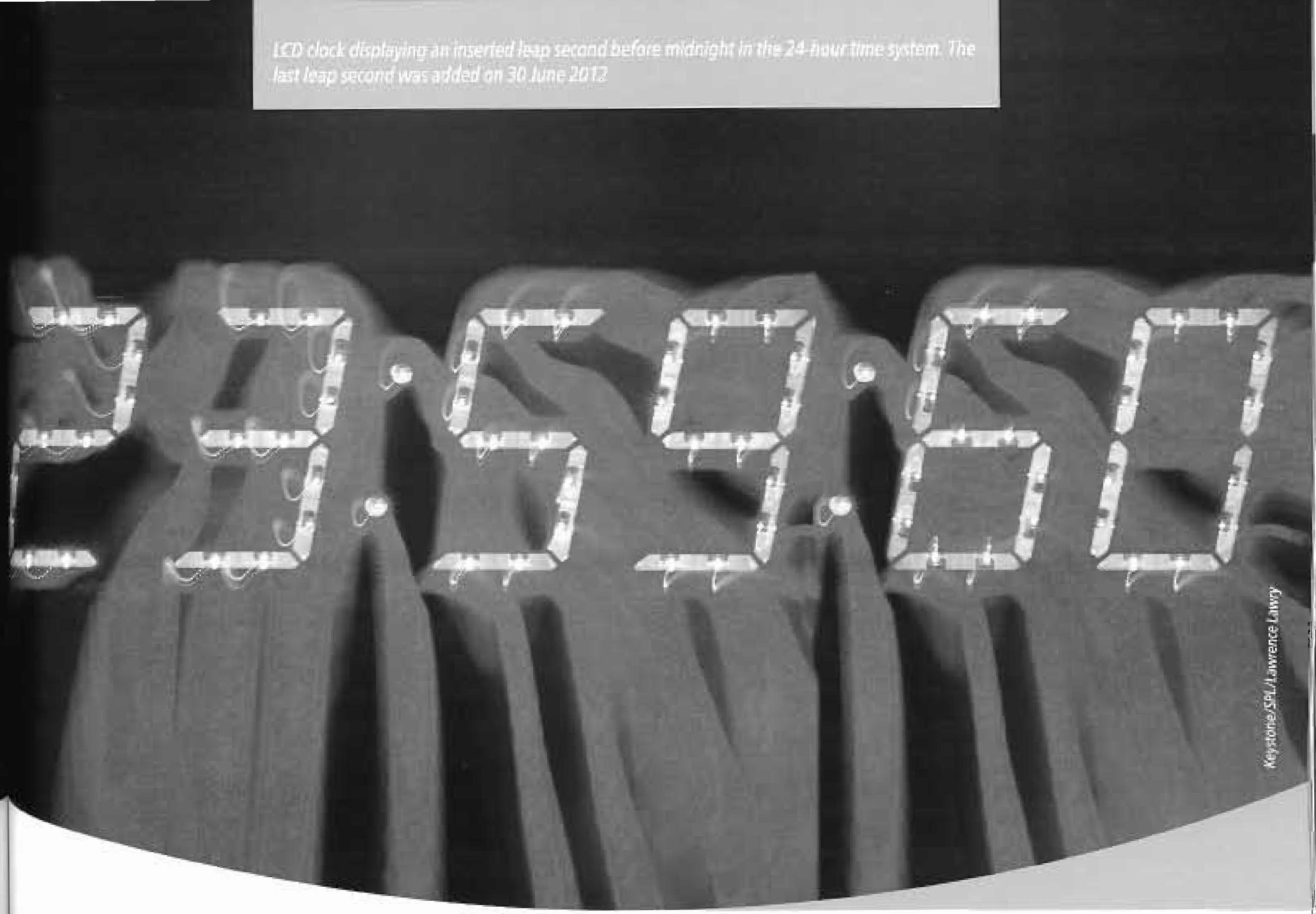
Example of an atomic clock, conceptual computer artwork

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

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

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

Keystone/SPL/Martin Riedl

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

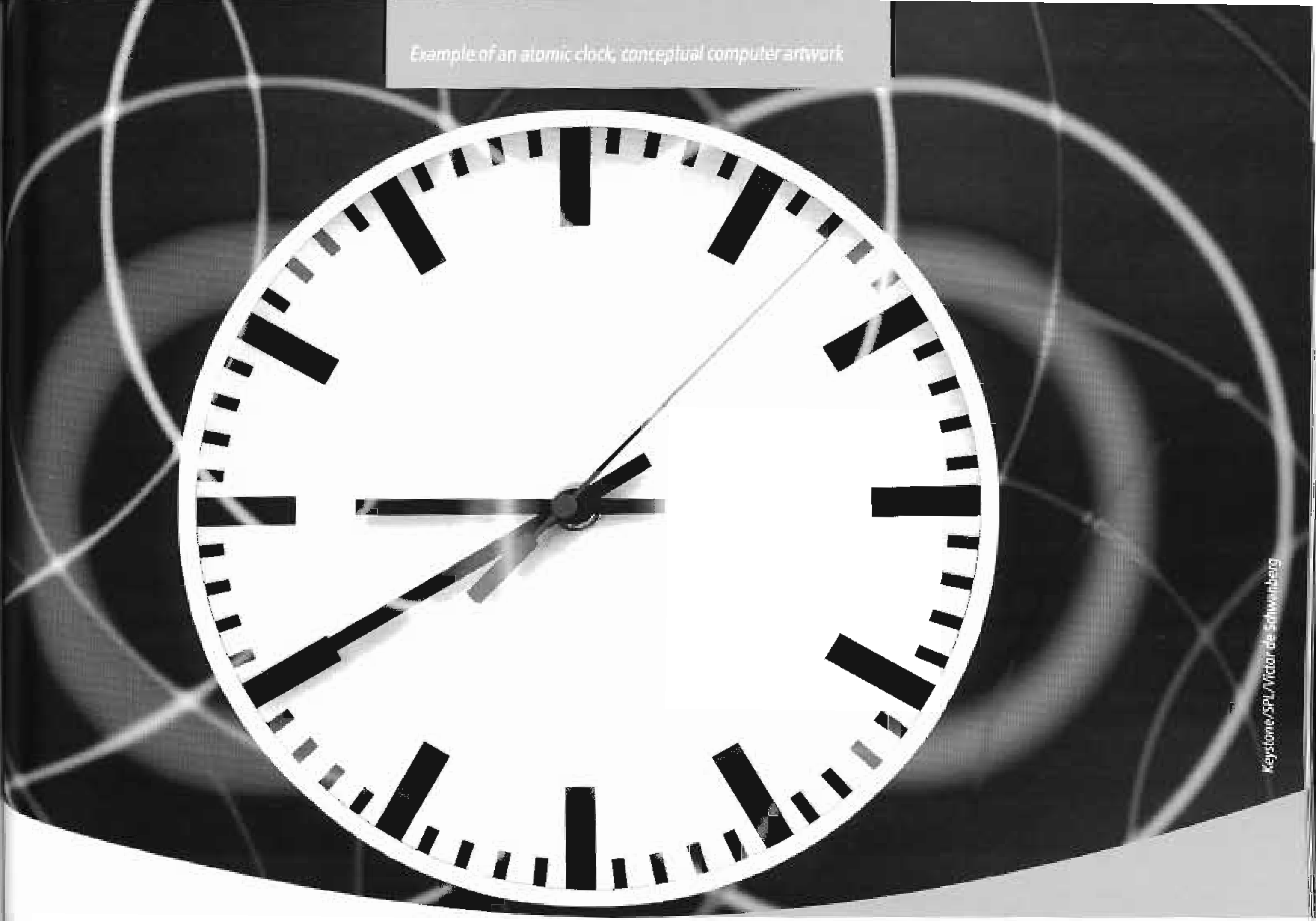
Leap seconds were introduced in 1972 as an attempt to ensure synchronization between clock time and Earth rotation. According to Recommendation ITU–R TF.460-6 on standard-frequency and time-signal emissions:

"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



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

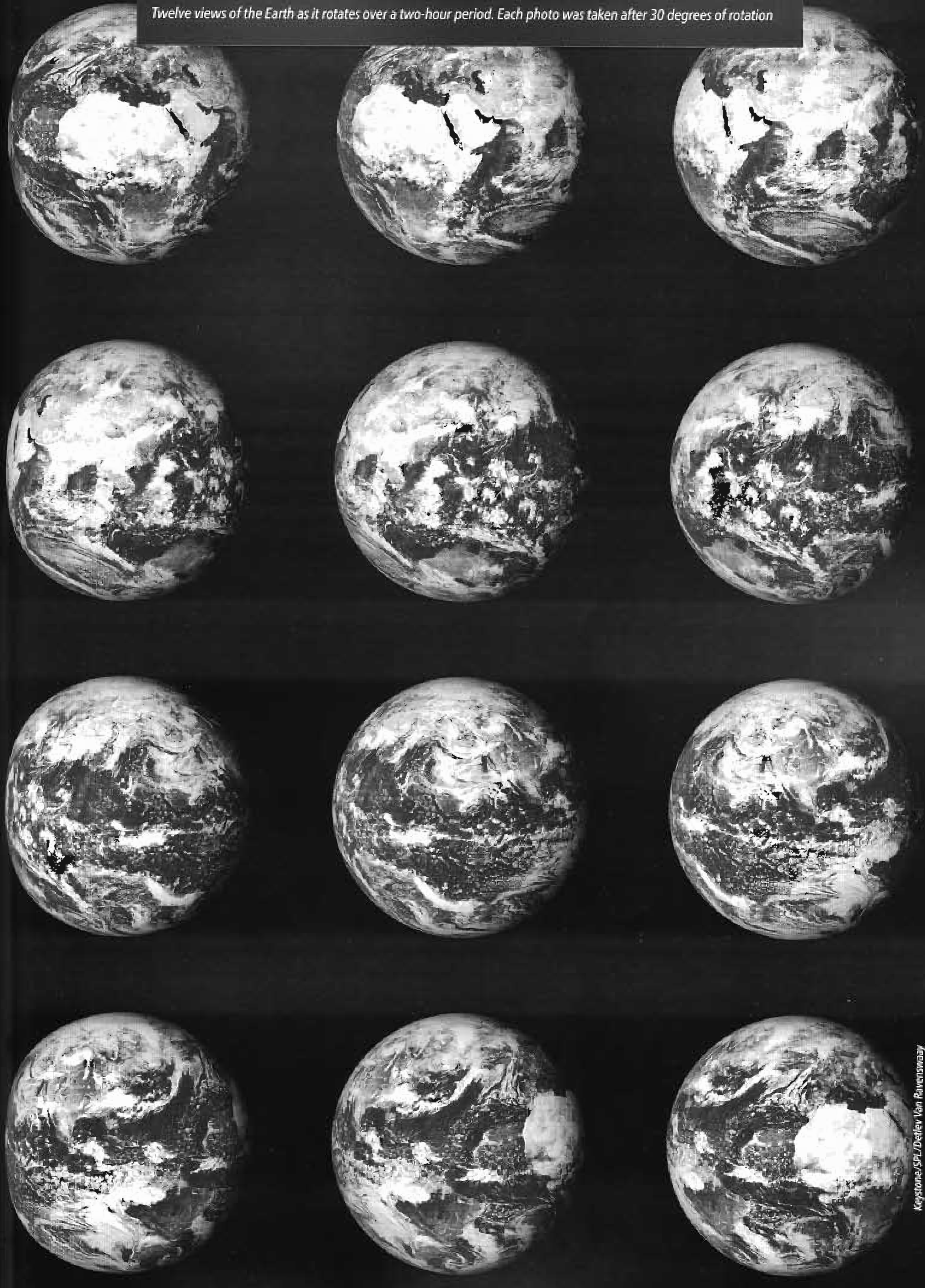
In recognition of rapidly changing technology and in order to meet the emerging needs of its users, IERS plans to create new products, and to move to more modern data file formats to improve the usability of its data. In addition, IERS will investigate the possibility of creating a real-time Earth-orientation 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



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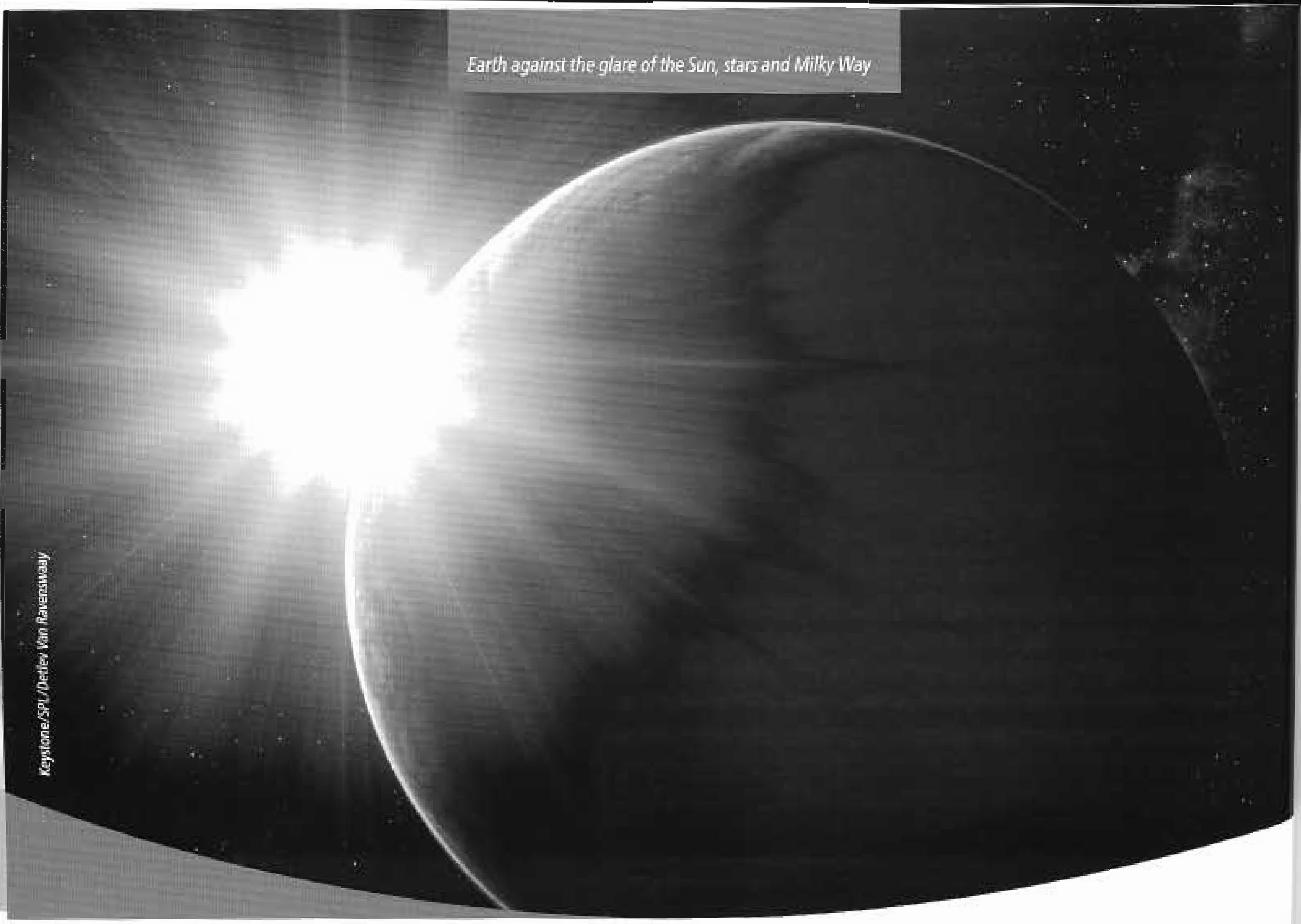


Earth against the glare of the Sun, stars and Milky Way

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.

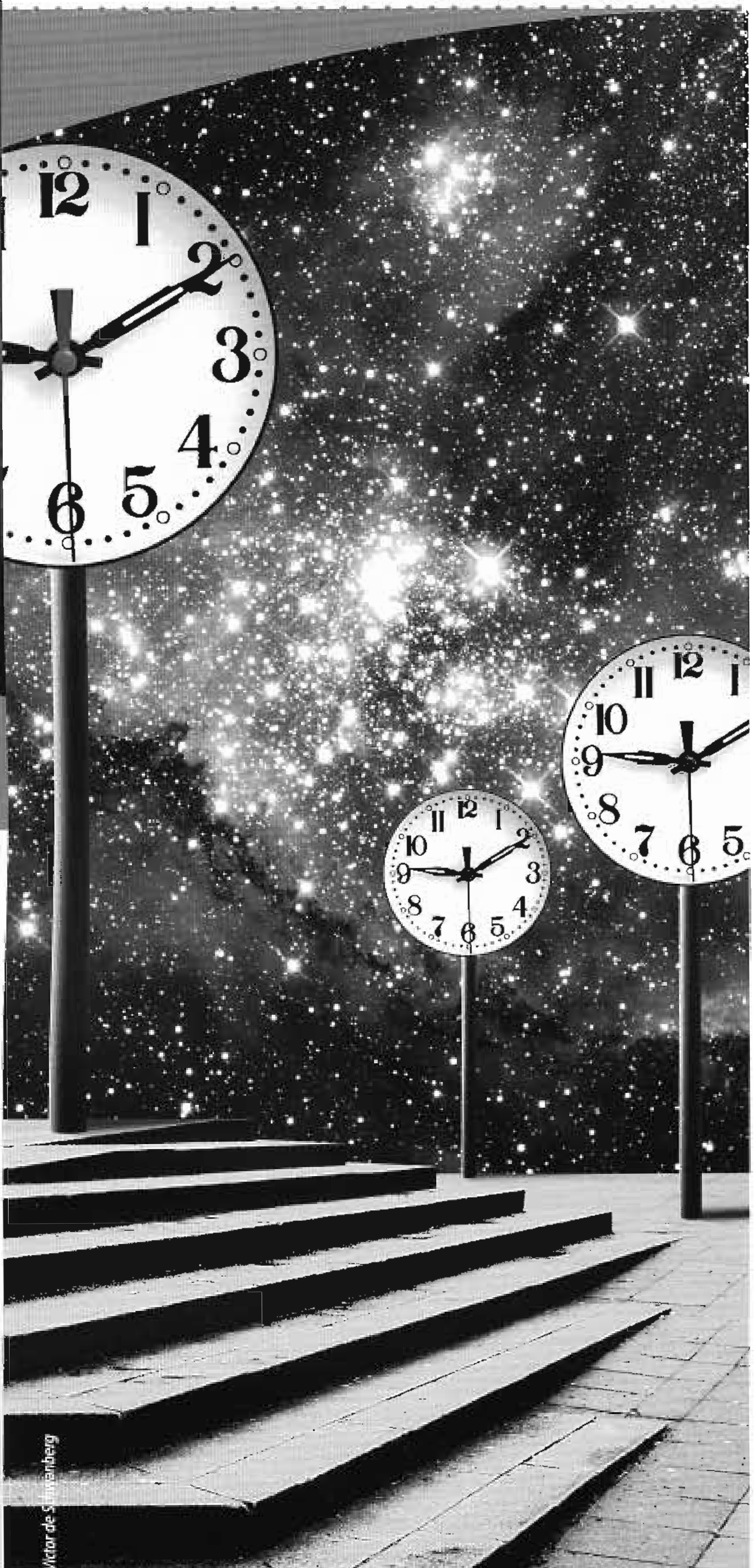
In response to this request, the IAU community carried out extensive studies and discussions on a possible redefinition of UTC. IAU established a working group for this purpose. According to its terms of reference, the working group was to discuss whether there is a requirement for leap seconds, as well 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



Keystone/SPL/Victor de Schwanberg

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.

What is in a name?

On the term Coordinated Universal Time

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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.

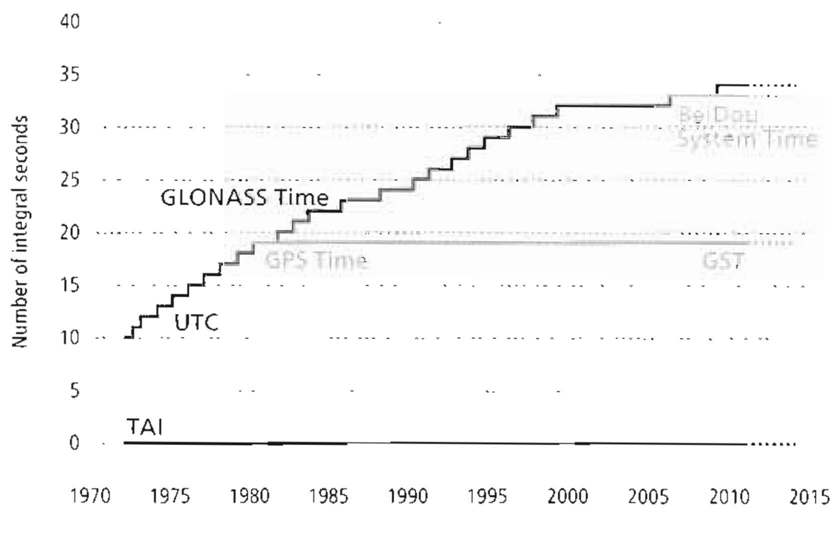
Because UTC is a stepped time-scale, the continuous internal time-scales of global navigation satellite systems become alternative time-scales for some applications. For example, the International GNSS Service (IGS) uses GPS Time for tagging some of its products.

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.