The future of

Coordinated Universal Time (UTC)

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Outline

- Historical background
- Evolution twards the adoption of atomic time
  - Motivations
  - Applications
- UTC with leap seconds
  - Still necessary?
  - Conflicts with present applications
    - Case of global navigation satellite systems (GNSS)
- Solutions
- Role of the BIPM

The second and the time scale, a little bit of history

- International Astronomical Union (IAU)
  - 1/86400 mean solar day
- CIPM (1956), IAU, CGPM(1960)
  - 1/31 556 925.9747 of the tropical year 1900
- CIPM (1964), CGPM(1967)
  - 9 192 631 770 periods of radiation corresponding to the transition between two hyperfine levels of the ground state of the Cs 133 atom

- Universal Time (UT)
  - Based on Earth Rotation (apparent daily motion of the Sun)
- Ephemeris Time (ET)
  - Based on the orbital motion of the Earth around the Sun
- ET was a timescale used only by astronomers, the practical timescale remained UT
- CCDS, CIPM (1970), CGPM (1971)
  - Definition of TAI
- International Telecommunication Union (ITU)
  - Definition of UTC
- CGPM (1971)
  - Endorses UTC

Some useful concepts

- The rate of rotation of the Earth is not uniform

  - The length of the day changes

  - The seconds do not have the same duration

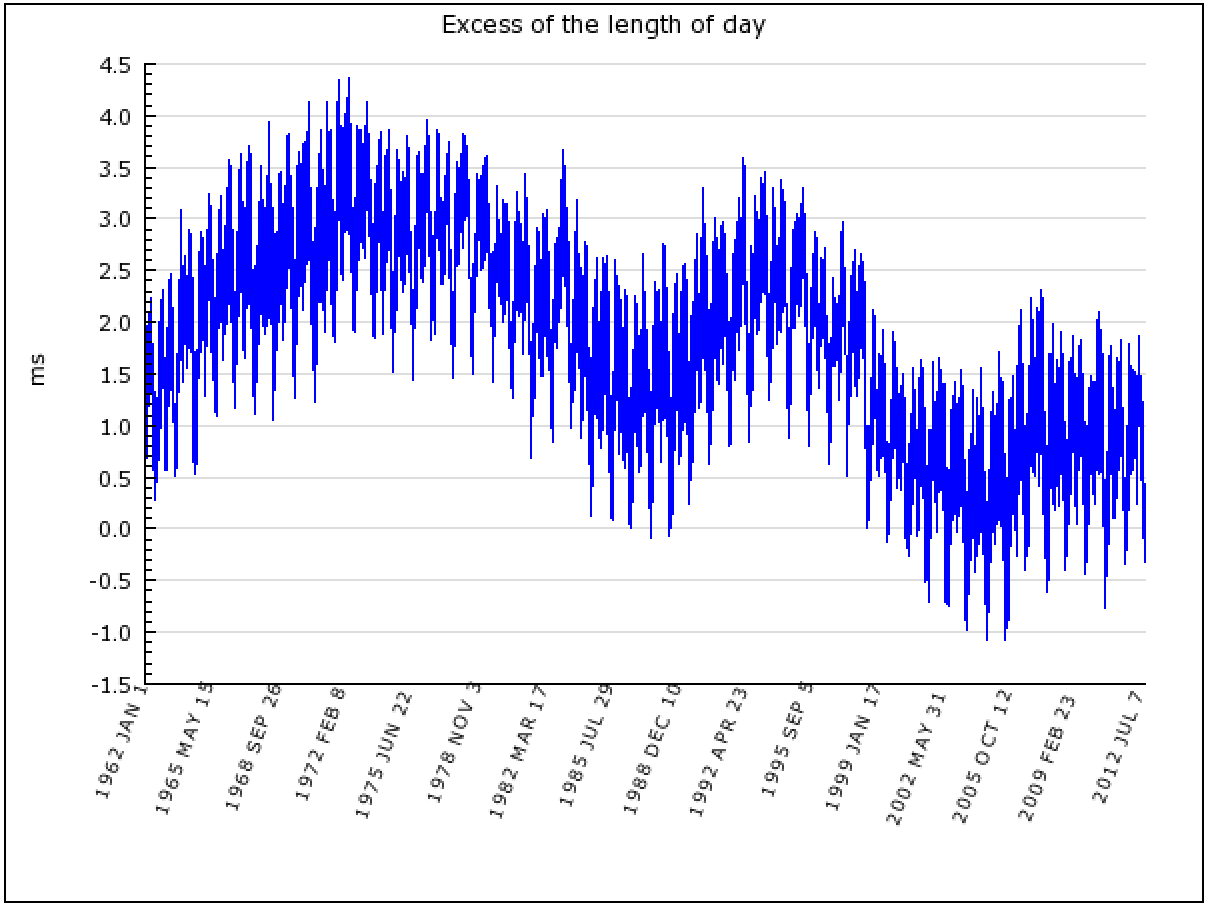
  - UT1 (a form of UT corrected for polar motion but affected by the irregular rotation of the Earth)

$$D(t) = \frac{\omega_0}{\omega(t)} \times 86400\ s \qquad \frac{d(UT1)}{dt} = \frac{\omega(t)}{\omega_0}$$

Length of the day

International Earth Rotation and Reference Systems Service (IERS)

- “Rotational” second defined as a fraction of the day



Some useful concepts

- Ephemeris time ET
  - Formally defined as the argument (t) in the dynamical equations of the apparent annual motion of the Sun;
  - Such argument represents uniform time;
  - Can be determined in post-real time only, from the difference between the observations and calculated positions of the Sun (Moon in the practice);
  - The second of ET was determined as ~ to the average duration to the second of mean solar time over the century; at the moment of its adoption, the ET second was shorter than the mean solar time second by 1.4×10^{-8};
  - The principle of continuity when a unit is redefined was violated, and
  - Consequences came later at the adoption of atomic time.

The adoption of atomic time

- The atomic second was defined to keep continuity with the ephemeris second, so shorter than that derived from the mean solar day;

- TAI can be considered as an average of clock readings, all on the rotating geoid and realizing with some approximation the SI second;

- By « averaging » the scale unit of TAI is realized, but the problem of fixing the origin (arbitrary) remains, necessary for providig a timescale capable of mesuring time intervals;

- TAI was fixed by considering it equal to UT (a particular form) on 1 January 1958, at 0 h UT.
- Changing from UT to TAI meant that

since ω decreases in the long term $\Rightarrow$

1 rotational day > 1 « atomic day »

Reasons for the change (1960s)

Improved dynamical theory required a revision of ET

Essen had developped the caesium frequency standard

UK, USA operated Cs standards

The BIH already included these standards in the calculation of the reference timescale

Any modification involved a major change

Reasons for not changing

Astronomical time was « the time of God »

Decorrelation with the solar rythm of human activities

Need of accessing UT1 with some precision

→

~~Defining different timescales for different applications~~

Defining a unique timescale adapted to all applications

Users of UT1

Astronomical navigation	Determination of longitude by observing celestial objects at known positions	Need to access UT1 with 1 s precision
Astronomers	Telescope pointing	Need to access UT1 with 1 s precision

Compromise to satisfy all users

- Adopt TAI, whose unit interval is the atomic second;
- Define UTC, as derived from TAI, with the atomic second as unit but modified for rendering it close to UT1;
- Establish a tolerance adequate to maritime navigation and astronomical observation:

  $|UT1 - UTC| < 0.9$ s

- Maintaining the two scales within the tolerance by addition of a second (leap second, positive or negative) to UTC whenever decided by the organization monitoring the Earth rotation (IERS today);

- The ITU-R approved a recommendation (ITU-R, TF-460.6, 1970) establishing the procedure for the application of leap seconds to UTC.

From *BIPM Annual Report on Time Activities*

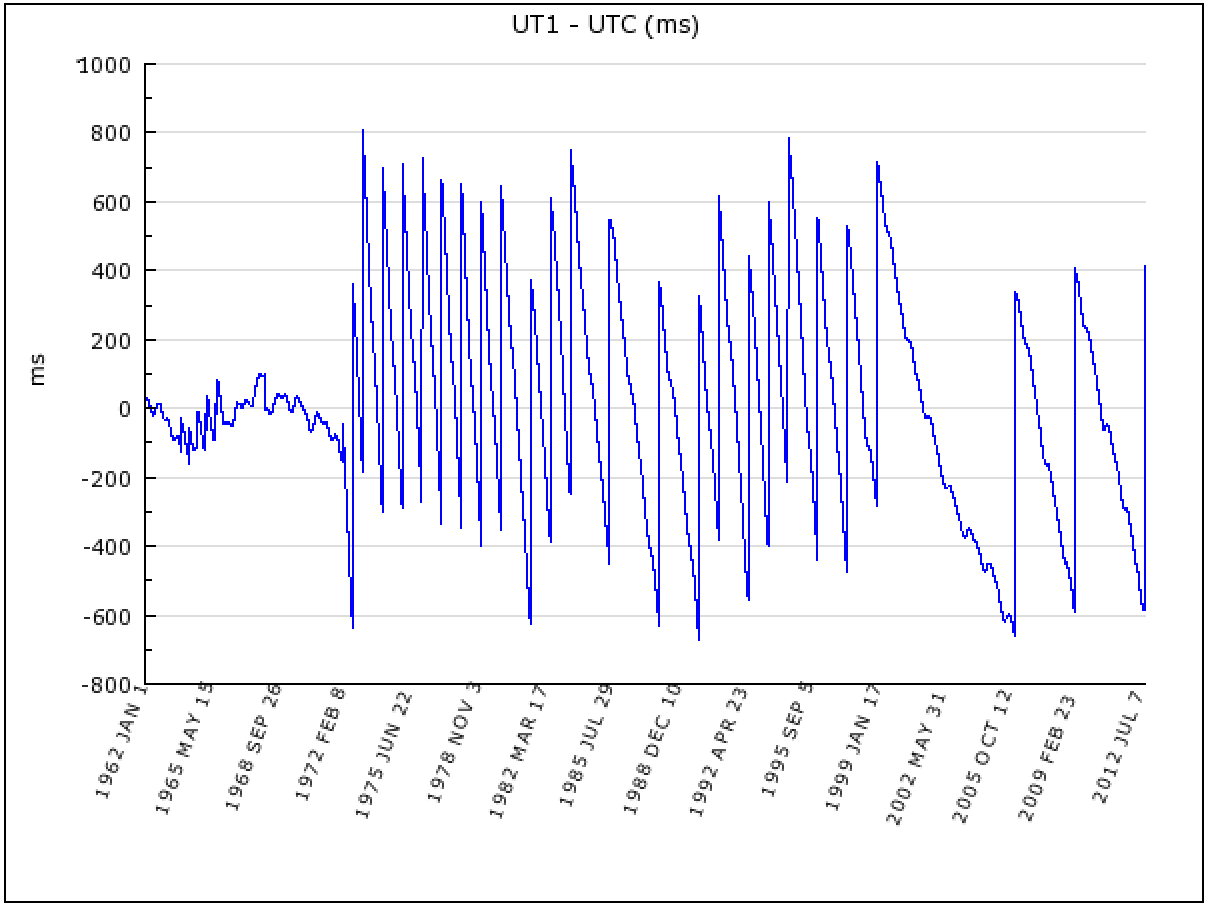
Before adoption of TAI and UTC

Limits of validity (at 0 h UTC)	[*TAI* - *UTC*] / s
1961 Jan. 1 - 1961 Aug. 1	1.422 8180 + (MJD - 37300) x 0.001 296
1961 Aug. 1 - 1962 Jan. 1	1.372 8180 + " "
1962 Jan. 1 - 1963 Nov. 1	1.845 8580 + (MJD - 37665) x 0.001 1232
1963 Nov. 1 - 1964 Jan. 1	1.945 8580 + " "
1964 Jan. 1 - 1964 Apr. 1	3.240 1300 + (MJD - 38761) x 0.001 296
1964 Apr. 1 - 1964 Sep. 1	3.340 1300 + " "
1964 Sep. 1 - 1965 Jan. 1	3.440 1300 + " "
1965 Jan. 1 - 1965 Mar. 1	3.540 1300 + " "
1965 Mar. 1 - 1965 Jul. 1	3.640 1300 + " "
1965 Jul. 1 - 1965 Sep. 1	3.740 1300 + " "
1965 Sep. 1 - 1966 Jan. 1	3.840 1300 + " "
1966 Jan. 1 - 1968 Feb. 1	4.313 1700 + (MJD - 39126) x 0.002 592
1968 Feb. 1 - 1972 Jan. 1	4.213 1700 + " "
1972 Jan. 1 - 1972 Jul. 1	10 (integral number of seconds)
1972 Jul. 1 - 1973 Jan. 1	11
1973 Jan. 1 - 1974 Jan. 1	12
1974 Jan. 1 - 1975 Jan. 1	13
1975 Jan. 1 - 1976 Jan. 1	14

After adoption of TAI and UTC, following the ITU recommendation

UT1-UTC

International Earth Rotation and Reference Systems Service (IERS)



35 leap seconds

Rules established by the ITU-R recommendation TF-460.6

- **DUT1**

The value of the predicted difference UT1 – UTC, as disseminated with the time signals is denoted DUT1.The values of DUT1 are given by the IERS in multiples of 0.1 s.

The magnitude of DUT1 should not exceed 0.8 s.

The departure of UTC from UT1 should not exceed ± 0.9 s.

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.

The IERS should decide upon and announce the introduction of a leap-second, such an announcement to be made at least eight weeks in advance.

ITU-R, TF-460.6 (1970,…, 2002)

FIGURE 3

Positive leap-second

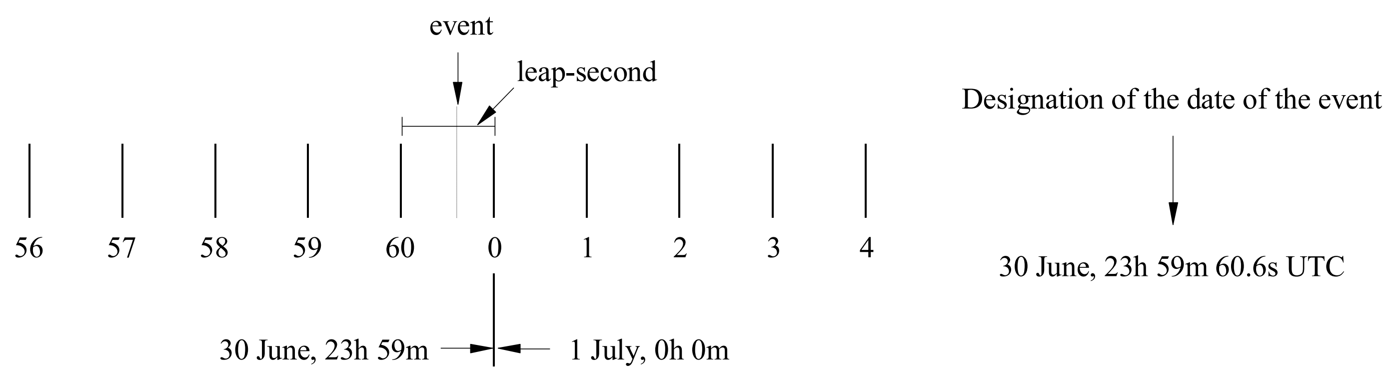
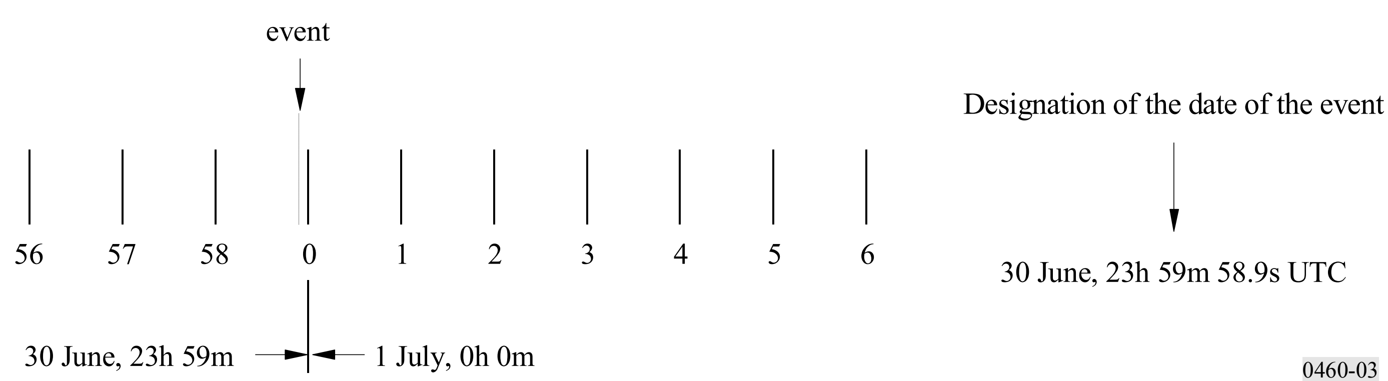


FIGURE 4

Negative leap-second



Are clocks prepared for beating the second 60 in a minute?

http://www.bipm.org/en/scientific/tai/time_server.html

Is a stepped UTC adapted for modern applications?

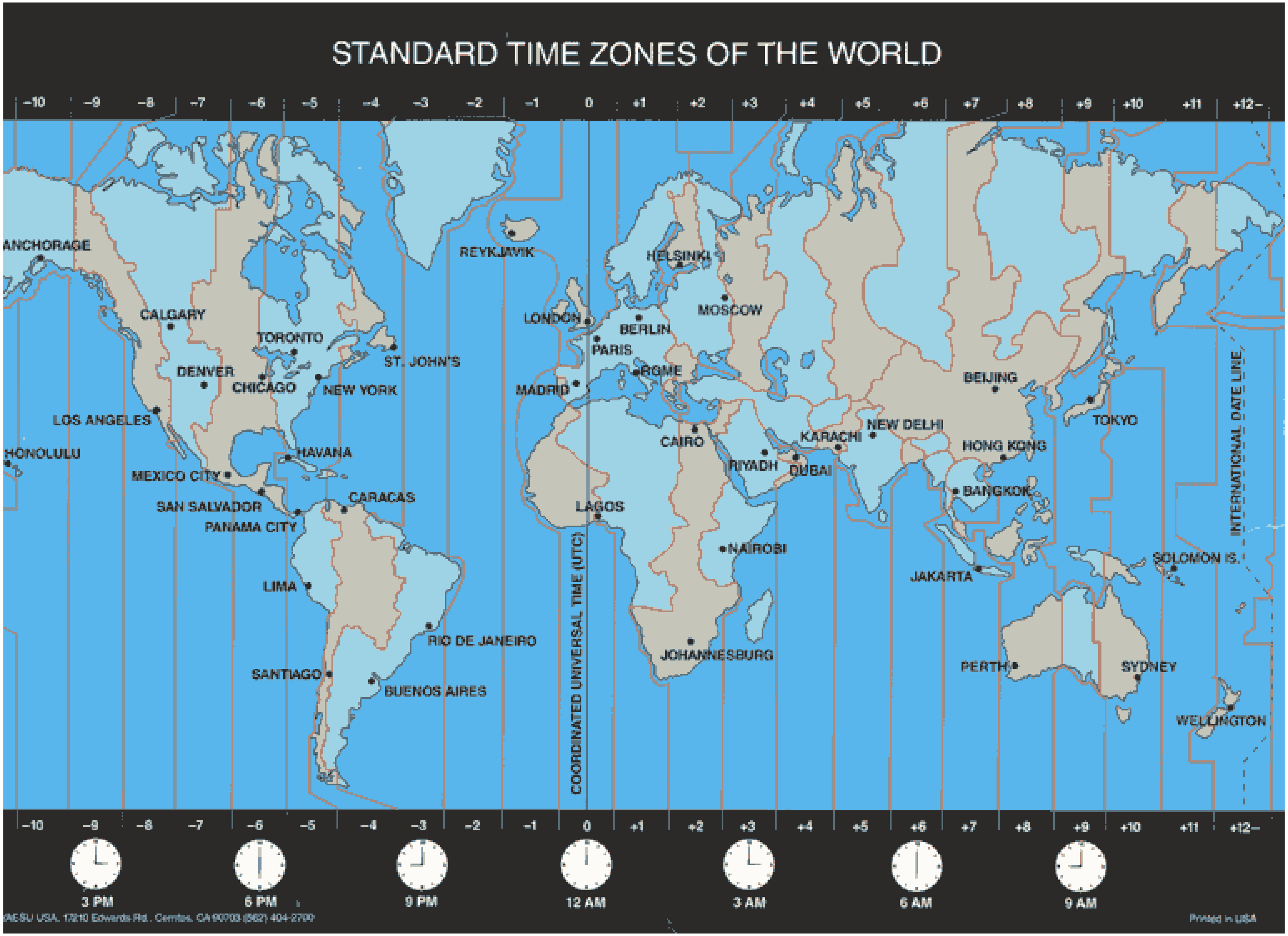
- The leap-second event (artificial injection of a second in a device not adapted for a second named « 60 ») provokes system interruptions, affecting:
- Synchronization of networks
  - Communications
  - NTP (network time protocole)
  - Computers
  - Electrical power distribution and control
  - …
- Satellite synchronization
  - GNSS times
- Space operations
  - Vehicles launching
- Air traffic control, airport operations
- Time dissemination in general

Negative points of UTC with leap seconds

- Breaks the essence of time: continuity
- Impredictable occurrence at irregular intervals
- Need of keeping archives manually updated
- Forced operation of clocks
  - Simplified today, Cs clocks can be programmed for leap second application
- Positive or negative?
  - Risk of 2 s offset
- Simultaneous all over the world, so at different local times
  - Impact is different depending on local times and of the date of application
- Non-respect of procedure of application
  - Applied on the first working day of the year (the lab is closed…)
  - Second 60 distributed over a number of seconds around midnight (steered seconds …)

Arguments to defend UTC with leap seconds

- Accomodates (uniform) atomic time to (non-uniform) Earth rotation time
  - But who really cares today?
- Gives acces to UT1 to better than 0.9 S
  - Predictions of UT1-UTC by the IERS give a more precise access
- Can be considered equal to UT1, so equal to GMT
  - GMT was abandoned in the 1950s by the IAU, replacing it by UT;
  - It was recommended not to use GMT or its acronym to avoid confusion with UTC since 1972
- Many people believe that by preserving UTC with the leap seconds they strictly follow solar time
  - What about legal times following time zones?
  - Good exemples: European Central Time, China without time zones, daylight saving times where 1-h offsets are applied between Summer and Winter times (people do not care…)


STANDARD TIME ZONES OF THE WORLD
−10 −9 −8 −7 −6 −5 −4 −3 −2 −1 0 +1 +2 +3 +4 +5 +6 +7 +8 +9 +10 +11 +12
ANCHORAGE
REYKJAVIK
HELSINKI
CALGARY
MOSCOW
LONDON
BERLIN
TORONTO
PARIS
ST. JOHN'S
DENVER
ROME
CHICAGO
BEIJING
MADRID
NEW YORK
LOS ANGELES
TOKYO
NEW DELHI
CAIRO
KARACHI
HONOLULU
HAVANA
HONG KONG
RIYADH
MEXICO CITY
DUBAI
BANGKOK
CARACAS
SAN SALVADOR
LAGOS
PANAMA CITY
INTERNATIONAL DATE LINE
NAIROBI
SOLOMON IS.
JAKARTA
LIMA
COORDINATED UNIVERSAL TIME (UTC)
RIO DE JANEIRO
JOHANNESBURG
PERTH
SYDNEY
SANTIAGO
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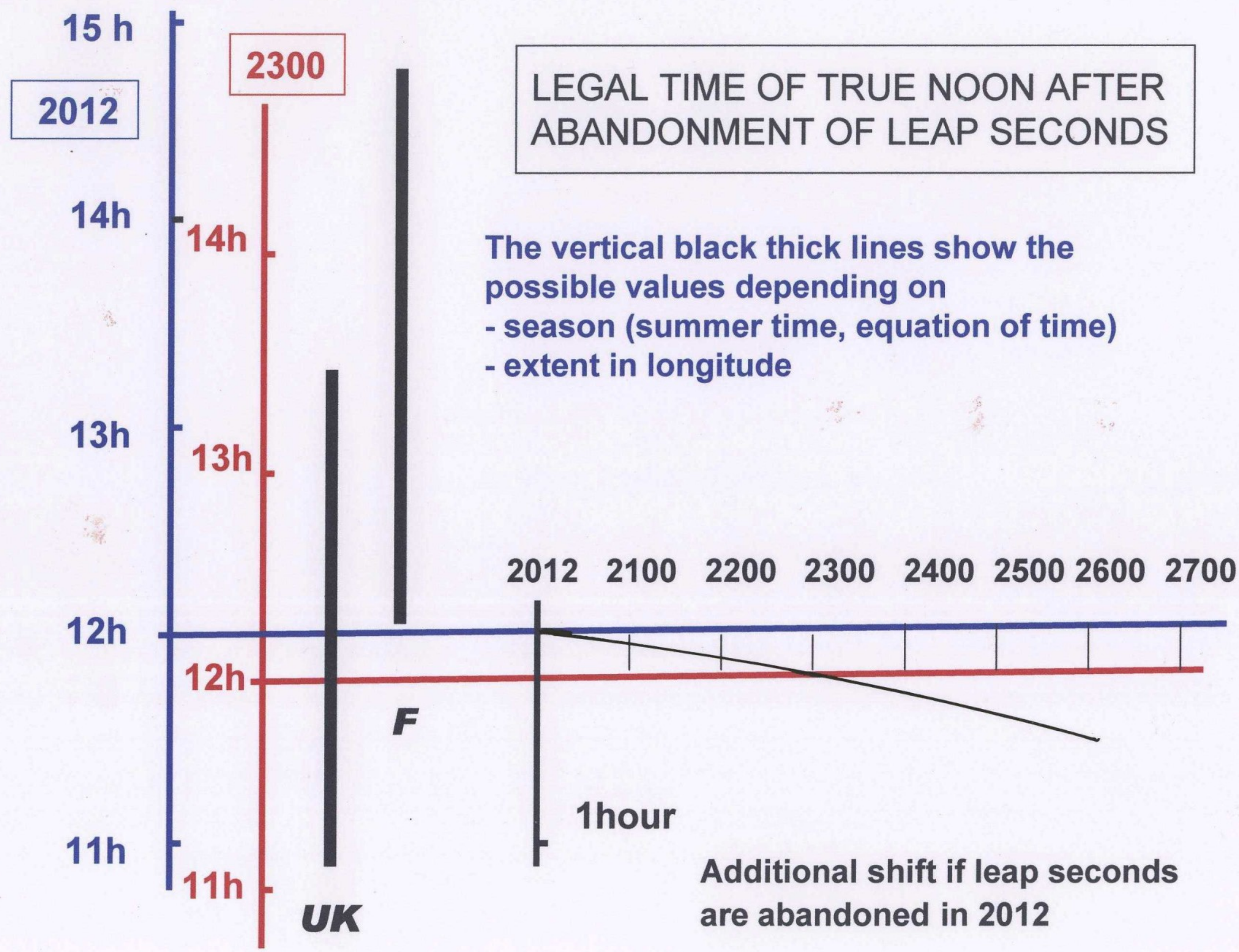


LEGAL TIME OF TRUE NOON AFTER ABANDONMENT OF LEAP SECONDS
The vertical black thick lines show the possible values depending on
- season (summer time, equation of time)
- extent in longitude
2012
2300
15 h
14h
13h
12h
11h
14h
13h
12h
11h
UK
F
2012 2100 2200 2300 2400 2500 2600 2700
1hour
Additional shift if leap seconds are abandoned in 2012

Typical problems and ambigüities arising from the LS

Timescales differing by seconds
http://leapsecond.com/java/gpsclock.htm

- Change of day problem
  - Some systems have time tagging on different timescales for different services;
  - At the leap second occurrence the change of day is not simultaneous for the timescales;
  - Happens in some GNSS, when the GNSS time and UTC are used.
- Change of week problem
  - Analogous to the change of day;
  - Dating in weeks is typical of GNSS
- MJD counting
  - Measure of time intervals by the number of days of 86400 s elapsed between the extremes of the interval

Elimination of the leap second application in UTC

- Decorrelation with UT1 (1 h in many hundreds of years…)
- Sofware not prepared for an unlimited difference UT1 – UTC
- Hardware not prepared for supporting DUT1 bigger than 1 digit
- Time is necessary for adapting the systems to the new definition

- Continuos reference timescale UTC
- No loss of time in leap second application (human resources, money)
- No more outages of systems affected by leap seconds
  - GLONASS is an example
- Interperability of GNSS facilitated, UTC will provide the direct reference for steering

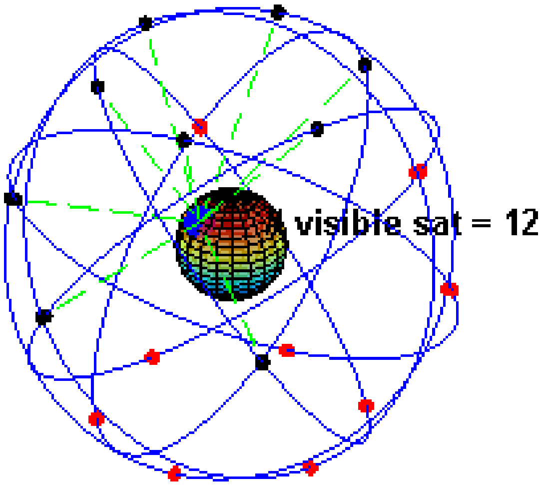
- Probable disparition of TAI (offset with UTCwill remain constant)
- Will stop proliferation of timescales and thus avoid confusion and minimize risks.

GNSS and the leap second

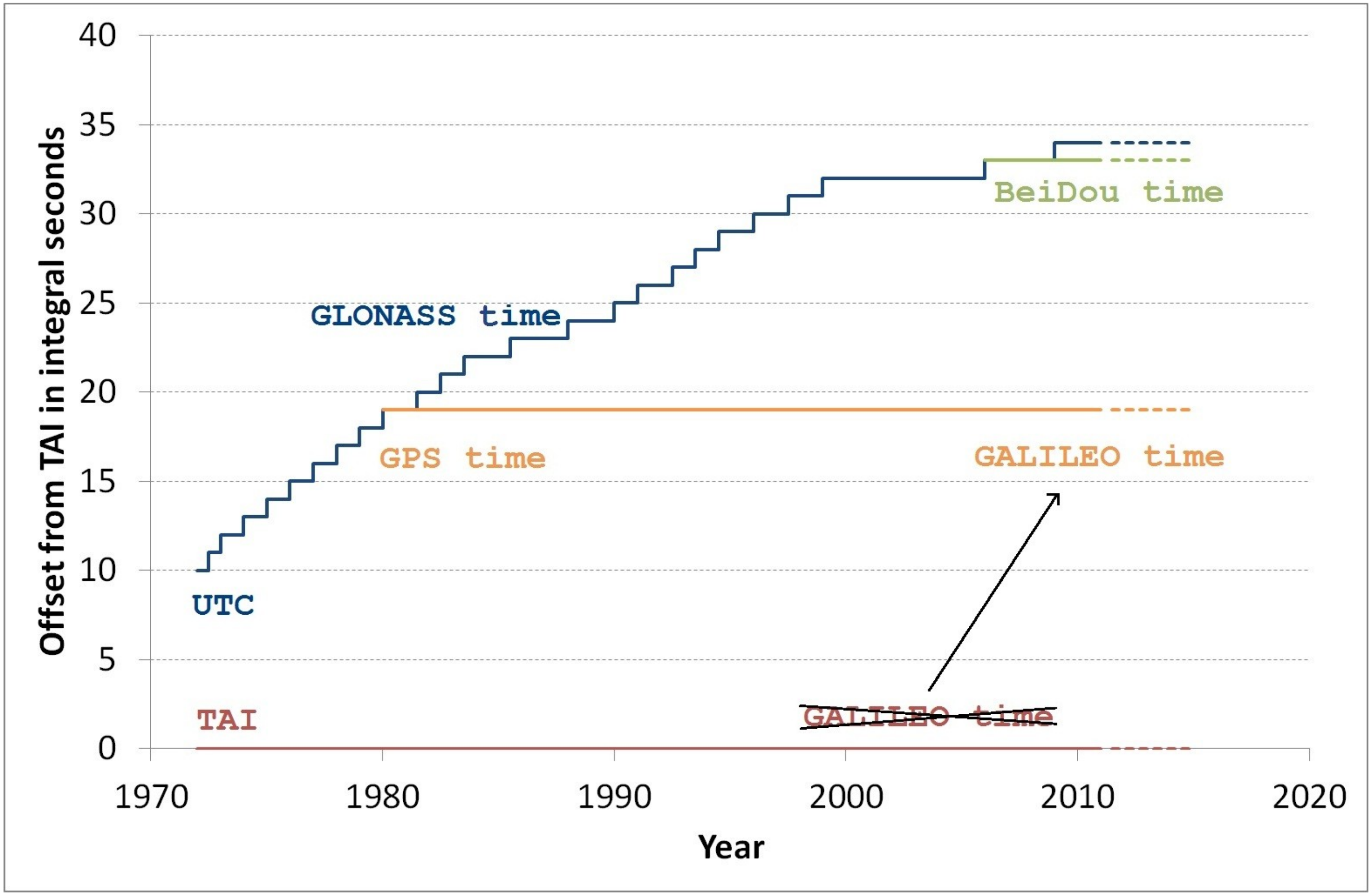
- ✓ GNSS define internal timescales for allowing system synchronization, they are necessary to achieve the navigation solution

GNSS time	Reference for synchro
GPS	UTC(USNO)
GLONASS	UTC(SU) [VNIIFTRI]
Galileo	UTC(k), k in Europe
BeiDou	UTC(k), k in China
EGNOS	UTC(OP)

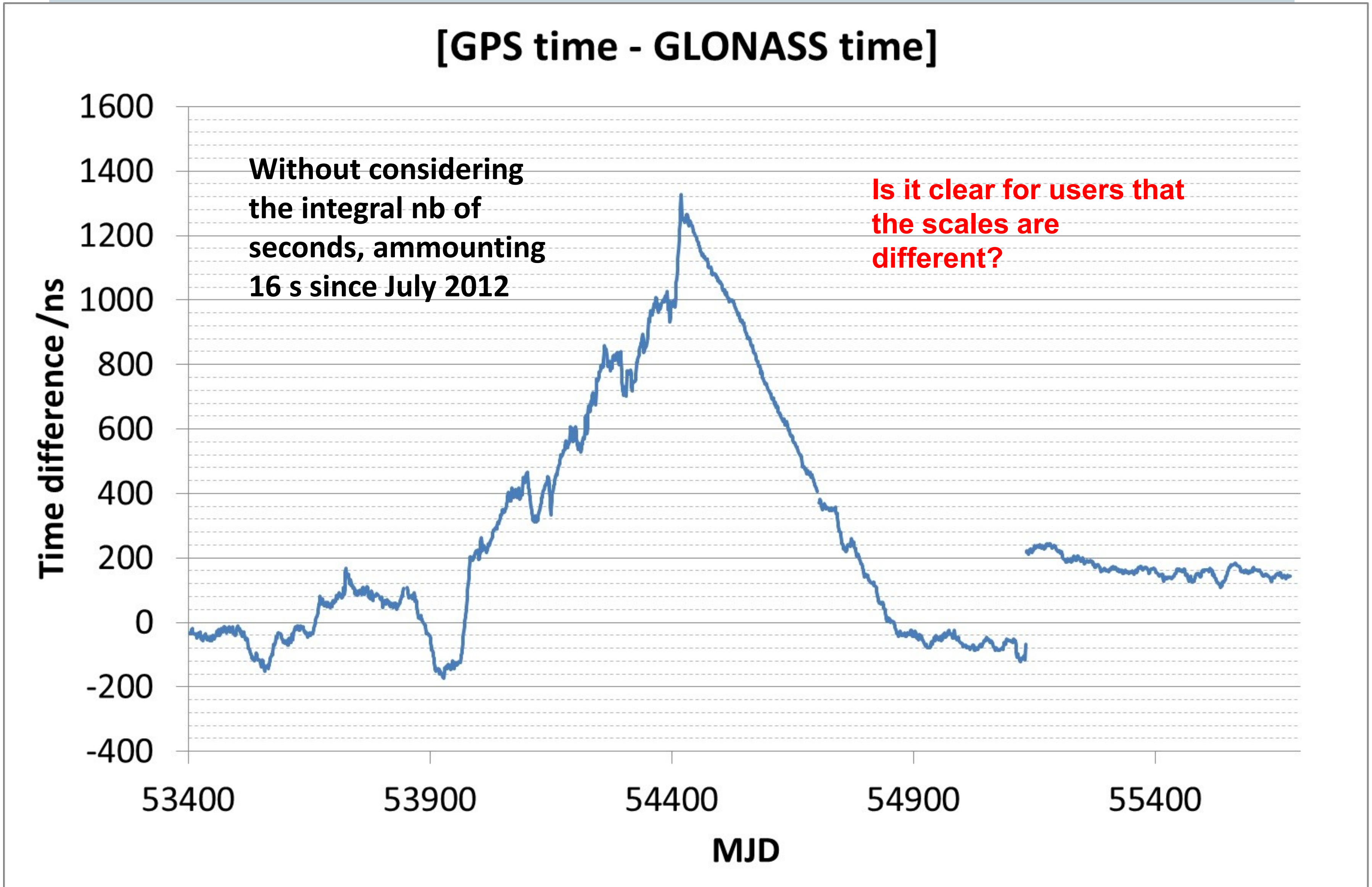
- ✓ GNSS timescales are continuos, constructed from clock ensembles, and steered to and external reference
- ✓ The external reference is UTC as realized in a laboratory
- ✓ UTC is stepped, so most GNSS steer to UTC(k) modulo 1 second
- ✓ GLONASS follows exactly UTC(SU)
- ✓ The choice of the number of integral seconds from UTC is arbitrary
- ✓ Conflict with interoperability



Relationship between TAI, UTC and the GNSS times



Relation between two GNSS times



Redefining UTC, the process

- The ITU has a very heavy process for approving/modifying recommendations (Working Party ⟶ Study Group ⟶WRC)

- The discussion has been in the WP7A for 12 years, strong opposition of one administration blocked the progress of the proposal. Three other administrations opposed in 2012.

- Arguments against the change have no technical support
  - Decorrelation to the Sun
  - Confusion of people, of nature in general, religious dates (the adoption of the Gregorian calendar for accomodating the dates of Easter implied the elimination of 10 days, 4 October 1582 has followed by 15 October, but was not adopted by all the world, only that linked to Rome)
  - UTC approximates UT1, and UT1 approximates GMT(legal time in UK); without leap seconds UTC and GMT will diverge (in fact there is no physical realization of GMT, it is the name given to UTC realized at UK by NPL)

Redefining UTC, the process (cont.)

- The draft recommendation TF-460.6 proposing a new definition of UTC without leap seconds was submitted to the Radiocommunication Assembly in January 2012.
  - Considering the need of adapting software, hardware and procedures, it would not be in force until at lest 5 years after approval

- A questionnaire sent by the ITU-R to the administrations previous to the RA was answered by about 15 members, only three opposing. In a previous survey, the IAU and the BIPM manifested their support to the elimination of the leap second.

- The RA took into consideration that there was some balance between the administrations with a clear opinion (either positive or negative) and those requesting for some analysis and information. In consequence the decision on the adoption of a continuous timescale was differed to the World Radio Conference in 2015.
  - The BIPM delegates to the ITU continue working on this direction…

Helping to the process, promoving discussion, educating

- A Special Issue of Metrologia, « Modern Timescales ». Published in July 2011
  - Guest editors are F. Arias (BIPM) and W. Lewandowski (BIPM) both delegates from the BIPM to the ITU-R
- Discussion at the Royal Society of London on 3-4 November 2011
  - Invited contributors only
  - Participation by invitation
  - T. Quinn, F. Arias organized
- Putting the discussion to the International Committee for GNSS (ICG)
- Promoting a reflexion on the responsibility for the definition of the world time reference,
  - ITU rules on the dissemination by signals, but is not the metrological authority
  - The well-established world metrology structure CGPM-CIPM-BIPM-NMIs should naturally take the responsibility

Last (?) leap second

End of June 2012

TAI-UTC = 35 s