Comments on the Debate over the Proposal to Redefine UTC

Presented to the
Timing Subcommittee of the
Civil GPS Service Interface Committee
September 8, 2014
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Disclaimer

- Official policy of the U.S. Government supports the ITU resolution to redefine UTC
  - US policy is based upon public input from both government and private sectors
  - The web sites noted in this talk are for general interest only
- This presentation includes personal observations of the presenter, which are not necessarily indicative of the motivation behind official policy.
- The numerical computations are predictions by the author. They ignore global warming, glacial rebound, and other factors.

Modern Life has LONGER days

~470 million years ago, day lasted only 21 hours

- Data from fossilized nautiluses, corrals
- Slowdown rate of ~2.3 mts/day/cty

Earth has lost 14 hours since 1815 BC

- Data from Chinese solar-eclipse records
- Slowdown rate of ~ 1.9 mts/day/cty

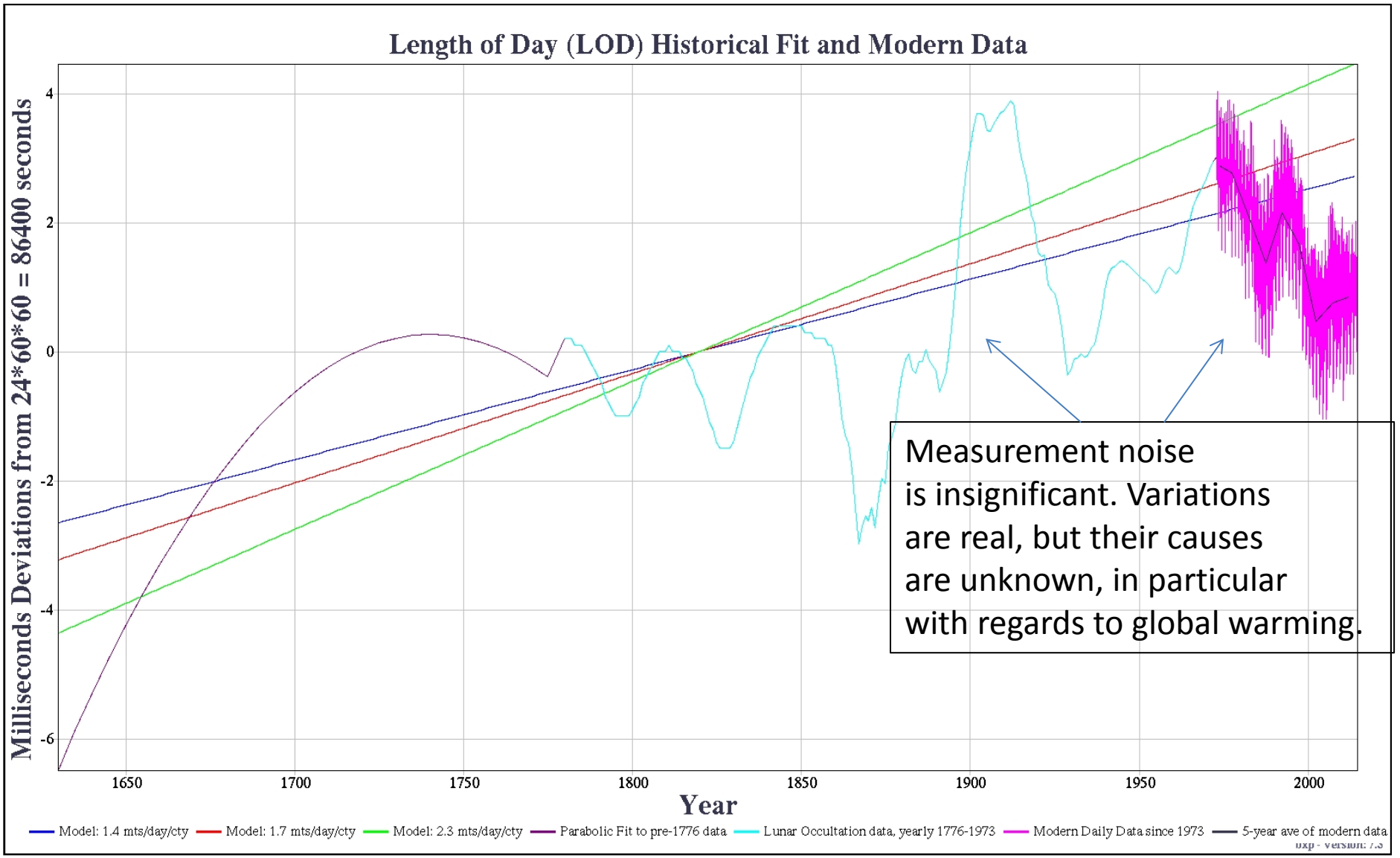
Earth has lost 3.25 hours since 136 BC

- Data from Babylonian solar-eclipse records
- Slowdown rate of ~ 1.4 mts/day/cty

Glacial Rebound

- Earth has an equatorial bulge
  - Due to centrifugal force
  - Equatorial radius is 20 km larger than polar radius
- Ice Ages are over; ice melting on Greenland and arctic
  - This raises mean sea level
  - Slows down Earth somewhat
- Light-weight crust rises due to decreased snow burden
  - Slows down Earth somewhat, decreased by cos(Latitude)
- Denser magma from equatorial region moves below raised crust (making Earth more evenly round)
  - It provides the uplifting force
  - Speeds up Earth
- Rigidity dampens short-term effects

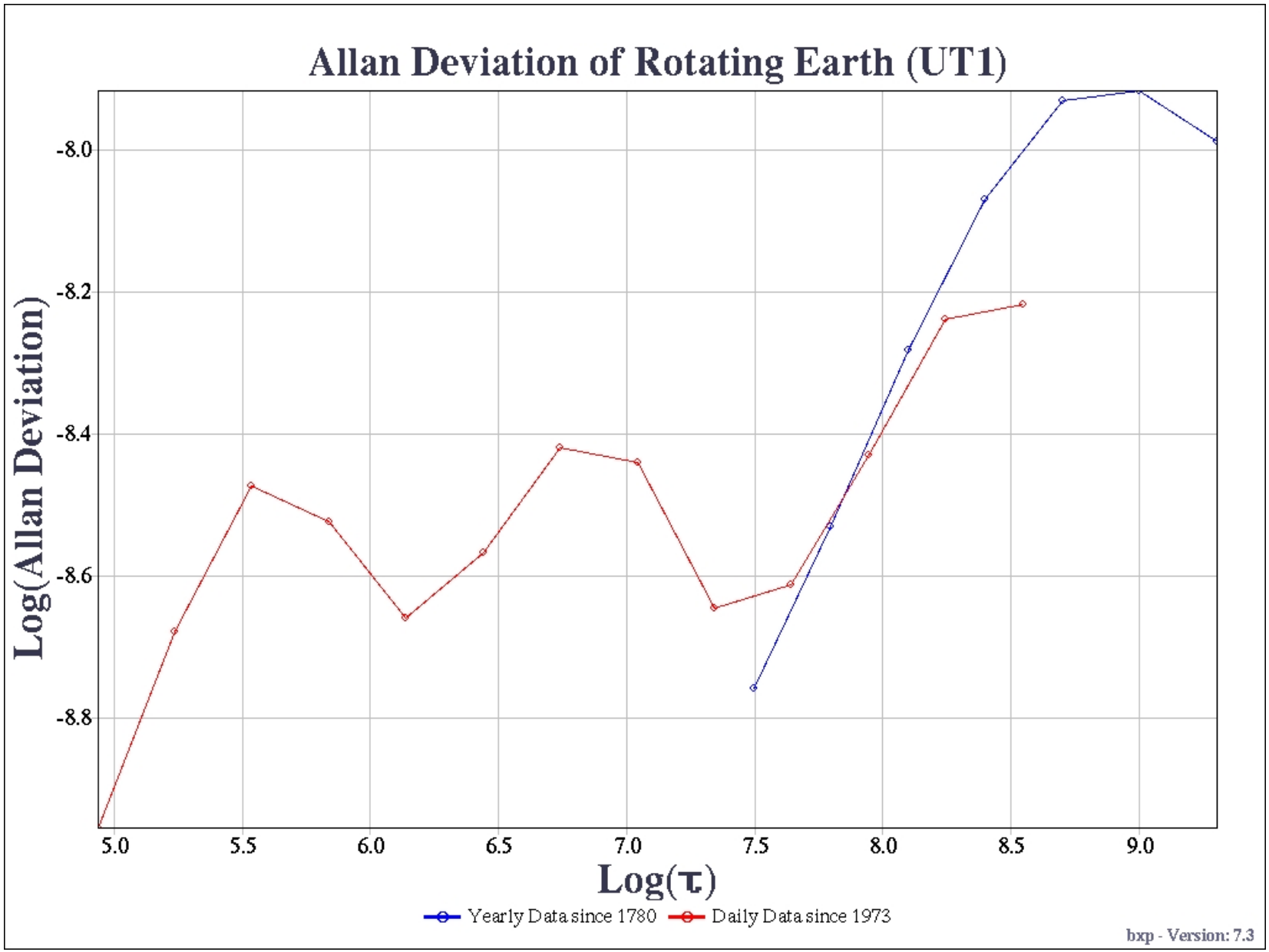
Length of Day (LOD) 1620-2014



Sources: F.R. Stephenson and L.V. Morrison, *Phil. Trans. R. Soc. London* **A313**, 47 – 70 (1984), http://maia.usno.navy.mil, and ftp://maia.usno.navy.mil/ser7/finals.all

UT1: Random Run on Recent Decadal Scales

(if so, the best predictor of Earth's rotation rate is its current value)

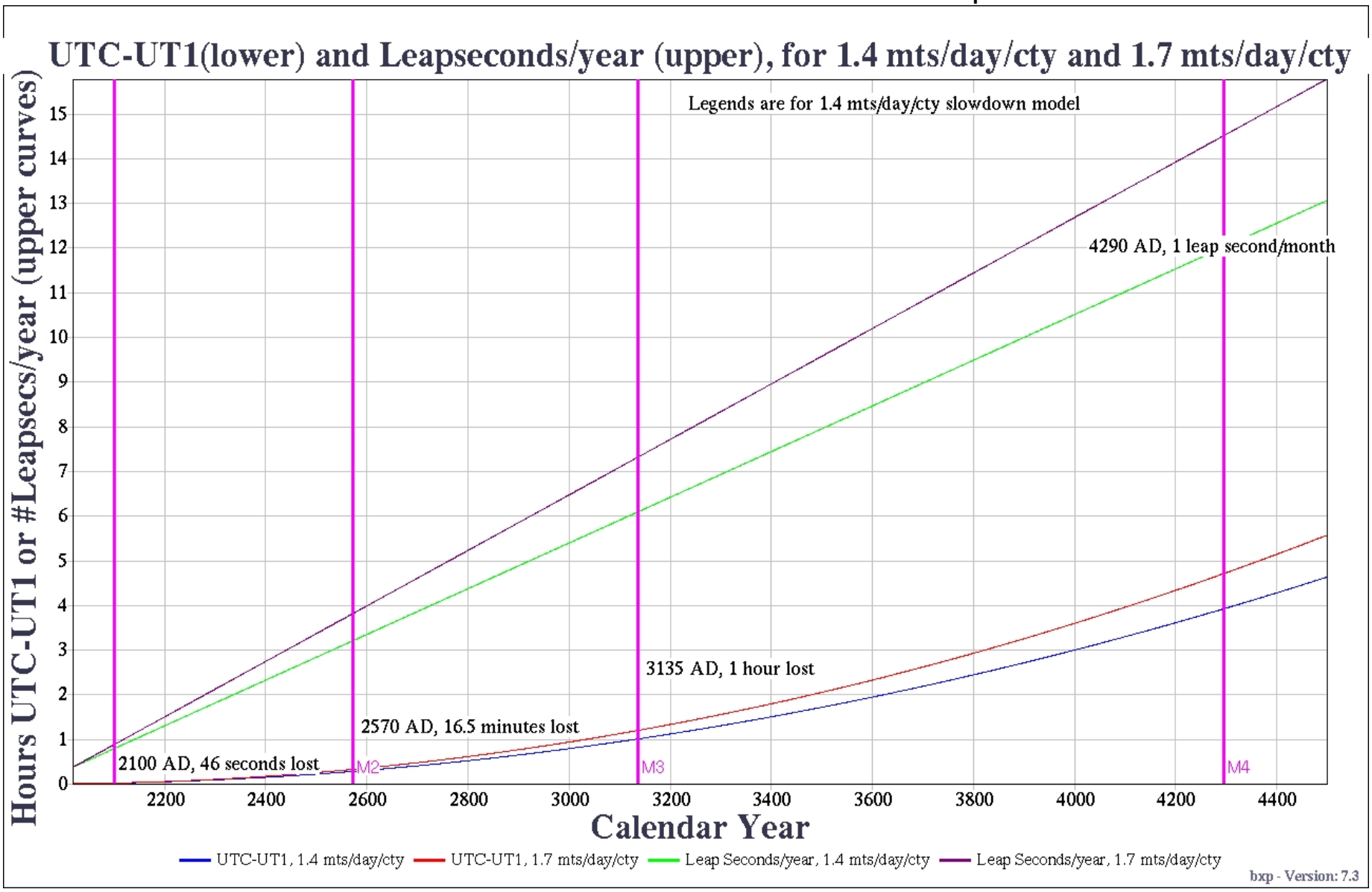


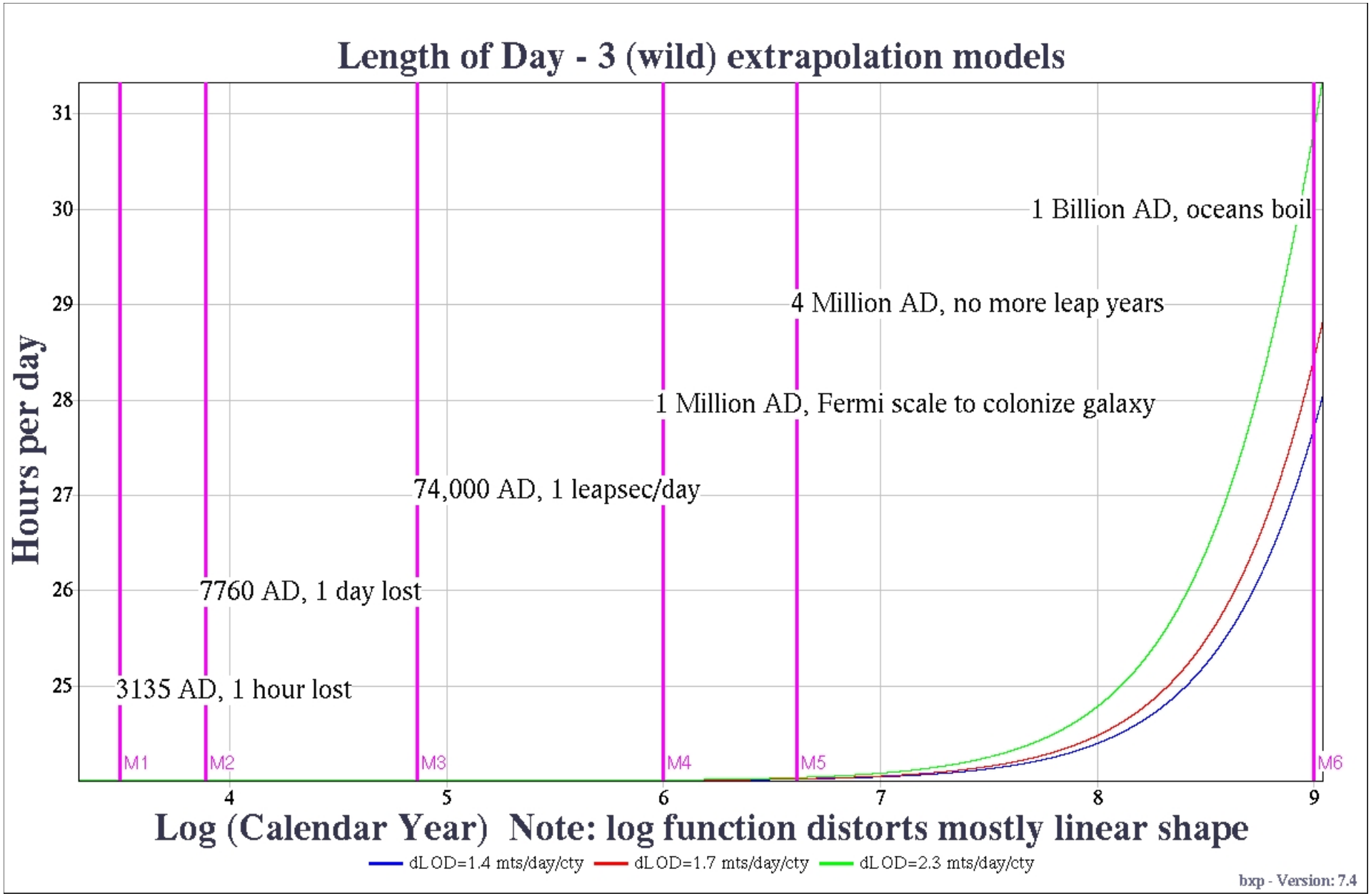
Enter man-made clocks

- Historical Length-of-Day data based on Moon's orbit
- 1932-1934 quartz clocks measure variations in UT1
  - UT1 = time based on Earth's rotation
  - German scientists Scheibe and Adelsberger
- 1955 caesium clock invented by Essen
- 1971 Coordinated Universal Time (UTC)
  - Frequency determined by atomic clocks
    - So that 86400 seconds = length of 1 day in 1830's
      - 86400 = 24 hrs * 60 minutes * 60 seconds
  - Leap second added to keep |UT1-UTC|<0.9 sec
    - Preferentially at end of Dec 31 or June 30
    - A second could be dropped then if needed

When will UTC *as-is* need revision?

Note: after (if) ice-caps melt, the slow-down rate will revert to larger values by 2100, most estimates predict a sea level rise of 0.5-2.0 meters - we have “70 meters of sea-level rise” stored in polar ice




Length of Day - 3 (wild) extrapolation models
Hours per day
31
30
29
28
27
26
25
1 Billion AD, oceans boil
4 Million AD, no more leap years
1 Million AD, Fermi scale to colonize galaxy
74,000 AD, 1 leapsec/day
7760 AD, 1 day lost
3135 AD, 1 hour lost
M1
M2
M3
M4
M5
M6
4
5
6
7
8
9
Log (Calendar Year) Note: log function distorts mostly linear shape
dLOD=1.4 mts/day/cty
dLOD=1.7 mts/day/cty
dLOD=2.3 mts/day/cty
bxp - Version: 7.4

The Debate

- Officially in favor: USA, Japan, France, India, Italy, Poland
- Officially against：United Kingdom, Russia
- Generally in favor: timekeeping scientists, including
  - Some English and Russian
  - Chinese timekeepers from Beidou, NTSC, and NIM
    - unanimously expressed personal support at URSI GA-14
  - Most who attend timekeeping meetings
- Sometimes against:
  - Some optical astronomers concerned about the conversion cost (see backup slides)
  - Some individual almanac-generators concerned about their software
    - USNO does not think this is a problem
    - See backup slides
- International scientific groups in favor:
  - BIPM, International Bureau of Weights and Measures (which generates UTC)
  - IUGG, International Union of Geodesy and Geophysics
  - URSI, International Union of Radio Scientists, Commission A

How do the English tabloids represent it?

Hannah Devlin Science Editor
Published at 12:01AM, May 14 2014

The Shepherd 24-hour Gate Clock at the Royal Greenwich Observatory
John Crook/The Times

After 14 years of political deadlock, there is little sign of a breakthrough: the US and France are backing an historic intervention, while Britain, Russia and China are strongly opposed. The matter at stake? Whether the leap second should be abolished.

A decision is due at a UN meeting in Geneva next year, but the government has decided to take stock of public opinion and will

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Behind the story:

Rogue second may mean time is up for Britain

The world's timekeepers have met to discuss whether the leap second should be abolished, which could have major...
Last updated at September 22 2013

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Seconds precious as Britain fights to be centre of time

China's space ambitions may mean the world changes its clocks as time starts to trun out for Greenwich Mean T... Published at December 31 2011

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How a split second could spell end of GMT

Scientists seek a new way to correct the anomaly between atomic clocks and astronomical time based on the Earth's... Published at December 16 2008

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Greenwich Mean Time could drift to the US, minister warns

David Willetts, the science minister, warns that night could become day and Greenwich Mean Time could drift to the US if plans to scrap leap seconds are given the go ahead

HE TIMES

Do the 1-second UTC jumps keep it "in harmony with the universe"?

- "Absolute time flows evenly with no respect to external phenomena."
  - Isaac Newton, *The Principia*
- Gamma-Rays Prove Einstein Right: Space-Time Is Smooth
  - "After 7 billion years of travel, high and low energy photons arrive at NASA's Fermi spacecraft a mere 900ms apart, suggesting that space-time isn't the bubbly foam of quantum theory but seems closer to Einstein's smooth rubbery membrane."
    - From http://www.space.com/15297-gamma-rays-prove-einstein-space-time-smooth-video.html

Do we need leap seconds to keep humans in harmony with the solar cycle?

- In a typical workday at USNO
  - 1/3 arrive before 7 AM
  - 1/3 arrive 7 AM-8 AM
  - 1/3 arrive after 8 AM
- By the time UTC-UT1 = 30 minutes
  - 1/3 will arrive before 7:30 AM (according to the clock)
  - 1/3 will arrive 7:30 AM-8:30 AM
  - 1/3 will arrive after 8:30 AM
- Schools, factories, and teleworkers too
- But nothing will have changed with respect to daylight

How is civil time now defined?

- Typically, as an offset to UTC
- Example: China's civil time = UTC+8 hours.
  - Geographically, it could encompass 5 time zones
- That offset can be changed as necessary

Will translators have to footnote time-of-day, as they now footnote currency units, and calendars? - Yes, but that's much easier than other issues

An example from Canterbury Tales, written the year 1340, or was it 1370?

Lines 10-15 of the *Man of Law's Tale*

And therefore by the shadwe he took his wit
That Phebus, which that shoon so clere and brighte,
Degrees was fyve and fourty clombe on highte,
And for that day, as in that latitude,
It was *ten of the clokke,* he gan conclude,
And sodeynly he plighte his horse aboute.

As Translated at
http://sites.fas.harvard.edu/~chaucer/teachslf/mlt-par.htm#INTRO

And therefore by the shadow his wit told him
That Phoebus, which shone so clear and bright,
Five and forty degrees had climbed on height,
And for that day, in the latitude,
It was *ten o'clock**, he did conclude
And suddenly he pulled his horse around.

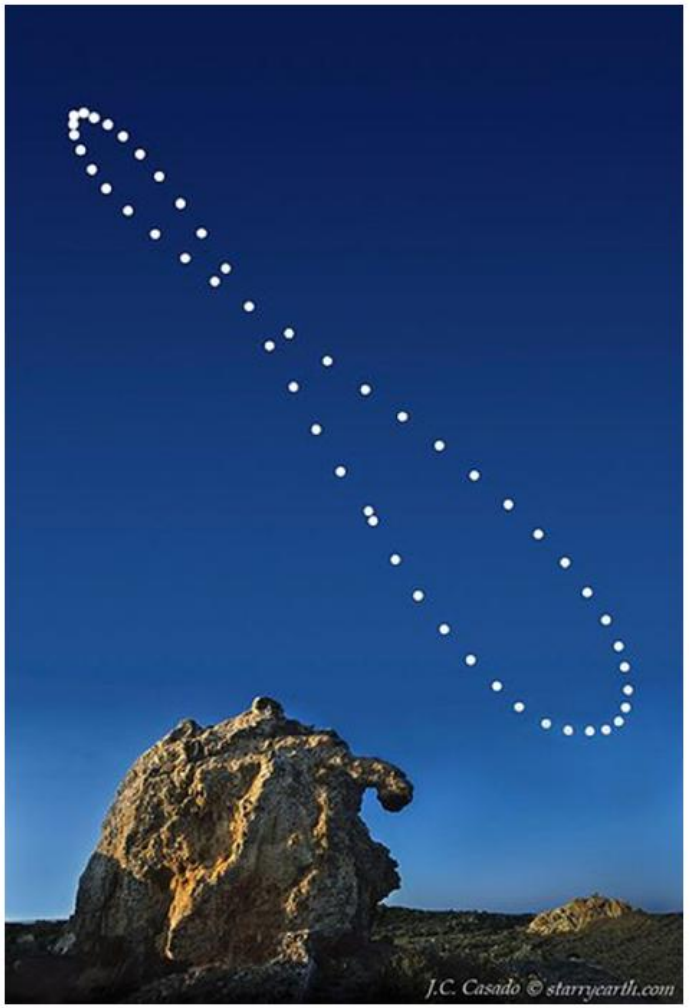
* Had time been measured with a continuous atomic timescale since Chaucer's days, the translation would have been ~10:30.

Will the Astronomical Almanacs break?

- Changes would have to be made
  - Some computations simplified if |UT1-UTC|<1 s
    - Rise and Set Times
  - But it's the opposite for occultations and eclipses
- Adjustments of similar difficulty are often made
  - To implement IAU resolutions, new models, etc.
- Almanacs typically printed 1-2 years in advance
  - ensuing UT1-UTC error < granularity of printed versions
  - On-line almanacs have no problem either way

Will sundials break?

- Most have dials that can be rotated easily enough
  - But not all
- Claims that shadows will not stop pointing due north at midday are incorrect
  - Such as “Sundials and shadows” tab in http://leapseconds.co.uk/background/
  - Shadows will stop pointing north at 12:00
    - They don’t exactly do that now
      - Time Zones, Daylight Time (Summer Time)
      - “Equation of Time”: up to 16 minutes
- The errors introduced by the Equation of Time imply a sundial would not have to be reset for 500 years
- Use of an updated analemma would extend the life indefinitely



Position of Sun at 12:00 each Sunday of a year

Will Celestial Navigation Fail If We Redefine?

- Best sextant accurate to 1 arcminute
  - Or 4 seconds of time on the equator (1.85 km)
  - More at higher latitudes: 1/cos(Lat)
- Therefore celestial navigation tables and clocks must be accurate to 4 seconds (4 leap seconds)
  - At least their extrapolations must be
- Percentage of navigators who can do celestial navigation is falling

What Is Risky About Leap Seconds?

… There are known knowns,

… There are known unknowns,

… But there are also unknown unknowns

NTP leap second failures are a *known known*

- If correctly configured, NTP and PTP can handle leap seconds
- Never has every NTP server monitored been known to handle a December 31 or June 30 correctly
  - At least since serious monitoring began, January 2008
  - http://www.maths.tcd.ie/~dwmalone/time/leaps/
- 10% of the servers in the “NTP pool” got it wrong in 2012
  - Most were fixed within an hour of the insertion
  - Others, not in pool, took up to a day
  - Some added a leap second on July 31, 2012
    - https://groups.google.com/forum/#!topic/comp.protocols.time.ntp/vhVlH4ENsJQ
  - Hackers have been accused of exploiting/causing this

How Important is NTP?

"Our infrastructure is held together by time - from time stamps on complex financial transactions to the protocols that hold the internet together. When the packets of data passing between computers get out of sync, the system starts to break down. *Without accurate time, every network controlled by computers is at risk.* Which means almost everything."

- Richard Hollingham

http://www.bbc.com/future/story/20130609-the-day-without-satellites

[Italics added for emphasis, though the point is overstated]

Software failures are a *known unknown*

- Most software undoubtedly assumes one day is 24 hours times 60 minutes times 60 seconds
- Data hard to gather as corporations, people, and institutions do not like to admit to failures or mistakes involving leap seconds
- POSIX has no built-in method for leap seconds
- Some software halts if time “goes backward”
  - Has shut down network servers, websites, commercial transactions, database control, etc.
- Some GPS receivers have gotten leap seconds wrong
  - One model failed because UTC had gone too long without a leap second
- Therefore, some facilities terminate operations when a leap second is scheduled
  - Including Japan’s legal time-stamping service, test ranges, etc.

Multiple simultaneous failures would be an *unknown unknown*

In 1 second the Earth's surface rotates 463*cos(latitude) meters

If an airplane or ground-controller's GPS-based system is misprogrammed

AND

If LORAN, or other possible backup, has also been disabled by leap seconds.

Something bad could happen.

Murphy's Law is based upon unknown unknowns

"If anything can go wrong, it will"
- and quicker than you think

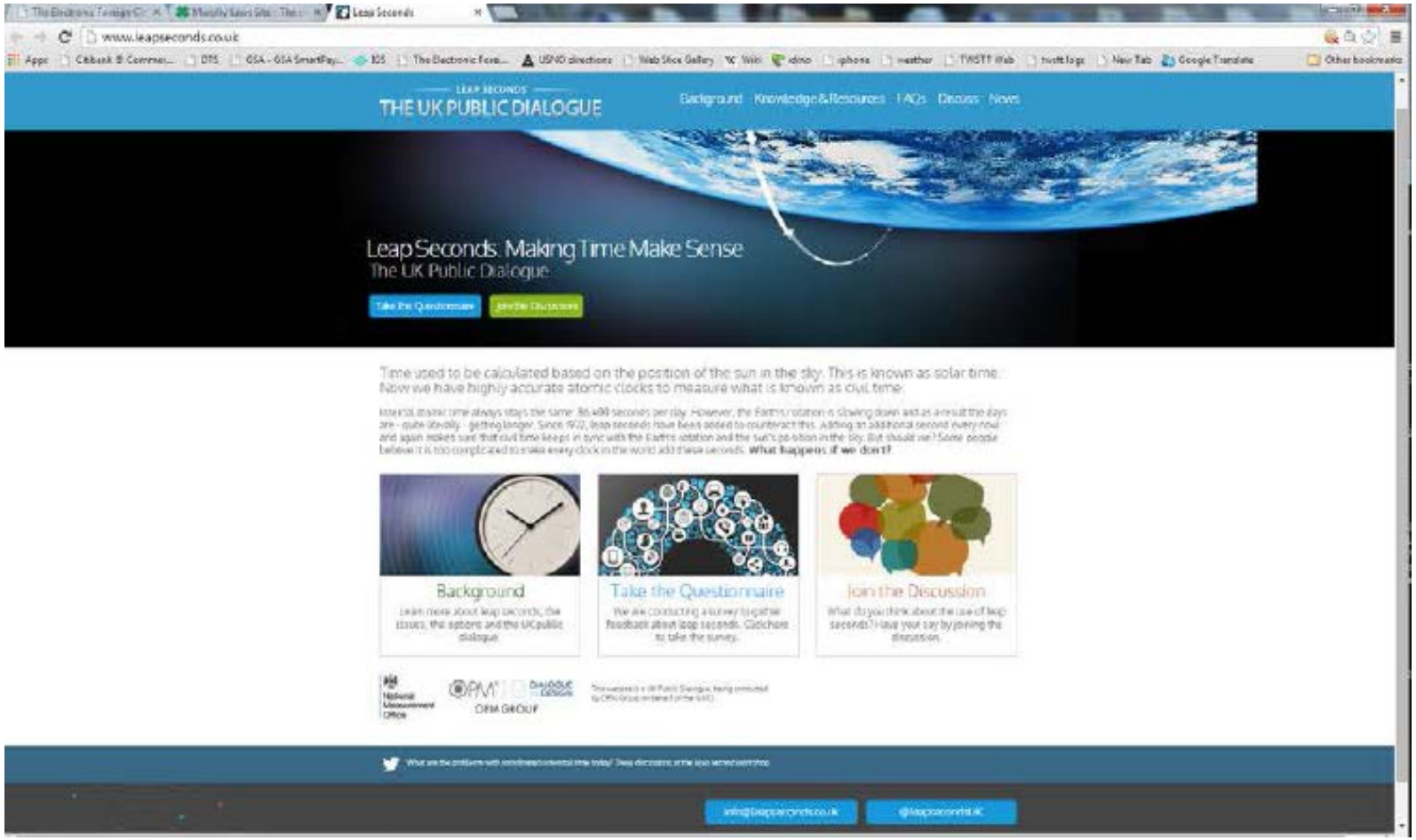
Will leap seconds ever be a "*public known*"?

- Many surveys have been conducted
  - Mostly finding little interest from those surveyed or the public
  - I conducted two URSI surveys (1999-2002 and 2002-2005)
    - In 2005, URSI decided it was best to do and say nothing
    - But in 2014, URSI Commission A passed a resolution in favor of the redefinition
  - IERS and many other groups have made surveys
  - Astronomical Groups have not taken a stand (IAU, AAS, IERS)
- U.S. policy based on NTIA and FCC findings
  - FCC requested public input
    - The responses from the public are on the internet
  - NTIA requested government input
    - DOD and NASA, for example
  - Results were favorable to a redefinition
- Occasional references can be found in mainstream news
  - Although movie stars' wardrobes get more attention

A relatively unknown and non-official forum
that is becoming more known

http://six.pairlist.net/mailman/listinfo/leapsecs

Putting a little English on it …

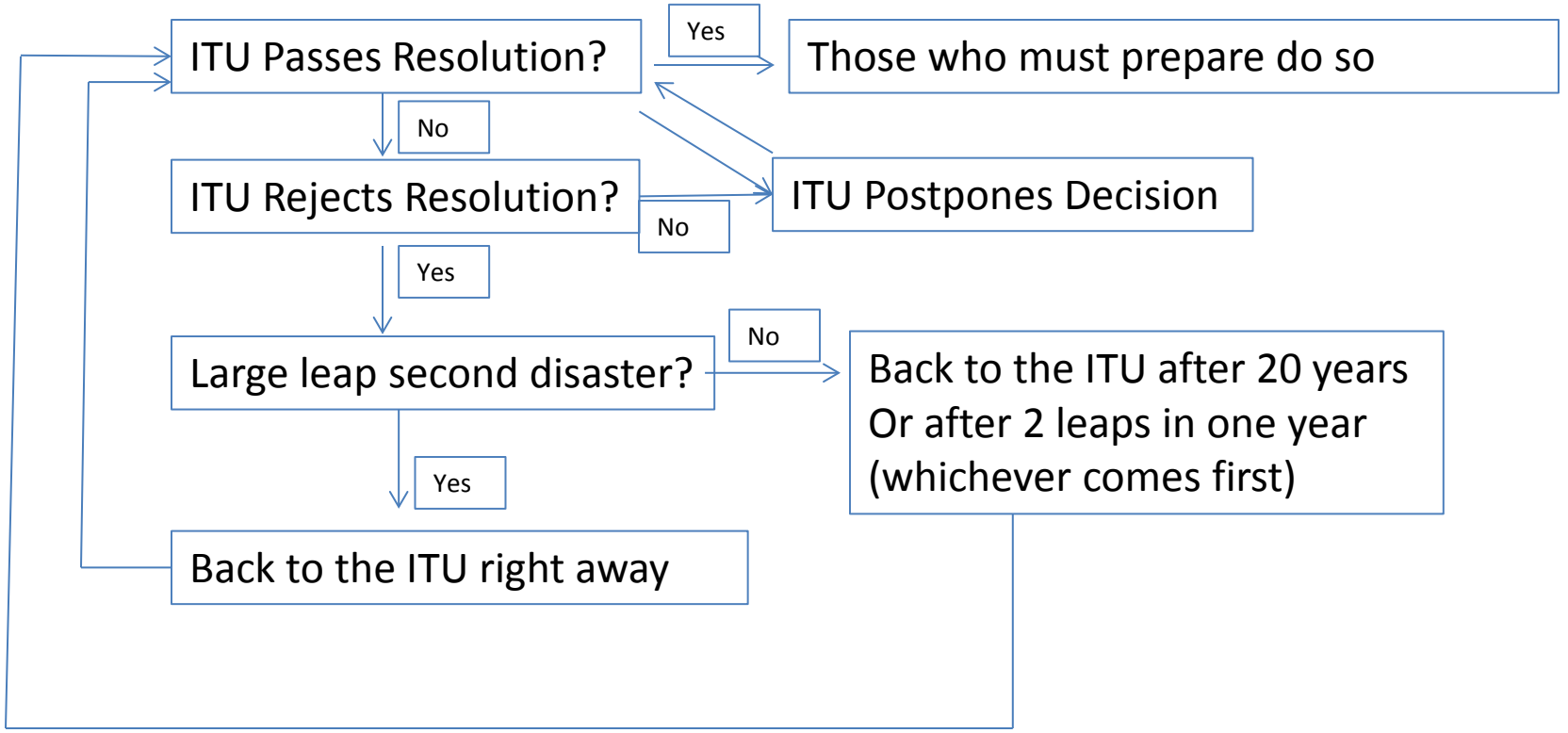


- A contribution by me, identified as an “American perspective”, also appears: http://leapseconds.co.uk/wp-content/uploads/A-US-perspective.pdf
- Total number of opinions expressed in general discussion: 10
- A twitter account was set up, but no tweets were sent (at least after I signed up)

My Summation

- In talk and backup slides I have tried to reference the reasoning on both sides of the question
- I don’t see an argument against the proposal that has no strong rebuttal (see backups)
- I see the strongest motivation for the redefinition to be the real-world impossibility of reliably implementing leap seconds
  - Programmers and engineers are not perfect
  - Most don’t even know leap seconds exist

Concluding Viewgraph: My Prognosis



Backups

- The backup slides provide the responses to all objections I have not had time to discuss
  - Ask me about your favorite issue
- They say there were riots about the Gregorian calendar reform in 1751

Would This Require Laws to be Rewritten?

- Proposal applies to Radiocommunication only
- Laws are NOT the subject of this proposal
  - But any law that based on UTC would not need revising
    - As is the case in USA and most countries
- The decision is made by official representatives of sovereign states
  - Scientists will advise on technical matters
  - For example:
    - UTC to remain an excellent approximation to GMT for centuries
    - The costs of redefining UTC
    - The price of keeping UTC unchanged
    - The risks and benefits either way

How much time would be “lost” by 2100, if we redefine UTC?

- Answer: most likely <1 minute
  - Last leap second might be in 2020
  - 80 years yields 30 seconds
    - At current rate of 1 every 3 years
  - continued slowing down would add another 10 seconds
    - if Earth is rotating 0.25 sec/year slower in 2100
    - [20= ½ (80*0.25)]
  - But decadal fluctuations cannot be predicted
- Some British sources give larger values to public
  - a BBC documentary says 1 minute in “a few decades”
  - http://leapseconds.co.uk/background/ has 2 minutes
    - This is a minor error. The site has several good things in it, see later

Must UTC be renamed?

- One of the ISO's 290 committees advises doing so
  - to *prevent* confusion
- But metrologists do not do such things
- For the obvious reason: to *avoid* confusion
  - GMT redefined in 1925 (day change at midnight, not noon)
  - UTC itself, when it did frequency adjustments only, i.e. no leap seconds, 1966-1971
  - More recently, the meter and the kilogram
- And the IAU redefined the term "planet" in 2006
- Who would be confused?
  - Most humans think the world runs on GMT
  - It would not confuse future pulsar astronomers
    - UTC and local times are just a means to compute Terrestrial Time (TT)
    - TT is published as a time series function of UTC: TT-UTC
- The redefined UTC would better fit its definition
  - *U* is for Universal time standard
    - Universal means followed by all
    - Universal means in tune with the universe
      - Some believe it means in tune with the Earth's rotation, as Iin UT1 and UT2
      - But maybe UT1 means universally accepted time #1, which happens to be in tune with the Earth's rotation
  - *T* is for Time
  - *C* is for coordinated between laboratories
- Those who oppose redefining UTC say it must be renamed; those in favor disagree
  - There is no one who supports the redefinition only if UTC is renamed

What would be the impact on amateur astronomers and other software users?

- Alignment errors are now the main problem
  - Most observatories use a large-angle finder telescope to center a star
  - As a byproduct, there is less sensitivity to Earth's rotation (UT1)
- Some astronomical software, including USNO products and celestial navigation, will require user to enter UT1-UTC rather than assume UT1=UTC
  - Amateur astronomers, who routinely discover comets and even pulsars, should be able to handle this
  - Affected software will have to be scrutinized, perhaps revised, and documented.
    - USNO's code can be modified within the 5-year warning period
  - Predictions of UT1-UTC can make software valid for an extended amount of time

Will Space Systems Fail if UTC is redefined?

- The preferred style for space is to do as much computation as possible on the ground
  - Space vehicles are given specific directions from Earth
- NASA, ESA, JAXA, and the U.S. Department of Defense all have considerable space assets and either support the redefinition or have not objected

Will religious events be mis-timed?

- USNO computes times relevant to several religions
  - Holidays, moonrise, sunrise, moonset, sunset, etc.
  - Others do too
- The user
  - May have to know his location
  - Then reads answer from internet, newspaper, or app
- Redefining UTC will not affect such religious applications

Will Earth rotation specialists lose their function?

- This has been suggested as a reason to oppose
- Users that require UT1 will become more visible as they must actively access it
  - Unless they get it from GNSS
    - But GNSS systems, already users, will also become direct re-broadcasters and therefore more prominent users
- The role of the IERS, as the disseminator of UT1, will therefore be enhanced

How Much Does it Cost to Convert?

- Most dollar-cost estimates are N*$10K
  - Similar in magnitude to what must routinely be spent to insert every leap second.
  - Usually based upon staff or contractor time to inspect many lines of computer code
  - USNO's estimate for its 1.5 m (61") telescope at Flagstaff, optical interferometer, and VLBI correlator is negligible
  - Some estimates are larger and based on Y2K cost estimates
    - Many question such estimates
- 5-year notice period helps
  - Could be increased as result of discussions

Will users have no way to access UT1?

- Many already get UT1-UTC directly with internet
- Creation of special UT1 time-services is assured
  - UT1-disseminating NTP servers will be set up
    - USNO has offered to do it
    - For specific users only
      - To avoid confusing the public
  - Adding an option to standard NTP has been suggested
    - In which case every server could provide it
  - GPSIII to broadcast UT1-UTC
    - And probably all GNSS will do so
- Some systems could be run on UT1 directly

Is the counter-proposal for two timescales a good idea?

- Proliferating timescales is asking for trouble
  - The BIPM quickly abandoned a display of TAI along with UTC
- One proposal would set up parallel alternative systems broadcasting a continuous time
  - This would double the cost of GPS!
- Another proposal would endorse GPS's navigational timescale as a continuous timescale alternative
  - But this doesn't address the problems of leap seconds
    - Some systems already use it this way
  - The difference between GPS time and UTC via GPS has resulted in some users being 10's of seconds off
    - Well-designed receivers don't let the users access the "wrong time"