

CONCLUDING ROUND-TABLE DISCUSSION

In the concluding discussion of *Decoupling Civil Timekeeping from Earth Rotation*, each attendee expressed parting thoughts regarding the topics raised during the presentations and earlier discussions. Issues of timekeeping terminology, standards, infrastructure, and public perceptions were raised. Short- and long-term planning, especially for software and broadcast systems, were discussed.

John Seago noted that there were no preconceived plans on how to finalize this colloquium, but the co-chairs were in agreement that each participant should be provided an opportunity to express any final thoughts, perceptions, and impressions based on the presentations and discussions of the meeting.

Dennis McCarthy offered some notes that he had written down that he had yet to share. He first wanted to clarify the nomenclature surrounding the term “Coordinated Universal Time.” He felt that many people think that term Coordinated Universal Time refers to the fact that Universal Time is somehow coordinated with respect to the Earth and somehow that is the source of the name Coordinated Universal Time, which is incorrect. Coordinated Universal Time is a historical term and has more to do with ephemerides than actual time. When the USA and UK decided to begin to put their ephemeris work together, in the late 1950’s Bill Markowitz and Humphry Smith decided that they would begin “coordinating the changes in time” which at that time were done by optical astronomical observations. These observations were used to make physical adjustments to the observatory clocks because Earth rotation was more accurate than the clocks of the time. They decided at that point, because the almanacs had *coordinated* their work, that the USA and UK would also coordinate their changes to clocks.¹ McCarthy hypothesized that these changes were announced by teletype in that era. So for these reasons, McCarthy said they called the time “Coordinated Universal Time” because Universal Time was the astronomical time that they were trying to maintain with astronomical observations. The practice of coordination grew with time and the terminology had nothing to do with the fact that the time scale is somehow coordinated with the rotation of the Earth.

Seago said that when Essen first proposed the idea of the leap second, he wrote that “Time scales have traditionally provided the time of day and the season of the year, as well as time interval, and if it is to be of universal use the atomic scale must be *coordinated* with astronomical scales.”² Seago agreed with McCarthy that the term “Coordinated Universal Time” had been used prior to leap seconds and that the word “coordinated” was introduced into that title for some of the reasons McCarthy noted; yet, Seago added that it would not be a misnomer to claim that “Coordinated Universal Time” is a time scale intending to be “coordinated with Universal Time” because the noted purpose of UTC with leap seconds was to be “coordinated” with Universal Time, and the word “coordinated” was the language of choice by those making the proposal. Neil deGrasse Tyson noted that the uses of the term are different; the original usage signified geopolitical coordination while the latter signified scientific coordination. Rob Seaman added that

“Universal Time” still means astronomical measurement of time regardless; McCarthy agreed, adding that astronomical time was the only basis for civil timekeeping in the 1950’s.

McCarthy also offered a reminder that, while this colloquium has focused on time as being important to many applications, a more important consideration of many users is frequency. Many users rely on clocks as an accurate source of frequency, as frequency is the inverse of time interval. As an example, GPS is often used to synchronize communication systems. McCarthy closed his remarks by saying that the colloquium was “terribly instructive” and quite useful.

Arnold Rots admitted that he was curious about the mixed responses to an earlier question of whether time services should be distributing TAI, or DTAI. Rots asked, “So why not distribute TAI?” Steve Allen offered that by the time the ITU-R decided that DTAI should be distributed, it was already too late for real-time POSIX-compliant applications. While POSIX can be hacked to allow real-time applications by using alternative, less-well-known APIs, that solution is also imperfect. Coupled with the fact that the abolition of leap seconds has been on the table for the past decade, there is zero incentive to develop uncertain capabilities within operating systems. Seaman asked why the POSIX compatibility should veto every possible alternative proposal: will POSIX matter in 100 years, in 400 years, in 10,000 years...? Allen noted that weapons systems, manufacturing systems, transportation systems, all require POSIX compatibility today. Seaman clarified that POSIX shouldn’t be ignored, but rather the utility of every proposal shouldn’t be based solely on whether POSIX allows it.

Allen sees the POSIX issue as a study of misfortune; this unfortunate compilation of a series of decisions made over the past 30 years “means that we’re stuck.” Seaman asked, “Who’s *we*?” as he has never had any professional concerns over POSIX. Tyson suggested that individual concerns may be irrelevant if fundamental elements of society rely on it. Agreements as to what people will generally use makes seemingly arbitrary decisions non-arbitrary and leads to the definition of a society. That becomes the force of society, rather than the individual. Tyson said if weapons systems, manufacturing systems, transportation systems are standardized to a particular convention, that convention cannot be disregarded. Seaman offered that if there was ever a more obscure societal topic than the definition of UTC, it is POSIX.

David Terrett noted that POSIX mattered only because everybody’s computer runs according to some type of standard. George Kaplan said that such an argument holds only for a while, as eventually some disruptive technology will come along that will not be running POSIX and a new standard will become prevalent. Allen said that until that time the POSIX-compliant kernel does not want to see a leap second, and the reason that the time zone database exists is to keep concepts separated. The kernel’s job should be easy and well defined and the complexity should be managed outside the kernel.

Because POSIX doesn’t technically keep UTC anyway, but rather an underlying count of integer seconds, Rots asked why not refer those seconds to TAI? Allen said that the installed base expects clocks to be tied to the “broadcast time” and that cannot be undone either. Rots countered that the broadcast time expected by POSIX doesn’t include leap seconds! Allen said that is the essential problem, and that this accidentally happened is why “we’re stuck.” Seago wondered if we should be trying so hard to accommodate POSIX if the standard is so confused. Allen noted that DTAI didn’t exist when POSIX needed such, it doesn’t have it now, and it therefore can’t tolerate it.

Rots noted that somehow POSIX seems to work notwithstanding that there are leap seconds in UTC, so what is the point in doing away with leap seconds? Allen said that some real-time systems do have problems when leap seconds happen. Seaman countered that Allen’s presentation

proved that POSIX can't "be real time" so POSIX should have nothing to do with those real time systems. Allen replied that there are many activities that are designated as being both real time and POSIX compliant. Seaman reiterated that it is easier to change the specification than to change the program: POSIX should change. Ken Seidelmann asked whether Allen's presentation showed that the POSIX behavior could be fixed. Allen clarified that his proposed software solution operated outside the kernel and POSIX doesn't care what happens outside the kernel. Interesting quirks might show up but these would not be fatal as might happen with a problem inside the kernel. Allen also repeated that his approach requires no special hardware and it is easy to test.

Seidelmann asked how POSIX had survived leap seconds all this time. Allen admitted that most systems—at least the ones that people are willing to talk about—don't really care about leap seconds. Allen speculated that there may be systems that no one will admit has problems that are in peril. Seidelmann asked why the entire world should change because of some hypothesized group of hidden users; if they exist, "why can't they just fix *their* problem?" Seaman suggested that "*their* problem" might be that they are required to conform to POSIX when it doesn't work for their application, which seemed a very silly issue. Allen said that it is difficult to guess about what people haven't admitted to talking about, but he noticed that the hard push to abolish leap seconds came right after the POSIX committee said in 1997 that the POSIX standard needed to be fixed to work in real-time applications.

Knowing that Rots had a pressing travel schedule, Seago interrupted the discussion to ask Rots if his question "why not distribute TAI?" was reasonably addressed by the discussion taking place. Rots said that he enjoyed the discussion, but he still preferred that the explicit broadcast standard be TAI or else broadcast DTAI. Allen offered that GPS provides TAI-like time broadcasts for those that need or prefer it. McCarthy said that the cessation of leap seconds would essentially conform to Rots requests, but Seaman clarified that the name would not change; it would still be called Coordinated Universal Time. Seidelmann also reminded that there is an offset between UTC without leap seconds and TAI. Rots clarified that his preference was to broadcast TAI rather than UTC without leap seconds. Allen said that TAI broadcast would never happen; Rots concurred that he didn't expect it. Rots also noted that civil clocks could continue to display something offset to UTC as currently defined; his preference was to simply have TAI as a background or basis time exposed. Seago noted that if TAI were the broadcast time scale, this would satisfy Allen's proposal to have a uniform broadcast time scale for POSIX. Allen said in his proposal he assumed that broadcast GPS time was available as a purchasable option. Rots said that he would gladly exchange his preference for TAI time by simply offsetting the GPS epoch if GPS time were a basis for time broadcasts.

Daniel Gambis said that it was very instructive hearing the interesting points of view coming from different domains. He wondered if it would be possible to have a summary of the colloquium's main points beyond the listing of abstracts. Seaman asked if Gambis had any specific main points that he thought should be clarified; Gambis said he would contemplate this. (Following the concluding roundtable, Gambis reported that his main perception from the colloquium was that there appears to be a lack of formal study regarding the broad ramifications of redefining UTC; thus, an official decision may need to be delayed.)

David Terrett said that it was a most-interesting couple of days. He wondered what happens now. What practical outcomes can result from the discussions, understanding that we have no influence with regard to the ITU-R process? Seago asked if Terrett had ideas about what *should* happen now. Terrett affirmed that there must be some means of ensuring practical distribution of

UT1-UTC into the future. McCarthy said that it would be wise to influence the IERS Directing Board to act on that issue.

Rob Seaman also asked what the action items might be going forward. He was skeptical that this or other meetings could influence delegations to the Radiocommunication Assembly in January 2012, but he clarified that the chairmen were planning on making proceedings available to potentially inform other meetings of the future, possibly including the upcoming Royal Society meeting on November 3-4, 2011, to which a few attendees from this colloquium would also be attending. If UTC is redefined, other meetings would likely happen, perhaps having narrower focus on more topical issues (astronomy, astrodynamics, etc.).

Steven Slojkowski was thankful to be able to attend as an observer on behalf of the NASA Goddard Space Flight Center (GSFC) Flight Dynamics Facility (FDF). He said the proceedings helped to expand his otherwise “myopic view” that the FDF would be able to handle whatever comes along. He now realizes that his organization should have greater concern about other groups providing data to the FDF, as it is unknown how well they will respond to a redefinition in UTC and whether this will affect the data products that FDF receives from them. It is also unclear now how recipients of FDF data products may handle a possible redefinition; a general lack of understanding by the FDF’s user base may demand unanticipated support from the FDF.

Neil deGrasse Tyson was thankful to actively participate in the discussions. His impression was that, if there was no such thing as a computer and people only relied on wrist watches, then a decoupling of civil timekeeping from Earth rotation could happen with much more blunt corrections over time. But practically everyone relies on computers today, which are synchronized to some time-source, and this level of coordination goes far beyond the scheduling of one’s daily routine. Evidenced by all of the energy that was invested in the conversations regarding all of the other elements of life, it is clear that we are all connected now in fundamental ways and we must count other systems—such as transportation and military applications—as users of civil timekeeping. Tyson doubted that changes to civil timekeeping could be applied to one sector and not another without unpredictable consequences, because of our connectivity through machines. Tyson could offer no “silver bullet” but appreciated all of the arguments heard and resonated with each one, as they all seemed to make sense. Unfortunately, this resulted in a lack of clear convergence. Tyson noted his respect for the significant gray areas, and would be happy to champion whatever outcome, not having a “horse in this race.”

Tyson sent a “tweet into the Twitter-verse” to gauge people’s interest in timekeeping issues. His tweet was “FYI: *Android phones use GPS time, omitting 15 leap secs added since 1980. So their clocks are wrong—15 secs ahead of iPhones.*” Tyson’s motivation was that he hoped people reading the message might compare clocks on different devices and thereby gain a better appreciation of the subtle complexities of civil timekeeping. Tyson asked if the language was correct (enough), and some arcane discussion of the technicalities ensued before Tyson sent the message. Allen noted that the quality of synchronization of iPhones could vary depending on many factors, including which carrier service was being used, but Reed noted that he had been following how well cellular telephones kept time for years, and affirmed that cellular phones will stay to within a second of the time supplied by the cellular network. He noted that his cellular telephone back in 2002 kept time to within 1/10 of a second relative to WWV signals; however, because people don’t use cellular telephones for precise timekeeping there is little commercial benefit for modern phones to maintain time that accurately. Seaman pointed out the irony that proposed changes to UTC are to supposedly benefit a telecommunications industry that can’t get cellular phones to provide time to within 15 seconds!

Tyson concluded that he finds the public to be enchanted by leap seconds and other adjustments to the calendar. People love thinking about leap days whether or not they fully understand them; they almost celebrate their introduction with anticipation. He noted that in the famous opera *The Pirates of Penzance*, a plot element hinges on how to determine the age of a character born on a February 29th. Public commentaries on time zones and daylight saving time provide evidence that calendar adjustments are entertaining to people. Tyson opined that the public will not worry over finer calendar adjustments; they will simply accept them and have fun doing it.

George Kaplan said that the colloquium was “an amazing couple of days;” it was hard to imagine that 17 fairly intelligent people could gather around a table and talk about how to count seconds for two days—some of them traveling thousands of miles to participate. It struck him that we are now talking about a very fundamental change to civil time. In his opinion the title of the colloquium was correct: we are indeed discussing the “decoupling of civil timekeeping from Earth rotation” for the first time in human history. Understanding this, one would think that a phone-book sized volume of pros and cons should already exist exploring the motivations, impacts, and repercussions that one might normally expect out of a decision-making process. Studies by the federal government generate piles of documentation for much less consequential questions, yet study documentation didn’t seem to exist for this question. Rather, it appeared that the decision would be left with a group that was presumably ignorant of many of the issues; that is, the voting memberships of the ITU-R are not experts in these issues but rather work for departments of State. It also seemed wrong that consideration appeared to be restricted to just the International Telecommunication Union; this question is larger than radio-communications, internet, and wireless protocols because it involves what we essentially mean by *time*. The narrow focus of the ITU-R process appeared “disturbing”; even within that very narrow focus of technical issues the documentation appeared very sparse. Kaplan admitted that he could go with either the status quo or the cessation of leap seconds, understanding that certain simplifications might result from predicting where things are in the sky for year to come, for example. Yet the process by which all this has taken place had been disturbing.

Allen noted that the expectations of the Royal Society meeting taking place in November 2011 were unclear, but he speculated that the context might be related to the recent *Metrologia* special issue, where Terry Quinn has proposed that the ITU-R should turn over authority for UTC definition to the CGPM (the directing body of the BIPM).³ Seidelmann suggested that the expectations of the Royal Society meeting might not be clear to anyone at this colloquium, but McCarthy offered some contextual perspective. McCarthy said that many years ago he brought the issue of UTC definition before a meeting of the Consultative Committee for Time and Frequency (CCTF), a technical advisory group to the BIPM. McCarthy testified that he was “essentially thrown out of the room” because the issue of UTC definition was felt to be beyond the scope of the International Bureau of Weights and Measures and was the responsibility of the ITU-R. Seaman noted that Quinn (former Director of the BIPM) seemed to think that UTC definition is a BIPM issue. McCarthy said he helped Quinn draft his 1999 letter which advocated the use of TAI wherever a uniform time scale was desired, which was the extent to which the BIPM involved itself.⁴ Seidelmann clarified that the discussion now centered on Quinn’s recent *Metrologia* article.² McCarthy noted that Quinn doesn’t run the BIPM now; thus, he is unsure how the CCTF would react to the proposal coming from Quinn as an Emeritus Fellow. Seidelmann offered that this will presumably be Quinn’s position at the Royal Society meeting and may be a topic of the discussions. McCarthy replied that the UK has been steadfastly against the proposal to cease leap seconds, and there was a feeling that there was no real technical expertise applied to that position within the UK; rather, it was a political decision to avoid the loss of GMT. McCarthy said that Quinn felt strongly that there was a need to organize some group discussion of the issue within

the UK, and Quinn had been working on getting some type of meeting together for the past two years. McCarthy said that the meeting of the Royal Society originally intended to serve that purpose but it appears to have changed its goal in recent months and he was unsure what the meeting would turn out to be. McCarthy thought that the audience originally intended to be the UK members of the Royal Society, but the invitation list had been expanded.

Wolfgang Dick said that this was one of the most interesting and entertaining meetings he had ever attended, and that he learned much. As a representative of the Central Bureau of the IERS he had not expected to hear so many thoughts expressed about the work of the IERS. For the benefit of the IERS Directing Board, he would attempt to summarize some of the various thoughts expressed regarding potential improvements of IERS products by those in attendance, understanding that the IERS is discussing changes to its products and many modernization efforts will be taking place within the IERS within the next year independent of the issue of UTC redefinition. Seaman said he felt that there was a certain fondness for the IERS and its products and he particularly enjoyed receiving *Bulletin D*. Dick said that in his opinion some IERS products seemed old-fashioned. Seaman said that he and Allen work on protocols for Celestial Transient Alerts with the Central Bureau for Astronomical Telegrams; these have message formats similar to IERS Bulletins but for different types of astronomical information. Dick said that the IERS Directing Board would meet in December and he would distribute his summary to some of this colloquium's attendees for their commentary before that. Seago remarked that if Dick's summary were generated soon, the colloquium chairmen might be able to leverage his summary efforts for the colloquium proceedings.

Paul Gabor offered thanks to the colloquium chairmen for organizing "such a wonderful venue at such a wonderfully low price." Seago acknowledged that the host organization, Analytical Graphics Inc. (AGI), was to be thanked primarily for that. Gabor noted that the colloquium was both exhilarating yet slightly frustrating because he was not really sure that he understood all of the main points. Questions such as "are we going to be able to explain to future generations why this is happening?" and "what are the motivations?" have not really been answered. One of his reasons for attending was to hopefully get a clearer understanding of the motivations behind the UTC redefinition issue, as this appears to be the first time in human history that civil timekeeping will be decoupled from Earth rotation *by design*. Although things may have went wrong or "hay-wire" through history, there was willingness to affect an eventual correction, as timekeeping has been principally perceived as an exercise in remaining faithful to what the heavens were doing. This is no longer going to happen if the proposed decoupling occurs. Gabor noted that even if this happens, pressure may be eventually brought about from this "principle of astronomical conformity" that will lead to a desire to recouple sometime in the future. Our question should be: can we somehow facilitate that recoupling now? How can we help future generations prepare for that? Evidence presented in the Thursday morning sessions seems to indicate that the inertia of developed software is a difficult burden to overcome.

Tyson commented that in the context of modern society, the development of software is not unlike agriculture of earlier cultures: it is an aspect of civilization forced annually for the sake of survival. Seaman quipped that, like agriculture, somebody still has to deal with the manure. Seago noted an interesting juxtaposition as it relates to software: whereas McCarthy noted that some computer technologists feel software should be replaced every decade, there does seem to be software inertia. Seago thought that the computer-science position makes sense if software languages are expected to rapidly evolve with time. McCarthy said that flexibility is critical so that software does not hold us back; many changes need to be made but inflexible software becomes prohibitively expensive to modify. Forward thinking is required in software design, including anticipating how people in the future might contemplate changing things.

Seaman noted that the Image Reduction and Analysis Facility (IRAF) project is older than 30 years and is very portable. He foresees it as software that that might still be operational a century from now. It was implemented according to the standards that were in affect at the time and is not broken. Changing the standard out from underneath software does not break software; rather it changes the way software is interpreted. McCarthy said that he has run into a number of situations where software changes were so prohibitively expensive that improvements could not be implemented. Tyson remarked this expression is nothing new; in nature, genetic codes contain many seemingly unused sequences that might have been useful at one time. McCarthy quipped that while humans can adapt, software can't. Gabor wondered if software inertia might be overcome if software design (or redesign) were managed by the computers themselves; because software development and management could become such a huge task, it may become too difficult to accomplish manually. Reed noted that Seaman's software searches for UTC usage seemed to demand such automation. Seidelmann said it would be amusing to tell a military General that we will now trust the computers to solve their own problems.

Steve Malys understood that the main topic of discussion relates to very fundamental changes. We may need to remind ourselves that computers work for people; people don't work for computers. Software inertia can be overcome; it is a solvable problem that just takes resources, and the codes we have now work. Our clocks work for people too; they were invented by humanity for specific reasons. When we are trying to explain to people a century from now why we made such a fundamental change to human timekeeping, it seems that there is no justifiable reason. It is mysterious who is actually pushing for this change based on the process in place, yet they have been pushing hard enough to be able to get the ITU-R to generate votes on the matter. There is no visibility into the process and Malys agreed with Kaplan that we should expect documentation on pros and cons and feedback from the affected communities. It is not obvious that some communities have had any input.

Malys continued by saying that within the US government, some informal surveys have been conducted by technical people who know something about the subject, but apparently there has not been a coordinated process even within the US government. This appeared to be a topic that should have required a significant level of coordination before a decision was made on behalf of the USA. Malys said that the National Executive Committee for Space-Based Positioning, Navigation, and Timing Executive Committee (PNT ExCom) seemed like the kind of place where a coordinated US position could have been developed, but to the best of Malys knowledge, this topic has never been raised within the PNT ExCom.

Seaman commented that the issue is never described the way the colloquium title presents the issue; rather, the issue is usually described as "let's cease leap seconds" rather than "let's redefine timekeeping." Malys agreed that if the issue were described as being a fundamental change to the way we keep time such that it was no longer tied to the Earth, more intense discussion would take place and different reactions would occur compared to a discussion limited to leap seconds. This aspect is also missing from available documentation. Gabor asked about UNESCO as a possible venue for further discussions, but Malys commented that even within the US government opinions are divided. By analogy, Seaman noted that we could not simply get rid of February 29th, because people who were born on that day would object. Malys agreed with some of the concerns of other contributors describing the process thus far as "disturbing" but he appreciated the opportunity to participate in an organized meeting attempting to raise some of the many issues. He hoped that there would be ways for colloquium participants to stay engaged until the ITU-R vote in January, and thought that it was not too late to influence opinions given the number of outstanding issues that already seem to be coming out of this small colloquium, particularly regarding possible impacts within the US DoD which may be unknown to voting US delegates.

Seago appreciated Malys optimism but commented that the topic has been discussed for over a decade and apparently hasn't received due attention. Malys suspected that this is because the issue is being (mis-)represented as simply a matter of whether or not to continue leap seconds. Seago concurred by deferring to a point made much earlier by McCarthy, namely that phrasings can be manipulated to elicit a desired response. McCarthy commented that the "effect of decoupling from the rotation of the Earth is not anything you're going to see for the next few hundred years." Seaman clarified that depends on the application; the decoupling will certainly affect astronomical software, which may be the "canary in the coalmine" for other software issues. McCarthy clarified that, for "civil timekeeping", the general man-on-the-street is not going to notice the decoupling. Seaman replied that technical applications are tied to UTC as the present basis of civil timekeeping, and the complicating issues regarding its redefinition have not been investigated.

Ken Seidelmann found the colloquium educational and "probably the most interesting discussion of this issue" that he has heard, and much was learned from having a number of varied stakeholder presentations from outside the very limited groups representing ITU-R interests. In practice, Seidelmann believes that an even broader group should be brought together to discuss this issue because there are still many more stakeholders (users) unrepresented at this colloquium, and consideration is still needed regarding *real* options. TAI, GPS time, and UTC (with and without leap seconds) have all been mentioned at some point, yet there seems to be advantages and disadvantages to all of these suggestions which have not been addressed if these are to be offered as realistic options.

Based on the discussions of the attending group, who had demonstrated a fair amount of knowledge on this subject, Seidelmann concluded that ITU-R delegations voting at the Radio-communication Assembly (RA) in January appear to be in no position to make an informed decision on this issue. Whatever the outcome, it will be effectively "the result of a lottery" not based on intelligence. Tyson remarked that action by the ITU-R at this time would therefore seem unwise, based on the potential impact of their decision. If the proposal is approved in 2012, Seaman offered that there may be an opportunity for discussing a reversal because the proposal does not go into effect until five years after adoption (after 2017). Allen was skeptical that this would happen, citing as an example the controversial demotion of Pluto as a planet, which has not been, and is not expected to be, reconsidered by the IAU. Seidelmann also expressed doubts, noting that there is hesitancy for people to admit mistakes in judgment after the fact. Seaman said suppression of earlier ITU decisions is not unusual, based on available records. Seago said that once the decision had been made, then cost assessments would necessarily occur and the reported expense might influence a campaign to repeal the decision. Seaman added that ITU-R approval will create complications, and that will generate an extended discussion.

Tyson asked if anyone had questioned the utility of leap seconds any earlier in their forty-year existence: why is it an issue only now? Allen suggested that now we carry devices that want to count every second whereas in the past we did not. Seidelmann offered that the issue seemed to reside more with a lack of knowledge within software engineering. Allen apologized for software engineers by saying that they lacked access to necessary information. Seaman said that problems were exacerbated because ITU-R recommendations were not freely available for decades. Seago offered that philosophical preferences may also be influencing both sides of the issue; while it is often recognized that civil timekeeping tied to Earth rotation is desirous based on traditional grounds, those who advocate pure atomic time may also perceive that civil time linked to Earth rotation "messes up" otherwise "perfect" timekeeping, and that a few purely philosophical arguments against Earth-rotation time can be found as far back as the 1970s.⁵ McCarthy said that increasing automation and growth of synchronizing networks is likely motivating some desires to cease leap seconds, as interruptions as small as one second can now have great repercussions.

Seaman suggested that the fundamental turning point was when the *SI* second was defined to be approximately related to time of day. There is no particular requirement that the *SI* unit of duration should be defined close to $1/86400$ of a day, and in fact this could be addressed by doubling or halving the current *SI* unit of duration to emphasize that it has no relation to time of day. Tyson acknowledged that the apparent definitional bias to fix the *SI* second close to the mean solar second was an interesting viewpoint. Terrett said that such a redefinition should not change the situation, because telecommunications is foremost interested in the uniformity of the unit of duration, a uniform time scale will diverge from Earth rotation regardless of its name or the duration of its unit. Seaman replied that no one is against the availability of uniform frequency, and time of day could be a data structure overlaid on the source of uniform frequency. Gabor said he perceived Terrett's concern simply as being with the Earth's lack of uniform rotation, to which Seaman replied that he didn't see that as a "problem" but rather as a charming fact of nature that must be accommodated somehow by civil timekeeping.

Seidelmann said that Gernot Winkler had privately admitted to him that perhaps they made a mistake when they calibrated the definition of the *SI* second against the ephemeris second. If the second had been defined closer to the length of the mean solar second of the late 20th century, then the need for leap seconds might have been put off. McCarthy added that these types of discussions might have been postponed for perhaps a century, although Storz noted that the need for adjustments would likely have been needed much sooner due to decadal fluctuations in Earth rotation. Seidelmann concluded his remarks by offering thanks to the chairmen for coordinating a venue whereby such discussions could take place.

Frank Reed also expressed his appreciation for the colloquium organization and his pleasure with meeting all the attendees. Reed said that no matter how this issue turned out, some people would perceive the decision as a small group of know-it-all scientists messing with something that is important to people's daily lives. That could turn into what he called a "Pluto moment," where people get angry and waste a lot of time defending one position or another. While the public may find a one-second adjustment entertaining, Reed said a proposed one-hour adjustment would be "tyranny". He offered a historical example: the Soviet Union called "permanent daylight-saving time" (one-hour ahead year-round) "decree time". He cited the Solzhenitsyn novel where one character in the gulag says to another:⁶

"Since then it's been decreed that the sun is highest at one o'clock." The other wonders, "Who decreed that?" And the first answers, "The Soviet government."

So at some point messing with daily time will seem to ordinary people like an authoritarian power that no small group should have. People complain enough about daylight-saving time; they will complain more if it becomes a bigger amount of time. Tyson remarked that this level of difference might not occur for a millennium, but Reed replied that people would talk about it as if time were already broken. It is an issue that could get ordinary people riled if they are not educated on the issues. That's the "Pluto moment." While Reed knew many people who feel that keeping the Sun aligned with noon o'clock is an important cosmological issue (in the old sense of that word), he felt that other operational time scales (TT, TAI, *etc.*) are aesthetically appealing in their own physical way, if perhaps not as cosmologically fundamental as the rotation angle of the Earth. Tyson remarked that the Pluto analogy seemed apt and well made, but only to a point: there is no Disney cartoon character involved and it is not something memorized from a young age, so there may be less personal investment in either type of time. Seaman said that Earth-rotation time apparently needed a mascot—perhaps a fluffy bunny rabbit.

Mark Storz said he learned a lot from the colloquium and thanked the chairmen. Storz commented that it was eye-opening to him that astronomers might use something like an "ephemeris

longitude”, or else perhaps shift cataloged right ascensions, in order to address some problems with the decoupling of civil timekeeping from Earth rotation. However, he noted that stop-gap measures do not appear to be viable options for the space-surveillance community. He had hoped by attending this colloquium that he would be introduced to some proposed workarounds that US Air Force Space Command could leverage, but now he is convinced that his organization will have to procure the funds to fix everything correctly if the proposal goes forward. One particularly important issue resulting from one of Seaman’s talks was the necessity of tools to assist in identifying where code is likely to break in order to identify the scale of the problems within various program offices.

Seaman suggest an investigation of strategies employed prior to Y2K might be fruitful due to the similarity of the problem, also noting that some systems simply introduced “pivot points” in code rather than truly fixing the systems large scale. Storz commented that he is already heading up an Air Force Space Command working group to consider the discontinuation of *status-quo* UTC. This group needs to audit their system software as soon as possible to educate their leadership on the costs and risks. He is also contemplating sending an official letter to DoD leadership seeking guidance on how they are to fix the issues since it appears that some elements of the DoD may have already decided to favor UTC redefinition. He hopes that such formal communication will make some elements of the DoD better aware of the potential magnitude of problems this issue might cause. Finally, Storz noted that metrological models (both terrestrial weather and space weather) are tied to UT1 and this technology sector was not represented at this colloquium.

Seago shared a parting thought from David Simpson, who left the day’s discussion early to address other professional obligations. Simpson had noted that he had not found any compelling reason for motivating a change in the definition of UTC, and thereby preferred the *status quo*.

Finally, John Seago shared that he did not see how humanity could usefully recouple civil timekeeping and Earth rotation once the two were officially decoupled. Based on these proceedings, it appeared that significant functionality and infrastructure was needed to maintain intercalary adjustments. If such infrastructure were phased out of civil timekeeping systems in the near term, the expense of reintroducing such infrastructure in the distant future seemed prohibitively burdensome. Alternate long-term proposals (leap minutes, leap hours, centennial adjustments, *etc.*) pushed the technicalities sufficiently far into the future such that the recoupling would not be pragmatically addressed when the declared time comes. For that reason, schemes involving very infrequent intercalary adjustments cannot be credibly presumed to work once leap seconds are formally abolished.

Malys added that if the differences between Earth rotation and civil time were allowed to accumulate to such a degree that a minute or more needed to be introduced, the disruption caused by a large adjustment would likely spawn many legal complications. A leap second, although possibly disruptive to some systems now, seems much more manageable compared to a more noticeable amount of time. Otherwise, financial transactions and other economic activity might have to be suspended, adding even more to the cost. Seago agreed, also adding that the fundamental issues involving leap seconds do not change by kicking the can down the road. Events occurring during a leap minute would still need to be tagged in some unconventional way as is required for a leap second, except that now people will be inconvenienced by re-building and testing specialized hardware and software to be used once in a lifetime versus a leap second introduced once every few years. It would seem to be a prohibitively expensive option that each generation would likely defer to the next. Kaplan added that safety-of-life systems, such as medical and transport systems, cannot be turned off for a minute or an hour or restarted in order to adjust a clock.

Reed offered that local offsets to civil time could be legislated much the way daylight-saving time is legislated today. Terrett noted that approach causes significant complications for people living close the International Dateline. Seago wondered if this legislative approach might foster a changeover of the civil day occurring at a time other than midnight o'clock, introducing another fundamental issue. Seaman remarked that the legislative approach would move what is now a common international standard into perhaps a thousand local time-zone decisions across different nations, states, and provinces, promoting historical chaos. Reed replied that such decisions are already being made with regard to zone times. Seago offered that the historic records of such decisions would be far-flung and harder to accurately reconstruct, perhaps conflicting with a desire to maintain very accurate civil timekeeping over long intervals.

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