Future Options for Civil Timekeeping: UTC and the Alternatives

P. Kenneth Seidelmann
University of Virginia

John H. Seago
Analytical Graphics, Inc.

Time Scales

- Mean Solar Time
- Universal Time (UT1)
- Ephemeris Time
- International Atomic Time
- Coordinated Universal Time (UTC)
- Dynamical Time Scales
- Special Time Scales, *e.g.* internal GNSS Times

Coordinated Universal Time

- Broadcast time services
- UT1 and TAI
- Frequency offsets unacceptable
- 1972 definition by CCIR
- UTC based on TAI, <0.9 s from UT1
- DUT1
- BIH
- BIPM
- IERS

Redefinition of UTC 2000 - 2012

- ITU WP 7A Proposal
- Surveys, Discussions, Studies
  - Surveys favor the *status quo*
  - Lack of cost estimates
  - No consensus
- Opposing votes in ITU-R
  - Working Party 7A
  - Study Group 7
- Forwarded to Radiocommunications Assembly in 2012

Status of Redefinition of UTC

- Radio Communications Assembly Jan 2012
  - 190 countries could vote
  - ISO resolution concerning changing the name
  - Equal division of For, Against, Undecided
  - Delay Decision until 2015
  - Call for a Study
    - continuous reference time-scale
    - other technical options
    - broader implications
  - IAG WG 1.1.1
    - “Nothing Gained” by changing

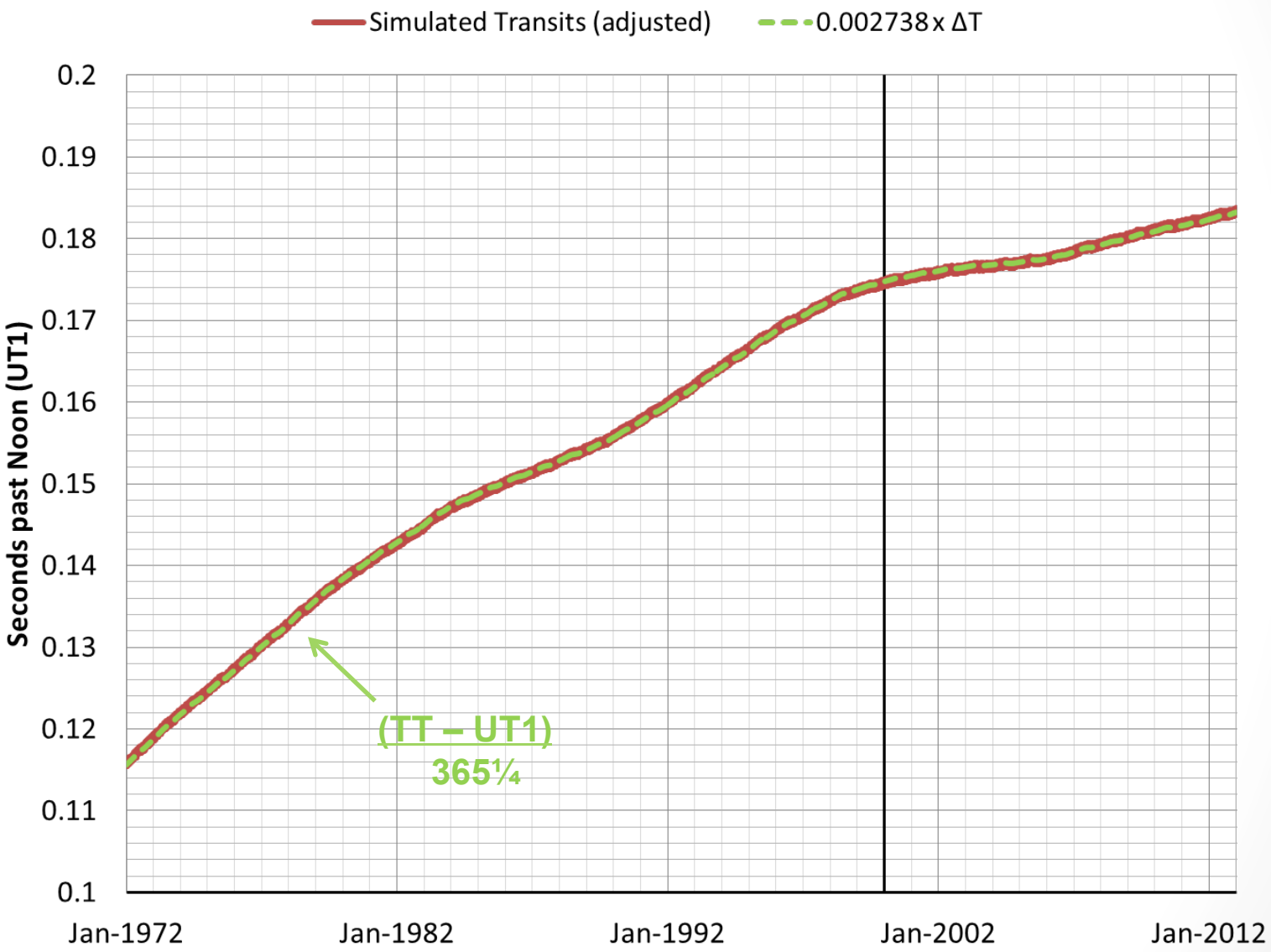
How Well Has UT Kept Up w/ GMT

- **Guinot (2011)***
  - **UT1 preserved as a representation of GMT w/ "*a departure which may reach one or two seconds*…"**
    - Imprecise solar-transits relative to stars: ~0.1^{s}
    - Algorithm changes to BIH "mean observatory": 10's of ms
    - Non-uniformity from polar motion: ~30 ms at Greenwich
    - Plate tectonics: centimeters (μs) per annum.
    - Longitude origin perturbed w/ terrestrial system changes (0.356^{s})

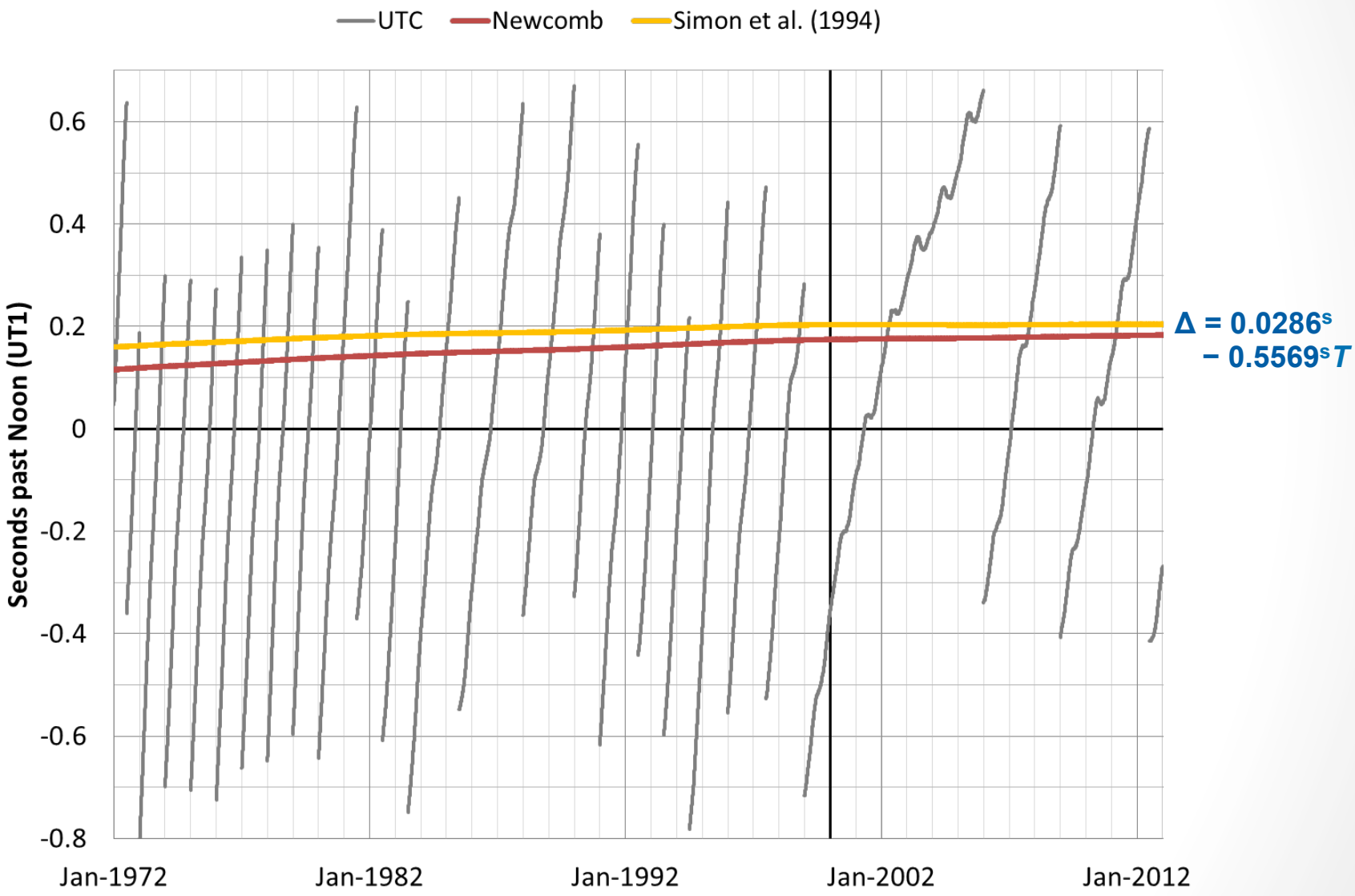
- **Expected discrepancy: ~(TT-UT) / 365¼**
  - R.A. of Newcomb's mean sun related to ET

*Guinot, B. (2011) "Solar time, legal time, time in use." *Metrologia*, Vol. 48, pp. S181-S185.

Simulated Transit Times



“Modern” Mean Sun



Requirements for Civil Timekeeping

- Constant Frequency for all time
- Uniform duration of time units (e.g., hour, minute, second)?
- Synchronization with Universal Time?
- Support for/compatibility with existing systems?
- Support for/compatibility with anticipated future systems?
- Accessibility?
- Equivalent to mean solar time?
- A common source for the legal time for all countries

Some Options

- Retain *status-quo* UTC as is
- Redefine UTC:
  - Cease leap seconds
    - Proposed but not adopted in 2012
  - Cease leap seconds but also change name
  - Replace leap seconds with leap minutes
- Officially supplement current UTC with an atomic scale:
    - TAI?
    - GNSS time?
    - Other?
- Other Options?

Some Options

- Recognize alternative adjustment methods
  - Computer clock slewing before leap second
  - Google rubber second in June 2012
- Unlikely or non-viable options
  - Redefining the SI second
  - Replacing leap seconds with leap hours or leap minutes

Study Group 7 Considerations

- Are time transmissions only for telecommunications?
  - Question not limited to technical and regulatory issues
- Societal implications of modification of civil time scale
- Organizational issues
- Use of other technical options
  - leap minute?
  - time scale with fixed offset from TAI?
- Timetable required for bringing new time scale into use

Continuous Reference Time-Scale

- Is UTC *discontinuous*?
  - Primary definition of continuous?
    - parts in immediate connection
      - contiguous
    - uninterrupted in sequence
    - definition does not prescribe means of labeling
- What are the requirements for:
  - UTC?
  - Continuous Reference Time-Scale?

Issues Concerning Recommendations to Redefine UTC

- Significance with respect to Radiocommunications
  - Technical, legal, and public issues
  - Continuous time scale
- Involvement of International Standards and Scientific Organizations
  - ITU-R non consensus
  - IAU, IERS, URSI, AAS, ISO
  - Software organizations
- Terminology
  - Change definition -> change name

Issues Concerning Recommendations to Redefine UTC

- Alternative Time Scales
  - GPS time already in use
  - TAI or equivalent, as a supplementary time scale
- User Preferences
  - Surveys favor *status quo*
  - Only "minor anomalies" with leap seconds reported
  - No substantial documentation supporting redefinition
- Software and Hardware Modifications
  - GNSS
  - Consult computer scientists and software developers

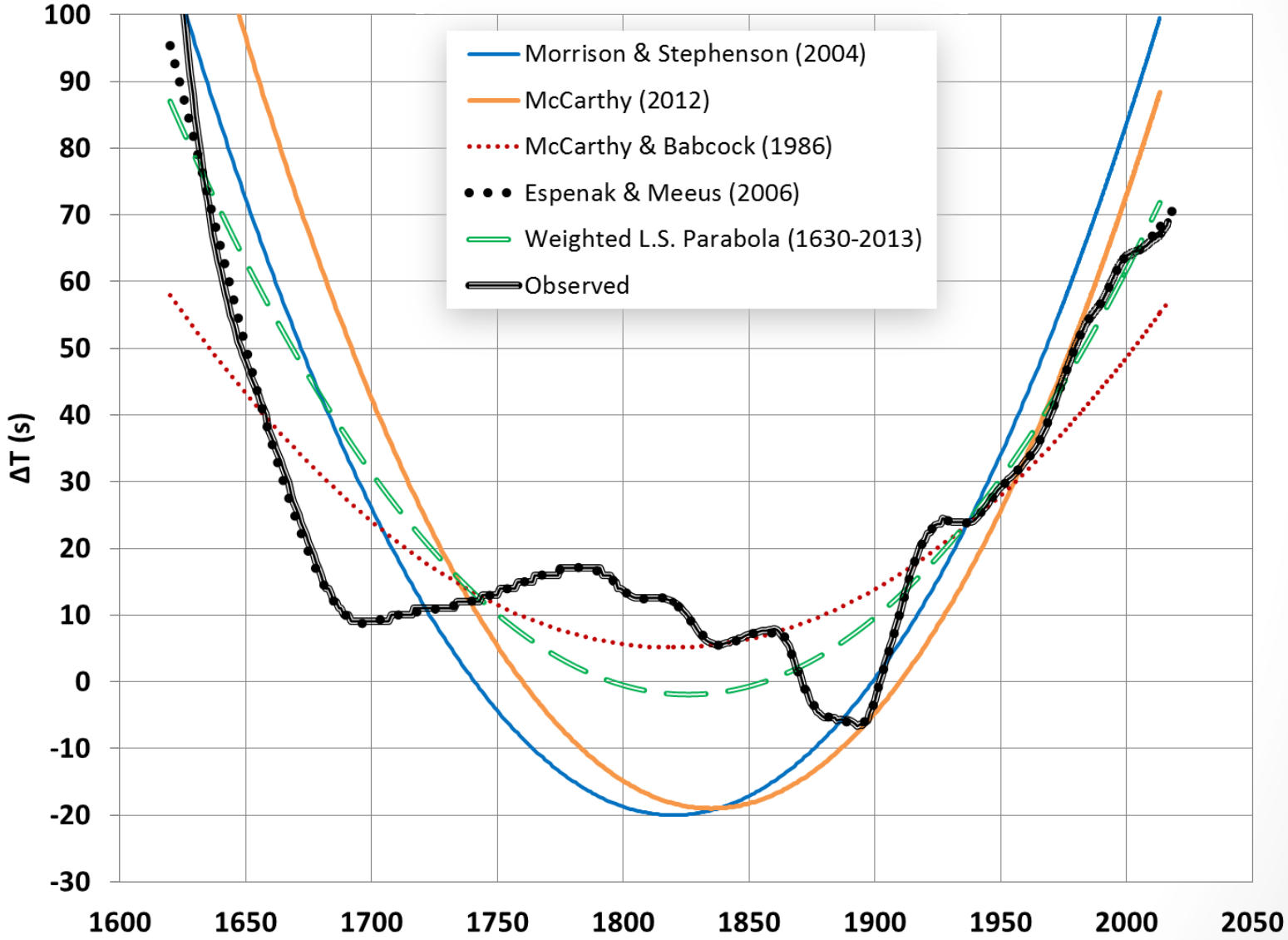
Issues Concerning Recommendation to Redefine UTC

- Distribution of UT1
  - Availability and distribution of UT1 by computer network
- Legal Considerations
  - Status of UTC as official time in countries
  - Mean Solar Time as official time in countries
- Re-education
  - Revision of literature and textbooks
    - Change of knowledge base affects large number of users otherwise unaffected
    - Potentially confusing to non-experts

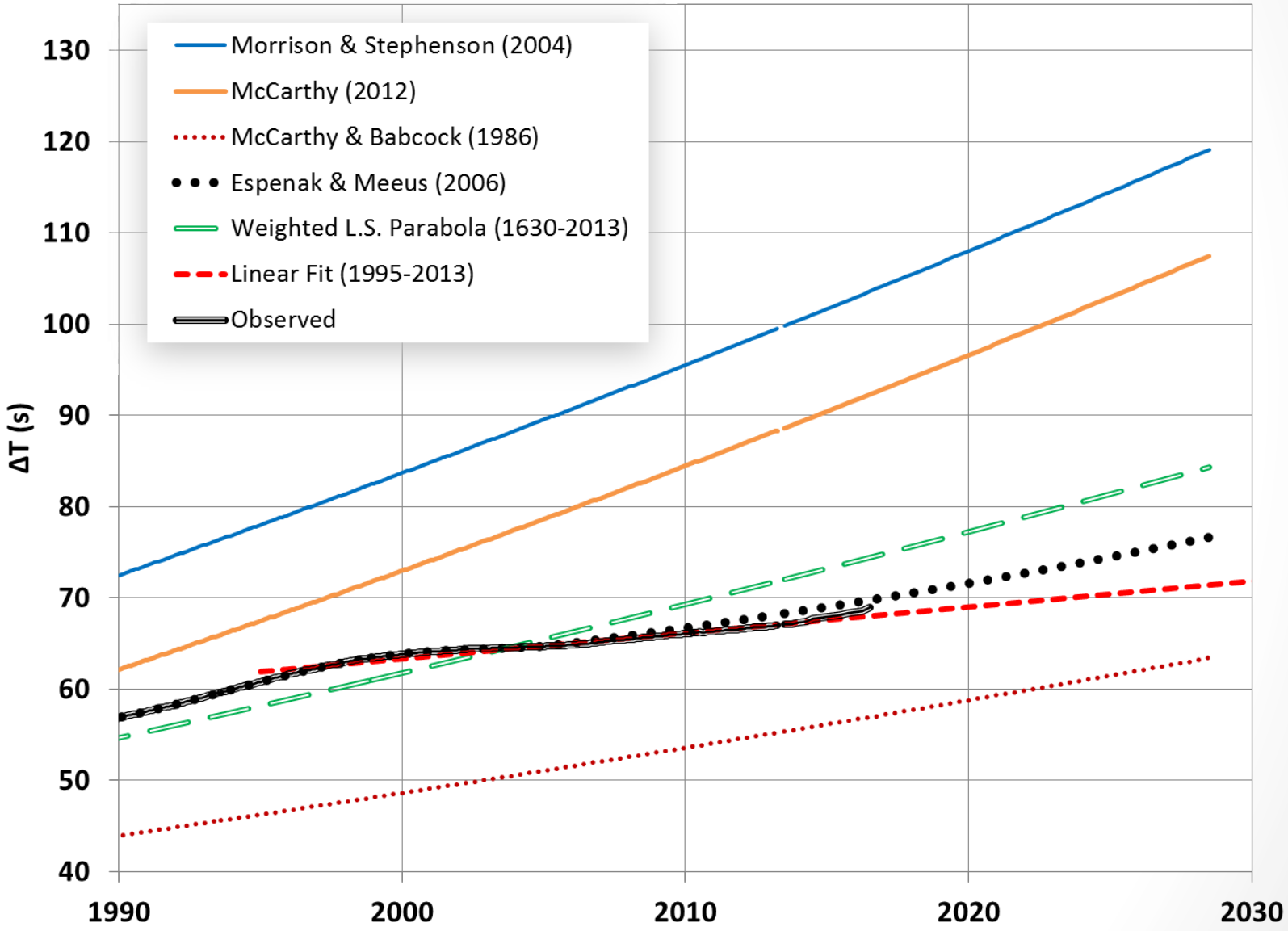
Issues Concerning Recommendation to Redefine UTC

- Celestial Navigation and Almanacs
  - Changes in almanacs and explanations of use
  - Problem of navigation in an emergency
- Rate of Earth Rotation
  - Long and short term trends in Earth-rotation rate
- Long-Term Societal Effects
  - Long term adjustment procedure?

Past ΔT Behavior



Future ΔT Behavior



Options and Requirements

	UTC as is	UTC sans leap seconds	UTC sans leap seconds (renamed)	UTC with leap minutes	UTC & TAI	UTC & TAI + n seconds	UTC & GNSS
Constant time interval	X	X	X	X	X	X	X
Constant Frequency	X	X	X	X	X	X	X
Synch with Earth Rotation	X				X	X	X
Current software Compatible	X				X	X	X
Meets future Requirements	X	X	X	X	X	X	X
Astronomical pointing	X				X	X	X
Meets legal times	X				X	X	X
Simple conversion to "days"		X	X		X	X	X
Current Global Navigation Systems	X				X	X	X
Public perceptions of time	X			?	X	X	X

Reasons for Keeping UTC As Is

- Many country's legal codes call for mean solar time
- Current navigation systems software based on current definition
- Software based on UTC-UT1< 1 s
- Public perception of civil time based on solar time
- Extensive documentation in books based on current definition
- If changed away from mean solar time, changing back will be difficult
- Different definitions of UTC will cause confusion
- An atomic time scale is currently available from GNSS
- Leap seconds give the time keeping community publicity

Reasons for Redefining UTC Without Leap Seconds

- Software difficulties in including leap seconds
  - Computer systems based on only 60 seconds per minute
- Confusion between time scales with different epochs
- Problems introducing leap seconds in time scales
  - Communicating leap seconds
  - Updating databases
- Problems time tagging transactions when leap seconds occur
- Inconvenience of leap seconds

Reasons for Adding an Atomic Time Scale to Current UTC

- Satisfy all requirements
- Formalize what is currently being done
- Establish an official time scale without leap seconds

Personal Recommendation

- Recognize current practices
  - Retain UTC as is
  - Officially recognize a distinct uniform atomic time scale for those who need such a time scale
    - Real-time TAI(k)
    - GNSS-based time scale
    - Some other offset from TAI
  - Other options for method of introducing leap second in time scales
    - Example: clock slewing for imprecise applications

Personal Recommendation

- Options with no cost increases or organization problems
  - CIPM coordination of background reference time scales, TAI, GNSS
  - Follow ITU-R recommendations for distributing UTC
    - "DTAI" per Recommendation 460-6
  - GNSS distribution of GNSS time scales
- Basically recognizing current practice

What's Next?

- Studies per WRC resolution
- Studies should consider
  - user requirements
  - options
    - pros and cons of each
- ITU/BIPM Workshop on the Future of the International Time Scale Geneva, 19-20 September 2013
- Educate all nations concerning all issues
  - Not just telecommunication/metrology concerns
- Decision in 2015?