TIMEKEEPING FOR TELESCOPE NETWORKS

CATALINA SKY SURVEY

ROB SEAMAN

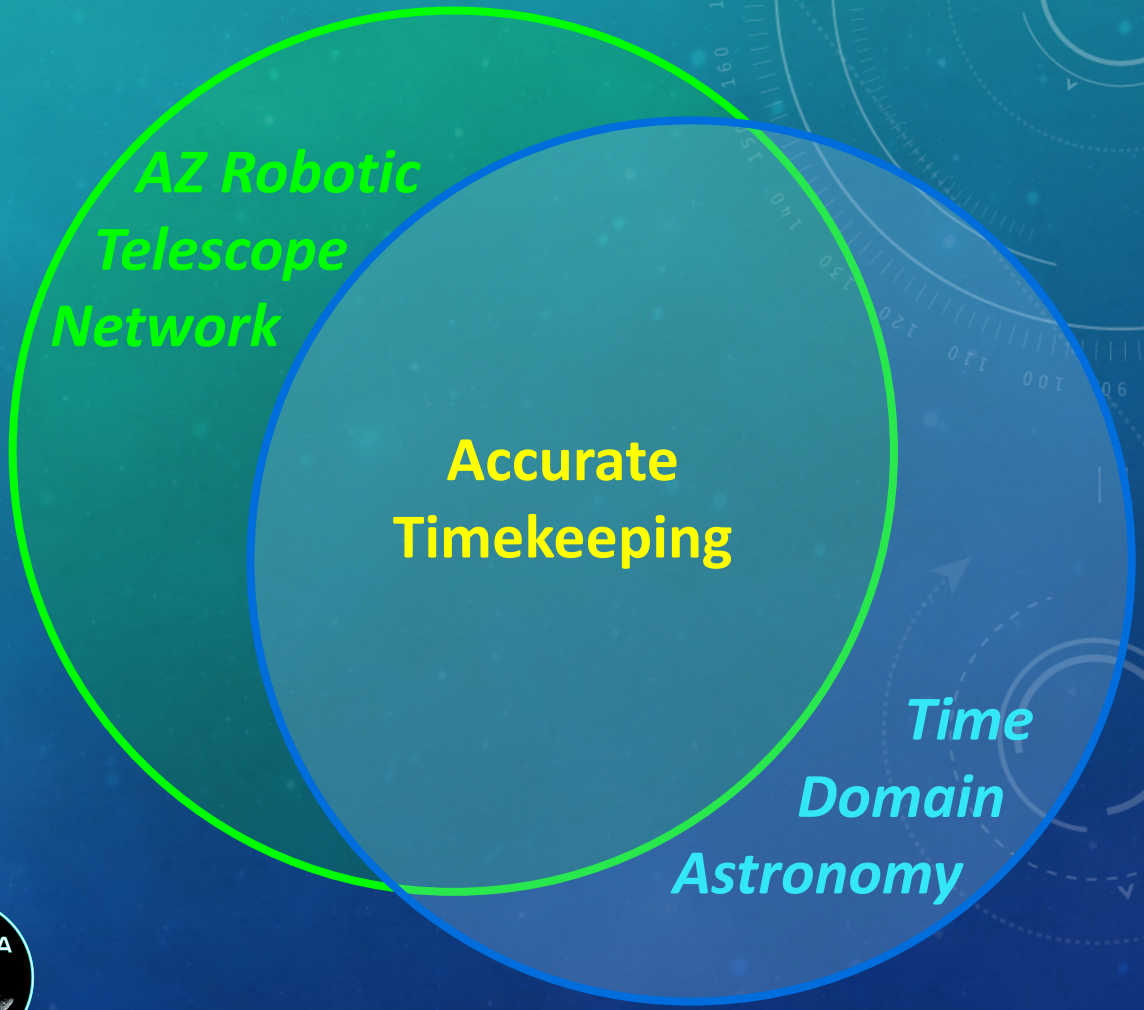
FOR THE CSS TEAM

WHY SHOULD ARTN CARE ABOUT TIME?

- ✓ Coordinated scheduling
- ✓ Coherent metadata
- ✓ Pointing / tracking

- ✓ Time series are *measurements*
  (of flux or other astrophysical quantities)
  versus *measurements* of time

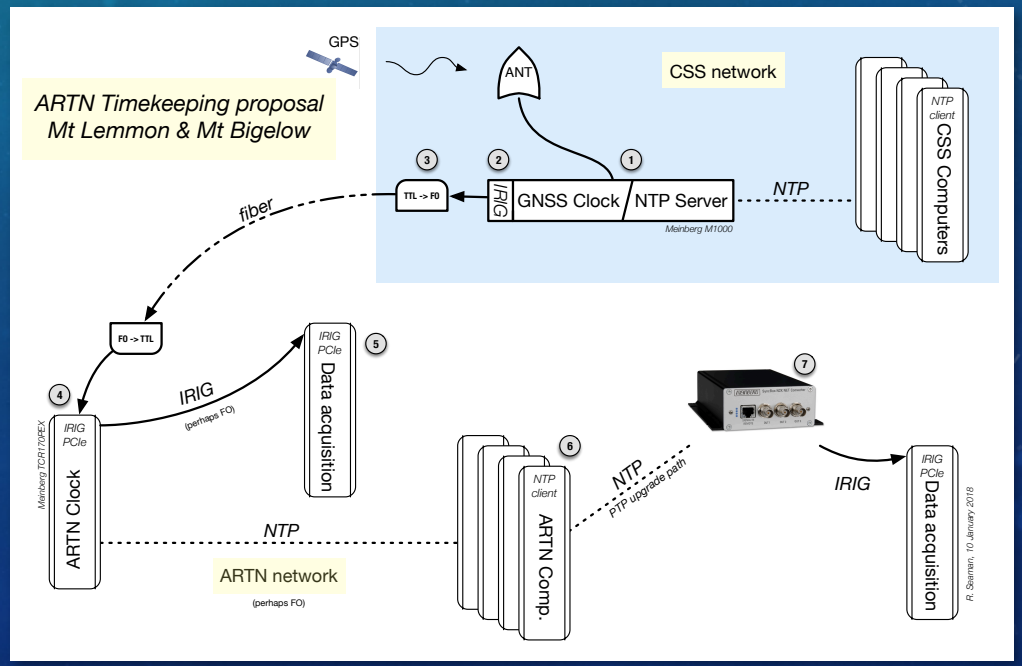
- ✓ Time Domain Science!



CATALINA SKY SURVEY

SUMMARY

- Piggyback ARTN on CSS clocks on Lemmon / Bigelow
  - excellent GPS (GNSS) reference clocks, UPS, FO-isolated
  - deployed local to each mountaintop
- Monitor the network of clocks as a whole
  - NTP pool is not designed for science
- Time signals for data acq. & TCS
  - hardware timestamps
  - appropriate timescale(s)



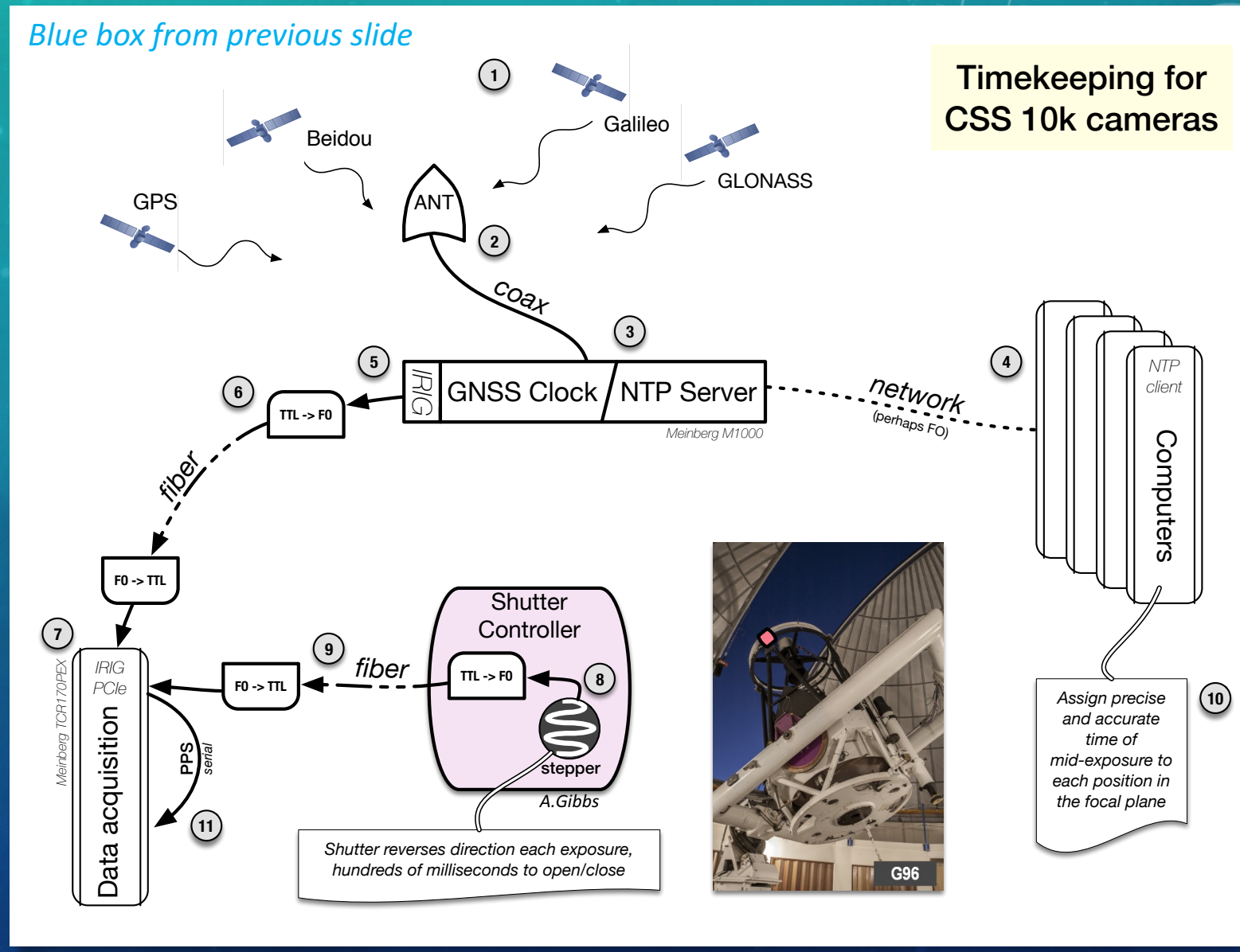
ACCURATE & PRECISE REFERENCE TIMEKEEPING

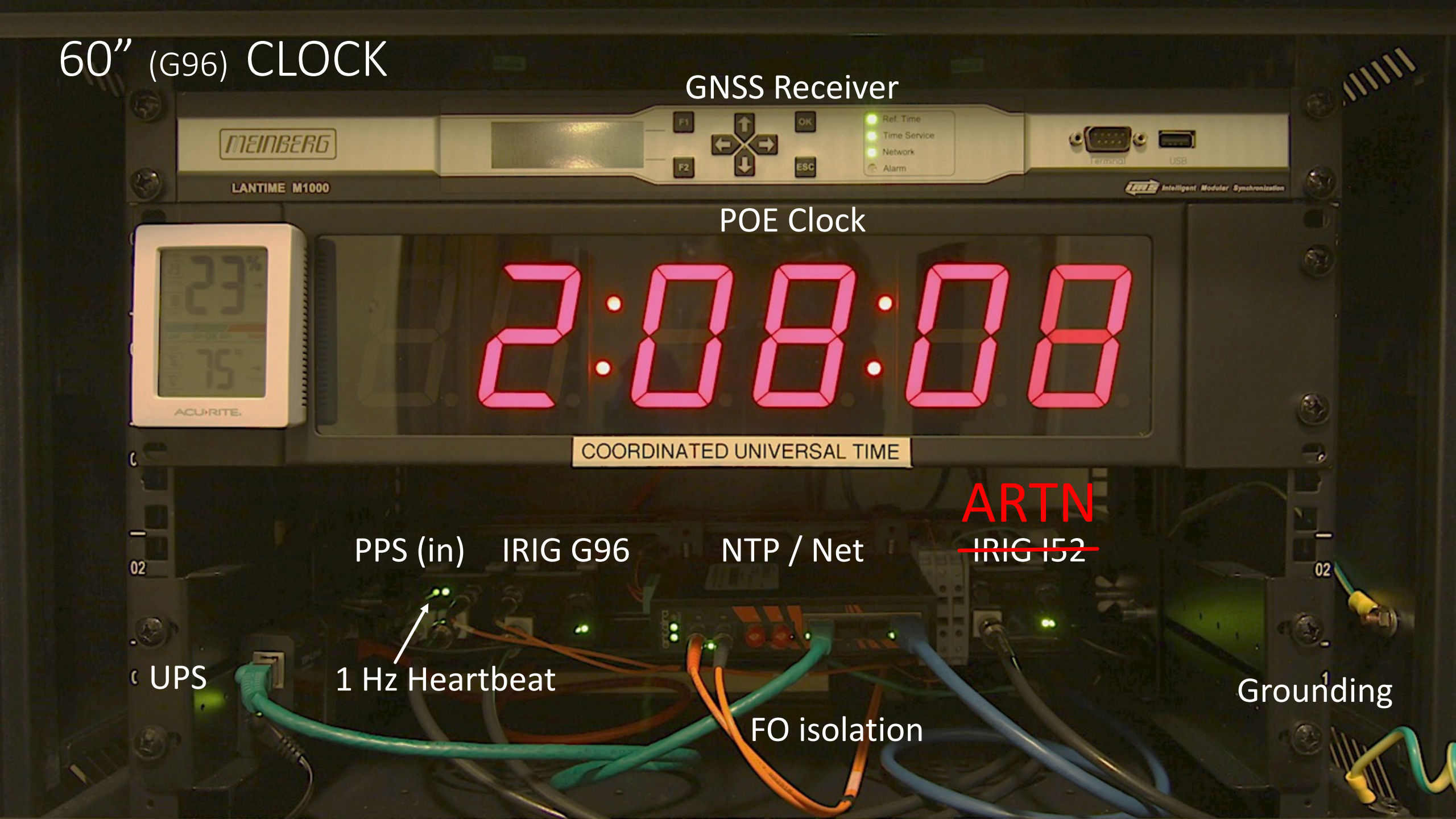
1. Multi-constellation GNSS
2. Radio clocks, *e.g.*, WWVB
3. Modular GPS receiver (Meinberg)
4. NTP server local to dome
5. IRIG* signal (IEEE 1344)
6. Fiber optics (media converters)
7. IRIG PCIe card *$79 on ebay*
8. Shutter motion pulses
9. Card supports time capture to +/- 5 µs
10. Time varies across focal plane
11. Monitor PPS and NTP clients

* IRIG = Inter-Range Instrumentation Group

** Alternative to IRIG is PTP (Precision Time Protocol = IEEE 1588)

Blue box from previous slide




60” (G96) CLOCK
GNSS Receiver
MEINBERG
LANTIME M1000
F1
F2
OK
ESC
Ref. Time
Time Service
Network
Alarm
Terminal
USB
POE Clock
2:08:08
COORDINATED UNIVERSAL TIME
ACU-RITE
ARTN
PPS (in)
IRIG G96
NTP / Net
IRIG I52
UPS
1 Hz Heartbeat
FO isolation
Grounding

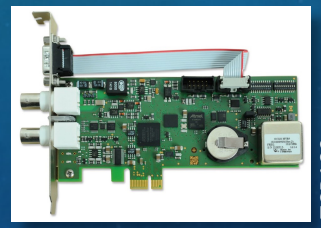
MEASURE TIME, DON'T ESTIMATE IT

TAKEAWAY #1

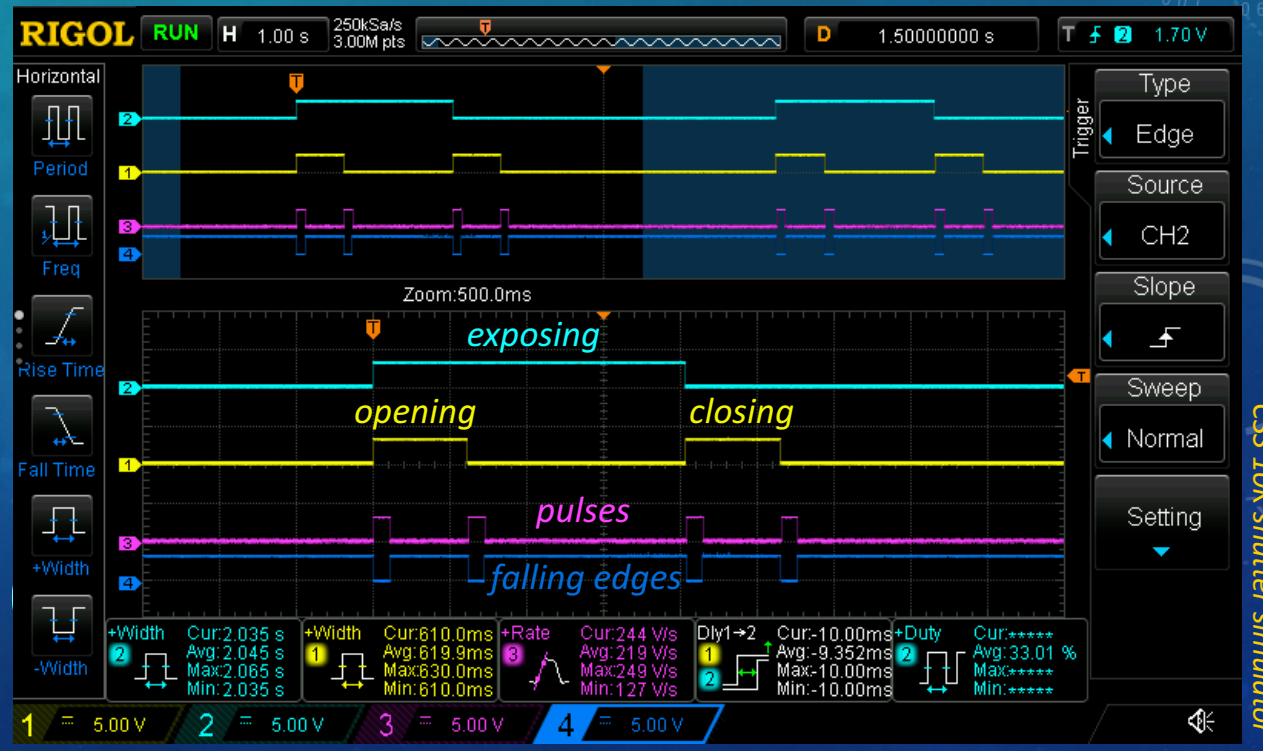
1. Computer clock chips are notoriously bad
2. System clocks are only constrained under a real-time OS
   arbitrary delays under Linux / Windows – intrinsically inaccurate
3. Data acquisition is composed of many operations
   e.g., charge flushing, readout, FITS, …

→ **Hardware time capture**

time the shutter, not the software
should be able to display on oscilloscope



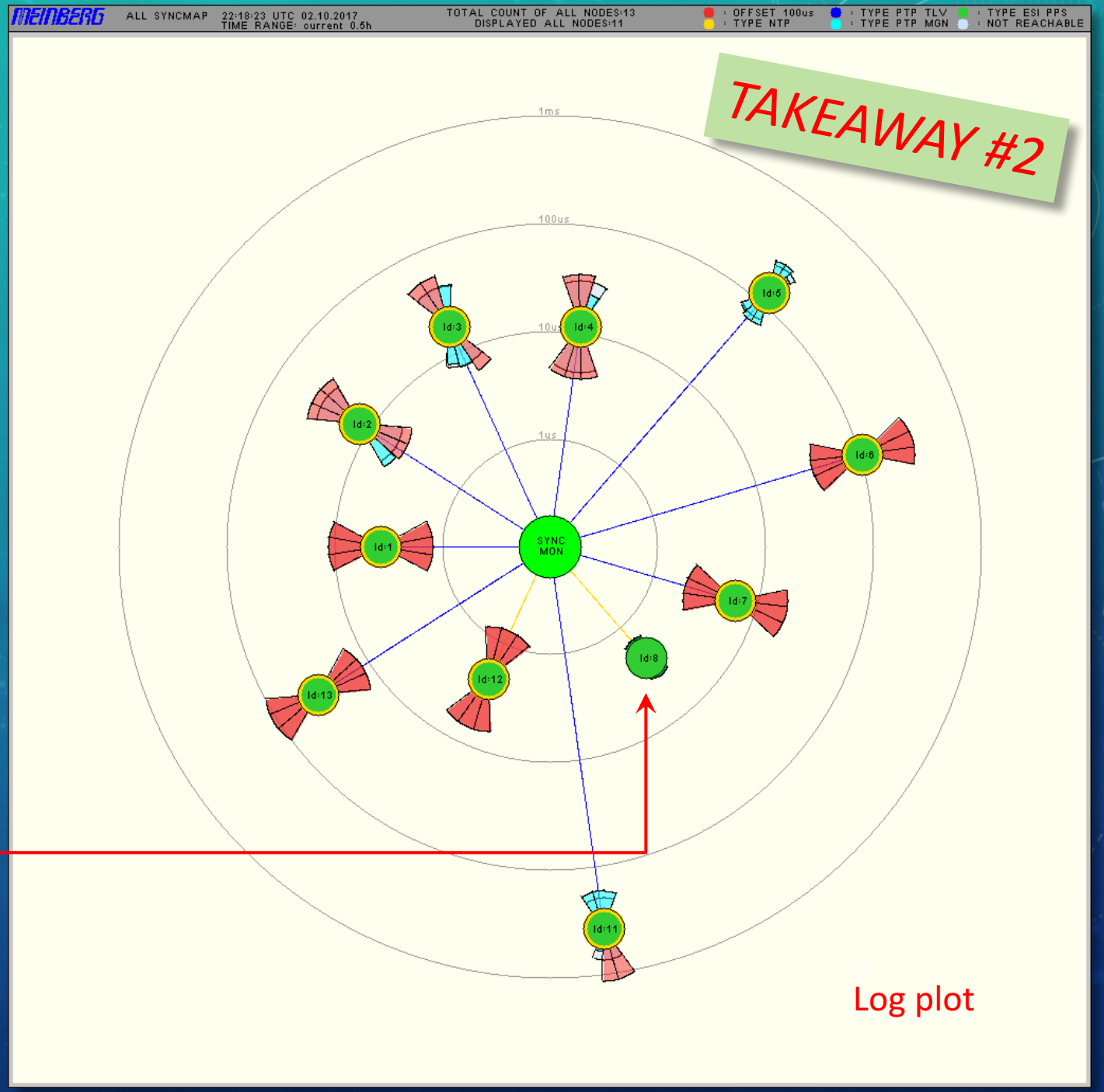
TCR180pex



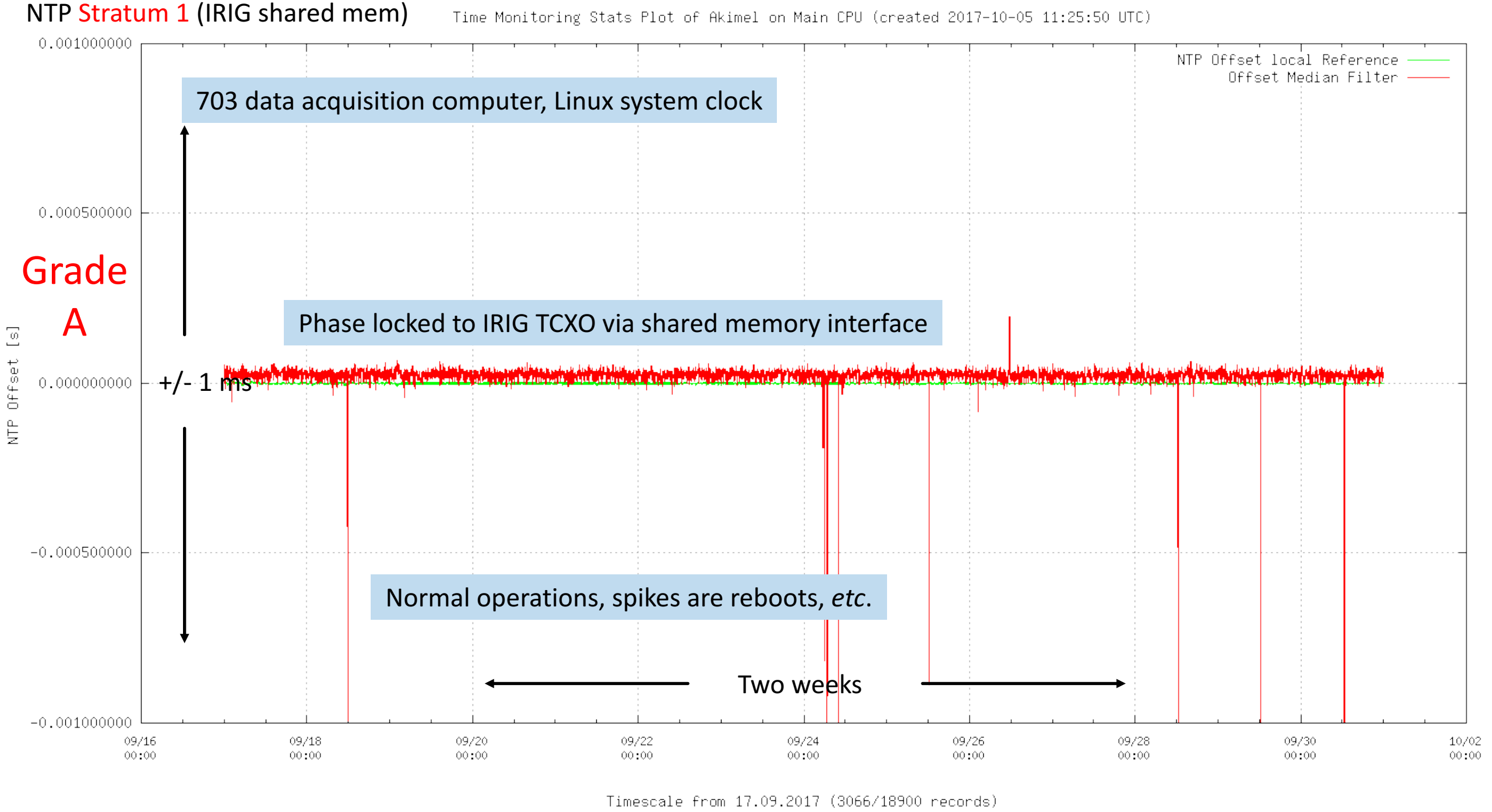
CSS 10K shutter simulator

MONITOR YOUR CLOCKS!

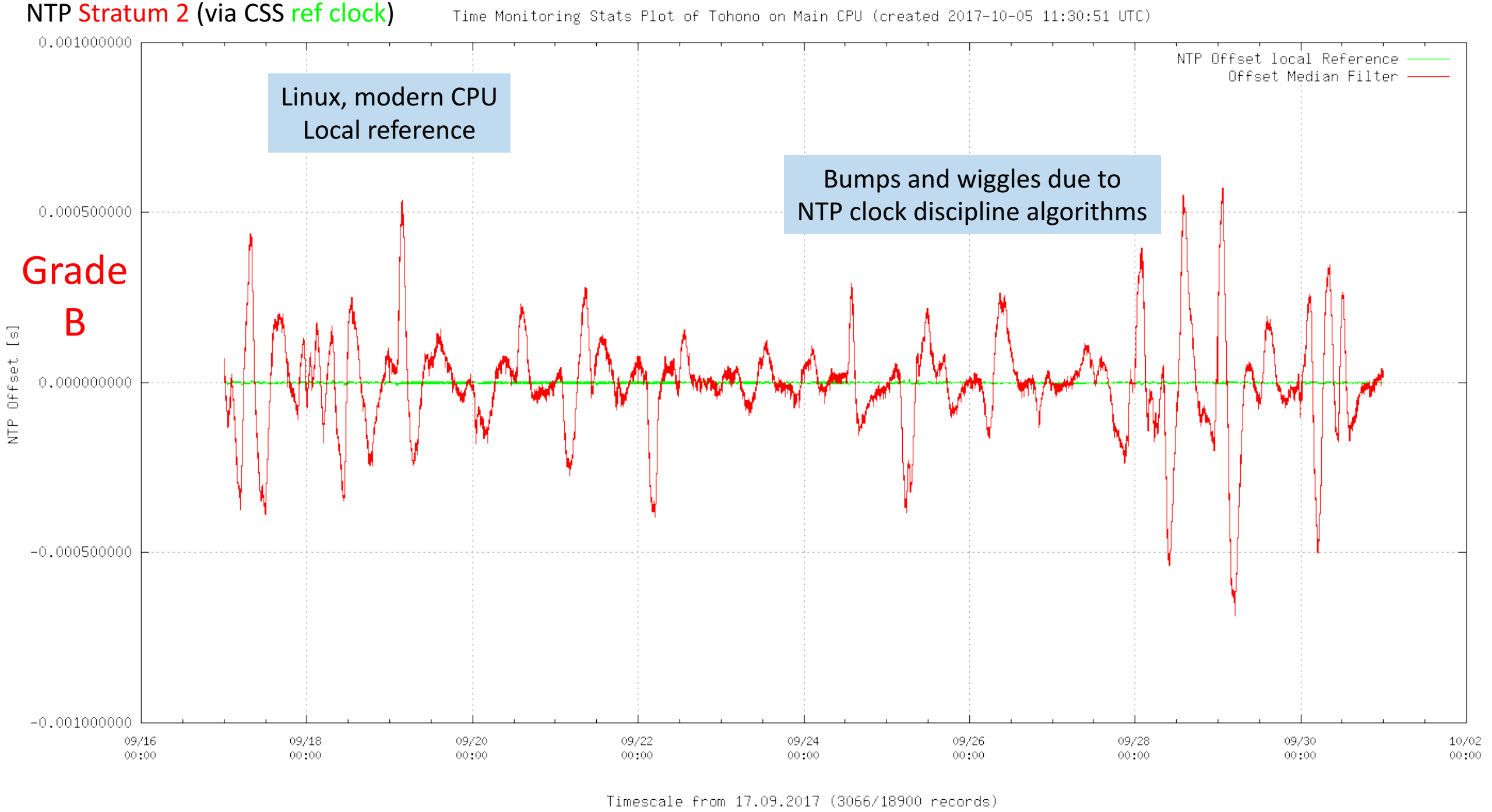
- Telescopes have many clocks
  - synchronize the whole network
  - Network Time Protocol for most
  - IRIG (or PTP) for real-time
- Monitoring tools
  - support diverse protocols
  - alert if NTP > 1 ms or IRIG > 10 µs



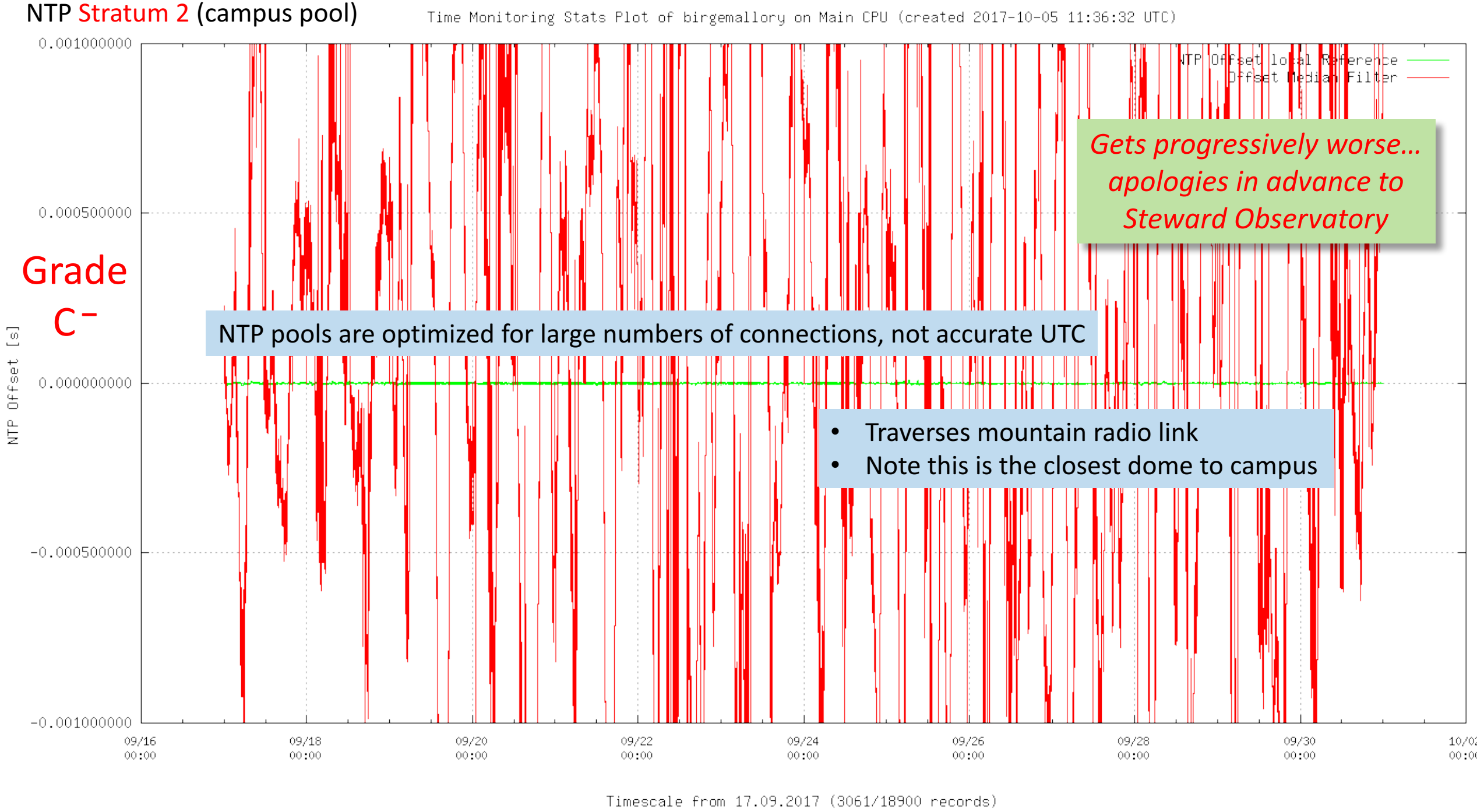
NTP Stratum 1 (IRIG shared mem)



NTP Stratum 2 (via CSS ref clock)



NTP Stratum 2 (campus pool)



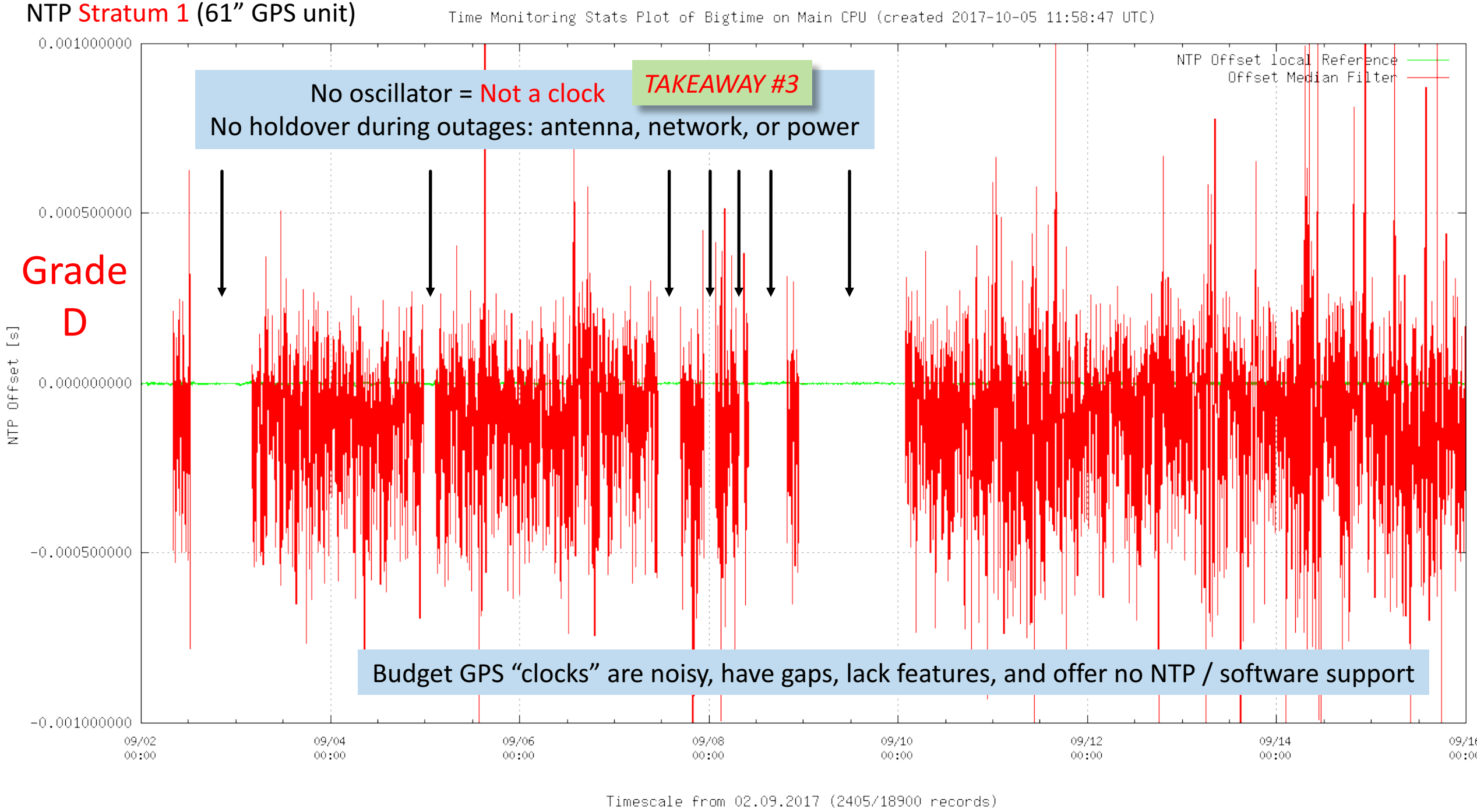
Grade C⁻

Gets progressively worse… apologies in advance to Steward Observatory

NTP pools are optimized for large numbers of connections, not accurate UTC

- Traverses mountain radio link
- Note this is the closest dome to campus

NTP Stratum 1 (61” GPS unit)



No oscillator = Not a clock

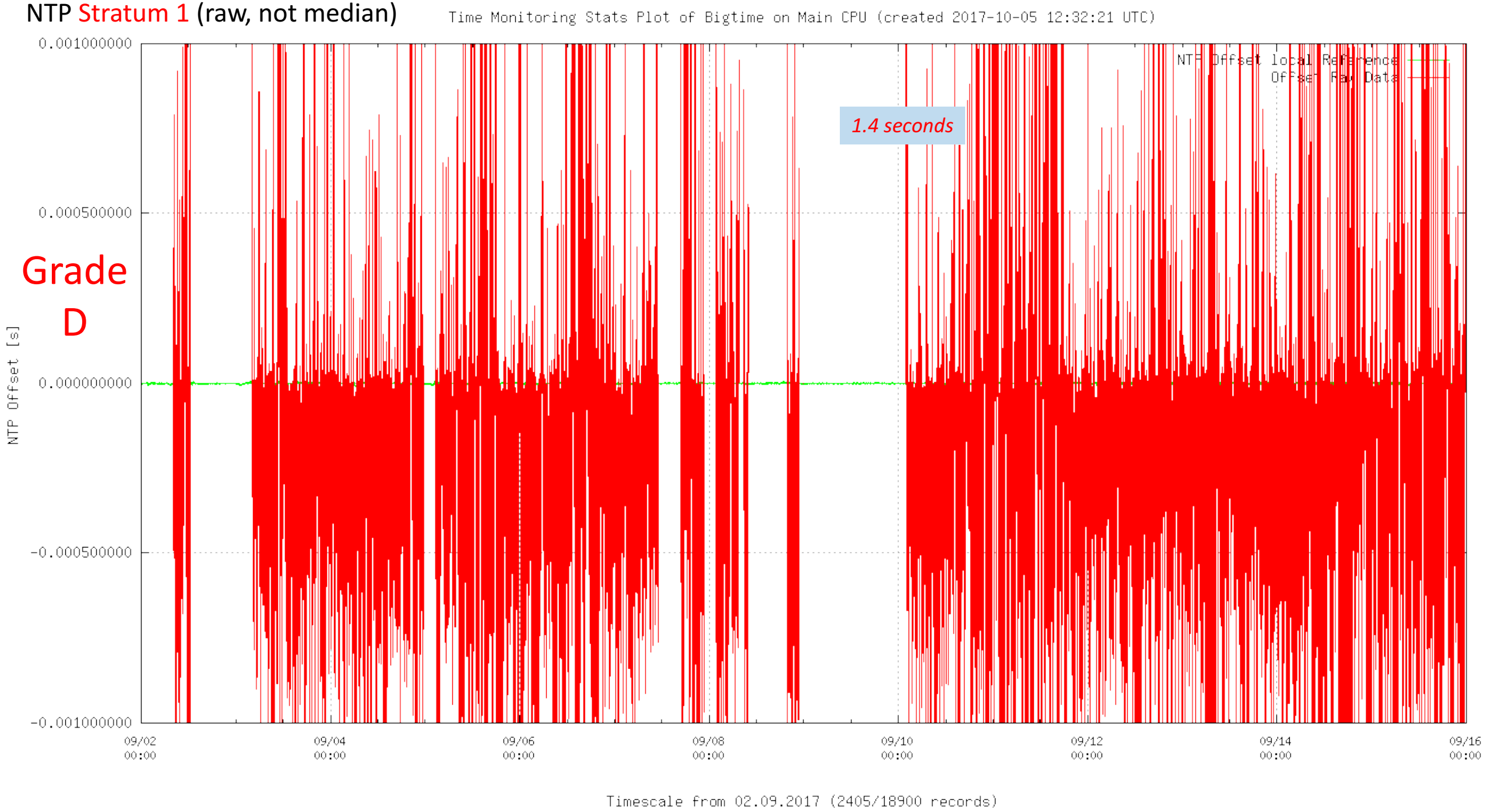
No holdover during outages: antenna, network, or power

TAKEAWAY #3

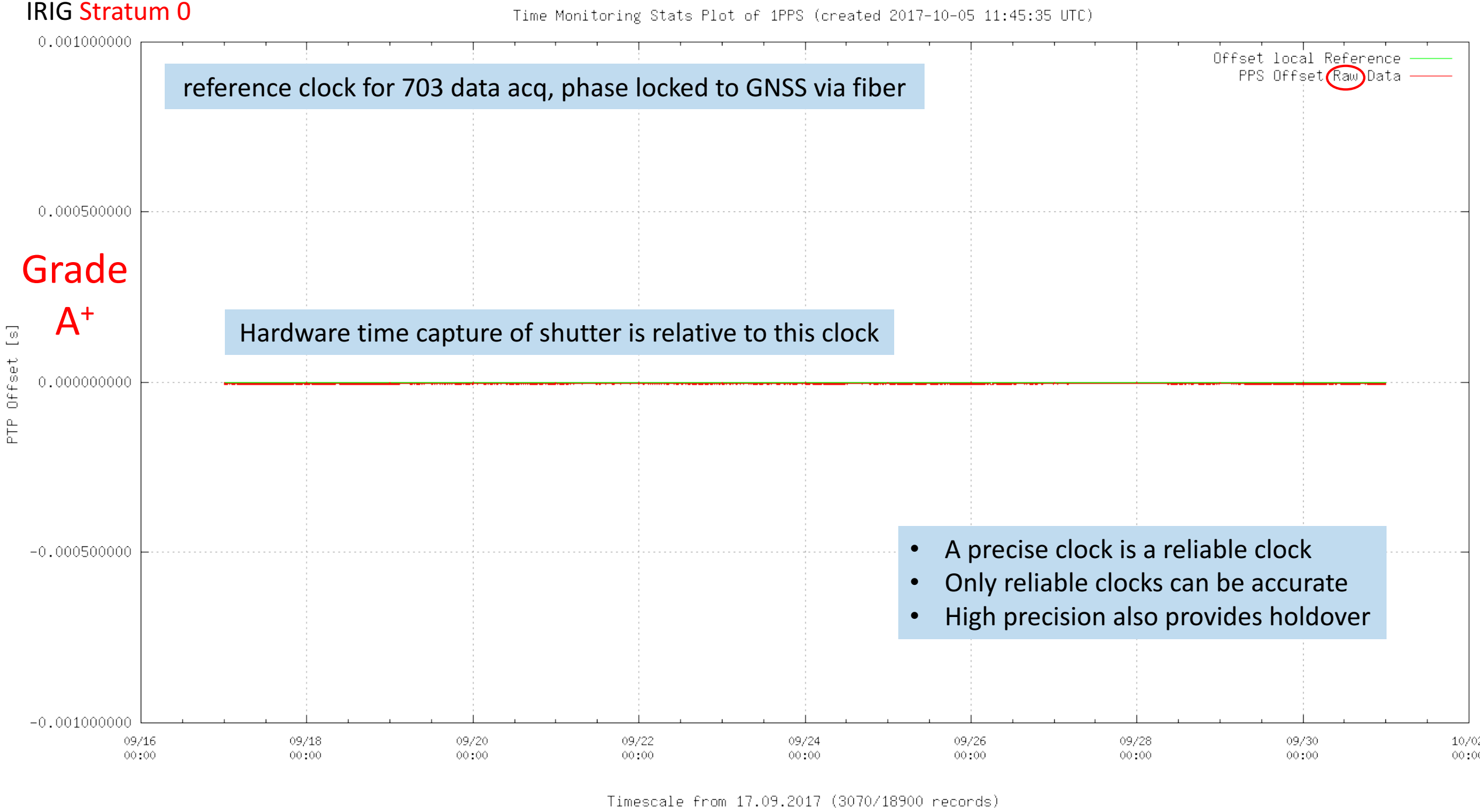
Grade D

Budget GPS “clocks” are noisy, have gaps, lack features, and offer no NTP / software support

NTP Stratum 1 (raw, not median)



IRIG Stratum 0



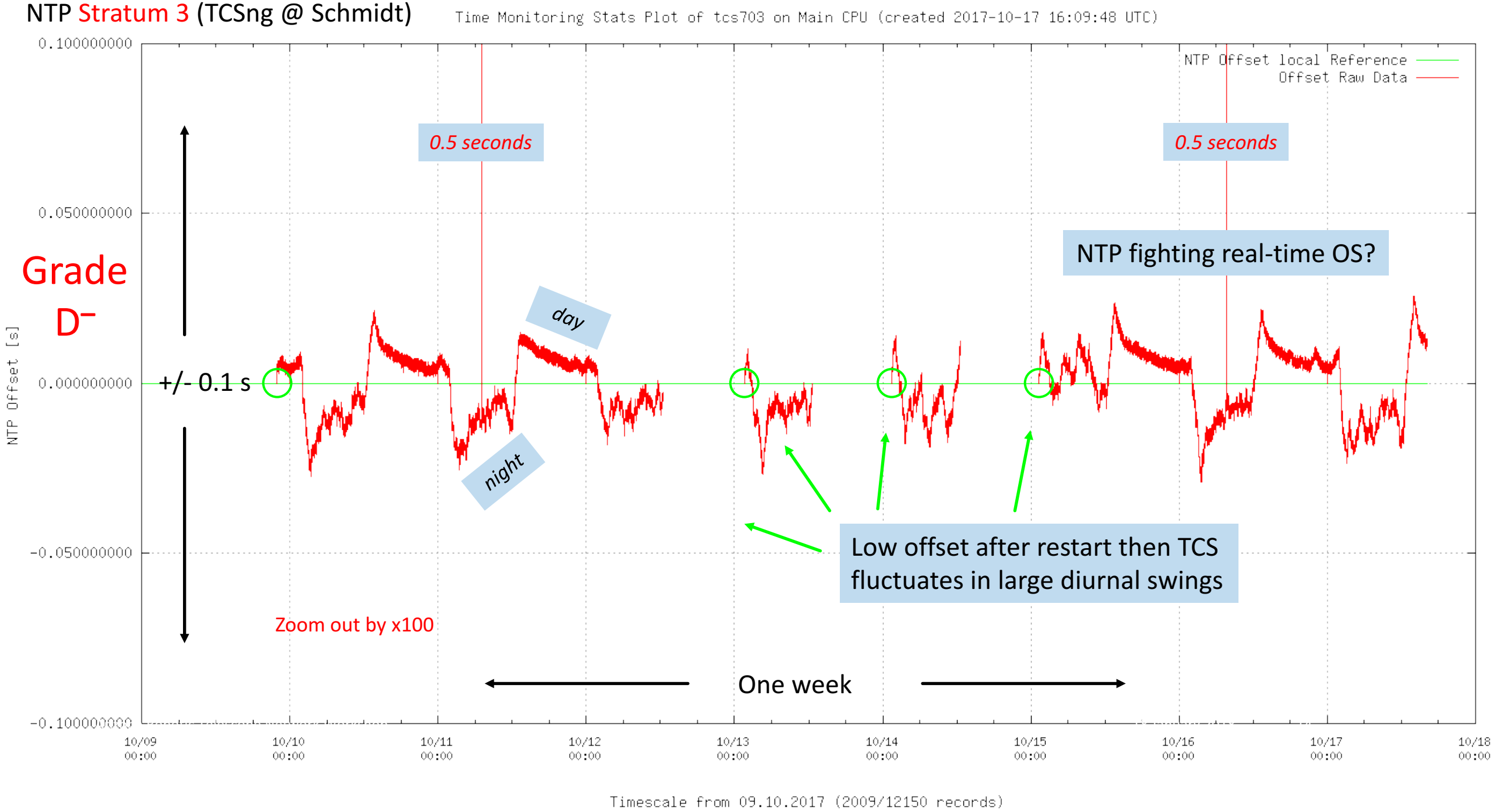
reference clock for 703 data acq, phase locked to GNSS via fiber

Grade A+

Hardware time capture of shutter is relative to this clock

- A precise clock is a reliable clock
- Only reliable clocks can be accurate
- High precision also provides holdover

NTP Stratum 3 (TCSng @ Schmidt)

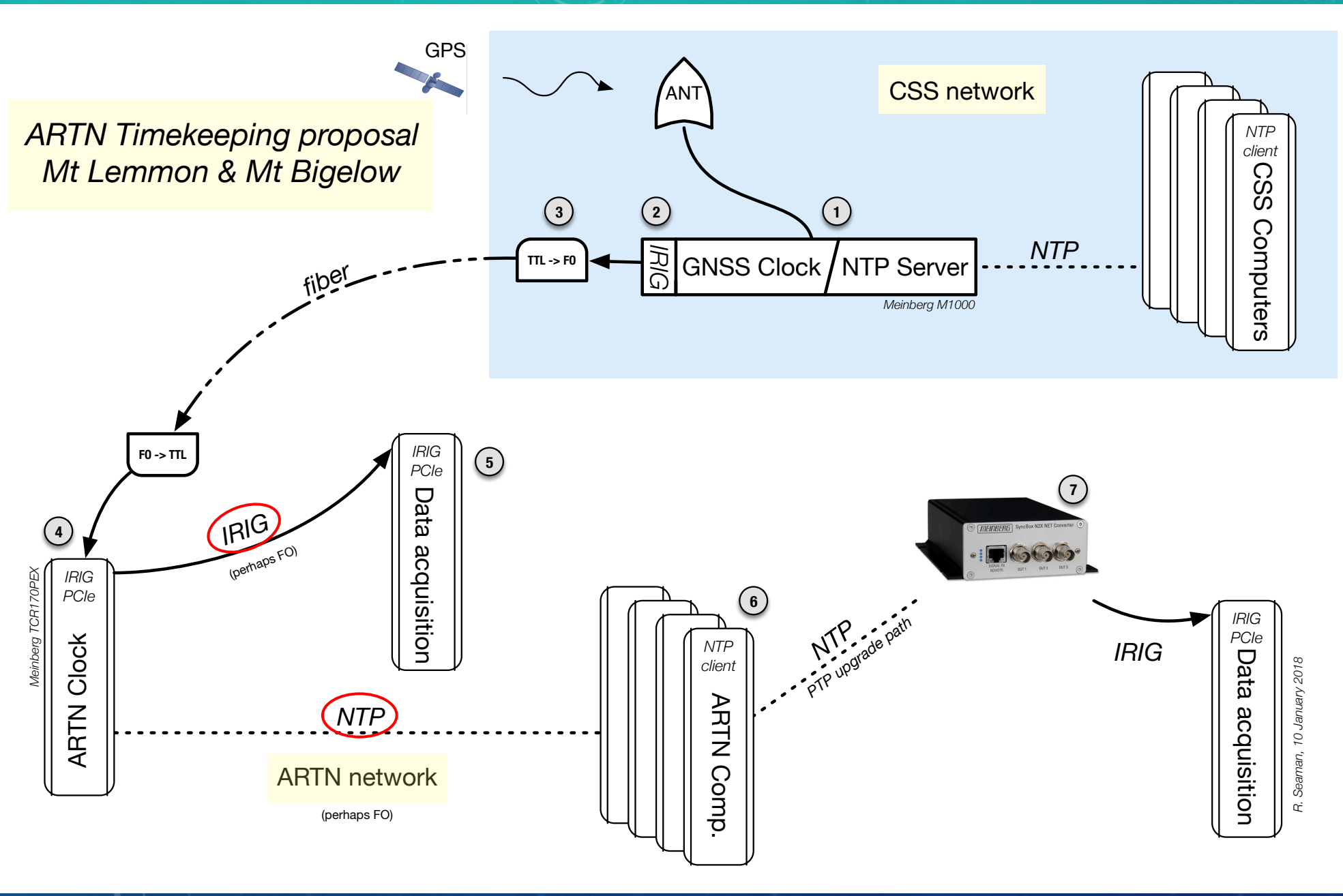


CAN ALSO CONVERT NTP BACK TO IRIG

- 1 ms accuracy (with local reference)
  - compared to 50 ns
    (1000 Hz vs 10 MHz)
- Power over ethernet (POE)
- TCXO standard (1s / month)
  - OCXO optional (50ms / month)
- Programmable outputs
  - including triggers
- Option for time capture inputs (to serial)
- Also supports PTP's » accuracy
  (upgrade path)

40" upgrade (I52)

CATALINA SKY SURVEY



1. CSS reference
   +/- 50 ns
2. Generates IRIG
   IEEE 1344
   +/- 5 us
3. Fiber isolation
   ~80 ns delay
   + 5 ns / meter

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4. ARTN reference
   60” (Lemmon)
   61” (Bigelow)
   +/- 5 us
5. Chain IRIG
   recommend FO
6. Local NTP
   +/- 1 ms
7. NTP -> IRIG
   +/- 1 ms

EXTRA SLIDES

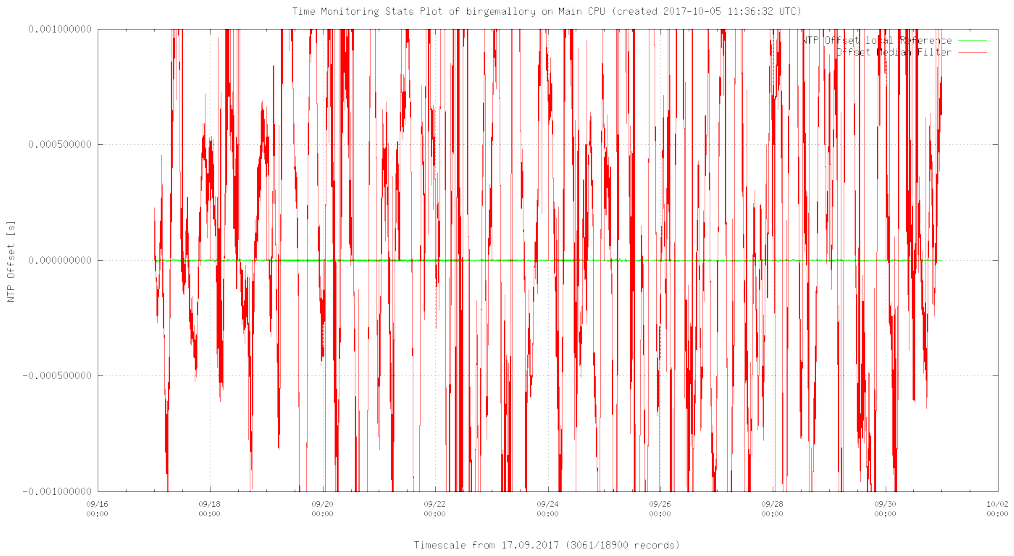
HARDWARE TIMESTAMPS FOR CMOS CAMERAS

- QHY174M-GPS
  - Compare to Video Time Inserter (IOTA-VTI v3)
- MU69 occultation campaign for New Horizons (M. Buie)
- No reason IRIG / PTP couldn't be built into other cameras or equipment

Aside:

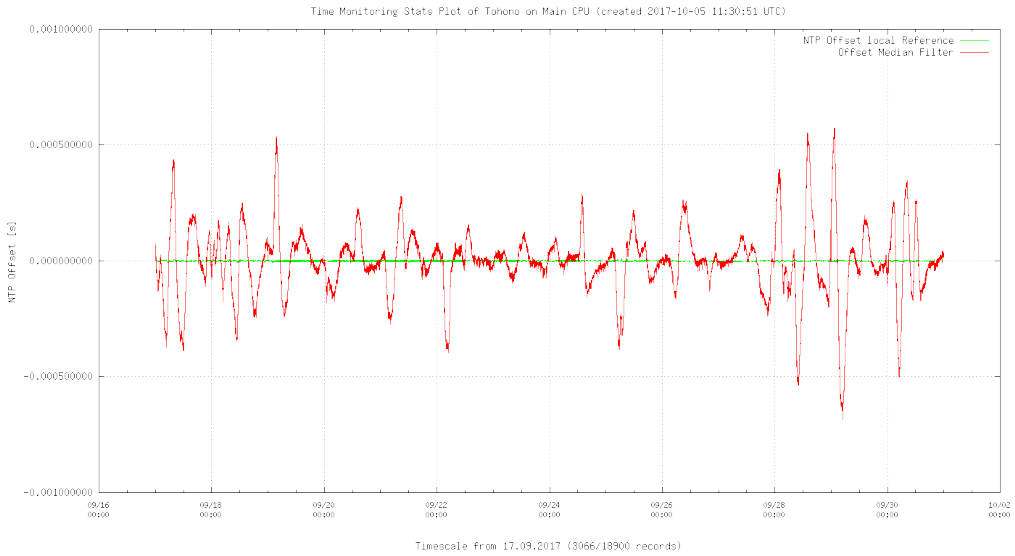
Most computers are Stratum 3, referencing Stratum 2 NTP pools

Without a local time reference, UTC via NTP cannot perform better than a convolution of the last two waveforms:



Remote time service

*



Local NTP heuristics

Also: the campus pool randomly reassigns servers to balance load

TIME THE CAMERA SHUTTER, NOT THE SOFTWARE

- Shutter stepper controller generates pulses for beginning / end of motion
- Schmitt trigger sharpens pulses
- TTL signals captured by PCIe card
- Various edge cases
- FITS keywords for mid-MJD, measured exposure duration, *etc*.
- MJD mid-exposure in middle of chip
- Shutter speed + direction flag allows removing +/- 0.3s jitter across focal plane

Calculated time of mid-exposure

Keyword	Calculated		Event	Time capture
MJDOPBEG=	57539.254673156218	/ [d]	Open shutter:	2016-05-31 06:06:43.7606972
MJDOPEND=	57539.254680077422	/ [d]	Open ended:	2016-05-31 06:06:44.3586895
MJDMID =	57539.254908091840	/ [d]	**Mid exposure:**	**2016-05-31 06:07:04.0591350**
MJDCLBEG=	57539.255136106265	/ [d]	Close shutter:	2016-05-31 06:07:23.7595814
MJDCLEND=	57539.255143026254	/ [d]	Close ended:	2016-05-31 06:07:24.3574683
EXP_MEAS=	39.9988841	/ [s]	Measured exposure duration	
OSHUTDUR=	0.5979920	/ [s]	Measured shutter open duration	
CSHUTDUR=	0.5978870	/ [s]	Measured shutter close duration	

Mid-exposure for each pixel Y location ← **Shutter Direction (reverses)** ← **Physical shutter speed (+ converging optics)** ← **Mid-exposure for the middle pixel of the detector**

LEAP SECONDS

INTERNATIONAL EARTH ROTATION AND REFERENCE SYSTEMS SERVICE (IERS)

SERVICE INTERNATIONAL DE LA ROTATION TERRESTRE ET DES SYSTEMES DE REFERENCE

SERVICE DE LA ROTATION TERRESTRE DE L'IERS
OBSERVATOIRE DE PARIS
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Tel. : +33 1 40 51 23 35
e-mail : services.iers@obspm.fr
http://hpiers.obspm.fr/eop-pc

Paris, 09 January 2018

Bulletin C 55

To authorities responsible
for the measurement and
distribution of time

INFORMATION ON UTC - TAI

NO leap second will be introduced at the end of June 2018.
The difference between Coordinated Universal Time UTC and the
International Atomic Time TAI is :

from 2017 January 1, 0h UTC, until further notice : UTC-TAI = -37 s

Leap seconds can be introduced in UTC at the end of the months of December or June, depending on the evolution of UT1-TAI. Bulletin C is mailed every six months, either to announce a time step in UTC, or to confirm that there will be no time step at the next possible date.

Christian BIZOUARD
Director
Earth Orientation Center of IERS
Observatoire de Paris, France

INTERNATIONAL EARTH ROTATION AND REFERENCE SYSTEMS SERVICE (IERS)
SERVICE INTERNATIONAL DE LA ROTATION TERRESTRE ET DES SYSTEMES DE REFERENCE

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http://iers.obspm.fr
email: services.iers@obspm.fr

Paris, 31 October 2017

Bulletin D 136

ANNOUNCEMENT OF DUT1

From the

30 November 2017, 0h UTC

proposed to grow without bound

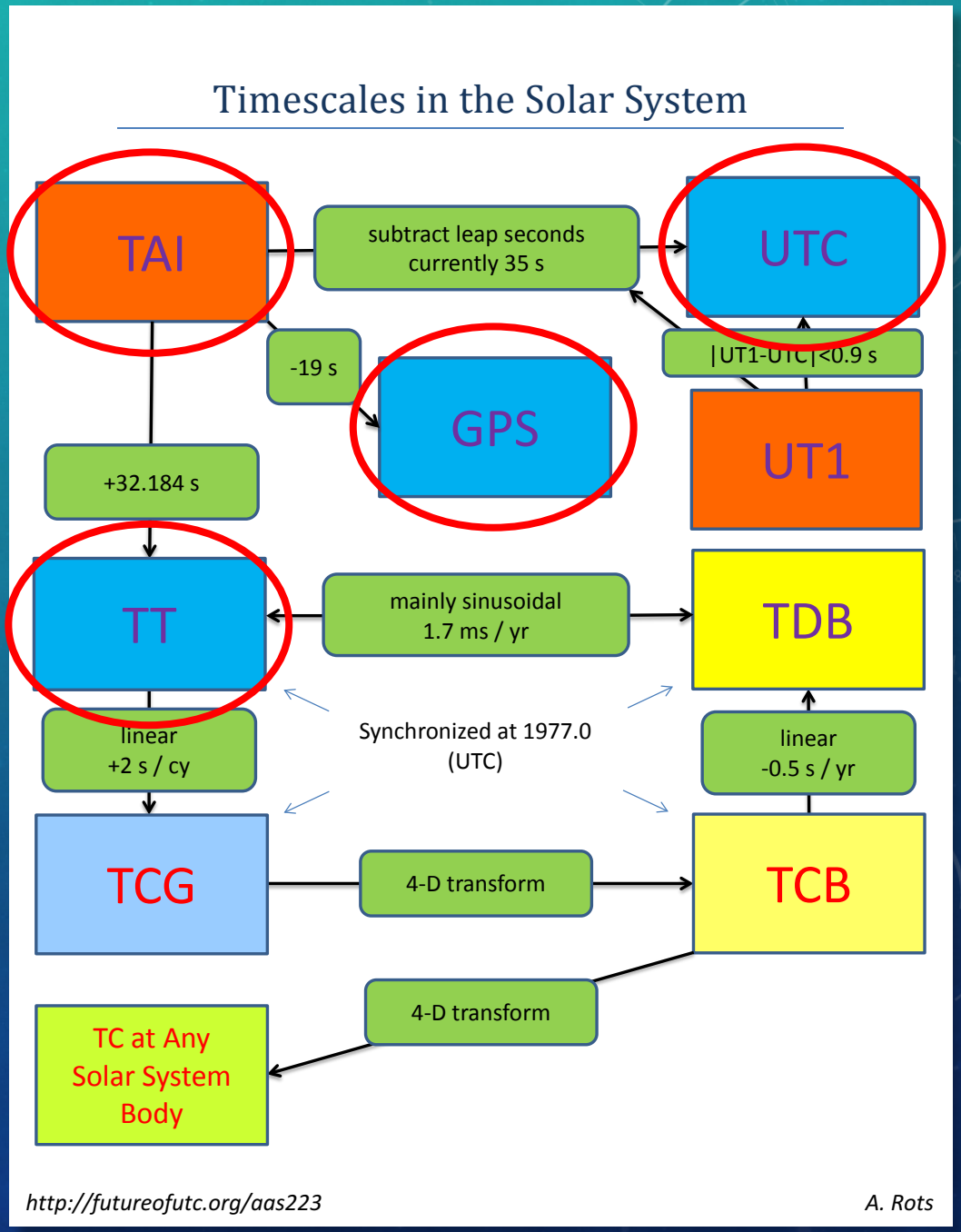
until further notice, the value of DUT1 to be disseminated with the time signals will be

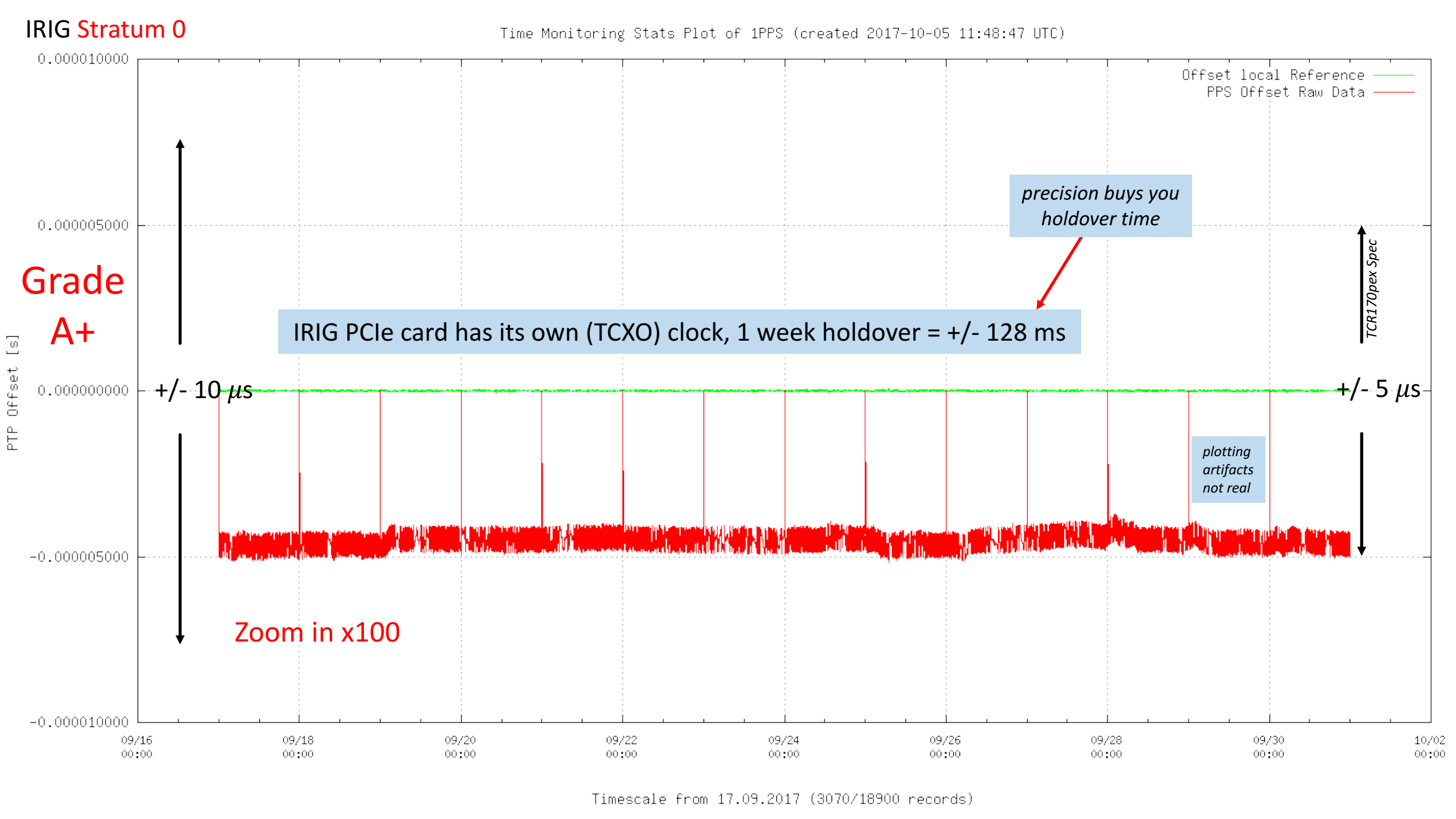
DUT1 = +0.2 s

Bulletin D 137 should be issued in February 2018

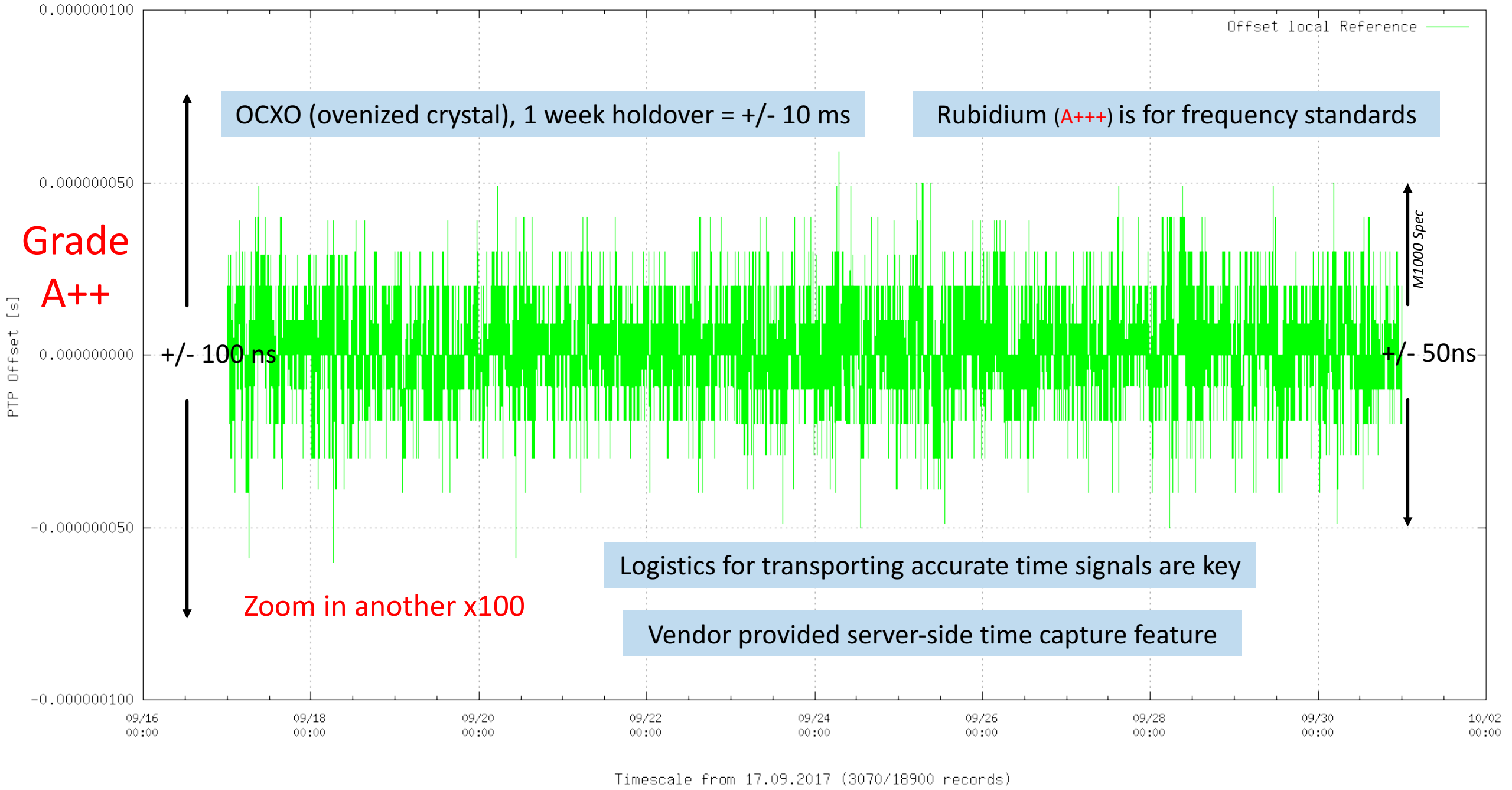
MJD IS NOT A TIMESCALE

- MJD is a representation (*e.g.,* ISO-8601)
  - MJD can be UTC or TAI, others
- Timescales will remain a topic
  - *e.g.*, UTC is required by MPC
- ITU *still* wants to redefine UTC
  - likely to succeed in offloading standard
- Commercial reference clocks support multiple timescales
  - but not UT1 (USNO NTP server)



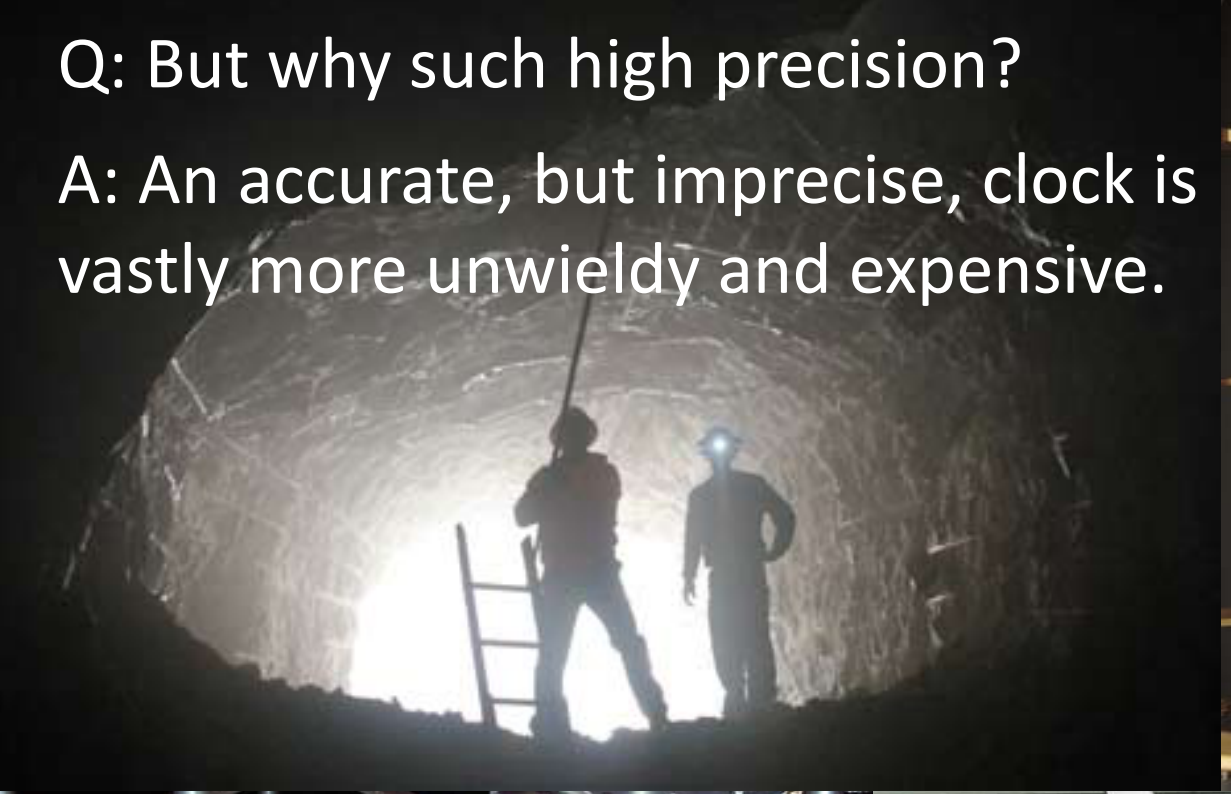

IRIG Stratum 0
Time Monitoring Stats Plot of 1PPS (created 2017-10-05 11:48:47 UTC)
Offset local Reference
PPS Offset Raw Data
0.000010000
0.000005000
0.000000000
-0.000005000
-0.000010000
PTP Offset [s]
Grade
A+
precision buys you holdover time
IRIG PCIe card has its own (TCXO) clock, 1 week holdover = +/- 128 ms
TCR170pex Spec
+/- 10 µs
+/- 5 µs
plotting artifacts not real
Zoom in x100
09/16 00:00
09/18 00:00
09/20 00:00
09/22 00:00
09/24 00:00
09/26 00:00
09/28 00:00
09/30 00:00
10/02 00:00
Timescale from 17.09.2017 (3070/18900 records)

GNSS Stratum 0 (Meinberg M1000)



Q: But why such high precision?

A: An accurate, but imprecise, clock is vastly more unwieldy and expensive.



http://longnow.org/clock