



CATALINA
SKY SURVEY

TIMEKEEPING FOR TELESCOPE NETWORKS

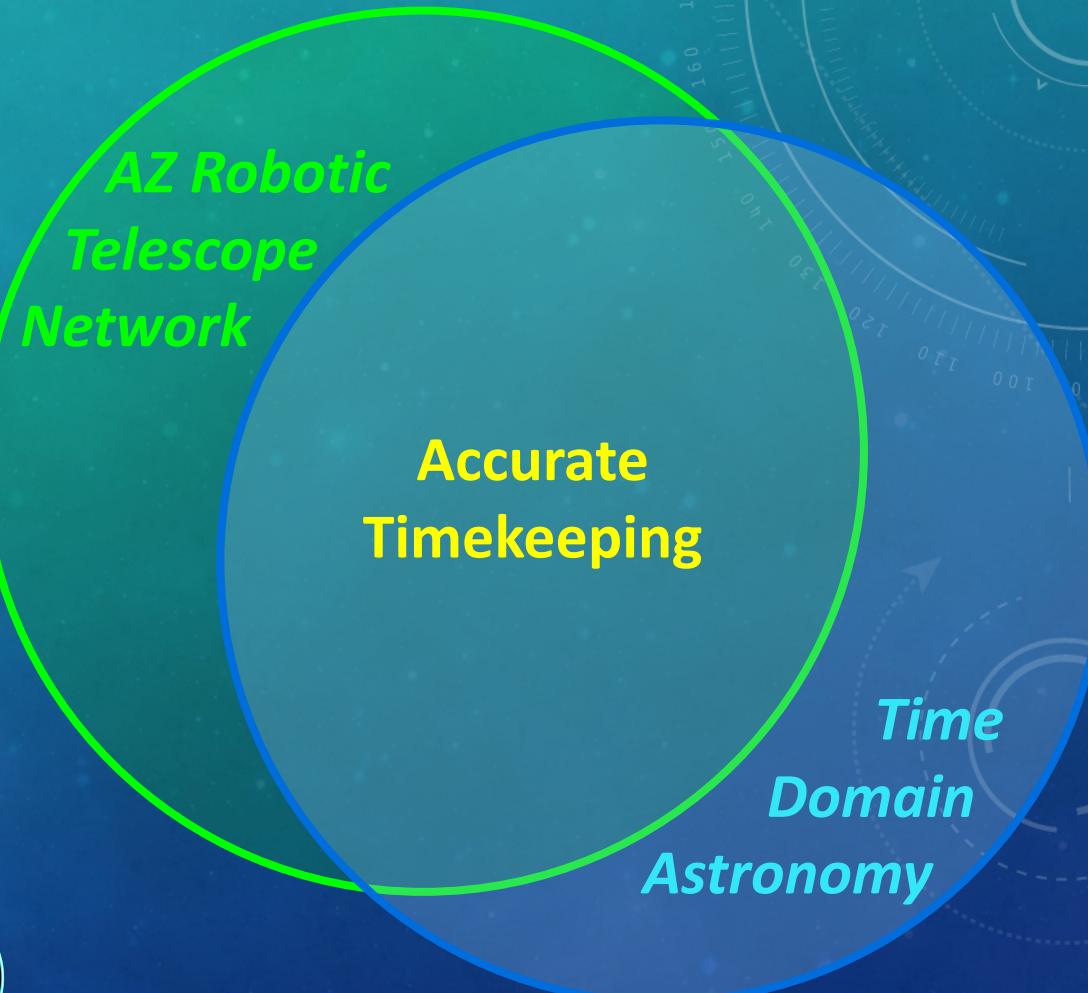
CATALINA SKY SURVEY

ROB SEAMAN

FOR THE CSS TEAM

WHY SHOULD ARTN CARE ABOUT TIME?

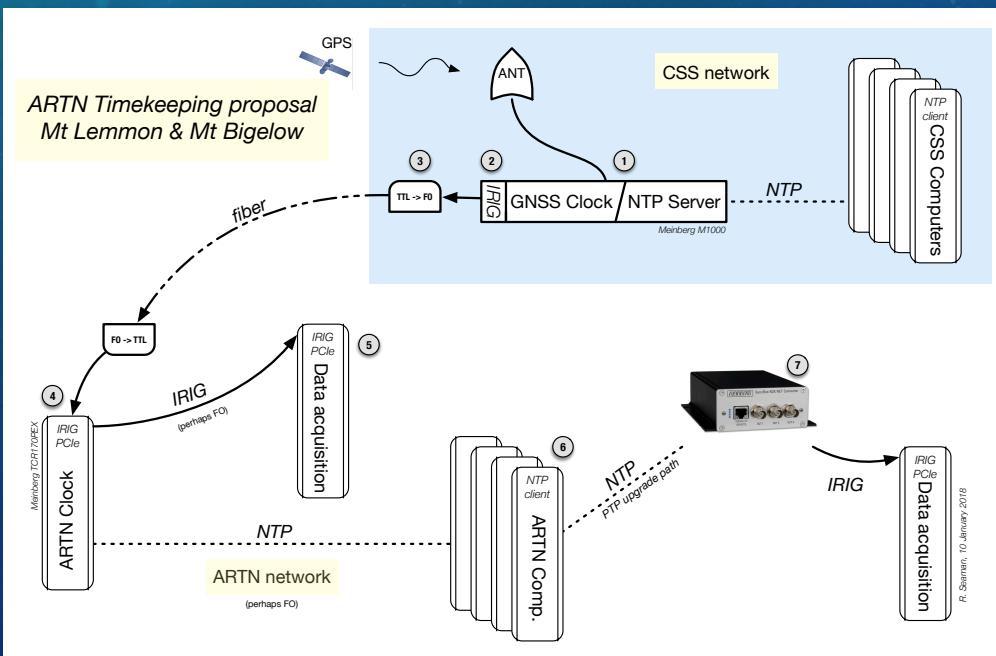
- ✓ Coordinated scheduling
- ✓ Coherent metadata
- ✓ Pointing / tracking
- ✓ Time series are *measurements*
(of flux or other astrophysical quantities)
versus *measurements of time*
- ✓ Science!



SUMMARY

- Use good GPS (GNSS) reference clocks
 - deployed local to each mountaintop (or dome)
 - avoid power cycling
- Monitor the network of clocks as a whole
 - NTP pool is not designed for science
- Time signals for data acq. & TCS
 - use **hardware timestamps**
 - use appropriate timescale(s)

Arizona Robotic Telescope Network Workshop

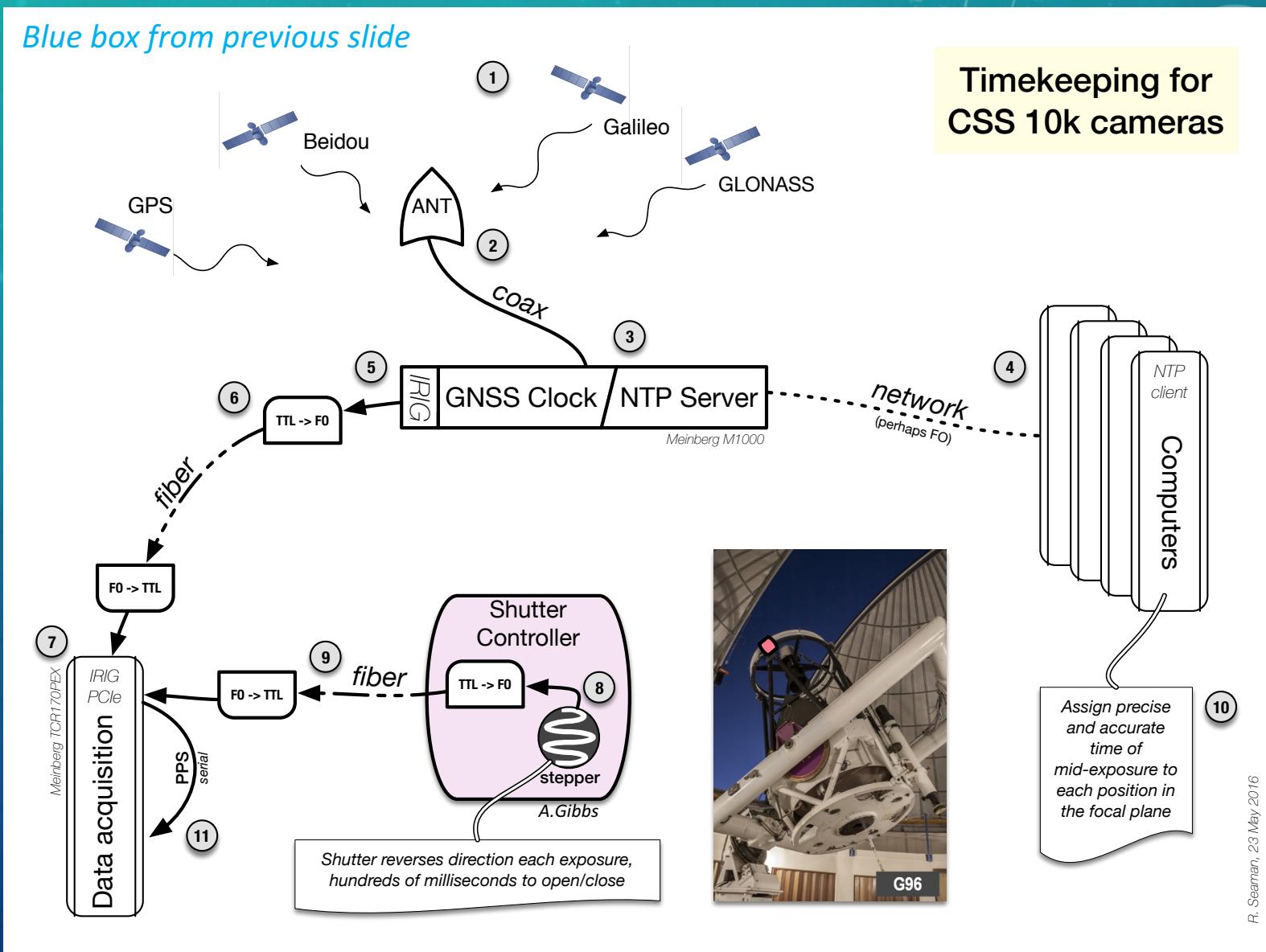


ACCURATE & PRECISE REFERENCE TIMEKEEPING

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 μ s
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)



60" (G96) CLOCK

GNSS Receiver



ARTN

~~IRIG I52~~

PPS (in) IRIG G96 NTP / Net

1 Hz Heartbeat

FO isolation

UPS

Grounding

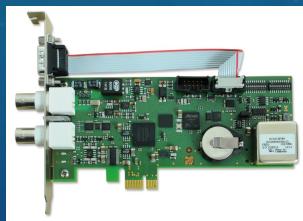
MEASURE TIME, DON'T ESTIMATE IT

TAKEAWAY #1

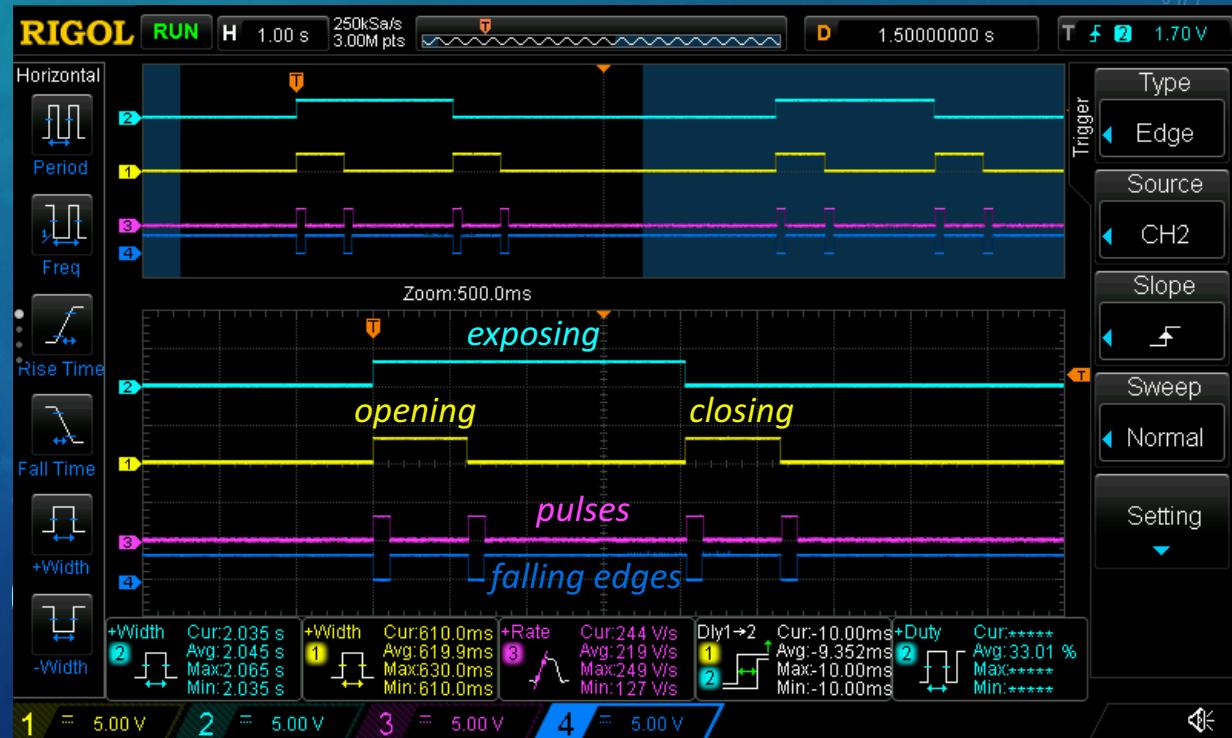
1. Computer clock chips are notoriously bad
2. System clocks are only constrained under a real-time OS
arbitrary delays under Linux / Windows – intrinsically inaccurate
3. Data acquisition is composed of many operations
e.g., charge flushing, readout, FITS, ...

→ Hardware time capture

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

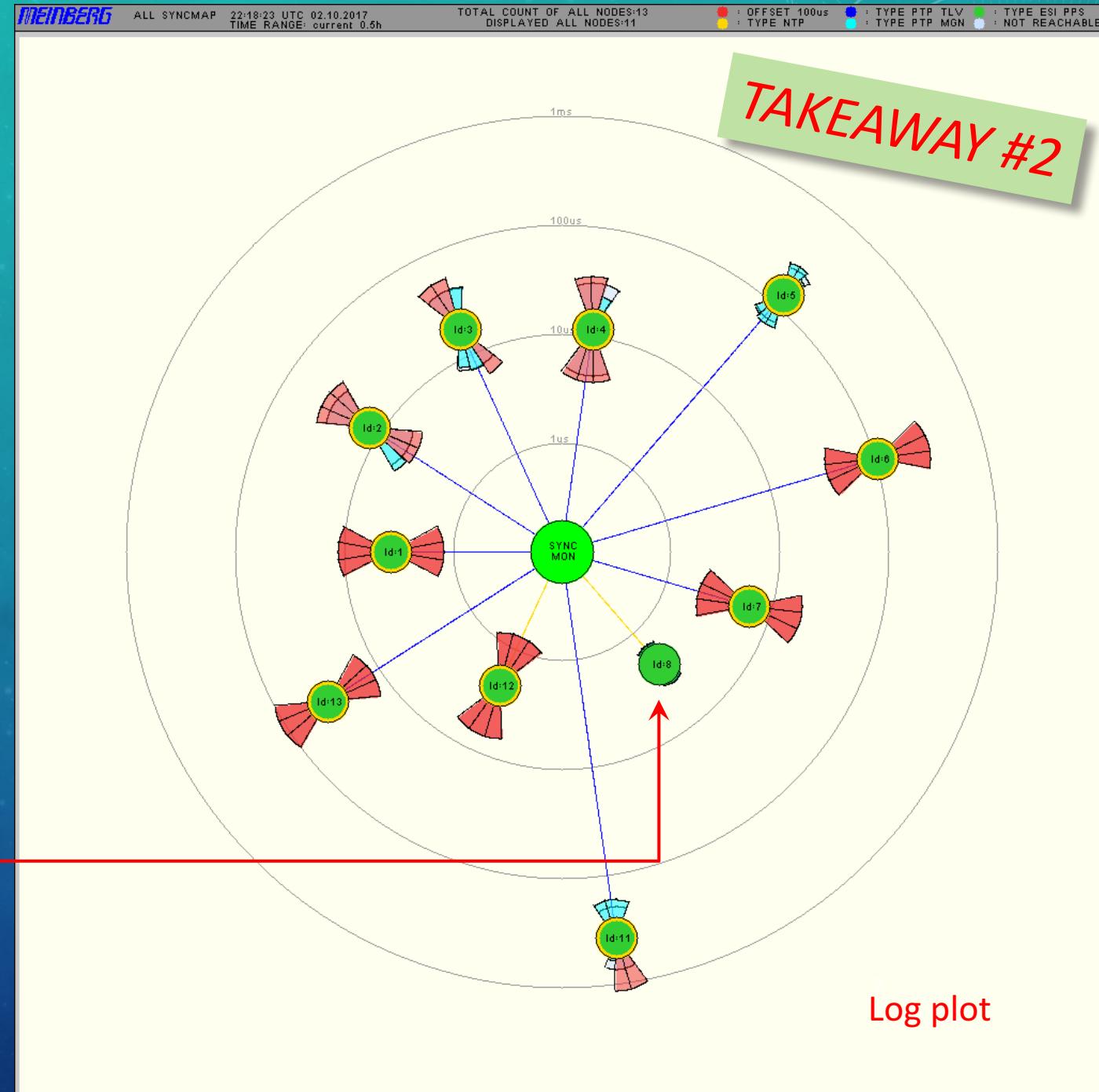


TCR180pex



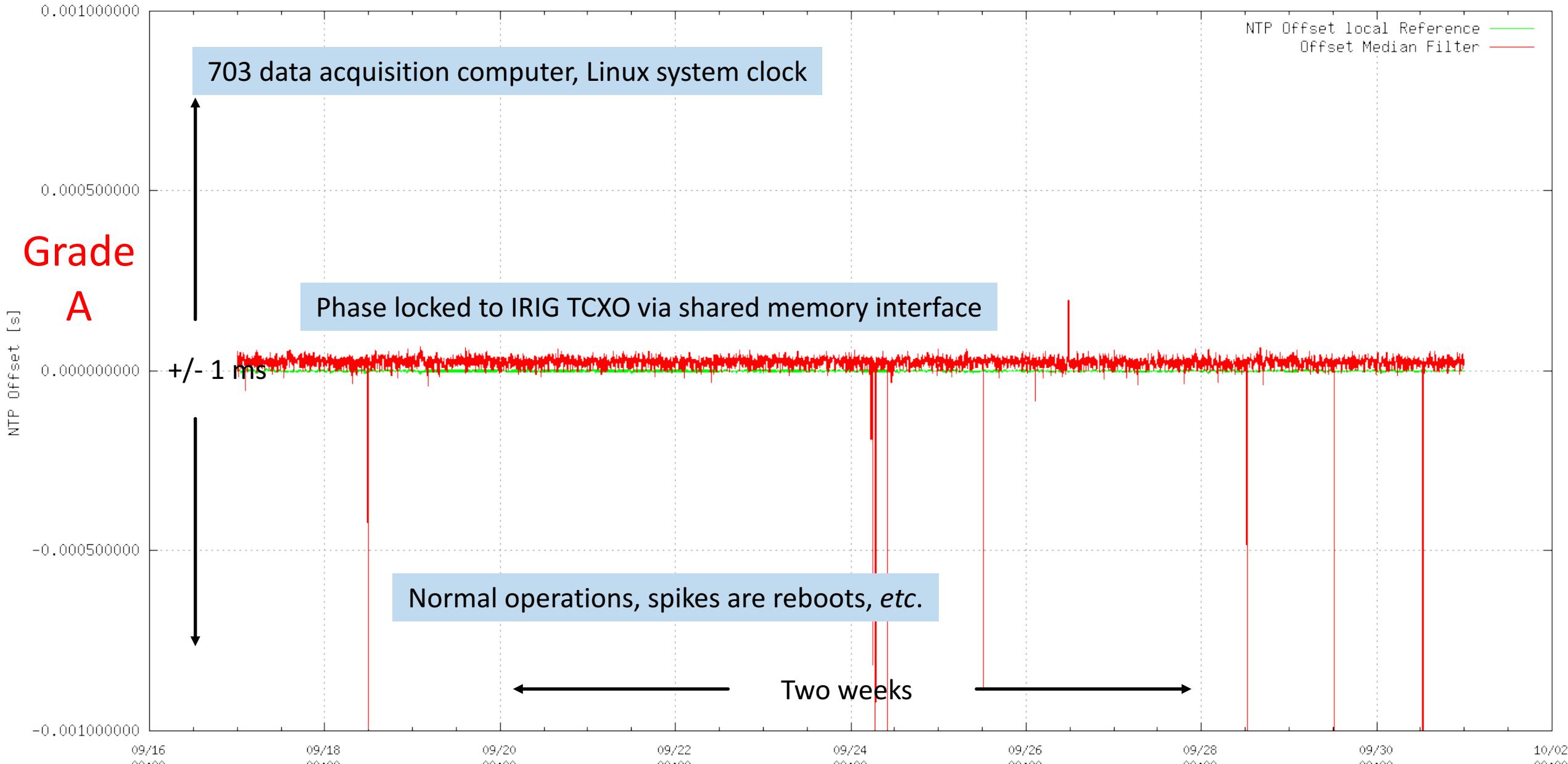
MONITOR YOUR CLOCKS!

- 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 μ s**



NTP Stratum 1 (IRIG shared mem)

Time Monitoring Stats Plot of Akimel on Main CPU (created 2017-10-05 11:25:50 UTC)

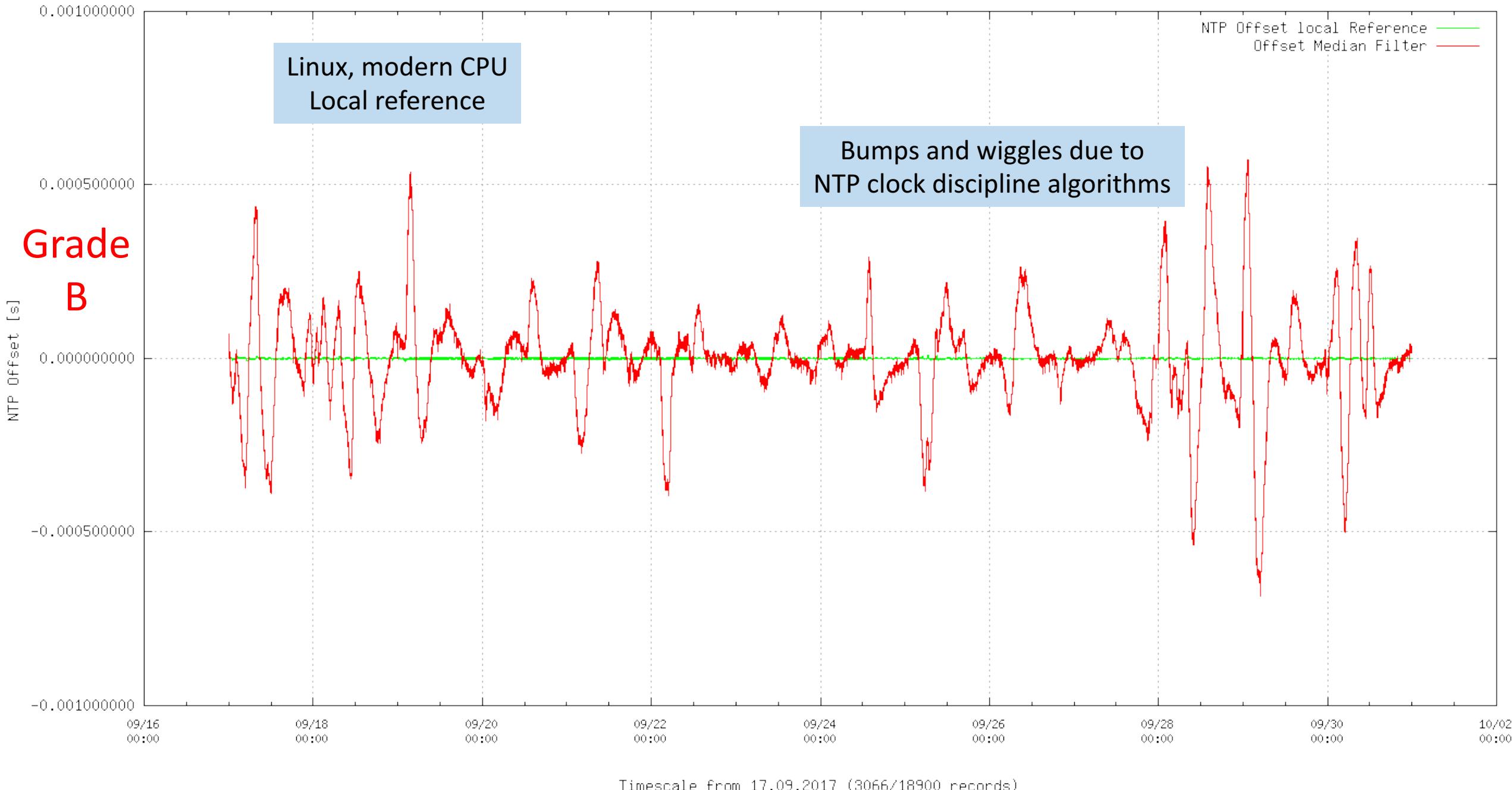


Timescale from 17.09.2017 (3066/18900 records)

NTP Offset local Reference
Offset Median Filter

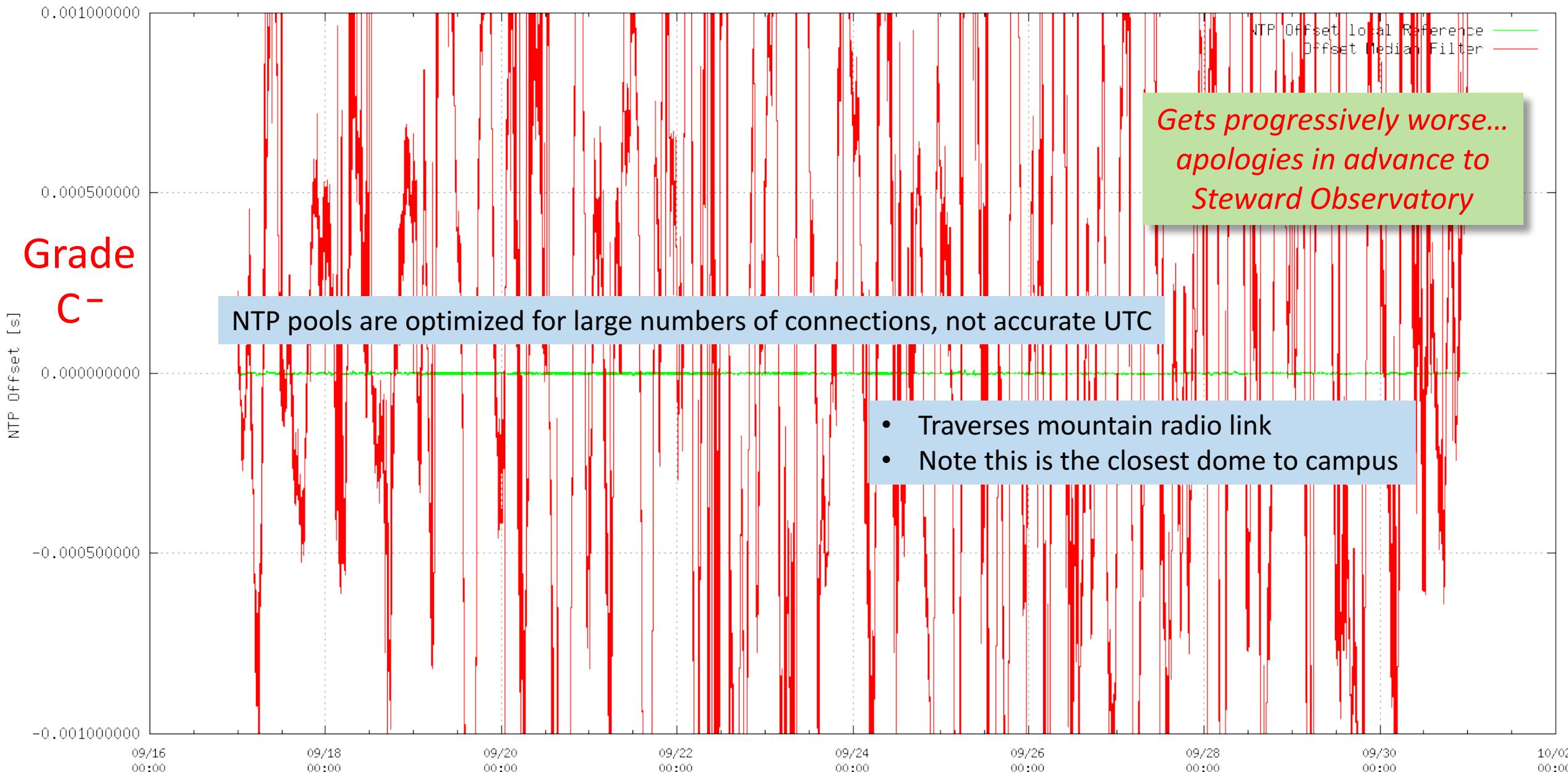
NTP Stratum 2 (via CSS ref clock)

Time Monitoring Stats Plot of Tohono on Main CPU (created 2017-10-05 11:30:51 UTC)



NTP Stratum 2 (campus pool)

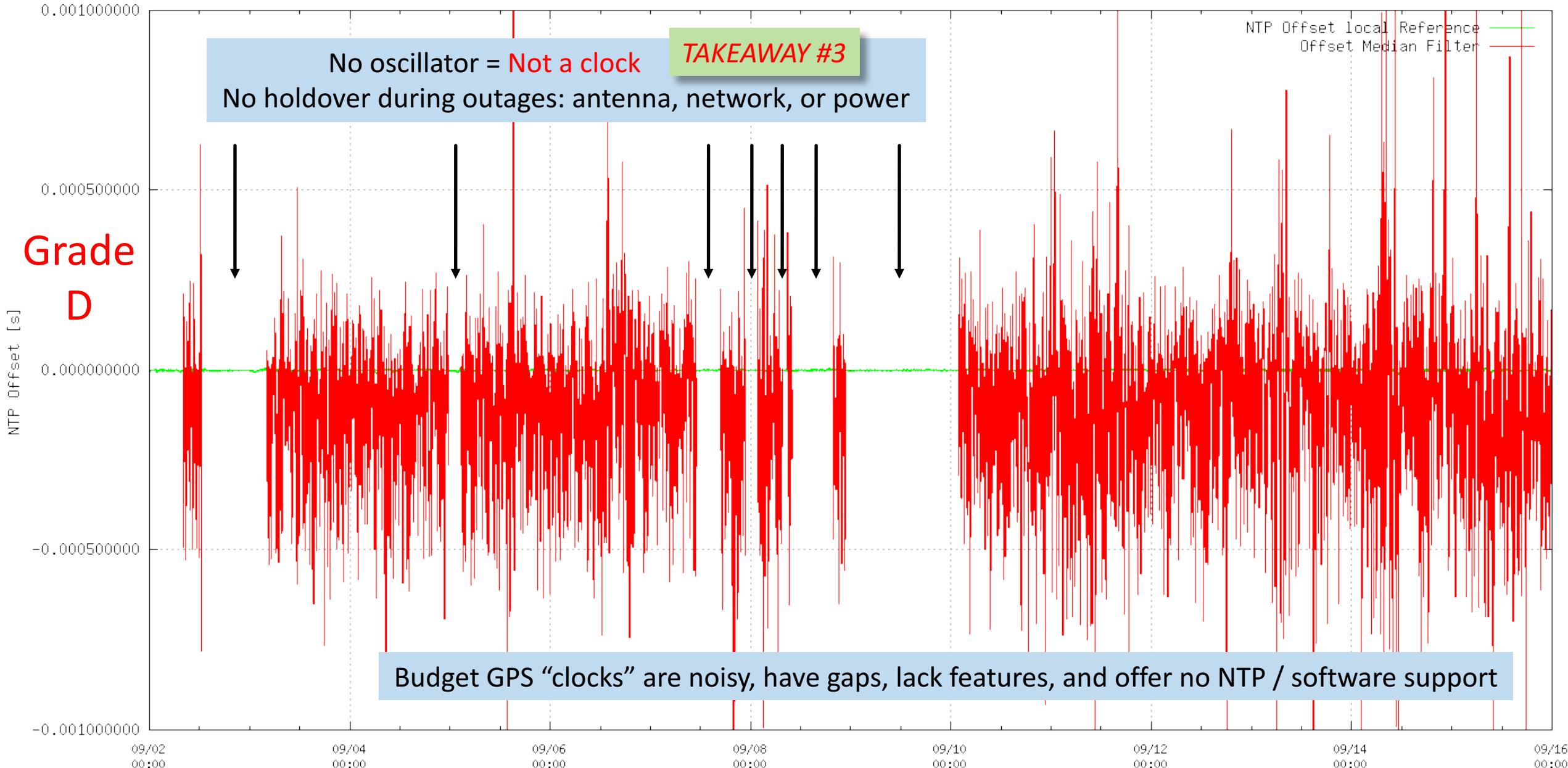
Time Monitoring Stats Plot of birgemallory on Main CPU (created 2017-10-05 11:36:32 UTC)



Timescale from 17.09.2017 (3061/18900 records)

NTP Stratum 1 (61" GPS unit)

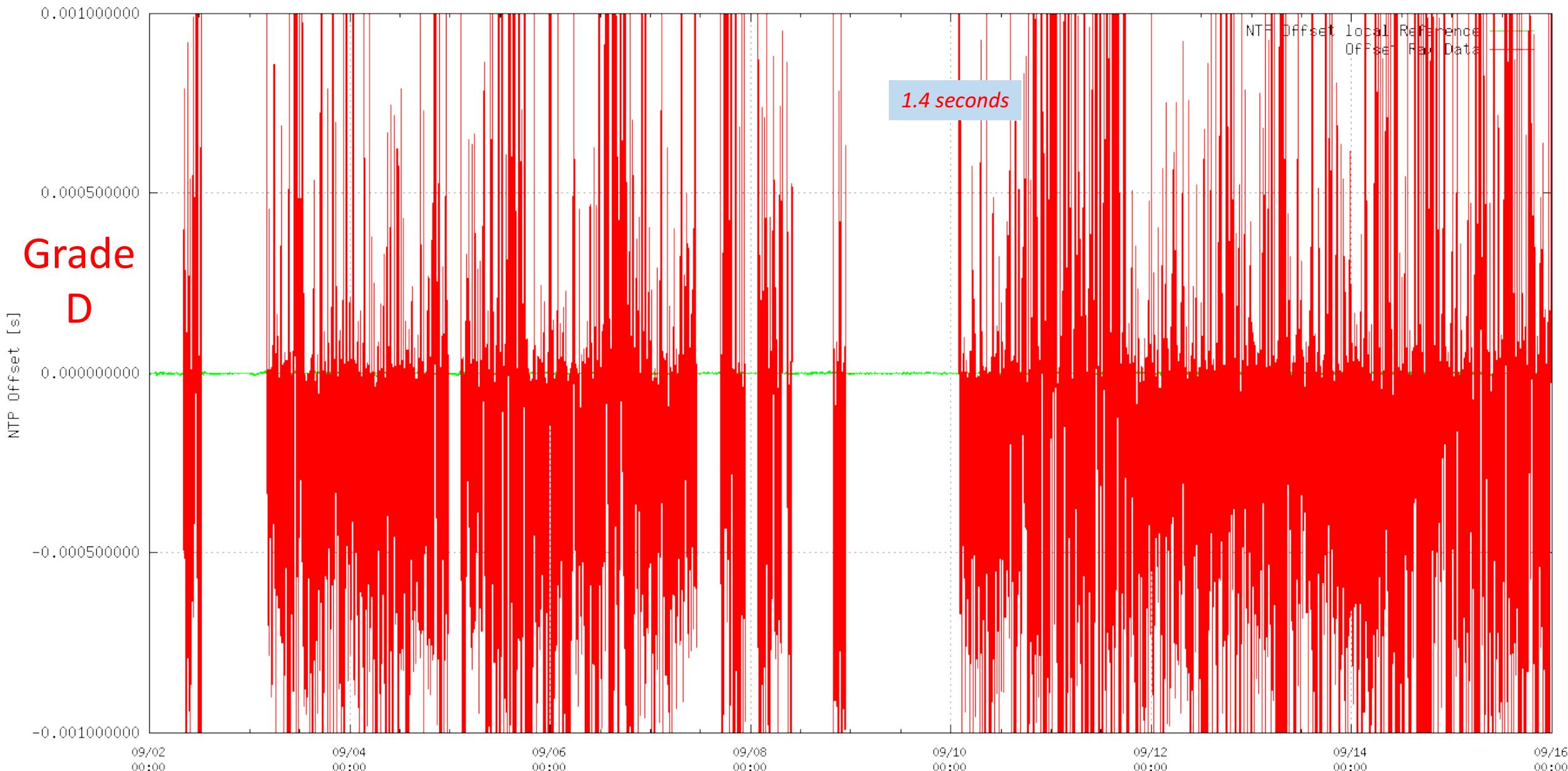
Time Monitoring Stats Plot of Bigtime on Main CPU (created 2017-10-05 11:58:47 UTC)



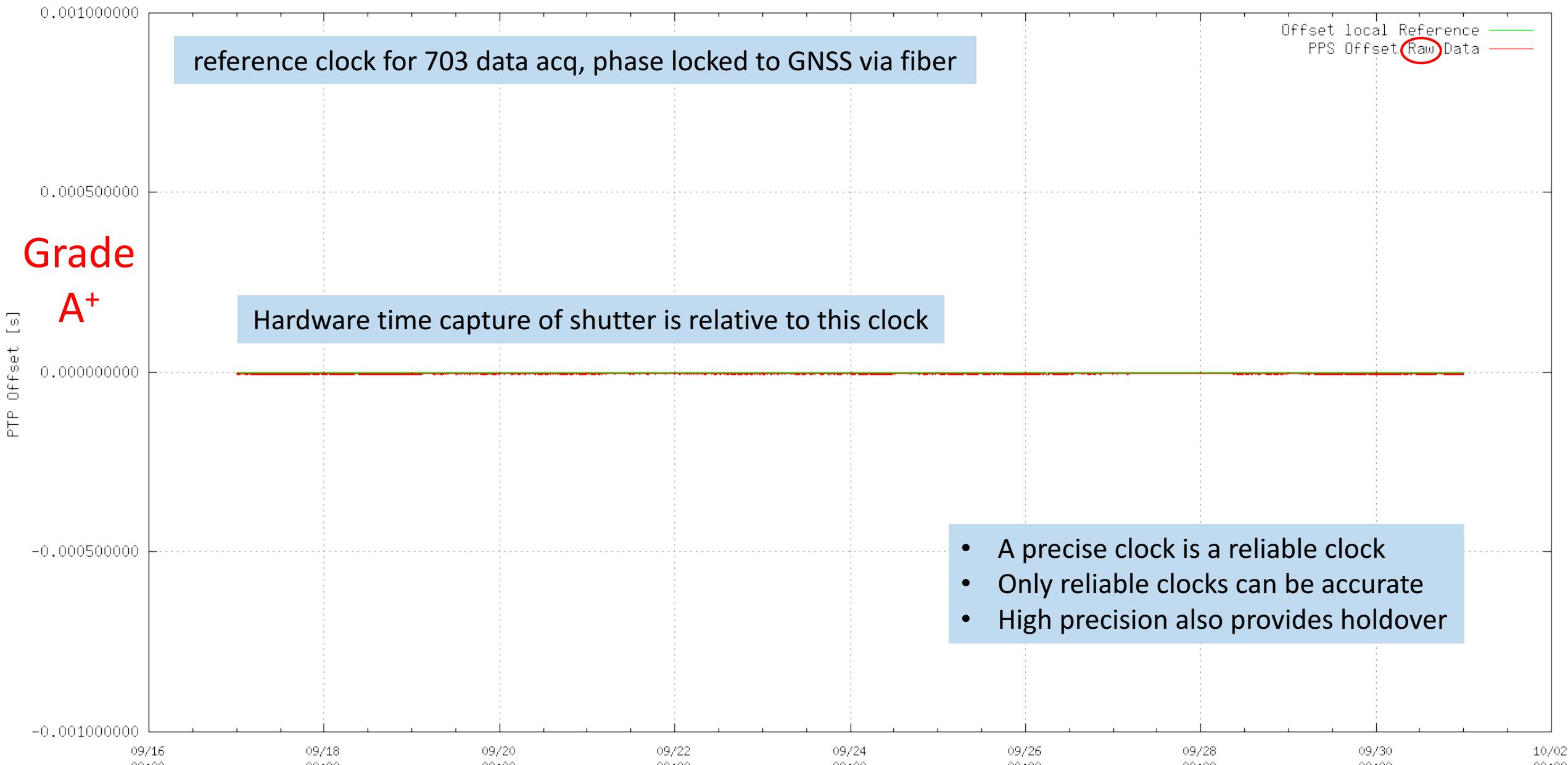
Timescale from 02.09.2017 (2405/18900 records)

NTP Stratum 1 (raw, not median)

Time Monitoring Stats Plot of Bigtime on Main CPU (created 2017-10-05 12:32:21 UTC)

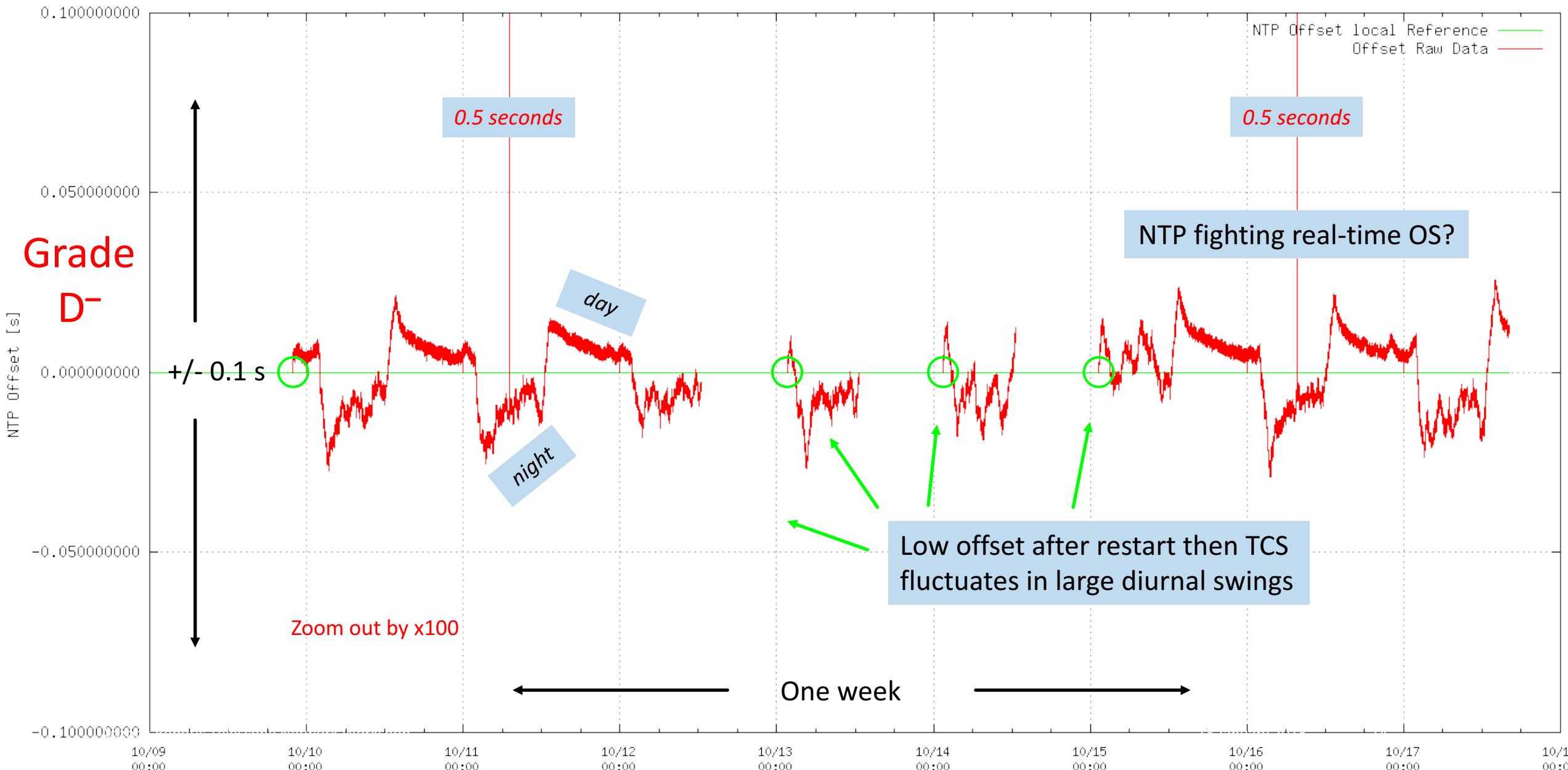


Timescale from 02.09.2017 (2405/18900 records)



NTP Stratum 3 (TCSng @ Schmidt)

Time Monitoring Stats Plot of tcs703 on Main CPU (created 2017-10-17 16:09:48 UTC)



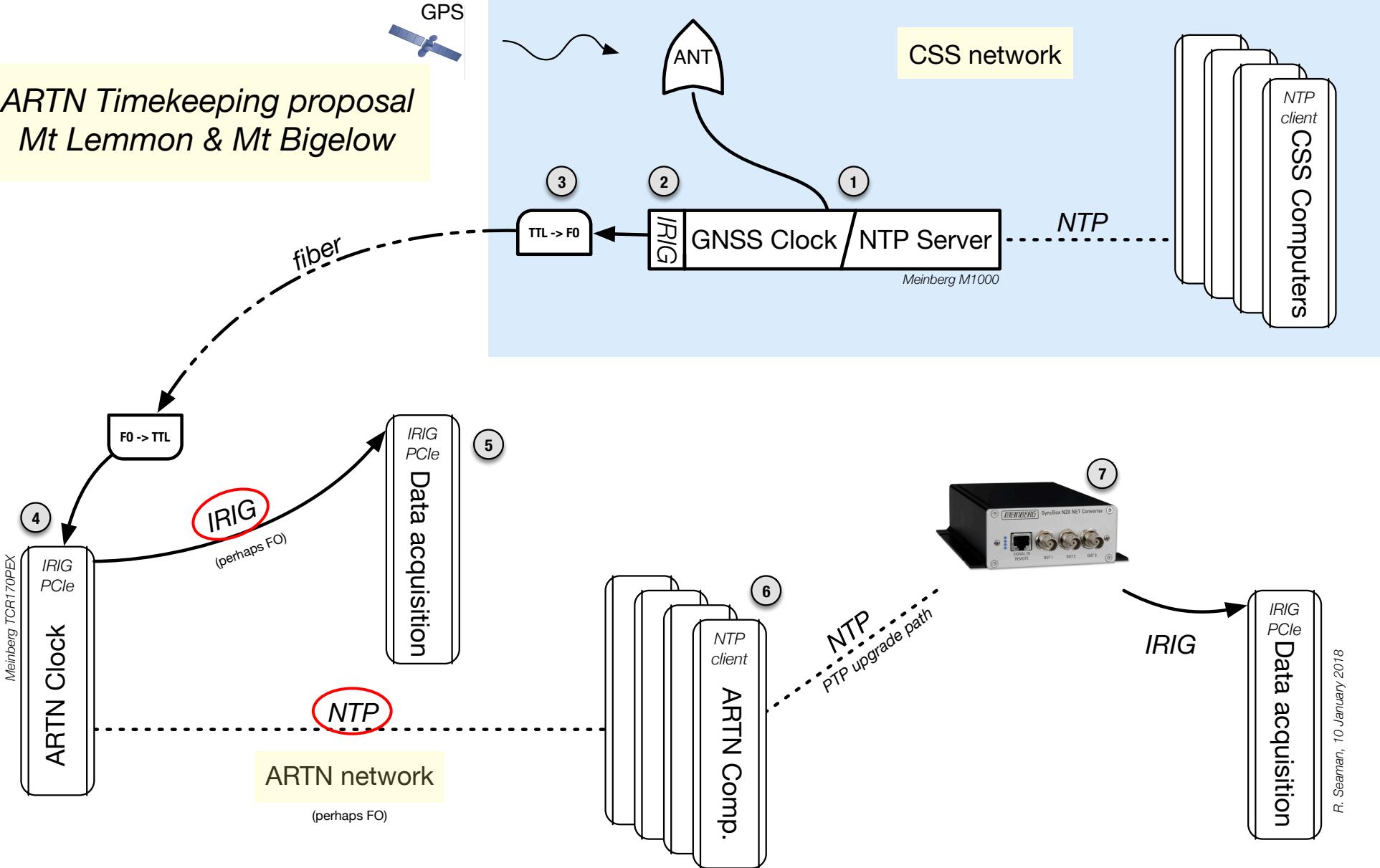
Timescale from 09.10.2017 (2009/12150 records)

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)



ARTN Timekeeping proposal Mt Lemmon & Mt Bigelow



1. CSS reference
 $\pm 50 \text{ ns}$
 2. Generates IRIG
IEEE 1344
 $\pm 5 \text{ us}$
 3. Fiber isolation
 $\sim 80 \text{ ns delay}$
 $+ 5 \text{ ns / meter}$
 4. ARTN reference
60" (Lemmon)
61" (Bigelow)
 $\pm 5 \text{ us}$
 5. Chain IRIG
recommend FO
 6. Local NTP
 $\pm 1 \text{ ms}$
 7. NTP \rightarrow IRIG
 $\pm 1 \text{ ms}$
- R. Seaman, 10 January 2018

EXTRA SLIDES



HARDWARE TIMESTAMPS FOR CMOS CAMERAS

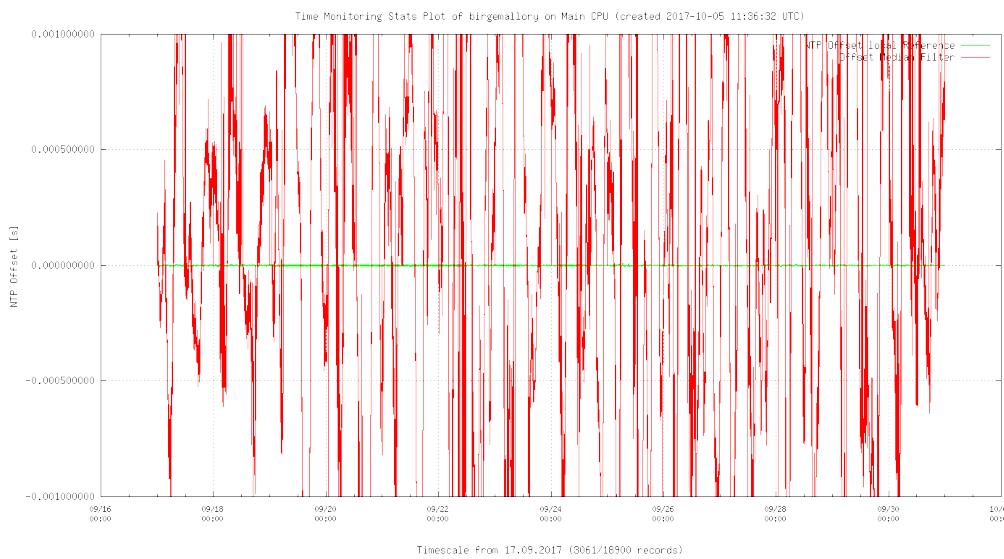
- QHY174M-GPS
 - Compare to Video Time Inserter (IOTA-VTI v3)
- MU69 occultation campaign for New Horizons (M. Buie)
- No reason IRIG / PTP couldn't be built into other cameras or equipment



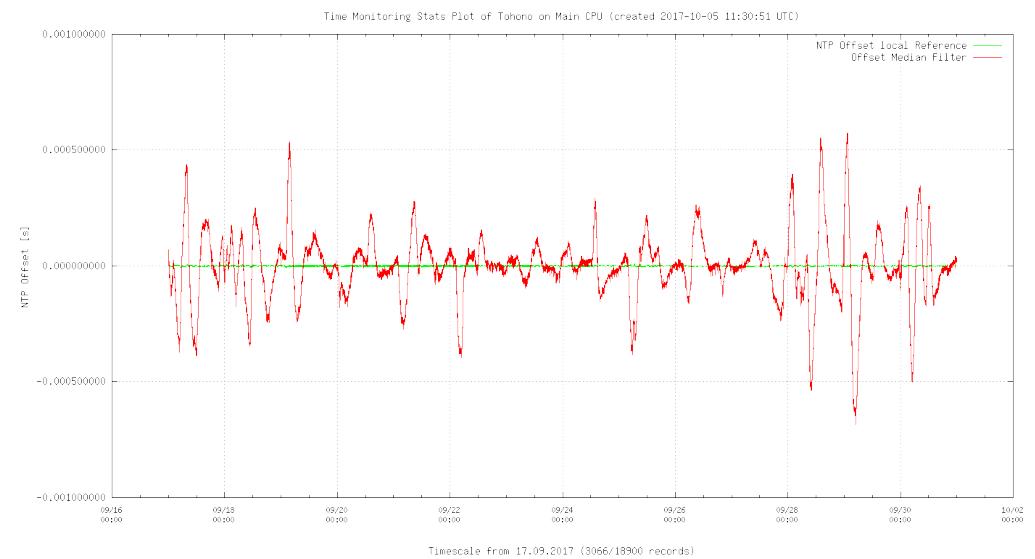
Aside:

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 reassigned 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**

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

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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

LEAP SECONDS

INTERNATIONAL EARTH ROTATION AND REFERENCE SYSTEMS SERVICE (IERS)
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Paris, 31 October 2017

Bulletin D 136

ANNOUNCEMENT OF DUT1

From the

30 November 2017, 0h UTC

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

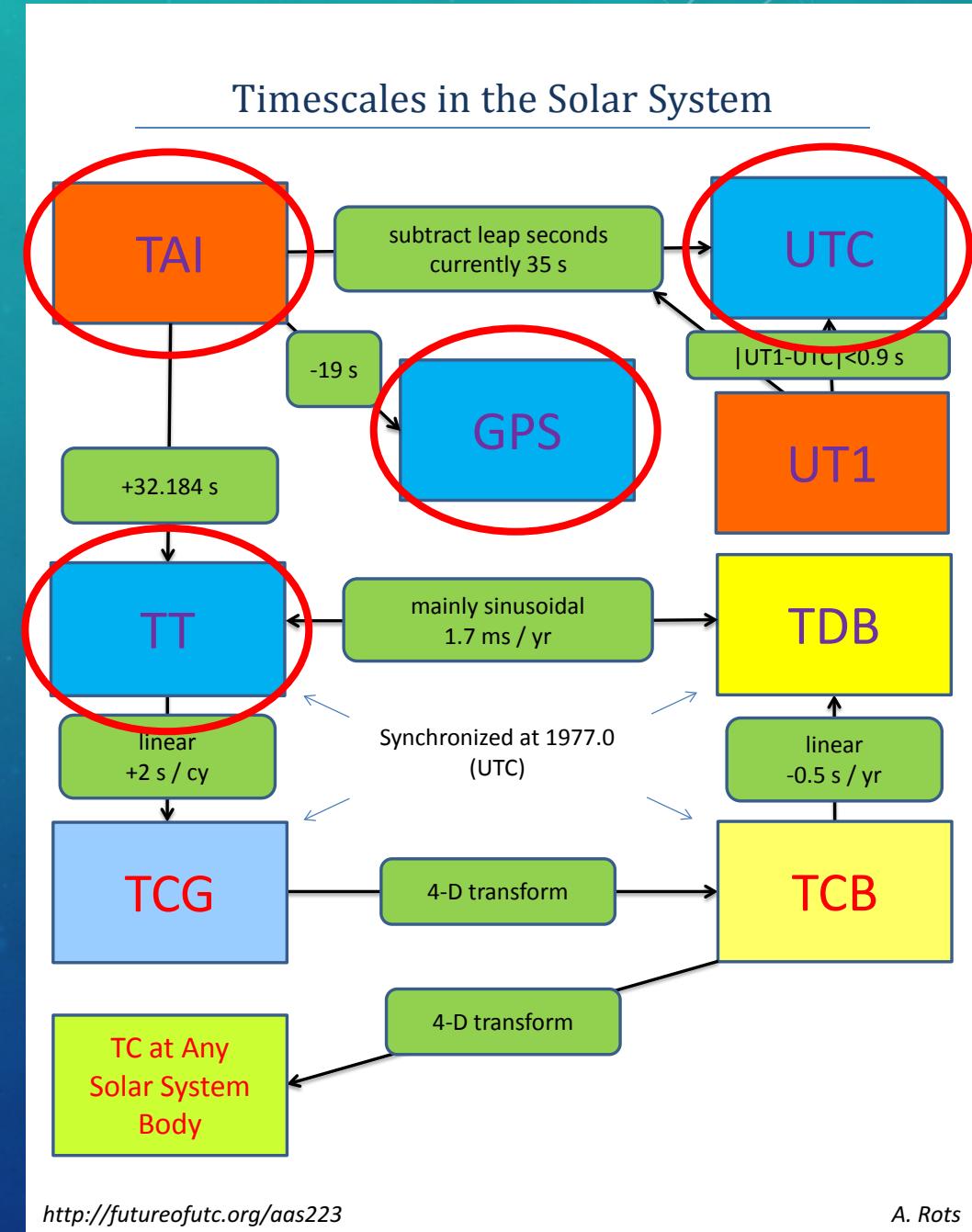
DUT1 = +0.2 s

**proposed to grow
without bound**

Bulletin D 137 should be issued in February 2018

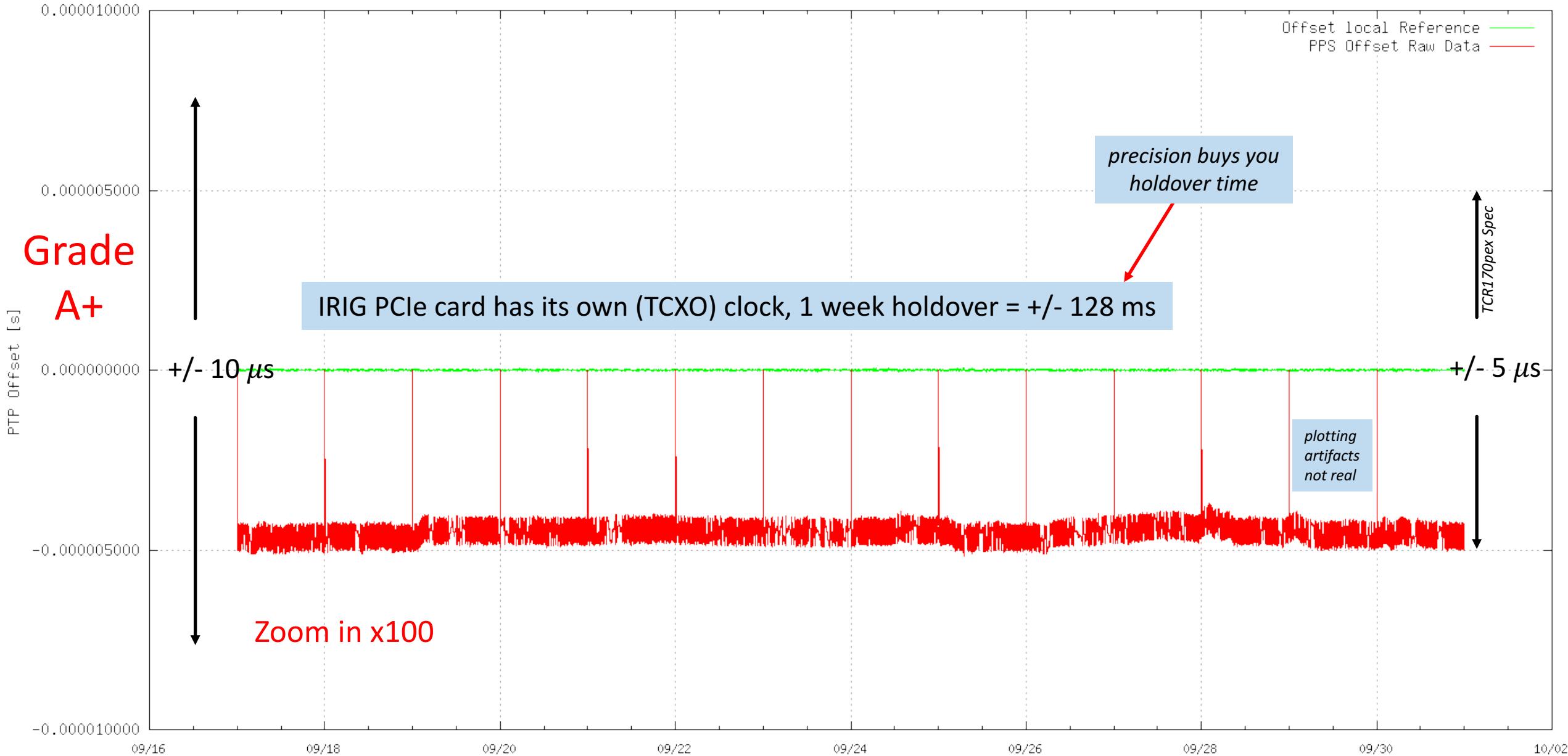
MJD IS NOT A TIMESCALE

- 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

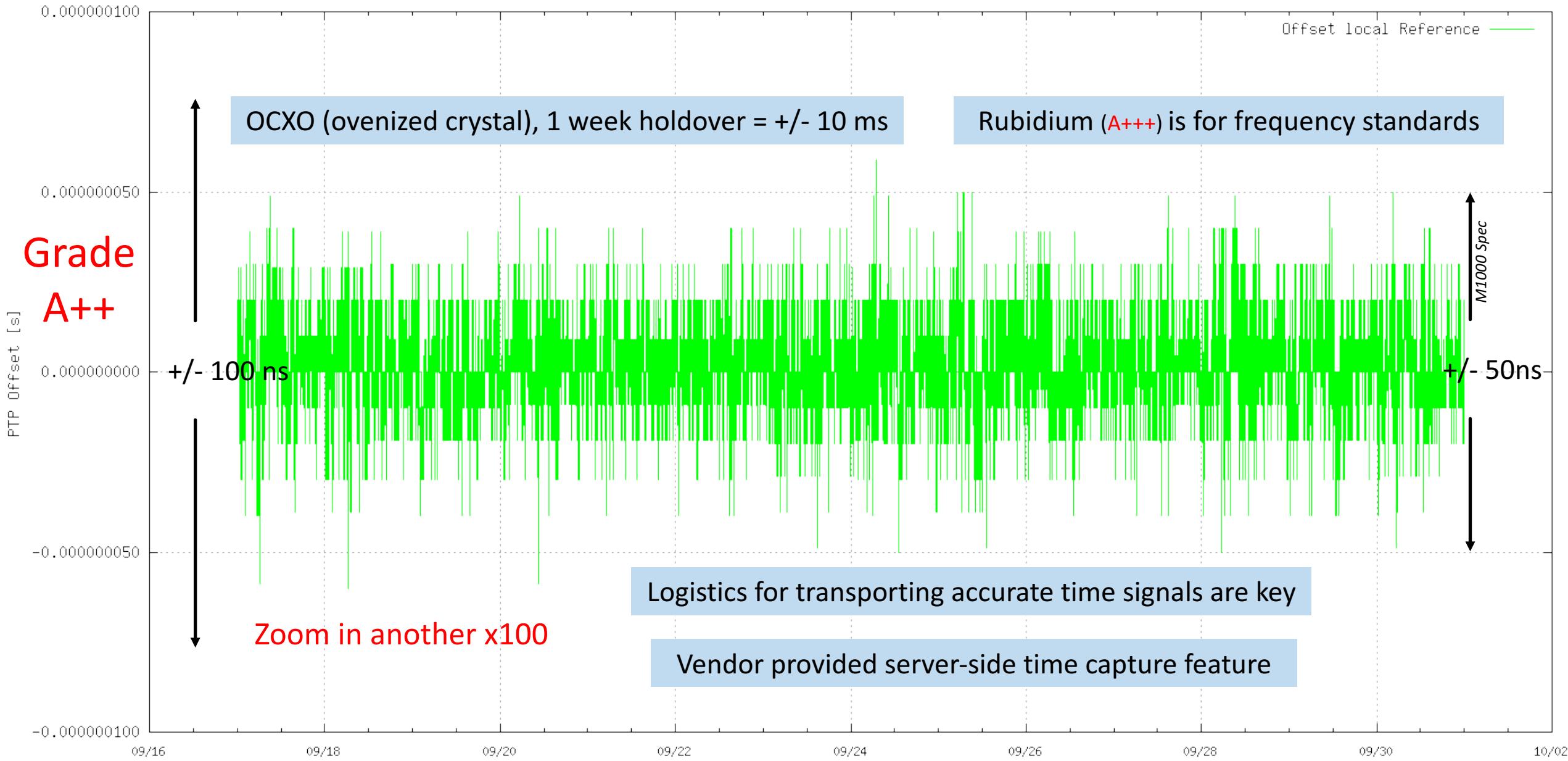
Time Monitoring Stats Plot of 1PPS (created 2017-10-05 11:48:47 UTC)



Timescale from 17.09.2017 (3070/18900 records)

GNSS Stratum 0 (Meinberg M1000)

Time Monitoring Stats Plot of 1PPS (created 2017-10-05 11:52:23 UTC)



Timescale from 17.09.2017 (3070/18900 records)

Q: But why such high precision?

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

