Low Cost, High Accuracy GPS Timing

- **Tom Clark**

  NASA Goddard Space Flight Center

  Greenbelt, MD

- **Rick Hambly**

  CNS Systems, Inc.

  Severna Park, MD

- **Reza Abtahi**

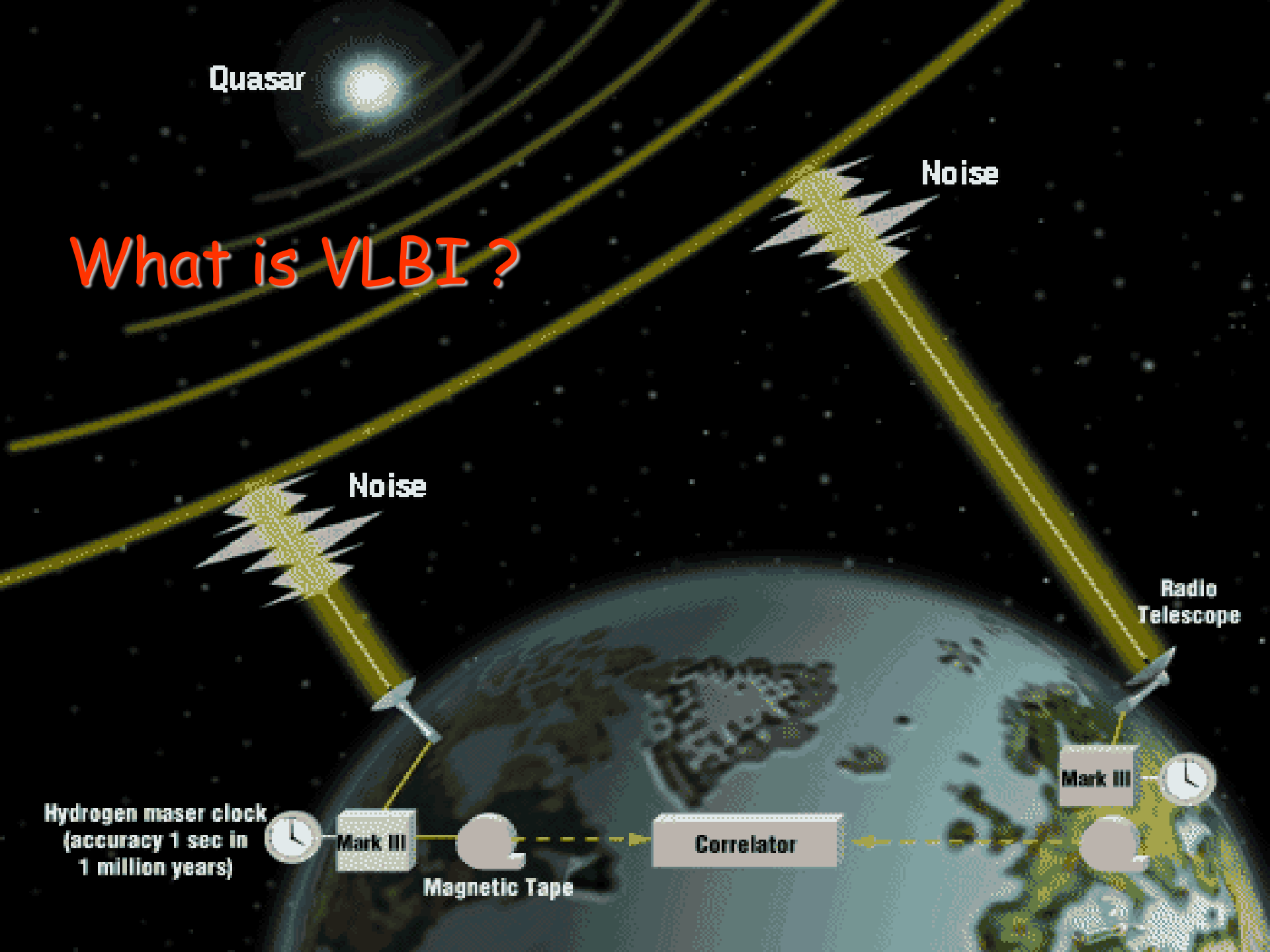
  Custom Navigation Systems

  San Jose, CA

ION -- Sept.20, 2000

Salt Lake City

What is VLBI ?


Quasar
Noise
Noise
Radio Telescope
Hydrogen maser clock (accuracy 1 sec in 1 million years)
Mark III
Magnetic Tape
Correlator
Mark III

Why did this effort get started?

- The VLBI community (Radio Astronomy and Geodesy) uses Hydrogen Masers at 40-50 remote sites all around the world. To achieve ~10° signal coherence for ~1000 seconds at 10 GHz we need the two oscillators at the ends of the interferometer to maintain relative stability of $\approx [10°/(360° \bullet 10^{10}\text{Hz} \bullet 10^{3}\text{sec})] \approx 2.8 \bullet 10^{-15}$ @ 1000 sec

- To correlate data acquired at 16Mb/s, station timing at relative levels ~50 nsec or better is needed. After a few days of inactivity, this requires $\approx [50 \bullet 10^{-9} / 10^{6}\ \text{sec}] \approx 5 \bullet 10^{-14}$ @ 10^{6} sec

- In Geodetic applications, the station clocks are modeled at relative levels ~30 psec over a day $\approx [30 \bullet 10^{-12}/86400\ \text{sec}] \approx 3.5 \bullet 10^{-16}$ @ 1 day

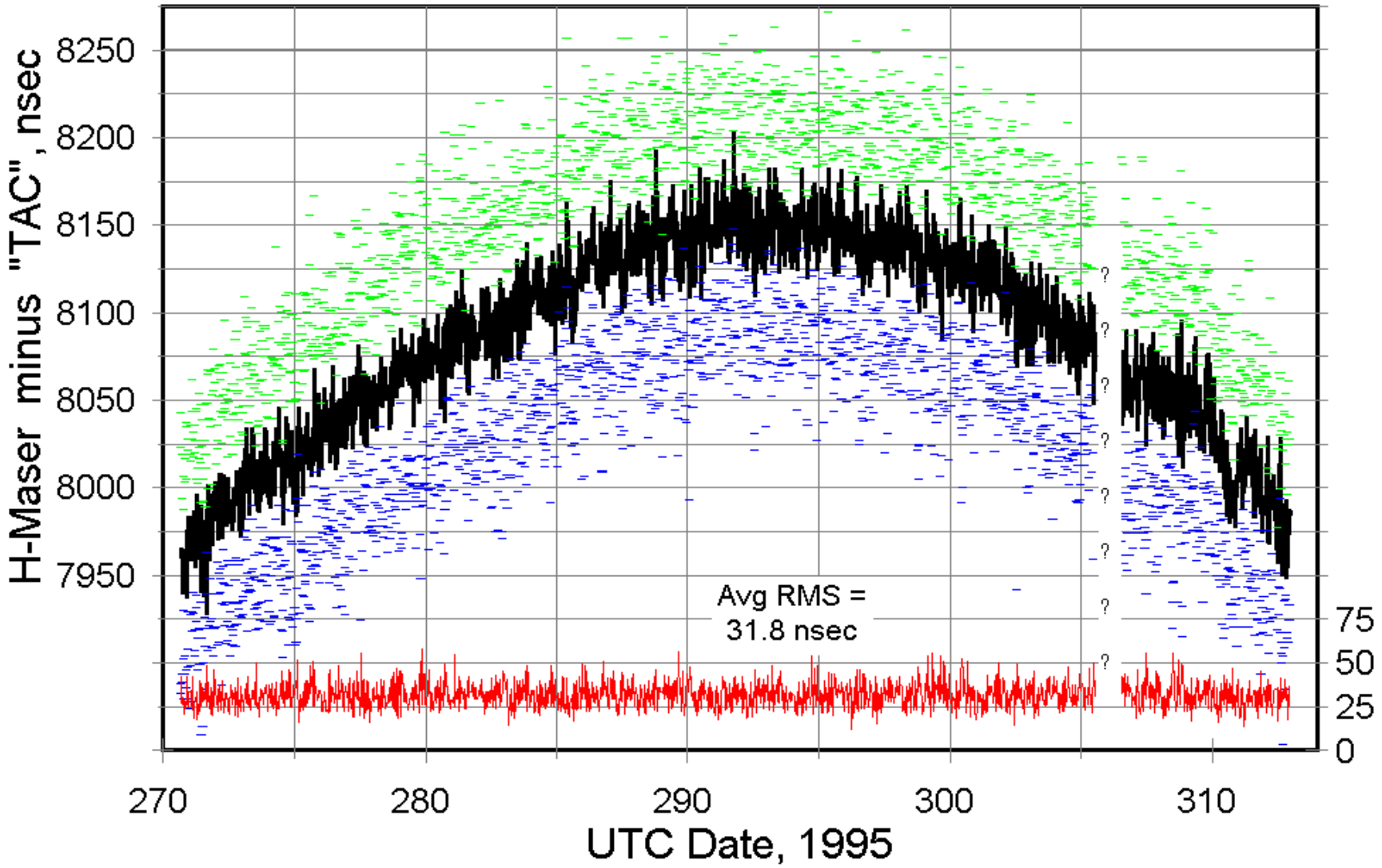
- Since VLBI defines UT1, we need to control $[UTC_{(USNO)} - UTC_{(VLBI)}]$ to an accuracy ~100 nsec or better.

An Isolated, Remote VLBI Site -- Urumqi in Xinjiang Province, China

Urumqi's 6-channel NASA-built TAC

Urumqi's Chinese H-Maser

ONSALA H-Maser vs "TAC" GPS

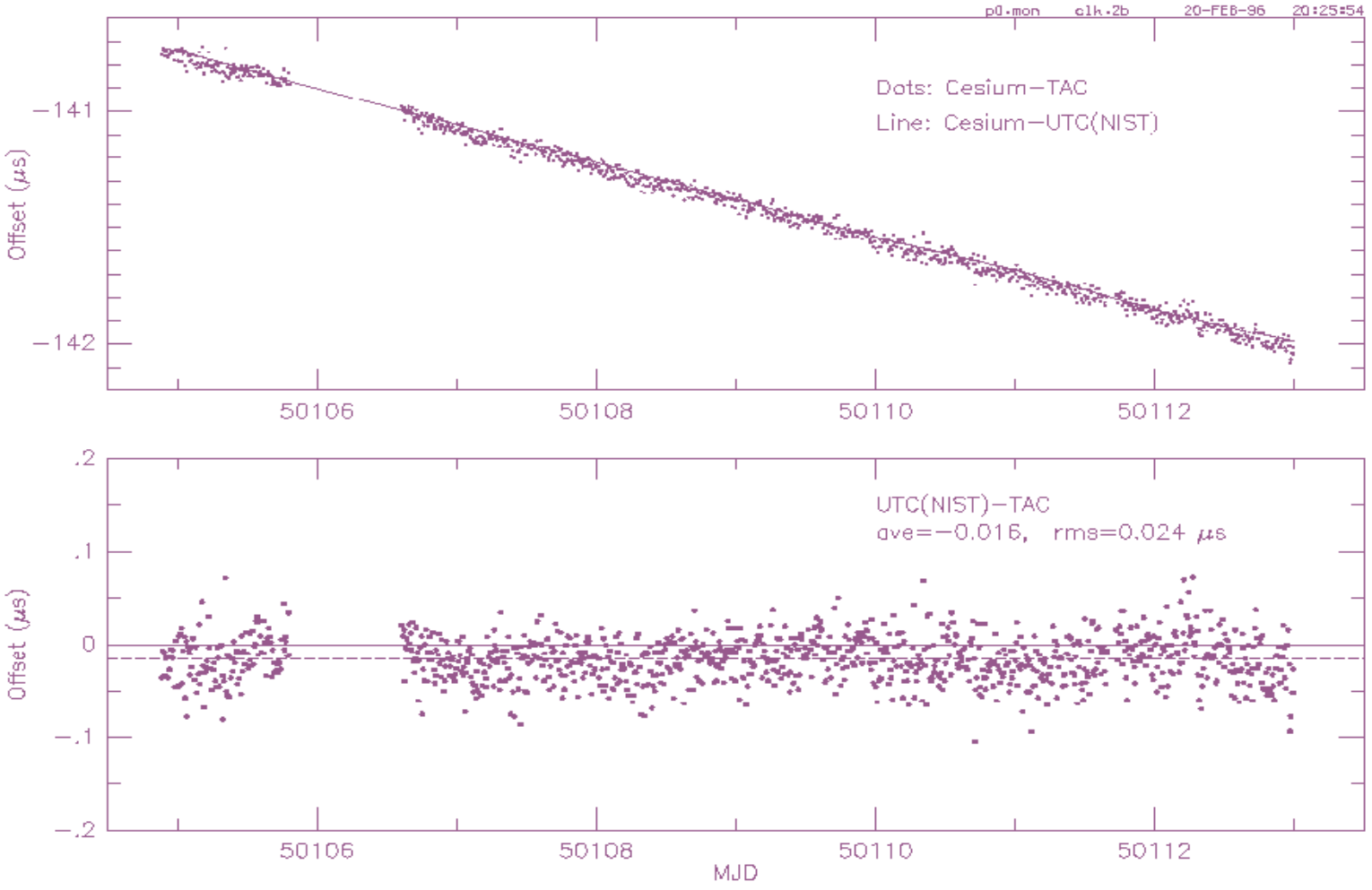


How to get ~30 nsec timing despite S/A

- Start with a good timing receiver, like the Motorola ONCORE
- Average the positioning data for ~1-2 days to determine the station's coordinates. With S/A on, a 1-2 day average should be good to <5 meters. Or if the site has been accurately surveyed, use the survey values.
- Lock the receiver's position in "Zero-D" mode to this average.
- Make sure that your Time-Interval Counter (TIC) is triggering cleanly. Start the counter with the 1 PPS signal from the "house" atomic clock and stop with the GPS receiver's 1PPS.
- Average the individual one/second TIC reading over ~5 minutes.

- These steps were automated in the SHOWTIME and TAC32Plus Software.

Joe Taylor tests TAC Accuracy at Arecibo



Our Intent for this Paper Changed . . .

- We originally planned to discuss the performance and some applications of single frequency GPS-Based timing receivers based primarily on our experiences with the Motorola VP and UT+ timing receivers. We planned to discuss some of the "tricks" we have used to mitigate against S/A's effects . . .

-- BUT --

- **DoD turned off S/A in early May**

-- AND --

- **Motorola discontinued the VP receiver**

So Now we will Discuss . . .

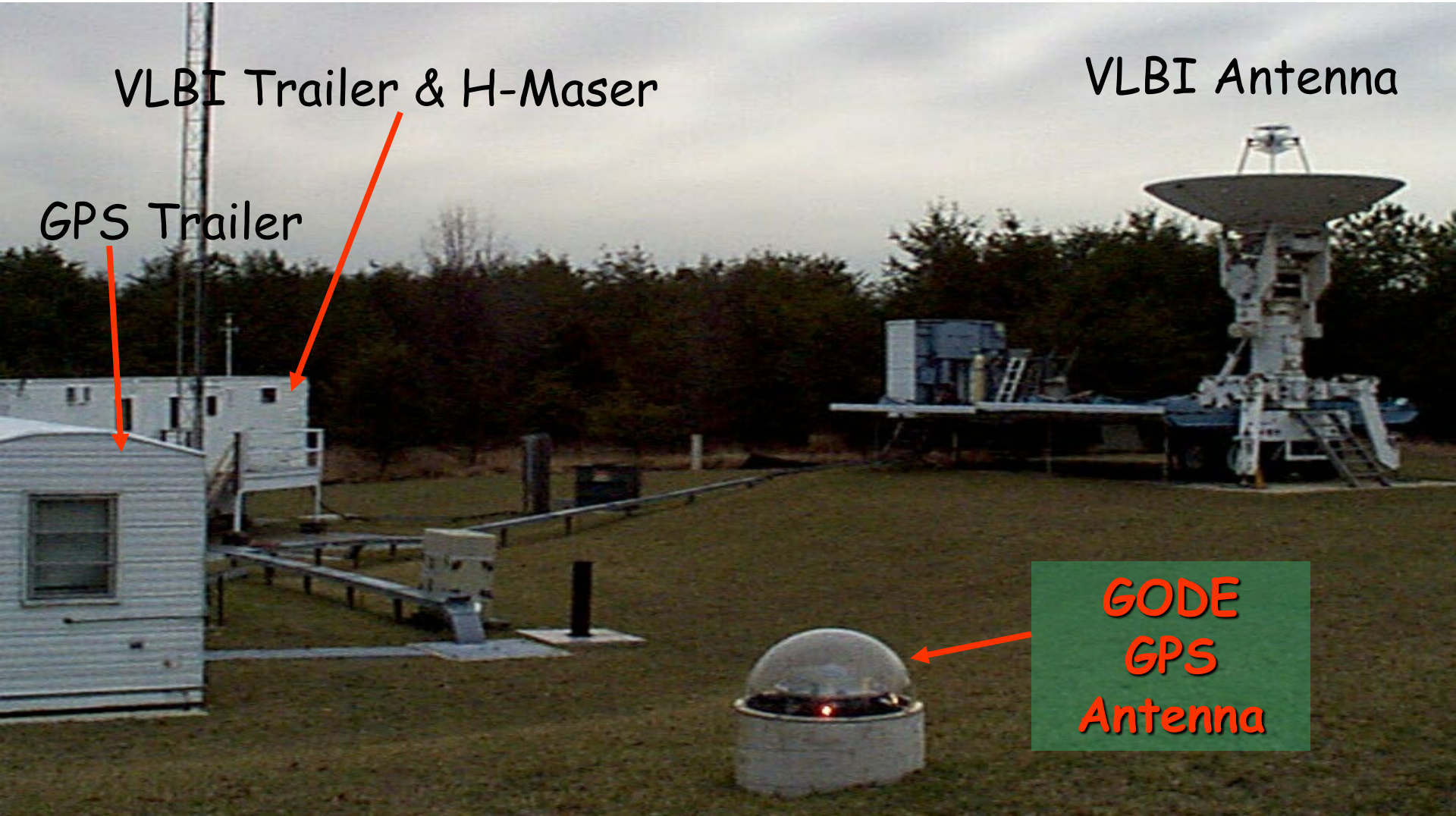
- A discussion of what happened when S/A was turned off.
- Some recent results obtained with prototypes of a new, low cost timing receiver:

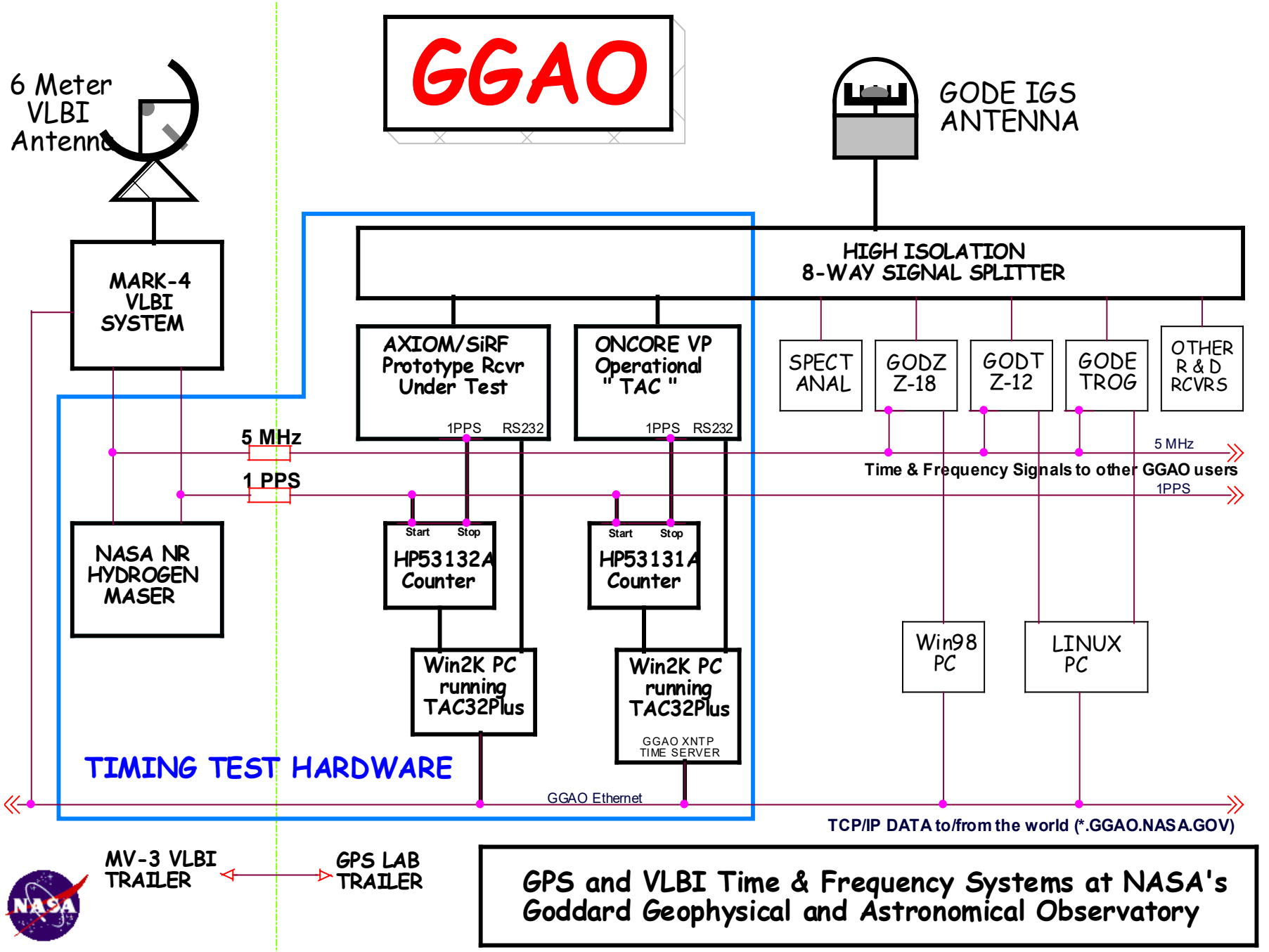
  OEM Chipset: SiRFStar 1

  Receiver Hardware: Axiom Navigation's Sandpiper with Custom Firmware by Reza Abtahi/CNST

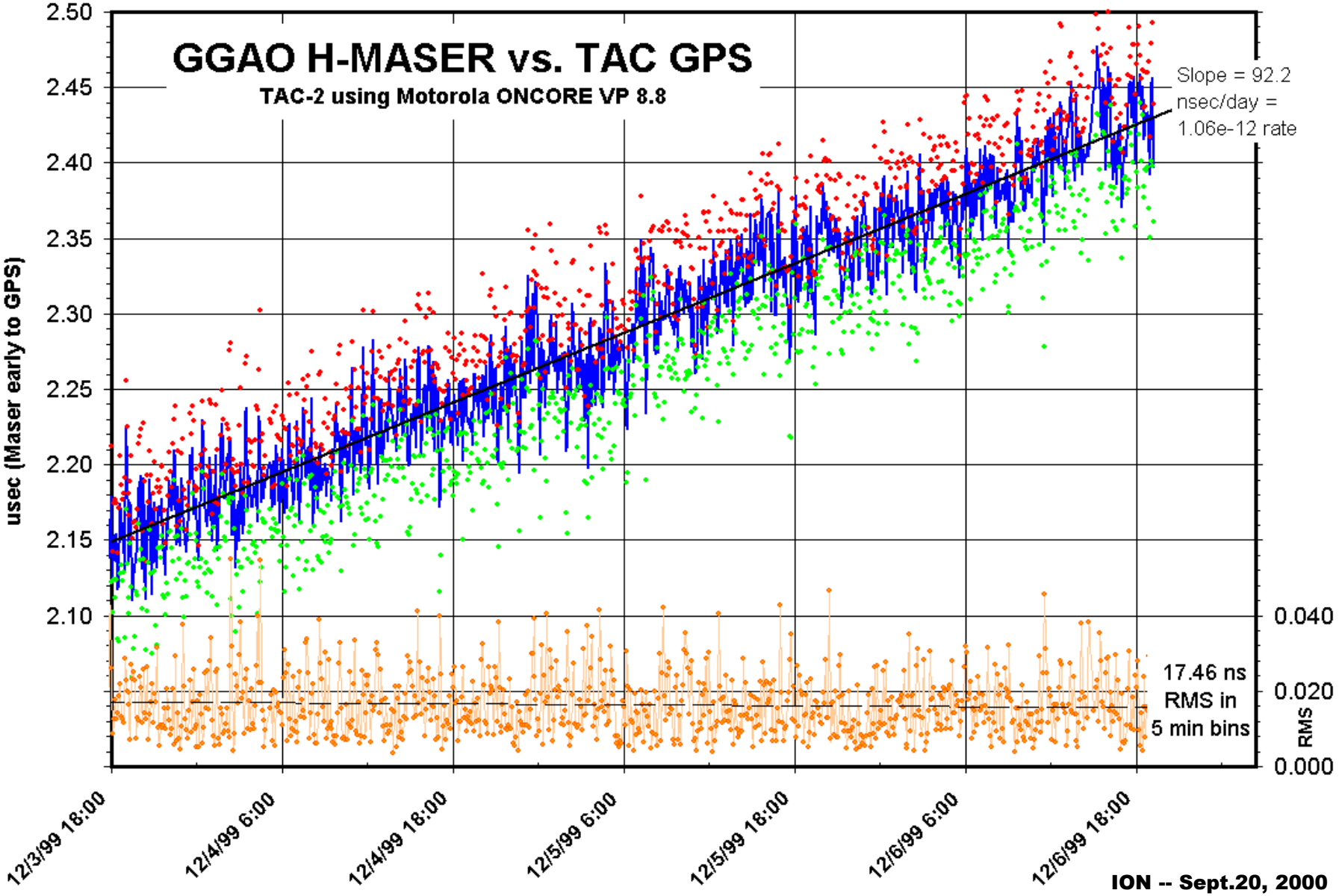
- A comparison of the new SiRF-based receiver with the venerable Motorola VP and UT+ receivers.
- A discussion of the timing accuracy that can be obtained with single-frequency receivers now that S/A is off.

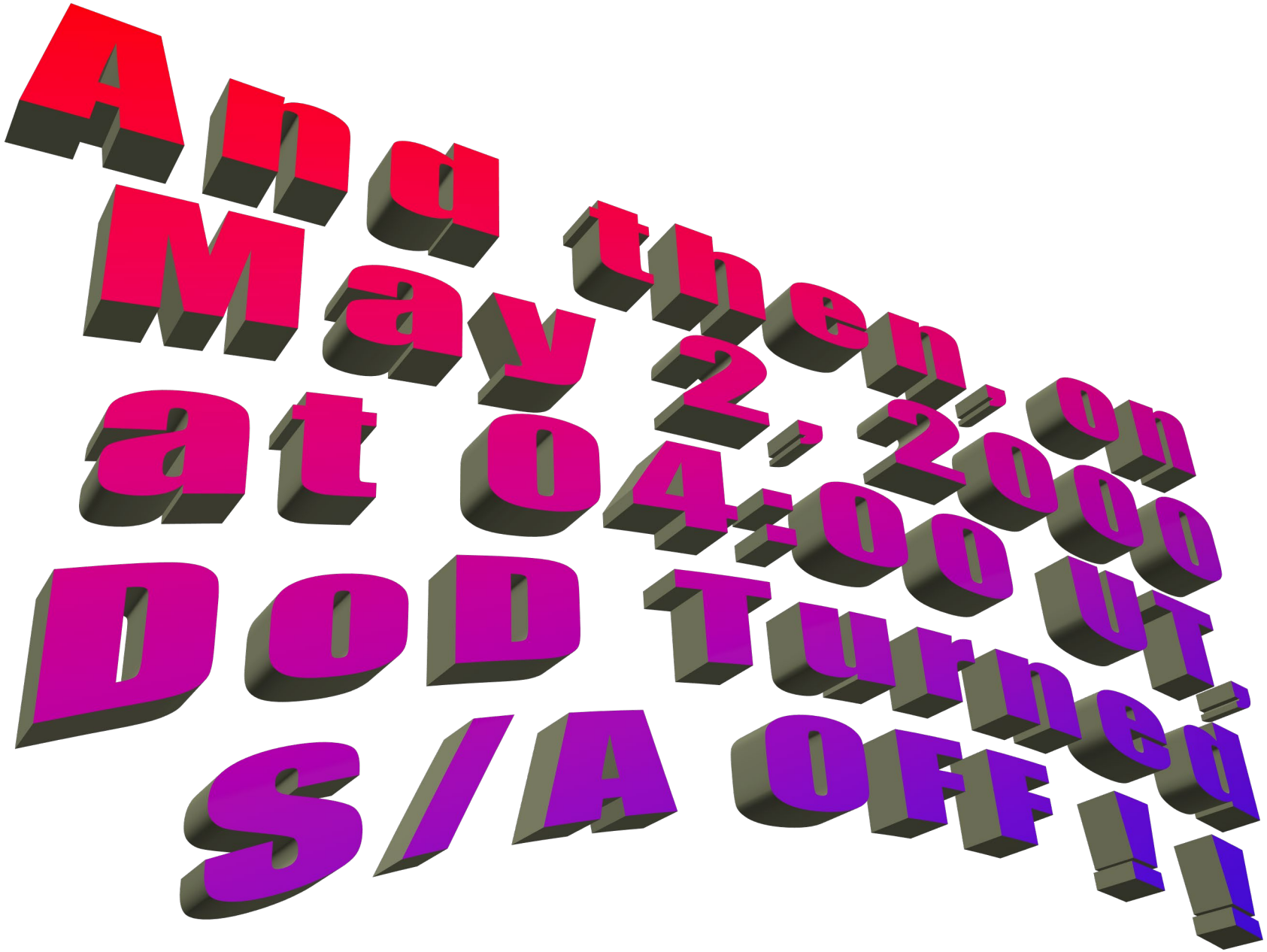
GGAO (Goddard Geophysical & Astronomical Observatory)




GGAO
6 Meter VLBI Antenna
GODE IGS ANTENNA
MARK-4 VLBI SYSTEM
HIGH ISOLATION 8-WAY SIGNAL SPLITTER
AXIOM/SiRF Prototype Rcvr Under Test
1PPS RS232
ONCORE VP Operational " TAC "
1PPS RS232
SPECT ANAL
GODZ Z-18
GODT Z-12
GODE TROG
OTHER R & D RCVRS
5 MHz
1 PPS
5 MHz
Time & Frequency Signals to other GGAO users
1PPS
NASA NR HYDROGEN MASER
Start Stop
HP53132A Counter
Start Stop
HP53131A Counter
Win2K PC running TAC32Plus
Win2K PC running TAC32Plus
GGAO XNTP TIME SERVER
Win98 PC
LINUX PC
TIMING TEST HARDWARE
GGAO Ethernet
TCP/IP DATA to/from the world (*.GGAO.NASA.GOV)
MV-3 VLBI TRAILER
GPS LAB TRAILER
GPS and VLBI Time & Frequency Systems at NASA's Goddard Geophysical and Astronomical Observatory
T.Clark 07 Sept.2000

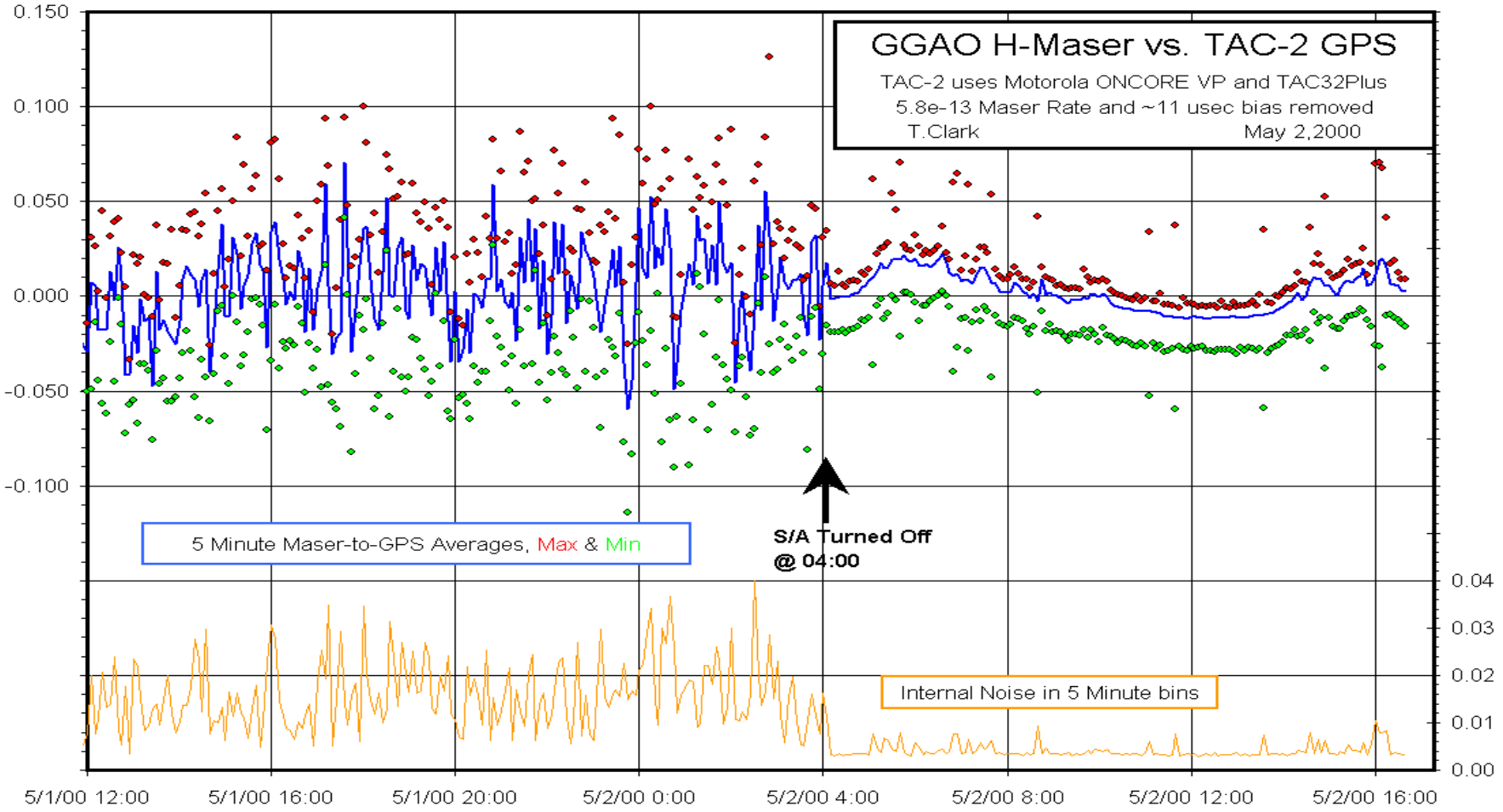
Before S/A was turned off . . .




And then on
May 2, 2000
at 04:00 UT,
DoD Turned
S/A OFF!!

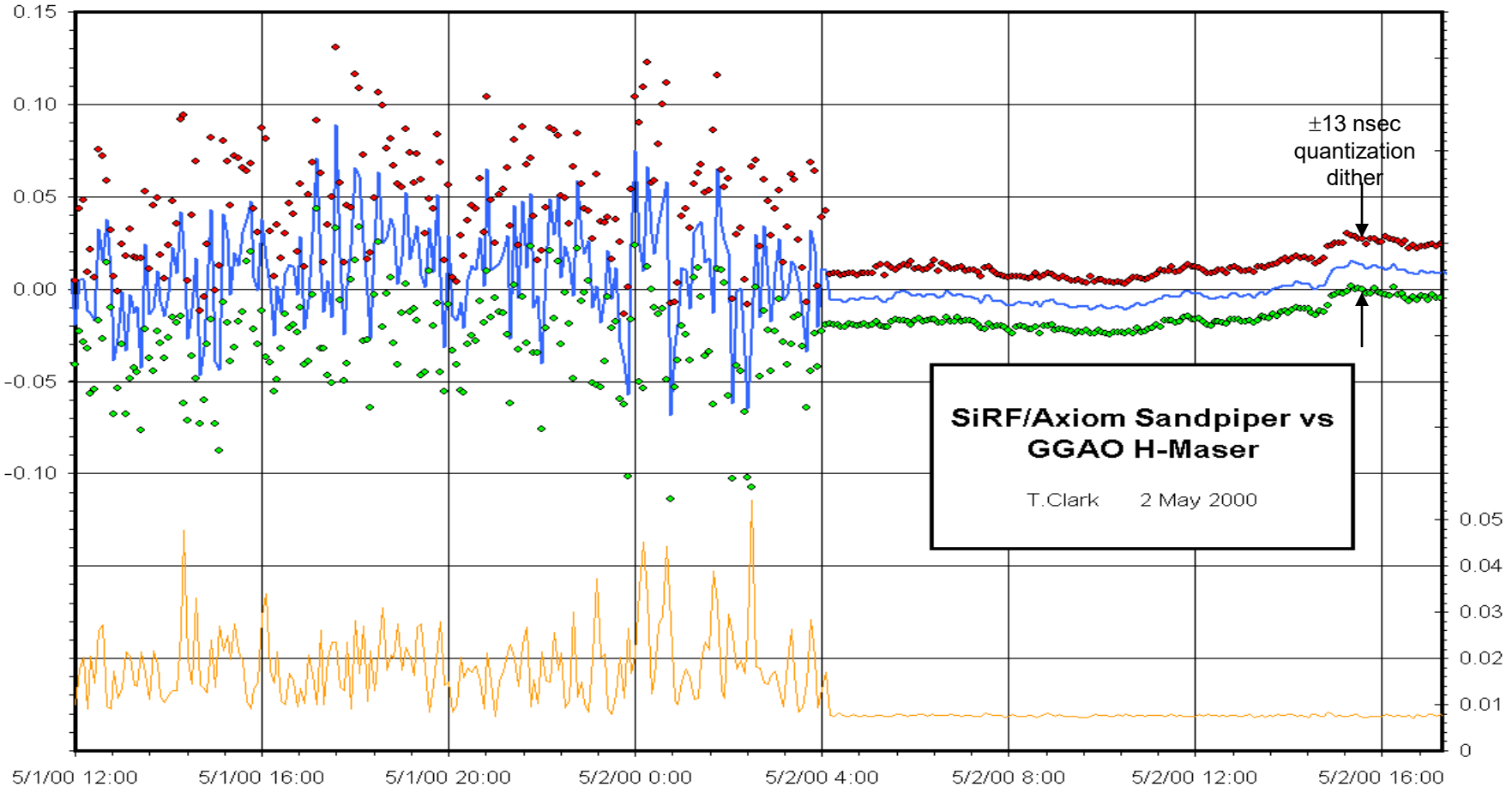
What happened when S/A went away?

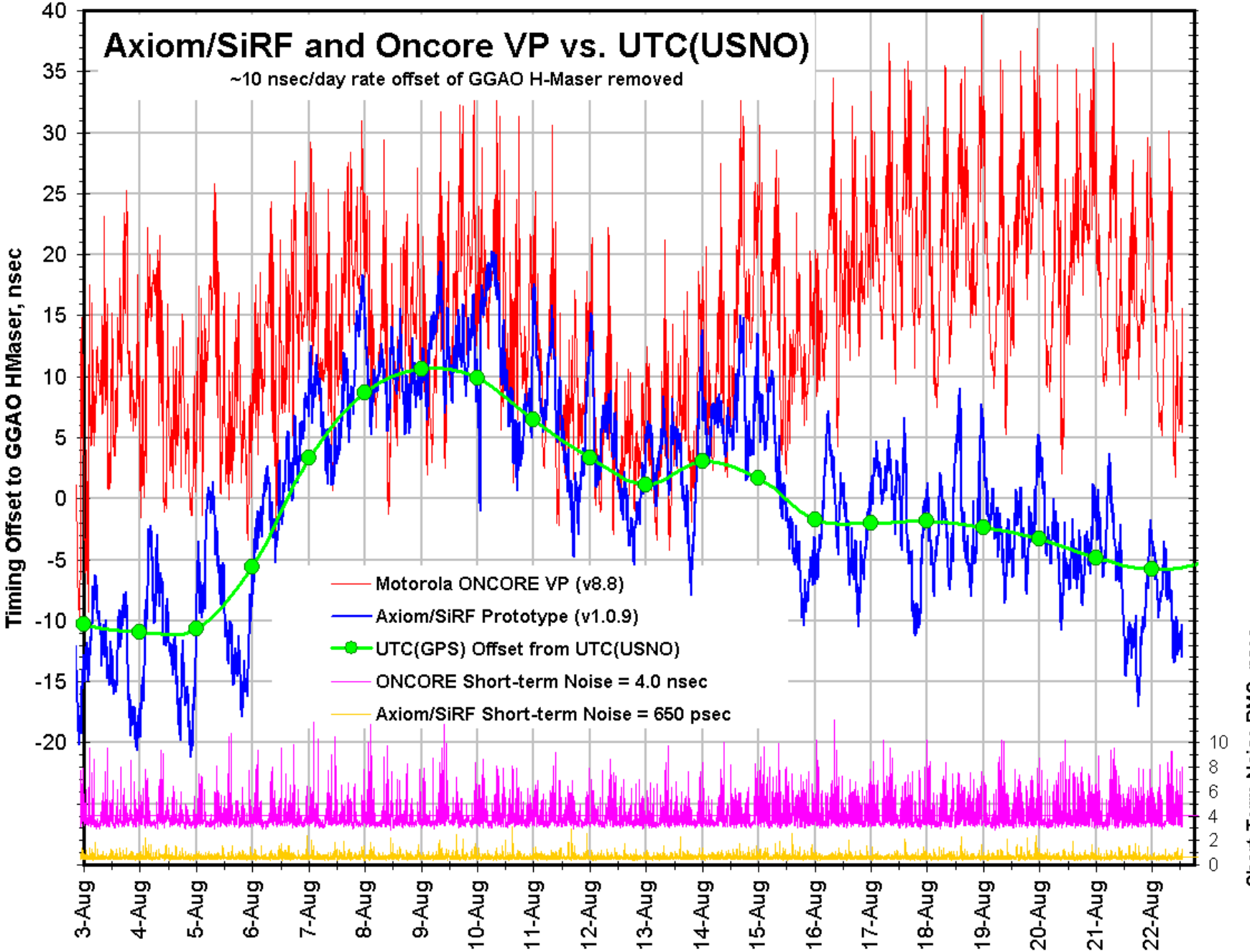
The Motorola ONCORE VP Receiver . . .

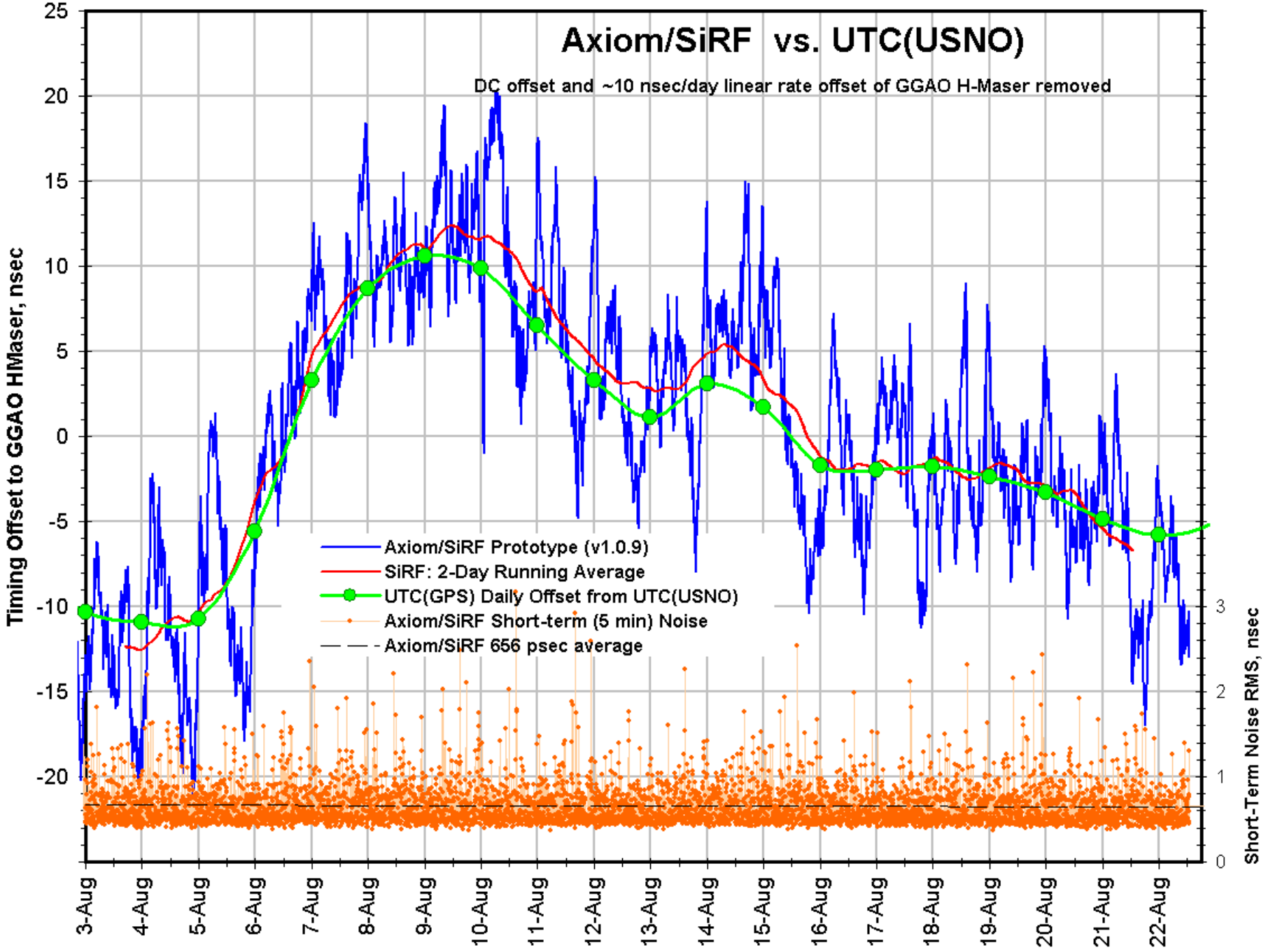


What happened when S/A went away?

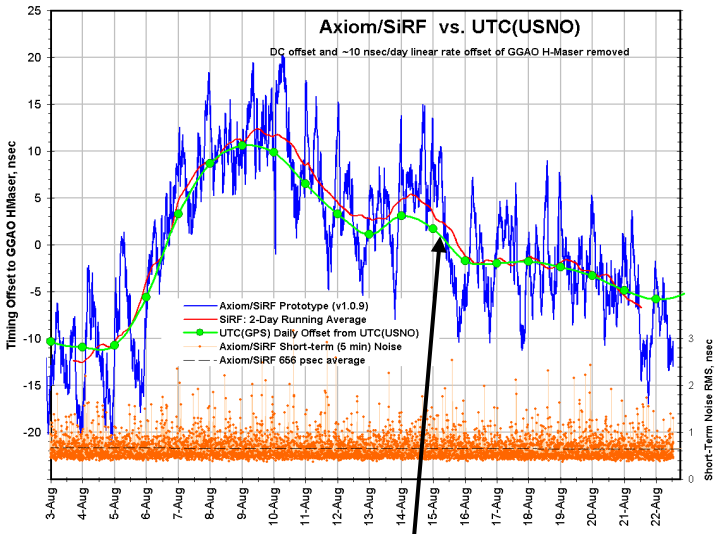
The SiRF/Axiom prototype receiver . . .




Axiom/SiRF and Oncore VP vs. UTC(USNO)
~10 nsec/day rate offset of GGAO H-Maser removed
Timing Offset to GGAO HMaser, nsec
Short-Term Noise RMS, nsec
Motorola ONCORE VP (v8.8)
Axiom/SiRF Prototype (v1.0.9)
UTC(GPS) Offset from UTC(USNO)
ONCORE Short-term Noise = 4.0 nsec
Axiom/SiRF Short-term Noise = 650 psec
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
10
8
6
4
2
0
3-Aug
4-Aug
5-Aug
6-Aug
7-Aug
8-Aug
9-Aug
10-Aug
11-Aug
12-Aug
13-Aug
14-Aug
15-Aug
16-Aug
17-Aug
18-Aug
19-Aug
20-Aug
21-Aug
22-Aug


Axiom/SiRF vs. UTC(USNO)
DC offset and ~10 nsec/day linear rate offset of GGAO H-Maser removed
Timing Offset to GGAO HMaser, nsec
Short-Term Noise RMS, nsec
Axiom/SiRF Prototype (v1.0.9)
SiRF: 2-Day Running Average
UTC(GPS) Daily Offset from UTC(USNO)
Axiom/SiRF Short-term (5 min) Noise
Axiom/SiRF 656 psec average
25
20
15
10
5
0
-5
-10
-15
-20
3
2
1
0
3-Aug
4-Aug
5-Aug
6-Aug
7-Aug
8-Aug
9-Aug
10-Aug
11-Aug
12-Aug
13-Aug
14-Aug
15-Aug
16-Aug
17-Aug
18-Aug
19-Aug
20-Aug
21-Aug
22-Aug

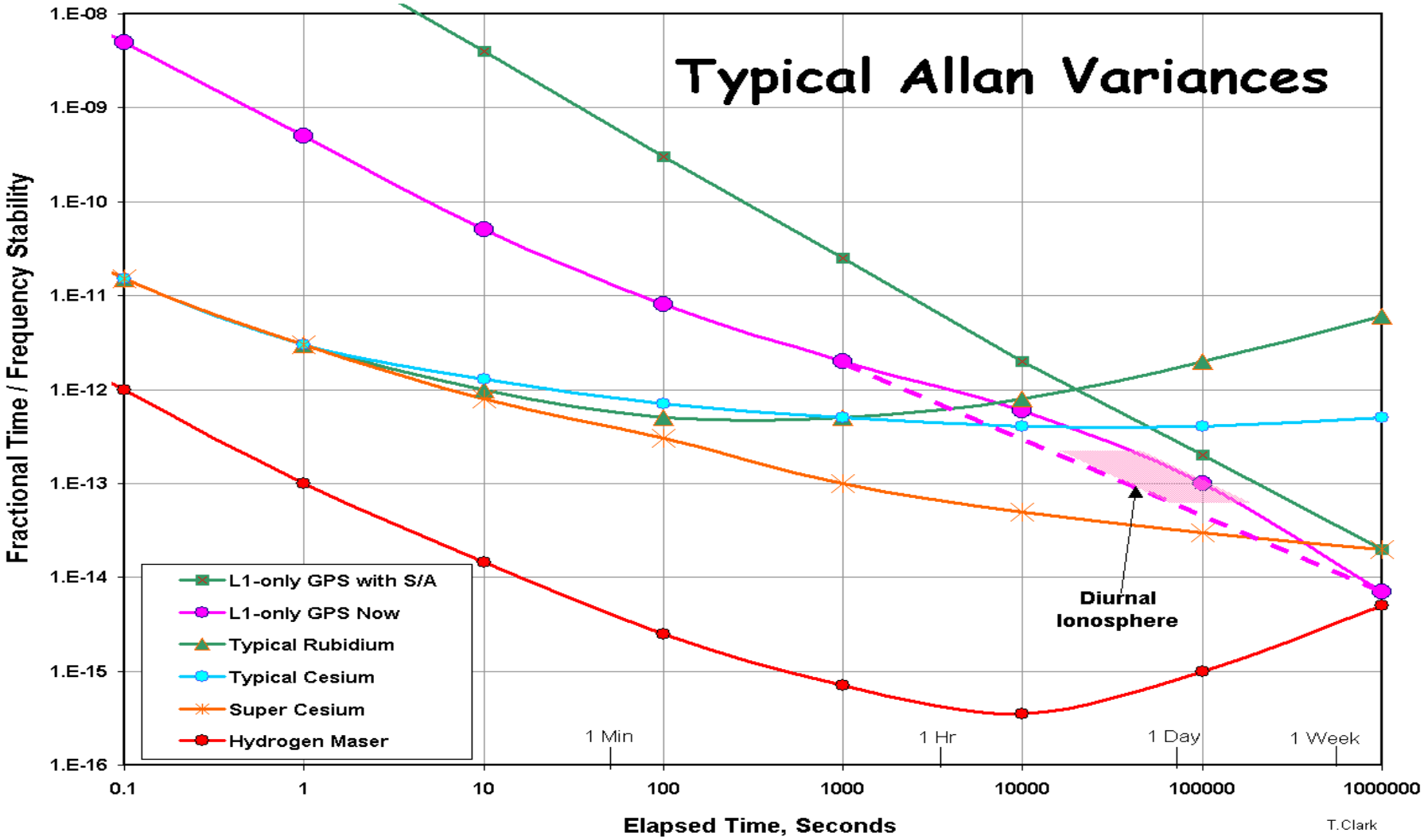
Low-Cost Global Time Synch to <10 nsec . . . The Recipe:



The Green (Daily Offsets from USNO Web Site) and Red (Remote GPS with 2-day smoothing) curves differ by under 3 nsec.

- Use a good receiver (like the SiRF prototype described here).
- Fit an offset rate for local atomic clock, after including the daily GPS Constellation offset value fetched from USNO Web Site.
- Smooth the results for at least 2 days to reduce the ionosphere biases.

Clock Performance --The Bottom Line . . .



Noise, Glitches and Jumps . . .

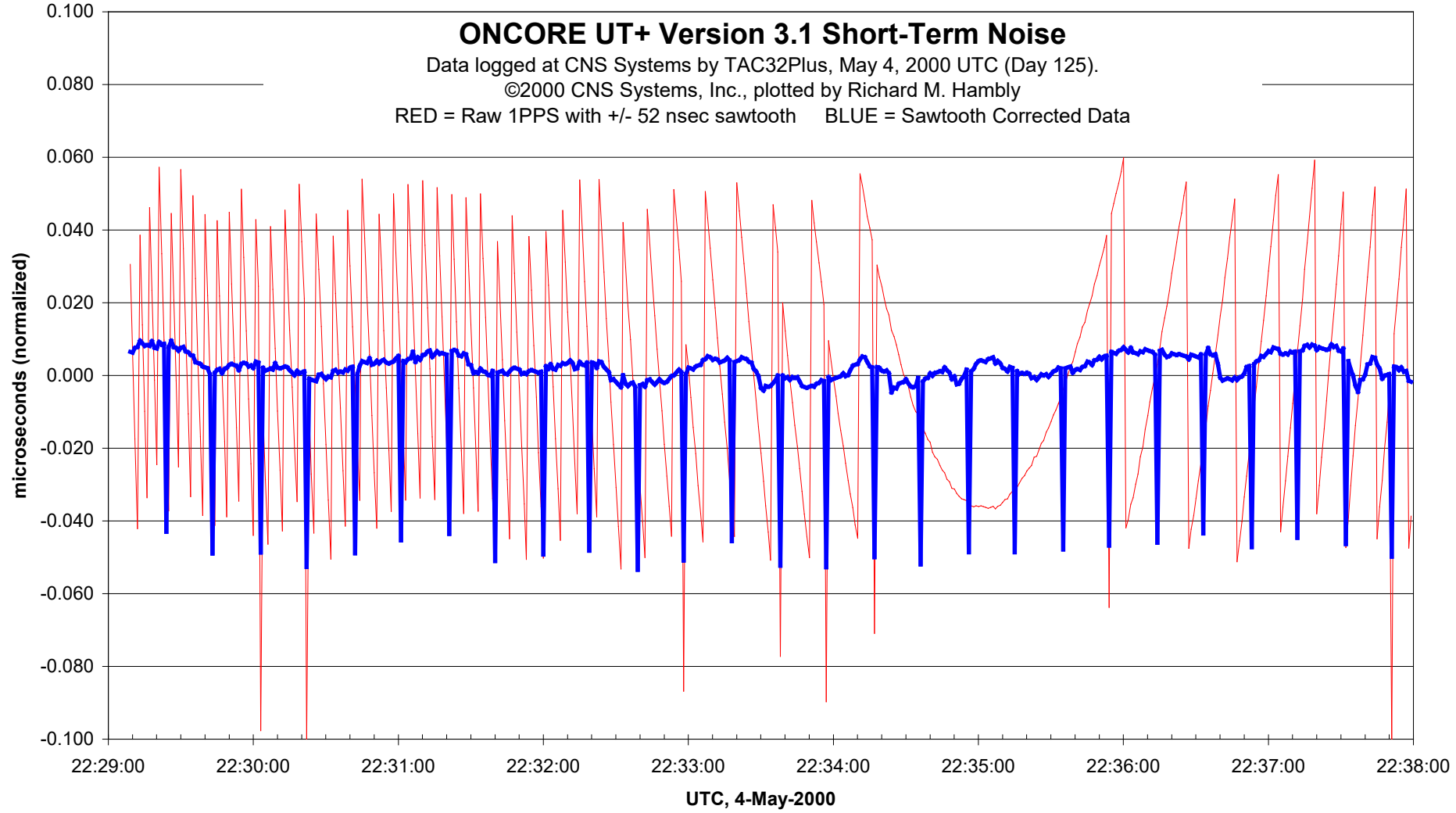
- The 1PPS signals from the ONCORE and Reza Abtahi's SiRF receivers are quantized at times defined by their internal clocks. The 1PPS pulse exhibits a sawtooth "dither" error with a period of 5-10 seconds:

  ONCORE: 9.54 MHz $\Rightarrow \pm 52$ nsec sawtooth

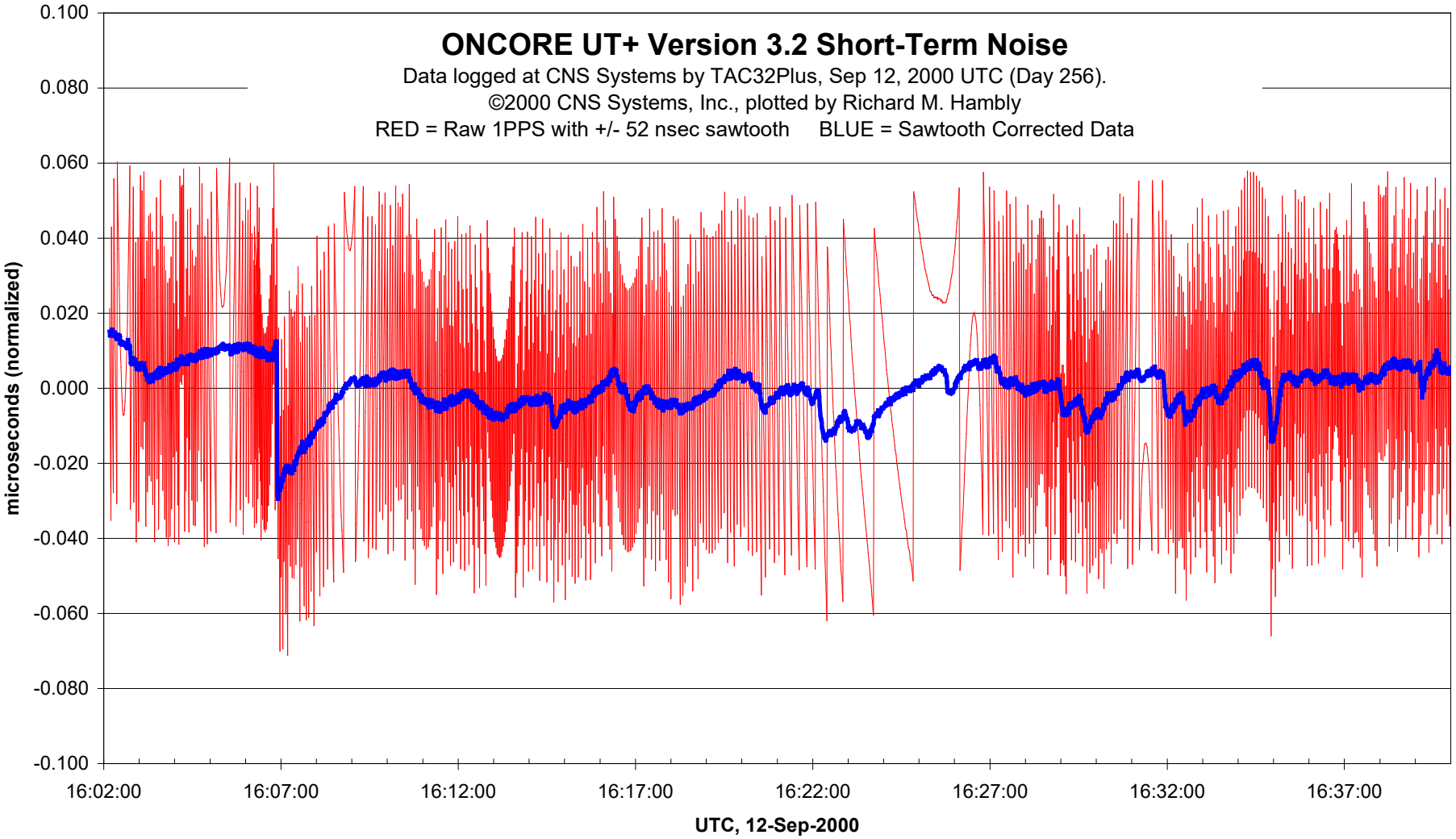
  SiRF: 38.192 MHz $\Rightarrow \pm 13$ nsec sawtooth

- Both receivers report the magnitude of the sawtooth error for the next 1PPS pulse in the serial data stream.
- The TAC32Plus software reads the Time Interval Counter, applies the sawtooth correction, and then logs the data.
- Do the receivers have any errors not included in the sawtooth correction that we now see since S/A has been turned off ? ?

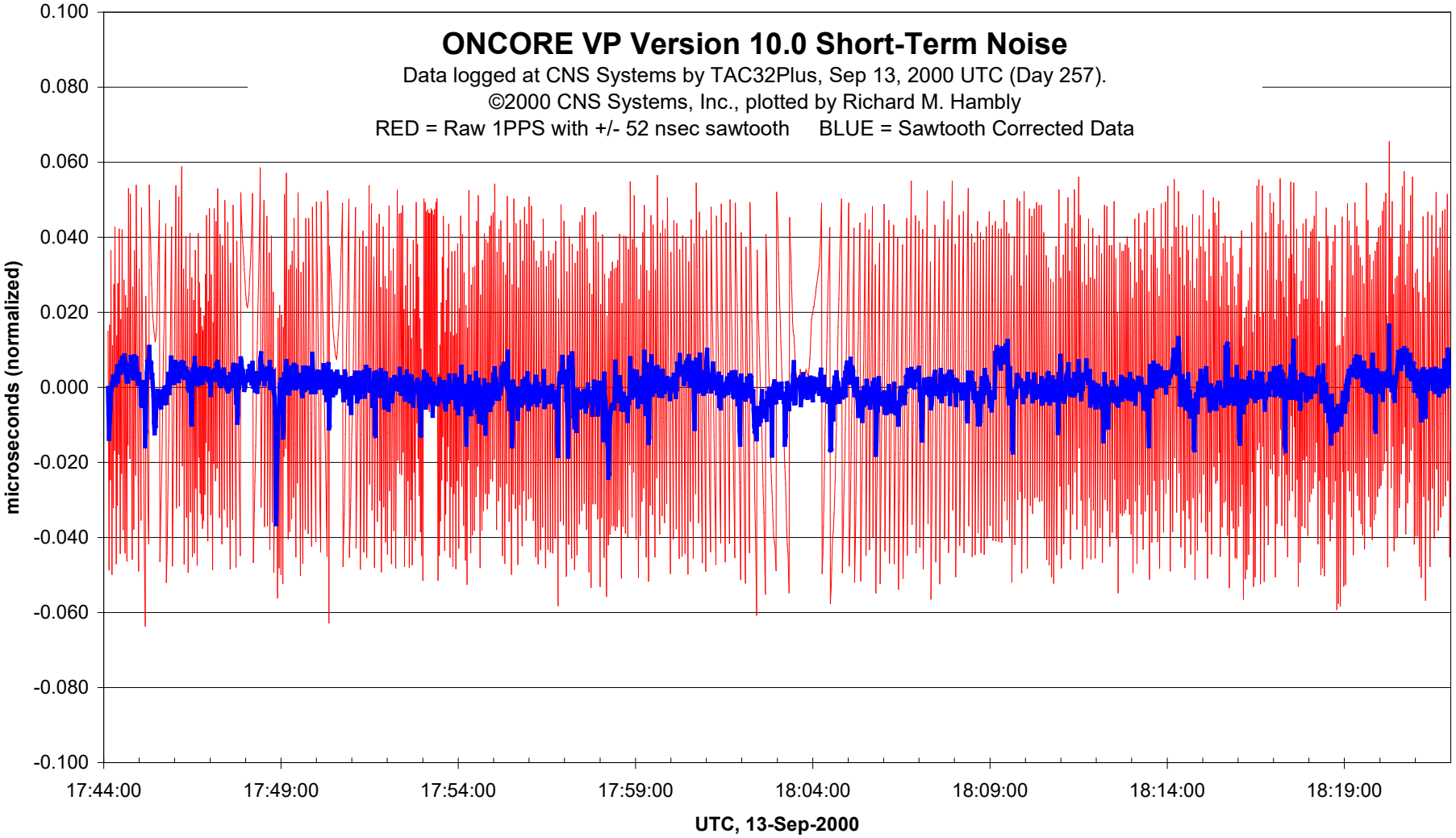
ONCORE UT+ V3.1 Short-Term Noise



ONCORE UT+ V3.2 Short-Term Noise



ONCORE VP V10.0 Short-Term Noise



SiRF/Axiom/CNST V1.0.8 Short-Term Noise