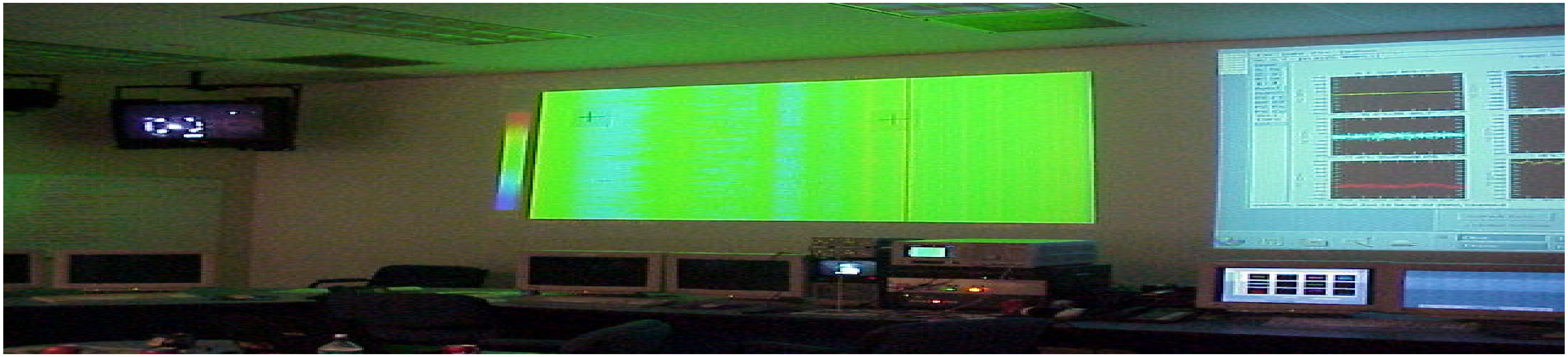
Laser Interferometer Gravitational-Wave Observatory (LIGO)

E7 status overview



Elba, 2002

Szabolcs Márka for the LIGO Collaboration

May, 2002

LIGO-G020257-00-D

The First Two Engineering Runs at LHO

3 – 4 April 2000   and   8 – 15 November 2000

E1

• One arm run at LHO

• Only at LHO

• The first of a series where the later episodes are just getting better and better…

• Good PEM results

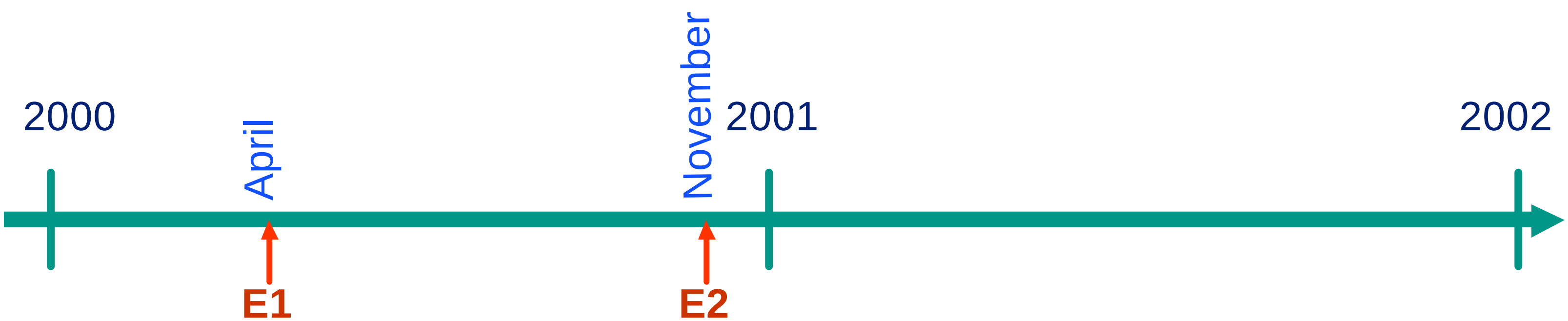
E2

• Recombined interferometer with Fabry-Perot arm cavities at LHO

• Excellent PEM results

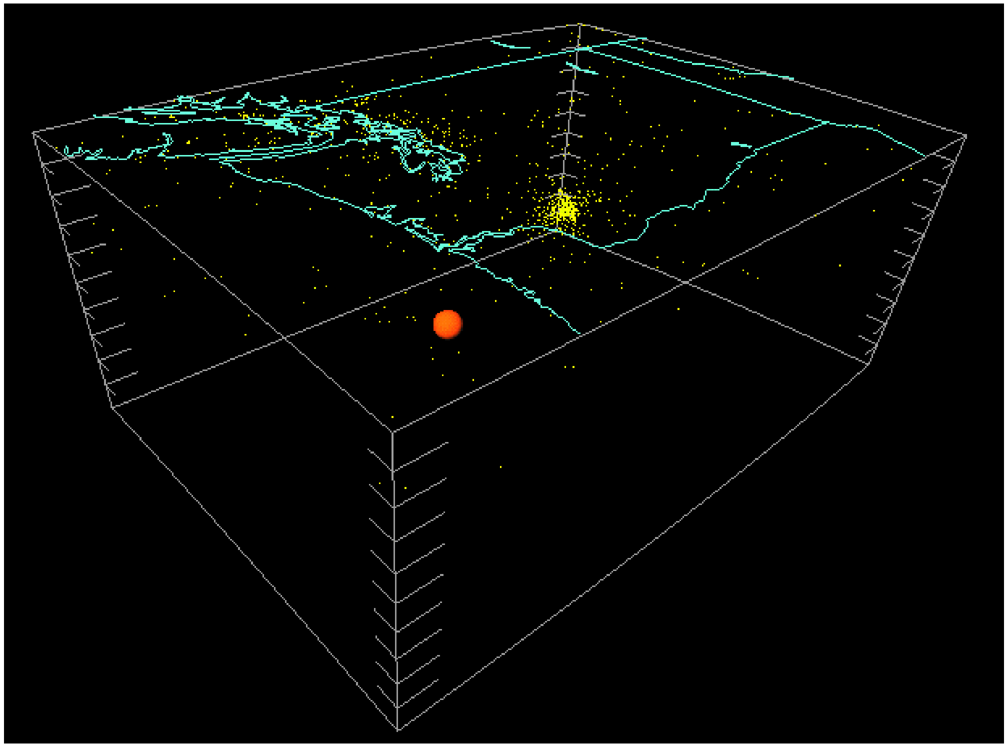
• Sets the standards for the Engineering Runs

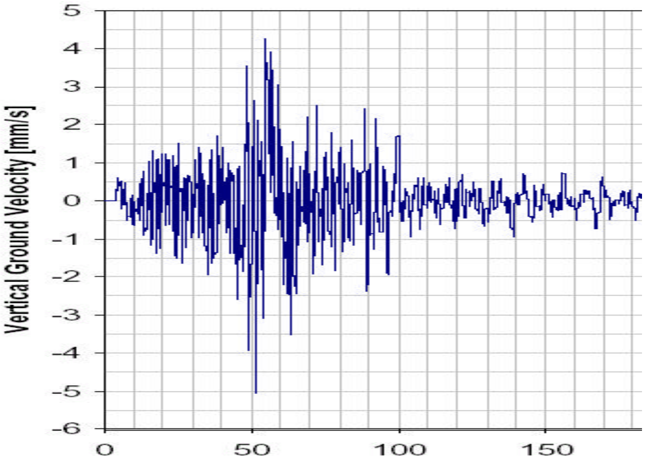
• More than 15 investigations !



February 28, 2001 10:55am PST
The Nisqually Earthquake

Magnitude:	**6.8**
Location:	**20km NE of Olympia, Washington**
	47.2 N 122.7 W
Depth:	**52 km**

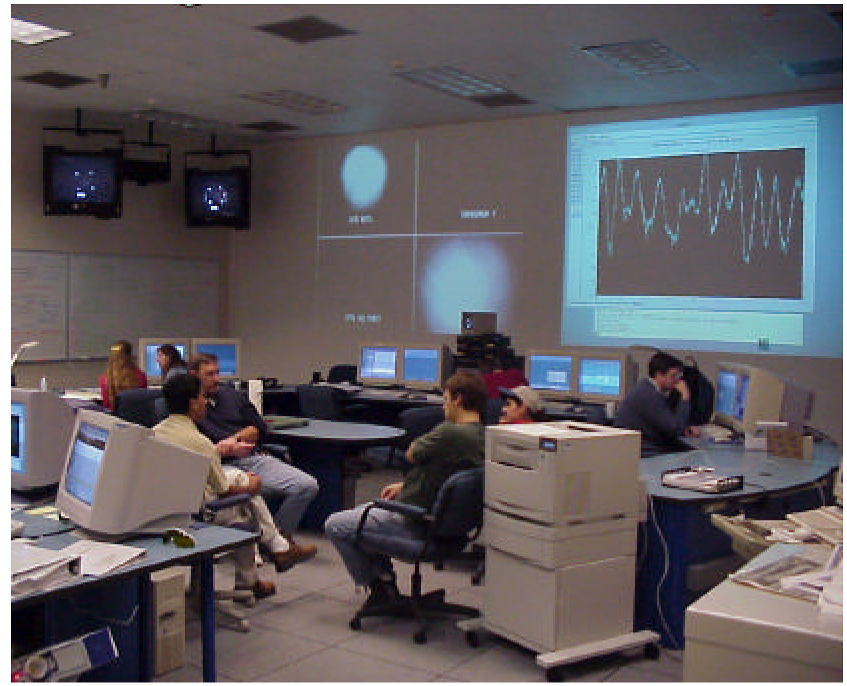


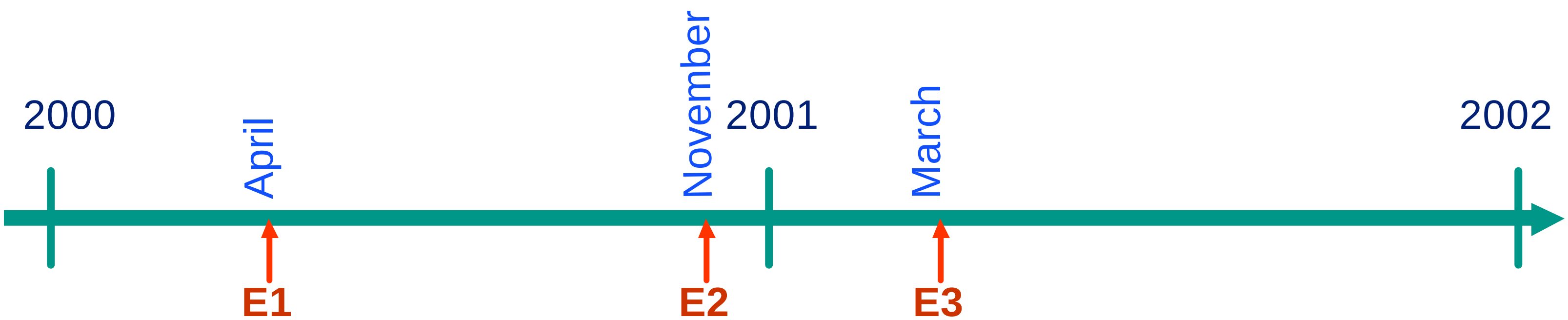


The Third Engineering Run at LXO

March 9-12

- First joint engineering run between LIGO sites
  - » **X-arm locked for LLO**
  - » **PEM for LHO**
- Principal goals:
  - » **High up time**
  - » **High overlap time for PEM**
  - » **Get experience with the detector**

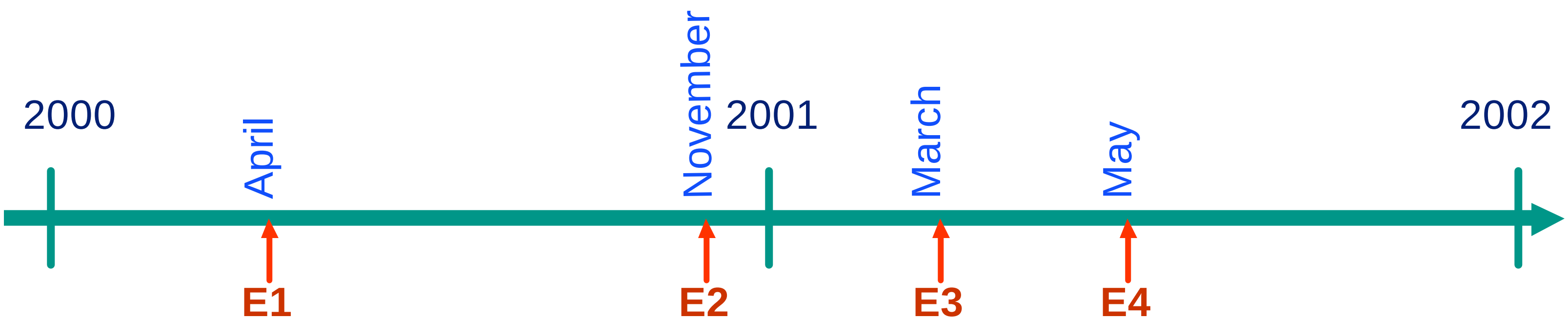




The Fourth Engineering Run at LXO

May 11-14

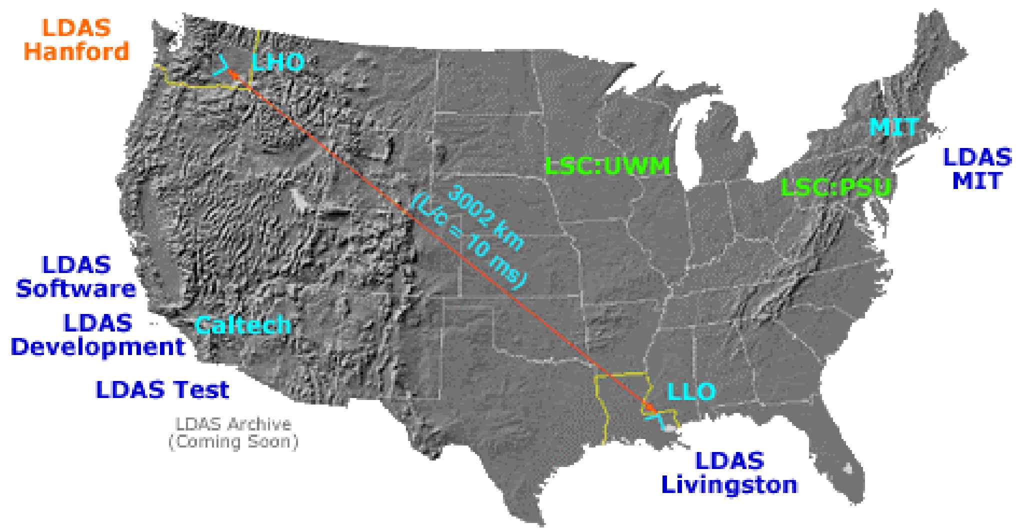
- Joint engineering run of LIGO sites
  - » **Recombined Fabry-Perot configuration for LLO**
  - » **PEM for LHO**
- Principal objectives:
  - » **Maintain lock for extended periods**
  - » **Collect data for PEM site correlations**
  - » **Access and learning opportunity for LSC**
  - » **Record data for investigations**
  - » **Hone our skills, identify bottle necks**

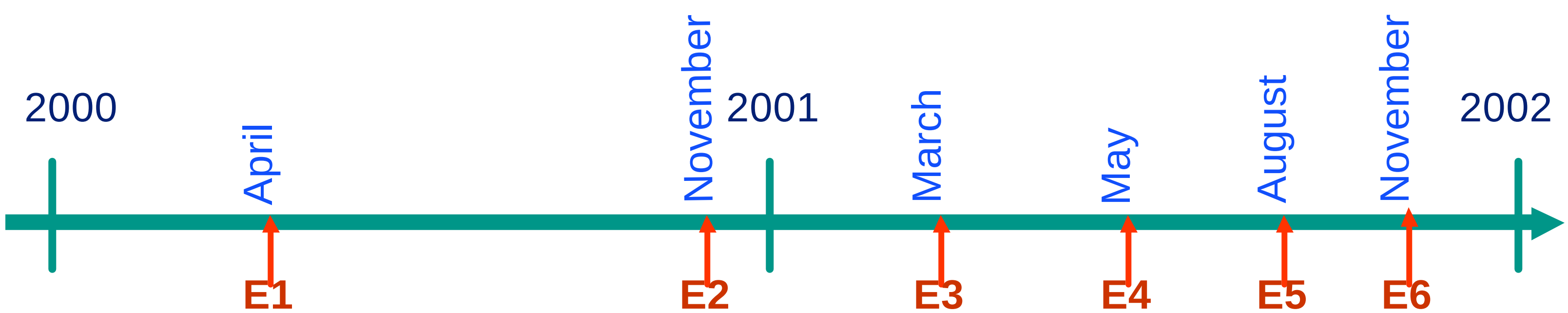


The Fifth and Sixth Engineering Run at LXO

August 3-6, 2001 and November 16-19, 2001

- Coordination among
  - 2 interferometric detectors
    - •LHO 2km
    - •LLO 4km

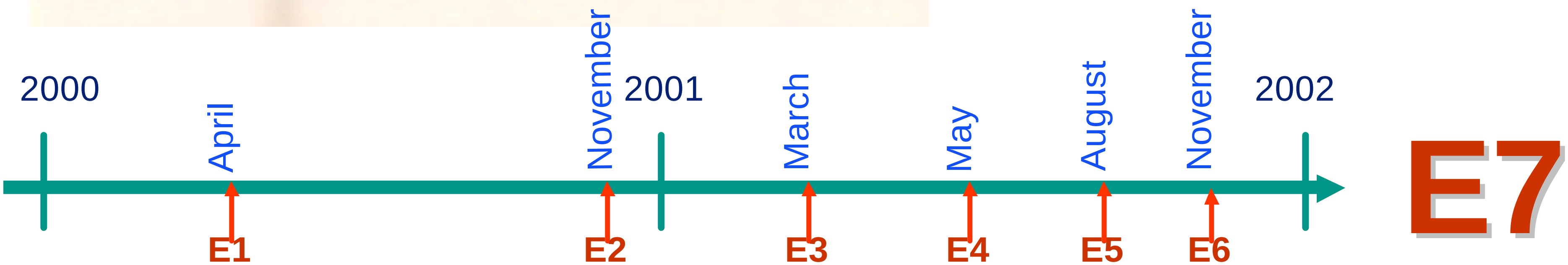




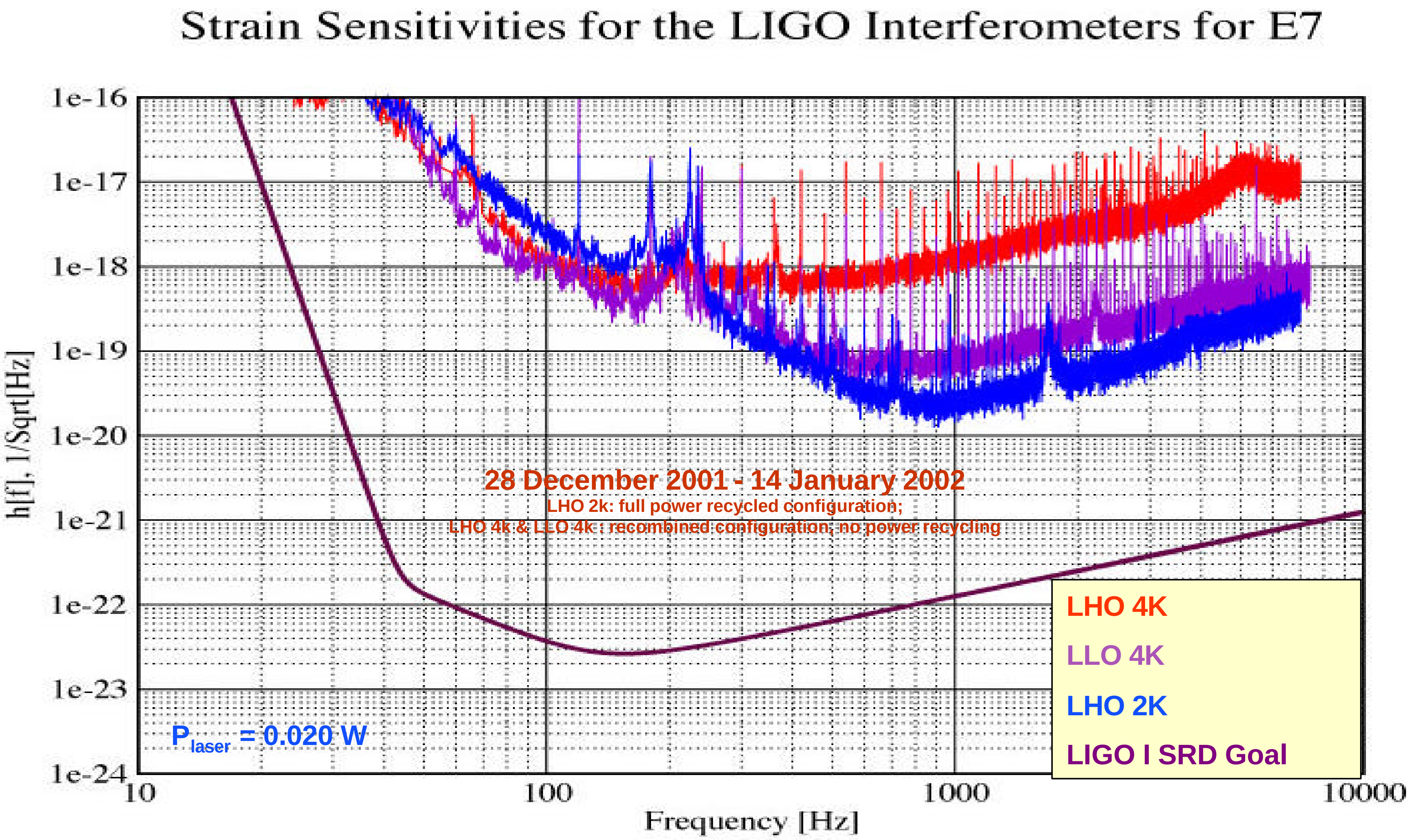
First Time :

International Network of Gravity Wave Detectors of various kind…

- Coordination among
  - 4 interferometric detectors
    - LHO 2km, Power recycled
    - LHO 4km, Recombined
    - LLO 4km, Recombined
    - GEO-600
  - A cryogenic bar detector
    - ALLEGRO



E7: Calibrated sensitivity



E7: DAQ and data

- The data acquisition system continuously sampled data on
  - » 6544 channels in Hanford
  - » 1348 channels in Livingston.
- Each channel was sampled at a rate between
  - » 16 Hz and16 kHz
- The data rate was
  - » 4.7 MB/s at Hanford
  - » 2.7 MB/s at Livingston.
- The acquired data were stored on local disk caches of
  - » 8.5 TB at Hanford
  - » 4.8 TB at Livingston
- The raw available for online data analysis.
- Also archived at the Caltech Center for Advanced Computing Research.

Courtesy of J. Zweizig

E7: Analysis is strongly going on at every front…

- **Burst searches**
  - » Externally triggered search
  - » Excess power detector
  - » Slope detector
  - » Time-Frequency cluster analysis
- **Inspiral searches**
  - » Conventional optimal Wiener filtering with chirp templates
  - » Fast Chirp Transform (FCT)
- **Periodic source searches**
  - » All sky unbiased
  - » Known pulsar
  - » Wide area search
- **Stochastic searches**
  - » Cross correlating the signal from the Hanford + Livingston IFOs
  - » Correlate LLO with ALLEGRO bar detector
    - – ALLEGRO was rotated into 3 different positions during E7 !

E7: Data Analysis

- Preliminary analysis of E7 data by LDAS at the sites.
  - Four symmetric multi-processor (SMP) servers
  - set of 16 Linux PCs forming a so-called Beowulf cluster
- Data segment and DMT trigger info ingested into the on-site relational databases
- The four data analysis working groups prepared 8 different search strategies, including
  - matched filter techniques using known templates and fast chirp transformation for inspirals
  - excess power, a signal slope and time-frequency clustering algorithm for burst detection
  - algorithm for correlating the stochastic background between the LIGO and ALLEGRO
  - algorithm for the continuous wave search.
- The data of all locked segments was run through one or more of these eight search strategies.
  - Close to 114,000 individual jobs were processed
  - ~95% completed successfully without generating an error condition.
  - Three quarters of the jobs were performing astrophysical and detector characterization tasks.
  - The remaining quarter were database and trigger related
  - These jobs generated a staggering 7M candidate events, inserted back into the database.
  - New thresholds and veto conditions are needed to reduce this number significantly.

Courtesy of K. Blackburn

E7: Timing
The Y2002 Surprise

- The TrueTime GPS bug hit us at New Year's Eve
  - » We set up new timeservers at both observatories
  - » These temporary servers were running until the end of E7
  - » Some data loss due to frame builder problems
- Fermilab experienced similar problems
- ALLEGRO, GEO and TAMA did not report any problems

TRUETIME

3750 Westwind Boulevard
Santa Rosa, California 95403

t 707.528.1230
f 707.527.6640
w www.truetime.com

Only ~10 product lines…

2002 Rollover Anomaly Bulletin #1 - January 2, 2002, 1:00 pm

Some TrueTime products have been affected by an anomaly that appeared following the January 1, 2002 date rollover. The symptom manifests itself by showing the date to be August 16, 2021 (as of January 1, 2002). The problem appears to be with an incorrect GPS epoch being reported. As of this date, we believe that the TIME of DAY is unaffected by this anomaly.

TrueTime is aggressively pursuing solutions to this problem and will continue to update all

E7: Lock Statistics 1

Courtesy G. Gonzalez, M. Hewiston and A. Lazzarini

Total Locked Times for Individual Interferometers

	All segments	*Long segments* *
L1 locked	284hrs (71%)	249hrs (62%)
L1 clean	265hrs (61%)	231hrs (57%)
H1 locked	294hrs (72%)	231hrs (57%)
H1 clean	267hrs (62%)	206hrs (48%)
H2 locked	214hrs (53%)	157hrs (39%)
H2 clean	162hrs (38%)	125hrs (28%)

The longest clean locked segment is:

- 3:58 hours for LIGO Livingston 4K (L1)
- 4:04 hours for LIGO Hanford 4K (H1)
- 7:24 hours for LIGO Hanford 2K (H2)

*Only segments longer than 15 minutes were considered.

Run duration:

28 Dec 2001 - 14 Jan 2002

~ 402 hours *(~ 306 "quiet" hours)*

Coincidence Statistics

	All segments	*Long segments* *
Double coincidence (H2, L1)		
locked	160hrs (39%)	99hrs (24%)
clean	113hrs (26%)	70hrs (16%)

H2,L1 longest coincident clean segment: 1:50

Triple coincidence (L1+H1+ H2)		
locked	140hrs (35%)	72hrs (18%)
clean	93hrs (21%)	46hrs (11%)

L1+H1+ H2 : longest clean segment: 1:18

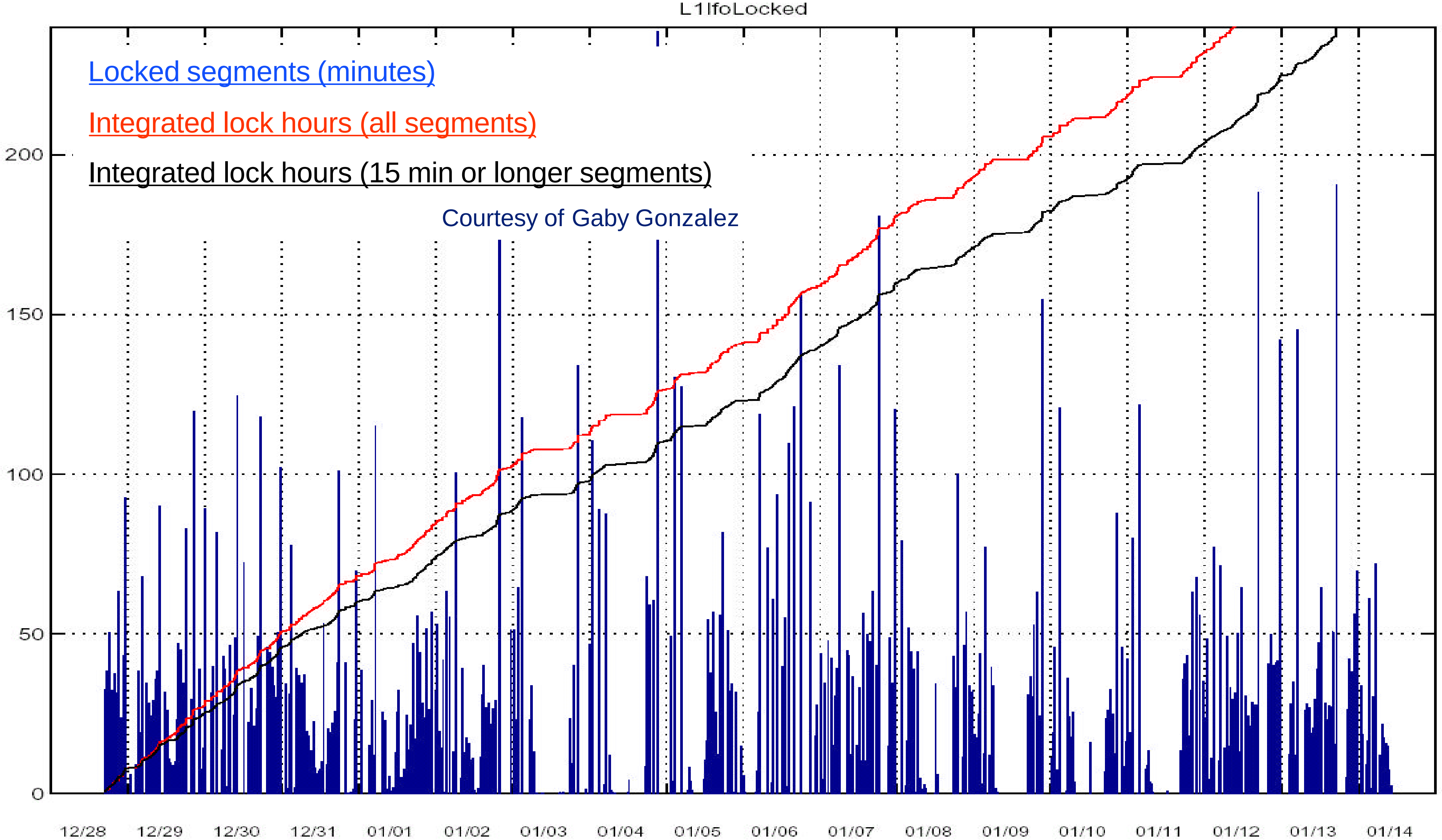
Quadruple coincidence (L1+H1+ H2 +GEO)

locked	77 hrs (23 %)	26.1 hrs (7.81 %)

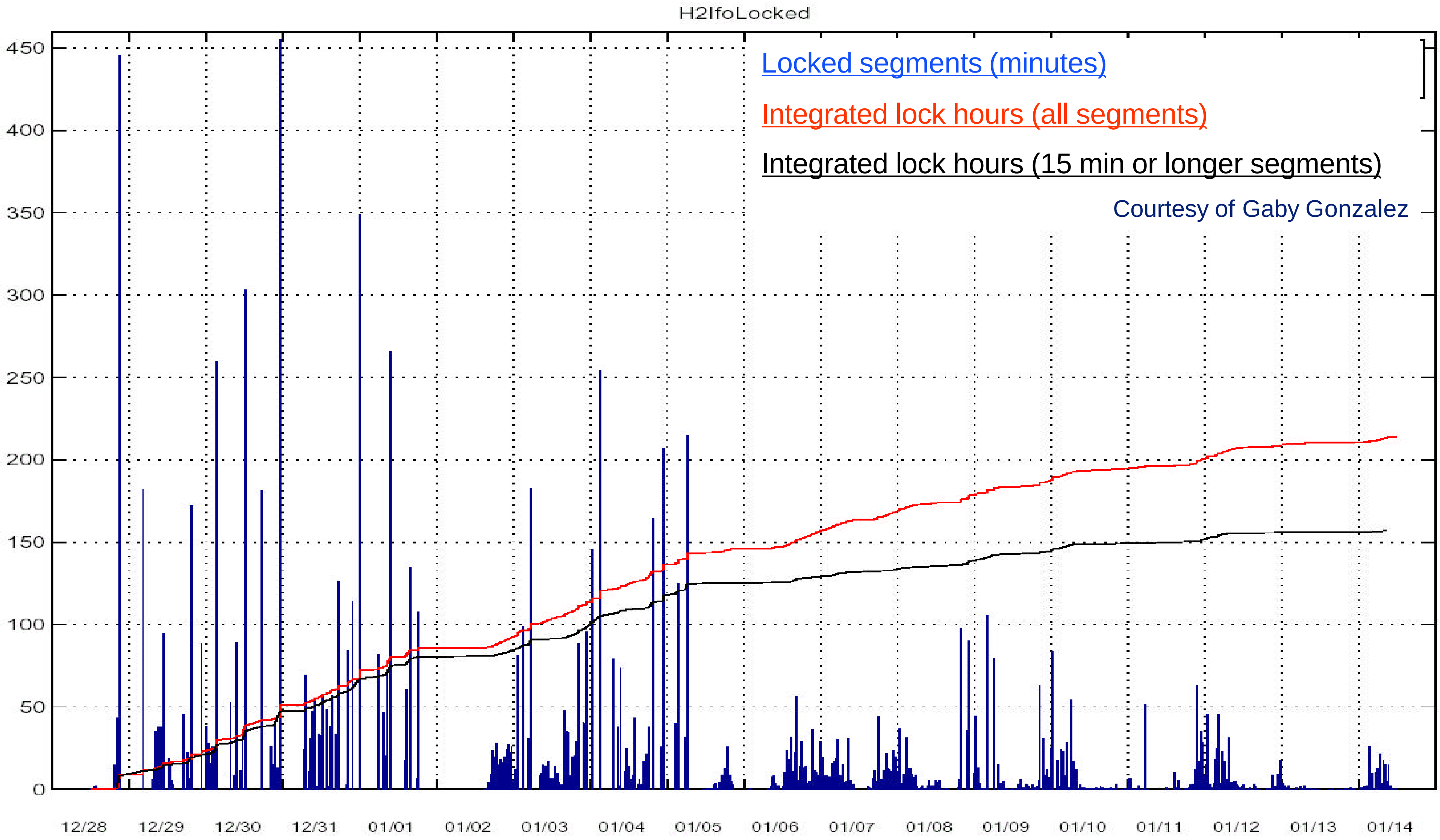
Quintuple coincidence *(L1+H1+ H2 +GEO+ALLEGRO)*

Sorry no data yet…

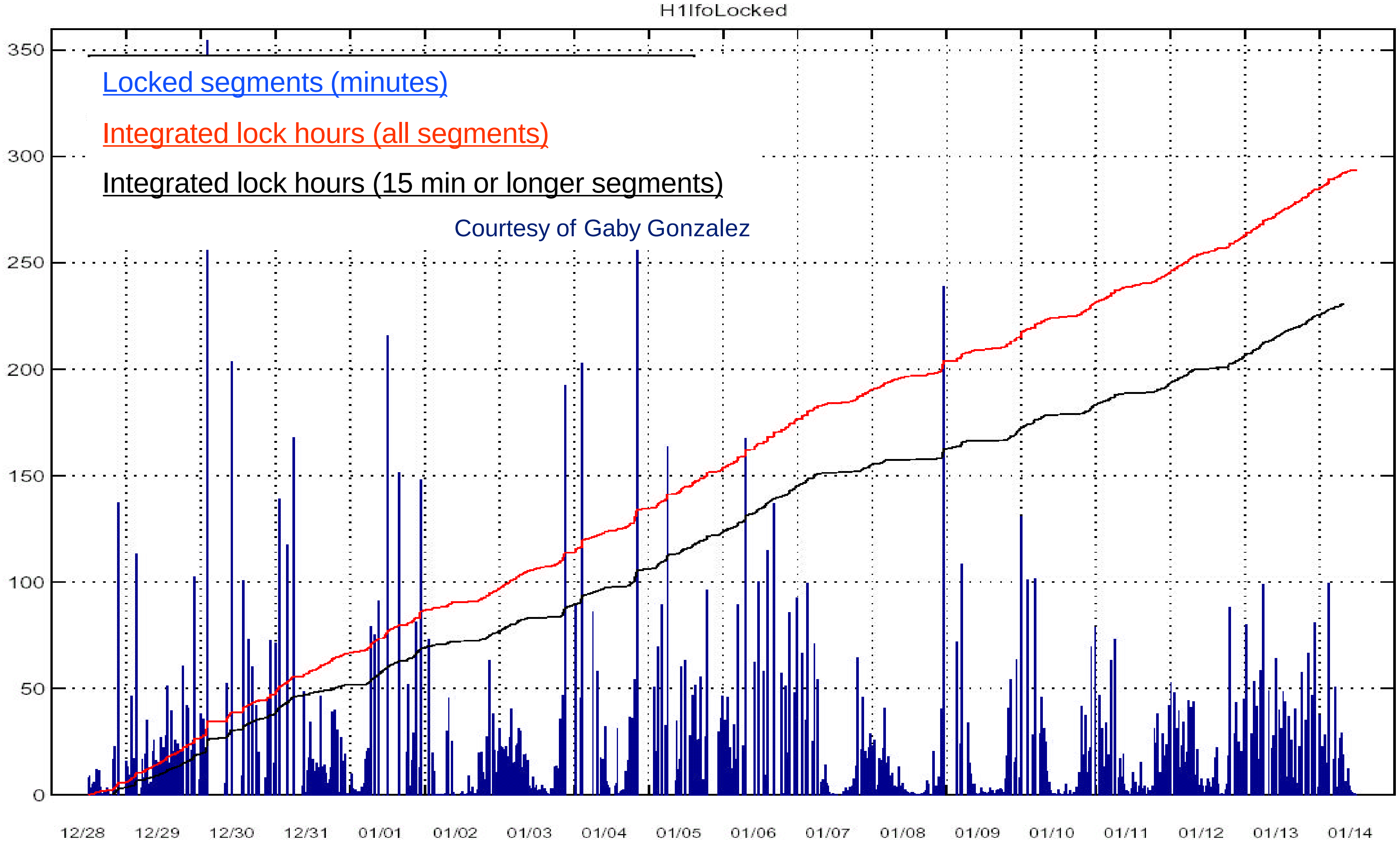
E7: LLO 4K lock history



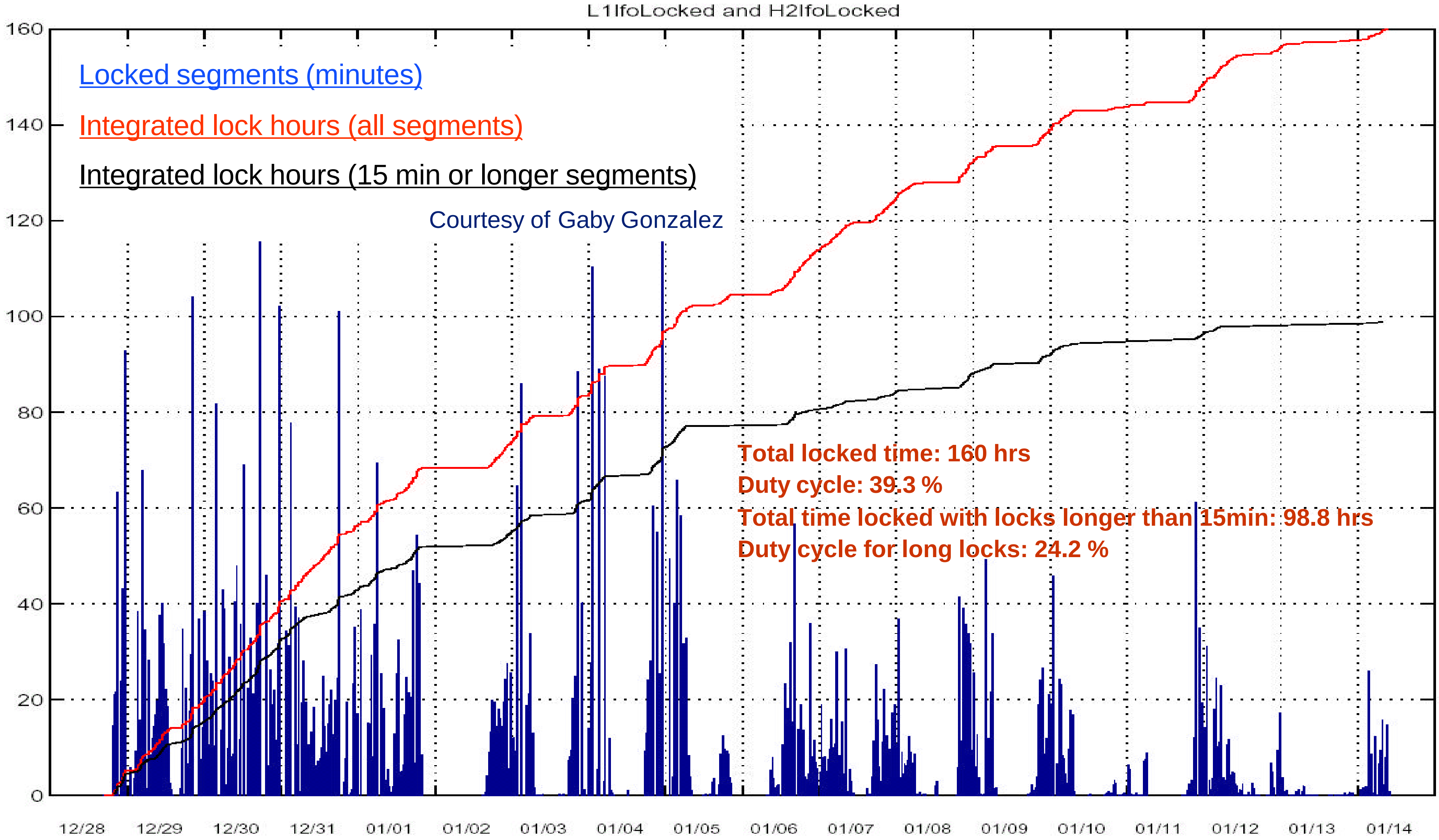
E7: LHO 2K lock history



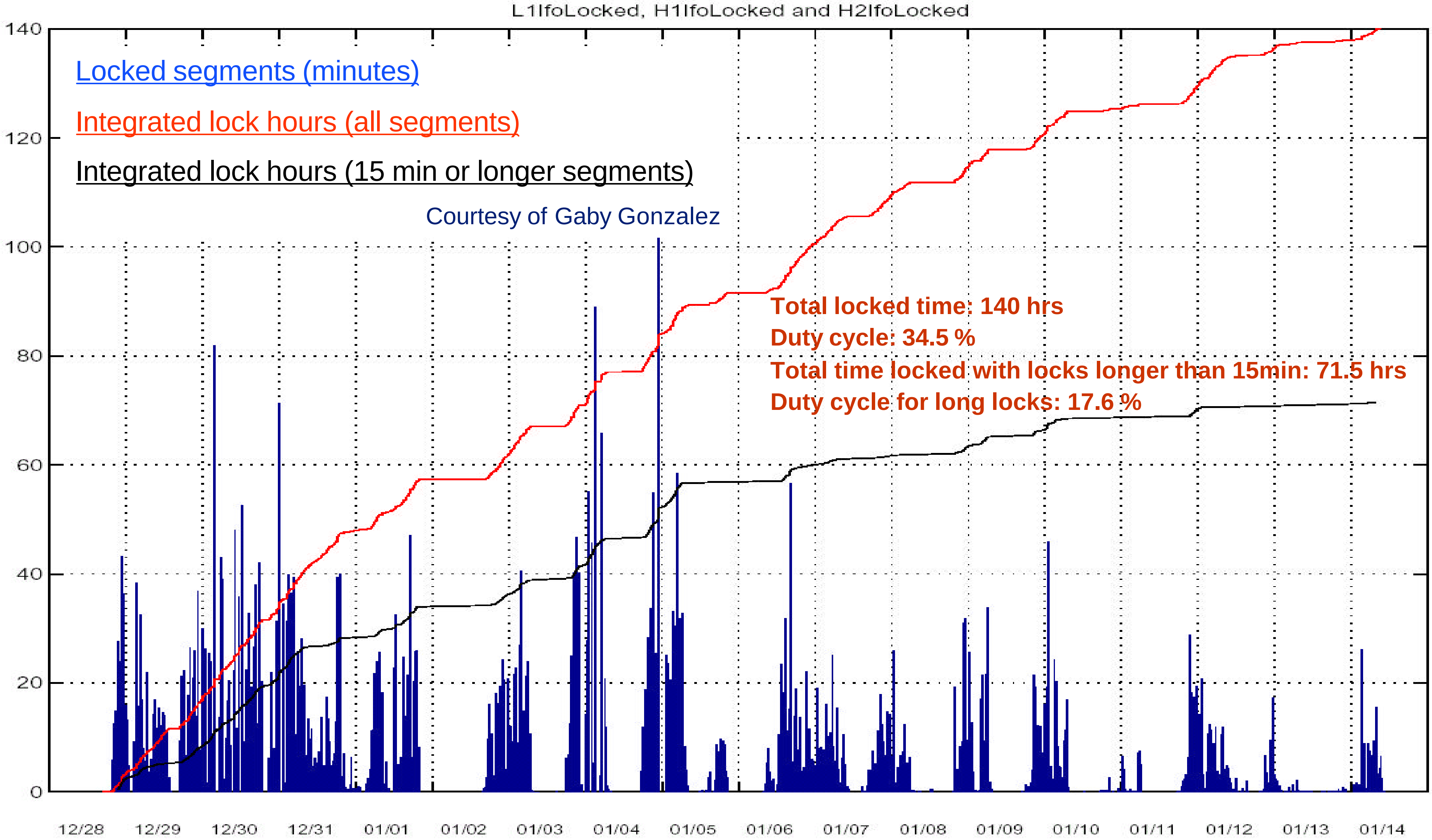
E7: LHO 4K lock history



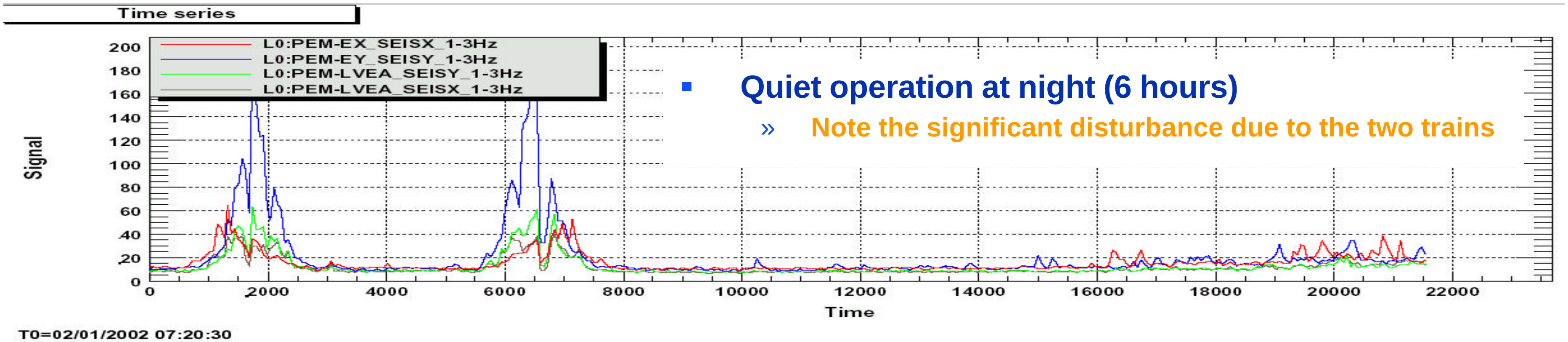
E7: LHO 2K – LLO 4K coincident lock history



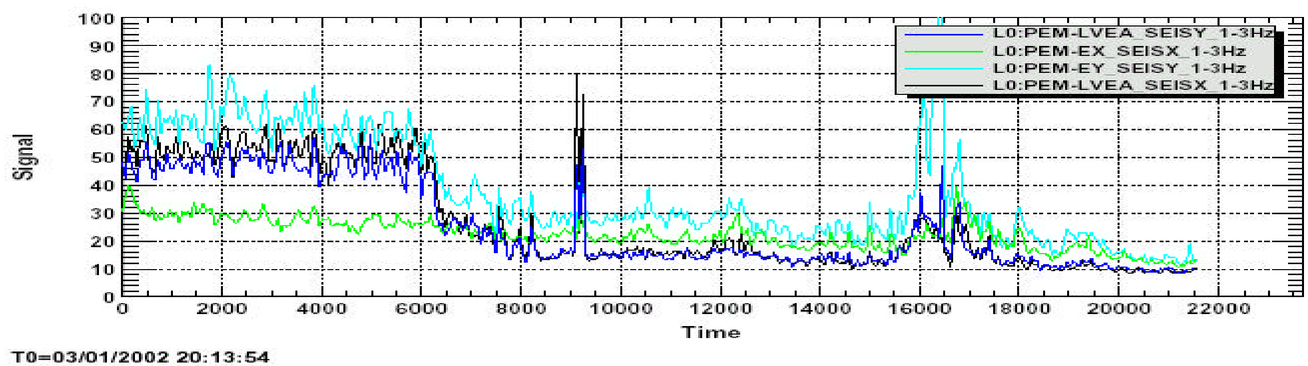
E7: LHO 2K – LHO 4K – LLO 4K coincident lock history



E7: Typical features of seismic RMS



- Quiet operation at night (6 hours)
  - » Note the significant disturbance due to the two trains



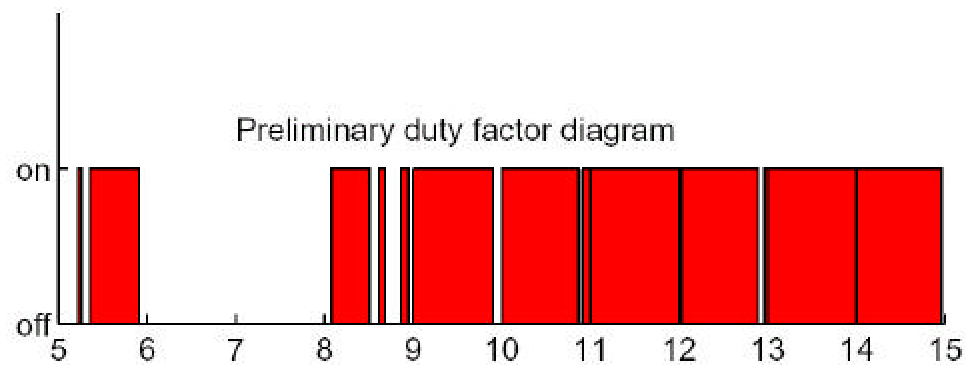
- Noisy to Quiet transition
  - » Note the significant change of LVEA and EY signals

Plots courtesy of E. Daw & J. Zweizig

E7: ALLEGRO lock history

Data collected in 3 Orientations

- Good data started with first alignment (~ IGEC alignment)
  - 48^0 W of N from UT008/01:21 to UT010/20:53
- Aligned to LLO Yarm – call this positive correlation
  - 18^0 W of N from UT010/23:27 to UT012/20:50
- Nearly null alignment to LLO – nearly 45^0 off the LLO Yarm
  - ~68^0 W of N from UT012/23:30 to UT014/22:13 (after E7)
  - (discovered uncertainty in last orientation. Will remeasure.)
- (missing data aligned to LLO Xarm – or negative correlation)



Courtesy of W. Johnson of LSU.

E7: GRB events during the run !

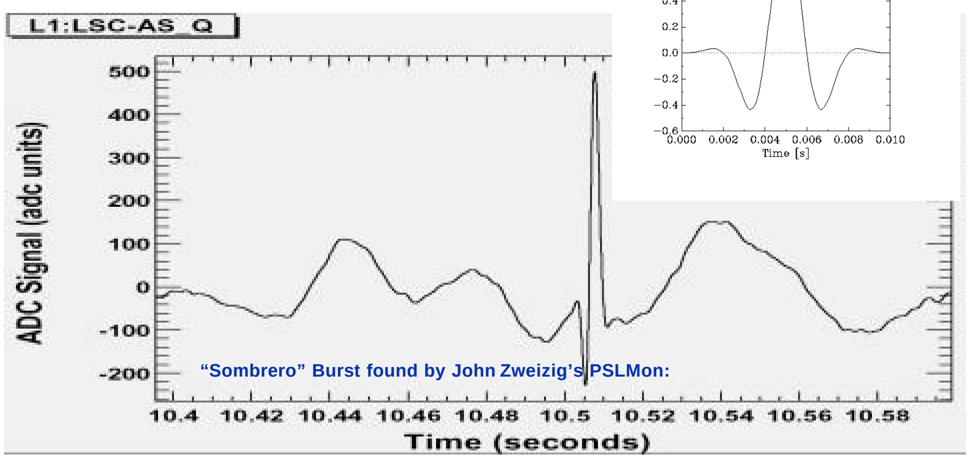
- 16 triggers for the duration of E7 !
- Various degrees of confidence
- Various degrees of directional information
- Very promising, the analysis is ongoing !

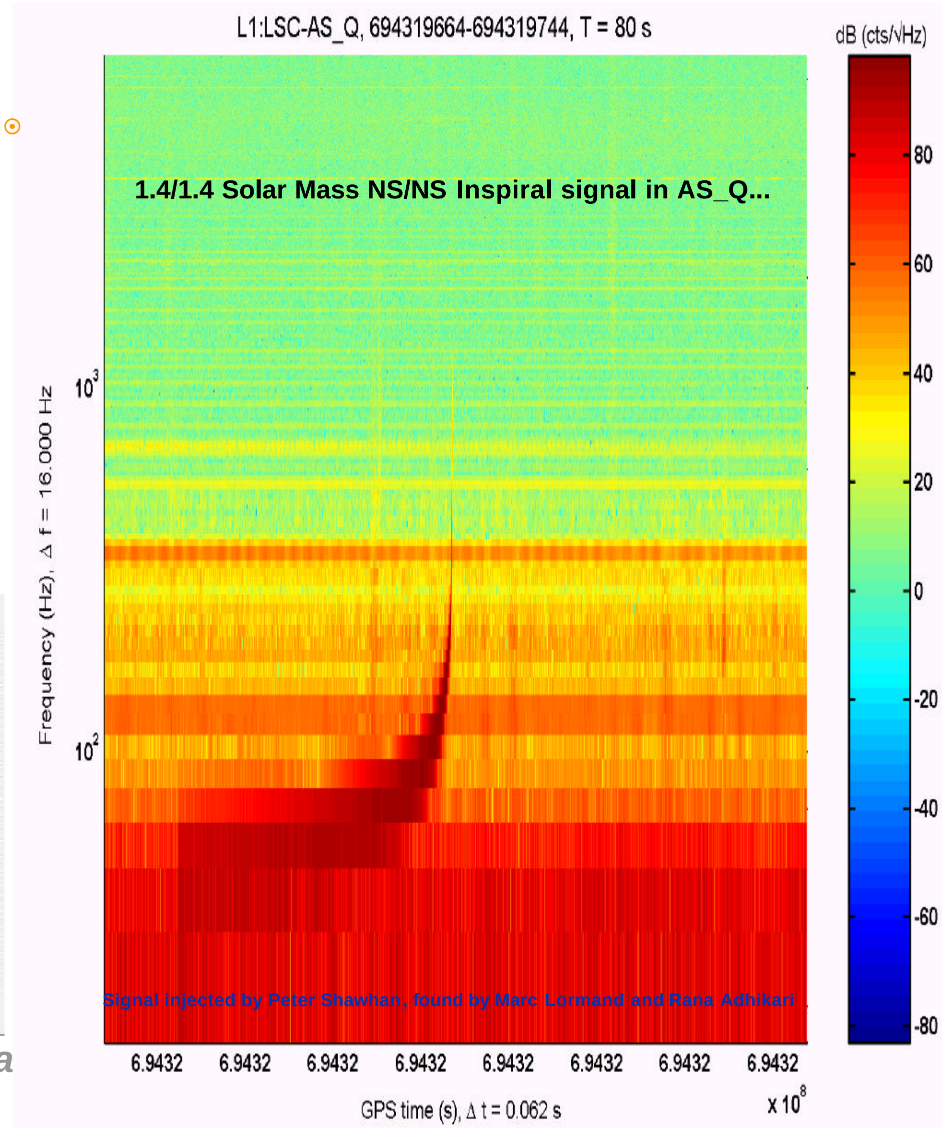
	Detector	DATE
1.	ULYSSES	01/12/28
2.	BEPPOSAX GRBM, ULYSSES, KONUS WIND	01/12/28
3.	BEPPOSAX GRBM	01/12/30
4.	BEPPOSAX GRBM	01/12/31
5.	KONUS WIND	02/01/02
6.	BEPPOSAX GRBM	02/01/02
7.	GCN/HETE	02/01/05
8.	BEPPOSAX GRBM	02/01/06
9.	ULYSSES, KONUS WIND	02/01/06
10.	GCN/HETE	02/01/08
11.	GCN/HETE	02/01/08
12.	GCN/HETE	02/01/10
13.	BEPPOSAX GRBM	02/01/12
14.	KONUS WIND, BEPPOSAX, HETE	02/01/13
15.	KONUS WIND, BEPPOSAX	02/01/13
16.	ULYSSES, HETE	02/01/14

This data here is the property and courtesy of various experiments (Ulysses, Konus, SAX, and HETE) and networks (IPN and GCN). It may not be used for any purpose without the prior approval of the corresponding group.

E7: Synchronized signal injection

- **Inspiral waveforms**
  - » L1+H1 simultaneously
  - » Several mass combinations from 1.4 + 1.4 to 7.4 + 2.7 $M_\odot$
- **Correlated noise**
  - » L1+H1 simultaneously
  - » 512 seconds long
- **Bursts**
  - » Inspired by the Zweiger-Muller catalog
  - » L1+H1, L1+H2 simultaneously
  - » Four different “idealized” waveforms
- **Signals were found in data**
  - – By eye
  - – Automatically





P. Shawhan, S. Bose, D. Brown, G. Gonzalez, R. Adhikari, J. Zwezig, Sz. Marka

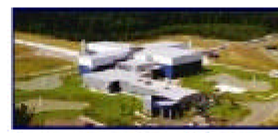
E7: Data Monitoring Tool

- Several computers dedicated to real time monitoring of the
  - DAQ system
  - Data quality
  - Environmental sensors
  - Interferometer status
  - Timing
  - …. And other important diagnostic issues
- Several monitors evolved and more is being crafted
- New ideas can be tested and prototyped rapidly
- High loads were managed well during E7

LIGO

GDS - Data Monitoring Tool Observer

A real time tool to to check GDS firmware state of health.
(click on the DMT name to get info)



LLO

DELARONDE
Alive and Up to Date, CPU usage 40%
DECATUR

LHO

SAND
Alive and Up to Date, CPU usage 43.5%
STONE
Alive and Up to Date, CPU usage 55.8%
FORTRESS

http://blue.ligo-wa.caltech.edu/gds/dmt/Monitors/spi.html

E7: DMT Monitor Processes 1

- **Data and timing integrity**
  - » BitTest: Search for channel readout errors
  - » Slice2: Search for DAQ system errors
  - » TimeMon: Check timing accuracy and stability
  - » IRIG-B: Check timing synchronization.
  - » blrms mon: Band limited RMS on PEM channels
- **Steady state noise**
  - » LLO ifo blrms: Band limited rms of IFO channels
  - » RmsBands: Band limited rms, various channels, bands
  - » MultiVolt: Power line stability (LHO Only)

Courtesy of D. Sigg and J. Zweizig

E7: DMT Monitor Processes 2

- **Transient detection**
  - » glitchMon: Search for transients.
  - » ZGlitch: Search for transients (PSLmon glitch tool)
  - » tidd: Search for and identify transients in T-F plane
  - » eqMon: Search for earthquakes (LHO Only)
- **IFO performance**
  - » LockLoss: Tag lock loss events
  - » ServoMon: Search for servo instabilities.
  - » SegGener: Identify segments to analyze
- **User tools**
  - » Glitch plotting: Utility based on DB records
  - » RaleighMonitor: Enhanced T-F plots in real time

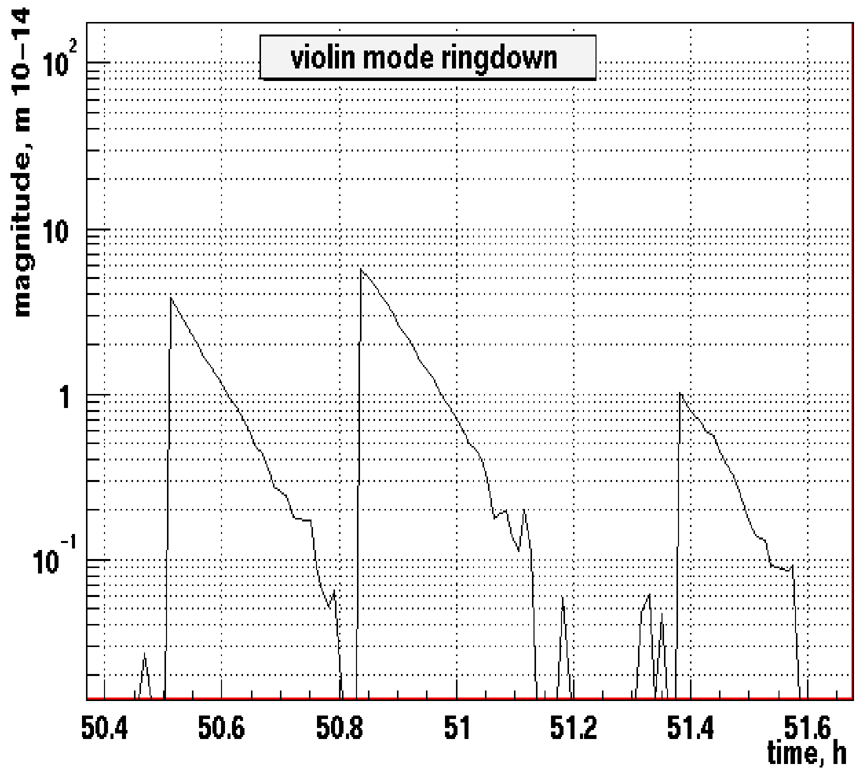
Courtesy of D. Sigg and J. Zweizig

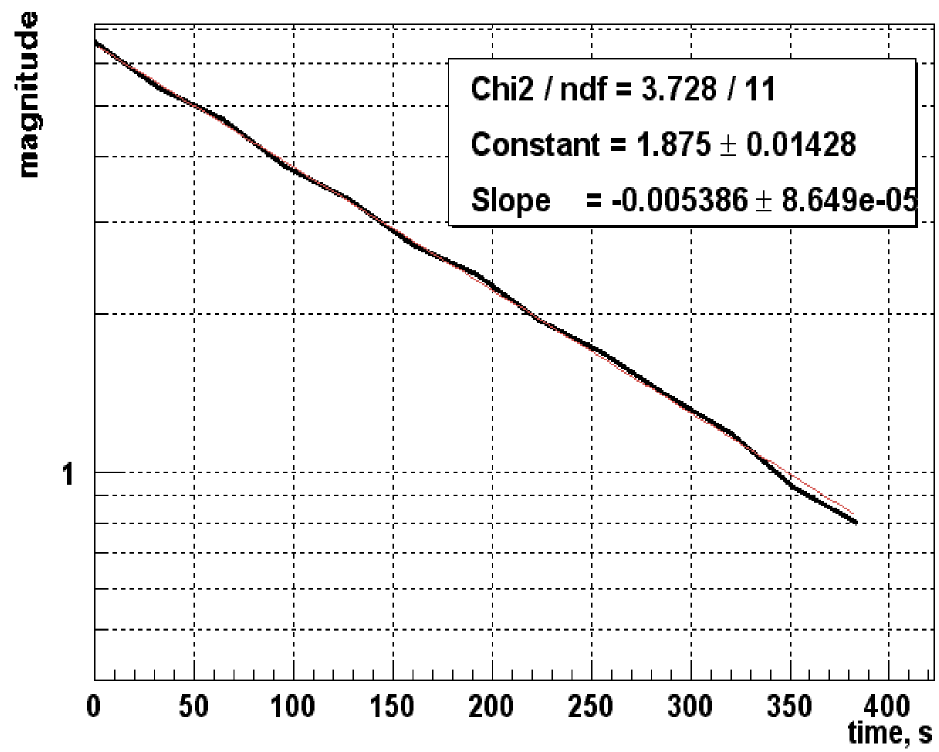
E7: Investigations

1. Quantify correlations between GW channel and other channels.
2. Quantify correlated ambient noise between sites
3. Quantify correlated environmental transients between sites
4. Identify & catalog environmental disturbances
5. Quantify calibration stability & stationarity of data
6. Investigate angular fluctuations
7. Check data against detailed tidal prediction
8. Investigate sources of lock losses
9. Quantify timing precision (intra- and inter-site)
10. Check data integrity end-to-end
11. Check data merging
12. Quantify strength and stability of line noise in GW channel
13. Test simulated astrophysical signal injection

and others evolve …

DMT example: Violin mode ringdown





- Excited by external events (usually start of lock)
- Can measure decay time and Q
- Clearly seen in E7 data
- Violin resonances are monitored during LIGO runs

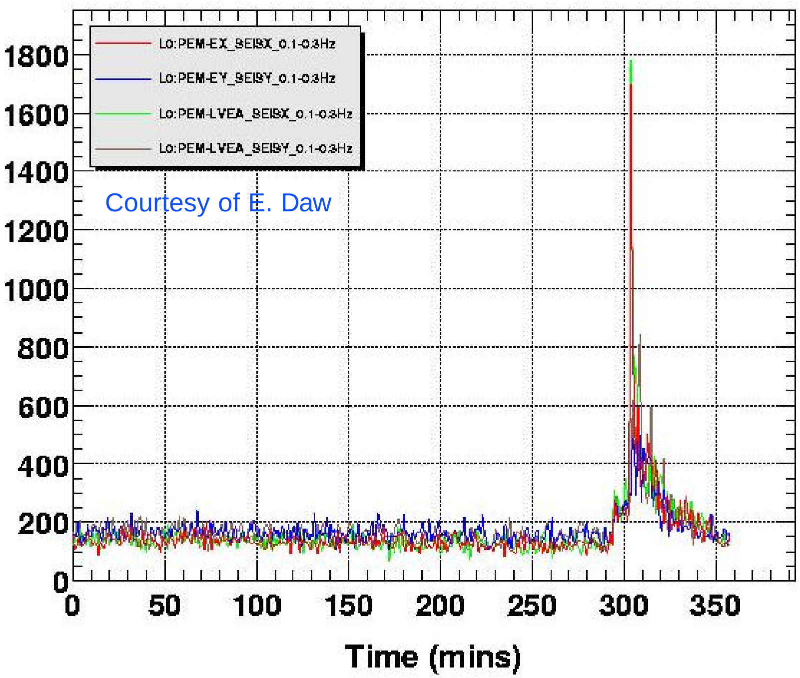
τ=185 s

f=343.667Hz

Courtesy of Sergei Klimenko of University of Florida

E7: "blrms" Earthquake example

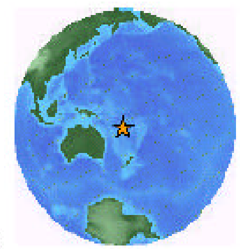
- **Predicted arrival times:**
  - Knoxville, Tennessee 113.75 14:42.5 17:37:31.5 Pdiff
  - Los Angeles, California 87.10 12:42.4 17:35:31.4 P
  - Seattle, Washington 90.13 12:56.7 17:35:45.7 P
  - Brownsville, Texas 101.59 13:48.5 17:36:37.5 Pdiff
  - Knoxville, Tennessee 113.75 14:42.5 17:37:31.5 Pdiff
  - Boston, Massachusetts 124.60 15:30.7 17:38:19.7 Pdiff

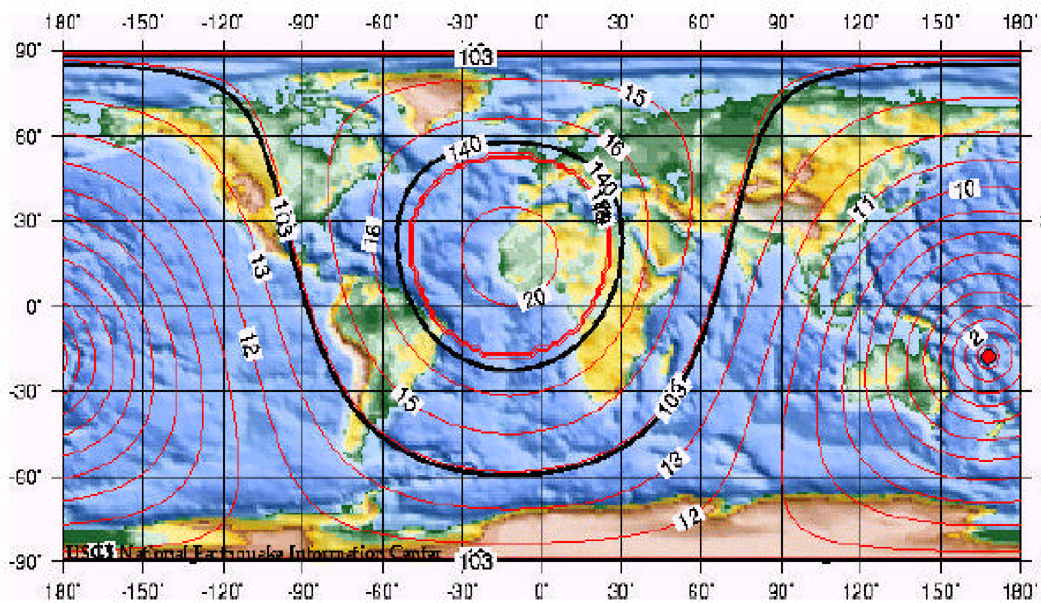


T0=02/01/2002 12:46:30

Theoretical P-Wave Travel Times

Date-Time	2002 01 02 17:22:49 UTC
Location	17.78S 167.88E
Depth	33.0 kilometers
Magnitude	7.2
Region	VANUATU ISLANDS
Reference	30 miles (45 km) W of PORT-VILA, Vanuatu

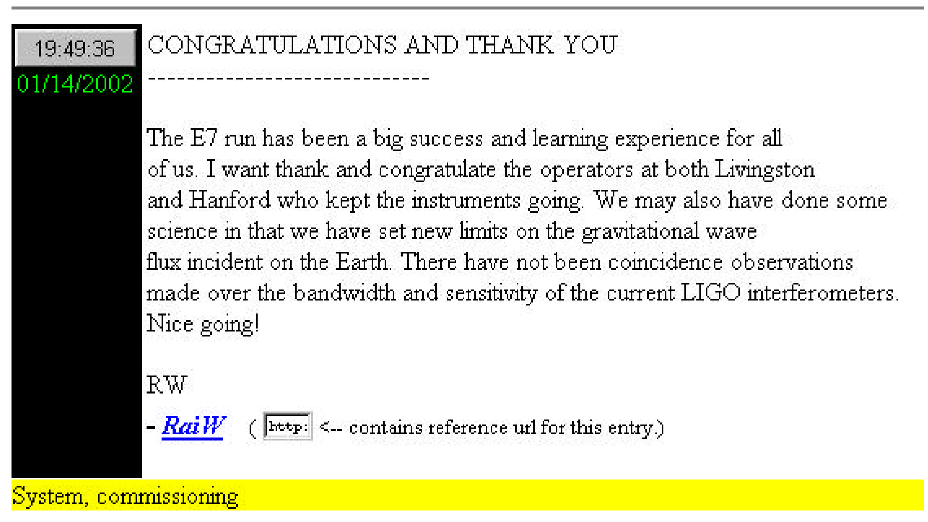




LIGO/CalTech

Summary

- **Consistent advance towards the sensitivity goal**
- **The data is quite "bursty" making time domain analyses harder**
- **Long lock sections were observed**
- **Duty cycle is very good at good times**
- **We clearly need better overall locking stability however**
- **Collected plenty of (coincident) data**
- **There is a strong analysis effort**
- The engineering run sequence is a definite success in general, E7 is successful in particular
  - » Principal goals:
    - – Good up time ✓
    - – Significant overlap time ✓
    - – Plenty of data for investigations ✓
    - – Hone our skills, identify bottle necks ✓
- Science run is scheduled for 2002



19:49:36
01/14/2002

CONGRATULATIONS AND THANK YOU

The E7 run has been a big success and learning experience for all of us. I want thank and congratulate the operators at both Livingston and Hanford who kept the instruments going. We may also have done some science in that we have set new limits on the gravitational wave flux incident on the Earth. There have not been coincidence observations made over the bandwidth and sensitivity of the current LIGO interferometers. Nice going!

RW

- *RaiW* (http: <-- contains reference url for this entry)

System, commissioning

Preliminary schedule of future runs

- **Engineering run 8**
  - » **June 8 – 10**
  - » **~72 hours only LHO**
  - » **Tool and procedure practice before S1**
- **Science 1 run: 13 TB data**
  - » **29 June - 15 July**
  - » **2.5 weeks - comparable to E7**
- **Science 2 run: 44 TB data**
  - » **22 November - 6 January 2003**
  - » **8 weeks -- 15% of 1 yr**
- **Science 3 run: 142 TB data**
  - » **1 July 2003 -- 1January 2004**
  - » **26 weeks -- 50% of 1 yr**