OVERVIEW OF THE LIGO INSTRUMENT AND THE DATA

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MIT

Review of the LIGO Open Data Proposal
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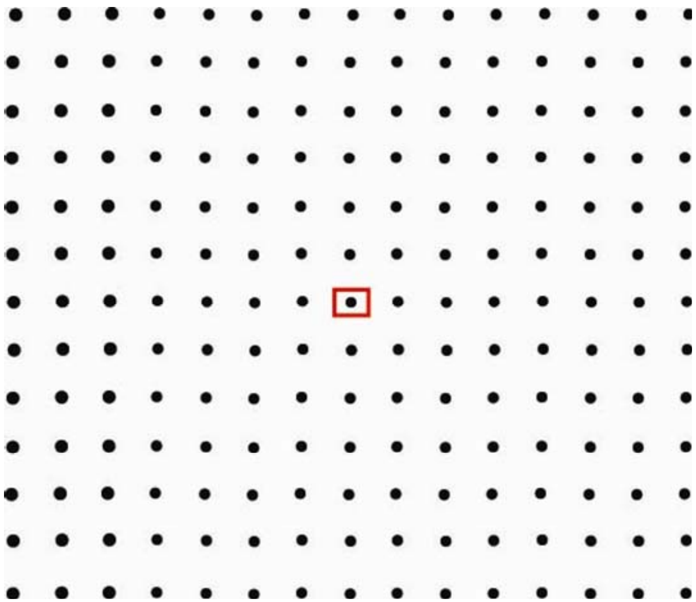
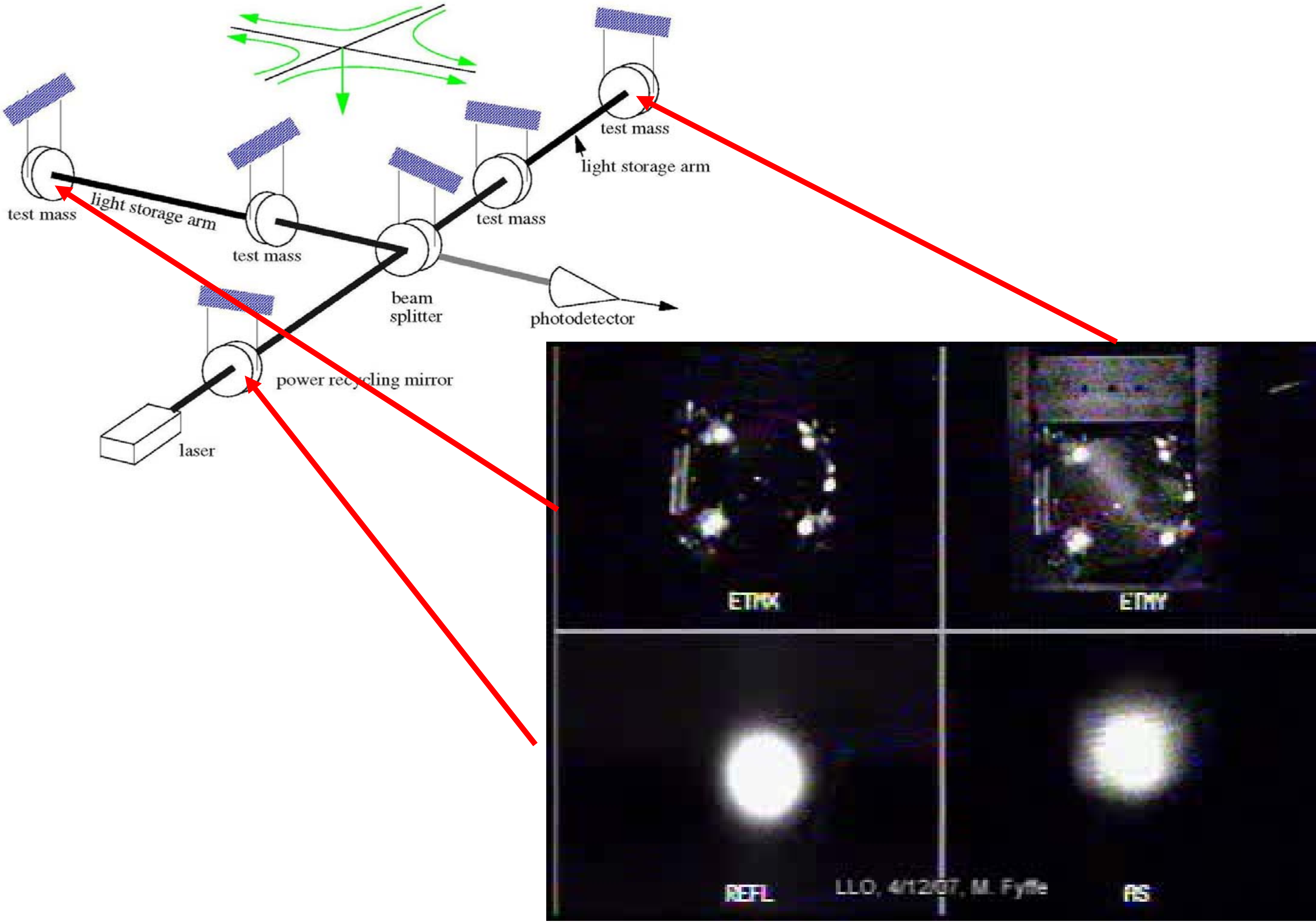
LIGO-G0900073-v1

OUTLINE

- The instrument: how it works
  - The interferometer: subsystems, the variety of signals
  - The environmental monitoring system
- The noise
  - The fundamental noises: stationary, Gaussian
  - The diagnostic technique: stimulus/response/estimate
  - The real noise: non-stationary, non-Gaussian
- Experiment styles: why is LIGO data unique
  - searches and measurements
- The nature of the data for a variety of searches
  - Calibration
  - Vetoes and Coincidence
  - Transient sources; compact binary inspiral and unmodeled
  - Steady state sources: pulsars, stochastic background





test mass
light storage arm
test mass
test mass
test mass
light storage arm
beam
splitter
photodetector
power recycling mirror
laser
ETMX
ETMY
REFL
LLO, 4/12/07, M. Fyffe
AS

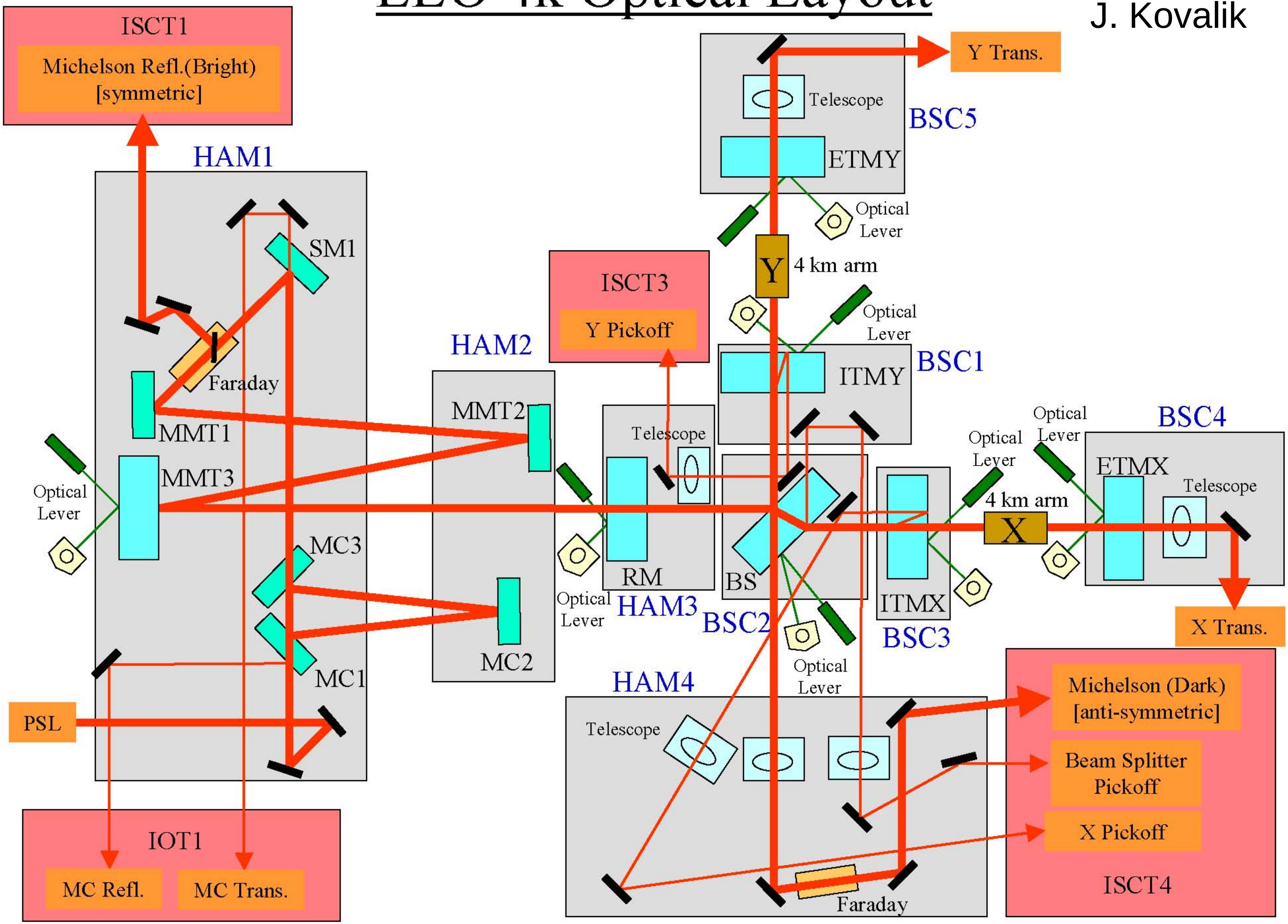
Detector Subsystems

Control by feedback

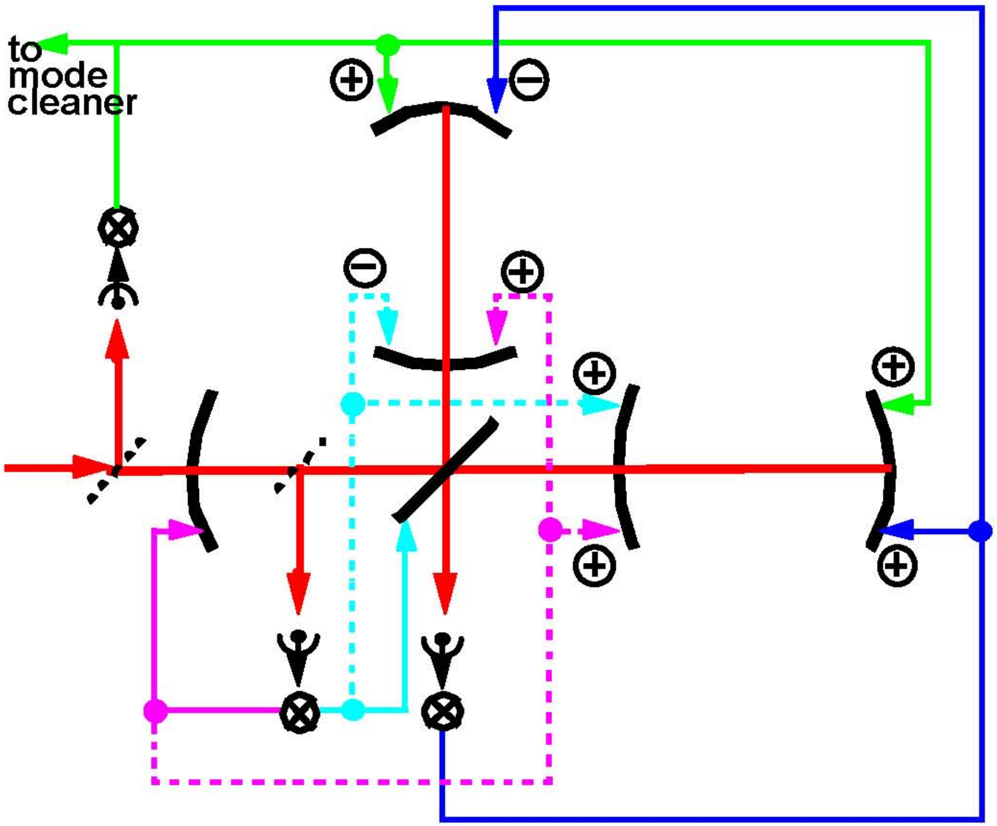
- Length sensing and control
  - Maintain the positions of the optics
- Angular sensing and control
  - Hierarchical alignment strategy
- Laser frequency stabilization
  - Nested frequency control system
  - Relative frequency control
- Laser amplitude stabilization
- Thermal wavefront correction
- Active seismic isolation (at L1 not H1)

LLO 4k Optical Layout

J. Kovalik

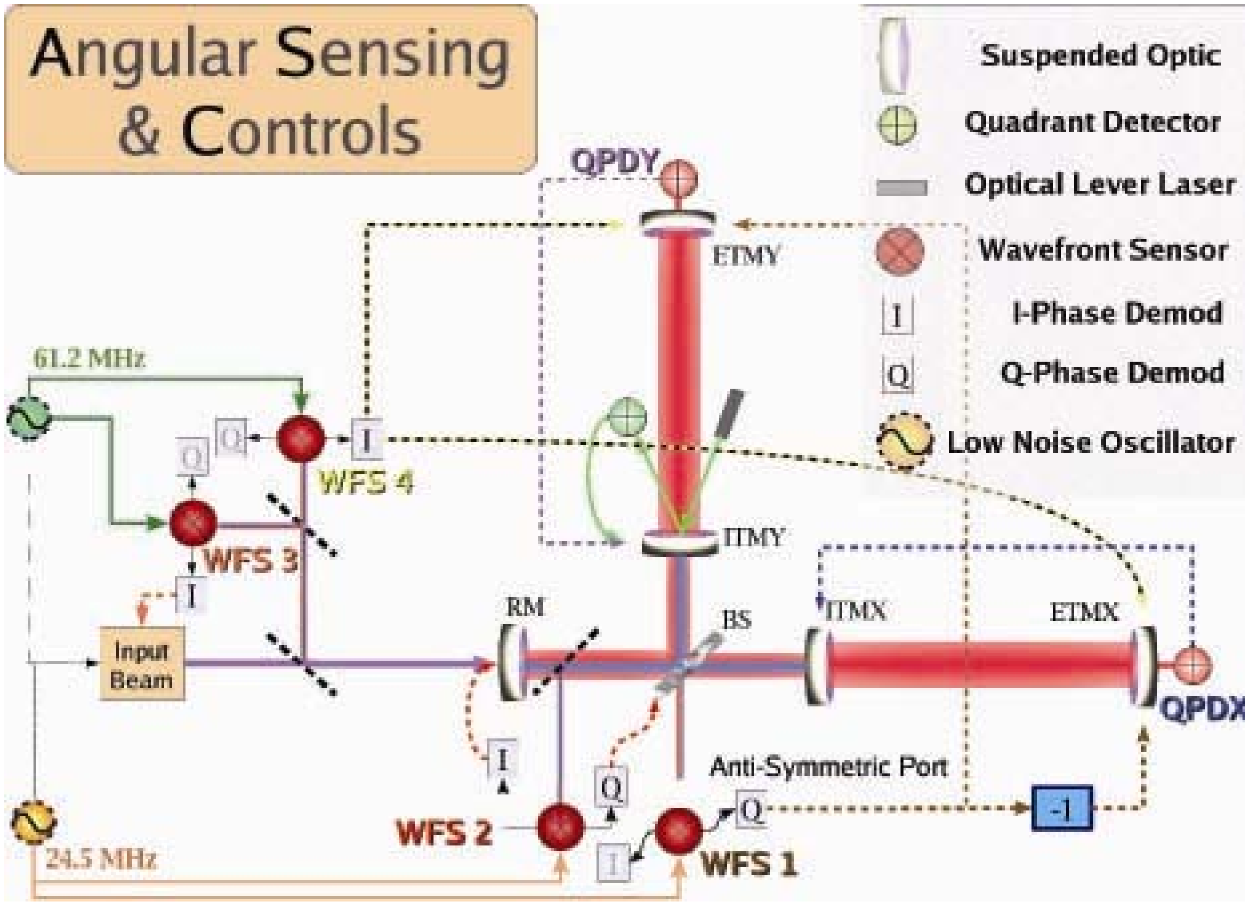


Feedback Control Systems

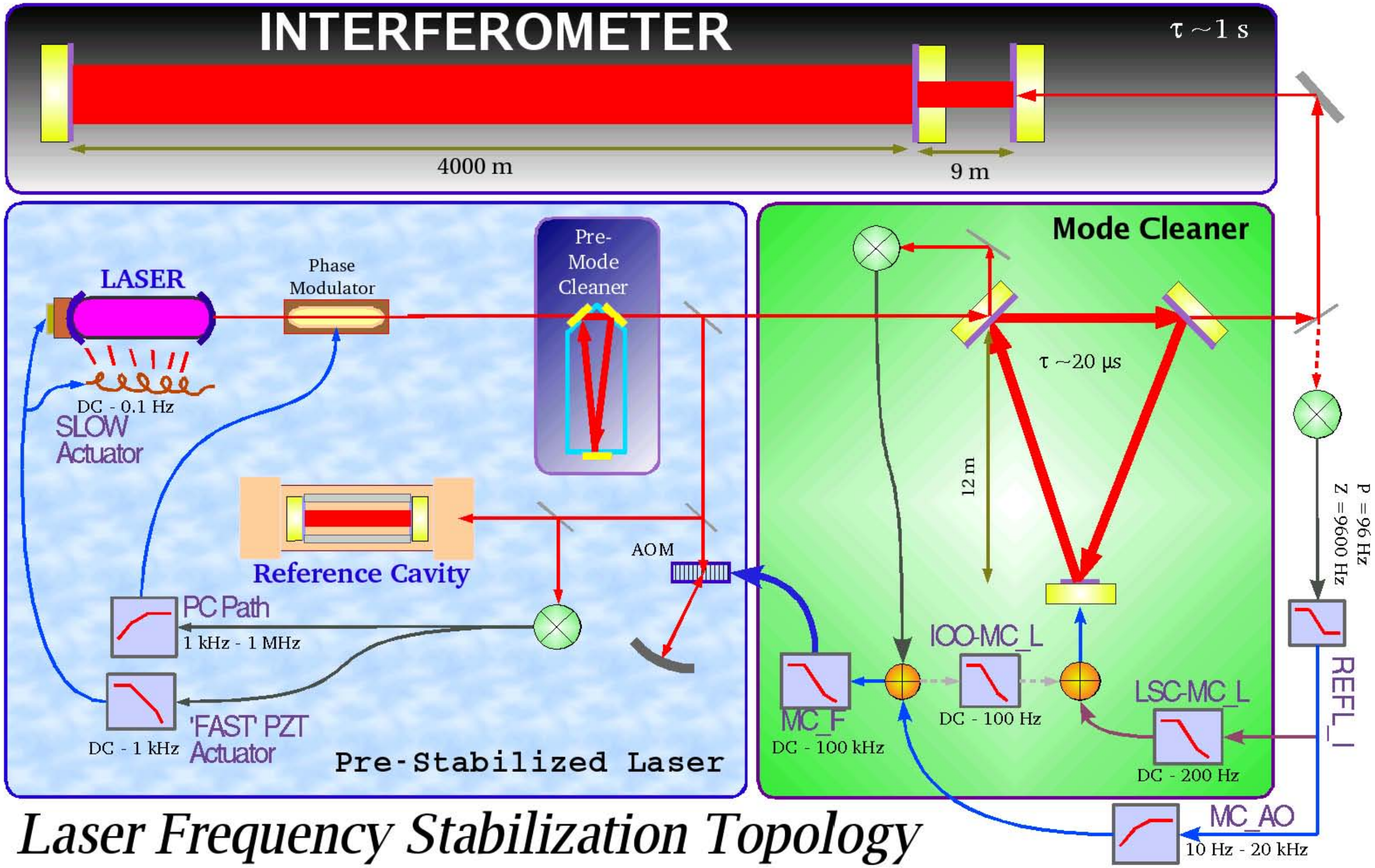


example: cavity length sensing & control topology

- Array of sensors detects mirror separations, angles
- Signal processing derives stabilizing forces for each mirror, filters noise
- 5 main length loops shown; total ~ 25 degrees of freedom
- Operating points held to about 0.001 Å, .01 µrad RMS
- Typ. loop bandwidths from ~ few Hz (angles) to > 10 kHz (laser wavelength)



Rana Adhikari



Laser Frequency Stabilization Topology

Rana Adhikari

Physical Environment Monitoring

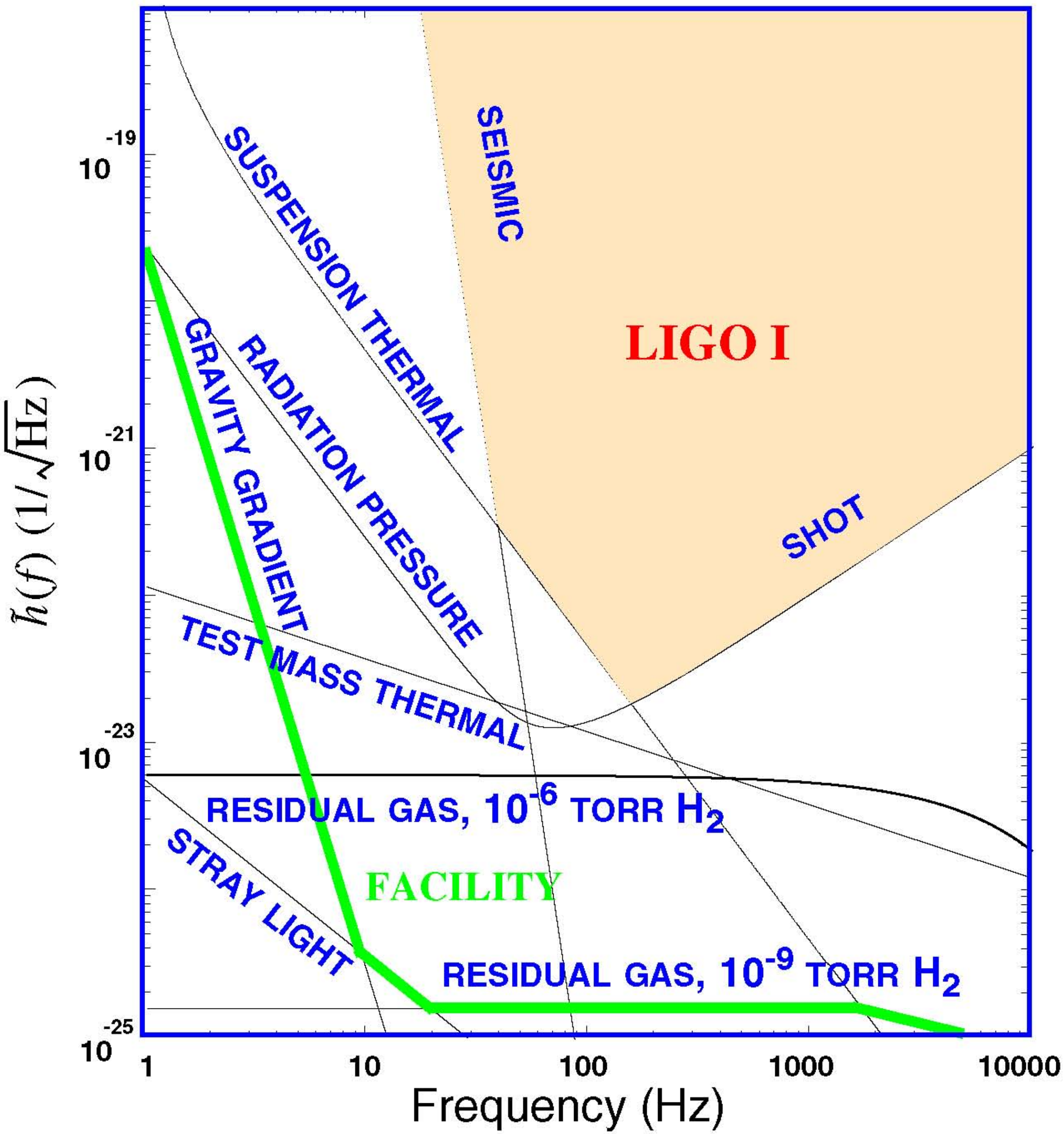
- Seismic motion
  - xyz seismometer/building
- Motion of test mass chambers
  - xyz accelerometers/chamber
- Acoustic excitation
  - microphone/building
- Magnetic fields
  - xyz magnetometer/building
  - xyz high sensitivity coil/site
- Radio Frequency interference
  - multiband 30kHz -100MHz receiver/site
- Main AC power monitor
  - 3 phase monitor/building
- Muon shower detector
  - scintillator-PM tube/site

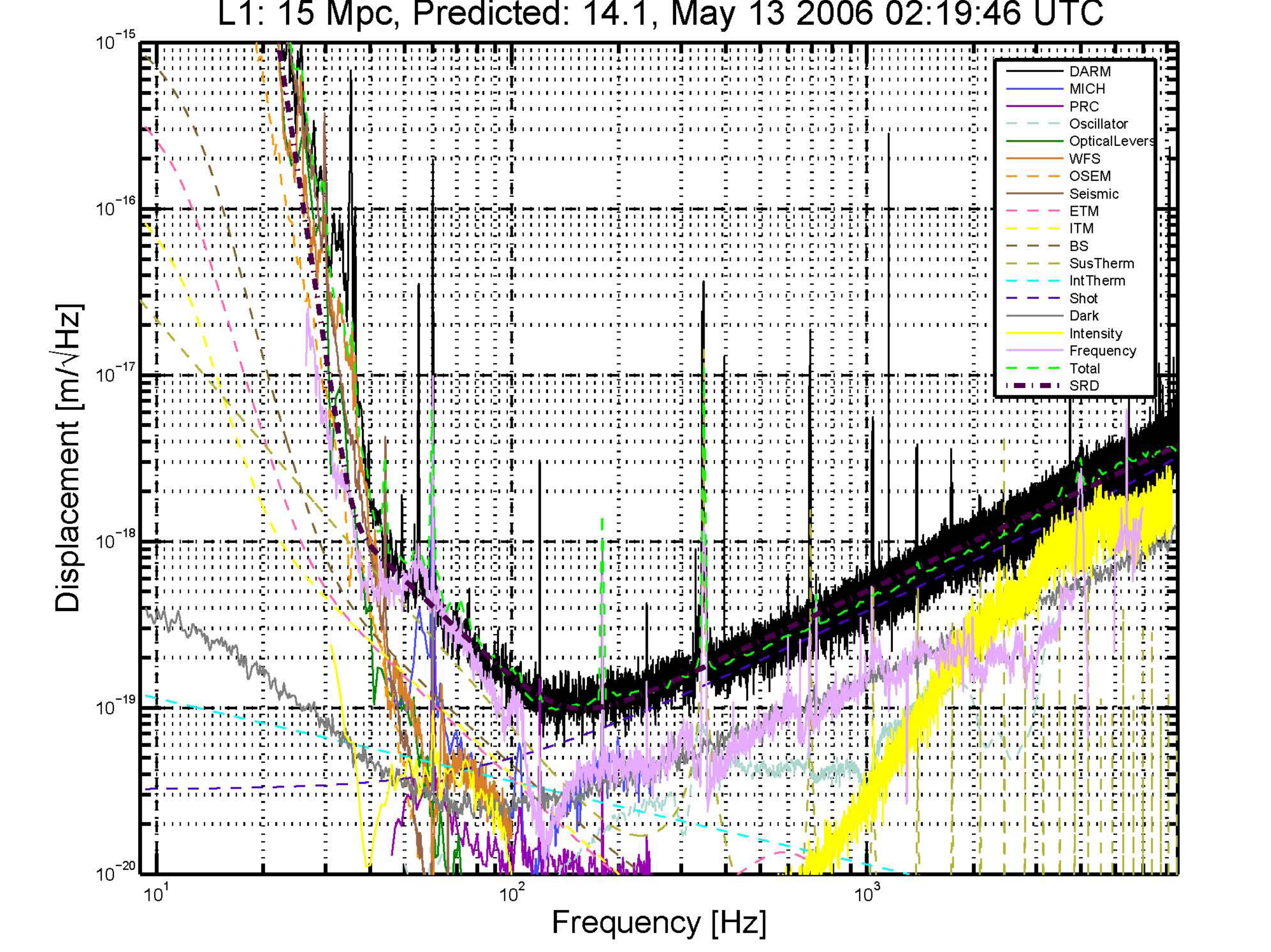
Data channels / L1 Interferometer

Full data on tape		Reduced data on disk	
Number of channels		Number of channels	Sample rate/sec
5		0	32768
46		14	16384
0		4	8192
30		8	4096
294		72	2048
0		1	1024
10		38	512
436		87	256
0		22	64
11594		50	16

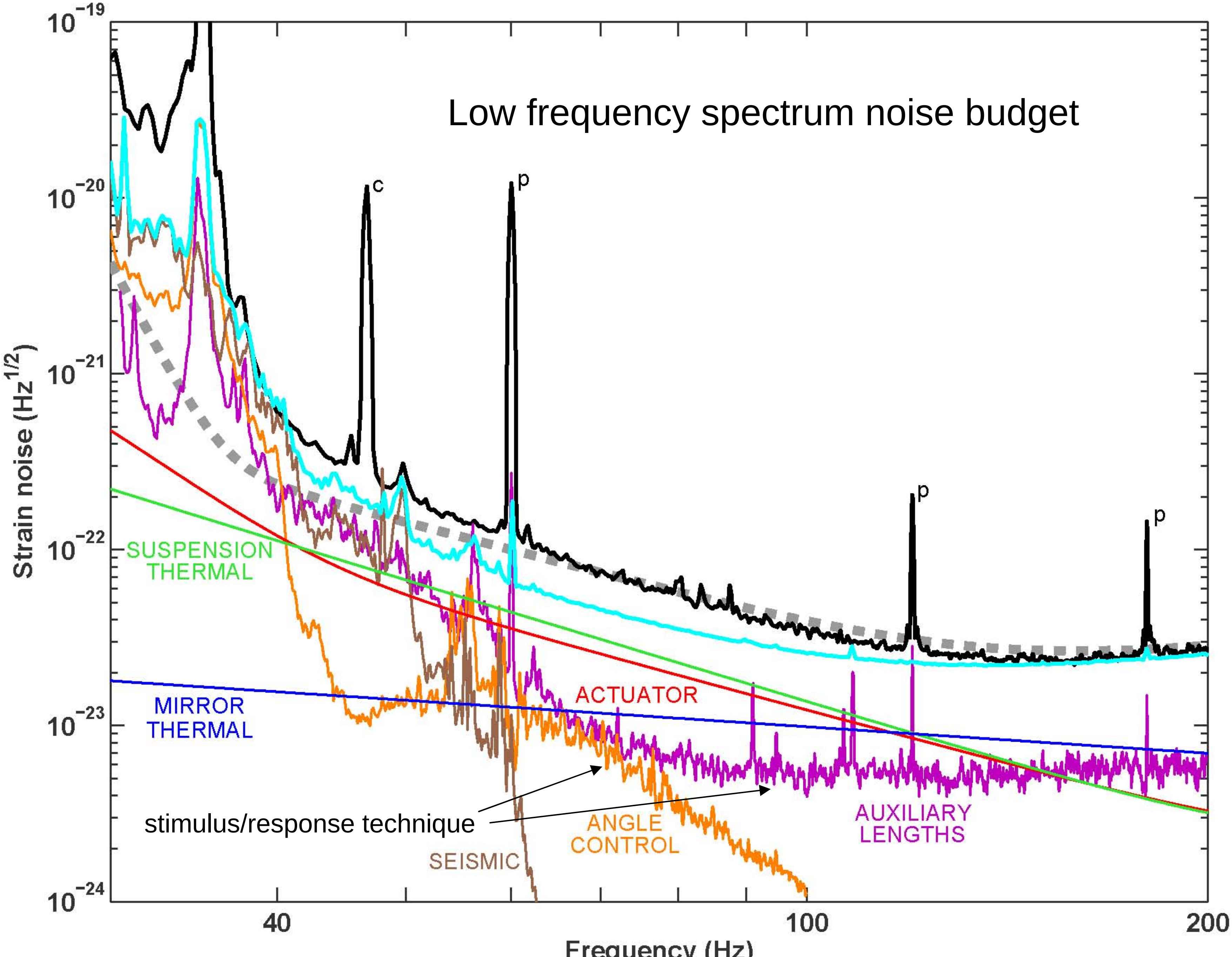
6.1 MB/s 0.69 MB/s

Mostly idealized and fundamental noise





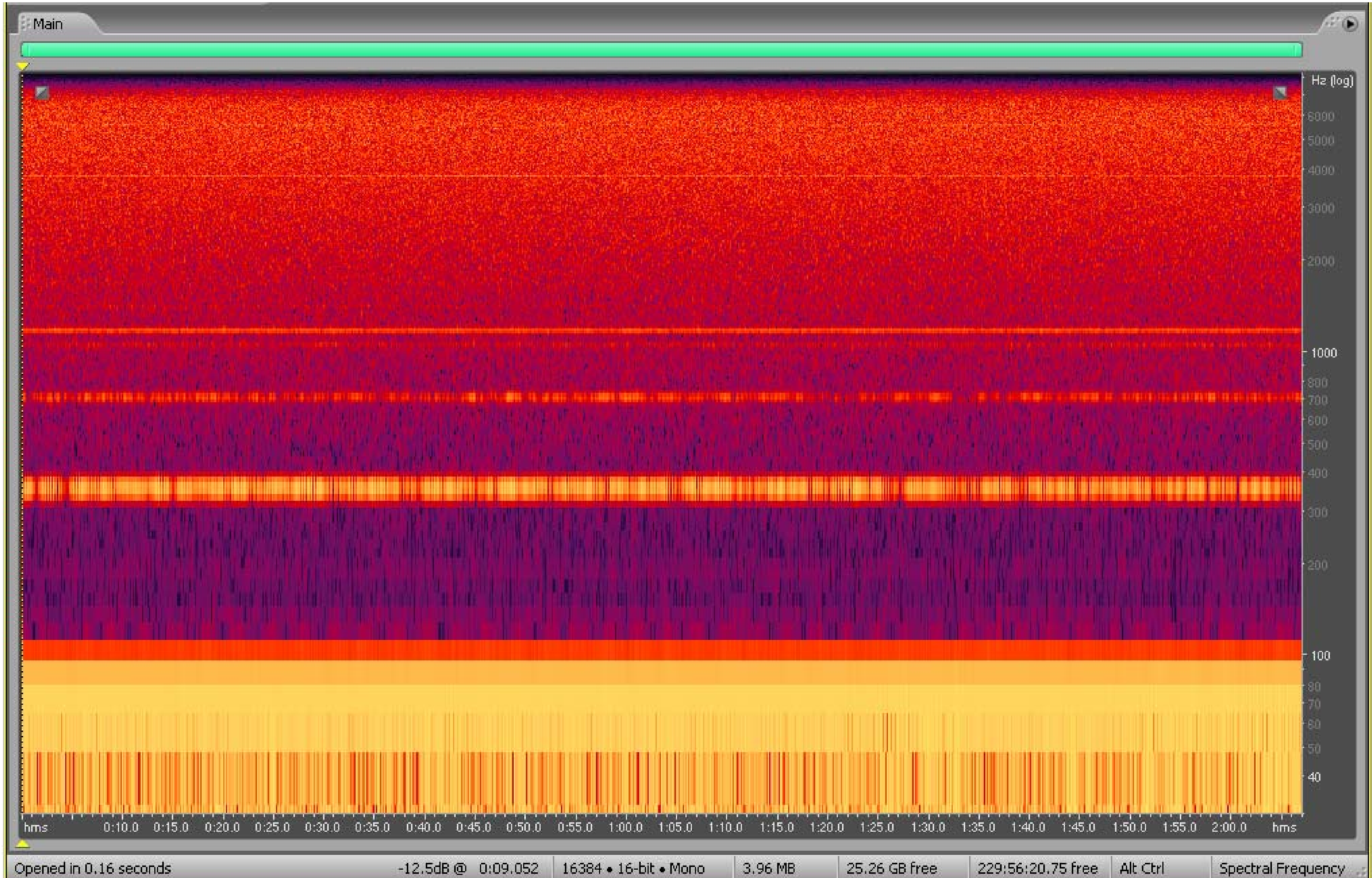
L1: 15 Mpc, Predicted: 14.1, May 13 2006 02:19:46 UTC
Displacement [m/√Hz]
Frequency [Hz]
DARM
MICH
PRC
Oscillator
OpticalLevers
WFS
OSEM
Seismic
ETM
ITM
BS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD


Low frequency spectrum noise budget
c
p
p
p
SUSPENSION
THERMAL
MIRROR
THERMAL
ACTUATOR
stimulus/response technique
ANGLE
CONTROL
SEISMIC
AUXILIARY
LENGTHS
Strain noise (Hz^1/2)
Frequency (Hz)
10^−19
10^−20
10^−21
10^−22
10^−23
10^−24
40
100
200

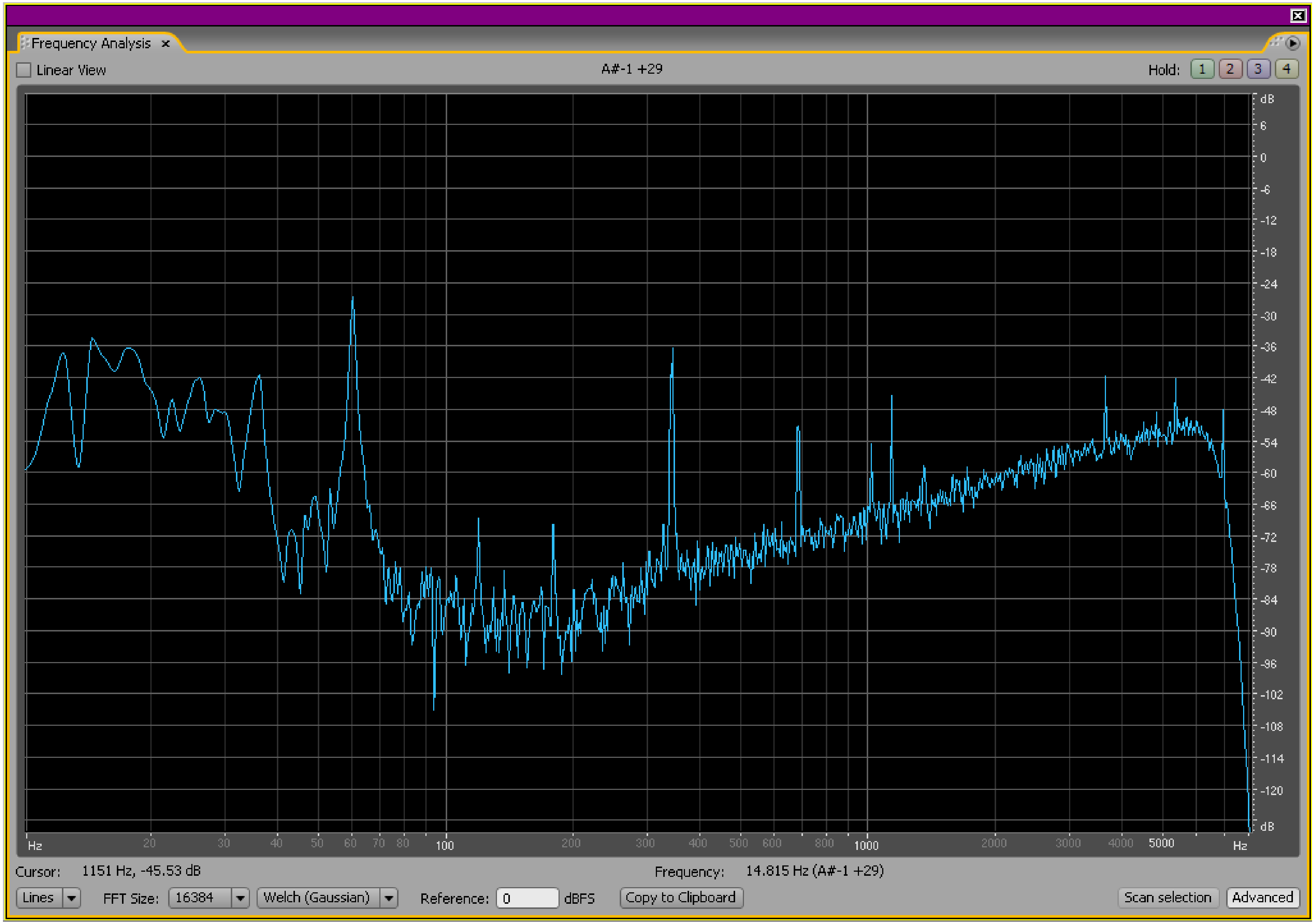
P. Fritschel

L1 Differential Arm Signal during S5

L1 differential arm signal spectrum vs time

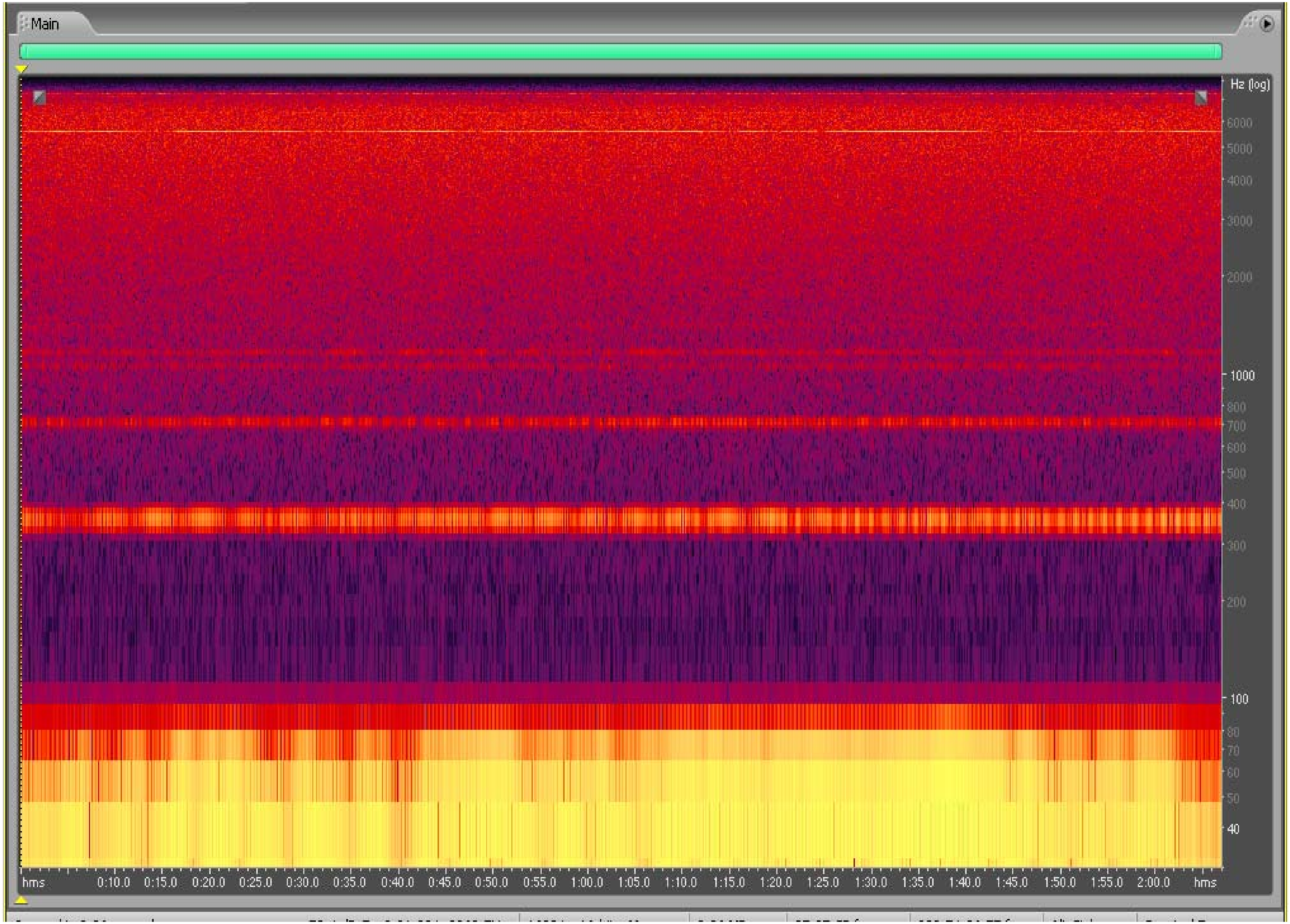


L1 differential arm spectrum during S5

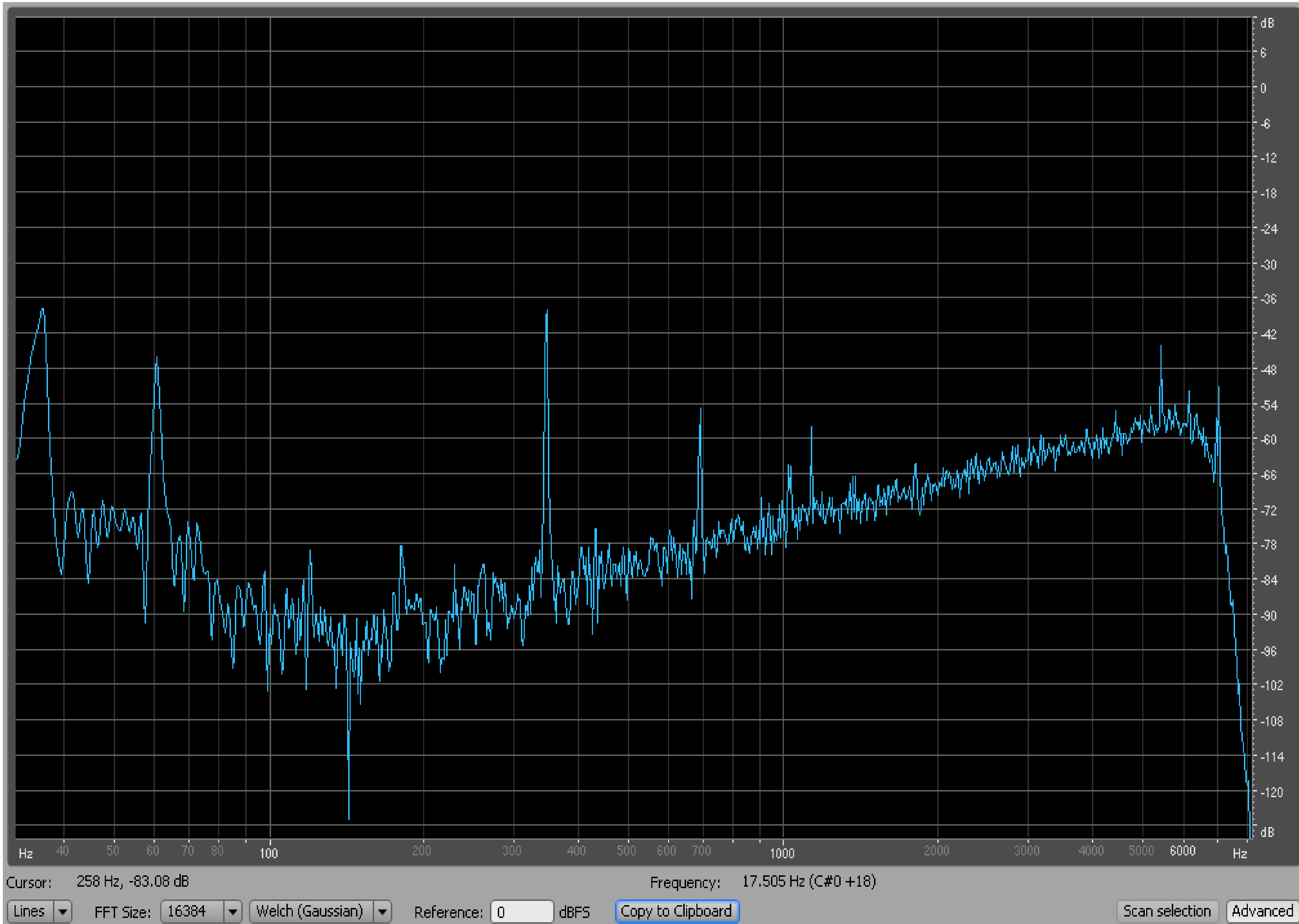


H1 differential arm signal during S5

H1 differential arm spectrum vs time in S5

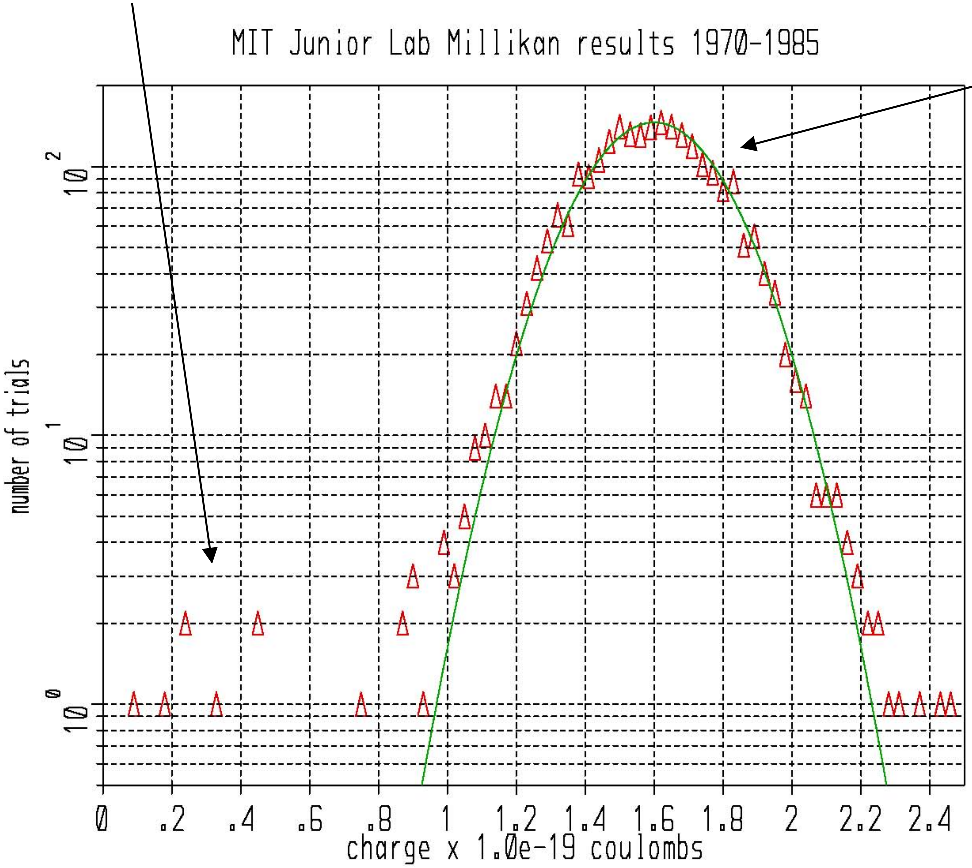


H1 differential arm spectrum in S5



Styles of Experiment

Quarks?

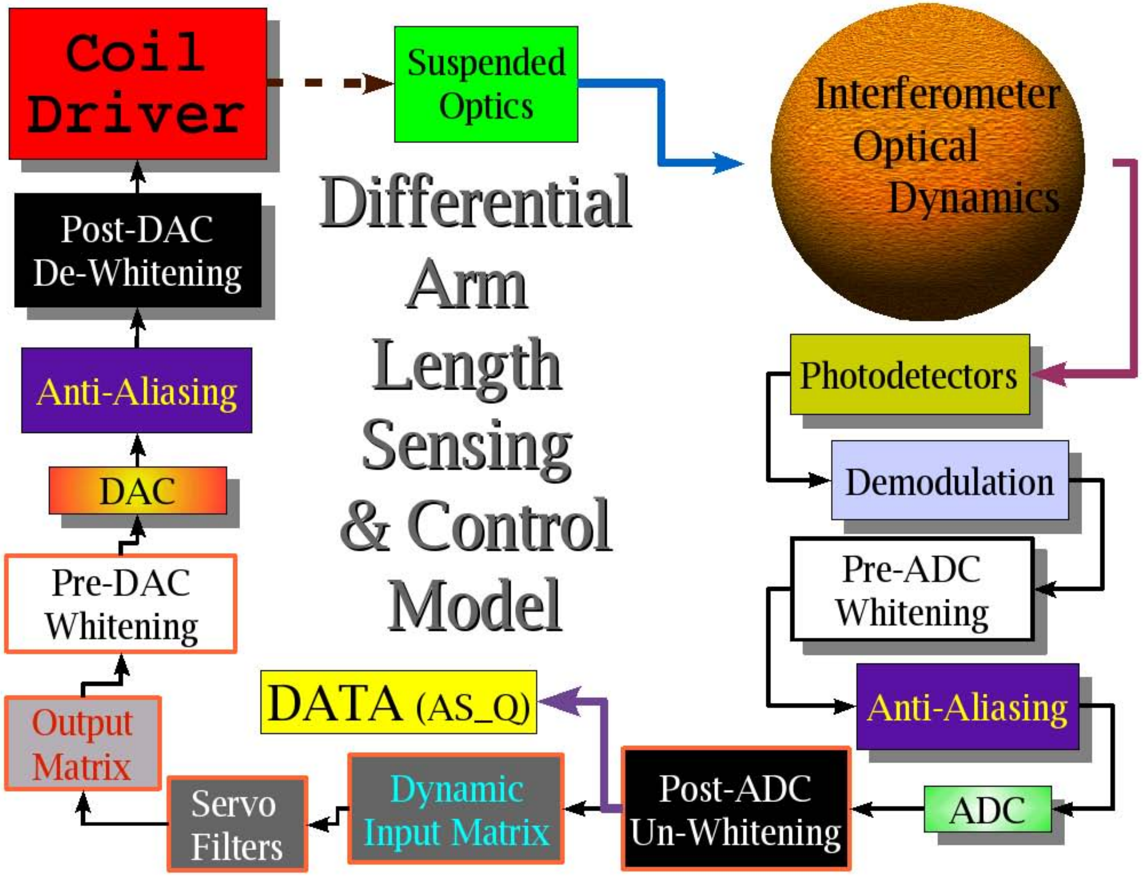


almost Gaussian with variance 0.2 , avg 1.6

The tails with their outliers can be neglected in this data – they represent poor control of the experiment parameters. *May also be true in LIGO but unfortunately the tail contains the signal.*

MIT Junior Physics Laboratory 15 year history with the Millikan oil drop experiment

CALIBRATION

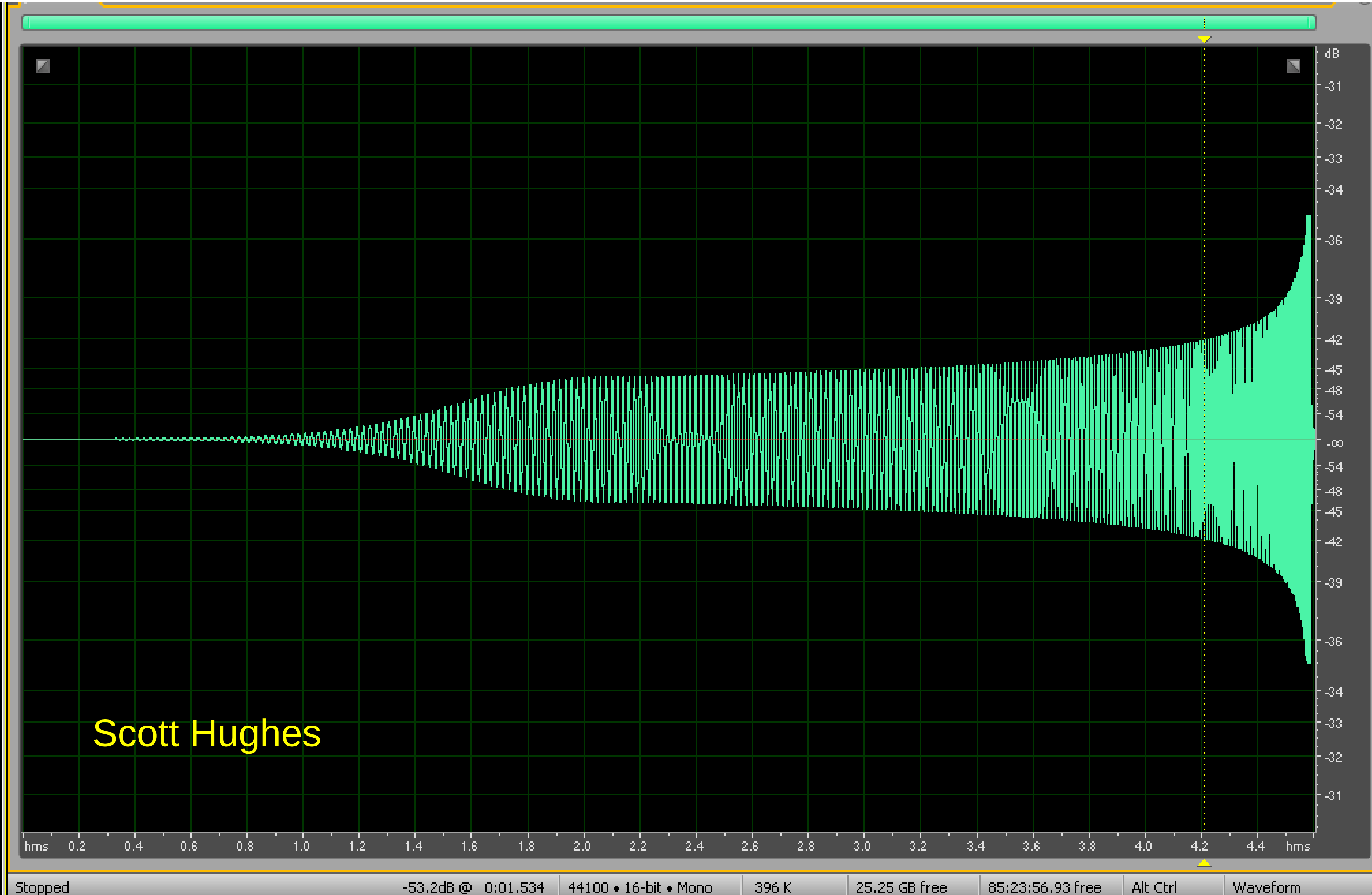


Rana Adhikari

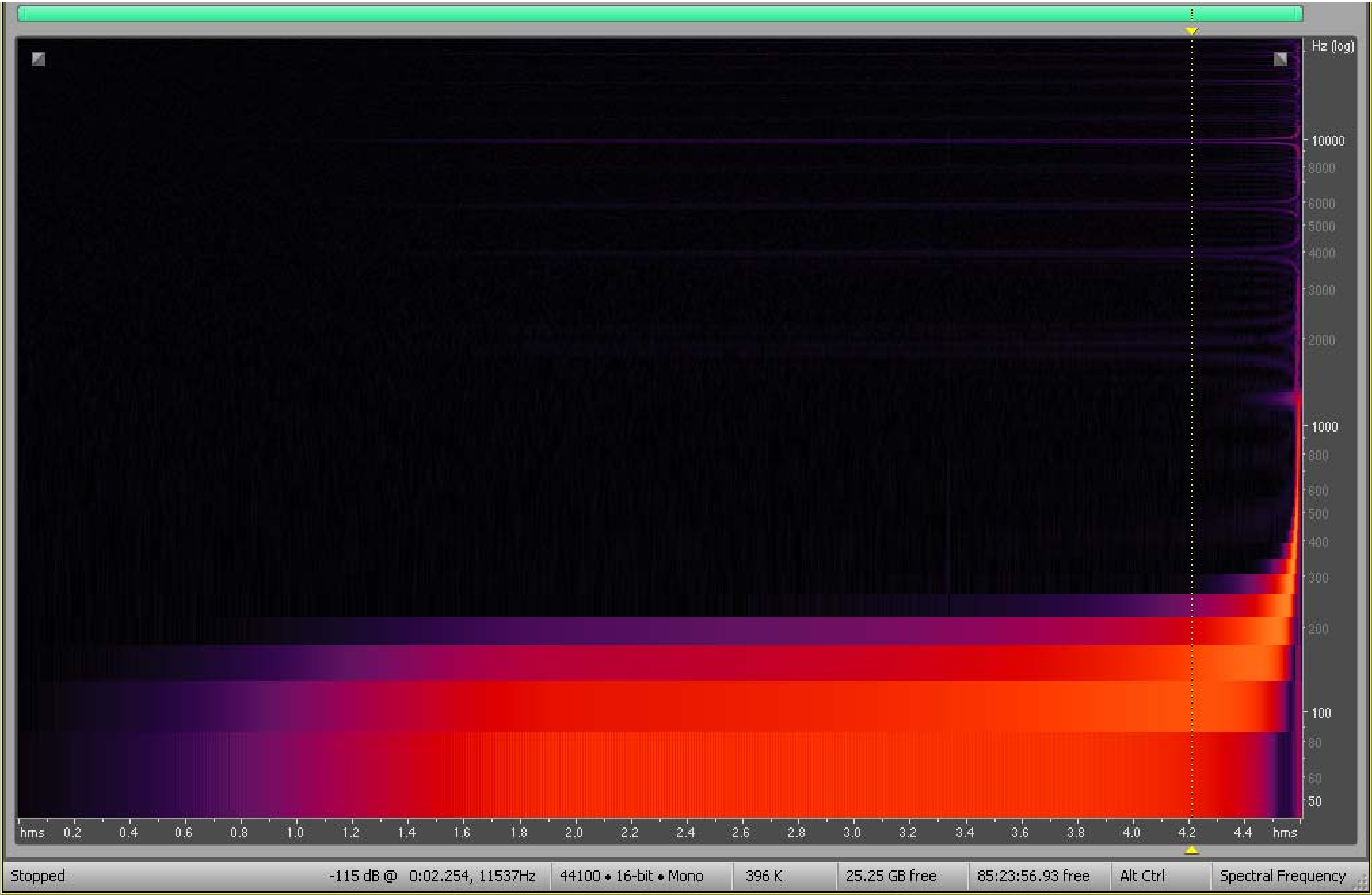
VETOES

- Interferometer subsystem and physical environment monitor signals decide data quality
  - statistical correlation to GW channel
  - stimulus/response measurement to GW channel
  - need to establish veto does not eliminate GW
  - need to determine effectiveness/duty cycle loss
- Highly interactive procedures with results that change with state of the instrument
- Still learning how to do this

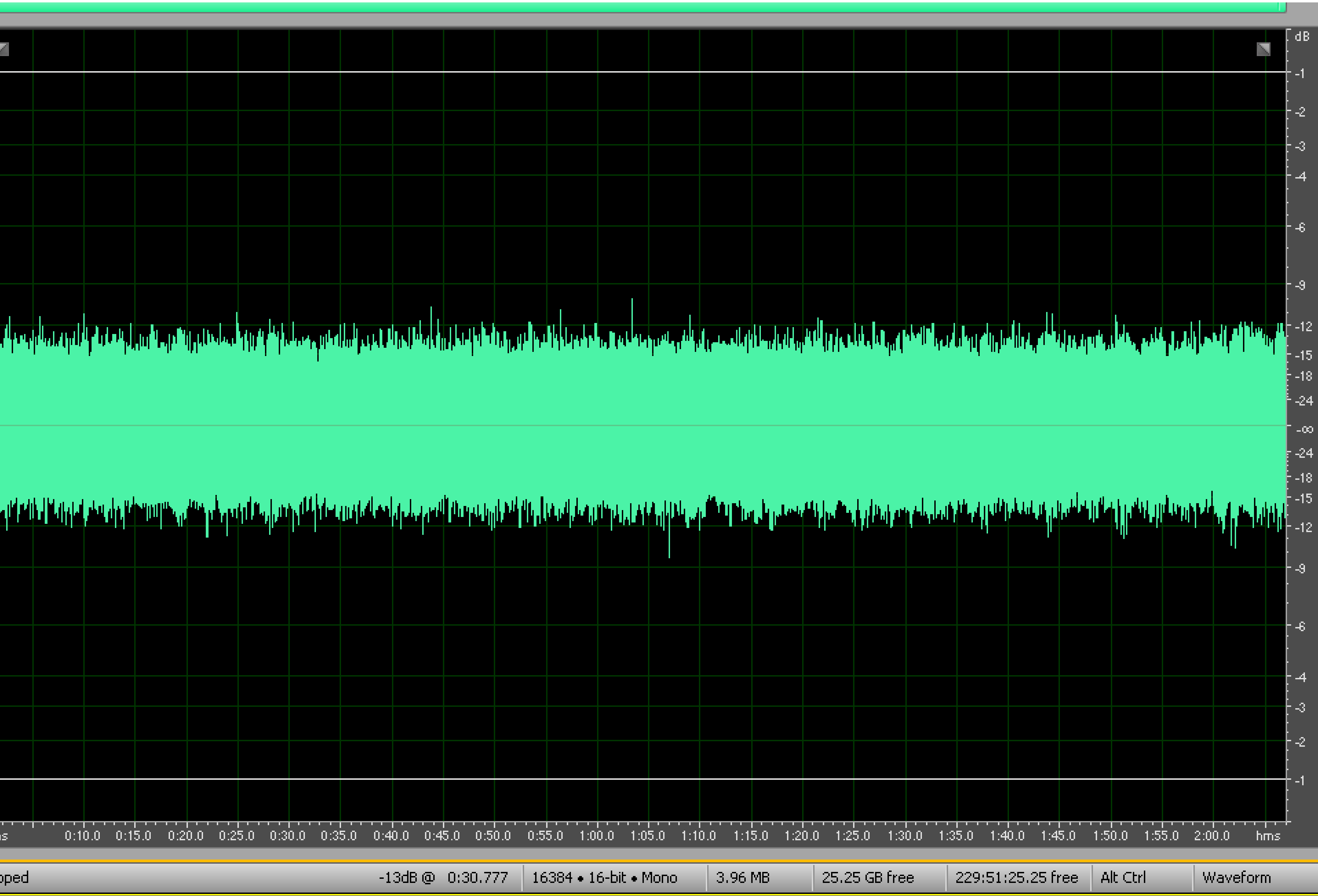
5 solar mass BH binary inspiral



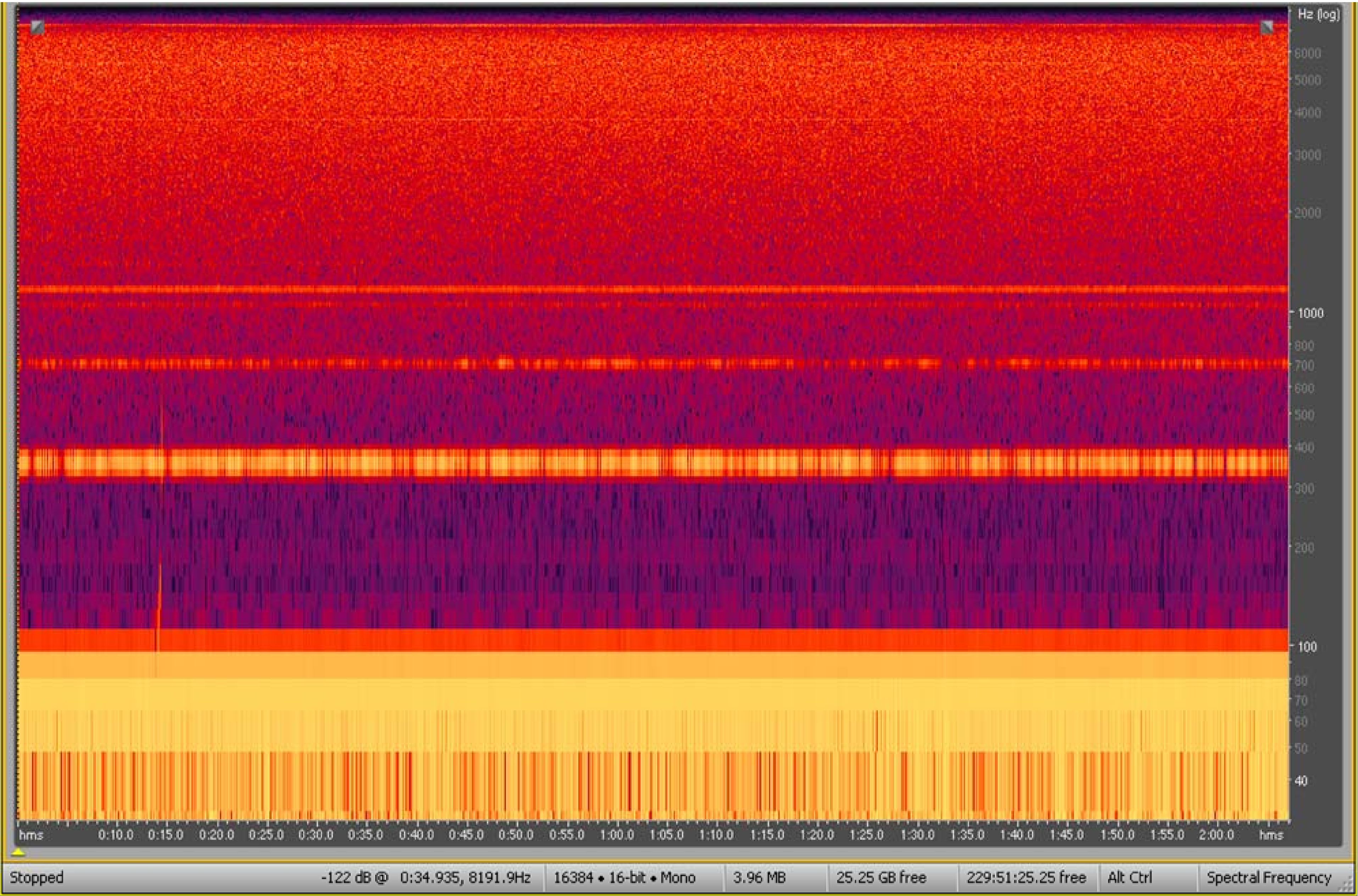
5 solar mass BH inspiral spectrum vs time



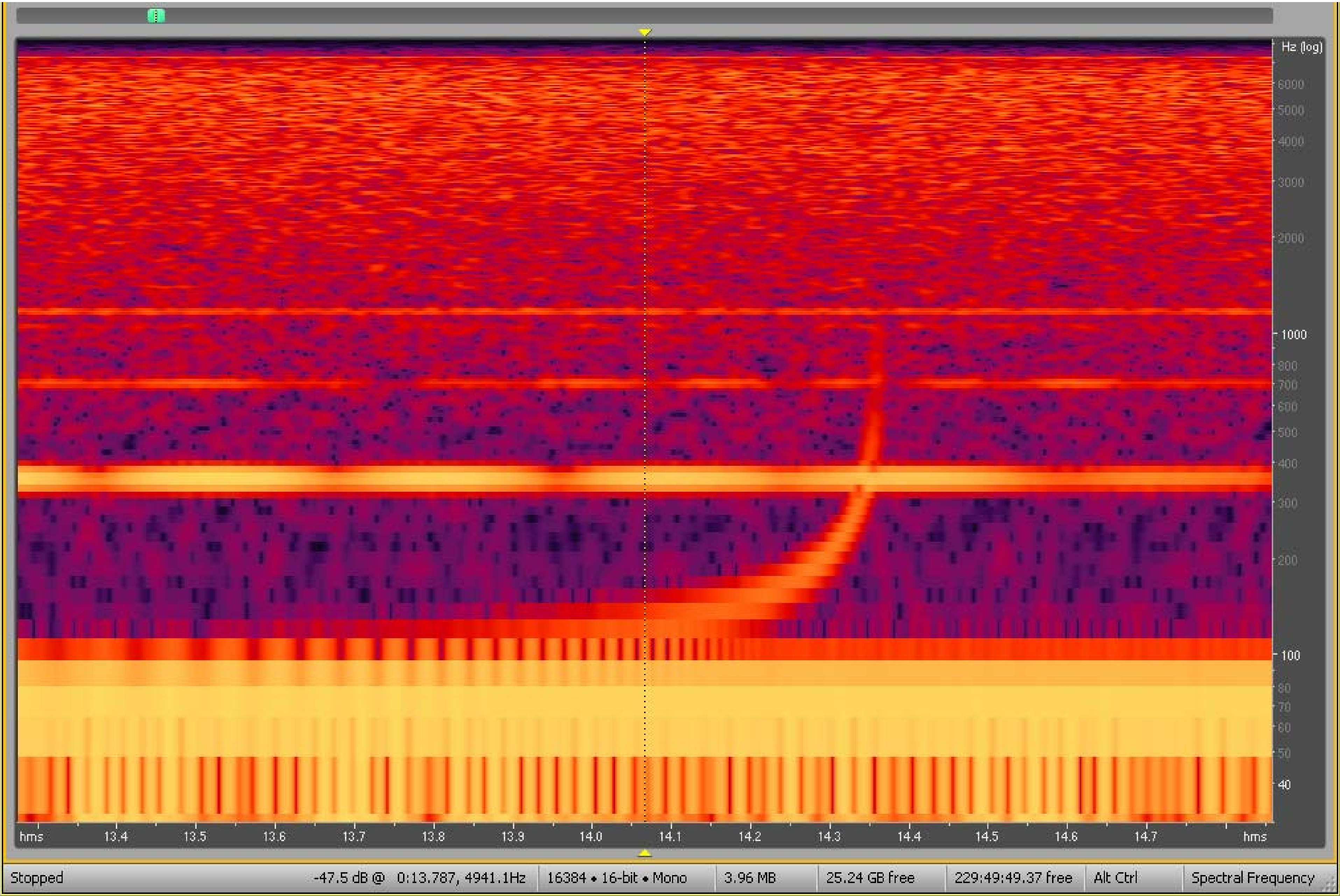
5 solar mass BH inspiral at 20Mpc in VIRGO measured in S5 at L1



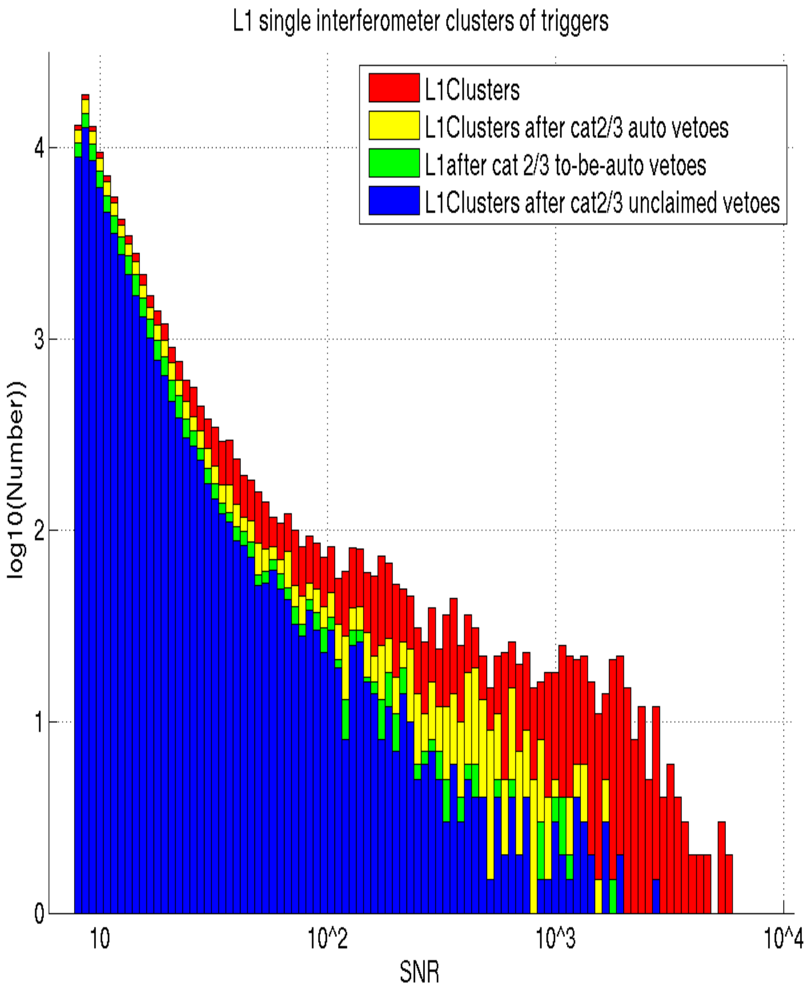
Spectrum vs time of 5 solar mass BH inspiral at 20Mpc VIRGO in S5 in L1

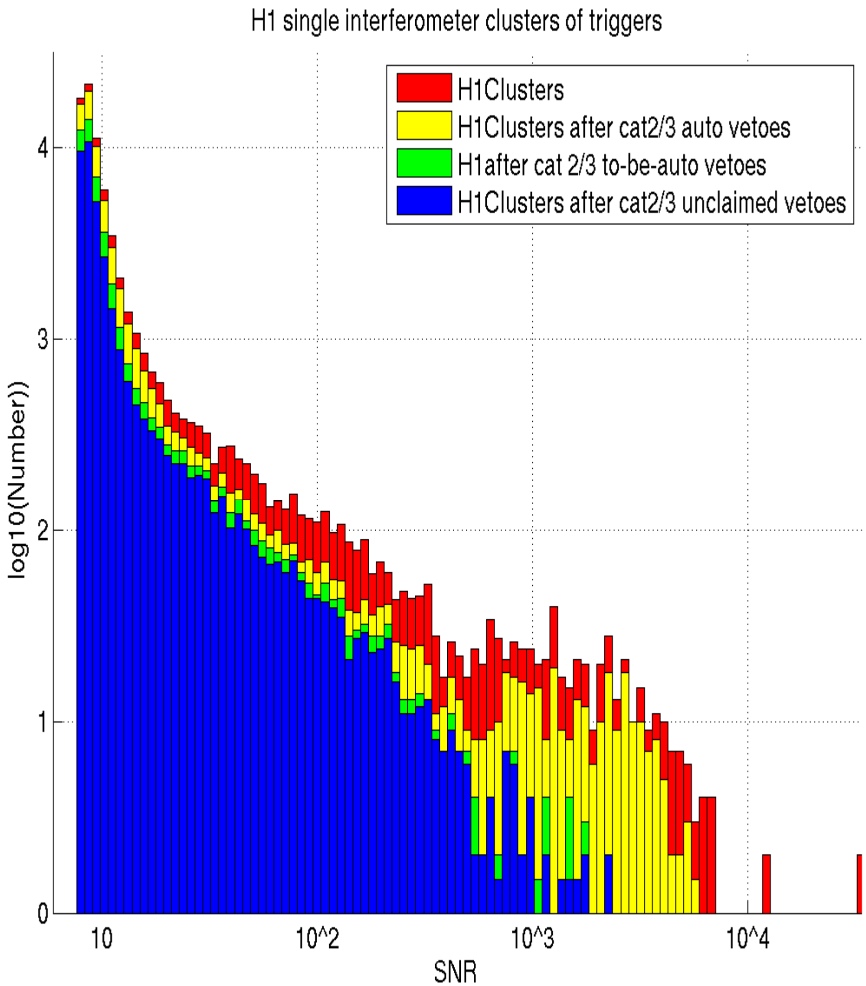


Enlargement of time axis of the previous slide

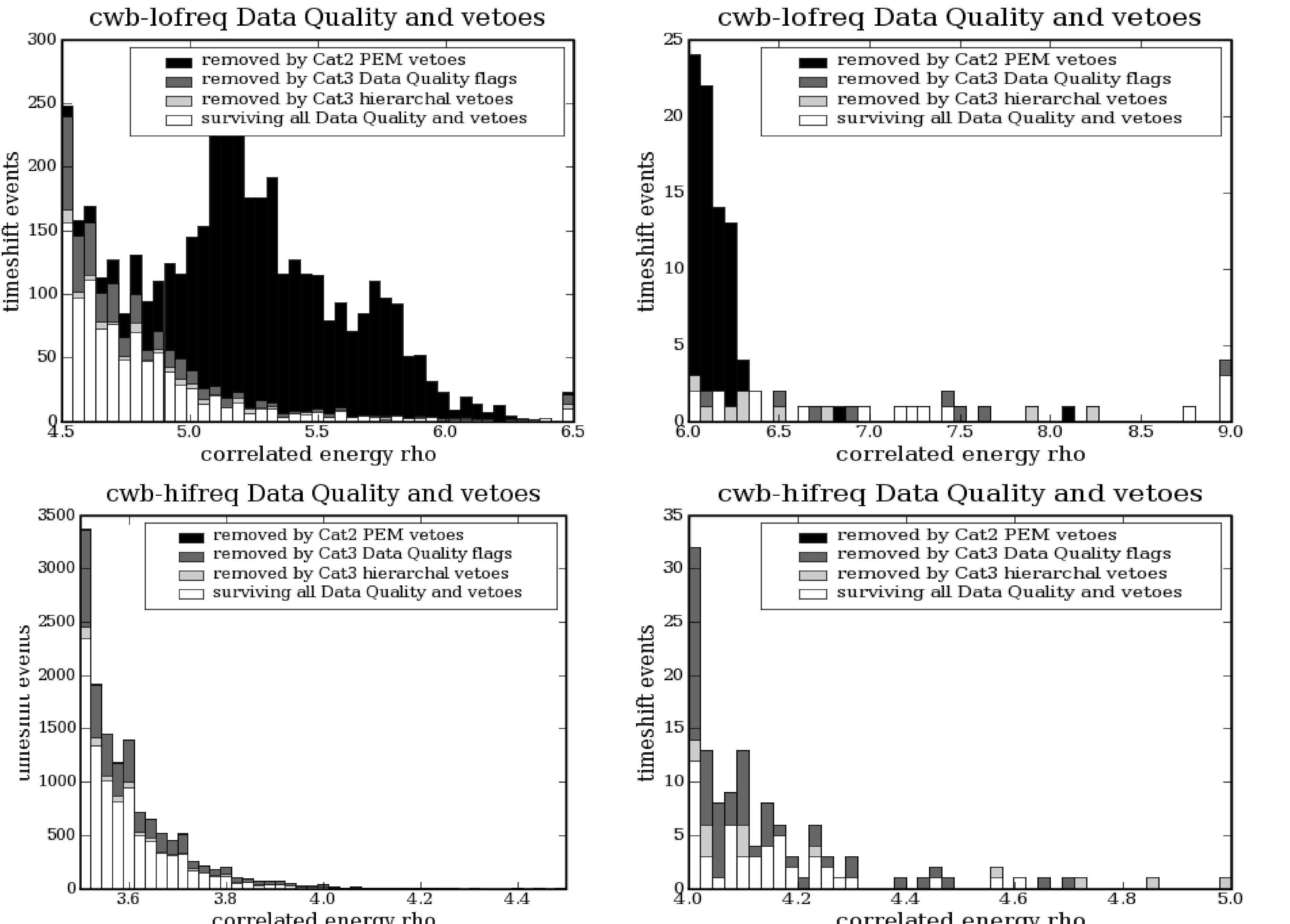


NS/NS binary inspiral triggers in the year 1 of S5 in L1 and H1



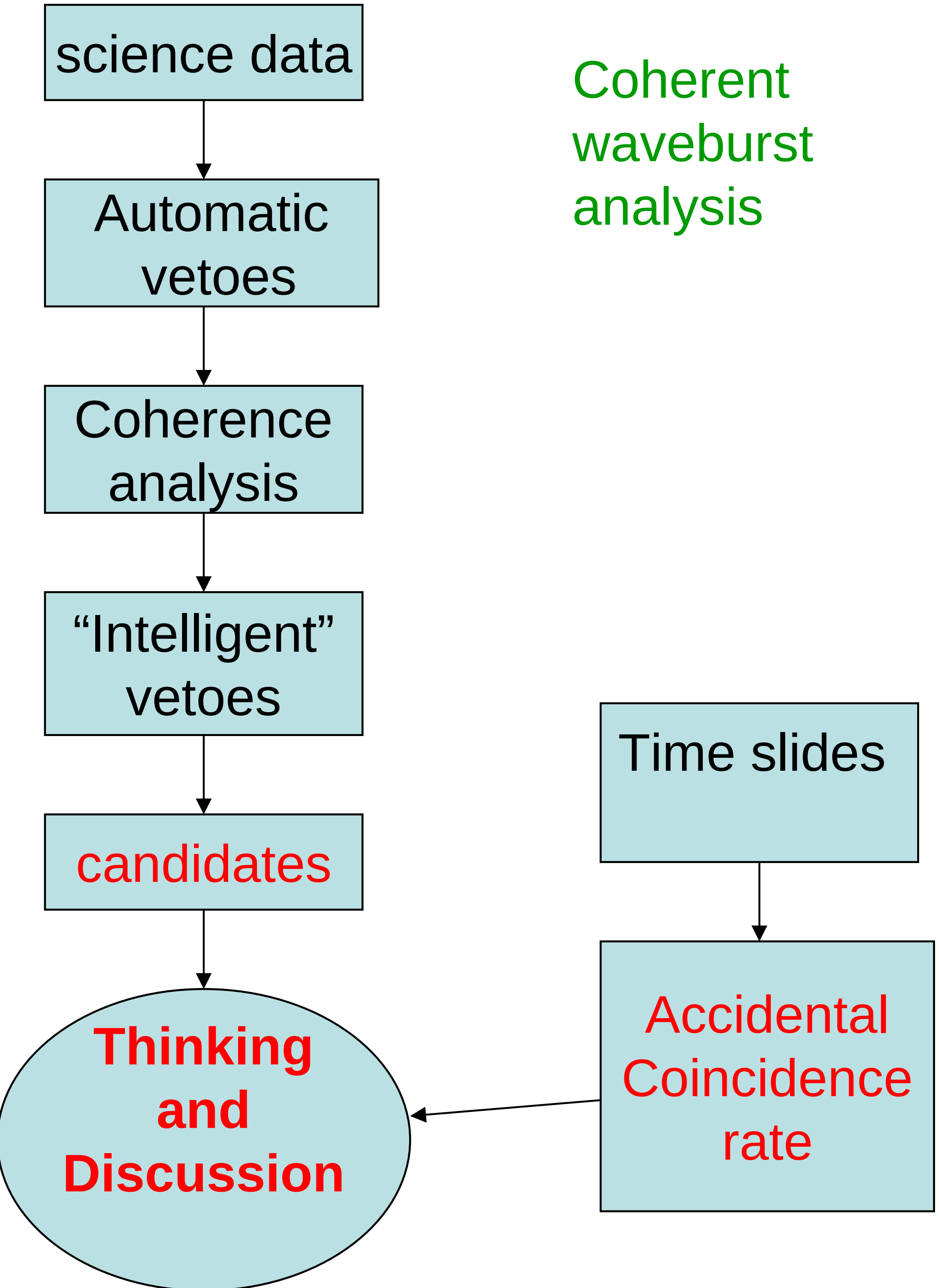


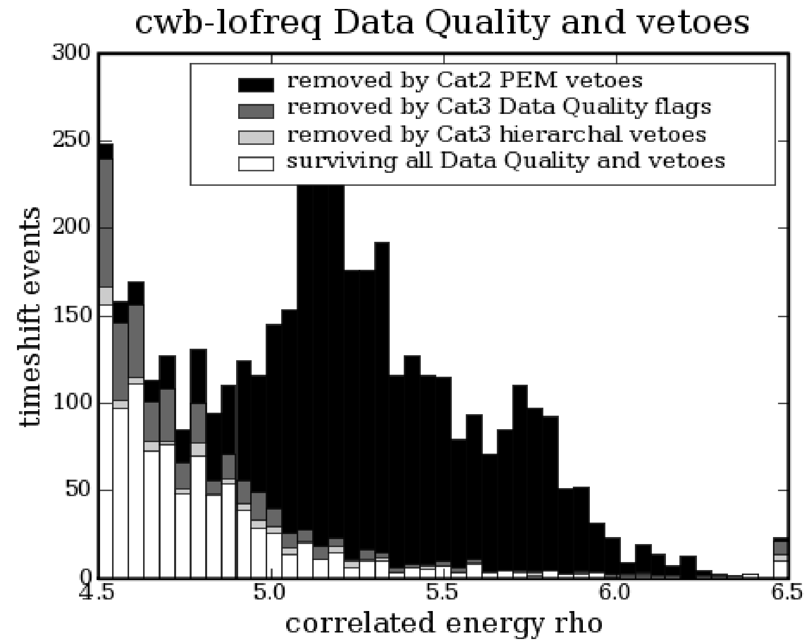
Jake Slutsky LSU

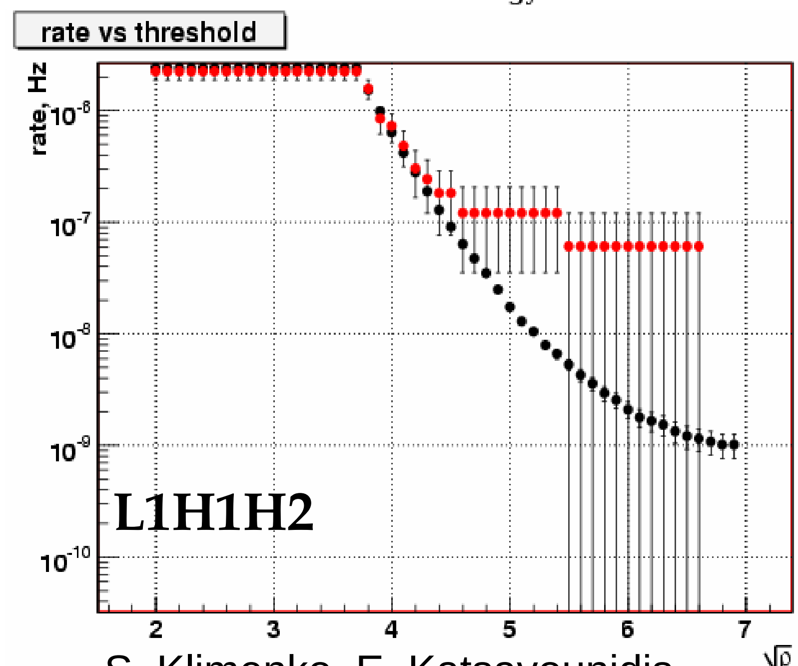


L. Blackburn, S. Klimenko

Coincidence rate estimation



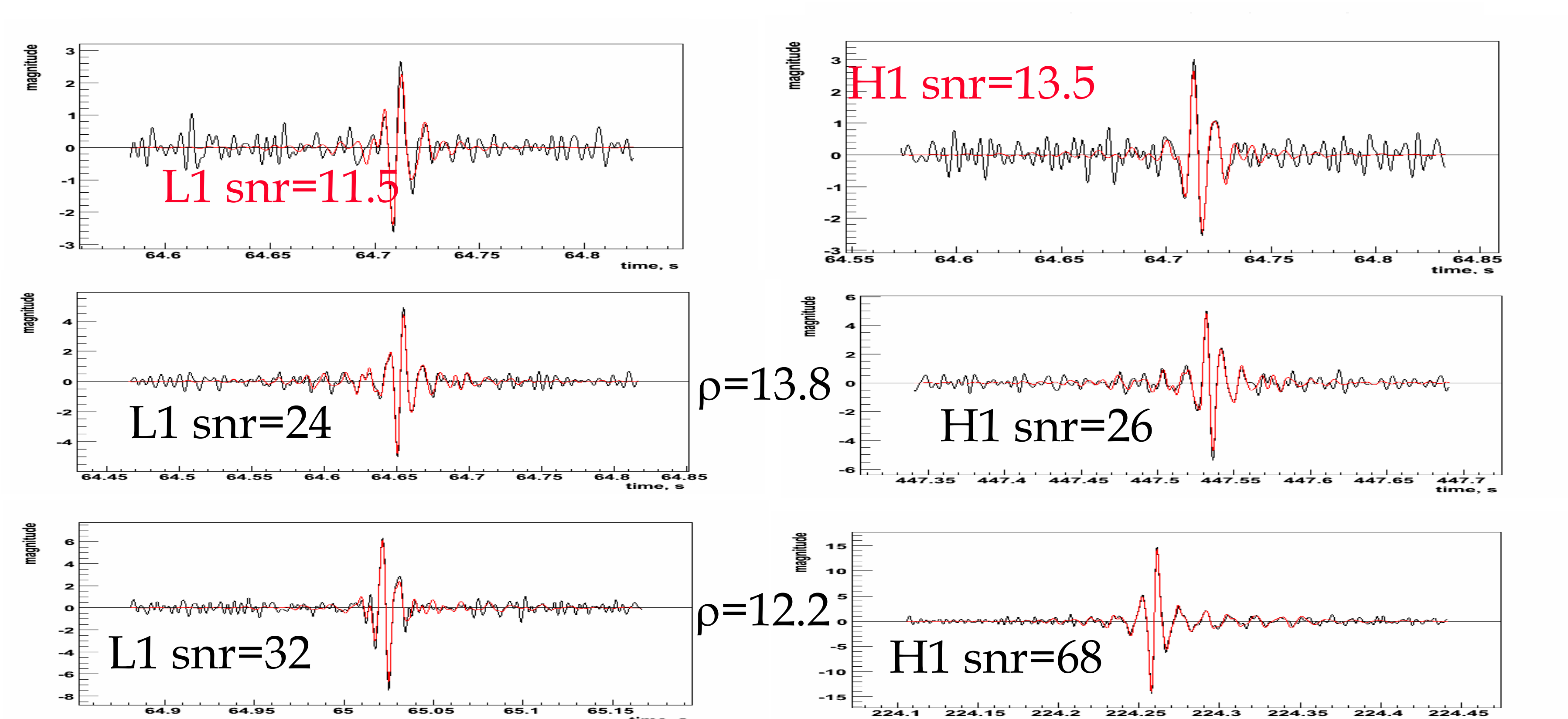




S. Klimenko, E. Katsavounidis

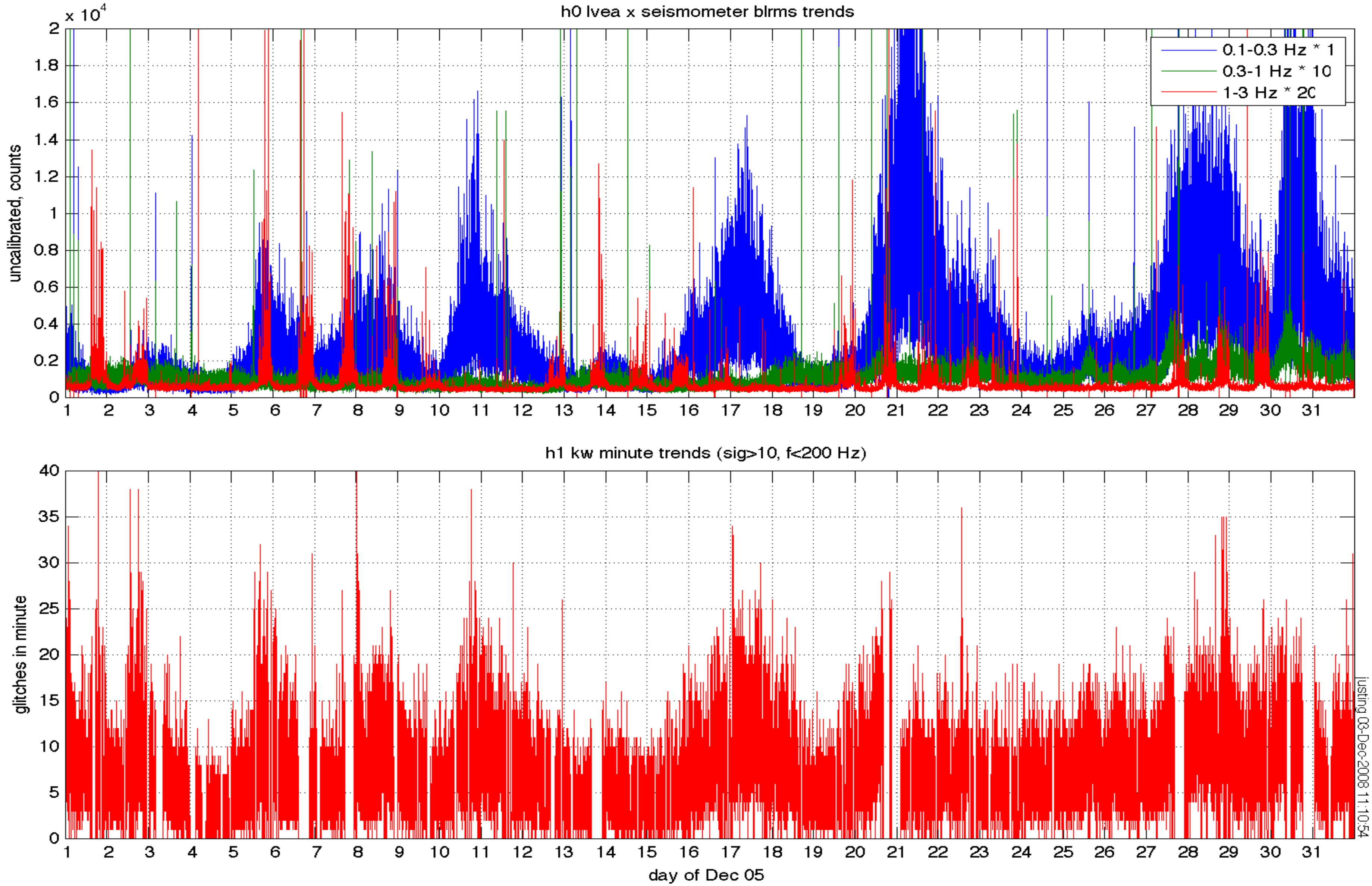
Constant background (L1H1H2) in S5

- **S5 events reconstructed by cWB**
  - –black – bandlimited detector responses
  - –red – reconstructed responses as if produced by a common GW signal
- **Pass the coherence test**



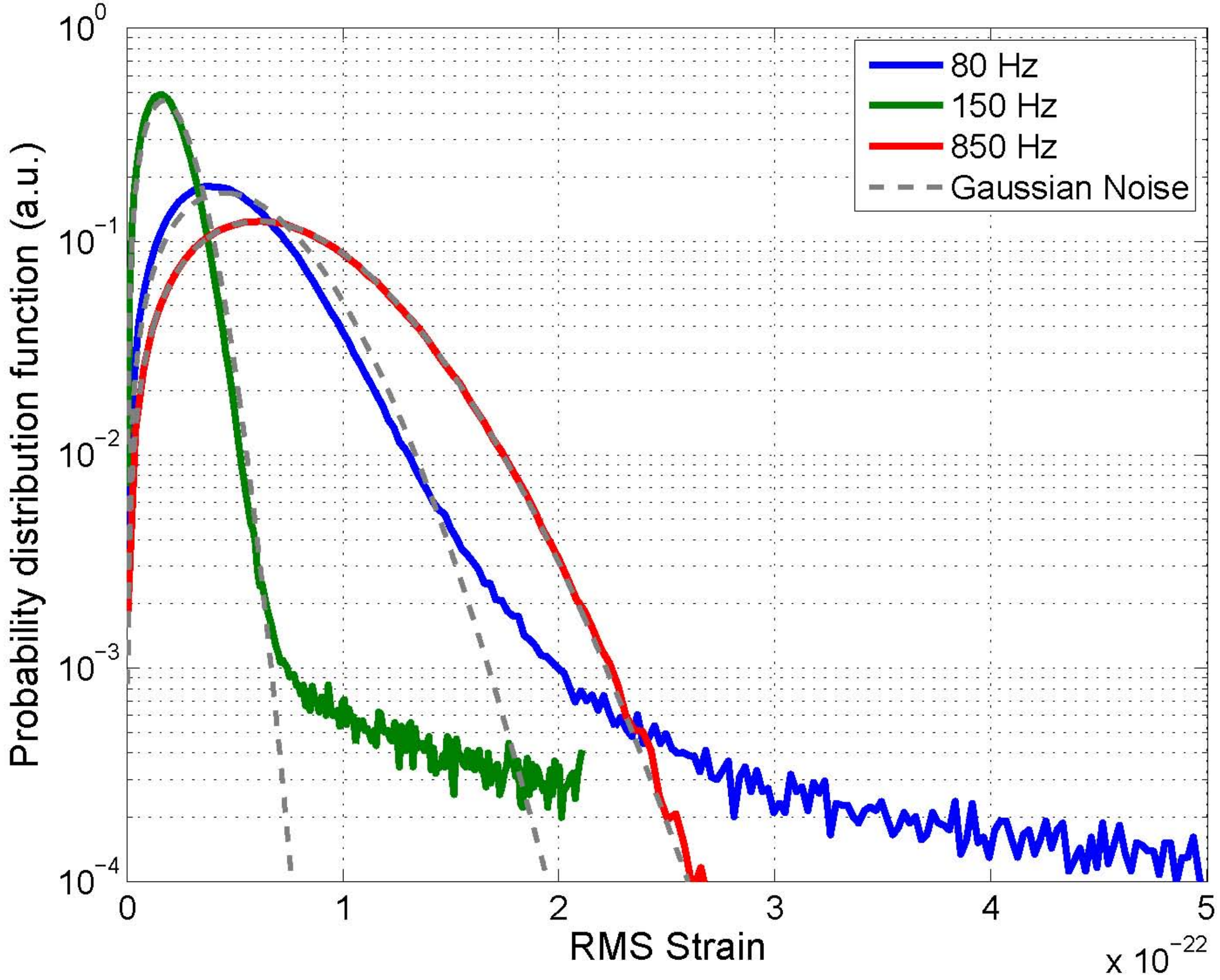
S. Klimenko, Univ of Florida

Up-Conversion: Seismic noise to pulses few oscillations at ~100Hz



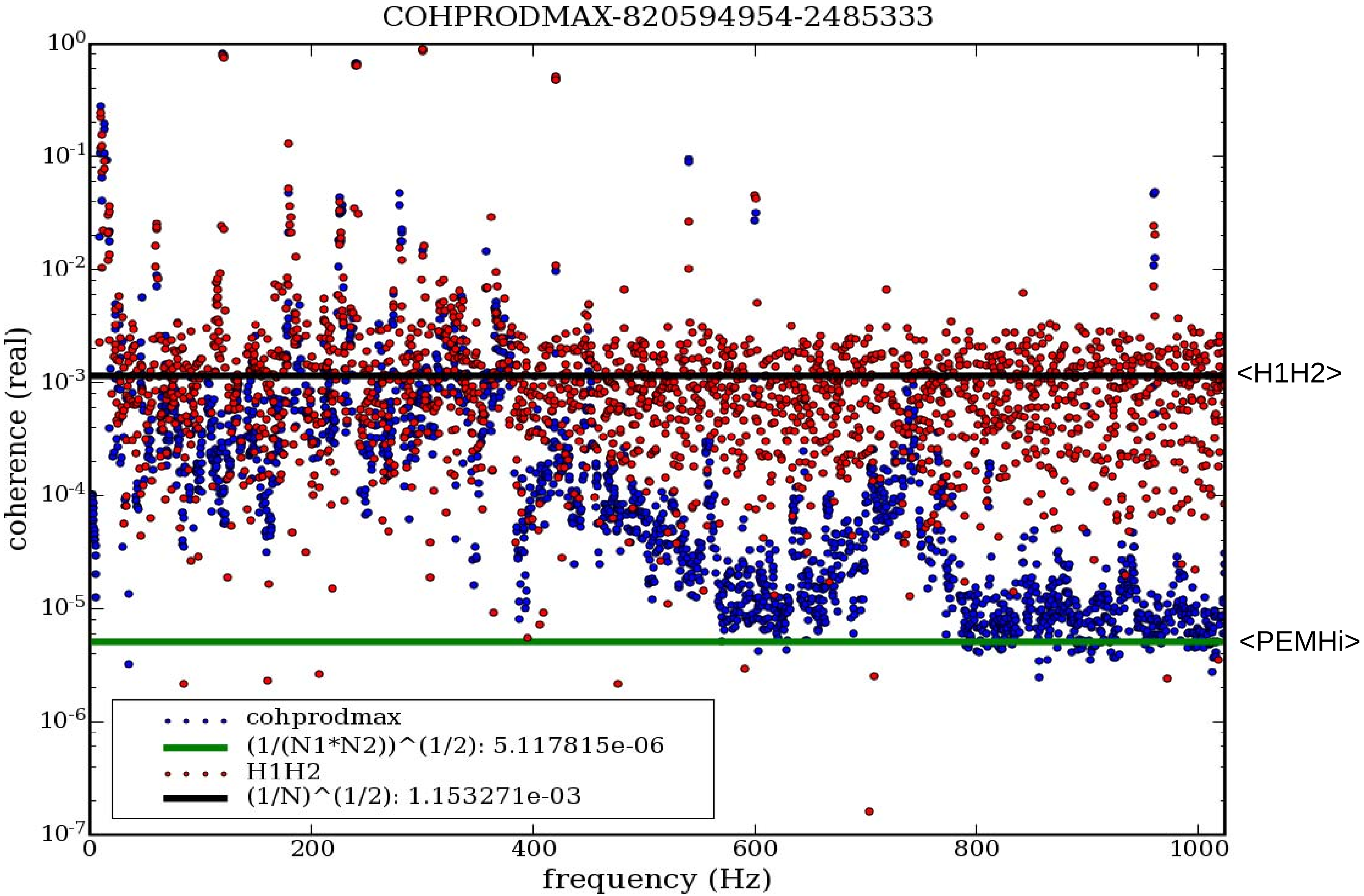
Justin Garofoli Syracuse

Rayleigh Distribution in Narrow Frequency Bands



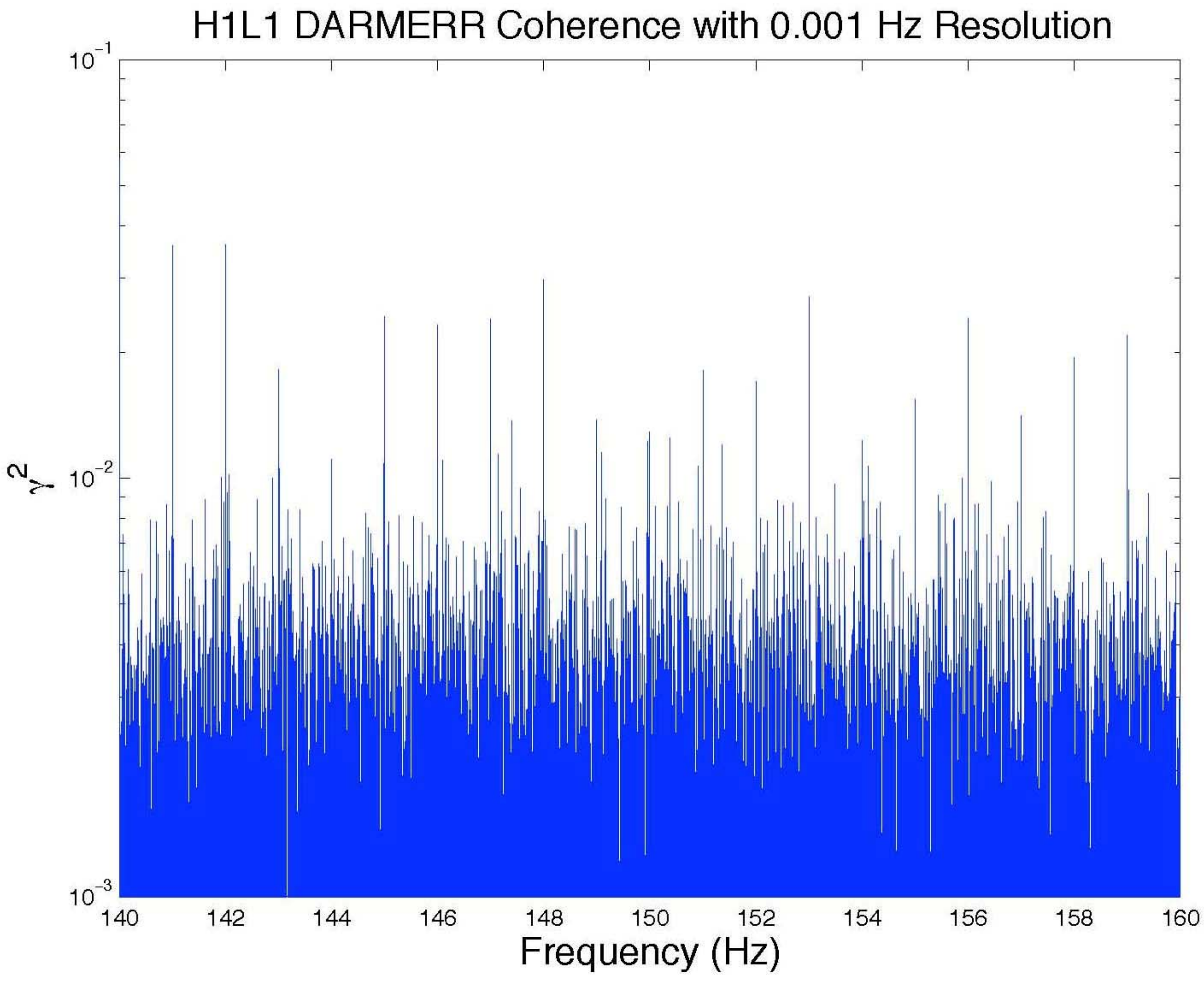
Sam Waldman

Coherence between H1,H2 and PEM vs Frequency



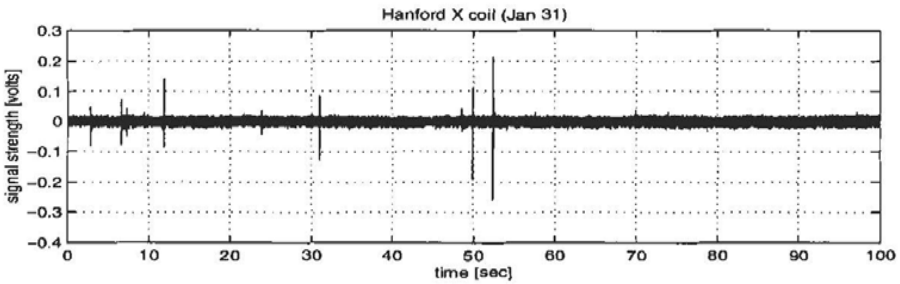
Nelson Christensen, Carleton College

Coherence between L1 and H1 vs Frequency



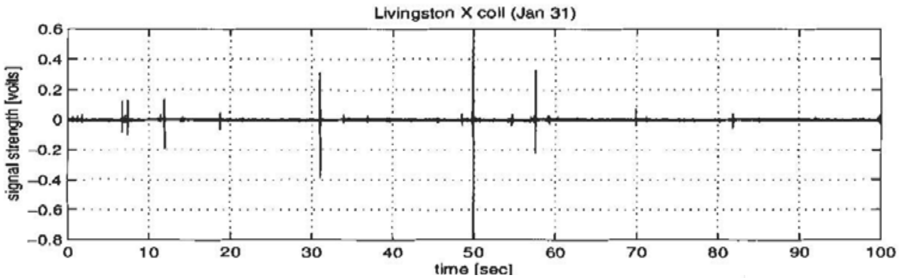
Vuc Mandic Univ of Minnesota

Magnetic pulses at H1 and L1: Lightning

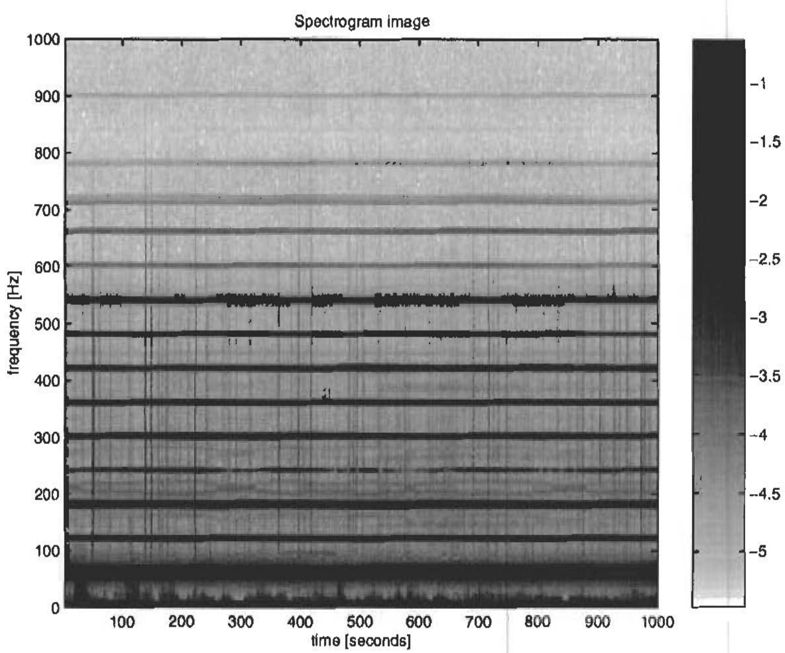


H1

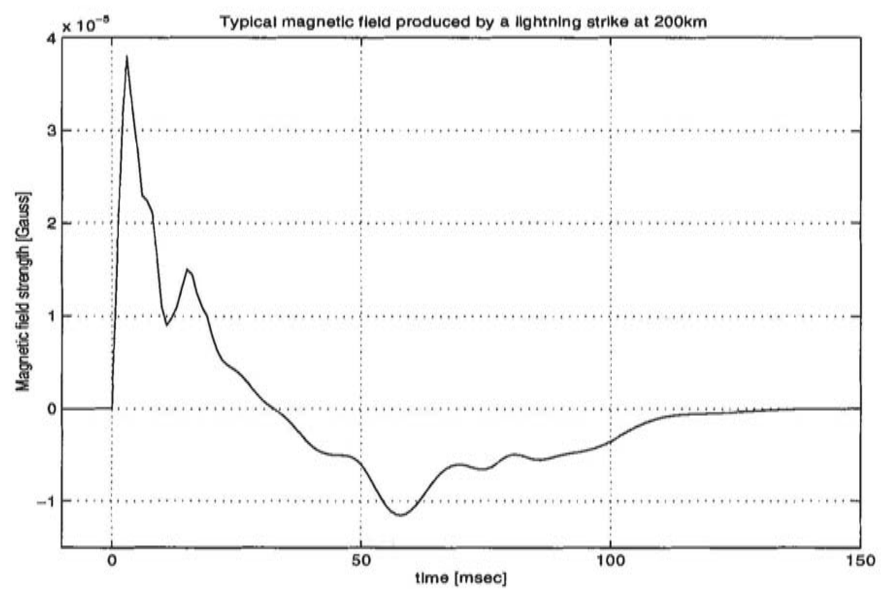
Magnetic field correlations at H1 and L1 from thunderstorms. Data from large coil magnetometers.



L1



Magnetic field vs time



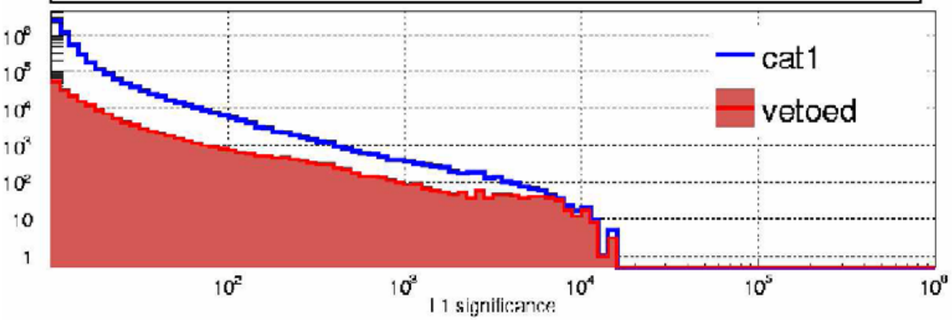
Sarah Veatch

Last words

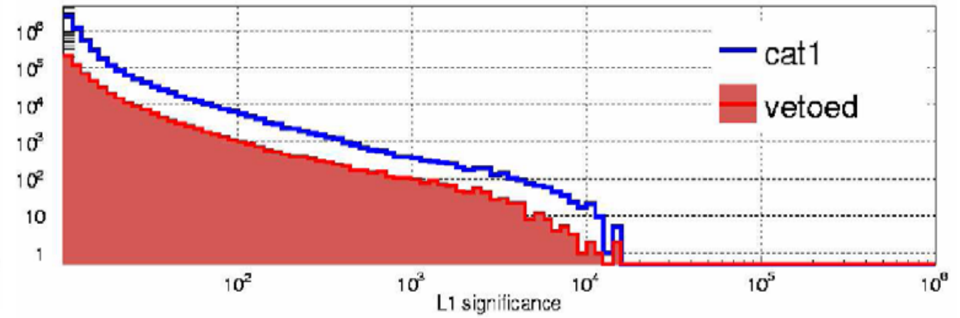
- David Reitze and Maria Alessandra Papa show some interesting results despite what I have told you.
- The combined efforts of the data analysts and the instrument commissioners are the way to reduce the non-Gaussian and non-stationery behaviour of the instrument.

Effect of data quality flags on L1 glitches (S5-year1)

DeadTime:	220164/19123335	=	1.1%
Significance > 10	190368/ 5060612	=	3.8%
Significance > 35	21446/ 168072	=	12.8%
Significance > 50	14757/ 101538	=	14.5%
Significance > 100	7908/ 40541	=	19.5%
Significance >1000	955/ 3037	=	31.4%



DeadTime:	1124227/19123335	=	5.9%
Significance > 10	569721/ 5060612	=	11.3%
Significance > 35	31016/ 168072	=	18.5%
Significance > 50	19018/ 101538	=	18.7%
Significance > 100	8132/ 40541	=	20.1%
Significance >1000	737/ 3037	=	24.3%



Blue trace: histogram of the glitch significance **after** "category-1" flags (include out-of-science mode, 30 seconds before lock-loss, corrupted data, hardware injections, PD saturations, calibration line dropouts)

Red-filled histogram: glitches **vetoed** by "category-2" flags (include saturations in the alignment control system, glitches in the power mains, uncertain calibration, and large glitches in the thermal compensation system)

Red-filled histogram: glitches **vetoed** by "category-3" flags (include 120 s prior to lock-loss, noise in power mains, transient drops in the intensity of the light stored in the arm cavities, times when one Hanford instrument is locked, times with particularly poor sensitivity, and times associated with severe seismic activity, high wind speed, or hurricanes.

Punch line: by using category 2&3 data quality flags alone (without event-by-event vetoes), a ~7% loss in livetime rejects more than 50% of the outliers

E. Katsavounidis