

# LSC Participation in Initial LIGO Detector Characterization

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Chair, LSC D.C. Working Group

# Elements of Detector Characterization

- Commissioning
- Online Diagnostics
- Environmental Monitoring (hardware)
- Offline Data Monitoring
  - » Performance Characterization
  - » Transient Analysis (subgroup chair: Fred Raab)
- Data Set Reduction (subgroup chair: Jim Brau)
- Data Set Simulation
  - » Parametrized simulation (subgroup chair: Sam Finn)
  - » End-to-End Model

# Goals of Working Group on Detector Characterization

- Quantify “Steady-State” Behavior of IFO’s
  - » Monitor instrumental & environmental noise
  - » Measure channel-to-channel correlations
  - » Quantify IFO sensitivity to standard-candle GW sources
  - » Characterization includes both description & correction
- Identify transients due to instrument or environment
  - » Avoid confusion with astrophysical sources
  - » Identify & correct contamination in data stream
  - » Diagnose and fix recurring disturbances

# Examples of Ambient Noise

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- Seismic
- Violin modes
- Internal mirror resonances
- Laser frequency noise
- Electrical mains (60 Hz & harmonics)
- Coupling of orientation fluctuations into GW channel
- Electronics noise (RF pickup, amplifiers, ADC/DAC)

# Examples of Transients

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- Earthquakes, Trains, Airplanes, Wind Gusts
- Army tanks firing (!)
- Machinery vibration
- Magnetic field disturbances
- Wire slippage
- Violin mode ringdown
- Flickering optical modes
- Electronic saturation (analog / digital)
- Servo instability
- Dust in beam

# Characterization Methods

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- Measured optical, RF, geometrical parameters
- Calibration curve
- Statistical trends & analysis (outliers, likelihood)
- Power spectra
- Time-frequency analysis
  - » Band-limited RMS
  - » Wavelets
- Principal value decomposition
- Non-linear couplings measurement
- Matched filters

# Evolution of LSC Detector Characterization Efforts

- Initial work:
  - » Developing infrastructure of online characterization tools:
    - Data Monitor Tool (DMT -- J. Zweizig)
    - Diagnostic Test Tool (DTT -- D. Sigg)
  - » Developing software tools & monitors for DMT (broad effort)
- Moving toward 2nd phase - two-pronged approach:
  - » Investigations focussed on engineering runs
    - 15 teams formed for E2 (Nov 2000)
    - 13 teams formed for E3 (March 2001)
    - Prelim reports from all E2 teams given at monthly DetChar telecons
    - Final presentations & written reports due at March LSC meeting
  - » Participation in four Upper Limits Working Groups for E6
    - Special session at March LSC meeting to identify where help needed

# Software Developed for the Data Monitor Tool (DMT)

<b>DMT Monitors</b>	<b>Scientists</b>	<b>Institutions</b>	<b>Online code available?</b>
Line Noise Monitoring	B. Allen, A. Ottewill S. Klimenko A. Sintes	UWM, Dublin Florida AEI-Potsdam	Yes Yes*
Seismic Noise Monitoring	E. Daw	LSU	Yes*
Inter-Channel Correlations	B. Allen, A. Ottewill	UWM, Dublin	Yes*
Bilinear Cross Couplings	S. Penn	Syracuse	Yes*
Band-limited RMS Monitor	E. Daw	LSU	Yes*
Non-Gaussian noise	L.S. Finn, G. Gonzalez	Penn State	
Power Spectral Transients	S. Mohanty	AEI-Potsdam	
Servo Instability Monitor	D. Chin, K. Riles	Michigan	Yes*
Event Catalog	J. Sylvestre	LIGO-MIT	Yes*
Adaptive Transient Detection	E. Chassande-Mottin	INFN	
Impulse Recognition	M. Ito	Oregon	Yes*
Magnetic Field Transients	R. Frey, R. Rahkola	Oregon	Yes*
Lock transitions	D. Chin, K. Riles	Michigan	Yes*
Power Mains Monitor	D. Sigg	LIGO-LHO	Yes*
GPS Time Ramp Monitor	S. Marka	LIGO-CIT	Yes*
Pre-Stab. Laser Glitches	R. Savage, J. Zweizig	LIGO-LHO/CIT	Yes*
Data Integrity (2 monitors)	J. Zweizig	LIGO-CIT	Yes*

<b>DMT Tools</b>	<b>Scientists</b>	<b>Institutions</b>	<b>Online code Available</b>
Operational State Conditions	D. Chin, K. Riles	Michigan	Yes*
Time-Frequency Plotting	S. Mohanty J. Sylvestre	AEI-Potsdam LIGO-MIT	Yes Yes*
Wavelet Analysis Tools	S. Klimenko	Florida	Yes*

\*Used in E2 and/or E3 engineering run & subsequent analysis

# Where does LDAS fit in?

- Detector characterization used online for diagnosis / warnings and offline for interpreting data
- Characterization conveyed downstream to LDAS via meta-database and frame-contained constants
- Meta-database entries (examples)
  - » Calibration constants and power spectra
  - » Environmental noise measures
  - » Cross-coupling coefficients (for regression)
  - » Line noise strength and phase
  - » Triggers (for veto or “handle with care”):
    - Environmental disturbances
    - Excess noise or unstable conditions

# Other Detector Characterization Software Tools from LSC

- Data Set Reduction:
  - » Wavelet methods (lossless & lossy) -- Sergey Klimenko (Florida)
  - » Data set summary -- Benoit Mours (Annecy/CIT) et al
  - » Data channel selection -- David Strom (Oregon)
- Data Set Simulation - Parametrized
  - » SimData package -- Sam Finn (Penn State)
    - Time domain simulation tool (shot noise, radiation pressure, thermal substrates, suspensions, seismic)
    - Integrated into End-to-End Model

# Engineering Run Investigations (E2 - November 2000)

Investigation	Scientists
Lock losses	Michigan: D. Chin, R. Gustafson, K. Riles* Oregon: M. Ito Rochester: W. Butler
Seismic noise	CIT: D. Ugolini LSU: E. Daw* Oregon: R. Schofield
Cross-correlations with GW channel	Carleton: N. Christensen* Dublin: A. Ottewill
Stationarity	LSU: E. Daw Oregon: R. Schofield* Syracuse: P. Saulson
Calibration stability	Ancey/CIT: B. Mours CIT: L. Matone, P. Shawhan LHO: M. Landry*
Non-Gaussianity	ANU: S. Scott CIT: V. Sannibale Syracuse: S. Penn*
Angular fluctuations	CIT: B. Bhawal LHO: D. Ottaway Penn State: G. Gonzalez*, T. Summerscales

\*Investigation leader

# Engineering Run Investigations (E2 - November 2000)

Impulses	LHO: R. Savage* Oregon: R. Frey, R. Rahkola
Bursts & chirps	MIT: J. Sylvestre* Oregon: M. Ito, R. Rahkola
Tidal model	CIT: M. Barton LHO: F. Raab, H. Radkins Oregon: D. Strom*
Timing precision	CIT: S. Marka LHO: D. Sigg* Tokyo: A. Takamori
Data integrity	CIT: J. Zweizig*
Line noise	AEI-Potsdam: A. Sintes Annecy: R. Flaminio ANU: S. Scott Florida: B. Whiting, S. Klimenko*, B. Whiting
Data compression	Annecy/CIT: B. Mours* Florida: S. Klimenko
Frequency noise	CIT: H. Yamamoto MIT: R. Adhikari*, P. Fritschel, D. Shoemaker, J. Sylvestre, M. Zucker

\*Investigation leader

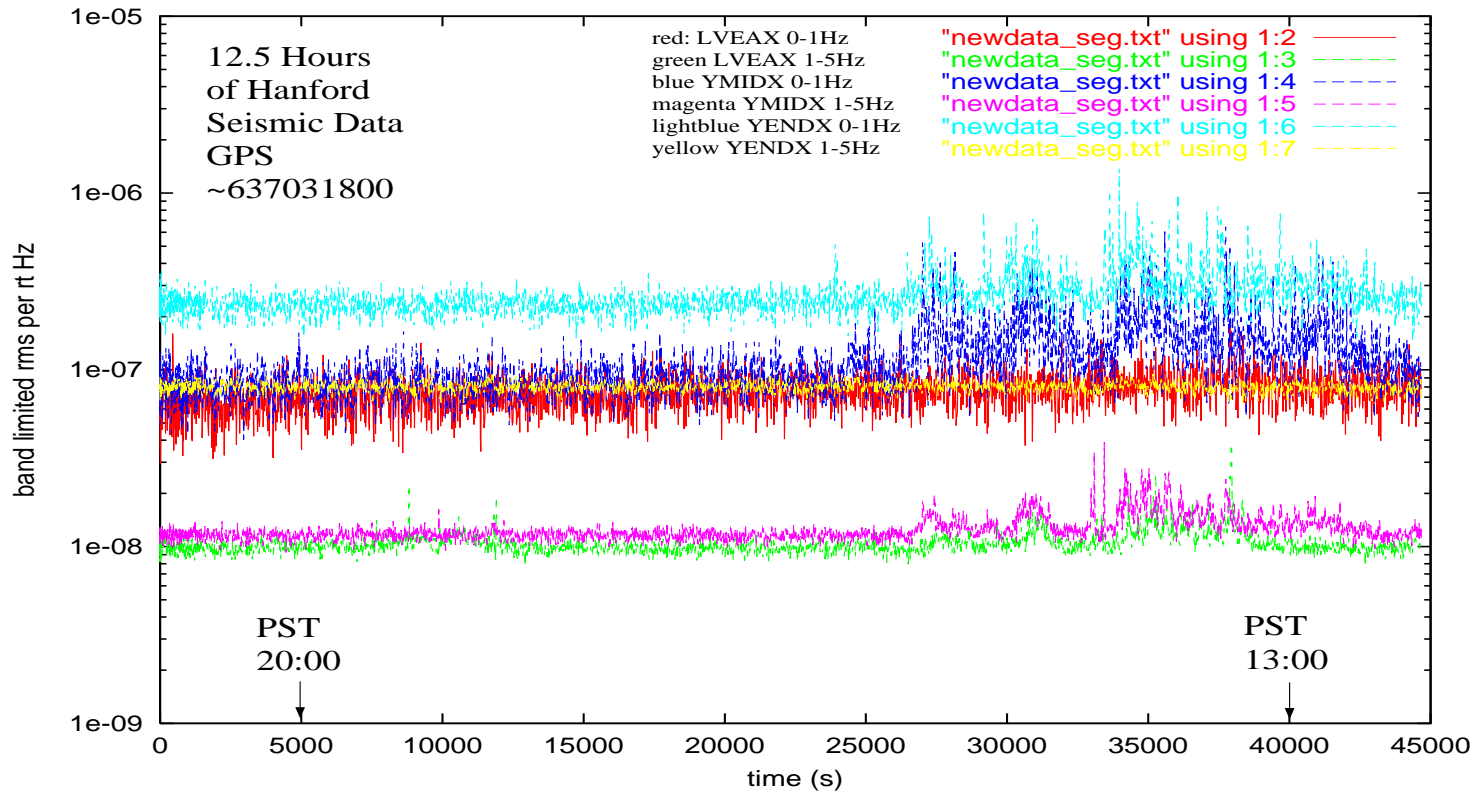
# Engineering Run Investigations (E3 - March 2001)

Investigation	Scientists
Seismic noise	CIT: P. Charlton* Louisiana Tech: D. Greenwood, N. Simicevic
Cross-correlations with GW channel	Carleton: N. Christensen* Dublin: A. Ottewill Syracuse: S. Penn
Inter-site environmental correlations	AEI-Potsdam: S. Mohanty LHO: M.Landry* Oregon: R. Rahkola, R. Schofield*
Catalog environmental disturbances	AEI-Potsdam: S. Mohanty MIT: J. Sylvestre Oregon: M Ito, R. Rahkola, R. Schofield* Syracuse: S. Penn, P. Saulson
Calibration stability	Annecy/CIT: B. Mours CIT: S. Marka, L. Matone LHO: M Landry* LSU: W. Johnson

# Engineering Run Investigations (E3 - March 2001)

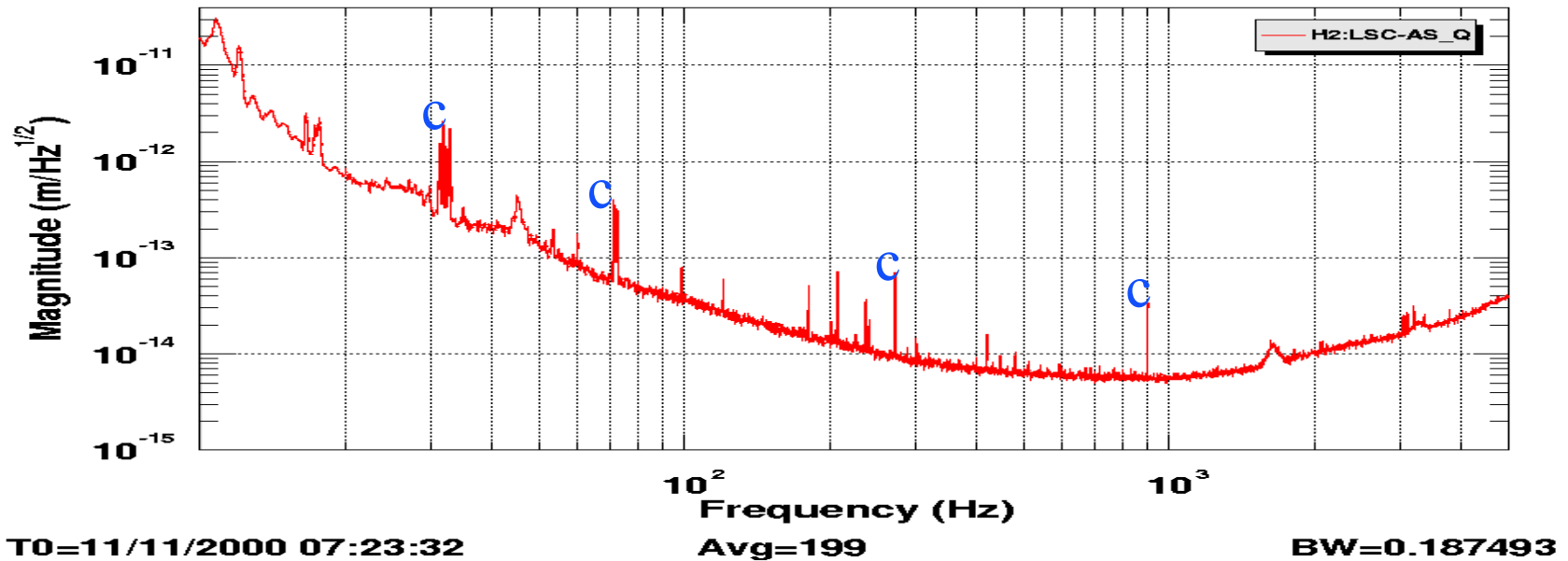
Angular fluctuations	Penn State: G. Gonzalez*, T. Summerscales
Tidal model	LHO: F. Raab* Oregon: D. Strom
Lock losses	Michigan: D. Chin, R. Gustafson, K. Riles* Oregon: M. Ito Rochester: W. Butler
Timing precision	CIT: S. Marka LHO: D. Sigg*
Data integrity	CIT: P. Shawhan, J. Zweizig*
Data merging	CIT: P. Shawhan*
Line noise	Florida: R. Coldwell, S. Klimenko*, B. Whiting
Frequency noise	CIT: A. Vicere MIT: R. Adhikari Wisconsin: D. Brown

# DMT Example: Seismic Noise Monitoring



LIGO-G010195-00-Z

# Engineering Run Results (Calibration studies)

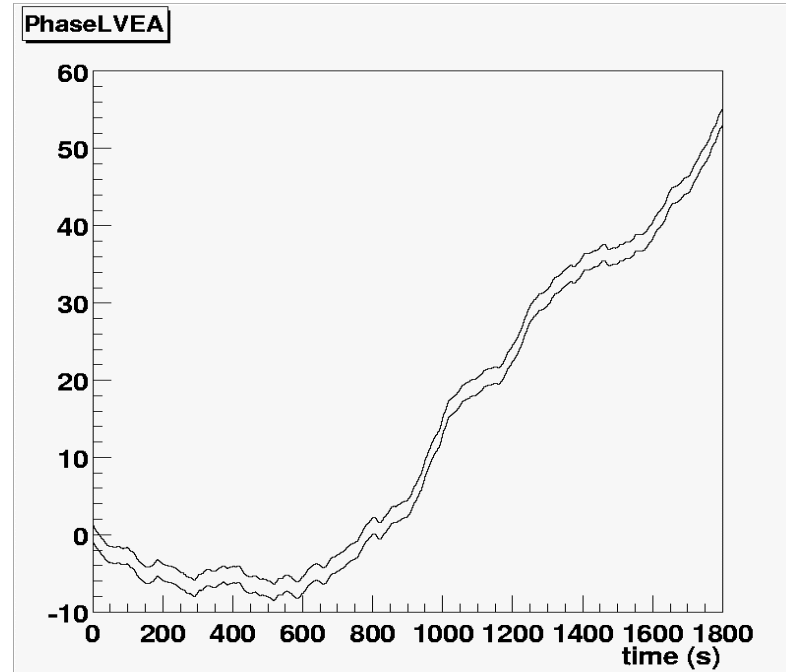
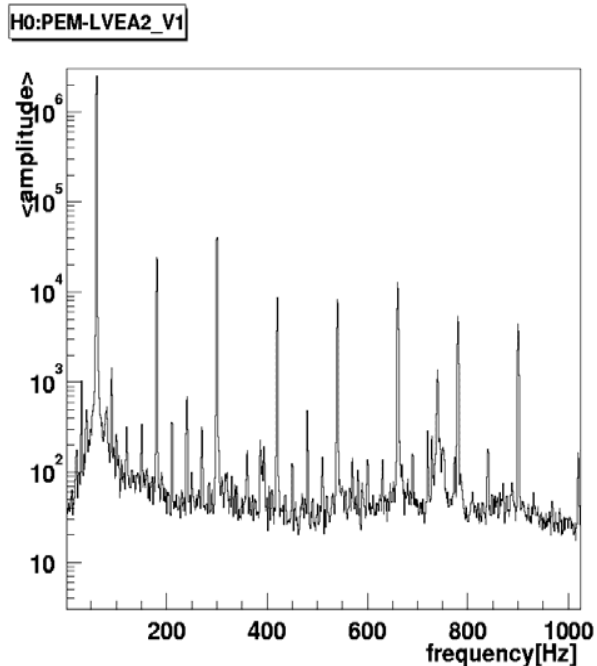


- Scale set by absolute calibration
- Visible calibration lines (“c”)
- 30% calibration accuracy

# Engineering Run Results (Line noise monitoring)

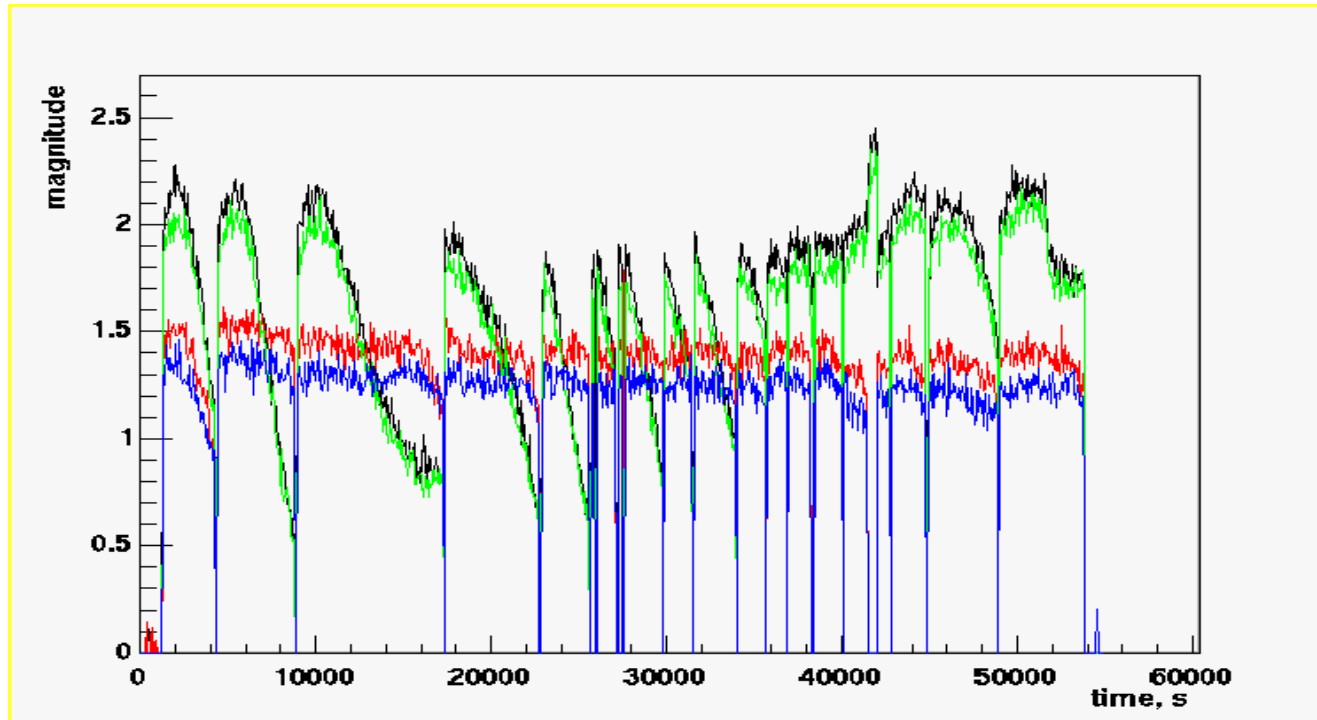
AC Power line monitor:

Phase of 60 Hz:



# Engineering Run Results (Line noise monitoring)

Tracking strength of injected calibration lines:  
(One arm stable; the other degrading with time in lock)



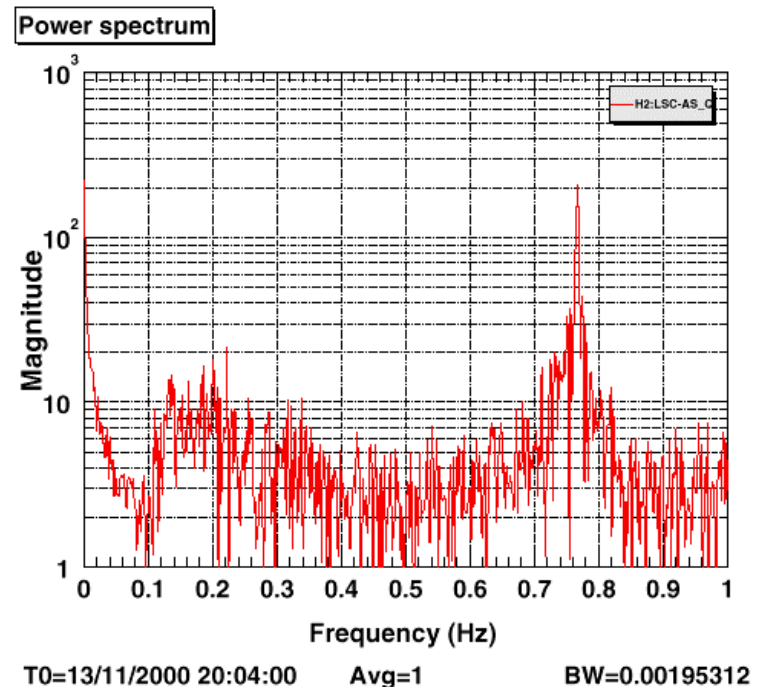
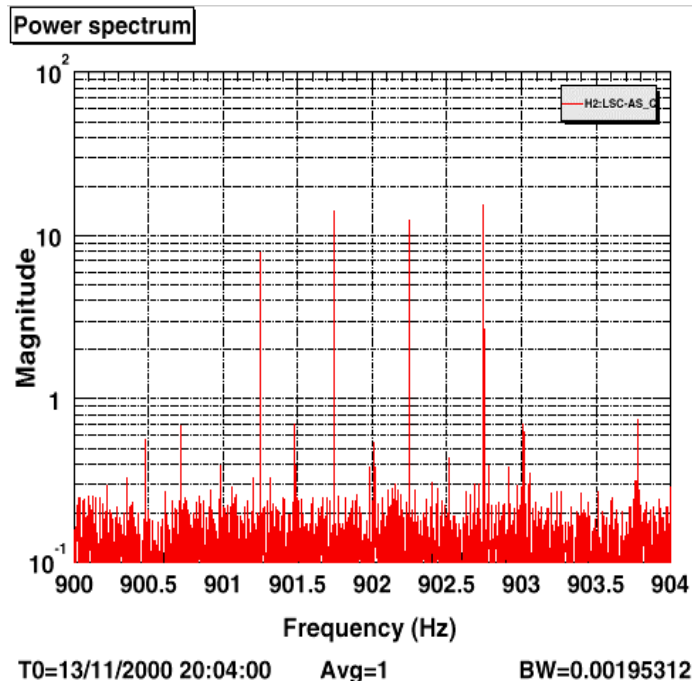
LIGO-G010195-00-Z

NSF Review - 2001.04.30

LIGO Scientific Collaboration - University of Michigan

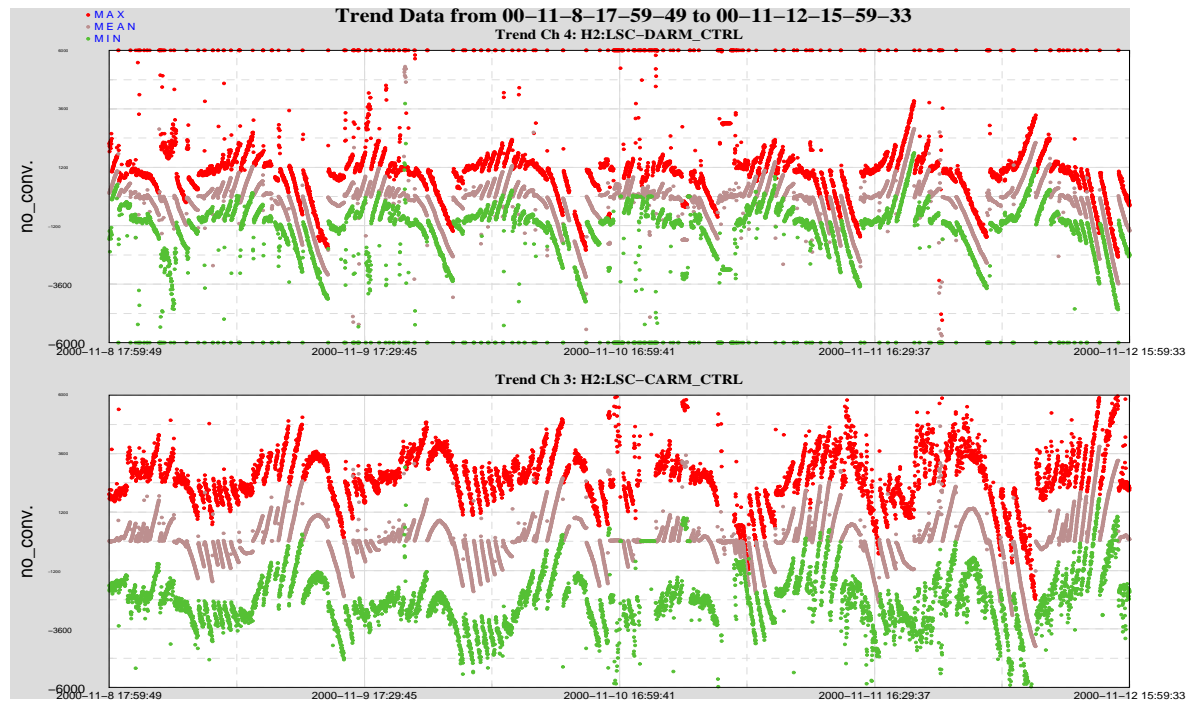
# Engineering Run Results (Line noise monitoring)

Non-linearity signature - sidebands on calibration lines:



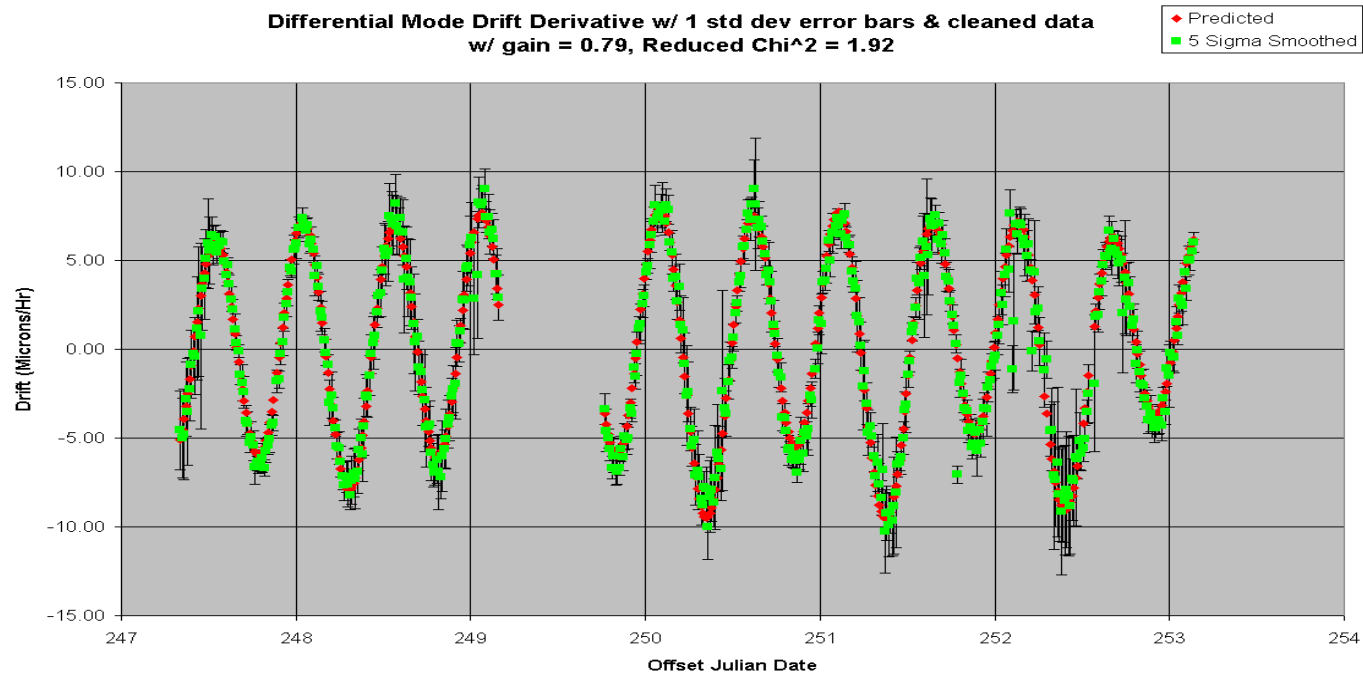
# Engineering Run Results (Lock losses)

Tidal correction disabled - periodic saturation of coils



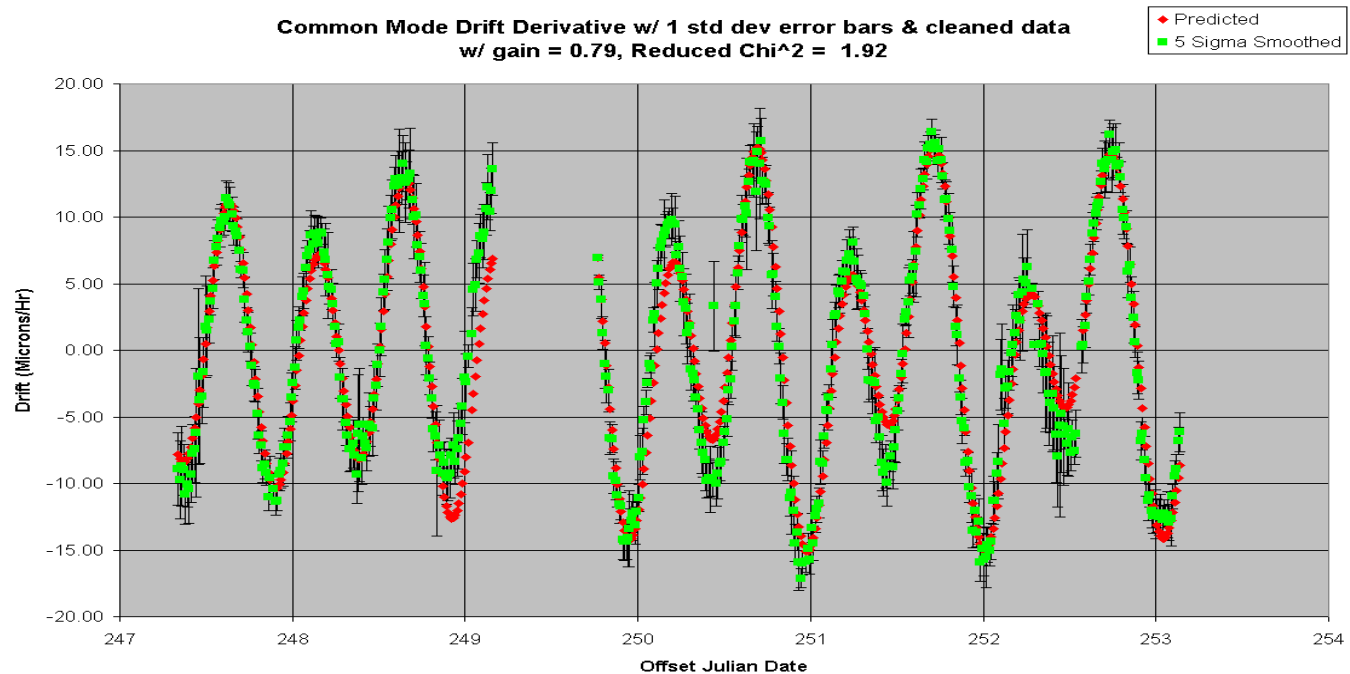
# Engineering Run Results (Tidal modelling)

Comparison of tidal *derivative* prediction with data  
(one free parameter): **Differential Mode**



# Engineering Run Results (Tidal modelling)

Comparison of tidal *derivative* prediction with data  
(one free parameter): **Common Mode**



# Engineering Run Results (Transients)

Airplane seen in E1 run: (seismometer time/freq plot)

