Preparing for LIGO Science:

Detector Characterization, Engineering Runs, and the LIGO Scientific Collaboration

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Outline

- LIGO Scientific Collaboration (LSC)
  - » Function and Organization
- Detector Characterization
  - » Goals
  - » Methods
- Engineering Runs
  - » Schedule & Operations
  - » Studies of Environment and Interferometer
  - » What we have learned

LIGO Scientific Collaboration (LSC)

- Chartered August 1997 : ~20 groups, ~200 members
- New groups apply for membership at biannual collaboration meetings
- LSC now has ~35 groups, ~350 members
  (~20 working on LIGO I, others on Advanced LIGO)
- Each group's role defined by MOU with the LIGO Laboratory

LSC Functions

- General
  - » Determine scientific needs of the project
  - » Present scientific case for the program
  - » Carry out the scientific & technical research program
  - » Carry out the data analysis and validate the scientific results
- Operations
  - » Maximize scientific returns in operations of LIGO facilities
  - » Determine relative distribution of observing/development time
  - » Set priorities for facility improvement
  - » Participate in operations and provide scientific guidance at the sites

LSC Functions

- Future (Advanced LIGO)
  - » Set priorities for the research and development program
  - » Assist in carrying out R&D program
  - » Establish the long term needs of the field
    - – Instrumental
    - – Analysis (algorithms and computing infrastructure)

LSC Organization

Technical Development Groups: (Advanced LIGO)

- Suspensions & Isolations Systems
  - » Chair: David Shoemaker - MIT
- Optics
  - » Chair: David Reitze - University of Florida
- Lasers
  - » Chair: Benno Willke - University of Hannover (GEO)
- Interferometer Configurations
  - » Chair: Ken Strain - University of Glasgow (GEO)

LSC Organization

Software Development Groups: (LIGO I)

- Astrophysical Sources and Signatures
  - » Chair : Bruce Allen - U. Wisconsin, Milwaukee
  - » Lab Liaison: Barry Barish - Caltech
- Detector Characterization **<<< Focus of this talk**
  - » Chair: Keith Riles - U. Michigan
  - » Lab liaison: Daniel Sigg - Hanford Observatory
- Analysis & Software Coordination
  - » Chair: Alan Wiseman - U. Wisconsin, Milwaukee

LSC Organization

Analysis Groups & Co-chairs: (proposal-driven, dynamic)

- Burst sources: Sam Finn - Penn State
  Peter Saulson - Syracuse
- Binary inspiral sources: Pat Brady - U. Wisconsin, Milwaukee
  Gabriela Gonzalez - Penn State
- Periodic sources: Stuart Anderson - Caltech
  Michael Zucker - MIT
- Stochastic sources: Joe Romano, UT Brownsville
  Peter Fritschel - MIT

LSC "Sociology"

At least three communities melded together into LSC:

- Pioneer interferometer physicists
  (Tradition of big tabletops at home, but small groups, intimate with prototype apparatus)

- Gravitational wave theorists / phenomenologists
  (Tradition of individuals & small, dynamic collaborations, mostly detached from apparatus)

- Newcomers from particle physics
  (Tradition of large projects / collaborations, distant labs, but quite different apparatus and analysis techniques)

LSC "Sociology"

- Scale of project demands organization comparable to medium-sized HEP experiment
- No previous experience with collaborations of this scale in gravitational physics
- Feeling our way, deliberately blurring lines between formerly distinct communities
- Engineering runs now providing "practice"

Elements of Detector Characterization

- Commissioning
- Online Interferometer (IFO) Diagnostics
- Environmental Monitoring
- Offline Data Monitoring
  - » Performance Characterization
  - » Transient Analysis
- Data Set Reduction
- Data Set Simulation
  - » Parametrized simulation (noise modelling)
  - » End-to-End Model (bottom-up Monte Carlo)

Dedicated Subgroups for Some Tasks

- Transient Analysis
  - » Chair: Fred Raab - Hanford Observatory
- Data Set Reduction
  - » Chair: Jim Brau - University of Oregon
- Data Set Simulation
  - » Chair: Sam Finn - Penn State University

Some Overriding Goals in 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

- Seismic
- Machinery vibration (local fans, pumps)
- “Violin modes” of suspension wires
- 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

- Earthquakes, wind gusts
- Trains, cars, lumber trucks
- Machinery power cycling
- Magnetic field disturbances
- Suspension wire slippage
- Violin mode ringdown
- Electronic saturation (analog / digital)
- Servo instability
- Dust in beam
- Airplanes, army tanks firing (!)

LIGO

Characterization Methods

- 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/offline characterization tools:
    - – Diagnostic Test Tool (software spectrum analyzer) : D. Sigg - Hanford
    - – Data Monitor Tool (development environment) -- J. Zweizig - Caltech
  - » Developing software tools & monitors for DMT (broad effort)
- Moving toward 2nd phase - two-pronged approach:
  - » Investigations focussed on “En” engineering runs
    - – 15 teams formed for E2 (November 2000)
    - – 13 teams formed for E3 & E4 (March & May 2001)
    - – Prelim reports given at monthly DetChar teleconferences
    - – Final presentations & written reports due at biannual LSC meetings
  - » Participation in four Upper Limits Analysis Groups for E6 run

Software Developed for the Data Monitor Tool (DMT)

DMT Monitors	Scientists	Institutions
Line Noise Monitoring	B. Allen, A. Ottewill S. Klimenko A. Sintes	UWM, Dublin Florida AEI-Potsdam
Seismic Noise Monitoring	E. Daw	LSU
Inter-Channel Correlations	B. Allen, A. Ottweill	UWM, Dublin
Bilinear Cross Couplings	S. Penn	Syracuse
Band-limited RMS Monitor	E. Daw	LSU
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
Event Catalog	J. Sylvestre	LIGO-MIT
Impulse Recognition	M. Ito	Oregon
Magnetic Field Transients	R. Frey, R. Rahkola	Oregon
Lock transitions	D. Chin, K. Riles	Michigan
Power Mains Monitor	D. Sigg	LIGO-LHO
GPS Time Ramp Monitor	S. Marka	LIGO-CIT
Pre-Stab. Laser Glitches	R. Savage, J. Zweizig	LIGO-LHO/CIT
Data Integrity (2 monitors)	J. Zweizig	LIGO-CIT

DMT Infrastructure	Scientists	Institutions
Operational State Conditions	D. Chin, K. Riles	Michigan
Time-Frequency Plotting	S. Mohanty J. Sylvestre	AEI-Potsdam LIGO-MIT
Wavelet Analysis Tools	S. Klimenko	Florida

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How is DetChar Information Used?

- Detector characterization used online for diagnosis / warnings and offline for interpreting data
- Characterization conveyed downstream to astrophysical analysis via database constants
- 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

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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

Other Detector Characterization Software Tools

- Data Set Simulation - End-to-End Model
  - » Leader: Hiro Yamamoto -Caltech
  - » Component-by-component simulation of intrinsic interferometer noise in Hanford / Livingston environments

    (analogous to GEANT)
  - » Includes finite time delay effects as option

    (like turning on EGS in HEP simulation)
  - » Proven invaluable in lock acquisition design (see Mavalvala talk)
  - » Being used for Advanced LIGO design

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Engineering Runs - Schedule

- E1 - April 2000 (24-hour run)
  - » One arm of Hanford 2-km IFO
- E2 - November 2000 (1-week run)
  - » Recombined two arms of Hanford 2-km IFO
  - » 24-hour shifts with 1 operator and 3 scientists (expert & trainees)

<<<< Tacoma Earthquake - February 2001 >>>>

- E3 - March 2001 (3-day run)
  - » One arm of Livingston 4-km IFO - 3-day run
  - » 24-hours shifts with 2 operators and 2 scientists

Engineering Runs - Schedule

- E4 - May 2001 (3-day run)
  - Recombined two arms of Livingston 4-km IFO - 3-day run
  - 24-hour shifts with 2 operators and 2 scientists
- E5 - August 2001 (3-day run, planned)
  - Recycled two arms of Hanford 2-km IFO
  - Recombined two arms of Livingston 4-km IFO (?, follows shutdown)
  - Recombined two arms of Hanford 4-km IFO (??)
  - 24-hour shifts with 2 operators and 2 scientists
- E6 - October 2001 (2-week run, planned)
  - Recycled two arms of all IFO's (We hope!)
  - **>>> Set first LIGO upper limits on GW sources**

Engineering Run Investigations (E3/E4 - March/May 2001)

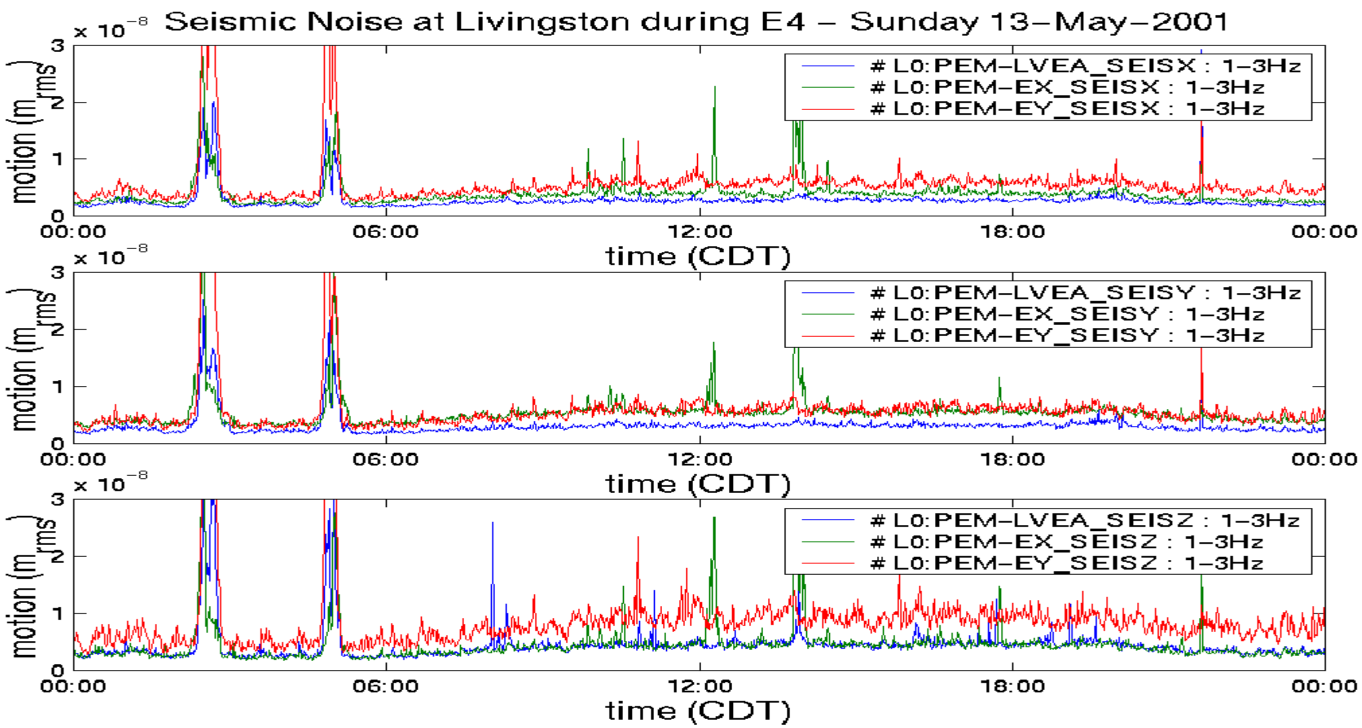
Investigation	Scientists
Seismic noise	CIT: P. Charlton* Louisiana Tech: D. Greenwood, N. Simicevic
Cross-correlations with GW channel	Carleton: N. Christensen* Dublin: A. Ottewill Syracuse: S. Penn
Inter-site environmental correlations	AEI-Potsdam: S. Mohanty LHO: M.Landry* Oregon: R. Rahkola, R. Schofield*
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/E4 - March/May 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

Engineering Run Studies
Seismic Noise at Livingston

One day in E4: Two early-morning trains, daytime traffic seen in 1-3 Hz seismic band



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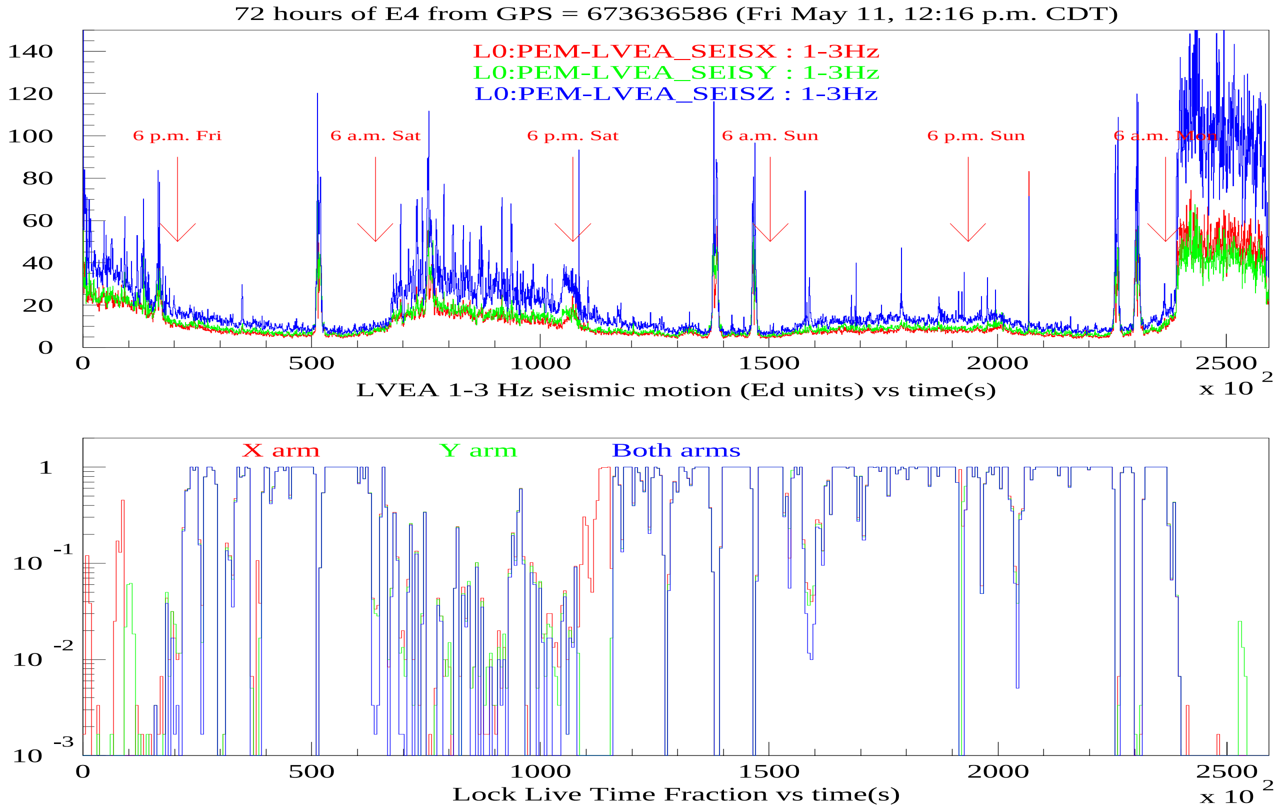
Engineering Run Studies
Seismic Noise at Livingston

1-3 Hz band strongly affects locking ability at present:



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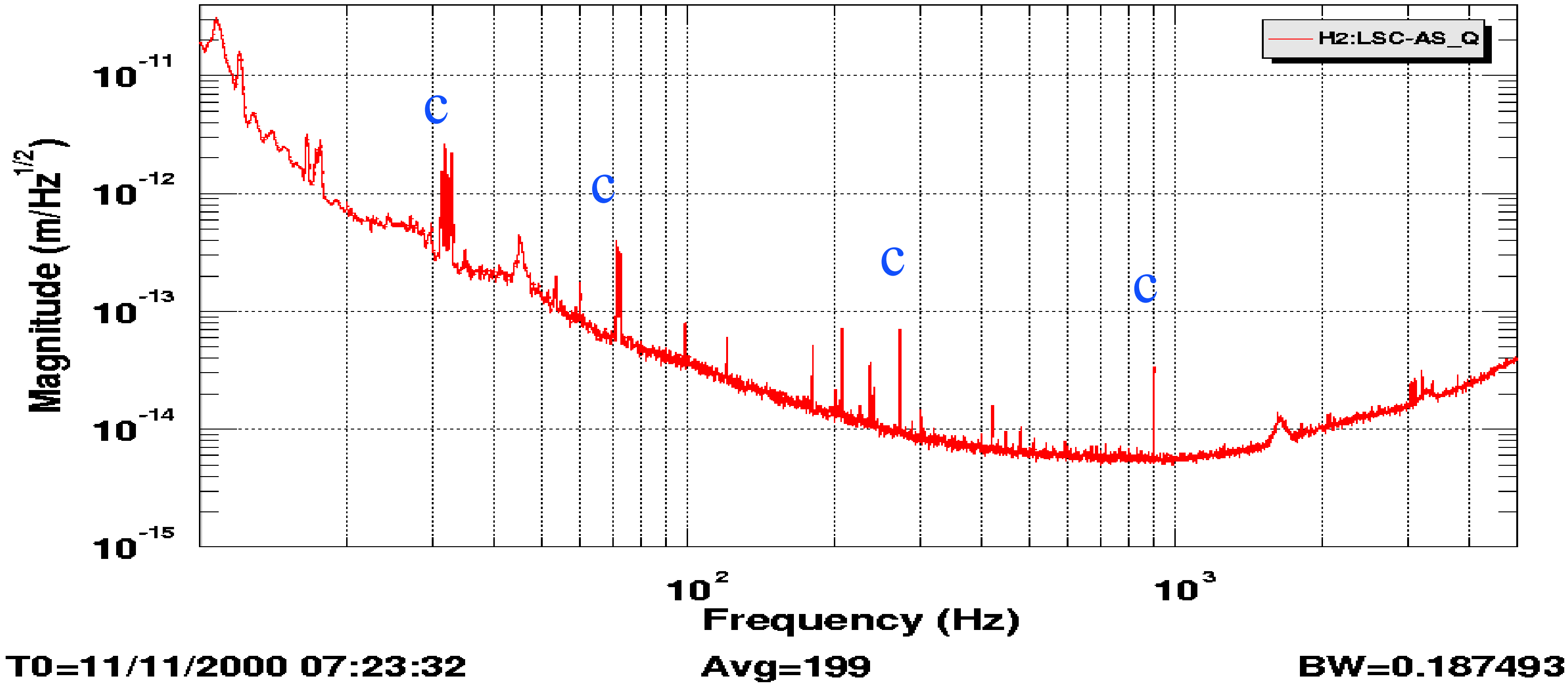
Engineering Run Studies (Calibration from E2)



- Scale set by absolute calibration
- Visible calibration lines ("c")

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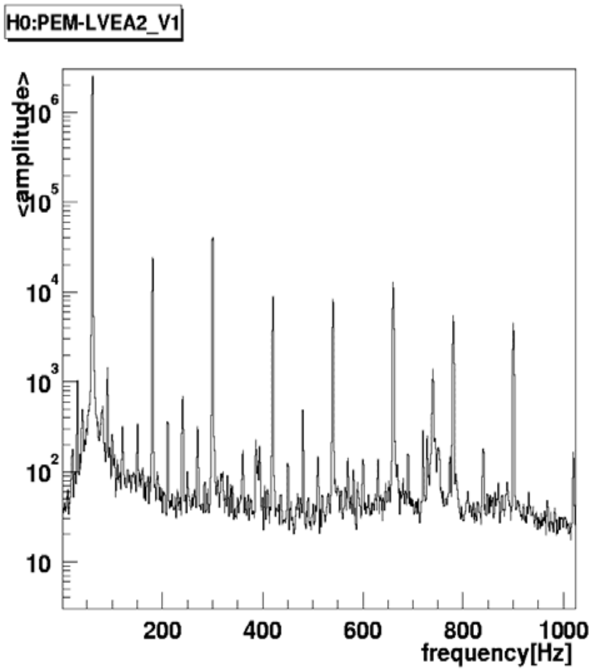
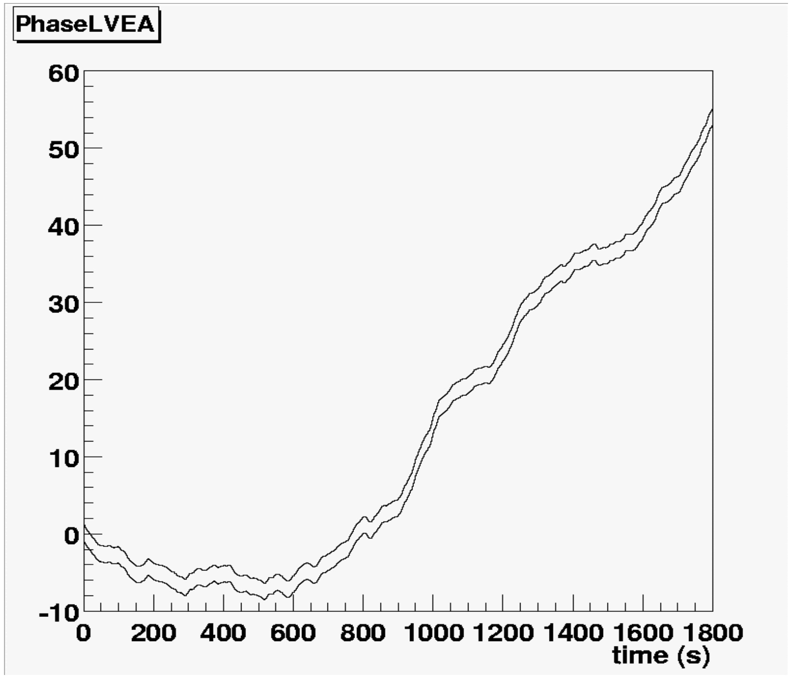
Engineering Run Studies (Line noise monitoring in E2)

AC Power line monitor:



Phase of 60 Hz:



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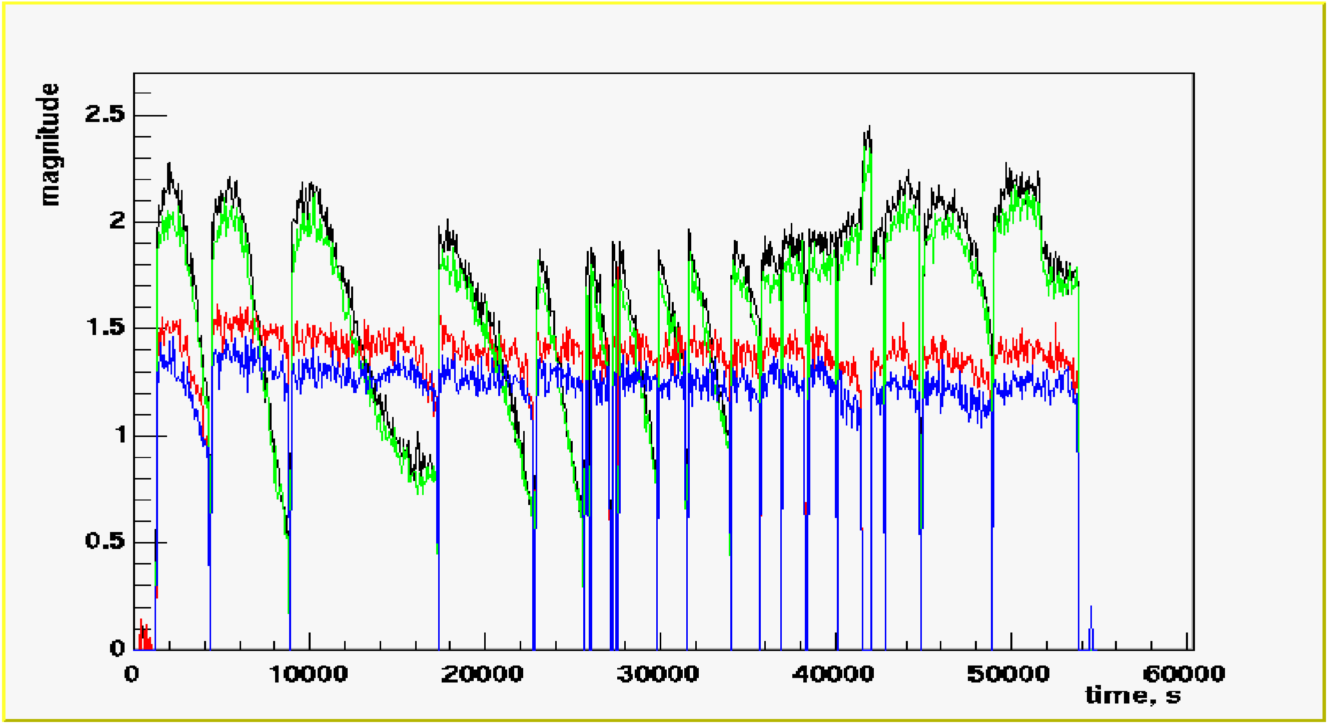
Engineering Run Studies (Line noise monitoring in E2)

Tracking strength of injected calibration lines:

(One arm stable; the other degrading with time in lock)



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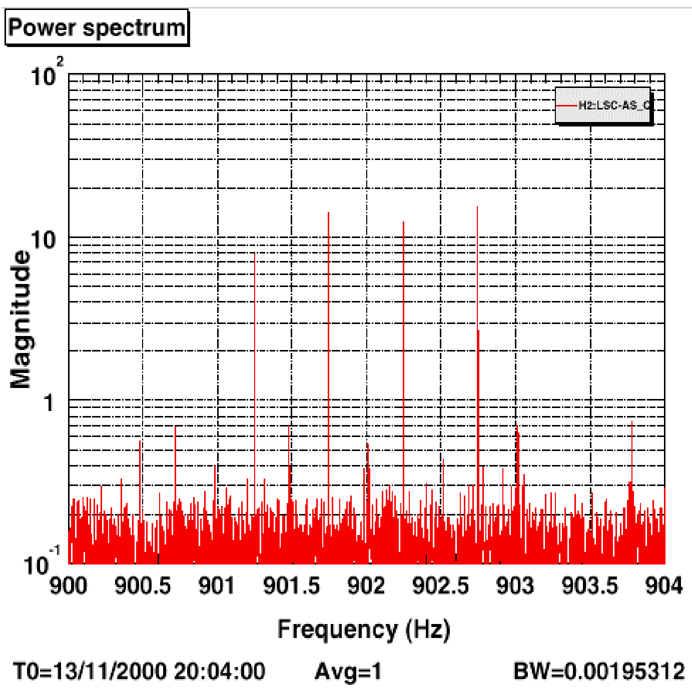
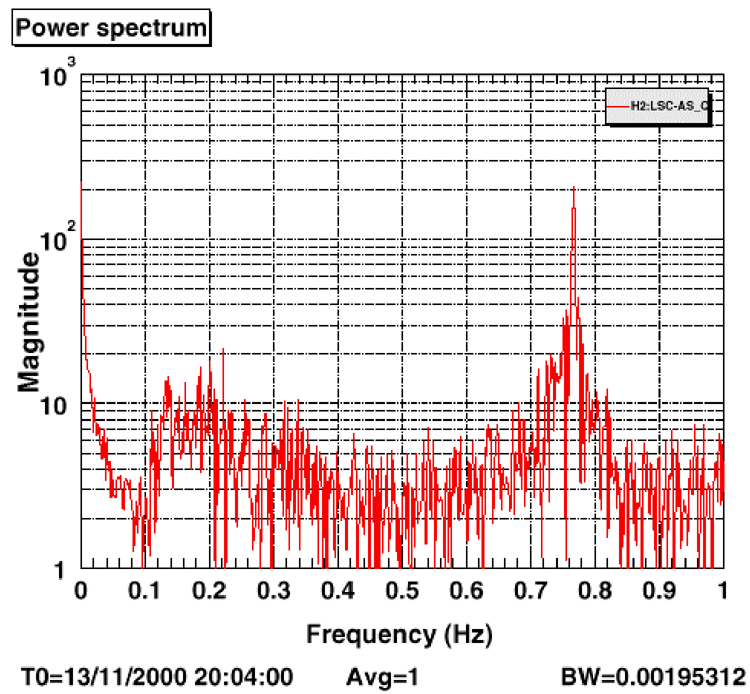
Engineering Run Studies
(Line noise monitoring)

Non-linearity signature - sidebands on calibration lines:





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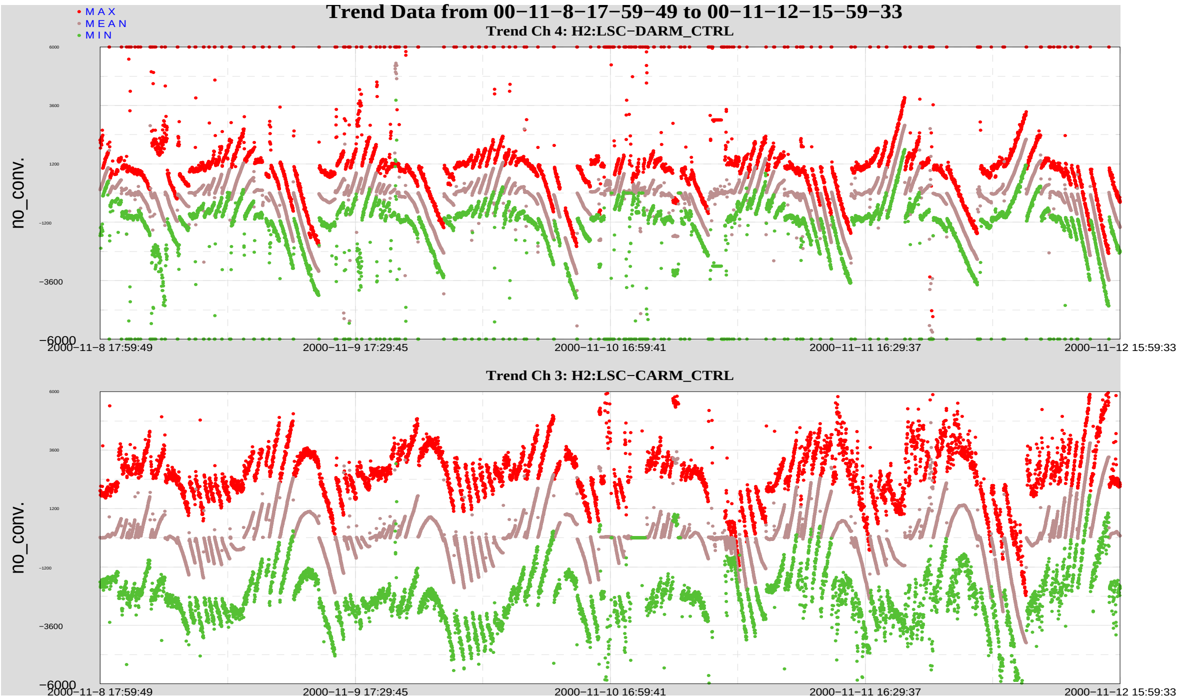
Engineering Run Studies (Lock losses)

Tidal correction disabled - periodic saturation of coils



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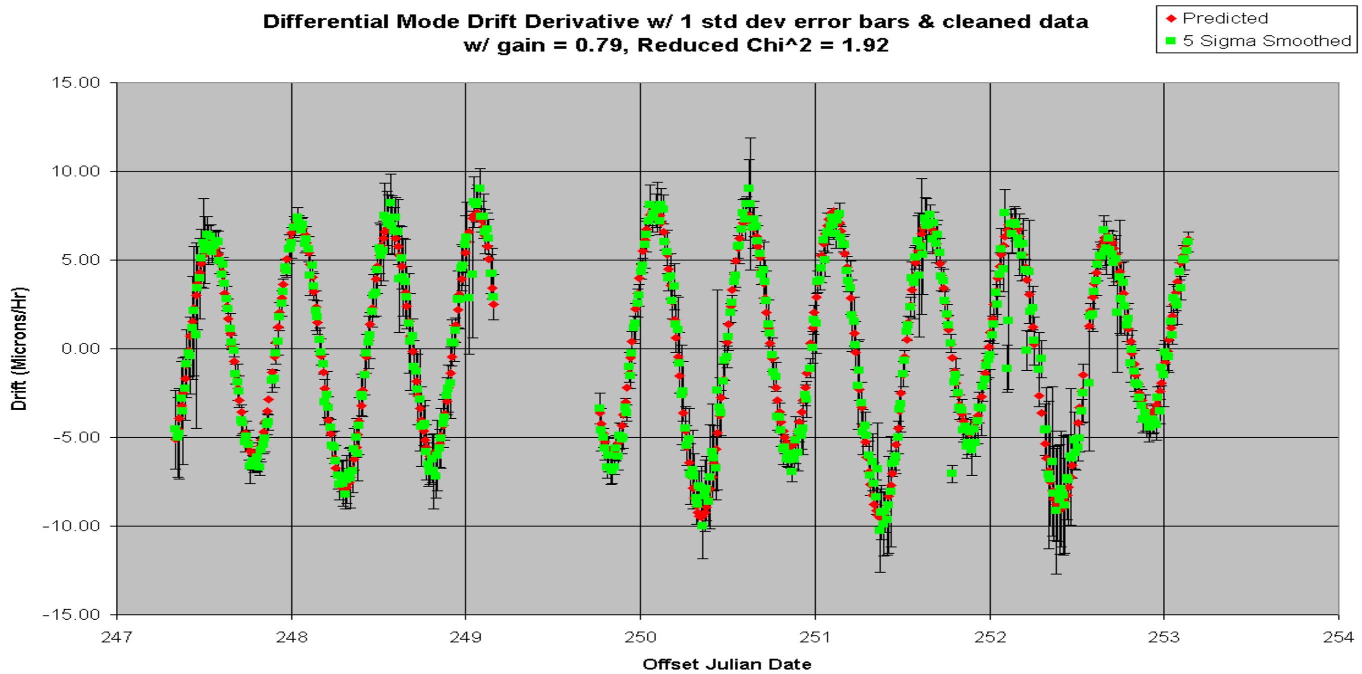
Engineering Run Studies (Tidal modelling)

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



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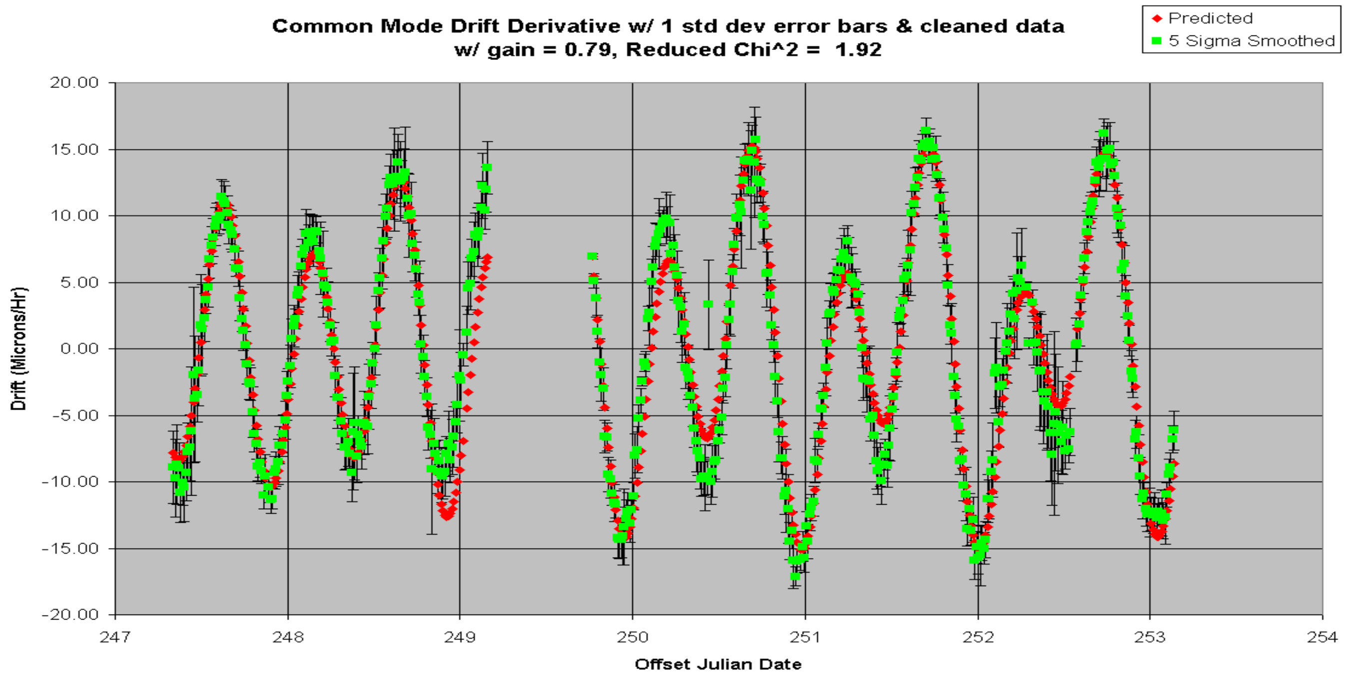
Engineering Run Studies (Tidal modelling)

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



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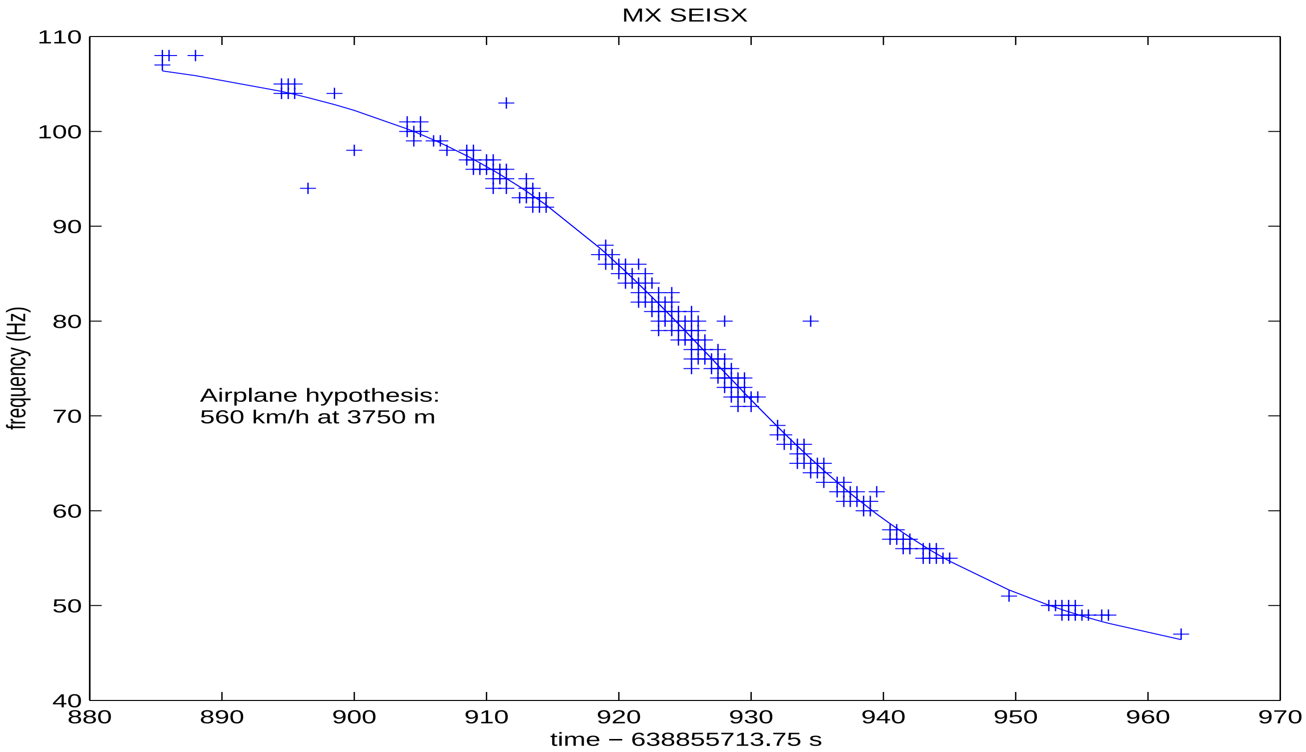
Engineering Run Studies (Transients)

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



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Summary

- Engineering runs preparing us:
  - » Collaboration learning how to run delicate interferometers day & night in uncooperative environments
    - – Defining operating procedures
    - – Defining alarm conditions
    - – Coping with external disturbances / noise (including the moon/sun!)
  - » Developing and testing analysis tools to understand interferometers and environment systematically
    - – Discovering unexpected (but benign) environmental transients
    - – Quantifying sensitivity to ambient noise
    - – Tracking down paths of noise intrusion
- Looking forward to Science Runs in 2002