The LSC Role in Detector Characterization

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Elements of Detector Characterization

- Commissioning (see P. Fritschel talk)
- Online Diagnostics & Data Monitoring
- Data Set Reduction
- Data Set Simulation (see H. Yamamoto talk)

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 can lead to correction

- Identify transients due to instrument or environment
  - » Avoid confusion with astrophysical sources
  - » Identify contamination in data stream
  - » Diagnose and fix recurring disturbances

Examples of Ambient Noise

- 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

- 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

- 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 Monitoring Tool (DMT -- J. Zweizig)
  - Diagnostic Test Tool (DTT -- D. Sigg)

  » Developing software tools & monitors for DMT (broad effort)
  - Many programs written by LSC scientists
  - ~30-40 background processes running 24/7 at the sites (see A. Lazzarini talk)

Evolution of LSC Detector Characterization Efforts

- Now in second phase - three-pronged approach:
  - » Assist in Interferometer operations and data taking
    - – Staffing of Scientific Monitoring (SciMon) shifts during data runs
      - Monitoring of data
      - Decisions on running mode and control parameter adjustments
    - – Support of monitoring tools to assist in commissioning
  - » Investigations focussed on engineering / science runs
    - – Typically ~dozen teams formed for each run (E2-E7, S1)
    - – Investigation reports given at regular DetChar telecons & at bi-annual LSC meetings
    - – Meant to assist commissioning, improve software tool effectiveness
  - » Participation in four Upper Limits Working Groups
    - – Detector characterization subgroups overlapping with investigation teams

      e.g., burst/inspiral veto team works with detchar glitches team, stochastic line removal team works with detchar line tracking team

Software Developed for the Data Monitor Tool (DMT)

Infrastructure features of the DMT: (J. Zweizig, D. Sigg, S. Marka & others)

- **Choice of background production or foreground root-based modes**
- **Signal processing tools (e.g., PSD's, filtering, filter design)**
- **Histogramming**
- **Real-time graphics display**
- **Trend frame file writing (visible to data viewer)**
- **Database triggers and segment generation**
- **Web-viewable summary files and graphics**
- **Control room alarms**

Software Developed for the Data Monitoring Tool (DMT)

(Listed alphabetically by primary author)

Dave Chin (Michigan):

- **LockLoss – Monitors / displays / records interferometer state transitions, detector livetime**
- **ServoMon – Watches for known longitudinal servo instabilities / pathologies**

Ed Daw (LSU):

- **Blrms – Monitors band-limited RMS in data channels – used mainly for seismic channels**
- **PeakMon – Monitors non-Gaussianity in selected high-pass-filtered data channels**

Masahiro Ito (Oregon):

- **GlitchMon – Monitors "glitches" in broad array of data channels – variable thresholding options**

Sergey Klimenko (Florida):

- **LineMon – Tracks amplitudes of known lines, looks for unexpected excited lines**
- **WaveMon – Watches for correlated very-low-threshold glitches between GW and other channels**

Szabi Marka (Caltech)

- **IRIG-B & TimeMon – Monitors of various absolute timing offsets in DAQ and servo controls system**

Software Developed for the Data Monitoring Tool (DMT)

Adrian Ottewill (Dublin):

- **MTLineMon – Tracks lines using multi-taper**

Steve Penn (Hobart-Smitch):

- **BicoMon – Monitors bicoherence in and between data channels (non-linear couplings)**

Rauha Rahkola (Oregon):

- **eqMon – Earthquake alarms**

Daniel Sigg (LHO):

- **MultiVolt – Monitors 60 Hz mains and harmonics**

Patrick Sutton (Penn State):

- **SenseMonitor – Monitors "seeing distance" (kpc) to binary inspiral coalescence**
- **RayleighMonitor – Time-frequency display of spectrogram and Gaussianity**

Natalia Zotov (Louisiana Tech):

- **PTMon – Monitors transients using USGS robust algorithm**

Software Developed for the Data Monitoring Tool (DMT)

John Zweizig (Caltech):

- **BitTest – Looks for stuck bits**
- **HistCompr – Channel histogrammer with filtering**
- **PSLMon – Package of useful tools (band-limited RMS, histogramming, glitch detection)**
- **SegGener – Stores “segments” in database of science mode lock stretches**

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)
  - » "Good data" segment lists
  - » Calibration constants and power spectra
  - » Environmental noise measures
  - » 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: (subgroup chaired by Jim Brau – Oregon)
  - » Wavelet methods (lossless & lossy) -- Sergey Klimenko (Florida)
  - » Data set compact summary -- Benoit Mours (Annecy/CIT) et al
  - » Initial data channel selection – Robert Schofield, David Strom (Oregon)
  - » Decimation in LDAS -- Philip Charlton (Caltech)
  - » Present channel selection & RDS coordination -- Isabel Leonor (Oregon)

- Data Set Simulation – Parametrized (H. Yamamoto talk)
  - » 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 / Science Run Investigation Teams

Data runs to date with IFO's and investigation teams

- E1 (April 2000) – LHO only (1-arm test)
- E2 (Nov 2000) – LHO only (15 teams)
- E3 & E4 (March & May 2001) – LLO only (13 teams)
- E5 (August 2001) – LHO only (12 teams)
- E6 (Nov 2001) – LHO & LLO (13 teams)
- E7 (Dec 2001 / Jan 2002) – LHO & LLO (13 teams)
- E8 (June 2002) – LHO only – (DMT development & tuning)

- S1 (August/September 2002) – LHO & LLO (12 teams)

Science Run Investigations (S1 – August/September 2002)

- Calibration stability

  Mike Landry (LHO)*, Rana Adhikari (MIT)*, Gaby Gonzalez (LSU), Sergey Klimenko (Florida), Szabi Marka(CIT), Brian O'Reilly (LLO), Patrick Sutton (Penn State)

- Violin modes

  Sergey Klimenko (Florida)*, Mario Diaz (Brownsville), Natalia Zotov (La Tech)

- Steady-state correlations

  Nelson Christensen (Carleton)*, Adrian Ottewill (Dublin)

- Glitches

  Joe Giaime (LSU)*, Ed Daw (LSU), Masahiro Ito (Oregon), Natalia Zotov (LaTech)

*Team leader(s)

Science Run Investigations (S1 – August/September 2002)

- Bilinear couplings

  Steve Penn (Hobart-Smith)*, Erika D'Ambrosio (CIT), Biplab Bhawal (CIT), Vijay Chickarmane (LSU), Tiffany Summerscales (Penn State), Dennis Ugolini (CIT)

- Correlated environmental transients between sites

  Robert Schofield (Oregon)*, Ray Frey (Oregon)

- Identify & catalog environmental disturbances

  Robert Schofield (Oregon)*, Rauha Rahkola (Oregon)

- Timing precision

  Daniel Sigg (LHO)*, Szabi Marka (CIT)

- Data quality

  John Zweizig (CIT)*, Ed Daw (LSU), Gaby Gonzalez (LSU), Rauha Rahkola (Oregon), Keith Riles (Michigan), Robert Schofield (Oregon), Daniel Sigg (LHO)

Science Run Investigations (S1 – August/September 2002)

- Data access

  Peter Shawhan (CIT)*

- Data set reduction

  Isabel Leonor*

- Hardware astrophysical signal injection

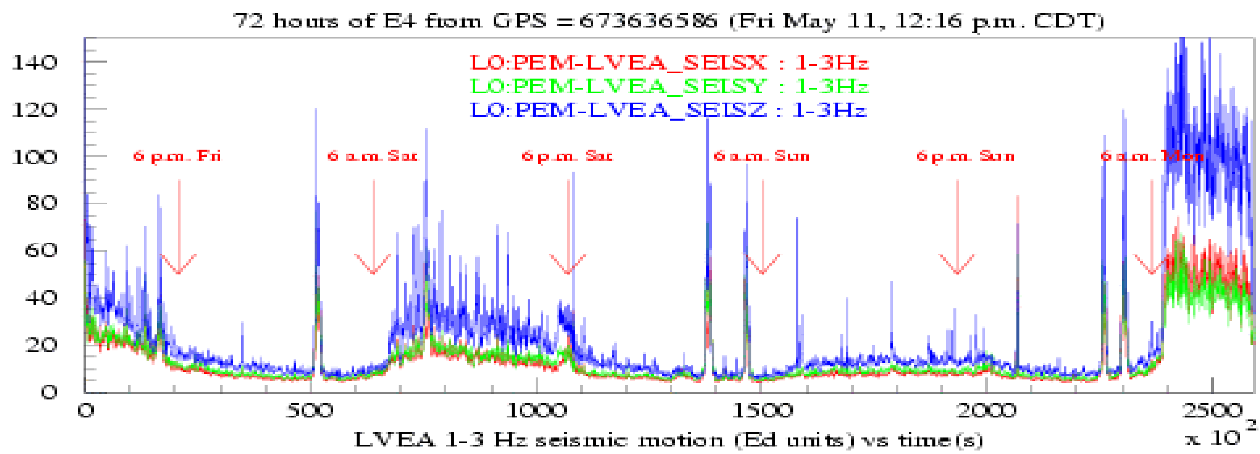
  Szabi Marka (CIT)*, Peter Shawhan (CIT)*, Sukanta Bose (Wash State), Isabel Leonor (Oregon)

DMT Example: Seismic Noise Monitoring

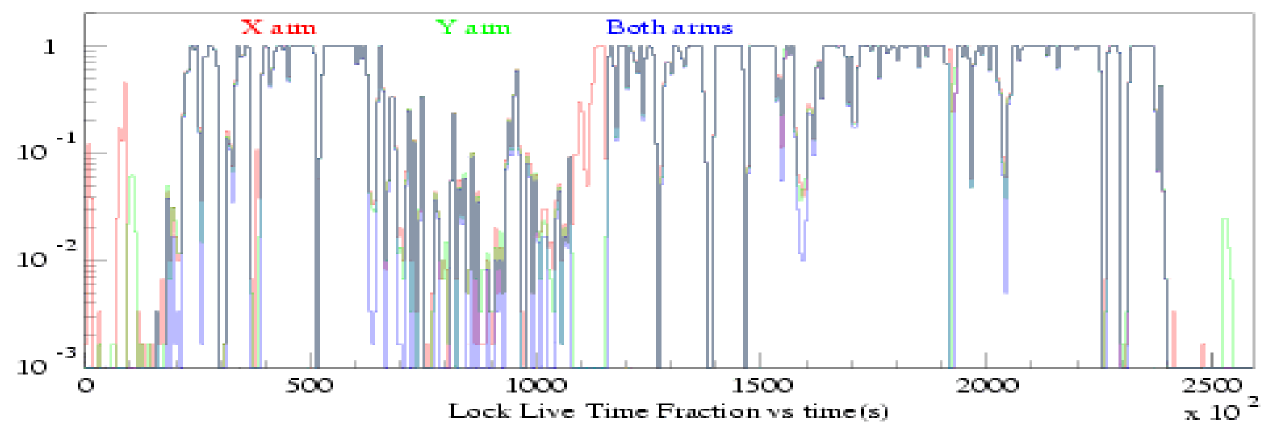
E. Daw (LSU)

DMT Example: Seismic Impact at LLO in E4

Seismic noise over the 3-day run



Resulting lock livetime fraction



KR (Michigan)

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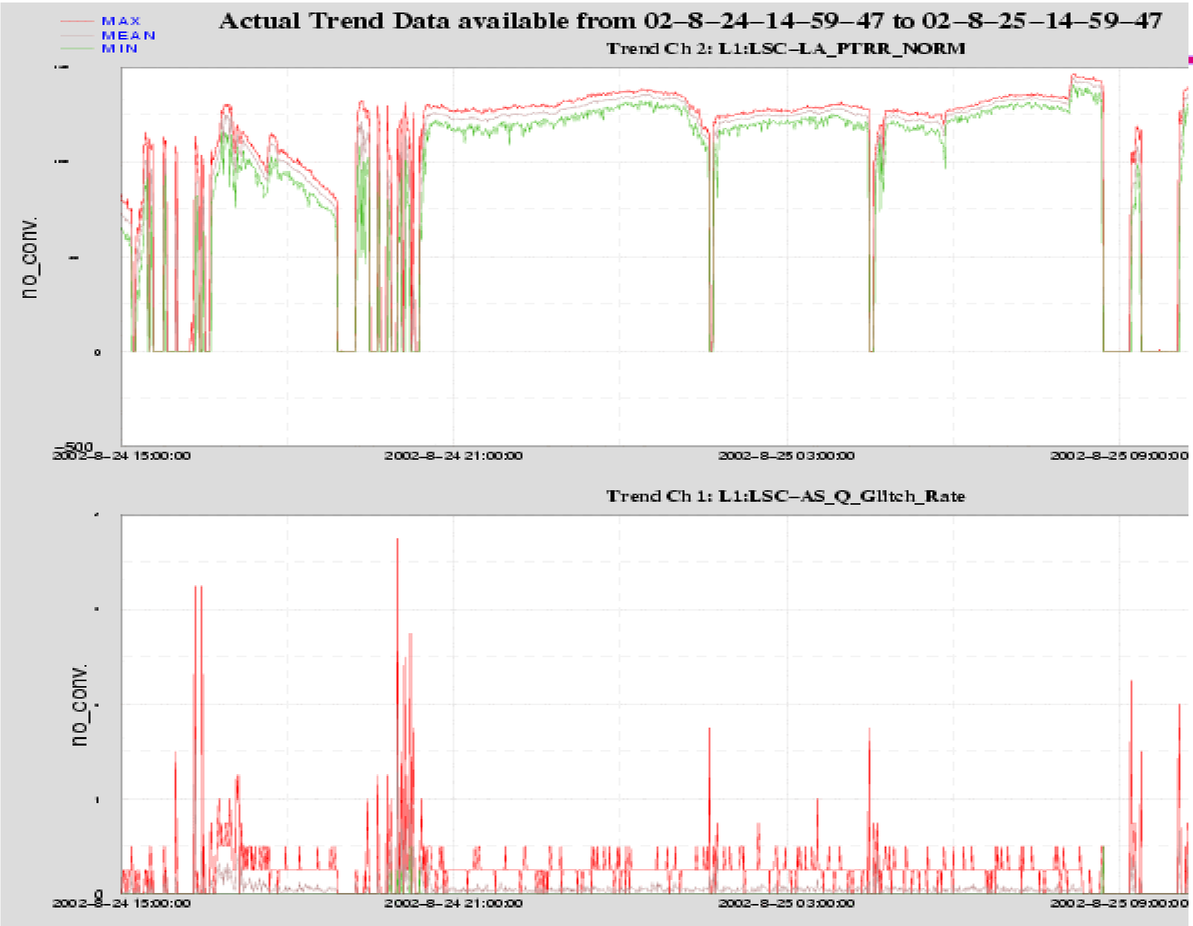
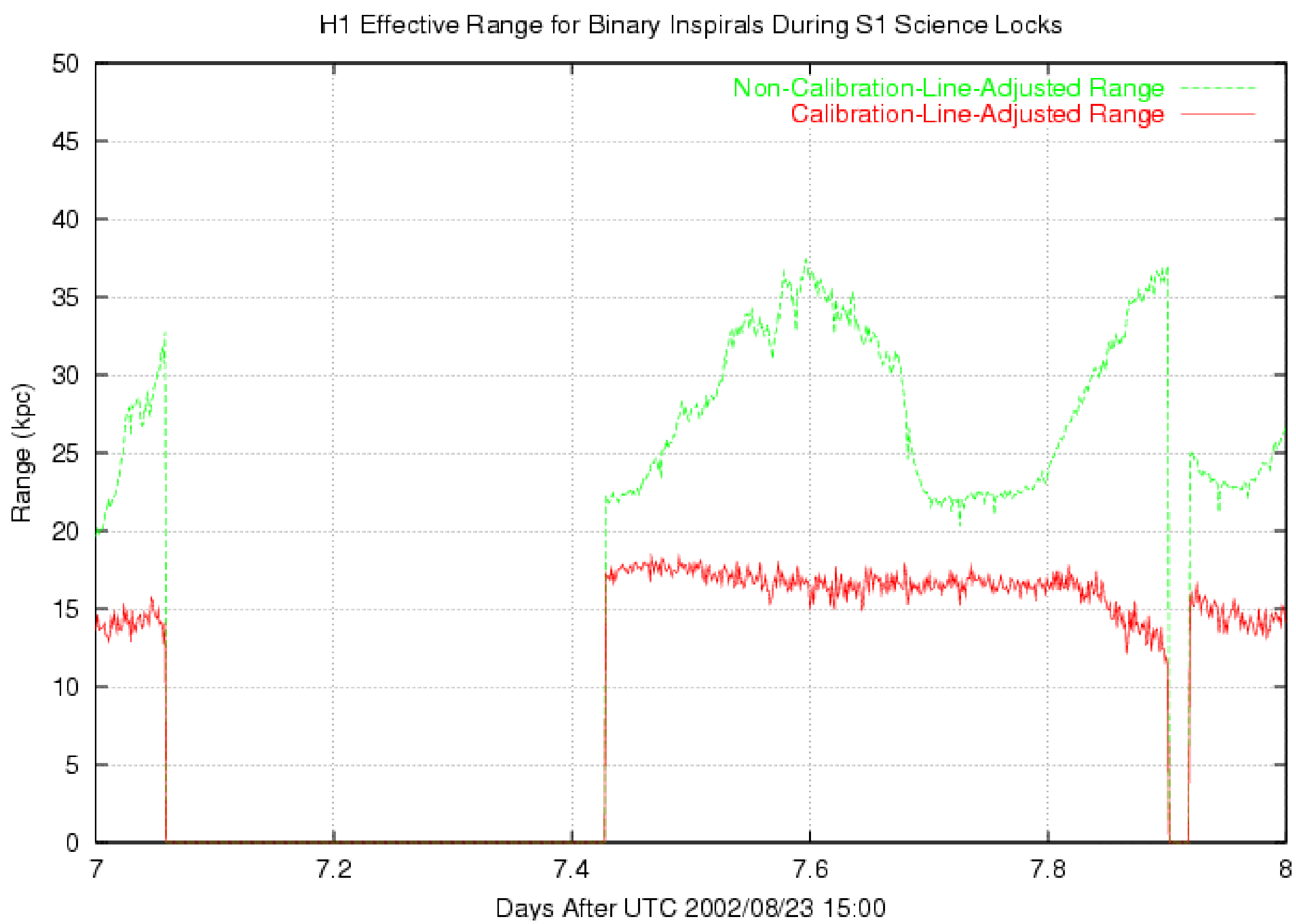
DMT Example: Time series of L1 IFO arm power and GW channel glitch rates (S1 day 2)



DMT Example:
H1 Binary Inspiral Range (S1 Day 8)

- Based on measured noise
- Calibration line tracking required

P. Sutton (Penn State)



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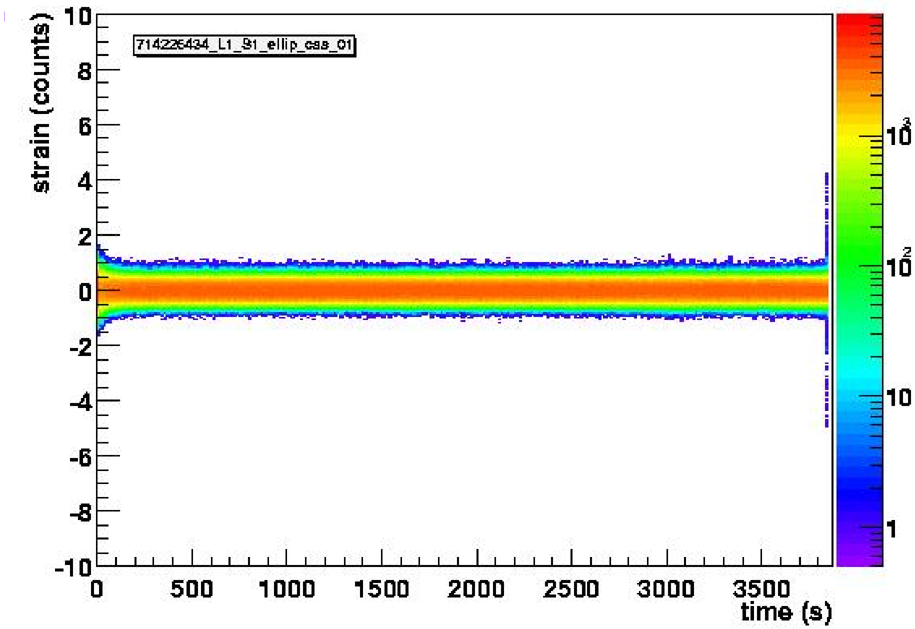
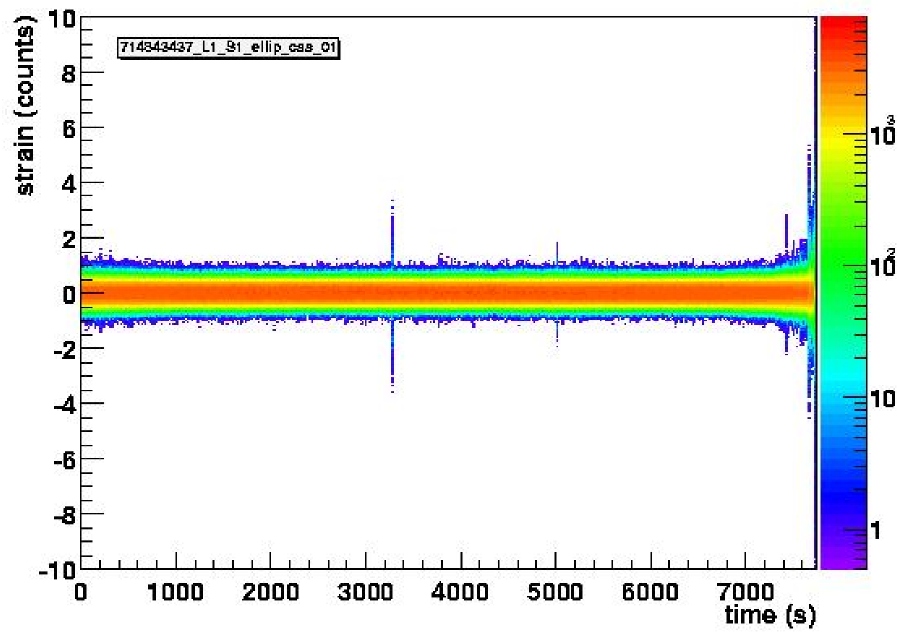
S1 Detector Characterization Studies (data quality)



CLEAN DATA

Histograms vs time of filtered GW channel

RAGGED DATA

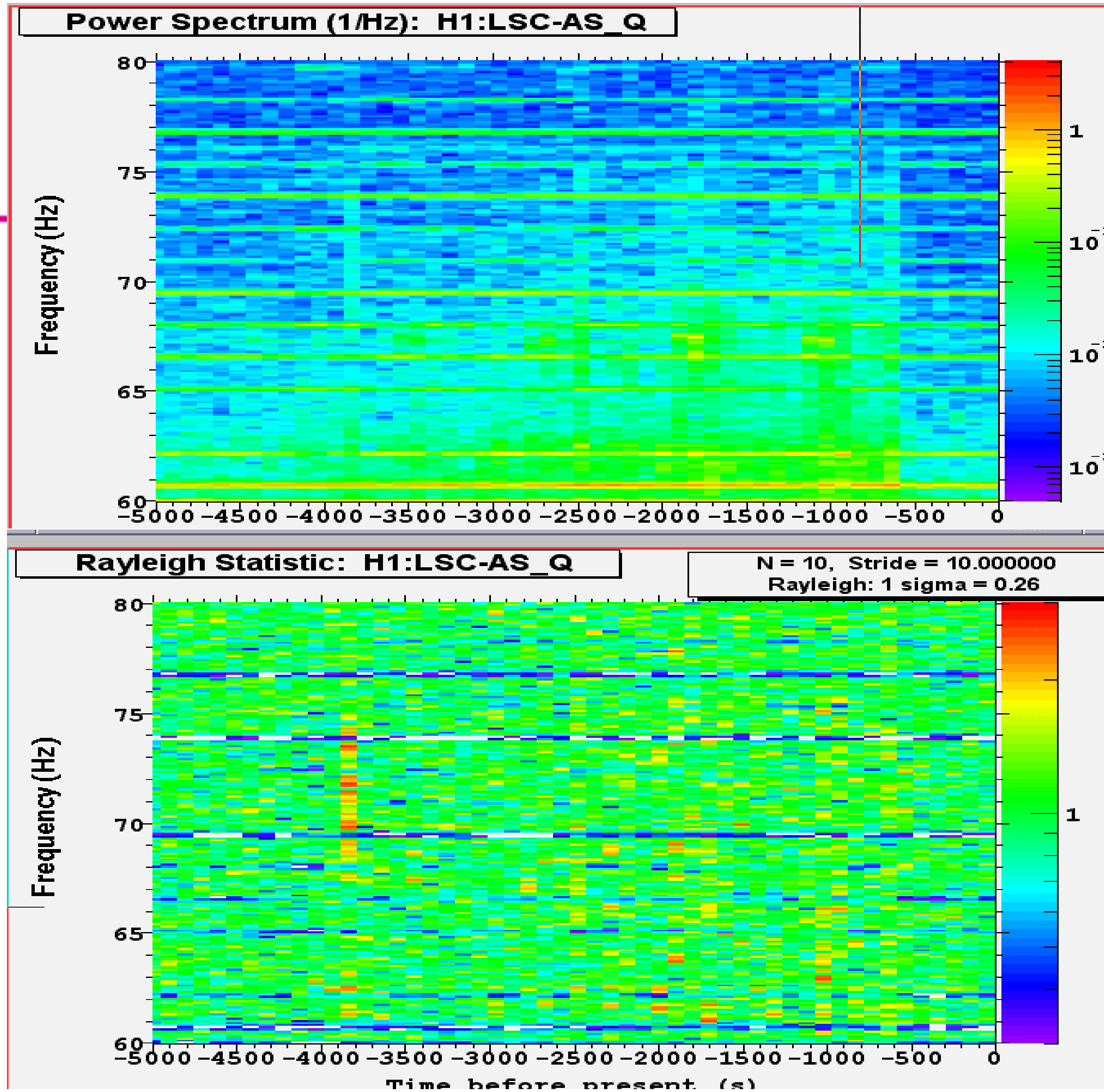


E. Daw (LSU)

DMT Example:

Time / Freq
& "Rayleigh Behavior" Monitor

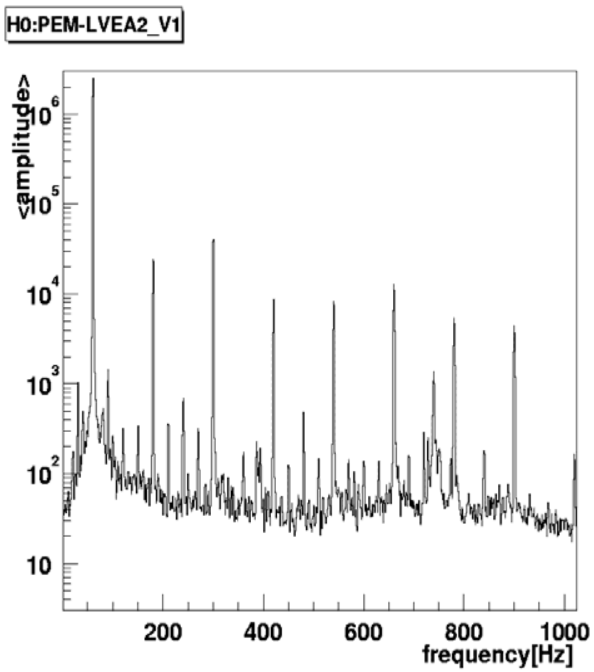
(snapshot during H1 "heartbeat")



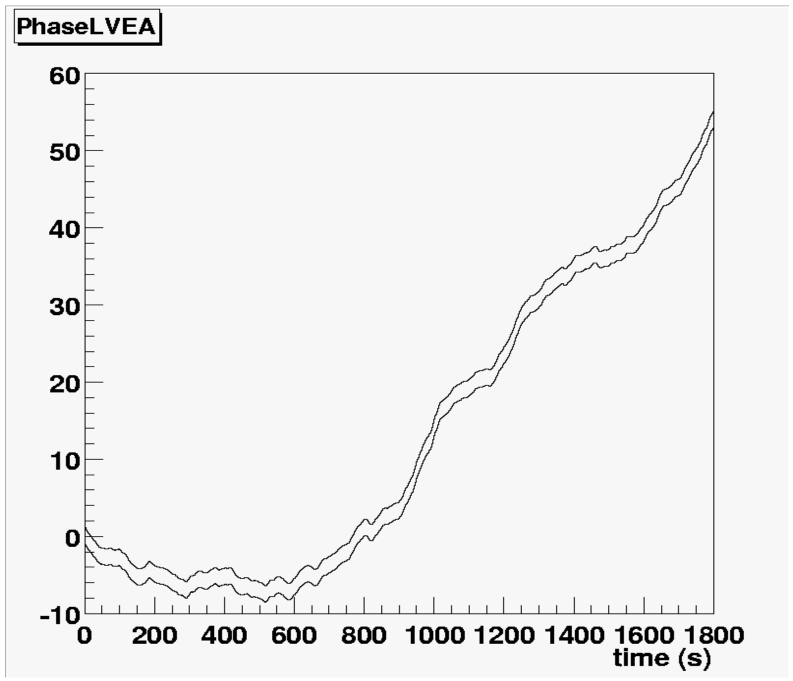
P. Sutton
(Penn State)

Engineering Run E2 Results (Line noise monitoring)

AC Power line monitor:



Phase of 60 Hz:

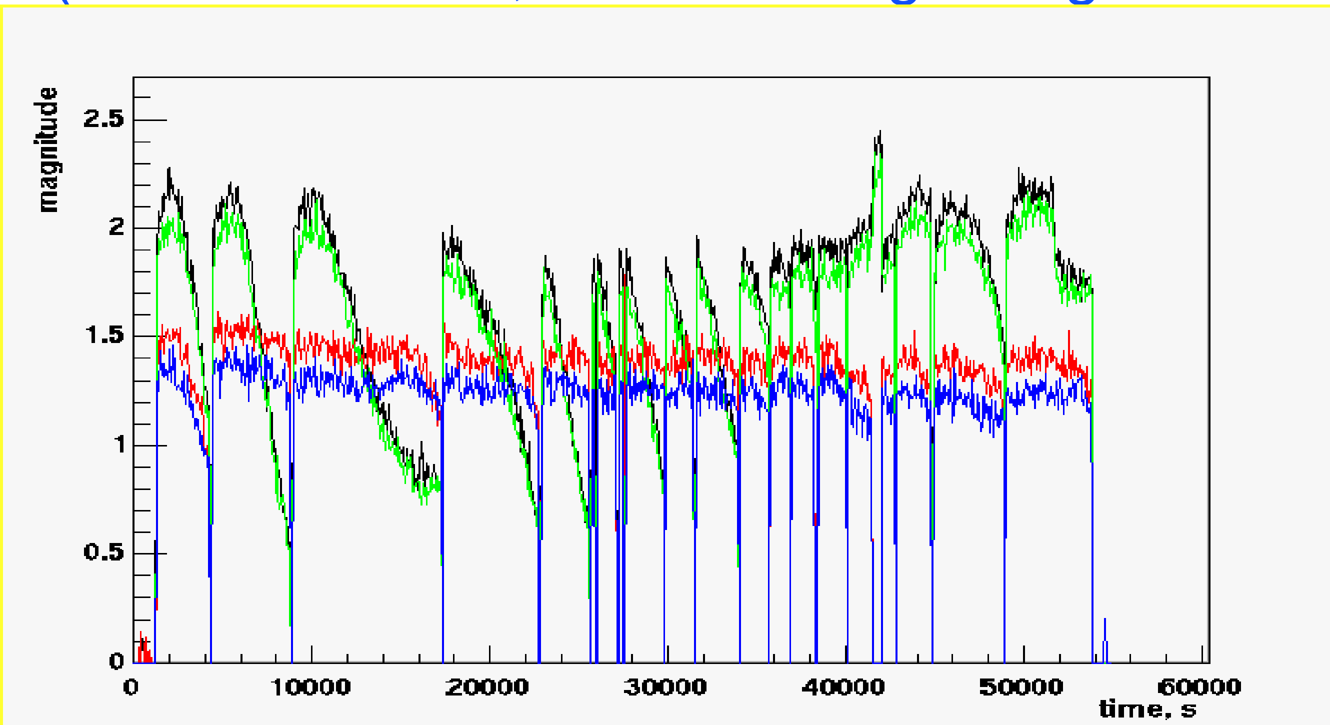


Sergey Klimenko (Florida)

Engineering Run E2 Results (Line tracking)

Tracking strength of injected calibration lines:

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



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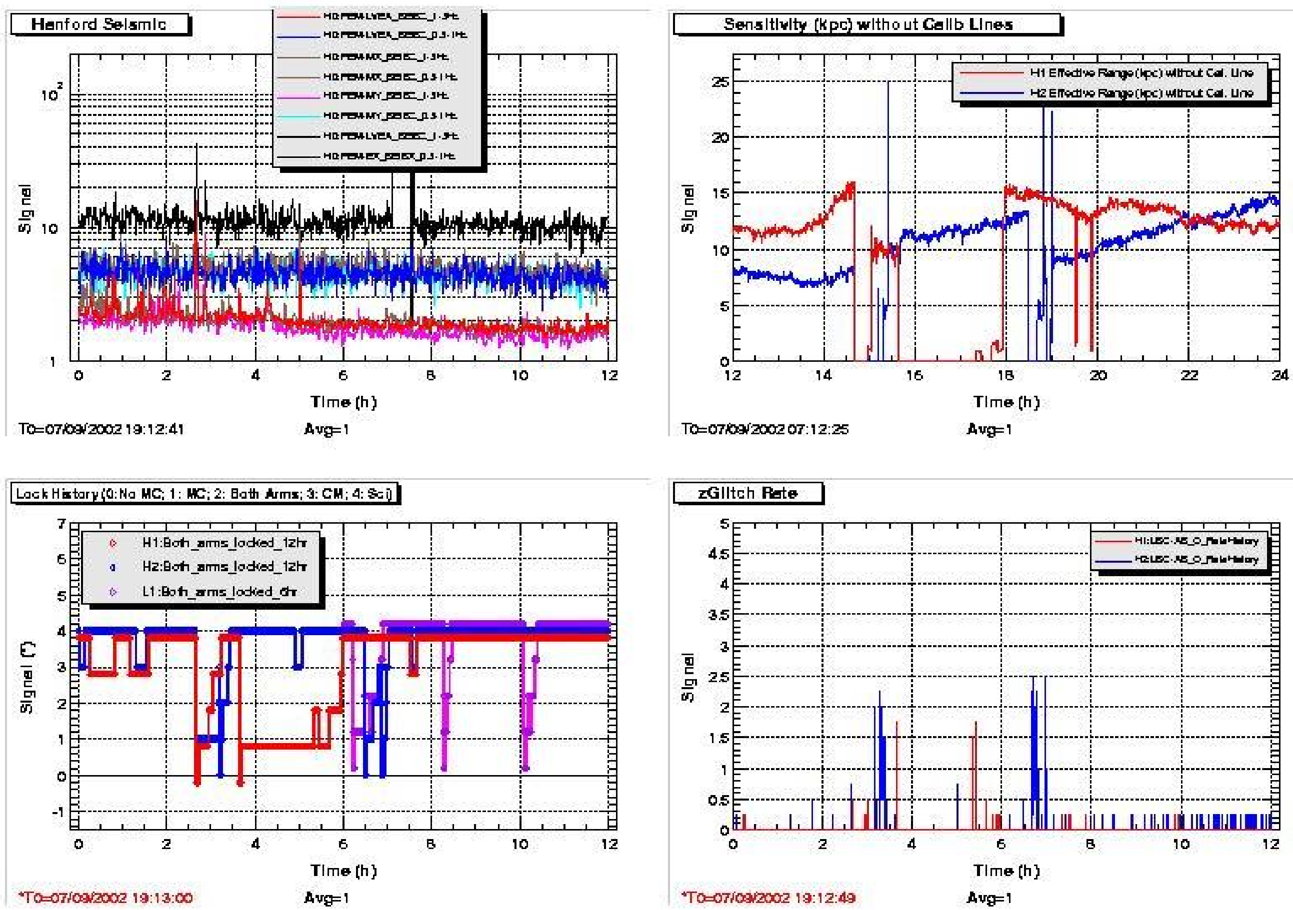
Sergey Klimenko (Florida)

Science Run S1
Sample “Big Board”



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Conclusions

- Detector Diagnostics & Data Monitoring well underway:
  - Infrastructure in place
  - Many useful real-time monitors up and running
  - Useful summary data recorded for downstream (astrophysical) analysis
  - Engineering & science run investigations paying off in understanding interferometers and improving software tools

- More work to be done:
  - Capitalize better on existing infrastructure / monitors

    (too many pathologies found after the run instead of during run!)
  - Improved automation of online monitor summary checking