Detector Noise Characterization with the Hilbert-Huang Transform

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Goddard Group Activities

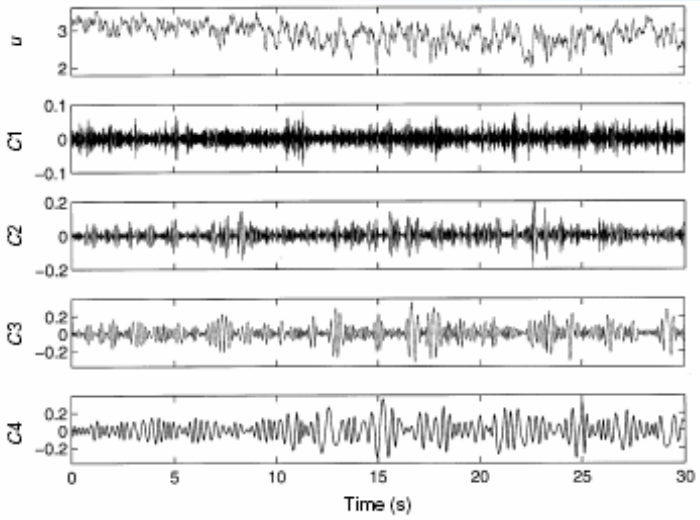
- Alex Stroeer new postdoc (12/07)
  - Full time now on HHT analysis
  - Development of time-frequency maps of glitches and other Burst group triggers
    - Useful for both signal characterization and veto
- HHT software almost ready for deliver to LHO
  - Provided by Kenji Numata
  - Robert Schofield will use for environmental studies
- Will hopefully have enough time to participate in NINJA mock data challenge
  - Short, frequency modulated signals are niche of HHT detection
  - Want to gain experience with characterizing these signals

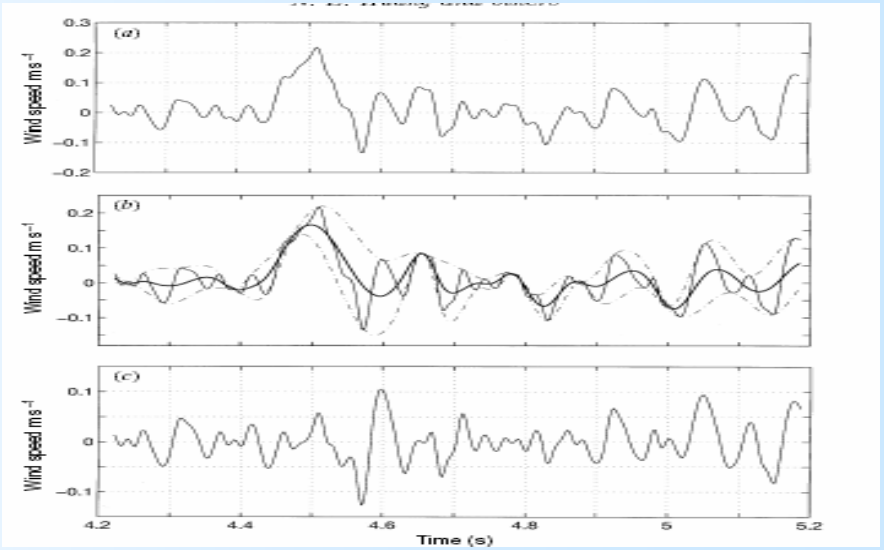
HHT – A new approach to time-series analysis

- Time-Frequency decomposition is key to identifying signals
  - Gravitational waves
  - Instrumental glitches
- Fourier and Wavelet analysis are "basis set" approaches
  - Express time-series as sum of fixed frequency waves
  - Works best when waves are actually present and stationary
  - If not, get time-frequency spreading: $\Delta t \, \Delta f \sim 1$
- HHT is adaptive approach
  - Does not impose any fixed form on decomposition
  - Allows very high t-f resolution
  - Not as good for persistent signal with low SN

HHT: Empirical Mode Decomposition

- Data $X(t)$ is *sifted* into symmetric components with zero mean: $X_i(t)$
  - Sifted components occupy different frequency ranges
  - Sifting process is adaptive and does not assume a basis set
  - Their sum forms the data



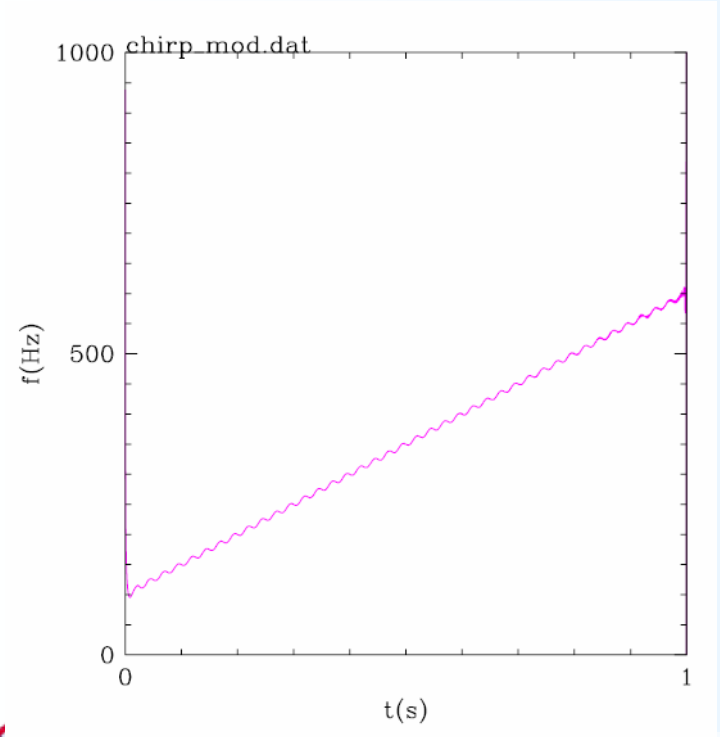


Sifting identifies, fits to, and subtracts using the data extrema

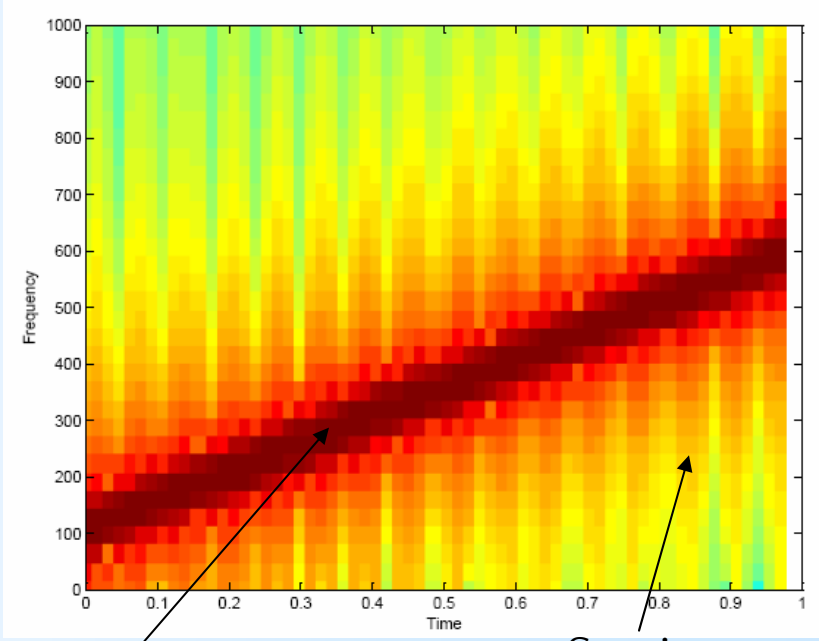
Hilbert Transform of sifted components gives high t-f resolution

$$y(t) = \sin\left[2\pi(100 + 500t) * t + 0.1 * \cos(2\pi(40) * t)\right]$$

Instantaneous Frequency
Hilbert Transform



Spectrogram
Fourier Transform



Time-frequency spreading

Spurious harmonics

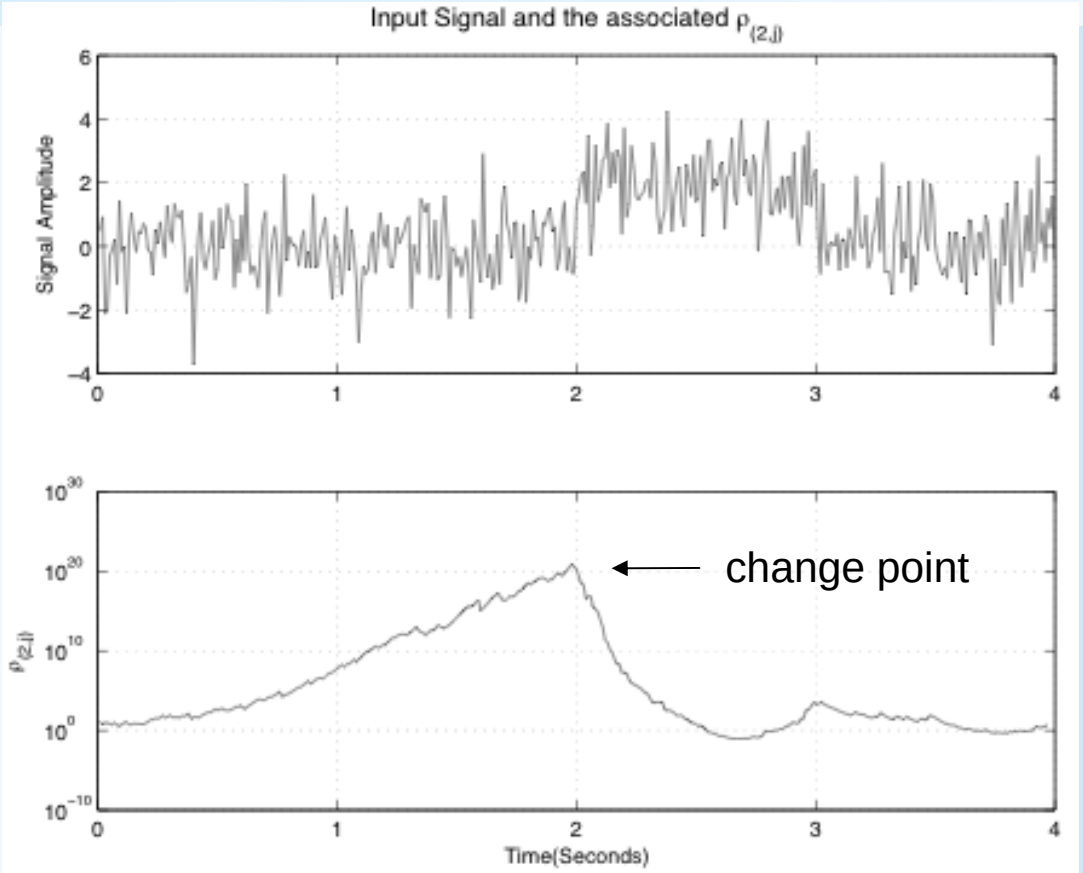
Bayesian Blocks are effective way to use HHT to identify burst noise

Bayesian Blocks (BlockNormal):
McNabb et al: Class.Quant.Grav. 21 (2004) S1705-S1710

- search for changes in mean and standard deviation of data with the Bayes factor criteria

- we use IA(t) to look for abrupt changes in power distribution over time

- Appears useful for both noise characterization and signal detection

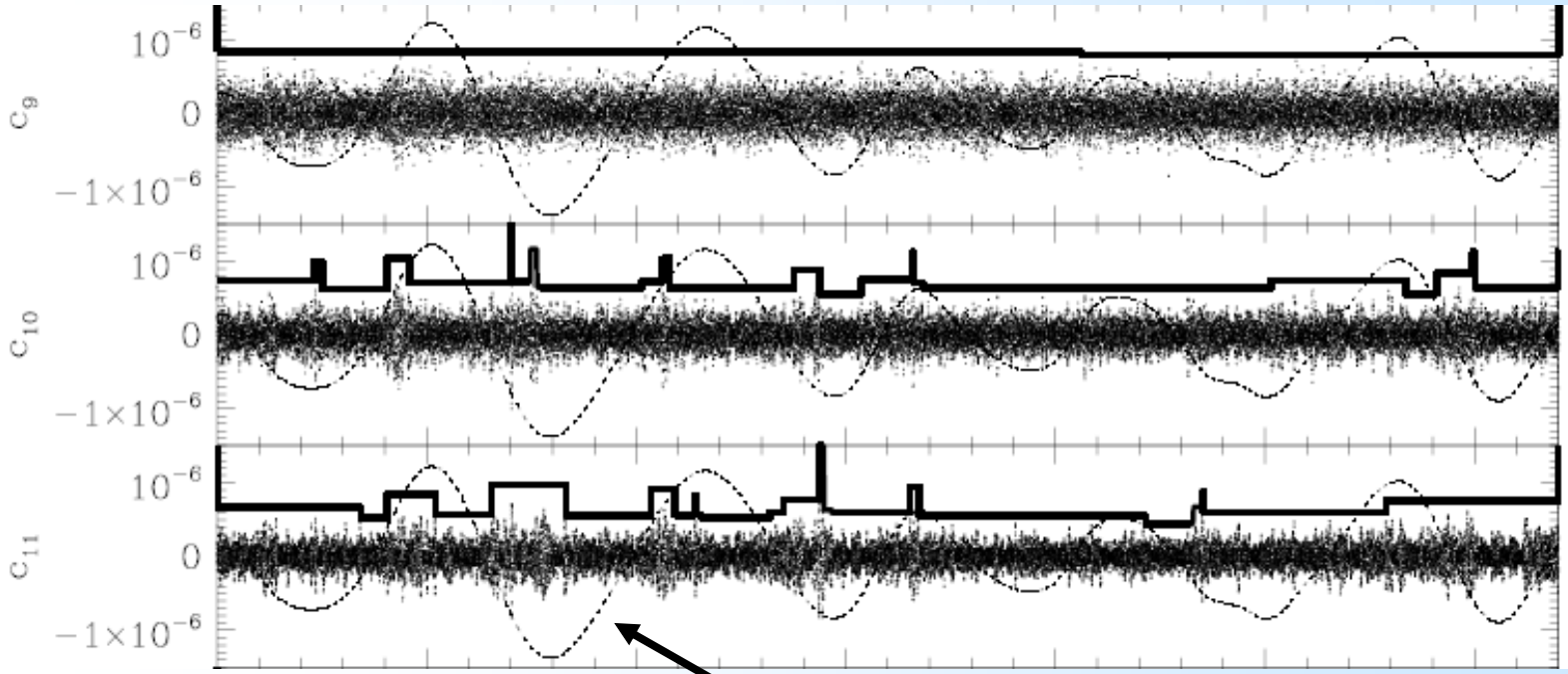


McNabb et al: Class.Quant.Grav. 21 (2004) S1705-S1710

Figure 1. (top) A sample of simulated data consisting of blocks of white noise with a mean of two between two and three seconds and zero elsewhere. (bottom) The associated figure of merit, $\rho_{2,j}$ as a function of the hypothetical change point time.

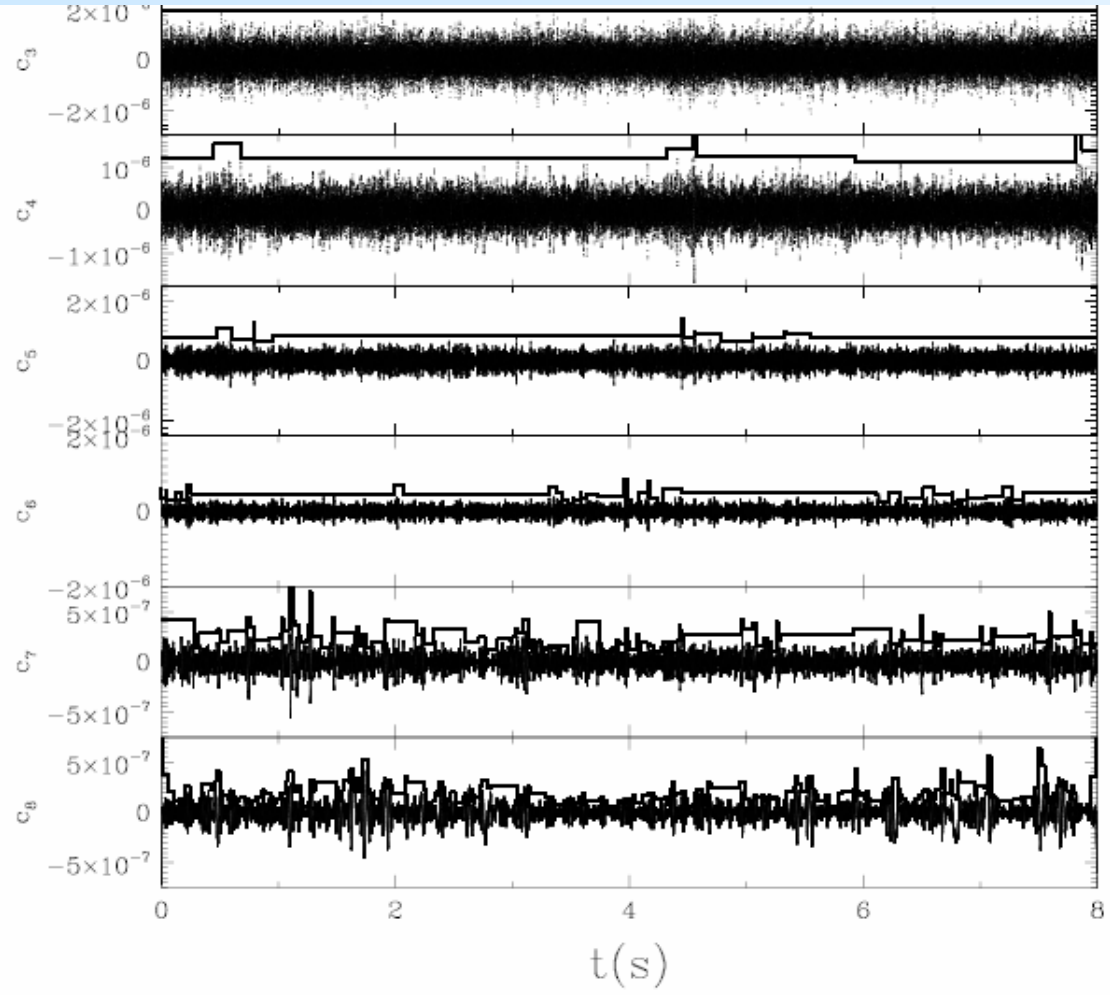
Bayesian blocks identify upconversion noise bursts

HHT of data stream contaminated with upconversion noise



Blocks are associated with low-frequency, elevated coil current during epochs of high microseismic activity

Looking for noise bursts in "normal" detector operation



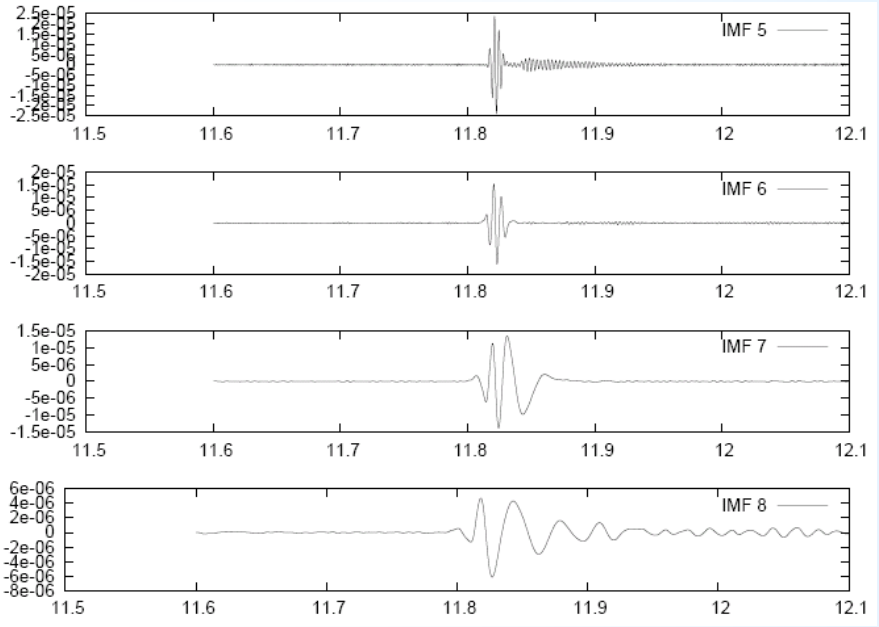
This approach is very efficient at finding noise bursts in data stream

Discussion on using HHT to monitor noise stationarity for triggered burst search

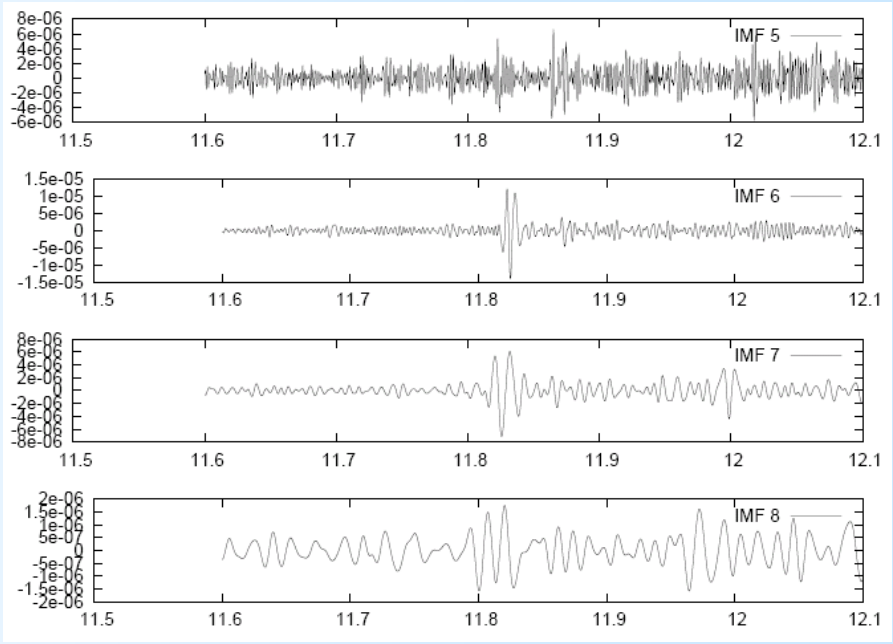
Develop statistics of noise bursts for Burst searches

H1-H2 coincidence "mystery events"

H1



H2

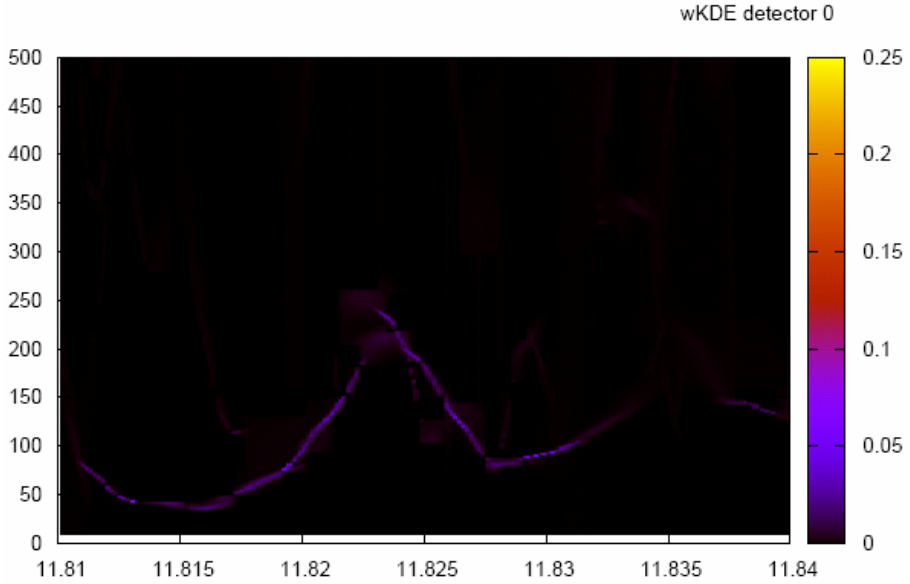


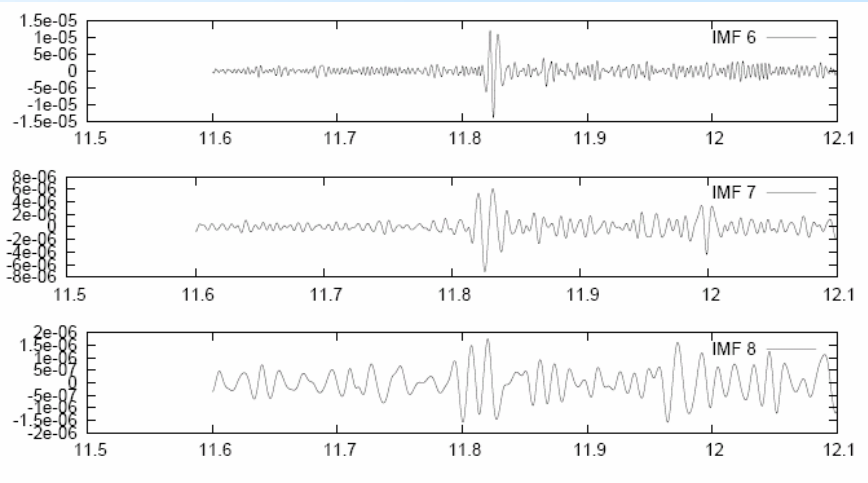
HHT sees these glitches with high time resolution but cause still unknown

We are going through the S5 list of these events

Time-Frequency maps of glitches

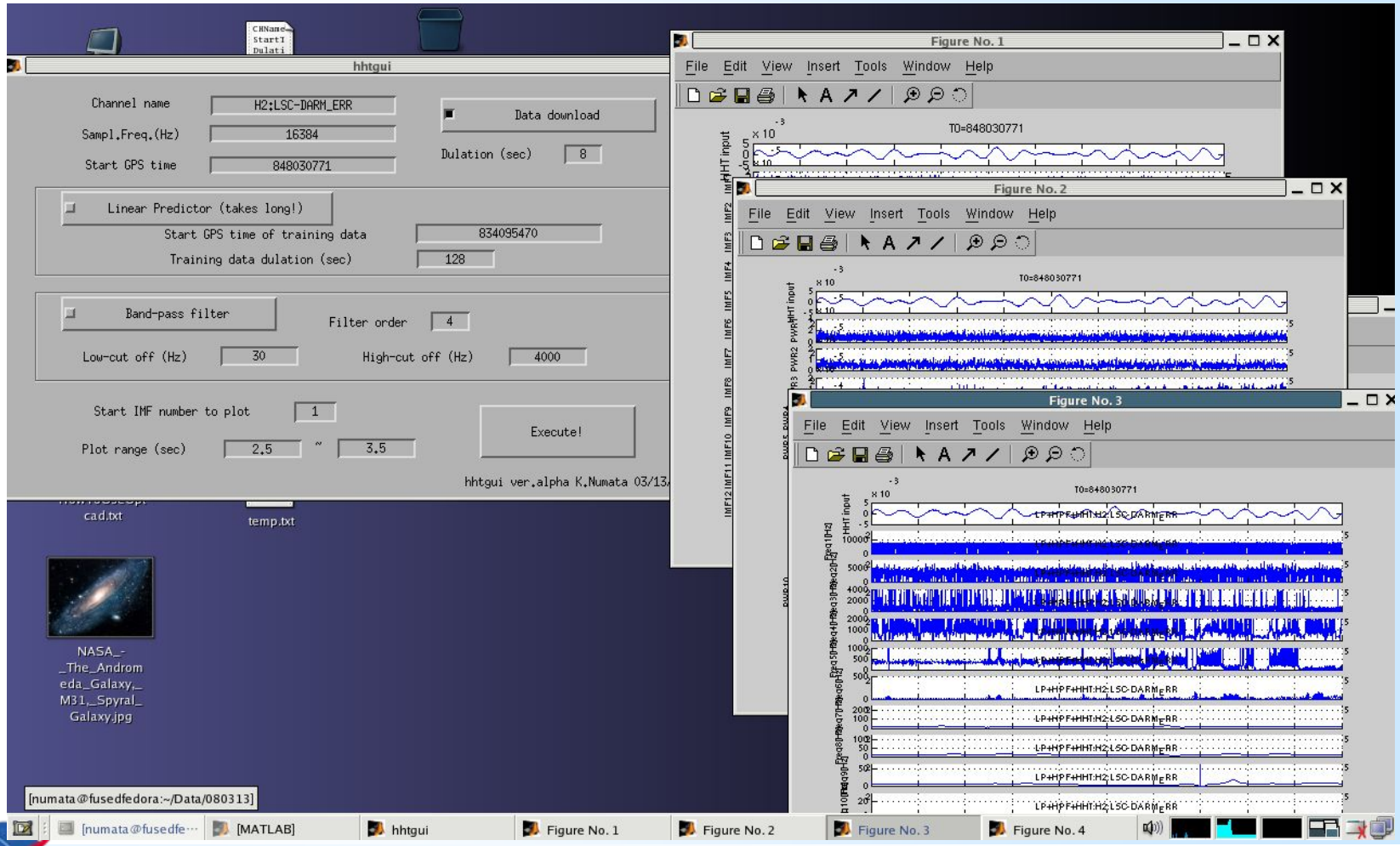
H2





Time-frequency maps contain very fine detail (intra-wave modulation). Will take some time to understand their interpretation: artifacts, etc…

HHT software being developed for installation at LHO (Schofield)



Summary

- Continue glitch analysis of mystery events
- Start looking at other interesting Burst triggers at high t-f resolution
  - Provide t-f maps like Q-scan
- Detector noise stationarity studies
- Deliver HHT monitoring software to LHO (Schofield)
- Participate in NINJA to understand HHT capabilities through comparison to other algorithms