First look at Injection of Burst Waveforms prior to S1

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Burst UL WG
LSC meeting,
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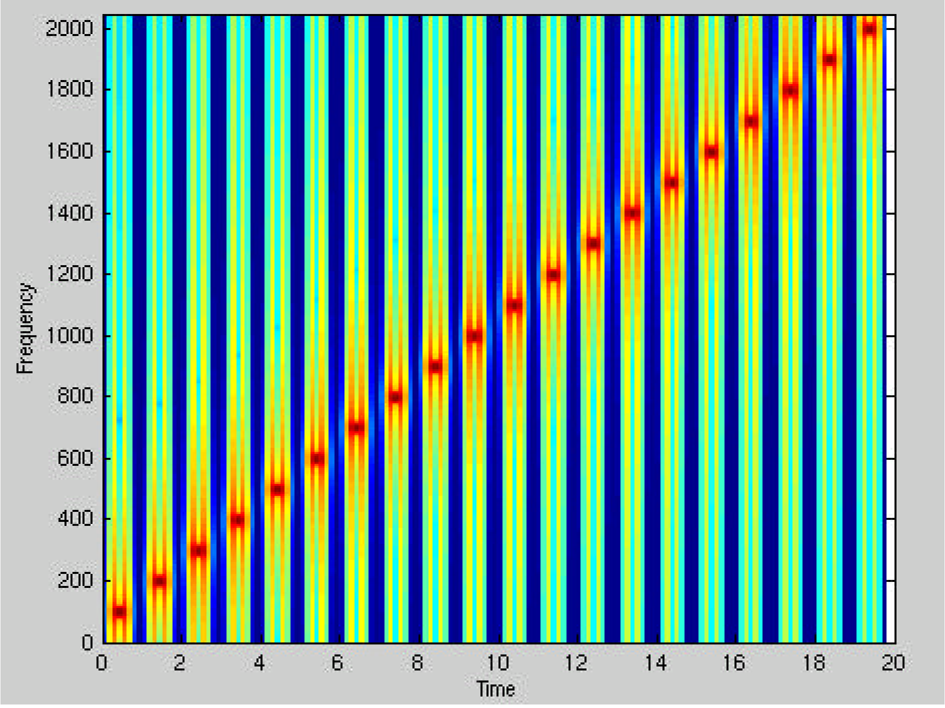
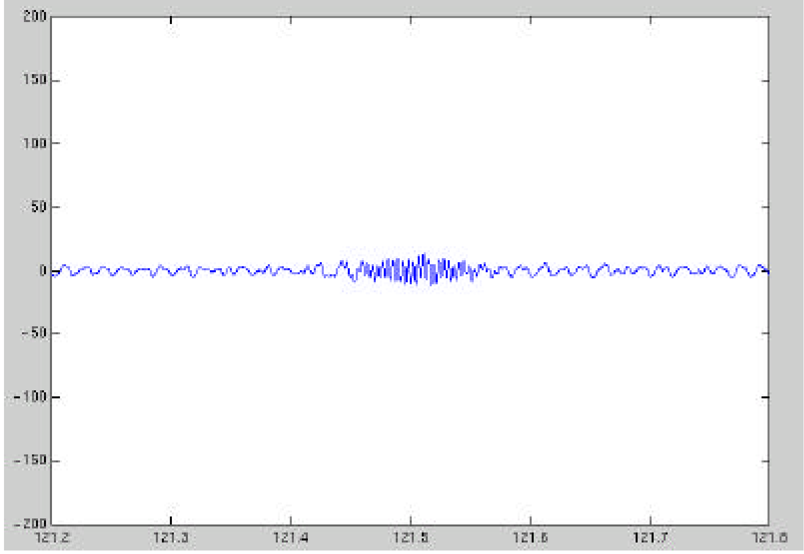




Elements of the Burst Injection Proposal

Goals:

- test our understanding of the entire signal chain from
  - » GDS excitation point →
  - » displacements of test masses →
  - » data logged in LSC-AS_Q and related DM and common mode channels →
  - » entire burst search analysis chain.
- In particular, we need a quantitative comparison between signals injected into the IFO and signals injected into the datastream in software (in LDAS).
- Test our understanding of the dependence on source direction and polarization.

Specific proposal

- Short, narrow-bandwidth signals (sine-Gaussians) provide the most direct and useful interpretation of IFO and data analysis responses. We envision a "swept-sine calibration" of sine-Gaussians of varying frequency, spanning the LIGO band of interest.
- Signal amplitudes should span the range from "barely detectable" to "large, but not so large as to excite a non-linear response". The IFO strain sensitivity varies over the frequency range of interest, so the amplitudes should vary as well.
- Signals are injected using the GDS excitation engine, which accepts 16384-Hz time series in units of counts to the coil driver. The frequency dependence of the test mass response must be taken into account.

Frequency f_0 (Hz)	**100**	**153**	**235**	**361**	**554**	**850**	**1304**	**2000**
Time from segment start t_0 (sec)	**40**	**80**	**120**	**160**	**200**	**240**	**280**	**320**

Burst_z and Burst_ang

Burst_z scan, into DARM or ETMX-ETMY:

- inject sine-Gaussians into all 6 end test masses, with durations of ~ 1 second, spaced 40 seconds apart.
- Scan 8 logarithmically-spaced central frequencies from 100 - 2000 Hz.
- Scan ~6 amplitudes from 1 to 100 times the nominal calibrated strain sensitivity at that central frequency.
- These 48 bursts should thus take 32 minutes.

Burst_ang scan, exciting both DARM and CARM, with IFO-IFO delays:

- Choose one central frequency and relatively large amplitude, and scan over 100 source directions and polarizations (5 in cosθ, 5 in φ, 4 in ψ; all with respect to the mean of the LHO/LLO zenith and orientation). This should take 67 minutes.

Injecting signals

The *multiawgstream* facility developed by I. Leonor and P. Shawhan was used to inject series of signals into the *LSC-ETMX_EXC*, and *LSC-ETMY_EXC*, or *DARM_CTRL_EXC* channels of the H2 and L1 interferometers. A subset of all the desired injections were made prior to S1:

- Signals were injected into both H2 and L1 on June 27, 2002. However, there were some bugs in the procedure (in particular, both ETMX and ETMY were excided with the same sign, so that the signal was mostly common-mode.)
- M. Landry injected signals into H2 on 8/14/02
- S. Marka injected signals into L1 on 8/16/02 and 8/17/02
- Szabi and Mike injected coincident bursts into H2/L1 on 8/22/02

Signal sent to GDS system

The signal that is sent to each of the ETMs by the GDS system is a product of factors:

- A waveform with units of strain, sampled at 16384 Hz, is input to the system.
- The peak strain amplitude can be scaled to a desired value.
- This is multiplied by the arm length (2000 m for H2 and 4000 m for L1), and by "antenna pattern" factors (for the two ETMs in each of the 3 interferometers) corresponding to a particular source direction and polarization.
- From the calibration[6], we know how many DAC counts, *G*, correspond to a motion of 1 nm, at frequencies much below the pendulum frequency (f_p = 0.74 Hz). *G* is typically on the order of 1 nm/count.
- Since sine-Gaussians are narrow band, with central frequency f_c, there is a factor of $(f_c / f_p)^2$ to account for the pendulum response to force from the GDS-controlled coil actuators. (more complicated filtering would be required for broad-band signals).
- Relative delays between the three interferometers are calculated based on the source direction (on the order of msec).

Driver files for injections

```
BURST_Z
#T_off  filename     H2_DELAY      M_ETMX      M_ETMY   L1_DELAY      M_ETMX      M_ETMY   H1_DELAY      M_ETMX      M_ETMY
#  (s)                    (s)                                 (s)                                 (s)

    40  wf100.dat      1.0000      0.0544     -0.0536     1.0000      0.0275     -0.0291     1.0000      0.0516     -0.0452
    80  wf153.dat      1.0000      0.0640     -0.0630     1.0000      0.0647     -0.0686     1.0000      0.1215     -0.1063
   120  wf235.dat      1.0000      0.0753     -0.0742     1.0000      0.0761     -0.0807     1.0000      0.2859     -0.2502
   160  wf361.dat      1.0000      0.0354     -0.0349     1.0000      0.0716     -0.0760     1.0000      0.6729     -0.5888
   200  wf554.dat      1.0000      0.0417     -0.0411     1.0000      0.0674     -0.0715     1.0000      1.5837     -1.3858
   240  wf850.dat      1.0000      0.0981     -0.0967     1.0000      0.1587     -0.1683     1.0000      3.7274     -3.2614
   280 wf1304.dat      1.0000      0.2310     -0.2275     1.0000      0.4670     -0.4952     1.0000     17.5450    -15.3519
   320 wf2000.dat      1.0000      0.5436     -0.5355     1.0000      1.9783     -2.0979     1.0000     61.9395    -54.1970
   360  wf100.dat      1.0000      0.2718     -0.2678     1.0000      0.1374     -0.1457     1.0000      0.2581     -0.2258
   400  wf153.dat      1.0000      0.3199     -0.3151     1.0000      0.3233     -0.3429     1.0000      0.6074     -0.5315
    …
```

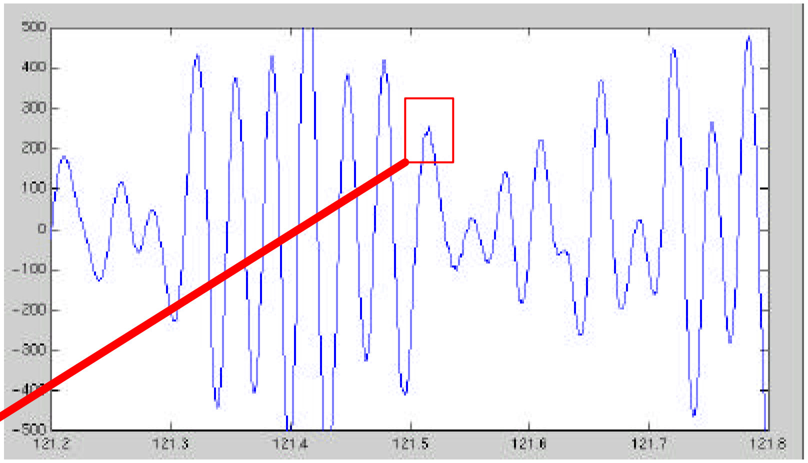
```
BURST_ANG
#T_off  filename     H2_DELAY      M_ETMX      M_ETMY   L1_DELAY      M_ETMX      M_ETMY   H1_DELAY      M_ETMX      M_ETMY
#  (s)                    (s)                                 (s)                                 (s)

    40  wf850.dat      0.0000      1.8795     -1.9080    -0.0000     -3.1329      3.2244     0.0000     71.3846    -64.3627
    80  wf850.dat     -0.0038      0.7602     -1.8054     0.0038     -2.3396      0.2829    -0.0038     28.8713    -60.9012
   120  wf850.dat     -0.0038      0.4389     -1.2321     0.0038     -0.9553      0.1659    -0.0038     16.6688    -41.5612
   160  wf850.dat     -0.0038      0.0000     -0.3286     0.0038      0.6849      0.0045    -0.0038      0.0000    -11.0849
   200  wf850.dat     -0.0043      1.0065     -1.2559     0.0043     -0.9788      0.6367    -0.0043     38.2277    -42.3656
   240  wf850.dat     -0.0043      0.7087     -0.4360     0.0043      0.4348      0.7272    -0.0043     26.9171    -14.7080
   280  wf850.dat     -0.0043      0.2210      0.5007     0.0043      1.7320      0.6229    -0.0043      8.3941     16.8906
   320  wf850.dat     -0.0043     -0.3259      1.3033     0.0043      2.5650      0.3516    -0.0043    -12.3781     43.9634
   360  wf850.dat     -0.0042      1.3805     -0.6045     0.0042     -0.0302      1.5366    -0.0042     52.4316    -20.3904
```

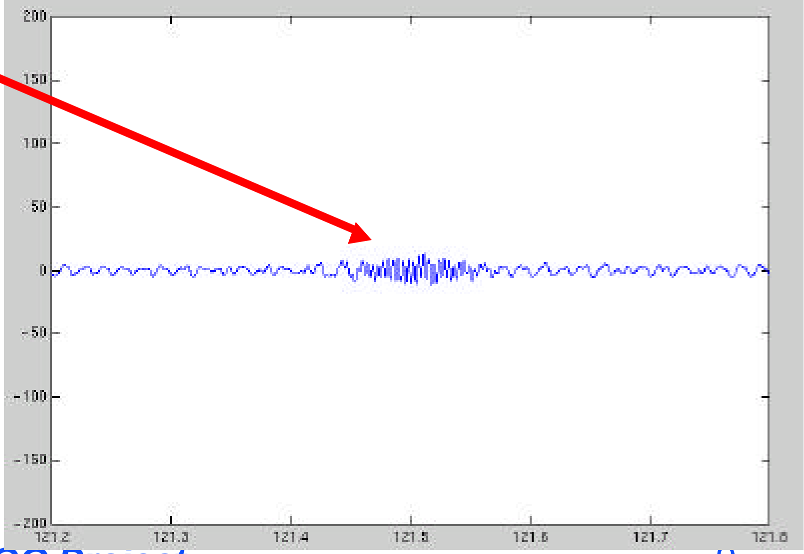
First look at 8/17/02 injections into L1:LSC-DARM_CTRL_EXC

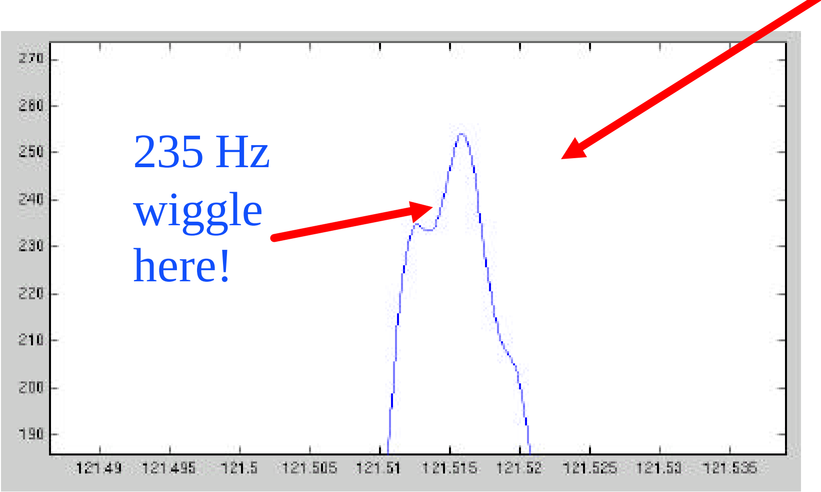
- Beginning with 360 seconds of injections (one every 40 seconds) with scale factors **7.5** and **30**
- Command: **darm_z_burst 713668660 1**
- Can we see the signals in the time series?
- Can we see the signals in spectrograms?
- Can the burst search DSOs see the signals?
- Do we quantitatively understand the amplitude of the signals? Do they compare well with software injections into the data stream in LDAS?

Can we see the signals in the time series?

- Surely not, given the very large low frequency noise.
- But we can zoom in, A LOT. (eg, zoom in on 235 Hz SG at 121 seconds after start).
- Or, we can HP filter the data.
  (eg, 10^{th} order Butterworth at 120 Hz)

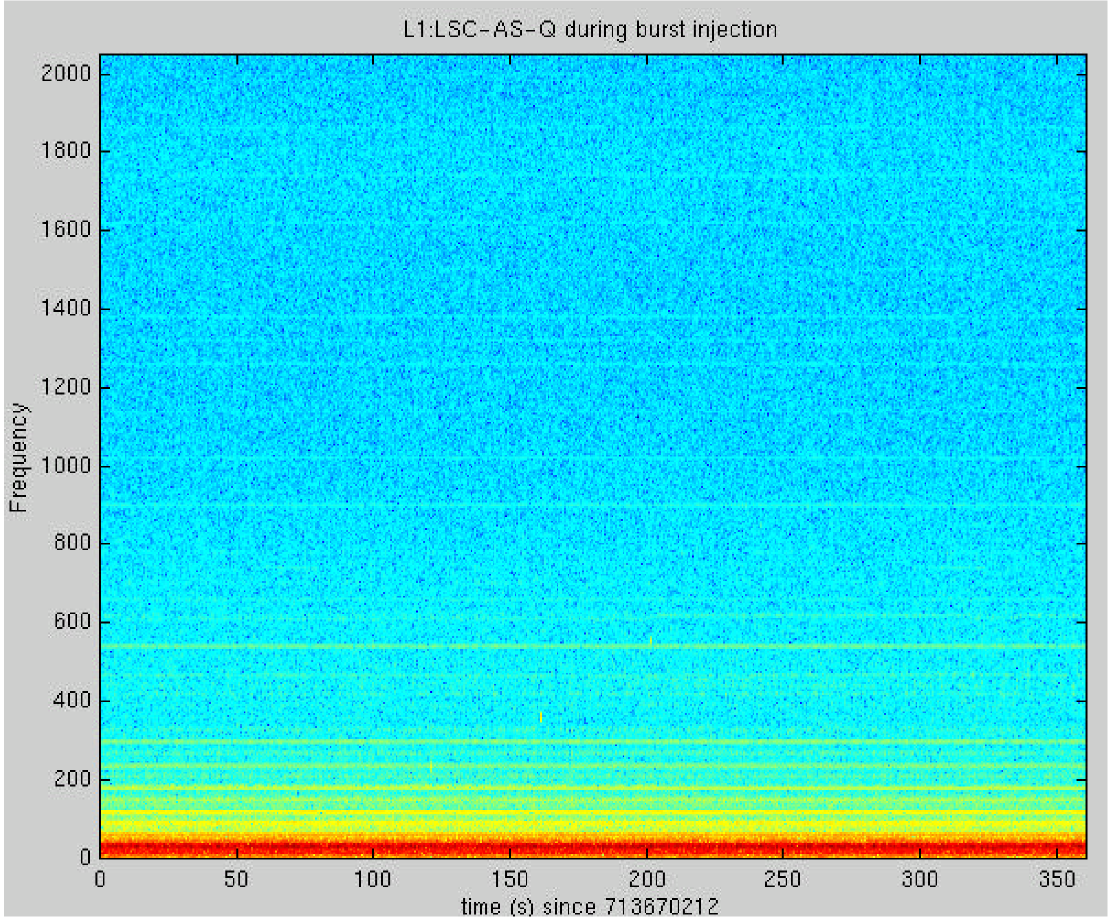




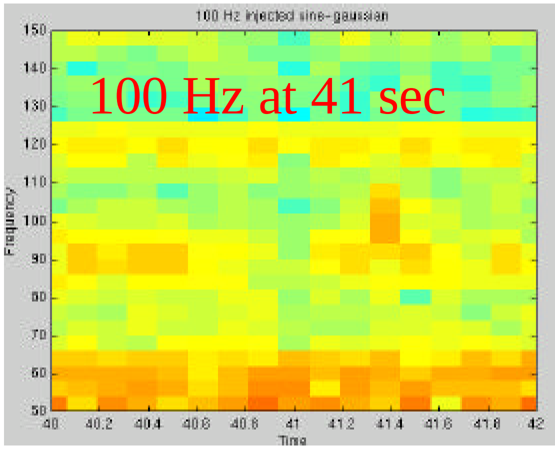


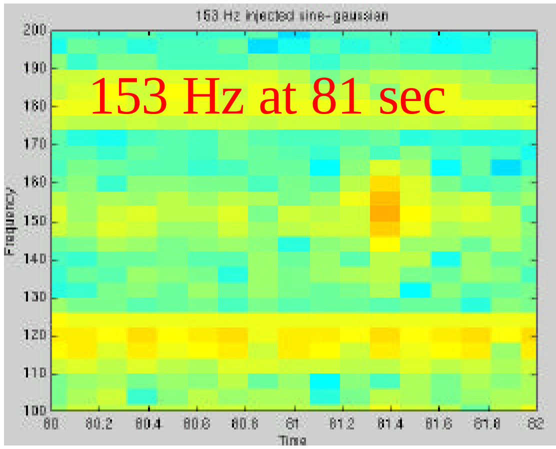
Can we see the signals in the spectrogram?

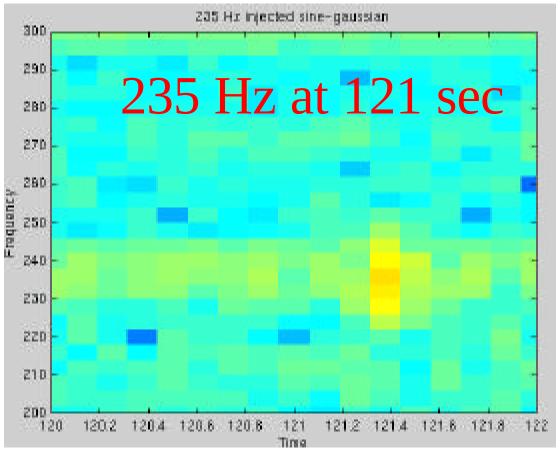
- Surely not, unless you really zoom in.
- But this shows that it's a pretty quiet stretch of data.

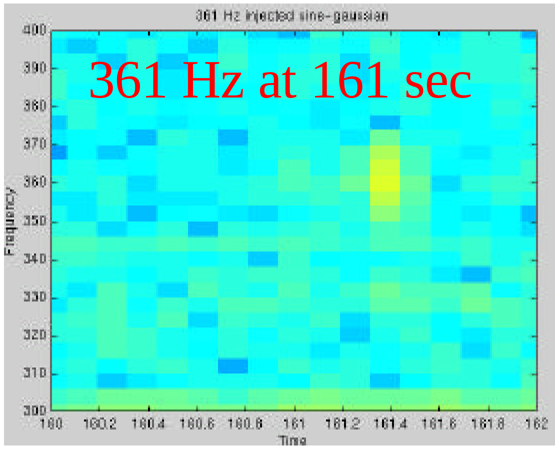


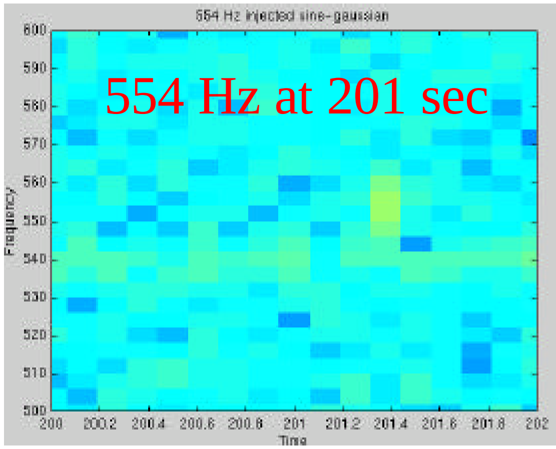
Zoom in on the spectrogram

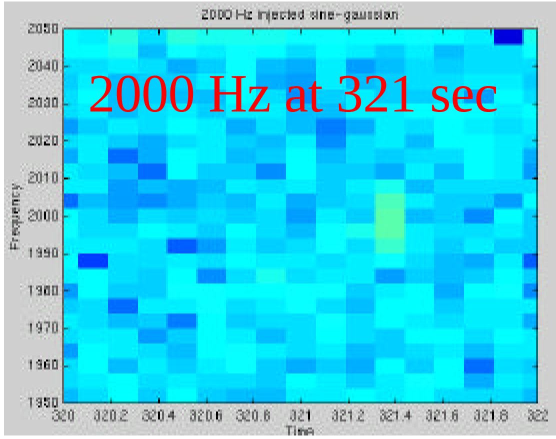












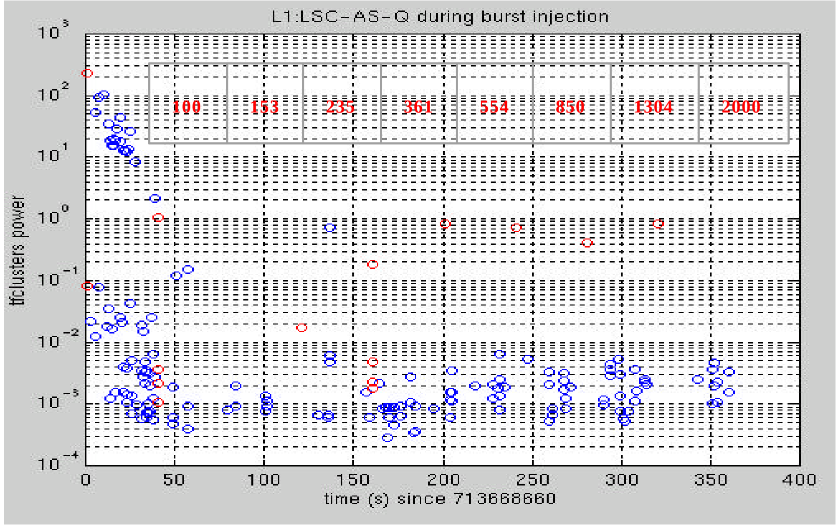
Can we see it in *tfclusters*?

- *tfclusters* (J. Sylvestre) is one of our well-tested burst search algorithms, running in LDAS as a *wrapperAPI* DSO
- It calculates excess power in pixels in the t-f plane, then looks for clusters of such pixels.
- It generates a list of triggers, with start_time, burst power, central frequency, bandwidth, duration.

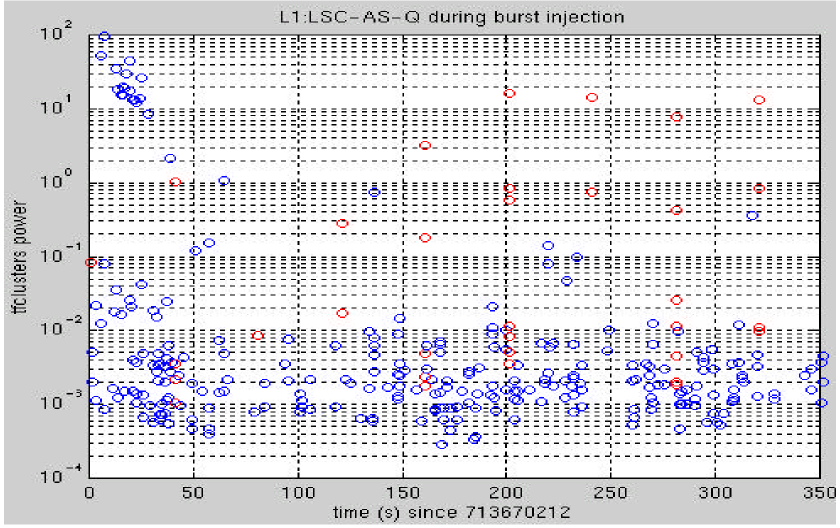
tfclusters triggers

- Triggers in time with injected bursts are indicated in red
- For scale factor 7.5, we find bursts above 150 Hz with large SNR
- Trigger "power" scales like $(30/7.5)^2$ as expected

scale factor 7.5



scale factor 30



Amplitude

- The real point of all this is to “cross-calibrate” hardware vs software injections, testing our understanding of all the gain factors.
- First check: injections into LLO with scale factors differing by factor 4, show up in tfclusters with “power” differing by ~ 4^2. OK!
- This work is in progress.