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S2 Hardware Pulsar Injections

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LIGO-G030479-00-Z

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Why Do Hardware Injections?

- Provides end-to-end validation of search code:
  - » Gain confidence about tricky things like floating point dynamic range in filtering process
  - » Helps algorithm/code developers in testing
  - » Provide a fixed point of reference to return to
- **Challenges** in the pulsar case:
  - » Realistic signals must last for hours (~10^7 cycles). This is unlike the burst (seconds) and inspiral (tens of seconds) case.
  - » Would like to avoid the "SB" scenario where the simulated signal dominates the data
  - » Getting the correct initial phase relationship at the different detector sites can be tricky (specifics later)
- **Simpler** in pulsar case:
  - » Calibration: signal is at a "single" frequency

S2 Pulsar Injection Parameters

- Signal is sum of two different pulsars, **P1** and **P2**

P1: Constant Intrinsic Frequency

Sky position: **0.3766960246** lattitude (radians)
5.1471621319 longitude (radians)
Signal parameters are defined at SSB GPS time **733967667.026112310** which corresponds to a wavefront passing:
LHO at GPS time **733967713.000000000**
LLO at GPS time **733967713.007730720**
In the SSB the signal is defined by
f = 1279.123456789012 Hz
fdot = 0
phi = 0
A+ = 1.0 x 10^{-21}
Ax = 0 [equivalent to iota=pi/2]

Note: At SSB GPS time **733967667.018380990** (wavefront passing LLO at GPS time **733967713.000000000**) f is the same, because fdot=0, and phi=**0.69546841529.**

P2: Spinning Down

Sky position: **1.23456789012345** lattitude (radians)
2.345678901234567890 longitude (radians)
Signal parameters are defined at SSB GPS time:
SSB **733967751.522490380**, which corresponds to a wavefront passing:
LHO at GPS time **733967713.000000000**
LLO at GPS time **733967713.001640320**
In the SSB at that moment the signal is defined by
f=1288.901234567890123
fdot = -10^{-8} [phase=2 pi (f dt+1/2 fdot dt^2+...)]
phi = 0
A+ = 1.0 x 10^{-21}
Ax = 0 [equivalent to iota=pi/2]

Note: at SSB GPS time **733967751.520850180** a wavefront passes LLO at (slightly earlier) GPS time **733967713.000000000**. At this time the signal is defined by **f = 1288.901234567906525** (slightly higher)
phi = 5.566551549393011918 85 radians
fdot, A+ and Ax are unchanged

What Are These Two Different SSB GPS times?

P1: Constant Intrinsic Frequency

Sky position: **0.3766960246** lattitude (radians)
5.1471621319 longitude (radians)

Signal parameters are defined at SSB GPS time **733967667.026112310** which corresponds to a wavefront passing:

LHO at GPS time **733967713.000000000**

LLO at GPS time **733967713.007730720**

In the SSB the signal is defined by

f = 1279.123456789012 Hz

fdot = 0

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Note: At SSB GPS time **733967667.018380990** (wavefront passing LLO at GPS time **733967713.000000000**) f is the same, because fdot=0, and phi=**0.69546841529.**

```
#! /bin/bash

bc -l << EOF
scale=20
pi=4*a(1)
f=1279.123456789012
phi=2*pi*(.01838099-.02611231)*f
Phi=phi+20*pi
print "phi=", phi, "\n"
EOF

phi=0.69546841529179172719
```

Note that in an April 14th email Bruce didn't notice that nsec had only 8 digits and incorrectly gave one of these times as 733967667.26112310

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How was simulated signal made?

- 12 hours of strain data was produced (with overall 10^{21} normalization factor) using LAL routines:

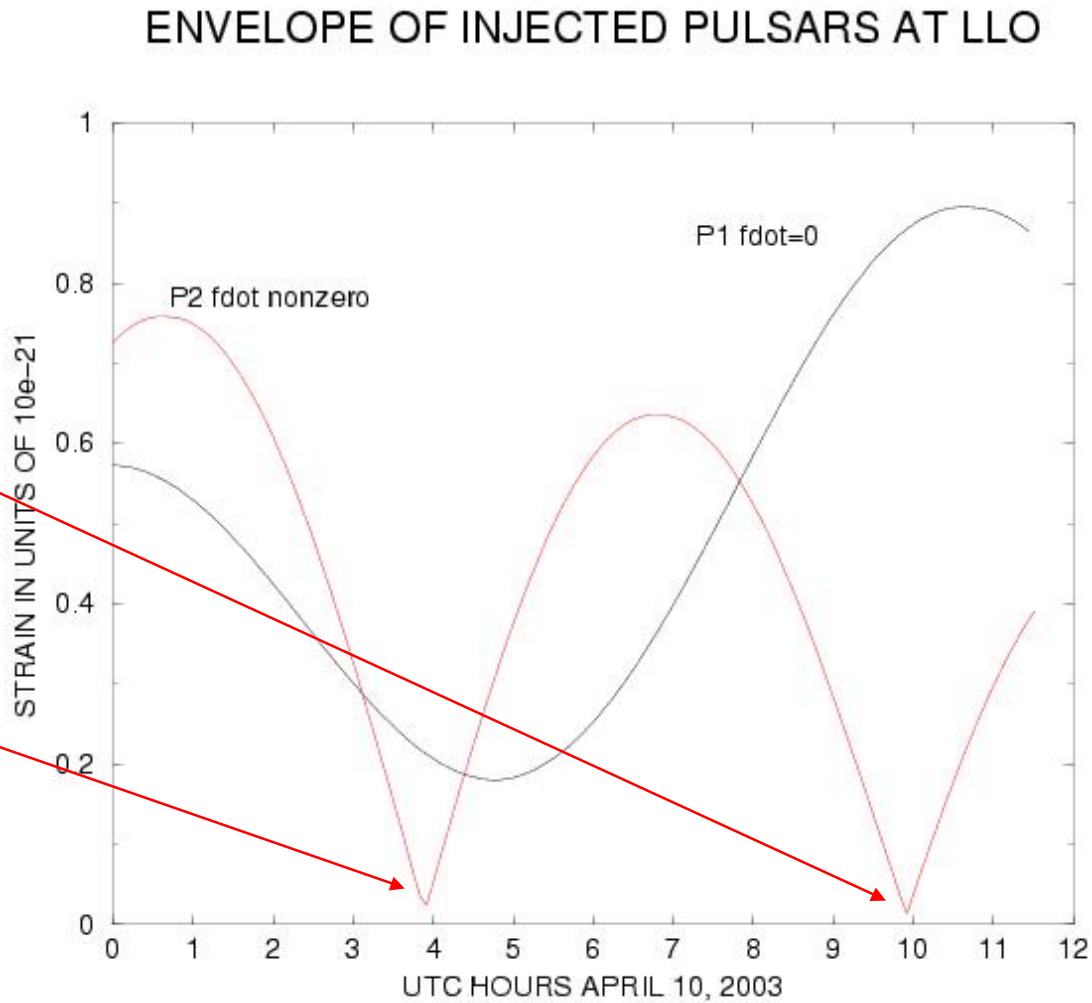
  S2_pulsar_LHO_733968013.dat
  S2_pulsar_LHO_733968313.dat
  S2_pulsar_LHO_733968613.dat
  ... and so on.

- 144 files (5 minutes each) were produced. Each file contains 16384*300+1 4-byte IEEE 754 floats:
  - Key 1234.5 (4 bytes)
  - Sample 0 xxxxxx (4 bytes)
  - Sample 1 yyyyyy (4 bytes)
  - …
- Time range was 00:00 –12:00 UTC April 10th
- The 2.8 GB of injection data was shipped to each site

Simulated strain: Detector Response Function

April 10th 10:00 UTC is:
LHO: 2 am April 10th
LLO: 4 am April 10th
simulated source is passing near a zero of the antenna pattern.

April 10th 04:00 UTC is:
LHO: 8 pm April 9th
LLO: 10 pm April 9th



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How and When?

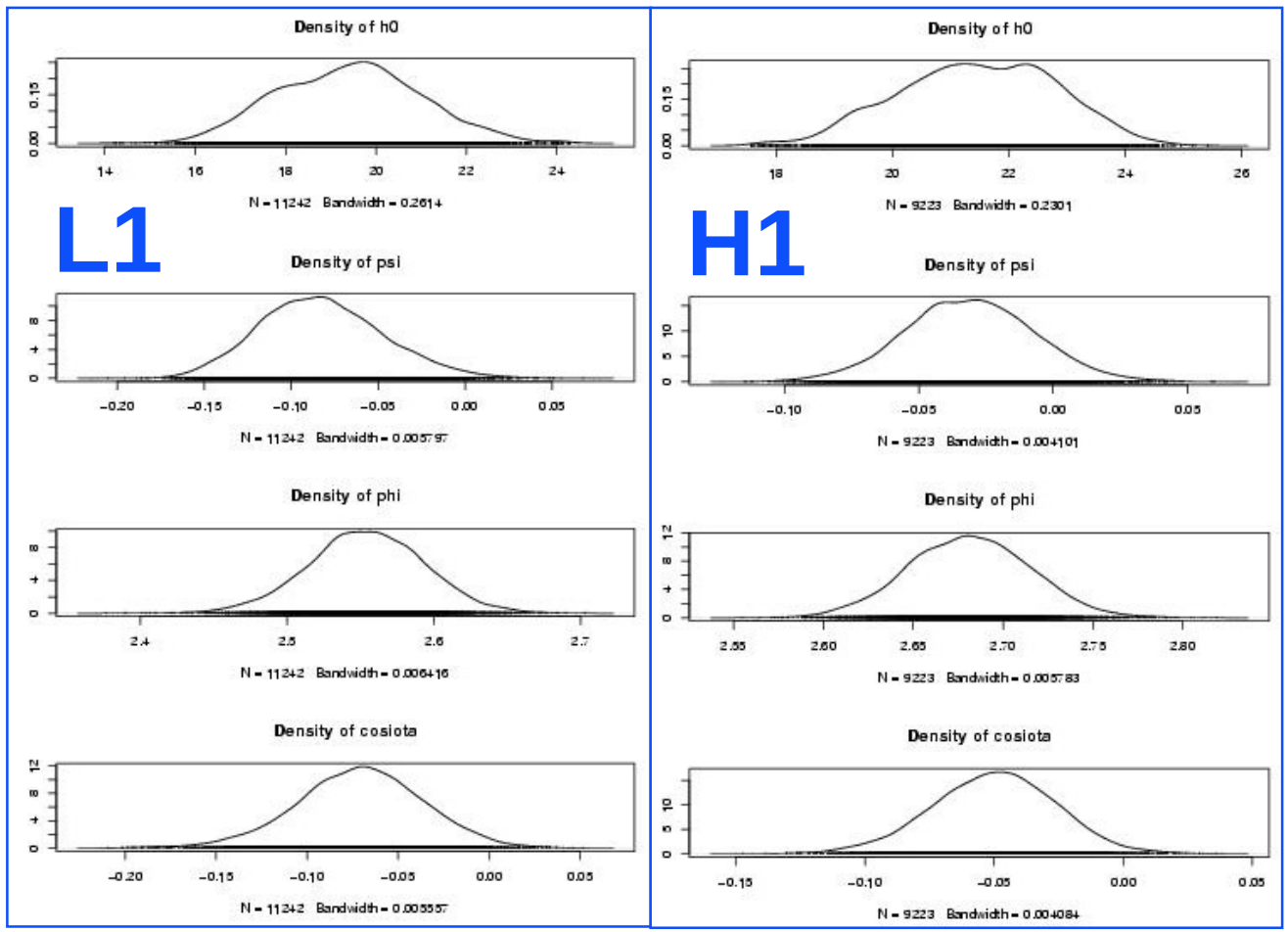
- More than 9 hours of pulsar injections into L1, H1 and H2
  - » Start 18:19 PDT on April 9
  - » Stop 04:03 PDT on April 10
- Instruments were in lock for almost the entire time
- Pulsar plus calibration line summed into DARM_CTRL
- ETM_X and ETM_Y used for other injections
- Strain/DARM_CTRL calibrations worked out at 1284 Hz, halfway between two signals. **NOTE: THESE WERE SUBSEQUENTLY REVISED FOR H1 AND H2 – SO AT THOSE DETECTORS THE OVERALL STRAIN FACTOR WAS NOT 1.e-21!**
- Injections started at 733974613 (01:50:00 UTC April 10) and continued until 734007889 (11:04:36 UTC April 10) with some minor interruptions (loss of lock, realignment, computer restarted because of lack of memory).

S2 Pulsar Hardware Injection Results for P1 (Time Domain Code)

These plots show the probability density functions obtained for h0, iota, phi and psi using the Markov Chain Monte Carlo method (N. Christensen, R. Dupuis, G. Woan).

They are all **SHARPLY PEAKED** at the correct values of h0, psi and iota. They are also sharply peaked at the wrong value of phi – but the same wrong value in H1, H2, L1. This is probably due to a typo (Bruce's fault) in an email specifying the correct time origin for defining the phase.

The injected signal has been detected (modulo typo) at the correct values of the parameters!



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Still to do…

- A quick look was done using the Frequency Domain method (F-statistic) within a few days after the run. The signals were seen at approximately the correct amplitude in all three instruments
- The Frequency Domain searches need to be repeated more carefully and better documented.
- The Time-Domain method still needs to look for the non-zero fdot signal. We also need to verify that with correct choice of initial GPS time, phi is peaked at zero (BA is almost 100% confident about this).

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What about S3?

- The pulgroup will try to provide a fast real-time function that can be called, which will return h(t). Perhaps this can be used to do longer-term injections during S3.
- Uta Weiland (GEO Hannover) is writing a routine for this purpose for GEO pulsar injections.
- I'd like to know what the LIGO experimenters need, please.
- *Discussion item: should we do long-term injections (weeks/months) during S3?*