The Continuous Waves UL Group: status report.

LSC Meeting

LIGO Hanford Observatory

August 2002

Activities:

- Coherent Searches:
  - Time domain targeted searches, isolated pulsars and in binaries (Glasgow, mostly in LAL)
  - Frequency domain (AEI for LAL, G.Mendell for LDAS)
    - isolated pulsars (AEI, in LAL)
    - pulsars in binary systems (Birmingham, to be LAL)
- Area searches (AEI, in LAL)
- Blind Searches (K. Riles, D. Chin)
- Signal injection (T. Creighton, in LAL)
- Barycentering routines (C. Cutler, in LAL)

we're doing quite well

Coherent Searches – our top priority:

- we are developing 2 independent full pipelines
- we have looked (one way or another) at all E7 data
- we will set upper limit using both LIGO and GEO data (Dec)
- we have set a preliminary upper limit using GEO data

Note that:

- the input data for one of the two pipelines is not the usual time-domain data – it's the SFTs
- the code is at least as complicated as the flat binary inspiral search code and that has been developed for years
- the UL group has not much more than a hand-full of people *actively* working on this and scattered between US and Europe.

Known Pulsar Searches: Time Domain Analysis

- **The procedure consists of three steps:**
  - coarse heterodyning that down-samples the data to 4 Hz in the frequency band of interest+ fine heterodyning that demodulates frequency and amplitude. This depends on (the known) values of f0,pos. sky,spin-down parameters
  - construction χ^2 variable which additionally depends on: i, ψ, φ_0, h0.
  - marginalization over i, ψ, φ_0 in order to compute posterior pdf of signal with amplitude h0 present in the data.

- **code developed in Glasgow** by G. Woan and R. Dupuis: '**`knownpulsartd`**' package submitted to LAL a few weeks ago.

Some functionality and documentation missing.

- **Upper Limit set on GEO E7 data:** $\sim 10^{-21}$ at the 1 σ level, without marginalization. Pulsar: J1939+2134.

Compare the output of the two search engines for a targeted search

The final product of both the analyses will be a curve, function of h0:

$$P (h_0 | \underline{t} , \{x\})$$

that represents the posterior pdf that a signal defined by the template parameters $\underline{t}$ (position of source, spin-down parameters, emission frequency) and maximum amplitude (on Earth) h_0, is present in the analyzed data set {x}.

This could be recast as, say, P (ε).

Frequency Domain Coherent Search

This is the code that takes **S**hort (time-baseline) **F**ourier **T**ransforms as input.

Search Engine:

- added amplitude demodulation: JKS's $\mathcal{F}$ statistic (gr-qc9804014)
- modified output to make it possible to do parameter estimation
- we understand what predicted output should be in noise-only case.
- we are validating the code with *completely* independent implementation by G. Mendell and B. Cameron.
- upper limit: we think that we know how to go from the $\mathcal{F}$ statistic to the pdf curve. We'll use a MC approach with *signal injection*.
- added possibility to deal with non-contiguous SFTs (was done just recently and the code has not been debugged).
- need to run MDC test on ``new'' code.

the Short Fourier Transform data.

• LIGO DATA ⟺ LDAS :

- SFTs for L1, H1, and H2 have been generated (driving scripts are in MDC CVS).
- E7 SFTs data are available from LDAS using getsftdata.tclsh script. (Need ligotools LDAS job package and LDAS password.)
- LDAS can read SFT data very quickly: 1 days worth of data in 1 Hz band in < 60 seconds.
- knownpulsardemod test jobs that produce the JKS F statistic have been run on E7 data.

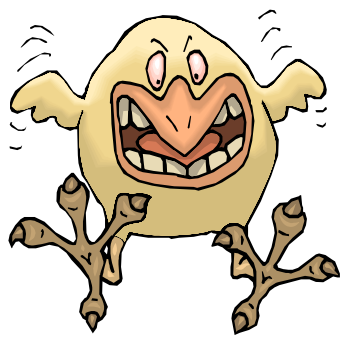
• GEO DATA:

- E7 data was studied first to find best format for these SFTs
- SFT data was produced for E7 with standalone straightforward program
- format is not frame, it's a very simple binary format
- it's very fast to read and write
- SFT data is being looked at
- data-preparation issues and inverse Sh weighting techniques discussed

the Short Fourier Transform data.

COMMENTS (on the existence of 2 difference SFT formats):

- The SFT header information is (almost) the same.
- Any simple program can read GEO SFTs.
- The other way round, is a little more complicated, now. Better after Greg's scripts.
- GEO decided it was more practical (would allow more work to be done) to develop a manageable format to access SFT – there's always time to go for more sophisticated solutions after you know what you want.



SFTs in new frame format

Code development to search for continuous waves from LMXB's

- The long-term goal is to set up a hierarchical code to search for quasi-monochromatic signals from rapidly rotating neutron stars in binary systems
- The science goal is to place upper-limits on continuous waves from LMXB's, such as Sco X-1
- So far we have tuned the code development on one specific target, Sco X-1, because it is the strongest source (Wagoner 1984; Bildsten 1998; Ushomirski et al., 2001) and it simplifies the analysis in several respects (Dhurandhar and Vecchio, 2001) :
  - circular orbit (only 3 additional search parameters, and not 5)
  - for up to about 1 month of coherent integration, the period is not a search parameter
  - for integration times up to two weeks the signal is monochromatic (in rest frame of source)

Code Status

- Short-term goal: analyze S1 data and, possibly, to exploit E7 data
- LALDemod was generalized to take into account binary motion (at present only circular orbit)
- New LAL function to place templates in the additional 3D parameter space (for Sco X-1, and a few weeks of integration time, only 2D); documentation still missing, and generalization to N-dimensions in progress
- The end-to-end coherent search code for known position, monochromatic waves and circular orbit is in place: this is all we need to place upper-limits on Sco X-1 over an integration time of about 10 days
- Testing and validation is the main focus right now – using GEO E7 data and Teviet's signal generation code

Area Searches (Hough Hierarchical):

- Could not devote much attention since last LSC meeting
- A first full pipeline is in place but works with old LALDemod code and must be updated
- Time was devoted to the Beowulf cluster that we'll use for this analysis. We survived all the bureaucracy and now a national (in Germany) open bid is out. Closing date to submit offers is September 13th.

LIGO

Unbiased CW Search *(Michigan)*

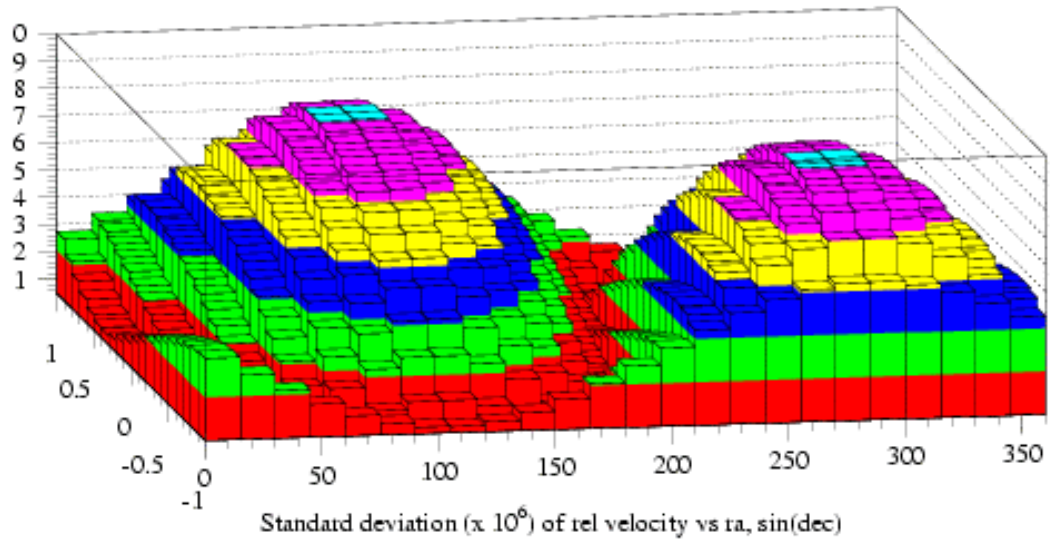
Analysis Strategy:

- Measure power in selected bins of averaged periodograms (start with SFTs produced by LDAS)
- Which bins one selects depends on the source parameters (f, RA, δ) and on the observation time [see figure]
- Estimate noise level and noise statistics by using neighbouring bins
- Set upper limit on quasi-sinusoidal signal on top of empirically determined noise
- Scale upper limit by antenna pattern correction (time averaged)

LIGO

Valid for E7

Doppler shift depends on relative motion between source and detector ($\Delta f/f \sim 10^{-6}$ -- 10^{-5}) and is different at different times for different locations in the sky.



Status:

- Limited progress since March meeting
  - Busy with other work
  - Technical problems in migration to LDAS
- Dave Chin devoting bulk of time to this effort after S1
- Expect more rapid progress with S1 data

Signal injection software

- **T. Creighton has added routines to LAL inject package to simulate CGW and their effect on the detector:**
  - **`GenerateTaylorCW` provides a routine to generate continuous quasiperiodic waveforms with Taylor-parametrized frequency evolution**
  - **`GenerateSpinOrbitCW` provides a routine to generate Taylor-parametrized waveforms, as above, with additional binary orbit Doppler modulations**
  - **`SimulateCoherentGW` provides a routine to simulate the detector response to a coherent wave with slowly-varying frequency and amplitude**
- **Added possibility to produce an idealized-heterodyned series, by defining a suitable freq. value (that will go to DC) and sampling time.**
- **Uses LALInitBarycenter, LALBarycenter.**
- **All search codes are now using these signal-generation routines.**
- **A *VERY* important piece of software for us**

Signal injection - hardware

• **PLAN: to build in Ruthe (GEO site, near Hannover) a small radio telescope that will provide a continuous monitor of the Crab and, based on this, produce a hardware signal that will be recorded into an auxiliary channel.**

Conclusions

- We will concentrate on setting upper limits on known isolated pulsars, as the top priority (**more in the next slide**).
- Proceed with work for setting UL on emission from ScoX1
- Hierarchical code for area searches:
  - modify driver code to deal with gaps in SFTs
  - integrate new LALDemod in driver
  - validate
  - run on E7 data
- Results from unbiased search techniques – *shoot for Dec deadline*.

Realistic timescale for delivery

- We will concentrate on setting upper limits on known isolated pulsars, as a first priority:
  - time domain:
    - complete the software (ma… ace and all software in LAL) and validate search engine
    - final upper limit o… using GEO E7 data.
    - upper limit on other pulsars using …)
  - frequency domain:
    - complete signal + noise generator code and ma… feedable into LDAS
    - finish debugging new search engine (t… in data),
    - check normalizations,
    - check that standalone driver pr… ame results as LDAS driver *on same data.*
  - check that time domain code and frequency… me $p(h_0)$ curve on same fake data with same target.
  - run LDAS co… dalone codes on GEO and LIGO data .
  - compare output

End of September LSC conf call

Mid December

Mid November

Mid November

Mid December