Work of the LSC Pulsar Upper Limits Group (PULG)

Graham Woan, University of Glasgow on behalf of the LIGO Scientific Collaboration
Pulsar Upper Limits Group (PULG)

- Community of LSC members interested in continuous wave sources

- Co-chairs:
  Maria Alessandra Papa (AEI, GEO)
  Mike Landry (LHO Hanford, LIGO)

- Search code development work has been underway since mid-to-late 1990s

- For S1: set upper limit on a single known pulsar

- For S2: set upper limits on generic continuous wave signals, and perform some wide-area and targeted searches
Search methods

• Incoherent searches:
  » Blind search
  » Stack–slide search
  » Hough transform search

• Frequentist coherent searches:
  » F-statistic area search
  » X-ray binary search

• Bayesian parameter estimation searches:
  » Time domain targeted search
  » MCMC search

Searches for excess monochromatic power

Deep searches over a broad parameter space

Finely tuned searches over a narrow parameter space
Blind all-sky search
D. Chin, V. Dergachev, K. Riles (U. Michigan)

- Measure power in selected bins (defined by frequency and sky-position) of averaged periodograms
- Estimate noise level & statistics from neighboring bins
- Set upper limit on quasi-sinusoidal signal, corrected for antenna pattern and Doppler modulation
- Refine with results from explicit signal simulation
- Follow up any unexplained power excess in single IFO with multi-IFO consistency checks
Stack-slide search
M. Landry, G. Mendell (LHO)

A. Stack the power
B. Slide to correct for spindown/Doppler shifts
C. Sum and search for significant peaks

- An incoherent search method that stacks and slides power to search for periodic sources.
- Can be used as part of a hierarchical search with coherent & incoherent stages
- Sources like LXMBs with short coherence times (~ 2 weeks) are well suited to incoherent methods

Bins with frequency domain data, e.g., from SFTs or F-statistic
Hough transform search
B. Krishnan, MA Papa, A. Sintes (AEI/UIB)

- Input data: Short Fourier Transforms (SFT)
- For every SFT, select frequency bins in which normalised power exceeds some threshold
  \( \rightarrow \) t-f plane of \{0,1\}

- Search for patterns in the t-f plane using the Hough Transform

- Generate summary statistics
- Frequentist upper limits: \( p(n|h_0) \)
  estimated by Monte Carlo signal injection

See poster
$F$-statistic area search

B. Allen, B. Krishnan, Y. Itoh, M. Papa, X. Siemens (AEI/UWM)

- Detection statistic:
  \[ F = \log \text{of the likelihood maximized over (functions of) the unknown parameters} \]

- Frequency $f$ of source in solar system barycentre (SSB)
- Rate of change of frequency $df/dt$ in SSB
- Sky coordinates $(\alpha, \delta)$ of source
- Strain amplitude $h_0$
- Spin-axis inclination $\iota$
- Phase, polarization $\varphi, \psi$
X-ray binary search (accreting neutron stars)
C. Messenger, V Re, A. Vecchio (U. Birmingham)

- Search Sco X-1 and other known LMXBs (~20 targets)
- Method: hierarchical frequency domain analysis
  » Coherent analysis over short data chunks
  » Add incoherently (stack-slide) chunks
  » Upper-limit using frequentist approach
- Parameter space:
  » Emission frequency (search bandwidth ~ tens of Hz)
  » 3 orbital parameters
  » Spin-down/up
- S2 analysis: upper-limit on Sco X-1 using a one-stage coherent search over short integration time ($T_{\text{obs}} = 6 \text{ hr}$)
  » Computationally bound: one month of processing time on 200 CPUs
Time domain targeted search
R. Dupuis, M. Pitkin, G. Woan (U. Glasgow)

- Targeting radio pulsars at known locations with rotational phase inferred from radio data
- Heterodyne stages to beat any time-varying signal down to ~d.c.
- Upper limits defined in terms of Bayesian posterior probability distributions for modelled pulsar parameters
MCMC search
N. Christensen, J. Veitch, G. Woan (Carleton/U Glasgow)

• Computational Bayesian technique (Markov Chain Monte Carlo) using Metropolis-Hastings routine

• MCMC can both estimate parameters and generate summary statistics (pdfs, cross-correlations, etc)

• 6 unknown parameters manageable so far: $h_0$, $i$, $\psi$, $\phi$, $f$, $df/dt$

• Initial Applications: fuzzy searches in restricted parameter space and SN1987a (location known but other parameters not known)
Computational engines used

- **Medusa cluster (UWM)**
  - 296 single-CPU nodes (1GHz PIII + 512 Mb memory), 58 TB disk space

- **Merlin cluster (AEI)**
  - 180 dual-CPU nodes (1.6 GHz Athlons + 1 GB memory), 36 TB disk space

- **Tsunami (Birmingham)**
  - 100 dual-CPU nodes (2.4 GHz Xeon + 2 GB memory), 10 TB disk space
Talks to come…

- **10:15-10:30**  
  Rejean J. Dupuis · University of Glasgow · GEO  
  *Analysis of LIGO S2 data for gravitational waves from isolated pulsars*

- **10:30-10:45**  
  Nelson Christensen · Carleton College · LIGO  
  *Pulsar Detection and Parameter Estimation with MCMC - Six Parameters*

- **11:15-11:30**  
  Bruce Allen · U. Wisconsin - Milwaukee · LIGO  
  *Broad-band CW searches in LIGO & GEO S2/S3 data*

- **11:30-11:45**  
  Alberto Vecchio · University of Birmingham · GEO  
  *Searching for accreting neutron stars*

- **11:45-12:00**  
  Yousuke Itoh · Albert-Einstein-Institute · LIGO/GEO  
  *Chi-square test on candidate events from CW signals coherent searches*