TwoSpect: an all-sky search for continuous gravitational waves from neutron stars in binary systems

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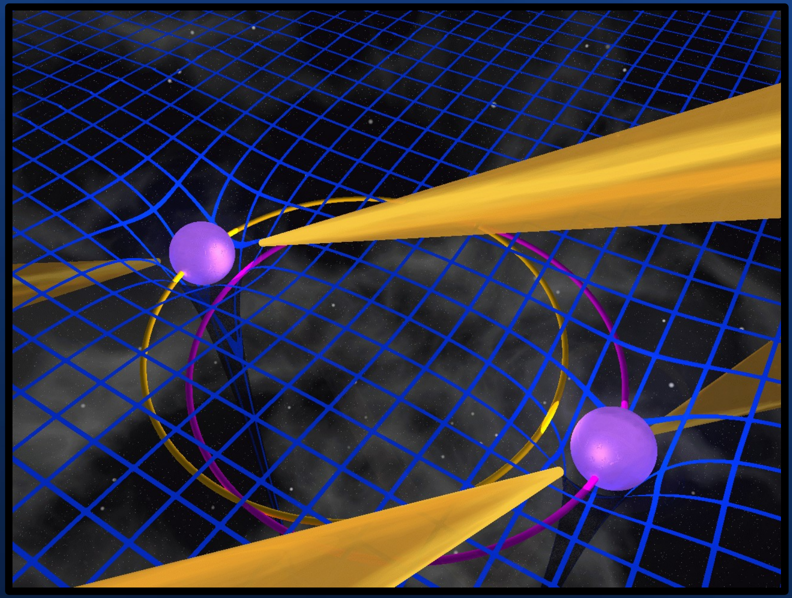
American Physical Society, April 2009 meeting

Motivation



Credit: M. Kramer

- Significant fraction of neutron stars are located in binary systems
- Accretion onto NS and other perturbative processes of the NS can drive gravitational radiation
- Current all-sky gravitational wave search algorithms are designed for isolated NS
- Additional binary orbital parameters requires an efficient, new algorithm in order to be computationally feasible

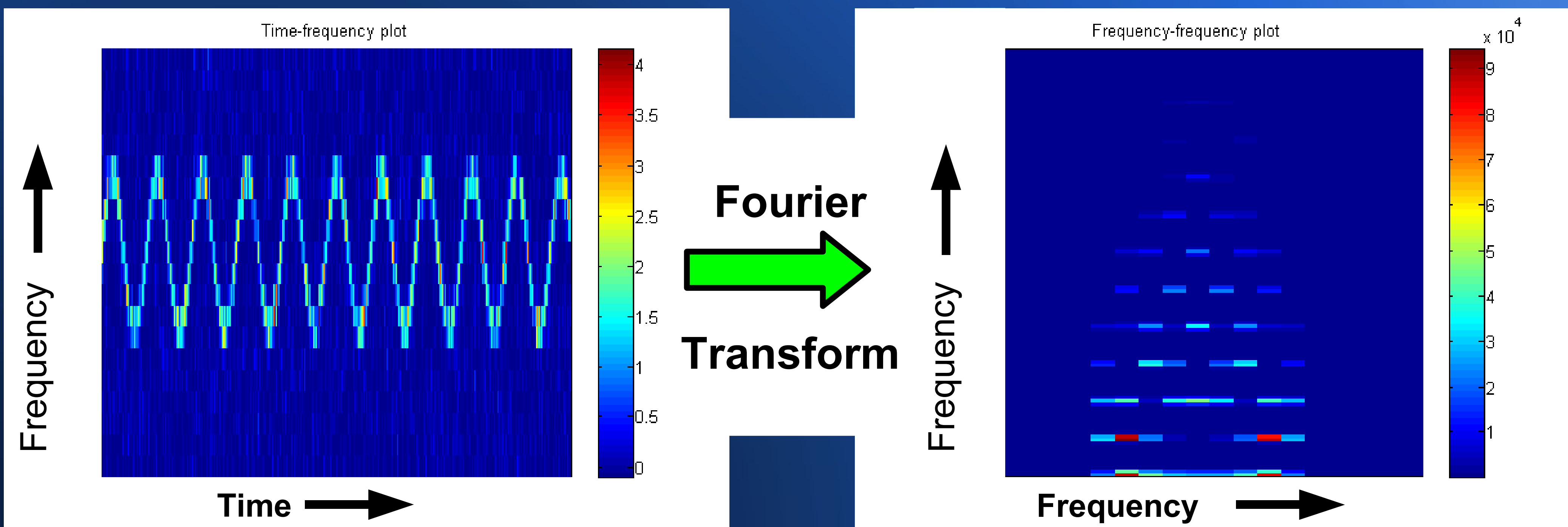
Search strategy

- Fourier transform short segments of data (~few to 30 minutes)
- Align the spectra, Fourier transform after mean subtraction for each band
- Fundamental + higher harmonics of the FM signal occur at frequencies corresponding to the period of the binary orbit, determined by binary system
- Use hierarchical TwoSpect algorithm to detect potential GW signals

Search strategy

First Fourier transform:

Second Fourier transform:



Optimal TwoSpect statistic

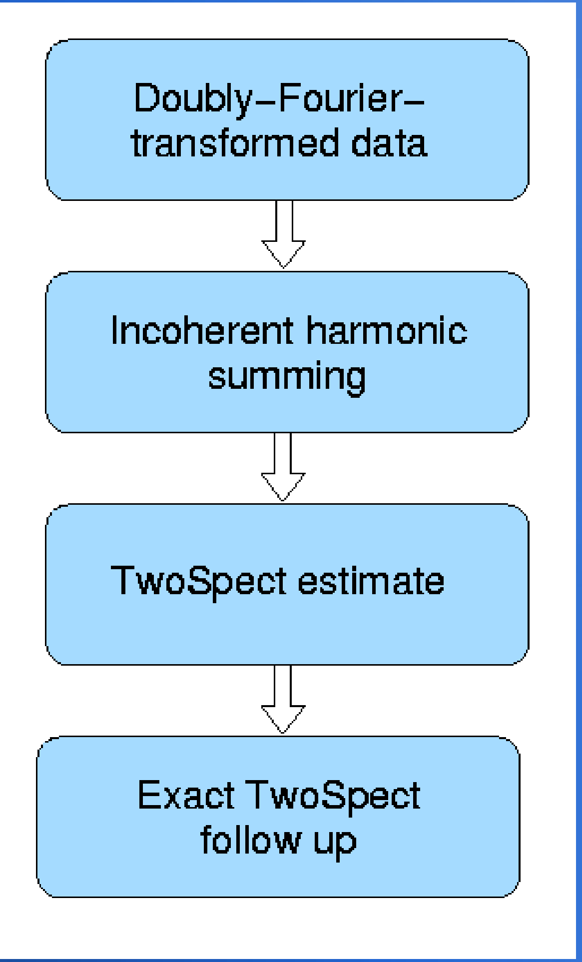
- Use weights from a template to match against the doubly-Fourier-transformed data
- Weights are determined by source signal frequency, signal modulation depth, and modulation frequency
- Purpose of the weights is to identify and quantify the “hot” pixels
- The optimal TwoSpect statistic

$$R = \frac{\sum_{n=0}^{N-1} \epsilon_n \left(x_n - \langle s_n \rangle\right)}{\sum_{n=0}^{N-1} \epsilon_n^2}$$

Twice FFTed data
Noise subtracted
Weight

Algorithm pipeline

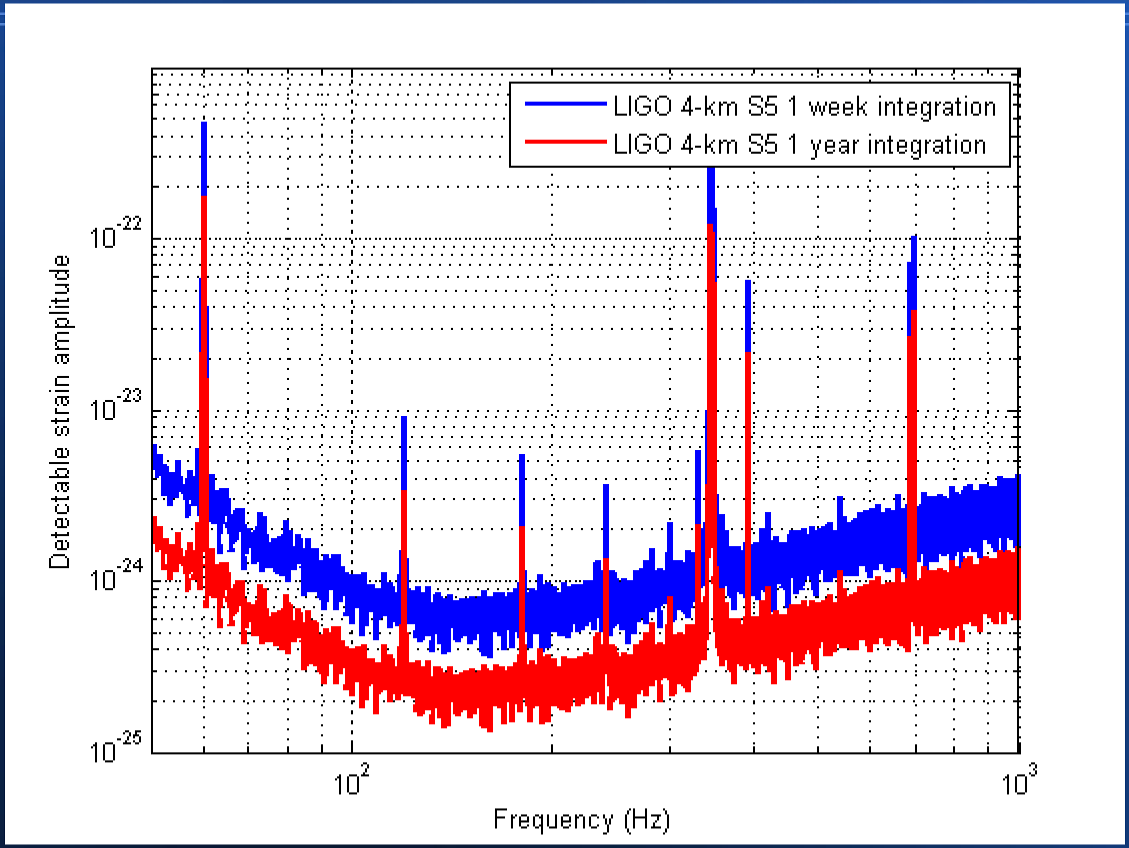
- The double-Fourier transform is computed after corrections for the Earth's orbital and spin motions
- Increasing sensitivity but increasing computation cost at each stage
- Incoherent harmonic summing algorithm threshold applied to columns
- Candidates are followed up using approximate weights for the TwoSpect *R* statistic
- Survivors are subjected to a threshold test using an exact template to determine *R*



TwoSpect search sensitivity

- Determine a false alarm rate threshold of *R* for a set of weights by 10,000 trials of random, white, Gaussian noise ($\langle s_i \rangle = 0$, $\sigma = 1$)
- Determine efficiency by injecting signals of various amplitudes with noise
- Scale amplitude value to the strain amplitude detectable, *h*, using Parseval's Theorem and the detector strain noise
- Search sensitivity is dependent on strain spectral noise density, observation time, SFT coherence time, and signal modulation depth

TwoSpect search sensitivity



- Amplitude scaled for comparison with an initial LIGO detector noise curve
- Single template, no amplitude modulation,1 year observation time with FFT coherence time of 1000 s yields maximum sensitivity near 150 Hz of ~2×10^{-25}

- In the final pipeline we expect the large number of templates and the antenna pattern corrections to degrade the sensitivity by an order of magnitude

Conclusions

- TwoSpect provides:
    - Reasonable computational scaling
    - Astrophysically interesting upper limits
    - Accessibility to new region of parameter space
- Expect to begin full-scale testing and implementation within the next few months on real LIGO data with a search beginning a few months later