An all-sky search for continuous gravitational waves from neutron stars in binary systems using the TwoSpect algorithm

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A search for continuous gravitational waves (GWs) from unknown pulsars in binary systems is notorious for its computational challenge. Data analysis techniques for GWs from unknown isolated sources have been in use for a number of years, while all-sky analysis techniques for sources in binaries have only recently begun development. We present a new hierarchical binary search method called TwoSpect, which exploits the periodic orbital modulations of the source waves by searching for patterns in doubly-Fourier-transformed data. We will describe the TwoSpect search pipeline, including its mitigation of detector noise variations and corrections for Doppler frequency modulation caused by changing detector velocity. Sensitivity estimates based on simulations will be presented.

▸ GWs from spinning neutron stars in binary systems

- A significant fraction of known neutron stars (NSs) exist in binary systems
- Spinning NSs may emit GWs at frequency $f_{gw} = 2\nu$ where ν is the spin frequency of the NS
- Accretion or other perturbations might cause the emission to be stronger than that from an isolated source
- A number of unknown NSs likely exist in binary systems which could be emitting GWs strong enough to detect with LIGO, Virgo, or other similar GW detectors
- Methods have been developed to perform targeted searches for known NS and all-sky searches for unknown continuous wave sources (see, for example, [1])
- For unknown sources in binaries, we need new, efficient algorithms

▸ Overview of the TwoSpect analysis

- TwoSpect has been developed to take advantage of the periodic Doppler modulation of the source waves due to the binary system (see Figure 1)
- After pre-processing the detector $h(t)$ data, analysis proceeds through a multi- stage pipeline to find potential signals buried in noise: 1) incoherent harmonic summing, 2) so-called "Gaussian" templates, 3) and more precise "exact" templates (see Figure 2)
- At intermediate stages, a clustering algorithm is employed to isolate the best parameters for individual candidates, and reduce computational costs
- Candidates are subjected to threshold tests at each stage to minimize false alarms

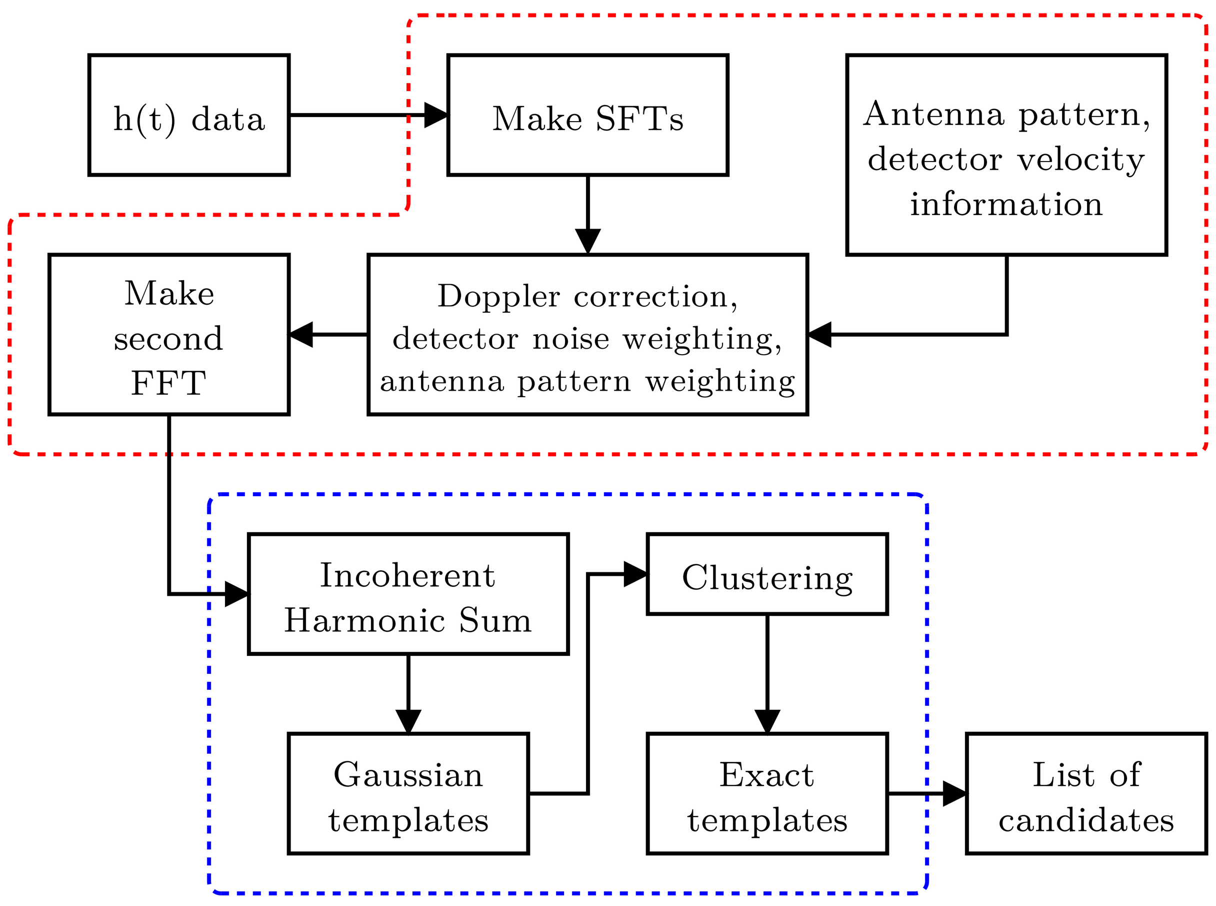

Figure 2: Schematic diagram of the TwoSpect analysis program. The red box encloses the pre-processing stage, and the blue box encloses the TwoSpect analysis pipeline.

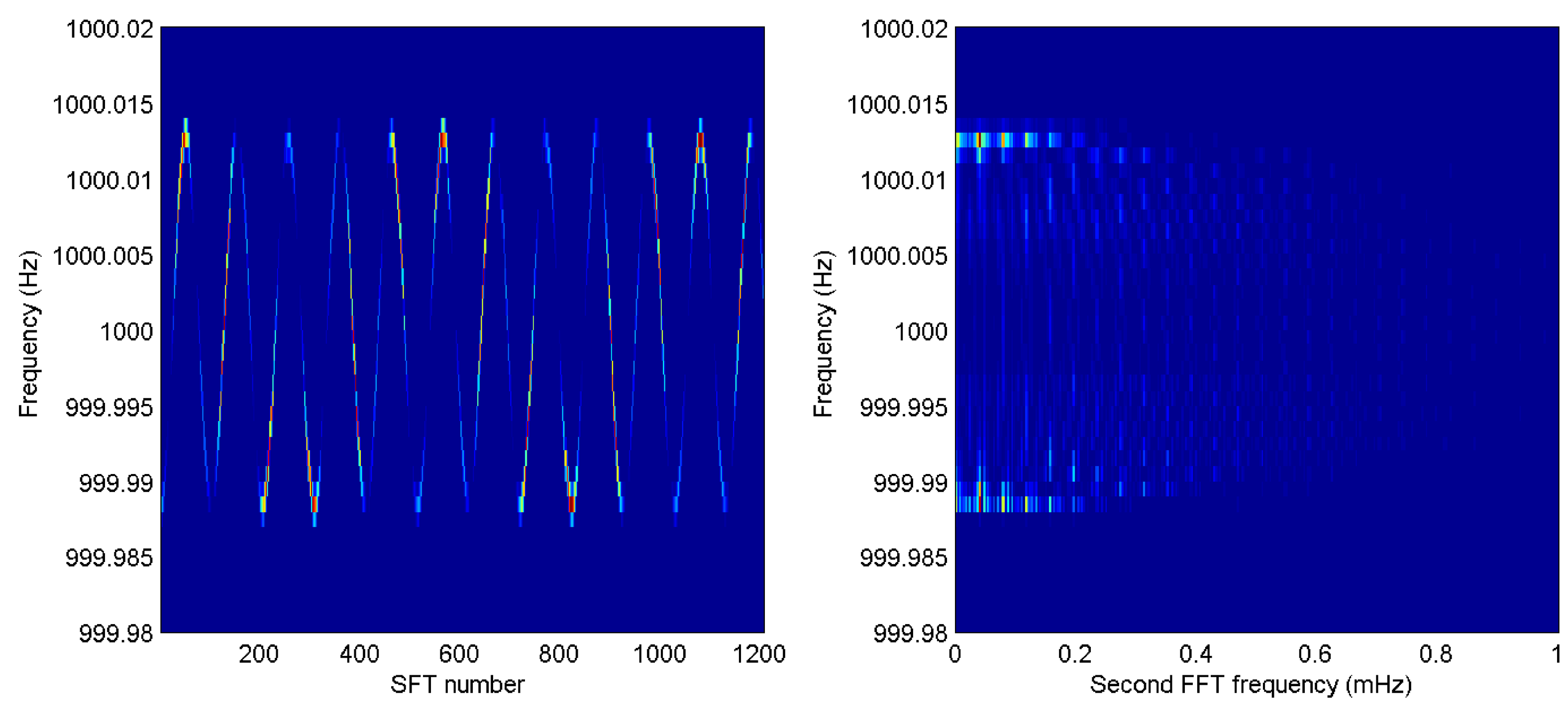

Figure 1: Simulated source of strong GWs in a binary system. Left: time-frequency plot shows the periodic nature of the binary Doppler modulation. The amplitude modulation is due to the changing antenna pattern of the detector. Earth's orbital and rotational modulation has been removed by shifting frequency bins of each SFT. Right: power spectra of each frequency bin as a function of time is computed. The brightest pixels are the fundamental or harmonics of the binary orbital period. Other bright pixels are due to the amplitude modulation caused by the daily variation of the detector antenna pattern.

▸ Search strategy

- Search over a wide band, 50 Hz to 1 kHz, in ∼2 Hz segments and over all sky locations for candidates using incoherent harmonic summing passing threshold tests
- Candidates are passed to "Gaussian" and "exact" templates for further tests and analyzed according to the TwoSpect search statistic [2]:

$$R = \frac{\sum_n \epsilon_n (x_n - \langle s_n \rangle)}{\sum_n \epsilon_n^2} \qquad (1)$$

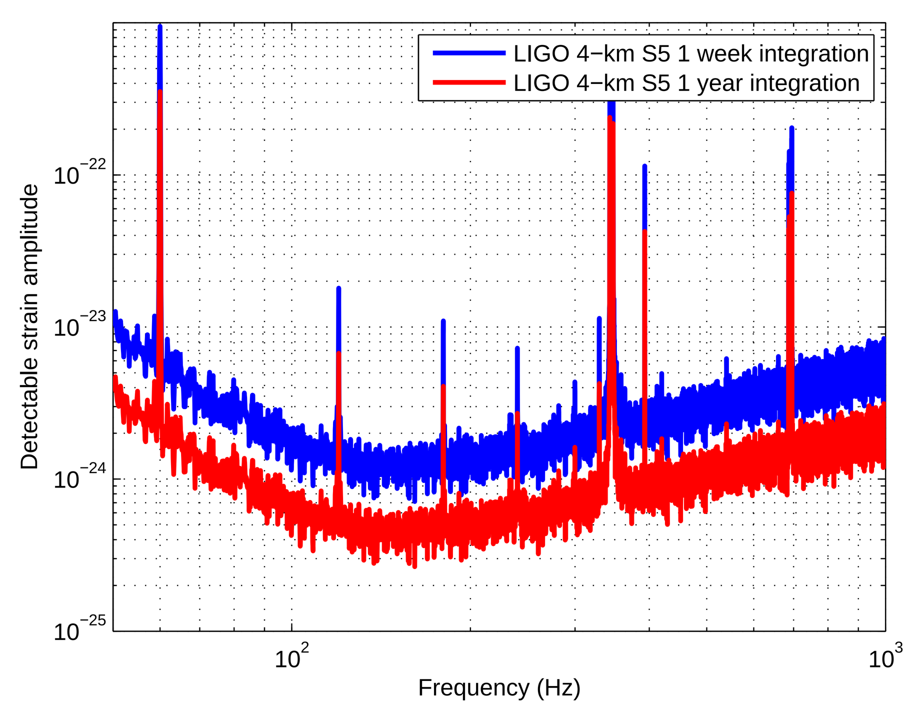

Figure 3: Detectable amplitude of GWs at 95% confidence level for the S5 LIGO science run. Simulations and extrapolation assumed 1 sky location, no detector motion, no antenna pattern for an injected signal with period $P = 57600$ s and modulation depth $\Delta f = 3.6$ mHz.

▸ TwoSpect sensitivity

- Recovery of signals within 1 cell of true value occurs when the statistic exceeds the threshold 95% of the time (see Figures 3 and 4)
- Expect all-sky search sensitivity to be worse by factor of ∼5 by the number of sky templates required and the detector antenna pattern

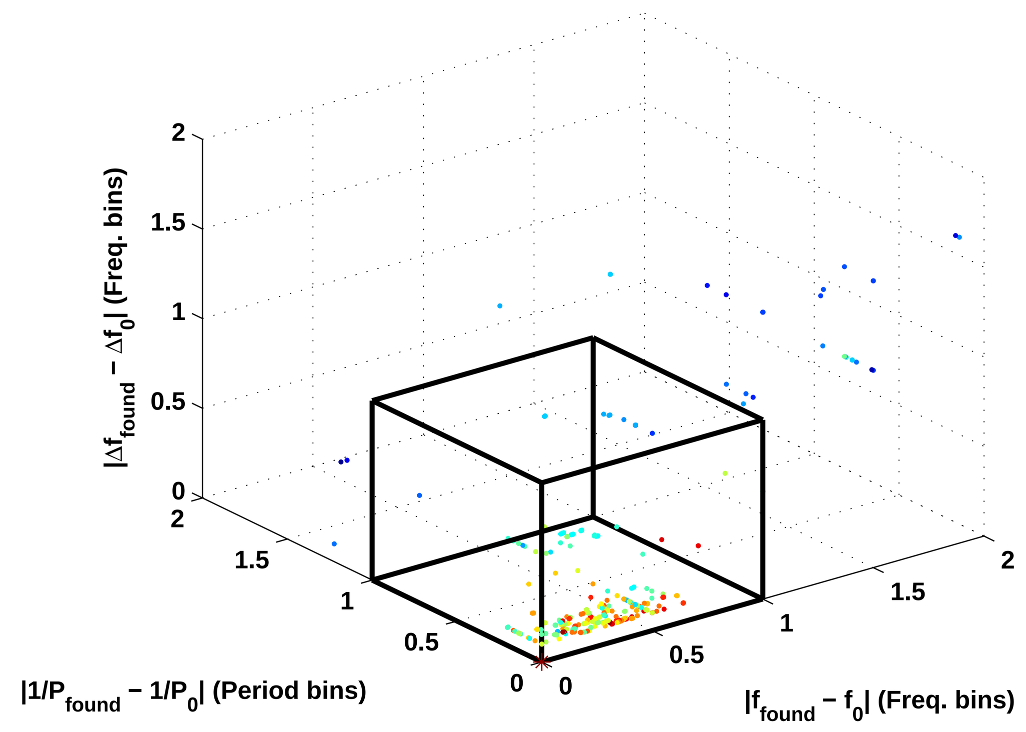

Figure 4: Zoomed view of recovered injections. The red star indicates the true injection parameters. The black box indicates the edges of a 1 cell error in recovered parameters. For this set of injections at this amplitude, at least 1 candidate appeared in the list of candidates within this cell for each injection. Additionally, the most significant candidates appeared within this cell.

▸ Conclusions

- TwoSpect is able to probe new regions of parameter space with reasonable computational scaling
- The sensitivity of TwoSpect should provide astrophysically interesting upper limits for NSs in binary systems
- TwoSpect can provide the more sensitive targeted searches with a narrow region of parameter space to search for potential signals

▸ References

1. B P Abbott *et al.* 2009 *All-Sky LIGO Search for Periodic Gravitational Waves in the Early Fifth-Science-Run Data* Phys. Rev. Lett. **102** 111102
2. E Goetz and K Riles 2009 *TwoSpect: an all-sky search for continuous gravitational waves from neutron stars in binary systems* Gravitational Wave Data Analysis Workshop poster

LIGO-G0901063-v1