A new veto strategy for continuous gravitational wave signals

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Abstract In this paper we present a χ^2 veto adapted to the Hough transform searches for continuous gravitational wave signals; we characterize the χ^2-significance plane for different frequency bands; and discuss the expected performance of this veto in LIGO analysis.

1 Introduction

Continuous gravitational wave (CW) signals emitted by neutron stars in our galaxy are among the targets of on-going searches for gravitational waves using GEO600, LIGO and VIRGO data. Examples of such searches include targeting known radio pulsars [2] and the low-mass X-ray binary system Scorpius X-1 [3, 4], as well as all-sky surveys for unknown rotating neutron stars [3, 1, 5]. The first type of searches typically use matched filtering techniques and are not very computationally expensive. The second type look for as yet undiscovered sources. This involves searching over large parameter space volumes and turns out to be computationally limited, as the number of templates that must be searched over increase rapidly with the observation time. The ultimate goal for wide parameter searches for continuous signals over large data sets is to employ hierarchical schemes which alternate coherent and semi-coherent techniques [7], as those currently employed by Einstein@Home [10], a distributed-computing effort that uses the idle CPU time of computers across the world.

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The Hough transform [8] is a semi-coherent method that can be used to select candidates in parameter space to be followed up. Results of the Hough transform to search the entire sky have been reported in [1, 5].

In all hierarchical methods it is crucial that the selection of candidates done by the semi-coherent stage is as effective as possible, since it determines the final sensitivity of the full pipeline. For this reason the development of veto and/or coincidence tests is very important in order to reduce the number of false alarms. In this paper we present a brief description of a broader work on χ^2 veto adapted to the Hough transform searches for CW signals [9] and we discuss the expected performance of this veto in LIGO analysis.

2 The Hough transform method

The Hough transform is a well known method for pattern recognition that has been applied to the search for CWs. In this case it is used to find a signal whose frequency evolution fits the pattern produced by the Doppler shift and the spin-down in the time-frequency plane of the data.

The starting point for the Hough transform are N short Fourier transforms (SFTs) at different times. Each of these SFTs is digitized by setting a threshold on the normalized power. In this way, each SFT is replaced by a collection of zeros and ones called a peak-gram. Each point in parameter space corresponds to a pattern in the time-frequency plane, and the number count n is the weighted sum of the ones and zeros of the different peak-grams along this curve.

The significance s of the observed number-count n is defined as $s = \frac{n - \langle n \rangle}{\sigma}$ where $\langle n \rangle$ and σ are the expected mean and standard deviation for pure noise.

3 The χ^2 veto

To derive a χ^2 discriminator for the different implementations of the Hough transform, the idea is to split the data into p non-overlapping chunks, each of them containing a certain number of SFTs and analyze them separately. The χ^2 statistic will look along the different chunks to see if the SNR accumulates in a way that is consistent with the properties of the signal and the detector noise. Small values of χ^2 are consistent with the hypothesis that the observed SNR (or more precisely the significance) arose from a detector output which was a linear combination of Gaussian noise and the continuous wave signal. Large values of χ^2 indicate either the signal did not match the template or that the detector noise was non-Gaussian.

4 Application of the χ^2 veto on LIGO S4

We use as playground the SFT data produced during LIGO's 29.5-day fourth science run (S4) and analyze it by means of the weighted Hough scheme, combining the data of the three LIGO detectors. An all-sky search for periodic gravitational waves using the S4 data is reported in [5]. The paper reported no evidence of periodic gravitational radiation.

To characterize the χ^2-significance plane in order to discriminate between instrumental noise and real signals, we first study some small frequency bands of the S4 data. In the presence of signals, if there was no mismatch between the signals and the templates we would obtain the same χ^2 distribution as for the Gaussian noise only case. But in a real search, templates are placed on a grid and due to the mismatch there is a dependency of the χ^2 values with the significance [6]. For this reason we select 22 narrow frequency bands between 50 and 1000 Hz free of spectral disturbances and we analyze them by means of Monte-Carlo software injections. For each of these bands we inject at least 10000 artificial signals of different amplitudes, frequencies, inclination angles and sky locations. In figure 1 we represent the results obtained for three of these different bands. For each of the analyzed bands we find a veto curve

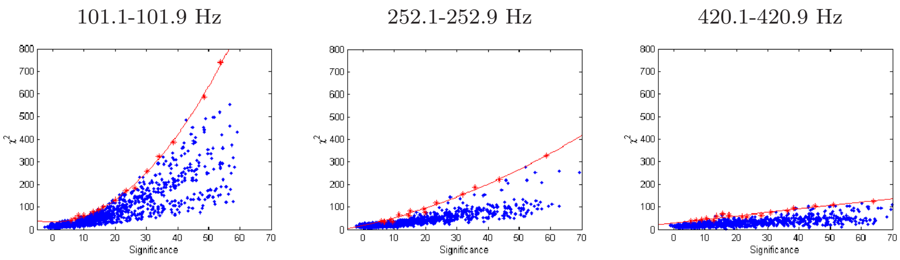

Fig. 1 χ^2 versus significance for software injected pulsar signals. We represent the results for three different frequency bands free of spectral disturbances, together with the best fitted quadratic curve of the envelope of the obtained points.

by fitting a curve to the upper contour of the χ^2-significance planes. From the set of these curves we deduce empirically the best frequency-dependent parameters of a quadratic curve valid for any frequency between 50 and 1000Hz. In a search, one will set a threshold on the significance (a threshold of 7 was used for selecting triggers in the S4 search in [5]), and for each trigger one will compare if the χ^2 value is above or below the veto curve.

Using this veto curve we have analyzed the whole S4 data, being able to veto more disturbances than what it was obtained in [5] by analyzing the candidates by means of a coincident test. This χ^2 discriminator is able to veto all the violin modes present in the data (see Fig.2) and many other narrow instrumental lines.

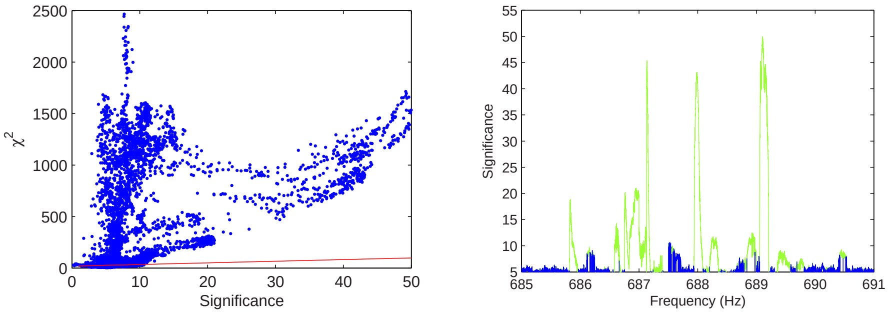

Fig. 2 Veto of the violin modes. Left: χ^2- significance plane.The solid line corresponds to the veto curve. Right: Significance versus frequency before (green line) and after (blue line) applying the χ^2 veto. The dots below the veto curve with small values of significance are consistent with the expected distribution in the case of Gaussian noise.

5 Conclusions

In this paper we have presented a new χ^2 veto adapted to the Hough transform search for continuous gravitational wave signals and discussed the performance of this veto using the data from LIGO fourth science run. The implementation of this veto is very simple, does not imply a considerable increase in computational cost and vetoed more than 90% of false candidates in real data.

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