Searching for intermediate-duration gravitational-wave transients

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Introduction

Intermediate-duration: occurring over a period lasting between several seconds to several weeks.

- Some objects are known to flare photonically with time-scales of seconds to weeks.
- Many of these objects may be sources of gravitational waves, though models are to varying degrees conjectural.
- Opening new detection channels can yield surprises: e.g., the discovery of gamma-ray bursts and the cosmic microwave background.
- With modest resources we can probe this new parameter space.
- The same infrastructure can be used for data quality analysis and commissioning in order to identify and mitigate undesirable instrumental artifacts.
- Work is in progress to develop an *intermediate (IM) pipeline* to search for gravitational-wave transients.

Astrophysical sources

A variety of sources have been proposed as possible sources of intermediate-duration gravitational waves (see Fig. 1). They fall into three categories:

- **supernovae & long GRBs:** proto-neutron star (PNS) convection (Ott 2009), dynamical rotational instabilities (Corsi & Mészáros 2009), r-modes in young neutron stars, Chandrasekhar-Friedman-Schutz (CFS) rotational instabilities, torus instabilities (Piro & Pfahl 2007), torus excitations (van Putten 2002)
- **short GRBs:** dynamical rotational instabilities, CFS rotational instabilities, r-modes
- **isolated neutron stars:** pulsar glitches (van Eysdan & Melatos 2008), SGR flares (B. P. Abbott et al 2009)

Many of these sources are characterized by the frequency of a rotating system and are thus narrowband, e.g., pulsar glitches. Others, such as PNS convection, are broadband.

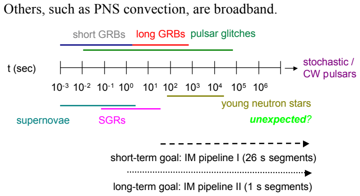


Figure 1. Possible sources of intermediate-duration gravitational-wave transients. The current pipeline has a timing resolution of 26 s. This can eventually be reduced.

Relationship to other pipelines

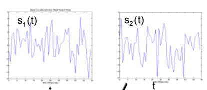
The intermediate pipeline begins with cross-correlated data from two or more detectors:

- Effectively use one interferometer's h(t) as a matched filter for the other.
- This "noisy filter" is not optimal for waveforms we can predict precisely, but it is very convenient for situations where we know little about the waveform.
- Cross-correlation acts to pre-filter glitches that are not coincident in time and direction.
- The cross-correlated data are very nearly Gaussian and thus it is straightforward to estimate the significance of a candidate event.

Algorithm

Strain time series from two or more spatially-separated detectors are combined to make a frequency-time (ft) map of SNR. In addition to the time series, SNR depends on the sky location of the source **Ω** and its polarization angle, ψ. The ft-map is analyzed by clustering algorithms designed to identify different features such as lines or curves. If the background is well-behaved, the probability that a candidate event is due to background can be estimated analytically owing to the near-Gaussian distribution of the SNR.

raw time series data



pre-processing

search direction: **Ω**
polarization angle: ψ

Intermediate data frames
52 s Hann windowed segments
C = cross-spectral density
P_1,P_2 = power spectral densities

$$SNR(A,f,t,\vec{\Omega}) = \frac{Y}{\sigma} = \mathrm{Re}\left[\frac{C(f,t)}{\sqrt{P_1(f,t)P_2(f,t)}}\,\frac{\gamma_A(f,t,\vec{\Omega})}{|\gamma_A(f,t,\vec{\Omega})|}\right]$$

Search and Recovery

In order to identify gravitational-wave signals we may employ a variety of pattern recognition algorithms. Different algorithms are better suited for different classes of signals. For example, a "Locust" algorithm—which looks for signals by connecting local maxima above some threshold—may be best suited for relatively short, narrow-band signals. Longer narrowband signals may be better recovered with a Radon transform, which maps lines in ft-space to points in Radon space (see Fig. 2). Investigations are underway to evaluate the advantages of different pattern recognition algorithms.

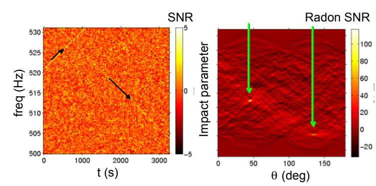
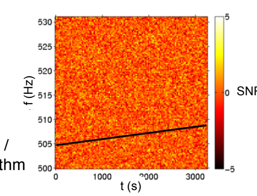


Figure 2. Left: an ft-map of Monte Carlo background noise plus two simulated narrow-band gravitational-wave signals. The faint signals are indicated by black arrows. Right: the Radon transform of the ft-map. The two line-like signals are transformed into spots (indicated with green arrows).

ft-map of SNR

search manifold / clustering algorithm



$$R \equiv \left(\sum_i (y_i/\sigma_i^2)\right)\left(\sum_i \sigma_i^{-2}\right)^{-1/2}$$
$$= \left(\sum_i (SNR_i/\sigma_i)\right)\left(\sum_i \sigma_i^{-2}\right)^{-1/2}$$

calculate probability of event: P(R)

Recovery

We have tested our ability to recover a simulated intermediate-duration transient gravitational wave. In Fig. 3 we show recovered sky maps for a broadband unpolarized injection. For short signals, a two-detector network can constrain the sky location to a circle. As the signal length increases, the rotation of the Earth breaks this degeneracy. (The picture is more complicated with polarized signals.)

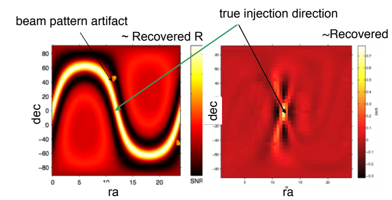


Figure 3. Left: recovered sky map for short (~10 min) injection. Right: recovered sky map for day-long injection. The injection is broadband and unpolarized.

Literature cited

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