Complementing inspiral searches with burst pipelines

Externally triggered GW searches for inspiral events performed with matched filter pipelines can be complemented with coherent burst pipelines, which are designed to find short-duration (typically a few seconds or less) GW bursts with little or no further knowledge of the expected waveform. Though burst pipelines are not as sensitive as matched filter pipelines to precisely specified waveforms such as theoretical predictions of inspirals preceding compact binary coalescence (CBC) events, their generality may allow them to detect unpredicted signals or parts of signals (such as the merger phase of CBC events) that templated searches may miss. We estimate the sensitivity of several coherent burst pipelines to the inspiral phase of CBC events using simulated noise and GRB070201 sky position and trigger time.

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1. Inspiral Events

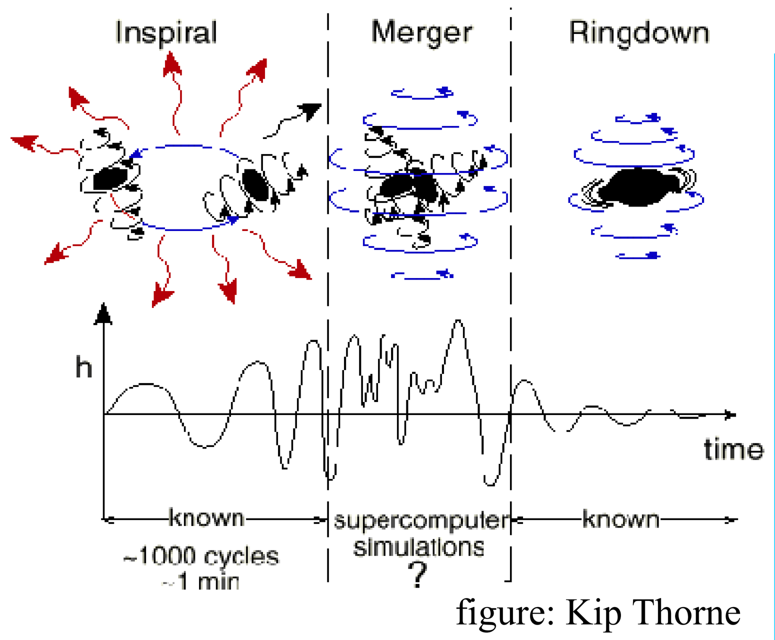

figure: Kip Thorne

One class of progenitors for Gamma Ray Bursts (GRBs) is compact binary coalescence (CBC) events – the inspiral and merger of binary systems of neutron stars (NS) and black holes (BH). These systems emit GW in three stages:

- inspiral stage – well-modelled, templated searches possible
- merger stage – modelling efforts with numerical relativity
- ringdown stage – well-modelled

2. Specialist: Templated Searches

The conventional approach to searches for GW associated with inspiral events takes advantage of the well-modelled inspiral phase of the event by performing a matched filter search. LIGO data is correlated against templates matching theoretical CBC waveforms within the relatively narrow parameter space [1].

Templated searches provide optimal sensitivity to the target waveforms. However, their sensitivity to GW signals outside of the template bank drops as the correlation decreases.

3. Generalist: Coherent Burst Searches

Coherent burst searches are designed to detect any signal in the detector's band lasting less than about a second. They use fully coherent addition of GW detector data streams to sensitively search small patches of the sky for gravitational wave bursts without the need for source modelling. There are many expected GW burst sources besides the inspiraling compact binaries: supernovae, soft gamma repeaters, cosmic string cusps. These burst-type GW events are often unmodelled or poorly-modelled. Coherent burst searches typically don't make assumptions about waveforms beyond duration and bandwidth ranges.

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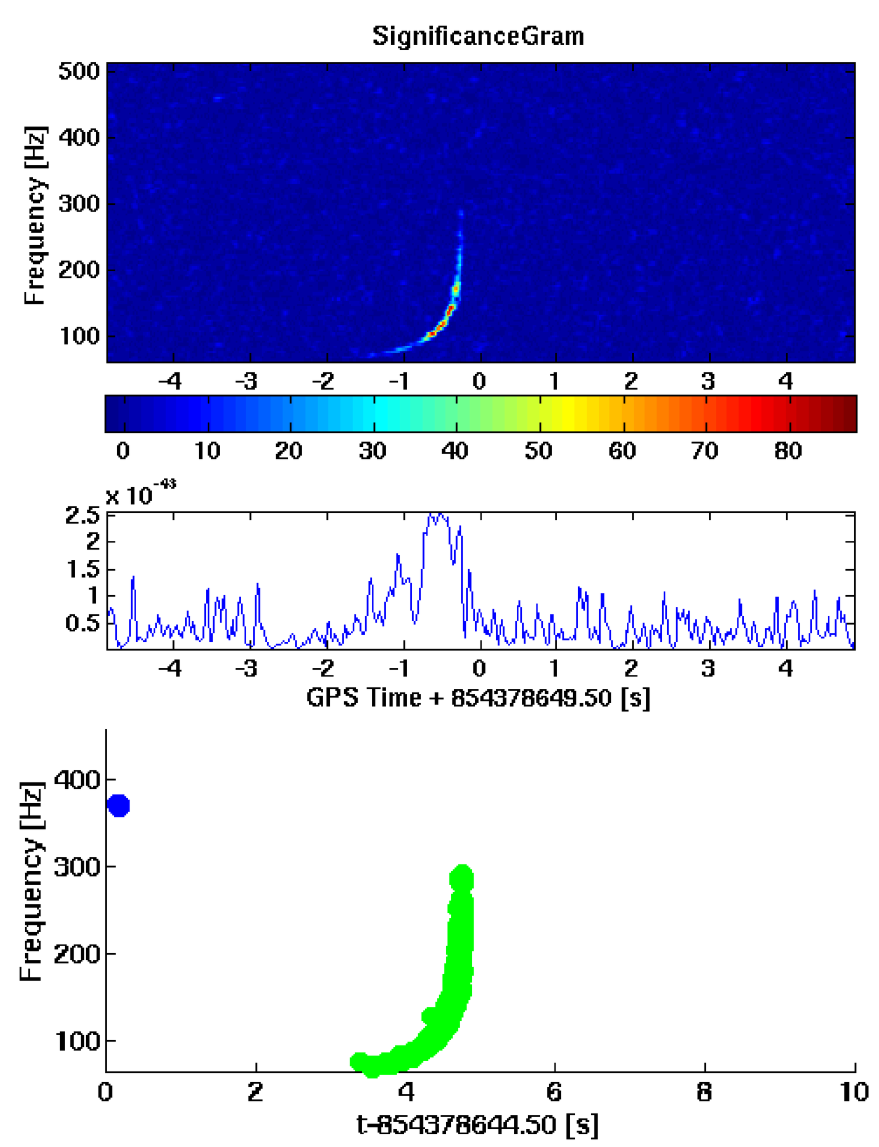
4. Flare Pipeline



Example 1.4-10 solar mass binary inspiral injected into H1+H2 data and recovered by the Flare pipeline. From top to bottom: Flare significancegram, band plot, and reconstructed cluster showing noise rejection.

The Flare pipeline is a simple but effective coherent burst pipeline, capable of performing either one-detector or two-detector triggered searches [2].

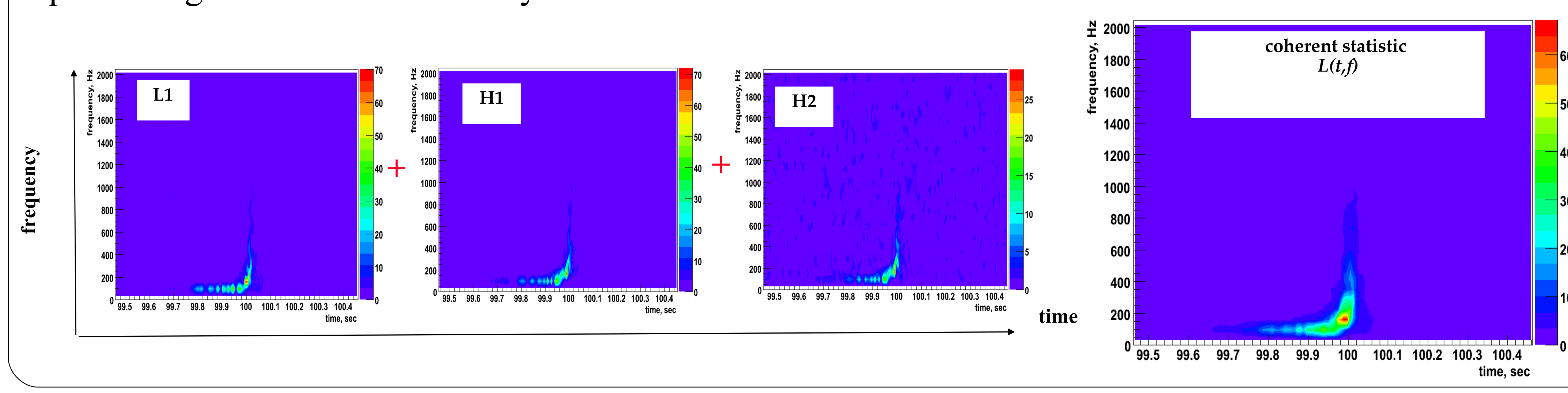
The Flare pipeline conditions LIGO data with a bandpass filter and a notch filter (generated at runtime using a line finding routine) in the time domain. Spectrogram transformation produces PSD TF tilings separately for separate detectors, which may be combined using a pixel correlation method. The background at each frequency is subtracted, creating an excess power TF tiling, and each frequency bin is normalized by the variance, creating a significance TF tiling. A clustering routine is applied to tiling pixels above a significance threshold.

5. X-Pipeline

X-Pipeline is a software package designed to detect unmodelled GW bursts in noisy detector data while vetoing noise-induced glitches [3]. By time-shifting the data from each detector, X-Pipeline coherently sums the GW contributions from a particular sky position Ω for each polarization (h+ and hx) and also produces a GW-free null stream for consistency testing. Time-frequency maps are made of the energy in the reconstructed h+, hx, and null streams. X-Pipeline then identifies clusters of pixels with large E+, the energy in the h+ stream [4].

6. Coherent WaveBurst Pipeline (cWB)

cWB is an end-to-end multi-detector coherent pipeline based on the constrained likelihood method [4] capable of handling arbitrary number of co-aligned and misaligned detectors. It performs reconstruction of GW waveforms and detector responses and uses coherent statistics for rejection of instrumental and environmental artifacts. cWB combines detector data streams into the coherent likelihood statistic representing total SNR detected by the network:



7. GRB 070201 – Inspiral Event in M31?

The error box on the location of GRB 070201 was consistent with the position of M31 – the Andromeda Galaxy, located only 770 kpc from Earth. At the time of the event LIGO's H1 and H2 detectors were taking science mode data. If GRB 070201 did indeed originate from M31, and if the progenitor was a binary inspiral event, then LIGO would almost certainly detect associated GW. A templated inspiral search detected no GW, and a CBC progenitor in M31 was ruled out at high confidence [5]. For m1 and m2 in the ranges [1,3] and [10,13] solar masses, the inspiral search yielded physical distance lower limits of ~8 and ~15.5 Mpc at 90% and 50% detection efficiencies.

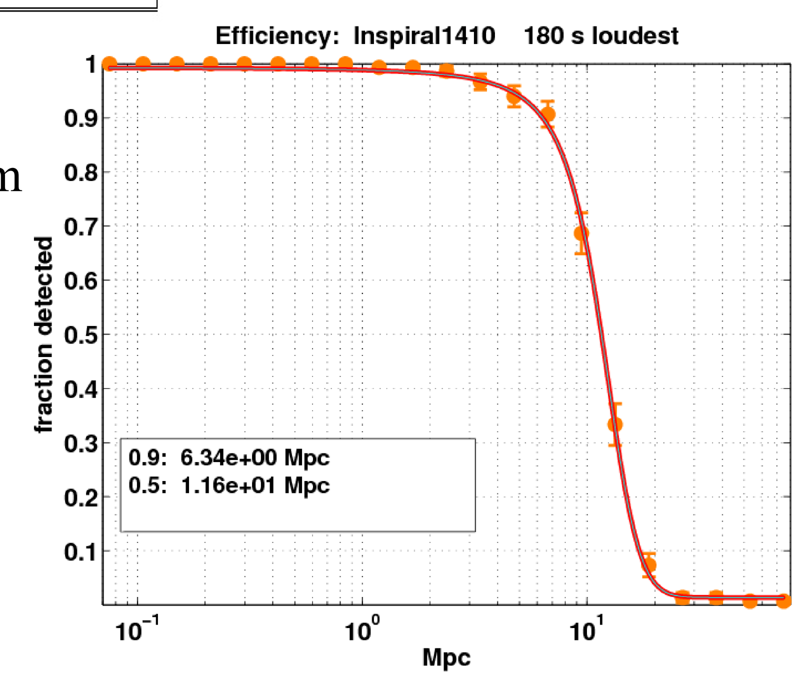
We have performed mock GRB 070201 loudest event searches using coherent burst pipelines and simulated LIGO noise (produced for LIGO-VIRGO *project Ib* [6]). On-source region was [-120,60] seconds around trigger time and search range was 64-1024 Hz. Signals simulating 1.4-10 solar mass inspiral events originating in M31 were injected into the simulated noise.

8. Mock GRB 070201 Inspiral Results

Pipeline	90% efficiency	50% efficiency
X-Pipeline	5.1 Mpc	10.1 Mpc
Flare	5.4 Mpc	9.9 Mpc

Above: physical distance lower limits for 1.4-10 solar mass M31 simulated inspirals. Binary system orientation and polarization angle were chosen randomly for each injection. 15% has already been subtracted from the inspiral results; this is approximately the same as the overall uncertainty subtracted from inspiral results in [5]. We estimate up to additional ~20% error from use of simulated data.

Below: Flare efficiency curve for 1.4-10 solar mass inspiral injections.



9. Conclusion

Coherent burst pipelines are less sensitive to the well-predicted inspiral phase than templated searches. However, their larger search phase space could allow them to succeed where templated searches fail:

- If inspiral stage predictions are incorrect
- When merger phase contributes significantly to signal power
- In triggered searches where the progenitor event may not be CBC
- For events outside of the matched filter search template bank (e.g. outside of the mass or spin range).

1. Blanchet, Living Rev. Rel., 9, 3 (2006)
2. Kalmus et al., Class. Quantum Grav. 24 (2007) S659–S669
3. Chatterji et al. PRD 74 082005 (2006)
4. Klimenko et al., PRD 72 122002 (2005)
5. Abbot et al., astroph/0711.1163 (2007)
6. Beauville et al., gr-qc/0701026