CCSNe Algorithmic Developments for the Advanced LIGO Observation Era

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Internal/External Collaboration

CCSNe Theory

CCSNe Data Analysis

LIGO Burst Data Analysis
O1/O2 Search Pool of Waveforms

Rotating Core-Collapse

Scheidegger+10
sch1: R1E1CA_L_thetaX.XXX_phiX.XXX
sch2: R3E1AC_L_thetaX.XXX_phiX.XXX
sch3: R4E1FC_L_thetaX.XXX_phiX.XXX

Dimmelmeier+08
dim1: signal_s15a2o05_ls
dim2: signal_s15a2o09_ls
dim3: signal_s15a3o15_ls
O1/O2 Search Pool of Waveforms

Neutrino-driven Explosion

Mueller+12
mul1: L153_thetaX.XXX_phiX.XXX
mul2: N202_thetaX.XXX_phiX.XXX
mul3: W154_thetaX.XXX_phiX.XXX

Ott+13
ott1: s27fheat1p05_thetaX.XXX_phiX.XXX

Yakunin+15
yak1: B12WH07
yak2: B15WH07
yak3: B20WH07
yak4: B25WH07
Outlook of Current Searches

- Extraction of waveform
  - Extraction of physical parameters
    - Non-CCSNe detection
    - CCSNe detection
    - Veto event
    - Report & perform follow-up
  - Relax pipeline thresholds to increase sensitivity
Outlook of Current Searches

Set priors in pipelines based on robust features present in waveform families (slowly rotating/RR/non-rotating)

Tune the pipelines to the waveforms that explore the parameter space of the progenitors.

Extraction of waveform

Extraction of physical parameters

Non-CCSNe detection

CCSNe detection

Veto event

Report & perform follow-up

Relax pipeline thresholds to increase sensitivity
Outlook of Current and Future Searches

For more details, please refer to 3G panel-specific slides!
Current Internal LVC Algorithms used for SN Searches

- Coherent WaveBurst (cWB)
- Supernova Model Evidence Extractor (SMEE)
- BayesWave (BW)
- Two-Step De-noising (TSD) Filter
Current Internal LVC Algorithms used for SN Searches

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Coherent analysis - combines data from the detector network into a unique list of “triggers”

(will be covered by Sergey & Marek)
Current Internal LVC Algorithms used for SN Searches

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- *Supernova Model Evidence Extractor (SMEE)*
- BayesWave (BW)
- Two-Step De-noising (TSD) Filter

It determines the explosion mechanism of a CCSN GW detection using Principal Component Analysis (PCA)
Current Internal LVC Algorithms used for SN Searches

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- **BayesWave (BW)**
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reconstruct the signal waveform using basis functions from the GW detector output & estimate appropriate parameters of the waveform (such as central time and frequency, signal duration and bandwidth)
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- **Two-Step De-noising (TSD) Filter**

**calculating an estimator of the signal spectral density from the noisy observations s.t. the expectation value of the distortion between the true signal and its estimate is minimized before it enters the search pipeline**
Supernova Model Evidence Extractor (SMEE)

  - One detector study
  - Gaussian noise

  - Three detectors, non-Gaussian non-stationary noise

- Powell, Heng (In prep)
  - Distinguishing CCSNe from other astrophysical and noise gravitational-wave transients.

[1] Jade Powell
Supernova Model Evidence Extractor (SMEE)

To test SMEE’s CCSN waveform classification performance in future detectors 3 days of O1 data were recolored to each detector’s estimated sensitivity curve.

Two sets of principal components: Dimmelmeier and Murphy

Injected 16 waveforms from the Murphy catalog (neutrino mechanism) and 128 waveforms from the Dimmelmeier catalog (magnetorotational mechanism)

Each waveform injected at 10 different times over a 24 hour period to explore entire antenna pattern. 1440 total injections.

Supernova Model Evidence Extractor (SMEE)

Dimmelmeier Efficiency vs Distance

Murphy Efficiency vs Distance

Magnetorotational Maximum Distances

A+:
Voyager:
Einstein Telescope:
Cosmic Explorer:

~ 325 kpc
~ 450 kpc
~ 1200 kpc
> 2500 kpc

Neutrino Maximum Distances

A+:
Voyager:
Einstein Telescope:
Cosmic Explorer:

~ 32 kpc
~ 51 kpc
~ 115 kpc
~ 240 kpc

Supernova Model Evidence Extractor (SMEE)

Examples of some Principal Components...

[1] Jade Powell

Kiranjyot Gill  
SN Workshop 2017  
03/17/2017
BayesWave Breakdown

“Search”

Triggers (glitches and GWs)

BayesWave

“Parameter Estimation”

Sky location

Waveform Reconstruction

Glitch Rejection

SN source already known

Kiranjyot Gill

SN Workshop 2017

03/17/2017
BW “Priors” Tailored to SN Searches

List of Priors to be modified:

- Sky Location (Done)
- Glitch SNR (currently being tested)
- Signal SNR (Done)
- Number of wavelets (currently being tested)
- Waveform Type (Done)
- Clustering (currently being tested)

The quest to maximize the estimation of appropriate parameters of the waveforms of interest

<table>
<thead>
<tr>
<th>Priors</th>
<th>IMBH</th>
<th>Rapidly Rotating CCSNe</th>
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</thead>
<tbody>
<tr>
<td>Sky Location ((\theta, \phi))</td>
<td>Uniformly Distributed (All-Sky)</td>
<td>Specific to direction of CCSN</td>
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<tr>
<td>Glitch SNR</td>
<td>(p(SNR) = \frac{SNR}{SNR_0^2}e^{-SNR/SNR_0^2})</td>
<td>Adjust to number of wavelets needed to reconstruct CCSN waveform</td>
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<tr>
<td></td>
<td>(Ns [1, 100]; Ng [1, 100]*Nd)</td>
<td>s15a3o15 55 ms</td>
</tr>
<tr>
<td>Wavelets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waveform Type</td>
<td>[10, 500] (M_\odot) 0.4 s</td>
<td></td>
</tr>
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</table>
TSD

* Takes conditioned data from CWB, increases SNR, and then processed data is analysed by the next stages of CWB where detection takes place.
* Plugin is implemented in C++
* Analysis is done on small sections of data (overlapping frames)

Please direct TSD specific questions to Soma!
# TSD

<table>
<thead>
<tr>
<th>Emission type</th>
<th>Identifier</th>
<th>FAR [Hz]</th>
<th>Eff cWB</th>
<th>Eff cWB+TSD</th>
<th>Eff increment</th>
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<td>41.7%</td>
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<td>1.0e-5</td>
<td>34.4%</td>
<td>42.4%</td>
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<td></td>
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<td>1.0e-4</td>
<td>35.3%</td>
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<td>5.3%</td>
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<td>46.1%</td>
<td>51.7%</td>
<td>5.6%</td>
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<td></td>
<td>dim3</td>
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<td>71.6%</td>
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*Please direct TSD specific questions to Soma!*
An example where the bridge between SN theory and data-analysis is needed….

**Understanding:** The frequency ramp up (high frequency linear g-modes) is robustly present in the most numerical simulations available on the “CCSNe market”

**Exploring:** Using a special tuning we can double the visible volume - should an optimized tuning be introduced just for the slowly rotating models (given their theoretical expected rate of occurrence to average around 99%)?
Questions to Address

Our understanding: only one group has exploding models in 3-D with first principle (approximated) physics included with common progenitor properties (i.e, another model explodes with a star at unusual density in the outskirt).

- Large spikes in 2-D models seem to be related to unusually large funnels that do not happen in 3-D & tend to develop around the $\theta=0$ axis (of the reference frame)?

- Are the rapidly rotating waveforms short and linearly polarized or do they also have a turbulent phase similar to the slowly rotating scenario progenitors?

- What is the exact weight the LVC should give to phenomenological models?

- How can we catch more serious issues, i.e. the non-linear low frequency g-mode bug that produced the acoustic mechanism mode (now discarded but that made the initial LIGO SN result paper)?
Sketching out Future Steps

- Provide waveforms
- Provide consensus on robust features
- Feedback on how realistic are different models (including phenomenological models)
- Promote cross correlation and checks of the results among theory groups
- Promote systematic exploration of the parameter span of progenitors
Extra Slides
Coherent WaveBurst

Coherent analysis - combines data from the detector network into a unique list of “triggers”

- Identifies burst candidate events by tiling data in a time-frequency plane via wavelet transformation
- Extracts significant events using a likelihood statistic
- With the analysis of the background and features extracted from the injected signals, efficiency curves are produced

Multilayer decomposition of GW data
Coherent WaveBurst

Expansion on the wavelet packet ideology: construction from generic T-F patterns using the superposition of basis wavelets

Summation of the energy of total # of pixels calculated value in the central pixel

& repeat for entire T-F map…

Multilayer decomposition of GW data

Klimenko et al.