Flexible analysis of gravitational wave data: signal polarization and detector glitches

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\[ p(h' \| d) = \frac{p(d \| h')p(h')}{p(d)} \]

\[ d = R[h] + n \]

\[ p(d \| h') \sim p(d - R[h']) \sim p(n) \]
Template-based analysis

**Strong prior**: most sensitive, less flexible
Generic analysis

Weak prior: less sensitive, more flexible

\[ h' \rightarrow \sum_{\bar{y}}^{N} w(\bar{y}) \]
The basis functions/frame is non unique, for example “chirplets”
One sample from the MCMC
Reversible Jump MCMC

Avoids/mitigates overfitting
Reversible Jump MCMC

![Diagram of posterior density vs. total mass for GW170729 ($M_\odot$)]

![Diagram of posterior density vs. dimensionality](image)

![Scatter plot of total mass for GW170729 ($M_\odot$) vs. samples](image)

![Scatter plot of dimensionality vs. samples](image)
Signal reconstructions

Agreement where the signal is strongest

Weaker prior -> Larger uncertainty

The generic analysis needs to “see” the signal in order to reconstruct it
Gravitational wave polarizations

Two propagating degrees of freedom

\[ h = F_+ h_+ + F_\times h_\times \]

Need at least 2 detectors to measure independently, 2+ if the sky location is unknown (in practice Hanford/Livingston don’t fully count)
Compact binary

\[ h^+ = -\frac{2\mu m}{Dr} \cos 2\Phi (1 + \cos^2 \iota) \]

\[ h^x = -\frac{4\mu m}{Dr} \sin 2\Phi \cos \iota \]

- Face on: \( h_+ = h^x \), strongest emission
- Edge on: \( h^x = 0 \), weakest emission
Elliptical polarization

\[ h_+ = \sum_{i=1}^{N} w(f; A, \phi_0, Q, t_0, f_0) \]

\[ h_\times = e^{i\pi/2} h_+ \]

Ellipticity: related to binary inclination

Consistent with all events from O2
Generic polarization

\[ h_+ = \sum_{\text{c}}^{N} w(f, A^+, \phi_0^+ (Q, t_0, f_0)) \]

\[ h_\times = \sum_{\text{c}}^{N} w(f, A^\times, \phi_0^\times (Q, t_0, f_0)) \]

Nature shouldn’t care how we oriented the detectors

- Spin-precession
- Higher order modes
- Eccentricity
- Supernova (?)
- Bursts
Spin precession


Elliptically polarized signal

Elliptically t-dependent ellipticity

Whitened data
Elliptical polarization
Generic polarization
Stokes parameters

\[ U = \tilde{h}_+ \tilde{h}_+^* + \tilde{h}_x \tilde{h}_x^* \]
Generic polarizations modes

The wave polarization affects the inferred sky location

(a) Plus (+)  
(b) Cross (x)  
(c) Vector-x (x)  
(d) Vector-y (y)  
(e) Scalar (s)
Beyond general relativity

Example: Brans-Dicke (scalar tensor) theory

\[ h^b = \frac{-4\mu \tilde{S}}{D} \]

\[ h^+ = - \left( 1 - \frac{1}{2} \xi \right) \frac{2G\mu m}{Dr} \cos 2\Phi (1 + \cos^2 \iota) \]

\[ h^\times = - \left( 1 - \frac{1}{2} \xi \right) \frac{4G\mu m}{Dr} \sin 2\Phi \cos \iota \]

It’s possible (though extreme) to not have tensor modes. Ruled out after GW170817 to \( \sim 10^{20} : 1 \)

LVC (arxiv:1903.04467)

Test: Isi+ (arxiv:1710.03794)
Adding polarizations: scalar mode

\[ h = F_+ h_+ + F_\times h_\times + F_b h_b \]

\[ h_+ = \sum_{N} w(f; A^+, \phi_0^+, Q, t_0, f_0) \]

\[ h_\times = \sum_{N} w(f; A^\times, \phi_0^\times, Q, t_0, f_0) \]

\[ h_b = \sum_{N_b} w(f; A^b, \phi_0^b, Q^b, t_0^b, f_0^b) \]
Assuming the proposed ZTF sky location

Graham+ (arxiv:2006.14122)
Simulated signal with scalar power

4 detectors (O4) of comparable sensitivity (not O4)
Need information from all detectors

The sky location affects how much power from each mode the detector sees

Chatziioannou+ (in preparation)
Detector glitches

Disclaimer: that’s a BIG one
The signal behind the glitch

Another monster glitch

Fake signal

Pankow (including KC) (arxiv:1808.03619)
**Increased glitch rate**

The next neutron star binary will very likely overlap with a glitch.
Signals and glitches

We won’t always be so “lucky”

The signal is in both detectors, the glitch only in one

LIGO-Livingston raw data

Signal

Monster glitch

LVC (arxiv:1710.05832)

The next step: compact binaries and glitches

**Signal:**

$h' \to \sum_{N}$

**Glitch:**

LIGO Hanford

LIGO Livingston

Chatziioannou+ (arXiv:2101.01200)
Example: blip glitch
Reconstructions and Parameters

LIGO Hanford

LIGO Livingston

Real glitch from O2

Simulated signal

Ignoring the glitch would bias the inferred parameters
Glitch subtraction

Full data

Full data - glitch model

Full data - glitch model - CBC model

Ready for downstream analyses

Chatziioannou+ (arXiv:2101.01200)
Example: scattered light

Real glitch from O2

Simulated signal

Chatziioannou+ (arXiv:2101.01200)
Glitch subtraction

Full data

Full data - glitch model

Full data - glitch model - CBC model
Back to GW170817

LIGO Hanford

LIGO Livingston

$\sigma_{\text{noise}}$

$t (s)$ from GPS 1187008881.4457

Data CBC Glitch
Flexible analyses are essential both for analyzing unmodeled/partially modeled sources and for supporting or cross-checking standard analyses.

Thank you