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

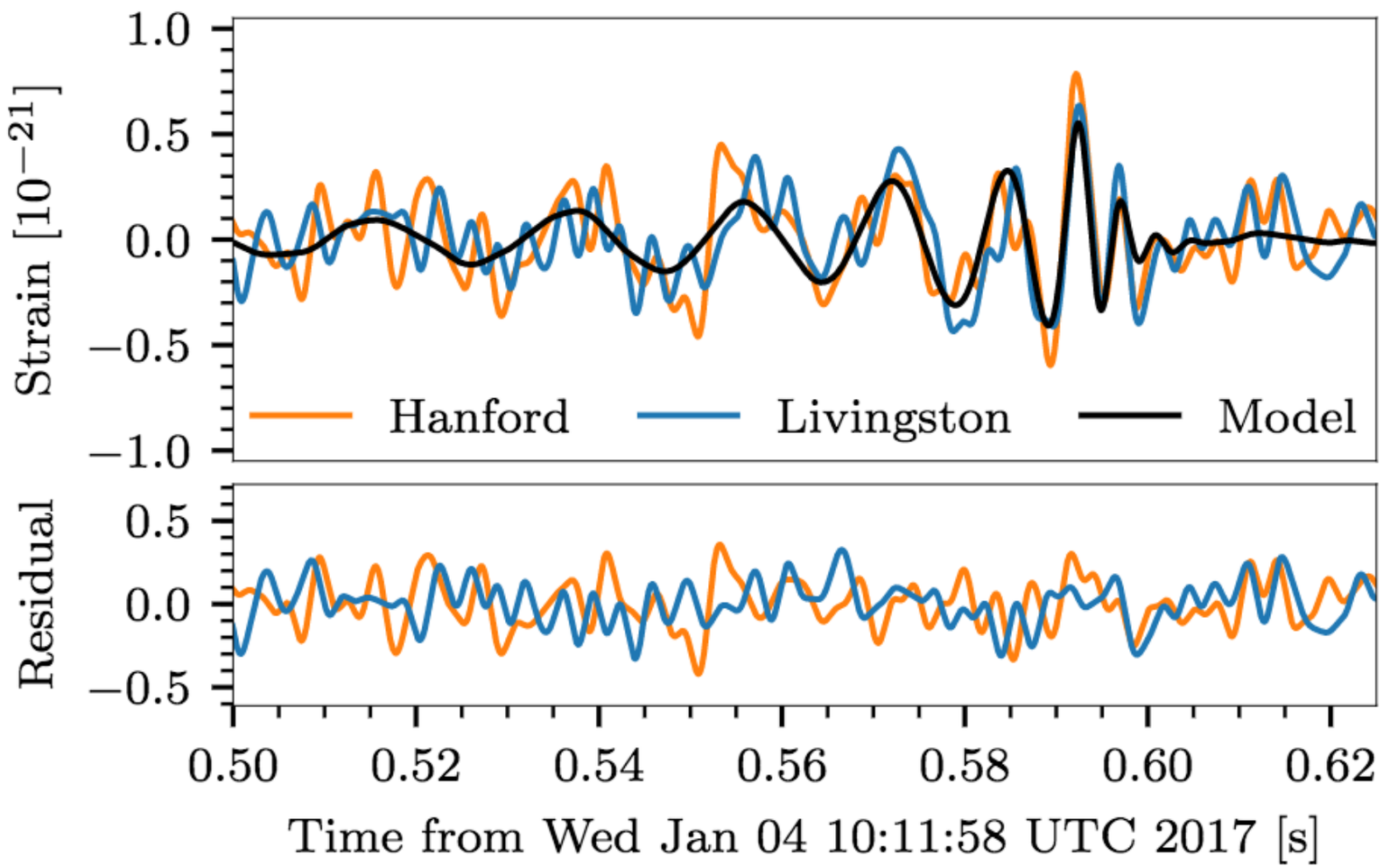
Katerina Chatziioannou
Caltech

Meeting of the National Research Group on Gravitational Waves
March 30, 2021

Millhouse/Cornish/Littenberg/LVC

LIGO Inference

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



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

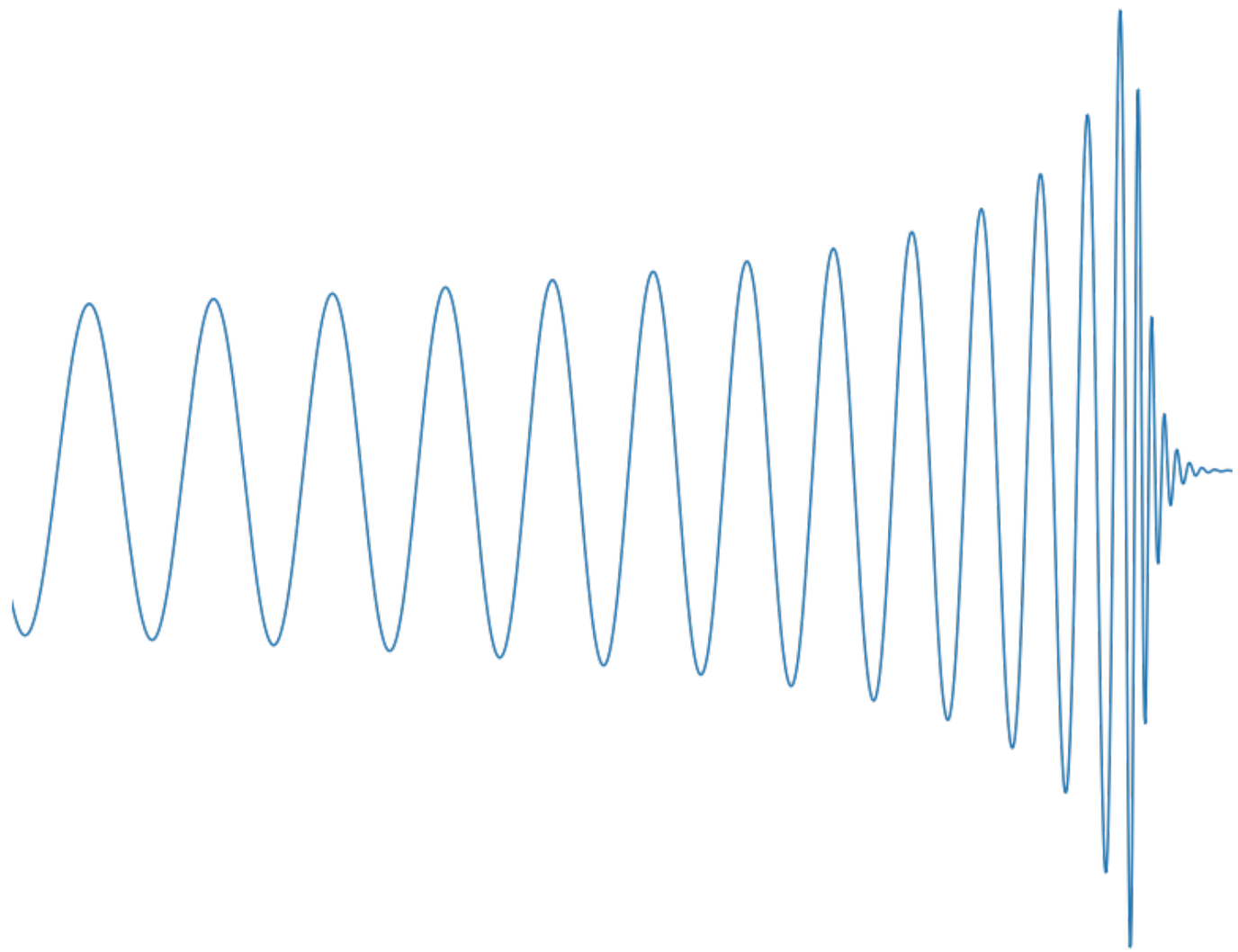
$$p(d|h') \sim p(d - R[h']) \sim p(n)$$

LVC (arxiv:1706.01812)

Template-based analysis

Strong prior: most sensitive, less flexible

$h' \rightarrow$



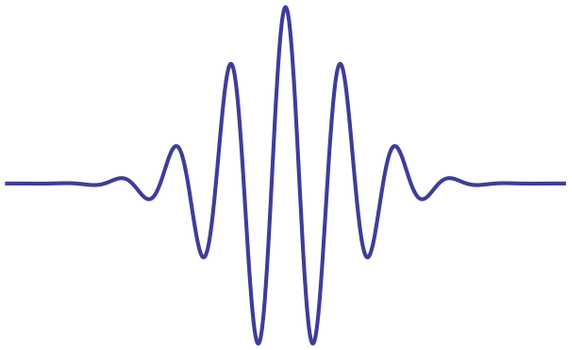
Generic analysis

Weak prior: less sensitive, more flexible

$$h' \to \sum^{N} w(\vec{y})$$

BayesWave

$$h' \rightarrow \sum^{N}$$



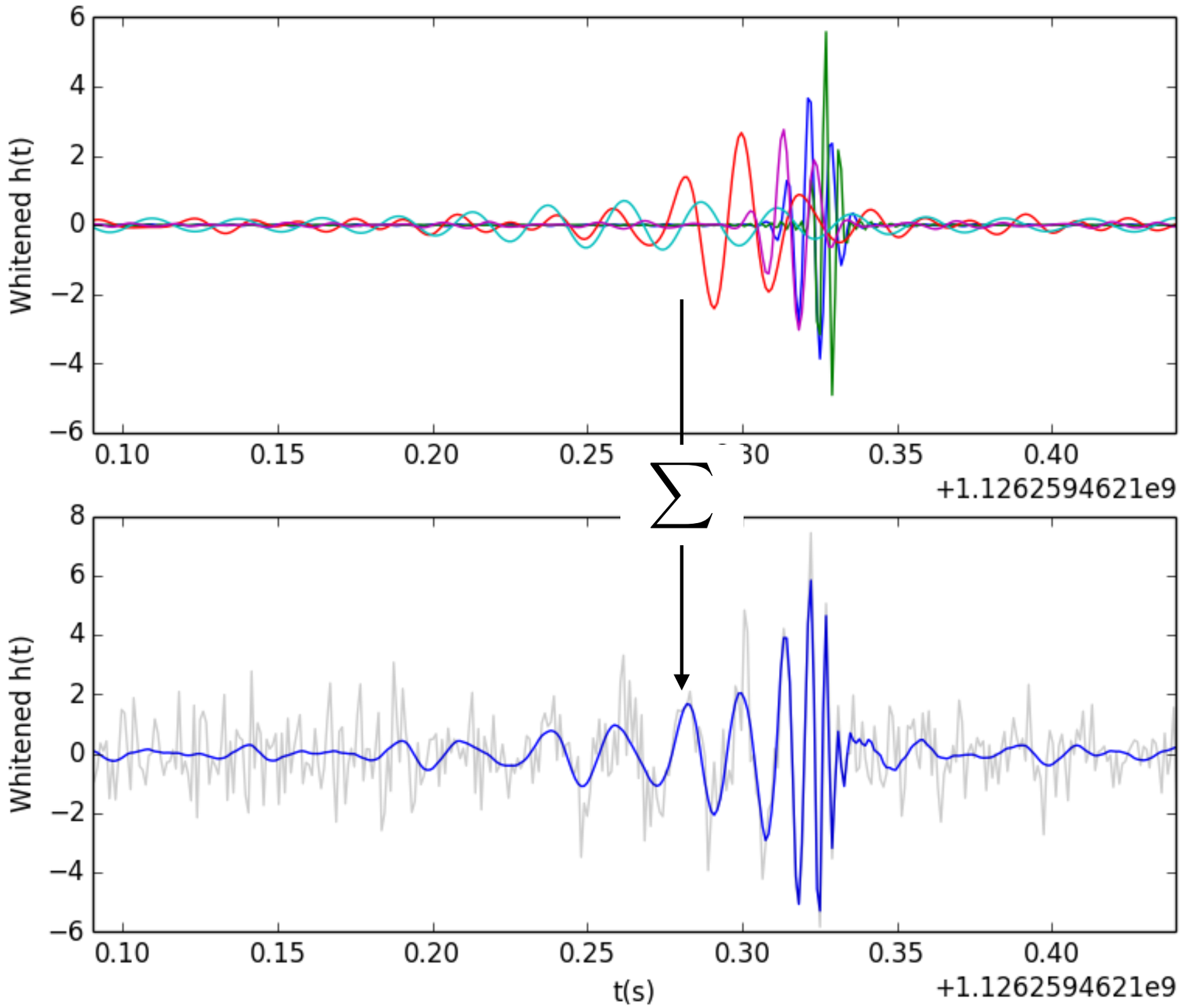
$$w(t; A, f_0, Q, t_0, \phi_0) = Ae^{-(t-t_0)^2/\tau^2} \cos(2\pi f_0(t - t_0) + \phi_0)$$

Cornish+ (arxiv:1410.3835)

The basis functions/frame is non unique, for example “chirplets”

Millhouse+ (arxiv:1804.03239)

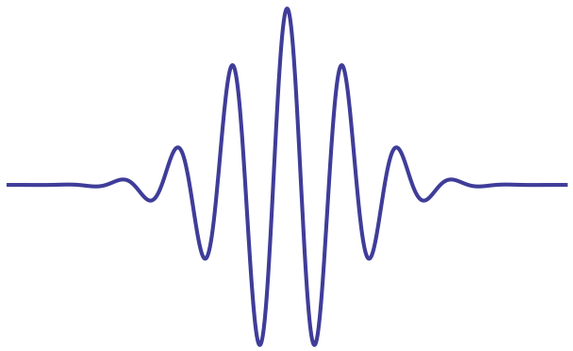
One sample from the MCMC



Millhouse/LVC

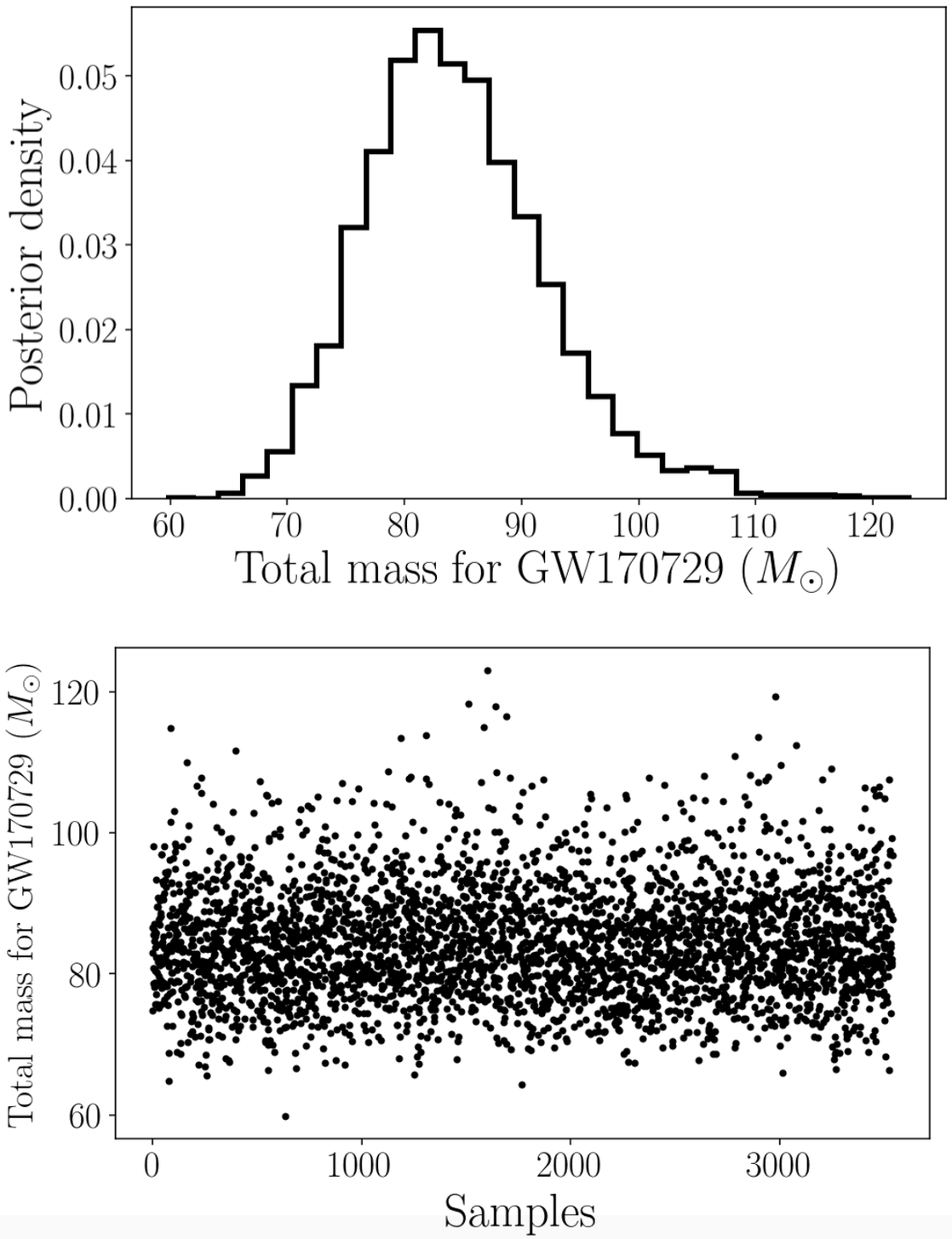
Reversible Jump MCMC

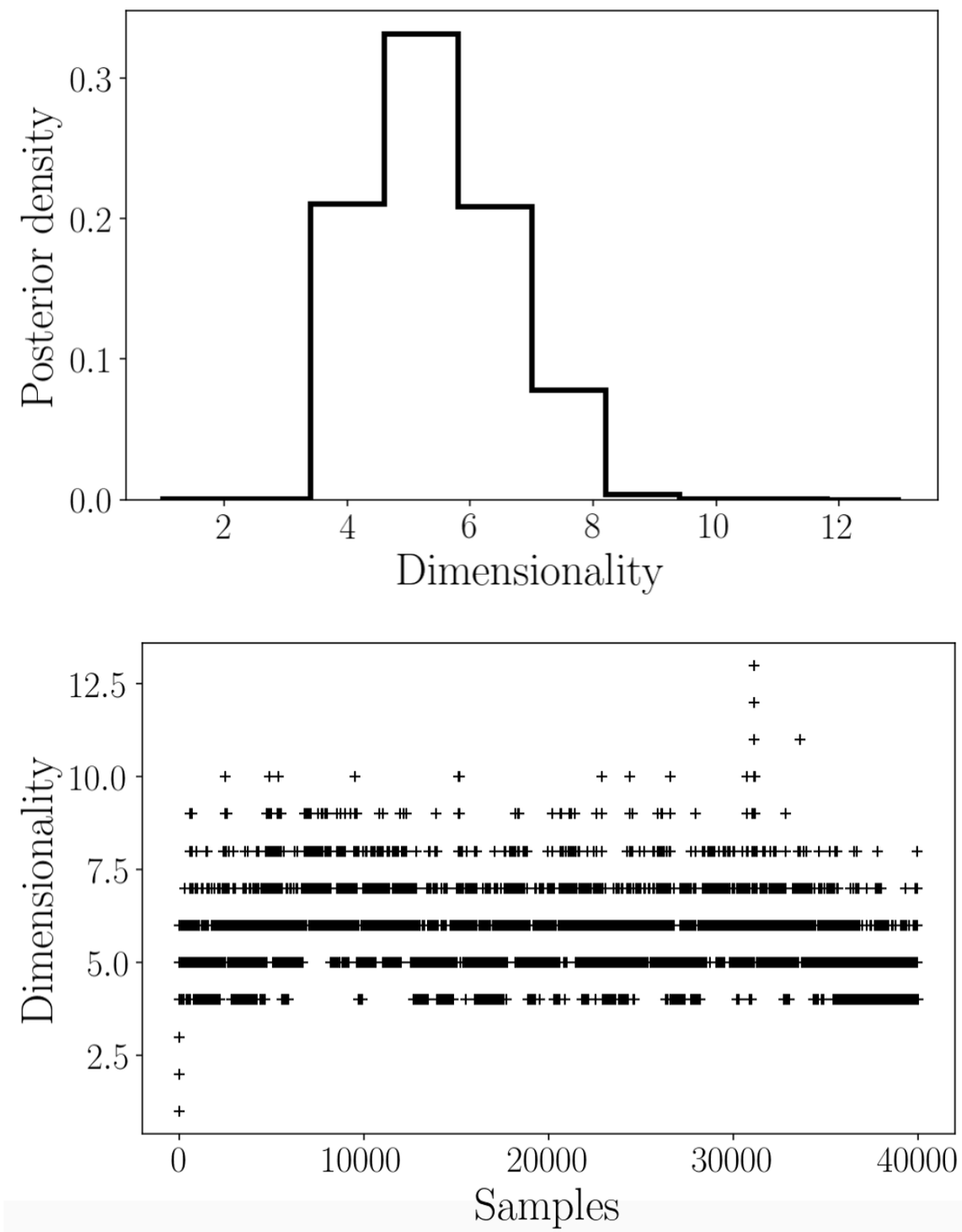
$$h' \rightarrow \sum^{\boxed{N}}$$



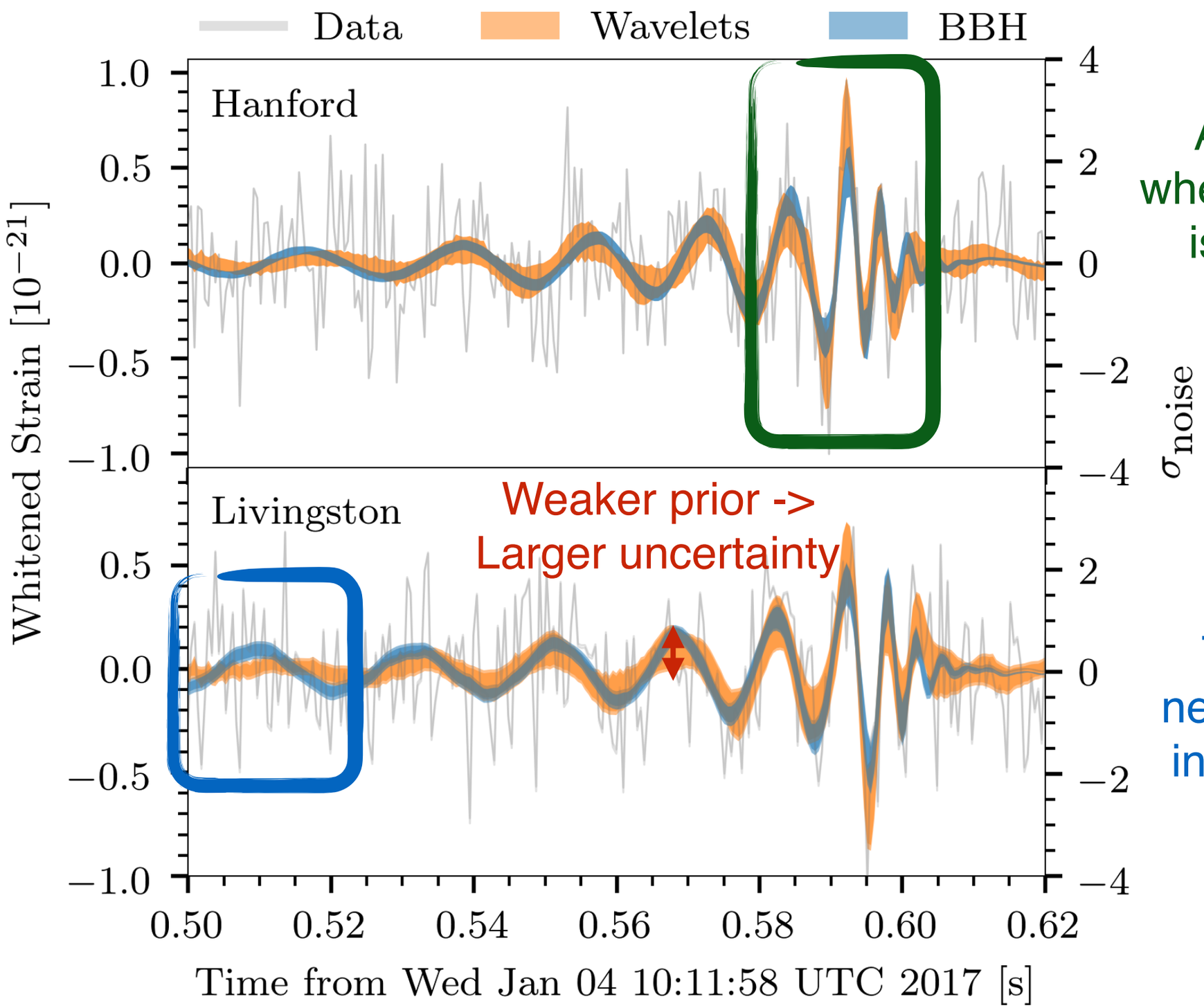
Avoids/mitigates overfitting

Reversible Jump MCMC





Signal reconstructions



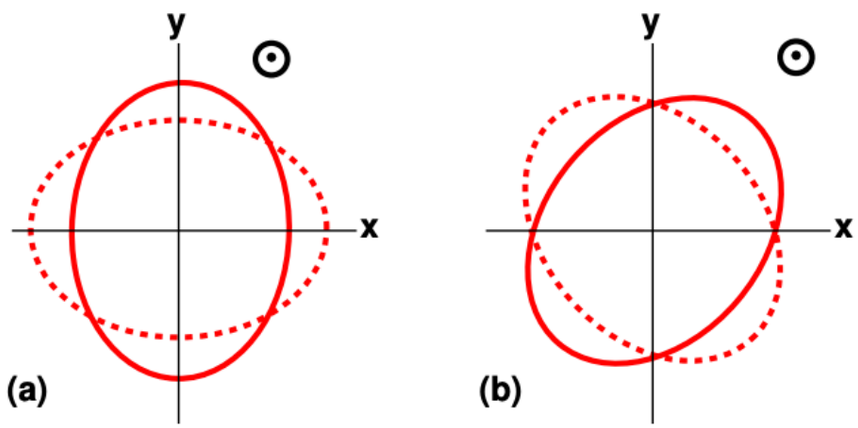
Agreement where the signal is strongest

The generic analysis needs to "see" the signal in order to reconstruct it

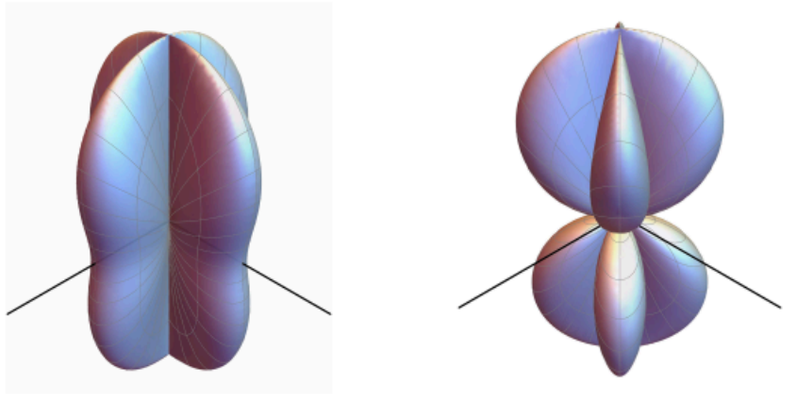
LVC (arxiv:1706.01812)

Gravitational wave polarizations

Two propagating degrees of freedom



Will (arxiv:1403.7377)



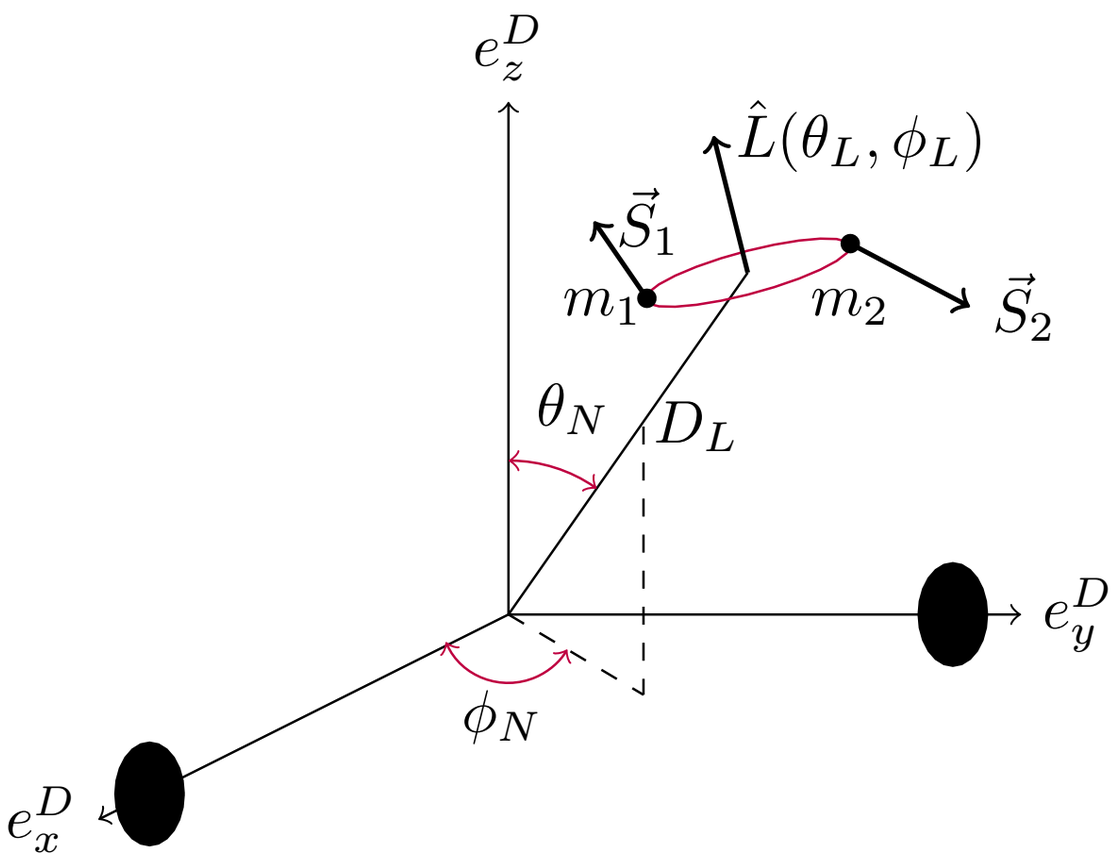
(a) Plus (+) (b) Cross (×)

Isi+ (arxiv:1710.03794)

$$h = F_+ h_+ + F_\times h_\times$$

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

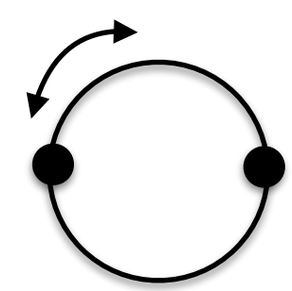
Compact binary



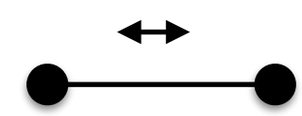
$$h^+ = -\frac{2\mu m}{Dr}\cos 2\Phi(1+\cos^2\iota)$$

$$h^\times = -\frac{4\mu m}{Dr}\sin 2\Phi\cos\iota$$

- Face on: $h_+ = h_\times$, strongest emission



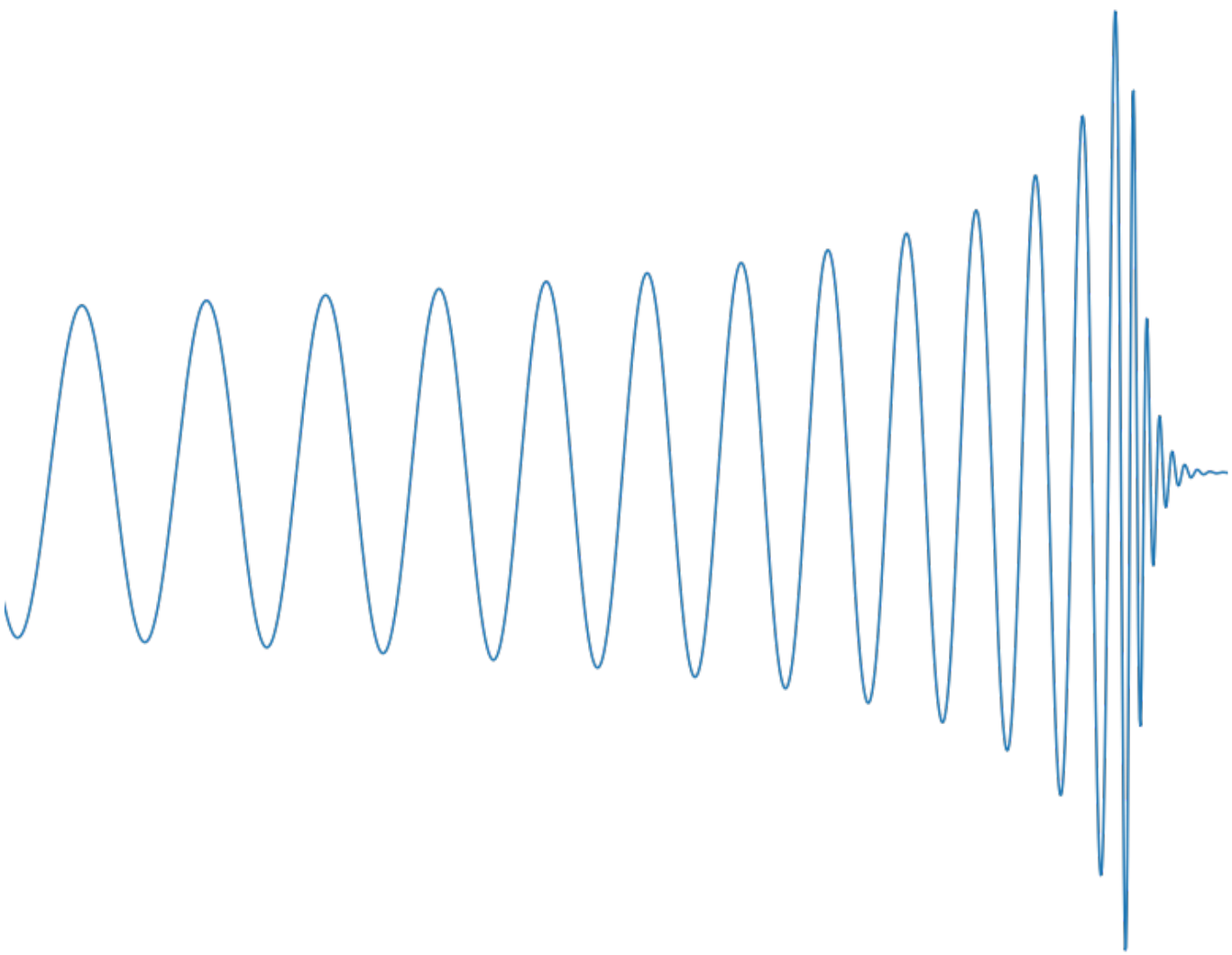
- Edge on: $h_\times = 0$, weakest emission



Elliptical polarization

$$h_+ = \sum^{N} w(f; A, \phi_0, Q, t_0, f_0)$$

$$h_\times = \epsilon e^{i\pi/2} h_+$$



Ellipticity: related to binary inclination

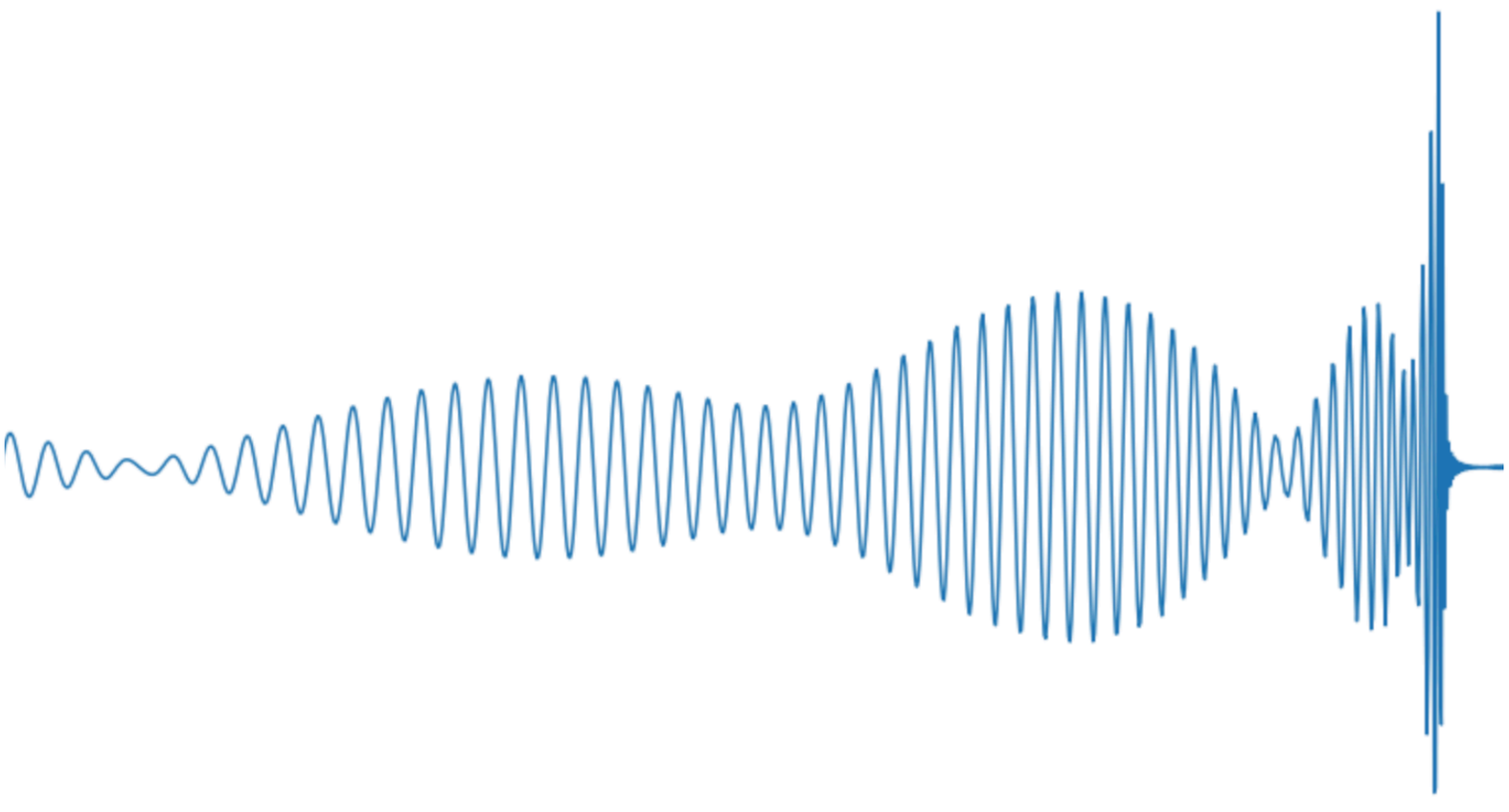
Consistent with all events from O2

Generic polarization

$$h_+ = \sum^N w(f; A^+, \phi_0^+, Q, t_0, f_0)$$

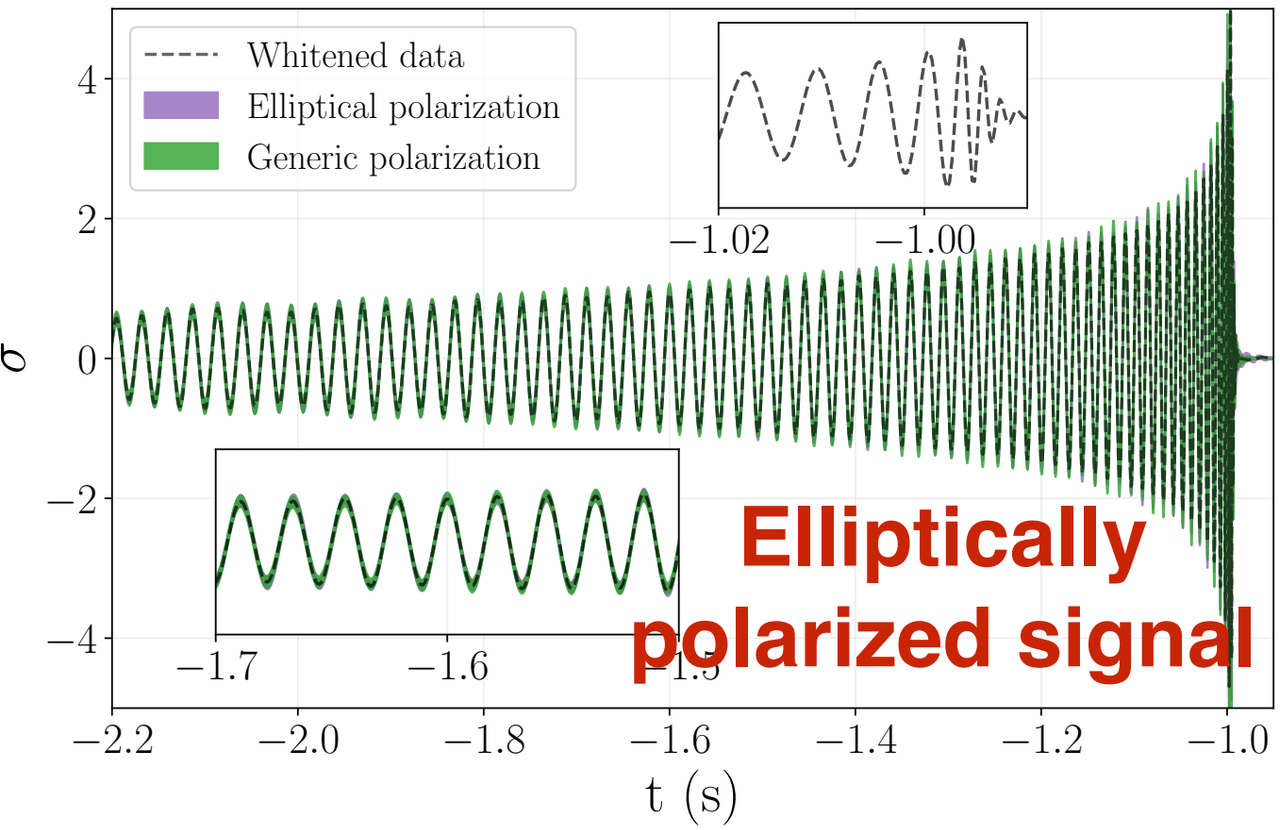
$$h_\times = \sum^N w(f; A^\times, \phi_0^\times, Q, t_0, f_0)$$

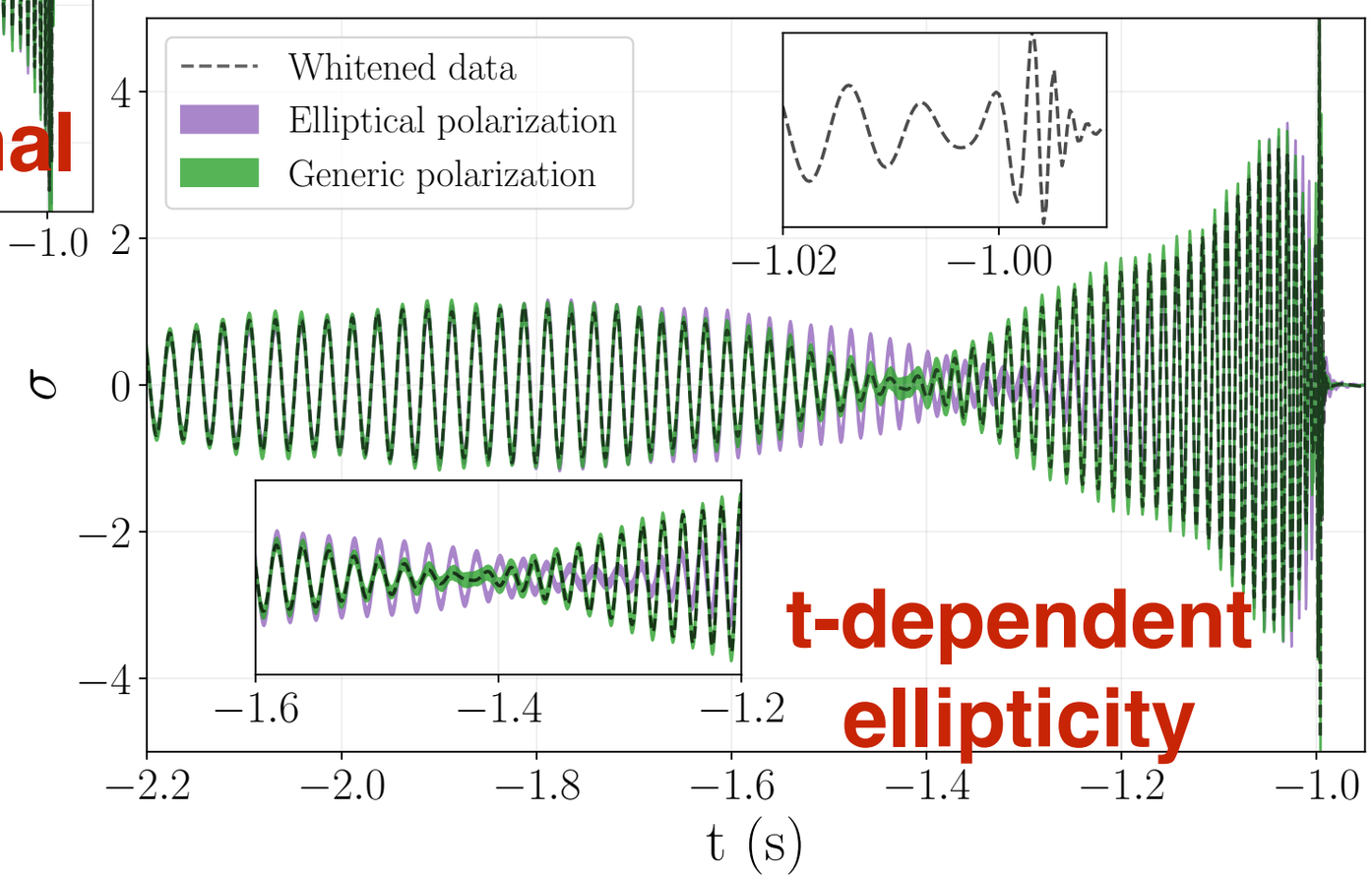
Nature shouldn't care how we oriented the detectors



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

Spin precession

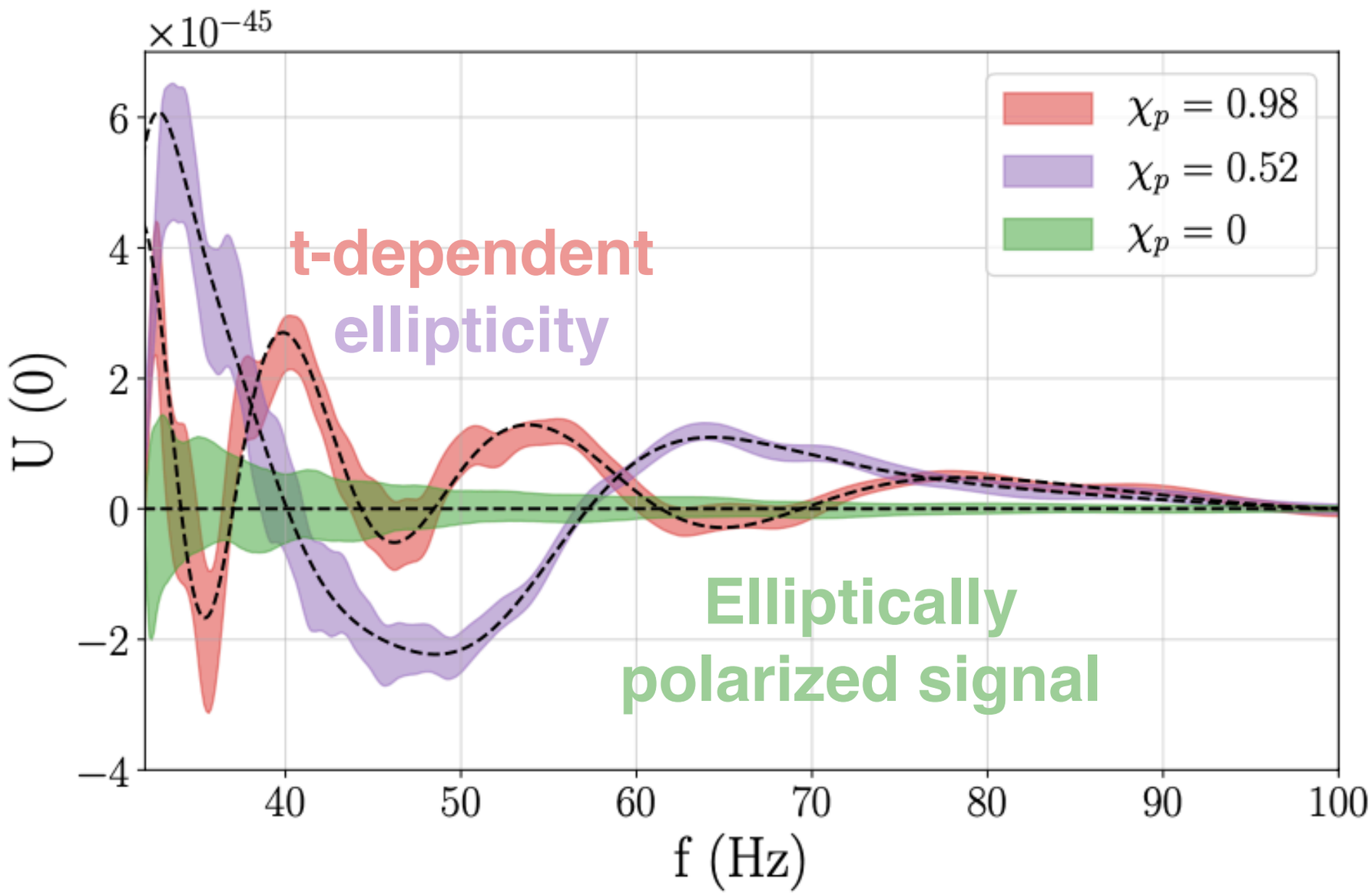




Cornish+ (arXiv:2011.09494)

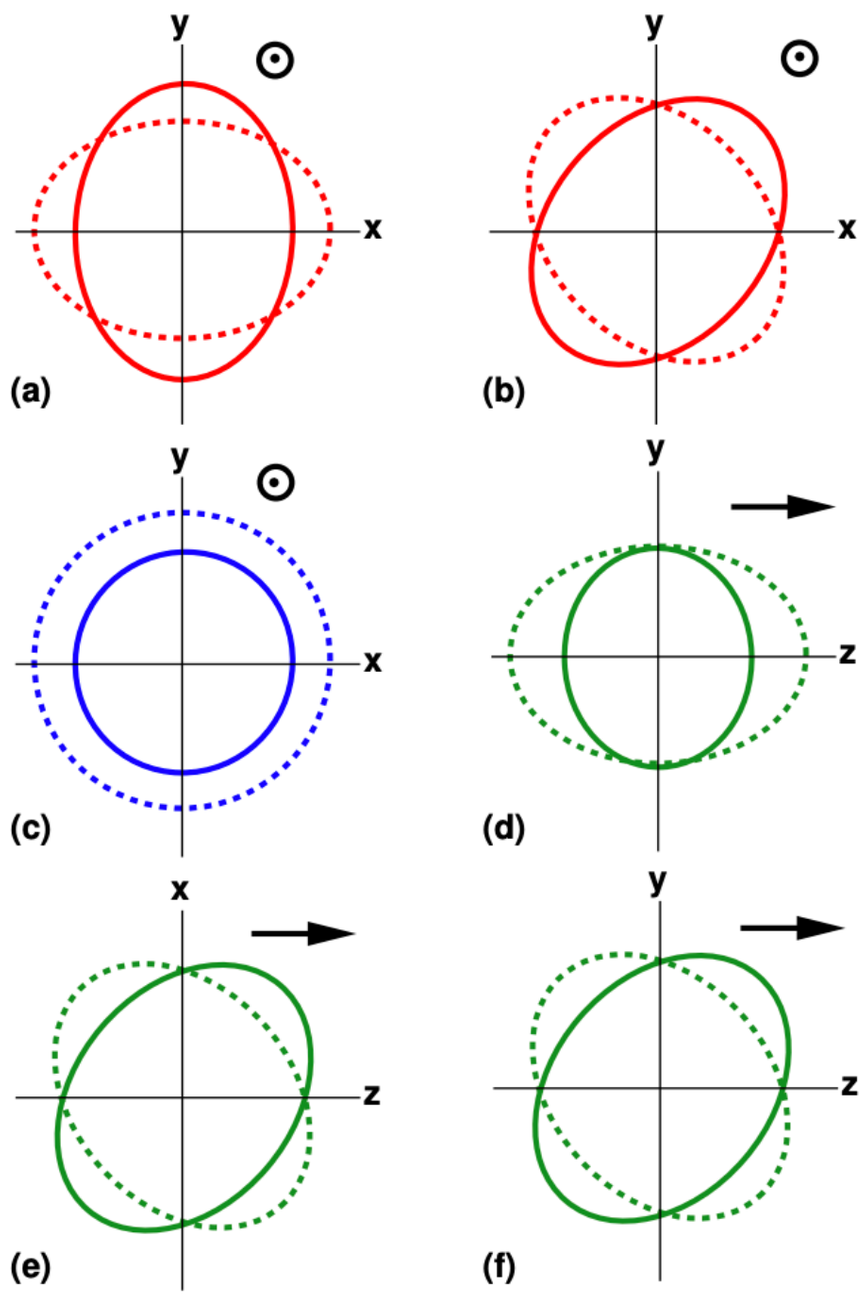
Stokes parameters

$$U = \tilde{h}_+ \tilde{h}_\times^* + \tilde{h}_\times \tilde{h}_+^*$$

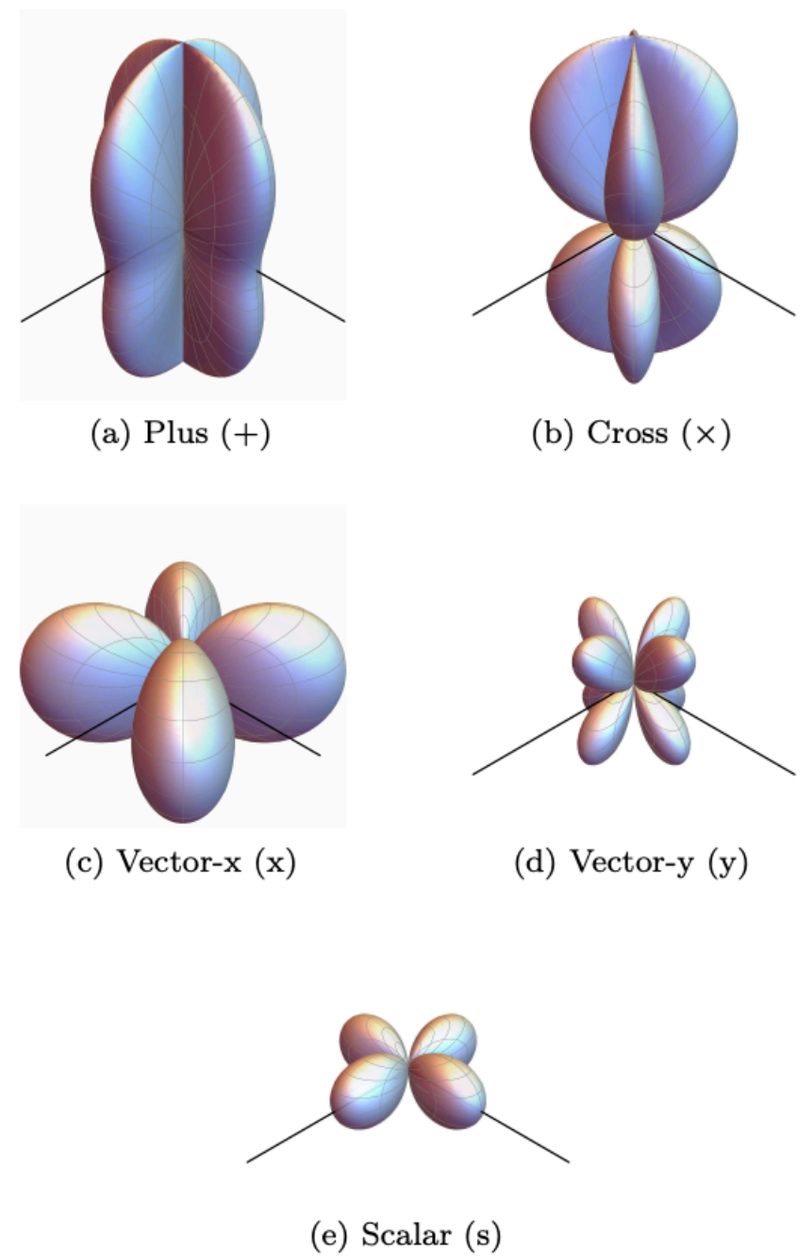


Cornish+ (arXiv:2011.09494)

Generic polarizations modes



The wave polarization affects the inferred sky location



Will (arxiv:1403.7377)

Isi+ (arxiv:1710.03794)

Beyond general relativity

Example: Brans-Dicke (scalar tensor) theory

$$
\begin{aligned}
h^{\mathrm{b}} &= \frac{-4\mu\bar{S}}{D} \\
h^{+} &= -\left(1-\frac{1}{2}\xi\right)\frac{2G\mu m}{Dr}\cos 2\Phi(1+\cos^2\iota) \\
h^{\times} &= -\left(1-\frac{1}{2}\xi\right)\frac{4G\mu m}{Dr}\sin 2\Phi\cos\iota
\end{aligned}
$$

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

$$h = F_+ h_+ + F_\times h_\times + F_b h_b$$

$$h_+ = \sum^{N} w(f; A^+, \phi_0^+, Q, t_0, f_0)$$

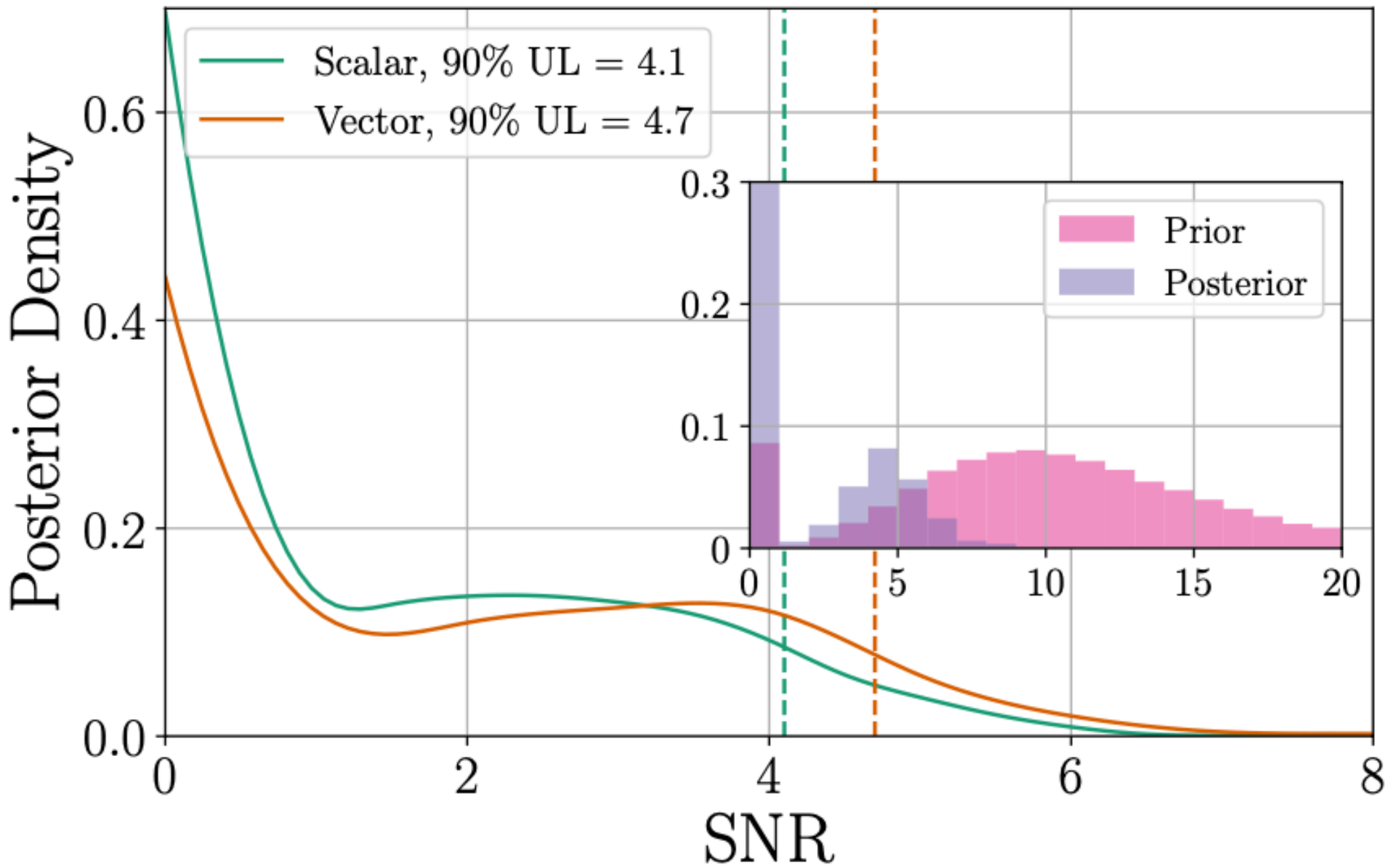
$$h_\times = \sum^{N} w(f; A^\times, \phi_0^\times, Q, t_0, f_0)$$

$$h_b = \sum^{N_b} w(f; A^b, \phi_0^b, Q^b, t_0^b, f_0^b)$$

GW190521

Assuming the proposed ZTF sky location

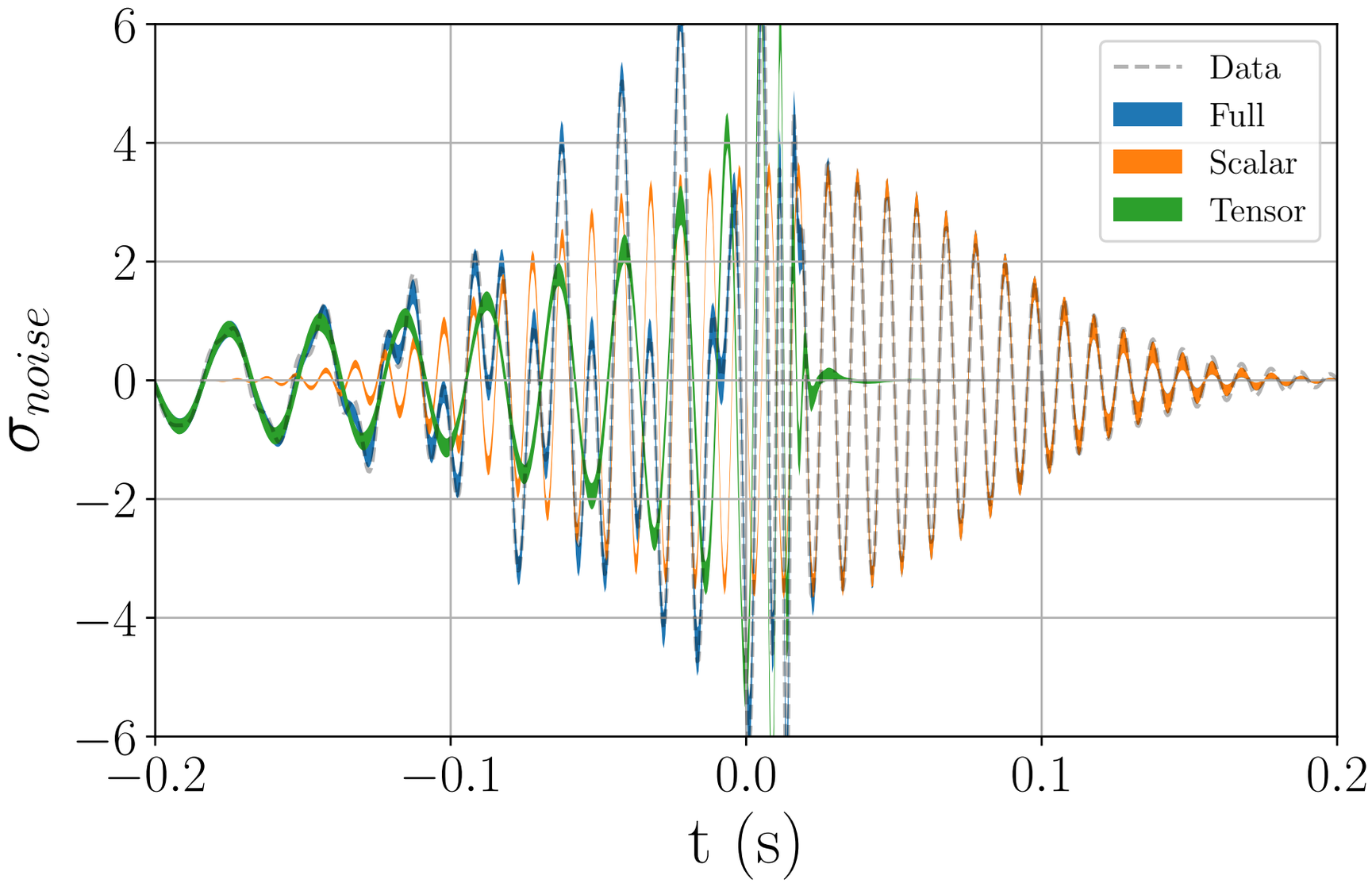
Graham+ (arxiv:2006.14122)



Chatziioannou+ (in preparation)

Simulated signal with scalar power

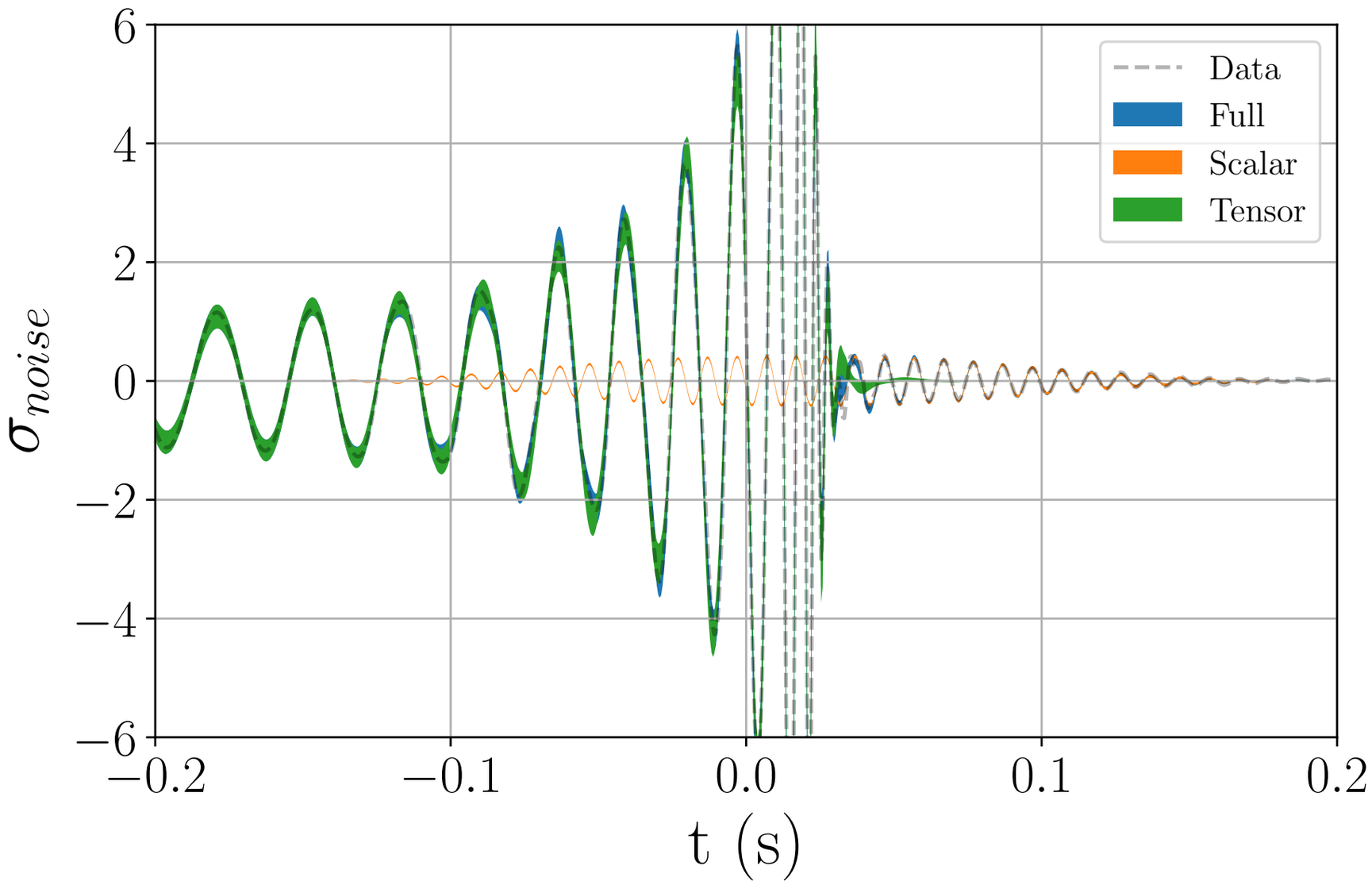
4 detectors (O4) of comparable sensitivity (not O4)



Chatziioannou+ (in preparation)

Need information from all detectors

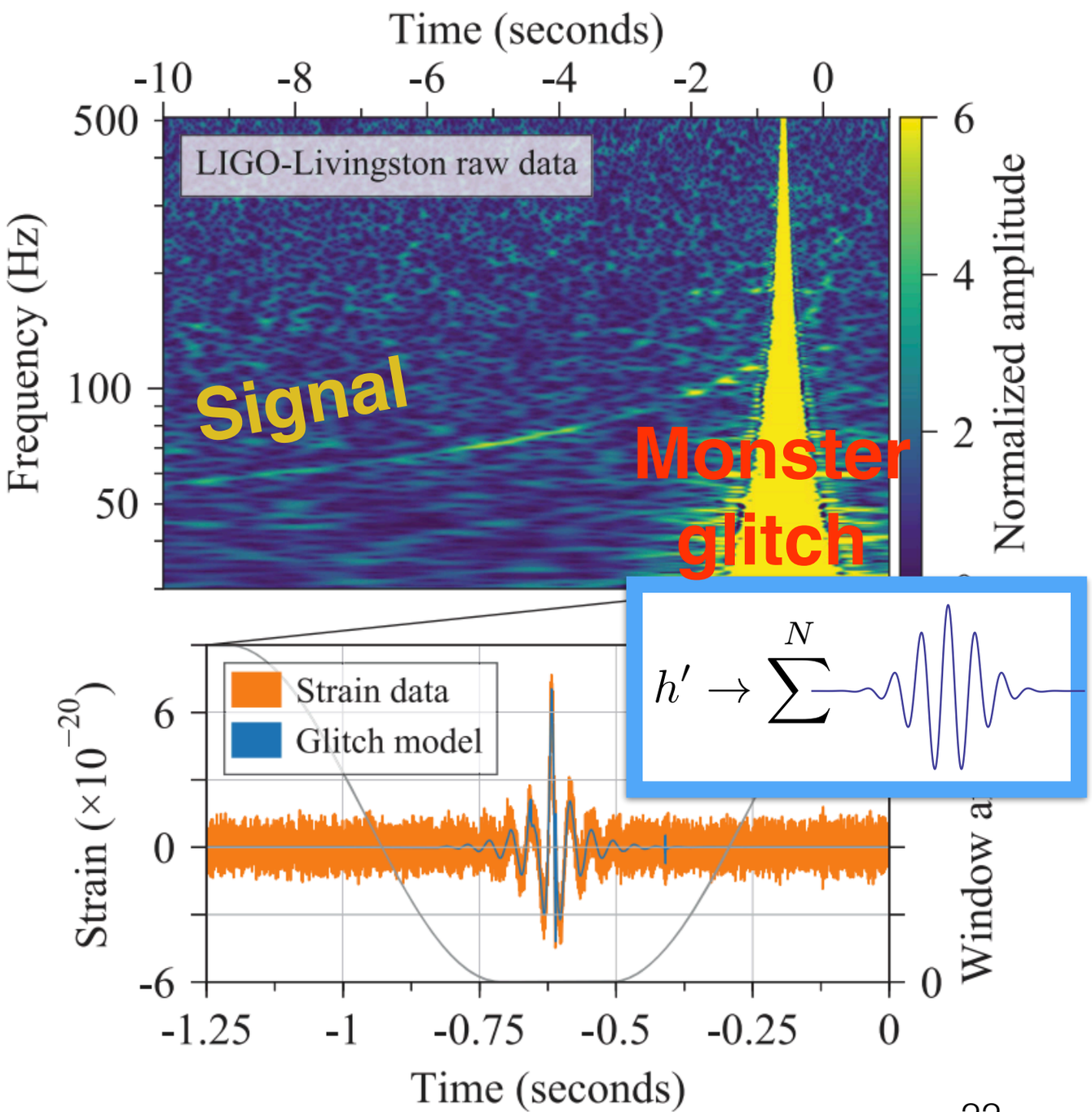
The sky location affects how much power from each mode the detector sees

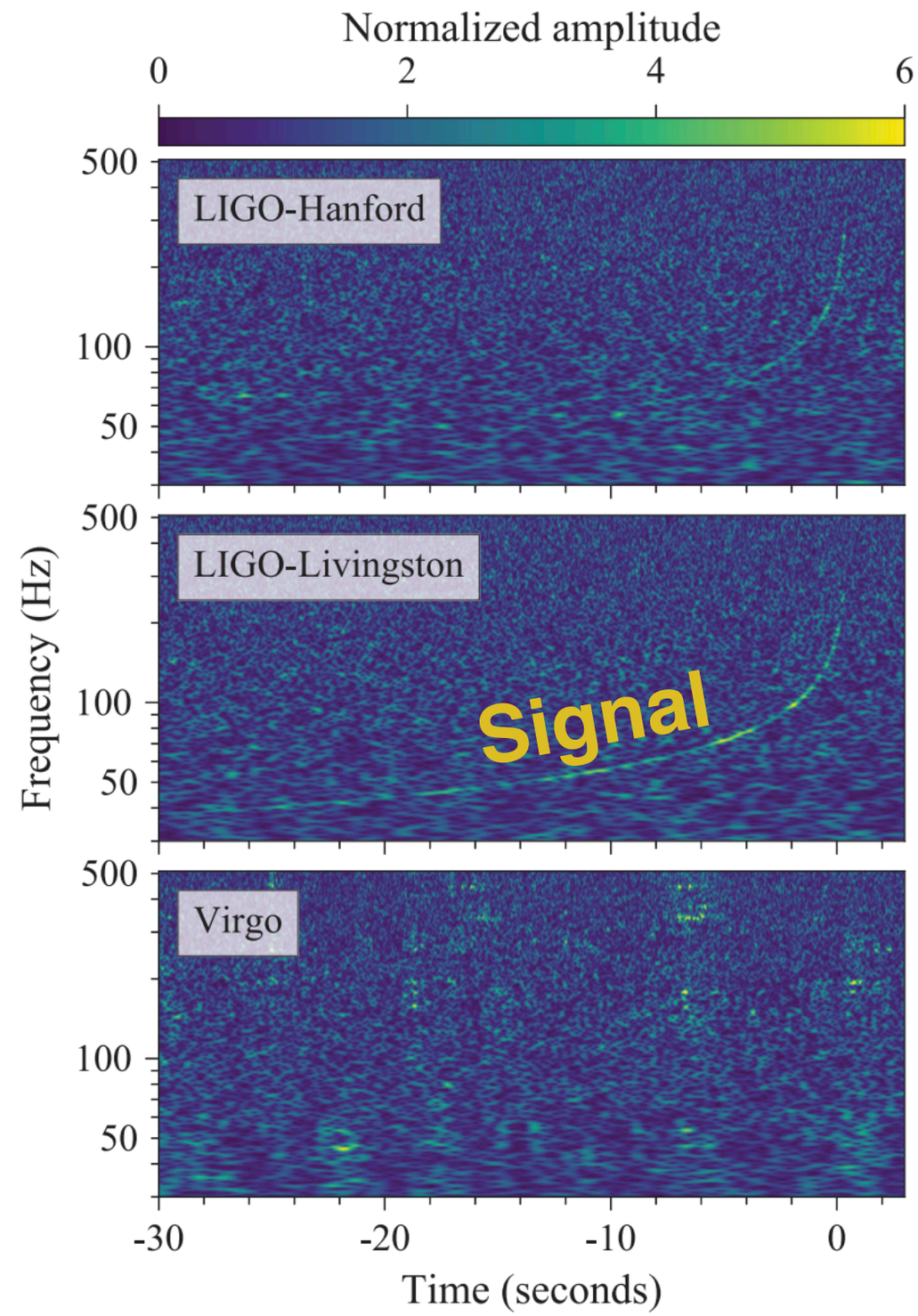


Chatziioannou+ (in preparation)

Detector glitches

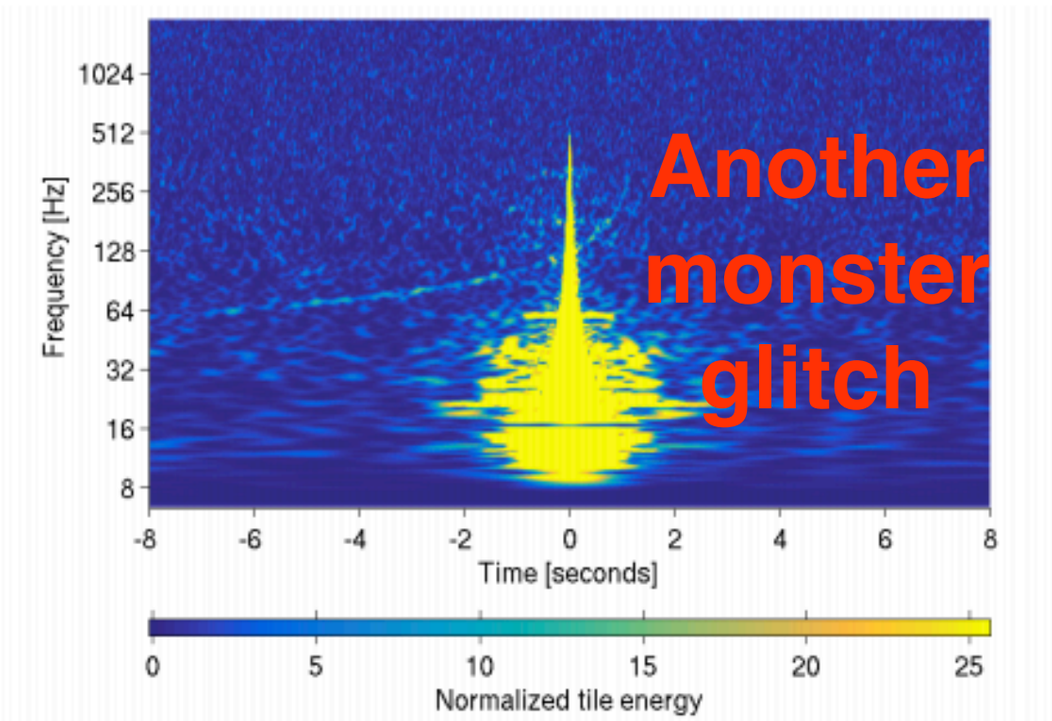
Disclaimer: that's a BIG one

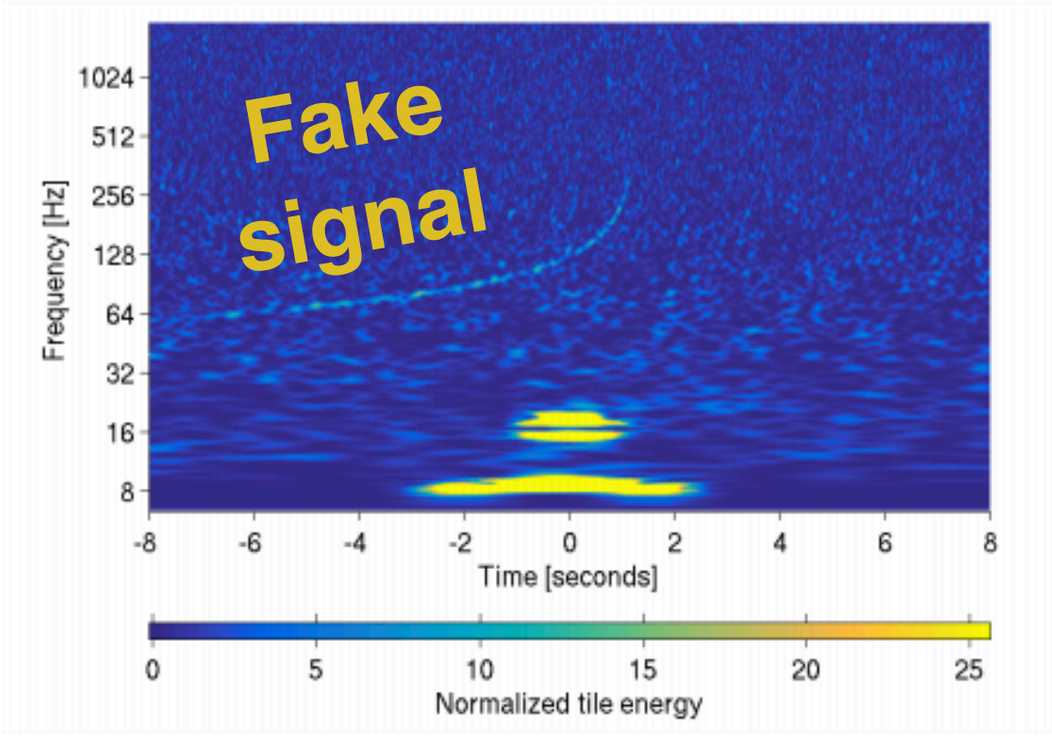


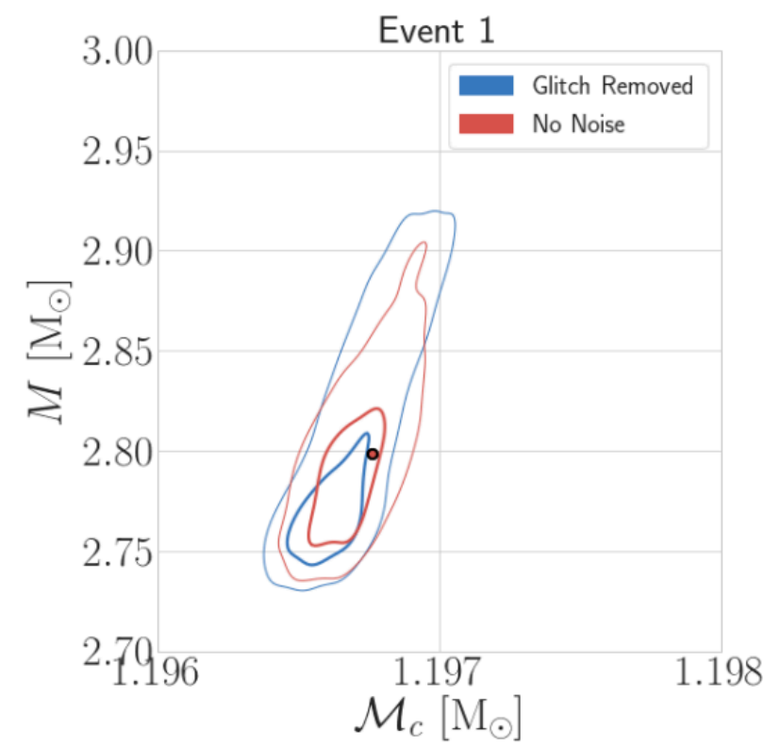


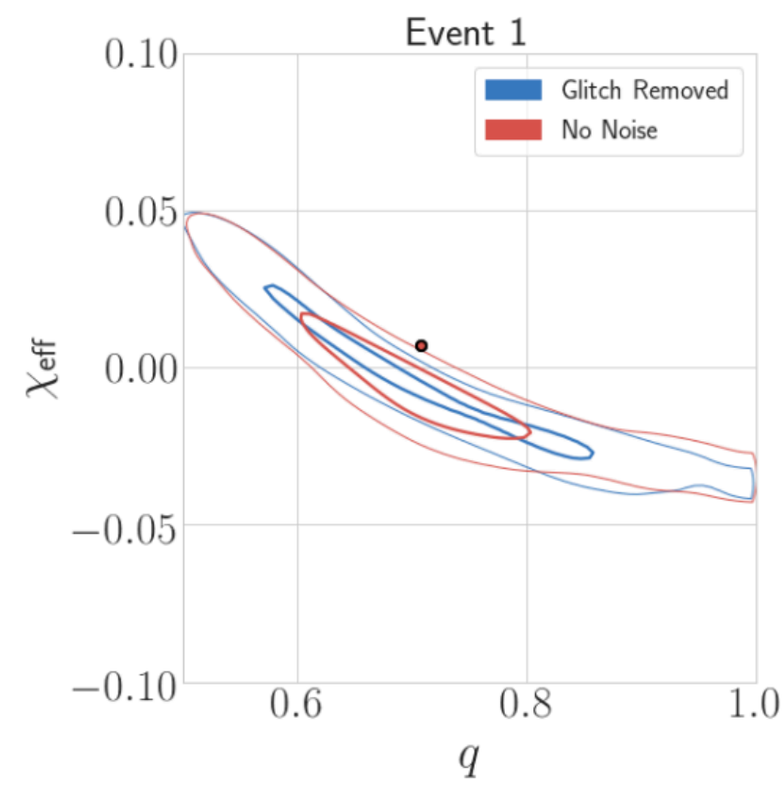
LVC (arxiv:1710.05832)

The signal behind the glitch



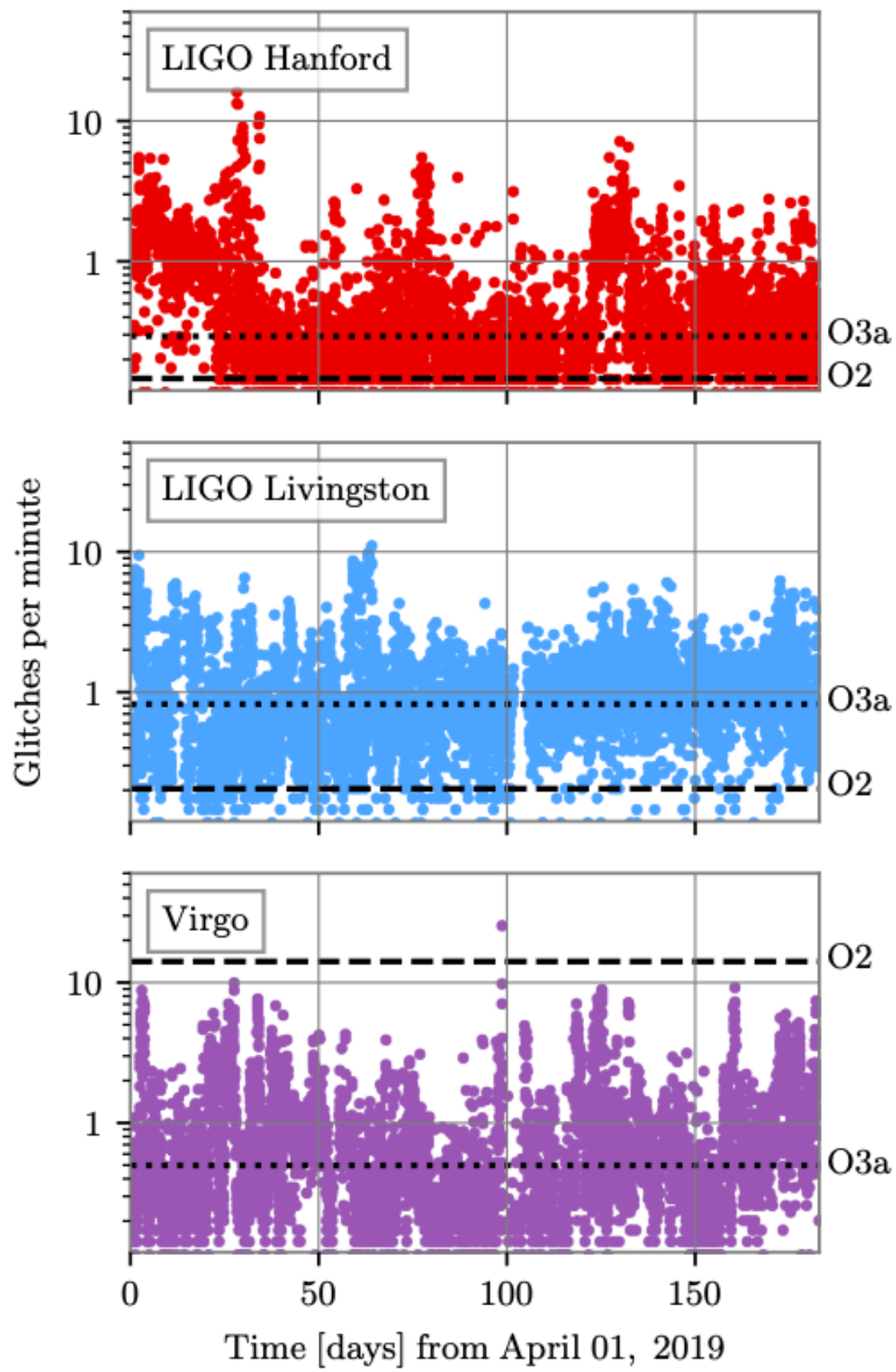






Pankow (including KC) (arxiv:1808.03619)

Increased glitch rate

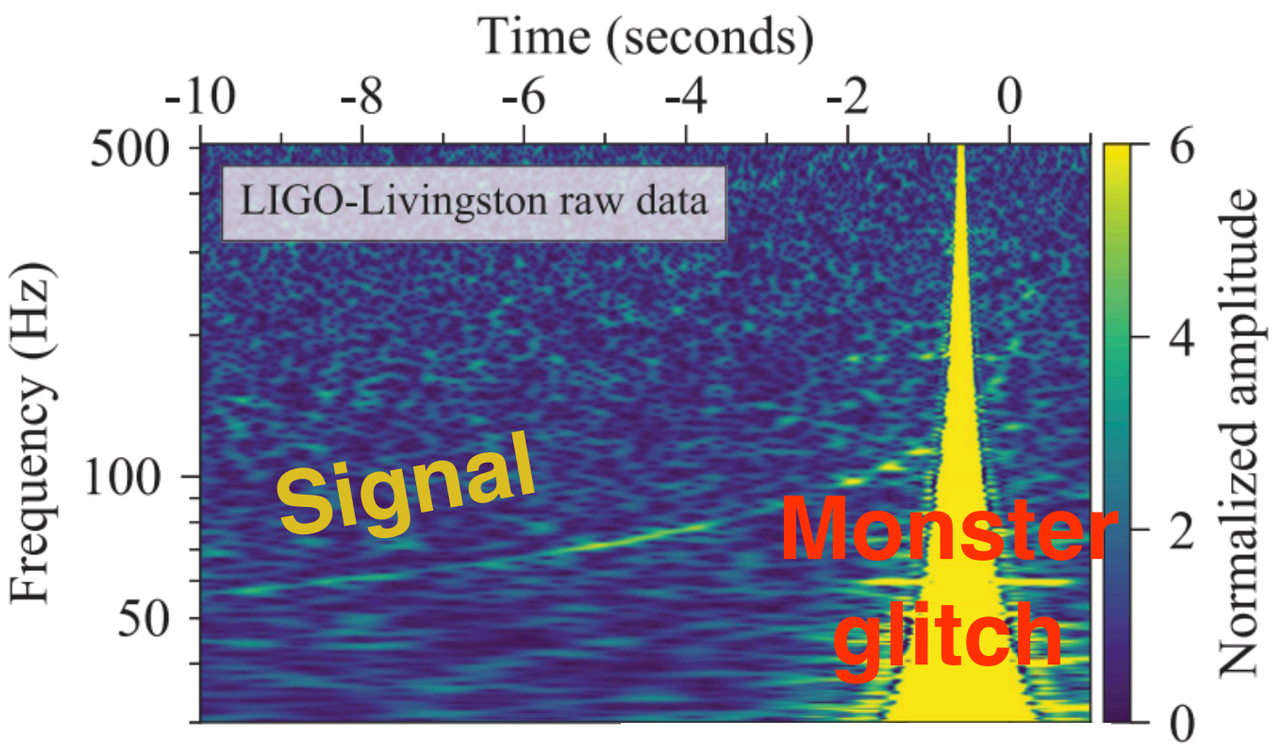


The next neutron star binary will very likely overlap with a glitch

LVC (arxiv:2010.14527)

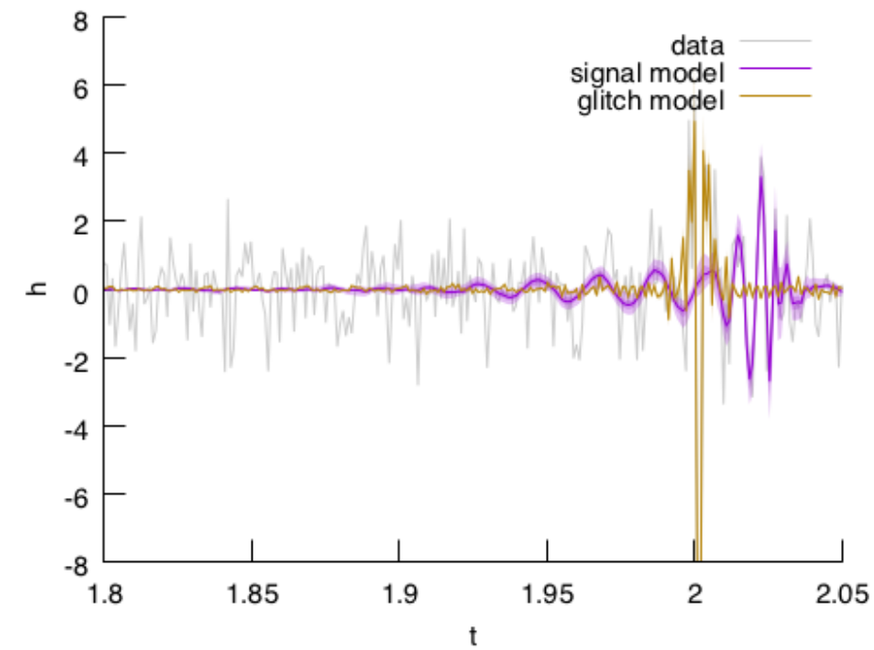
Signals and glitches

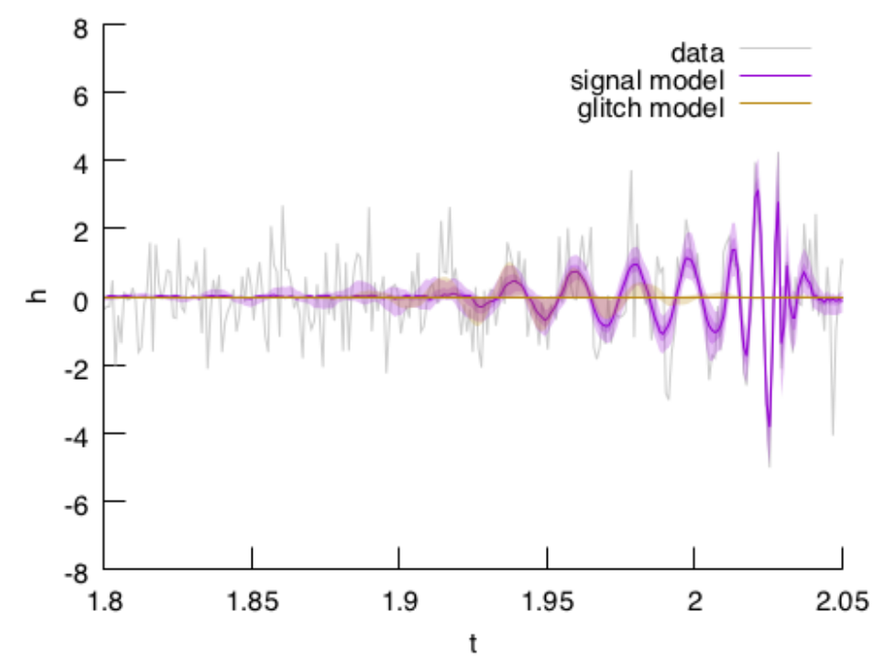
We won't always be so "lucky"



LVC (arxiv:1710.05832)

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

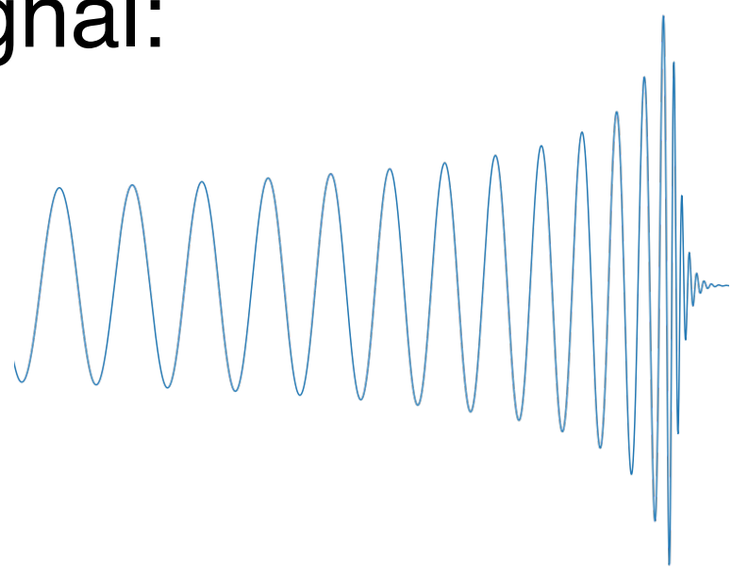




Cornish+ (arXiv:2011.09494)

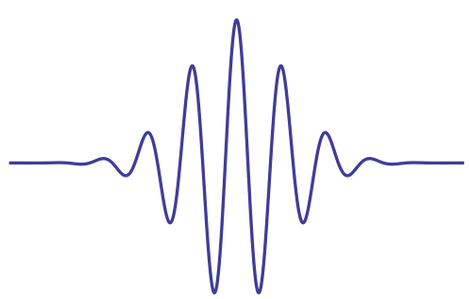
The next step: compact binaries and glitches

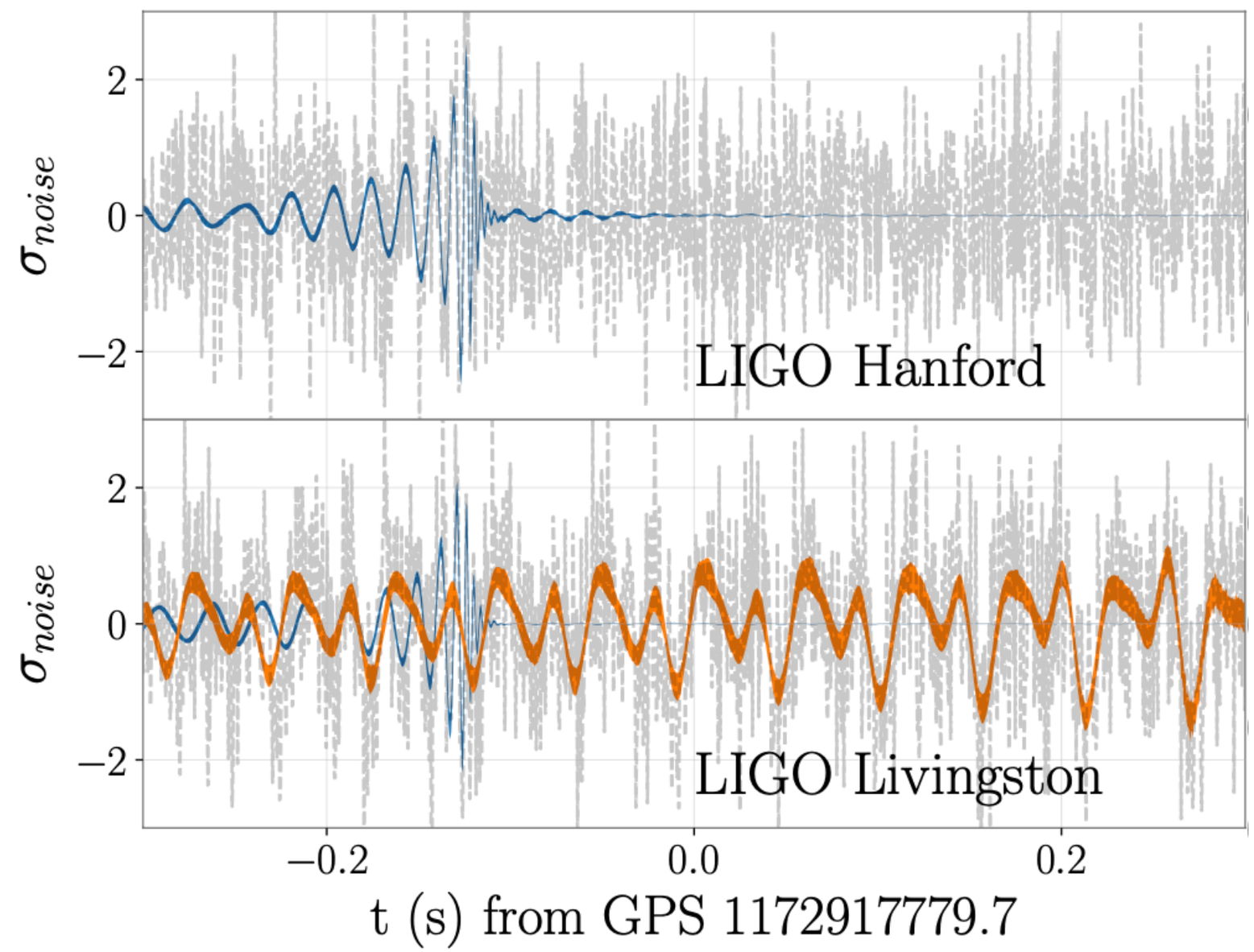
Signal:



Glitch:

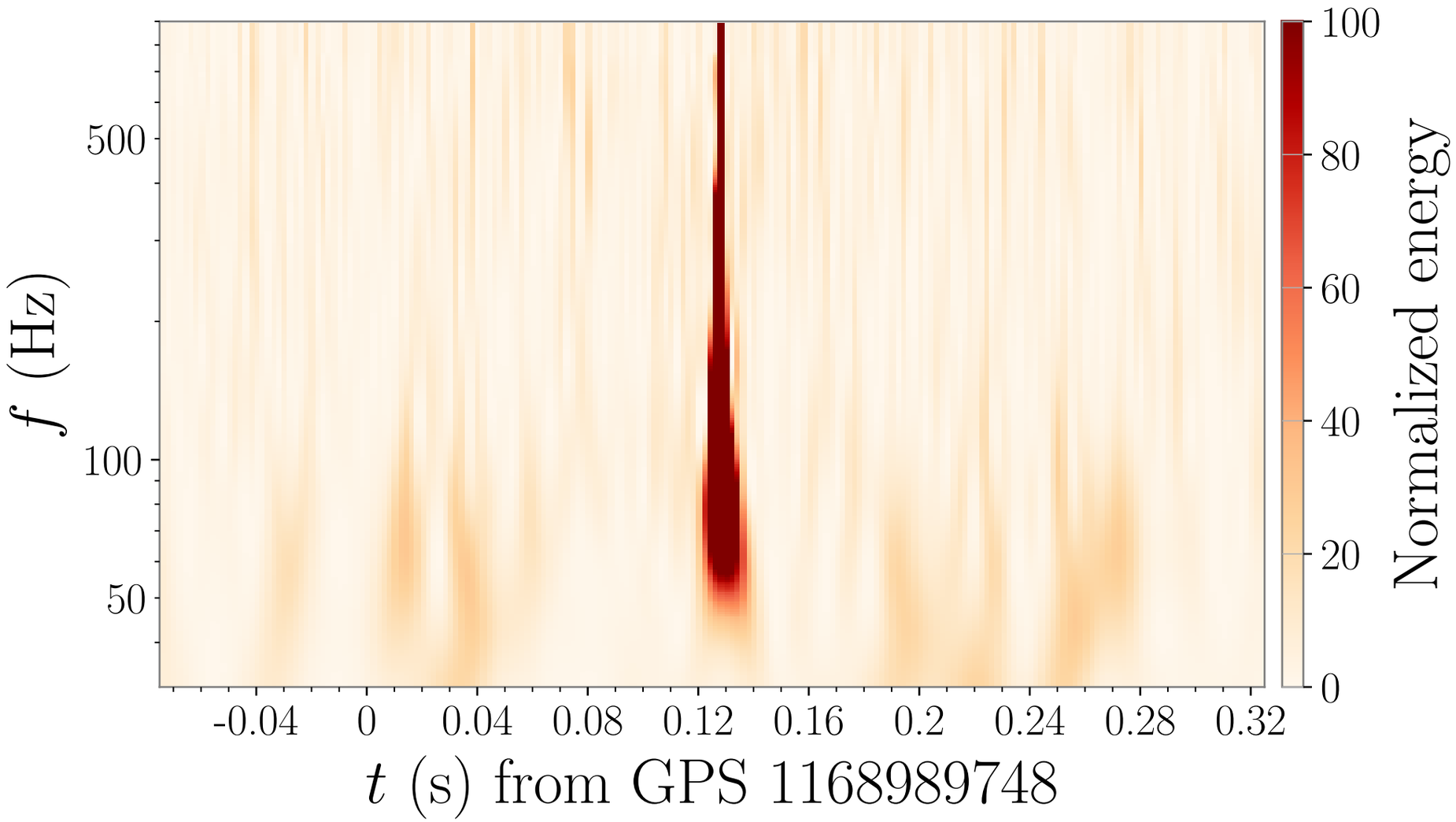
$$h' \rightarrow \sum^{N}$$





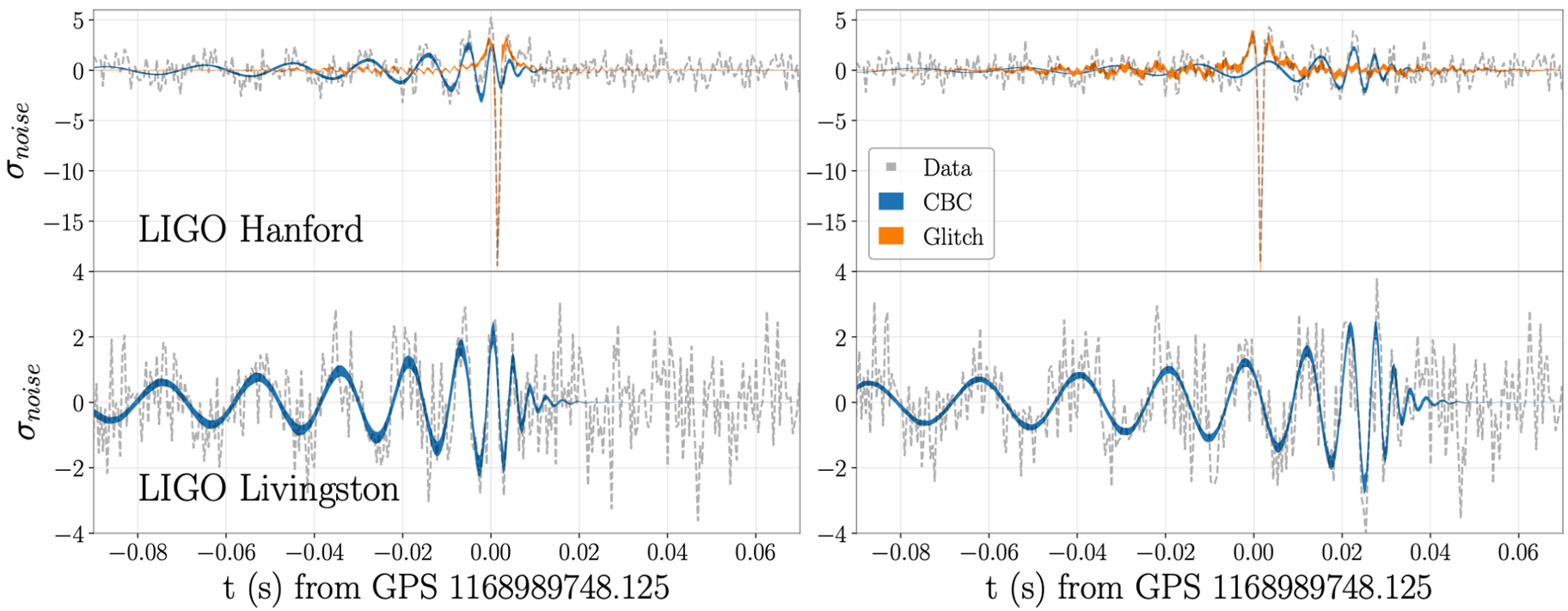
Chatziioannou+ (arXiv:2101.01200)

Example: blip glitch



Chatziioannou+ (arXiv:2101.01200)

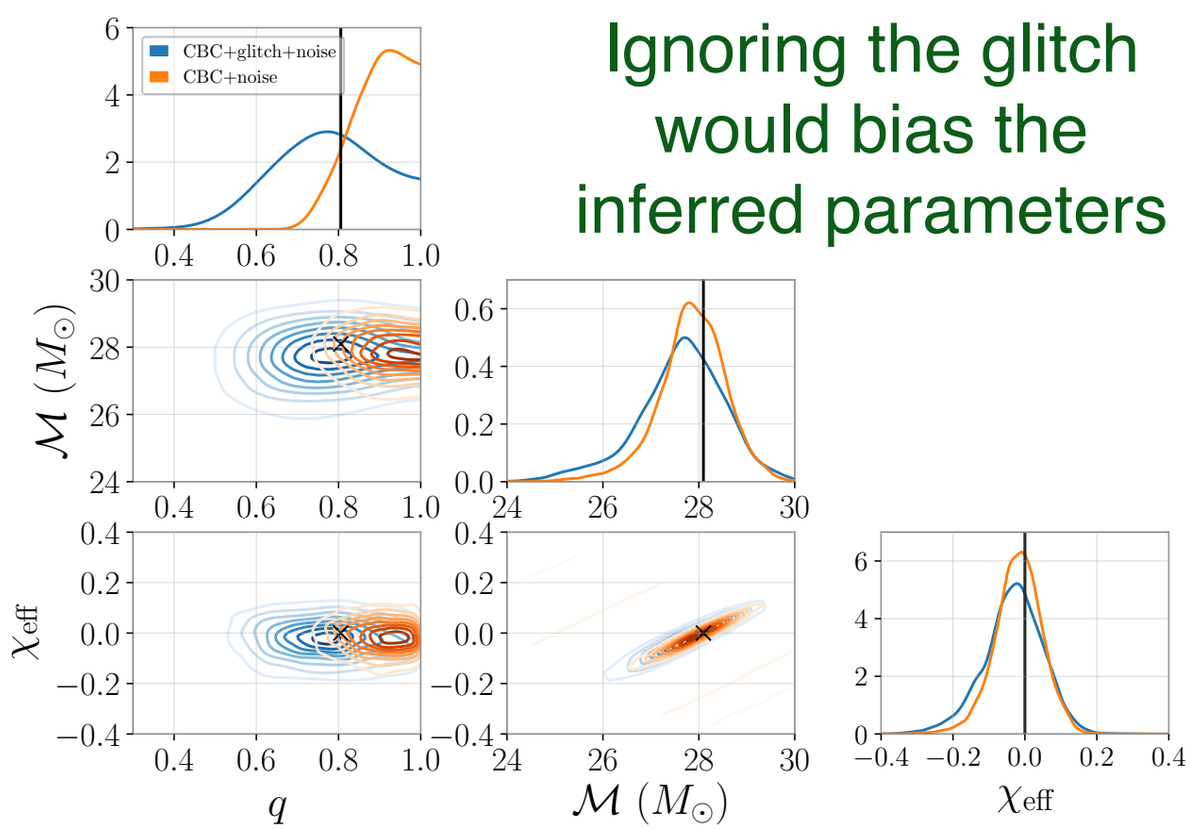
Reconstructions and Parameters

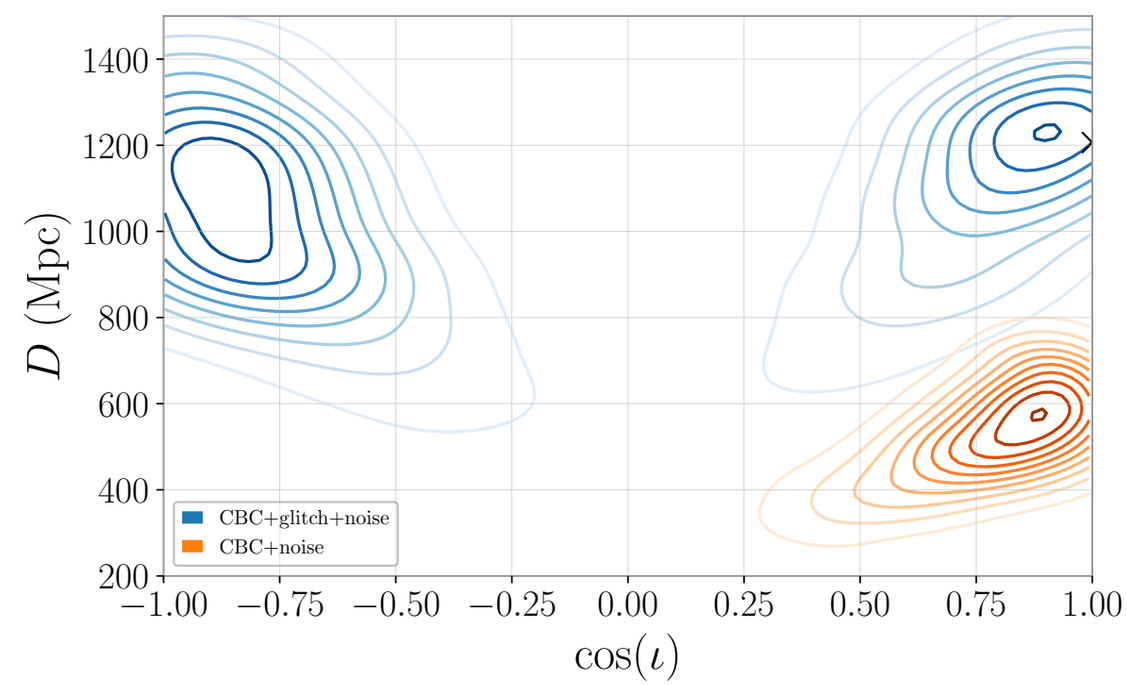


Real glitch from O2

Simulated signal

Ignoring the glitch would bias the inferred parameters

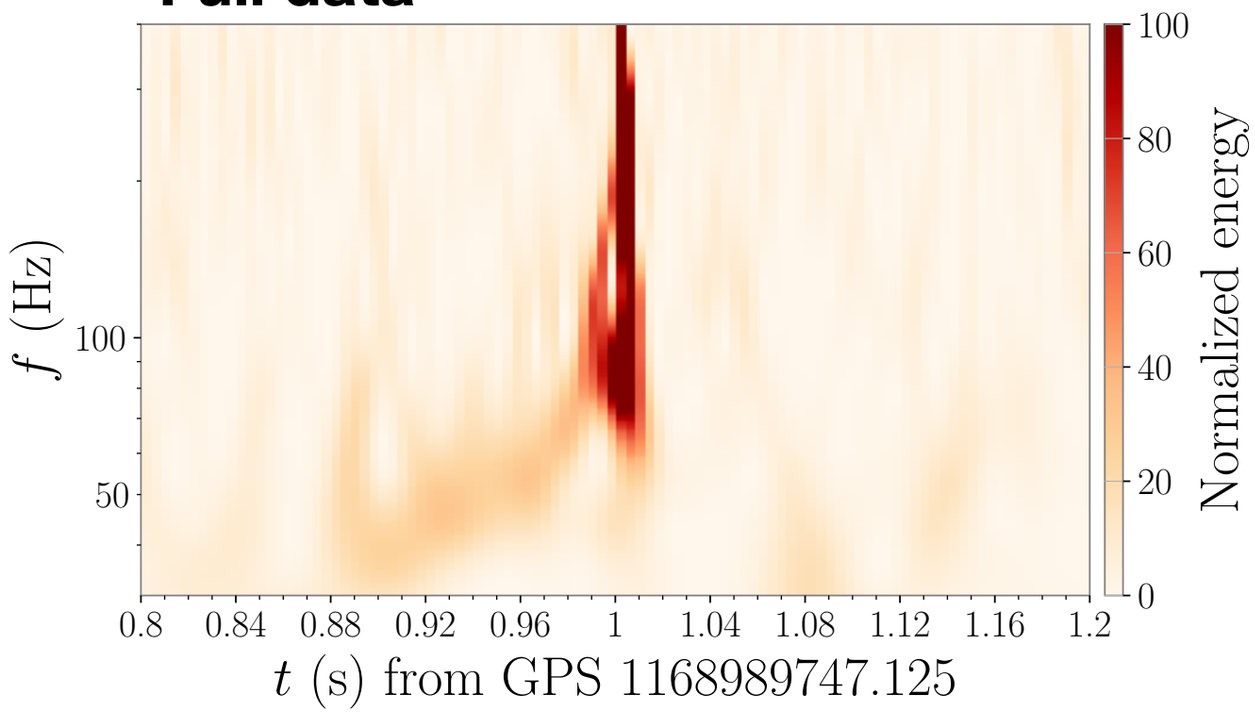




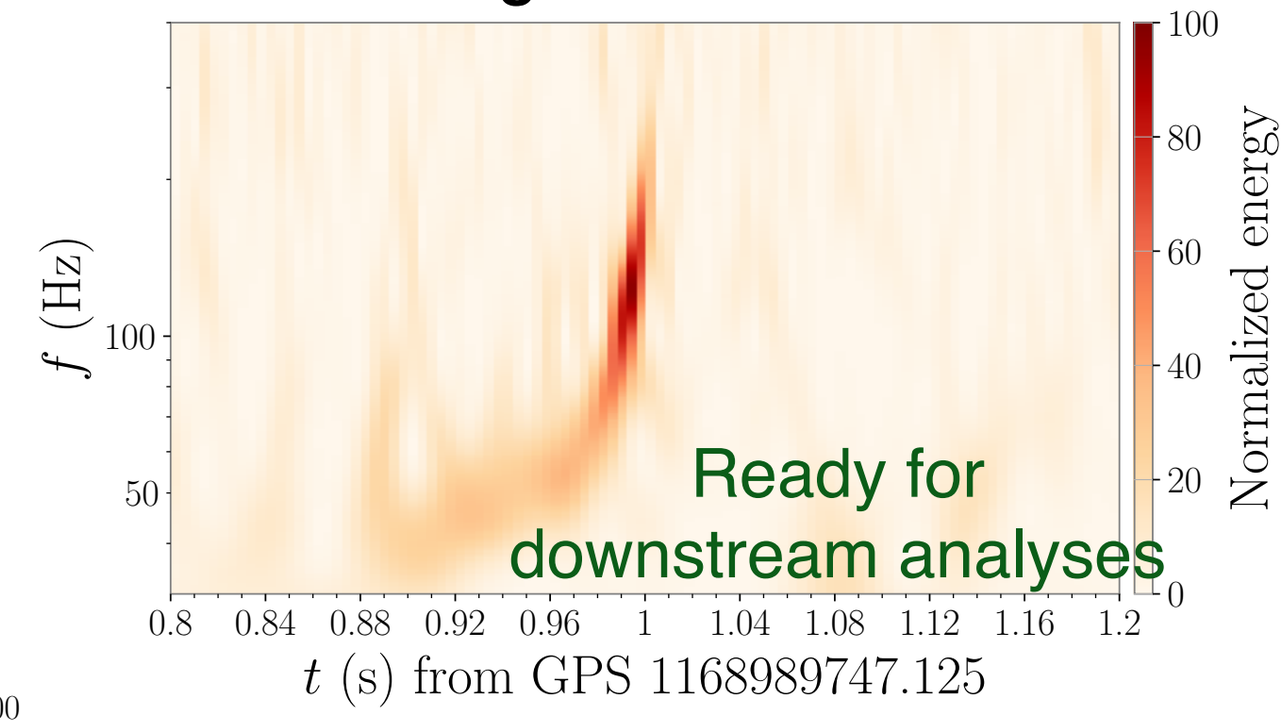
Chatziioannou+ (arXiv:2101.01200)

Glitch subtraction

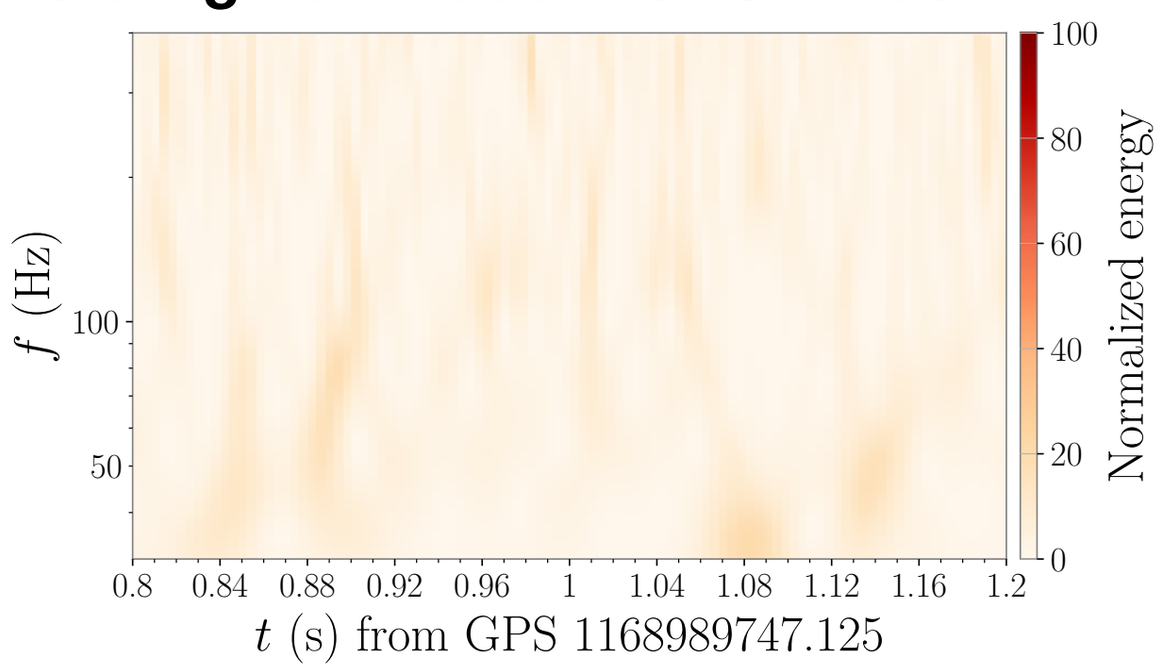
Full data



Full data - glitch model

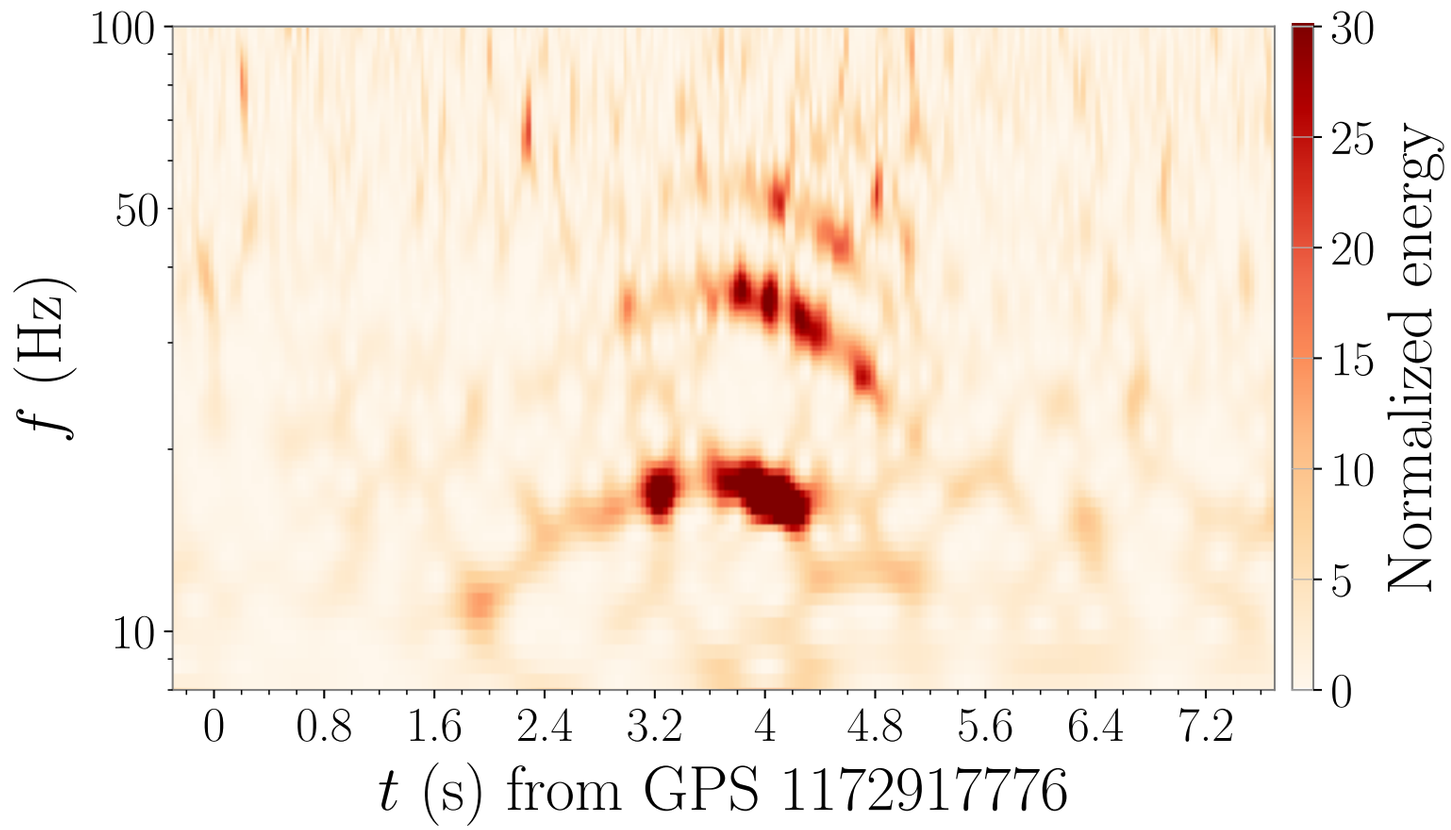


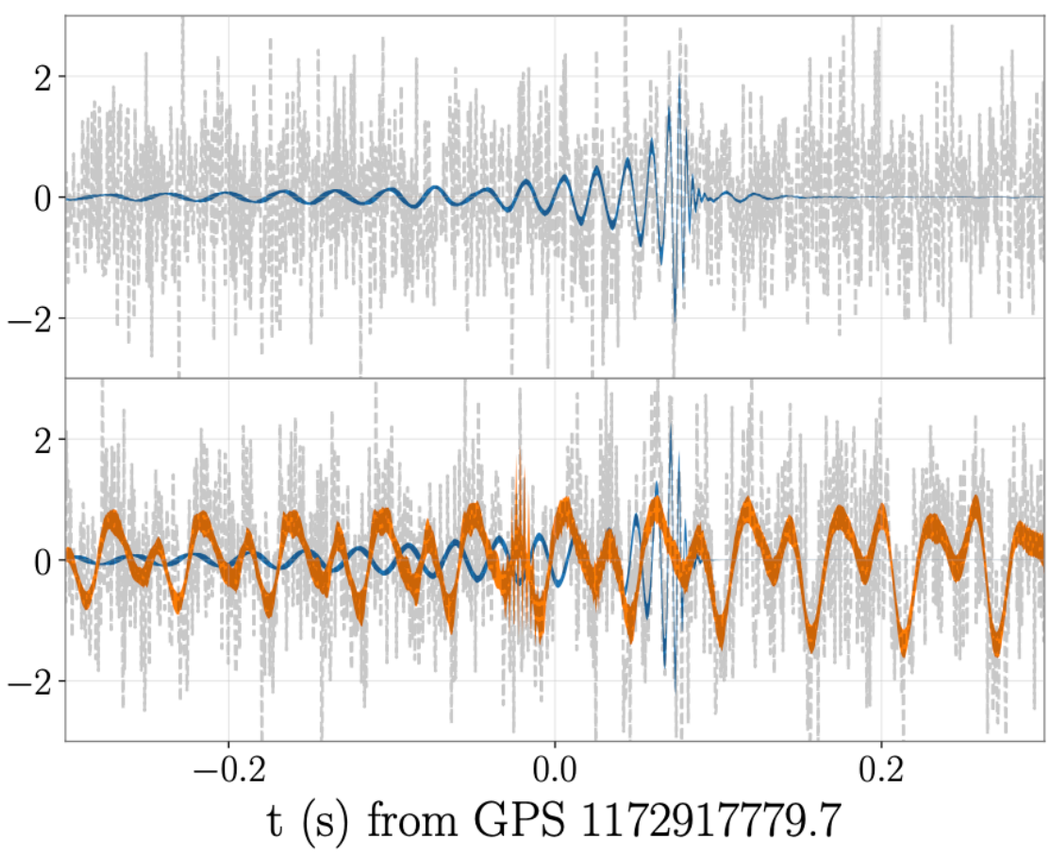
Full data - glitch model - CBC model



Chatziioannou+ (arXiv:2101.01200)

Example: scattered light





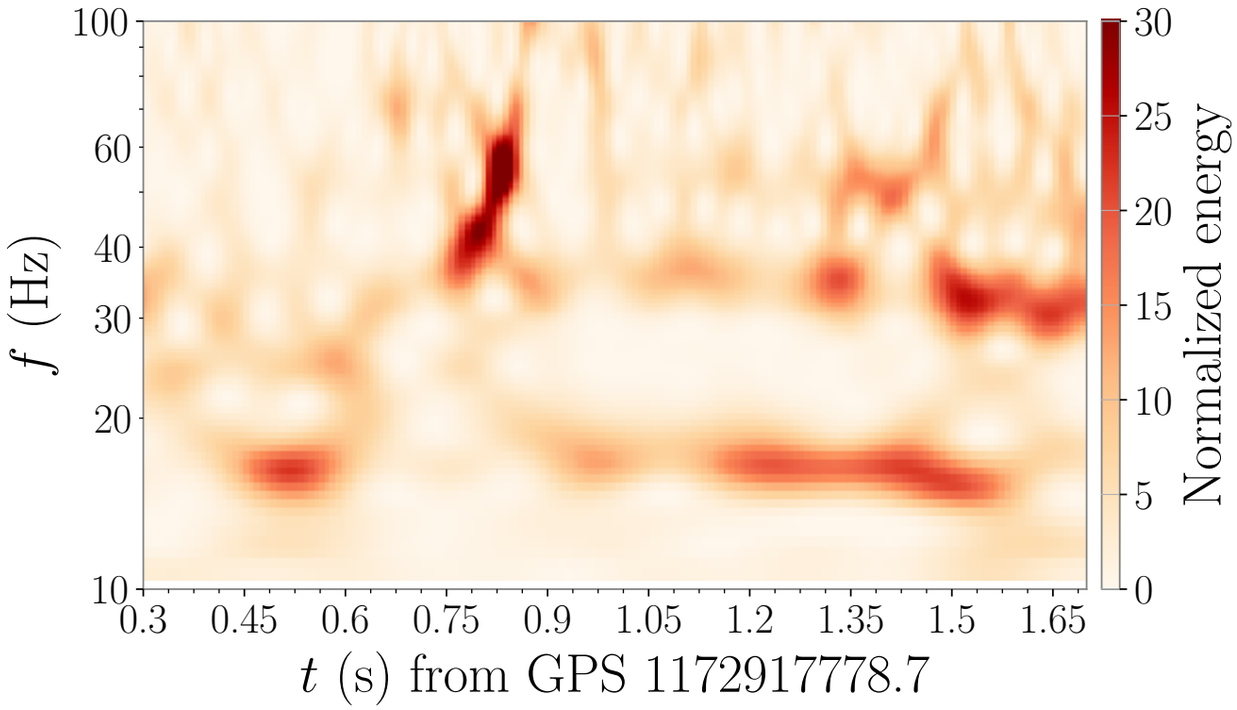
Real glitch
from O2

Simulated signal

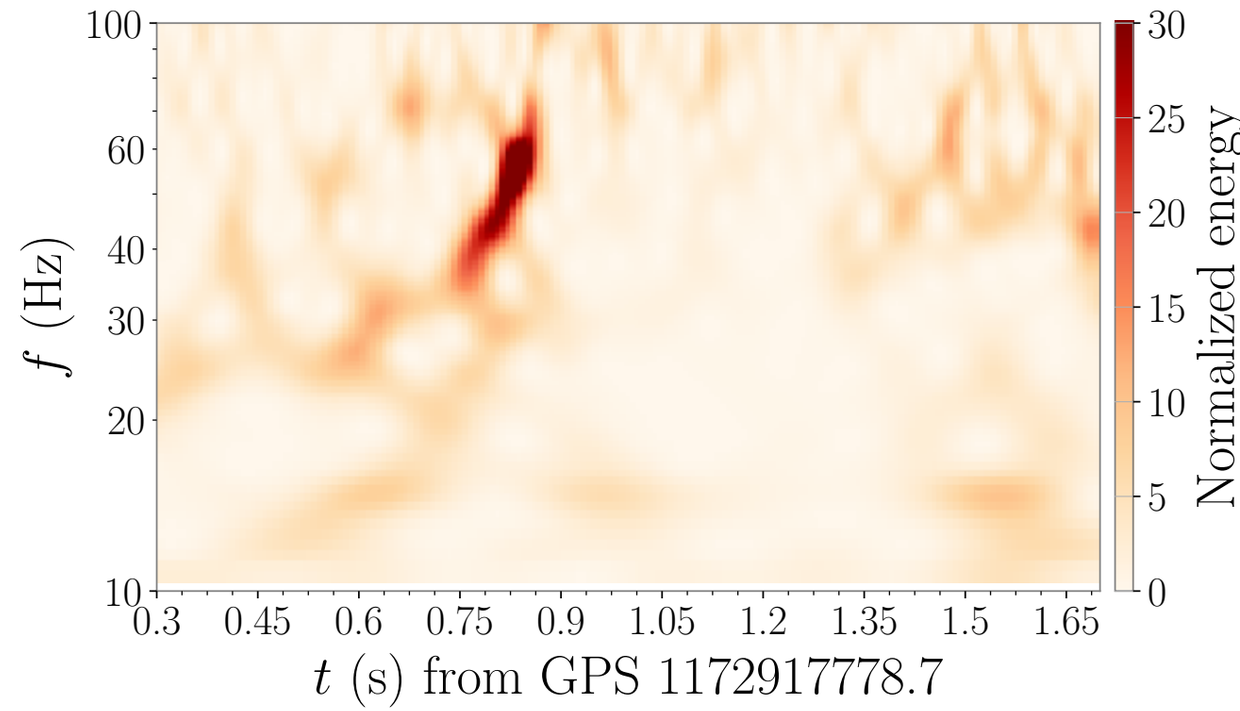
Chatziioannou+ (arXiv:2101.01200)

Glitch subtraction

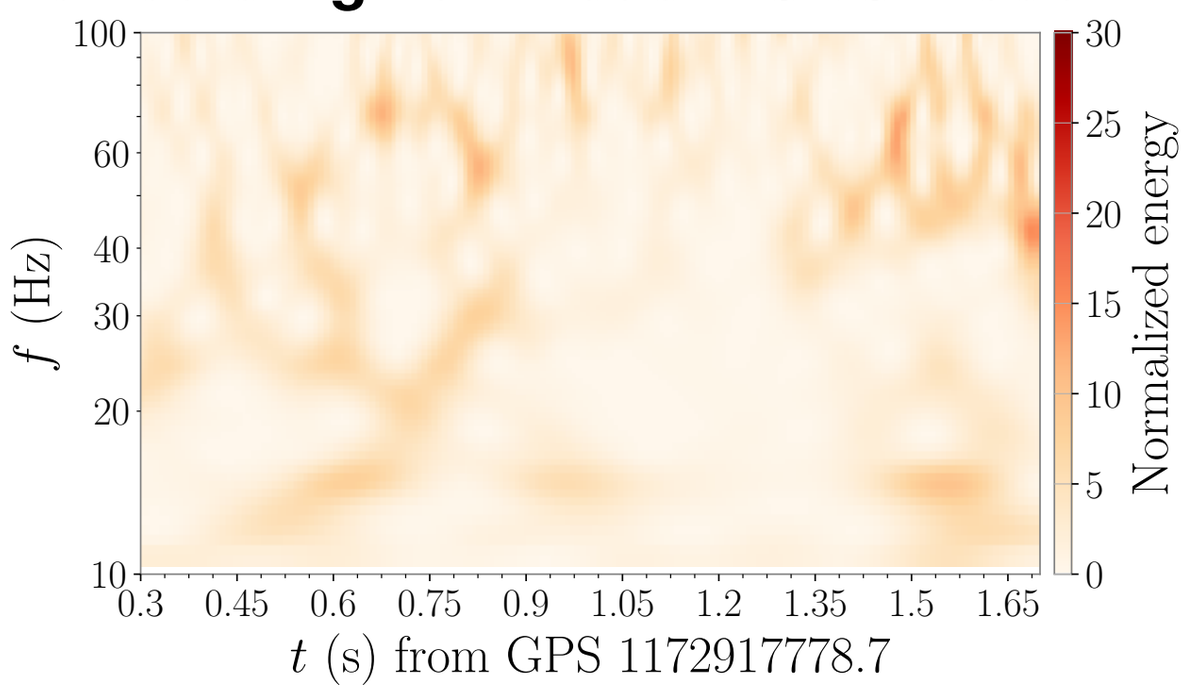
Full data



Full data - glitch model

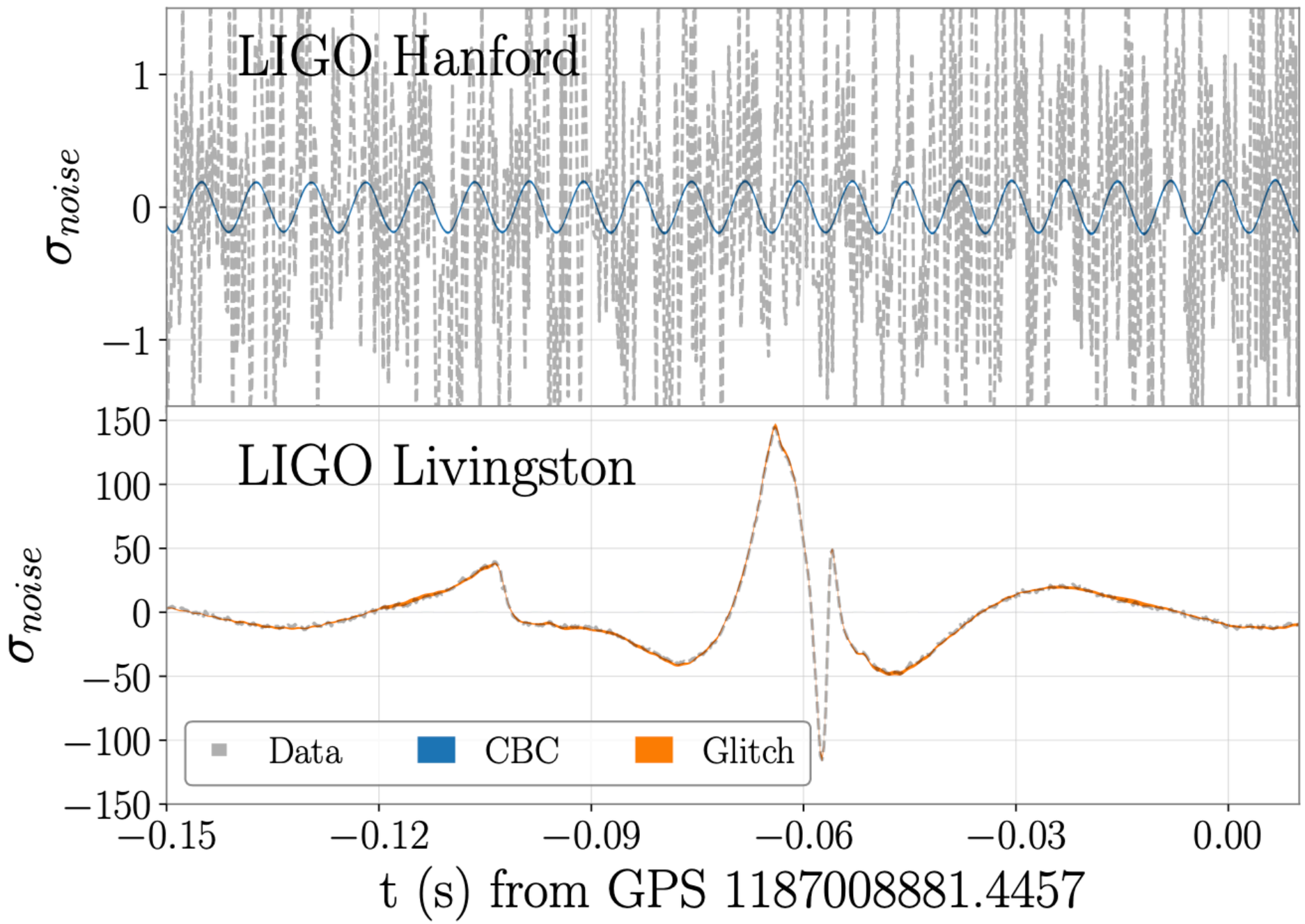


Full data - glitch model - CBC model



Chatziioannou+ (arXiv:2101.01200)

Back to GW170817



Chatziioannou+ (arXiv:2101.01200)

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

Thank you