Enhancing the Sensitivity of Searches for Gravitational Waves from Core-Collapse Supernovae with a Bayesian classification of candidate events

Kiranjyot Gill

Collaborators: Wenhui Wang, Oscar Valdez, Marek Szczepanczyk, Michele Zanolin & Soma Mukherjee

For LIGO folk: S5 data used

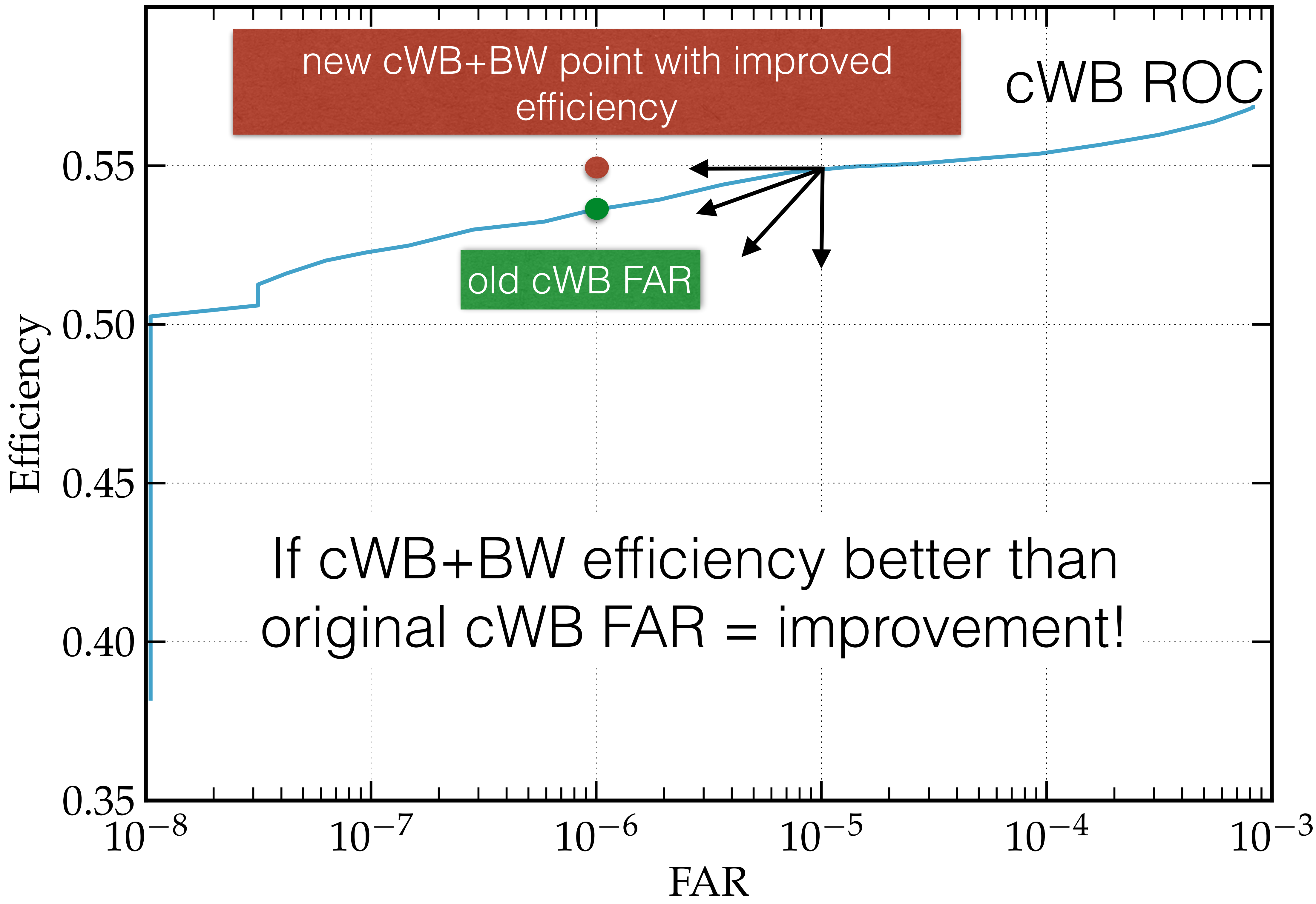
The Need for BayesWave

Goal for LVC-SN Searches: reduction of the false alarm rate produced by cWB in order to improve the ROC curve for GW detection

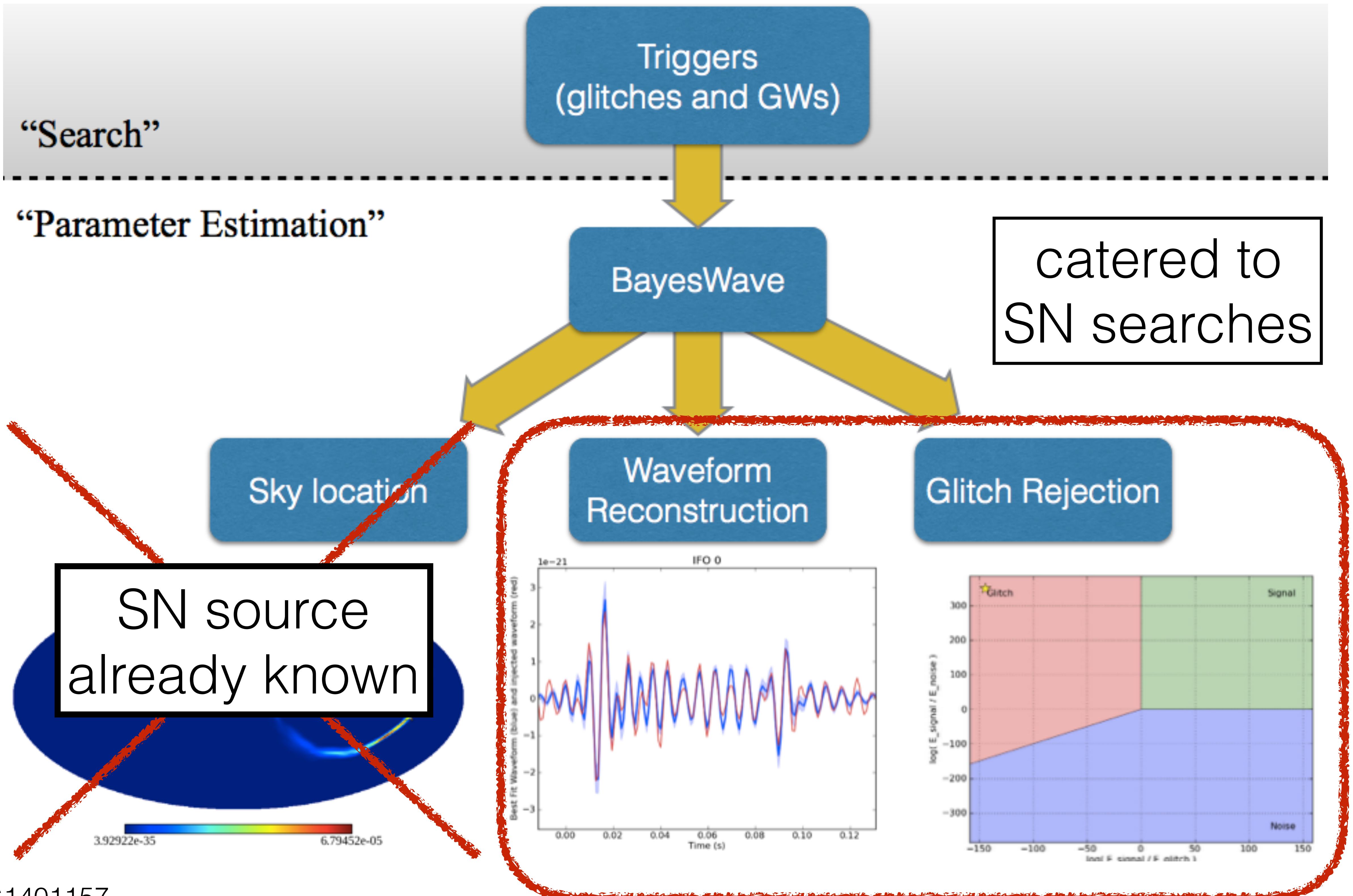
Procedure

1) cWB outputs a *'ranking statistic'* that is used to *separate the background noise from the injected triggers*
2) All surviving triggers that are above the nominal value of the ranking statistic are then *post-processed through BW*
3) BW initially produces results using a scatterplot that differentiates between *glitches, noise, and signals* present in the data
4) This secondary classification is applied to the cWB ROC curve in hopes of *improving the false alarm rate - and essentially the detection efficiency of each waveform family*

The Need for BayesWave



BayesWave Breakdown



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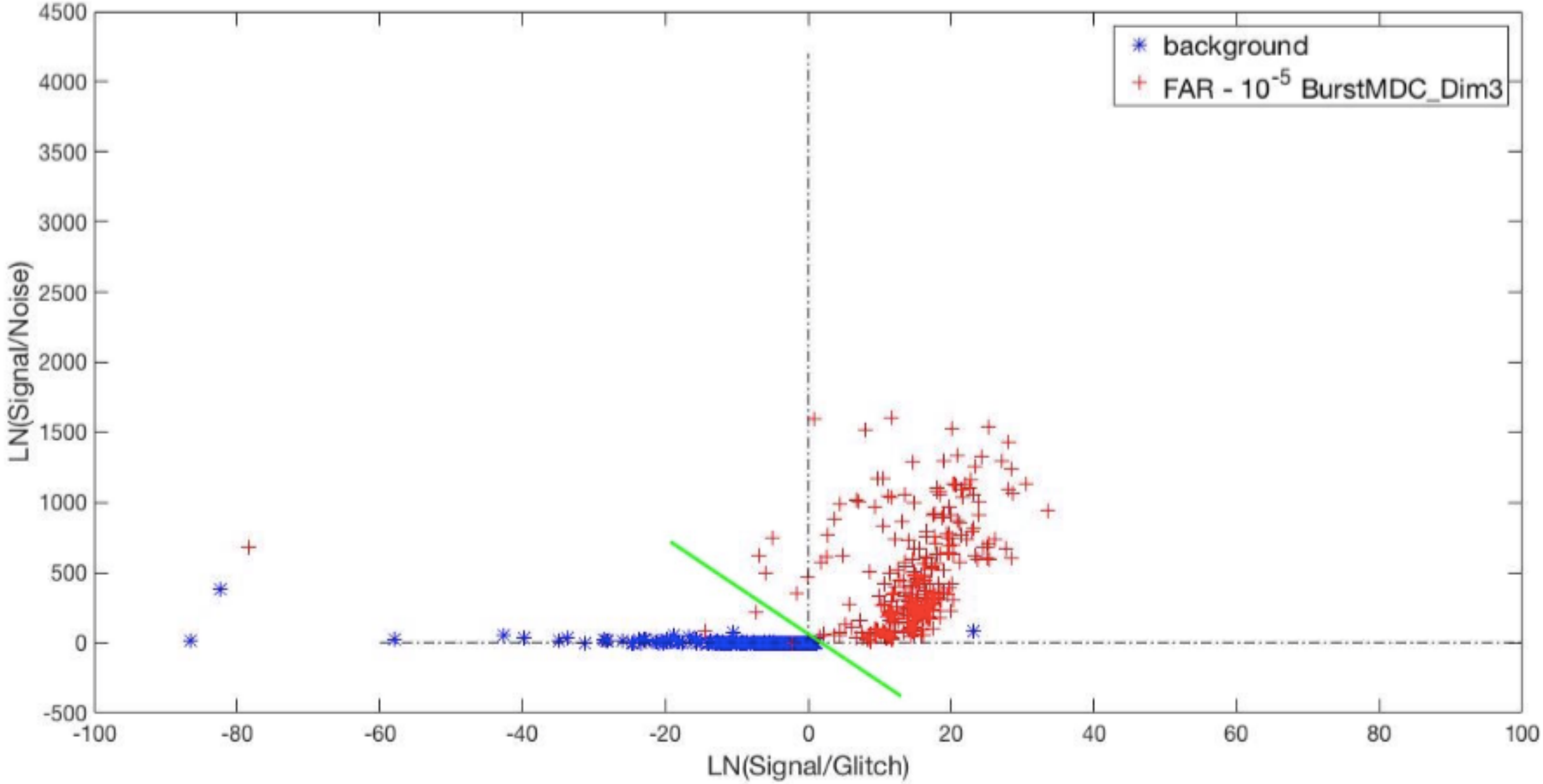
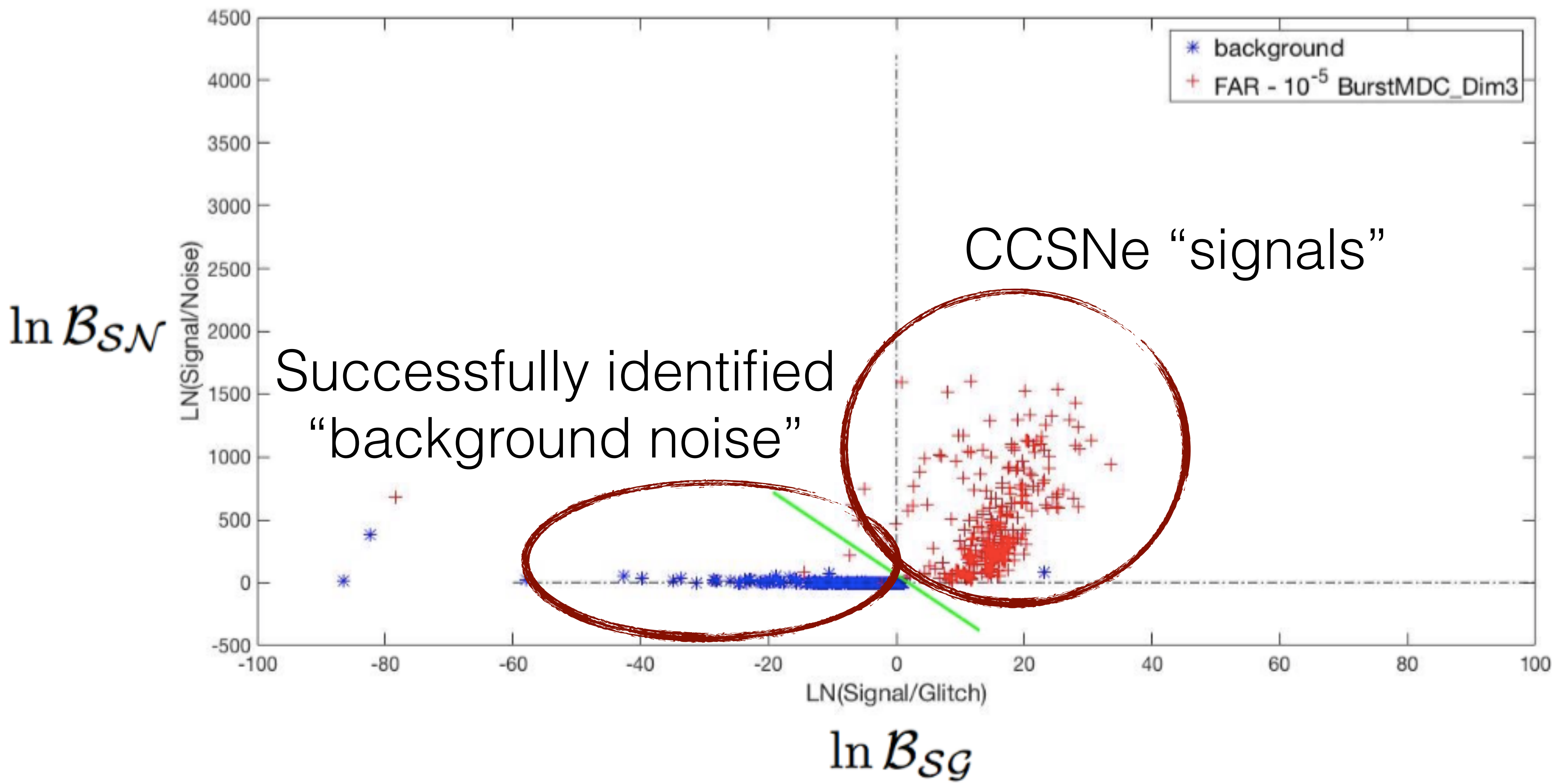
Seeing through the eyes of BW



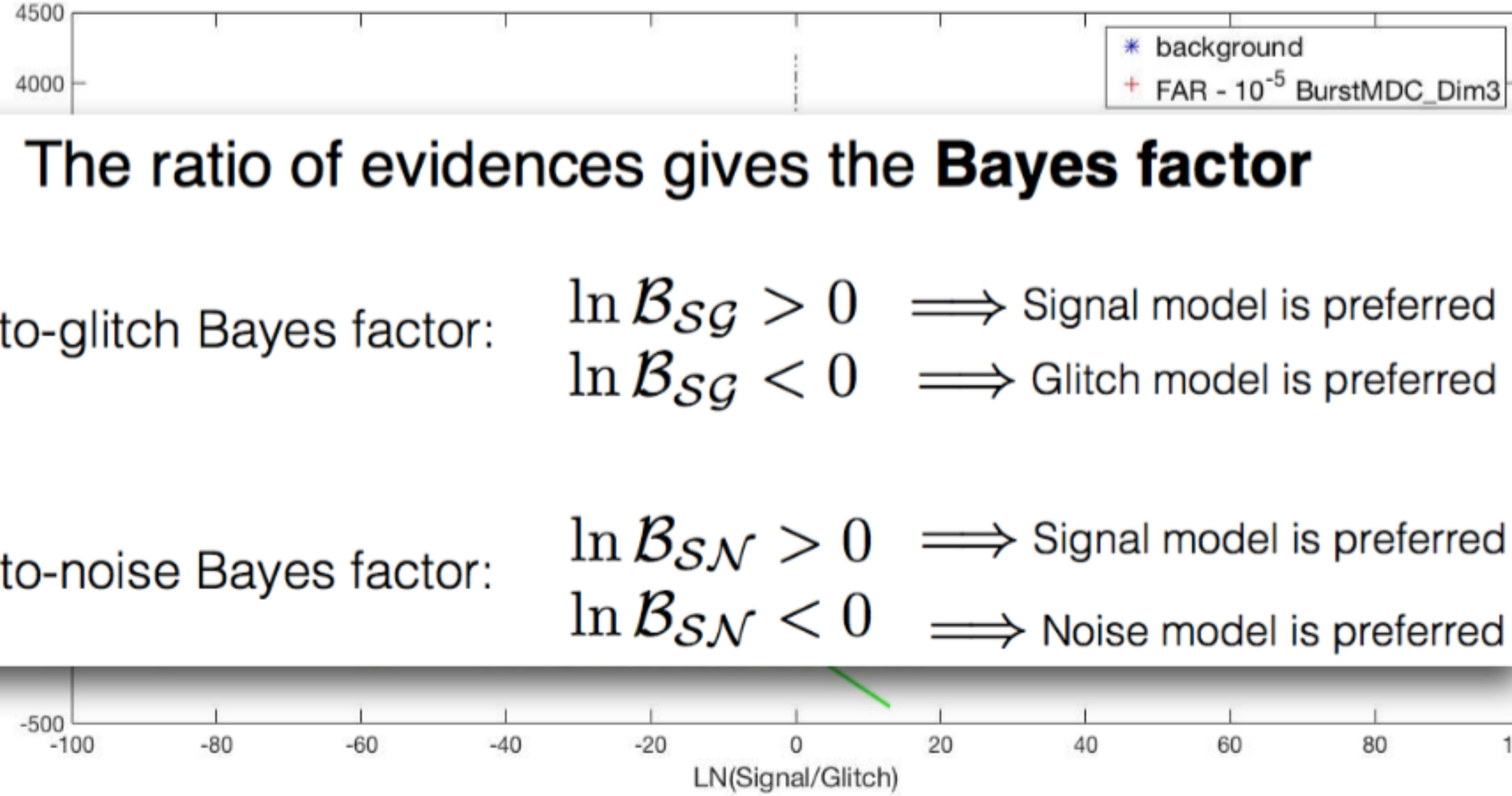
$\ln \mathcal{B}_{\mathcal{SN}}$

$\ln \mathcal{B}_{\mathcal{SG}}$

Seeing through the eyes of BW



Seeing through the eyes of BW



The ratio of evidences gives the Bayes factor

Signal-to-glitch Bayes factor:

$\ln \mathcal{B}_{\mathcal{SG}} > 0 \implies$ Signal model is preferred

$\ln \mathcal{B}_{\mathcal{SG}} < 0 \implies$ Glitch model is preferred

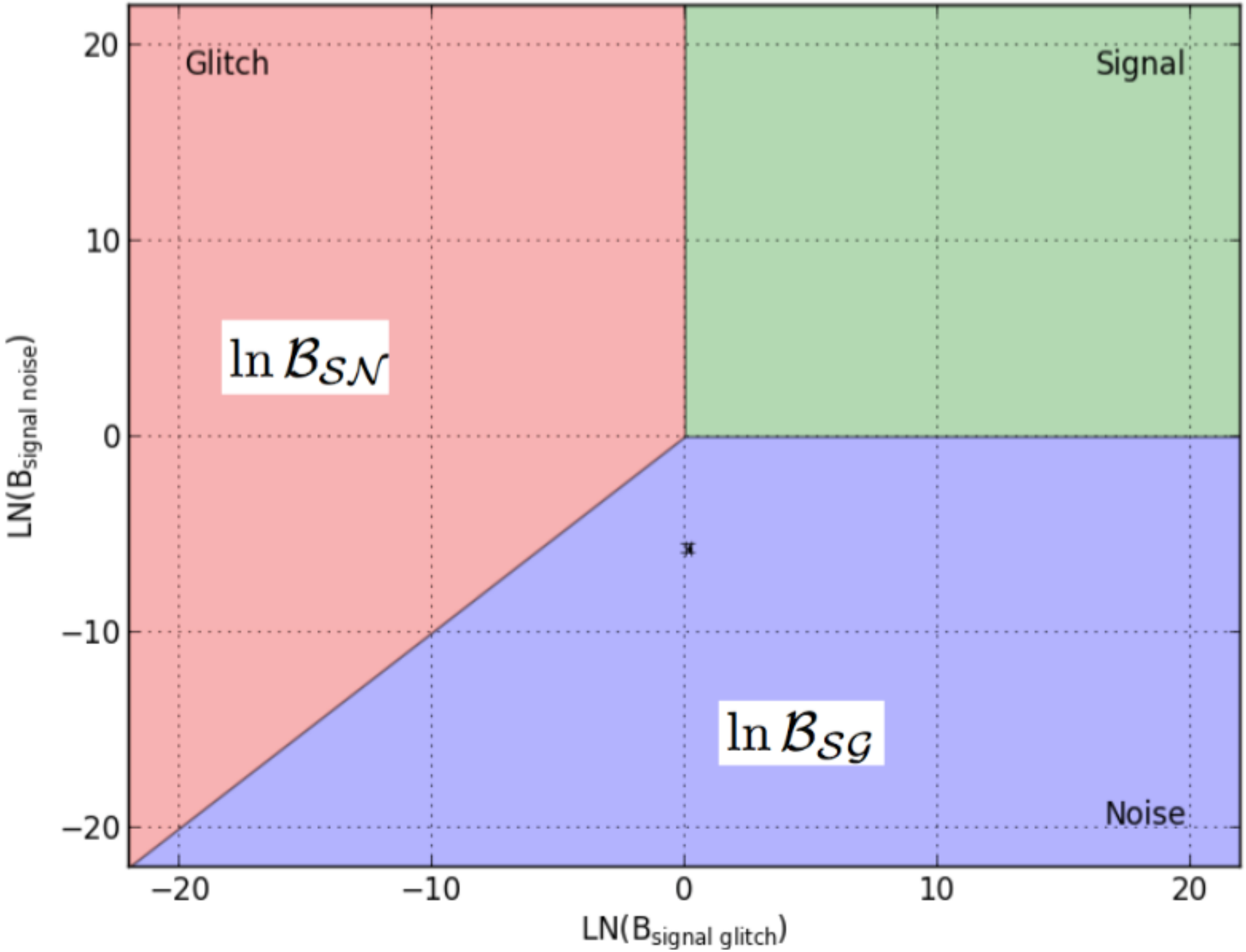
Signal-to-noise Bayes factor:

$\ln \mathcal{B}_{\mathcal{SN}} > 0 \implies$ Signal model is preferred

$\ln \mathcal{B}_{\mathcal{SN}} < 0 \implies$ Noise model is preferred

$\ln \mathcal{B}_{\mathcal{SG}}$

Seeing through the eyes of BW



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

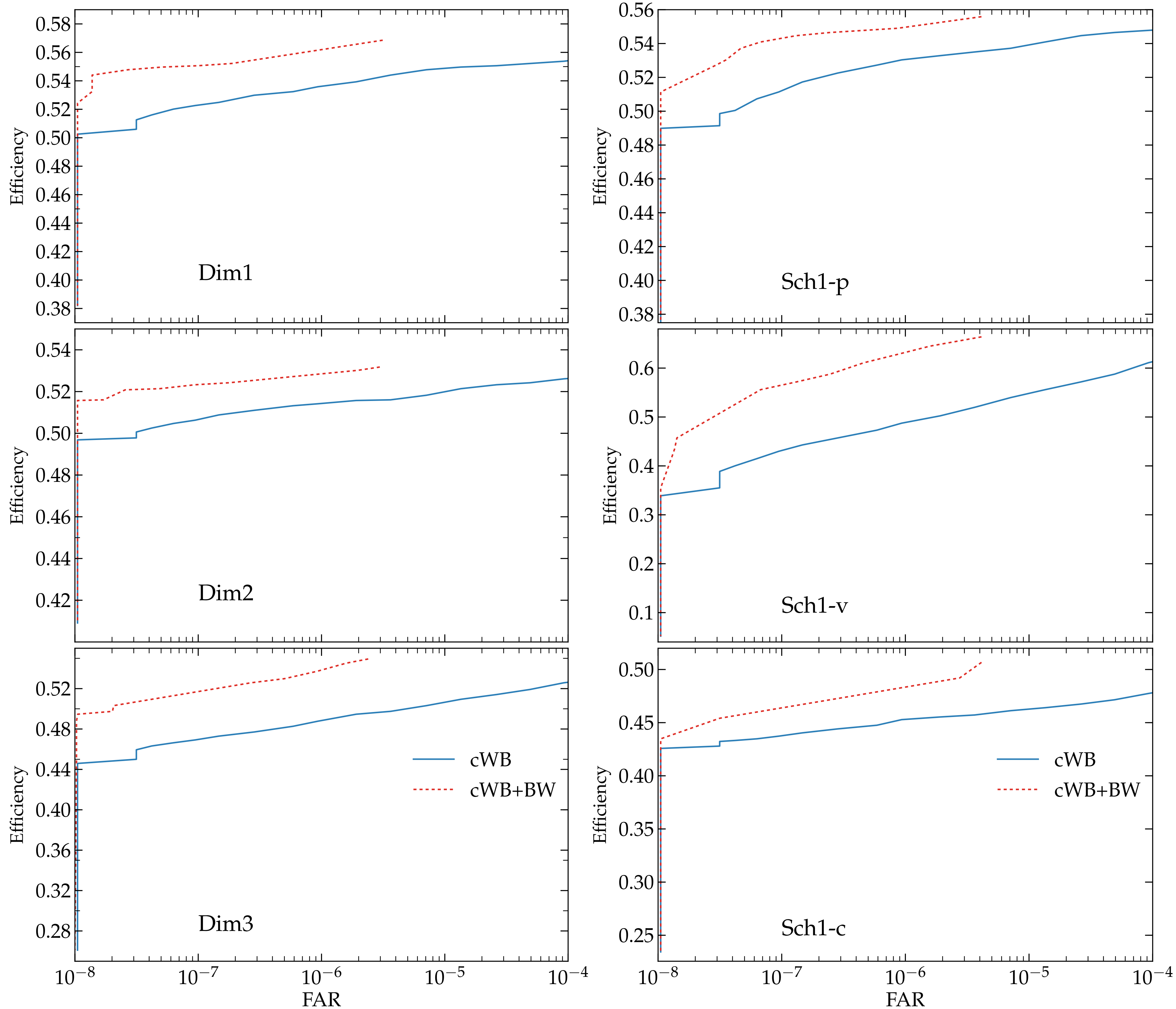
yak1: B12WH07

yak2: B15WH07

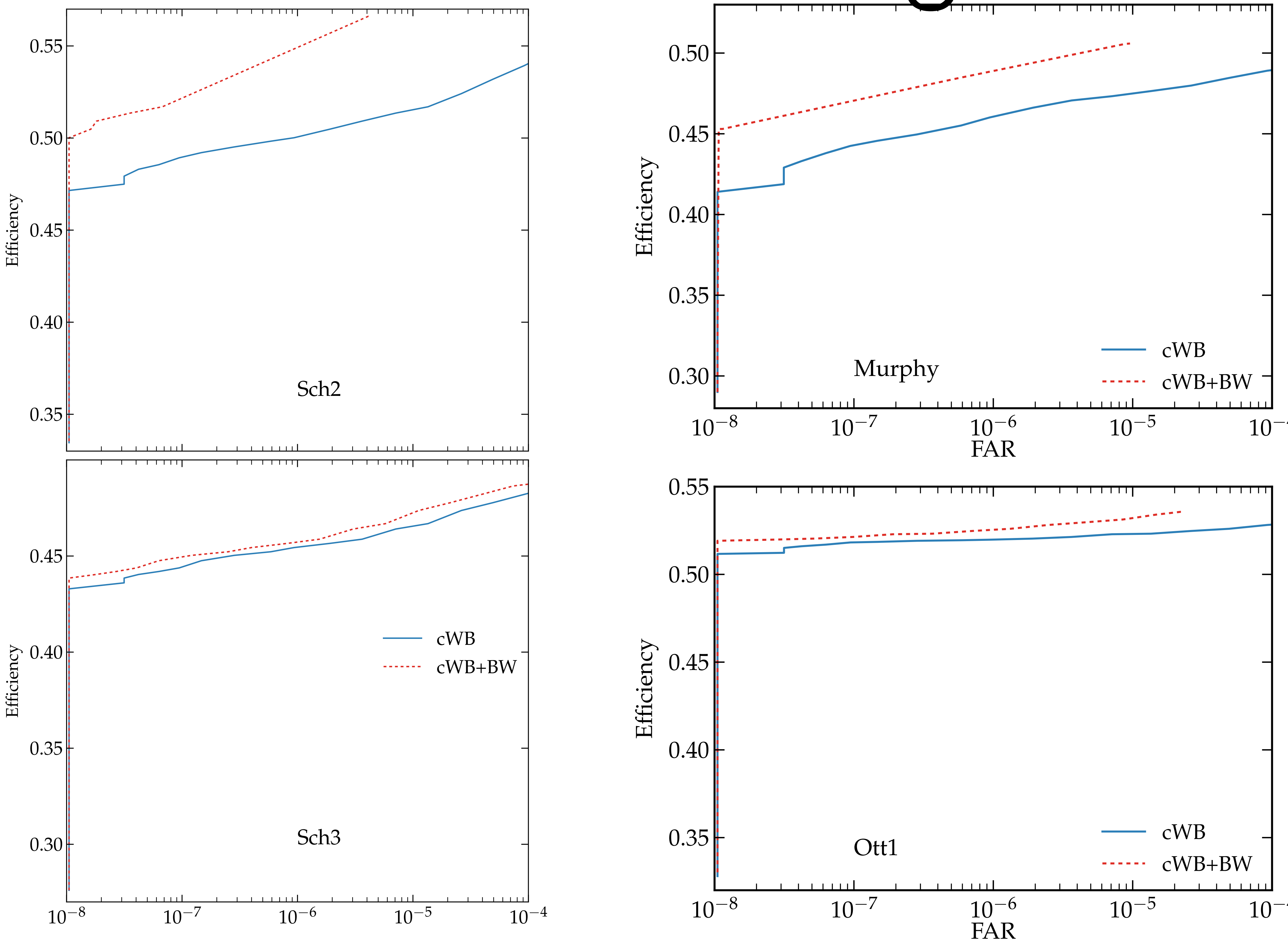
yak3: B20WH07

yak4: B25WH07

BW Post-Processing Results



BW Post-Processing Results



cWB+BW ROC Improvement

Waveform	FAR	cWB+BW
sch1-wf12	10^{-6}	**13.184% increase**
sch2	10^{-6}	**10.243% increase**
sch3	10^{-6}	**1.1643% increase**
dim1	10^{-6}	**4.522% increase**
dim2	10^{-6}	**3.062% increase**
dim3	10^{-6}	**10.434% increase**
murphy	10^{-6}	**12.412% increase**
ott1	10^{-6}	**1.193% increase**

First paper is on the way!

Enhancing the Sensitivity of Searches for Gravitational Waves from Core-Collapse Supernovae with a Bayesian classification of candidate events

K. Gill,[1] W. Wang,[2] O. Valdez,[2] M. Szczepańczyk,[1] M. Zanolin,[1] and S. Mukherjee[2]

[1] *Embry Riddle University, 3700 Willow Creek Road, Prescott Arizona, 86301, USA*

[2] *The University of Texas Rio Grande Valley, One West University Boulevard, Brownsville, 78520, USA*

Extracting astrophysical information from core-collapse supernovae (CCSNe) using gravitational-wave (GW) detections is a possibility brought forth by the technical advancement of the current pipelines used by the LIGO-Virgo Collaboration. This requires an accurate reconstruction and estimation of parameters of the signal waveform of interest from the GW detector output. In this paper, we demonstrate how a morphological veto involving Bayesian statistics (BayesWave) can improve the receiver operating curves of the current search for CCSNe as implemented by the Coherent Waveburst (cWB) algorithm. Examples involving two implementations of BayesWave, one that makes no assumption of the polarization state of the gravitational wave and one that uses the same elliptical polarization settings adopted in previous usages for Binary systems are provided on the set of waveforms currently adopted for the O1-O2 targeted CCSNe search. A comparison of the performance for all-sky searches versus the targeted searches with optical triggers is provided.

O1/O2 Search Pool of Waveforms

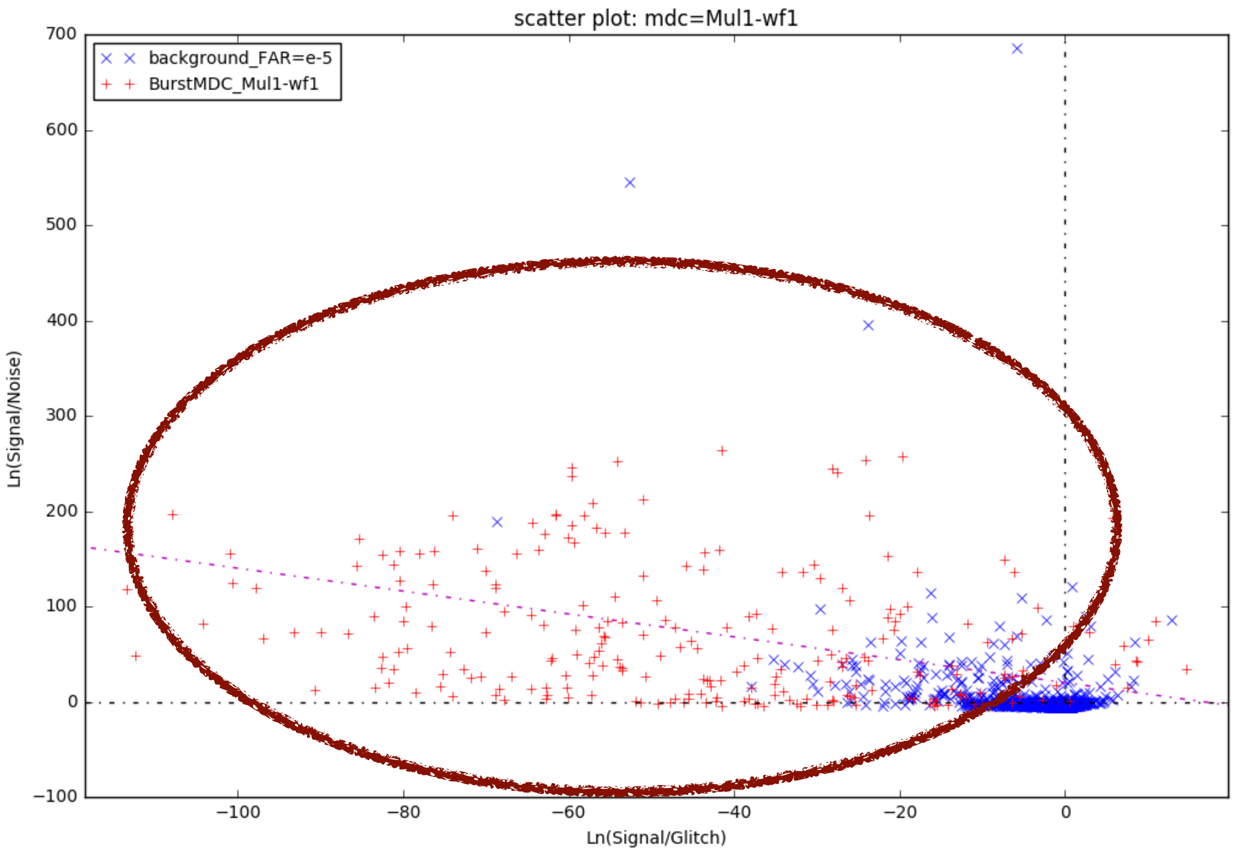
Linear polarization v Non-linear polarization

Emission Type	Waveform Identifier	Polarization
Rotating Core Collapse	Dim1-s15A2O05ls	+
Rotating Core Collapse	Dim2-s15A2O09ls	+
Rotating Core Collapse	Dim3-s15A2O15ls	+
2D Convection	Yakunin-s15	+
3D Convection	Müller1-L15-3	+, x
3D Convection	Müller1-N20-2	+, x
3D Convection	Müller1-W15-4	+, x
3D Neutrino-Driven Convection and SASI	Ott-s15	+, x
3D Rotating Core Collapse	sch1-wf1p2	+
3D Rotating Core Collapse	sch1-wf12	+, x
3D Rotating Core Collapse	sch1-wf1c2	x
3D Rotating Core Collapse	sch2	+, x
3D Rotating Core Collapse	sch3	+, x
Neutrino mechanism	Murphy	+

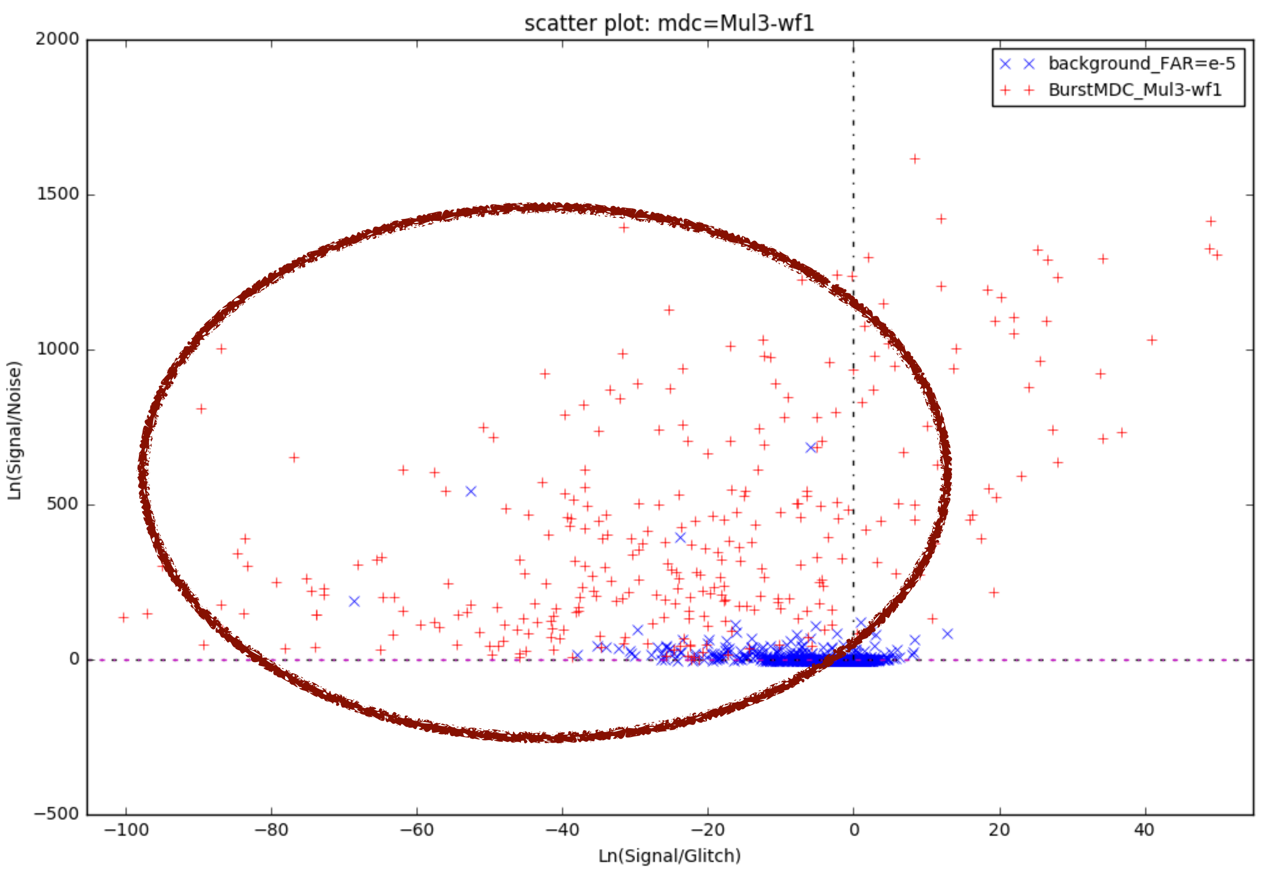
Mishandled CCSNe Waveforms

Example: Mul1 & Mul3 (linear polarized BW code)

[W. Wang runs]

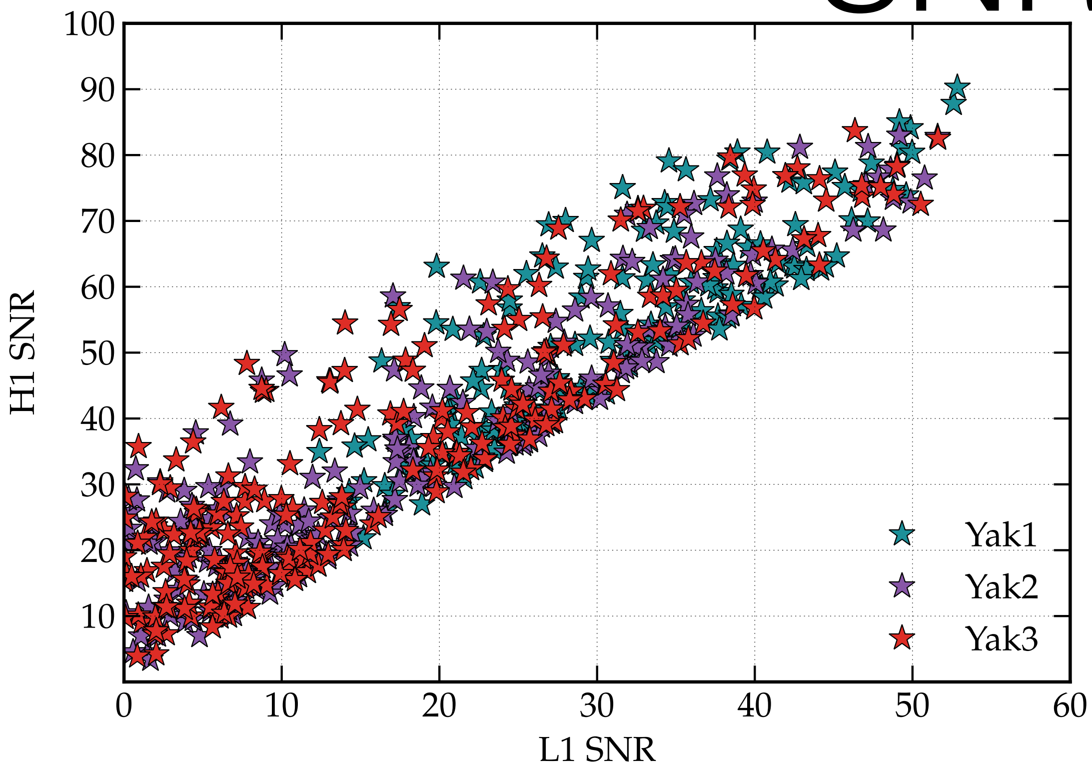


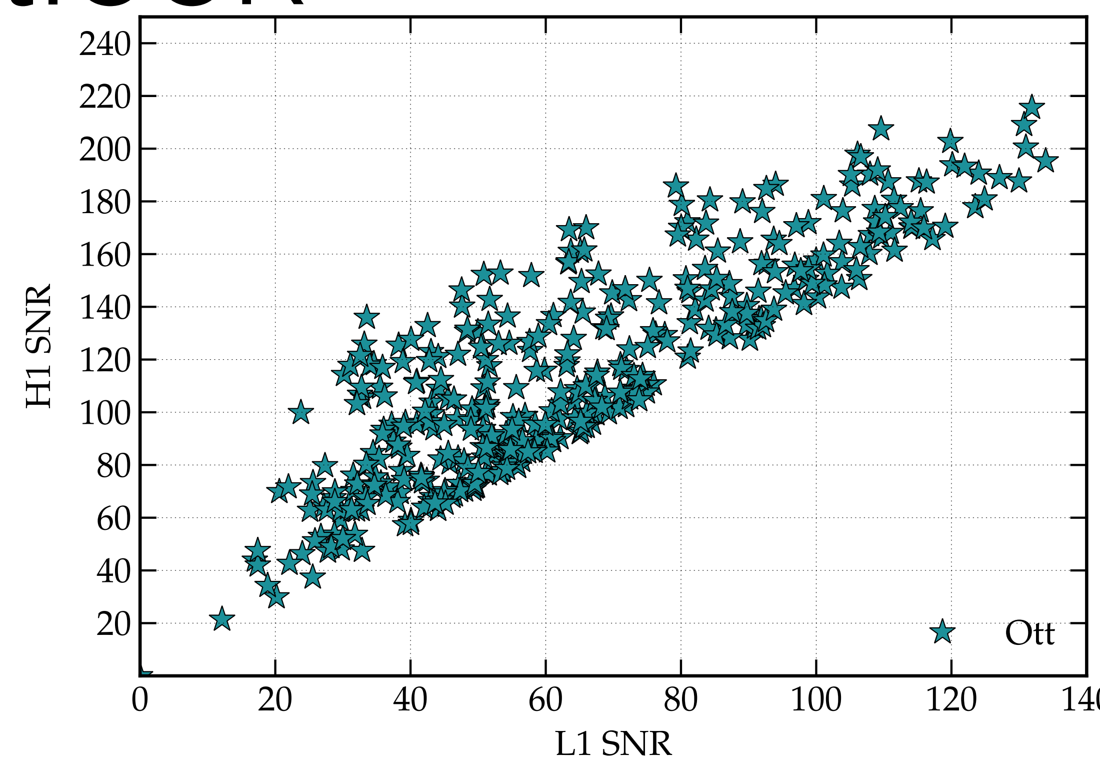
The waveforms are initially produced at 10 kpc (rescaled distances with scale factors)

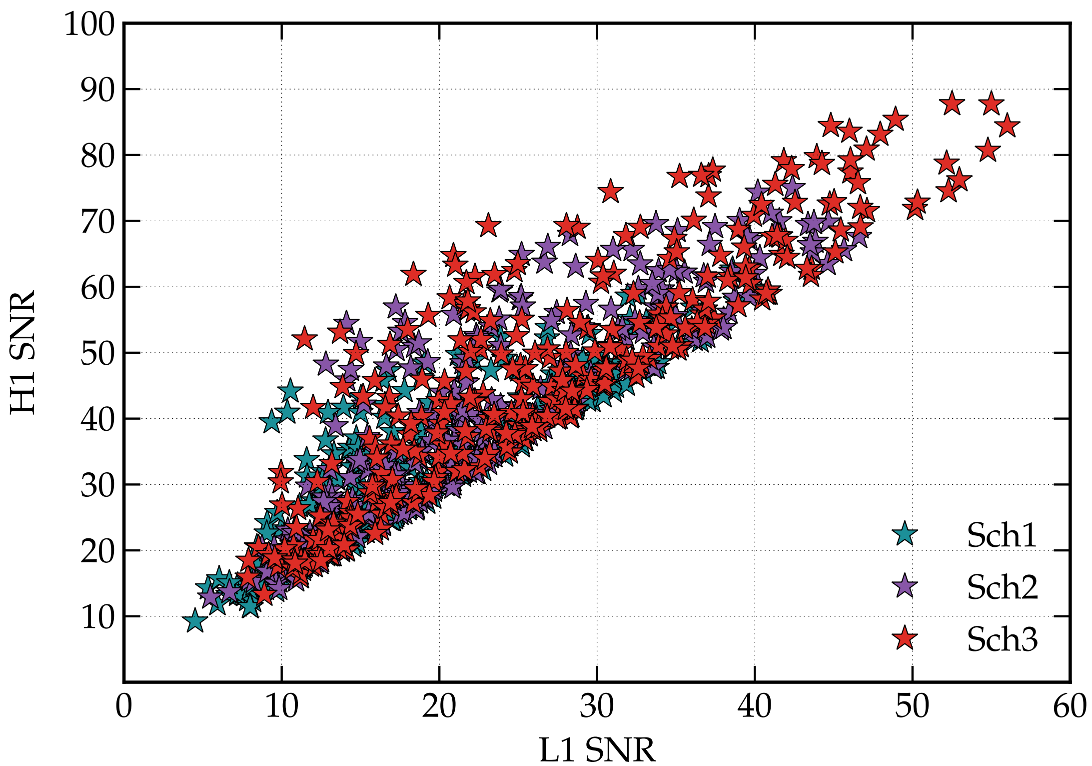


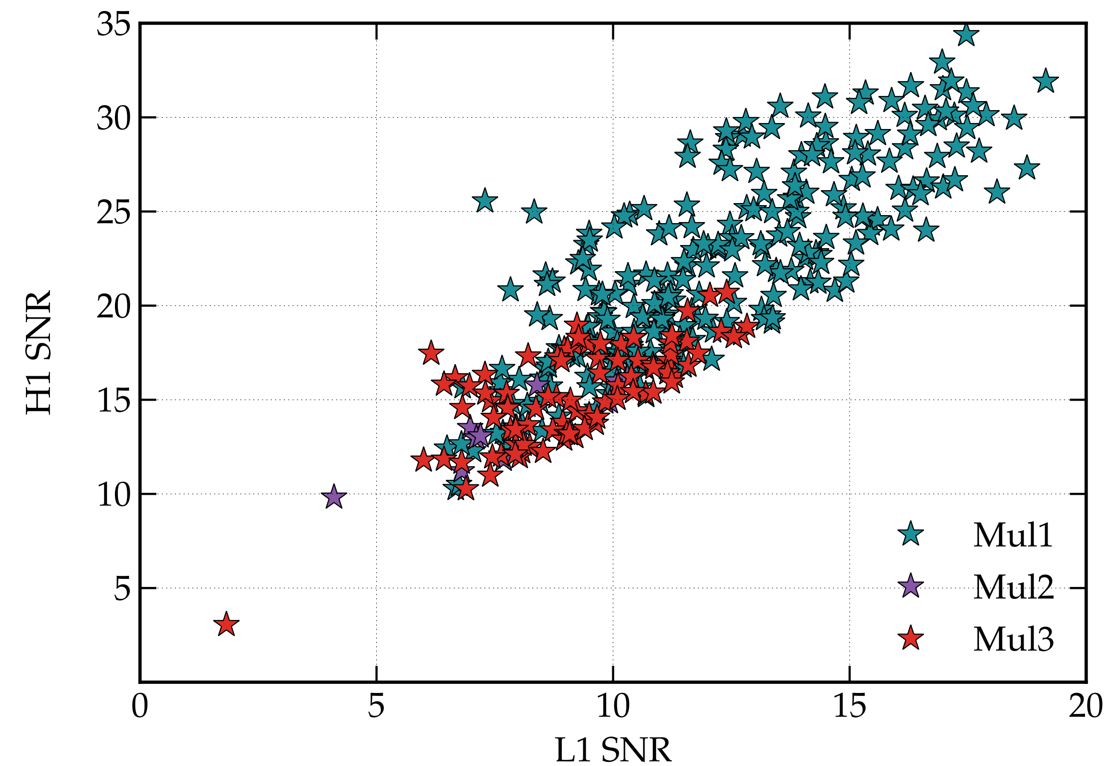
injections are identified as glitches instead of signals

Framing the Problem with an SNR Outlook

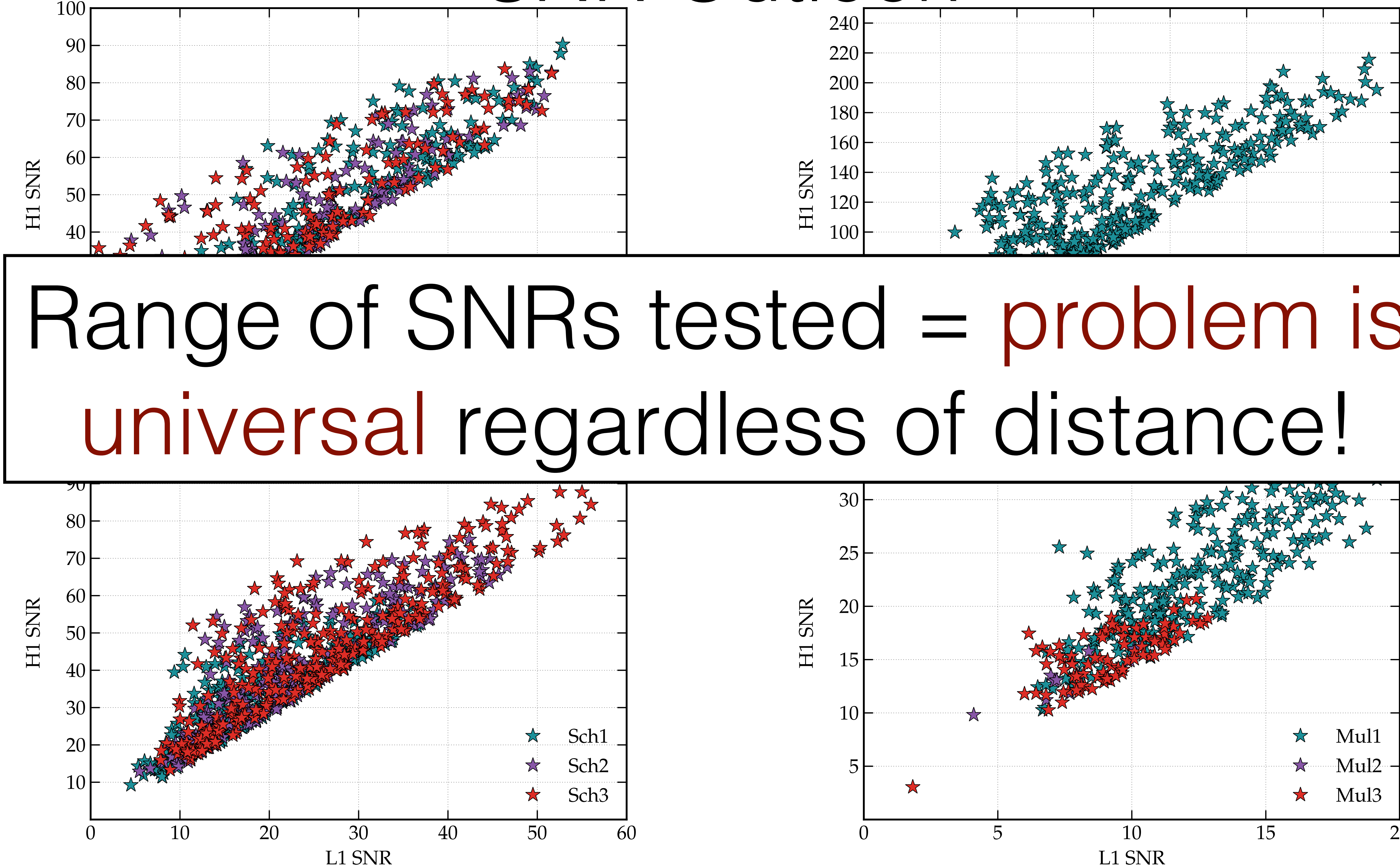






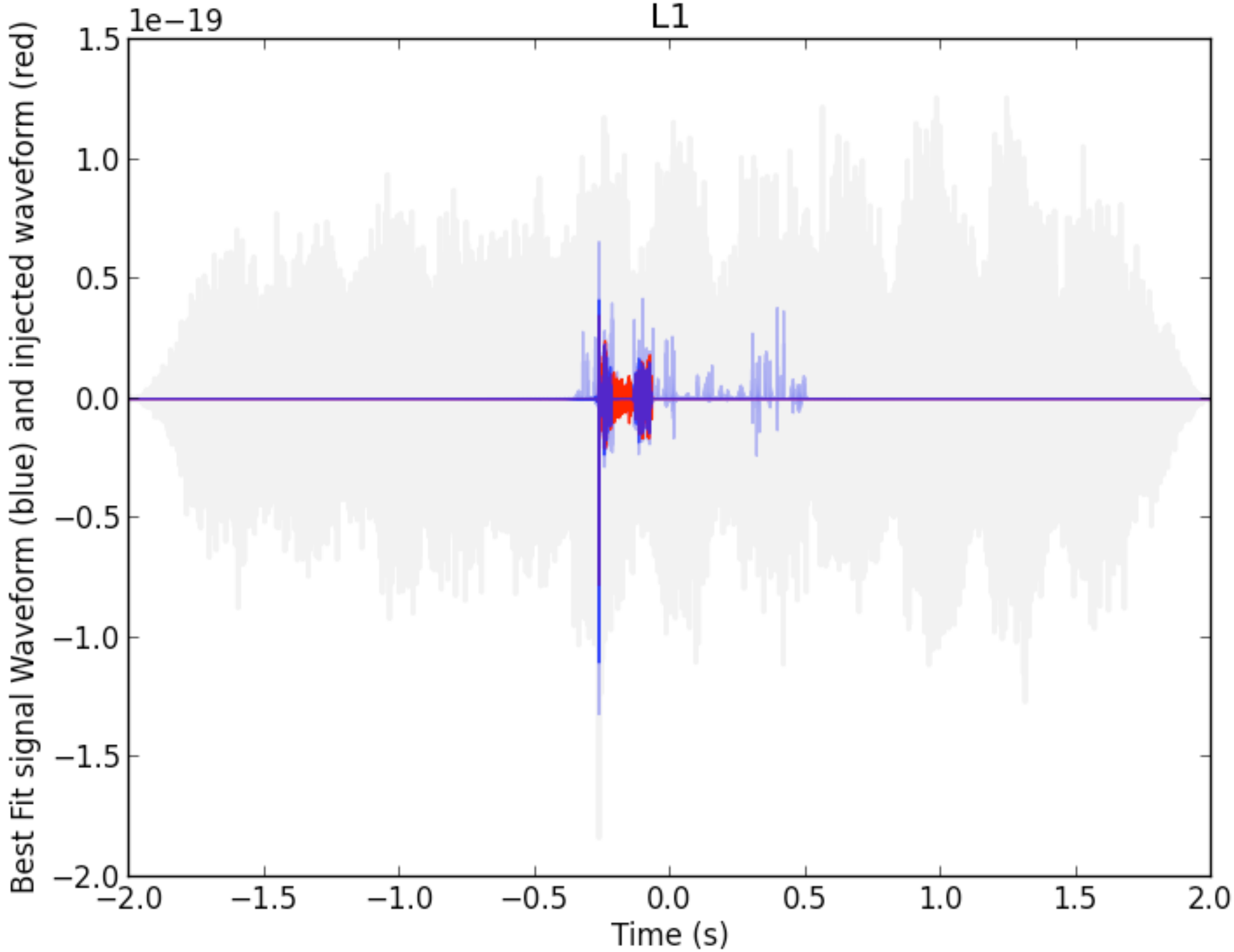


Framing the Problem with an SNR Outlook

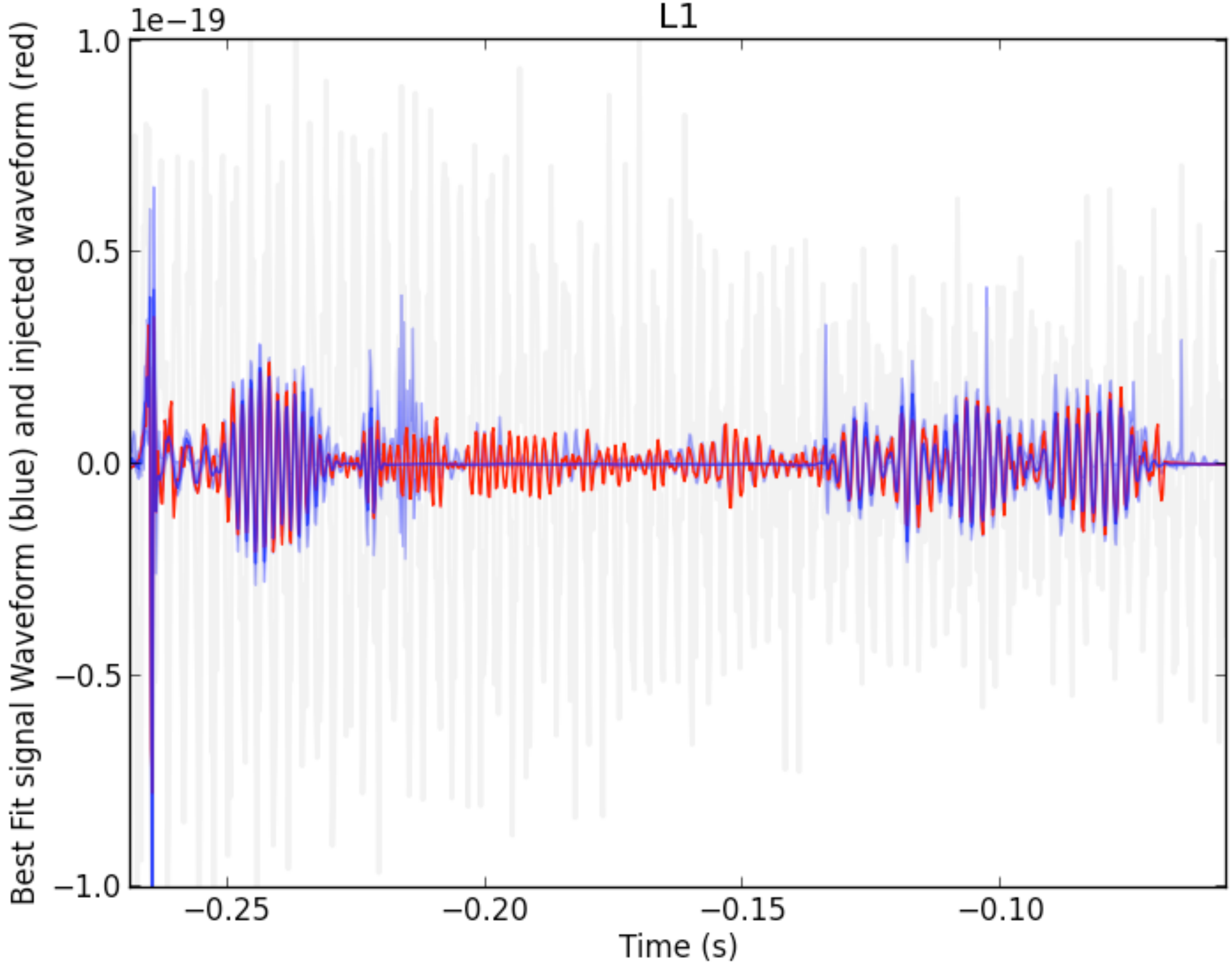


Range of SNRs tested = problem is universal regardless of distance!

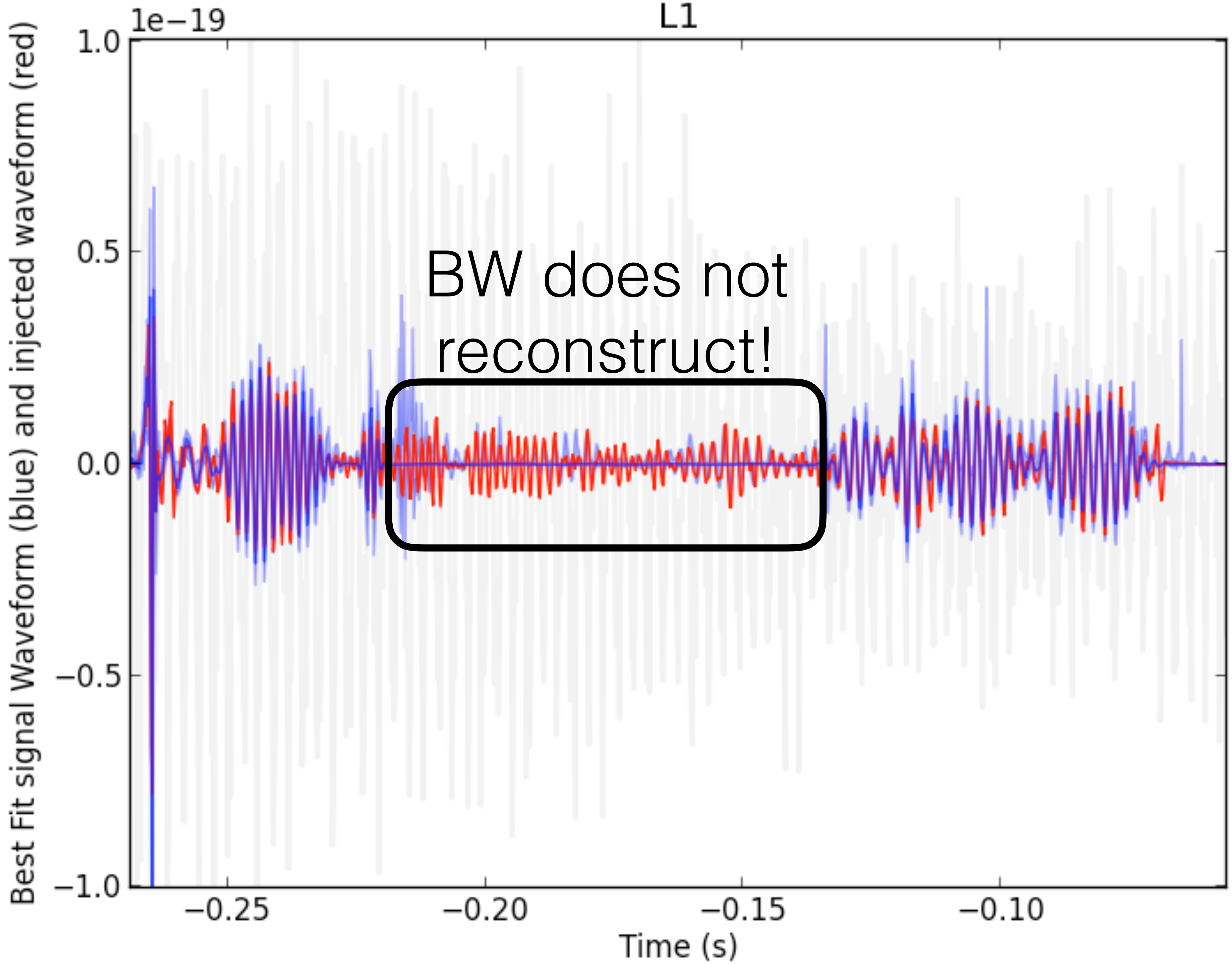
Sch2 BW Waveform Reconstruction



Let's take a closer look…



Let's take a closer look…

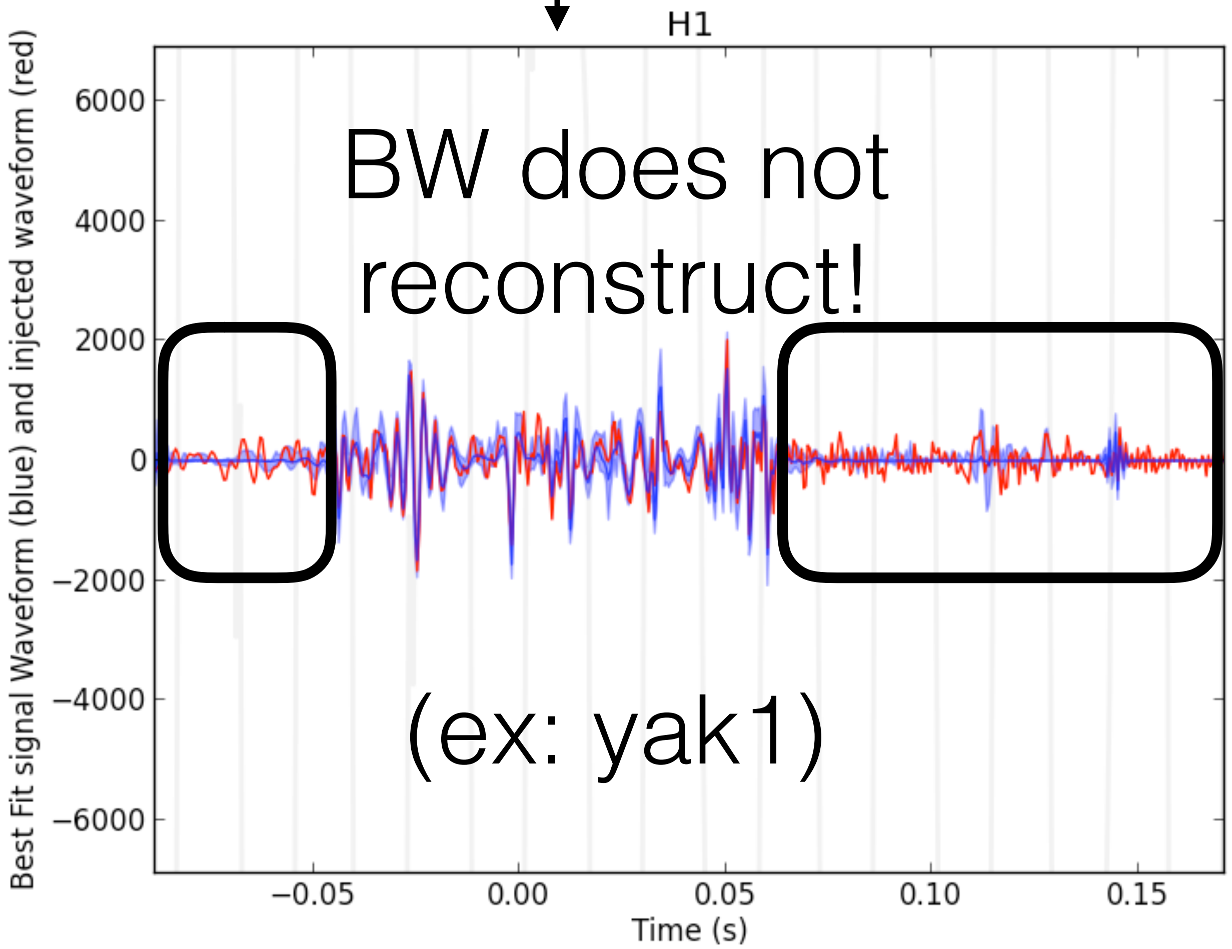


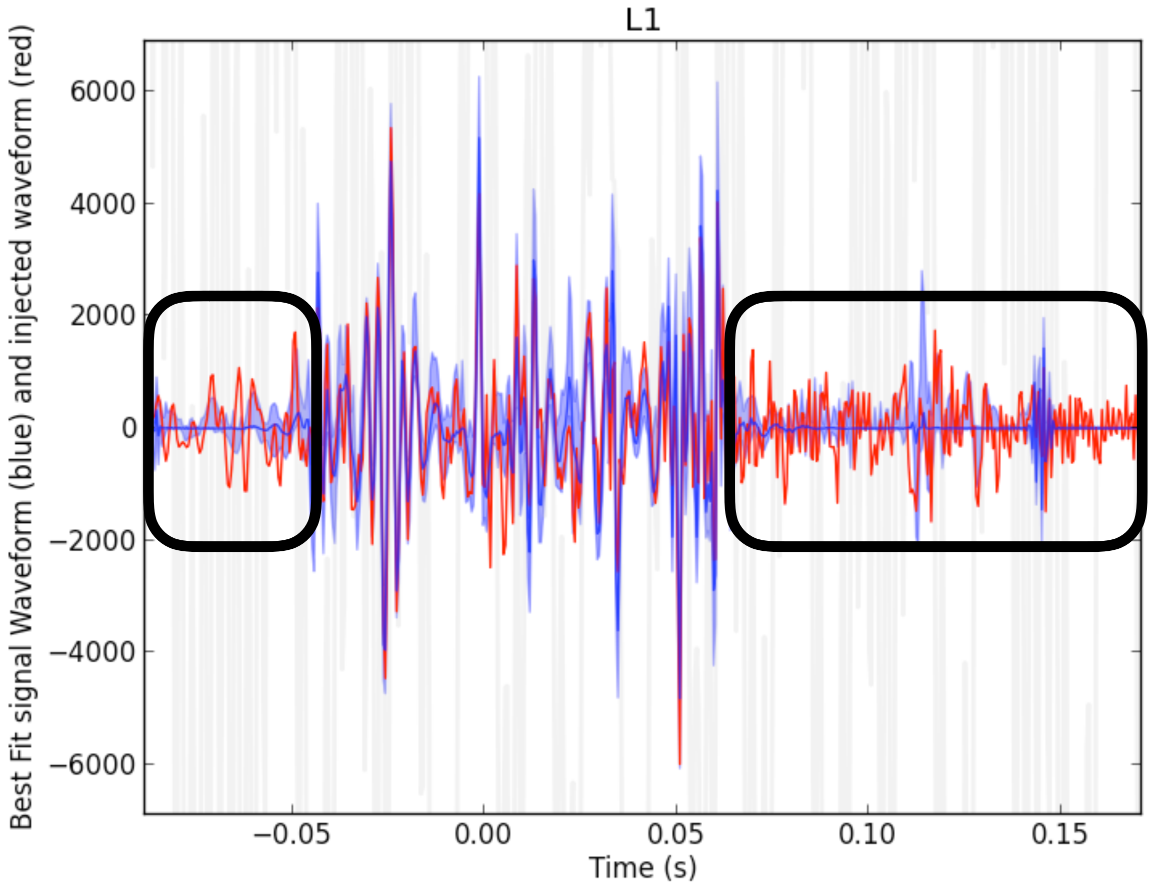
Re-evaluate Waveform Reconstruction Efforts

Example studies:

Sch2

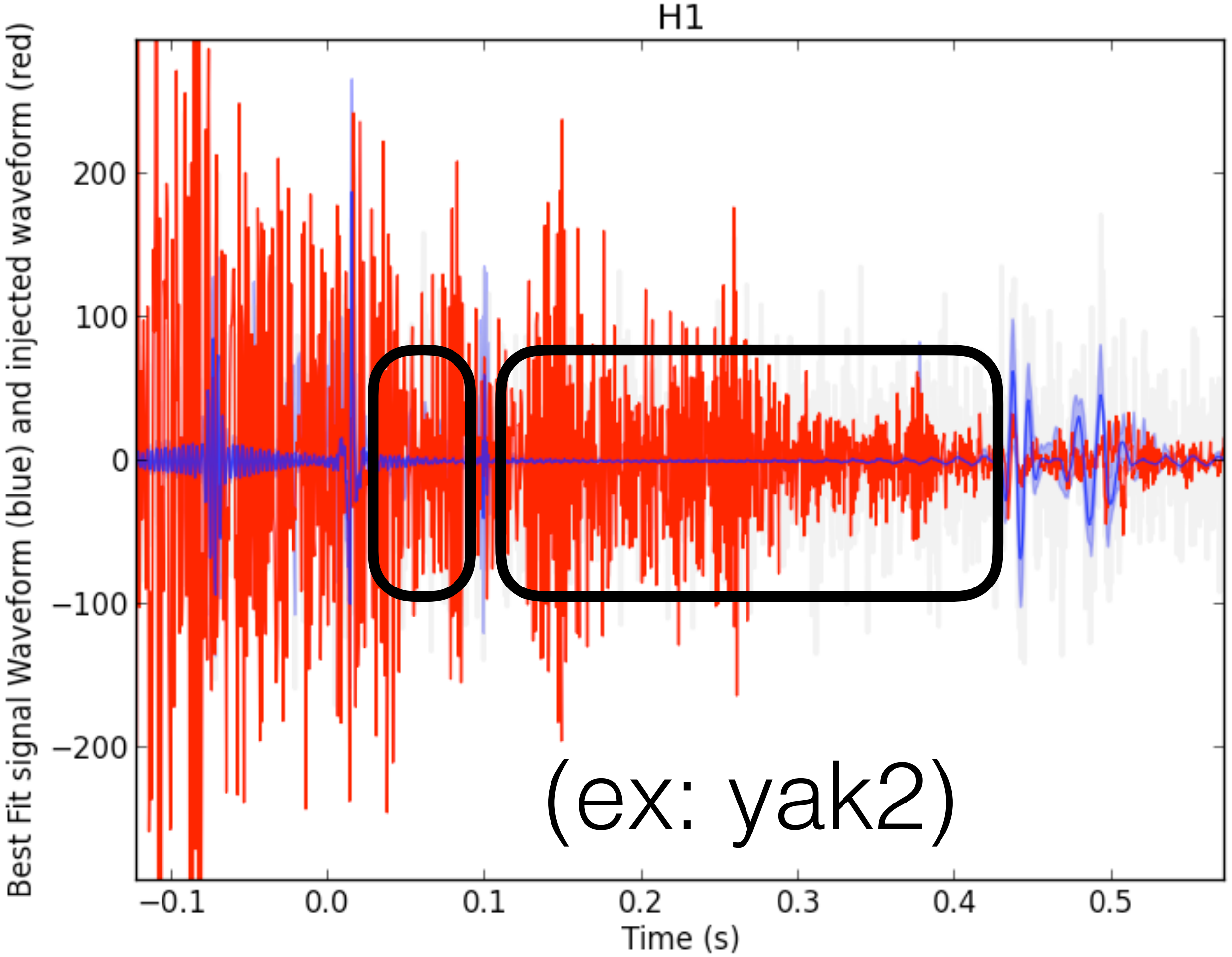
Yakunin+15

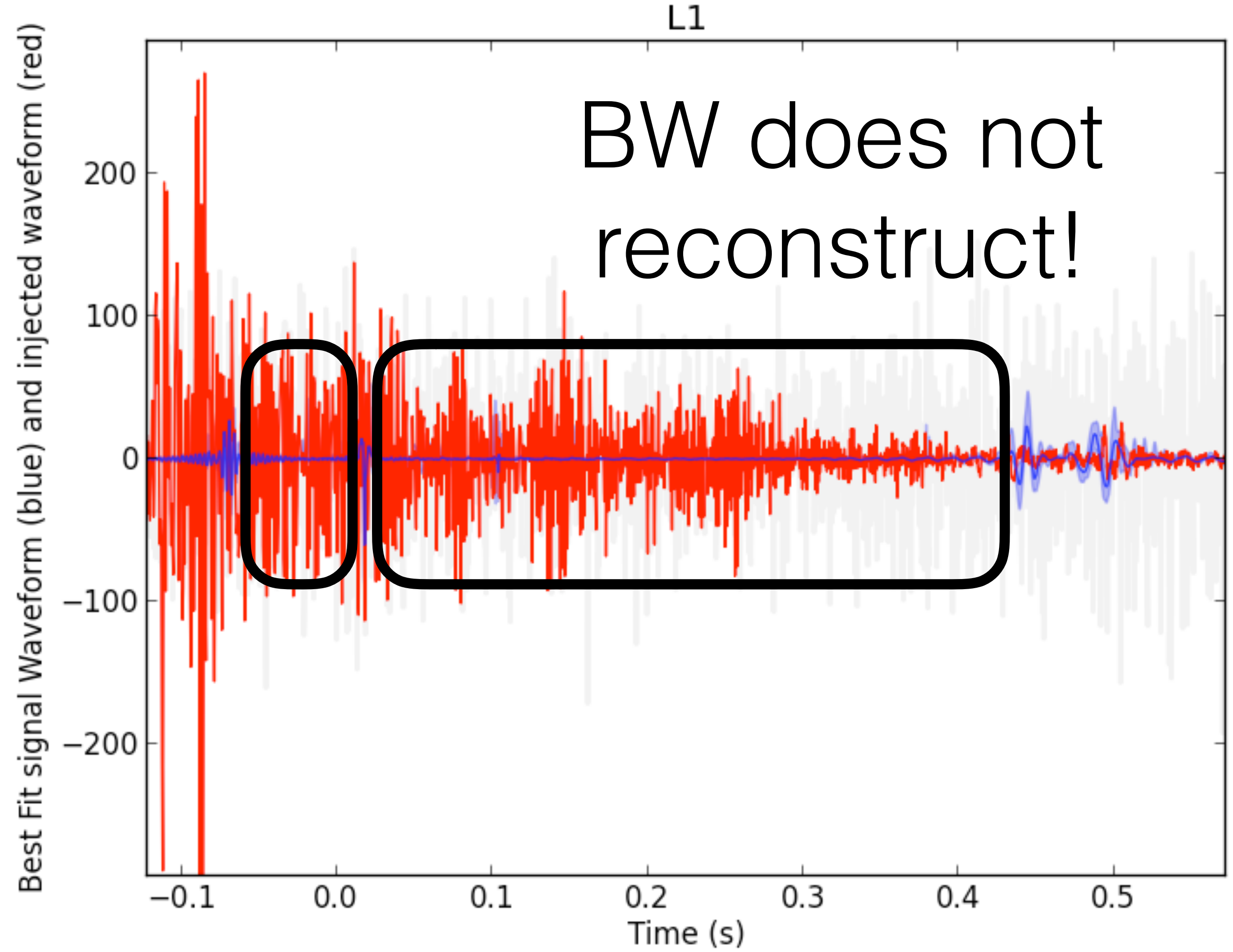




Re-evaluate Waveform Reconstruction Efforts

A more worrisome reconstruction example…





Key Introduction to Existing BW Code

Linear polarization v Non-linear polarization

- ★ Original BW code was catered toward IMBH searches
  - ✳ code assumed elliptical polarization
- ★ For the SN searches, we set ε = 0 for the linear polarized wf models (i.e., Dim)
  - ✳ nice approximation for the initial stages of the rapidly-rotating (RR) wf models
  - ✳ cannot make the same assumption for the later stages of the same RR models as we do not know the behavior of the waveform in its later stages (no simulation group has computed that far out yet that we know of) - via talks with Radice

Key Introduction to Existing BW Code

Linear polarization v Non-linear polarization

BW assumes that all signals are elliptically polarized

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

- where $\varepsilon \in [0, 1]$ is the ellipticity parameter
- 0 - linearly polarized signals
- 1 - circularly polarized signals

For linearly polarized waveforms, with either the + or × component, would be detectable within a LIGO-only network, and therefore made the elliptical constraint a fair approximation.

LIGO-P1600181

Key Introduction to Existing BW Code

Linear polarization v Non-linear polarization

it is not universally applicable in the case of SNe since the focus of our study is more on realistic and phenomenological waveforms, which are not all linearly polarized (such as Mueller 2012).

Introduction of non-linear polarization capabilities hardcoded into the BW pipeline

LIGO-P1600181

Current CCSNe-focused BW Testing

List of Priors to be modified:

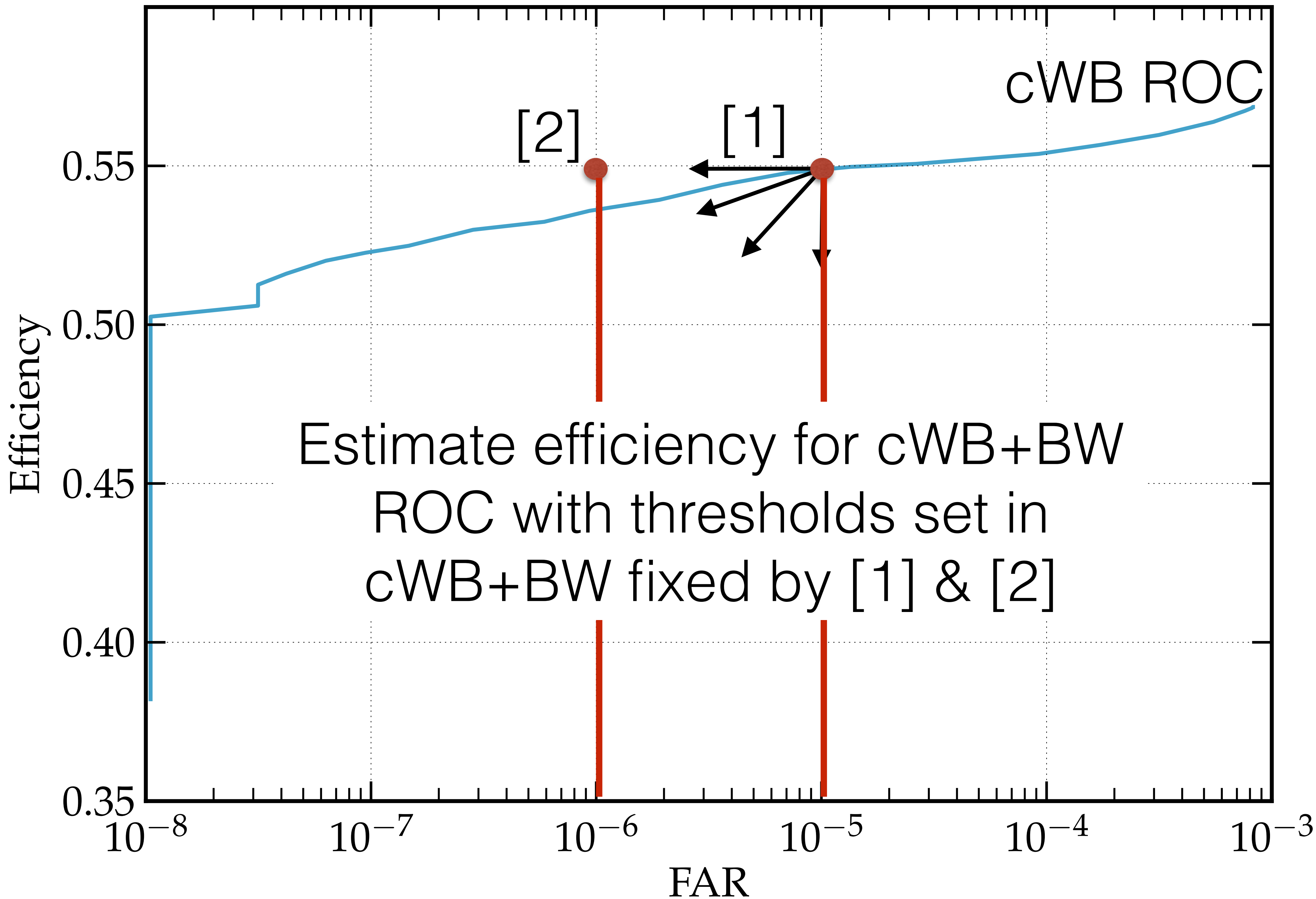
- Sky Location **(Done)**
- Glitch SNR **(currently being tested with Tyson)**
- Signal SNR **(Done)**
- Number of wavelets **(currently being tested)**
- Waveform Type **(Done)**
- Clustering **(currently being tested)**

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

Priors	IMBH	Rapidly Rotating CCSNe
Sky Location (θ, ϕ)	Uniformly Distributed (All-Sky)	Specific to direction of CCSN
Glitch SNR	$\mathrm{p(SNR)} = \frac{\mathrm{SNR}}{\mathrm{SNR}_*^2} e^{-\mathrm{SNR}/\mathrm{SNR}_*^2}$	$\mathrm{p(SNR)} = \frac{\mathrm{SNR}}{\mathrm{a}} e^{-\mathrm{SNR}/\mathrm{b}}$
Wavelets	Ns [1, 100]; Ng [1, 100]*Nd	Adjust to number of wavelets needed to reconstruct CCSN waveform
Waveform Type	[10, 500] $M_\odot$ 0.4 s	s15a3o15 55 ms

Extra Slides

cWB+BW ROC Improvement



Estimate efficiency for cWB+BW ROC with thresholds set in cWB+BW fixed by [1] & [2]

Bayesian model selection

* 3-part model: GW signal, Gaussian noise, non-Gaussian 'glitches'

Wavelet decomposition

* glitch and GW model parameters = wavelet amplitudes
* number/amplitude/location of active wavelet 'pixels' (model dimension) vary