Supernova burst signal reconstruction based on waveform catalogues

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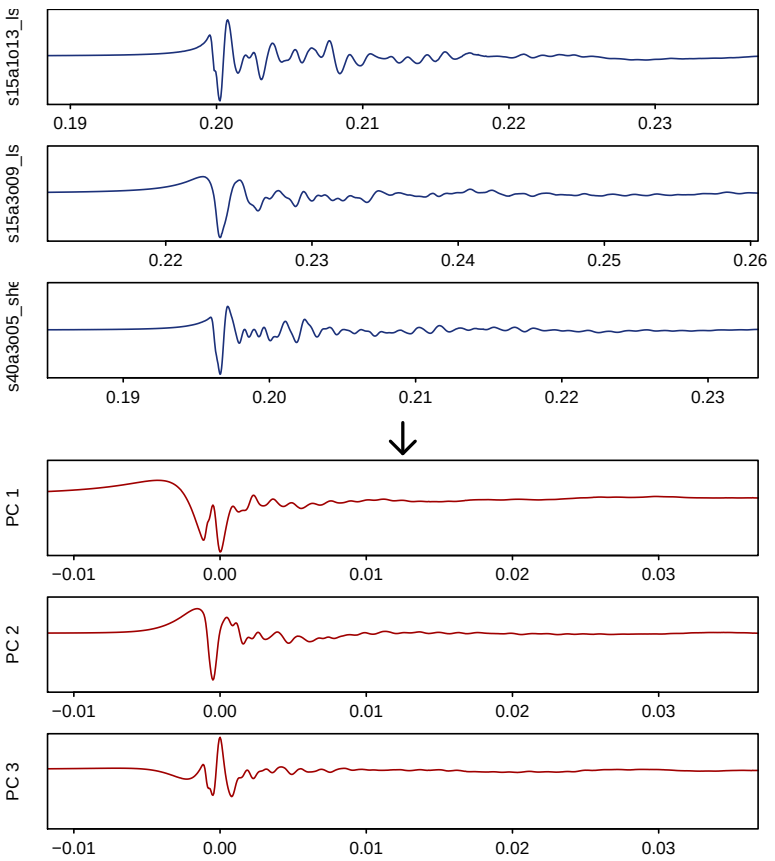
Waveform catalogues, PCA

- numerical supernova simulations yield GW waveforms
- used here: 130 stellar core collapse supernova waveforms by Dimmelmeier at al.; Parameters: EoS, mass, angular momentum, rotation rate,...
- derive templates from waveform catalogues
- similarity in catalogue's waveforms
  $\longrightarrow$ simplify, reduce dimensionality
- Principal component analysis (PCA):
  - $\star$ 10 basis vectors $\longrightarrow$ 85% minimal match
  - $\star$ 20 basis vectors $\longrightarrow$ 95% minimal match
- PCs as basis vectors: model burst as linear combination of few PCs



Linear model

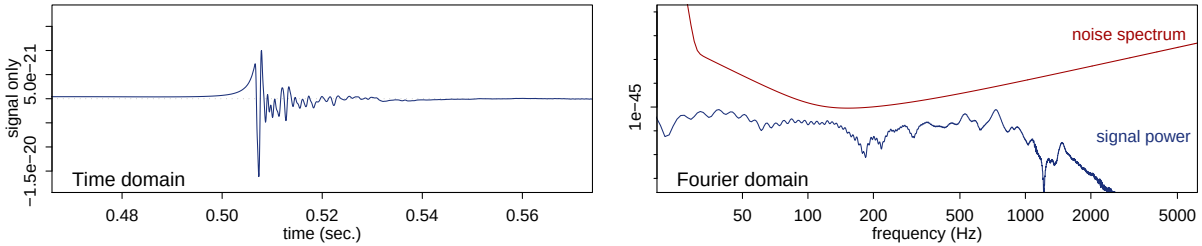
$$\mathbf{y} = \mathbf{X}_{(T)}\boldsymbol{\beta} + \mathbf{m} + \boldsymbol{\varepsilon}$$

- use z basis vectors (e.g., $z = 10$, $z = 20$).
- T shifts PCs in **time**; $\mathbf{X}_{(T)}$ is $(N \times z)$ matrix of *time-shifted* **PCs**
- $\boldsymbol{\beta}$ is (z-dim.) vector of **PC coefficients**
- **mismatch** $\mathbf{m}$ parameterised in terms of a "σ^2"-parameter,
  (**prior** ensures rough **mismatch percentage**)
- **noise** $\boldsymbol{\varepsilon}$ assumed Gaussian with known spectrum

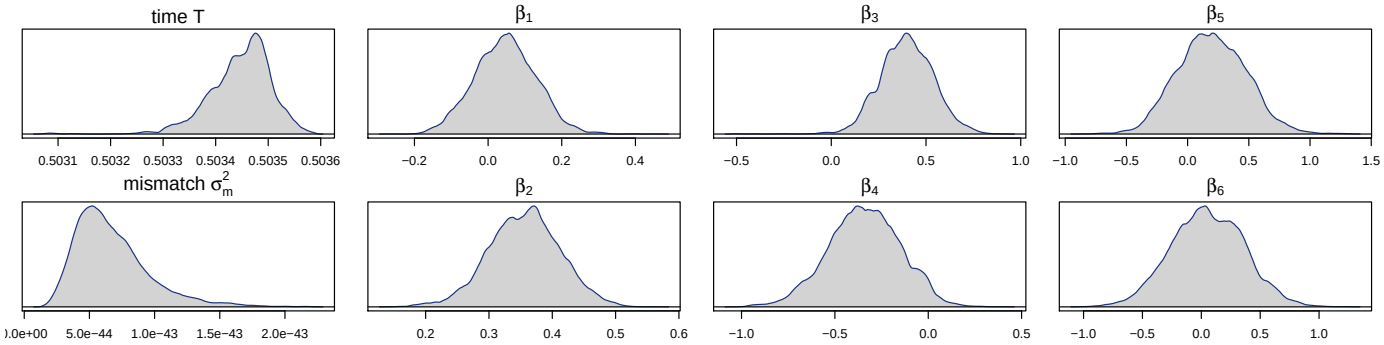
- *almost* analytically solvable: neglect σ_m^2, fix T, then $p(\beta|T, \mathbf{y})$ Gaussian
- use MCMC, iterate over $\beta|T, \sigma_m^2$, $T|\beta, \sigma_m^2$ and $\sigma_m^2|\beta, T$ (Gibbs sampling).

Example

- newly generated "off-catalogue" signal + initial LIGO noise, SNR 10
  1 second data, $z = 10$ basis vectors, expect match of $\approx 90\%$

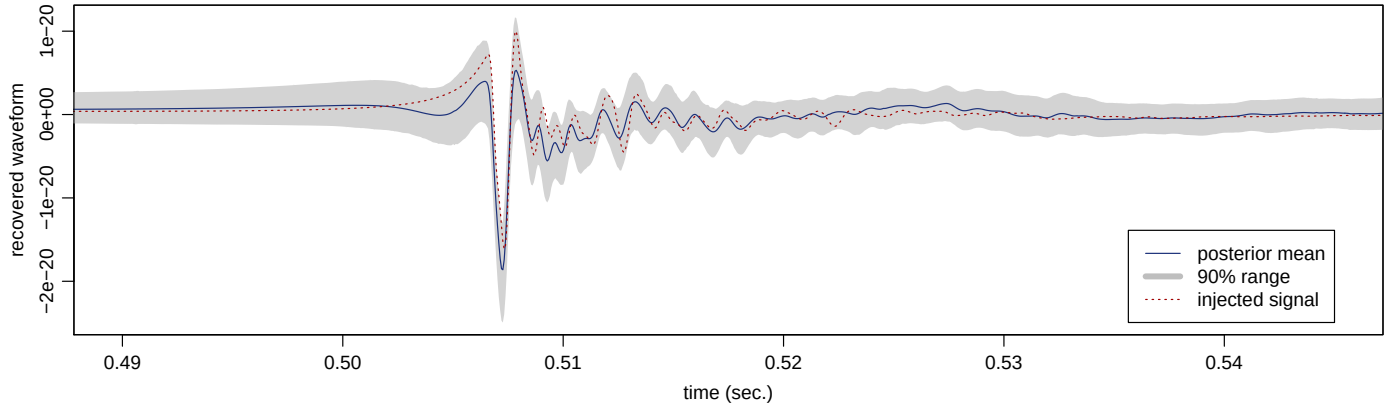


- Posterior distribution of all parameters (12 total):

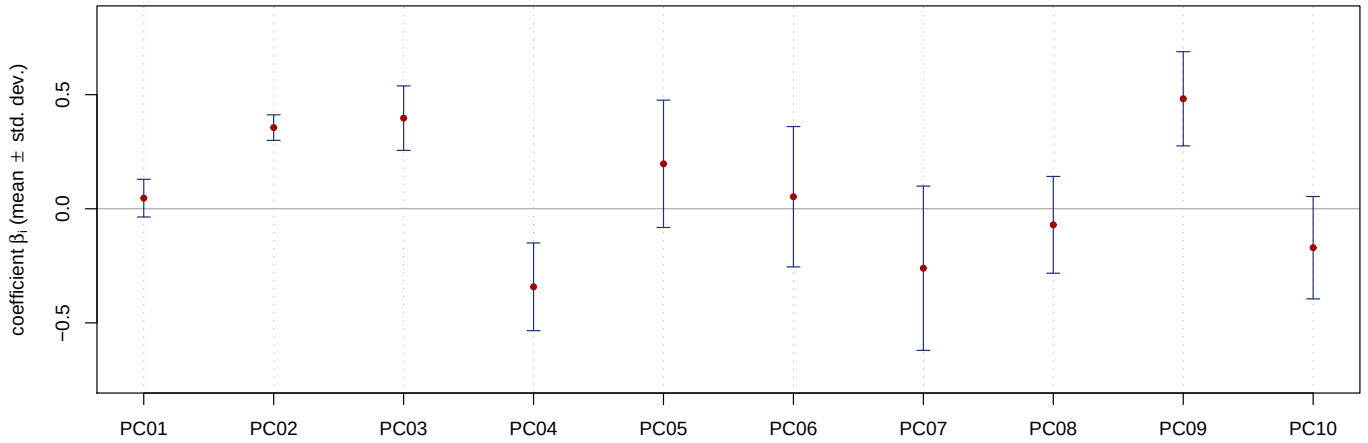


(...)

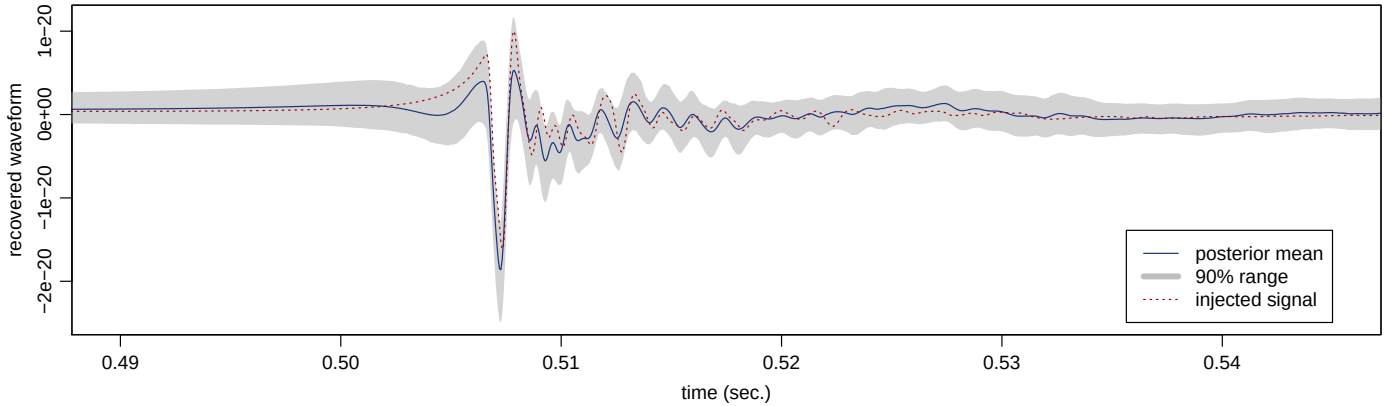
- Reconstructed waveform:



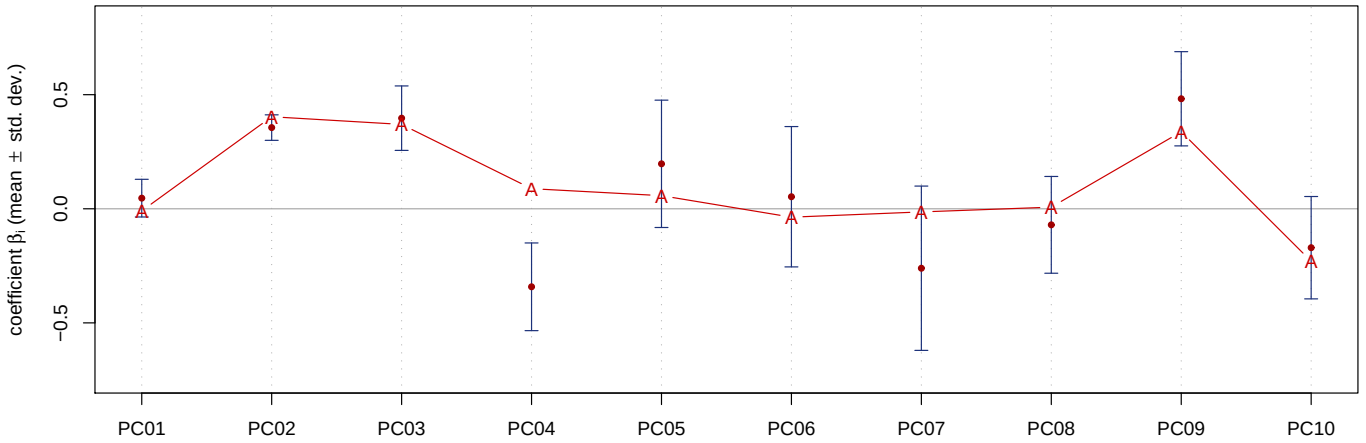
- Coefficients' posterior distribution:



- Reconstructed waveform:



- Coefficients' posterior distribution, matched catalogue waveforms:



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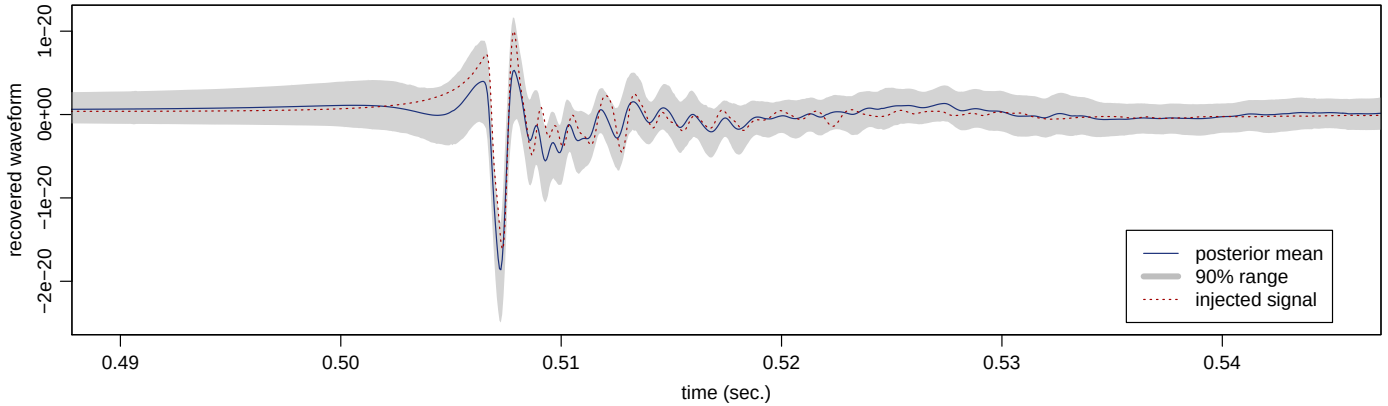

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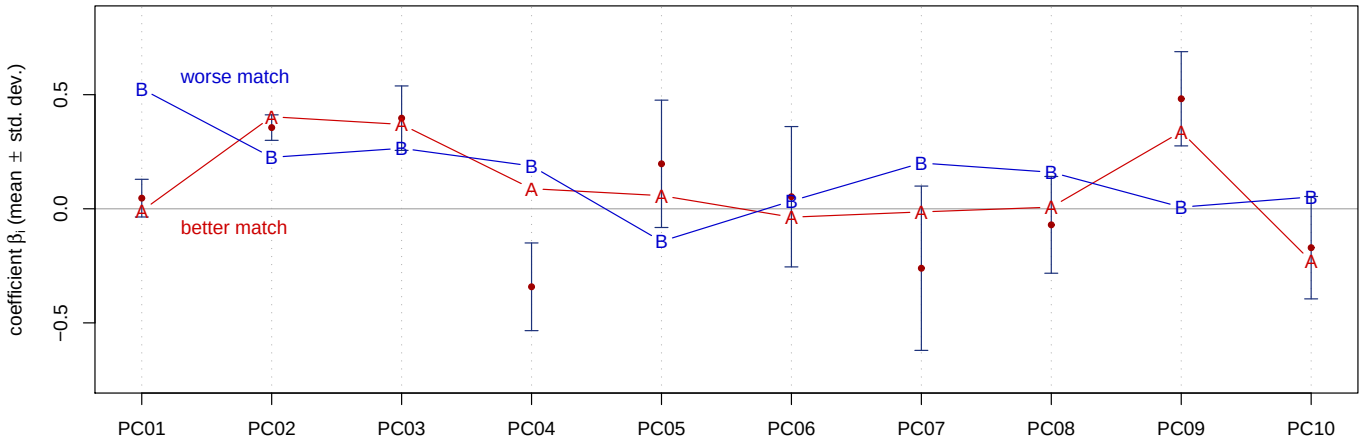

Physical interpretation

- match β posterior with catalogue; rank by (χ^2) mismatch:

	ID	χ^2	EoS	$M_{\rm prog}$ ($M_\odot$)	$\Omega_{c,i}$ (rad/s)	A (km)	$\beta_i/\beta_b/\beta_{pb}$ (%)	$\rho_{\rm max}$ ($\frac{10^{14}}{\rm g\,cm^{-3}}$)	d_E (kpc)
#1	s15a2o09_shen	15.4	Shen	15	4.56	1000	1.09/11.8/10.3	2.58	1.77
#2	s40a2o07_shen	22.2	Shen	40	3.40	1000	0.72/11.8/9.9	2.58	1.92
#3	s11a3o09_shen	26.6	Shen	11	8.99	500	0.72/9.7/8.0	2.71	1.41
#4	s20a2o09_ls	30.3	L/S	20	4.56	1000	0.90/8.8/8.3	3.31	1.34
#5	s20a3o05_ls	33.0	L/S	20	4.21	500	0.25/5.7/4.7	3.62	1.00
⋮	⋮	⋮							
	injected signal →		Shen	20	5.48	1000	1.27/11.86/10.5	2.62	1.67

- To do:
  - derive physically motivated/interpretable basis vectors
  - derive prior for β based on catalogue