GW extraction using Independent Component Analysis

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Motivation

- We propose to apply independent component analysis (ICA) for extracting gravitational wave (GW) signals.
- This approach **does not require templates** of waveform, so that it can be applied for testing general relativity, and also for finding **unknown GW**.

Previous works of ICA on GW

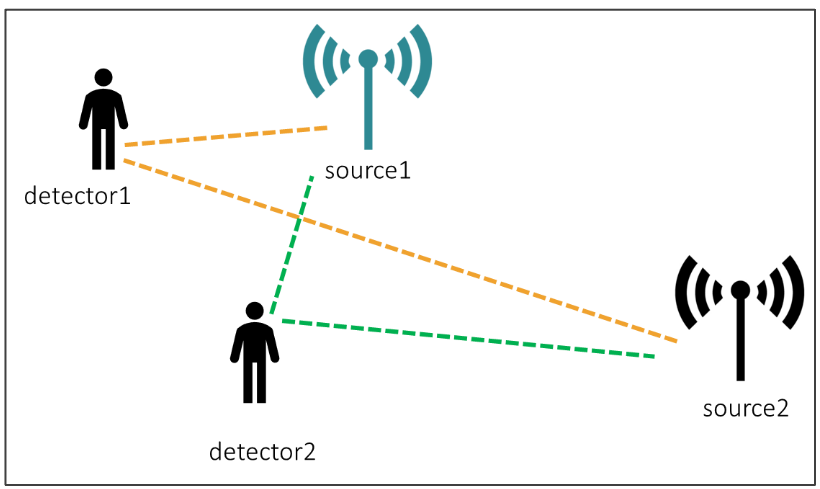
- The use of ICA in gravitational wave data analysis was first proposed by De Rosa et al. (2012), demonstrating its ability to enhance SNR by preprocessing data before matched filtering.
- Morisaki et al. (2016) suggested applying ICA for non-Gaussian noise subtraction.
- In 2020, the KAGRA collaboration applied ICA to real observation data (iKAGRA 2016), showing improved SNR and accurate parameter recovery by combining strain and seismic channels.

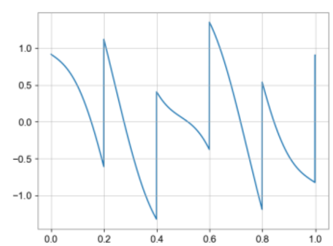
So far ICA approach has been proposed as a tool to identify noises: here we attempt to find gravitational waves directly.

Independent Component Analysis

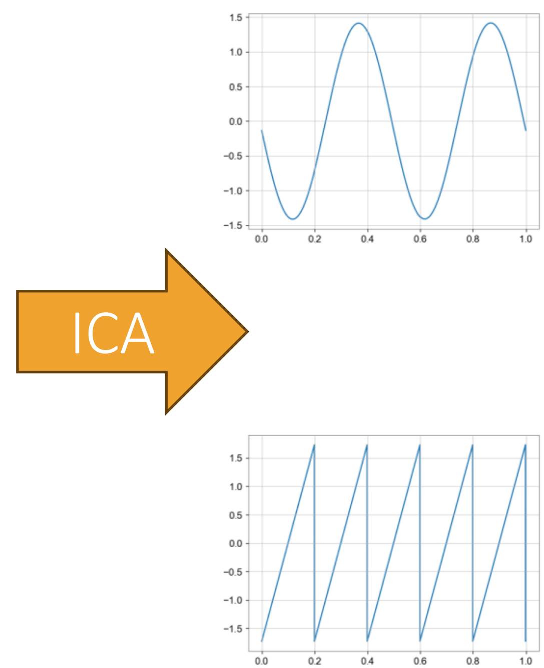
- Independent component analysis (ICA) is a method to separate the set of data as the new set has "statistical independency" of each component.

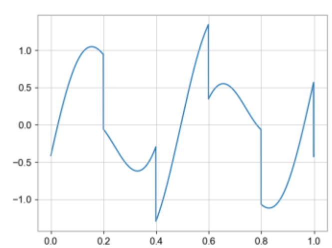
Blind Source Separation





detector1





detector2

Independent Component Analysis

$$\boldsymbol{x}(t) = A\boldsymbol{s}(t)$$

Received signal Source signal

$$\tilde{\boldsymbol{s}}(t) = \underline{\underline{W}}\boldsymbol{x}(t)$$

Reconstructed signal

Find W so as the components of $\tilde{\boldsymbol{s}}(t)$ "independent"

$$s_1(t) = \underline{\underline{\boldsymbol{w}_1^T V}}\boldsymbol{x}(t) \equiv \boldsymbol{w}_1^T \boldsymbol{z}(t)$$

Find to as maximize kurtosis.

$$\mathrm{kurt}(\boldsymbol{w}^T \boldsymbol{z}) = E[(\boldsymbol{w}^T \boldsymbol{z})^4] - 3\{E[(\boldsymbol{w}^T \boldsymbol{z})^2]\}^2$$

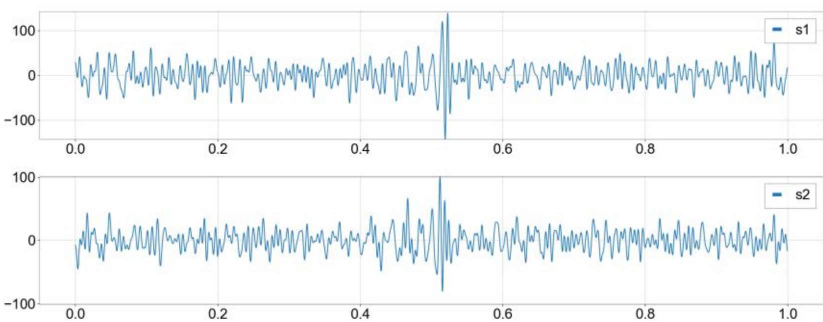
measure the distance from Gaussian

We coded using FastICA method.

Real data example: GW150914

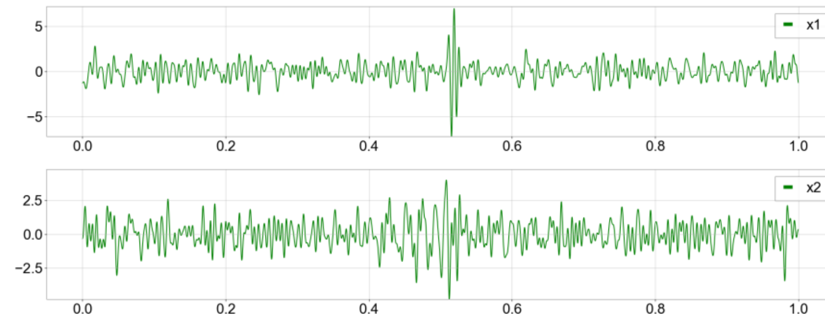
- after whitening, after filtering(20~200Hz), ICA extracts meaningful signal

$$\begin{cases} x_1(t) = h_{\mathrm{H}}(t) \\ x_2(t) = h_{\mathrm{L}}(t) \end{cases}$$

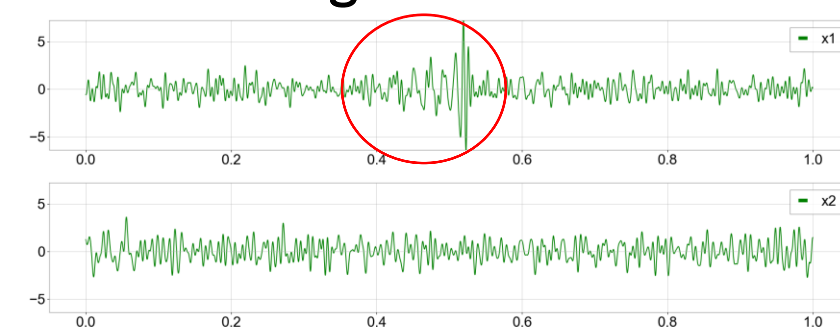


ICA

no shifted



shifted Livingston data -7.5ms



ICA works even with noisy data.
The difference in arrival time is $7.5^{+0.3}_{-0.3}$ ms.
The error was smaller than the one in the LV paper ($6.9^{+0.5}_{-0.4}$ ms).
By accurately knowing the difference in arrival time, we can provide narrow sky localization of the source.

Summary & Conclusion

Summary

- We apply ICA for extracting GW.
- Injection studies (to Gaussian noise, and to real noise) show that ICA can identify GW of SNR>10
- An application to GW150914: GW was identified best if we shifted Livingston data by $7.5^{+0.3}_{-0.3}$ ms advanced.
- Matched number with LV paper, and small error (LV paper says $6.9^{+0.5}_{-0.4}$ ms).
- Code is ready for 4 detectors.

Conclusion

- ICA can be a complement method for GW detection.
- New method without templates. Attractive for testing GR, and for finding unknown GW.