

Dixième Assemblée Générale du GdR Ondes Gravitationnelles, Oct 2026

Combining matched filtering with a convolutional neural network for CBC signal detection

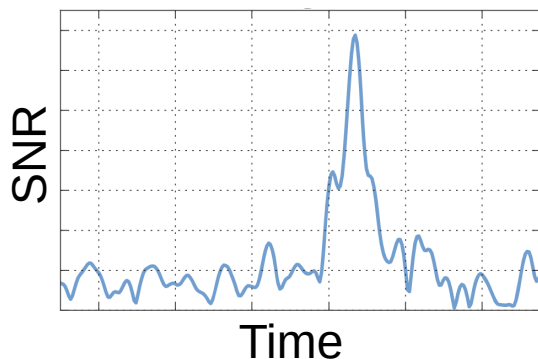
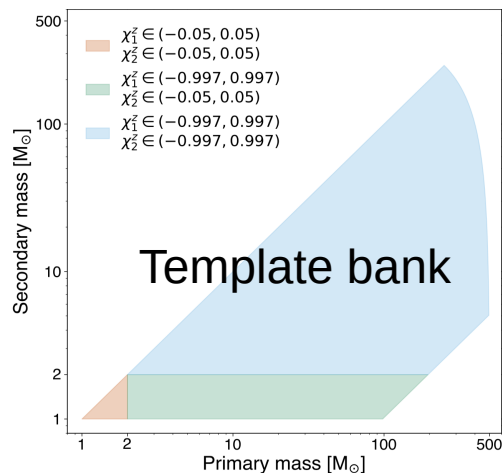
Mobilia et al 2026, arXiv:2603.09386

Lorenzo Mobilia, **Tito Dal Canton**, Gianluca Guidi

Summary

- Matched filtering for CBC detection
- Machine-learning for CBC detection
- Idea behind our study
- Simulations and results

Matched filtering for CBC detection



Signal-to-noise
ratio

$$\rho(t) = 4 \left| \int_{f_{\text{low}}}^{f_{\text{high}}} \frac{\tilde{d}(f) \tilde{u}^*(f | \boldsymbol{\theta}_{\text{int}})}{S_n(f)} e^{2i\pi f t} df \right|$$

Signal-based
discriminator

$$\chi_r^2 := \frac{p}{2p-2} \sum_{\ell=1}^p \left| z_{\ell} - \frac{z}{p} \right|^2$$

Candidate ranking statistic
(here reweighted SNR)

$$\rho(t)_{\text{rw}} = \frac{\rho(t)}{\left[\frac{(1+\chi_r^2)^2}{2} \right]^{\frac{1}{6}}}$$

Which signal-based discriminator to use?

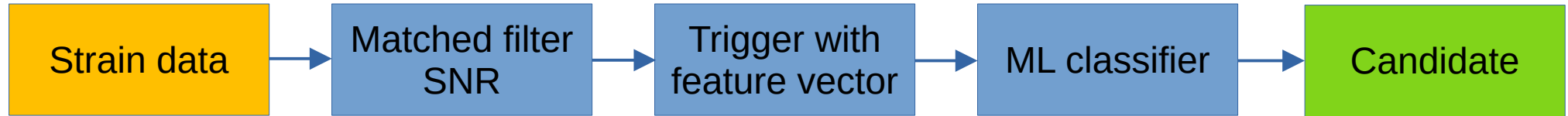
How to find the optimal ranking statistic?

Answers traditionally found by combining theory (e.g. likelihood ratio test) with heuristics and lots of simulations.

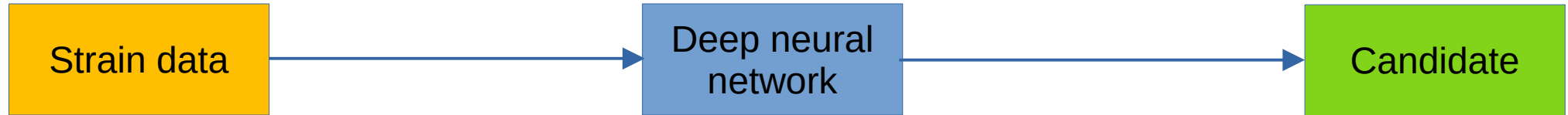
Most of the structure around the max SNR is usually discarded.

Machine learning for CBC detection

E.g. Kapadia et al 2017, Mobilia & Guidi 2026



E.g. methods compared by Schäfer et al 2023, Aframe (Marx et al 2025)



E.g. McLeod et al 2025, Yamamoto et al 2026, and this work



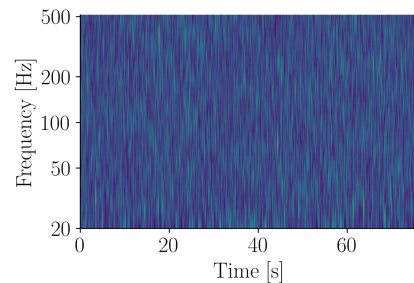
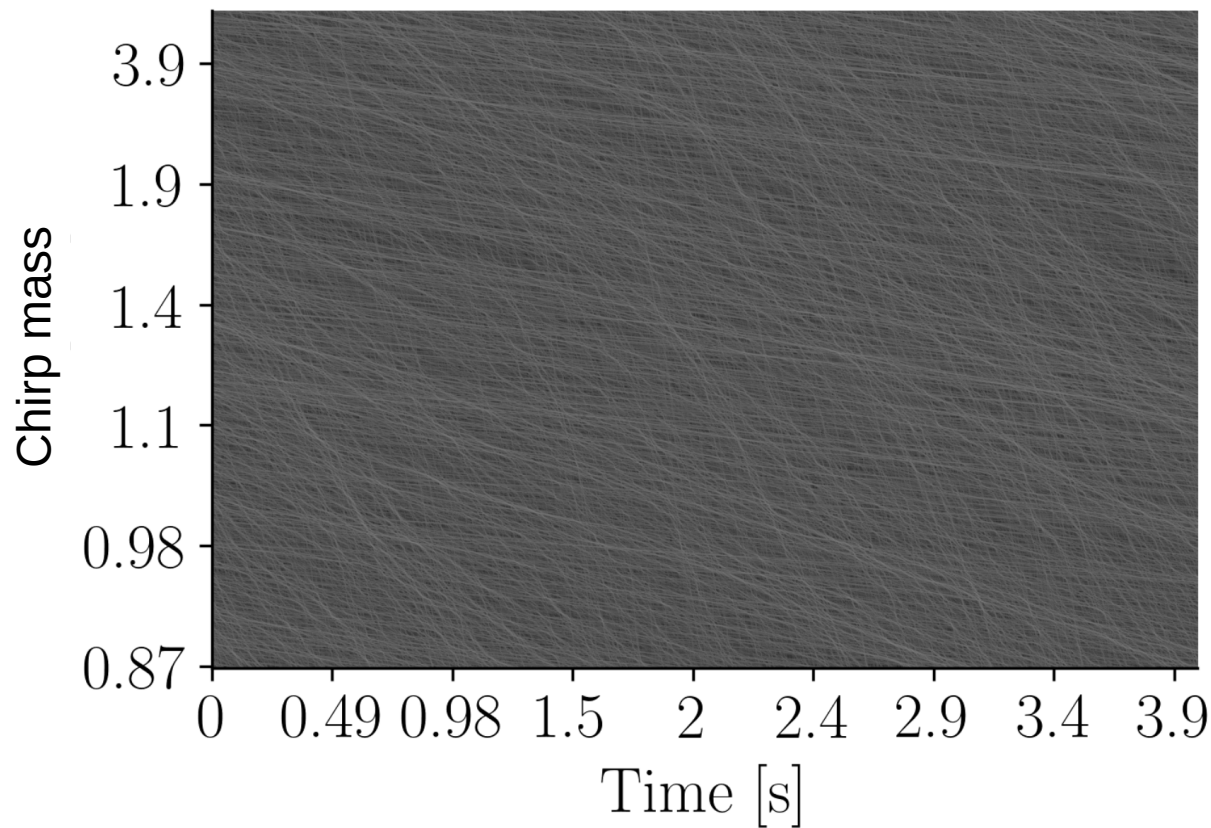
Idea behind our study

- Build a **one-dimensional template bank** covering equal-mass binaries from BNS to IMBH.
- For each template, calculate the SNR time series in a 4 s window.
- Organize the SNR data into a $N_{\text{time}} \times N_{\text{template}}$ matrix, the **time-template-SNR map**.
- The map will contain the maximum SNR, and a surrounding structure determined by the projection of the data on the filter bank (ambiguity function).
- Is such structure useful for detecting and discriminating a CBC signal?
- Can we cast the CBC detection/discrimination problem as an image recognition problem?
- This is going to be an exploratory study, not a ready-to-use search pipeline.

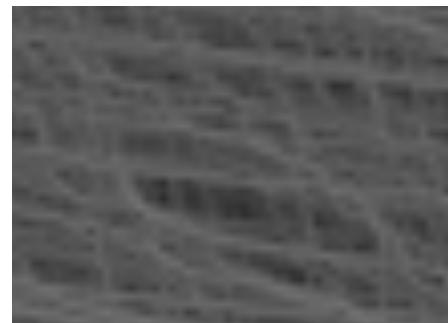
Idea behind our study

Time-template-SNR
map

Gaussian Noise



$$\bar{\rho}(t) = \frac{\log(\rho(t)) - \log(b_{\min})}{\log(b_{\max}) - \log(b_{\min})}$$

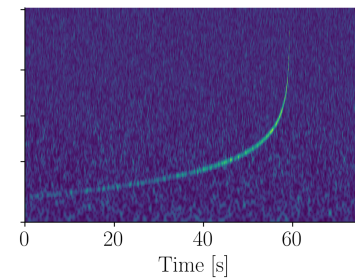
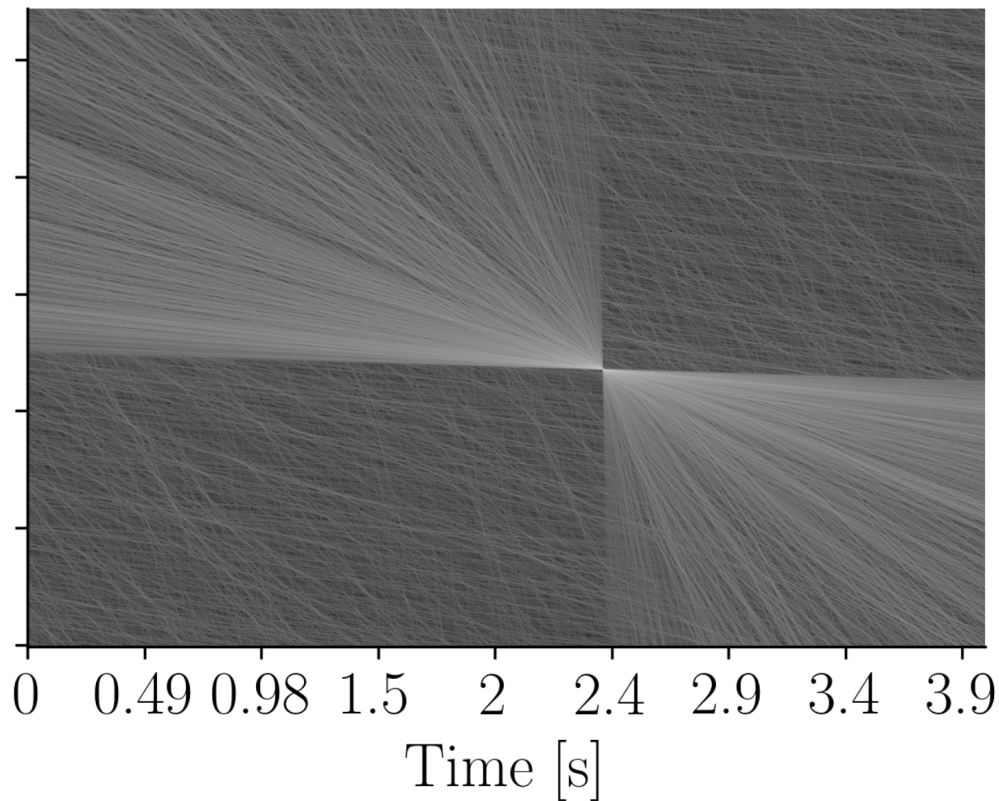


Idea behind our study

Time-template-SNR
map

Chirp mass

Injection



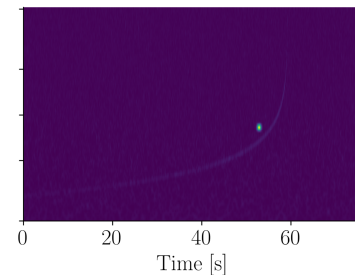
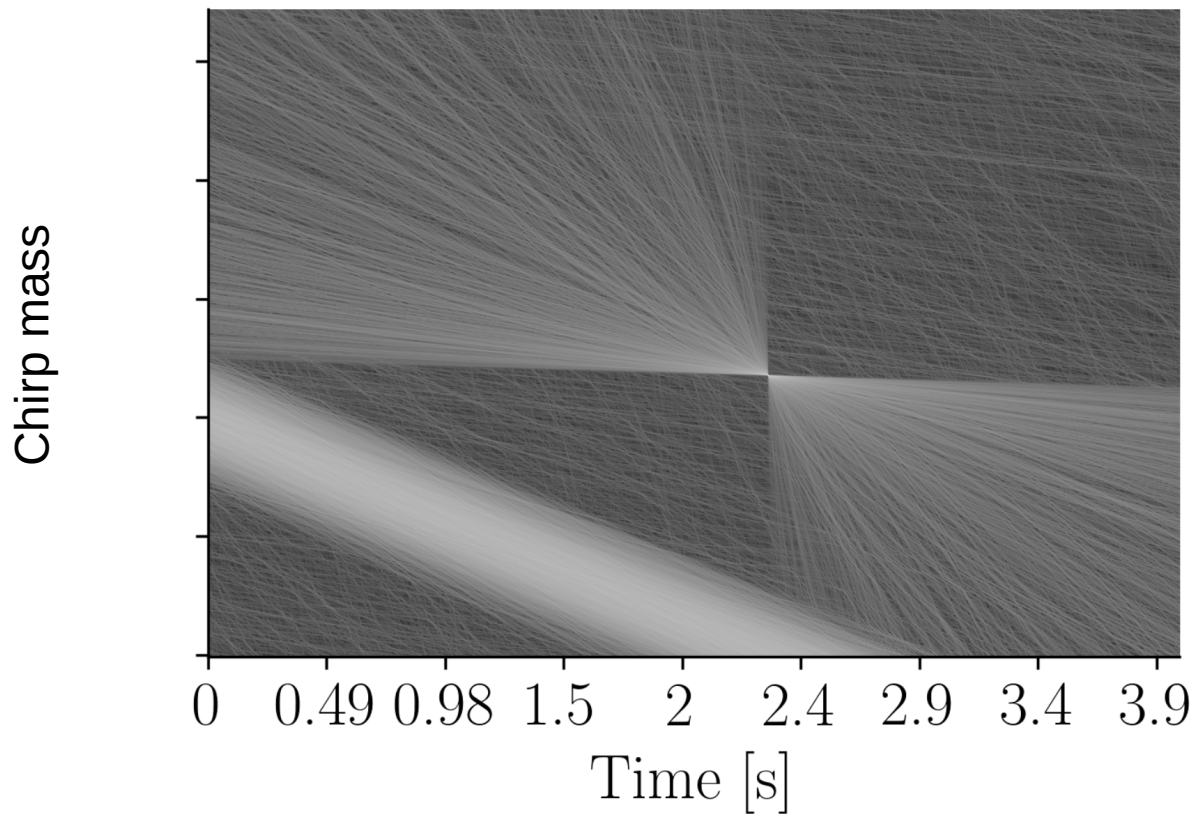
$$\bar{\rho}(t) = \frac{\log(\rho(t)) - \log(b_{\min})}{\log(b_{\max}) - \log(b_{\min})}$$



Idea behind our study

Time-template-SNR
map

Injection + Glitch

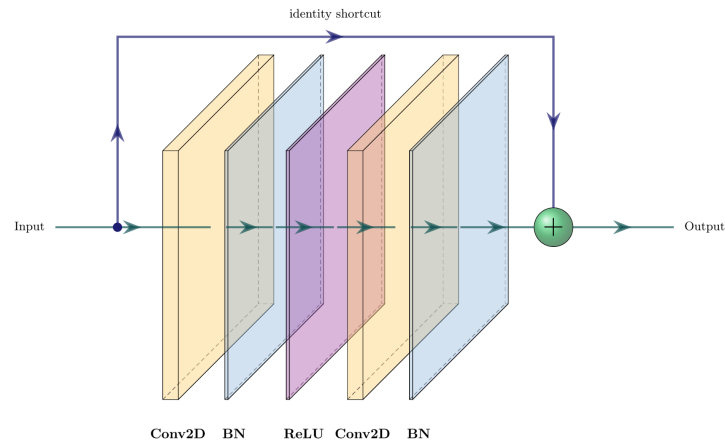
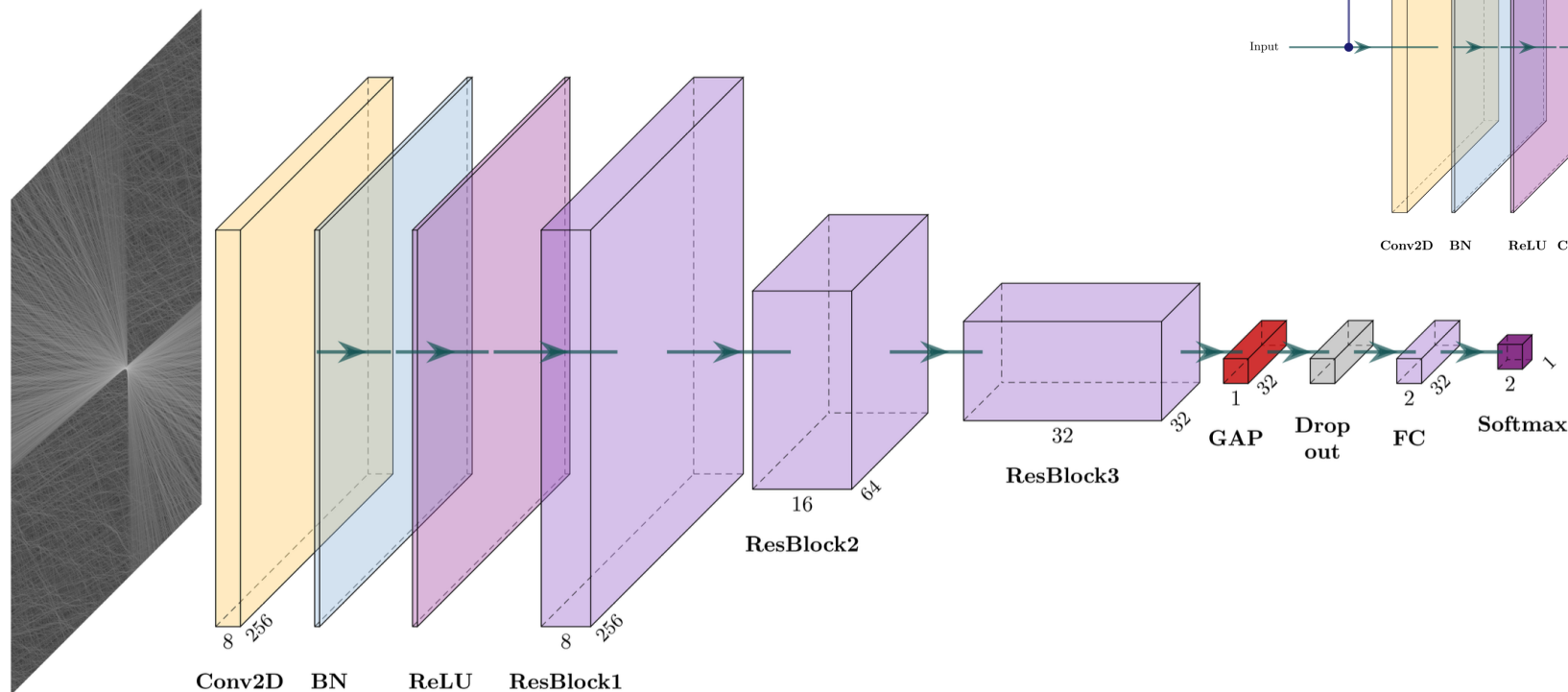


$$\bar{\rho}(t) = \frac{\log(\rho(t)) - \log(b_{\min})}{\log(b_{\max}) - \log(b_{\min})}$$

The structure has a pretty well-defined and distinctive behavior. Can we train a neural network to see it?

Idea behind our study

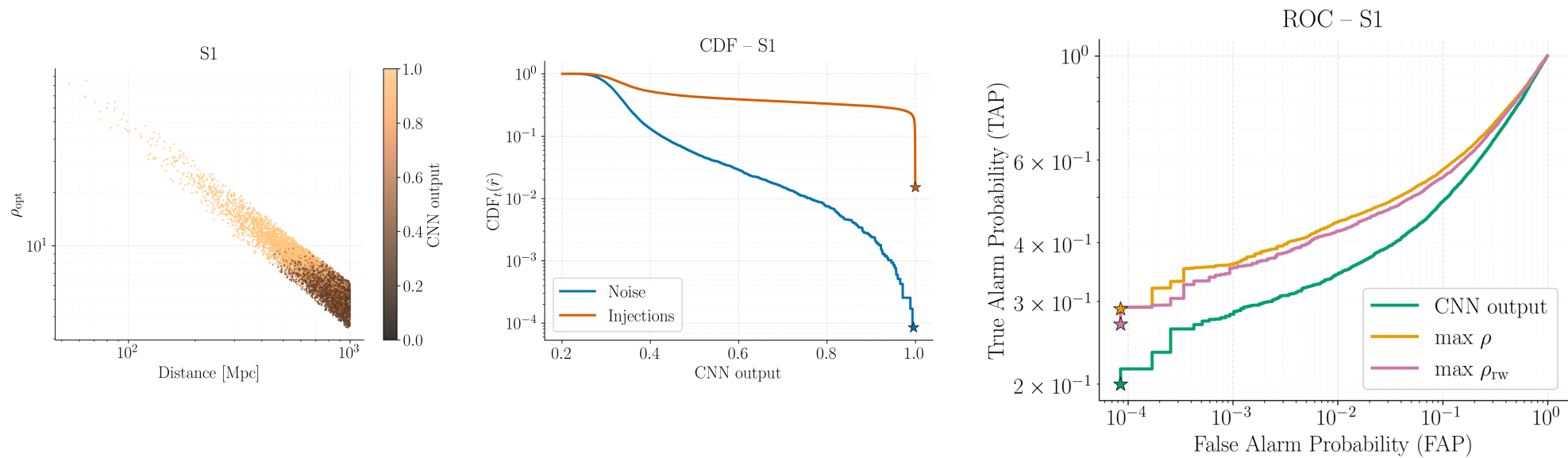
Convolutional neural network with residual block
(residual network, He et al 2016)



Output:
ranking
statistic
between
0 and 1.

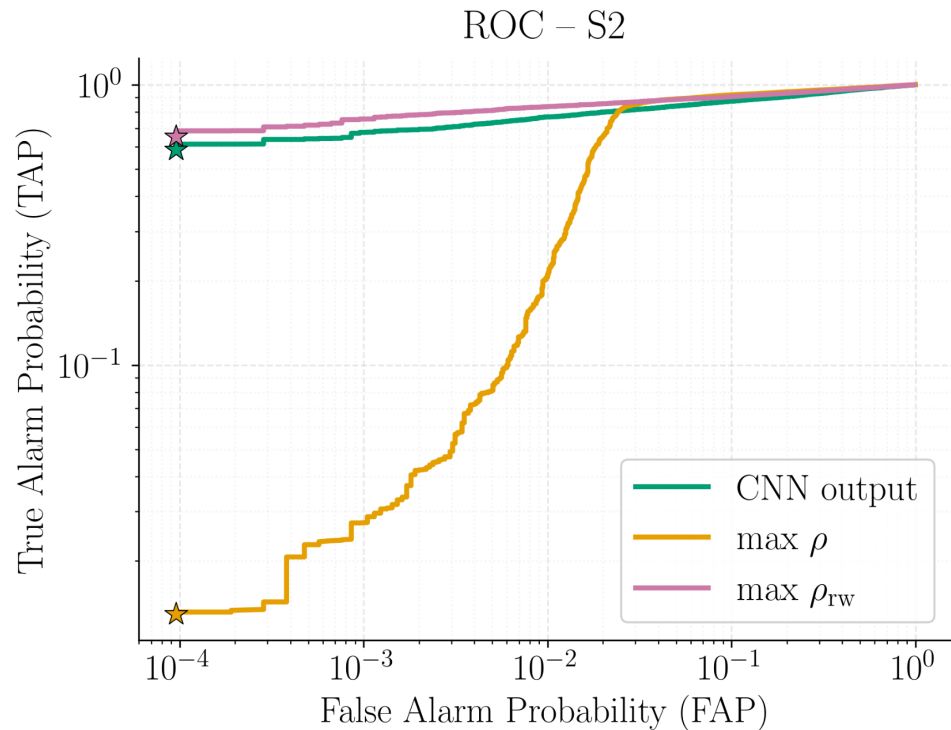
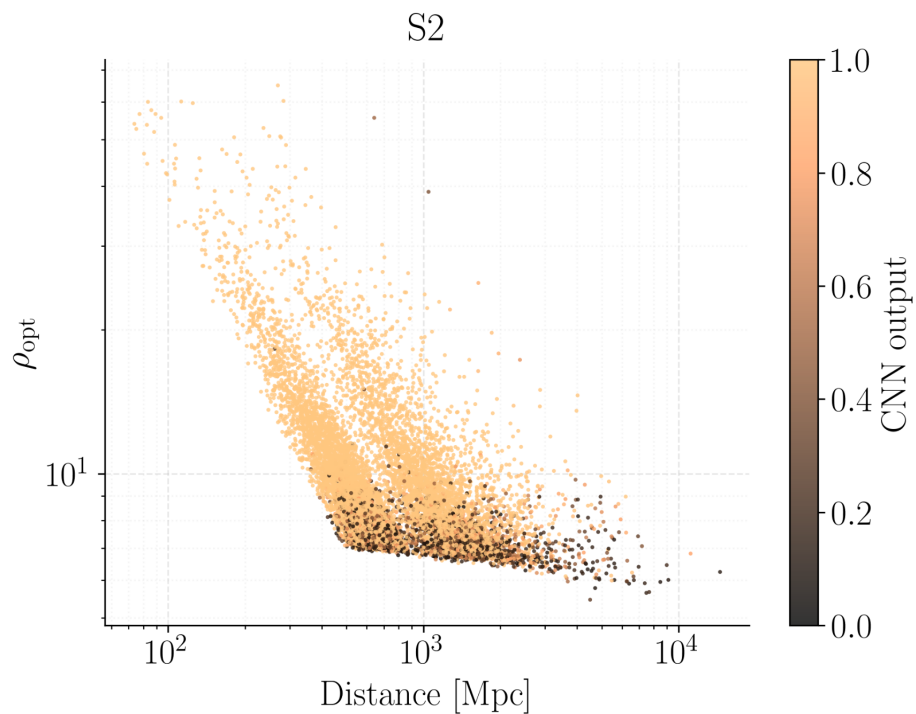
Simulations and results

Simulation 1: BNS waveforms in ideal Gaussian noise.



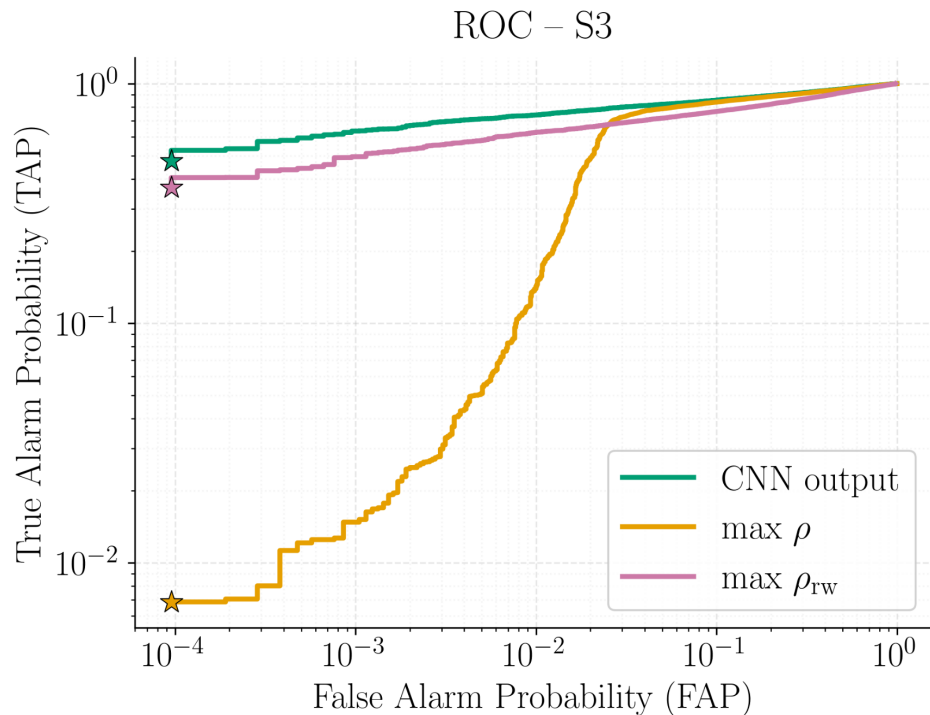
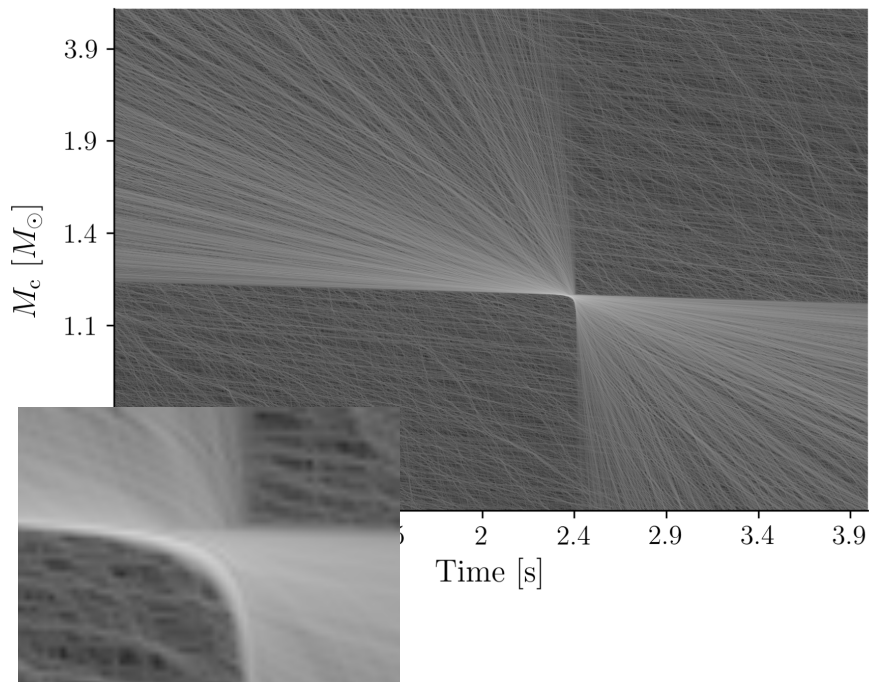
Simulations and results

Simulation 2: BNS / **BBH** waveforms **and glitches** in ideal Gaussian noise.



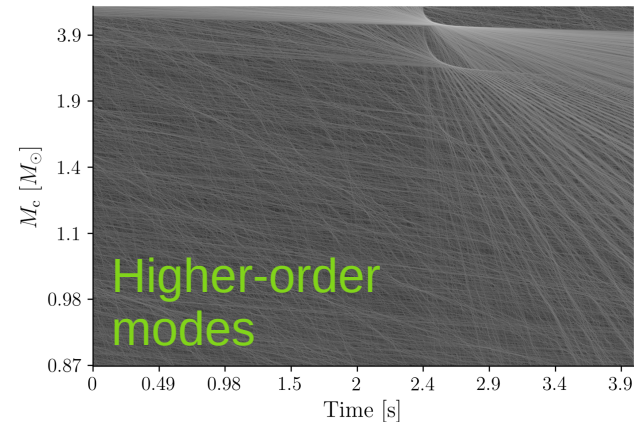
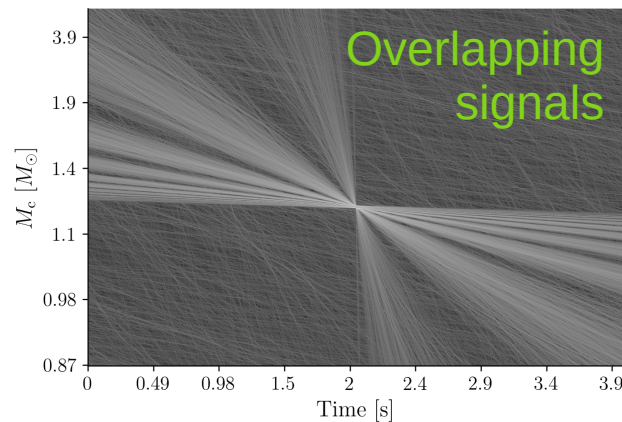
Simulations and results

Simulation 3: BNS / BBH waveforms and glitches **with spin** in ideal Gaussian noise.

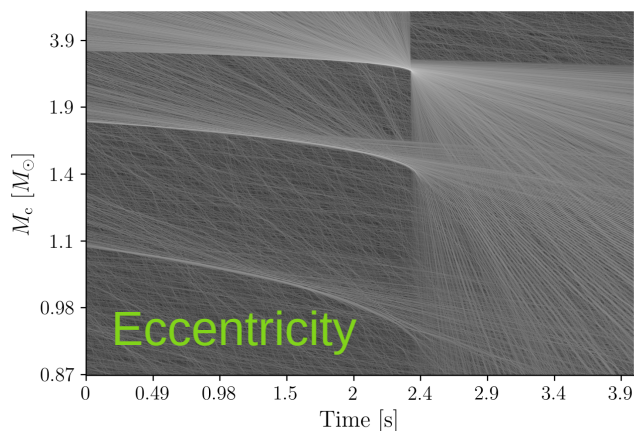
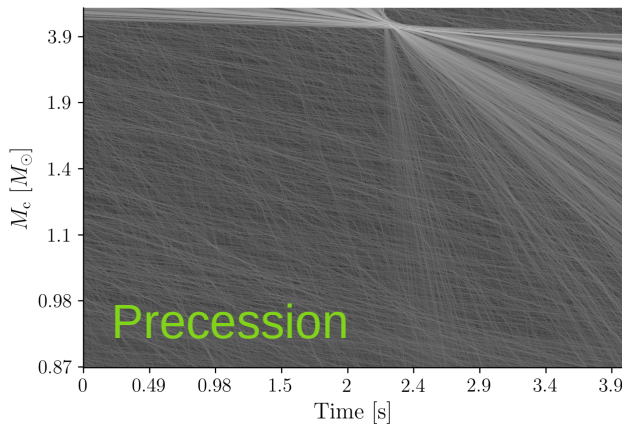


Simulations and results

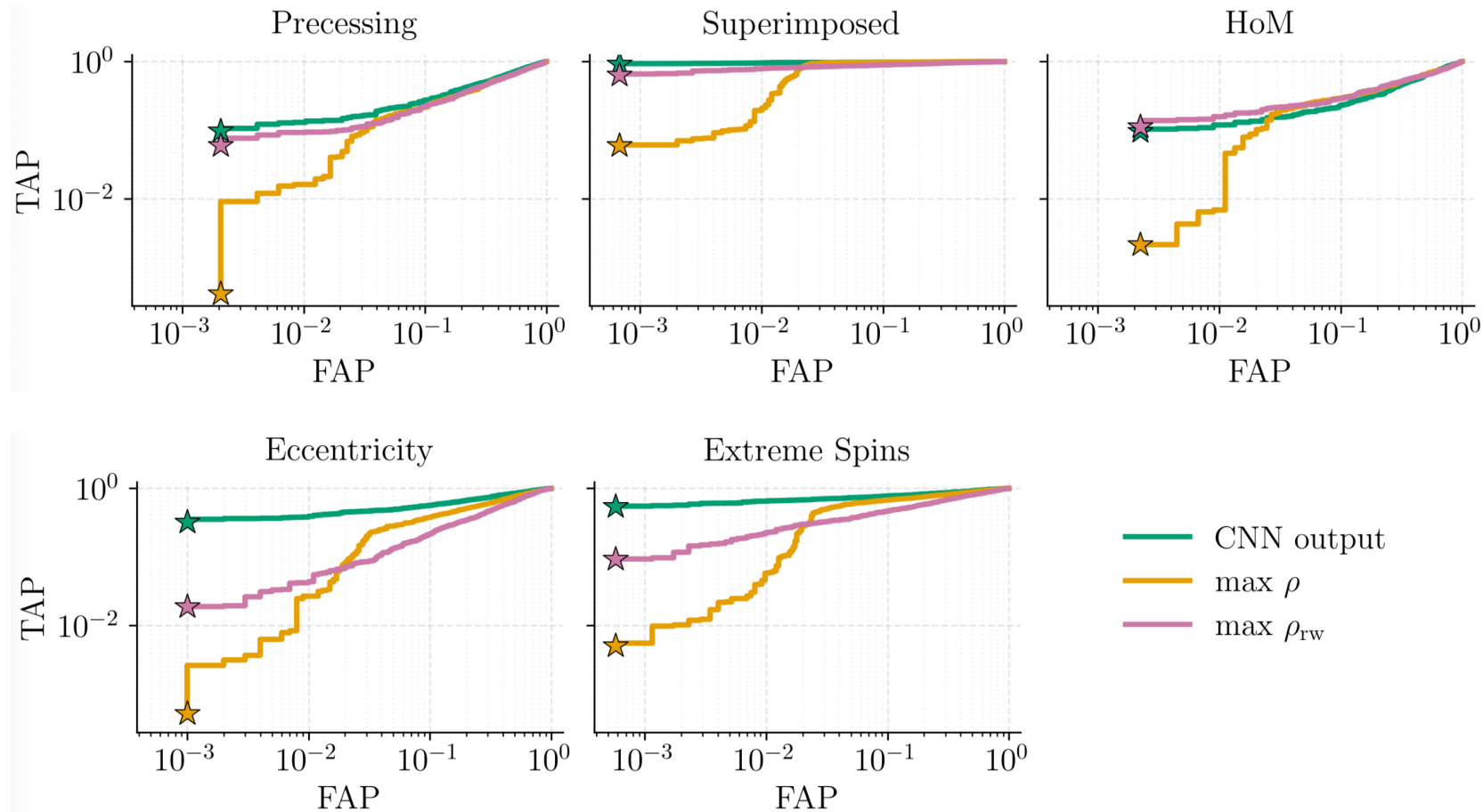
Simulation 4:
a variety of physical
effects not modeled in
the bank.



After “dechirping” the
data, the extra physics
becomes very evident
and recognizable
(for loud signals).

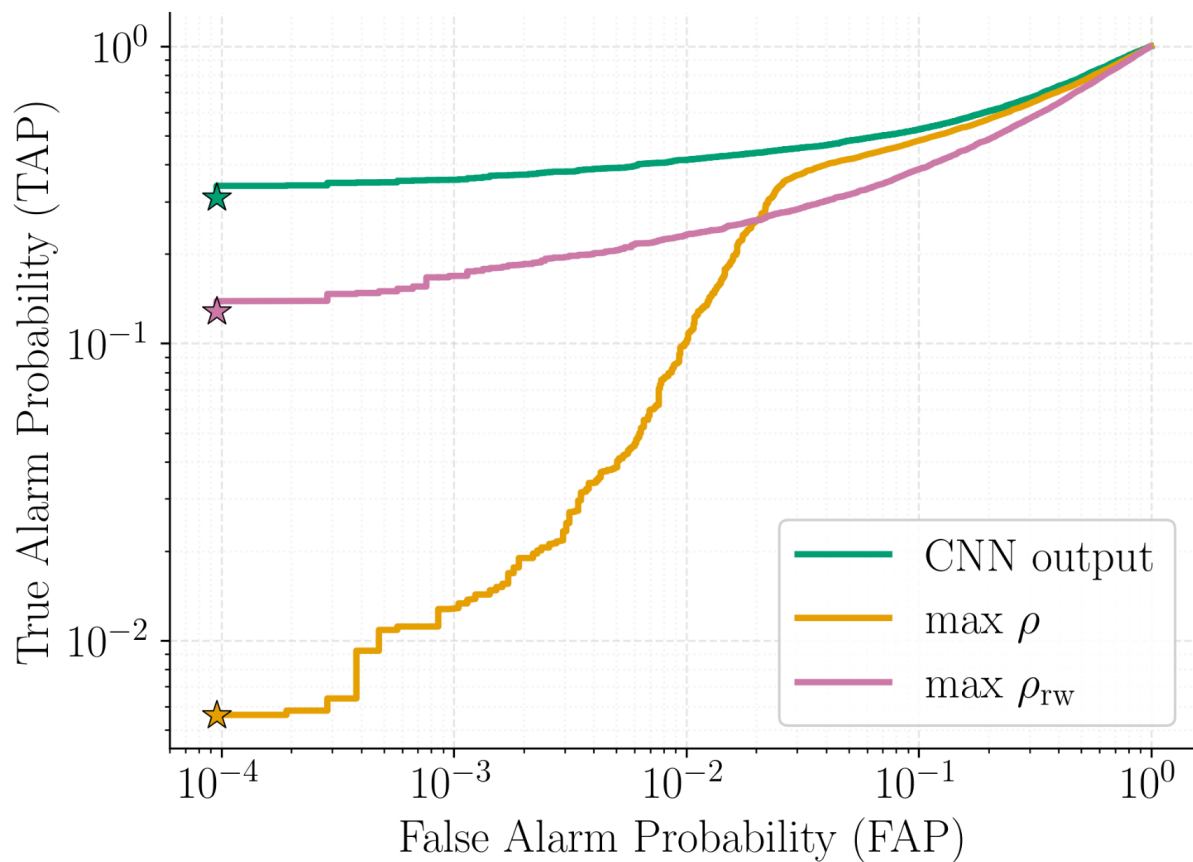


Simulations and results



Simulations and results

ROC – S4



Conclusions

- A residual network can be trained to take in the collective ensemble of SNR over multiple search parameters, and separate CBC signals from noise.
- For signals that match the templates well, this method is almost equivalent to the standard matched-filter triggering + ranking.
- For signals with more physics than the templates, this method can significantly outperform the standard methods, which kill the triggers due to the signal-based discriminators.
- This was a proof-of-concept, not a complete search pipeline. Should use multiple detectors, assign a proper significance, etc.
- Could a similar method be used for rapid parameter estimation from the time-template-SNR map?