Robust multi-detector statistics for coherently searching for signals from coalescing compact binaries

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The two detector coherent statistic

$$1D \text{ case}: L = |C|^2 = |(x,S)|^2 = (x,s_0)^2 + (x,s_{\pi/2})^2 = c_0^2 + c_{\pi/2}^2 \equiv \rho^2.$$

$$\text{For detector "1"}, \quad C_1(t+\tau_1) = \langle x_1(t+\tau_1), s_0\rangle_1 + i\langle x_1(t+\tau_1), s_{\pi/2}\rangle_1$$

$$= c_{1,0}(t+\tau_1) + i c_{1,\pi/2}(t+\tau_1)$$

$$= \rho_1 e^{i\varepsilon_1}$$

$$\text{For } 2D \text{ case}, \quad L = 2\ln\Lambda(t)\big|_{A,\vartheta_0} = \left|\vec{Q}(\psi,\iota,\theta,\varphi)\cdot\vec{C}(t)\right|^2$$

$$= \left|Q_1 C_1(t+\tau_1) + Q_2 C_2(t+\tau_2)\right|^2,$$

$$\text{where } Q_I \propto E_I(\psi,\iota,\theta,\varphi), \text{ and } \left\|\vec{Q}\right\| = 1.$$

Multiple (non-aligned) detectors

The 2-D Case:

$$L = 2\ln\Lambda(t)\Big|_{A,\vartheta_0} = \left|\vec{Q}(\psi,\iota)\cdot\vec{C}(t)\right|^2,$$

$$L = 2\ln\Lambda(t)\Big|_{A,\vartheta_0,\psi,\iota} = \left\|\vec{C}(t)\right\|^2 = \left[\rho_1{}^2(t+\tau_1)+\rho_2{}^2(t+\tau_2)\right]$$

The *M*-D Case:

$$L = 2\ln\Lambda(t)\Big|_{A,\vartheta_0,\psi,\iota} = \left\|\vec{C}(t)\right\|^2 = \left[\left|C_+(t)\right|^2+\left|C_-(t)\right|^2\right]$$

$$= \left[c_{+0}{}^2(t)+c_{+\pi/2}{}^2(t)+c_{-0}{}^2(t)+c_{-\pi/2}{}^2(t)\right],$$

where

$$C_\pm(t) \equiv \vec{v}_\pm\cdot\vec{C}(t) = c_{\pm0}(t)+ic_{\pm\pi/2}(t)$$

and $\vec{v}_\pm$ is determined by the M-dim $\vec{F}_{+,\times}$.

-SB, Pai, Dhurandhar, **Int.J.Mod.Phys.D9:325-329,2000**
e-Print Archive: **gr-qc/0002010**

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Null-stream statistic for inspirals

Instead of maximizing the likelihood ratio, try fitting the data to the signal:

$$\left\|\vec{x}-\vec{h}\right\|^2,$$

and minimize it to get the “null stream” statistic:

$$\left({}^{2D}N\right)^2 = \frac{1}{2}\left|\zeta_1^{-1}C_1(t)-\zeta_2^{-1}C_2(t)\right|^2 \Big/ \left(\zeta_1^{-2}+\zeta_2^{-2}\right)$$

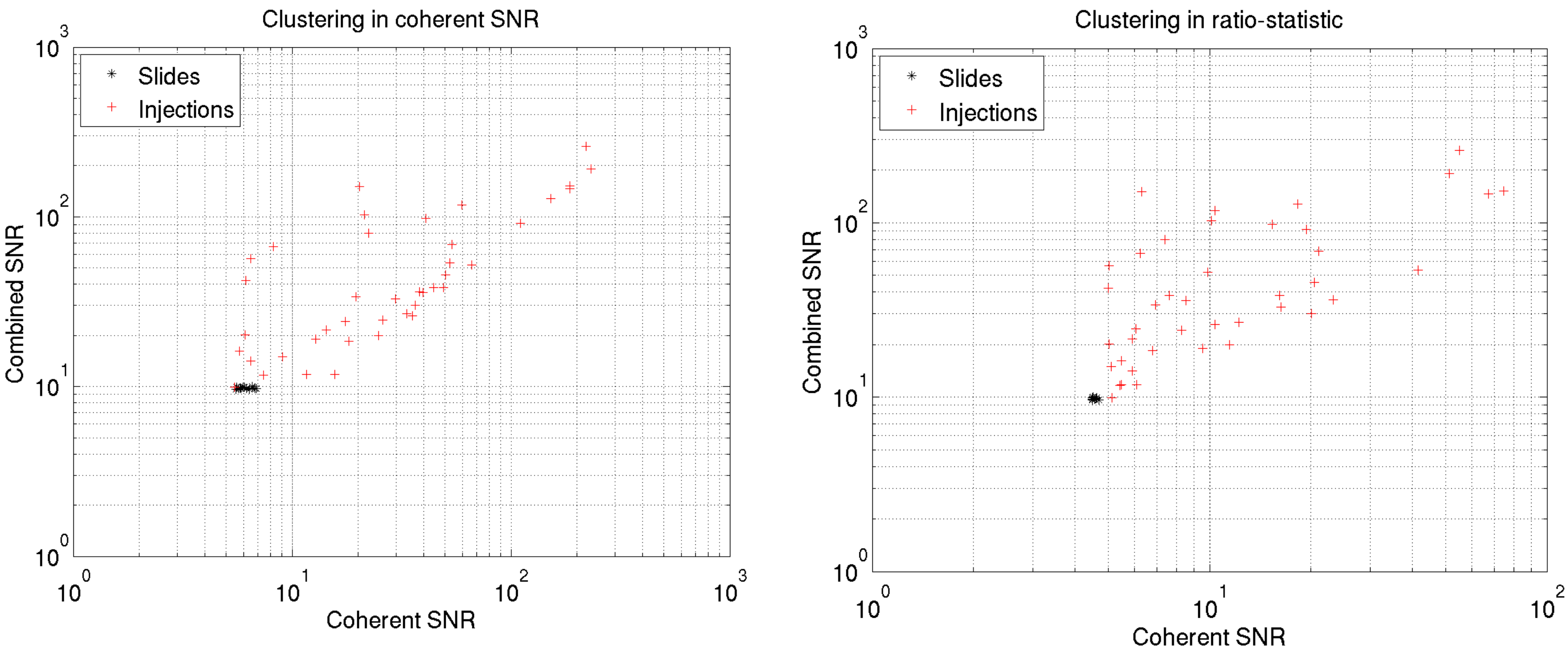
$$\leq \frac{1}{2}\frac{\left(\rho_1 - x^{-1}\rho_2\right)^2}{1+x^{-2}}, \quad \text{where } x \equiv \frac{\zeta_2}{\zeta_1}$$

For 3 detectors:

$${}^{3D}N \propto \left|\sum_{k=1}^{3}\varepsilon_{klm}F_+^l F_\times^m \zeta_{(k)}^{-1} C^k(t)\right|^2.$$

[SB, E. Messaritaki, M. Tinto, et al., unpublished]

Detection in Gaussian Noise



Let null-stream, N = A + C, where A and C are the auto- and cross-correlation pieces of the null-stream. Clustering in ratio-statistic (right figure) improves separability of injections and background.

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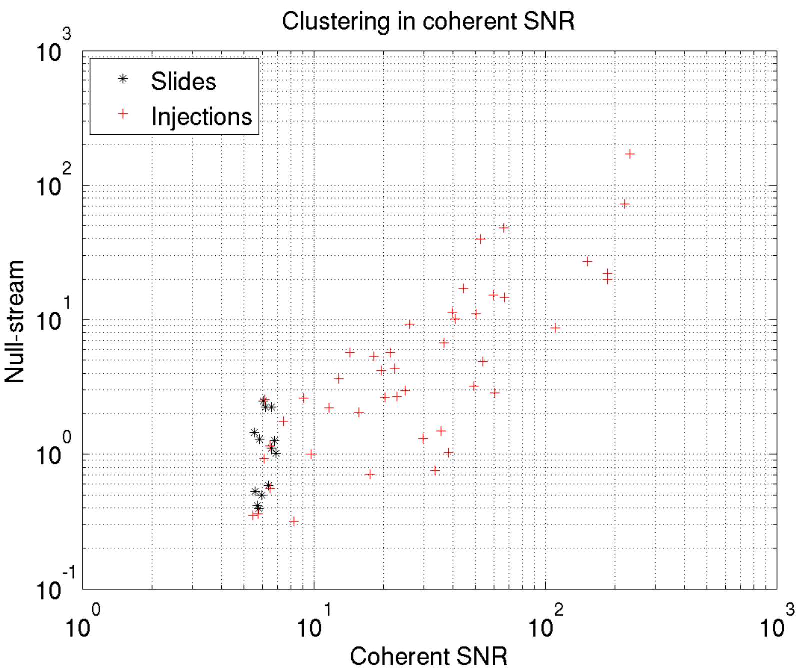
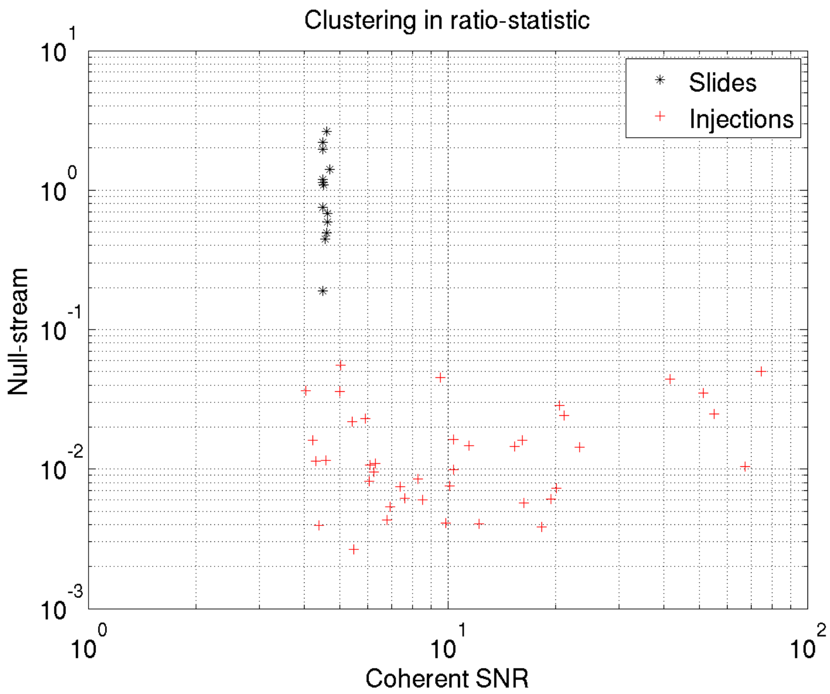
Further improvement with Null-stream





Compared to previous figures, these ones have 7 additional injections at distances between 10-30Mpc. Note how the use of both ratio-statistic clustering and null-stream has the potential to dig deeper into the noise.

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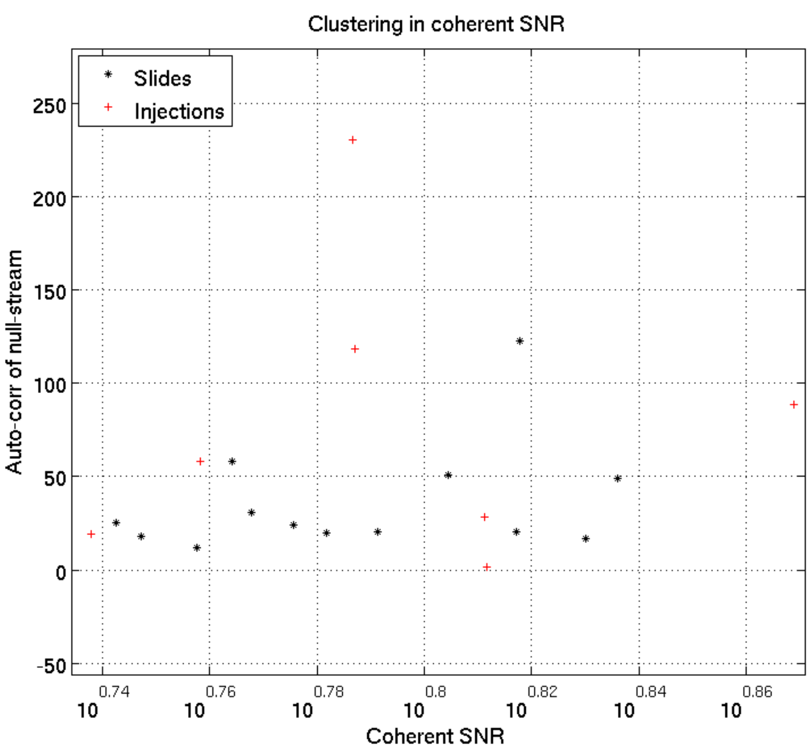
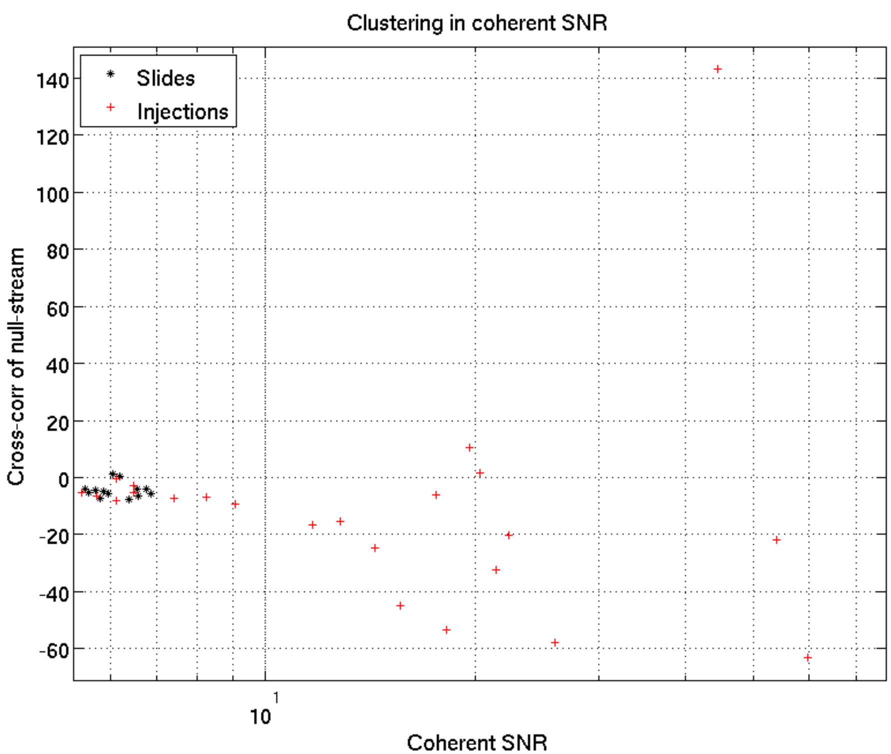
Alternative statistics: pieces of coherent SNR and null-stream





Clustering in coherent SNR: These plots show why such a clustering performs worse: In Maximizing with respect to the coherent SNR, the search often picks up triggers that do not have a low null-statistic value, which is an aspect they share with noise triggers. *(Here, we dropped the four injections with coherent SNR < 5.0.)*

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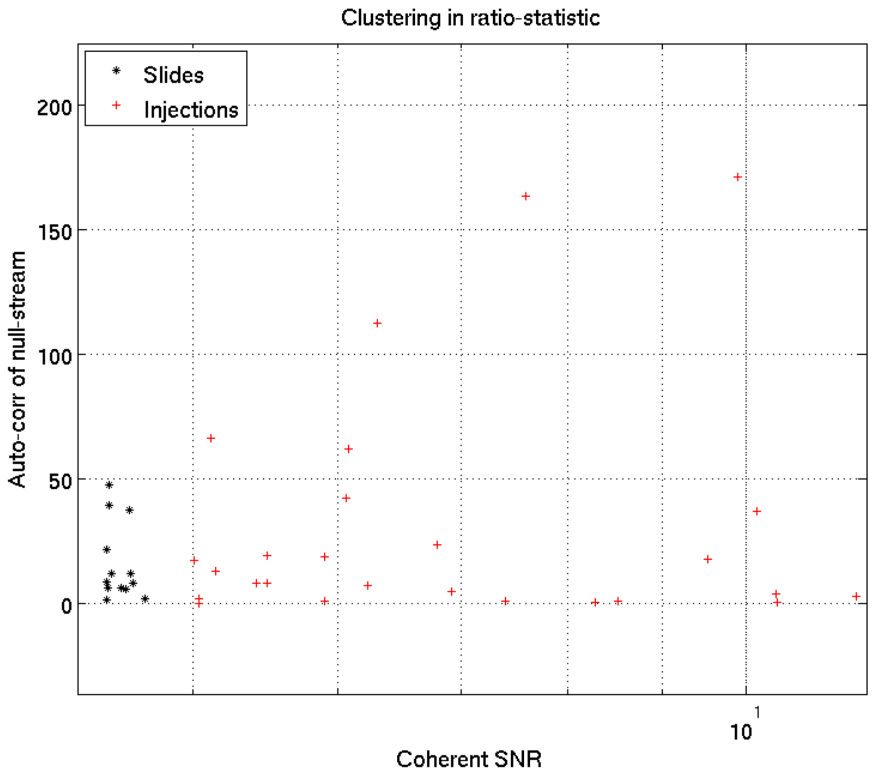
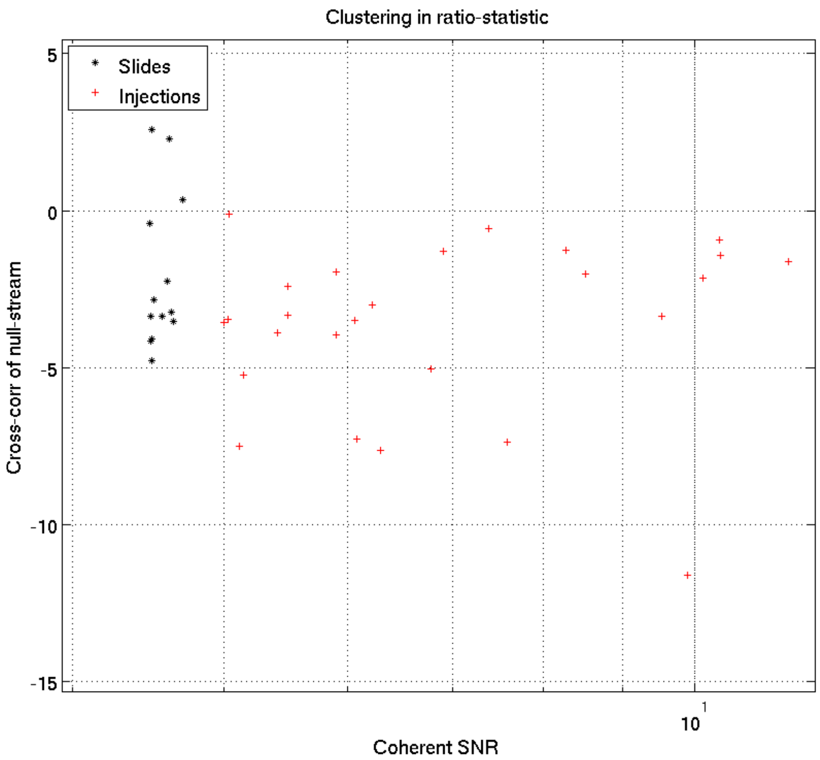
Alternative statistics: pieces of coherent SNR and null-stream





Maximizing ratio-statistic *does* help discriminate the injections from the slides. The coherent SNRs of the clustered noise triggers drop more. This clustering performs better because it optimizes the search by looking for low null-stream triggers while not sacrificing too much their strength in the individual IFOs.

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Summary

1. Clustering in ratio-statistic yields better performance than clustering in coherent SNR, in the week-long sample of Gaussian, but non-stationary, data we studied.

2. Employing null-stream helps in creating a greater separation between the background and injection triggers.

3. The coherent code in the LV CBC pipeline is equipped to compute multiple alternative statistics and pick the best performing discriminator Although, here we have shown them only for Gaussian noise, they have been applied to real data from S5/VSR1 and S6/VSR2.

4. We plan to study the effect of sine-Gaussian type (incoherent) glitches on the high-mass pipeline, where the chi-square veto is less effective.

5. External-triggered searches, where the sky-position is already known will also be studied, with expectedly, better performance gains.