Searching for Binary Black Holes with Spin Aligned with Orbital Angular Momentum

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LIGO SURF 2013
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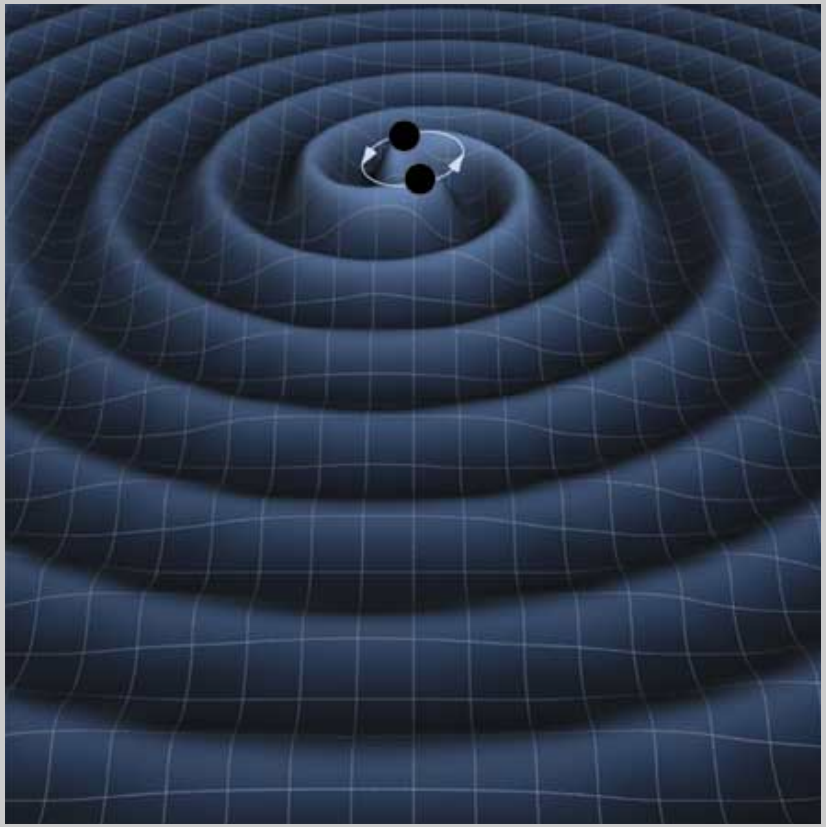
Gravitational Wave Detection from Binary Black Holes

- Coalescing BBHs are a promising source of GWs.
- The core technique in GW searches of compact binaries is the use of matched filtering.
- BBHs are expected to have significant spin.
- No previous searches of LIGO data have included the effects of spin.

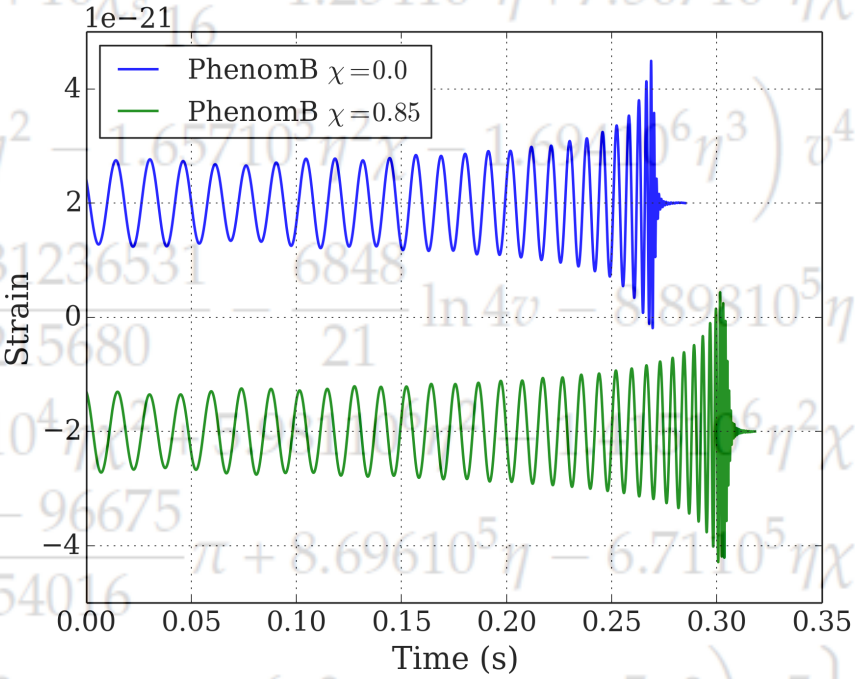


Waveforms with Spin – IMRPhenomB

$$\chi \equiv \frac{a_1 m_1 + a_2 m_2}{M}$$

- Phenomenological fit to post-Newtonian and numerical relativity hybrid waveforms.
- Includes all three phases of coalescence: inspiral, merger, ringdown.
- Spin aligned with orbital angular momentum.

IMRPhenomB with m1 = m2 = 10 Msun



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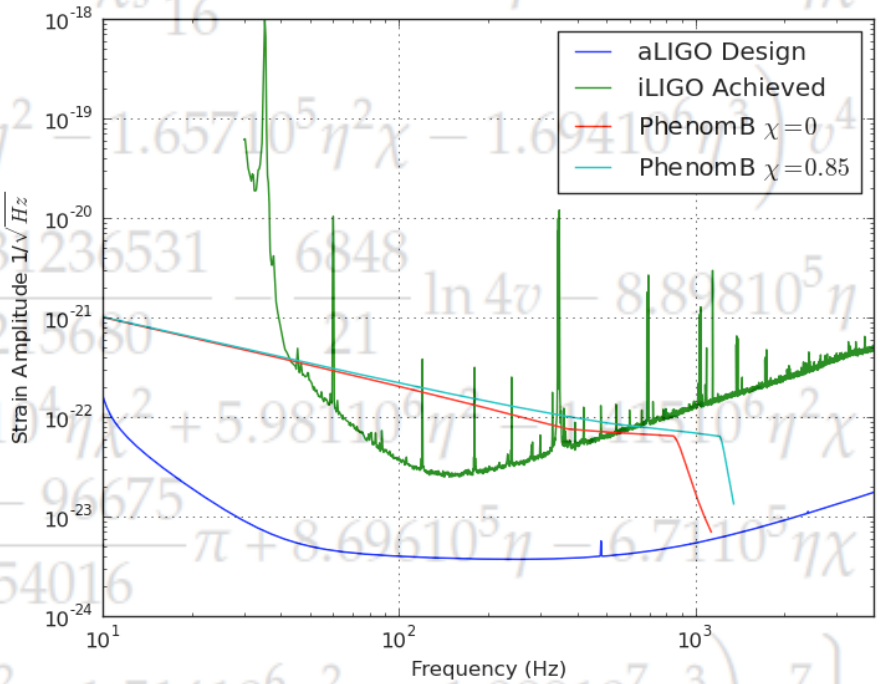
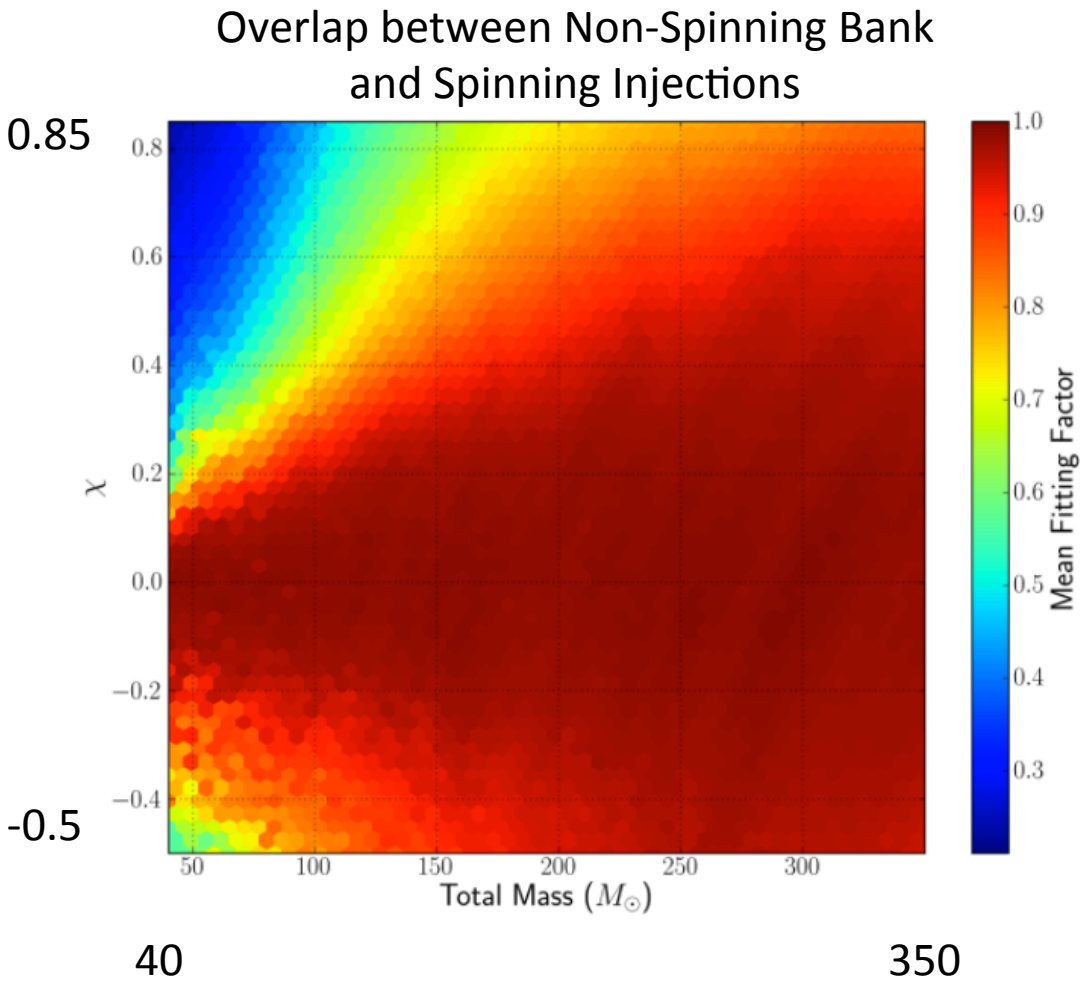


Non-Spinning Bank vs. Spinning Injections



- Negative spin matches with higher-mass non-spinning templates.
- Spin matters less for higher-mass positive spinning injections due to their shorter waveforms.
- Significant loss in sensitivity to lower mass injections with positive spin.

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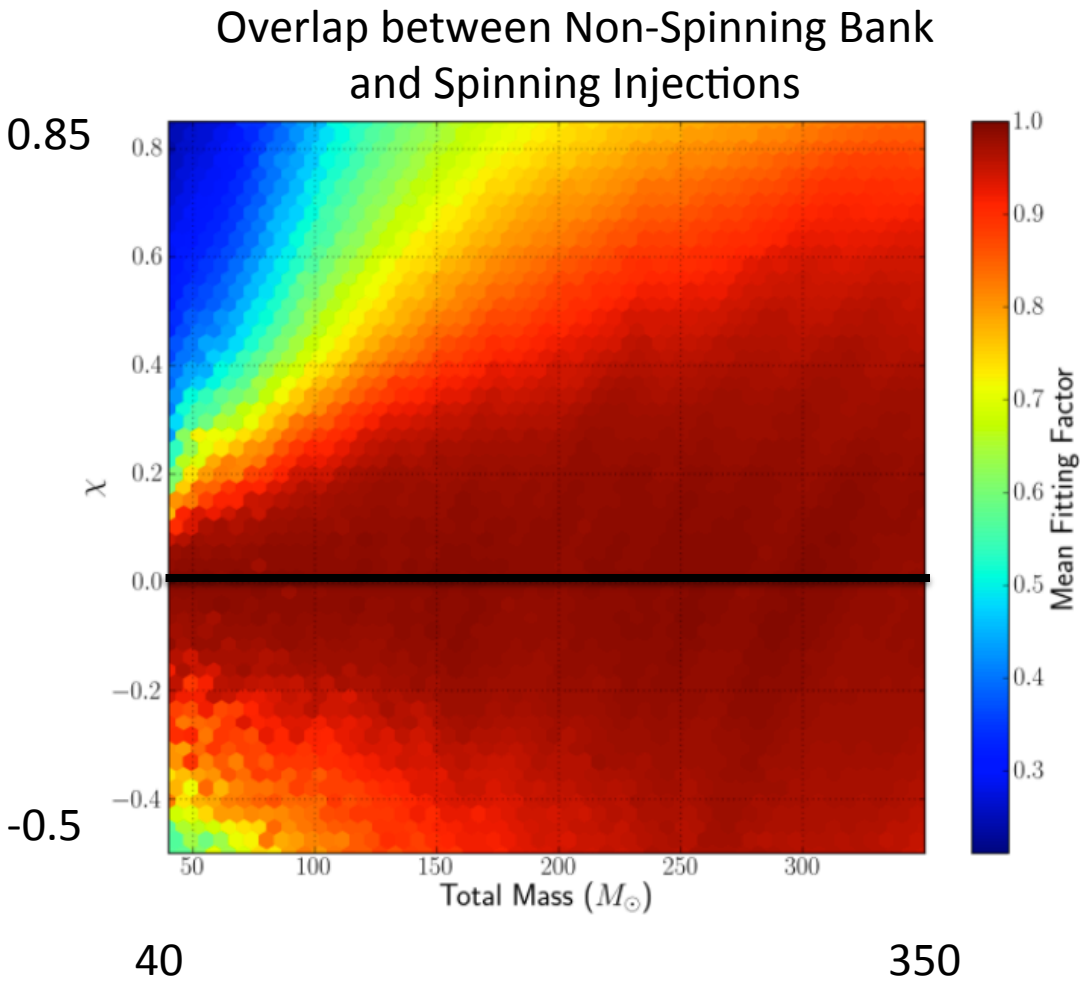

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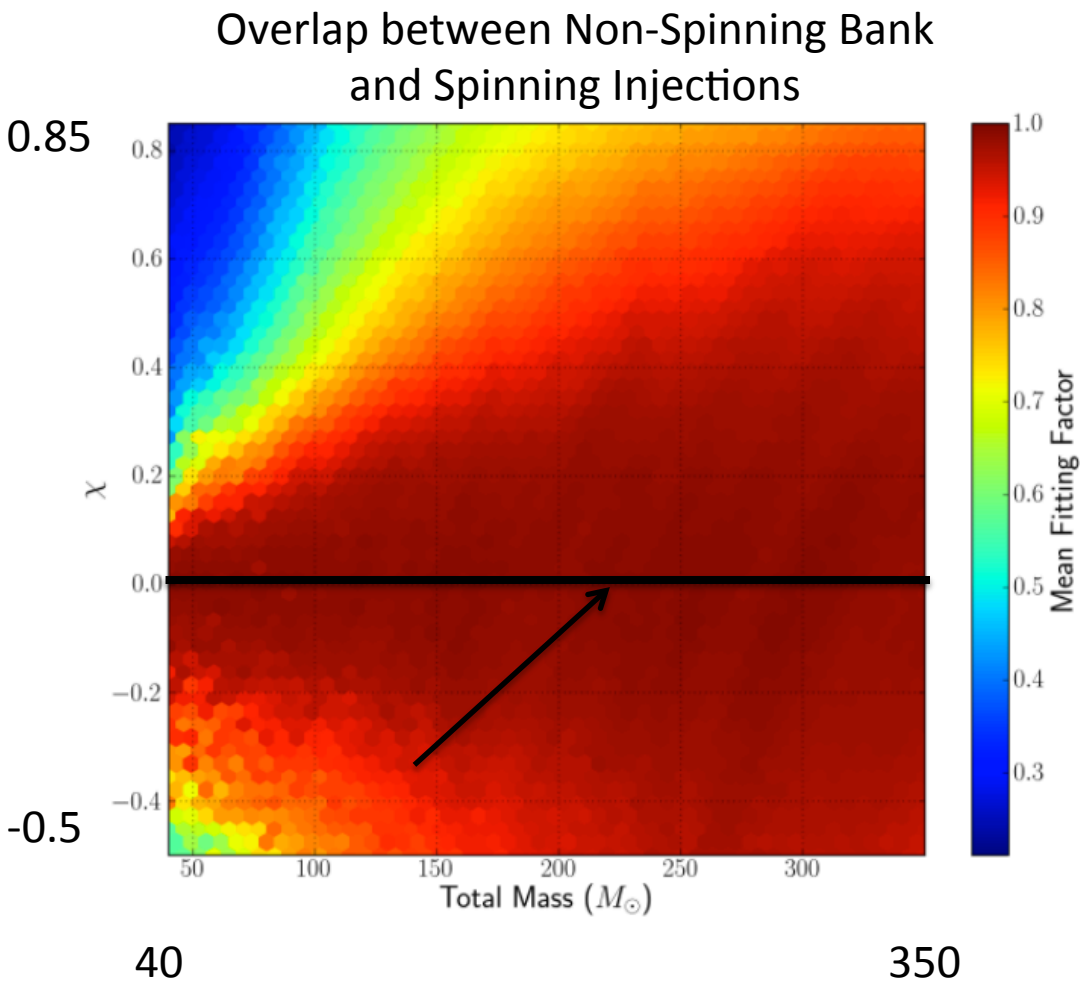

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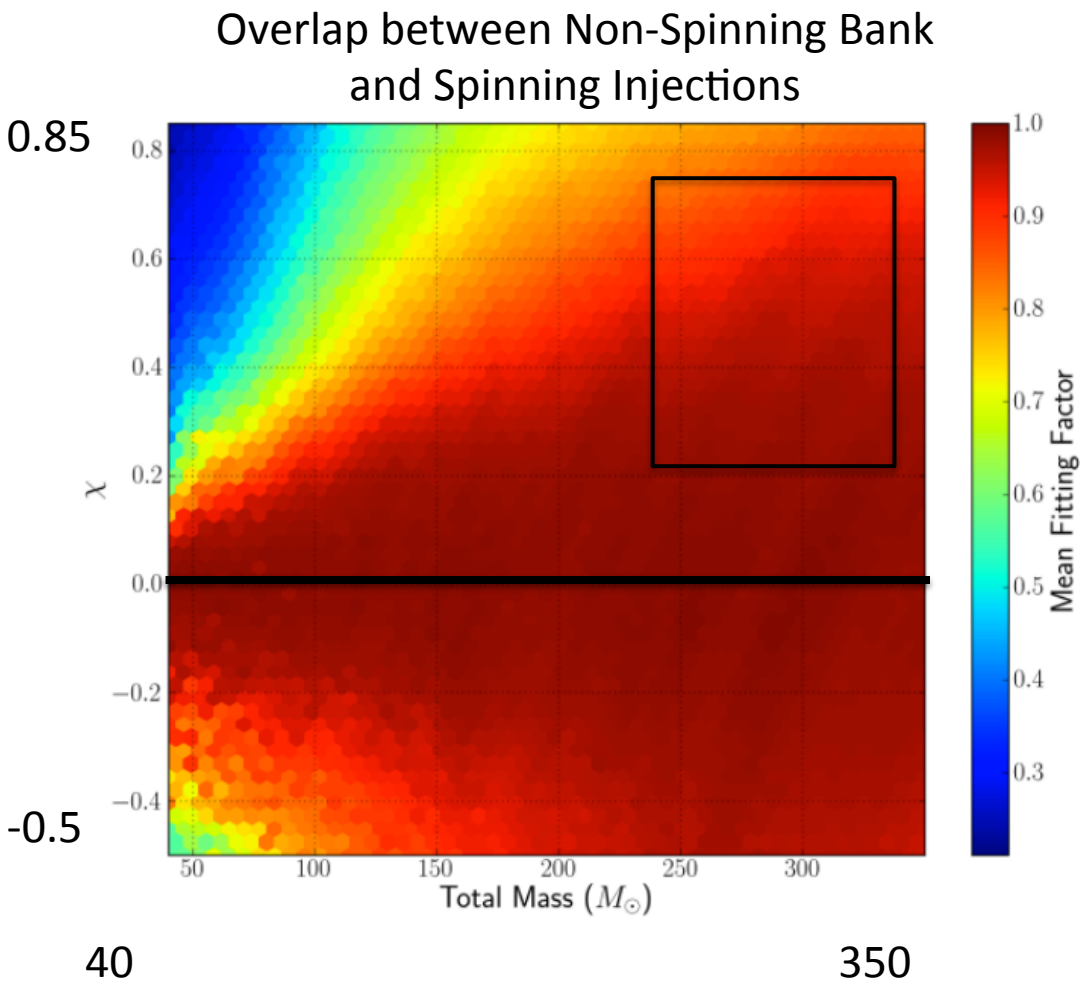

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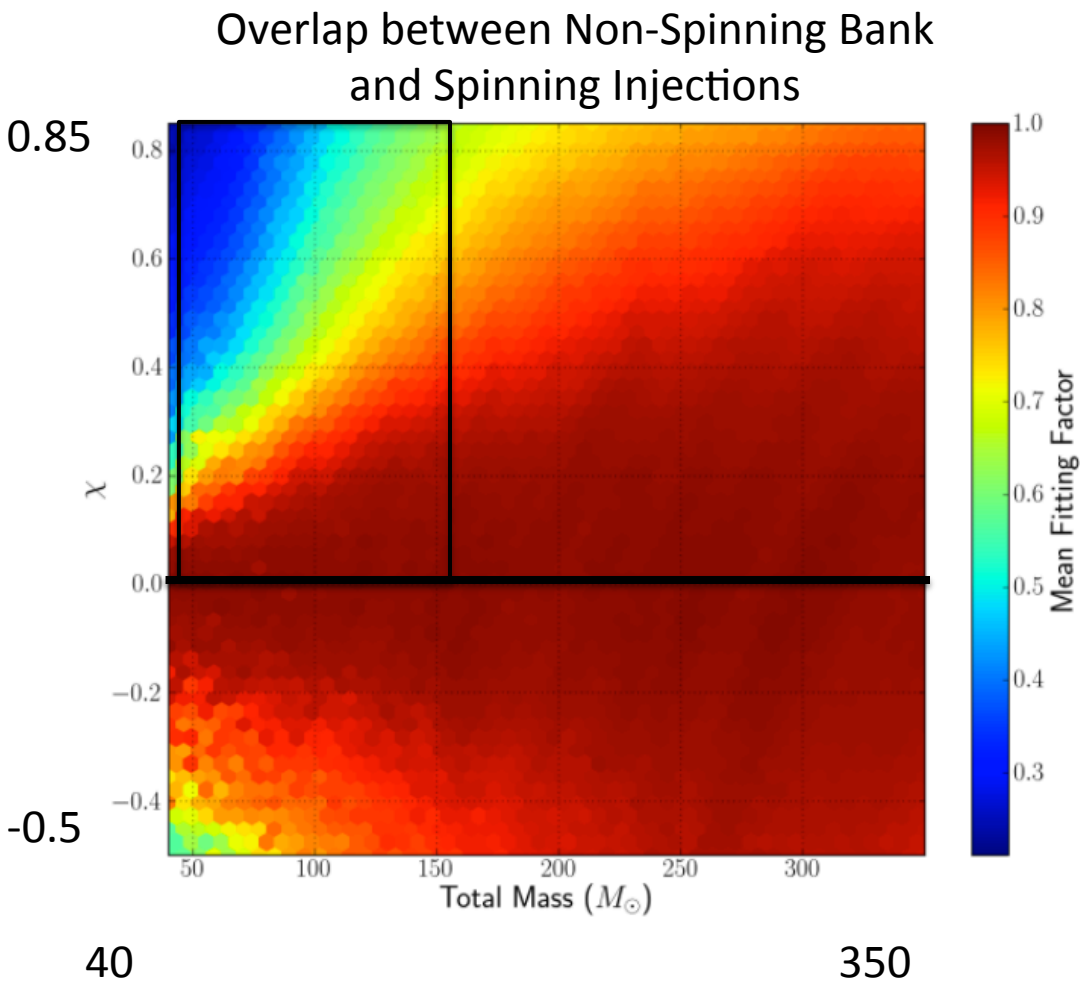

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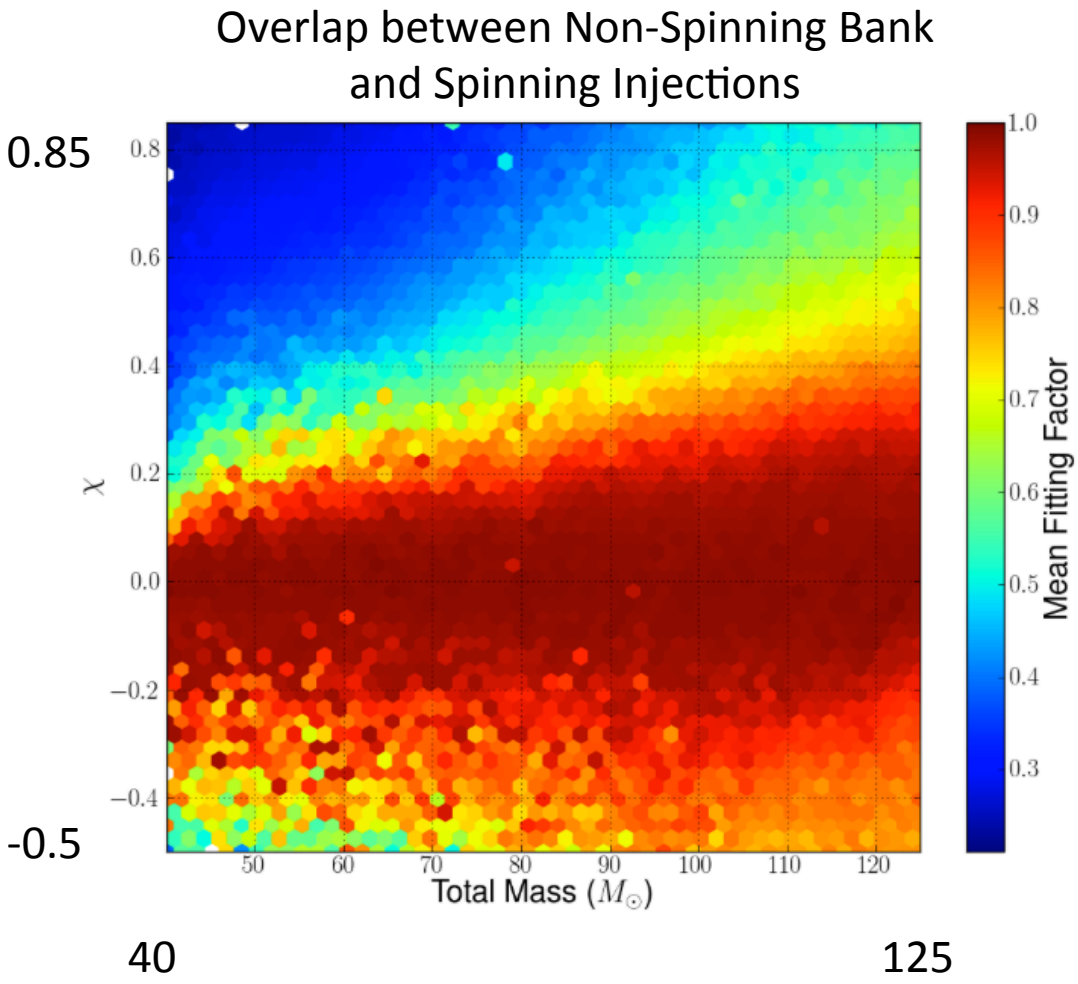

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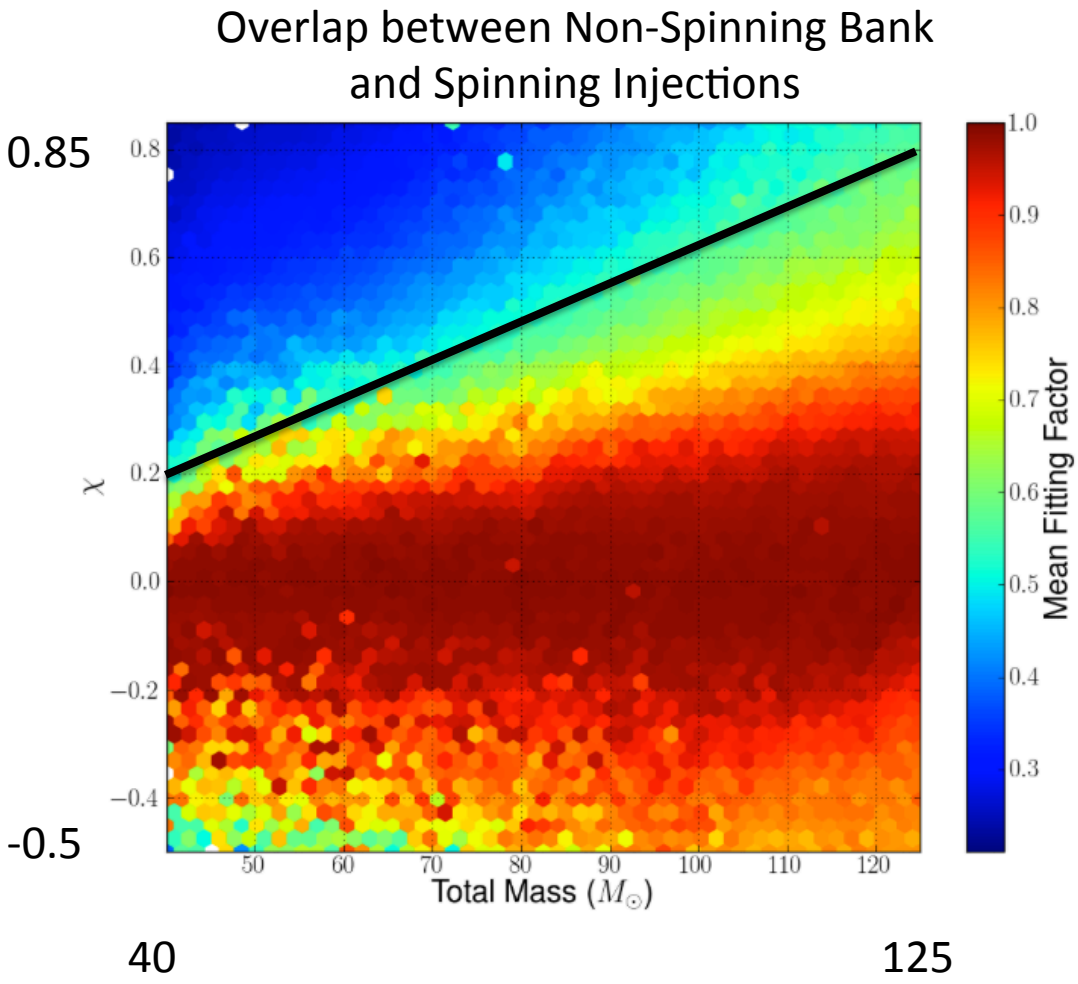

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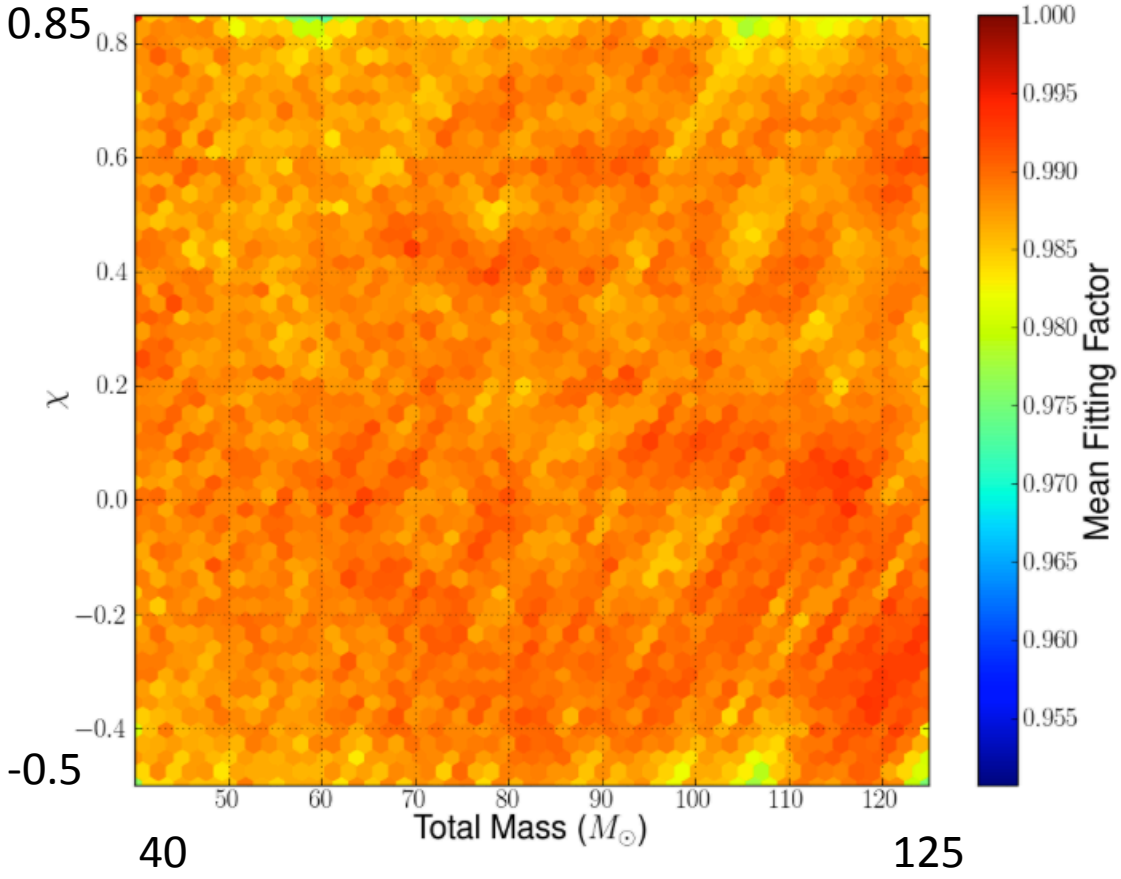
Non-Spinning Bank vs. Spinning Injections

Overlap between Spinning Bank
And Spinning Injections



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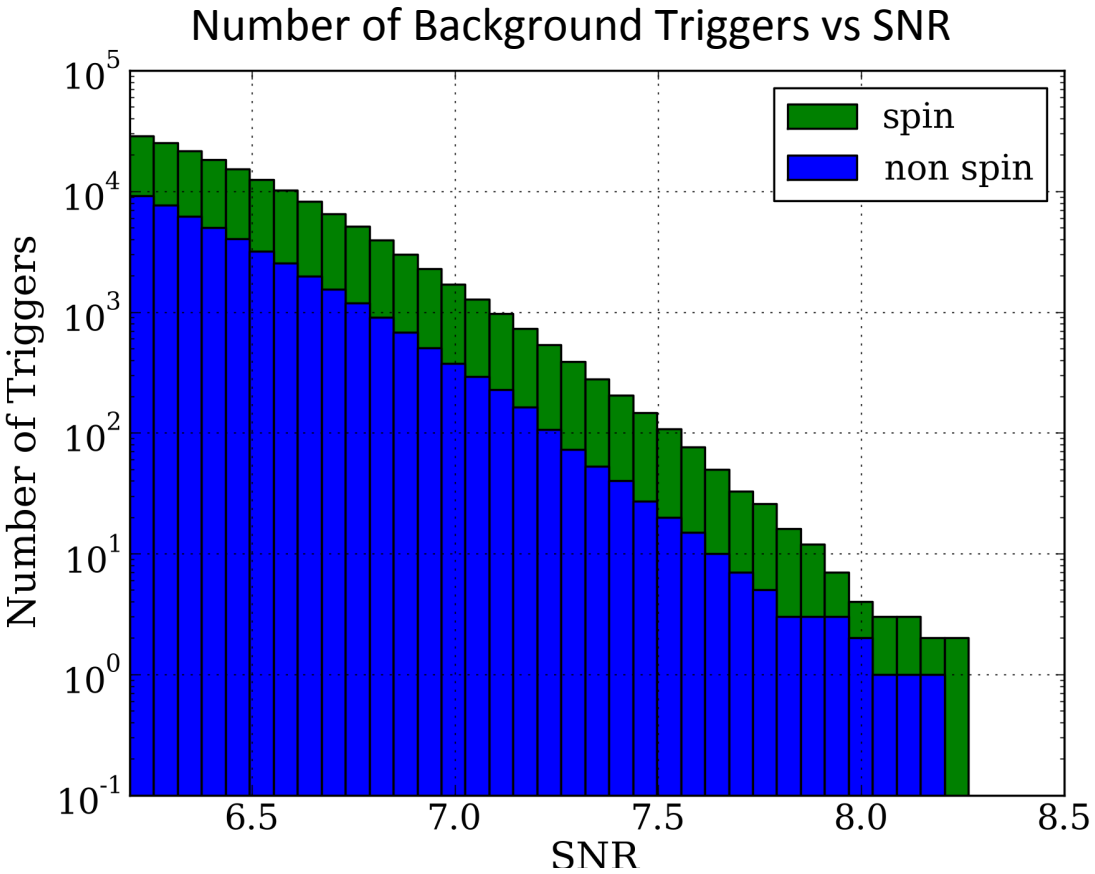
Parallel Pipeline Runs

- Non-spin matched filter template bank
- Positive aligned-spin matched filter template bank
- Gaussian distributed background noise

More Templates – More False Alarm Triggers

- SNR not the whole story.
- Spin increases the number of templates in the bank by ~5.
- Number of triggers proportional to the FAR.
- At fixed FAR must increase SNR threshold.
- Gains in SNR offset by losses through increased false alarm triggers.



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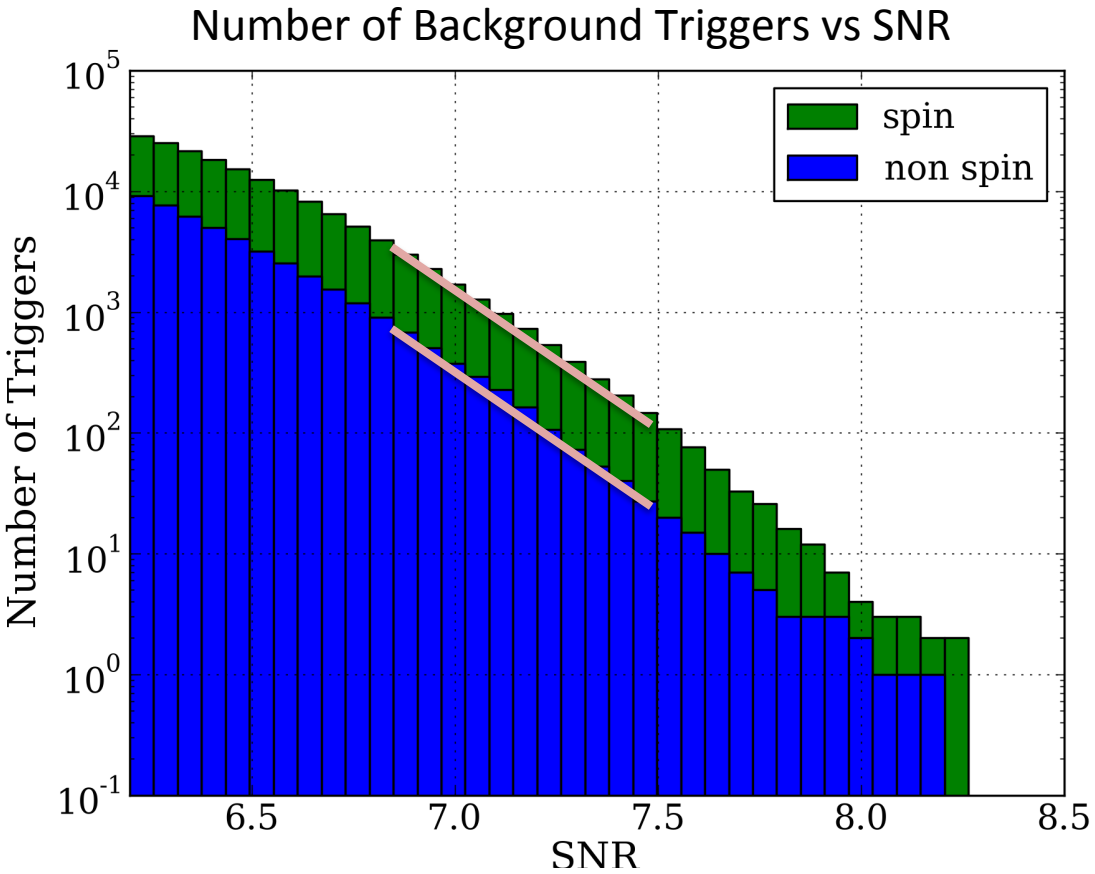

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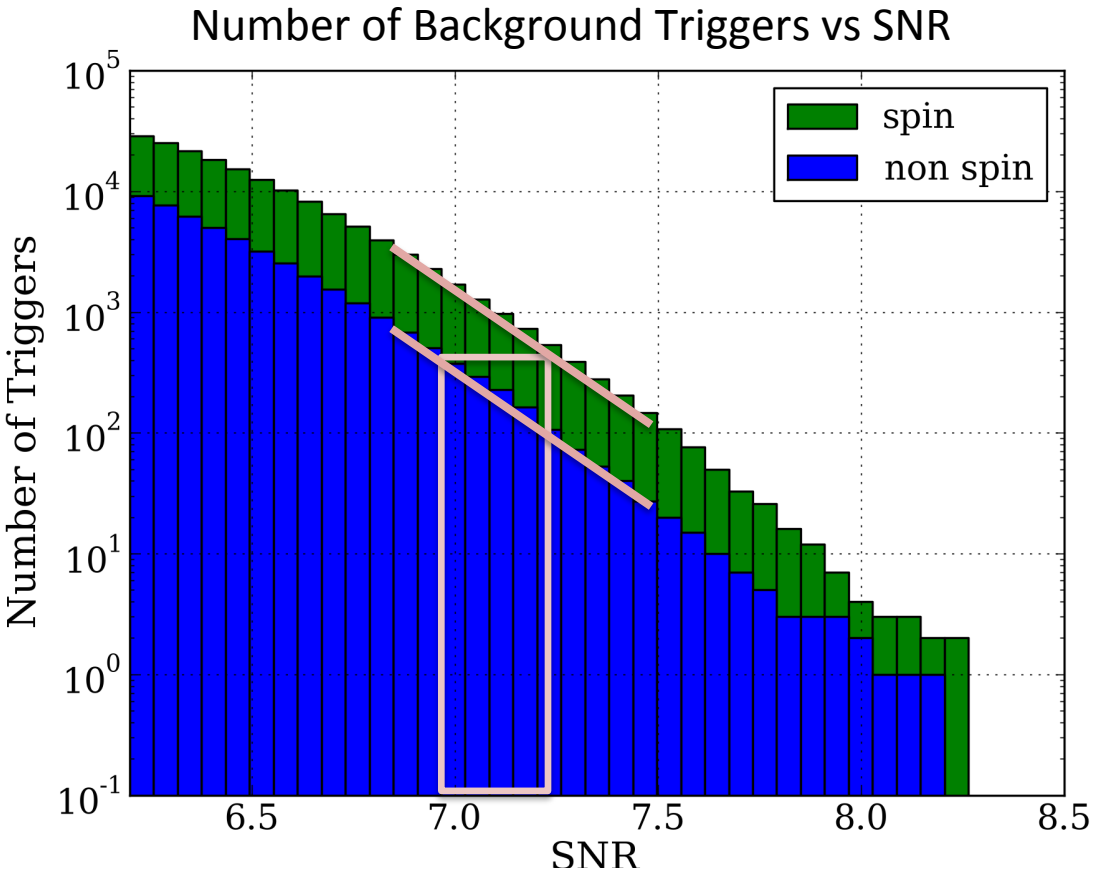


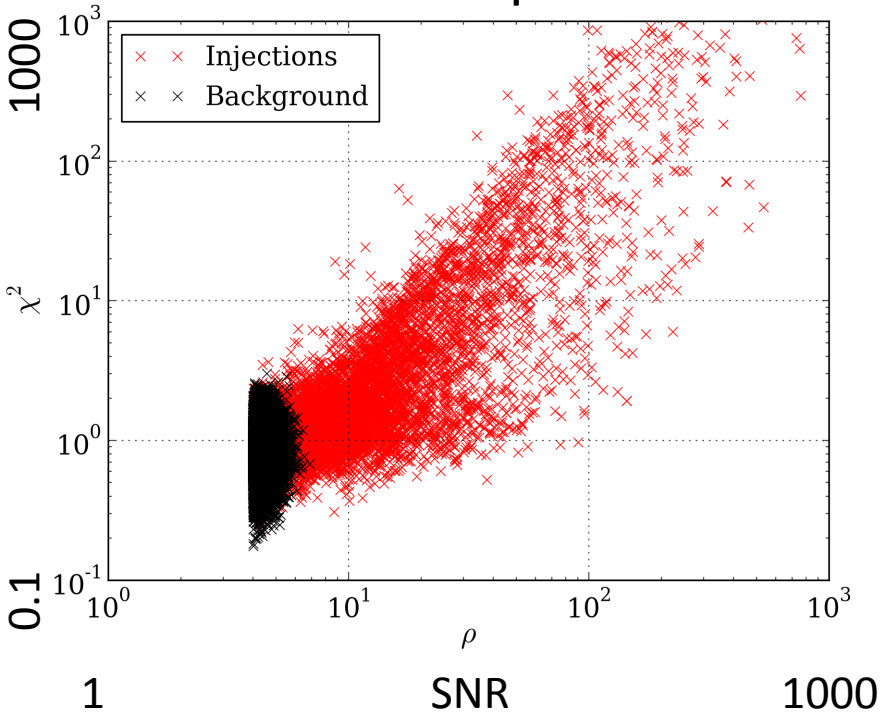
$$N_{bg} \simeq e^{-\rho^2}$$

Methods for BG Rejection

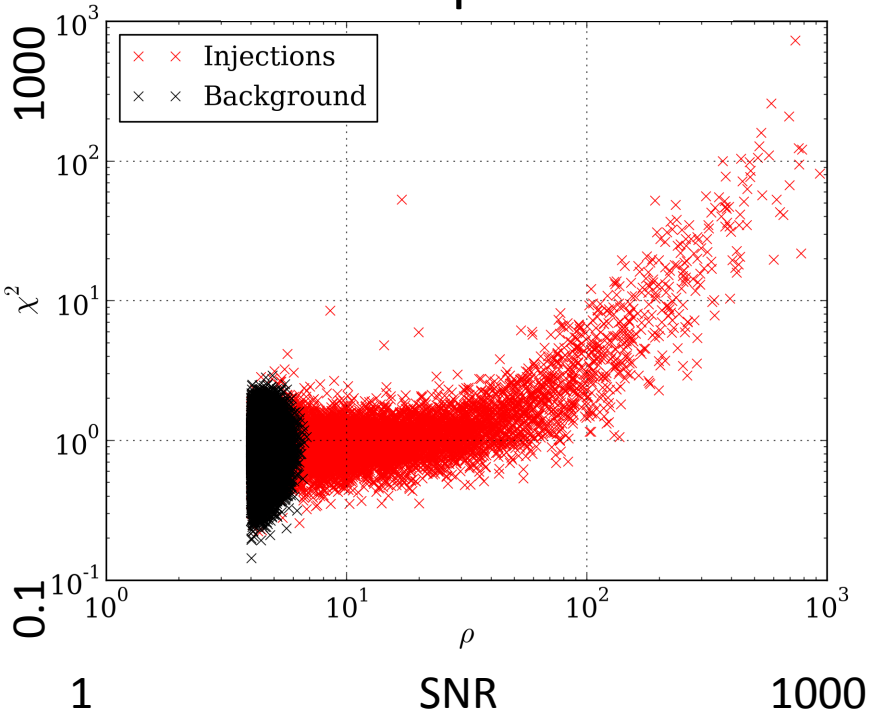
- Auto-correlation signal consistency test - tells us how consistent our data is with Gaussian distributed noise plus signal.

- Exact mass and spin coincidence between detectors – same template must be rung up in both detectors to be considered a possible detection.

Non-Spin



Spin



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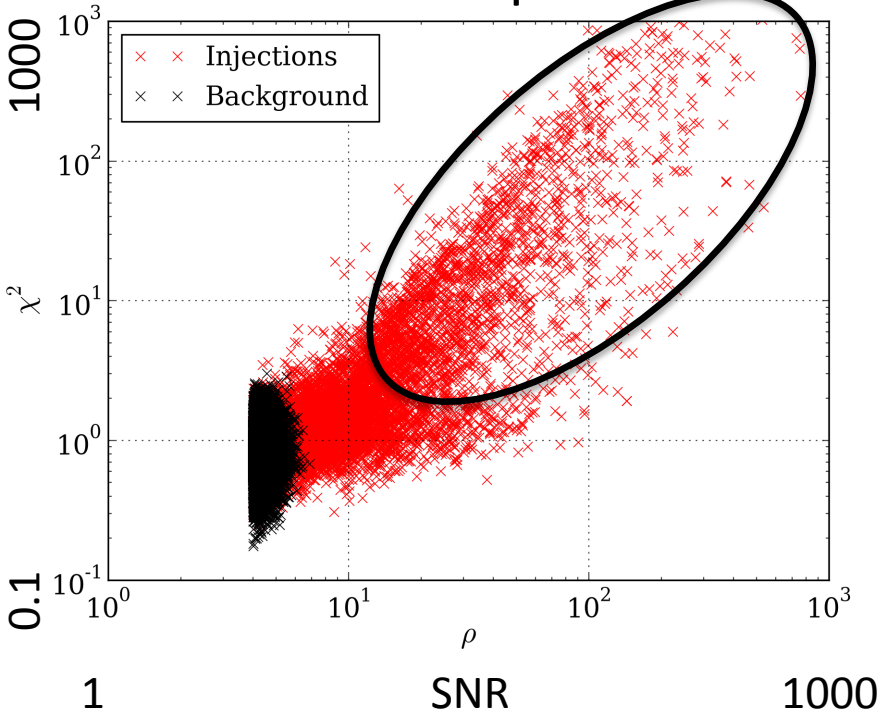

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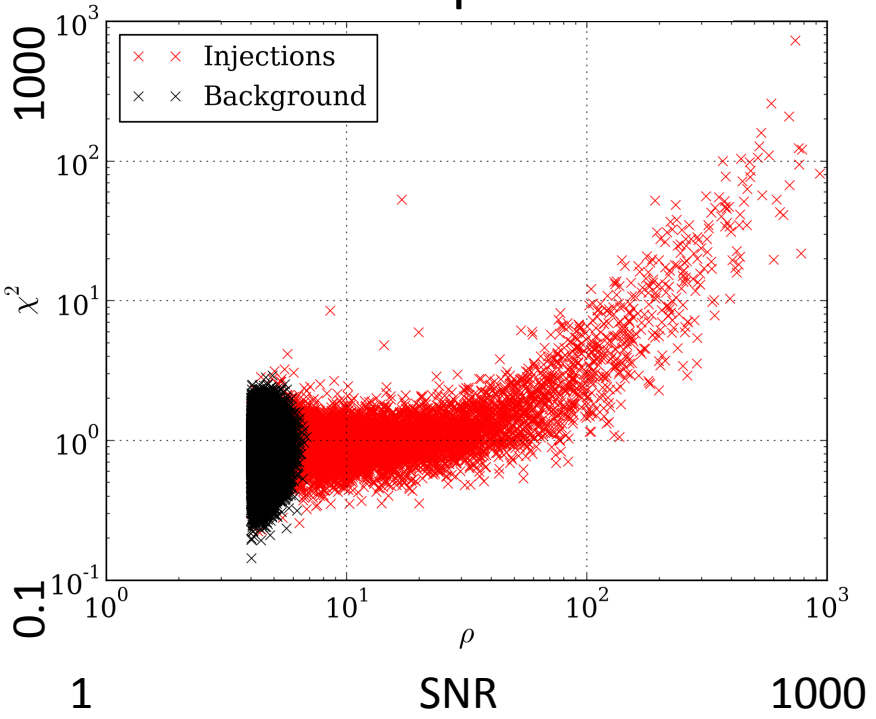

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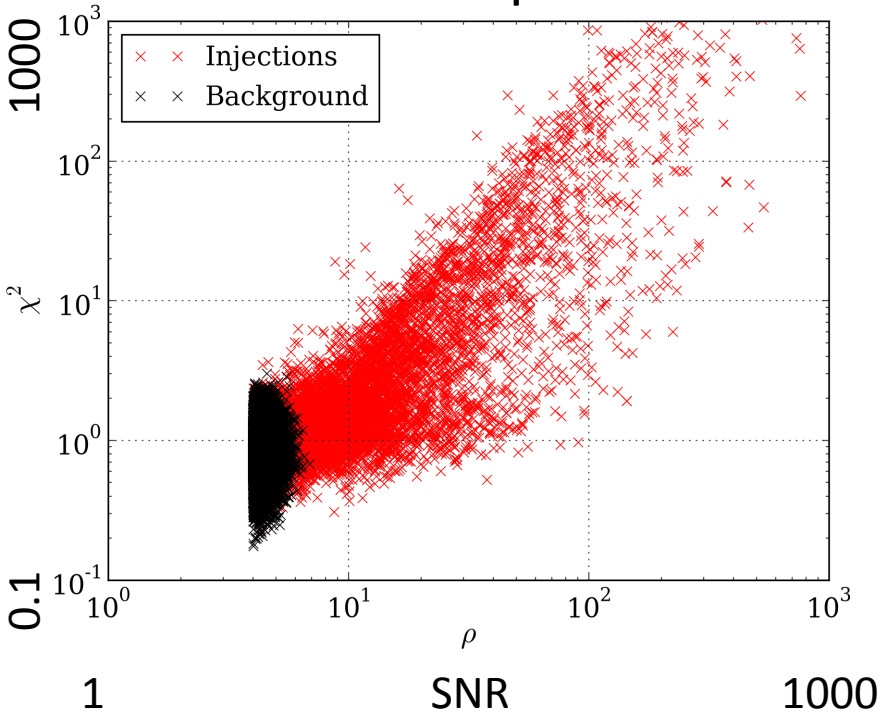

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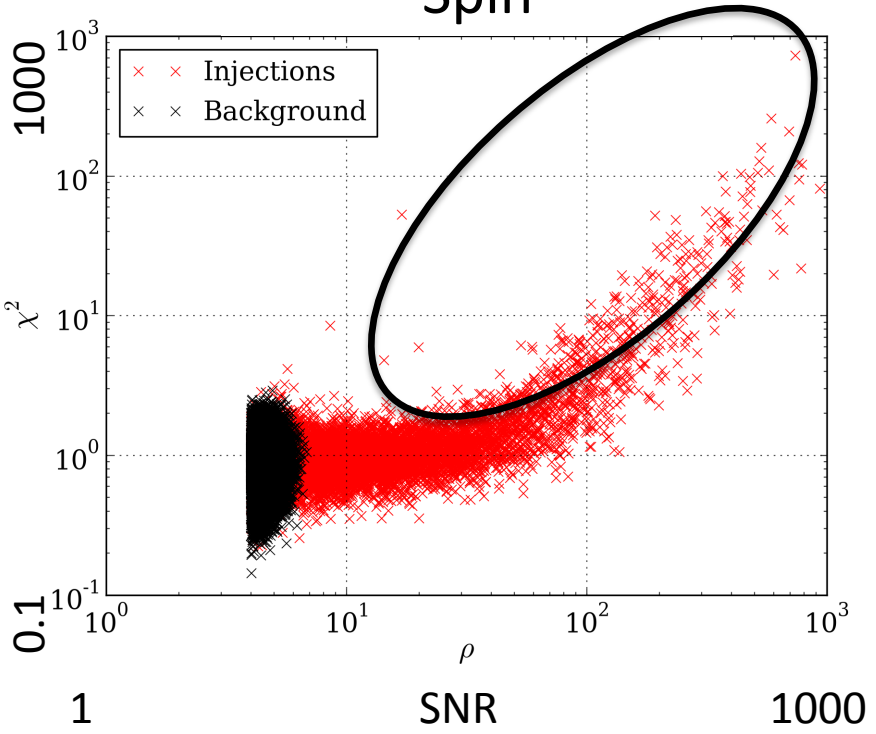
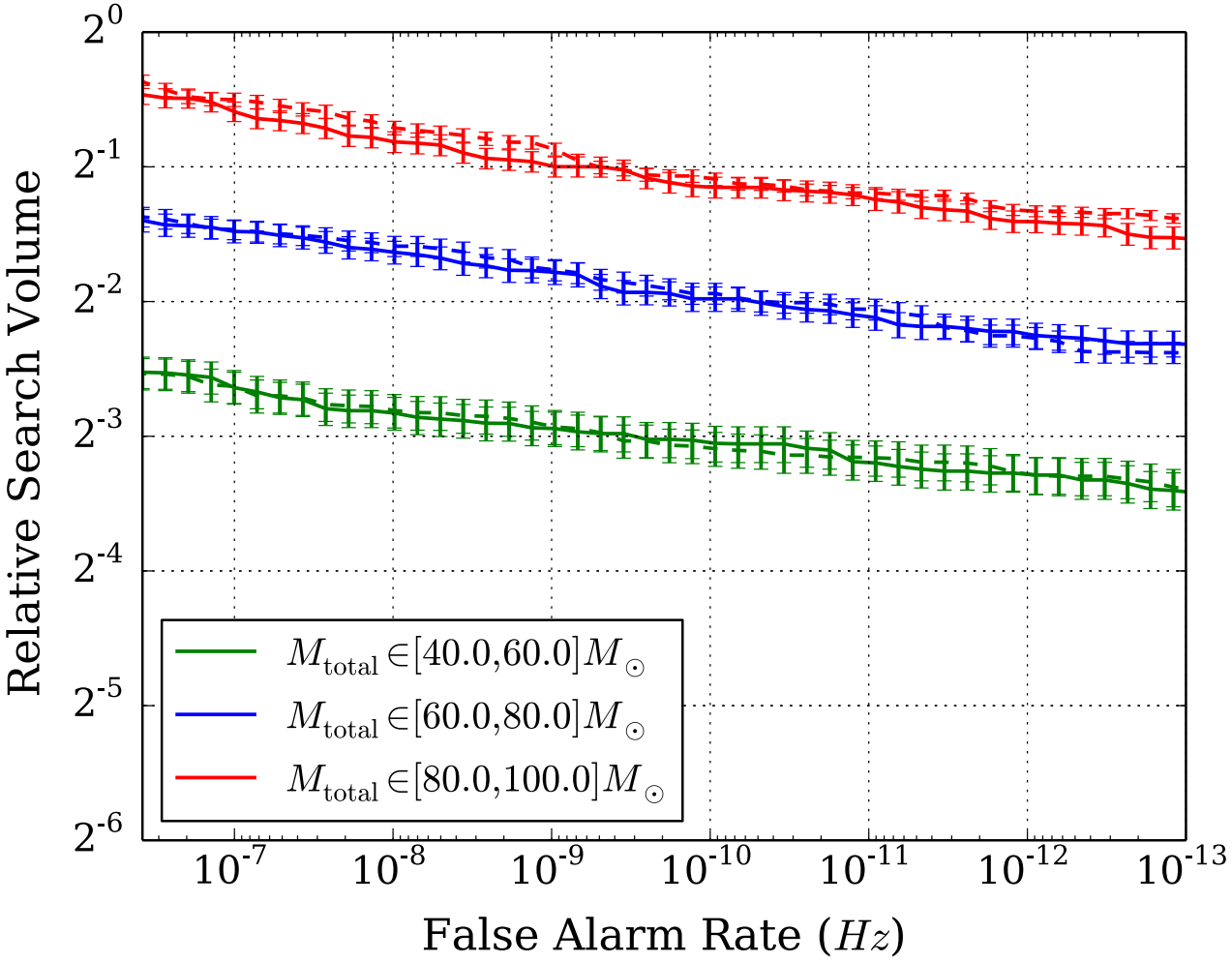


Volume Sensitivity

False Alarm Rate vs Relative Search Volume with $\chi \in [0.0, 0.2]$

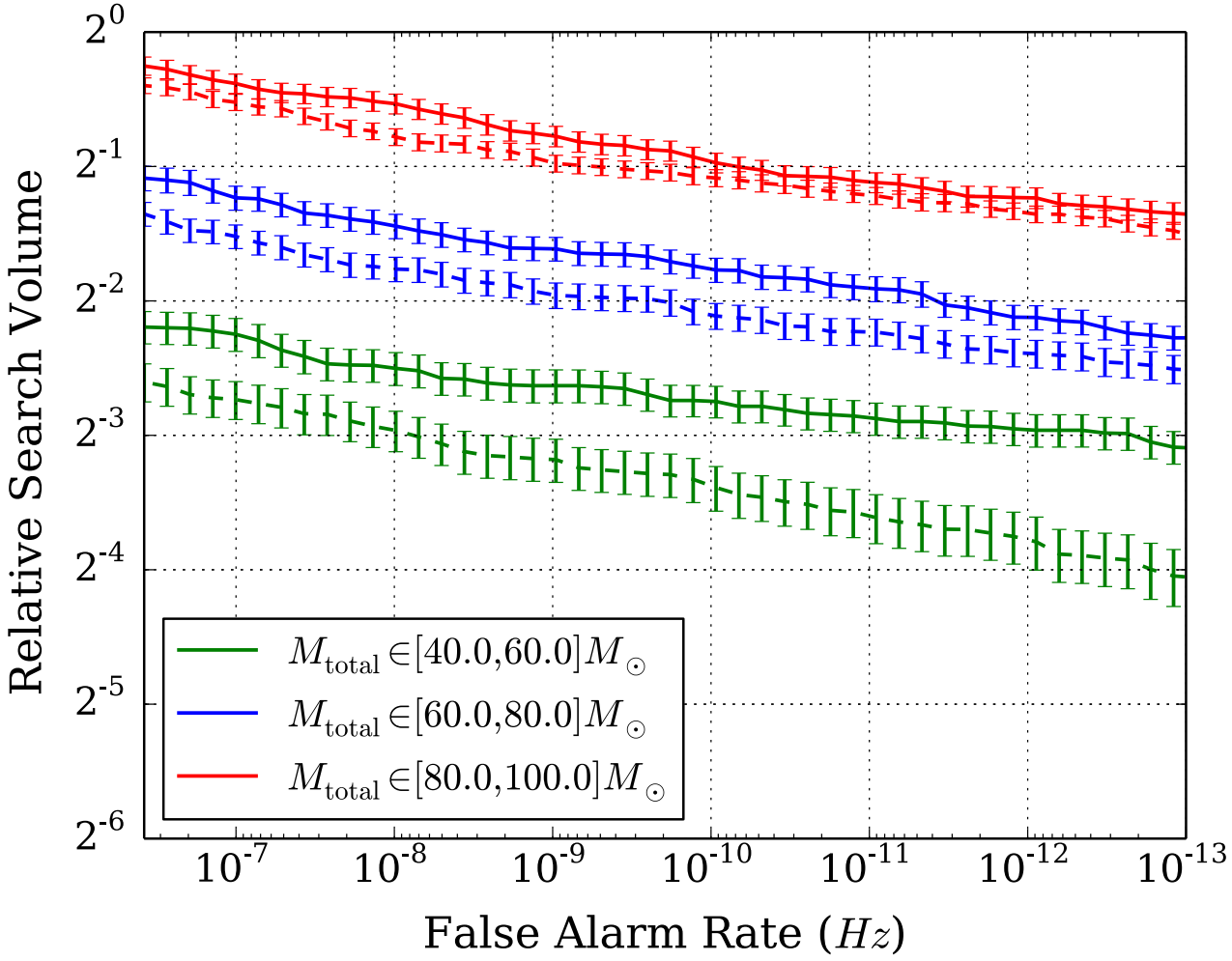


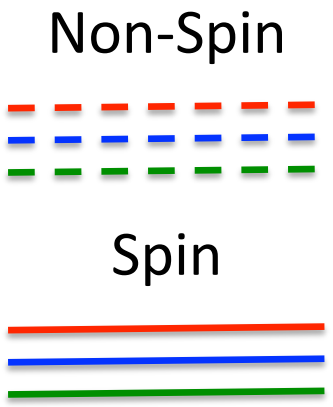
Non-Spin

Spin

Volume Sensitivity

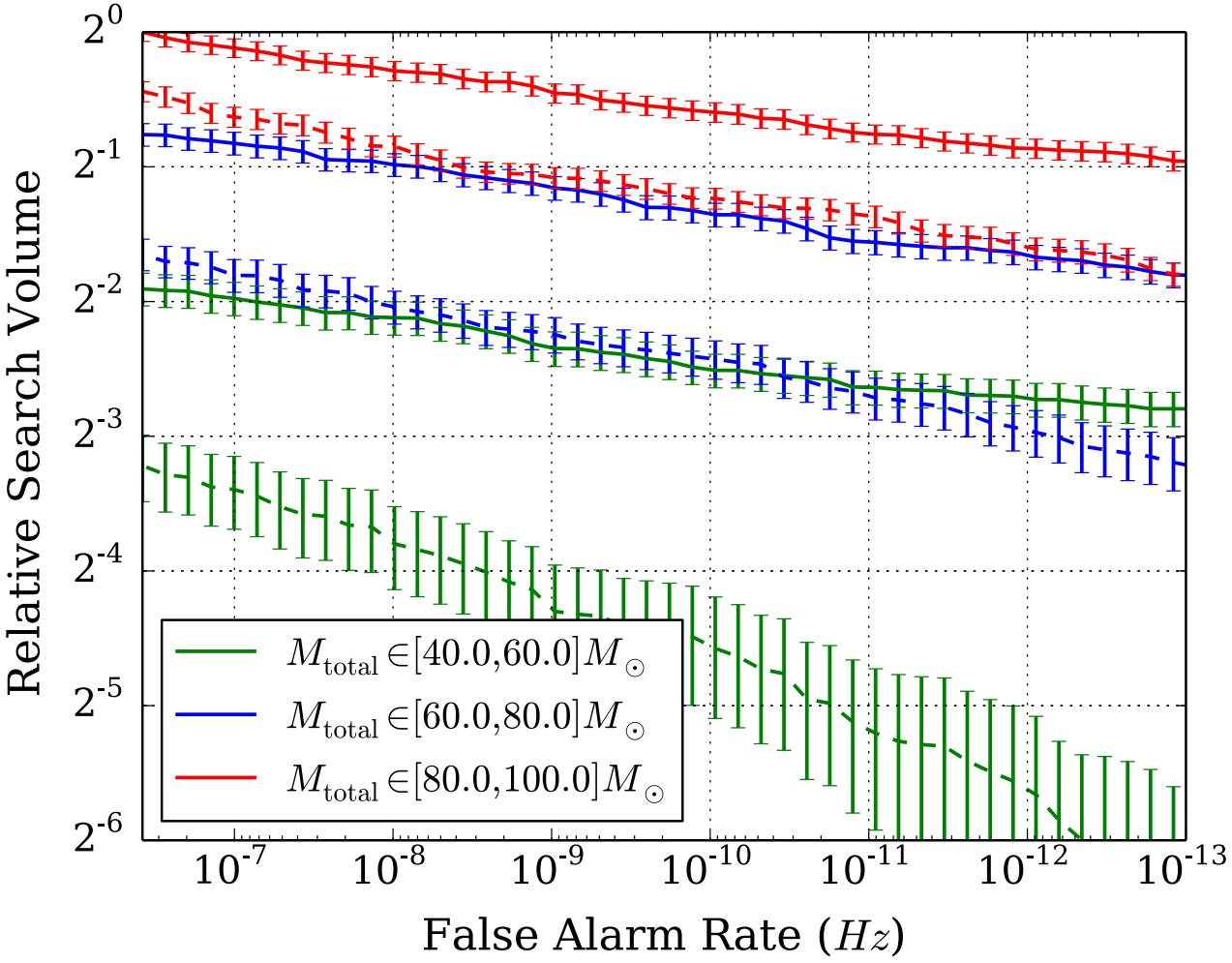
False Alarm Rate vs Relative Search Volume with $\chi \in [0.2, 0.5]$





Volume Sensitivity

False Alarm Rate vs Relative Search Volume with $\chi \in [0.5, 0.85]$

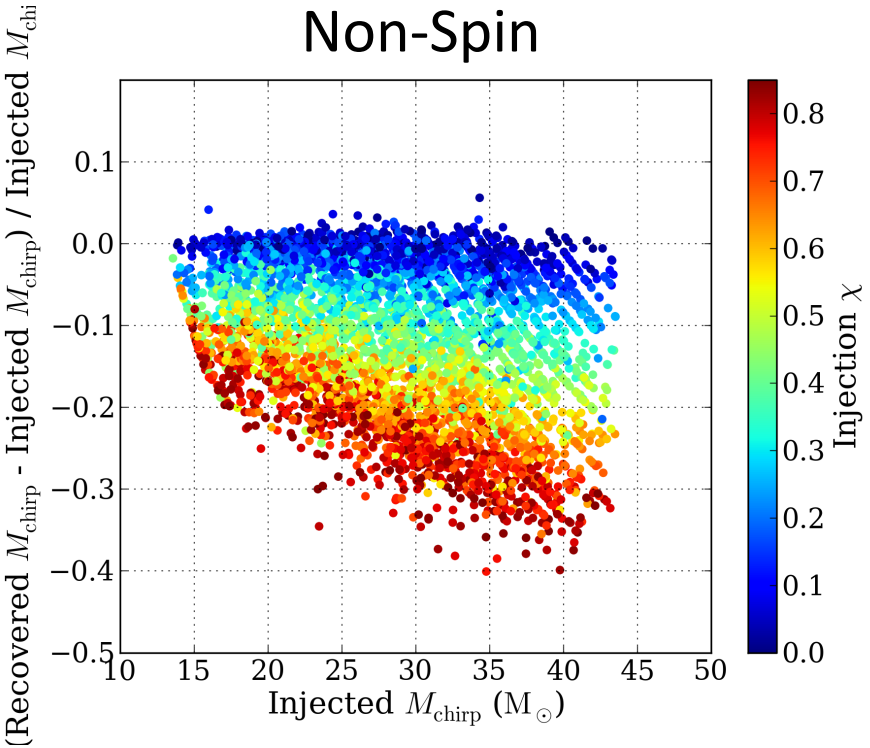


Non-Spin

Spin

Parameter Recovery

Non-Spin



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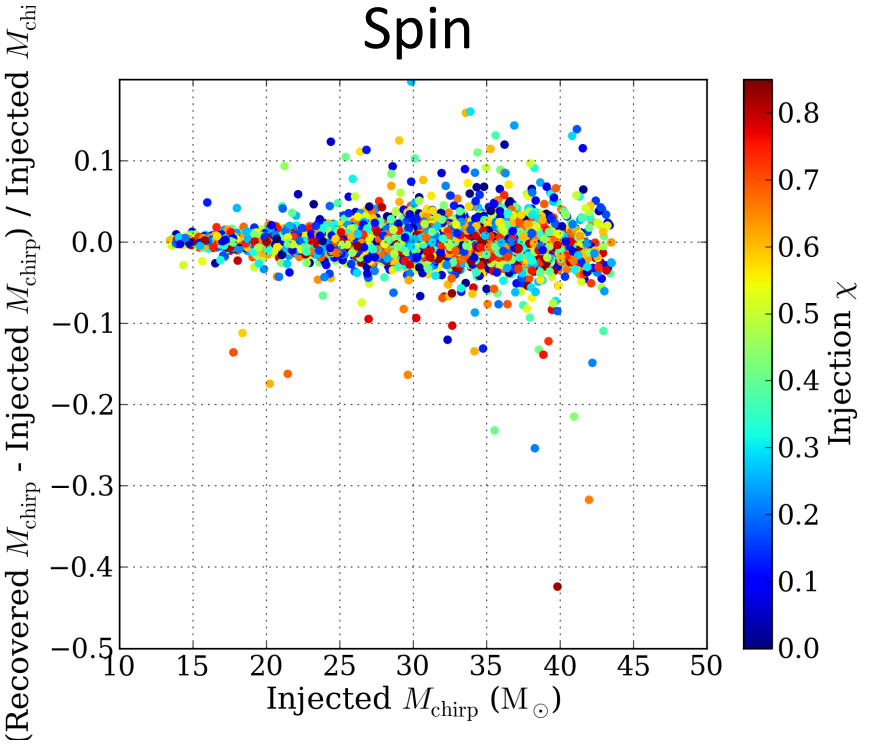
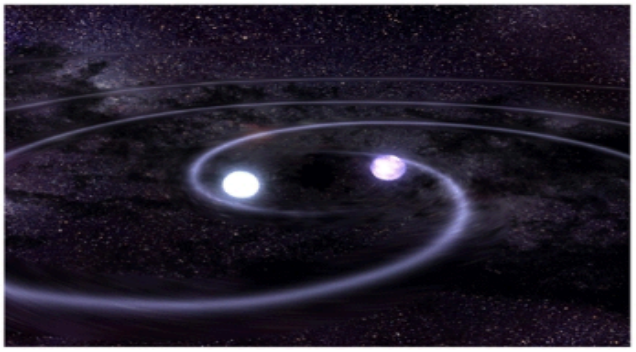
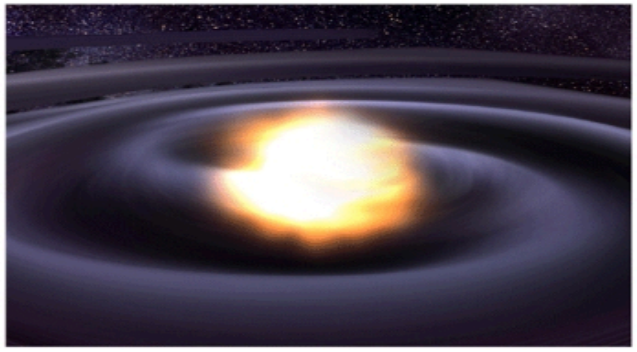


$$\mathcal{M}_{chirp} = M\eta^{\frac{3}{5}} \qquad \eta = \frac{m_1 m_2}{M^2}$$

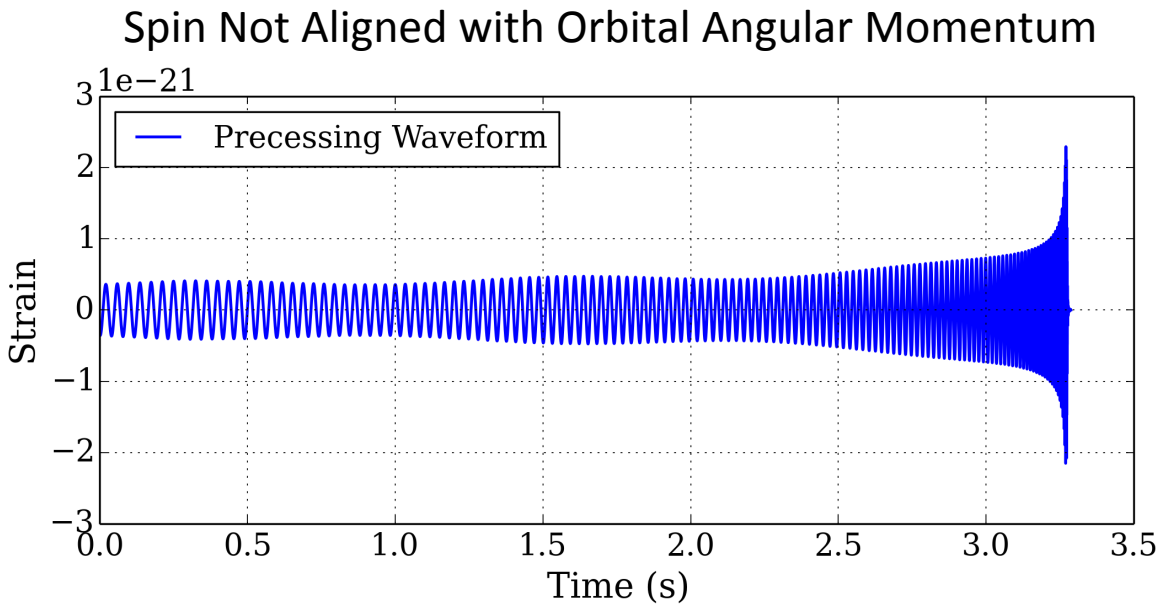
More accurate parameter recovery when spin is included.





Future Work

- Non-Gaussian noise
- Waveforms that cover the total mass range 10-40 solar masses
- Holy grail: templates with spin not aligned with orbital angular momentum.



Muchas Gracias!

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