Implementation of a search for aligned spinning black hole and neutron star systems

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NSBH as spinning sources

- Black holes in Neutron Star-Black Hole (NSBH) binary systems may have considerable spin.
- The neutron stars are not likely to be spinning much so we can consider single exact spin on only BH.
- The lightness of NSBH systems means that motion and signal are more strongly affected by spin.
- Lighter NSBH systems merge at higher frequencies so merger and ringdown can be neglected.

What makes this possible?

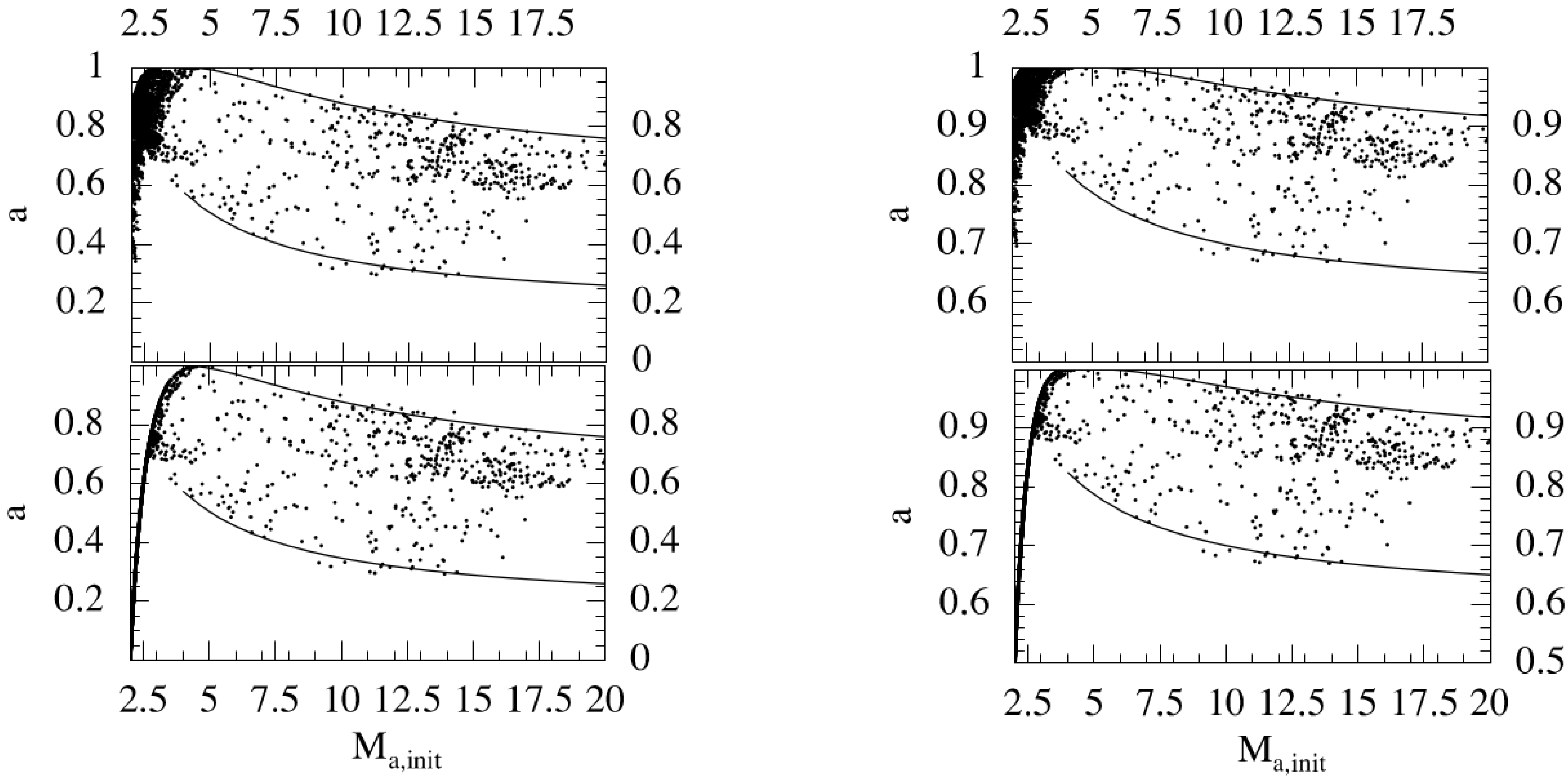
- Wider, better detector sensitivity in aLIGO era
- Better knowledge of spin effects at higher pN
- Use signal vetoes in non-Gaussian data;
  chi squared and new SNR
- Faster analysis tools, running on GPUs
- More scalable database

Stellar mass black hole parameters

system	binary type	M_solar	D (kpc)	method	a_*
A0620-00	LMXBT K 0.5	6.61±0.12	1.06±0.12	CF	0.12±0.18[4]
XTE J1550-564	LMXBT G or K 1.5 1.54 days	9.10±0.61	4.38±0.50	CF QPO Fe	0.34±0.28[8] 0.7±0.01[2] 0.55±0.22[8]
GRO J1655-40	LMXBT F5 2.6 days	6.30±0.27	3.2±0.5	CF QPO	0.7±0.05[4] 0.75±0.01[2]
GRS 1915+105	LMXBT KIII 30.8 days	14.0±4.4	11.0±1.0	CF QPO	>0.98[4] 0.68±0.08[2]
4U 1543-47	LMXBT Roche	9.4±1.0	7.5±1.0	CF	0.80±0.05[4]
H 1743-322	LMXBT Roche	11.3	10	QPO QPO	>0.68[1] 0.74[2]
LMC X-3	HMXB wind	10	50	CF	<0.3[4]
M33 X-7	HMXB wind	15.65±1.45	840±20	CF	0.84±0.05[4]
LMC X-1	HMXB wind	10.9	50	CF	0.92±0.07[4]
Cyg X-1	HMXB wind OB 19.2±1.9 5.6days	14.8±1.0	1.86±0.12	QPO Fe CF	0.49±0.01[5] 0.97±0.02[6] >0.983(3σ)[3,7]

Sources: *1. Mondal, ApJ 708 (2010),*
2. Mukhopadhyay, ApJ 694 (2009)
3. Gou et al., ApJ 742 (2011)
4. McClintock et al.,, CQG 28 (2011)
5. Axelsson et al., AA 438 (2005),
6. Fabian et al., 1204.5854
7. Gou et al. 1308.4760
8. Steiner et al. MNRAS 416 (2011)

Effect on spins due to common envelope phase



Black hole final spins due to HCE phase (top) and accretion after collapse (bottom) assuming BH natal spins of 0 (left) and 0.5 (right).

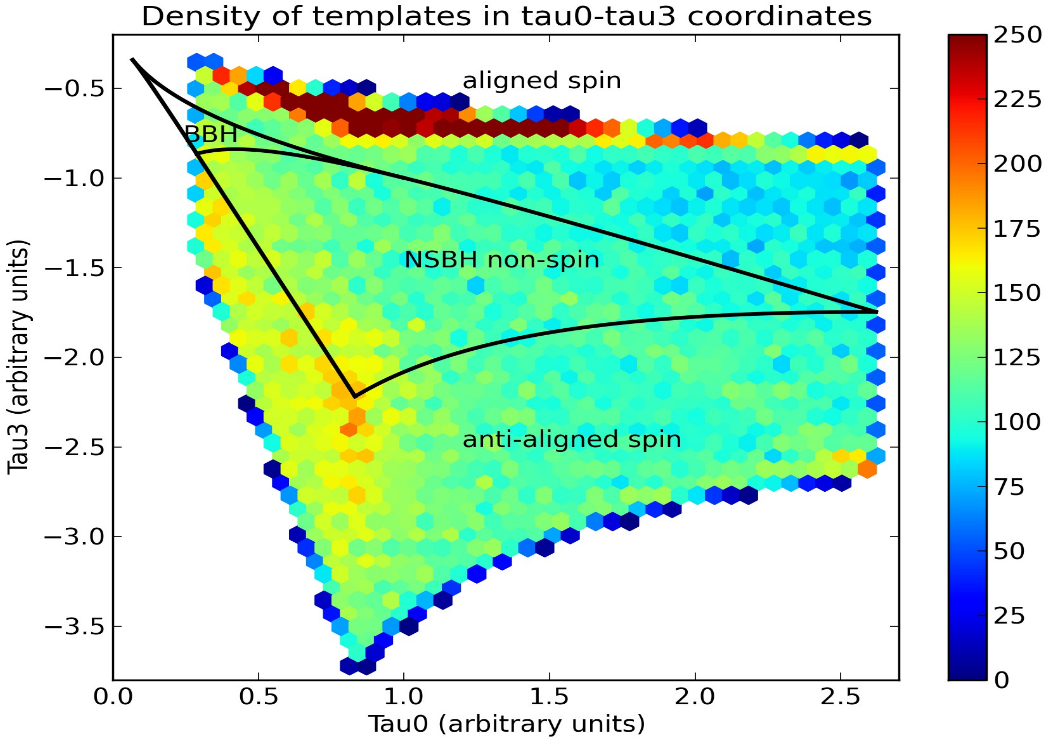
Source: *O'Shaughnessy et al. ApJ 632 (2005)*

Search parameters details

- **Data:** Early-recolored MDC, H1, L1, approx 25 hrs
- **Templates:** spins -1 to +1 (BH), -0.4 to +0.4 (NS), masses 3 to 15 M_s (BH), 1 to 3 M_s (NS), TaylorF2, 30 Hz to ISCO, pylal_aligned_stoc_bank
- **Injections:** spins flat -1 to +1 (BH), -0.05 to 0.05 (NS), masses Gaussian around 7.8M_s (BH), 1.35M_s (NS), distance 40-100Mpc, inclination face-on, 3.5 pN SpinTaylorT2 waveforms, 14 Hz to MECO, lalapps_inspinj

Spinning template banks for early aLIGO

- 27,752 templates in non spinning stochastic
- 88,213 templates in spinning geometric
- 150,977 templates in spinning stochastic



Relevant search statistics

Signal to Noise Ratio (SNR)

$$\rho = 4\,\Re \int \frac{e^{-2\pi i f t}\,\tilde{s}(f)\,\tilde{h}^{*}(f)}{A_n^2(f)}\,df$$

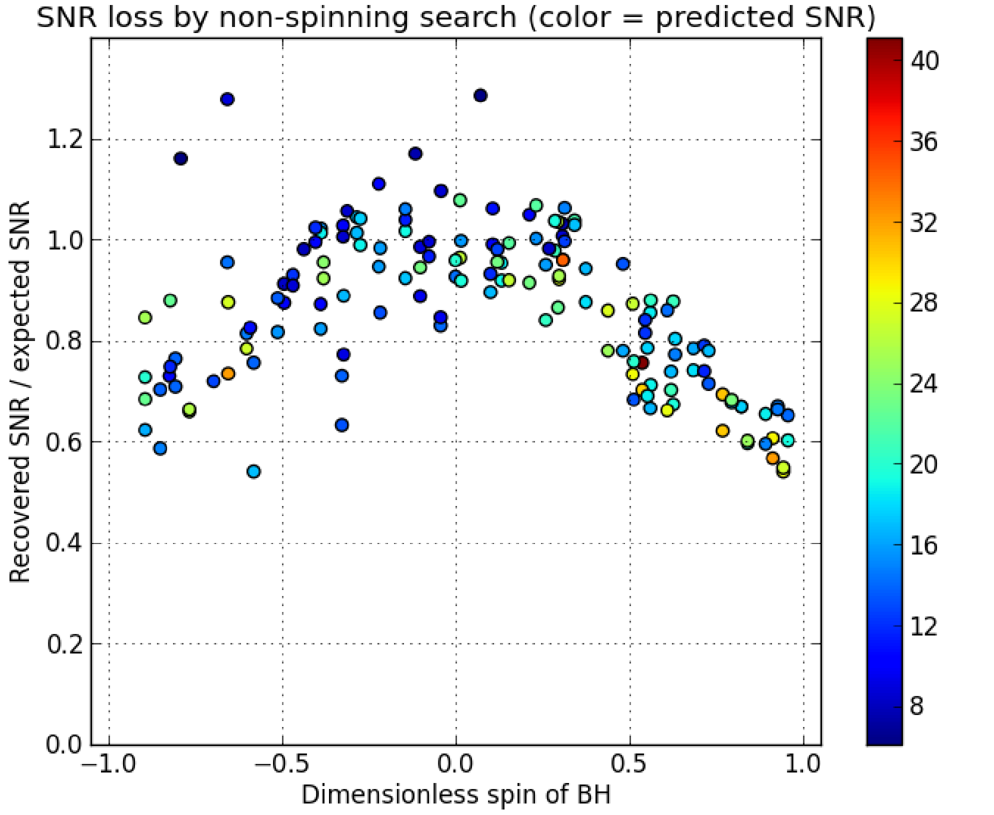
Chi squared

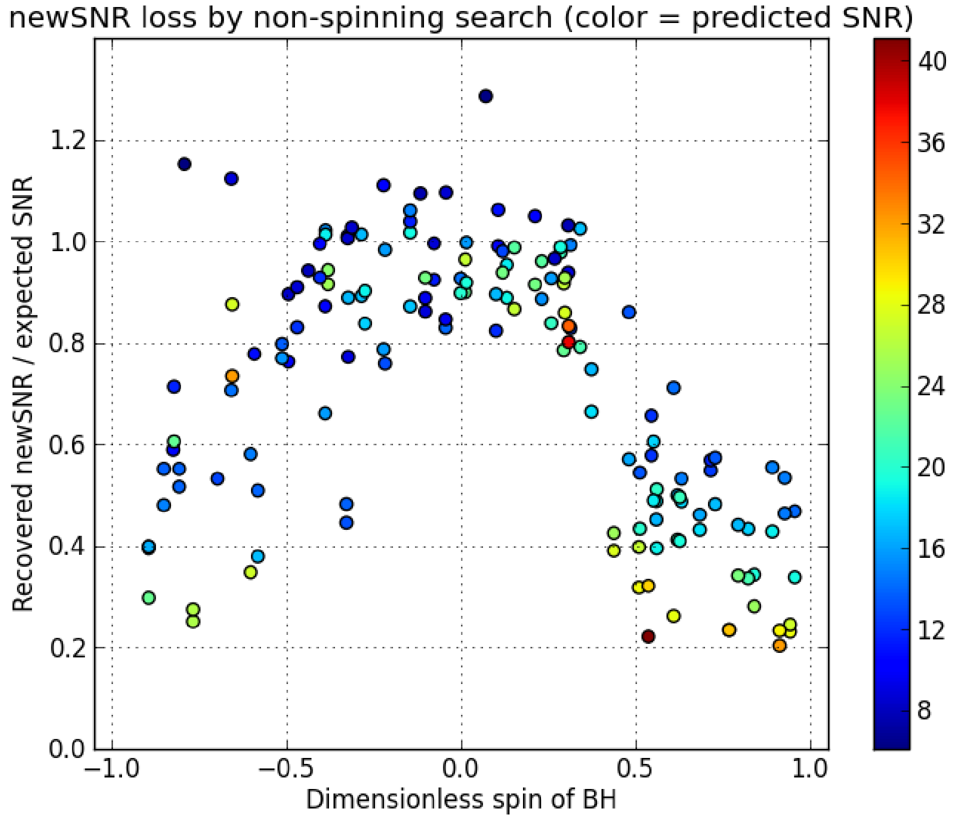
$$\chi_r^2 = \frac{N \sum_{j=1}^{N} \left(\rho_j - \frac{\rho}{N}\right)^2}{2n-2}$$

New SNR

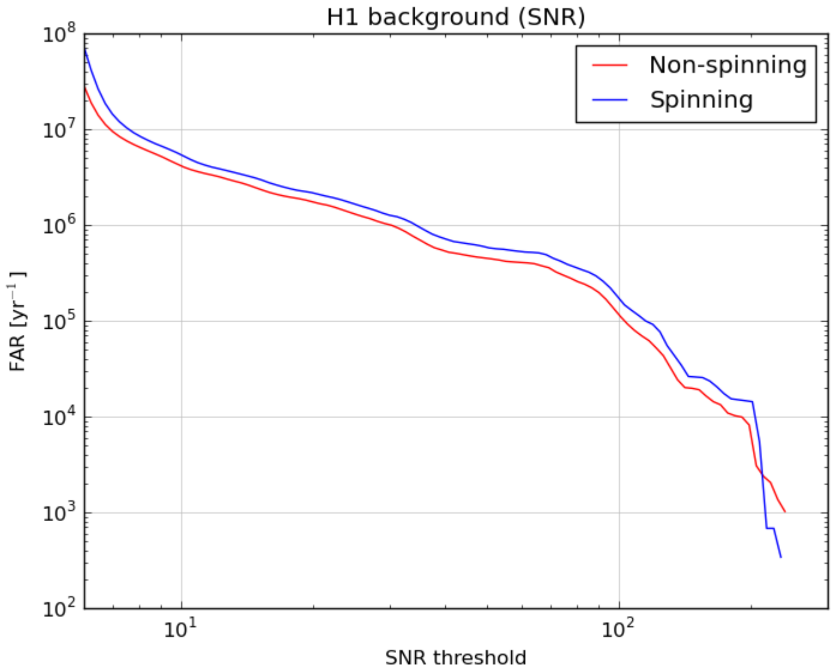
$$\hat{\rho} = \frac{\rho}{\left[\left(1 + \left(\chi_r^2\right)^3\right)/2\right]^{1/6}}$$

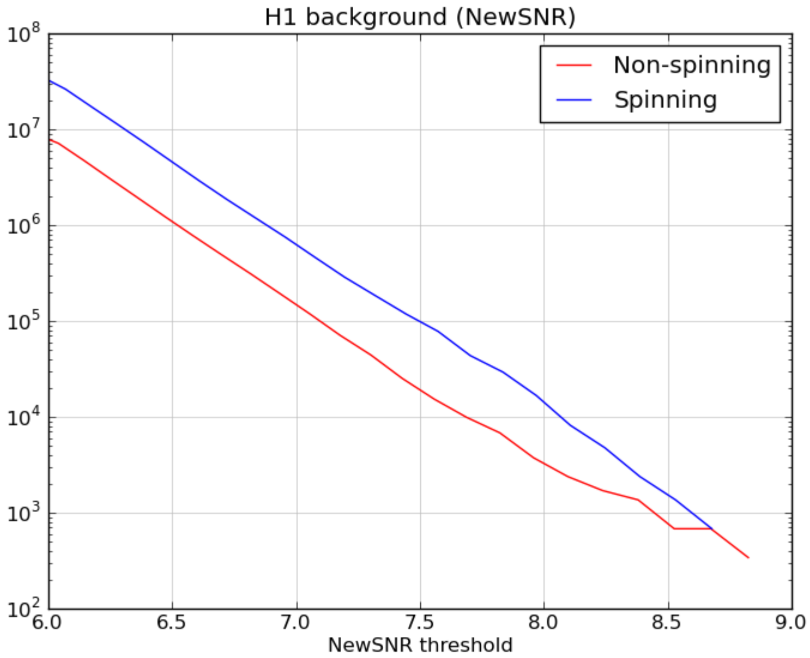
Recovered SNRs relative to expected SNRs for non-spinning templates



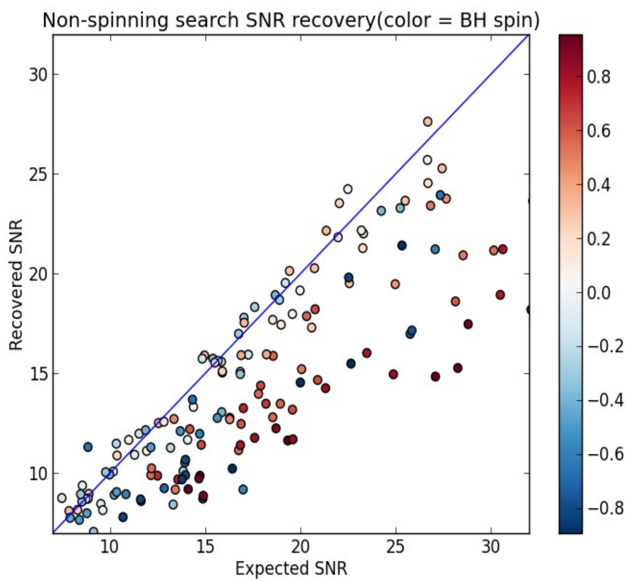


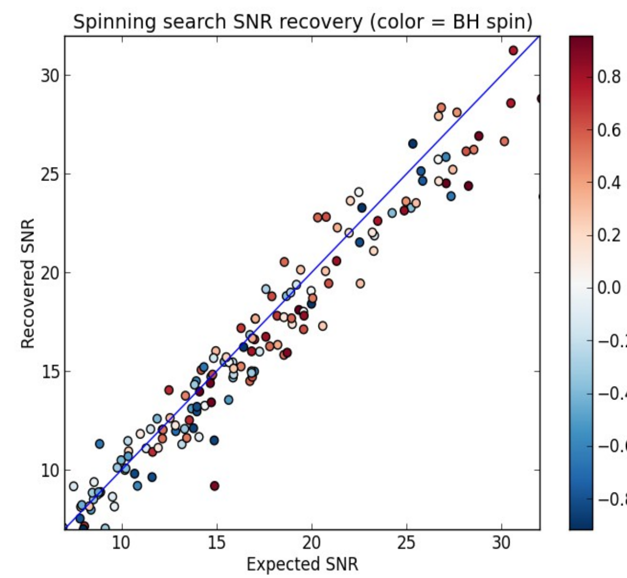
SNR recolored background

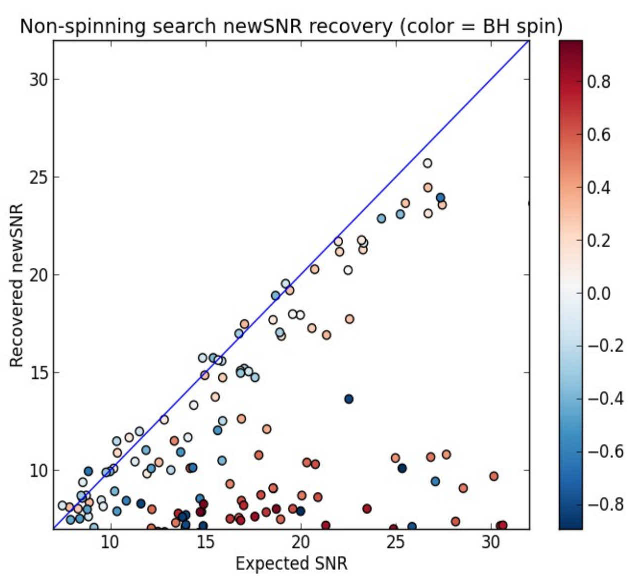


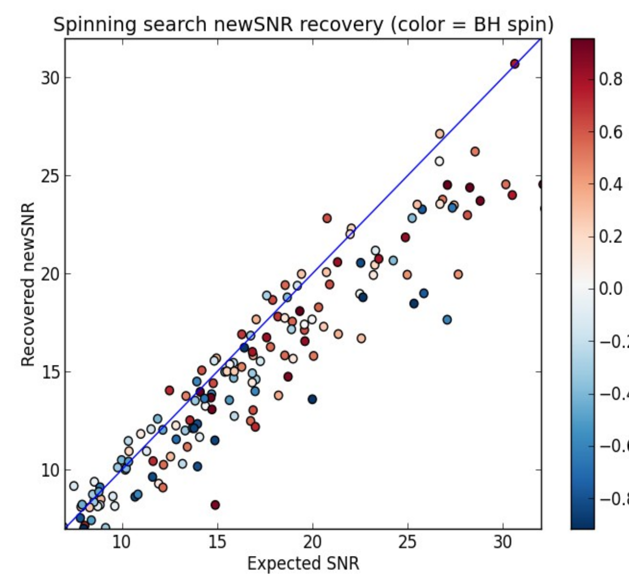


Recovered SNR

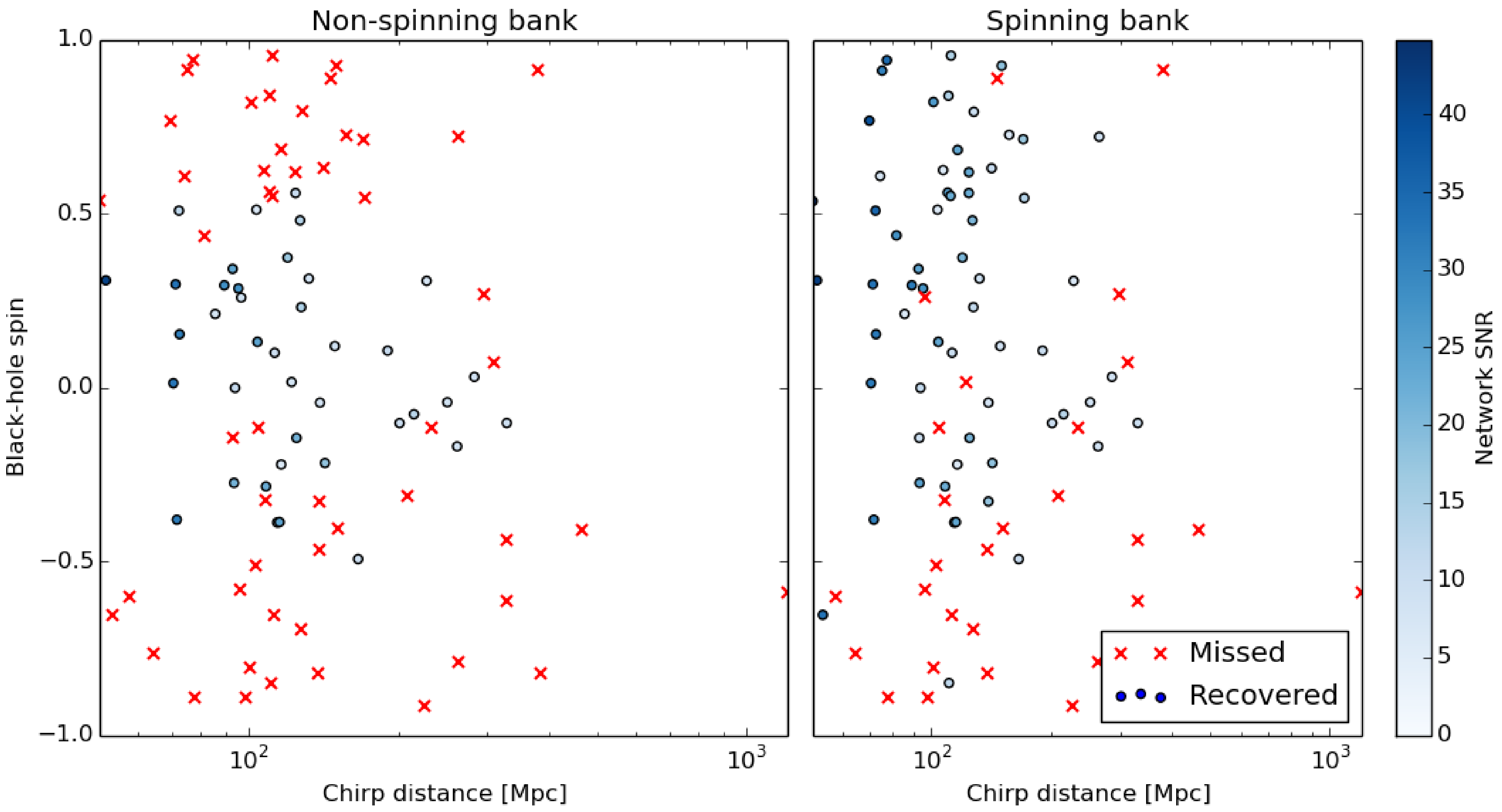




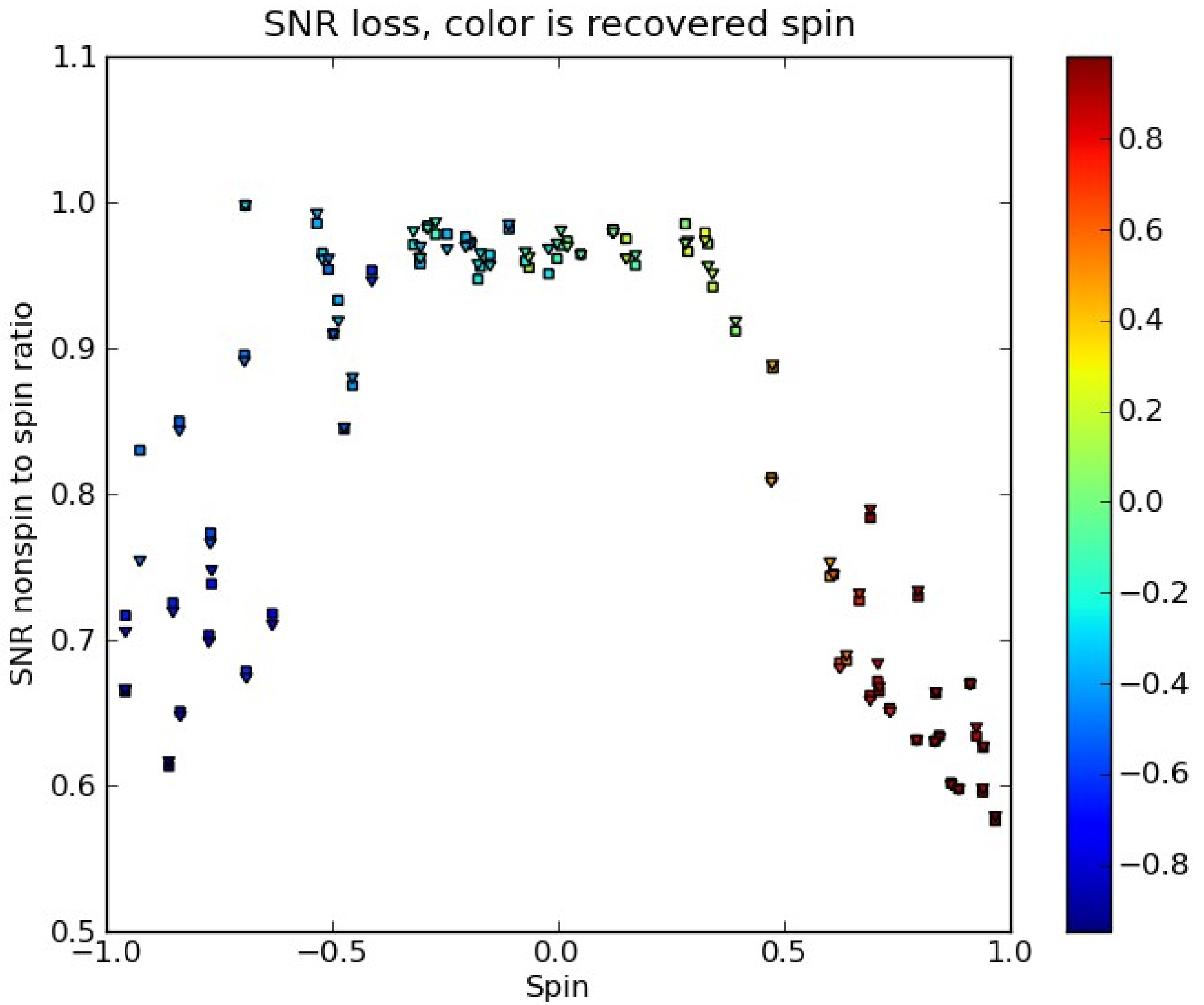




Recovered versus missed injections



Precessing signal recovery improvement with non-precessing spin template bank

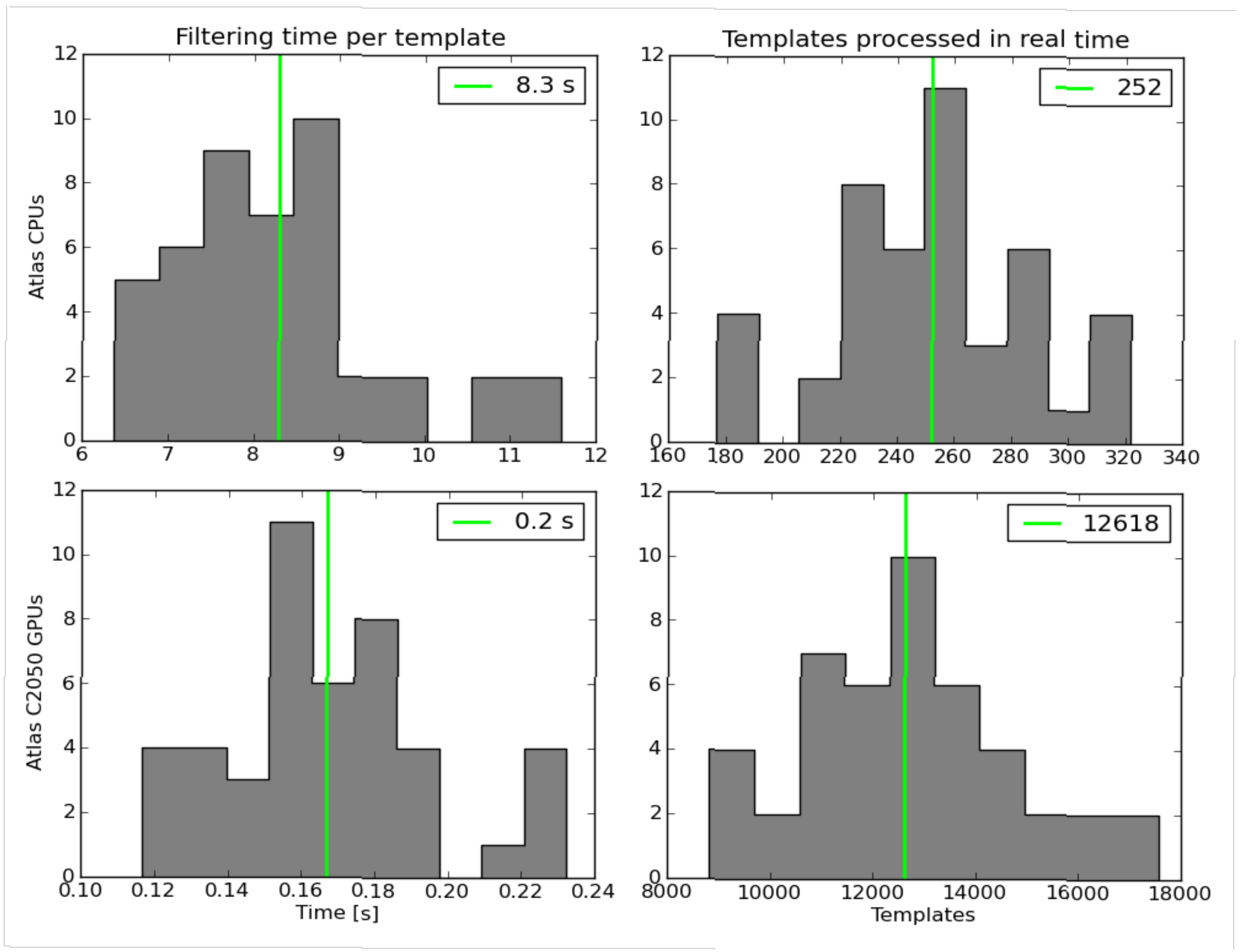


PyCBC - aims

- Python based code
- Create a flexible, extensible software for CBC analysis that can be released for the public
- Enable simple, easy and transparent access for various many-core architectures like GPUs
- Ultimately become the data analysis tool of the ‘advanced era’

GPU running

- Identical runs ~x50 faster on GPUs (Tesla C2050) compared to CPUs, Atlas



Conclusions

- The available evidence suggests that stellar sized black holes in compact binaries may have considerable spin.
- Searching for these systems with spinning templates may significantly increase the detection rate.
- The challenges are largely computational; longer running times and larger trigger sets.

Thank you