Assessing the Detectability of Gravitational Waves from Coalescing Binary Black Holes with Precessing Spin

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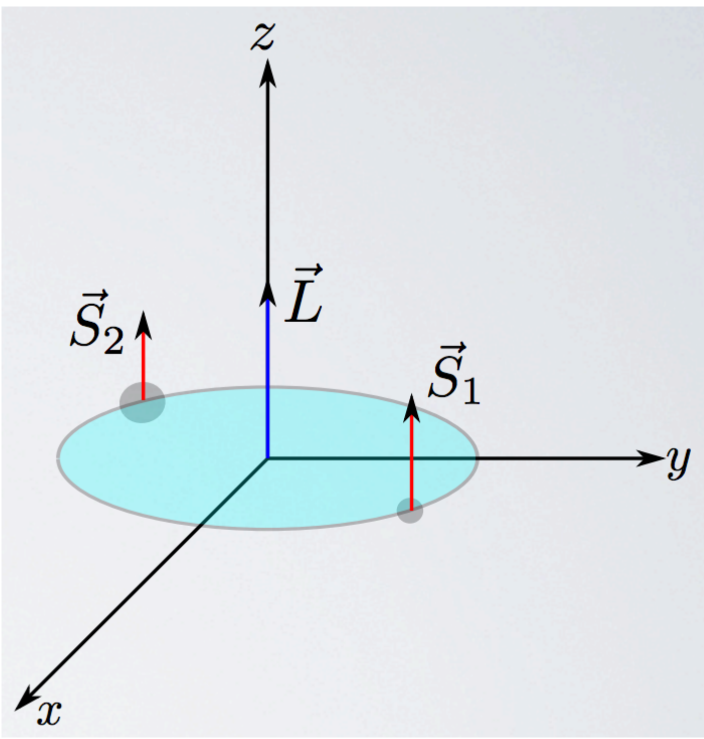
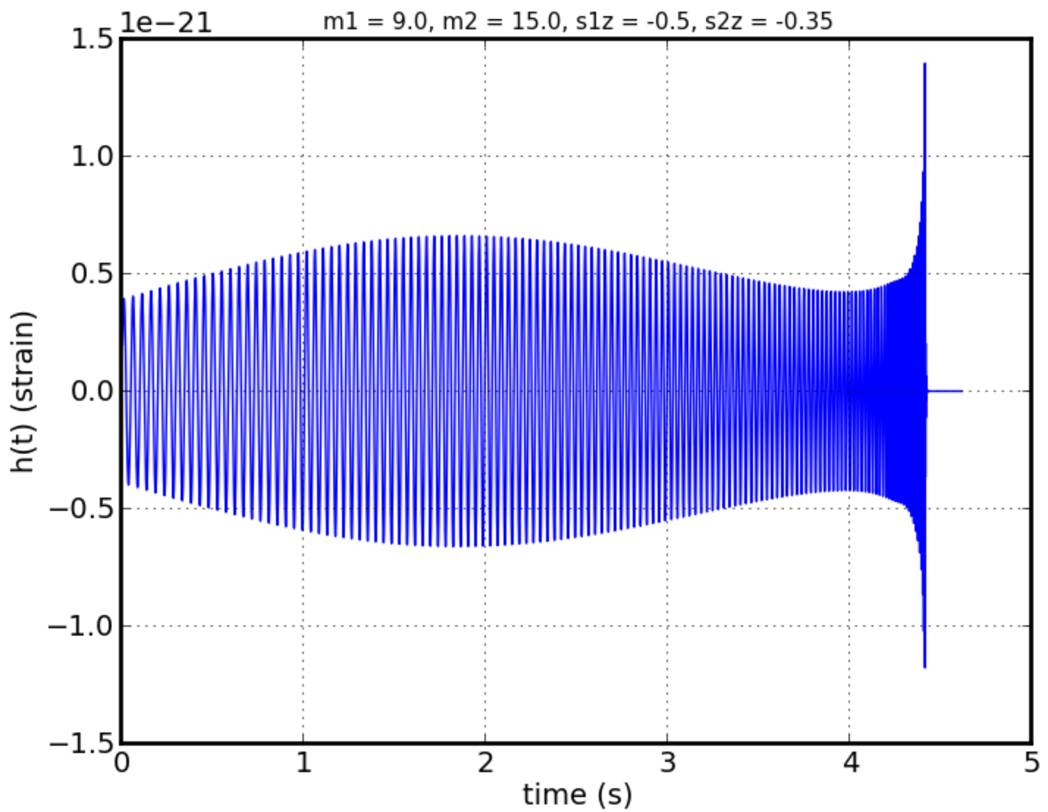
Binary Black Holes

- Coalescence: Inspiral-Merger-Ringdown
- Gravitational Wave Signal
  - Which waveform models are best?
  - Template banks
- Spin

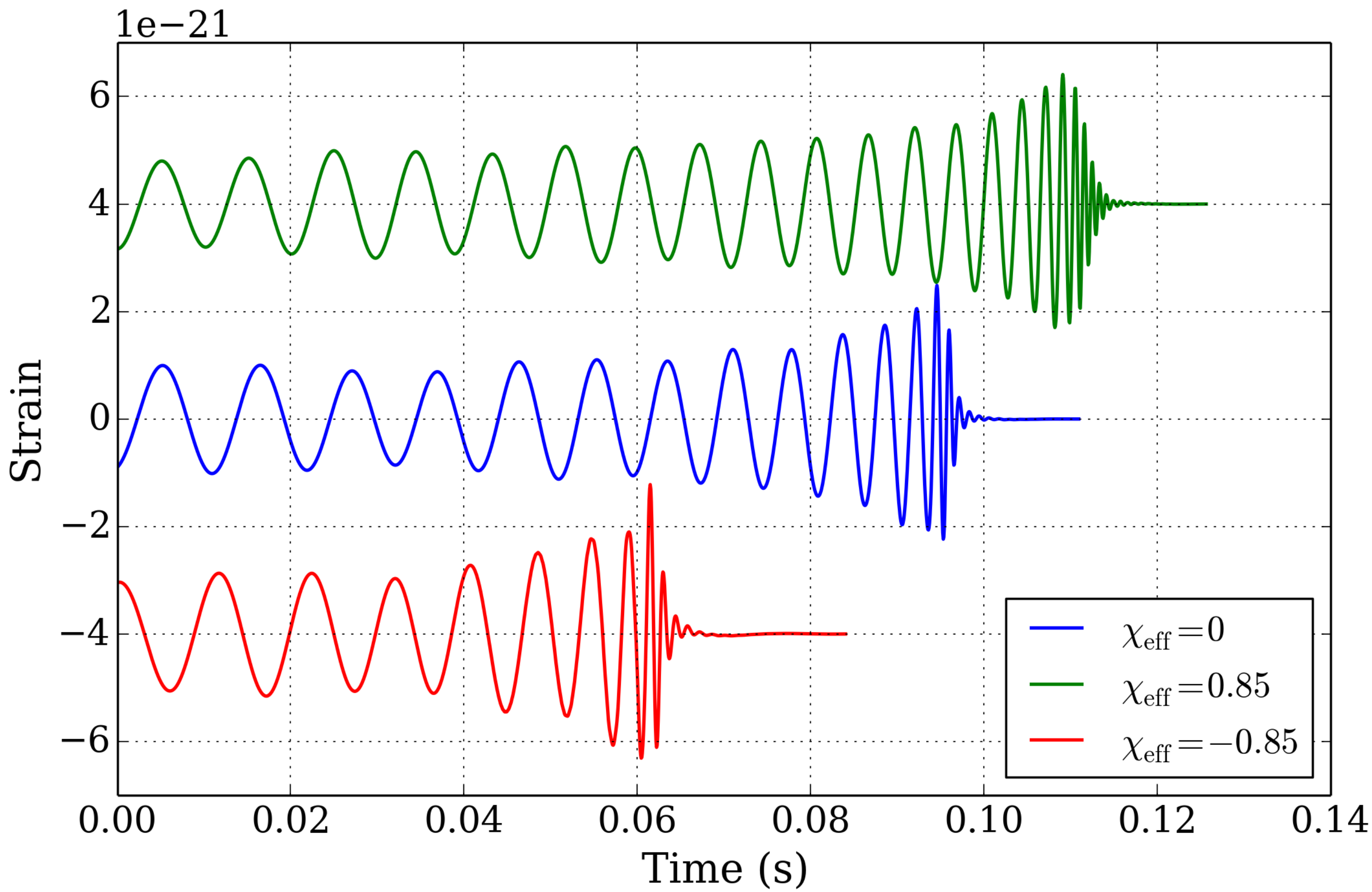
Spin

- Aligned spin vs. Precessing spin





IMR Phenomenological Waveforms



LIGO

Matched Filtering

$$\langle s, h \rangle = 2 \int_0^\infty \frac{\tilde{s}(f)\tilde{h}^*(f) + \tilde{s}^*(f)\tilde{h}(f)}{\underbrace{S_n(f)}_{\text{PSD}}} \, \mathrm{d}f$$

$$\rho = \langle \vec{s}, \hat{h} \rangle$$

$$\hat{h} = \frac{h}{\sqrt{\langle h|h \rangle}}$$

Matched Filtering

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$$\rho = \langle \vec{s}, \hat{h} \rangle \qquad \hat{h} = \frac{h}{\sqrt{\langle h|h \rangle}}$$

➡Signal very important for searches

Model Parameters

Intrinsic Parameters

m_1	m_2	s_{1x}	s_{2x}
s_{1y}	s_{2y}	s_{1z}	s_{2z}

Extrinsic Parameters

right ascension	α
declination	δ
inclination angle	ι
polarization angle	ψ
coalescence time	t_{coal}
coalescence phase	ϕ_{coal}
distance	D

LIGO

Model Parameters

Intrinsic Parameters

m_1	m_2	~~s_{1x}~~	~~s_{2x}~~
~~s_{1y}~~	~~s_{2y}~~	s_{1z}	s_{2z}

aligned spin

$$\chi_{eff} \equiv \frac{m_1 s_{1z} + m_2 s_{2z}}{m_1 + m_2}$$

Extrinsic Parameters

right ascension	α
declination	δ
inclination angle	ι
polarization angle	ψ
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Model Parameters

Intrinsic Parameters

m_1	m_2	s_{1x}	s_{2x}
s_{1y}	s_{2y}	s_{1z}	s_{2z}

precessing spin

$\chi_p(m_1, m_2, \vec{s_1}, \vec{s_2})$

Extrinsic Parameters

right ascension	α
declination	δ
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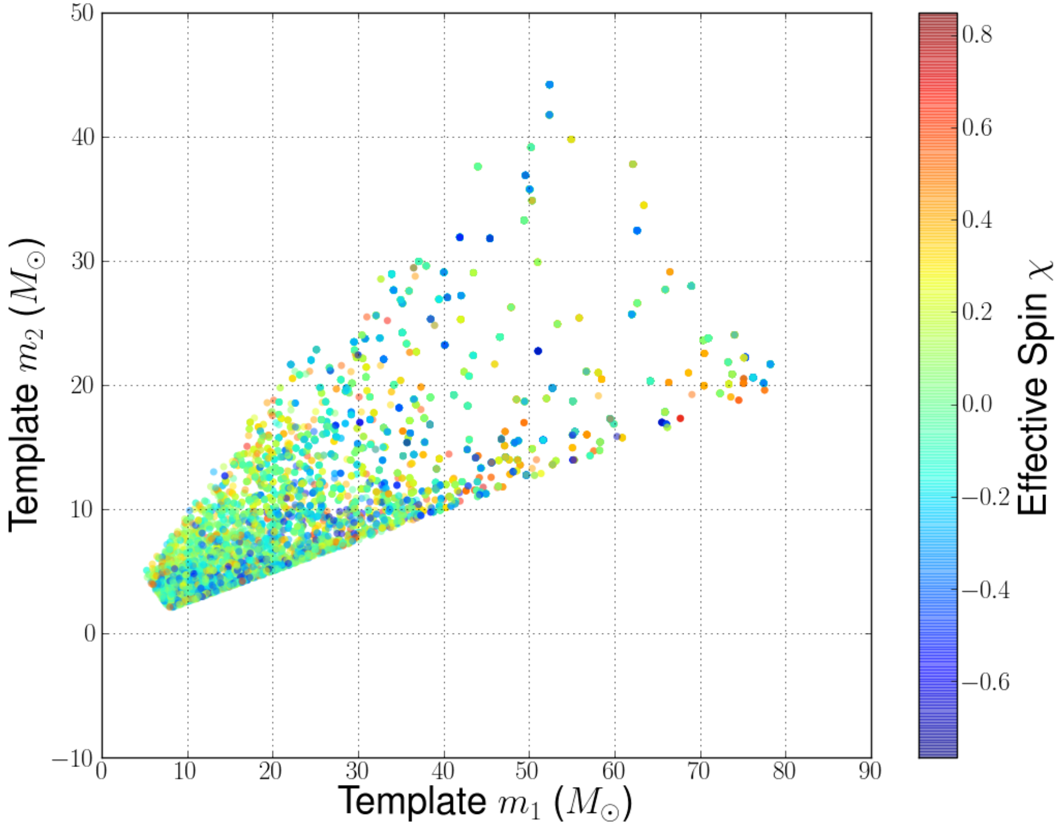
Template Bank

- Stochastic bank algorithm
  - Minimum required match: 0.97

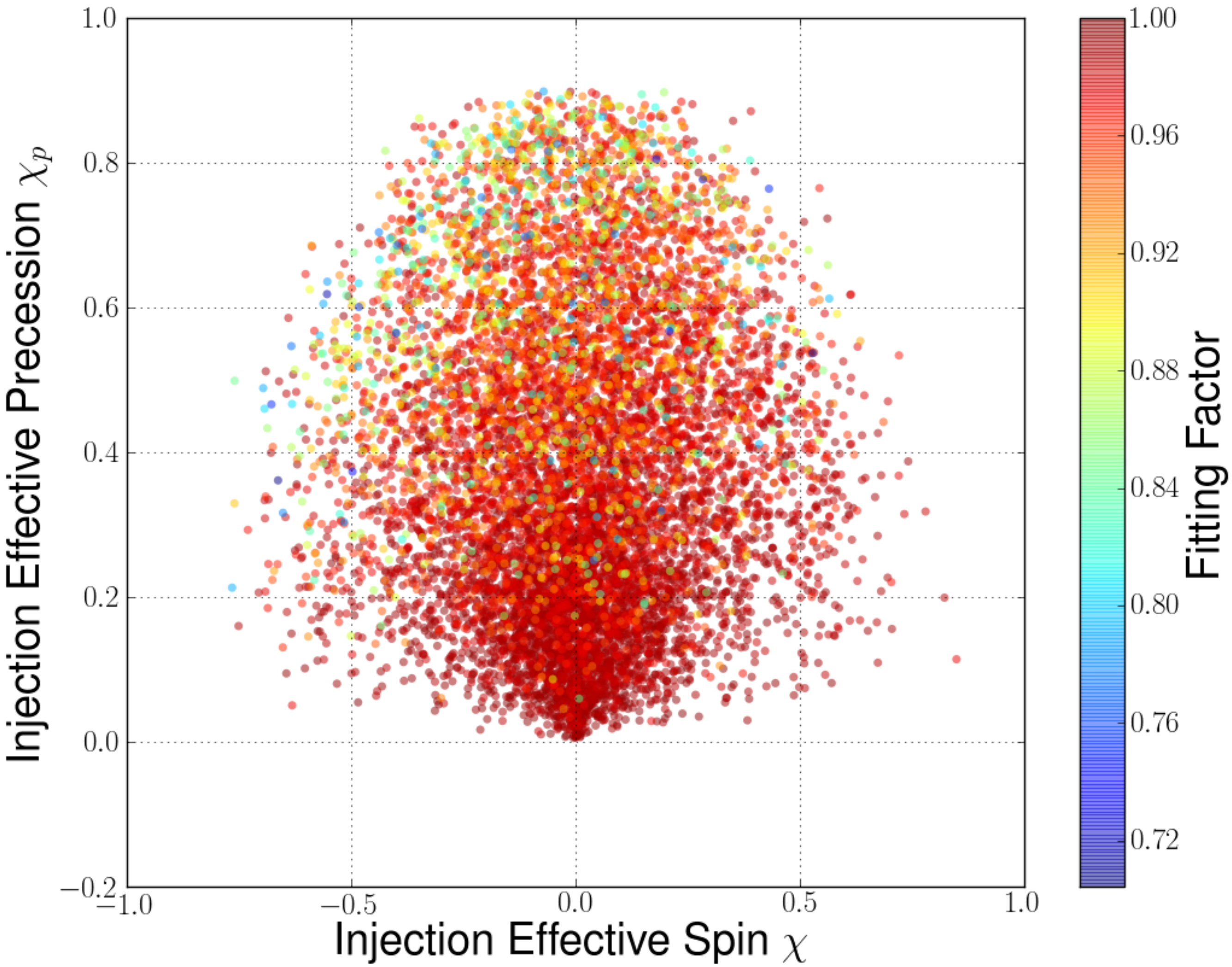


Template Bank Simulations

- Injections
- Tests whether bank is useful
  - effectualness - the overlap between templates and signals maximized over intrinsic and extrinsic parameters

LIGO

χ_p vs. χ_{eff}

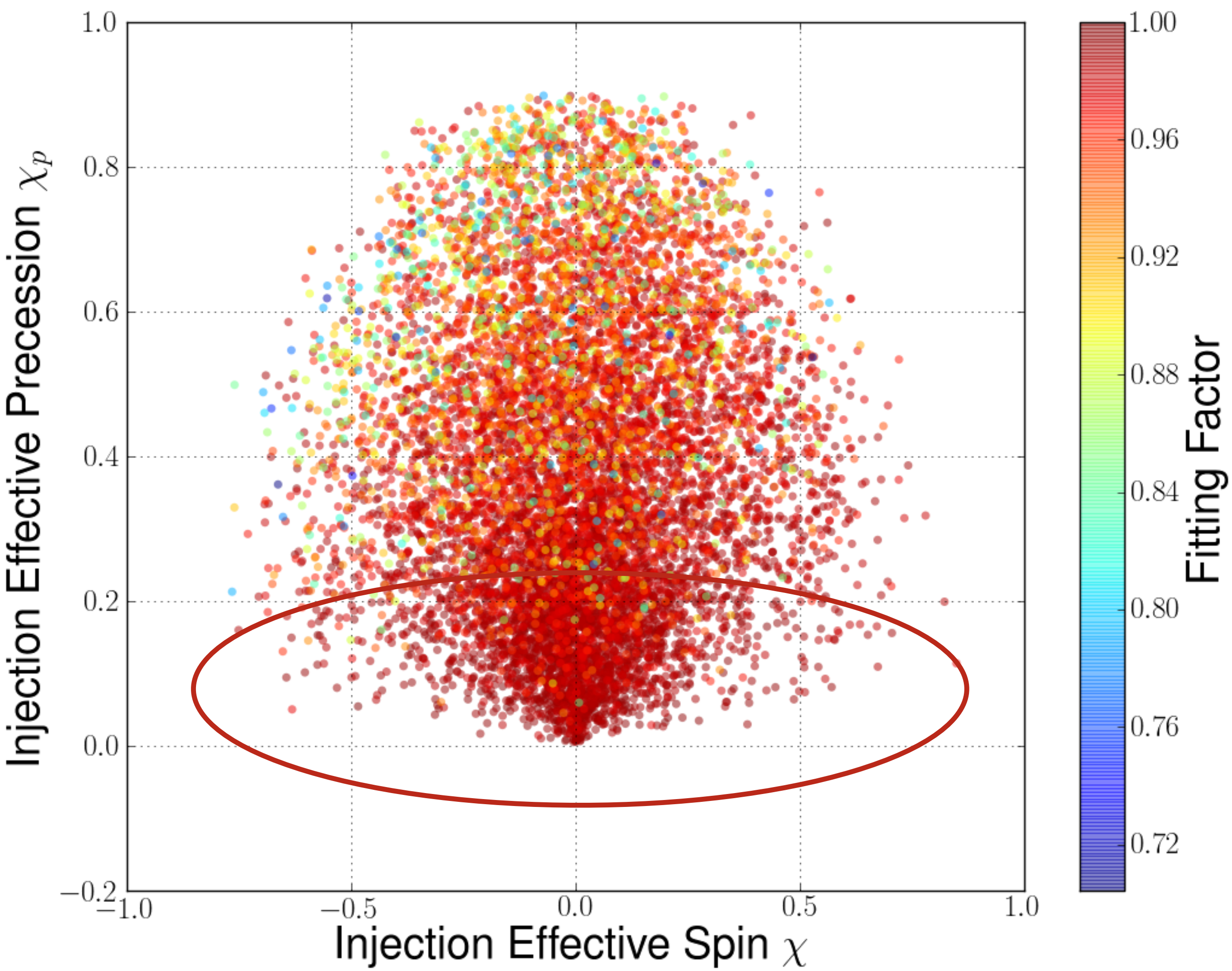


Total mass
{10 $M_\odot$,100 $M_\odot$}

Effective spin
{-0.9,0.9}

f_{low} = 30 Hz

χ_p vs. χ_{eff}



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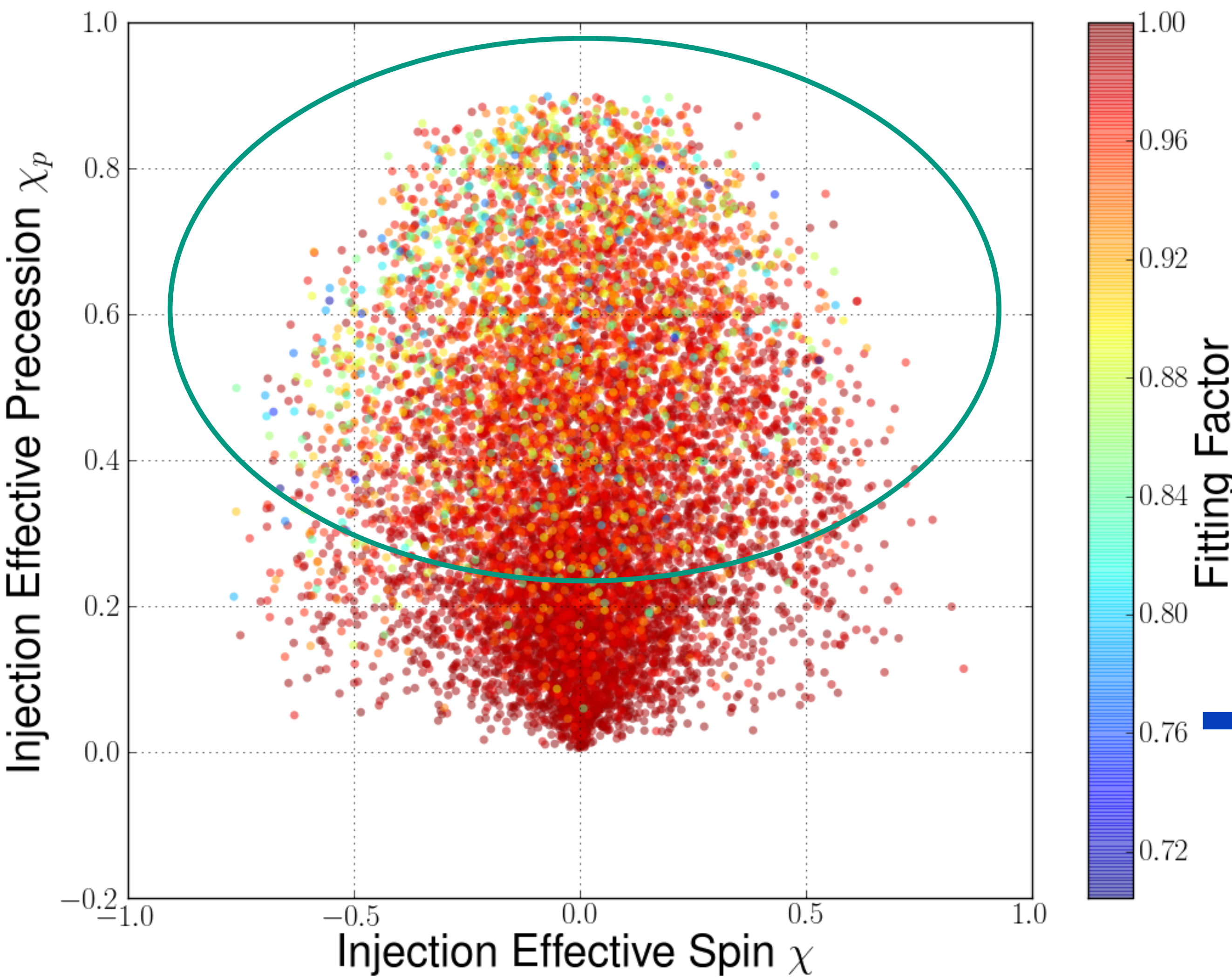

Total mass

{10 M$_\odot$,100 M$_\odot$}

Effective spin

{-0.9,0.9}

f_{low} = 30 Hz

➡We expect worse fitting factors where spin deviates from being aligned

Future Work

- Recover simulated precessing signals in “real” data
  - Does the inclusion of spin improve sensitivity of actual search pipelines to precessing signals?
- Construct bank down to lower frequencies
- Assess effectualness of available precessing waveform models

Acknowledgments

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LIGO SURF

NSHP

NSF

References

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Waveform Models

- IMRPhenomA/B (non-spinning)
- IMRPhenomC (aligned spin)
- IMRPhenomP (precessing)
  - Inspiral-Merger-Ringdown, analytical model based on phenomenology of sources
  - Includes effects of precession of orbital plane of BBH
  - “Twisting up” of spin-aligned IMR waveforms
- EOBNR (non-spinnning)
- SEOBNR (aligned/precessing spin)

Calculation of Precession Parameter

$$\chi_p \equiv \frac{S_p}{m_2^2}$$

$$S_p = \frac{max(A_1 S_{1\perp}, A_2 S_{2\perp})}{A_1}$$

$$A_i = 2 + \frac{3m_{3-i}}{2m_i}$$

Template Bank

- Stochastic bank algorithm
  - Minimum required match: 0.97