Characterizing Compact Binaries with LIGO

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KITP: Astrophysics from LIGO's First Black Holes

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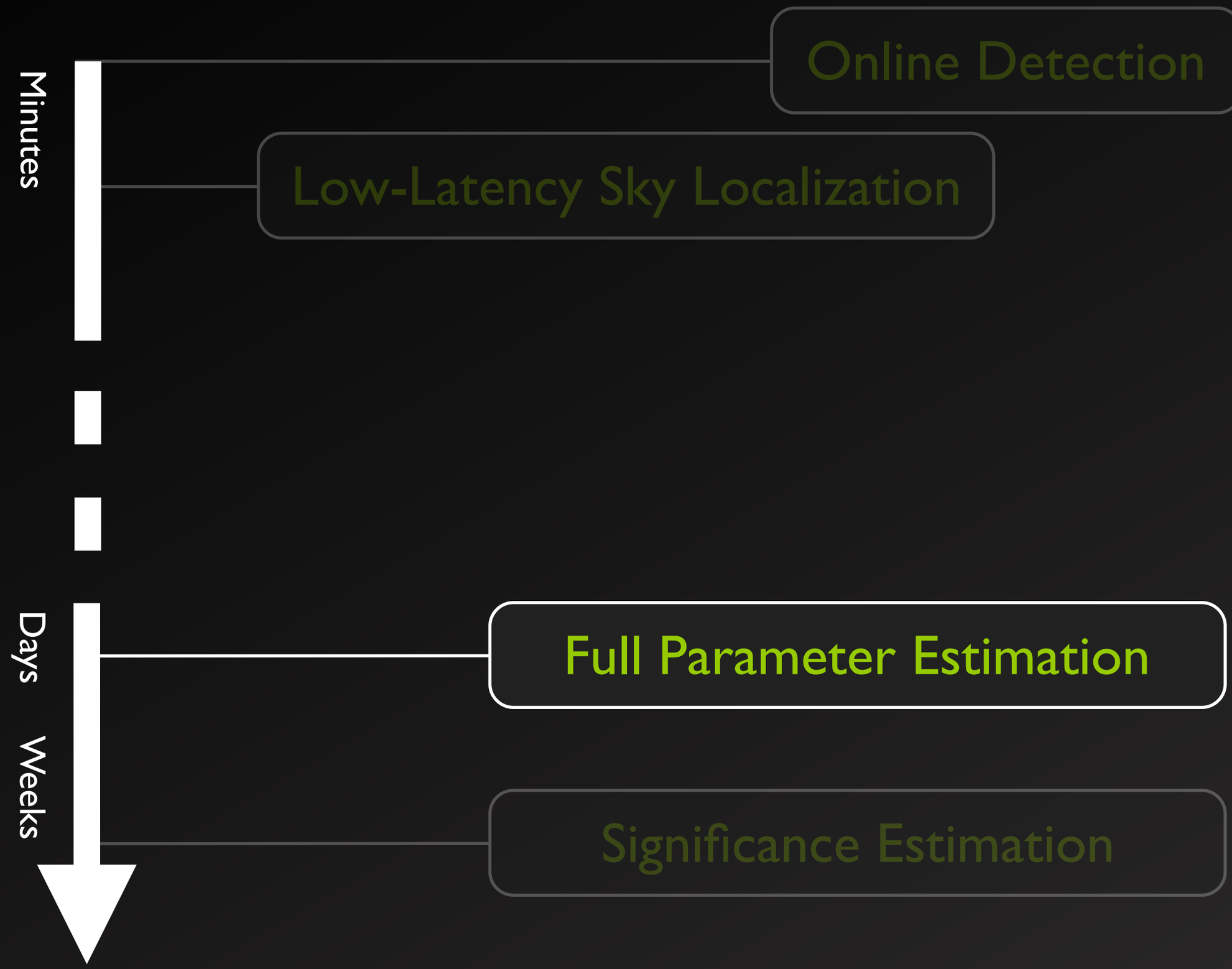
Overview

I. How parameters are measured

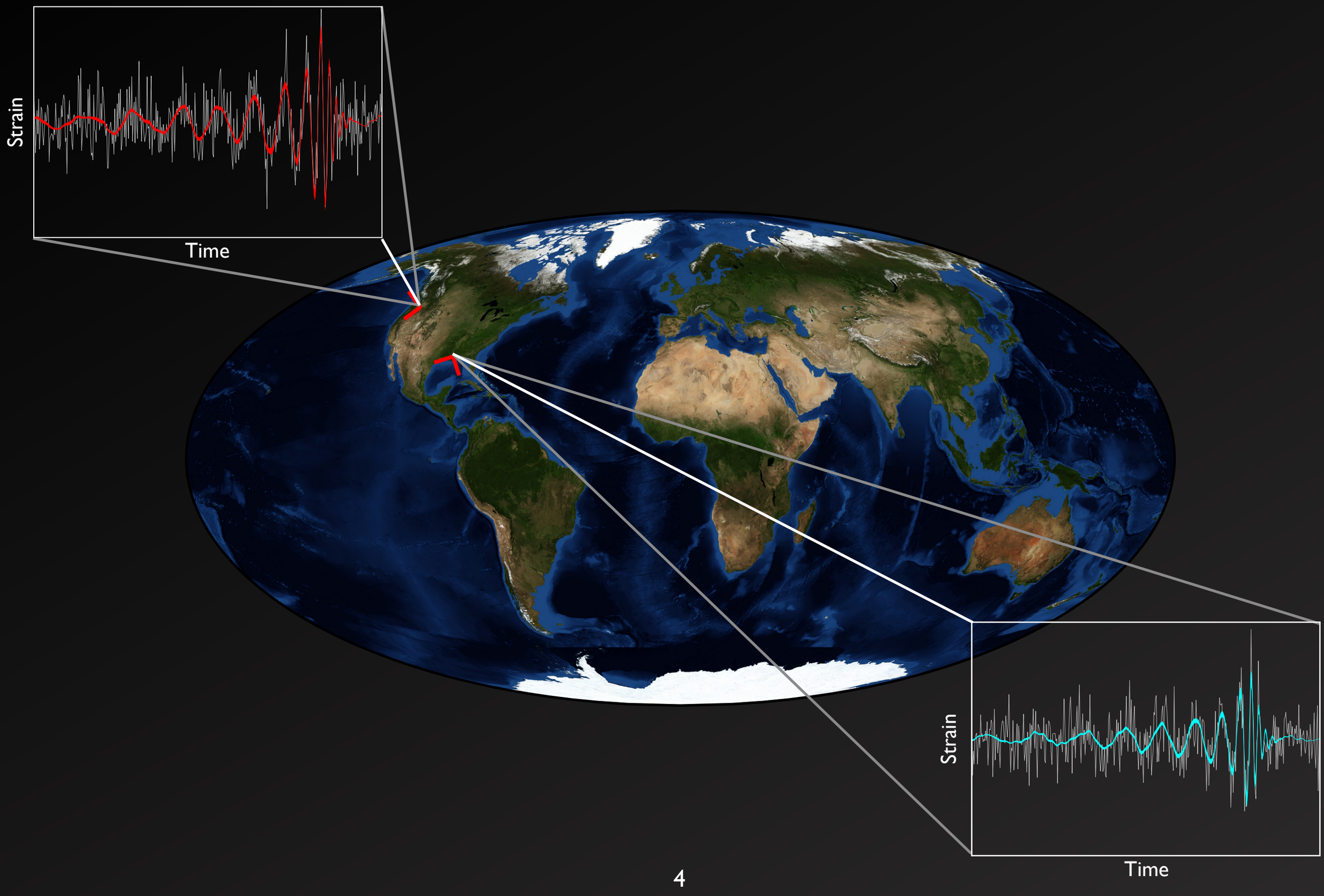
II. How well parameters are measured

III. BBH parameter estimates from O1

Compact Binary Pipeline



Parameter Estimation



Bayesian Inference

$$p(\vec{\theta}|d) \propto p(\vec{\theta})p(d|\vec{\theta})$$

Posterior

Prior

Likelihood

Priors

"Uninformative" priors:

- Flat in component mass space.
- Volumetric in space.
- Flat in time, phase, orbital orientation.
- Uniform and isotropic spins.

Likelihood Function

$$p(d|\vec{\theta}) \propto \exp\left[-\frac{1}{2}\left\langle h(\vec{\theta}) - d \middle| h(\vec{\theta}) - d \right\rangle\right]$$

Where *d* assumed to be Gaussian noise with some signal.

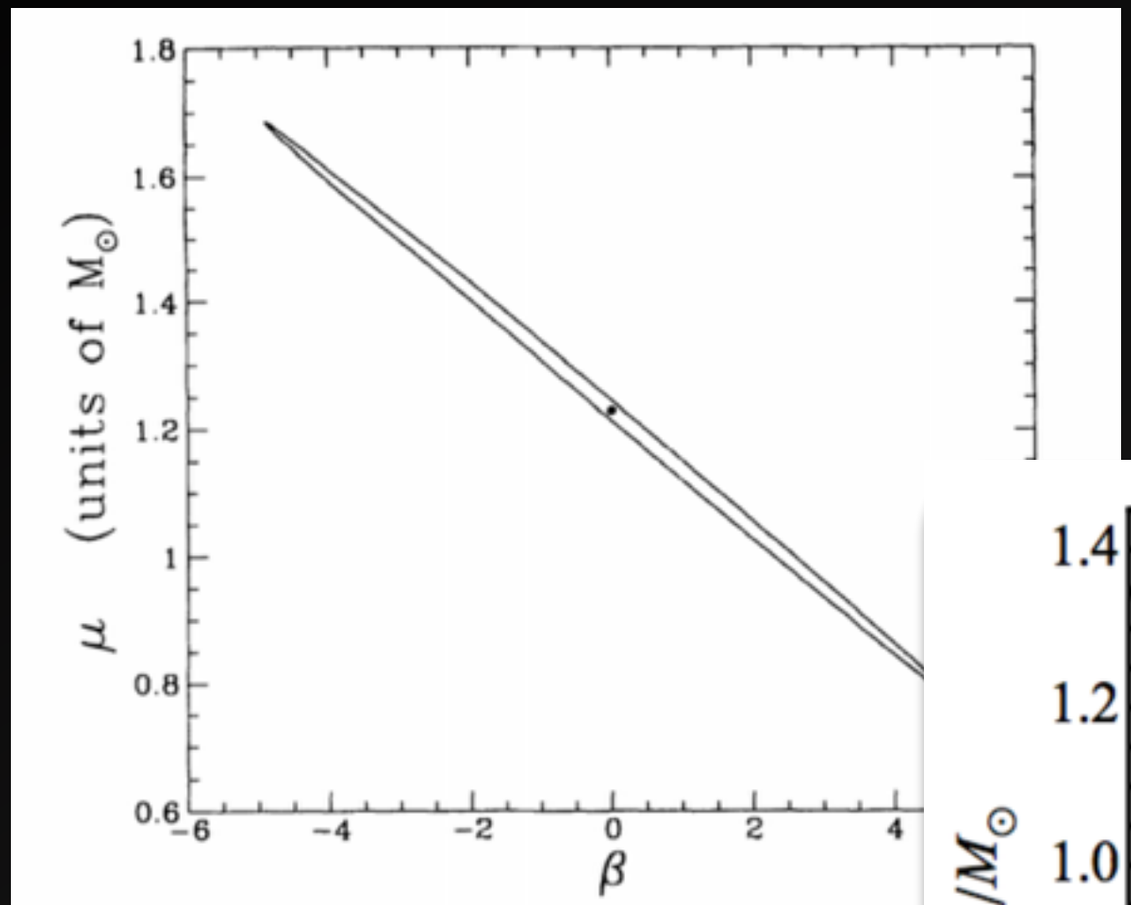
h is the model signal.

$\langle a|b\rangle$ is the noise-weighted inner product.

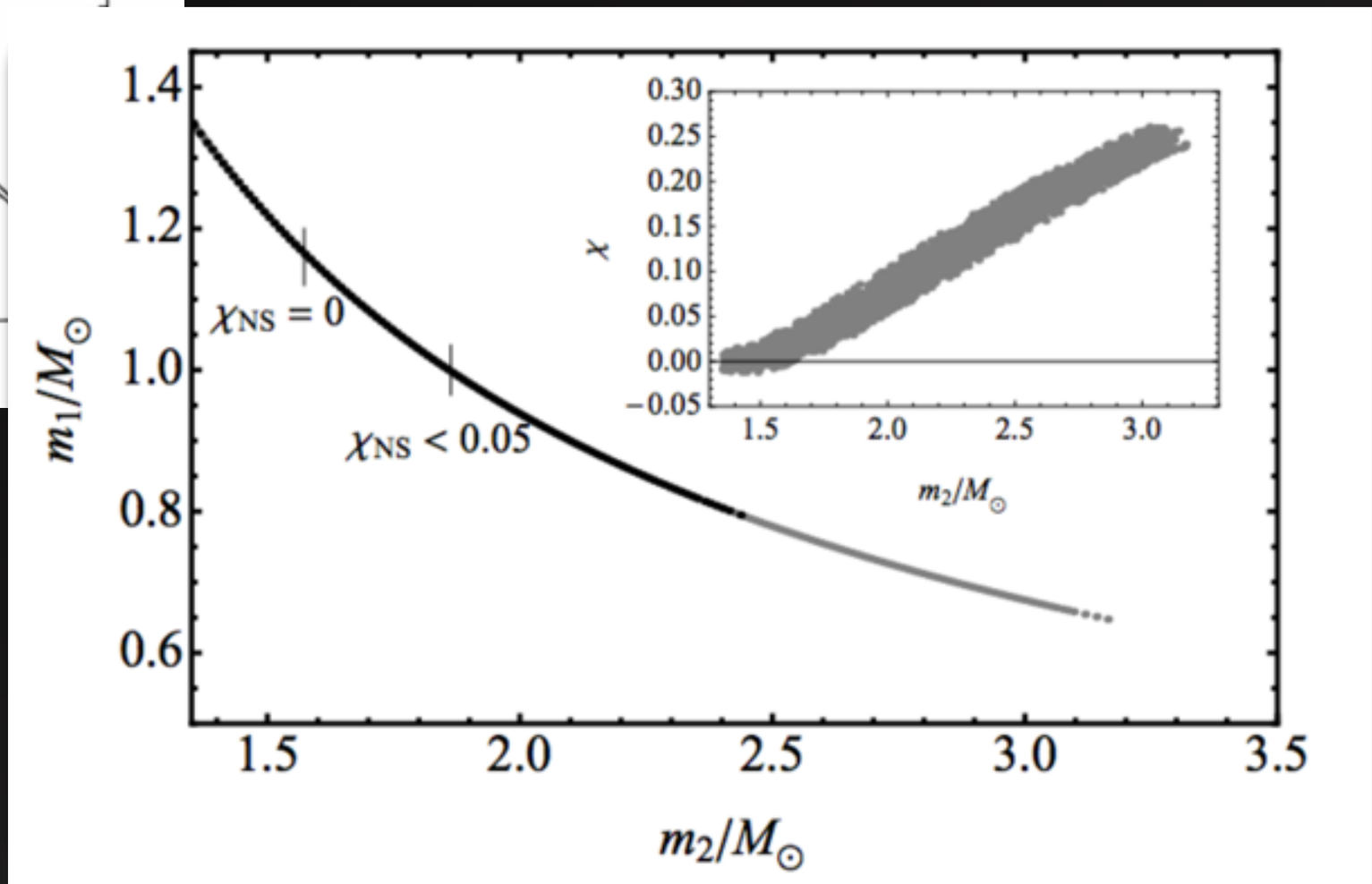
Model Parameters

Well Constrained	Not-so-well Constrained
Chirp mass (for low-mass BBHs) Total mass (for high-mass BBHs) Coalescence Time	Mass ratio Spins Distance Inclination Sky position Orientation

Mass-Spin Degeneracy

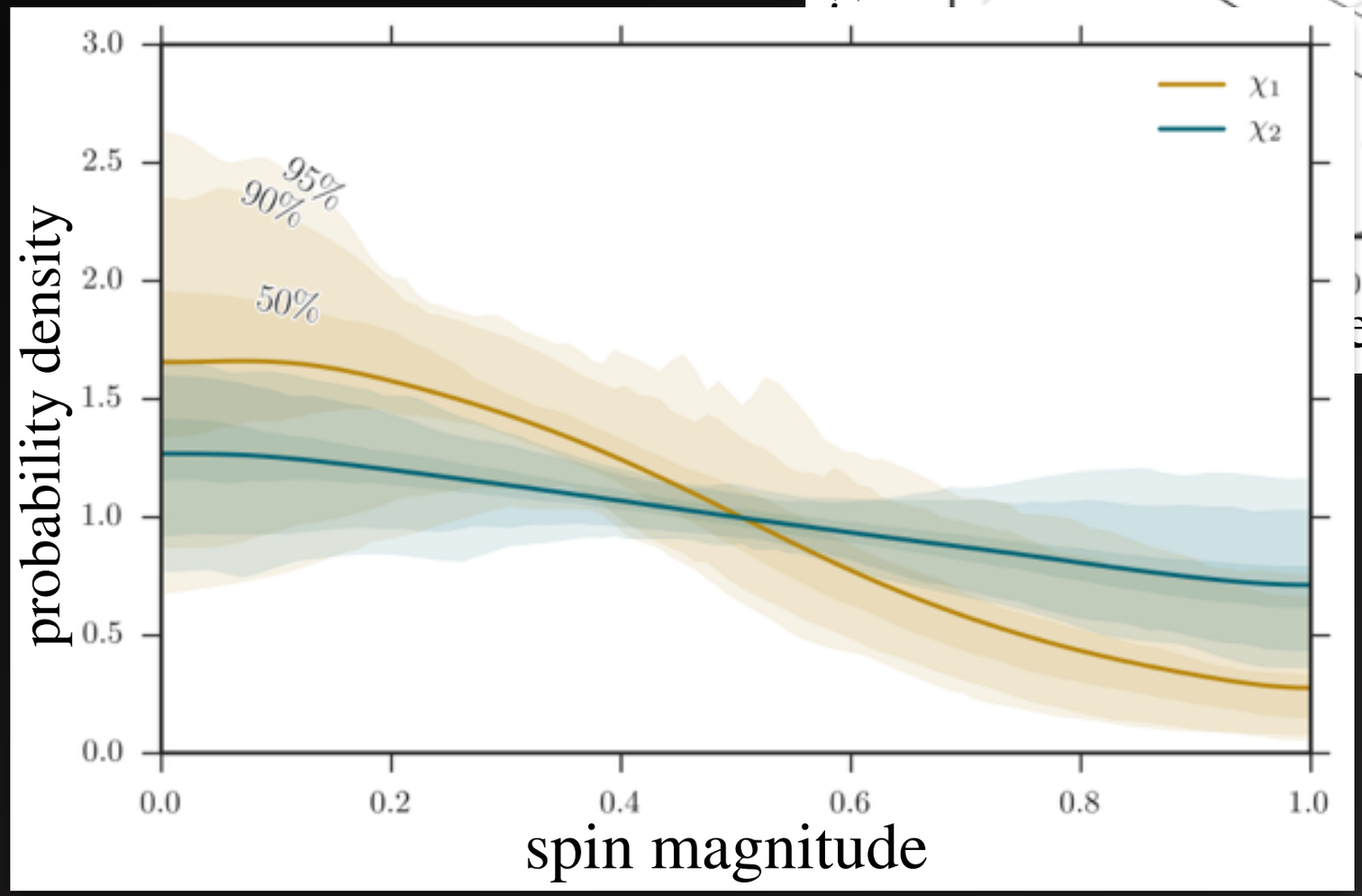


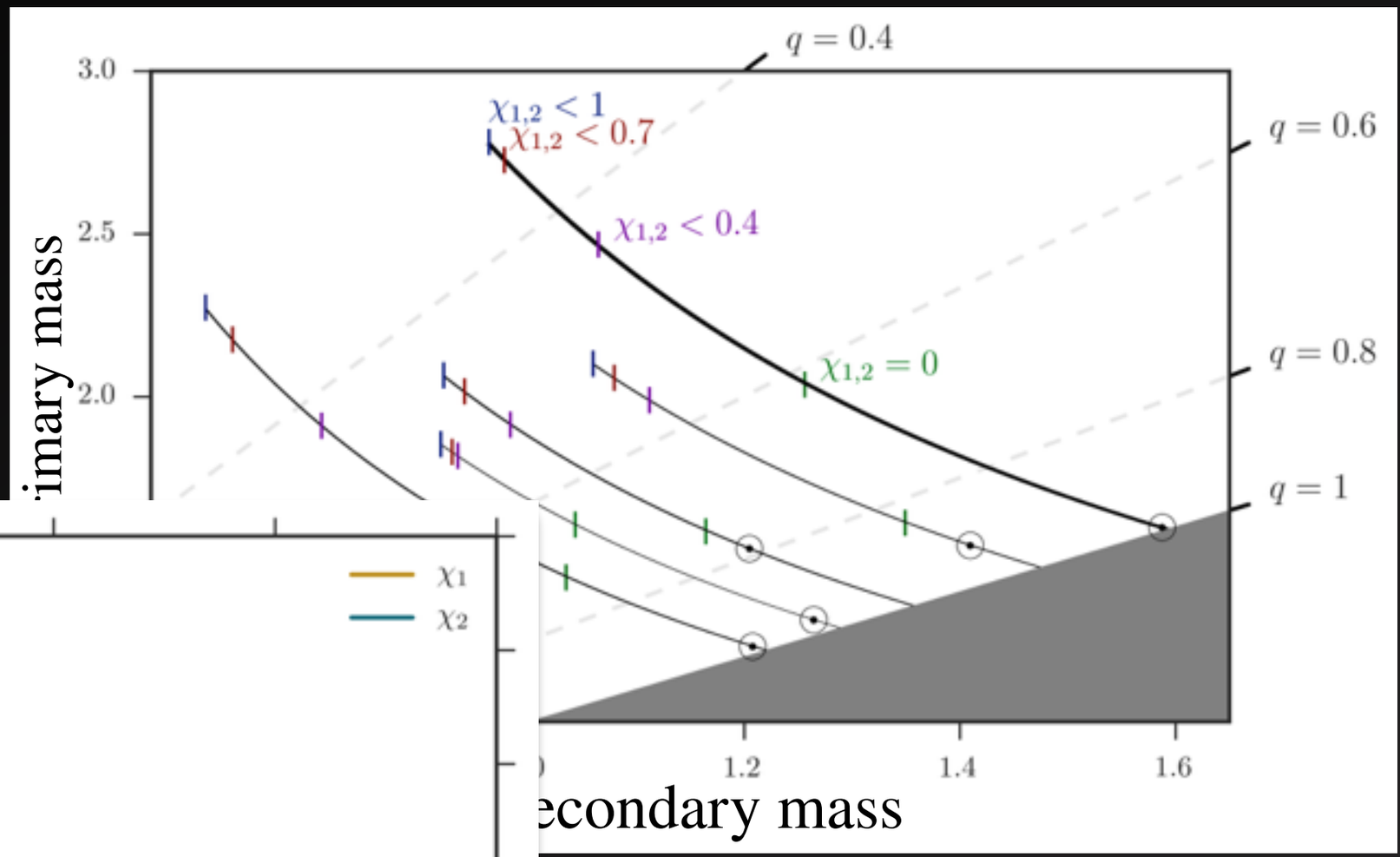
Cutler & Flanagan



Hannam et al. (2013)

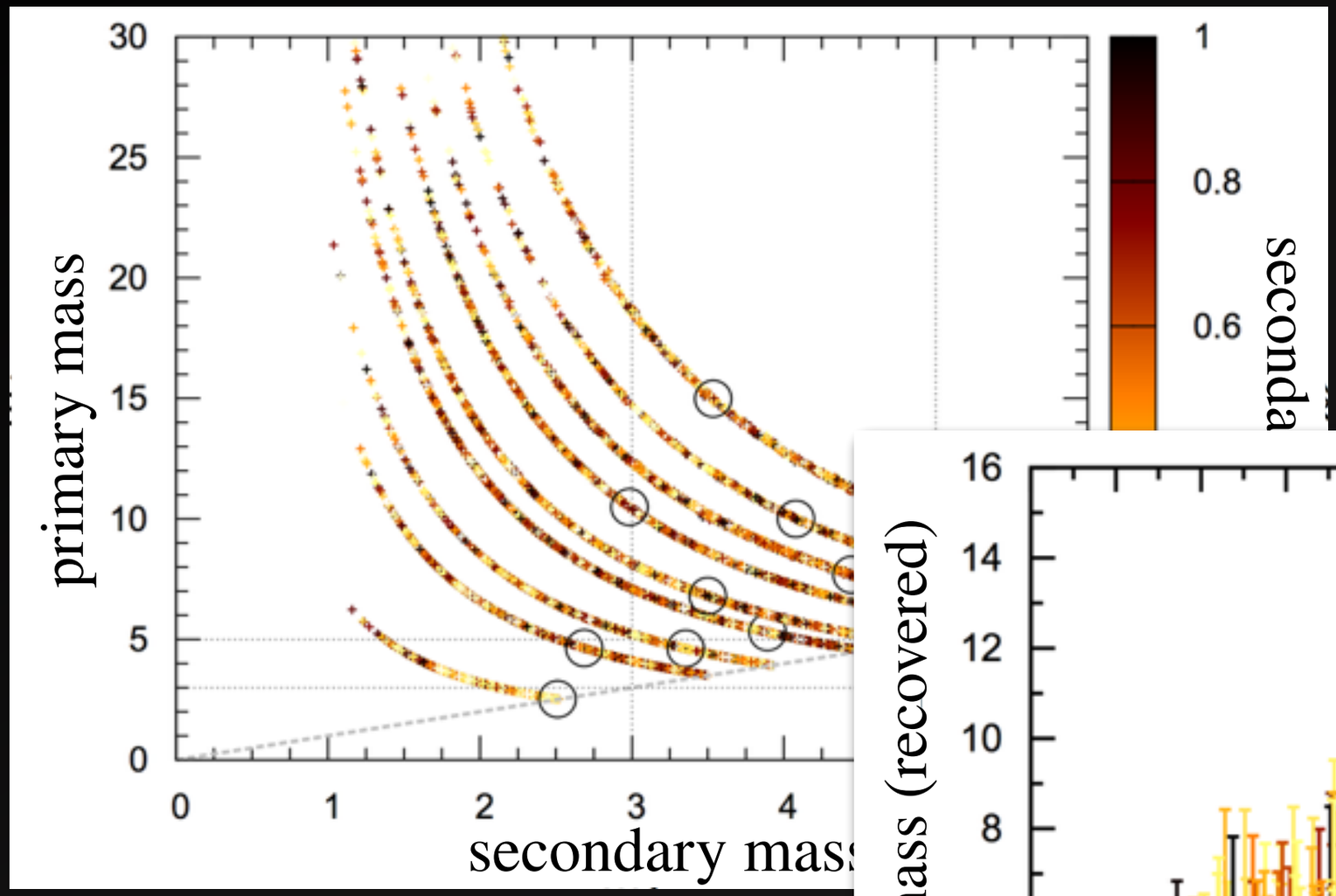
Mass-Spin Degeneracy

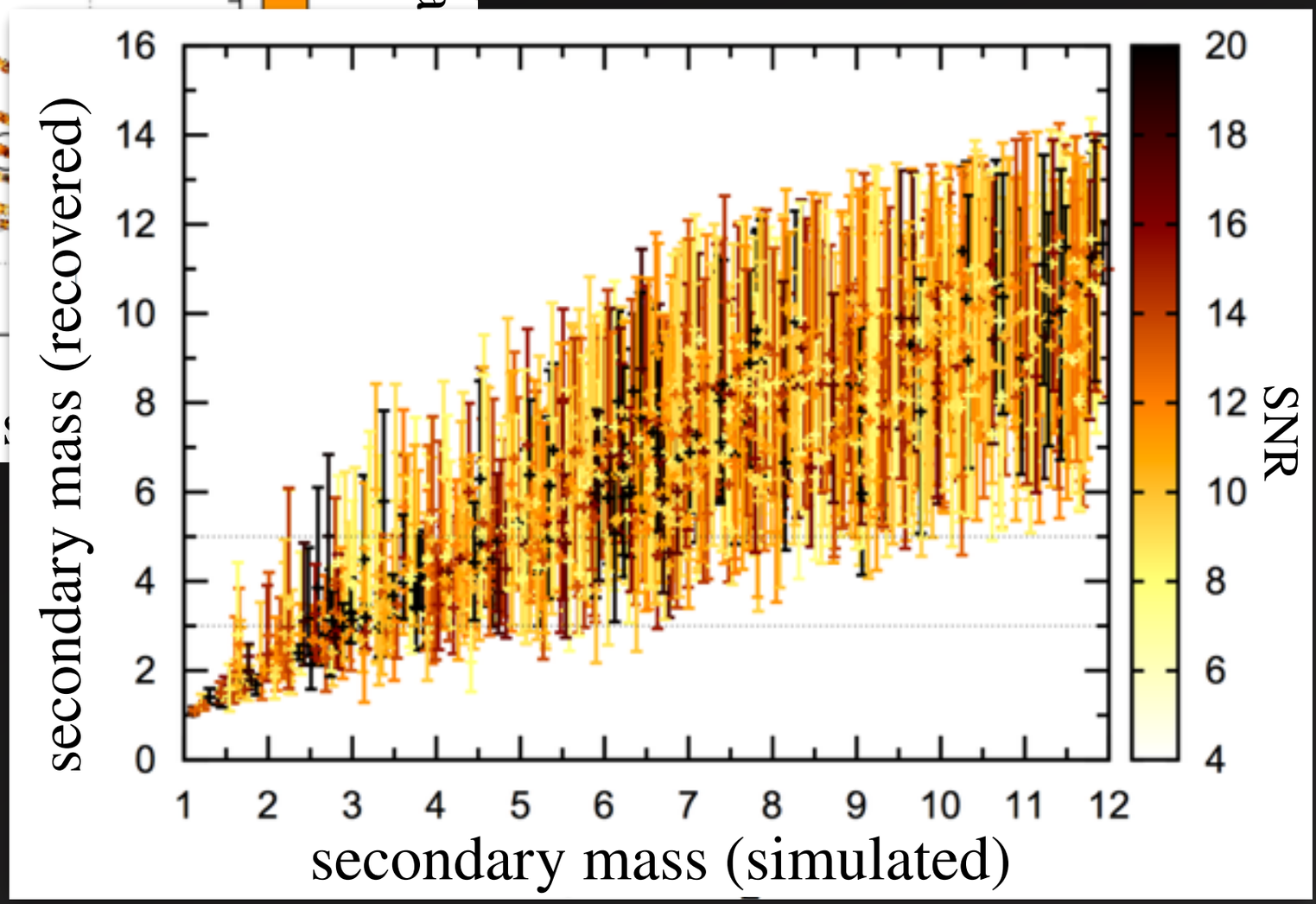




Farr et al. (2016)

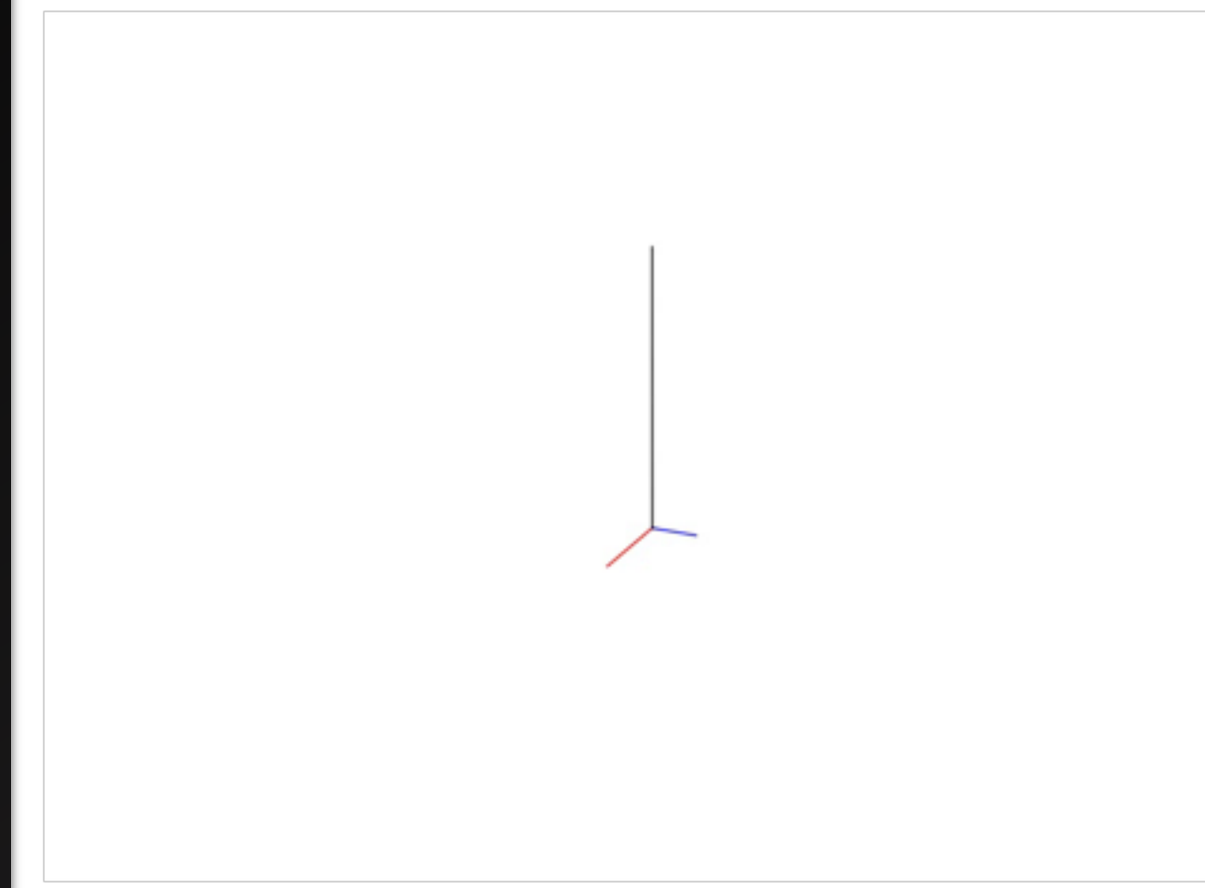
Mass-Spin Degeneracy

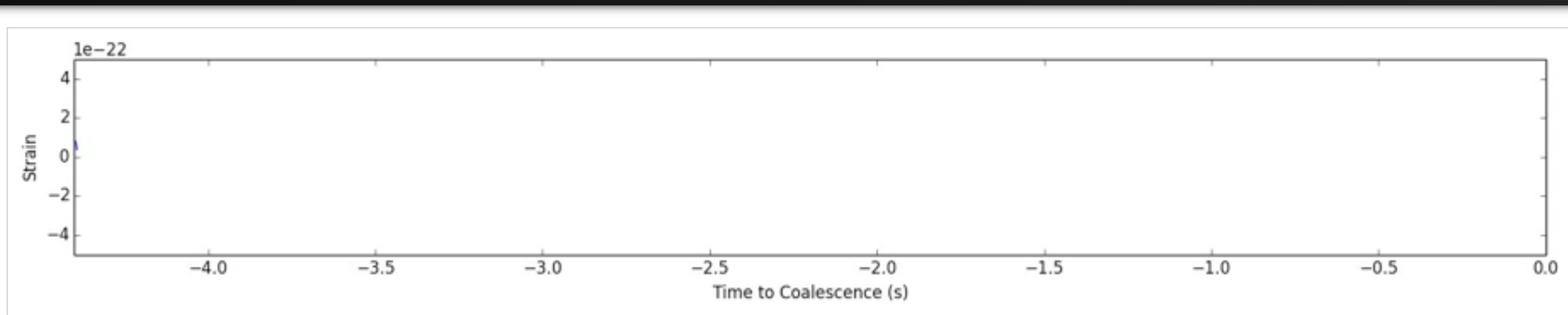




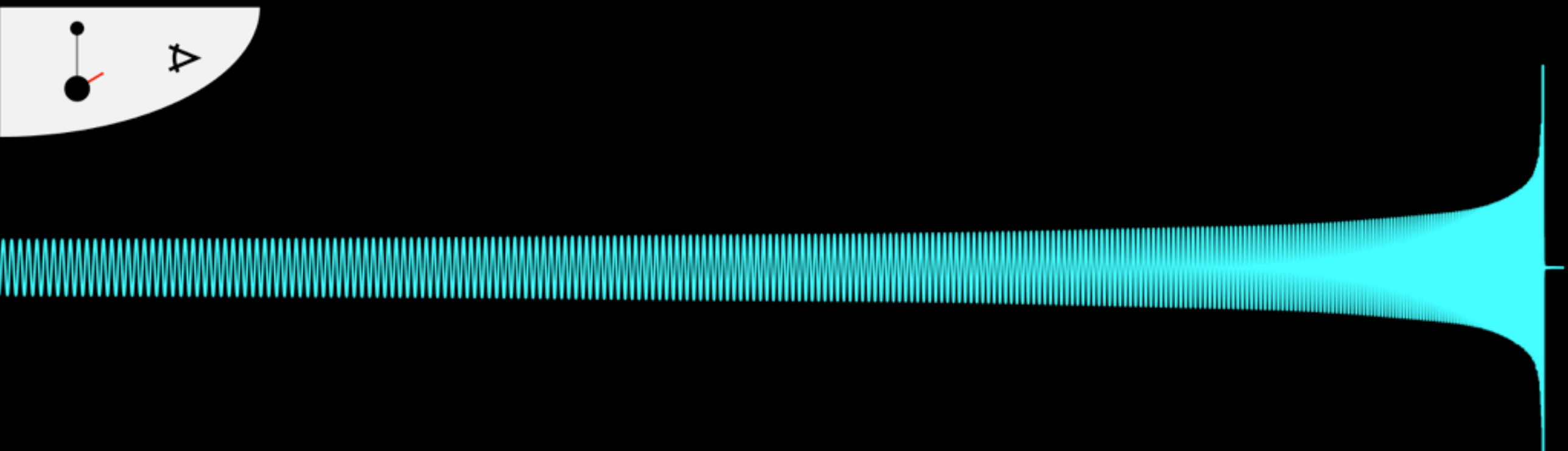
Littenberg, Farr, Couglin et al. (2015)

Precession Effects

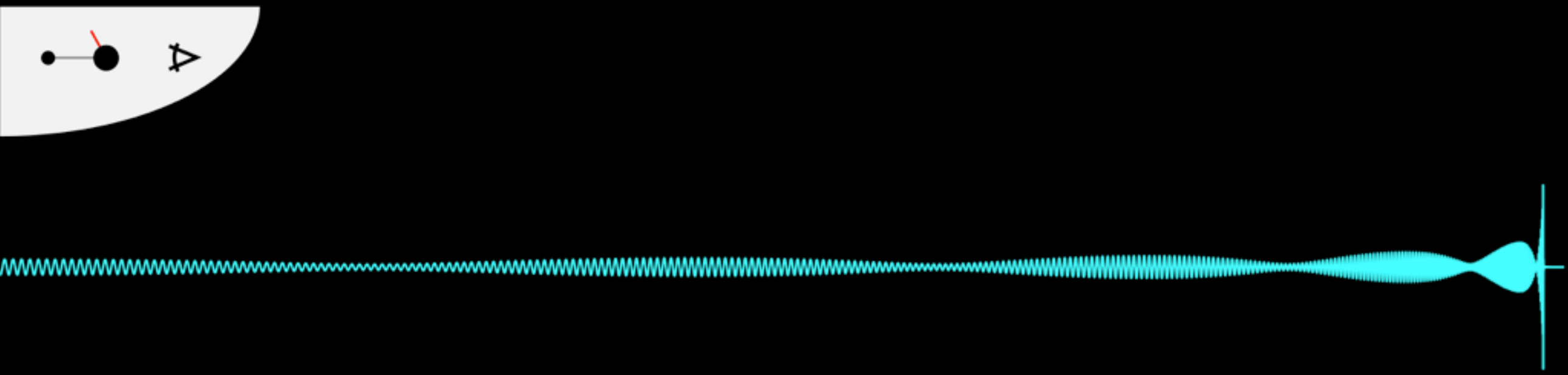




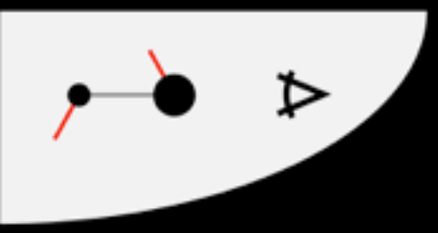
Precession Effects

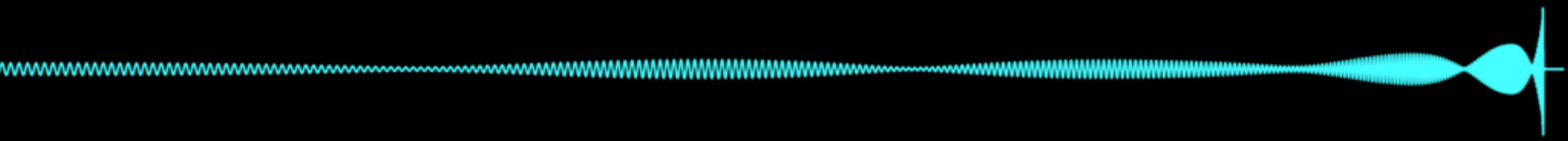


Precession Effects



Precession Effects





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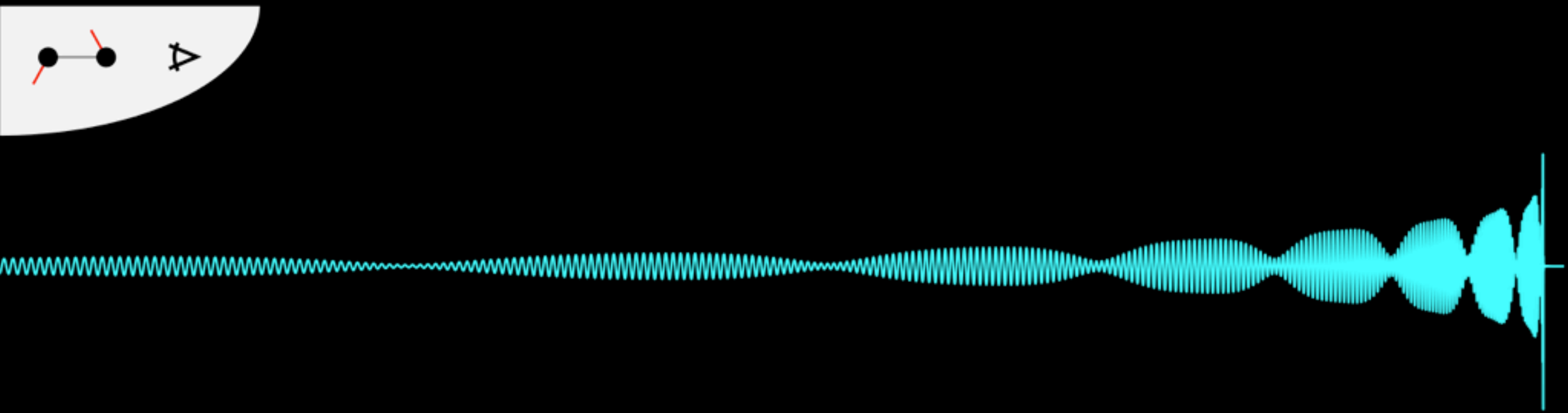

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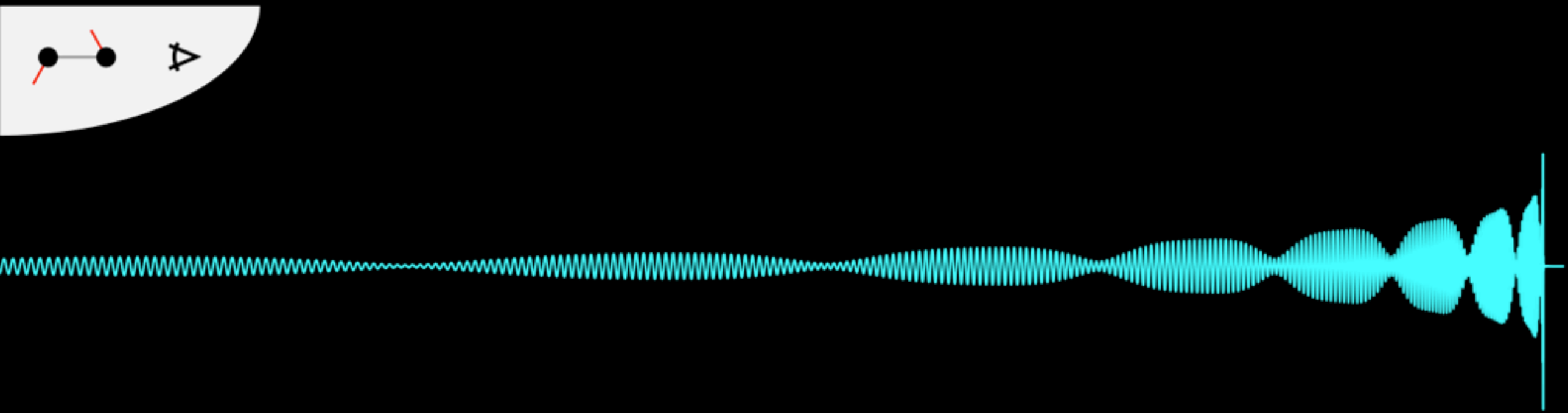
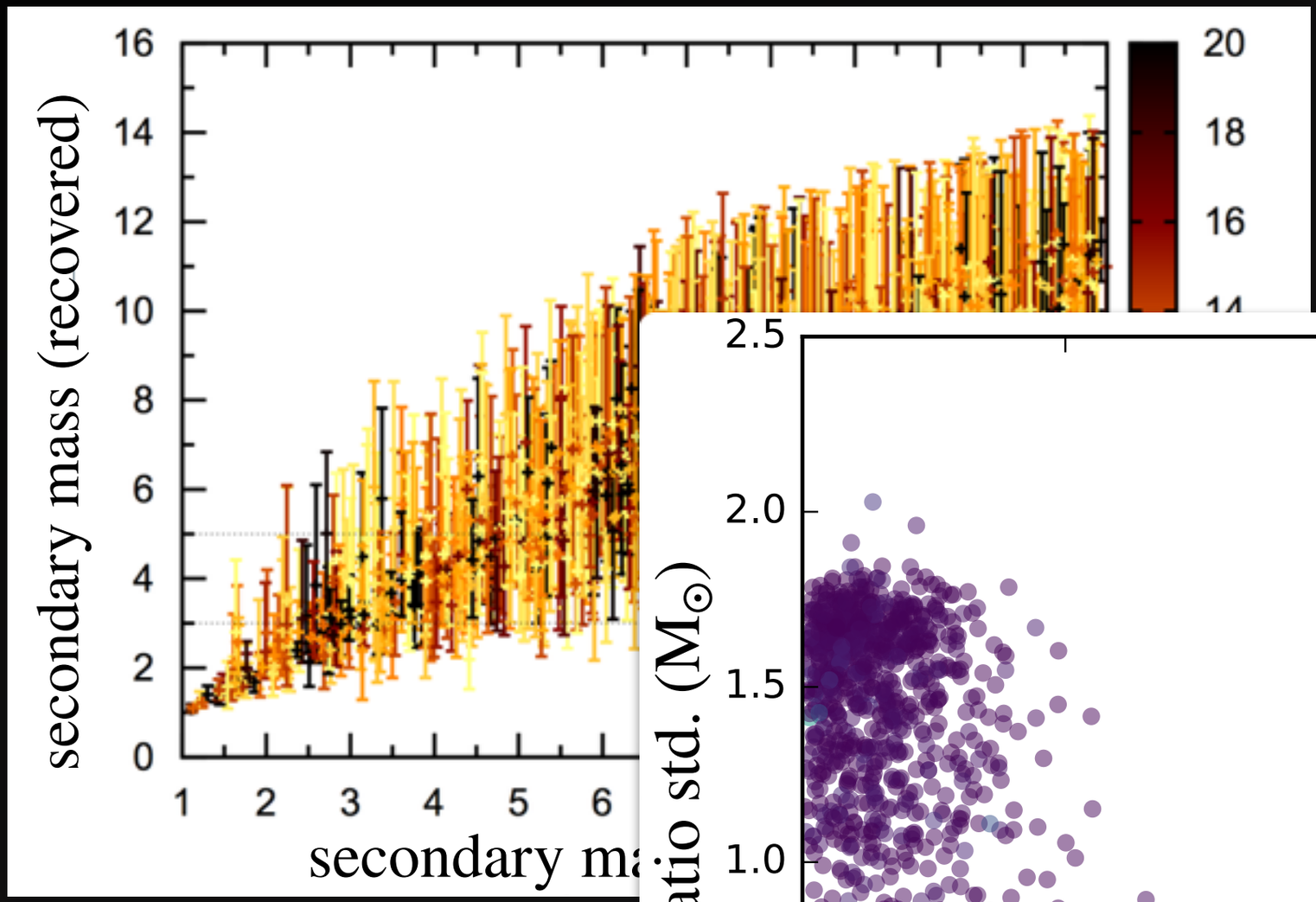
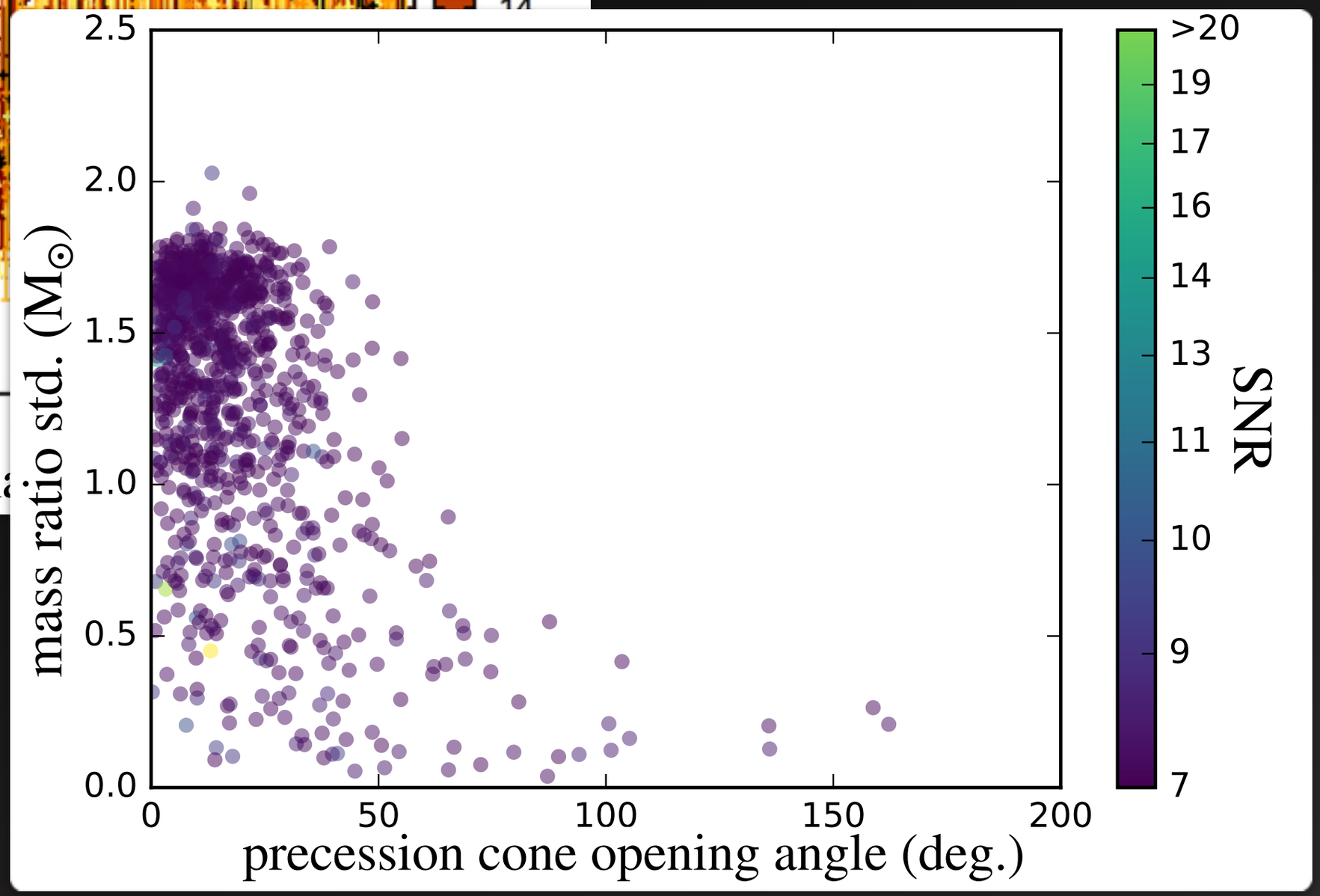


- Precession breaks degeneracies
- Only the primary component is well constrained for unequal-mass binaries
- Equal-mass binaries with two misaligned components are *rich* with information

Mass-Spin Degeneracy





Littenberg, **BFF**, Couglin et al. (2015)

Current Models

Inspiral - merger - ringdown waveforms (necessary for BBH):

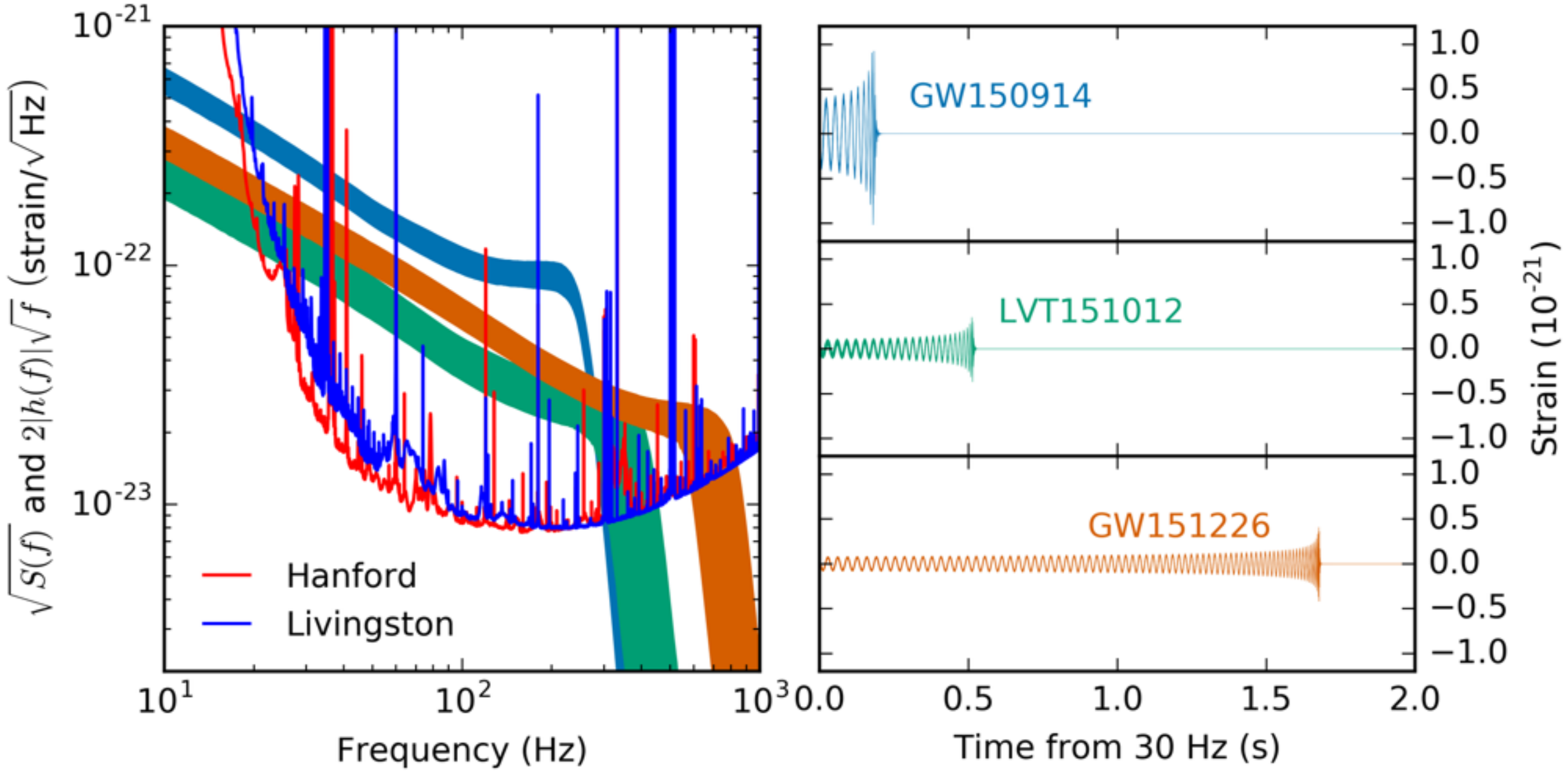
SEOBNR(v2): double-spin, non-precessing

IMRPhenomP(v2): precessing, effective spins

SEOBNR(v3): precessing, double-spin

BBHs in O1

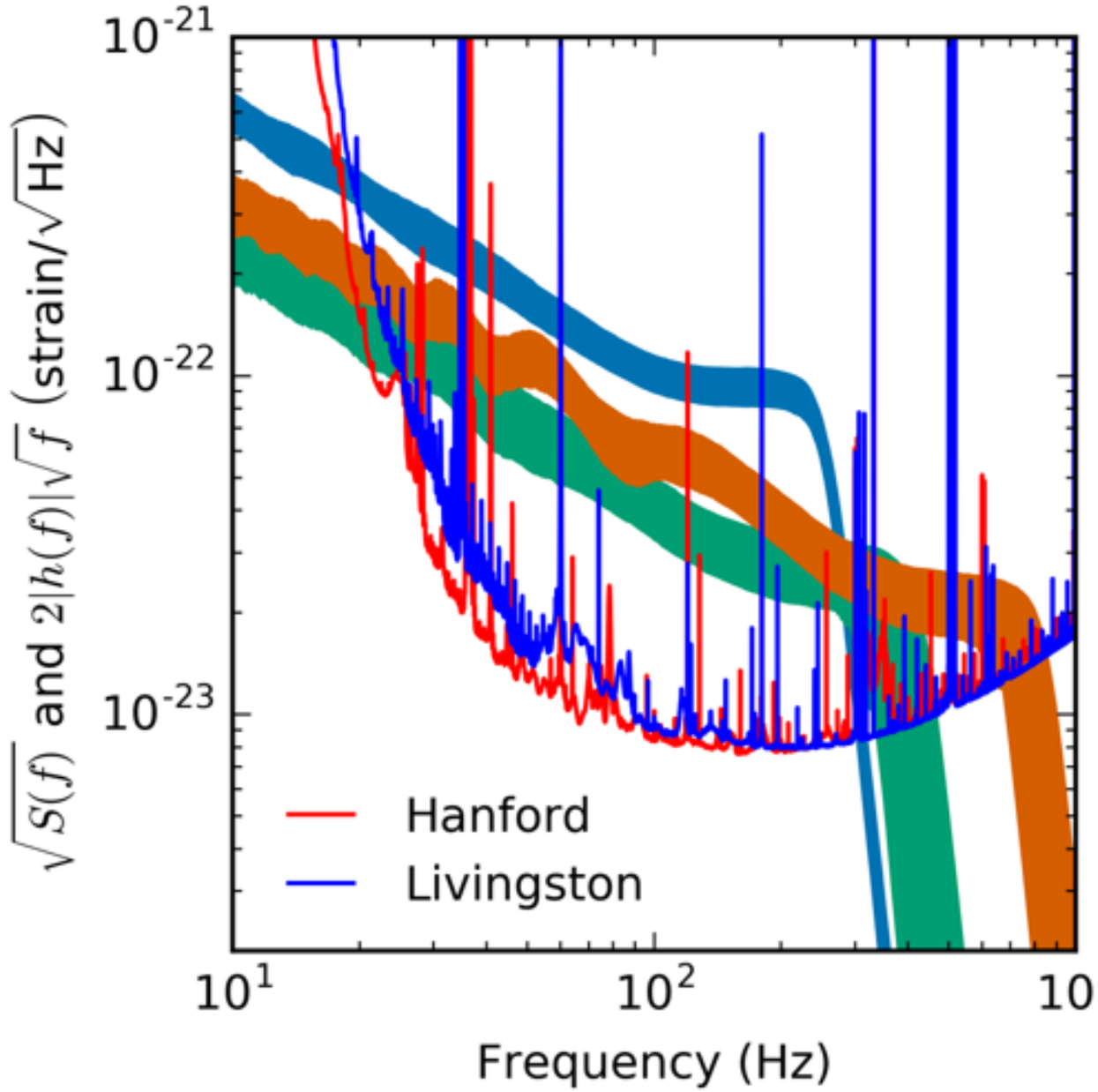
non-precessing

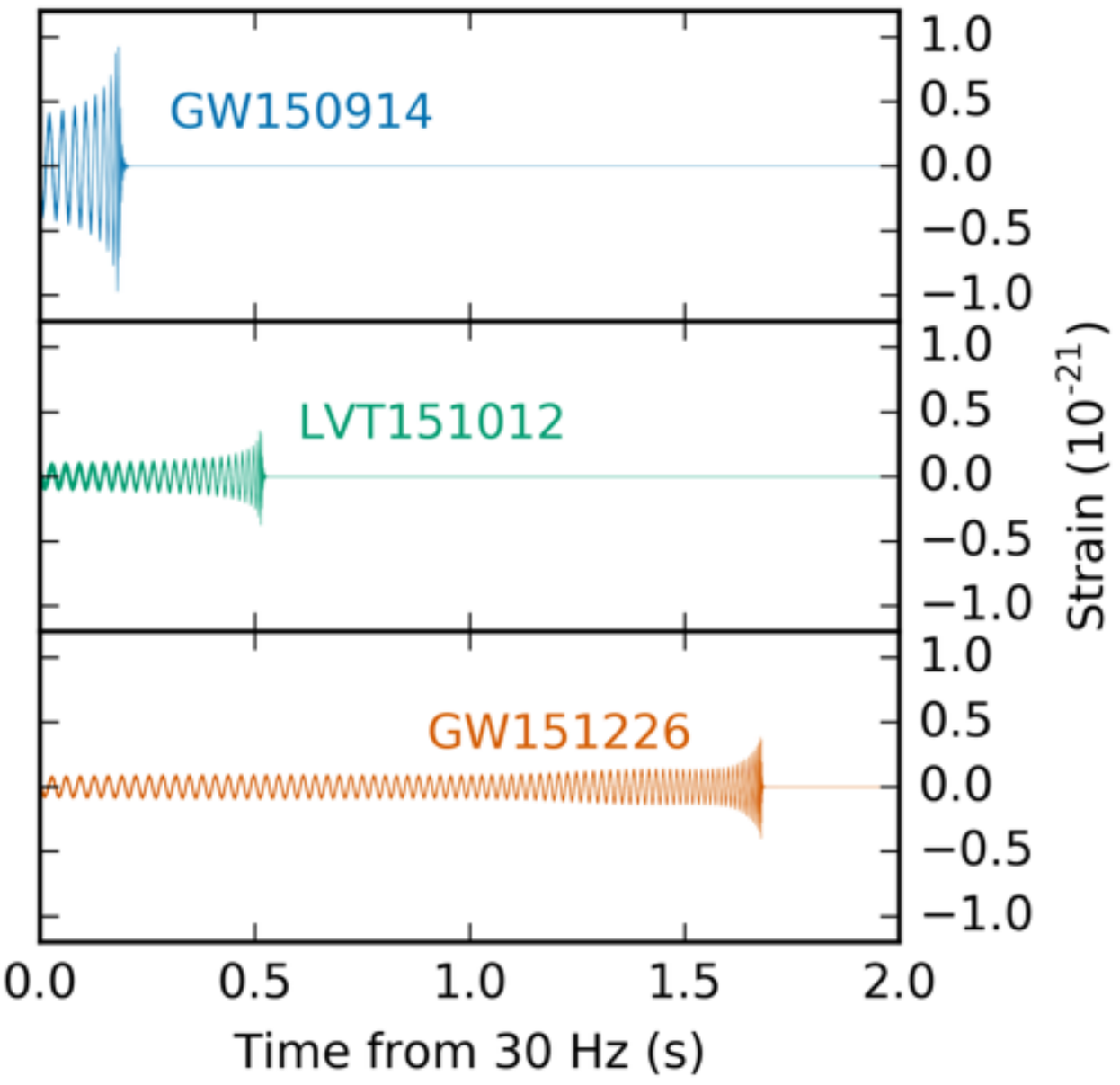


Abbott et al. (2016)
arXiv:1606.04856

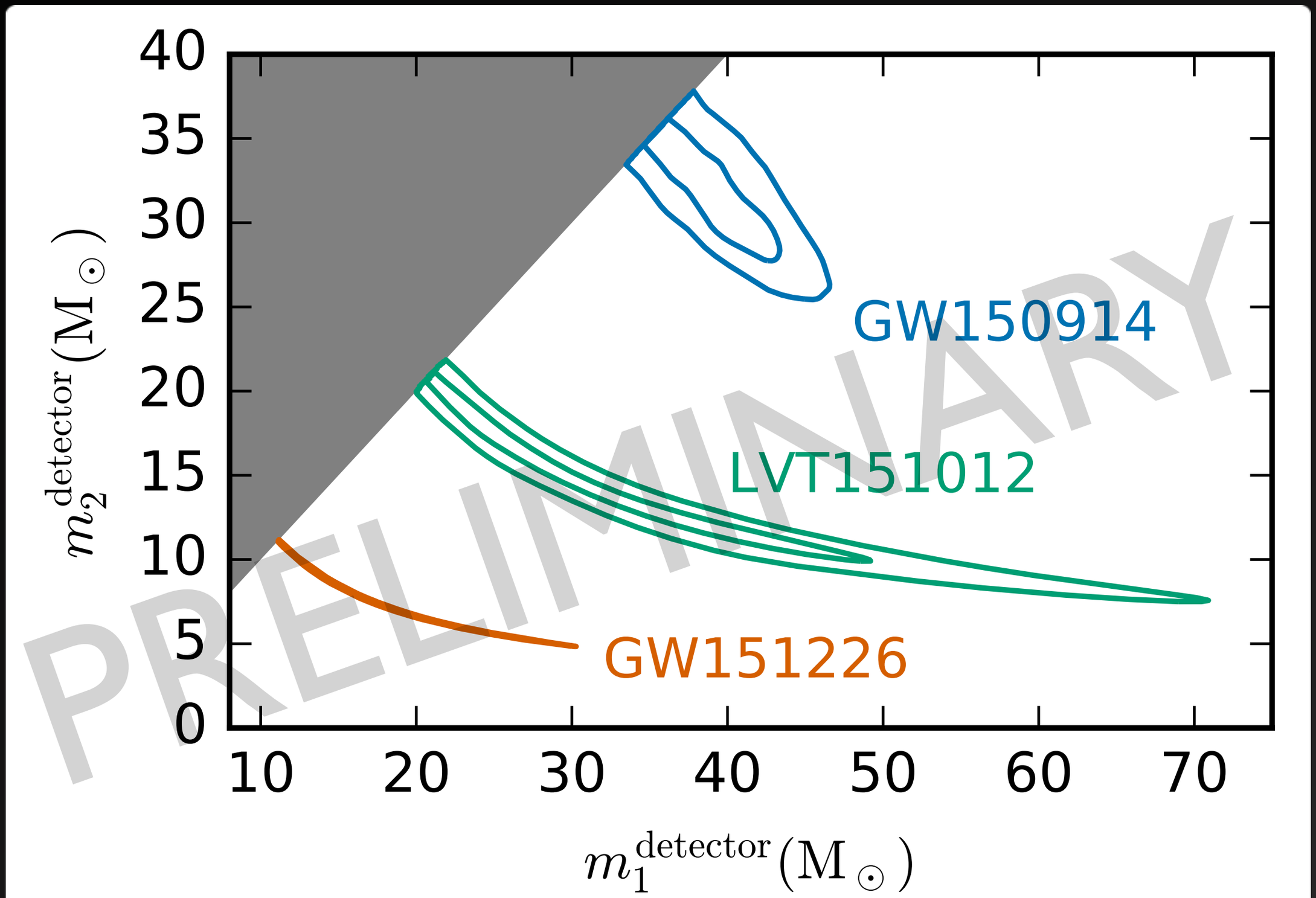
BBHs in O1

precessing

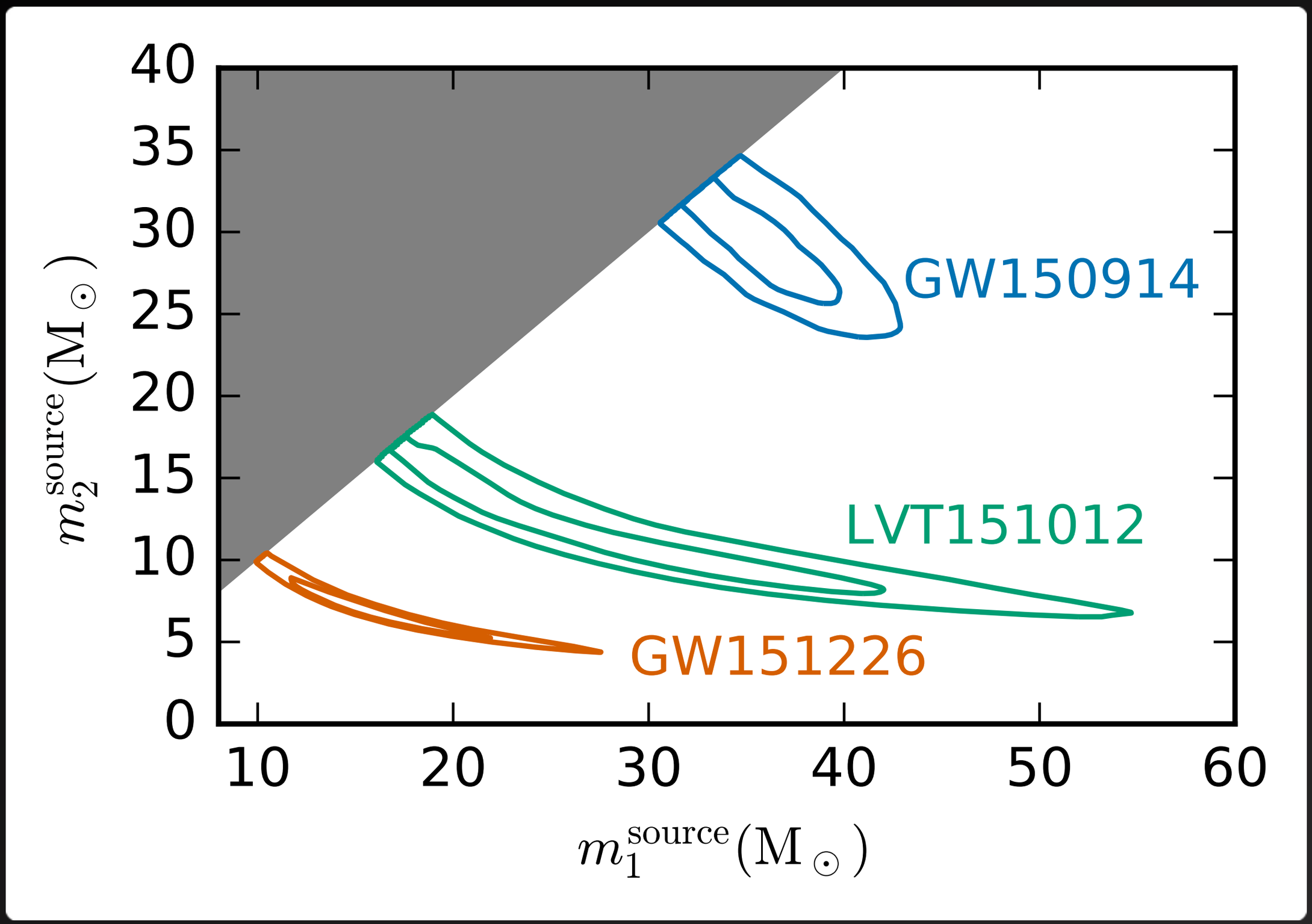




Masses


40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
$m_2^{\mathrm{detector}}(\mathrm{M}_\odot)$
$m_1^{\mathrm{detector}}(\mathrm{M}_\odot)$
GW150914
LVT151012
GW151226
PRELIMINARY

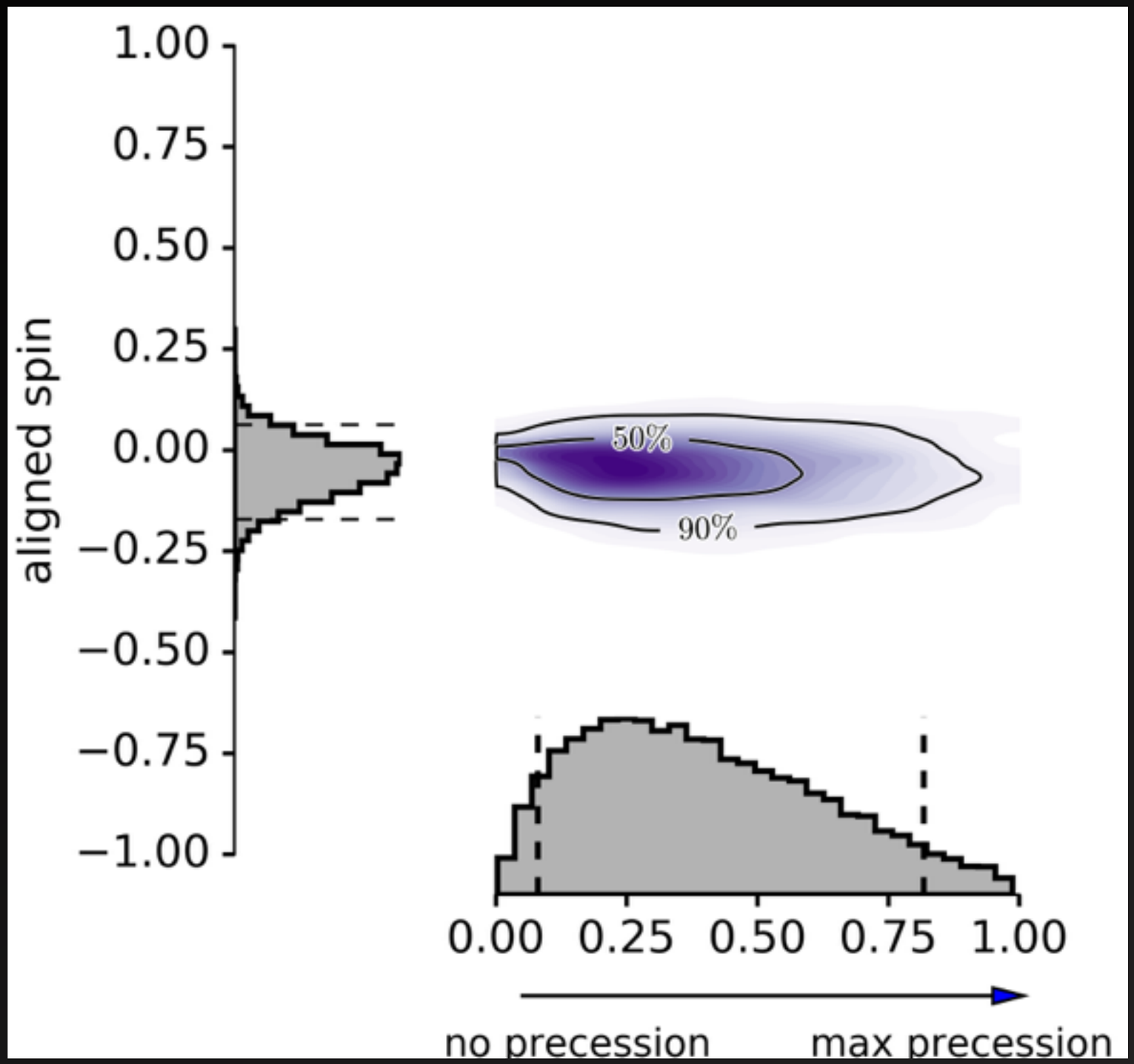
Masses



Abbott et al. (2016)
arXiv:1606.04856

Effective Spin Estimates

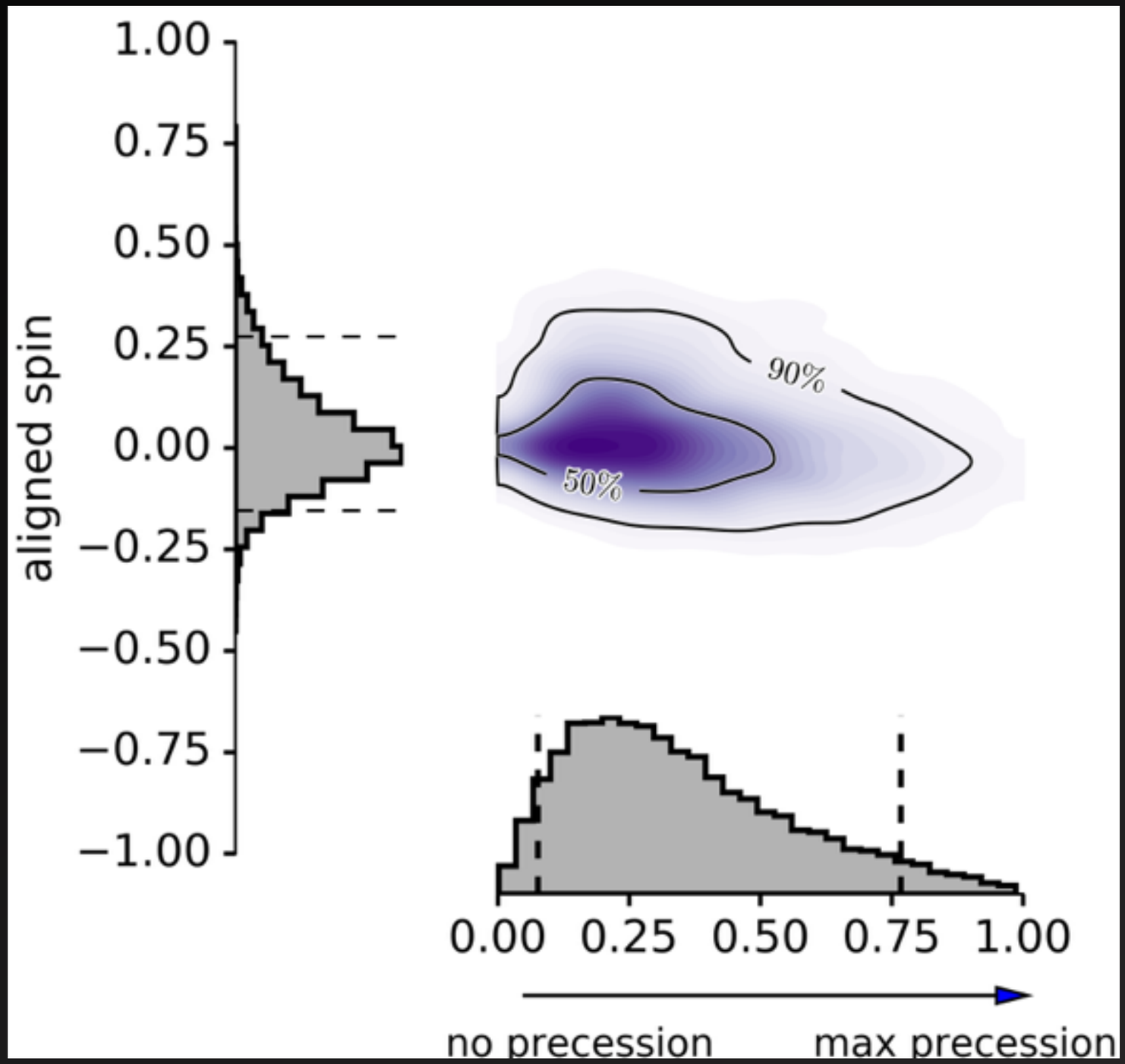
GW150914



Abbott et al. (2016):
PRL **116**, 241102

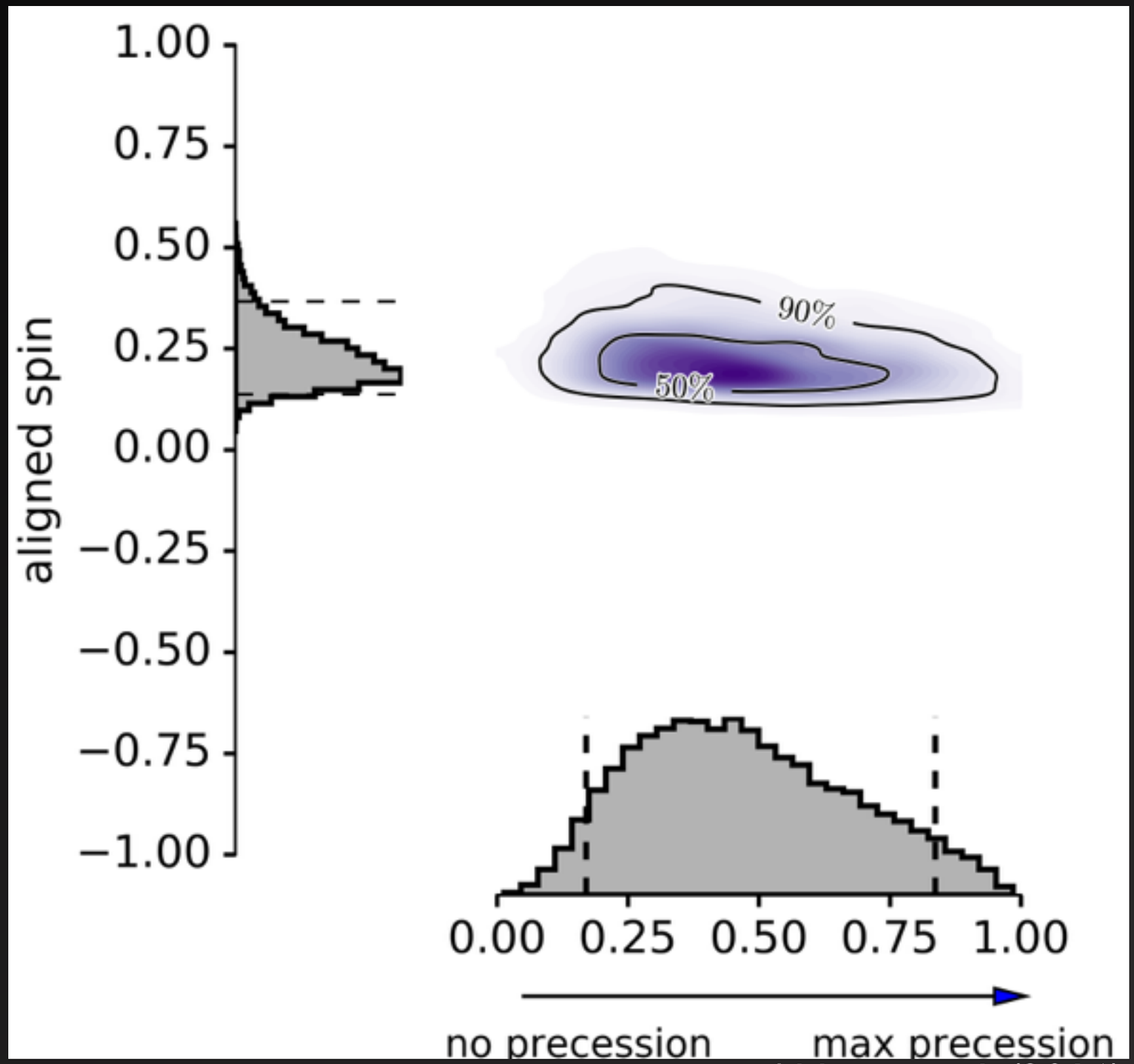
Effective Spin Estimates

LVT151012



Effective Spin Estimates

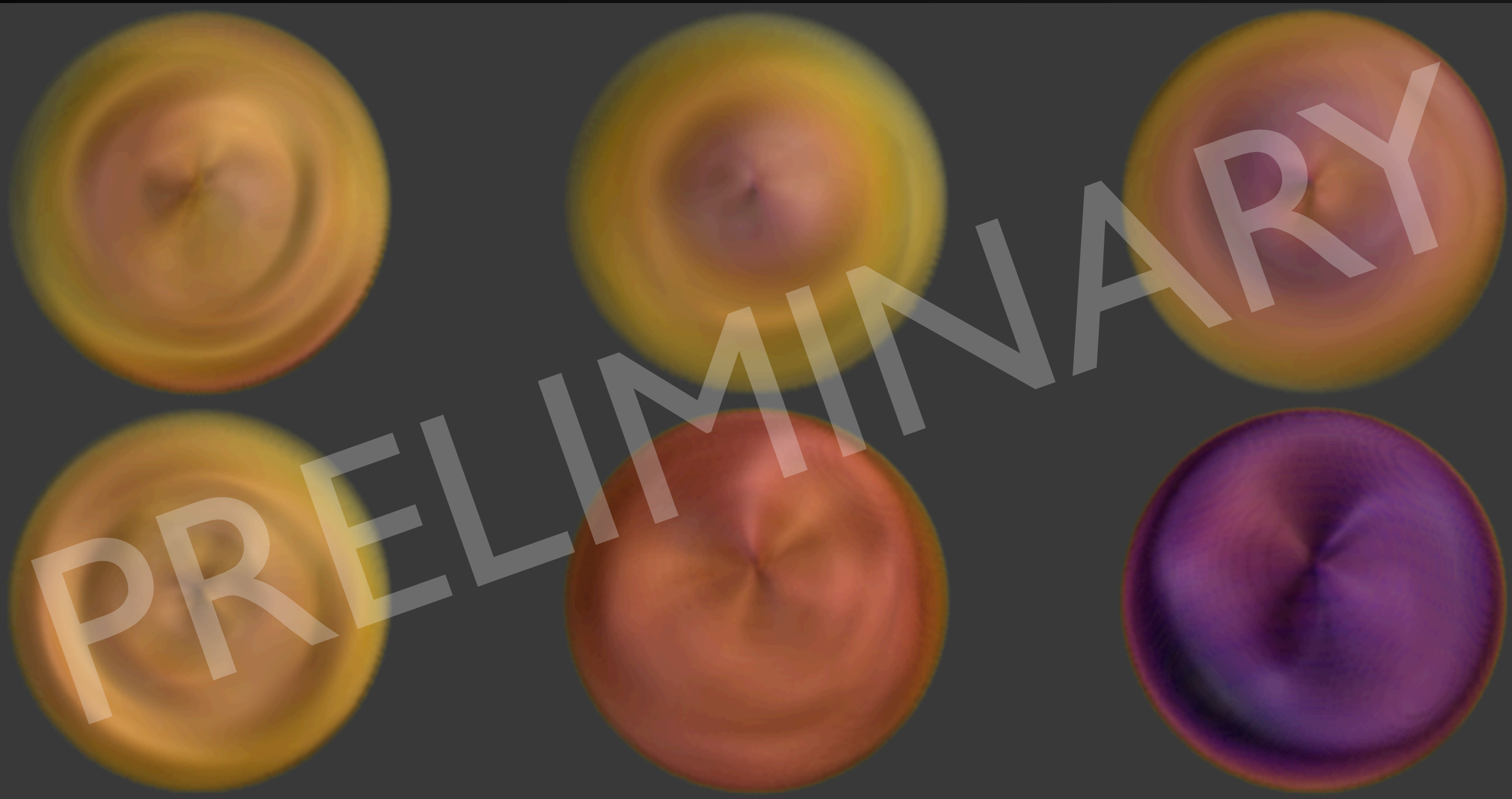
GW151226



Abbott et al. (2016): PRL **116**, 241103

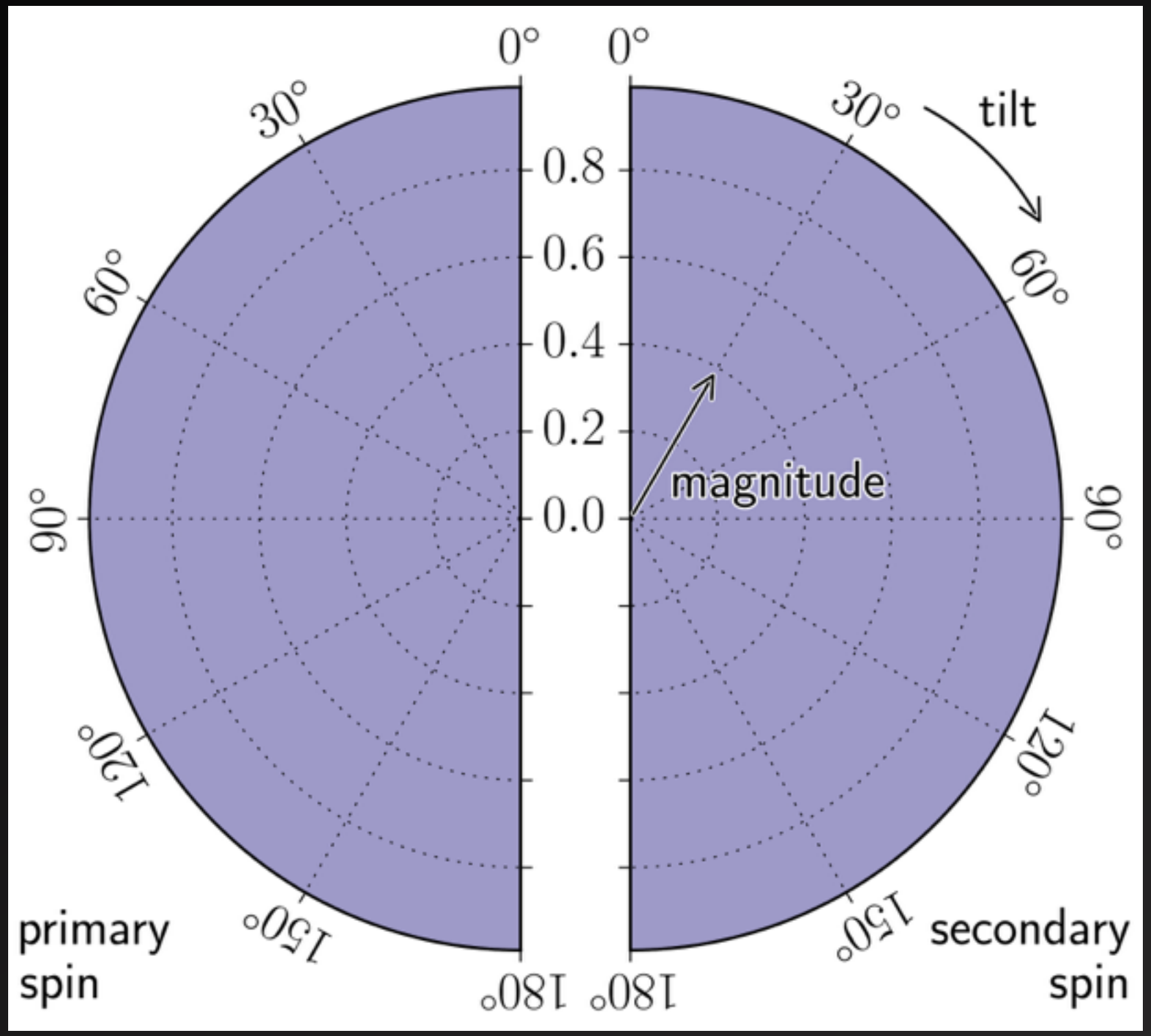
BH Spin Estimates

GW150914 LVT151012 GW151226



BH Spin Estimates

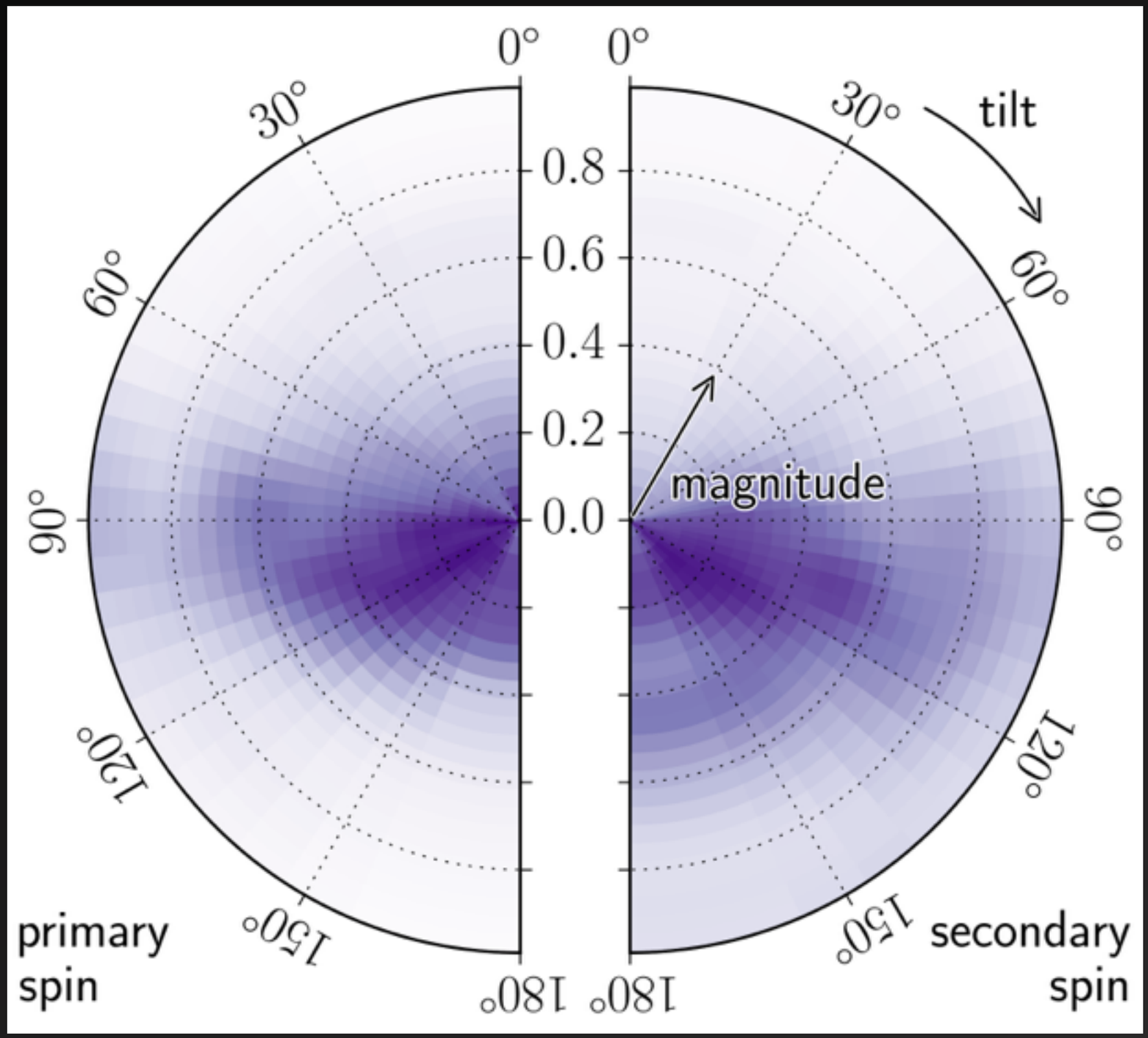
prior



BH Spin Estimates

GW150914

BH spin
not extremal



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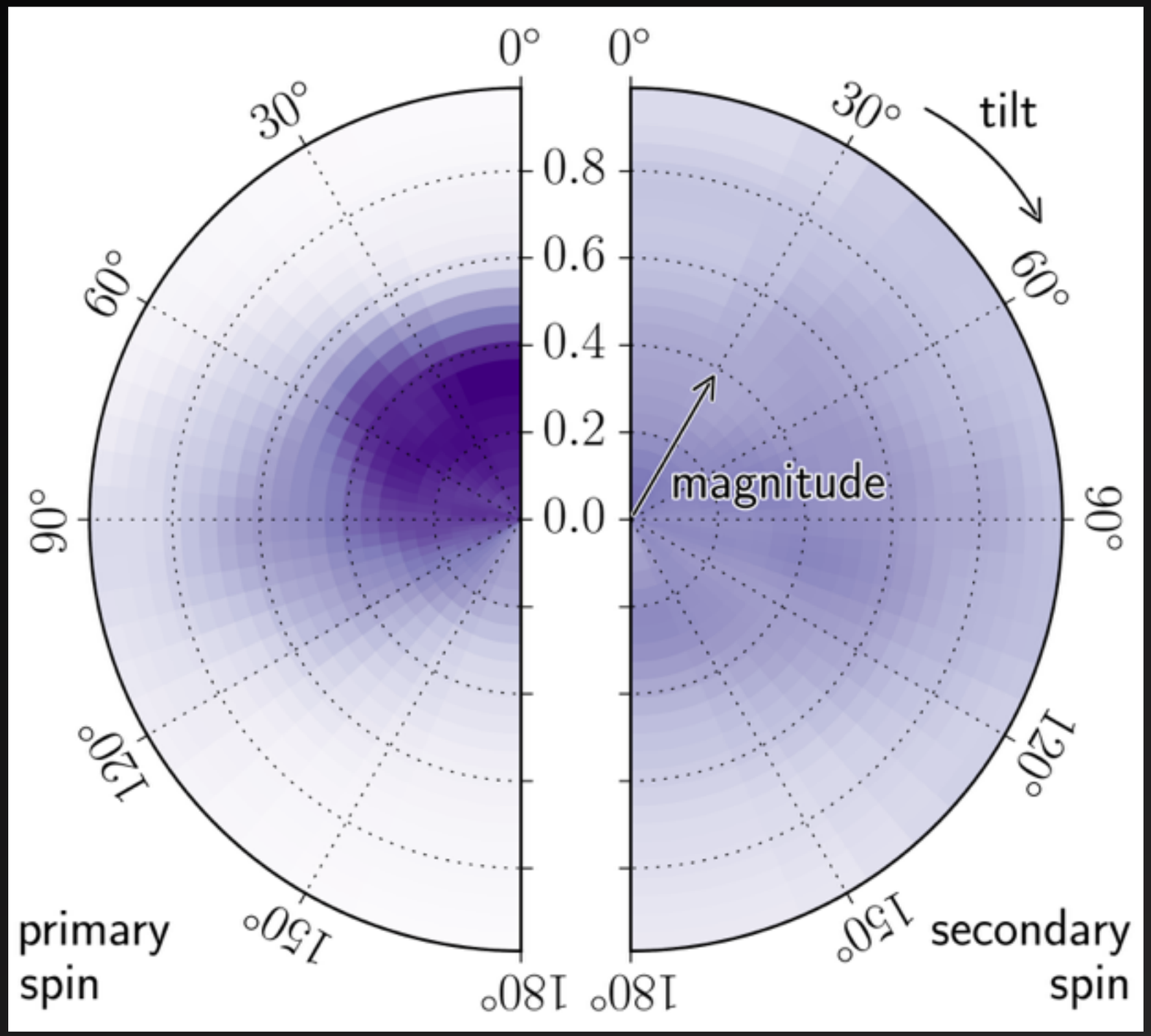
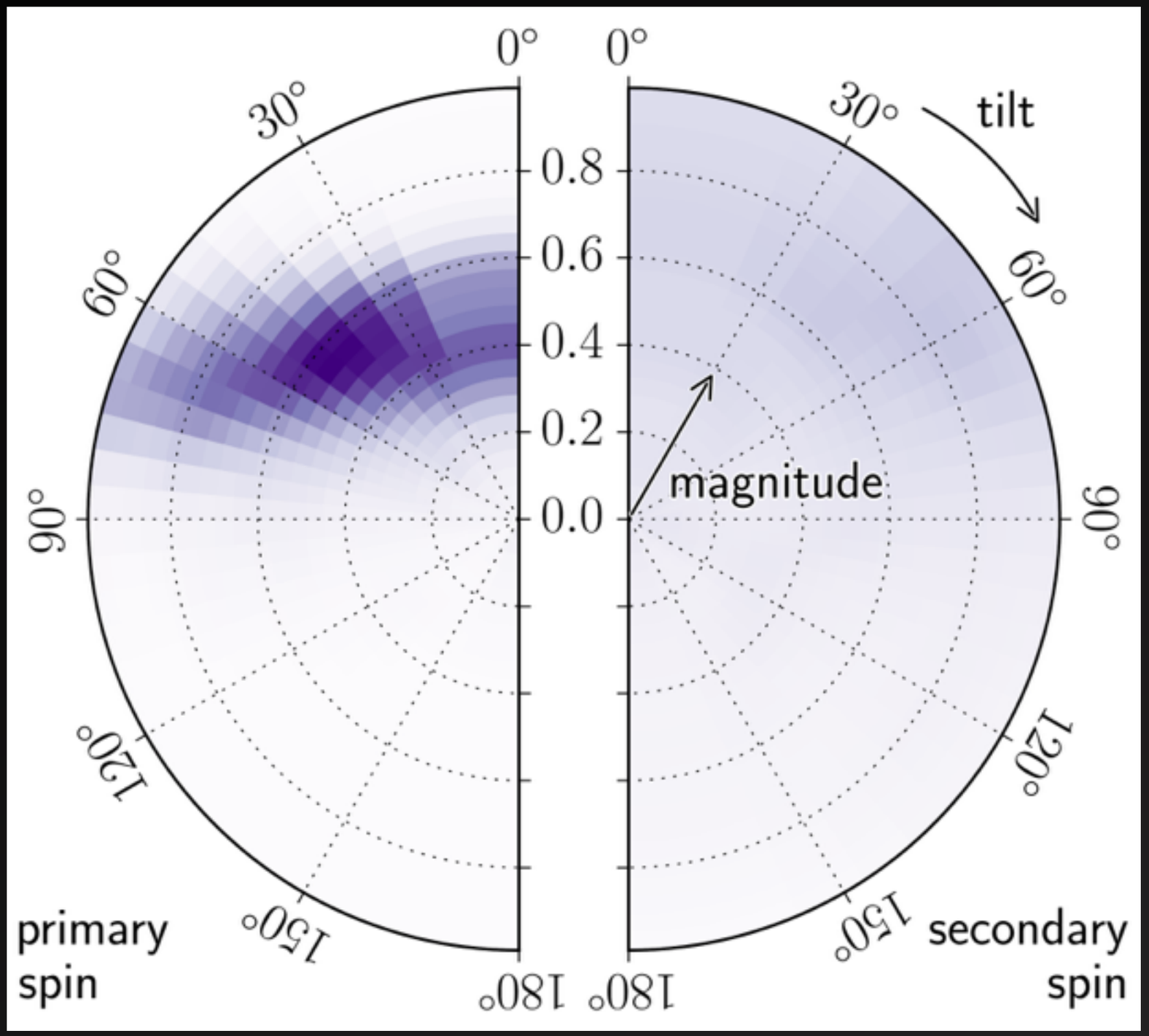
BH Spin Estimates

LVT151012



BH Spin Estimates

GW151226



At least one spinning BH

Abbott et al. (2016):
PRL **116**, 241103

Summary

Chirp mass is well constrained.

Mass ratio and spins poorly constrained, except for optimally oriented precessing binaries.

From O1:

- Not all BHs have extremal spin.
- Not all BHs have no spin.
- Many more BBHs to come…