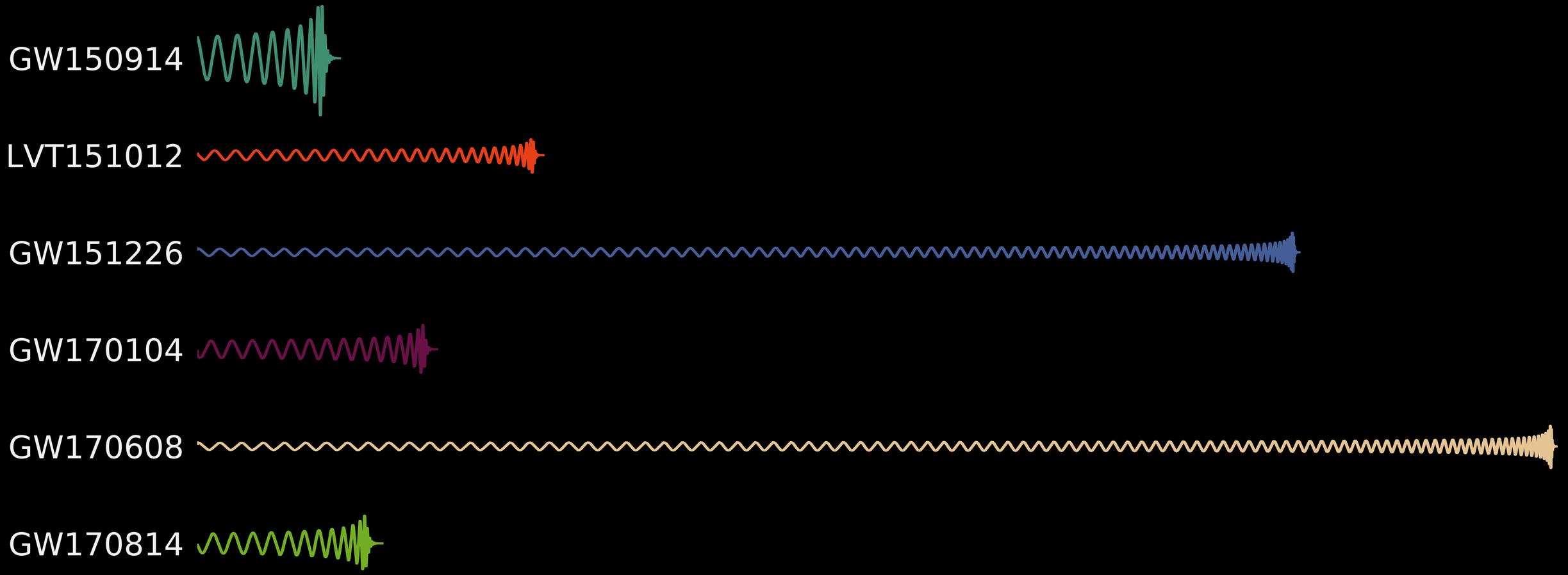
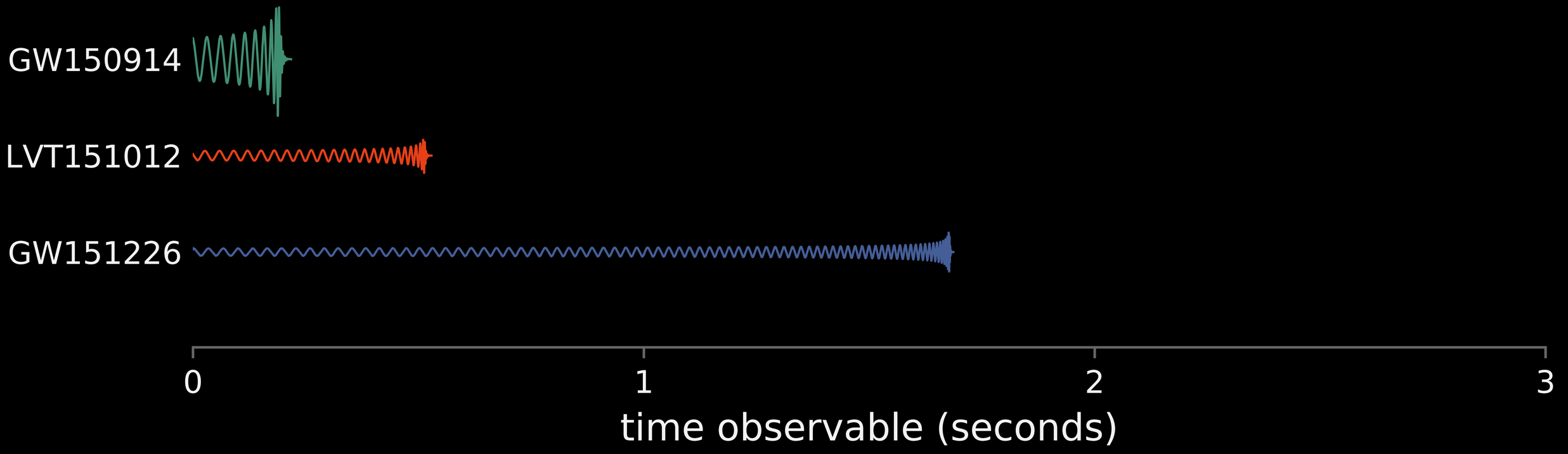
The Binary Black Hole Census
after LIGO/Virgo's Second Observing Run



Ben Farr

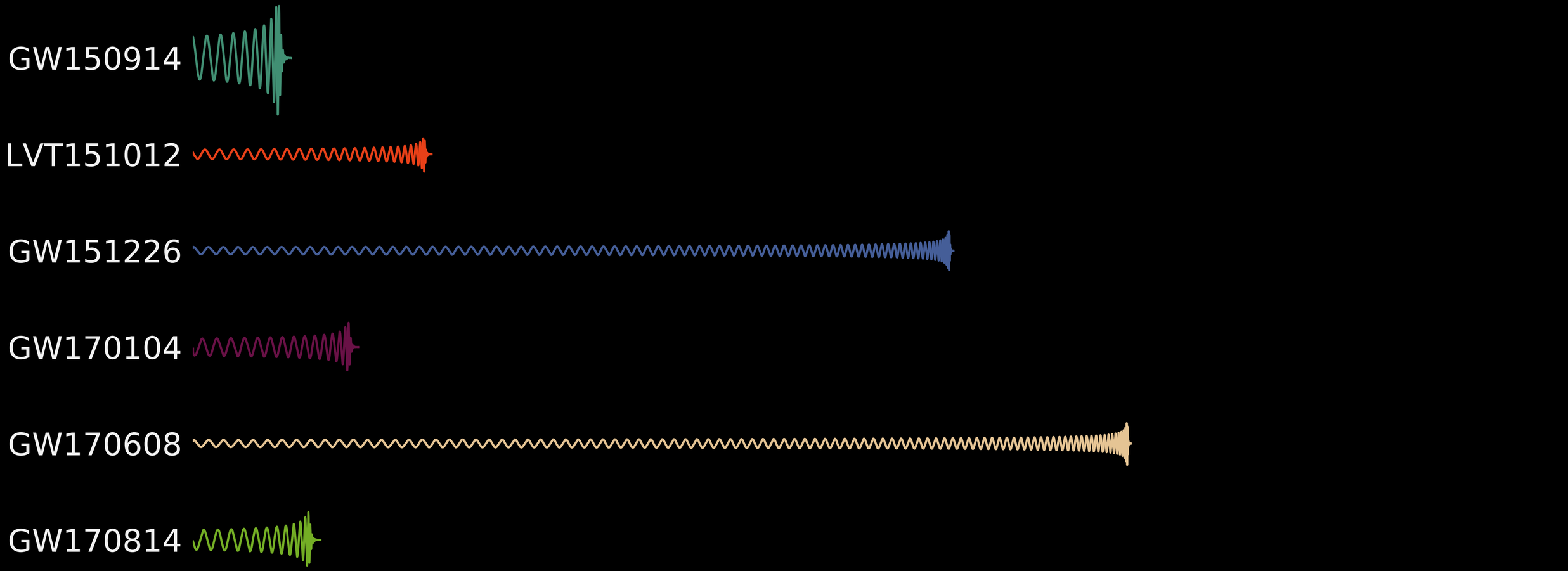
LIGO-G1800924

O1 BBHs



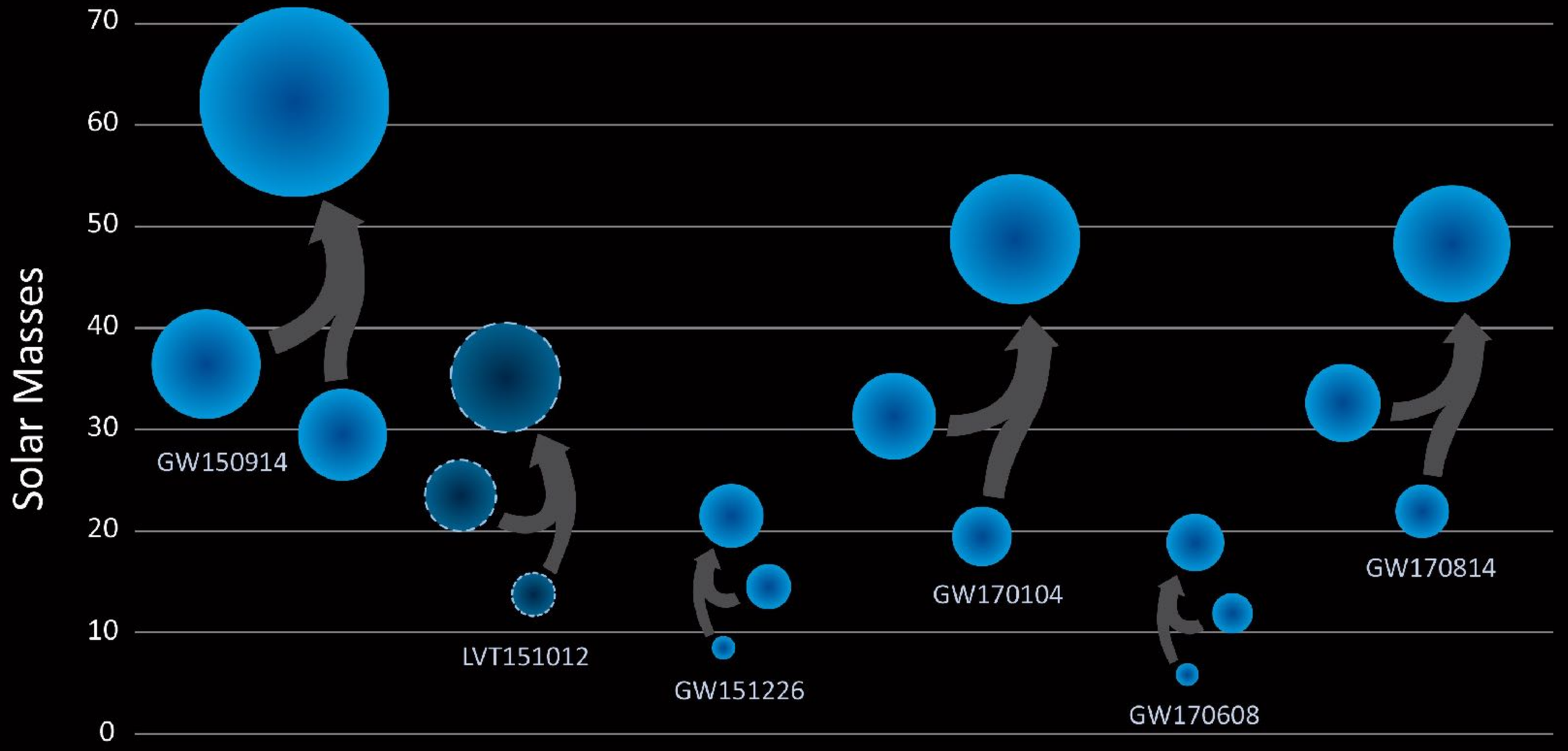
LIGO/University of Oregon/Ben Farr

O1+O2 BBHs



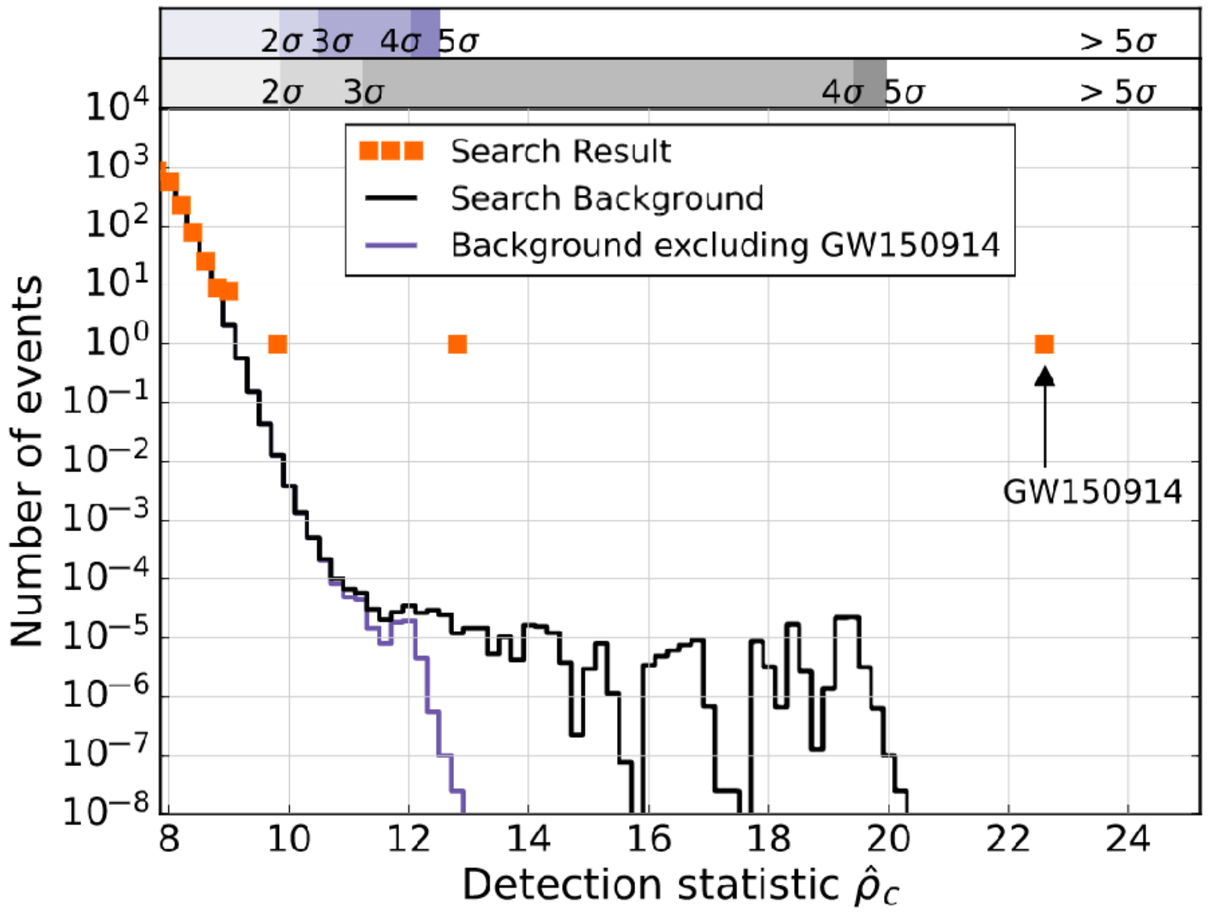
LIGO/University of Oregon/Ben Farr

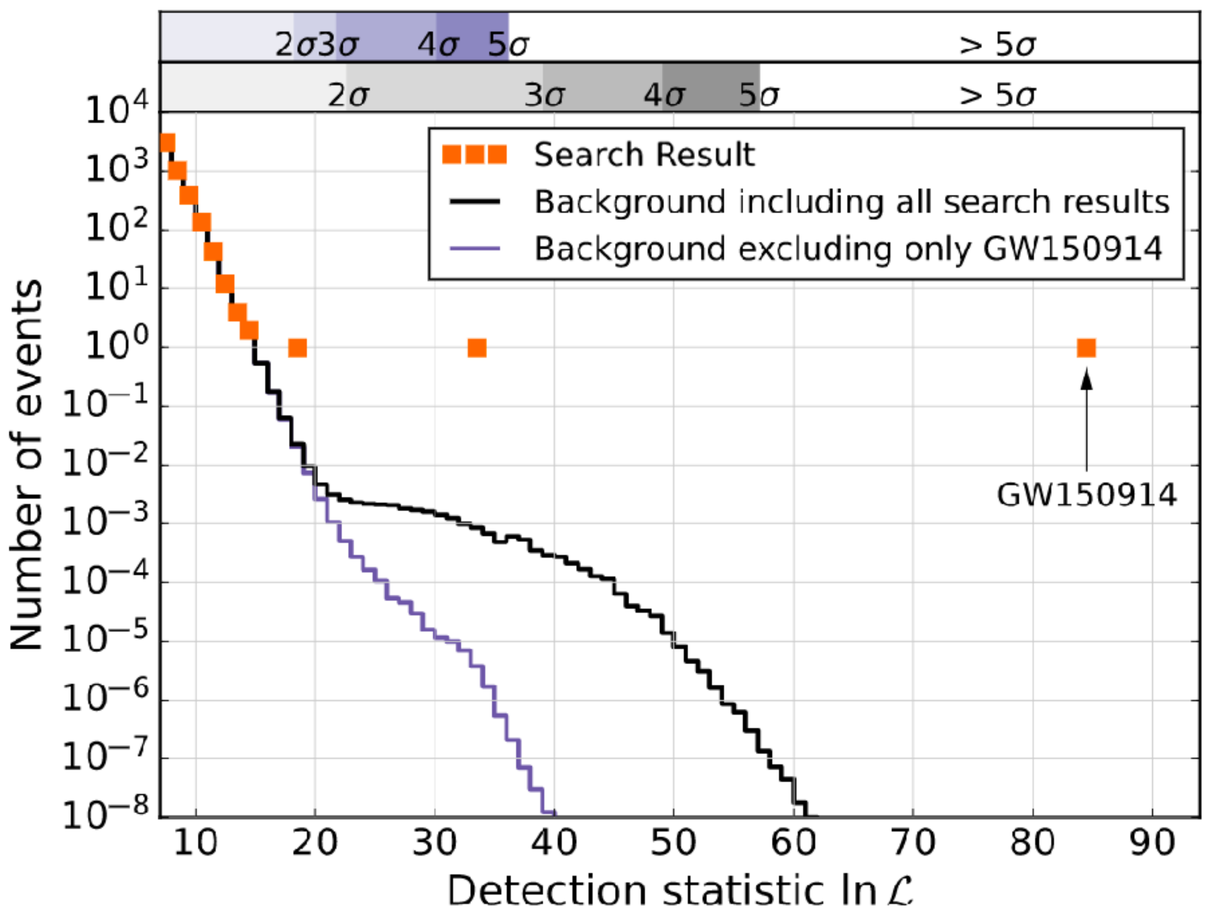
LIGO-Virgo's BBHs



LIGO/VIRGO

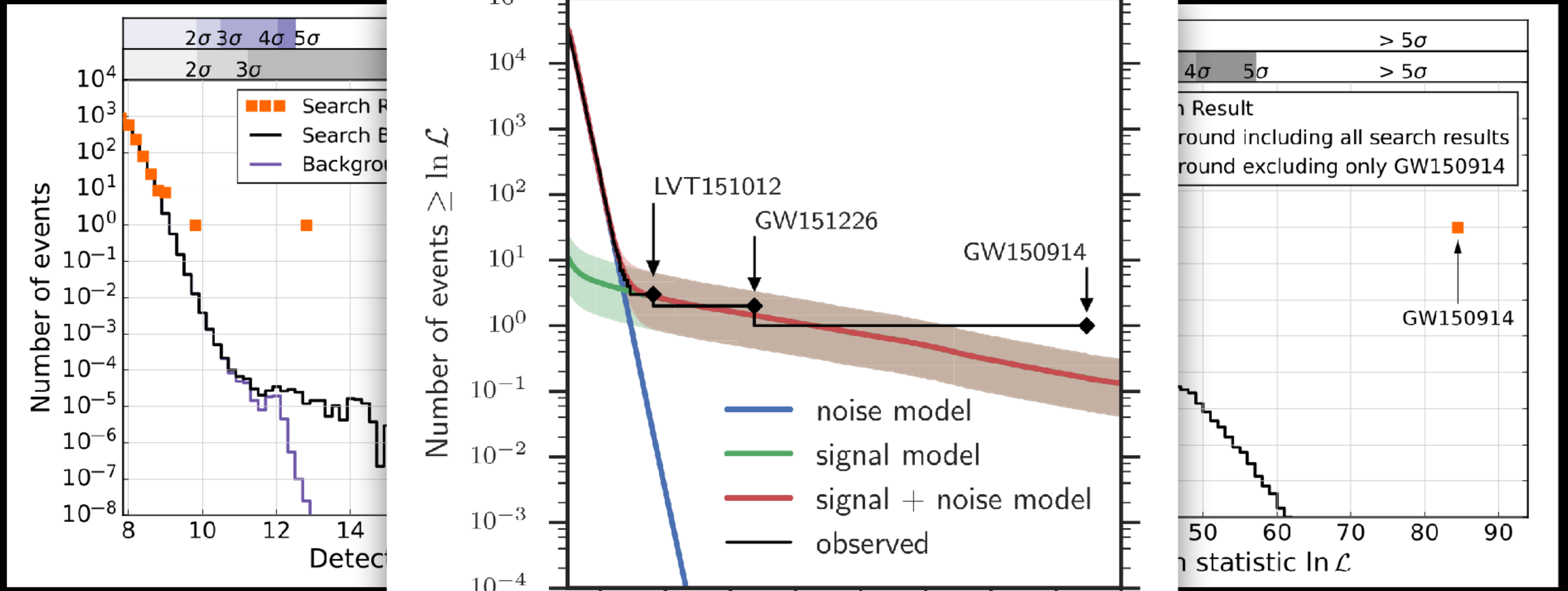
Q: What's just below threshold?





O1 BBH:
Abbott et al. (2016)
PRX 6, 041015

Q: What's just below threshold?



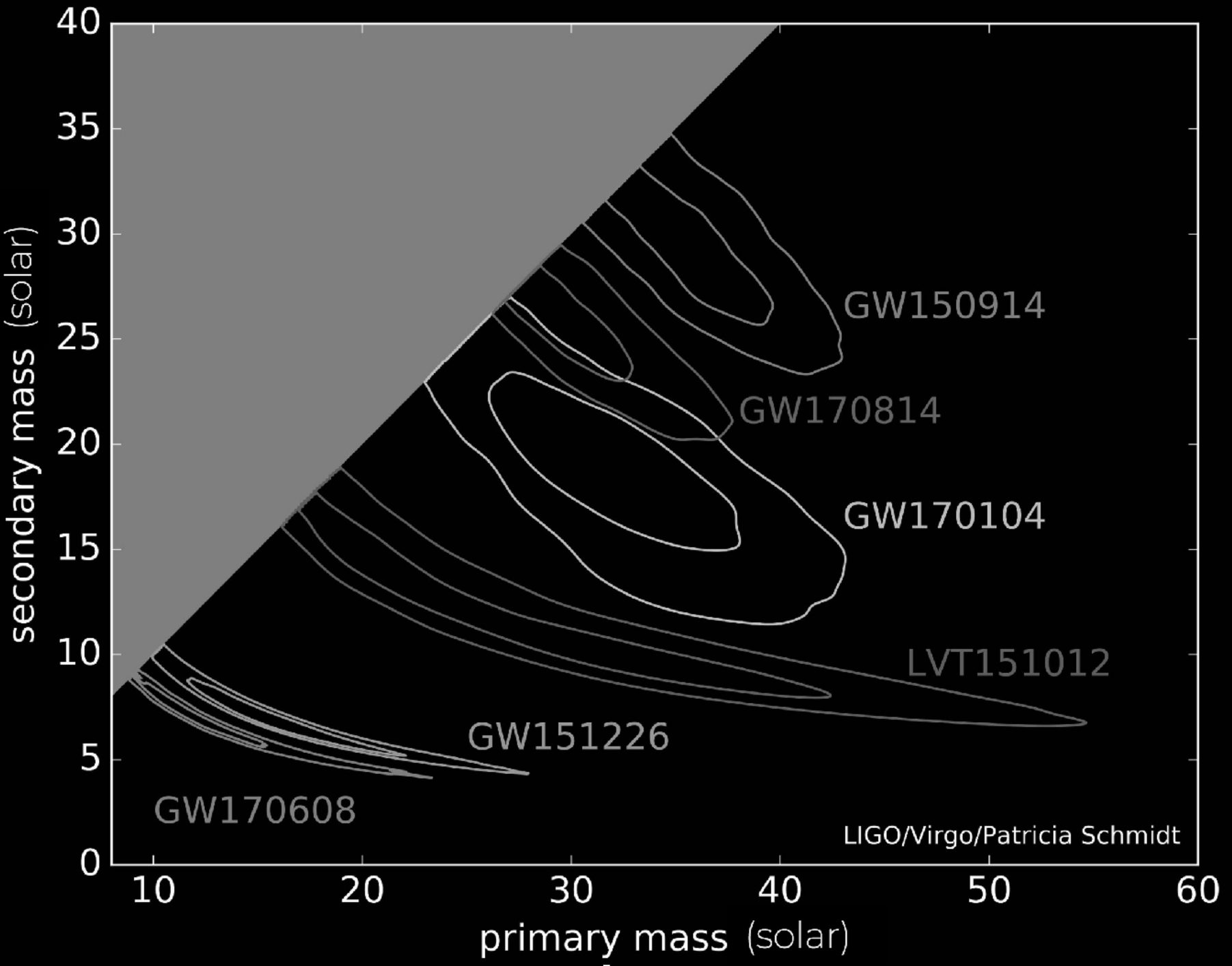
O1 BBH:
Abbott et al. (2016)
PRX 6, 041015

O1 BBH:
Abbott et al. (2016)
PRX 6, 041015

GW170104:
Abbott et al. (2017)
PRL 118, 221101

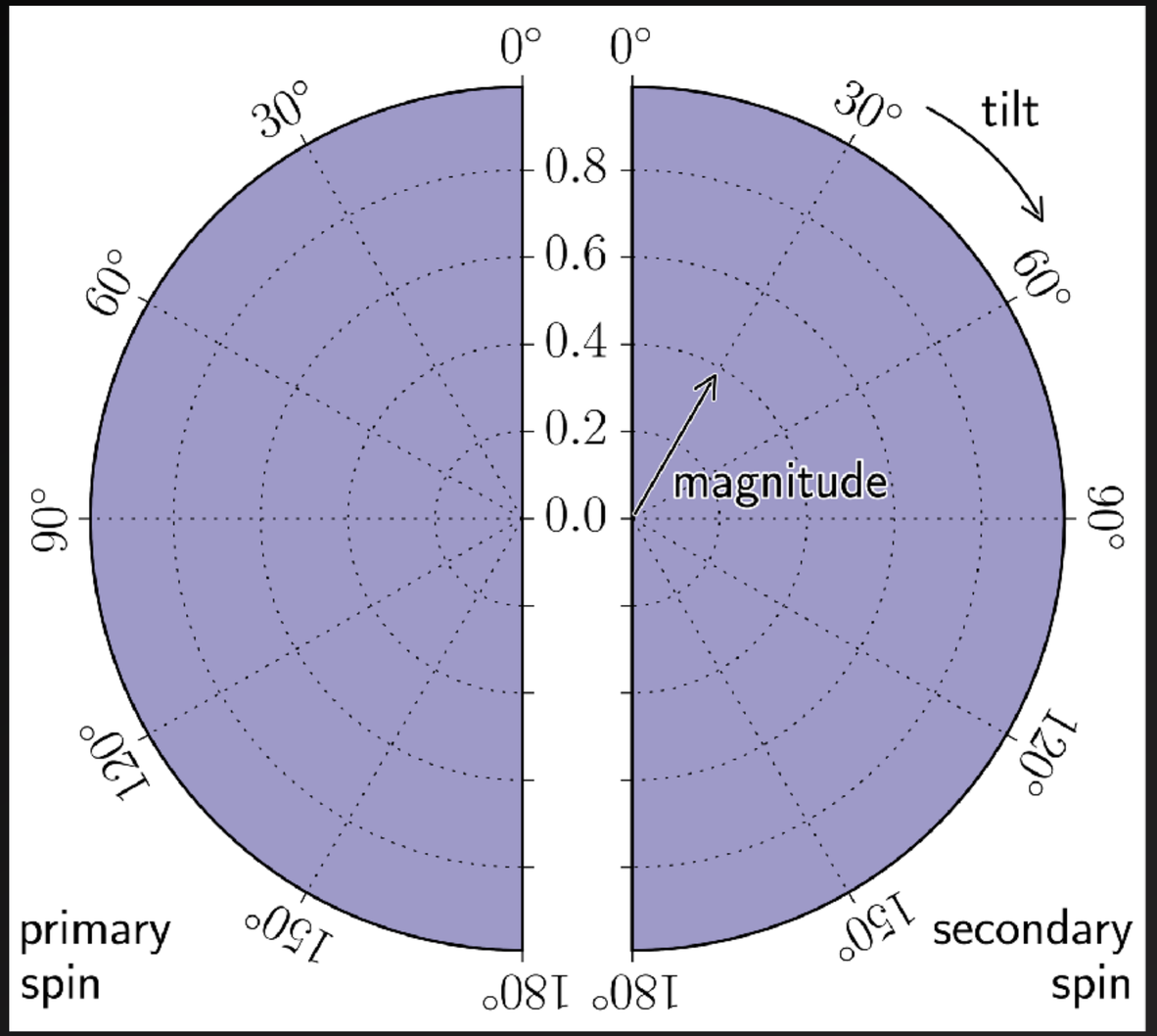
GW170608:
Abbott et al. (2017)
ApJL 851 L35

GW170814:
Abbot et al. (2017)
PRL 119, 141101



Black Hole Spins

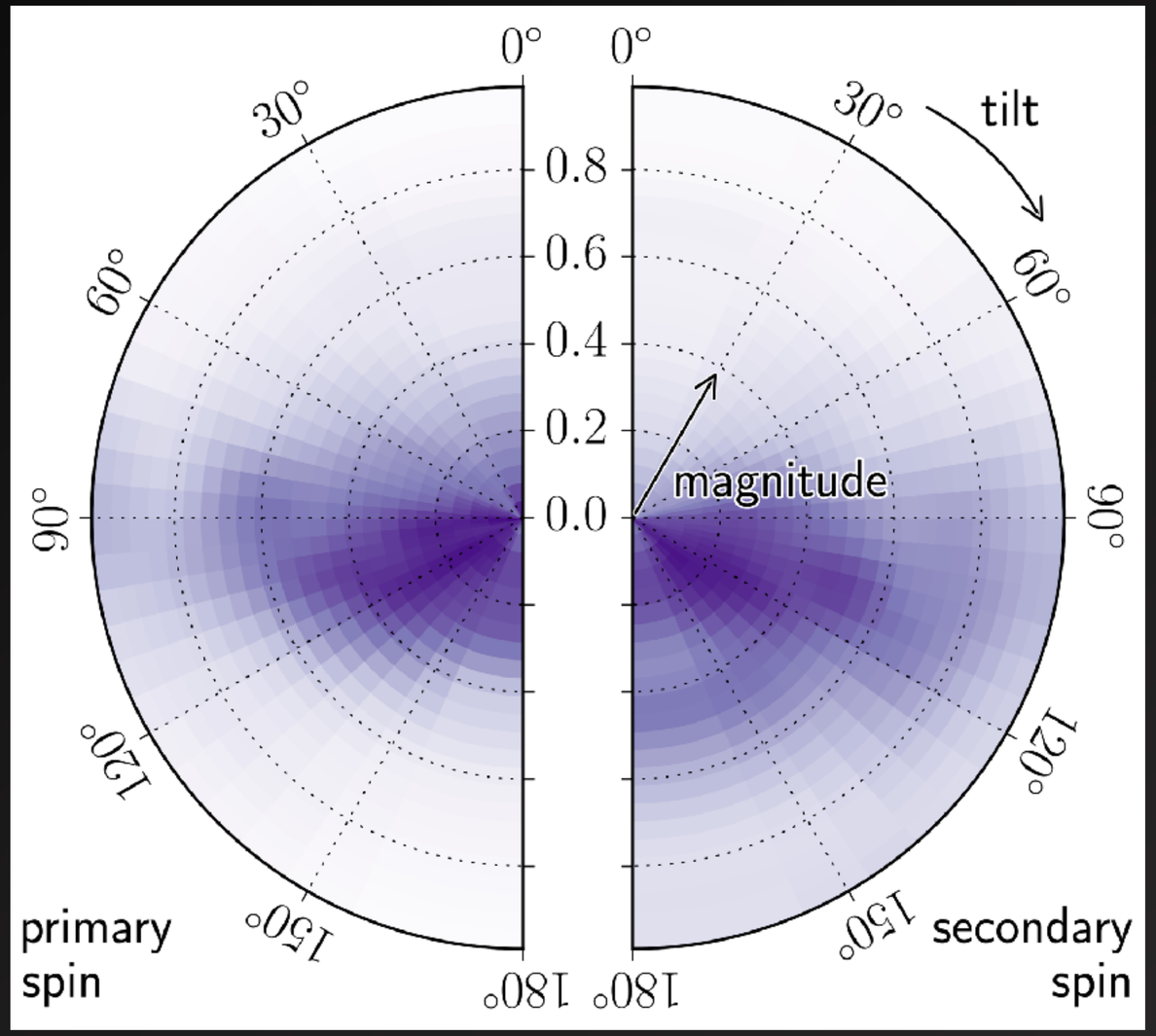
prior



Black Hole Spins

Abbott et al. (2016):
PRX **6**, 041015

GW150914

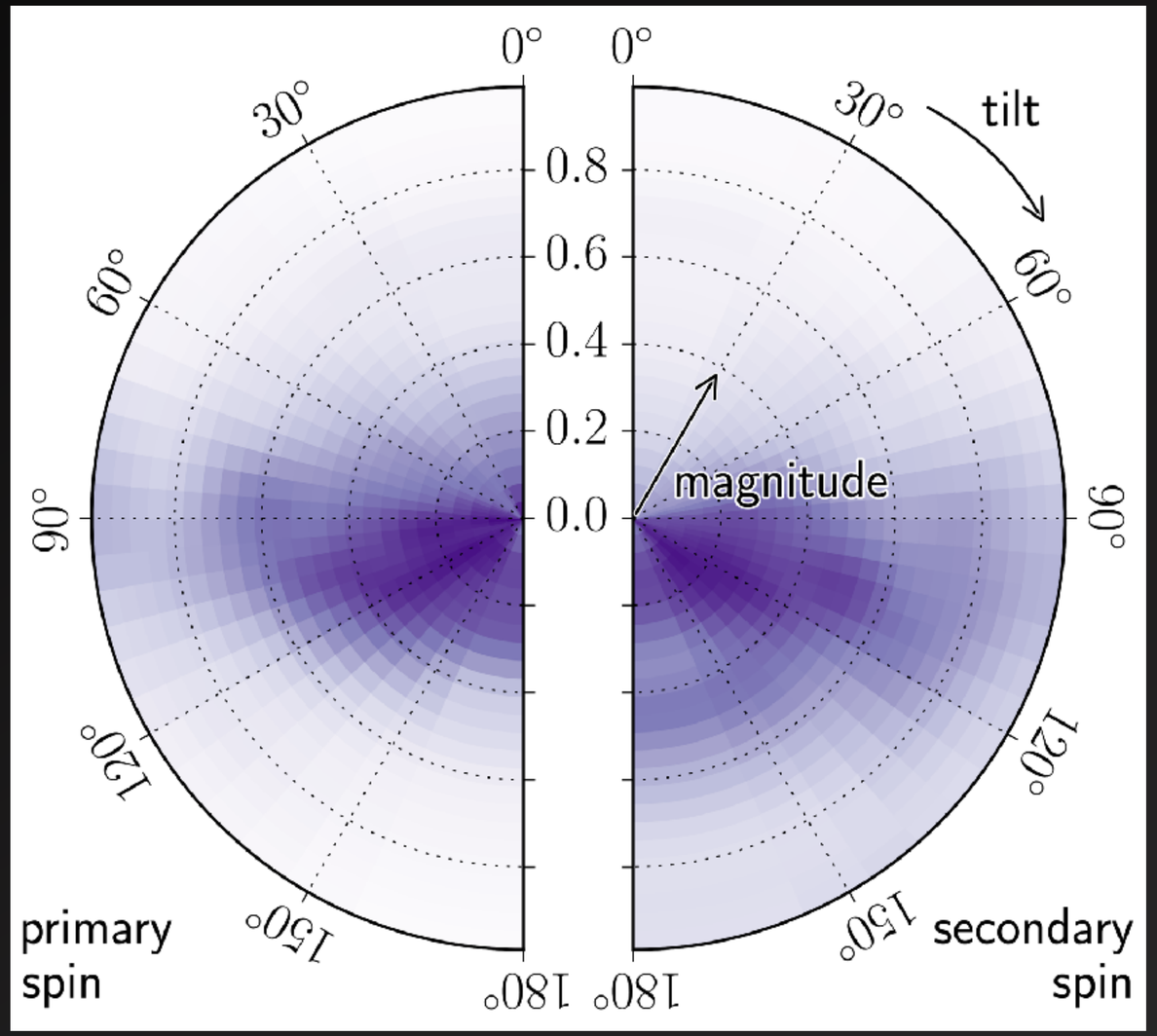


Black Hole Spins

Abbott et al. (2016):
PRX **6**, 041015

GW150914

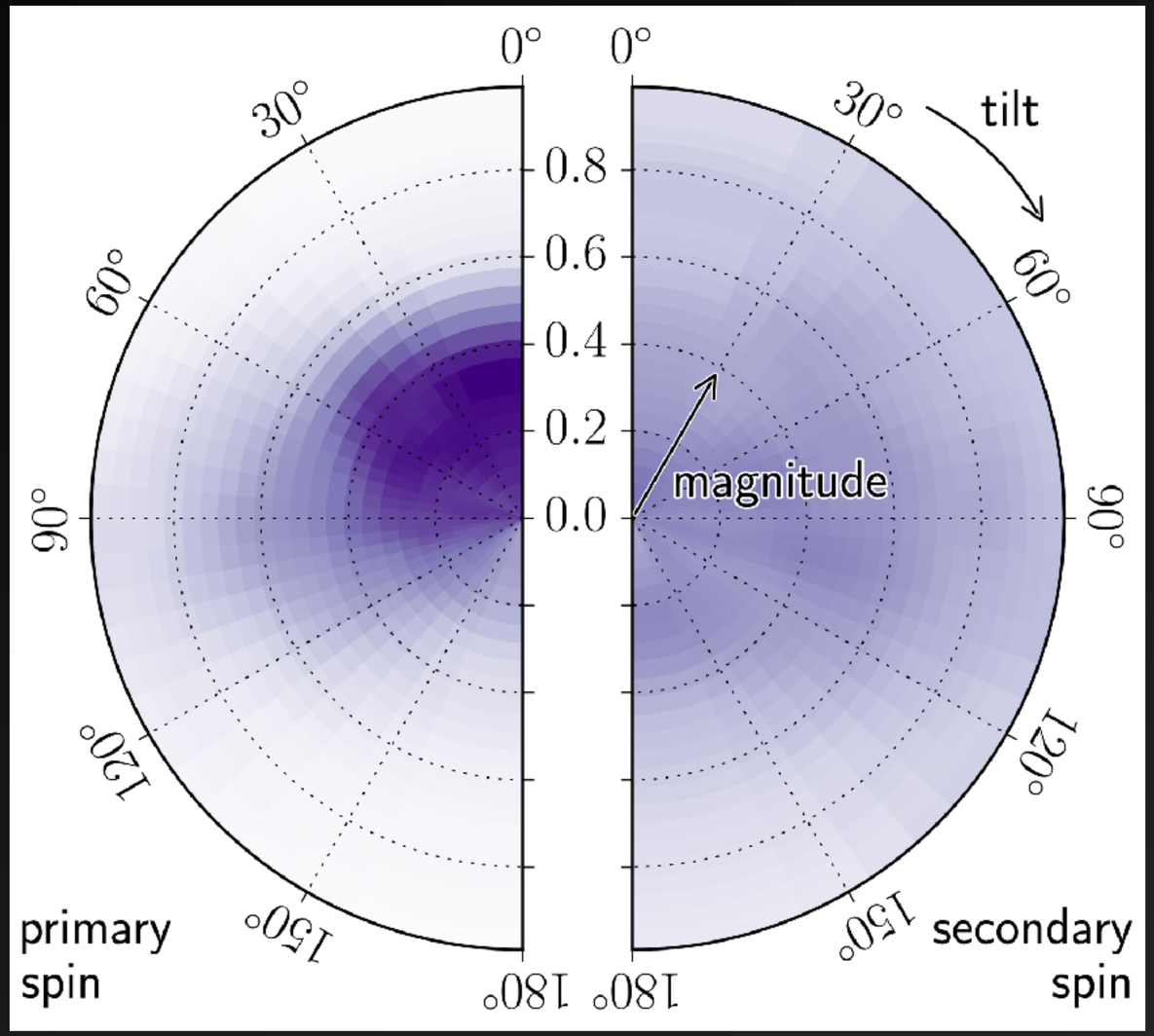
BH spin
not extremal



Black Hole Spins

Abbott et al. (2016):
PRX **6**, 041015

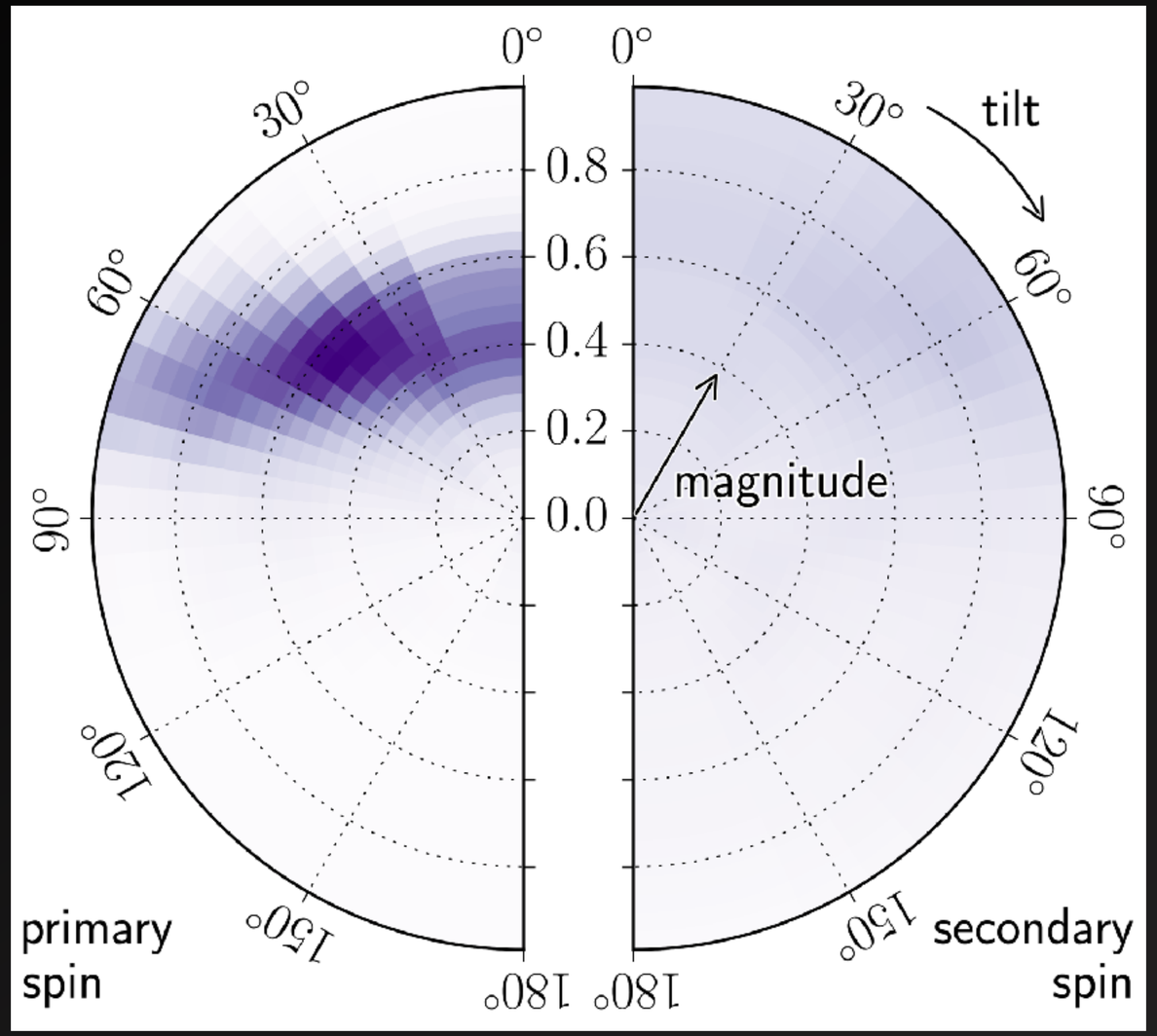
LVT151012



Black Hole Spins

Abbott et al. (2016):
PRX **6**, 041015

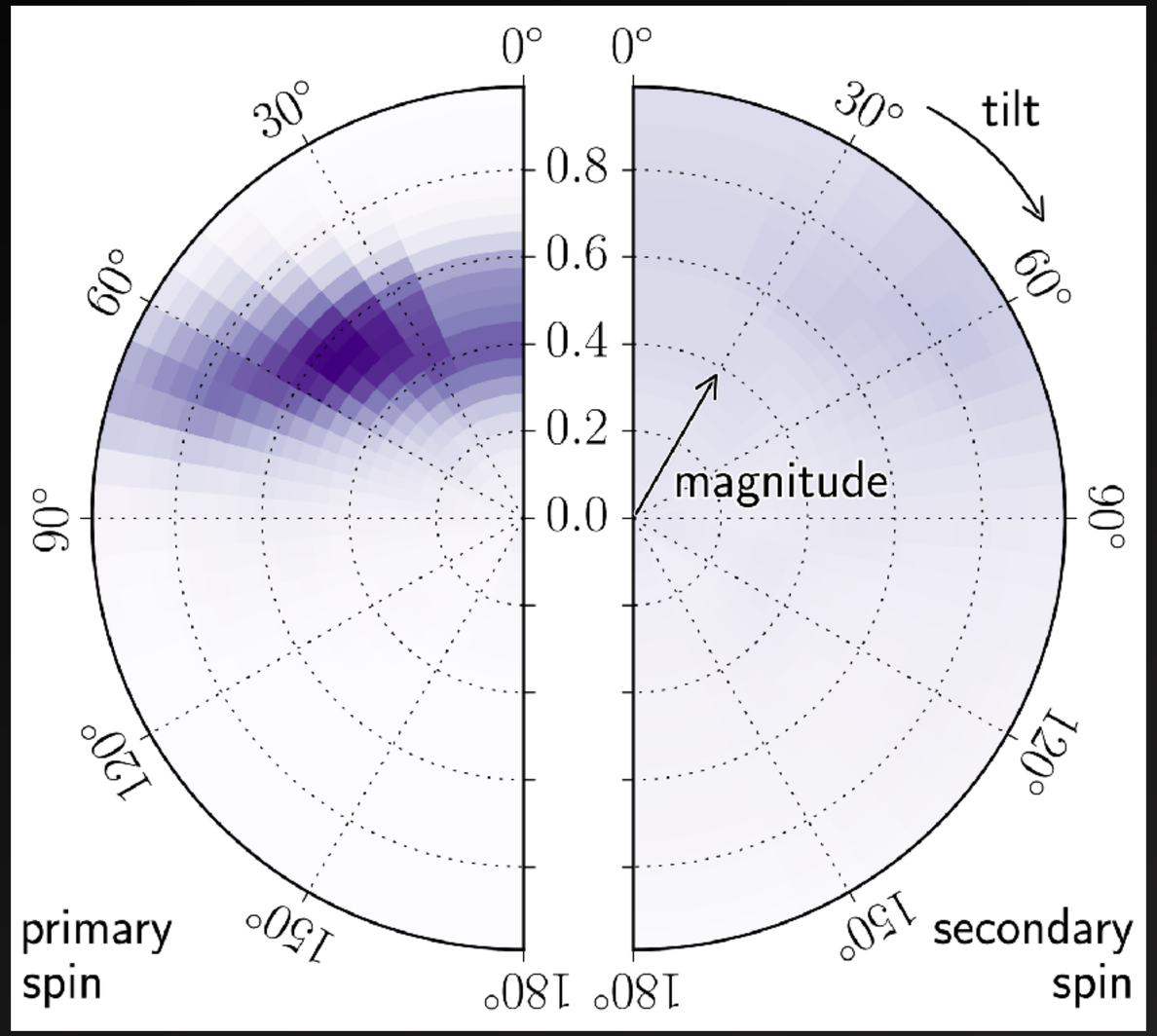
GW151226



Black Hole Spins

Abbott et al. (2016):
PRX **6**, 041015

GW151226

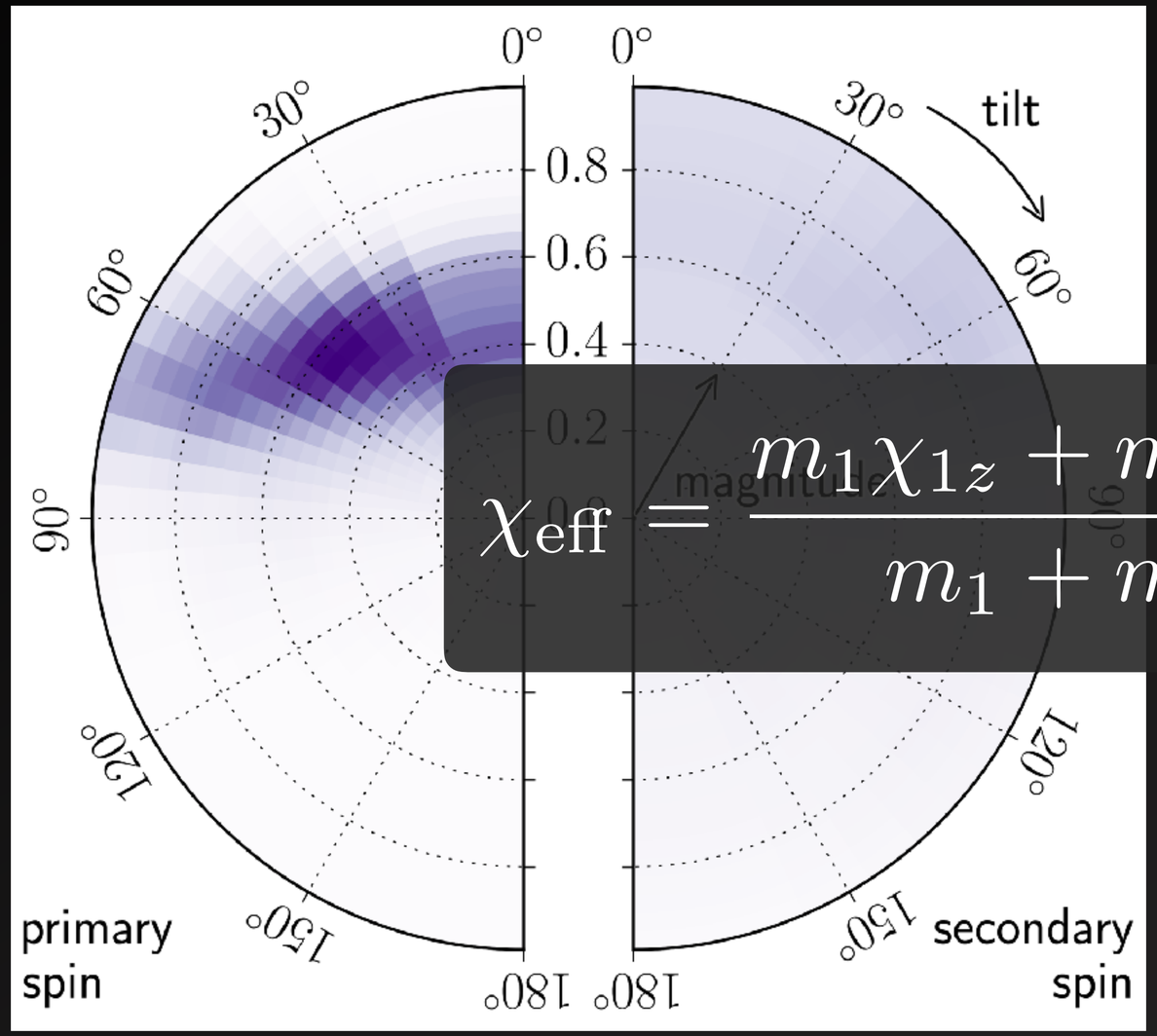


At least one spinning BH

Black Hole Spins

Abbott et al. (2016):
PRX **6**, 041015

GW151226

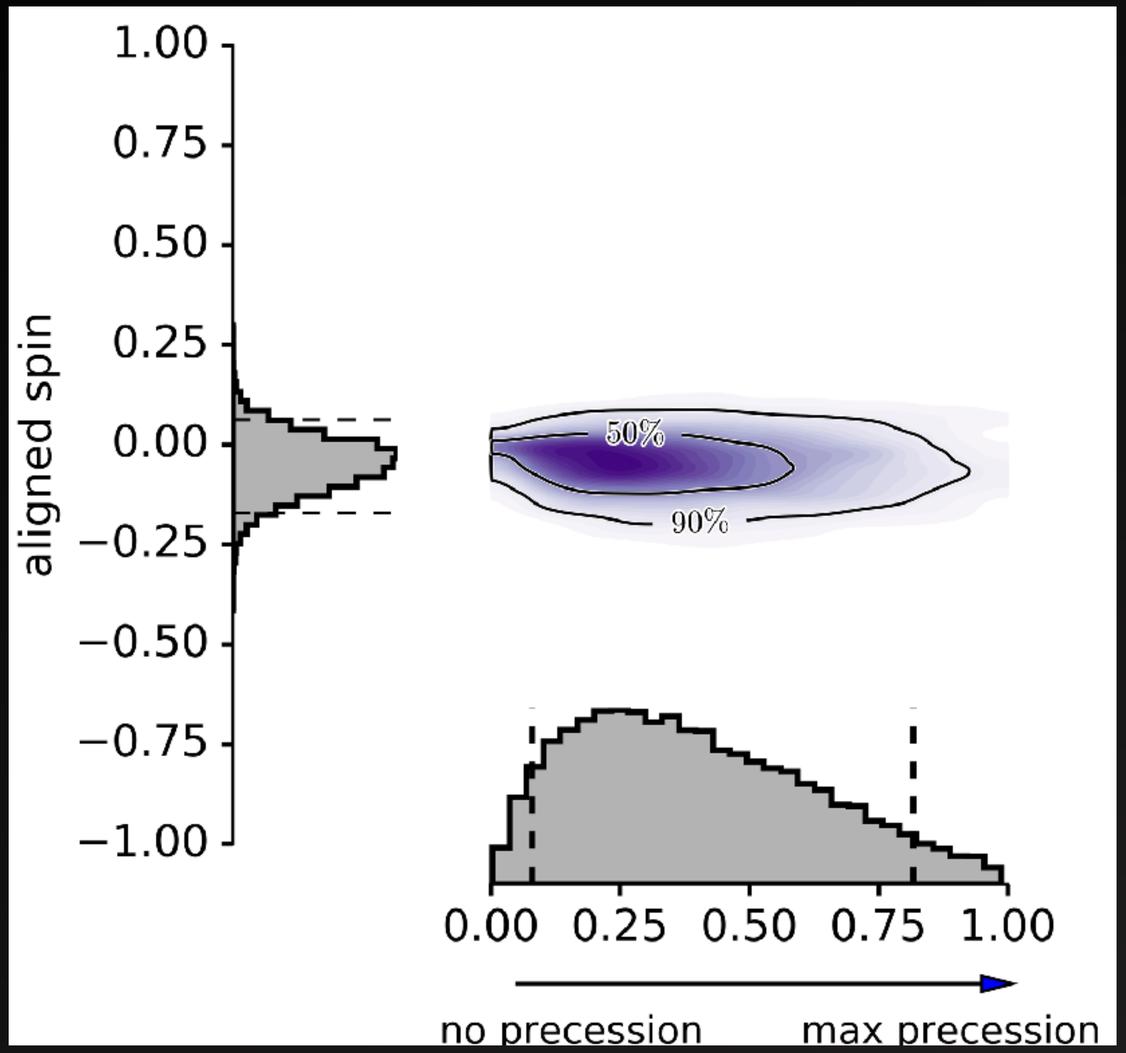


$$\chi_{\rm eff} = \frac{m_1\chi_{1z} + m_2\chi_{2z}}{m_1 + m_2}$$

At least one spinning BH

Effective Spin Estimates

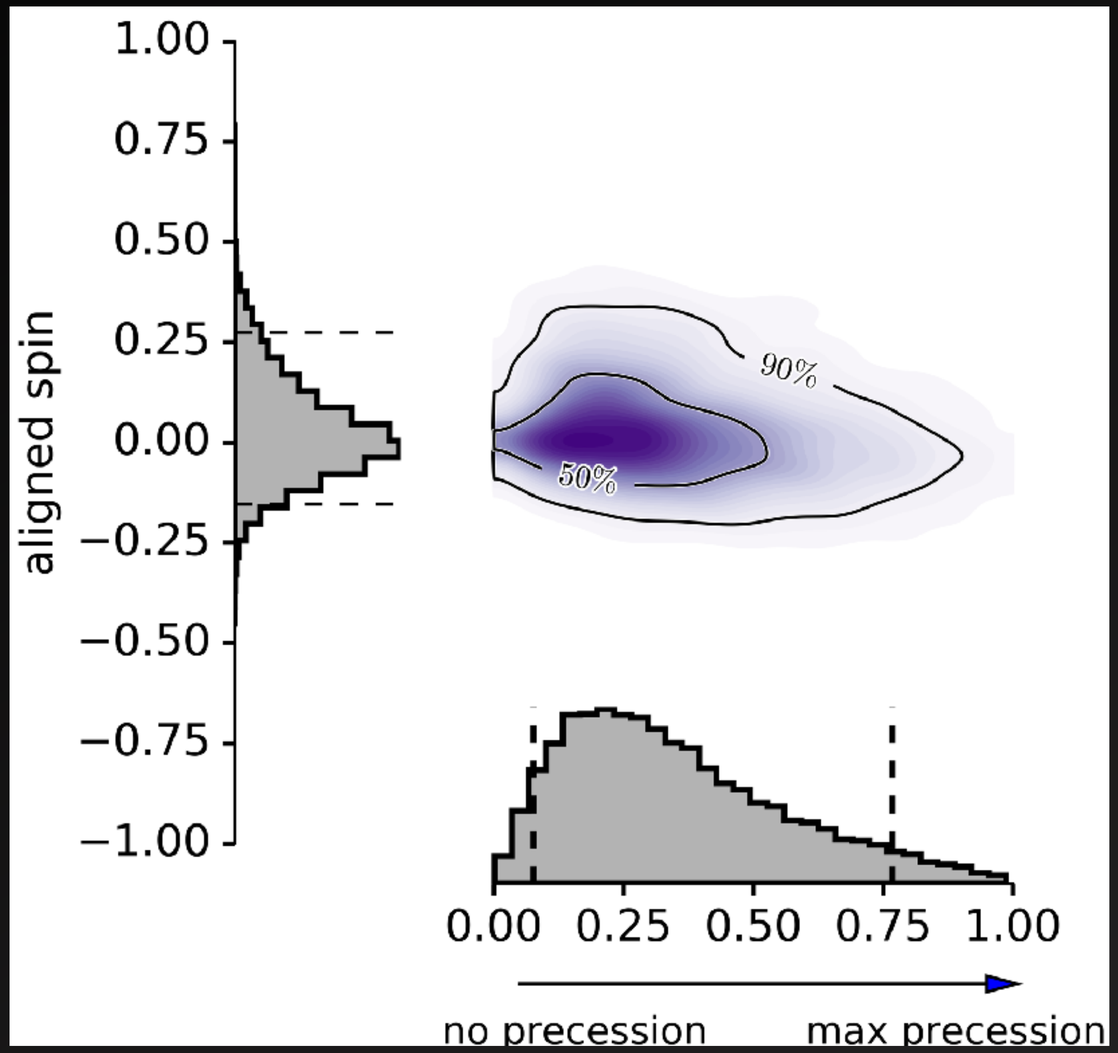
GW150914



Abbott et al. (2016)

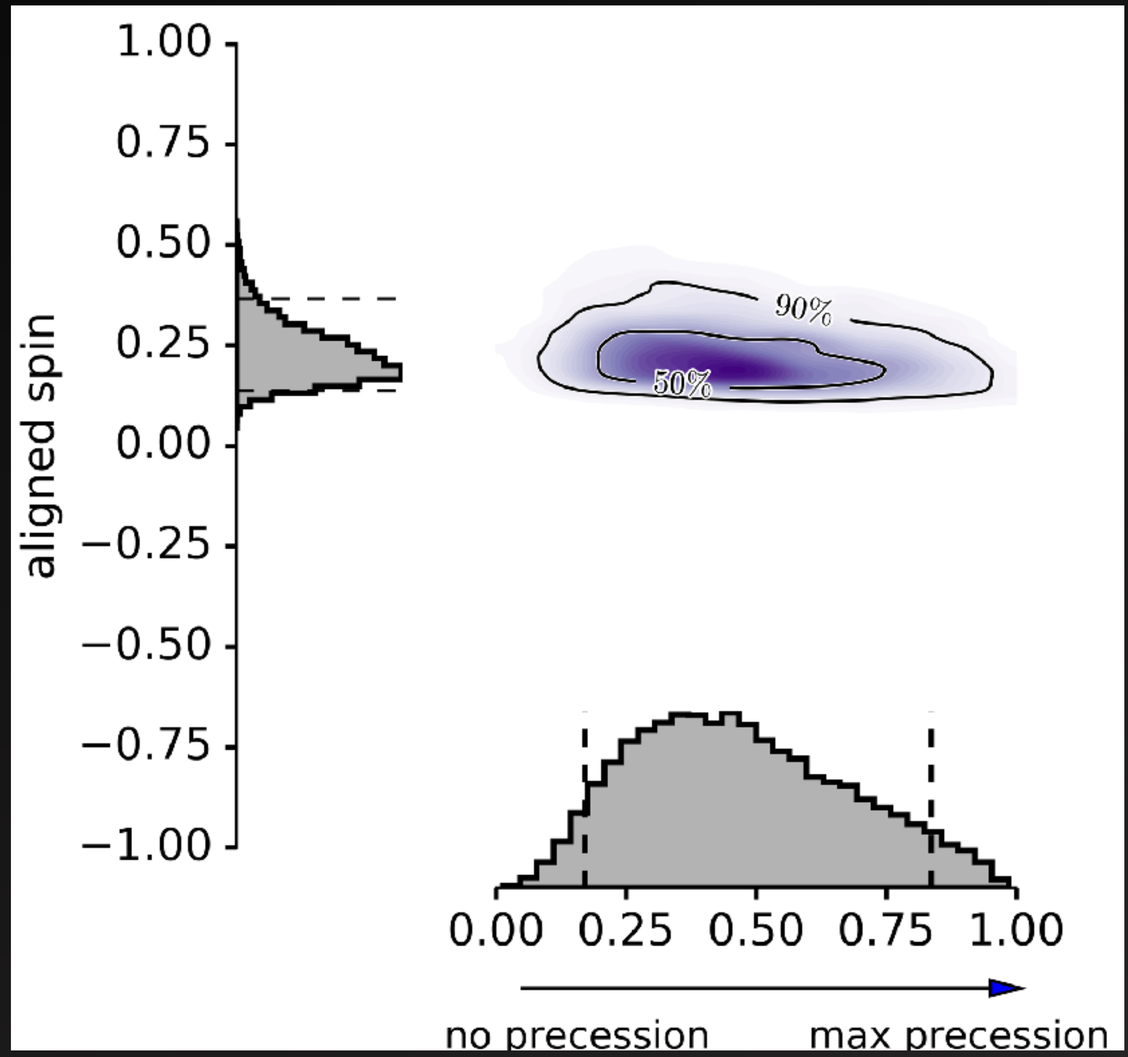
Effective Spin Estimates

LVT151012



Effective Spin Estimates

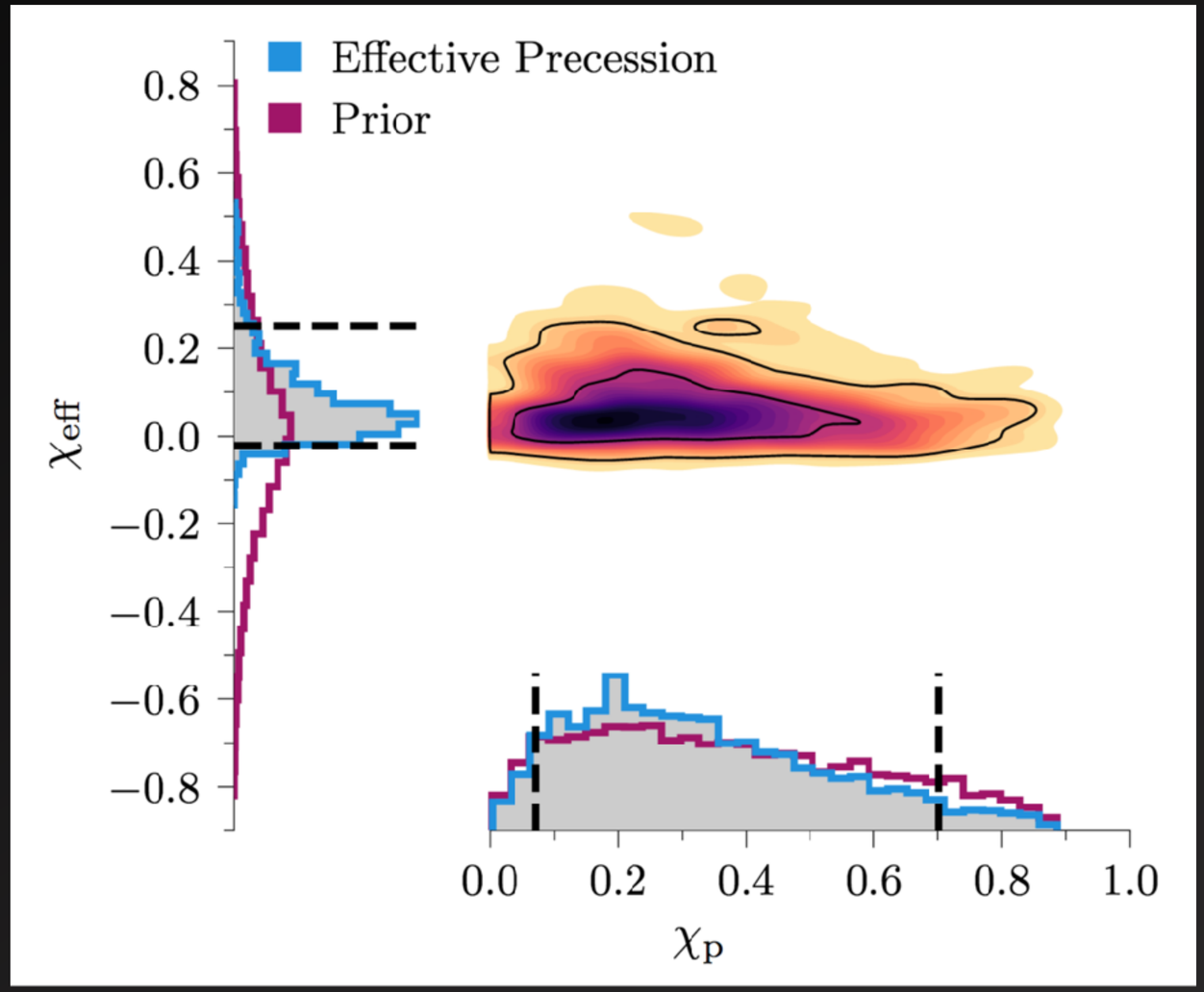
GW151226



Abbott et al. (2016)

Effective Spin Estimates

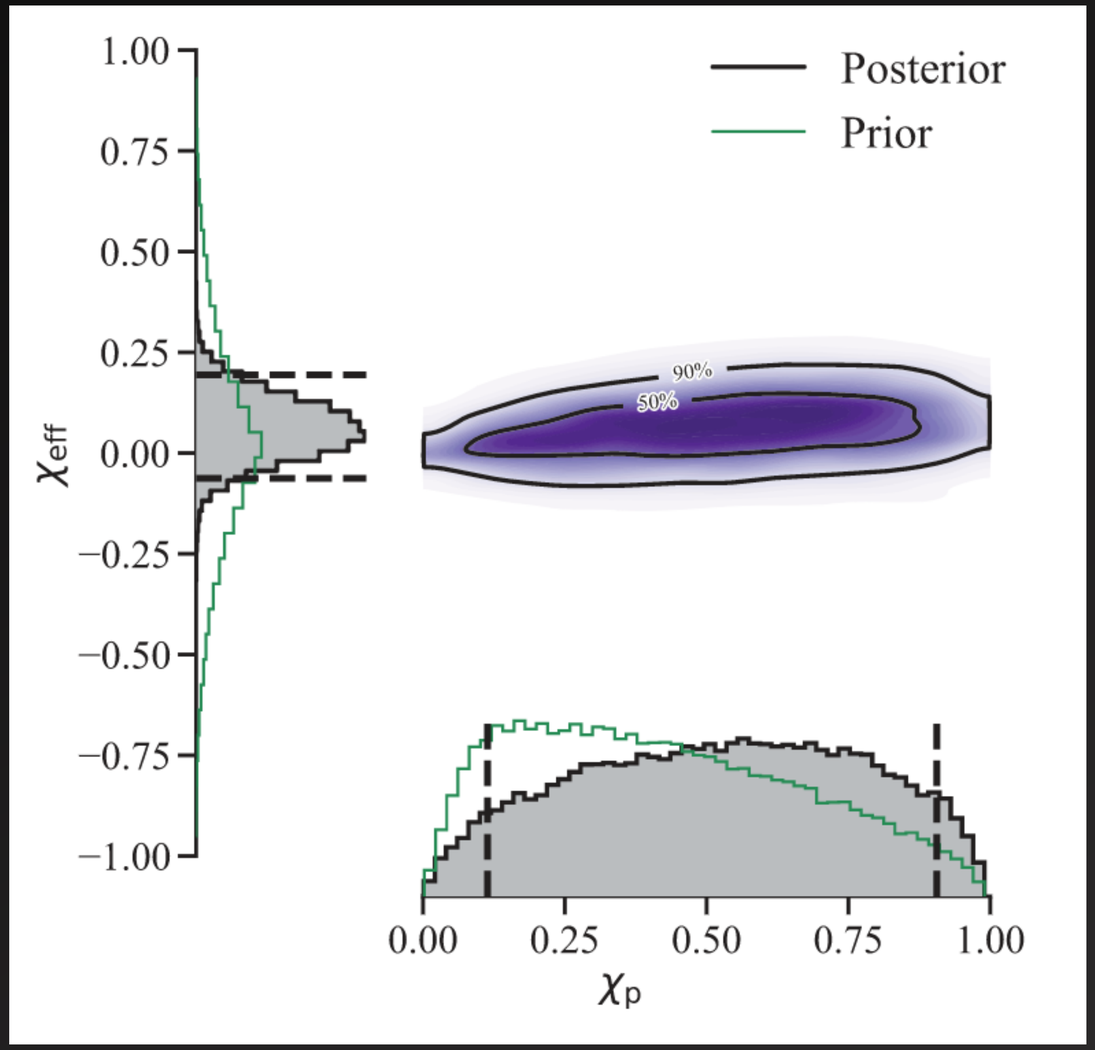
GW170608



Abbott et al. (2017)

Effective Spin Estimates

GW170814



Abbott et al. (2017)

Single-Event Posterior

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

Posterior

Prior

Likelihood

Next Step: Population Inference

Goal: Use multiple detections to infer population characteristics

Challenges:

- We never precisely characterize sources
- Detections may sparsely cover parameters space

Hierarchical Bayesian Inference

Population posterior density:

$$p(\vec{\alpha}|\{d_i\}) \propto p(\vec{\alpha}) \int p(\{d_i\}|\{\theta_i\}) p(\{\theta_i\}|\vec{\alpha}) d\{\theta_i\}$$

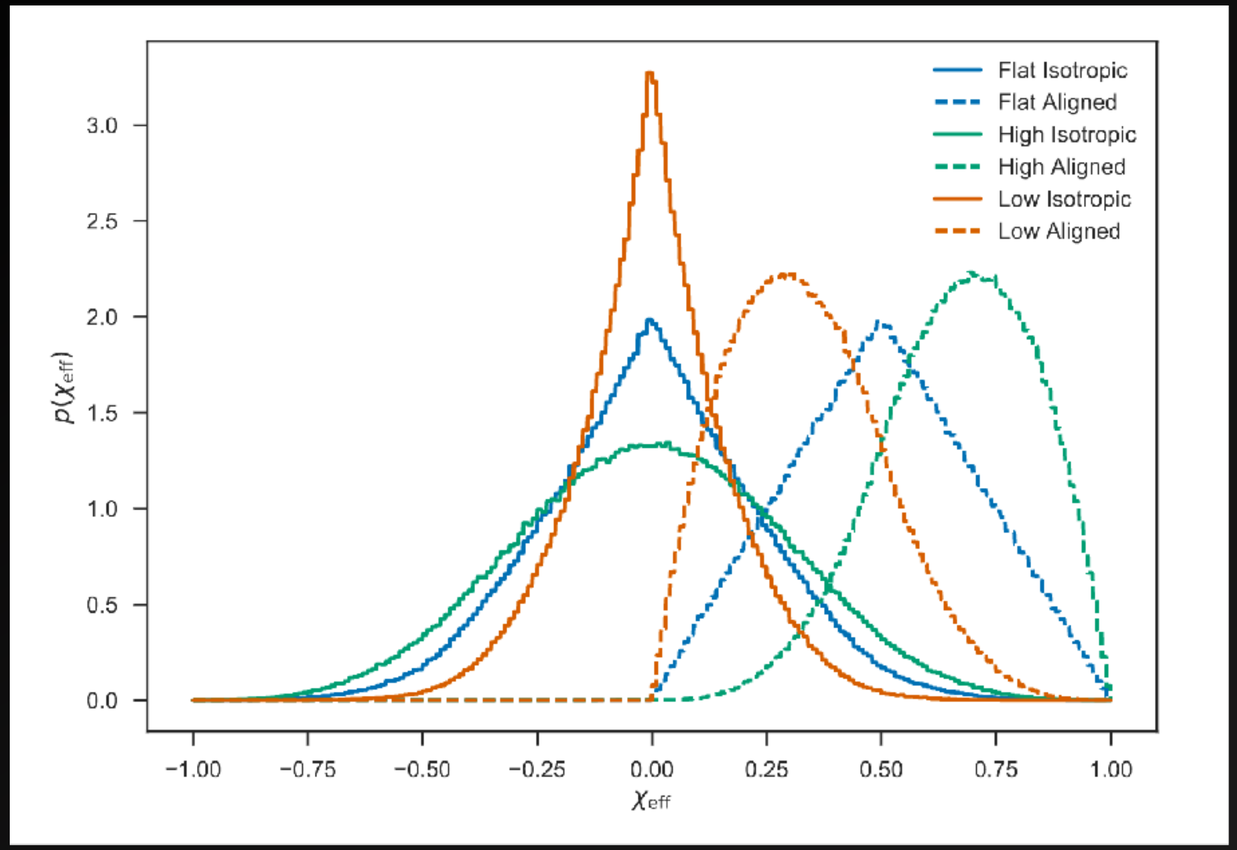
Single-event likelihood

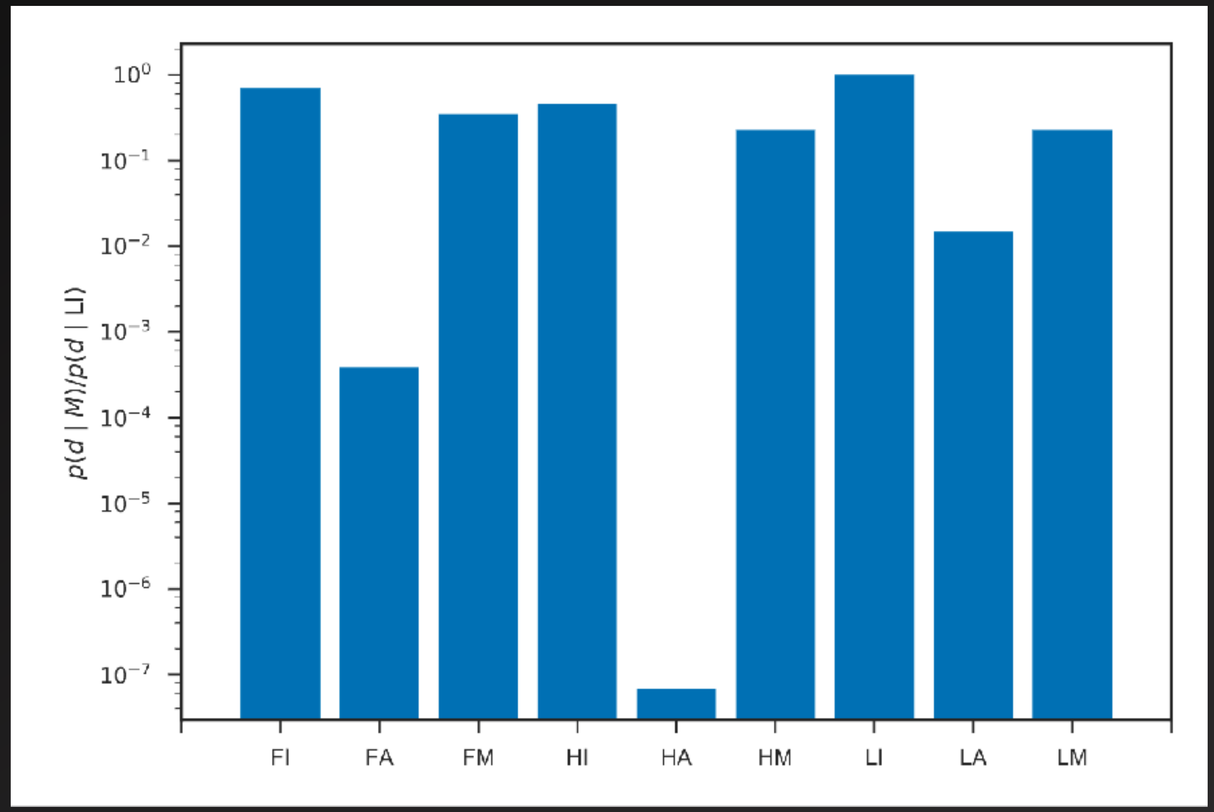
Single-event (population-based) prior

Population prior

Simple Spin Pop. Modeling

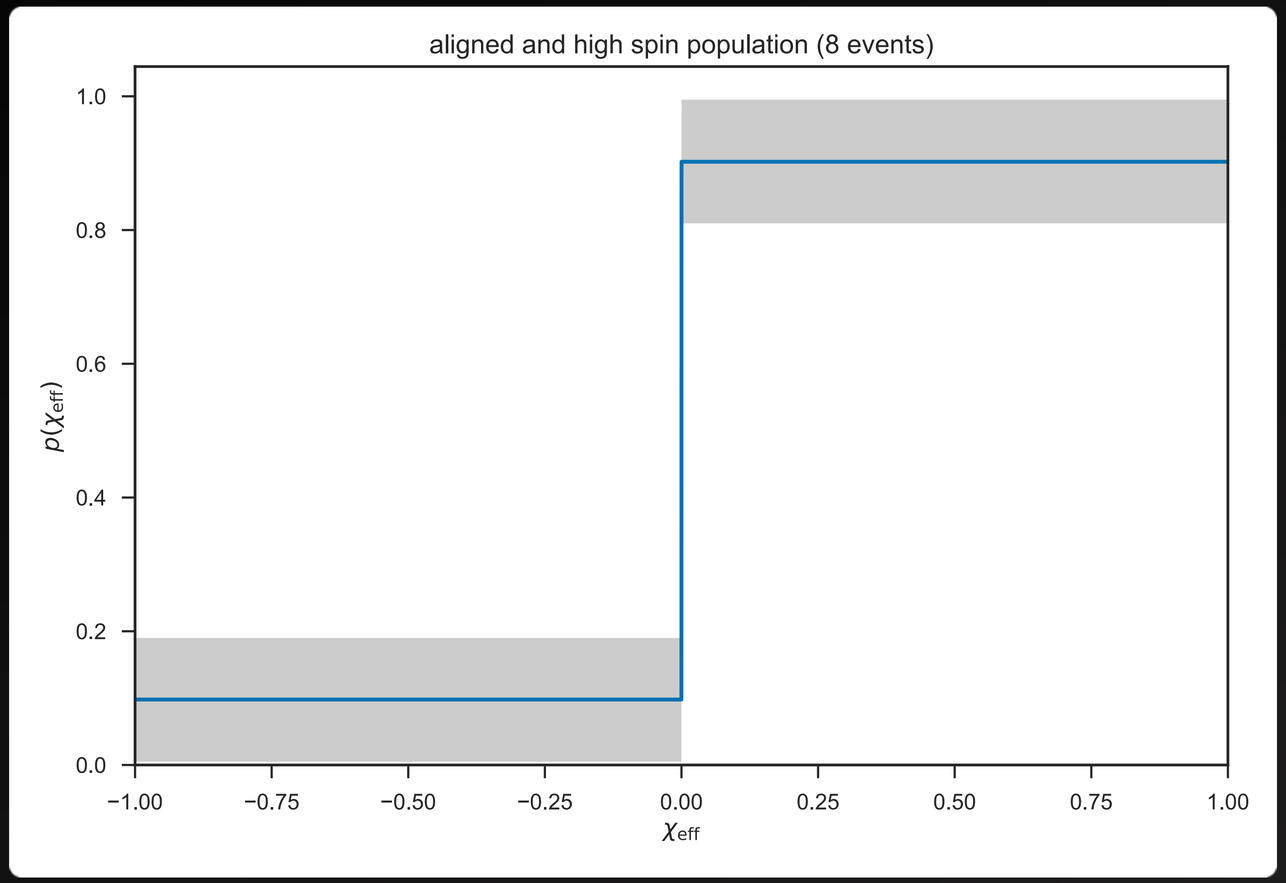
Farr, Stevenson, Miller, Mandel, **Farr'**, Vecchio (2017)

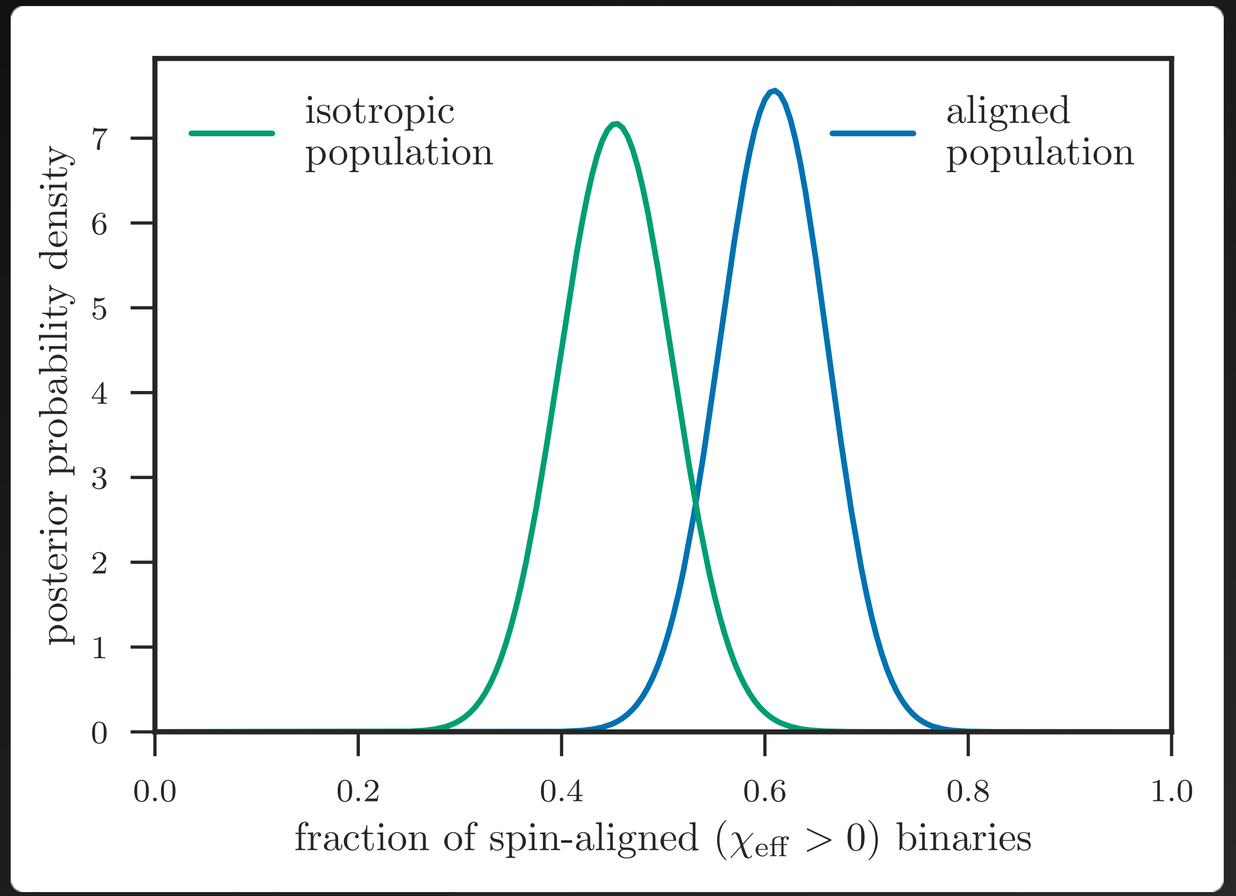




odds ratio of 67
favoring an **isotropic** angular distribution

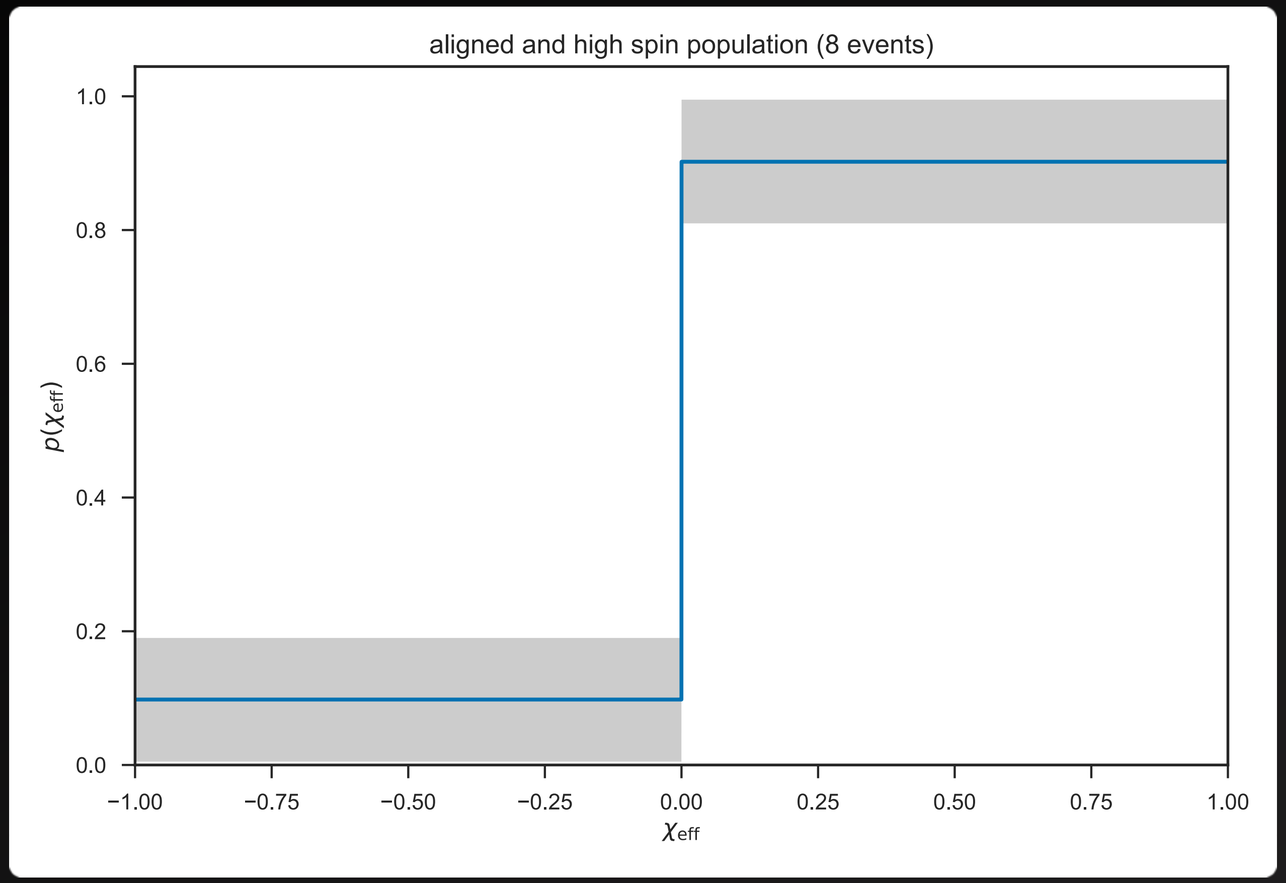
Another Simple Spin Pop. Model

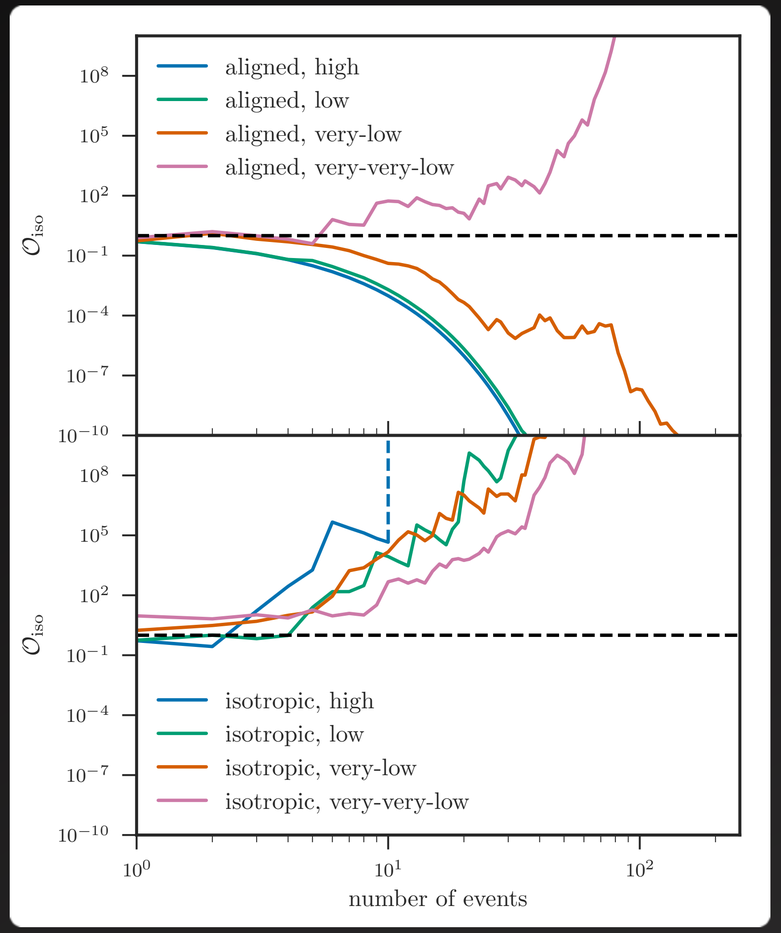




Farr', Holz, Farr (2018)

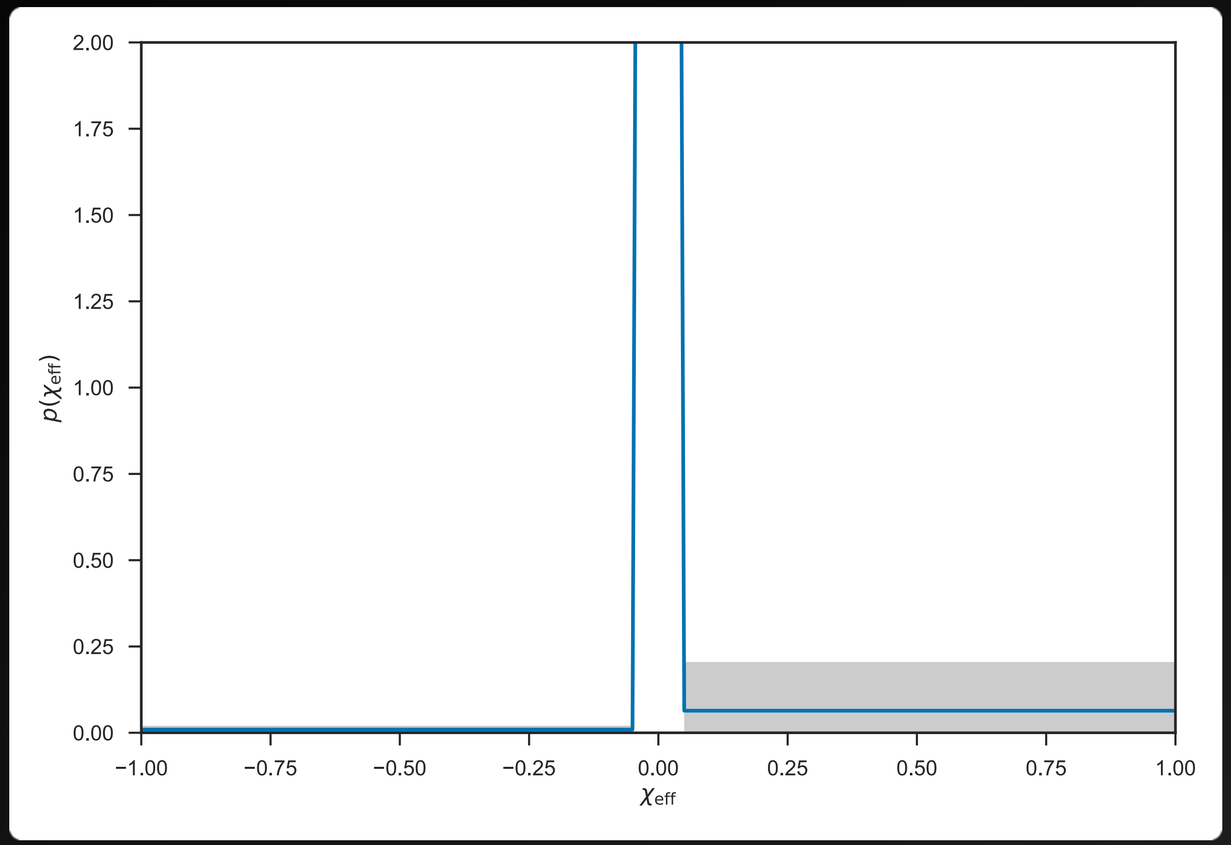
Another Simple Spin Pop. Model

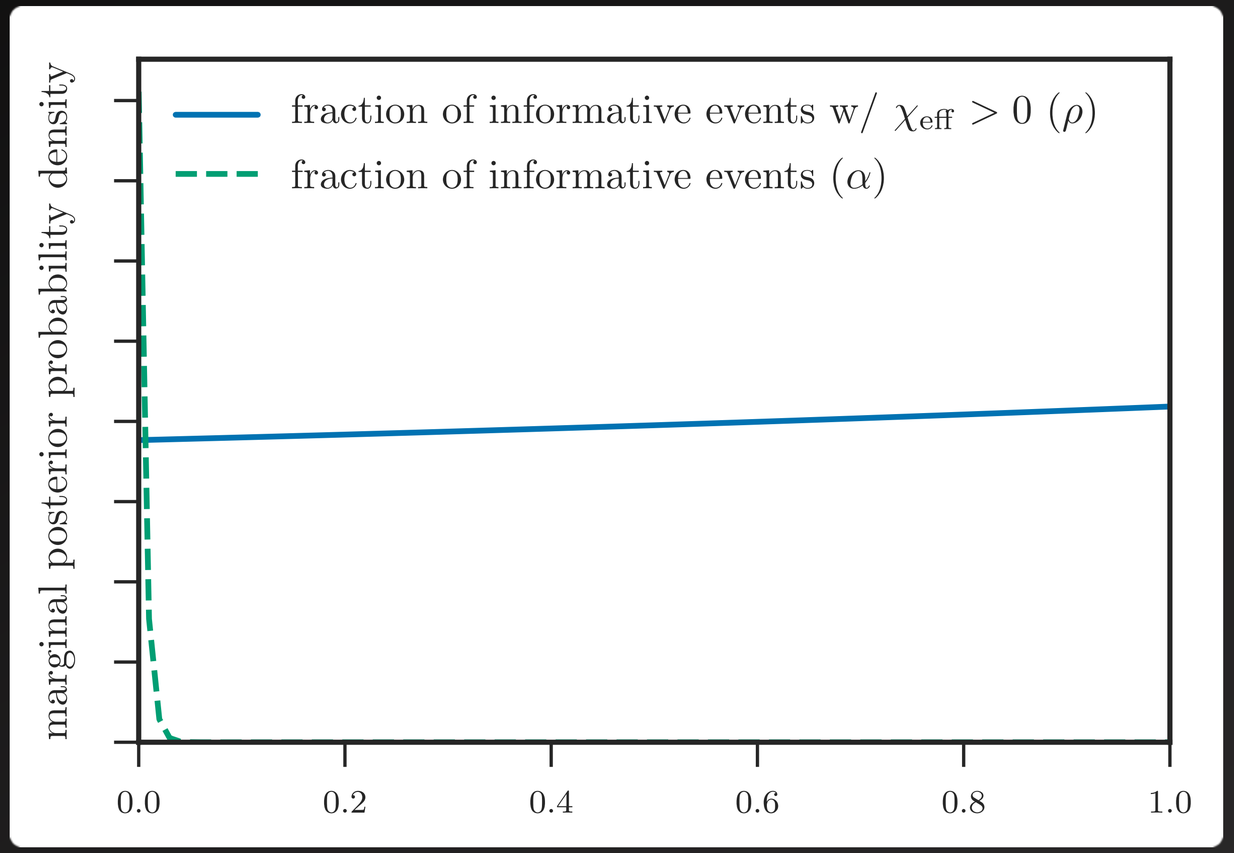




Farr', Holz, Farr (2018)

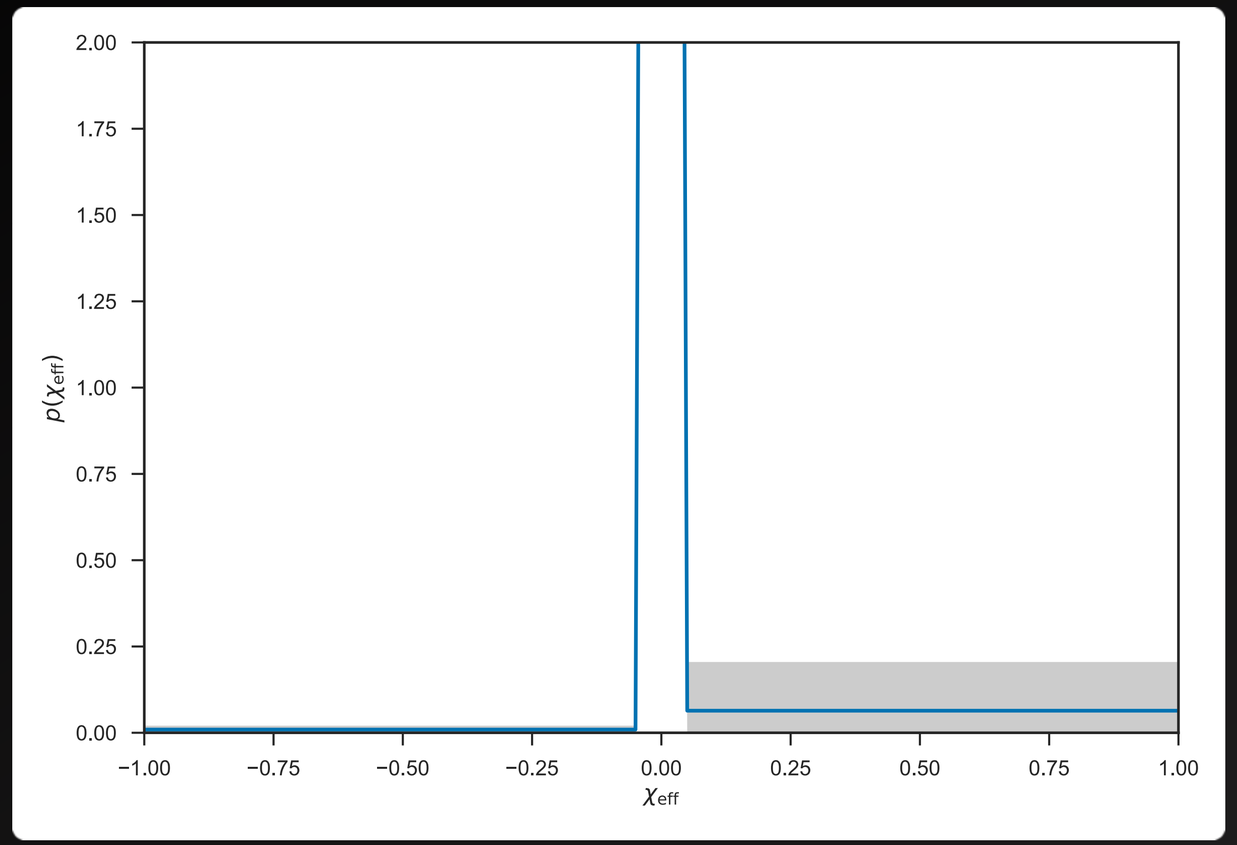
Next Simplest Model

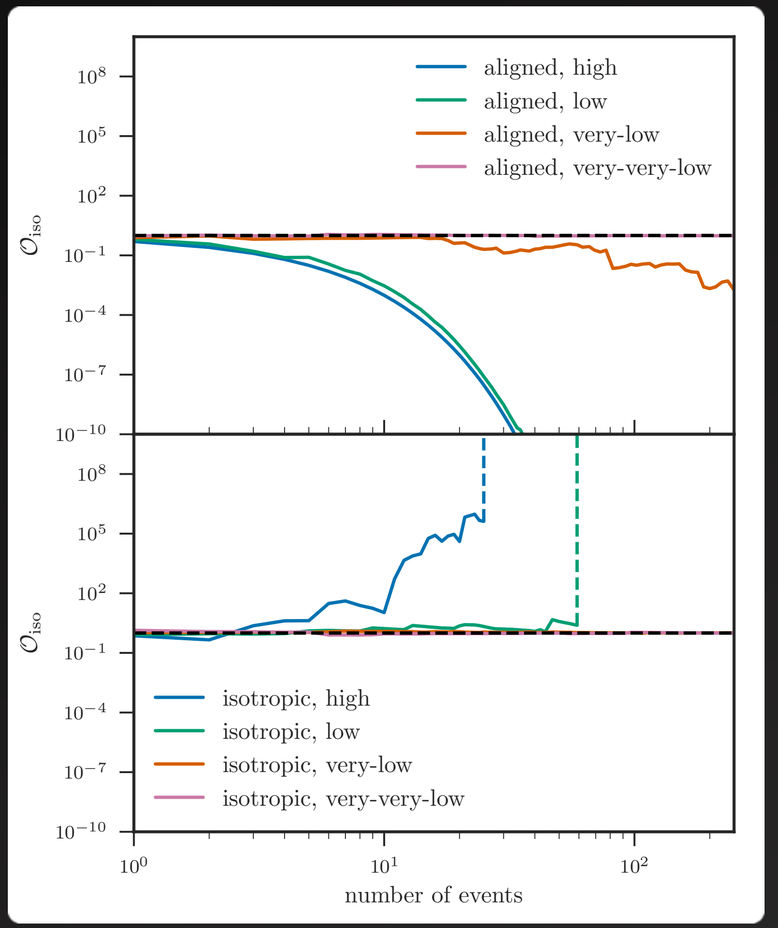




Farr', Holz, Farr (2018)

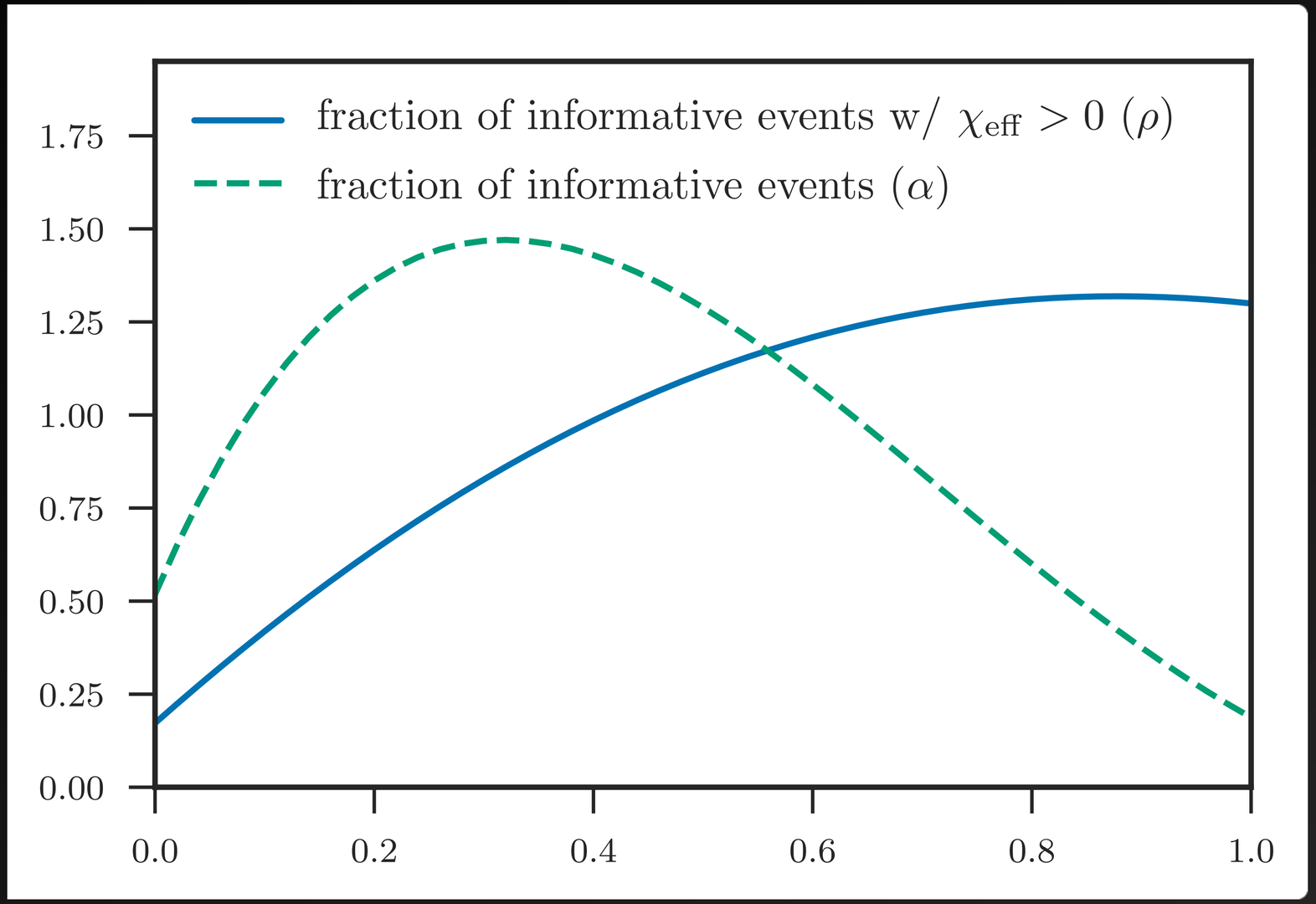
Next Simplest Model





Farr', Holz, Farr (2018)

Current(ish) Results

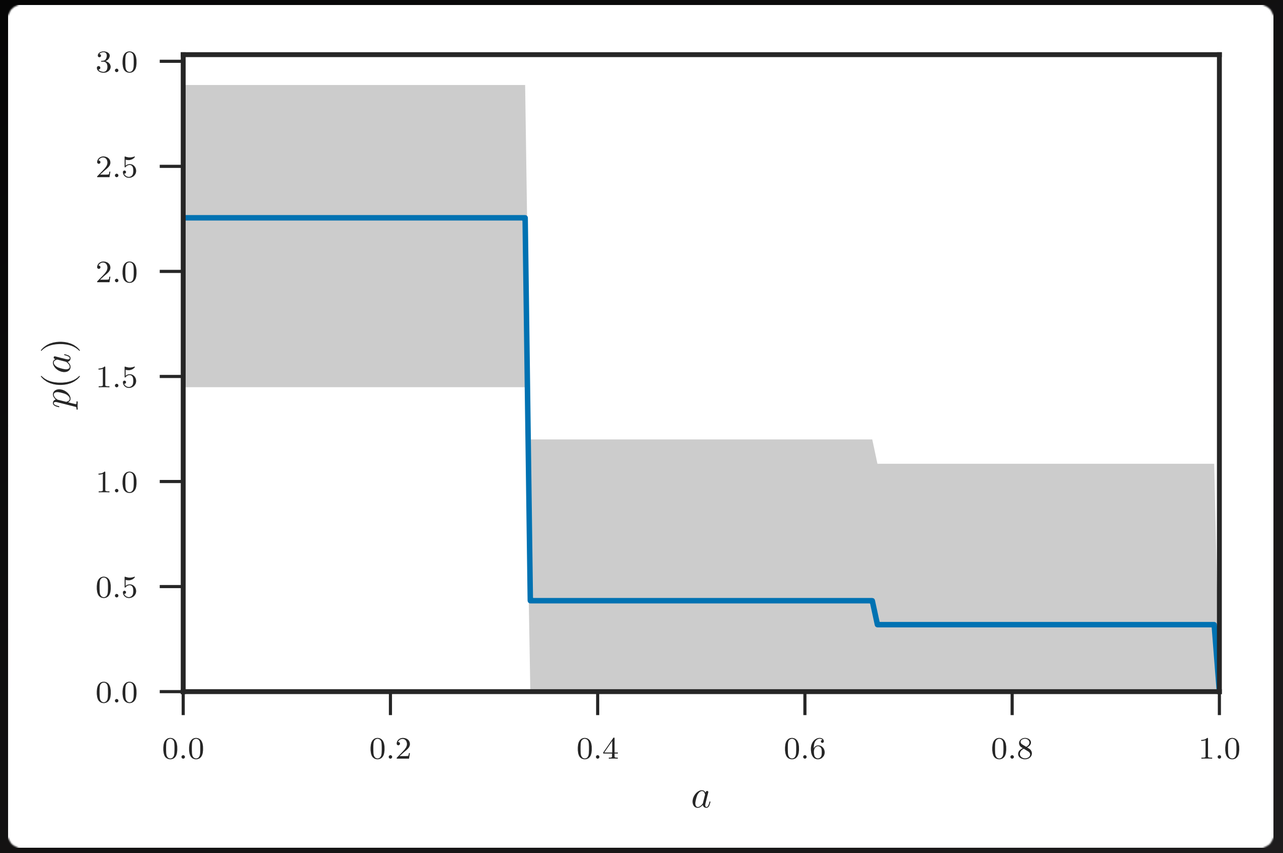


odds ratio of 1.1
(barely) favoring an **aligned** angular distribution

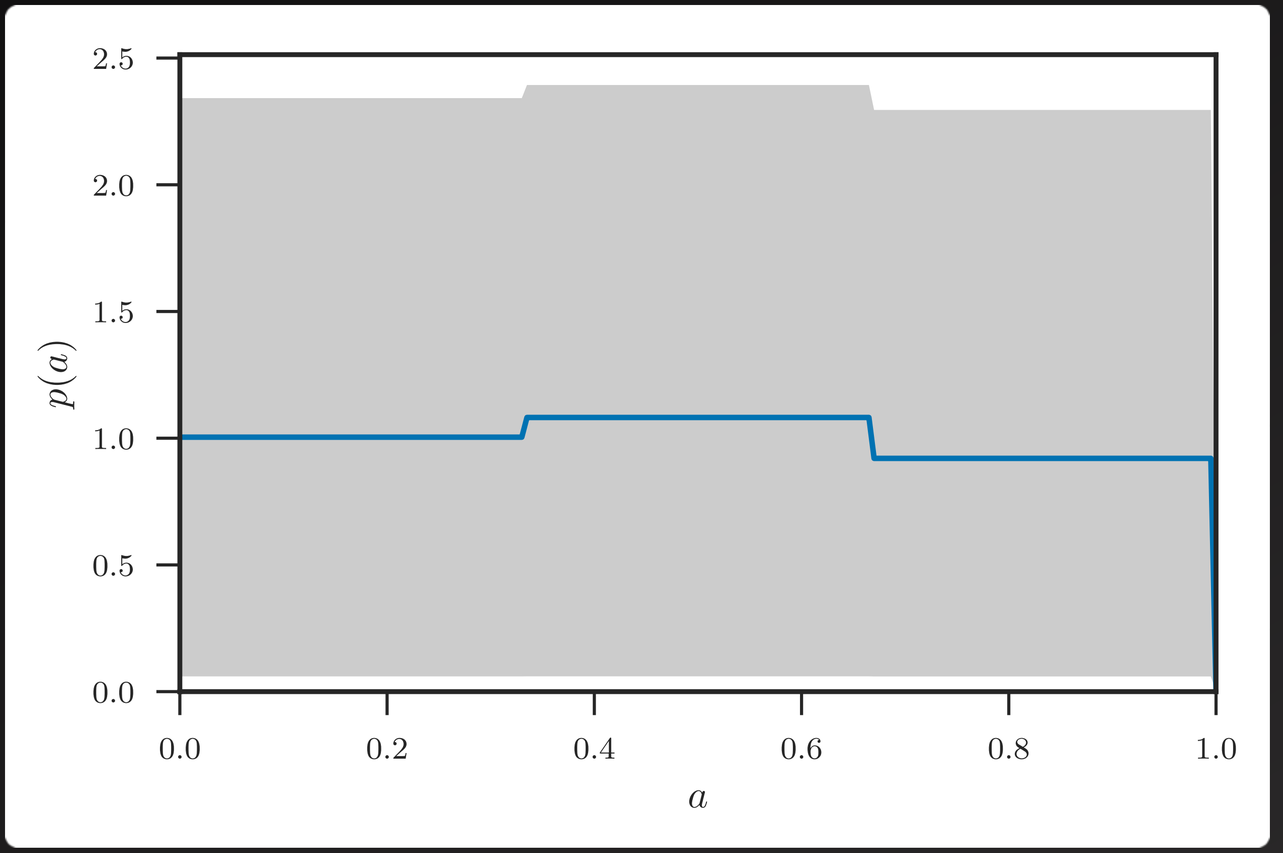
Farr', Holz, Farr (2018)

Spin Magnitudes

Aligned



Isotropic



Farr', Holz, Farr (2018)

Summary

Data are ***suggesting*** that:

1) BH spins are small

— **or** —

2) BH spins are isotropically oriented

More to come…