

Reducing Spin-Prior Bias in Population Inference of Binary Black Holes

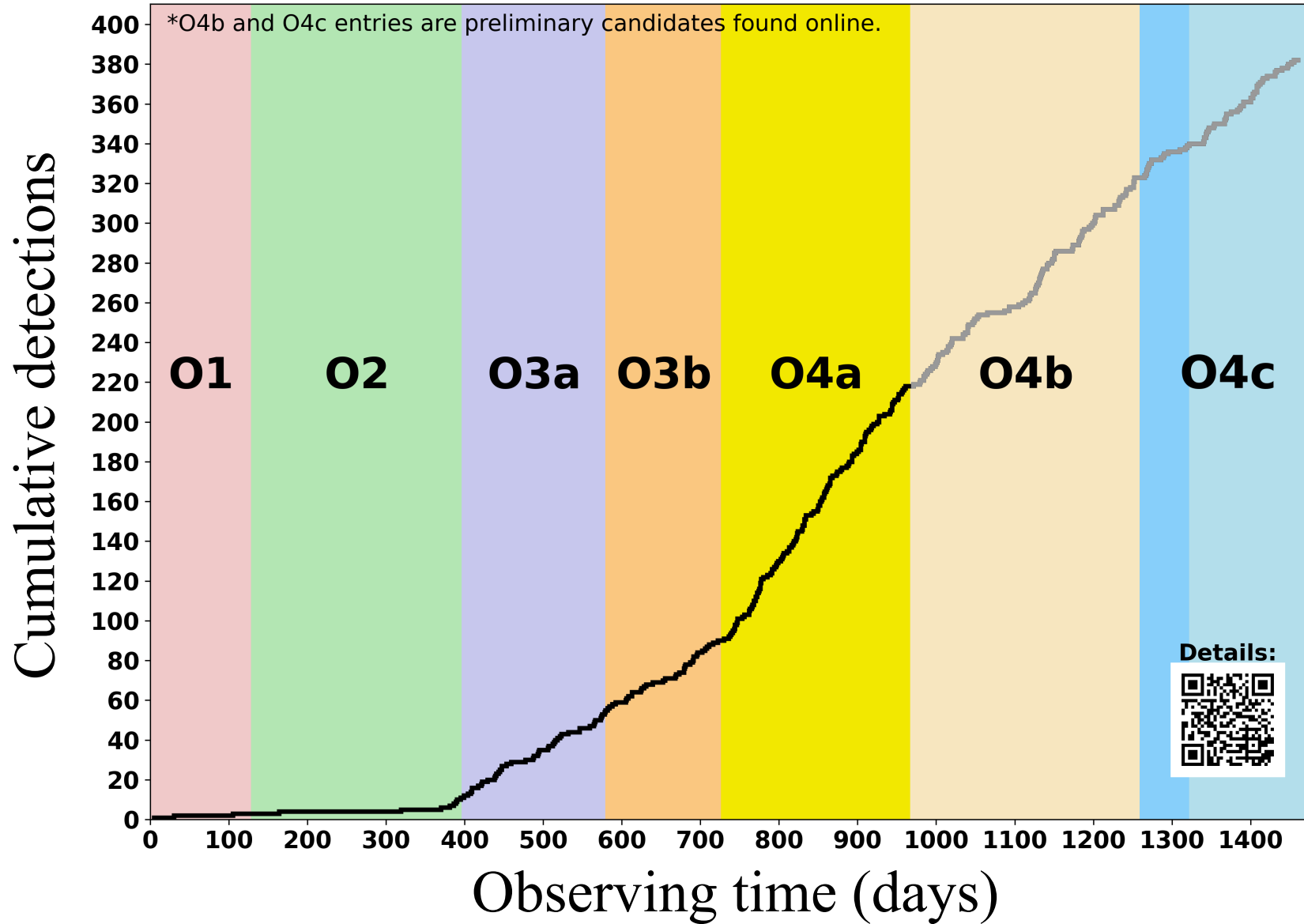
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O1+O2+O3+O4a = 218, O4b* = 105, O4c* = 59, Total = 382



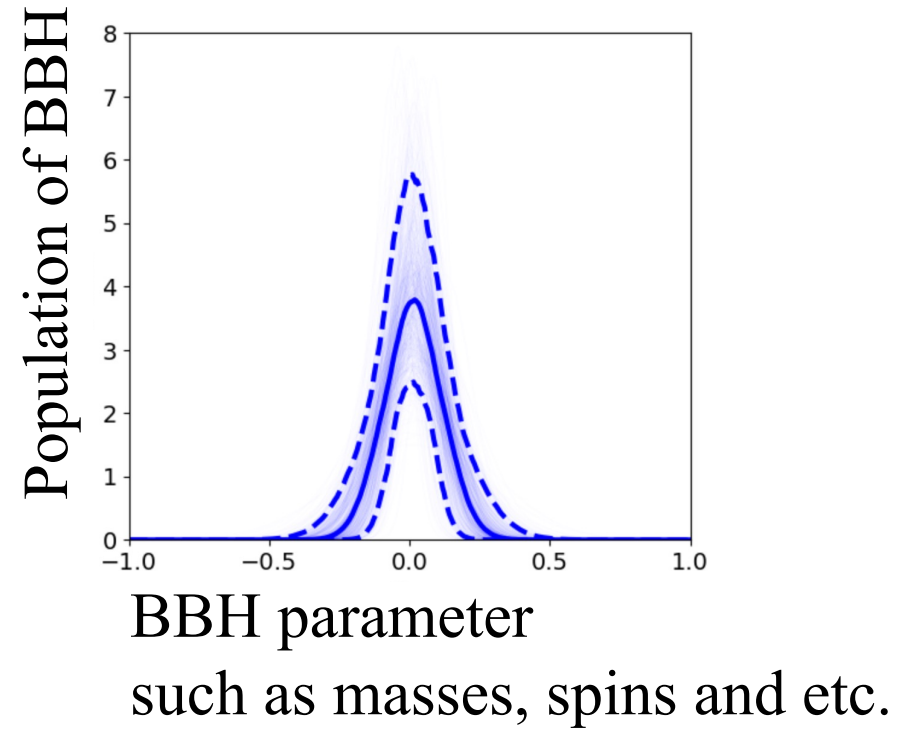
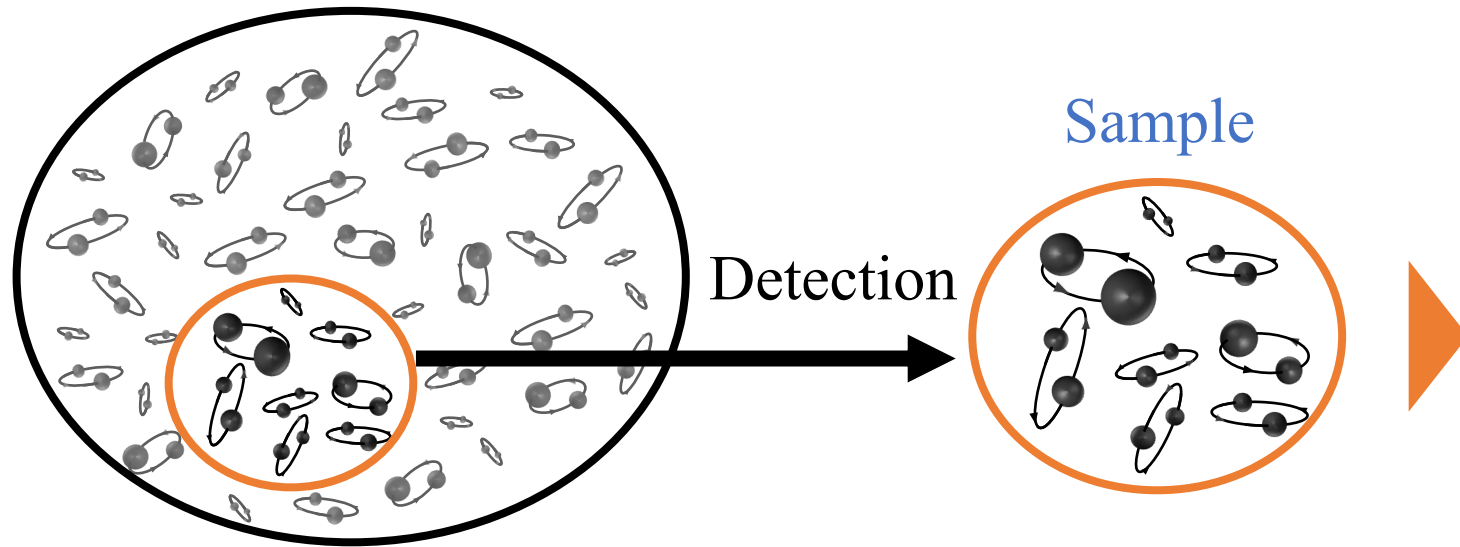
218 events!!

were observed up to the O4a run.

Population analysis = Statistical survey

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Whole population of BBH

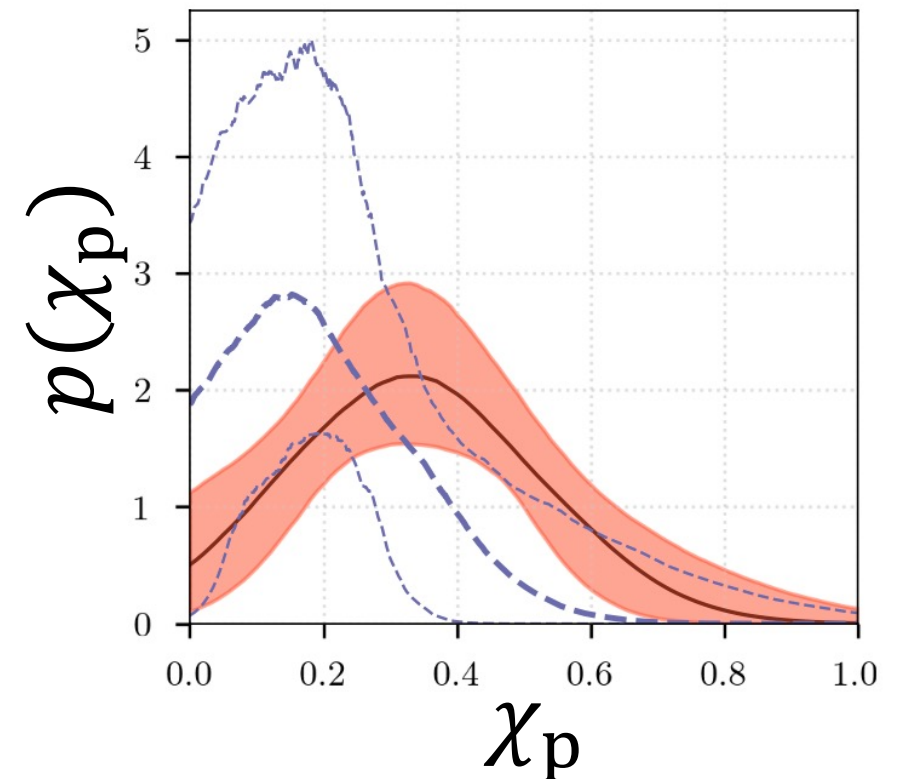
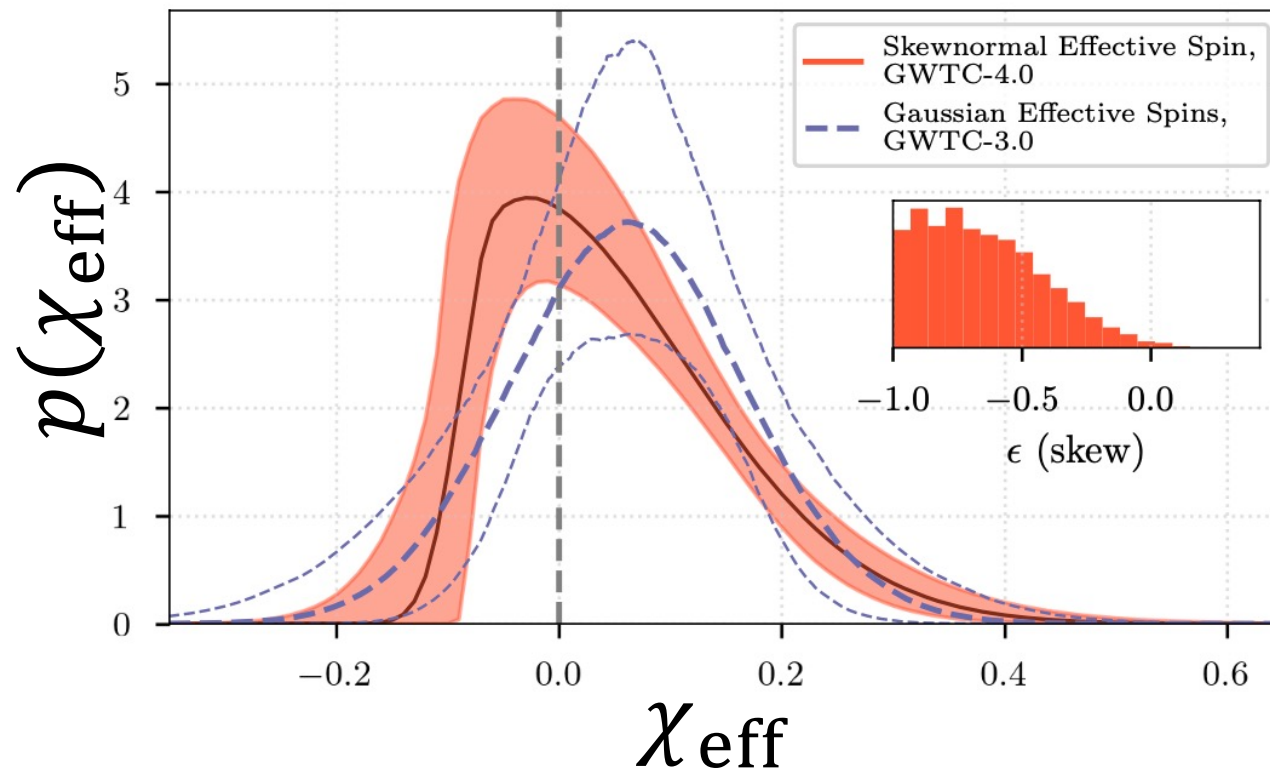


Population of spins up to O4a

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χ_{eff} : Effective spin **aligned** with the \vec{L} of binary.

χ_p : Effective spin **perpendicular** to the \vec{L} of binary.



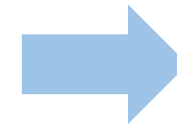
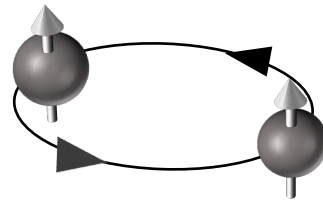
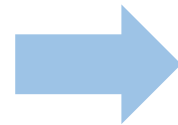
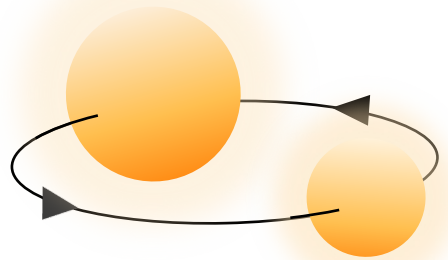
The spin population strongly depends on the formation process.

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[1] K. Belczynski et al. Nature 534, 512 (2016)

[2] S. F. P. Zwart, et al. The Astrophysical Journal 576, 899 (2002)

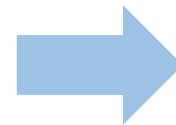
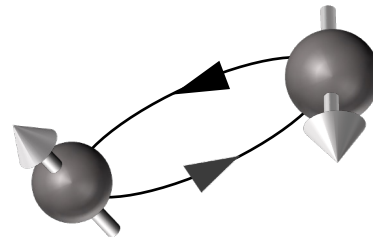
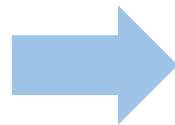
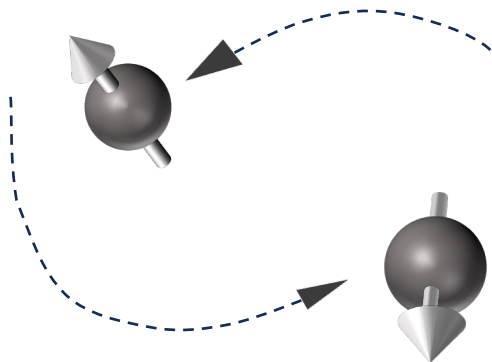
- Isolated binary formation^[1]



Population:

χ_{eff} : Positive.
 χ_p : Zero.

-
- Dynamical formation^[2]



Population:

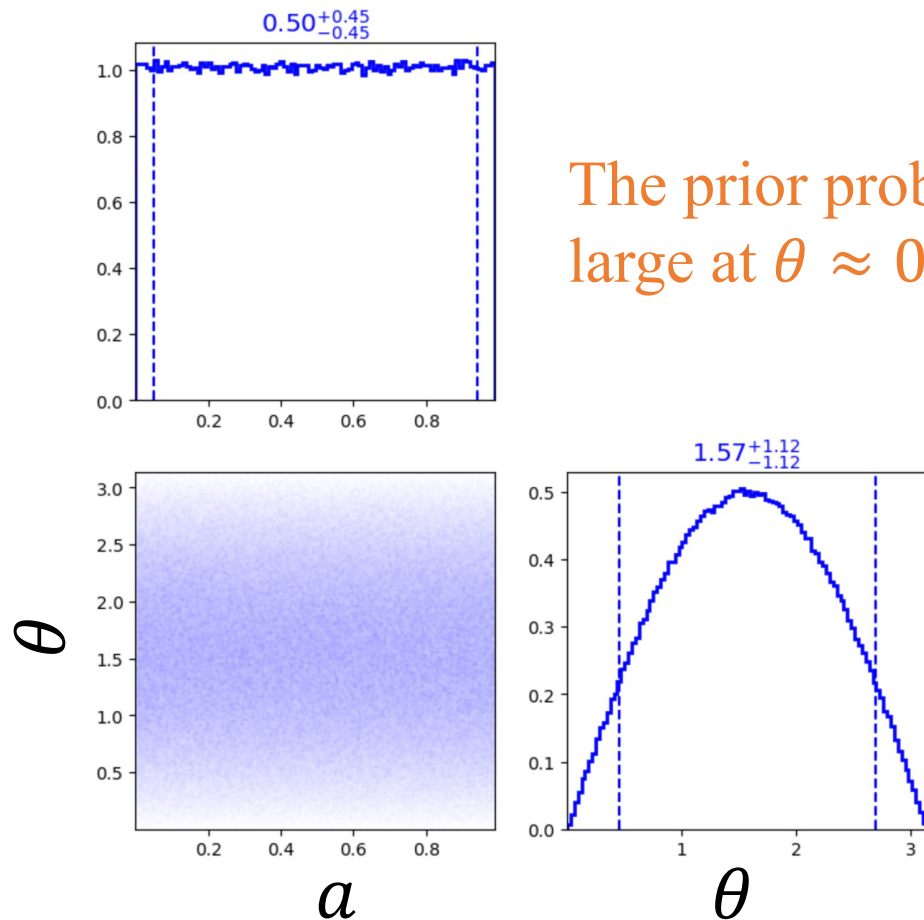
χ_{eff} : Positive or negative.
 χ_p : Not only zero.

Issue in the previous analysis

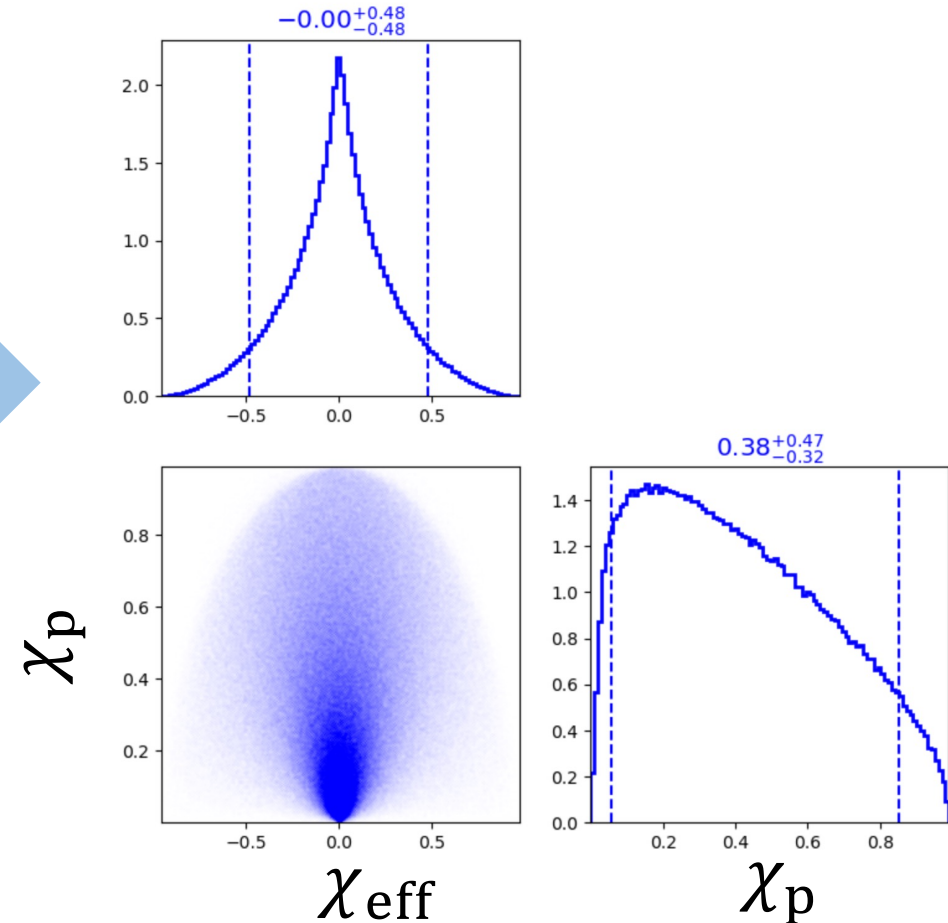
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[1] The LIGO Scientific Collaboration, the Virgo Collaboration, the KAGRA Collaboration
arXiv:2508.18083(2025)

Prior distribution of parameter estimation in previous analysis^[1]



The prior probability is large at $\theta \approx 0$.



Issue in the previous analysis

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[1] The LIGO Scientific Collaboration, the Virgo Collaboration, the KAGRA Collaboration
arXiv:2508.18083(2025)

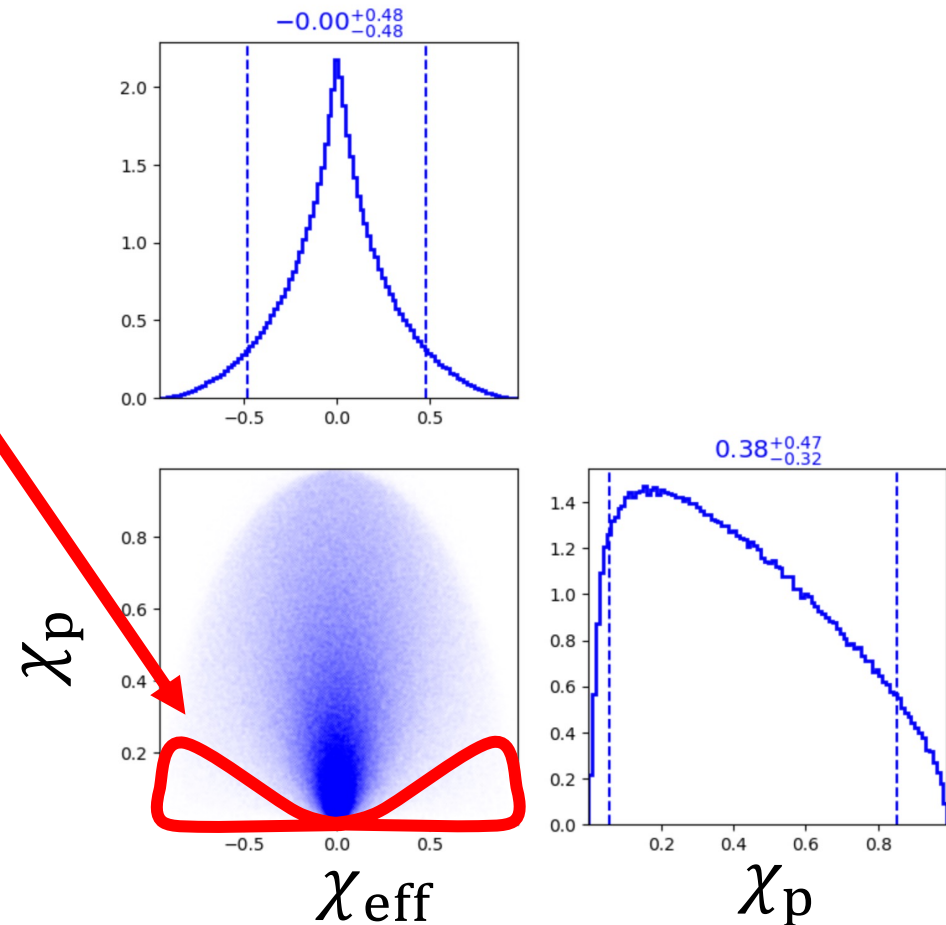
The finite number of posterior samples cannot adequately cover **this region**.



Monte Carlo integral using the posterior samples, required for population inference, may be inaccurately evaluated.



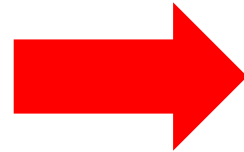
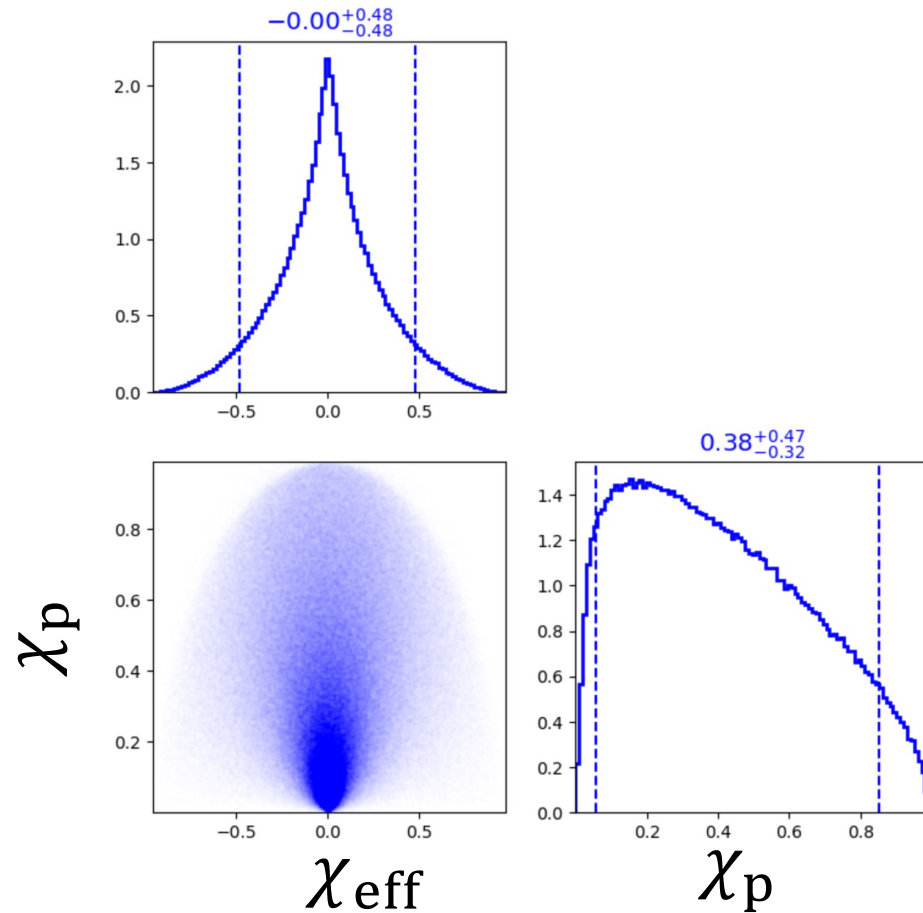
Previous method may have **misestimated** the population of effective spins.



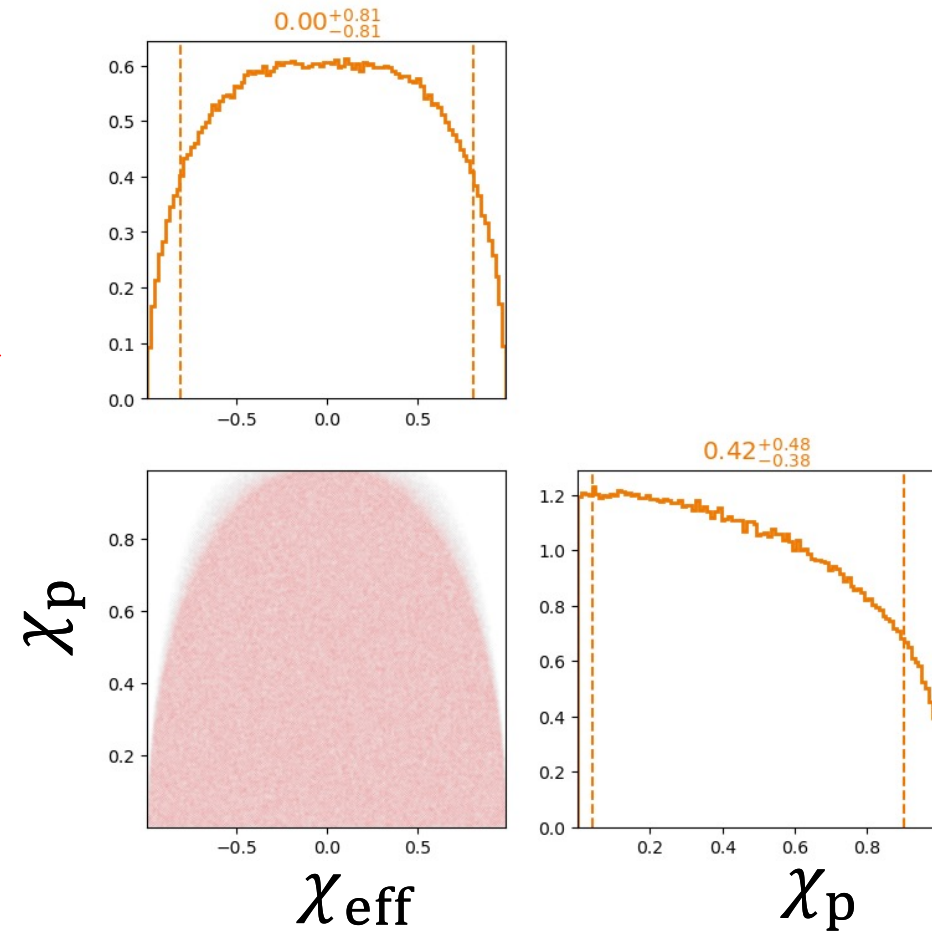
Solution: changing the prior

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Previous prior: uniform a , isotropic θ

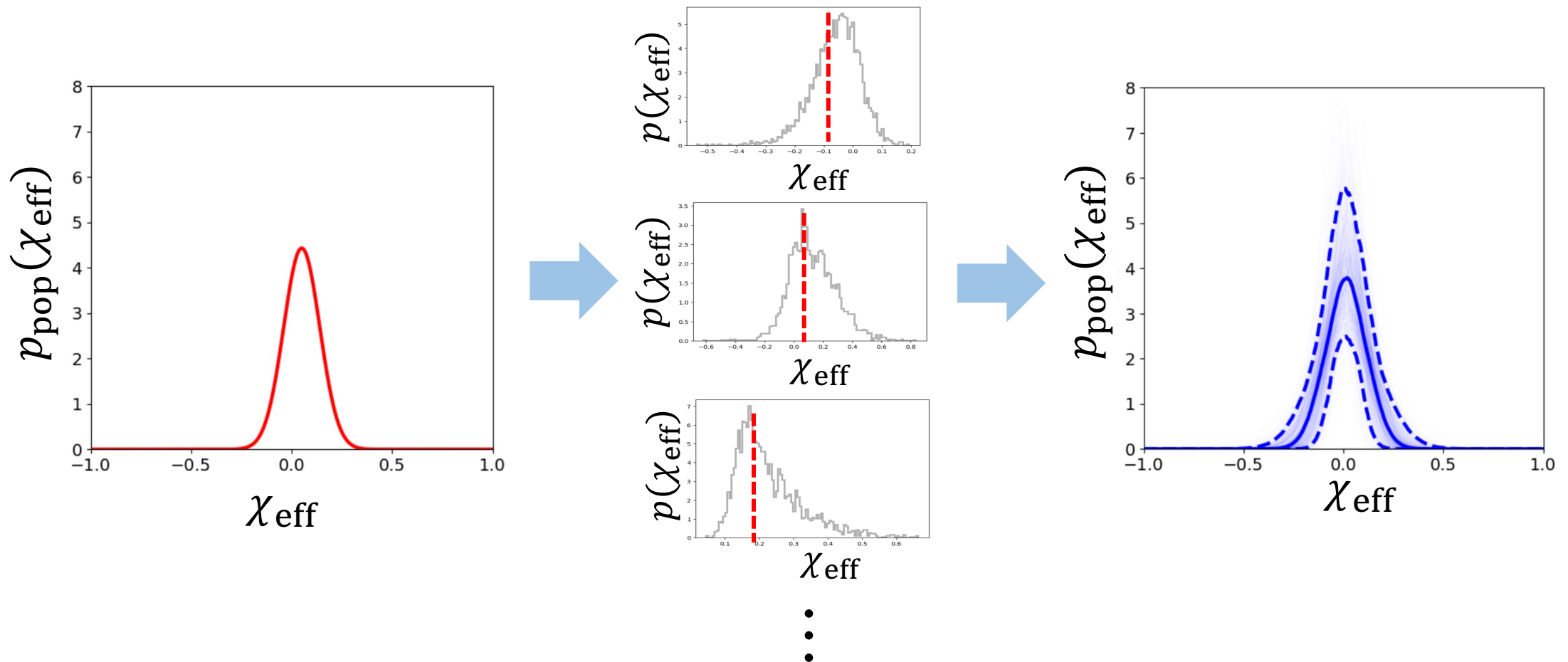


New prior: uniform in χ_{eff} , χ_p



Simulation for mock population to demonstrate the effectiveness of our approach

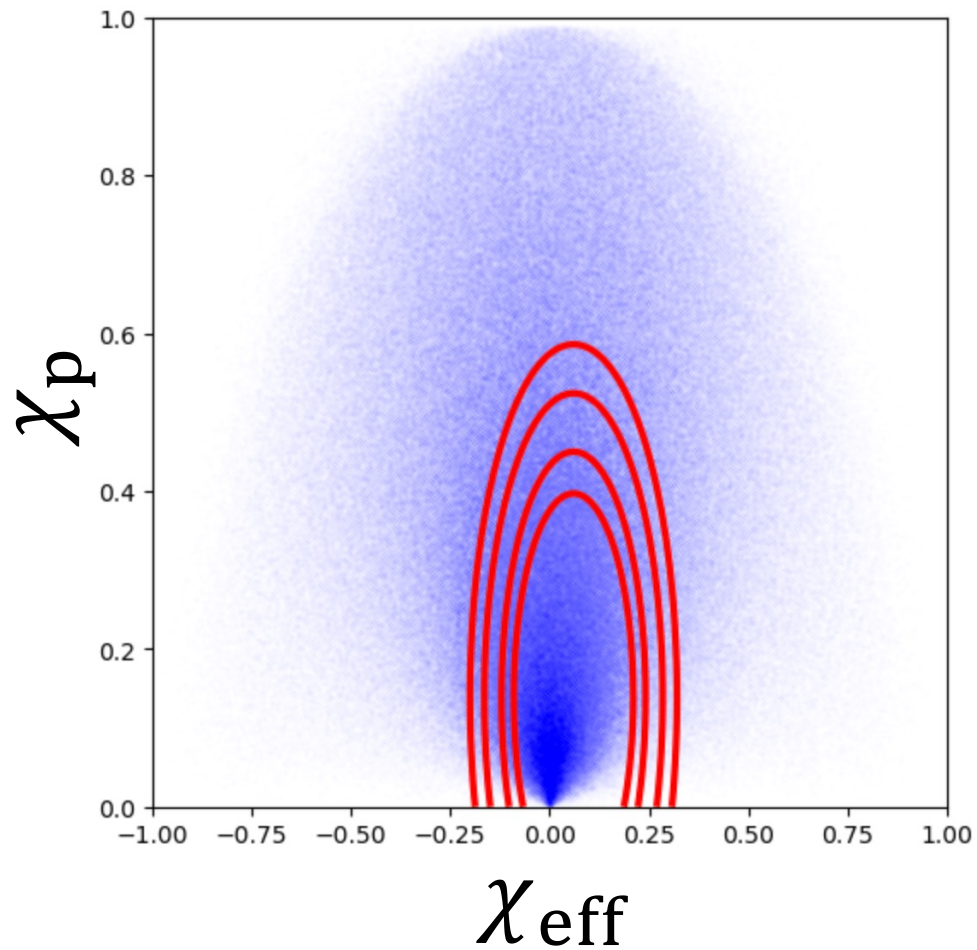
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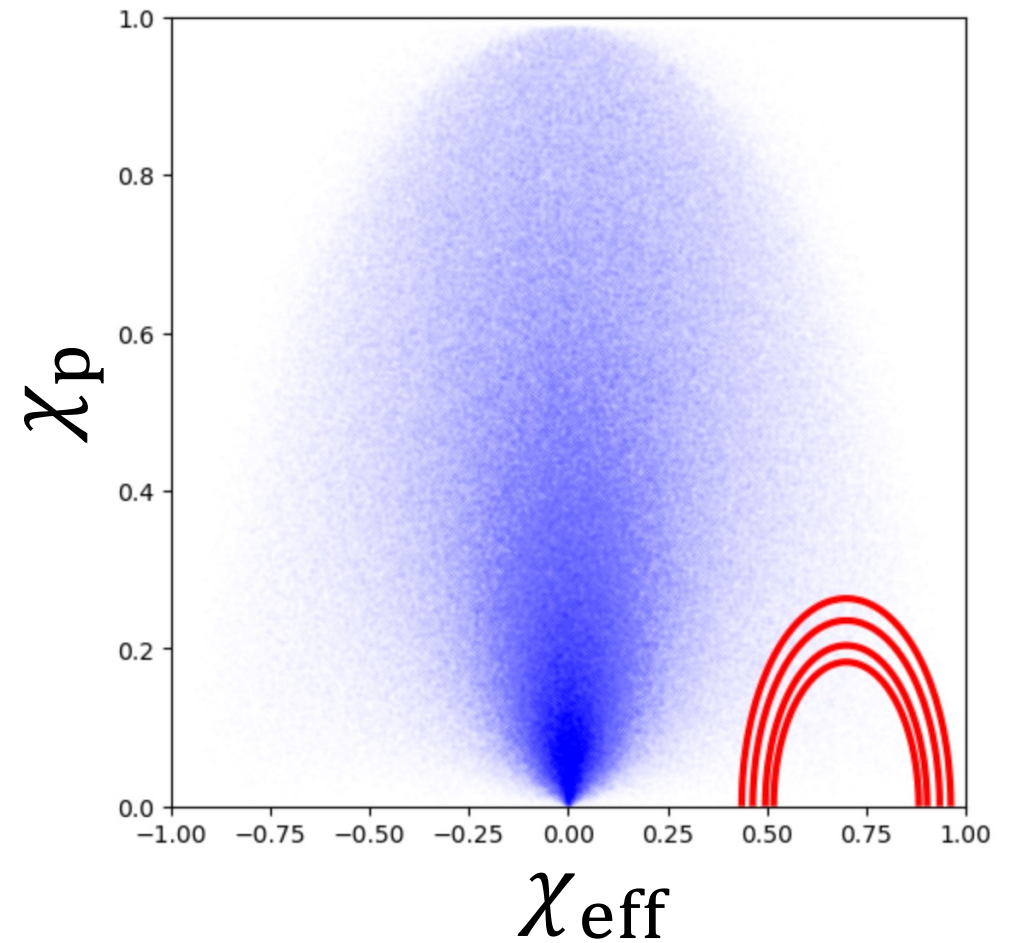
Assumed populations for spins

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GWTC-3 like population



Large χ_{eff} population



- Generation of injections
 - SNR threshold: 10
 - Assume typical O3 sensitivity
 - $N_{\text{injections}} = 20, 40, 70$
- Population model for effective spins: 2D Gaussian
- Waveform model: IMRPhenomXPHM^[1]
- N_{eff} for individual injections: 10, for selection function: $4 \times N_{\text{injections}}$
- Bayesian parameter estimation: Bilby^[2]
- Population inference: emcee^[3]

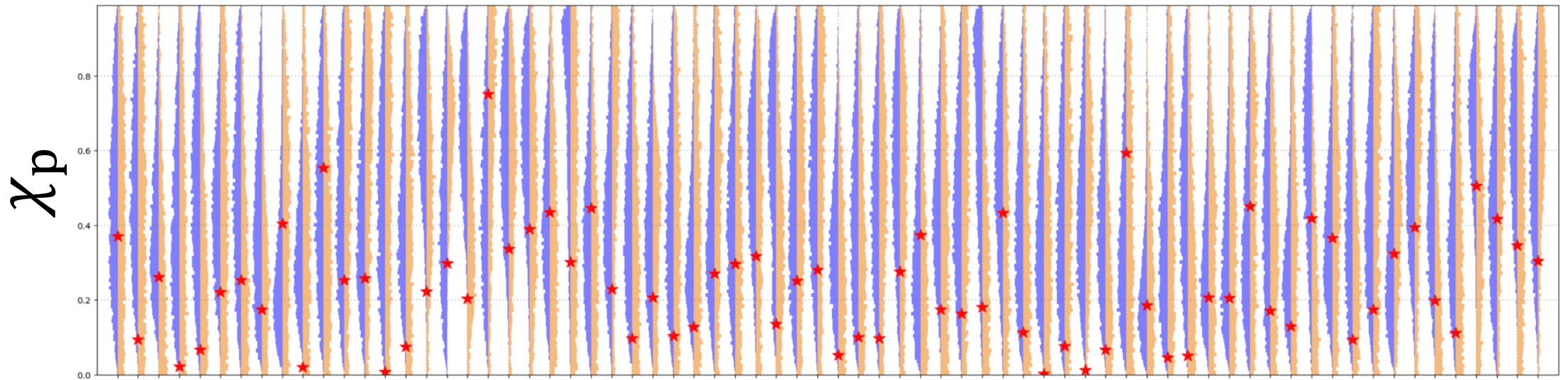
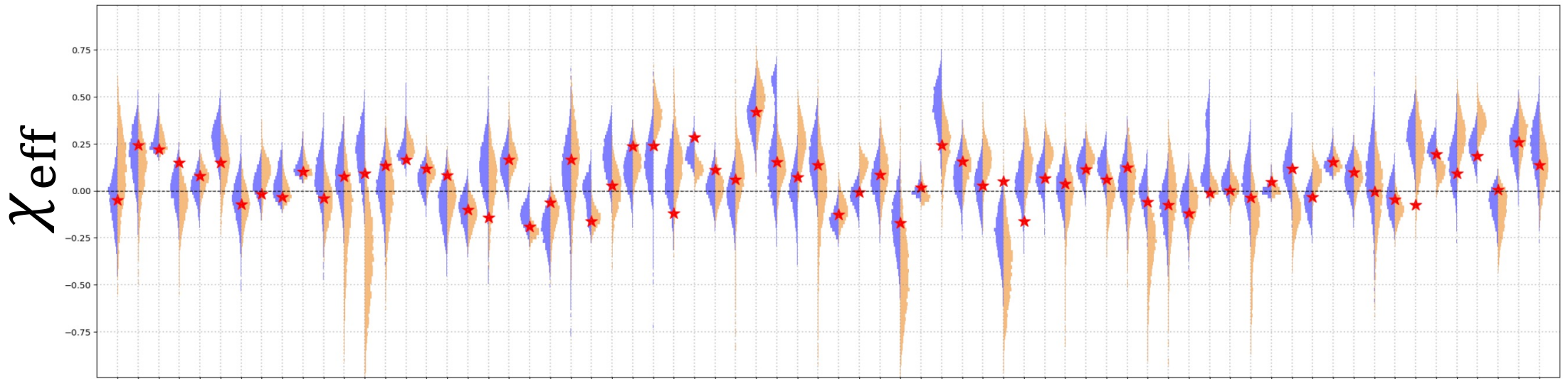
[1] Geraint P, et al. arXiv:2004.06503 (2021)

[2] Gregory Ashton et al. arXiv:1811.02042(2019)

[3] D. Foreman-Mackey et al. arXiv:1202.3665 (2013)

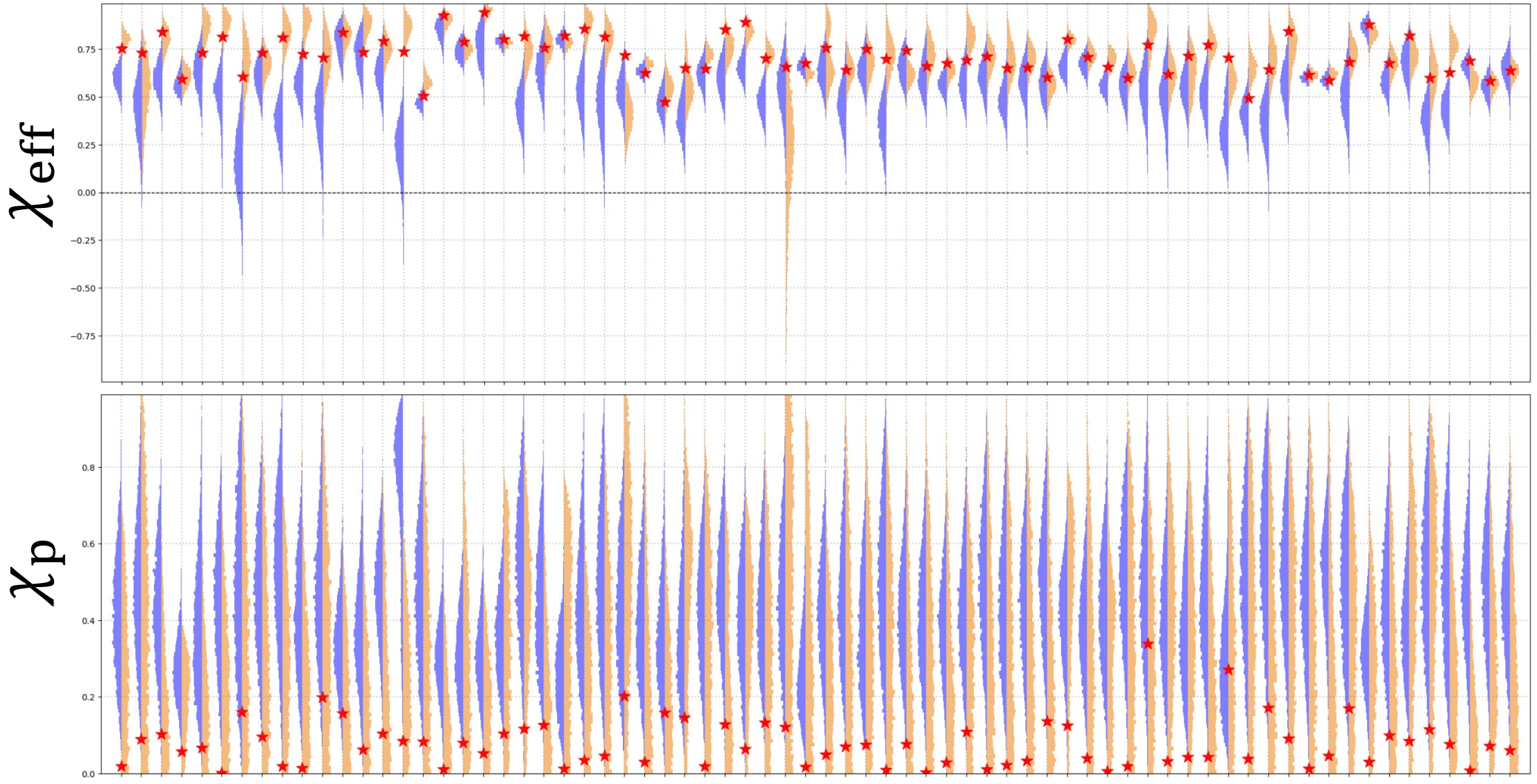
Individual posteriors from GWTC-3 like population

Red: injection value, Blue: isotropic, Orange: χ_{eff} , χ_p uniform



Individual posteriors from large χ_{eff} population

Red: injection value, Blue: isotropic, Orange: $\chi_{\text{eff}}, \chi_{\text{p}}$ uniform

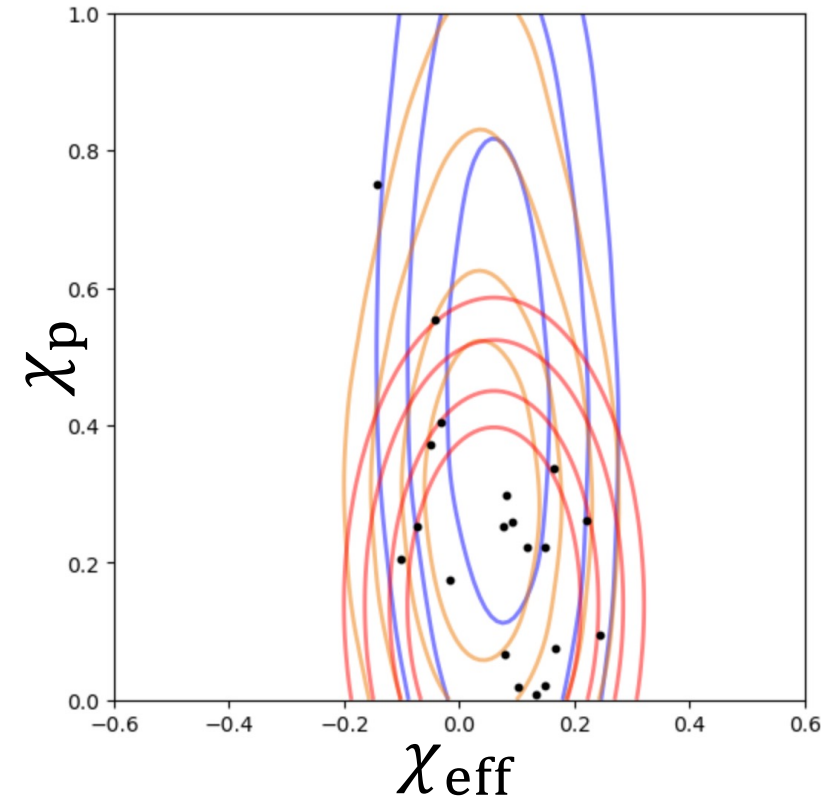


Reconstructed populations from GWTC-3 like case

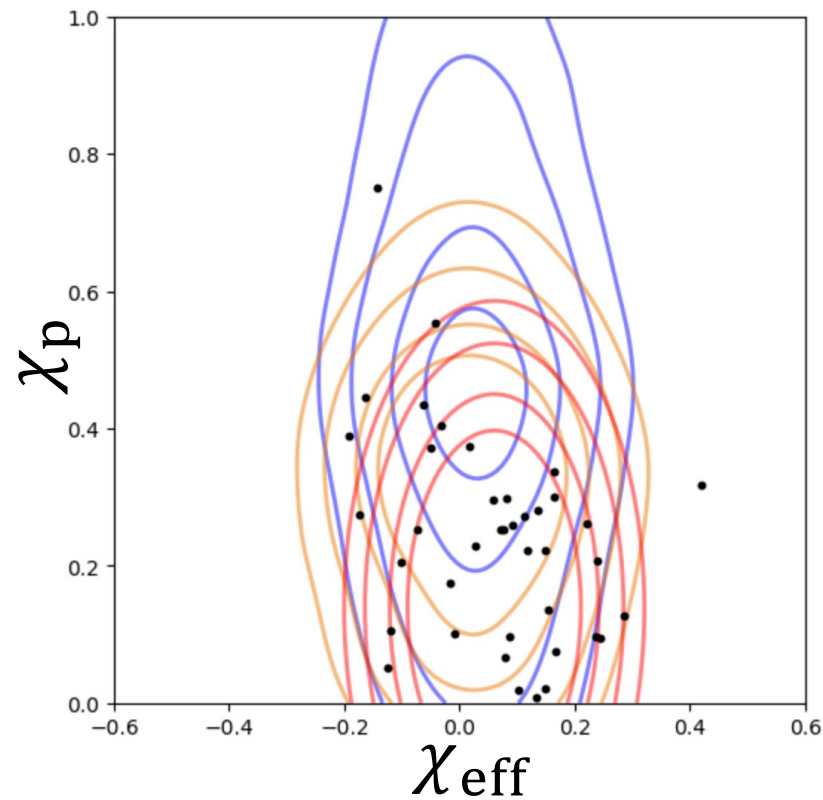
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The blue (isotropic case) and orange ($\chi_{\text{eff}}, \chi_p$ uniform case) contours should match the assumed population (red). The black points are the injection values from assumed population.

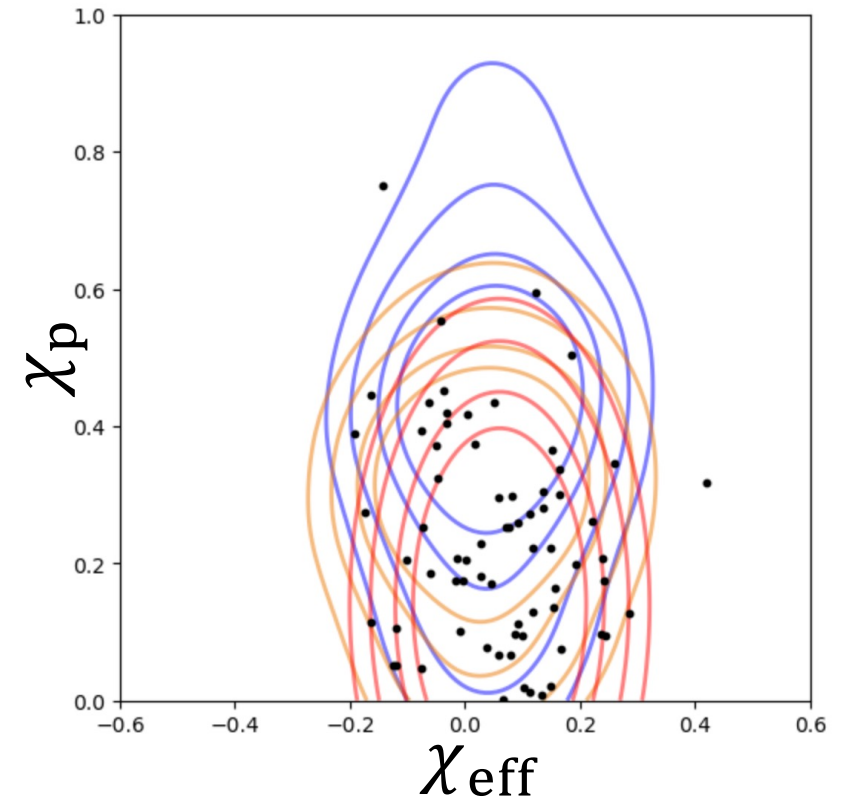
$N = 20$



$N = 40$



$N = 70$

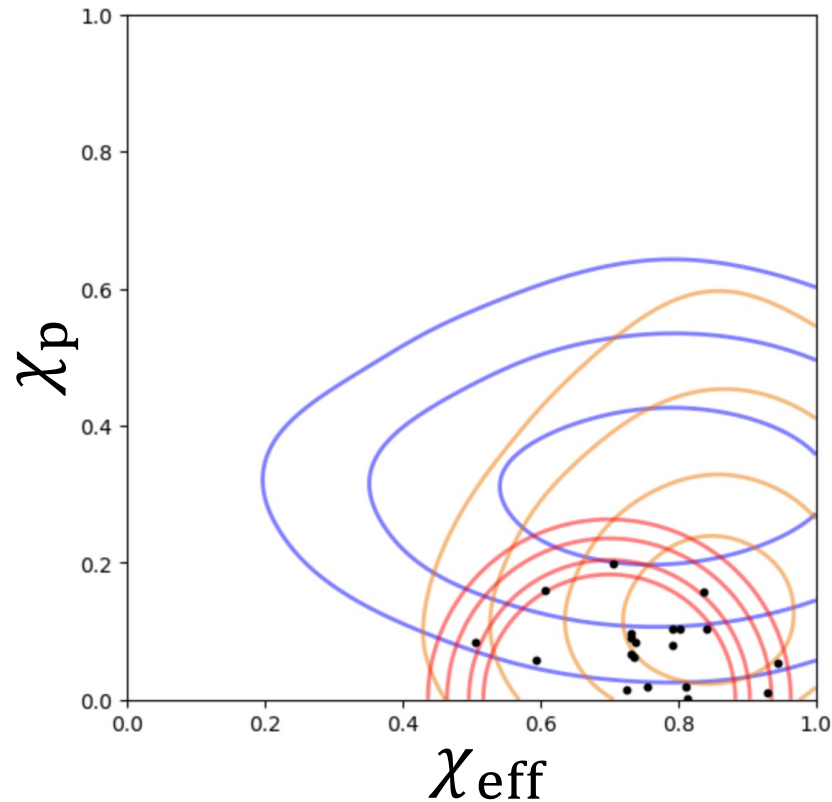


Reconstructed populations from Large χ_{eff} case

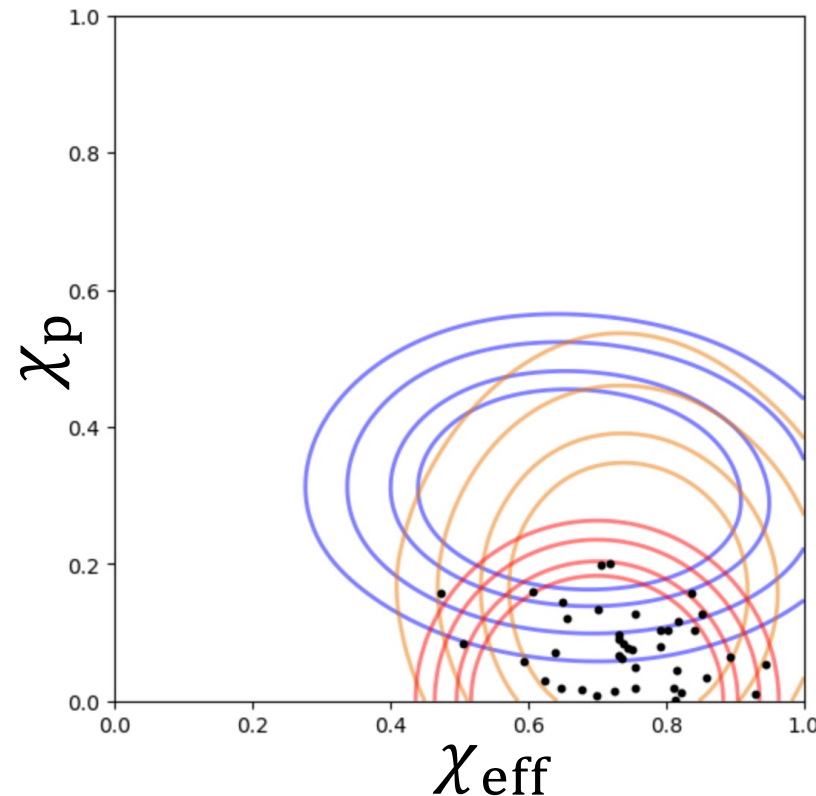
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The blue (isotropic case) and orange ($\chi_{\text{eff}}, \chi_p$ uniform case) contours should match the assumed population (red). The black points are the injection values from assumed population.

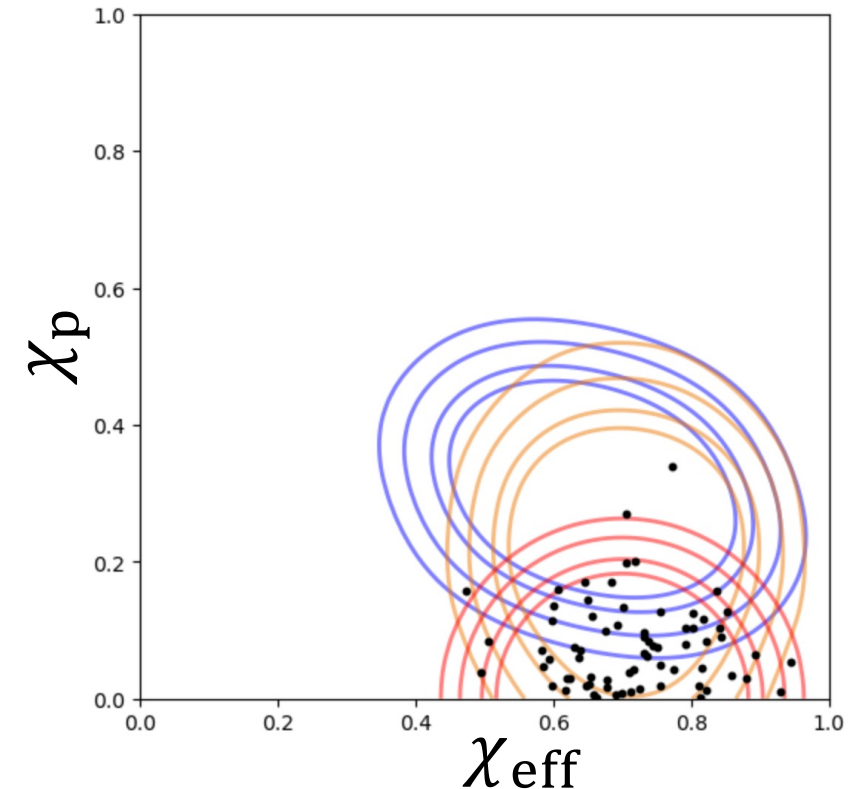
$N = 20$



$N = 40$



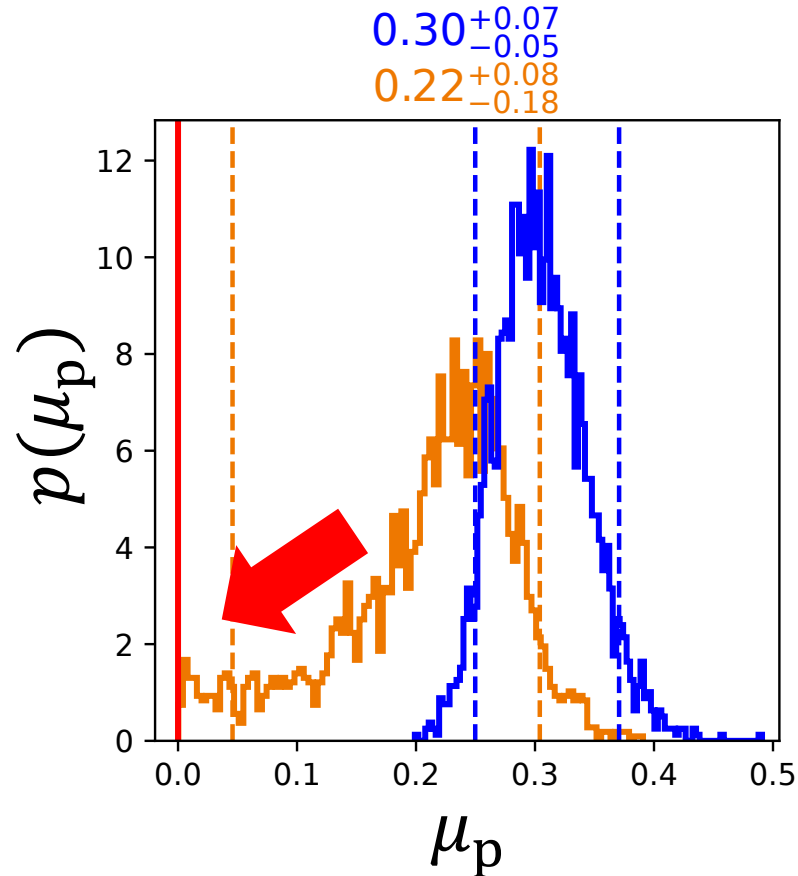
$N = 70$



Results of Large χ_{eff} population case

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$N = 70$



Red: value of assumed population

Blue: isotropic

Orange: $\chi_{\text{eff}}, \chi_p$ uniform

The μ_p is mean of the Gaussian population model for χ_p .

The left panel shows the posterior for μ_p .



The $\chi_{\text{eff}}, \chi_p$ uniform case does not rule out the injected values, **making this approach more effective!**

Settings: analysis for real data

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- Event selection^[1]:
 - Up to O3(our analysis for O4a data is on going)
 - False alarm rate $< 1/\text{year}$

 **69 events**

- Population model for effective spins: 2D Gaussian
- Waveform model: IMRPhenomXPHM^[2]
- Bayesian parameter estimation: Bilby^[3]
- Population inference: emcee^[4]

[1] R. Abbott et al. arXiv:2111.03634 (2022)

[2] Geraint P, et al. arXiv:2004.06503 (2021)

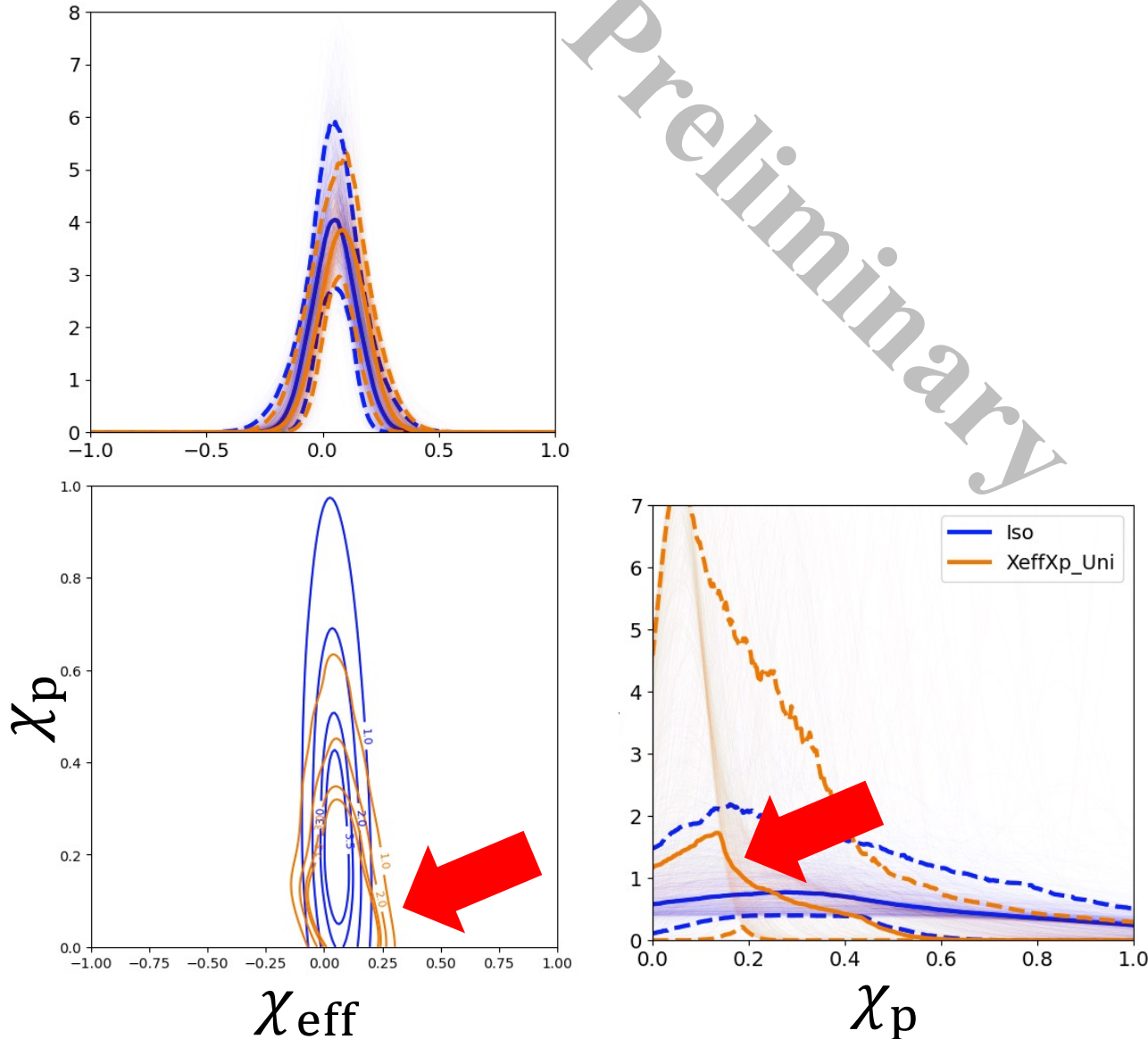
[3] Gregory Ashton et al. arXiv:1811.02042(2019)

[4] D. Foreman-Mackey et al. arXiv:1202.3665 (2013)

Results of population analysis (preliminary)

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Preliminary



Blue: isotropic

Orange: $\chi_{\text{eff}}, \chi_p$ uniform

The distribution of χ_{eff} does not change much, but for χ_p , specifically, the population around $\chi_p = 0$ increases.



BBH formation may depend more on isolated binary formation than previously thought.

Conclusion and future work

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- Analyses that use priors from previous studies may introduce the bias in estimating the population of the effective spins.
- By using the prior we developed, **our analysis can reduce that bias and provide a more accurate estimate for effective spins.**
- BBH formation may rely more on isolated binaries than previously thought.
- As future work, we plan to apply our method to analysis for O4a data.
- Our method will be useful when considering **subpopulations** in the region where the effective spin are large.

Thank you for your attention!