BUILDING BETTER SPIN MODELS FOR MERGING BINARY BLACK HOLES

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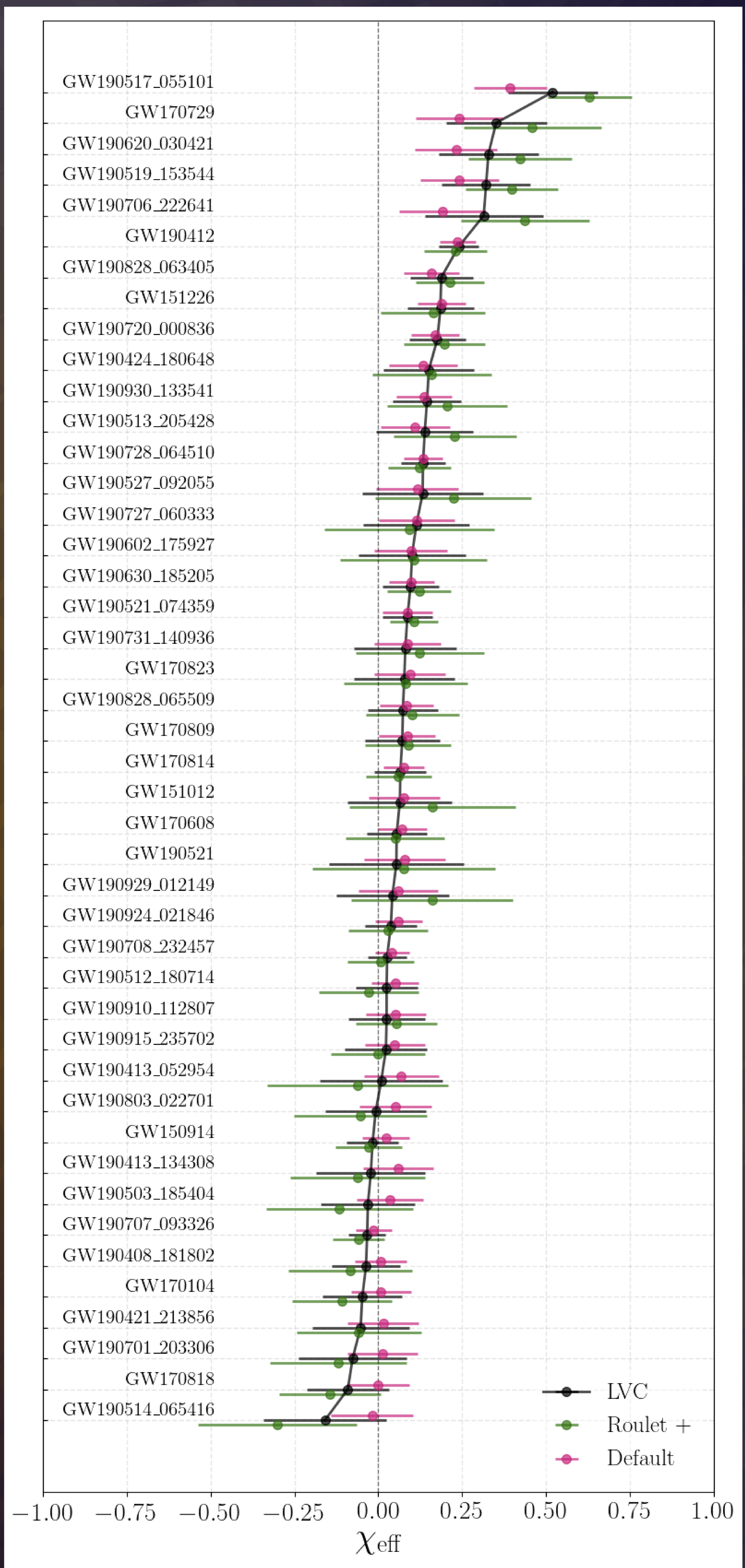

FIGURE 1: Posteriors distributions of events analysed in [2] showing the mean and standard deviation of $\chi_{\rm eff}$ for different prior assumptions.

ABSTRACT

Recent work paints a conflicting portrait of the distribution of black hole spins in merging binaries measured with gravitational waves. In this work, we scrutinise models for the distribution of black hole spins to pinpoint possible failure modes in which these models could yield a faulty conclusion. We reanalyse data from the second LIGO/Virgo gravitational-wave transient catalogue (GWTC-2) using a revised spin model, which allows for a sub-population of black holes with negligible spins. In agreement with recent results by Roulet et al. 2021, **we show that the GWTC-2 detections are consistent with two distinct sub-populations**. We estimate that **~80% (90% credible interval) of merging binaries contain black holes with negligible spin $\chi \approx 0$.** The remaining binaries are part of a second sub-population in which the spin vectors are preferentially (but not exactly) aligned to the orbital angular momentum. The black holes in this **second sub-population are characterised by spins of $\chi \approx 0.5$**. We suggest that the inferred spin distribution is consistent with the hypothesis that all merging binaries form via the field formation scenario.

BINARY BLACK HOLE SPIN DISTRIBUTION + POPULATION MODELS

Gravitational waves from merging binaries encode information about the mass and spin of the component black holes; providing clues as to how the binary formed. Two scenarios are frequently invoked to explain merging binary black holes: **Isolated** and **Dynamical**. These two scenarios yield distinct predictions for the distribution of black hole spin vectors.

Black hole binaries formed via isolated evolution tend to have spins that are preferentially aligned with the orbital angular momentum, whereas an isotropic distribution of spin orientations is expected from the dynamical channel.

Population analysis [1] of events from GWTC-2 [2] found evidence of black holes being misaligned >90° with respect to the orbital angular momentum; potentially a signature for dynamically formed binaries. A more recent study [3] found no clear evidence, this is further supported by looking at Fig. 1, where all events are consistent with $\chi_{\rm eff} \geq 0$ (effective inspiral parameter). These conflicting results raise a few questions:

- Why did checks in [1], designed to validate the observation of $\chi_{\rm eff} < 0$, not reveal the model-dependency of this result?
- Can we develop a new model to address the shortcomings of the models used in [1]?
- Are we able to confirm the results in [3], and what else will an improved analysis reveal about the population?

We explore these questions in detail in our paper: **arXiv:2109.02424**

SPIN PARAMETERS

$\chi_{1,2}$	spin magnitude of the binary components
μ_χ	mean of the Beta distribution for the spin magnitude
σ_χ	width of the Beta distribution for the spin magnitude
α_χ, β_χ	parameters defining shape of Beta distribution
λ_0	fraction of binary black holes in zero-spin peak
$z_{1,2}$	cosine of the spin orientation of the binary components
ζ	mixing fraction of mergers with preferentially aligned spin
σ_t	spread in projected misalignment of preferentially aligned black holes
$z_{\rm min}$	minimum value of the projected misalignment angle

SPIN MODELS: Default and Extended

spin magnitude

$$\boxed{\pi(\chi_{1,2} \mid \alpha_\chi, \beta_\chi) = \mathrm{Beta}(\chi_{1,2} \mid \alpha_\chi, \beta_\chi)} \quad [1,4]$$

$$\pi(\chi_{1,2} \mid \alpha_\chi, \beta_\chi, \boxed{\lambda_0}) = \boxed{(1-\lambda_0)}\mathrm{Beta}(\chi_{1,2} \mid \alpha_\chi, \beta_\chi) + \boxed{\lambda_0 G_t(\chi_{1,2})}$$

spin orientation

$$\boxed{\pi(z_{1,2} \mid \zeta, \sigma_t) \propto \zeta G_t(z_{1,2} \mid \sigma_t) + (1-\zeta)\mathfrak{I}(z_{1,2})} \quad [1,5]$$

$$\pi(z_{1,2} \mid \zeta, \sigma_t, \boxed{z_{\rm min}}) \propto (\zeta G_t(z_{1,2} \mid \sigma_t) + (1-\zeta)\mathfrak{I}(z_{1,2}))\boxed{\Theta(z_{1,2} - z_{\rm min})}$$

EVIDENCE FOR TWO SUBPOPULATIONS: $\chi \approx 0$ and $\chi \approx 0.5$

The **Extended** model is an extension of the **Default** model used in [1]. This model has flexibility to allow for a sub-population with negligible spins modelled by a Delta function at $\chi = 0$ and allows for the minimum misalignment angle to vary from [-1, 1]. We find that:

- there is evidence of two sub-populations: one at $\chi \approx 0$ and the other at $\chi \approx 0.5$ (Fig. 2)
- the distribution finds that most binary black holes merge with negligible spins ($\lambda_0 = 0.81^{+0.09}_{-0.11}$)
- the distribution is likely not cut off at near-exact alignment with $z_{\rm min} = (-0.36, 0.66)$ at 90% credibility.
- the **Extended** model is preferred over the **Default** model by a Bayes factor of $\log_{10} \mathcal{B} \approx 17.6$

Fig. 3 illustrates the model-dependancy of the conclusions drawn from each analysis. The **Extended** model is able to capture the information about the sub-populations. We recommend careful consideration of possible *sharp features*— in this case, a narrow peak at $\chi_{1,2} \approx 0$

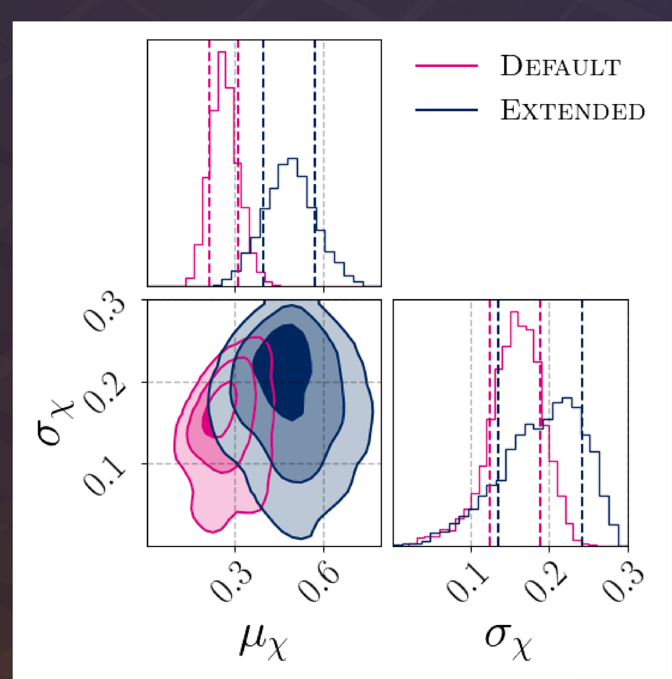

FIGURE 2: Mean and standard deviation of Beta distribution for spin magnitudes.

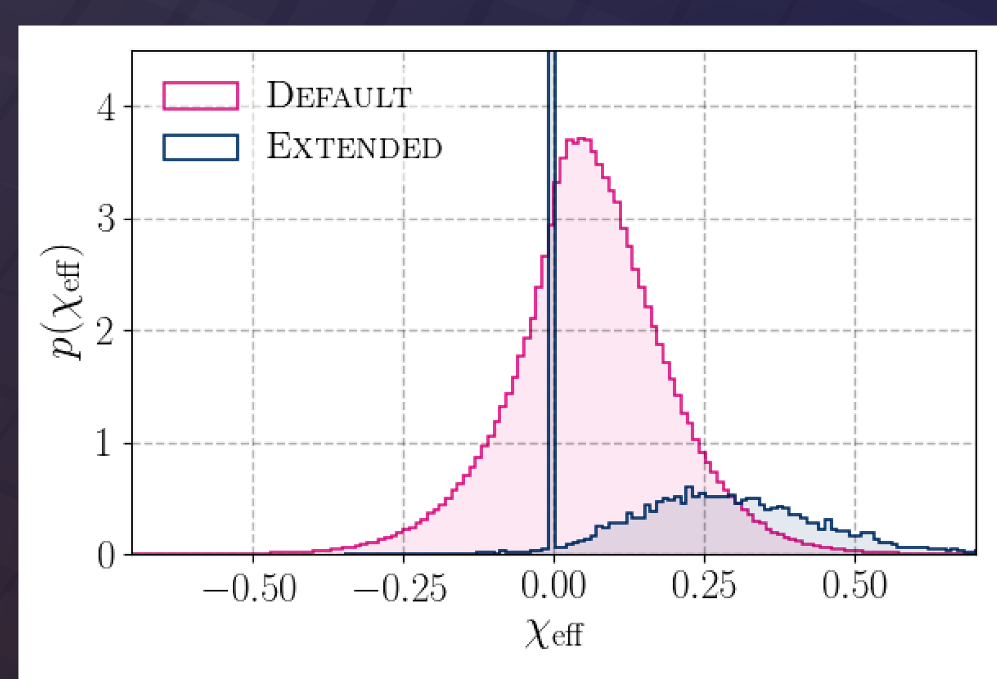

FIGURE 3: Population predictive distribution of $\chi_{\rm eff}$ for the Default and Extended models

REFERENCES

[1] Abbott et al. 2021, ApJL, 913, L7

[2] Abbott et al. 2021, PRX, 11, 021053

[3] Roulet and Zaldarriaga, 2019, MNRAS, 484, 421

[4] Wysocki, Lange, & O'Shaughnessy, 2019, PRD 100, 043012

[5] Talbot, & Thrane, 2017, PRD, 96, 023012

SUMMARY

In this work we explore the subtleties in diagnosing model misspecification, which can lead to overly model-dependent conclusions; and we reanalyse GWTC-2 using a new model which is an extension of those used in [1]. We find that:

- around 80% of merging black hole binaries contain black holes with negligible spin, the remaining are rapidly spinning ($\chi \approx 0.5$)
- the population consistent with the hypothesis that all merging binaries form via the isolated formation scenario.
- our results are consistent with the findings in [3], and more care is needed in checks for populations with potential sharp features.

Read more details on **arXiv:2109.02424**; supplementary materials are available at **github.com/shanikagalaudage/bbh_spin**

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