

# Probing Signatures of Parity Asymmetry in the Universe

## Through Gravitational Waves from Binary Black Hole Mergers

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[arXiv:2501.abxyz](https://arxiv.org/abs/2501.abxyz) (next Monday)



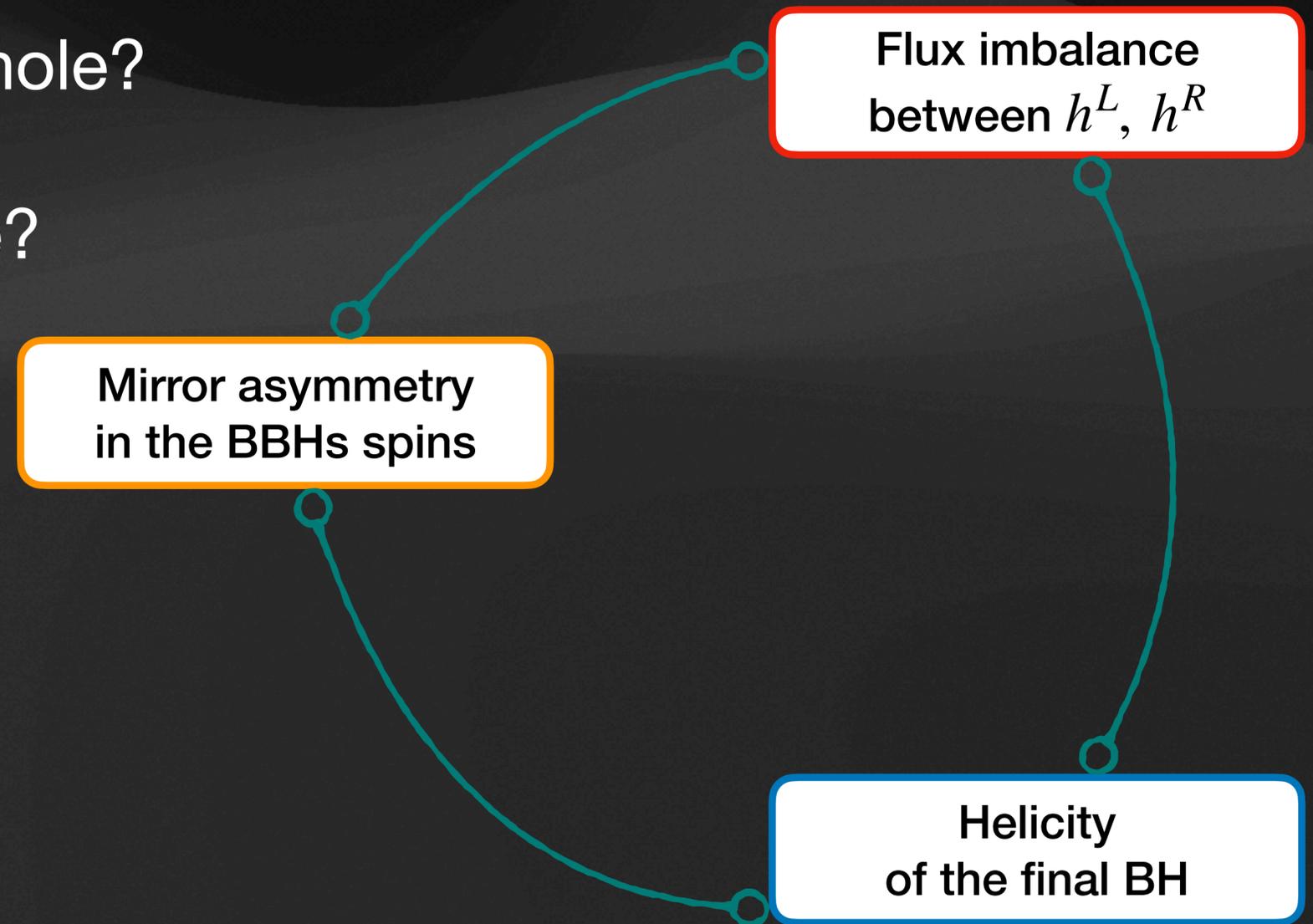
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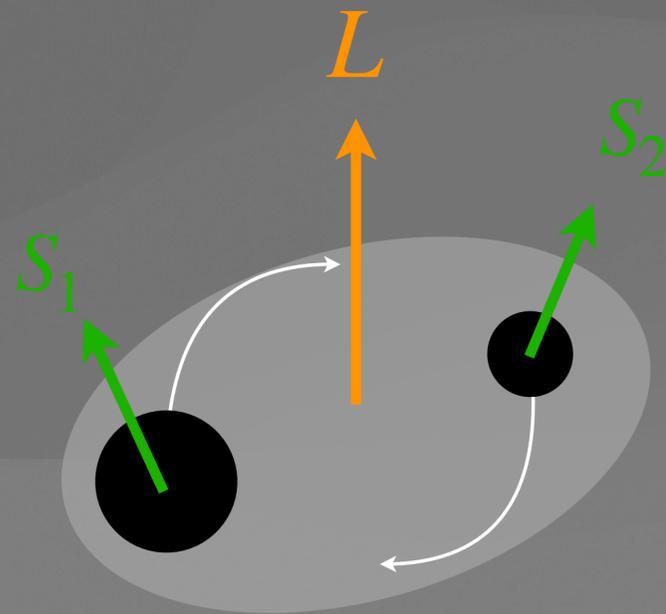
# In this talk:

- What is  $V_{\text{GW}}$ ?
- Relation with precessing binary black hole?
- Relation with helicity of final black hole?
- Real data from GWTC-3.



# Life of a binary black holes

## Inspiral

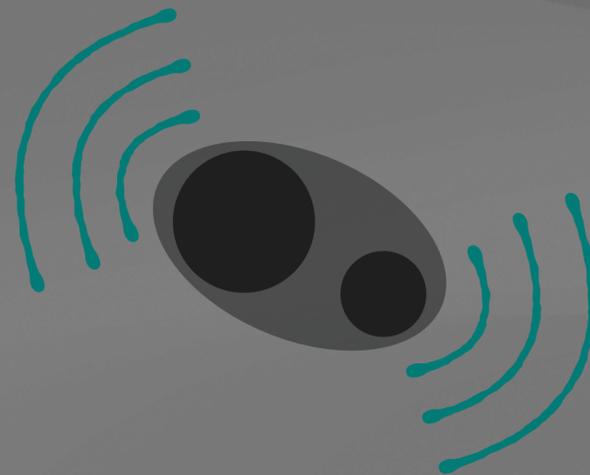


Two BHs still far apart

$L$ : Orbital angular momentum

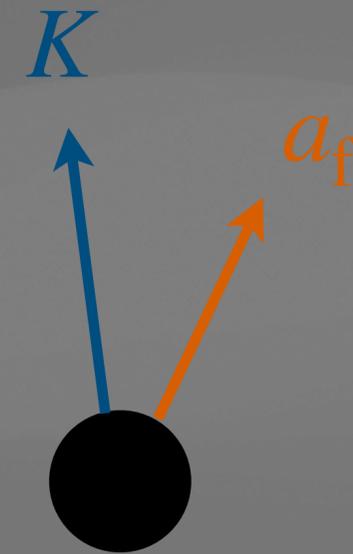
$S_{1,2}$ : Spins of the BHs

## Merger & Ringdown



Highly non-linear dynamics

## Remnant black hole



BH acquires a **kick (recoil)** and possesses a **spin**

**Helicity:**  $h = \langle \hat{K}, \hat{a}_f \rangle$

# The gravitational Stokes $V$ parameter

## Measuring the imbalance in circularly polarised waves

- The GW from binary black holes can be decomposed into the harmonics:

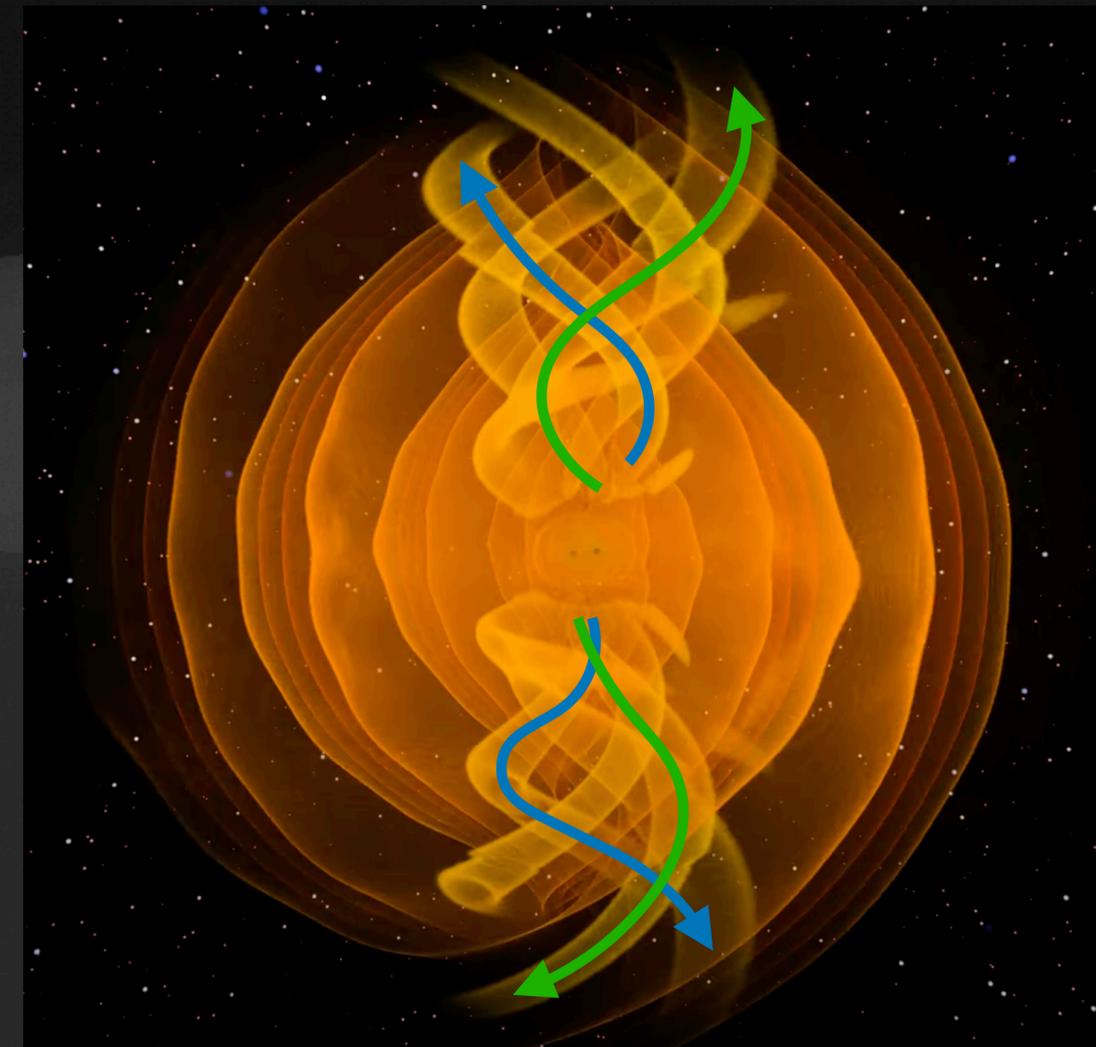
$$h = \sum_{\ell \geq 2} \sum_{m=-\ell}^{\ell} \underline{h^{\ell,m}} {}_{-2}Y_{\ell,m}$$

- Then we define  $V_{\text{GW}}$  using these harmonics modes:

$$V_{\text{GW}} \equiv \int_0^{\infty} d\omega \omega^3 \sum_{\ell m} \left[ \boxed{\overline{h_+^{\ell m}(\omega) + i h_{\times}^{\ell m}(\omega)}}^2 - \boxed{\overline{h_+^{\ell m}(\omega) - i h_{\times}^{\ell m}(\omega)}}^2 \right]$$

Right-handed GW                      Left-handed GW

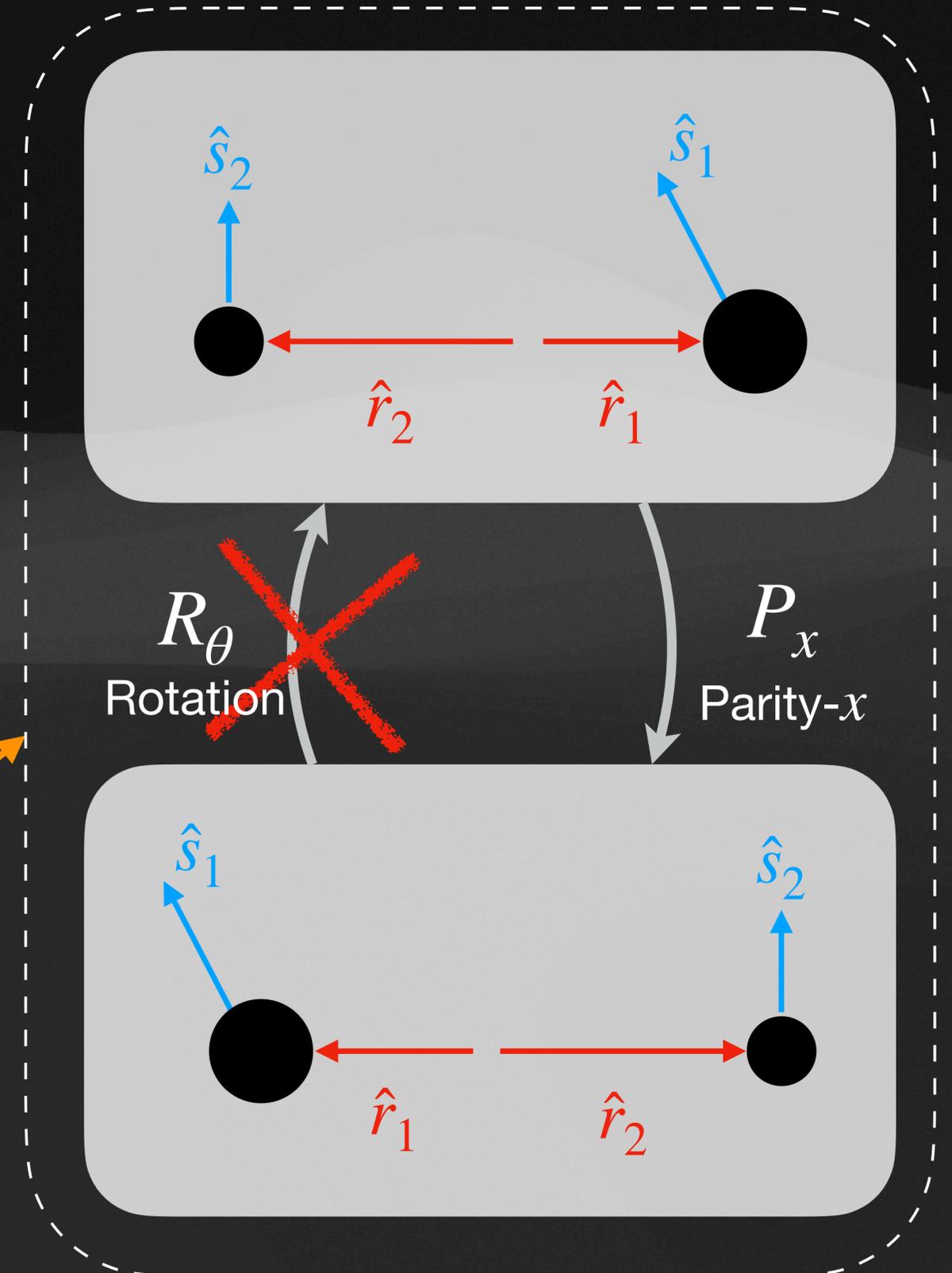
→ It measures the flux difference between the two circularly polarised GW



# Connecting $V_{\text{GW}}$ with spins configuration

## Precessing binary black holes

- Aligned-spin BBHs have their spins parallel to the orbital angular momentum.
- Due to this mirror symmetric configuration, they necessarily have  $V_{\text{GW}} = 0$ .
- Precessing binaries, however, are not mirror symmetric
- We found that they indeed have  $V_{\text{GW}} \neq 0$ .

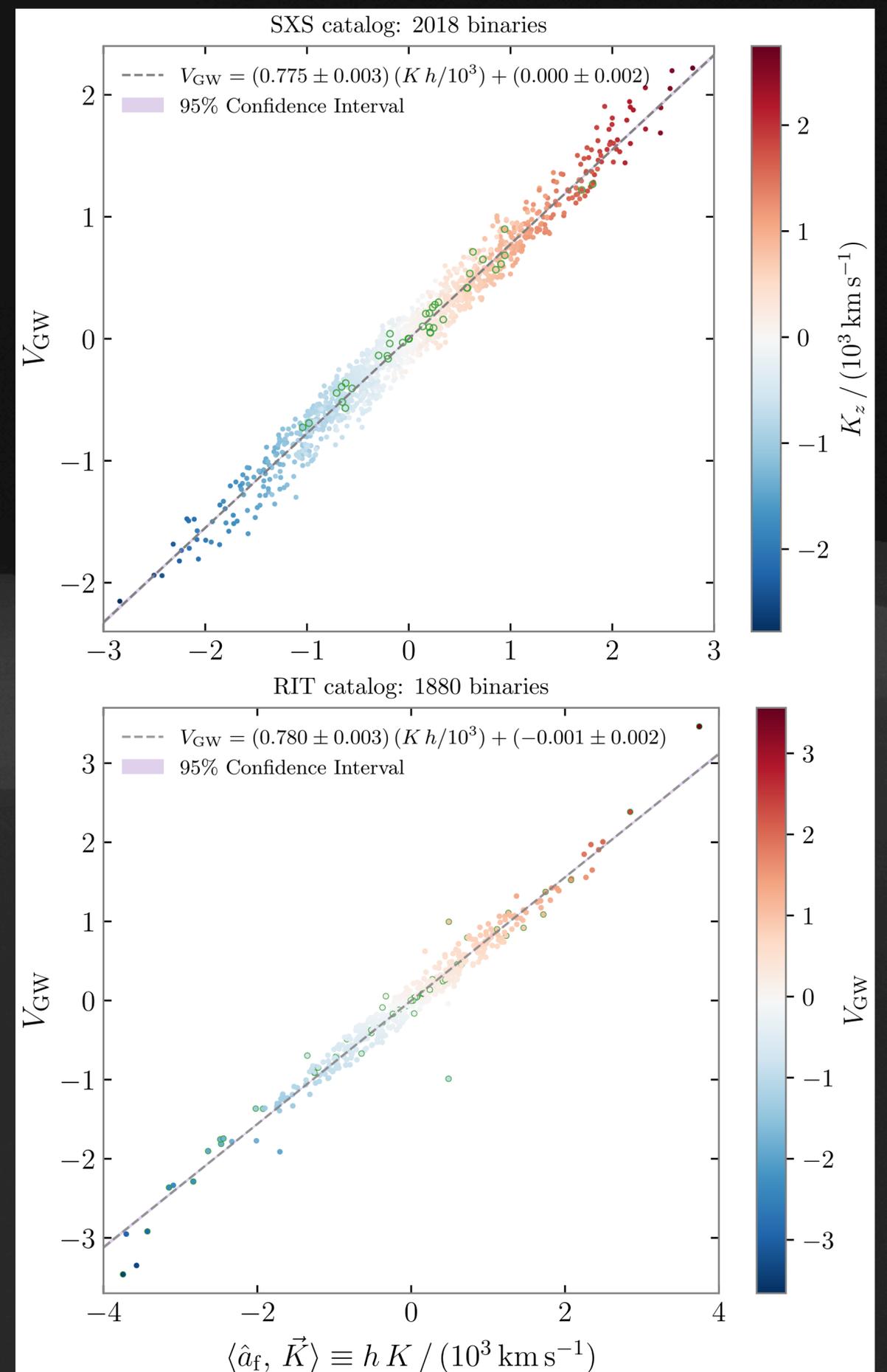


# Surprising *linear* relation

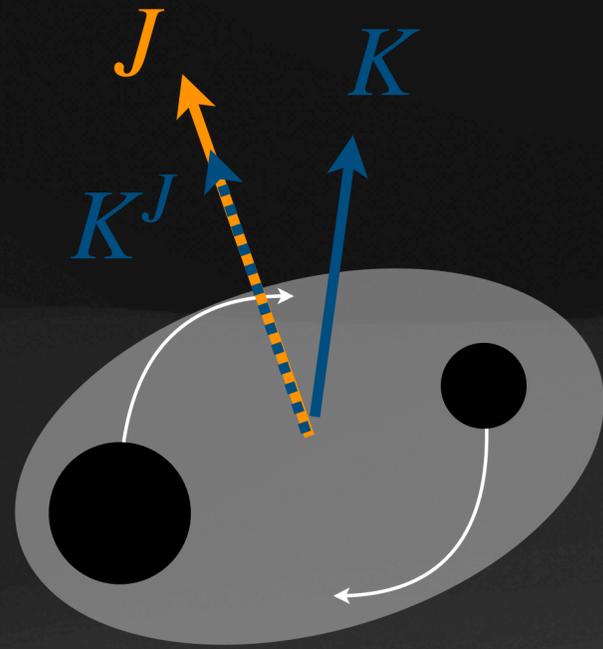
## Helicity and $V_{\text{GW}}$ !?!?

- Compute  $V_{\text{GW}}$  using BBH numerical simulations from two catalogues: SXS & RIT.
- We find that it follows a linear relationship with the helicity of final black hole
- It is surprising because they are manifestly different quantities!!
- They share a common feature though: Both of them are chiral quantities

(Will appear in arXiv on Monday...)

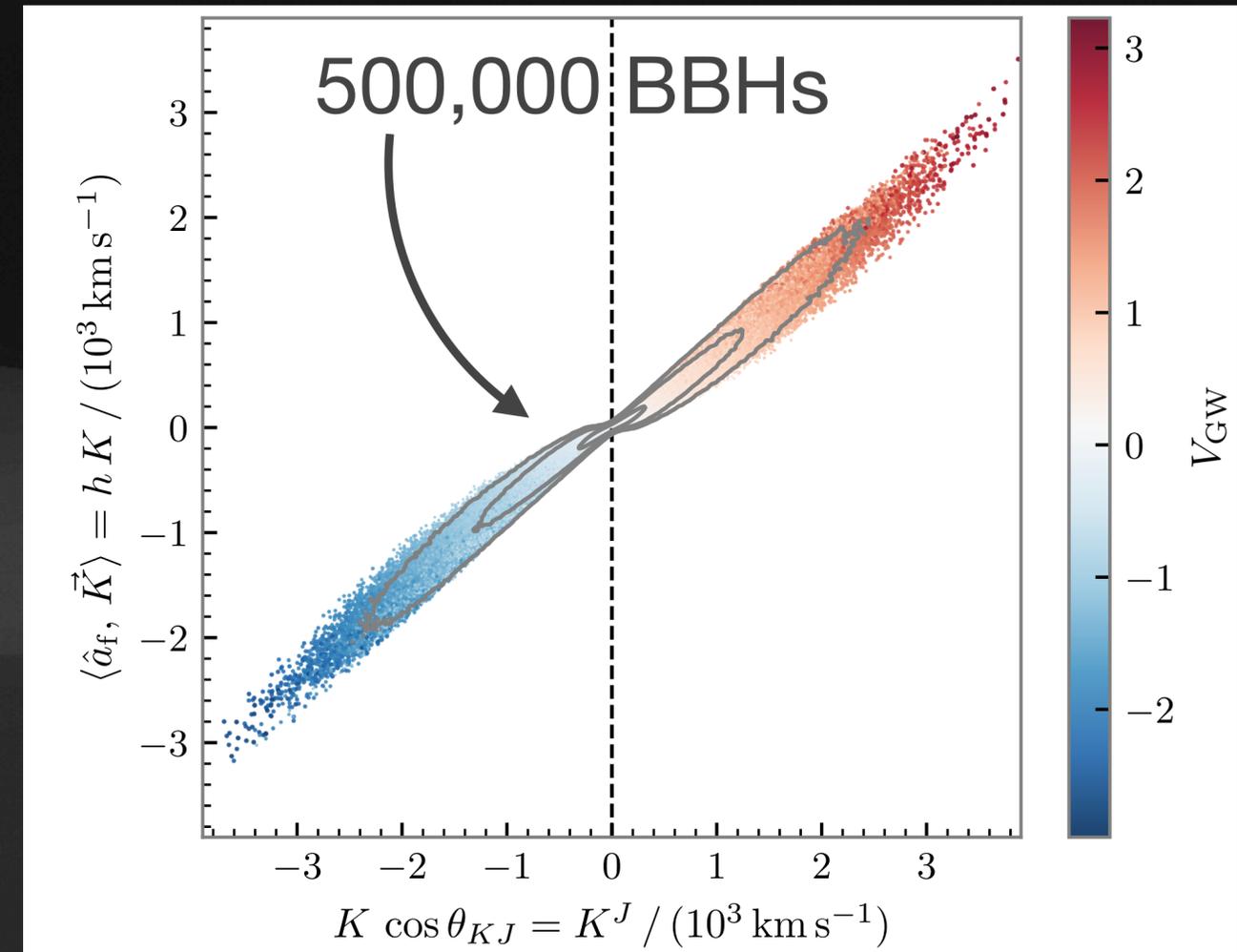


# The off-plane kick component



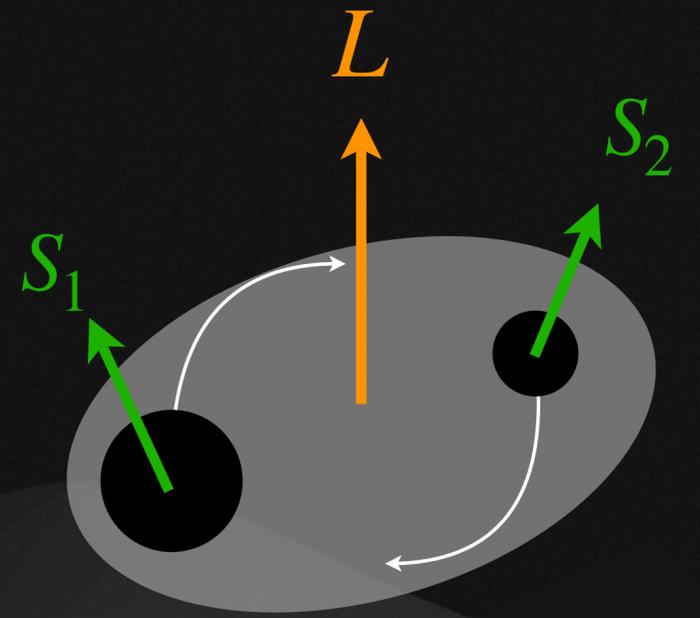
- Furthermore, the total angular momentum is roughly aligned with the final spin.
- The same linear relationship is found between  $V_{\text{GW}}$  and  $K^J$  (off-plane kick)

→ How well can we recover the off-plane kick directly reflect the accuracy of  $V_{\text{GW}}$  that we can measure



# Quick summary

## Three aspects of chirality

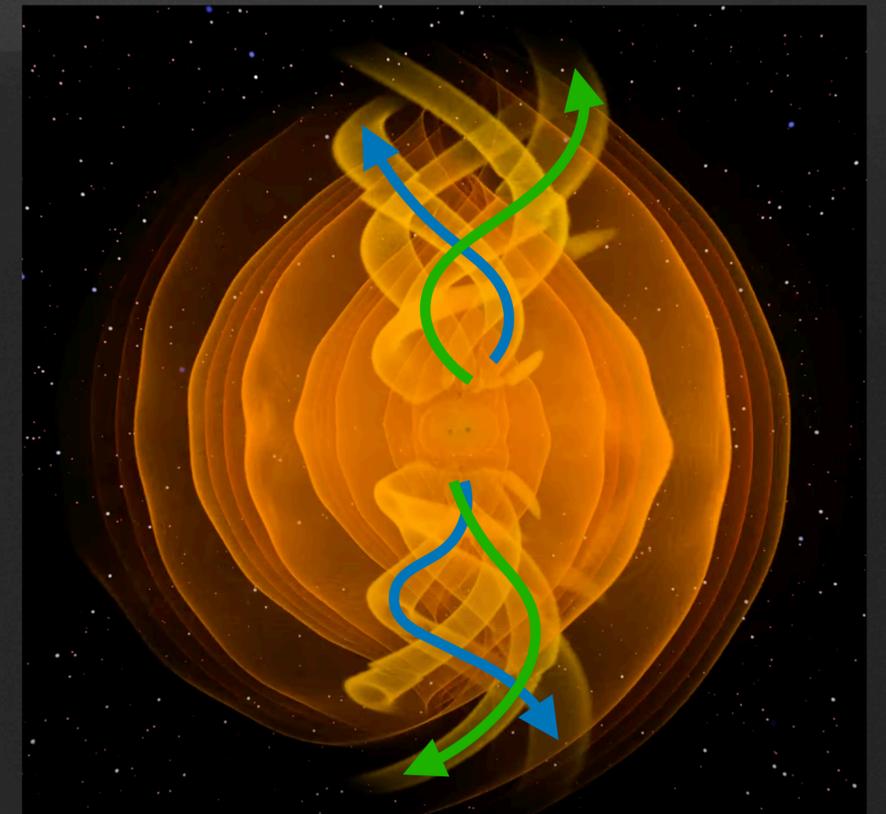
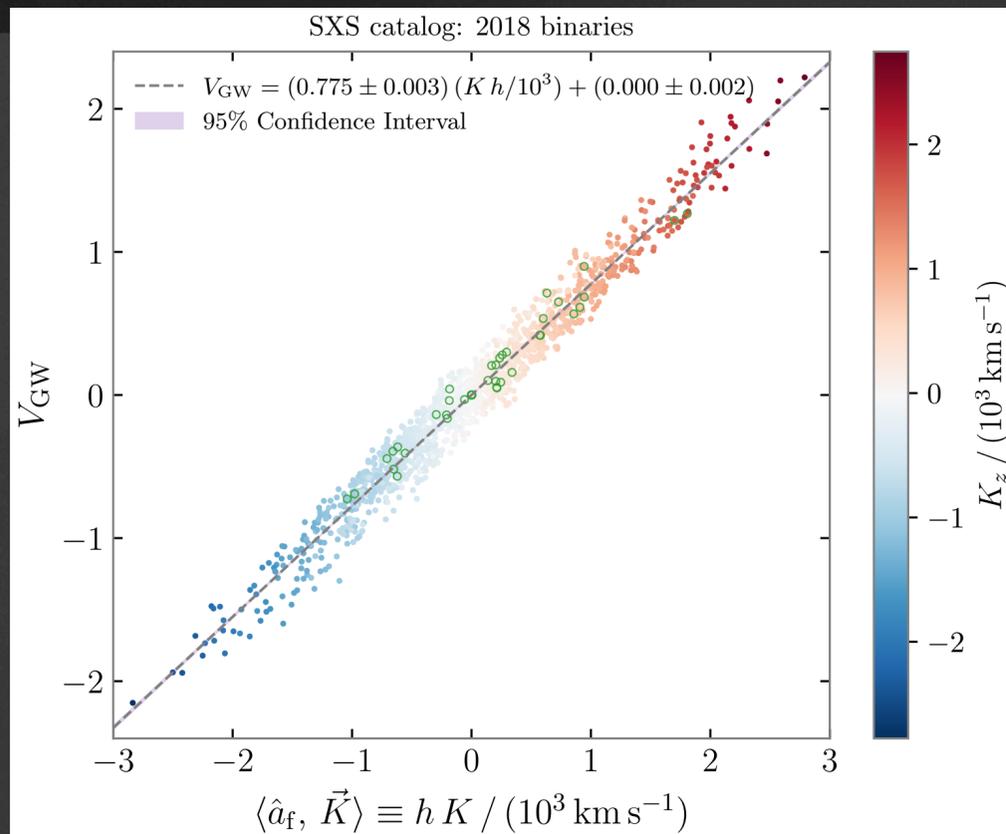


Mirror asymmetry  
in the BBHs spins

Helicity  
of the final BH

$V_{\text{GW}}$

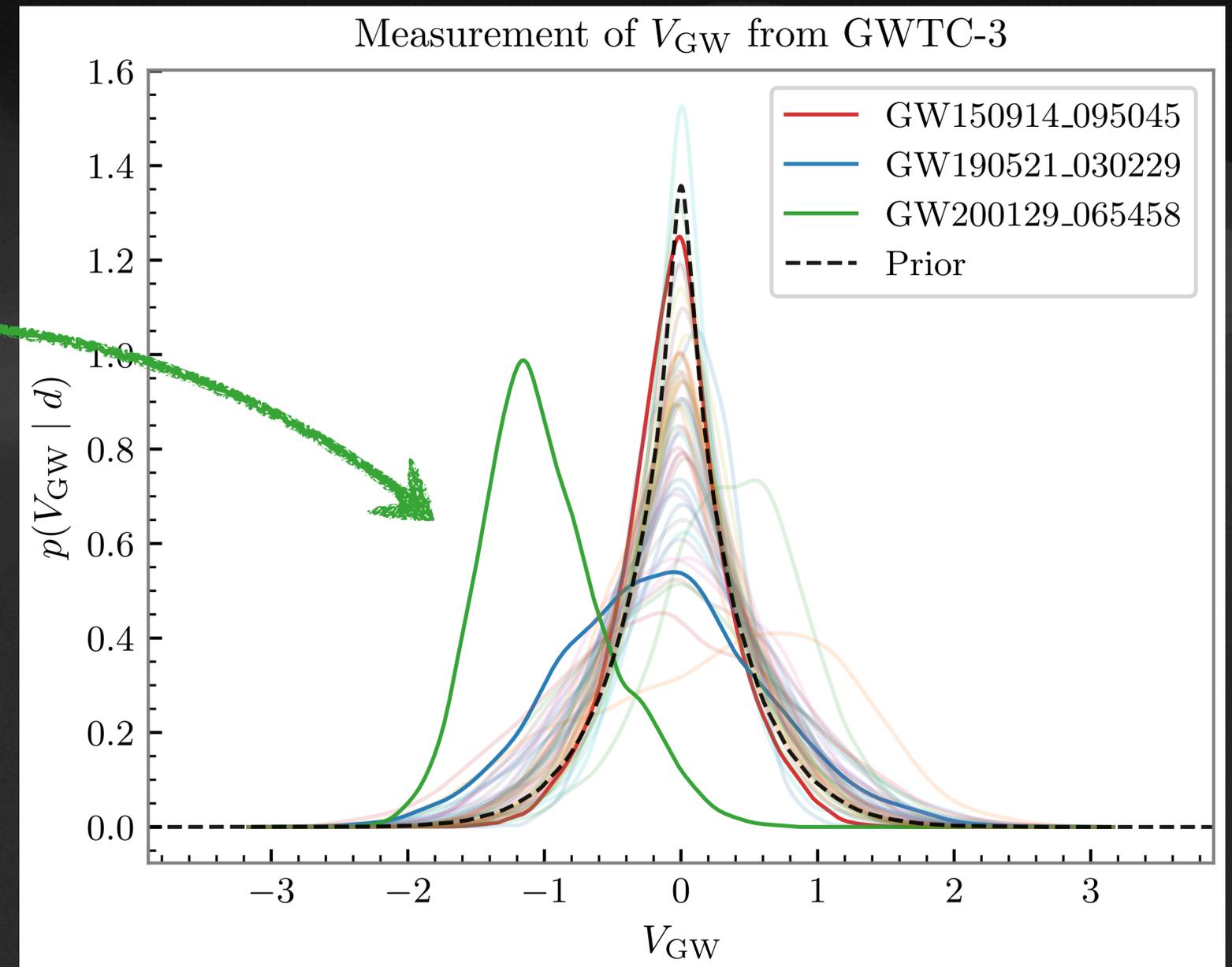
Flux imbalance  
between  $h^L, h^R$



# Measurement from GWTC-3

## Our Universe still preserves parity symmetry

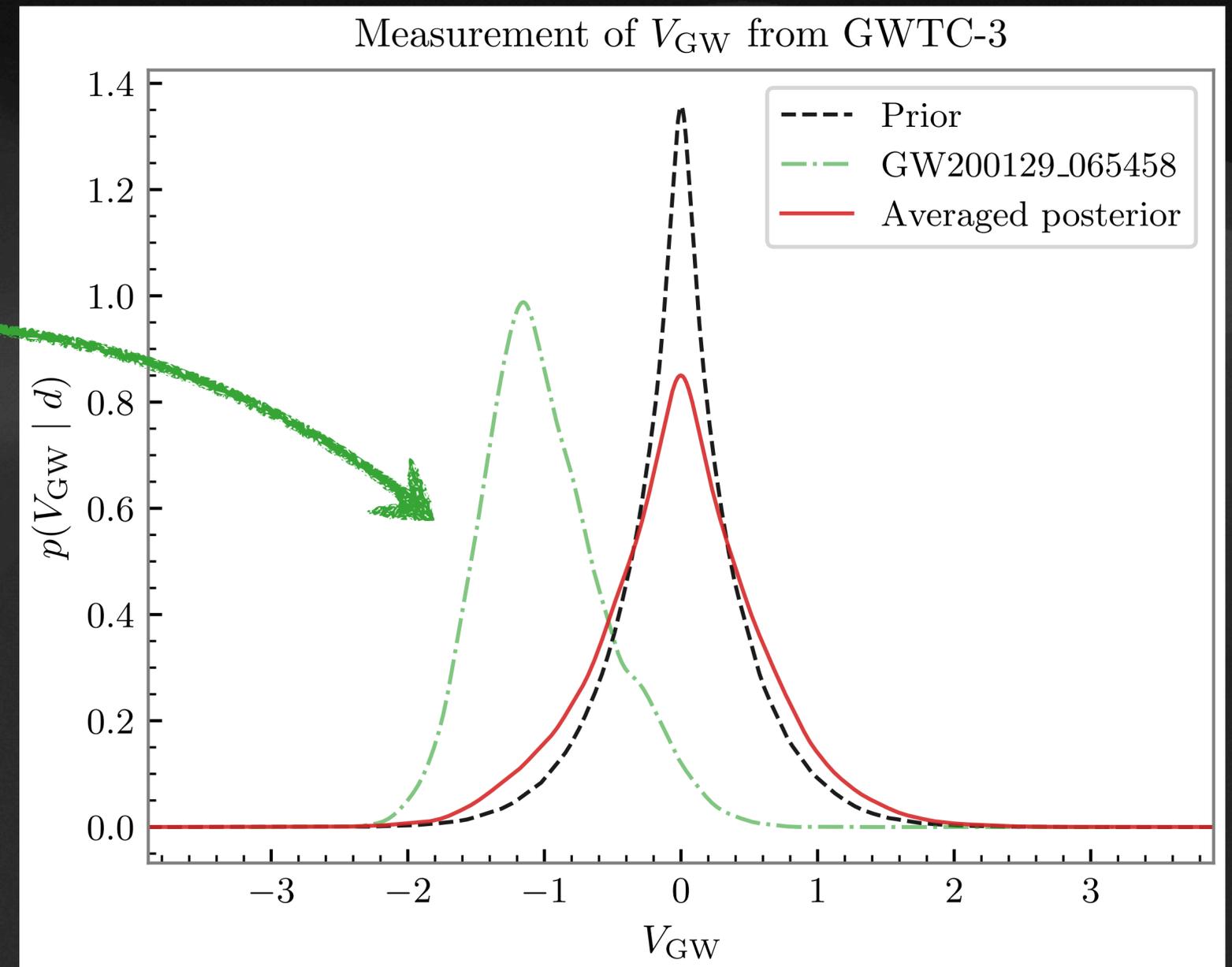
- Analysed 47 events from the latest GW catalogue
- Only one event — **GW200129**, known to be highly precessing, shows large deviation from zero
- On average,  $V_{\text{GW}}$  is still zero.  
→ No evidence that our Universe prefers a particular handedness (yet).



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# Conclusion

- We devise a quantity  $V_{\text{GW}}$  as a measure of parity asymmetry in a binary black hole system.
- It has a intricate relationship with precessing binaries and the helicity of the final black hole.
- The latest GW catalogue does not show evidence of parity asymmetry on the large scale of the Universe.

*“Gravitational analogue of the Wu’s experiment”*

