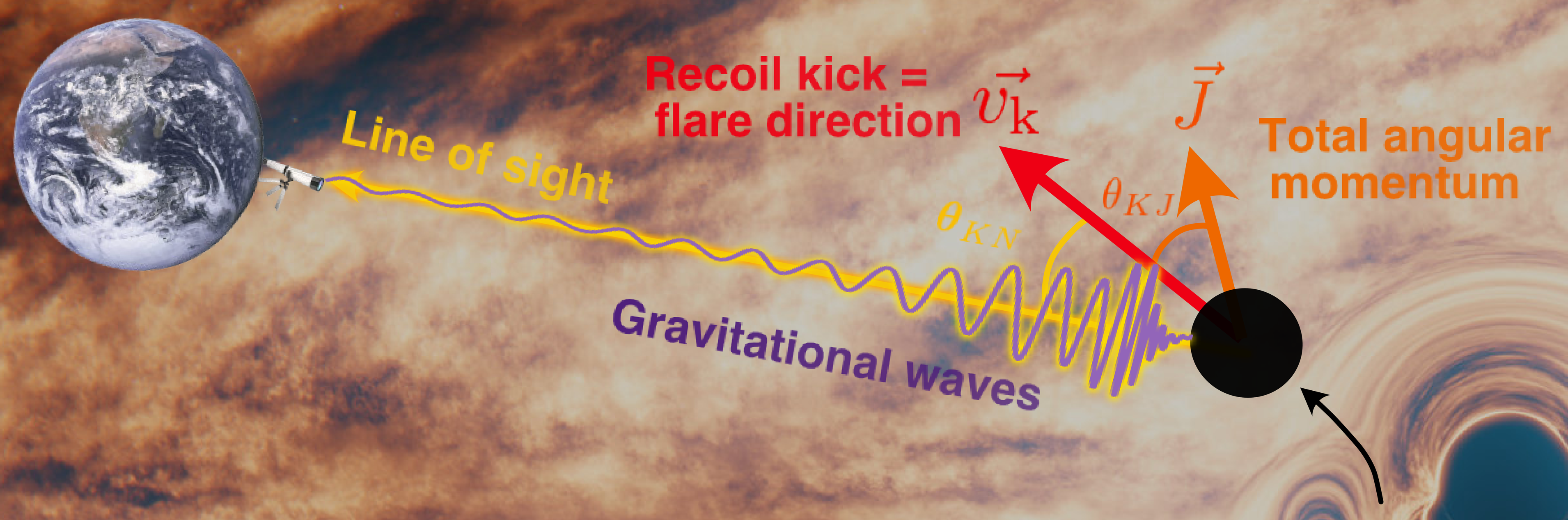
REFINING COSMOLOGICAL MEASUREMENTS USING BLACK-HOLE RECOILS IN AGN DISKS

Samson H.W. Leong[1], Juan Calderón Bustillo[1,2], Koustav Chandra[3,4]

Contact me: samson.leong@link.cuhk.edu.hk

[1] Department of Physics, The Chinese University of Hong Kong (CUHK), Hong Kong
[2] Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, Spain
[3] Department of Physics, Indian Institute of Technology Bombay (IIT Bombay), India
[4] Institute for Gravitation & the Cosmos and Department of Physics, The Pennsylvania State University, USA



References

[1]: McKernan 2019, ApJL 884 L50
[2]: Graham 2020, PRL 124, 251102
[3]: Graham 2023, ApJL 942 99
[4]: Calderón-Bustillo 2018, PRL 121, 191102
[5]: Calderón-Bustillo 2023, arXiv:2211.03465

Motivation

- A binary black hole (BBH) merger within an AGN can produce an EM flare counterpart, this is a promising candidate for measuring the Hubble constant.
- Traditional method to assess association is through the consistency of sky locations, but it is likely to have false positives.
- Moreover, this approach is leaving out the physics in the flare emission process:
  1. The jet opening angle confines the allow range of the alignment angle θ_{KN}.
  2. The disk viewing angle constrains where the jet and the observer can be.

Our Injection Study

1. Choose 10 different spin configurations
2. Choose two mass ratios: Q = 1.5, 3.0
3. For a range of SNRs: 8, 15, 20, 30, 50

- Waveform model: NRSur7dq4
- Sampler: Dynesty

Goal:
Test whether the kick direction has the ability to accept or reject the coincidence with AGN, and for which θ_{KN} value is this most effective.

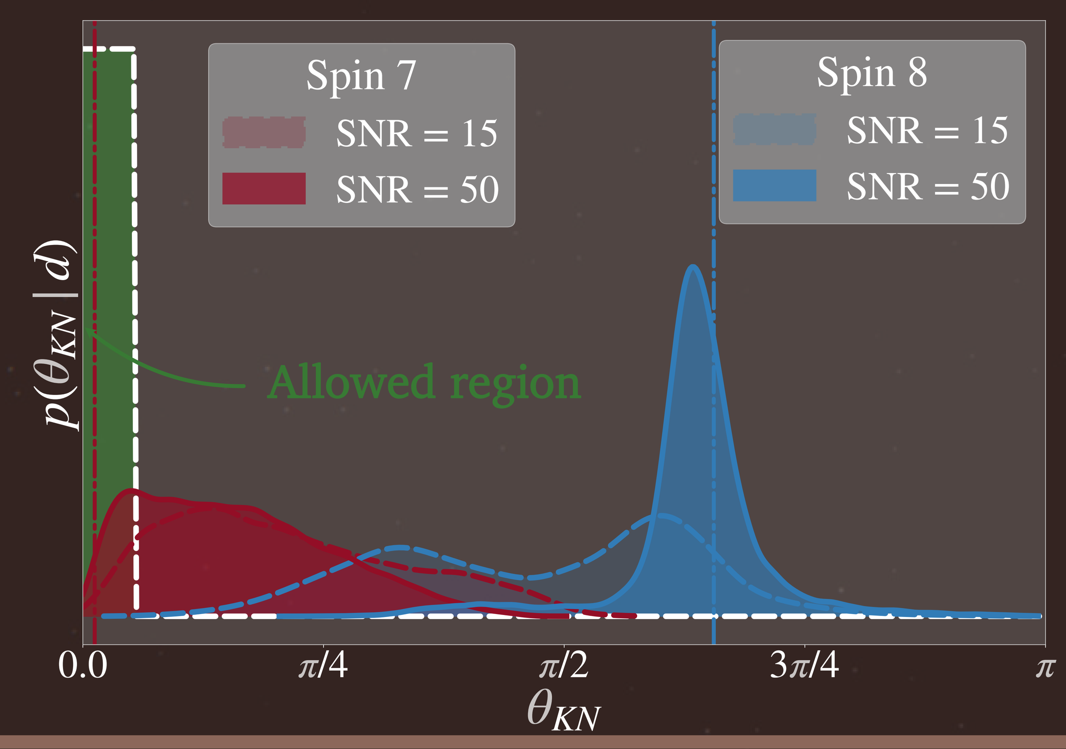
What is Coincidence? — Overlap Integral

- It tells how consistent the posterior distribution is with the prior imposed by the electromagnetic observation.

$$\mathcal{I}_k = \int \frac{p(k \mid d)\, \tilde{\pi}_{\mathrm{AGN}}(k)}{\pi(k)}\, \mathrm{d}k$$

- k represents the kick parameters, namely: θ_{KN}, θ_{KJ}, θ_{JN}
- $\pi(k)$ is the prior distribution from GW analysis
- $\tilde{\pi}_{\mathrm{AGN}}(k)$ is the constraints on the parameters k if the EM flare is observed.

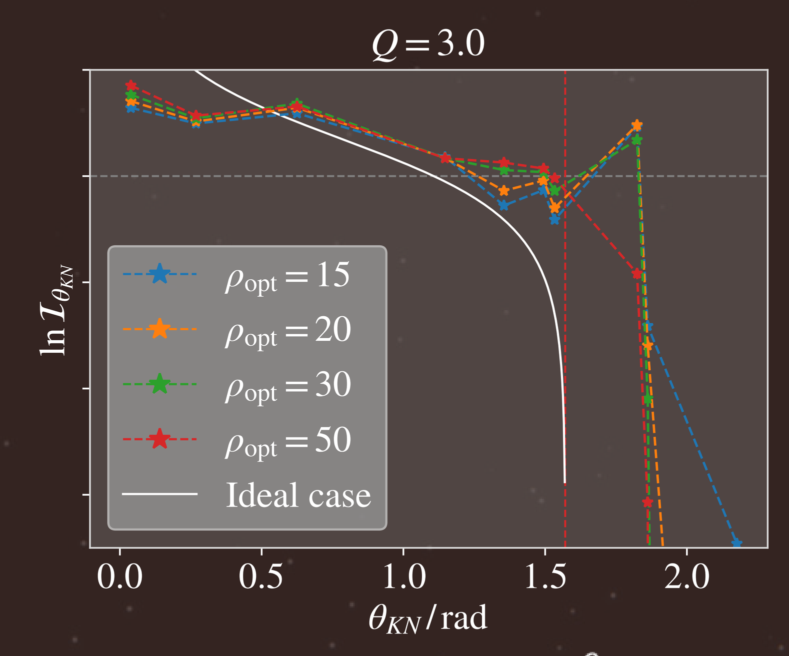
$$\tilde{\pi}_{\mathrm{AGN}}(k) \propto \Theta(\theta_{KN} \leq 10°)\, \Theta(\theta_{KJ} \leq 60°)\, \Theta(\theta_{JN} \leq 60°)$$



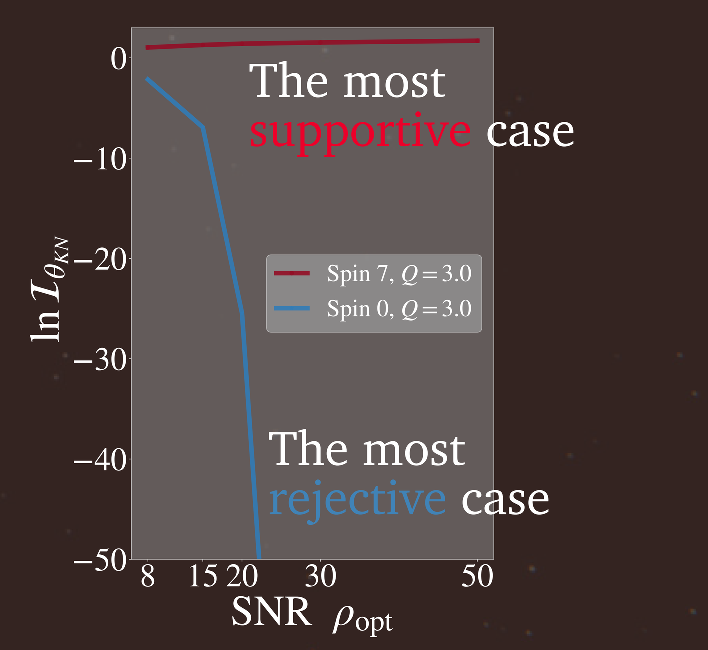
Results — Most effective on rejection

At SNR 15 $\ln \mathcal{I}_{\theta_{KN}}$	$\theta_{KN}^{\mathrm{true}}$	Diffusive ($\theta_{KN} \leqslant 90°$)	Collimated ($\theta_{KN} \leqslant 10°$)
Spin 7, Q = 3.0 (max)	2.23°	+1.594	+2.268
Spin 2, Q = 3.0	65.72°	+0.019	-2.643
Spin 8, Q = 1.5	118.0°	-0.413	-2.948
Spin 0, Q = 3.0 (min)	124.6°	-8.874	-∞

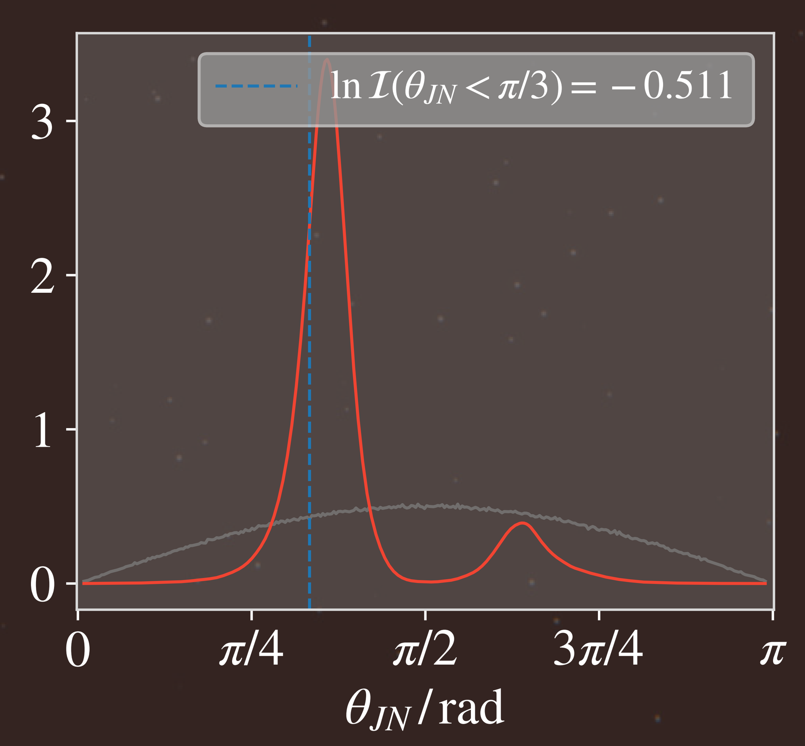
- For both flare models, we find that in general, the evidences for rejection is higher. In cases where the posterior is so narrow that it is completely outside of the valid θ_{KN} range, we yield a perfect rejection, which is often the case at even higher SNRs.

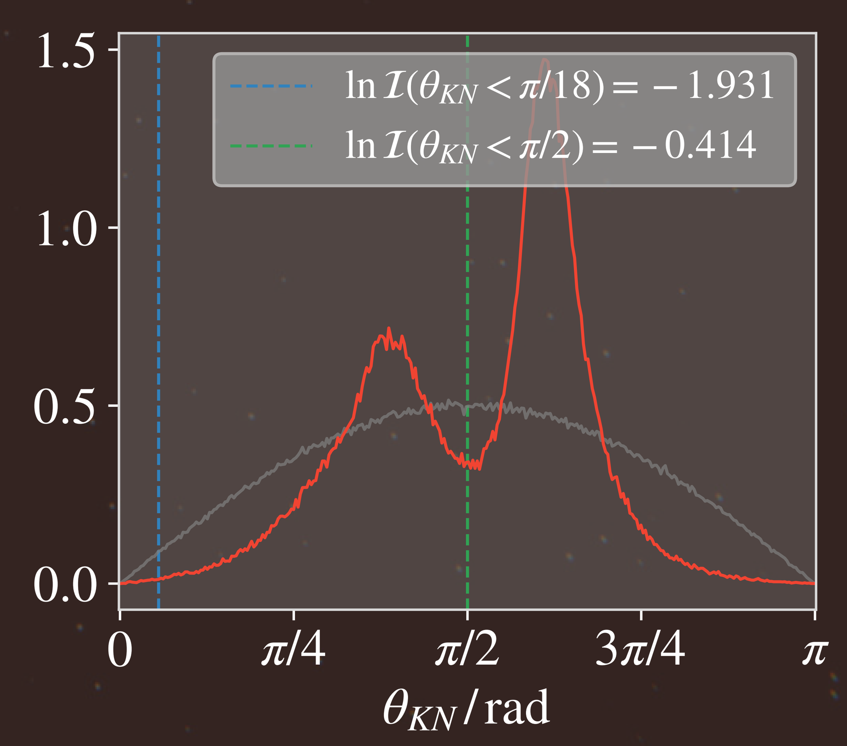


- The trend with varying θ_{KN}



- Increasing loudness only makes the rejection more distinctive.





- For the GW event GW190521, our analysis shows that the log evidence for AGN is further reduced by $\ln \mathcal{I}_k = -2.535$, in other words, the odds is reduced by 12.6 times. Note that, the redshift inferred from GW analysis is peaked at 0.8, whereas the flare was observed at redshift 0.433, which would have lead to a biased measurement on the Hubble parameter.

Conclusion

BBH mergers in AGN disks are promising candidates for multi-messenger astronomy. However, current method to identify EM counterpart is prone to include false positives. Our work shows that including the recoil direction can conclusively reject unphysical EM counterparts from AGN, which is a necessary test for AGN to be the source environment.

Applications

1. Assess the coincidence between GWTC-3 events and flares observed by ZTF (Zwicky Transient Facility)
2. The measurement of the Hubble constant will be biased by the unphysical GW-EM coincidences, our method provides an extra check to eliminate them.

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