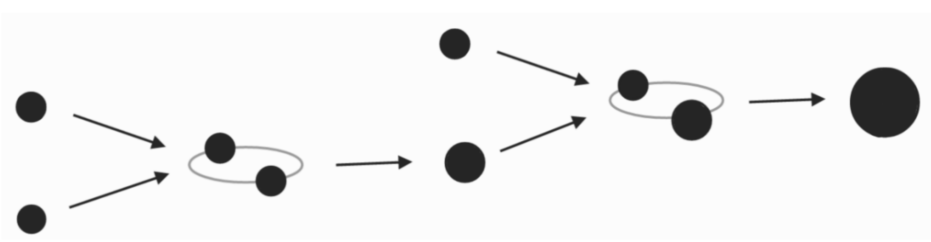
Specks of light from AGNs as possible indicators of dynamical formation of binary black holes

M. Paola Vaccaro

PhD candidate - Heidelberg University

Introduction

In recent years, gravitational wave (GW) detections have provided invaluable information on the population of black holes (BHs) in the local Universe [1]. The observed BHs with mass greater than roughly $50\,M_\odot$ may have originated dynamically. In environments with high stellar density, three-body interactions are frequent and can give rise to the **dynamical formation** of binary BHs (BBHs). These BBHs can then inspiral and merge. If their merger remnant is not ejected from the cluster, it can undergo further three-body encounters, form new BBHs and go through new mergers. This process is called **hierarchical mergers** and can lead to the formation of remnant BHs with progressively higher and higher mass.



In this work, we explore the process of hierarchical BH mergers in active galactic nuclei (AGNs). The AGN environment stands out with respect to other potential hosts of hierarchical BBH mergers because of the presence of a dense gaseous disk which fuels mass accretion onto a central super-massive BH (SMBH). The stellar-sized BHs orbiting the SMBH are thus subject to strong gas torques and change their orbital properties, similarly to what happens to planets in protoplanetary disks. This process can significantly increases the rate of three-body interactions, thus leading to the efficient production of higher-mass BHs [2].

Hierarchical mergers in AGN disks

We model the evolution of a single stellar BH (*1g*) using **orbital-evolution** models that account for the effect of gas torques. We calculate the typical timescale it takes for it to pair-up with another BH and **form a BBH** and we compute the precise delay between BBH formation and **merger** considering the combined effect of GW emission and gas torques.

The merger remnant can go through the same evolution of its progenitors many times, unless something hinders it. This can happen for a few different reasons, such as:

- The disk may have evaporated therefore any effect due to gas may cease,
- Merger remnants receive a relativistic kick due to the asymmetric emission of GWs and this may cause ejection from the system,
- The number of BHs in the cluster is finite, therefore the BH may not find any companions to pair-up with.

If merger remnants can interact efficiently with the disk, we follow their evolution accounting for the same physical effects we considered for stellar BHs.

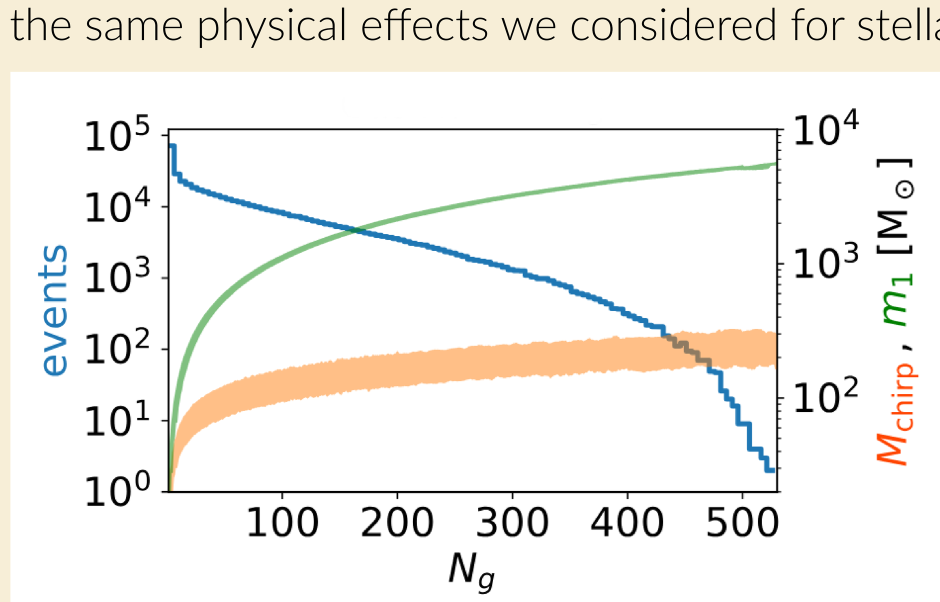


Figure 1. Number of BBH merger events, chirp mass, and primary mass (25% to 75% percentiles) for each hierarchical merger generation *Ng* [2].

Formation of high-mass binaries

Thanks to the computational efficiency of our code [3, 4], we are able to explore the properties of BBH mergers in a variety of AGN systems with different physical properties and test different physical assumptions.

In all scenarios where gas torques are fully accounted for, the system forms binaries with **high primary mass** and **possible spin alignment** (high effective spin).

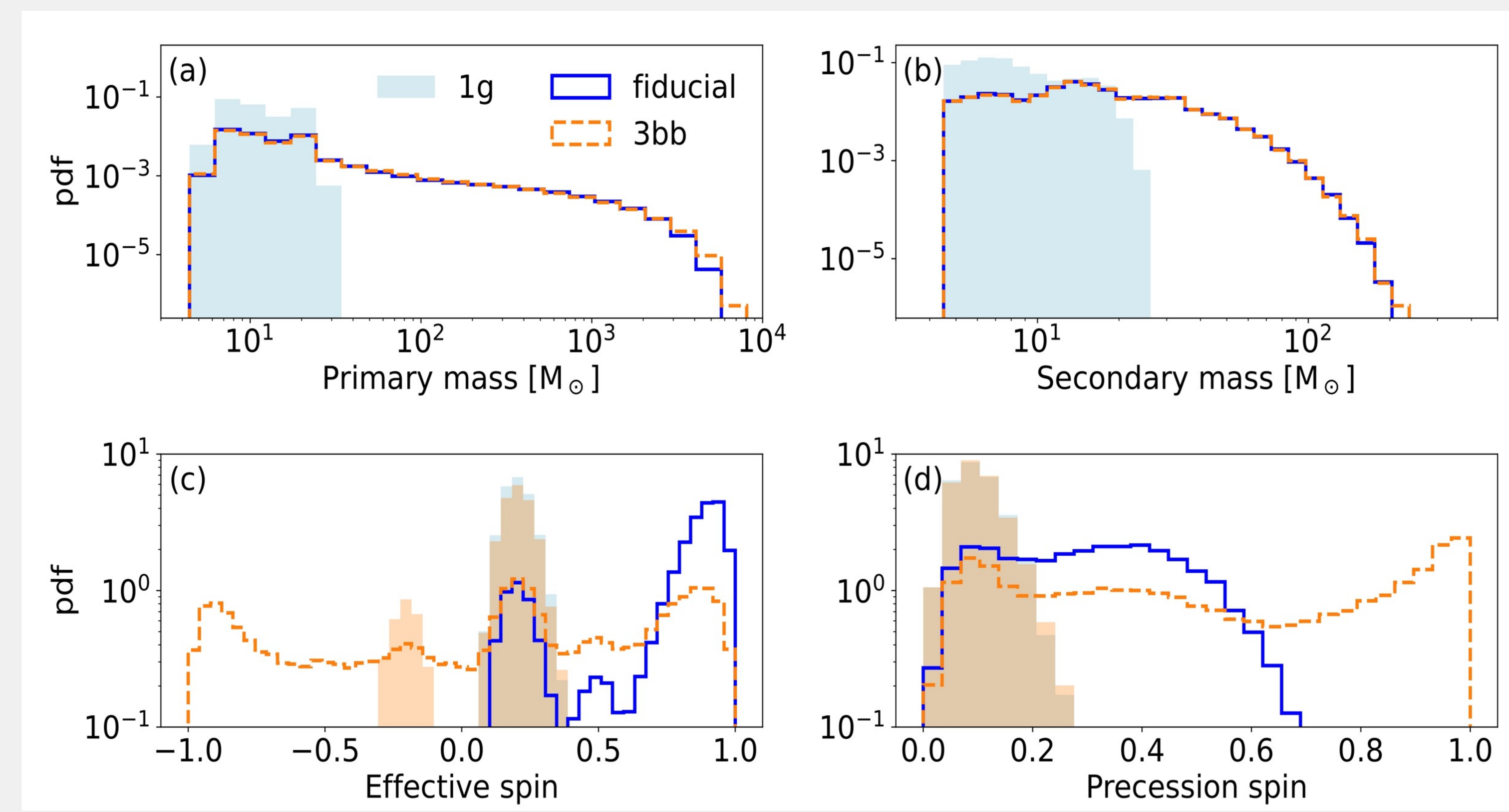


Figure 2. Our *fiducial* [2] model in comparison with a model where three-body interactions (*3bb*) are enhanced [M. P. Vaccaro et al., in preparation].

The case of GW190521

The detection of **GW190521, the most massive BBH merger** confidently detected to date [1], was followed by the **AGN flare ZTF19abanrhr**, detected by the Zwicky Transient Facility at the 78% spatial contour for GW190521's sky localization, making it the prime candidate for an AGN-origin GW event. Our AGN disk models successfully reproduce BBH mergers with the reconstructed properties of GW190521, and the association with the AGN flare is **preferred over a random coincidence** of the two transients with a log Bayes' factor of 8.6 [5].

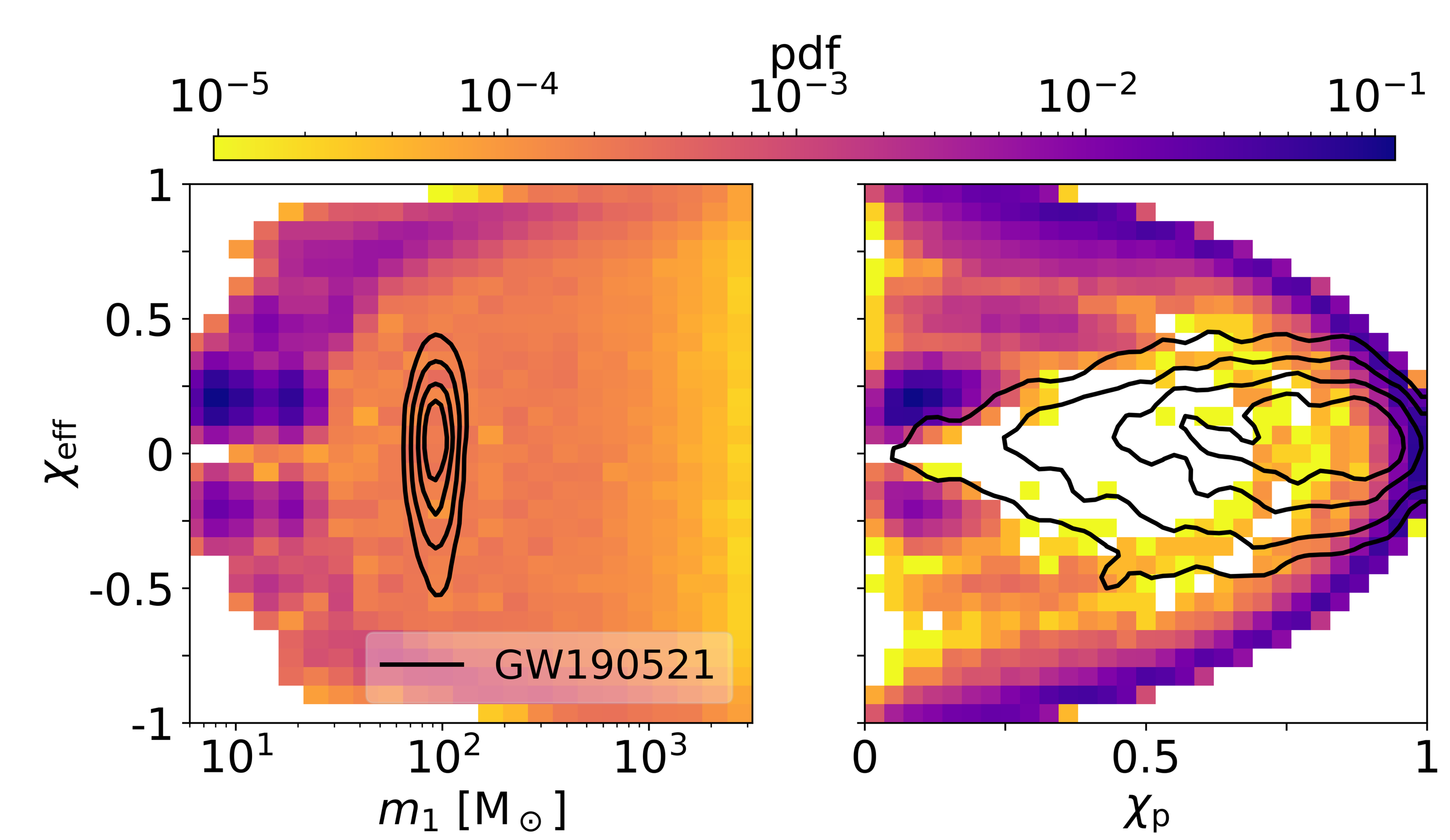
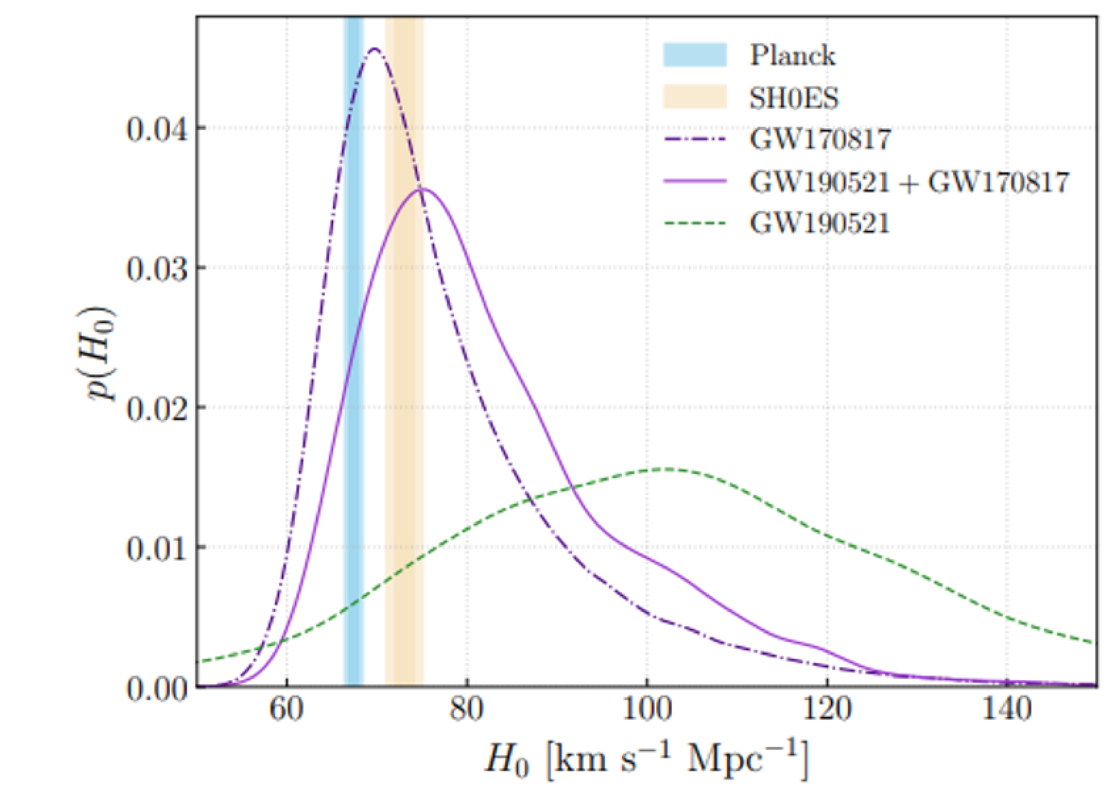


Figure 3. Probability density distribution for primary BH mass m_1, effective spin $\chi_{\rm eff}$ and precession spin $\chi_{\rm p}$ compared with posterior contour plots at credibility levels 25%, 50%, 75%, and 90% of LVK BBH merger event GW190521.

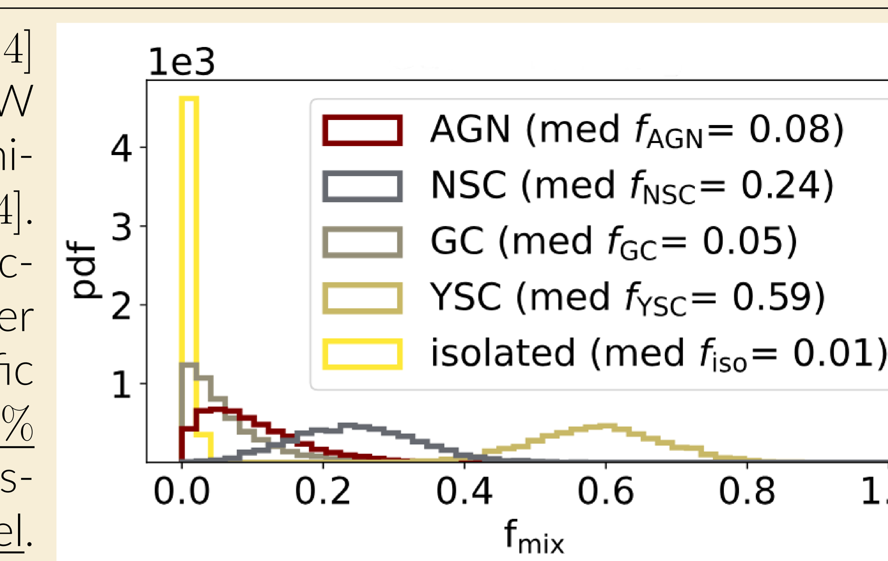
Estimation of the Hubble constant

GW events with EM counterparts can be used to determine the Hubble constant. The GW signal from the binary neutron star merger GW170817 has been confidently associated with its EM counterpart, thus allowing for a **standard siren measurement of the Hubble constant** H_0. Using the association between GW190521 and the AGN flare ZTF19abanrhr, it is possible also to use GW190521 as a standard siren obtaining $H_0 = 102^{+27}_{-25}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$ [5].



Mixing fractions

We compare our models [2, 3, 4] against the 56 high-purity GW events analyzed by [6] using a hierarchical Bayesian approach [4]. We compute the mixing fractions, i.e. the fraction of merger events associated with a specific channel. No more than ~ 20% of all merger events can be associated with the AGN channel.



Key References

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Acknowledgements

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