Black holes and where to find them: *The curious case of missing stellar mass black holes*

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Synopsis: The observed number of black holes (BHs) in a binary with a high mass Main Sequence (MS) companion is very small compared to the number of Wolf Rayet (WR) stars in a similar binary configuration, whereas the latter are the progenitors of the former. We study the origin of this discrepancy based on the detectability and lifetime of BHs in a binary system. A BH is 'observable' if there is an accretion disk around it and X-Ray radiation is emitted from the accretion disk that we can measure. We determine whether an accretion disk can form around a BH using a criterion for the formation of an accretion disk that depends on the masses of the binary components, the orbital separation, and stellar wind velocity of the MS companion. We find that, if the wind velocity of MS star near the BH is $\sim$2000 km/s, an accretion disk does not form around the BH for the majority of the MS lifetime of its companion, making them 'unobservable'.

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Black hole + MS binaries and accretion disks

- Langer+2020: ∼3 out of every 100 massive MS stars in binaries to harbour a BH as its companion.
- Average WR+MS binary lifetime (∼ 0.4 Myrs) < lifetime of BH+MS binary.
- So where are all these BHs?
- Since BHs by themselves don't emit light, we need accretion disks around them, that emit X-Rays, to make them 'observable'.

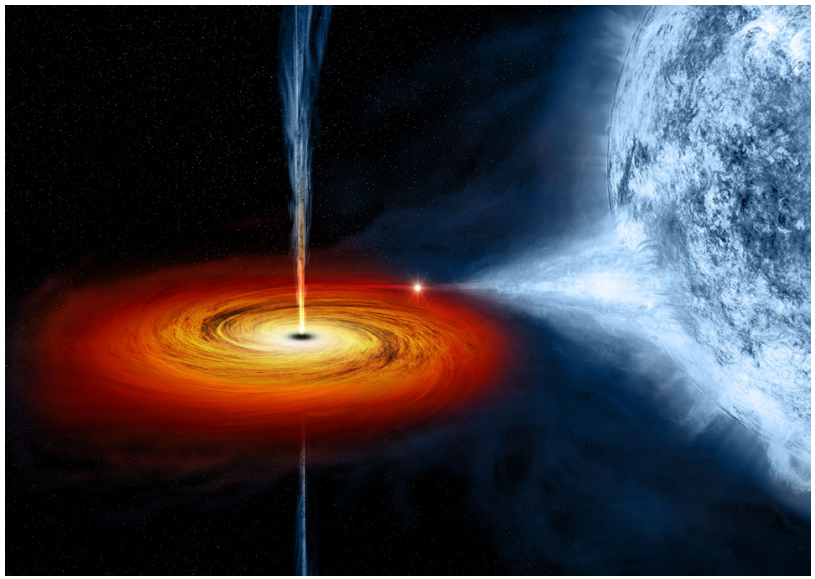

Fig. 1: Artist impression of an accretion disk around a black hole in a BH+MS binary system. Credits: NASA, CXC, M. Weiss

But how often can these spectacular accretion disks form around a BH?

Formation of accretion disks

Assuming that the accreted matter from the stellar wind (v_w) of the MS companion (with specific angular momentum given by Shapiro+1976) goes into a Keplerian orbit (with radius $\mathrm{R_{disk}}$) around the BH, an accretion disk can form if the $\mathrm{R_{disk}}$ is greater than the innermost stable circular orbit radius ($\mathrm{R_{ISCO}}$) of the BH. Mathematically, this **disk formation criterion** becomes

$$\frac{2}{3}\frac{\sigma^2 G^3 (M_{MS}+M_{BH}) M_{BH}^2 c^2}{a^3 v_{rel}^8} \geq 1 \quad \text{——(1)}$$

where σ is an efficiency parameter (assumed as unity), G is the gravitational constant, a is the orbital separation, c is the speed of light, M_{MS} and M_{BH} are the masses of the MS star and BH respectively. v_{rel} is the relative velocity between the v_w of the MS star and the orbital velocity of the BH. $v_w = v_\infty(1 - R_*/a)$ where v_∞ is the terminal velocity, R_* is the stellar radius of the MS companion. For a detailed derivation, see Quast et. al. (2020) in prep.

- Disk formation criterion: steep dependence on v_{rel} and in turn v_w of the MS star.
- Vink+2001: $v_w \geq 2000$ km/s for massive MS stars.
- Taking 17 observed WR+MS star systems in the Solar neighbourhood, we predict the birth properties of the resulting BH+MS systems following Vanbeveren+2020.
- The further evolution of these BH+MS systems are calculated using the Geneva stellar models (Ekstrom+2012). We calculate the time for which an accretion disk can form (i.e. the X-Ray bright lifetime) using Eqn. 1.

Detectability and lifetime of BH+MS systems

- An accretion disk can form around the BH towards the end of MS evolution of the companion when its radius increases and v_w decreases.
- **Comparison**: X-Ray bright lifetime of the BH+MS systems vs. total lifetime of the WR+MS systems.
- **Prediction**: ∼12 BH+MS systems for the 17 progenitor WR+MS systems.
- **Observation**: Only 1 BH+MS system in the Solar neighbourhood.
- **BUT!** If $v_w = 2000$ km/s (Vink+2001) near the BH for the entire MS lifetime of the companion (Fig. 2), **only 2 of the 17** WR+MS progenitor binaries produce BH+MS systems that can form an accretion disk.
- Hence, when the high v_w of MS stars are accounted for, it is plausible that most of the BHs are 'undetectable'.

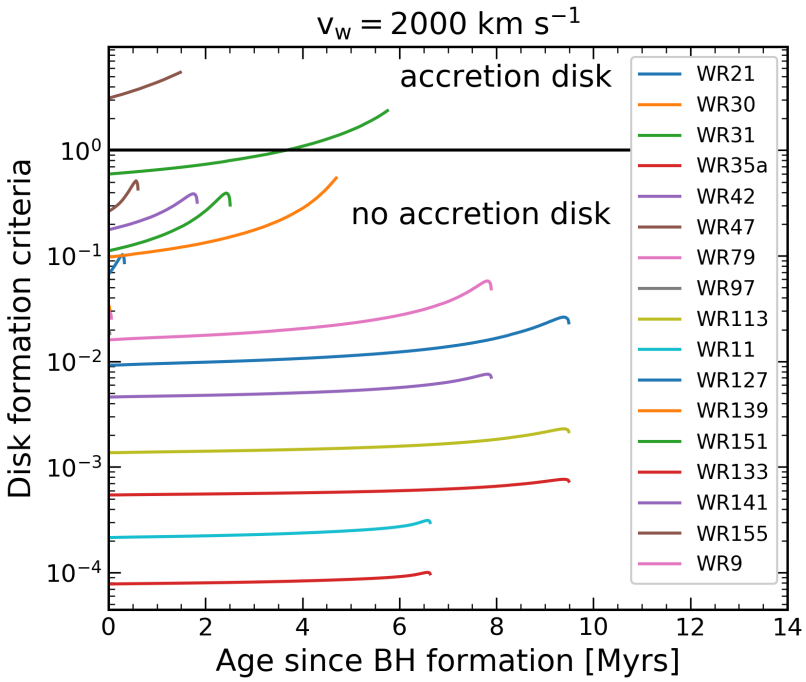

Fig. 2: LHS of accretion disk criteria (Eqn. 1) as a function of the age of the BH+MS binary for the progenitor WR+MS systems assuming $v_w = 2000$ km/s. Sen et. al. (2020) in prep.

- Measuring radial velocity variations in spectroscopic MS binaries is an alternative to indirectly infer their existence (Langer+2020).