Searching for ultralight bosons within spin measurements of a population of binary black hole mergers

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Method paper: PRD 103, 063010 (1908.02312)
Current result: PRL 126, 151102 (2011.06010)

Overview of boson superradiance

Ultralight bosons

- Any boson with *very light* mass

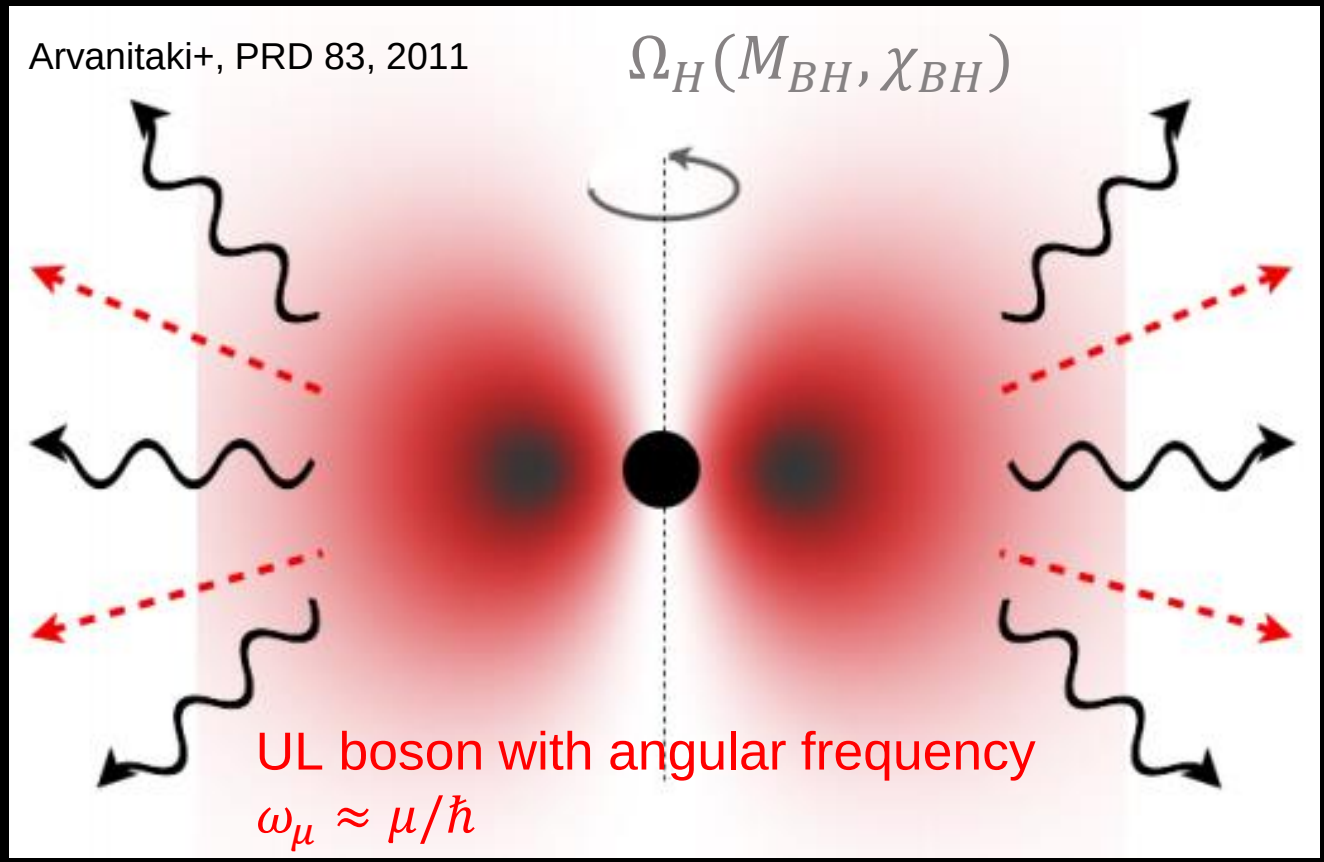
$$10^{-33}\text{eV} \lesssim \mu \lesssim 10^{-5}\text{eV}$$

- Possible particles in this category
  - QCD axion
  - Wave dark matter
  - Dilatons in string theory

Gravitational atom

- Superradiance of spinning BH
- Hydrogen-like cloud structure
  - extracts BH's energy and momentum
  - BH spins down!

- Criterion: $\omega_\mu \leq m\Omega_H$
- Coupling: $\alpha_G = \frac{r_{\rm BH}}{\lambda_\mu} = \frac{GM_{BH}\mu}{\hbar c}$

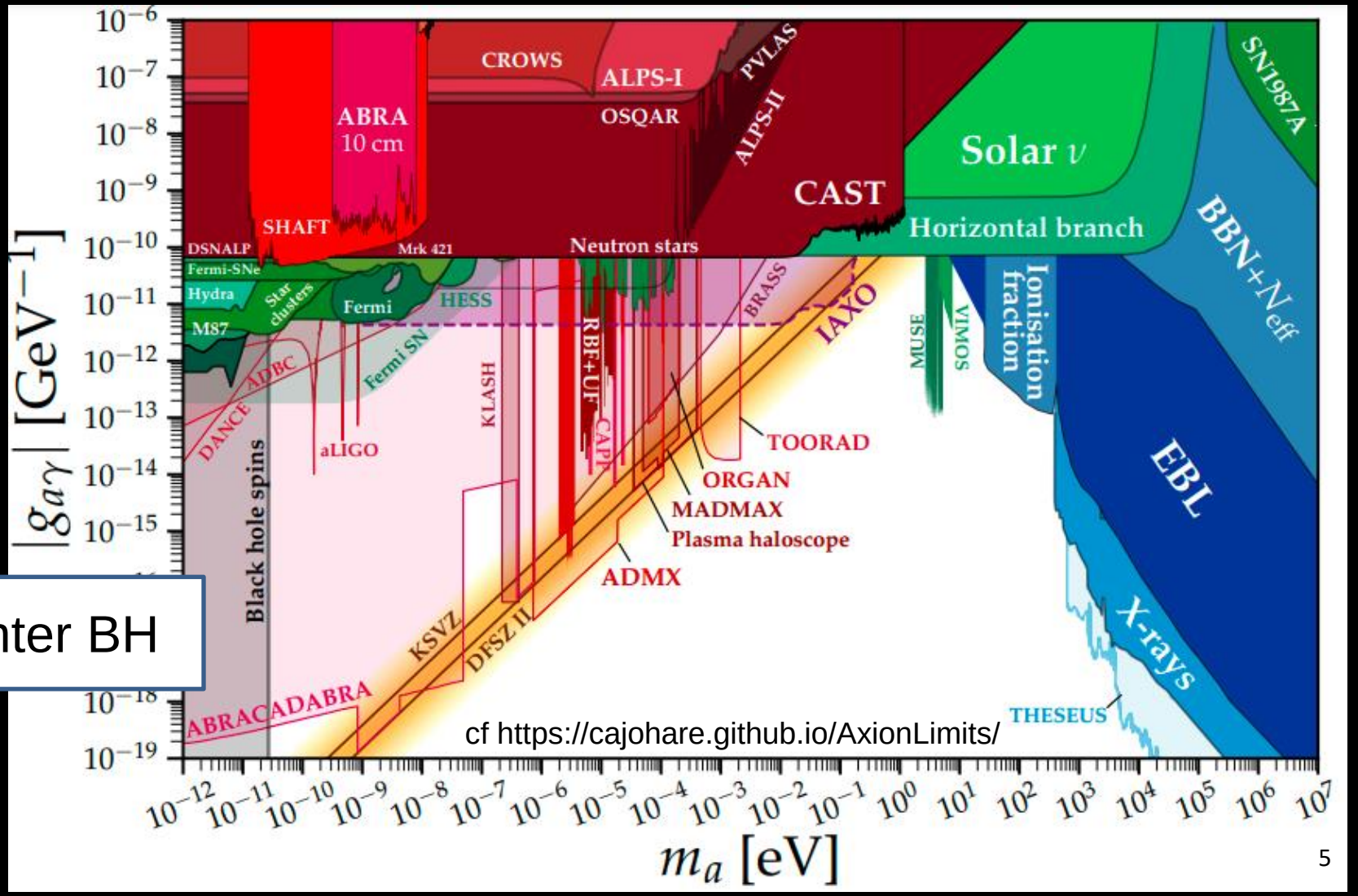


Existing constraints

$$\alpha_G \propto \mu M_{BH}$$

Heavier BH ← Lighter BH

10^{-20}eV



Superradiant timescale

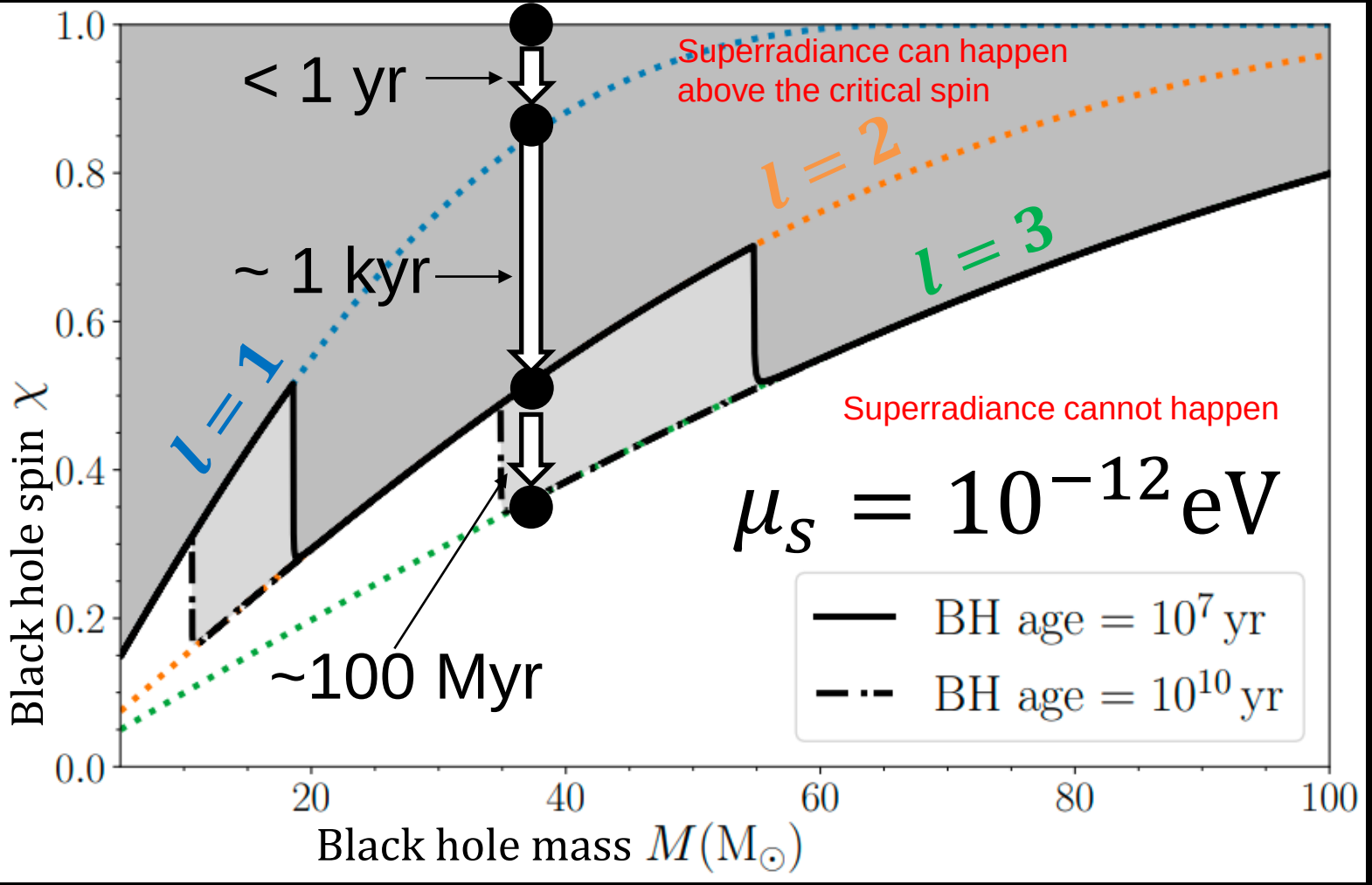
- One e-folding timescale: $\tau^{\rm inst}_{nlm} \propto 1/\alpha_G^{4+2l+2m}$
  - Smaller α_G, weaker effective potential, harder to form the cloud
  - Clouds of higher modes grow slower

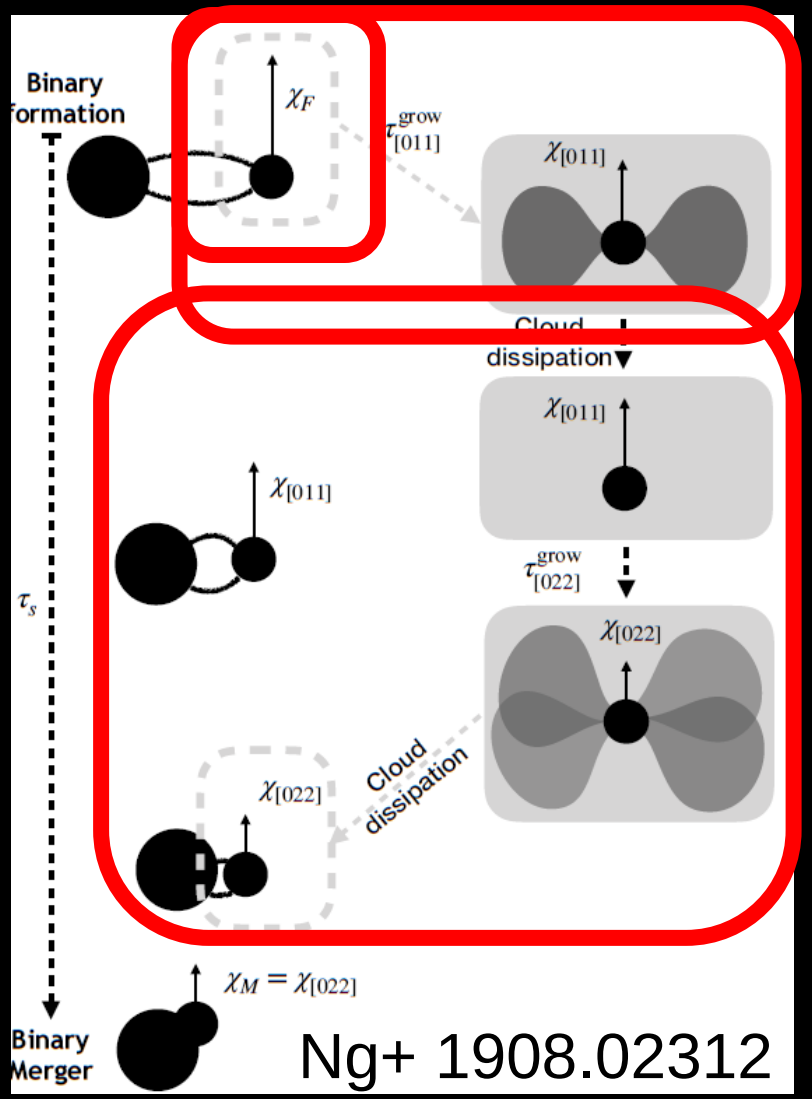
$\boldsymbol{M = 30\ \mathrm{M}_\odot}$ $\boldsymbol{\mu_s = 10^{-12}\mathrm{eV}}$	$l = m = 1$	$l = m = 2$	$l = m = 3$
$\tau^{\rm inst}_{nlm}$	$\mathcal{O}(< \mathrm{yr})$	$\mathcal{O}(< \mathrm{kyr})$	$\mathcal{O}(< \mathrm{Myr})$

- Takes ~ 180 e-foldings to form the cloud
- Need to compare this with BH's finite lifetime

Superradiance effect on a binary black hole

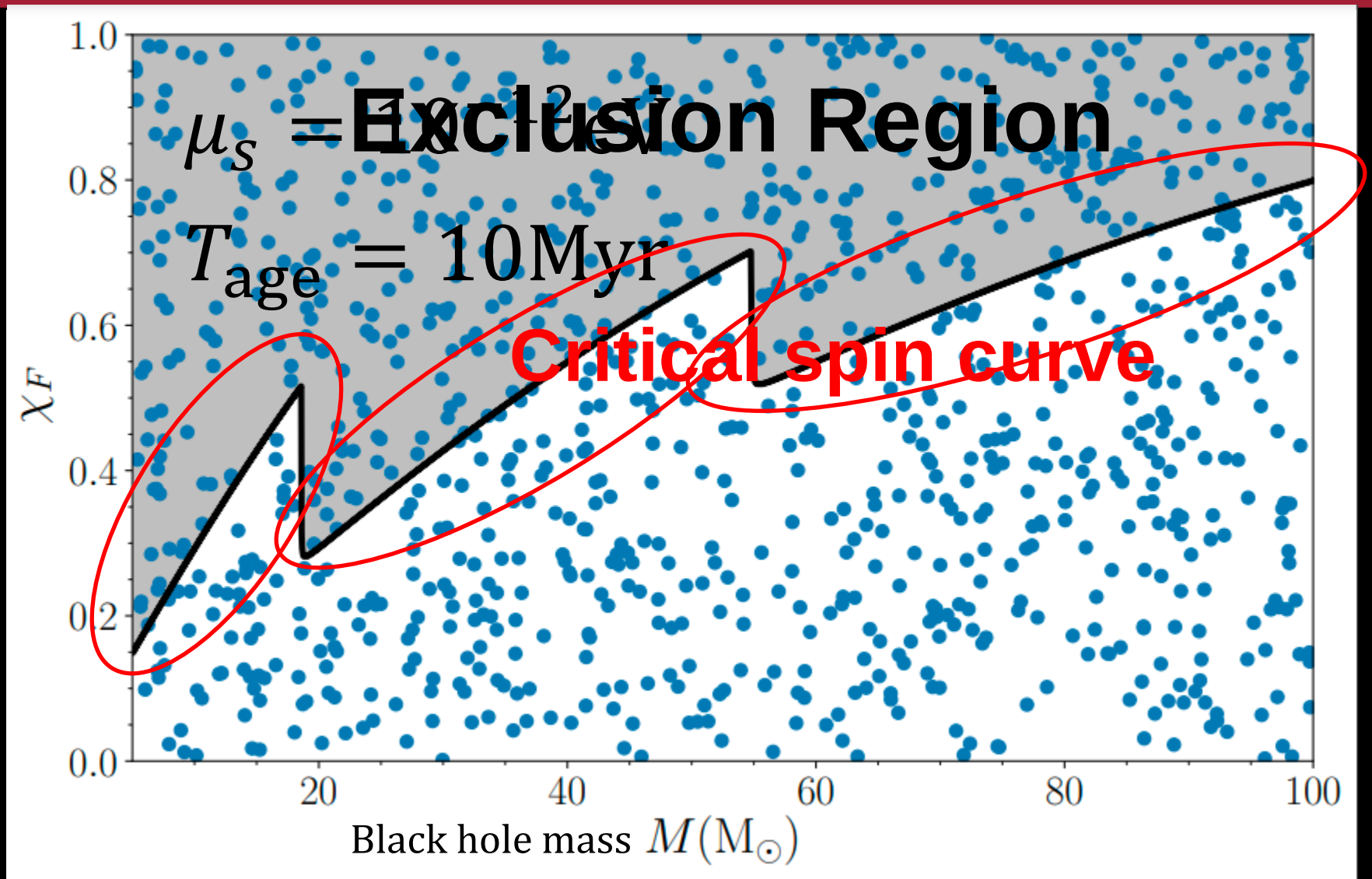
Effect on binary black hole





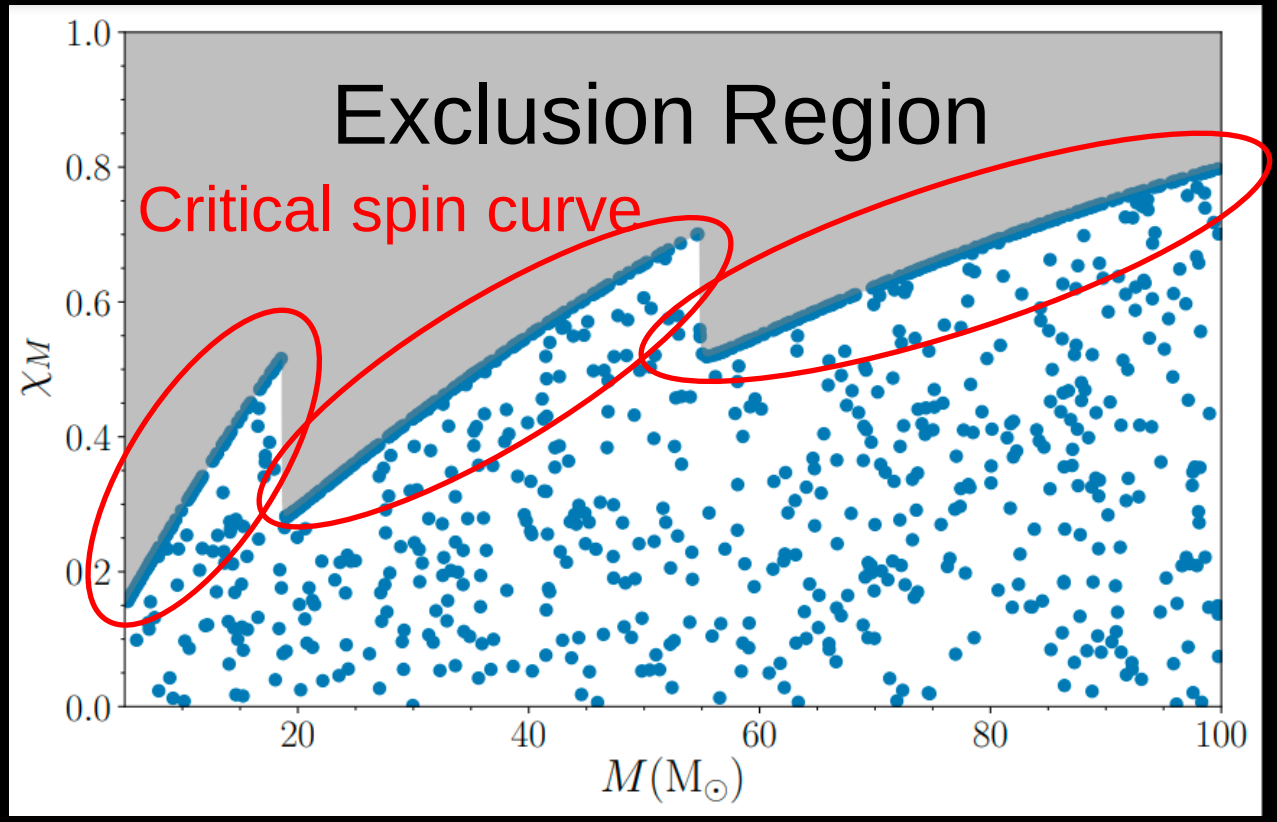
Signature of superradiance among many binary black holes

Signatures in the BH population



Search strategy

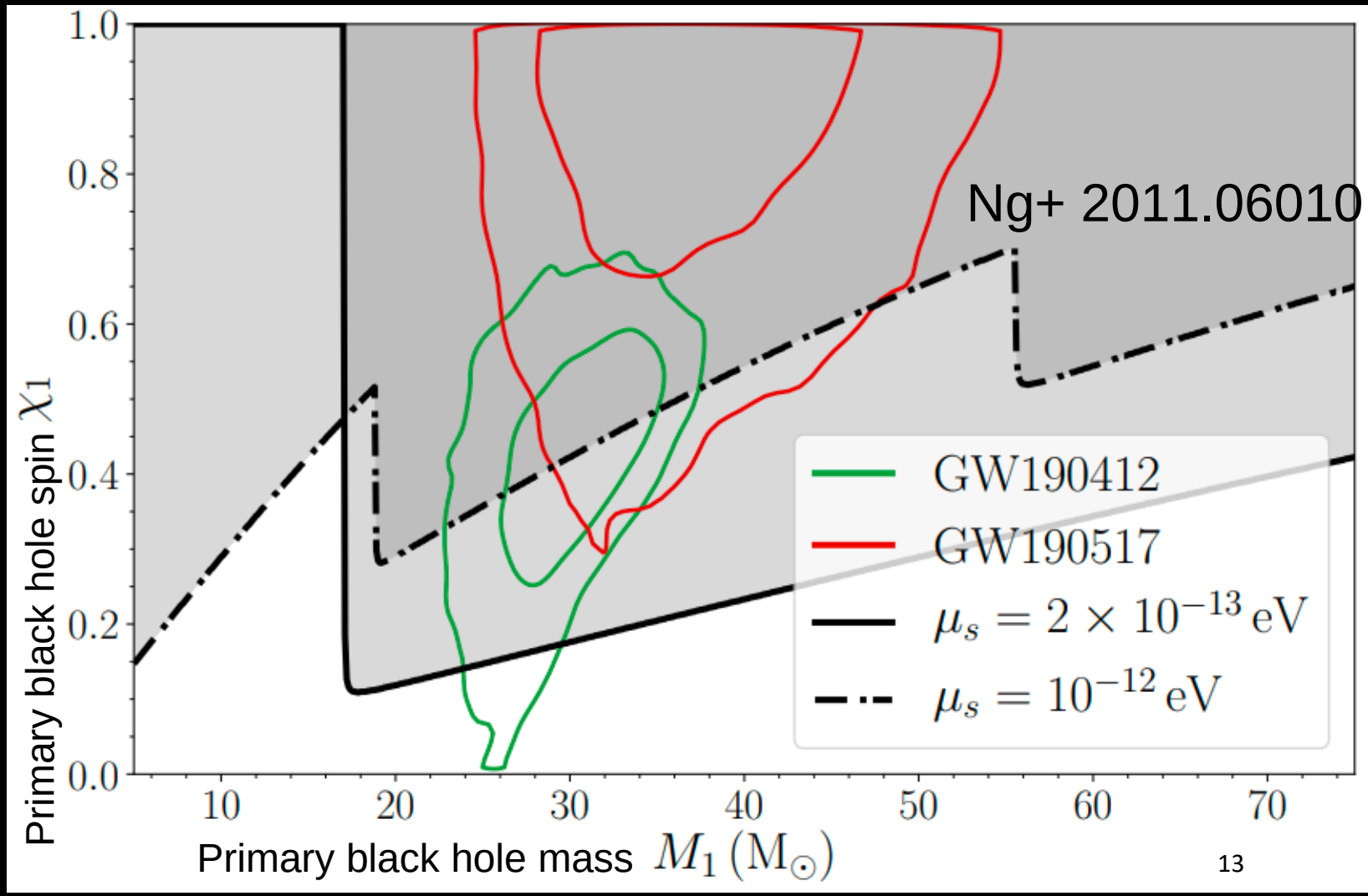
- BH mass & spin measurements from GWs
- Rule out even if one BH is inside the exclusion region
- Confirm if there are enough BHs tracing the critical curve
- Bayesian framework to combine all measurements



Results based on GWTC-2 BBHs

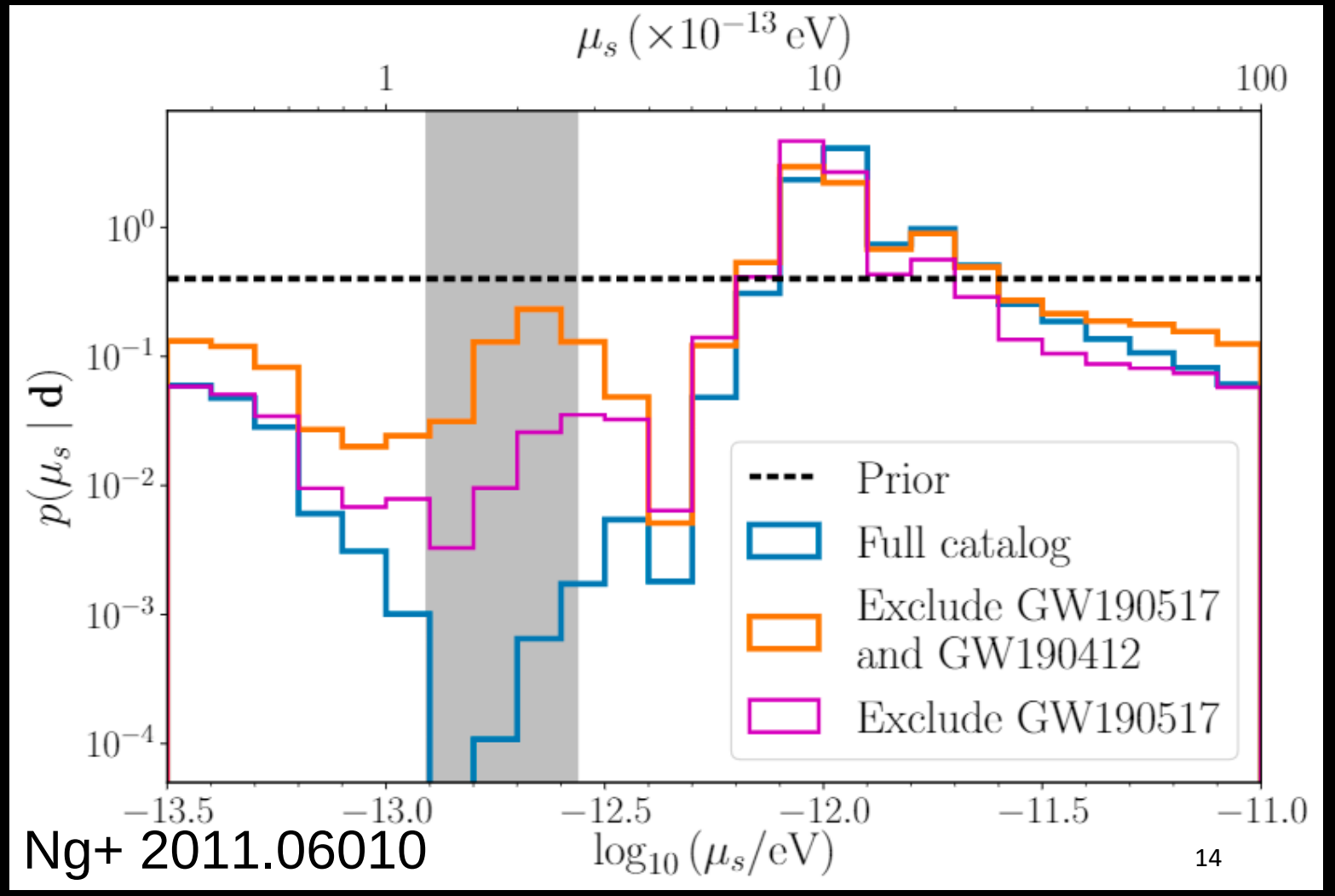
GW190412 & GW190517

- A large overlap with the exclusion region of $\mu_s = 2 \times 10^{-13}\mathrm{eV}$
- Are these two enough to set some constraints?



GWTC-2 constraints

- Only 0.01% posterior probability for $\mu_s \in [1.3, 2.7] \times 10^{-13}\text{eV}$
- Need both GW190517 and GW190412 to drive the constraints



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Q&A