Probing dark photon superradiance through follow-up searches

Nils Siemonsen
Princeton Gravity Initiative

November 19, 2024

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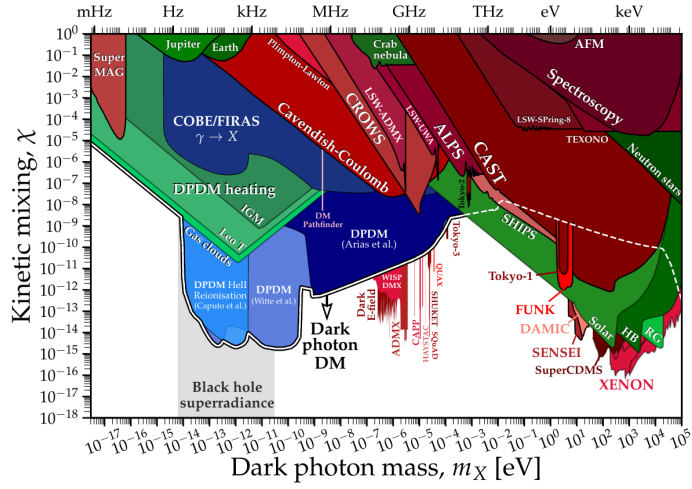

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Unique features:

- Only gravitational interaction
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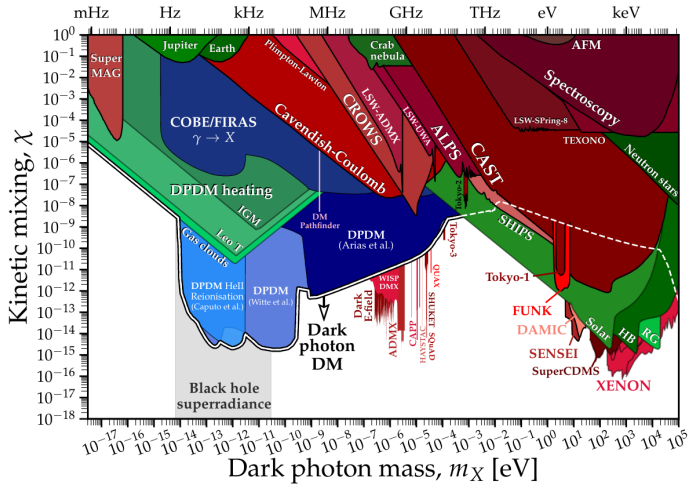

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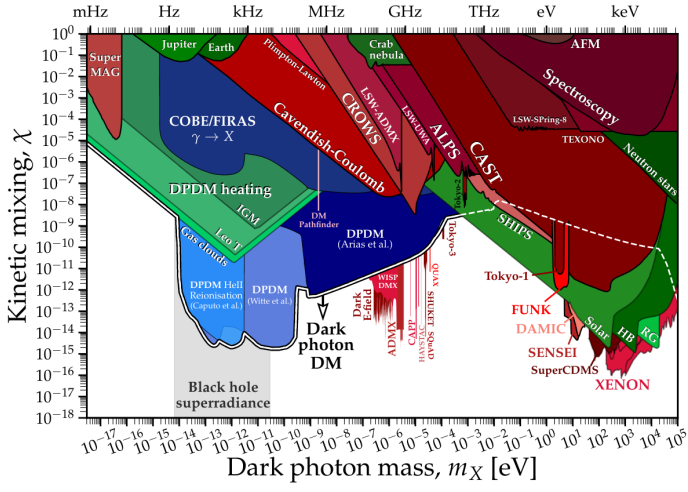
Requirements:

1. Isolate search strategy
2. Understand theory

[Caputo et al., 2021]



Waveform modelling

Large body of work

[Arvanitaki, Baryakhtar, Brito, East, Yoshino, Kodama, ...]

- Growth rates, power, frequency evolution
- Across parameter space, various modes
- Scalar & vector fields
- (Semi-)analytic, numerical techniques

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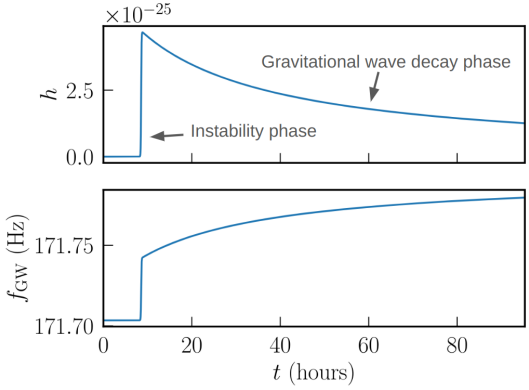

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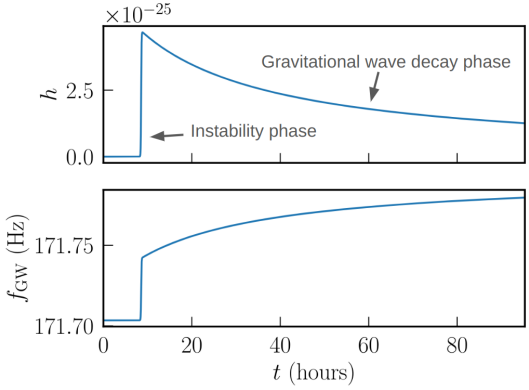
`SuperRad` waveform model [**NS** et al., 2023]

- Combine all results on a single platform
- Goal: fast & easy-to-use (`python`-based)



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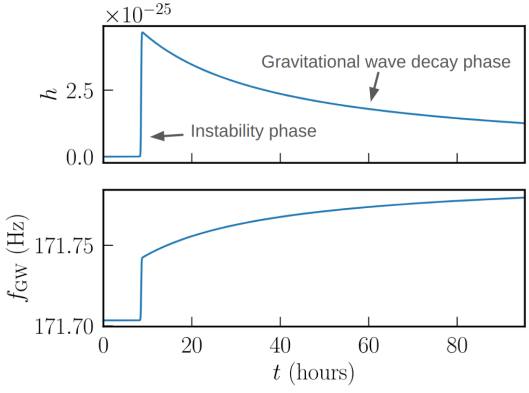

`SuperRad` v2 [May et al. (incl. **NS**), 2024]

- Accurately model the frequency evolution & understand theoretical uncertainties
- Current waveform phase error $\Delta\phi \lesssim 1$ across parameter space

Is the theory well-understood?

Well yes, but no.

$\Rightarrow$ There is a need to understand non-gravitational interactions

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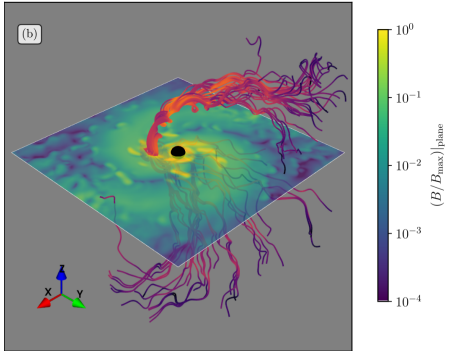

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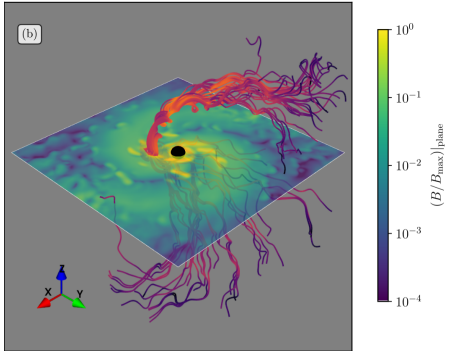
  $\Rightarrow e^{\pm}$ experience Lorentz force
- Synchrotron assisted pair plasma production
- Luminosity: $L \lesssim 10^{43}$ erg/s

⇒ Superradiance mechanism largely unaffected

- Evidence for periodicity ⇒ "fake pulsars"
- $B \lesssim 10^8$ Gauss ⇒ X-ray & γ-ray

⇒ High-energy electromagnetic signatures



Leverage follow-up searches

How is the gravitational wave signal modified?

[**NS**, Modino, Egaña-Ugrinovic, Huang, Baryakhtar, East, 2023]

- GW amplitude may decay more rapidly
- GW frequency may evolve more quickly

$\Rightarrow$ Understand impact on GWs as function of ε

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How does this affect follow-up searches?

[Jones et al. (incl. **NS**), in prep]

- CW search methods are flexible
- Exploit this to map constraints
- Quantitatively:
  - Next-generation sensitivity
  - Population of merger remnants
- No need to modify search!

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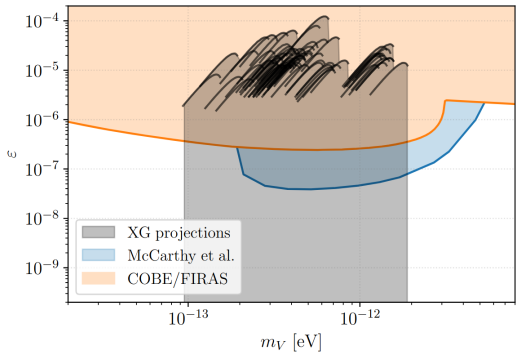

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Higgs-Abelian model:

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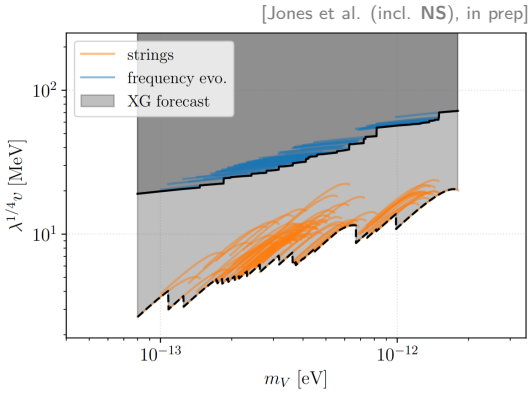

Summary

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- Waveform modelling basically complete
- Understanding non-gravitational interactions is important

Outlook dark photon superradiance:

- Impact on accretion disks
- Microscopic understanding of plasma dynamics

Outlook:

- Waveform modelling: higher-order modes? get frequency evolution to matched-filter level?
- Weakly nonlinear effects in Higgs-Abelian sector
- What about LISA?