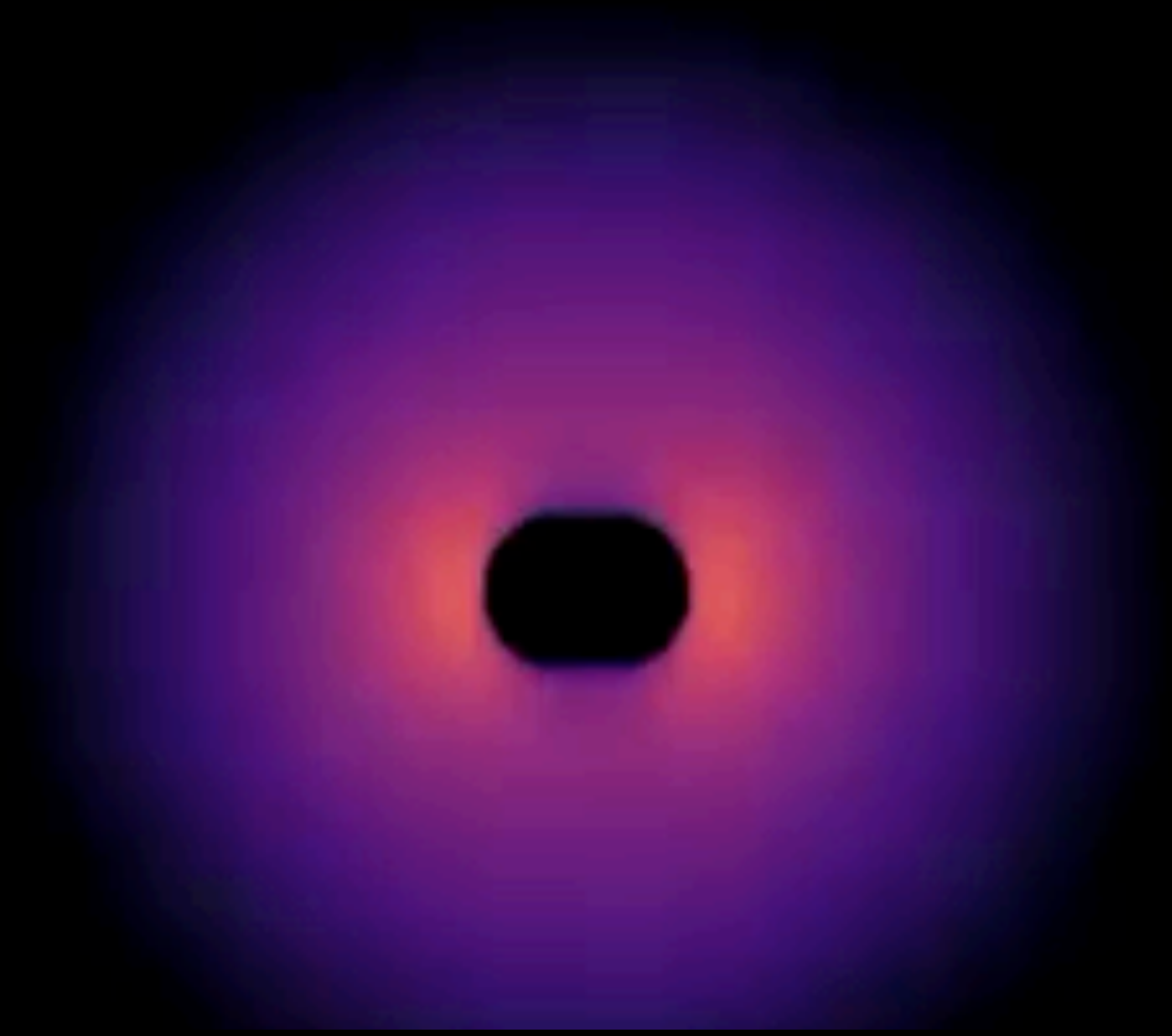
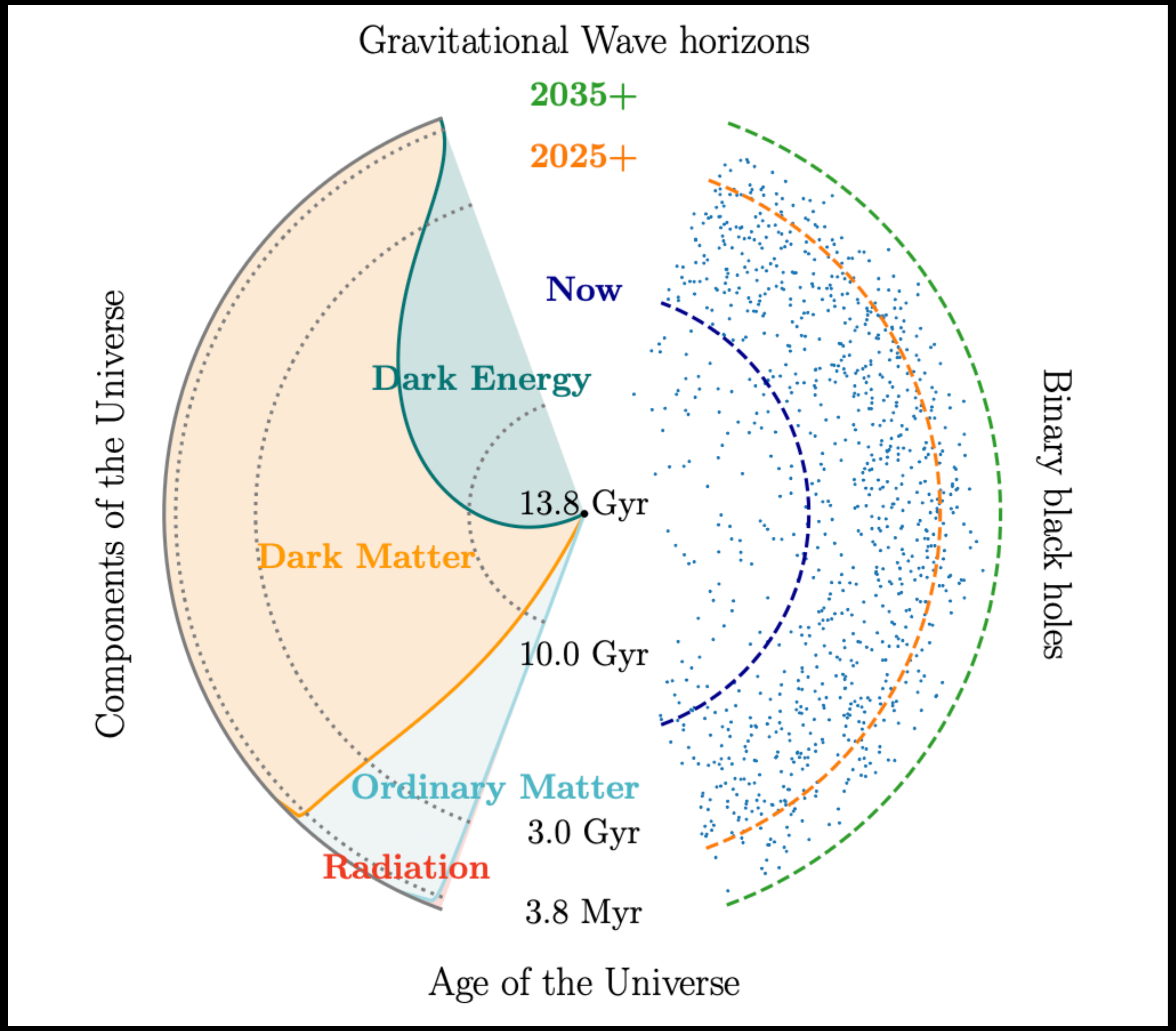
Dark Matter, Dark Energy, and the Early Universe

Masha Baryakhtar and Jose María Ezquiaga

April 24 2024

Gravitational Waves Carry Information from Extreme Environments and Early Eras





Next talk by Jose María Ezquiaga

Enabling discovery of new particles

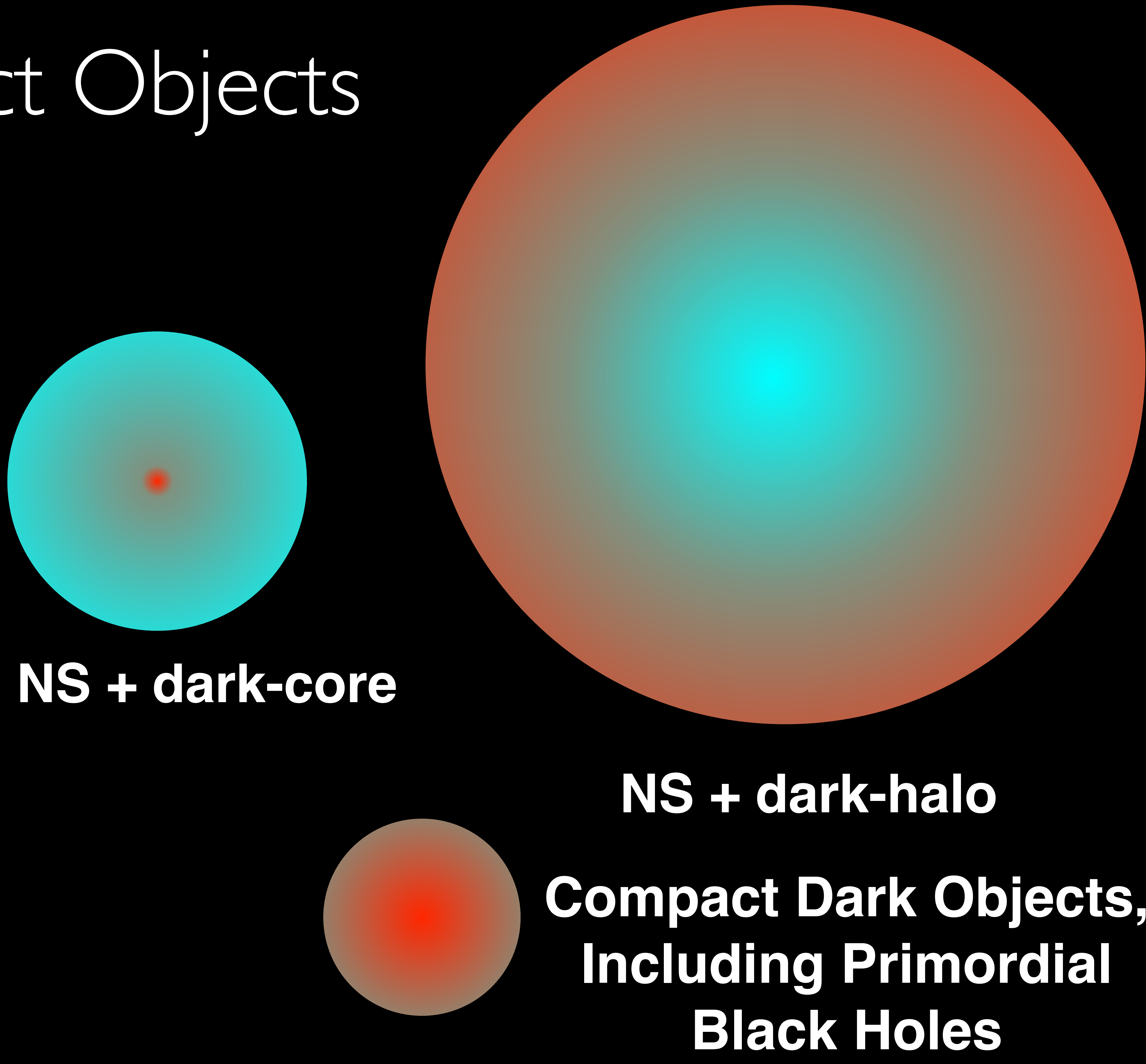
and measurement of the history of our universe

Extreme environments
provide unique testbeds of new particles:

QCD axions, ultralight bosons, asymmetric bosonic dark matter

Anomalous Compact Objects

Gravitational wave observations of binary compact objects whose masses and tidal deformabilities differ from those expected from neutron stars and stellar black holes would provide conclusive evidence for new physics

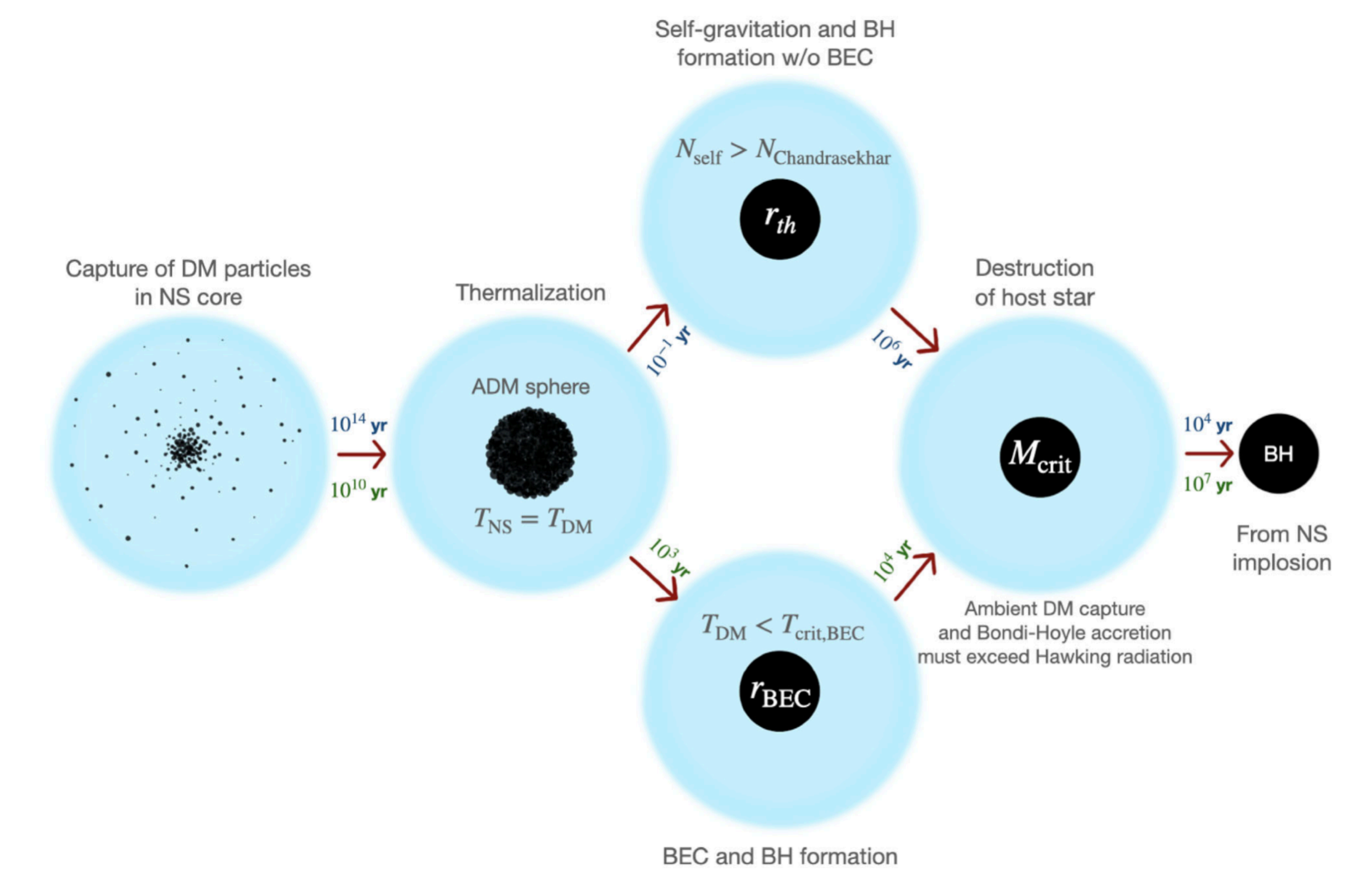


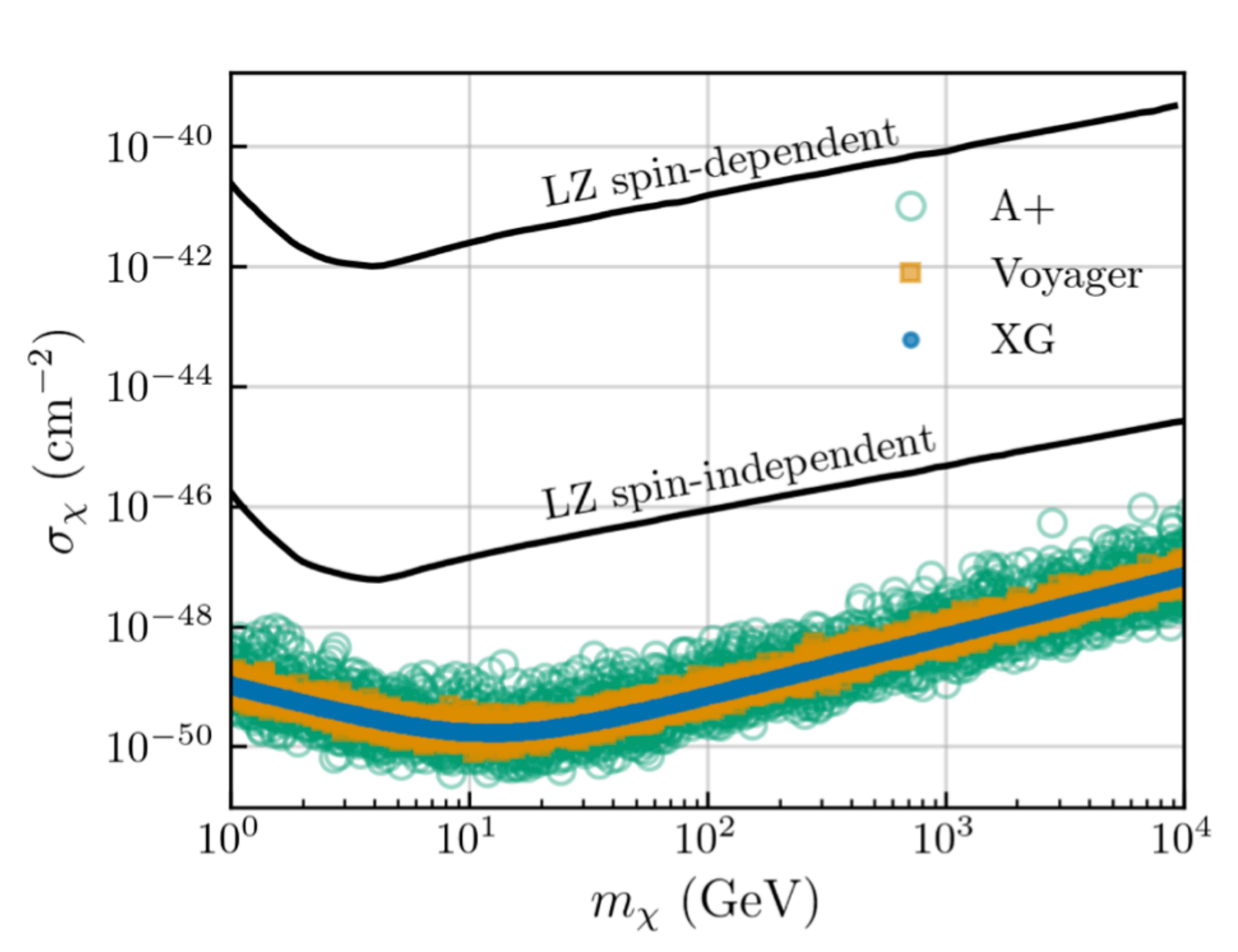
Bramante, Linden Tsai PRD 2018

Singh, Gupta, Berti, Reddy, Sathyaprakash PRD 2023

Nelson, Reddy, Zhou (2018) Horowitz & Reddy (2018)

Anomalous Compact Objects

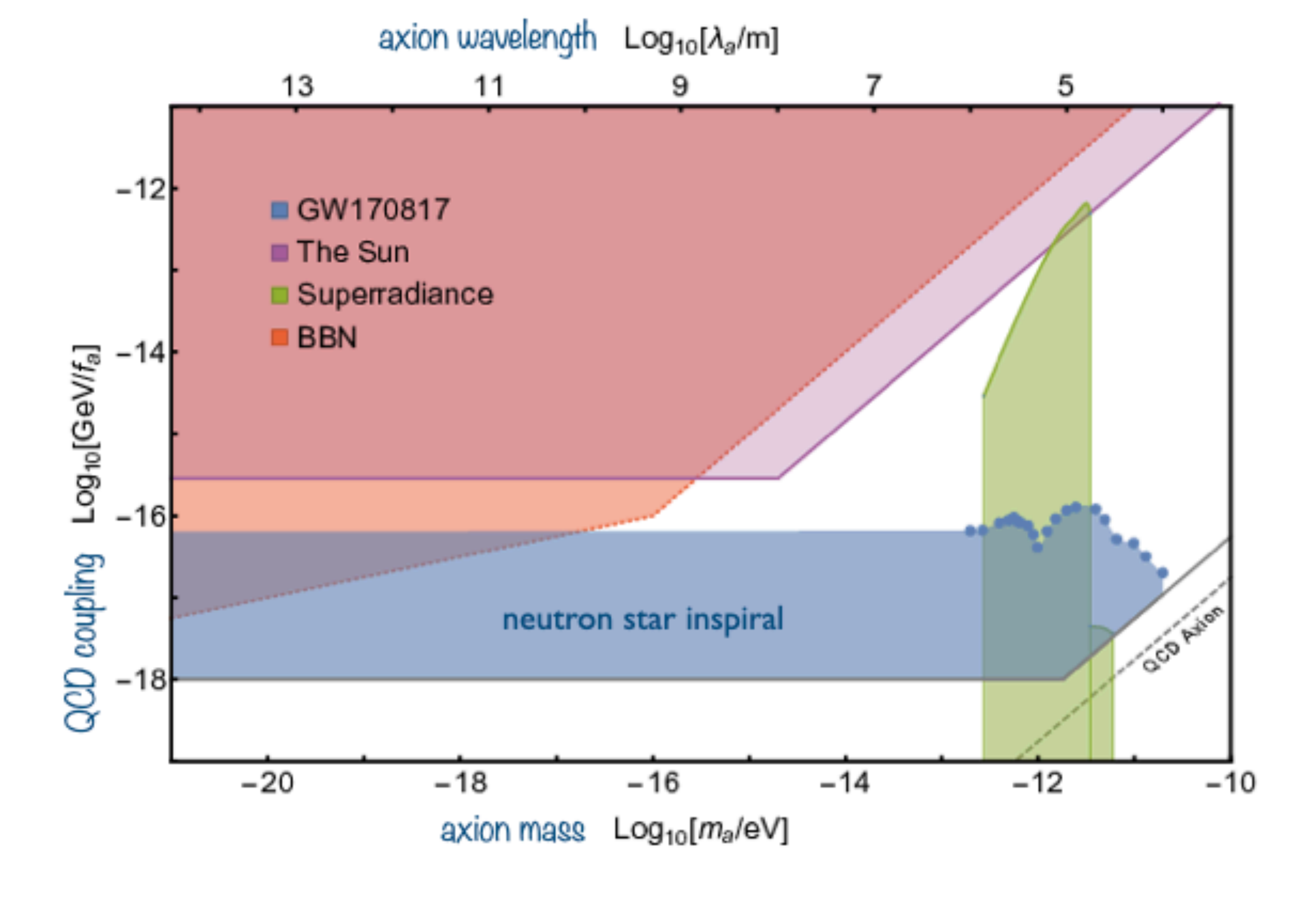




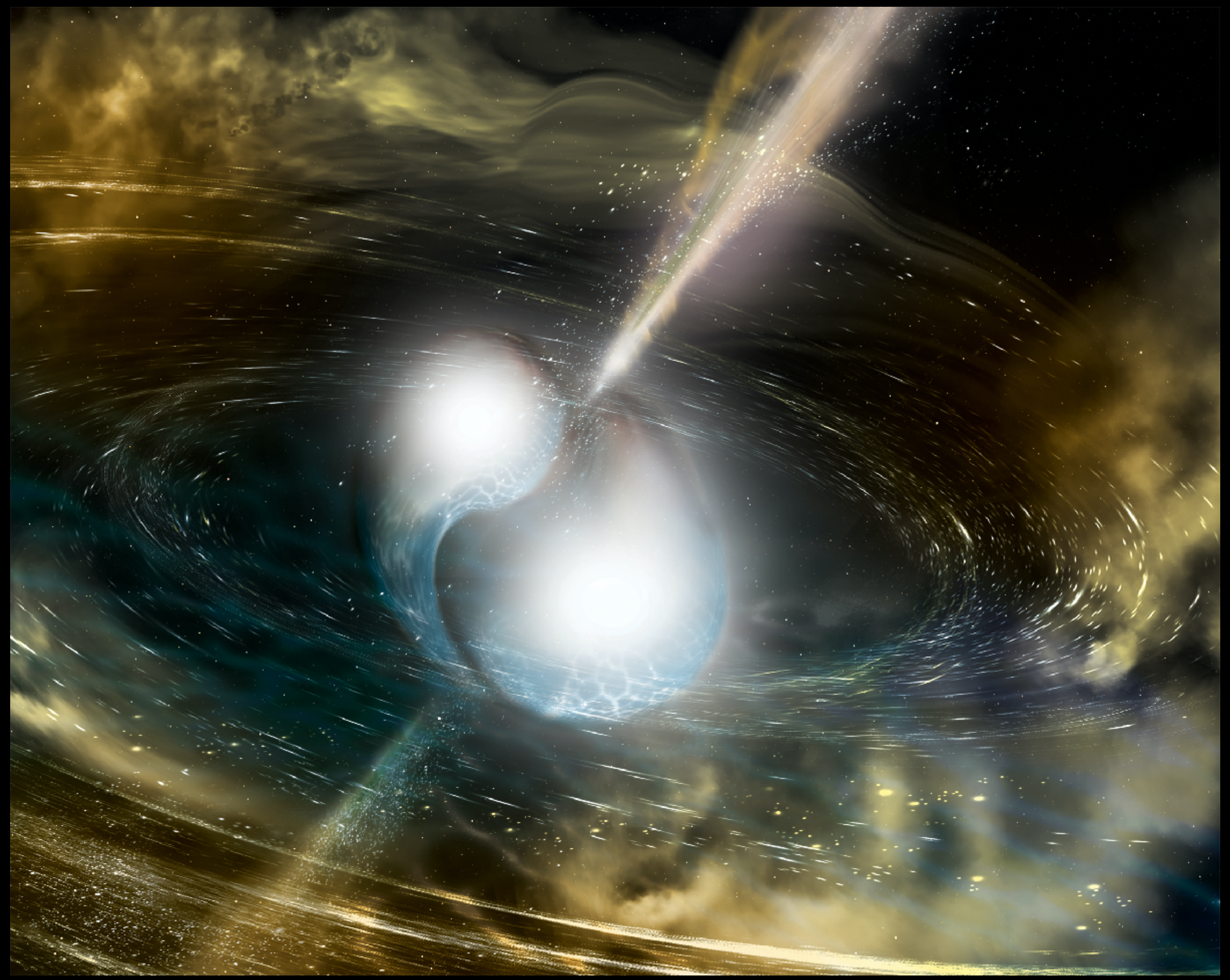
Singh, Gupta, Berti, Reddy, Sathyaprakash PRD 2023

Bosonic asymmetric dark matter can cause Neutron Star to Black Hole implosions, changing NSNS, BHBH, NS-BH merger rates

New Neutron Star Forces



Zhang, Lyu, Huang, Johnson, et al PRL 2021

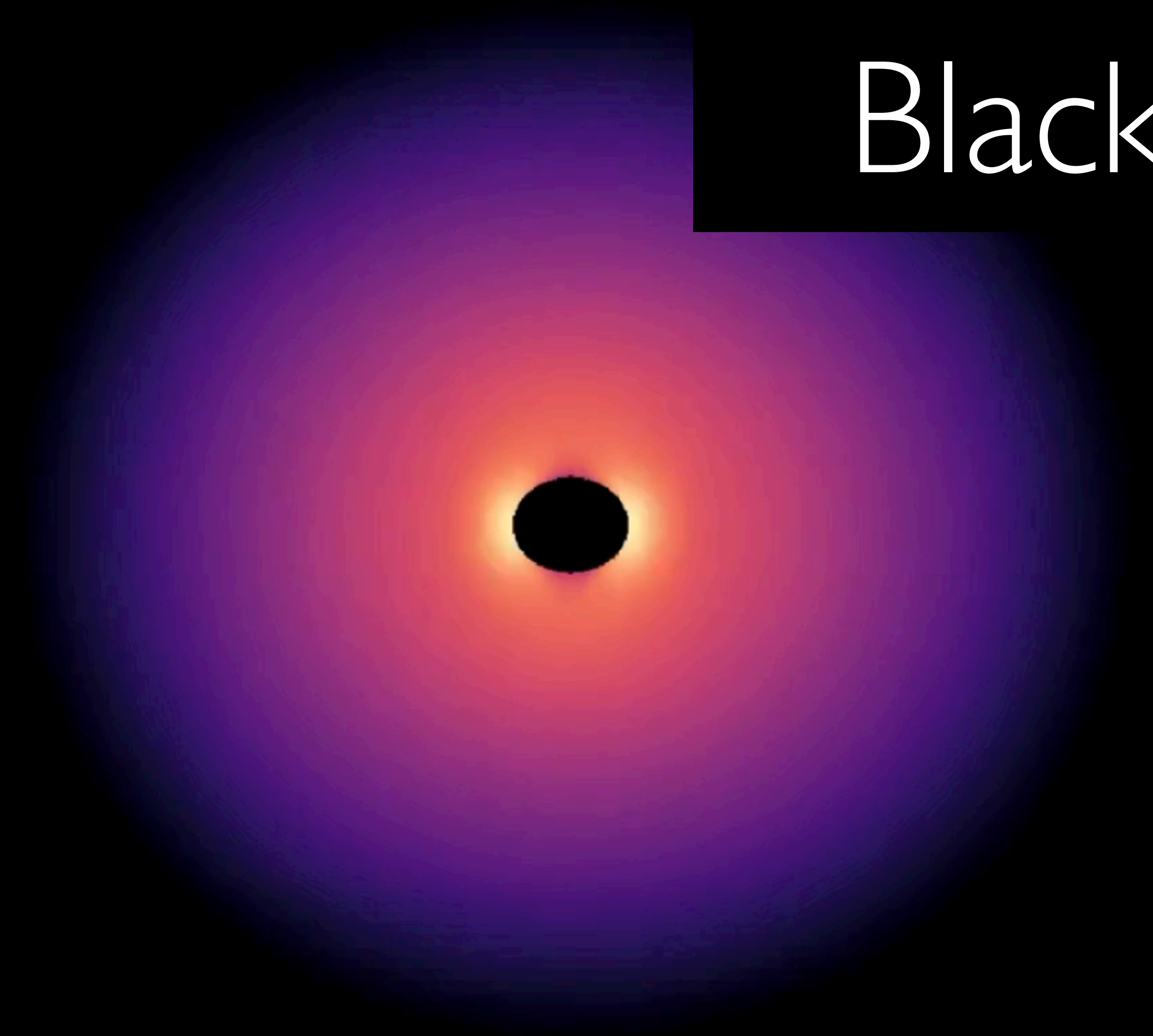


Credit: National Science Foundation/LIGO/Sonoma State University/A. Simonnet.

A lighter-than-expected axion can alter neutron star properties and mediate forces between neutron stars, altering inspiral waveform

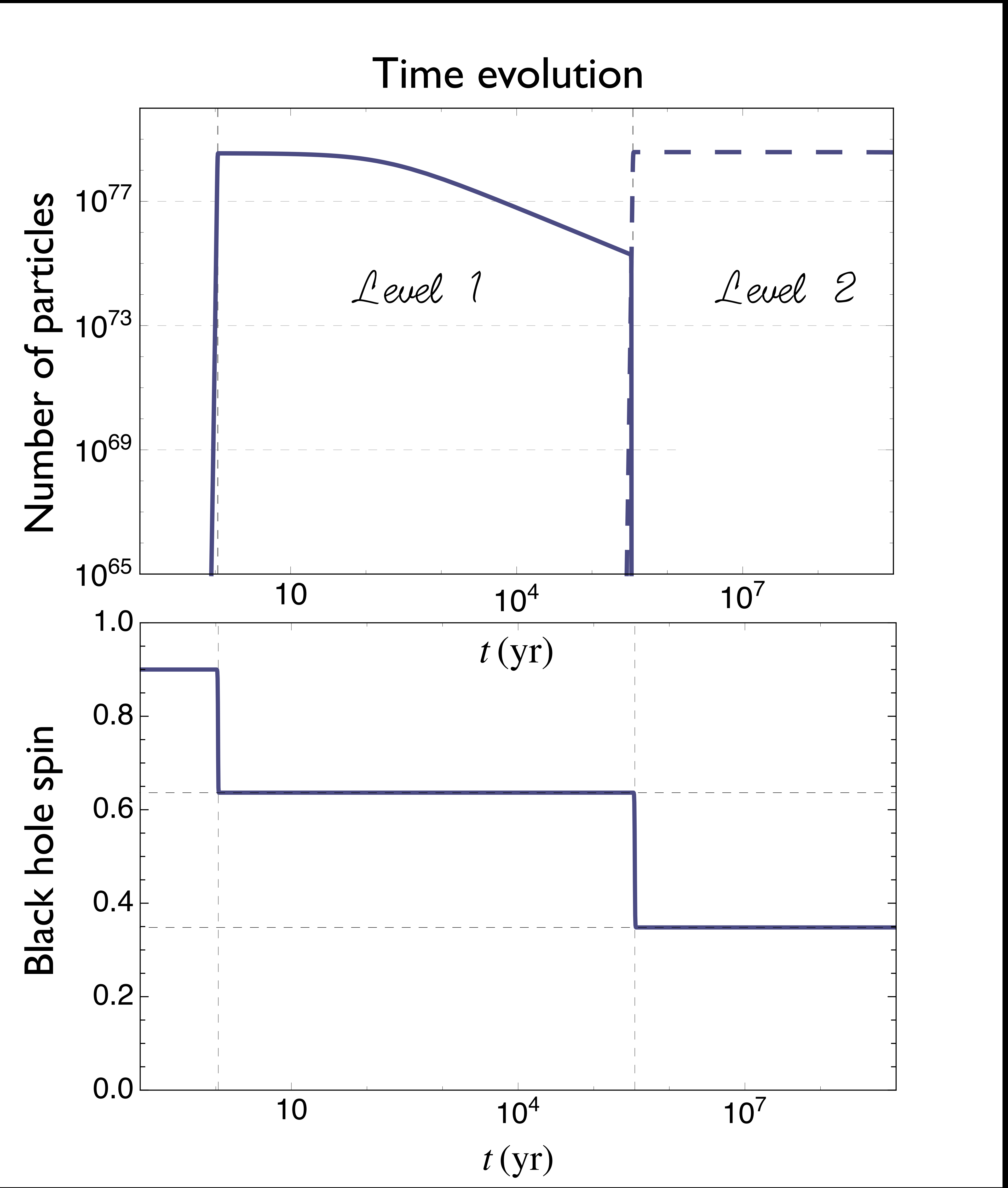
Hook, Huang JHEP 2017
Kumamoto, Reddy, Huang, MB *in prep*

Black Hole Superradiance of Ultralight Bosons



Numerical GR simulation by Will East

MB, M. Galanis, R. Lasenby, O. Simon *PRD 2021*



- BH spins down and exponentially large cloud of bosons is formed
- Once BH angular velocity matches that of the level, growth stops
- Few percent of black hole mass distributed over (tens of black hole radii)^3 volume

Arvanitaki, Dimopoulos, Dubovsky, March-Russell, Kalloper 2009
Arvanitaki, Dubovsky 2010
Arvanitaki, MB, Huang 2015
Brito, Cardoso, Pani 2015

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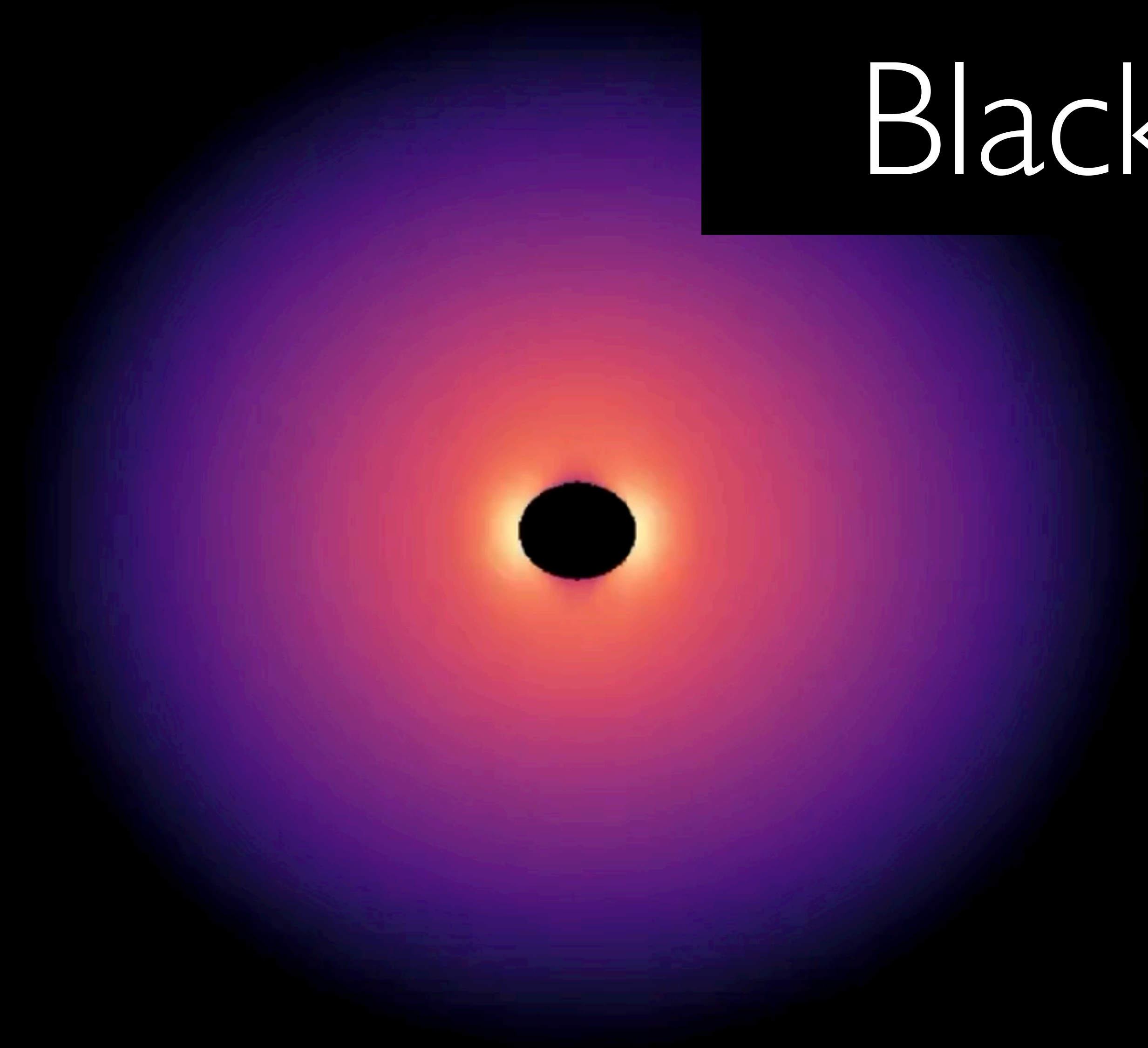

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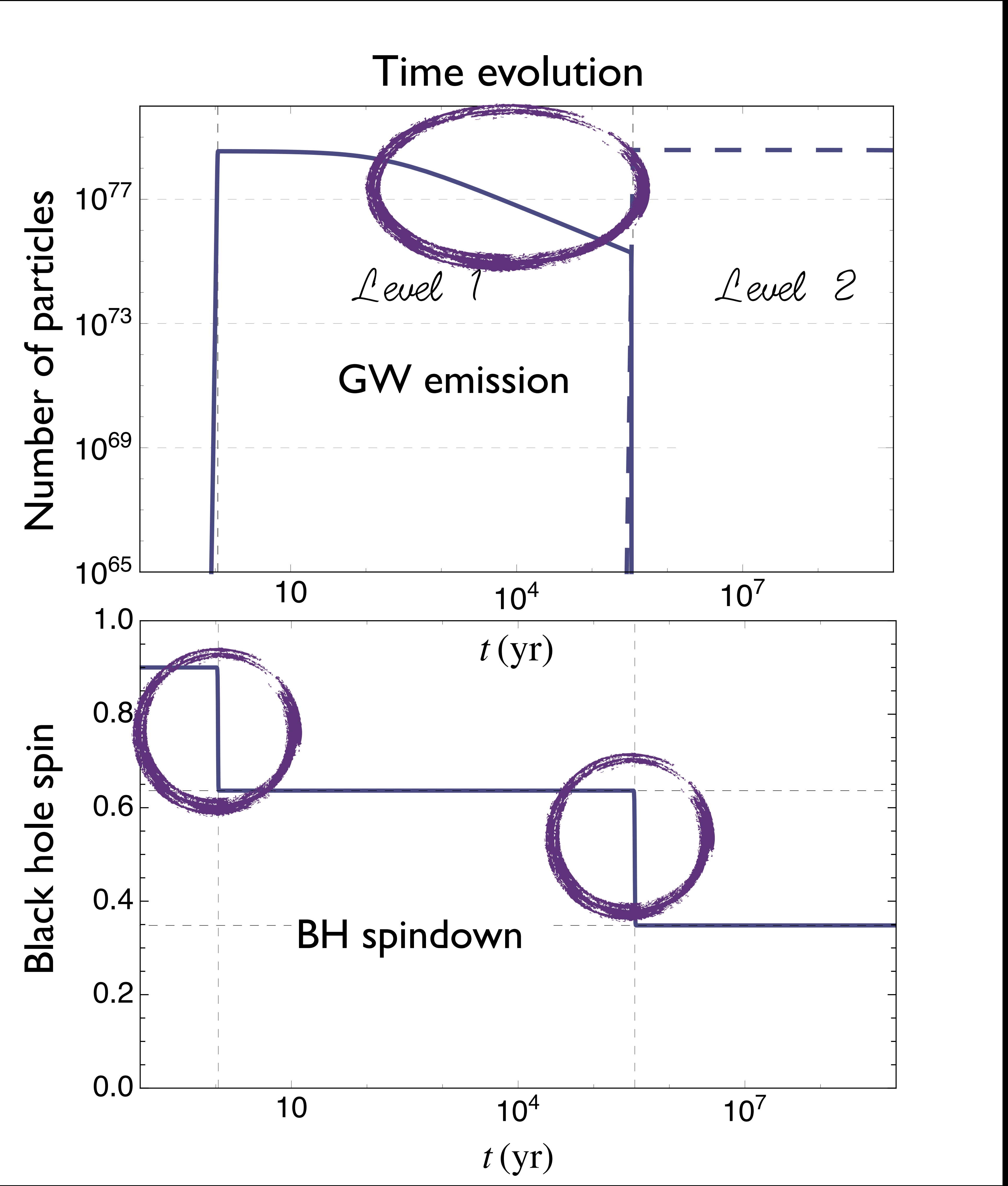
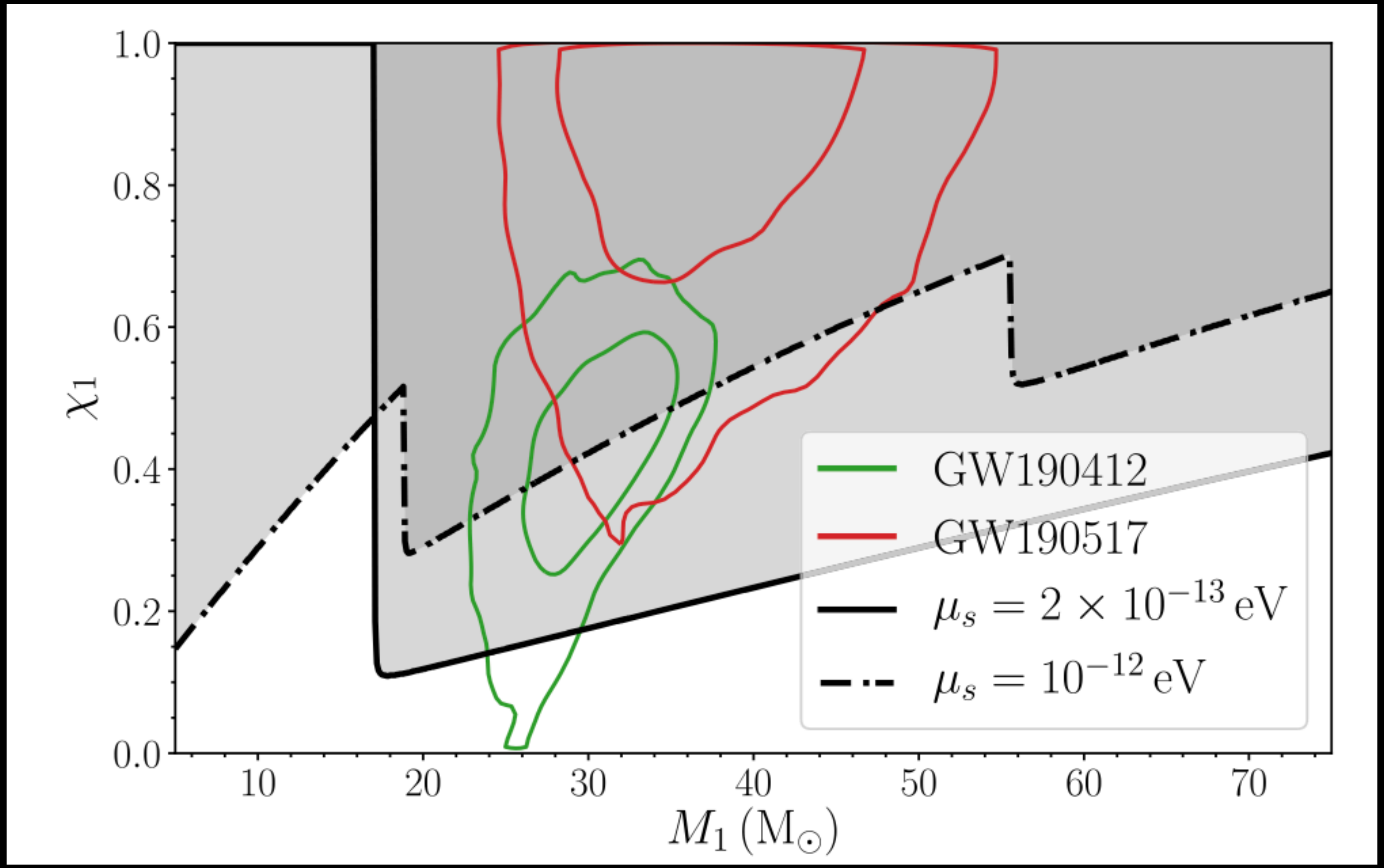
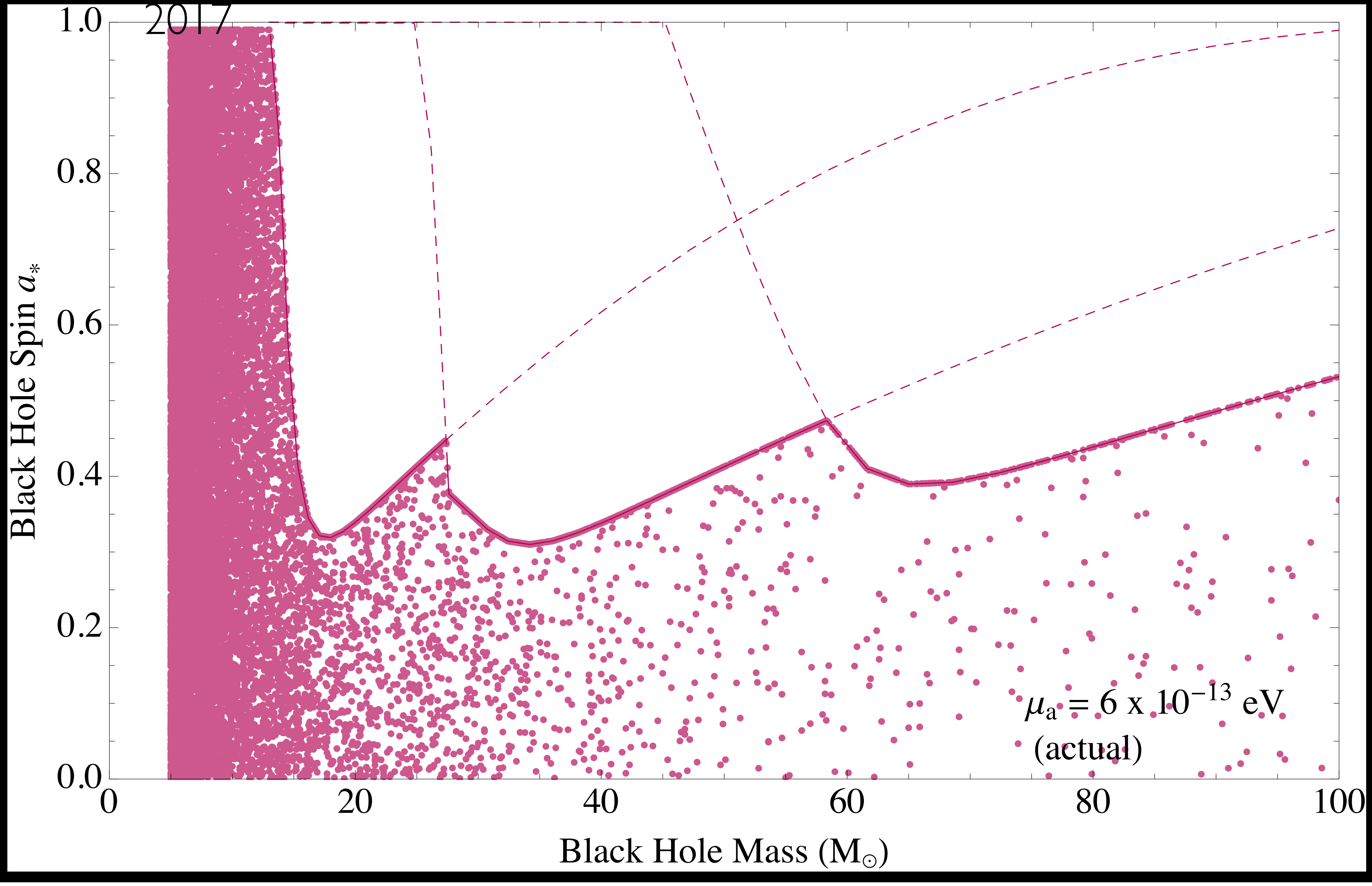


Arvanitaki, Dimopoulos, Dubovsky, March-Russell, Kalloper 2009
Arvanitaki, Dubovsky 2010
Arvanitaki, MB, Huang 2015
Brito, Cardoso, Pani 2015

Black holes spin searches for ultralight bosons



Ng, Vitale, Hannuksela, Li PRL & PRD 2021

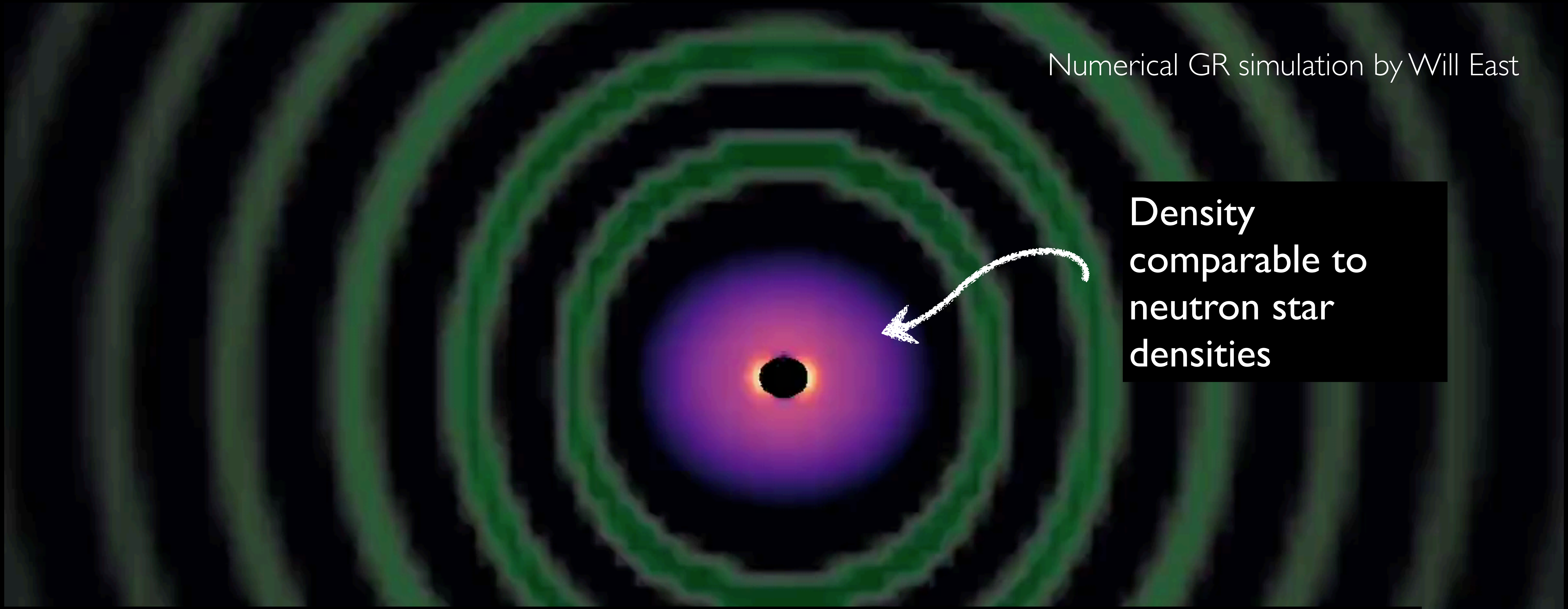


Arvanitaki, Baryakhtar, Dimopoulos, Dubovsky, Lasenby PRD 95 (2017) no.4, 043001

Bound state grows by spinning down rotating black holes through superradiance

LVK measurements already rule out weakly interacting axions around 10^-13 eV
Hundreds of high SNR mergers can at future observatories can yield a detection!

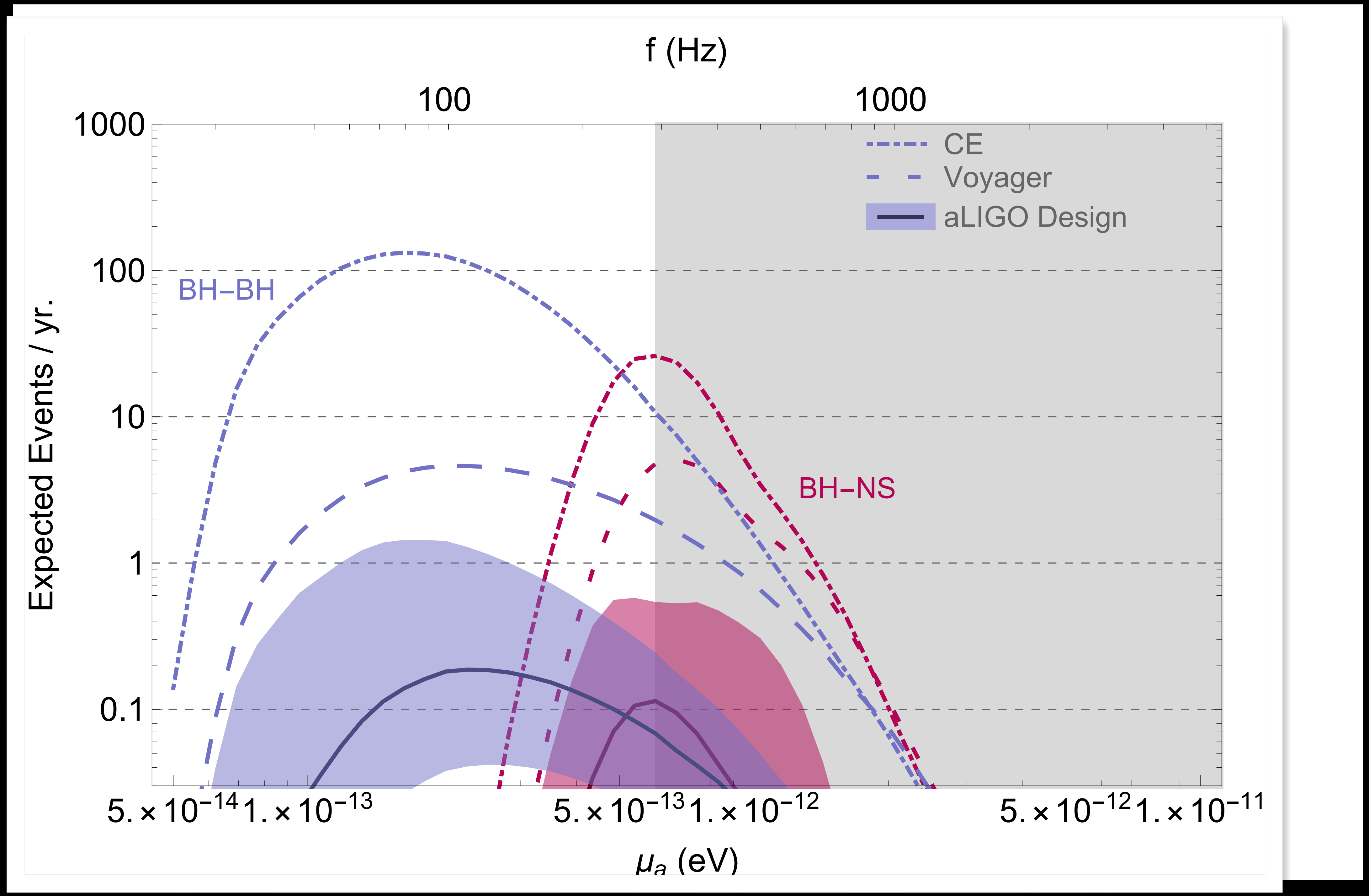
Black holes as laboratories for ultralight particles



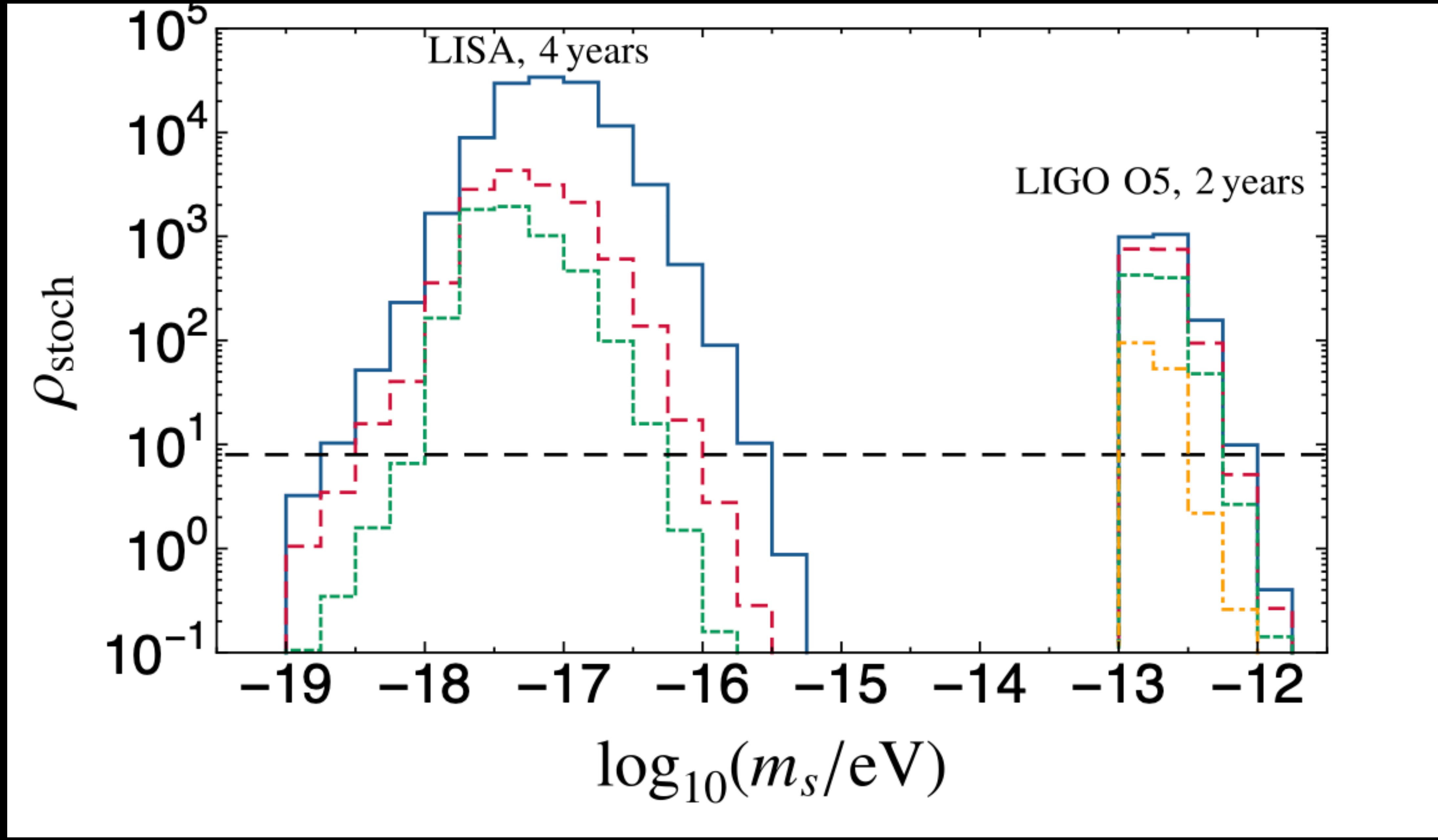
Huge Density of Ultralight Particles Sources Coherent Radiation

- **gravitational**: continuous wave strategies at LIGO Virgo Kagra
- **axionic**: repurpose dark matter searches
- **electromagnetic**: multi messenger signals

Gravitational wave signals from ultralight bosons



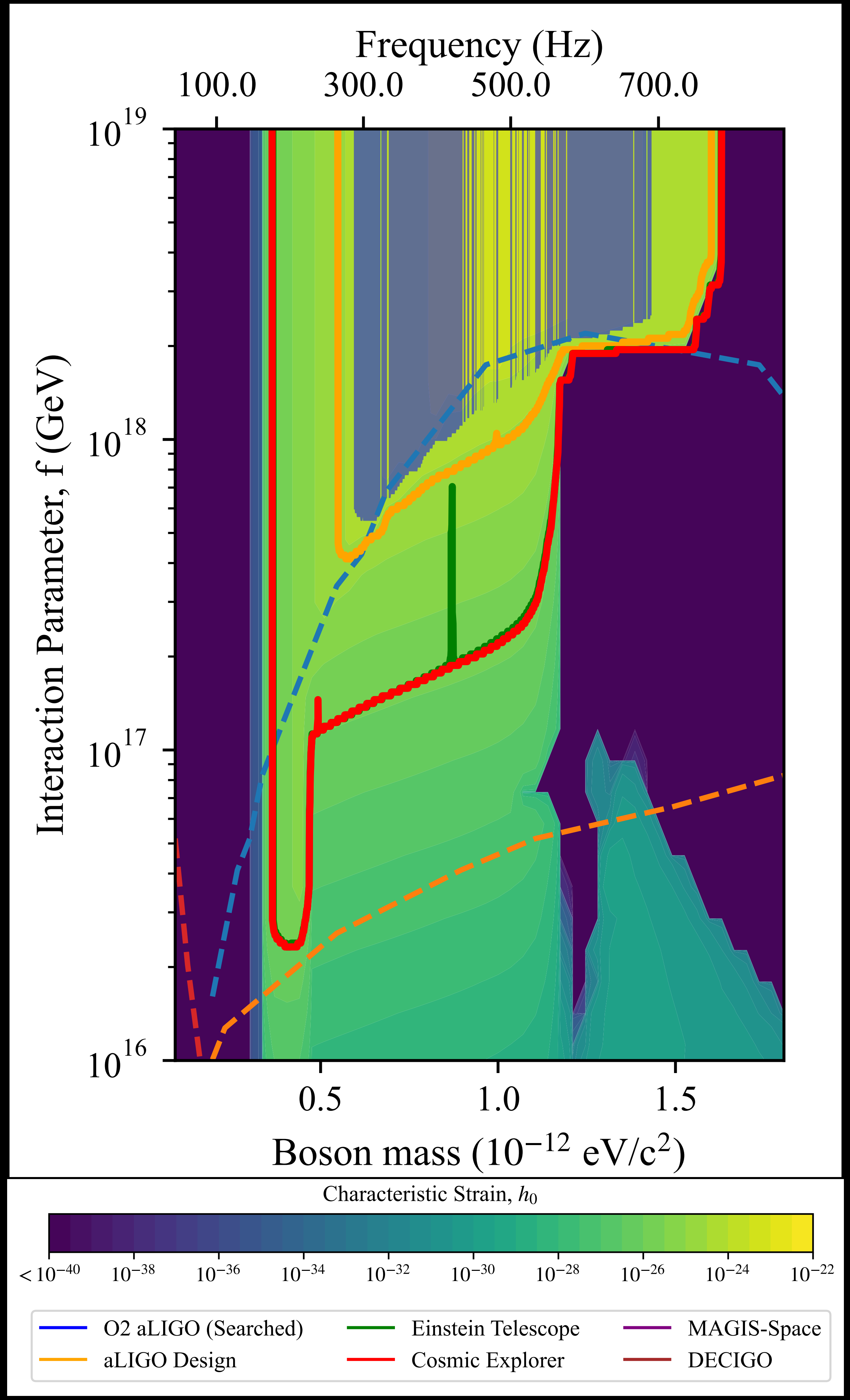
Phys.Rev. D95 (2017) no.4, 043001



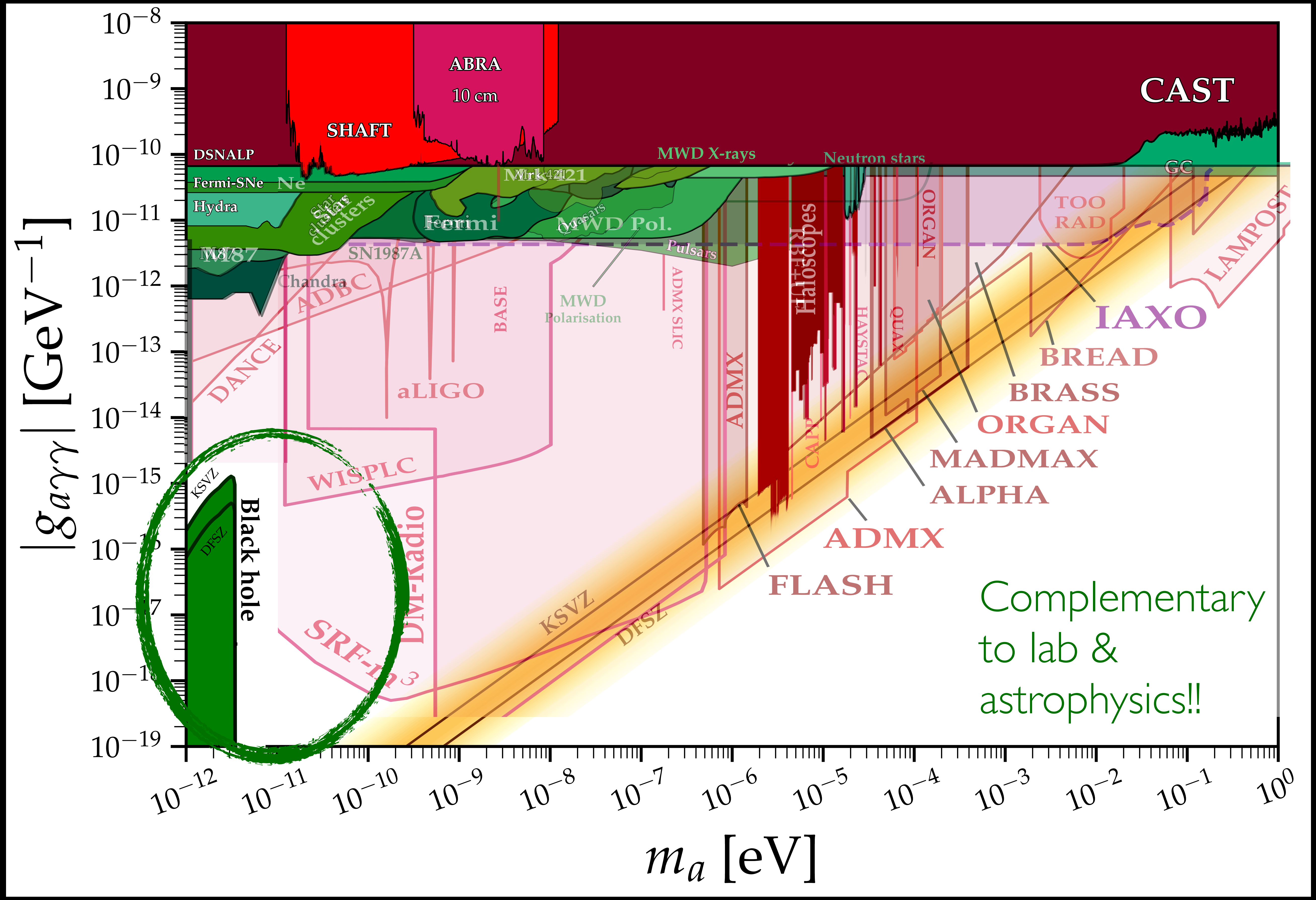
Phys.Rev.Lett. 119 (2017) 13, 131101

Searches for follow-up continuous waves signals from mergers and blind searches or stochastic excess in a narrow frequency range

Gravitational wave discovery potential for Axions



Collaviti, Sun, Galanis, Baryakhtar *in prep*



Future facilities such as Cosmic Explorer can robustly discover or exclude new particles, including interacting axions and dark photons

Hidden particle sectors and dark matter

- Extreme environments are a unique source of feebly interacting dark matter and new particles: high energies and densities overcome weak interactions of particles that otherwise may be impossible to produce and detect
- Sensitive to only gravitational interactions: may be only way to detect `nightmare scenario' dark matter candidates
- Searches promising for long searched-for particles such as the QCD axion at future gravitational wave observatories
- Next generation detectors can robustly test new particle parameter space