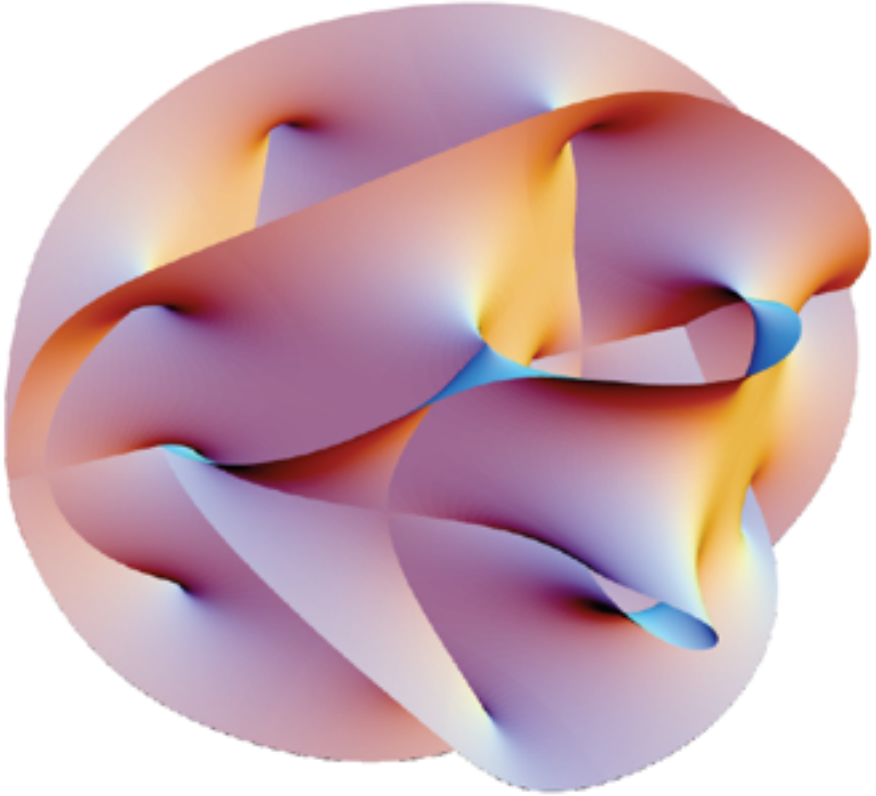
Black Hole Portal
into
Hidden Valleys

Sergei Dubovsky
CCPP, NYU

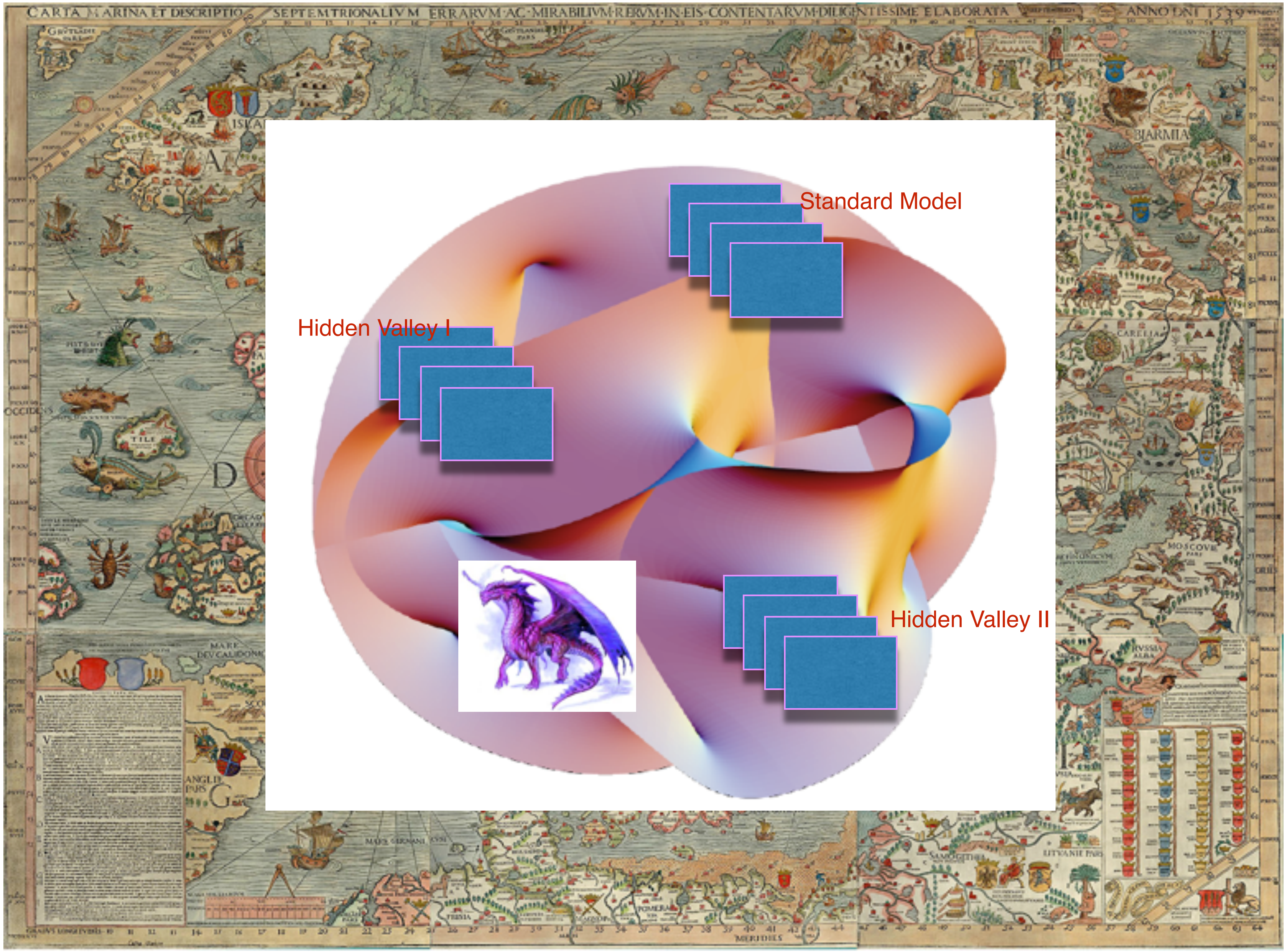


String Lanscape:

Plenitude ('$\sim 10^{500}$ ') of vacua

Ultimate Unification of Fundamental Physics and Geography


CARTA MARINA ET DESCRIPTIO SEPTEMTRIONALIVM TERRARVM AC MIRABILIVM RERVM IN EIS CONTENTARVM DILIGENTISSIME ELABORATA ANNO DNI 1539
ISLANDIA
FINMARCHIA
SCRIGFINIA
BIARMIA
LAPPIA
BOTNIA
CARELIA
SCANDIA
NORVEGIA
SVECIA
MARE SVEVICVM
MOSCOVIE
TILE
OCCIDENS
GOTHIA
DANIA
SCOCIE PARS
ANGLIE PARS
OCEANVS BRITANICVS
MARE GERMANICVM
MARE GOTICVM
LITVANIE PARS
MERIDIES



In both cases no reasons to apply Occam’s razor

Expect to see more structures of the type we already saw:

- **Gauge sectors**

Theory: Abundantly come from stacks of D-branes wrapping cycles in the compactification manifold

Observations: SU(3)xSU(2)xU(1)

- **Axions**

Theory: Abundantly come from zero modes of higher-dimensional gauge fields in the presence of cycles

Observations: Strong CP problem provides a tantalizing hint

Landscape geography implies new search strategies for new physics:

- ✦New physics can be (exponentially) light:

  Axions are gauge fields in disguise. Not massless due to non-perturbative (Aharonov-Bohm) effect.

- ✦And very weakly (gravitationally) coupled to us

  Consequence of geographic separation

Theorist's detector for light axions:

SD, Arvanitaki, Dimopoulos, Kaloper, March-Russel
SD, Arvanitaki

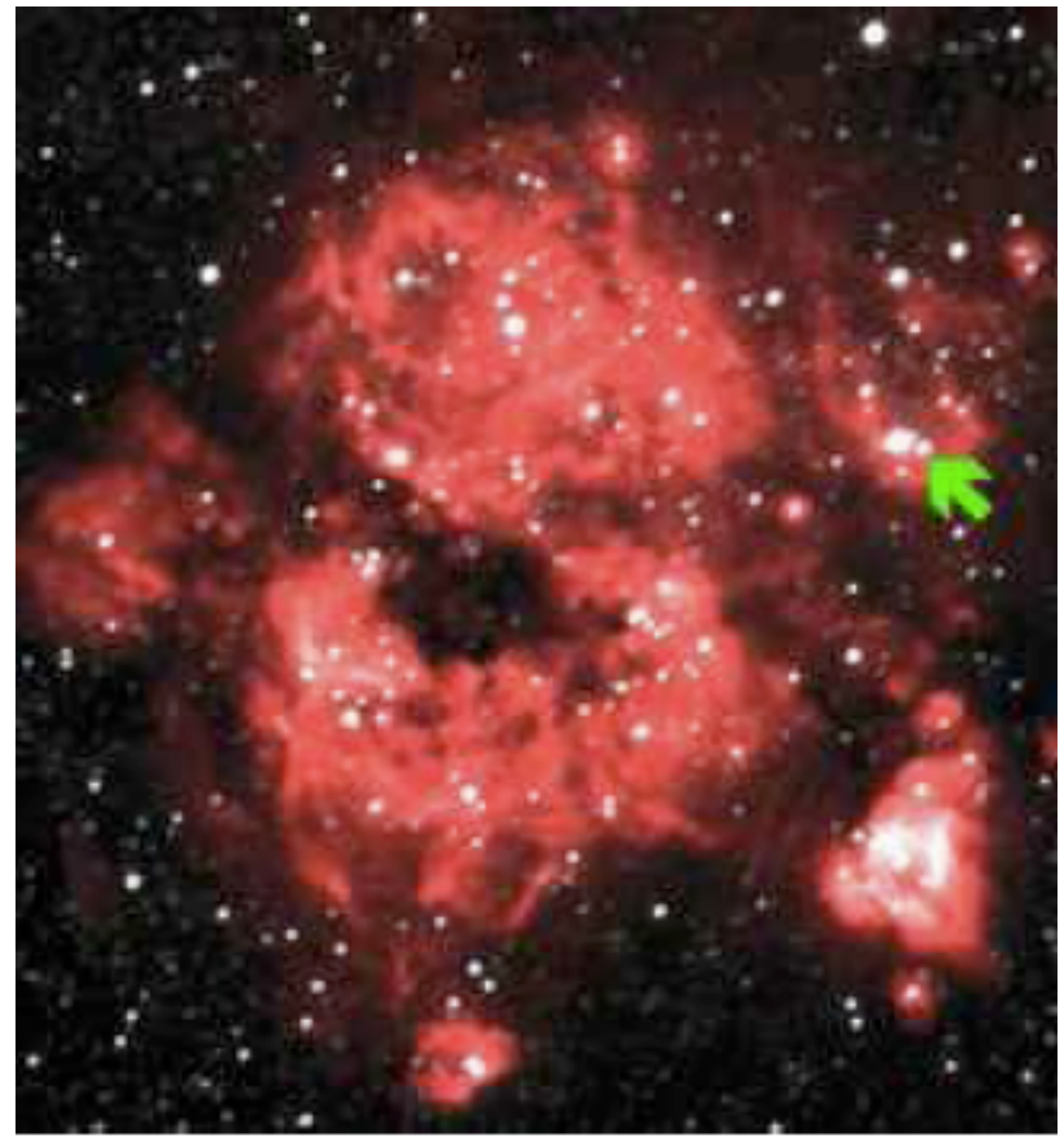
LMC X-1

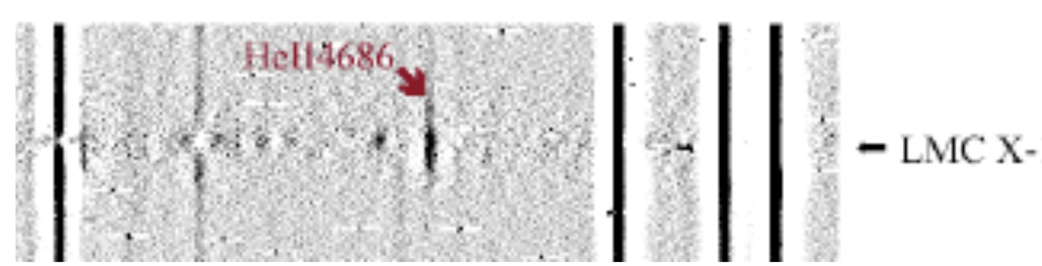
$$10 M_\odot \, , \; a/R_g \simeq 0.91$$

$$m_a \gtrsim 2 \cdot 10^{-11} \; eV$$

for the QCD axion translates into

$$f_a \lesssim 3 \cdot 10^{17} \; GeV$$

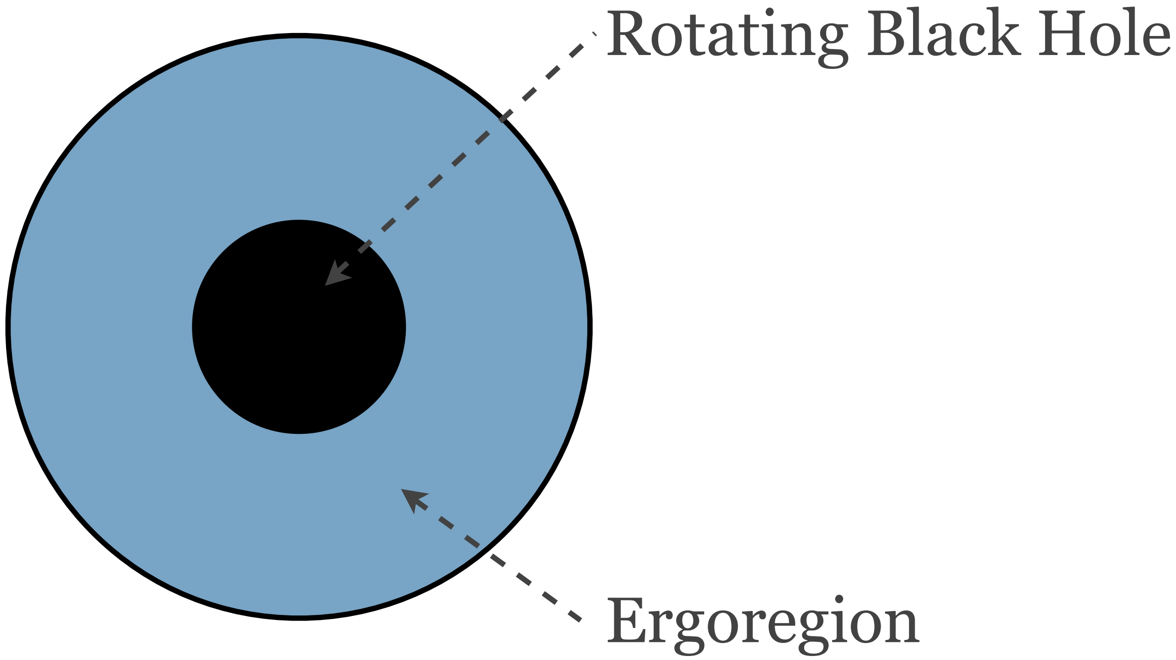




Black Hole Superradiance

Penrose Process

Penrose; Zeldovich; Misner; Starobinsky



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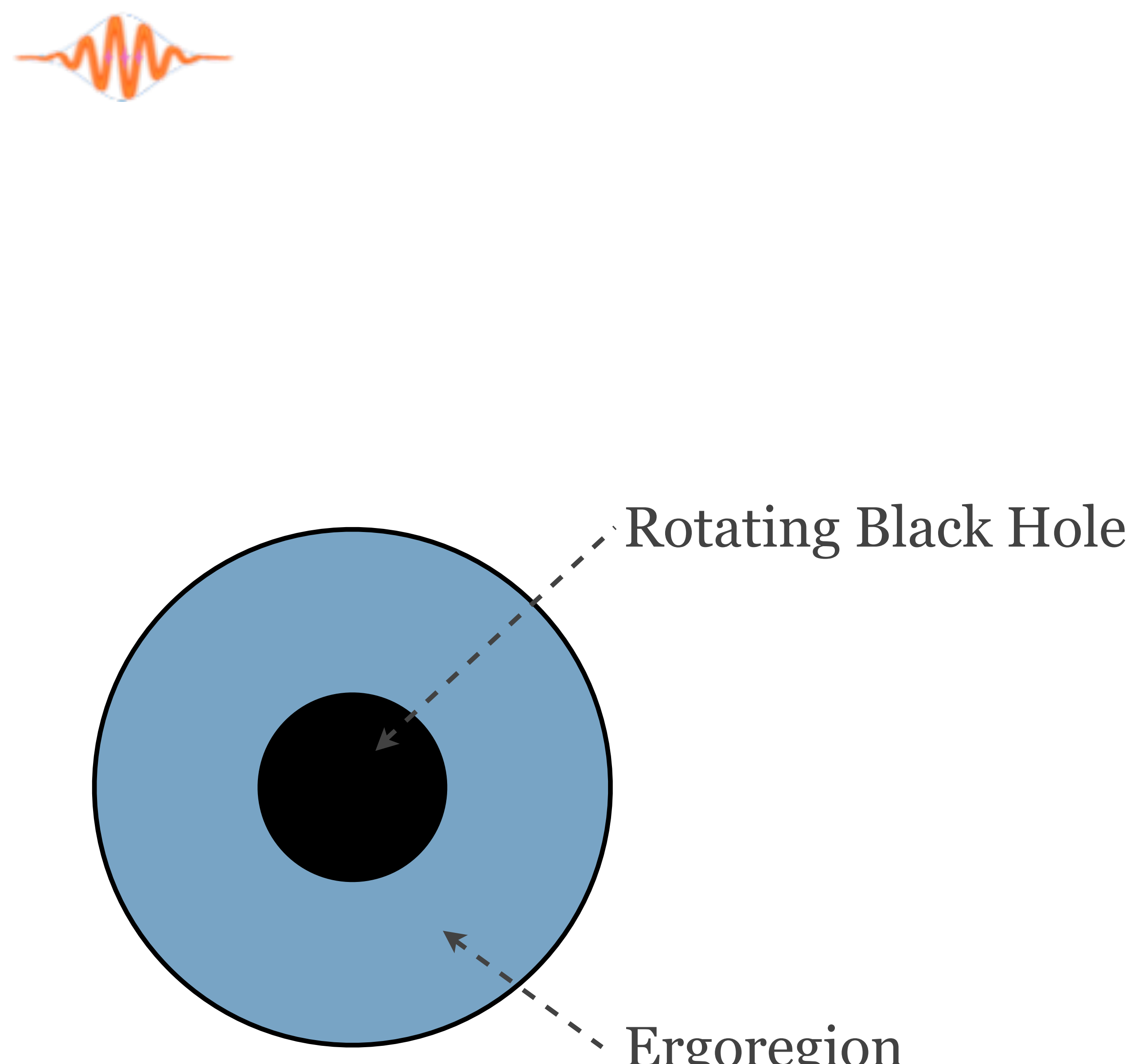
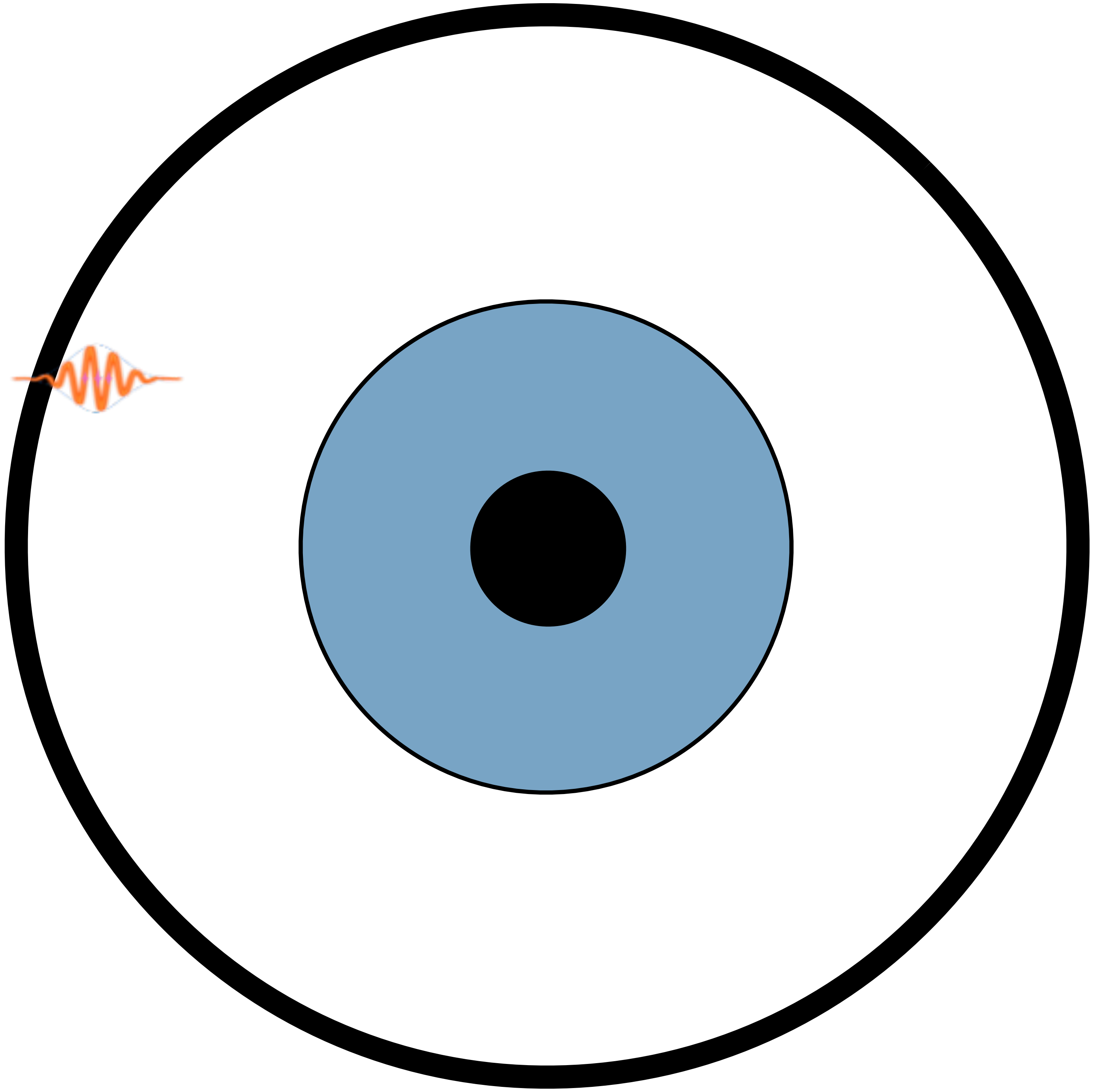


Extracts angular momentum and mass from a spinning black hole

Black Hole Bomb

Press & Teukolsky



Photons reflected back and forth from the black hole
and through the ergoregion

Black Hole Bomb

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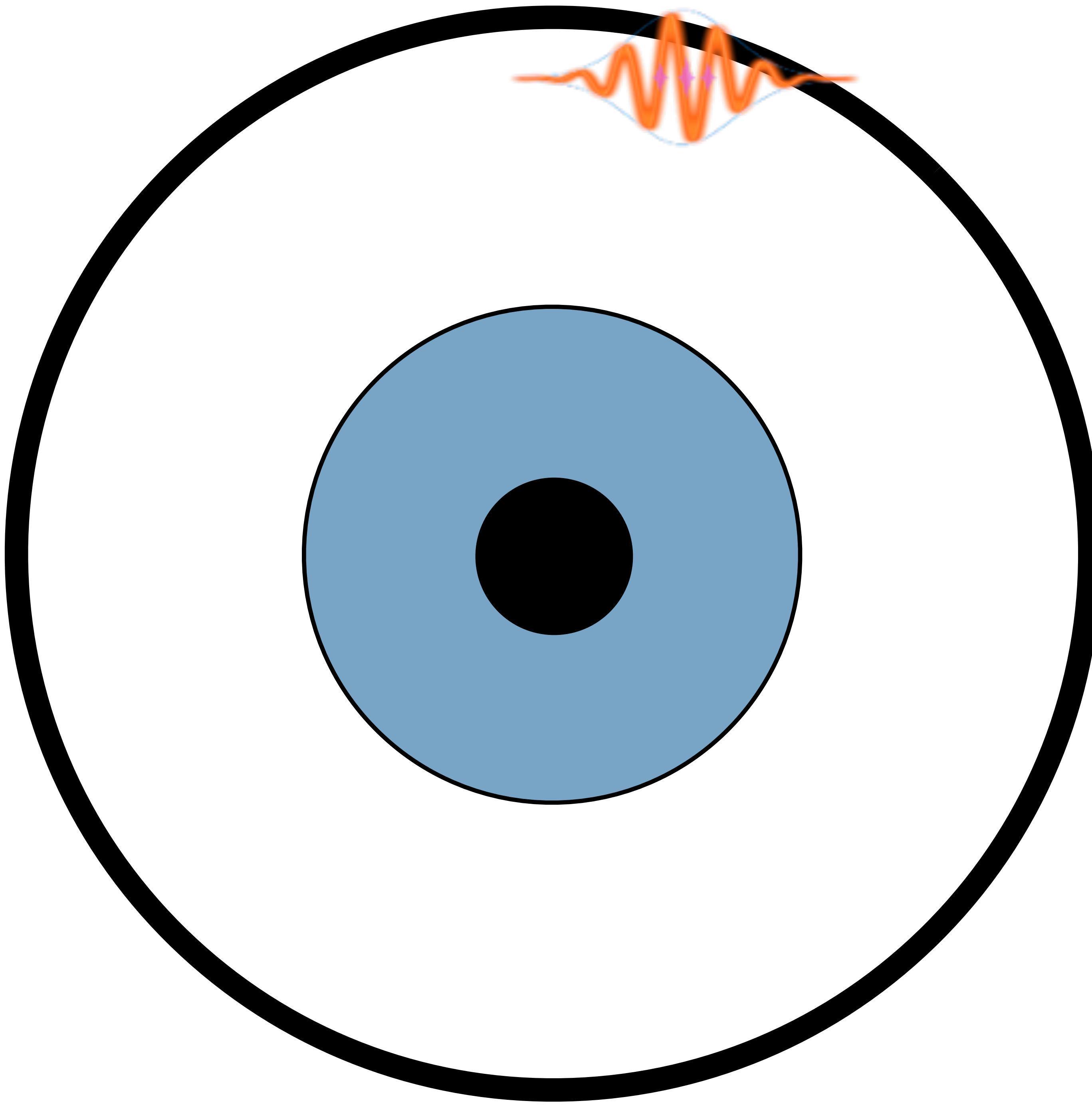

Photons reflected back and forth from the black hole
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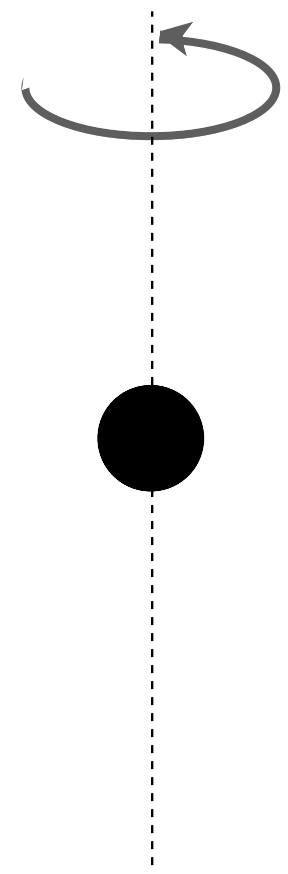
Superradiance for a massive boson

Penrose Process

Damour et al; Gaina et al.;
Detweiler; Zouros & Eardley;



Particle Compton Wavelength comparable to the size of the Black Hole

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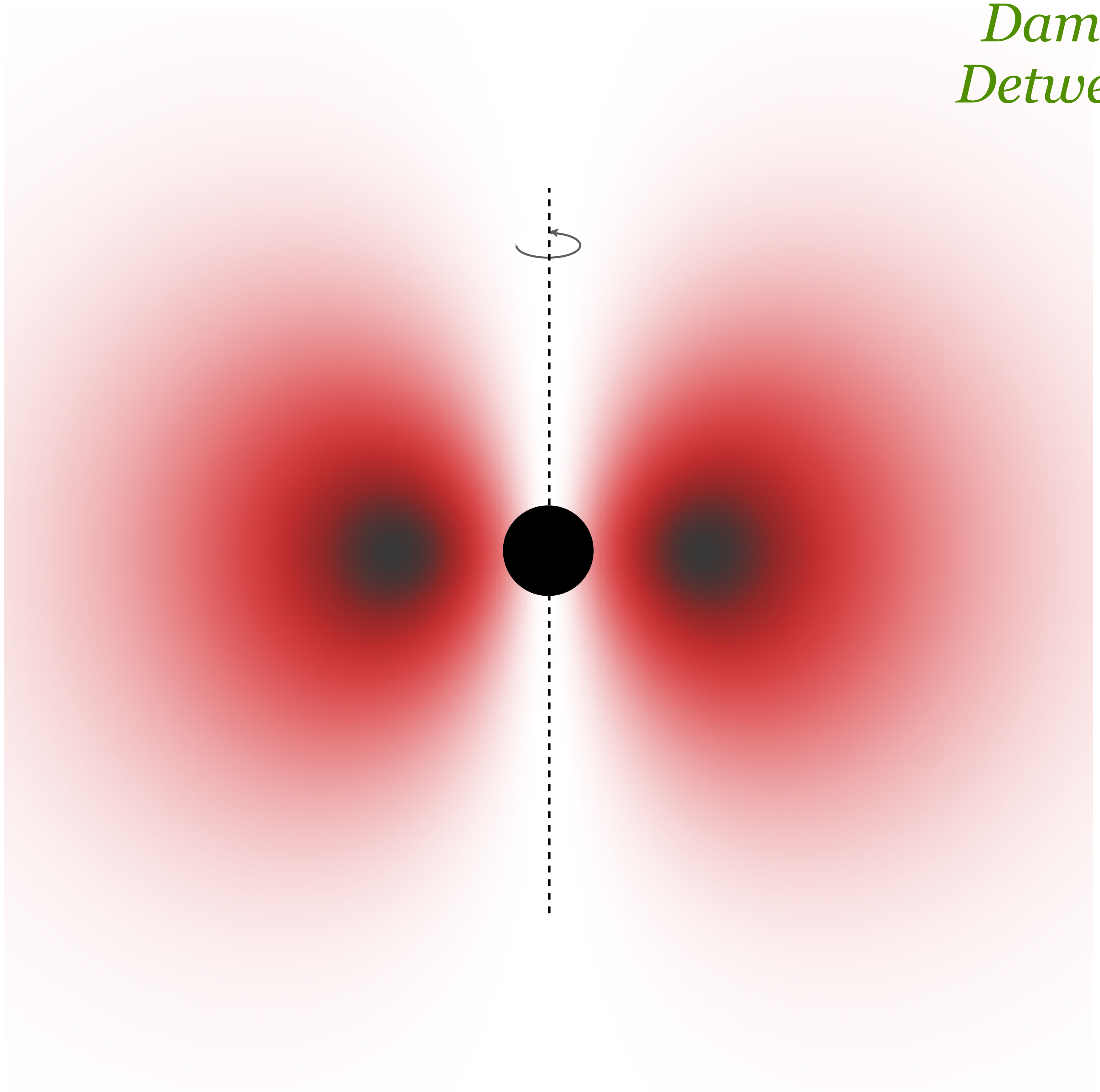


Particle Compton Wavelength comparable to the size of the Black Hole

Gravitational Atom in the Sky

Away from the Black Hole: Newtonian Potential

The gravitational Hydrogen Atom

$$\alpha_{EM} = \frac{e^2}{4\pi} \qquad \longrightarrow \qquad \alpha = G_{\rm N} M_{\rm BH} \mu_a = R_g \mu_a$$

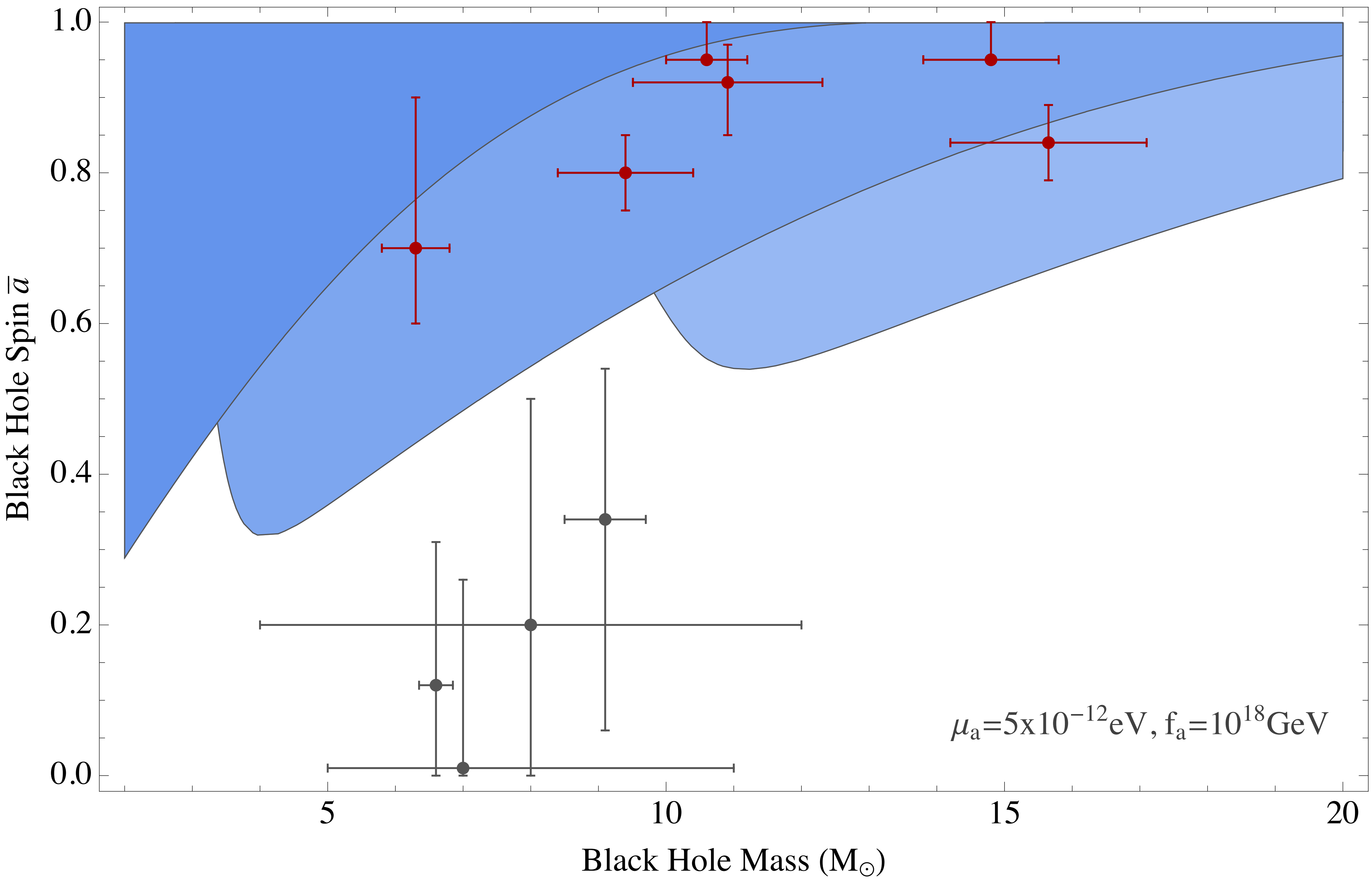
$$E_{\rm binding} = -\frac{\alpha_{EM}^2 m_e}{2n^2} \qquad \longrightarrow \qquad E_{\rm binding} = -\frac{\alpha^2 \mu_a}{2n^2}$$

$$\text{fermions} \qquad \longrightarrow \qquad \text{bosons}$$

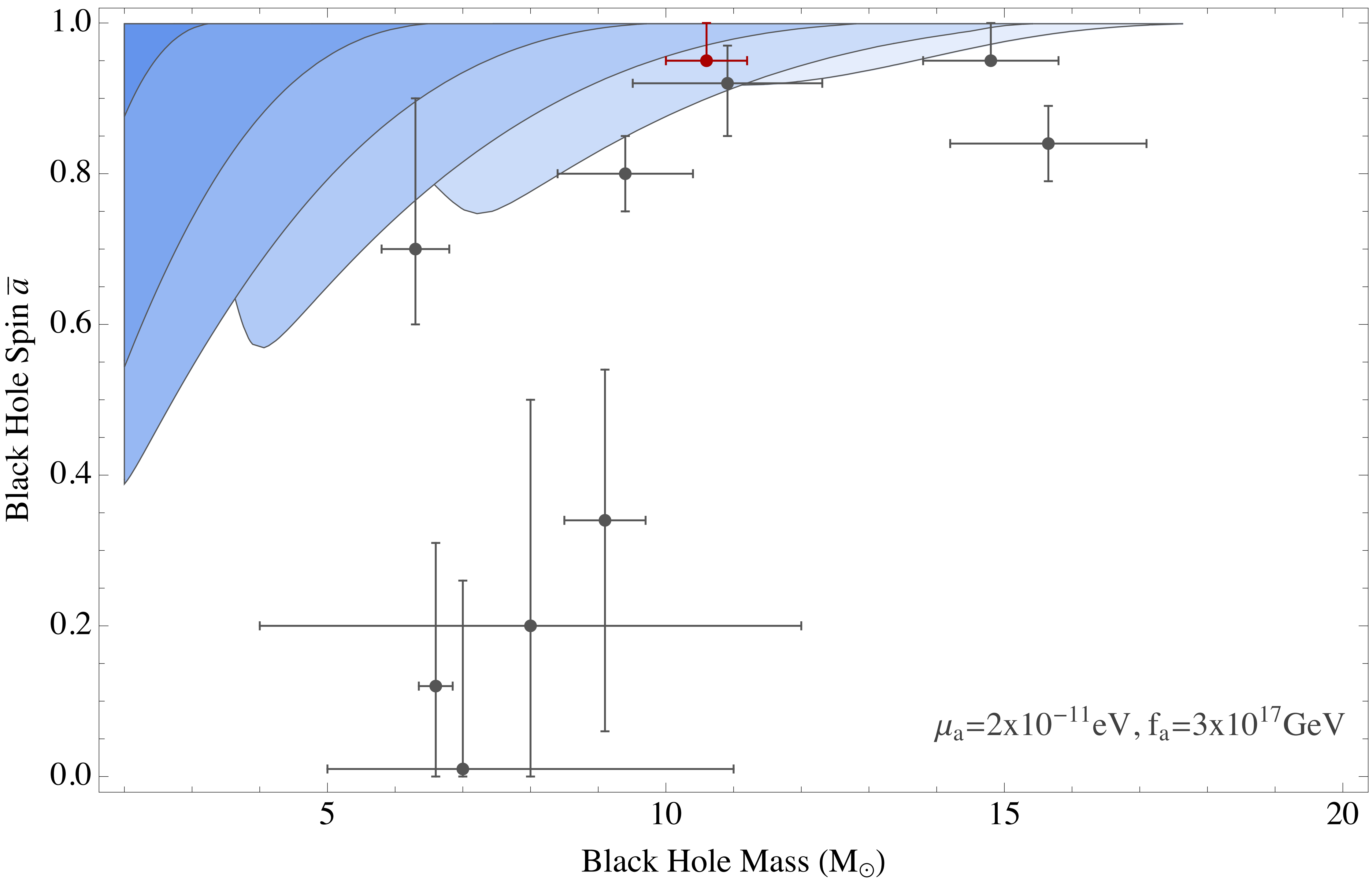
Occupation number

$$1 \qquad \longrightarrow \qquad 10^{75}$$

Spin Gap for the QCD Axion

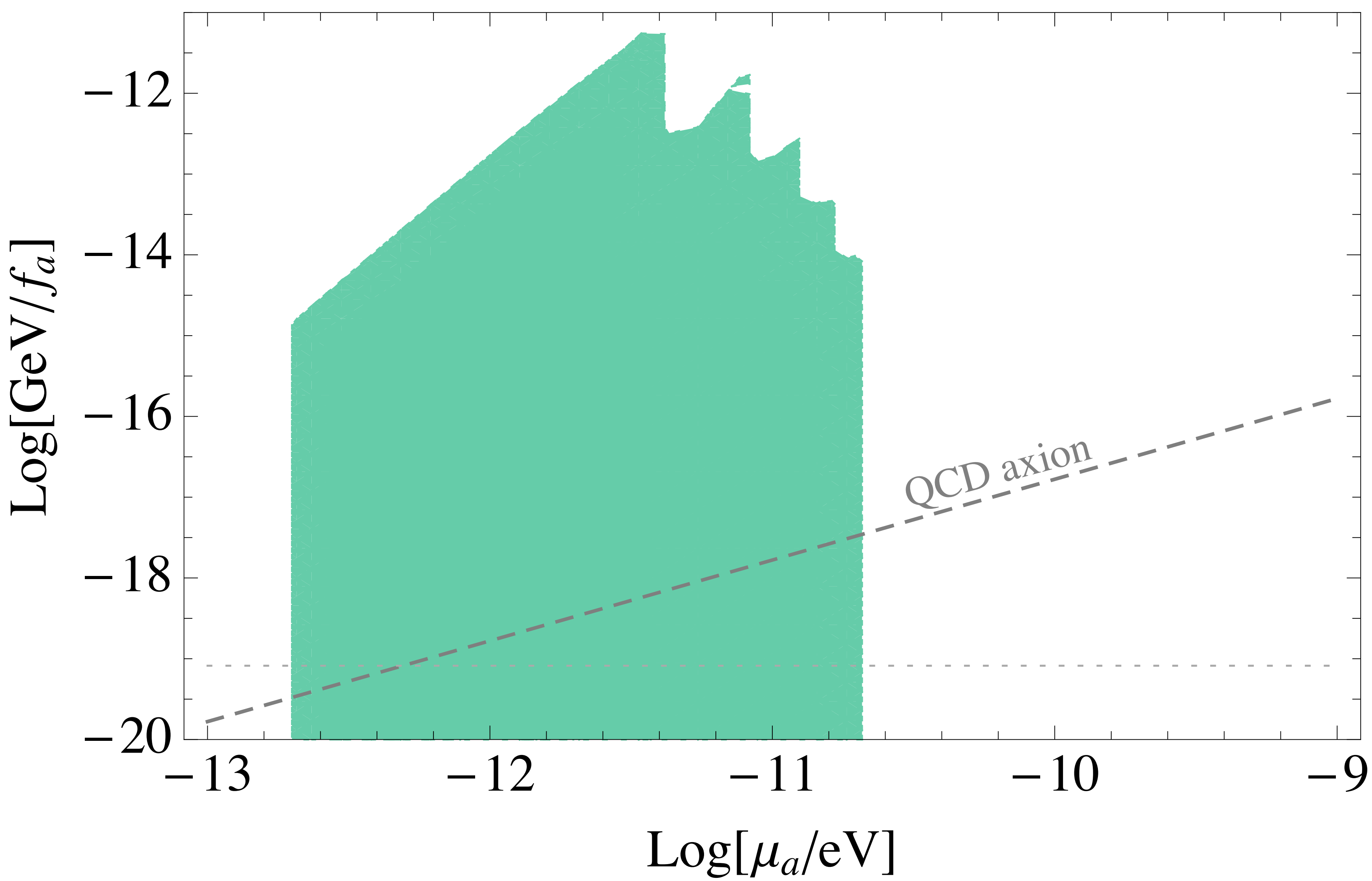


Spin Gap for the QCD Axion



Combined Exclusion plot

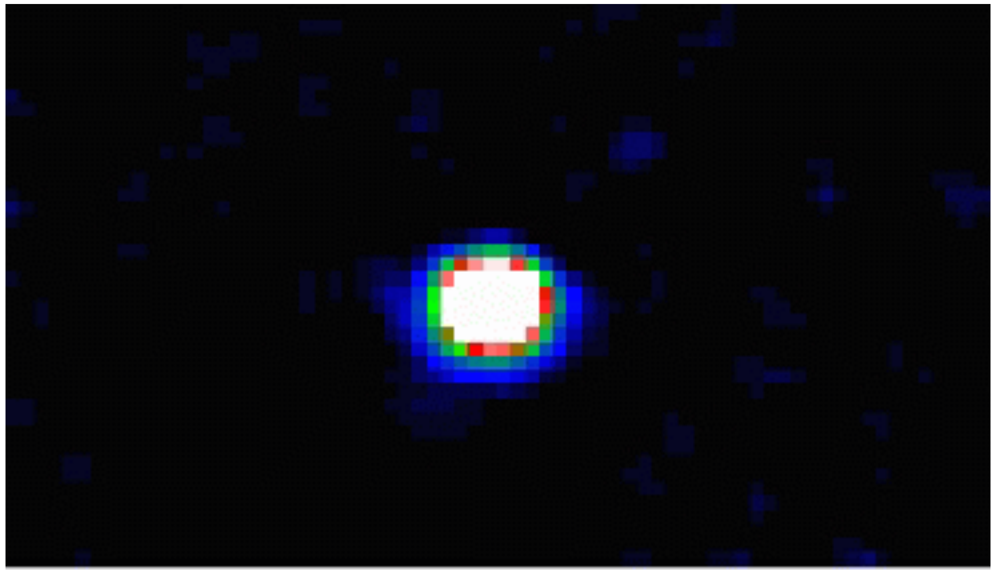
Arvanitaki, Baryakhtar, Huang, to appear



Bose Einstein Condensate in a Trap

The effect of attractive self-interactions

$E_{trap} \sim E_{inter.}$



http://www.nist.gov/public_affairs/bosenova.htm

The Bosenova

Happens when $$\frac{M_{\text{cloud}}}{M_{\text{BH}}} \sim \frac{f_a^2}{M_{\text{Planck}}^2}\frac{l^2}{\alpha^2} \sim 10^{-4}$$

Repeats 10-100 times

Wait 10^3-10^4 τ_{sr} to stop superradiating

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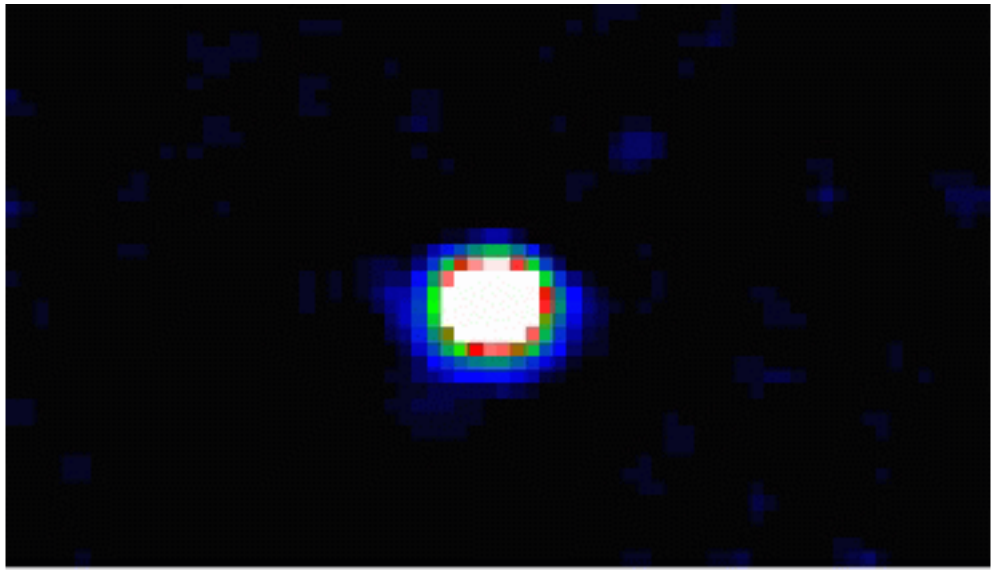

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What about signals, rather then exclusions ?

- Gravitational waves from the cloud.
  Advanced LIGO has chances to become a discovery machine for the QCD axion.

- Electromagnetic signals ?
  The hope is that inside the cloud $\theta_{QCD} \sim 1$.
  This is a very different QCD !

Electromagnetic Signals: Echoes of Hidden Valleys

SD, Gorbenko

Setup:

✦Axion, coupled to QCD-like sector.
At least 3 light quark flavors with close masses.
Pure glue also may work.

✦Some portal, allowing for hidden pions to annihilate into SM. Simplest example: dark photon with kinetic mixing.

Effective action describing axion and mesons:

$$\mathcal{L} = \frac{F_\pi^2}{4}\mathrm{Tr}\,\partial U^\dagger \partial U + \frac{\Lambda^3}{2} Tr\left(M\mathrm{e}^{-i\theta/N}U + M\mathrm{e}^{i\theta/N}U^\dagger\right)$$

Axion Monodromy

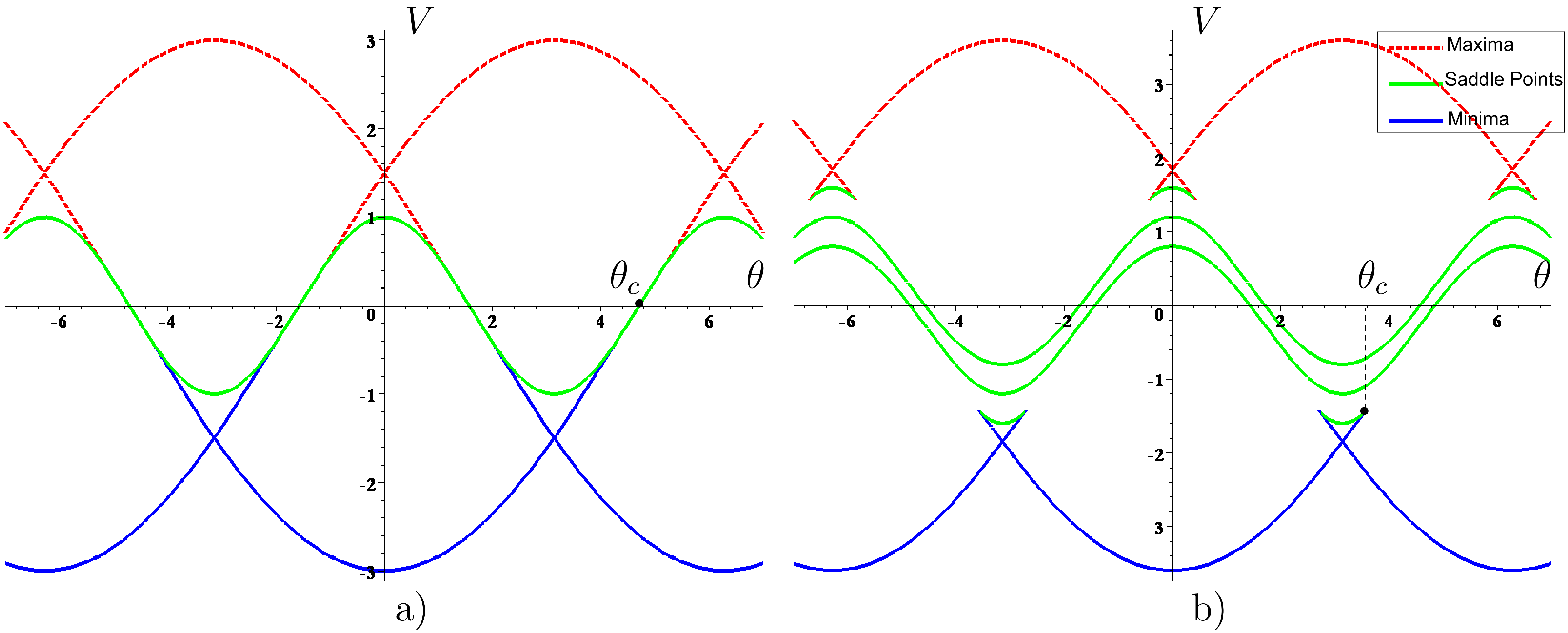
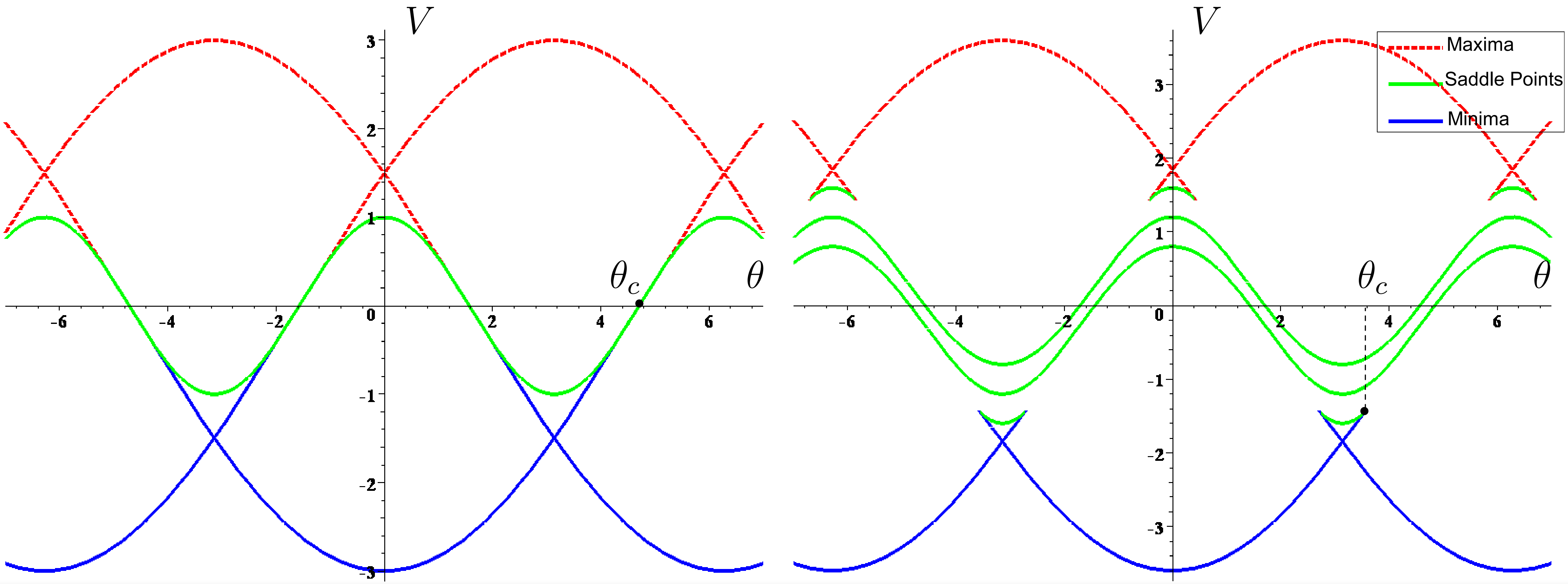


Figure 1: Extrema of the axion potential at $N = 3$ for equal quark masses (left), and for mass ratios 1:1.2:1.4 (right).

Axion Monodromy



Superradiance puts QCD’ in an overheated state.
Eventually, triggers a local phase transition,
latent heat is released in the form of hidden hadrons.
They may efficiently annihilate into photons/electrons.

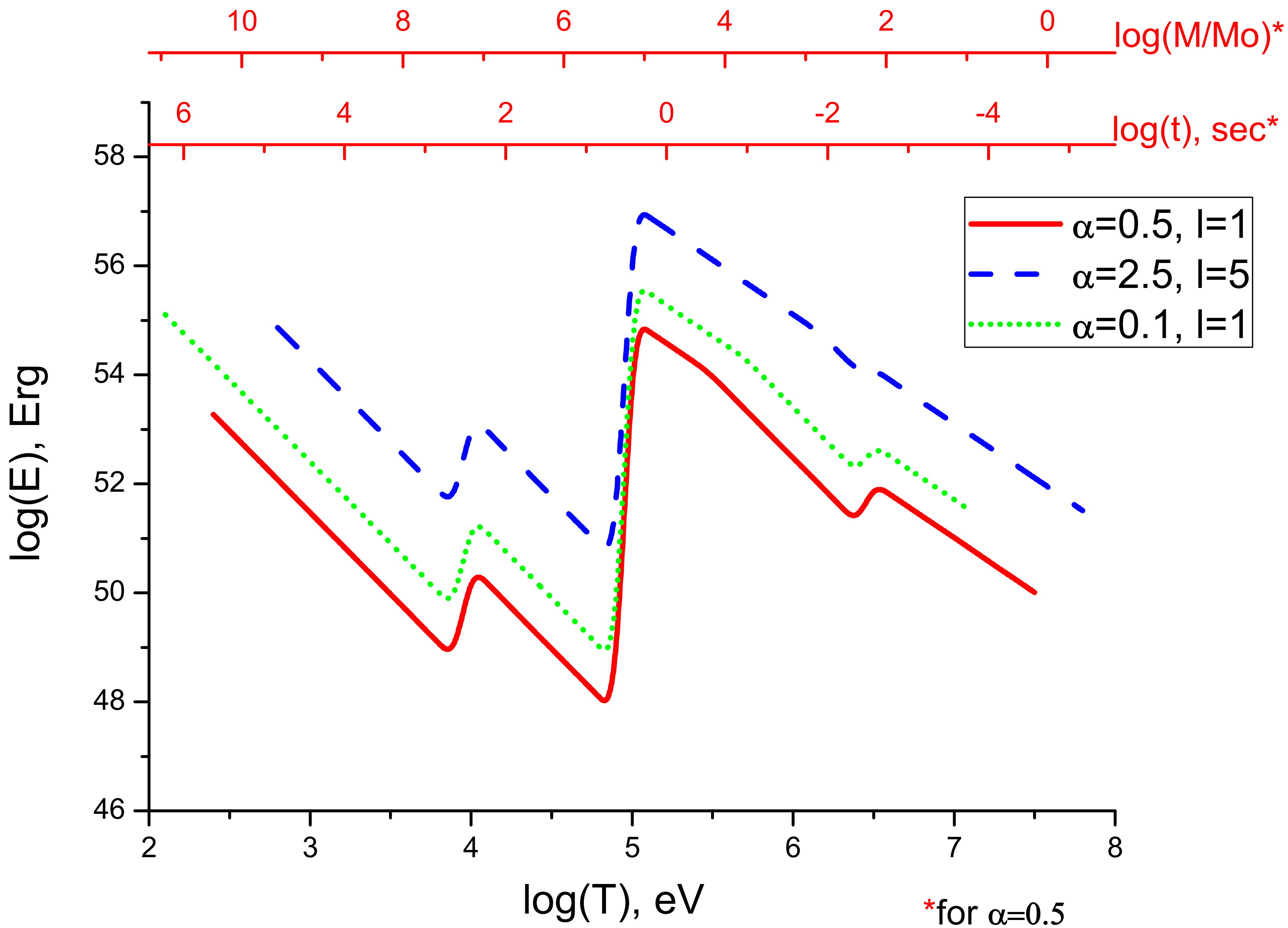


Figure 2: A total energy release as a function of a characteristic temperature of a fireball for different values of parameters α and l. Two red axes on top represent a corresponding black hole mass and time scale for $\alpha = 0.5$, $l = 1$. For the blue line a black hole mass is 5 times larger than the value on the red axis and a time scale is 5 times longer. For the green line a black hole is 5 times lighter and a time scale is $\sim 5^{1/3}$ times longer.

Conclusions

✳New physics does not necessarily mean high energies.

✳Opens a window for new experimental and observational probes.