Title: Conclusions and Outlook

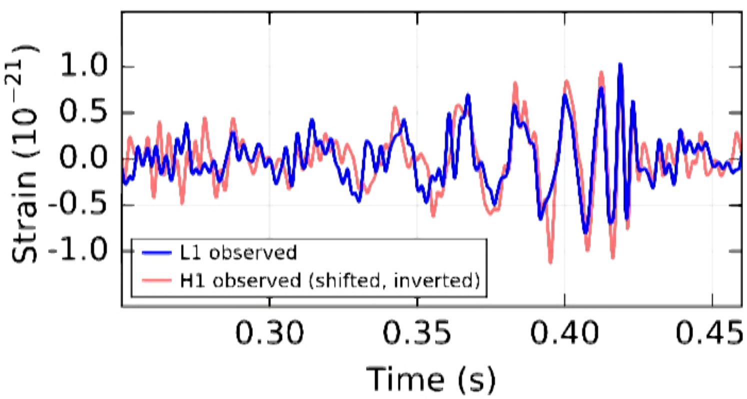
Date: May 11, 2018 02:30 PM

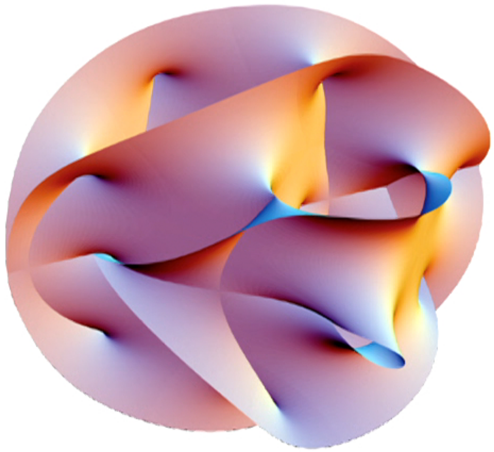
URL: http://pirsa.org/18050037

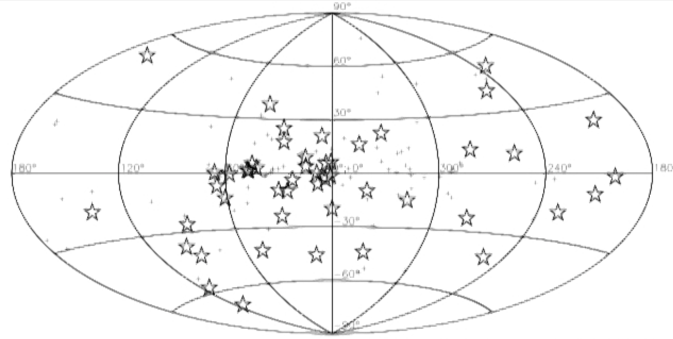
Abstract:

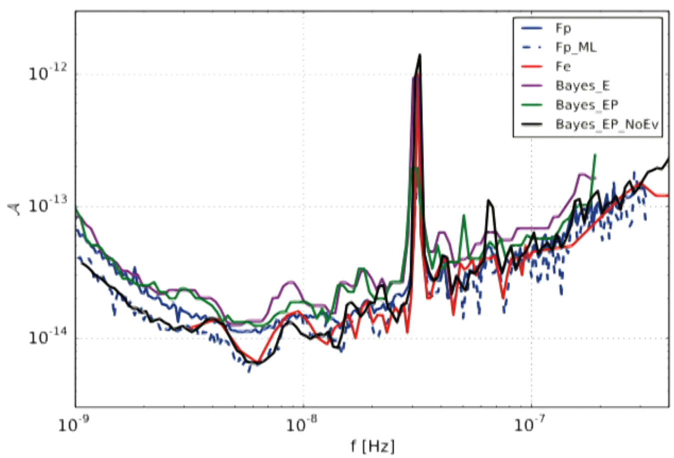
Looking for new fundamental physics with gravitational waves and black holes

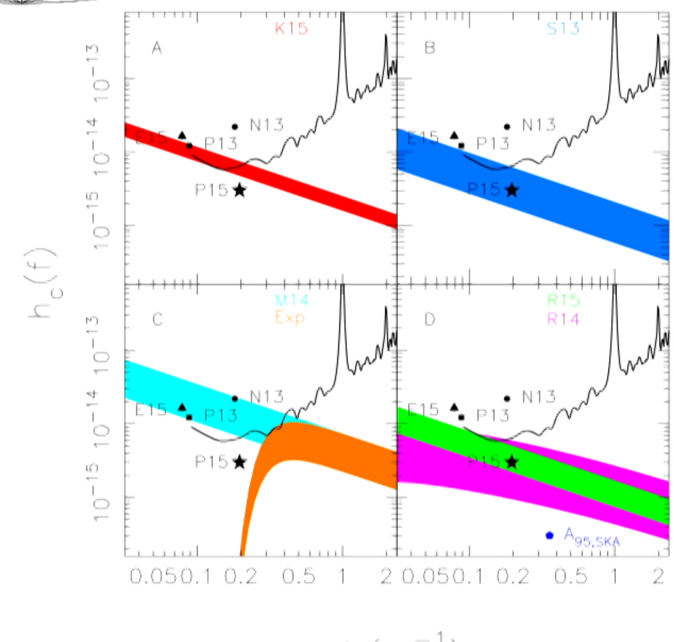
Sergei Dubovsky
CCPP (NYU)





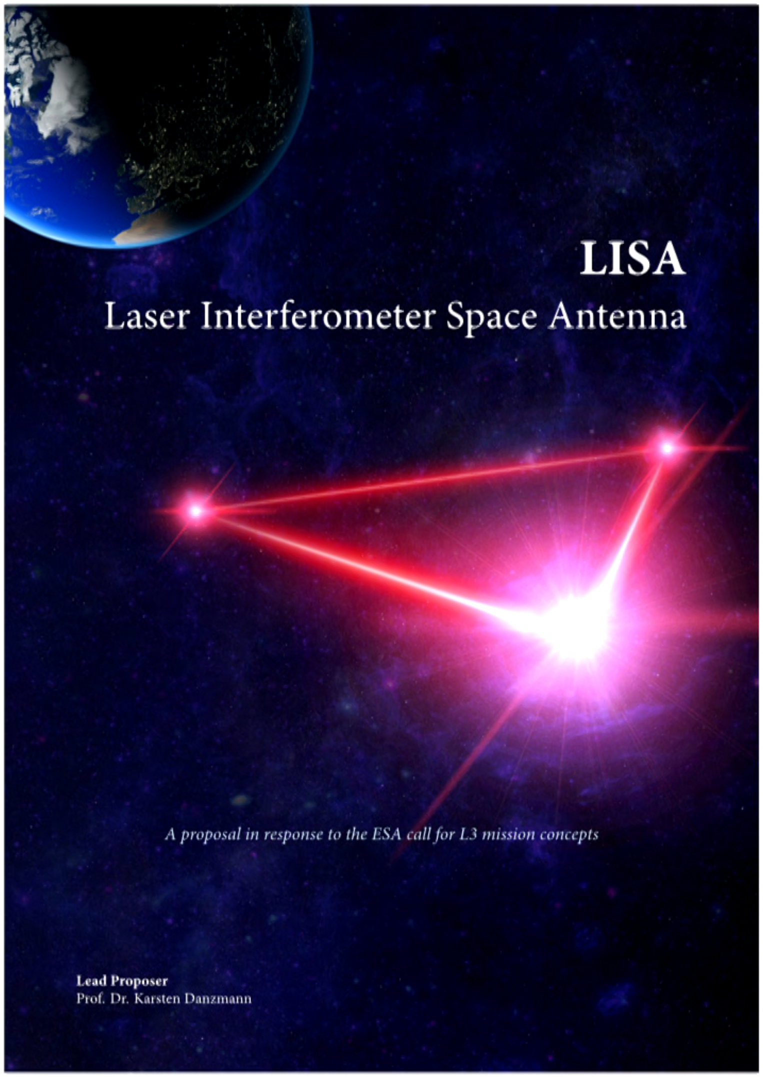


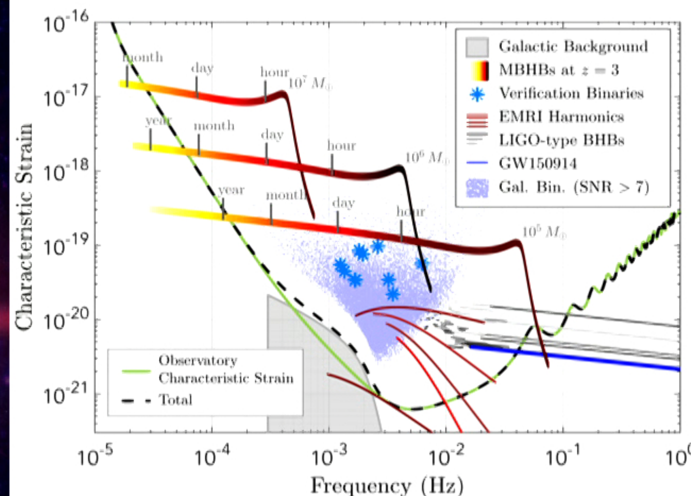




Becker et al, 1705.11022

Shannon et al, 1509.07320


LISA
Laser Interferometer Space Antenna
A proposal in response to the ESA call for L3 mission concepts
Lead Proposer
Prof. Dr. Karsten Danzmann


Characteristic Strain
Frequency (Hz)
Galactic Background
MBHBs at $z = 3$
Verification Binaries
EMRI Harmonics
LIGO-type BHBs
GW150914
Gal. Bin. (SNR > 7)
Observatory Characteristic Strain
Total
$10^7 M_\odot$
$10^6 M_\odot$
$10^5 M_\odot$
year
month
day
hour

The Dawn of Precision Black Hole Physics

- Totally exciting astronomy/astrophysics
- Can we also do "new fundamental" physics with these data?

New Fundamental Physics

(for the purpose of this talk):

impossible to decide true or false for an infinitely smart theorist equipped with an infinitely powerful computer

- ✦Shouldn't be possible to derive from known physics
- ✦Should be consistent with known physics
- ✦Should be consistent with known math
- ✦Should be consistent with known common sense

Three "Frontiers"
(at least)

- (High Energy) Precision Frontier: look for "high" energy modifications of gravity

- (Low Energy) Precision Frontier: look for IR modifications of gravity

- Energy Frontier: look for new particles at the "collider" energy scale

10 orders of magnitude in energy in our case!

“High Energy” modifications of gravity

recent detailed study by
Endlich, Gorbenko, Huang, Senatore, 1704.01590

$$S_{gr} \simeq M_{Pl}^2 \int \sqrt{g}(R + \frac{R^4}{\Lambda^6} + \dots)$$

Better to call high curvature rather than high energy

$$\Lambda^{-1} \sim 10 \text{ km}$$

- Consistent and familiar framework
- Only high frequency detectors (LIGO,...) have a shot
- Need to be *really* lucky
- Interesting theoretical challenge to construct a UV model

“Low Energy” modifications of gravity: graviton mass

SD, hep-th/0409124
SD, Tinyakov, Tkachev, hep-th/0411158
SD, Tinyakov, Zaldarriaga, 0706.0288

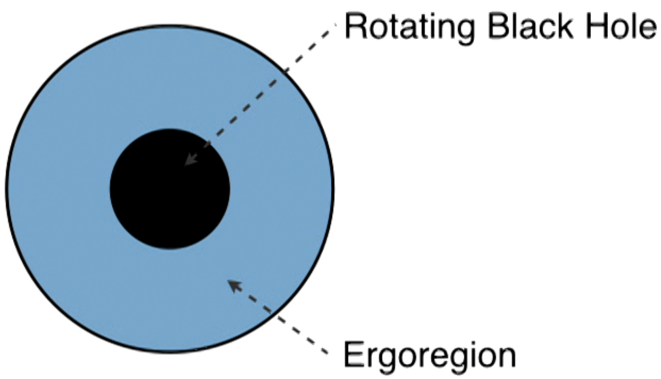
- Gravitational waves are massive
- Scalar and vector perturbations are the same as in GR
- Flat cosmological solutions are the same as in GR
- LIGO bound on the graviton mass is meaningful
- Need to be lucky
- Interesting theoretical challenge to construct a UV model

...and signals may propagate instantaneously...

“collider regime:”

Penrose Process

Penrose’69; Zeldovich’71; Misner'72; Starobinsky’73



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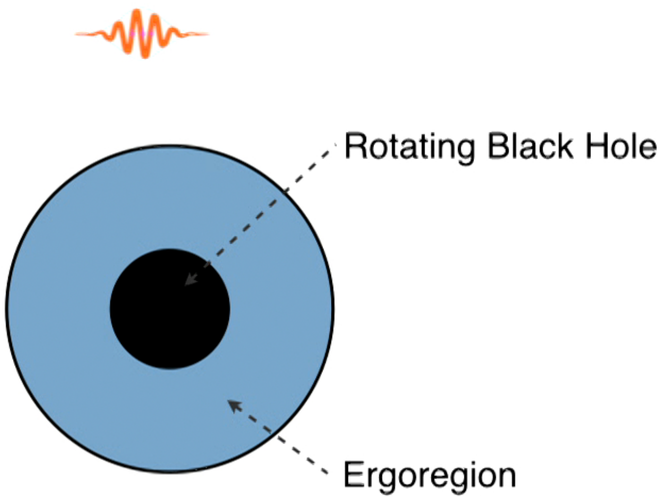
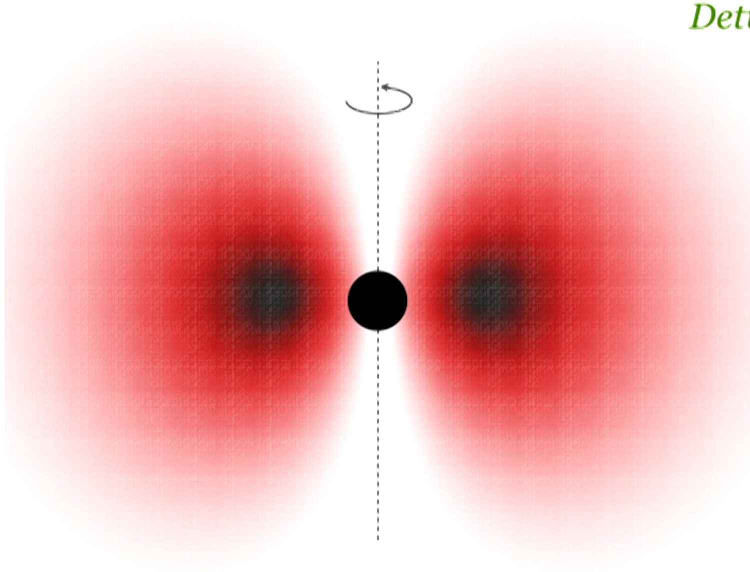


Extracts angular momentum and mass from a spinning black hole

Superradiance for a massive boson

Press & Teukolsky'72

Damour et al.'76; Gaina et al.'78; Detweiler'80; Zouros & Eardley'79;



Particle Compton Wavelength comparable to the size of the Black Hole

Gravitational Atom in the Sky

Arvanitaki, Dimopoulos, SD, Kaloper, March-Russel 0904.4720
Arvanitaki, SD 1004.3558

Far from the Black Hole: Newtonian Potential

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

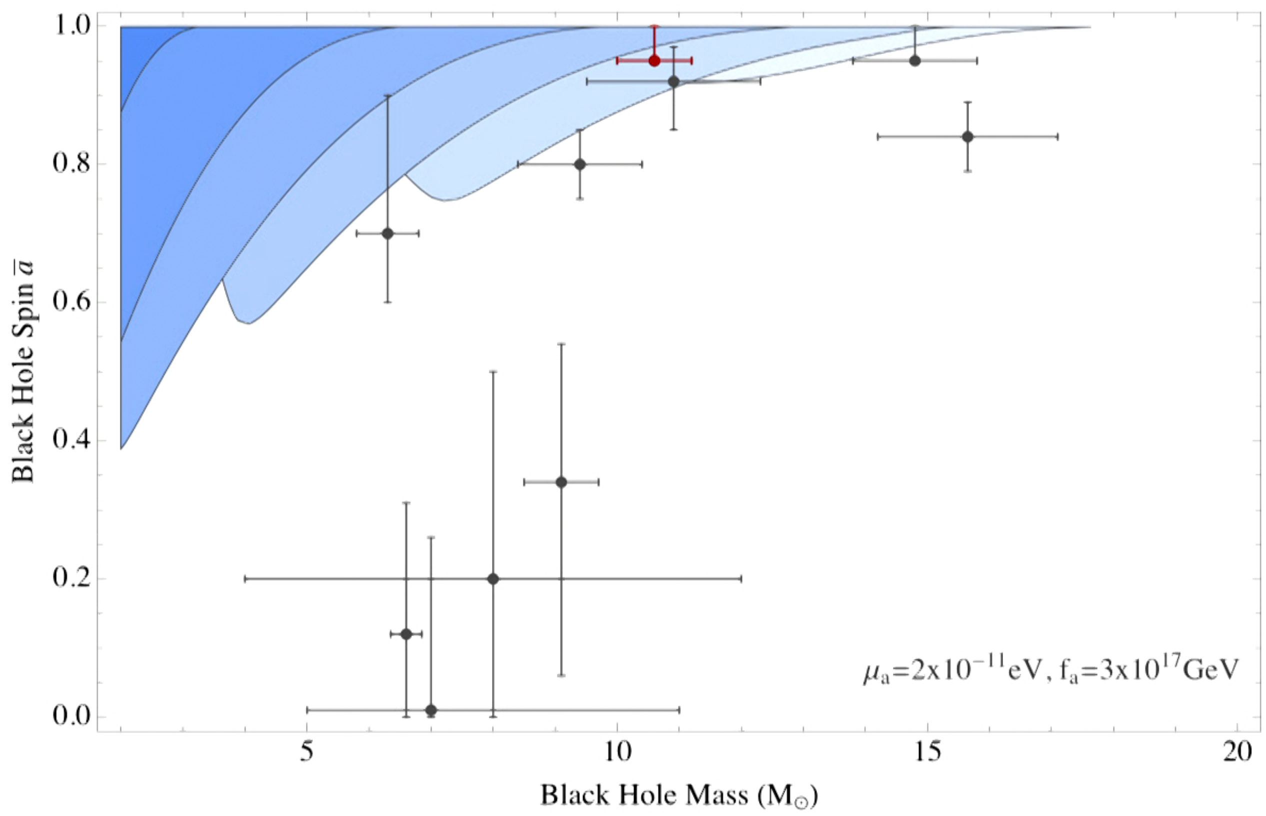
$$E_{\rm binding} = -\frac{\alpha_{EM}^2 m_e}{2n^2} \quad \longrightarrow \quad E_{\rm binding} = -\frac{\alpha^2 \mu_a}{2n^2}$$

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

Occupation number

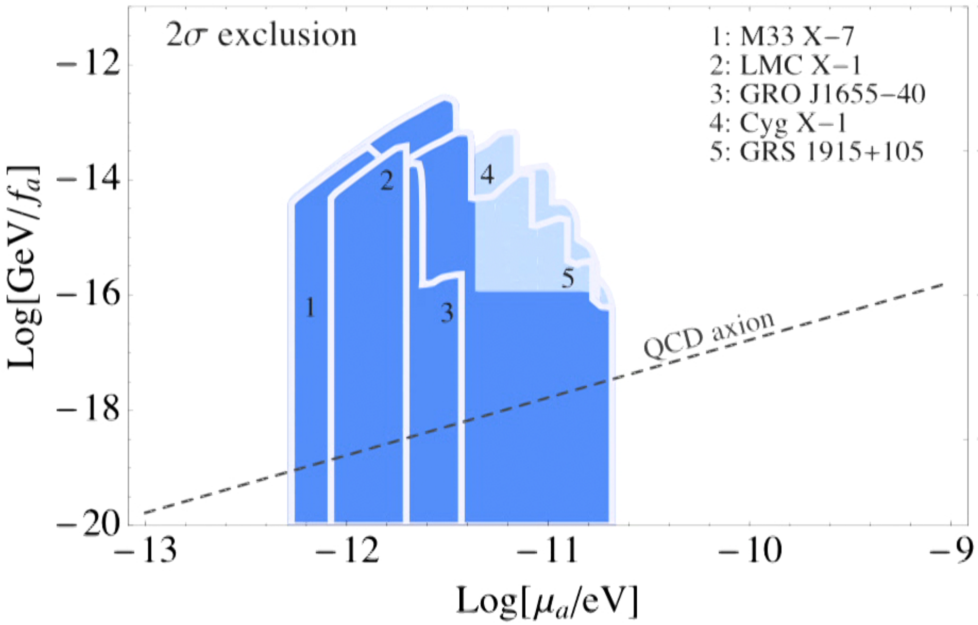
$$1 \quad \longrightarrow \quad 10^{75}$$

Spin Gap for the QCD Axion



Combined Exclusion Plot

Arvanitaki, Baryakhtar, Huang 1411.2263

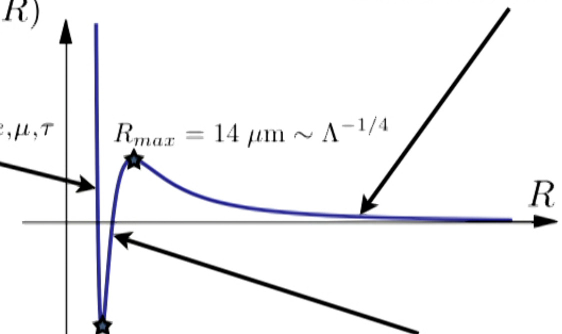


Standard Model Landscape

Arkani-Hamed, SD, Nicolis, Villadoro hep-th/0703067

What are the vacua in the Standard Model?

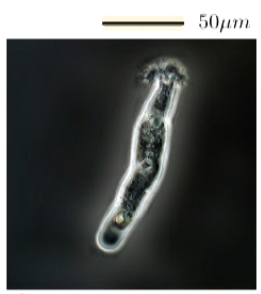
Radion Potential



$AdS_3 \times S_1$

vacuum with

$$2\pi R_0 \approx 20\mu\text{m}$$
$$l_{AdS} \approx 3.7 \cdot 10^{27} cm$$



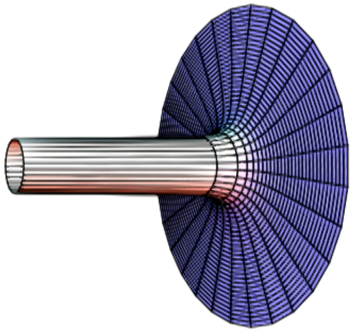
Trichamoeba sp.

typical habitant of the SM Landscape

Many More Vacua

Extremal Reissner-Nordstrom black holes connect between flat and $AdS_2 \times S_2$ vacua

$$ds^2 = (1 - \frac{r_h}{r})^2 dt^2 - \frac{dr^2}{(1 - \frac{r_h}{r})^2} - r^2 d\Omega_2^2$$



Particles in $AdS_3 \times S_1$ vacuum

- All of the Standard Model
- Radion (a cousin of graviton) with

$$m_R \sim \frac{R_0^{-2}}{M_{Pl}} \sim 10^{-40}\mathrm{GeV}$$

- Axion (a cousin of photon/Aharonov-Bohm flux) with

$$m_a \sim eR_0^{-2}\mathrm{e}^{-2\pi R_0 m_e} \sim \mathrm{e}^{-10^8}$$

$$f_a^2 \sim \frac{1}{2\pi R_0 e^2}$$

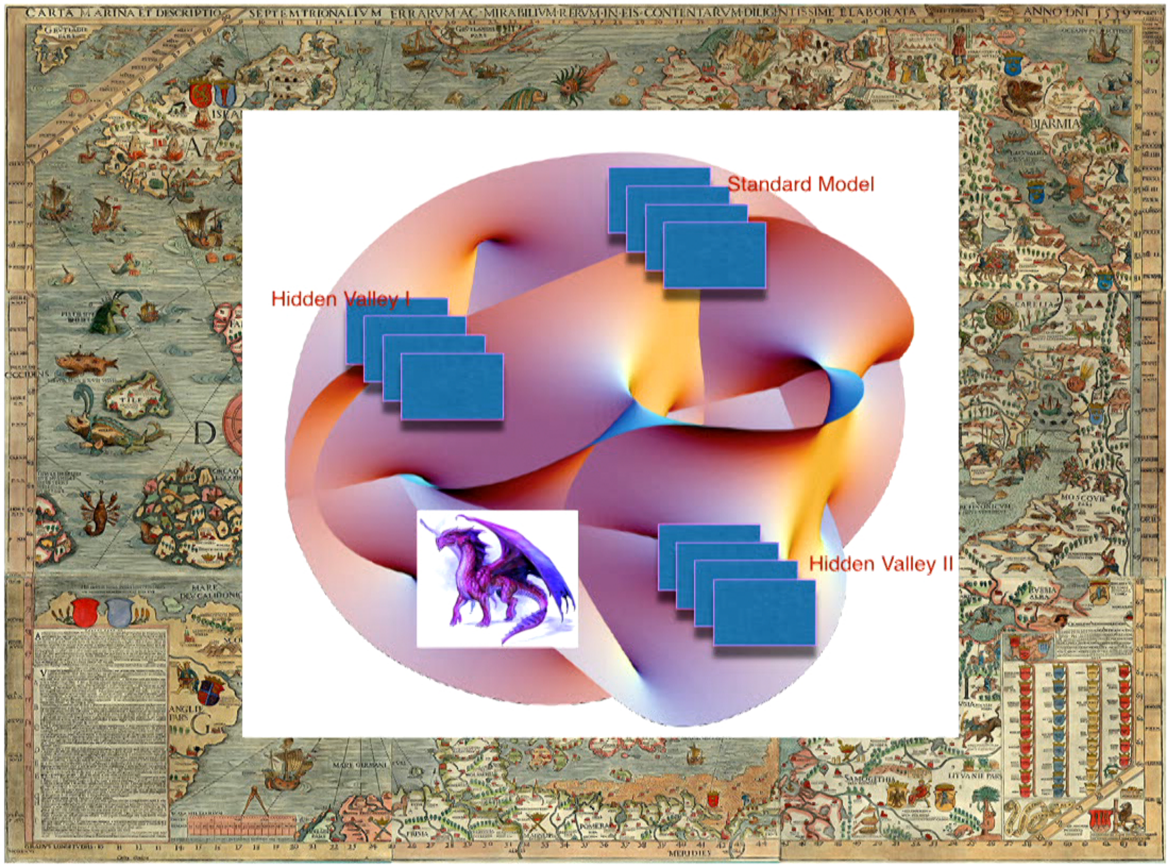
Exponentially light axion comes from power-like small f_a

String Lanscape:

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

Ultimate Unification of
Fundamental Physics and Geography


ISLANDIA
FINMARCHIA
BIARMIA
SCANDIA
NORVEGIA
SVECIA
GOTHIA
DANIA



In both cases no reasons to apply Occam's razor

Axions in String Theory

Exactly the same story! Starting from a higher dimensional theory, and very small and very complicated internal compact manifold

$$\mu_a \propto e^{-\frac{M_{Pl}}{f_a}}$$

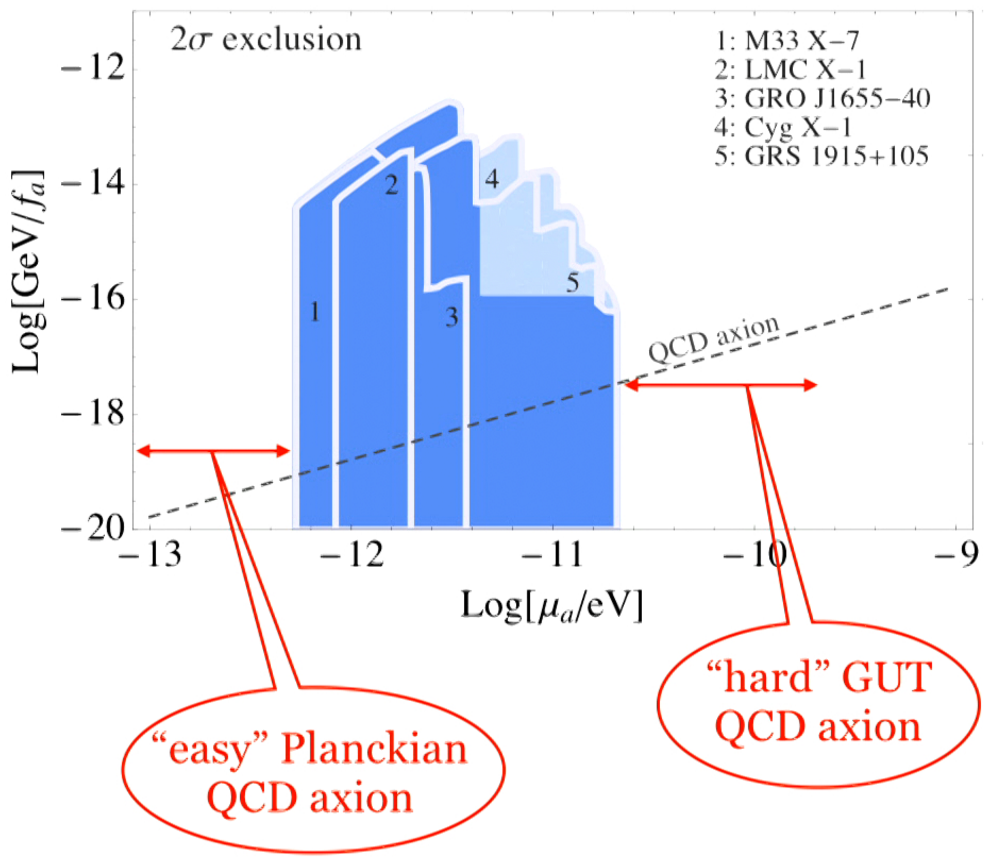
suggests

$$\frac{M_{Pl}}{f_a} \sim 100$$

the same factor is suggested by gauge coupling unification

Combined Exclusion Plot

Arvanitaki, Baryakhtar, Huang 1411.2263



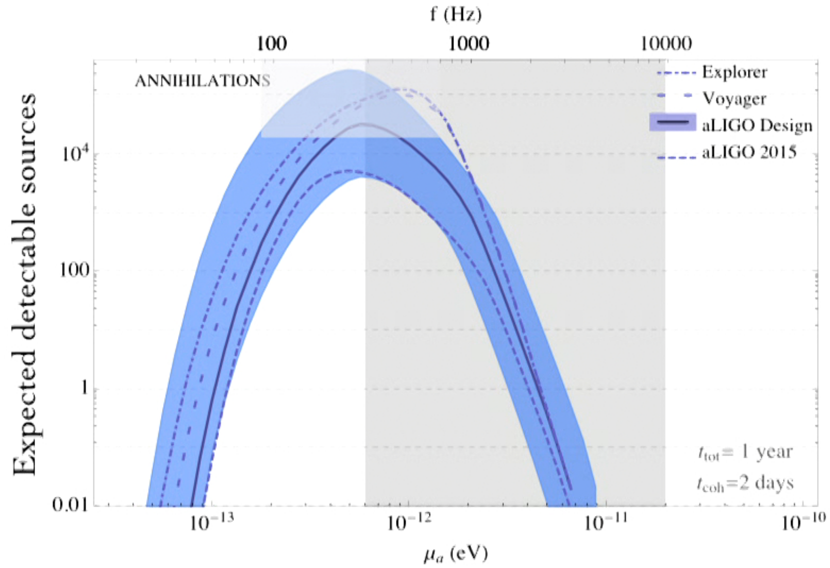
Planckian QCD axion

- This is what we mostly talked about. l=1, small α regime
- Spindown and annihilations signals
- Suggests no new physics up to Planck scale. Somewhat surprising theoretically, but maybe not crazy given how much new physics we saw at the LHC.

Expected Events from Annihilations

Arvanitaki, Baryakhtar, Dimopoulos, SD, Lasenby 1604.03958

Large uncertainties coming from tails of BH mass distribution

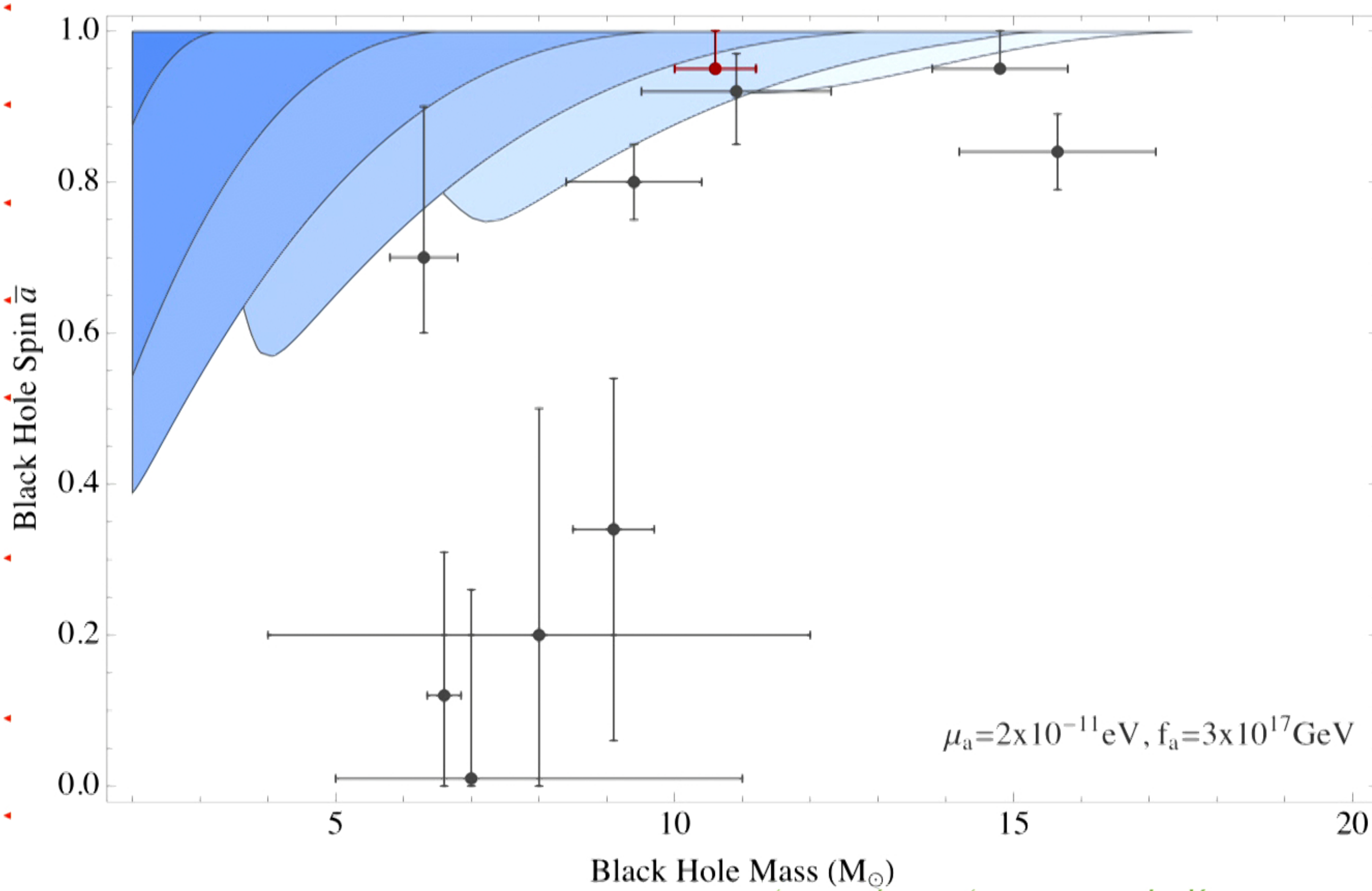


Pessimistic: flat spin distribution and 0.1 BH/century

Realistic: 30% above spin of 0.8 and 0.4 BH/century

Optimistic: 90% above spin of 0.9 and 0.9 BH/century

GUT QCD axion



GUT QCD axion

- Running out of BHs. l>1, large α regime
- Spindown and annihilations signals are too small
- Most conservative from theory viewpoint
- Need to think how to go for high frequencies

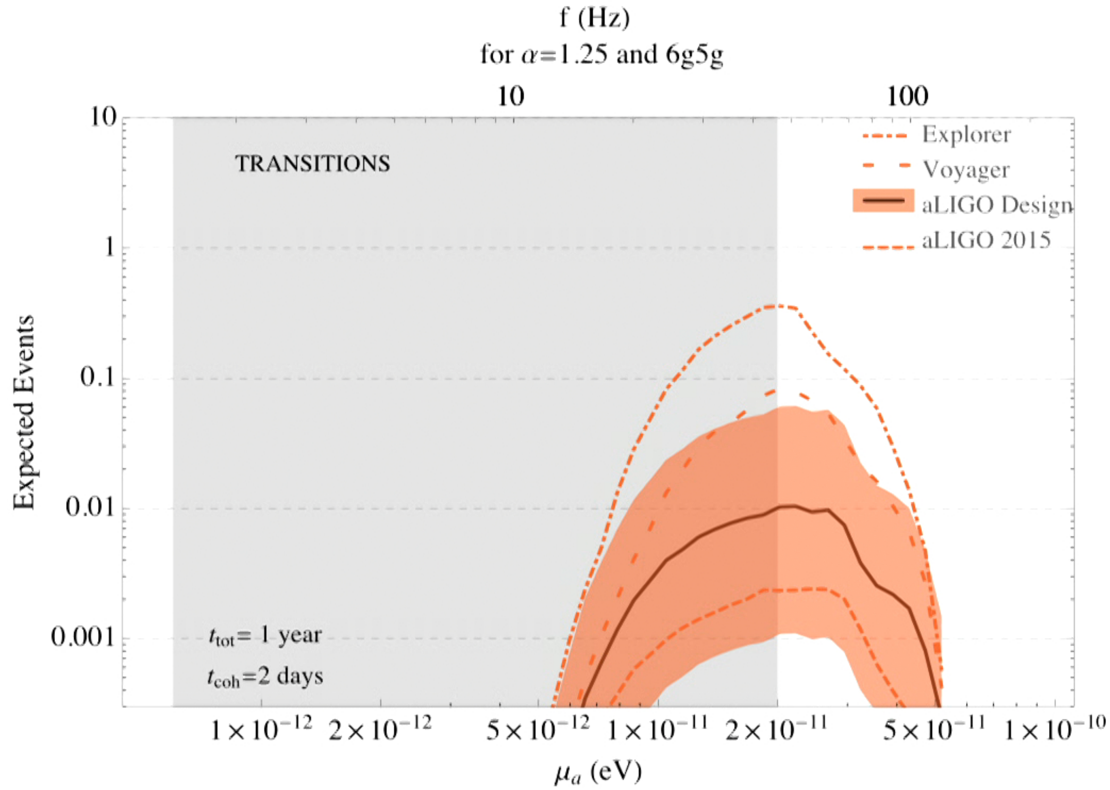
Arvanitaki, Geraci 1207.5320

- Need to understand axion non-linearities. Bosenova burst?
- Need to look for possible ways to transmit GW power into lower frequencies:
- 6g-5g transitions?
- Resonances in binary systems?

Baumann, Sheng Chia, Porto 1804.03208

Transition Events Estimates

- Lower number of observable sources due to signal duration



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Arvanitaki, Geraci 1207.5320

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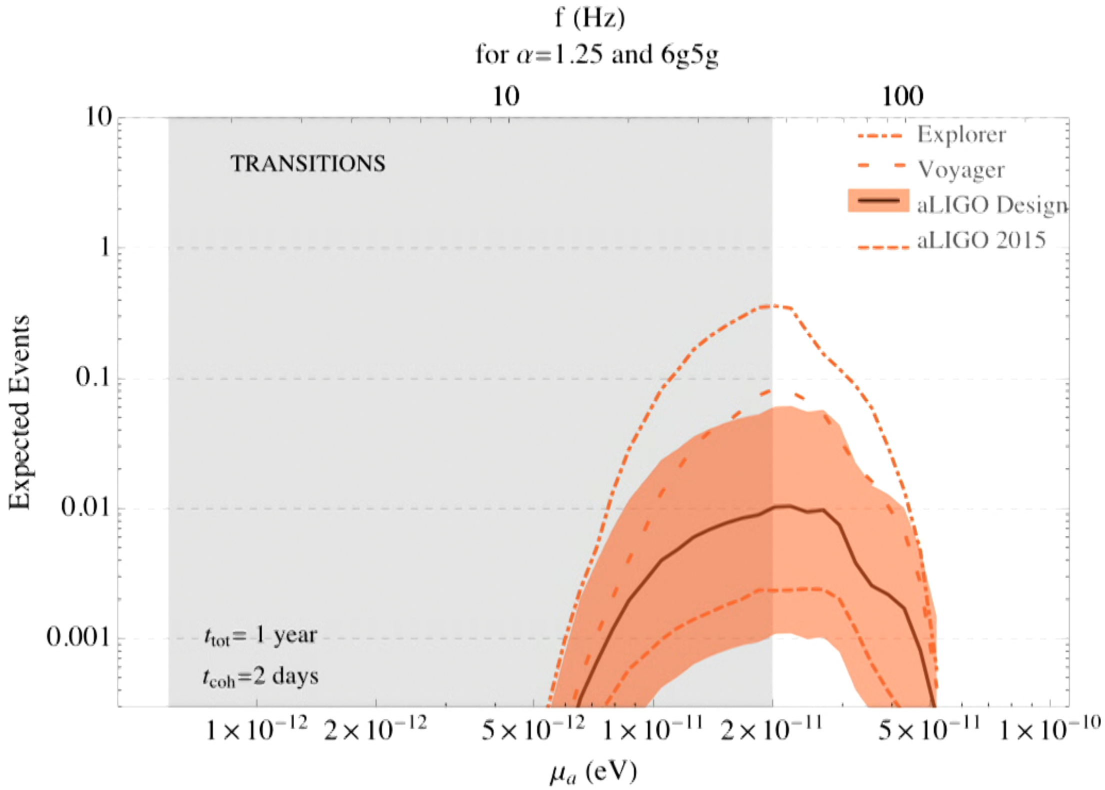


Remaining 10 orders of magnitude in masses:

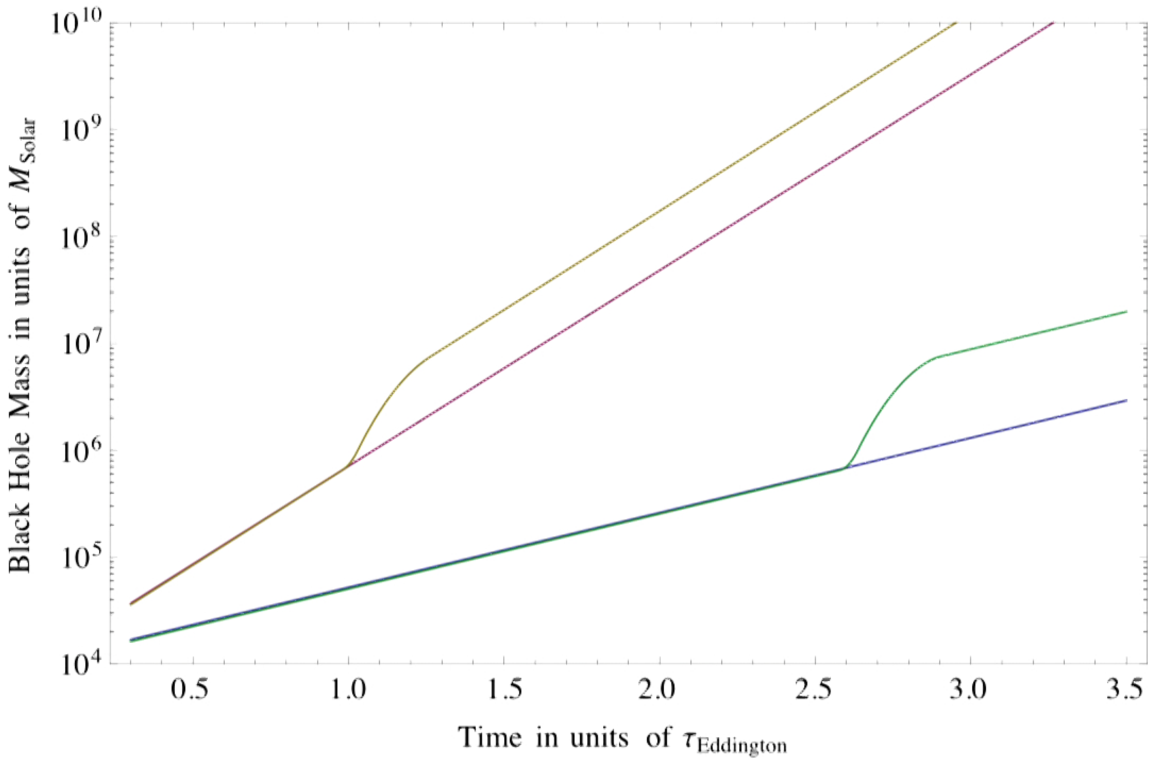
Many ways to be inventive!

Some of it was covered in Richard Brito talk

Effects on BH accretion rate

Arvanitaki, SD 1004.3558

Axion spins BH down and accelerates the accretion rate



Axion Monodromy

SD, Gorbenko, 1012.2893

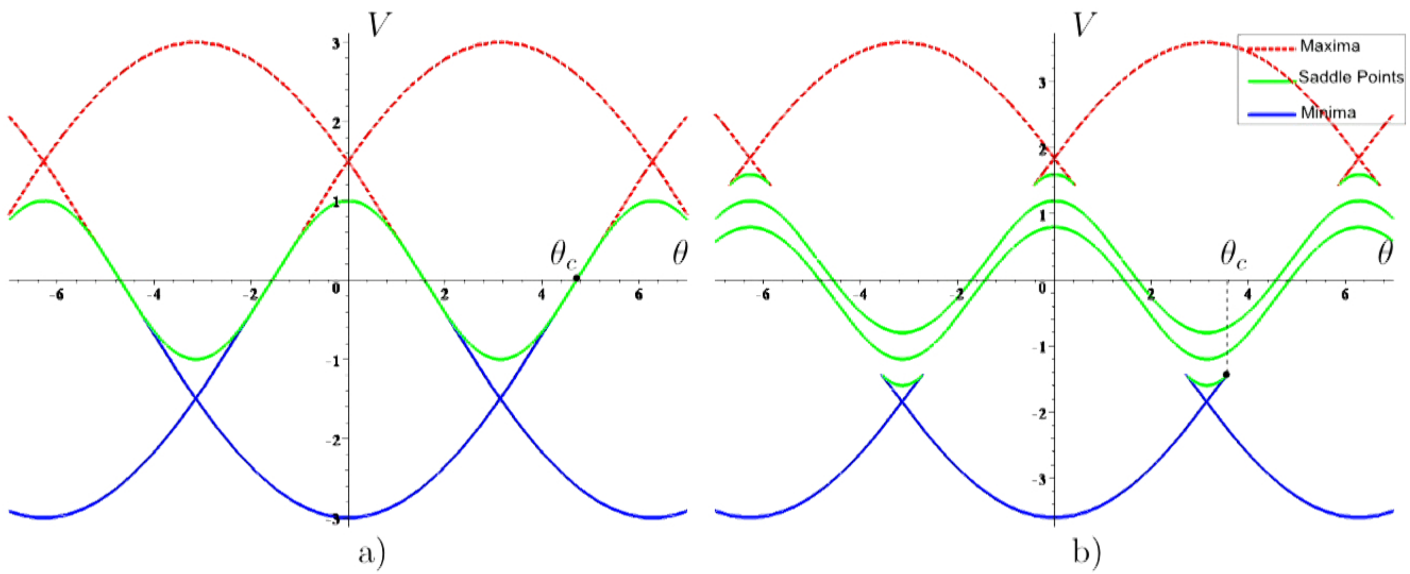


Figure 1: Extrema of the axion potential at $N = 3$ for equal quark masses (left), and for mass ratios 1:1.2:1.4 (right).

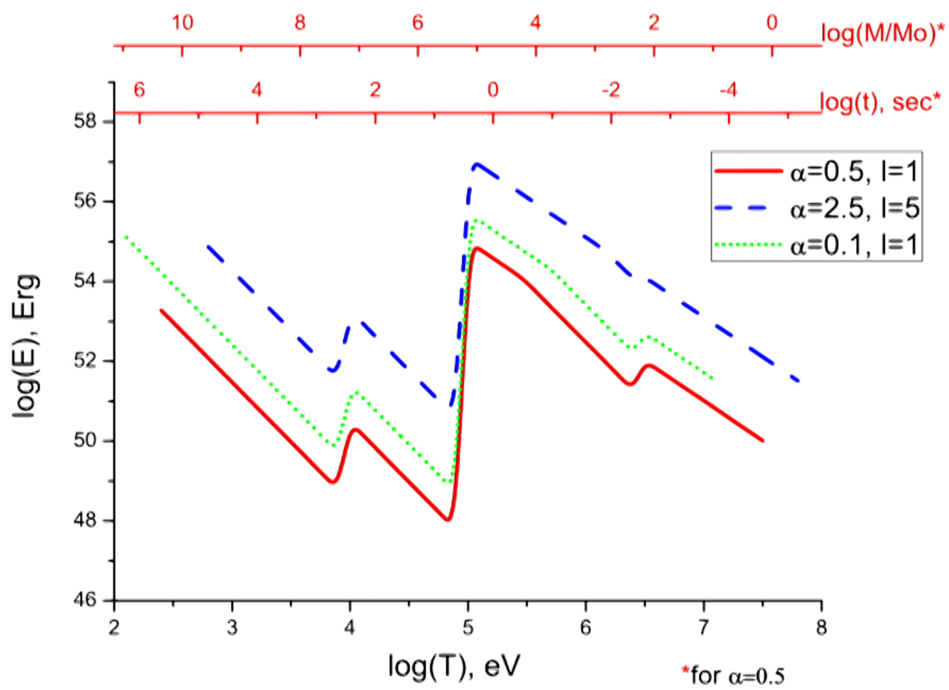


Figure 2: A total energy release as a function of a characteristic temperature of a fireball for different values of parameters α and l. Two red axes on top represent a corresponding black hole mass and time scale for $\alpha = 0.5$, $l = 1$. For the blue line a black hole mass is 5 times larger than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

- Thank you Mina, Masha, William and Robert!
- Thank you everybody!
- We need to repeat this!
- Hopefully one of the next times we will be talking also about mass/spin determinations of axions