# Future perspectives on axion dark matter


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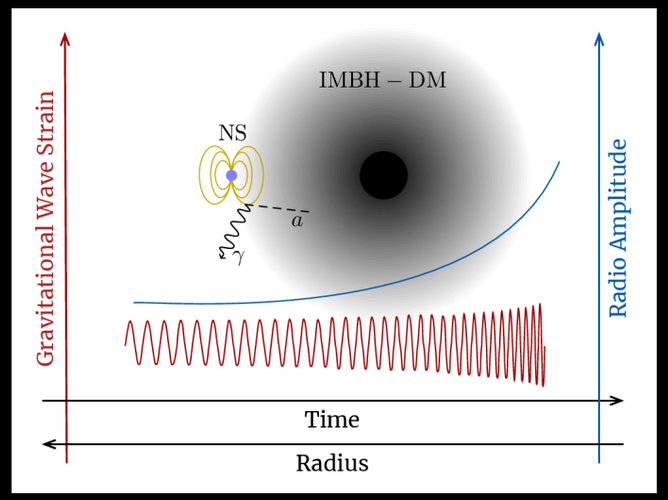
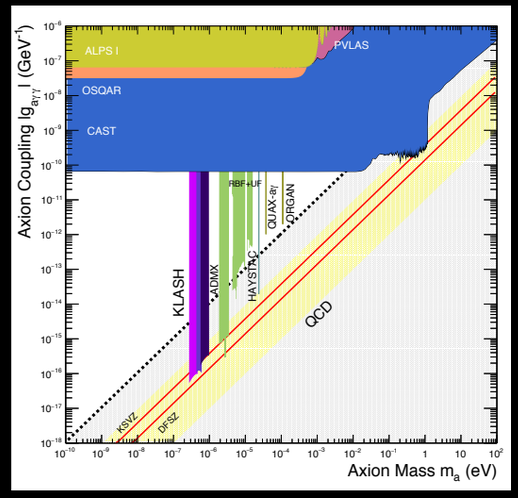
# OUTLINE

1. Recent work




2. Present work




3. Future projects

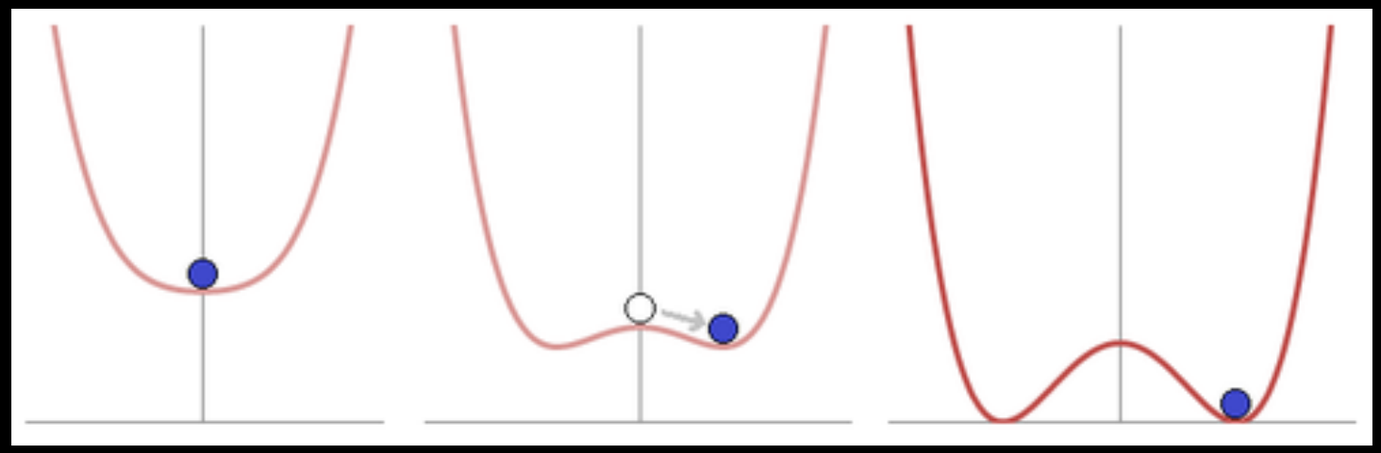
# Recent work by the group

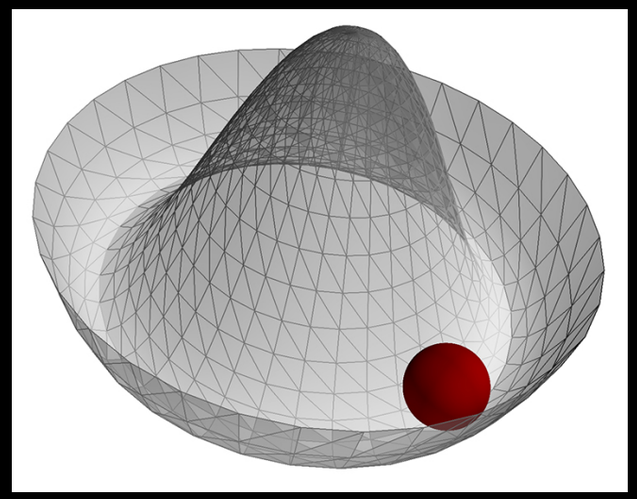
Recent focus on light particles as the dark matter: the QCD axion



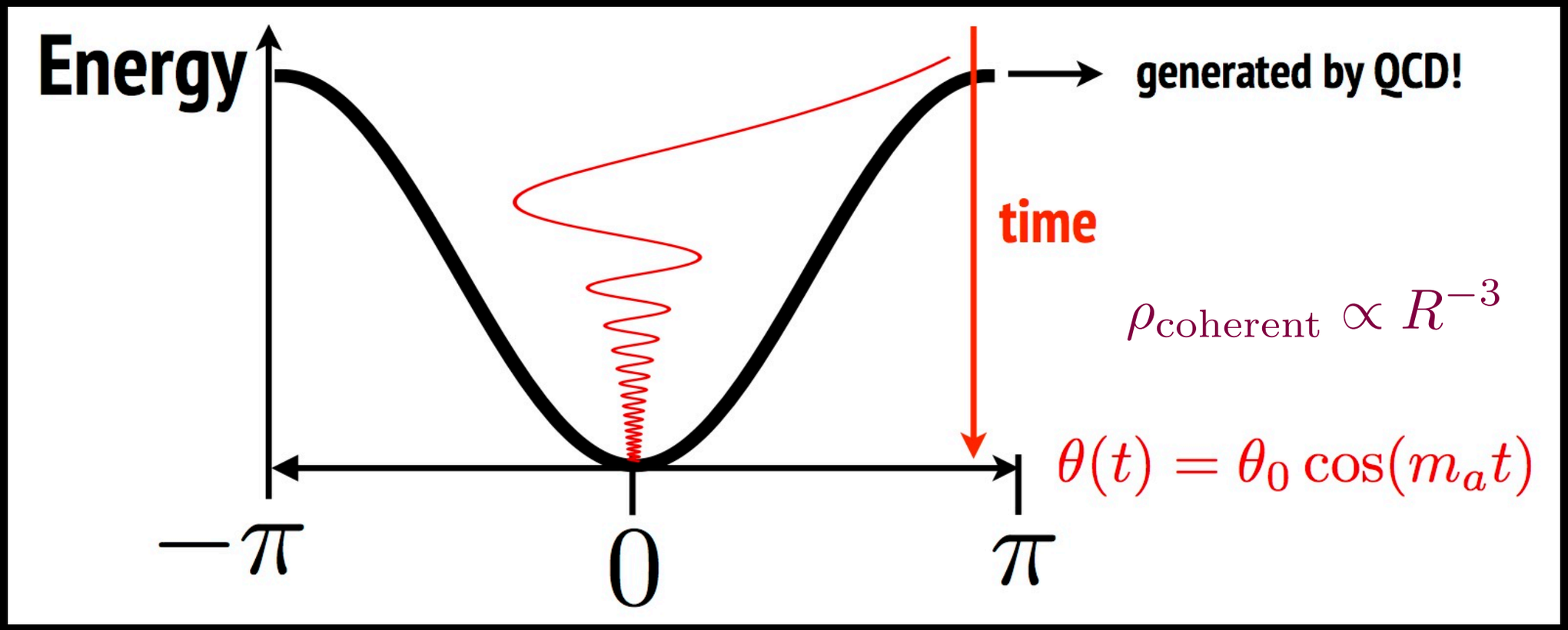
Steady growth in the interest on the axion

# Early-Universe dynamics of the axion



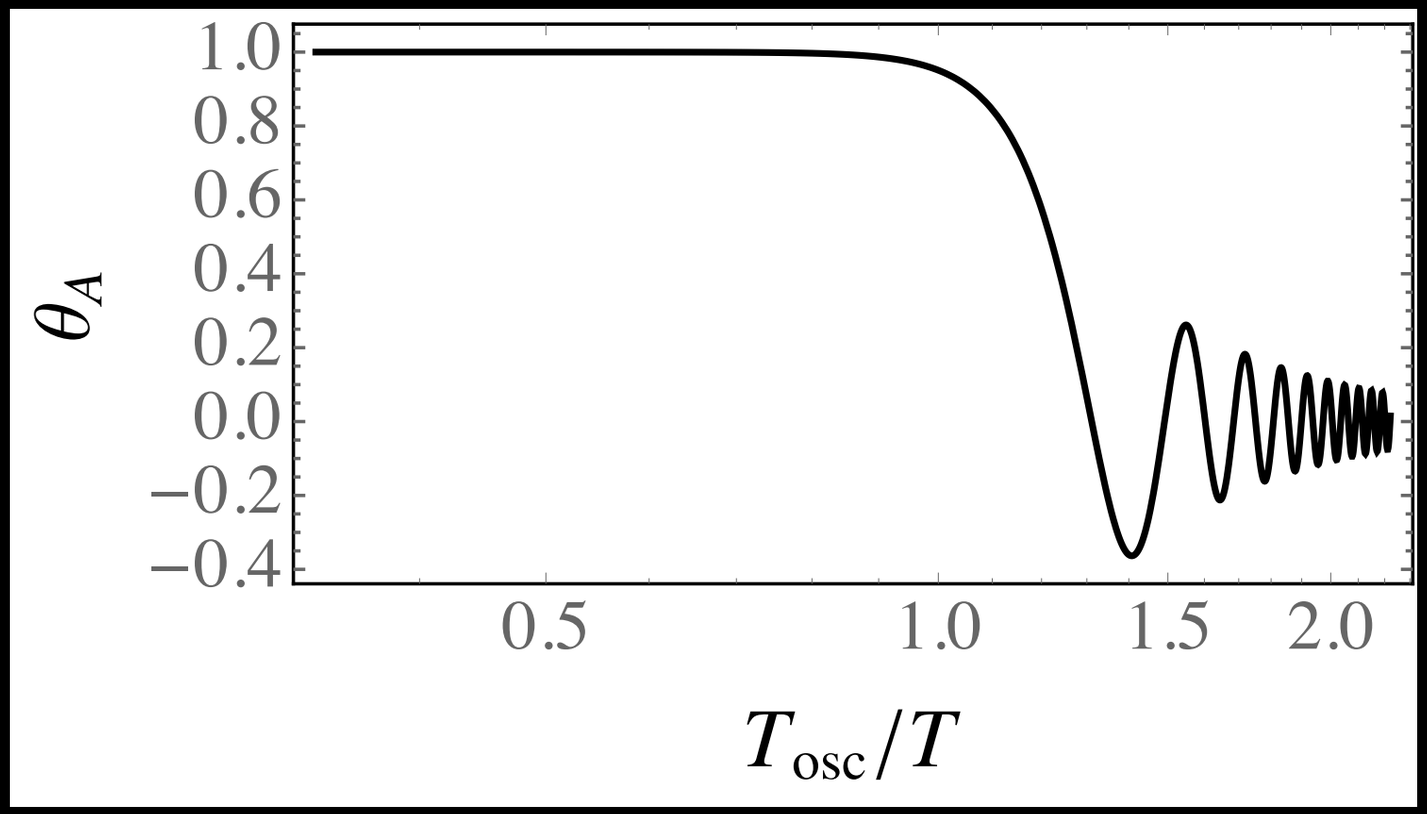


$T \gtrsim f_a$ $T \sim f_a$ $T \lesssim f_a$ $T \sim \Lambda_{\rm QCD} \ll f_a$



# The parameter space of the QCD axion

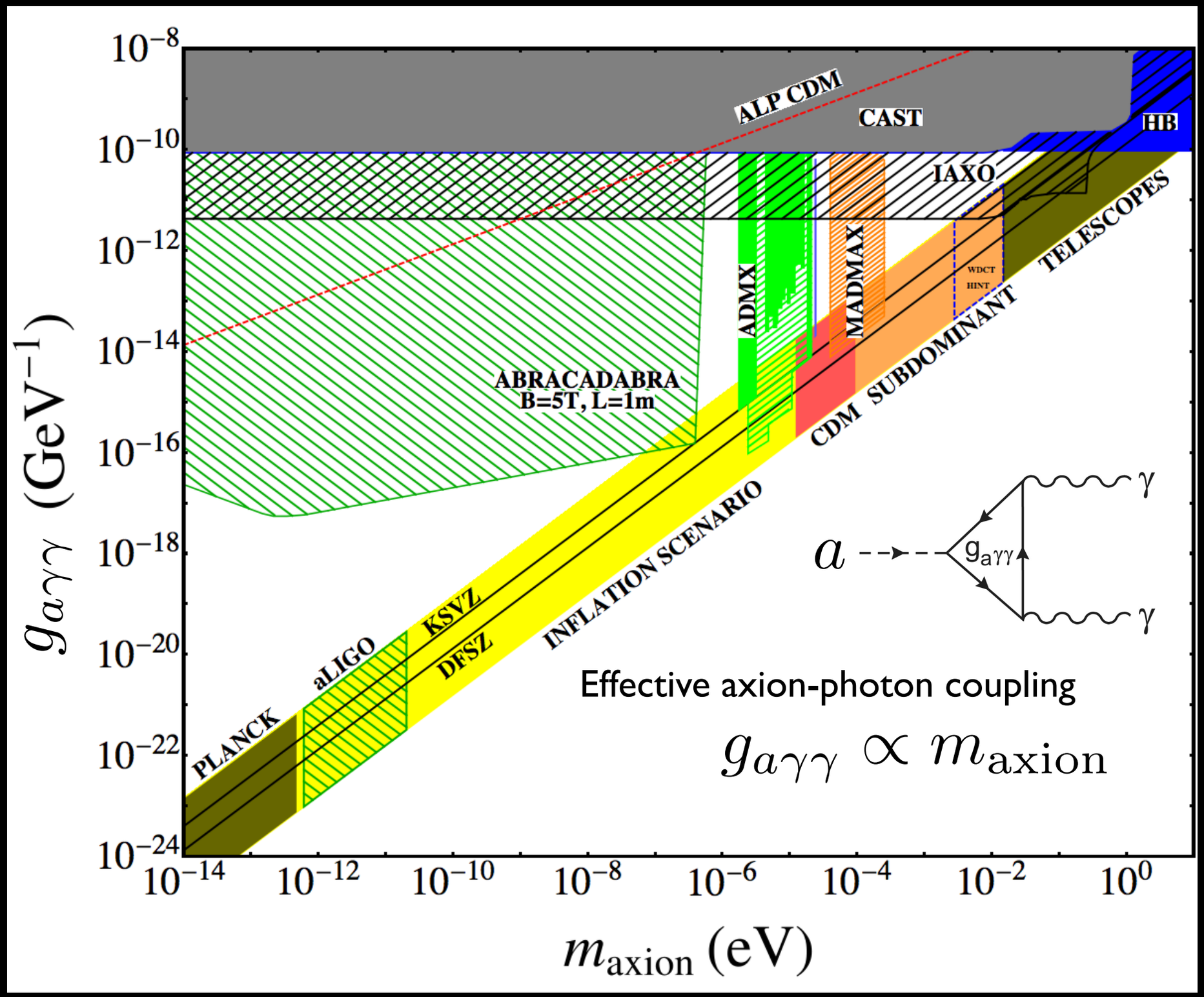
$$\ddot{\theta}_A + 3H\dot{\theta}_A + m_A^2(T)\sin\theta_A = 0$$



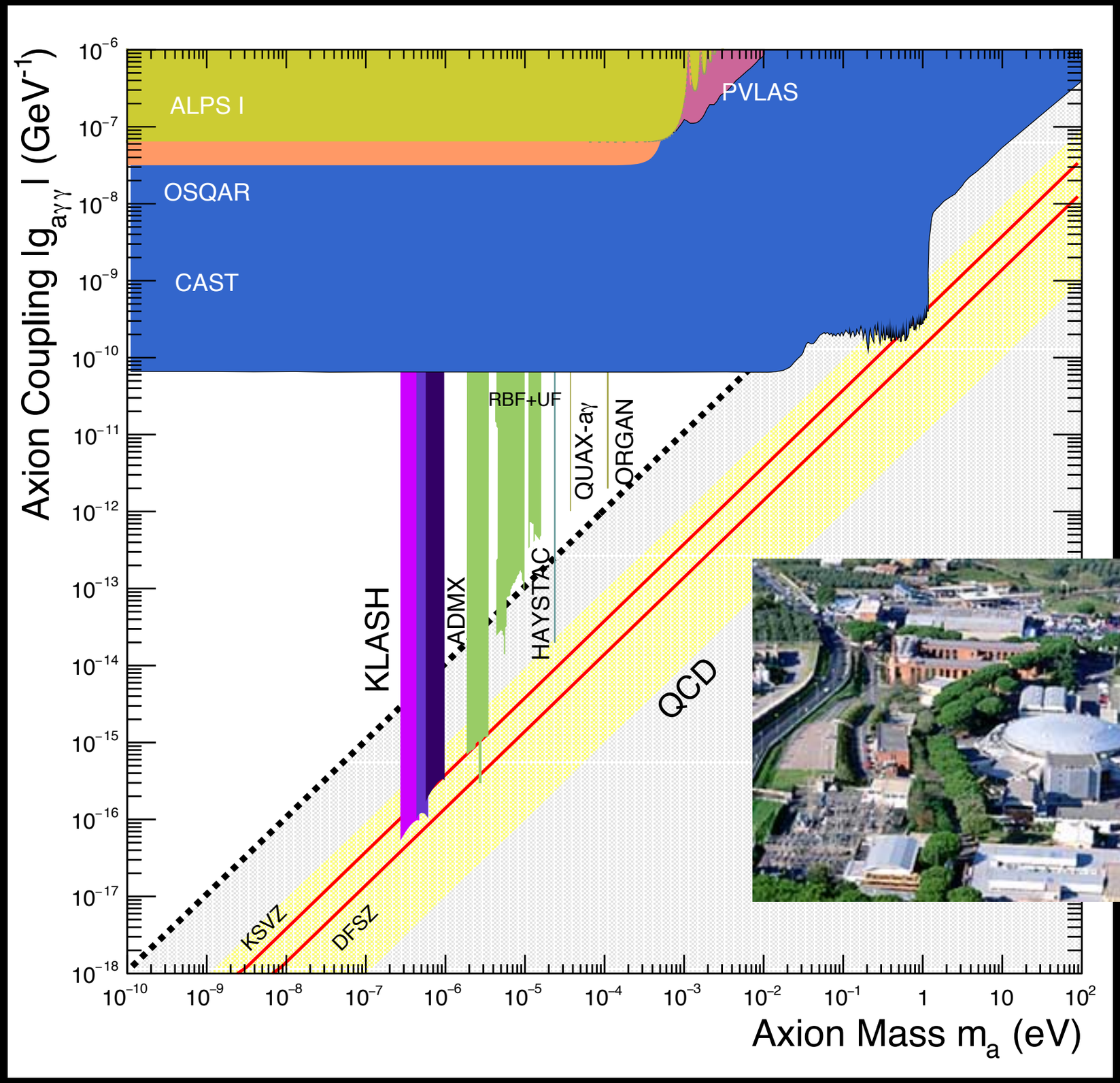

$$m_A(T_{\rm osc}) \approx 3H(T_{\rm osc})$$

Depends on particle physics  Depends on cosmology

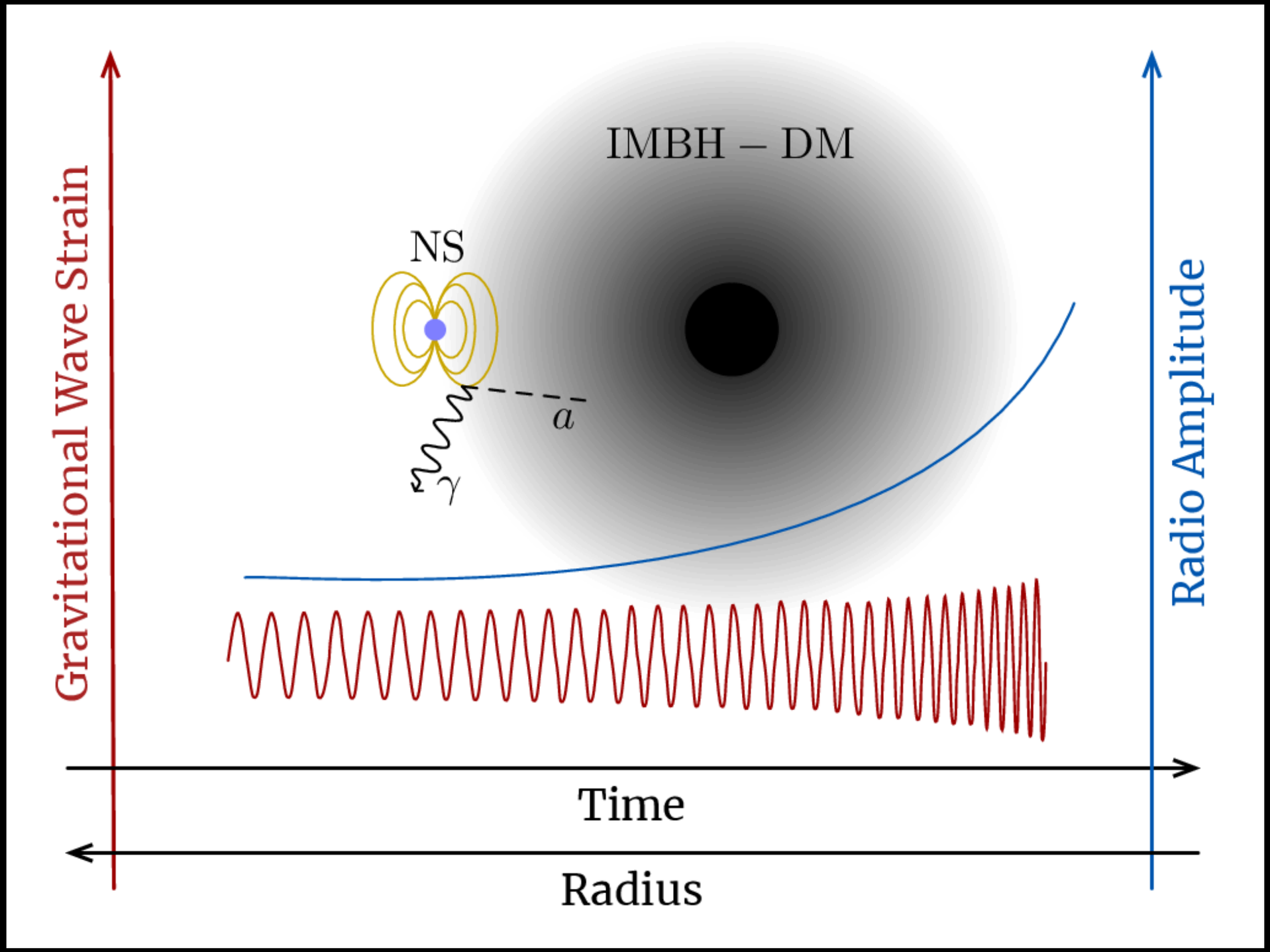
# One-parameter theory, falsifiable



# KLoe magnet for Axion SearcH (KLASH)

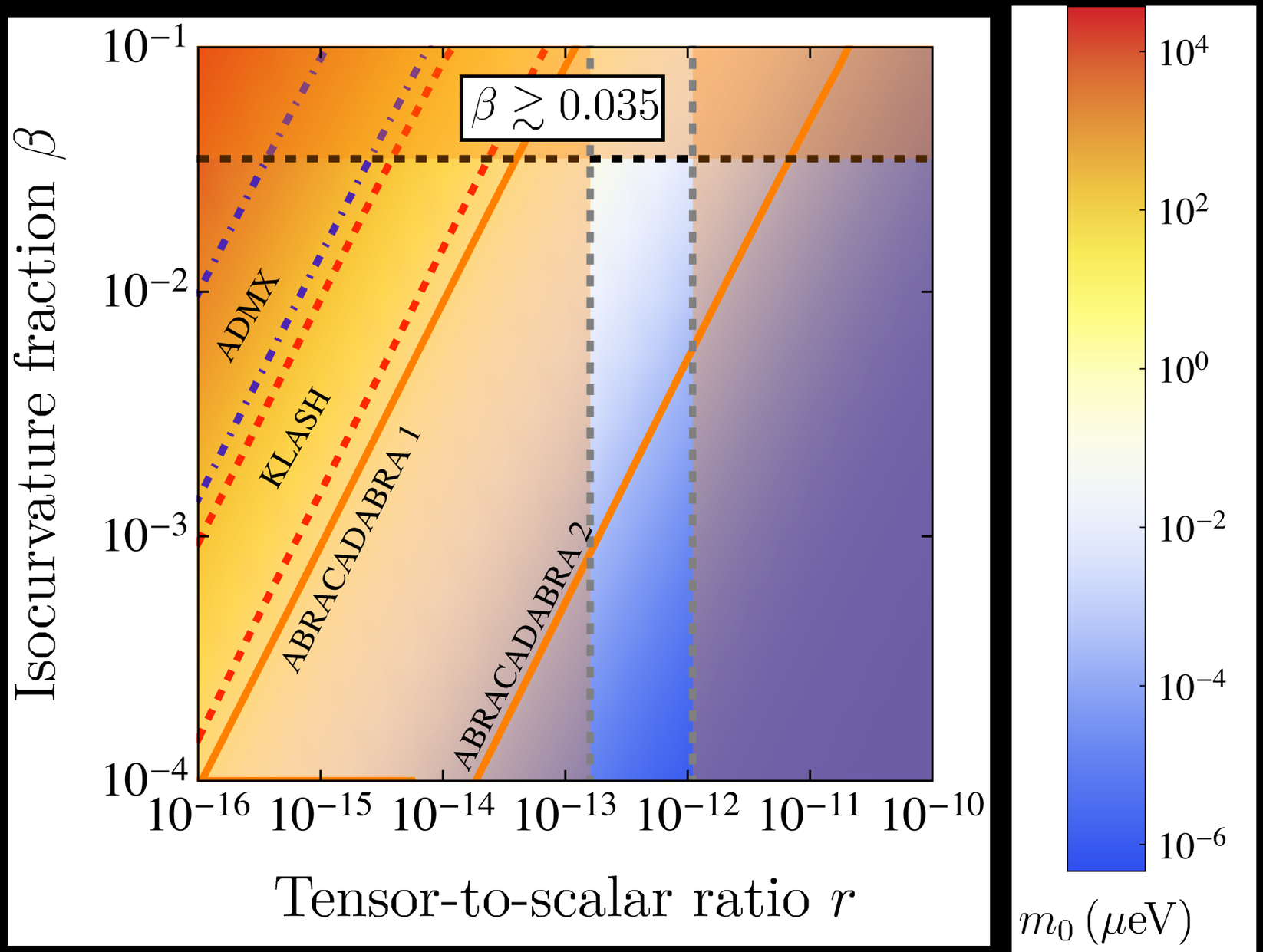


# Multi-messenger axion-GW astrophysics




T.D.P. Edwards *et al.* 1905.04686

# The dark matter axion mass




T. Tenkanen & **LV**, JCAP **1908**, 033 (2019), 1906.11837

# Present work

# Review on axion models

## The landscape of QCD axion models

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*Institute for Theoretical Physics Amsterdam and Delta Institute for Theoretical Physics,*
*University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands*

# Axion miniclusters

Regions with overdensities $\Phi = \delta\rho/\rho$

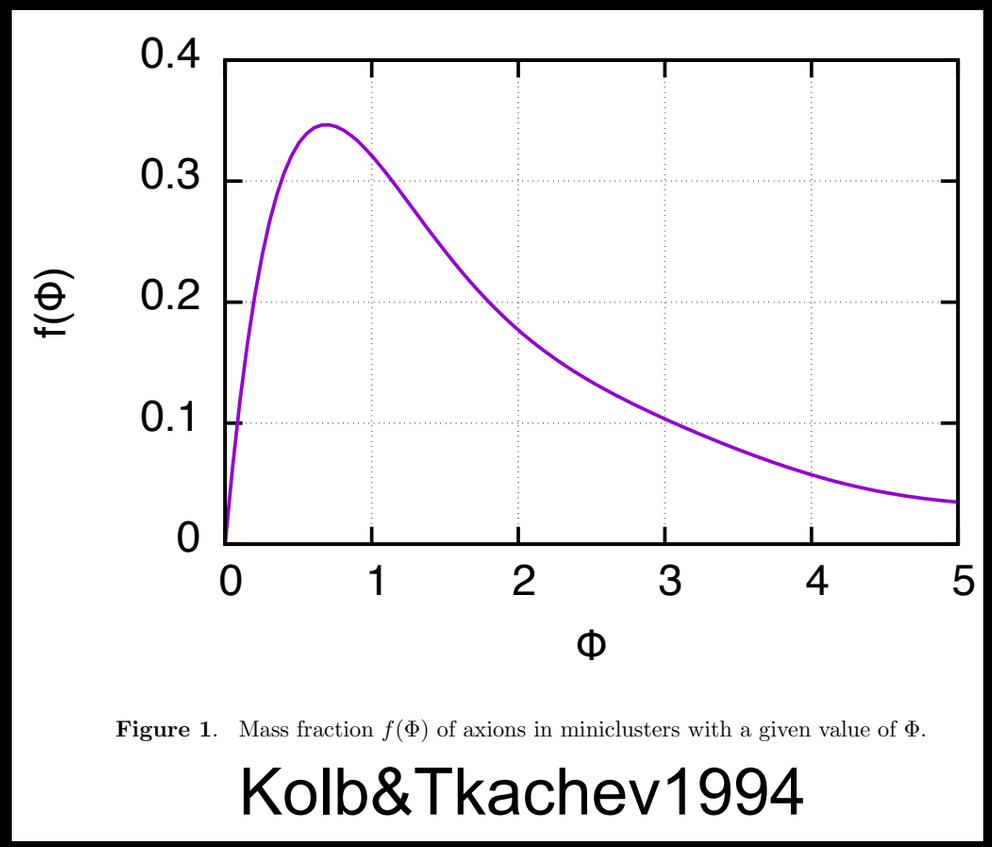



**Figure 1**. Mass fraction $f(\Phi)$ of axions in miniclusters with a given value of $\Phi$.

Kolb&Tkachev1994

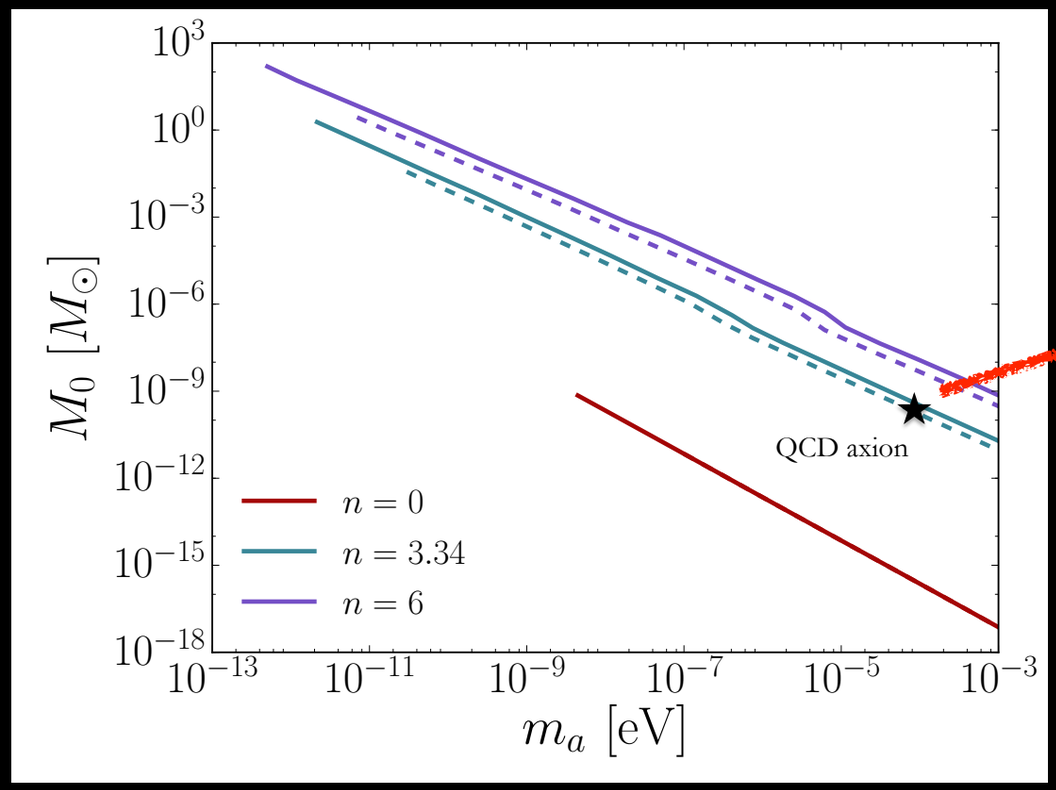
collapse at temperature $T_{\rm collapse} = \Phi\, T_{\rm eq}$

Density of miniclusters $\rho \sim 140(1+\Phi)\Phi^3 \rho_{\rm eq}$

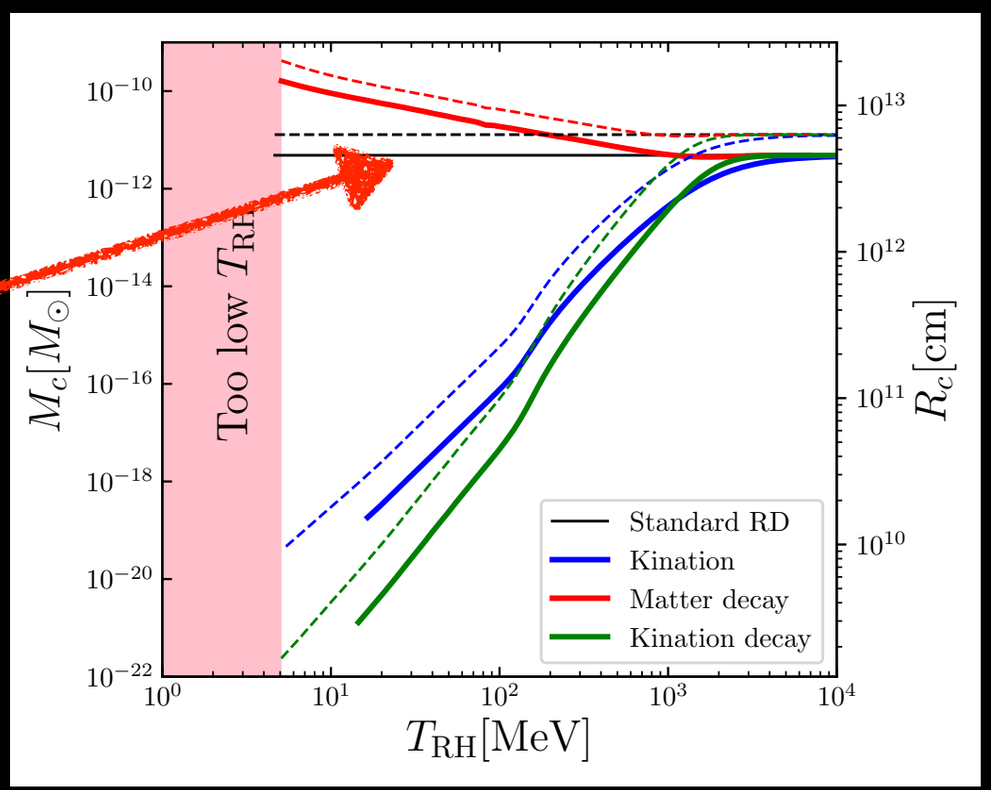
# Axion miniclusters

**Mass** $M_{\rm MC} \sim 10^{-10} M_\odot$ **(enclosed at** $H^{-1}_{\rm QCD}$ **)**

**Radius** $R_{\rm MC} \sim 1\,{\rm AU}/\Phi$ .

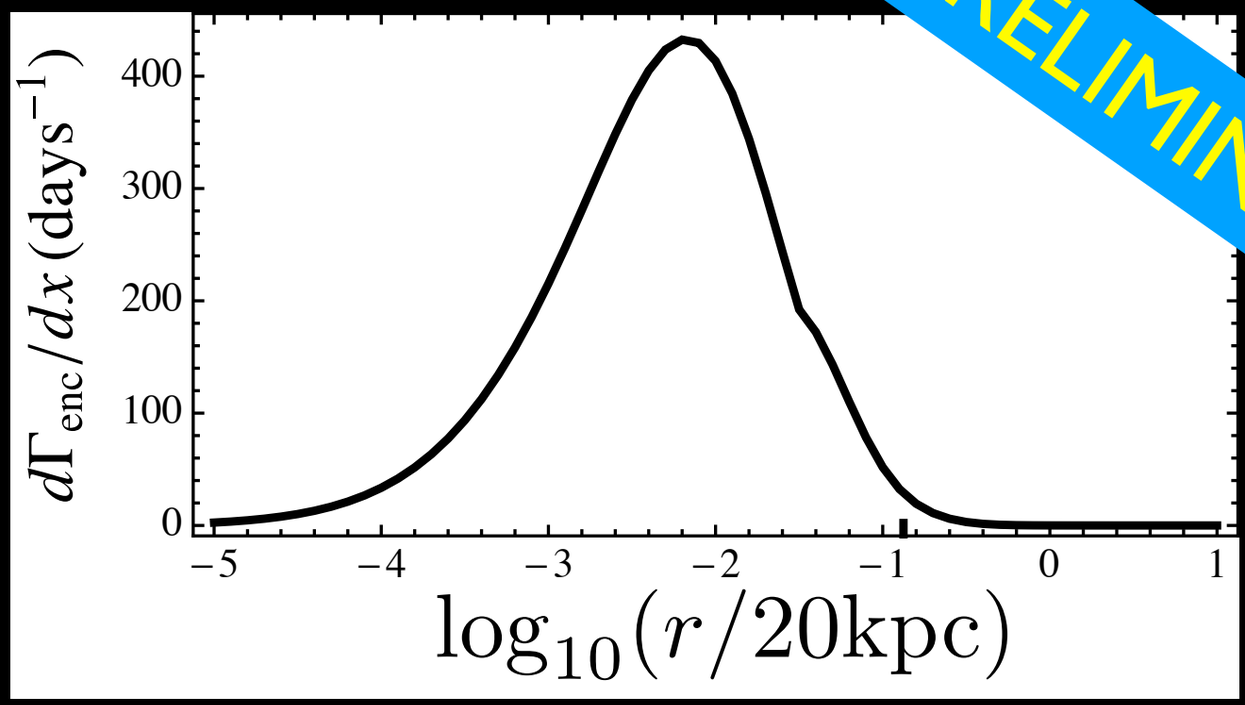



Fairbairn+2017




**LV** & Redondo 1808.01879

# Neutron stars "eating up" axion miniclusters




Edwards+, *work in progress*

We are working on the signature of NS- axion MC encounters

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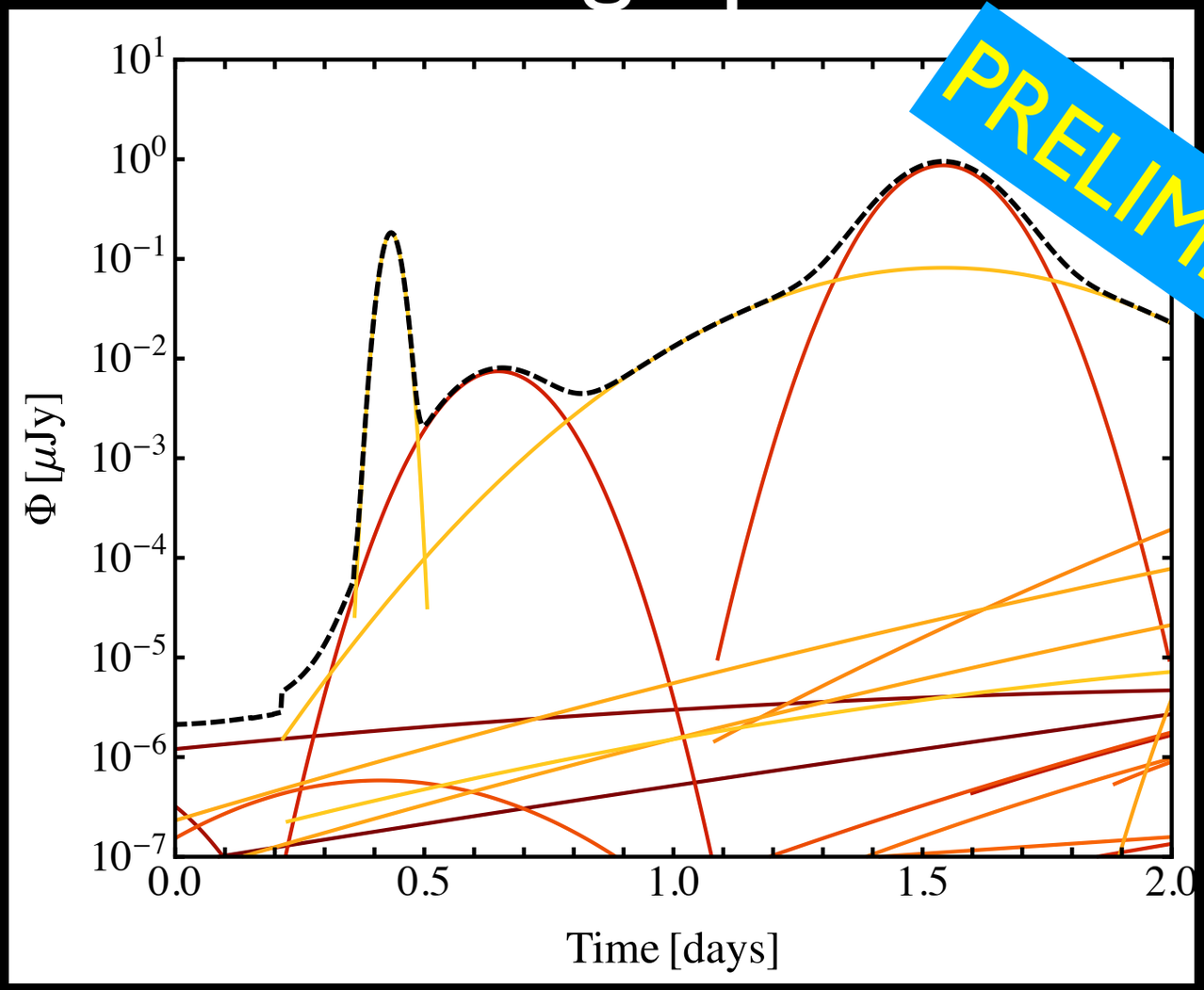


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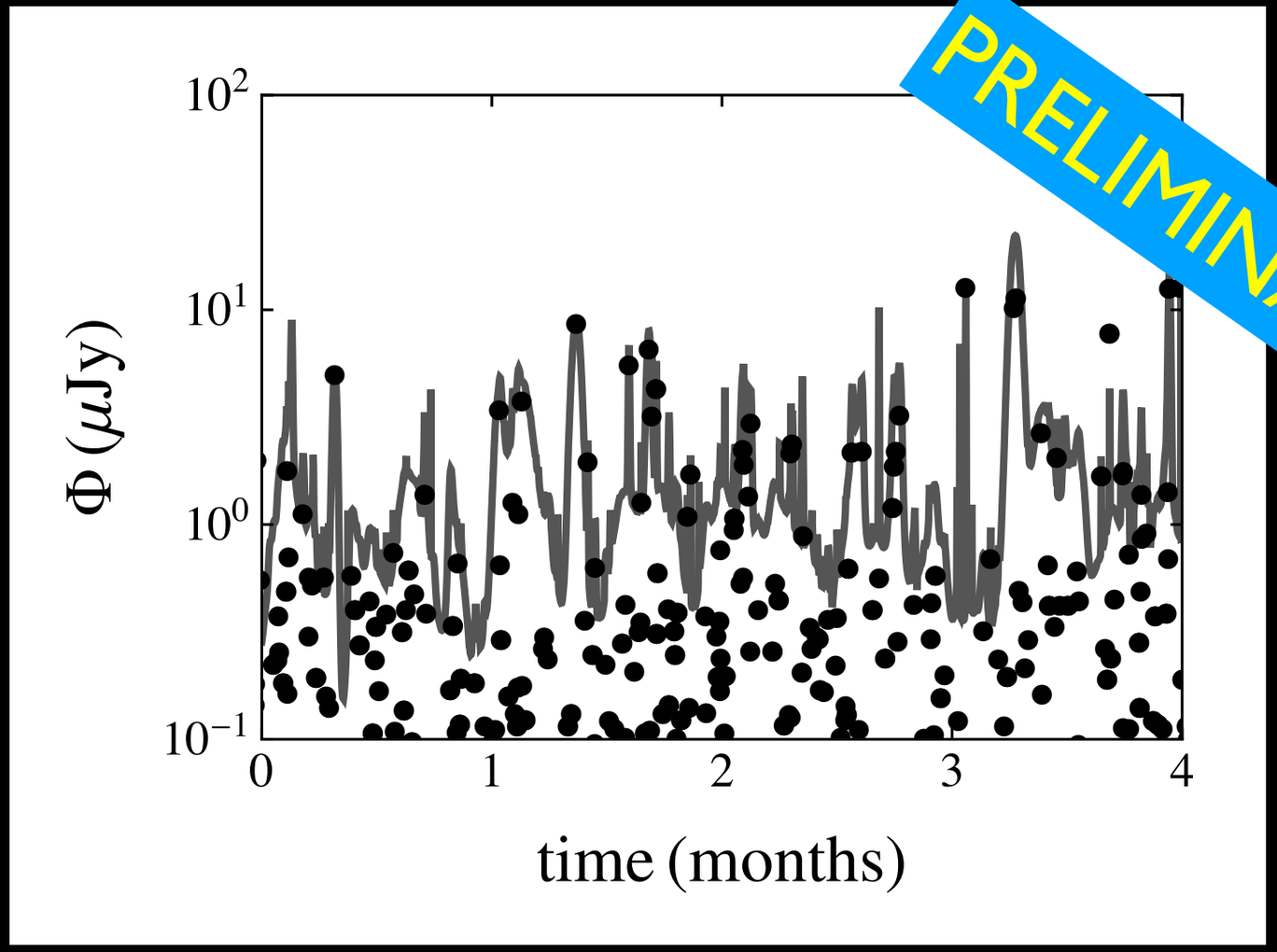


Edwards+, *work in progress*

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# The future? Axions-neutrino connections?

**Axions and neutrinos can share properties in some minimal BSM setups**

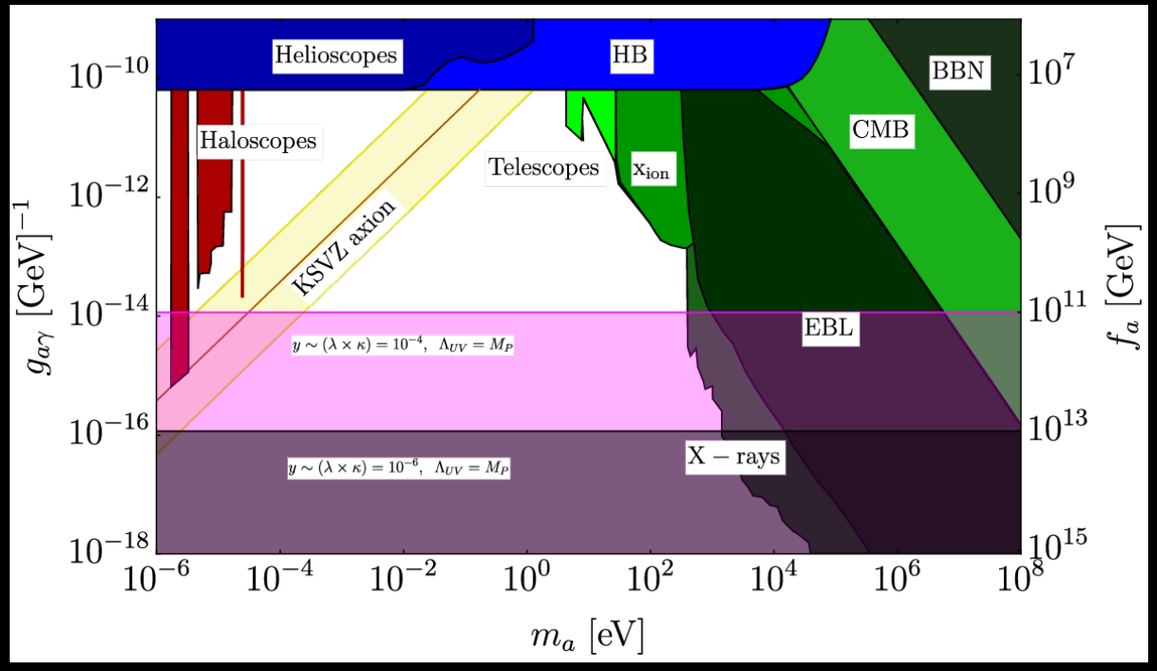
**Recent e.g. Peinado+ 1910.02961**

Notice that, unlike the Majorana case where one typically has

$$m_\nu^{\rm Majorana} \sim v_{EW}^2/f_a\,, \qquad (7)$$

for the Dirac case one obtains, from Eq. (5) [2]:

$$m_\nu^{\rm Dirac} \sim v_{EW} f_a/\Lambda_{UV}\,. \qquad (8)$$




**Type I Dirac See-Saw leads to an *upper* bound to the axion energy scale**

# Conclusions

- It is an exciting period to work on dark matter compact objects!
- Details require much further efforts. Work in progress...
- Miniclusters and axion stars are possible laboratories!