CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Fuzzy Dark Matter candidates from Strings

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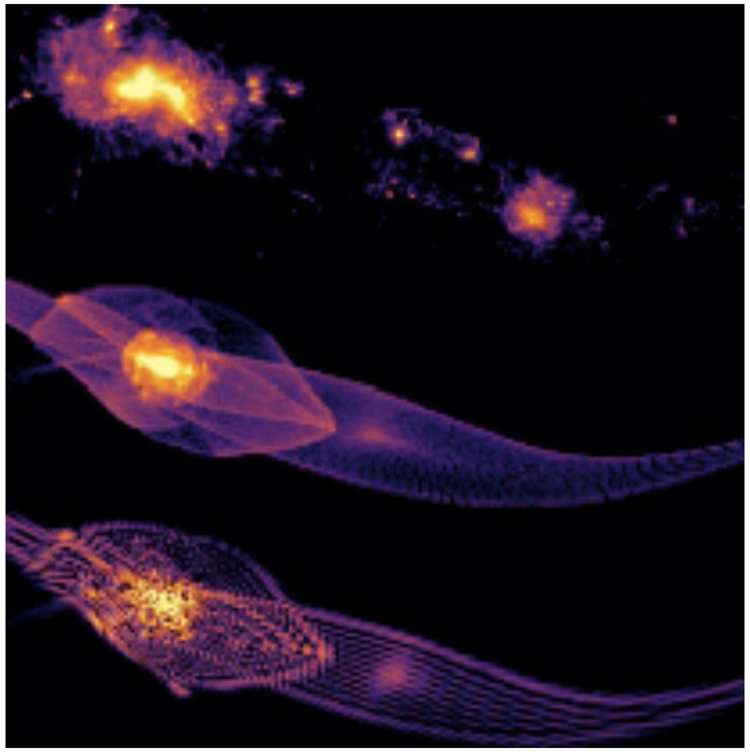
Introduction to FDM

DM made of ultralight particles [Hu, Barkana and Gruzinov ’00]

$\longrightarrow$ solves the cusp-core problem of WIMPs

$\longrightarrow$ reduces the number of low mass halos



[Mocz et al ’19]

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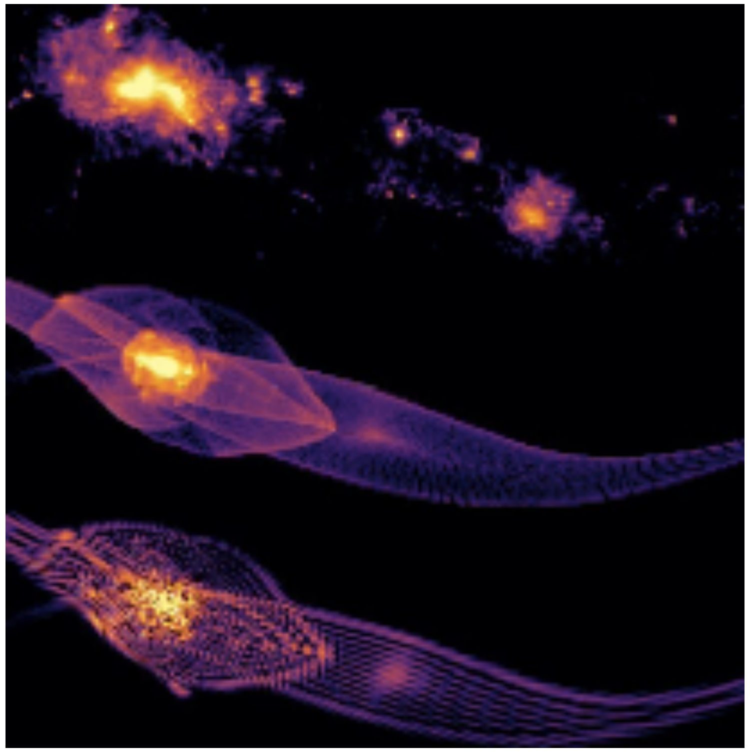


[Mocz et al '19]

Ultralight axions as FDM [Hui, Ostriker, Tremaine and Witten '16]

$$m \gtrsim 10^{-22} \quad \text{eV}$$

$$f \sim 10^{16\div17} \quad \text{GeV}$$

$\longrightarrow$ Possible sign of the string axiverse?

+ clash with WGC? [Alonso, Urbano '17] [Hebecker, Mikhail, Soler '18]

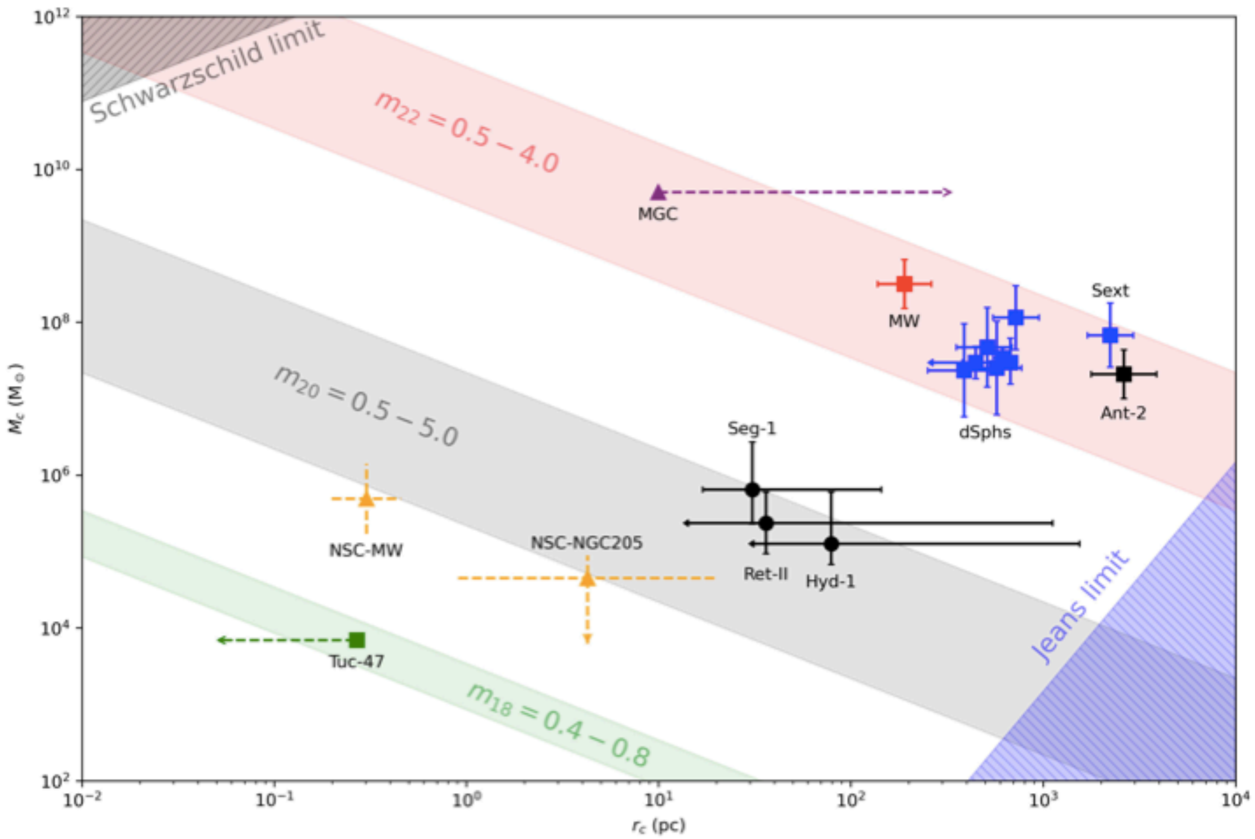
$$f\,S \gtrsim M_p$$

$\rightarrow$ highly sensitive to extremality bound

FDM AS STRING AXION

Motivated by

- high decay constant
- possible multiple nature of FDM "nested" solitons



[Broadhurst et al '18]

Because in string theory

- plentitude of axions naturally arises in the 4d effective theory
- acquire different masses from different effects (as instantons and gaugino condensation)

However, they do not come for free!

FDM as string axions: effective theory

4d Lagrangian: $$\mathcal{L} = \frac{1}{2} f^2 (\partial a)^2 - M_p^4 A e^{-S} \cos(a)$$

Axion mass: $$m_a^2 = M_p^4 \frac{A\, e^{-S}}{f^2}$$

FDM abundance:
$(H < f)$

$$\frac{\Omega_a h^2}{0.112} \simeq 1.4 \left(\frac{m_a}{10^{-22} \text{ eV}} \right) \left(\frac{f}{10^{17} \text{ GeV}} \right) a_{in}^2$$

[Cicoli, Goodsell, Ringwald '12]

Type IIB axiverse

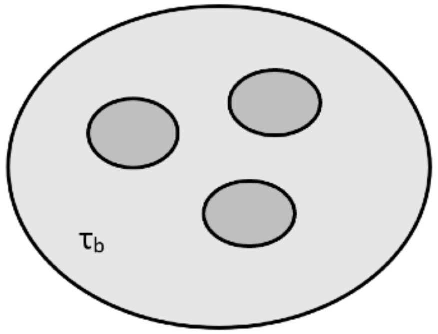
Closed String Axion	Sf
C_0	$\sim 1/\sqrt{2}\, M_P$
B_2	$\lesssim\ M_P$
C_2	$\sim \sqrt{g_s}\, M_P$
$C_4\ (1\ dof)$	$\sim \sqrt{3/2}\, M_P$
$C_4\ (2\ dof)$	$< \sqrt{3}/2\, M_P$
$C_{2,thrax}$	$\sim$ $S_{ED1} f \sim \mathcal{V}_{marginal}^{1/3} \mathcal{V}_{CY}^{-1/3}\ M_P$ $S_{eff} f_{eff} \sim \text{flux-ratio} \times \mathcal{V}_{marginal}^{1/3} \mathcal{V}_{CY}^{-1/3}\ M_P$

Large Volume Scenario

FDM from C4 axion

Swiss-Cheese Calabi-Yau:

$$\mathcal{V} \sim \tau_{big}^{3/2}$$



$$S \sim \frac{2\pi}{N} \tau_{big}$$

$$f_{\theta_{\mathcal{V}}} = \sqrt{\frac{3}{2}} \frac{M_p}{S}$$

$$m^2_{\theta_{\mathcal{V}}} \simeq g_s W_0 \frac{A S^3 e^{-S}}{\mathcal{V}^2} M_p^2$$

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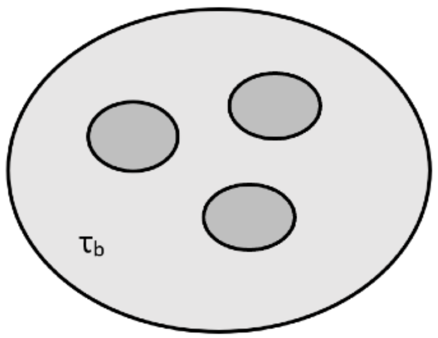

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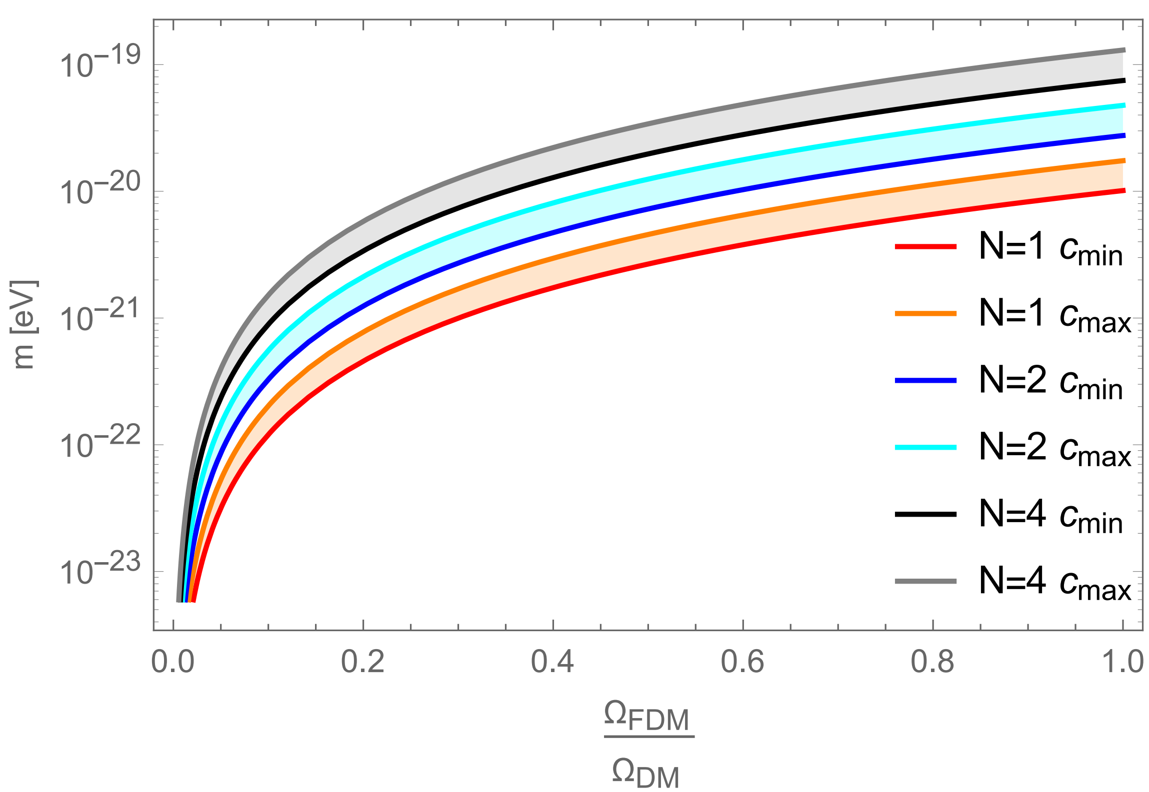
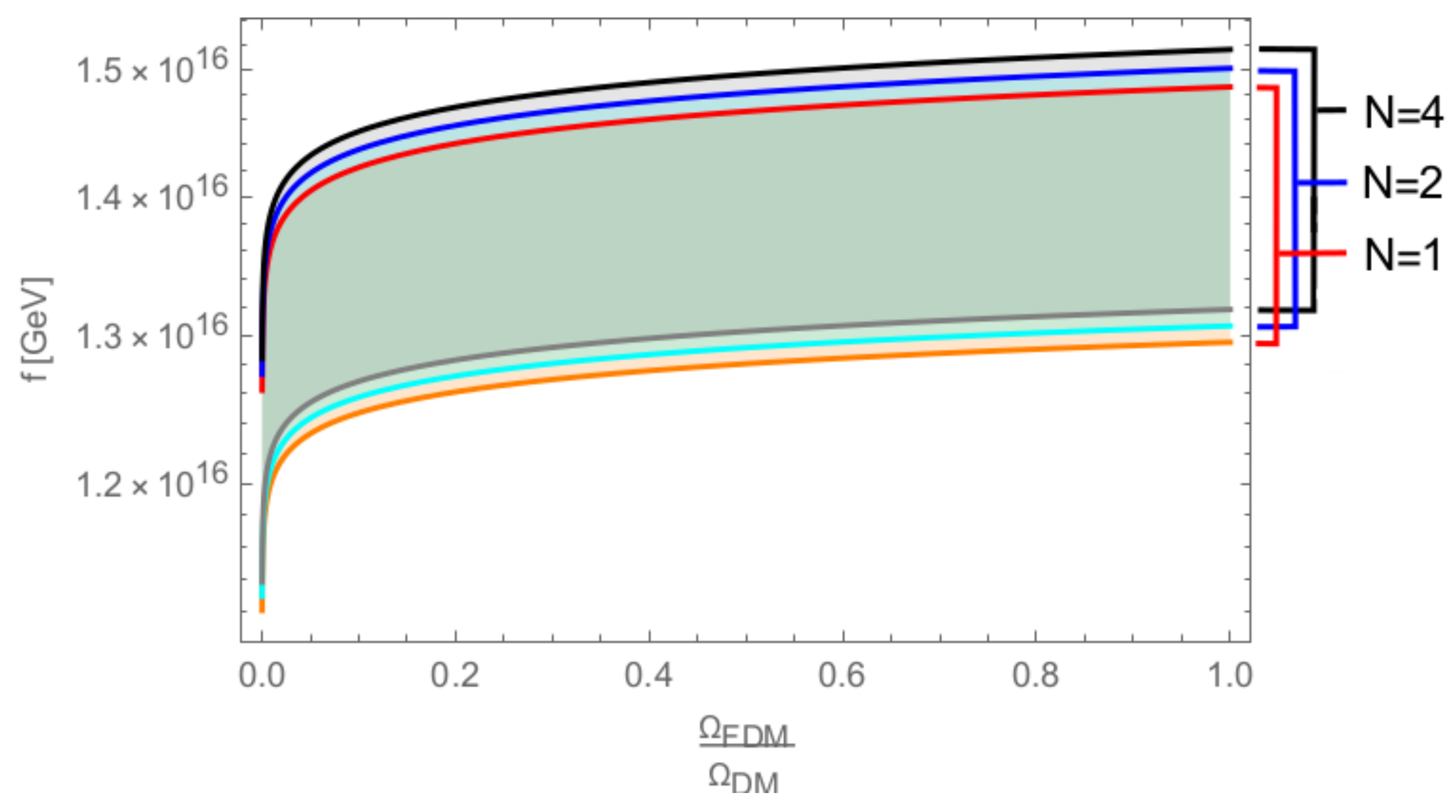
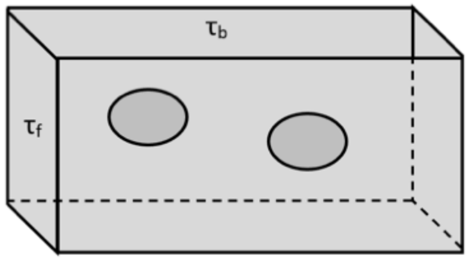




FDM from C4 axion

Fibred Calabi-Yau:

$$\mathcal{V} \sim \tau_{big}\sqrt{\tau_{fibre}}$$



$$f_{\theta_{big}} = \frac{M_p}{S_{big}} \qquad f_{\theta_{fibre}} = \frac{M_p}{\sqrt{2}S_{fibre}}$$

$$m^2_{\theta_{big}} = \frac{4\kappa S^3_{big} A_{big} W_0 e^{-S_{big}}}{\mathcal{V}^2} M_p^2$$

$$m^2_{\theta_{fibre}} = \frac{8\kappa S^3_{fibre} A_{fibre} W_0 e^{-S_{fibre}}}{\mathcal{V}^2} M_p^2$$

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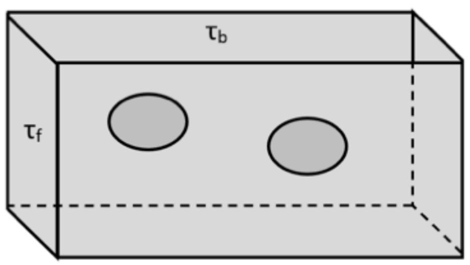

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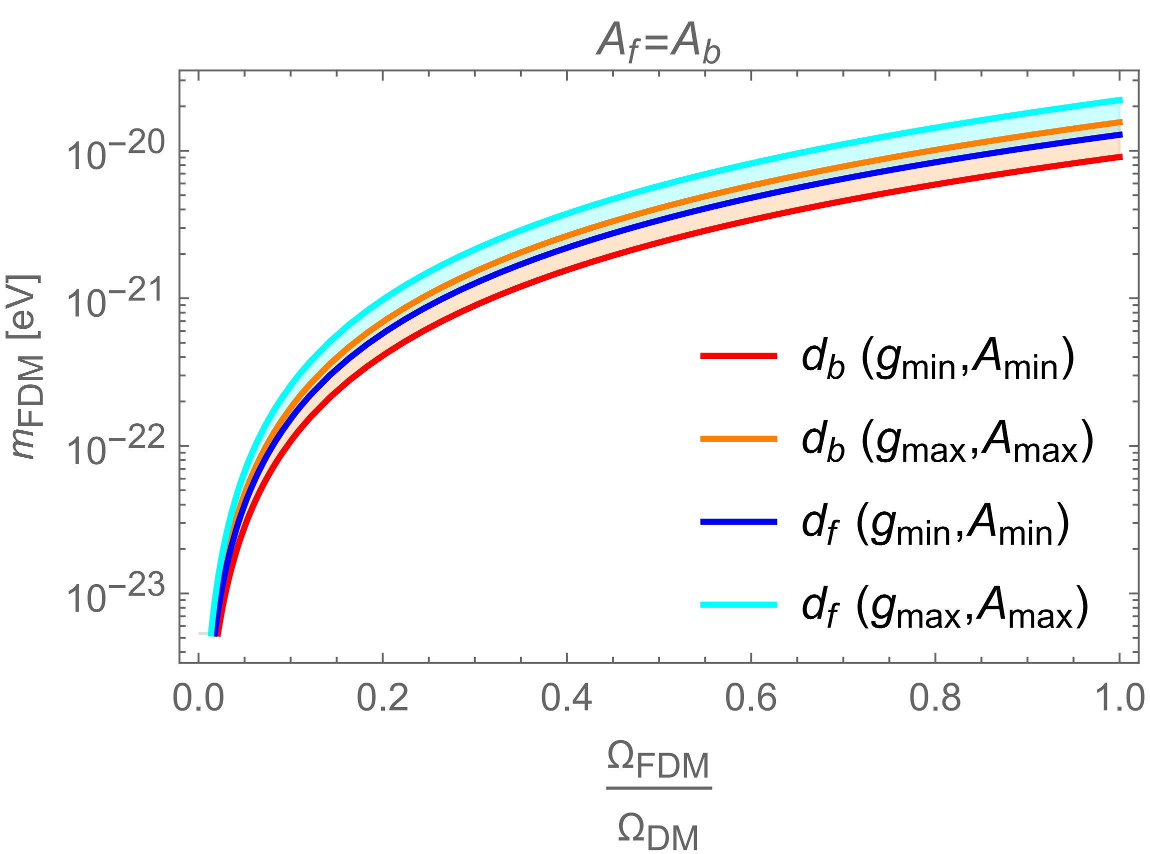
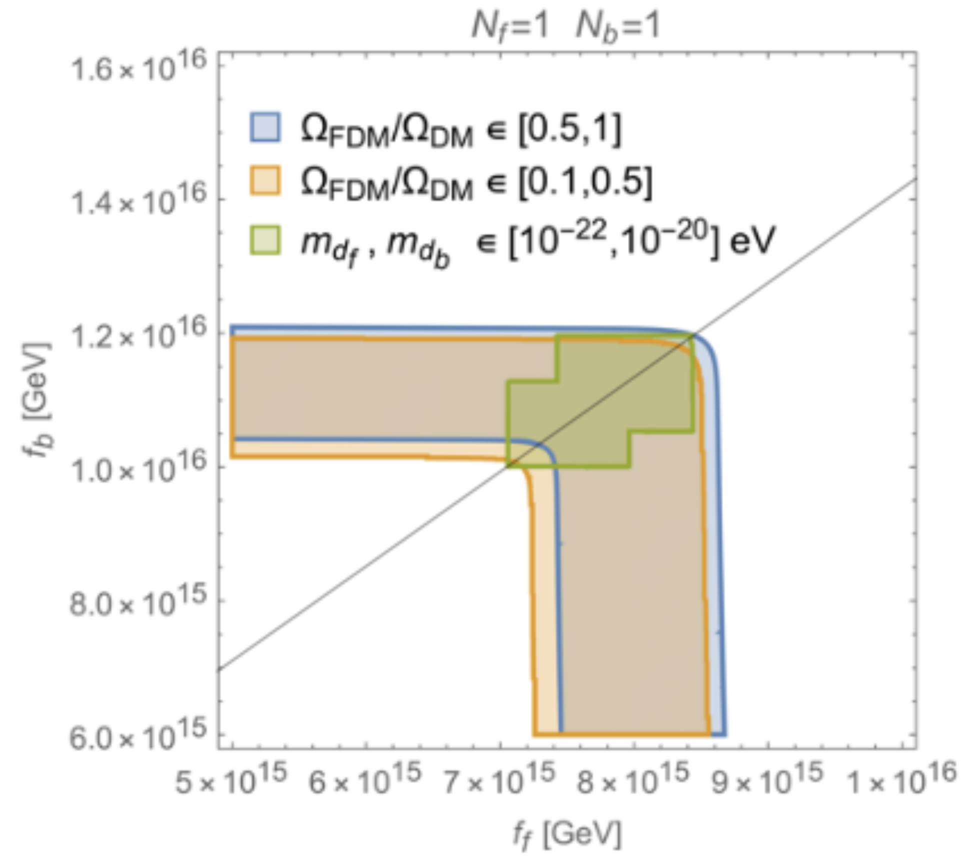




FDM from C_4 axion: comment on results

Assumptions:

- standard values for $< a_{in}^2 >\sim \pi^2/3$
- allow for a huge range of parameters $g_s,\ A_i,\ W_0$
- ignore self-interaction

Main outcomes:

- small overall volumes $\mathcal{V}$
- high KK scales $\sim 10^{15}$ GeV
- for multiple FDM models: heavier axions give higher $\frac{\Omega_{FDM}}{\Omega_{DM}}$

FDM FROM THRAXIONS

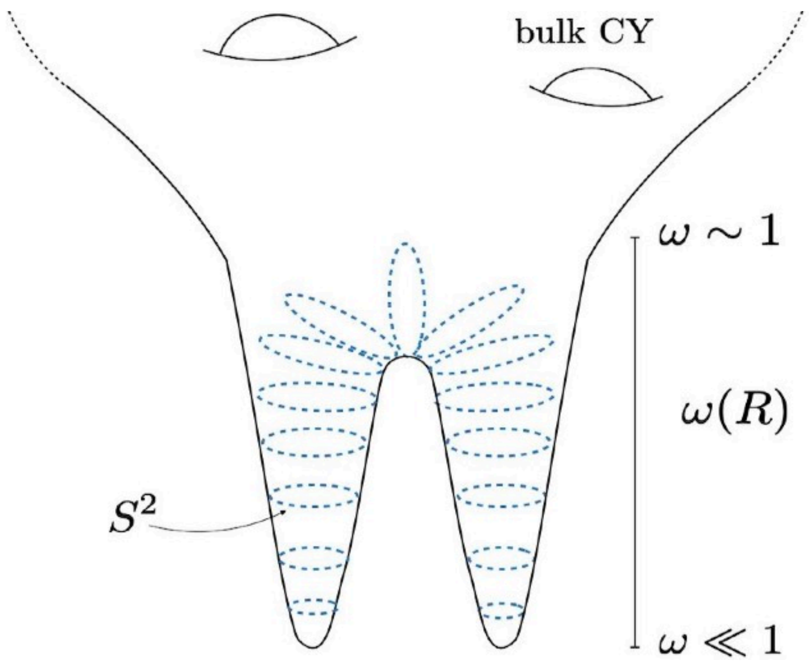
[Hebecker, Leonhardt, Moritz, Westphal '19]

$$S \sim \frac{2\pi\, K}{g_s\, M}$$

K, M = flux numbers

$$f \sim \frac{3\, g_s M}{\sqrt{2}\, \mathcal{V}^{1/3}} M_p$$

$$m^2 \sim \frac{2e^{-2S}}{\sqrt{3} M^2 \mathcal{V}^{2/3} S^{3/2}} M_p^2$$



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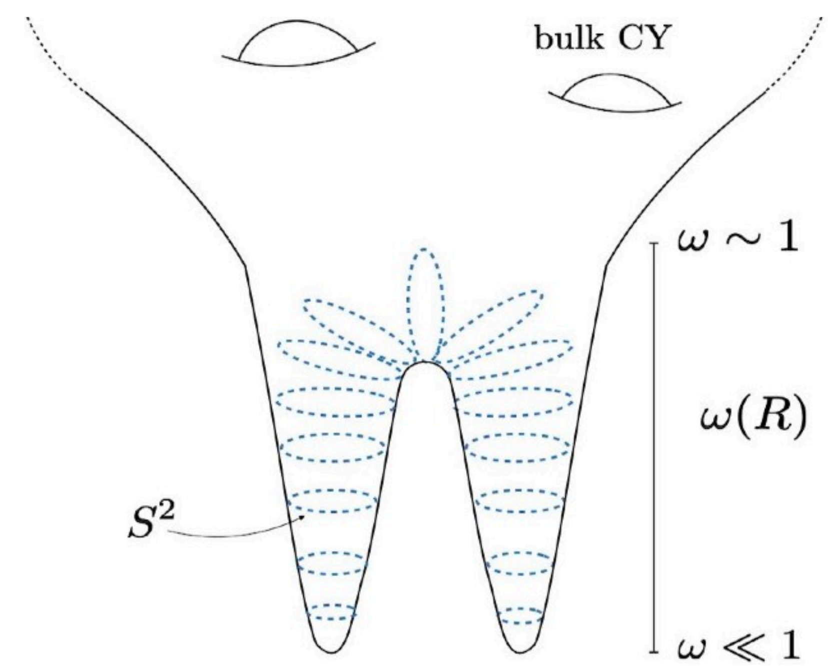

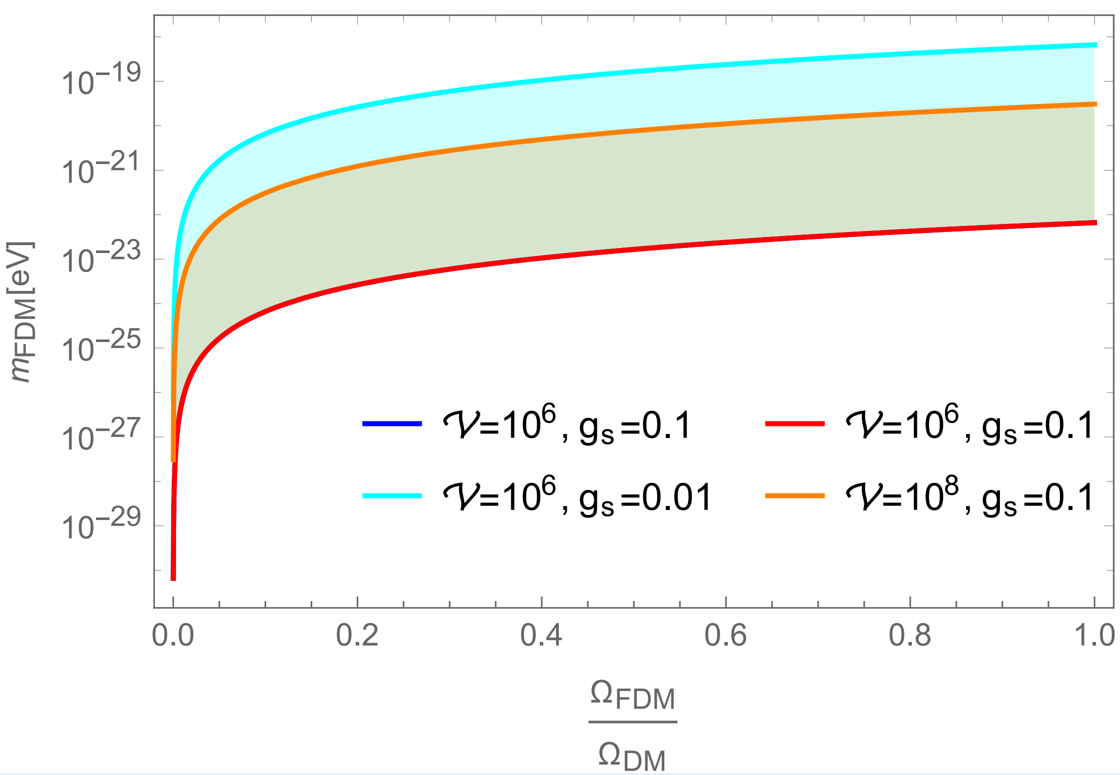

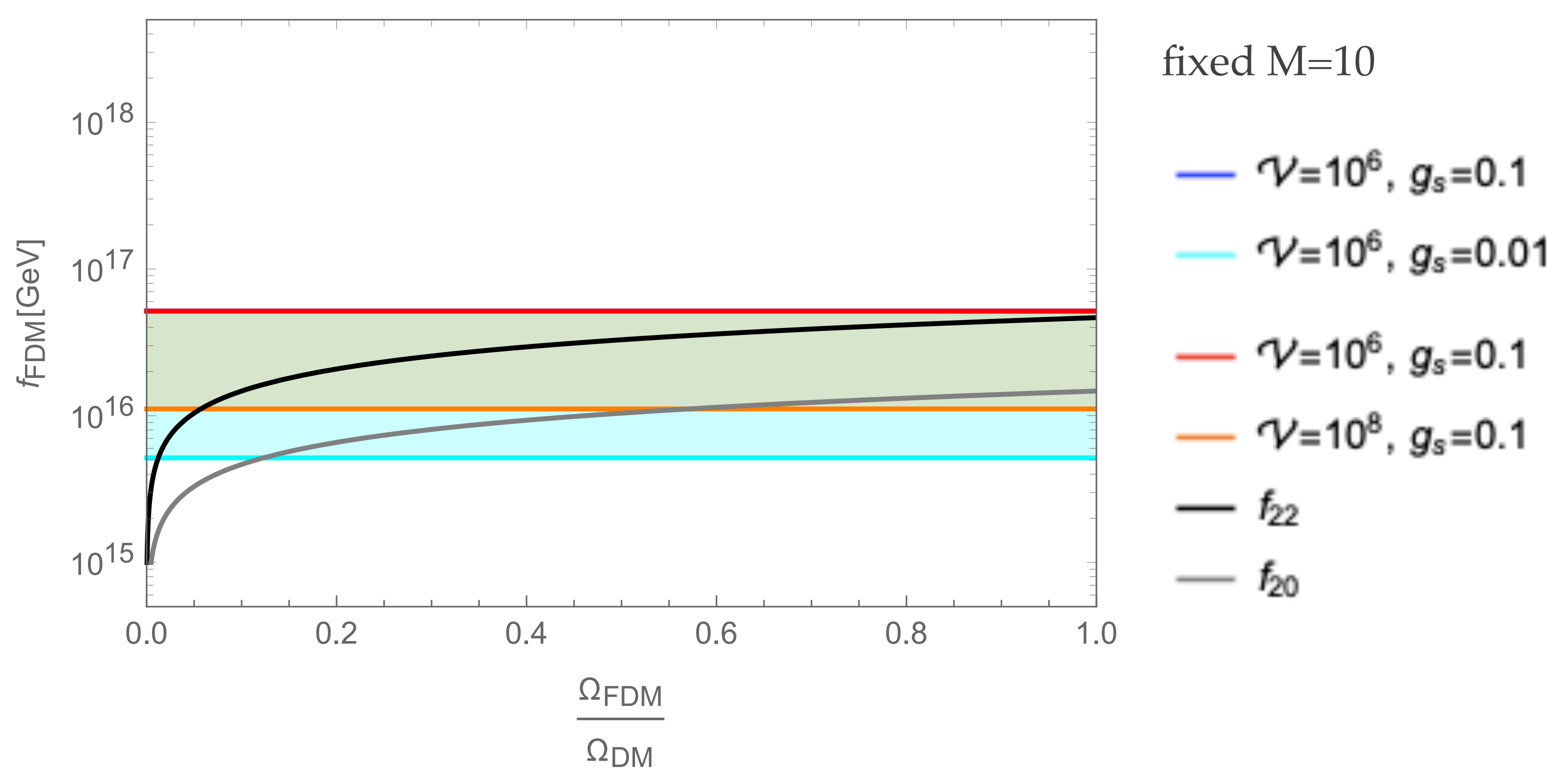

FDM from thraxions: comment on results

Assumptions:

- hierarchy among flux numbers $M \gtrsim \sqrt{\frac{K}{g_s M}}$

  (purpose: suppress short wavelength instantons, use mild WGC)

Main outcomes:

- low warped KK modes, ~ 10 TeV (work in progress)
- predictions not spoiled by Kahler moduli coupling (work in progress with Carta, Mininno, Westphal)
- insensitive to moduli stabilisation procedure (LVS & KKLT)
- preference for big $\mathcal{V}$

Pheno constraints from stringy FDM

from experimental constraints on isocurvature perturbations:

	C_4	thraxion
inflationary scale	$H_I < 10^{12}$ GeV	$H_I < 10^{13}$ GeV
tensor-to-scalar ratio	$r \lesssim 10^{-5}$	$r \lesssim 10^{-3}$

Conclusions

C_4 axions:

- masses higher than 10^{-22} eV
- predictions independent on microscopical tuning
- low inflationary scale

Thraxions:

- independent on compactifications
- bigger range of masses allowed
- tensor modes detectable with next generation experiments

Thank you!