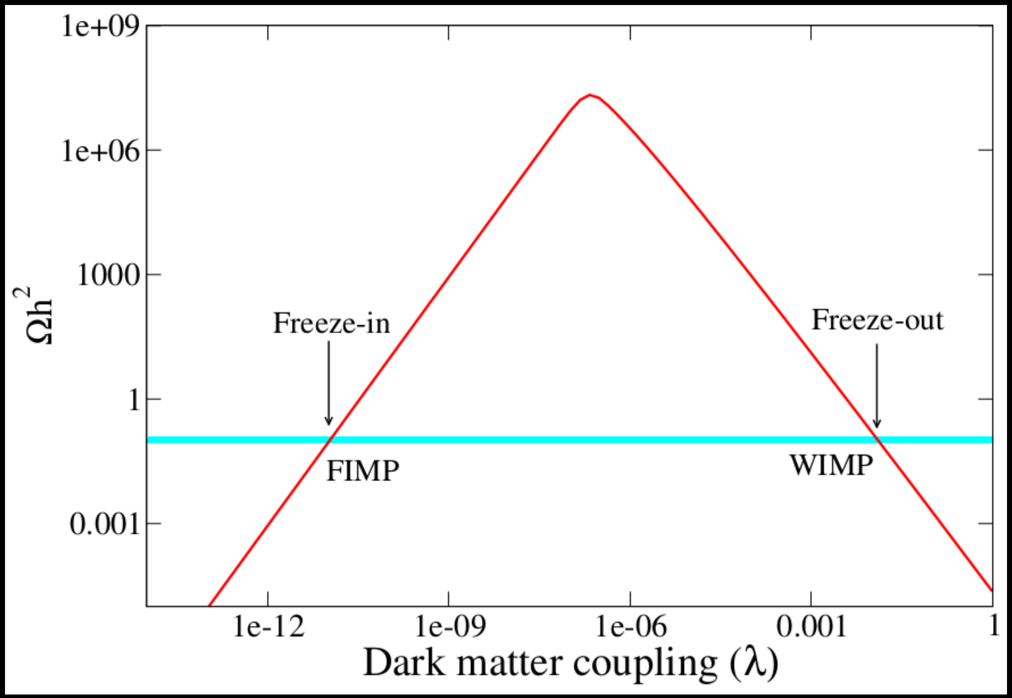
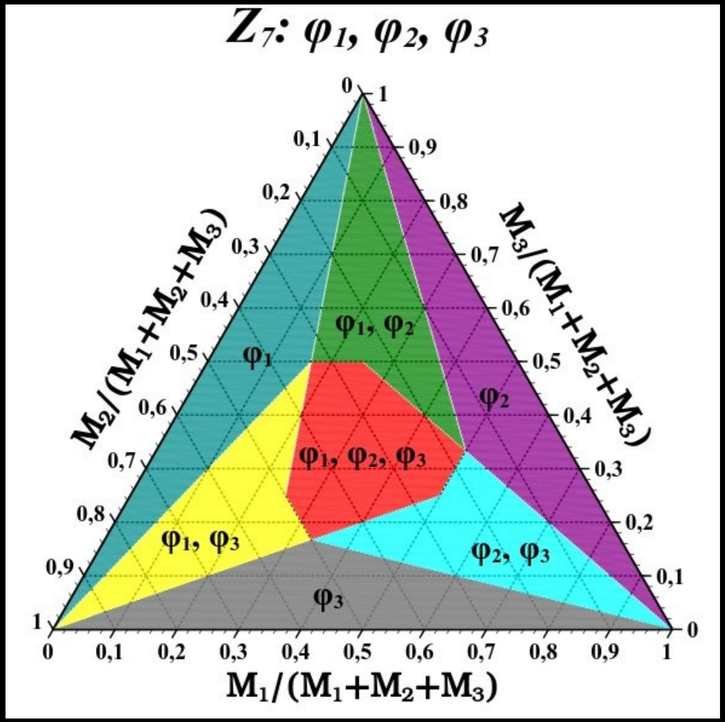
Dark Matter Theory

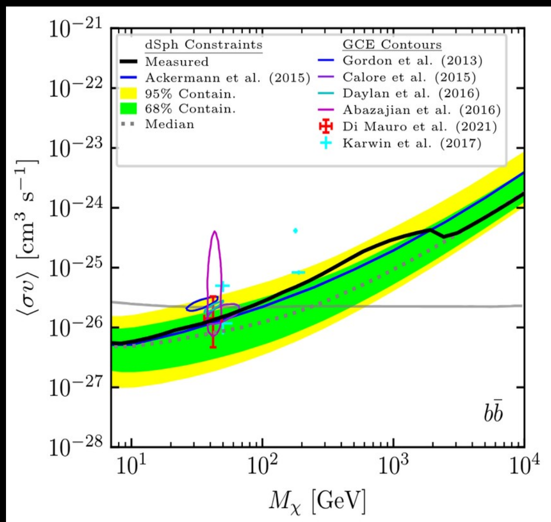




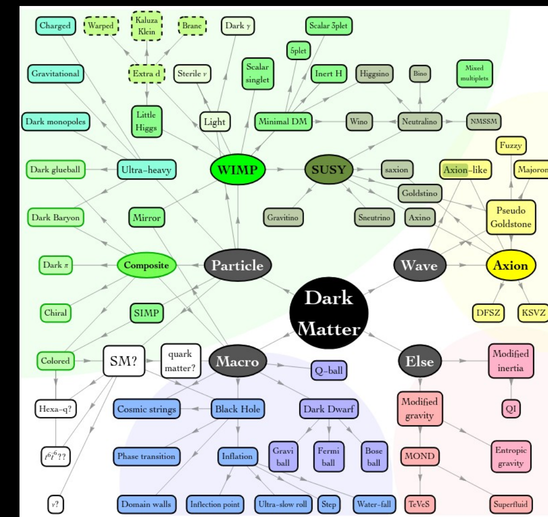
Carlos E. Yaguna
UPTC, Colombia

2024

The talk is divided into three parts



1. Motivation

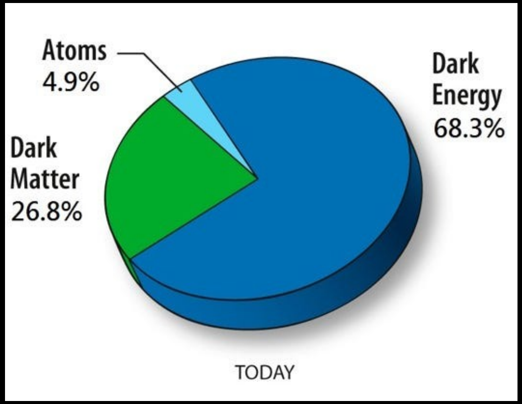


2. The DM landscape

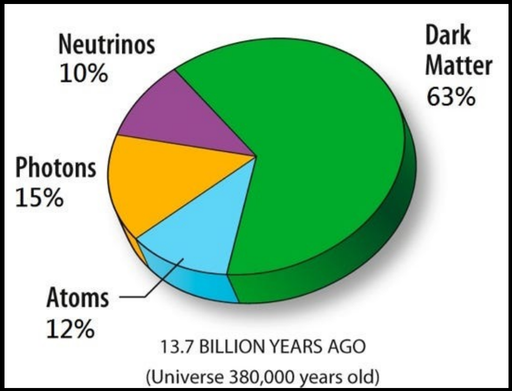
3. Some examples

Dark matter has been an essential component of our Universe

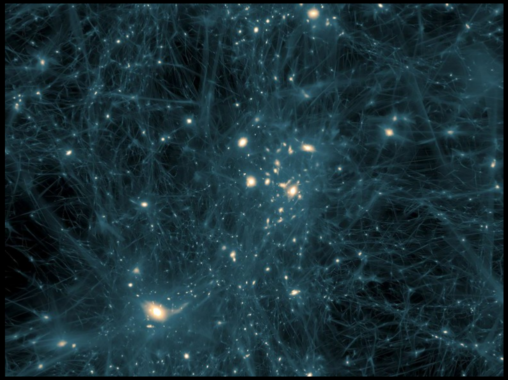
It is 5 times more abundant than normal matter



It dominated the Universe for most of its history

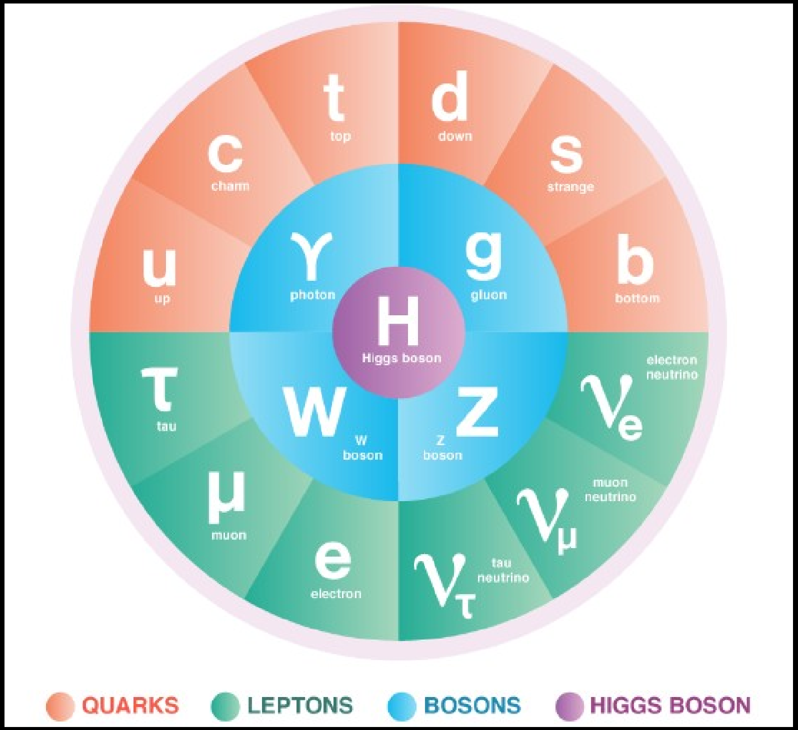


It plays a crucial role in structure formation



Dark matter requires physics beyond the Standard Model

The SM has been incredibly successful



But it cannot explain the dark matter

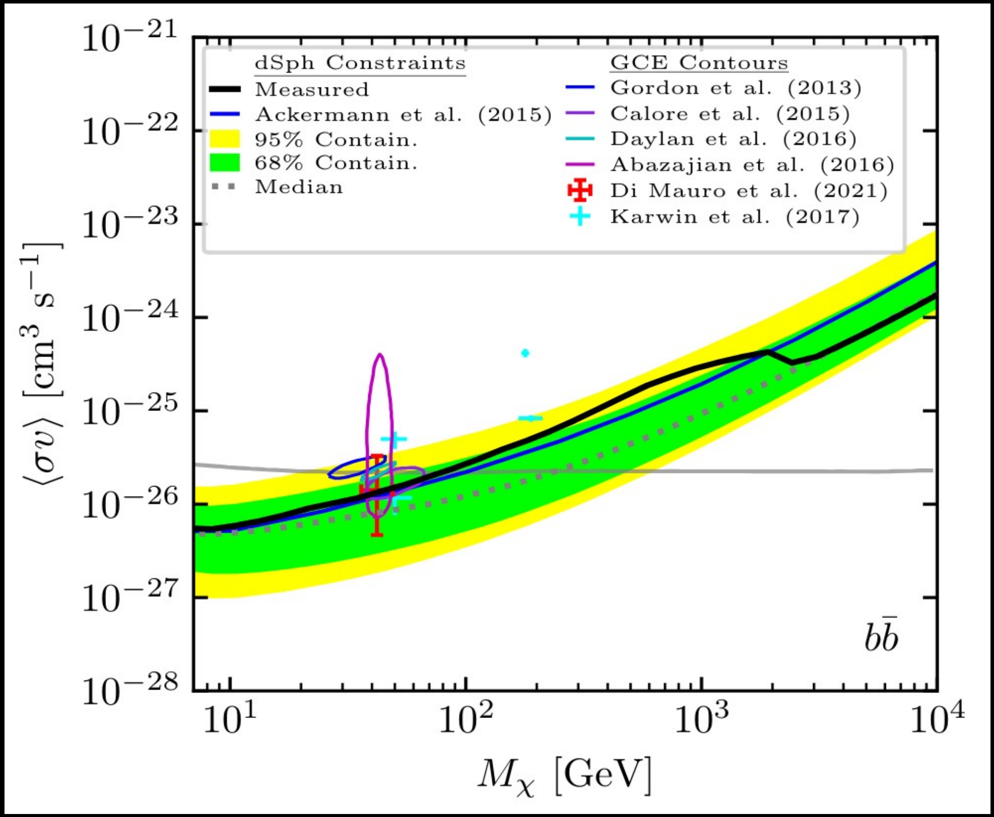
DM is a window into BSM physics

New particles and additional symmetries

The solution to the dark matter problem seems to be within reach

McDaniel 2023

DM particles appear in several SM extensions



Current experiments can probe many DM models

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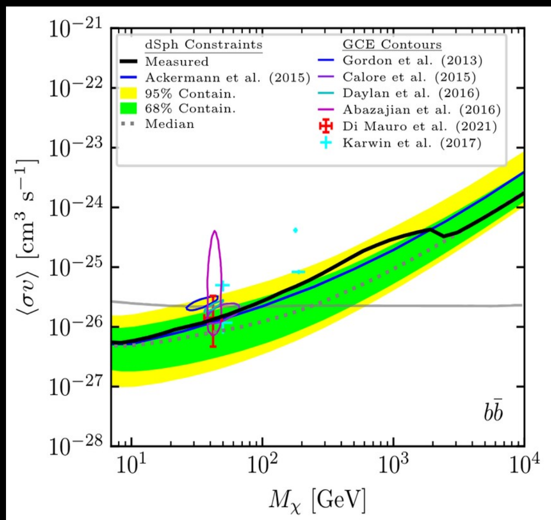

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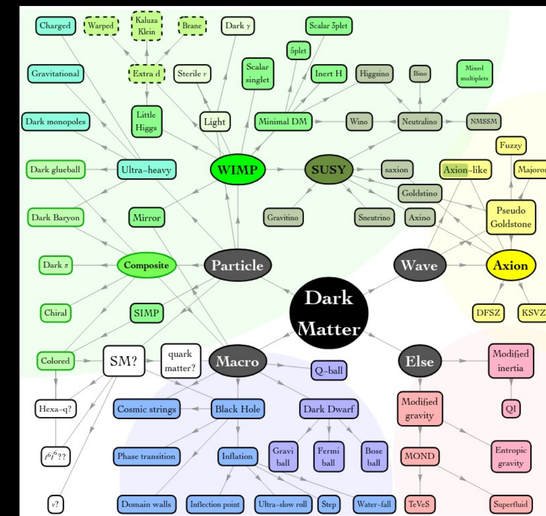

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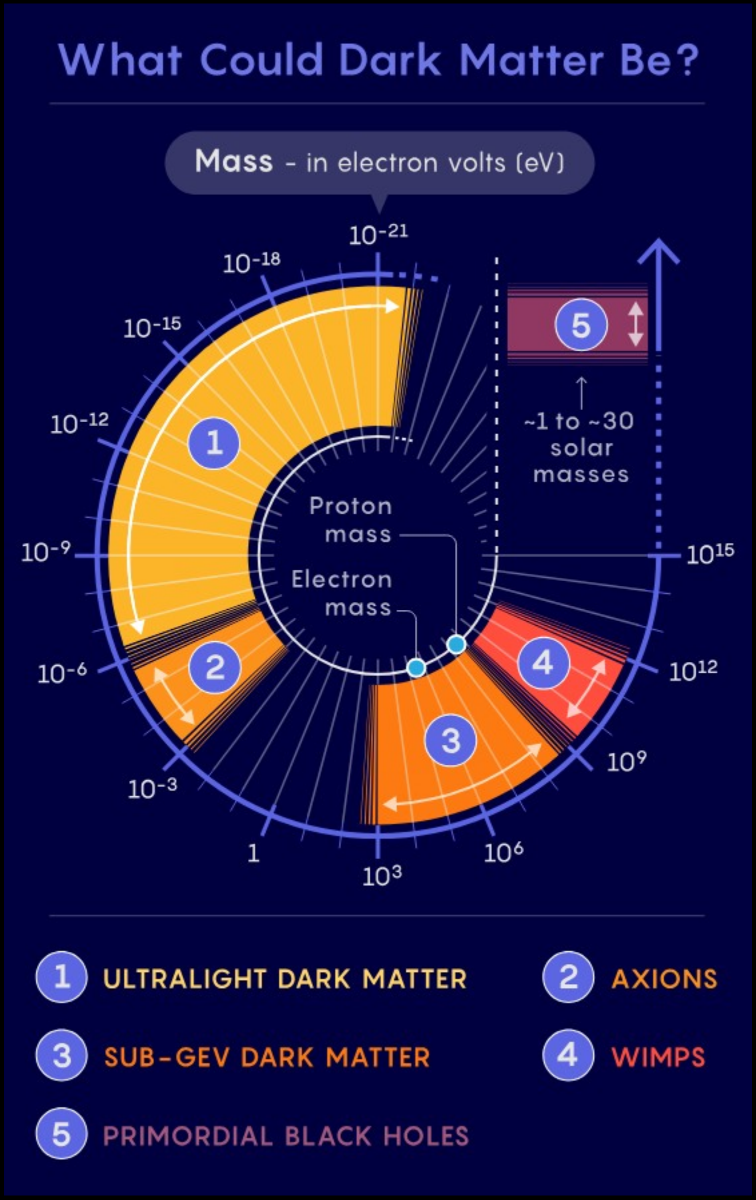
3. Some examples

We know very little about the dark matter particle

$\Omega_{DM} h^2 = 0.1200 \pm 0.0012$
and it is "cold"

It is neutral, stable and weakly interacting

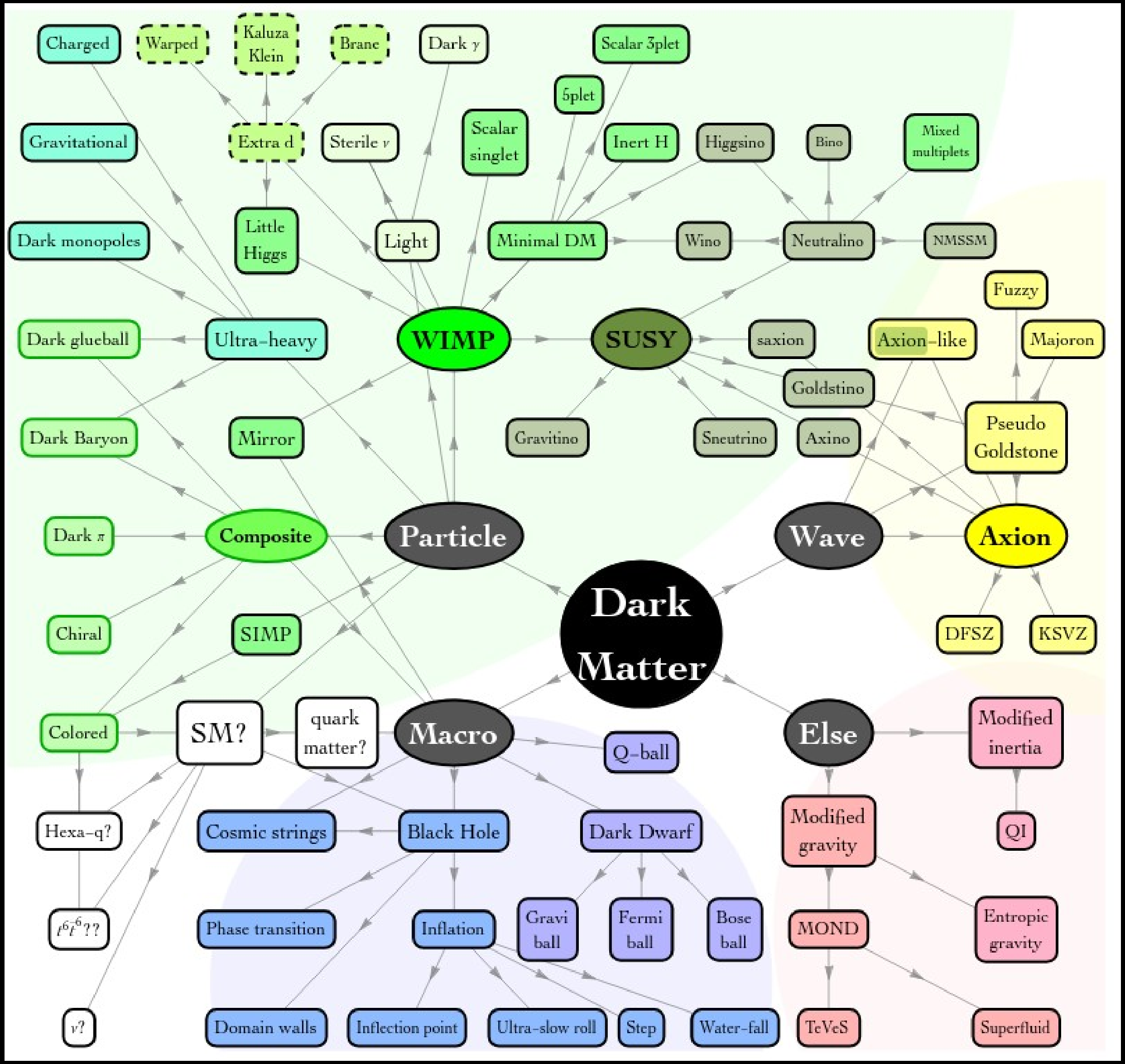
Mass, spin, couplings?
Is there a DM sector?



Hundreds of models have been proposed to explain the dark matter

Are they enough?

Preferred models vary with time



Cirelli et al, 2024

The axion was among the first dark matter candidates considered

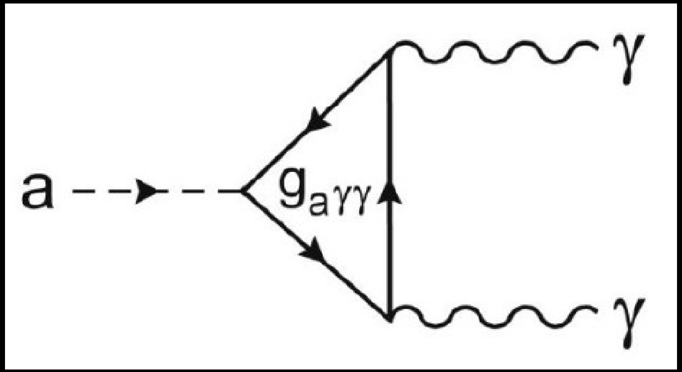
A solution to the strong CP problem

70’s-80’s

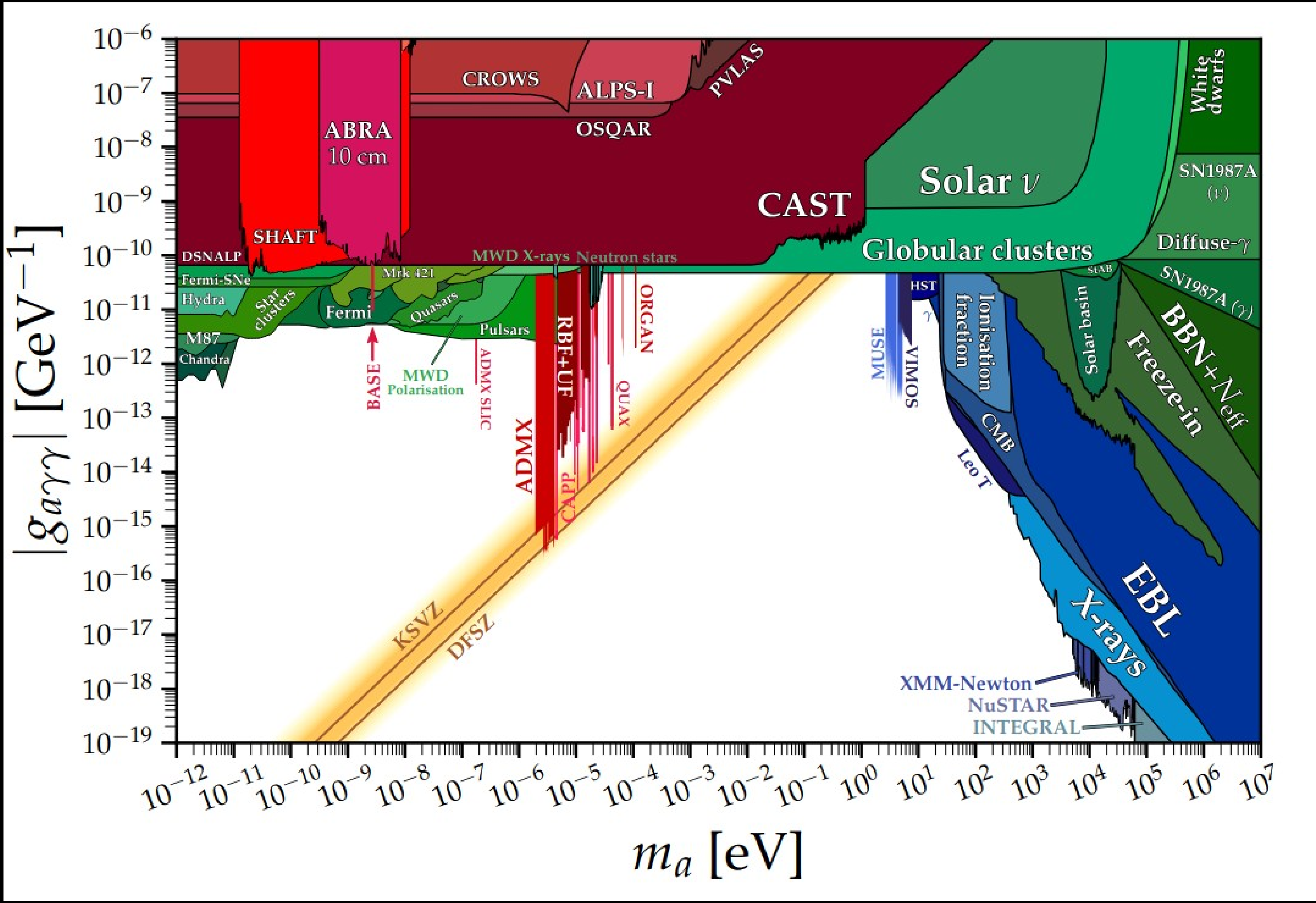
It is a light pseudoscalar field

m ~ 10^{-6} eV

It couples feebly to photons



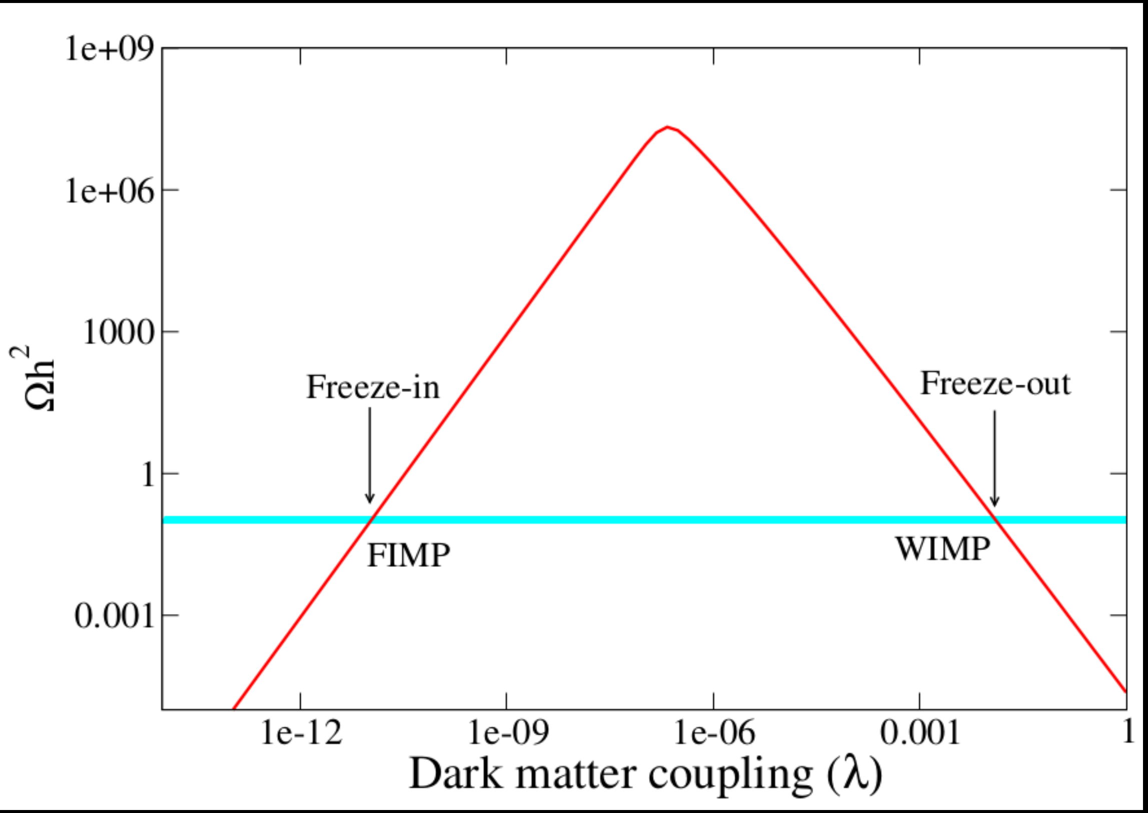
Axion experiments are currently probing the regions consistent with dark matter



PDG 2023

WIMPs and FIMPs are well-motivated scenarios for the dark matter

There are 2 solutions to $\Omega \sim \Omega_{DM}$

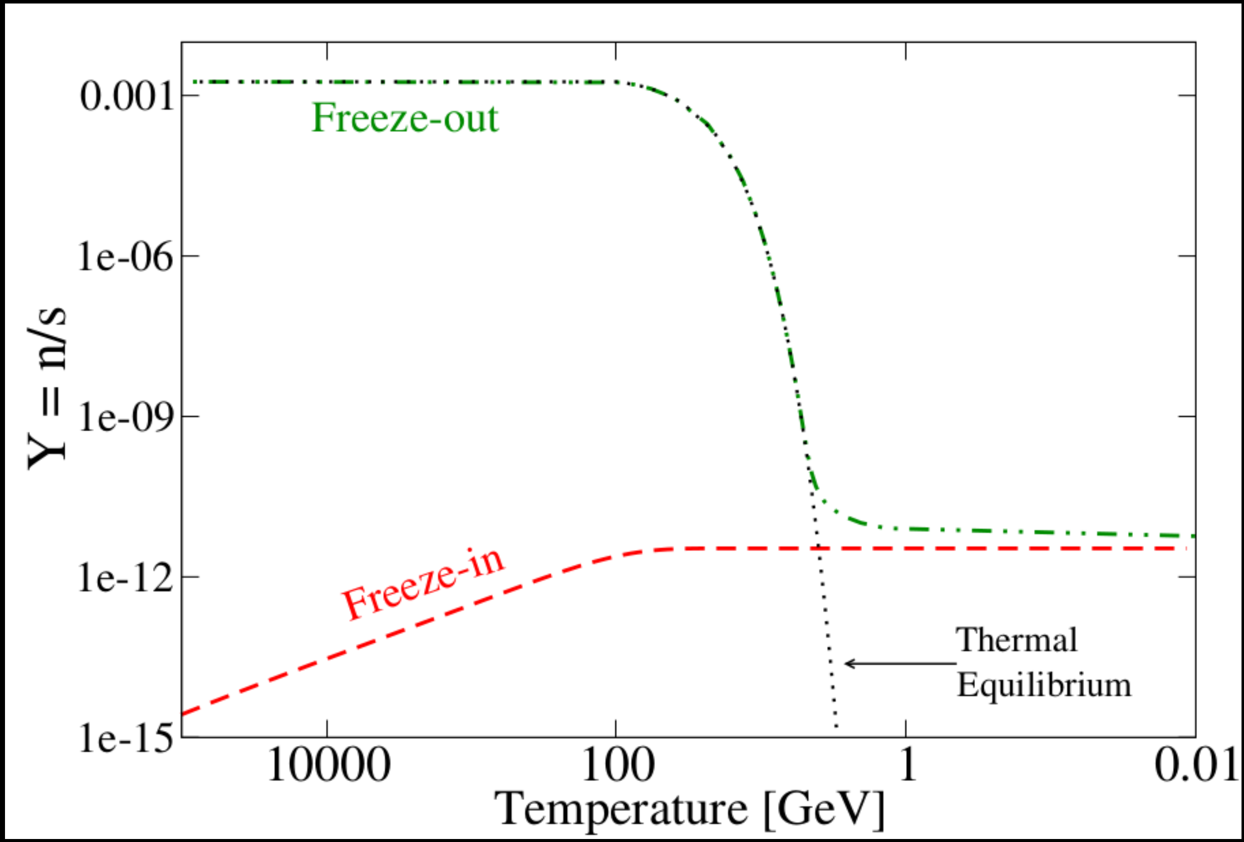


With very different couplings

WIMPs and FIMPs are produced in very different ways in the early Universe

FIMP masses span a very wide range

WIMPs require GeV to TeV masses

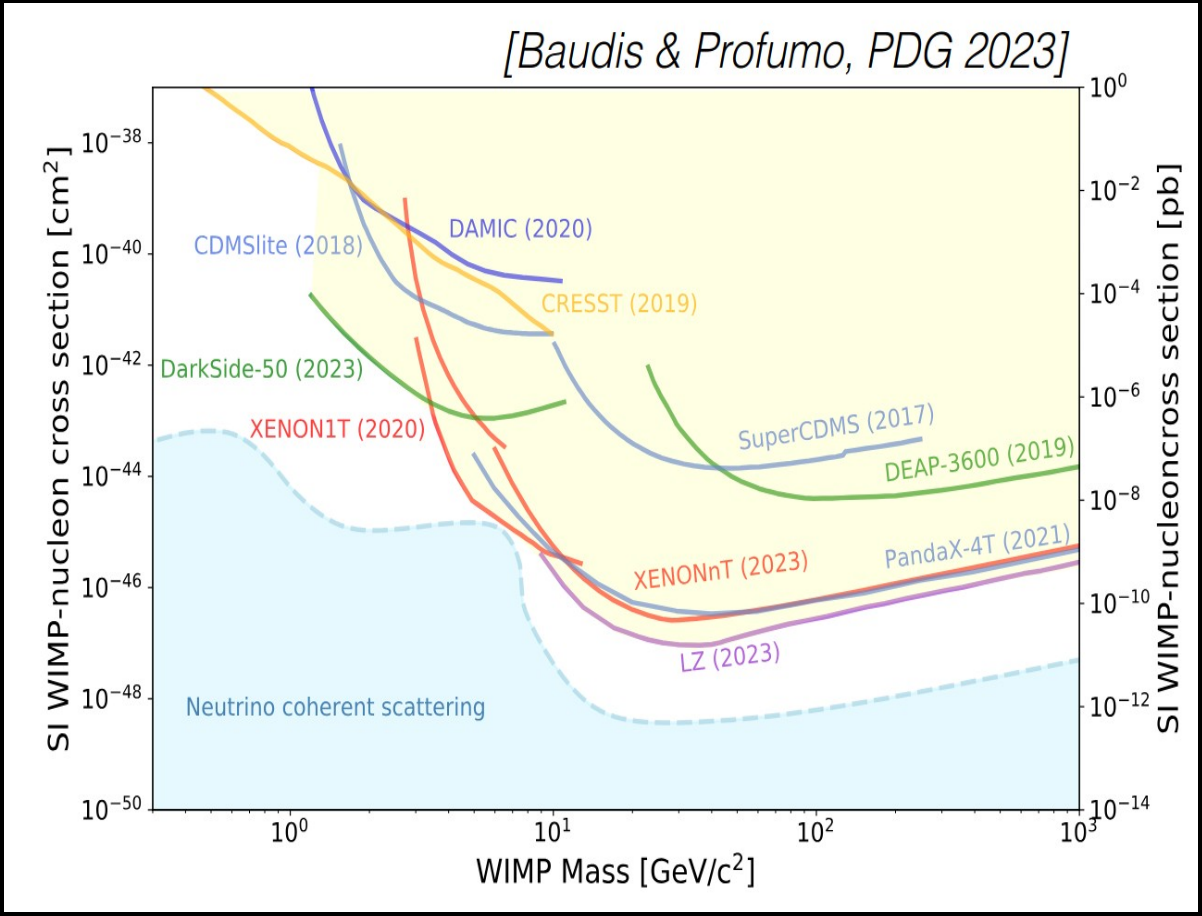


WIMPs have the advantage of being much easier to detect

Via collider, indirect and direct searches

Strong bounds on many DM models

Future signals?



Direct detection

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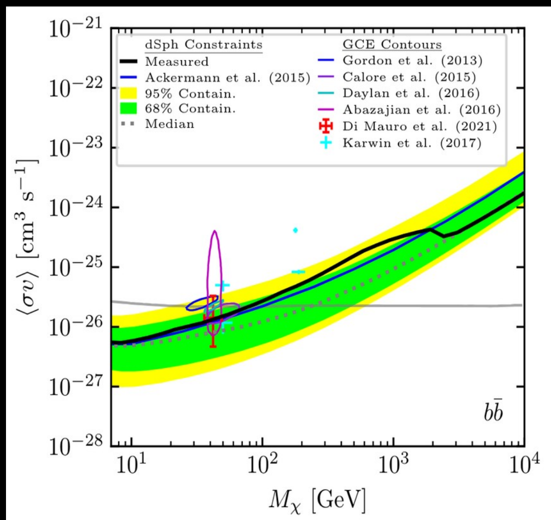

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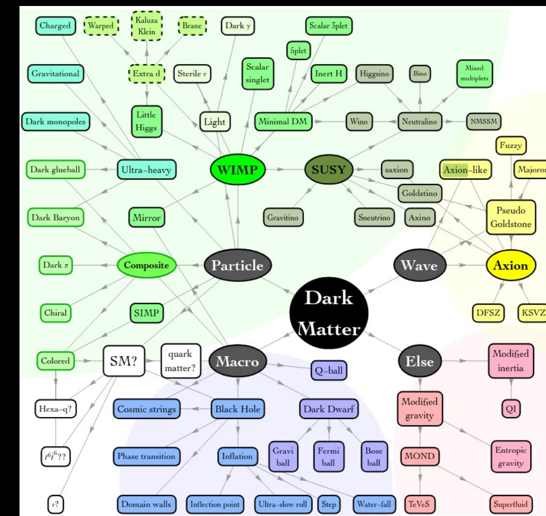

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The stability of the DM particle poses a challenge for model building

Most particles tend to be unstable

$\Gamma_{t,W,Z} \sim 10^{-25}$s

Impose an additional symmetry

Gauge, global or discrete?

A Z_2 is the most common choice

Even: $\varphi \rightarrow \varphi$ (SM)
Odd: $S \rightarrow -S$ (DM)

Replacing the Z_2 with a Z_N ($N \geq 3$) yields new DM models with a rich phenomenology

Z_N singlets

Z_N charged
At least 1 scalar

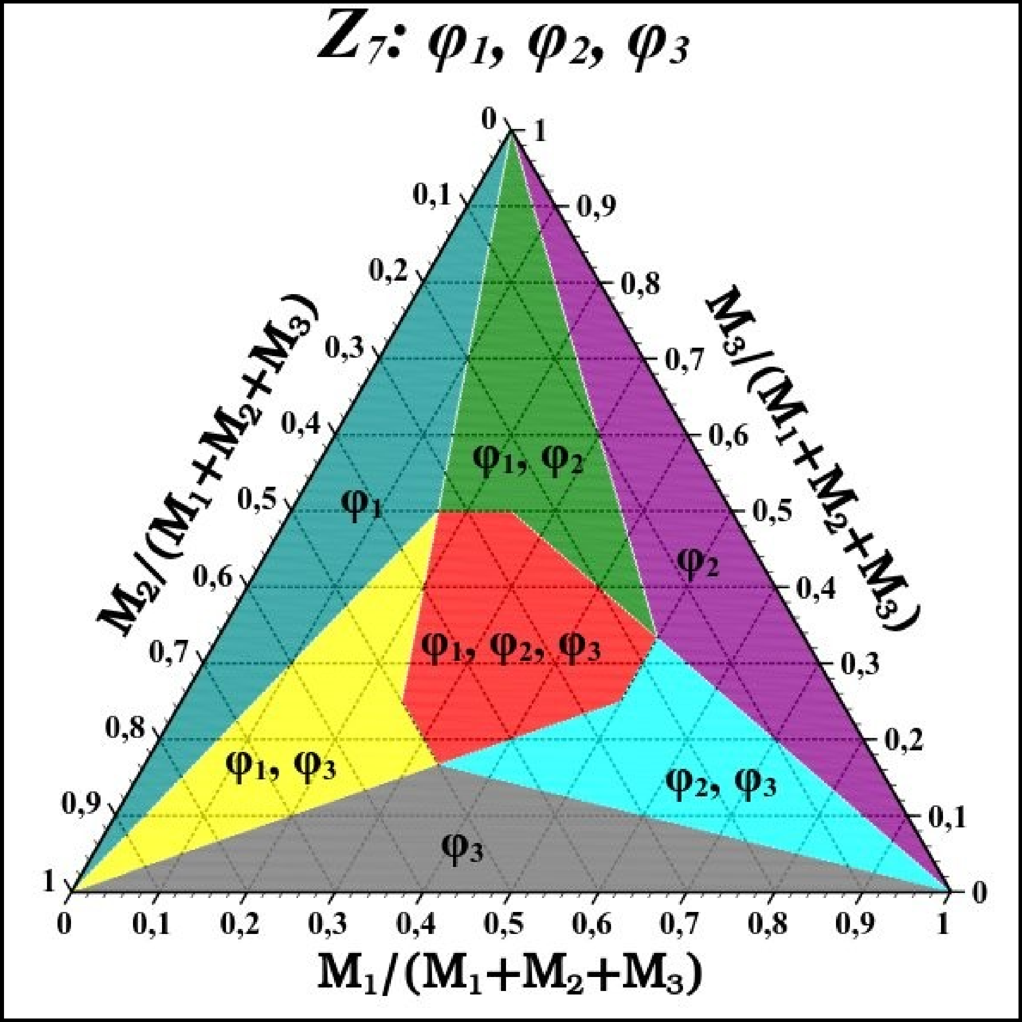
WIMP and FIMP DM can both be realized

Z_N symmetries with N≥3 naturally lead to multi-component dark matter

The DM may consists of different species

DM stability depends on the masses

New dark matter processes



Let us consider a scenario with 1 scalar (S) and 1 fermion (ψ) charged under a Z_4

$S \rightarrow -S$ and $\psi \rightarrow i\psi$ under the Z_4

$$\mathcal{L} = \frac{1}{2}\mu_S^2 S^2 + \lambda_S S^4 + \frac{1}{2}\lambda_{SH}|H|^2 S^2 + M_\psi \overline{\psi}\psi + \frac{1}{2}\left[y_s \overline{\psi^c}\psi + y_p \overline{\psi^c}\gamma_5 \psi + \text{h.c.}\right] S,$$

S is stable provided $M_S < 2M_\psi$

ψ is always stable

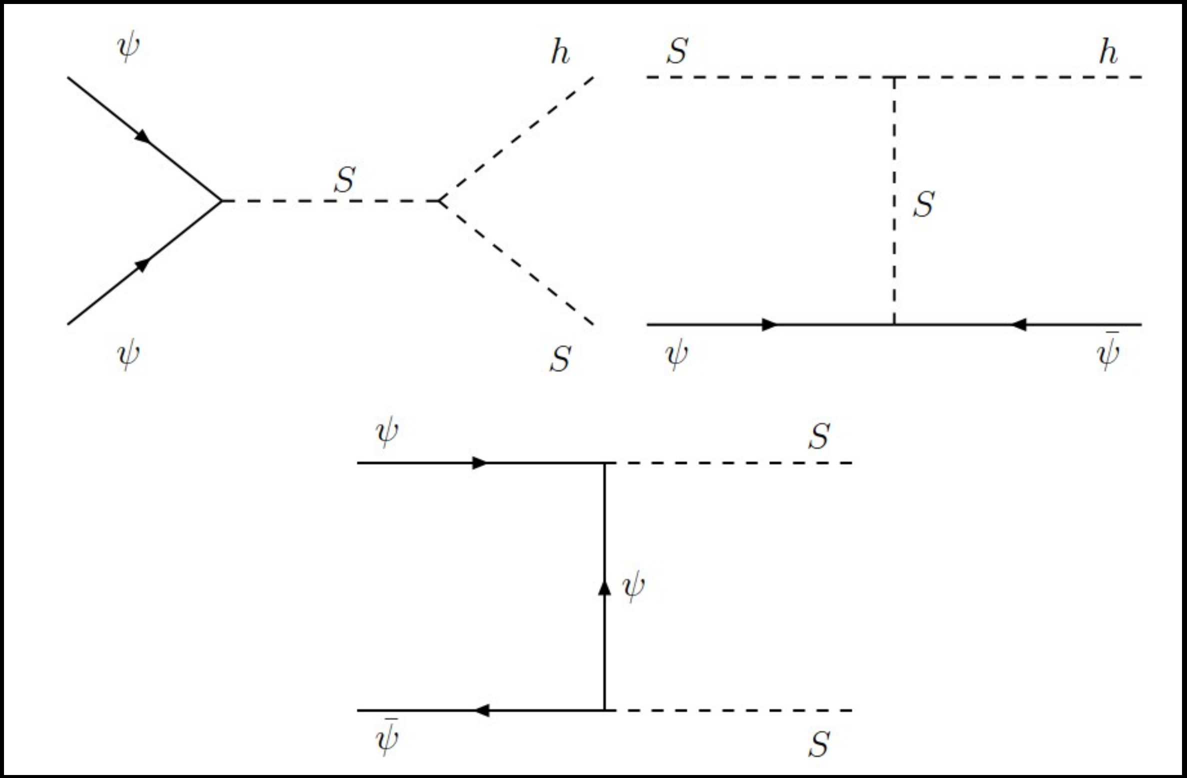
Just five free parameters!

M_S, M_ψ
λ_{SH}, y_s, y_p

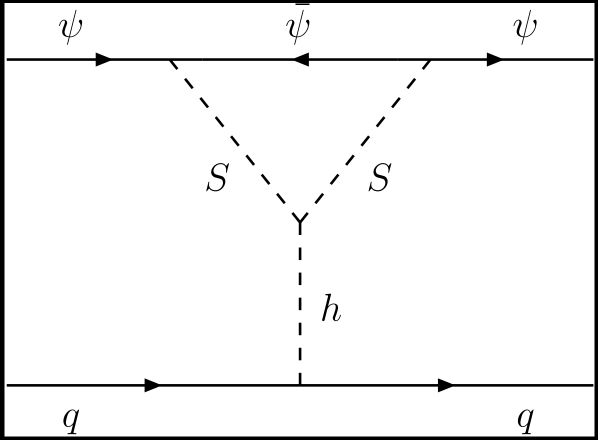
It predicts novel dark matter processes

Semi-annihilations:

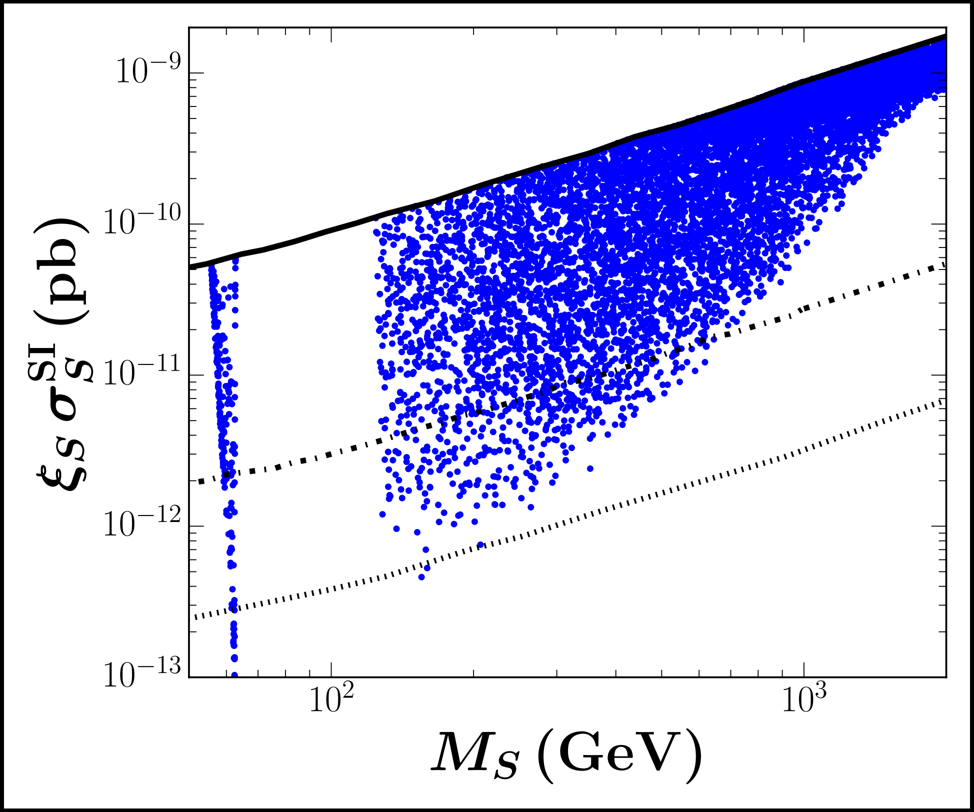
DM conversions:

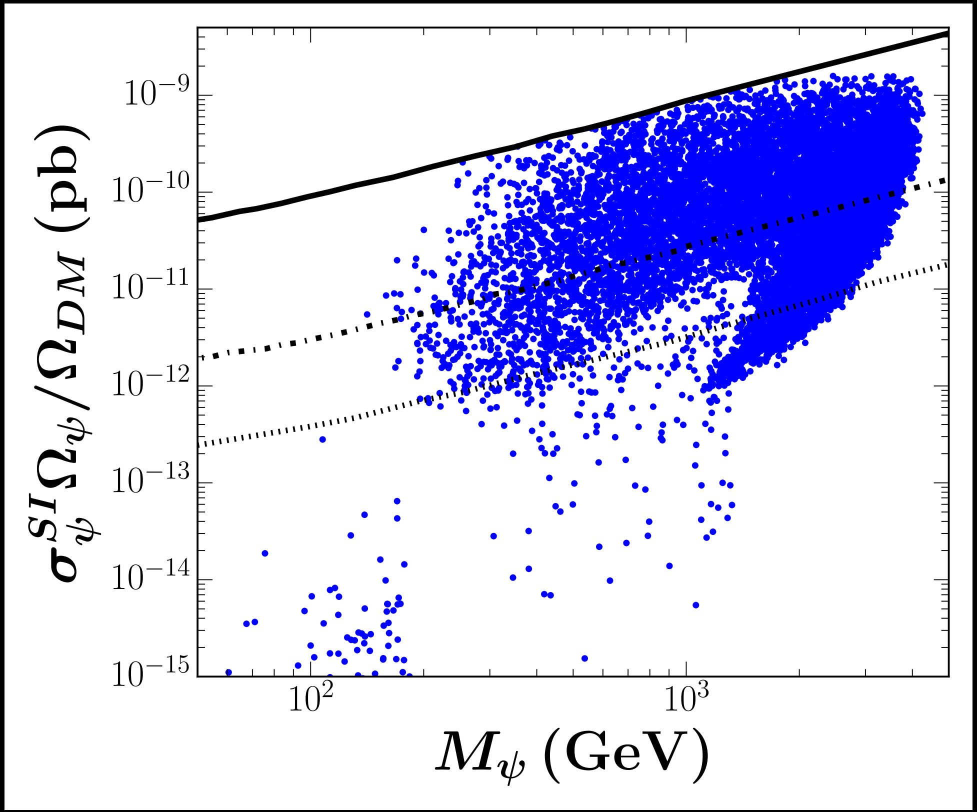


And direct detection at 1-loop



Both dark matter particles could be detected in future DD experiments





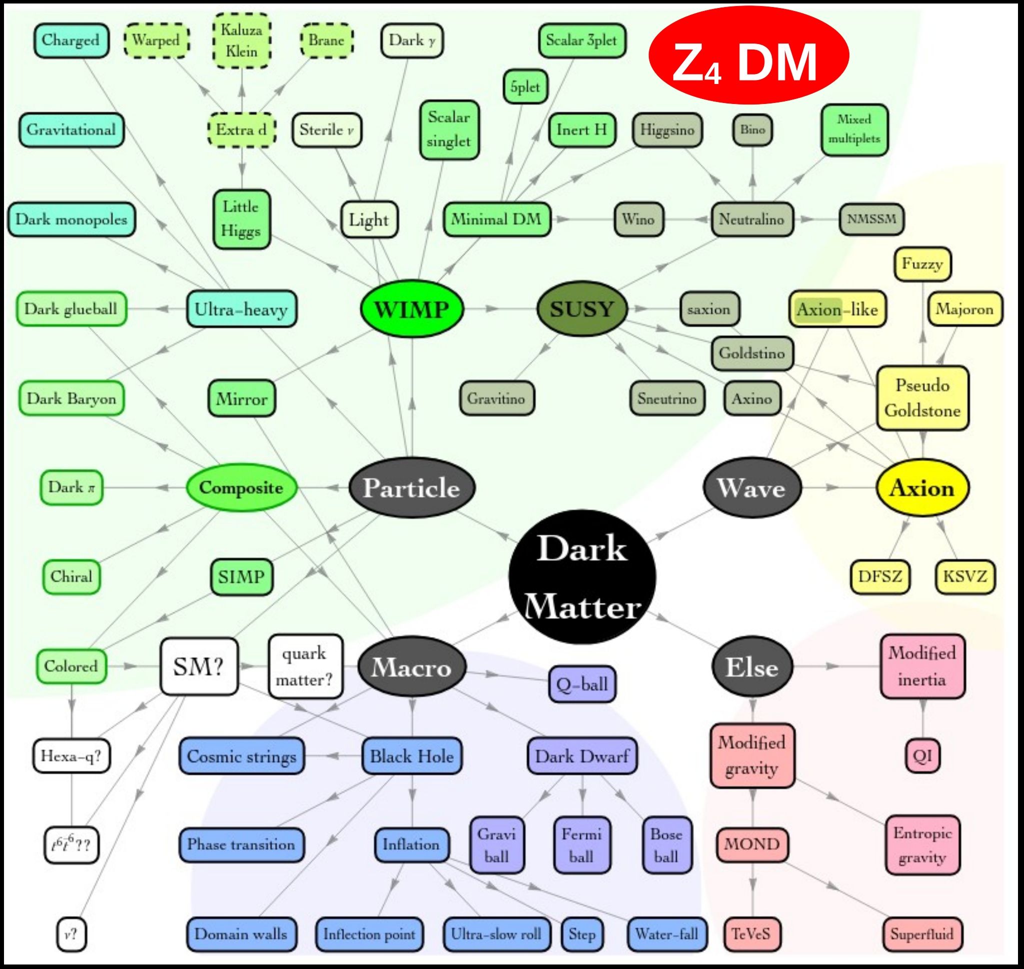
Similar results in scenarios with different Z_N symmetries

There is still plenty of room for new ideas on dark matter theories

Many models can explain the dm

Multi-component dark matter is appealing

We need experimental signals!



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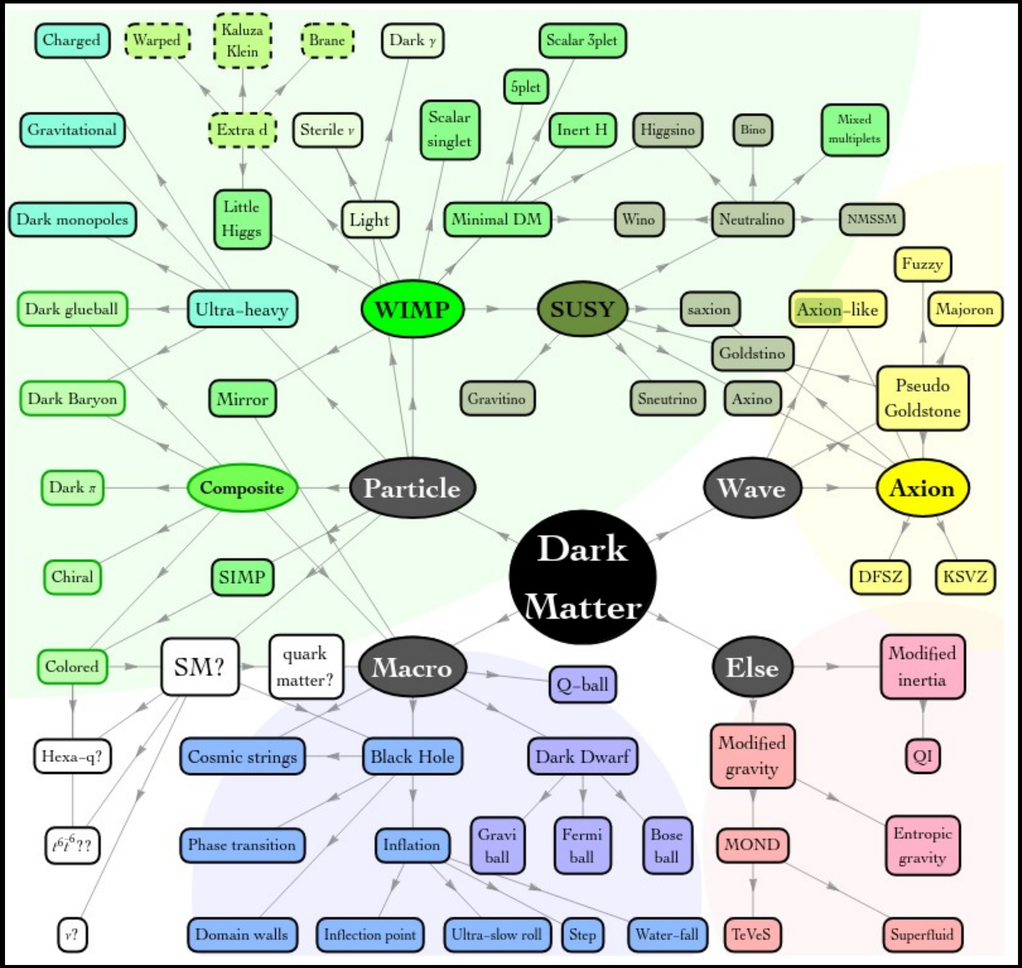
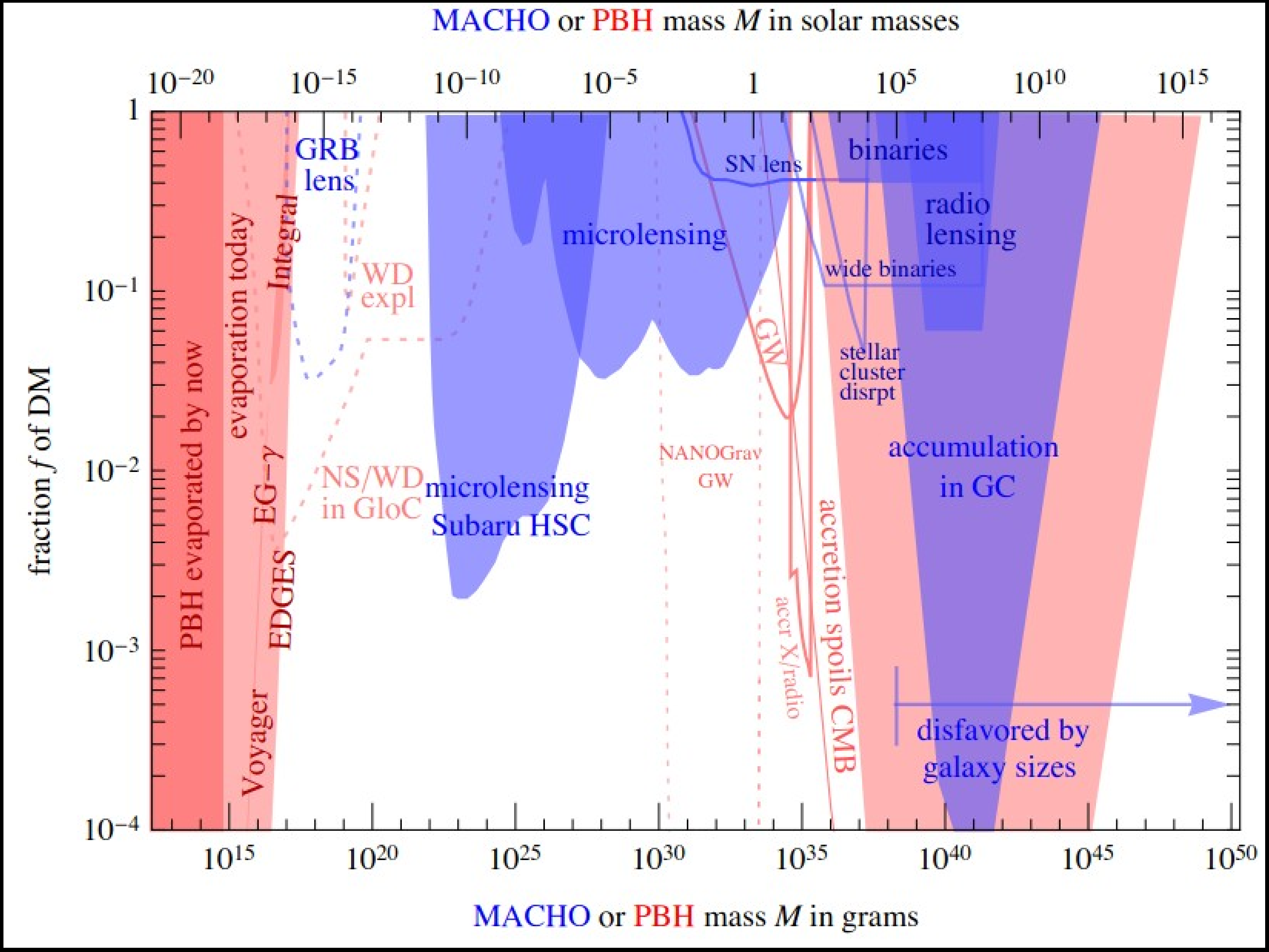
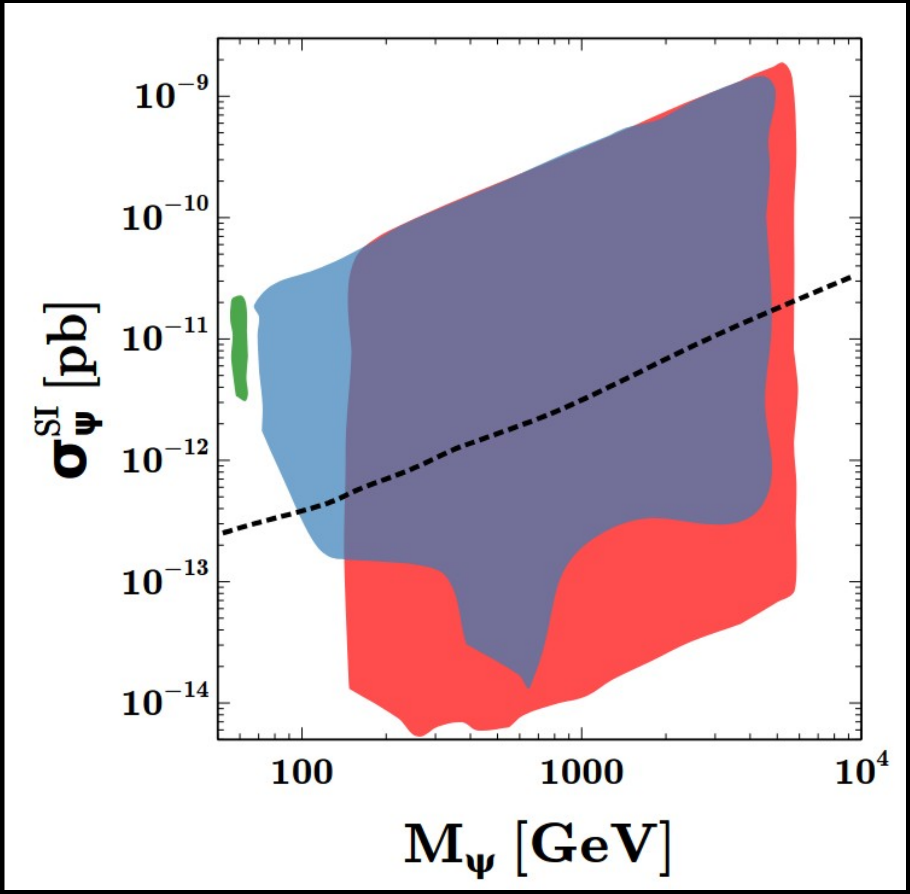


Constraints on Primordial Black Holes as dark matter

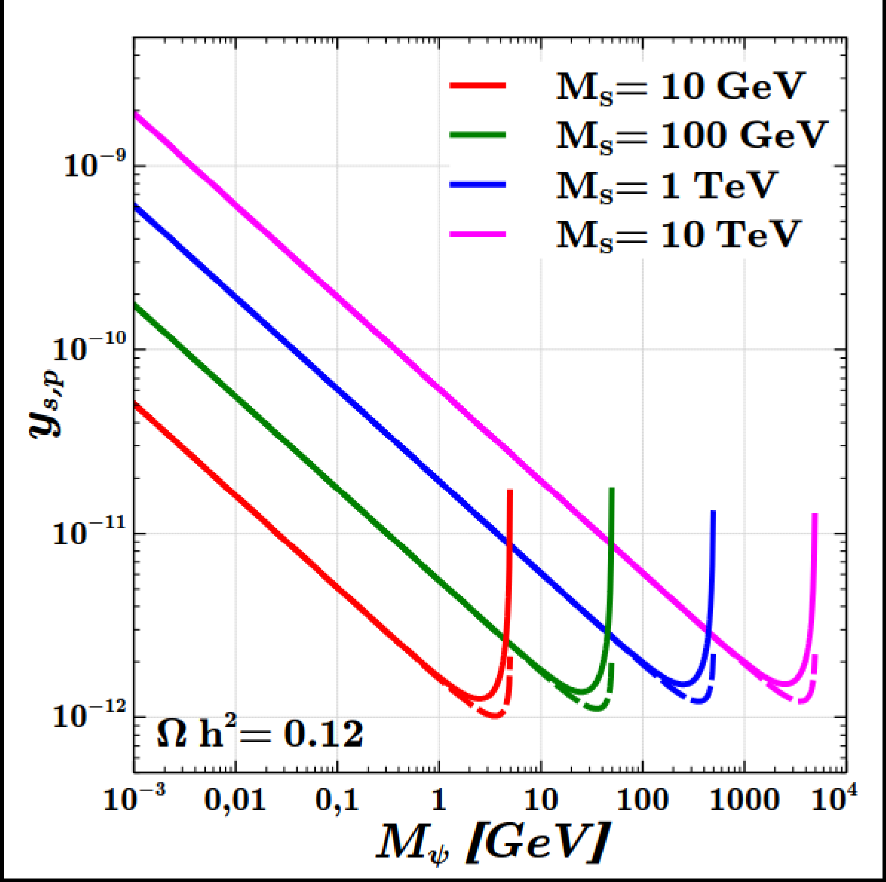


WIMP and FIMP dark matter can both be realized within this framework

WIMP: Z_6 Dirac DM



FIMP: Z_4 Dirac DM



Just 2 new particles and
4 free parameters