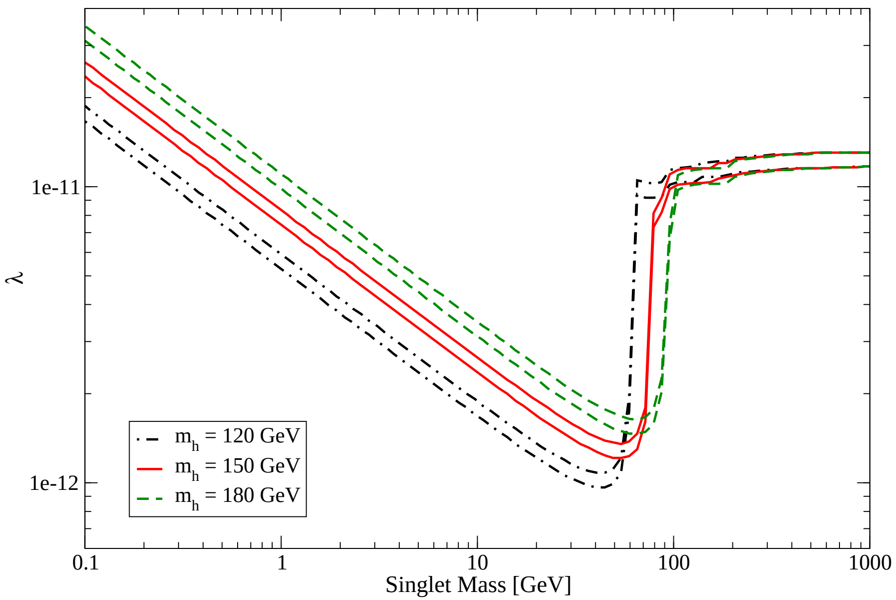
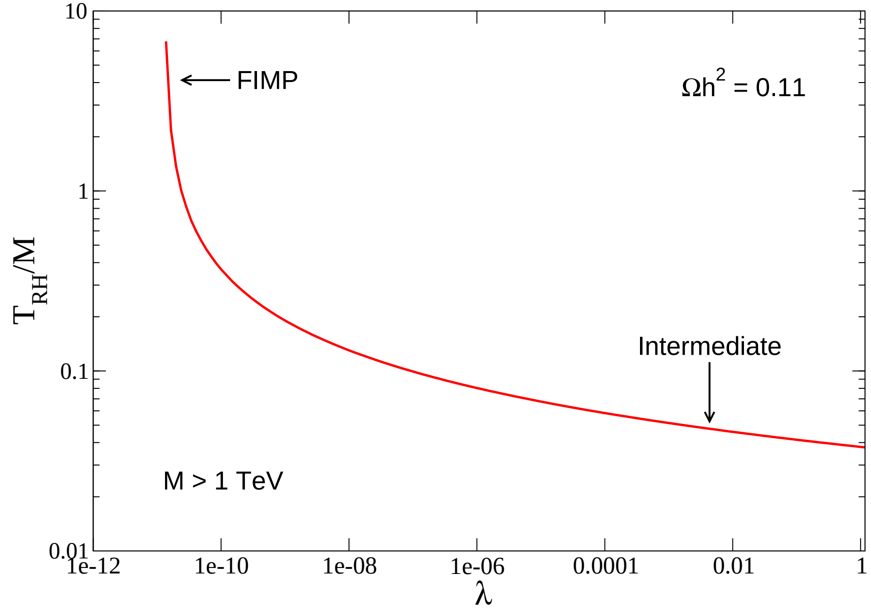
Beyond the WIMP paradigm of dark matter





Based on JHEP 1108(2011)060
and JCAP 02(2012)006

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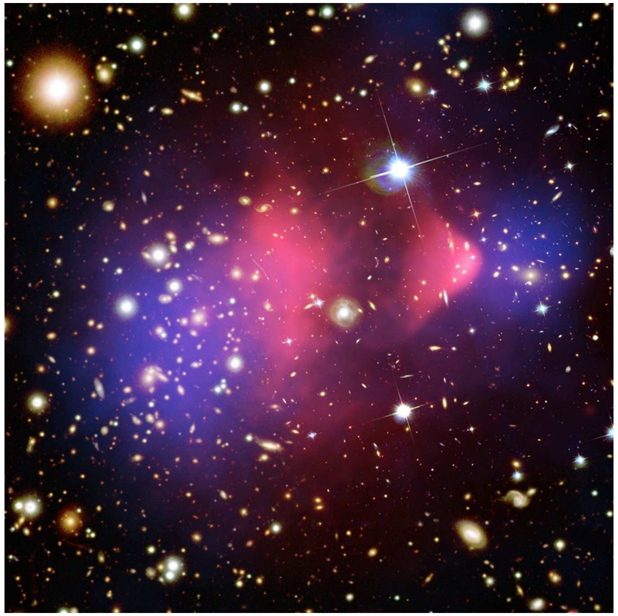
2012

Dark matter constitutes a significant fraction of the energy-density of the Universe

The evidence in favor of DM is overwhelming



Rotation curves
The Bullet Cluster
Large Scale Structure

The DM density is obtained from CMB data

$$0.097 < \Omega h^2 < 0.122$$

The existence of dark matter is a clear indication of physics beyond the Standard Model

DM candidates should be neutral and stable

Neutrinos?

Neutrinos cannot explain the dark matter

$\Omega_\nu \ll \Omega_{dm}$

ν's are not cold

The SM contains no dark matter candidates

New Physics !

The WIMP framework can naturally account for the dark matter

Assumptions:

A new neutral and stable particle

with a mass in the GeV-TeV range

and weak-strength interactions

Conclusion:

It's a good dm candidate

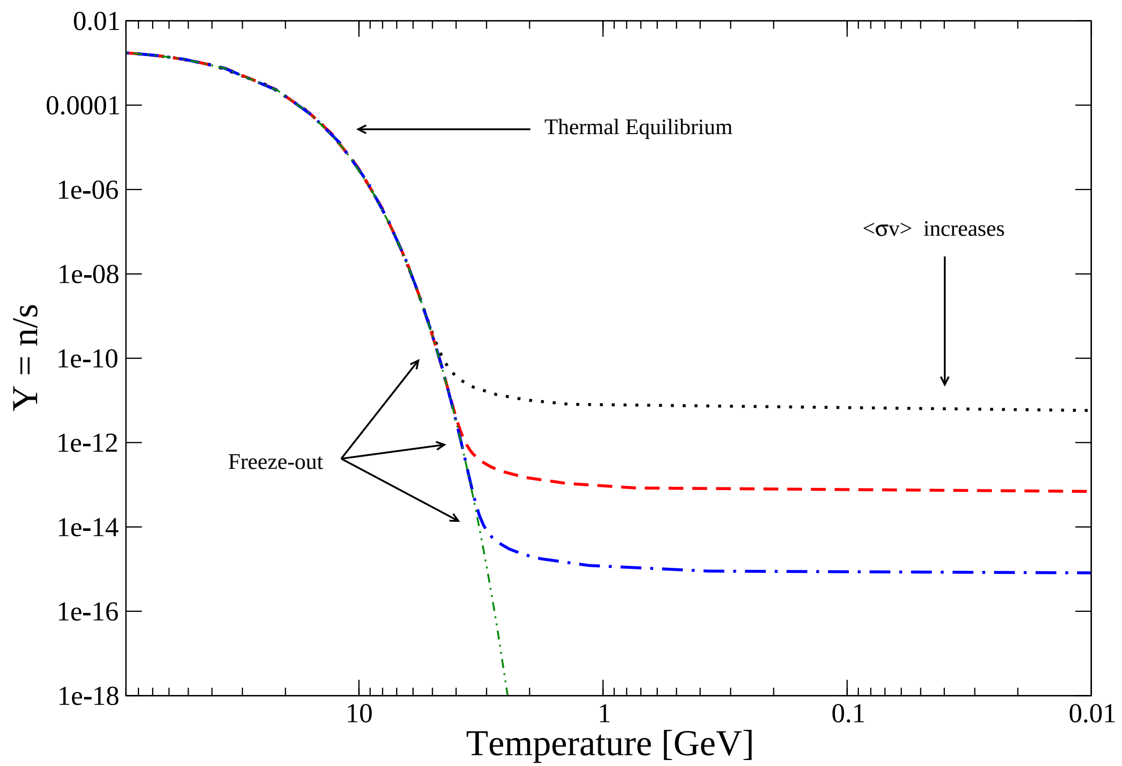
$\Omega h^2 \sim 0.1$

For WIMPs the relic density is the result of a freeze-out

They are in equilibrium at high T

They freeze out at at low T

The relic density is $\propto 1/\langle\sigma v\rangle$



In most models, the dark matter candidate is a WIMP

The χ^0 in the MSSM is the typical example

R-parity $\rightarrow$ stability
$M_\chi \sim M_{SUSY}$

Also in UED or in scalar models

Inert higgs, singlet, MDM,...

There are few notable exceptions

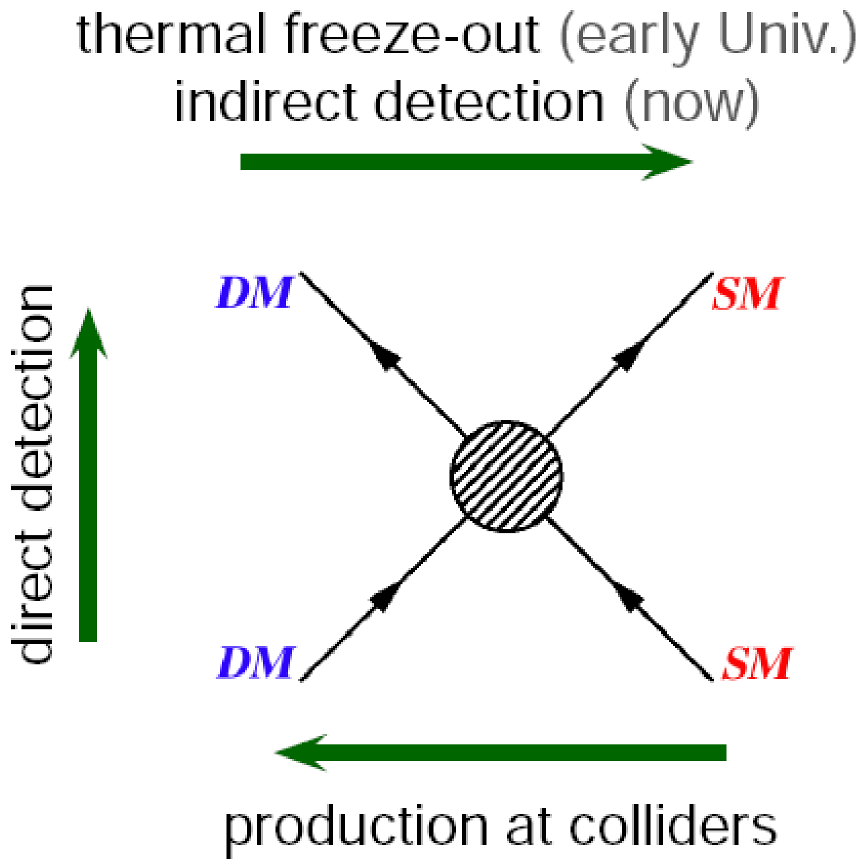
Axion, gravitino

WIMPs can be probed at colliders and in dark matter experiments

The signals are within the reach of current experiments

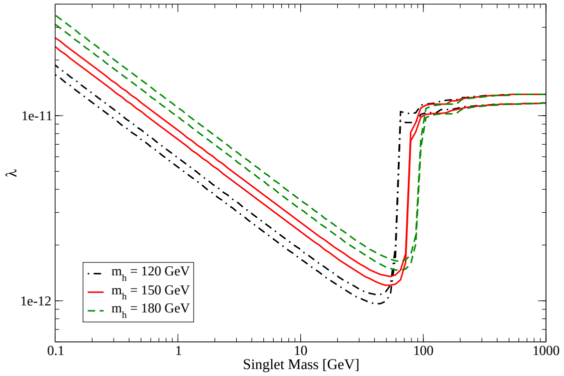
So far there is no evidence of WIMPs

What if dark matter is not made up of WIMPs?



I will discuss two alternative scenarios that are as simple and predictive as the WIMP one

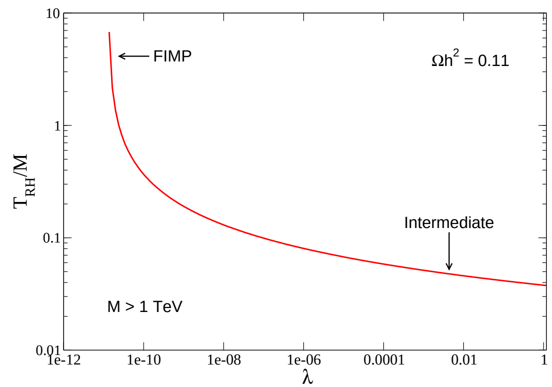
1. FIMPs or Freeze-in



The singlet scalar model

JHEP 1108(2011)060

2. The intermediate framework



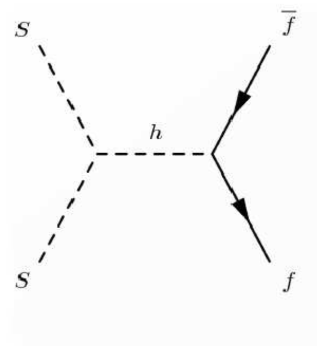
JCAP 02(2012)006

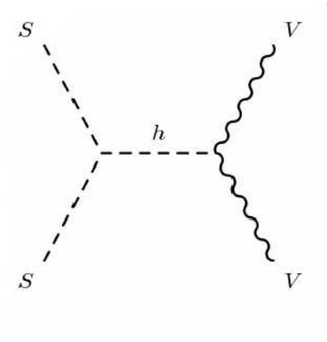
A real scalar singlet is a perfectly viable dark matter candidate

Add a gauge singlet and impose a Z_2 symmetry

$$\mathscr{L} = \mathscr{L}_{SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}m_0^2 S^2 - \lambda S^2 H^\dagger H - \frac{1}{4}\lambda_S S^4$$

S interacts with the SM fields via the higgs





The model contains only two parameters: λ, m_S

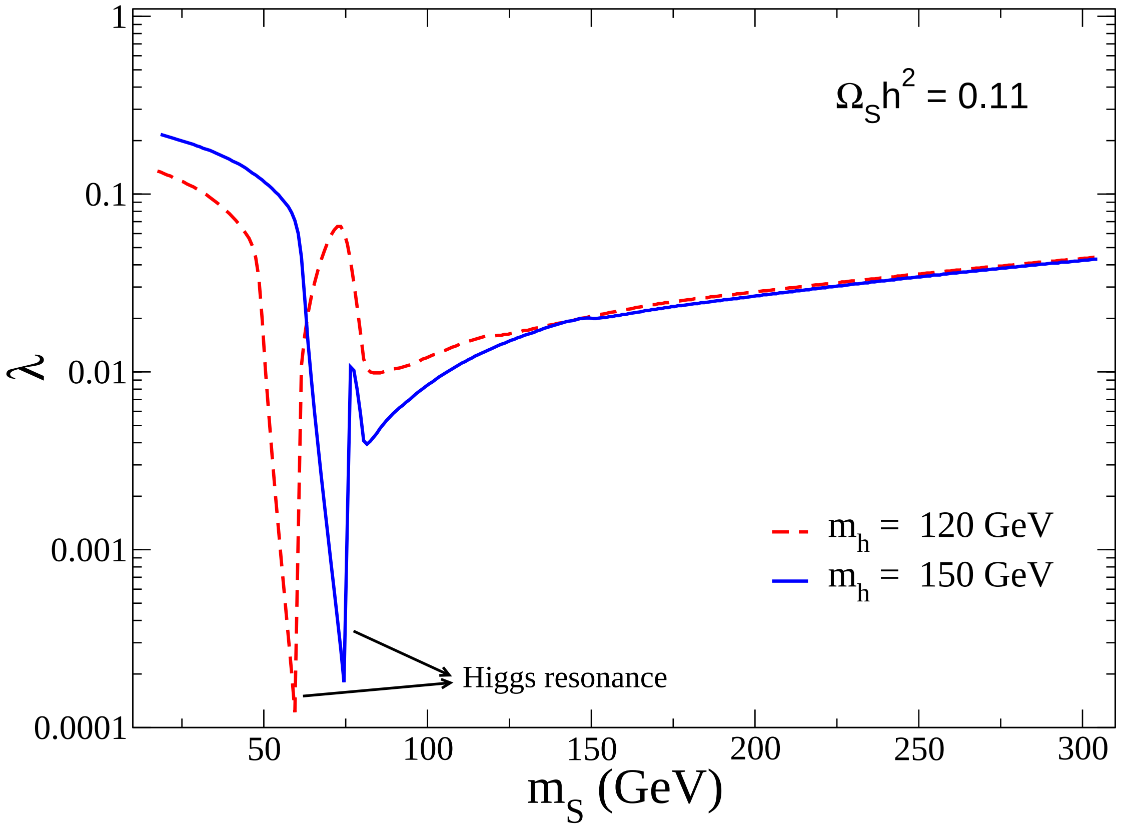
easy to analyze

The right relic density can be obtained within the WIMP regime

The viable region is a line in the plane (m_S, λ)

λ must be large at small m_S

λ must be small around the higgs resonance

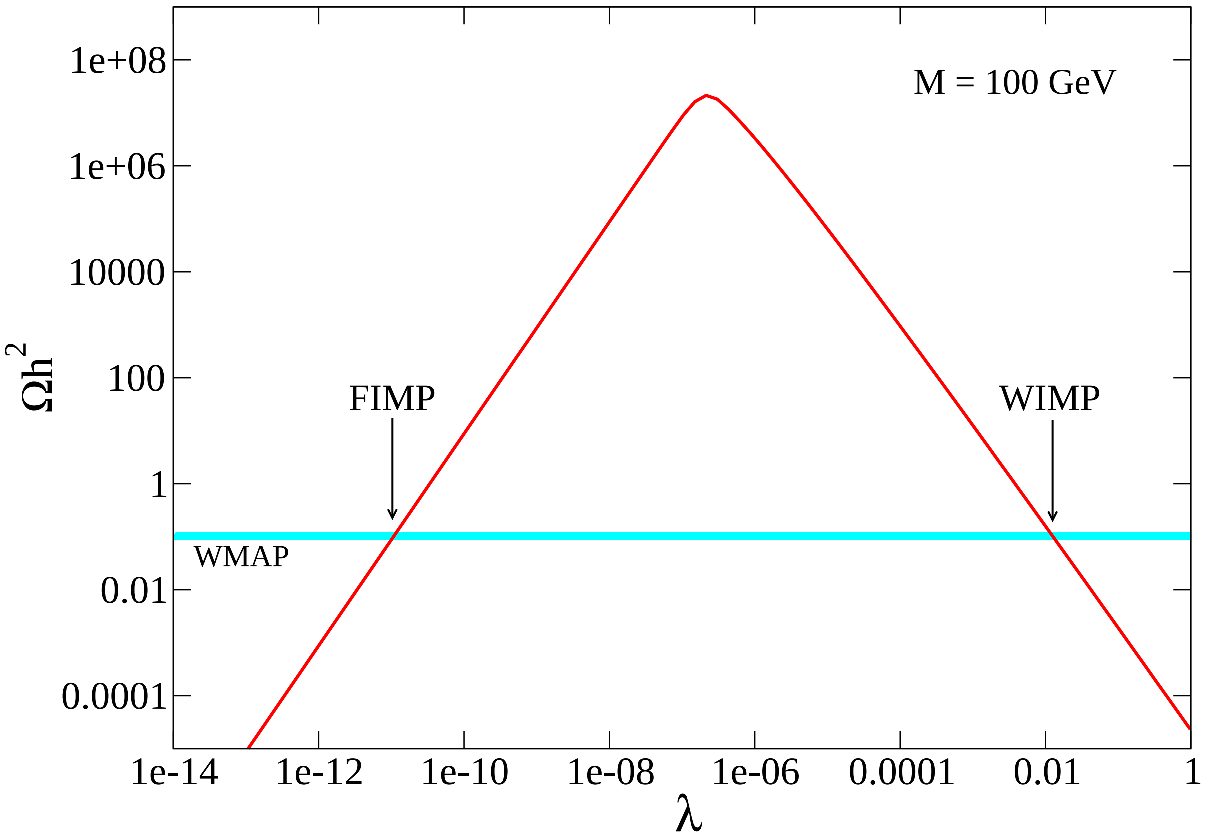


In this model, there has to exist additional solutions to the dark matter constraint

For thermal production
$\Omega h^2 \to 0$ as $\lambda \to 0$

Ωh^2 decreases with λ for WIMP-like solutions

$\Omega h^2 = 0.1$ is satisfied also for very small λ

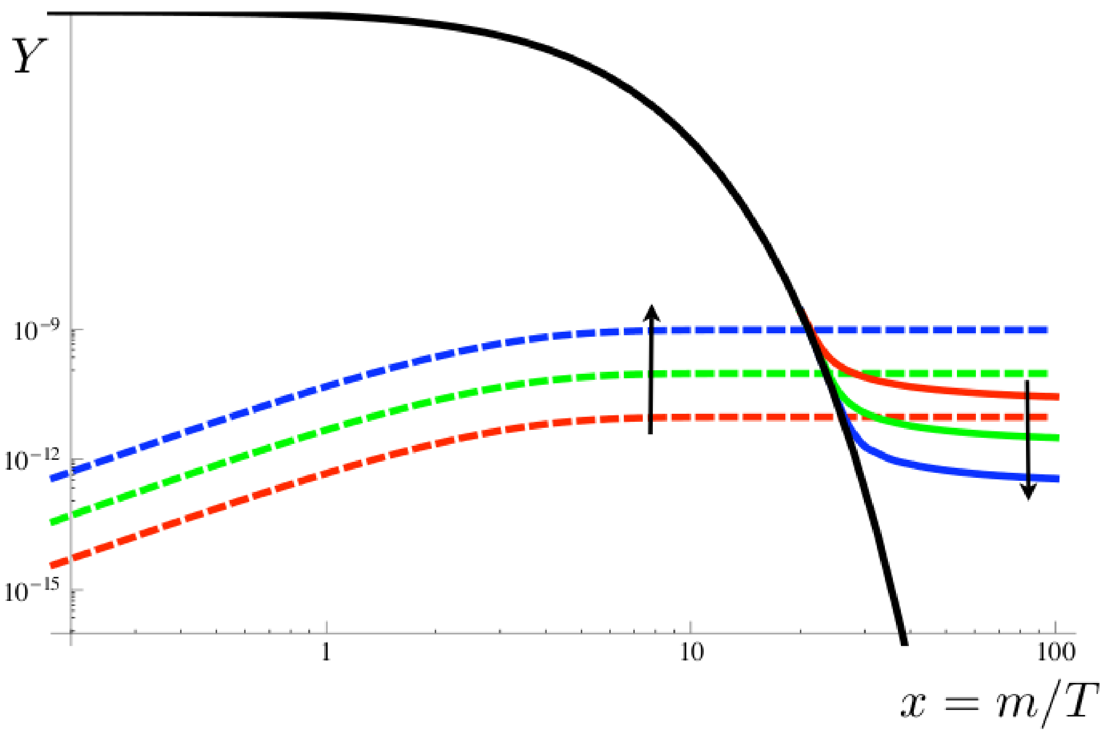


These new solutions correspond to the freeze-in production of FIMP dark matter

The dm particle interacts very weakly (feebly)

It does not reach thermal equilibrium

Ωh^2 is proportional to $\langle \sigma v \rangle$



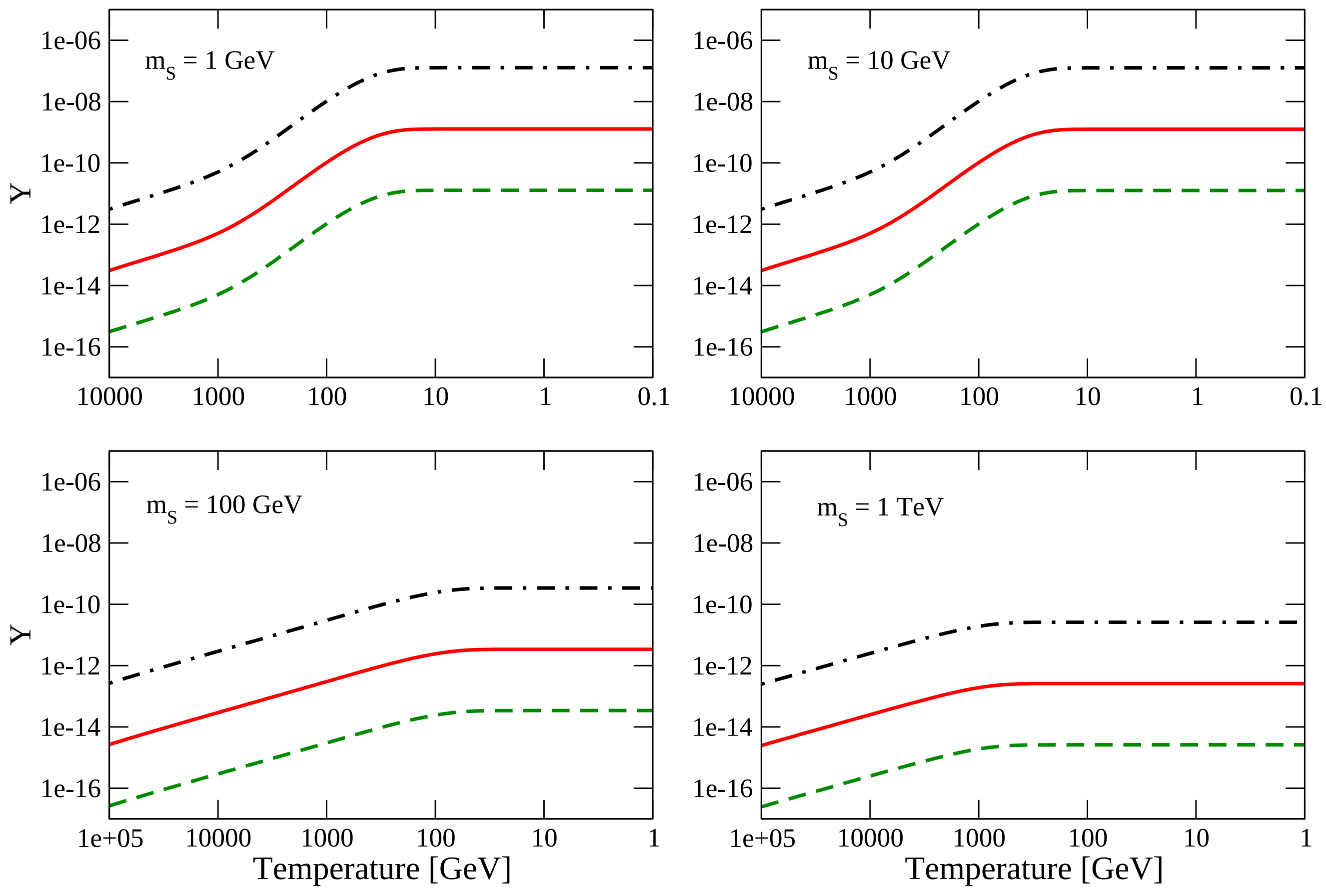
Hall, Jedamzik, March-Russell and West
JHEP 1003 (2010) 080

In the FIMP regime of the singlet model, Y increases with T until $T_{freeze\text{-}in}$

$$\frac{dY}{dT} = k\langle\sigma v\rangle Y_{eq}^2(T)$$

With $Y(T \gg m_S) = 0$

$$Y \propto \langle\sigma v\rangle \propto \lambda^2$$

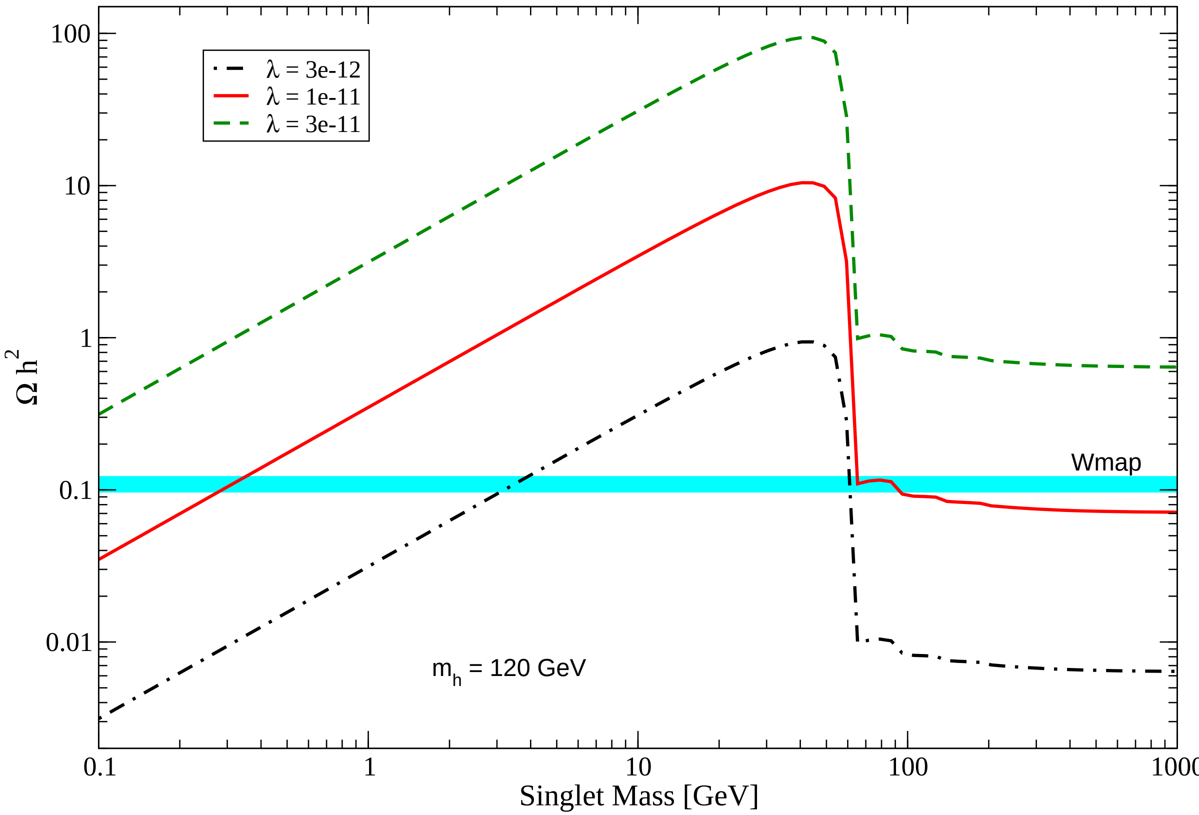


The singlet relic density depends on m_S and on λ

Below the higgs resonance Ωh^2 increases with m_S

Ωh^2 is almost constant for $m_S > m_{higgs}/2$

Ωh^2 changes drastically around the resonance

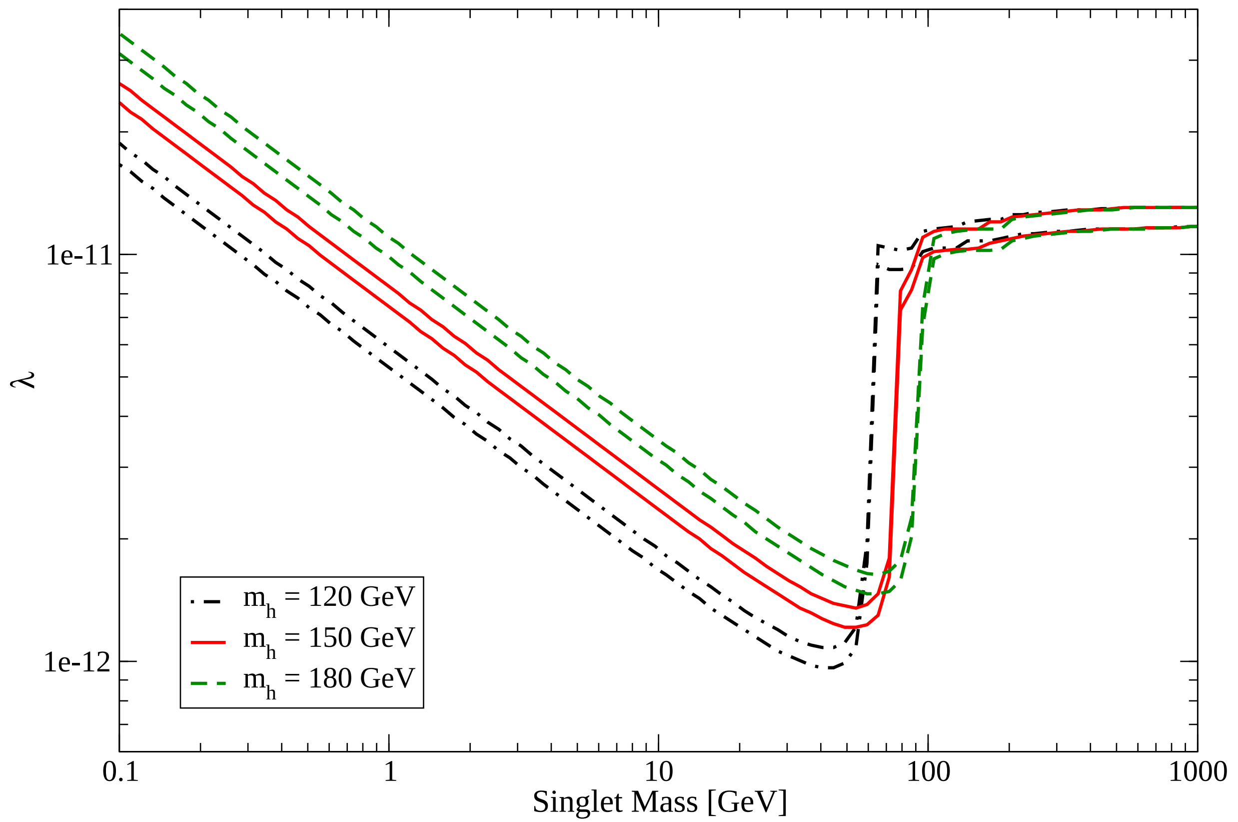


There is a new a viable region of the singlet model that corresponds to FIMP dark matter

It slightly depends on the higgs mass

λ should be between 10^{-11} and 10^{-12}

The viable mass range is quite wide



The detection of dark matter in this new viable region is hopeless

Since $\lambda \sim 10^{-11}$, all signals are suppressed

by $\sim 10^{-20}$ w.r.t WIMPs

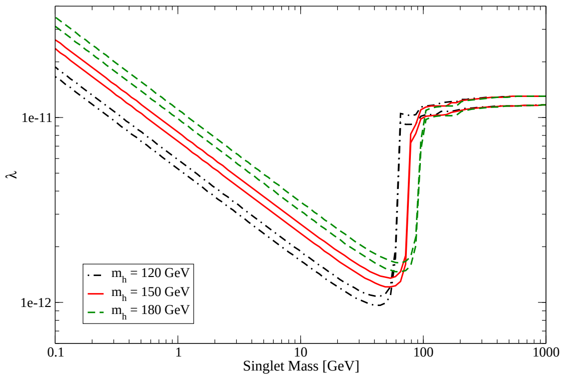
They lie well below the experimental sensitivity

even the futuristic ones

Is there a way to make dark matter detectable within a FIMP-like setup?

I will discuss two alternative scenarios that are as simple and predictive as the WIMP one

1. FIMPs or Freeze-in



The singlet scalar model

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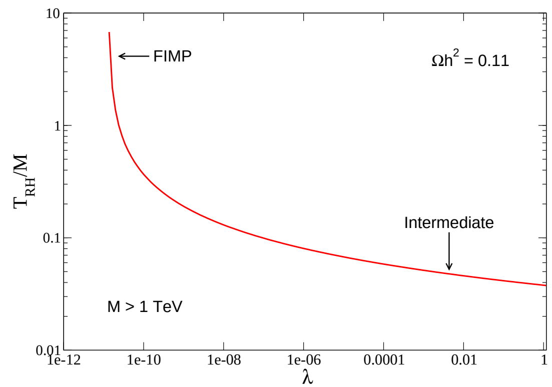
2. The intermediate framework



JCAP 02(2012)006

The essential feature of FIMPs is that they do not reach thermal equilibrium

There are at least two ways to achieve that:

1. **Very small coupling** — **Standard FIMP scenario**

2. **A small value of T_{RH}/M_{dm}** — **Intermediate scenario**

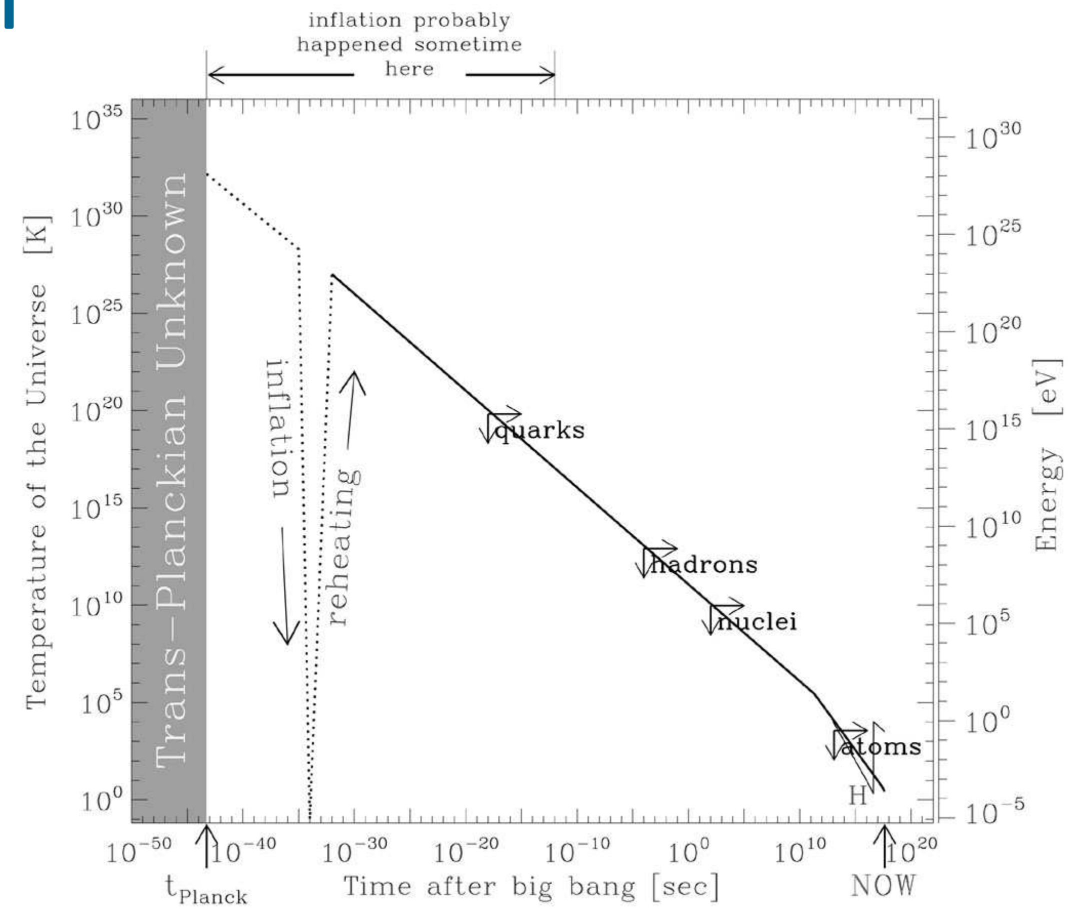
   T_{RH}:the reheating temperature of the Universe

T_{RH} marks the transition from inflation to the radiation dominated Universe

It's a Standard Cosmological parameter

Its value is unknown:
$T_{RH} \gtrsim 5$ MeV

Usually it is assumed to be very large



In the intermediate framework the initial conditions are different

$$\frac{dY}{dT} = k\langle\sigma v\rangle Y_{eq}^2(T)$$

Annihilation term is irrelevant

With $Y(T_{RH}) = 0$ and $T_{RH} \ll m_S$

Thermal production only

$$\Omega h^2 \propto \langle\sigma v\rangle \frac{m_S}{T_{RH}} e^{-2m/T_{RH}}$$

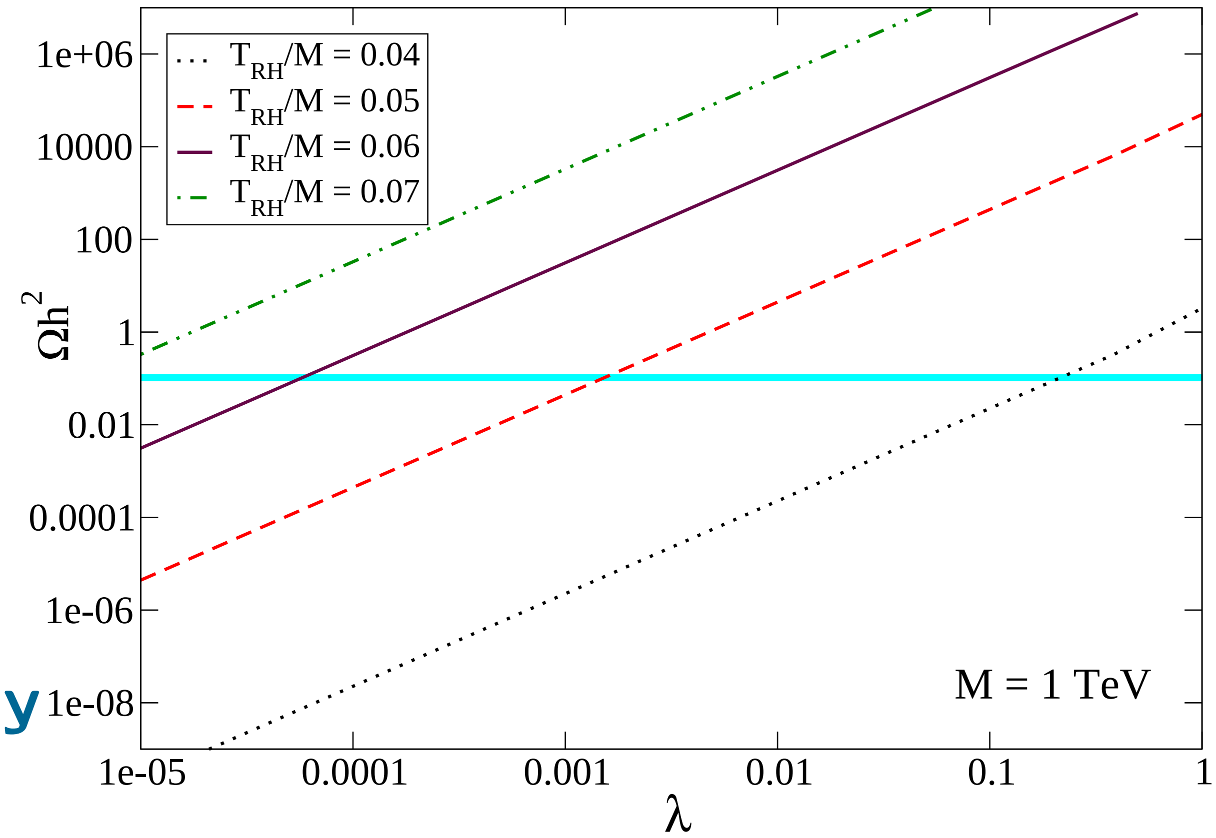
Strong dependence on T_{RH}

The relic density increases with the reheating temperature

We use T_{RH}/M as the free parameter

Ωh^2 is proportional to λ^2

Ωh^2 depends exponentially on T_{RH}/M

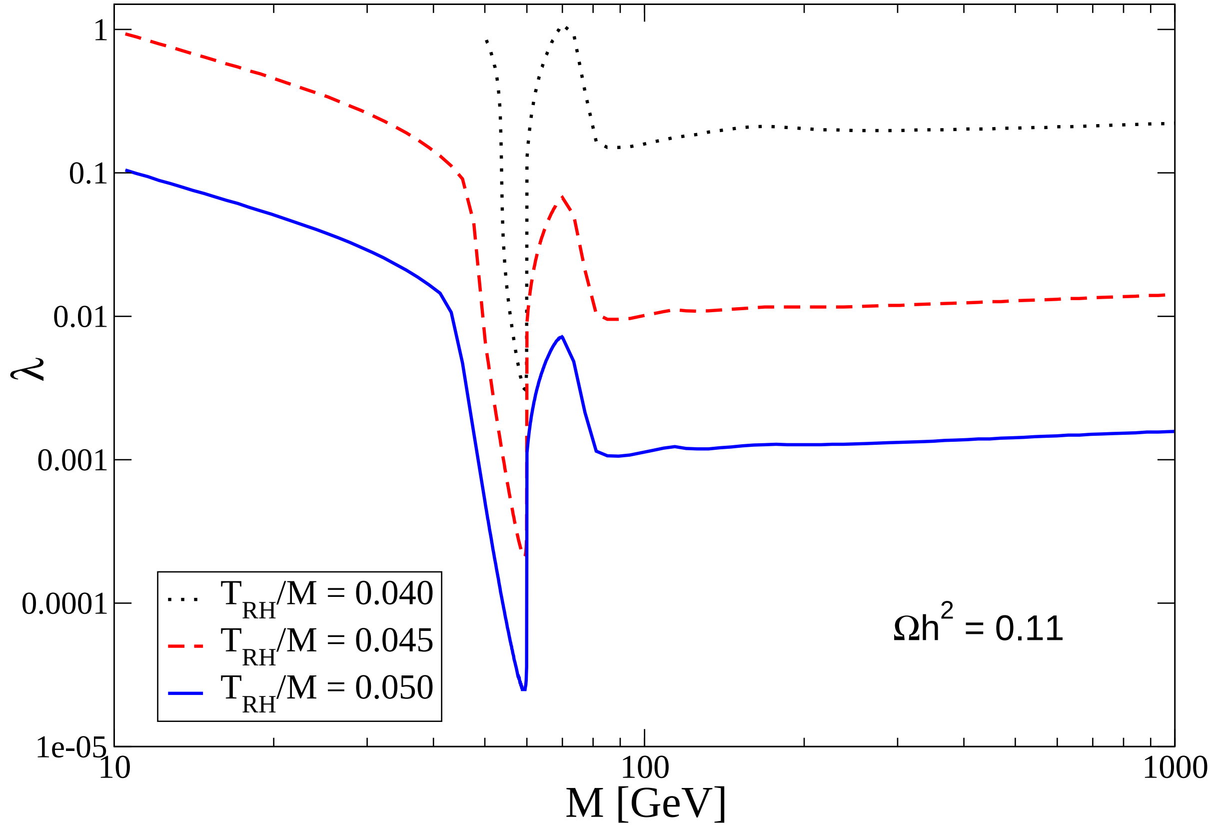


There are new regions that are also consistent with the dark matter constraint

They depend on T_{RH}/M

λ is not necessarily small

Dark matter could be detected

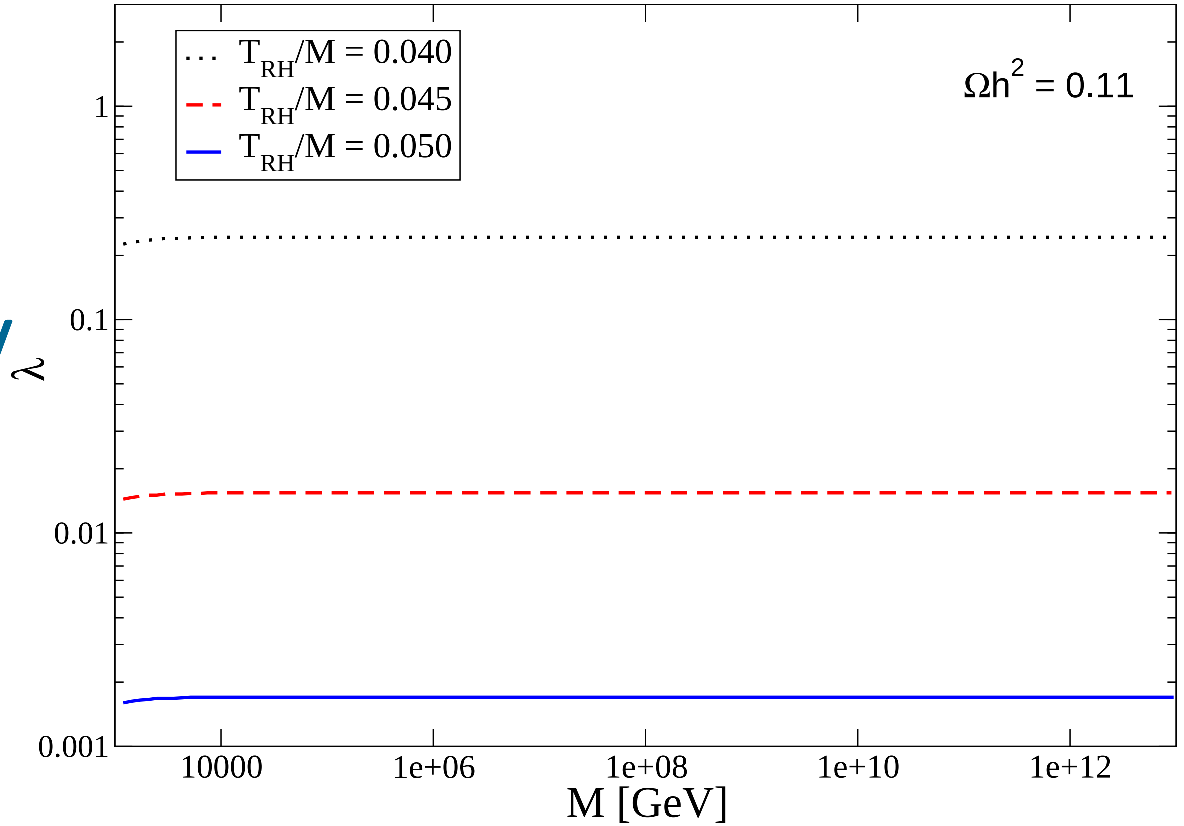


Super-heavy dark matter is viable in the intermediate regime

M does not need to be in the GeV-TeV range

M can be made arbitrarily large

T_{RH} is not necessarily low

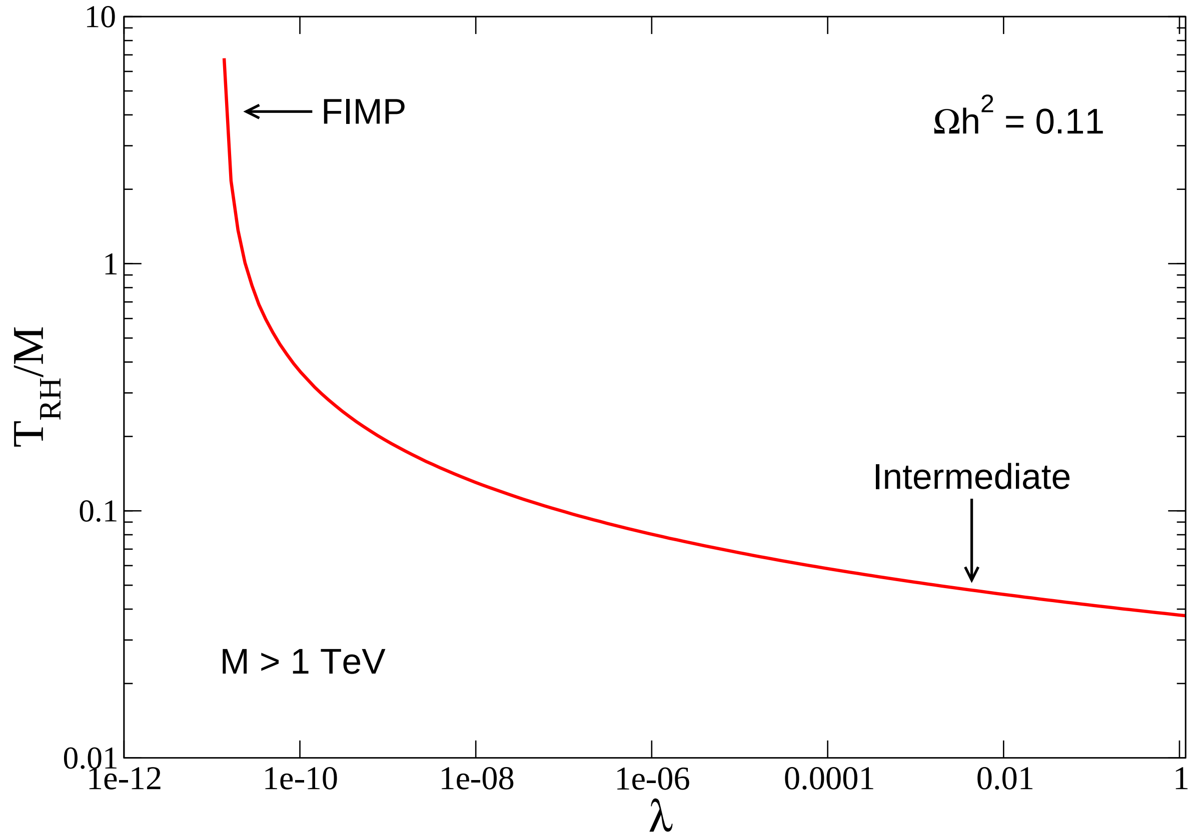


The intermediate regime is strongly connected to the FIMP regime

At high T_{RH}/M we get the FIMP regime

At low T_{RH}/M we get the intermediate one

They are particular cases of the general solution

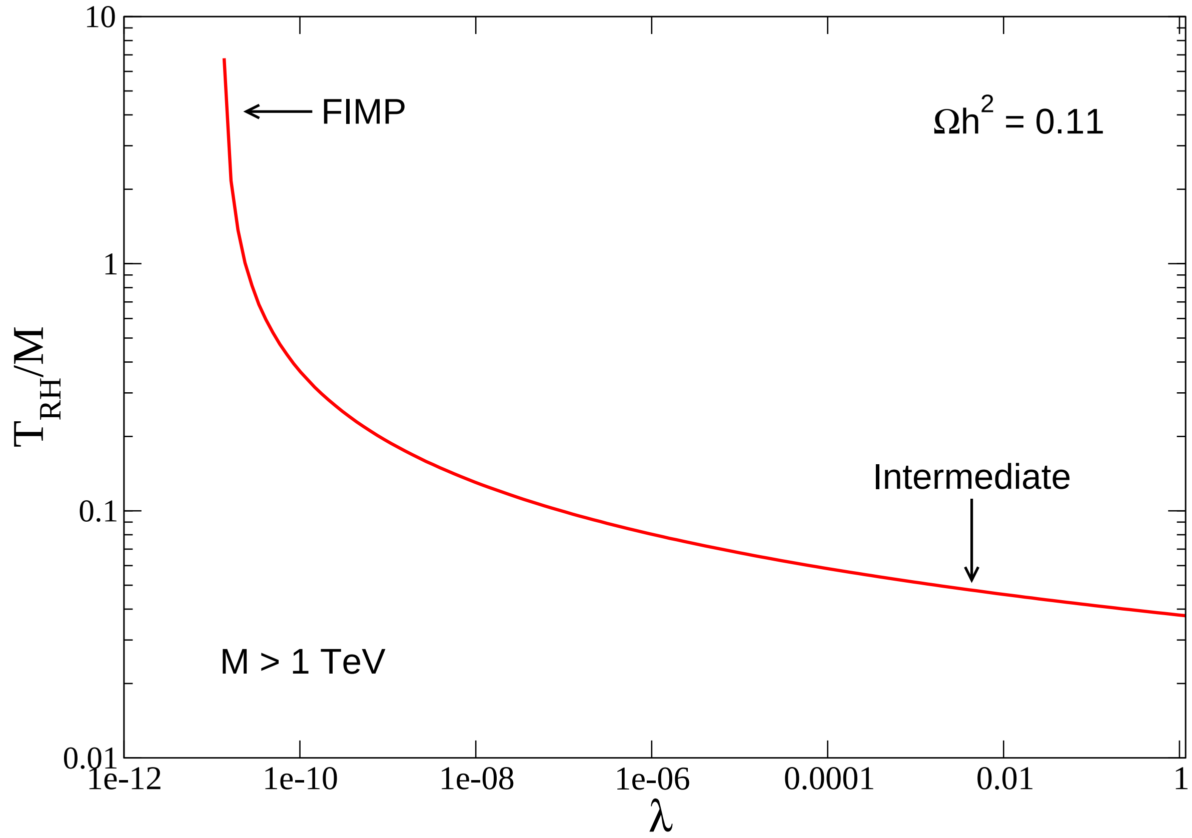


The intermediate scenario suggests a connection between dark matter and inflation

For typical values of λ we get:

$$T_{RH} \sim 4\text{-}5 \times 10^{-2} M$$

This is work in progress



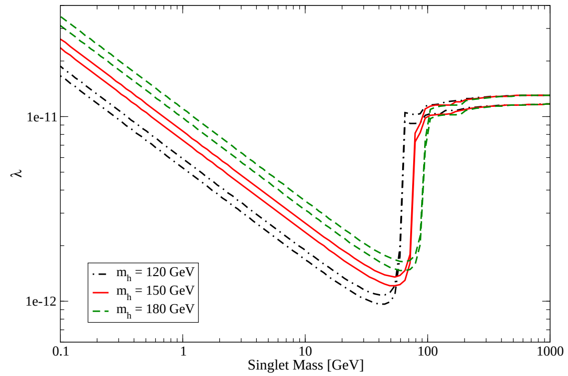
There certainly are interesting alternatives to the WIMP paradigm of dark matter

They are simple and predictive

They do not introduce exotic physics

The WIMP solution is not unique

1. The singlet scalar as FIMP dark matter



2. The intermediate scenario