PLANCK 2025

Antonio Masiero Fest - 29th May 2025

Antonio & the Dark Universe

Laura Covi

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Outline

- First meeting with Antonio during the PhD: Baryogenesis via Leptogenesis & Inflation in SU(5)GUT
- Long term inspiration on Dark Matter: SuperWIMPs, FIMPs, SuperFIMPs, Boltzmann suppressed FIMPs
- The astro/particle/cosmology connection for BSM: exploring all evidences and aiming to unify the two models: Standard Model and LambdaCDM
- Outlook

How I met Antonio

1995 Trieste, SISSA

As a PhD student at SISSA I was looking for a PhD project in the direction of cosmology/astroparticles and talking with the director Daniele Amati, he told me that a new professor was coming to SISSA in that field, Antonio Masiero.
As soon as he arrived at SISSA, I went to talk to him about possible projects and he suggested to apply Baryogenesis via Leptogenesis to SUSY models together with Esteban Roulet as co-supervisor, based on the papers

Baryogenesis Without Grand Unification

M. Fukugita (Kyoto U., Yukawa Inst., Kyoto), T. Yanagida (Tohoku U.) (Jan, 1986)

Published in: *Phys.Lett.B* 174 (1986) 45-47

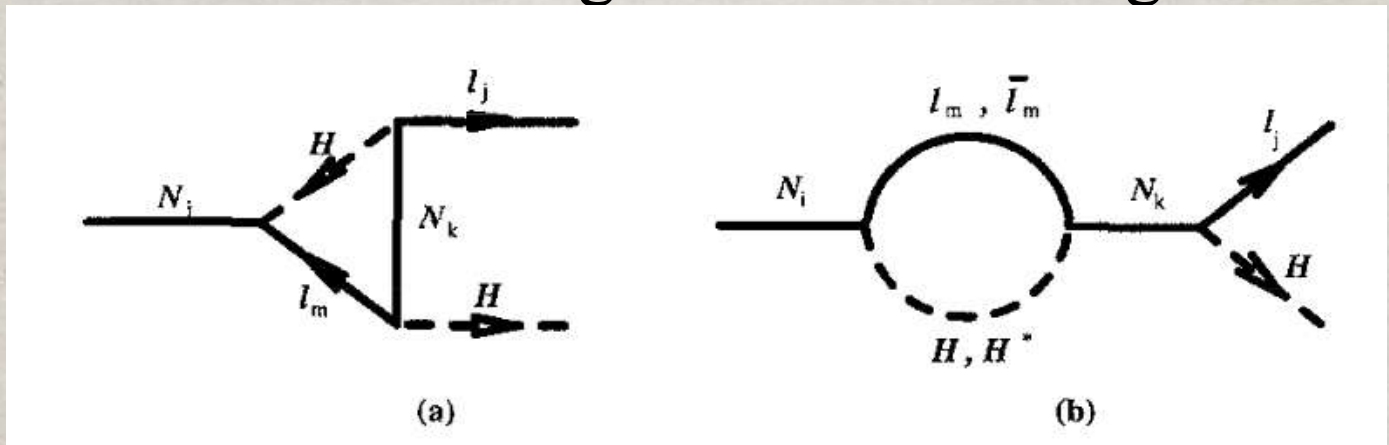
Baryogenesis via leptogenesis

M.A. Luty (Chicago U., EFI) (1992)

Published in: *Phys.Rev.D* 45 (1992) 455-465

CP violation for Leptogenesis

We computed the CP asymmetry with Francesco Vissani and quickly realised that one diagram was missing…



… and dominates for hierarchical masses, x 3 !

Antonio was involved in many discussions, but did not appear as author on the paper:

CP violating decays in leptogenesis scenarios

Laura Covi [a], Esteban Roulet [a], Francesco Vissani [b]

[a] *International School for Advanced Studies, SISSA-ISAS, Via Beirut 2/4, I-34014, Trieste, Italy*

[b] *International Centre for Theoretical Physics, ICTP, Strada Costiera 11, I-34100, Trieste, Italy*

Received 20 May 1996

Inflation in GUTs

After a visit of Gia Dvali at ICTP, we started to discuss about hybrid inflation in SU(5) and Antonio quickly suggested that we should involve also Gennaro Miele and Gianpiero Mangano and sent me to Napoli to work with them. We finished the project in record time:

Hybrid inflation from supersymmetric SU(5)

L. Covi [a,b], G. Mangano [c], A. Masiero [a,d], G. Miele [c]

[a] *International School for Advanced Studies, SISSA-ISAS, Via Beirut 2 / 4, I-34014 Trieste, Italy*
[b] *INFN, Sezione di Trieste, Via A. Valerio 2, I-34127 Trieste, Italy*
[c] *Dipartimento di Fisica, Universitá di Napoli ''Federico II'', and INFN, Sezione di Napoli, Mostra D'Oltremare Pad. 20, I-80125 Napoli, Italy*
[d] *Dipartimento di Fisica, Universitá di Perugia, and INFN, Sezione di Perugia, Via Pascoli, I-06123 Perugia, Italy*

Received 29 July 1997; revised 23 October 1997
Editor: R. Gatto

Erice School 1997

Thanks to Antonio, I was sent to present our results to a few meetings, in particular COSMO1997 near Lancaster, which ended up to be my next career station, and I was accepted to participate to the Erice School on Subnuclear Physics of that year…

35th Course:
Highlights: 50 Years later
Directors: G. ALTARELLI – G. VENEZIANO – A. ZICHICHI
26 August – 4 September 1997

Wonderful experience, having lunch with Antonio and great international physicists, among them Sheldon Glashow and Savas Dimopoulos, on a great place !

Dark Matter: On the shoulders of giants...

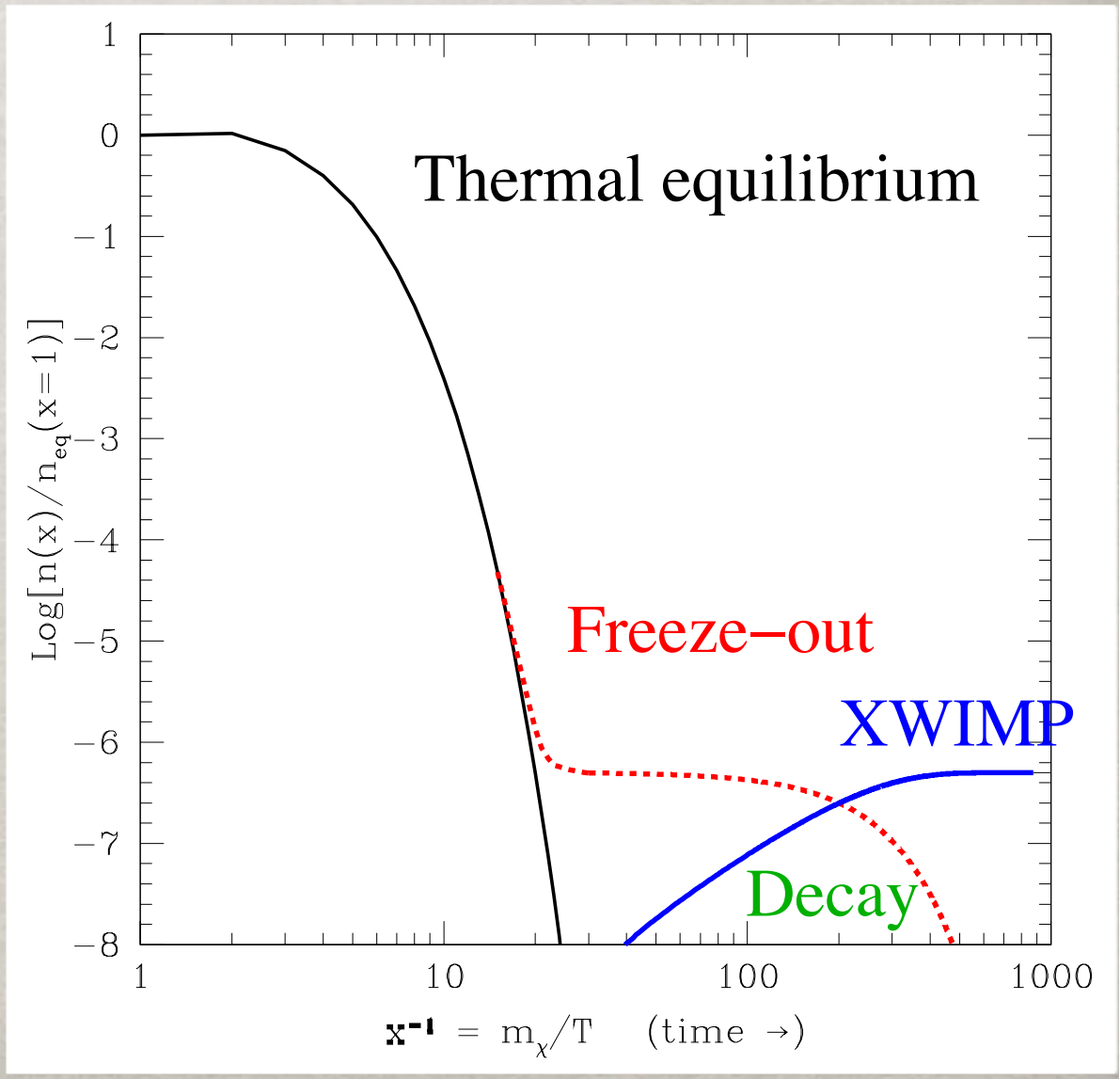
SuperWIMP mechanism

[JE Kim, A.Masiero, D.Nanopoulos *Phys.Lett.B* 139 (1984) 346-350]
[LC, JE Kim, L. Roszkowski *Phys.Rev.Lett.* 82 (1999) 4180-4183]
[J.L. Feng et al. *Phys.Rev.D* 68 (2003)063504]

- A long-lived WIMP particle can decay after decoupling and produce the DM population:

$$\Omega_X^{NT} = \frac{m_X}{m_{NLSP}} \Omega_{NLSP}$$

- In the decay also other particles are produced, but they should not disrupt BBN or any other cosmological observable…



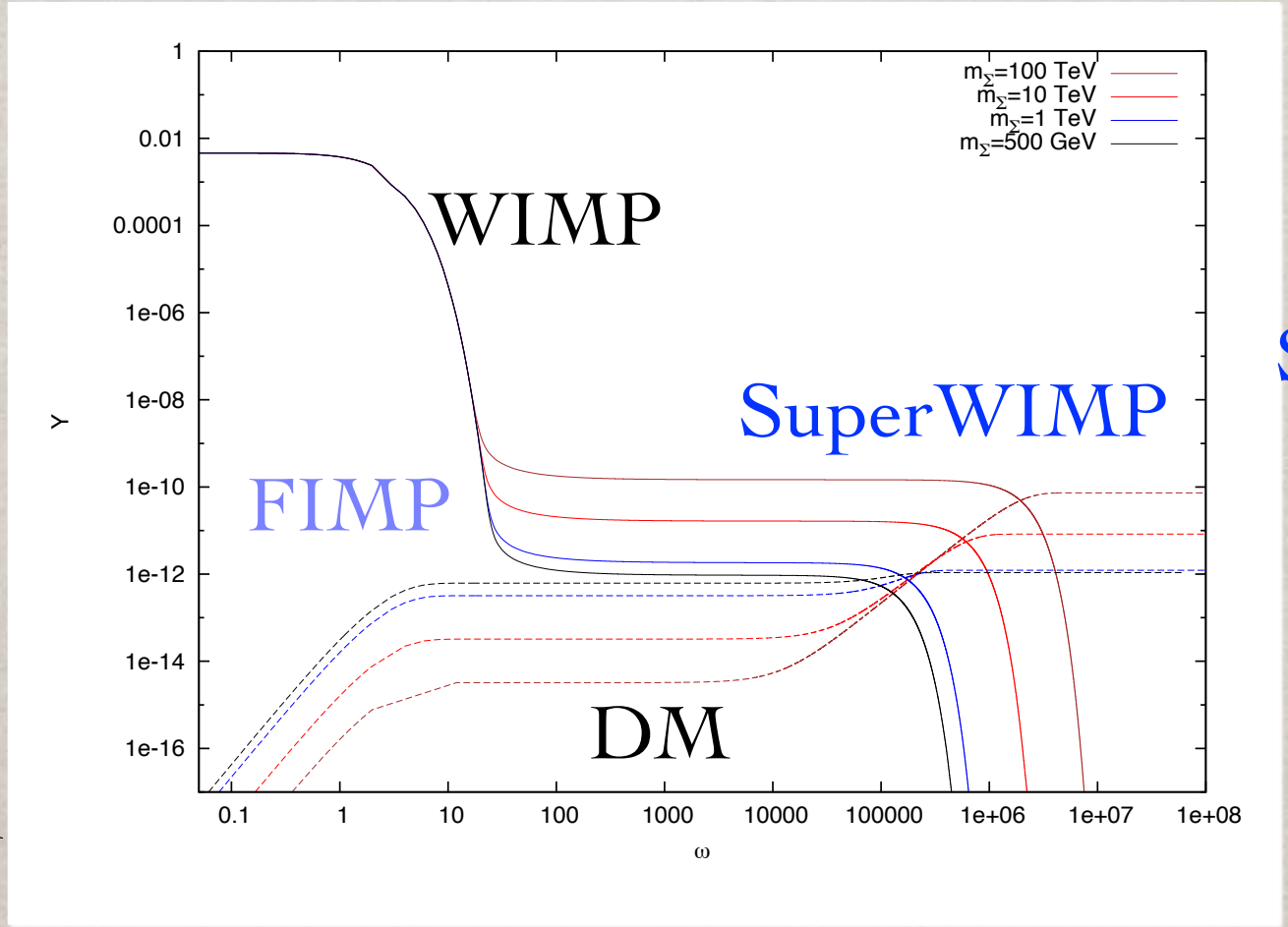
SuperWIMP/FIMP paradigms

Add to the BE a small decaying rate for the WIMP into a much more weakly interacting (i.e. decaying !) DM particle:

[Hall et al 10]

FIMP

DM produced by WIMP decay in equilibrium



[Feng et al 04]

SuperWIMP

DM produced by WIMP decay after freeze-out

Two mechanism naturally giving "right" DM density depending on WIMP/DM mass & DM couplings

SuperWIMP / FIMP

- The FIMP/SuperWIMP type of Dark Matter production is effective for any mass of the mother and daughter particle !
- Indeed if the mass ratio is large the WIMP-like density of the mother particle gets diluted:

$$\Omega^{SW} h^2 = \frac{m_\psi}{m_\Sigma} \, BR(\Sigma \to \psi) \, \Omega_\Sigma h^2$$

- Moreover the FIMP production is dependent on the decay rate of the mother particle not just the mass and can work also in different parameter regions…

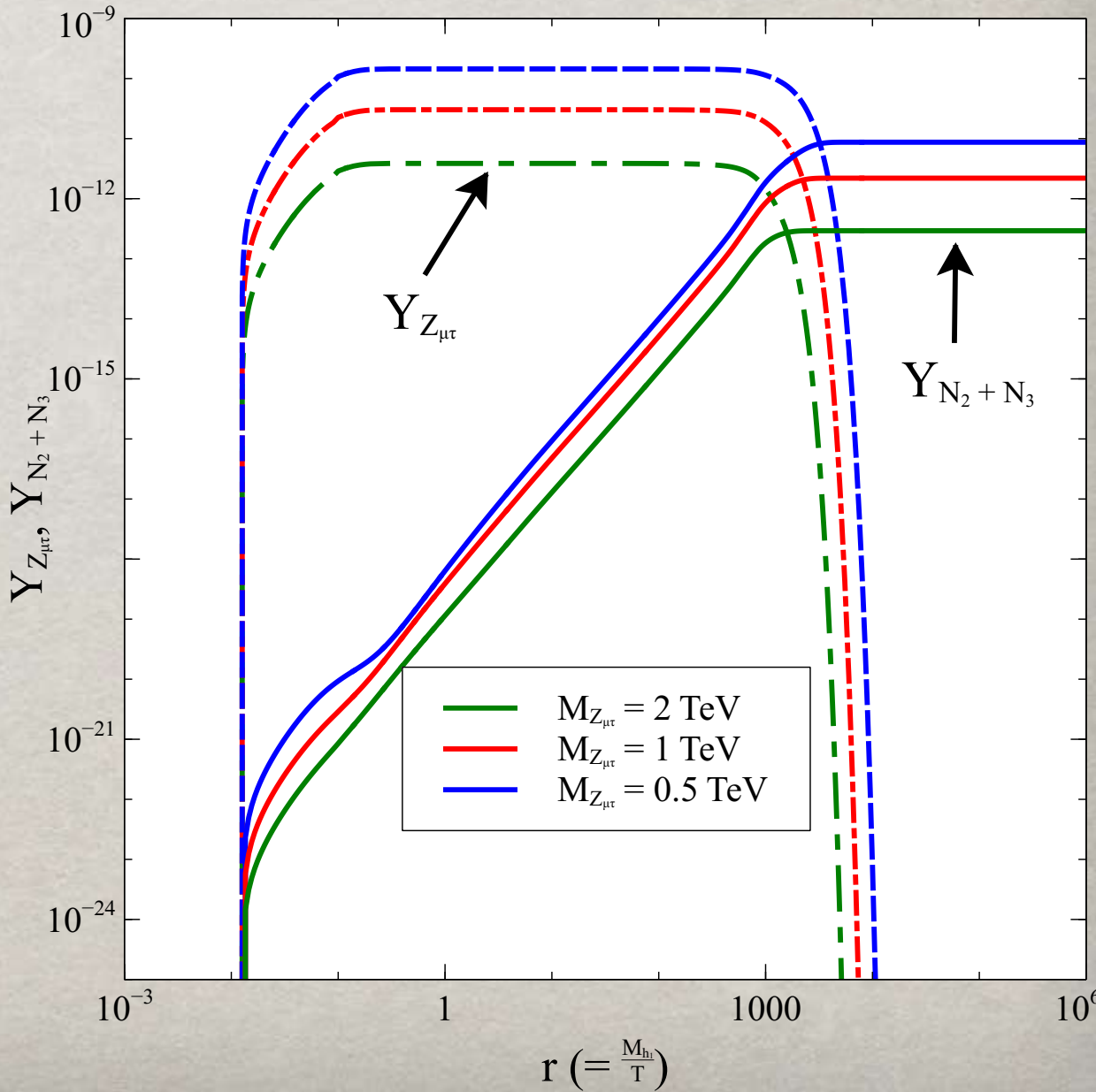
$$\Omega^{FI} h^2 = 10^{27} \, \frac{g_\Sigma}{g_*^{3/2}} \, \frac{m_\psi \Gamma(\Sigma \to \psi)}{m_\Sigma^2}$$

SuperFIMP: DM from a FIMP

[A. Biswas, S. Choubey, LC & S. Khan 2017]

Consider a decaying FIMP, e.g. a gauged $U(1)_{L_\mu - L_\tau}$ where the neutrino masses are generated radiatively and two RH neutrinos are stable DM produced from the gauge boson, itself a FIMP… Need though a very small gauge coupling:

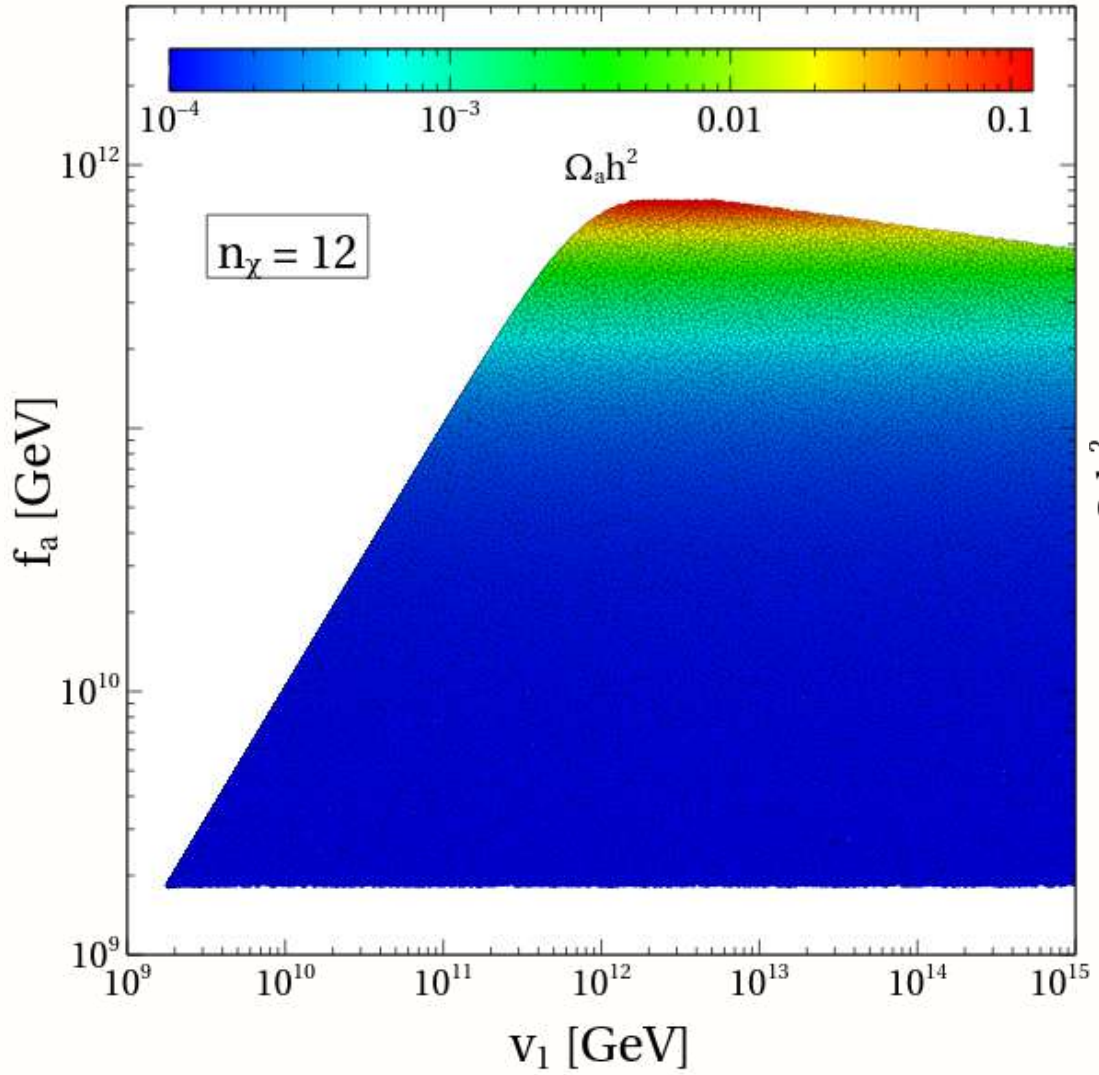
$$g_{\mu\tau} \sim 10^{-11}$$

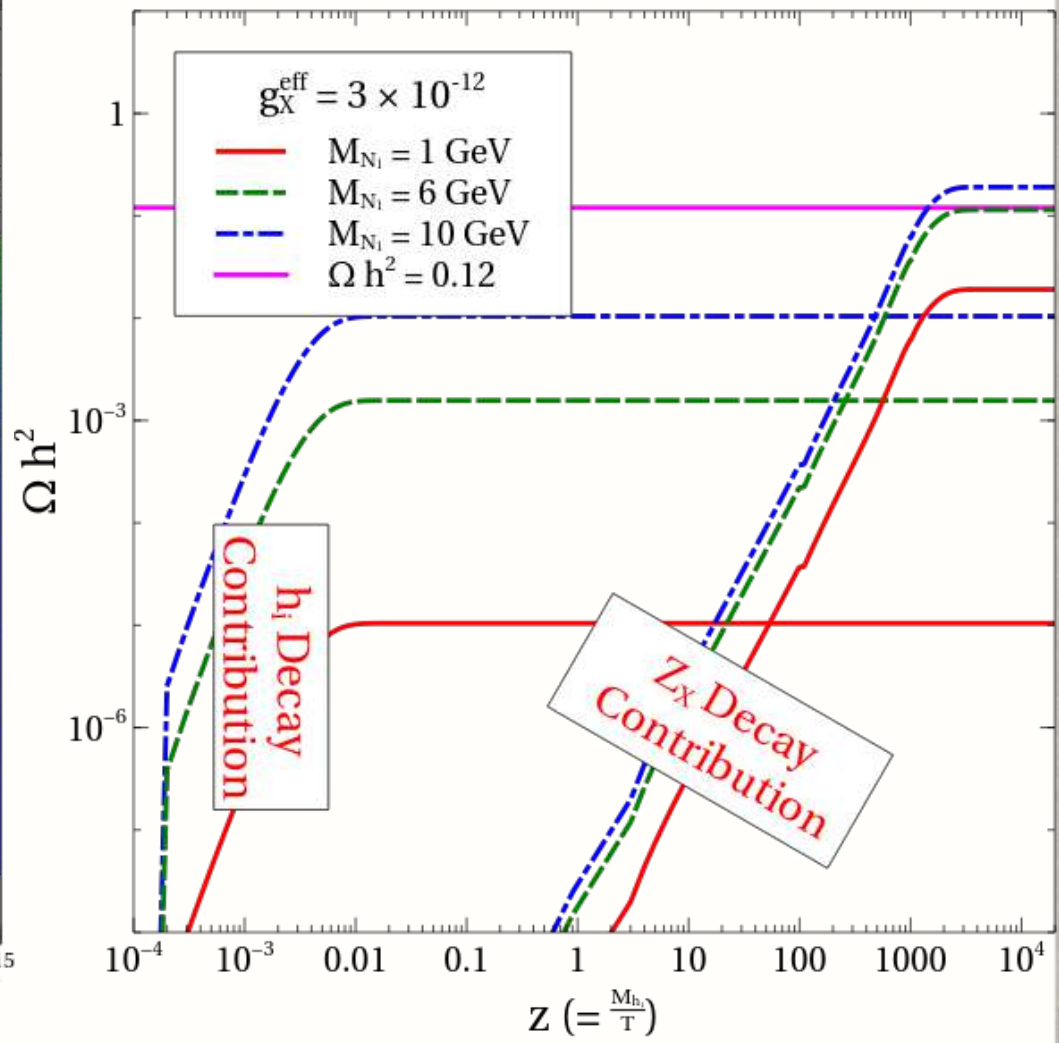


Axion & FIMP/SuperFIMP DM

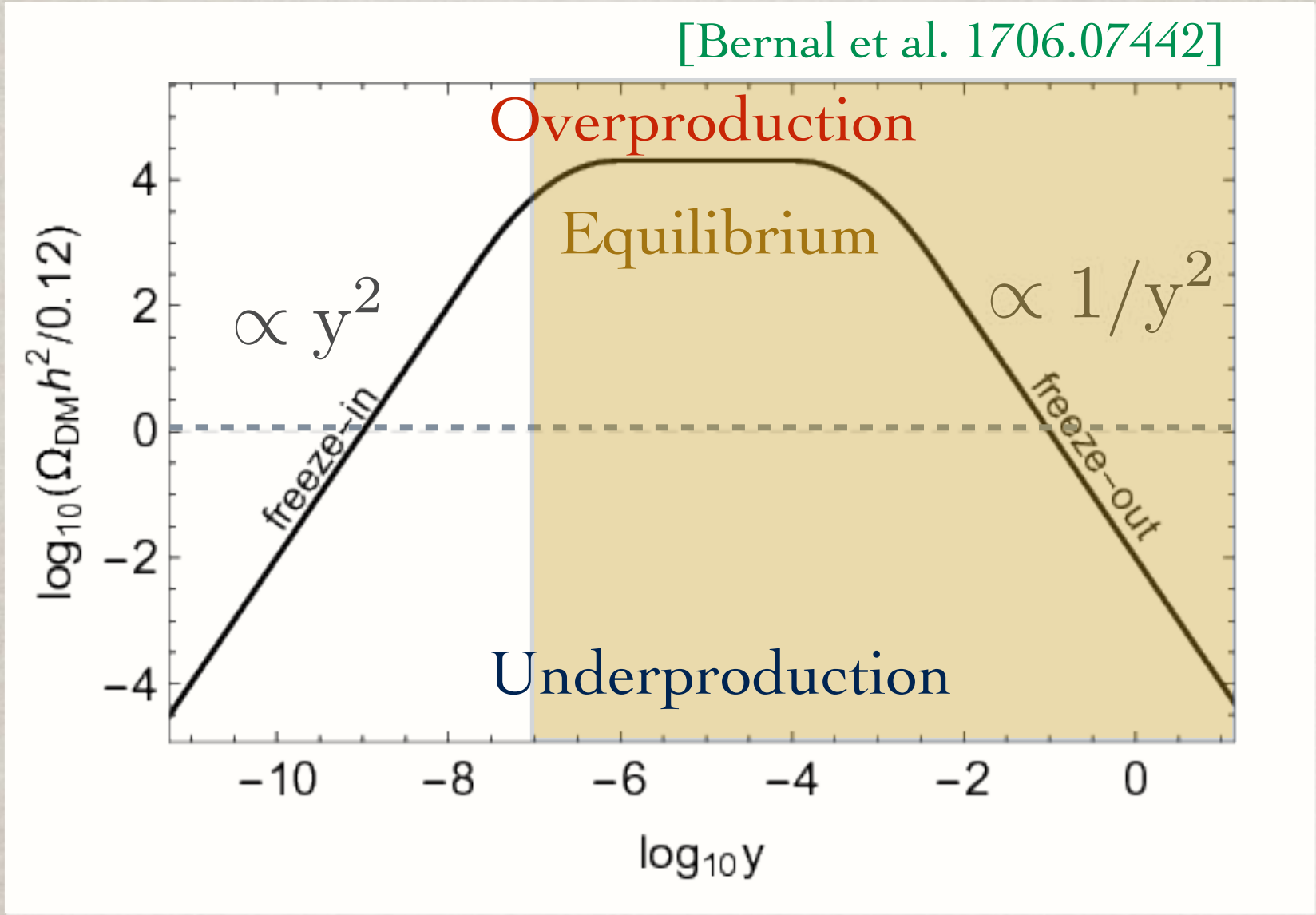
Models with two DM candidates possible, e.g. axions and RH neutrinos FIMPs…

[LC & S. Khan 22]





FIMP vs WIMP couplings



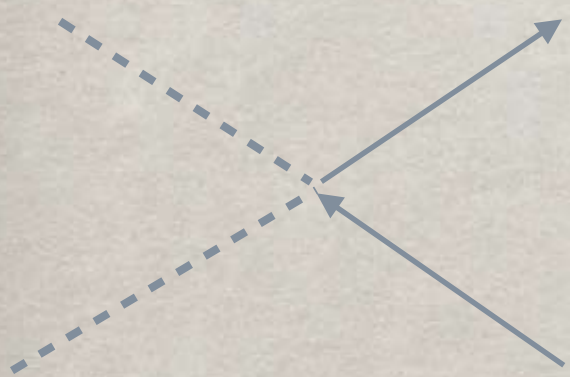
Usually FIMP and WIMP couplings very well separated !

Is it possible to go continuously from FIMP to WIMP ?

Boltzmann suppressed FIMP

[C. Cosme, F. Costa & O. Lebedev 2306.13061, 2402.04743,
G. Arcadi, F. Costa, A. Goudelis & O. Lebedev 2405.03760,
G. Arcadi, D. Cabo-Almeida & O. Lebedev 2409.02191,
F. Costa & L. Covi, 25xx.xxxxx]

Consider the case where the FIMP mass is larger than the temperature at the time of production, then the scattering rate is suppressed by a Boltzmann factor:



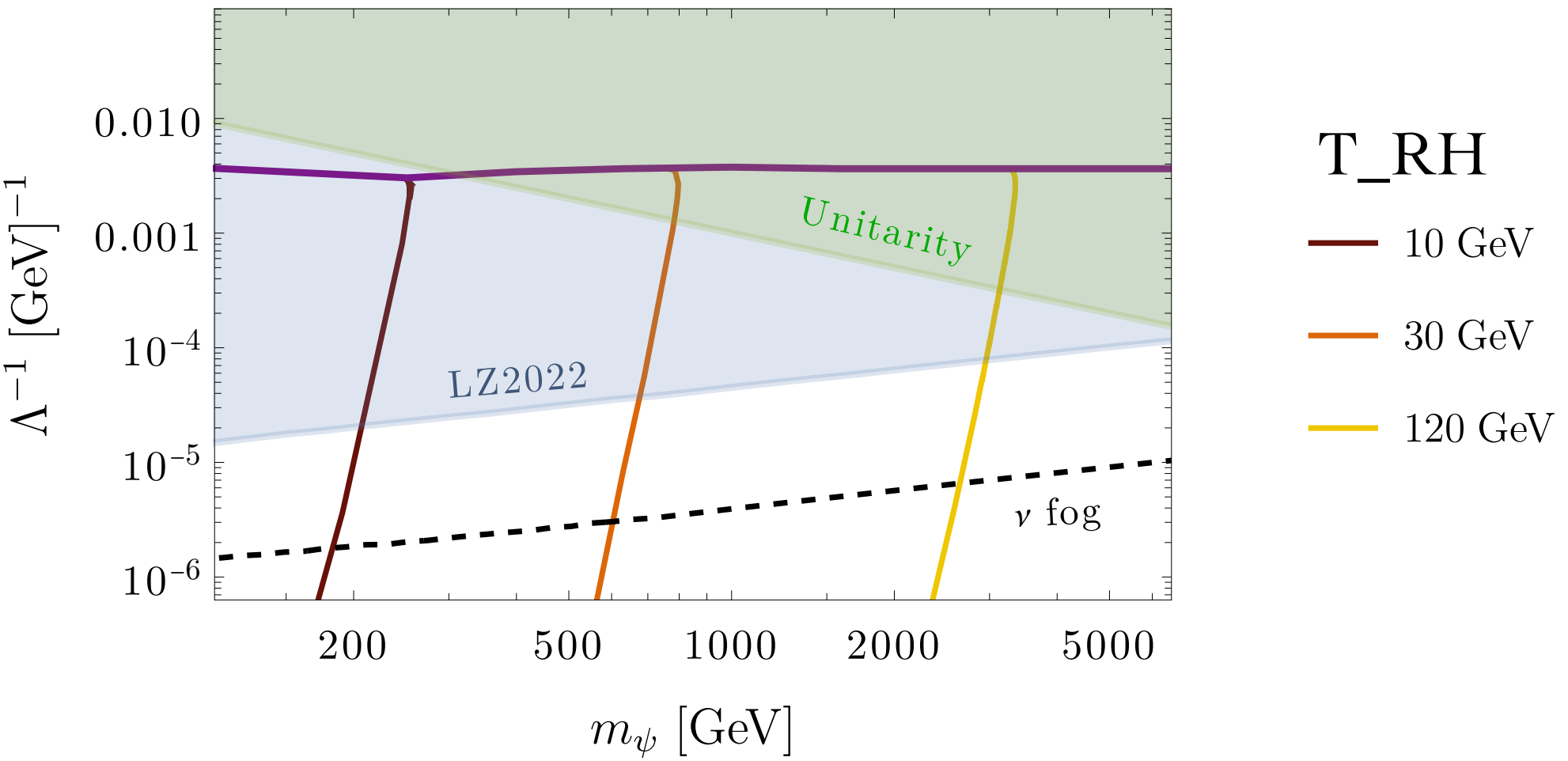
$$\mathcal{L} = \mathcal{L}_{kin,3/2} + \frac{1}{\Lambda}\psi^\mu \psi_\mu |H|^2 + \dots$$

$$\Gamma_{hh\to\psi\psi} \sim e^{-\frac{2m_\psi}{T}}\, y^2 \frac{m_\psi^3 T^3}{\pi^4 \Lambda^2}$$

So need larger couplings to compensate the suppression !

Boltzmann suppressed FIMP

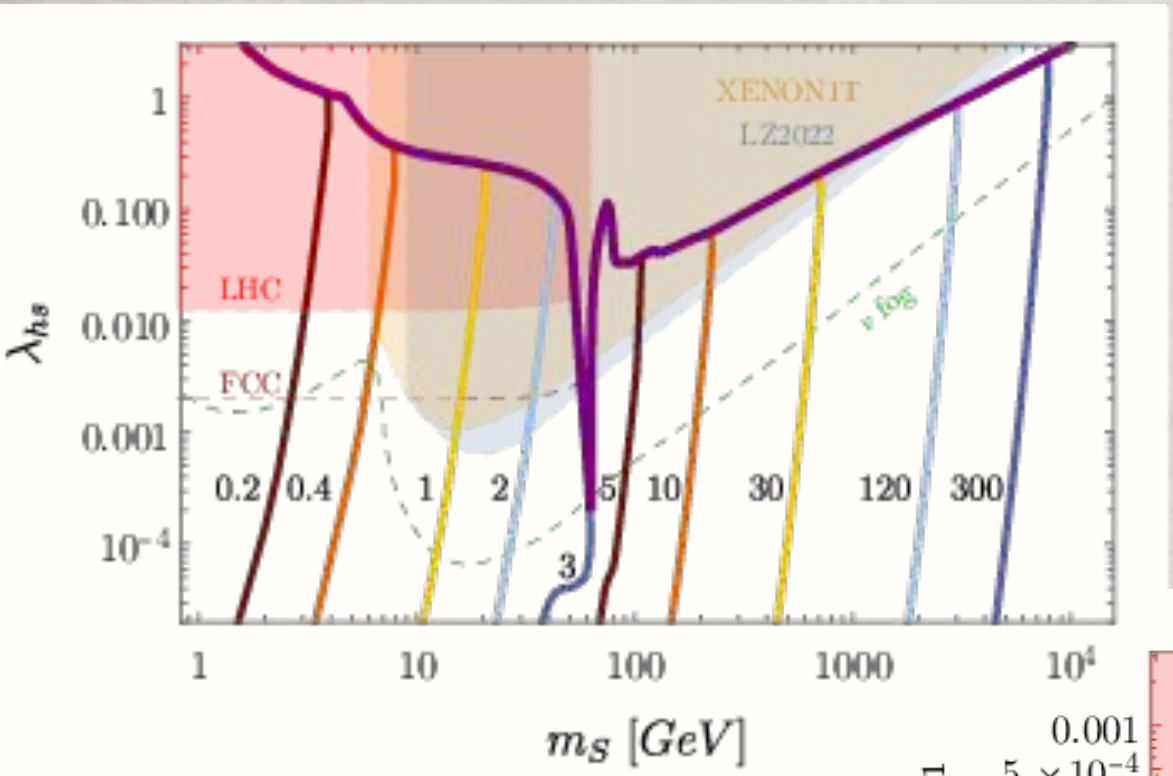
[F. Costa & L. Covi, 25xx.xxxxx]



It is possible to move continuously from FIMP to WIMP and possibly reach direct detection ! And maybe also ID !

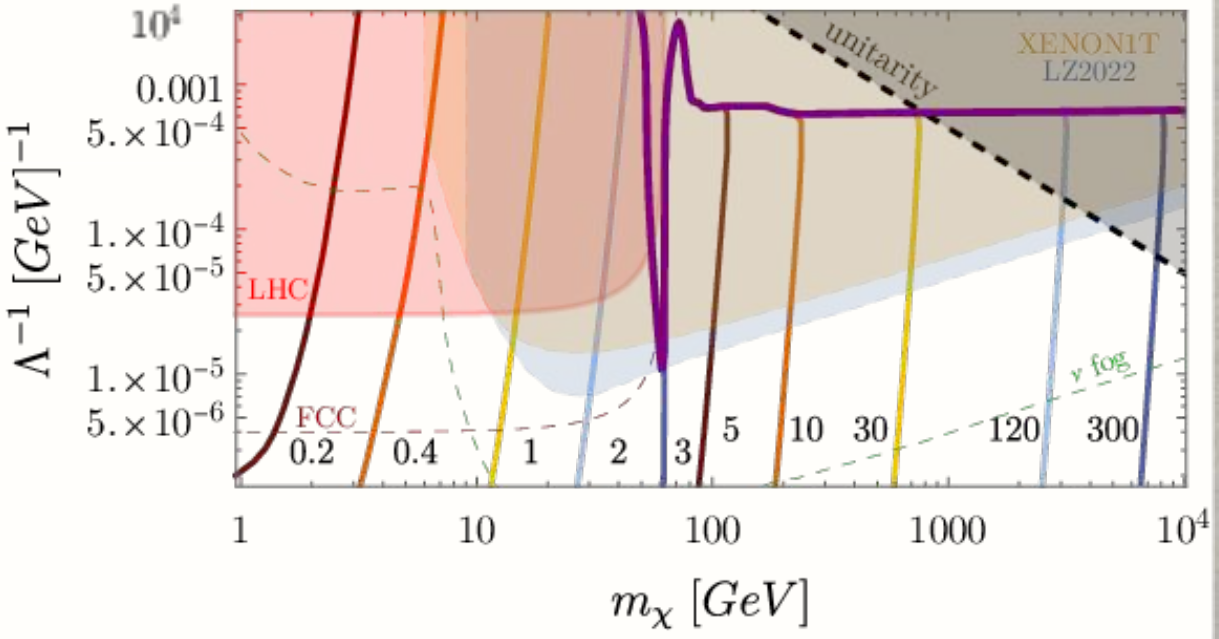
Boltzmann suppressed FIMP

[C. Cosme, F. Costa & O. Lebedev 2306.13061,
G. Arcadi,F. Costa, A. Goudelis and O. Lebedev 2405.03760]



Very similar picture also for the usual scalar Higgs portal !

As well as the fermion Higgs portal.



THE ASTRO/PARTICLE/ COSMOLOGY CONNECTION

Astroparticle for BSM By Antonio

Dark Matter Candidates: A Ten-Point Test

Neutralino dark matter detection in supersymmetry scenarios

Dark matter abundance and scalar - tensor dark energy

Light gravitino as mixed dark matter

Light dark matter: a common solution to the lithium and H 0 problems

On the Role of Neutrinos Telescope

Evolution Histories of the Early Universe and

Baryogenesis versus proton stability in theories with extra dimensions

Unstable Photino Mass Bound in Cosmology

Mixed dark matter from axino distribution

Constraining pre Big-Bang-Nucleosynthesis Expansion using Cosmic Antiprotons

Constraining pre Big-Bang-Nucleosynthesis Expansion using Cosmic Antiprotons

The Formation of cosmic structures in a light gravitino dominated universe

Hybrid inflation from supersymmetric SU(5)

Baryogenesis via B-L violation in SO(10) unified models

Radiative neutrino decay in SUSY and the ionization of hydrogen throughout the universe

A MONOCHROMATIC AXINO DOMINATED UNIVERSE

Towards a supersymmetric cosmology

COSMOLOGICAL BARYON PRODUCTION VERSUS INTERMEDIATE MASS SCALES?

Superhiggs Effect With Supersymmetry and Vanishing Cosmological Constant

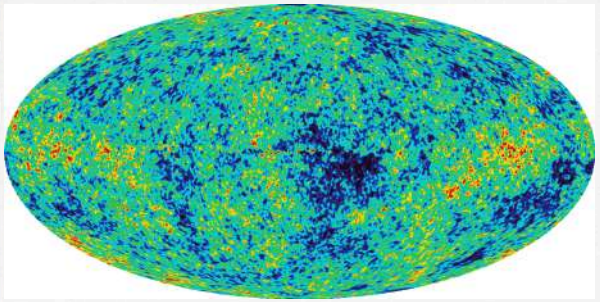
Baryon Asymmetry and Low-energy Parity Restoration

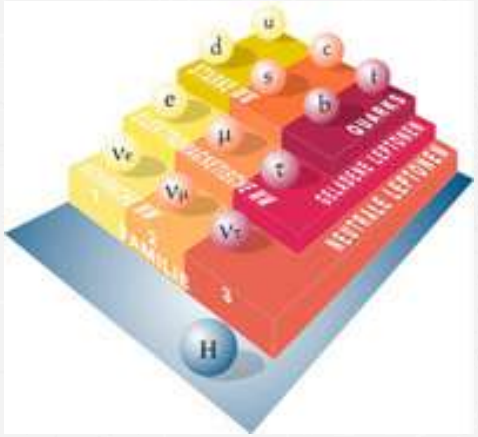
COSMOLOGICAL BARYON PRODUCTION THROUGH SUPERHEAVY FERMIONS

VH-NG-006
Particle Physics and Cosmology:
beyond the two Standard Models

Laura Covi

Two models, two worlds



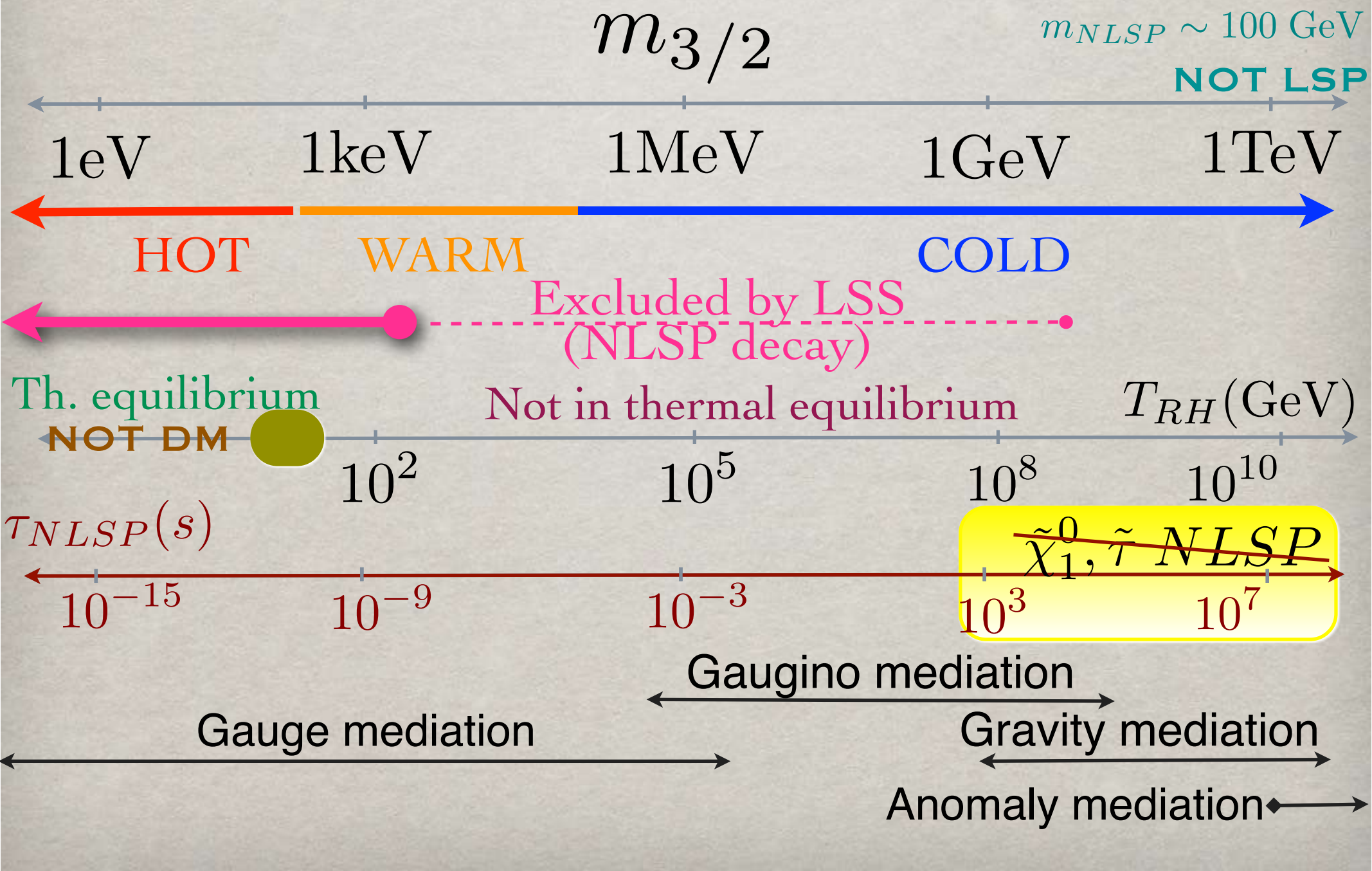


The Group VH-NG-006: collaboration between Hamburg and Padova (Italy)

- DESY & Uni Hamburg
  Wilfried Buchmueller, Jan Louis
- Padova University, ITaly
  Antonio Masiero, Antonio Riotto

Common project 2004-09
with activities on
Dark Matter,
GUT model building,
inflation

Gravitino DM summary



DECAYING DM

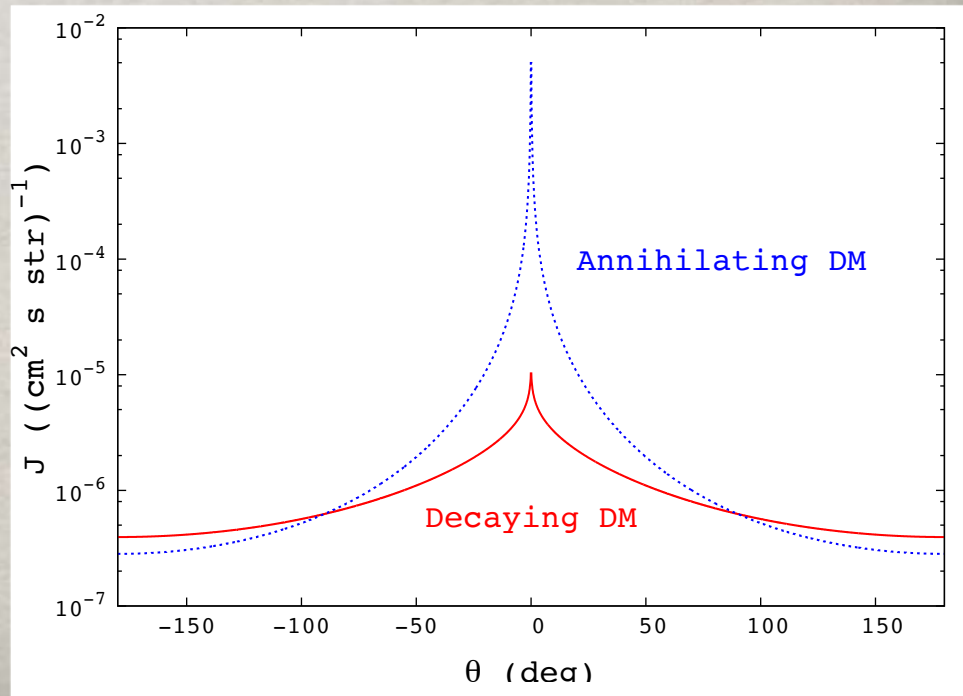
[G. Bertone, W. Buchmueller, L.Covi & A. Ibarra, 0705.2702]

- The flux from DM decay in a species i is given by

$$\Phi(\theta, E) = \frac{1}{\tau_{DM}} \frac{dN_i}{dE} \frac{1}{4\pi m_{DM}} \int_{l.o.s.} ds\ \rho(r(s,\theta))$$

Particle Physics — Halo property $J(\theta)$

- Very weak dependence on the Halo profile; what matters is the DM lifetime...
- Galactic & extragalactic signals are comparable...
- Spectrum in gamma-rays given by the decay channel! Smoking gun: gamma line...



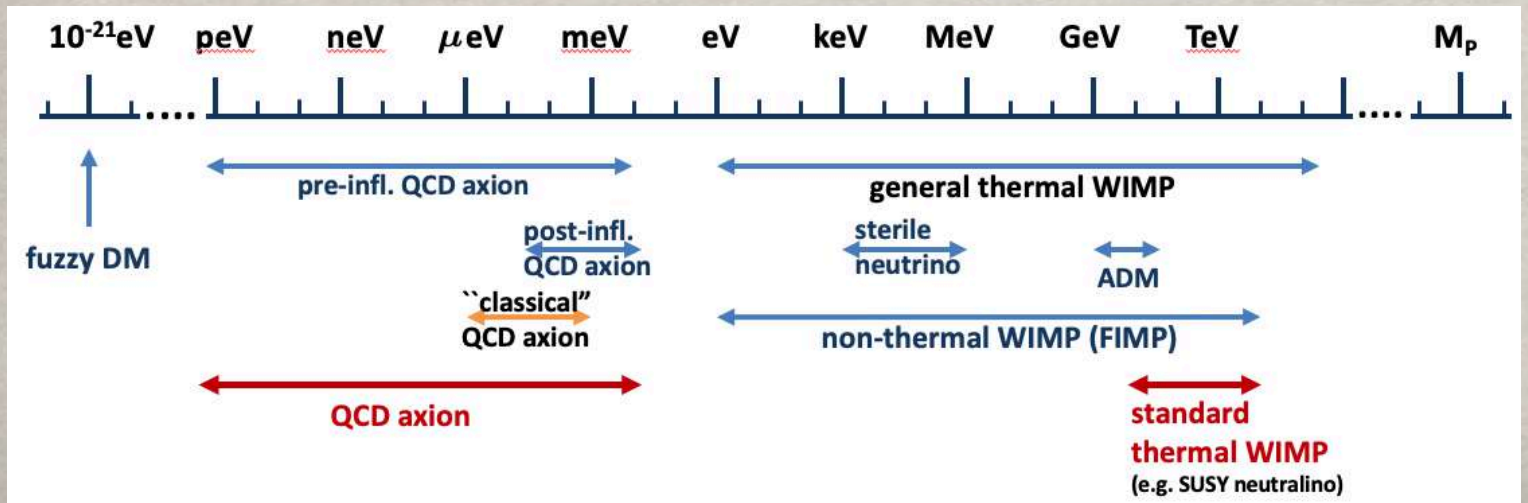
Dark Matter Candidates: A Ten-Point Test

Marco Taoso[1,2], Gianfranco Bertone[2], and Antonio Masiero[1]
[1] *INFN, Sezione di Padova, via Marzolo 8,Padova,35131,Italy and*
[2] *Institut d'Astrophysique de Paris, UMR 7095-CNRS,*
Université Pierre et Marie Curie, 98 bis Boulevard Arago 75014, Paris, France

1. *Does it match the appropriate relic density?*
2. *Is it cold?*
3. *Is it neutral?*
4. *Is it consistent with BBN?*
5. *Does it leave stellar evolution unchanged?*
6. *Is it compatible with constraints on self-interactions?*
7. *Is it consistent with direct DM searches?*
8. *Is it compatible with gamma-ray constraints?*
9. *Is it compatible with other astrophysical bounds?*
10. *Can it be probed experimentally?*

Guiding principles 4 DM

- The DM particle or the DM sector should fit into a BSM model solving more than the DM problem, e.g. hierarchy, neutrino masses, strong CP problem, etc…
- An effective DM production mechanism should be present, possibly independent from initial conditions.
- Possibly detectable Dark sector in the near future.



DARK MATTER paradigms

Opening new trends

Towards a supersymmetric cosmology

John R. Ellis (CERN), K. Enqvist (CERN), G. Gelmini (CERN), C. Kounnas (CERN), A. Masiero (CERN) et al. (May, 1984)

Published in: *Phys.Lett.B* 147 (1984) 27

Unstable Photino Mass Bound From Cosmology

Jihn E. Kim (CERN), A. Masiero (CERN), Dimitri V. Nanopoulos (CERN) (Feb, 1984)

Published in: *Phys.Lett.B* 139 (1984) 346-350

Cosmological signatures of supersymmetry with spontaneously broken R-parity

V. Berezinsky (Gran Sasso and Moscow, INR), A. Masiero (INFN, Padua), J.W.F. Valle (Valencia U.) (Jun, 1991)

Published in: *Phys.Lett.B* 266 (1991) 382-388

unifying particle and cosmo

decaying DM

Light gravitinos as mixed dark matter

Stefano Borgani [a,b], Antonio Masiero [c], Masahiro Yamaguchi [d,1]

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[b] *SISSA-International School for Advanced Studies, via Beirut 2–4, I-34013 Trieste, Italy*

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[d] *Institute für Theoretische Physik, Physik Department, Technische Universität München, D-85747 Garching, Germany*

Received 24 May 1996

Editor: R. Gatto

multicomponent DM

A minimal ADM+WIMP model

[A. Biswas, S. Choubey, LC & S. Khan 2018]
[LC, S. Dey, S. Khan & S. K. Rai, 2504.09632]

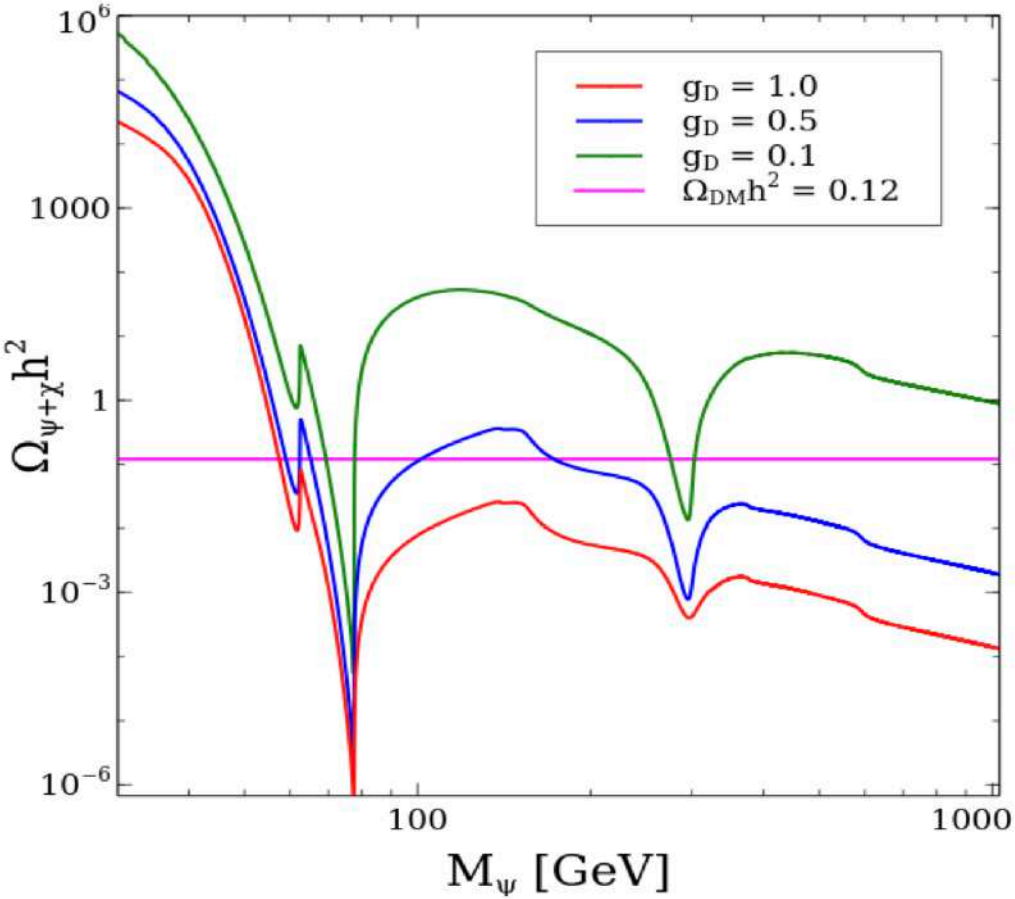
Let us consider a minimal model for leptogenesis with two RH neutrinos to explain the neutrino masses and give the correct mixing matrices, as well as leptogenesis.

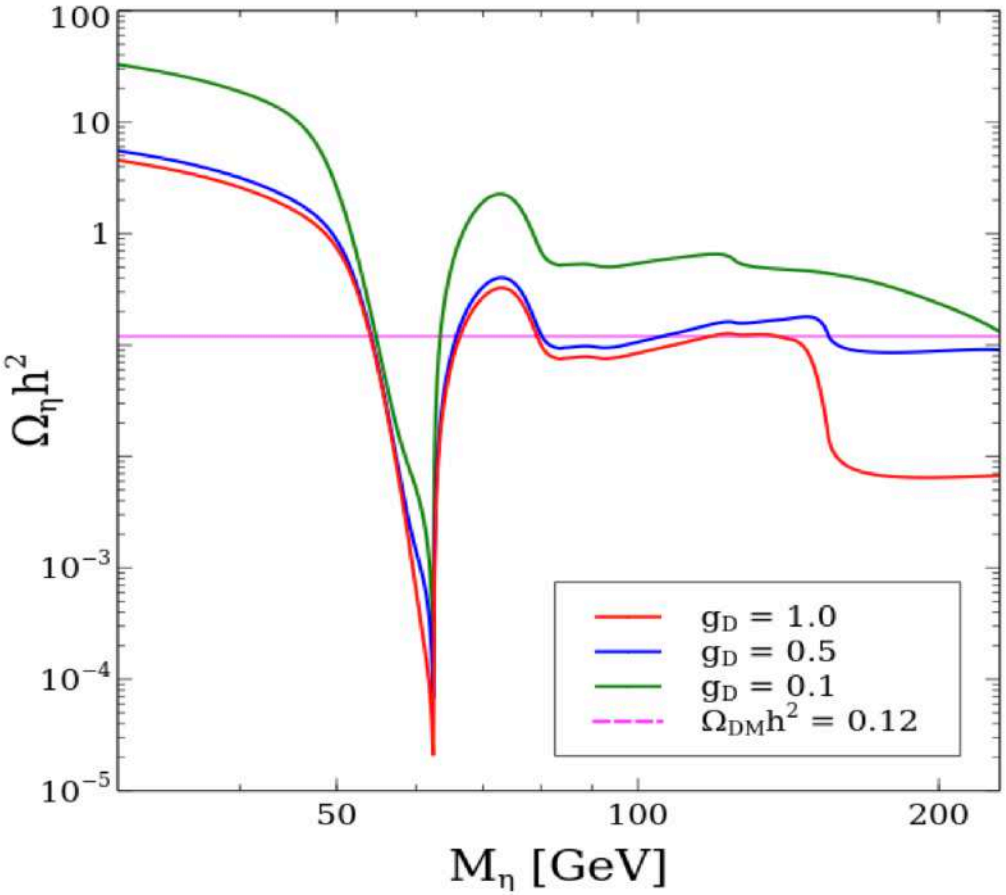
Gauge	Fermion Fields							Scalar Fields		
Group	$\Psi_{1L} = (\psi_1, \psi_2)^T_L$	ψ_{1R}	ψ_{2R}	$\Psi_{2L} = (\psi_3, \psi_4)^T_L$	ψ_{3R}	ψ_{4R}	N_i	ϕ_h	ϕ_D	η_D
$SU(3)_c$	1	1	1	1	1	1	1	1	1	1
$SU(2)_L$	1	1	1	1	1	1	1	2	1	1
$SU(2)_D$	2	1	1	2	1	1	1	1	2	2
$\mathbb{Z}_3 \times \mathbb{Z}_2$	$(\omega, 1)$	$(\omega, 1)$	$(\omega, 1)$	$(\omega^2, -1)$	$(\omega^2, -1)$	$(\omega^2, -1)$	$(1, 1)$	$(1, 1)$	$(1, 1)$	$(\omega, 1)$

We need an additional Dark SU(2) in order to annihilate away the symmetric DM component and a discrete symmetry to reduce the number of possible couplings.
BOTH ADM and WIMP DM are possible !

MULTICOMPONENT DM

[L.Covi, S. Dey, S. Khan & S. K. Rai, 2504.09632]

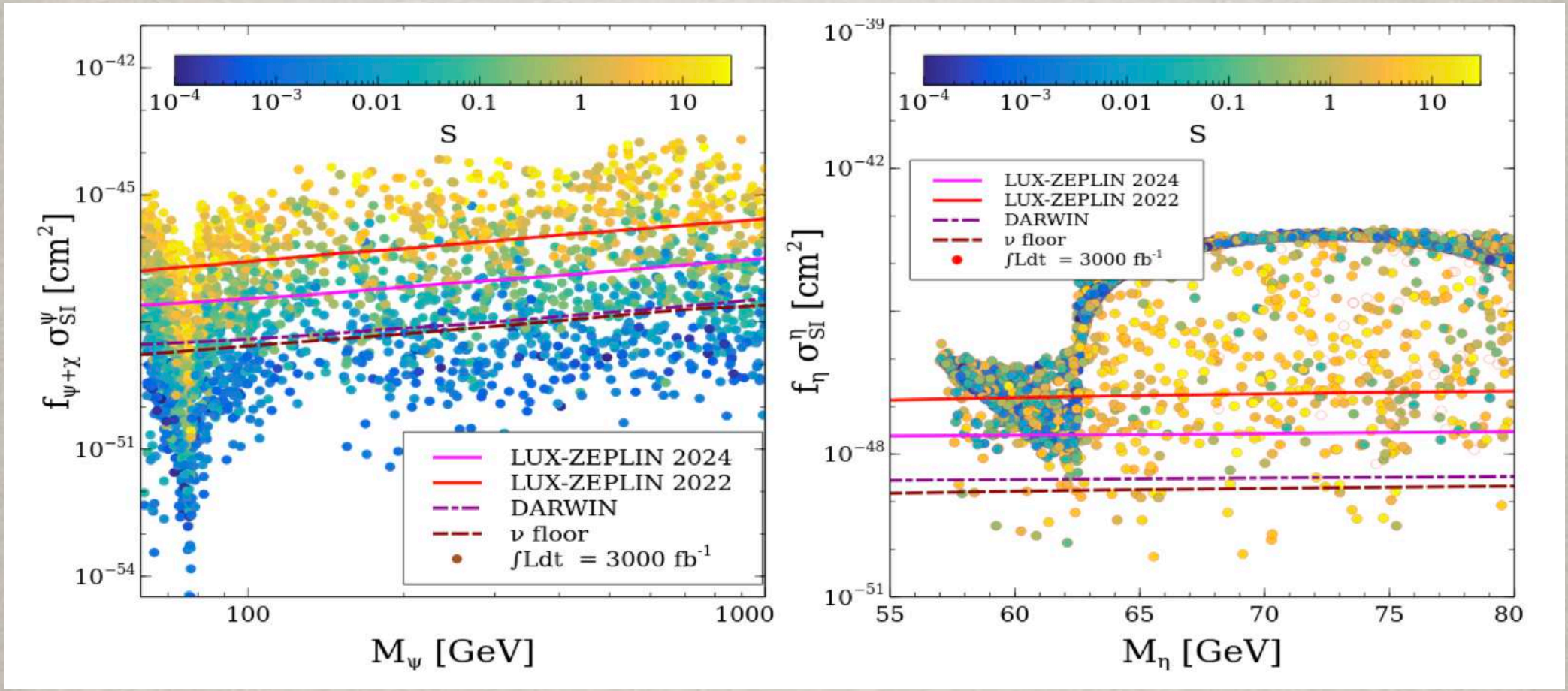




Two stable particles due to discrete symmetries, both can be DM with the right density via WIMP and SuperWIMP mechanisms, depending on the dark gauge coupling & masses

MULTICOMPONENT DM

[L.Covi, S. Dey, S. Khan & S. K. Rai, 2504.09632]



Direct detection partially correlated with collider signals in jets and missing E_T since driven by the mixing angle in the scalar sector between the SM and exotic Higgs field

Outlook

- Antonio has worked on a plethora of subjects as shown in the talks in this session, moving from formal subjects in Supersymmetry to particle phenomenology and astroparticle physics and opening new trends in all directions and keeping in view the great picture. A great example to follow !
- Particle physics has changed a lot since my PhD times and the road towards astroparticle physics/cosmology has become well-trodden, thanks also to Antonio, who really recognised the power of the astroparticle/cosmology connection and has applied and propagate it.
- He has been always a very supportive and encouraging teacher and a great supervisor, not only for me, but for a long list of students, so as a representative I would like to say:

Happy Birthday, Antonio,

And Thanks for all !