Geneviève Fest

Dark Matter in the Era of Geneviève

Bryan Zaldívar (CSIC Valencia) — 26.01.2026

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- Writing 90+ papers on dark matter is so prolific that I got paralised and procrastinated a lot while preparing these slides

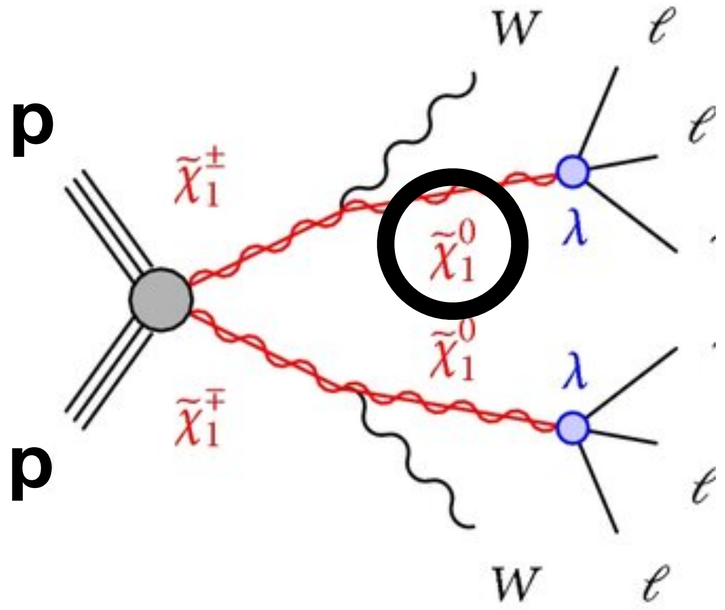
Content (not in sequential order)

- Some dark matter physics
- Software
- Personal anecdotes
- Admiration disguised as humor

Dark Matter mood circa ~2000

Mostly revolving around Supersymmetry — neutralino as the canonical WIMP candidate

SUSY as a very appealing guiding principle…
…including a O(100 GeV) DM candidate



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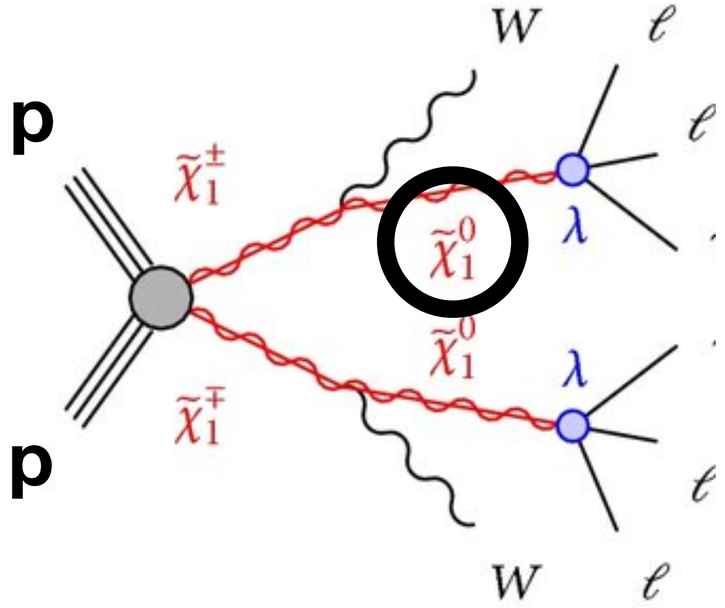
$\mathcal{O}(1000+)$ Feynmann diagrams
(Self-annihilation + co-annihilation)



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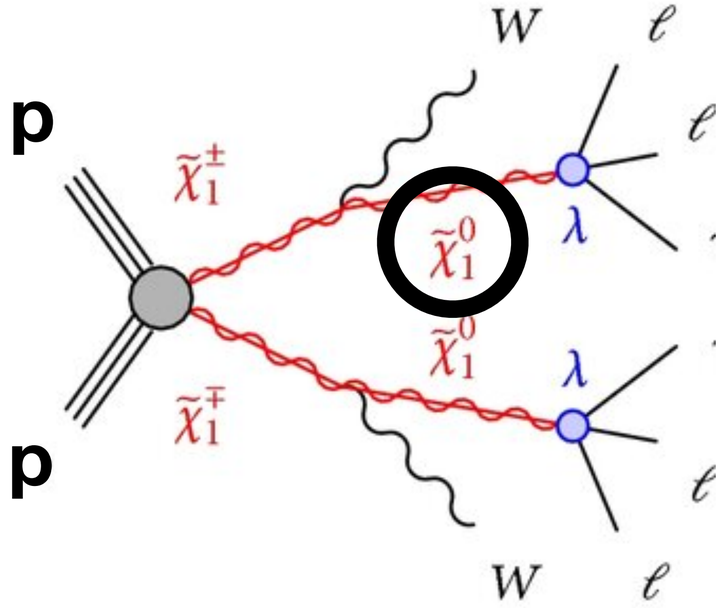
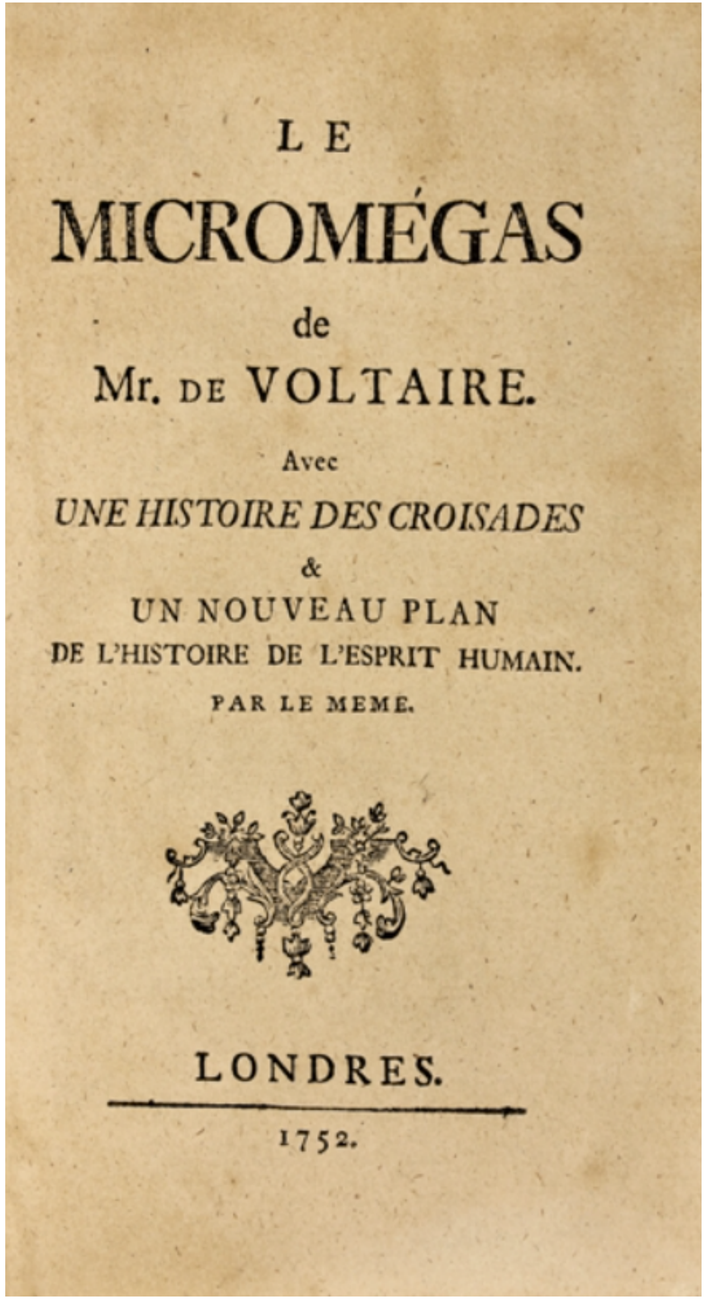


Existing Boltzmann codes (e.g. DarkSUSY)
were hard-coded

Voltaire inspiration

New player at the table


LE

MICROMÉGAS

de

Mr. DE VOLTAIRE.

Avec

UNE HISTOIRE DES CROISADES

&

UN NOUVEAU PLAN

DE L'HISTOIRE DE L'ESPRIT HUMAIN.

PAR LE MEME.

LONDRES.

1752.

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December 2001

micrOMEGAs: A program for calculating the relic density in the MSSM

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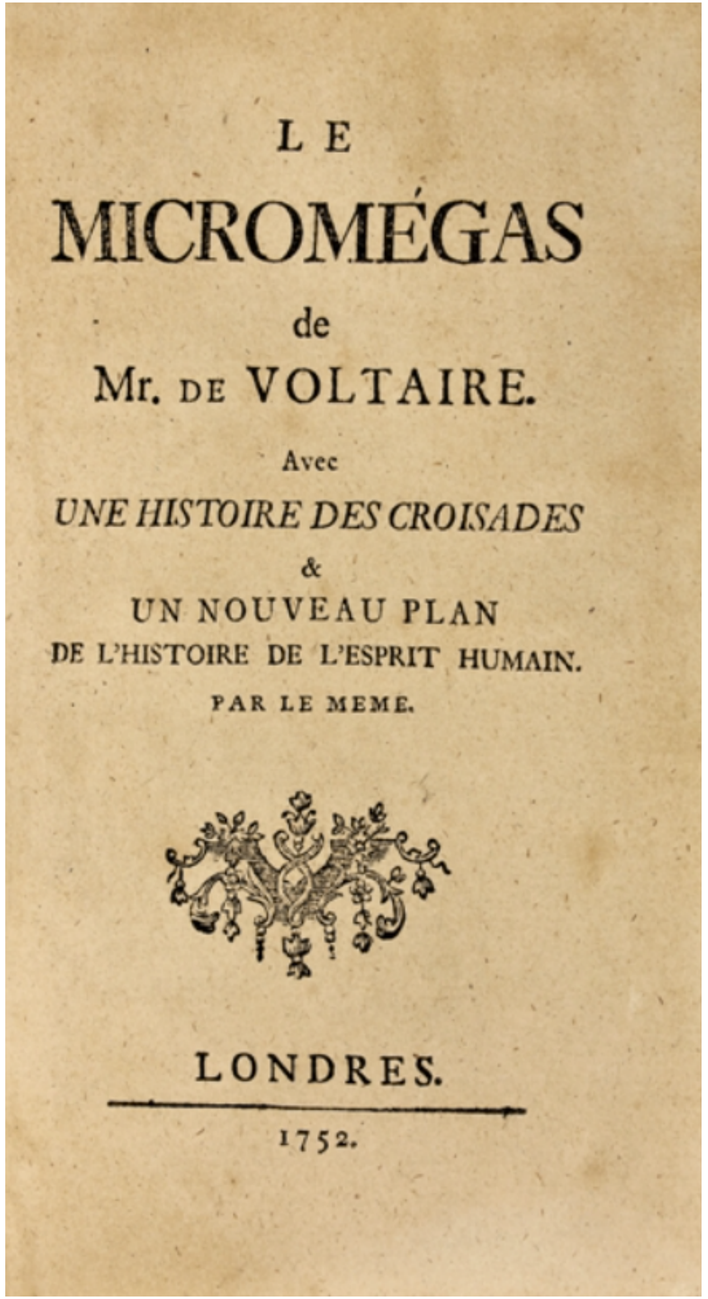

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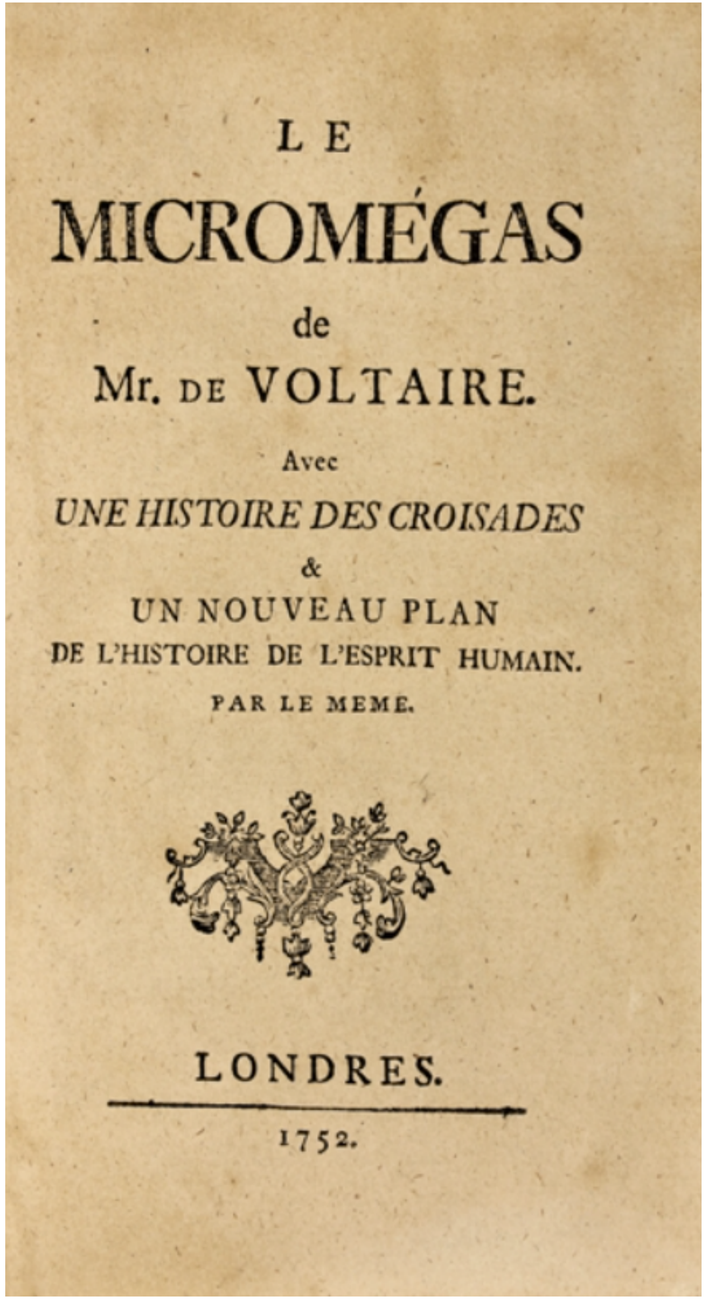

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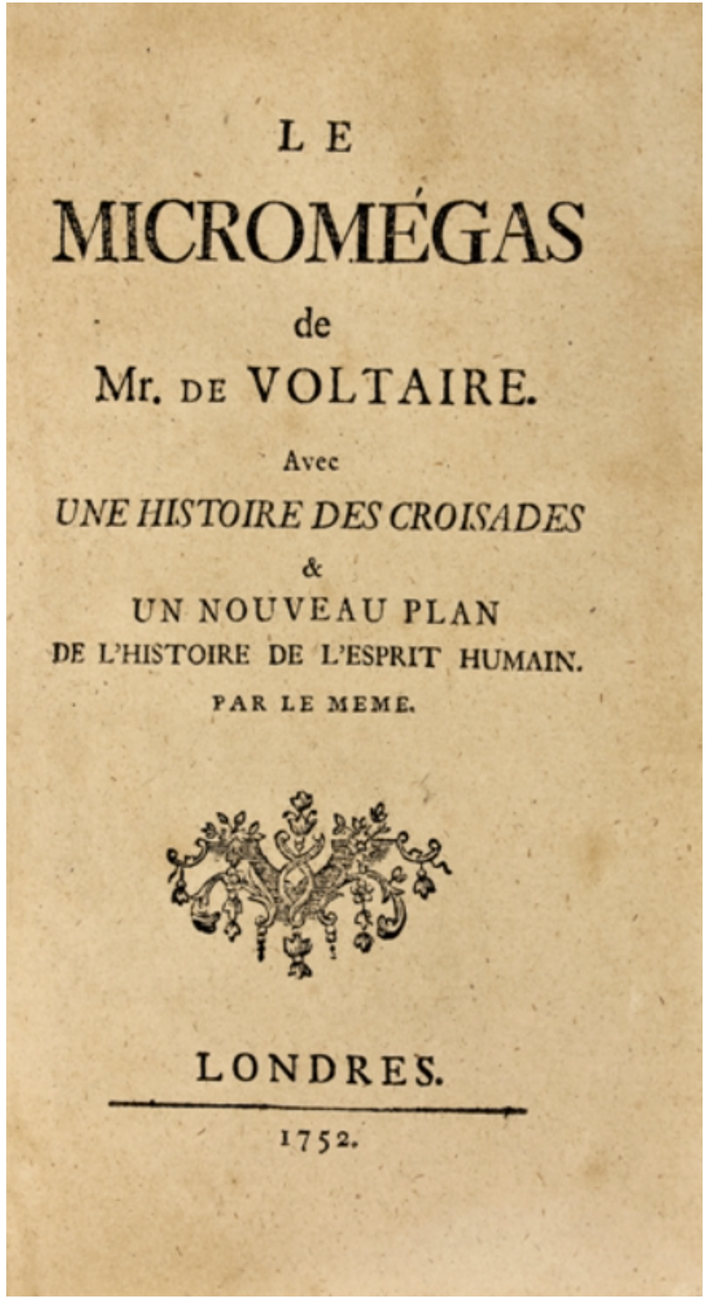
Game changer!!



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User's favourite Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{g_i}{\Lambda^2} (\bar{q}_i \gamma^\mu q_i)(\bar{\chi} \gamma_\mu \chi)$$

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Derivation of Feynmann Rules → LanHEP

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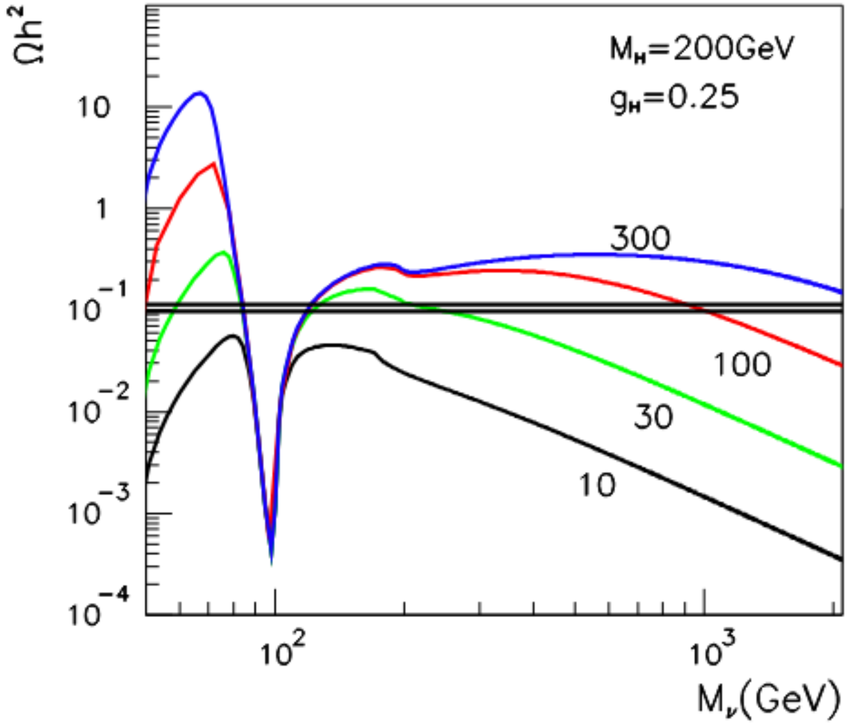
Geneviève Bélanger[a], Alexander Pukhov[b] and Géraldine Servant[c,d]

JCAP 01 (2008) 009



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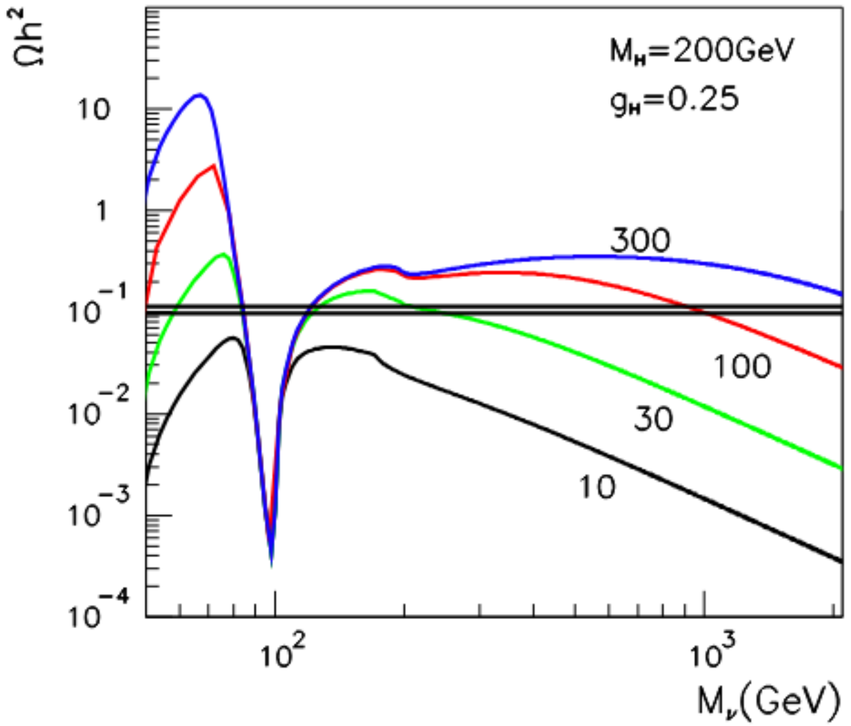

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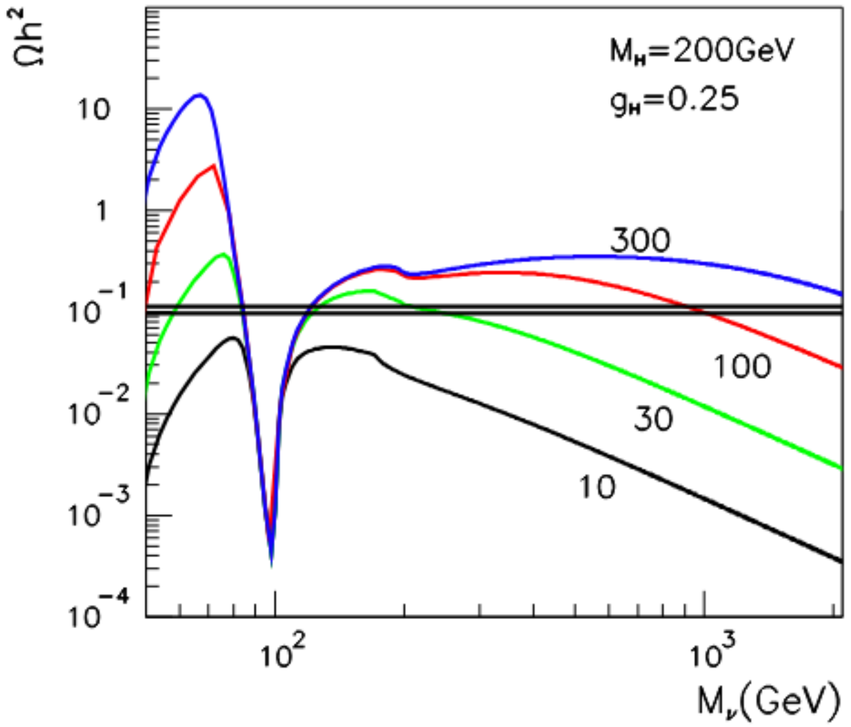

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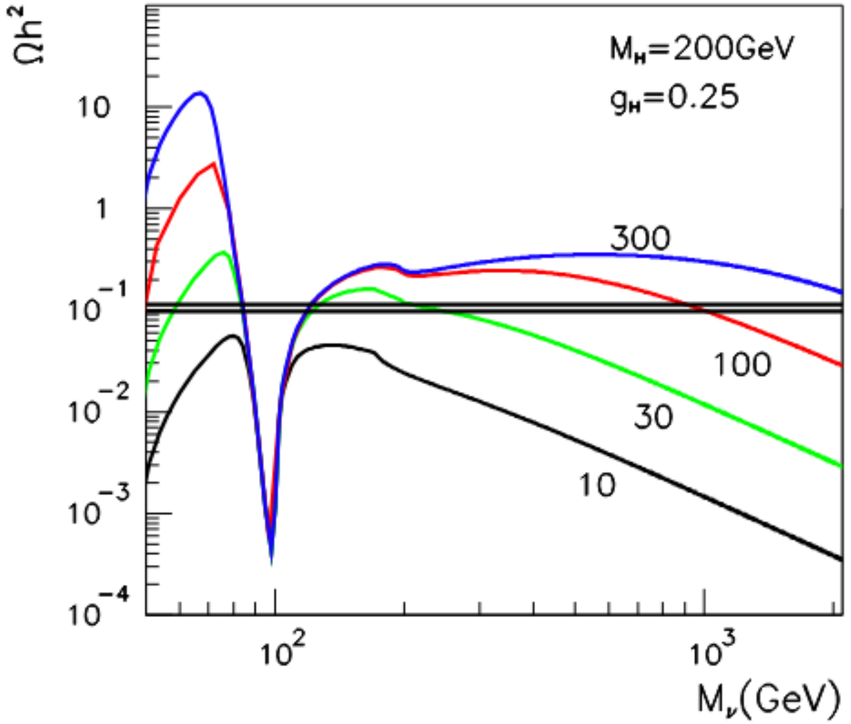

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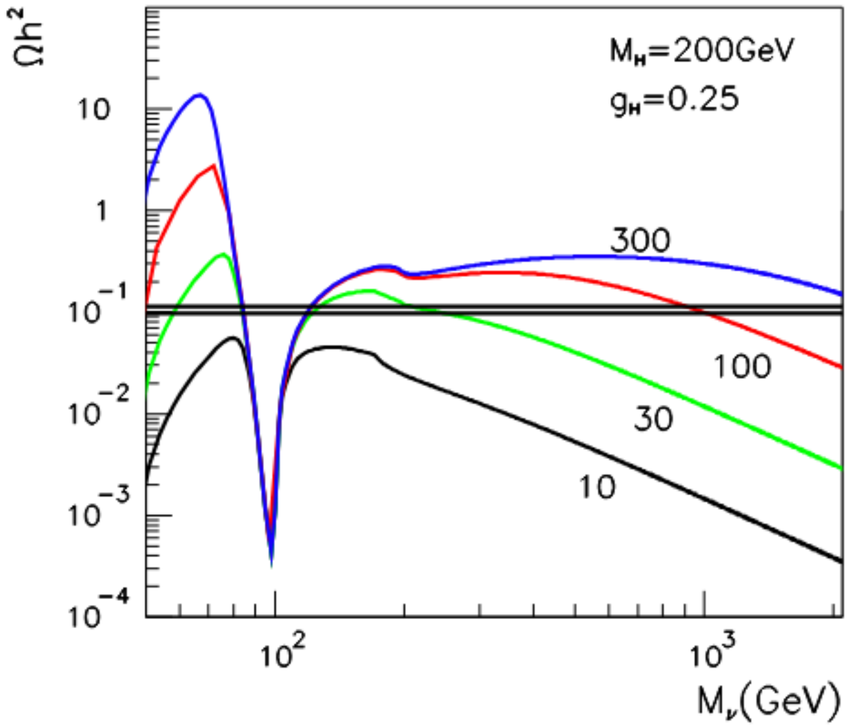

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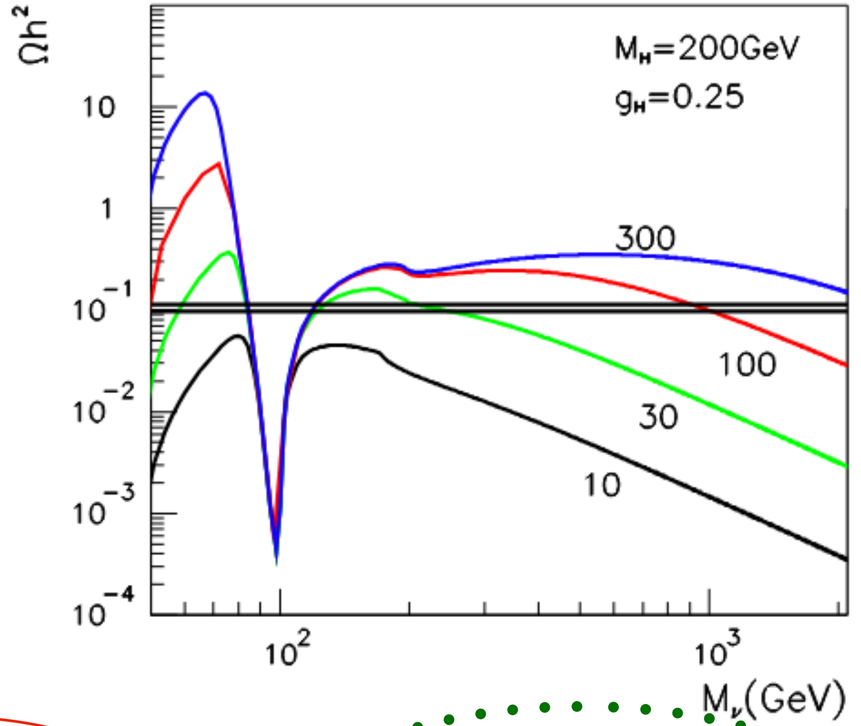

"Which search strategy would you bet will first discover dark matter?"

Geneviève

So nice…
She clearly saw I'm exhausted and decided to ask a completely harmless question

Bryan

Sequel…

Asymmetric DM, Semi-annihilations, (improved) Pheno

May 2013 ——

micrOMEGAs_3 : a program for calculating dark matter observables

Comput.Phys.Commun. 185 (2014) 960-985

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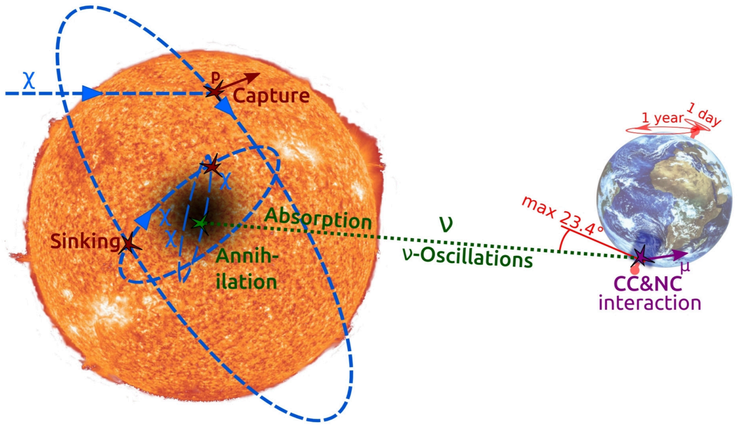

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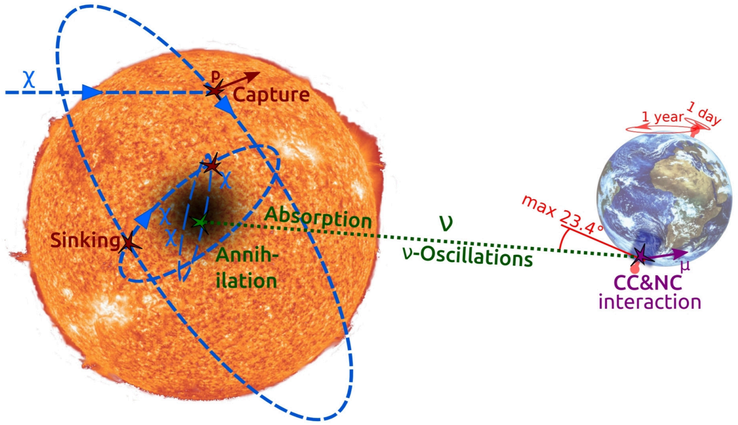

Improved

Gamma-ray line searches

DM profile

Direct Detection rates

Loop-induced Higgs production

…many more stuff

Example

Asymmetric DM, Semi-annihilations, (improved) Pheno

micrOMEGAs— sailing at full speed

~ 300 citations in the first two years after v3 piublished

Full phenomenological studies possible

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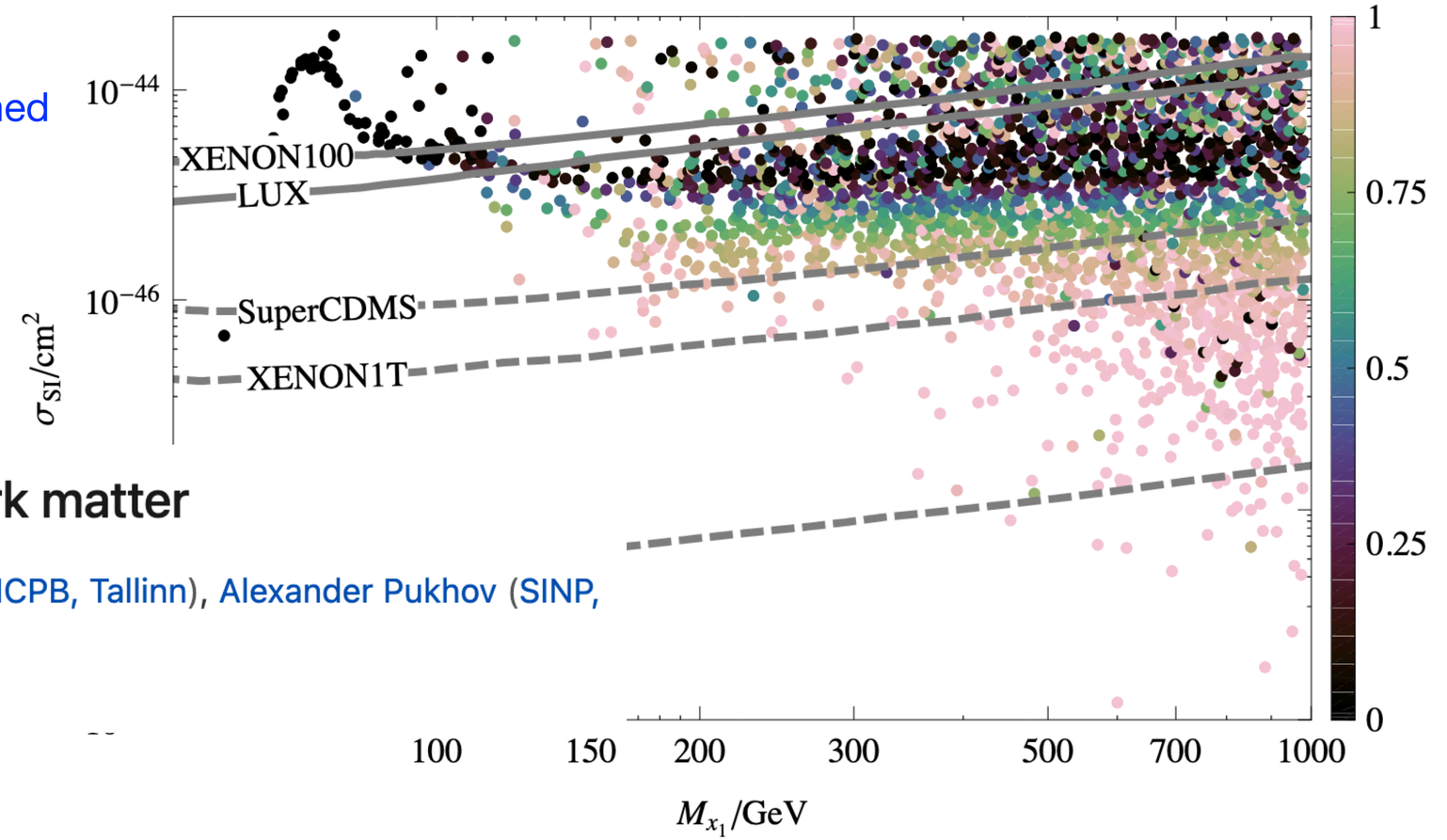

Minimal semi-annihilating $\mathbb{Z}_N$ scalar dark matter

Geneviève Bélanger (Annecy, LAPTH), Kristjan Kannike (NICPB, Tallinn), Alexander Pukhov (SINP, Moscow), Martti Raidal (NICPB, Tallinn)

Mar 19, 2014

Another Sequel

July 2014 ——— **micrOMEGAs4.1: two dark matter candidates**

Comput.Phys.Commun. 192 (2015) 322-329

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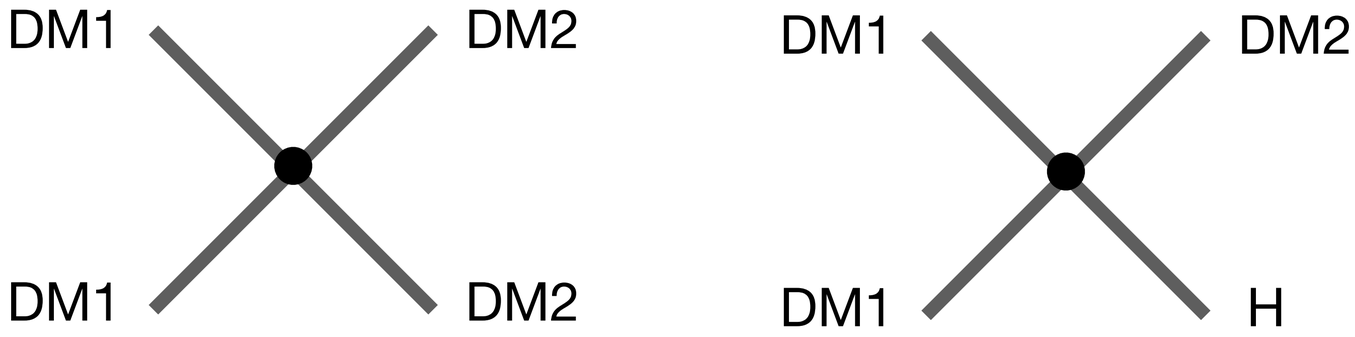

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And then we started working…

WIMP phenomenology (emphasis on LHC)

Freeze-in and micrOMEGAs

WIMP Pheno and colliders circa 2016

Lots of discussions around LHC DM searches in that period
(Fawzi, Sabine, Benjamin, Shankha, Daniele, …)

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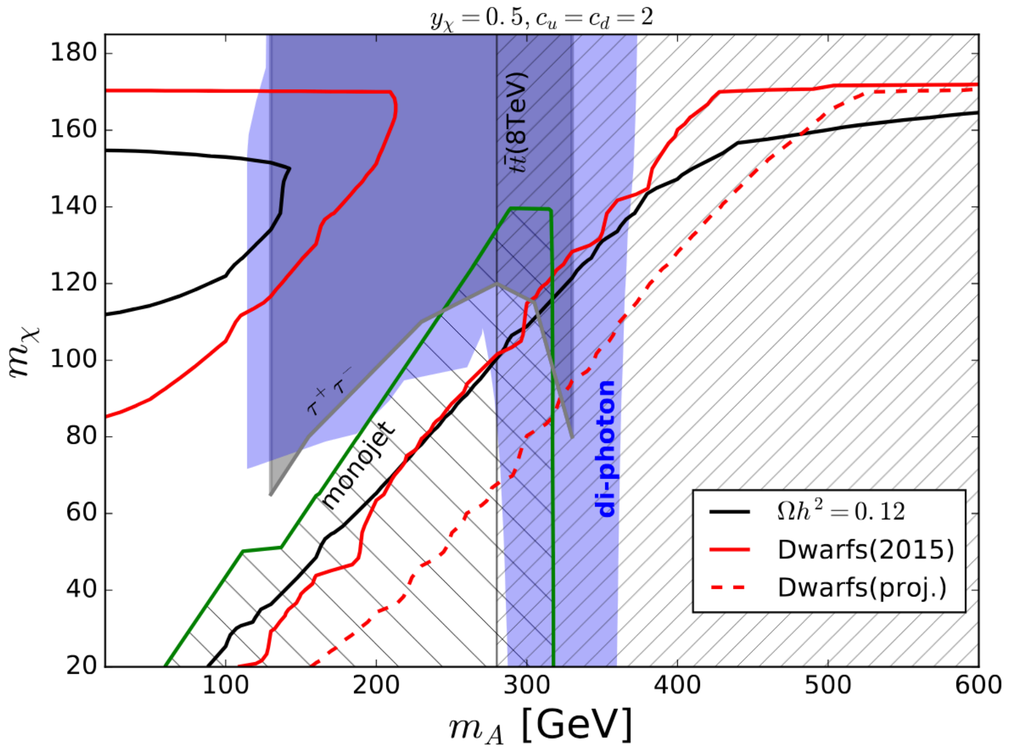
Cornering pseudoscalar-mediated dark matter with the LHC and cosmology

JHEP 07 (2017) 080

Shankha Banerjee[a], Daniele Barducci[b], Geneviève Bélanger[a], Benjamin Fuks[c,d], Andreas Goudelis[c] and Bryan Zaldivar[a]



2016 and plans for next micrOMEGAs v5

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I’m glad it seemed to be the case!!

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I rather talked about my ankle and the plaster, and about old man in my post-operating room saying I will never leave that hospital

January 2018

micrOMEGAs5.0 : freeze-in

Comput.Phys.Commun. 231 (2018) 173-186

G. Bélanger[1†], F. Boudjema[1‡], A. Goudelis[2§], A. Pukhov[3¶], B. Zaldivar[1††]

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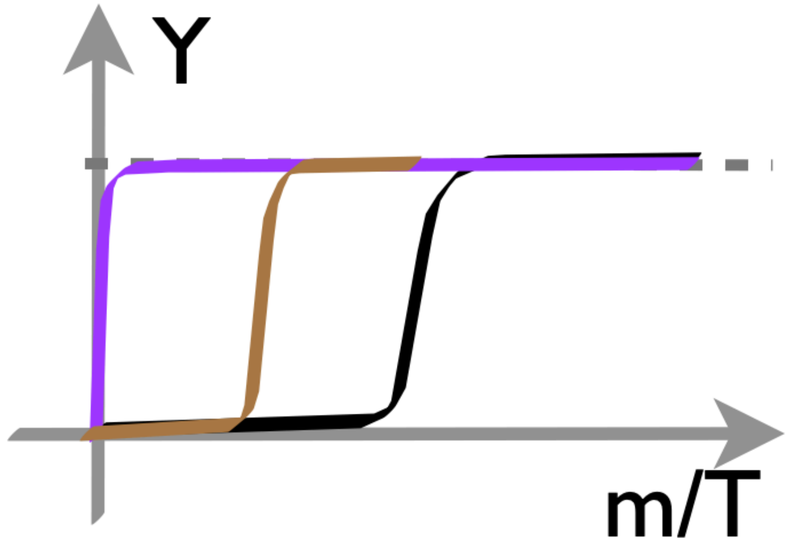
> Production time depending on mass ratios



January 2018 —— **micrOMEGAs5.0 : freeze-in**

Comput.Phys.Commun. 231 (2018) 173-186

G. Bélanger[1†], F. Boudjema[1‡], A. Goudelis[2§], A. Pukhov[3¶], B. Zaldivar[1††]

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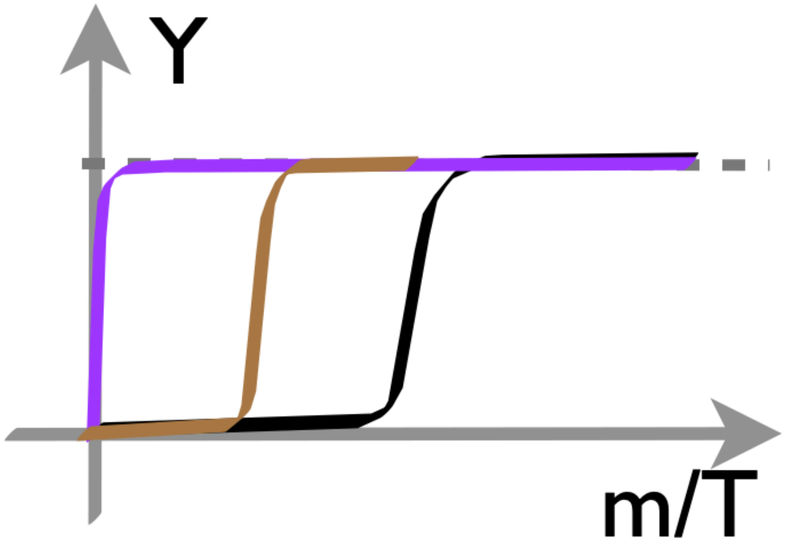
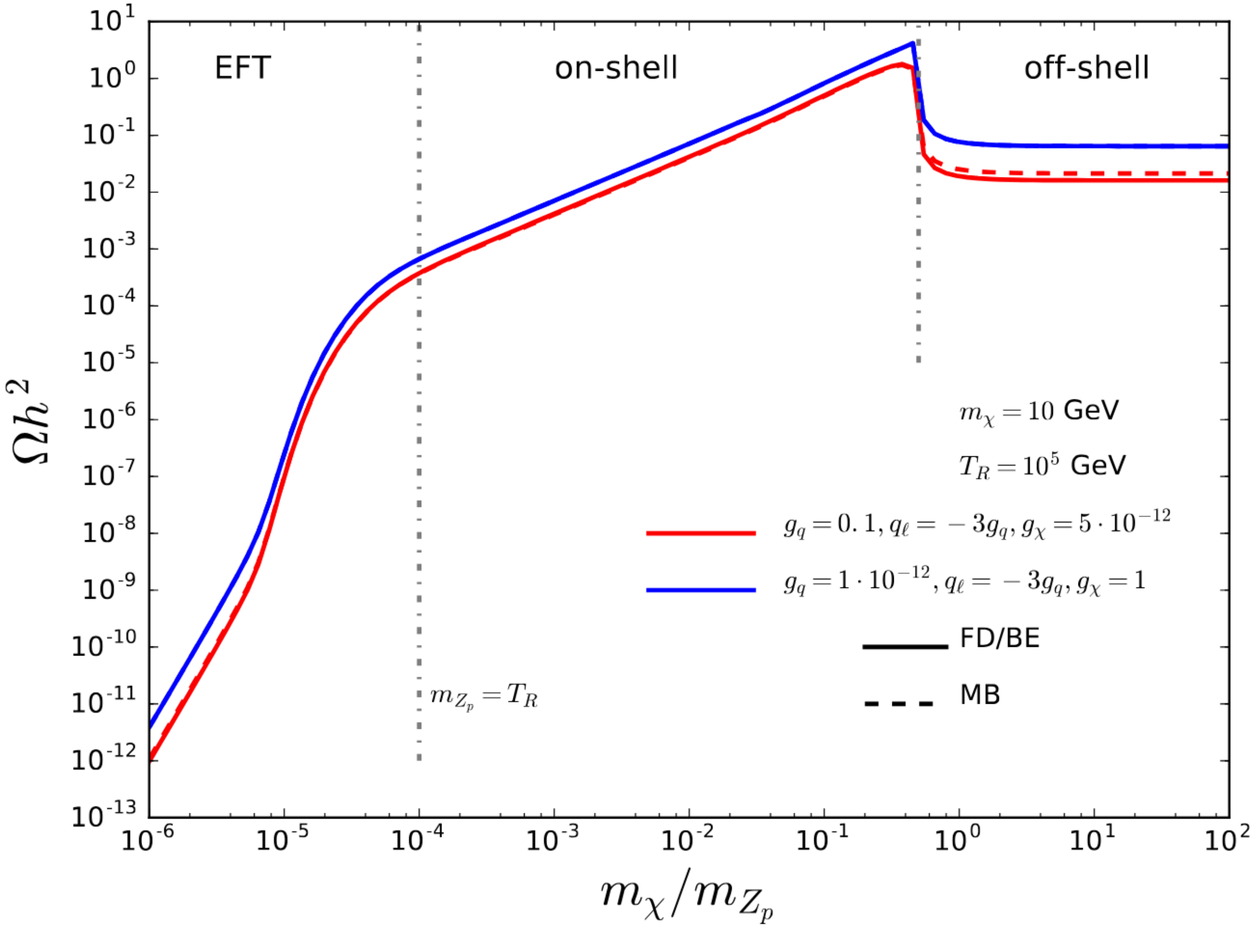




Geneviève’s boosting micrOMEGAs as much as a ‘Dragon Boat’

Circa 2017-2018

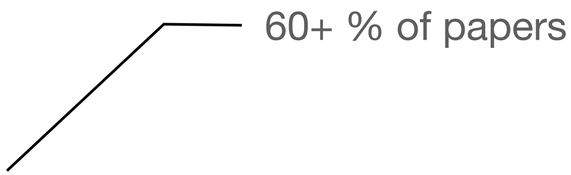
LAPTh participation

Geneviève looks like a 20 year-old leader on the boat

So much fun that day!

Geneviève's DM interest since ~2000

a G.Belanger.1 and date after 2000 and (t micromegas or t dark or t relic or t neutralino* or t WMAP or t freeze*)*



Dark Matter

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60+ % of papers

Dark Matter

Production mechanisms

Freeze-out— WIMPs

Intermediate regimes

Freeze-in: the coolest for sure

semi-annihilation

Multi-component DM

Asymmetric DM

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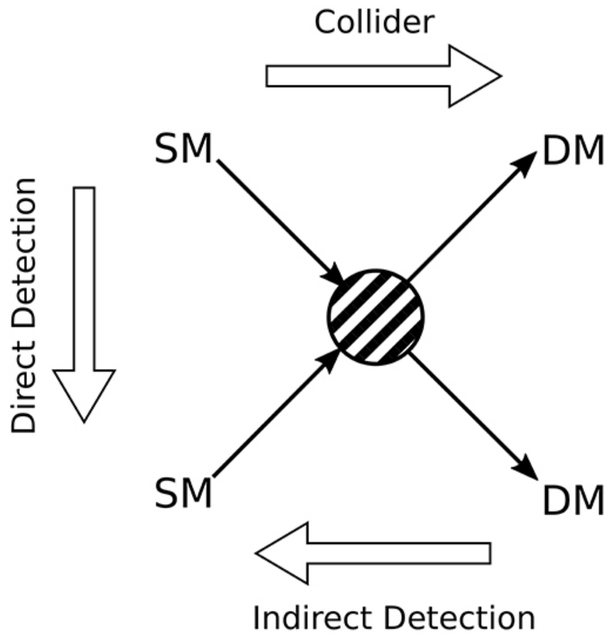

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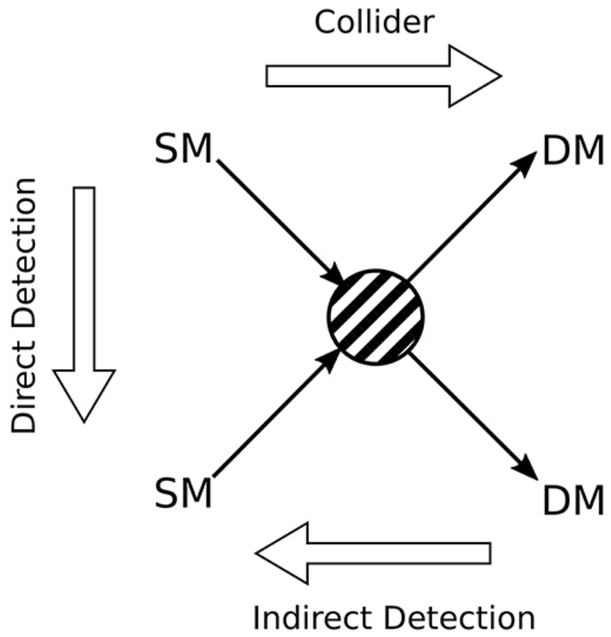

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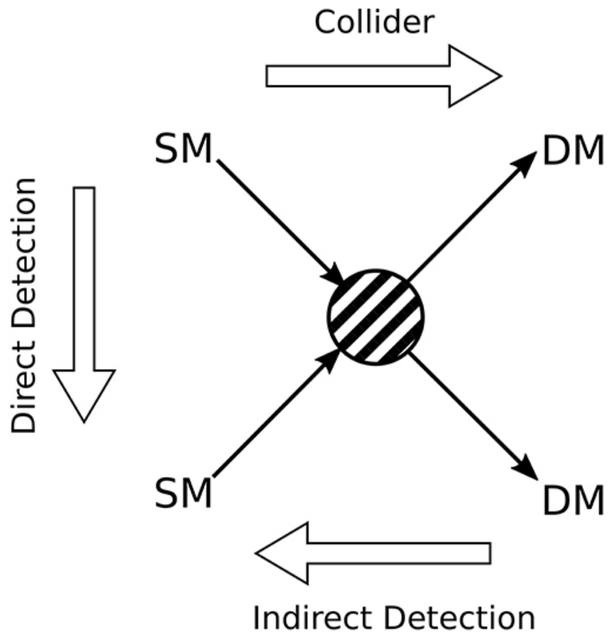

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Collaborators

Sasha

Fawzi

Sabine

Rohini

Pierre

+95 more

Example Freeze-in pheno at LHC

LHC-friendly minimal freeze-in models

JHEP 02 (2019) 186

G. Bélanger[a] N. Desai[b] A. Goudelis[c] J. Harz[d] A. Lessa[e] J.M. No[f] A. Pukhov[g] S. Sekmen[h] D. Sengupta[i] B. Zaldivar[a,f] J. Zurita[j,k]

Conceived aux Houches 2017

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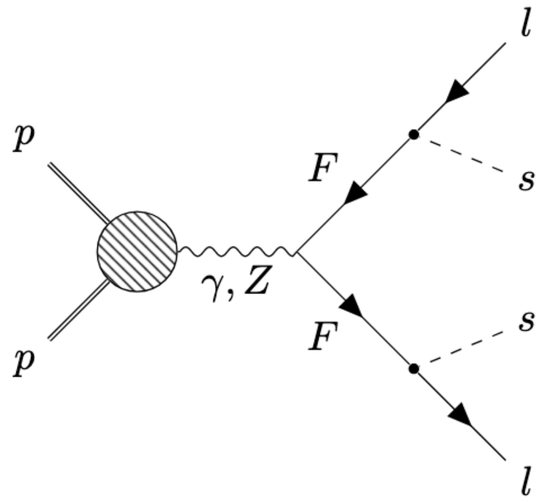

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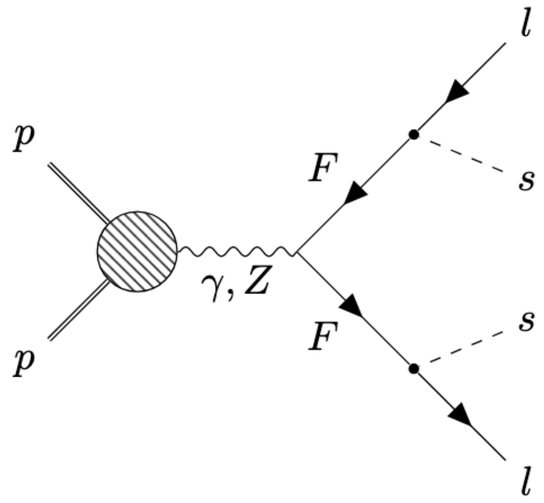

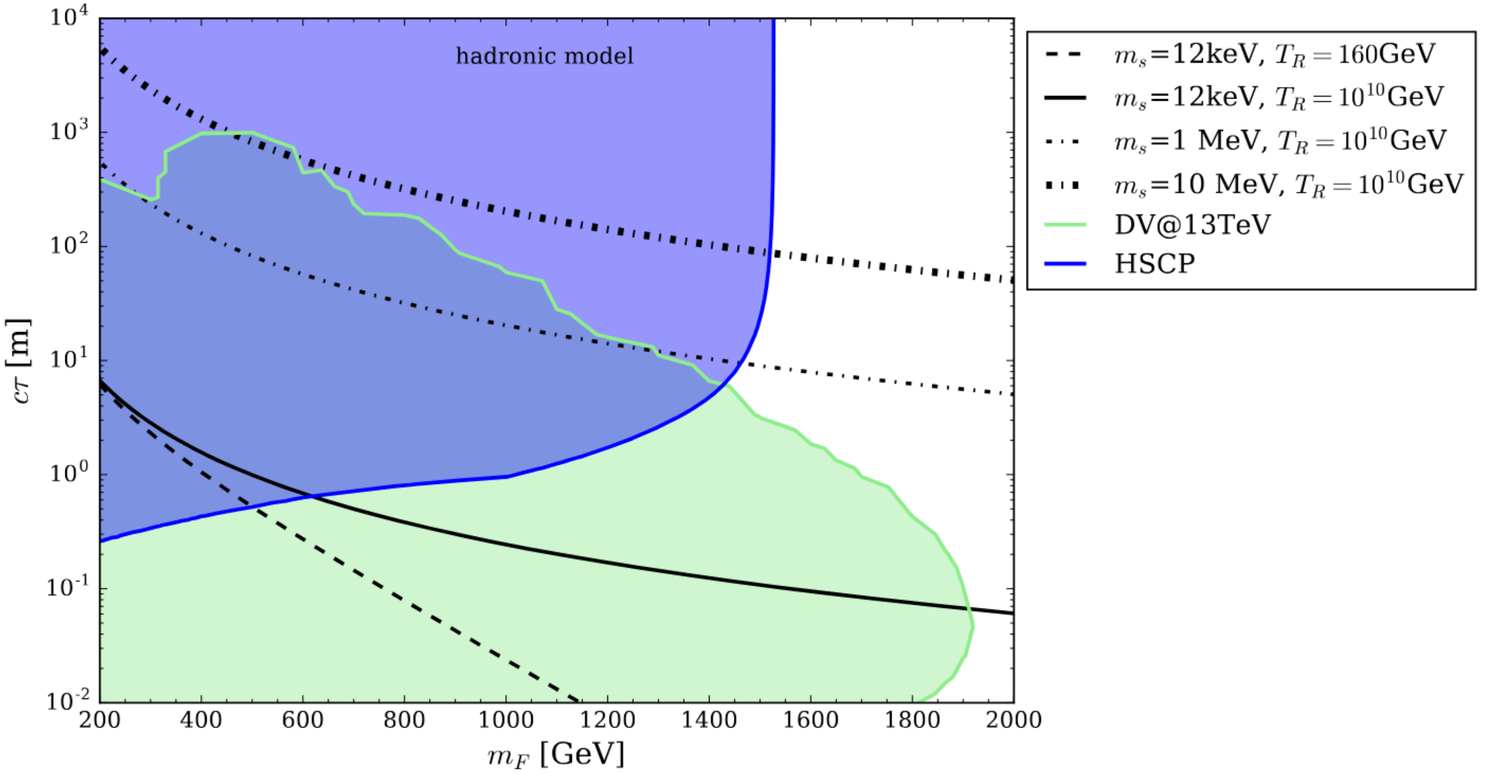

Recent example SUSY DM

PHYSICAL REVIEW LETTERS **131,** 011802 (2023)

Is Light Neutralino Thermal Dark Matter in the Phenomenological Minimal Supersymmetric Standard Model Ruled Out?

Rahool Kumar Barman,[1,*] Geneviève Bélanger,[2,†] Biplob Bhattacherjee,[3,‡] Rohini M. Godbole,[3,§] and Rhitaja Sengupta[3,‖]

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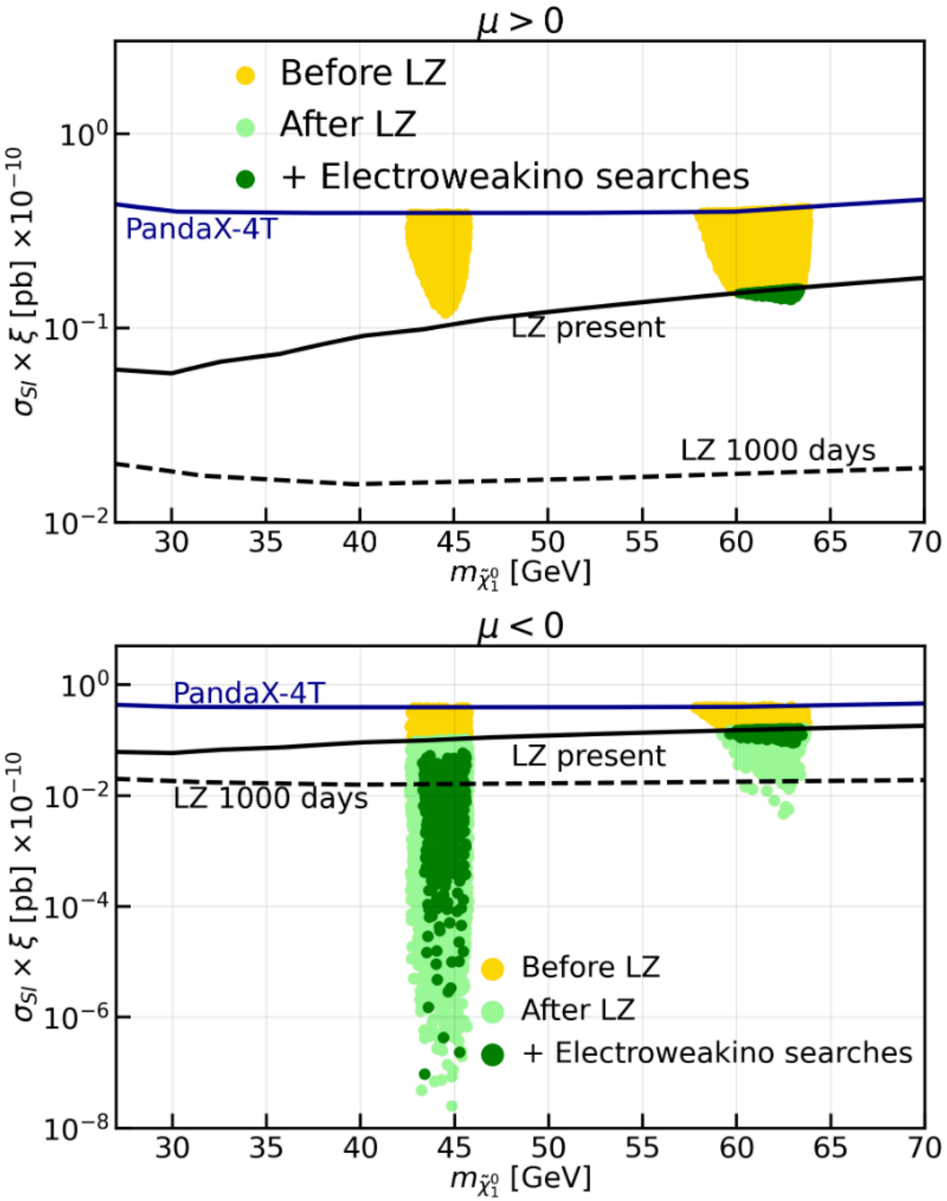

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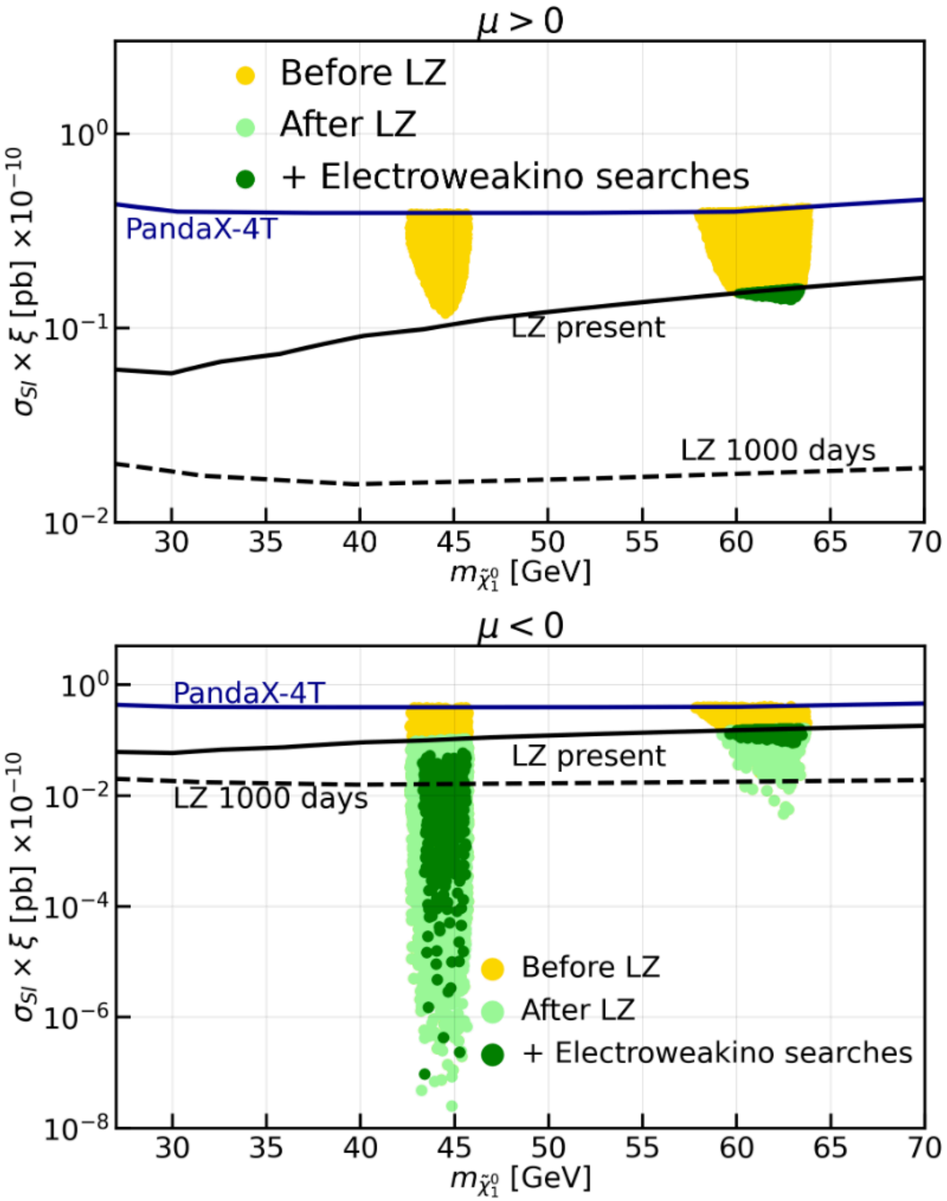
One in a large number of collaborations
LAPTh - India (Rohini)



Lunch chez Geneviève

Rohini, Shankha, Bryan+Chabe+baby

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Rohini was the cook (Spinach curry, Paratha, …)

(So damn good…)

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Geneviève

Sequel…

December 2023 —— **micrOMEGAs 6.0: N-component dark matter**

Comput.Phys.Commun. 299 (2024) 109133

G. Alguero[1], G. Bélanger[2], F. Boudjema[2], S. Chakraborti[3],
A. Goudelis[4], S. Kraml[1], A. Mjallal[2], A. Pukhov[5]

Reasons for the new version: Previous versions of micrOMEGAs worked within the assumption that dark matter is composed of one or two components. The new version allows for more components which can be either weekly or feebly interacting. The possibility of co-scattering is also implemented.

Sequel…

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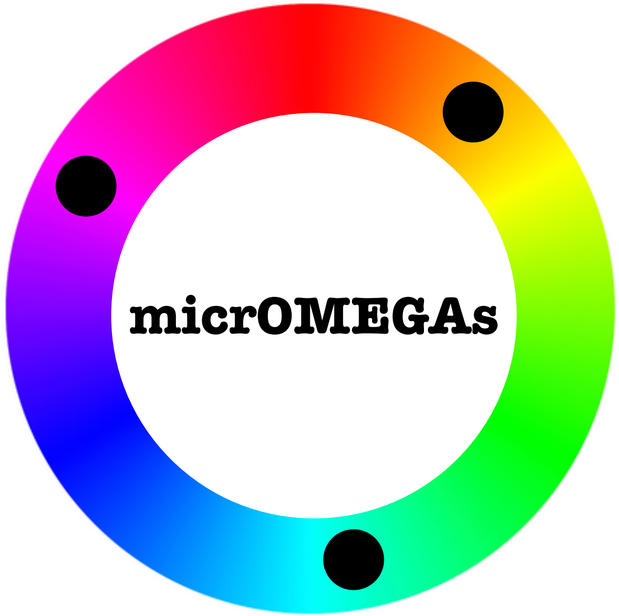
Models of DM interacting only on Mondays :-)

Present and future plans?



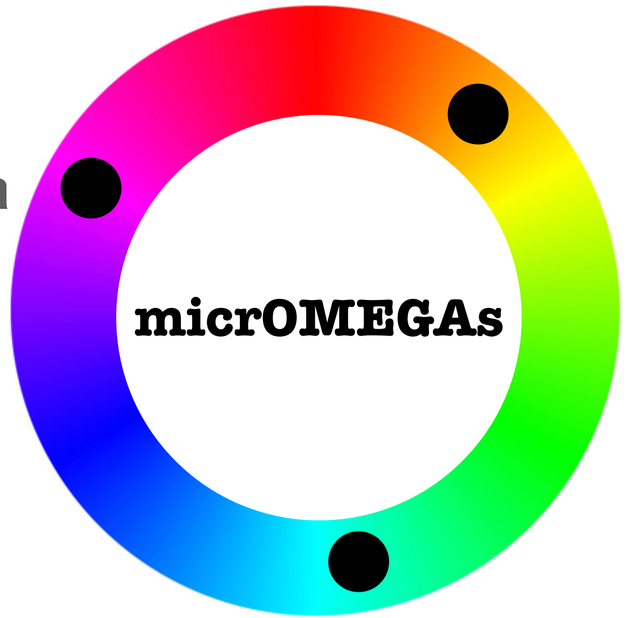
Present and future plans?

New physical phenomena

Inflation

EWPT

Many other



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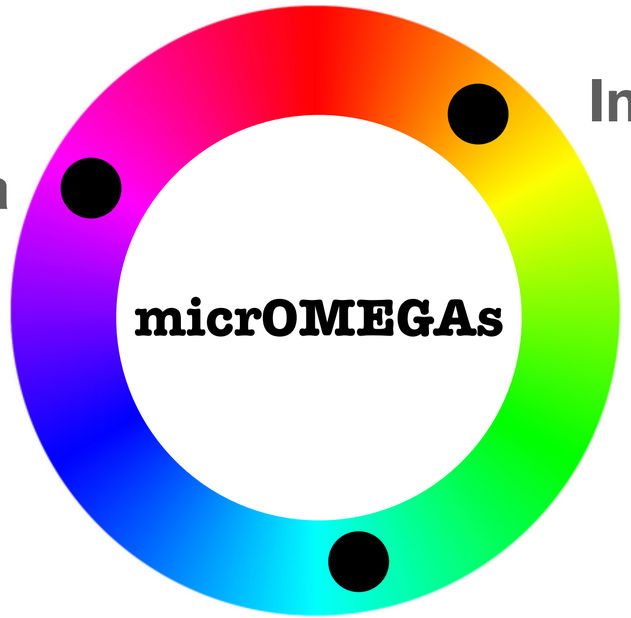

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Better recasting

More experiments

Full statistical inference

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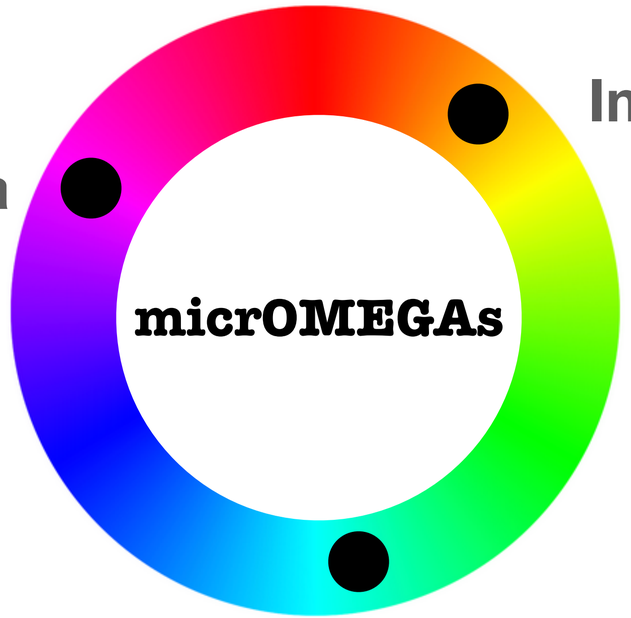

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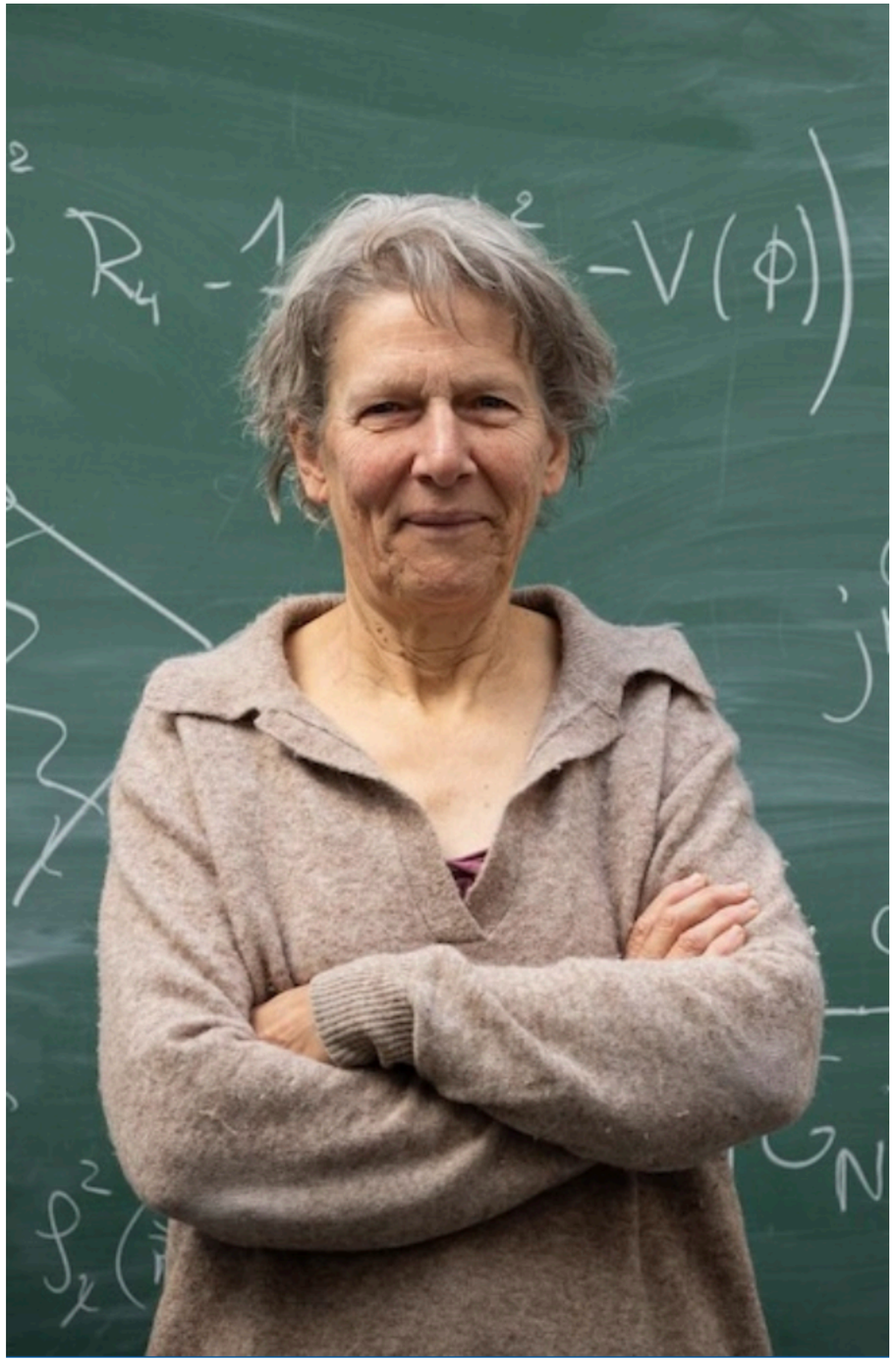
Coding

Interface

Comments

AI-assisted

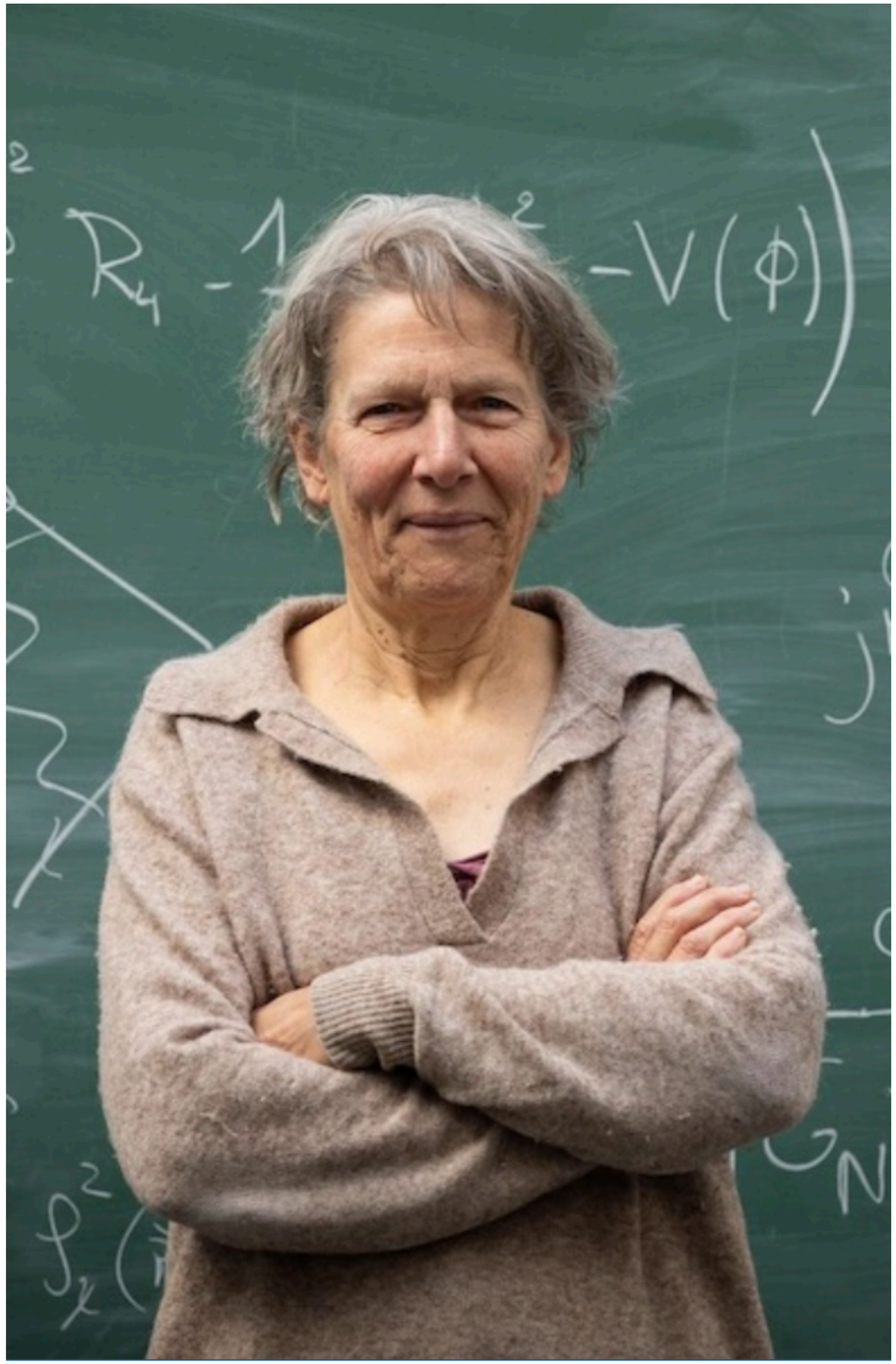
Closing — Legacy



Closing — Legacy

Scientific

She has made **very** well-known contributions to DM physics



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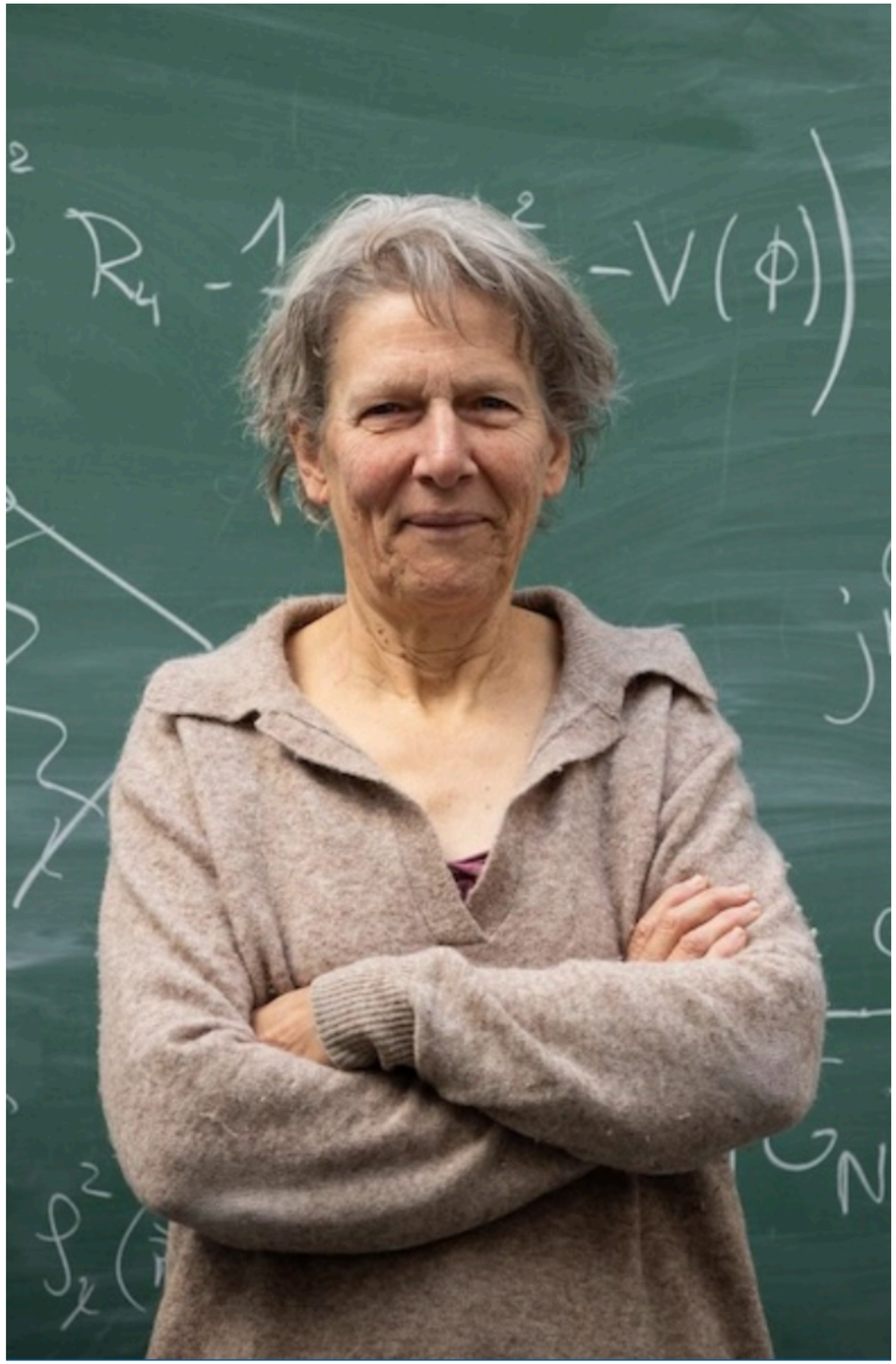

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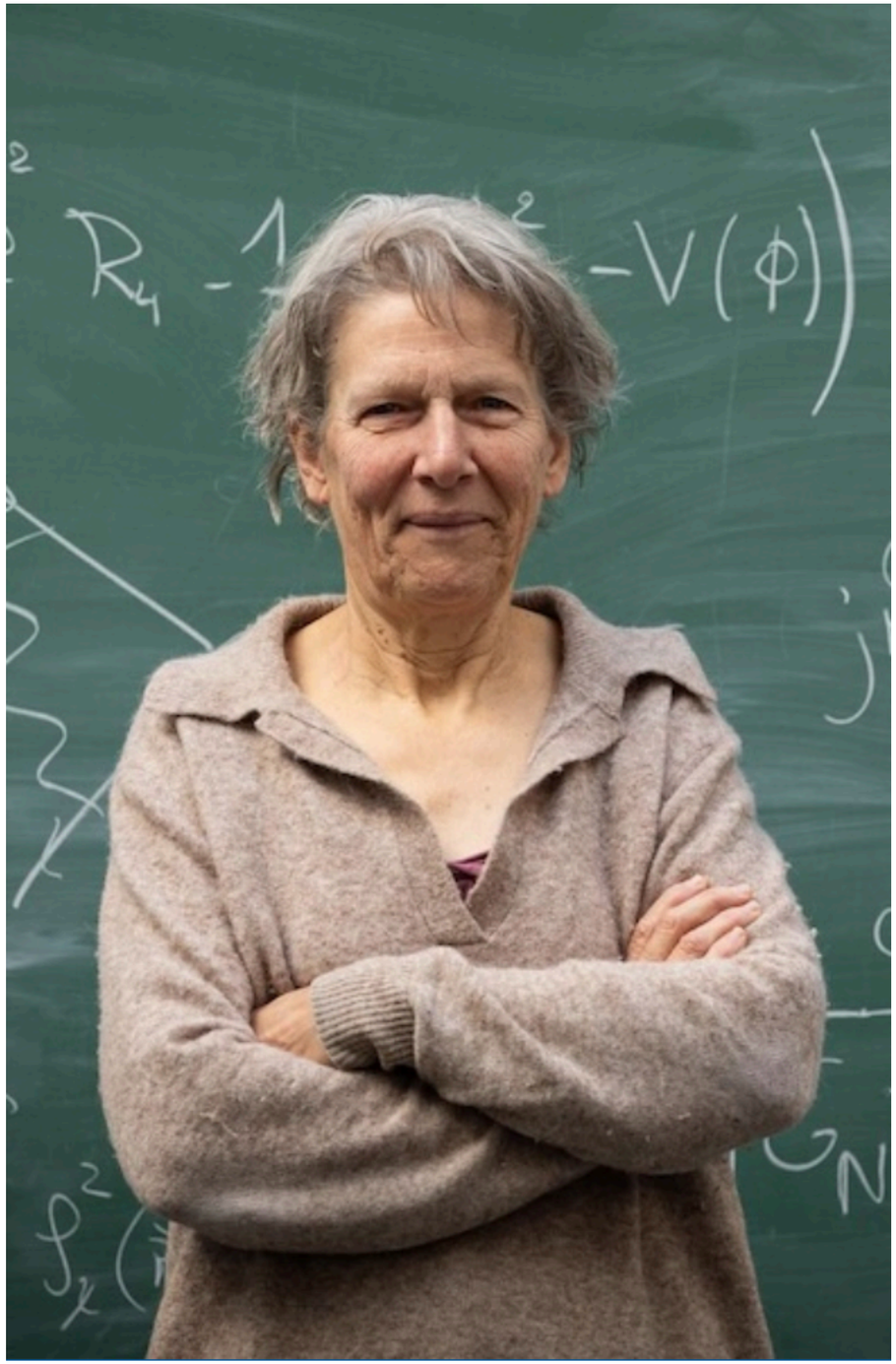

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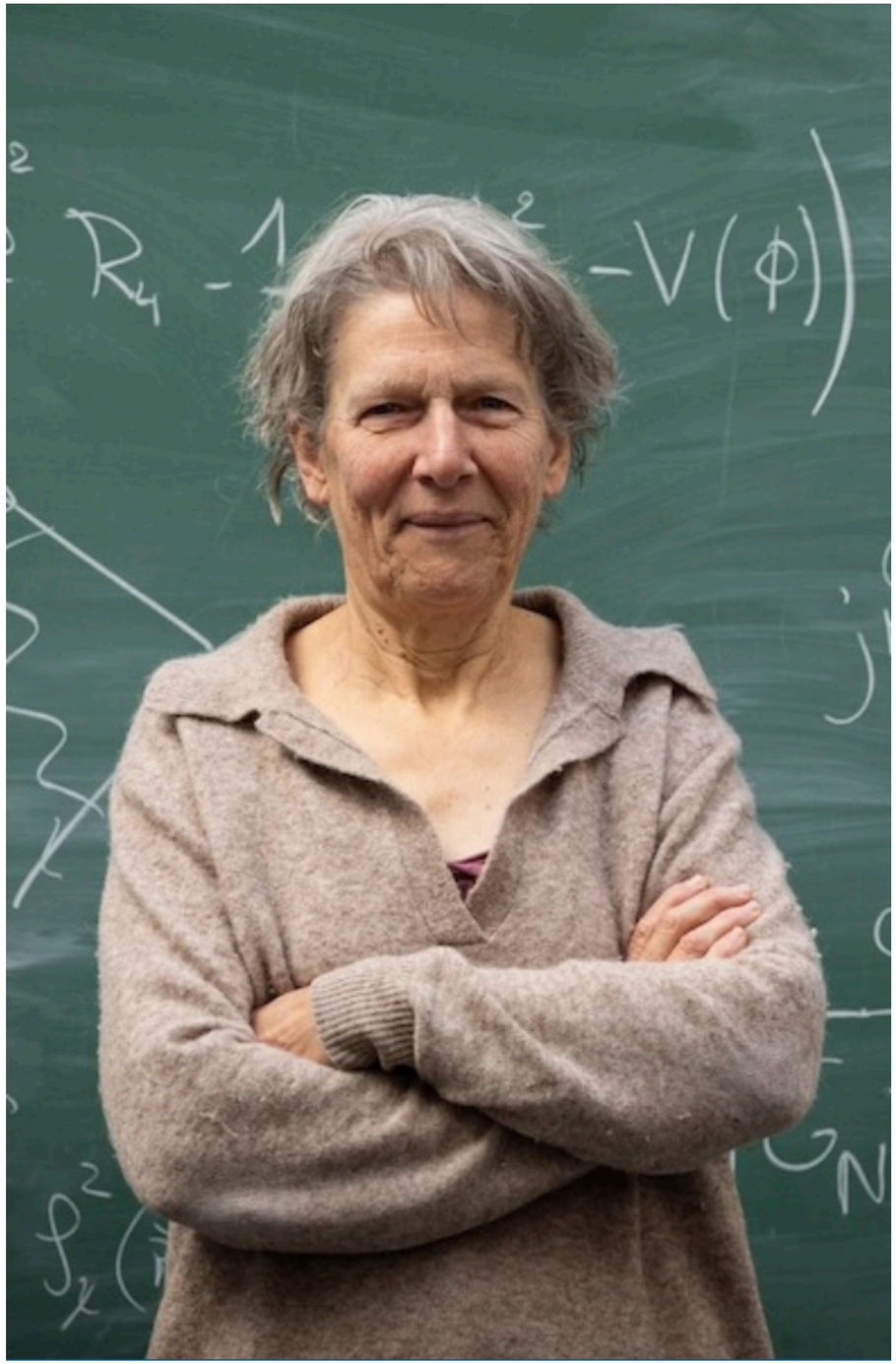
Whatever the future of DM physics is,
the way we do DM has been shaped by Geneviève



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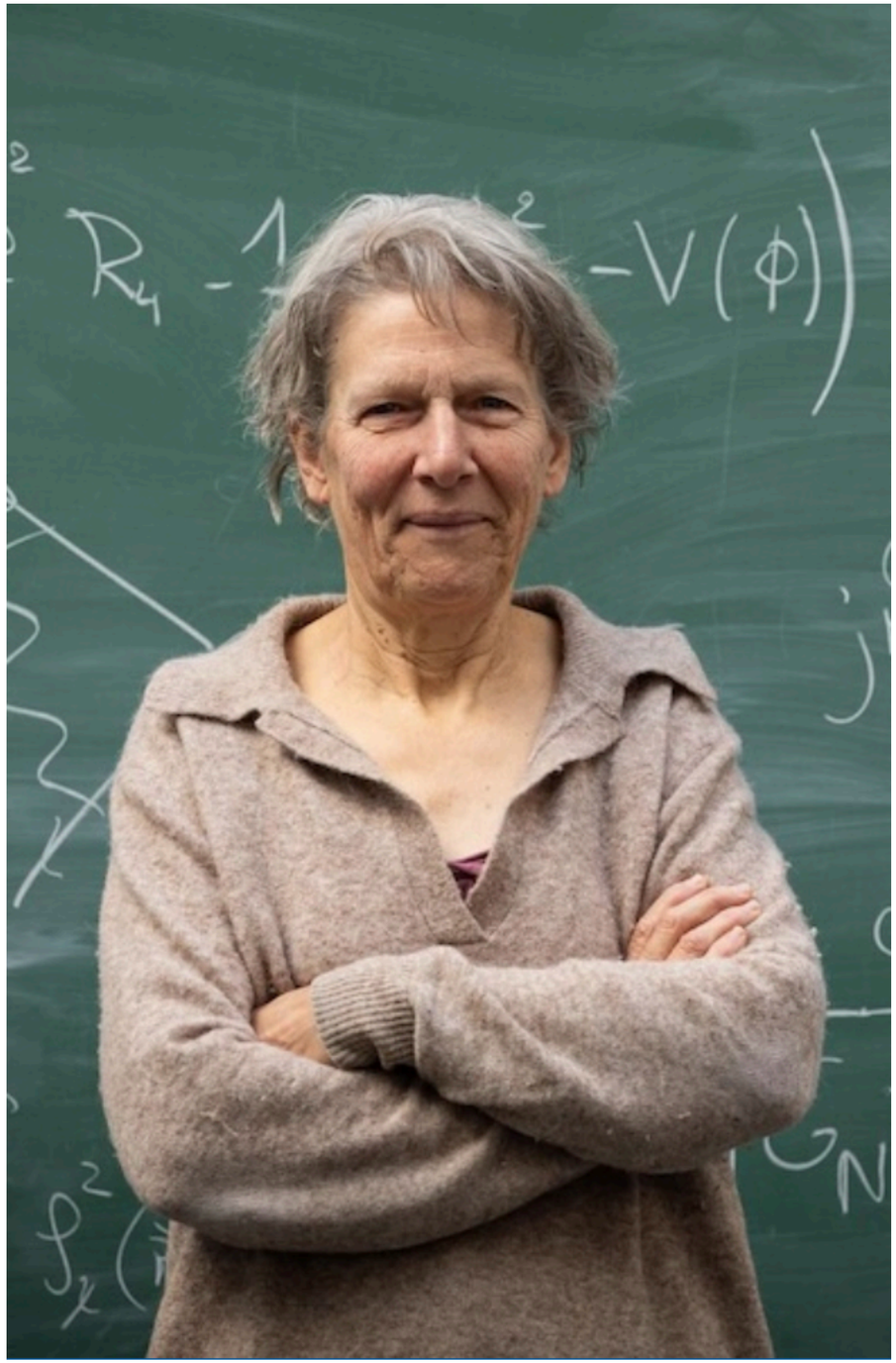

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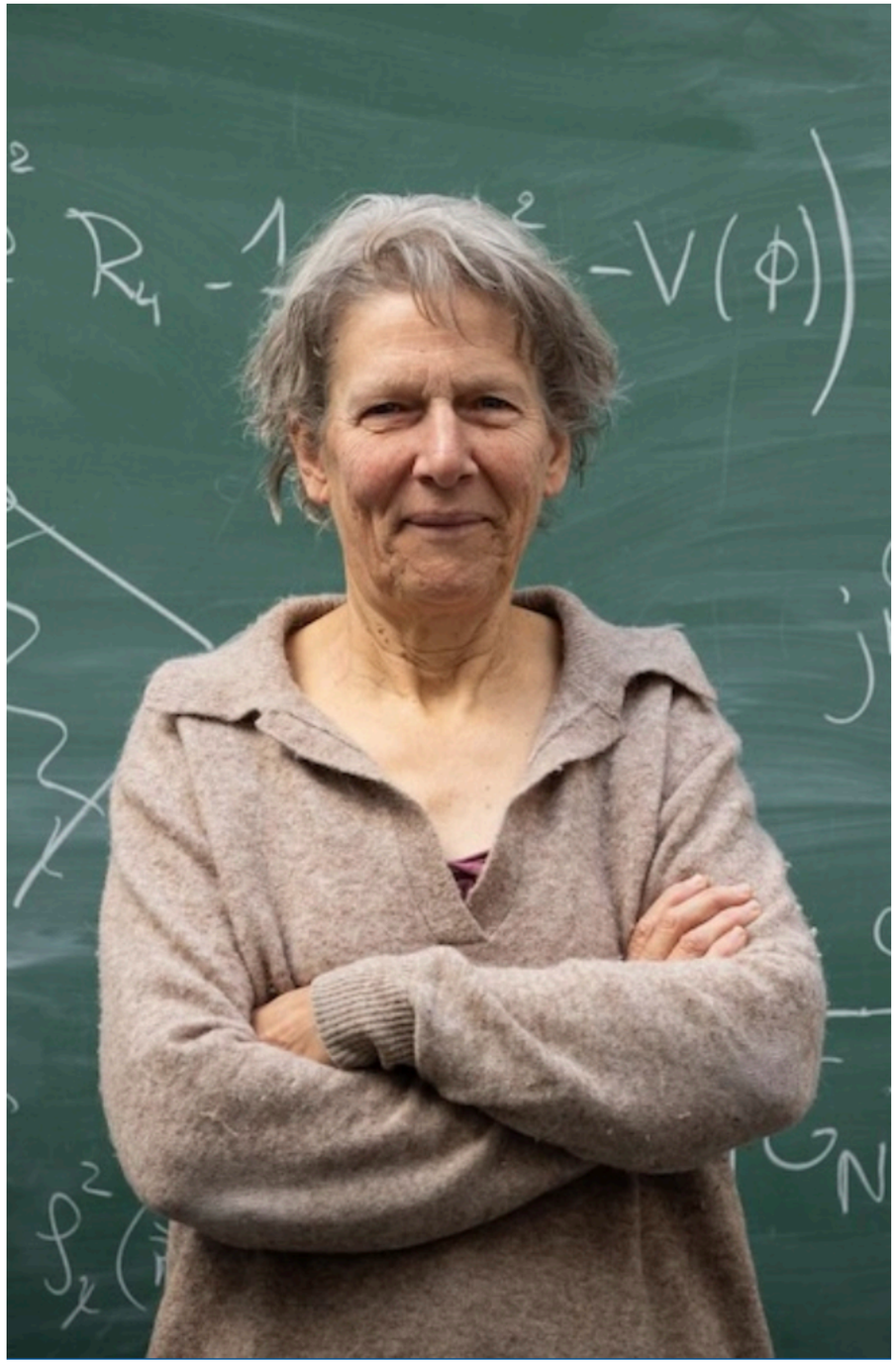
My period in Annecy clearly surpassed my expectations, and it all started with her



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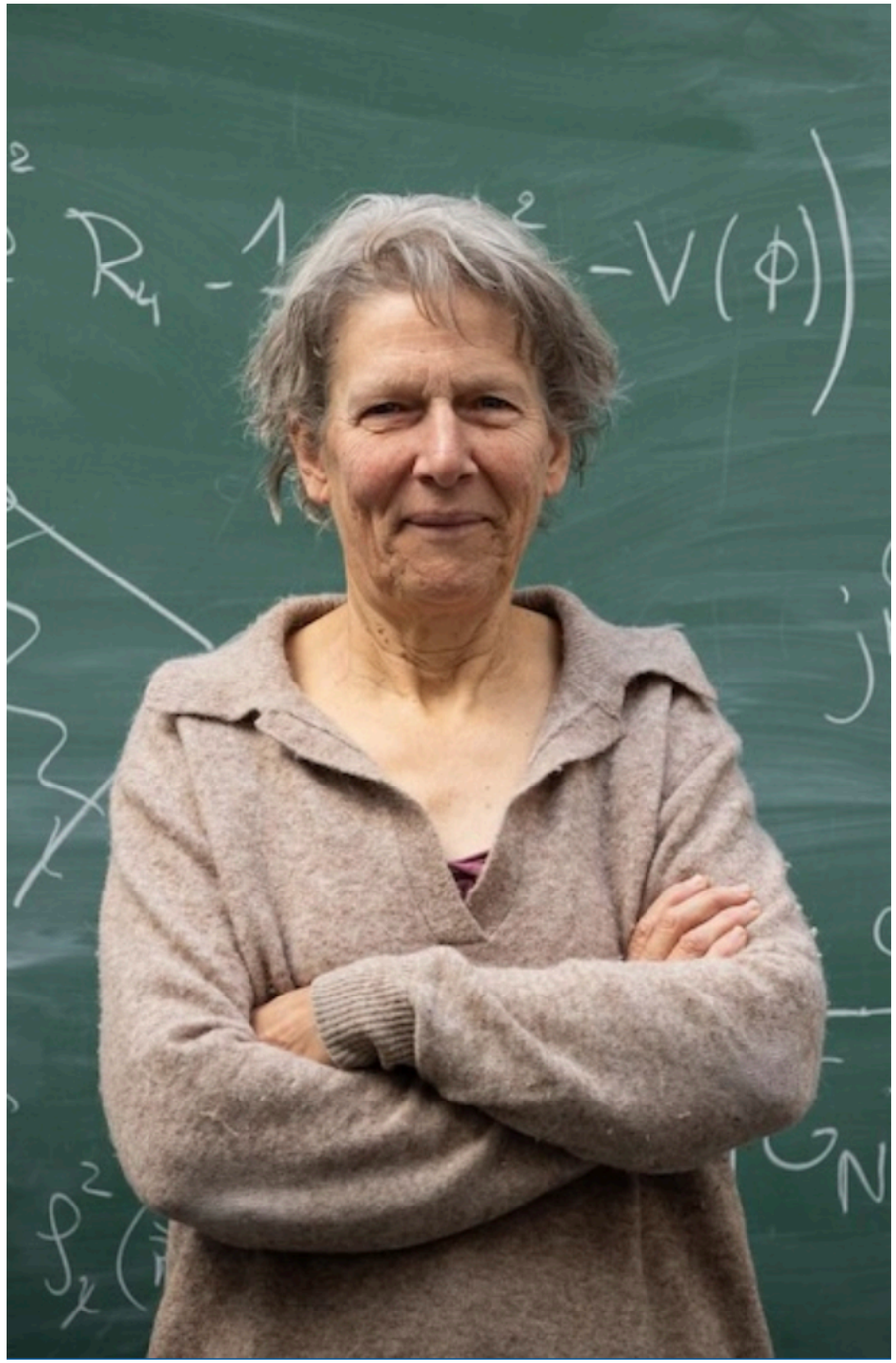

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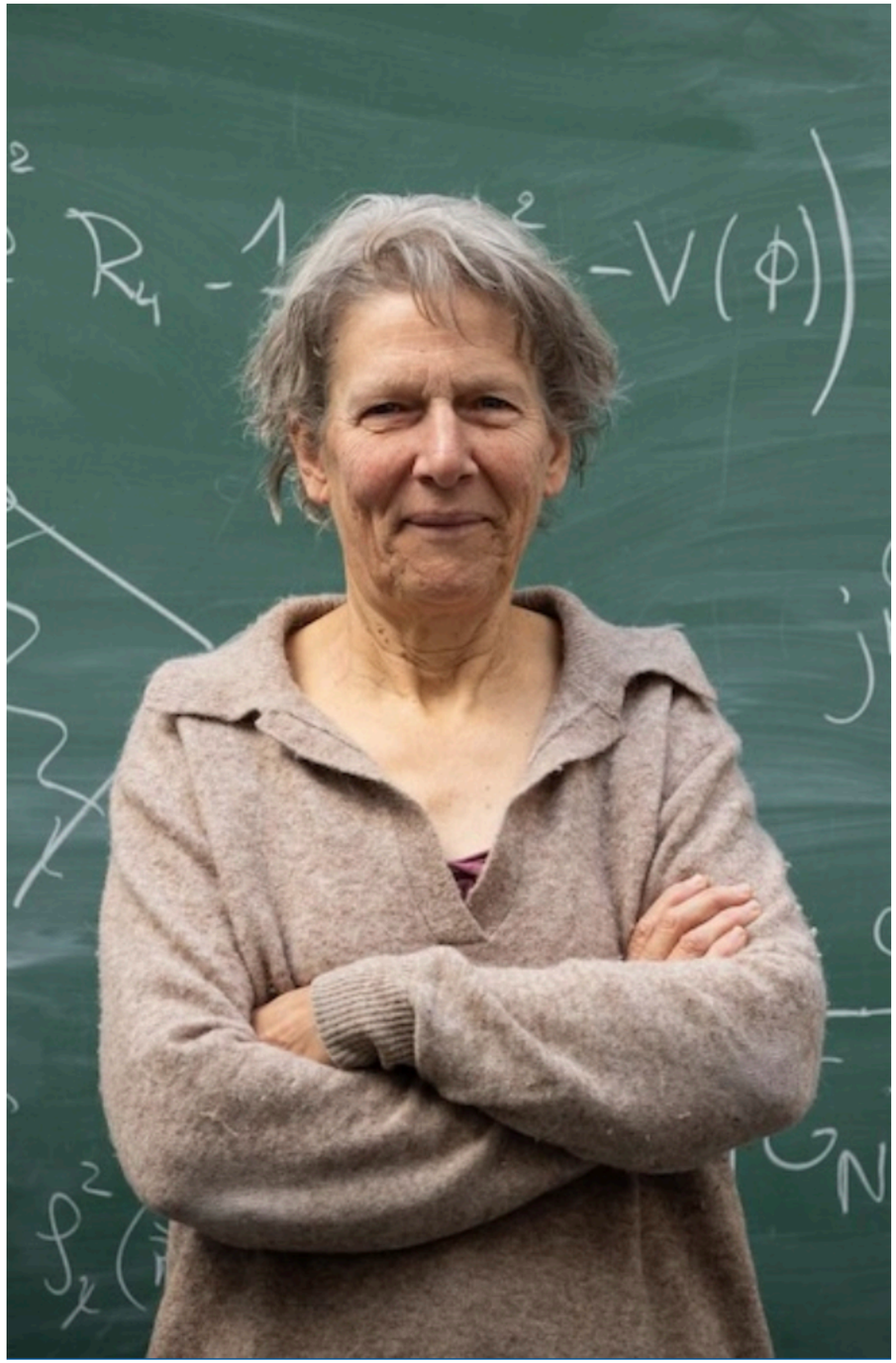
If I have concept of “scientfic family”, it is thanks to her, and she’s part of it



Merci Geneviève!!