Dark Matter

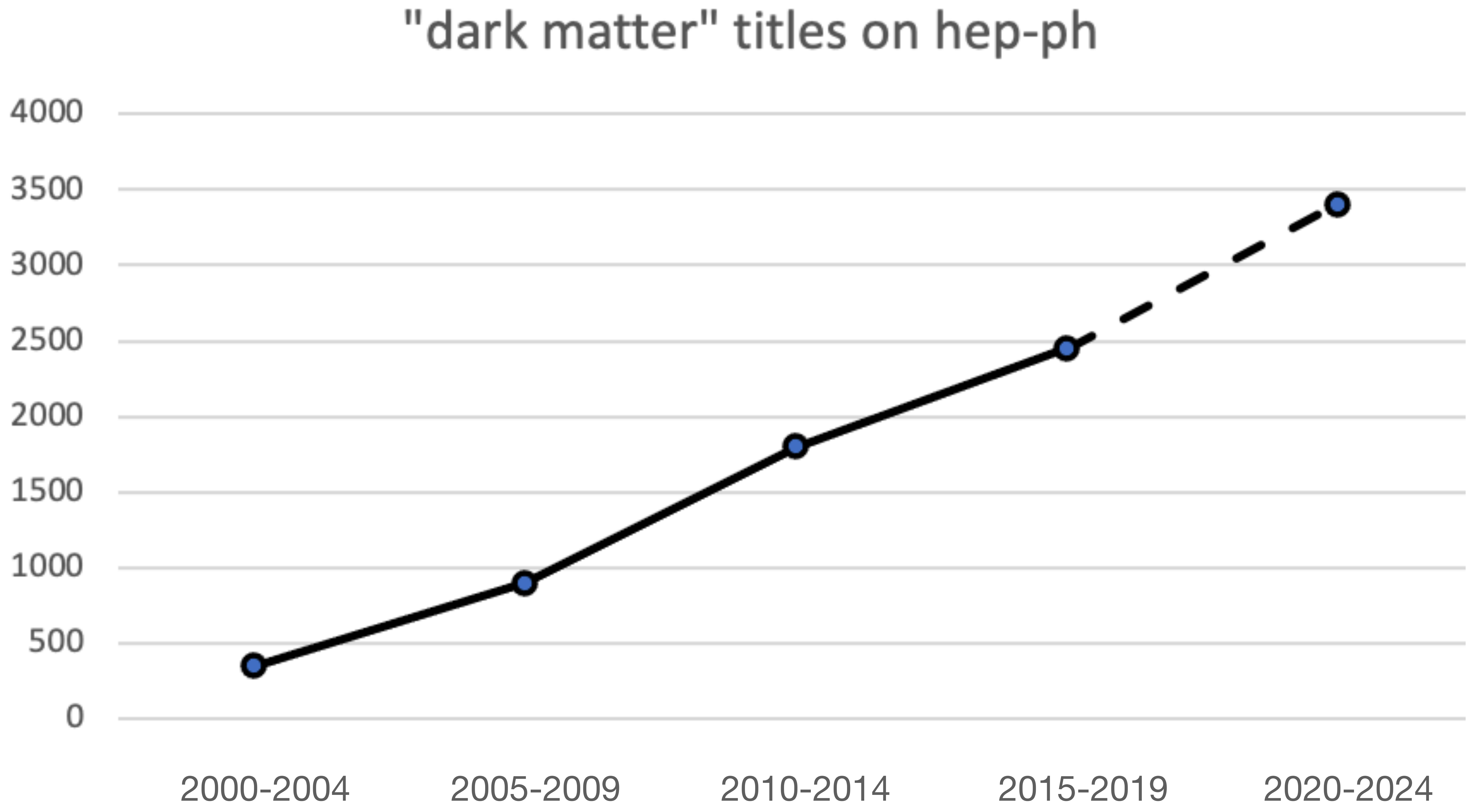
Theory and Paradigmatic Models

… and EuCAPT's activities

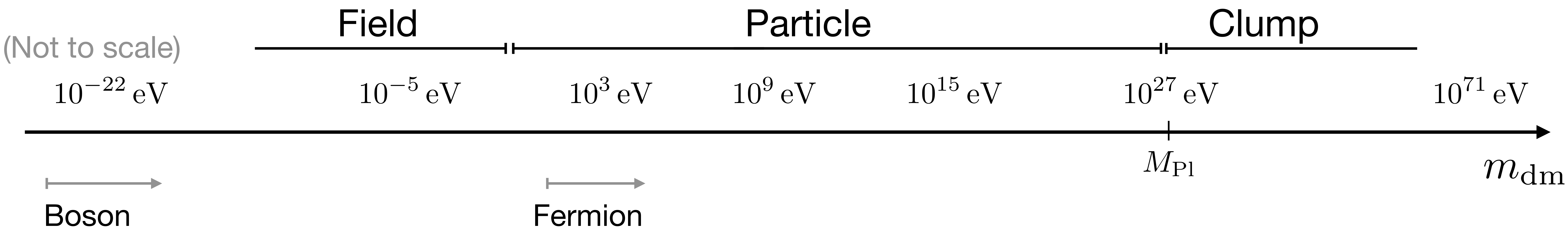
David Marsh, Stockholm University

iDMEu kick-off meeting 11th May 2021

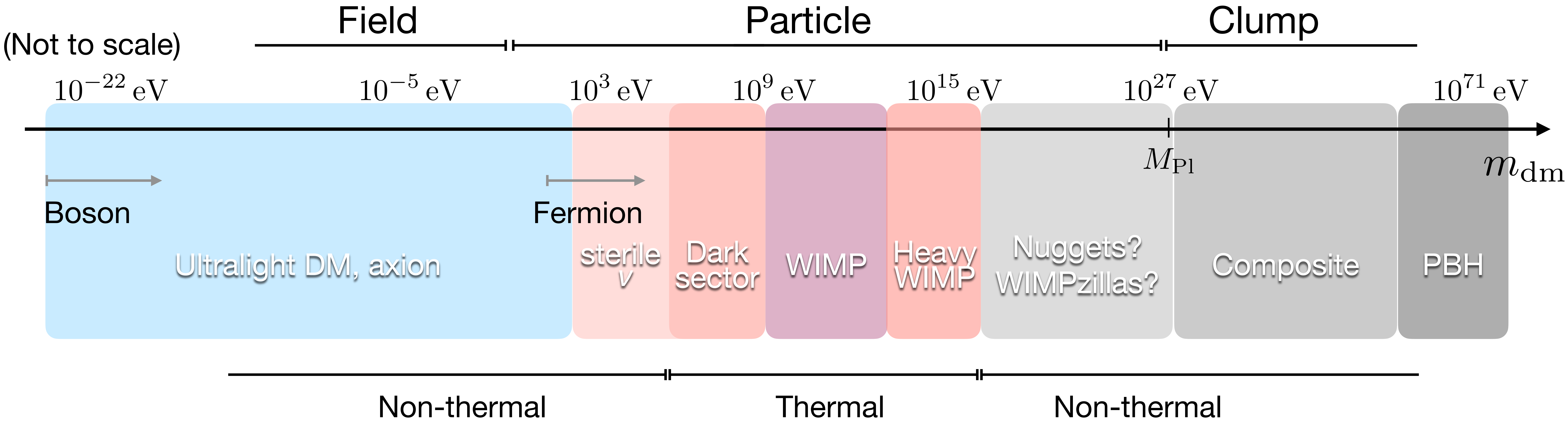
Theory papers on dark matter



Model independent results

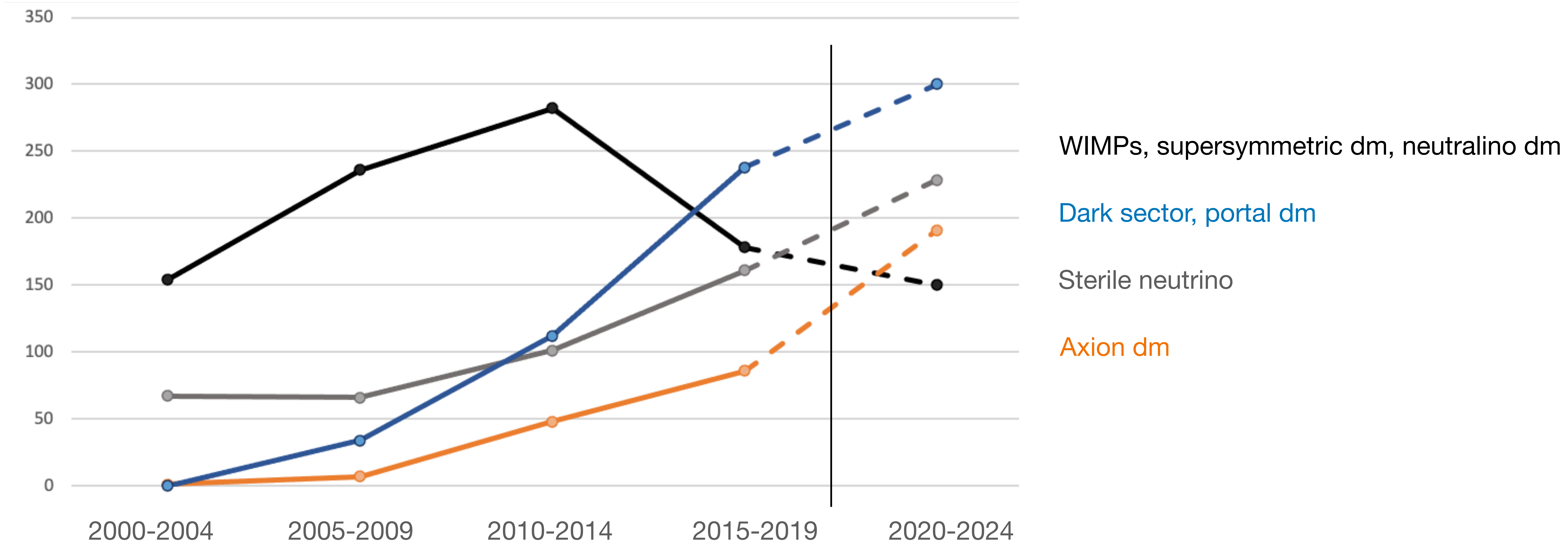


Paradigmatic models



What models do people work on?

(caveats apply)



Point 1:

Thermal models are still going strong

Point 2:

Non-thermal models are increasingly tested

Point 3:

The theory community strives to be open-minded and inter-connected

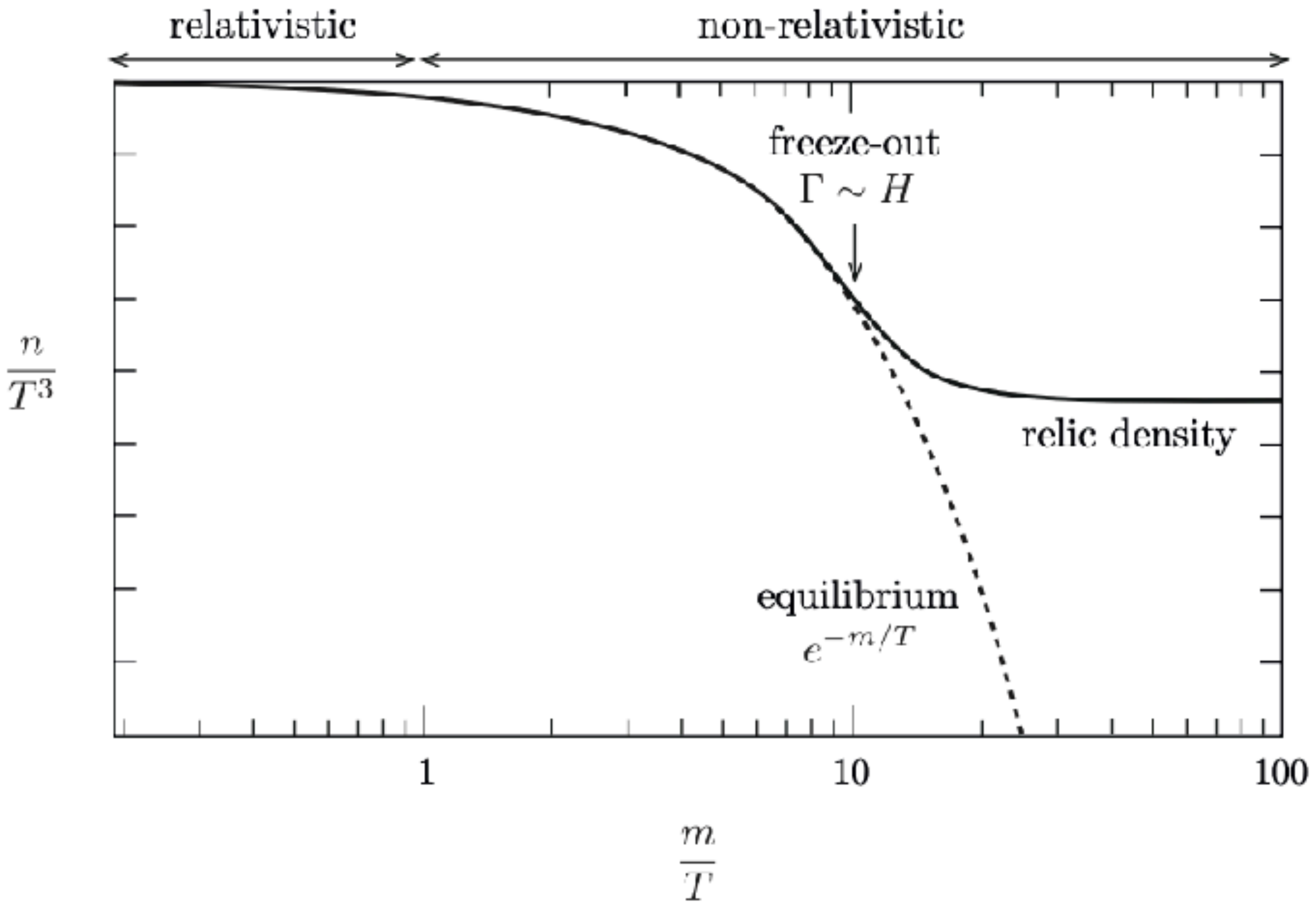
Point 1:

Thermal models are still going strong

WIMPs

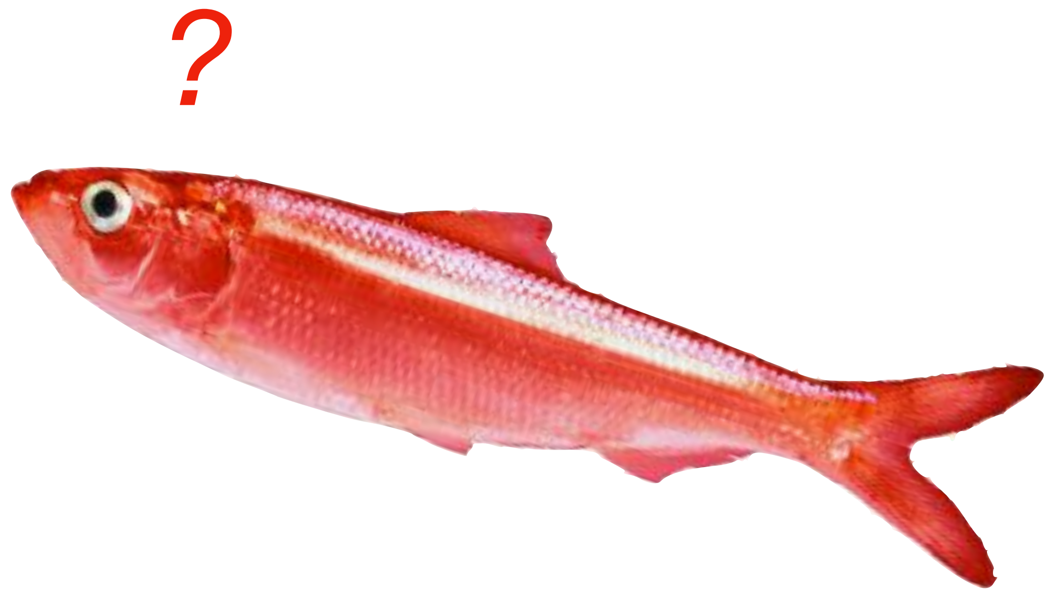
Thermal freeze-out: $\Omega_{\rm dm} \approx 0.2$ if

$$\langle \sigma_{\rm ann} v \rangle \sim \frac{\alpha_w^2}{m^2} \sim \frac{1}{(\rm TeV)^2}$$



Traditionally $\quad {\rm GeV} \lesssim m \lesssim {\rm TeV}$

Works well with low-energy supersymmetry

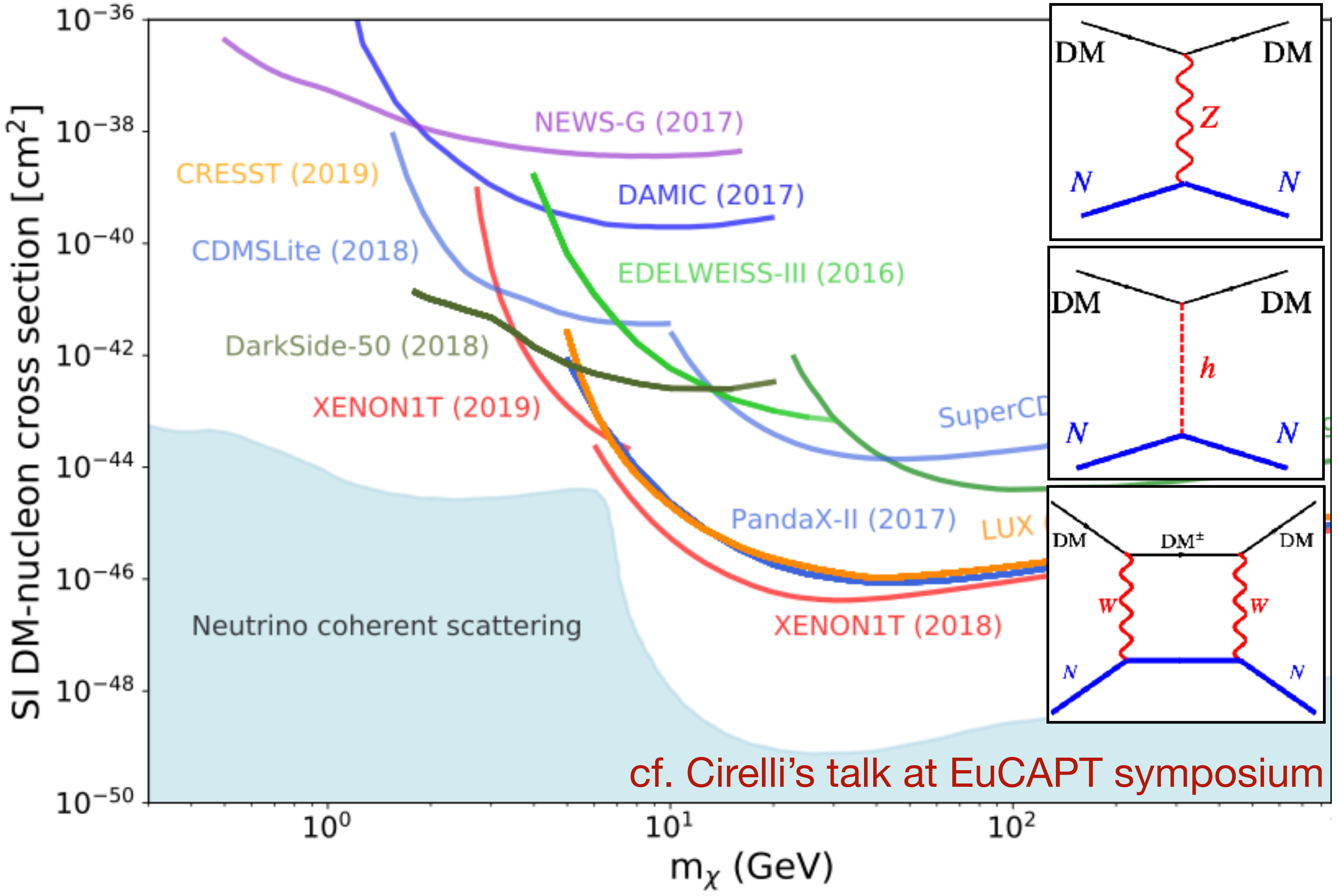


WIMPs

Viable models down to & within the neutrino "fog"

cf. Baudis talk

Hints from indirect detection
(subject to astrophysical uncertainties)
inspire sharpened model building



cf. Cirelli's talk at EuCAPT symposium

Challenges & developments:

WIMPs that do more

Highlight underlying assumptions

Dark sectors

Thermal dark matter beyond WIMPs

$$\langle \sigma_{\rm ann} v \rangle \sim \frac{\alpha_x^2}{m^2}$$

New mediator

e.g. vector that kinematically mixes with Z, γ

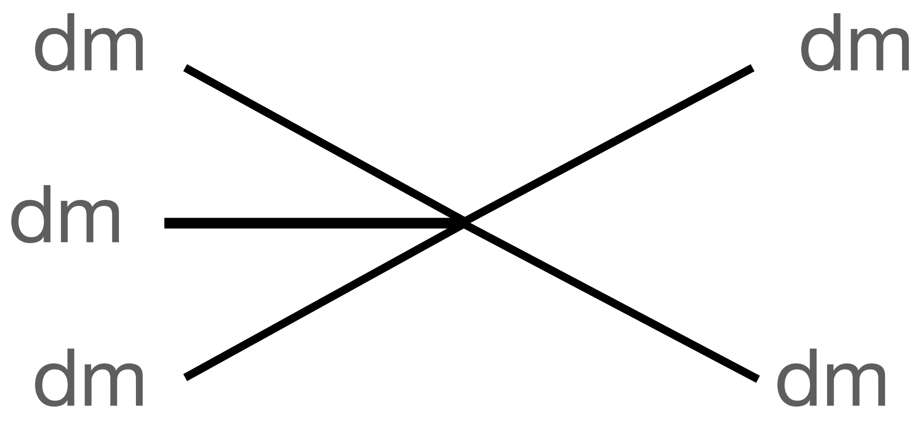
Feng, Kumar 0803.4196

Broad viable mass range: $\mathrm{keV} \lesssim m \lesssim 100\,\mathrm{TeV}$

Simplified models, effective field theory parametrisation

Review: Lin 1904.07915

Many realisations, *e.g.* SIMP dark matter:



$$m \sim 100\,\mathrm{MeV}$$

$$\alpha_x = 1$$

Hochberg et al. 1402.5143

Dark sectors

Both the dark matter and the mediator can be searched for

Synergetic with many new proposals for direct detection of light dark matter

cf. Privitera's talk

Many models have additional cosmological constraints, e.g. from $N_{\rm eff}$

Astrophysical constraints among the most stringent

Challenges & developments:

Model building and phenomenology alongside experimental and observational efforts

Point 2:

Non-thermal models are increasingly tested

Sterile neutrinos

Singlet fermions that mix with neutrinos

$$\frac{1}{2}\left(\bar{\nu}_L\,,\ \bar{\nu}_R^c\right)\begin{pmatrix} 0 & m_D \\ m_D & M \end{pmatrix}\begin{pmatrix} \nu_L^c \\ \nu_R \end{pmatrix} \ + \ \mathrm{h.c.}$$

See-saw mass, and small mixing $\theta = \frac{m_D}{M}$

Narrow mass range: $\mathrm{keV} \lesssim M \lesssim \mathrm{few} \times 10\,\mathrm{keV}$

Review: Boyarsky et al. 1807.07938

Production: thermal non-thermal

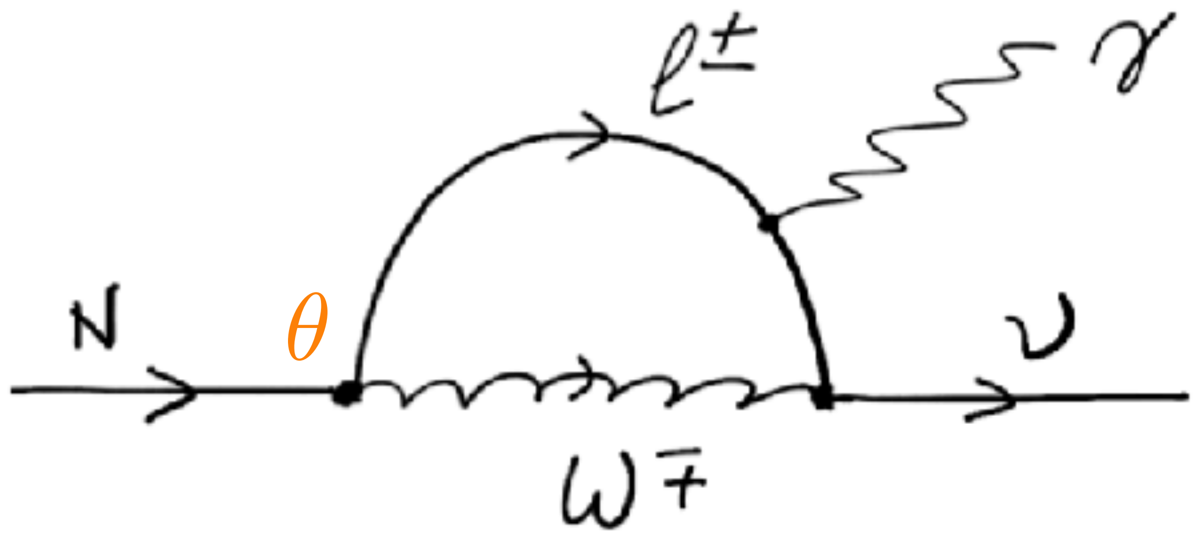
Always there

cannot produce *all* dm

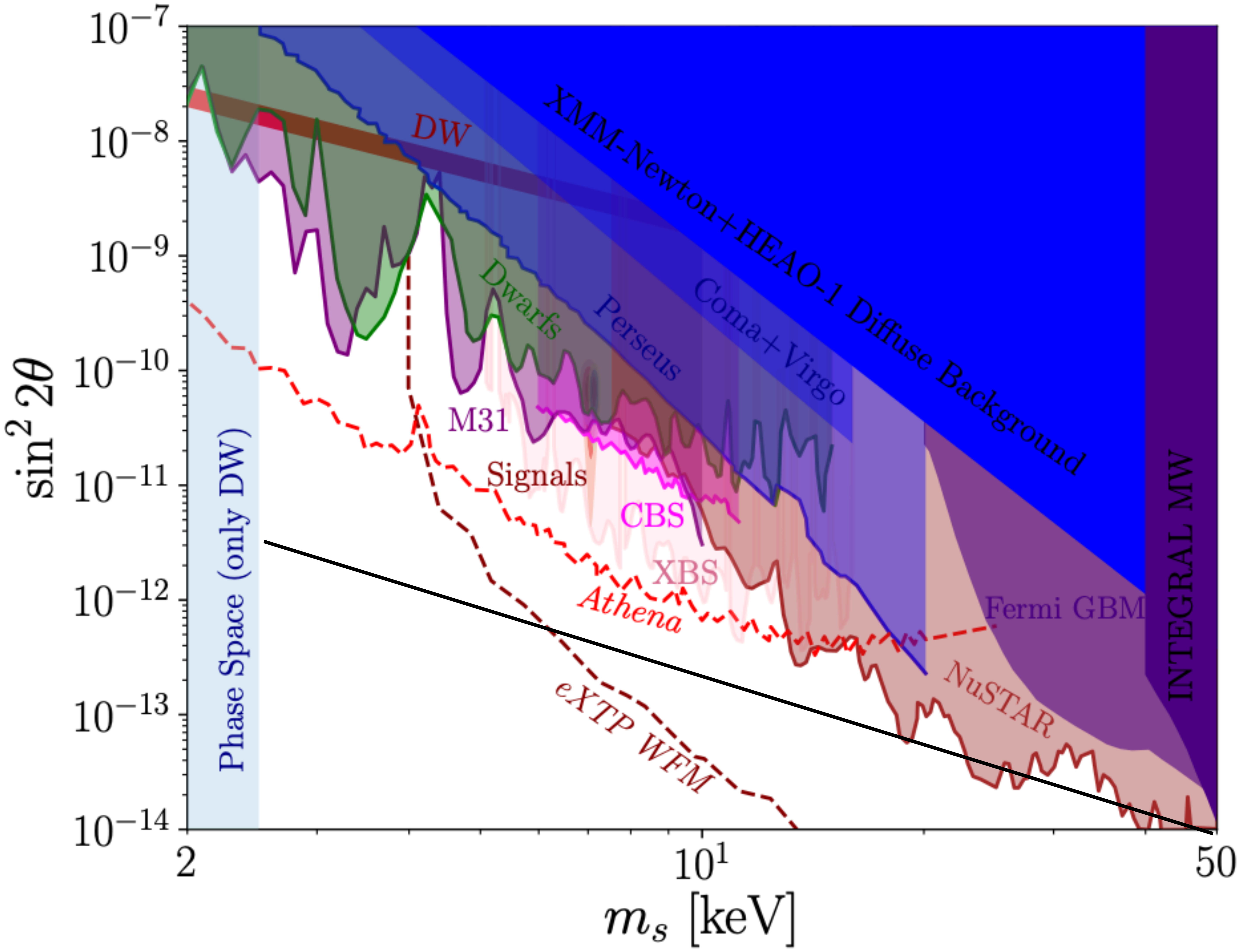
MSW resonance

in-medium mass degeneracy, if *L* is sufficiently large

Sterile neutrinos



Test: X-ray line signal



Challenges & developments:

Robust calculations of spectrum

How to generate large enough *L*?

Non-minimal models

Review: Abazajian 2102.10183

Axions

A class of naturally light (pseudo-) scalar dark matter candidates

cf. Majorovits talk

The QCD axion:

- Naturally light
- Couples to photons
- Couples to gluons
- Nulls neutron EDM
- One parameter: m_a

Axion-like particles (ALPs):

- Naturally light
- Does not couple to gluons
- All Wilson coefficients are parameters: m_a , $g_{a\gamma}$
- Ubiquitous in string theory

Excellent cold dark matter candidates

Behaves like classical field

Axions

Viable mass range for QCD axion dark matter depends on cosmology

I. Homogeneous across the universe

"Pre-inflationary scenario"
axion misalignement

$$m_a \leq 0.15\,\mathrm{meV}$$

$$m_a \gtrsim 0.1\,\mu\mathrm{eV} \quad (\mathrm{or}\ 10^{-12}\,\mathrm{eV})$$

II. Random initial conditions when formed

"Post-inflationary scenario"
axion misalignement + topological defects

$$m_a \stackrel{?}{=} (25.2 \pm 11.0)\,\mu\mathrm{eV}$$

A single viable value,
but hard to compute

Buschman et al. [1906.00967]
Review: Di Luzio et al. [2003.01100]

ALPs can comprise ultralight dark matter:

$$m_a \gtrsim 10^{-22}\,\mathrm{eV}$$

Axions

Most interesting parameter space is now probed experimentally

Strong synergy with astroparticle physics

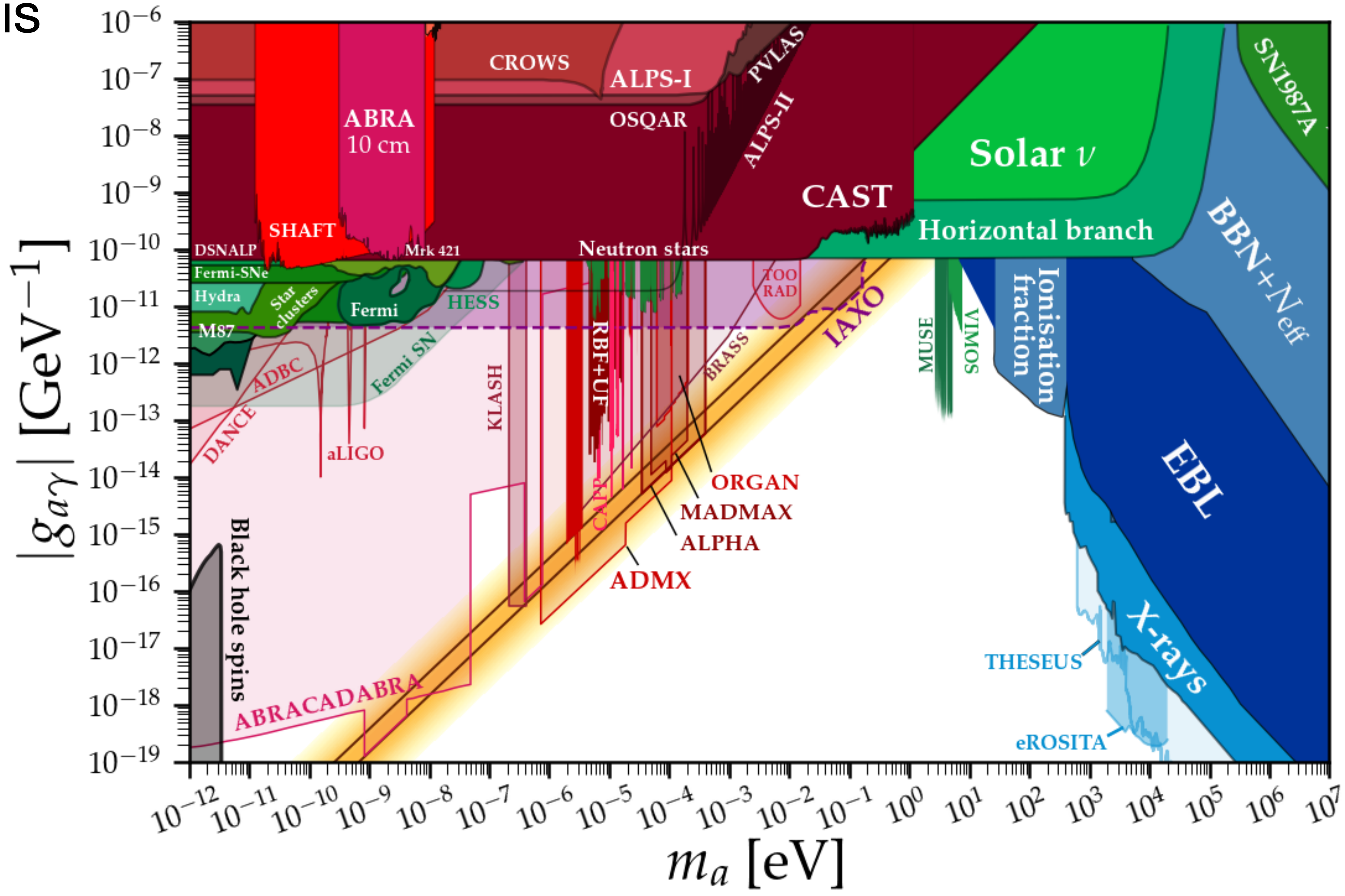
Challenges & developments:

Get predictions right

New ways to probe

Populating the parameter space

Theoretical expectations for ALP models



Point 3:

The theory community strives to be open-minded and inter-connected

EuCAPT aims to:

- bring together the European community of theoretical astroparticle physicists and cosmologists
- increase the exchange of ideas and knowledge
- coordinate scientific and training activities
- help scientists attract adequate resources for their projects
- promote a stimulating, fair and open environment in which young scientists can thrive

Fonded in 2019 by APPEC and CERN.

Team

Steering committee:

Gianfranco Bertone
(director)

 Piero Ullio

 Philippe Brax

 Licia Verde

 Vitor Cardoso

 Gian Giudice

 David Marsh

 Andrew Taylor

 Toni Riotto

 David Langlois

 Silvia Pascoli

Junior contributor: Nikolina Sarcevic

EuCAPT

Activities

Meetings & talks:

Annual symposium

Thematic workshops

Virtual colloquia

Community building:

White paper

Training

Communication:

Newsletter

Webpage

List of virtual seminars

Community profiles

Research highlights

Code of conduct

Census

eucapt.org

Summary

Dark matter theory isn't a topic, but a wide field

Models offer a way to organise huge span of possibilities; suggest paths for detection; highlight tacit assumptions

Each sub-field has its own challenges; developments on many fronts

Several sub-fields develop closely with experiments and observations

Several long-standing paradigms are facing critical tests

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