Introduction to Dark Matter Candidates

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NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

NARODOWE CENTRUM NAUKI

PAiP-2025 Particle Astrophysics in Poland

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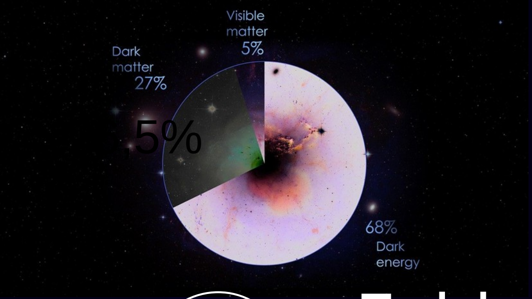


Dark Matter (DM)

Evidence

→ Cosmology and astrophysics (CMB, gravitational lensing, rotation curves, ...)

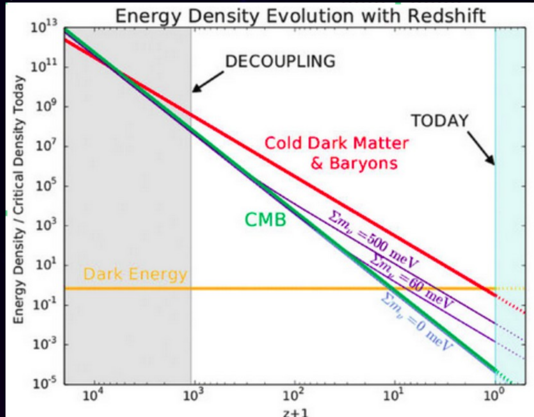
DM beyond gravity

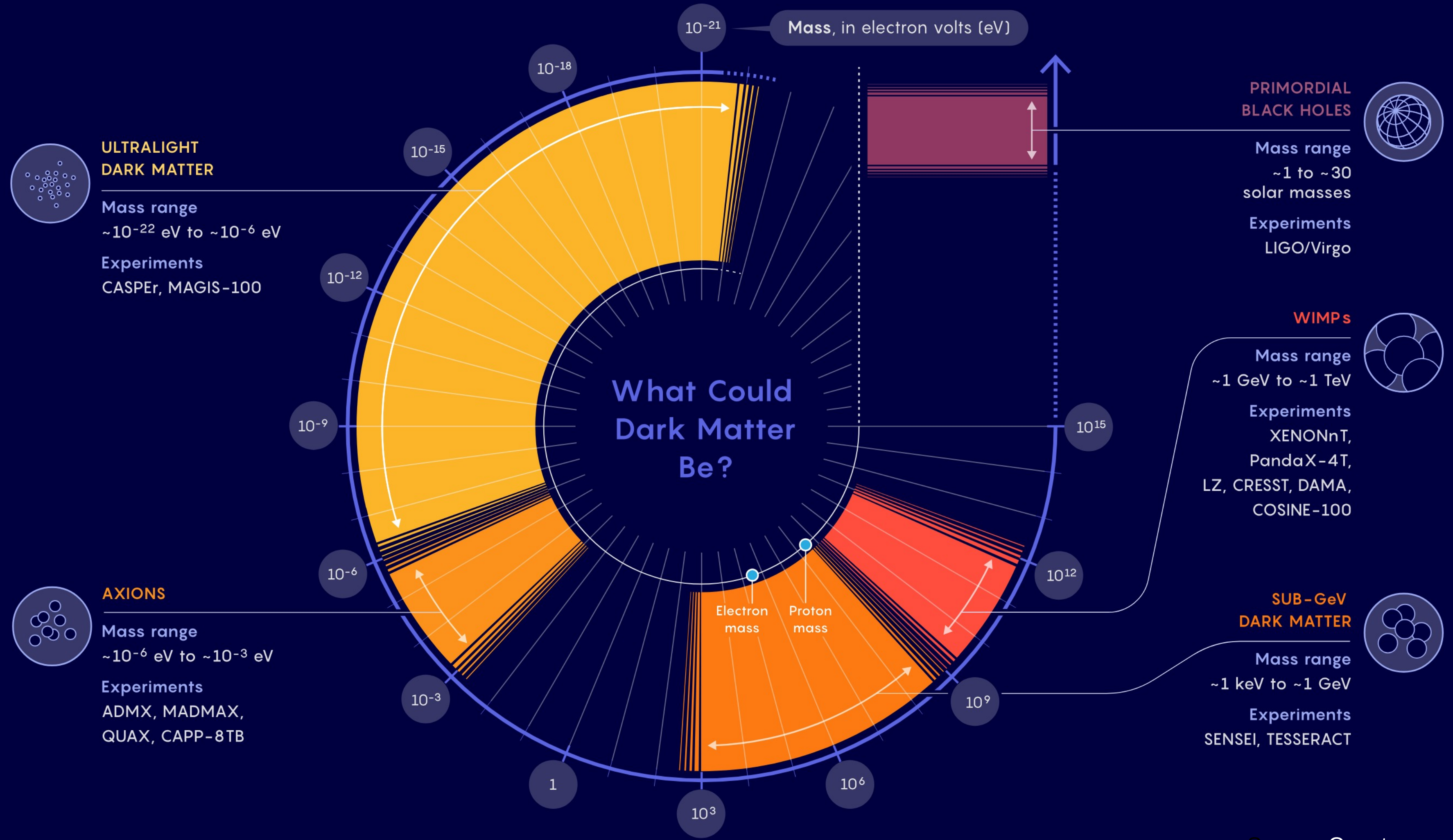
→ Searches continue (direct & indirect detection, accelerator-based, new experiments, astrophysics)

Questions

→ Microscopic nature of DM? (non-baryonic; bounds on DM interactions)

→ Origin of DM in the universe?





Source: Quanta magazine

WIMPs

Mass range

~1 GeV to ~1 TeV

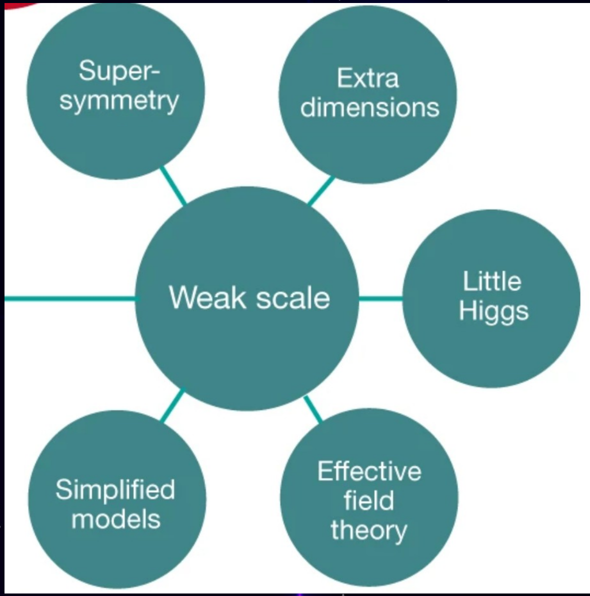
G. Bertone, T.M.P. Tait, 1810.01668

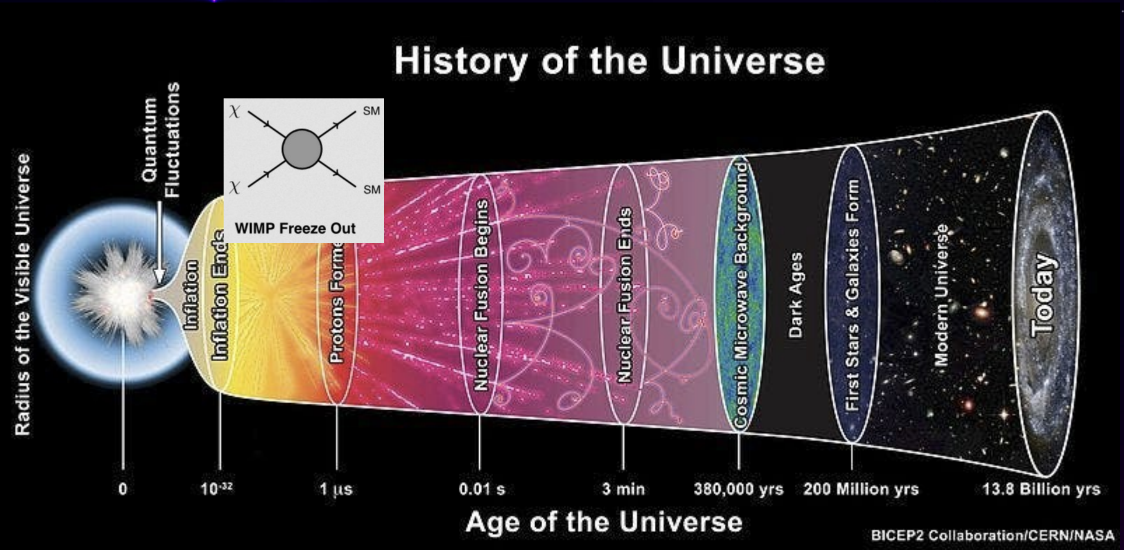
WIMPs
(Weakly Interacting Massive Particles)

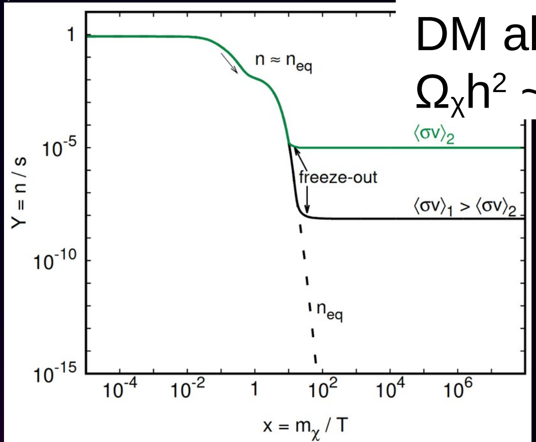
→ Traditionally the leading DM candidate

→ Could be well motivated theoretically

→ Production: thermal freeze-out ("WIMP miracle")







DM abundance:

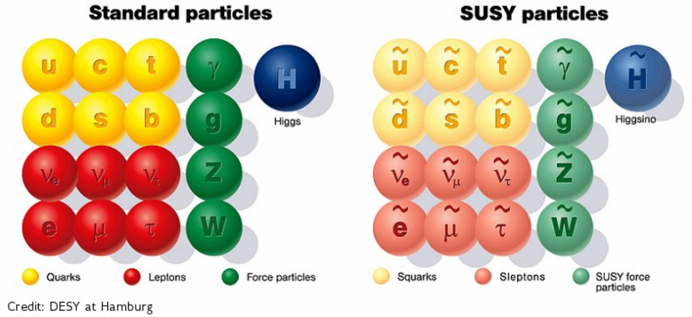
$\Omega_\chi h^2 \sim 1/\langle\sigma v\rangle$

→ Sample WIMP — Lightest Supersymmetric Particle

→ Higgsino DM

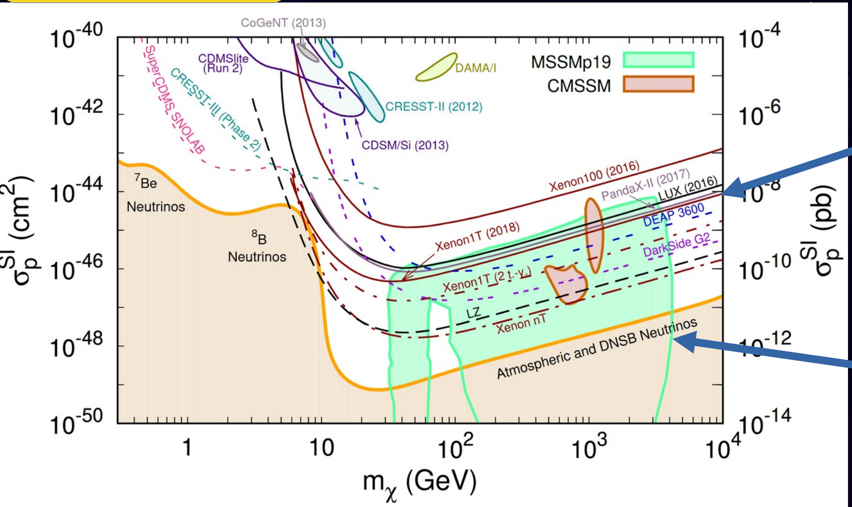
→ Searches: direct and indirect detection, colliders

→ Tightening bounds...
but much remain to be tested

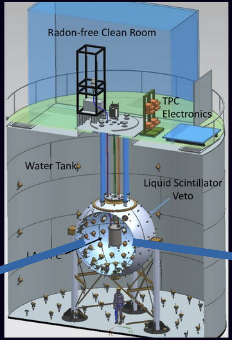


Status in 2017

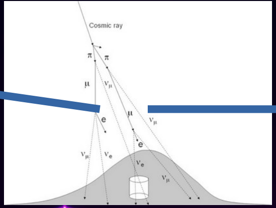
L. Roszkowski, E.M. Sessolo, ST, 1707.06277



Direct detection bounds

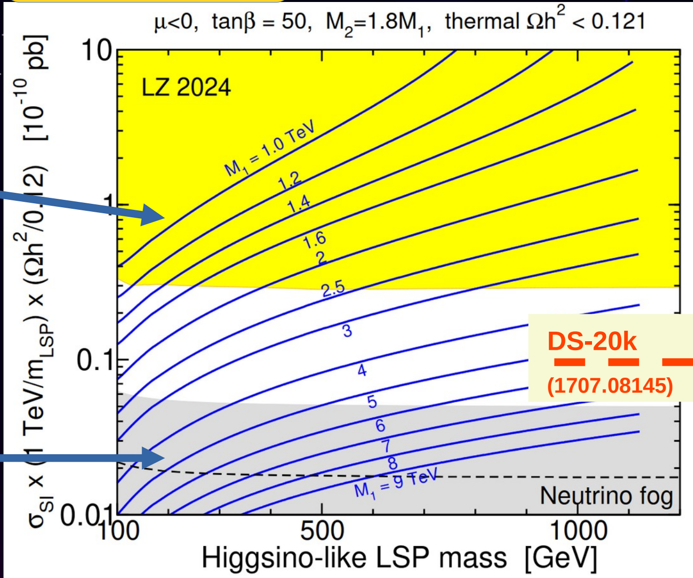


ν floor



December 2024

S.P. Martin, 2412.08958

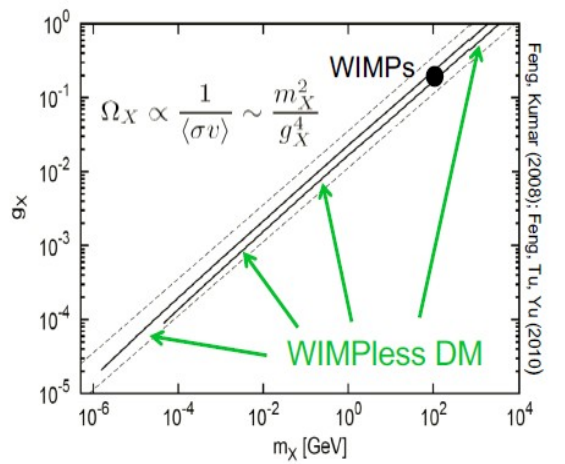


SUB-GeV DARK MATTER

Mass range ~1 keV to ~1 GeV

Sub-GeV thermal DM

→ "WIMP-like miracle" holds for a range of DM masses m_X and couplings g_X



→ Light (especially sub-GeV) DM:

- relic targets (correct DM abundance) within the reach but requires novel experimental approaches

→ Below 1-10 MeV: strong astrophysical and cosmological bounds

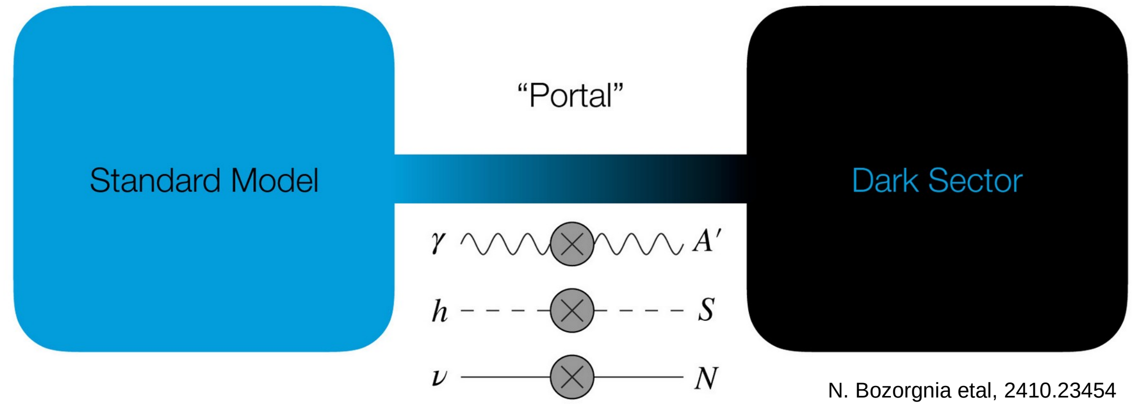
→ Simple "portals" to describe DM interactions with the Standard Model

→ Renormalizable portals:

dark vector (dark photon)

dark scalar (dark Higgs)

heavy neutral lepton (sterile ν)



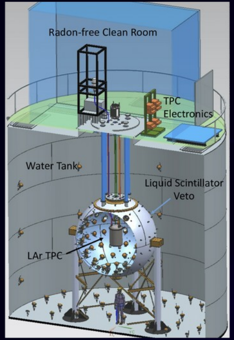
N. Bozorgnia etal, 2410.23454

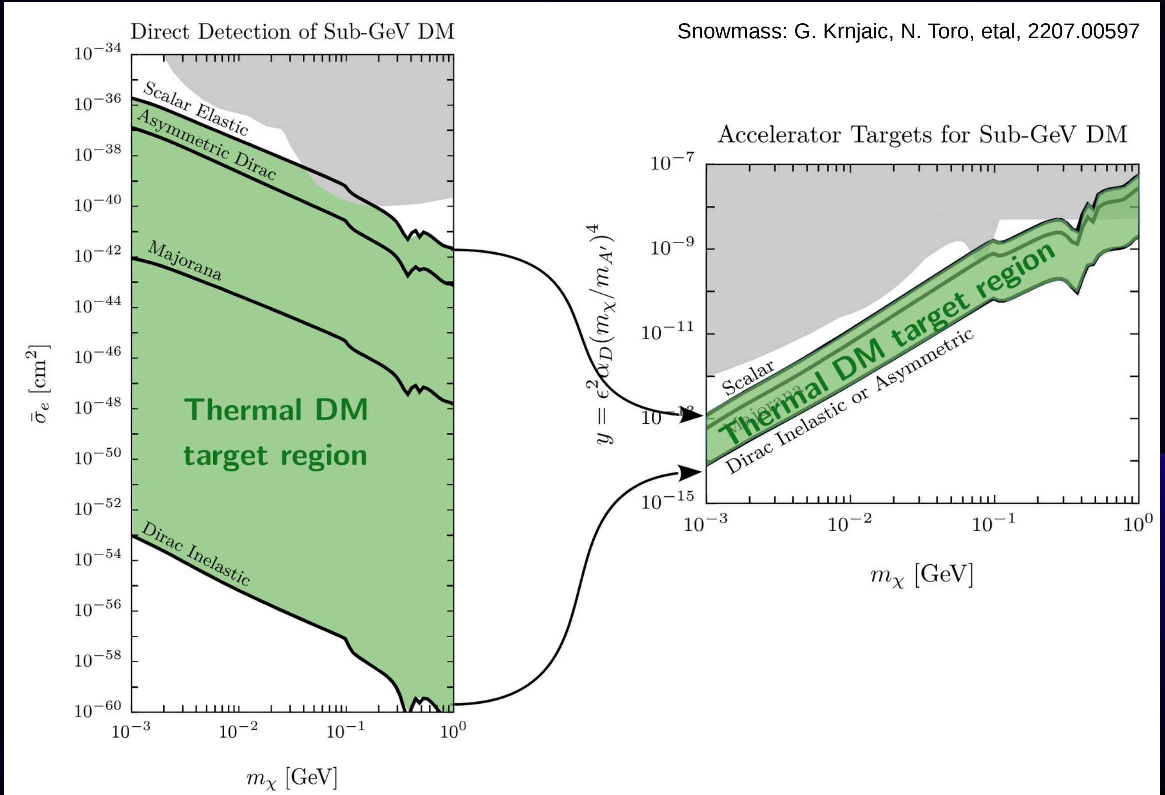
Sub-GeV thermal DM

Closer to early universe conditions

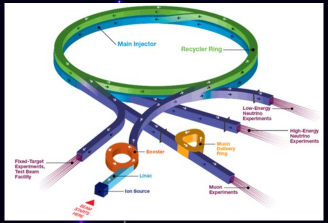
Example: dark photon mediator

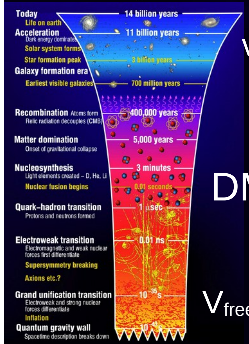
Direct detection bounds





Accelerator-based (direct) searches





$v_{today} \sim 10^{-3}$ c

DM velocity

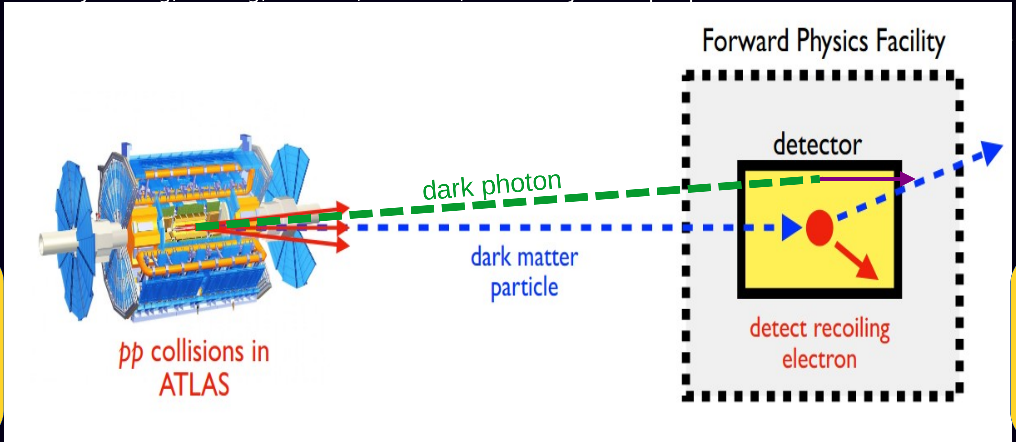
$V_{freeze\text{-}out} \sim 0.3$ c

SUB-GeV DARK MATTER

Mass range ~1 keV to ~1 GeV

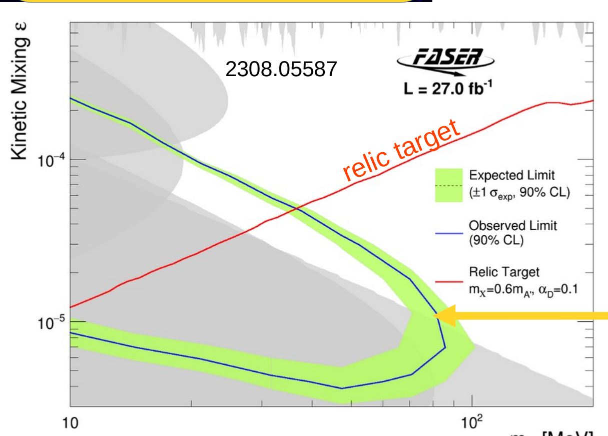
Forward searches @ LHC

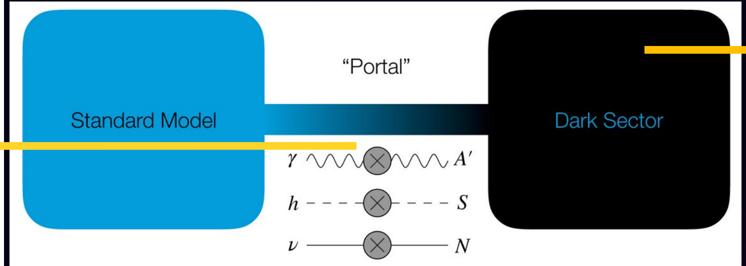
with: J.L. Feng, F. Kling, I. Galon, B. Batell, and many more people

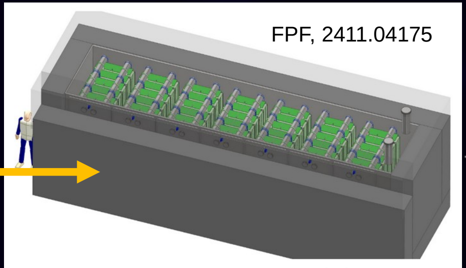


FASER (1708.09389)
Search for mediators
"Portal particles"
Decay signature

FLArE (2101.10338)
Search for DM particles
Relativistic DM scattering
LAr TPC







Currently design

Brookhaven National Laboratory

SUB-GeV DARK MATTER

Mass range ~1 keV to ~1 GeV

Neutrino-DM interactions

→ Relatively less constrained than other DM couplings

$$u_{\nu\mathrm{DM}} = \frac{\sigma_{\nu\mathrm{DM}}}{\sigma_\mathrm{T}} \left(\frac{m_\mathrm{DM}}{100\ \mathrm{GeV}}\right)^{-1}$$

→ Bounds from
DM indirect detection & studying ν properties

→ Early universe — lab for ν-DM testing

Example accelerator search: J. Adhikary etal, 2412.10315

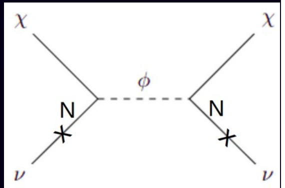
→ ν-DM scatterings affect matter power spectrum

G. Magano etal 0606190
P. Serra etal, 0911.4411
R.J. Wilkinson etal, 1401.7597

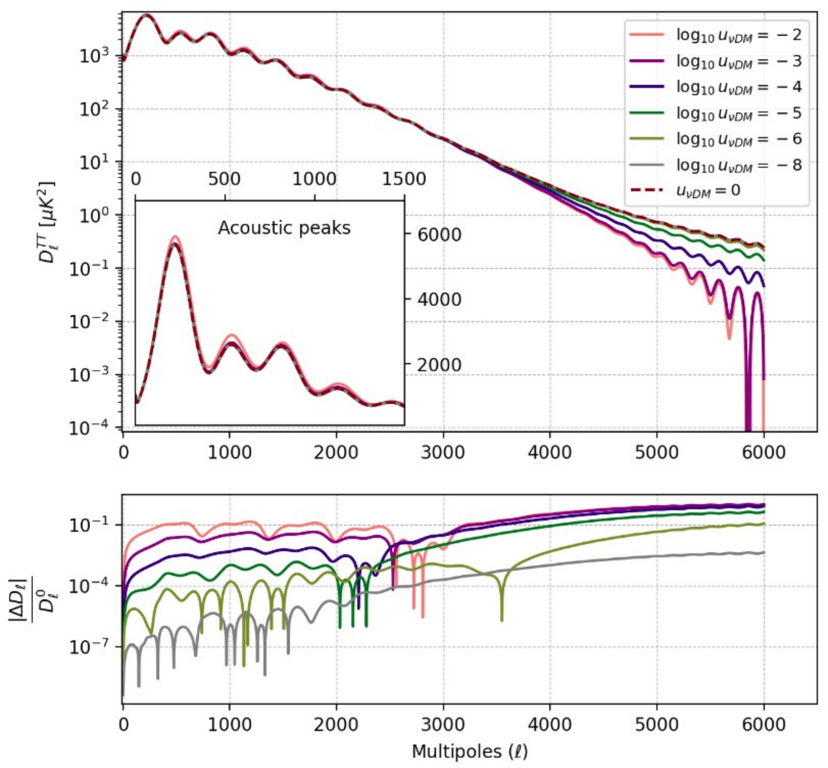
→ High-multipole CMB — new window to test ν-DM

P. Brax etal (with ST) 2303.16895, 2305.01383

→ How to couple ν & DM?
e.g. via a new heavy neutral lepton



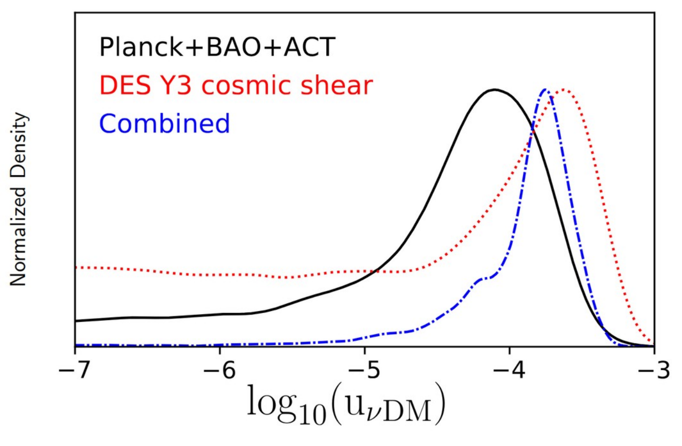
B. Bertoni, etal, 1412.3113
B. Batell, etal, 1709.07001



νDM & CMB, weak lensing

(2303.16895, 2305.01383, 2501.13785)

with: P. Brax, C.v.d.Bruck, E. Di Valentino, W. Giare, Y.-L. Sming Tsai, C. Zhang, L. Zu



→ Datasets:
- Planck (TT, TE, EE, lensing)
- ACT (DR6)
- DES Y3 (3x2pt)
- BOSS (DR12, also DR16)

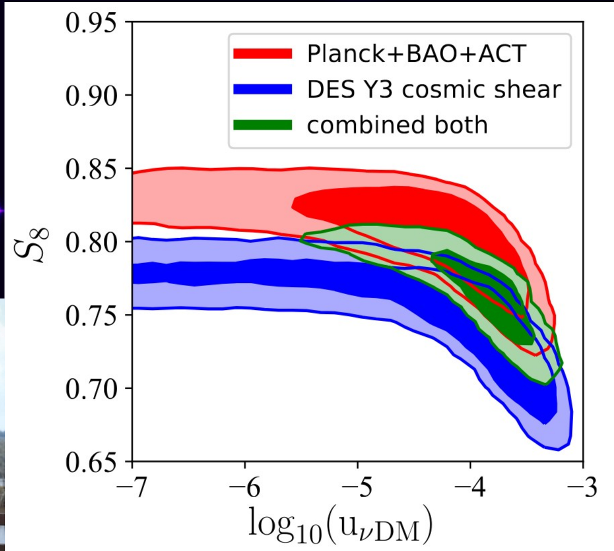
→ Combined ~3σ preference for $u_{\nu DM} \sim 10^{-4}$

→ S_8 discrepancy between CMB & weak lensing — alleviated

→ Similar hints in Lyman−α (D.C. Hopper, M. Lucca, 2110.04024)

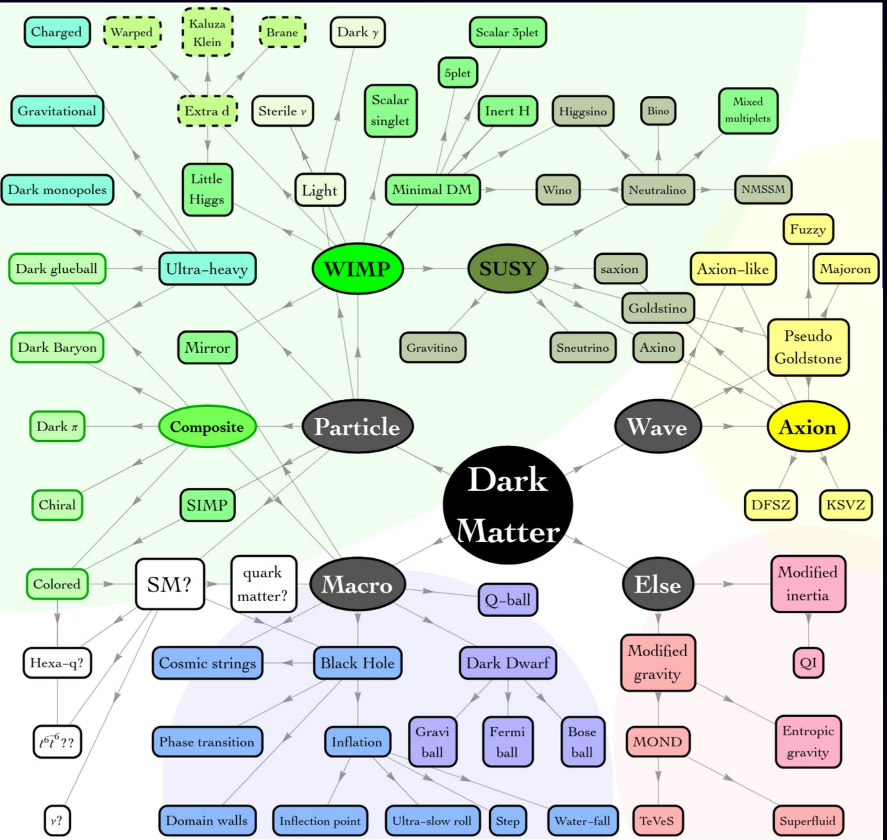
→ Future surveys will probe this thoroughly

LSST: $u_{\nu DM} < 10^{-5.9}$



Take away

M. Cirelli, A. Strumia, J. Zupan, 2406.01705



Dark matter nature

Recent decade: broadening the paradigm of DM studies (both theory & exp.)

Dark matter origin

Numerous possible mechanisms

Thermal production – attractive target

Dark matter searches

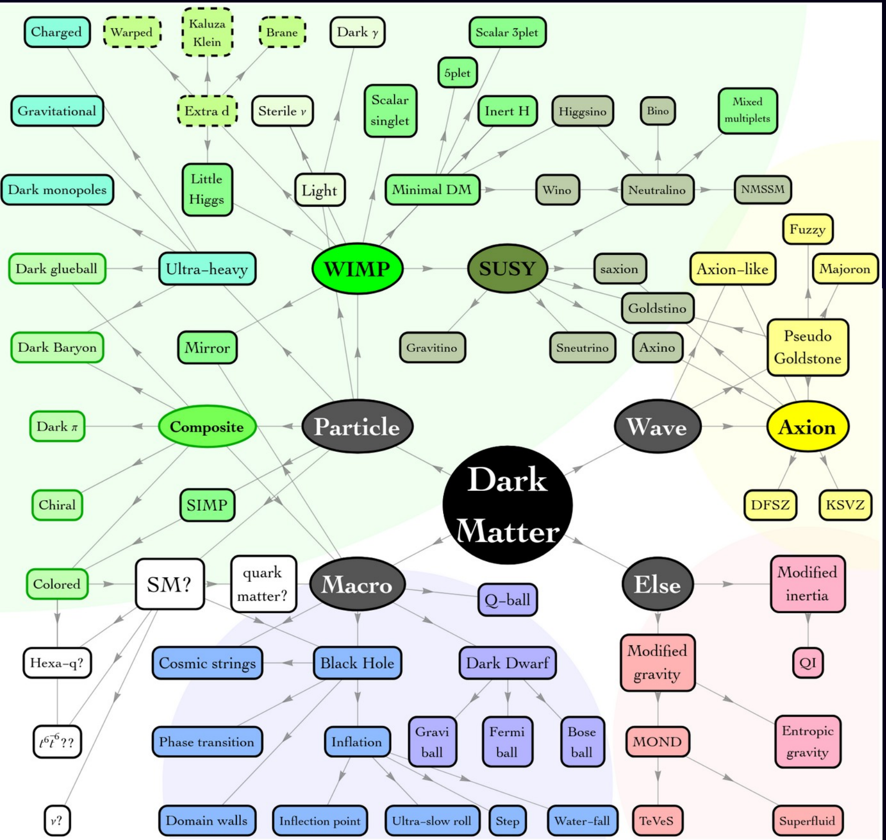
Heavy thermal DM – ongoing and future exp. (in)direct, colliders

Light thermal DM – novel experiments, astrophysics

See talk: J. Hoefken Zink

Take away

M. Cirelli, A. Strumia, J. Zupan, 2406.01705



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