2 October 2025
Journées de l'ATPEM 2025, Amphi Charpak, Jussieu

Origin of Dark Matter:
where are we now?

Marco Cirelli
(CNRS LPTHE Jussieu Paris)

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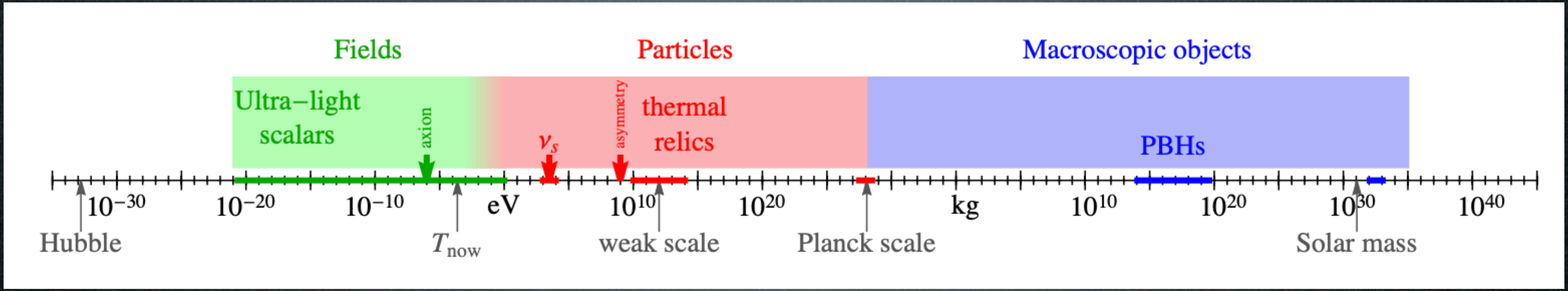
LPTHE LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

cnrs dépasser les frontières

SORBONNE UNIVERSITÉ CRÉATEURS DE FUTURS DEPUIS 1257

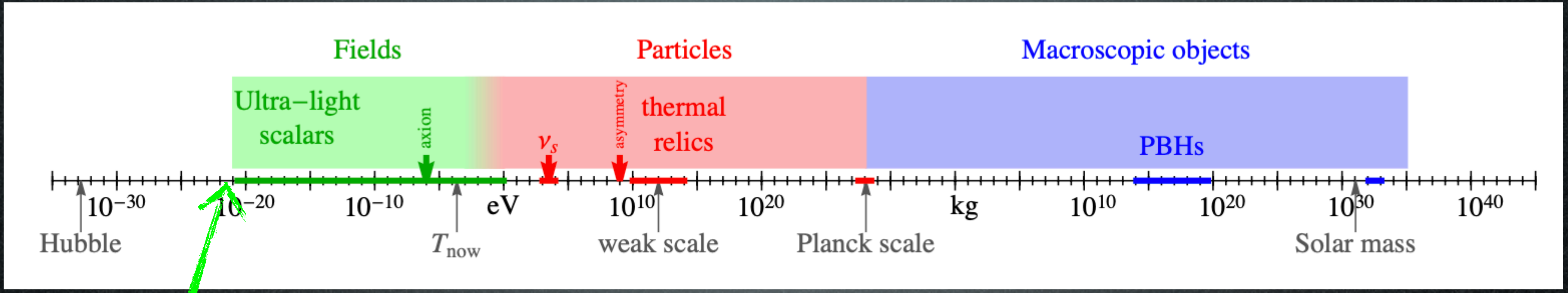
Answer

Somewhere on this plot:



90 orders of magnitude!

Candidates



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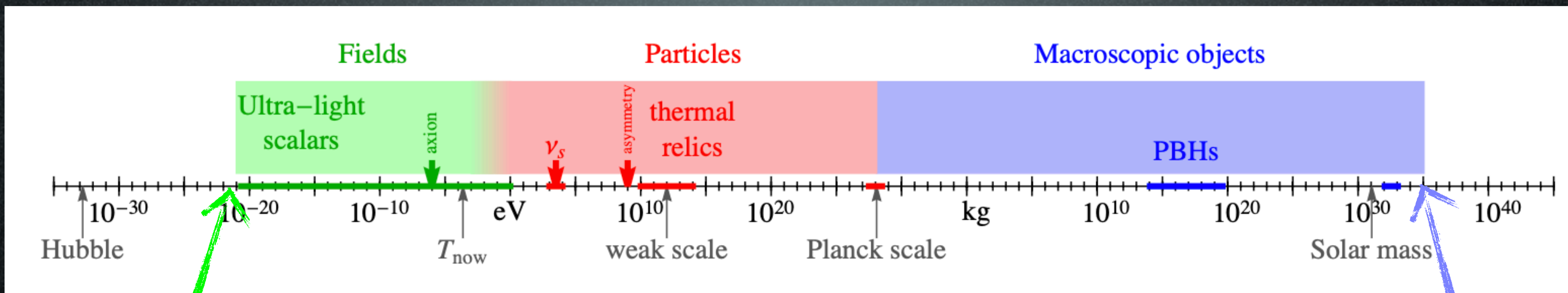
as diffuse as a dwarf galaxy

DM de Broglie wavelength

$$\lambda = 2\pi/Mv \lesssim 1 \text{ kpc}$$

Candidates



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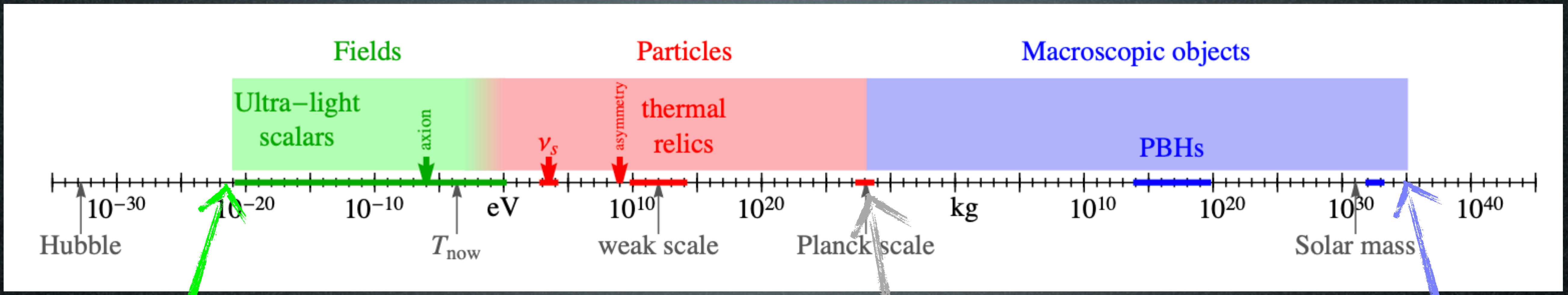
as big as a dwarf galaxy

DM mass

$$M \lesssim 10^4 \, M_\odot$$

Candidates



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as diffuse as a dwarf galaxy

most likely elementary | most likely composite

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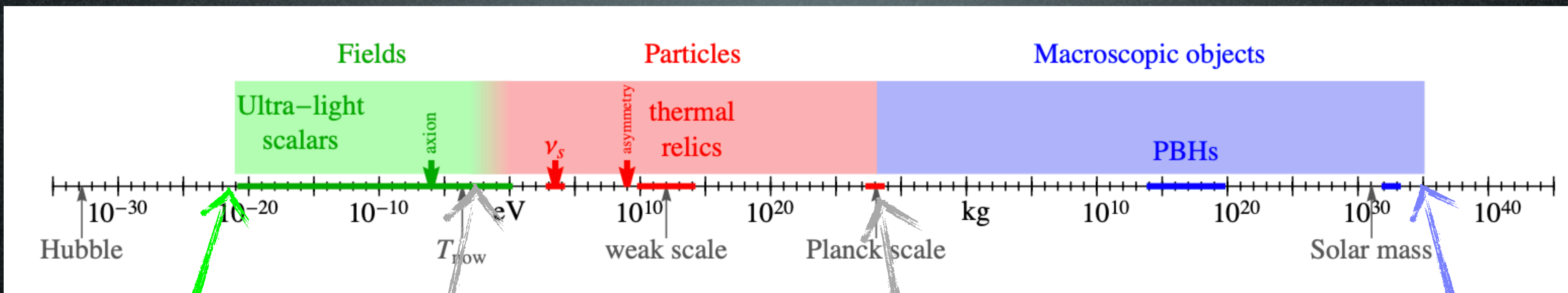

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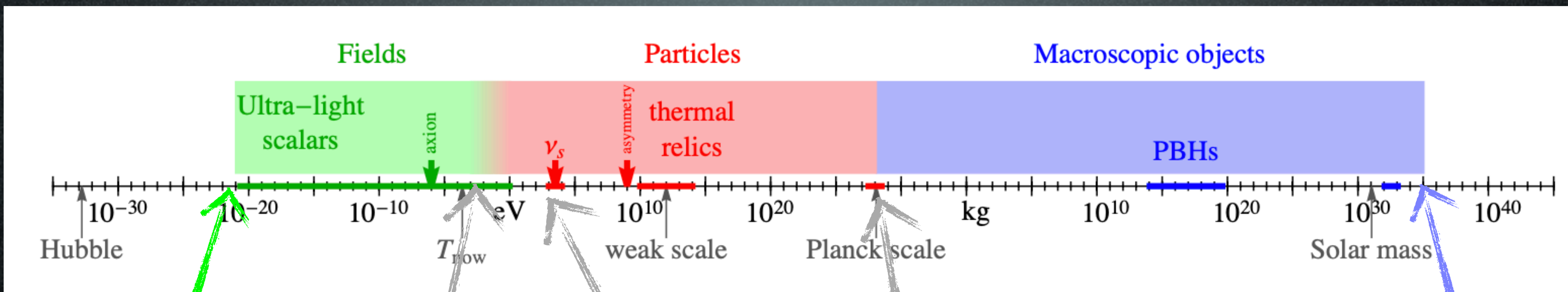
best described as classical field | best described as particle

Candidates



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$\lambda = 2\pi/Mv \lesssim 1$ kpc

most likely
elementary

most likely
composite

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DM mass
$M \lesssim 10^4\ M_\odot$

occupation number
$$N \simeq \frac{\rho}{M/\lambda^3}$$

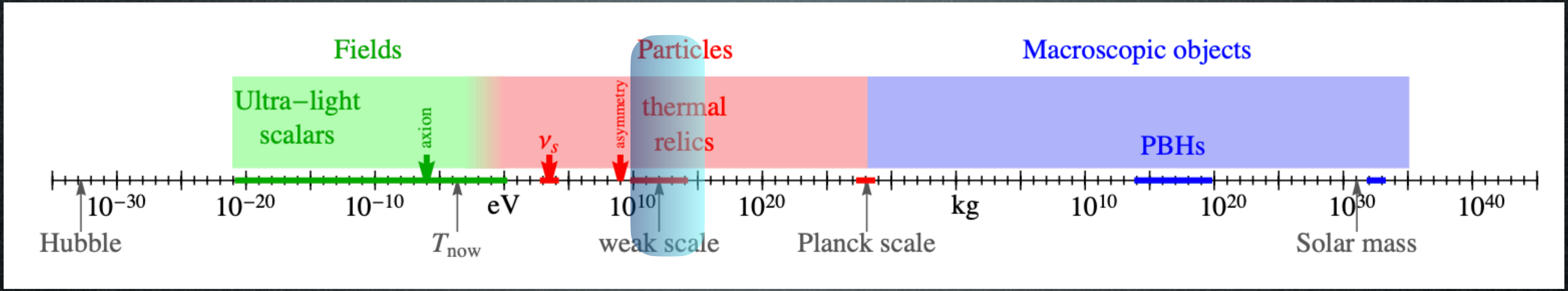
best described as
classical field

best described as
particle

$M \lesssim 0.1\,\mathrm{keV}$
necessarily
bosonic

$M \gtrsim 0.1\,\mathrm{keV}$
bosonic or
fermionic

Candidates



Fields
Particles
Macroscopic objects
Ultra−light scalars
axion
ν_s
asymmetry
thermal relics
PBHs
10^{-30}
10^{-20}
10^{-10}
eV
10^{10}
10^{20}
kg
10^{10}
10^{20}
10^{30}
10^{40}
Hubble
T_{now}
weak scale
Planck scale
Solar mass

Candidates

WIMPs

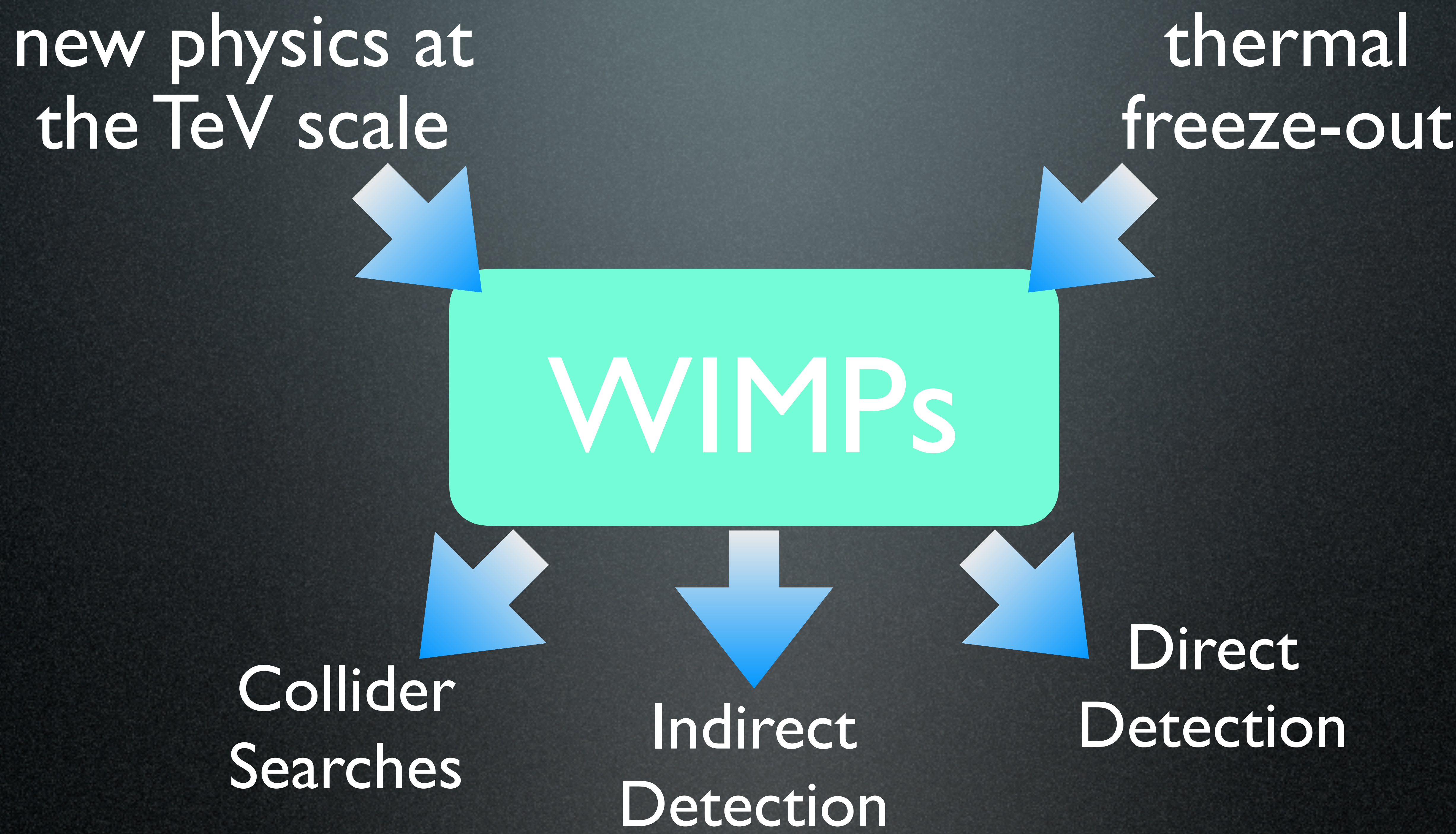
Candidates

new physics at the TeV scale

thermal freeze-out

WIMPs

Candidates


new physics at the TeV scale
thermal freeze-out
WIMPs
Collider Searches
Indirect Detection
Direct Detection

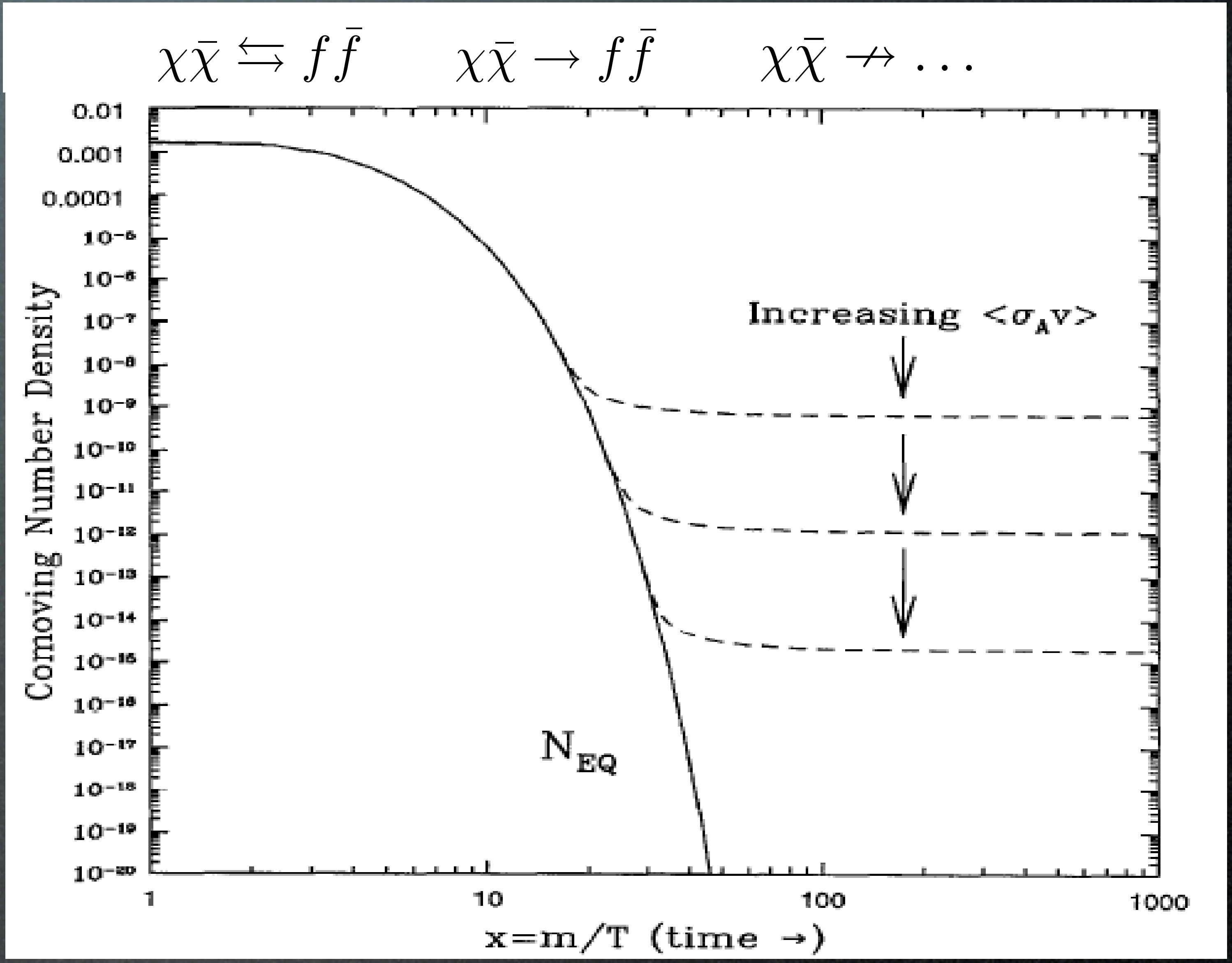
DM as a thermal relic from the Early Universe

Boltzmann equation
in the Early Universe:

$$\Omega_X \approx \frac{6\ 10^{-27}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma_{\rm ann} v\rangle}$$

Relic $\Omega_{\rm DM} \simeq 0.26$ for

$$\langle \sigma_{\rm ann} v\rangle = 3 \cdot 10^{-26}\mathrm{cm}^3/\mathrm{sec}$$



Kolb,Turner, The Early Universe, 1995

Weak cross section:

$$\langle \sigma_{\rm ann} v\rangle \approx \frac{\alpha_w^2}{M^2} \approx \frac{\alpha_w^2}{\mathbf{1\ TeV}^2} \Rightarrow \Omega_X \sim \mathcal{O}(\text{few } 0.1)$$

(WIMP)

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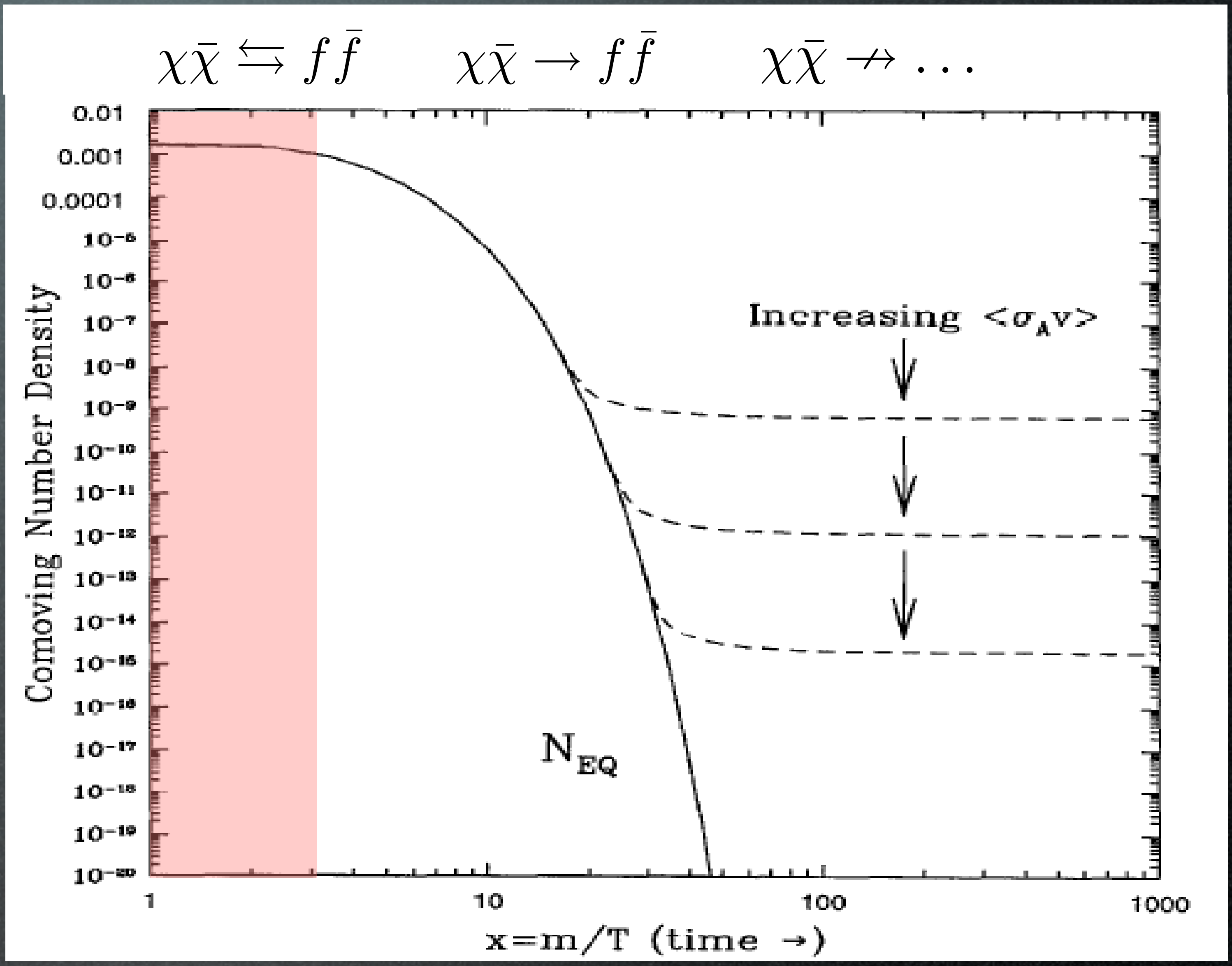

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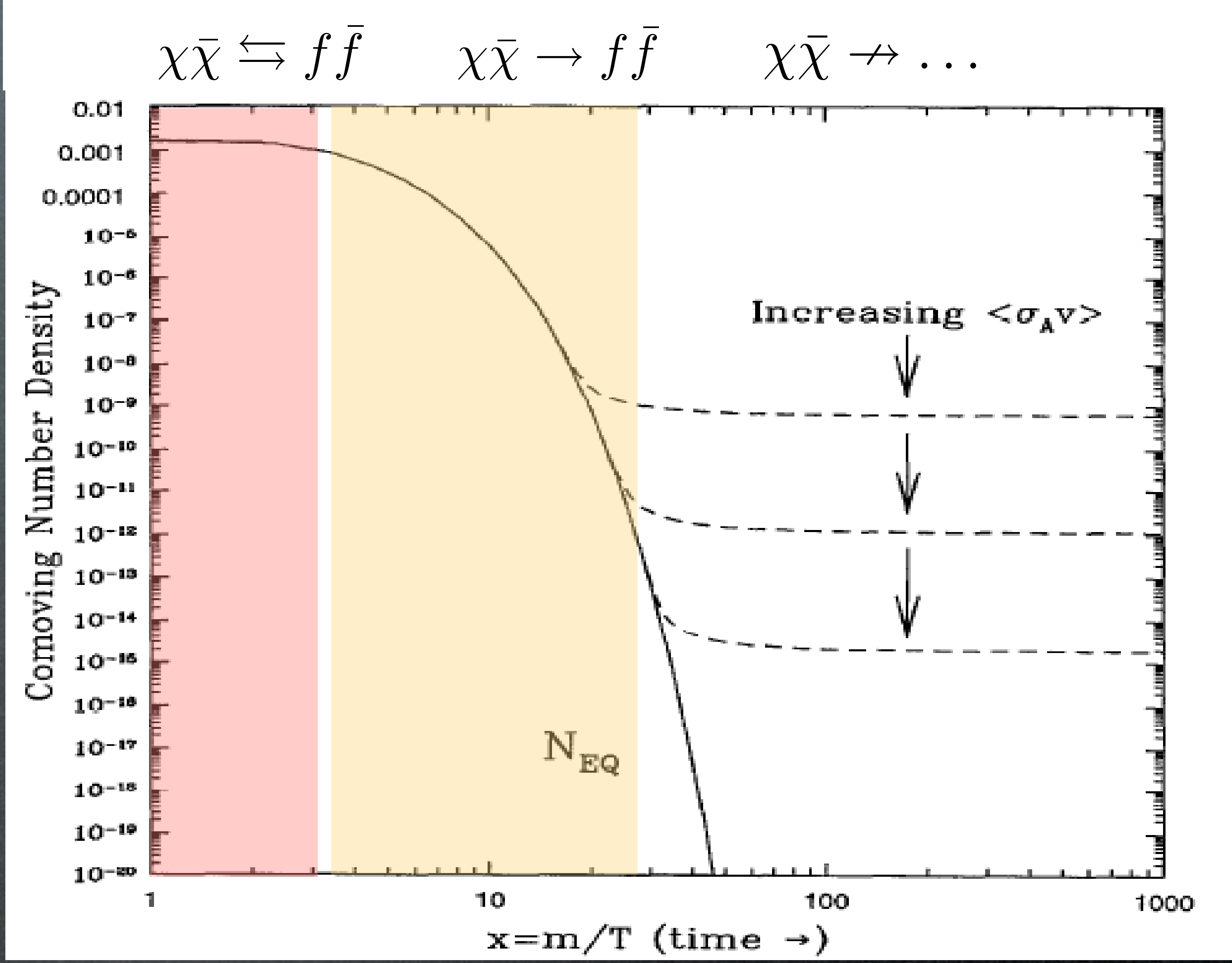

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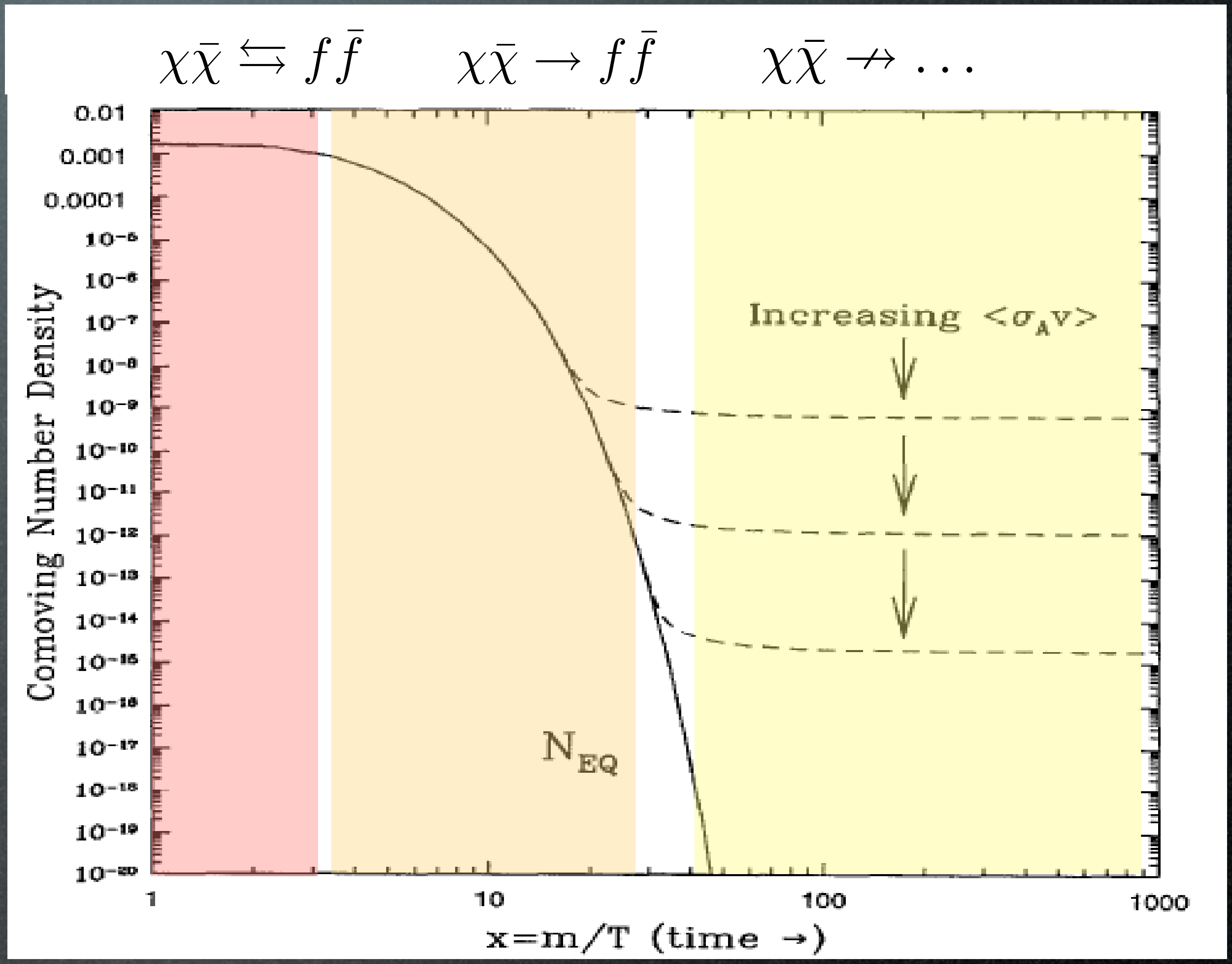

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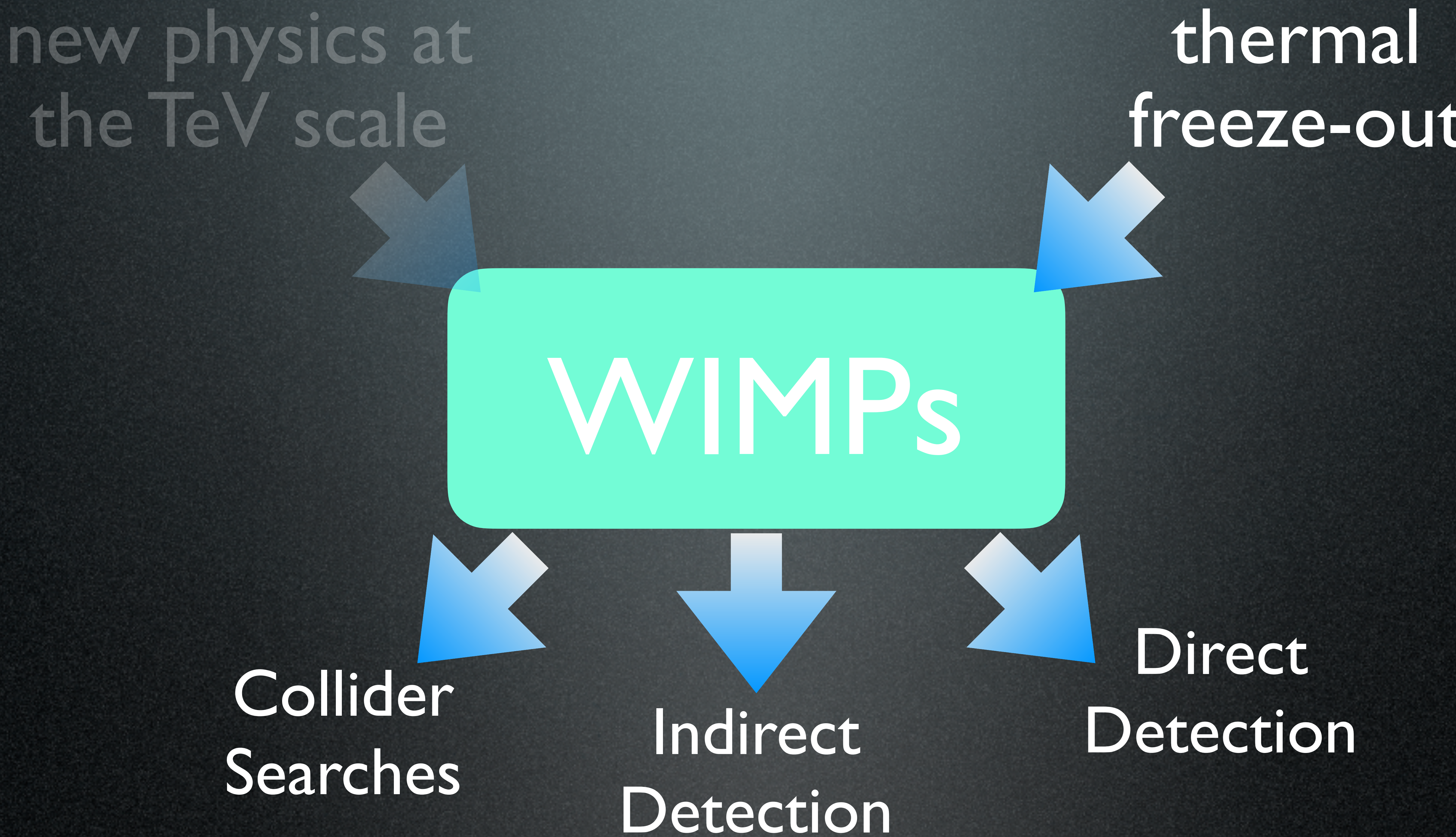
(WIMP)

Candidates


new physics at the TeV scale
thermal freeze-out
WIMPs
Collider Searches
Indirect Detection
Direct Detection

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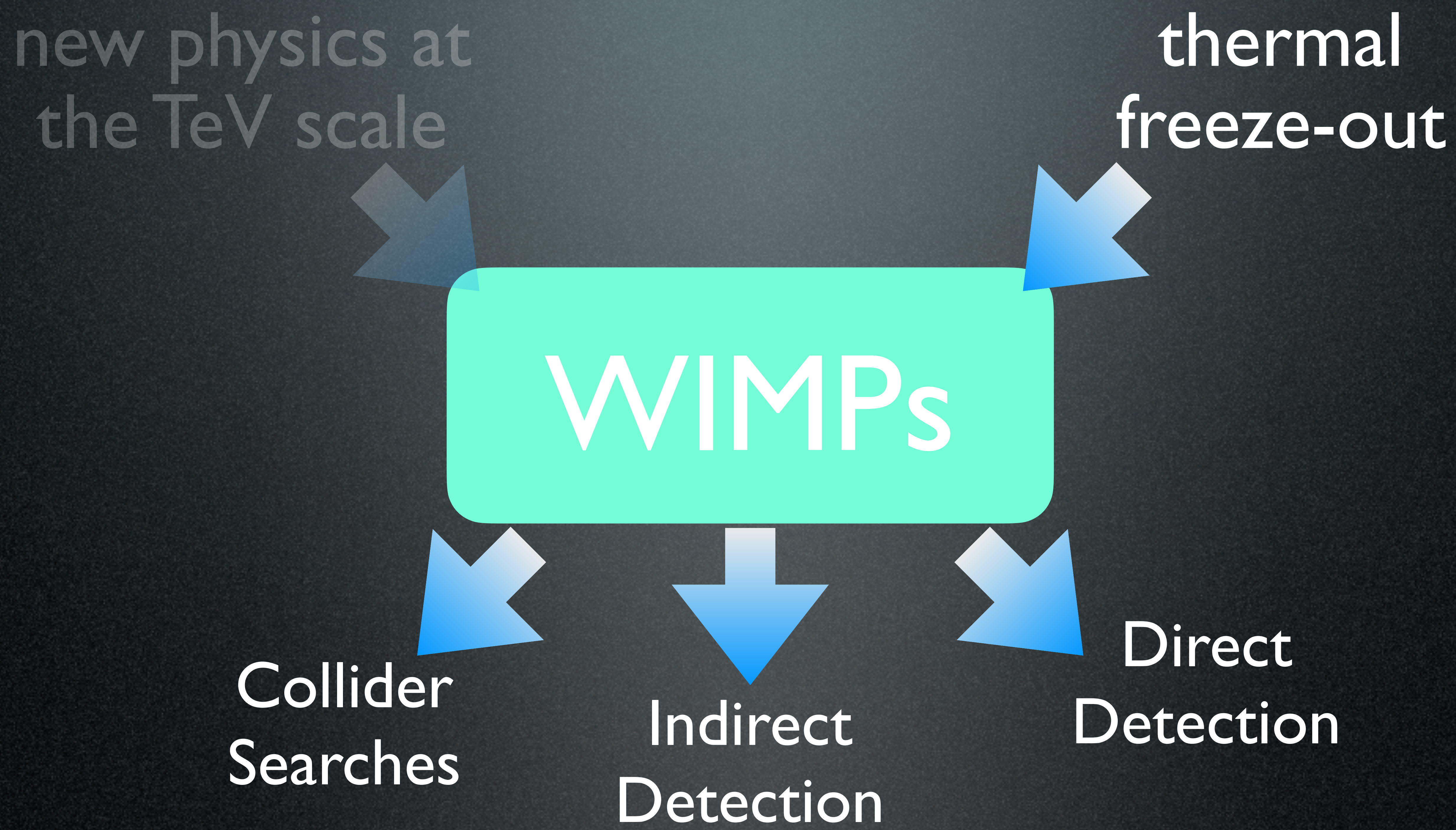
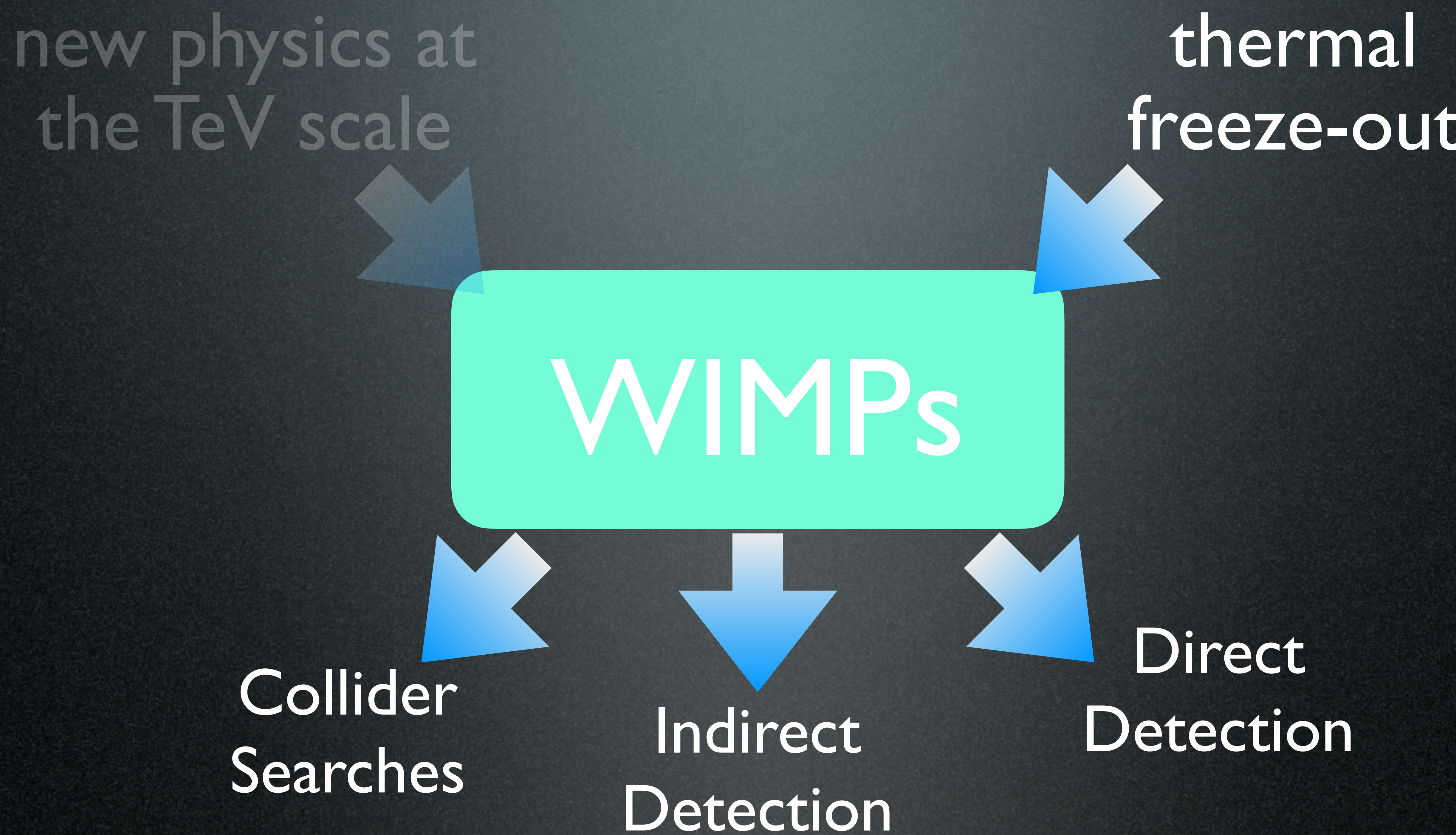


1. even without a larger framework, WIMPs are still appealing
2.

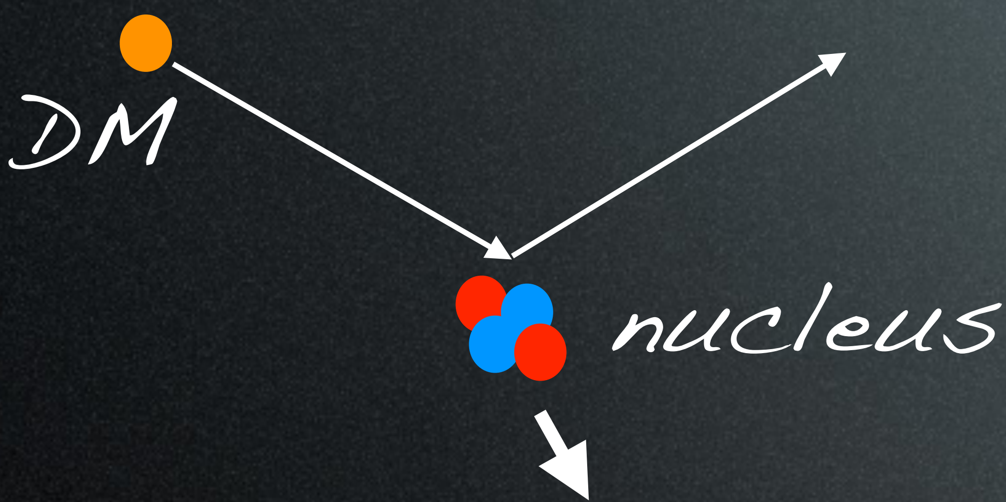
Candidates

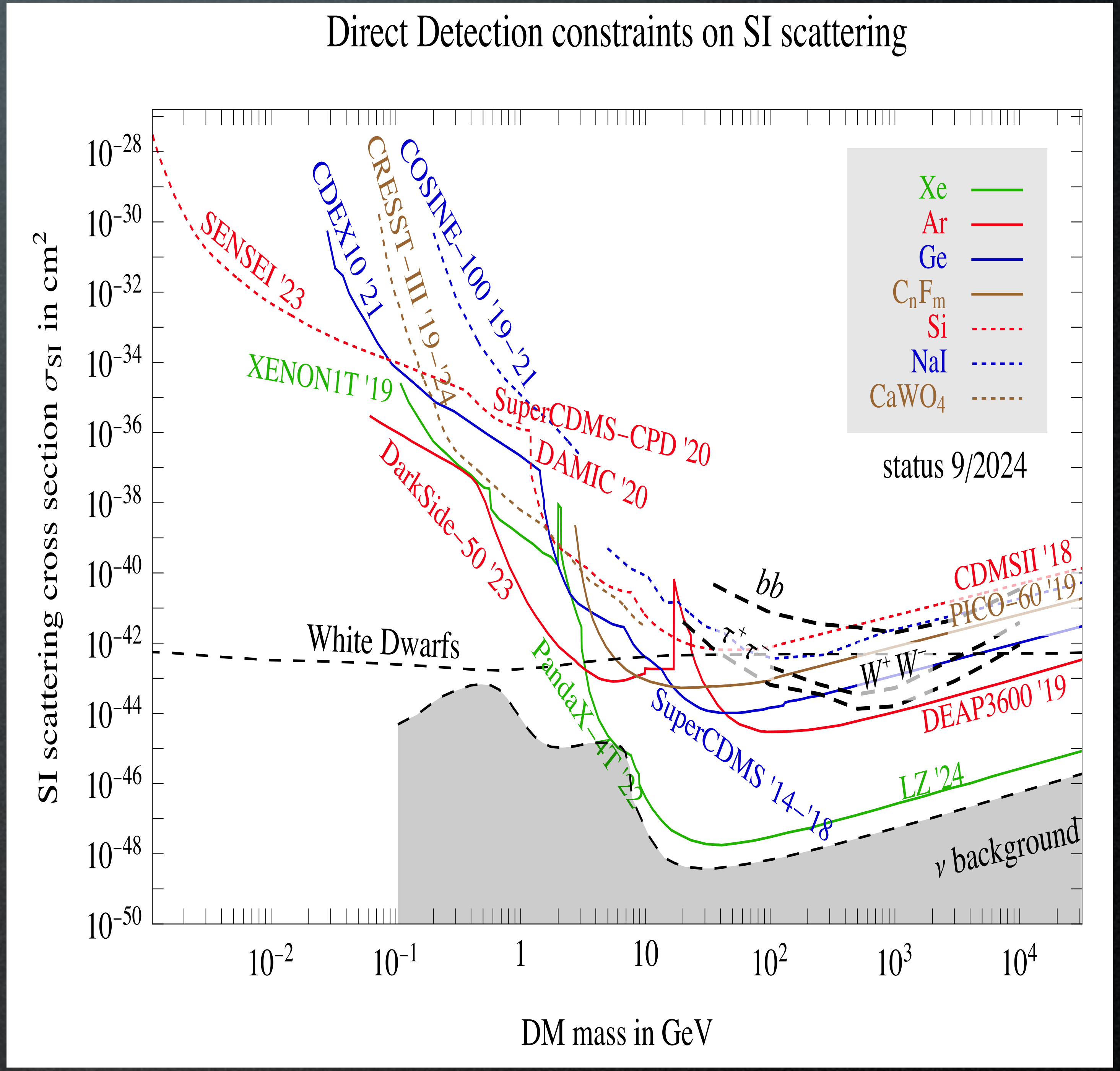


1. even without a larger framework, WIMPs are still appealing
2. the three search strategies are complementary

WIMP Direct Detection

SM weak scale SI interactions





M. Cirelli, A. Strumia, J. Zupan 'Dark Matter', 2406.01705

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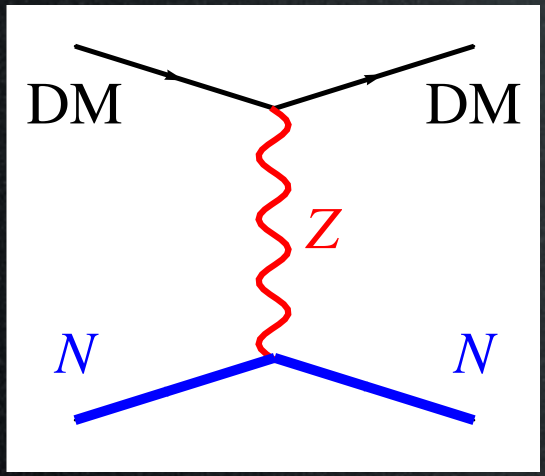
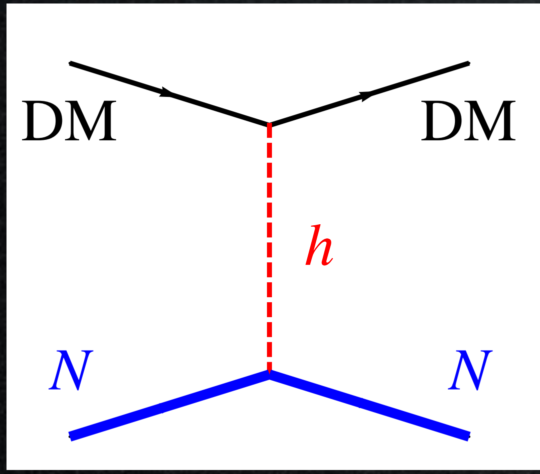
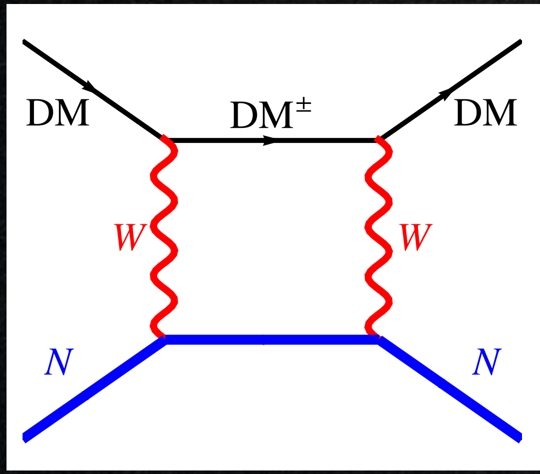


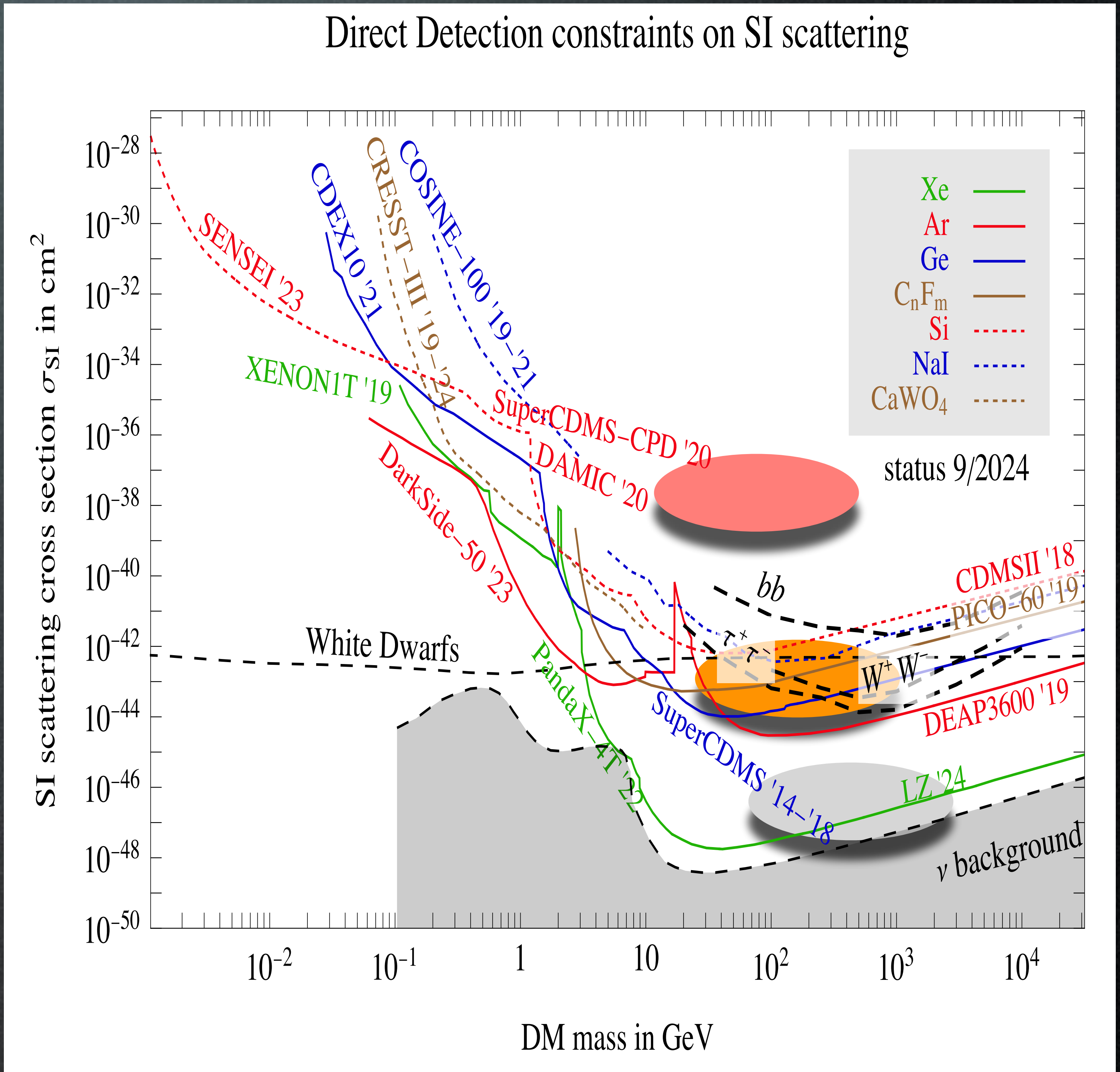
tree level, vector



tree level, scalar



one loop



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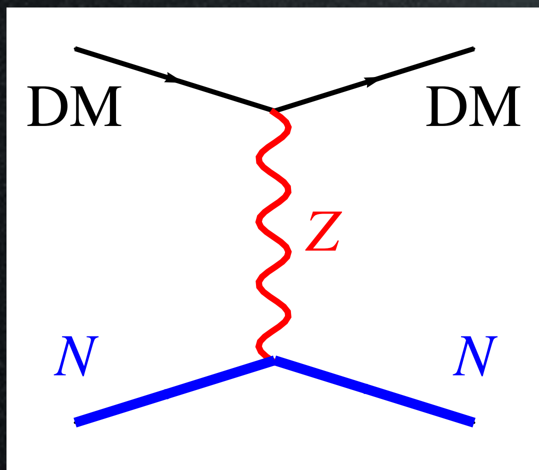
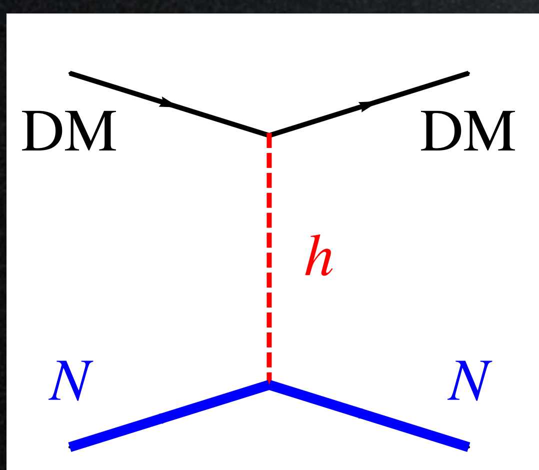


tree level, vector



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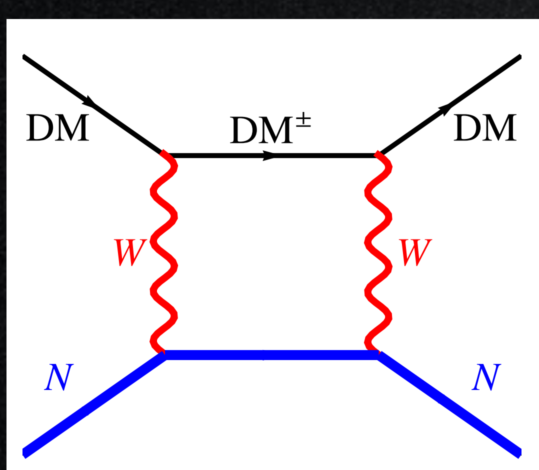

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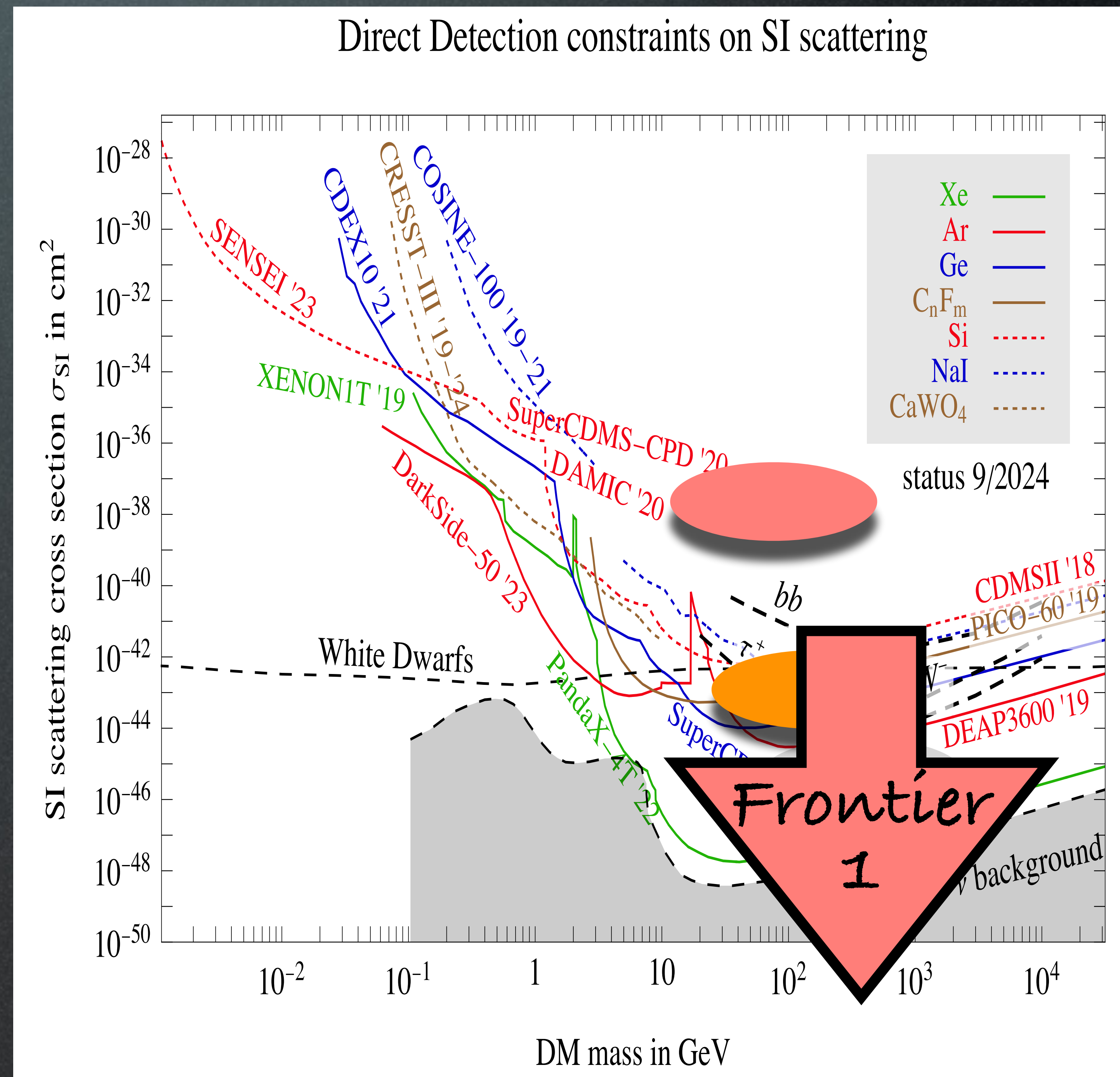

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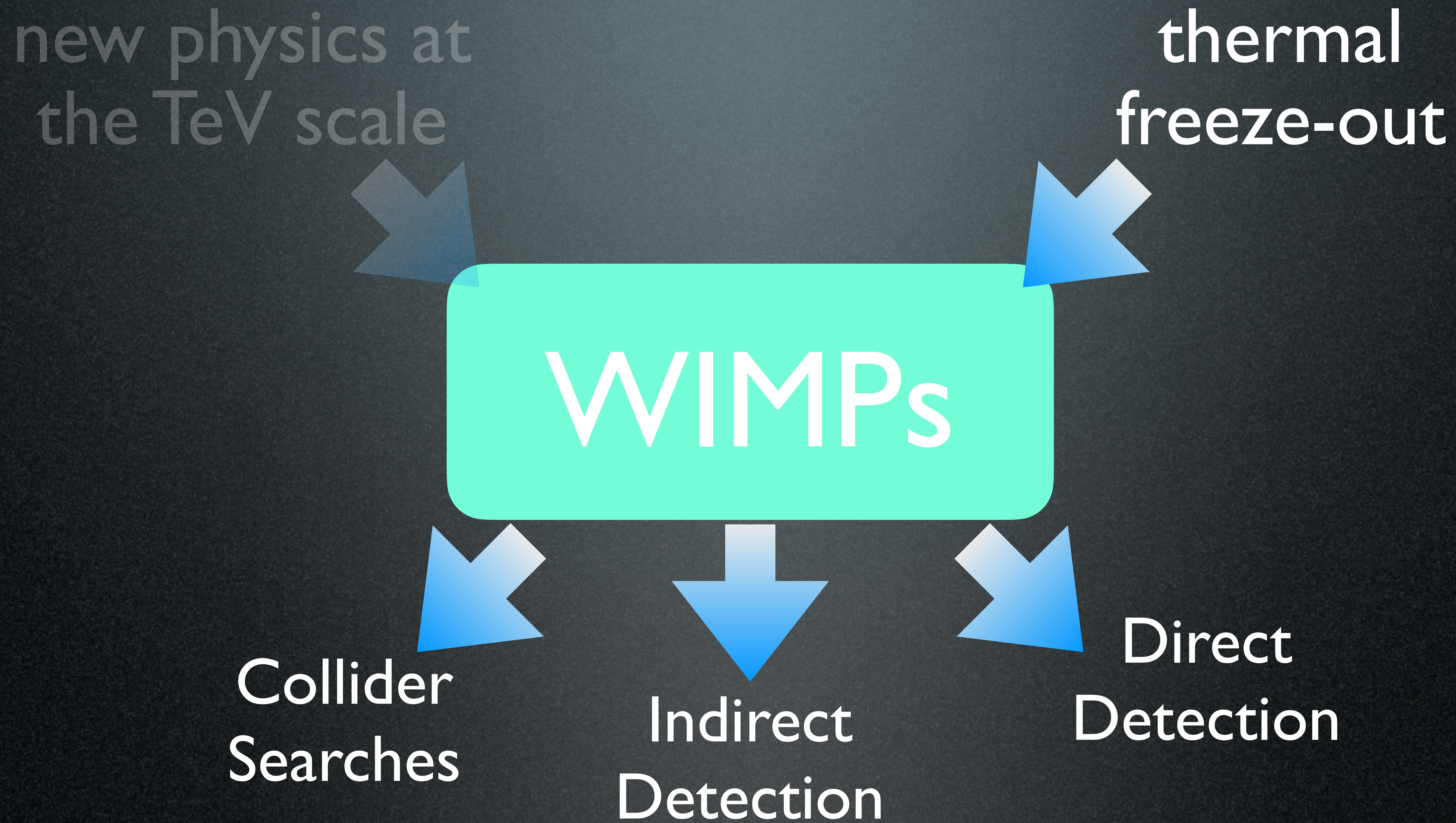
Candidates



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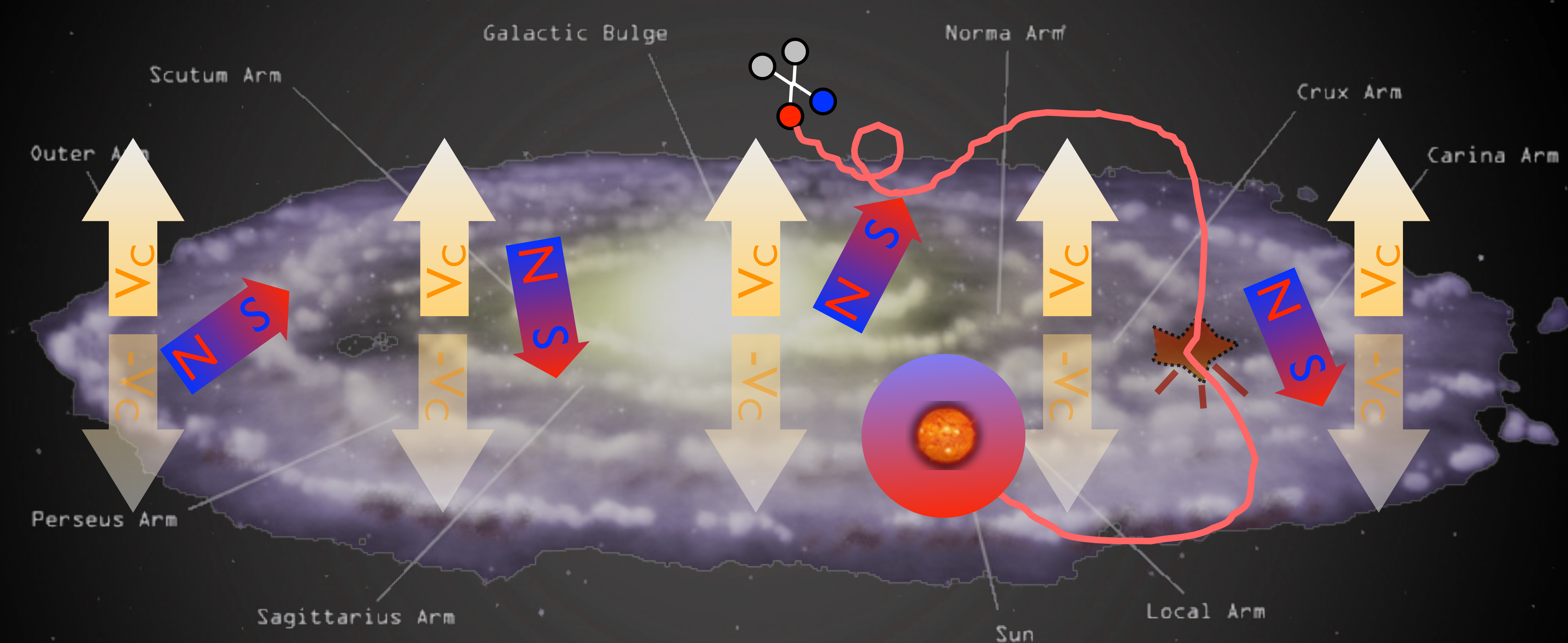
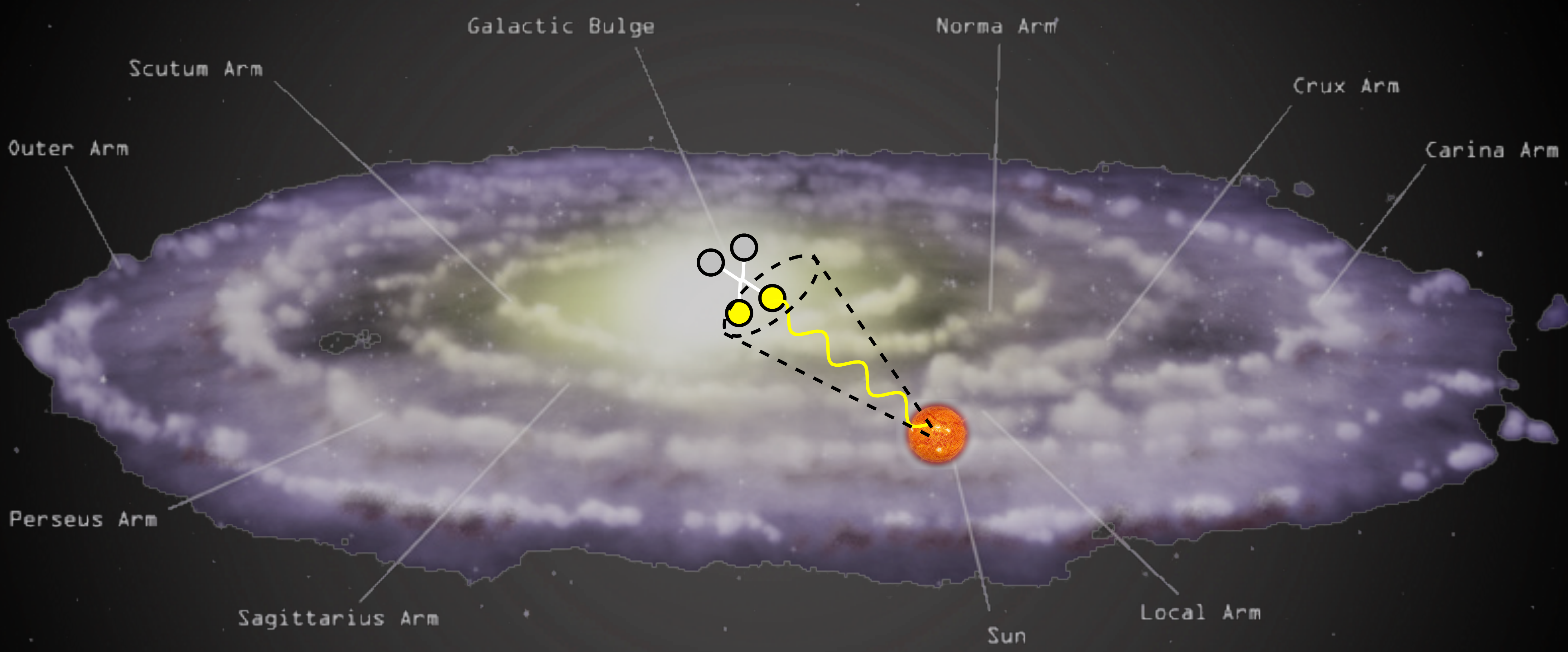
Indirect Detection: charged CRs

$\bar{p}$ and e^+ from DM annihilations in halo

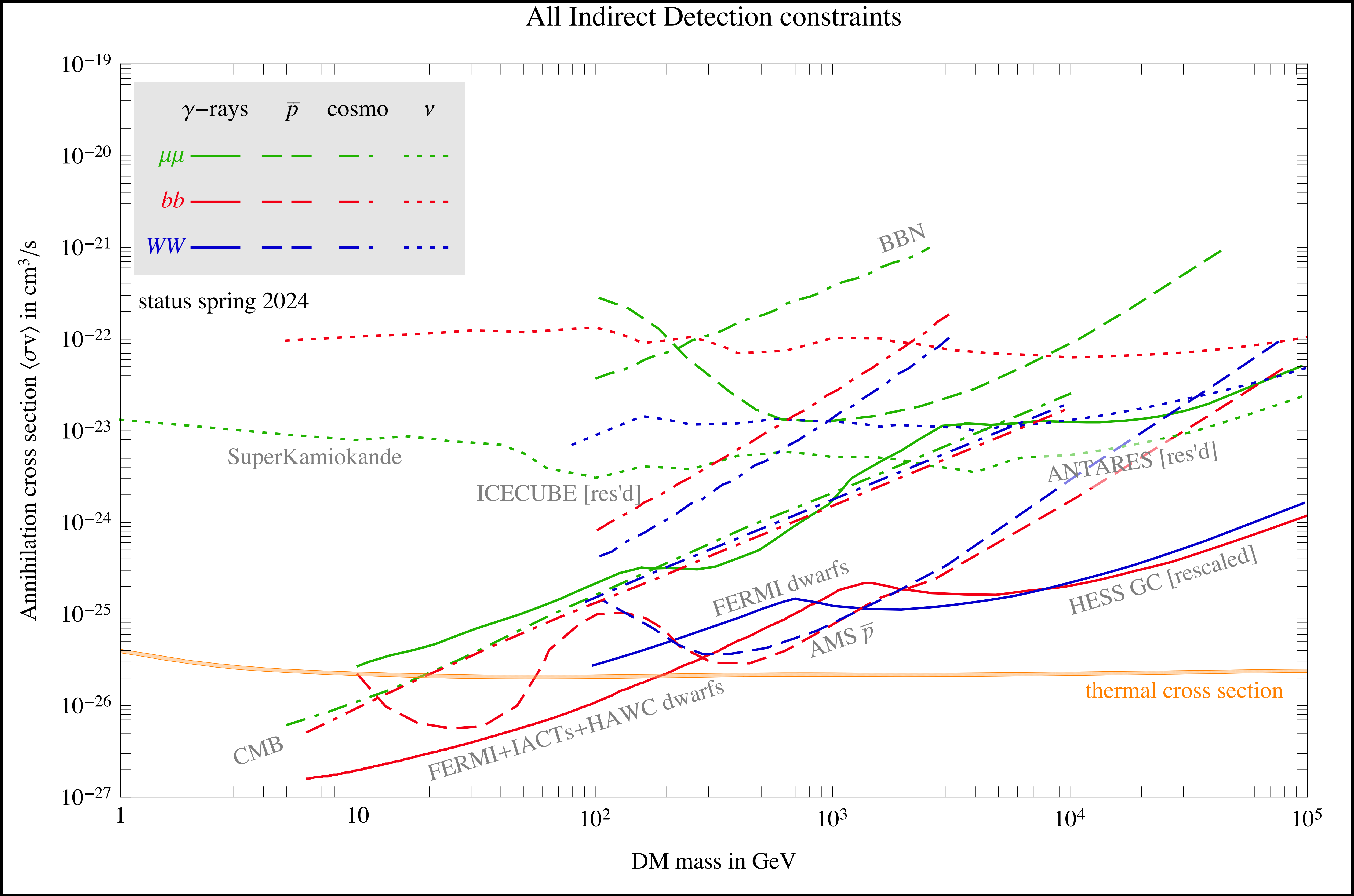


Indirect Detection: photons

γ from DM annihilations (e.g. in the GC)



WIMP Indirect Detection



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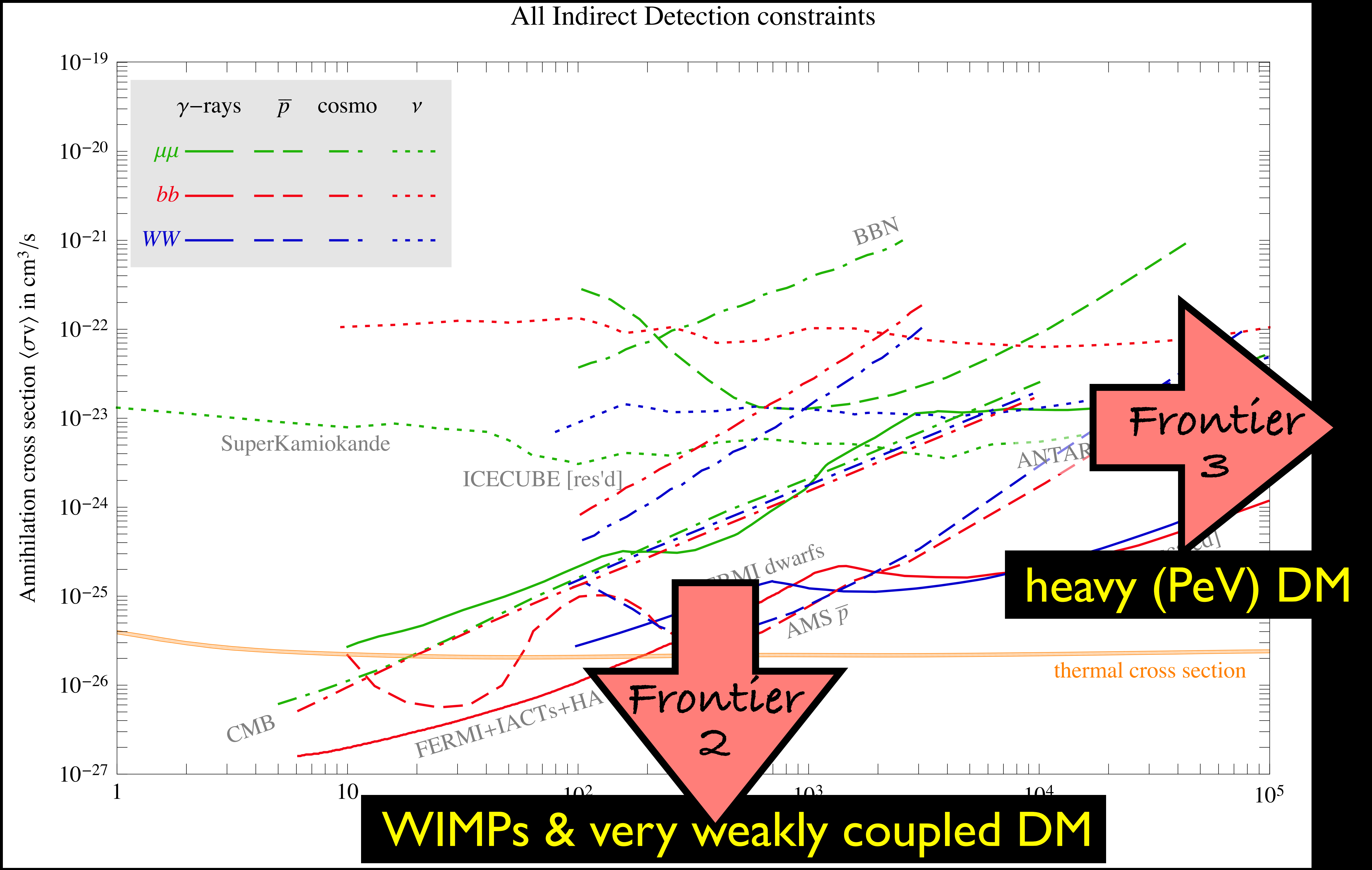

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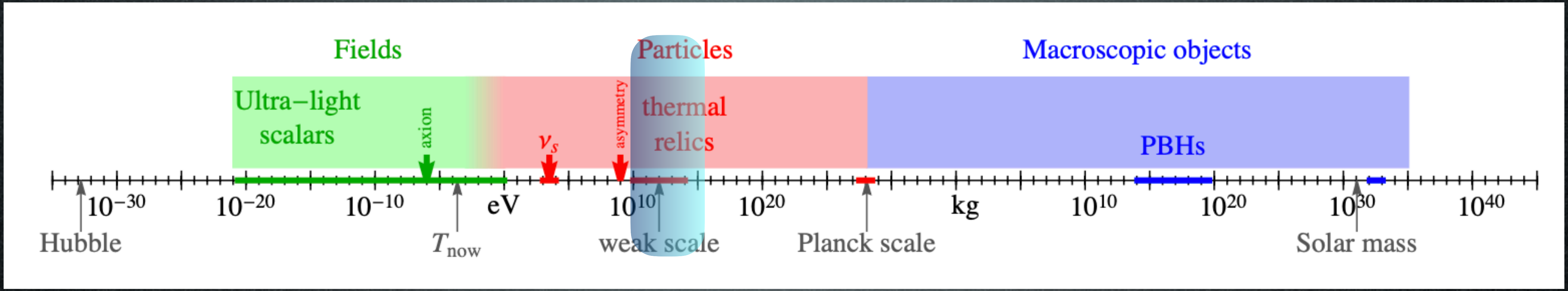
Candidates

A matter of perspective: plausible mass ranges



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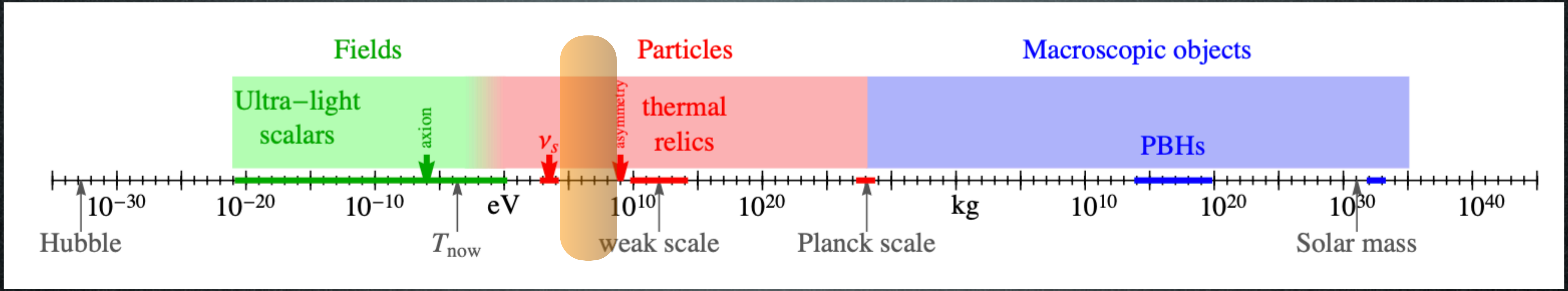
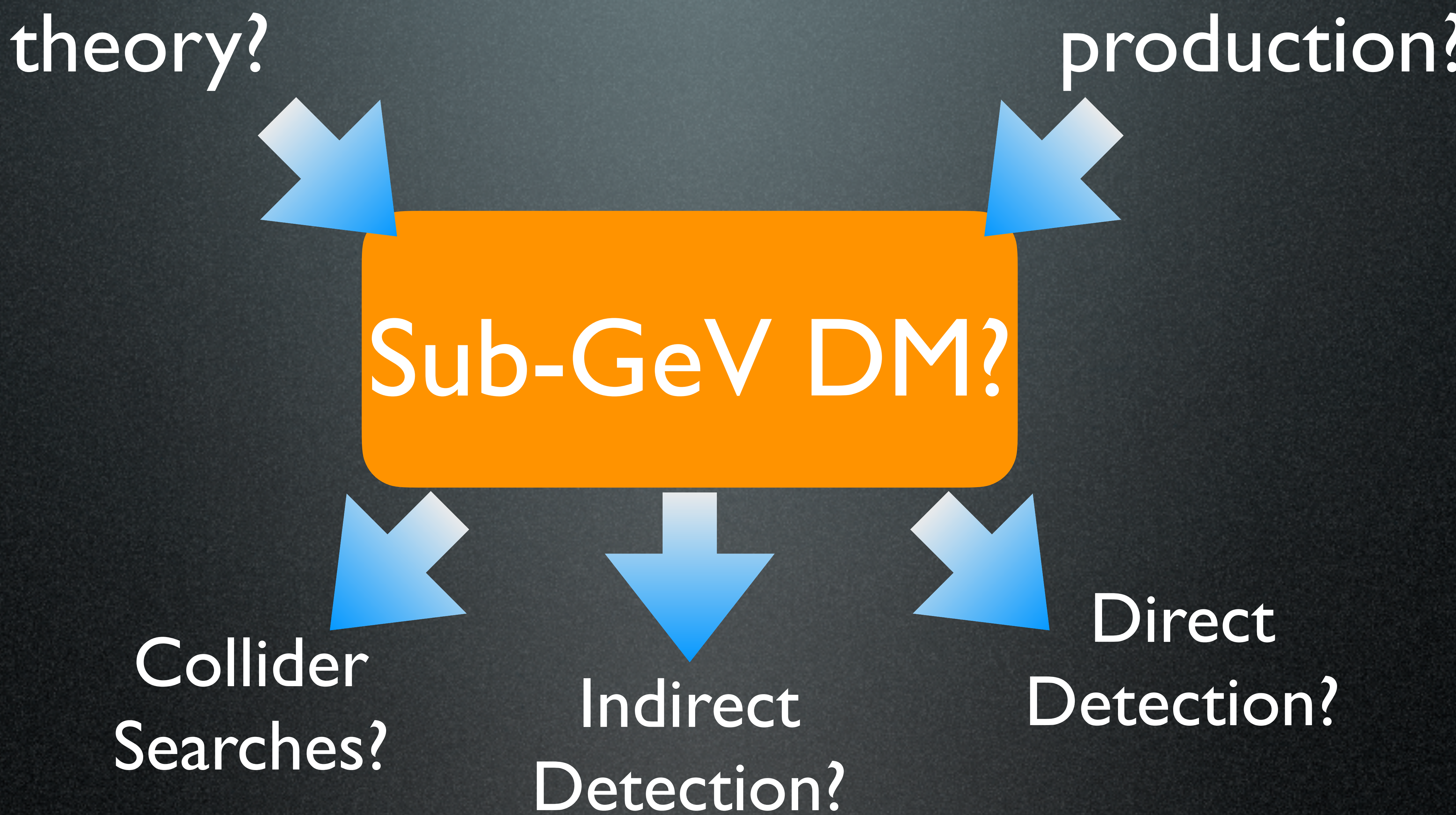


Sub-GeV DM?

Candidates


theory?
production?
Sub-GeV DM?
Collider Searches?
Indirect Detection?
Direct Detection?

Theory

Sub-GeV DM

- 'MeV (scalar) DM'

Boehm & Fayet hep-ph/0305261

In conclusion, scalar Dark Matter particles can be significantly lighter than a few GeV's (thus evading the generalisation of the Lee-Weinberg limit for weakly-interacting neutral fermions) if they are coupled to a new (light) gauge boson or to new heavy fermions F (through non chiral couplings and poten-

Theory

Sub-GeV DM

- WIMPless Dark Matter

Feng & Kumar 0803.4196

a.k.a. hidden sector DM

$\sim$ secluded DM

Theory

Sub-GeV DM

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$$\langle \sigma_{\rm ann} v \rangle \approx \frac{\alpha_w^2}{M^2} \approx \frac{\alpha_w^2}{\rm TeV^2}$$

a.k.a. hidden sector DM

$\sim$ secluded DM

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

Theory

Sub-GeV DM

- WIMPless Dark Matter

  Feng & Kumar 0803.4196

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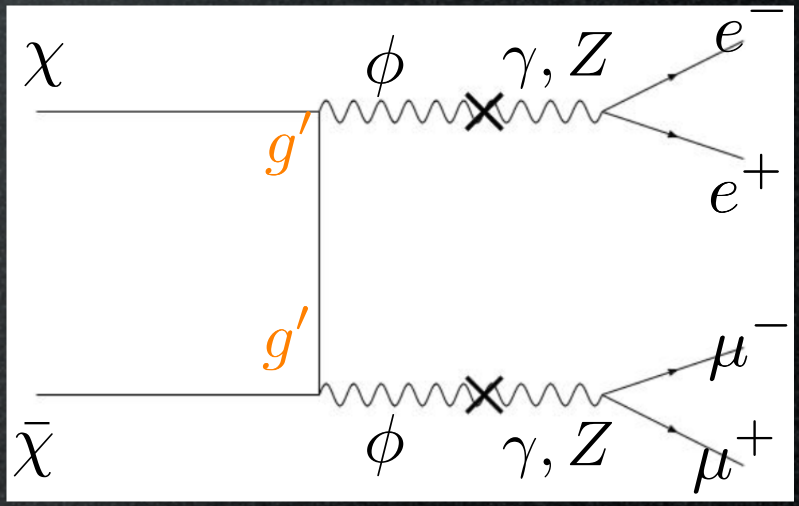
a.k.a. hidden sector DM
$\sim$ secluded DM

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

if g_x is small,
m 'naturally' small
(but nothing points to a precise value)



Production mechanism:
just thermal freeze-out
of these annihilations

Theory

Sub-GeV DM?

- WIMPless Dark Matter
- ‘SIMP miracle’
- Asymmetric DM
- ‘MeV (scalar) DM’ (Integral 511 KeV excess)
- ‘simplified (light) DM models’
- …

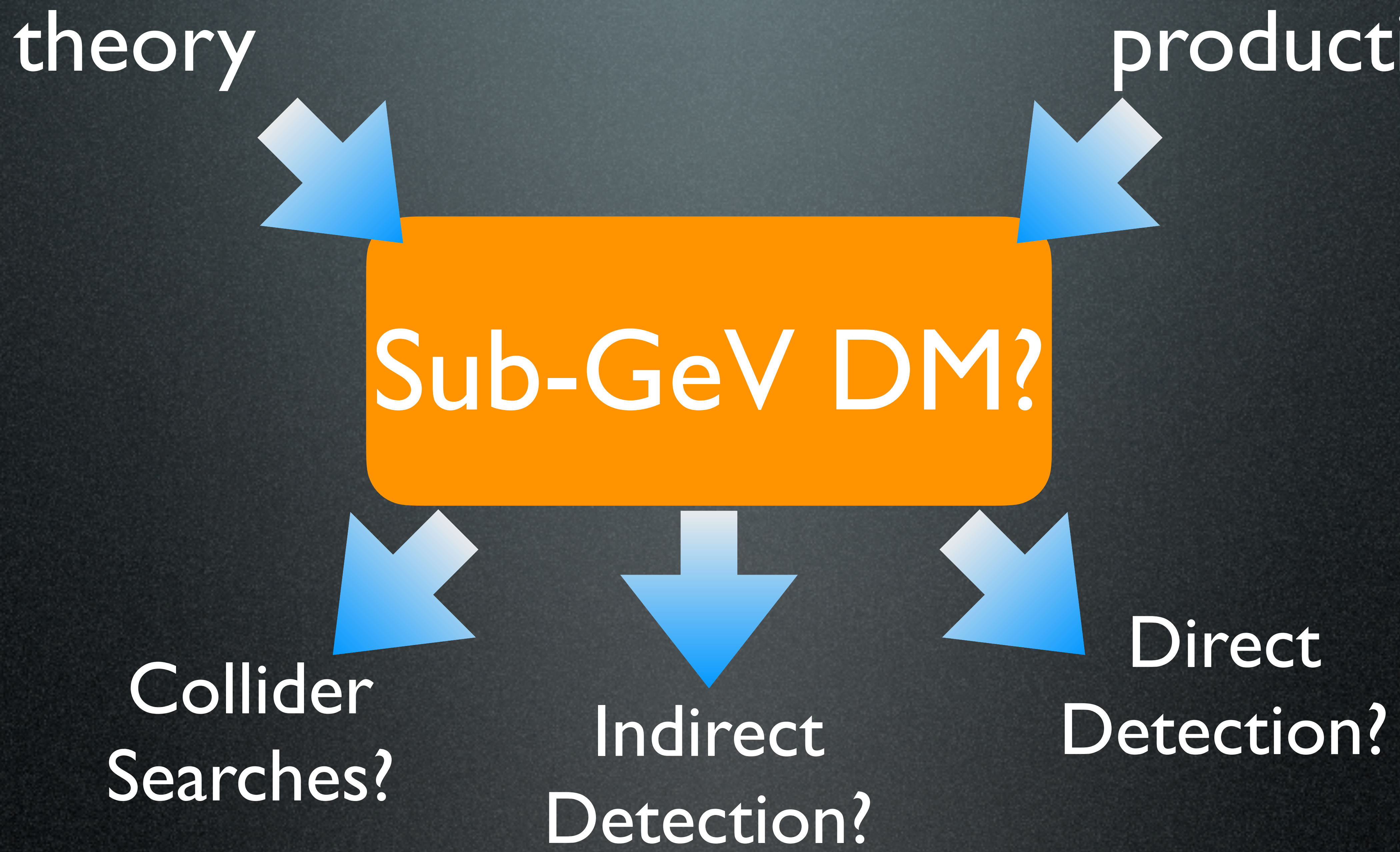
Theory

Sub-GeV DM?

Why not!

- WIMPless Dark Matter
- ‘SIMP miracle’
- Asymmetric DM
- ‘MeV (scalar) DM’ (Integral 511 KeV excess)
- ‘simplified (light) DM models’
- ...

Candidates


theory
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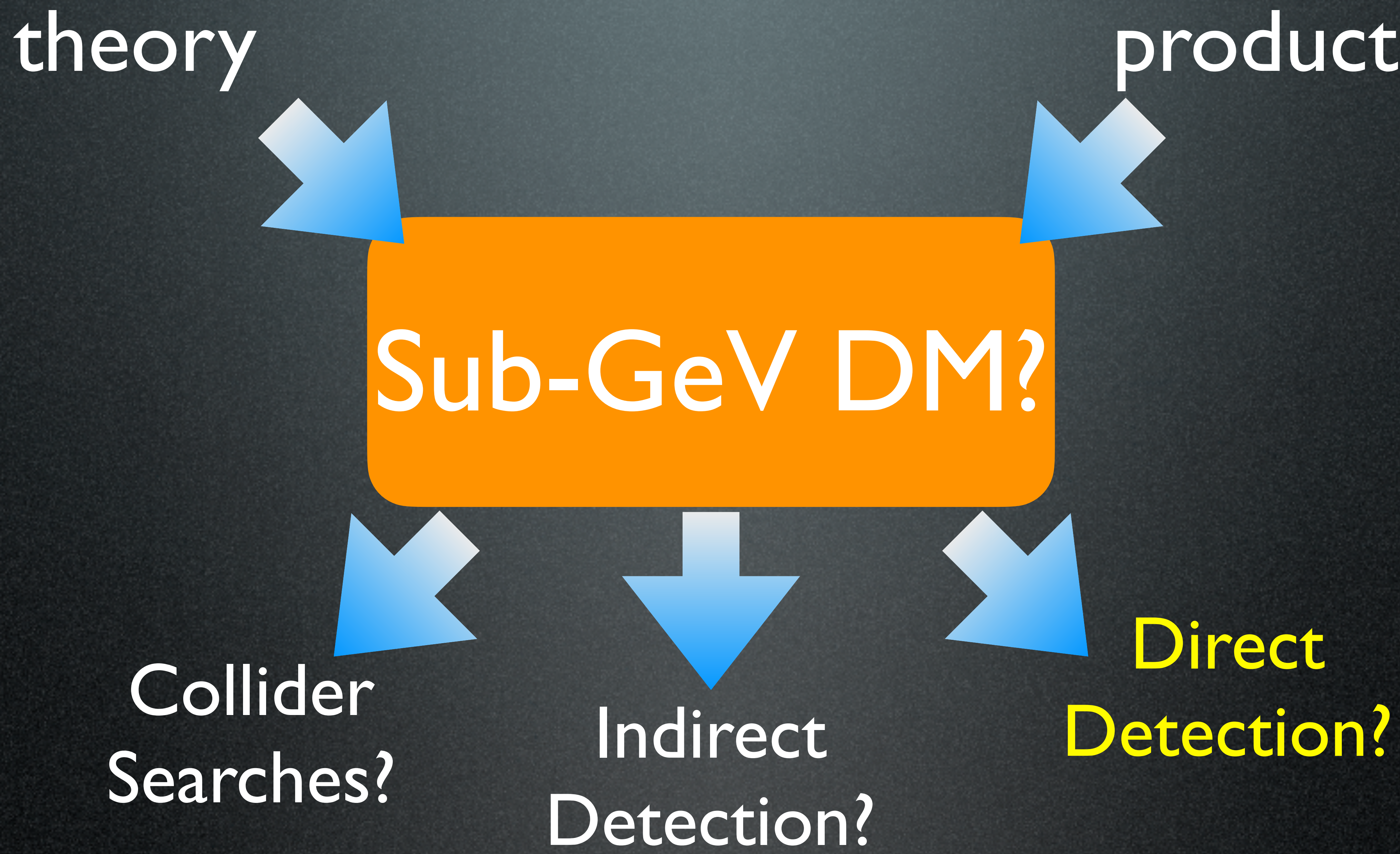
Sub-GeV DM?
Collider Searches?
Indirect Detection?
Direct Detection?

Candidates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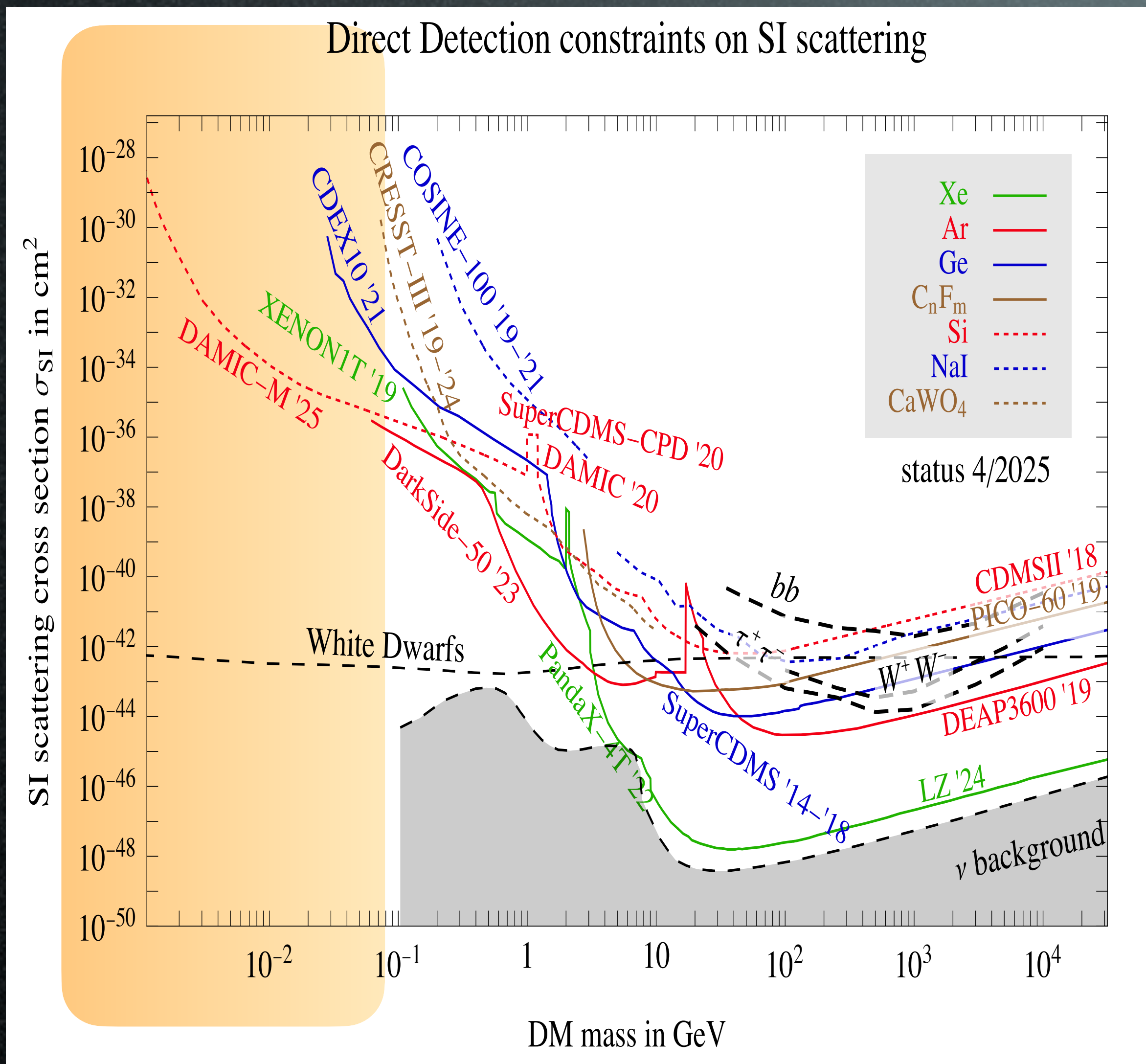
Direct Detection of sub-GeV DM



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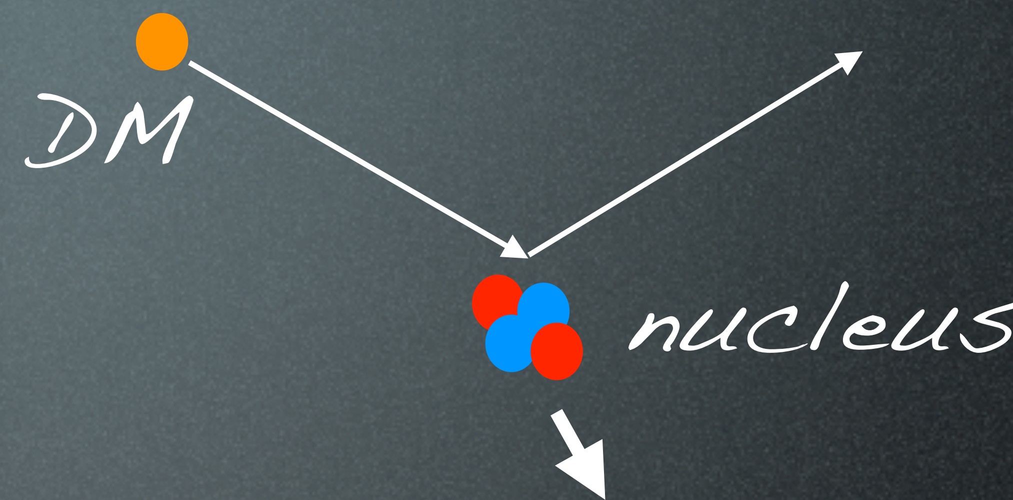
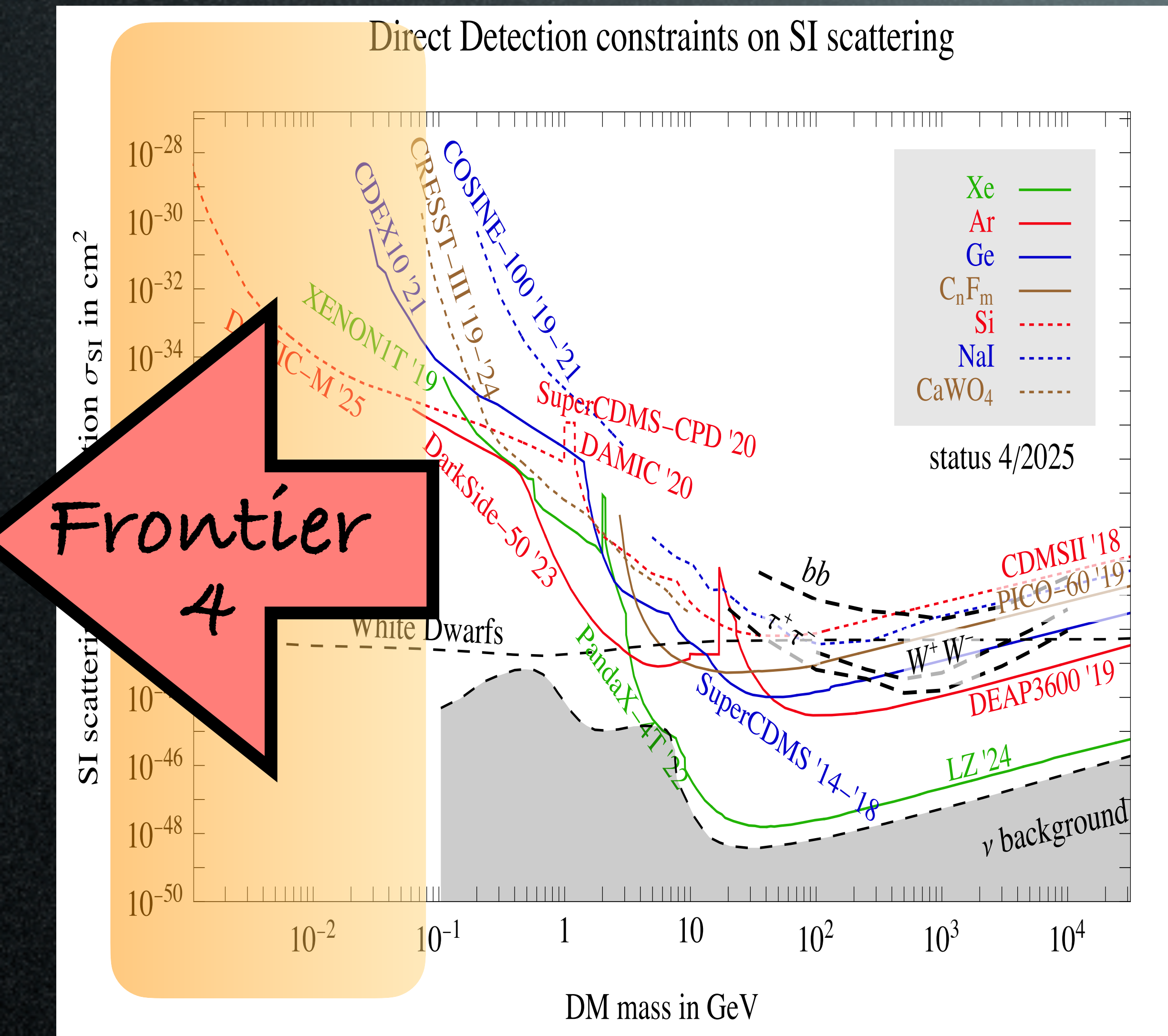


deposited energy is **below threshold** for typical <u>nuclear</u> recoil experiments

- electron recoil signal
- Migdal effect
- new experimental strategies

Direct Detection of sub-GeV DM



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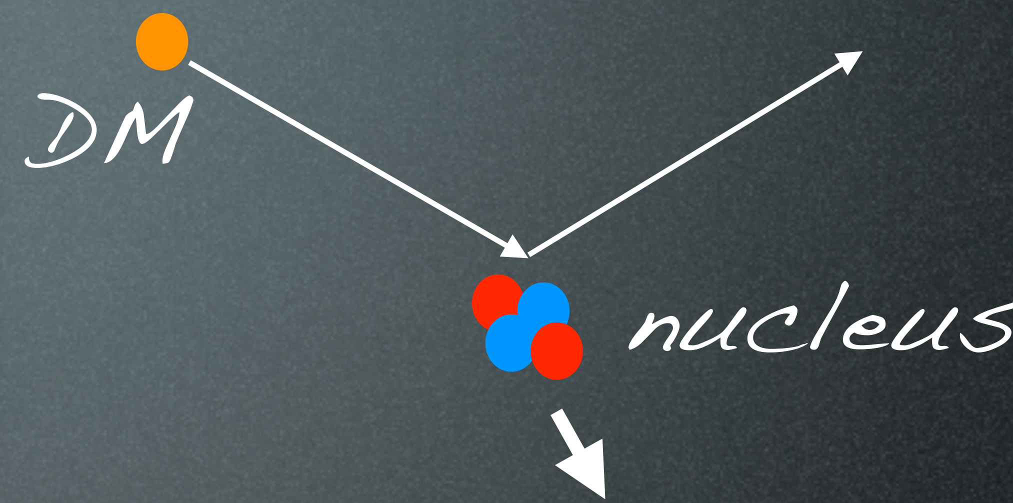

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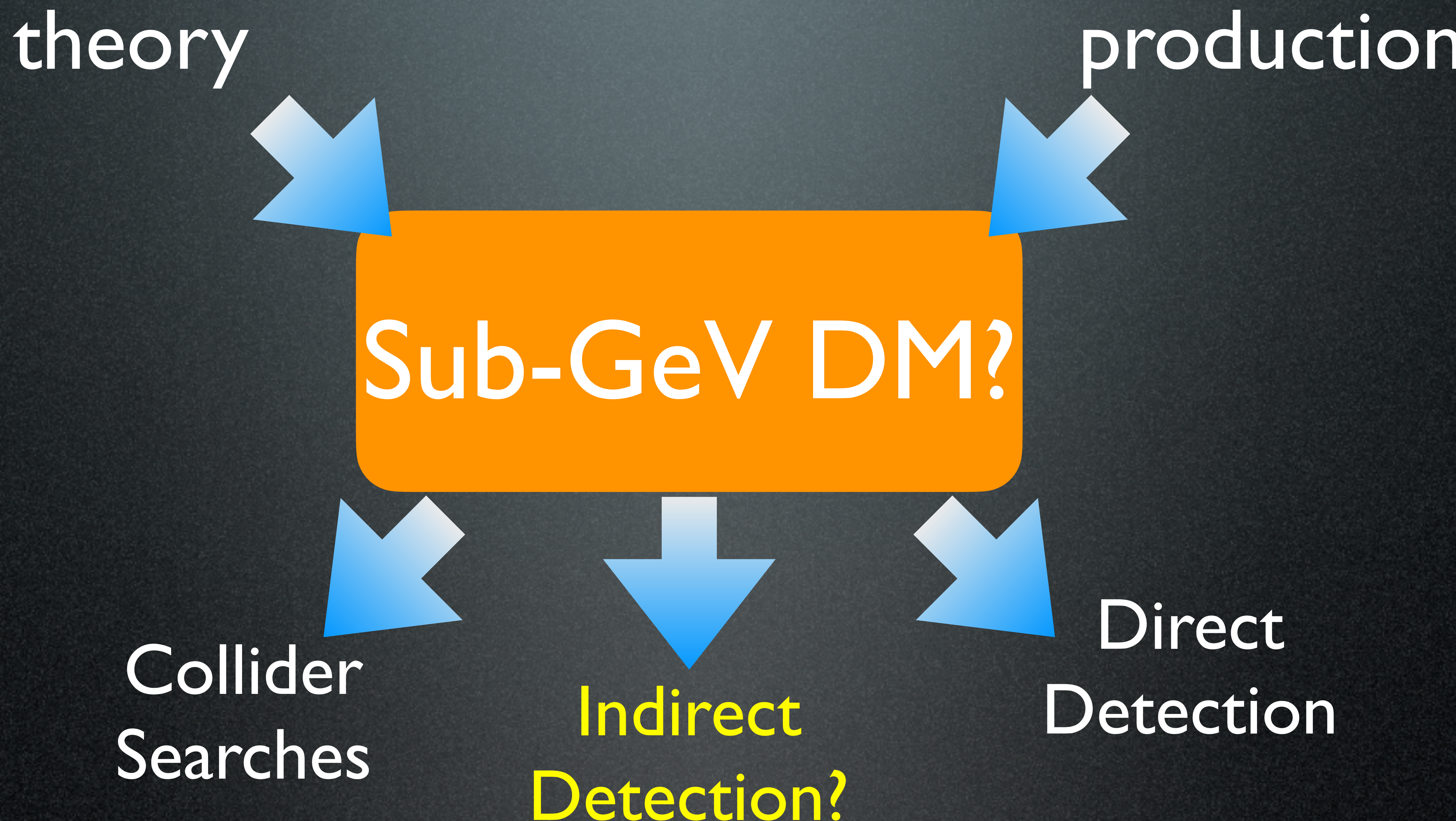
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Indirect Detection: charged CRs

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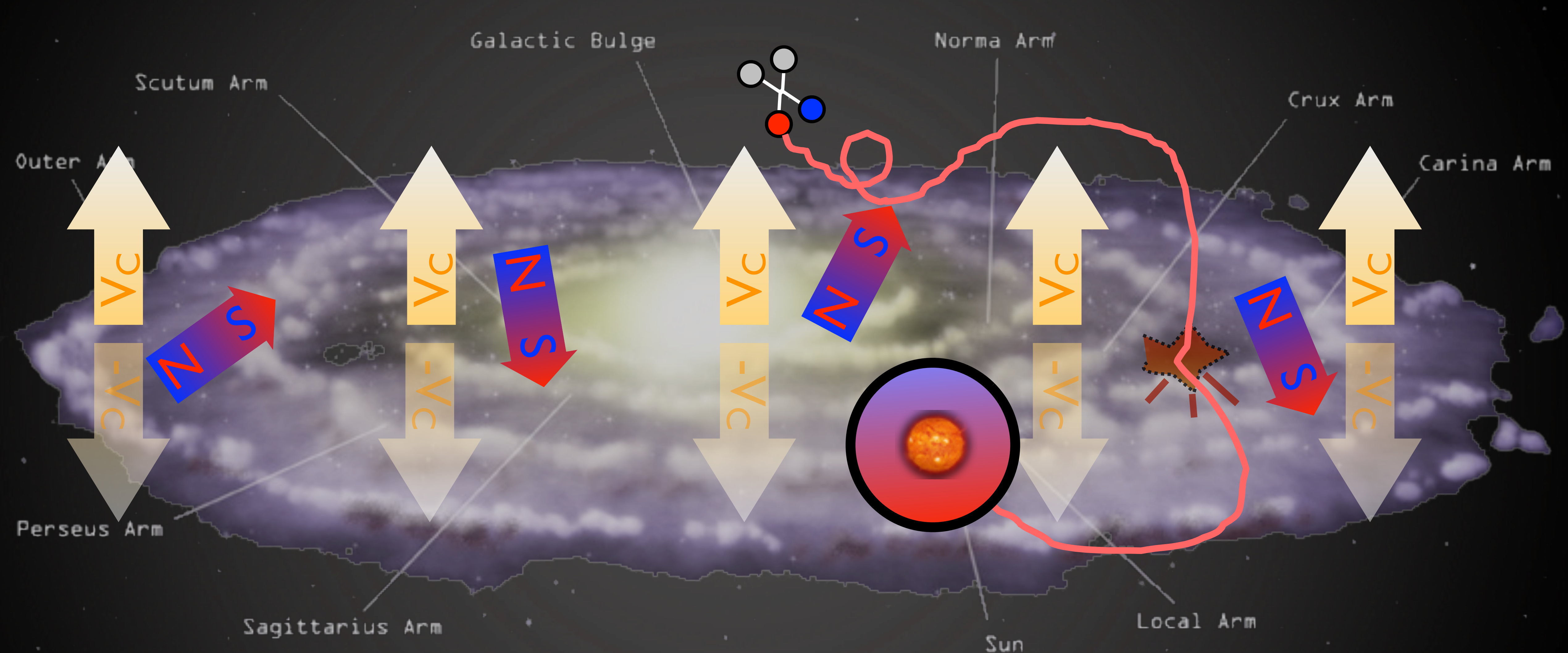

Indirect Detection: charged CRs

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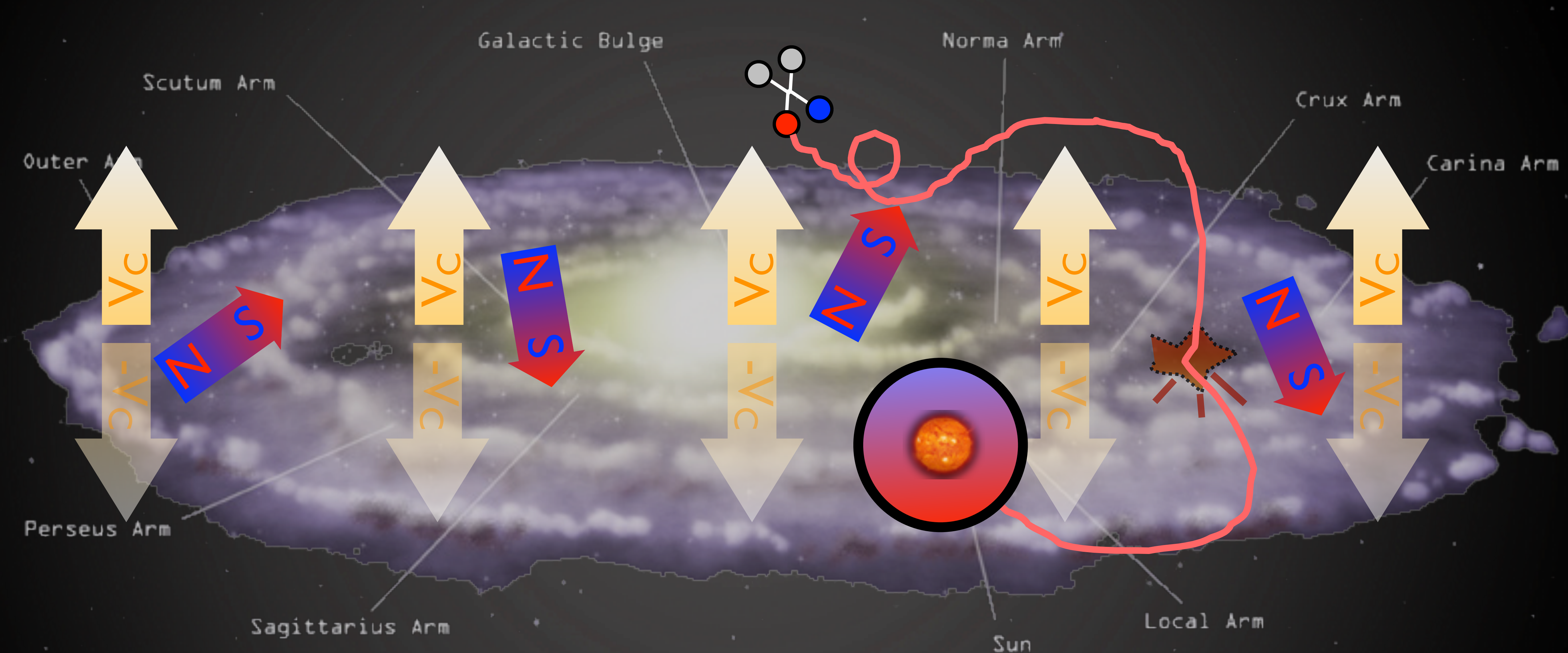
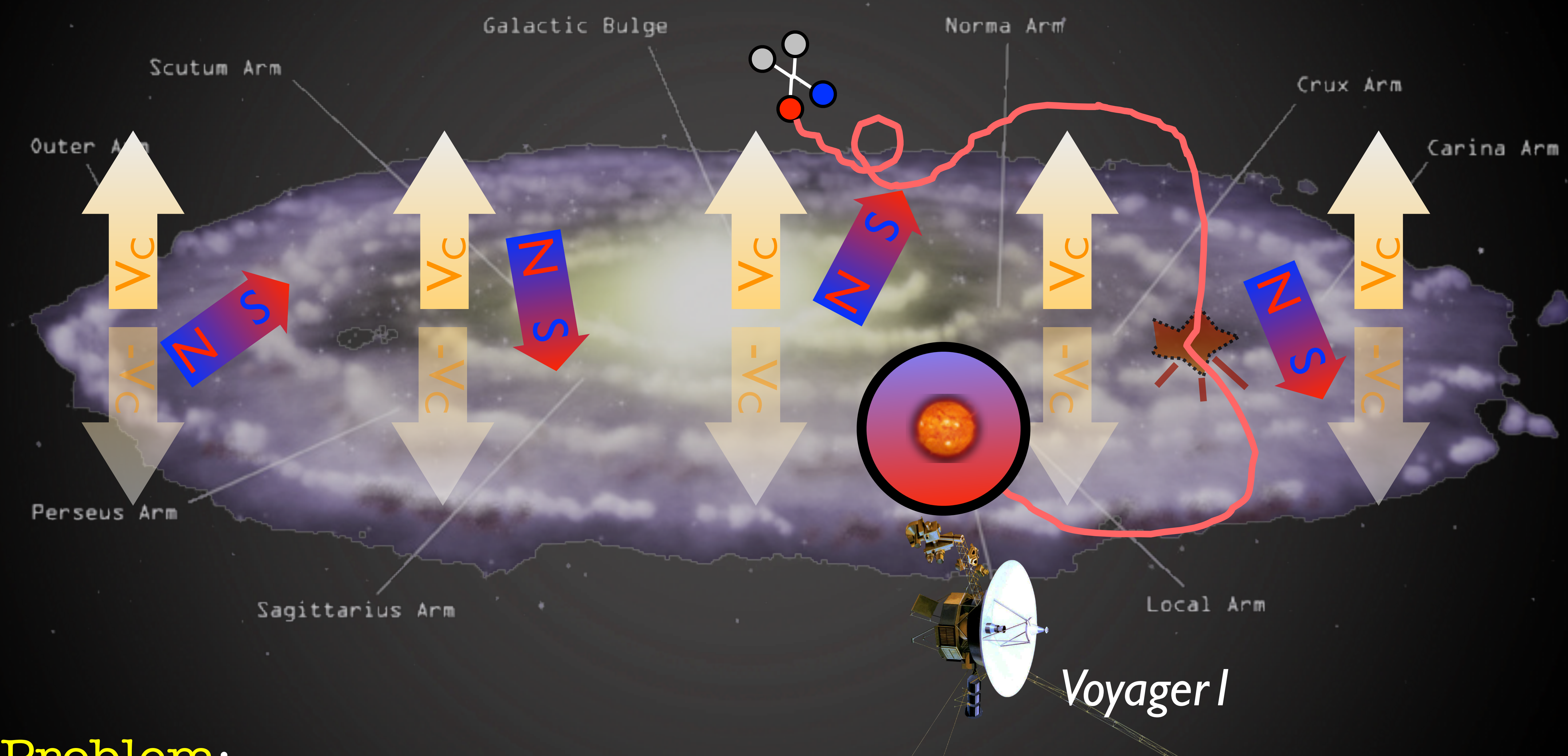


Problem:

sub-GeV charged CRs do not penetrate the heliosphere, experiments cannot collect

Indirect Detection: charged CRs

$\bar{p}$ and e^+ from DM annihilations in halo



Problem:

sub-GeV charged CRs do not penetrate the heliosphere, experiments cannot collect... with one exception!

Indirect detection: photons

Sub-GeV DM produces sub-GeV γ-rays

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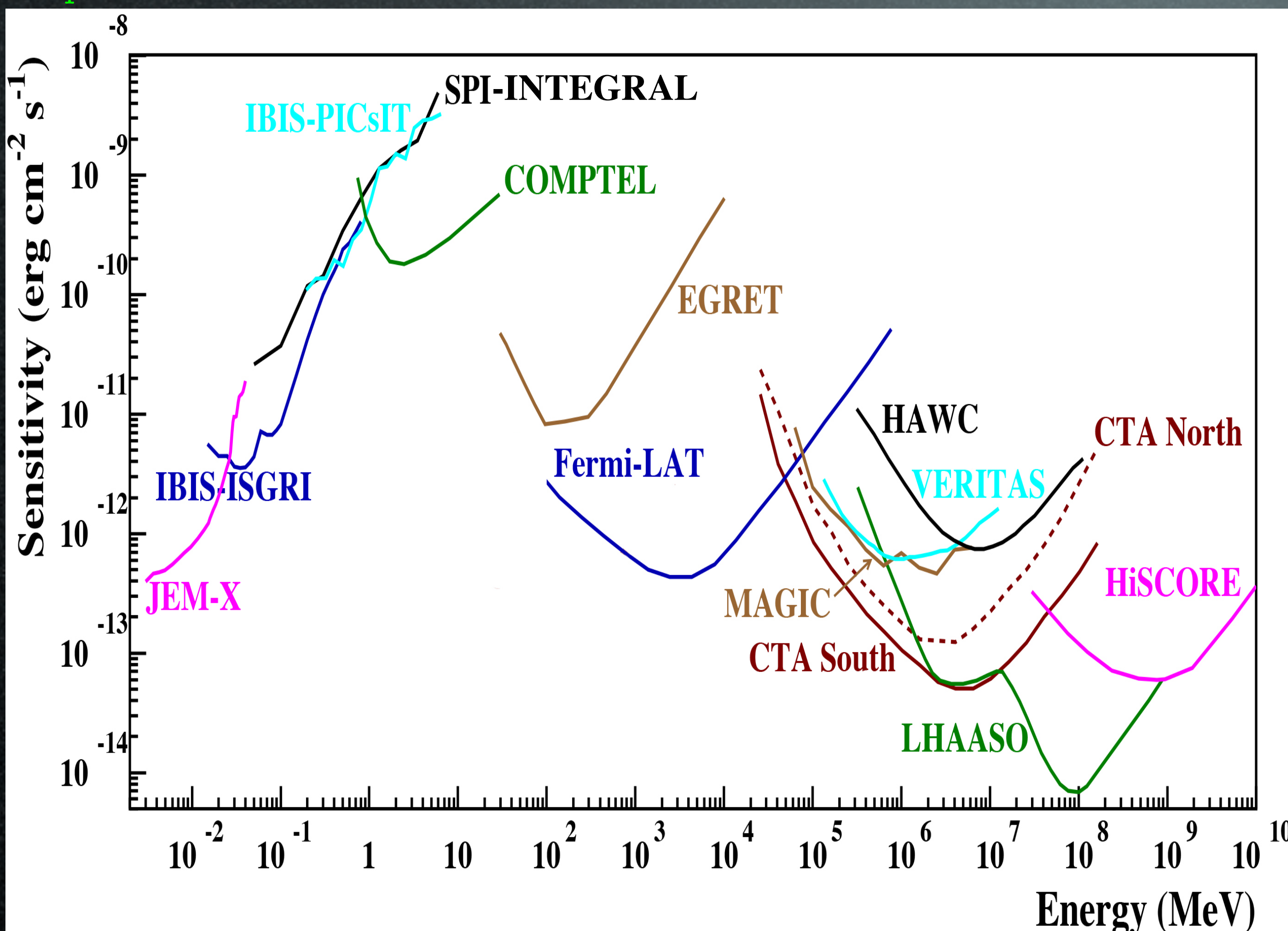
Sub-GeV DM produces sub-GeV γ-rays

adapted from 1611.02232



Past/current experiments:
Integral, Comptel, Fermi
(2002 ⟶ 2025) (1991-2000) (2009 ⟶)

Planned/proposed experiments:
e-Astrogam?, Amego?, MAST?

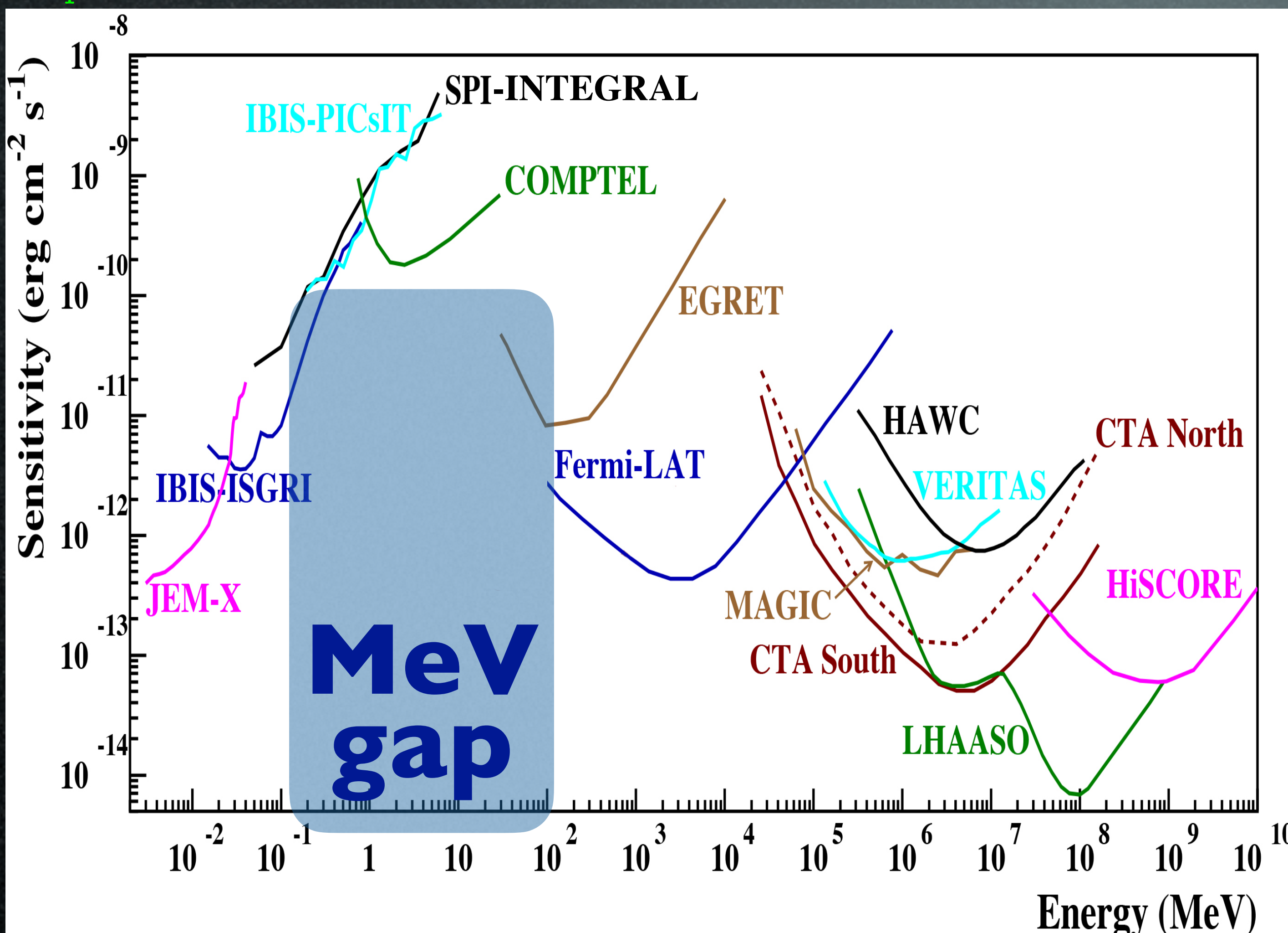
AMEGO	satellite	2020s?	HEP detectors	γ-rays	0.2 – 10 GeV
COMPAIR	satellite	2020s?	HEP detectors	γ-rays	0.2 – 500 MeV
SKA	S.Africa+Australia	2020s?	radio telescope	radio	50 MHz – 30 GHz
INO-ICAL	India	2020s?	calorimeter	neutrinos	1 – 100 GeV
E-ASTROGAM	satellite	2030s?	HEP detectors	γ-rays	0.3 MeV – 3 GeV

Cirelli, Strumia, Zupan 2406.01705

Indirect detection: photons

Sub-GeV DM produces sub-GeV γ-rays

adapted from 1611.02232



Past/current experiments:
Integral, Comptel, Fermi
(2002 ⟶ 2025) (1991-2000) (2009 ⟶)

Planned/proposed experiments:
e-Astrogam?, Amego?, MAST?

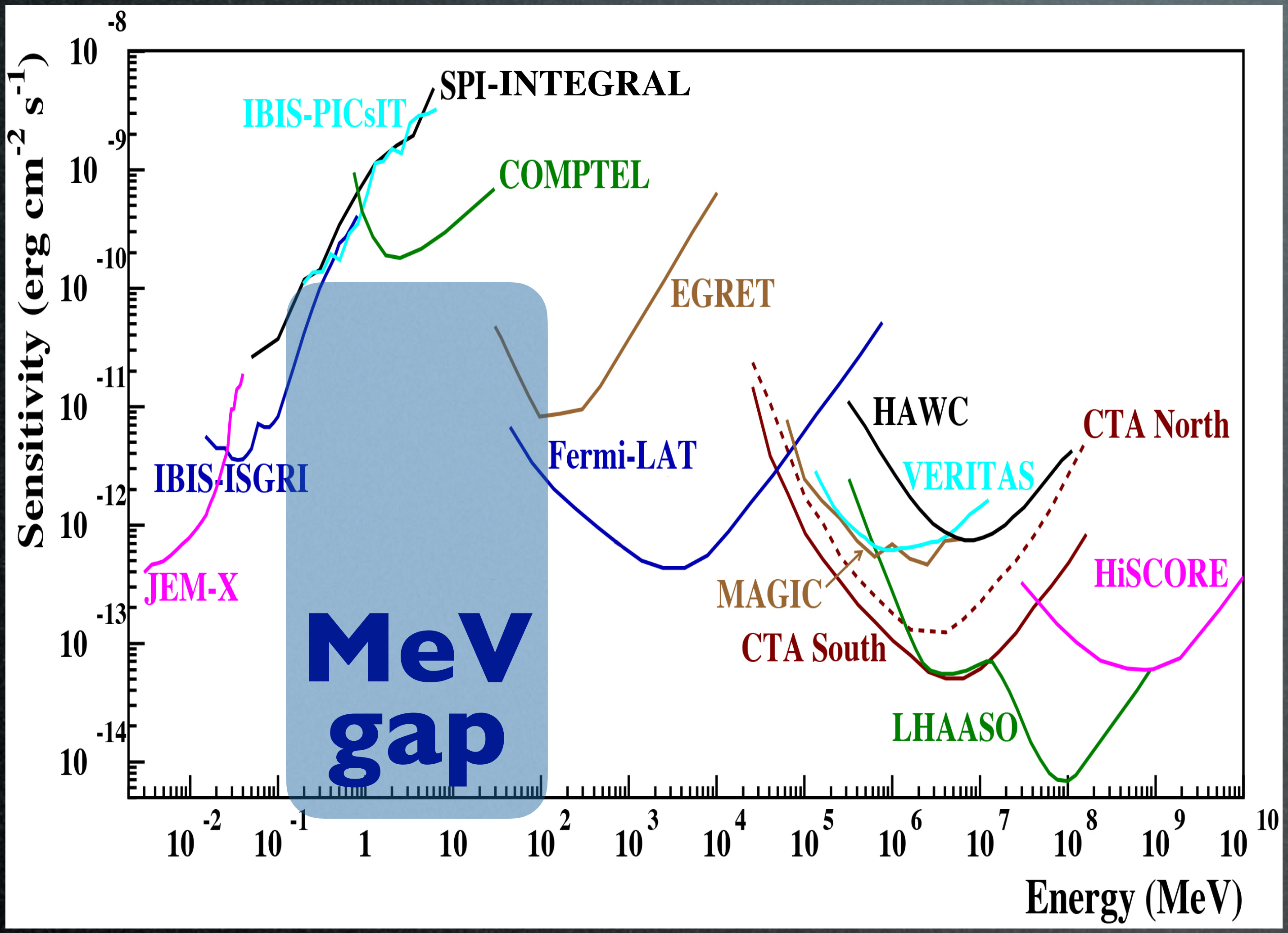
Amego	satellite	2020s?	HEP detectors	γ-rays	0.2 – 10 GeV
Compair	satellite	2020s?	HEP detectors	γ-rays	0.2 – 500 MeV
Ska	S.Africa+Australia	2020s?	radio telescope	radio	50 MHz – 30 GHz
Ino-Ical	India	2020s?	calorimeter	neutrinos	1 – 100 GeV
e-Astrogam	satellite	2030s?	HEP detectors	γ-rays	0.3 MeV – 3 GeV

Cirelli, Strumia, Zupan 2406.01705

Indirect detection: photons

Sub-GeV DM produces sub-GeV γ-rays

adapted from 1611.02232

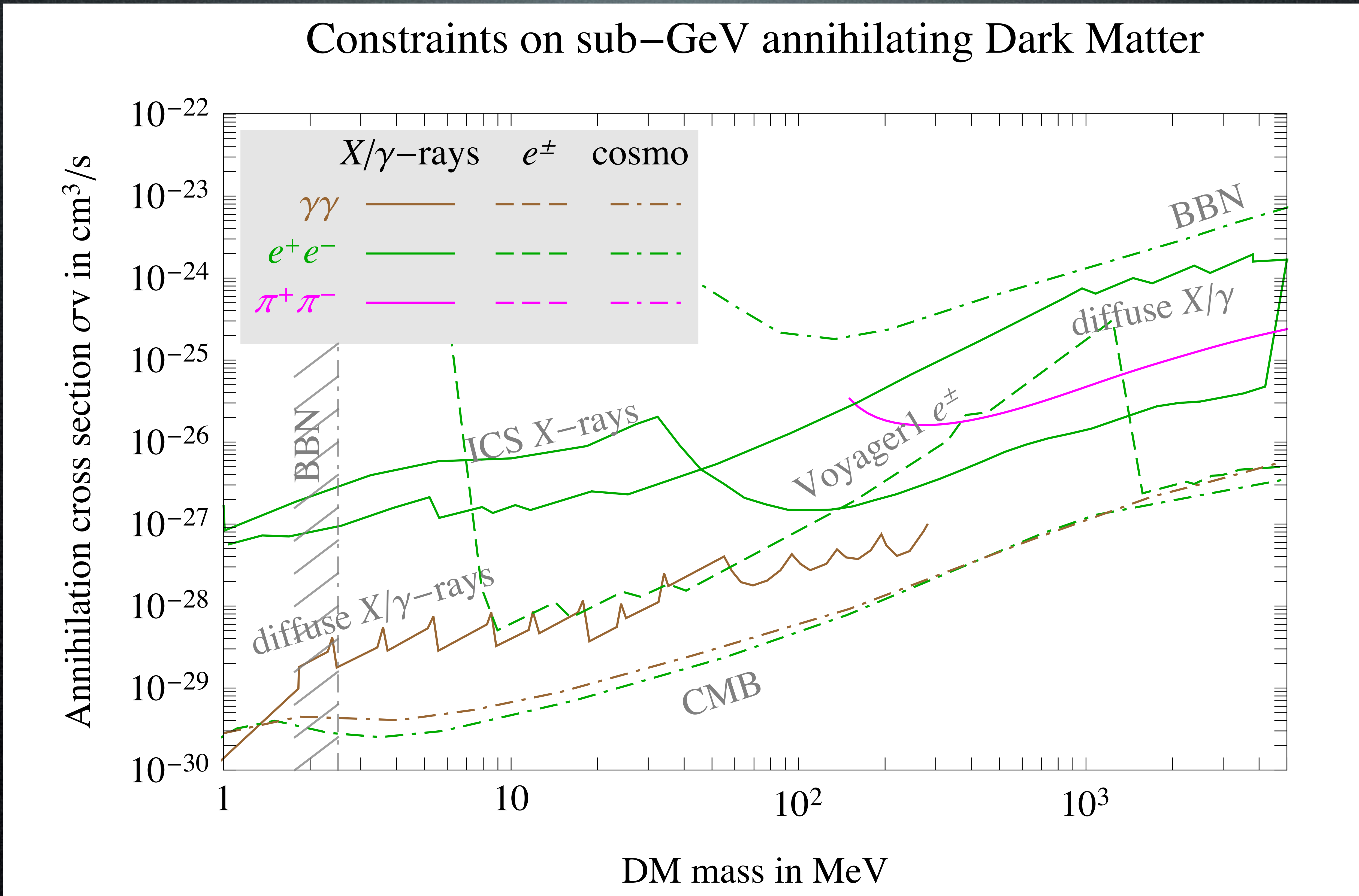


How to do better?

ICS & X-rays!

Cirelli, Fornengo, Kavanagh, Pinetti 2007.11493
Cirelli, Fornengo, Koechler, Pinetti, Roach 2303.08854

Comparing all bounds



M. Cirelli, A. Strumia, J. Zupan 2406.01705 **v3** (includes eROSITA from 2506.02310)

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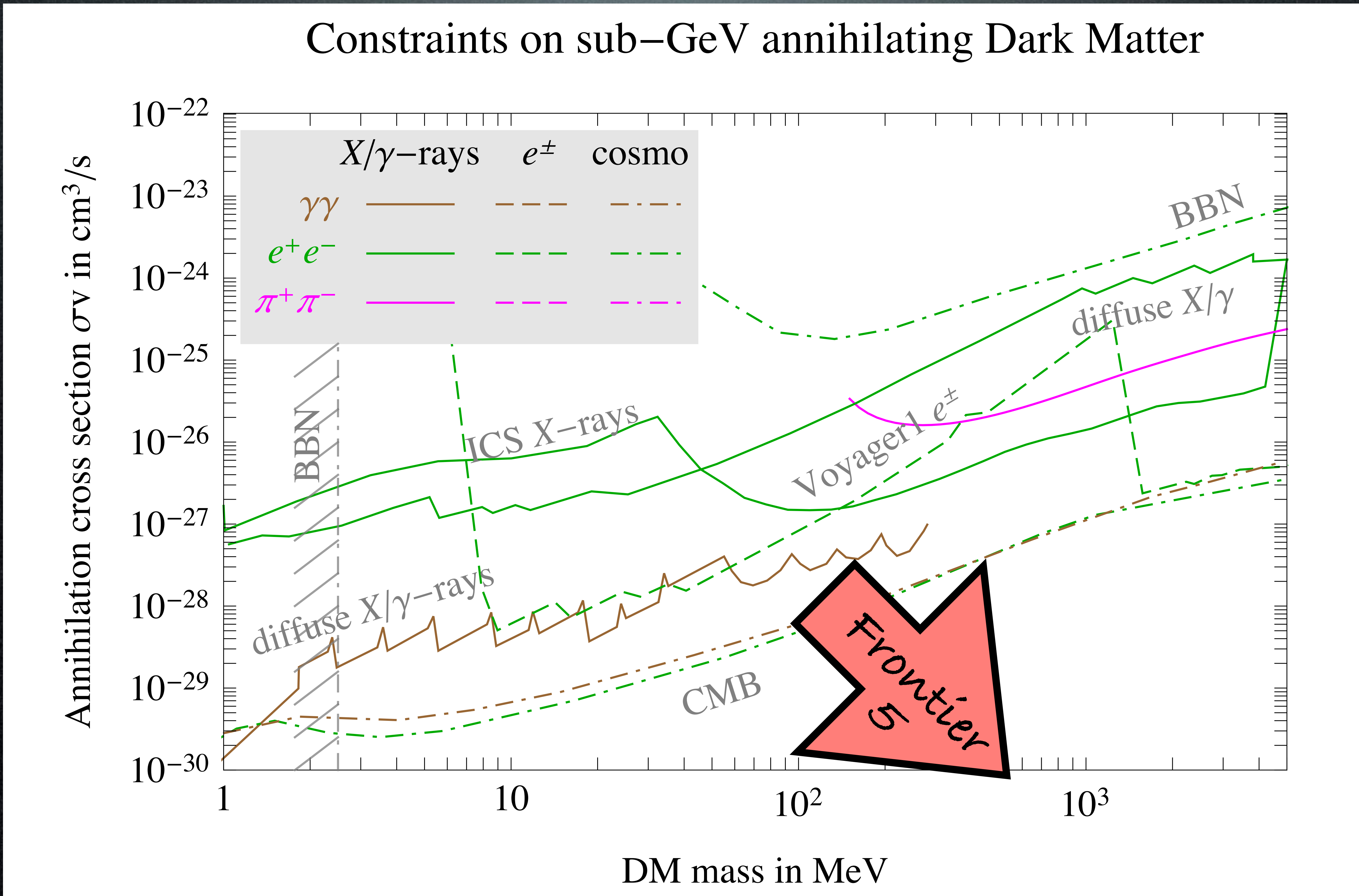
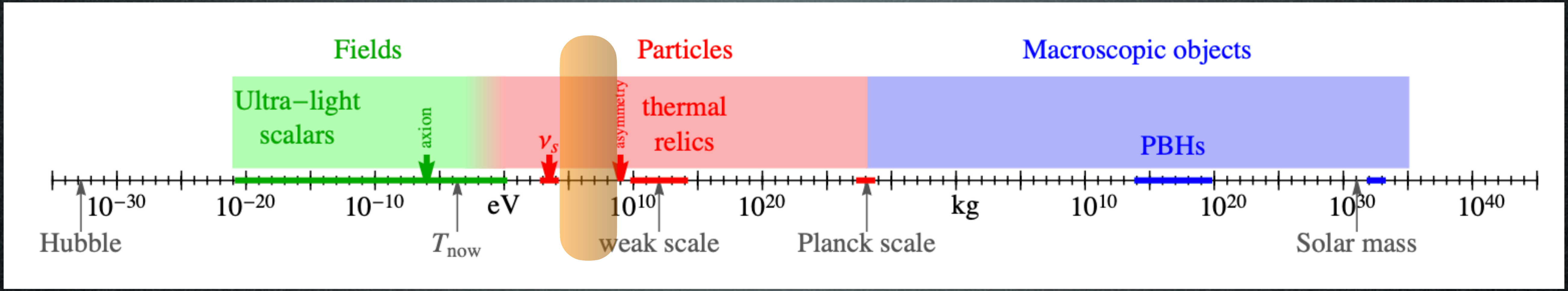


M. Cirelli, A. Strumia, J. Zupan 2406.01705 **v3** (includes eROSITA from 2506.02310)

Candidates

A matter of perspective: plausible mass ranges



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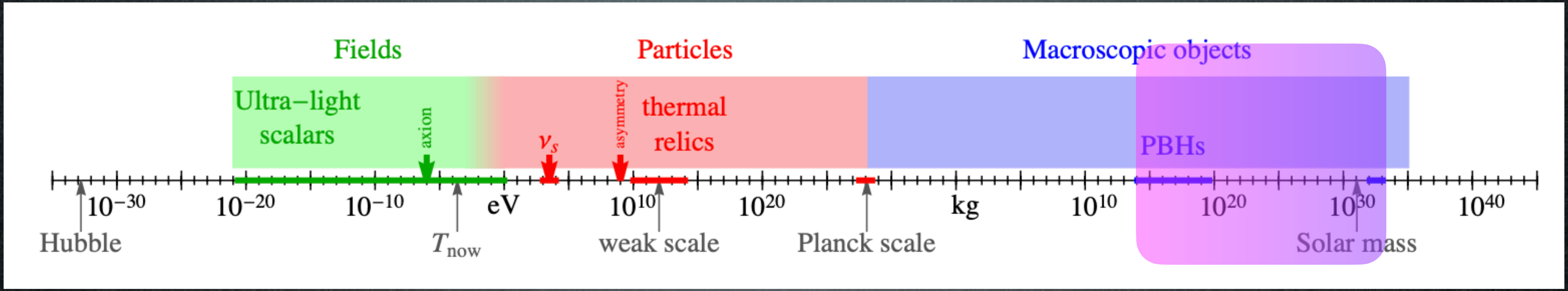

DM can **NOT** be:

an astro *je ne sais pas quoi*:

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- Black Holes
- brown dwarves

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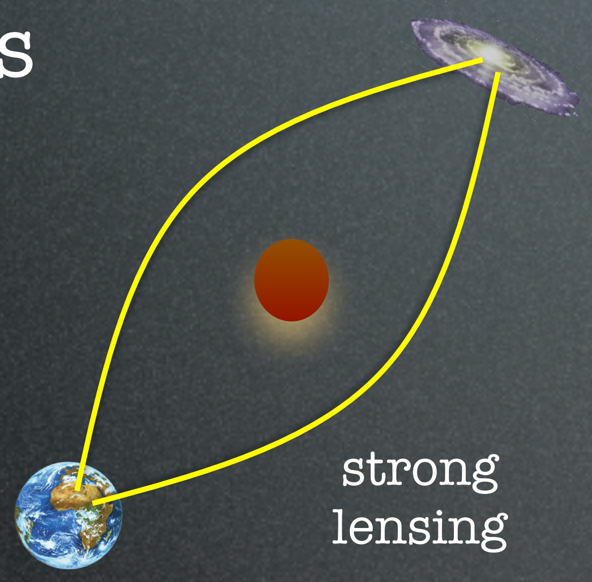
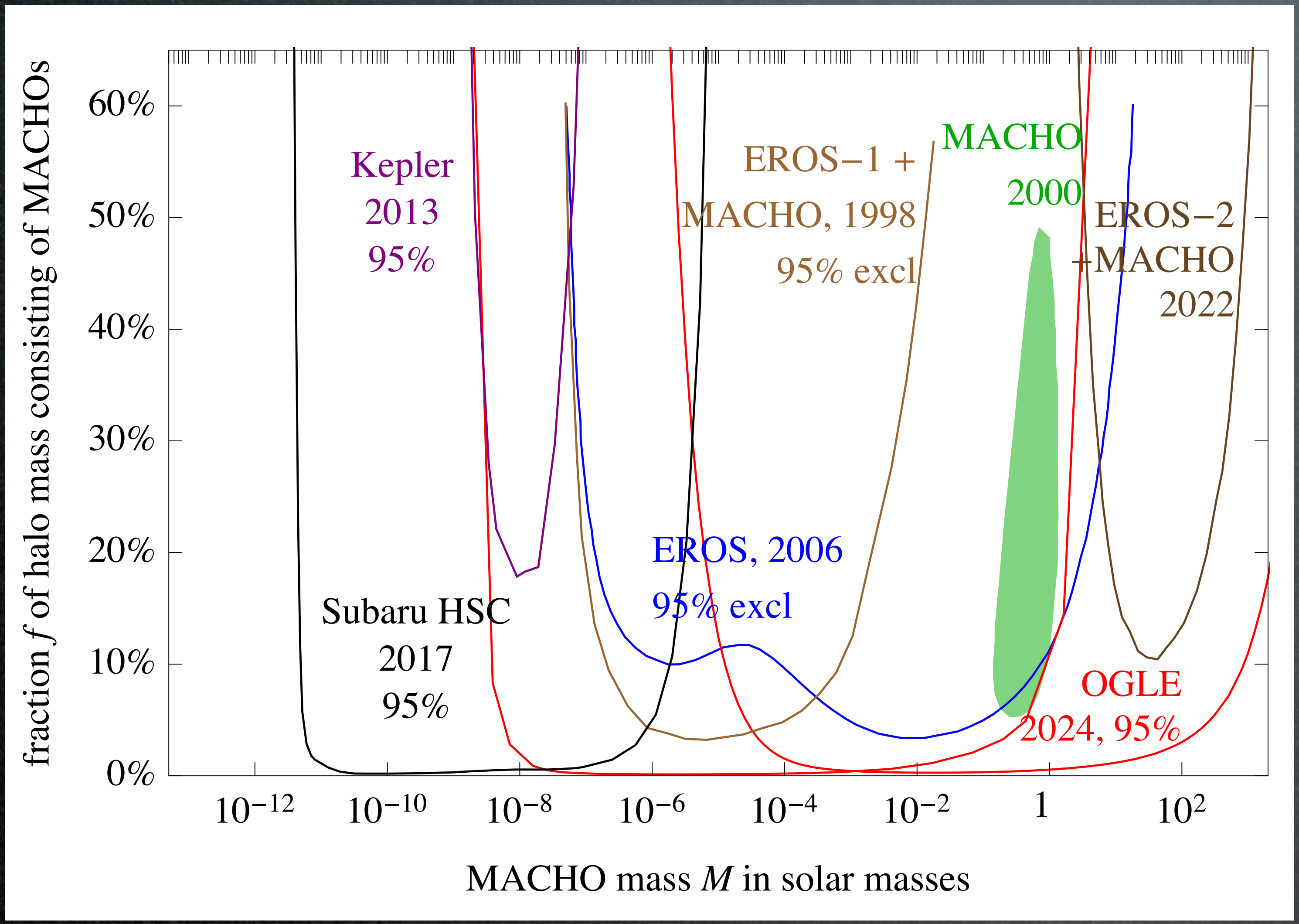


MACHOs or PBHs as DM



M. Cirelli, A. Strumia, J. Zupan 'Dark Matter', 2406.01705

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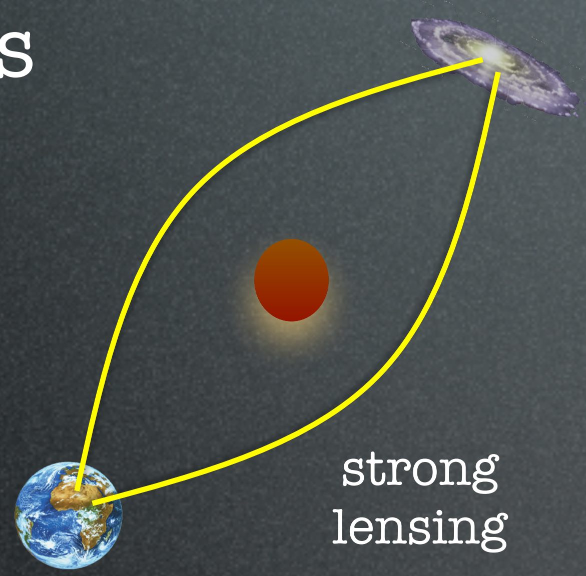

a baryon of the SM:

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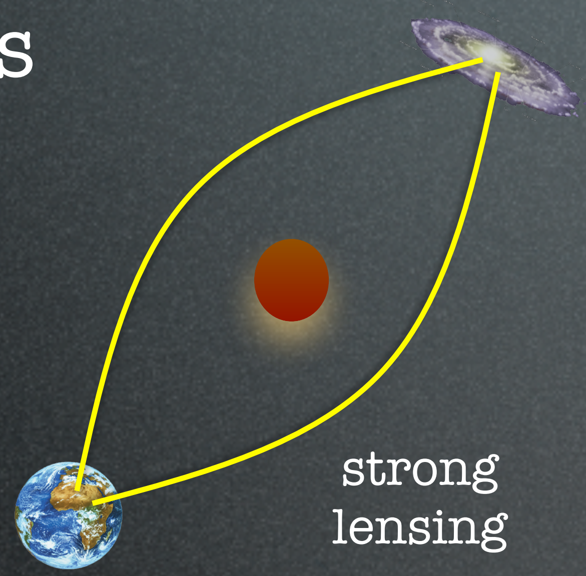

a ~~baryon of the SM~~:

- BBN computes the abundance of He in terms of primordial baryons:
  too much baryons => Universe full of Helium

- CMB says baryons are 4% max

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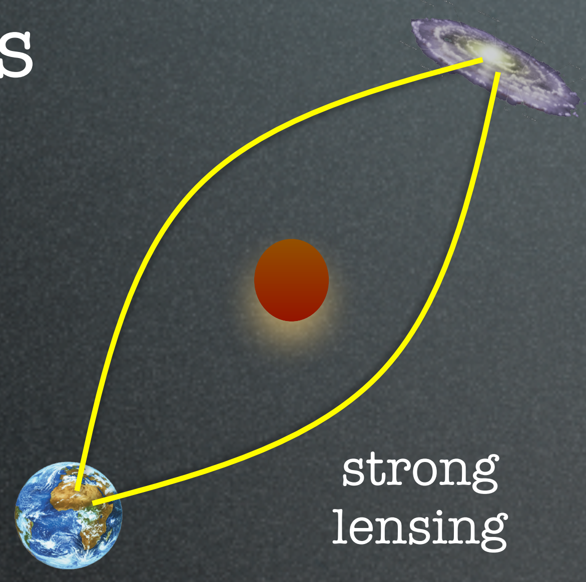

a ~~baryon of the SM~~:

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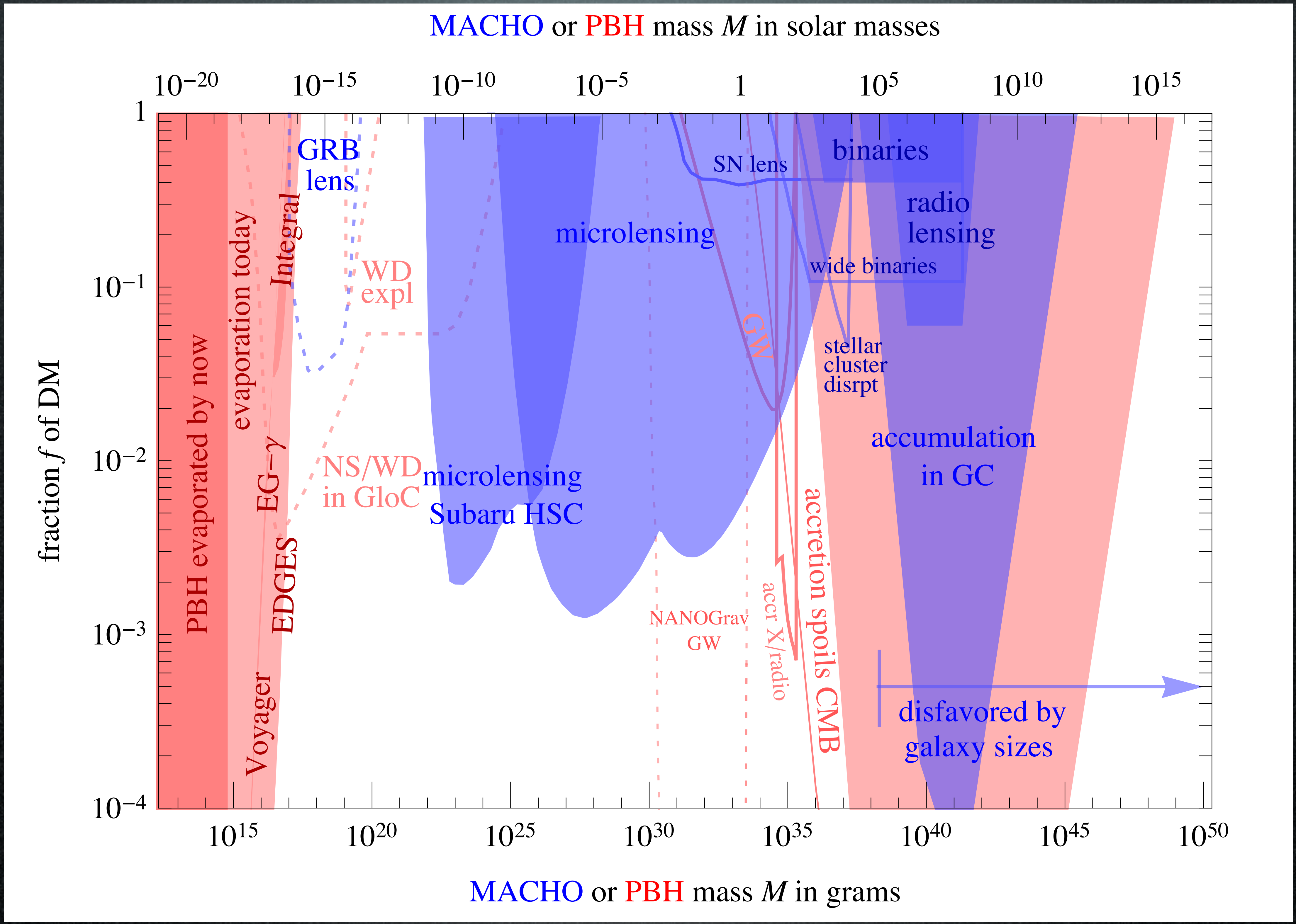
A loophole: Primordial Black Holes!

- produced before BBN
- with masses too small/large to lens
- perhaps LIGO-VIRGO have seen them?

PBHs as DM



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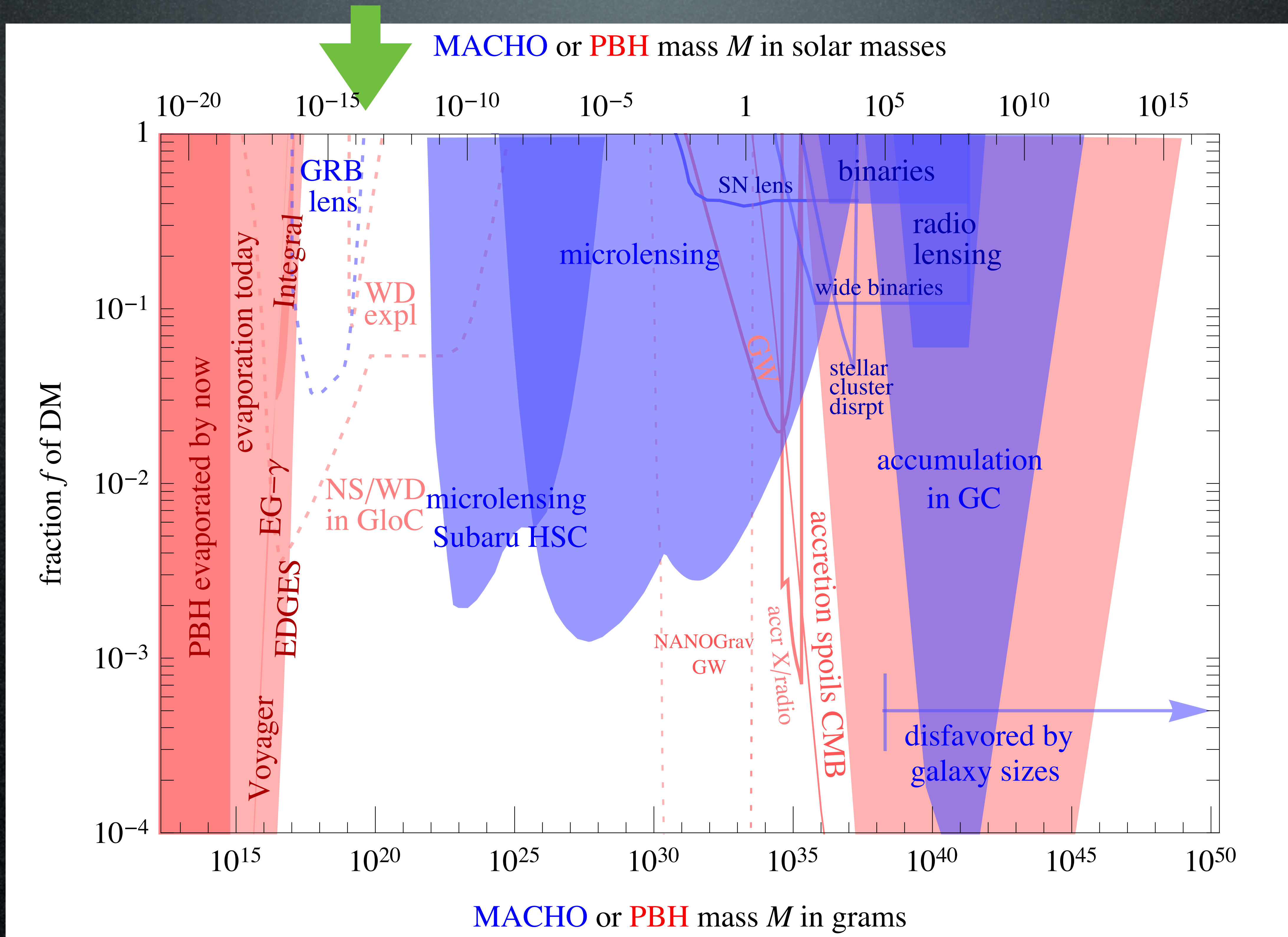
PBHs as DM

window still open?



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PBHs as DM

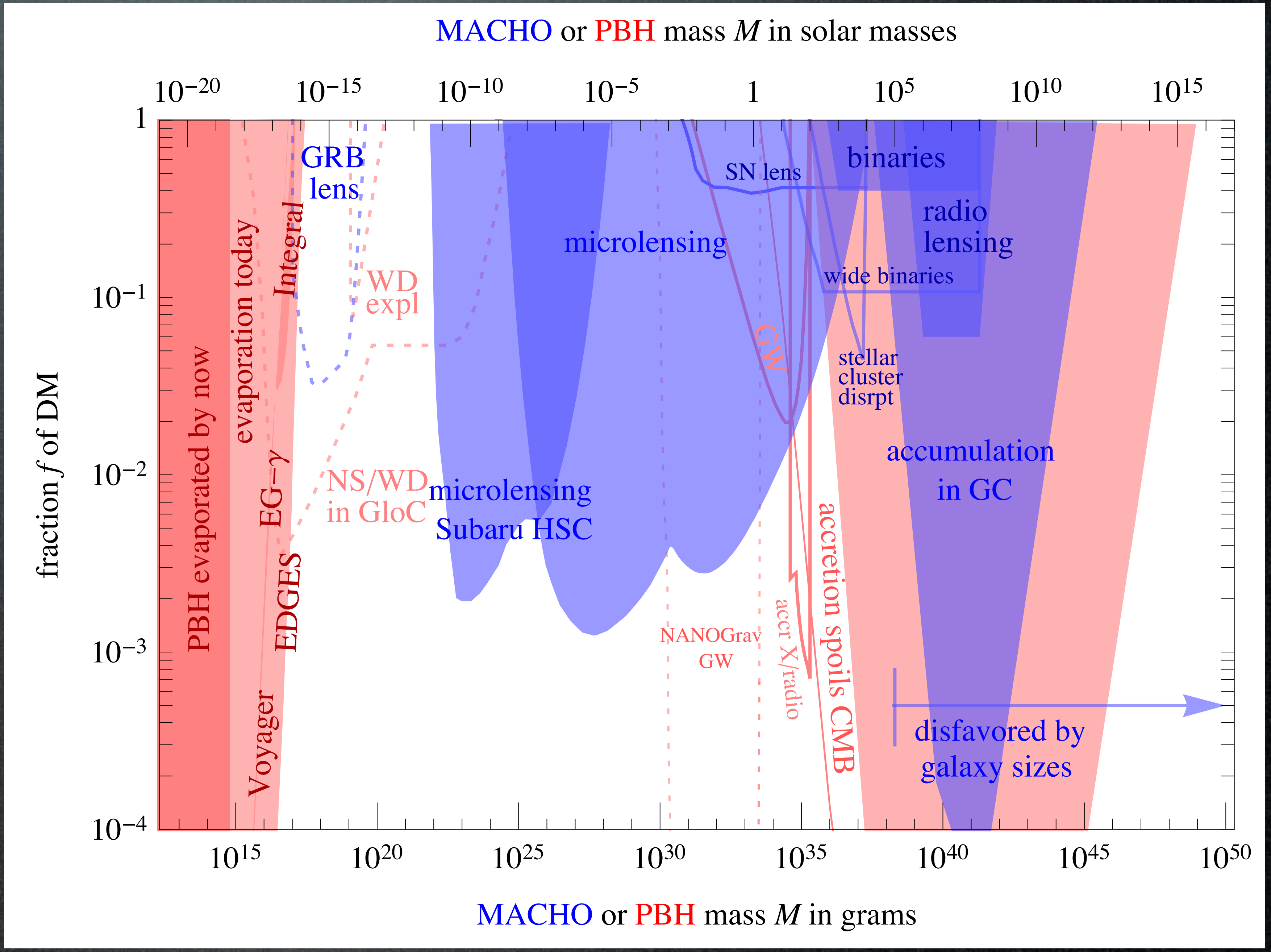
Constraints on Primordial Black Holes

DM could consist of PBHs

huge range of sizes:

$$M \simeq 10^{15}(t/10^{-23}\ \text{sec})\ \text{g}$$

constraints



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PBHs as DM

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constraints

'small' PBHs emit today by Hawking evaporation

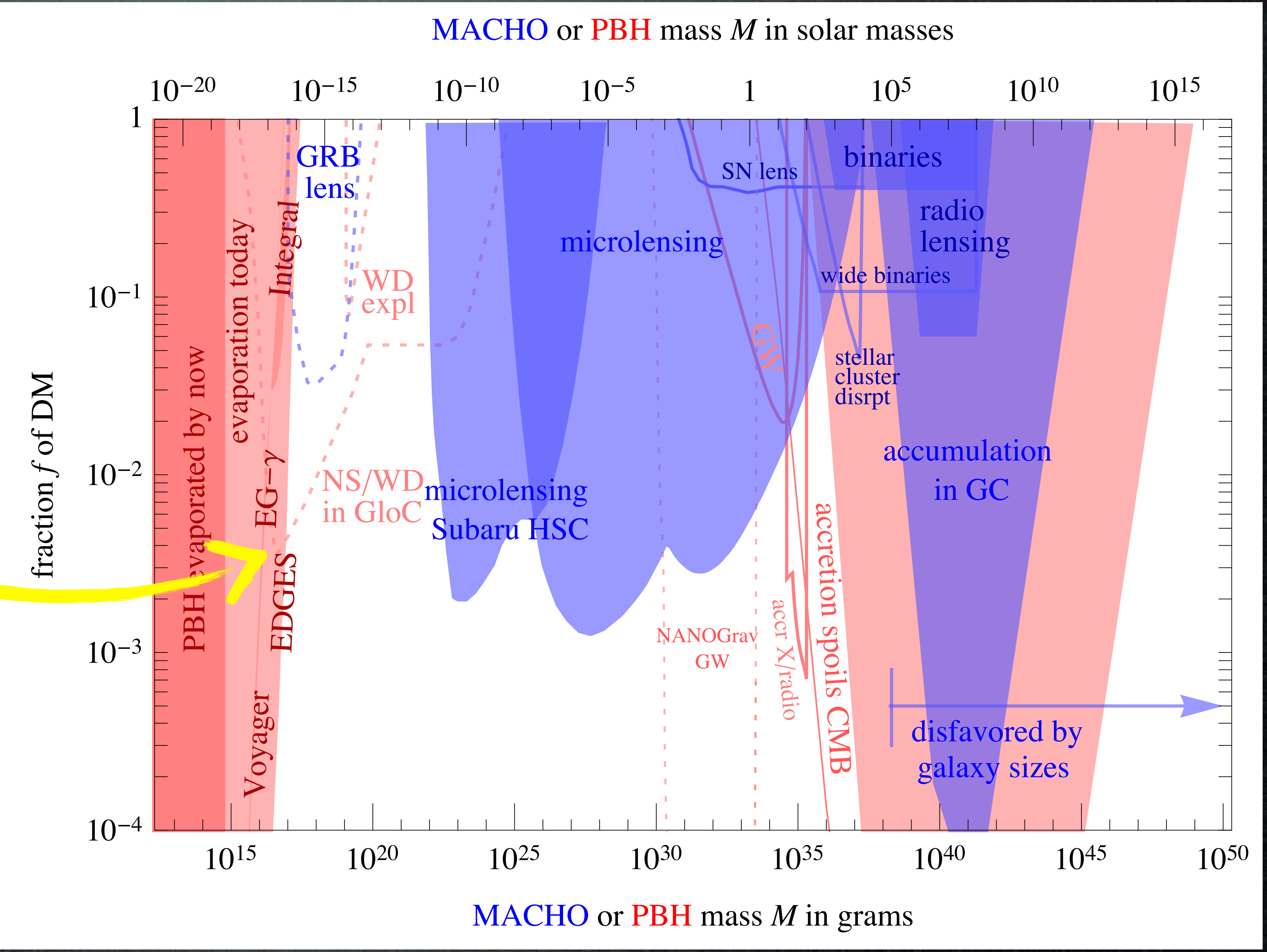
$$T = \frac{1}{8\pi G_N M}$$

rate

$$\frac{dM}{dt} \simeq -5\times 10^{25} f(M) \left(\frac{\text{g}}{M}\right)^2 \text{g/s}$$

spectrum

$$\frac{dN}{dt\,dE} = \frac{27}{2\pi}\frac{G^2M^2E^2}{e^{E/T}+1}$$



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

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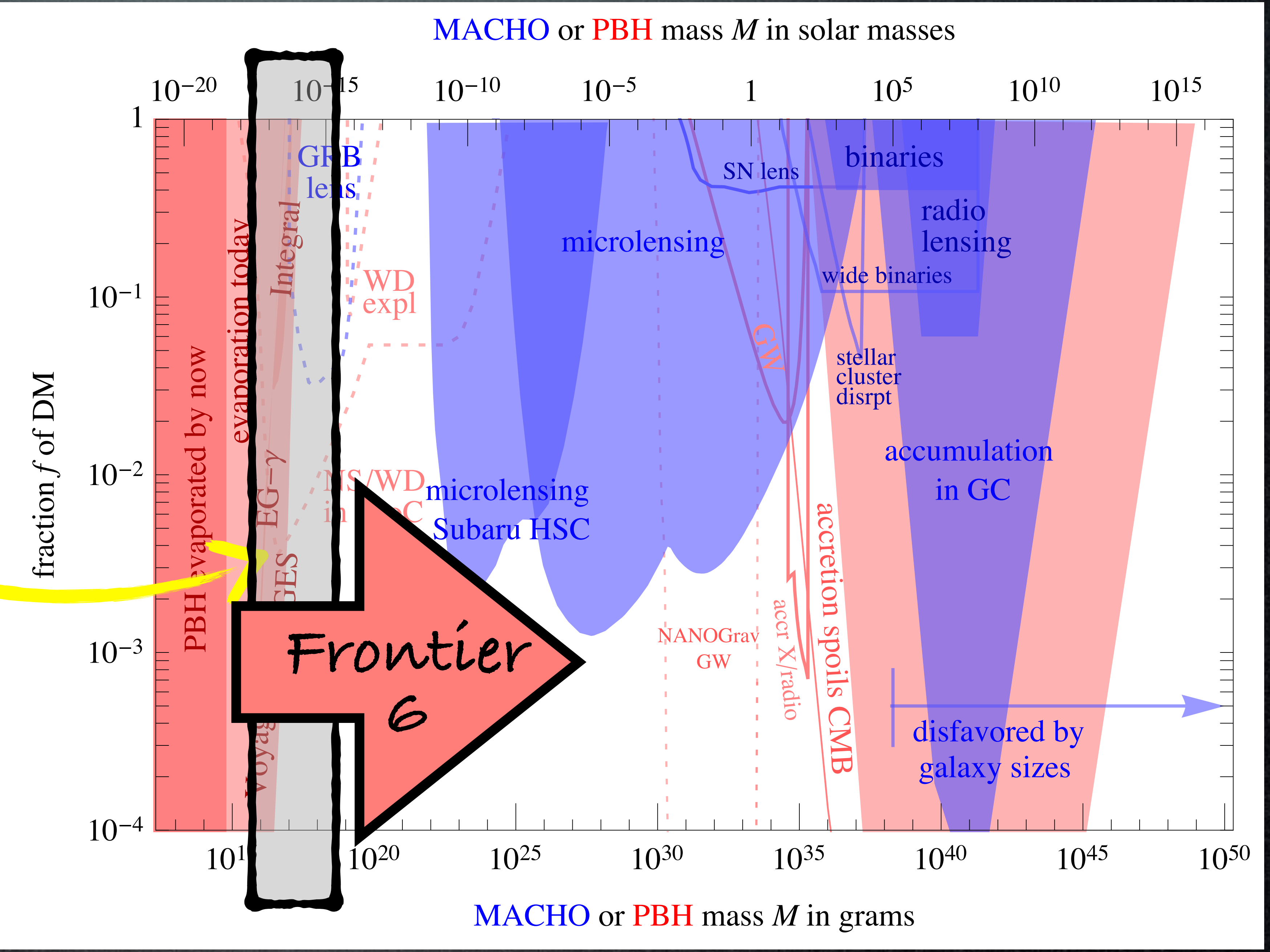
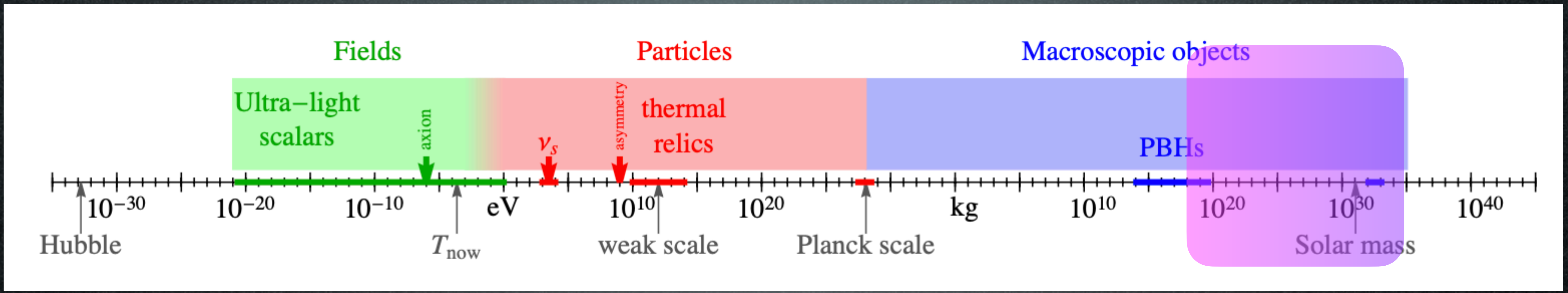


M. Cirelli, A. Strumia, J. Zupan 2406.01705

Candidates

A matter of perspective: plausible mass ranges



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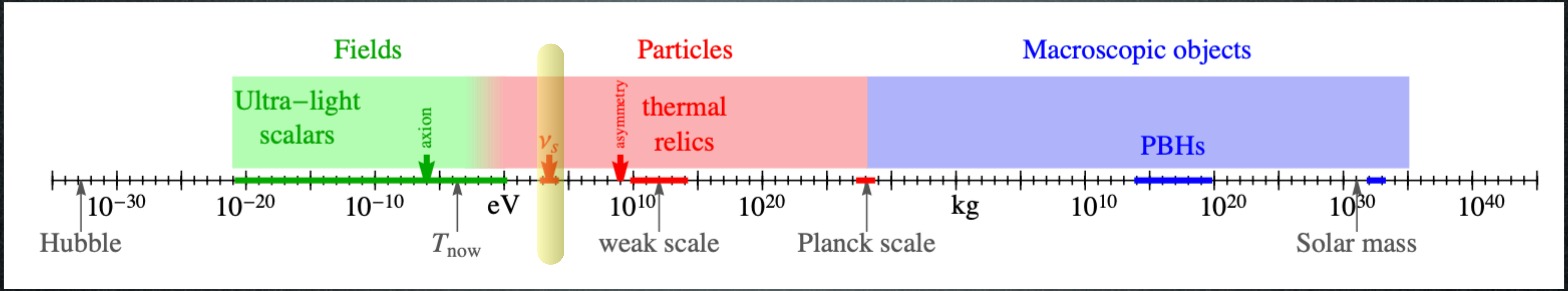


KeV DM?

X-ray line

Bulbul et al., 1402.2301

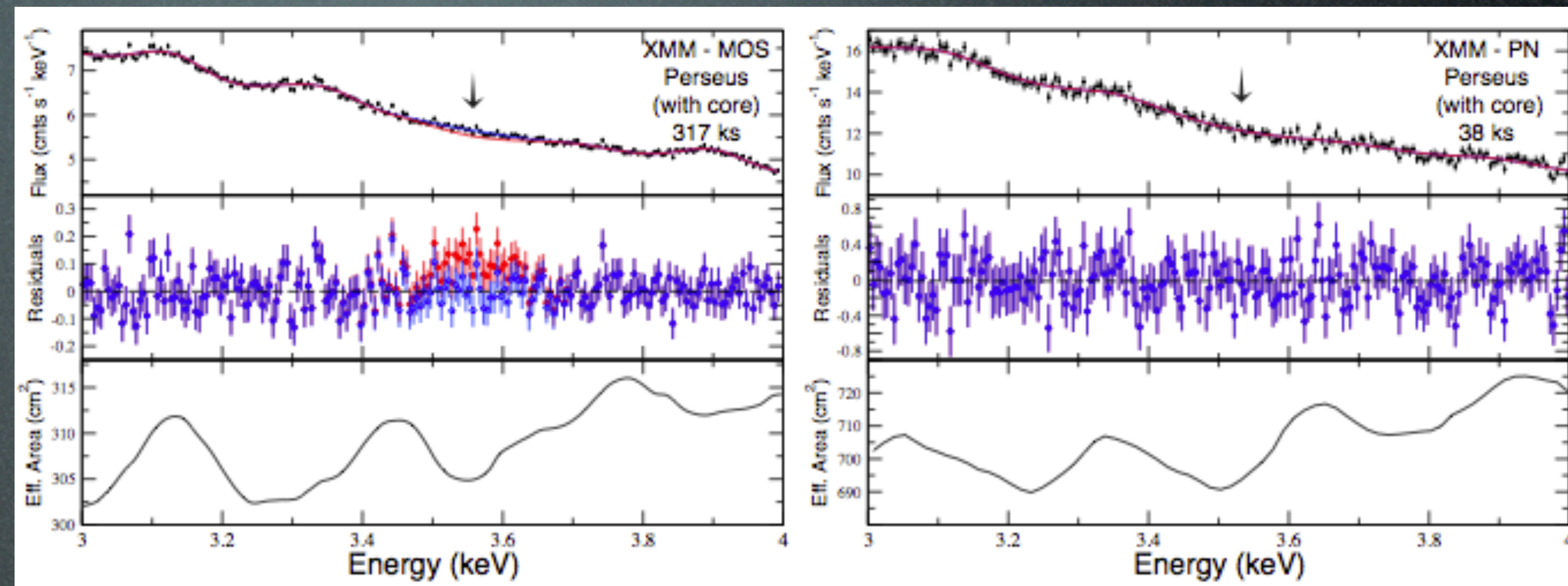
3.55 - 3.57 ± 0.03 KeV

73 clusters

(Chandra & XMM-Newton)

z = 0.01 - 0.35

$\gtrsim 4\sigma$



Boyarsky, Ruchayskiy, 1402.4119

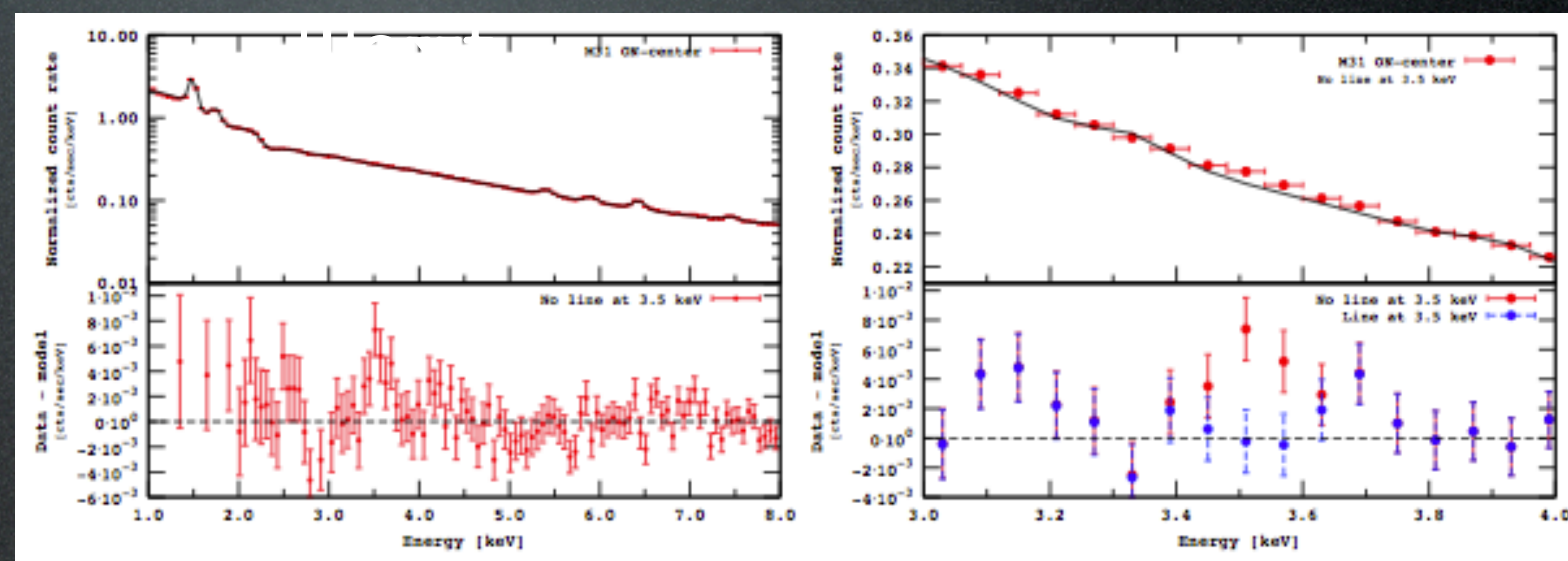
3.5 KeV

Andromeda galaxy
+ Perseus cluster

(XMM-Newton)

z = 0 and 0.0179

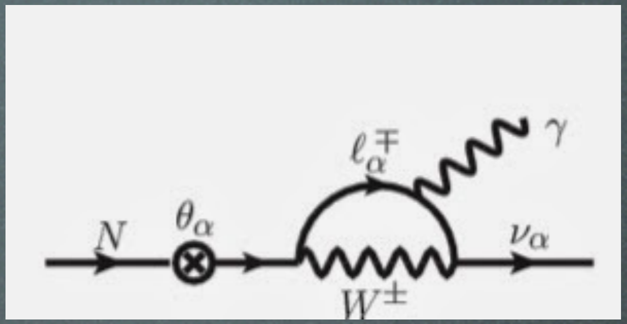
4.4σ

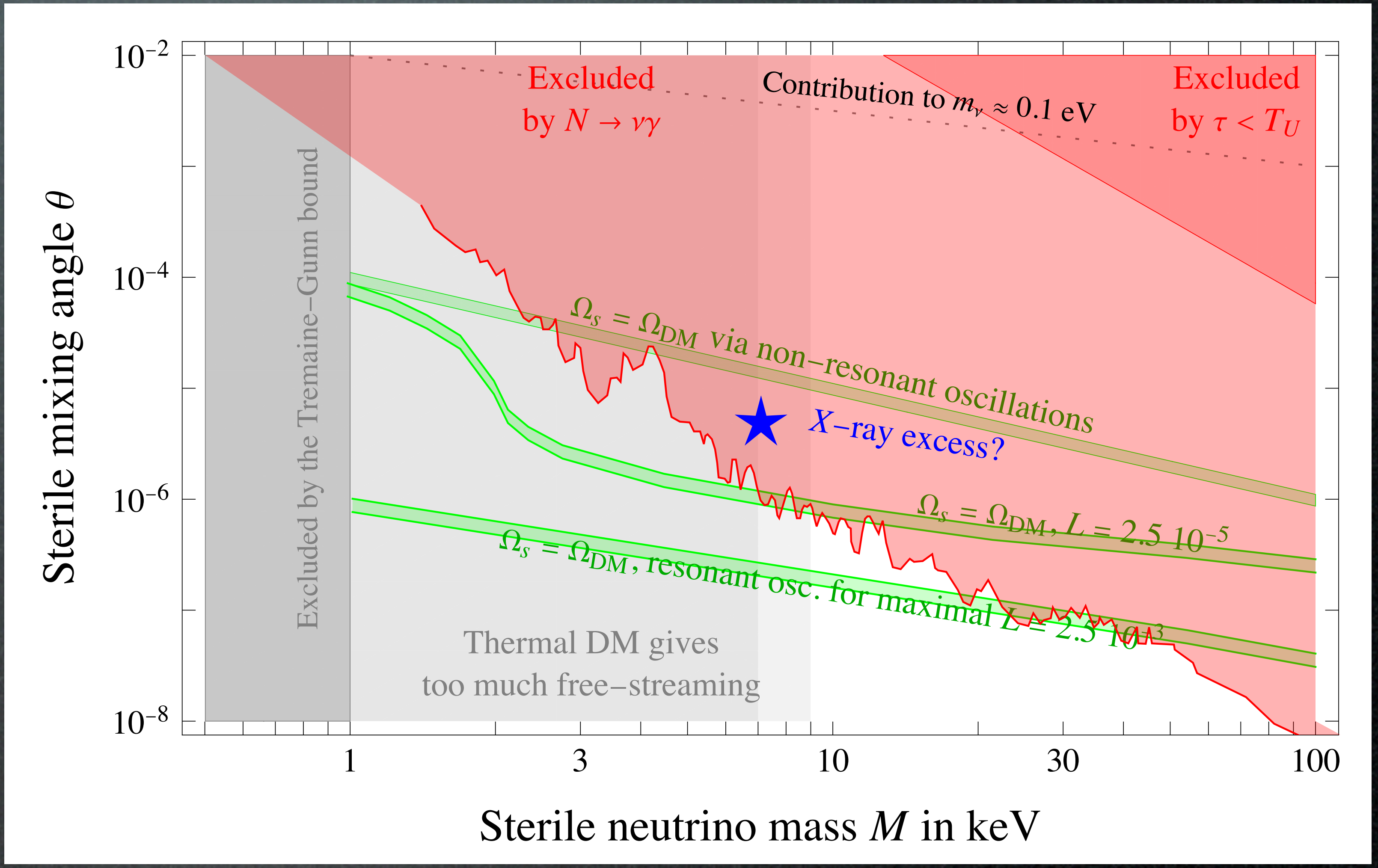


X-ray line

Sterile neutrino decay

$$m_\nu = 7.1 \text{ KeV}$$
$$\tau \simeq 10^{29} \text{ sec}$$
$$\sin^2 2\theta \sim \text{few } 10^{-11}$$





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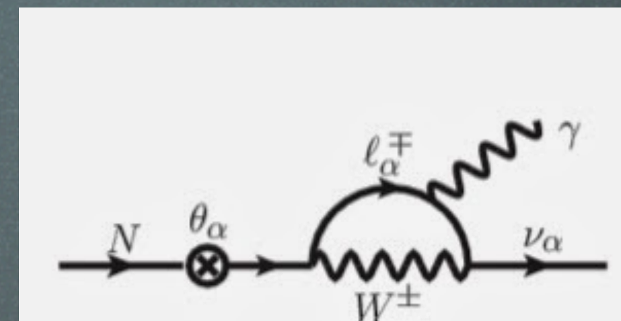

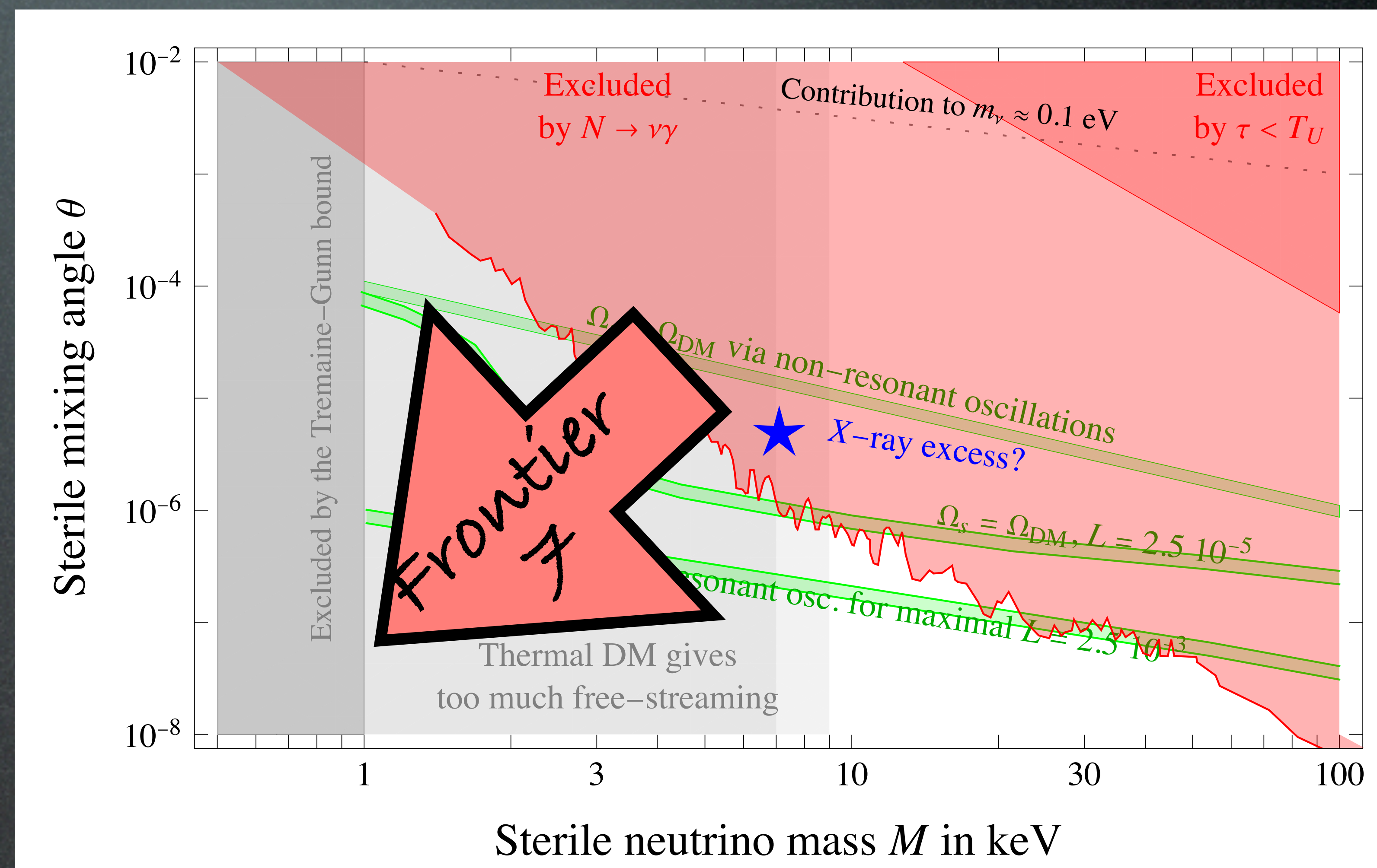

M. Cirelli, A. Strumia, J. Zupan 2406.01705

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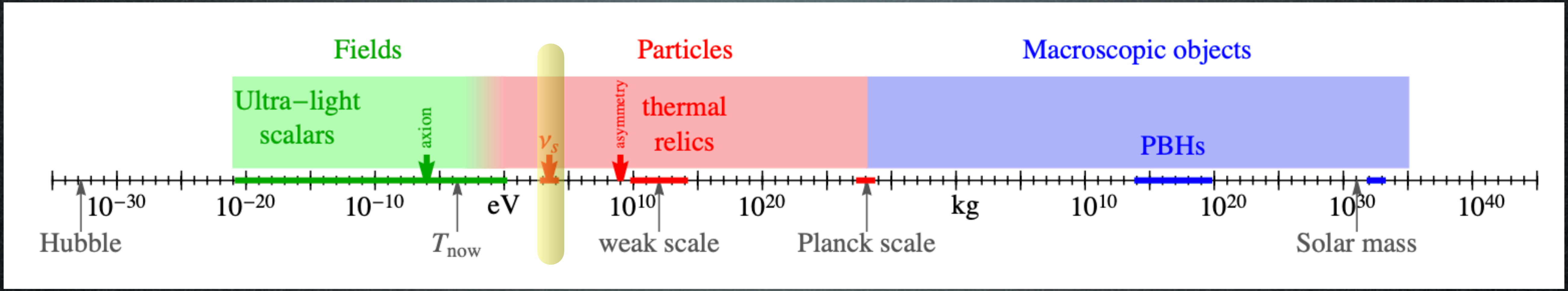

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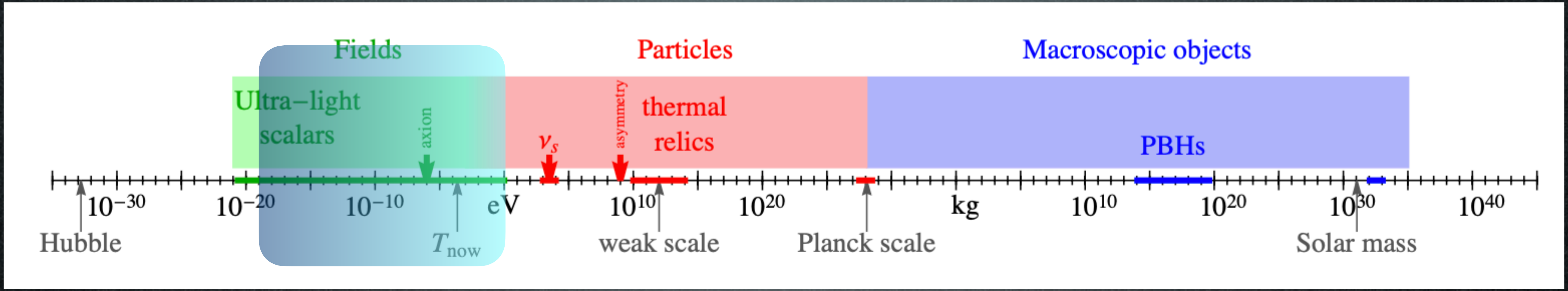


Axions

Theoretically motivated:

one can add to the SM $\mathscr{L} = \mathscr{L}_{\rm SM} - \theta \frac{g_3^2}{64\pi^2} G^a_{\mu\nu}\tilde{G}^a_{\mu\nu}$ $\left(\tilde{G}^a_{\mu\nu} \equiv \frac{1}{2}\epsilon_{\mu\nu\alpha\beta}G^a_{\alpha\beta}\right)$

which induces $d_n \approx \theta\ e\ m_\pi^2/m_N^2 \approx 10^{-16}\ \theta\ e\,\mathrm{cm}$

but experimentally $|d_n| \lesssim 3\ 10^{-26}\ e\,\mathrm{cm}$

so why is $|\theta| \lesssim 10^{-11}$?

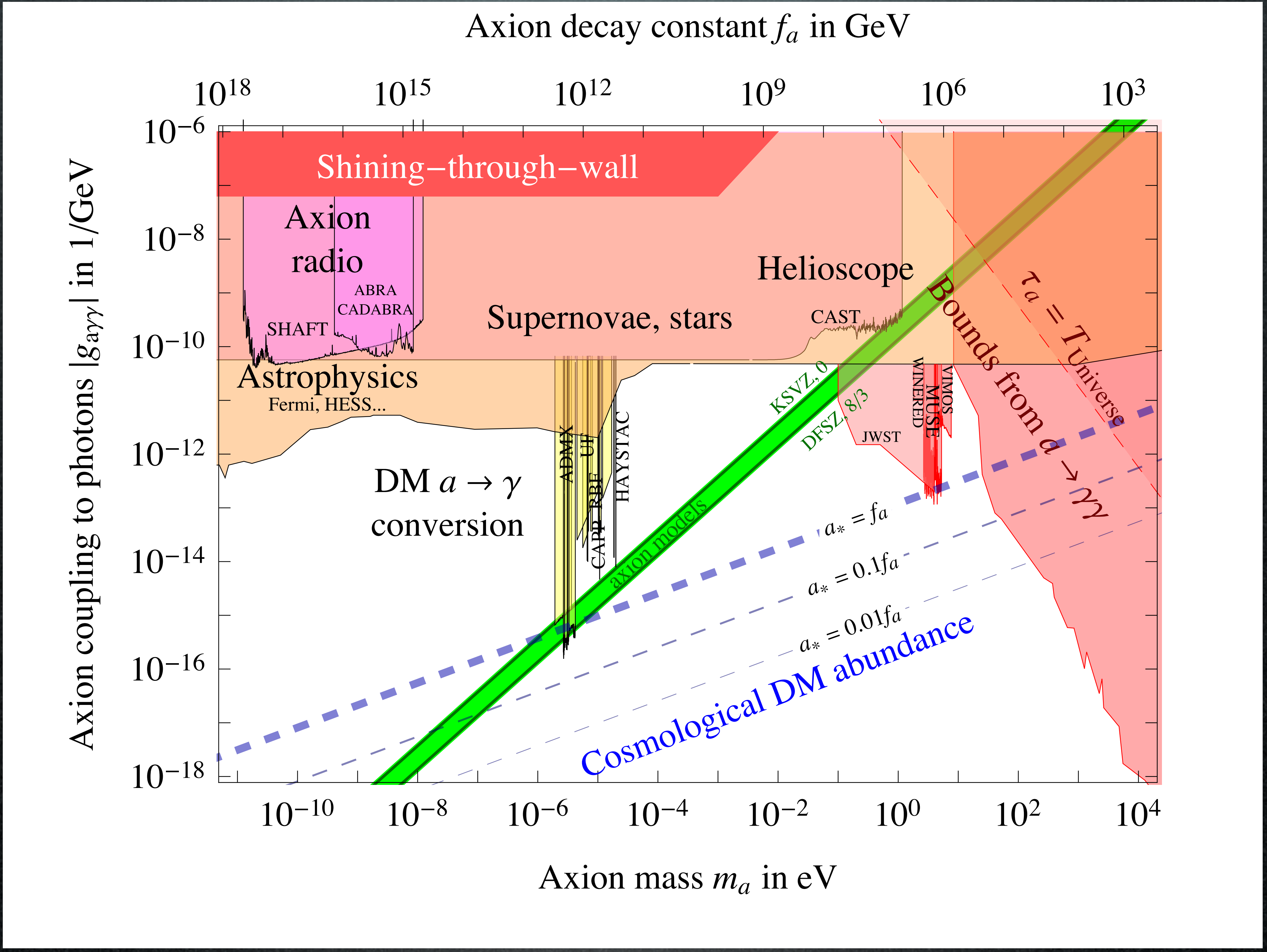
Perhaps because θ is dynamical (a field)

and driven to (almost) zero by its potential (symmetrical under $U(1)_{PQ}$).

In this case $m_a \approx 0.6\,\mathrm{meV}\frac{10^{10}\ \mathrm{GeV}}{f_a}$

Axions

Searches:



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

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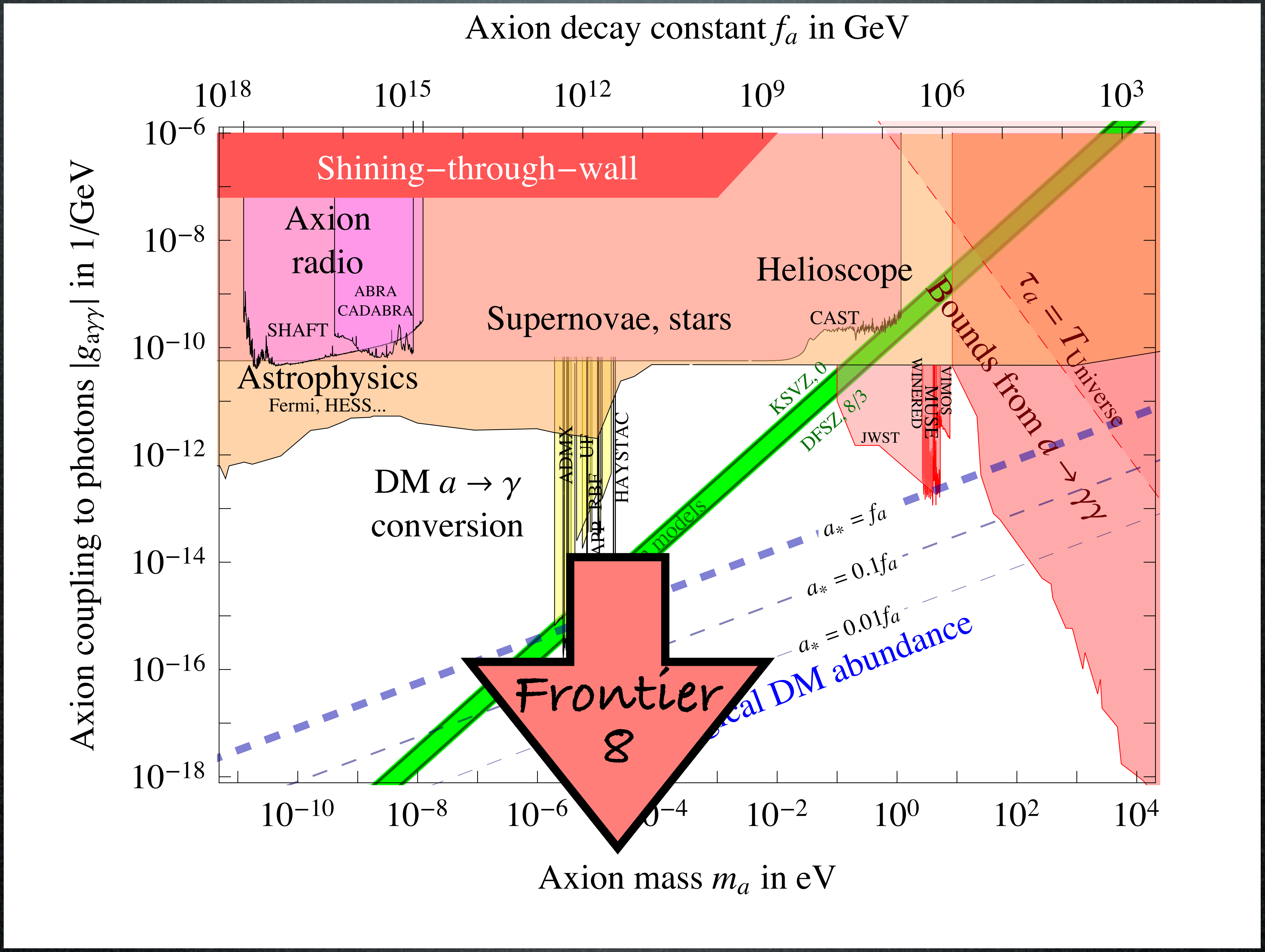

M. Cirelli, A. Strumia, J. Zupan 2406.01705

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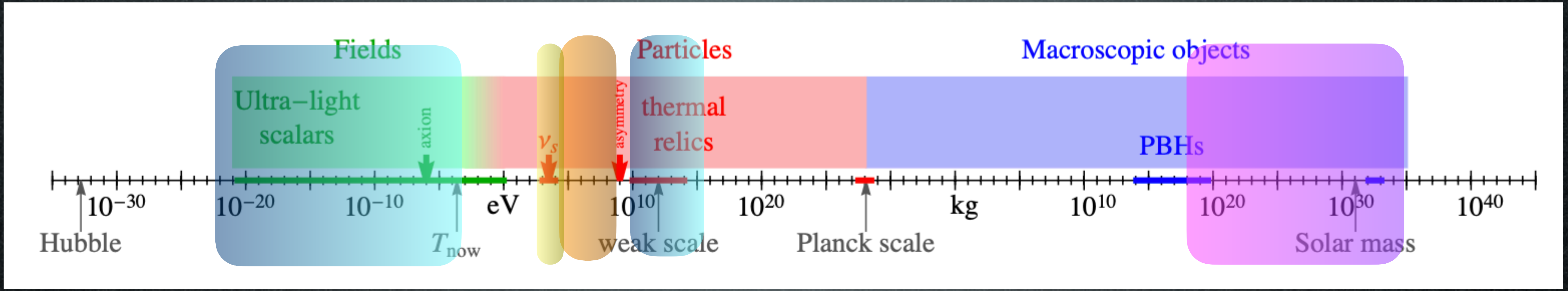

90 orders of magnitude!

Thermal DM?

Sub-GeV DM?

PBH DM?

KeV DM?

Ultralight DM?

Conclusions

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The physics of Dark Matter is
in an experiment driven phase

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Theory can (does) point to preferred directions,
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Conclusions

The physics of Dark Matter is
in an experiment driven phase

Theory can (does) point to preferred directions,
but actually too many…

Thermal DM? still motivated, frontier is heavy DM
Sub-GeV DM? why not? Challenging detection
PBH DM? old idea with new vibes
KeV DM? phenomenological
Ultralight DM? old idea with new vibes

Conclusions

The physics of Dark Matter is
in an experiment driven phase

Theory c… n (does) point to prefe… ctions,
but ac… too many…

Thermal DM?
Sub-GeV D…
PBH DM?
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Ultralight DM?

still w… d, frontie… heavy DM
why … ot? Chall… ection
old idea … ew vibes
…nomenological
o… with new vibes

Frontier 1

Frontier 2

Frontier 3

Frontier 4

Frontier 5

Frontier 6

Frontier 7

Frontier 8

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? Frontier 9

Frontier 6

Frontier 4

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Frontier 2

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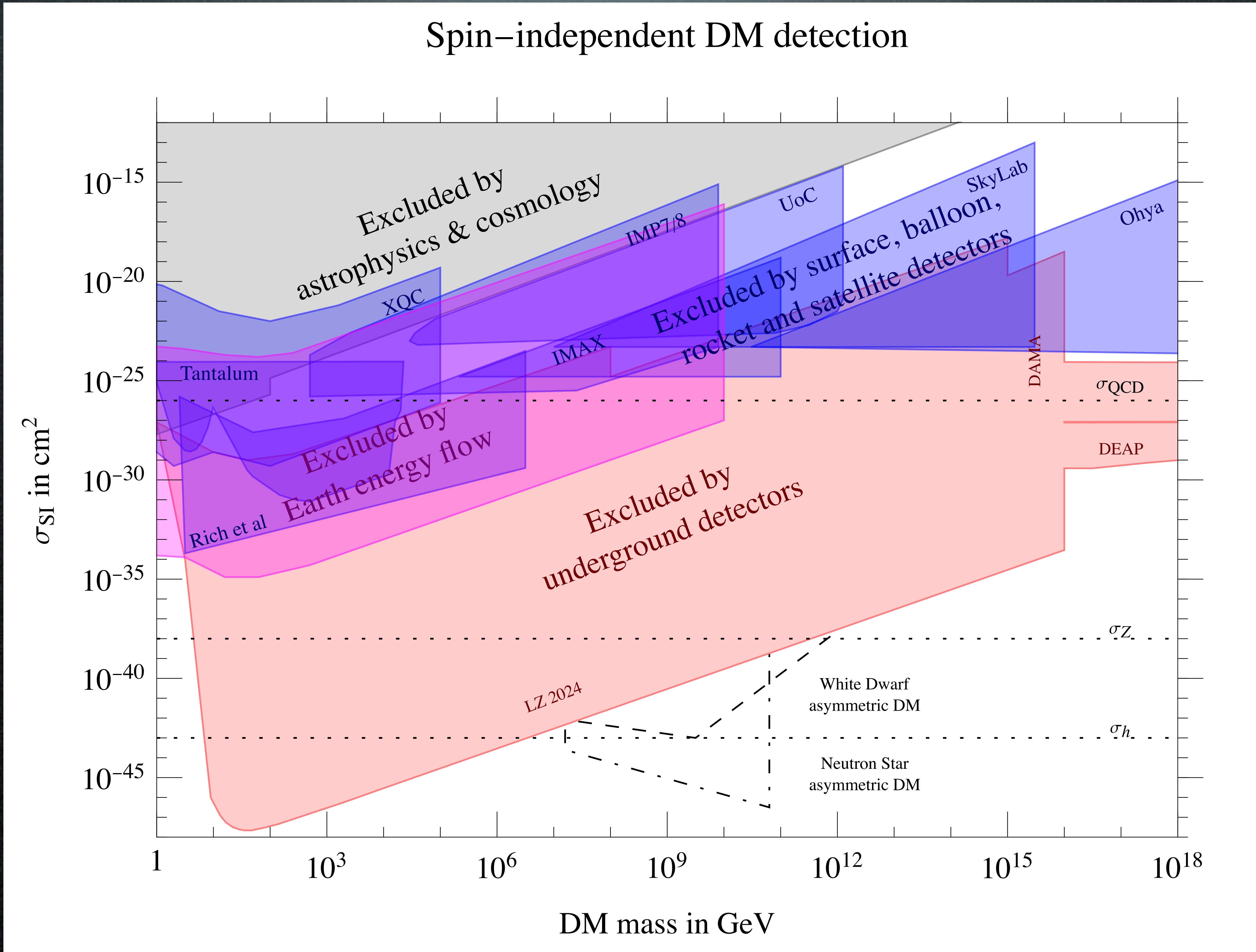
Frontier 7

Frontier 8

Frontier 5

DD of strongly int DM



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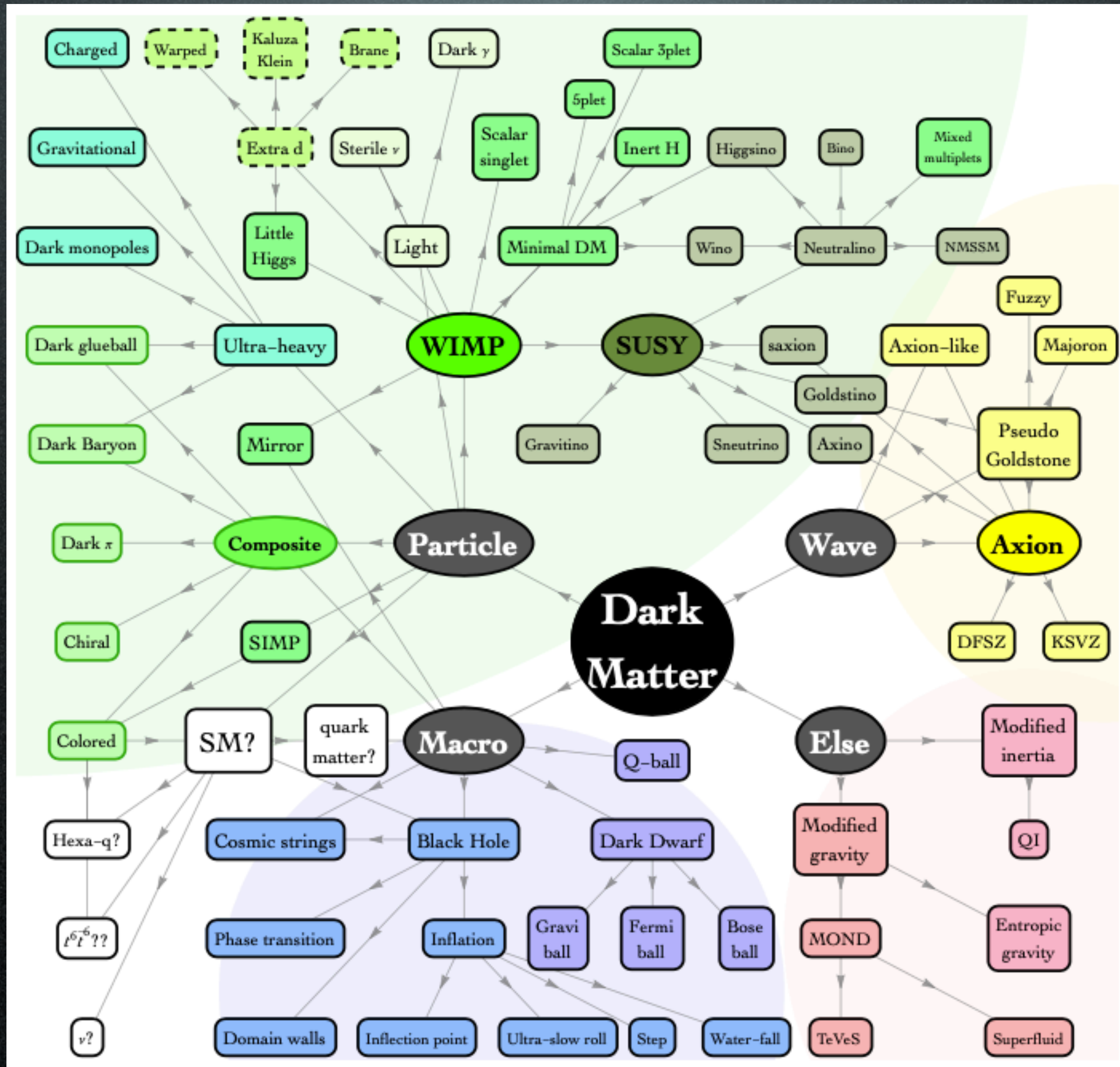
A map of DM candidates



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Backup

Candidates

The Dark Matter
theory space:

Candidates

The Dark Matter
theory space:

SuSy DM

Non SuSy DM

Candidates

The Dark Matter theory space:

SuSy DM

Non SuSy DM

NON SOLO PIZZA

LA VERDADERA PIZZA Y PASTA ITALIANA
PLAZA P. CANA - BAVARO - 809 552 1547

?

Candidates

A matter of perspective:

SuSy neutralino

other exotic candi- dates

Candidates

A m
p

graviballs DM
Zombie DM
Puffy DM
Steal DM
Large Nightmare DM
omeopathic DM
Ballistic DM
Spectato DM
Undulating DM
Fuzzy DM
Minimal DM
Impede DM
Cannibal DM
Anapole DM
Axino
Scalar singl
dipolar DM
Little Higgs DM
Fluffy DM
Asym-metric DM
ELDER DM
SuSy neutralin
self-destructing DM
SIMPs
foamy DM
ISPy DM
Techi-baryon
Rayleig DM
-inter DM
GUTz DM
eXciting
Inflatable DM
WIMPzillas
Dichromatic DM
xio
STUMP DM
charming DM
Vector DM
Leptobary DM
Pandemic DM
bidden DM
WIMPless DM
eclu DM
Relentless DM
ncentrated DM
heavy higgs DM
rr atte
Sterile Neutrino
Luminous DM
Geometric DM
luza ein DM
Elko DM
Gravitino
Q-balls
quark uggets
MeV DM
Fluorescent DM
dark photon
Imperfect DM
Magnetic inelasti DM
Higgs ploding DM
Mimetic DM

Candidates

The Dark Matter theory space:

Candidates

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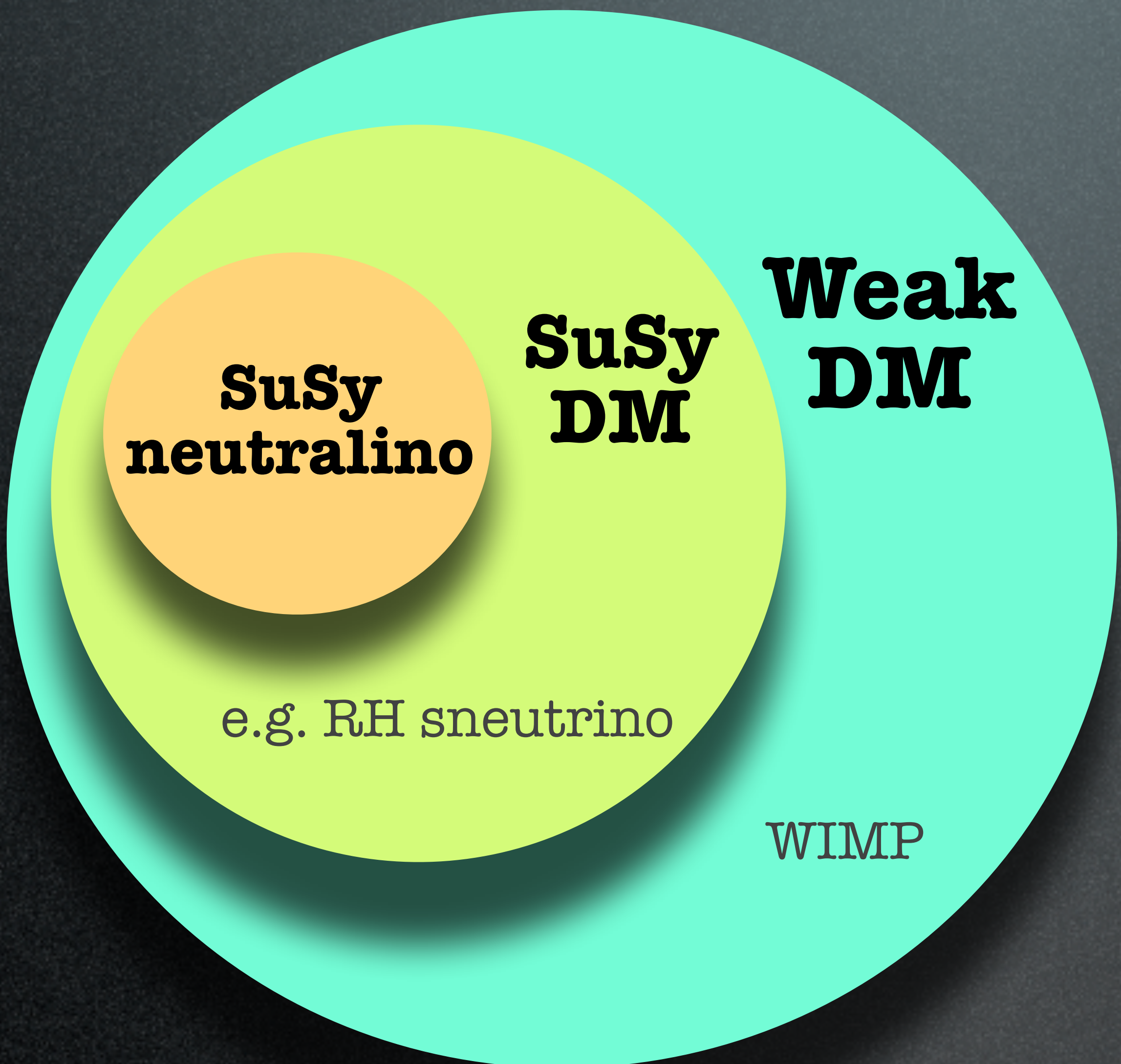
Candidates

The Dark Matter
theory space:



Candidates

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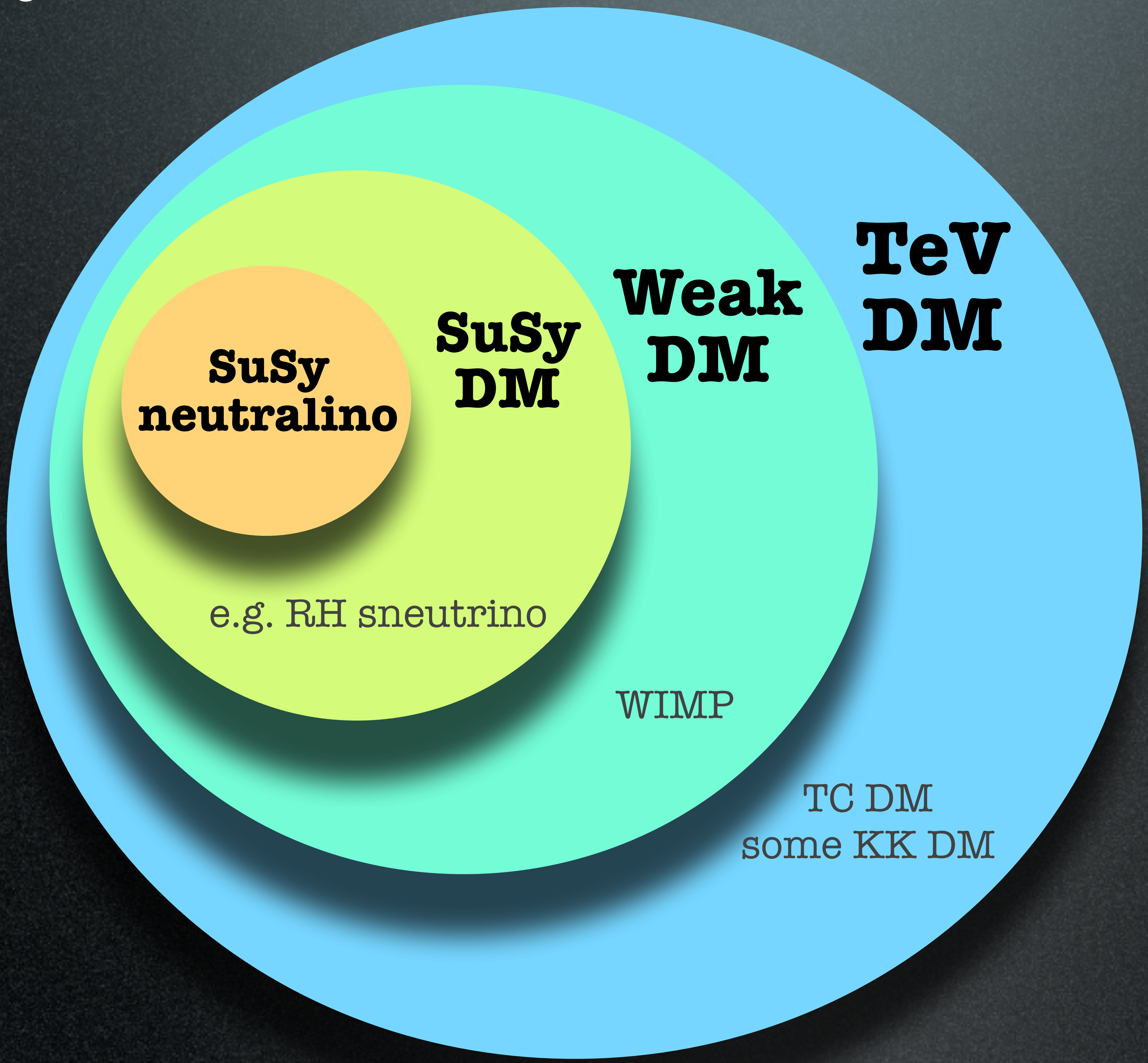

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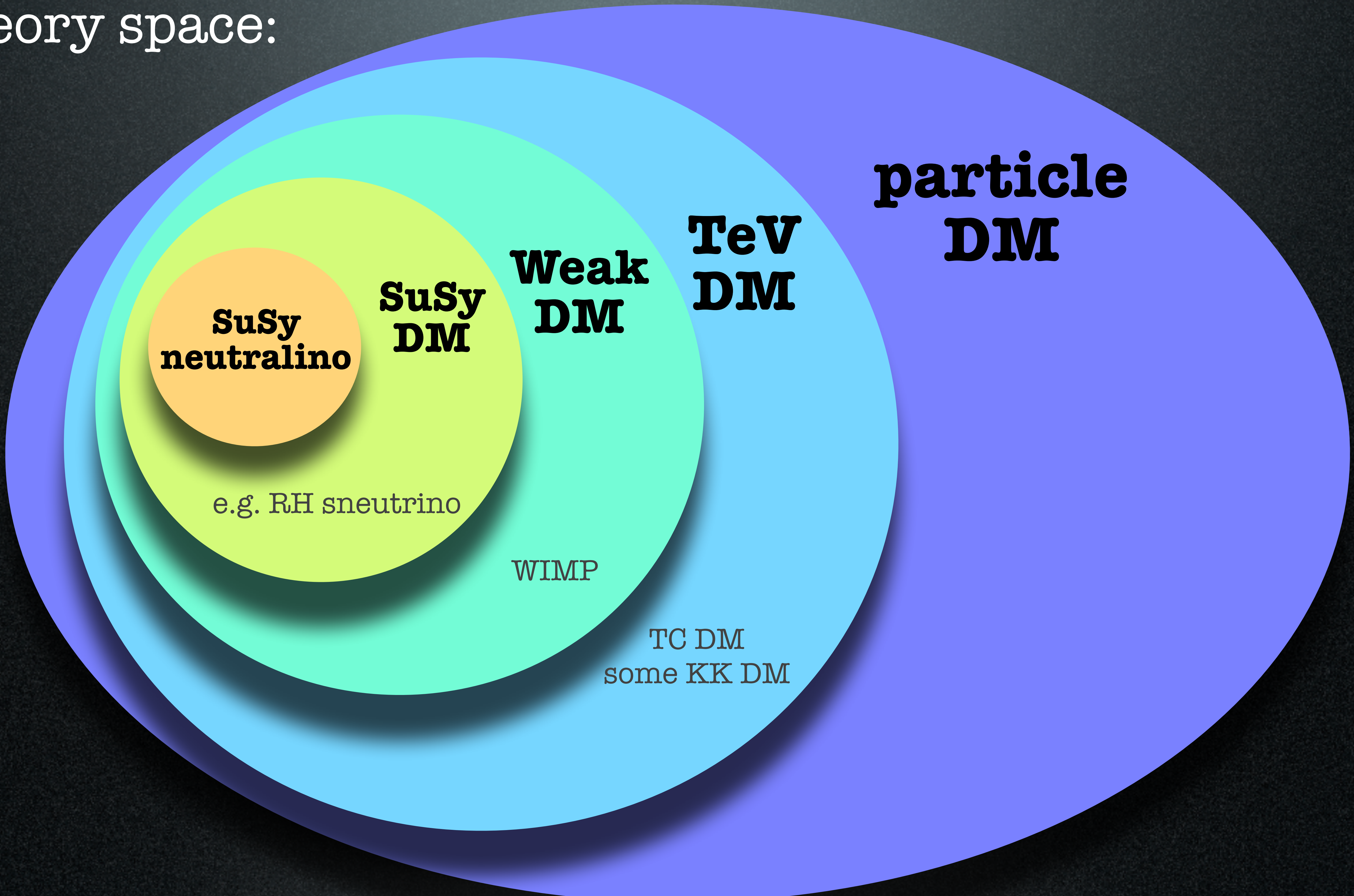

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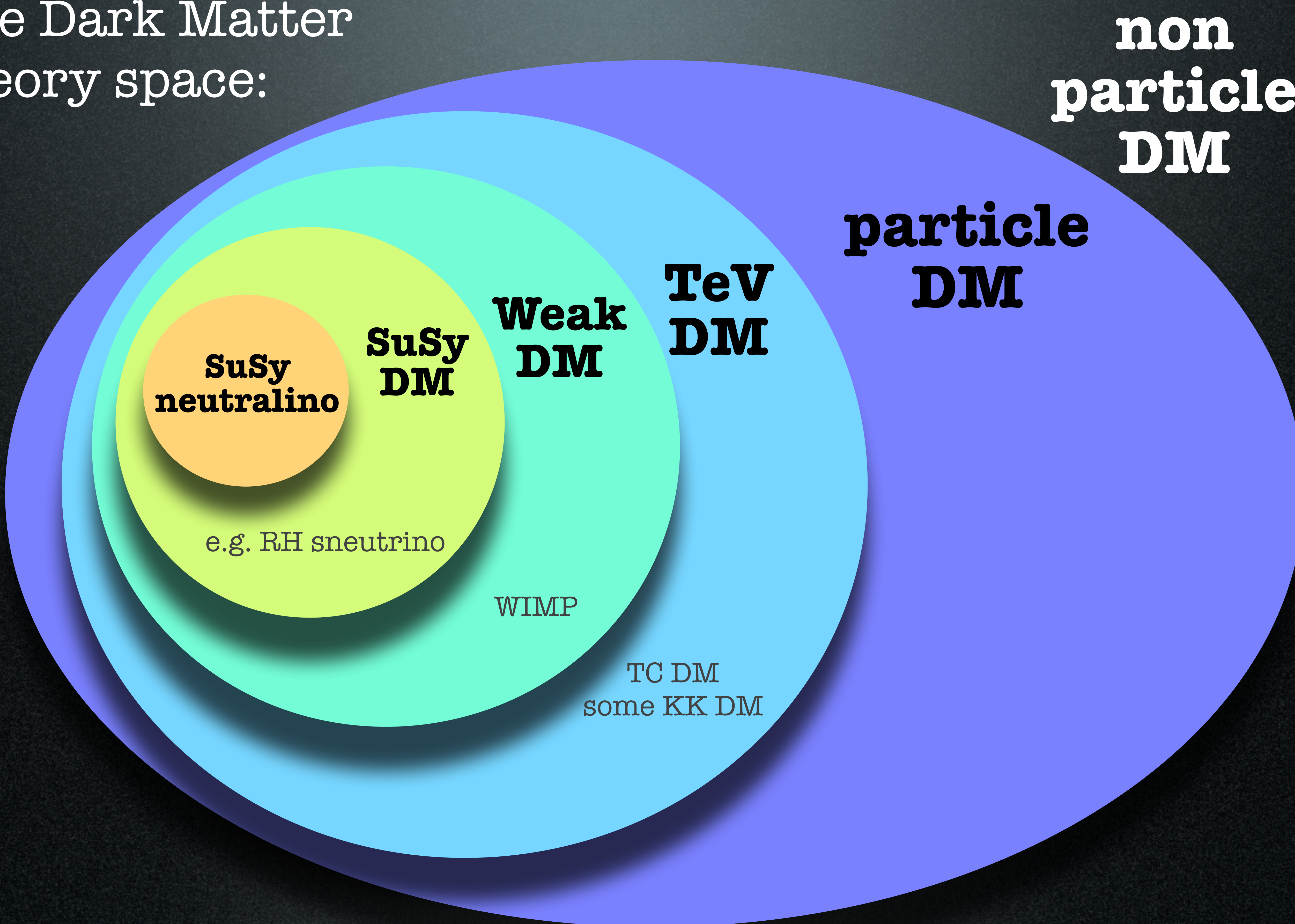
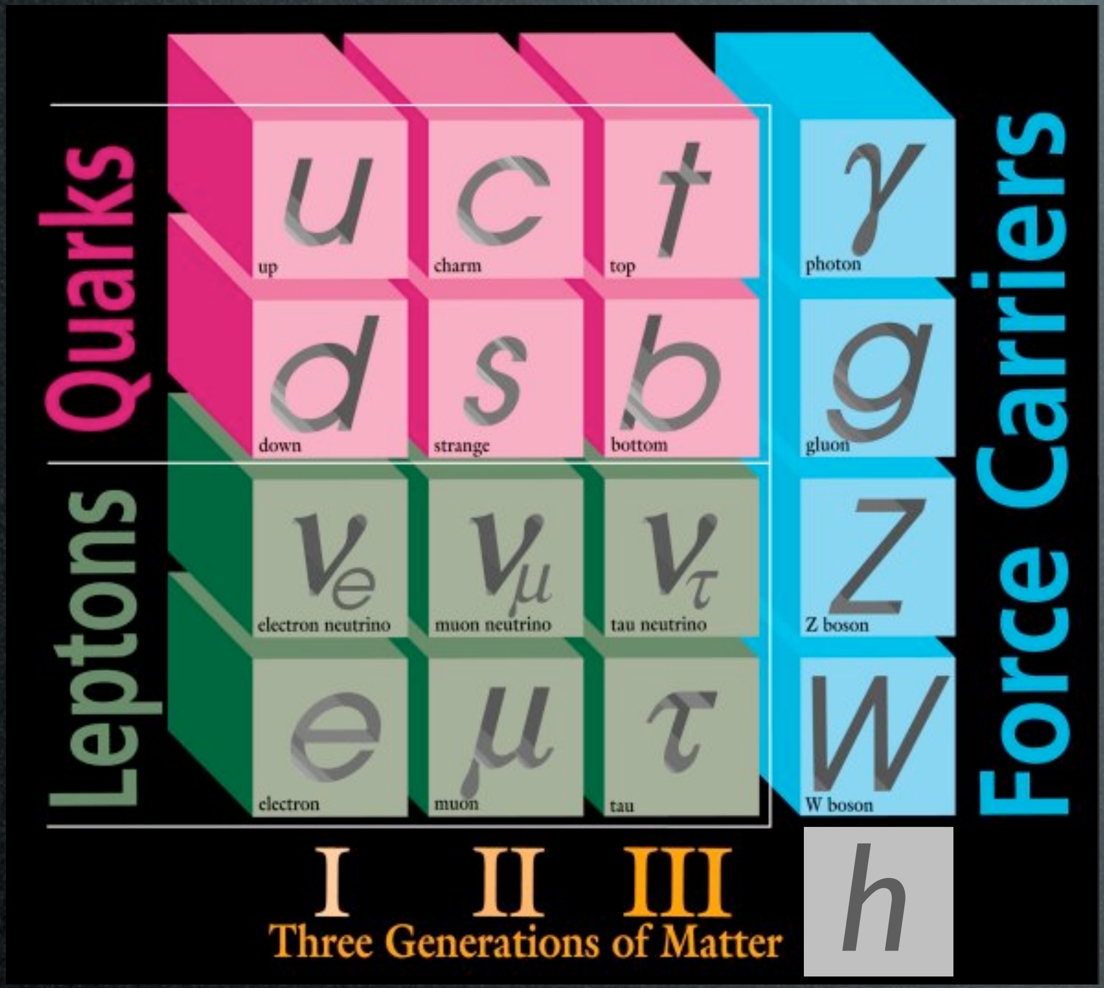


SuSy DM in 2 minutes



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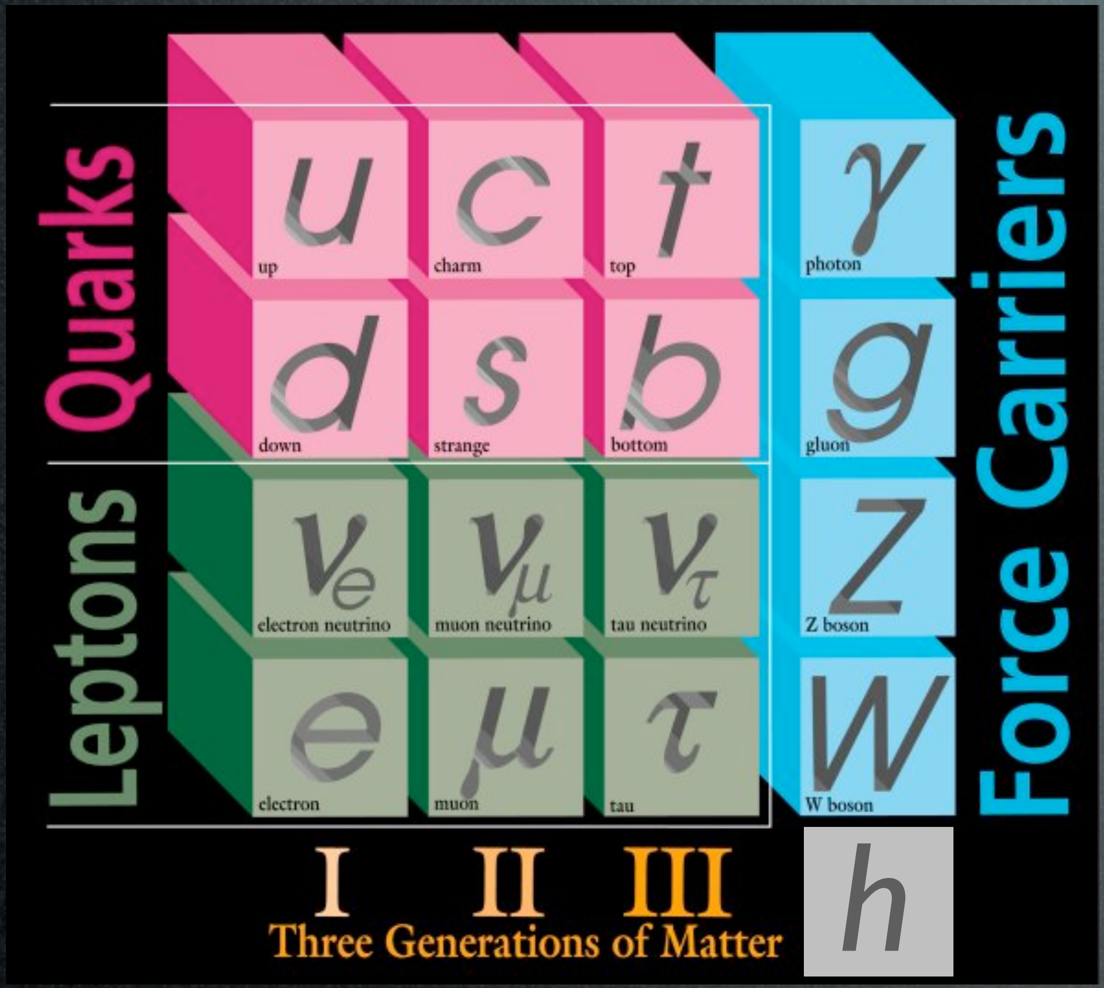
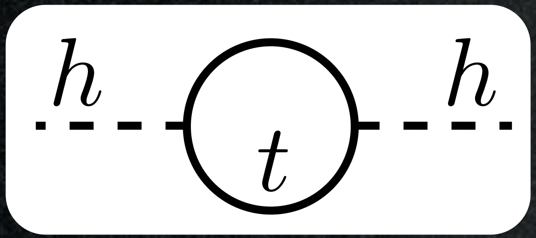


$m_{\mathrm{h}} \simeq 125\ \mathrm{GeV}$



$\Delta m_{\mathrm{h}} \propto 10^{19}\ \mathrm{GeV}$

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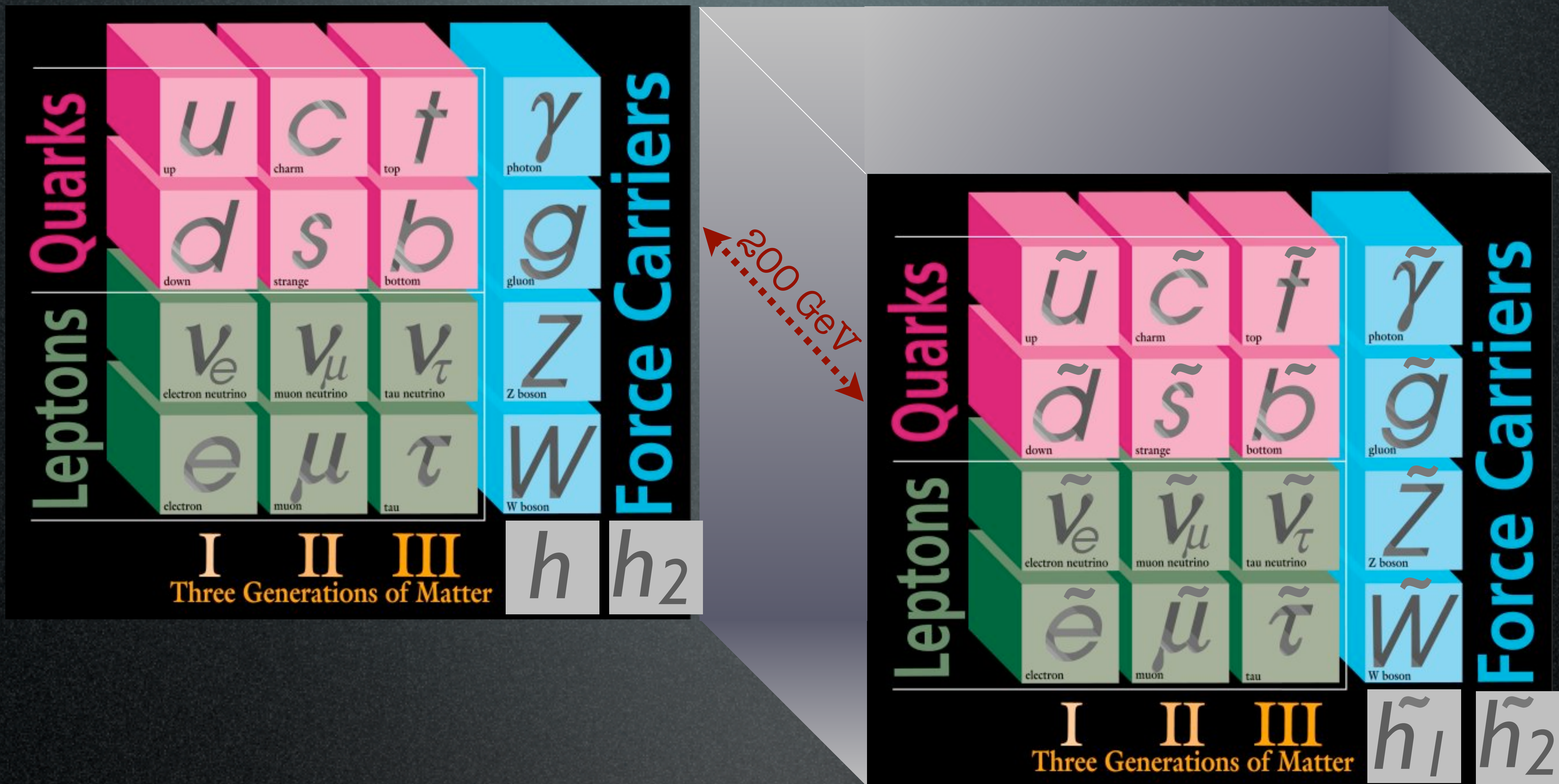
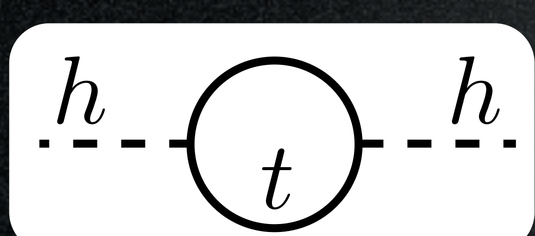


$m_{\rm h} \simeq 125$ GeV



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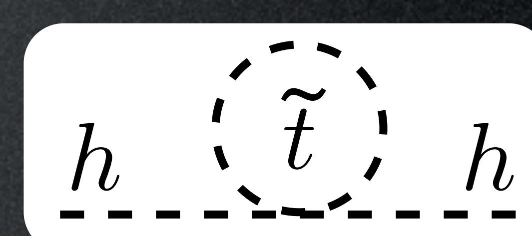

$\Delta m_{\rm h} \propto -10^{19}$ GeV

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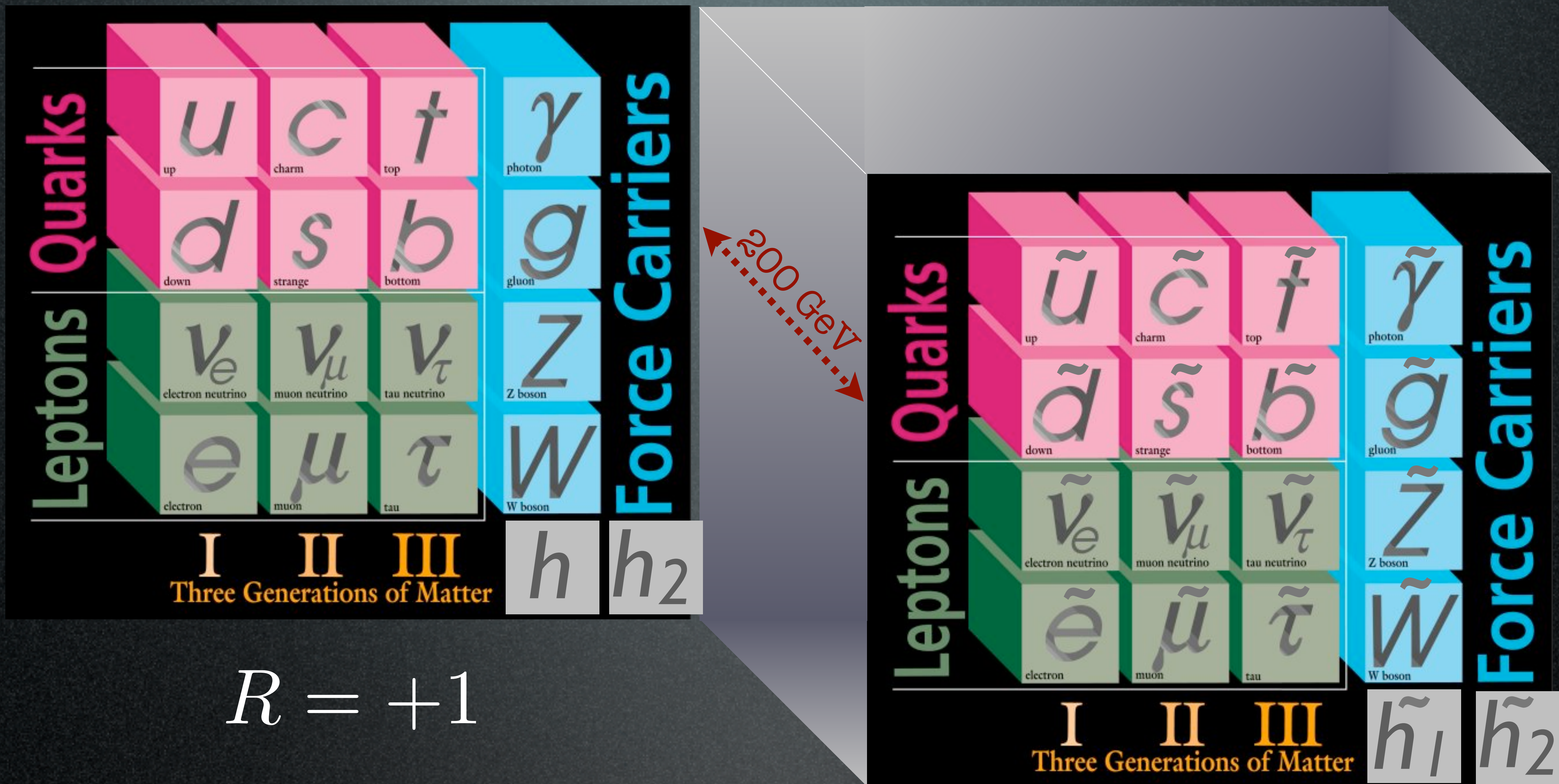
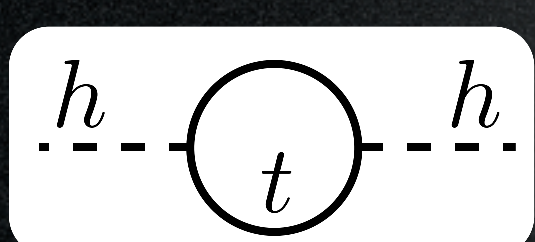


$R = +1$

$R = -1$

$m_{\mathrm{h}} \simeq 125$ GeV



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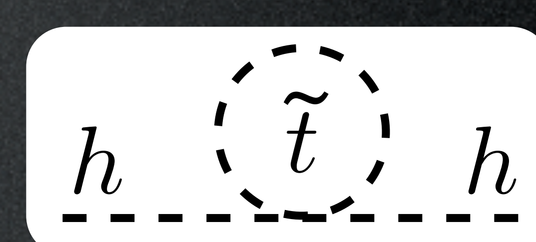
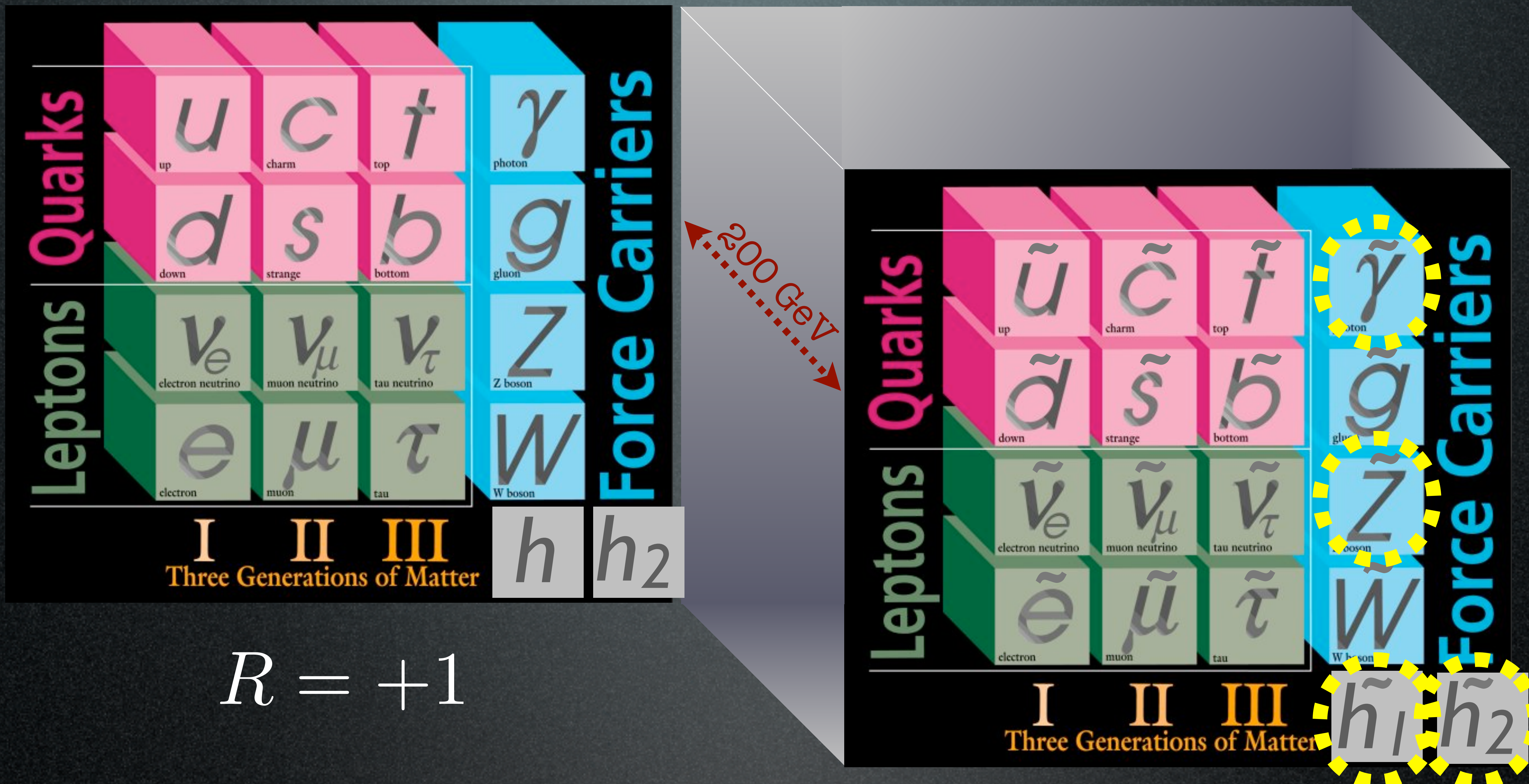


$\Delta m_{\mathrm{h}} \propto -10^{19}$ GeV

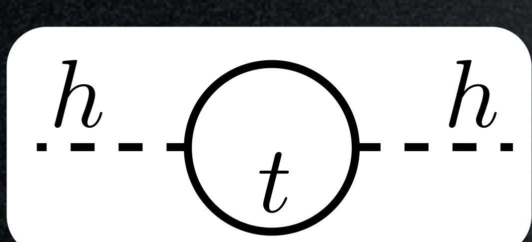
SuSy DM in 2 minutes



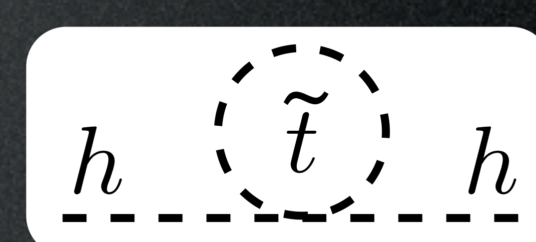
$$R = +1$$

$$R = -1$$

$$m_{\rm h} \simeq 125 \text{ GeV}$$



$\Delta m_{\rm h} \propto 10^{19}$ GeV



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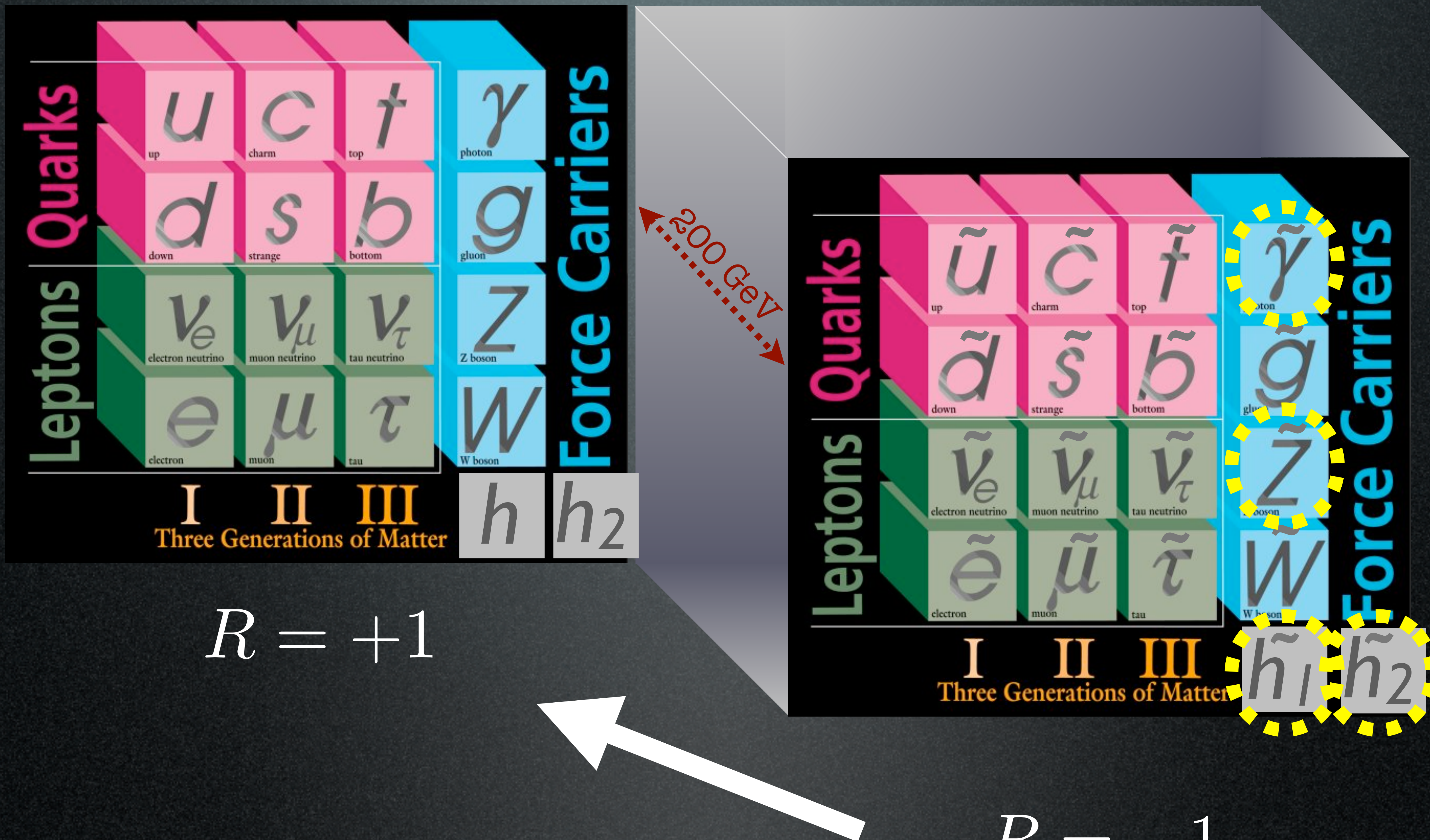

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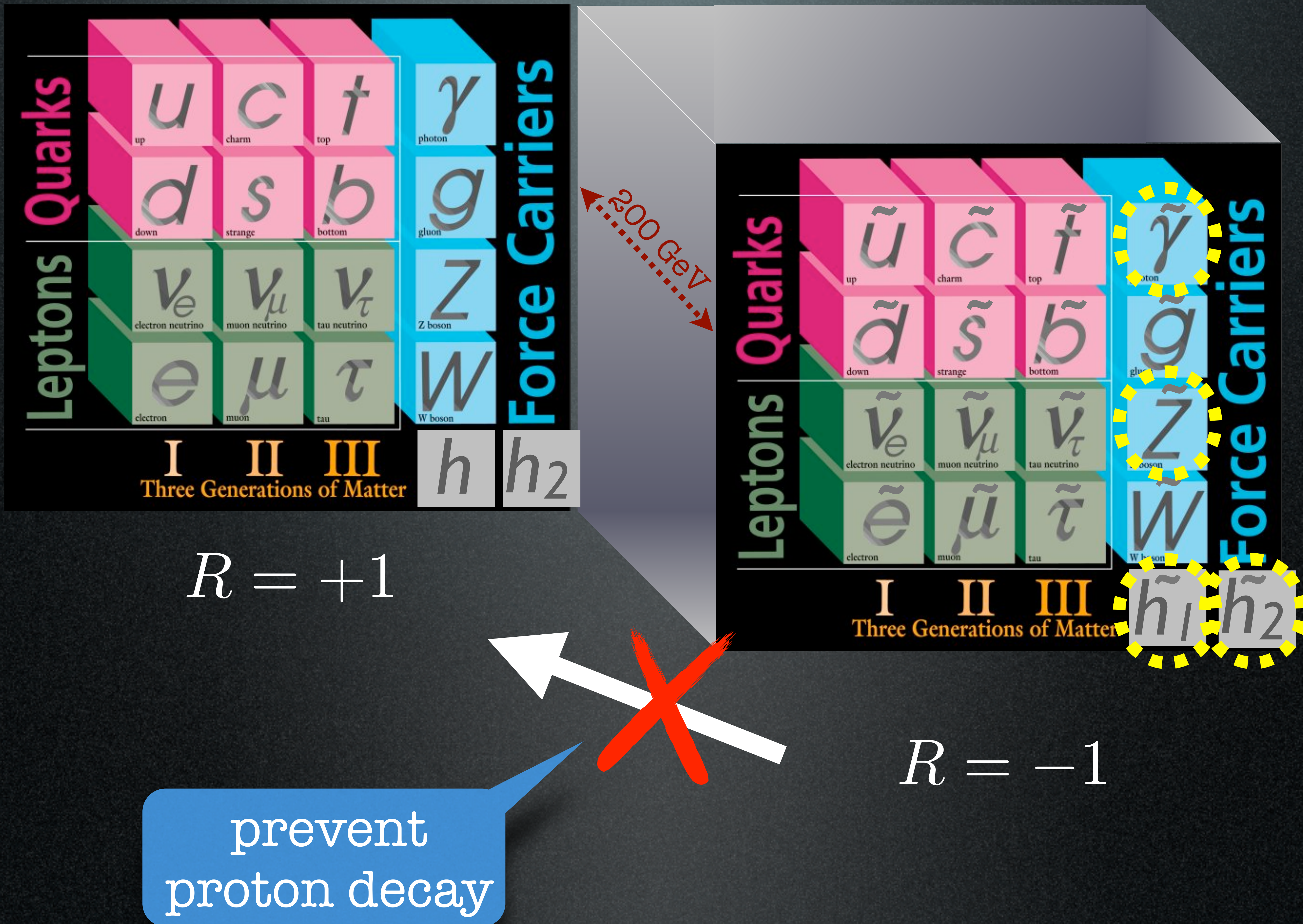

WIMP DD: ‘**theory**’

SM weak scale SI interactions

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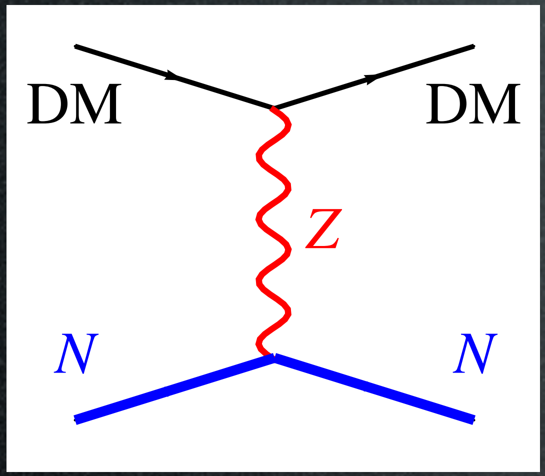

tree level,
vector

$$\sigma_{\rm SI} \sim \frac{\alpha^2\ m_N^2}{M_Z^4}$$

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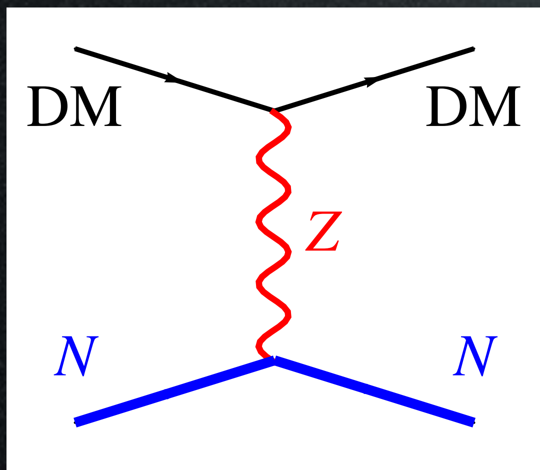
SM weak scale SI interactions



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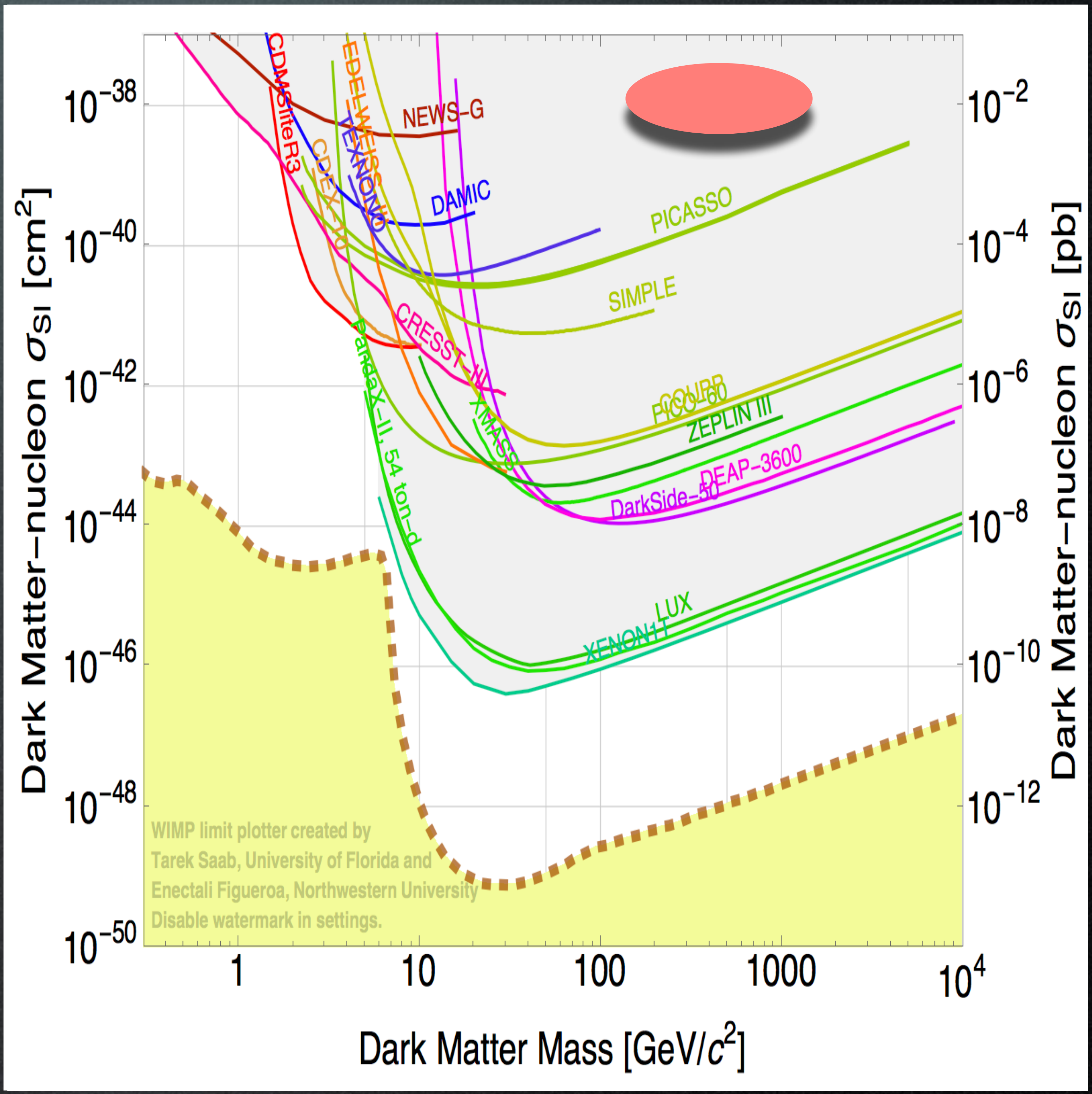

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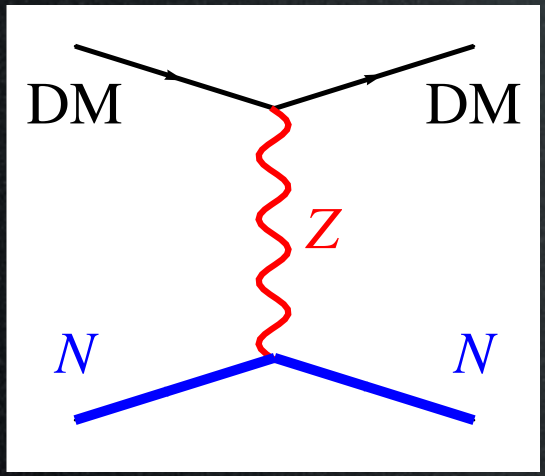

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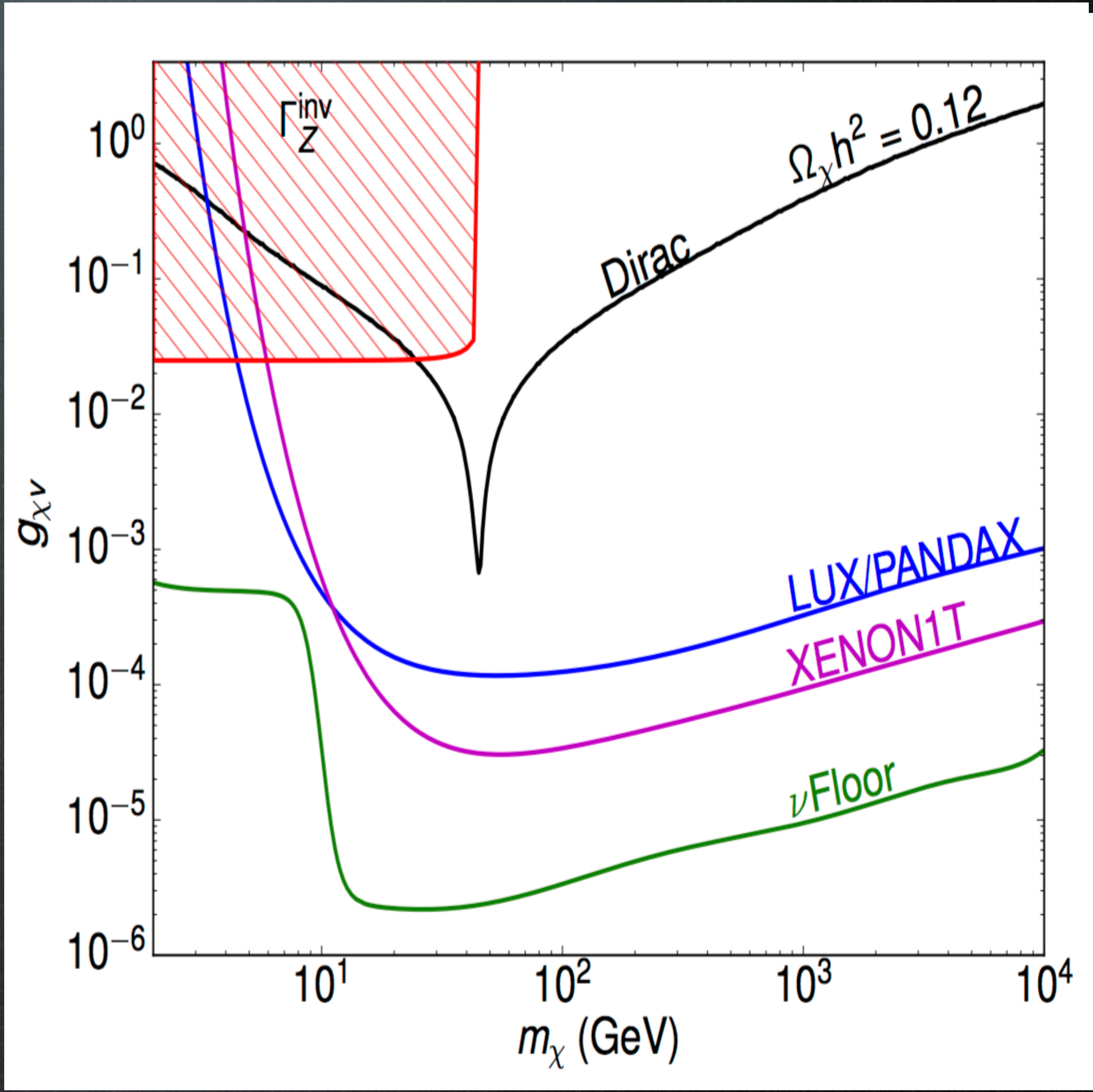

Escudero, Berlin, Hooper, Lin 1609.09079

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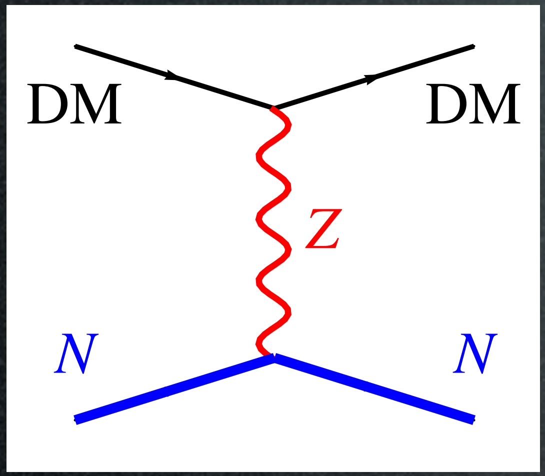

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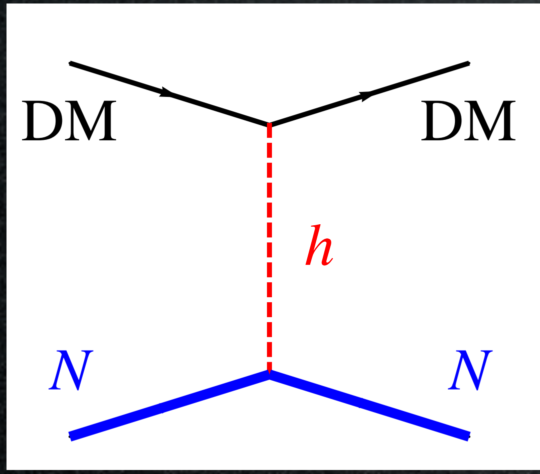

tree level, scalar

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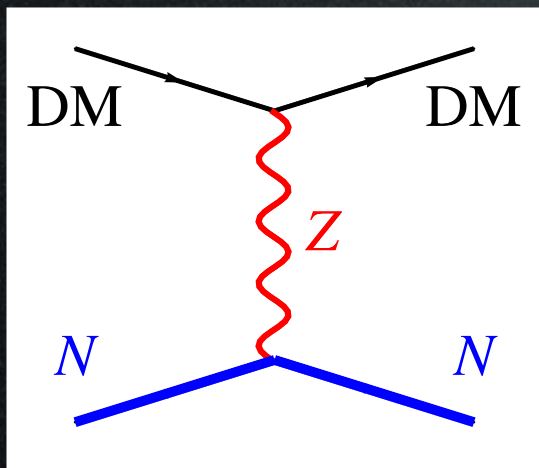
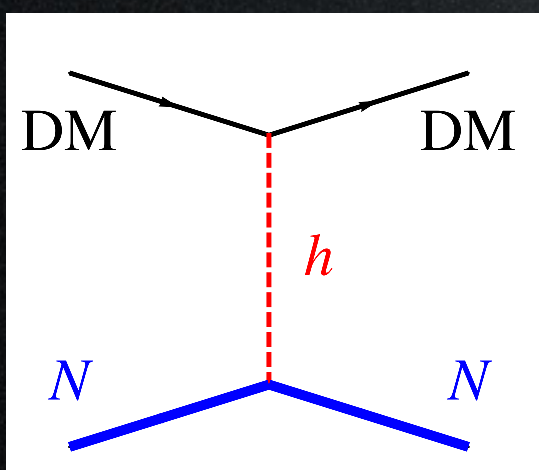
WIMP DD: 'theory'

SM weak scale SI interactions



tree level, vector



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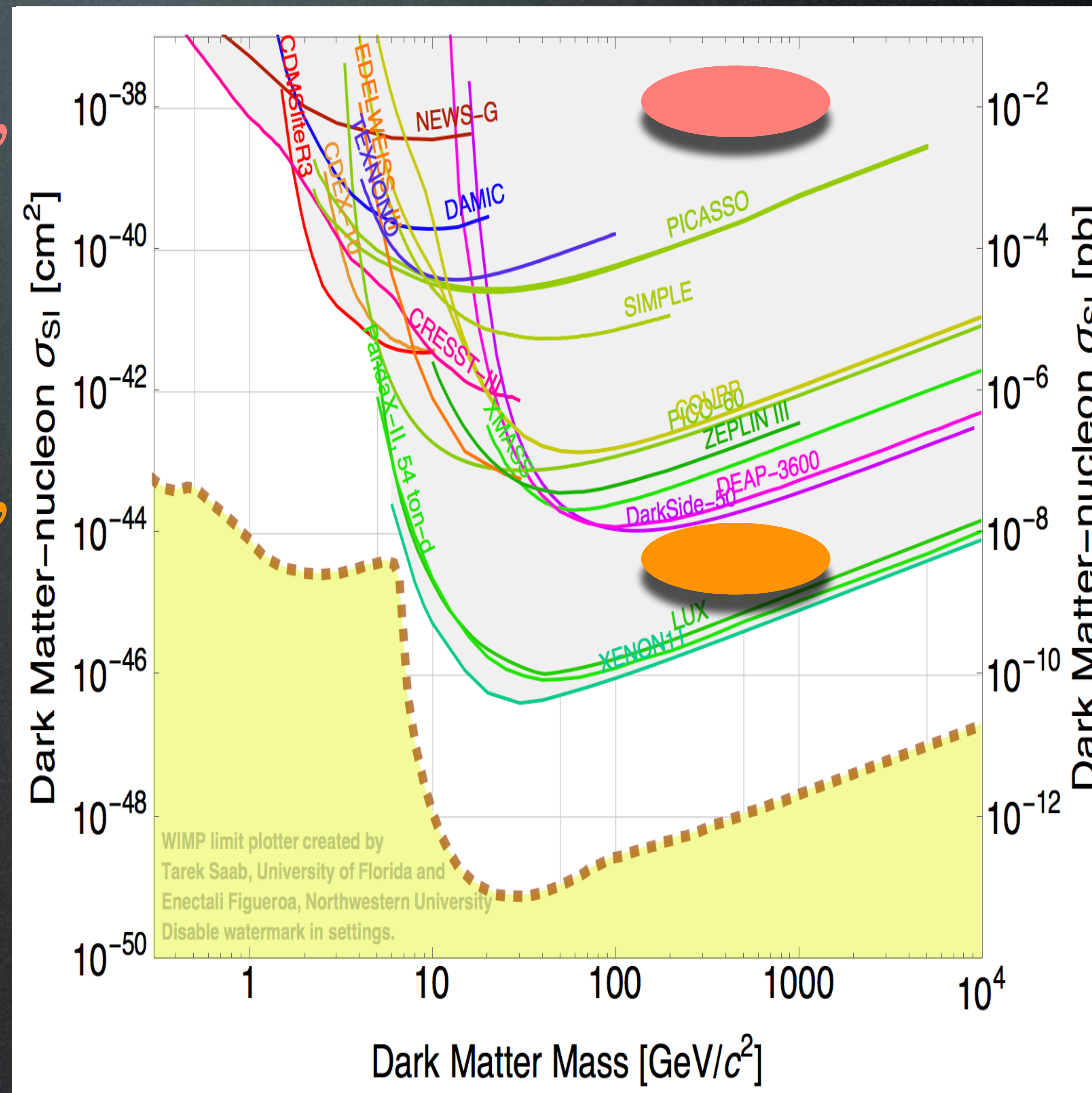

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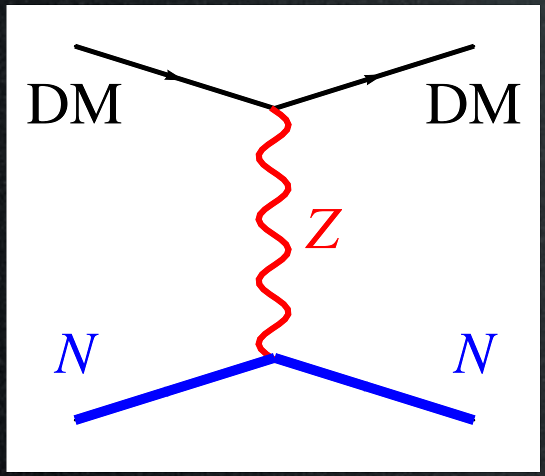

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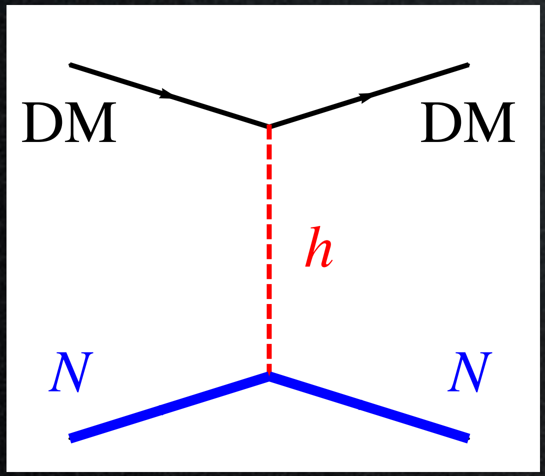

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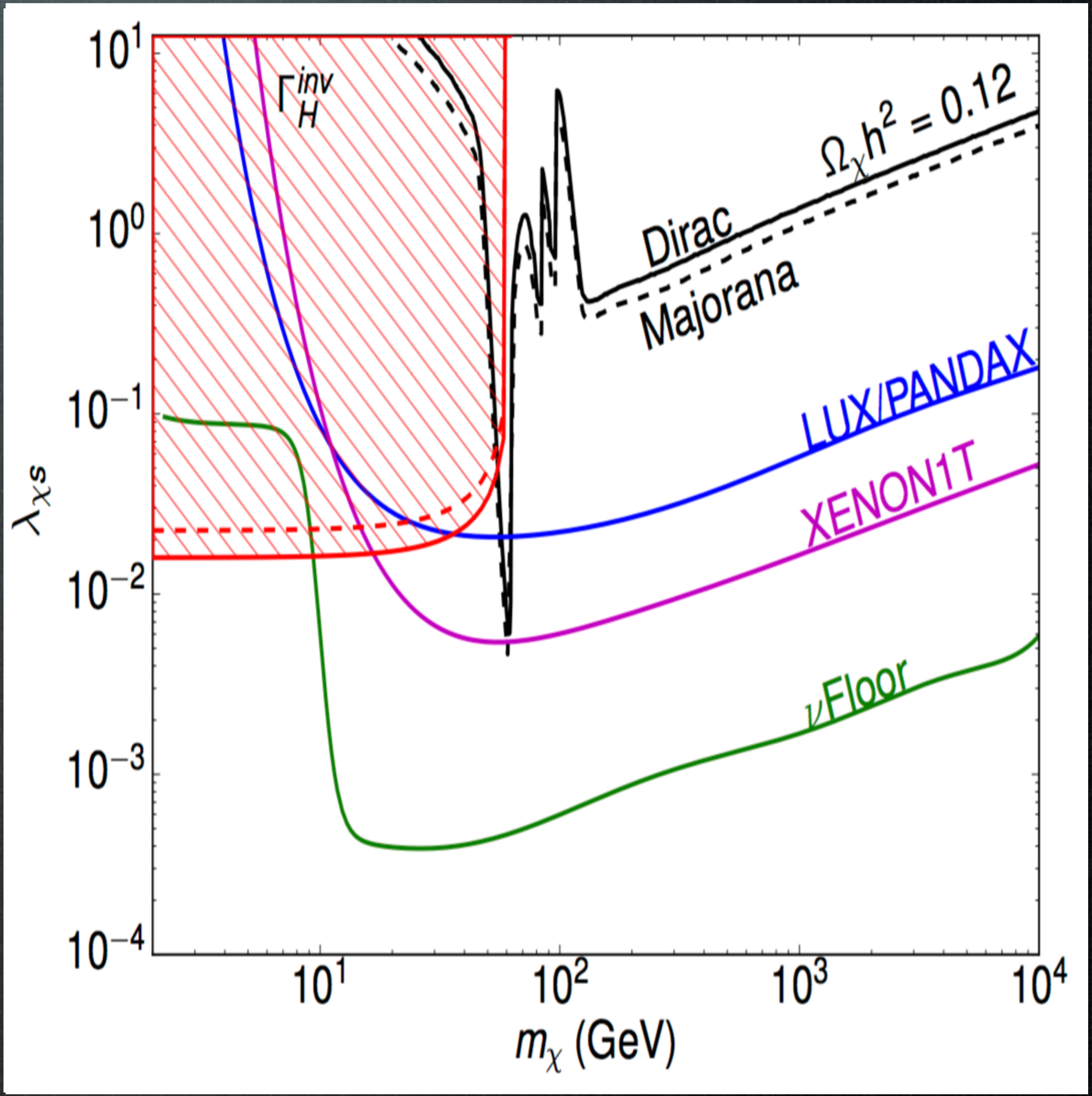

Escudero, Berlin, Hooper, Lin 1609.09079

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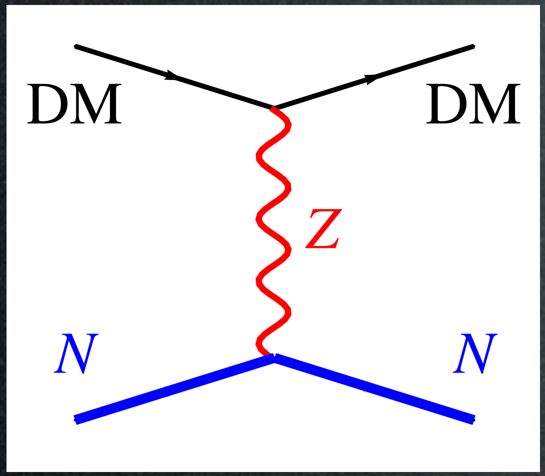

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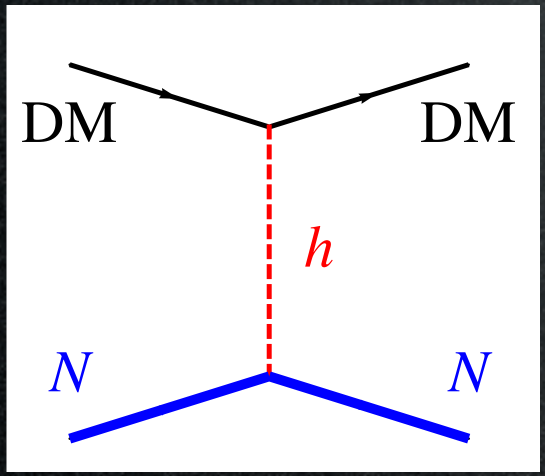

tree level, scalar

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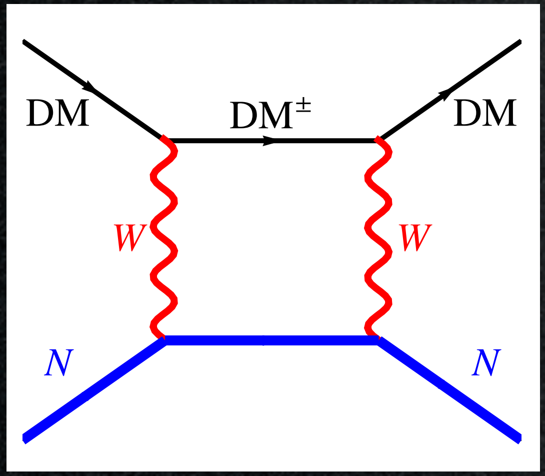
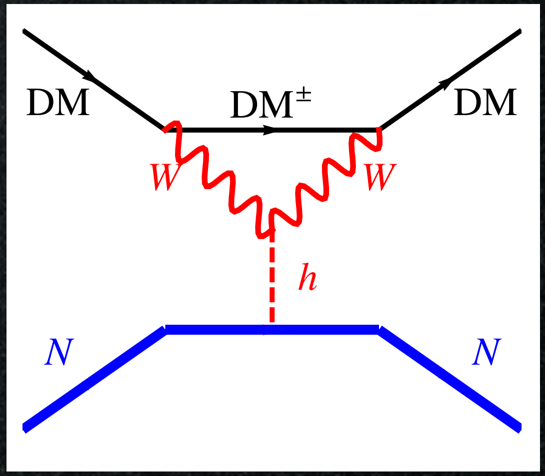


one loop

$$\sigma_{\rm SI} \sim \frac{\alpha^4\ m_N^4}{M_W^6}$$



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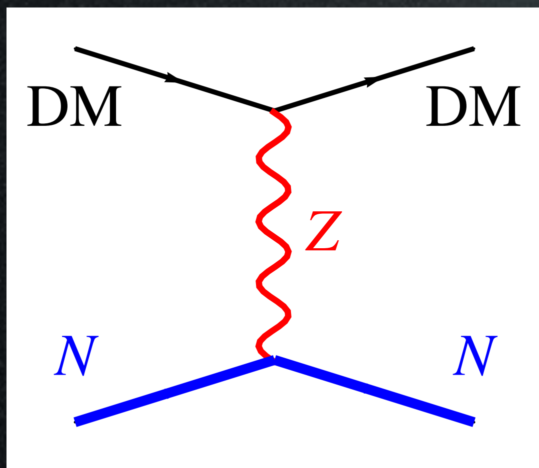
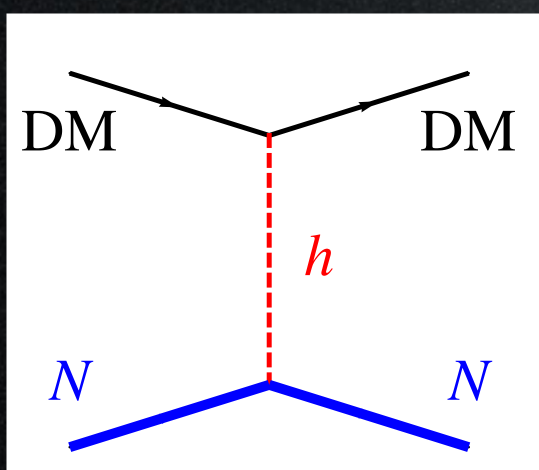
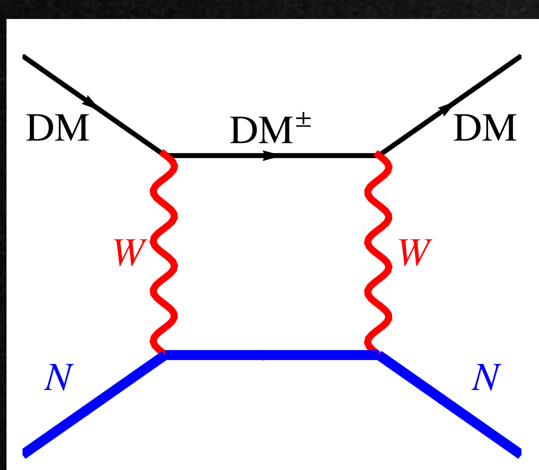


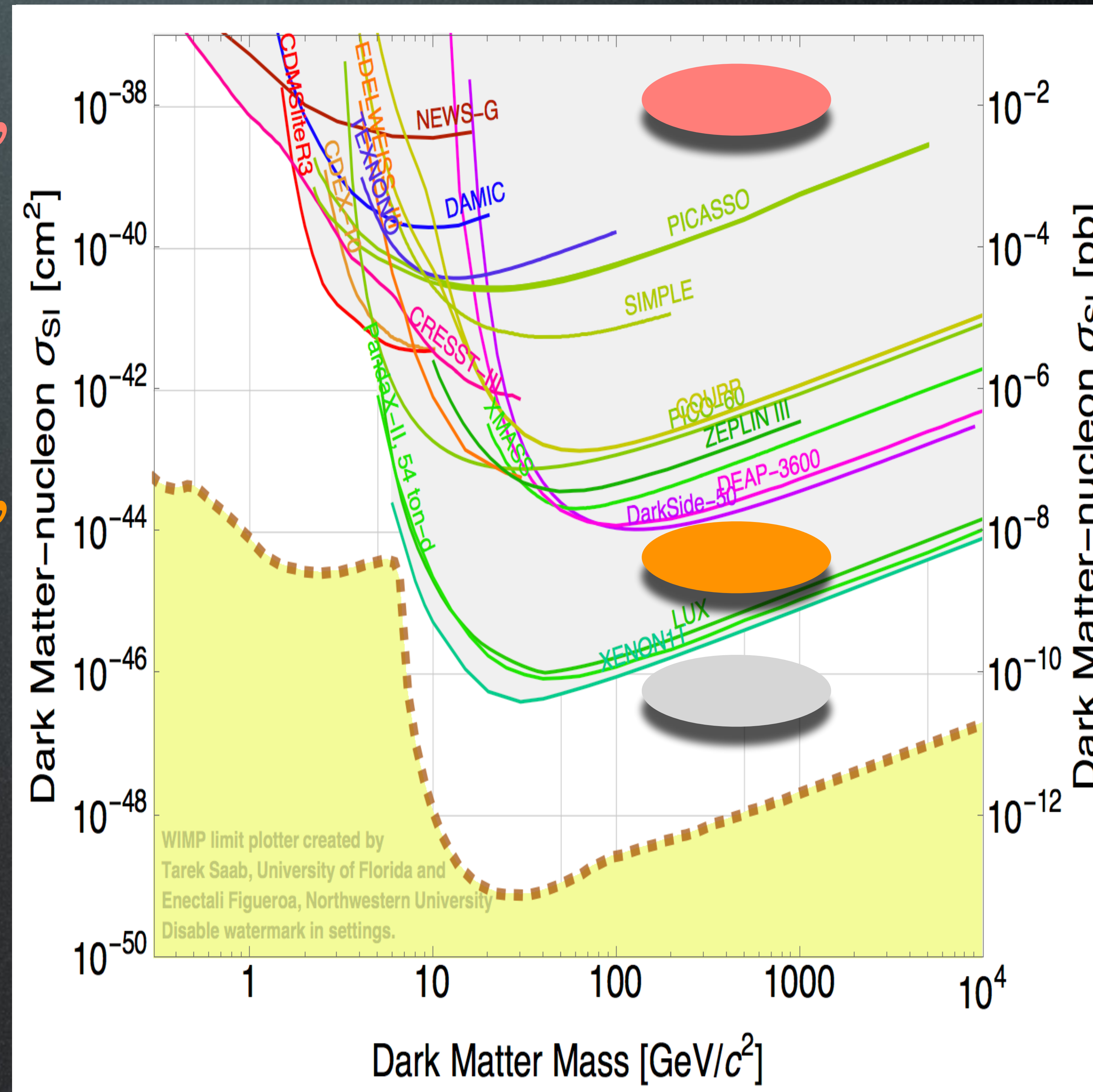
tree level, vector



tree level, scalar



one loop



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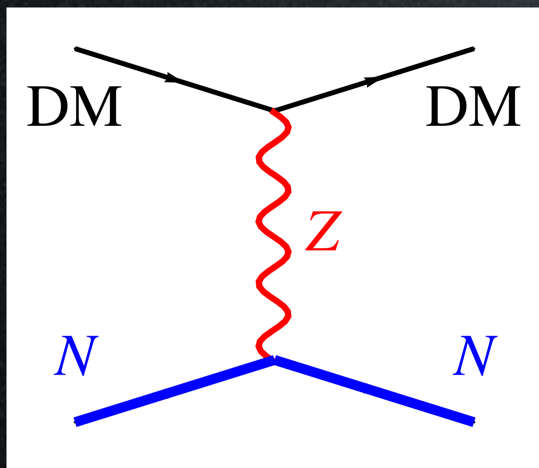

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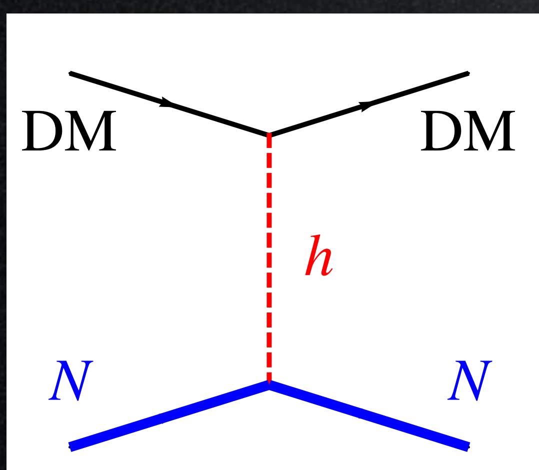

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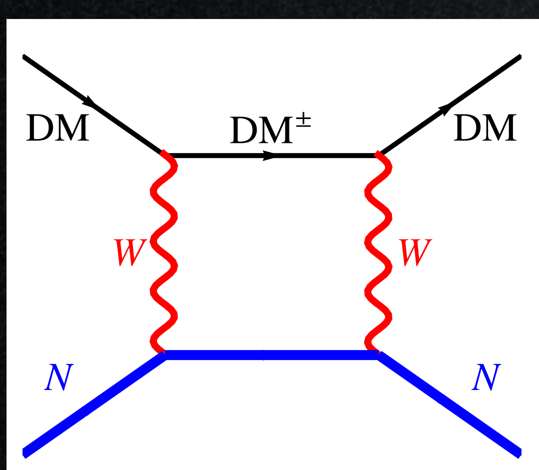

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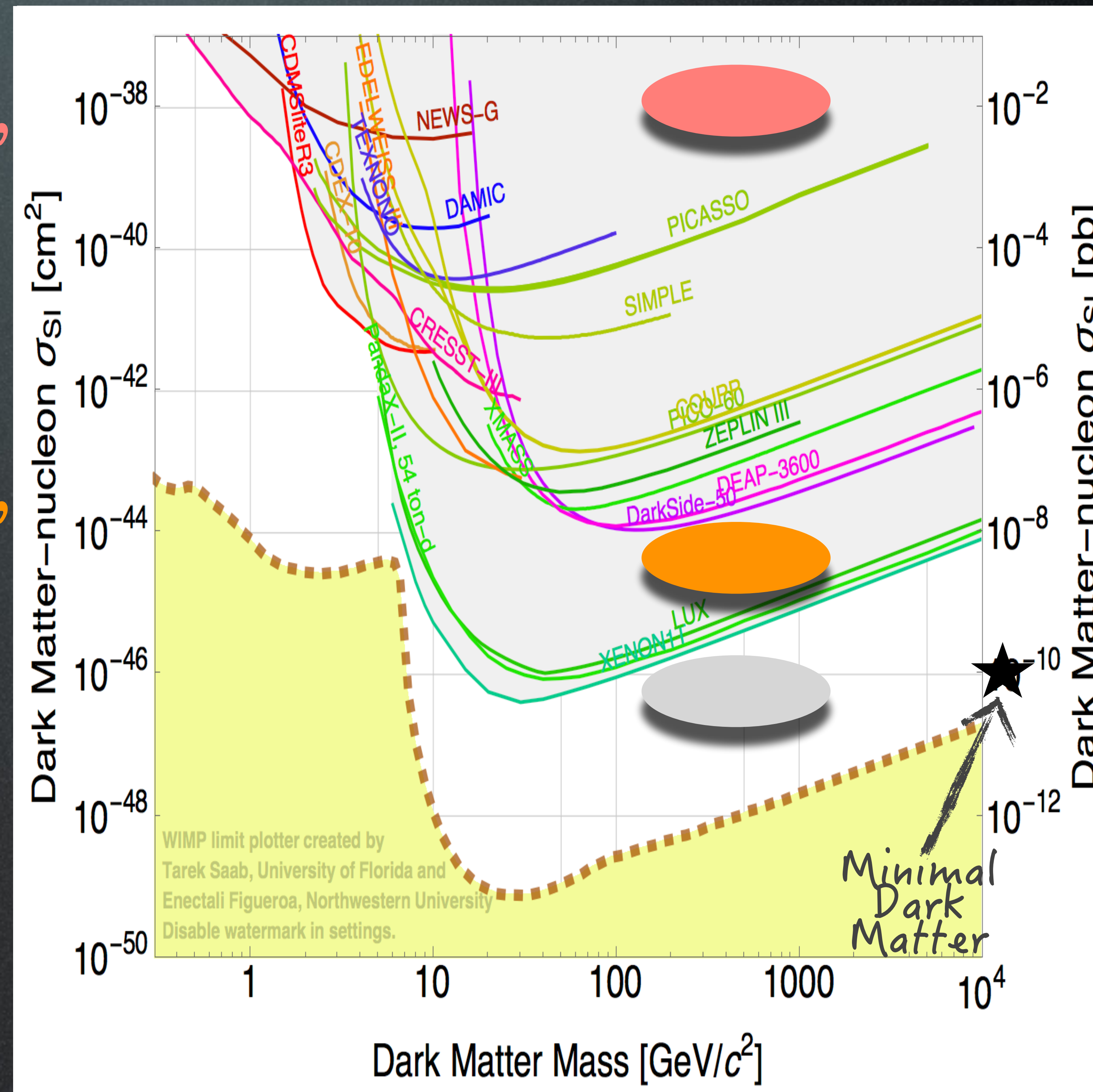

Cirelli, Fornengo, Strumia hep-ph/0512090

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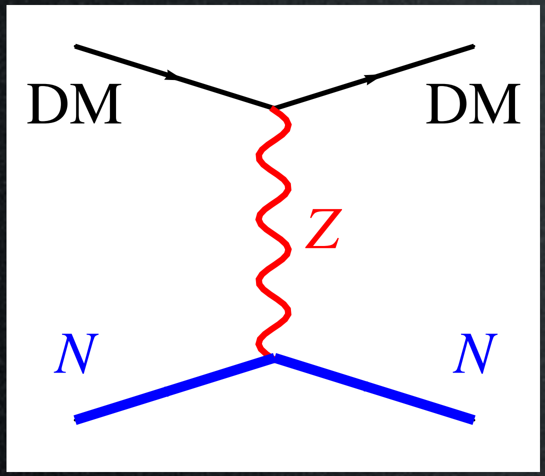
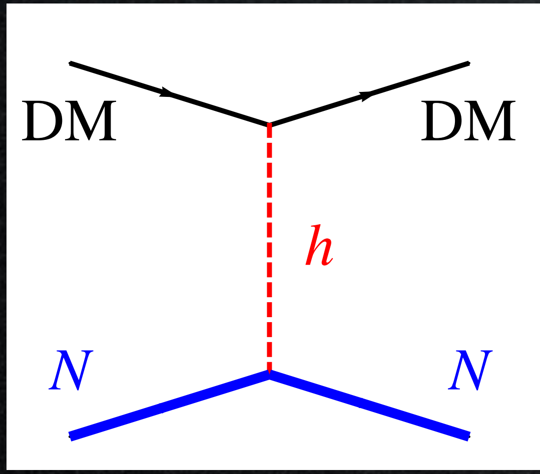
SM weak scale SI interactions

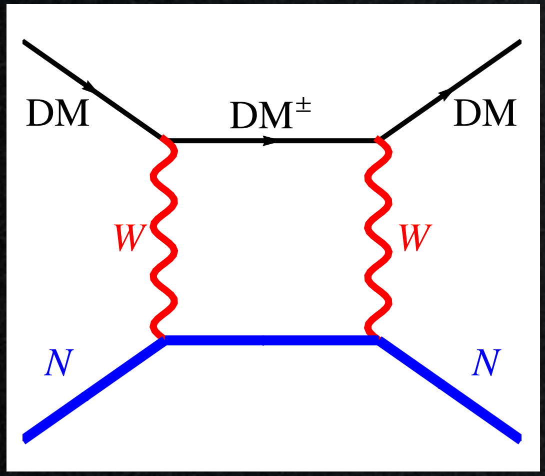


tree level, vector

Still viable under which conditions?



tree level, scalar



one loop

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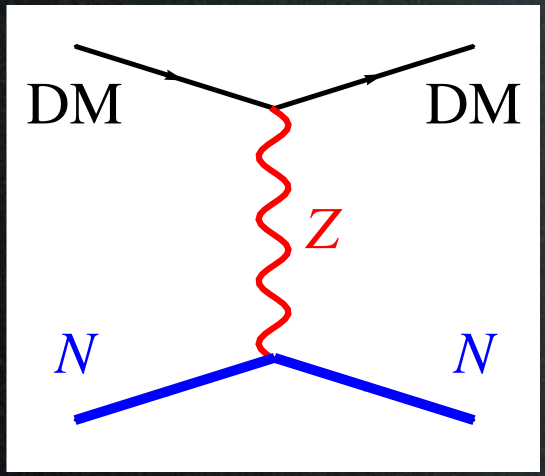

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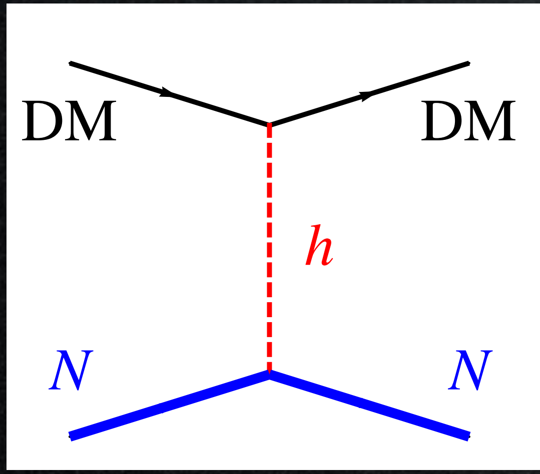

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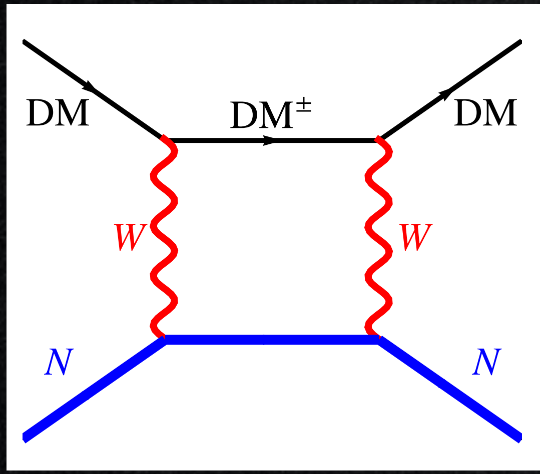

one loop

Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)

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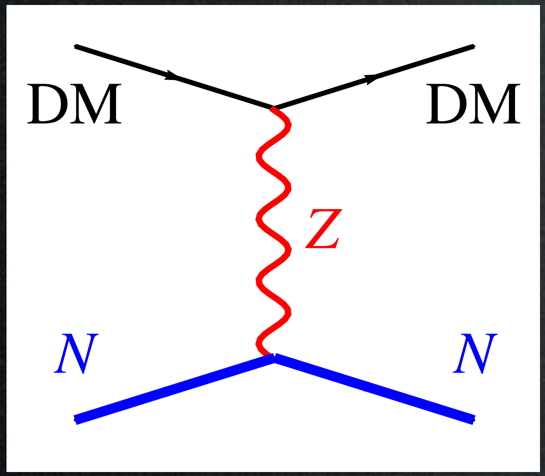

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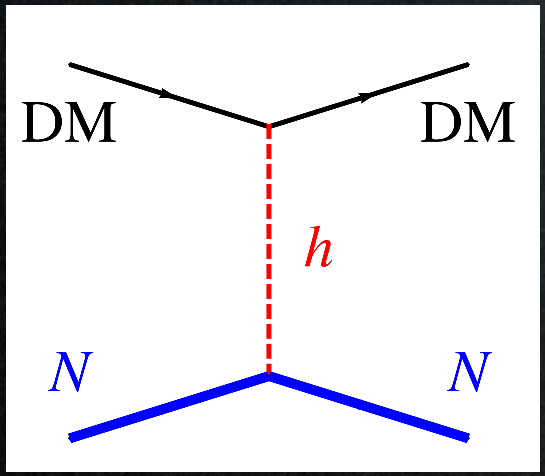

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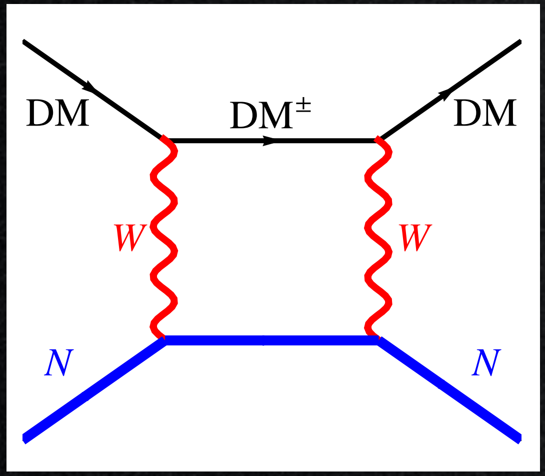

one loop

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WIMP DD: ‘theory’

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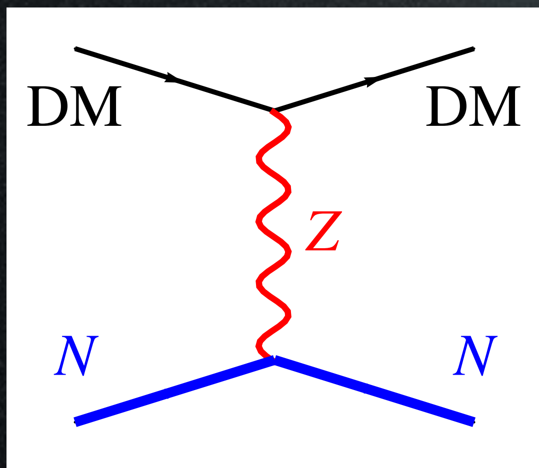

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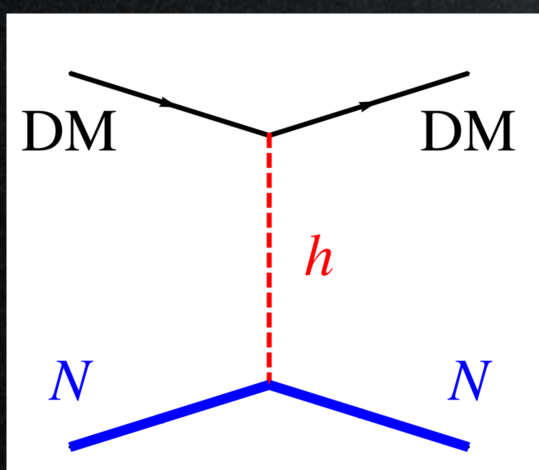

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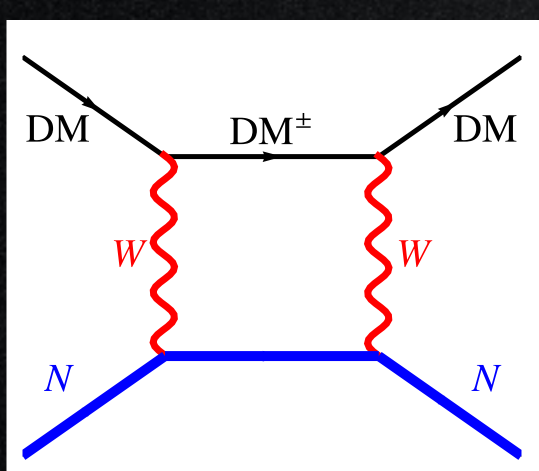
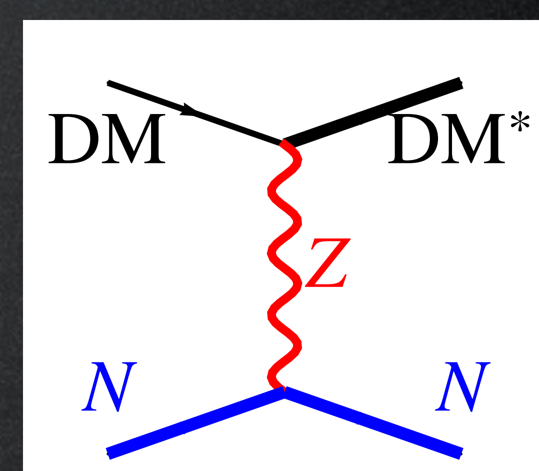


one loop

Still viable under which conditions?

- real particle
  (Majorana fermion, real scalar)
- hypercharge $Y = 0$
- SD interactions only
- inelastic scattering



Indirect Detection

Frontier 3:
heavy (PeV) DM

Indirect Detection

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- ‘Pure WIMP’ models foresee multi-TeV DM

  models with only DM beyond SM,
  no other ingredients

Indirect Detection

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heavy (PeV) DM

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- Heavy DM => weak force as a long-range force

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  Sommerfeld enhancement
  Bound state formation enhancement
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  Bound state formation enhancement
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- Unitarity bound (~300 TeV) can be overcome

Asymmetric DM: a completely different relic

$$\frac{\Omega_{\rm DM}}{\Omega_{\rm B}} \simeq 5$$

Just coincidence? Or: signal of a link?

Possibly a common production mechanism:

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Baryogenesis:

$$\eta_{\rm B} = \frac{n_{\rm B} - n_{\bar{\rm B}}}{n_\gamma} = 6 \cdot 10^{-10}$$

BBN, CMB...

$$\Omega_{\rm B} \propto m_{\rm B}\, \eta_{\rm B}$$

'Darko'genesis:

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$$\boxed{m_{\rm DM} \simeq 5\ {\rm GeV}}$$

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'Darko'genesis:

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A variety of specific models/ideas:

transferring or co-genesis

cfr J. March-Russell

DM stores the anti-B number

via leptogenesis

connection to neutrino masses

Asymmetric DM: a completely different relic

$\chi\bar{\chi} \leftrightarrows f\bar{f} \quad \chi\bar{\chi} \to f\bar{f} \qquad \chi\,? \nrightarrow \ldots$

Consider a particle χ:

- subject to $\chi\bar{\chi} \to \ldots$
- 'heavy' (e.g. $\gtrsim$ GeV)
- 'stable'
- in an expanding Universe
- **A**symmetric abundance
- large annihilation cross sec

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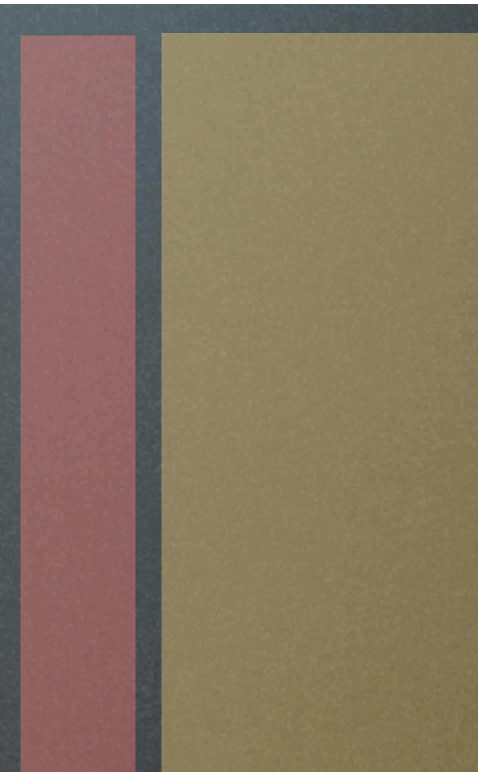

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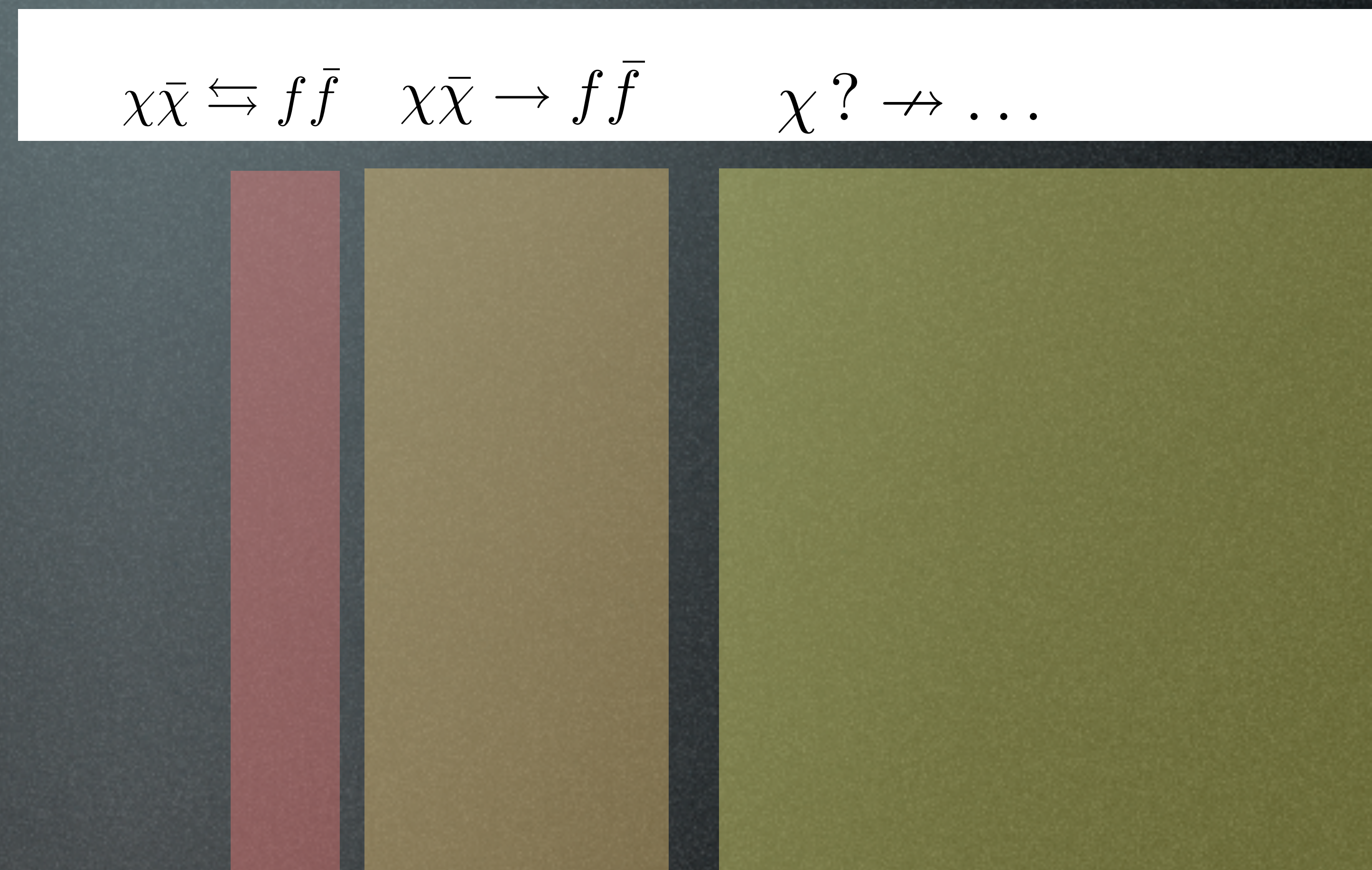


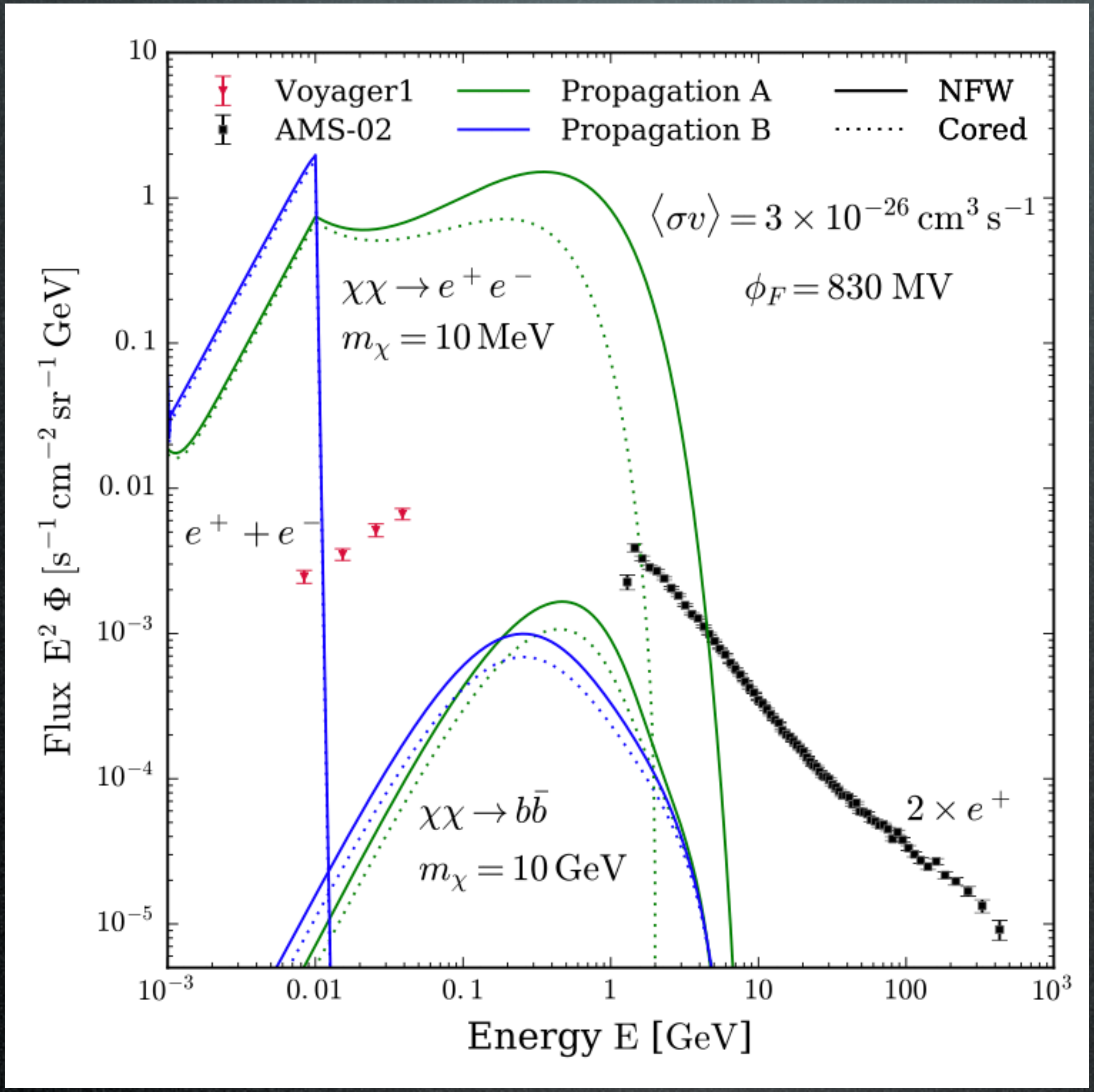
$$\Omega_X \simeq \frac{m_X\, s}{\rho_{\rm crit}} \eta_0$$

The relic abundance is determined by η_0 and m_X.

Indirect Detection: charged CRs

Boudaud, Lavalle, Salati 1612.07698

Electron+positron measurements by Voyager I

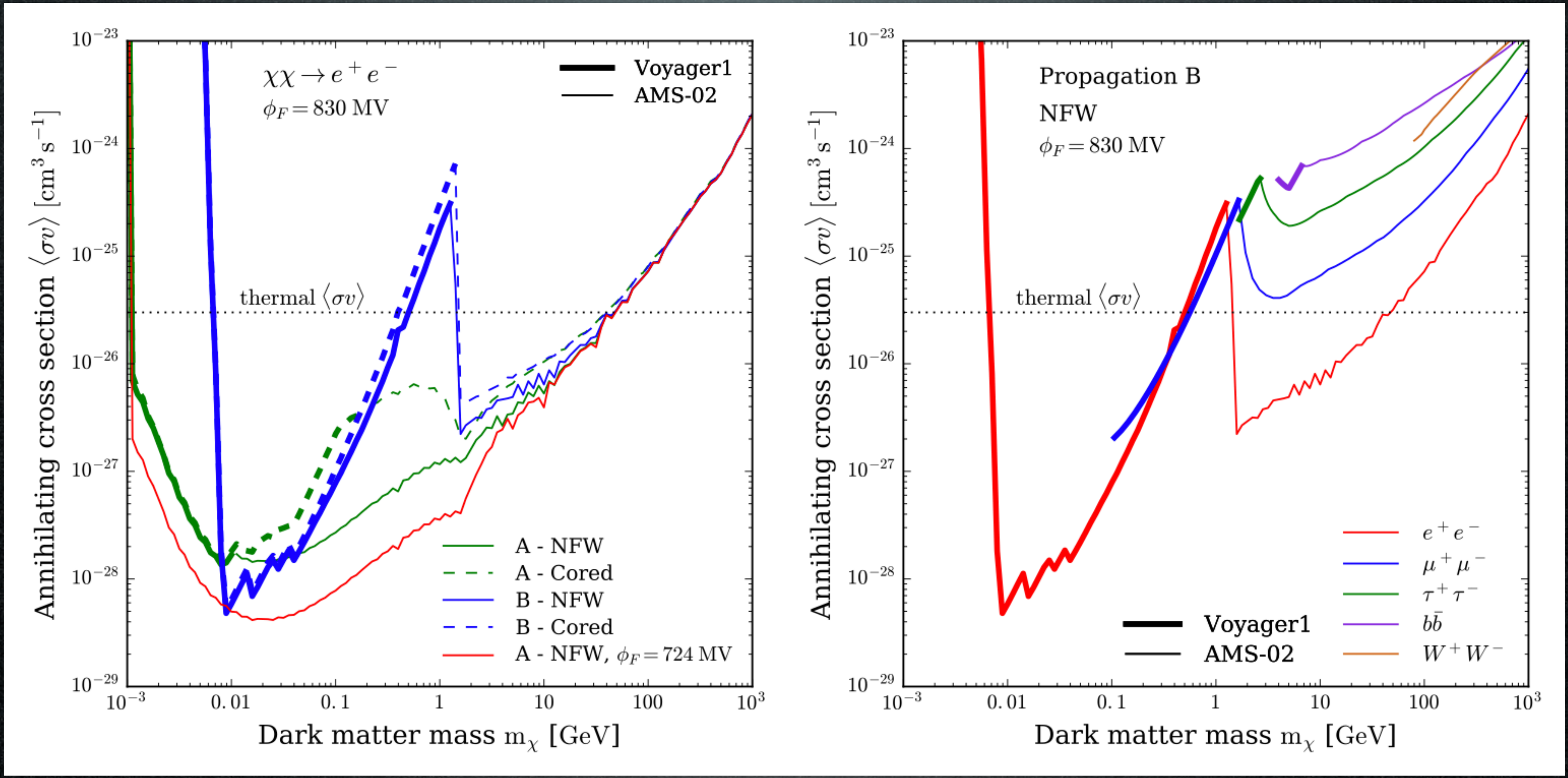


Propagation A = strong reacceleration
Propagation B = weak/no reacceleration

Indirect Detection: charged CRs

Boudaud, Lavalle, Salati 1612.07698

Electron+positron measurements by Voyager I



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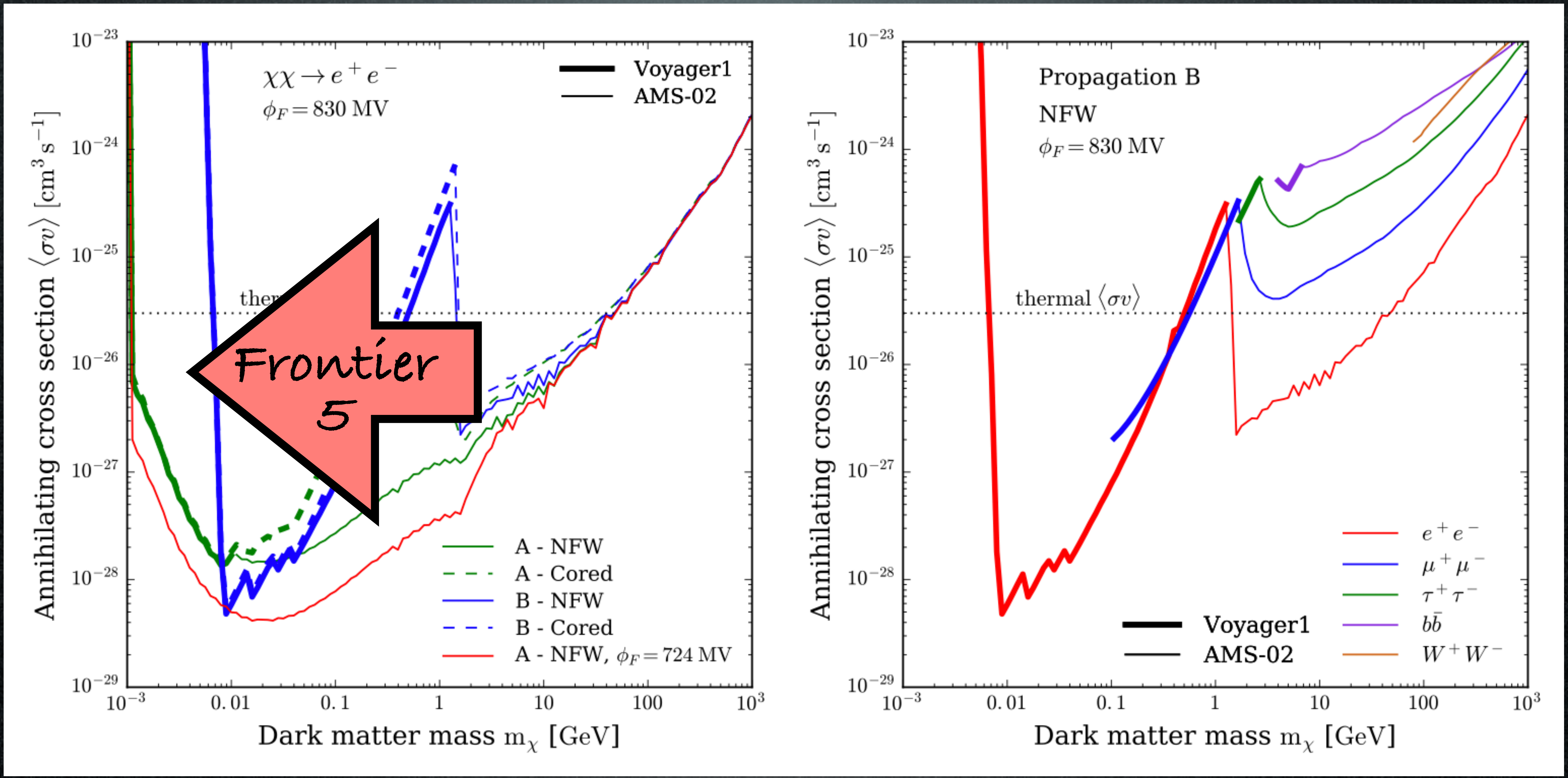

Sub-GeV DM & X-rays

Annihilation channels, focus on the MW (assume standard NFW profile)

$$\mathrm{DM\ DM} \rightarrow e^+e^-$$

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$$\mathrm{DM\ DM} \rightarrow \pi^+\pi^-$$

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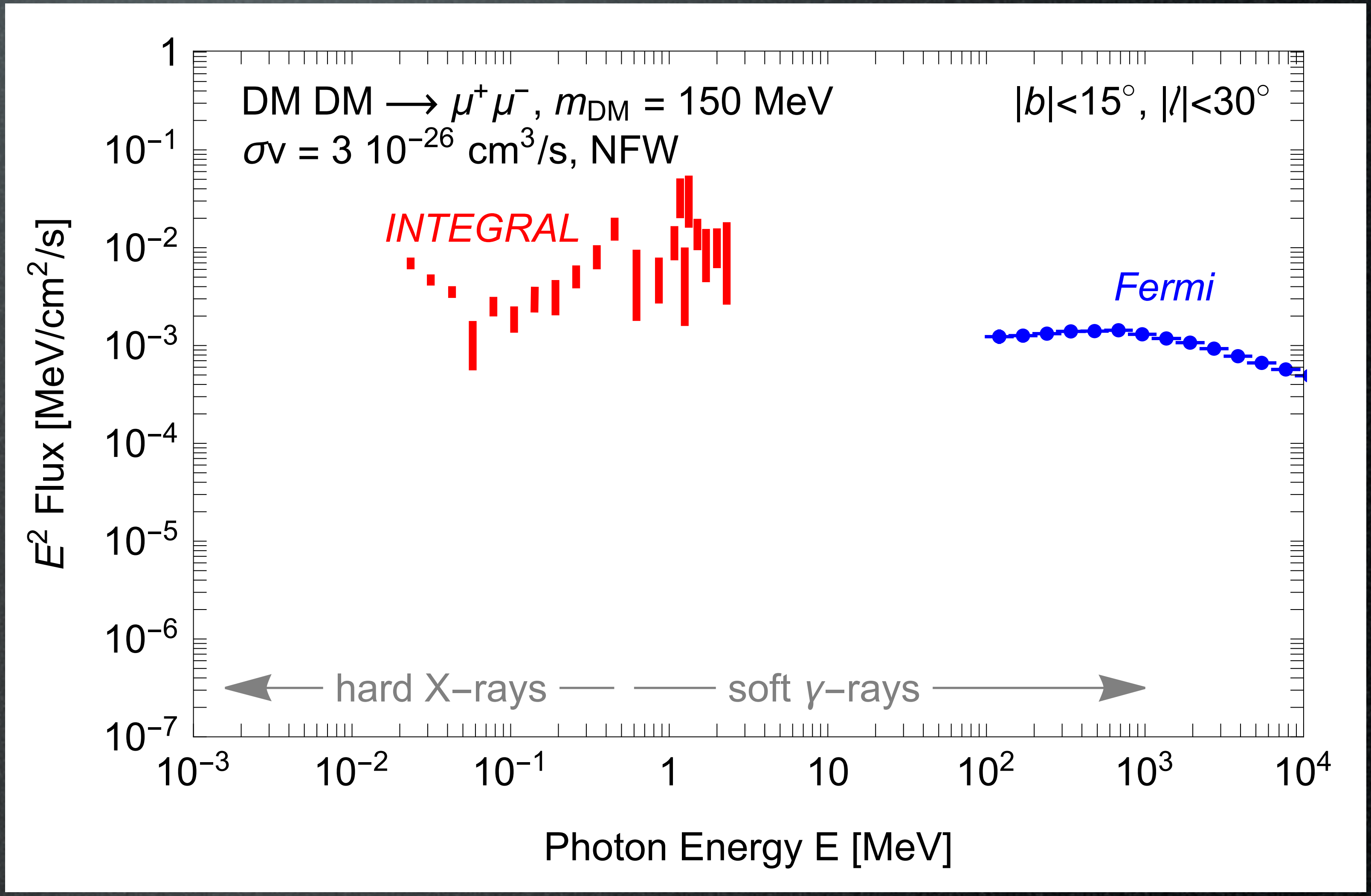

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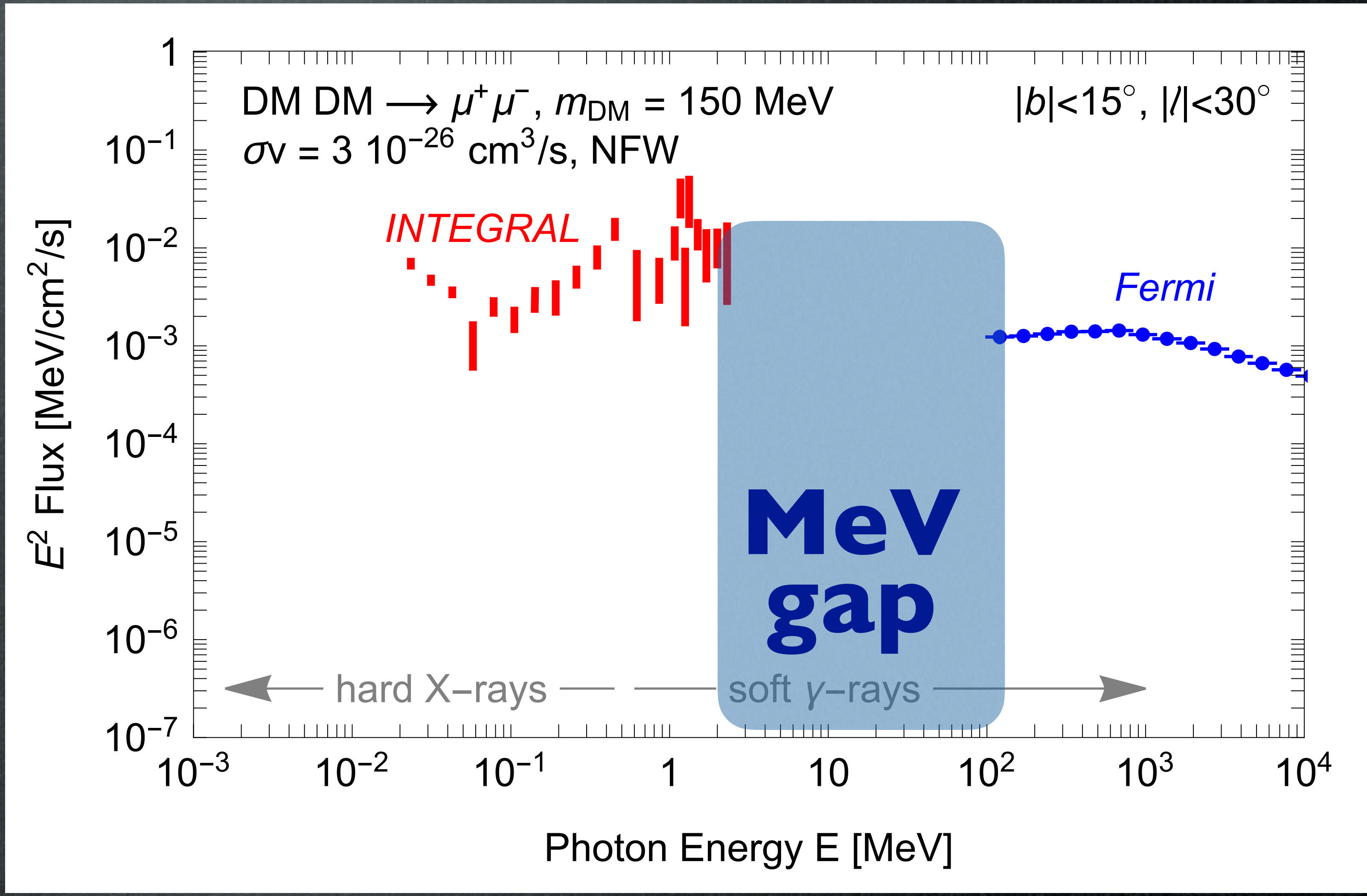

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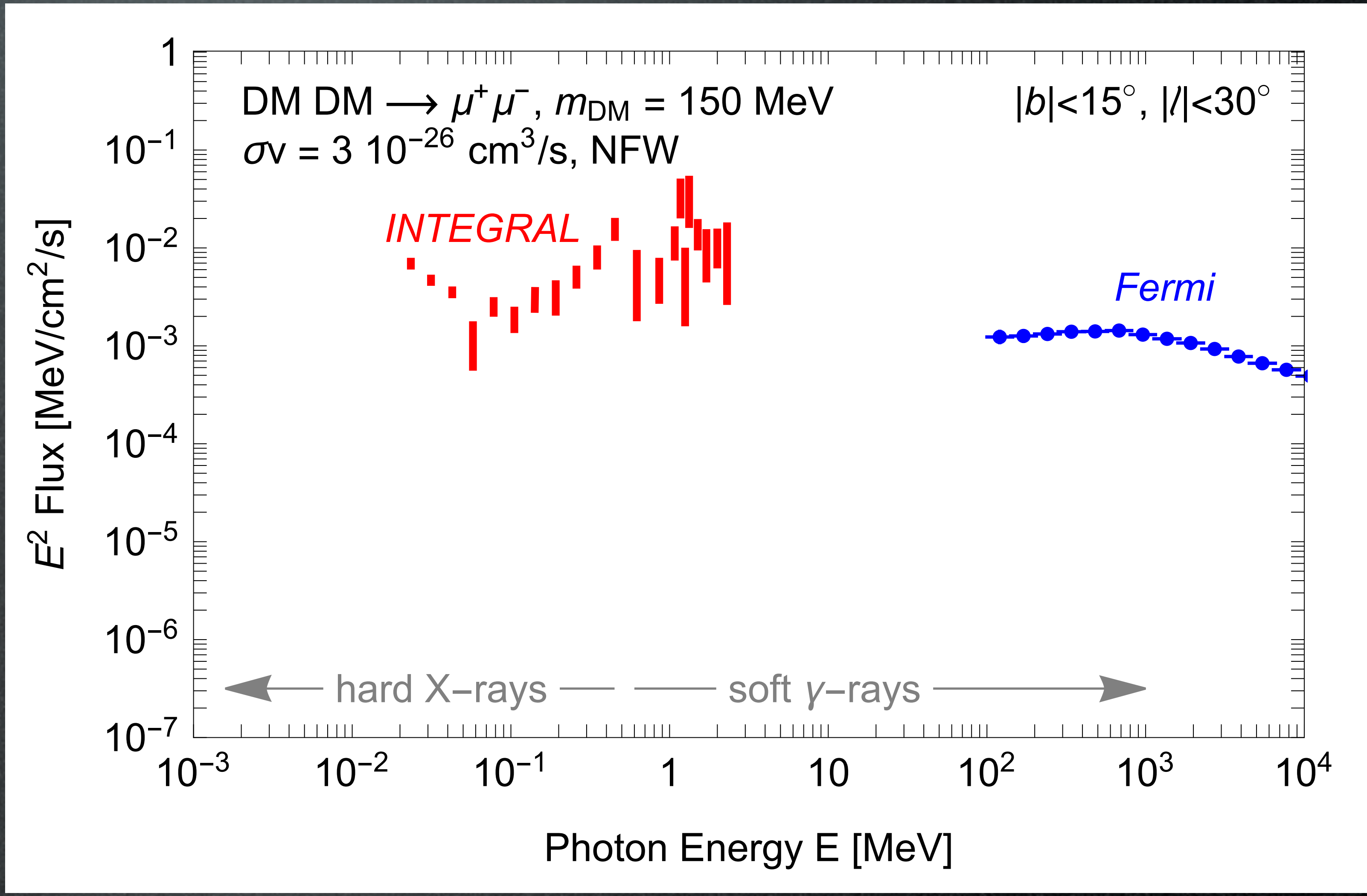

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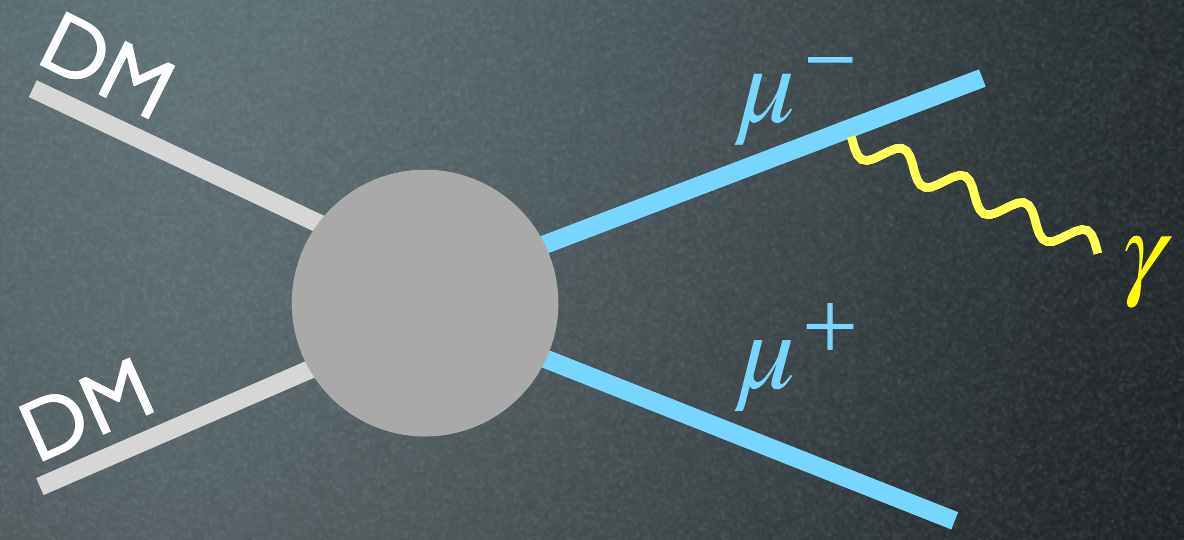
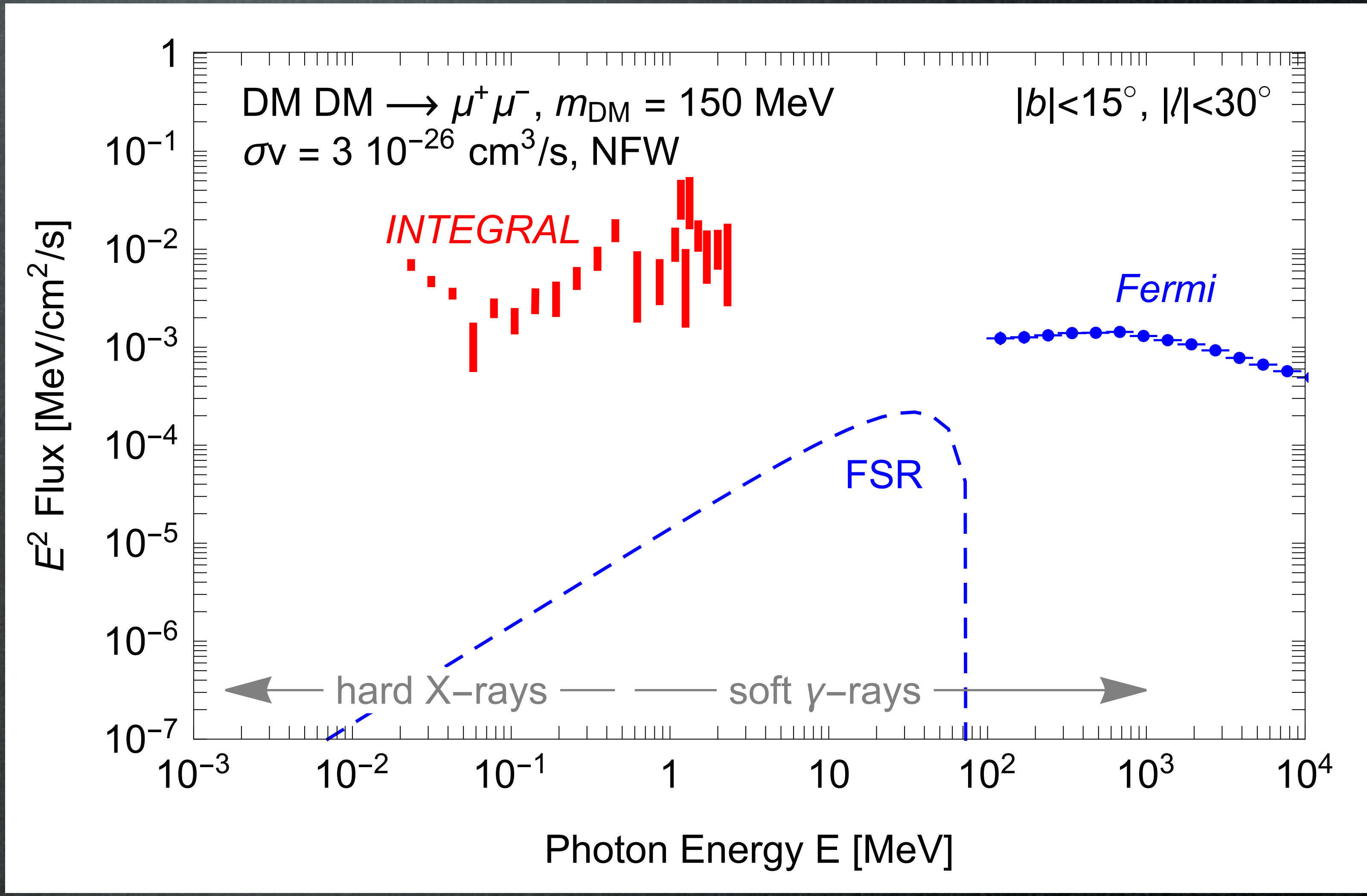


'Prompt' emission:

Final State Radiation (FSR)



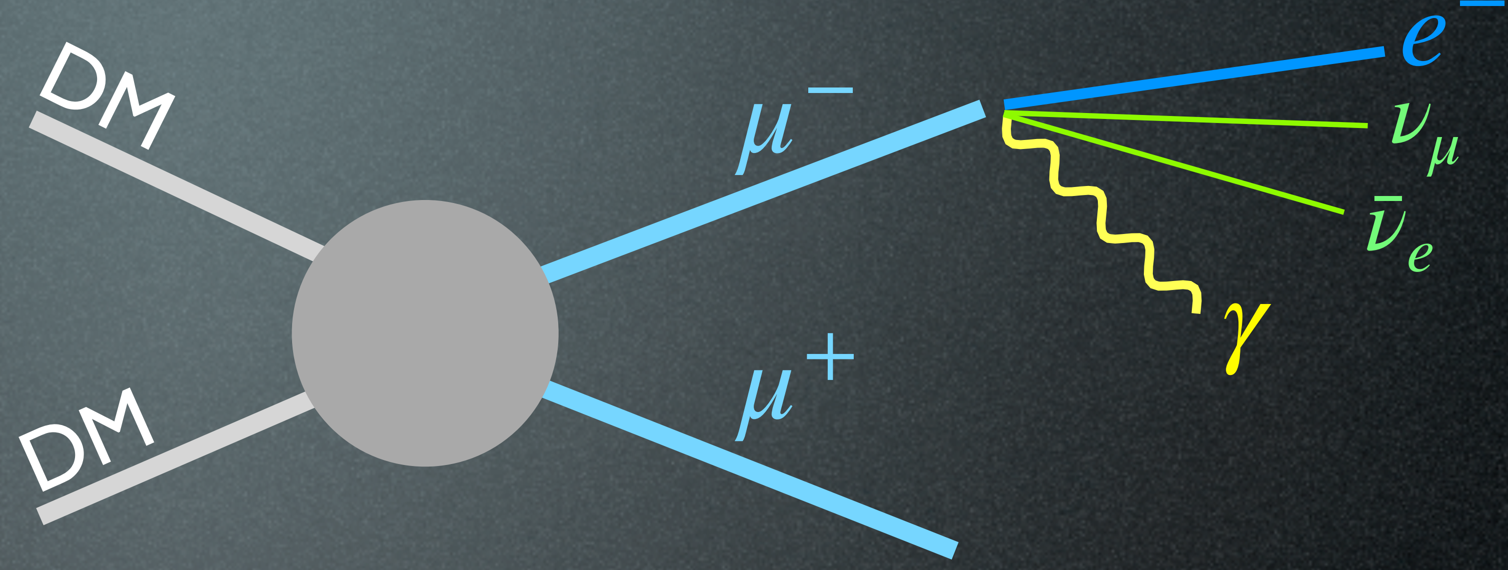
Sub-GeV DM & X-rays

Annihilation channels

$\mathrm{DM\ DM} \to e^+e^-$

$\mathrm{DM\ DM} \to \mu^+\mu^-$

$\mathrm{DM\ DM} \to \pi^+\pi^-$

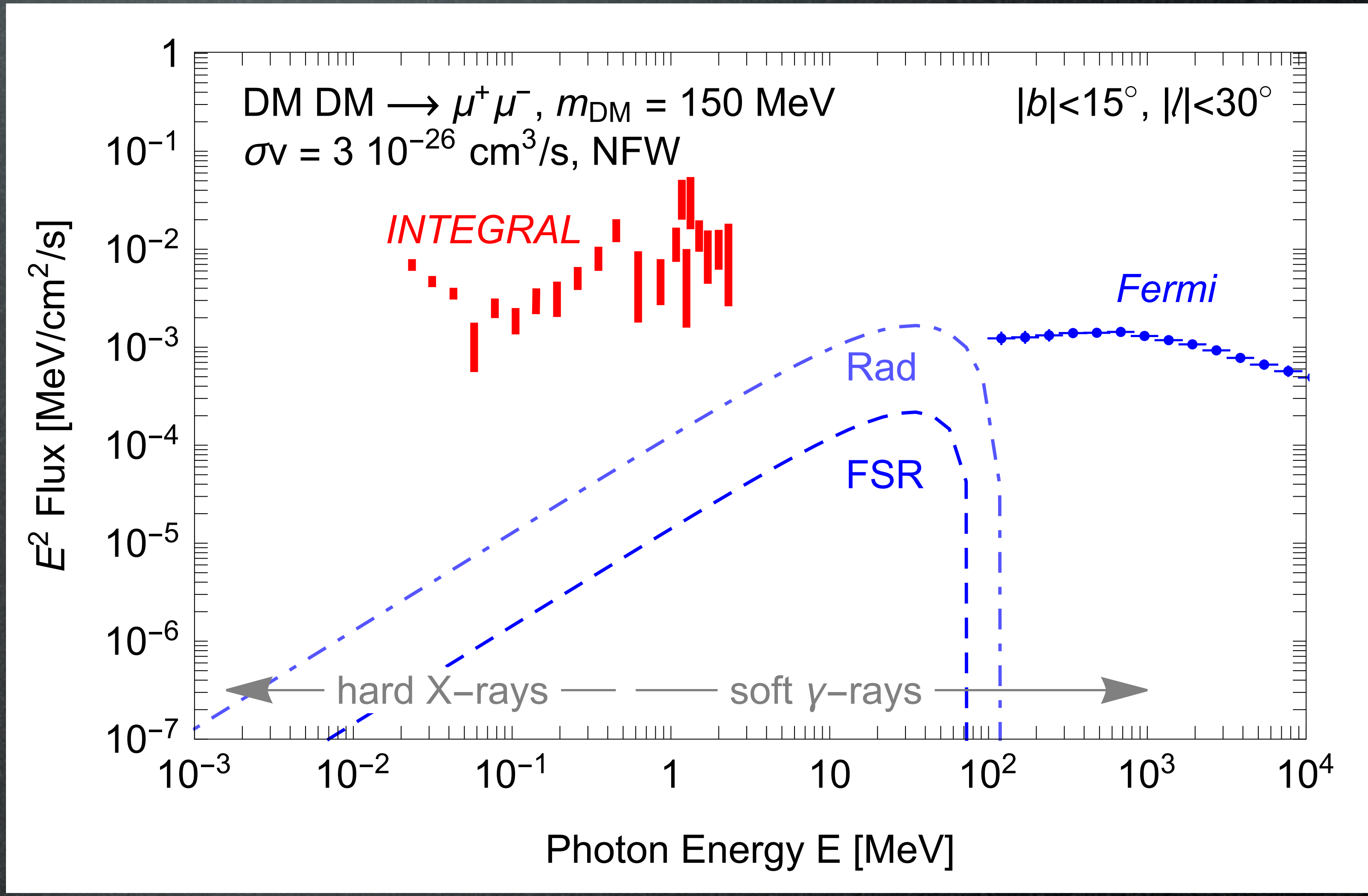


'Prompt' emission:

Final State Radiation (FSR)

Radiative μ decay

Usually irrelevant, but <u>not</u> for μ decaying 'at rest'!



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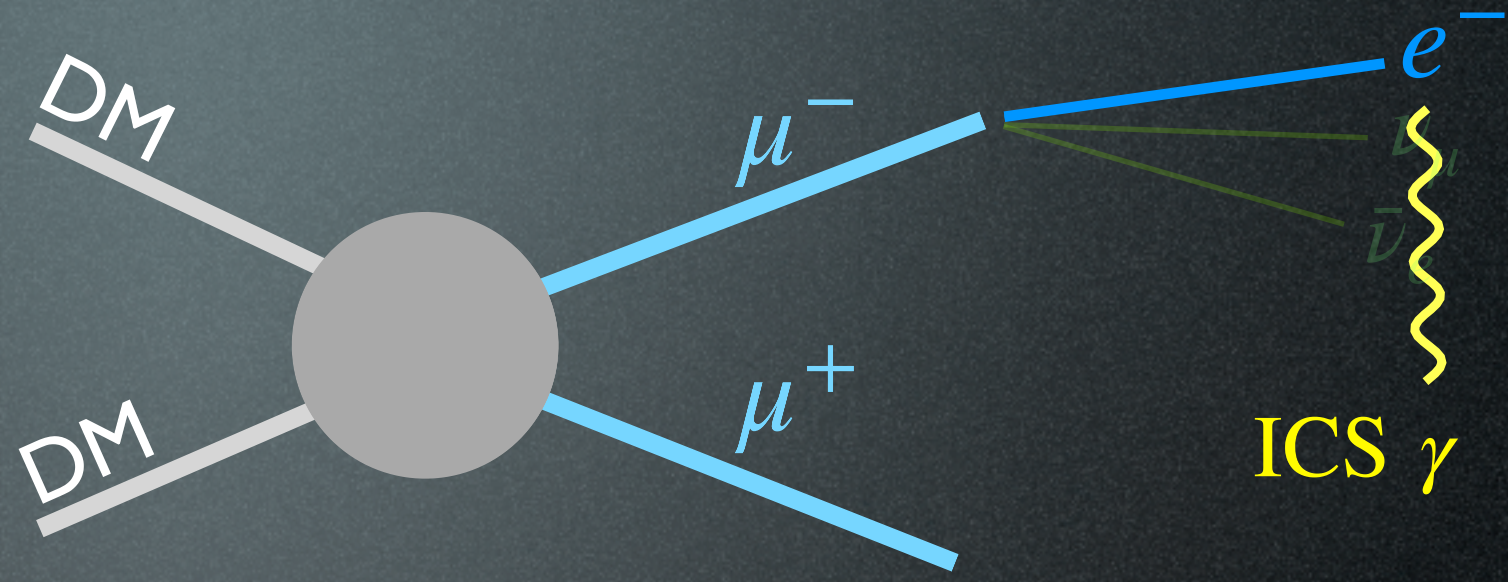


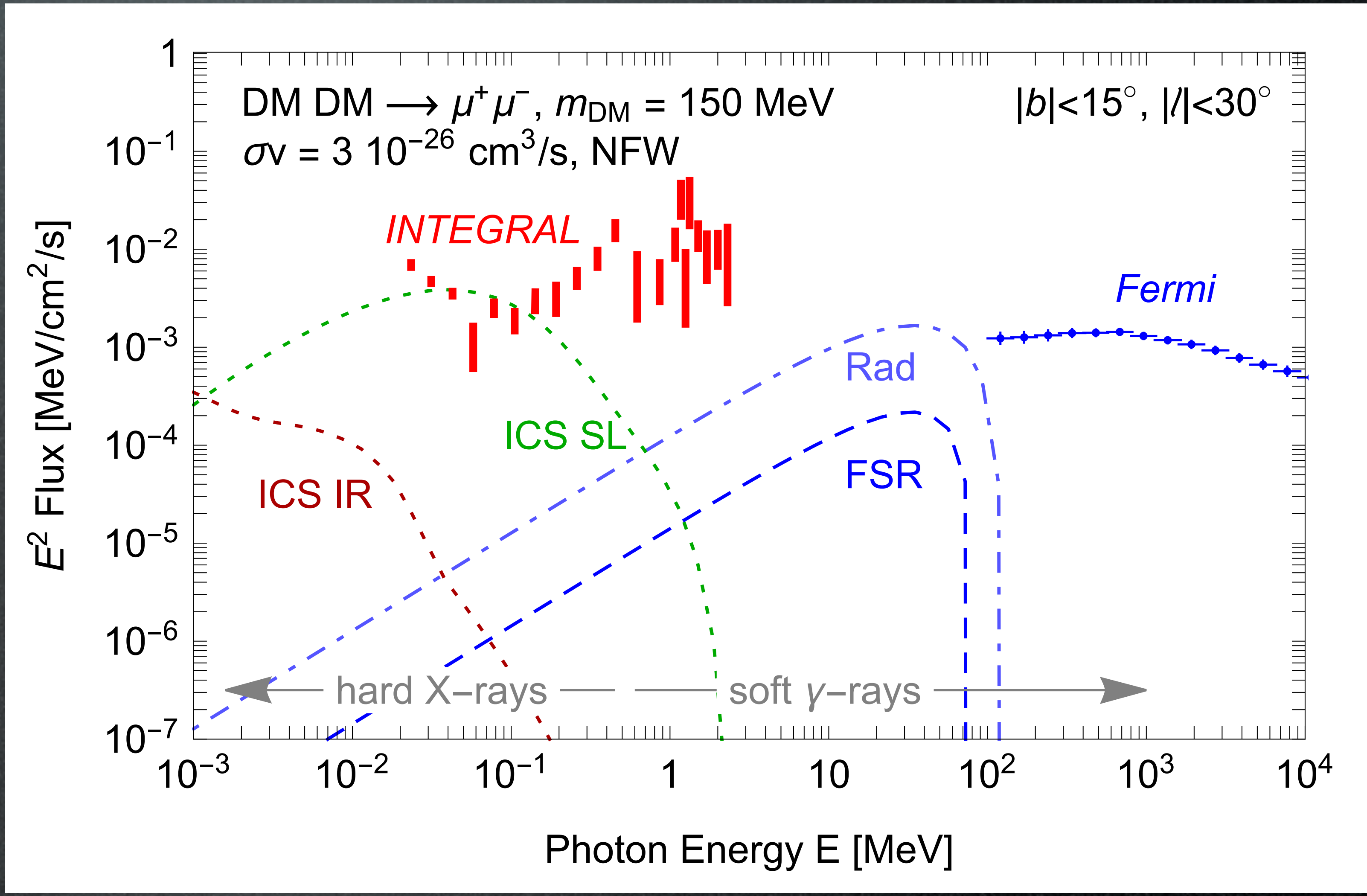
'Prompt' emission:

Final State Radiation (FSR)

Radiative μ decay

Secondary emission:

ICS: inevitably associated to annihil to charged states



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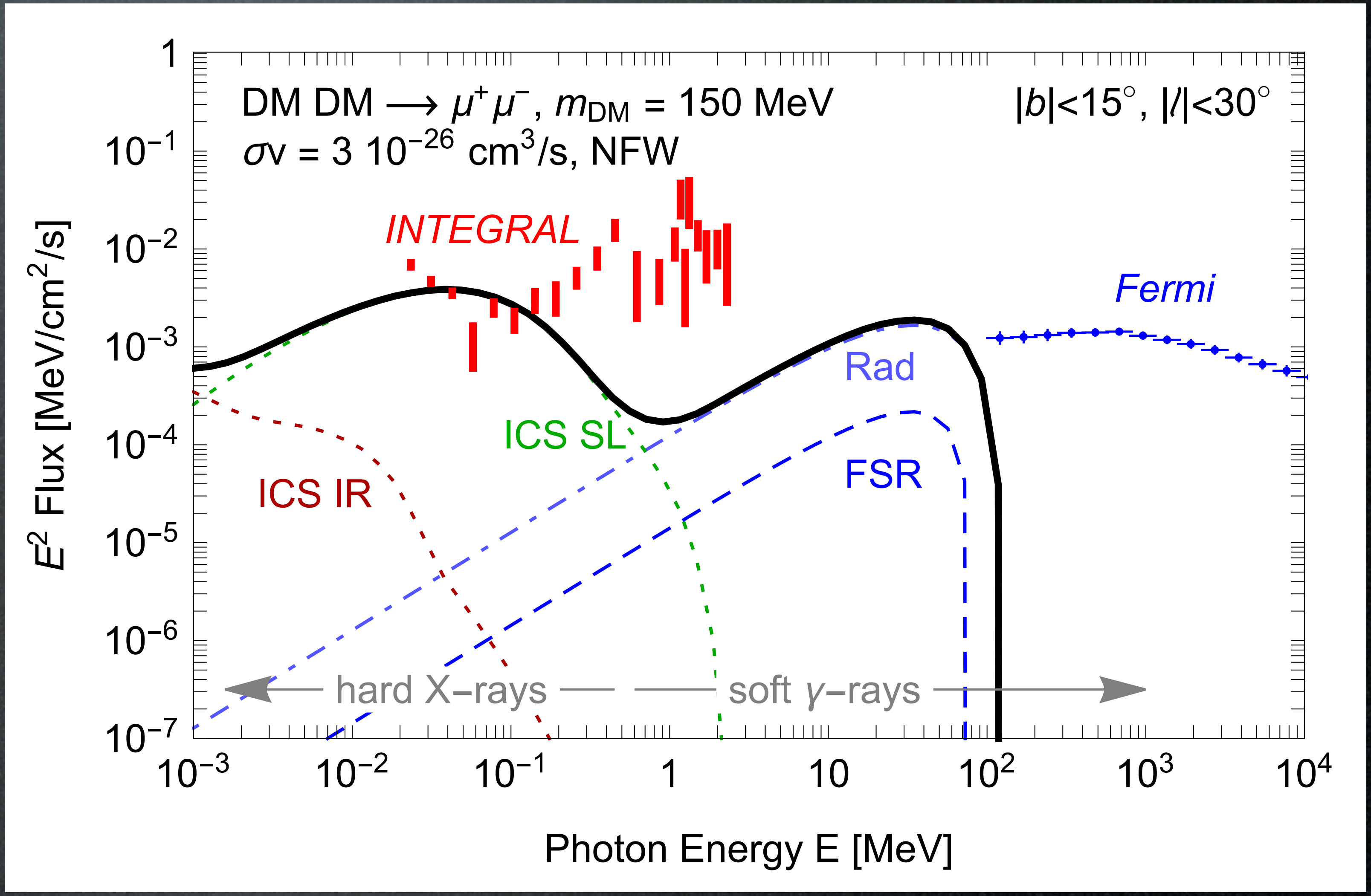
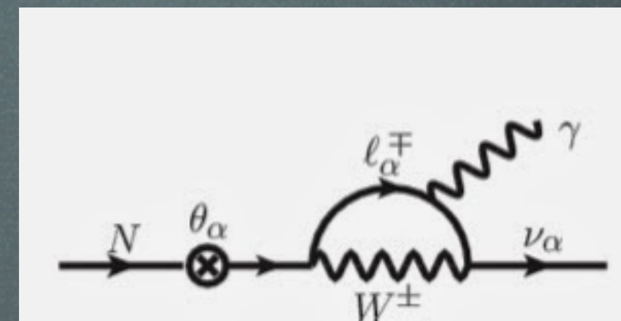


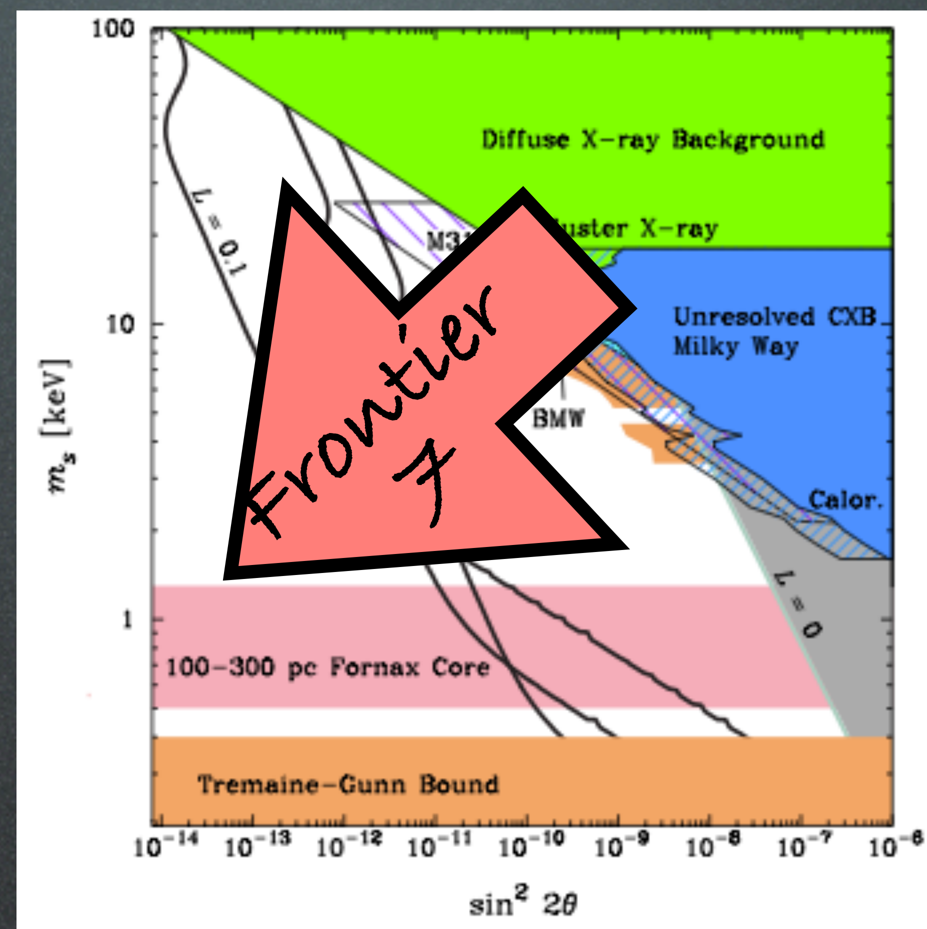
ICS allows to probe sub-GeV DM with X-ray data

X-ray line

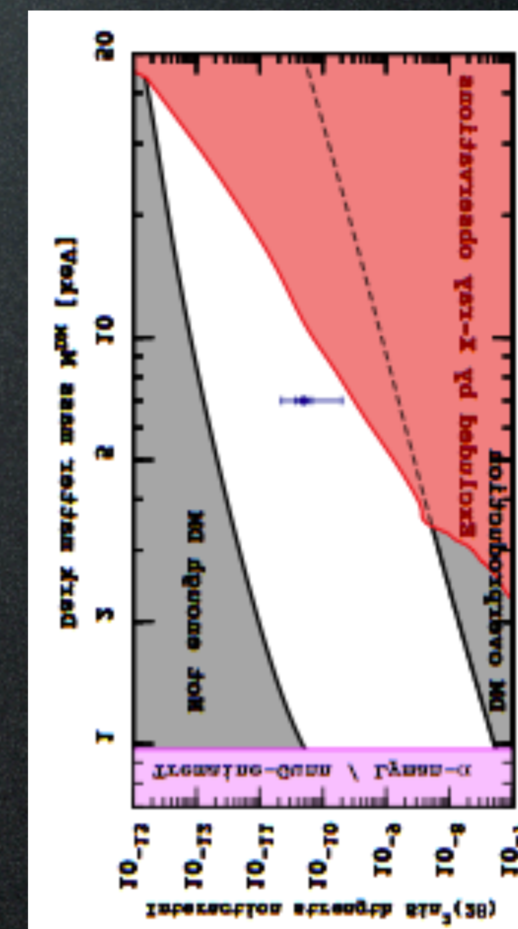
Sterile neutrino decay

$m_\nu = 7.1$ KeV
$\tau \simeq 10^{29}$ sec
$\sin^2 2\theta \sim$ few 10^{-11}





Bulbul et al., 1402.2301



Boyarsky, Ruchayskiy et al., 1402.4119

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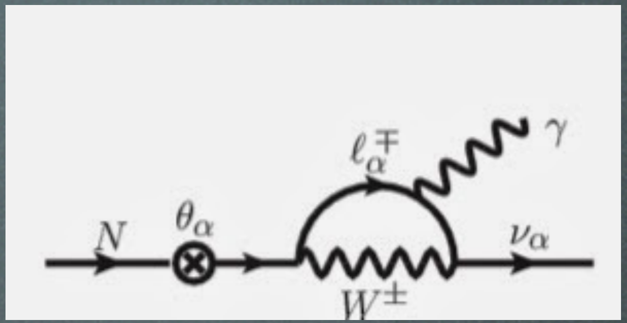
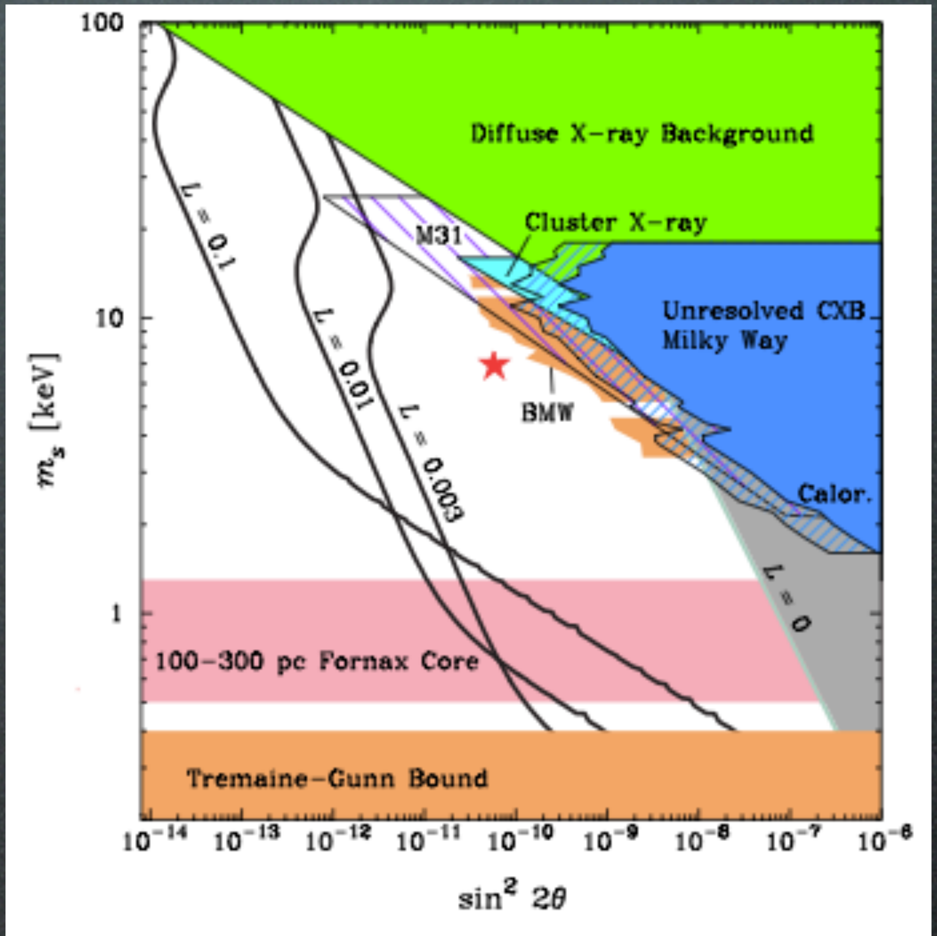
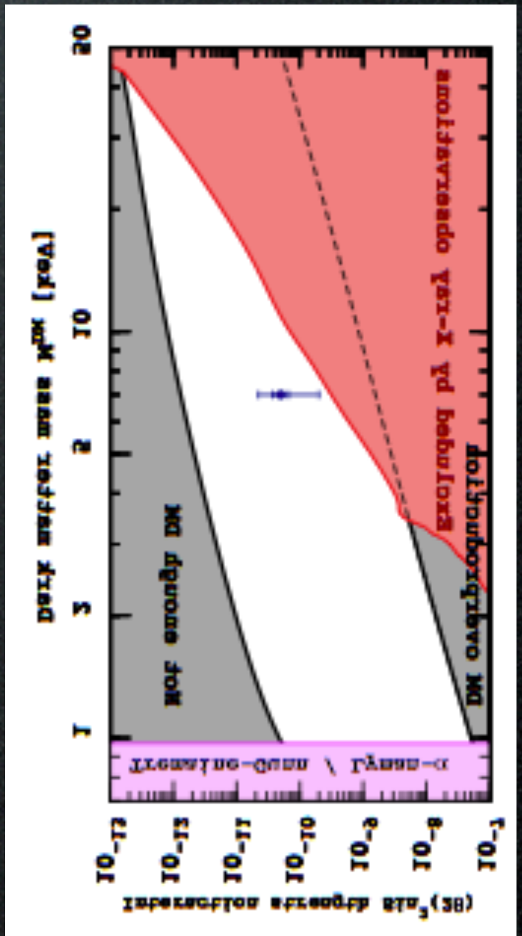


Possible challenges:

- EU production?
- Perseus flux too large?



Bulbul et al., 1402.2301



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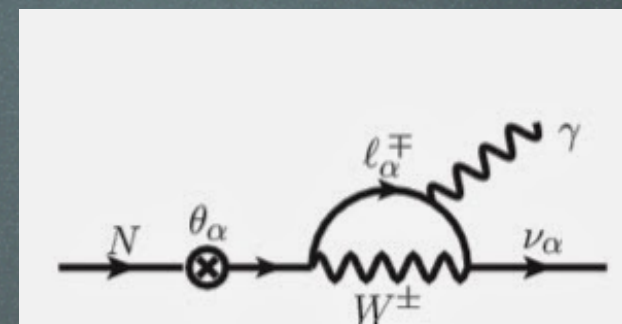


Possible challenges:

- EU production?
- Perseus flux too large?

Caveat:

Riemer-Sørensen, 1405.7943

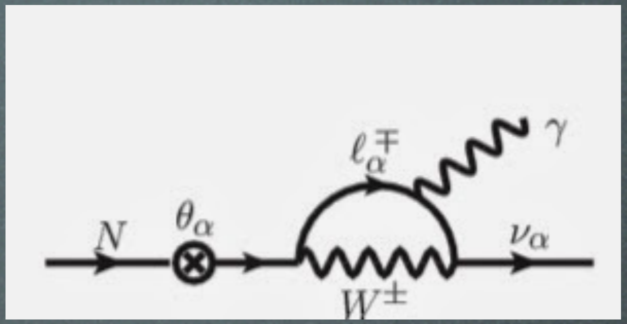
- no line seen with Chandra in the Galactic Center (but conclusion depends on how one models the local background)
- no line seen in dSphs (but results are not conclusive) Malyshev et al., 1408.3531
- no line seen in other galaxies (but errors might be underestimated? says Boyarski's group) Anderson et al., 1408.4115
- no line seen in other clusters (but seen in Perseus with Suzaku! maybe it's proper of Perseus?)
- morphology incompatible with DM Carlson, Profumo², 1411.1758 Urban, Strigari et al., 1411.0050
- but seen in Milky Way halo with NuStar, and Chandra!

Neronov, Malyshev, 1607.07328
Cappelluti+ 1701.07932

Perhaps reconciled if it is excited DM?
Cline & Frey, 1410.7766

X-ray line

Sterile neutrino decay



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Possible challenges:

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Caveat 2:

- Jeltema & Profumo, 1408.1699: it's just Potassium/Clorine lines
- Bulbul et al. 1409.4143, Boyarsky at al. 1409.4388: bulls#!t
- Jeltema & Profumo, 1411.1759: insist...

X-ray line

Sterile neutrino decay

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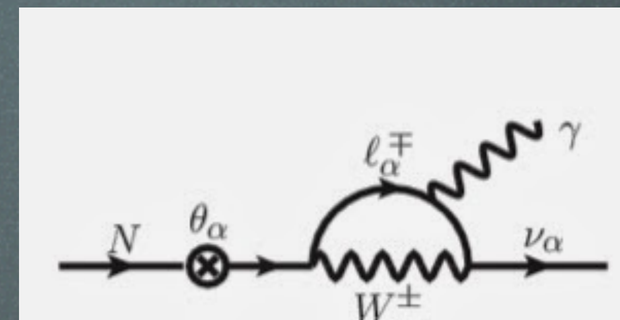

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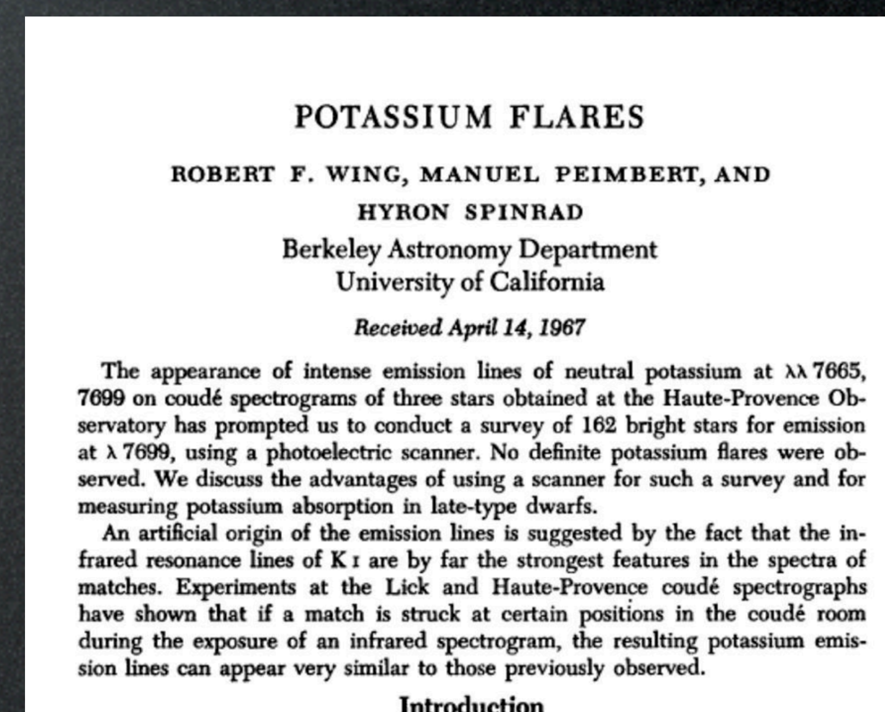

POTASSIUM FLARES

ROBERT F. WING, MANUEL PEIMBERT, AND HYRON SPINRAD

Berkeley Astronomy Department
University of California

Received April 14, 1967

The appearance of intense emission lines of neutral potassium at λλ 7665, 7699 on coudé spectrograms of three stars obtained at the Haute-Provence Observatory has prompted us to conduct a survey of 162 bright stars for emission at λ 7699, using a photoelectric scanner. No definite potassium flares were observed. We discuss the advantages of using a scanner for such a survey and for measuring potassium absorption in late-type dwarfs.

An artificial origin of the emission lines is suggested by the fact that the infrared resonance lines of K I are by far the strongest features in the spectra of matches. Experiments at the Lick and Haute-Provence coudé spectrographs have shown that if a match is struck at certain positions in the coudé room during the exposure of an infrared spectrogram, the resulting potassium emission lines can appear very similar to those previously observed.

Introduction

Publications of the Astronomical Society of the Pacific, Vol. 79, No. 469, p.351
hat-tip: S. Profumo, Brian Siana

X-ray line

Sterile neutrino decay

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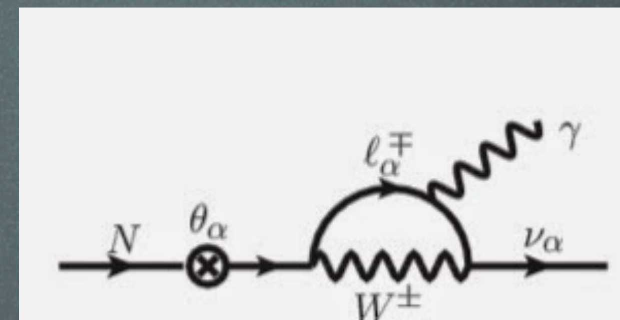
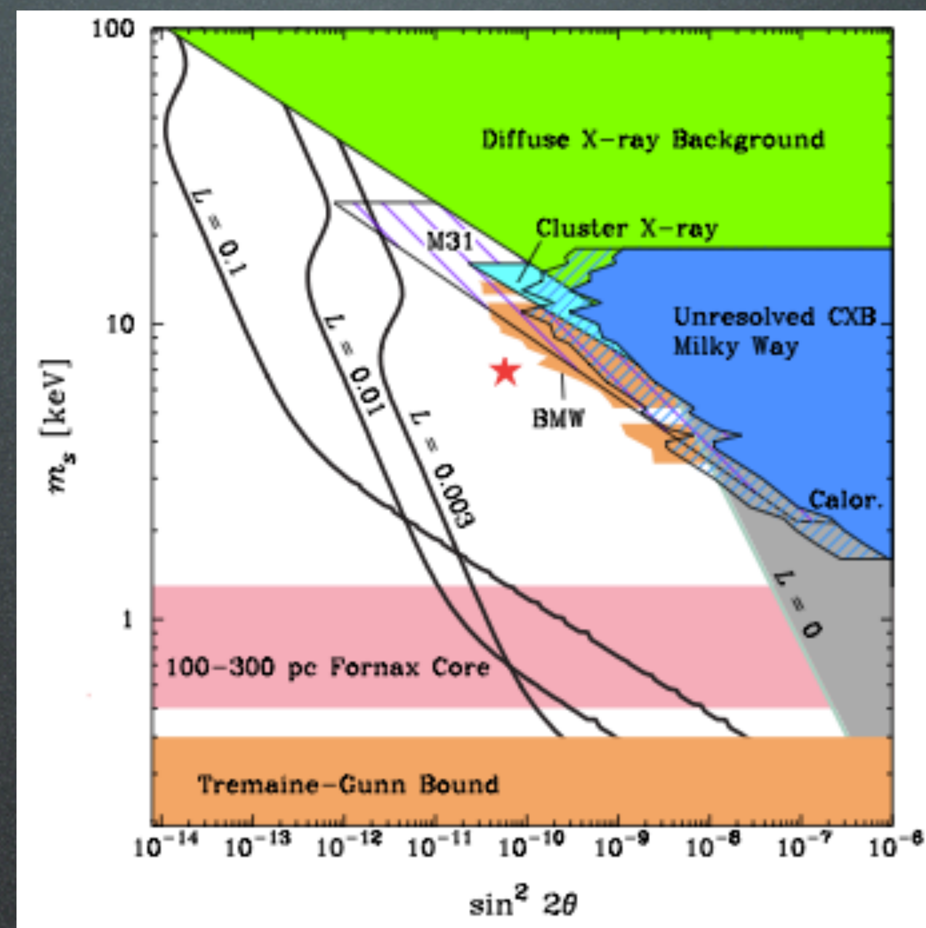
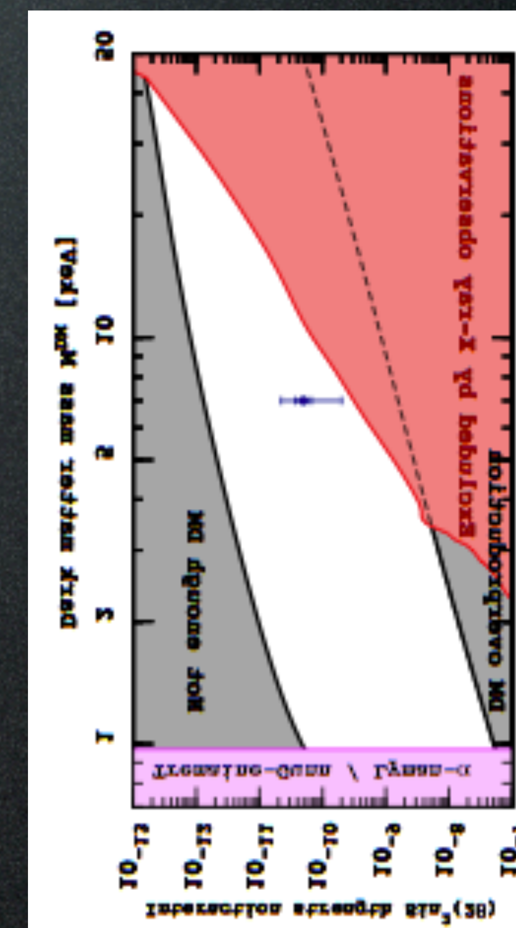




Bulbul et al., 1402.2301



Boyarsky, Ruchayskiy et al., 1402.4119

Possible challenges:

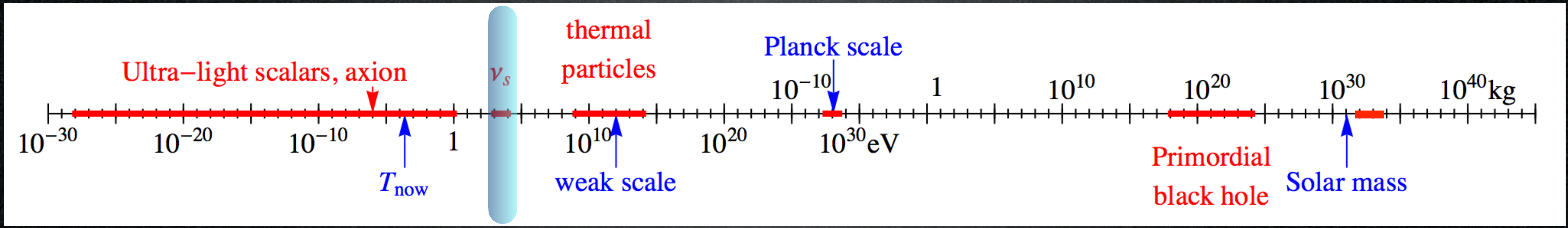
- EU production?
- Perseus flux too large?

Other possibilities:

axion (1402.7335), axino (1403.1536, 1403.1782, 1403.6621), modulus (1403.1733), ALP (1403.2370), gravitino (1403.6503), excited DM (1404.4795), the good the bad and the unlikely (1403.1570), sgoldstino (1404.1339), magnetic DM (1404.5446), majoron (1404.1400), annihilating effective DM (1404.1927), 7KeV scalar DM (1404.2220)...

Candidates

A matter of perspective: plausible mass ranges



'only' 90 orders of magnitude!