Connections between DM and neutrinos at the cosmological level

Andrés Olivares-Del Campo

IPPP, Durham University

Work in collaboration with:
Celine Boehm, Silvia Pascoli,
Sergio Palomares-Ruiz

GEMMA, Lecce, June 2018

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arXiv: 1711.05283

European Research Council

ν mass

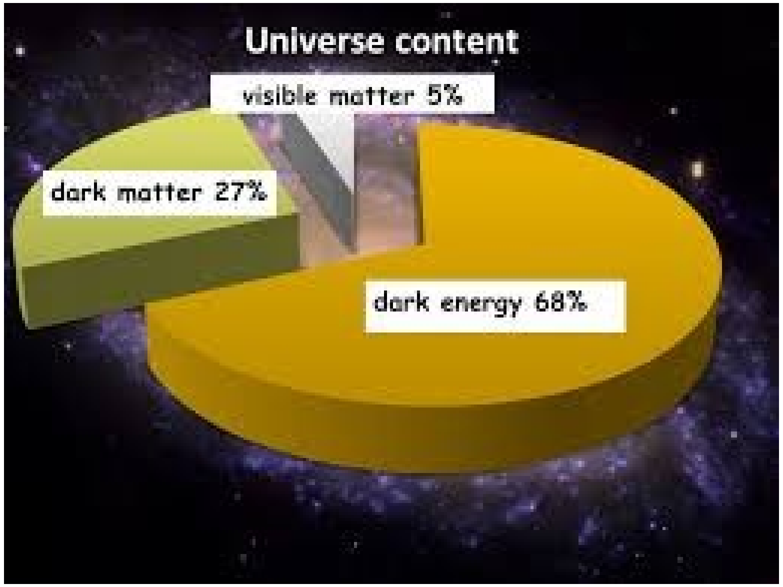
SEVENTH FRAMEWORK PROGRAMME

IP3

Durham University

Motivation

- A particle description of DM is still **missing**



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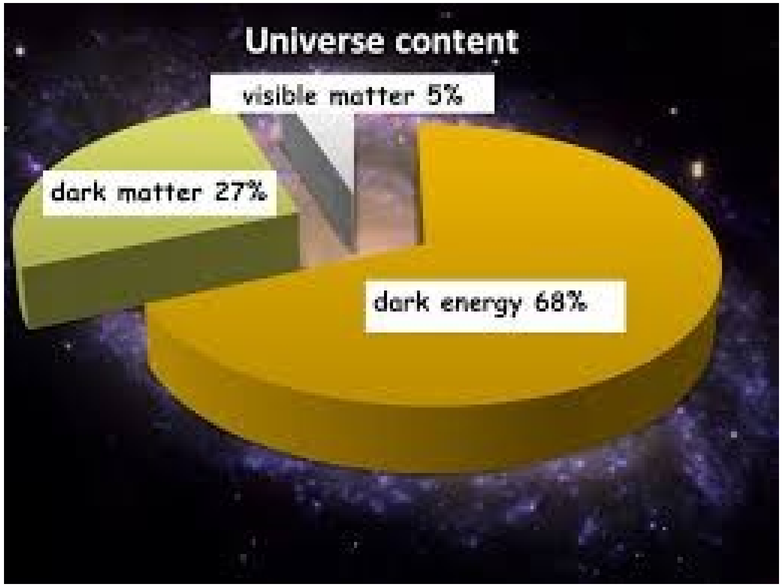

- We do not know **why** neutrinos have **mass**

Motivation

Neutrino masses can be generated from neutrino-DM interactions

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[S. Pascoli, et. al., 1208.2732 and C. Yaguna, et.al., 1308.3655]

Constraints

How can we relate **cosmological observables** to the **particle physics nature** of DM?

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Elastic Scattering $\sigma_{\rm dm-\nu}$

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- Thermal relic
- N_{eff}
- Indirect detection

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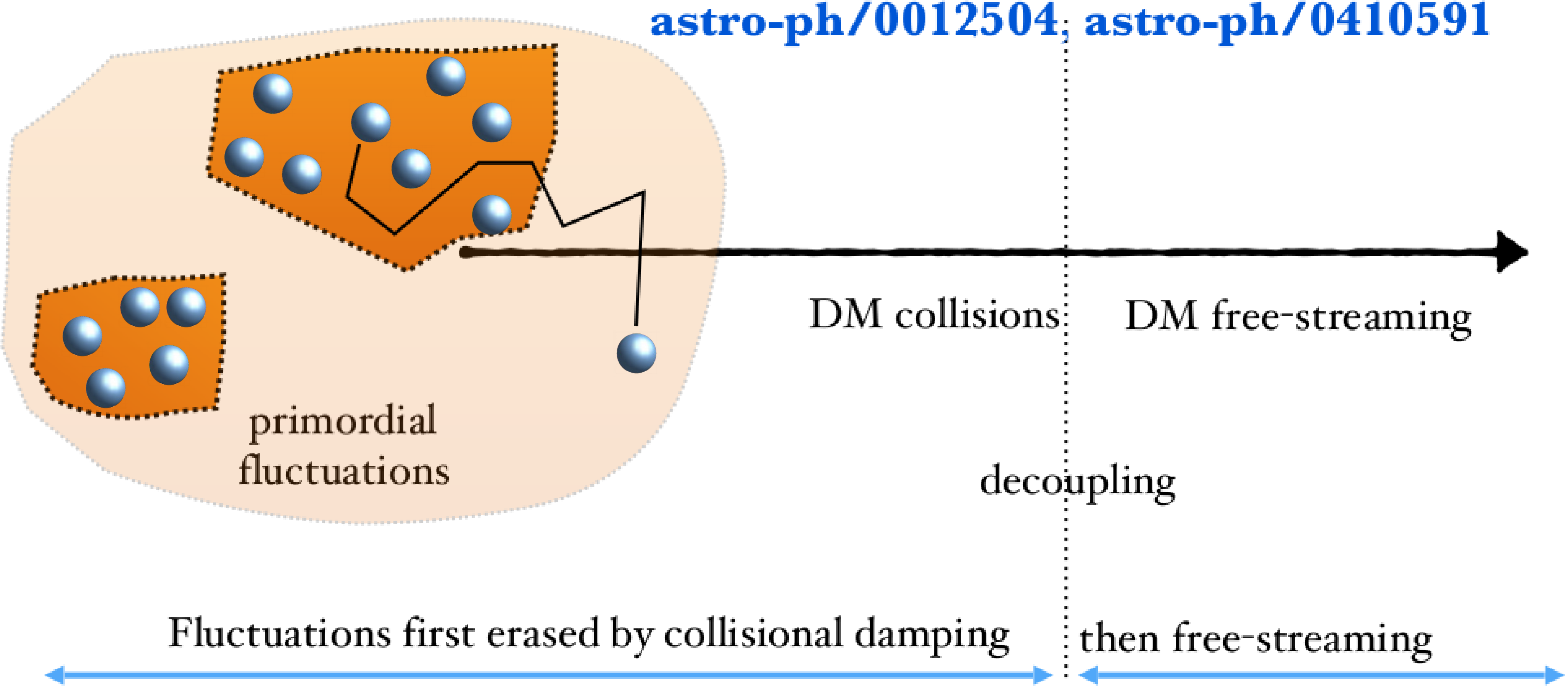
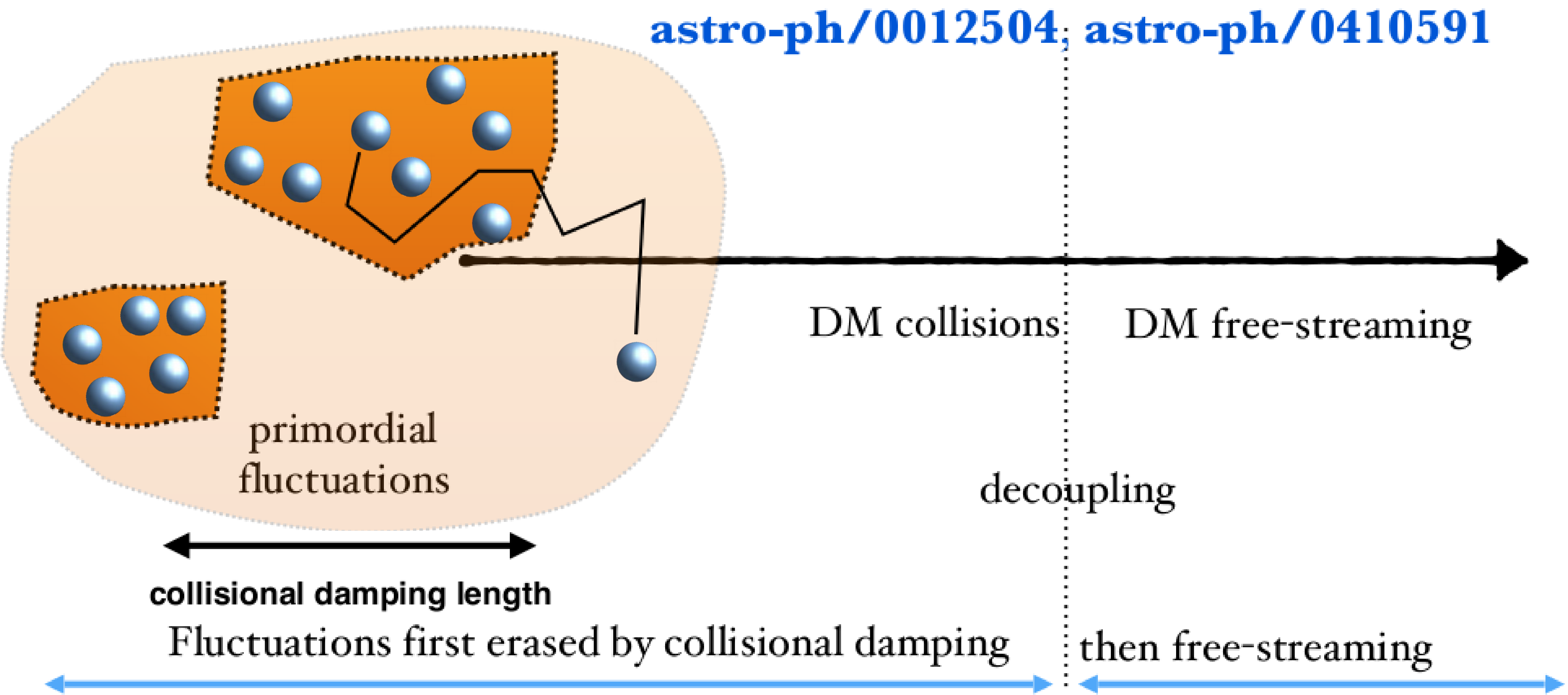
Large Scale Structure

astro-ph/0012504; astro-ph/0410591



[Modified from Celine Boehm's slide]

Large Scale Structure



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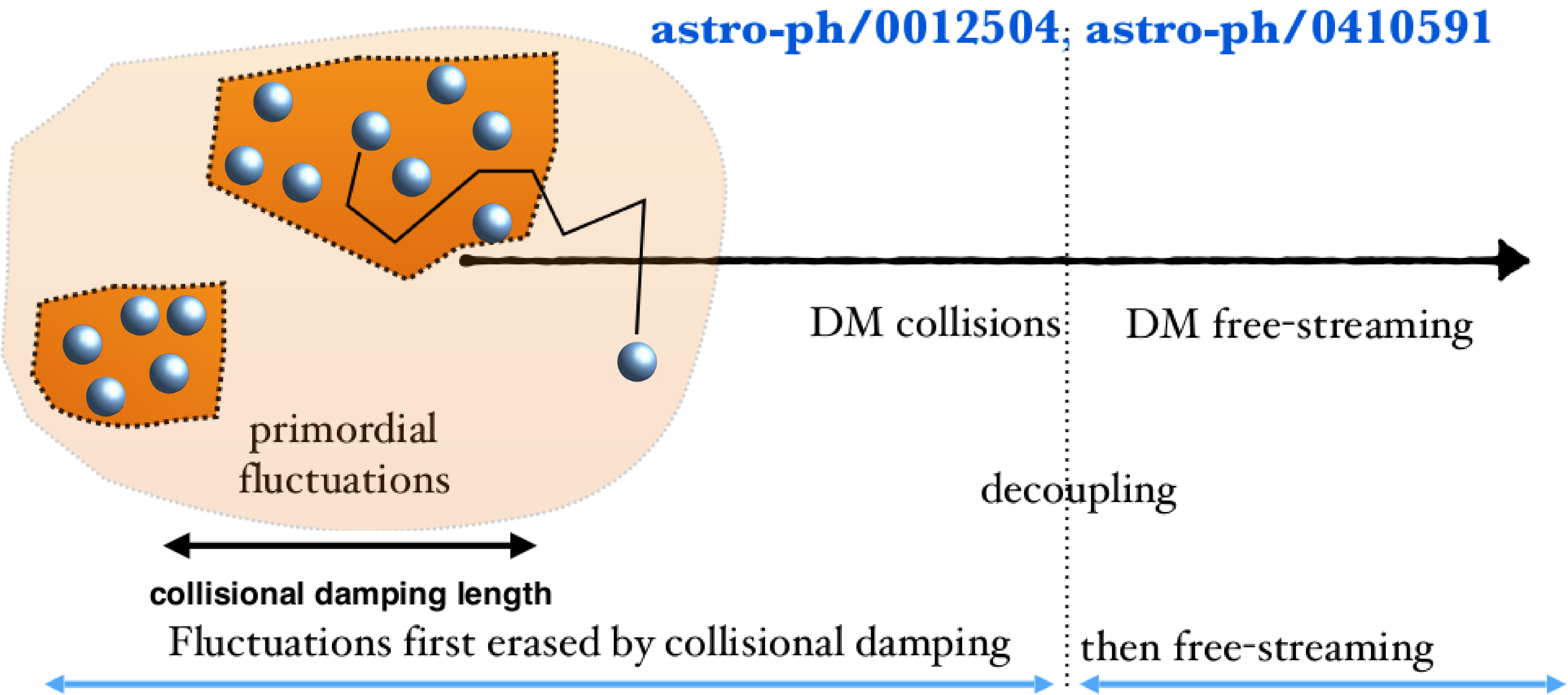
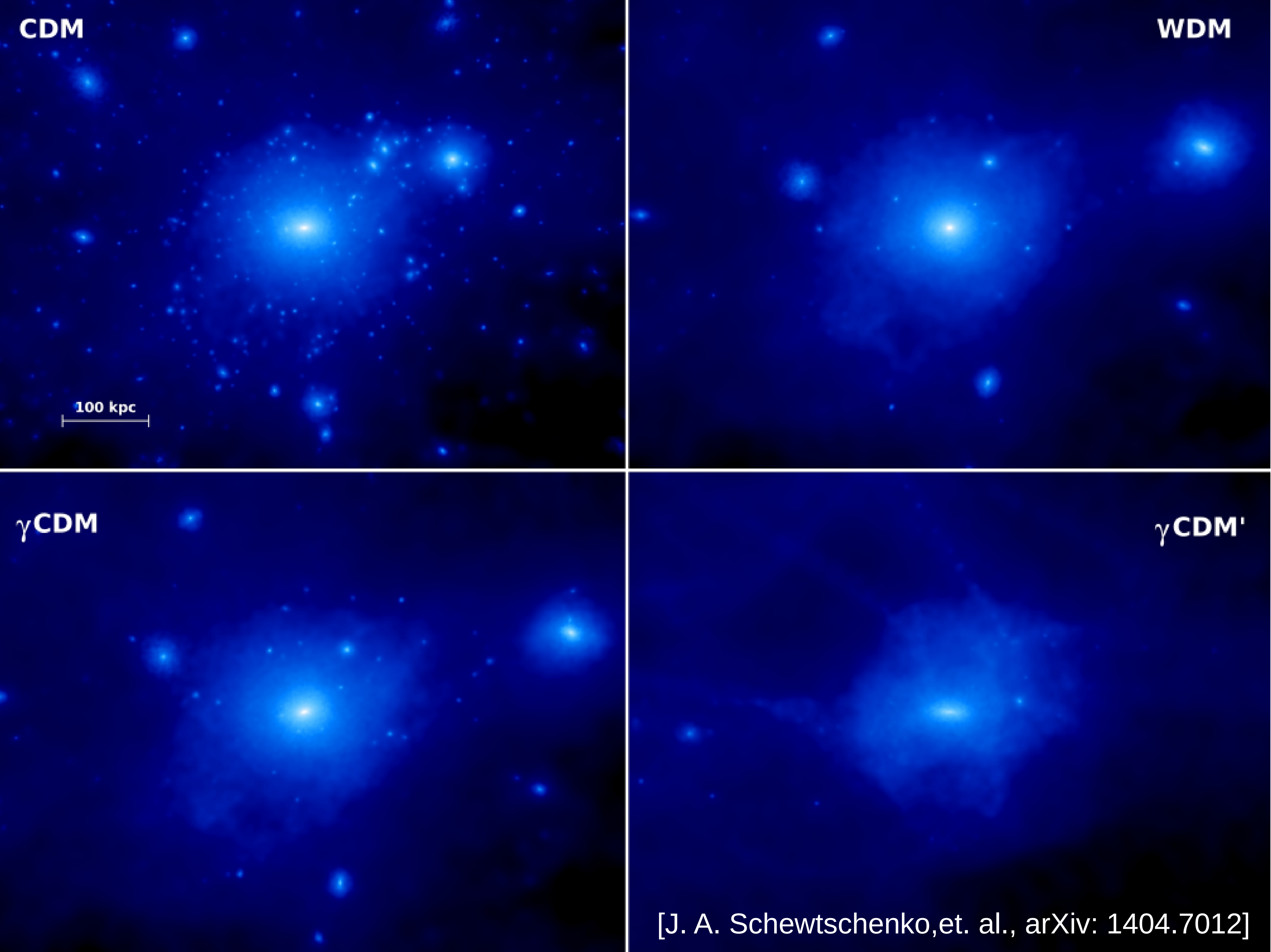
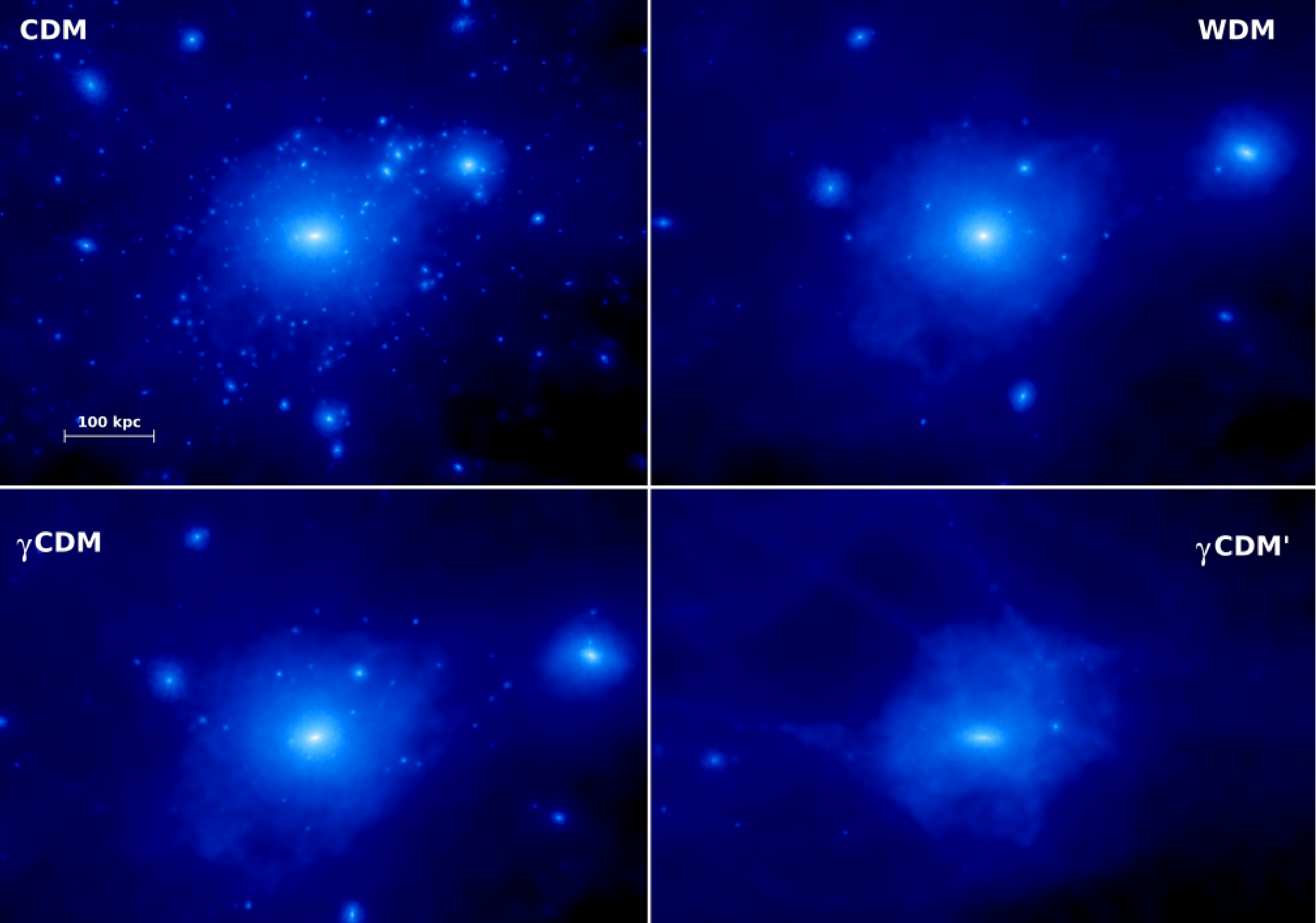


[Modified from Celine Boehm's slide]

This suppresses **matter perturbations** and reduces the amount of small structures today



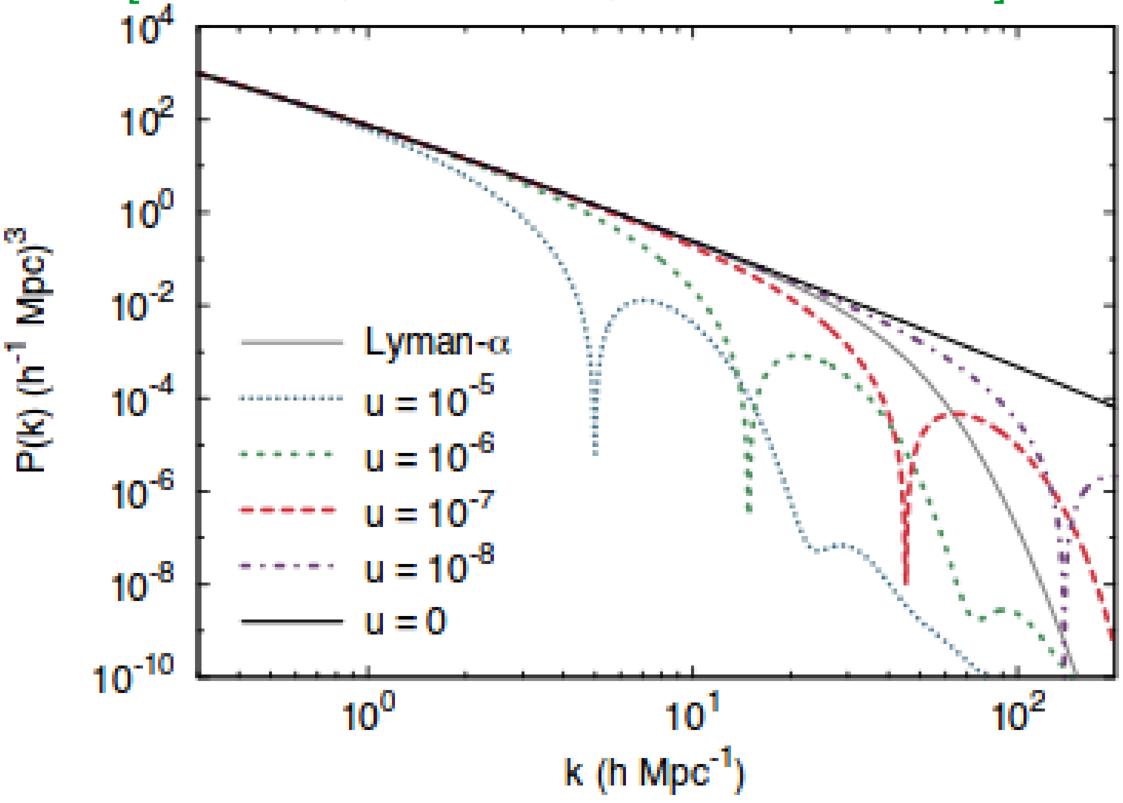
[J. A. Schewtschenko,et. al., arXiv: 1404.7012]



https://www.youtube.com/watch?v=YhJHN6z_0ek [J. A. Schewtschenko,et. al., arXiv: 1404.7012]

Large Scale Structure

[C.Boehm,R.Wilkinson, arXiv: 1401.7597]



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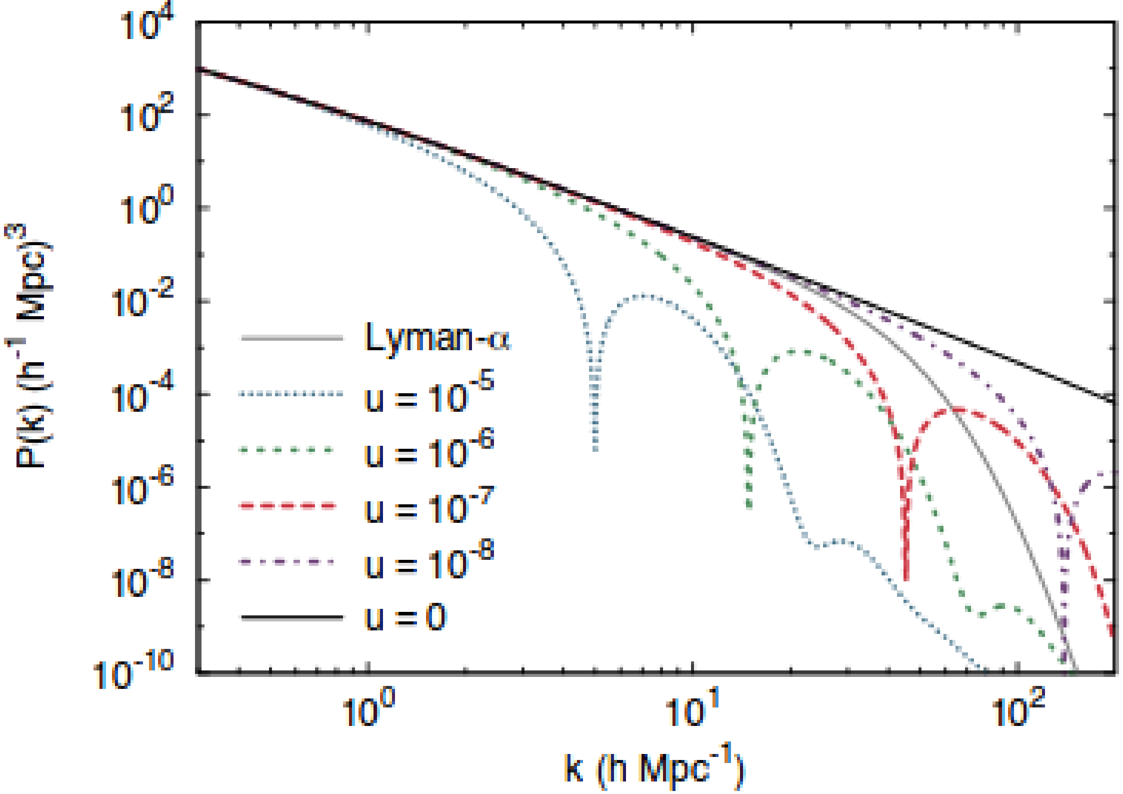


REQUIRE:

Constant Cross Section

$$\sigma_{\rm el} \lesssim 10^{-36} (\frac{m_{\rm DM}}{\rm MeV}) \ {\rm cm}^2$$

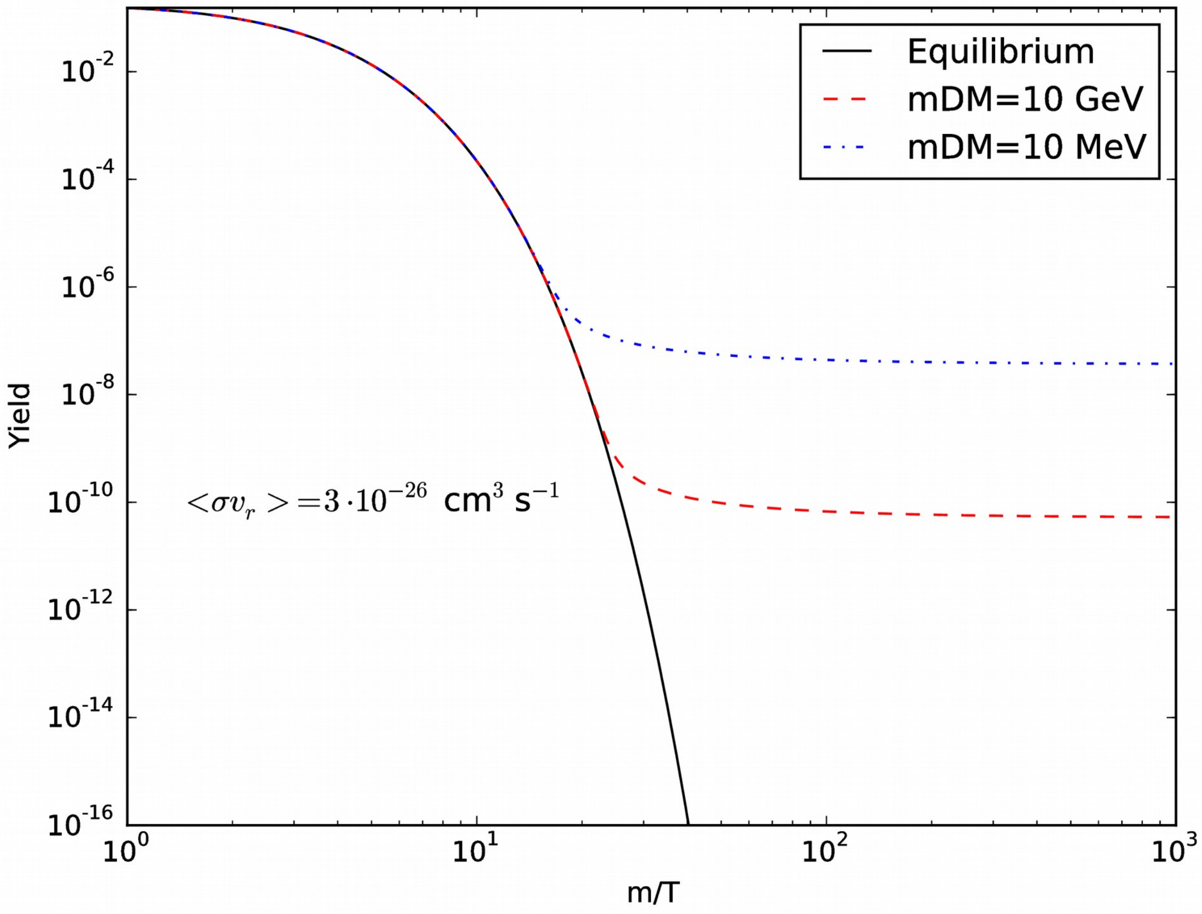
T- dependent Cross Section

$$\sigma_{\rm el} \lesssim 10^{-48} (\frac{m_{\rm DM}}{\rm MeV}) \ (\frac{T}{T_0})^2 \ {\rm cm}^2$$

Annihilation cross section

Relic Abundance

$$\chi + \overset{(-)}{\chi} \leftrightarrow \nu_{\mathrm{L}} + \bar{\nu}_{\mathrm{L}}$$



- Sets the amount of DM today

Relic Abundance

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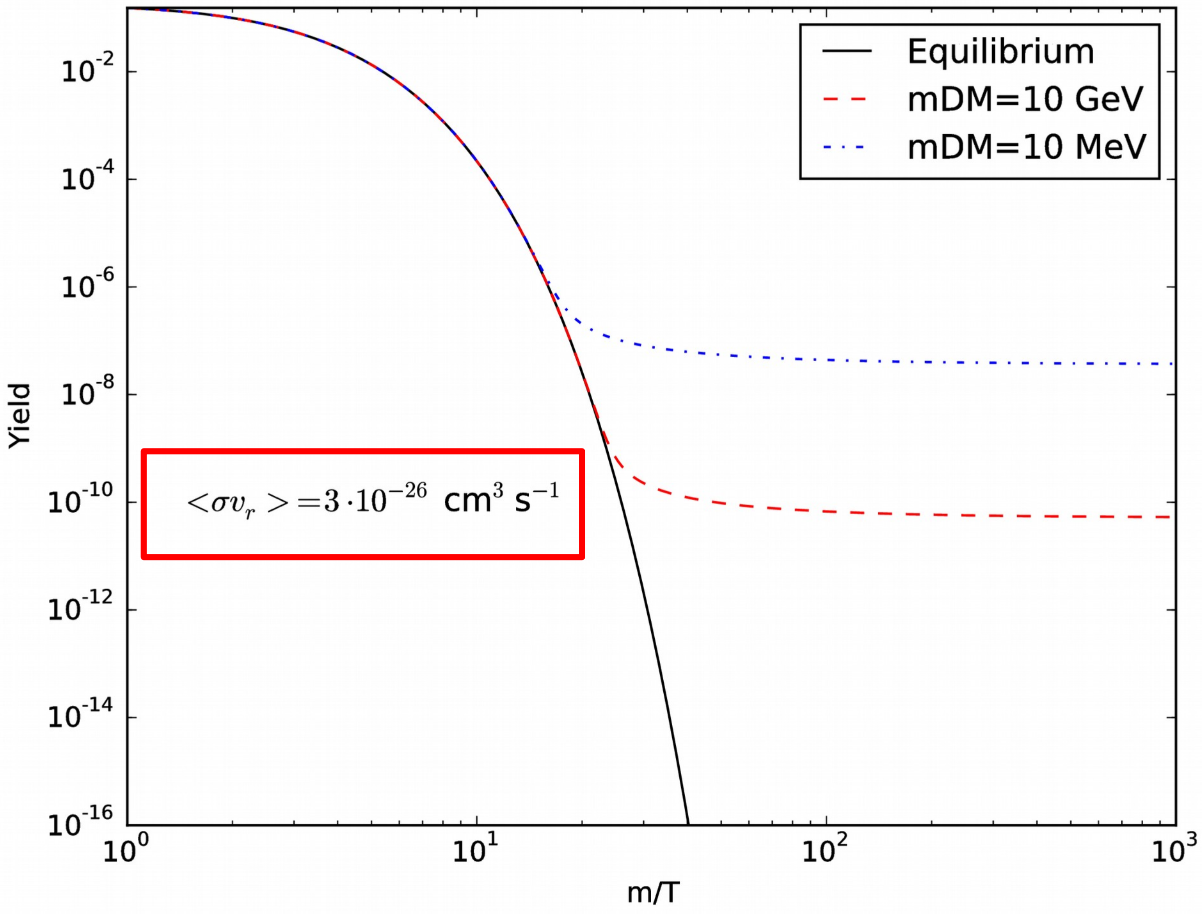
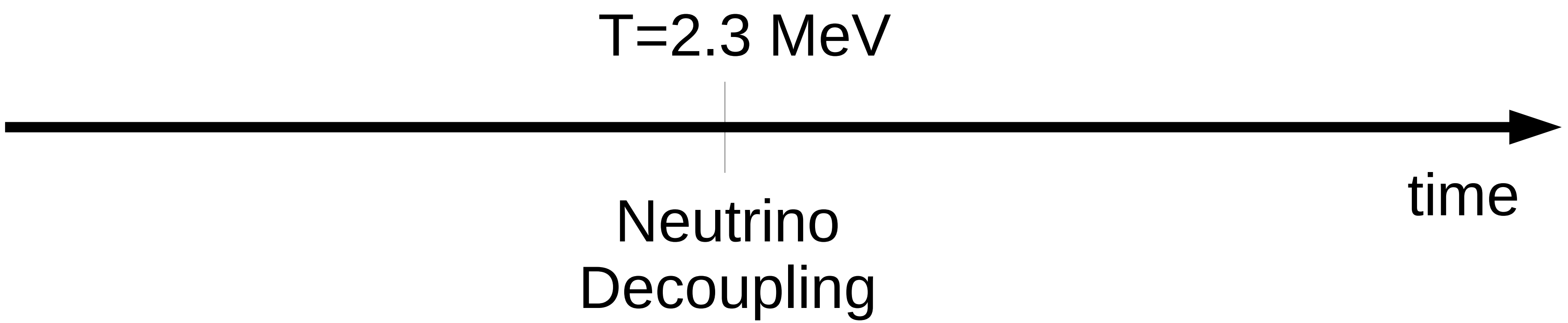
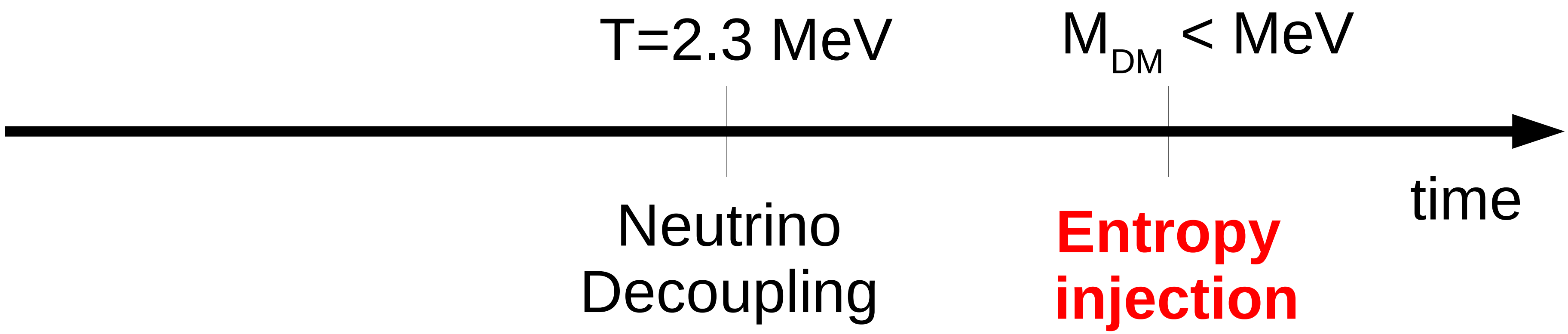


- Sets the amount of DM today

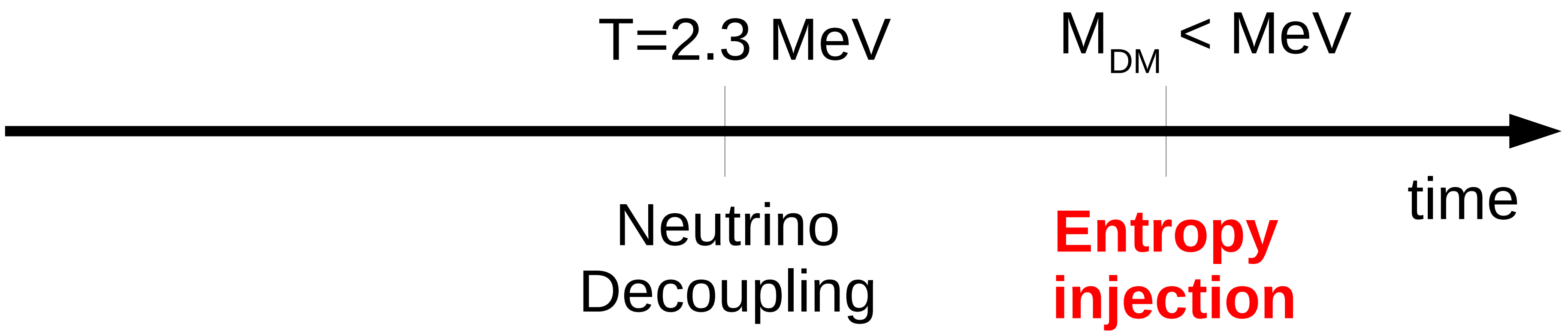
Relativistic Neutrino Species



Relativistic Neutrino Species



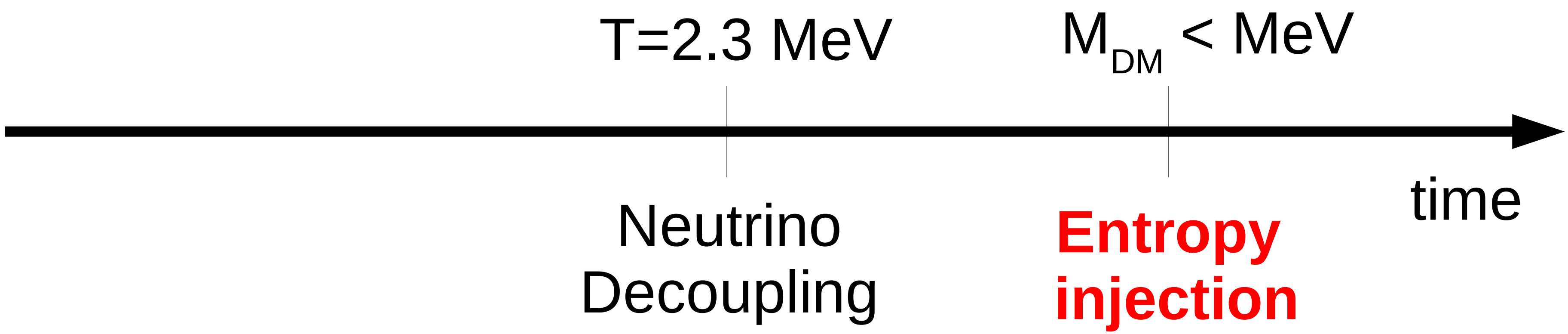
Relativistic Neutrino Species

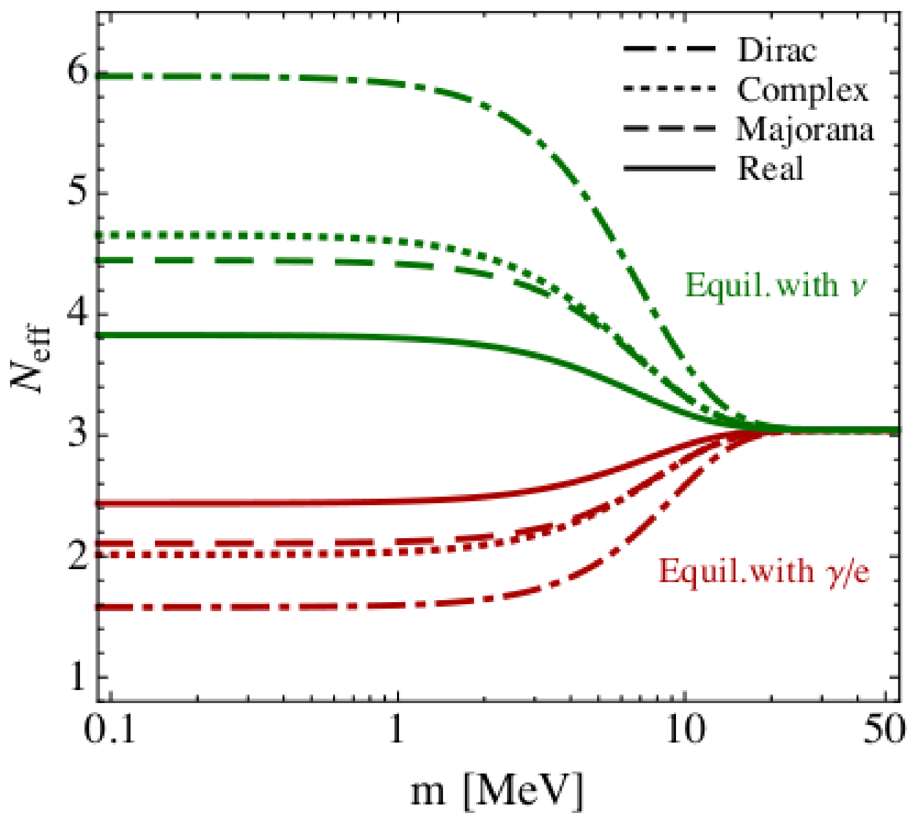


$$N_{\rm eff} = N_\nu \left(\frac{4}{11}\right)^{-4/3} \left(\frac{T_\nu}{T_\gamma}\right)^4 .$$

Andrés Olivares-Del Campo

Relativistic Neutrino Species





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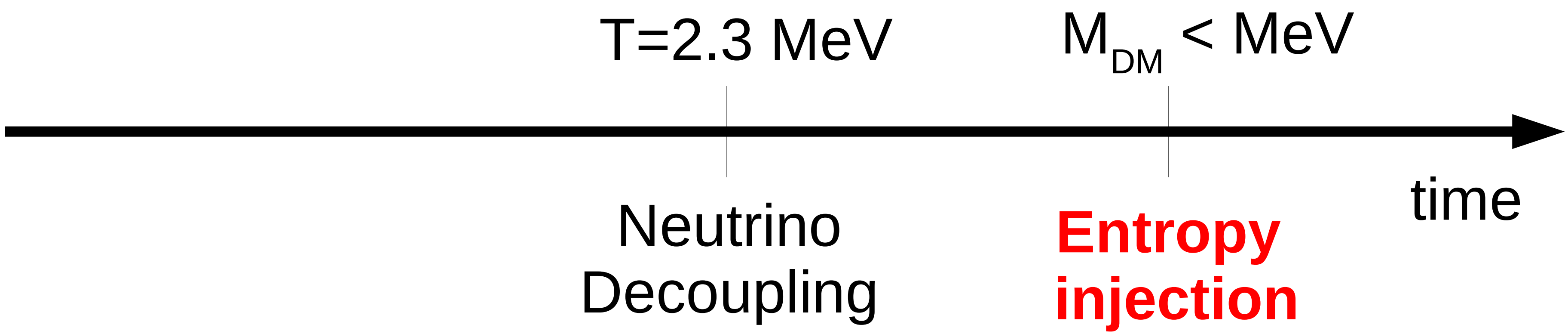

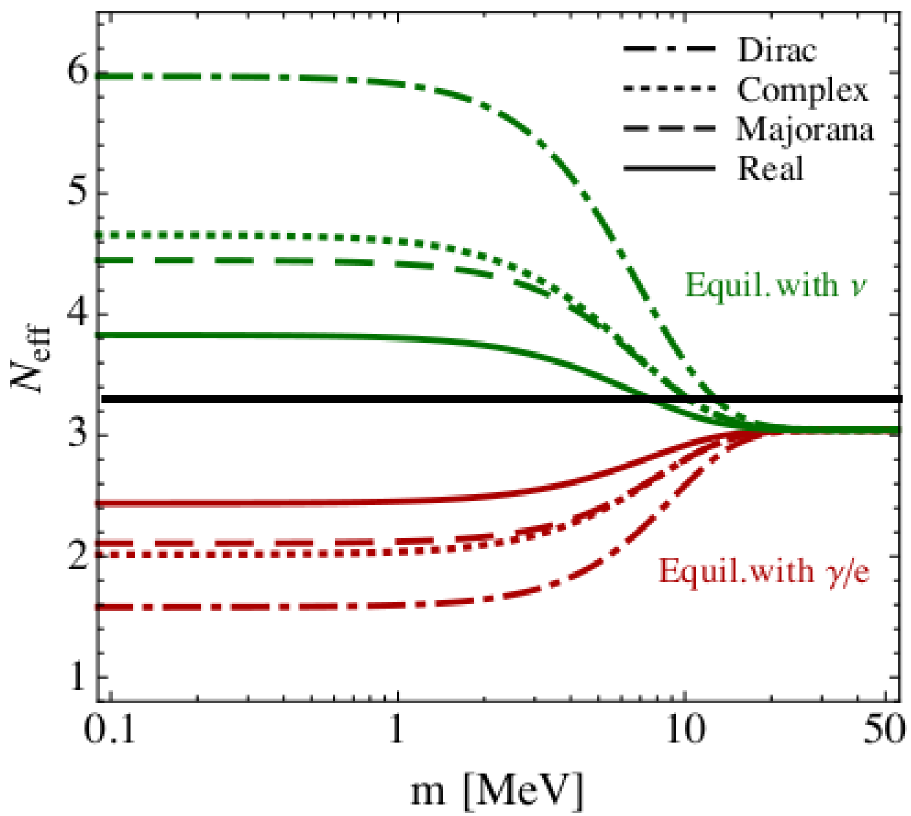

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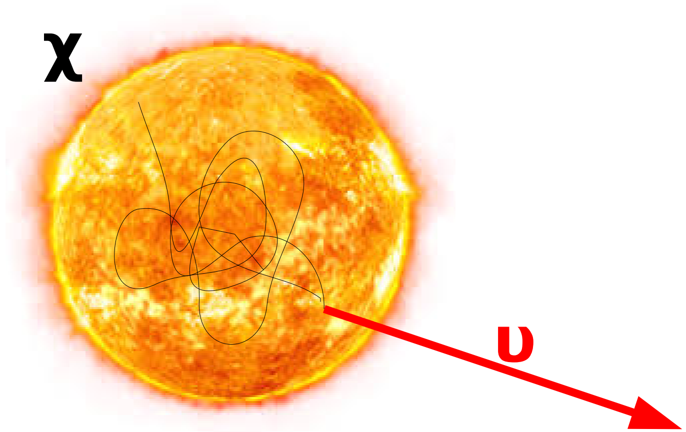
Compare to meassured value

$$N_{eff} = 3.30^{+0.54}_{-0.51}$$

Neutrino Signals from DM



- Sensitive to DM-Nucleon scattering

[C. Rott, et. al., arXiv: 1510.00170,
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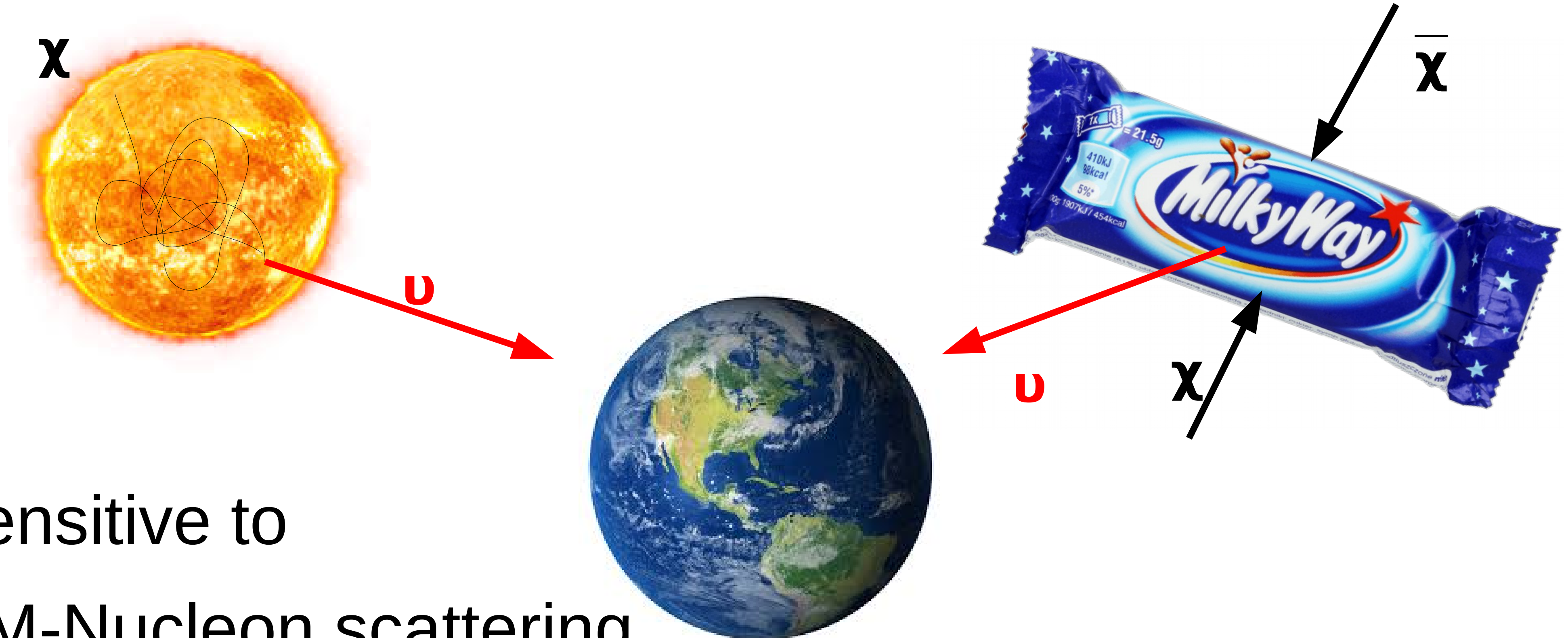

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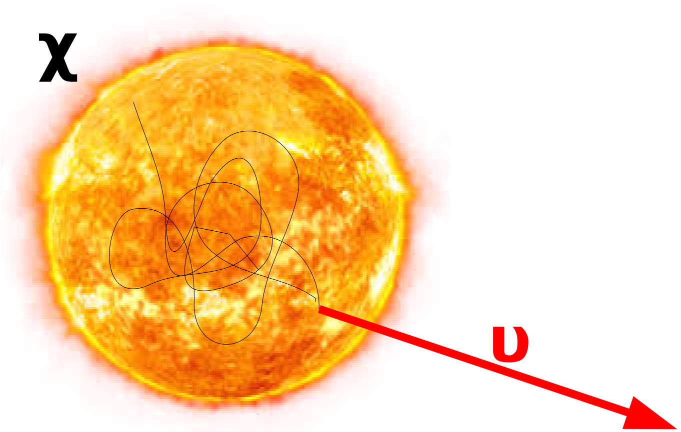

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[C. Boehm, AOC, S. Palomares-Ruiz, S. Pascoli, 1711.05283, K. Frankiewicz, arXiv: 1510.07999, S. Palomares-Ruiz, et. al., arXiv: 0710.5420]

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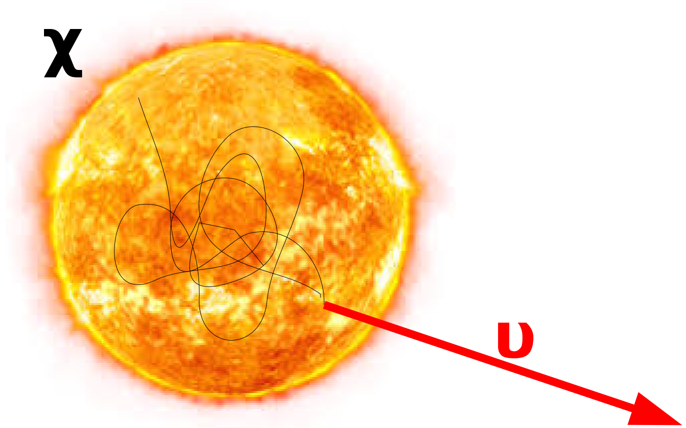

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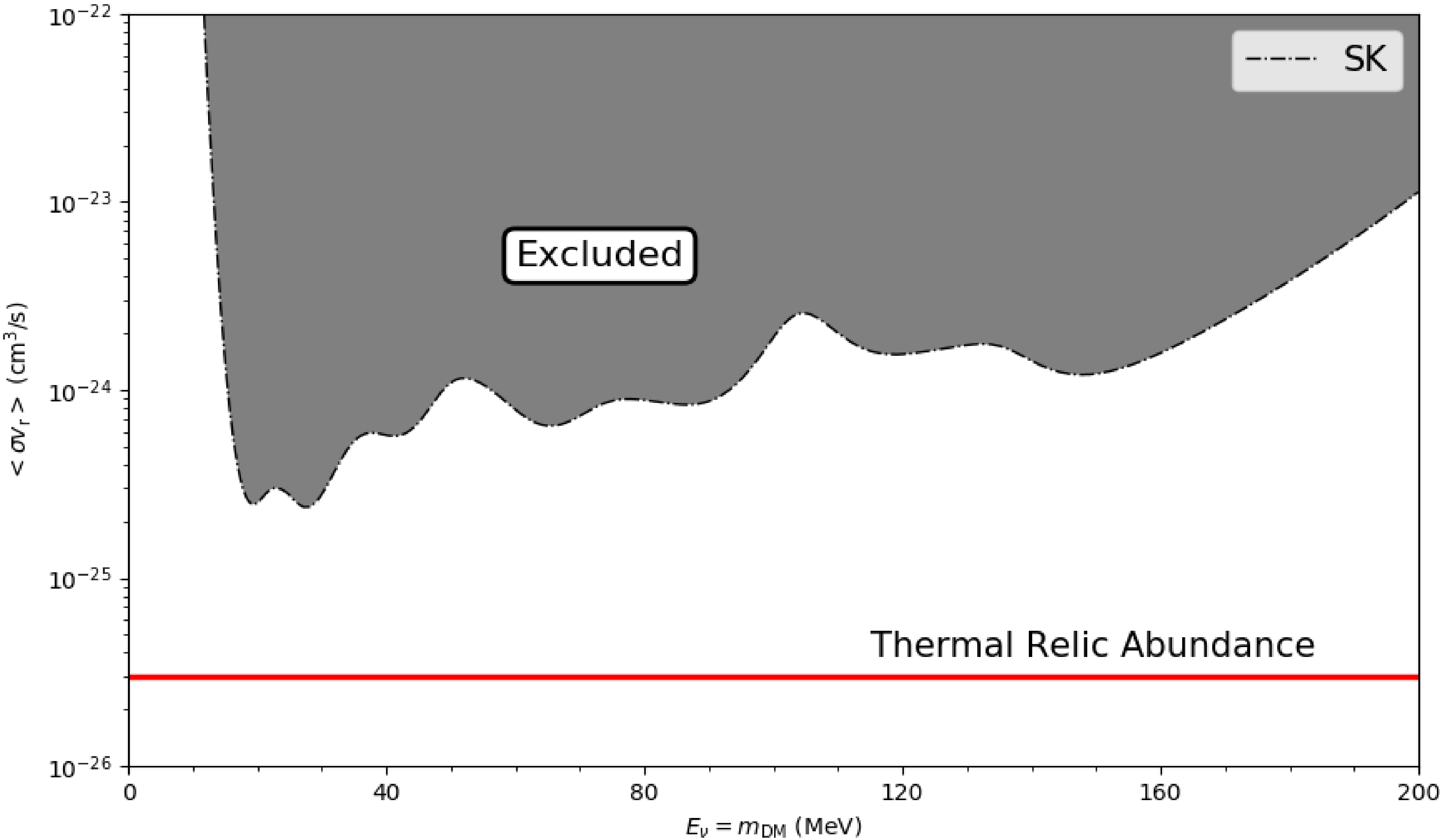
Neutrinos from the Milky Way



[AOC, et al., arXiv: 1805.09830]

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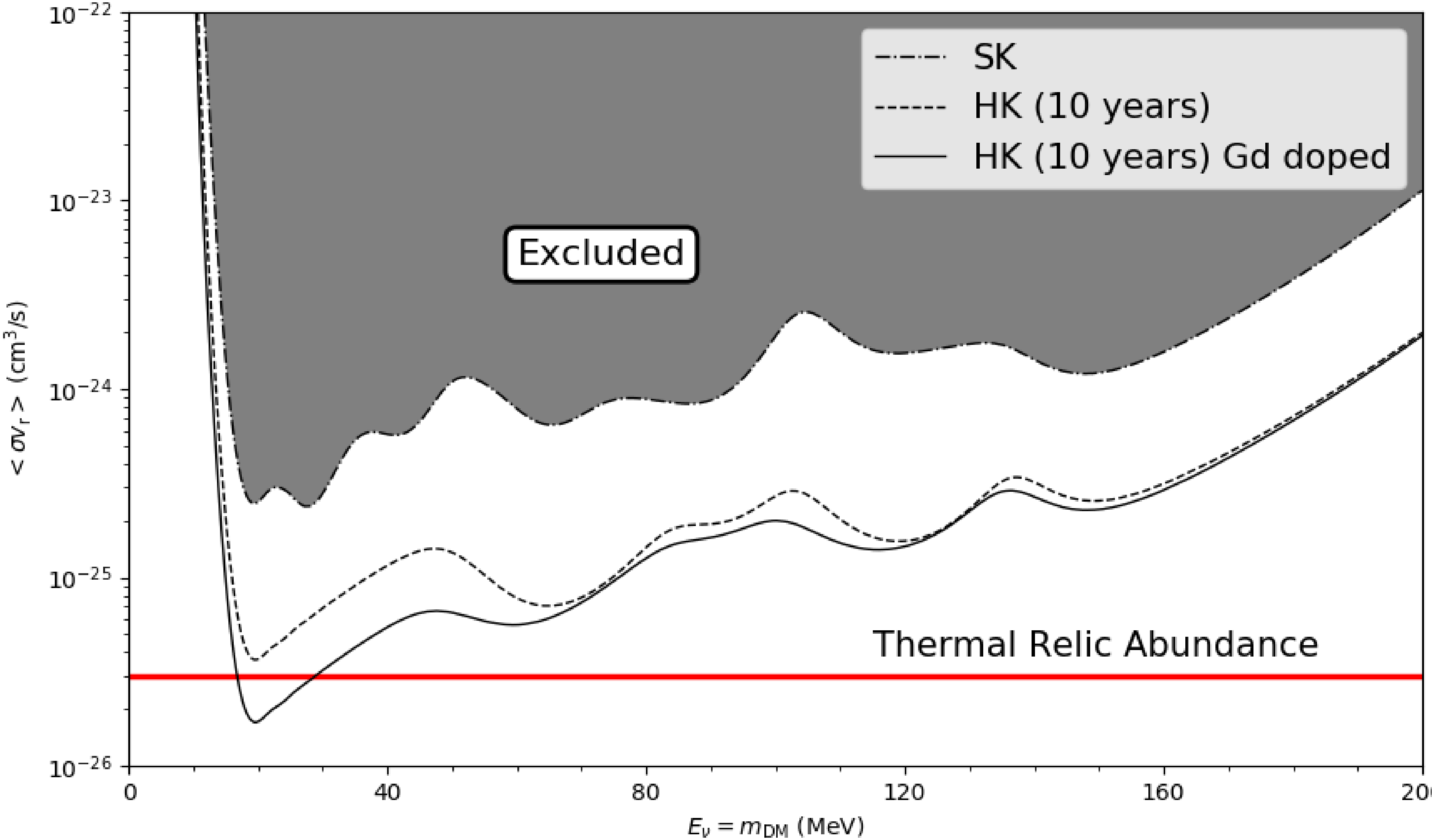

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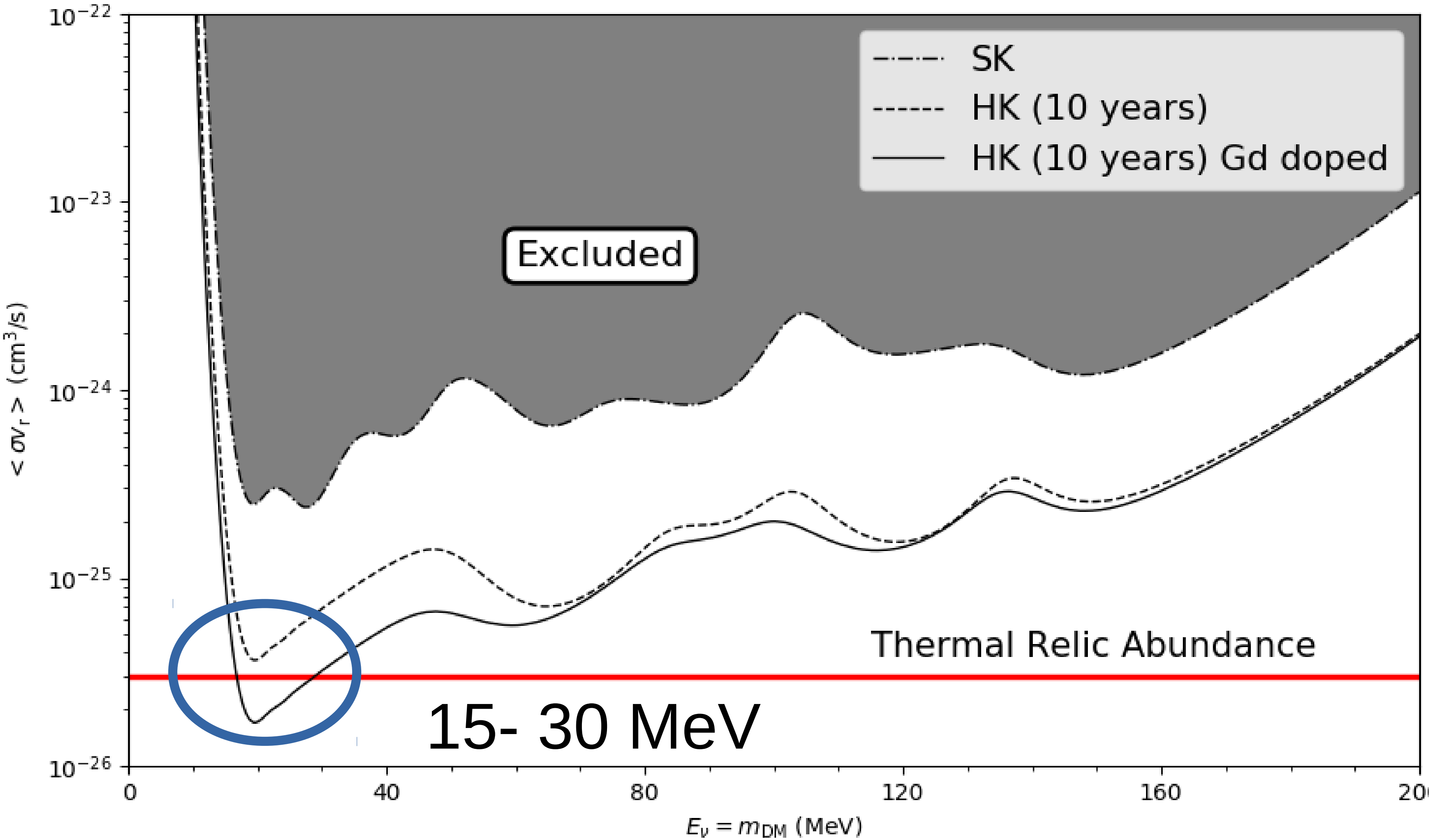

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(...

Gauge Invariance

- SM: $SU(3)_C \times SU(2)_L \times U(1)_Y$

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Can neutrino-DM interactions be **enhanced**?

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[A. Merle, et. al., 1005.3116 and T. Hambye, et.al., 1706.06600]

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→ The nature of the DM and the mediator [A. Merle, et. al., 1005.3116 and T. Hambye, et.al., 1706.06600]
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- **Concrete Model:** Dirac Neutrino Portal [T. Han, et. al., 1709.07001]

...)

Results

Set up

- **Simplified model** approach, considering D=4 interactions with l**eft handed** neutrinos only

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  - Spin 0 and ½ mediators

  - Spin 1 mediators

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Dirac DM, scalar Mediator

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Dirac DM, scalar Mediator

$$\mathcal{L}_{\text{int}} \supset -\sum_{\alpha} g_\alpha \bar{\chi}_R \, \phi \cdot L_\alpha \; + \; \text{h.c.}$$

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Dirac DM, scalar Mediator

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$m_{\phi} > m_{\text{DM}}$

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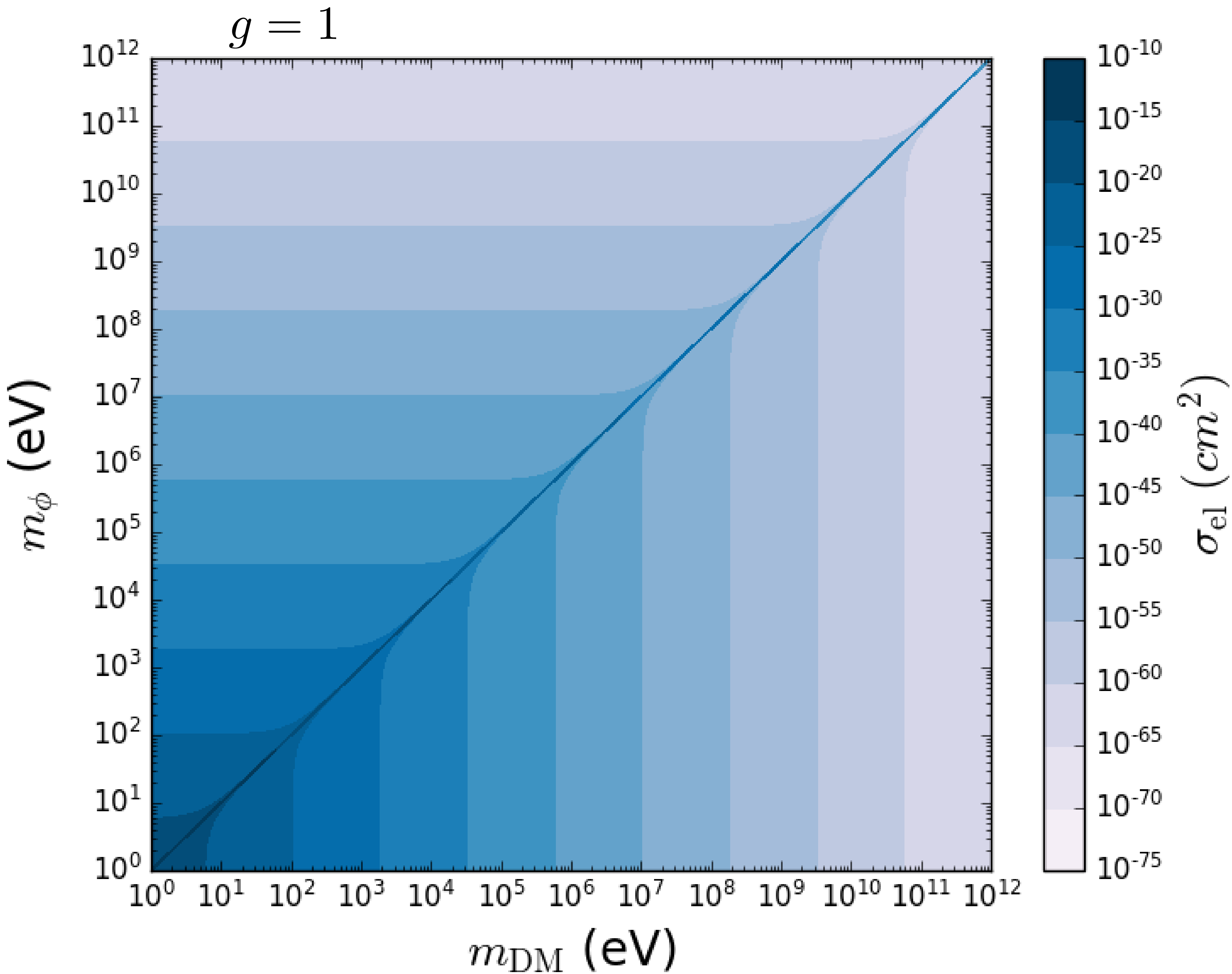

$g = 1$
m_ϕ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{\rm el}$ (cm^2)
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
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10^{-45}
10^{-50}
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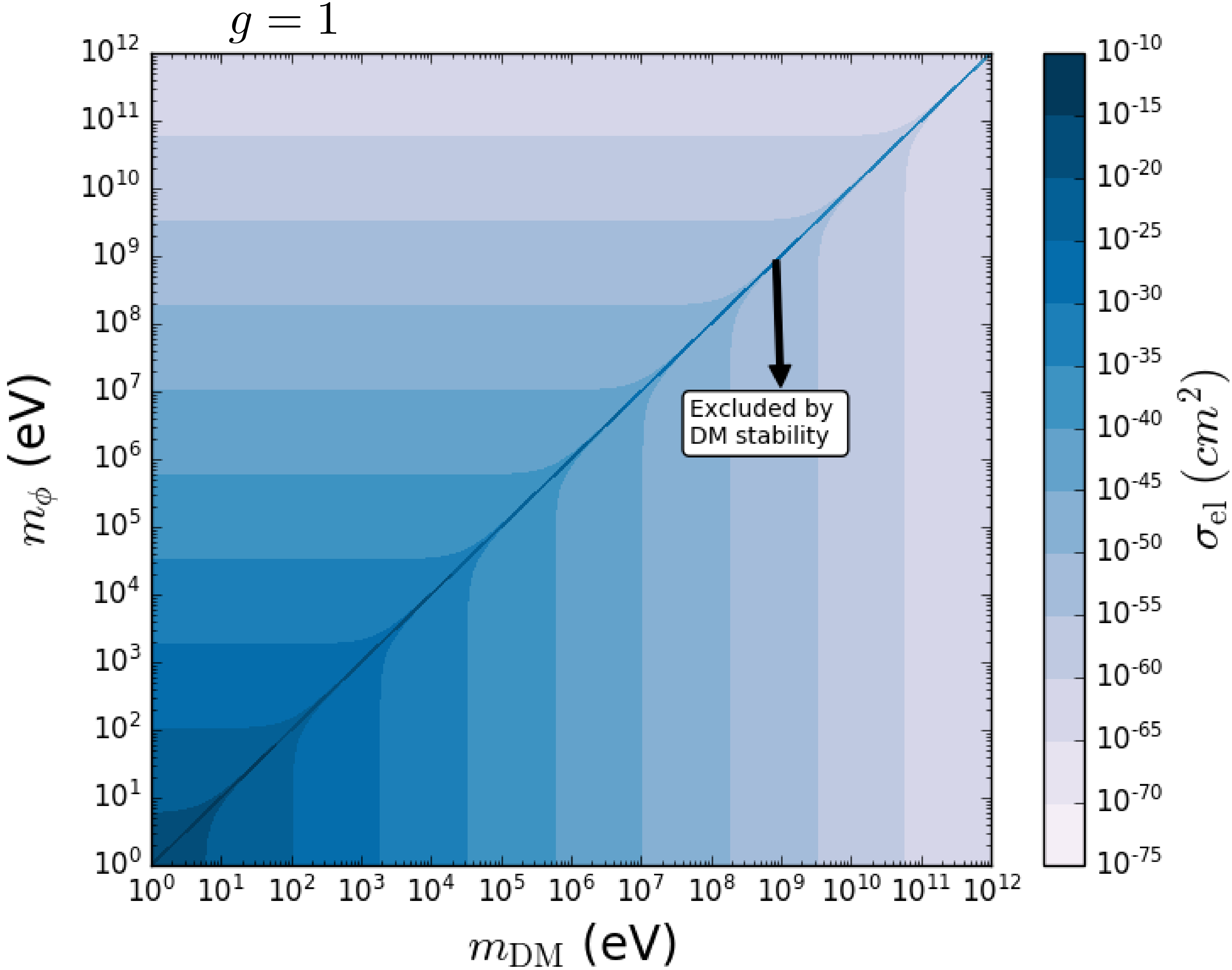
10^{-60}
10^{-65}
10^{-70}
10^{-75}



$g = 1$
m_ϕ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{\rm el}$ (cm^2)
Excluded by
DM stability
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
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10^{-45}
10^{-50}
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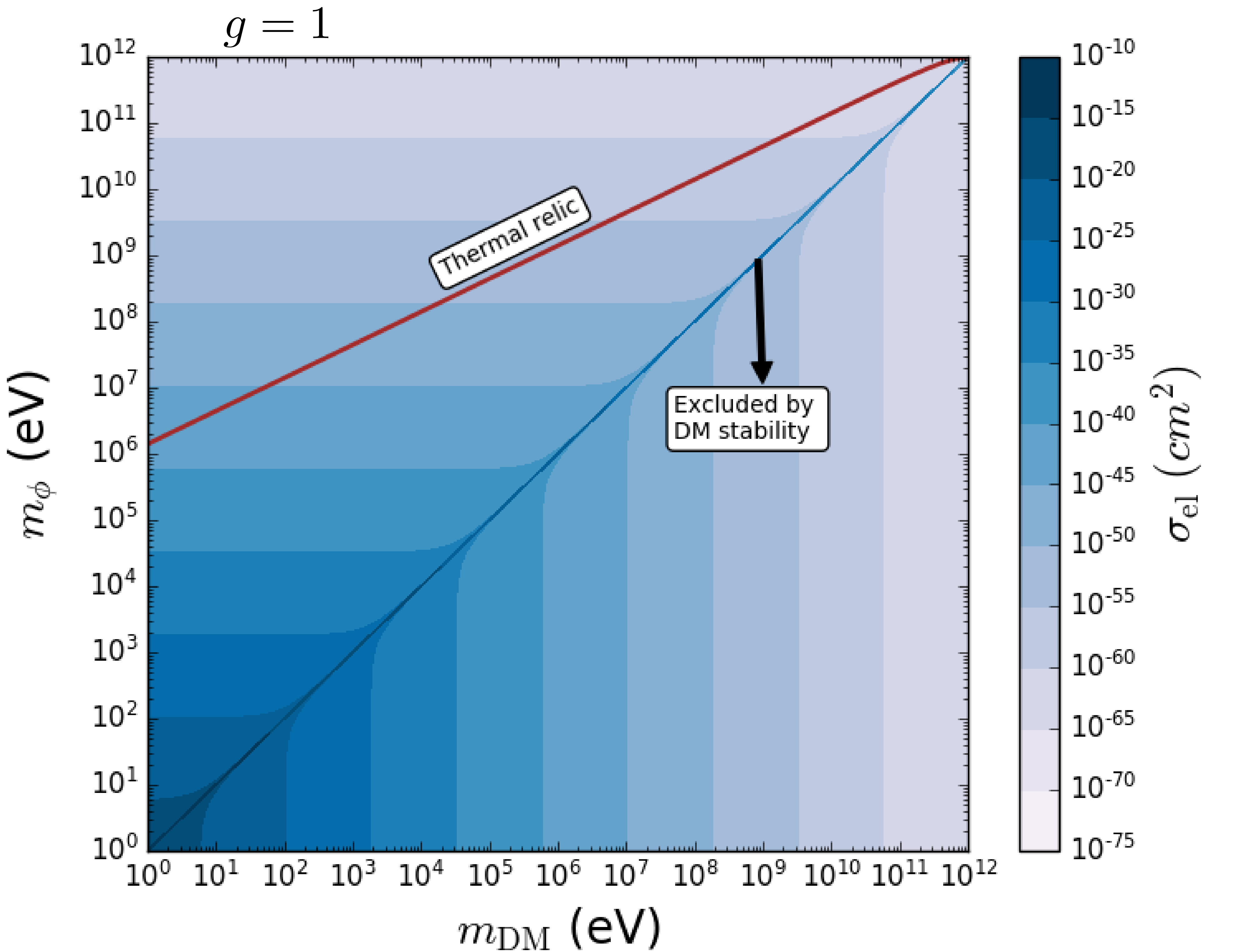
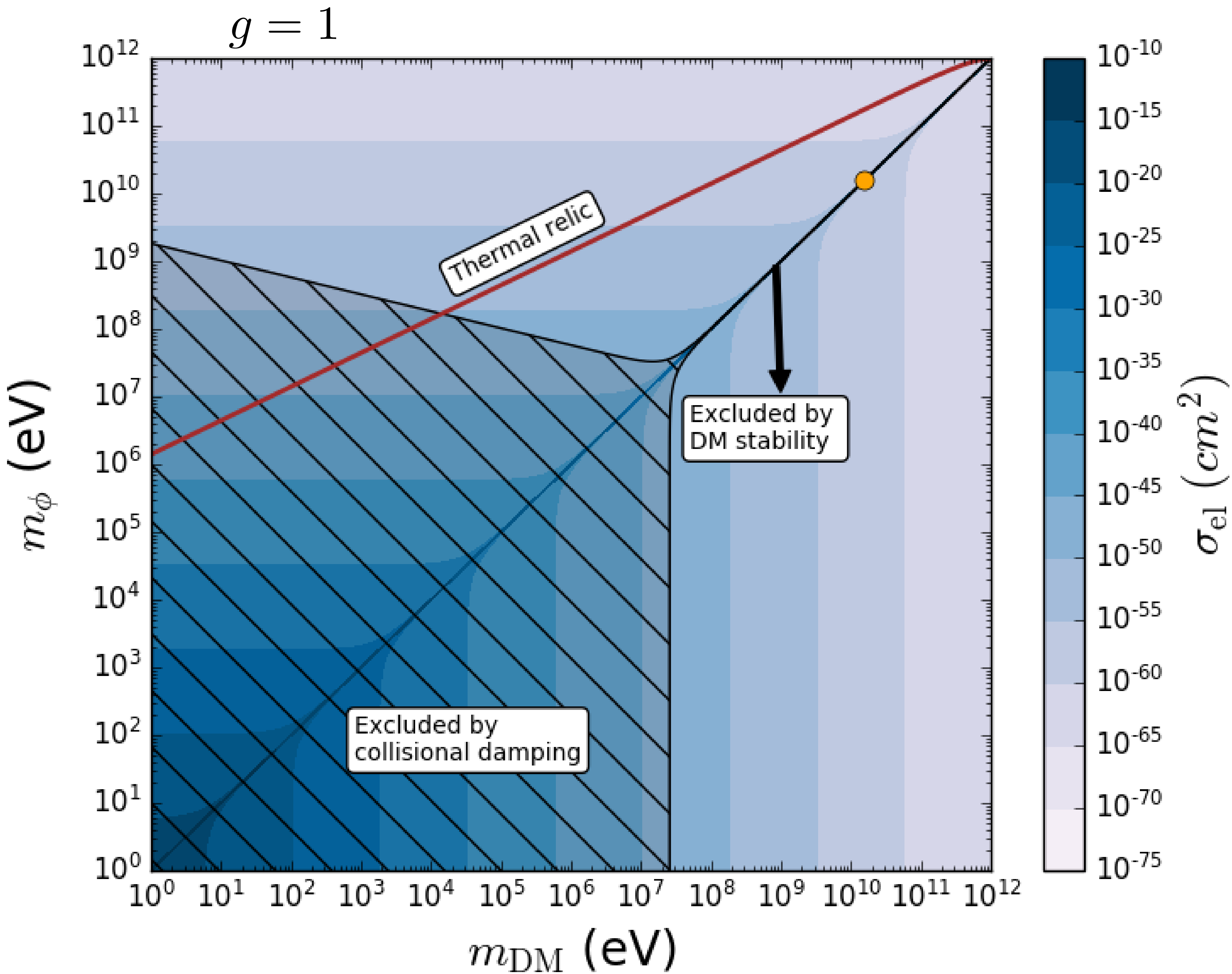
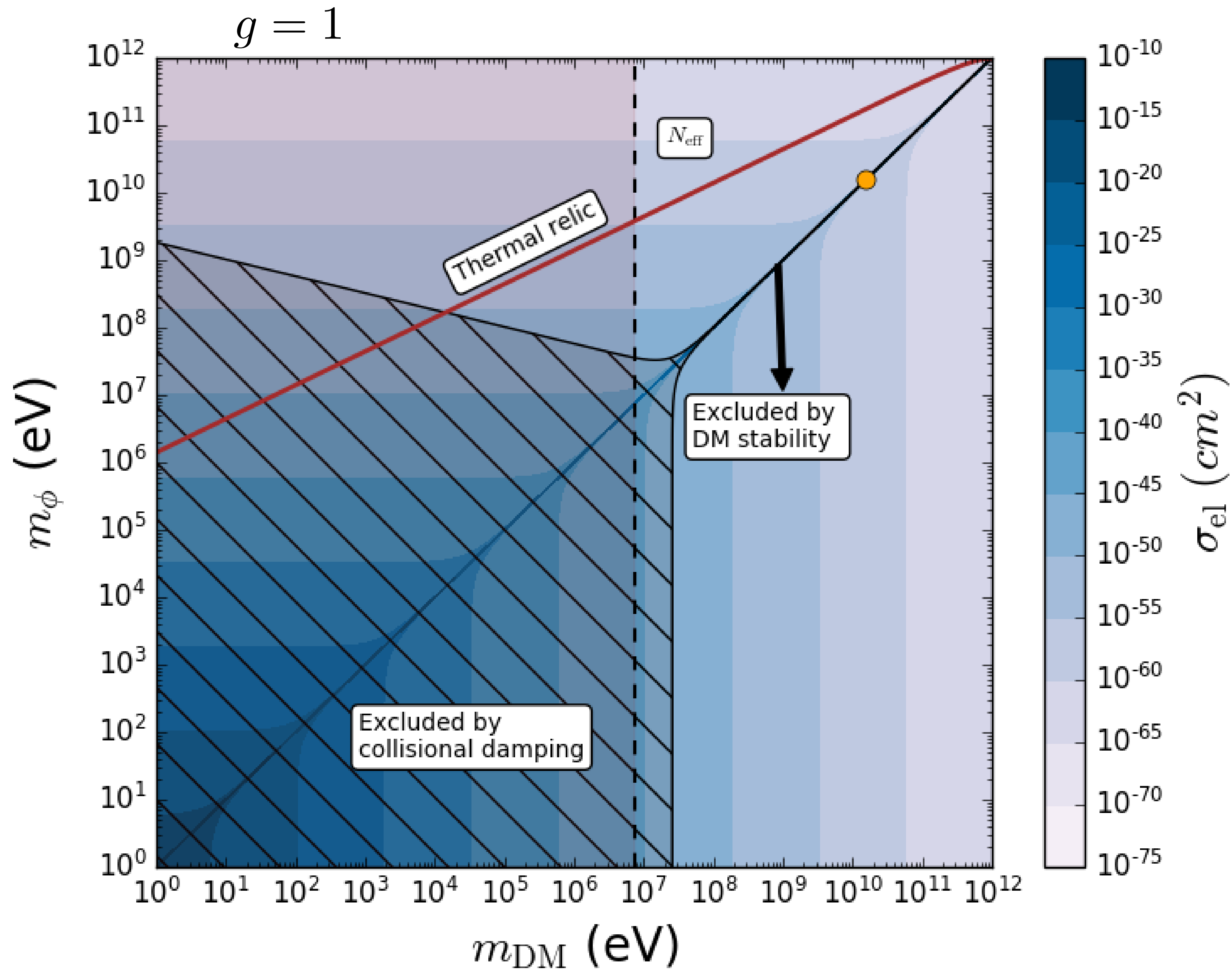
10^{-60}
10^{-65}
10^{-70}
10^{-75}



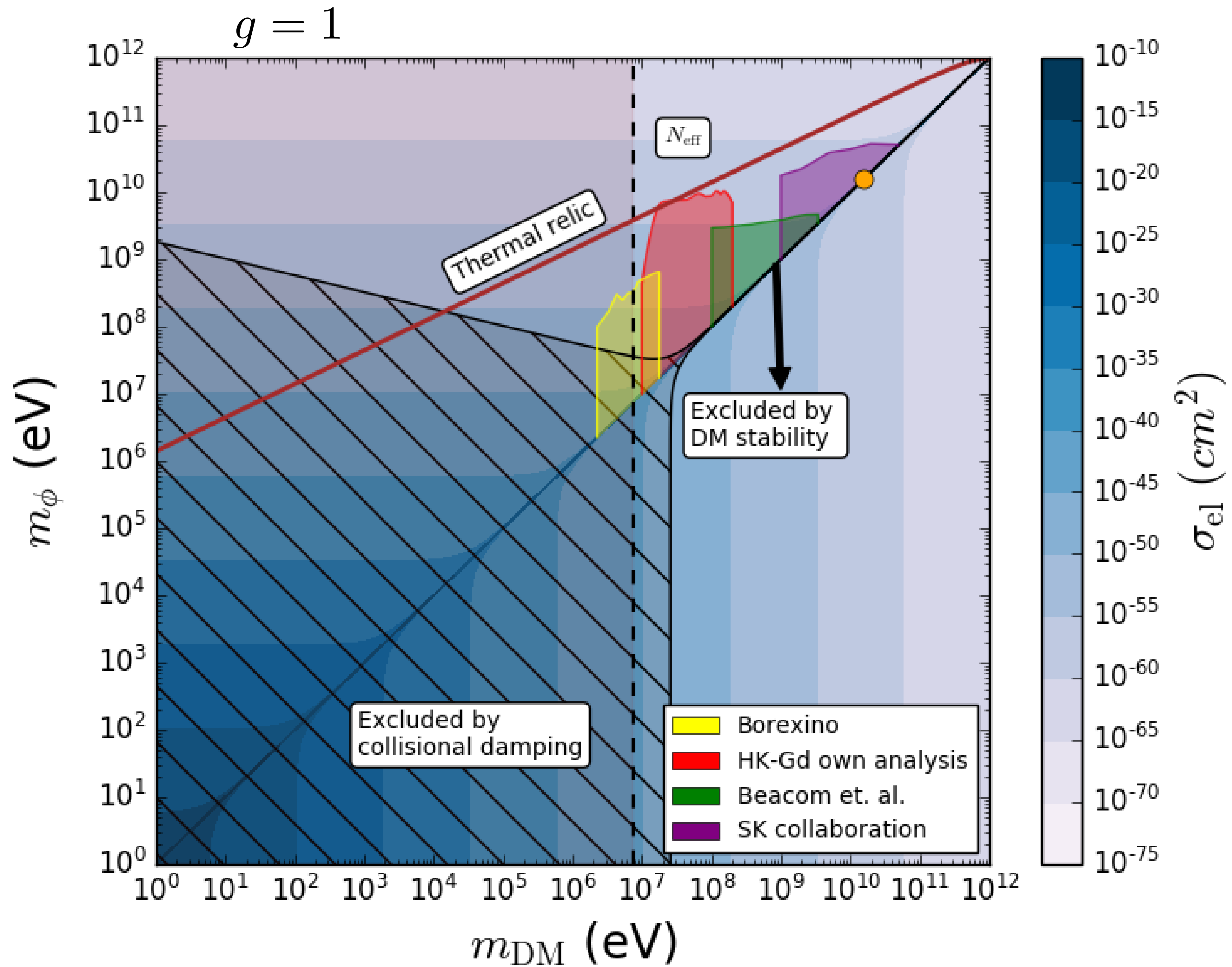
$g = 1$
Thermal relic
Excluded by
DM stability
m_{ϕ} (eV)
$m_{\rm DM}$ (eV)
$\sigma_{\rm el}$ (cm^2)
10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12}
10^{-10} 10^{-15} 10^{-20} 10^{-25} 10^{-30} 10^{-35} 10^{-40} 10^{-45} 10^{-50} 10^{-55} 10^{-60} 10^{-65} 10^{-70} 10^{-75}



$g = 1$
Thermal relic
Excluded by DM stability
Excluded by collisional damping
m_ϕ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{\rm el}$ (cm^2)



$g = 1$
Thermal relic
$N_{\rm eff}$
Excluded by DM stability
Excluded by collisional damping
m_ϕ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{\rm el}\ (cm^2)$

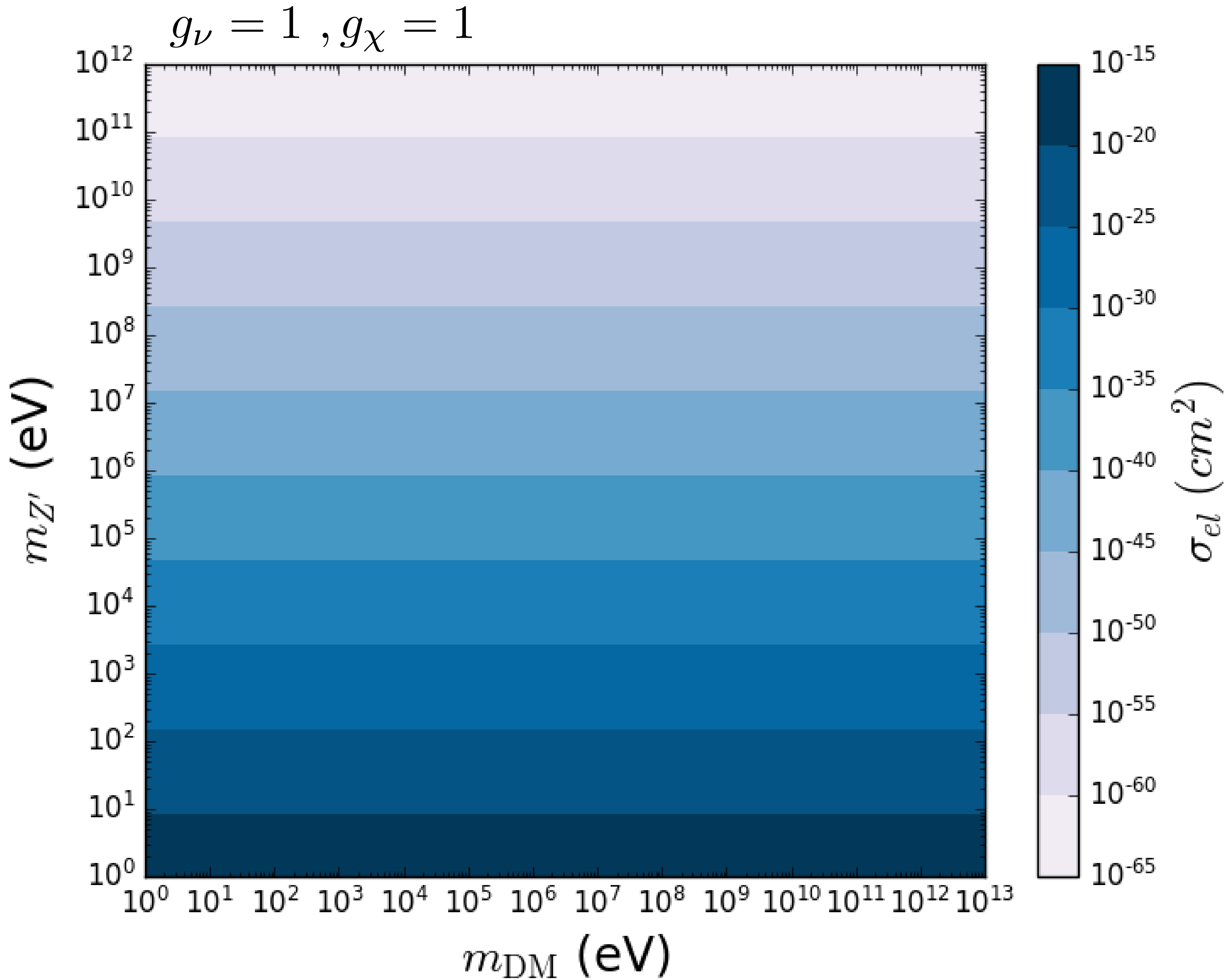


$g = 1$
Thermal relic
$N_{\rm eff}$
Excluded by DM stability
Excluded by collisional damping
Borexino
HK-Gd own analysis
Beacom et. al.
SK collaboration
m_ϕ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{\rm el}$ (cm^2)
10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12}
10^{-10} 10^{-15} 10^{-20} 10^{-25} 10^{-30} 10^{-35} 10^{-40} 10^{-45} 10^{-50} 10^{-55} 10^{-60} 10^{-65} 10^{-70} 10^{-75}

Dirac DM
Vector Mediator

Dirac DM
Vector Mediator

$$\mathcal{L}_{\rm int} \supset -g_\nu \overline{\nu_{\rm L}} \gamma^\mu Z'_\mu \nu_{\rm L} - g_\chi \overline{\chi} \gamma^\mu Z'_\mu \chi$$



$g_\nu = 1 \, , g_\chi = 1$
$m_{Z'}$ (eV)
m_{DM} (eV)
$\sigma_{el}\ (cm^2)$
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{-15}
10^{-20}
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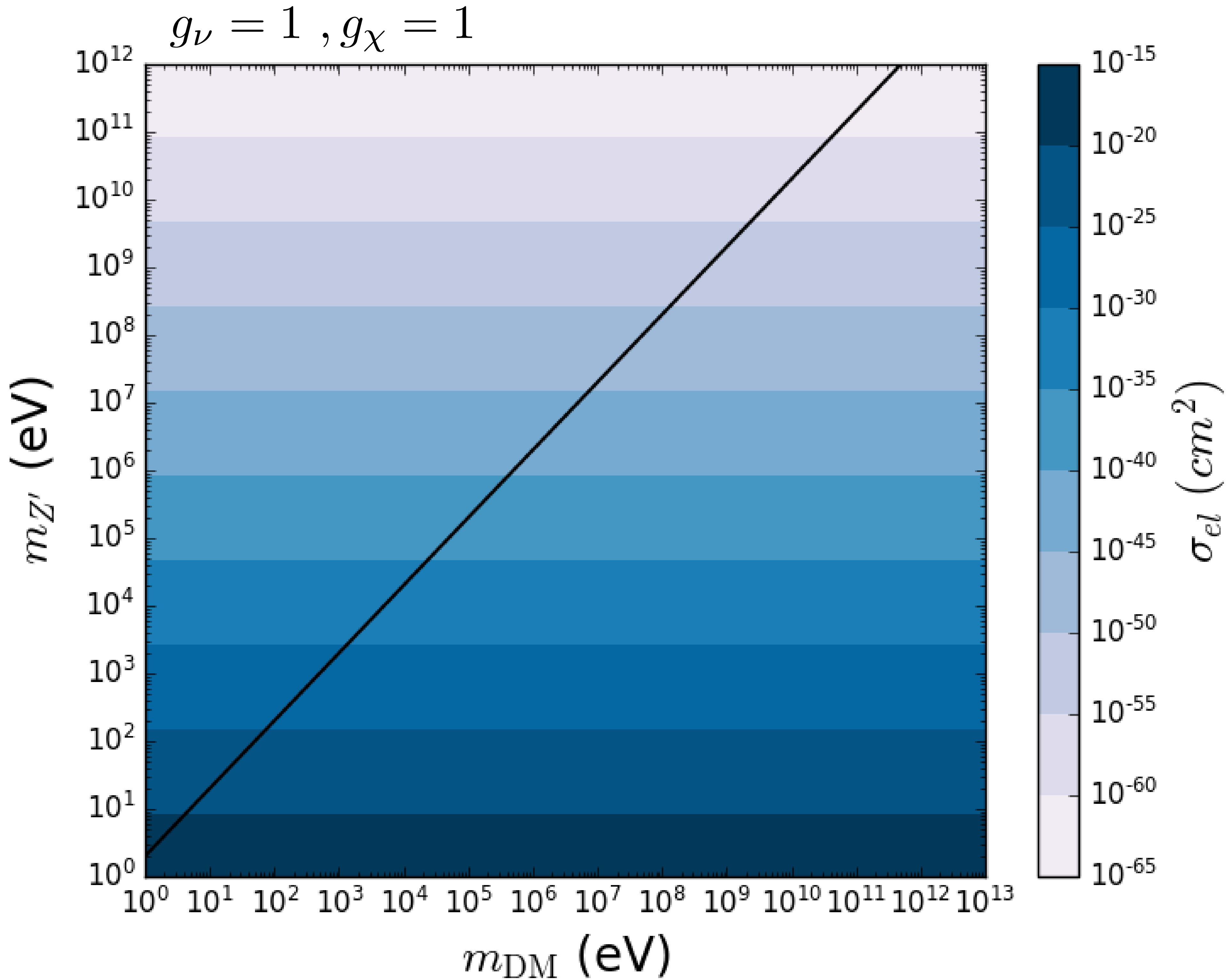
10^{-50}
10^{-55}
10^{-60}
10^{-65}



$g_\nu = 1\ , g_\chi = 1$
$m_{Z'}$ (eV)
$m_{\rm DM}$ (eV)
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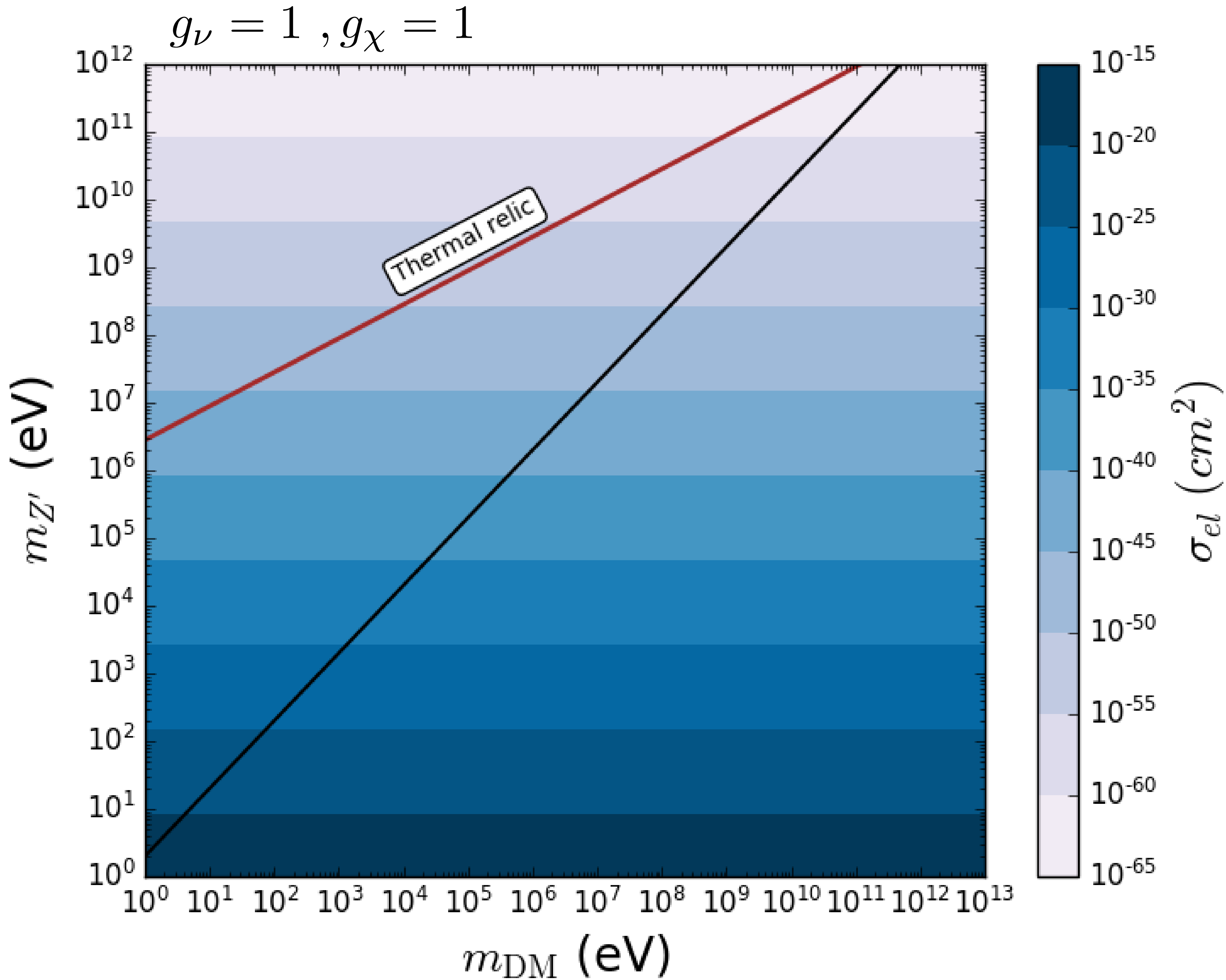
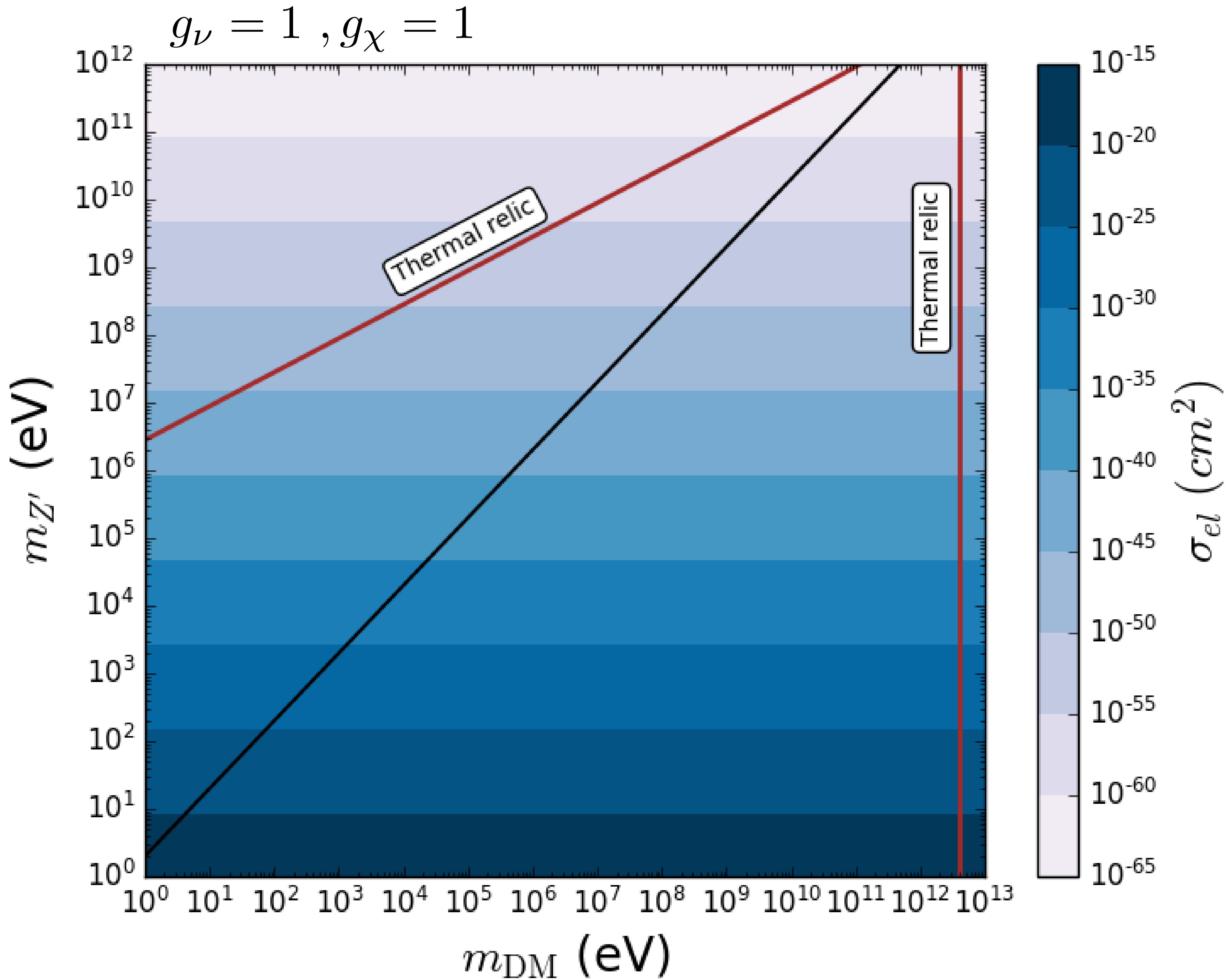
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13}
10^{-15} 10^{-20} 10^{-25} 10^{-30} 10^{-35} 10^{-40} 10^{-45} 10^{-50} 10^{-55} 10^{-60} 10^{-65}



$g_\nu = 1\ , g_\chi = 1$
Thermal relic
$m_{Z'}$ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{el}\ (cm^2)$
10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13}
10^{-15} 10^{-20} 10^{-25} 10^{-30} 10^{-35} 10^{-40} 10^{-45} 10^{-50} 10^{-55} 10^{-60} 10^{-65}



$g_\nu = 1\ , g_\chi = 1$
Thermal relic
Thermal relic
$m_{Z'}$ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{el}\ (cm^2)$
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{-15}
10^{-20}
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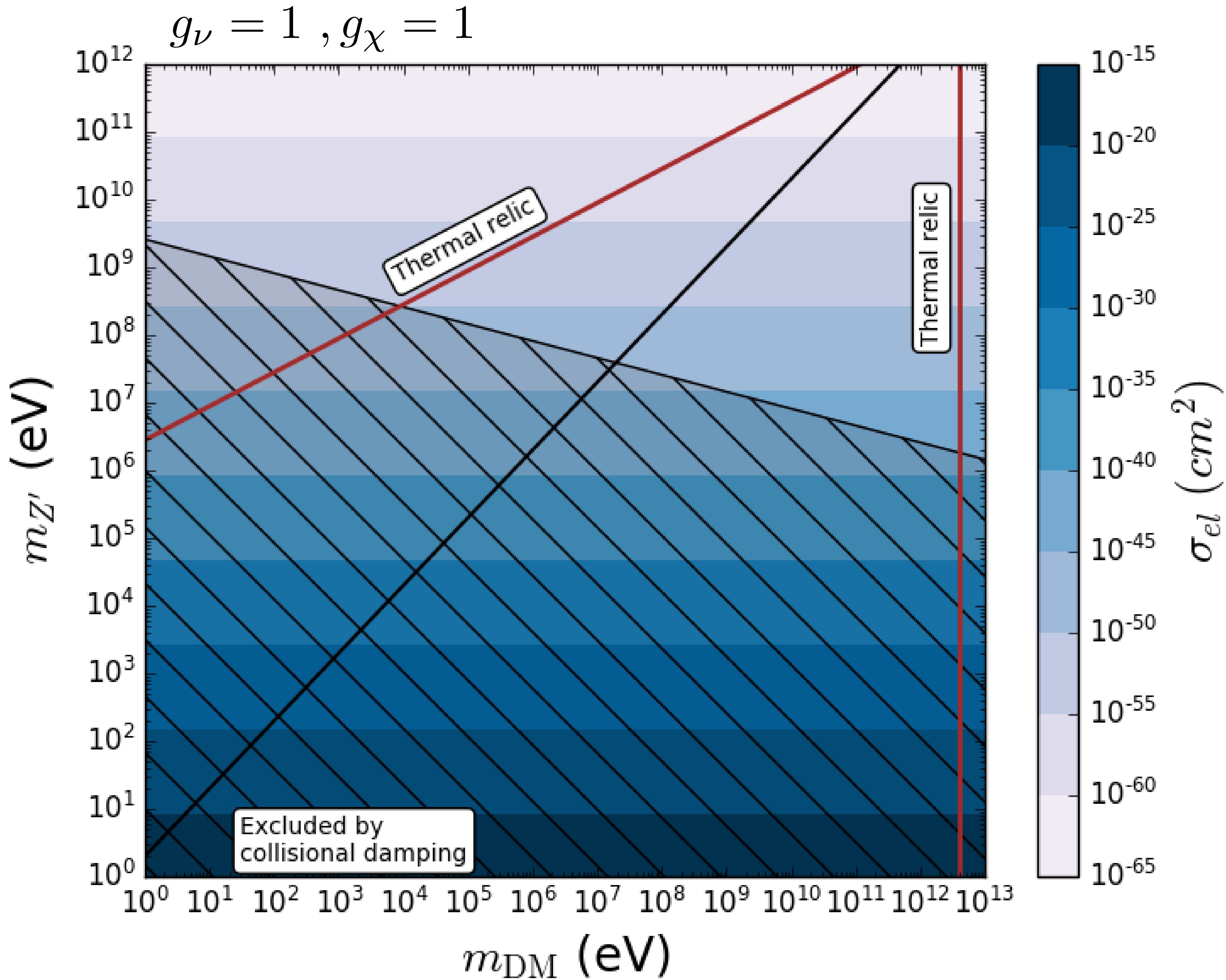
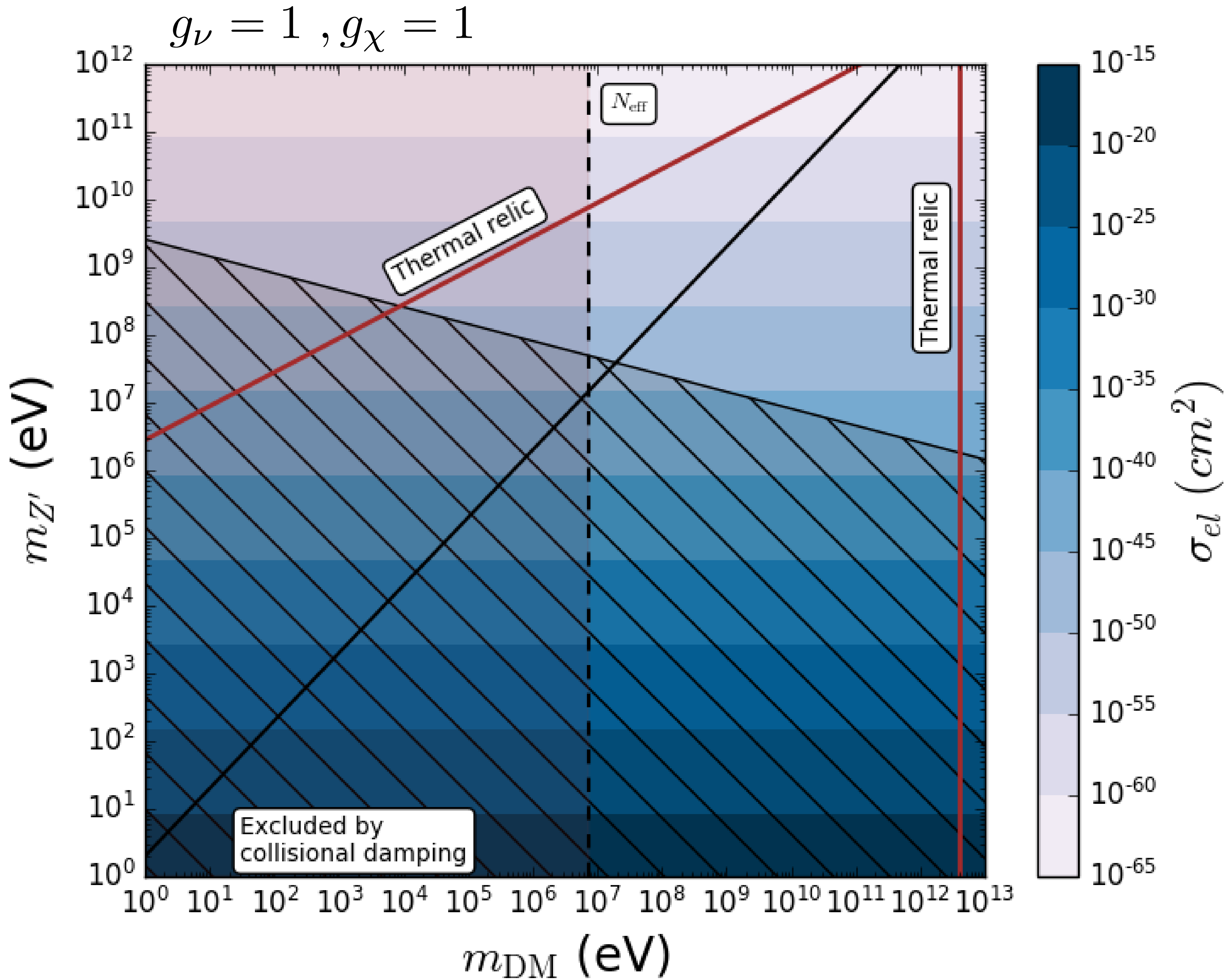
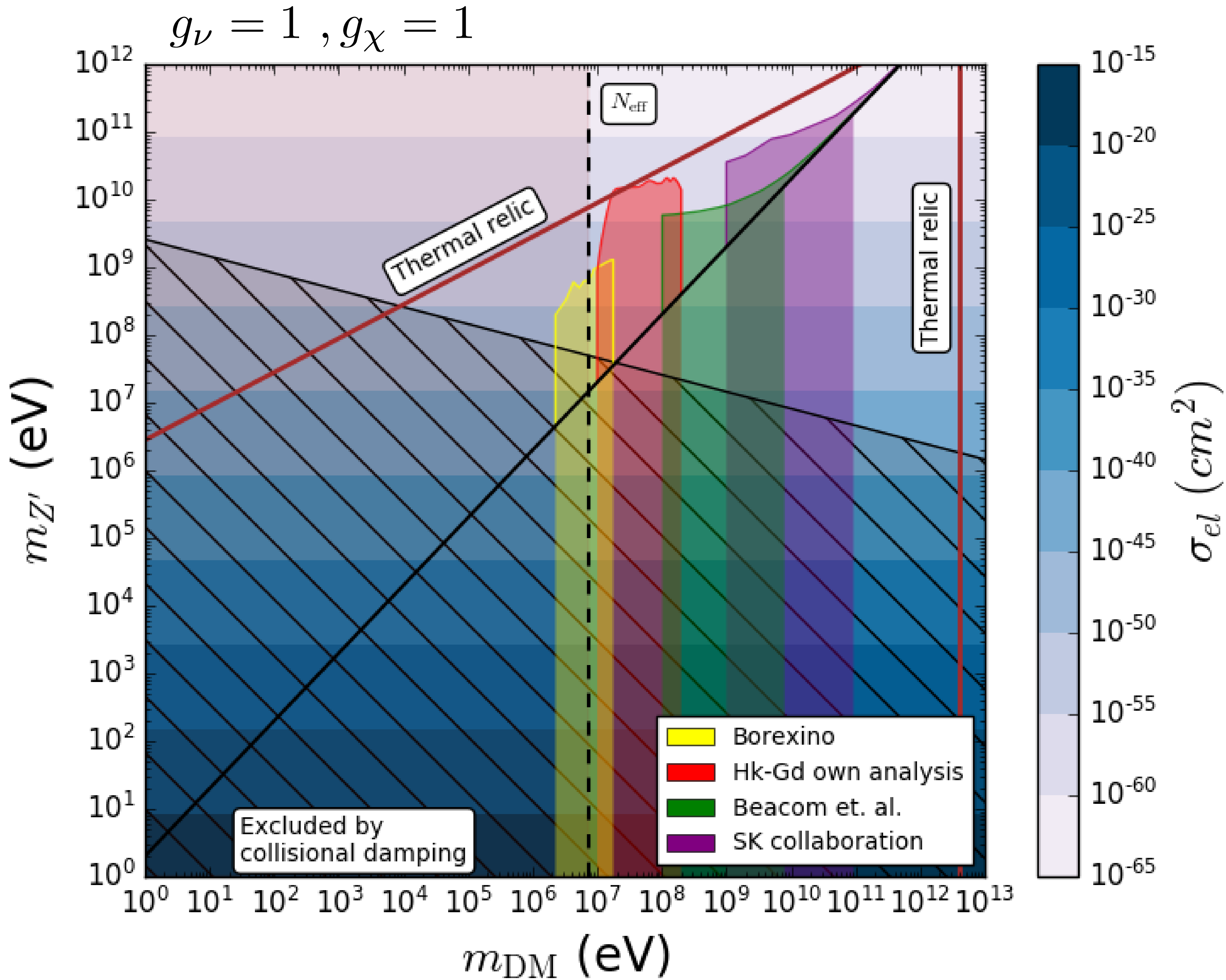
10^{-30}
10^{-35}
10^{-40}
10^{-45}
10^{-50}
10^{-55}
10^{-60}
10^{-65}



$g_\nu = 1 \ , g_\chi = 1$
Thermal relic
Thermal relic
Excluded by
collisional damping
$m_{Z'}$ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{el}\ (cm^2)$



$g_\nu = 1 \, , g_\chi = 1$
$m_{Z'}$ (eV)
m_{DM} (eV)
$\sigma_{el}\ (cm^2)$
Thermal relic
Thermal relic
N_{eff}
Excluded by
collisional damping



$g_\nu = 1\ , g_\chi = 1$
$N_{\rm eff}$
Thermal relic
Thermal relic
Borexino
Hk-Gd own analysis
Beacom et. al.
SK collaboration
Excluded by collisional damping
$m_{Z'}$ (eV)
$m_{\rm DM}$ (eV)
$\sigma_{el}\ (cm^2)$

TAKE HOME MESSAGE

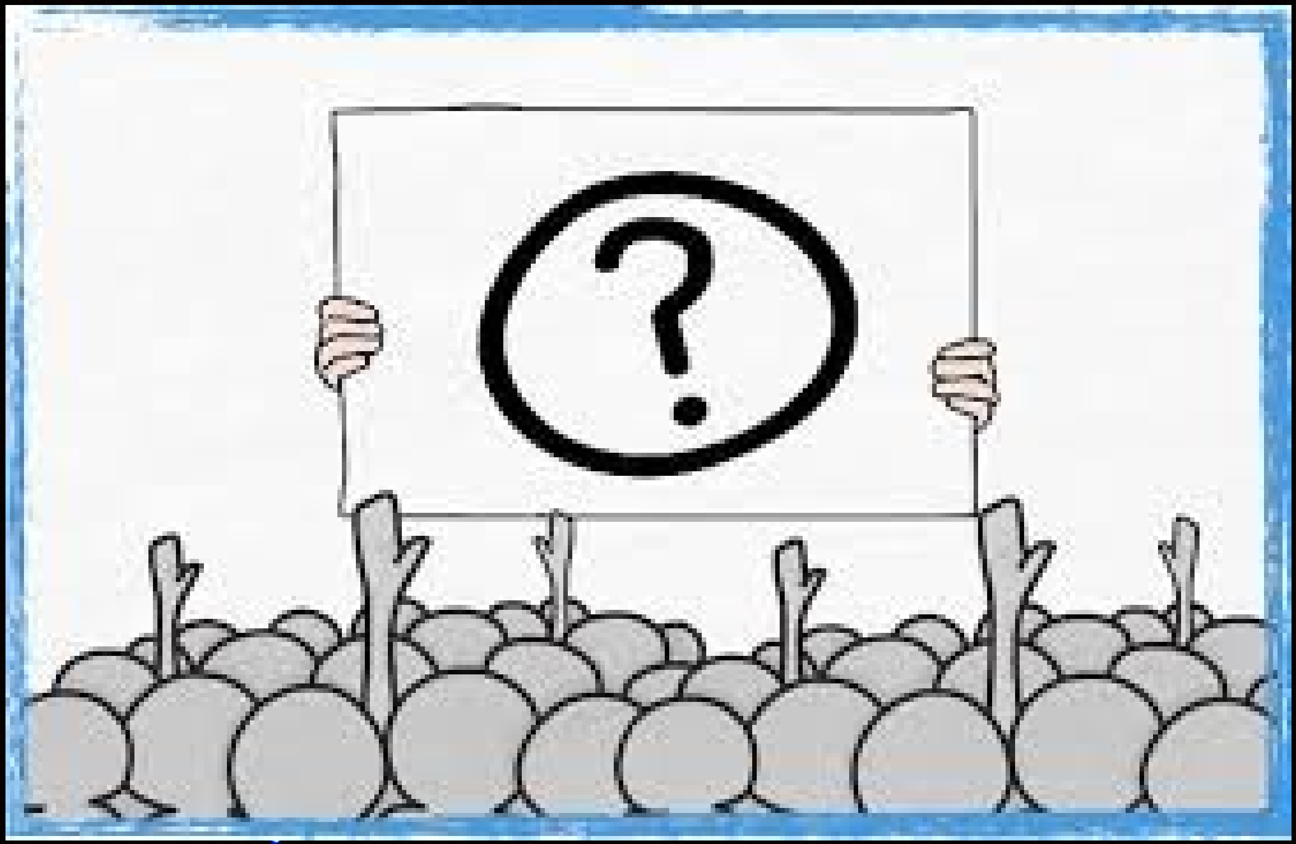
The complementarity between cosmology and indirect detection searches is a powerful tool to constrain the parameter space of different DM models

TAKE HOME MESSAGE

The **complementarity** between **cosmology** and **indirect detection searches** is a powerful tool to constrain the parameter space of **different DM models**

Particularly relevant for **light** DM and mediator masses

Thanks for listening



Questions?

Andrés Olivares-Del Campo

Summary of Results Spin 0 and ½

Scenario	Lagrangian ($\mathcal{L}_{\text{int}}$)	$\sigma \mathbf{v}_{\text{r}}$	σ_{el}
Complex DM Dirac Mediator	$-g\,\chi\,\overline{N_{\text{R}}}\,\nu_{\text{L}} \;+\; \text{h.c.}$	$\frac{g^4}{12\pi}\frac{m_{\text{DM}}^2}{(m_{\text{DM}}^2+m_{\text{N}}^2)^2}\,v_{\text{CM}}^2$	$\frac{g^4}{32\,\pi}\frac{m_{\text{DM}}^2\,y^2}{(m_{\text{N}}^2-m_{\text{DM}}^2)^2}$
Real DM Dirac Mediator		$\frac{4\,g^4}{15\pi}\frac{m_{\text{DM}}^6}{(m_{\text{DM}}^2+m_{\text{N}}^2)^4}\,v_{\text{CM}}^4$	$\frac{g^4}{8\,\pi}\frac{m_{\text{DM}}^6\,y^4}{(m_{\text{N}}^2-m_{\text{DM}}^2)^4}$
Complex DM Majorana Mediator		$\frac{g^4}{16\pi}\frac{m_{\text{N}}^2}{(m_{\text{DM}}^2+m_{\text{N}}^2)^2}$	$\frac{g^4}{32\,\pi}\frac{m_{\text{DM}}^2\,y^2}{(m_{\text{N}}^2-m_{\text{DM}}^2)^2}$
Real DM Majorana Mediator		$\frac{g^4}{4\pi}\frac{m_{\text{N}}^2}{(m_{\text{DM}}^2+m_{\text{N}}^2)^2}$	$\frac{g^4}{8\,\pi}\frac{m_{\text{DM}}^6\,y^4}{(m_{\text{N}}^2-m_{\text{DM}}^2)^4}$
Dirac DM Scalar Mediator	$-g\overline{\chi_{\text{R}}}\nu_{\text{L}}\phi \;+\; \text{h.c.}$	$\frac{g^4}{32\,\pi}\frac{m_{\text{DM}}^2}{(m_{\text{DM}}^2+m_{\phi}^2)^2}$	$\frac{g^4}{32\,\pi}\frac{m_{\text{DM}}^2\,y^2}{(m_{\text{DM}}^2-m_{\phi}^2)^2}$
Majorana DM Scalar Mediator		$\frac{g^4}{12\,\pi}\frac{m_{\text{DM}}^2}{(m_{\text{DM}}^2+m_{\phi}^2)^2}\,v_{\text{CM}}^2$	$\frac{g^4}{16\pi}\frac{m_{\text{DM}}^2\,y^2}{(m_{\text{DM}}^2-m_{\phi}^2)^2}$
Vector DM Dirac Mediator	$-g\overline{N_{\text{L}}}\gamma^{\mu}\chi_{\mu}\nu_{\text{L}} \;+\; \text{h.c.}$	$\frac{2\,g^4}{9\pi}\frac{m_{\text{DM}}^2}{(m_{\text{DM}}^2+m_{\text{N}}^2)^2}$	$\frac{g^4}{4\,\pi}\frac{m_{\text{DM}}^2\,y^2}{(m_{\text{DM}}^2-m_{\text{N}}^2)^2}$
Vector DM Majorana Mediator		$\frac{g^4}{6\pi}\frac{m_{\text{N}}^2}{(m_{\text{DM}}^2+m_{\text{N}}^2)^2}$	

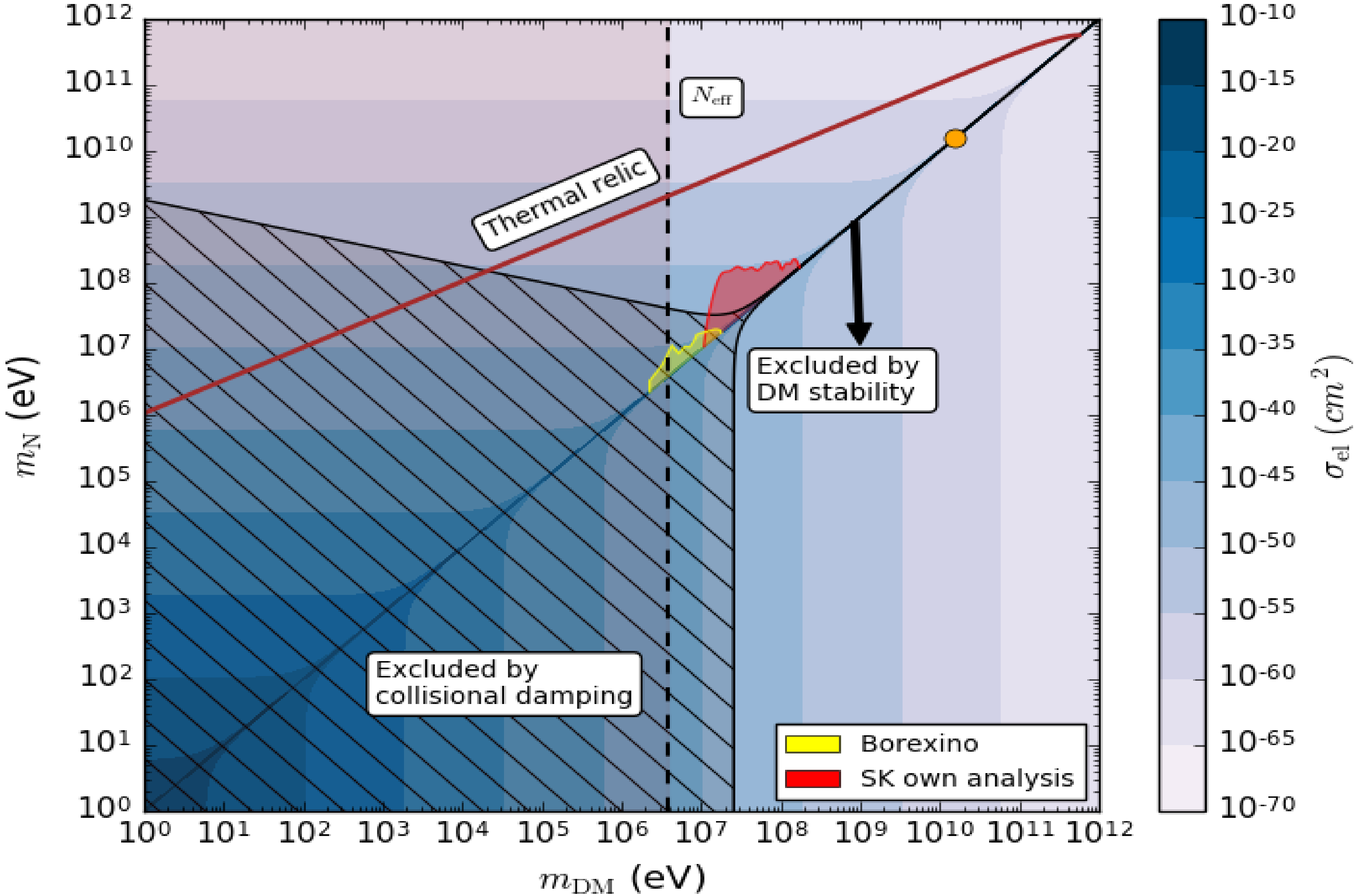
Andrés Olivares-Del Campo

Summary of Results
Spin 1

Scenario	Lagrangian ($\mathcal{L}_{\rm int}$)	$\sigma \mathbf{v}_{\rm r}$	$\sigma_{\rm el}$
Complex DM Vector mediator	$-g_\chi Z'^\mu((\partial_\mu \chi)\chi^\dagger - (\partial_\mu \chi)^\dagger \chi)$ $-g_\nu \overline{\nu_L} \gamma^\mu Z'_\mu \nu_{\rm L}$	$\frac{g_\chi^2 g_\nu^2}{3\pi} \frac{m_{\rm DM}^2}{(4m_{\rm DM}^2 - m_{Z'}^2)^2} v_{\rm CM}^2$	$\frac{g_\chi^2 g_\nu^2}{8\pi} \frac{m_{\rm DM}^2 y^2}{m_{Z'}^4}$
Dirac DM Vector Mediator	$-g_{\chi_{\rm L}} \overline{\chi_{\rm L}} \gamma^\mu Z'_\mu \chi_{\rm L} - g_{\chi_{\rm R}} \overline{\chi_{\rm R}} \gamma^\mu Z'_\mu \chi_{\rm R}$ $-g_\nu \overline{\nu_L} \gamma^\mu Z'_\mu \nu_{\rm L}$	$\frac{g_\chi^2 g_\nu^2}{2\pi} \frac{m_{\rm DM}^2}{(4m_{\rm DM}^2 - m_{Z'}^2)^2}$	$\frac{g_\chi^2 g_\nu^2}{8\pi} \frac{m_{\rm DM}^2 y^2}{m_{Z'}^4}$
Majorana DM Vector Mediator	$-\frac{g_\chi}{2} \bar{\chi} \gamma^\mu Z'_\mu \gamma^5 \chi$ $-g_\nu \overline{\nu_L} \gamma^\mu Z'_\mu \nu_{\rm L}$	$\frac{g_\chi^2 g_\nu^2}{12\pi} \frac{m_{\rm DM}^2}{(4m_{\rm DM}^2 - m_{Z'}^2)^2} v_{\rm CM}^2$	$\frac{3 g_\chi^2 g_\nu^2}{32\pi} \frac{m_{\rm DM}^2 y^2}{m_{Z'}^4}$
Vector DM Vector Mediator	$-g_\chi \frac{1}{2} \chi^\mu \partial_\mu \chi^\nu Z'_\nu + {\rm h.c.}$ $-g_\nu \overline{\nu_L} \gamma^\mu Z'_\mu \nu_{\rm L}$	$\frac{g_\chi^2 g_\nu^2}{\pi} \frac{m_{\rm DM}^2}{(4m_{\rm DM}^2 - m_{Z'}^2)^2} v_{\rm CM}^2$	$\frac{g_\chi^2 g_\nu^2}{8\pi} \frac{m_{\rm DM}^2 y^2}{m_{Z'}^4}$

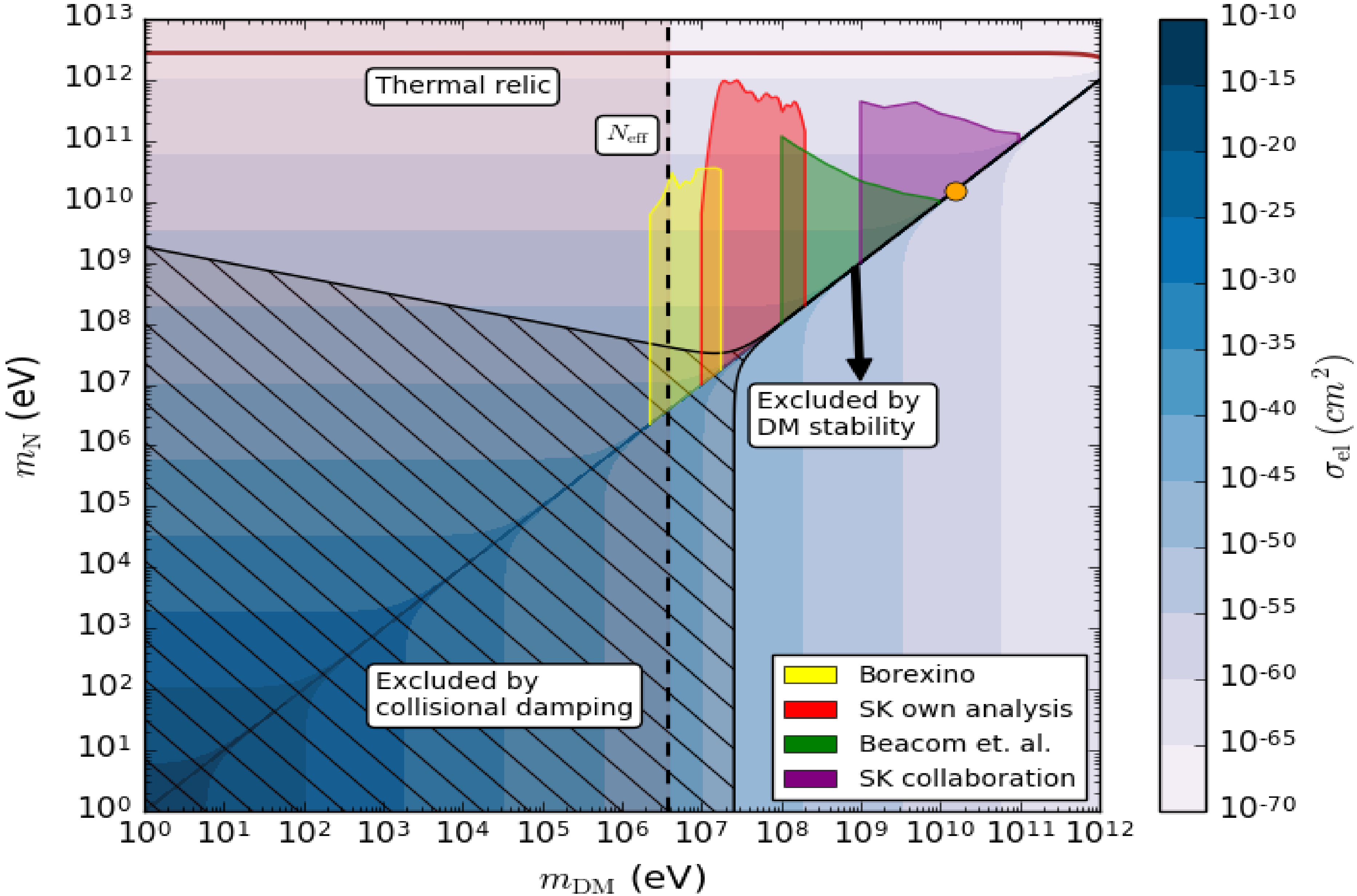
Complex DM, Dirac Mediator

$g = 1$

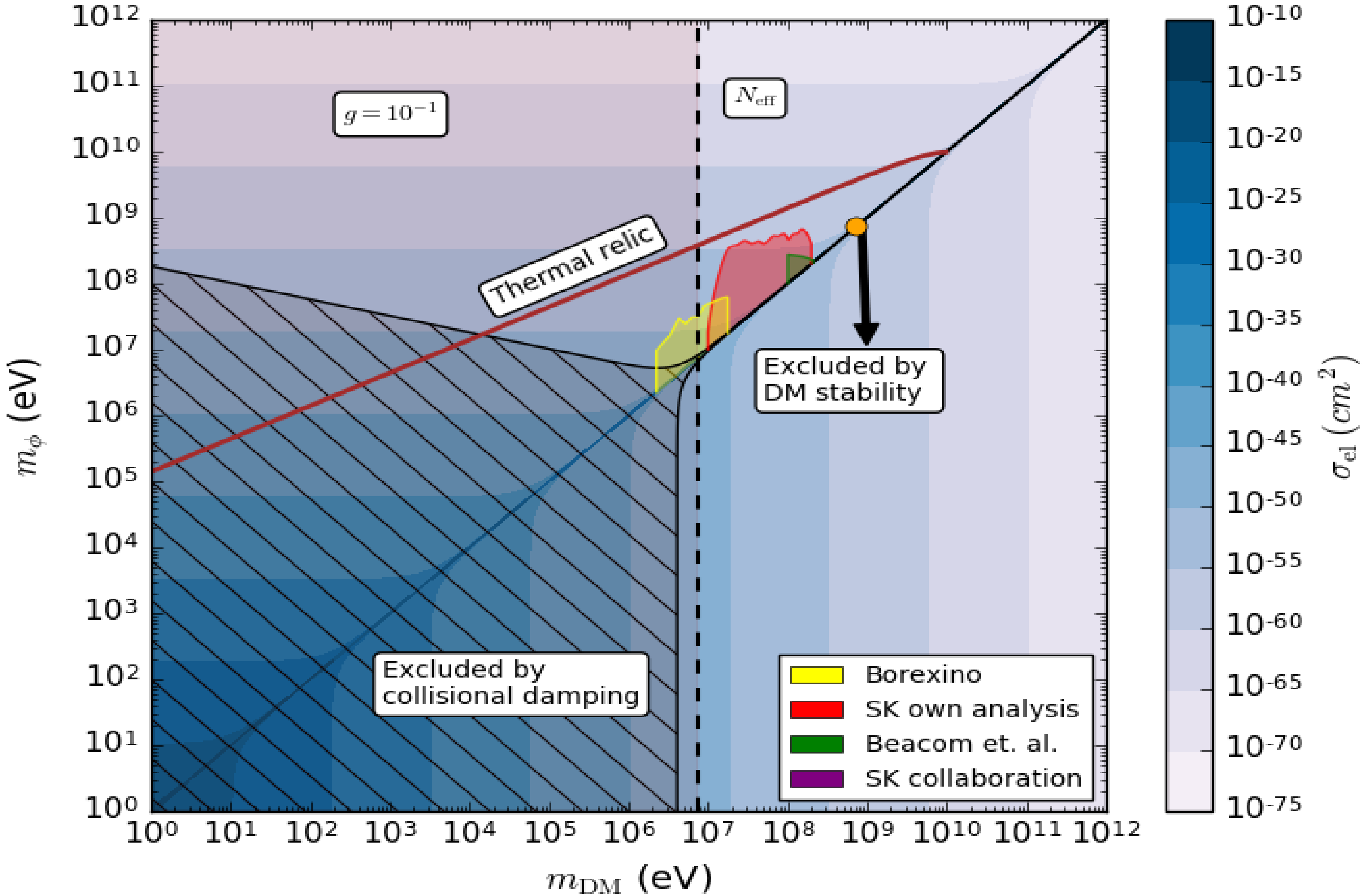


Complex DM, Majorana Mediator

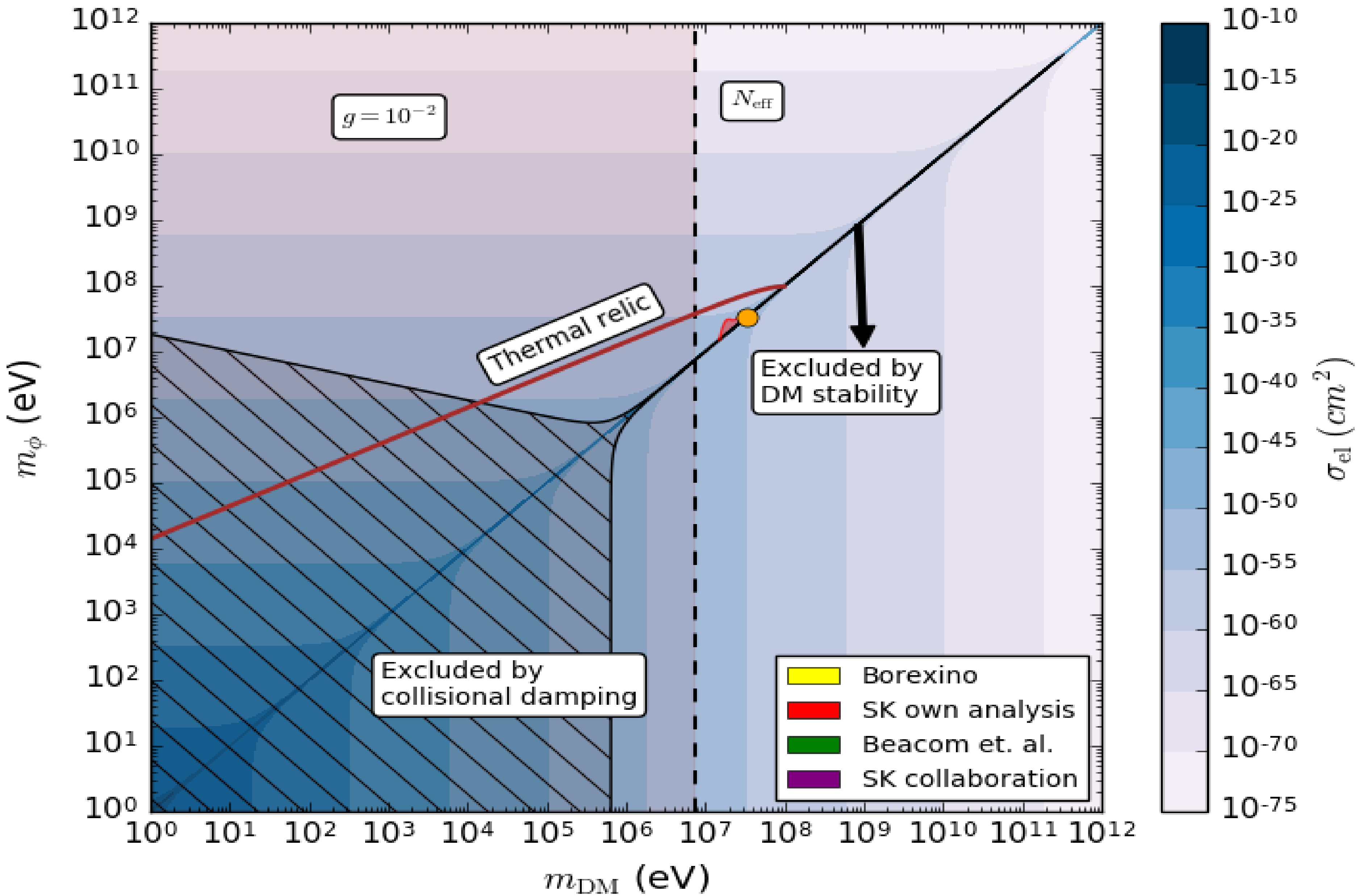
$g = 1$



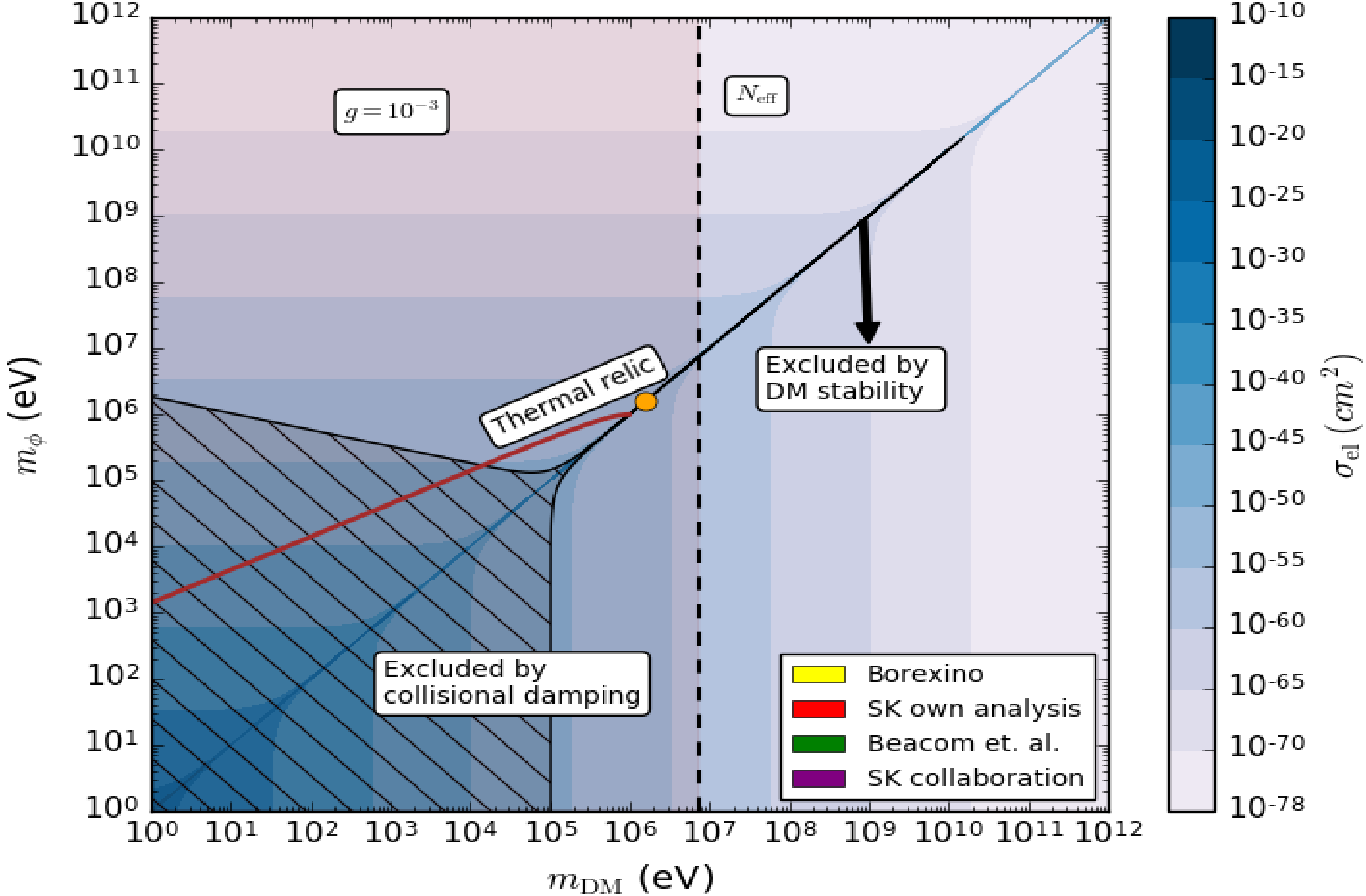
Small coupling (I)



Small coupling (II)



Small coupling (III)



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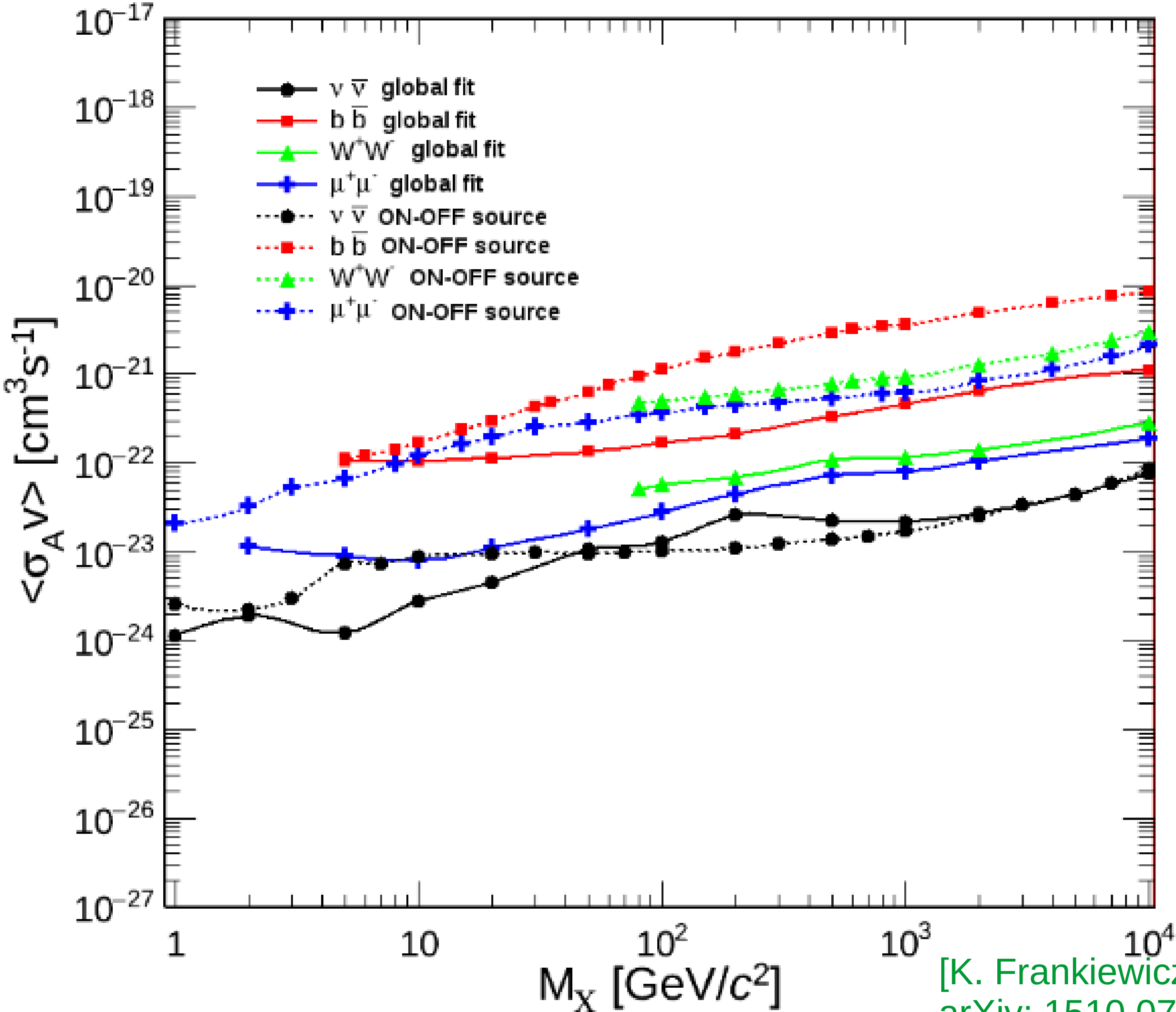
Galactic Centre GeV Analysis



[K. Frankiewicz, arXiv: 1510.07999]

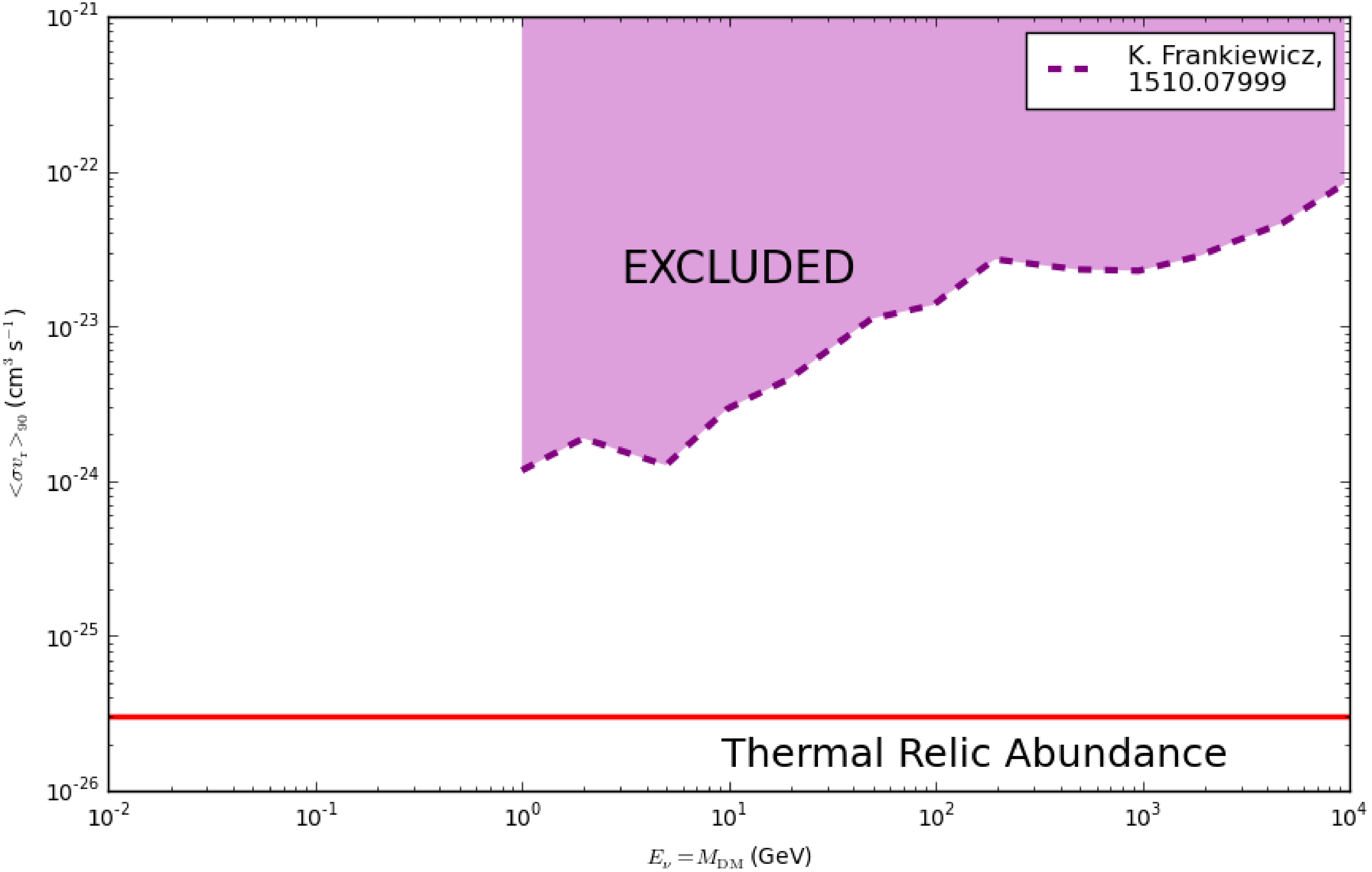
N-effective constraints

	From [1]	From [2]
Real scalar DM	No constraint	$m_{\rm DM} < 4$ MeV
Complex scalar DM	$m_{\rm DM} < 3.9$ MeV	No constraint
Dirac DM	$m_{\rm DM} < 7.3$ MeV	$m_{\rm DM} < 10$ MeV
Majorana DM	$m_{\rm DM} < 3.5$ MeV	No constraint
Vector DM	No constraint	No constraint

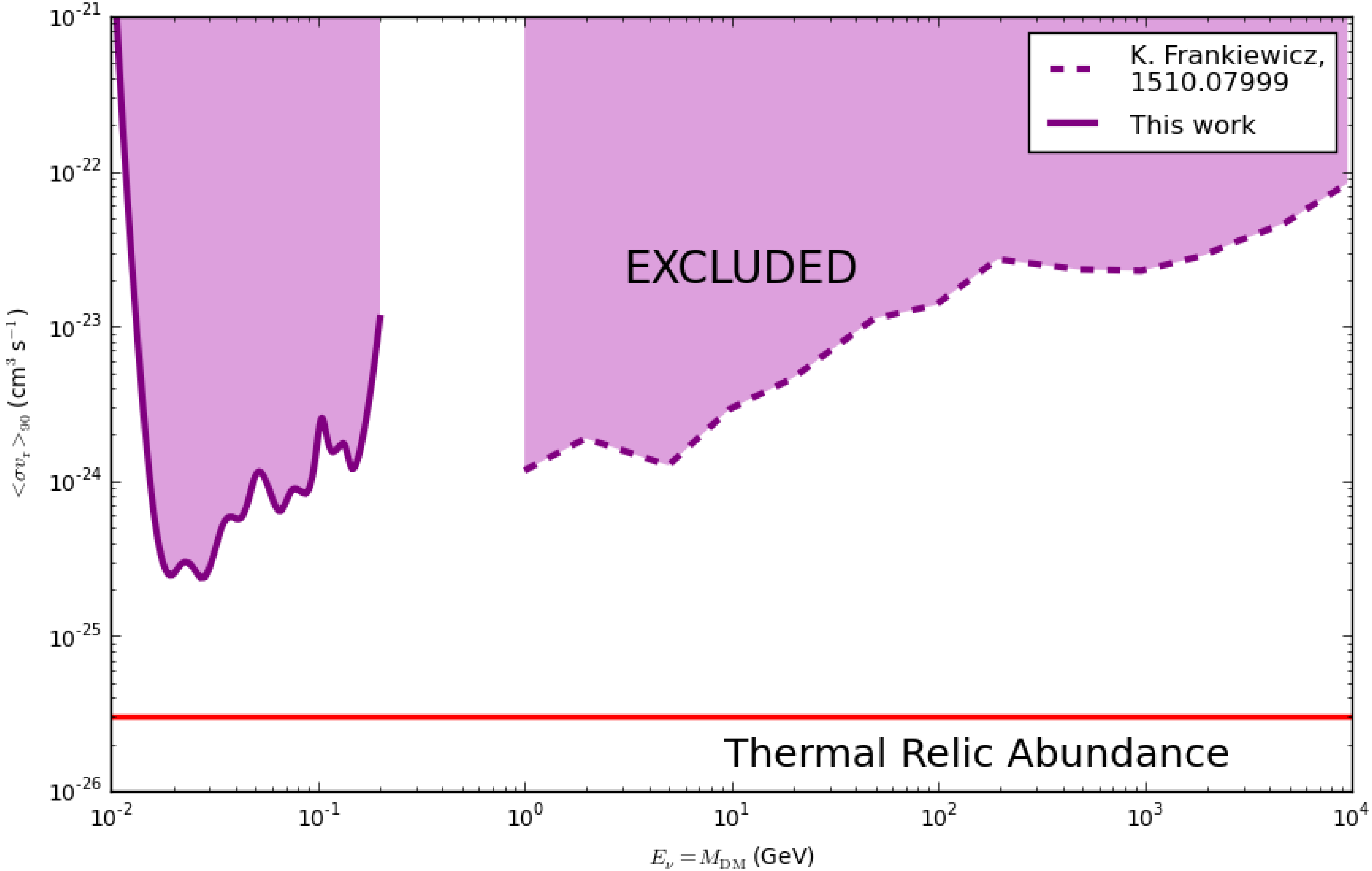
[1: C. Boehm, et., al., arXiv: 1303.6270]

[2: C. Boehm, et., al., arXiv: 1602.01114]

Result Comparition



Result Comparition



[AOC, et., al.,
arXiv: 1711.05283]