Macro$_{\text{scopic}}$ Dark Matter

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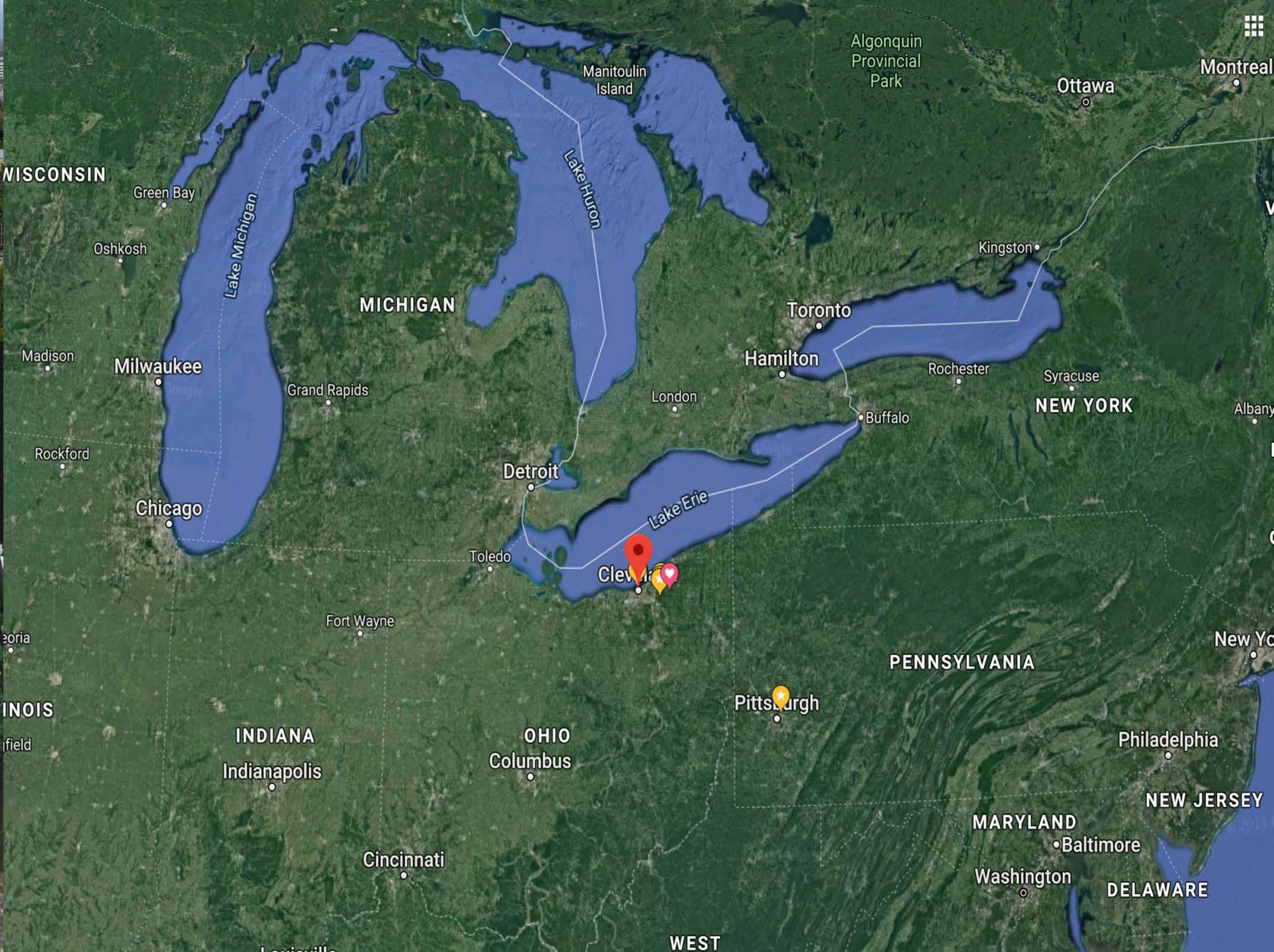
ISORIGINS


Algonquin Provincial Park
Montreal
Ottawa
Manitoulin Island
WISCONSIN
Green Bay
Lake Michigan
Lake Huron
Oshkosh
MICHIGAN
Kingston
Toronto
Hamilton
Rochester
Syracuse
NEW YORK
Madison
Milwaukee
Grand Rapids
London
Buffalo
Rockford
Detroit
Lake Erie
Chicago
Toledo
Fort Wayne
PENNSYLVANIA
INDIANA
OHIO
Columbus
Indianapolis
Philadelphia
NEW JERSEY
MARYLAND
Baltimore
Washington
DELAWARE
Cincinnati
WEST

What do we really know about DM?

Dark:

- Does not automatically mean σ is small!

How could this be?

Interaction rates go as $\Gamma \sim n_\chi \sigma_\chi v \sim (\sigma_\chi/m_\chi)\, \rho_\chi v$

Gravitational observations fix ρ_χ

What matters is (σ_χ/m_χ) -- the "reduced cross-section"

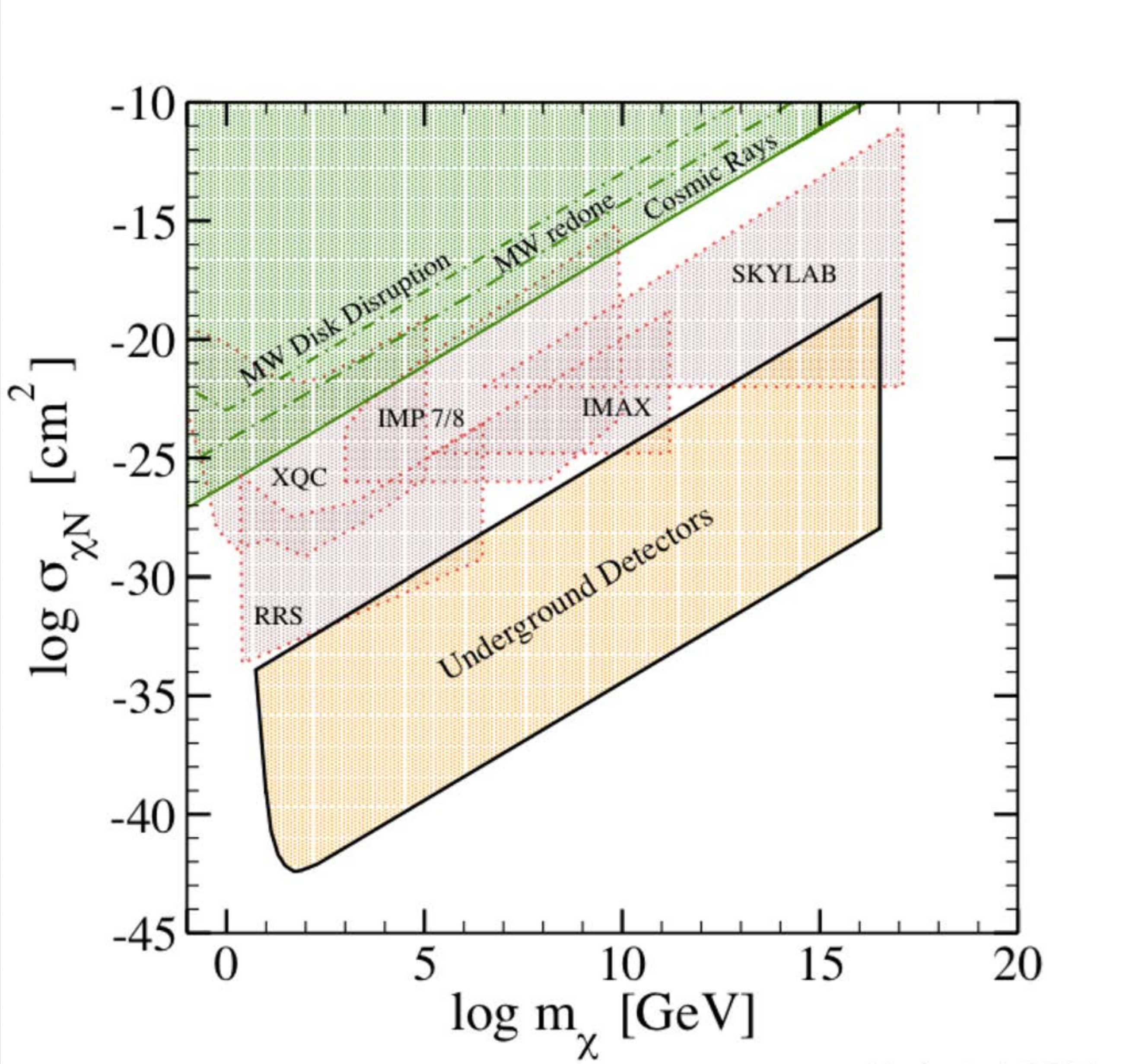
DM can be low-mass-very-low-σ,

or high-mass-not-so-low-σ !

MACROscopic Dark Matter

What do we know about DM σ?

- Strongly-interacting dark matter: Starkman *et al.* (1990), ...,   Mack *et al.* (2007)
- More or less constrained up to ~ 10^{17} GeV



Mack, et al. (2007)

What about macroscopic stuff – m > ~1g ?

Macros – what are they?

~~Ordinary Standard Model matter:~~

- ~~Stellar remnants – WD, NS, BH~~
- ~~Planets and other smaller~~

SBBN, CMB

If DM is baryons it must be "sequestered" before BBN, and esp. before "recombination"

Macros – what are they?

Primordial Black Holes

In the Standard Model

- Strange Quark Nuggets, Witten (1984)
- Strange Baryon Matter (Lynn et al., 1990)
- Strange Chiral Liquid Drops (Lynn, 2010)
- Other names: nuclearites, strangelets, ,CUDOs

Macros – what are they?

Almost (?) Standard Model

- Compact Composite Objects/
  Baryonic Color Superconductors (+ axion) (Zhitnitsky, 2003)
- Crypto-baryonic DM (Froggat & Nielsen, 2005)

(Well) Beyond the Standard Model

e.g. SUSY Q-balls, topological defect DM, ...

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Dark Matter may be a Standard Model phenomenon!

So... what's allowed for Macros?

- A systematic probe of "macroscopic" dark matter candidates that scatter geometrically with matter

- Basic parameters: mass, cross section:

$$M_X, \quad \sigma_X = \pi R_X^2$$

- Other parameters: charge (Q), composition (B>0 or B<0), surface composition, ...

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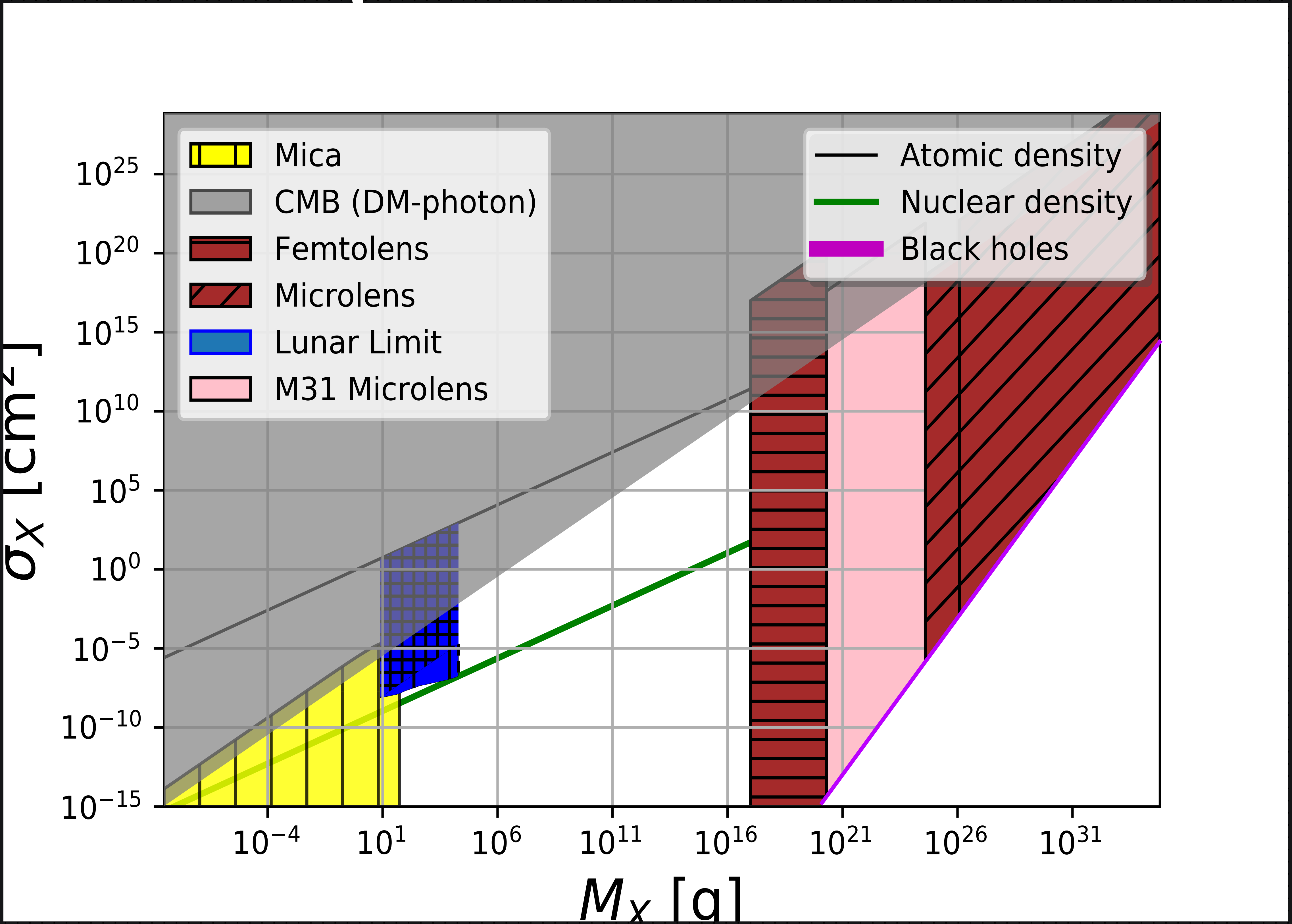
Model-independent constraints

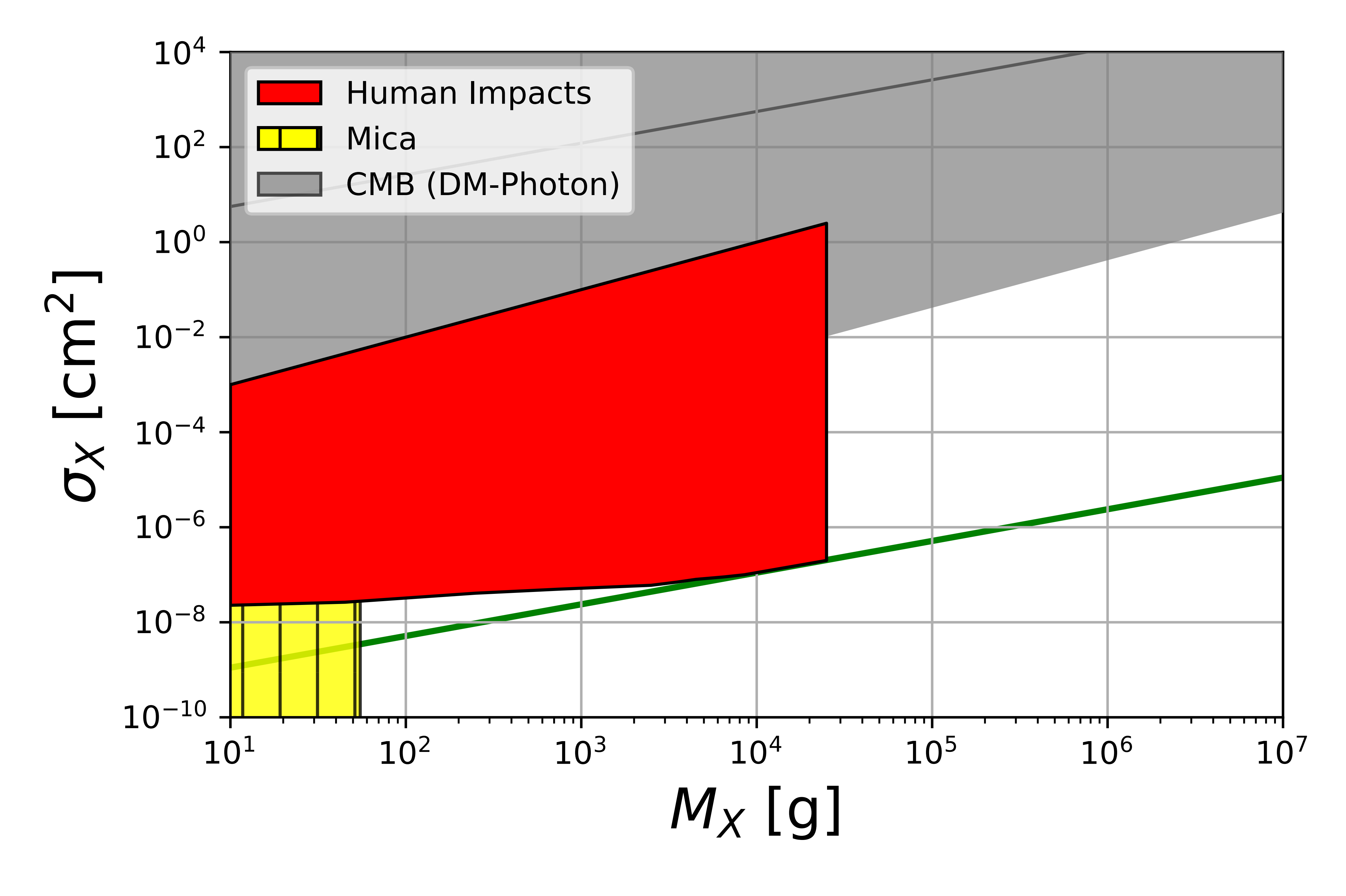
- Gravitational effects (lensing)
- Elastic and inelastic coupling of
    - Macros to baryons
    - Macros to other Macros
    - Macros to photons

Old model-independent macro constraints



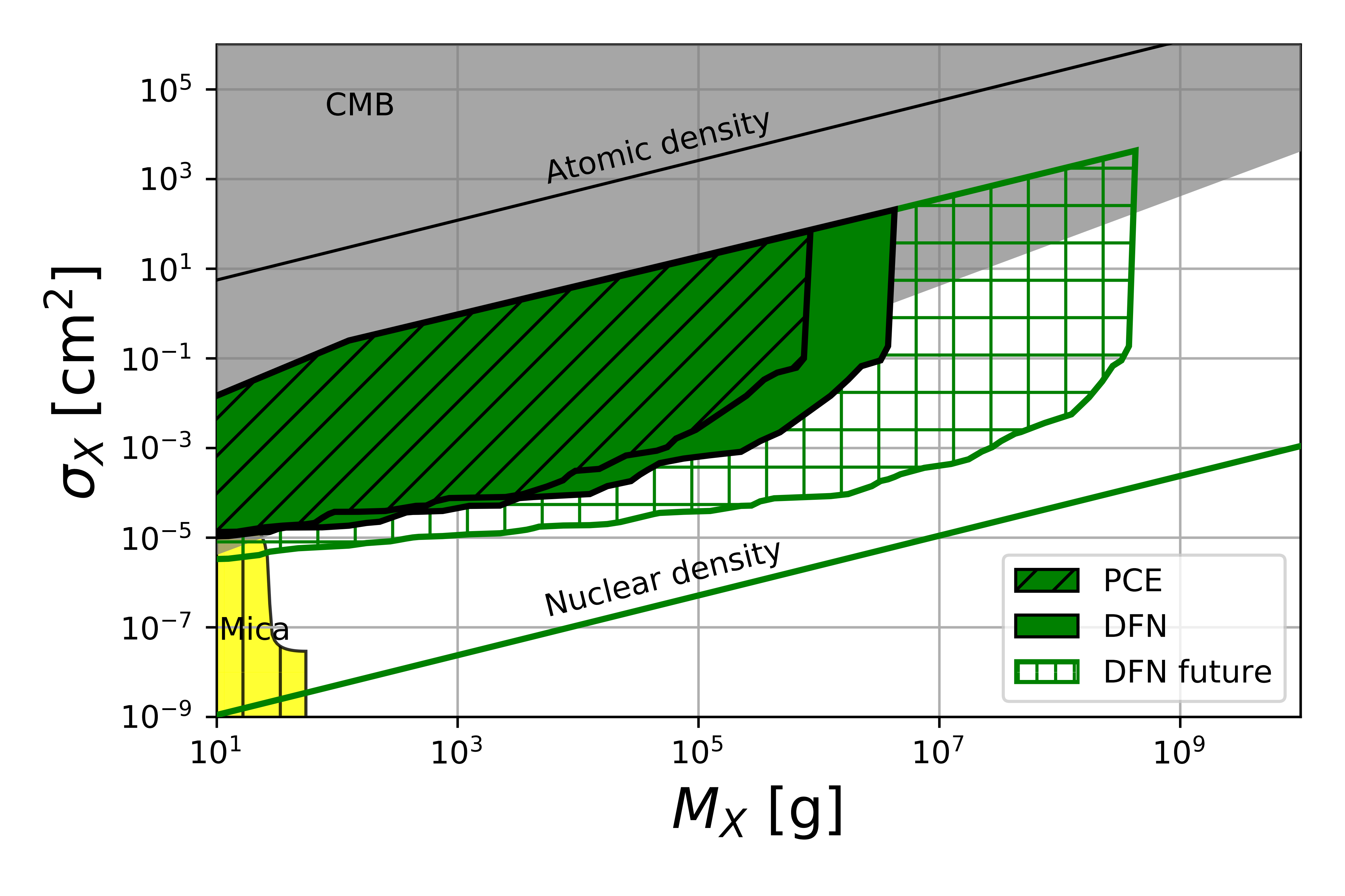
Cyncynates et al. (2016); updated by J. Sidhu

Model-independent constraints: people



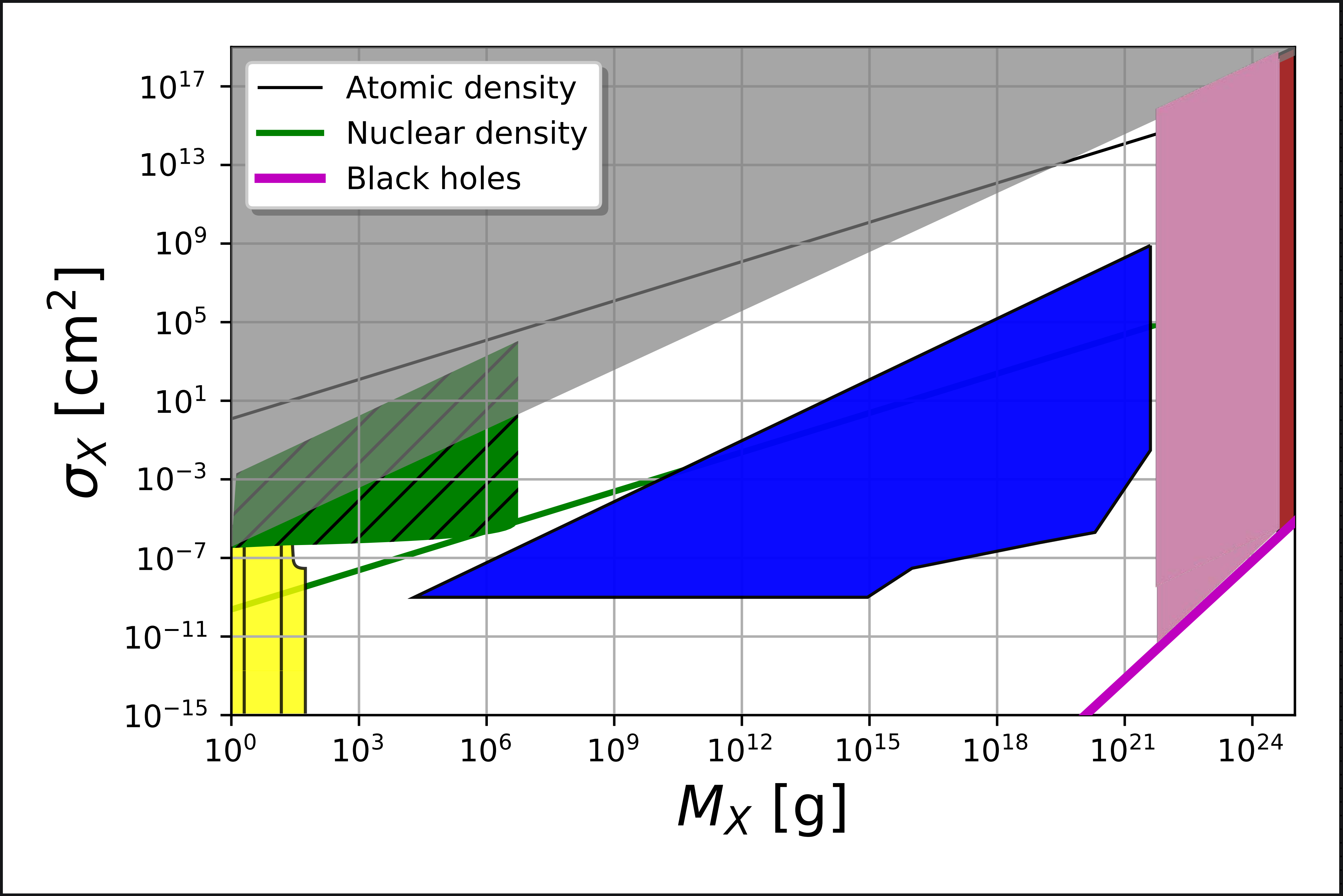
J. Sidhu, R. Scherrer, GDS Physics Letters B 803, 135300 (2020); arXiv:1907.06674

Model-independent limits: bolide searches



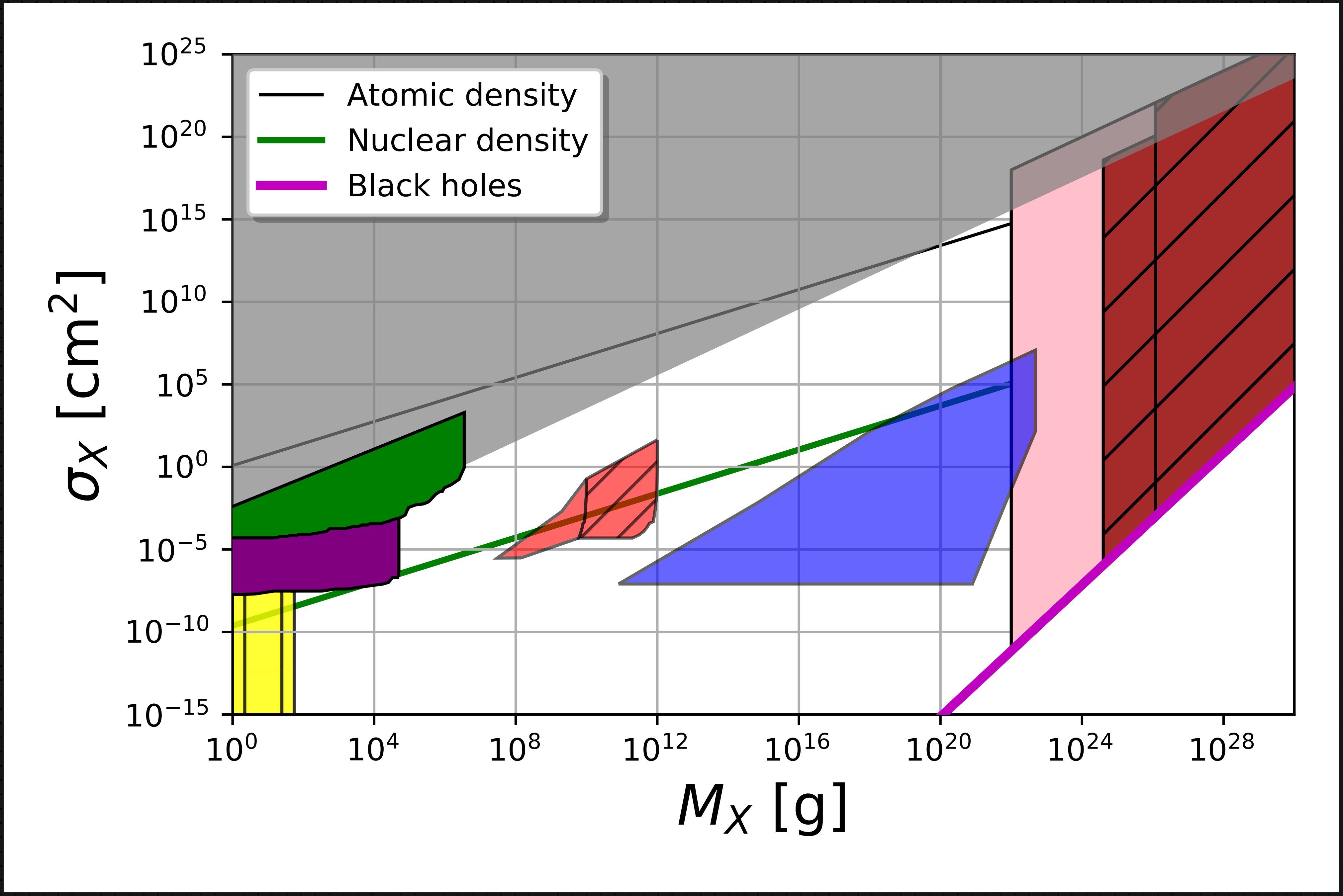
J. Sidhu, GDS, Phys.Rev.D 100 (2019) 12, 123008

Model-independent constraints: WD thermal runaways



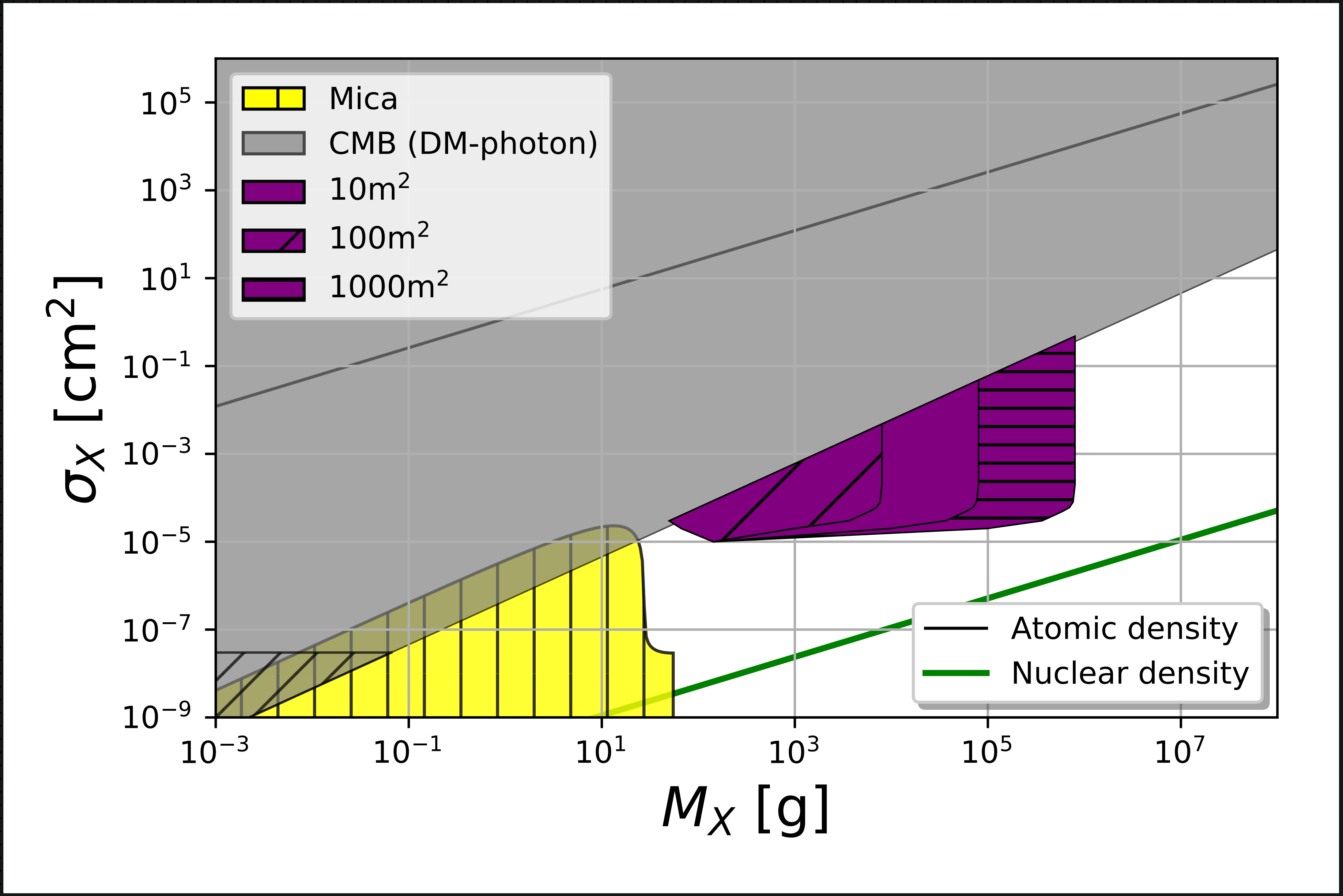
P. W. Graham, S. Rajendran, and J. Varela, Phys. Rev. D 92, 063007 (2015)

Model-independent limits:
NS→ SN; WD runaways (updated)



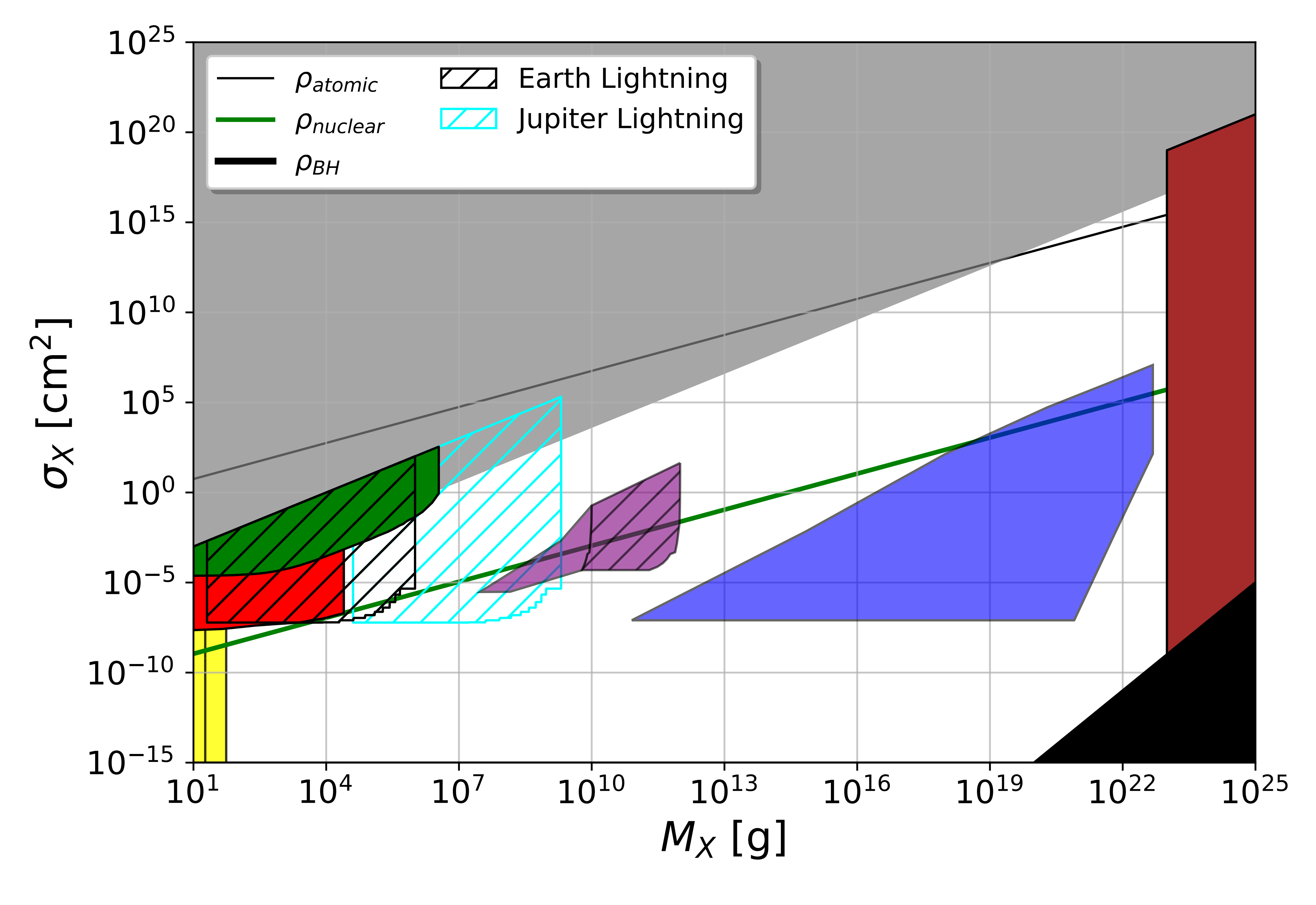
J. Sidhu, GDS Phys.Rev.D 101 , 083503 (2020); e-Print: 1912.04053

Prosepctive model-independent probes: granite slabs



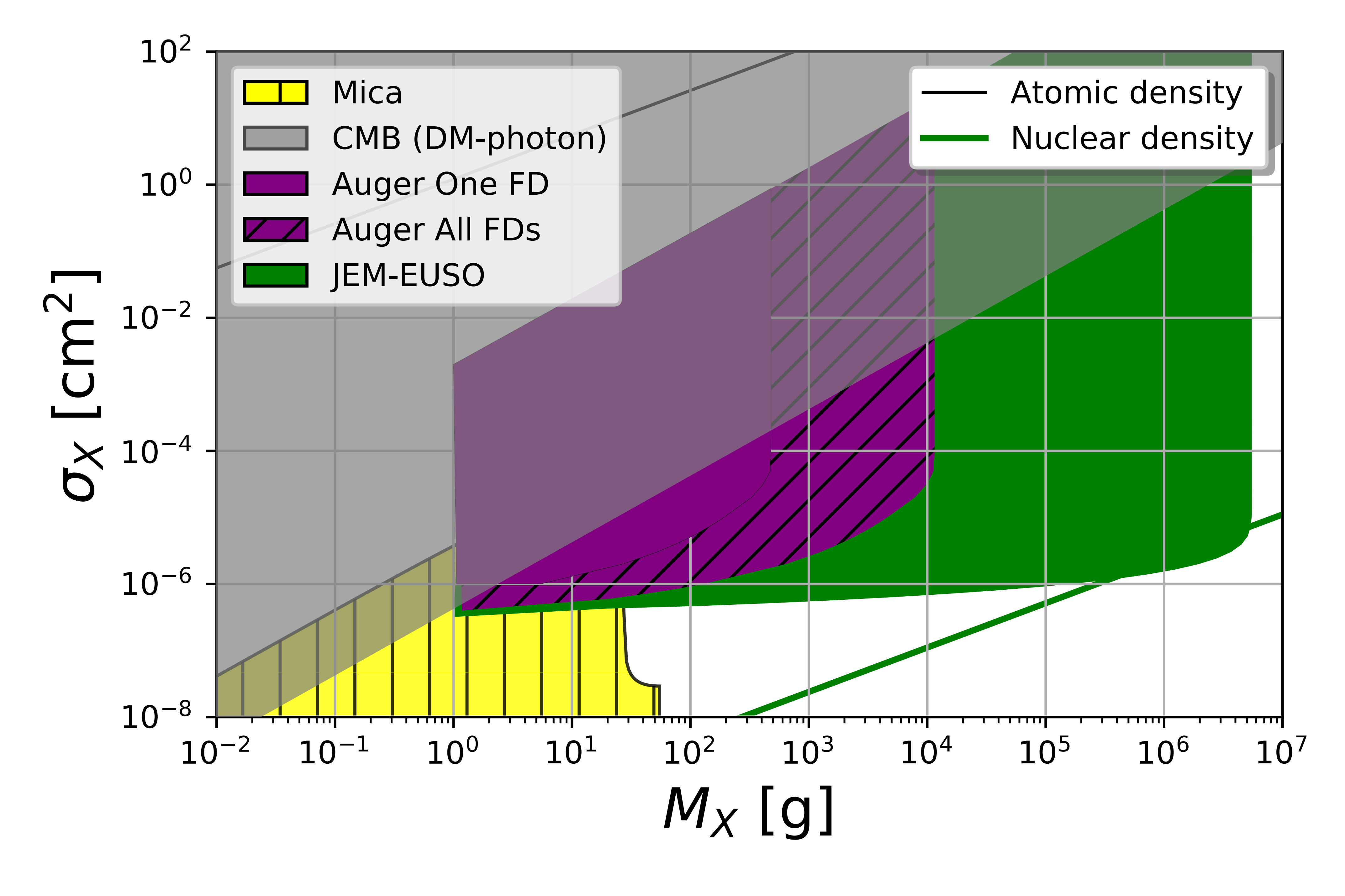
J. Sidhu, R. Harvey, GDS, *Phys.Rev.D* 100 (2019) 10, 103015; e-Print: 1905.10025

Prosepctive model-independent probes: straight lightning



N. Starkman, J. Sidhu, H. Winch, GDS e-Print: 2006.16272

Model-independent probes: UHECR detectors



J. Sidhu, R. Abraham, C. Covault, GDS (2019) JCAP 1902, 2037

UHECR detectors: Auger, JEM-USO

J. Sidhu, R. Abraham, C. Covault, GDS (2019) JCAP 1902, 2037

- Detect N fluoresence as macros traverse atmosphere
- Extremely large area
- Requires alterations to (hardware/software) trigger to admit slow-moving macros

Model-dependent considerations

Model-dependent constraints: Continued solar existence

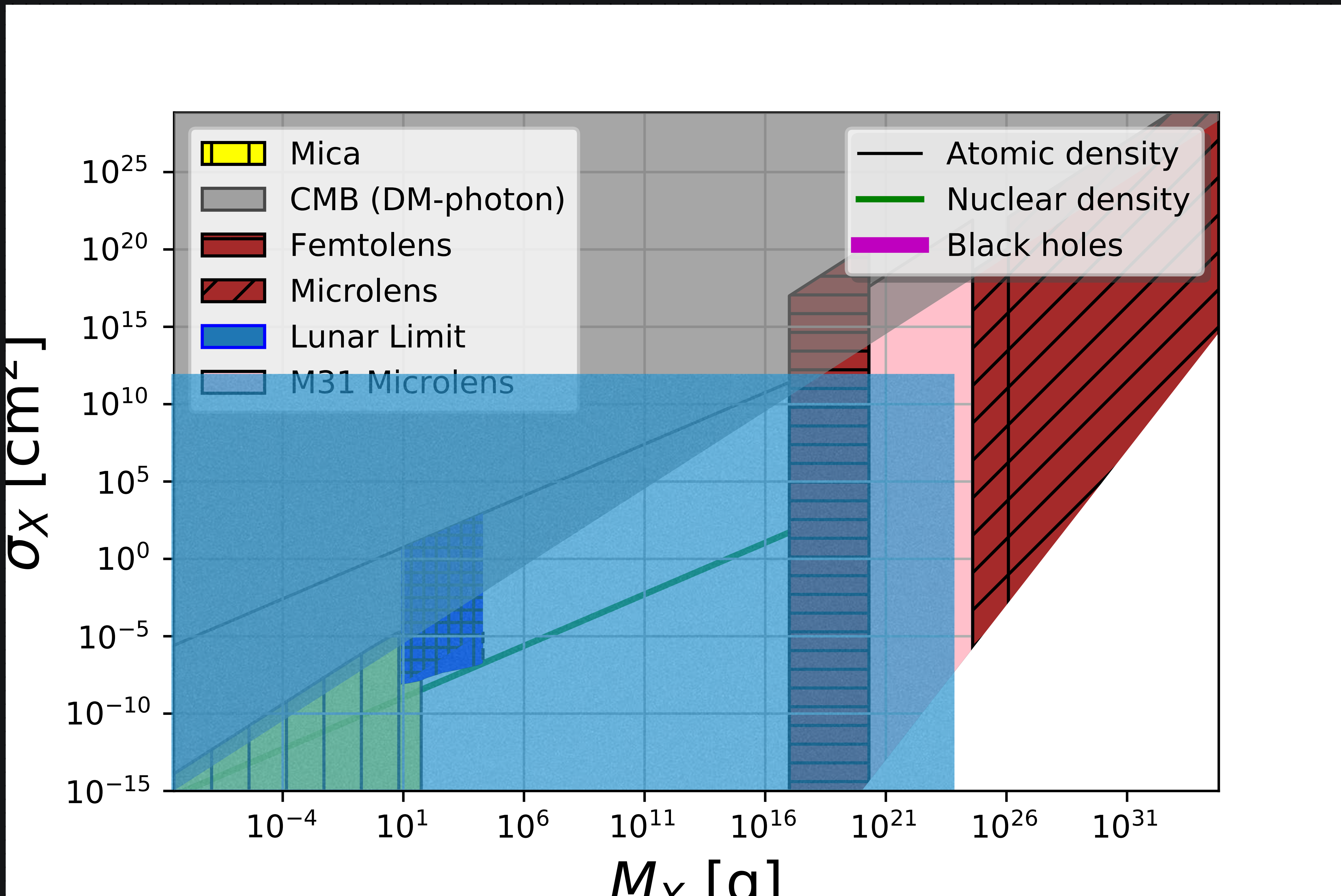
Jacobs, GDS, Lynn (2014)

Target	$\Gamma\ [M_X^{-1} \mathrm{g\ s}^{-1}]$	$\Gamma\ [M_X^{-1} \mathrm{g\ yr}^{-1}]$
NS	48	1.5×10^9
WD	4.8×10^3	1.5×10^{11}
$\odot$	3.9×10^6	1.2×10^{14}
$\oplus$	44	1.4×10^9
☾	3.2	1.0×10^8

Table 1. Expected Macro impact rates for a neutron star, white dwarf, the sun, the earth, and the moon. We have taken $v_X = 250$ km/s, $R_{NS} = 10$ km, $R_{WD} = 10^3$km, $f_\rho = 1$, and $M_{NS} = M_{WD} = M_\odot$. For example, if $M_X = 1$ g then there would be about 3 impacts per km^2 per year on the earth.

- If the macro would "convert" ordinary matter, then solar stability requires

  $M_X > 10^{24}$g or small enough σ_X



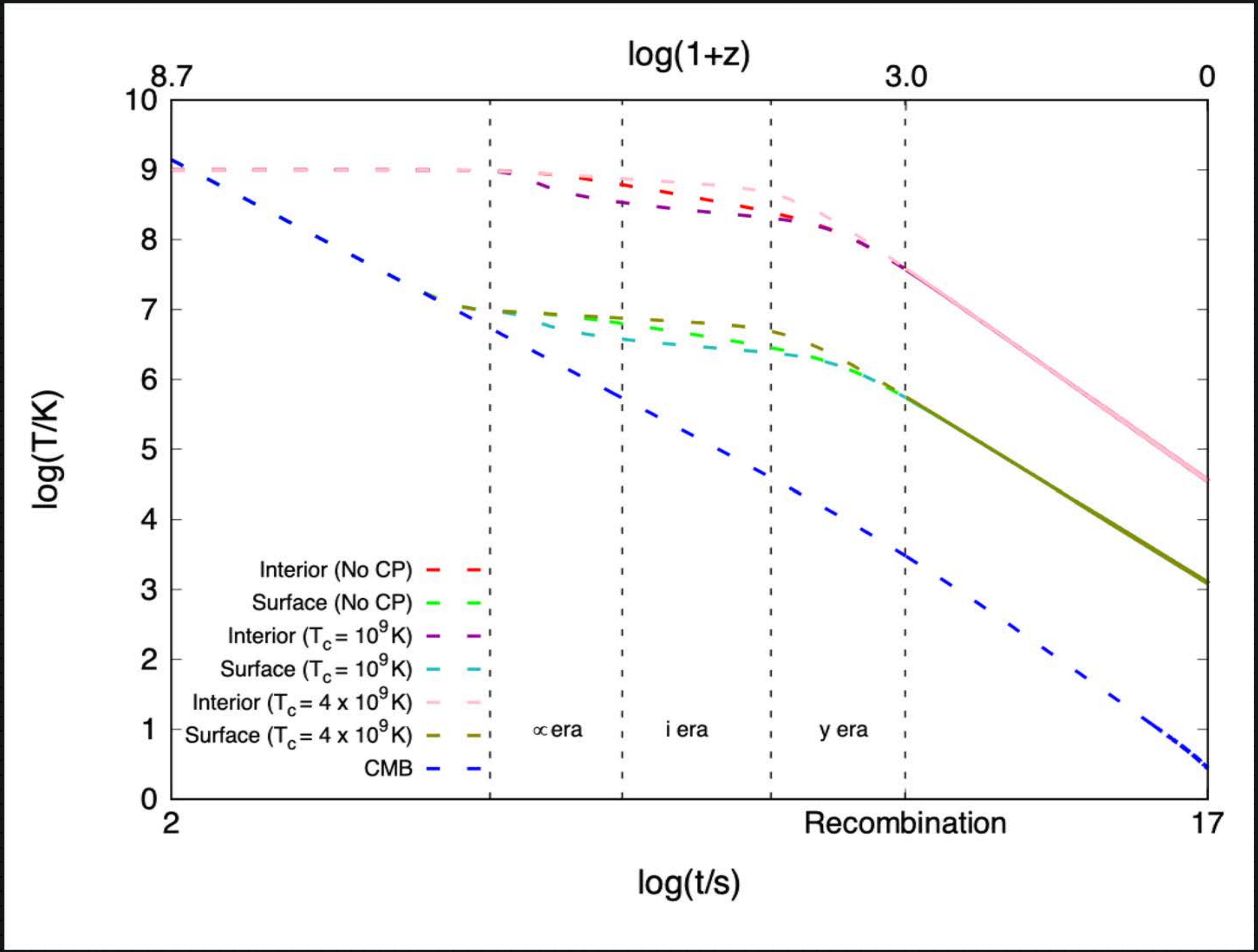
Mica
CMB (DM-photon)
Femtolens
Microlens
Lunar Limit
M31 Microlens
Atomic density
Nuclear density
Black holes
10^{25}
10^{20}
10^{15}
10^{10}
10^{5}
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-4}
10^{1}
10^{6}
10^{11}
10^{16}
10^{21}
10^{26}
10^{31}
σ_X [cm^2]
M_X [g]

CMB Spectral Distortions

S. Kumar et al. Phys. Rev D99 (2019) 023521

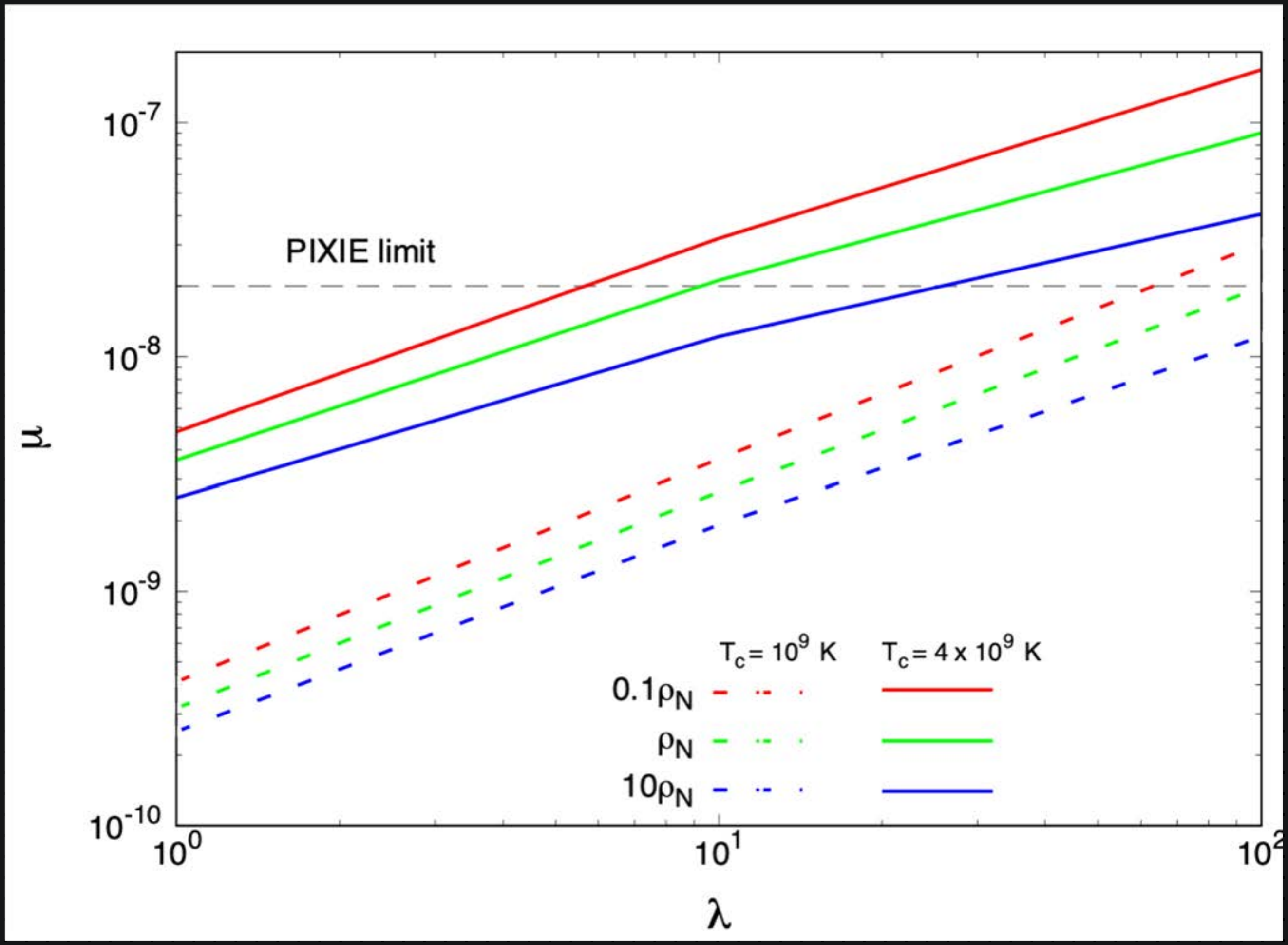
- Macros cool by neutrino and photo emission
- Will stay warmer than the surrounding plasma
- Results in y, mu and intermediate distortions.
- Model dependent: use neutron star as proxy for straw man

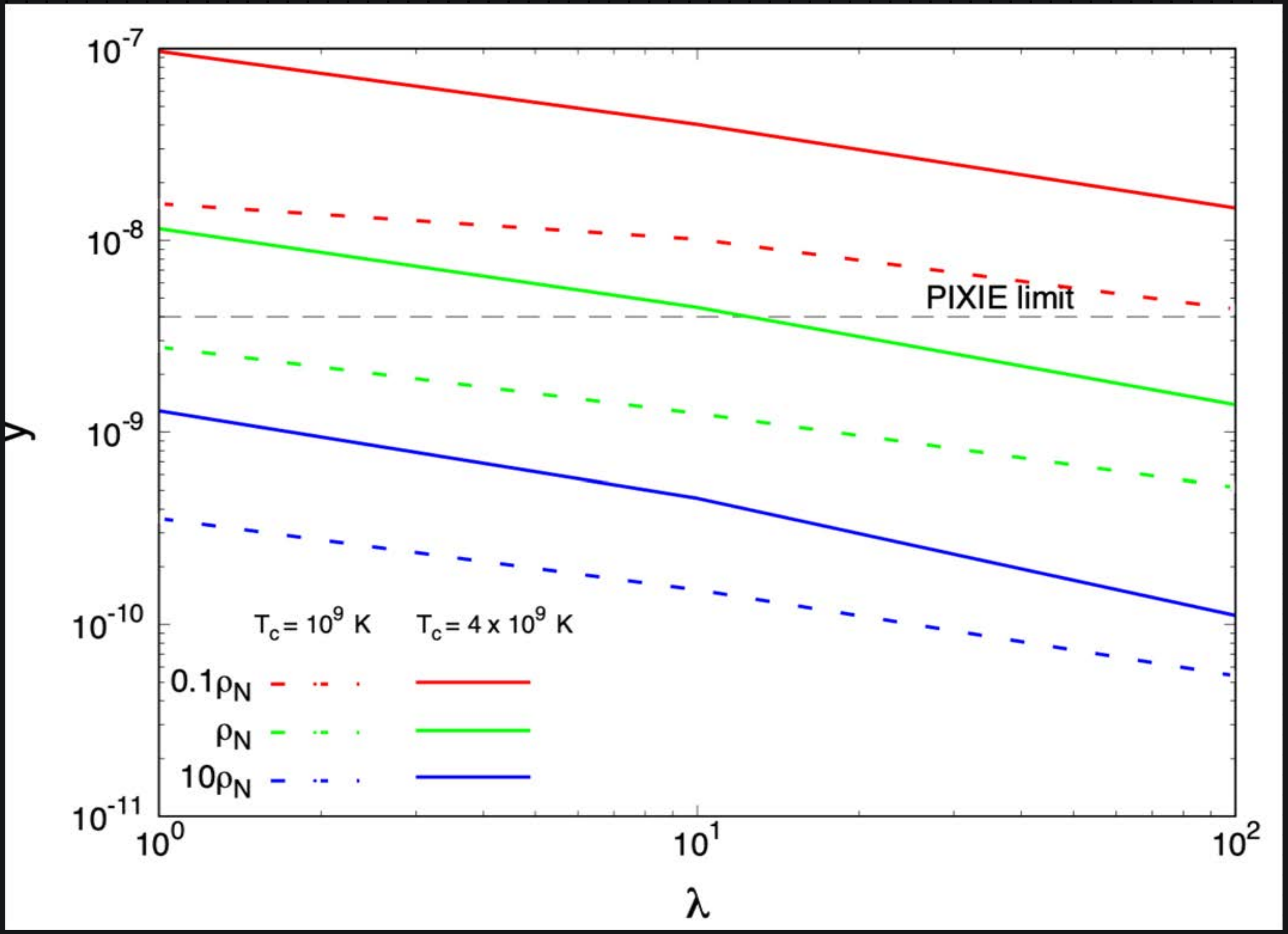
RESULTS: T vs. z



Saurabh Kumar, E. Dimastrogiovanni, GDS, C. Copi, B. Lynn.

RESULTS: μ & y distortion





Saurabh Kumar, E. Dimastrogiovanni, GDS, C. Copi, B. Lynn.

Conclusions

- Dark matter doesn't have to interact weakly if it's very massive.
  It might even arise within the Standard Model.

- Regardless of its nature, there are unconstrained regions of size vs. mass.

- There are many potential probes: UHECR detectors, cameras, the CMB spectrum , seismological (terrestrial and lunar), atmospheric and marine observations (light, sound) , rocks, people, lightning

- Such "strongly" interacting dark matter candidates may (not) be relevant to outstanding issues in CDM cosmology (cusp vs. core, missing satellites,...)

- We need to extend existing searches and explore the full parameter space