CONSTRAINING BSM PHYSICS WITH GALACTIC CENTER GAS CLOUDS

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Based on work with Joseph Bramante, Fatemeh Elahi, Sarah Schön, Ningqiang Song and Javier Acevedo.

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OVERVIEW

1. **Constraining new physics with Galactic Center gas clouds.**

2. **Ultra-light dark photon dark matter.**

3. **Milli-charged dark matter.**

4. **Sub-MeV dark matter.**

Gas Clouds As Dark Matter Detectors

174 gas clouds 100s of pcs from center of Milky Way galaxy
(see Astrophysical Journal Letters 770, L4 2013)

Extremely cold interiors
Coldest clouds sensitive to small heating from dark matter.

Parsec sized
Much larger than any terrestrial detector.

WHY GAS CLOUDS?

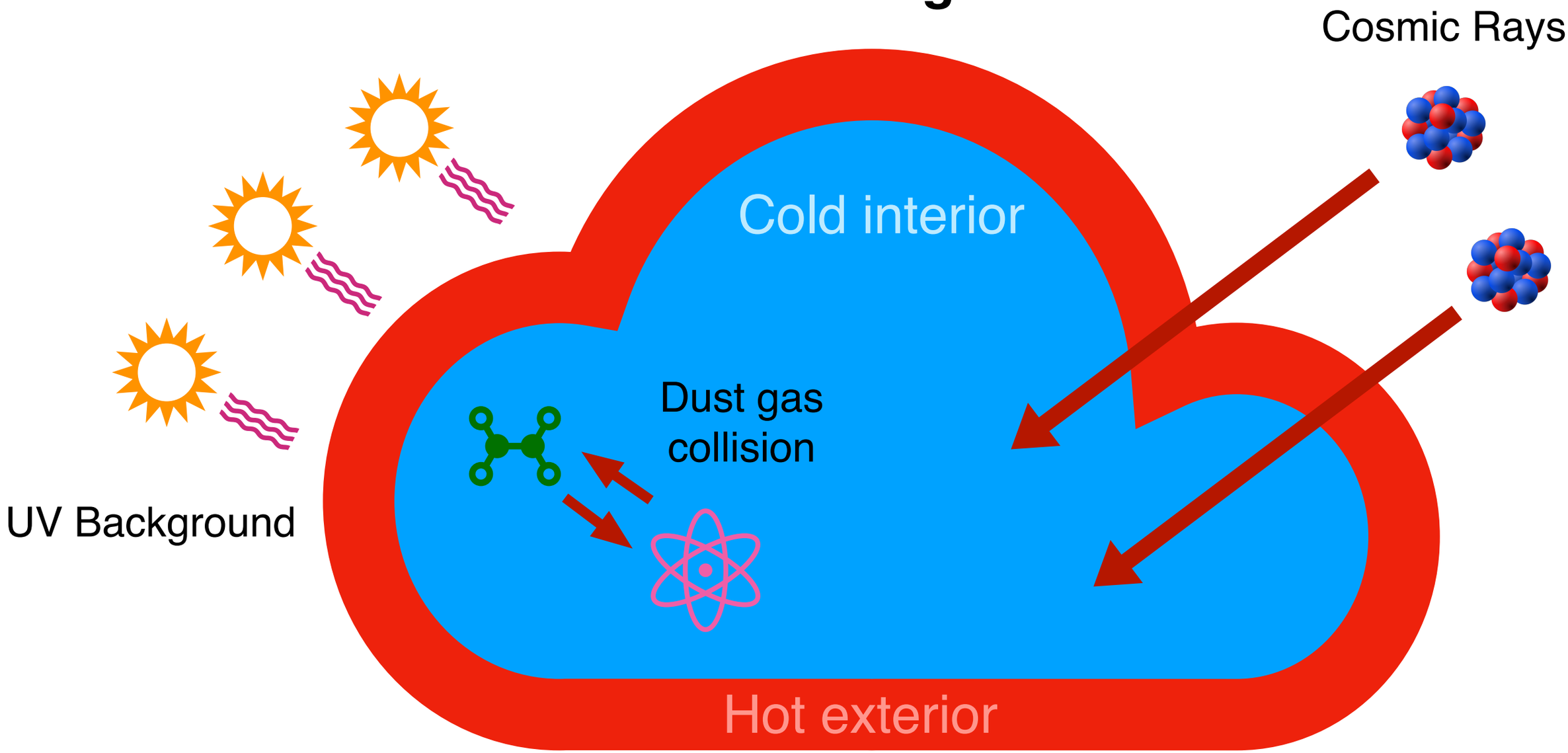
Million year existence*
Exposure time much larger than terrestrial detectors.

Sizeable amounts of ionized gas
Extremely sensitive to dark matter-nucleon interactions.

**** Not relevant for this presentation.***

Gas Clouds As Dark Matter Detectors

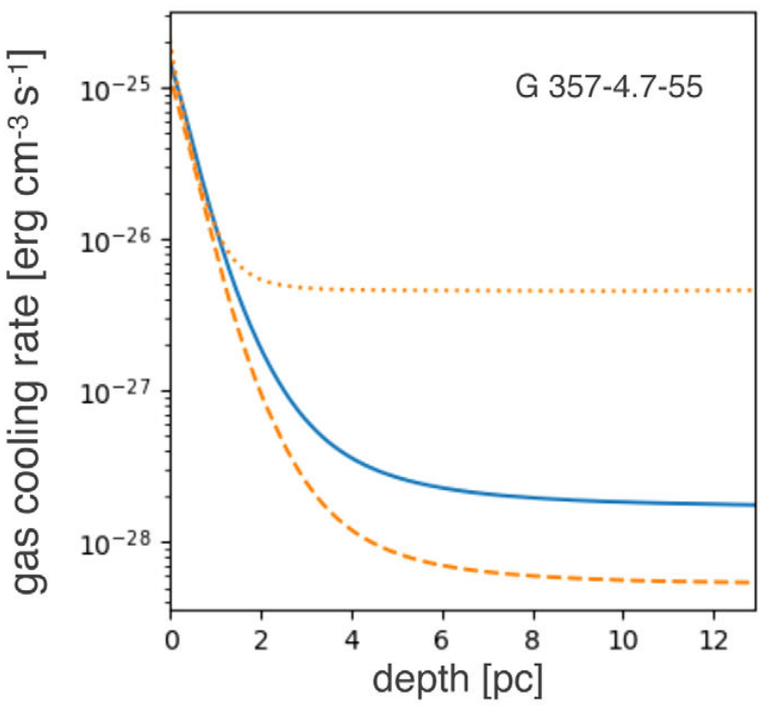
Cooling inferred mainly from molecular excitation and de-excitation.

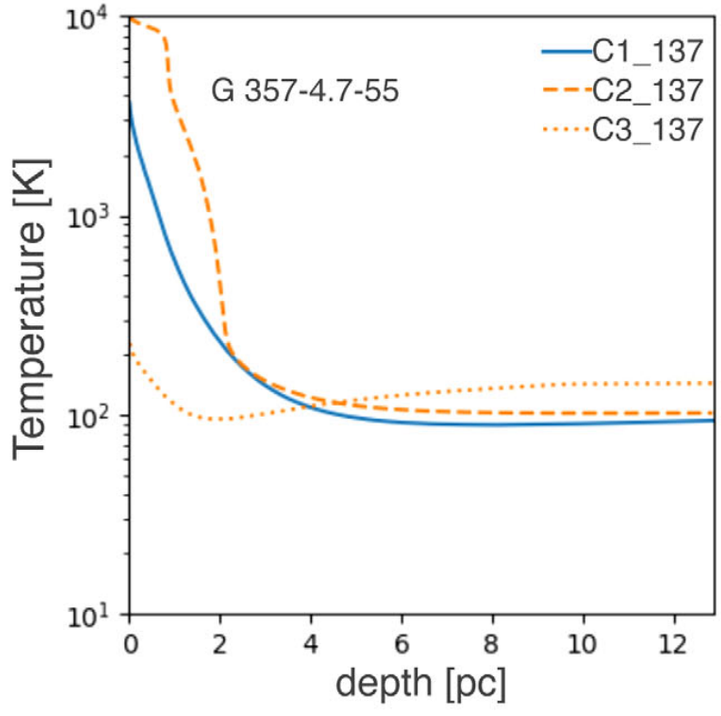


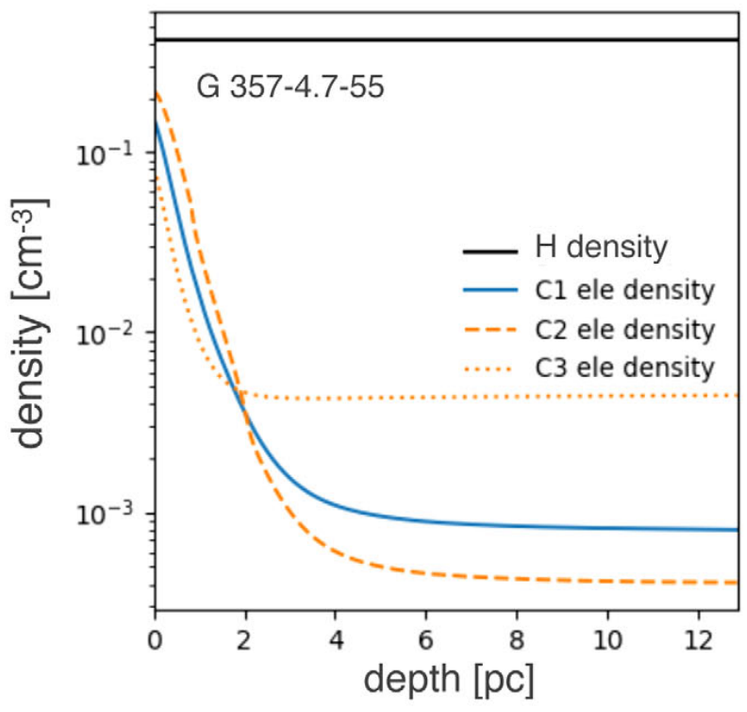
Gas Clouds As Dark Matter Detectors

Cloudy simulation results

Dark matter Model	$\bar{T}$(K)	Radius (pc)	$\bar{\rho}$ (cm^{-3})	$Z/Z_\odot$	Grains	UV	CR (s^{-1})	$\bar{n}_e$ (cm^{-3})	Ave. cooling (erg cm^{-3} s^{-1})
C1-22	22	8.2	0.29	1	No	0.1	1×10^{-18}	2.3×10^{-4}	1.9×10^{-29}
C2-22	22	8.2	0.29	0.1	No	1.9×10^{-3}	1.9×10^{-19}	9.7×10^{-5}	1.6×10^{-30}
C3-22	22	8.2	0.29	5	No	0.1	5×10^{-18}	5.6×10^{-4}	6.2×10^{-28}
C1-137	137	12.9	0.421	1	Yes	1	5×10^{-17}	1×10^{-3}	3.4×10^{-28}
C2-137	137	12.9	0.421	0.1	Yes	1	3×10^{-18}	5×10^{-4}	8.2×10^{-29}
C3-137	137	12.9	0.421	5	Yes	1	1.9×10^{-16}	6.2×10^{-3}	6.1×10^{-27}
C1-198	198	12.3	1.57	1	Yes	1	2.9×10^{-16}	1.2×10^{-2}	2.4×10^{-26}
C2-198	198	12.3	1.57	0.1	Yes	1	1.1×10^{-16}	7.4×10^{-3}	8.2×10^{-27}
C3-198	198	12.3	1.57	5	Yes	1	1.4×10^{-15}	4.5×10^{-2}	1.5×10^{-25}







Gas Clouds As Dark Matter Detectors

VSHR Heating rate from Standard Sources.

$$\text{VCD} \geq \text{VSHR} + \text{VDHR}$$

VCD
Cooling rate by excitation.

VDHR: Heating rate from dark matter.

No assumptions about thermodynamic equilibrium.

Gas Clouds As Dark Matter Detectors

1. Ultra-light dark photon dark matter.

Extend Standard Model by a massive U(1) gauge boson.

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + m^2 A'_\mu A'^\mu - \frac{e}{(1+\epsilon)^2} (A_\mu + \epsilon A'_\mu) J^\mu_{\rm EM},$$

1. Dark electric field in the gas.

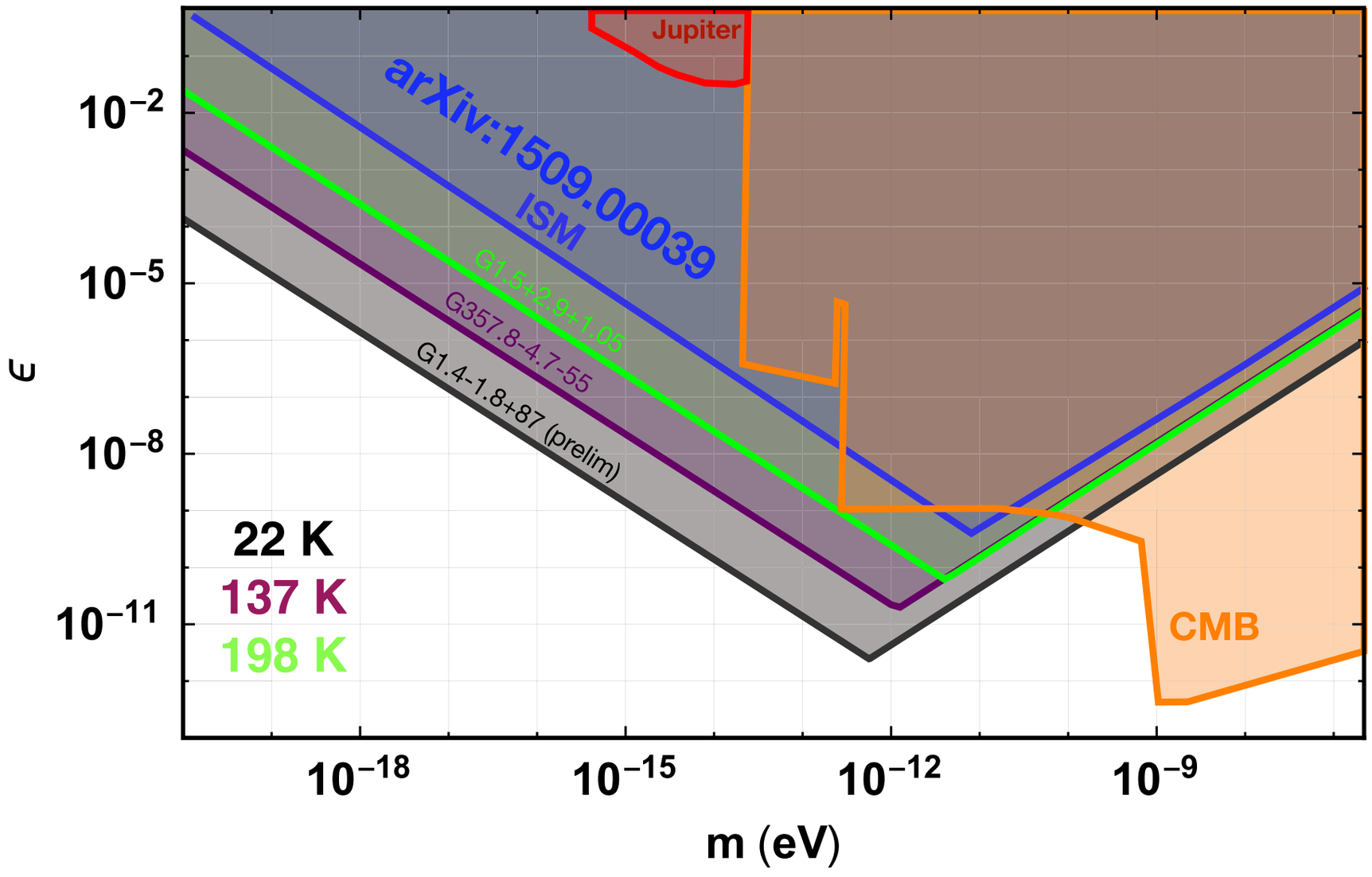
2. Free electrons accelerated - current.

3. Gas medium is not a perfect conductor.

4. Heat dissipation.

Gas Clouds As Dark Matter Detectors

Ultra-light dark photon dark matter.



Not shown: comparable constraints from Leo T Dwarf Galaxy (see PRD103, 123028 (2021).

Gas Clouds As Dark Matter Detectors

2. Milli - Charged dark matter.

Dark matter with a small Electromagnetic coupling.

m = 0

$$\mathcal{L} = \frac{1}{2}m^2 A'_\mu A'^\mu + eJ^{EM}_\mu A^\mu + \left(\frac{g}{\sqrt{1-\epsilon^2}}J^D_\mu - \frac{e\epsilon}{\sqrt{1-\epsilon^2}}J^{EM}_\mu\right)A'^\mu.$$

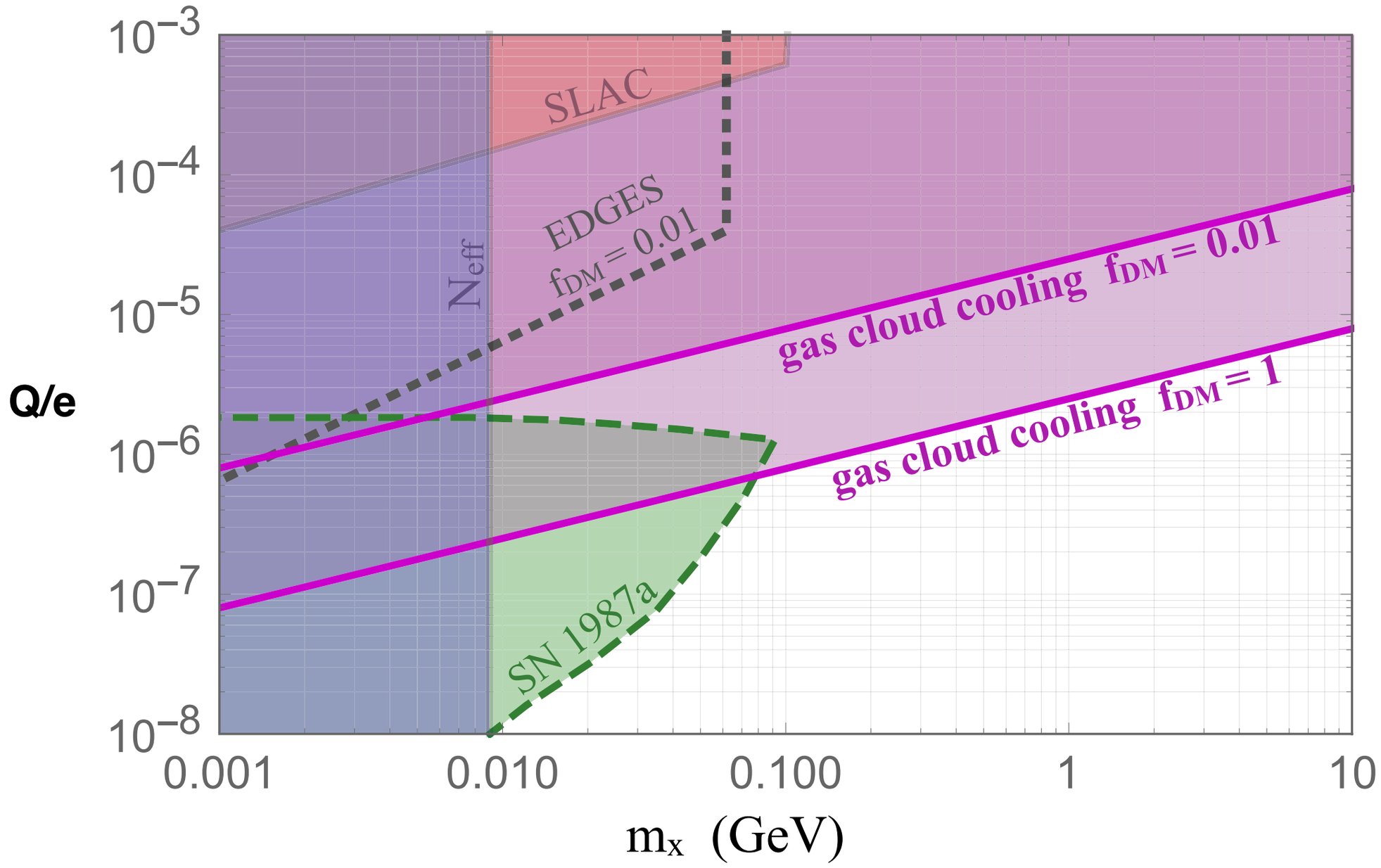
Dark sector
acquires milli-charge

Heating effect just like charged particles energy dissipation.

Bethe-Bloch formula with $e \to \epsilon e$

Gas Clouds As Dark Matter Detectors

Milli - Charged dark matter.



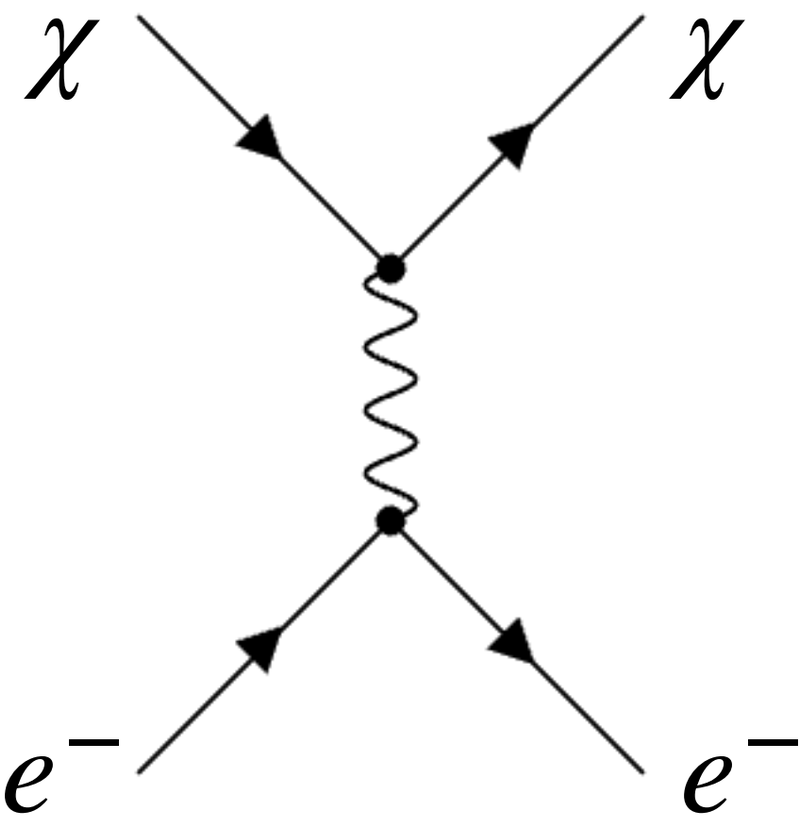
Gas Clouds As Dark Matter Detectors

3. Sub - MeV Dark Matter

Dark photon mediator to DM Fermion

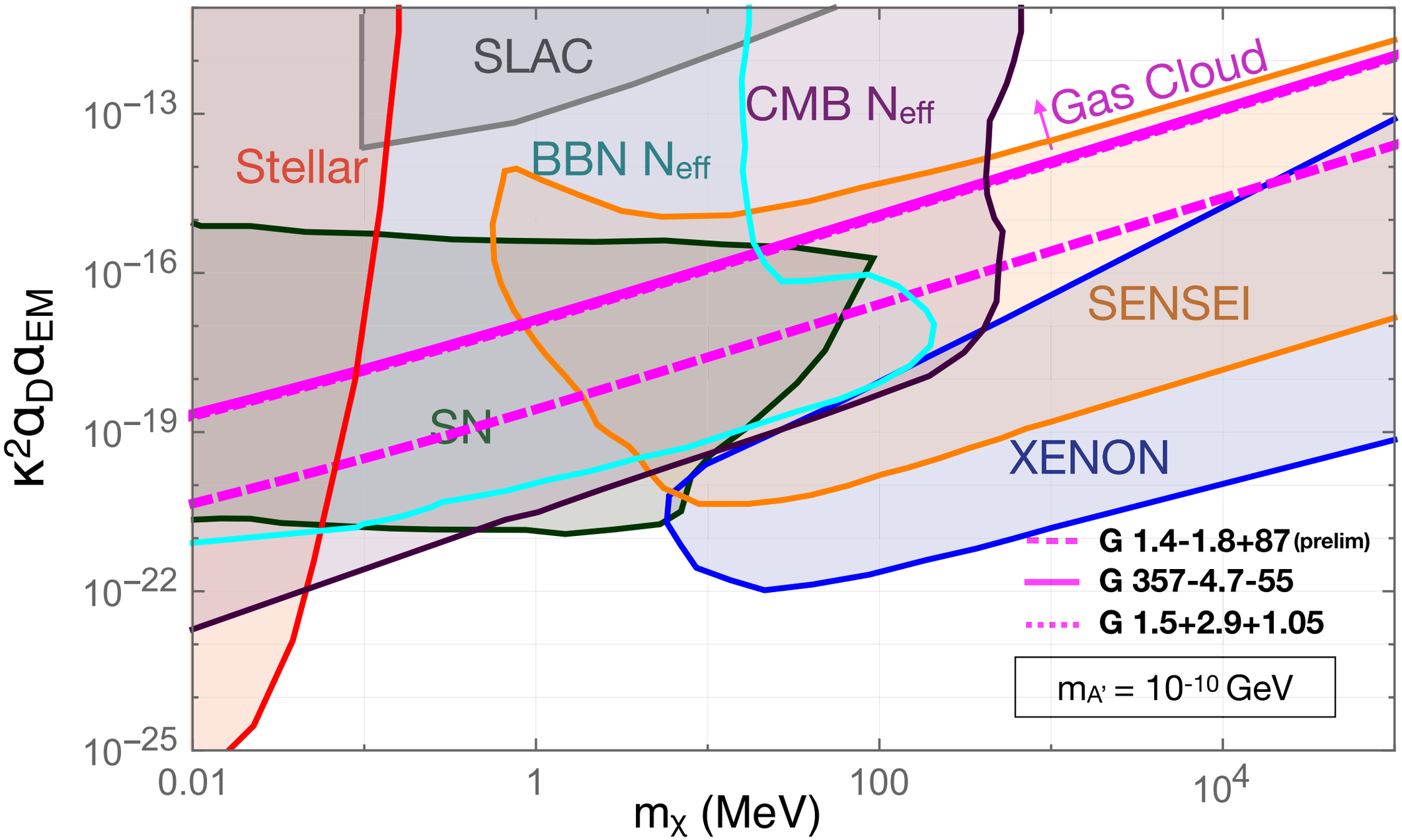
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{1}{2} m_{A'}^2 A'_\mu A'^\mu - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} - \frac{\kappa}{2} F_{\mu\nu} F'^{\mu\nu} - g_D A'_\mu \bar{\chi} \gamma^\mu \chi .$$

Gas cloud free



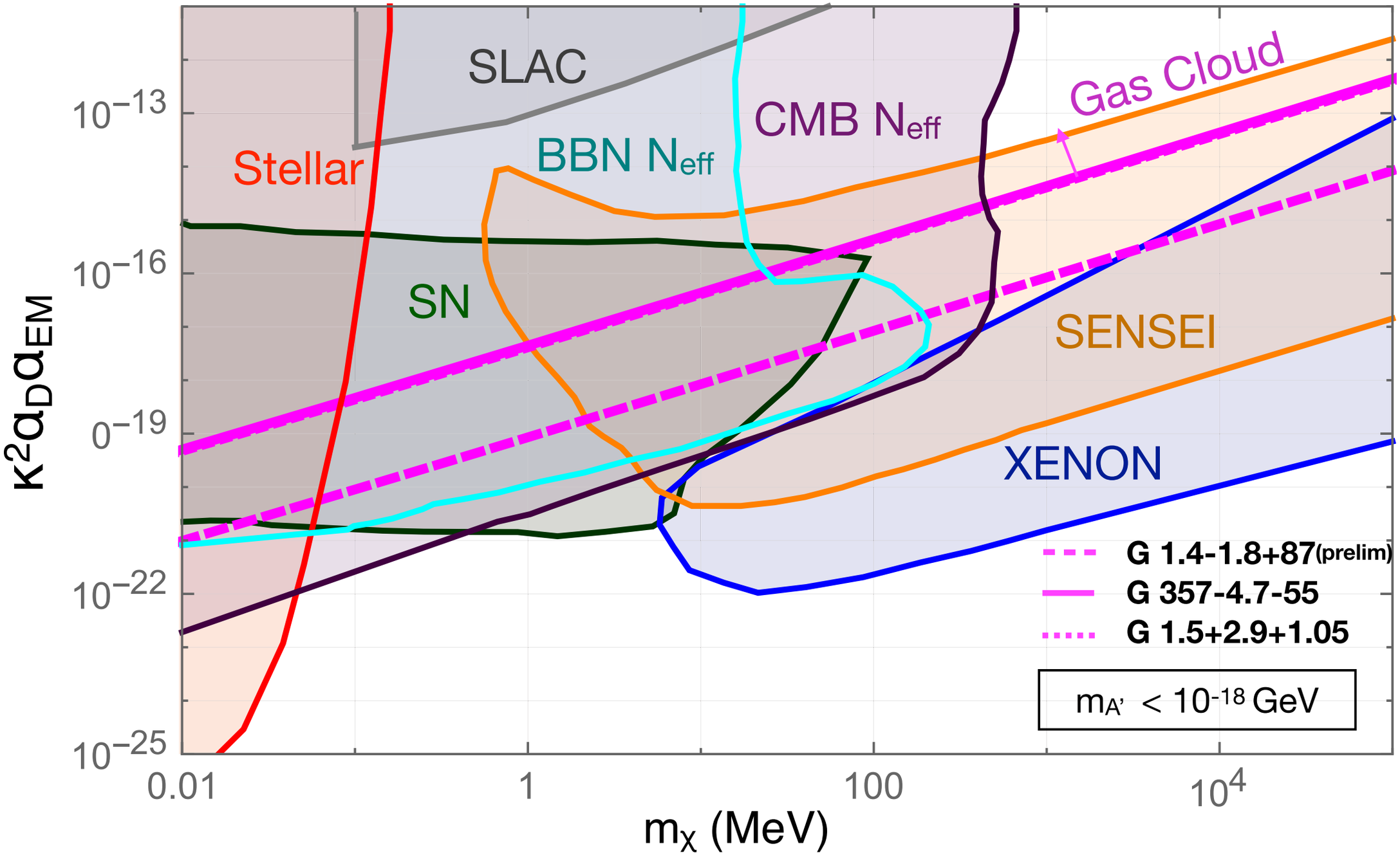
Gas Clouds As Dark Matter Detectors

Sub - MeV fermonic dark matter.



Gas Clouds As Dark Matter Detectors

Sub - MeV fermonic dark matter.



Gas Clouds As Dark Matter Detectors

THANK YOU!