Gas-rich dwarfs as powerful sub-GeV DM detectors

(Jay) Digvijay Wadekar
NYU

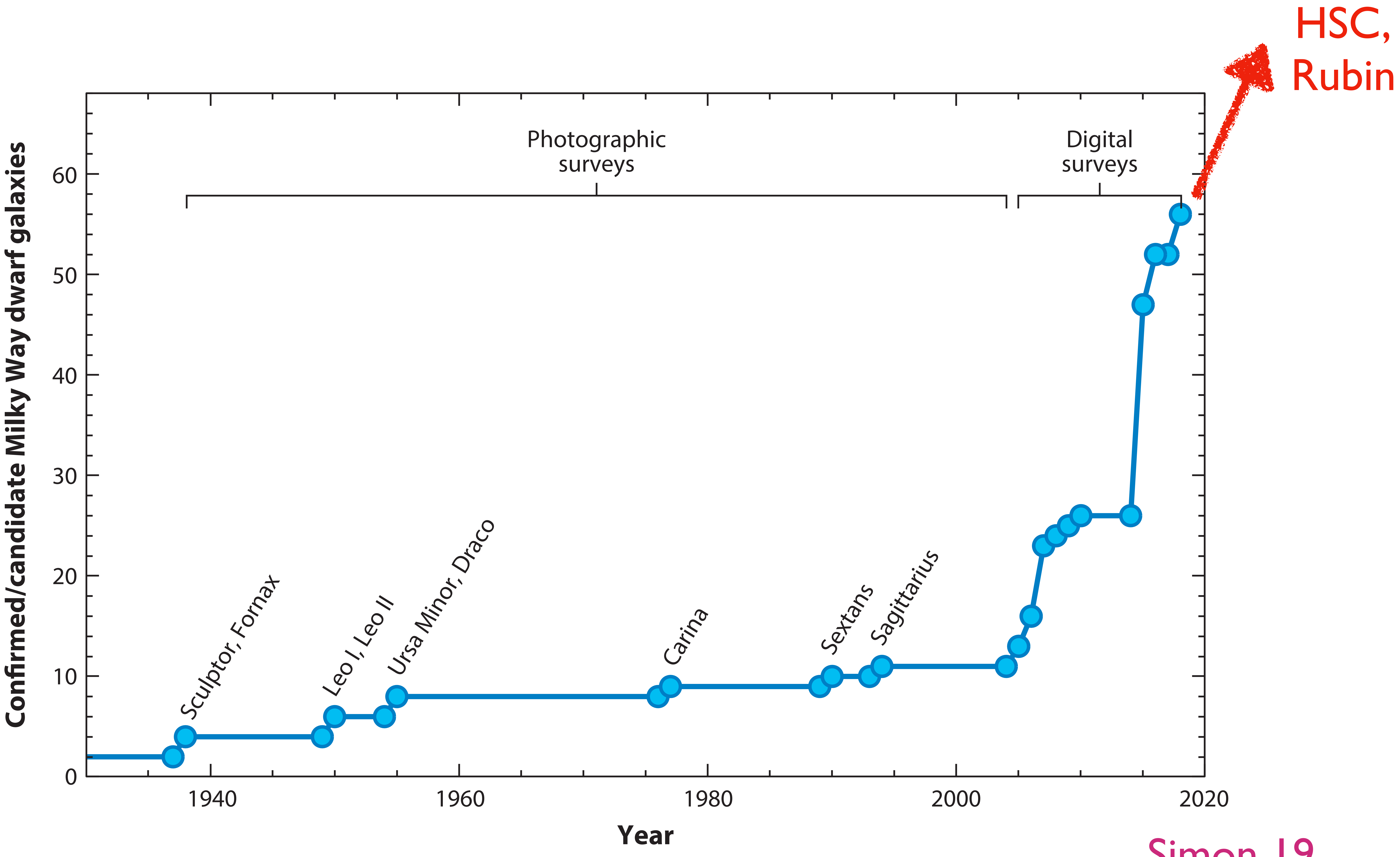
with Glennys Farrar

aXiv:1903.12190 & in prep.

Motivation: Dwarf galaxies to probe DM

- Popular alternatives to CDM affect structure at small scales
  e.g., fuzzy DM, warm DM, self-interacting DM
- Baryonic feedback in dwarf galaxies is low
  - pristine laboratories for non-standard interactions

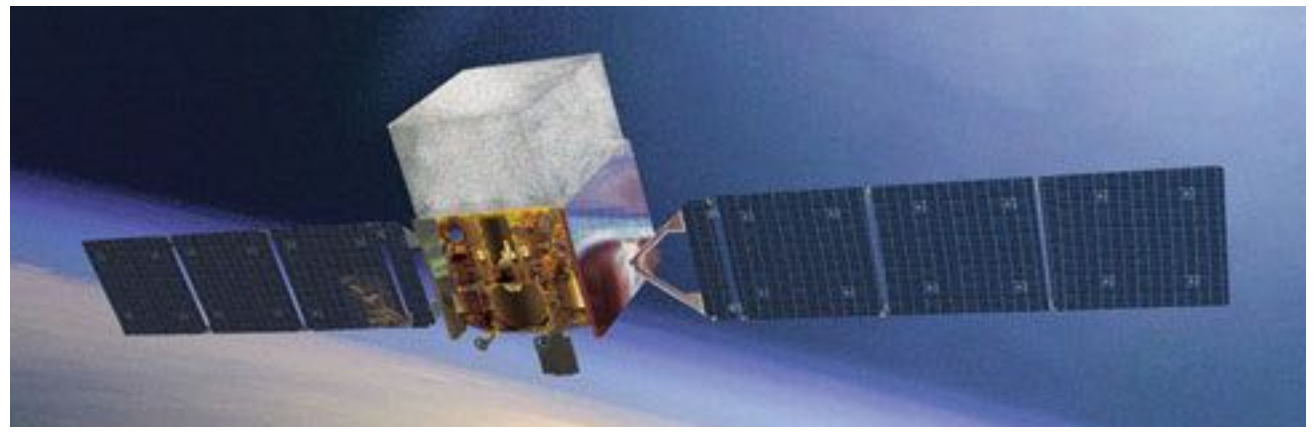
Motivation: Dwarf galaxies to probe DM



Simon 19

Dwarf galaxies have been used to probe DM annihilation or DM decays

$\chi + \chi$ → $\mathrm{SM} + \mathrm{SM}$ → γ rays →

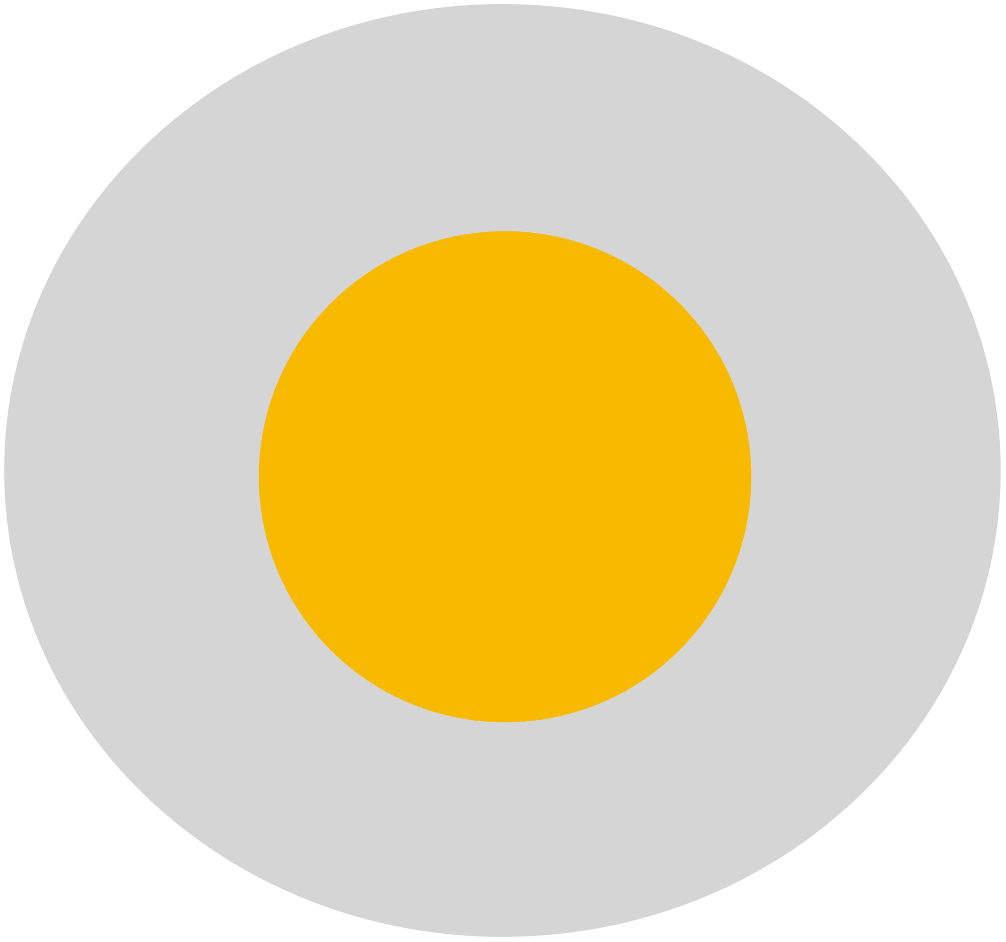


Eg. Draco,
Eridanus,
Sculptor,
Fornax,
....

$\chi \to \mathrm{SM{+}SM}$ ✓.

$\chi + \mathrm{SM} \to \chi + \mathrm{SM}$ ✗

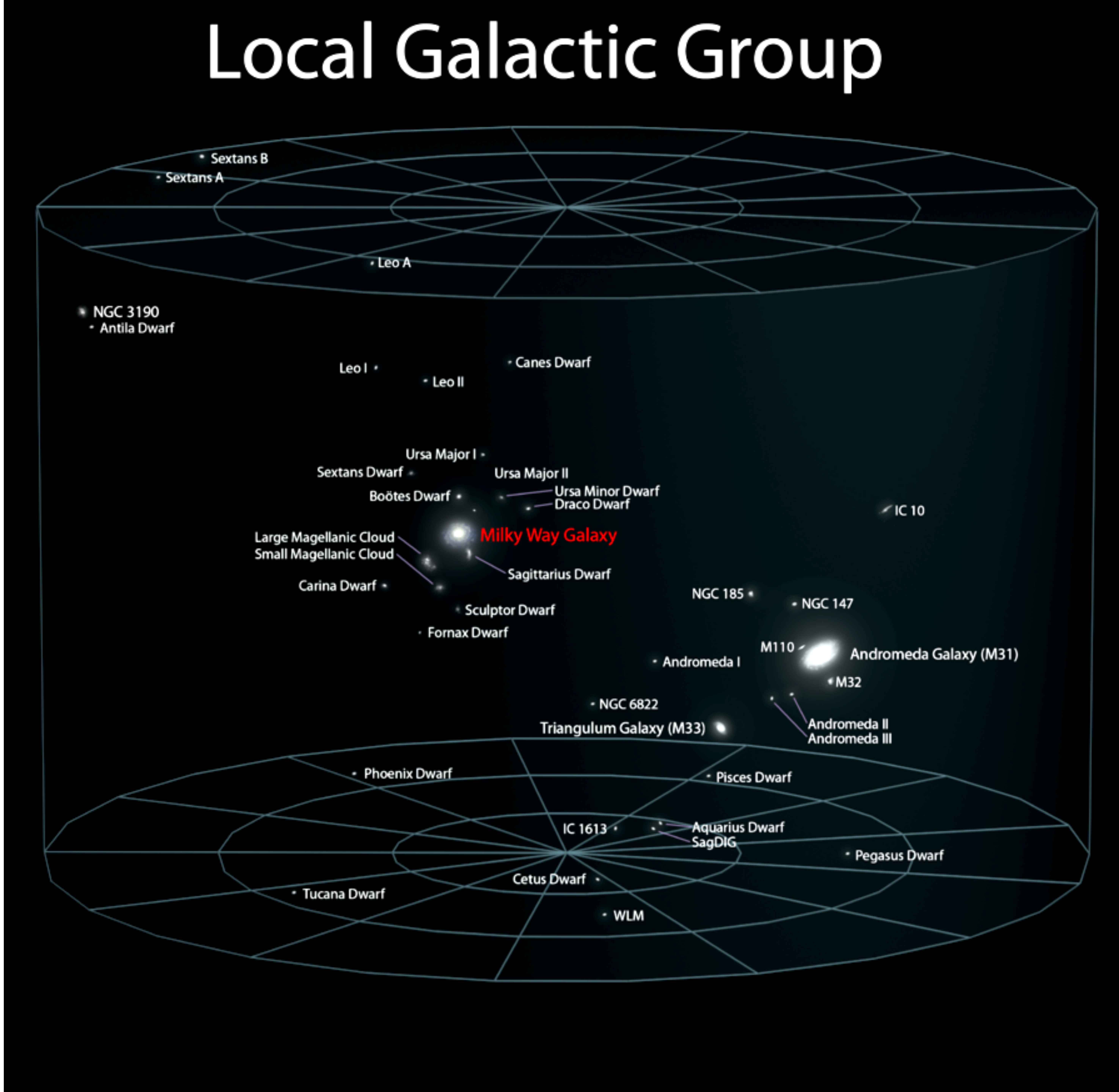
Gas-rich dwarfs can probe DM-SM interactions



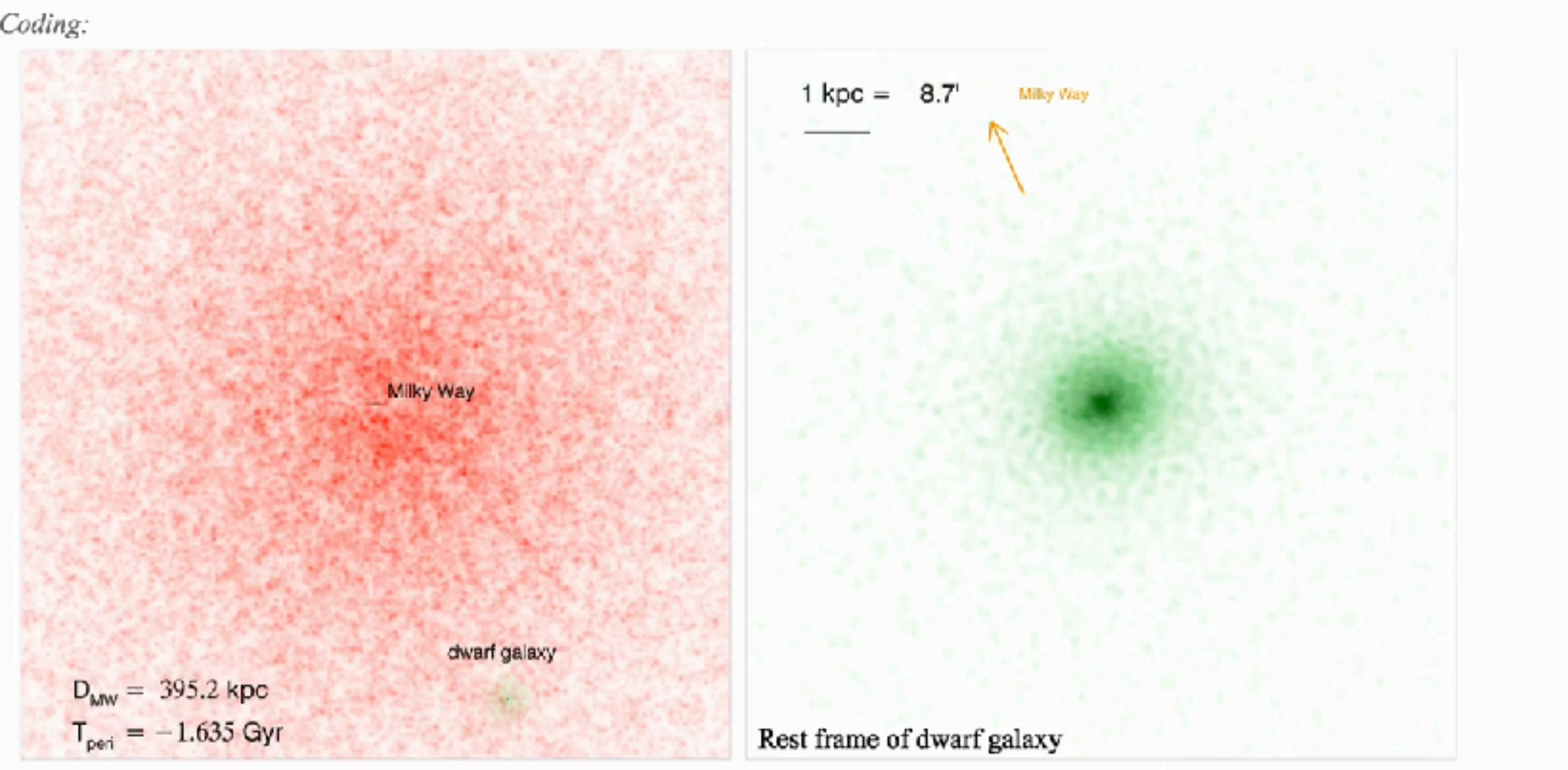
Neutral hydrogen (HI)

$$\chi + \mathrm{SM} \to \chi + \mathrm{SM} \quad \checkmark .$$

Gas-rich dwarfs only recently discovered

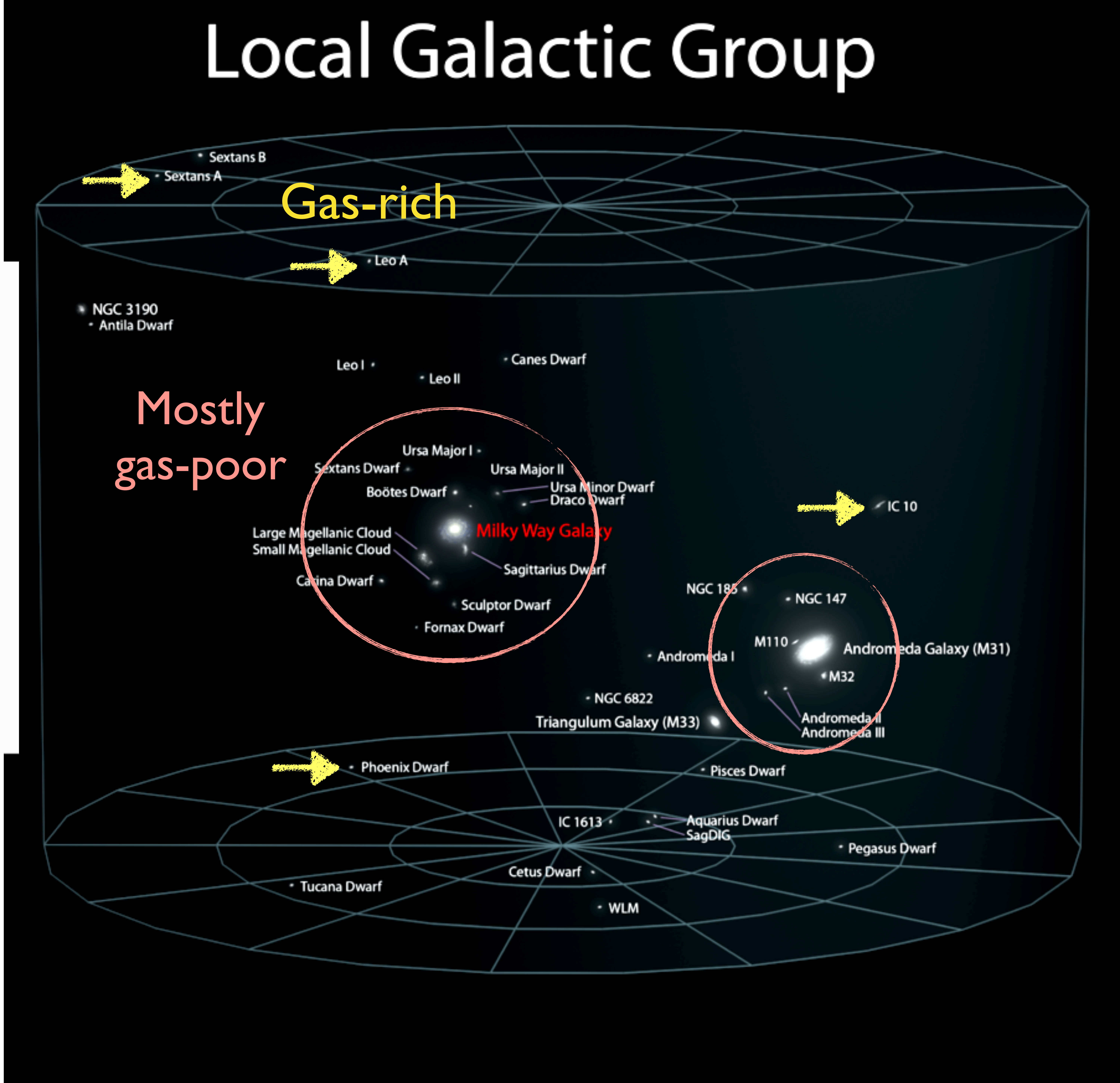


Gas-rich dwarfs only recently discovered



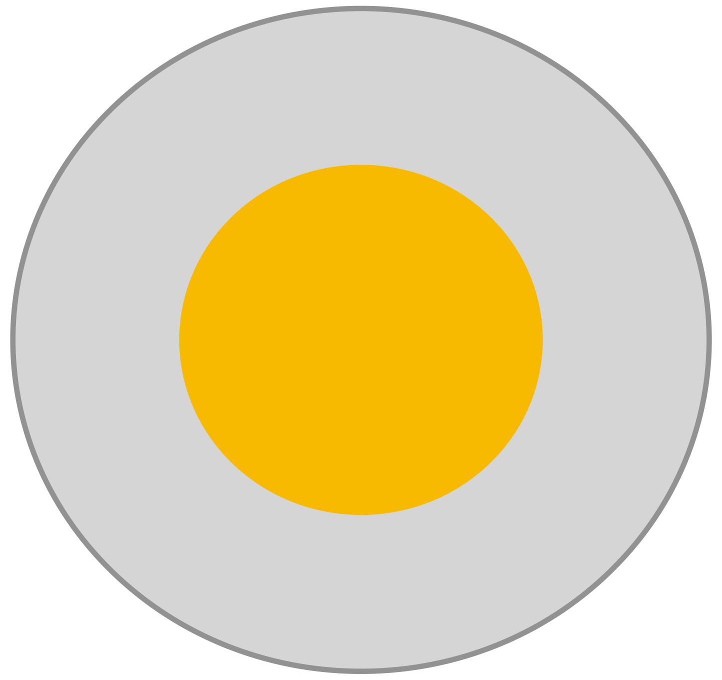
A gas-rich dwarf galaxy is falling into the hot gas of the Milky Way halo.

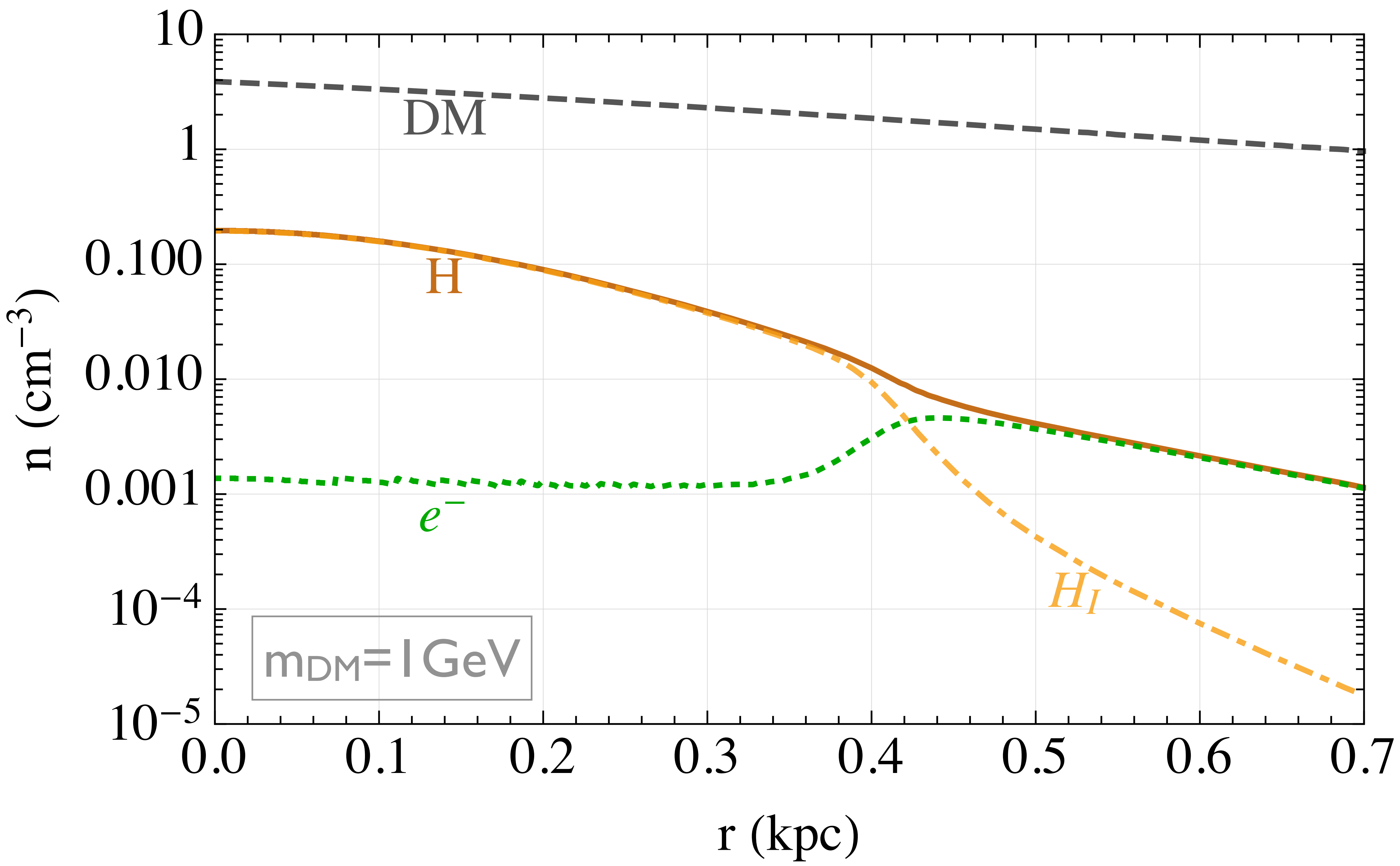
Video: Yang et al. 2014



Leo T gas-rich dwarf

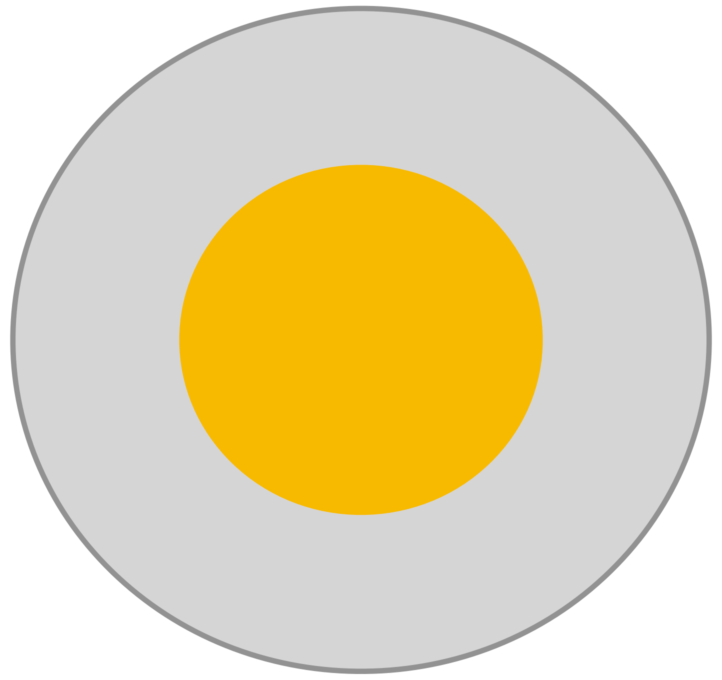
- Local group dwarf (420 kpc away)



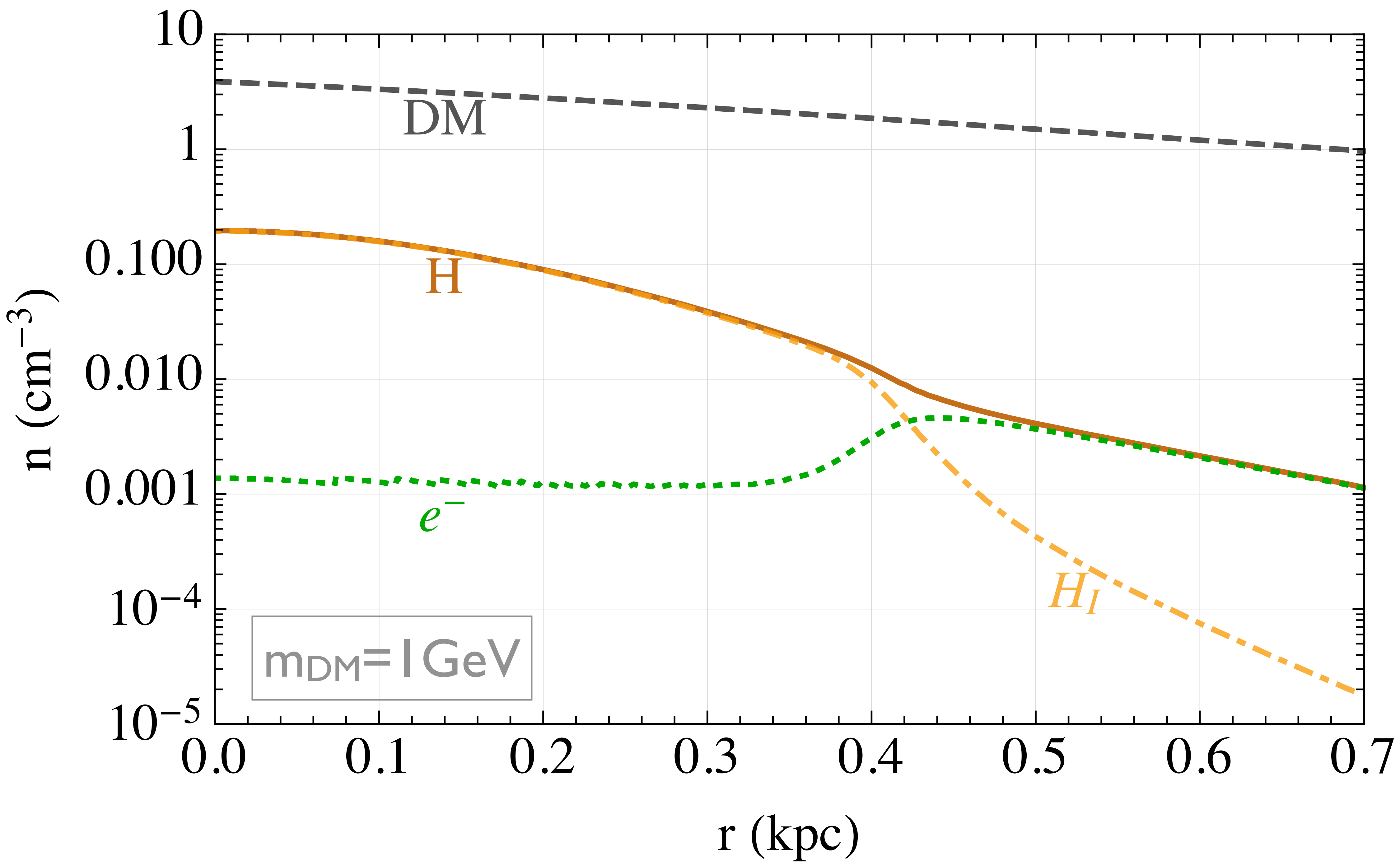


Faerman et al. 13

Leo T gas-rich dwarf



- Local group dwarf (420 kpc away)
- Ideal for our study
  1. DM dominated and gas rich
  2. Good observation data from GMRT+WSRT (radio), HST+SDSS+Keck (optical)
  3. DM and ionization profile modeled by Faerman et al. (2013)
  4. "Cleaner" system to study than large galaxies like the Milky Way

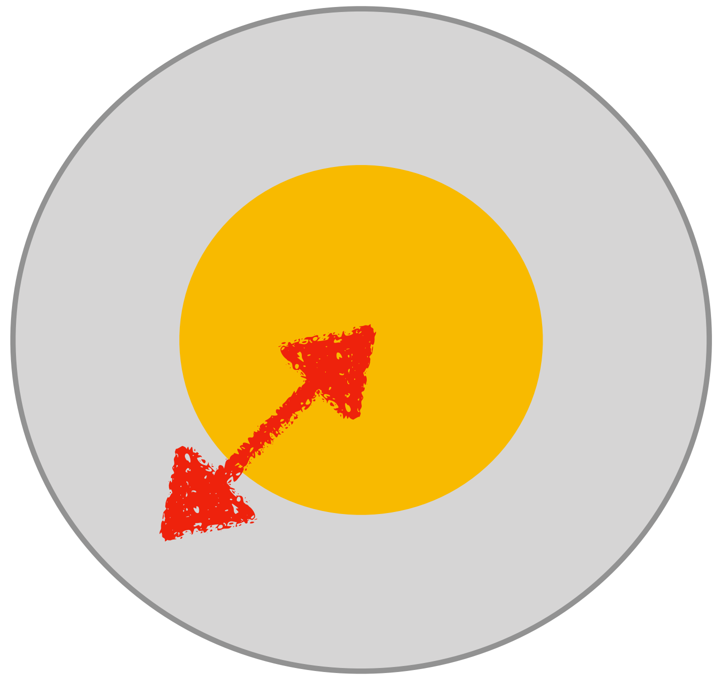


Faerman et al. 13

Constraints from DM heat exchange

- Heat exchange is analogous to two fluids in thermal contact

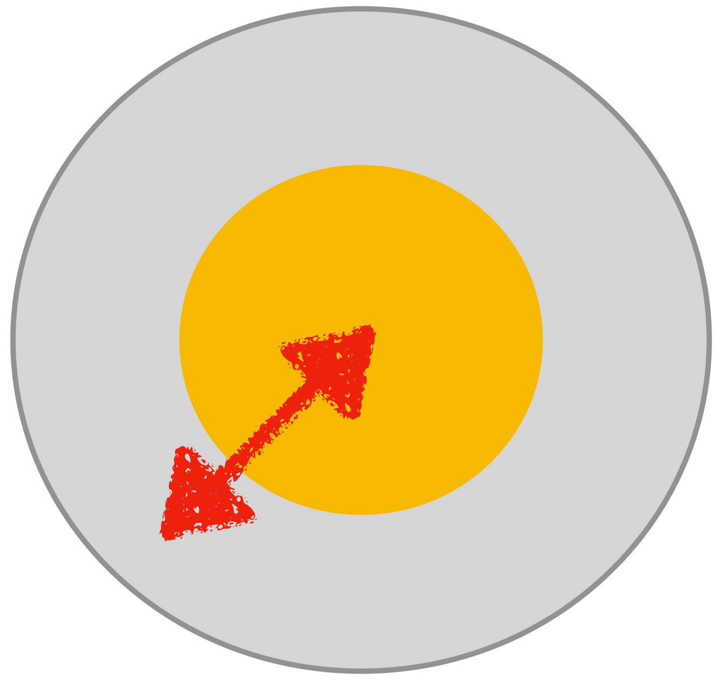
$$\dot{E} \equiv \frac{dE}{dV\,dt} \propto \sigma\,(T_{\rm DM} - T_{\rm gas}) \qquad (T_{\rm DM} \propto m_{\rm DM}\; v^2_{\rm DM})$$



Constraints from DM heat exchange

- Heat exchange is analogous to two fluids in thermal contact

$$\dot{E} \equiv \frac{dE}{dV\,dt} \propto \sigma\,(T_{\rm DM} - T_{\rm gas})$$



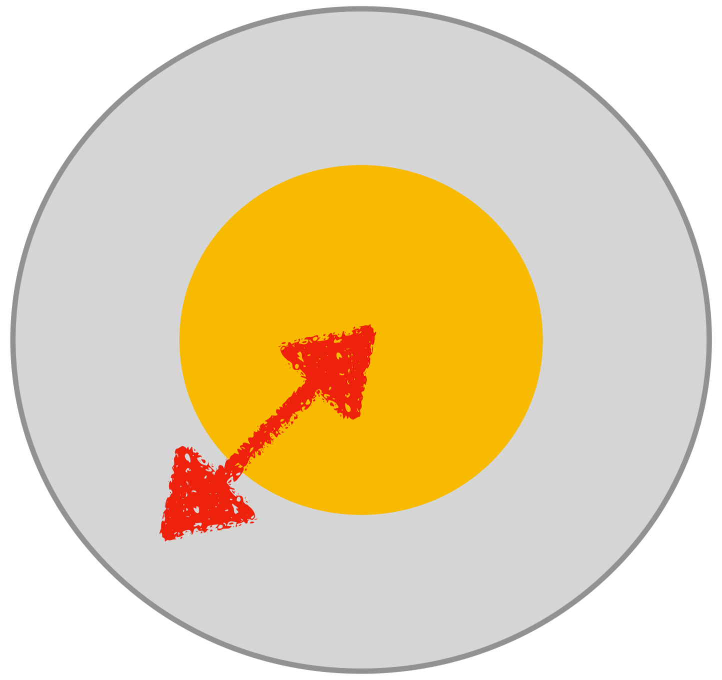
- To set limits:
  |DM heat exchange rate| ≤ |Gas cooling rate|

- Logic: System which cools slowly is more sensitive to energy transfer by DM

Constraints from DM heat exchange

- Heat exchange is analogous to two fluids in thermal contact

$$\dot{E} \equiv \frac{dE}{dV\,dt} \propto \sigma\left(T_{\rm DM} - T_{\rm gas}\right)$$



- To set limits:
  |DM heat exchange rate| ≤ |Gas cooling rate|

- Logic: System which cools slowly is more sensitive to energy transfer by DM

$$\dot{C} = n_{\rm H}^2\,\Lambda(T)\,10^{[{\rm Fe/H}]}$$

Metal fraction of gas relative to sun
(~0.02 for Leo T)

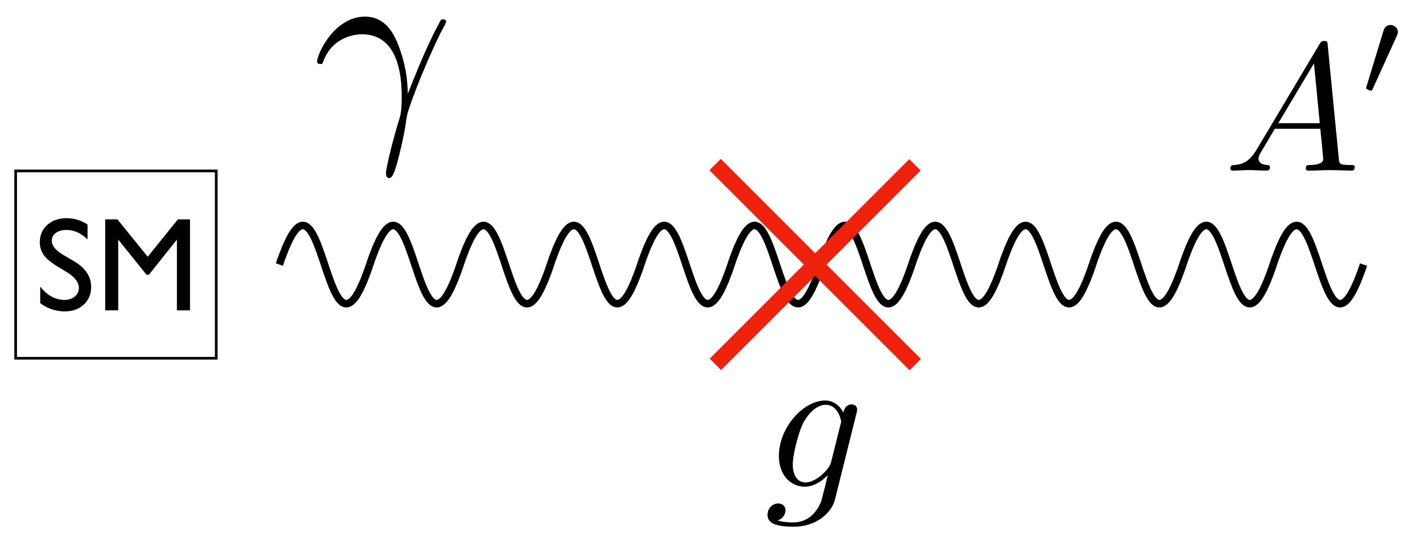
(More metals ⟶ More lines available for cooling)

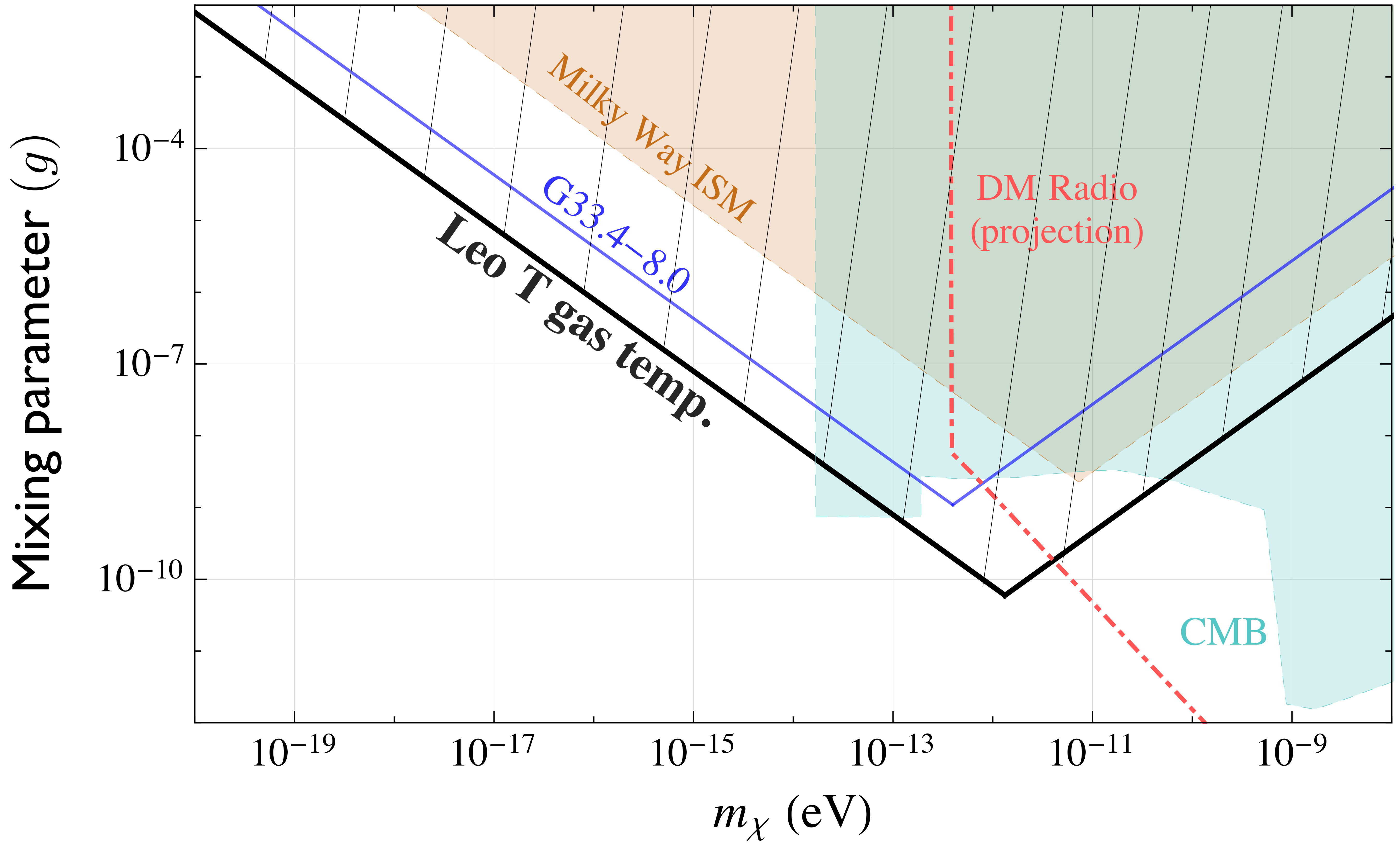
DM candidates constrained by Leo T

1. Hidden photon DM
2. Primordial black holes (PBHs)
3. Axions / ALP
4. Millicharge DM
5. s-wave, p-wave DM annihilation

1. Results for ultra-light hidden photon DM

- Dark sector comprised of vector bosons only
  (no corresponding fermion)

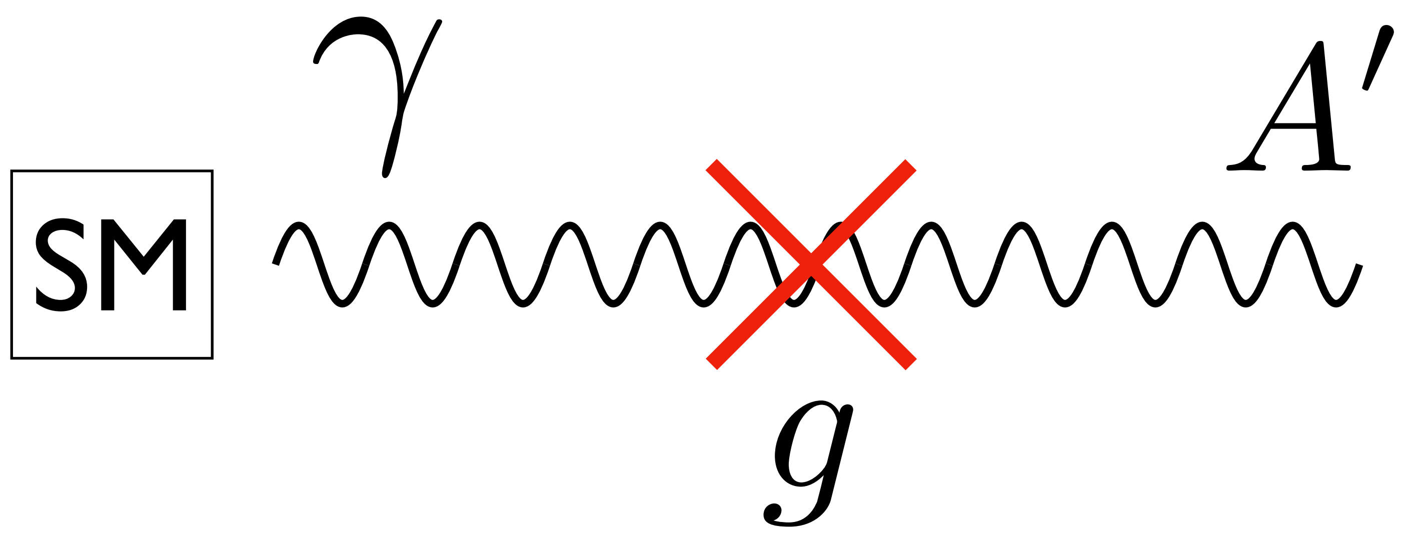


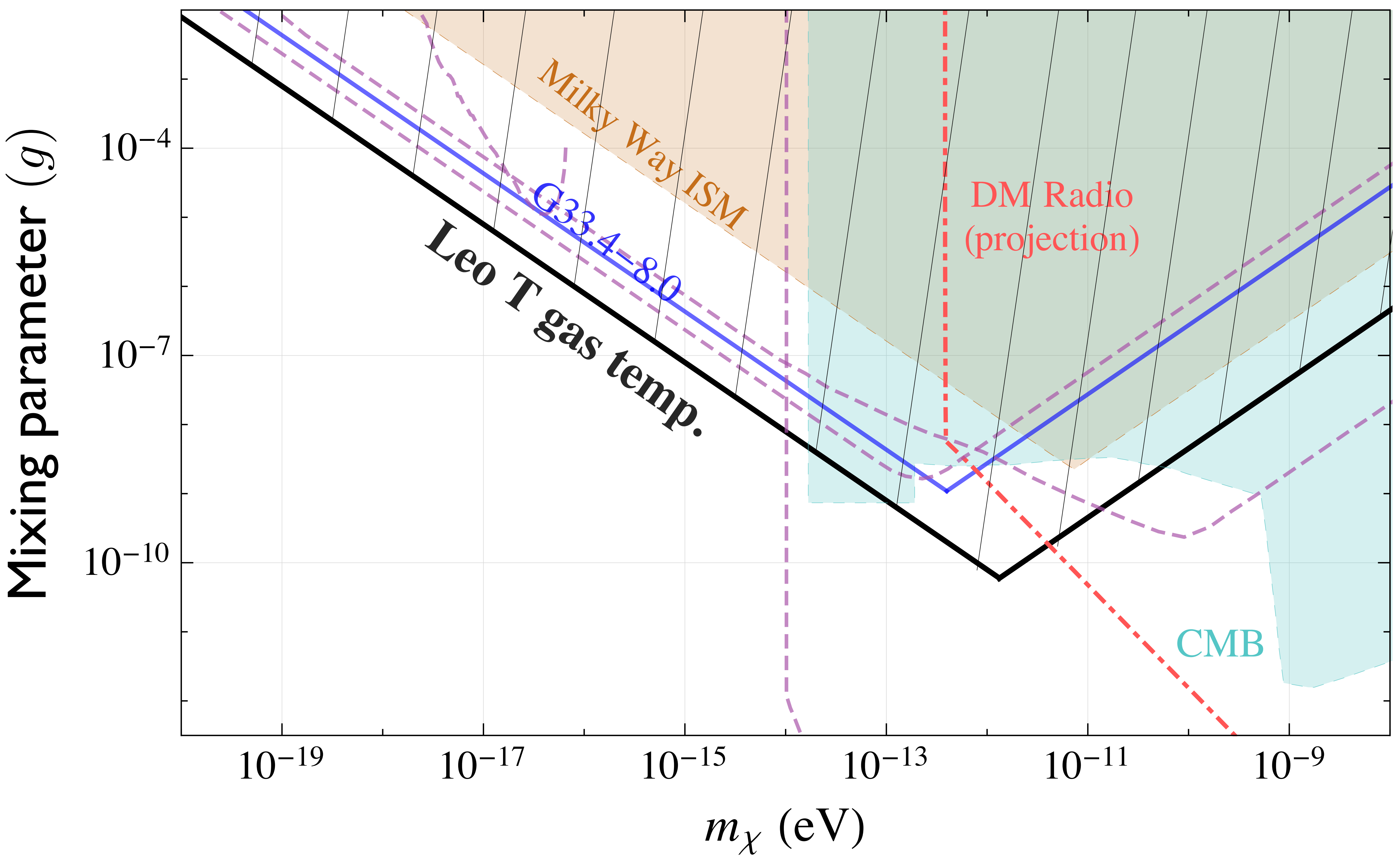


DW & G. Farrar 19

1. Results for ultra-light hidden photon DM

- Dark sector comprised of vector bosons only
  (no corresponding fermion)

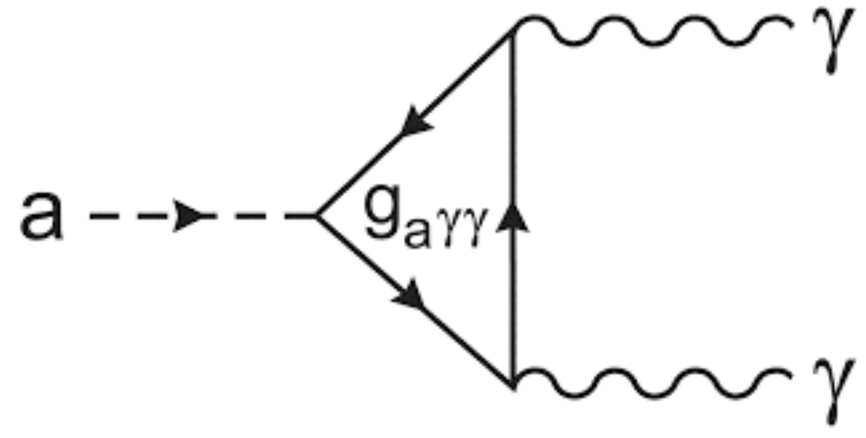




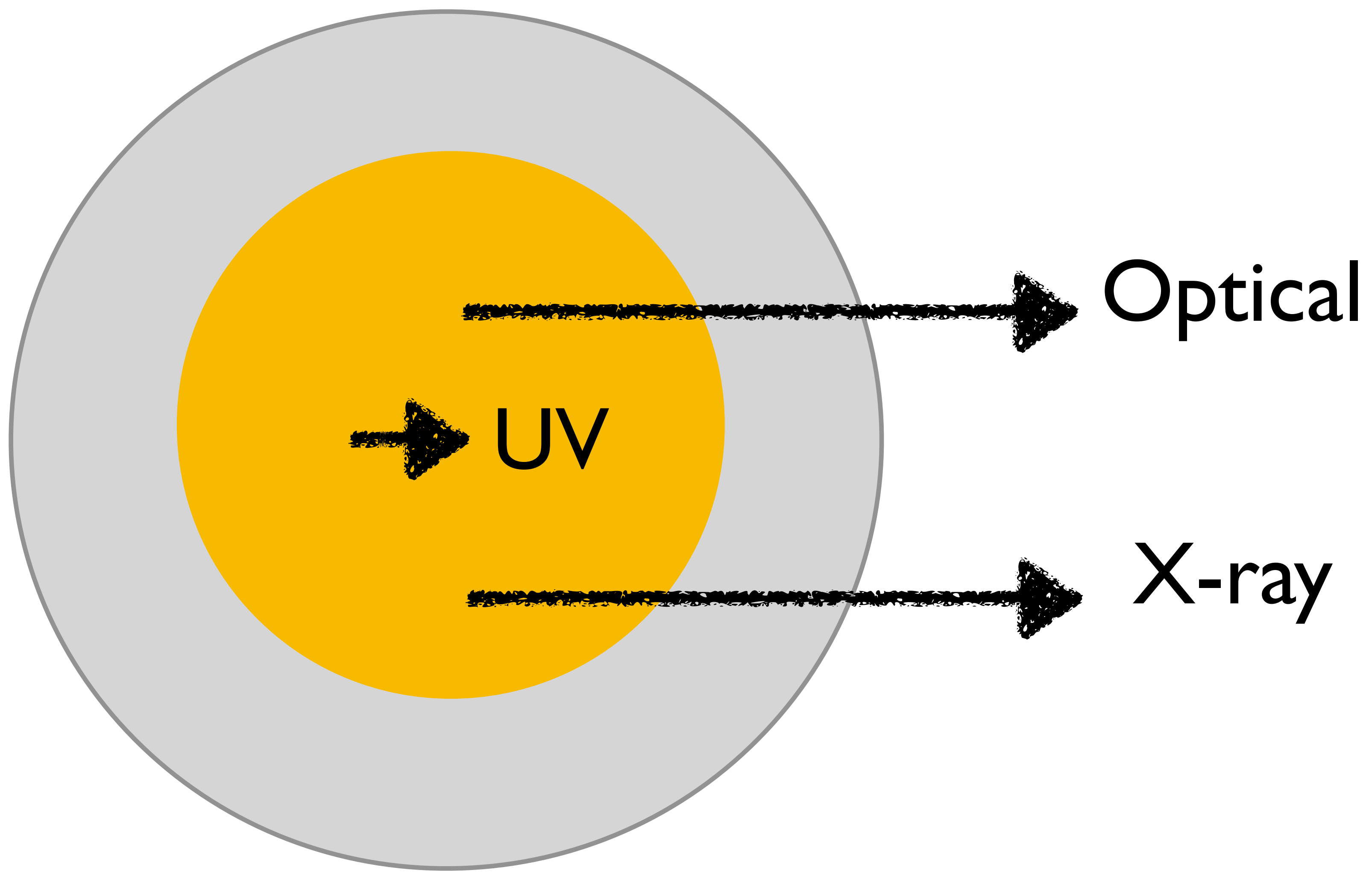
DW & G. Farrar 19

See also: McDermott et al. 20
Caputo et al. 20
Fedderke et al. 21

2. Limits on axion/ALP decays

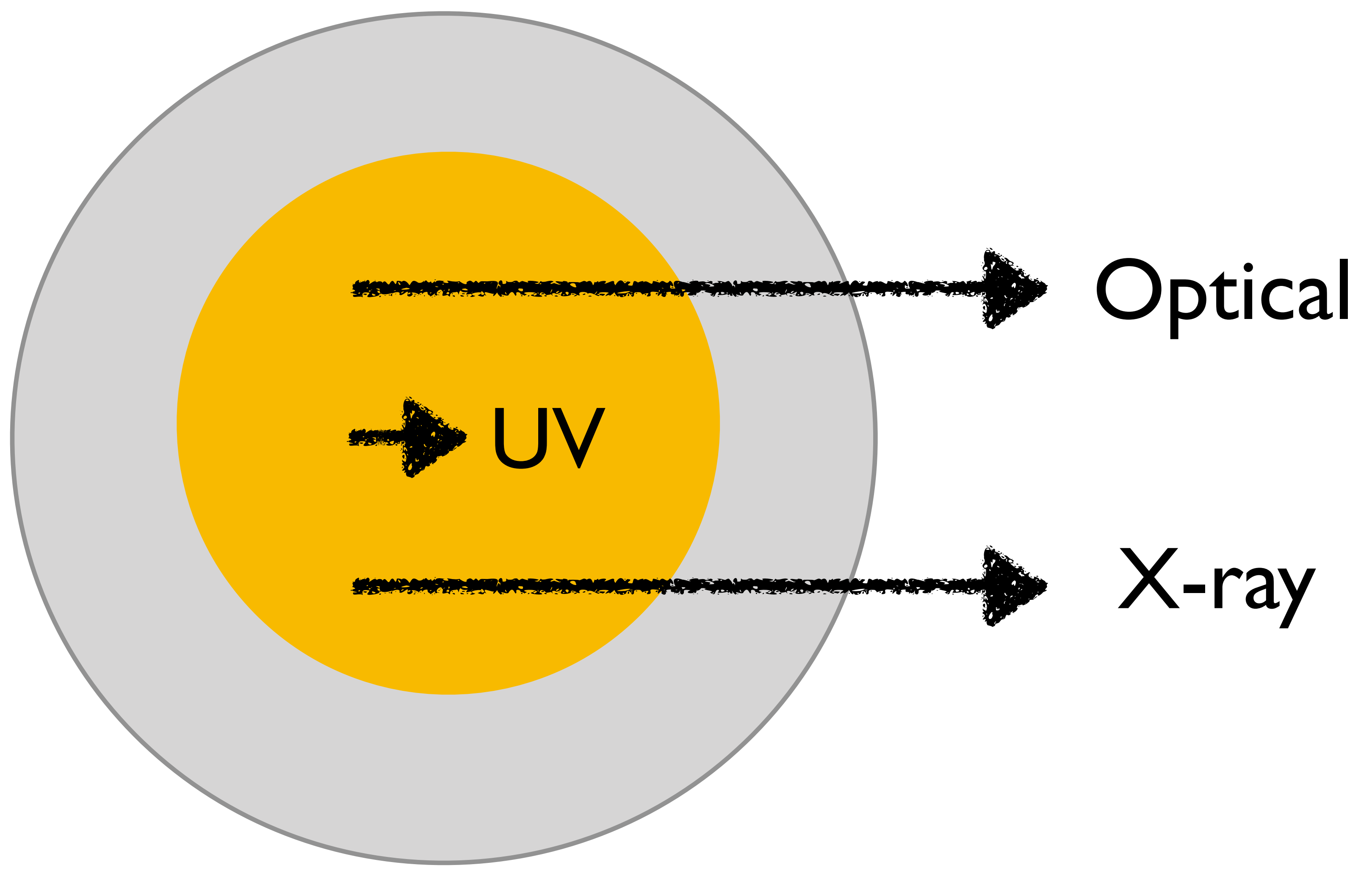


$$\chi \rightarrow 2\gamma$$

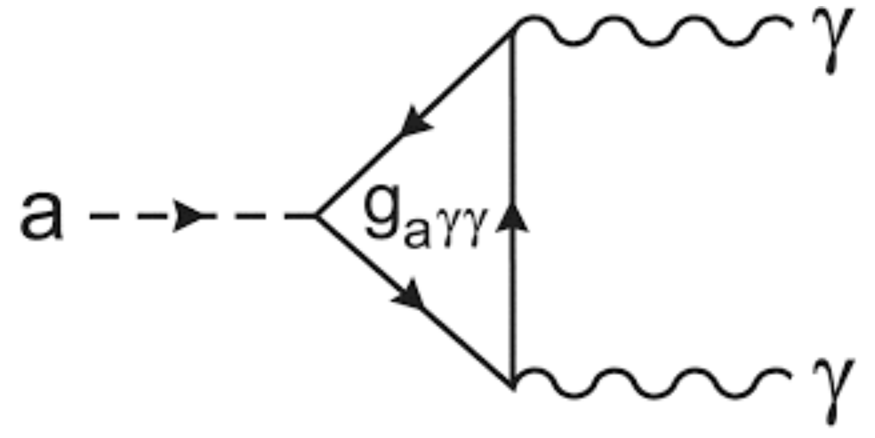


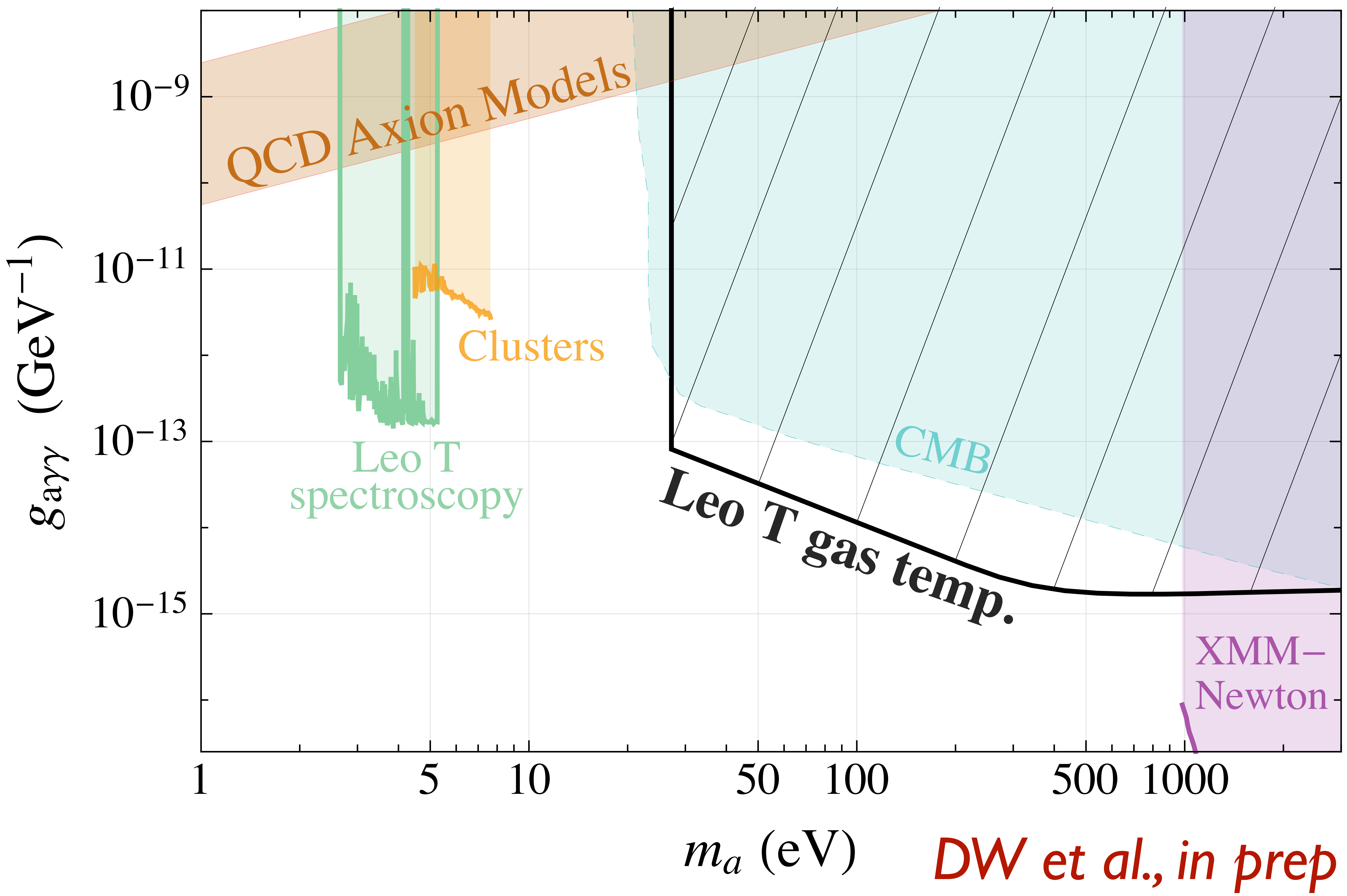
- UV radiation is efficiently absorbed by the gas

2. Limits on axion/ALP decays



- Our limits are complementary to optical & X-ray searches
- Significant pressure on proposed axion expl. for XENON1T anomaly if they form a fraction of DM

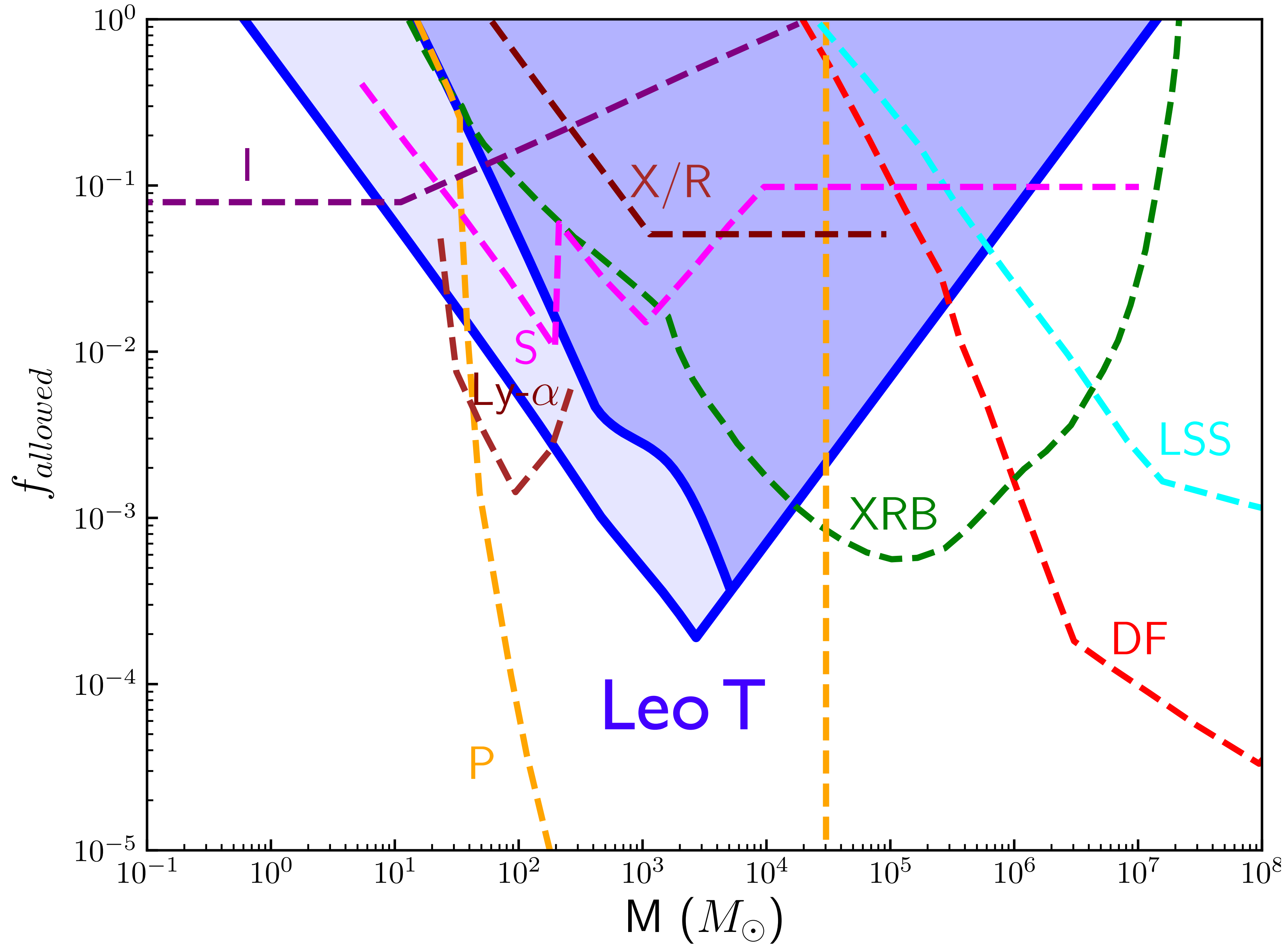




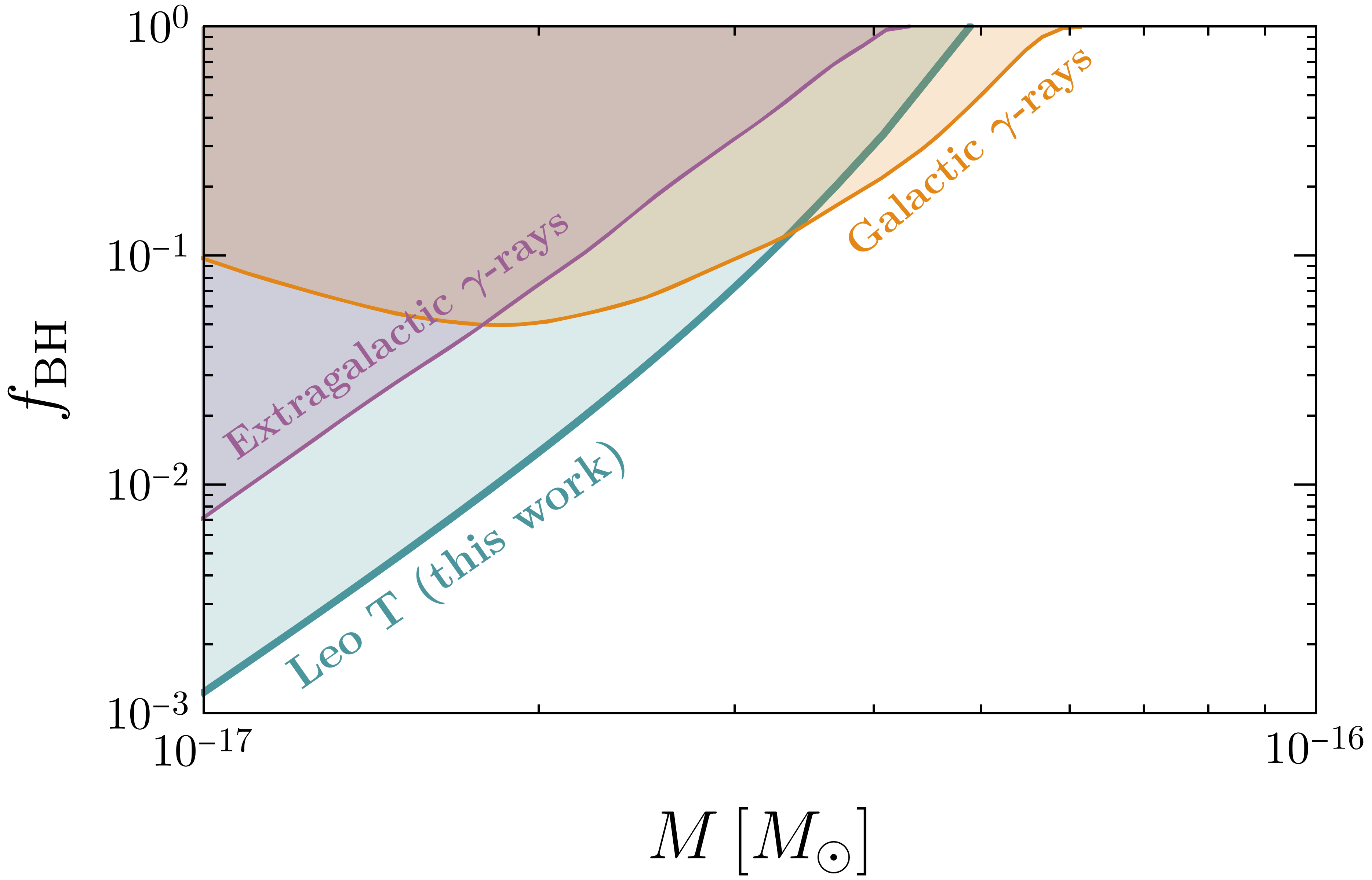
DW et al., in prep

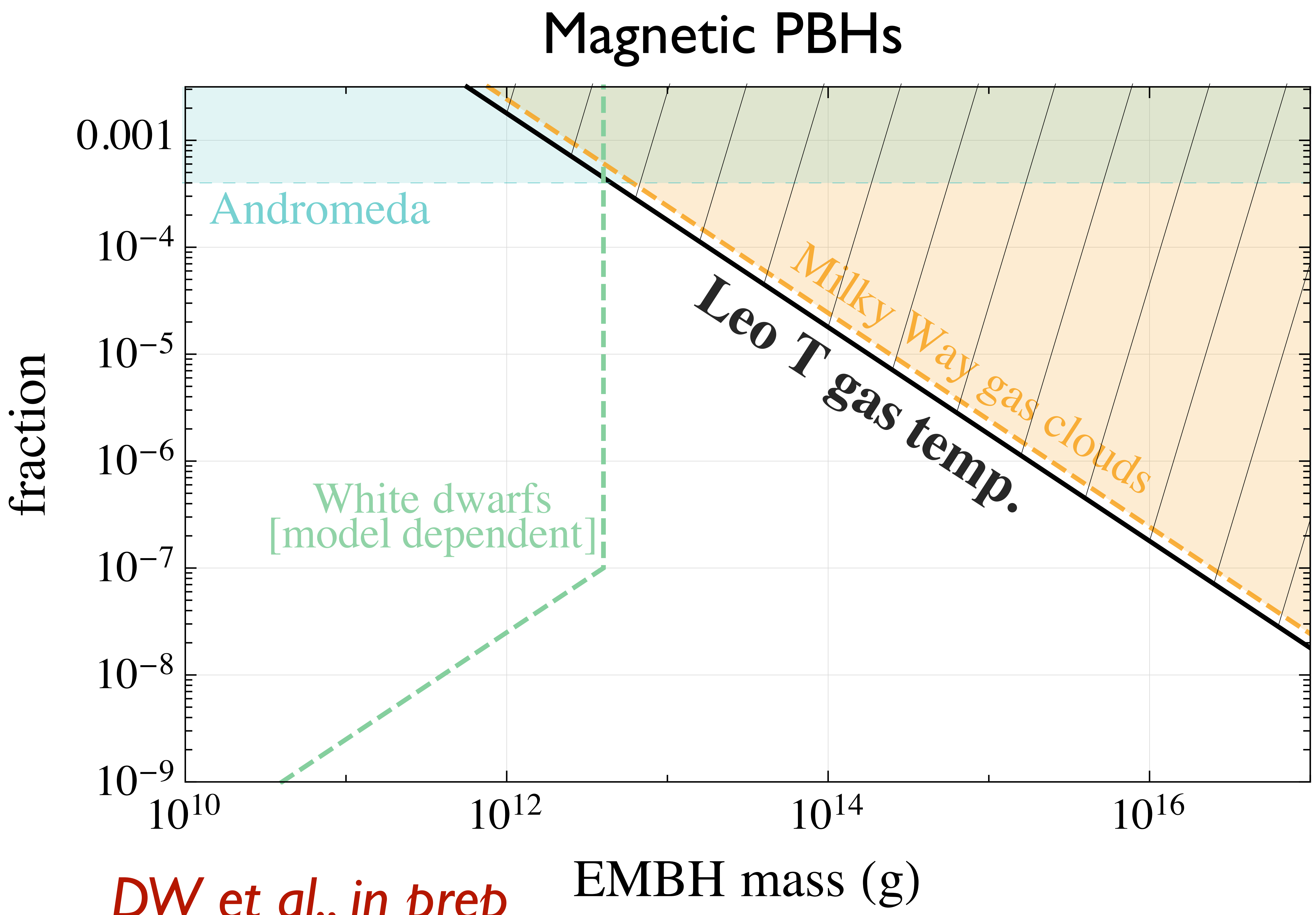
3. PBH (primordial black hole) limits from Leo T

Lu et al. 20



Kim 21, Laha et al. 21



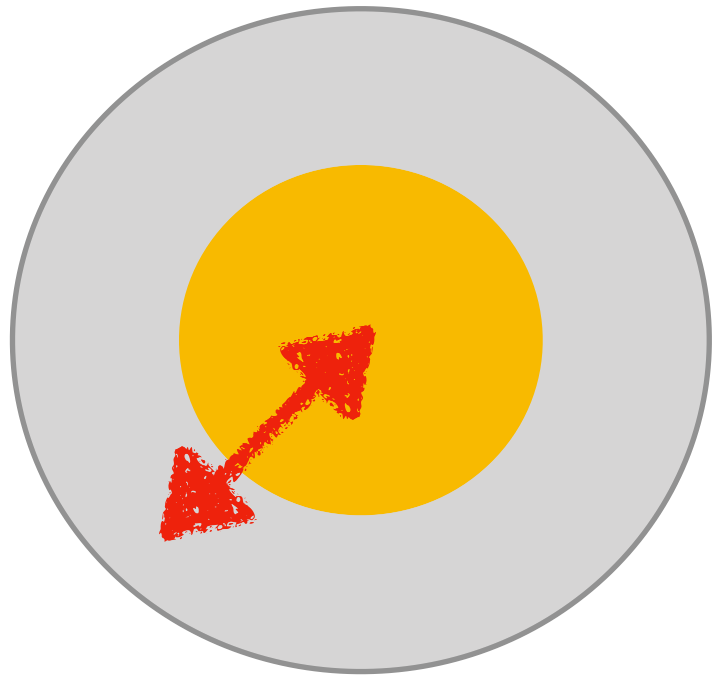


DW et al., in prep

Leo T is promising for constraining non-standard heating scenarios

- Simple pipeline for setting bounds

$$|\dot{E}| \lesssim 4 \times 10^{-30}\ \mathrm{erg/s}$$



$$n_{\rm HI} \simeq 0.1/\mathrm{cm}^3 \qquad n_{\rm DM} \simeq 2\,\mathrm{GeV/cm}^3$$
$$v_{\rm gas} \simeq v_{\rm DM} \simeq 7\ \mathrm{km/s}$$

- Suggestions for more candidates are welcome!

Recent surveys of gas-rich dwarfs

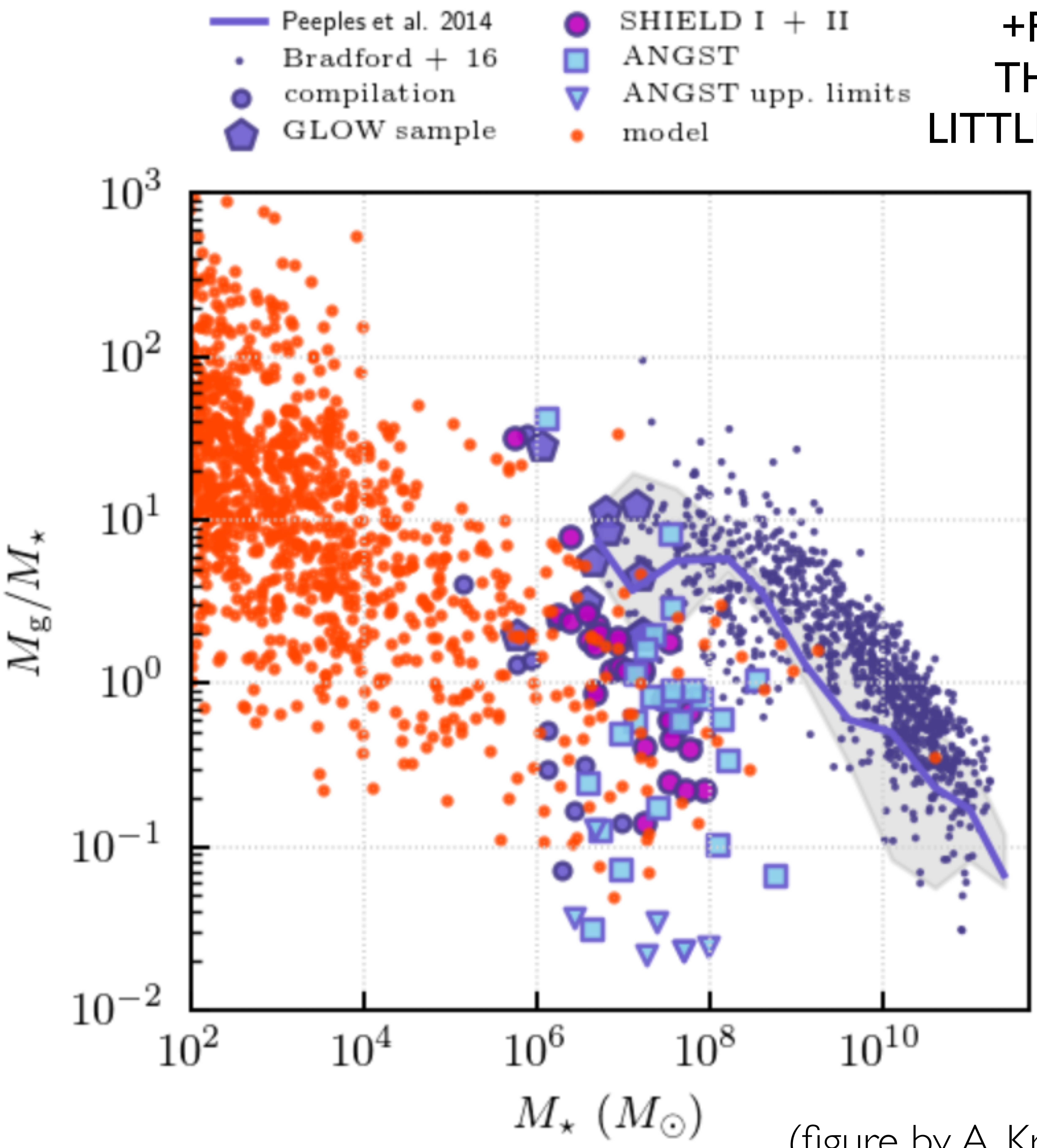
- Lot of recent interest (driven by galaxy formation studies)

  - Star formation in metal-poor ISM (relevant for formation of massive BHs seen in LIGO)

  - Baryonic content of low mass halos and reionization feedback

- Possible synergies with DM studies

+FIGGS
THINGS
LITTLE THINGS



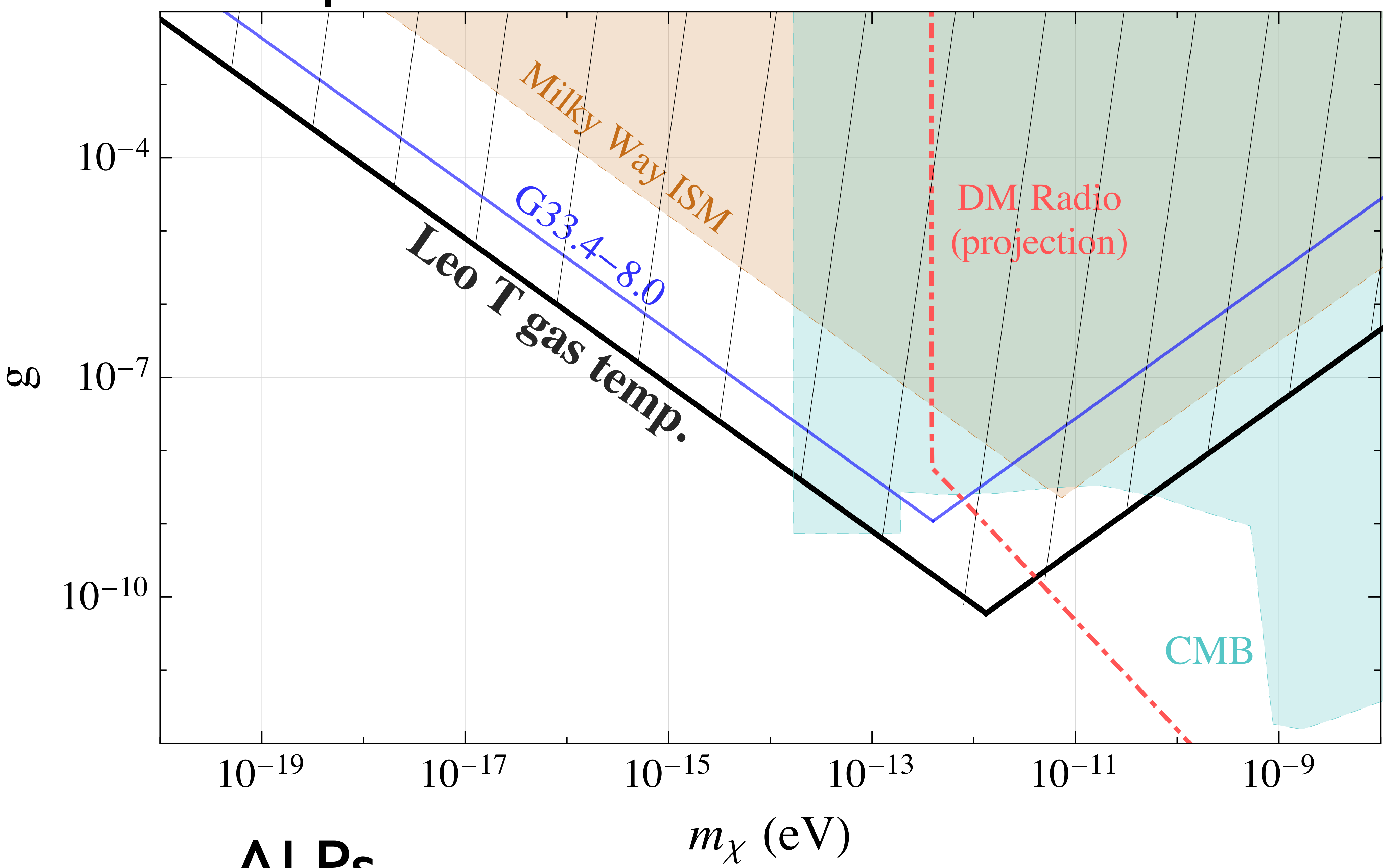
(figure by A. Kravtsov)

Summary

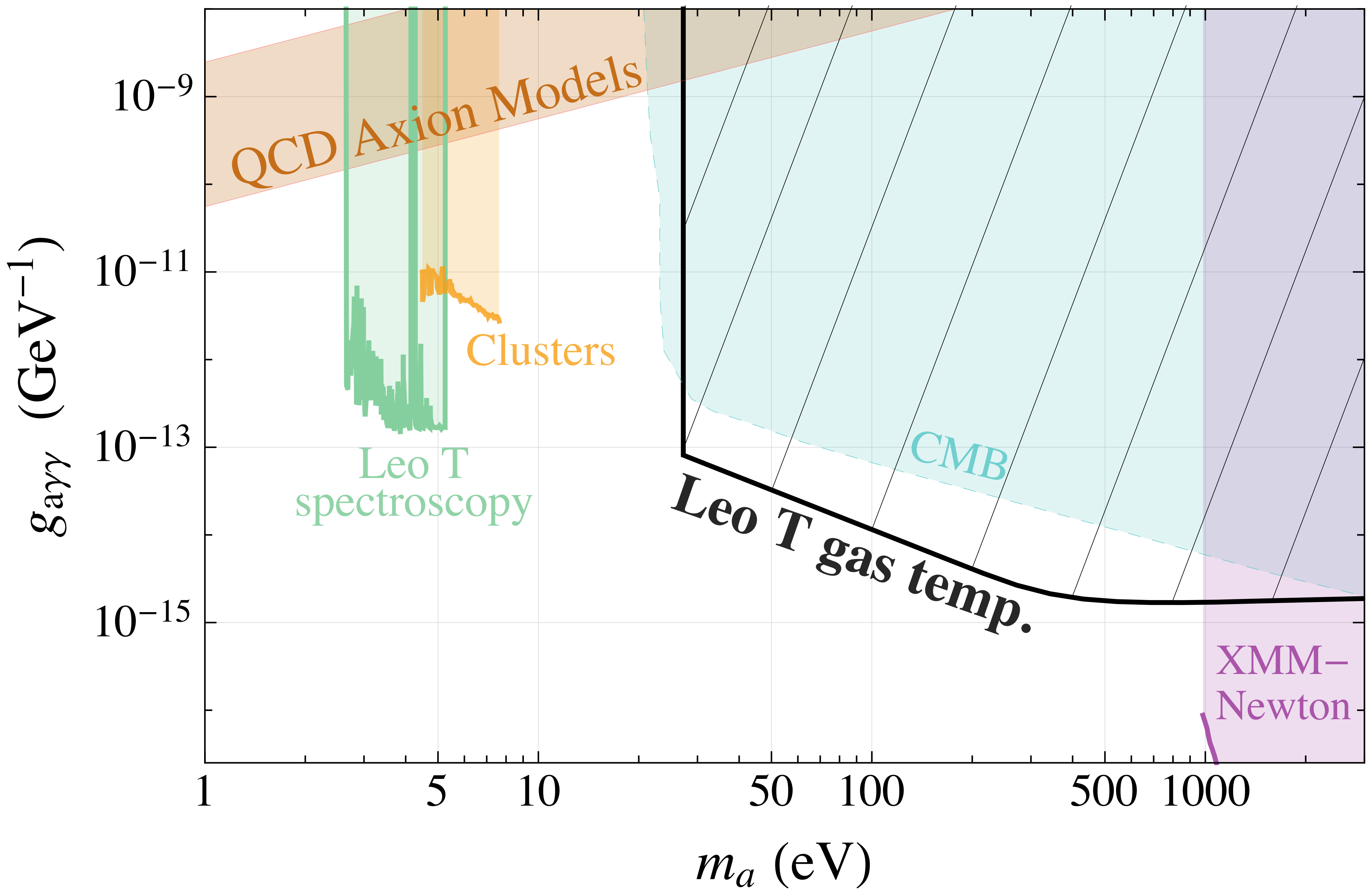
- Gas-rich dwarfs are very sensitive probes of non-standard DM-ordinary matter interactions

- Leo T gives strong constraints on
  - Hidden photon DM
  - Millicharged DM
  - Axion like particles
  - Primordial BHs
  - DM annihilations

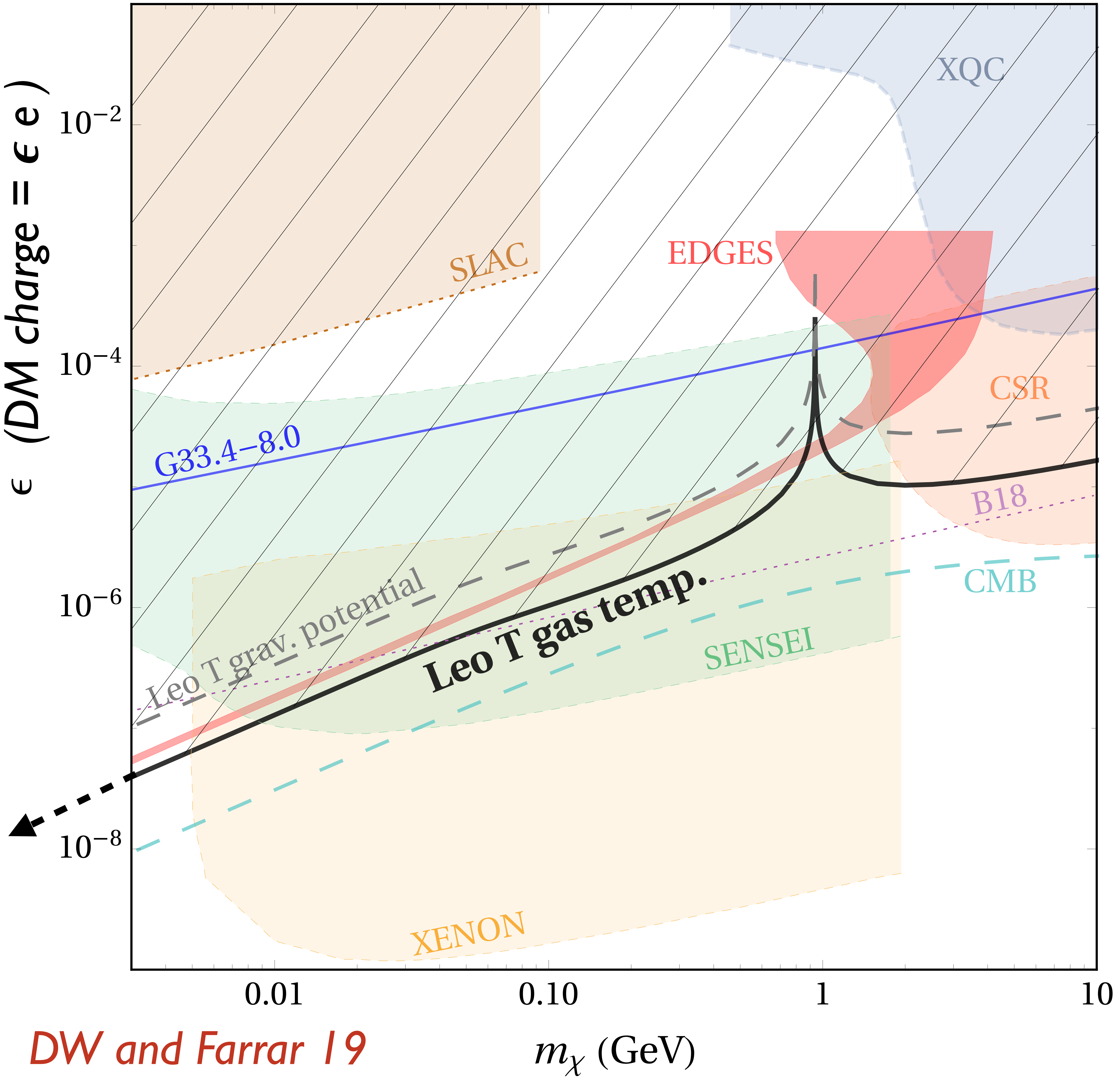
Dark photon DM



ALPs



4. Results for Millicharged DM



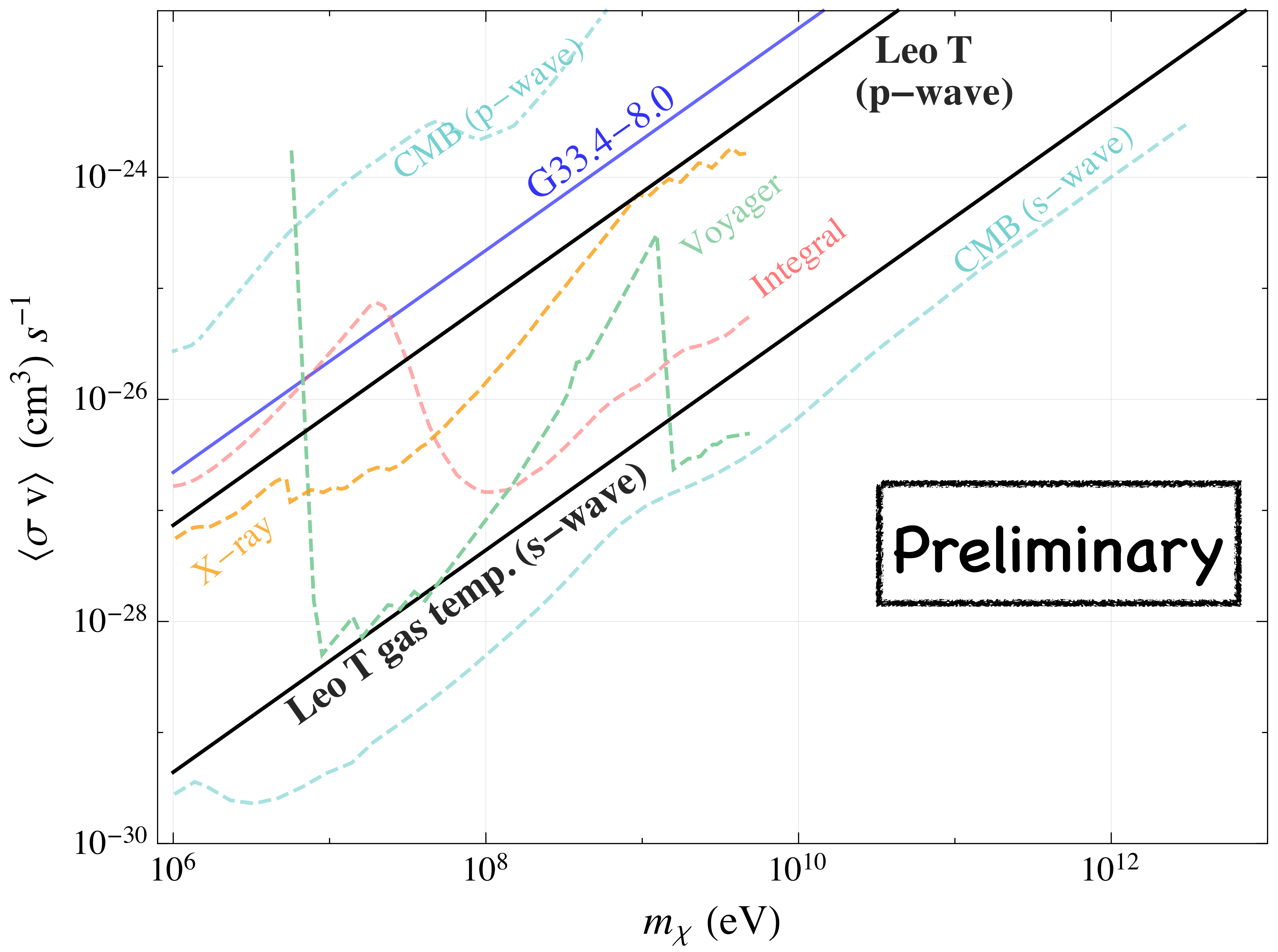
DW and Farrar 19

Valuable complement to:

1. *Early universe limits (CMB/BBN):*
   - Assumptions about cosmology

2. *Direct-detection limits:*
   - Uncertainities in vel. distribution and number density of DM at Earth
   - Uncertainities in charged DM distribution because of strong magnetic fields & supernovae in the Milky Way

5. DM annihilation (s-wave & p-wave)



DW et al., in prep

4. Constraining Millicharged DM

Possible interaction between baryons and dark-matter particles revealed by the first stars

Rennan Barkana[1]

nature
International journal of science

- Barkana 18 hypothesized DM interactions of the form $\sigma_{\mathrm{Coulomb}} \propto v_{\mathrm{rel}}^{-4}$
- Lowest DM-gas v_{rel} occurs at cosmic dawn ~ 0.3 km/s

4. Constraining Millicharged DM

Possible interaction between baryons and dark-matter particles revealed by the first stars

Rennan Barkana[1]

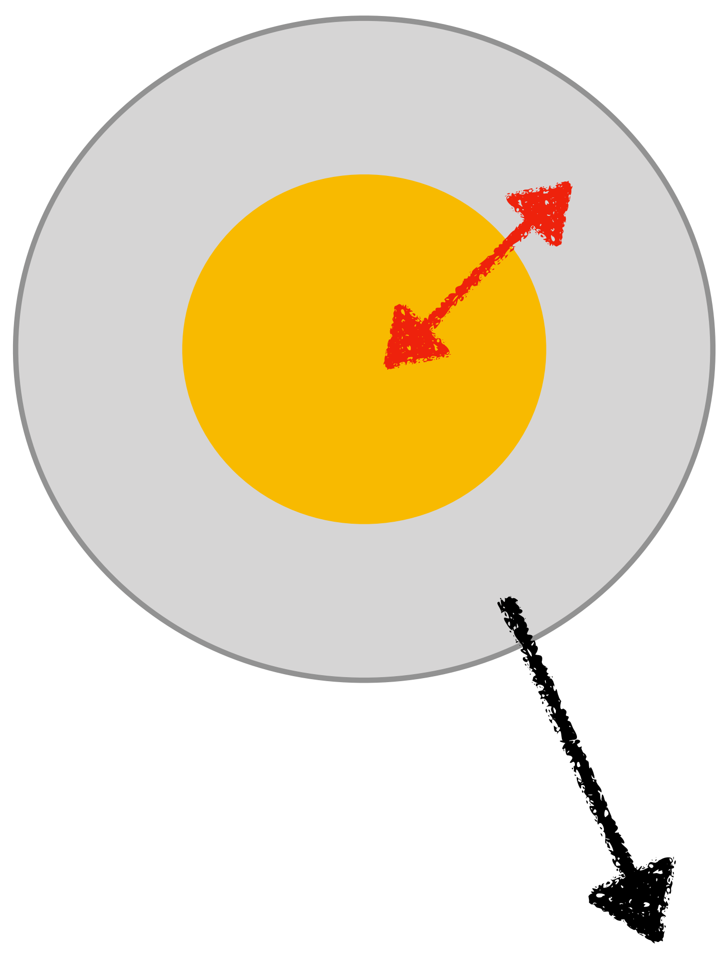
nature
International journal of science

- Barkana 18 hypothesized DM interactions of the form $\sigma_{\rm Coulomb} \propto v_{\rm rel}^{-4}$
- Lowest DM-gas $v_{\rm rel}$ occurs at cosmic dawn ~ 0.3 km/s

- High $v_{\rm rel}$ in Milky Way ~ 300 km/s
  ($\sigma \propto v_{\rm rel}^{-4}$ evades traditional astrophysical constraints)

- Dwarf galaxies can constrain such interactions ($v_{\rm rel}$ ~ O(10 km/s))

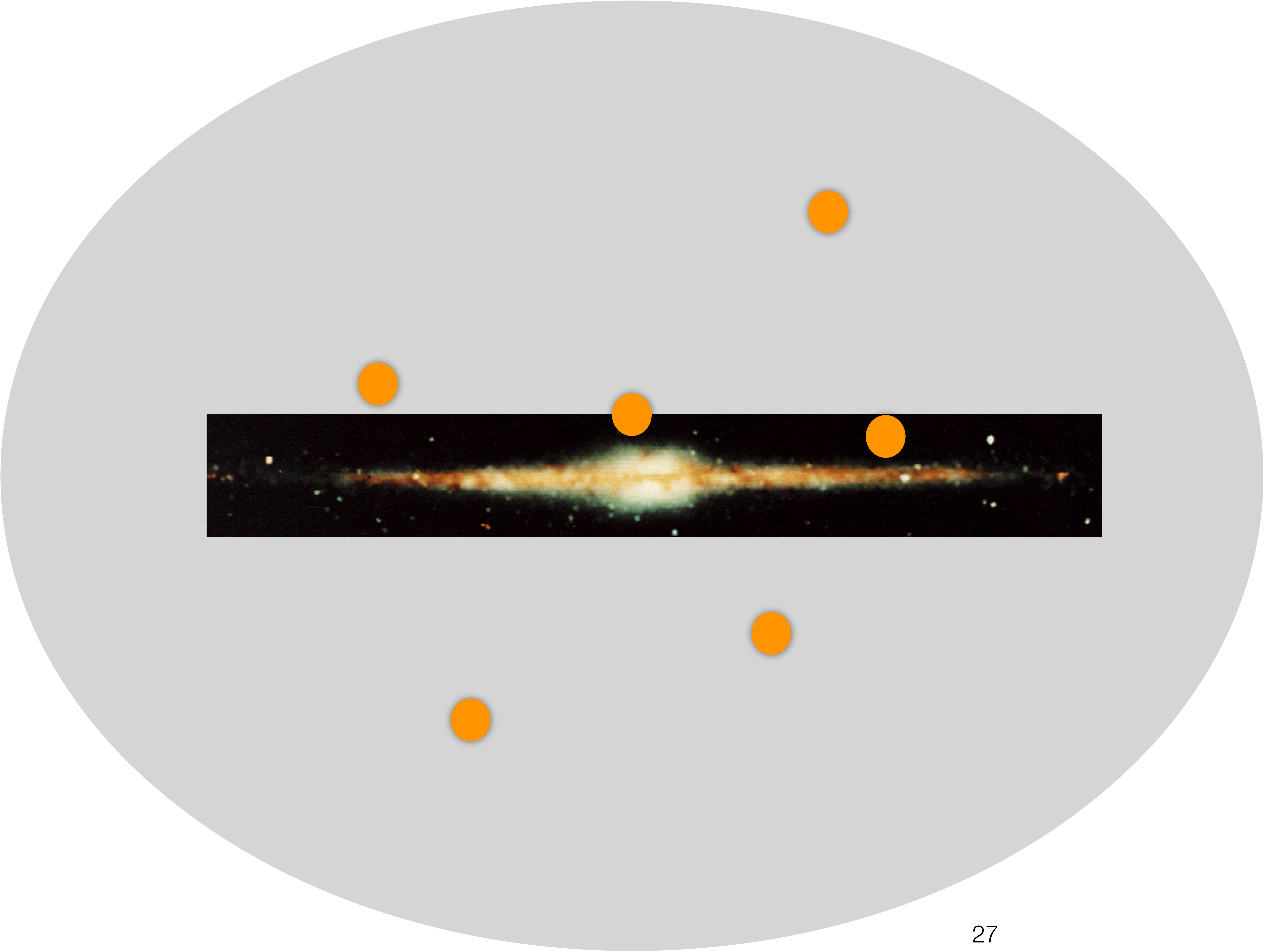
Caution: limits on fractional component of DM



1% millicharged DM escapes

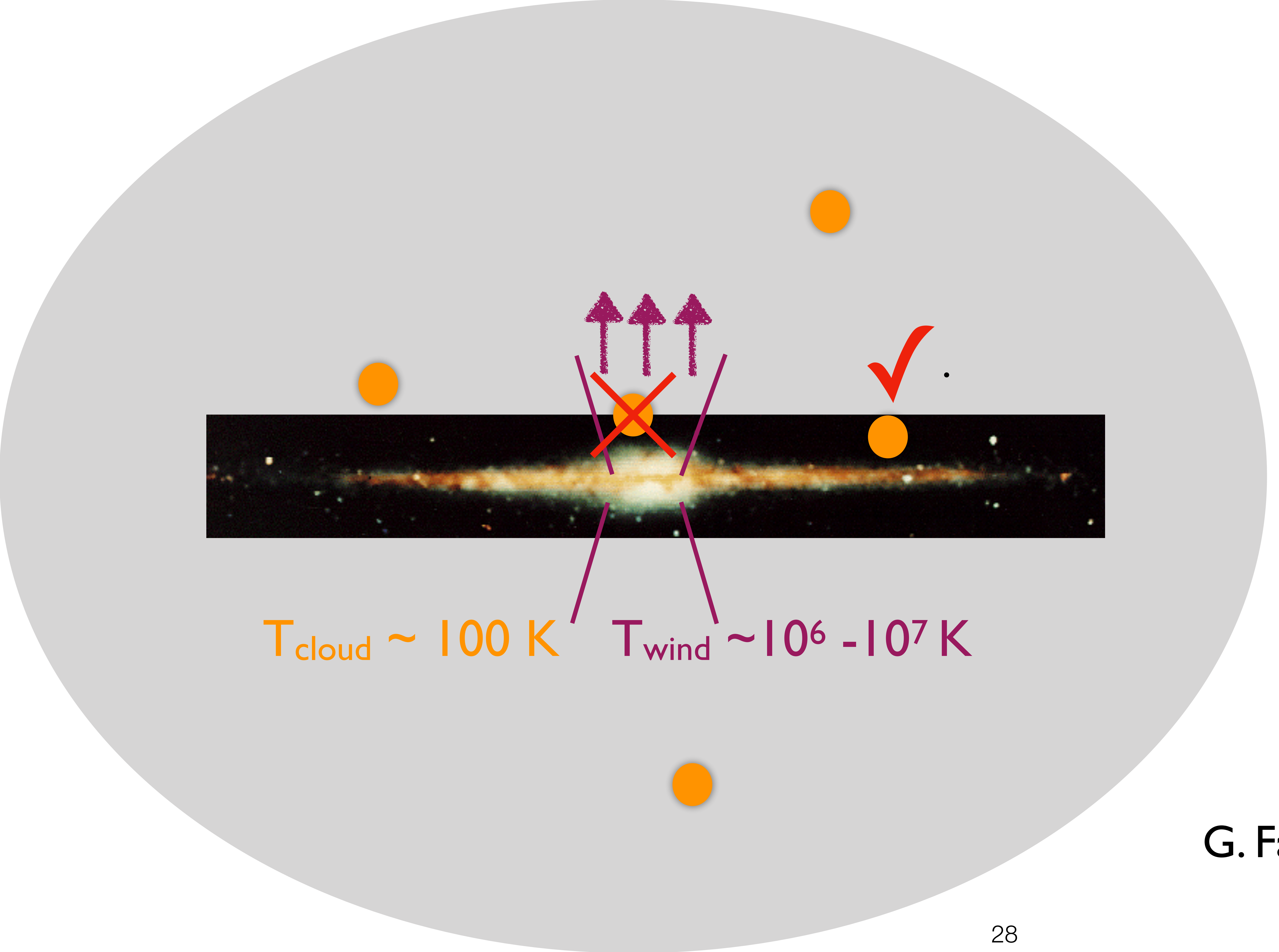
➡ no observable change

Alternate systems for constraining DM-SM interactions: Milky Way gas clouds

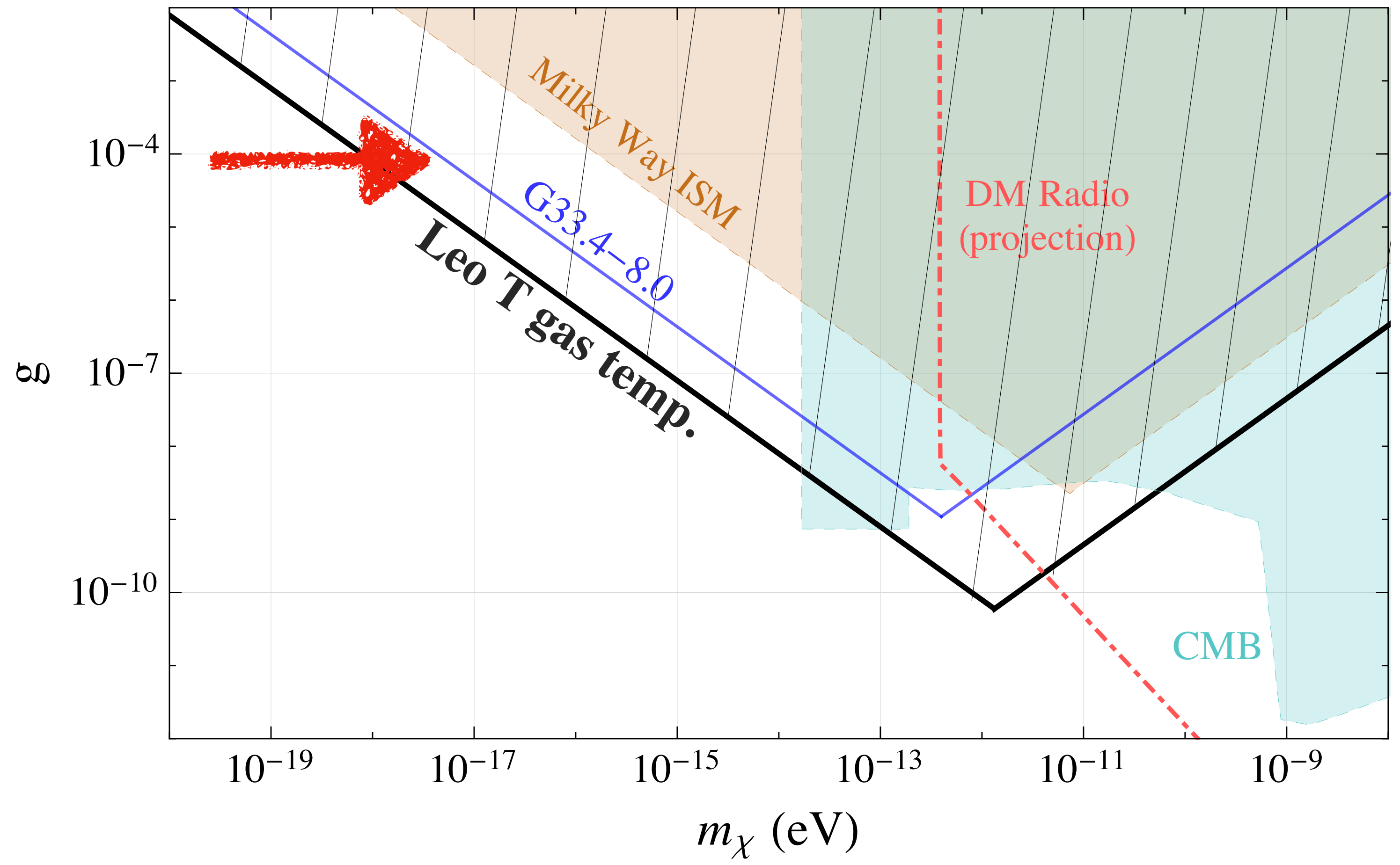


Chivukula et al. 1990
Dubovsky & Hernandez 2015
Bhoonah et al. 2018a, b
Bhoonah et al. 2020

Alternate systems for constraining DM-SM interactions: Milky Way gas clouds



Chivukula et al. 1990
Dubovsky & Hernandez 2015
Bhoonah et al. 2018a, b
Bhoonah et al. 2020



G. Farrar,.., DW et al. , 2019