Galactic Gas Clouds as Dark Matter Detectors

Pandemic Double Feature

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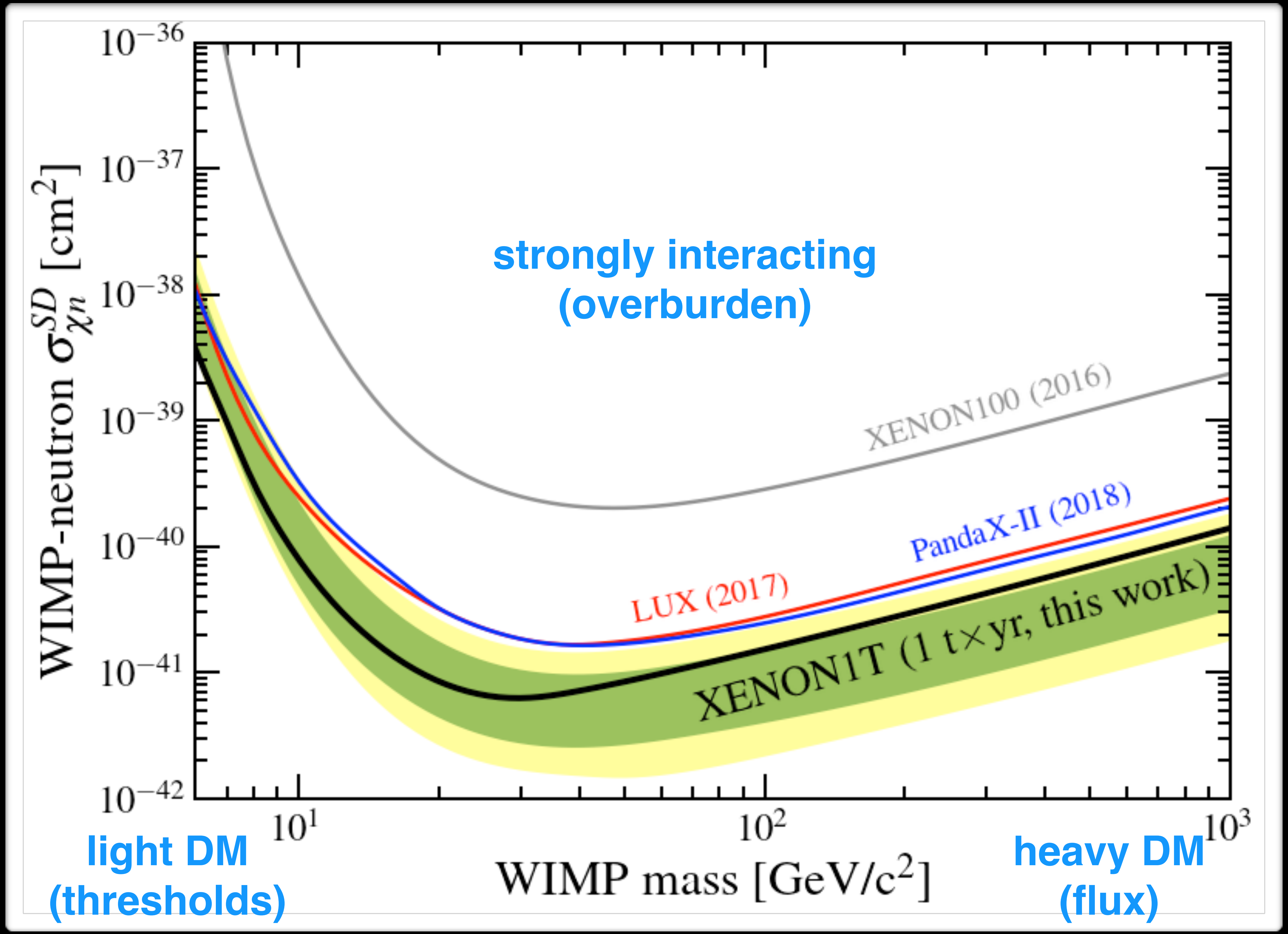
MI and Queen's University are situated in the traditional territory of the of the Anishinaabe and Haudenosaunee First Nations

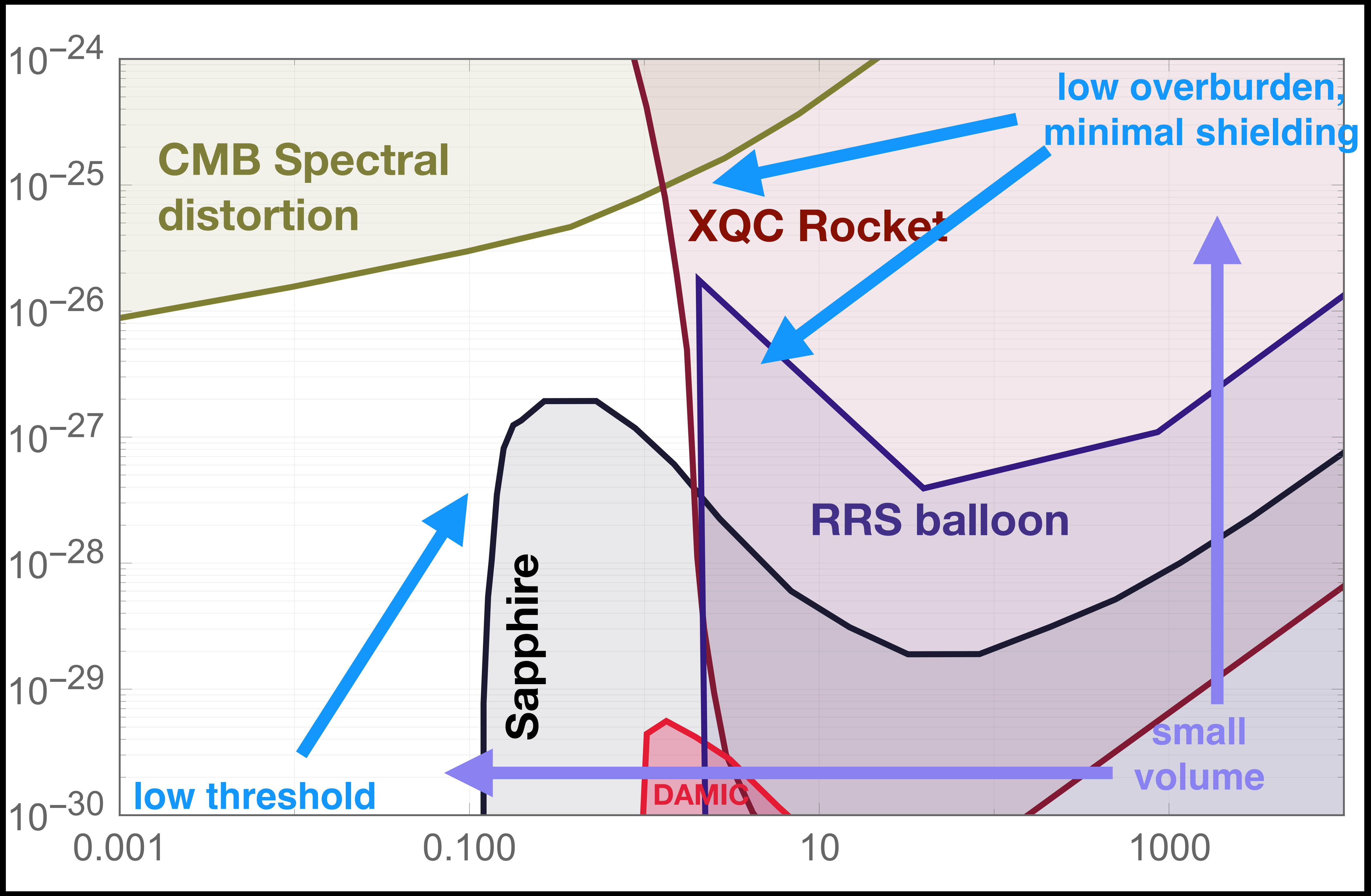
8th December 2020

references:
Arxiv:1806.06857
Arxiv:1812.10919
Arxiv:2010.07240

Motivation



Xenon 1T 2018



DM Constraints from the ISM

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Bounds on Halo-Particle Interactions from Interstellar Calorimetry

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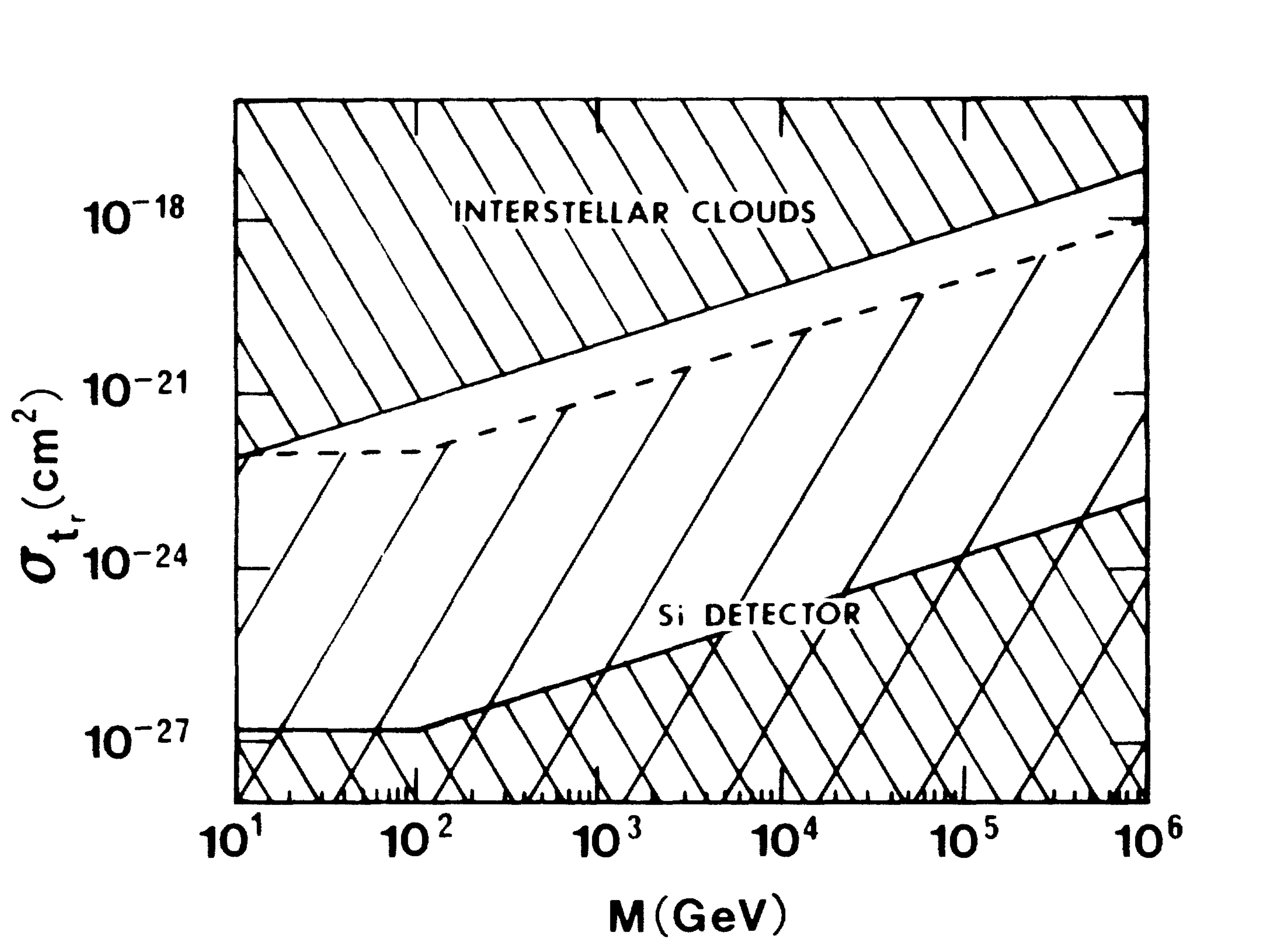
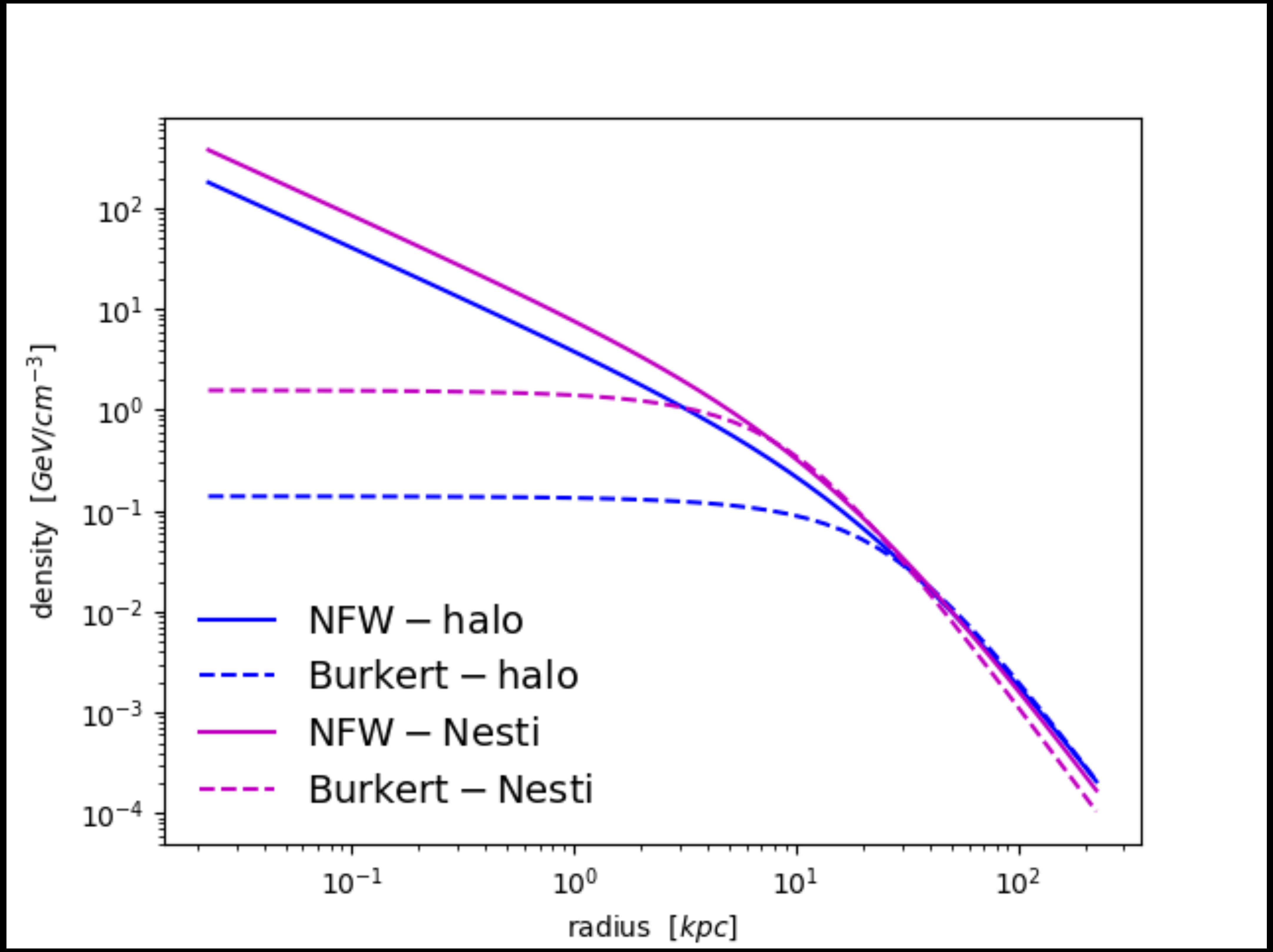
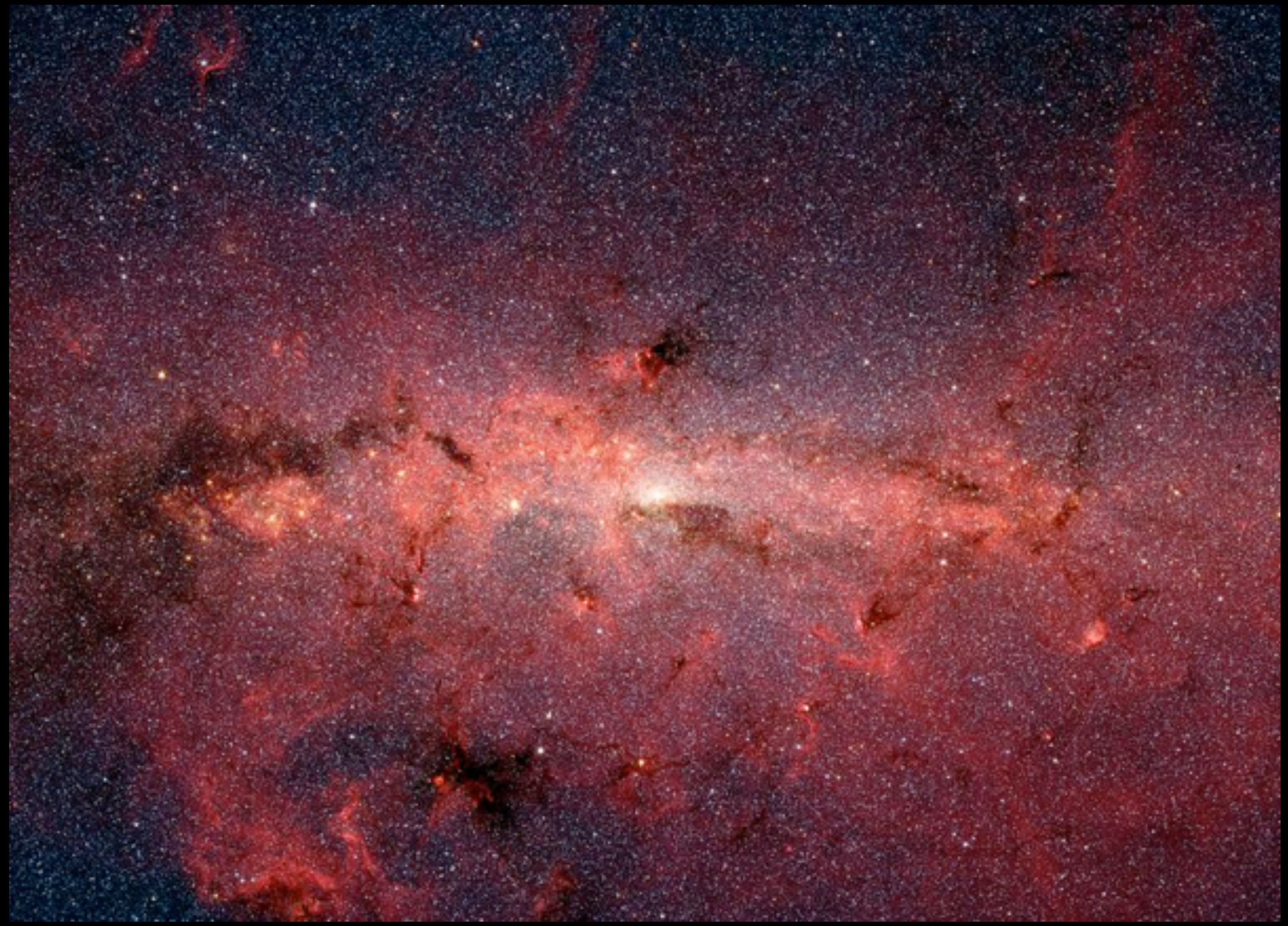
(Received 20 October 1989)

- Assume thermal equilibrium
- Halo DM at greater temperature than gas
- T~30-80 , 10 -200 cm^-3
- Cooling via de-excitation of C*+

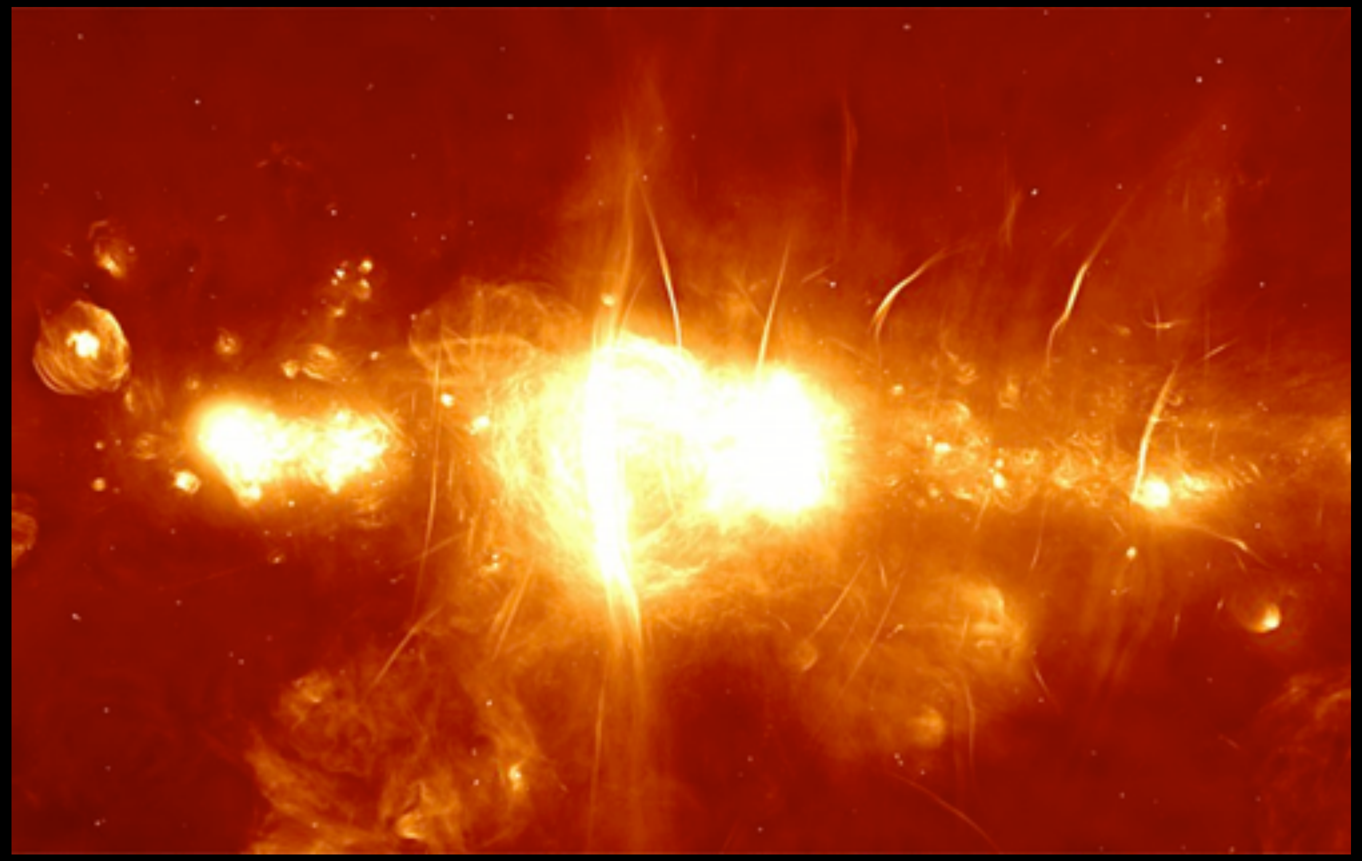


The Galactic Center and ISM



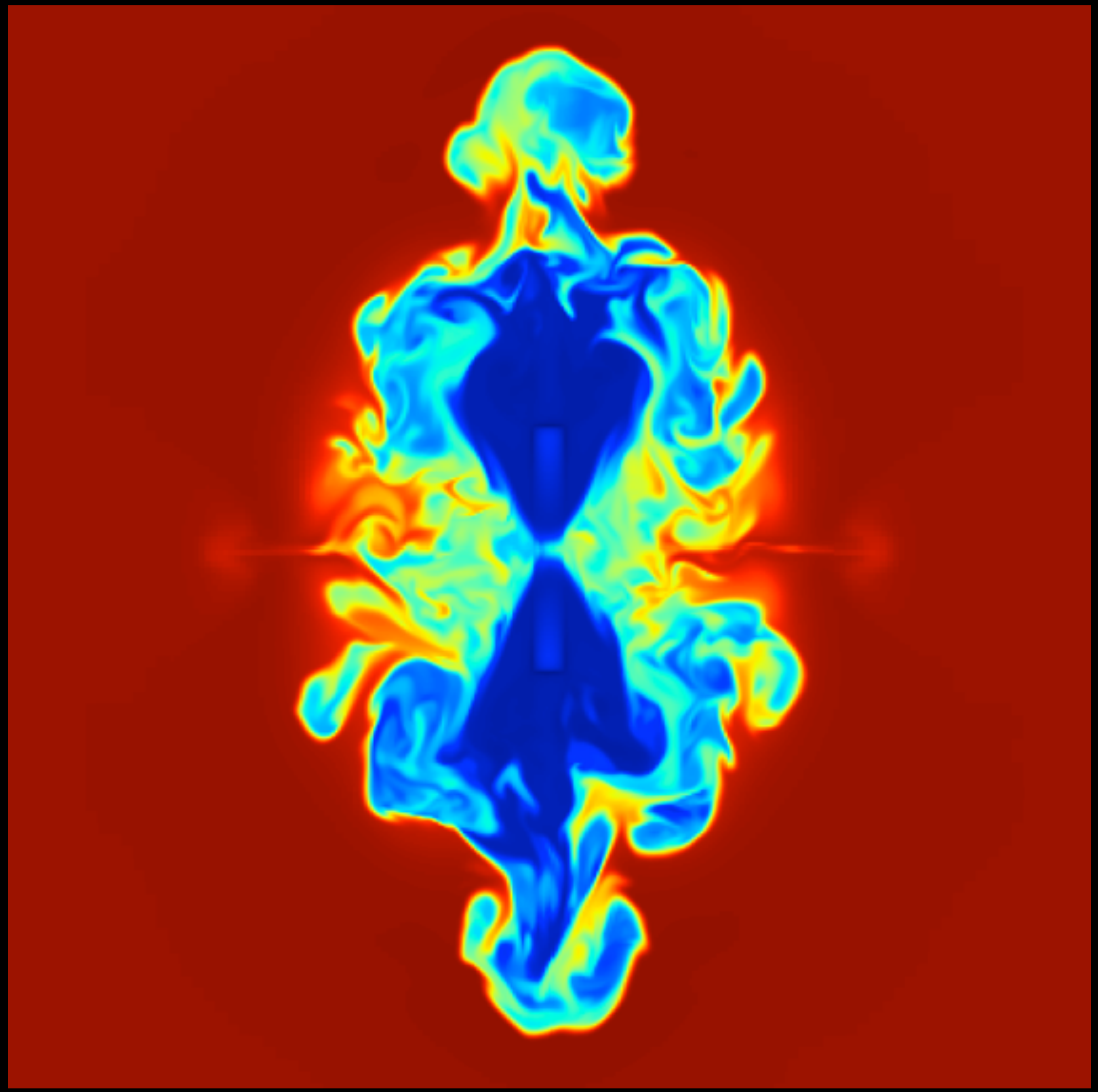


Spitzer/NASA



MeerKAT

The Galactic Center and ISM



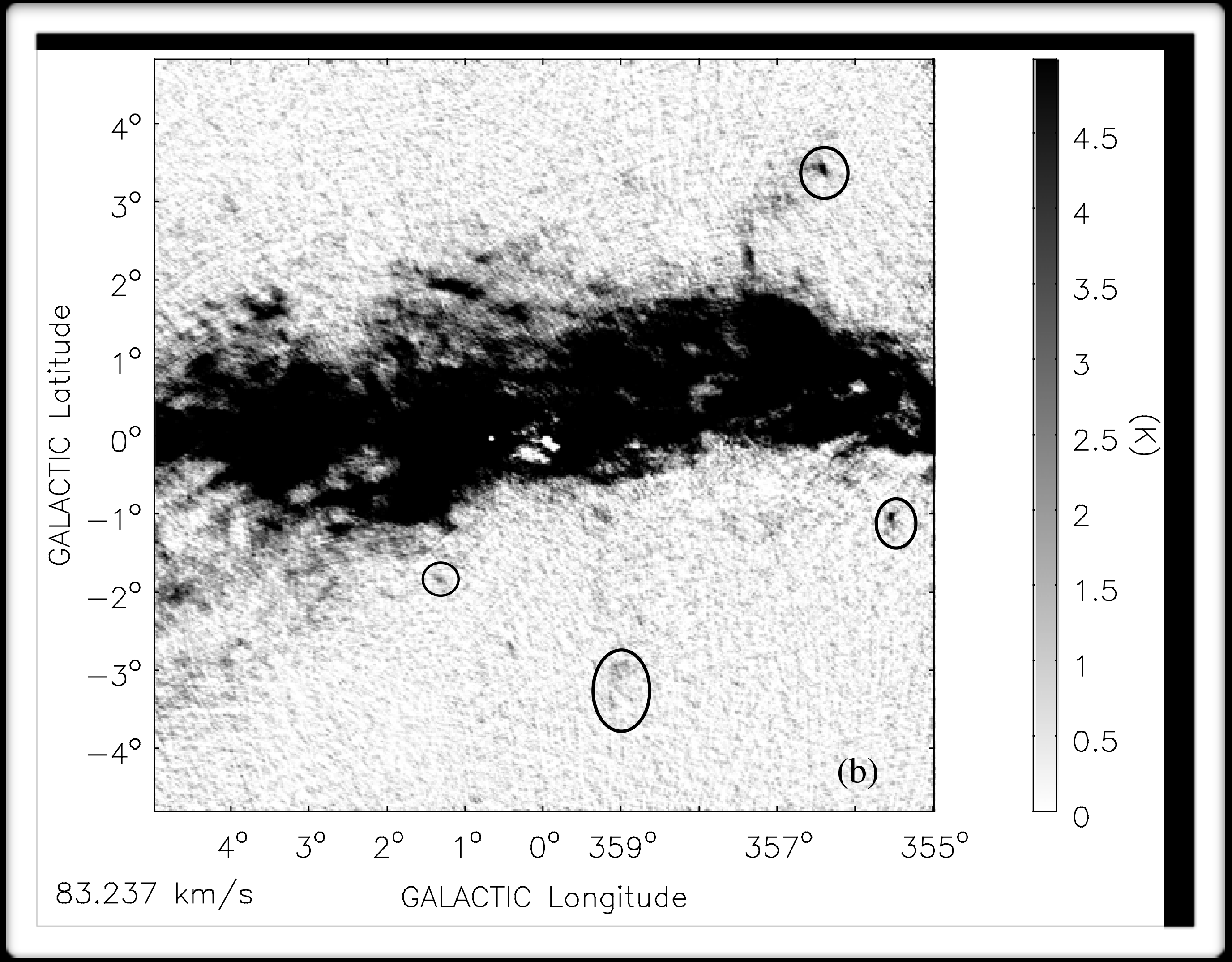
Simulation of an AGN jet in a galaxy cluster
Ricker et al.

Name	State of H	Typical n [cm^-3]	T(K)	Heating	Cooling
Molecular Clouds	H2	>1000	10-80	cosmic rays	CO
HI Clouds	H	~30	100	PE dust	CII
Warm HI	H	0.1	8000	PE dust	CII
Warm HII	H+	0.03	10^4	H photoion	OII, SII
HII regions	H+	>100	10^4	H photoion	OIII
Hot ISM	H+	10^-3	10^6.5	shocks	X-rays

ARAA 1990 Mathis

Background

HI Survey - Gas Cloud Souffle

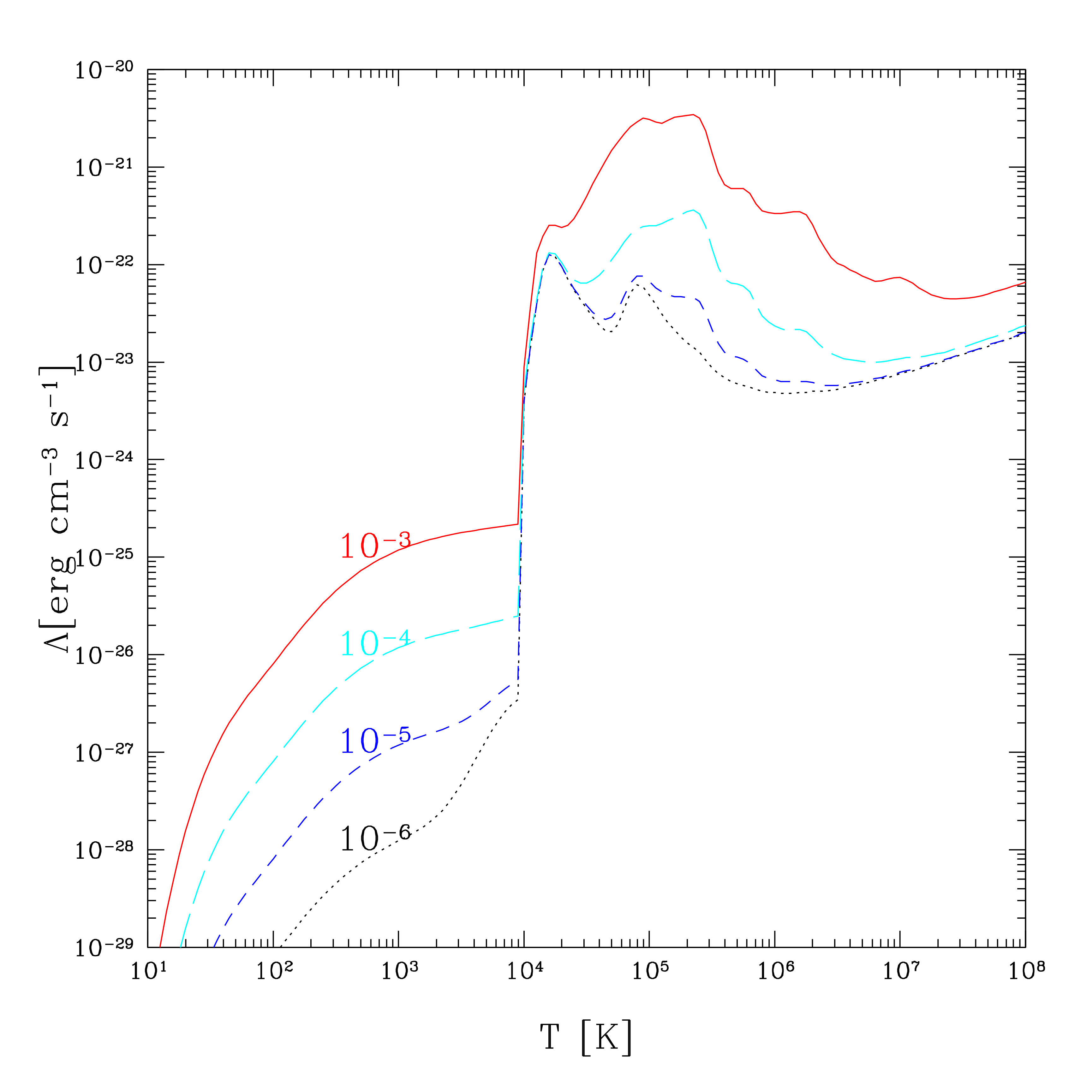


McClure-Griffiths 2013

	Mass [M_sol]	r [pc]	n [cm^_3]	T [K]	v [km/s]
G1.4-1.8+87	17	8.2	0.3	22*	87.2
G357.8-4.7-55	237	12.9	0.4	137	-54
G1.5+2.9+105	311	12.3	1	198	105.7

Heating and Cooling

- photoelectric heating by grains and ionisation
- UV background
- X-rays
- Cosmic Rays
- magneto/hydrodynamic heating
- interstellar shocks

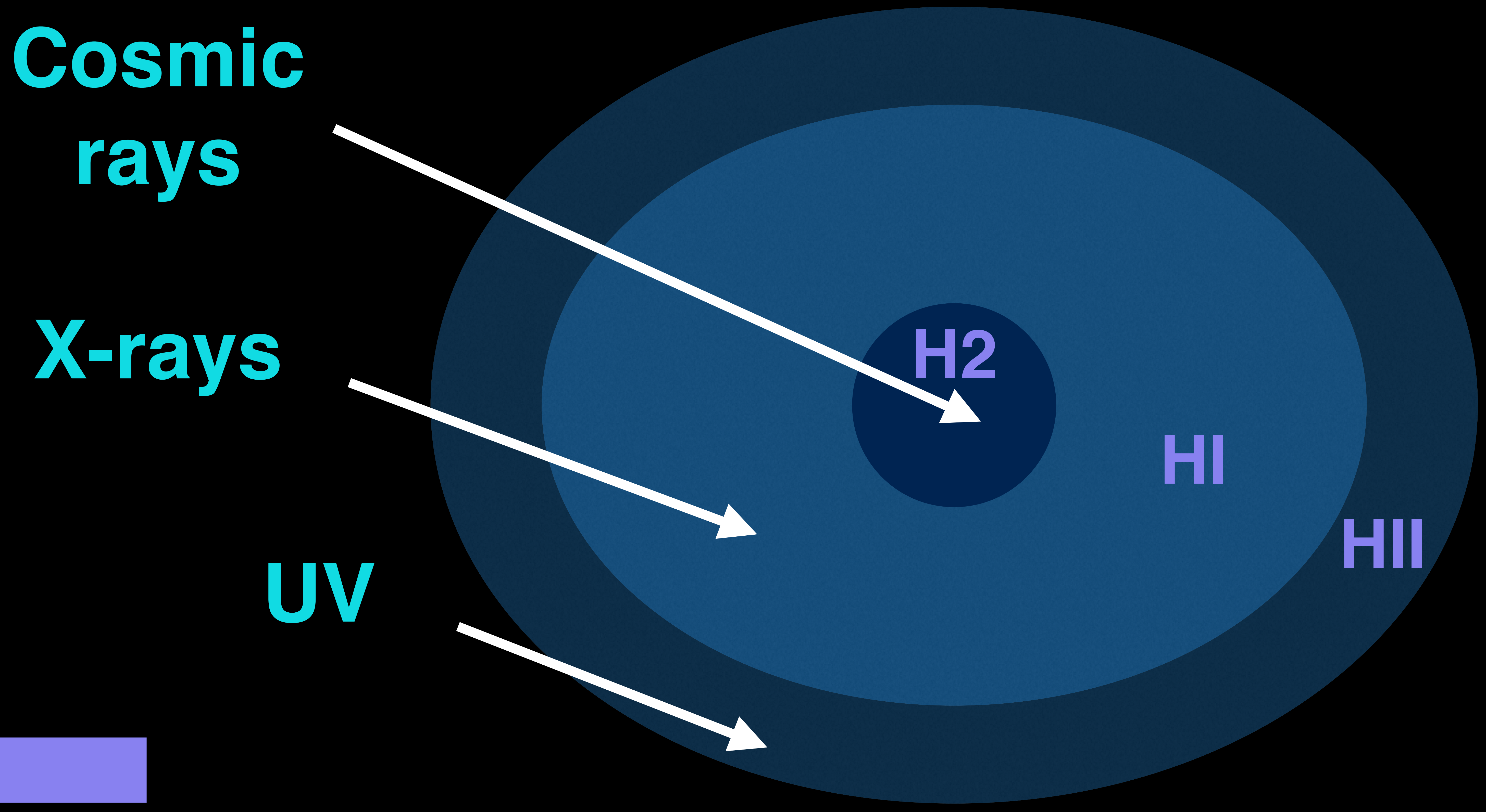


Maio et al 207

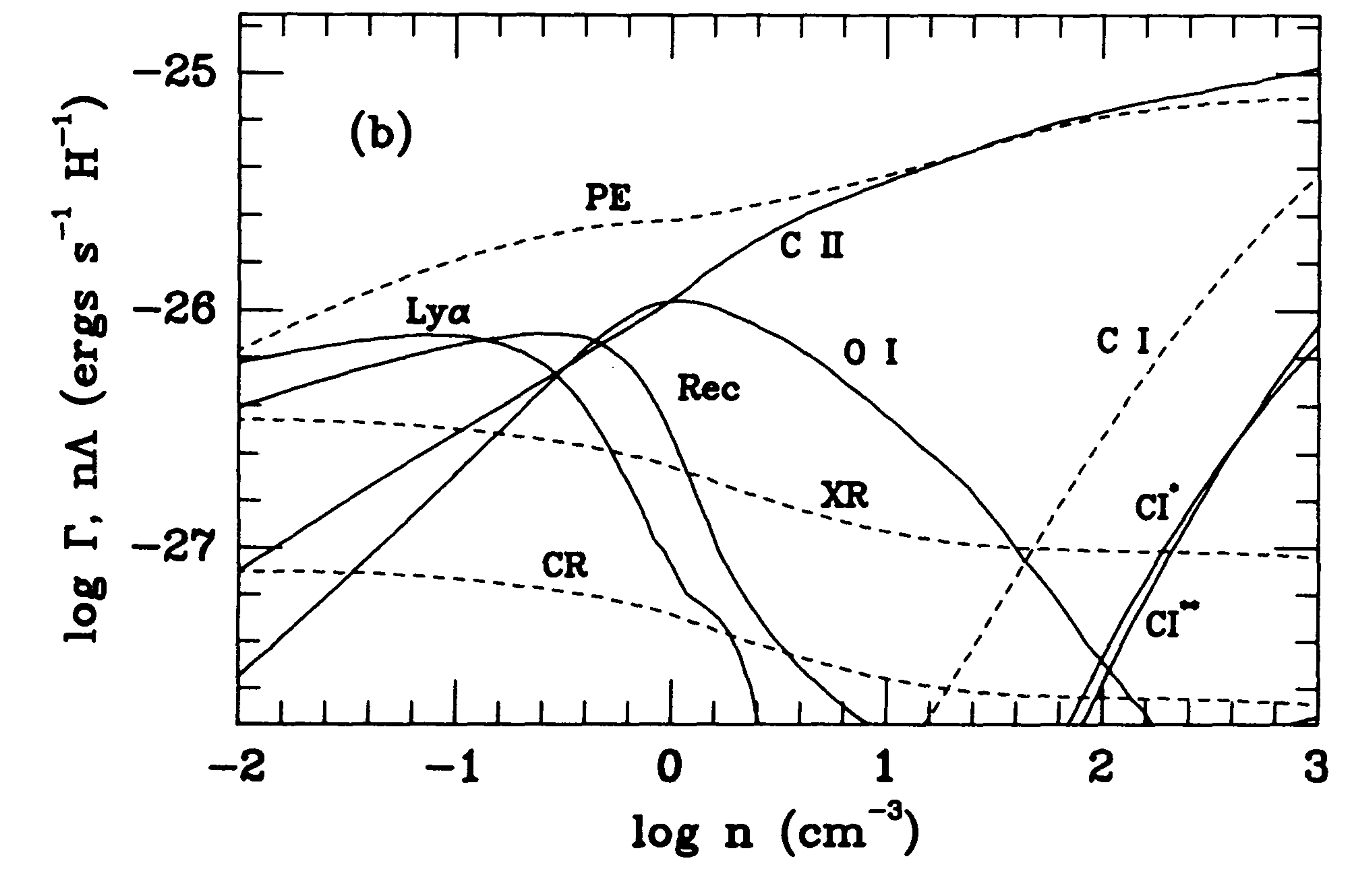
Cold, Neutral Hydrogen (and Helium)

Reactions	References for the rate coefficients
$H + e^- \rightarrow H^+ + 2e^-$	A97 / Y06
$H^+ + e^- \rightarrow H + \gamma$	A97 / Y06
$He + e^- \rightarrow He^+ + 2e^-$	A97 / Y06
$He^+ + e^- \rightarrow He + \gamma$	A97 / Y06
$He^+ + e^- \rightarrow He^{++} + 2e^-$	A97 / Y06
$He^{++} + e^- \rightarrow He^+ + \gamma$	A97 / Y06
$H + e^- \rightarrow H^- + \gamma$	A97 / Y06
$H^- + H \rightarrow H_2 + e^-$	A97 / Y06
$H + H^+ \rightarrow H_2{}^+ + \gamma$	A97 / Y06
$H_2{}^+ + H \rightarrow H_2 + H^+$	A97 / Y06
$H_2 + H \rightarrow 3H$	A97
$H_2 + H^+ \rightarrow H_2{}^+ + H$	S04 / Y06
$H_2 + e^- \rightarrow 2H + e^-$	ST99 / GB03 / Y06
$H^- + e^- \rightarrow H + 2e^-$	A97 / Y06
$H^- + H \rightarrow 2H + e^-$	A97 / Y06
$H^- + H^+ \rightarrow 2H$	P71 / GP98 / Y06
$H^- + H^+ \rightarrow H_2{}^+ + e^-$	SK87 / Y06
$H_2{}^+ + e^- \rightarrow 2H$	GP98 / Y06
$H_2{}^+ + H^- \rightarrow H + H_2$	A97 / Y06
$D + H_2 \rightarrow HD + H$	WS02
$D^+ + H_2 \rightarrow HD + H^+$	WS02
$HD + H \rightarrow D + H_2$	SLP98
$HD + H^+ \rightarrow D^+ + H_2$	SLP98
$H^+ + D \rightarrow H + D^+$	S02
$H + D^+ \rightarrow H^+ + D$	S02
$He + H^+ \rightarrow HeH^+ + \gamma$	RD82, GP98
$HeH^+ + H \rightarrow He + H_2^+$	KAH79, GP98
$HeH^+ + \gamma \rightarrow He + H^+$	RD82, GP98

$$\frac{\partial n_i}{\partial t} = \sum_{j \neq i} n_j R_{ji} + \text{source} - n_i\left(\sum_{ji} R_{ij} + \text{sink}\right) = 0\,[\text{cm}^{-3}\text{s}^{-1}],$$



Metallicity and the Chemical Network

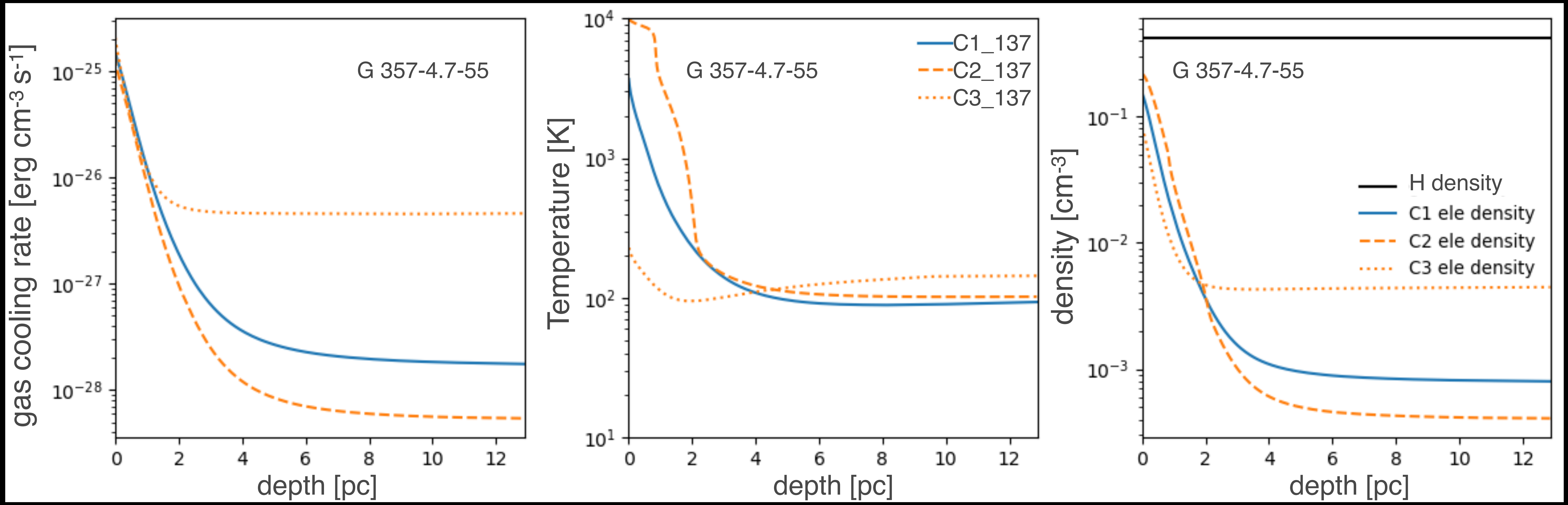


Wolfire et al 1995

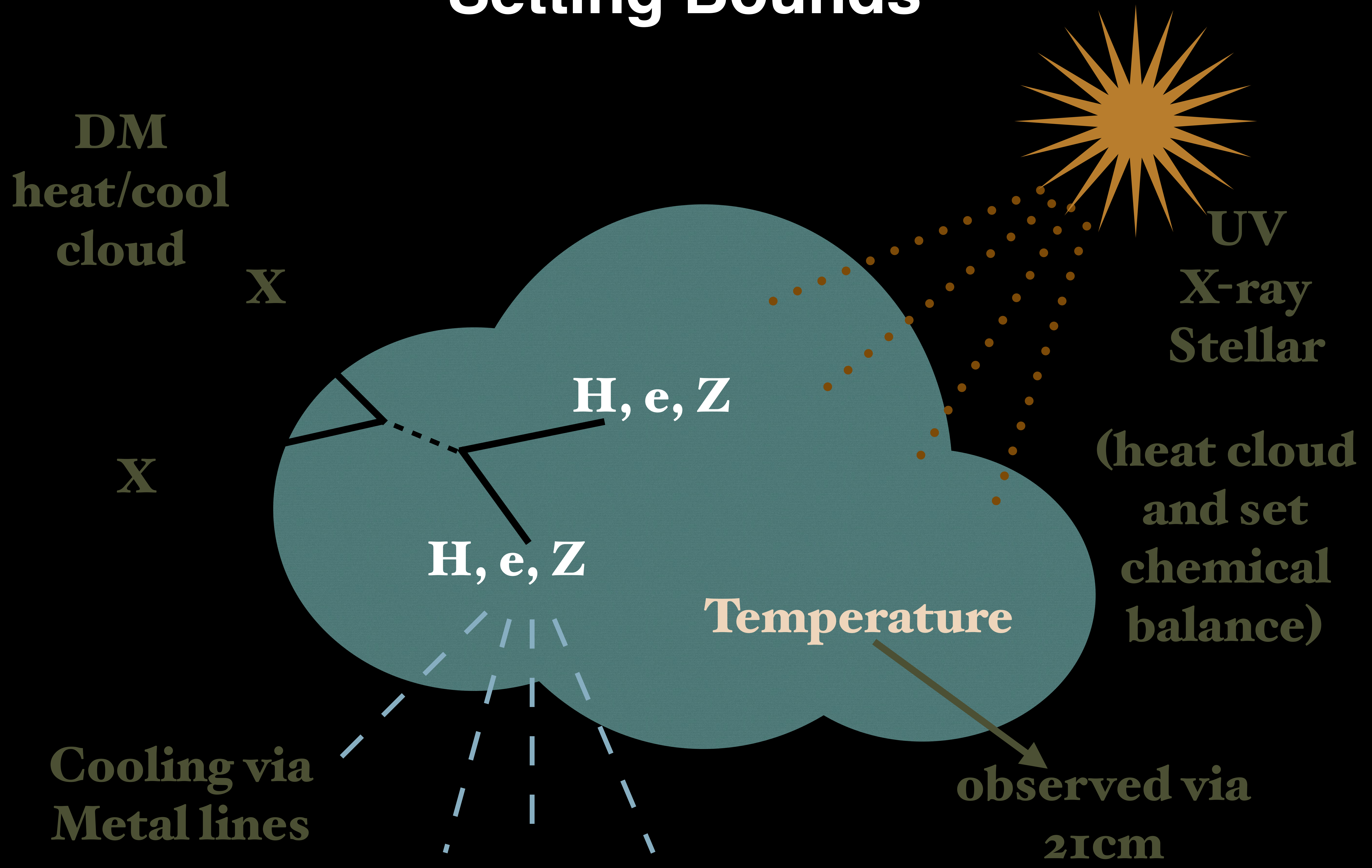
NASA/ESA

Gas Cloud Modelling

DM 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}



Setting Bounds



Dark Matter Bounds

Ultra Light Dark Photon DM

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

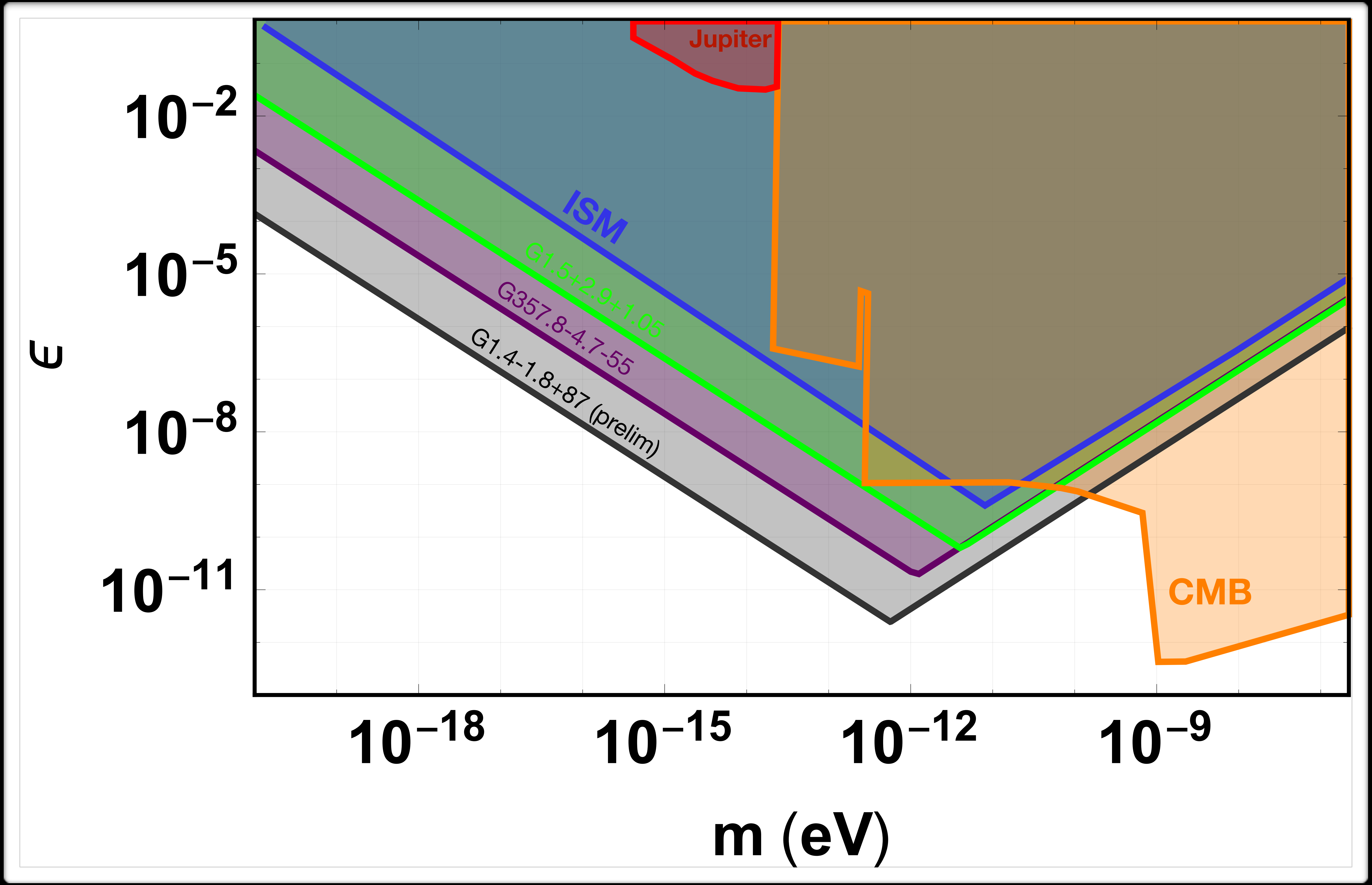
- **ultra light dark photon produces an oscillating electric field through mixing with the SM photon > Dubovsky 2015!**
- **free electrons and ions in the gas are accelerated by this field and eventually scatter and heat the gas**

$$\omega_p = \sqrt{\frac{4\pi n_e}{m_e}} \approx 5 \times 10^{-13}\ eV \left(\frac{n_e}{2 \times 10^{-4}\ \mathrm{cm}^{-3}}\right)^{1/2}$$

$$\gamma_h = \begin{cases} -\frac{\nu}{2}\left(\frac{m}{\omega_p}\right)^2 \frac{\epsilon^2}{1+\epsilon^2}, & m \ll \omega_p \\ -\frac{\nu}{2}\left(\frac{\omega_p}{m}\right)^2 \frac{\epsilon^2}{1+\epsilon^2}, & m \gg \omega_p, \end{cases}$$

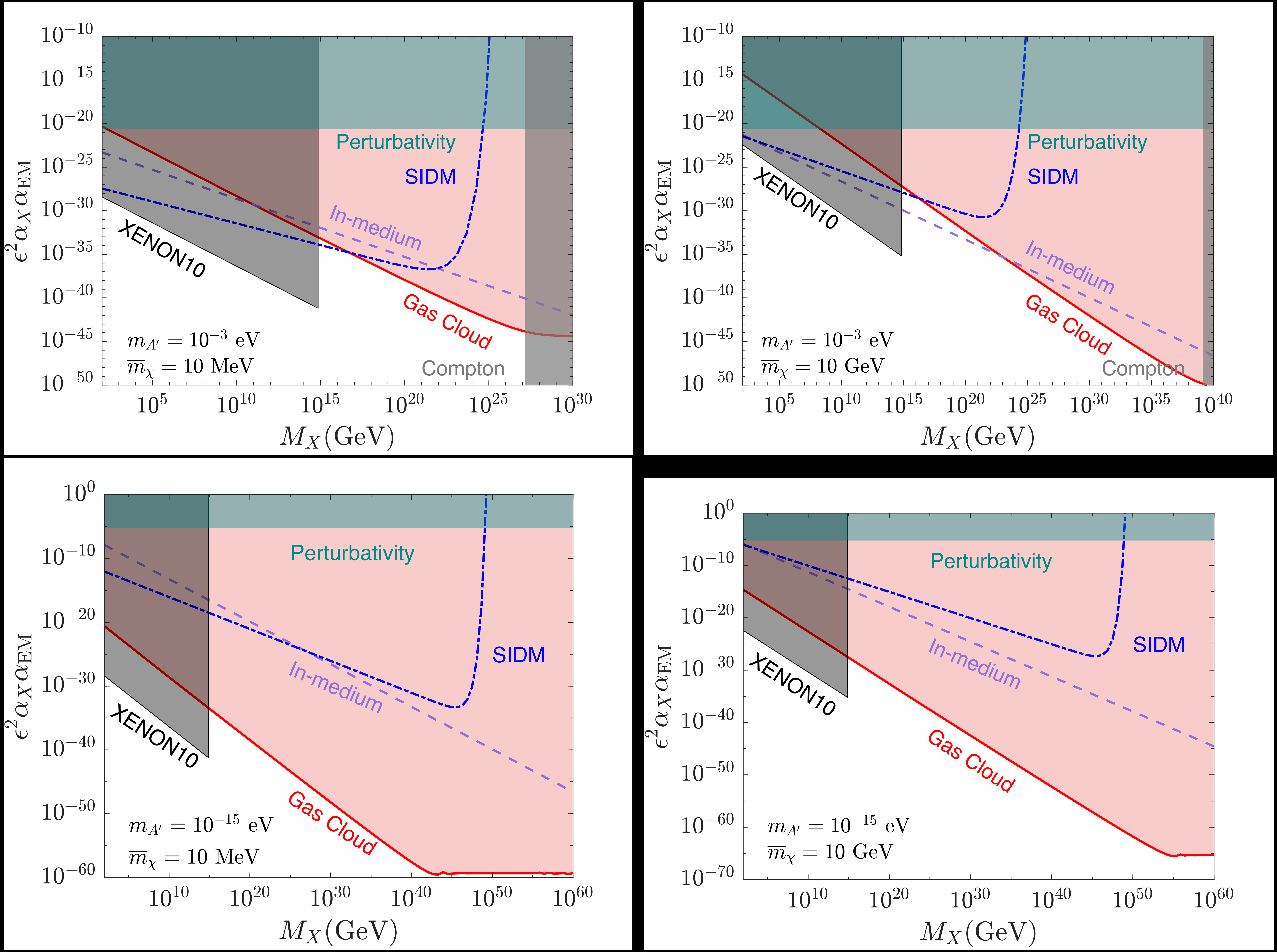
$$Q = 2|\gamma_h|\rho_x$$

Ultra Light Dark Photon DM



Composite Asymetric DM

- due to their size, gas clouds are well suited to test super heavy dark matter, also
  avoid the problem of overburden
- consider a model consisting of asymmetric dark matter bound together by a scalar field
- parameterise the model via the reduced constituent mass $\bar{m}_\chi$ and the total nugget mass M_χ
- assume long range interaction with SM via dark photon mediator $m_{A'}$

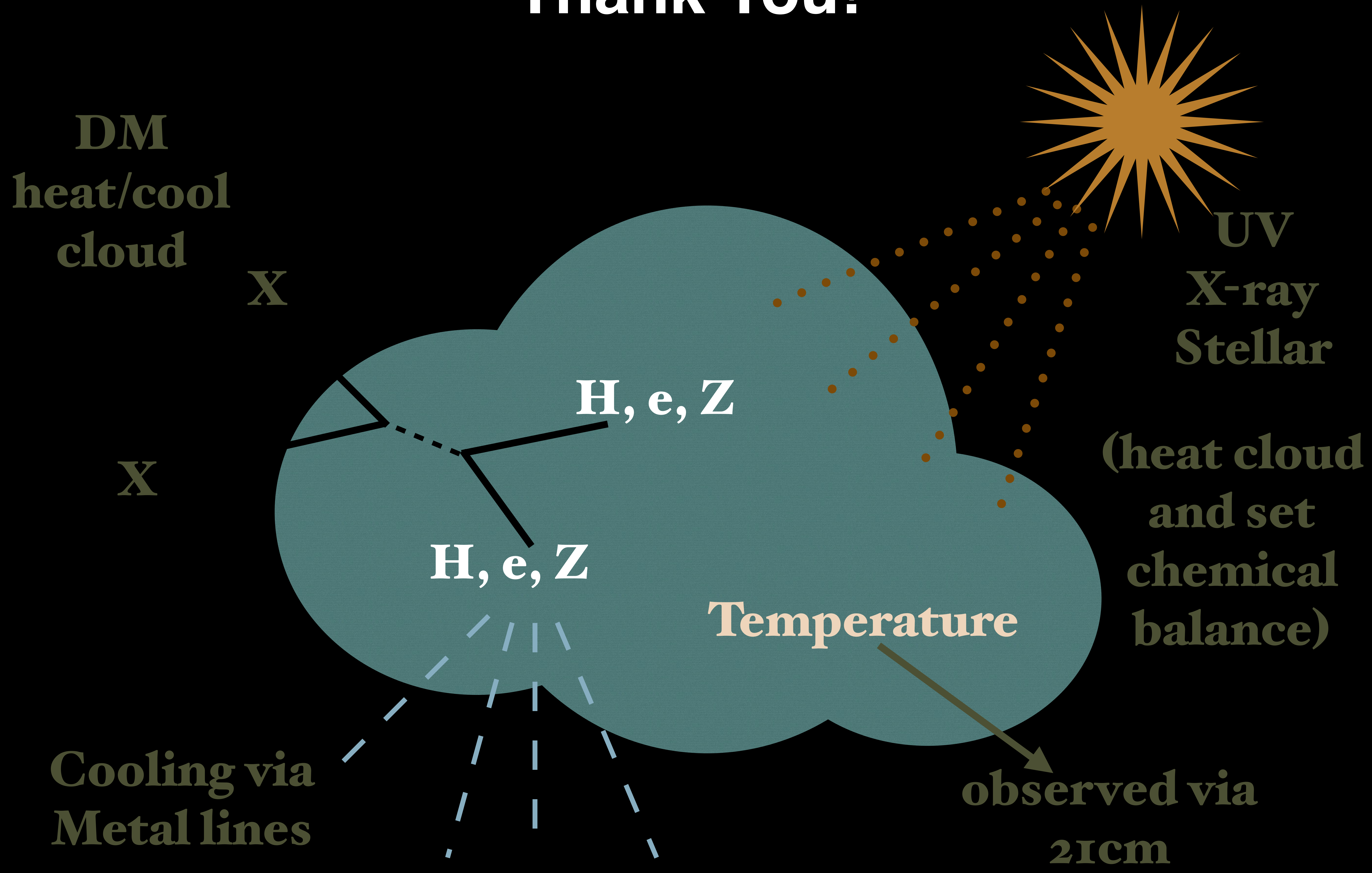


10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
10^{-35}
10^{-40}
10^{-45}
10^{-50}
$\epsilon^2 \alpha_X \alpha_{\rm EM}$
Perturbativity
SIDM
In-medium
XENON10
Gas Cloud
Compton
$m_{A'} = 10^{-3}$ eV
$\overline{m}_\chi = 10$ MeV
10^5
10^{10}
10^{15}
10^{20}
10^{25}
10^{30}
M_X(GeV)
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
10^{-35}
10^{-40}
10^{-45}
10^{-50}
$\epsilon^2 \alpha_X \alpha_{\rm EM}$
Perturbativity
SIDM
XENON10
In-medium
Gas Cloud
Compton
$m_{A'} = 10^{-3}$ eV
$\overline{m}_\chi = 10$ GeV
10^5
10^{10}
10^{15}
10^{20}
10^{25}
10^{30}
10^{35}
10^{40}
M_X(GeV)
10^{0}
10^{-10}
10^{-20}
10^{-30}
10^{-40}
10^{-50}
10^{-60}
$\epsilon^2 \alpha_X \alpha_{\rm EM}$
Perturbativity
SIDM
In-medium
XENON10
Gas Cloud
$m_{A'} = 10^{-15}$ eV
$\overline{m}_\chi = 10$ MeV
10^{10}
10^{20}
10^{30}
10^{40}
10^{50}
10^{60}
M_X(GeV)
10^{0}
10^{-10}
10^{-20}
10^{-30}
10^{-40}
10^{-50}
10^{-60}
10^{-70}
$\epsilon^2 \alpha_X \alpha_{\rm EM}$
Perturbativity
SIDM
In-medium
XENON10
Gas Cloud
$m_{A'} = 10^{-15}$ eV
$\overline{m}_\chi = 10$ GeV
10^{10}
10^{20}
10^{30}
10^{40}
10^{50}
10^{60}
M_X(GeV)

Future Designs

- Consider more involved heating mechanisms
- Develop the gastro-physics
- Look for signatures in the chemical network
- Quantify systematics of setting gas cloud bounds (paper coming soon!)

Thank You!


DM
heat/cool
cloud
X
X
H, e, Z
H, e, Z
Temperature
UV
X-ray
Stellar
(heat cloud
and set
chemical
balance)
Cooling via
Metal lines
observed via
21cm