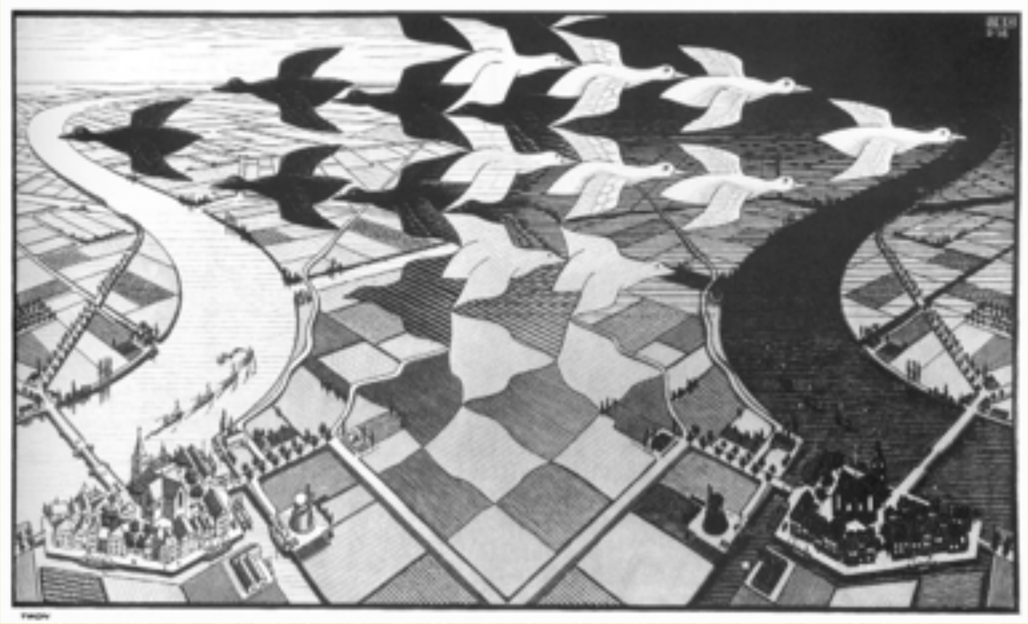
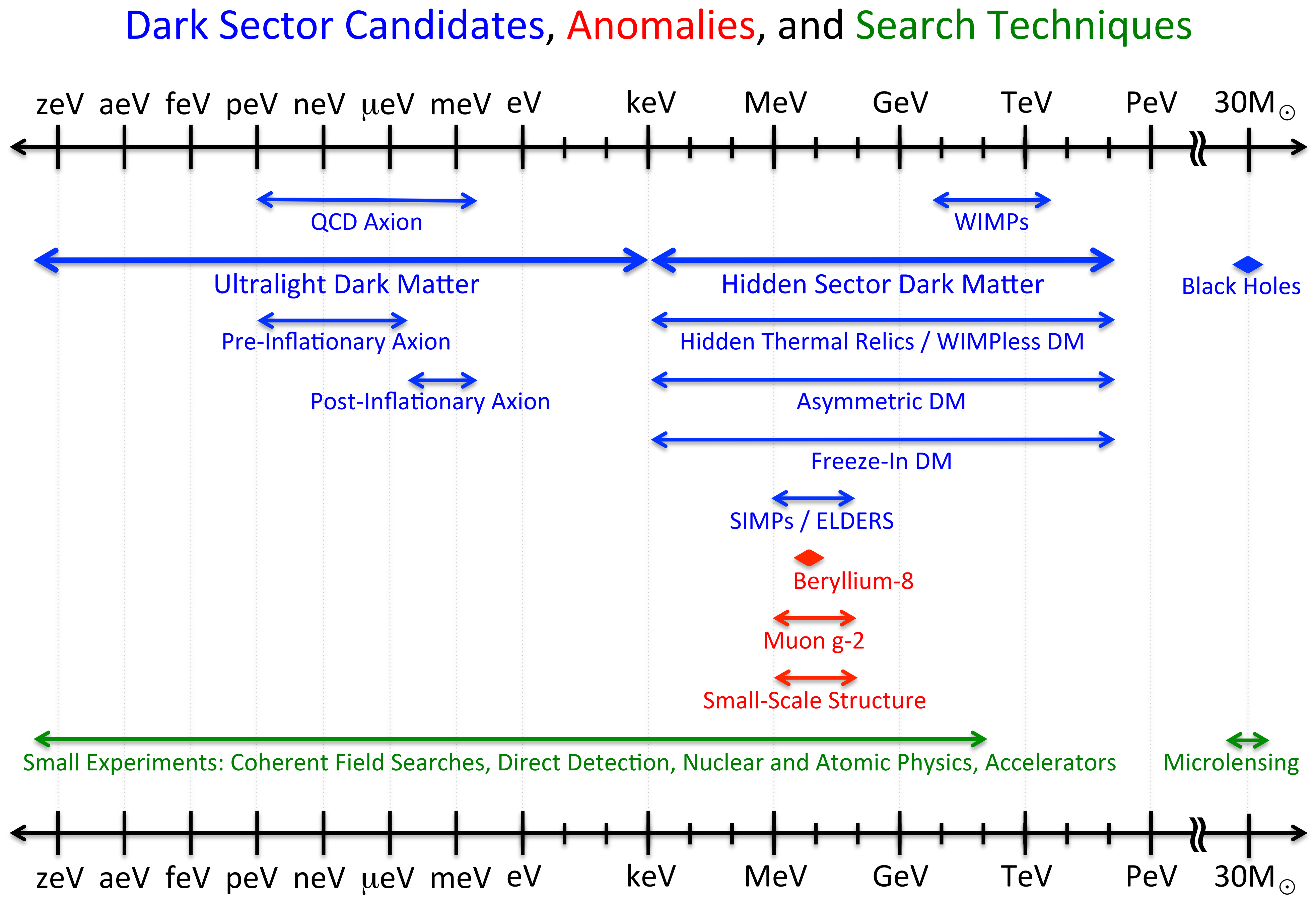
SEARCHING FOR DARK MATTER IN THE LATE UNIVERSE

Variations on a Theme



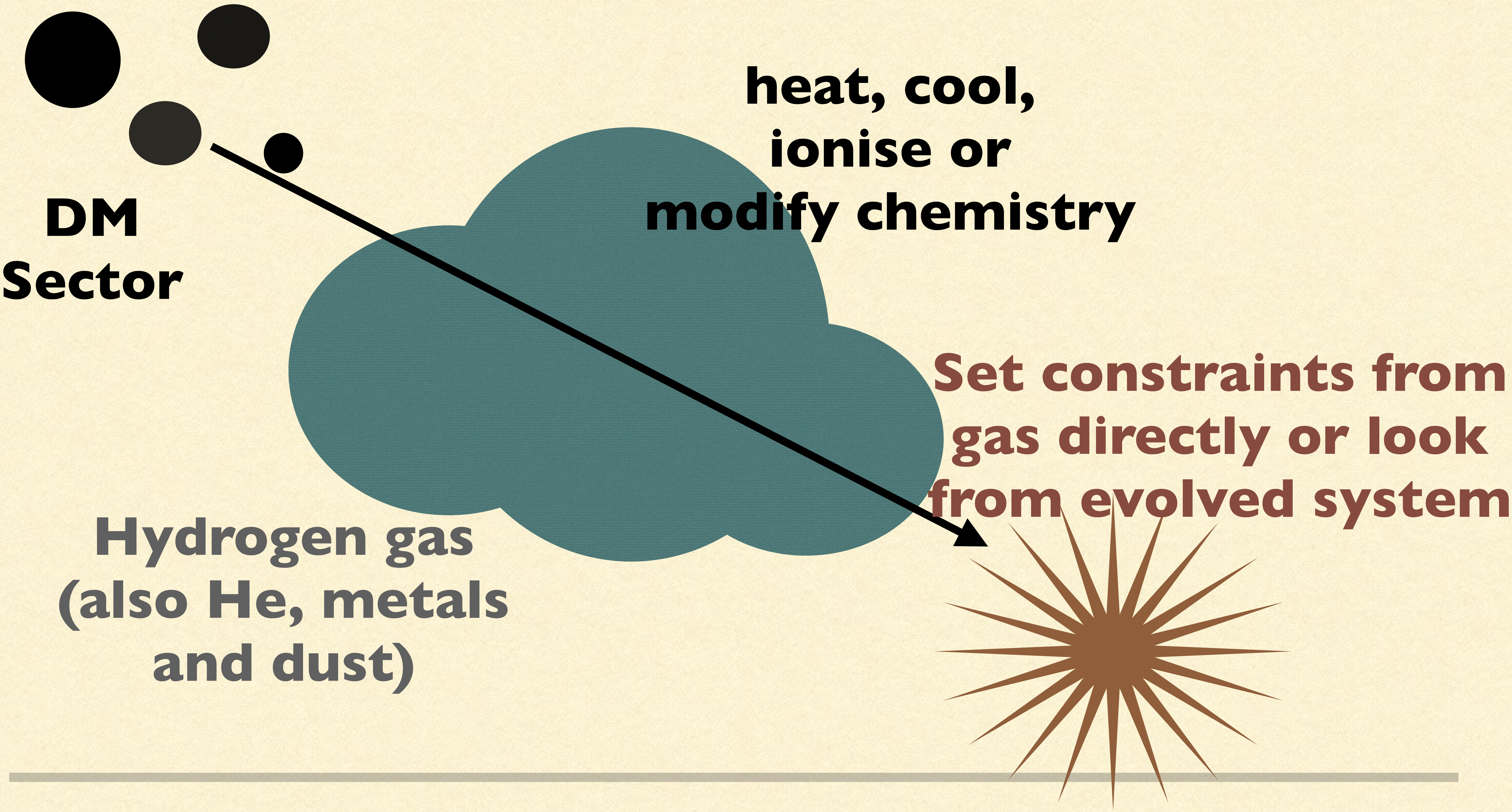
Sarah Schön
McDonald Institute, Queen's University
EDSU 2020

MAY YOU LIVE IN INTERESTING TIMES…

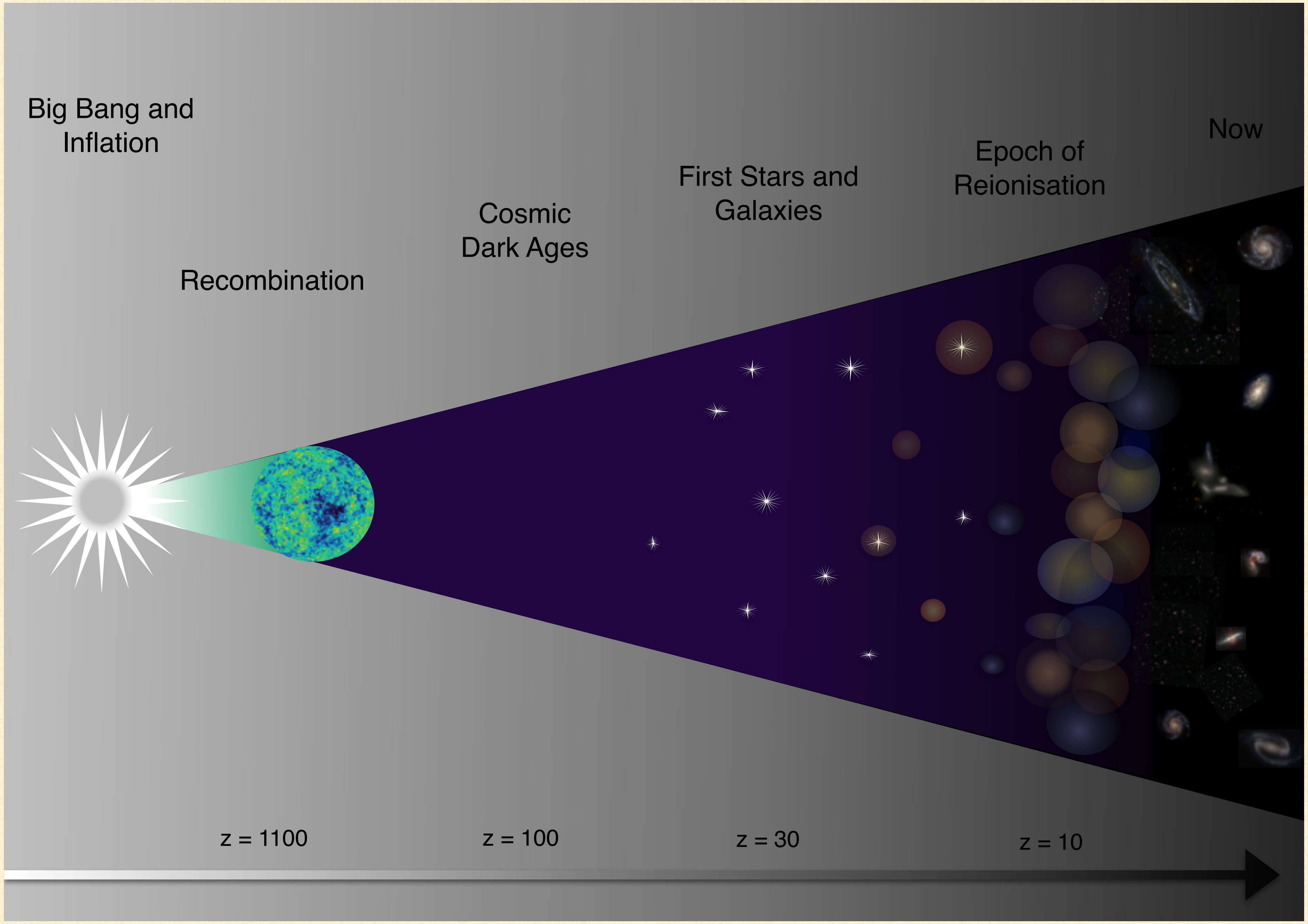


U.S. Cosmic Visions: New Ideas in Dark Matter 2017

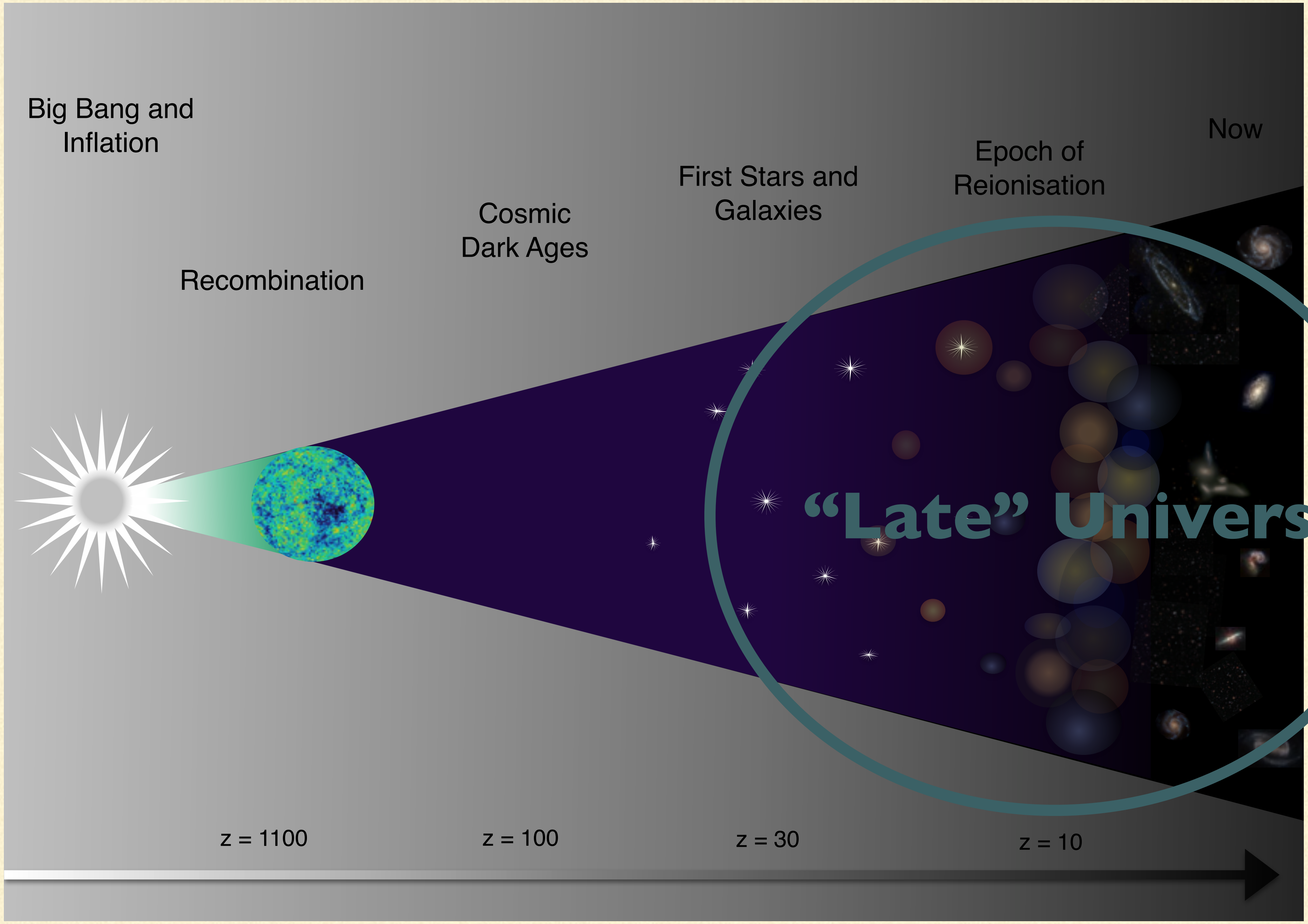
HYDROGEN AS DM DETECTORS



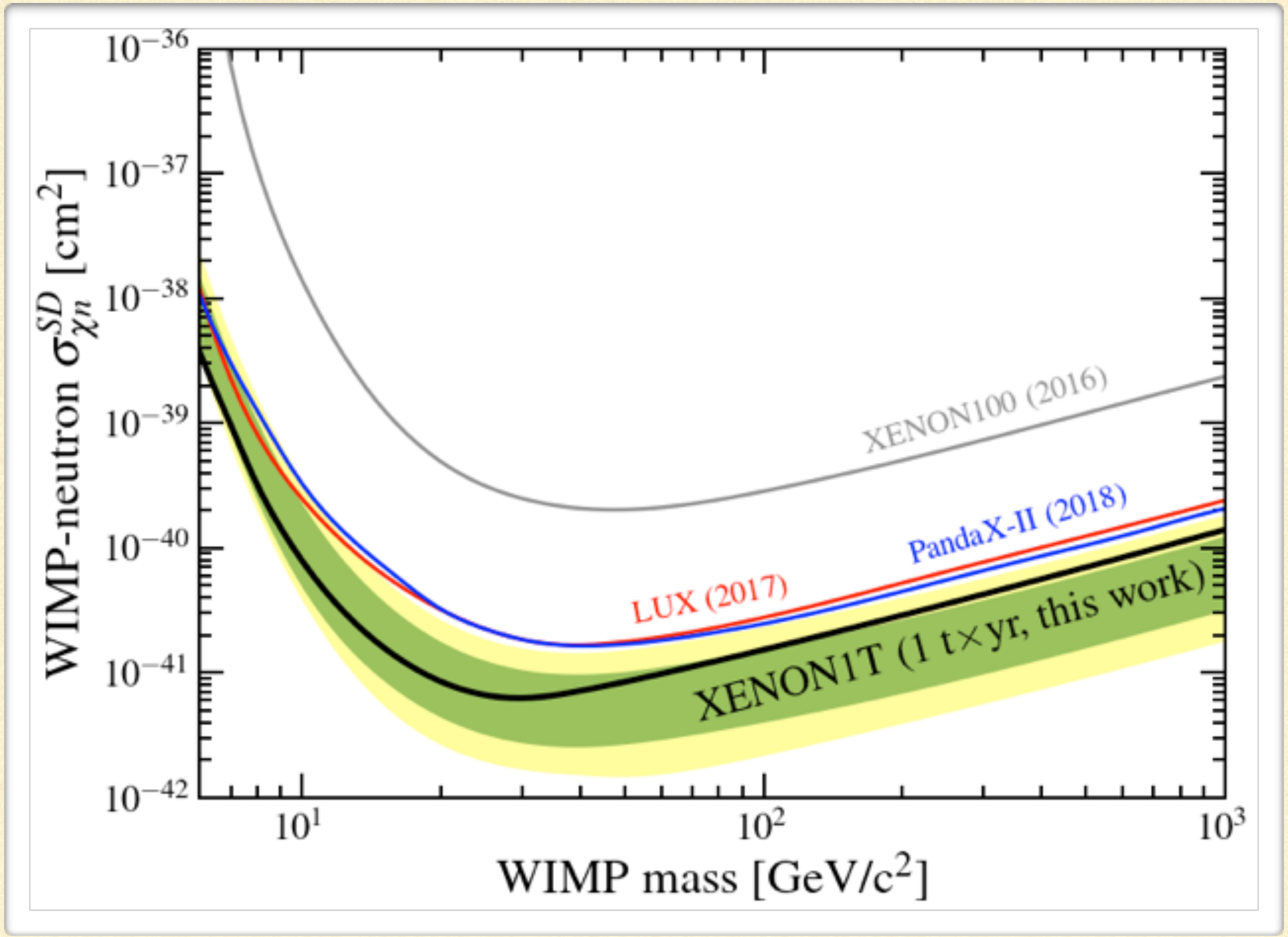
EPOCHS OF INTEREST



EPOCHS OF INTEREST

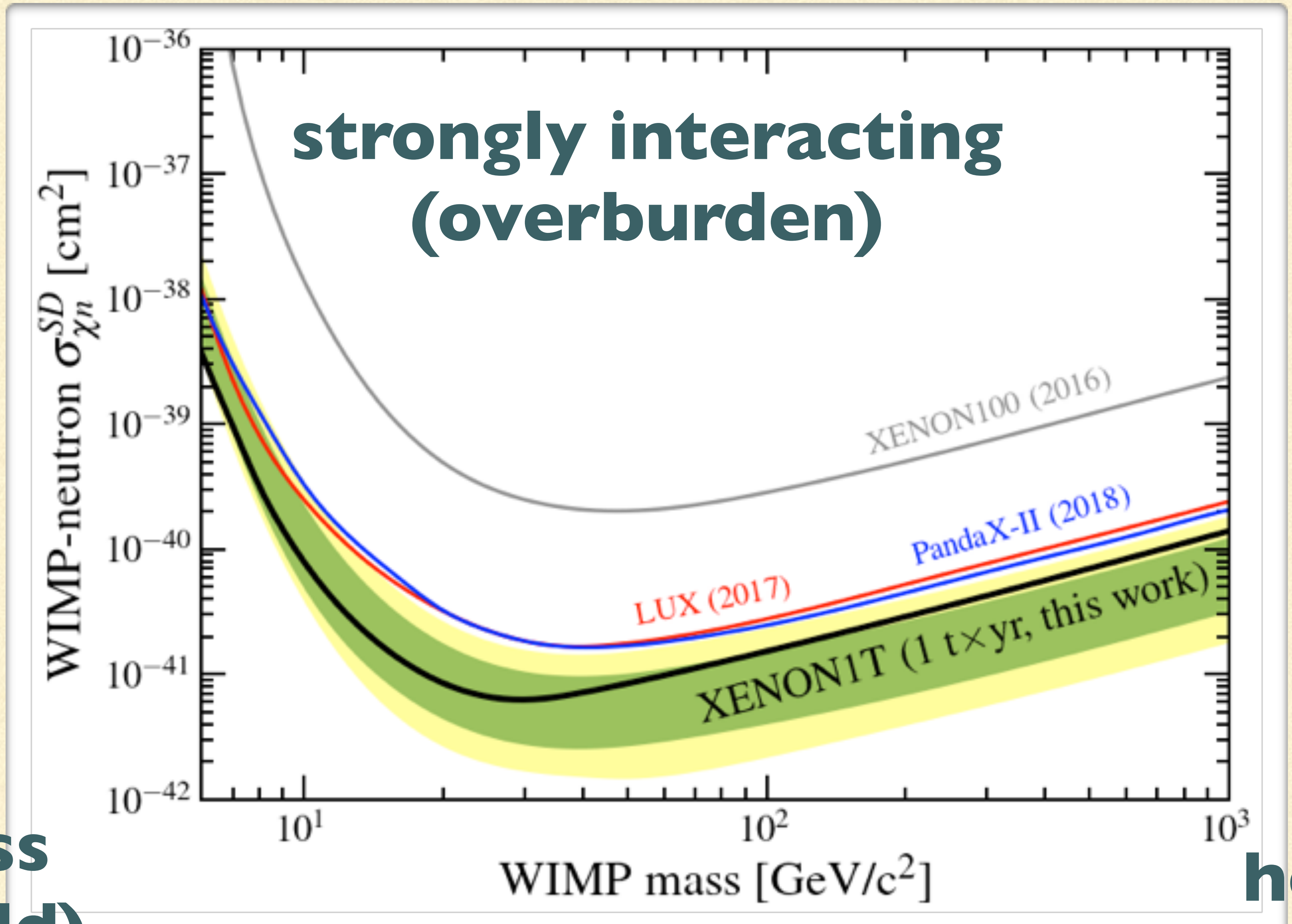


DM DETECTORS IN THE GALACTIC CENTRE



Xenon 1T 2018

DM DETECTORS IN THE GALACTIC CENTRE

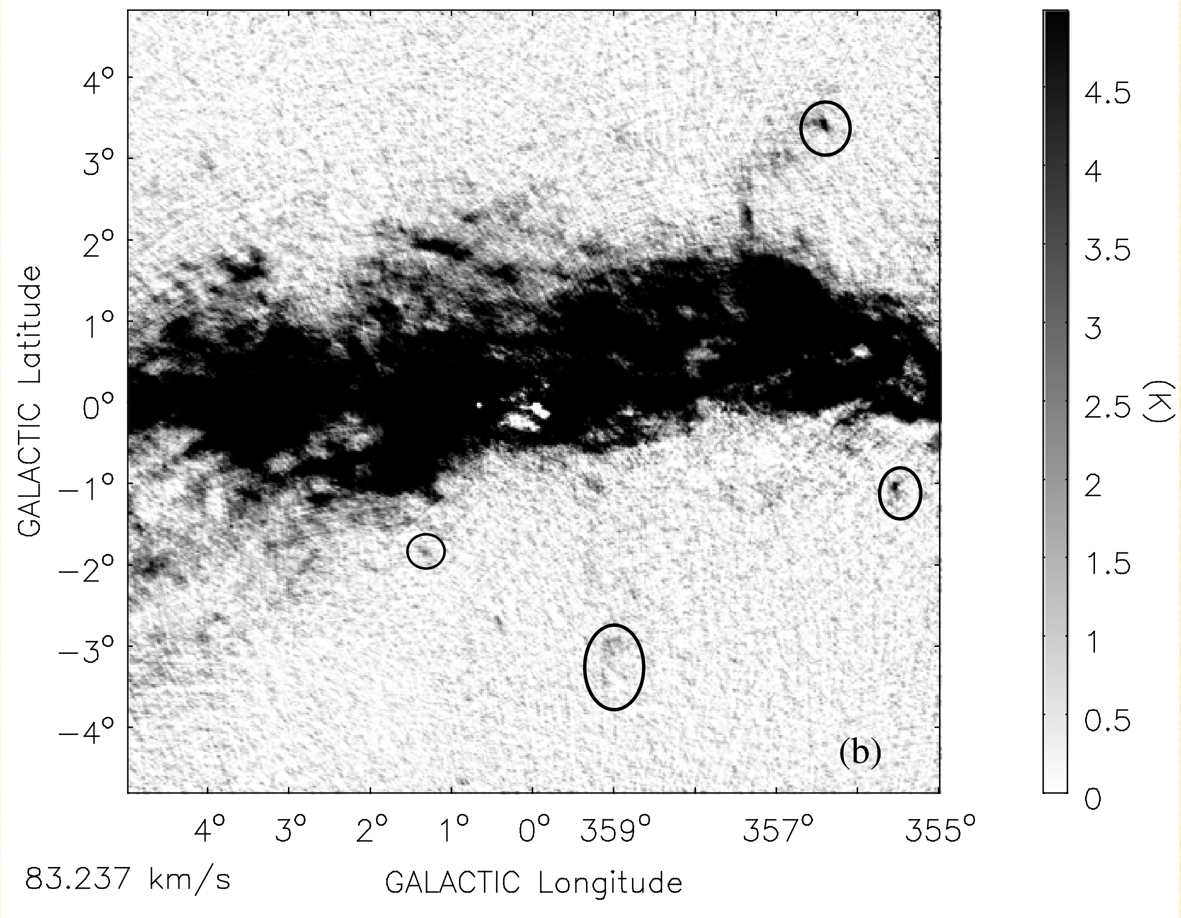


low mass (threshold)

heavy DM (flux limited)

COLD, ATOMIC HI CLOUDS

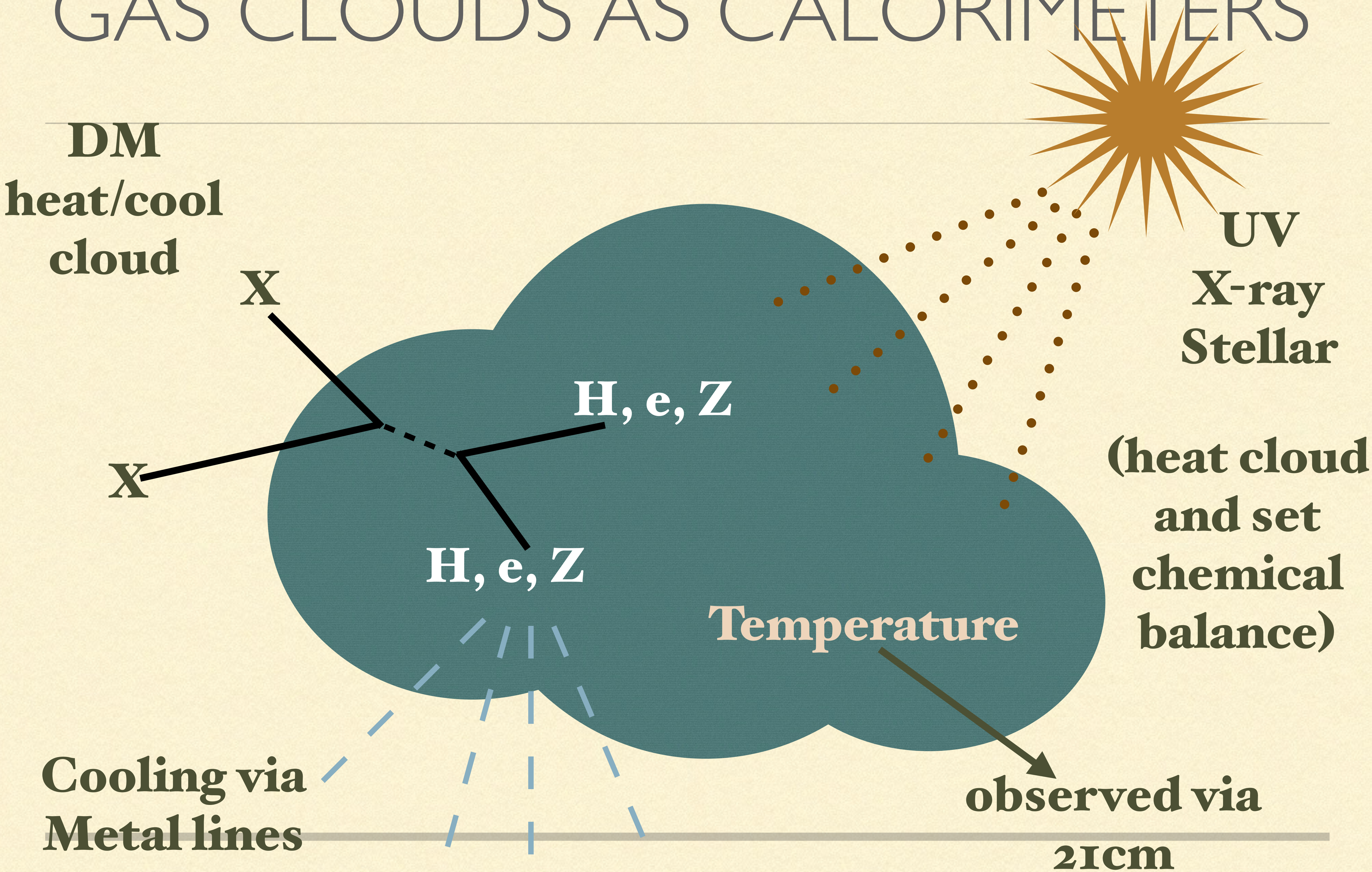
- A soufflé of cold, atomic gas clouds presented as part of the ATCA HI Galactic Centre Survey
- Likely embedded in a galactic outflow driven by stellar winds or similar mechanism



McClure-Griffiths 2013

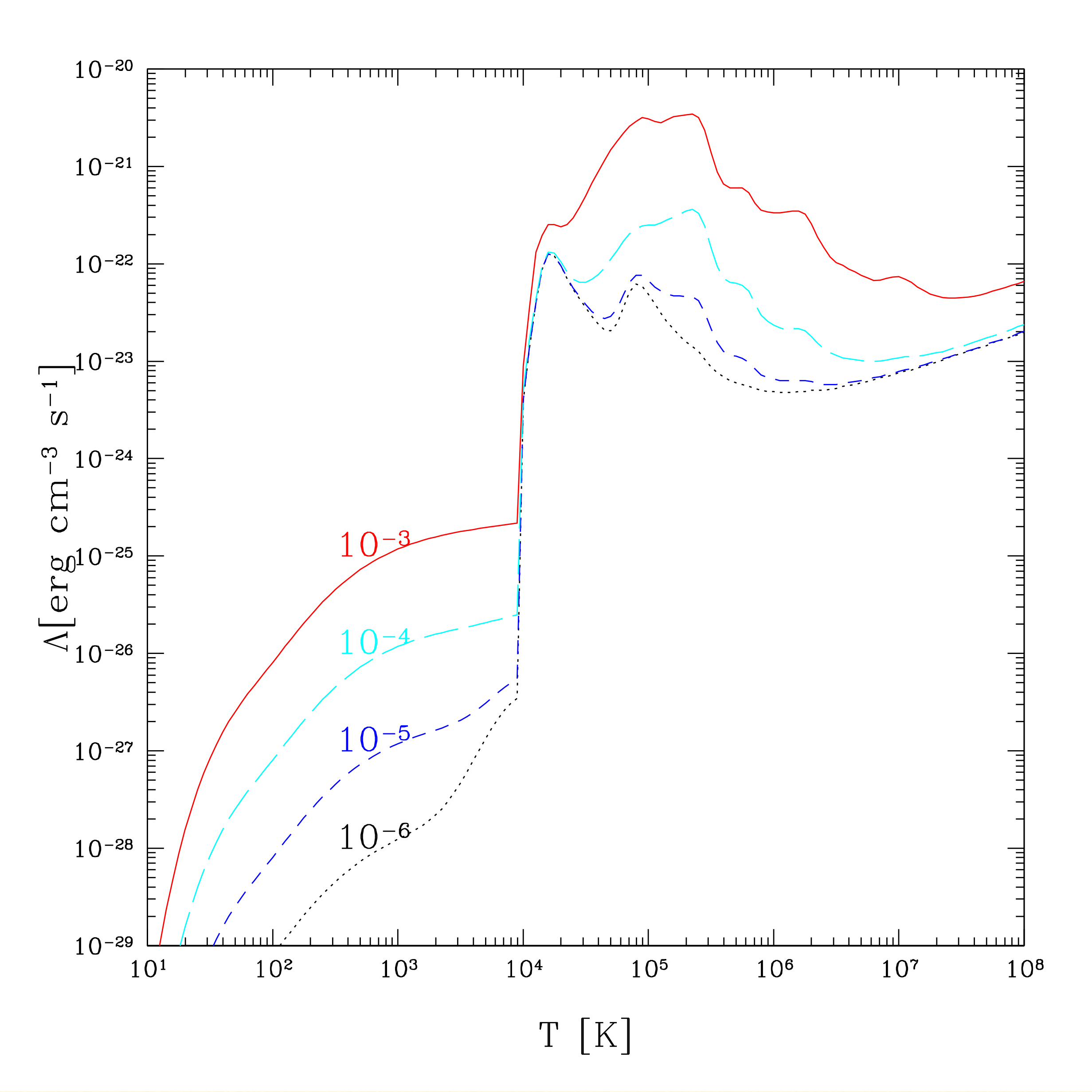
ArXiv:1806.06857
ArXiv:1812.10919

GAS CLOUDS AS CALORIMETERS



SETTING BOUNDS

- Observe that for fixed metallicity and density, the cooling rate is monotonically decreasing with temperature
- Use this upper limit to set conservative limits on DM heating by assuming all heating due to non-standard sources

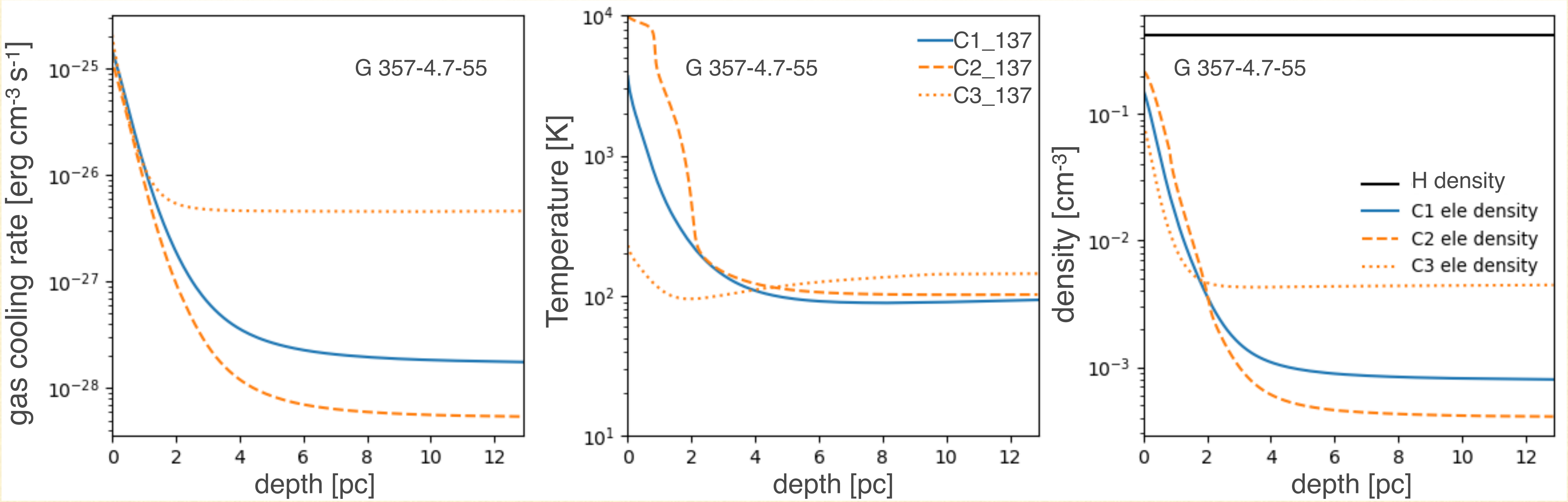


Maio et al 2007

MODELLING GAS CLOUDS

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}

MODELLING GAS CLOUDS



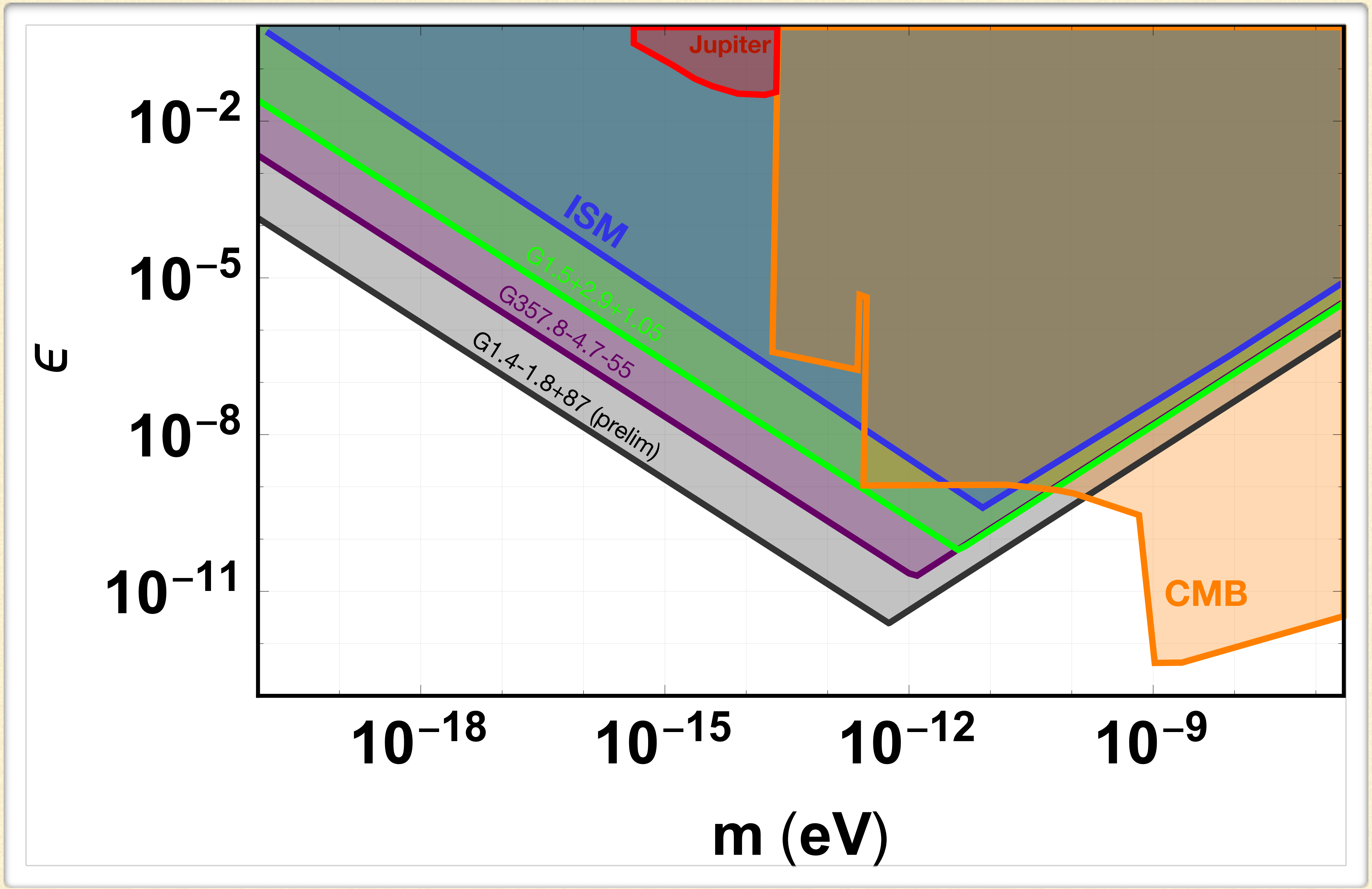
ULTRA-LIGHT DARK PHOTON DM

- Simple local U(1) extension of the Standard Model
- The additional gauge boson can be treated as a DM candidate

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

- Ultra light dark photons produce an oscillating electric field through mixing with the SM photon
- Plasma of free electrons and ions in the gas cloud are accelerated and eventually heat the gas through subsequent scattering

ULTRA-LIGHT DARK PHOTON DM

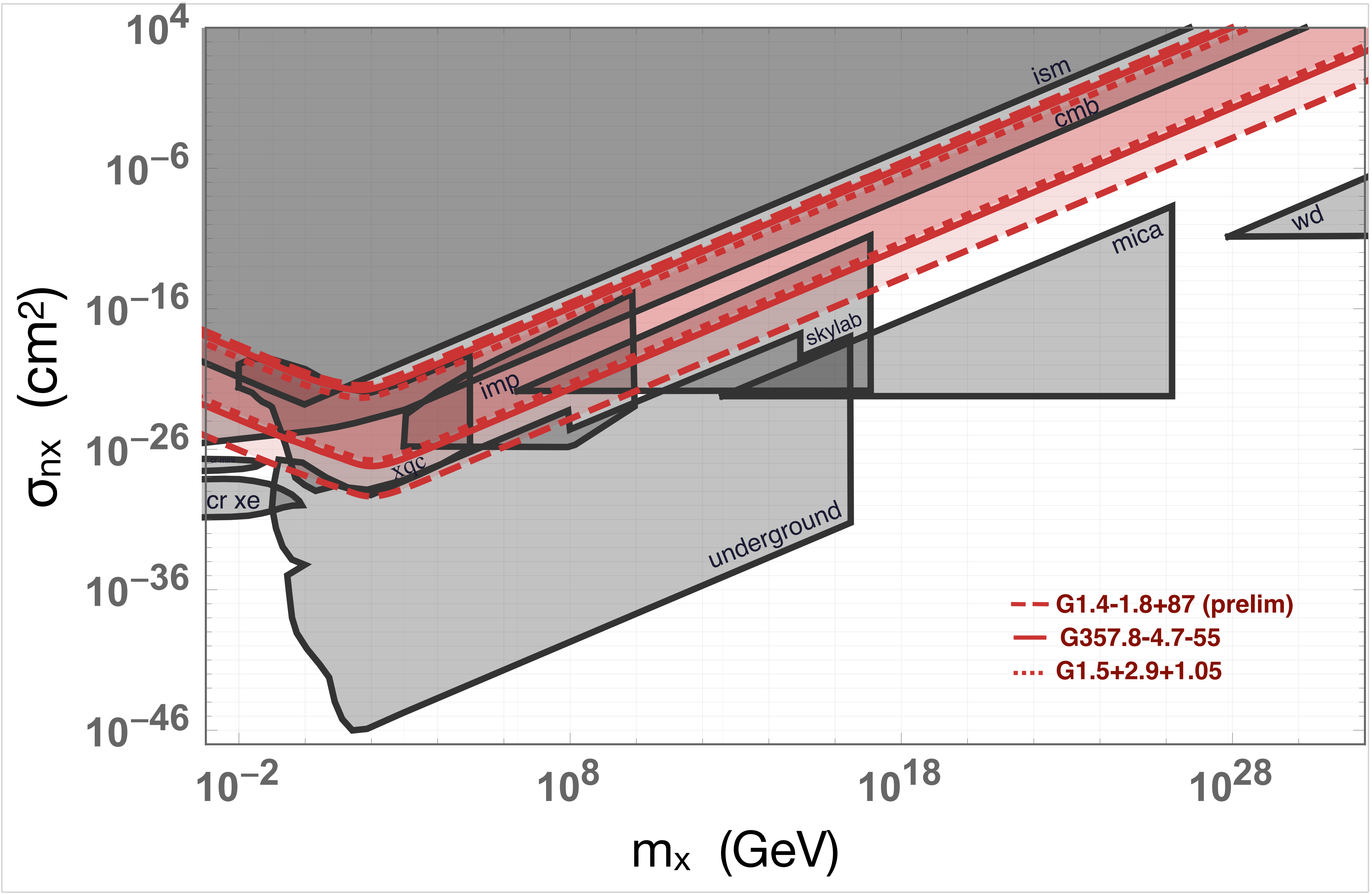


DM NUCLEON SCATTERING

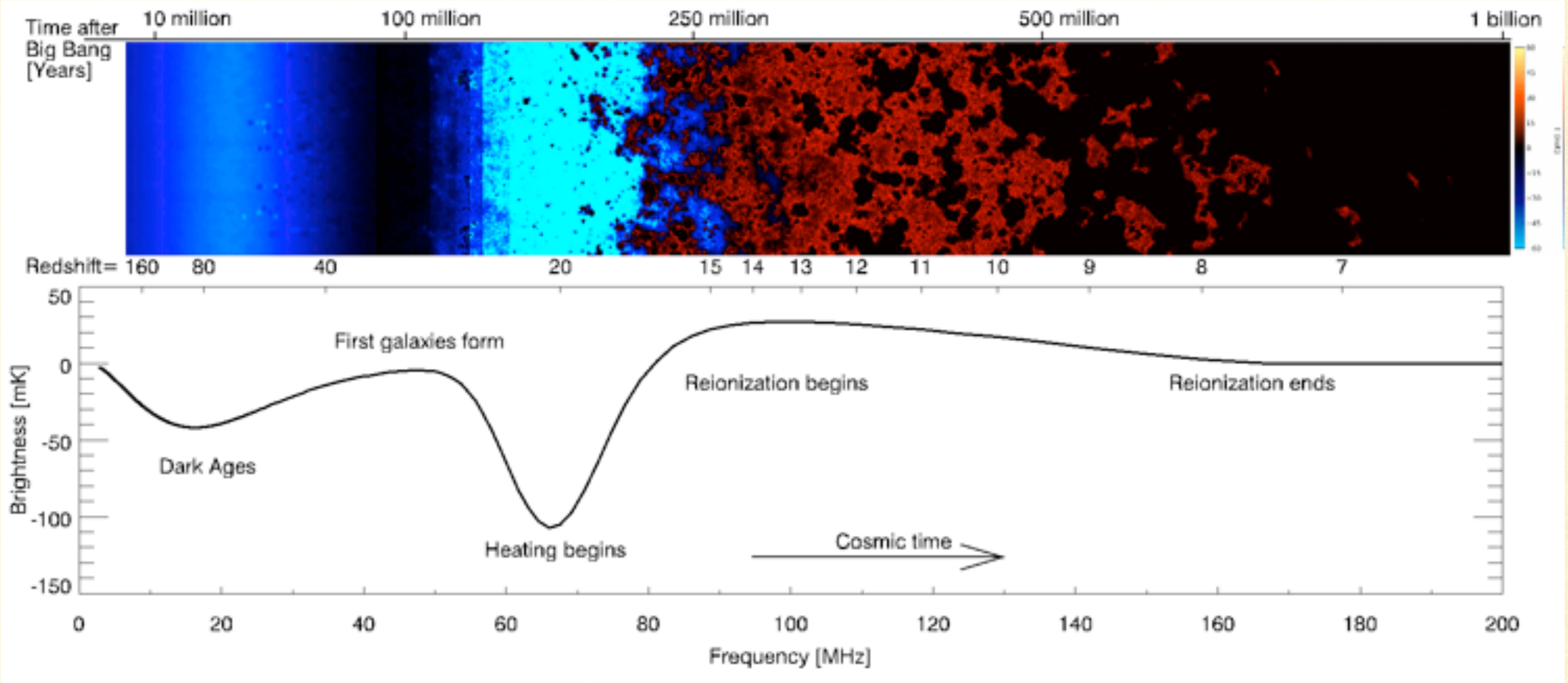
- Consider strongly interacting or heavy, composite dark matter
- For massive candidates, the flux at fixed radii from the galactic centre decreases and for strongly interacting models the natural overburden of terrestrial experiments limits detectability
- Our gas clouds are well suited to constrain these models due to their size and location

$$m_x \simeq 3 \times 10^{60}\ \mathrm{GeV}\ \left(\frac{r_g}{10\ \mathrm{pc}}\right)^2 \left(\frac{\rho_x}{10\ \mathrm{GeV/cm^3}}\right) \left(\frac{v}{0.001c}\right) \left(\frac{t_g}{10^6\ \mathrm{yrs}}\right) \left(\frac{10}{N_f}\right).$$

DM NUCLEON SCATTERING

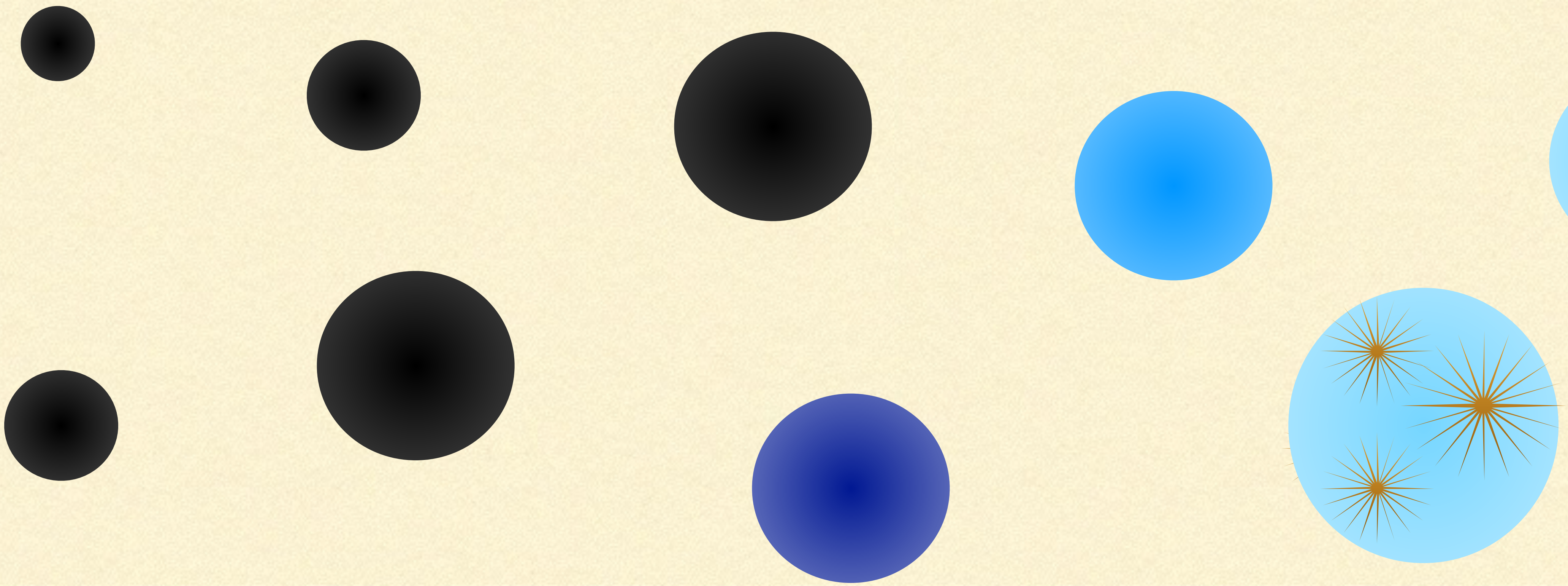


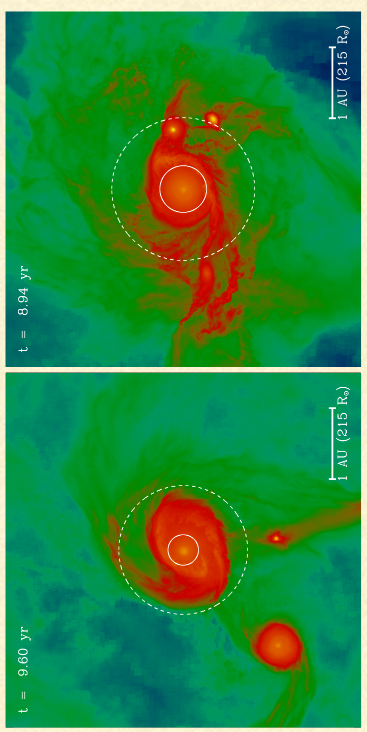
INTERGALACTIC MEDIUM



Pritchard, 2012

THE FIRST STARS AND GALAXIES



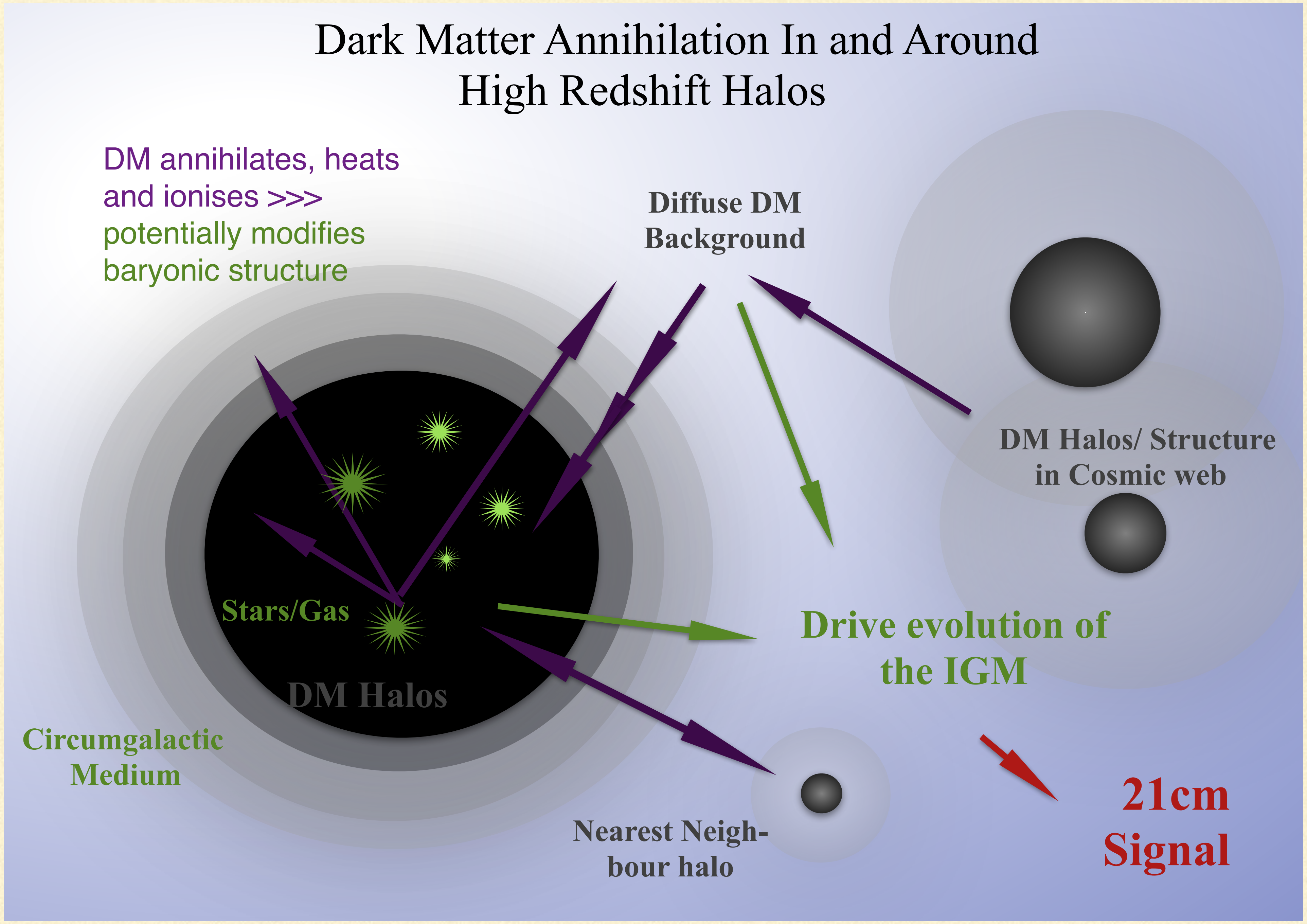


Dark Matter Halos collapse (low mass halos first)

Gas assembles in massive enough halos and begins

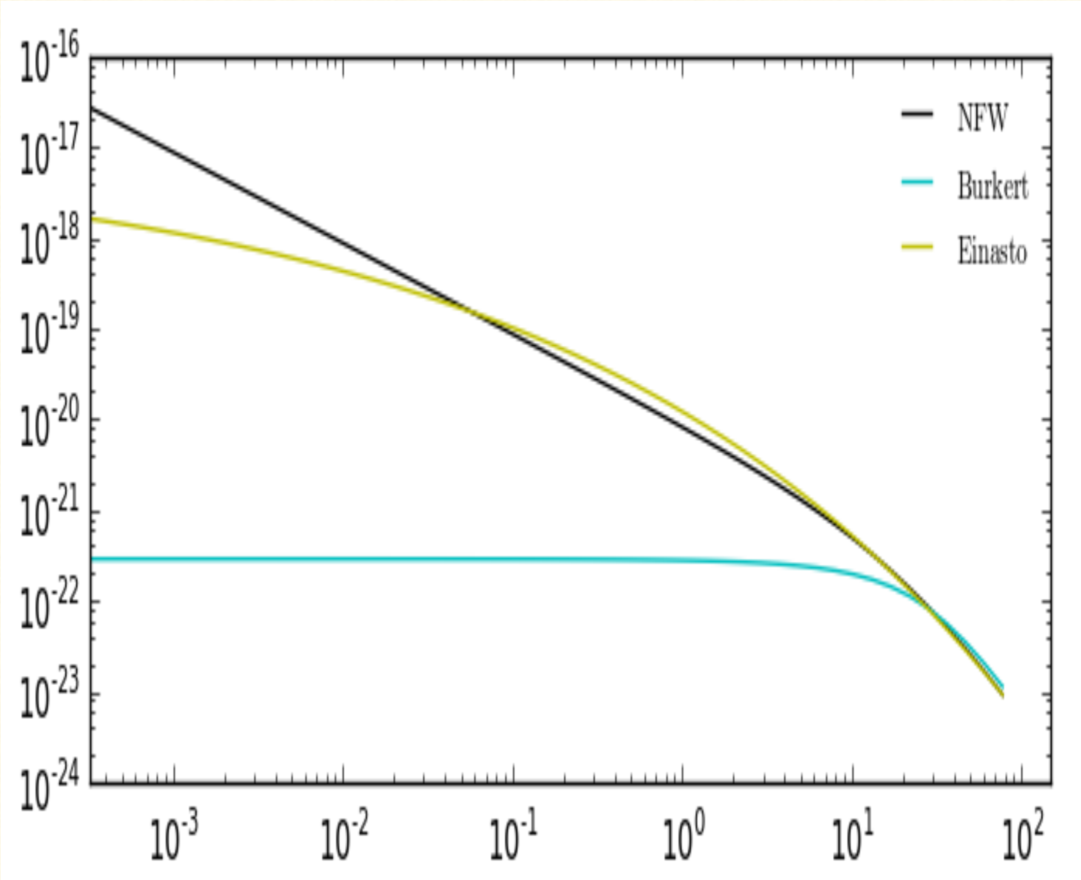
The first PopIII stars form

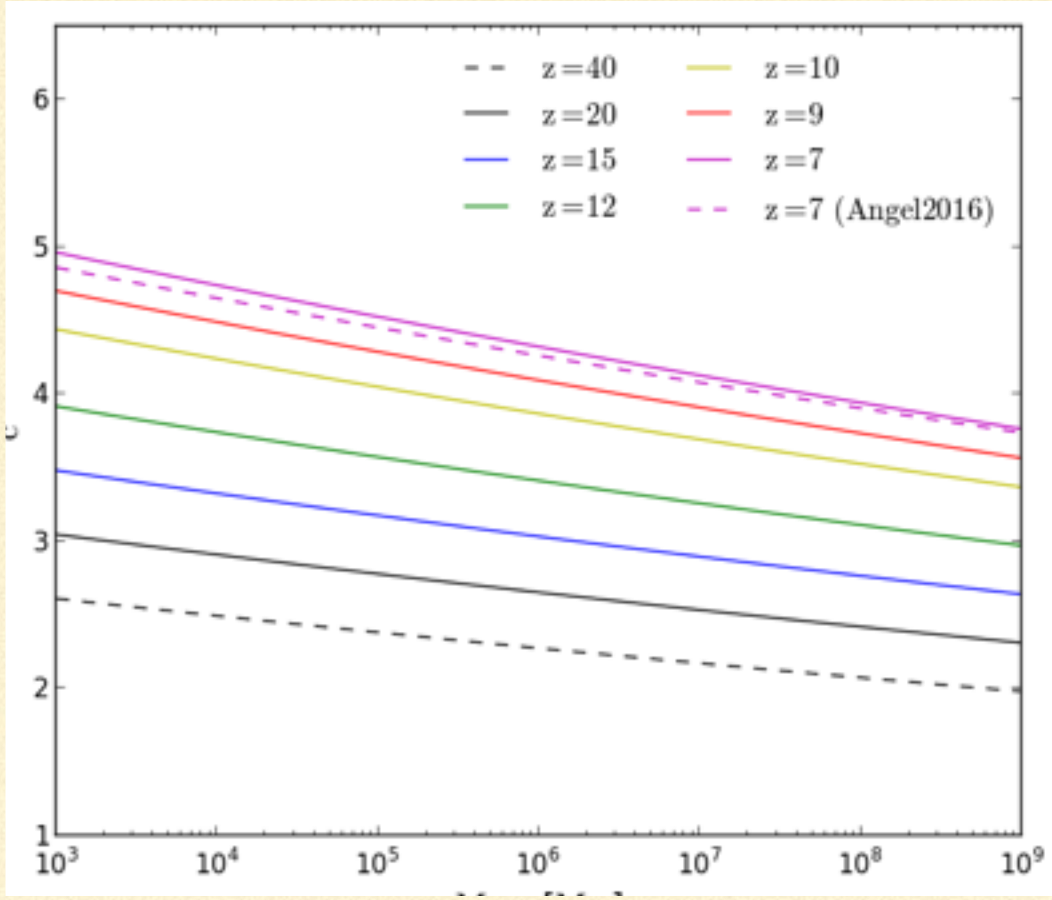
PULLING STRINGS



HALOS AND IMPORTANT UNCERTAINTIES

Halo Mass Profiles

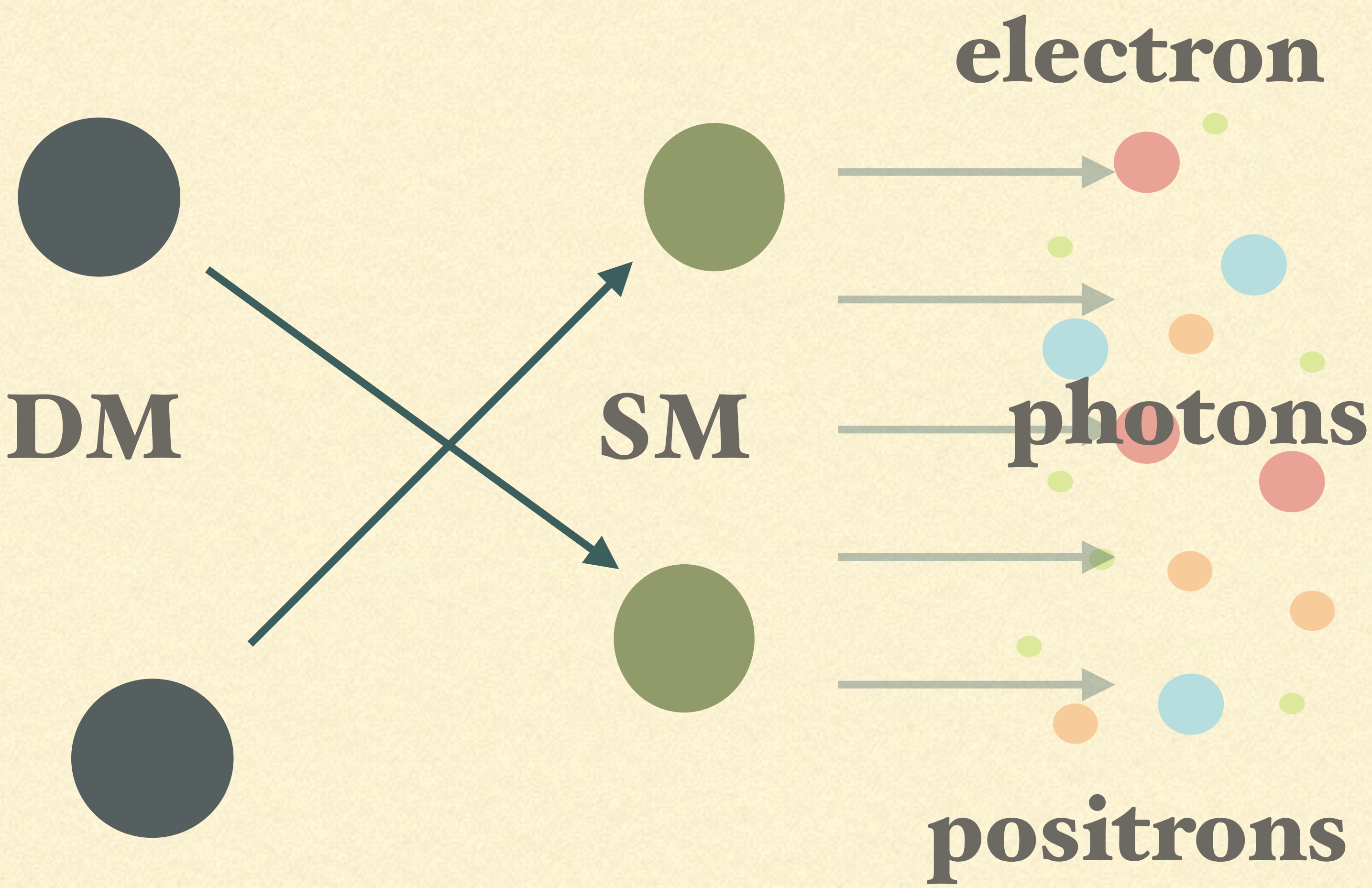


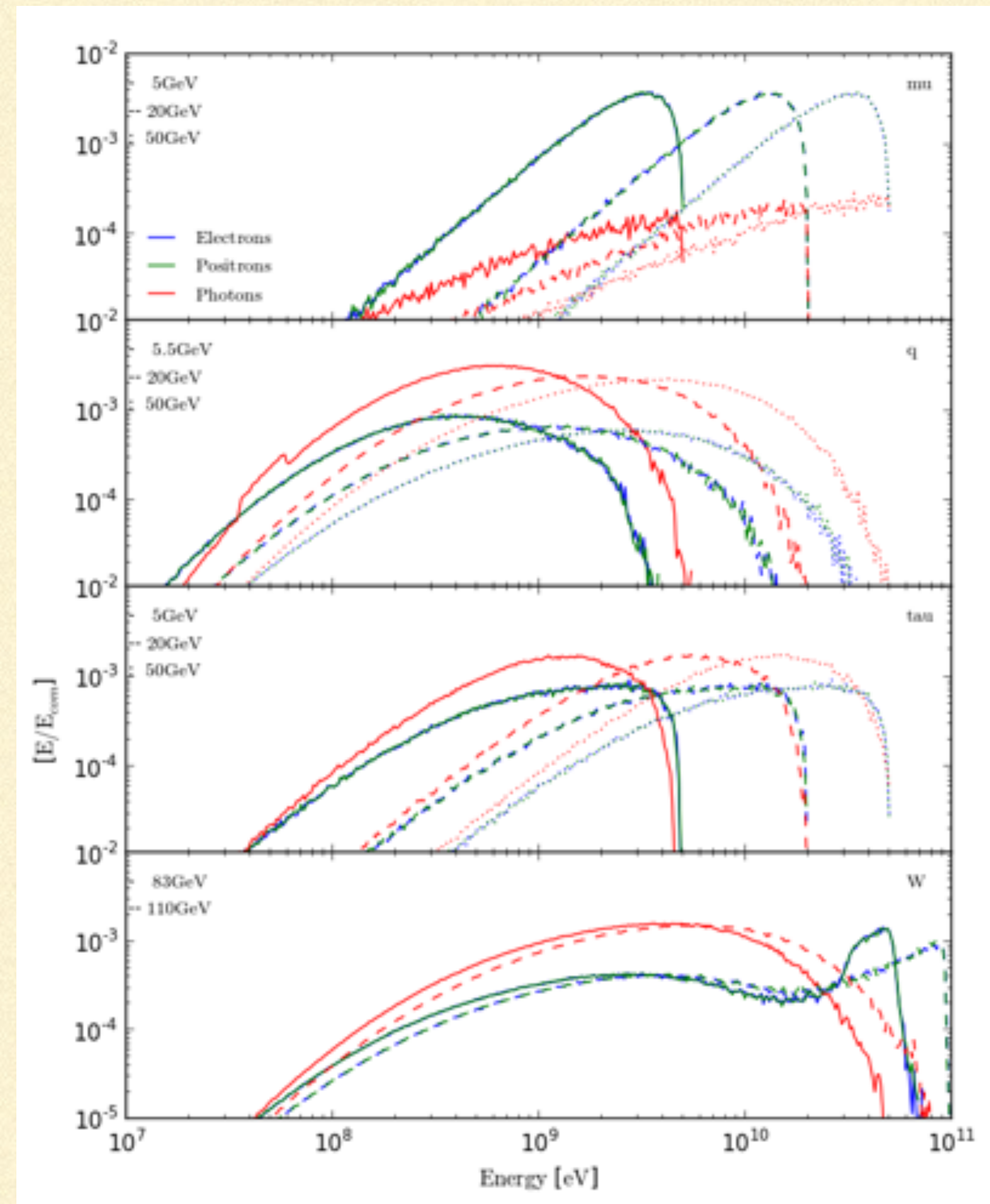


Mass Concentration Parameter

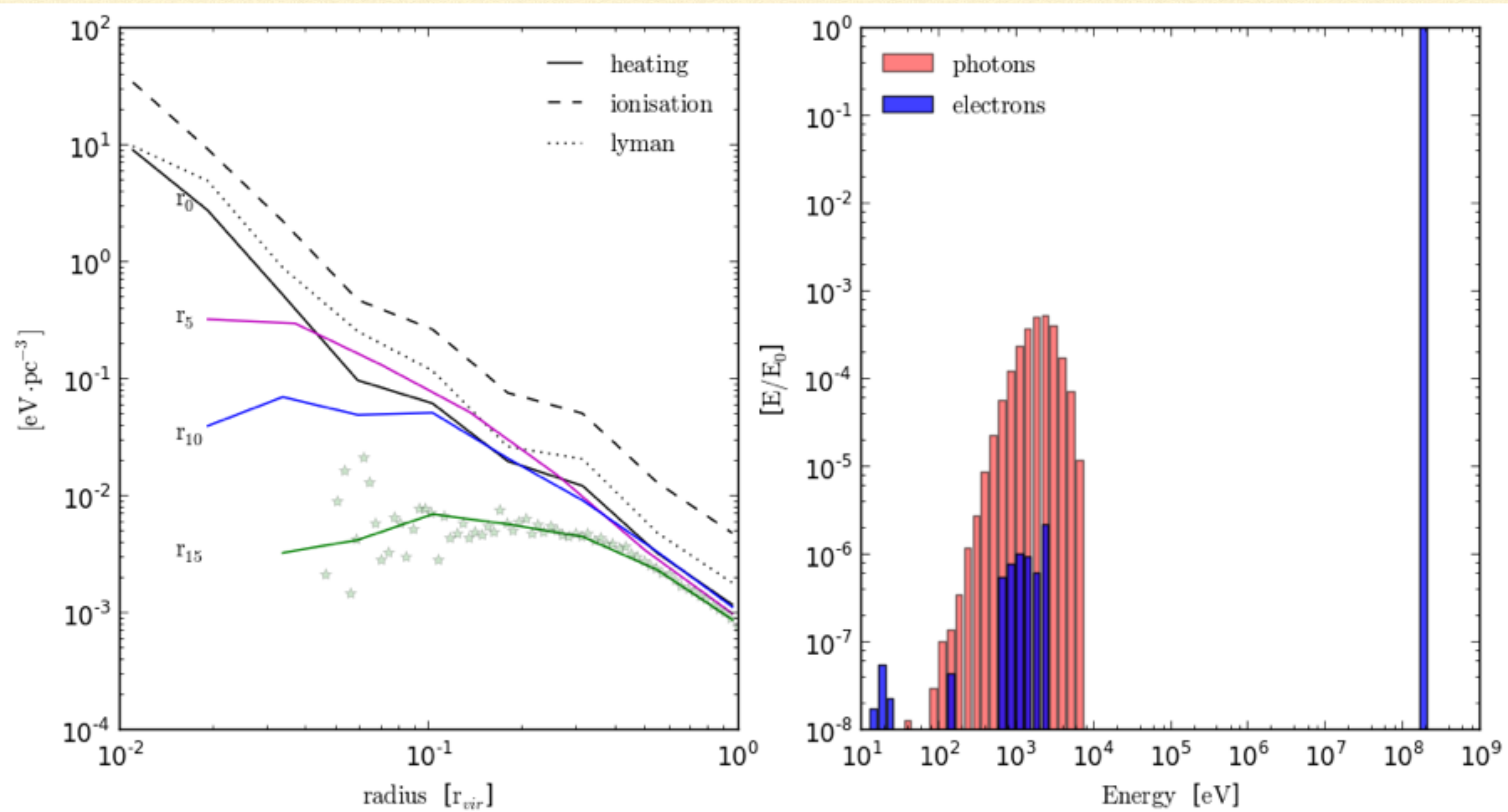
ArXiv:1706.04327
ArXiv:1411.3783

ENERGY INJECTION FROM DM





ENERGY INJECTION FROM DM



HEATING THE CGM

DM virializes, producing a potential, with gas in hydrostatic equilibrium

$$\nabla p_b = -\rho_b \nabla \phi$$

Assuming adiabatic evolution,

$$\frac{p_b}{\bar{p}_b} = \left(\frac{\rho_b}{\bar{\rho}_b}\right)^{\frac{5}{3}}$$

gives

$$\frac{\rho_b}{\bar{\rho}_b} = \left(1 - \frac{2}{5}\frac{\mu m_p \phi}{k_b \bar{T}}\right)^{\frac{3}{2}}$$

for

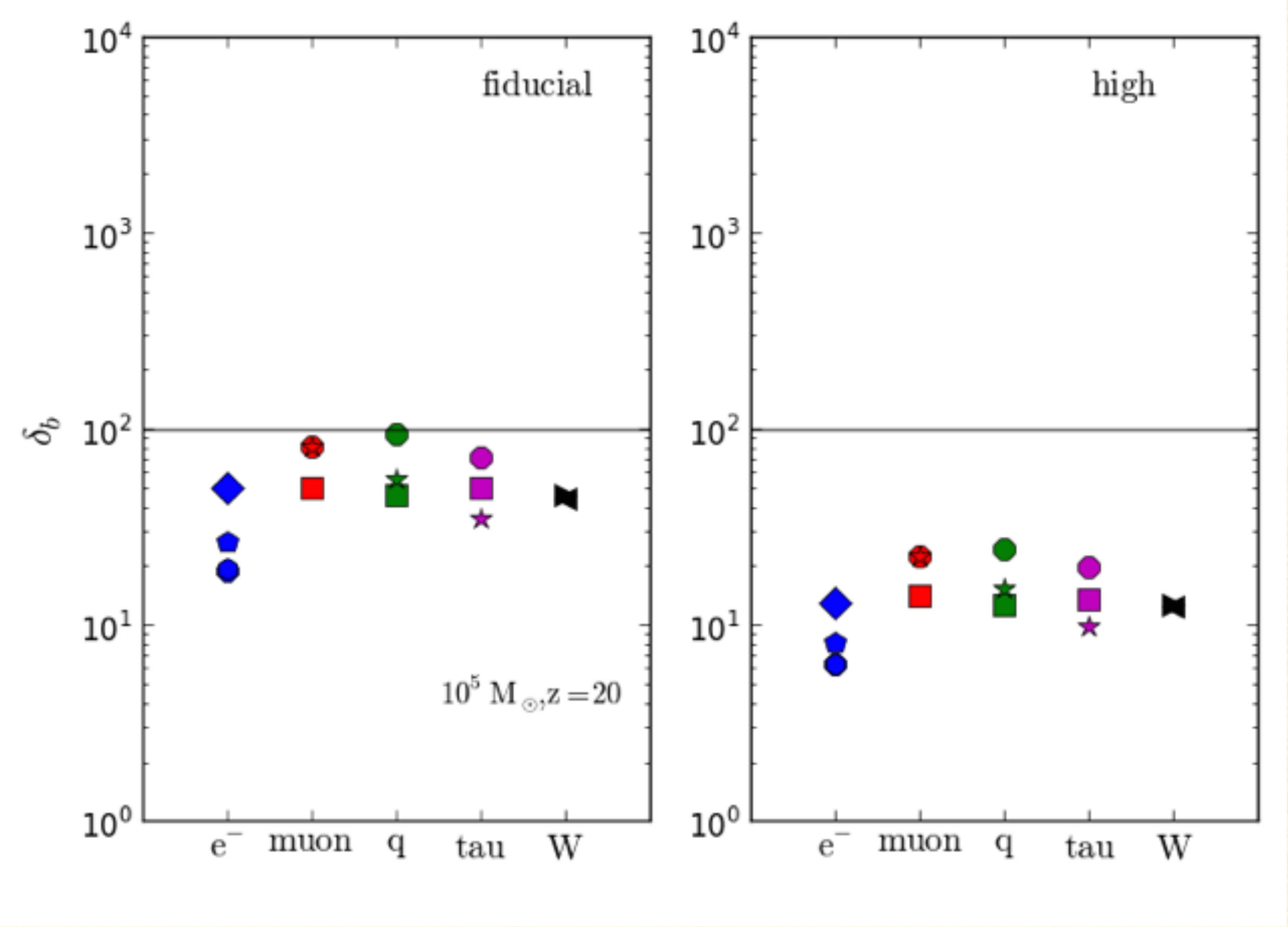
$$T_{vir} = -\frac{1}{3} m_p \phi / k_b$$
$$\bar{T} = \bar{p}_b \mu m_p / k_b \bar{\rho}_b$$

$$\delta_b = \frac{\rho_b}{\bar{\rho}_b} - 1 = \left(1 + \frac{6}{5}\frac{T_{vir}}{\bar{T}}\right)^{\frac{3}{2}} - 1$$

$$\delta_b = \left(1 + \frac{6}{5}\frac{T_{vir}}{(\bar{T} + \Delta T)}\right)^{\frac{3}{2}} - 1$$

Loeb, 2007

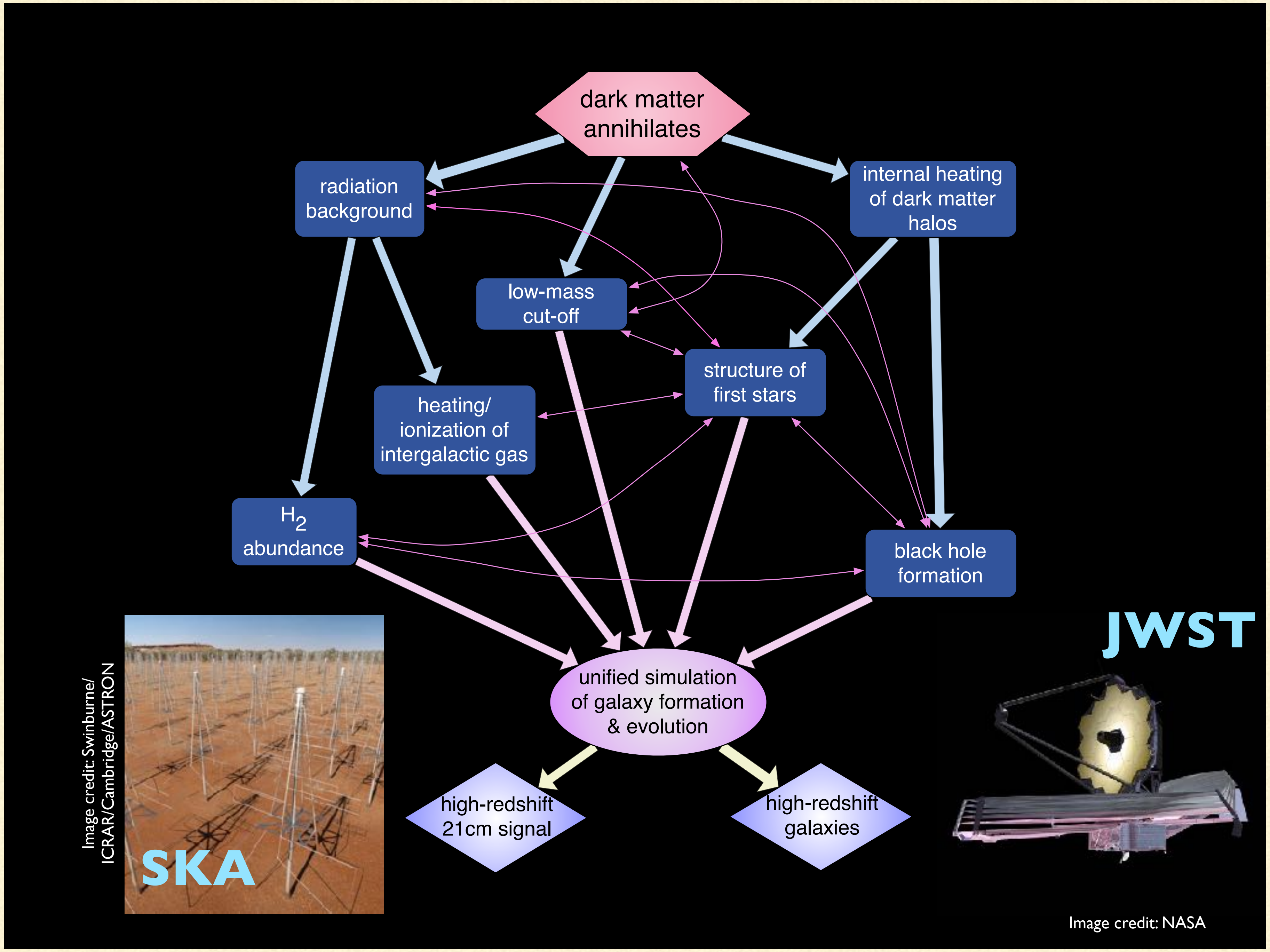
SUPPRESSION OF GAS INFALL



ALL THE STRINGS

- To arrive at a self-consistent description must include and propagate DM energy injection across cosmic history
- IGM heating and ionisation, as well as additional radiation field
- Productions and dissociation of molecular hydrogen
- modification of stellar evolution
- potential formation of exotic objects like Dark Stars and direct collapse black holes

POTENTIAL AVENUES OF DETECTION



CONCLUSIONS

- Astrophysical systems are well suited probes of non-gravitational Dark Matter interactions
- Modification of the galactic and IGM gas's thermo-chemical properties can be used to set bounds on these interactions
- Future observations from the Cosmic Dawn may provide DM signatures that are non-degenerate with the expected baryonic phenomenology
- The usual dark matter-baryon physics detangling caveats apply

Thank You!