Dark Matter at Cosmic Dawn

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PHYSICS
COLLEGE OF SCIENCES

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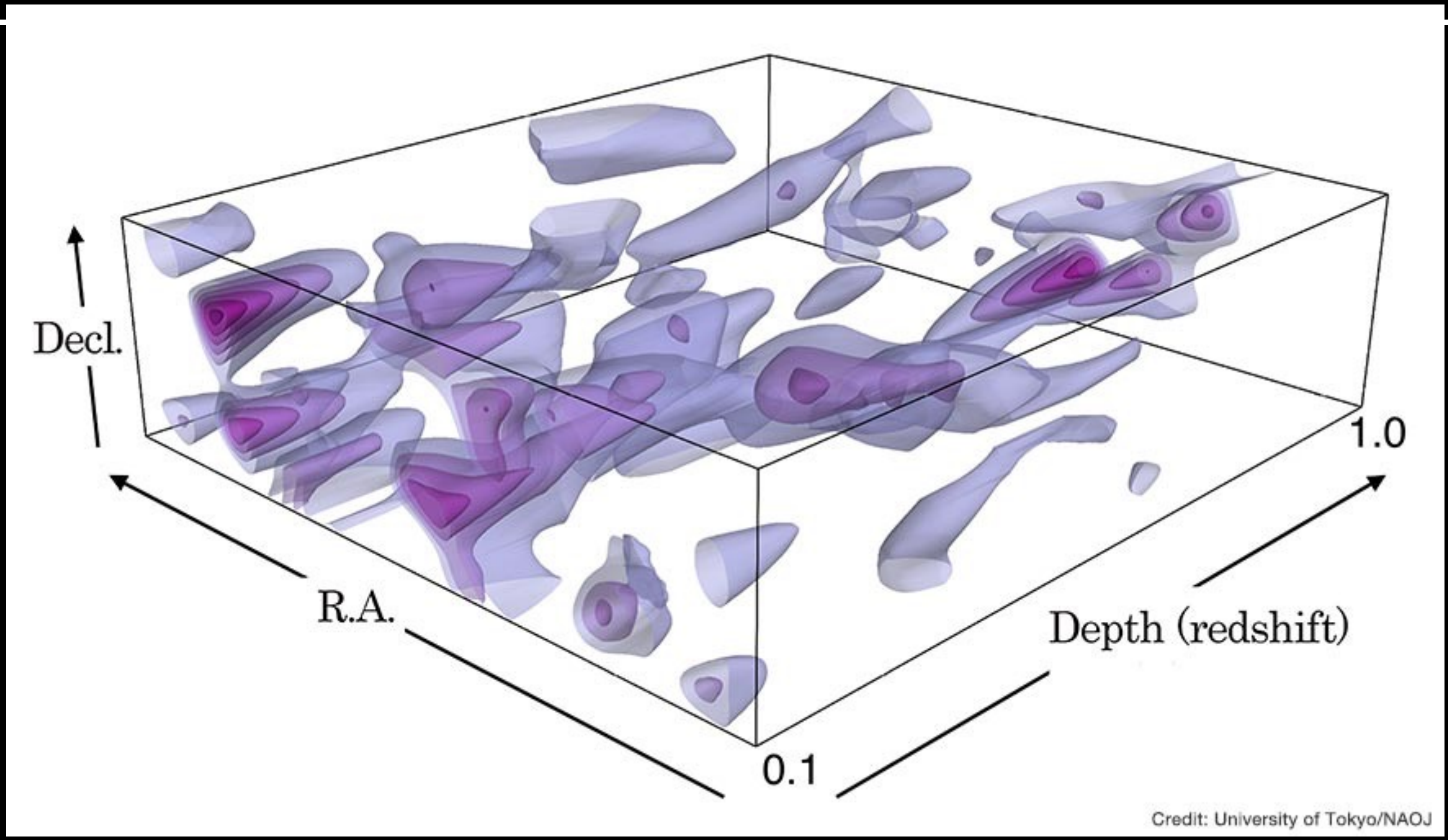
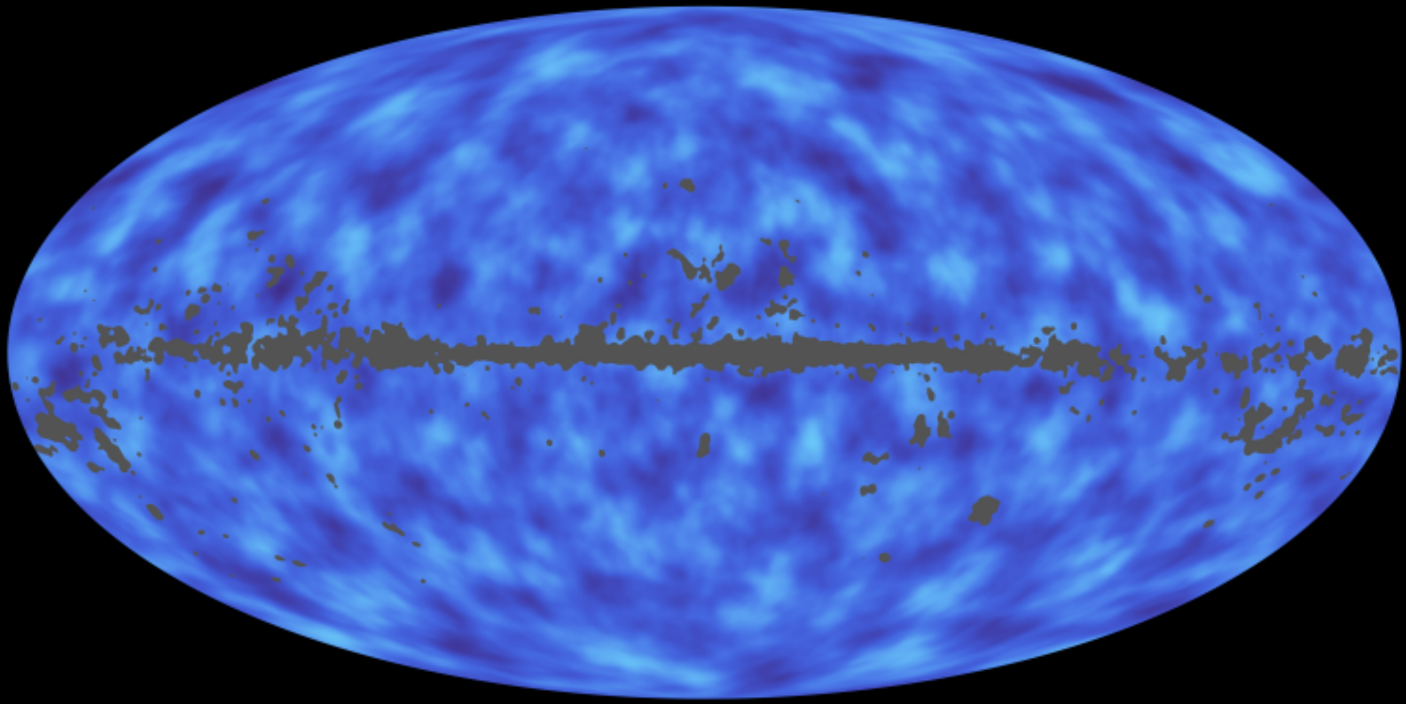
Leadership in Public Science

www.astrokatie.com
: @AstroKatie

What We Do Know

- Where it is
- How much is out there
- What it's doing
- (to some degree) what it isn't





Planck Collaboration

What We Don't Know

Particle Zoo

- Origin / particle type
- Particle mass
- Thermal history
- Non-trivial evolution?
- One component or many?
- Non-gravitational interactions (self or SM)?
- Small-scale behavior (mass of smallest halos)

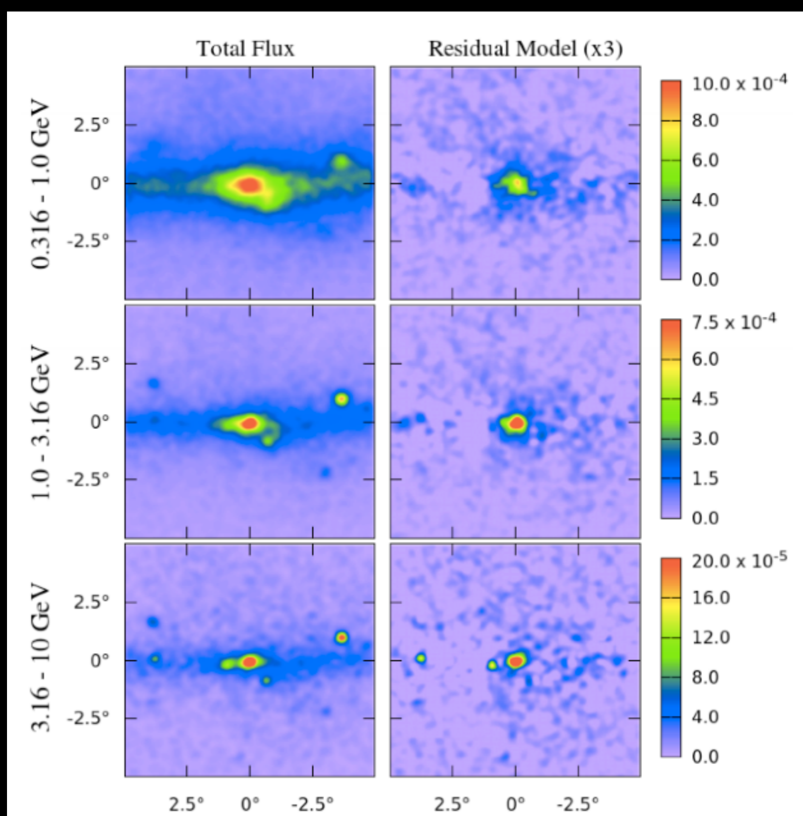
Candidates (incomplete list)

- Weakly Interacting Massive Particles (WIMPs)
  - Something not included in the Standard Model of Particle Physics, generally with weak interactions
  - May be thermally produced (or not)
- Annihilating (e.g., SUSY neutralino WIMP)
- Decaying (e.g., sterile neutrino)
- Warm (WDM) (e.g., axino)
- Self-interacting (SIDM) (particle + dark sector force)
- Axion (e.g., QCD axion / string axion) (Mack 2011; Mack & Steinhardt 2011)
- Fuzzy DM (tiny mass, large deBroglie wavelength)
- MACHO (e.g., primordial black holes) (Mack, Ostriker & Ricotti 2007; R,O,M 2008)

Possible Hints/Signals from Indirect Detection

Annihilation?

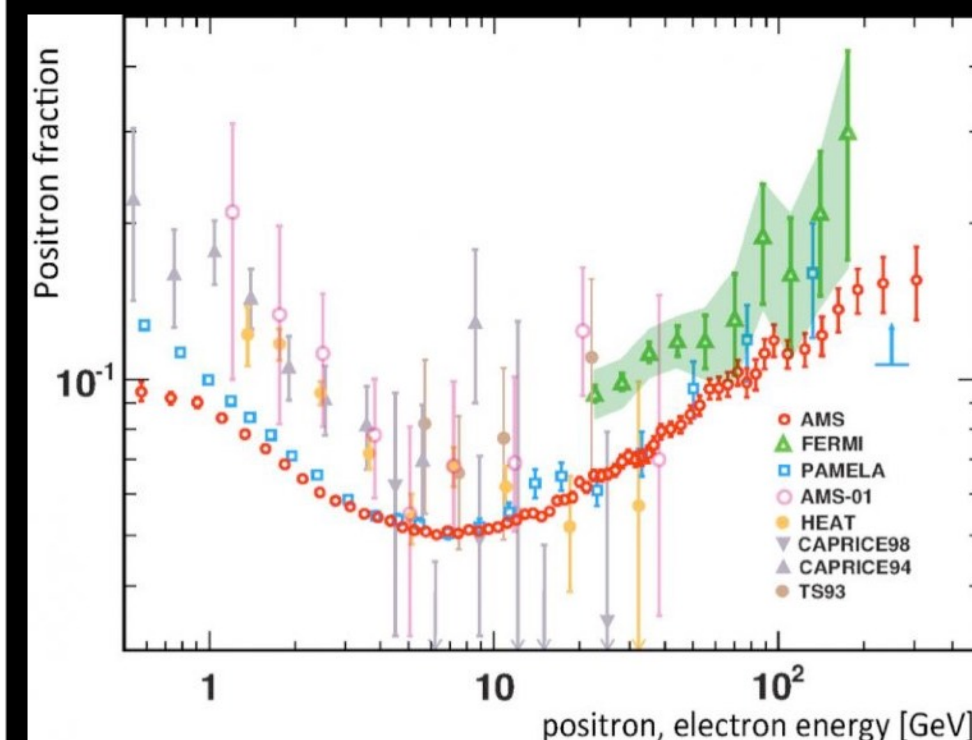
Gamma rays in the Galactic Center



Daylan et al. 2014

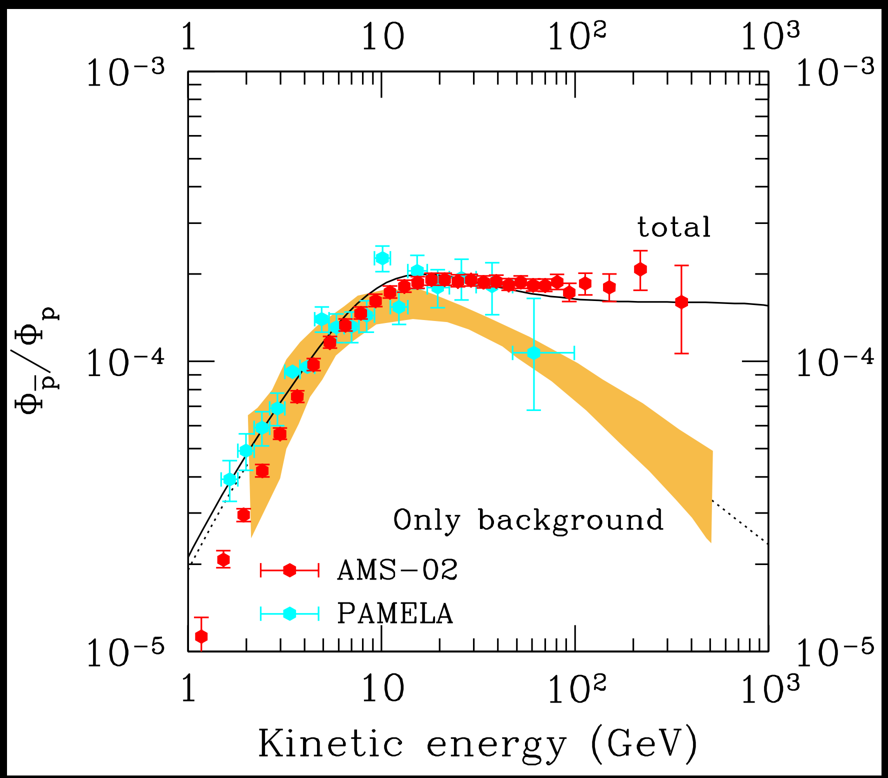
... but maybe pulsars

Excess positrons at high energy



AMS Collaboration 2013

Excess antiprotons at high energy



Kohri et al. 2015

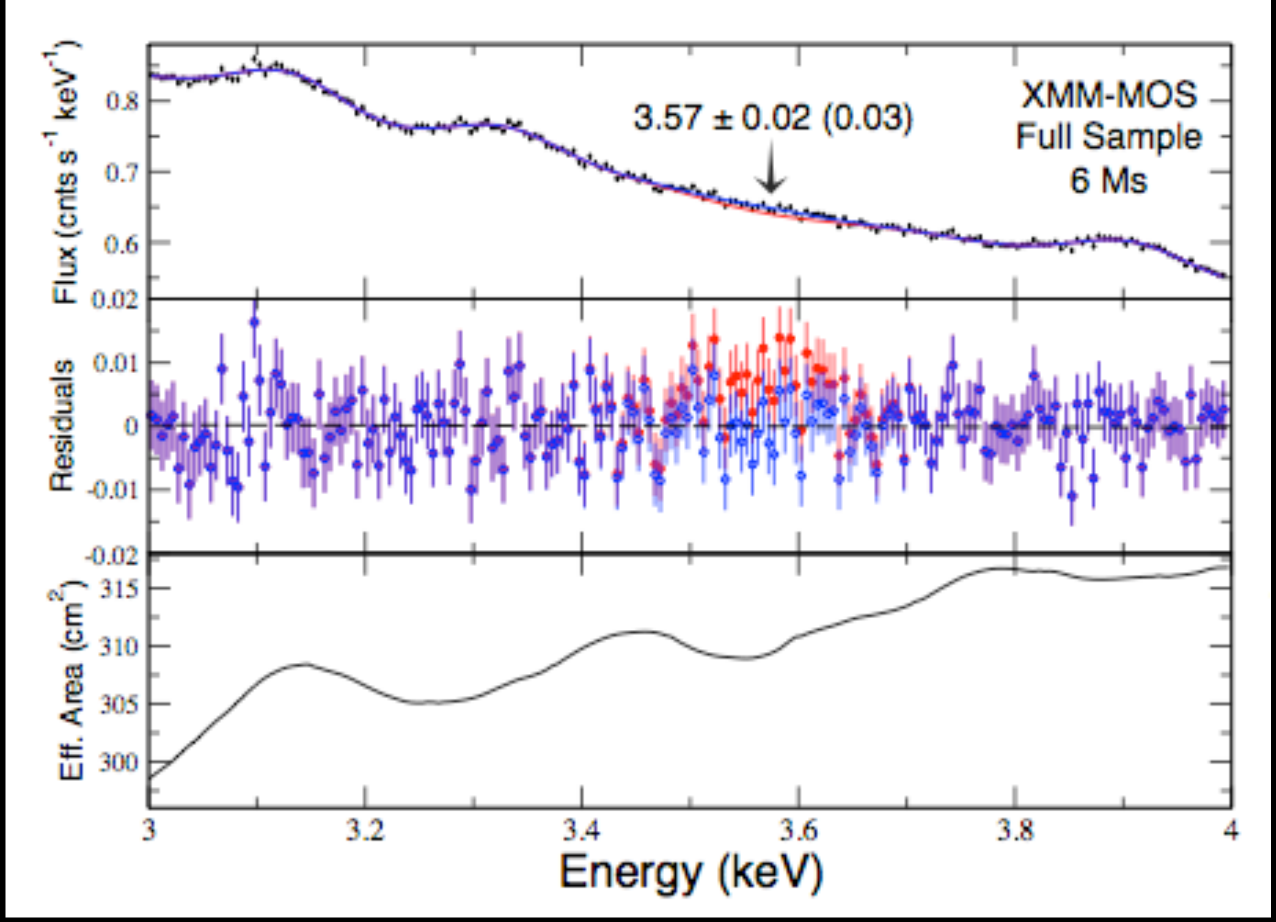
Not pulsars!

... but maybe supernova remnant

... or background uncertainties

Decay?

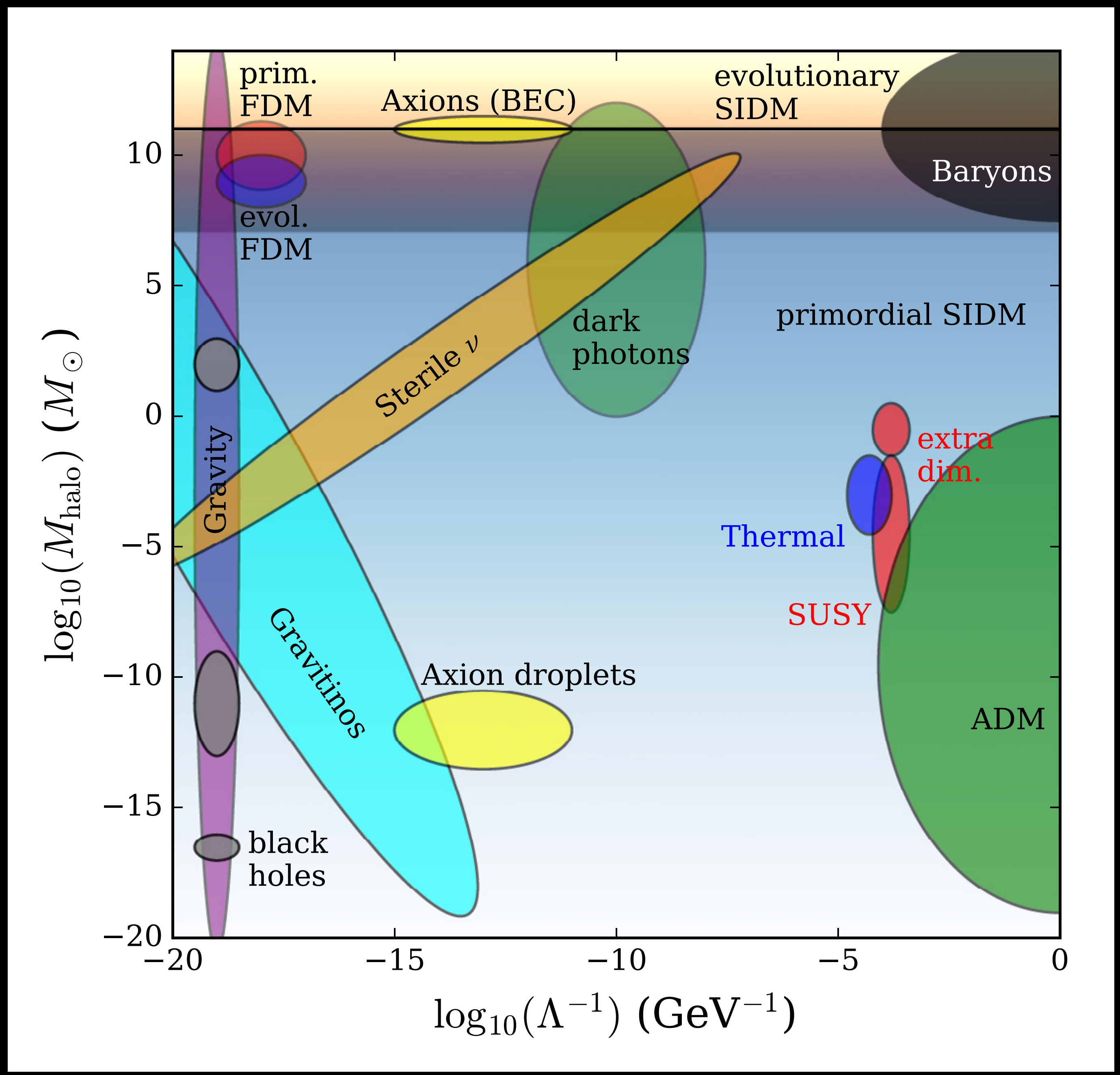
Excess x-rays in galaxy clusters



Bulbul et al. 2014

... but maybe line contamination

Astrophysical Impact



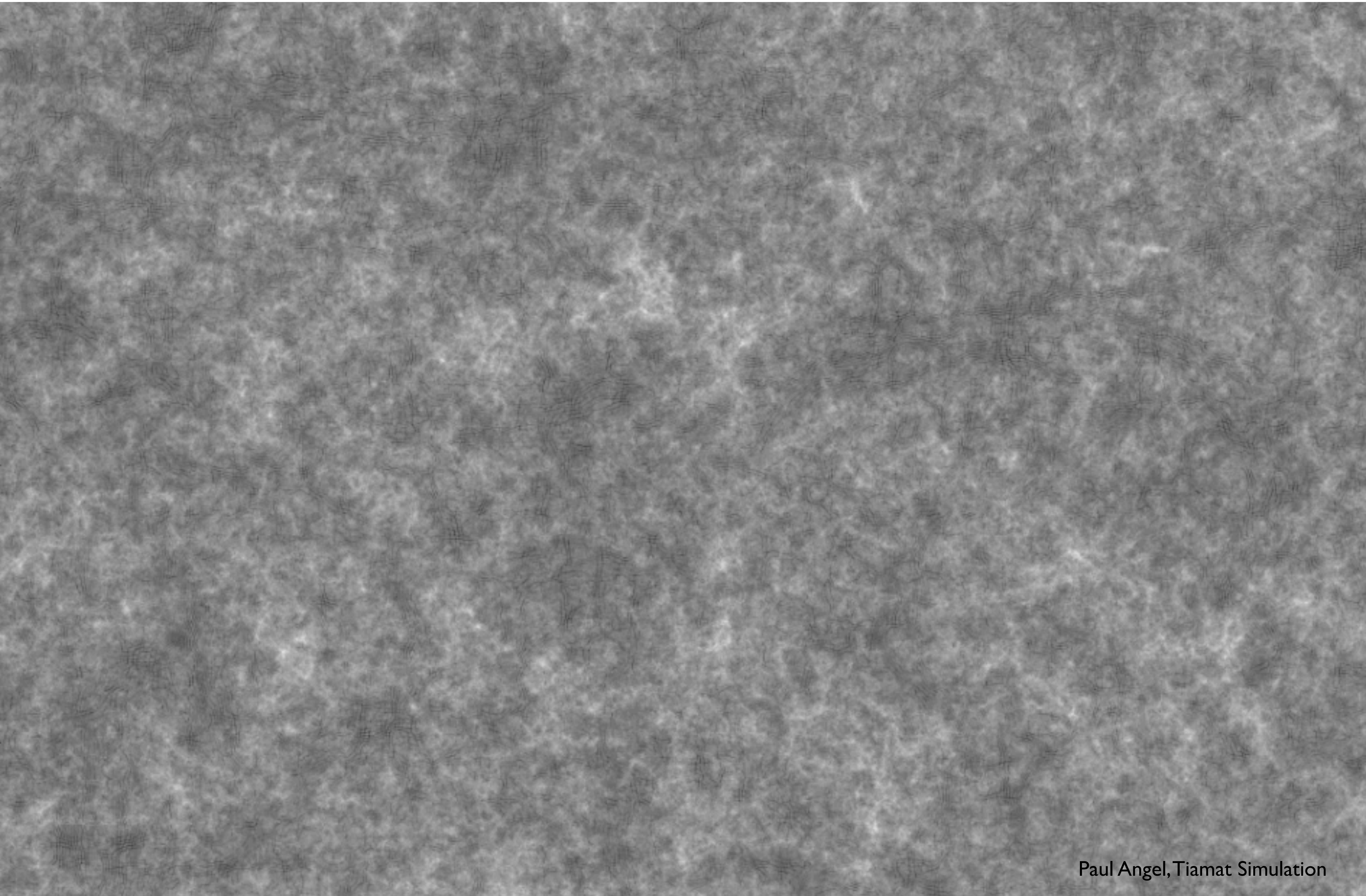
halo mass vs SM interaction

(where we expect to see a deviation from CDM)

Peter & Buckley 2018

The Cosmic Frontier

Dark Matter: Cosmology

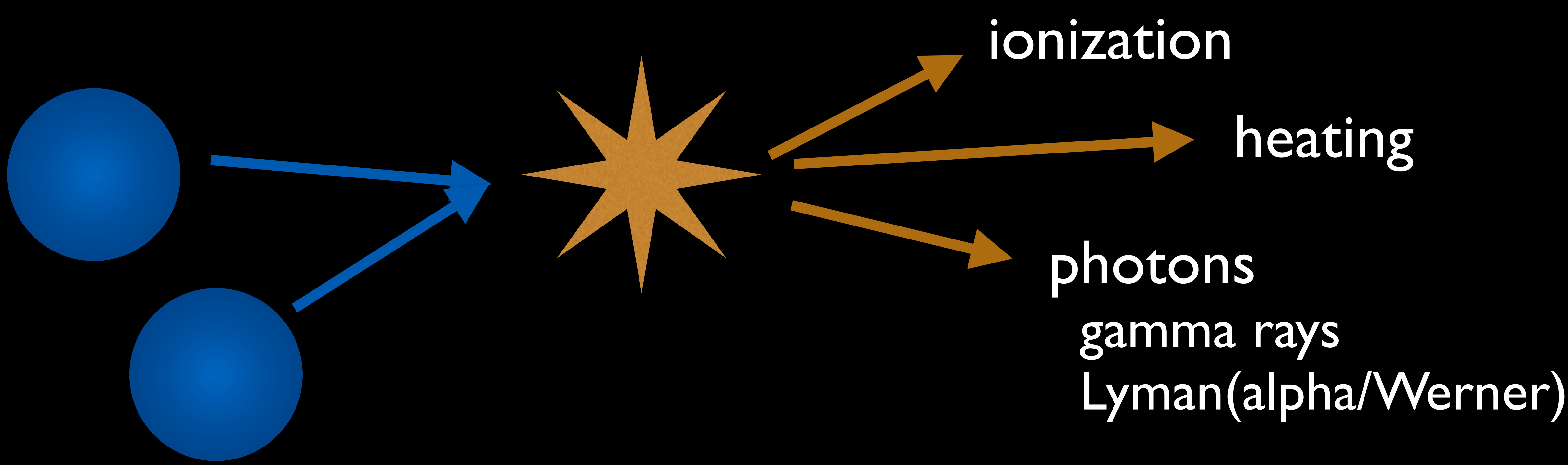


Paul Angel, Tiamat Simulation

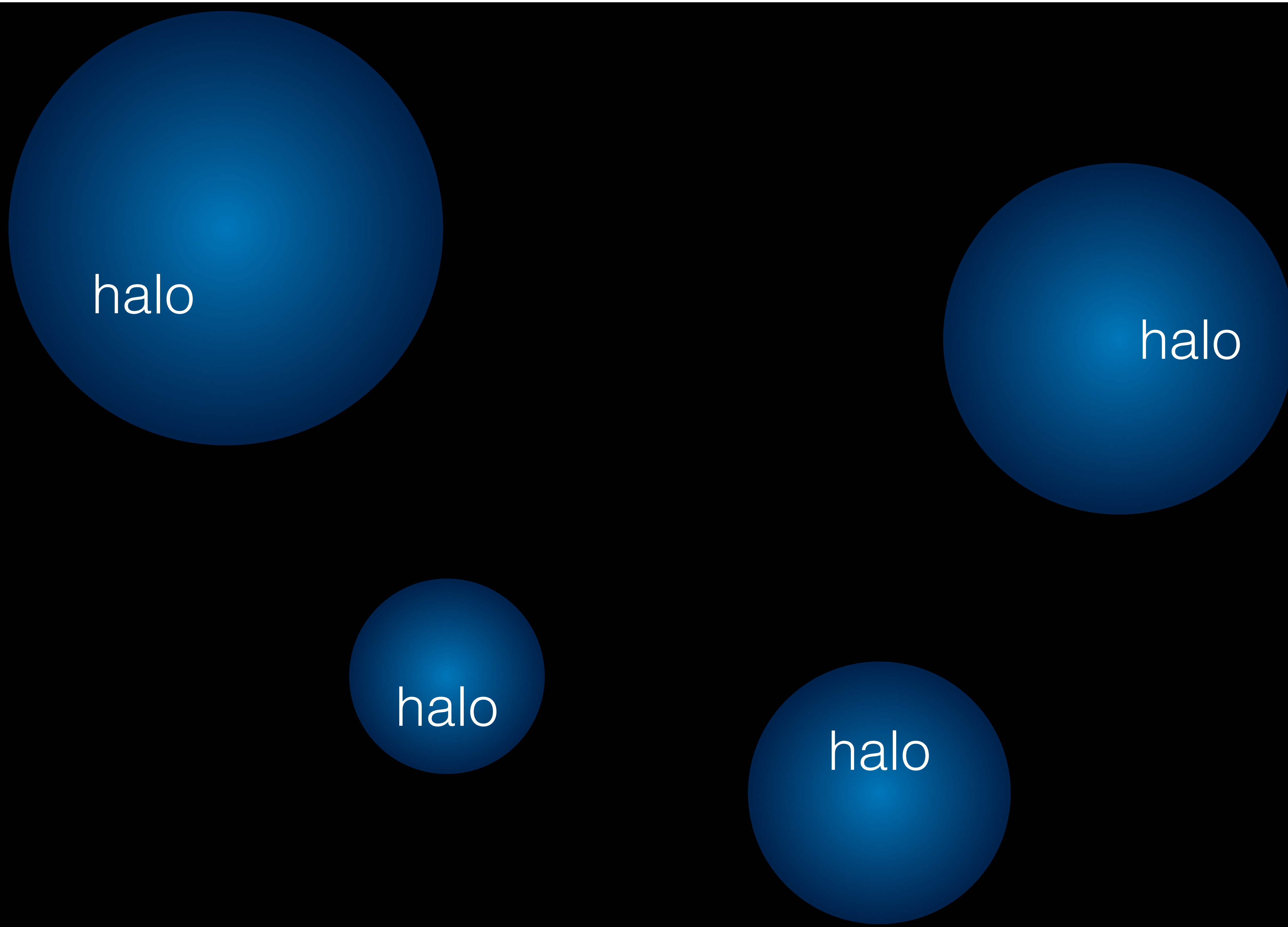
Impact of Dark Matter Annihilation

Major unanswered question:

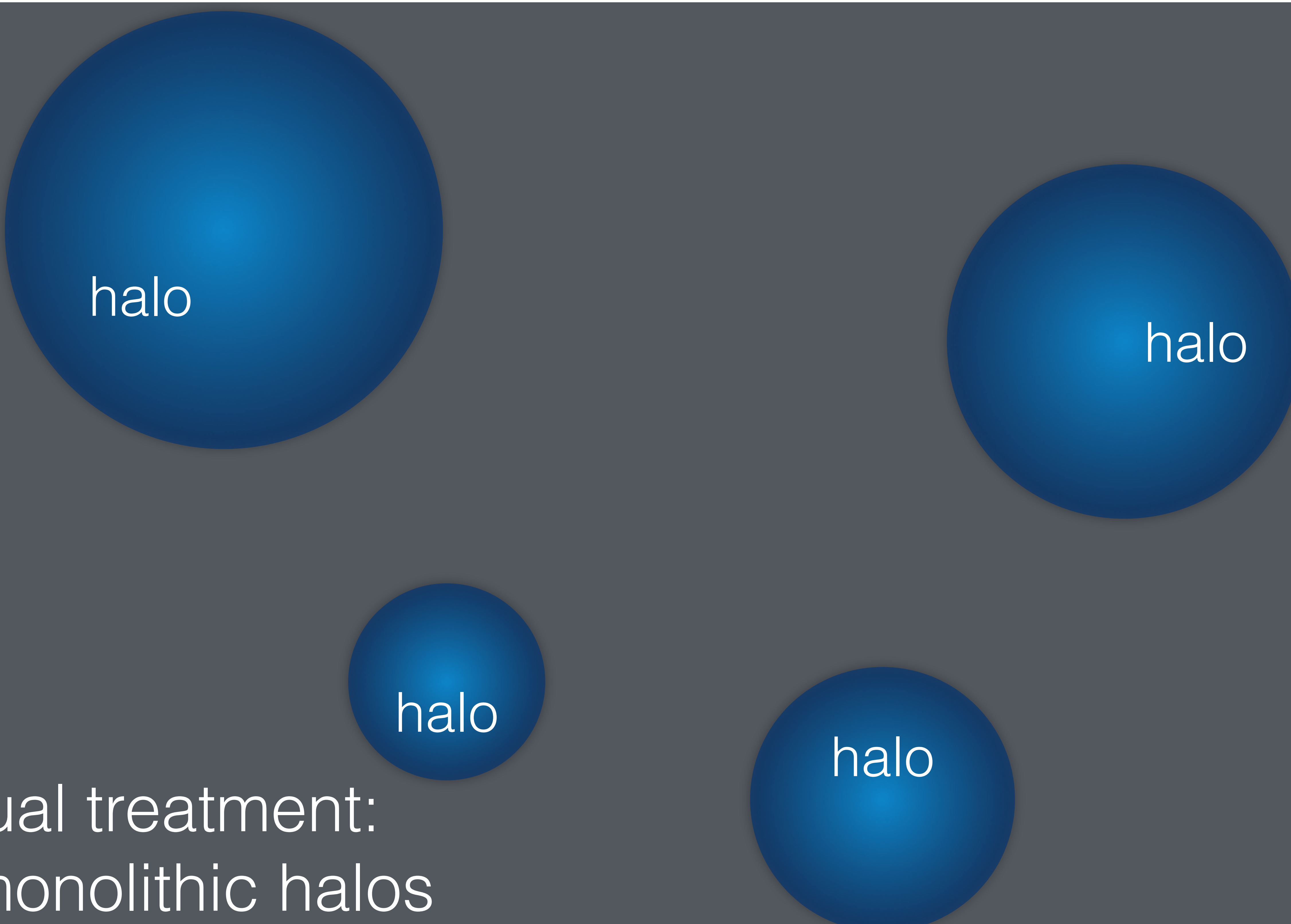
If dark matter **annihilates** across all of cosmic time, **how does it affect the first stars and galaxies?**



Annihilation in the Intergalactic Medium



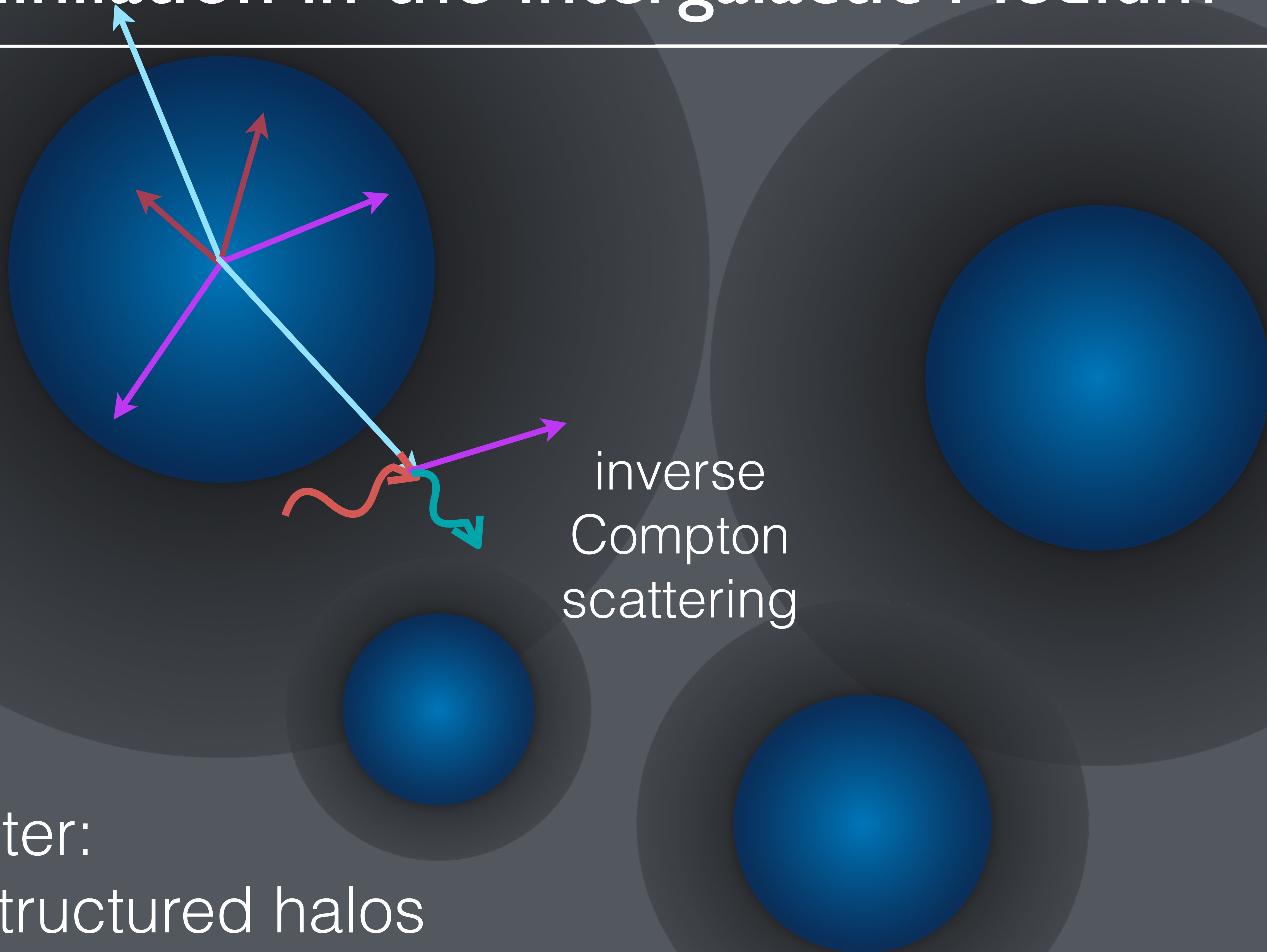
Annihilation in the Intergalactic Medium



Usual treatment:

- monolithic halos
- immediate uniform energy deposition

Annihilation in the Intergalactic Medium

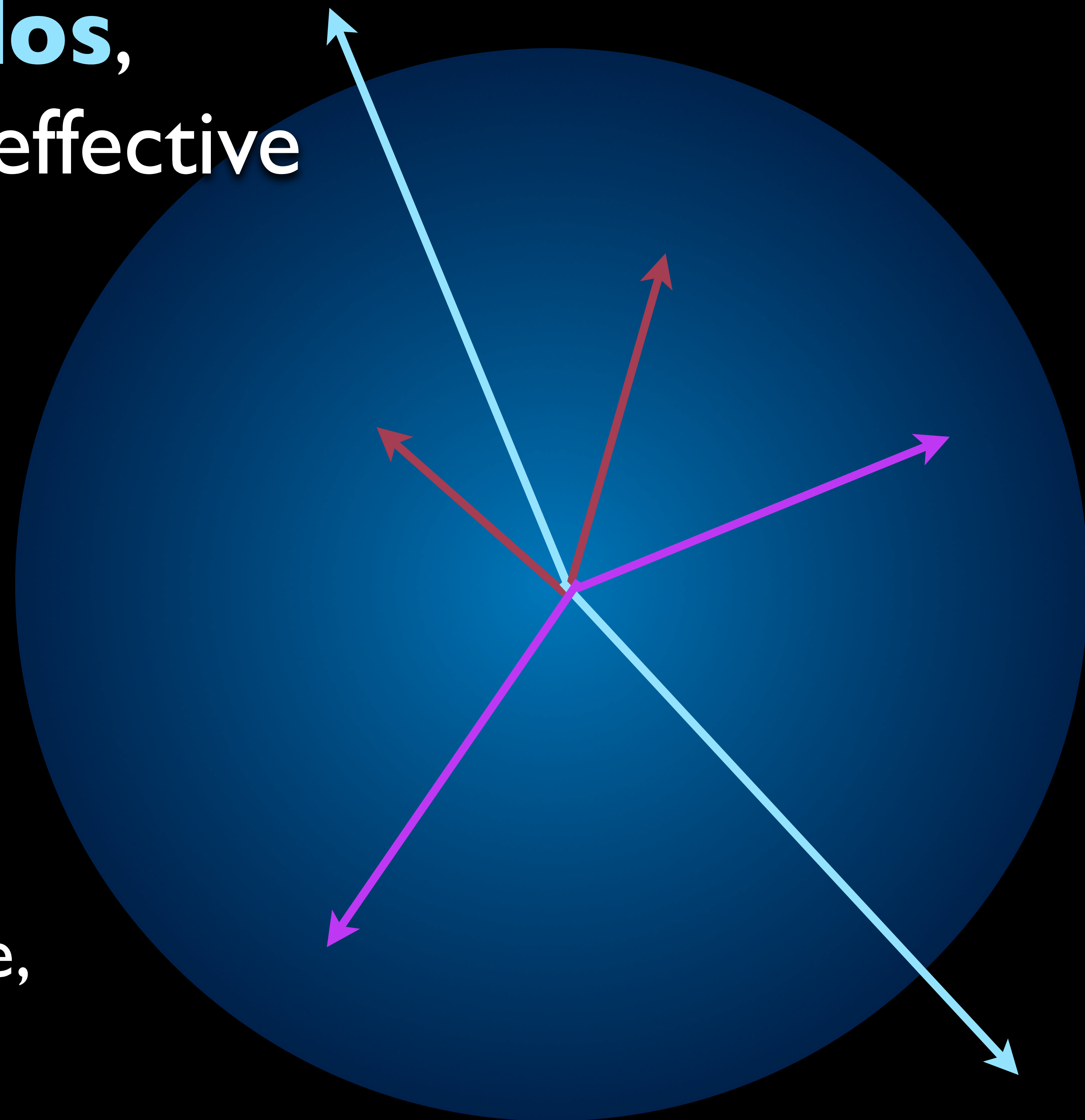


Better:

- structured halos
- delayed energy deposition

Annihilation Feedback on Halo Gas

If dark matter is annihilating **within baryonic halos**, does this constitute an effective **“feedback”** process?

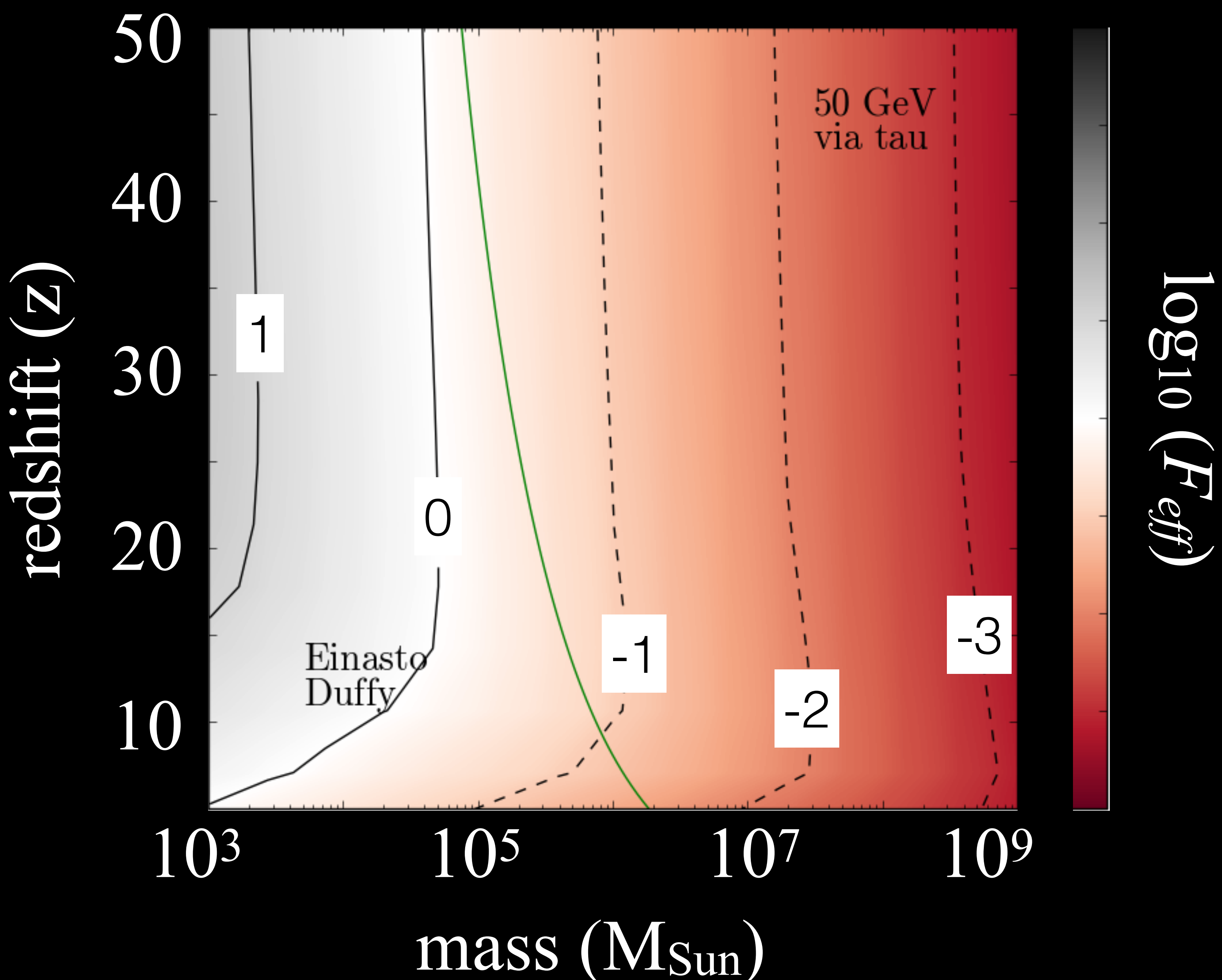


PYTHIA code: dark matter annihilation events

MEDEA2 code: energy transfer to baryons

Halo models: density profile, mass-concentration

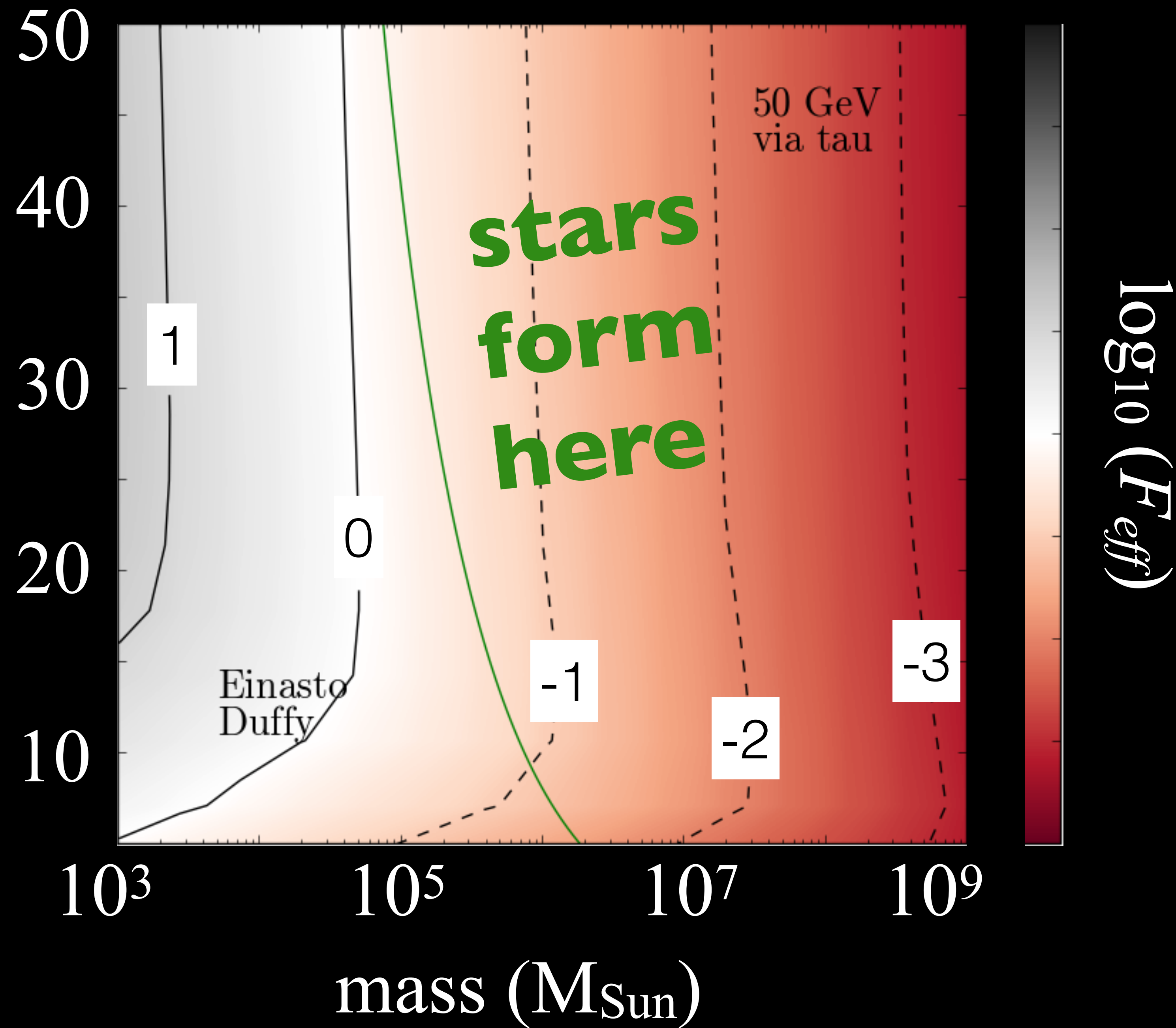
Annihilation Feedback on Halo Gas



Comparing:
dark matter annihilation energy
(over Hubble time)
to:
gas binding energy

Schon, Mack+ 2015, MNRAS [arxiv: 1411.3783]

Annihilation Feedback on Halo Gas



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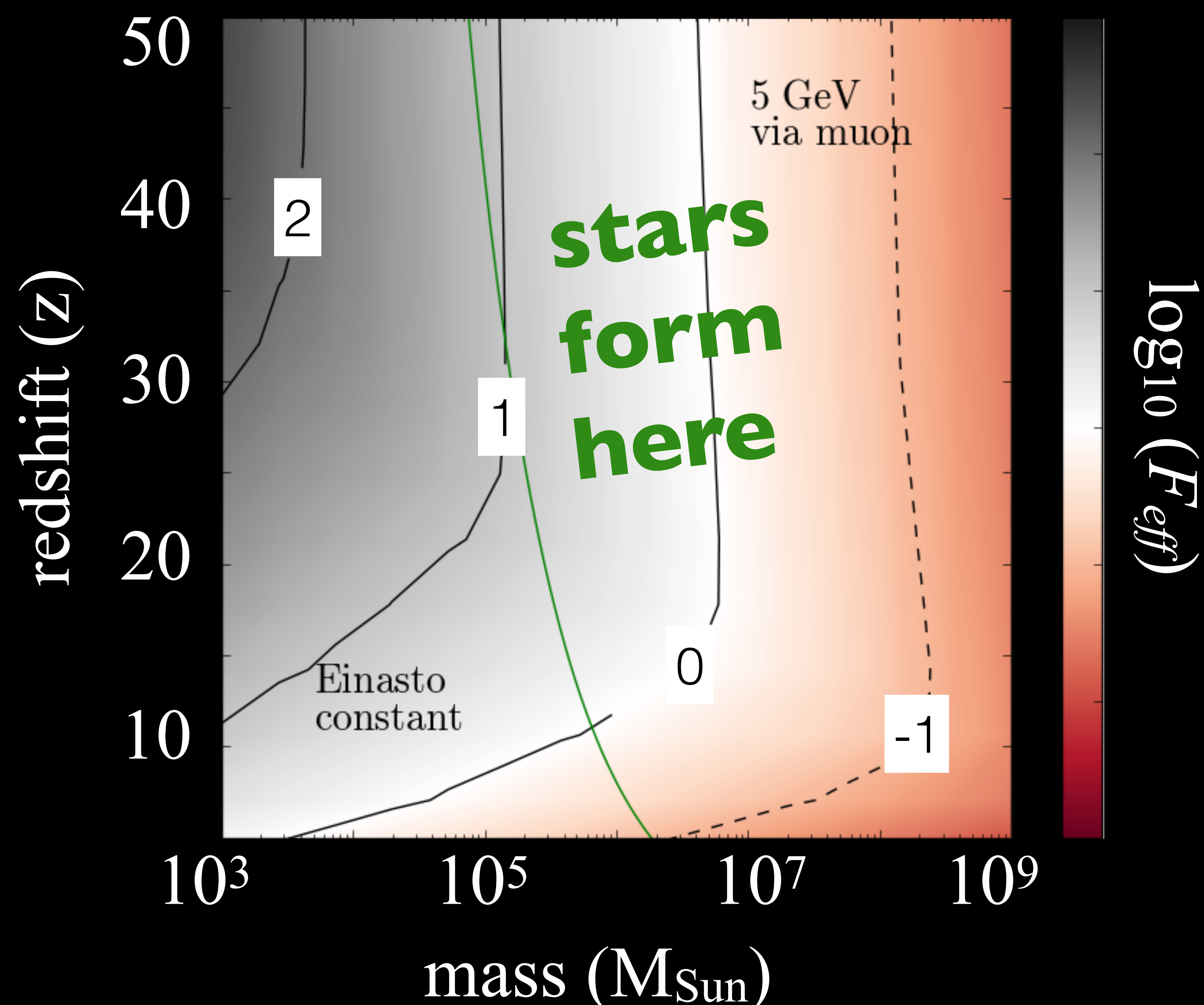

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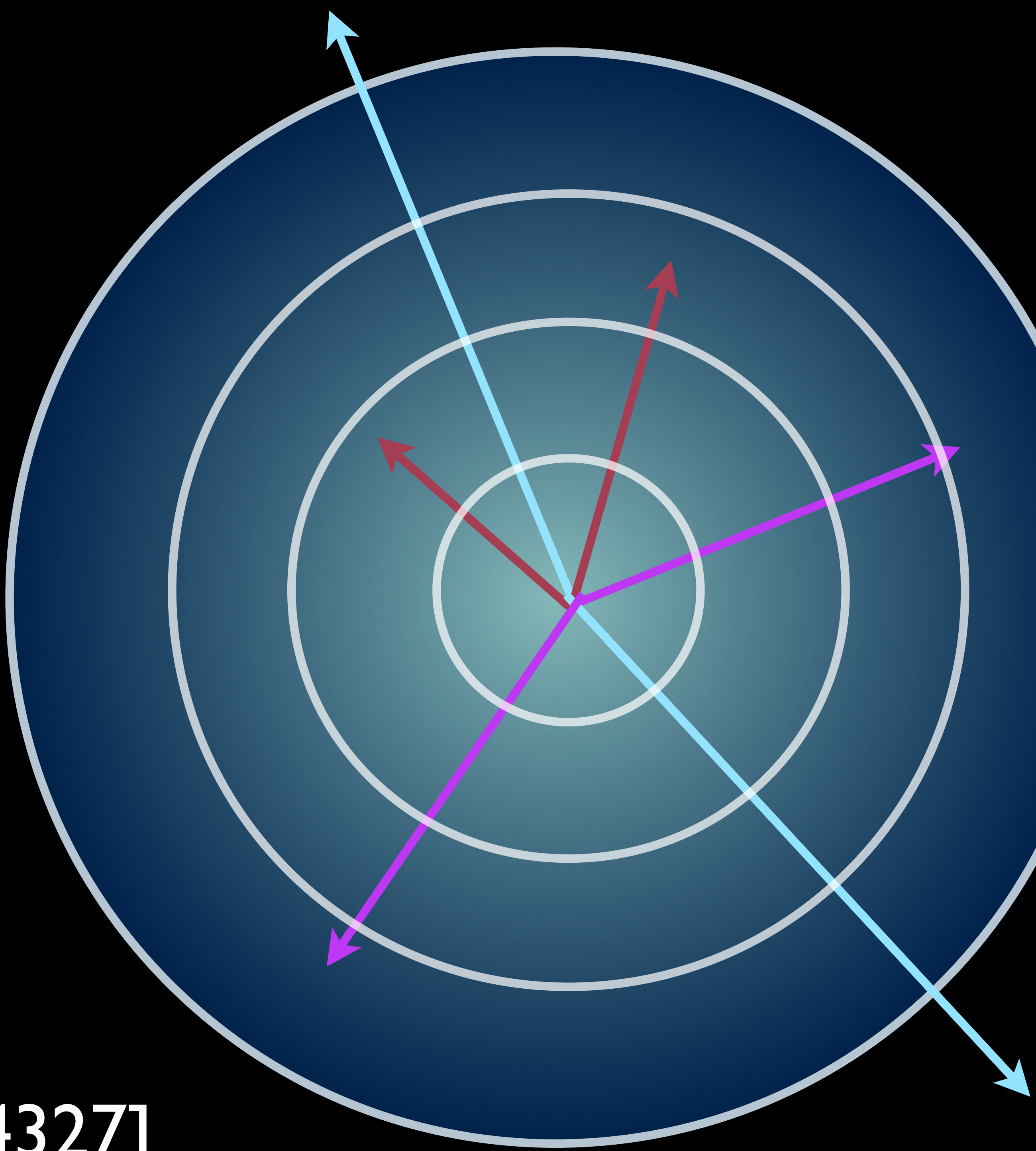
Halo Structure and Environment

Improved code: tracks full particle cascades & deposition within halos

Main questions:

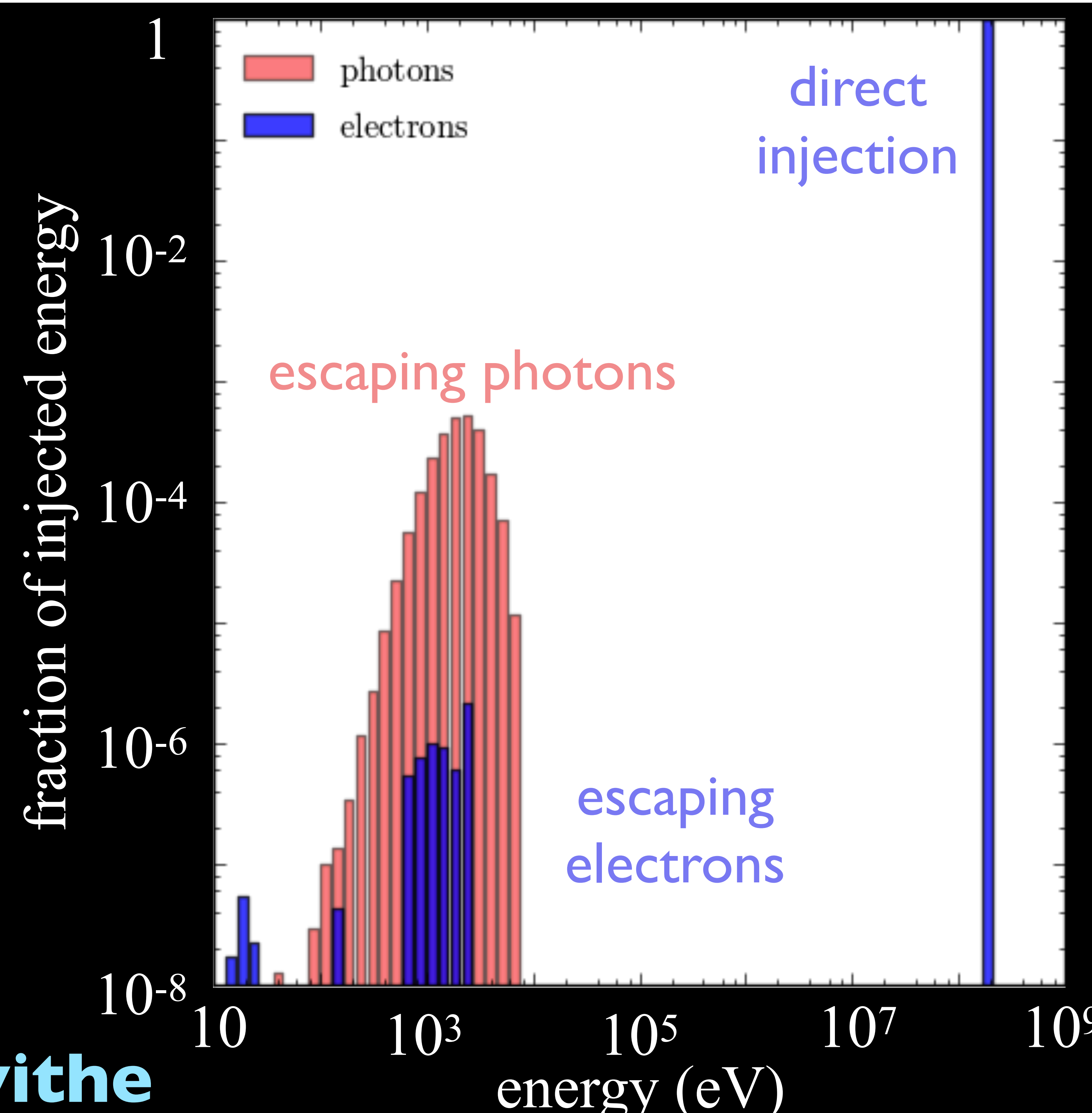
- Where is the energy deposited?
- What is the effect on the halo environment?



Schon, Mack & Wyithe 2018, MNRAS [arxiv:1706.04327]

Halo Structure and Environment

Annihilation products **filtered** through halo baryons



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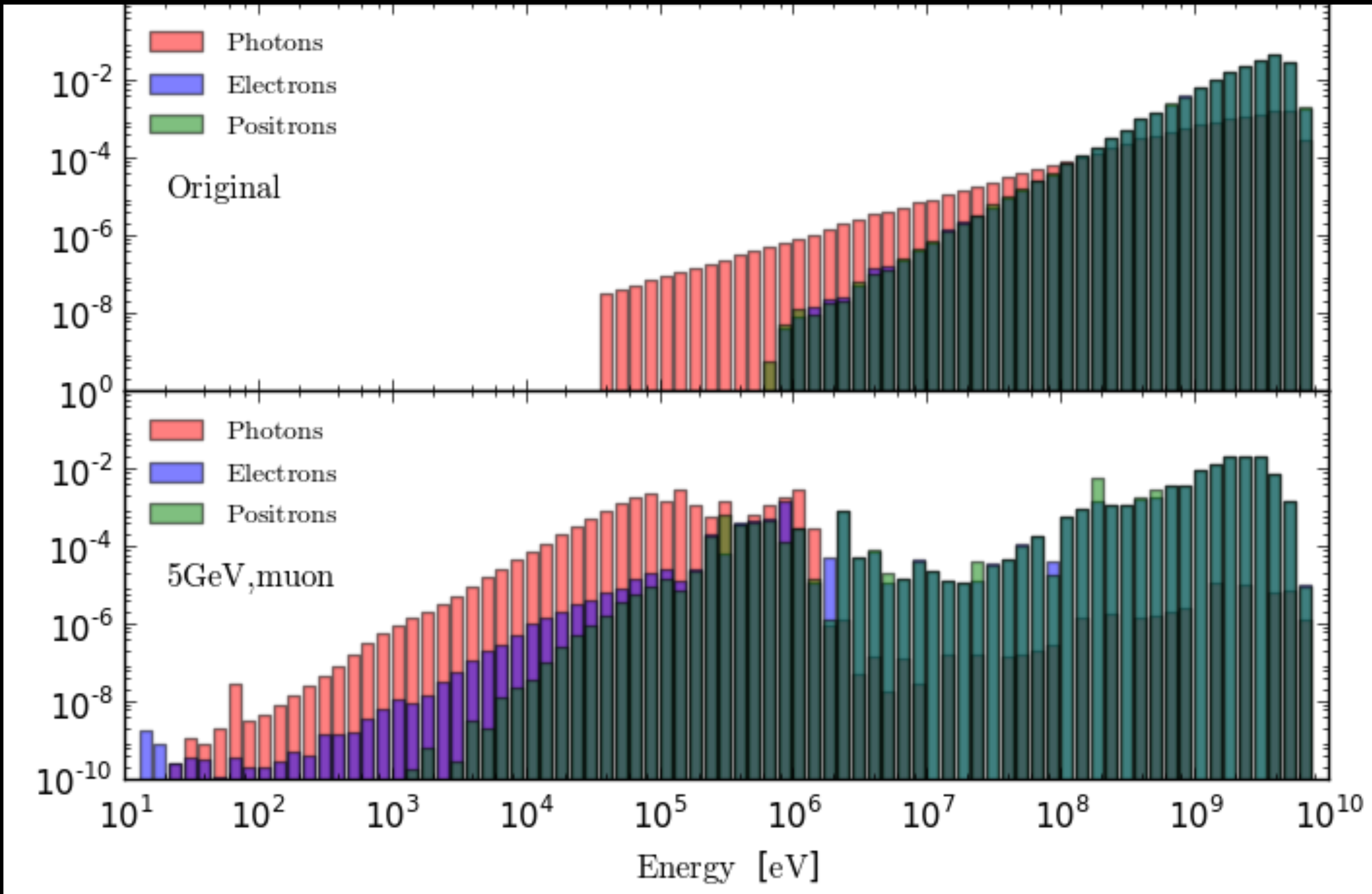
Halo Structure and Environment



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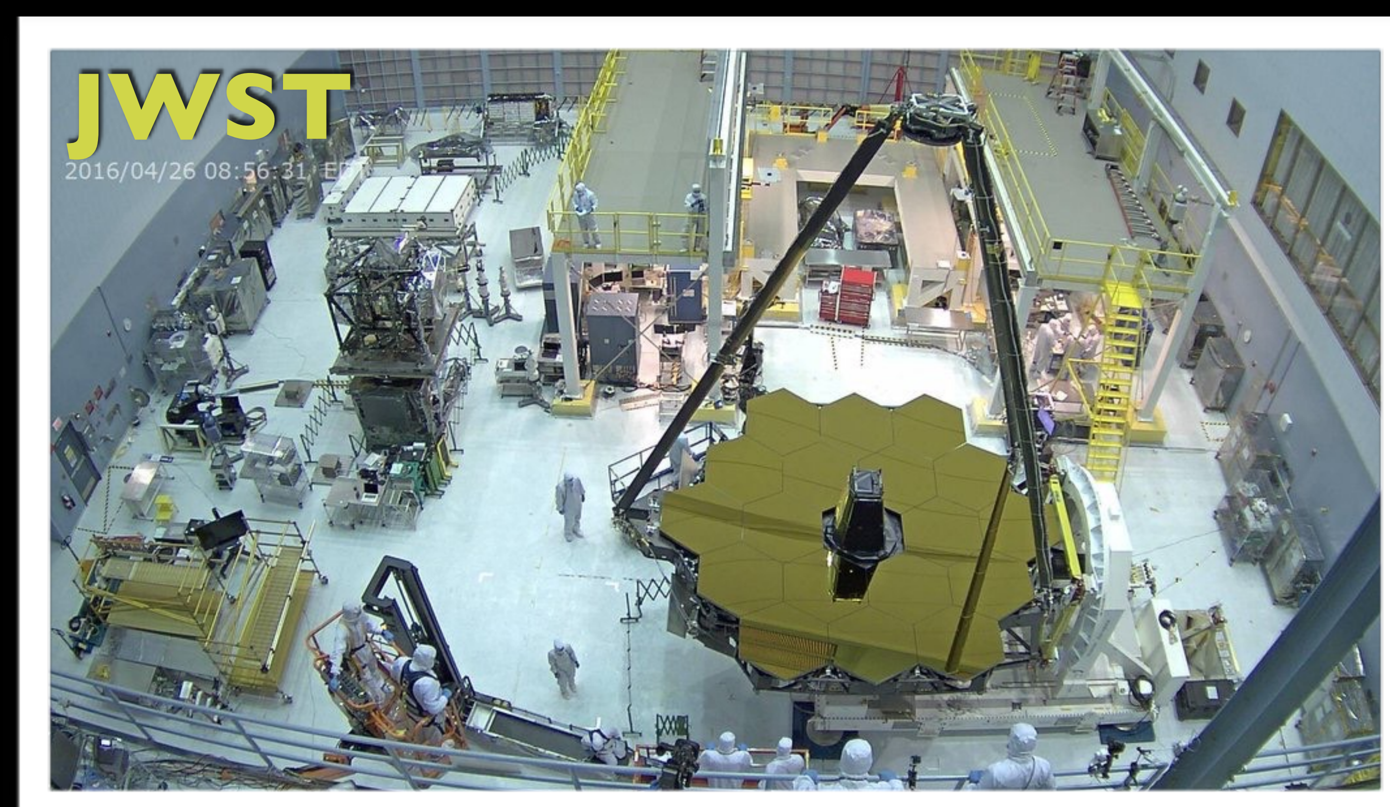
Probing Cosmic Dawn

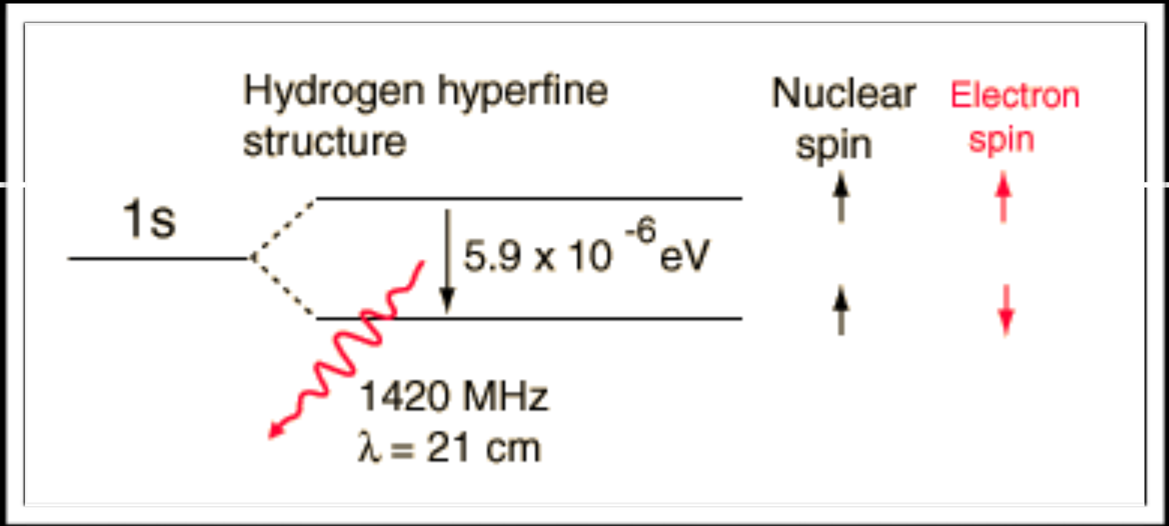
Djorgovski et al., Caltech

current instruments

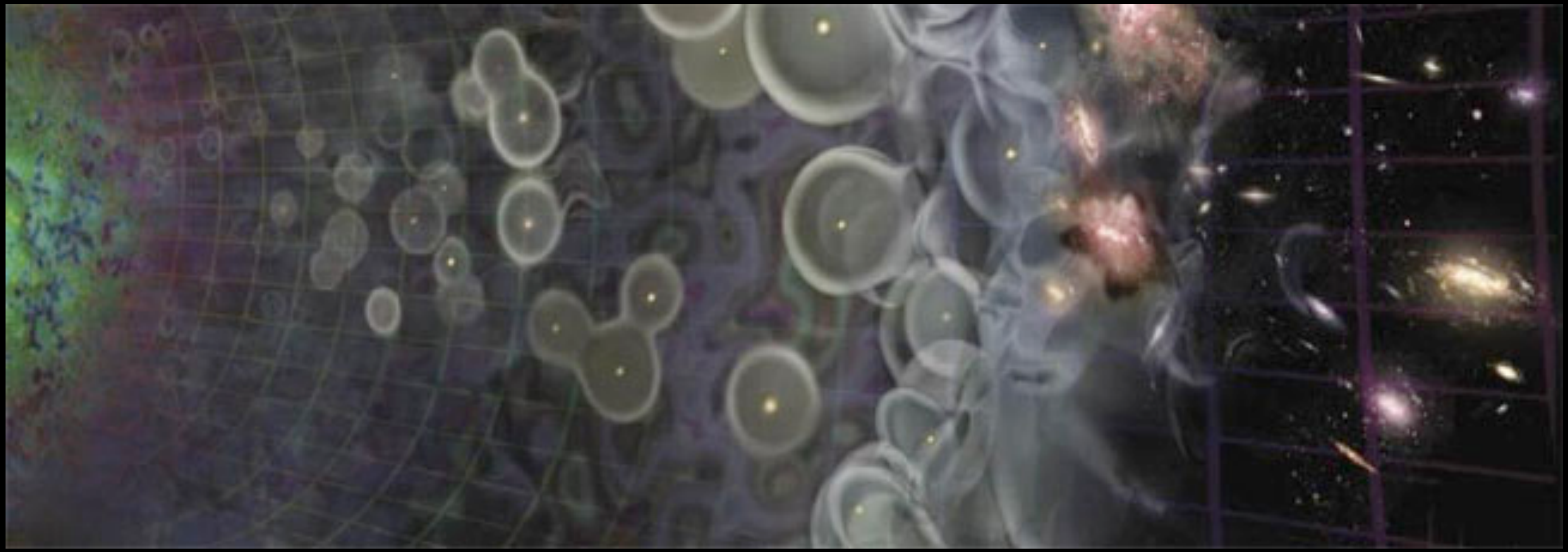
next decade



The 21cm Line



- Advantages for studying reionization / dark ages:
  - Unsaturated line => strong dependence on H properties, low attenuation
  - Can be seen in absorption or emission against CMB -- no bright source needed



z=50 ν=28 MHz

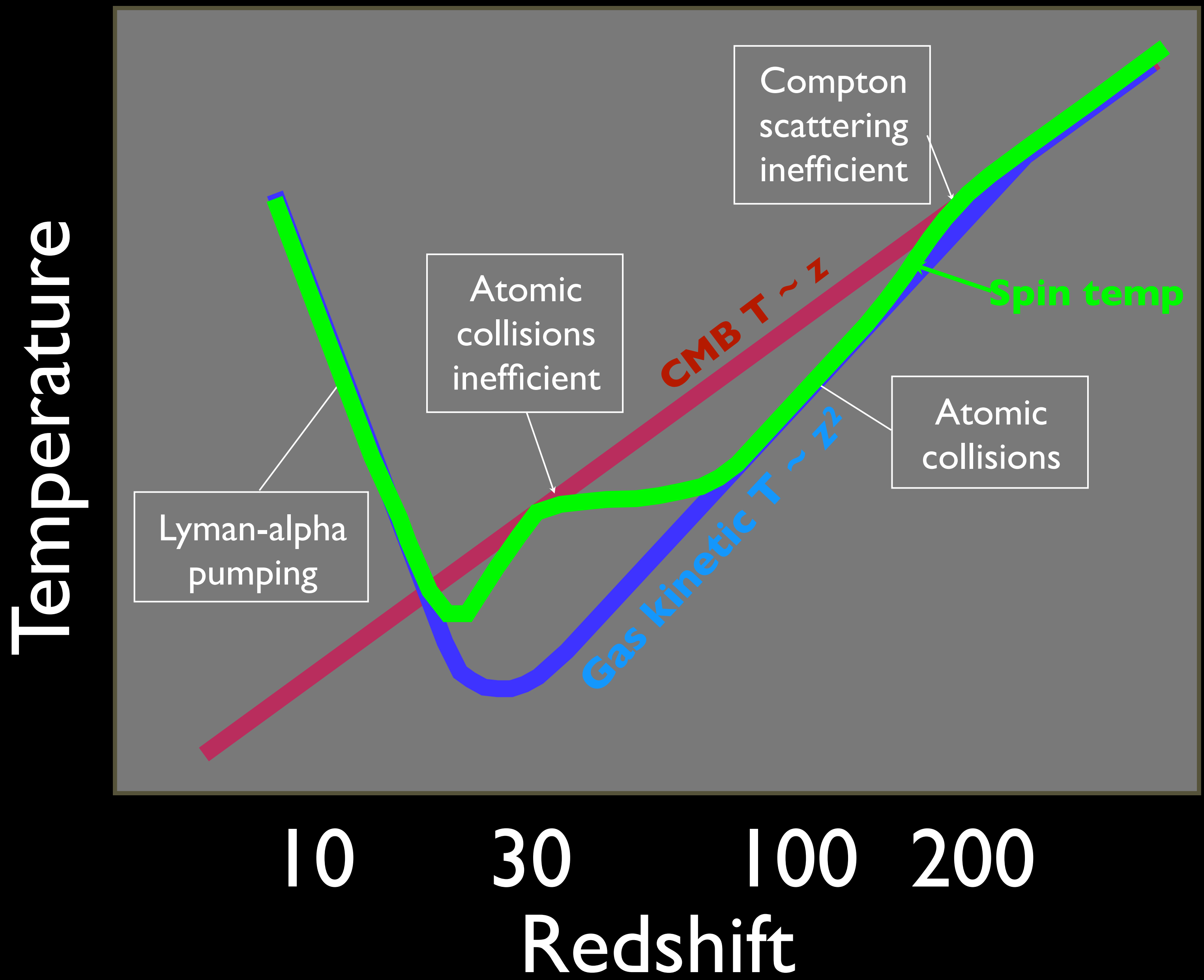
z=20 ν=70 MHz

z=13 ν=100 MHz

z=6 ν=200 MHz

z=0 ν=1420 MHz

High-redshift 21cm Astronomy

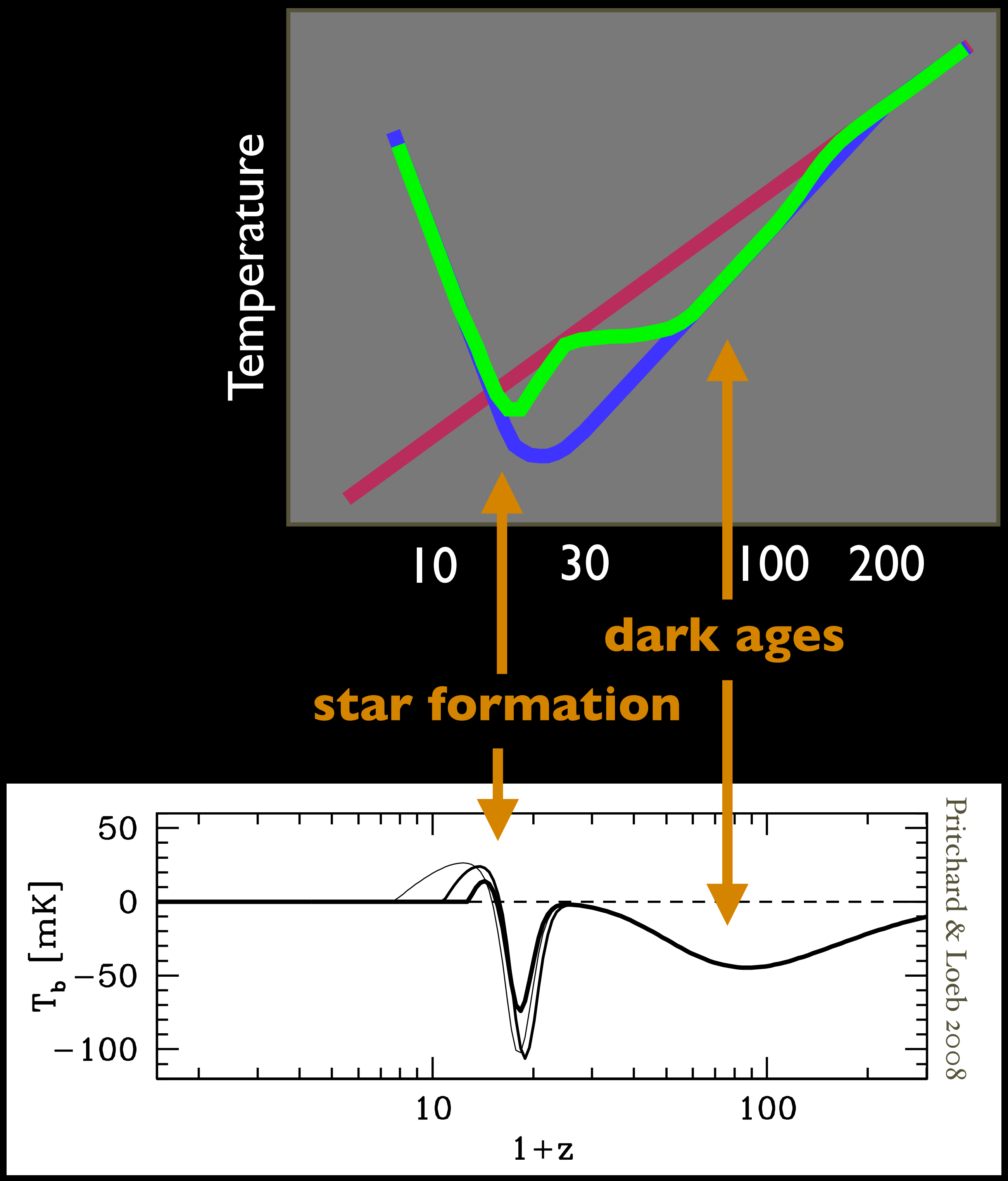


$$\frac{n_1}{n_0} = 3 \exp\left\{-\frac{T_*}{T_S}\right\}$$

$$T_S = \frac{T_{\rm CMB} T_k (1 + x_{\rm tot})}{T_k + T_{\rm CMB} x_{\rm tot}}$$

- The spin temperature determines the relative occupancy of the hyperfine levels

High-redshift 21cm Astronomy

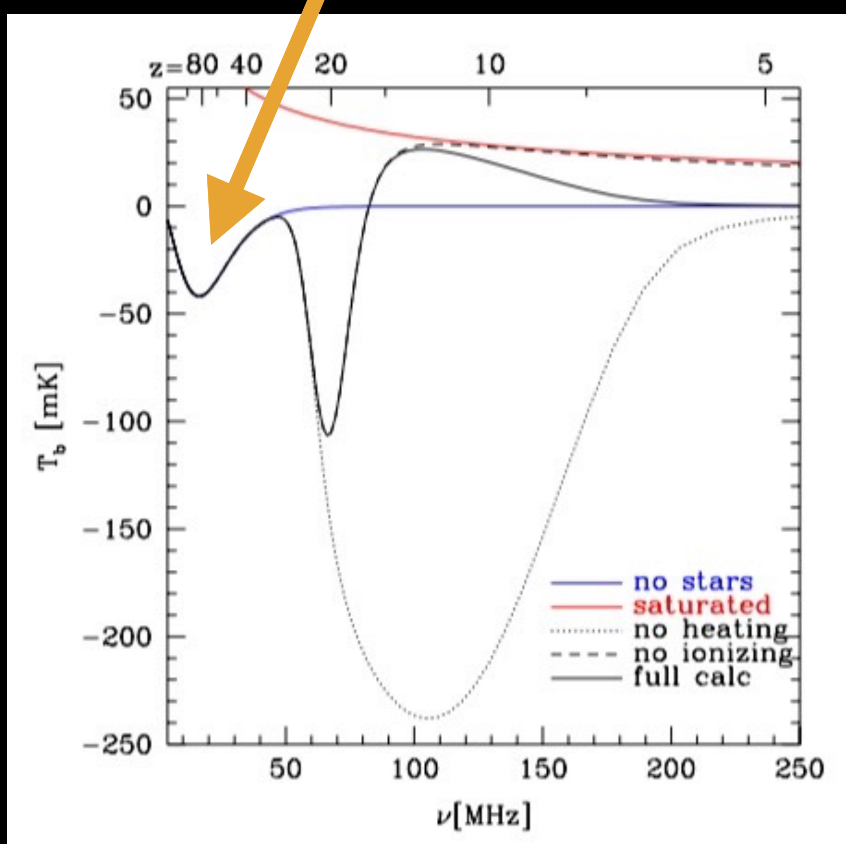


- The spin temperature determines the relative occupancy of the hyperfine levels
- The brightness temperature measured by observations is determined by the spin temperature's coupling to the CMB temperature

$$T_b \propto \frac{T_s - T_\gamma}{T_s}$$

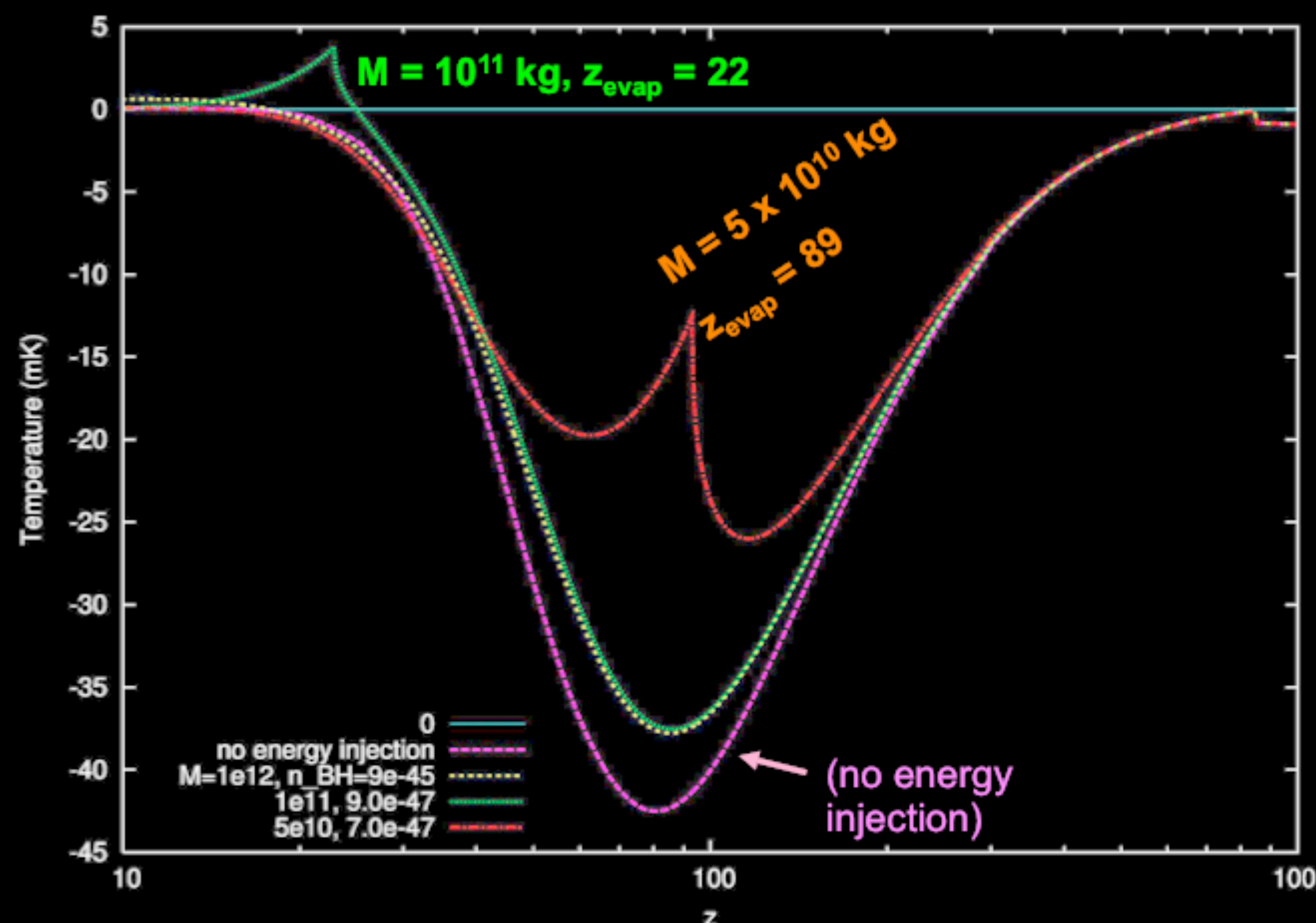
Exotic Physics & 21cm

Anything injecting energy in the Dark Ages: smoking gun for exotic physics



Unfortunately: very difficult to observe

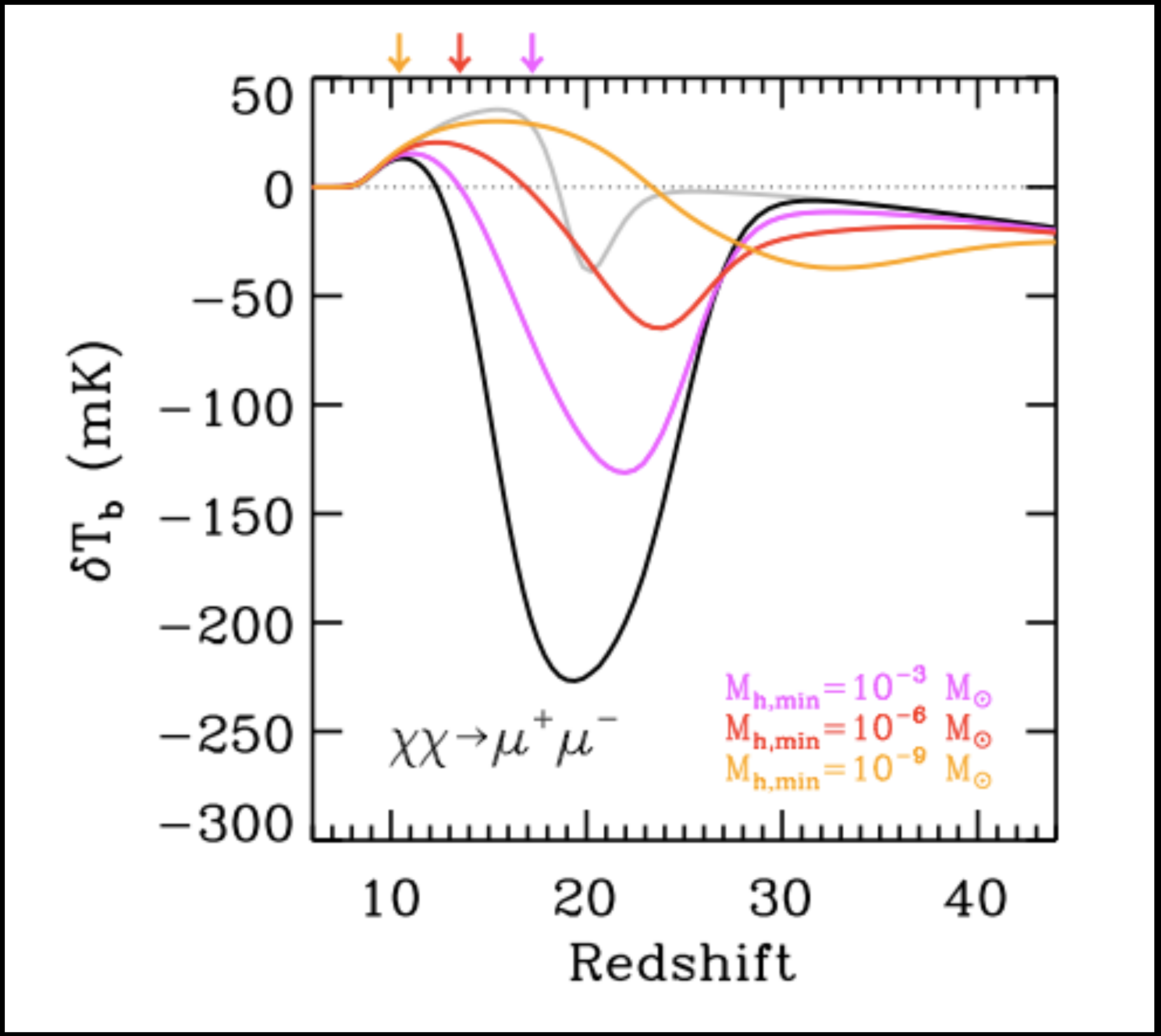
Example:
primordial black hole evaporation



Mack & Wesley, arXiv:0805.1531

Dark Matter & 21cm

DM annihilation at cosmic dawn



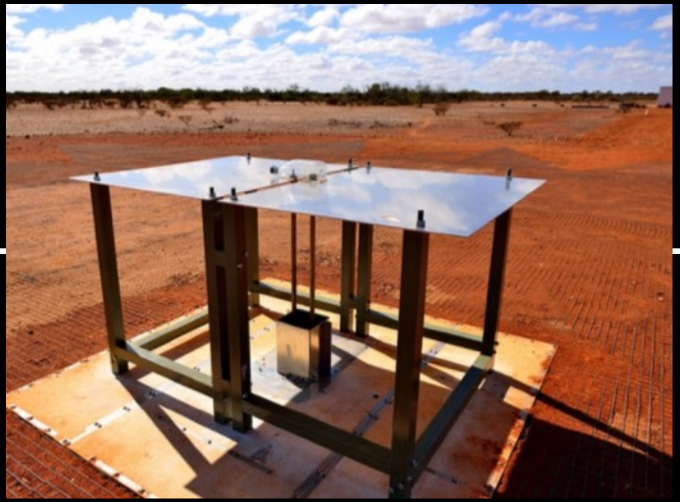
Evoli et al. 2014

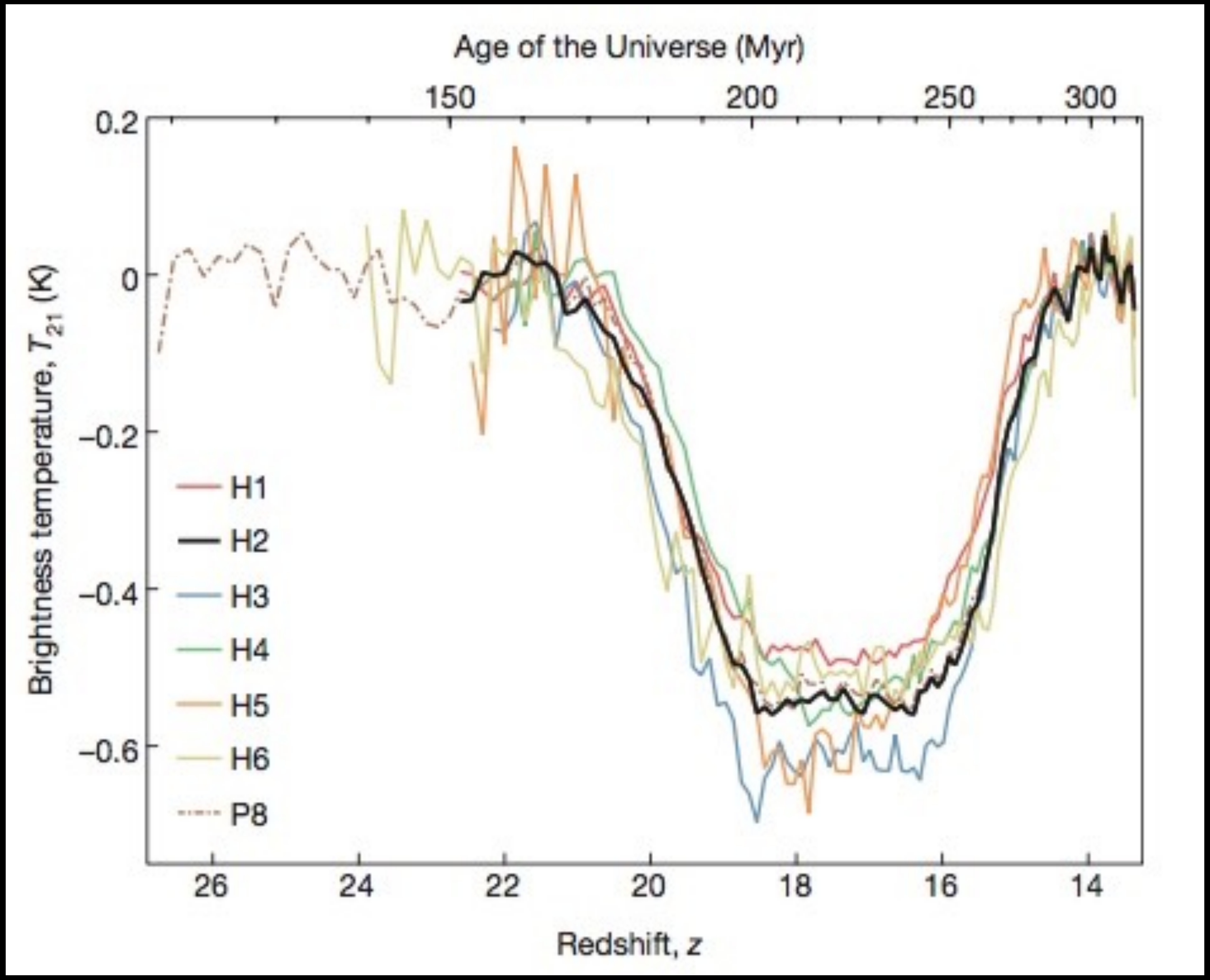
Annihilating dark matter can heat and ionize the IGM, altering the 21cm signal at cosmic dawn

(and even dominate heating at certain redshifts)

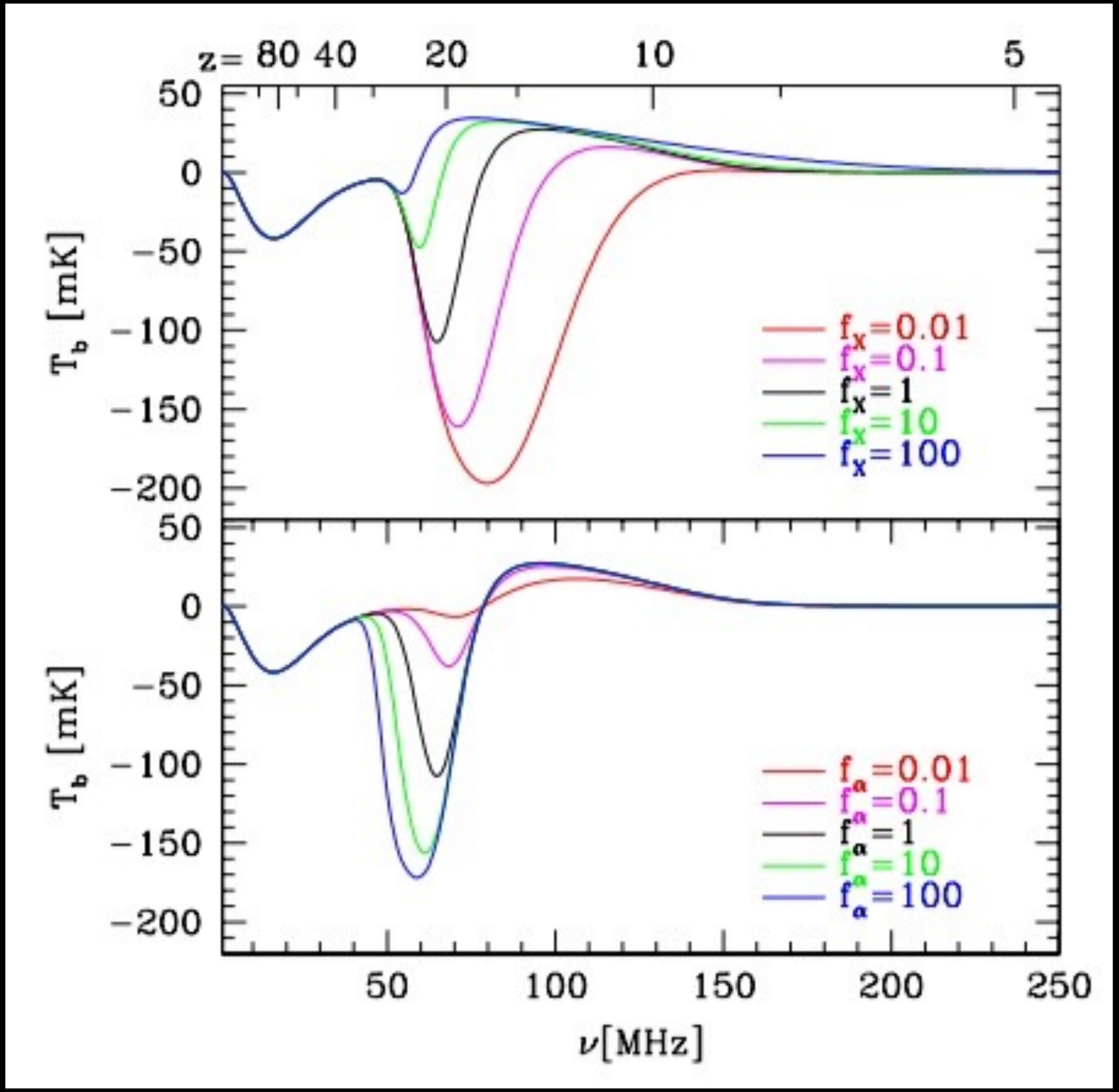
Dark Matter & 21cm

EDGES Experiment



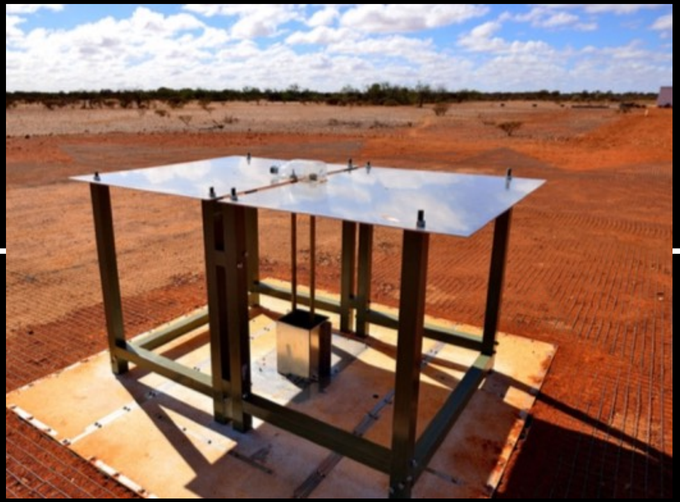


Bowman et al. 2018



Pritchard & Loeb 2010

EDGES



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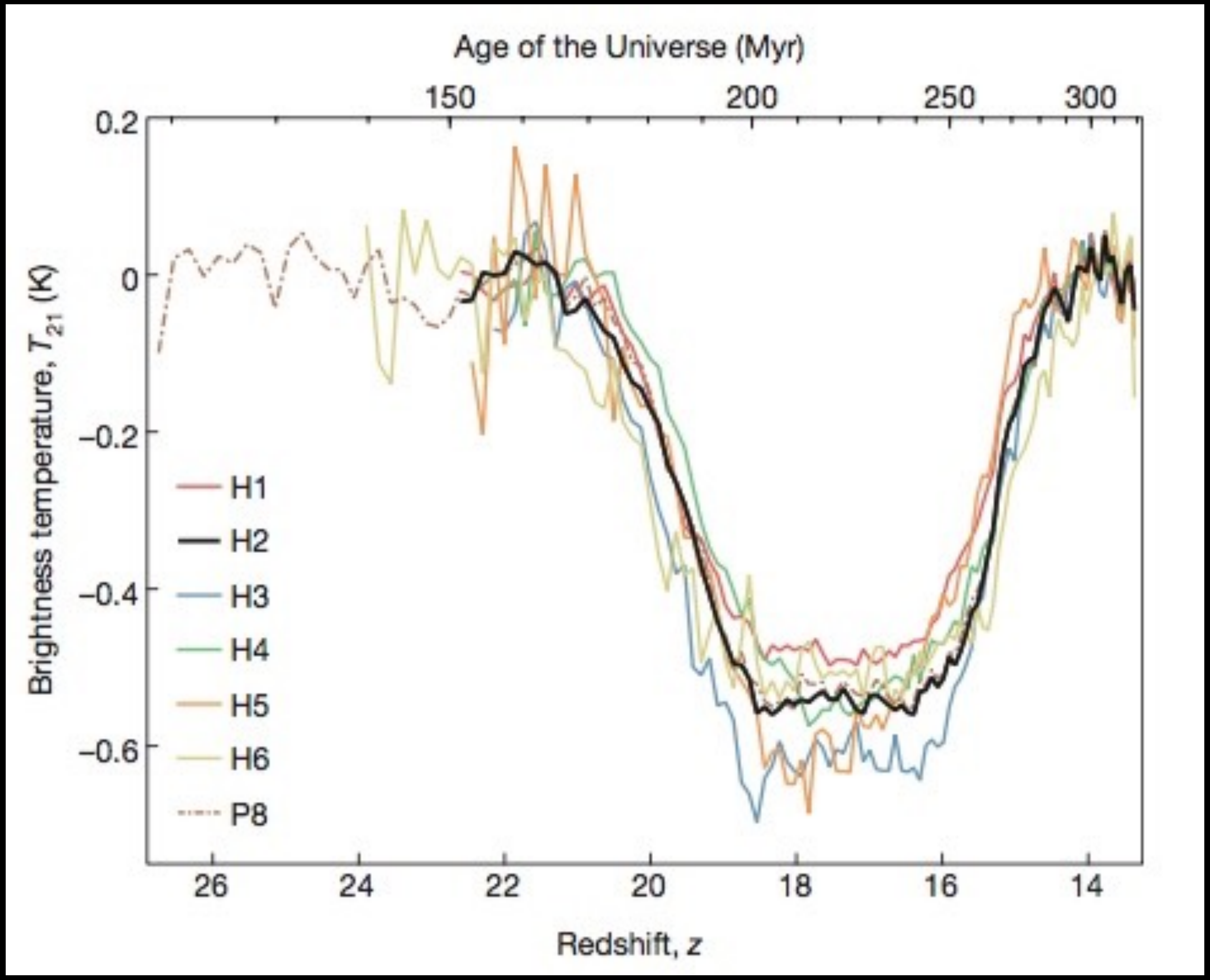
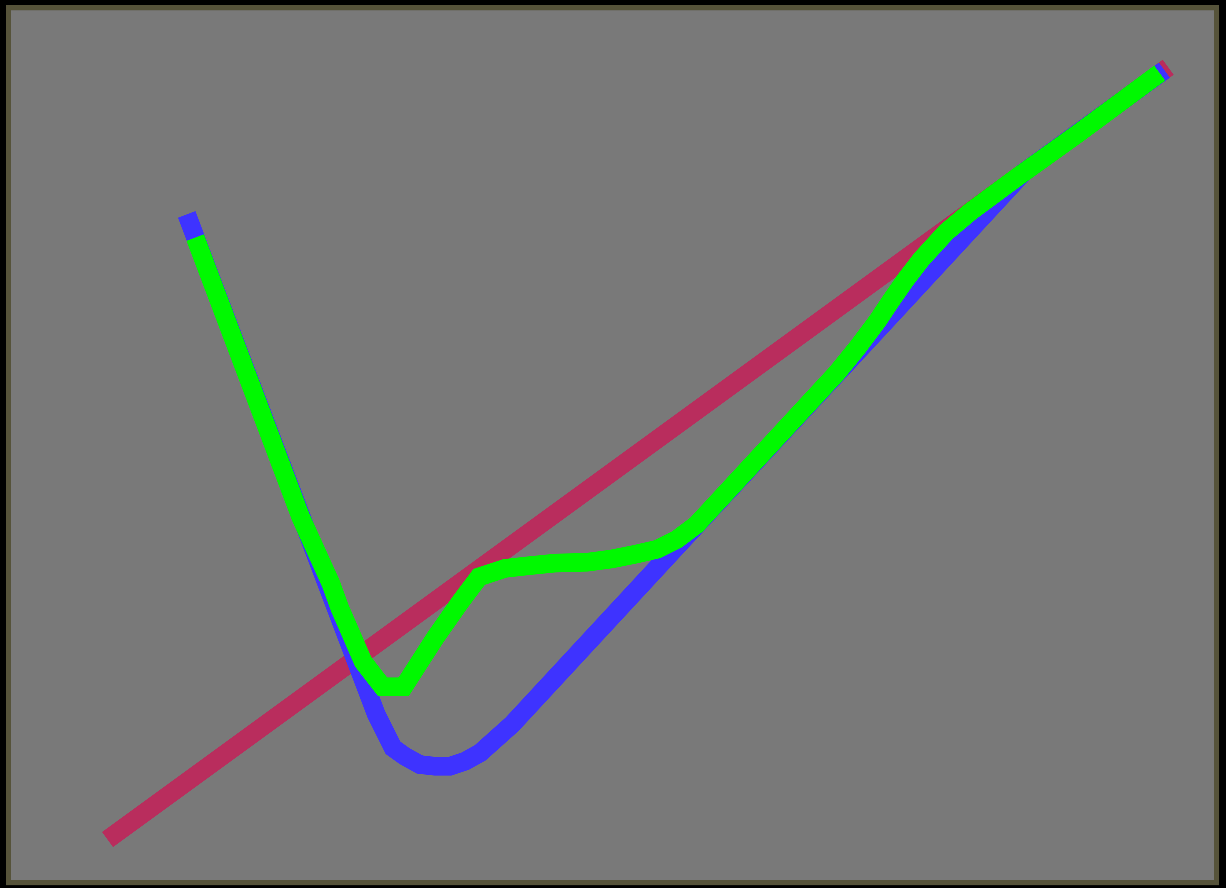
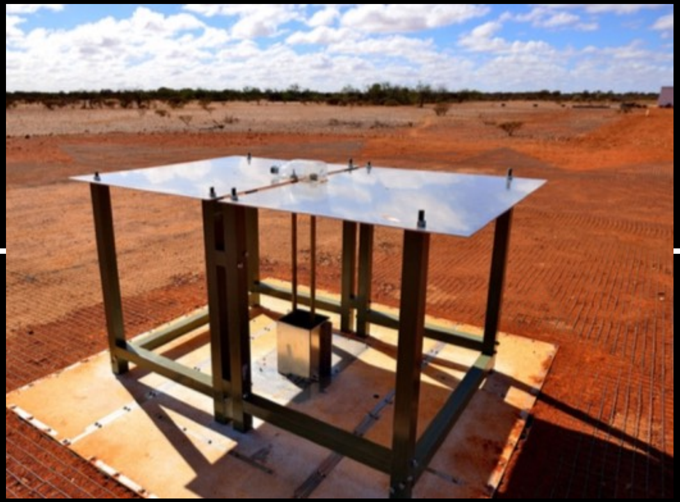


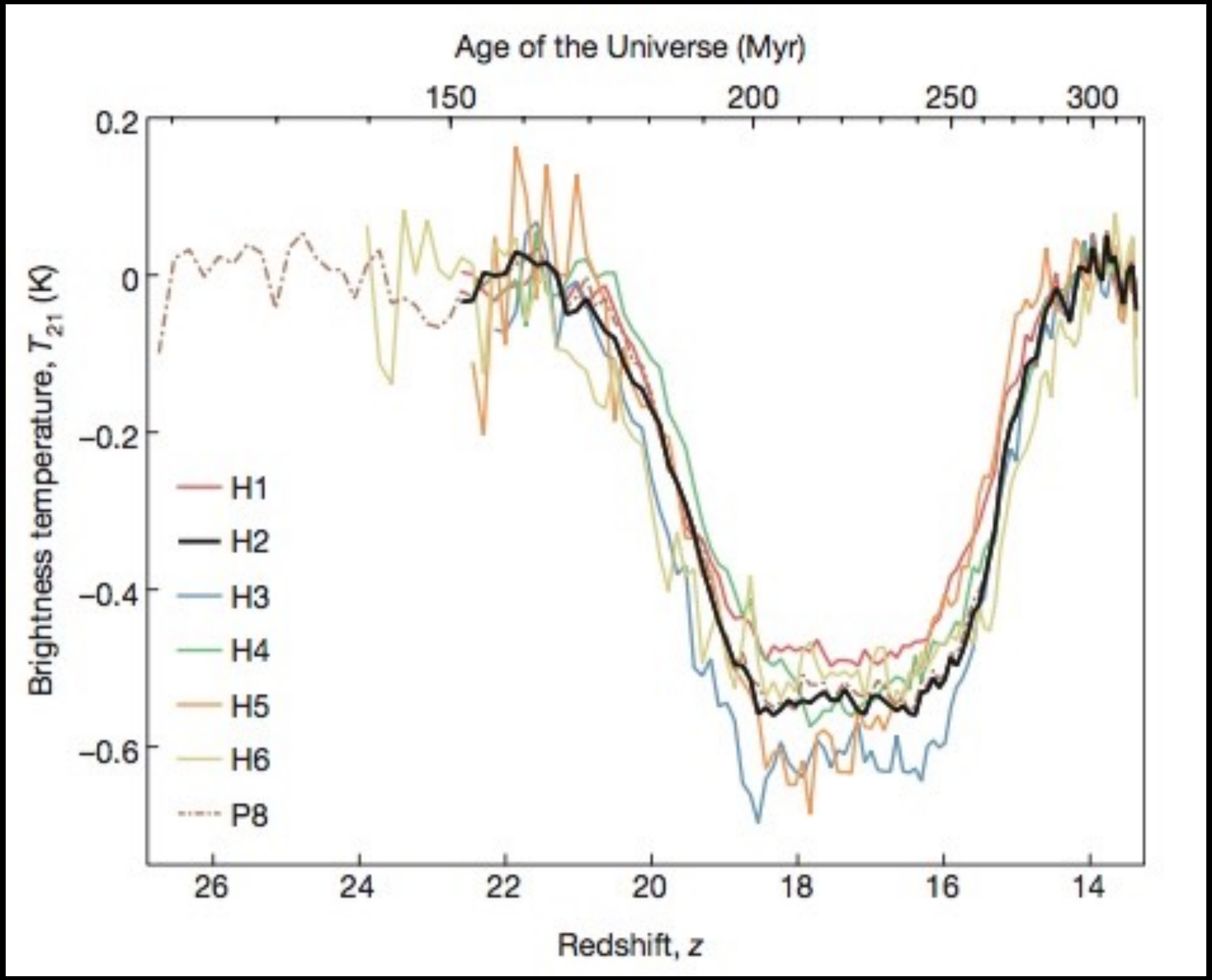


Bowman et al. 2018

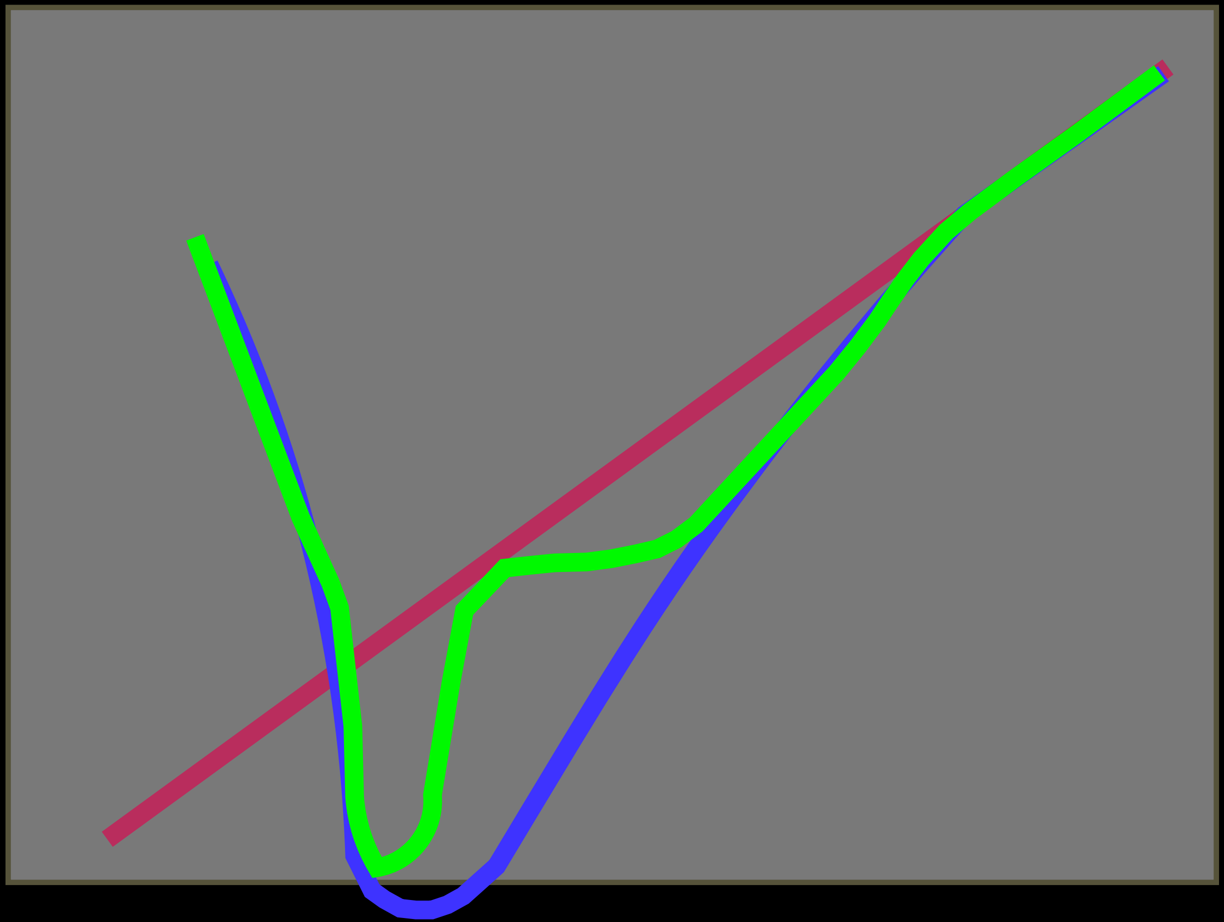
EDGES



EDGES Experiment



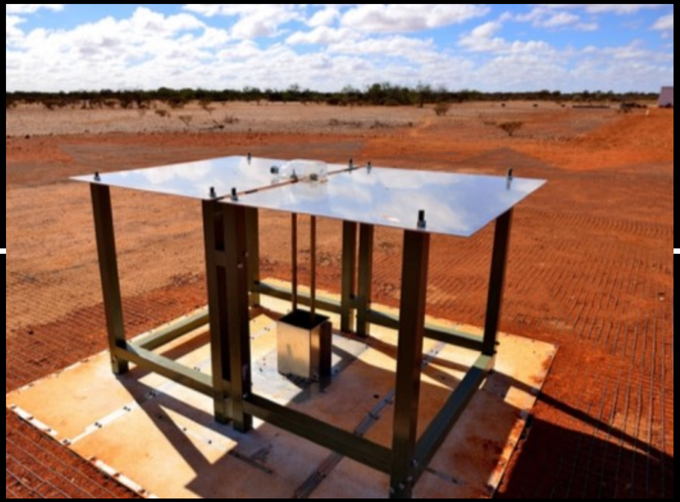
Bowman et al. 2018



Cold dark matter coupling?

Barkana 2018; Barkana+ 2018; Berlin+ 2018; Muñoz & Loeb 2018

EDGES



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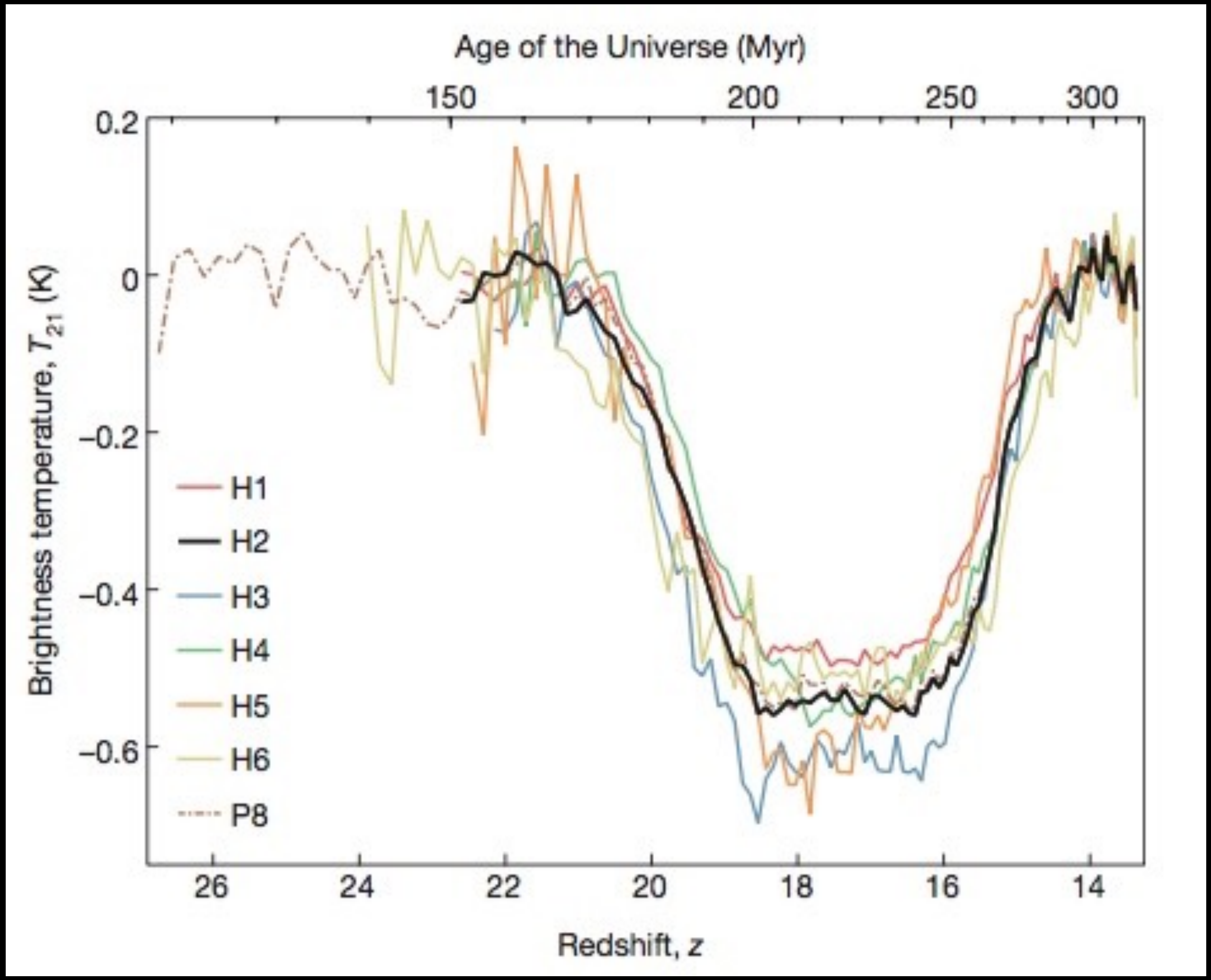
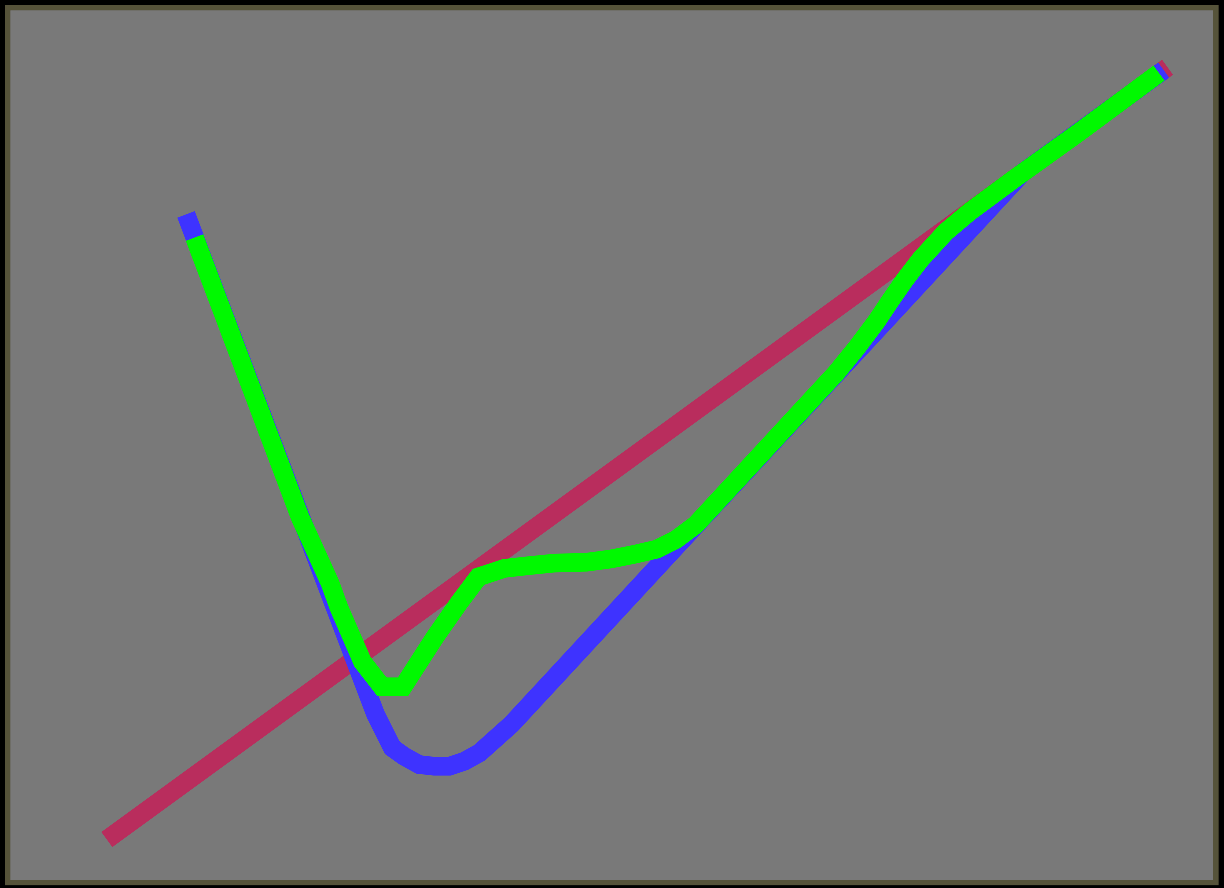
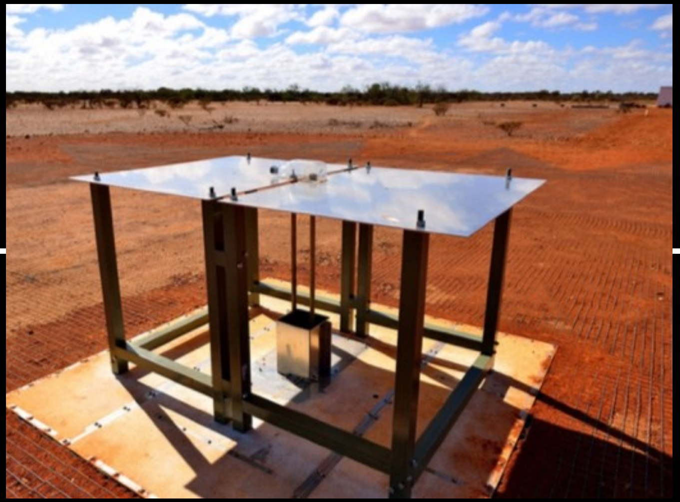




Bowman et al. 2018

EDGES



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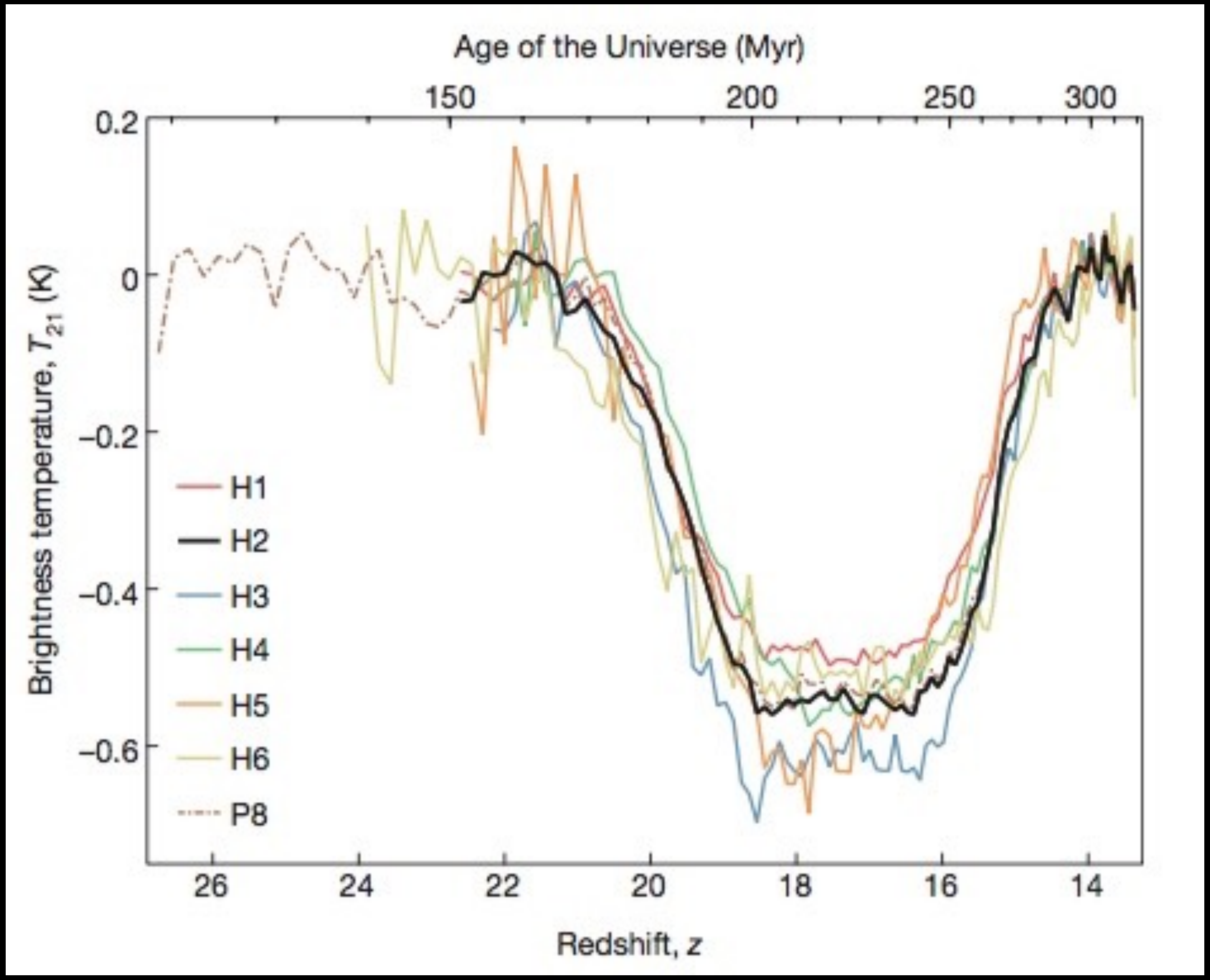
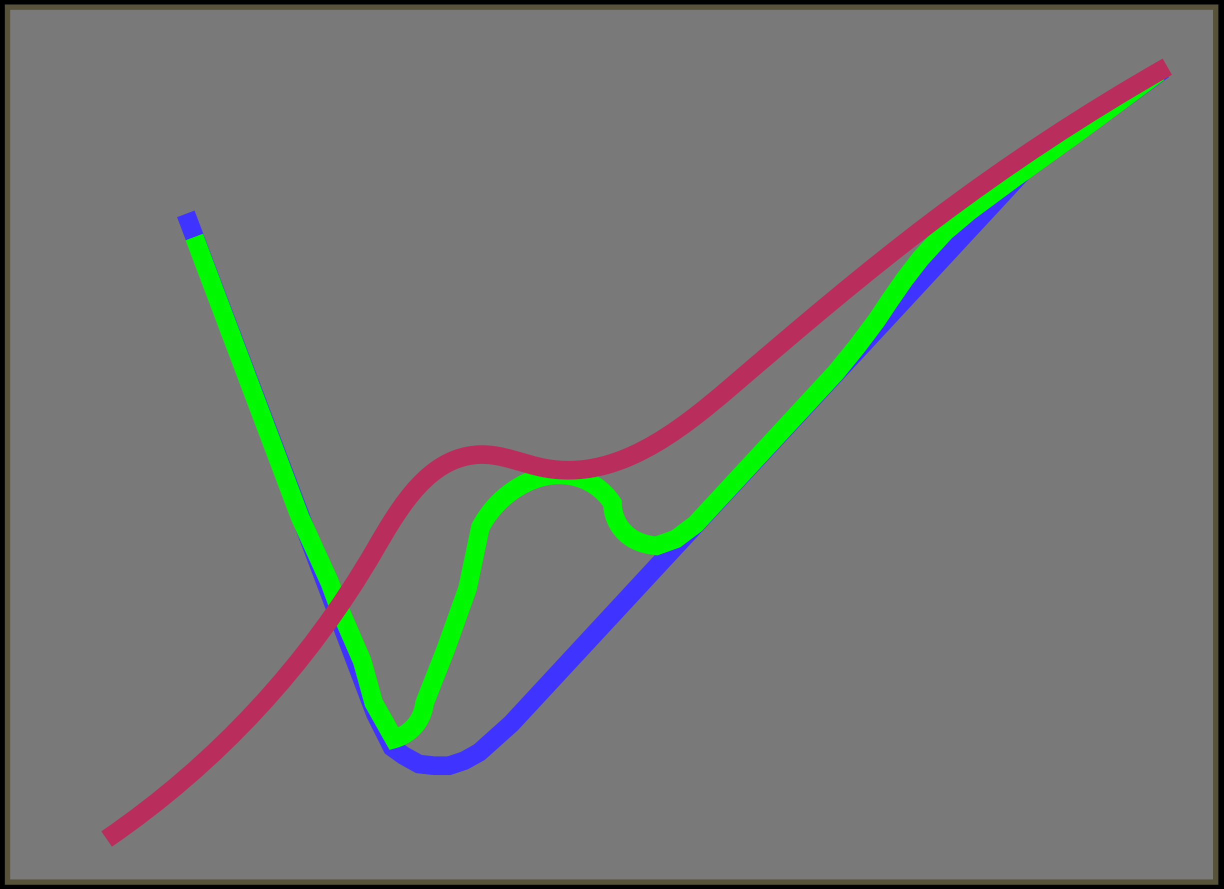




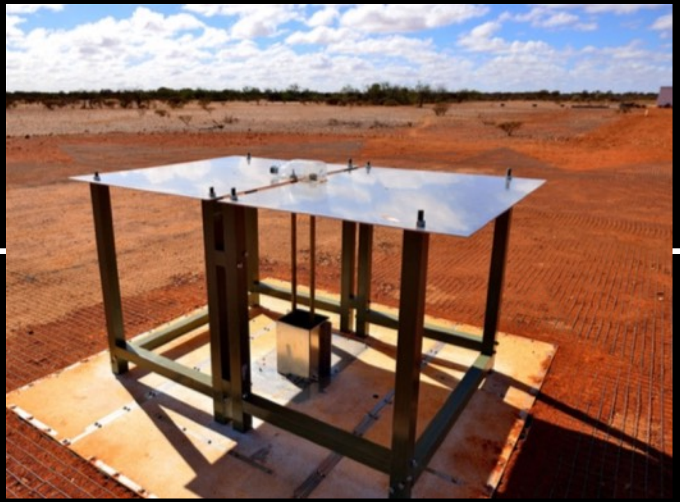
Bowman et al. 2018

Higher radiation background?

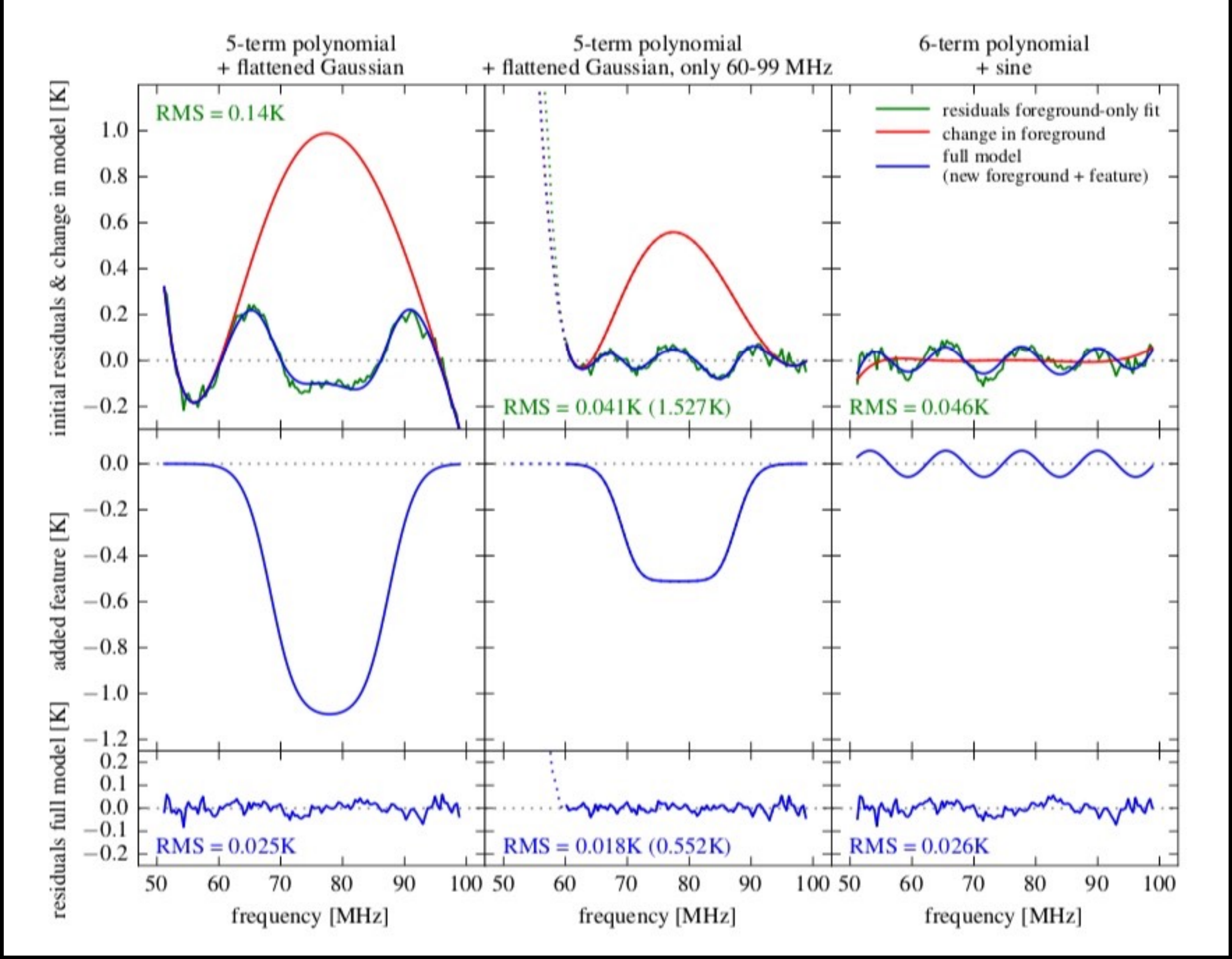
Ewall-Wice et al. 2018

Pospelov et al. 2018

Dark Matter & 21cm



EDGES Experiment



Foreground problems?

Hills et al. 2018

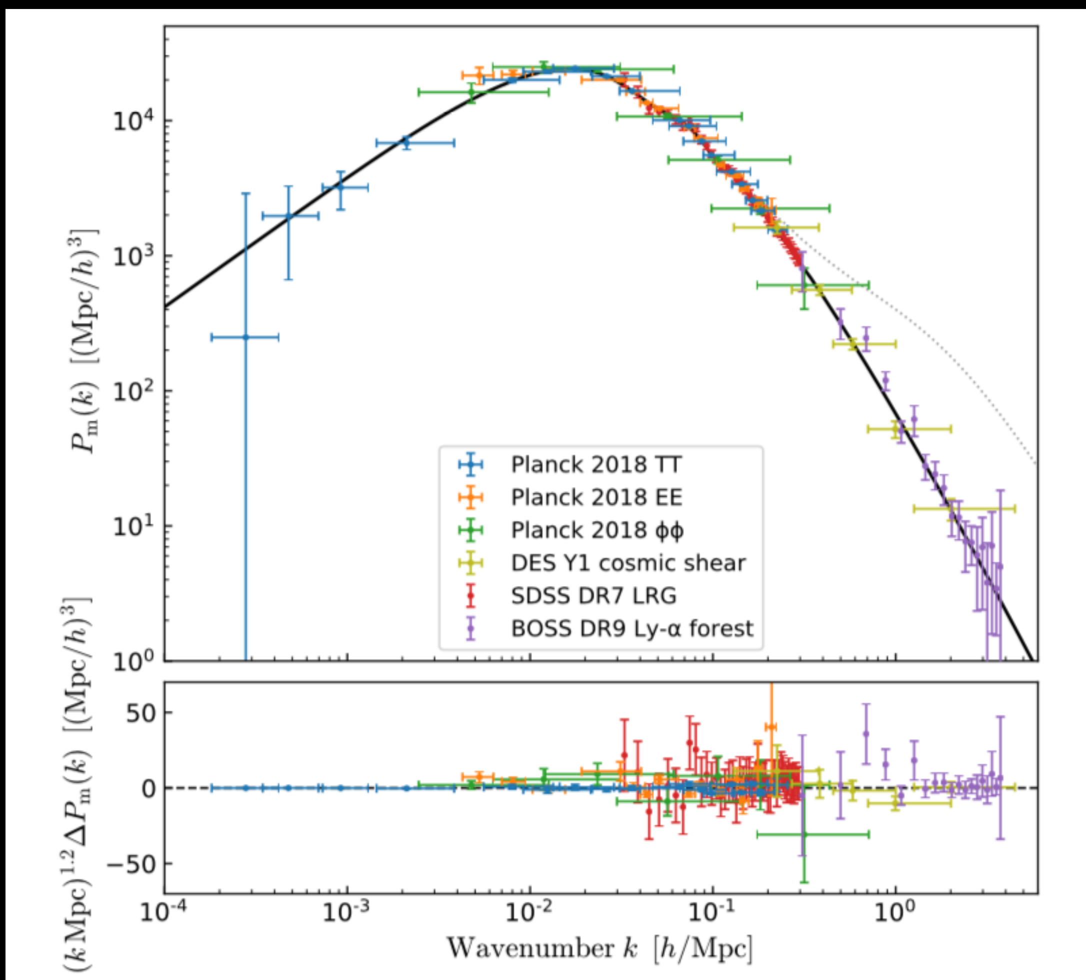
also

Spinelli et al. 2019

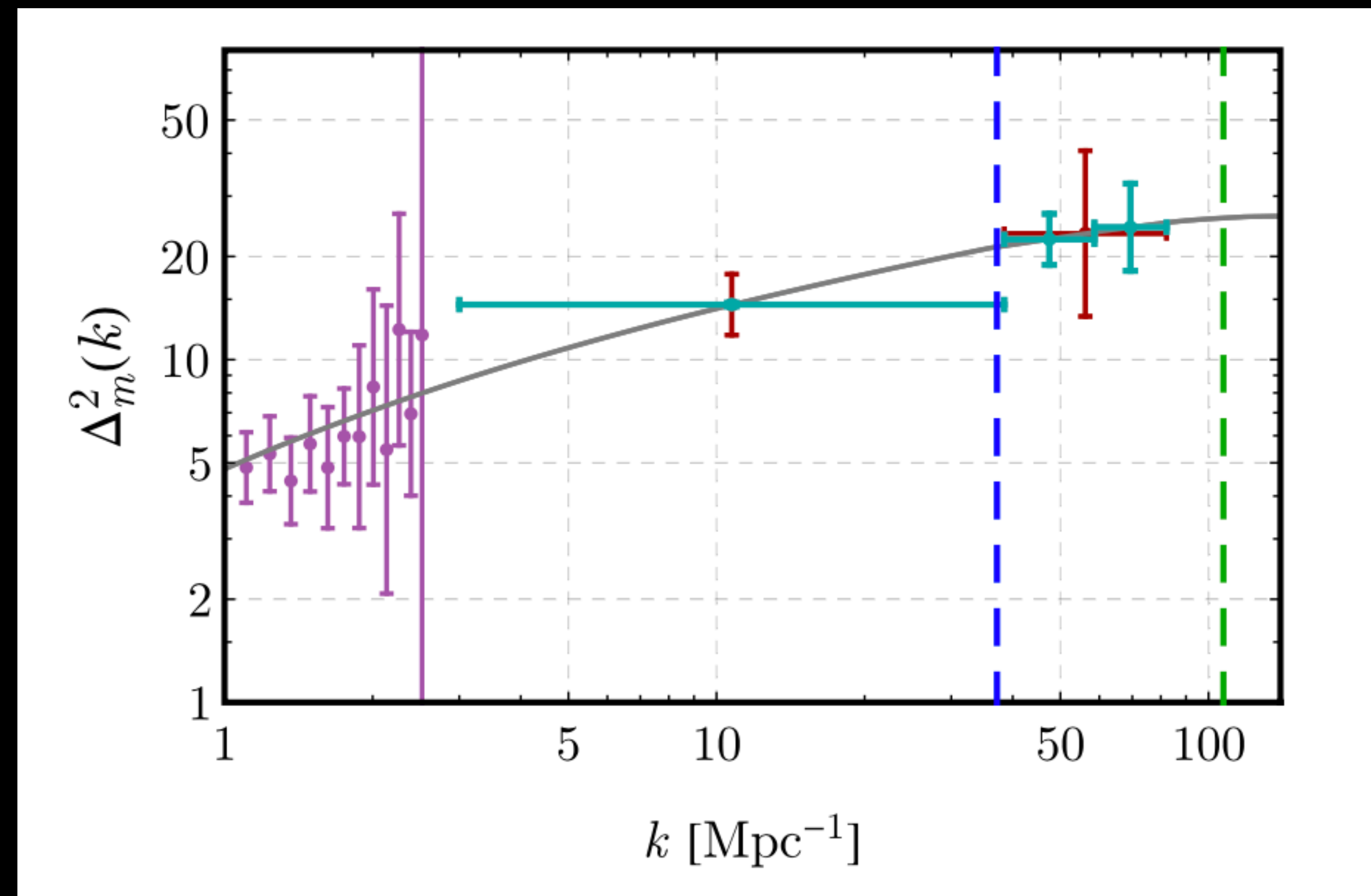
Sims & Pober 2020

Dark Matter & 21cm

Upcoming high-redshift 21cm experiments will probe matter power spectrum to much smaller scales



Chabanier et al. 2019

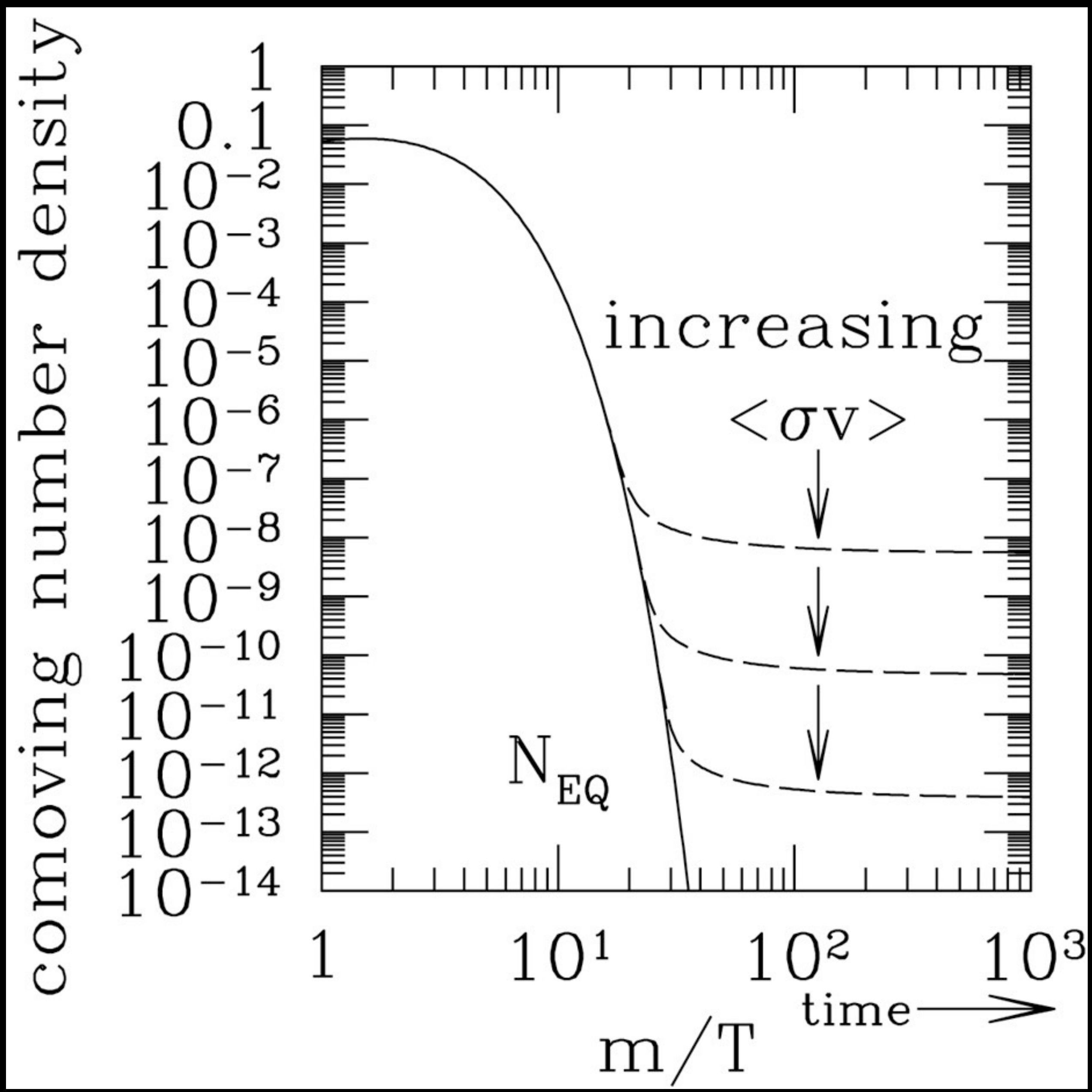


Muñoz, Dvorkin & Cyr-Racine 2020

$$\Delta^2(k) = \frac{k^3}{2\pi^2}P(k)$$

Work in Progress

Alternative DM Thermal Histories



Kolb & Turner 1990

Standard thermal WIMP dark matter

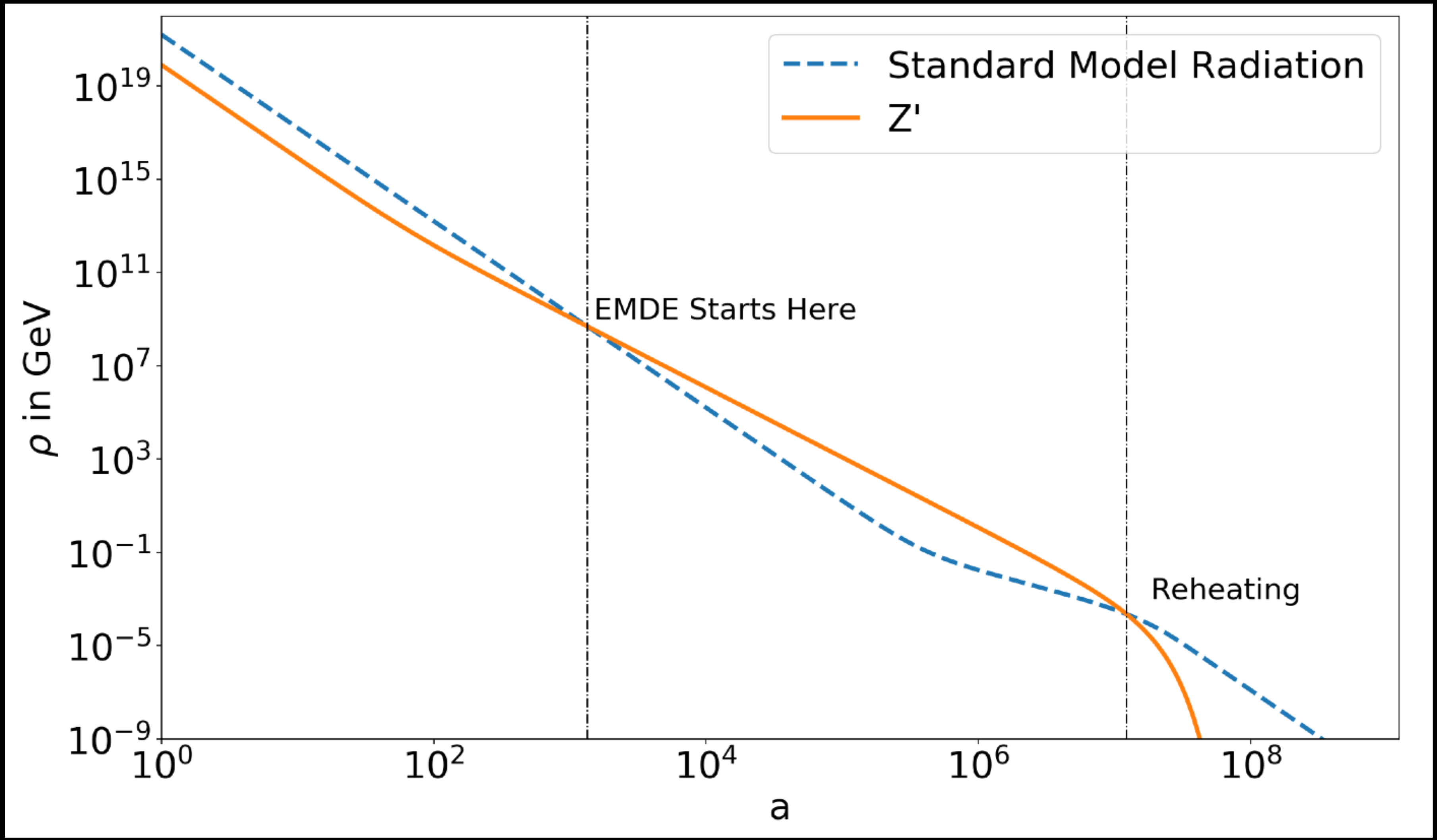
- WIMP-interaction-strength cross section mostly ruled out

➡ consider alternative histories

Alternative DM Thermal Histories

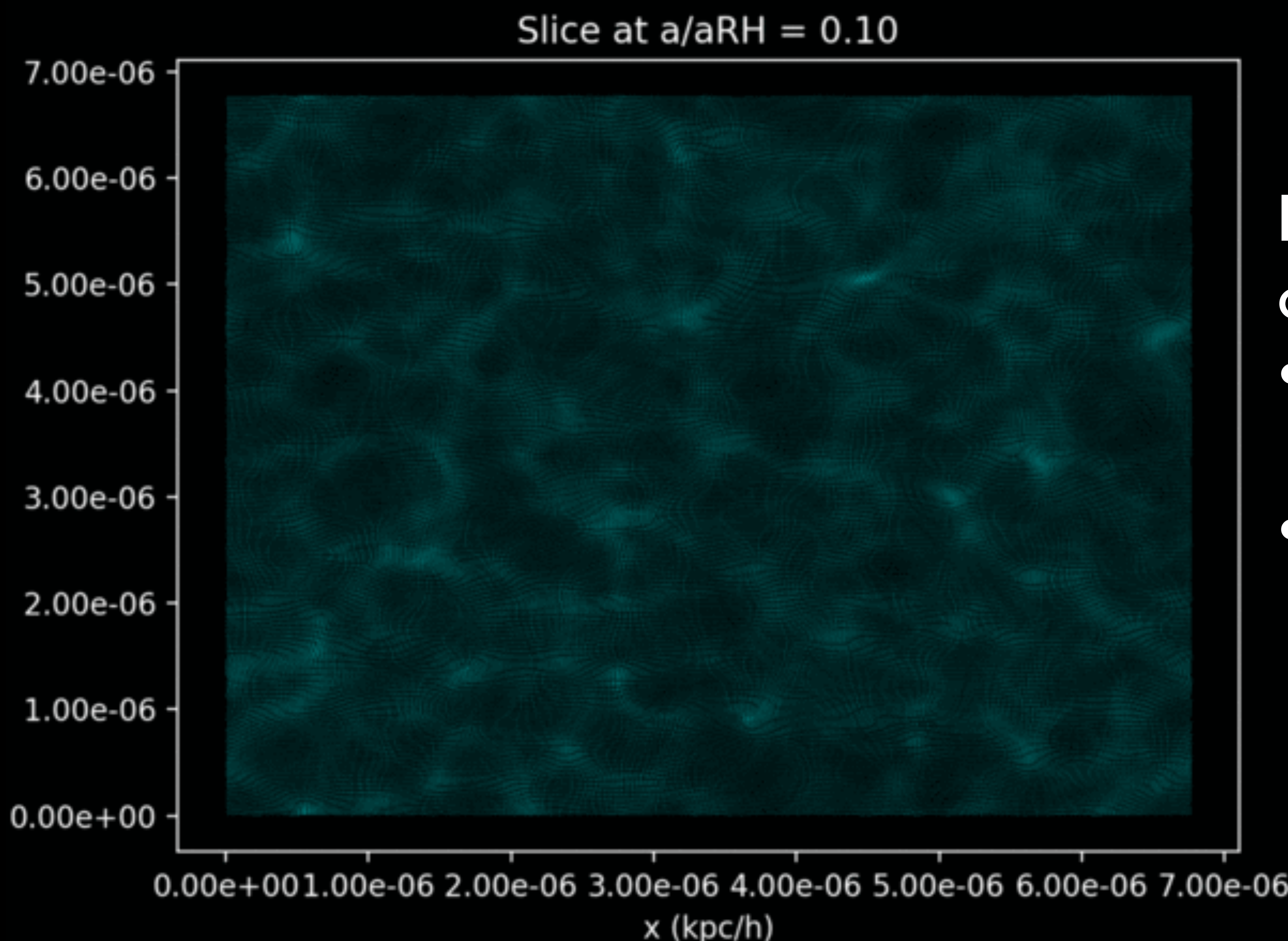
A. Erickcek, H. Ganjoo et al., in prep

Early matter-dominated epoch



- dark matter coupled to Standard Model only via mediator
- mediator dominates during radiation domination, initiating temporary matter-dominated era
- mediator decays, heating dark matter

Alternative DM Thermal Histories

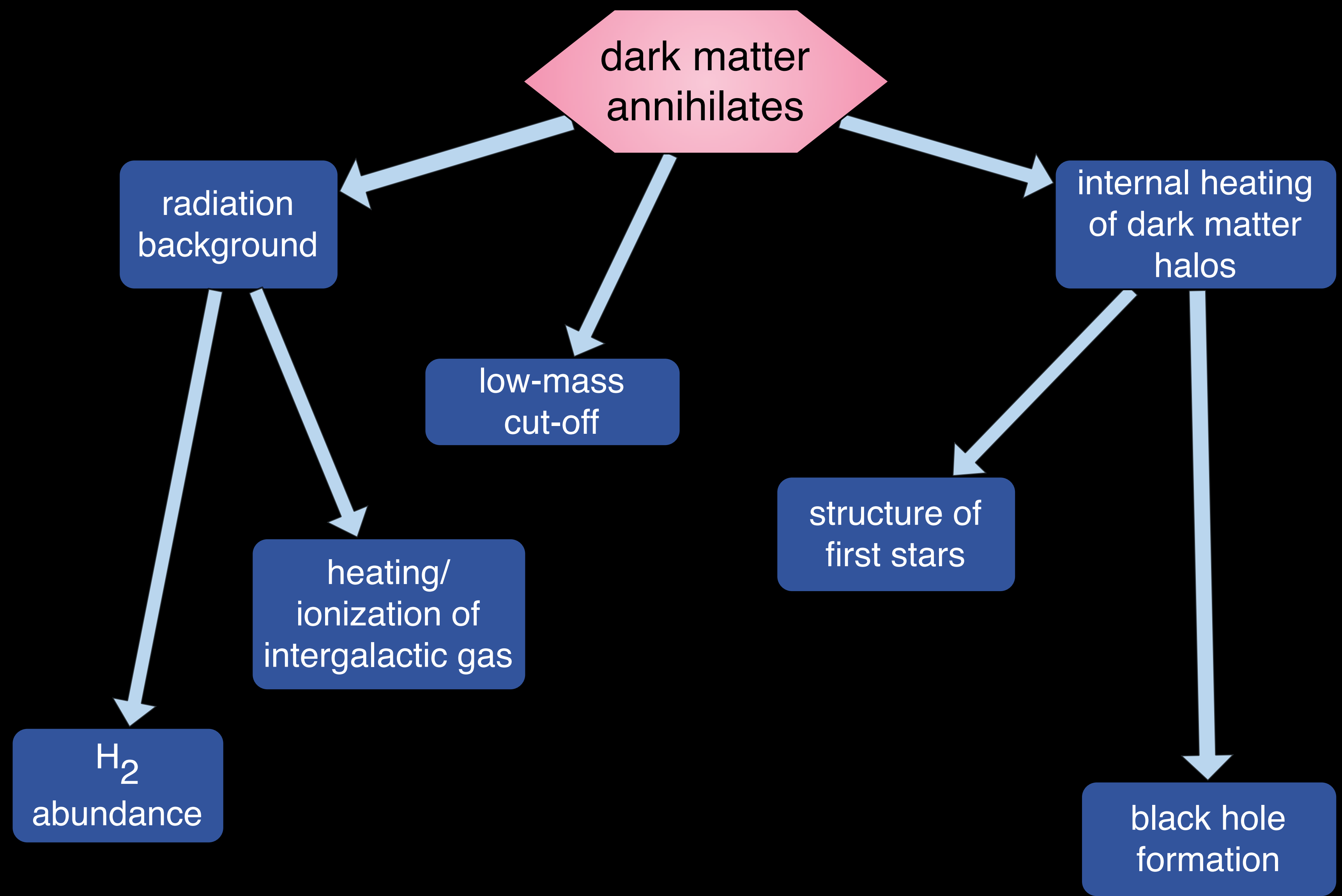


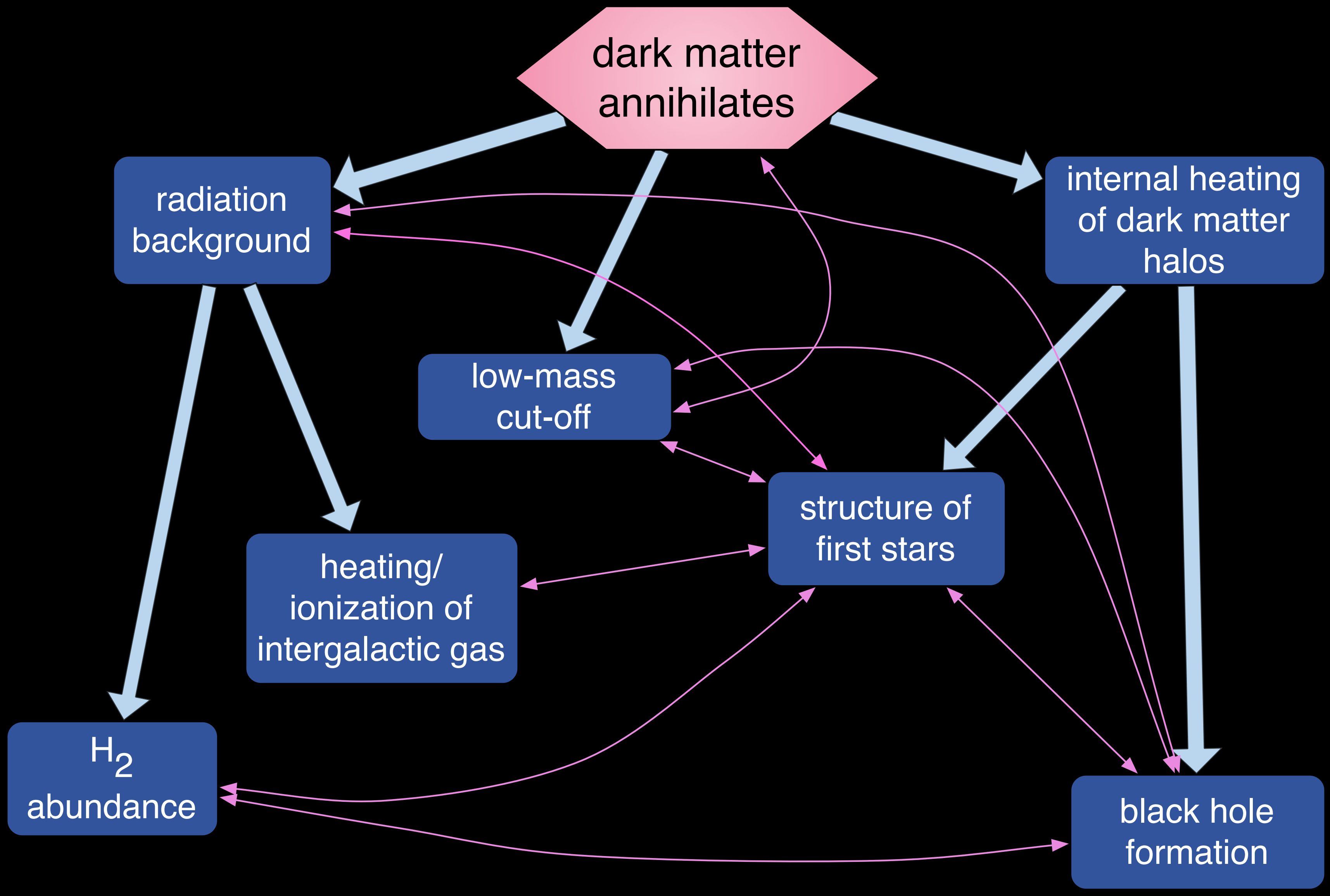
Potential impacts on:

- annihilation signal
- small-scale matter power spectrum

A. Erickcek, H. Ganjoo et al., in prep

dark matter
annihilates


dark matter annihilates
radiation background
low-mass cut-off
internal heating of dark matter halos
heating/ ionization of intergalactic gas
H_2 abundance
structure of first stars
black hole formation



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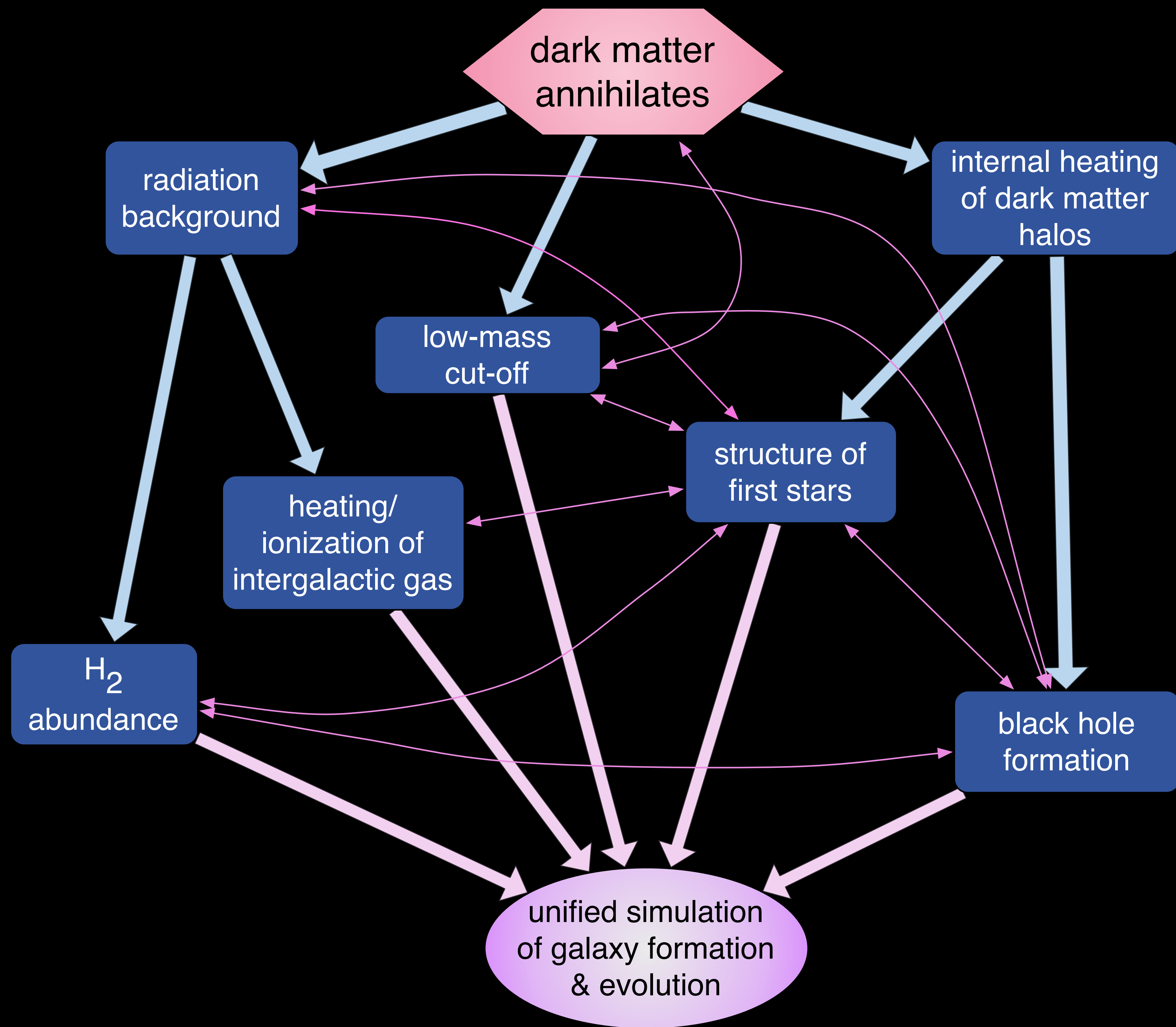

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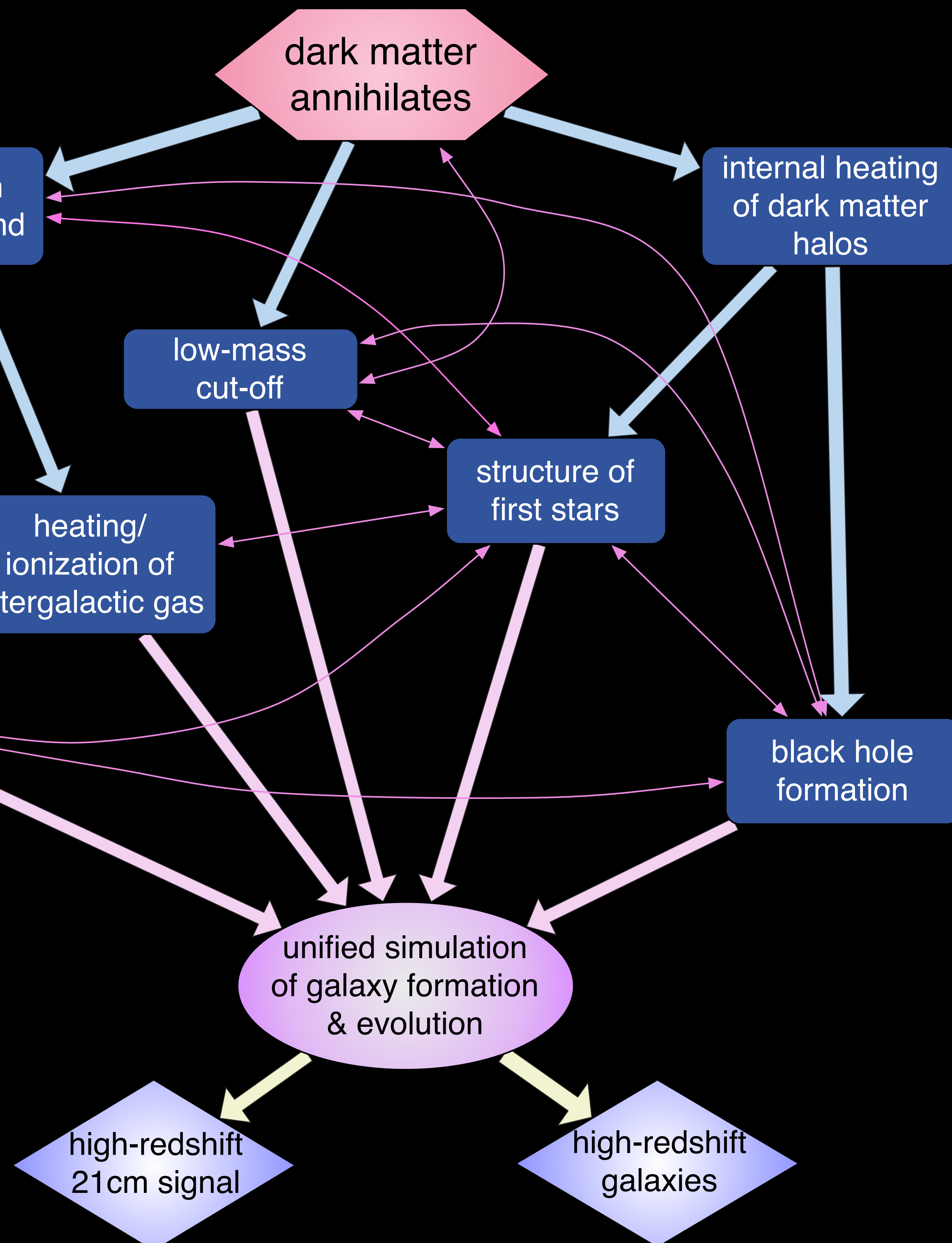
unified simulation of galaxy formation & evolution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high-redshift 21cm signal
high-redshift galaxies

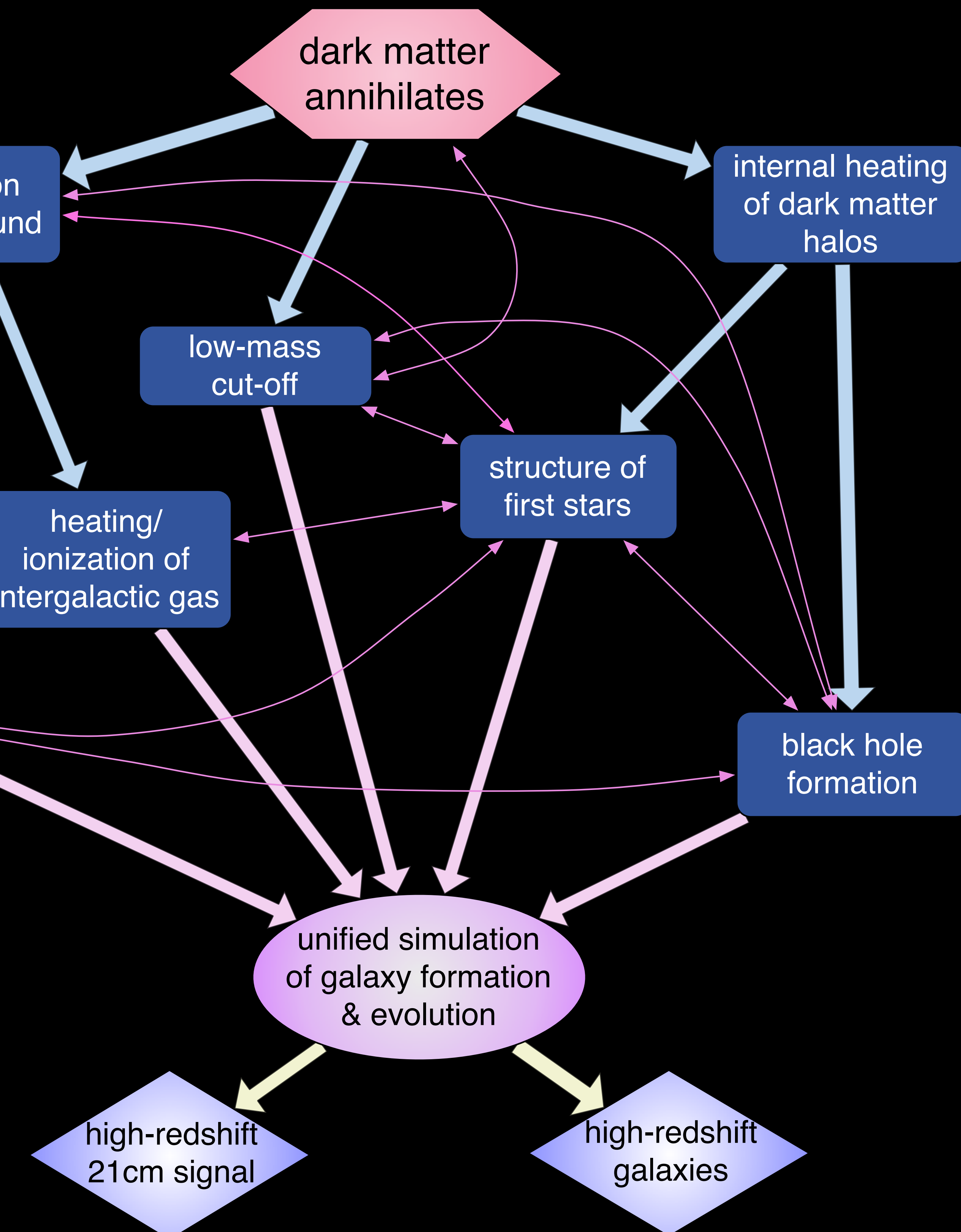

Image credit: Swinburne/ ICRAR/Cambridge/ASTRON

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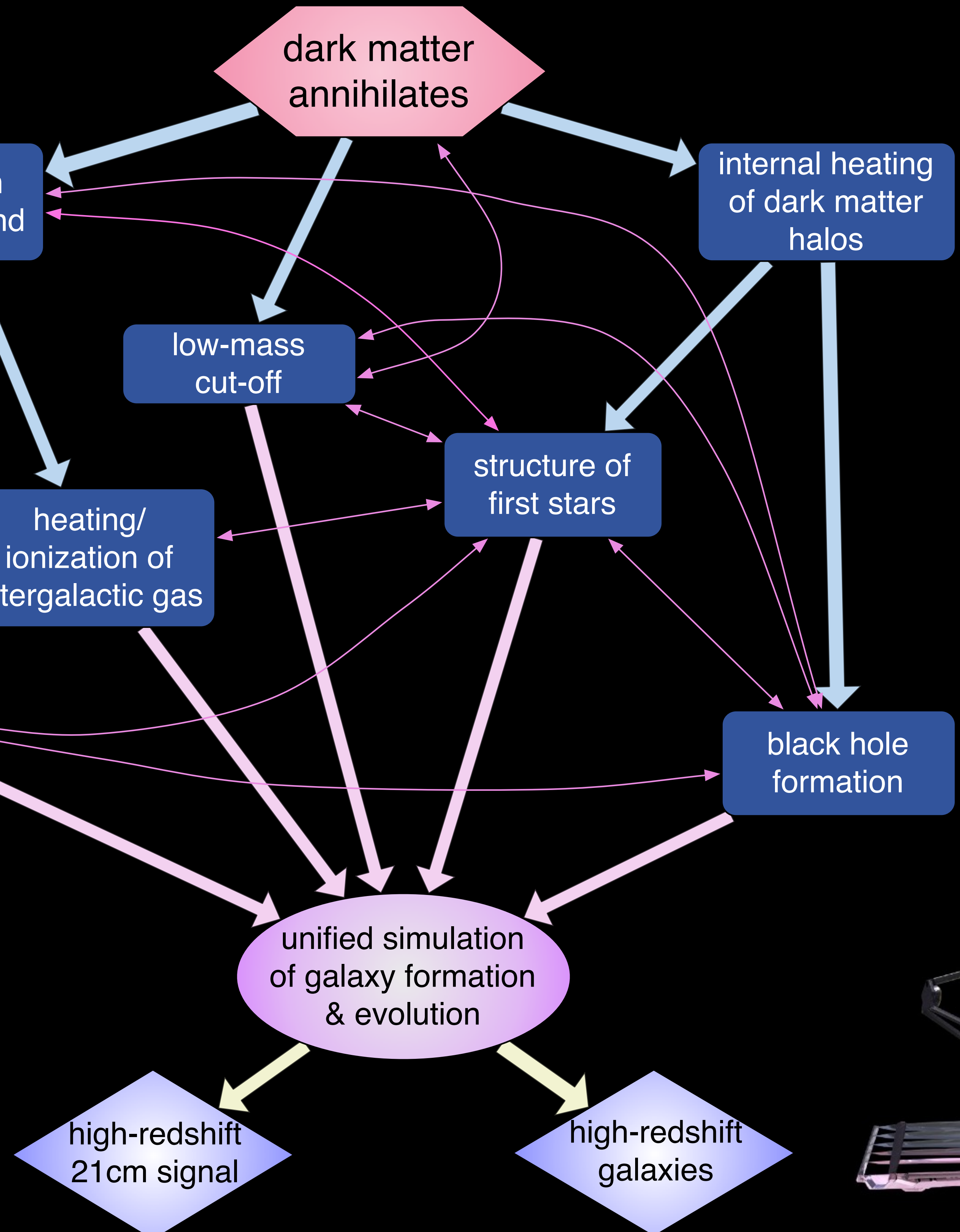

JWST

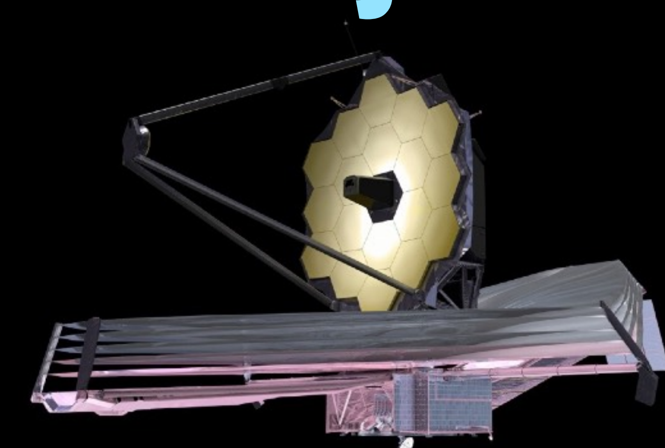

Image credit: NASA

Take-Home Messages

- Future surveys can probe the **particle physics of dark matter** and produce a more consistent picture of cosmology
- To determine dark matter's impact on high-redshift astrophysics, we need to understand **small halos** and their evolution (see: next talk!)

end