Dark Matter:
A Cosmological Perspective

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PHYSICS
COLLEGE OF SCIENCES

NC STATE UNIVERSITY
Leadership in Public Science

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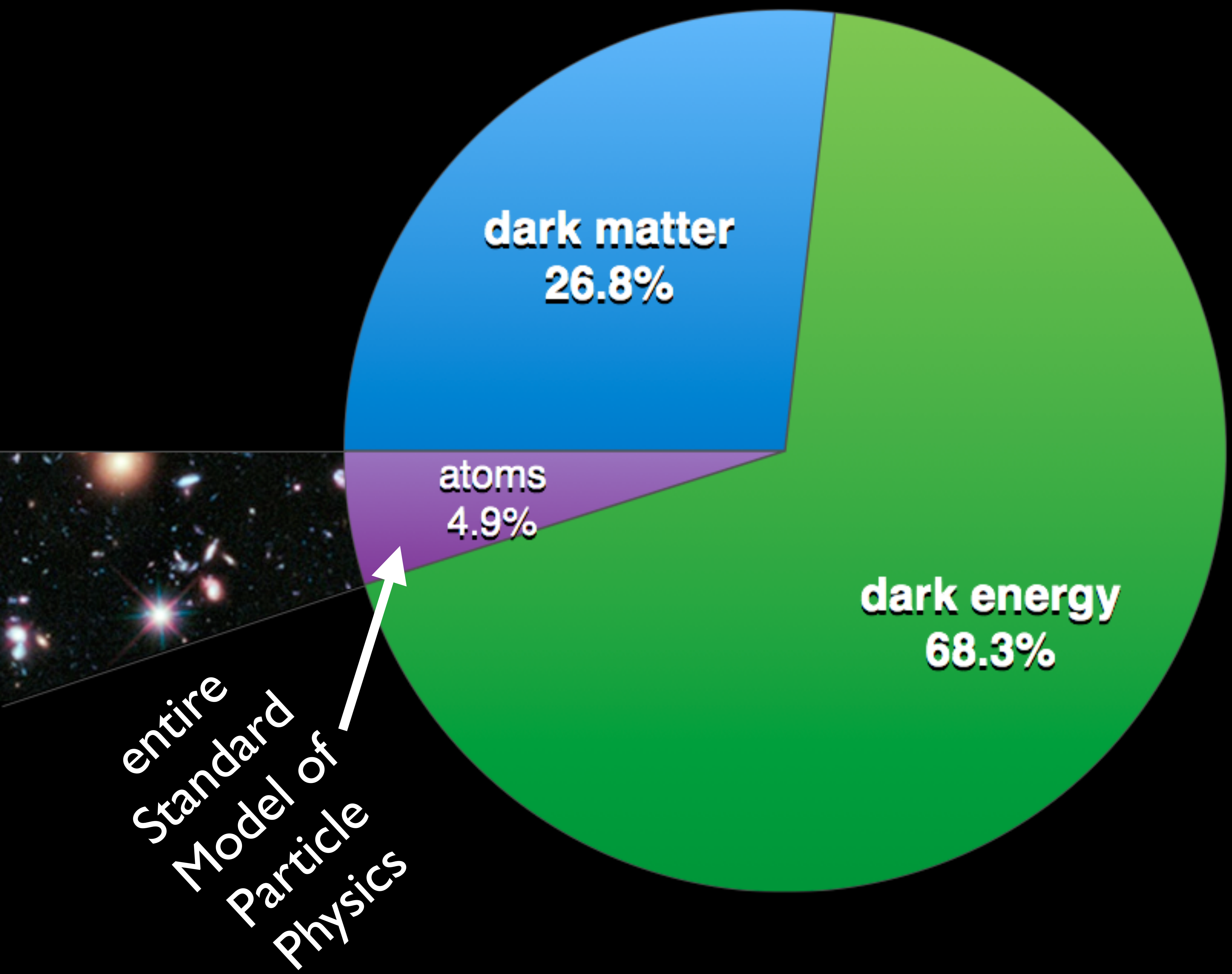

dark matter
26.8%
atoms
4.9%
dark energy
68.3%
entire Standard Model of Particle Physics

What We Don't Know

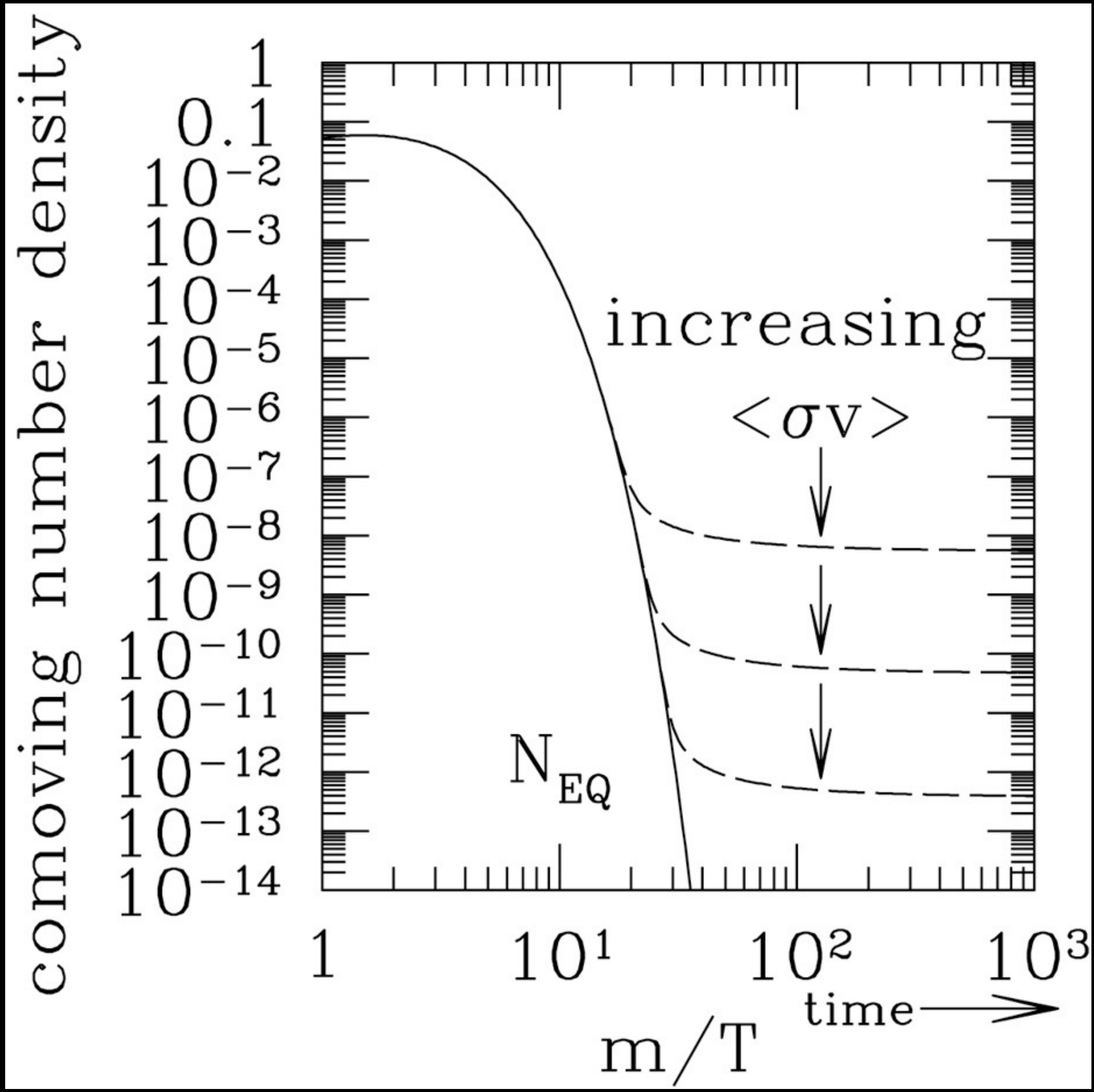
- Origin / particle type
- Particle mass
- Thermal history
- Non-trivial evolution?
- One component or many?
- Non-gravitational interactions (self or SM)?
- Small-scale behavior (mass of smallest halos)

Particle Zoo

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)
- Fuzzy DM (tiny mass, large deBroglie wavelength)
- MACHO (e.g., primordial black holes)

WIMP Miracle

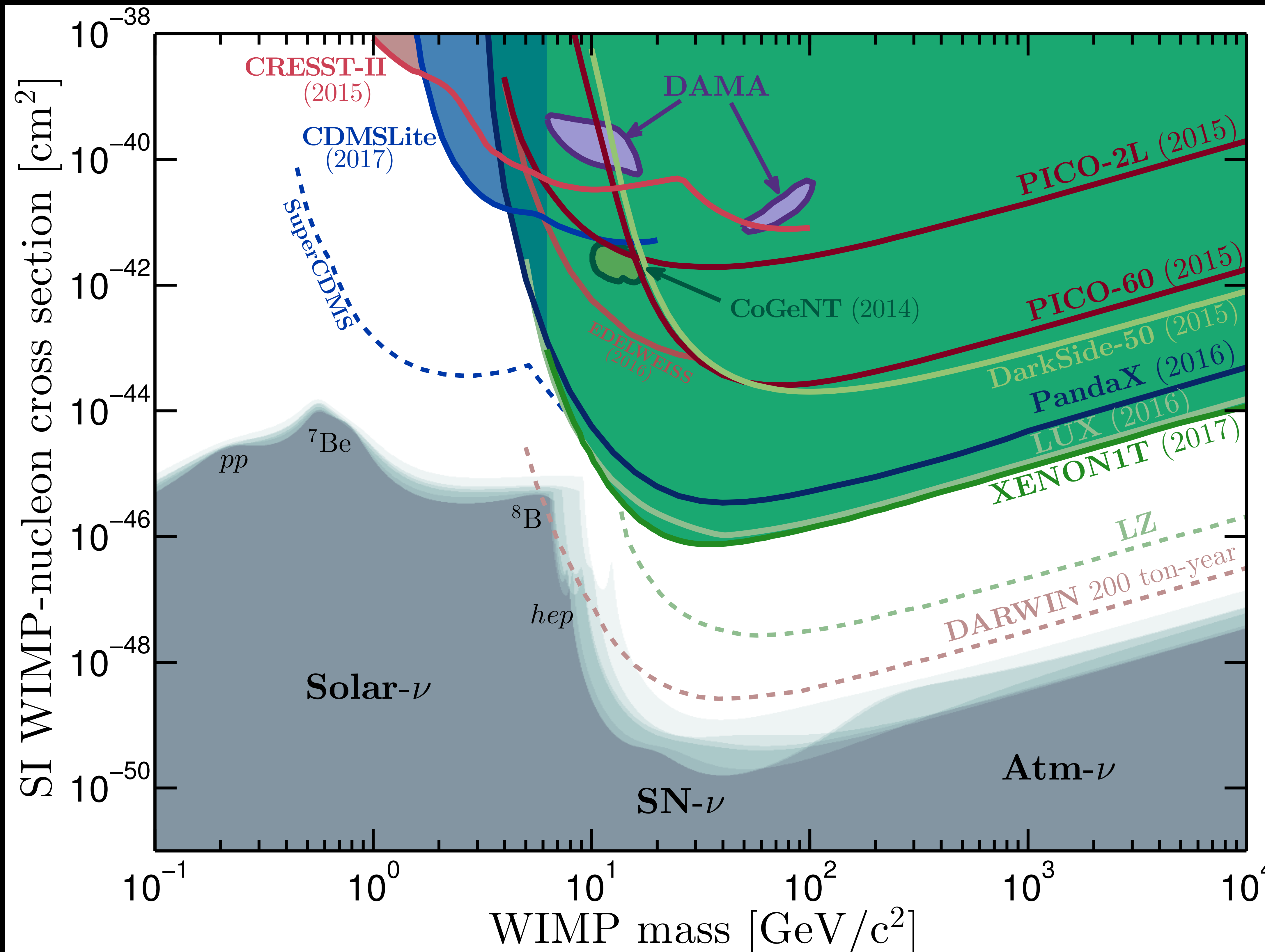


Kolb & Turner 1990

Standard thermal WIMP dark matter

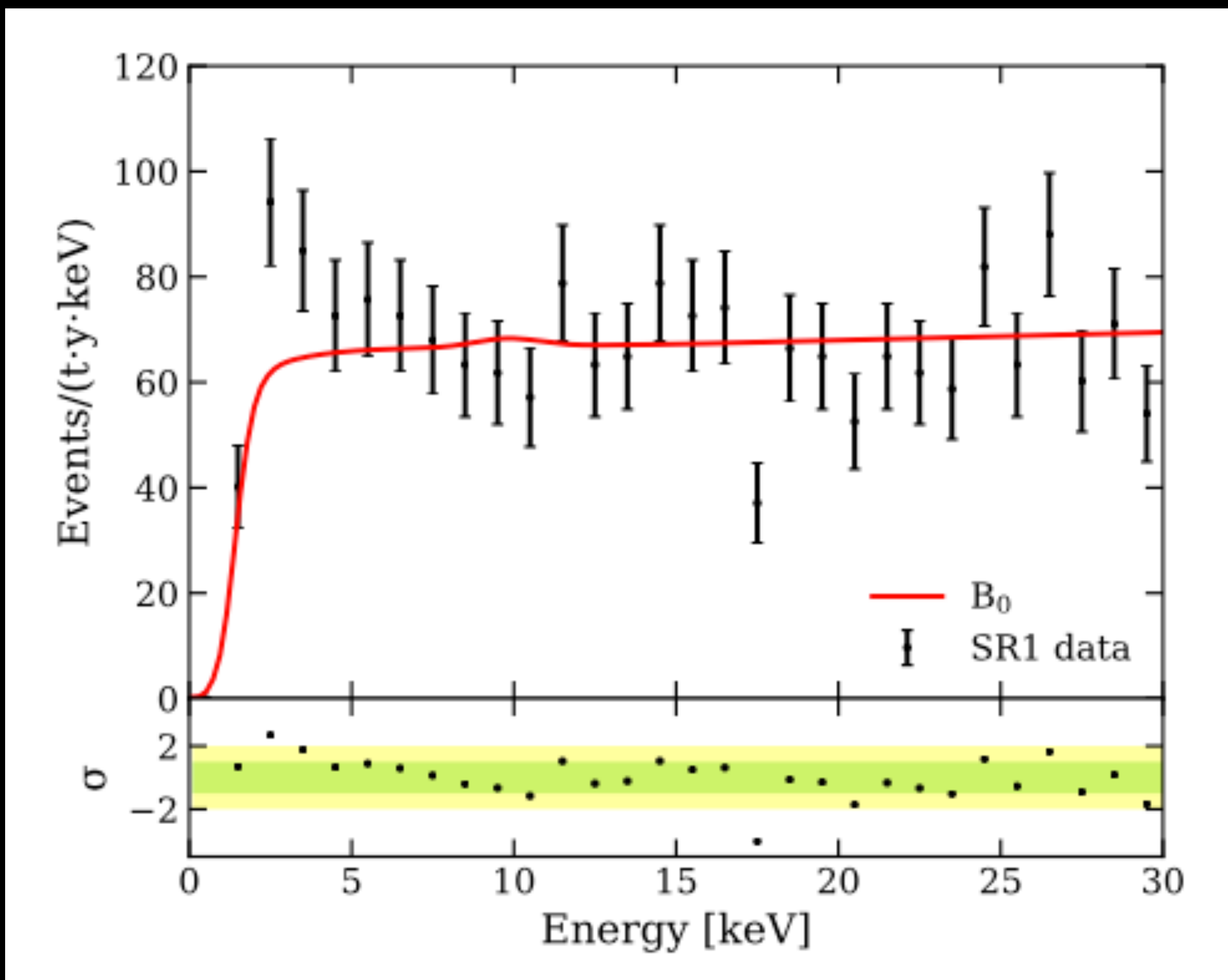
- freezes out when no longer in thermal equilibrium with baryons
- for weak-scale mass and cross-section, predict correct abundance of DM
- discovery opportunities: annihilation, scattering, production

WIMP Direct Detection

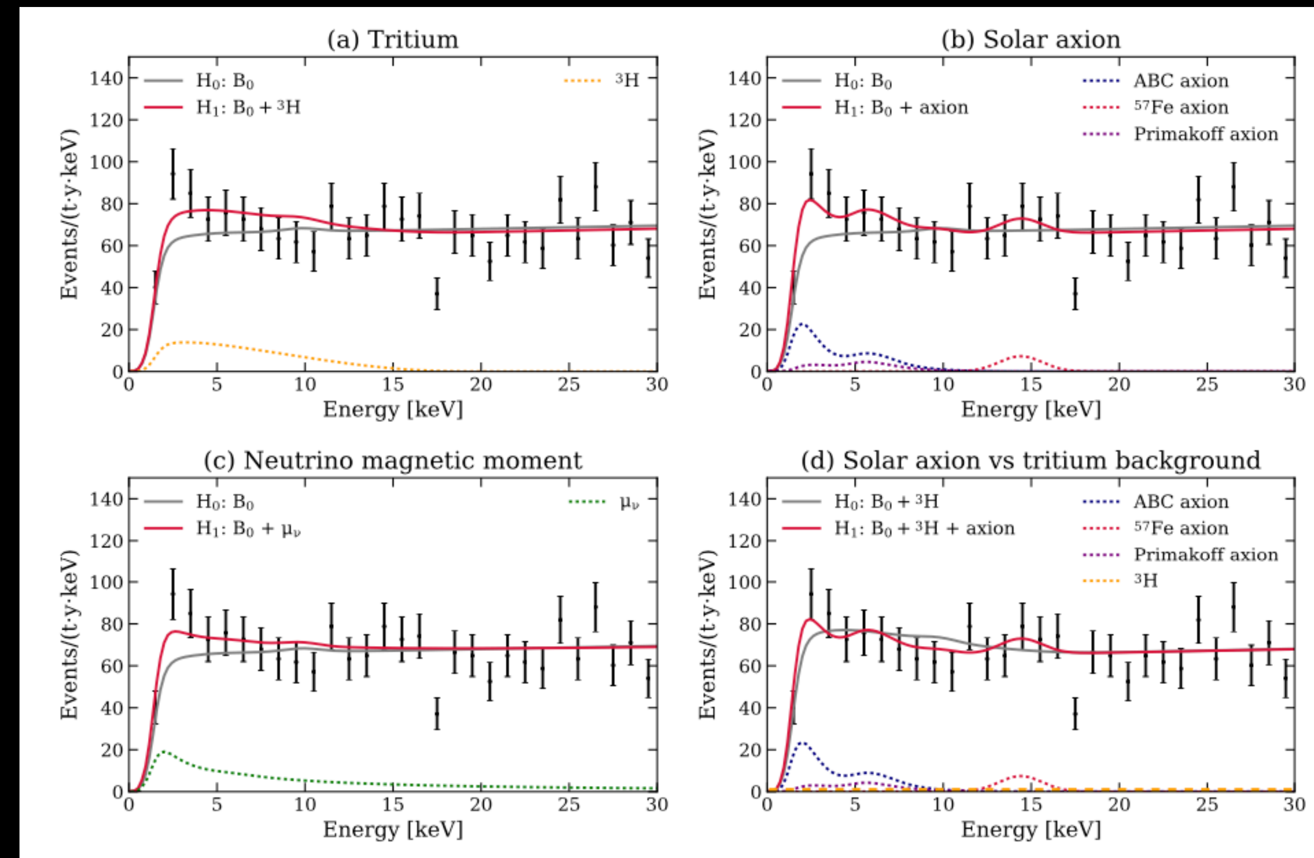


plot via Ciaran O'Hare

XENON1T Excess

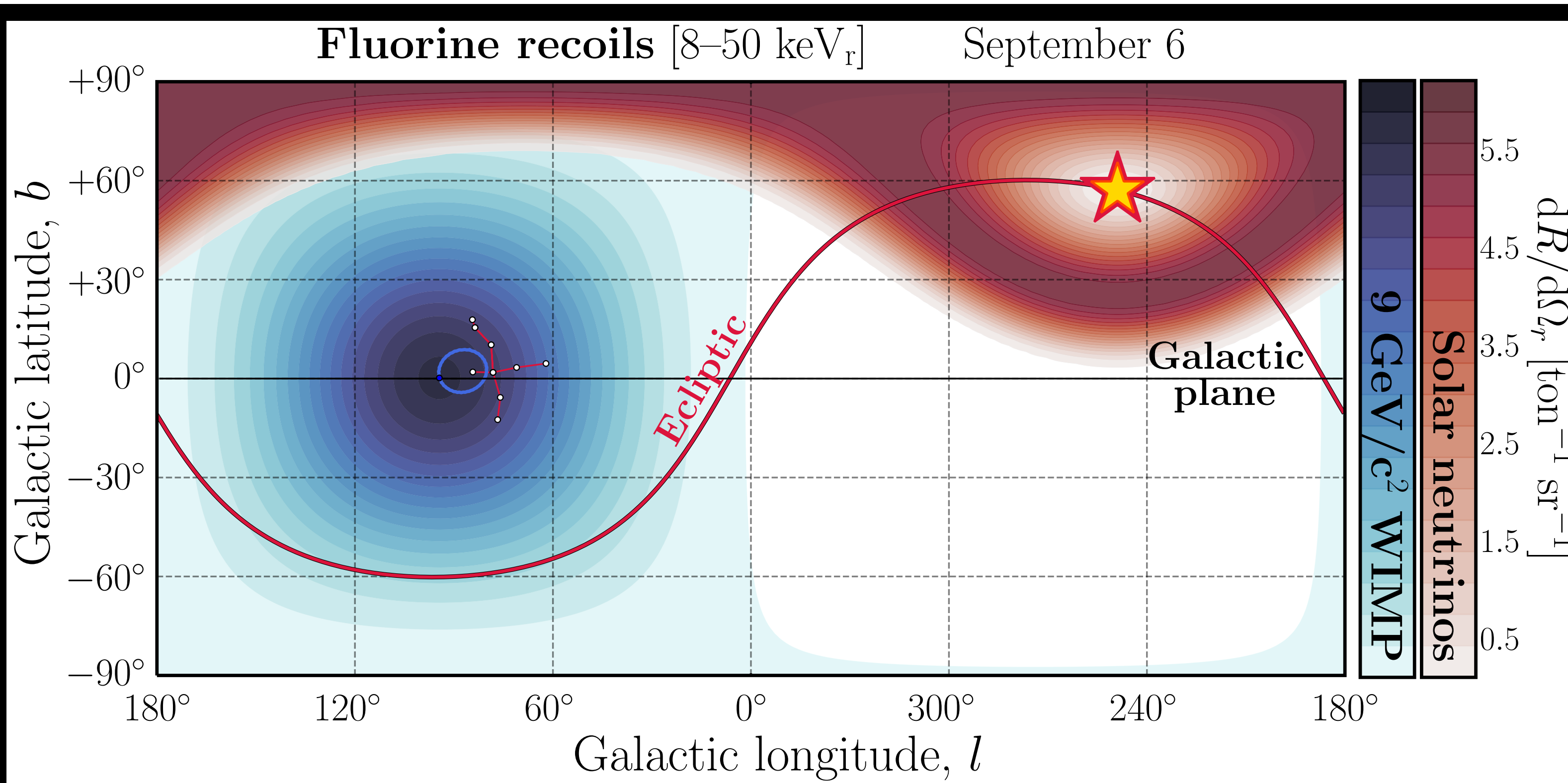


XENON1T Collaboration 2020

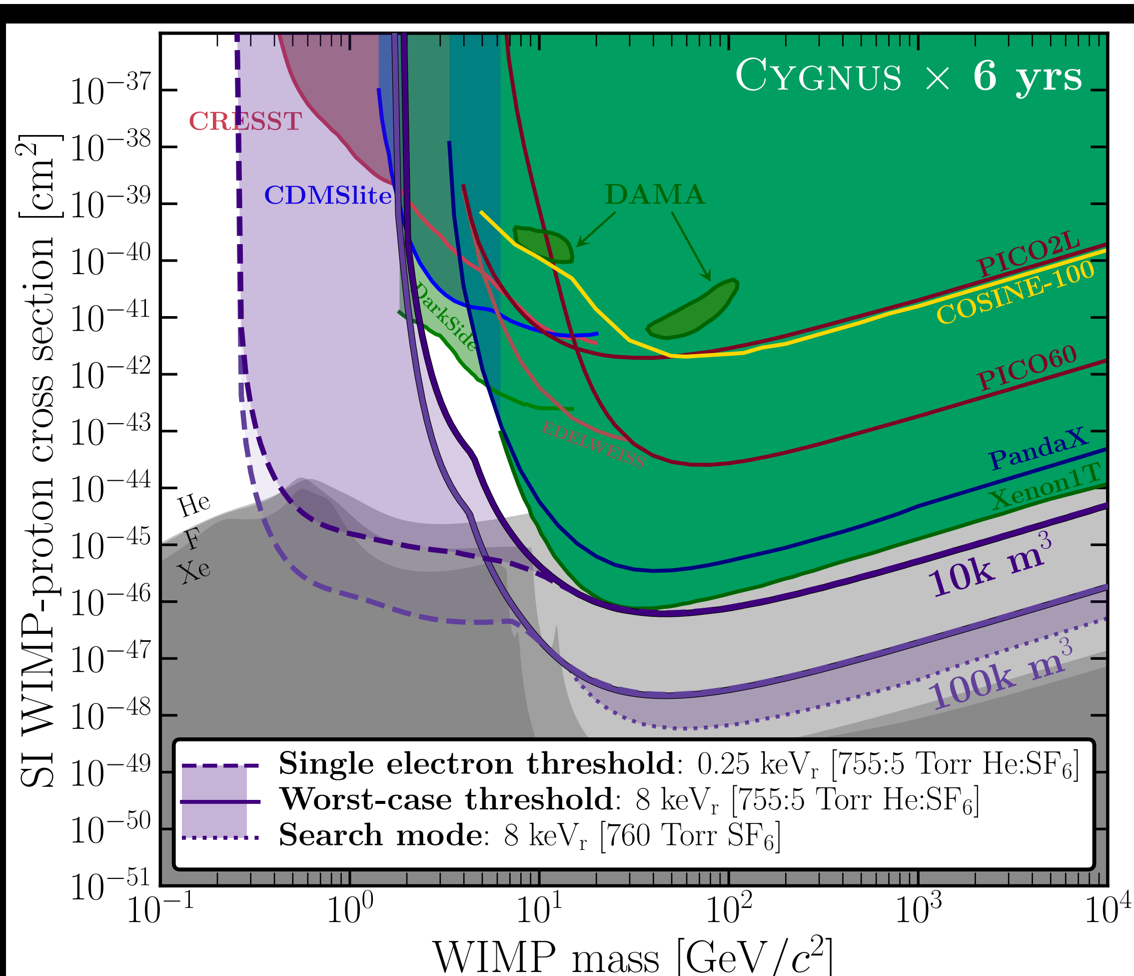


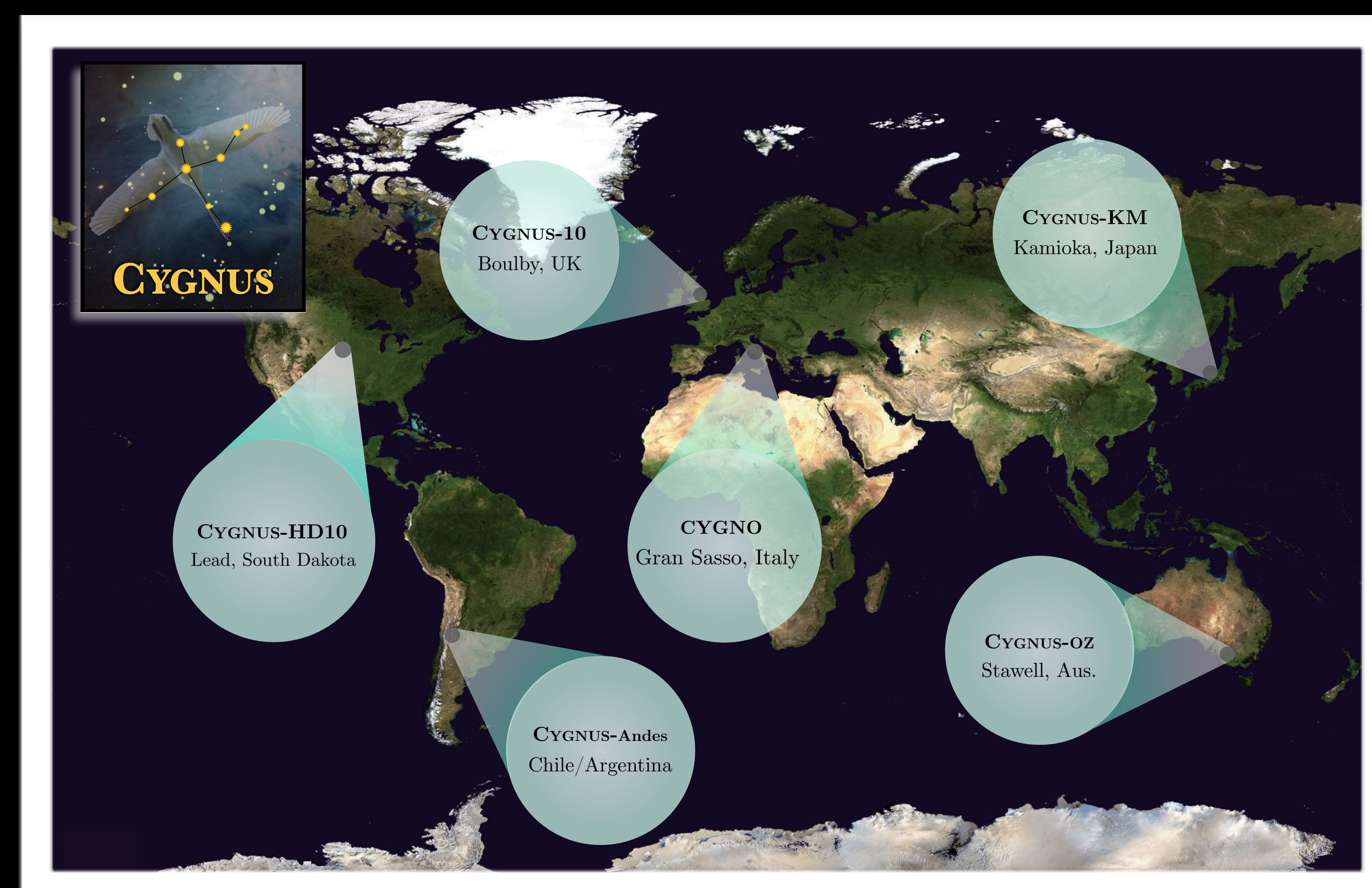
- may be background, or…
- solar axions / ALPs? (but stellar constraints)
- hidden photon DM?
- fast (subdominant) DM component?
- …? TBD.

Directional Detection



- unique opportunity to probe below "neutrino floor"
- CYGNUS feasibility paper: Vahsen+2020 arxiv:2008.12587





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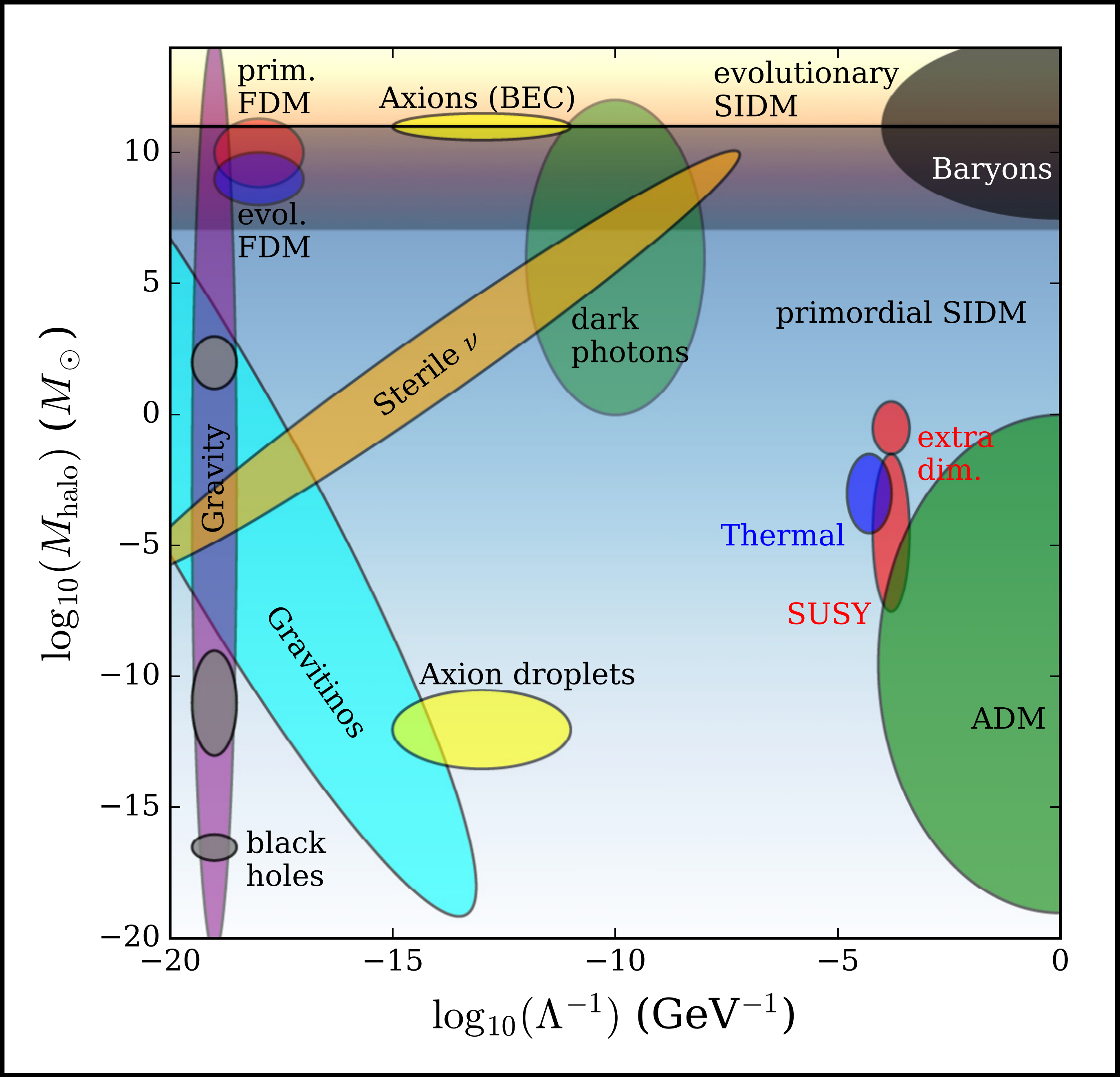
- Axion (e.g., QCD axion / string axion) (Mack 2011; Mack & Steinhardt 2011)
- Fuzzy DM (tiny mass, large deBroglie wavelength)
- MACHO (e.g., primordial black holes) (Mack, Ostriker & Ricotti 2007; R,O,M 2008)

Candidates (incomplete list)

halo mass



Standard Model interaction

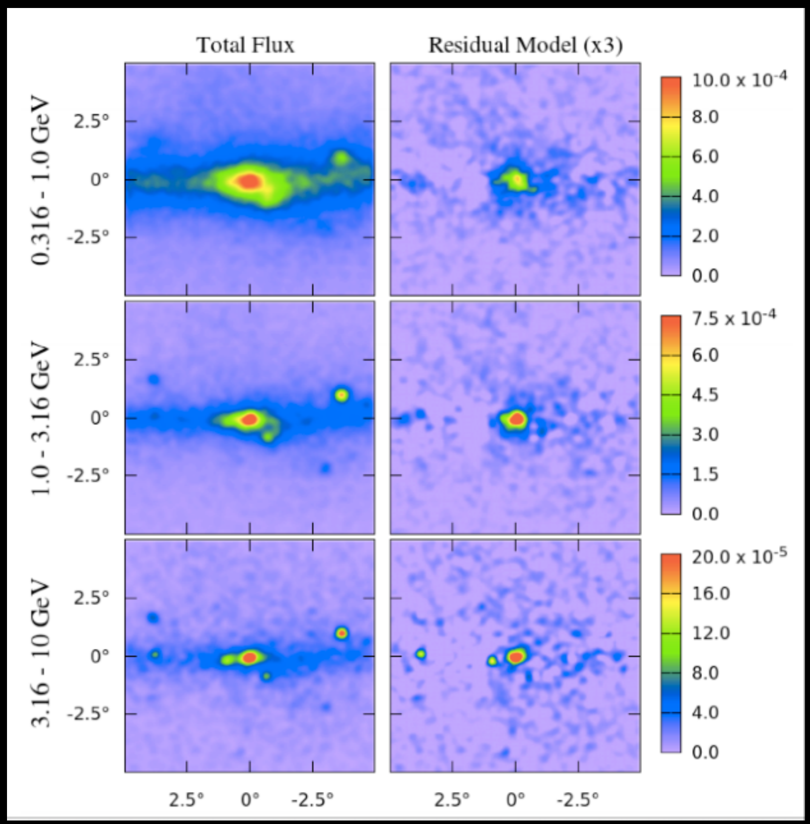
(where we expect to see a deviation from CDM)

Peter & Buckley 2018

Possible Hints/Signals

Annihilation?

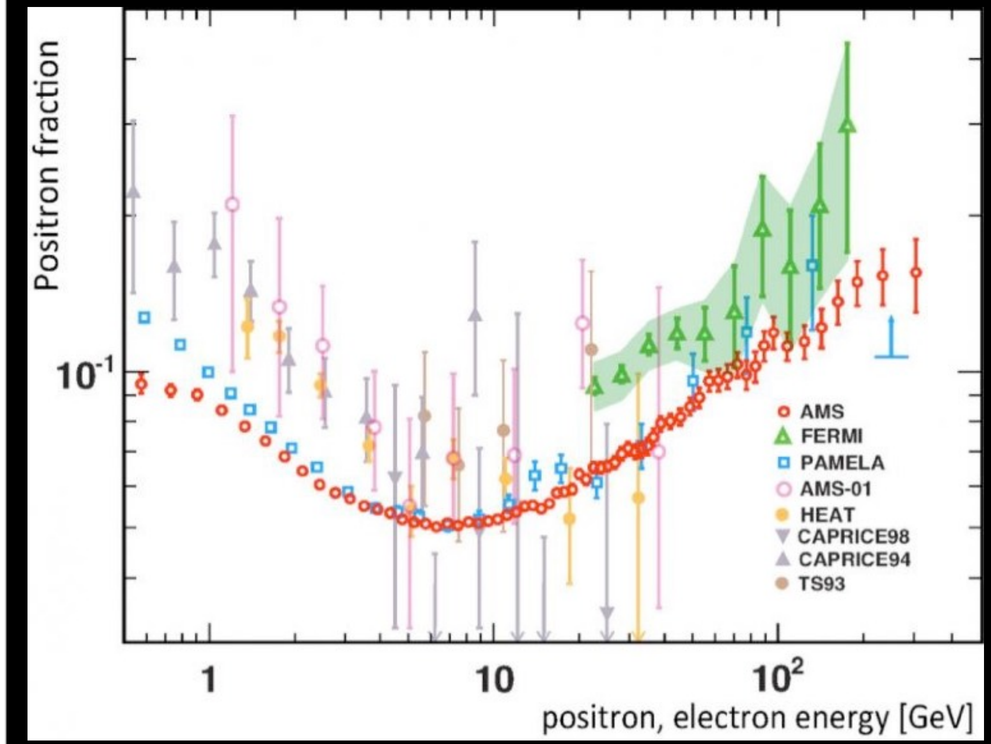
Gamma rays in the Galactic Center



Daylan et al. 2014

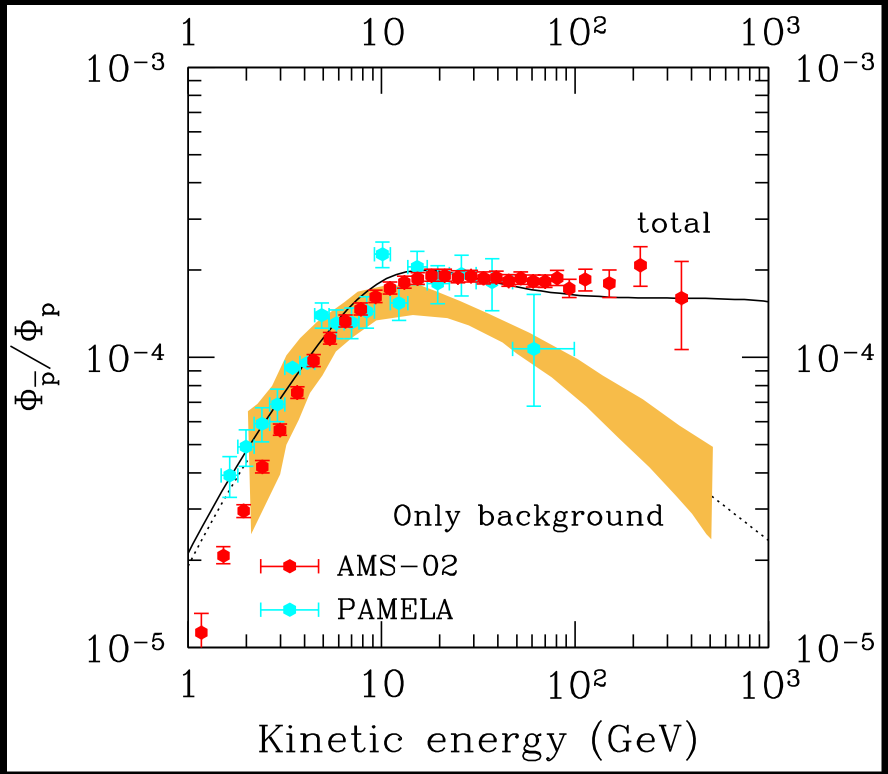
... but maybe pulsars

Excess positrons at high energy



AMS Collaboration 2013

Excess antiprotons at high energy



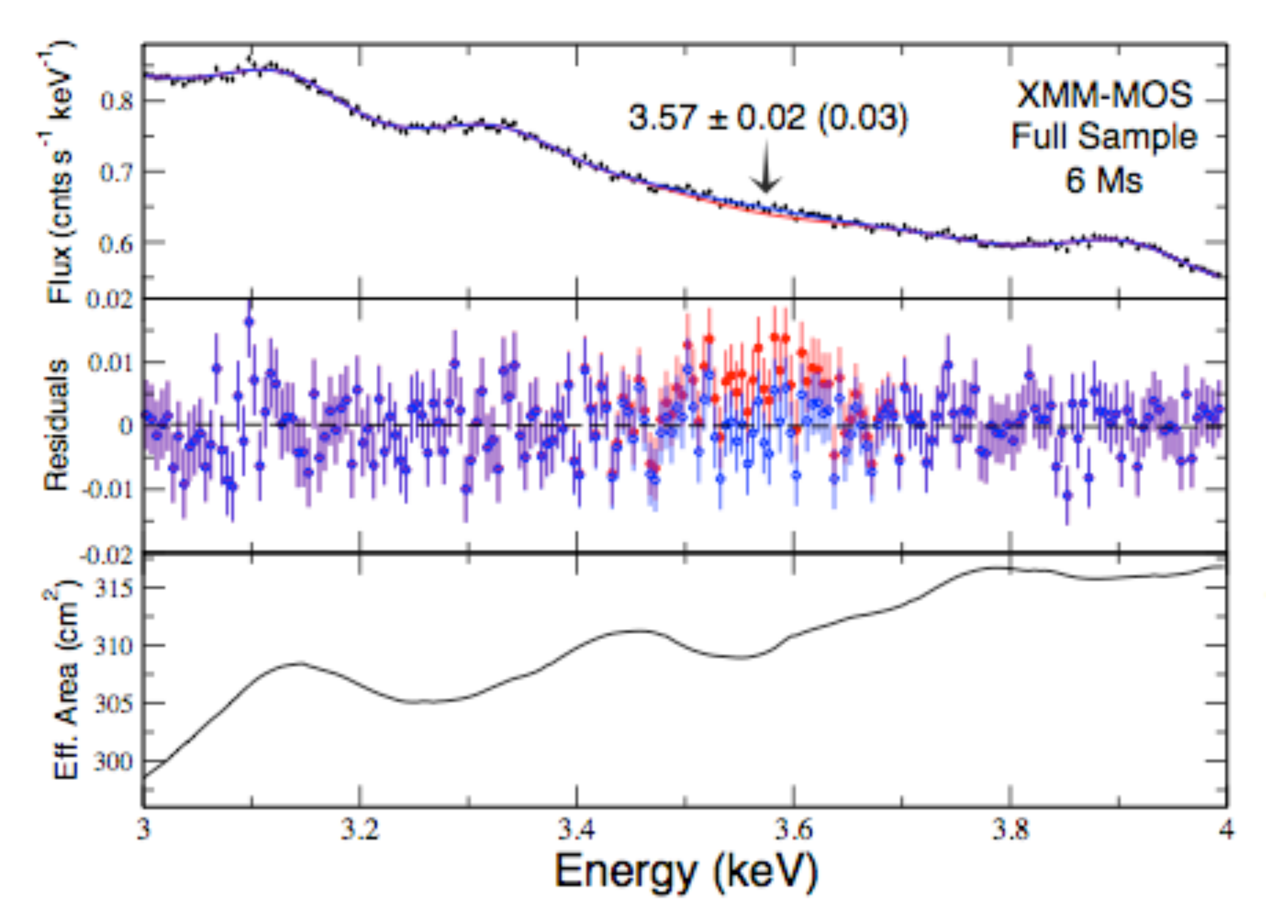
Kohri et al. 2015

Not pulsars!

... but maybe supernova remnant

Decay?

Excess x-rays in galaxy clusters

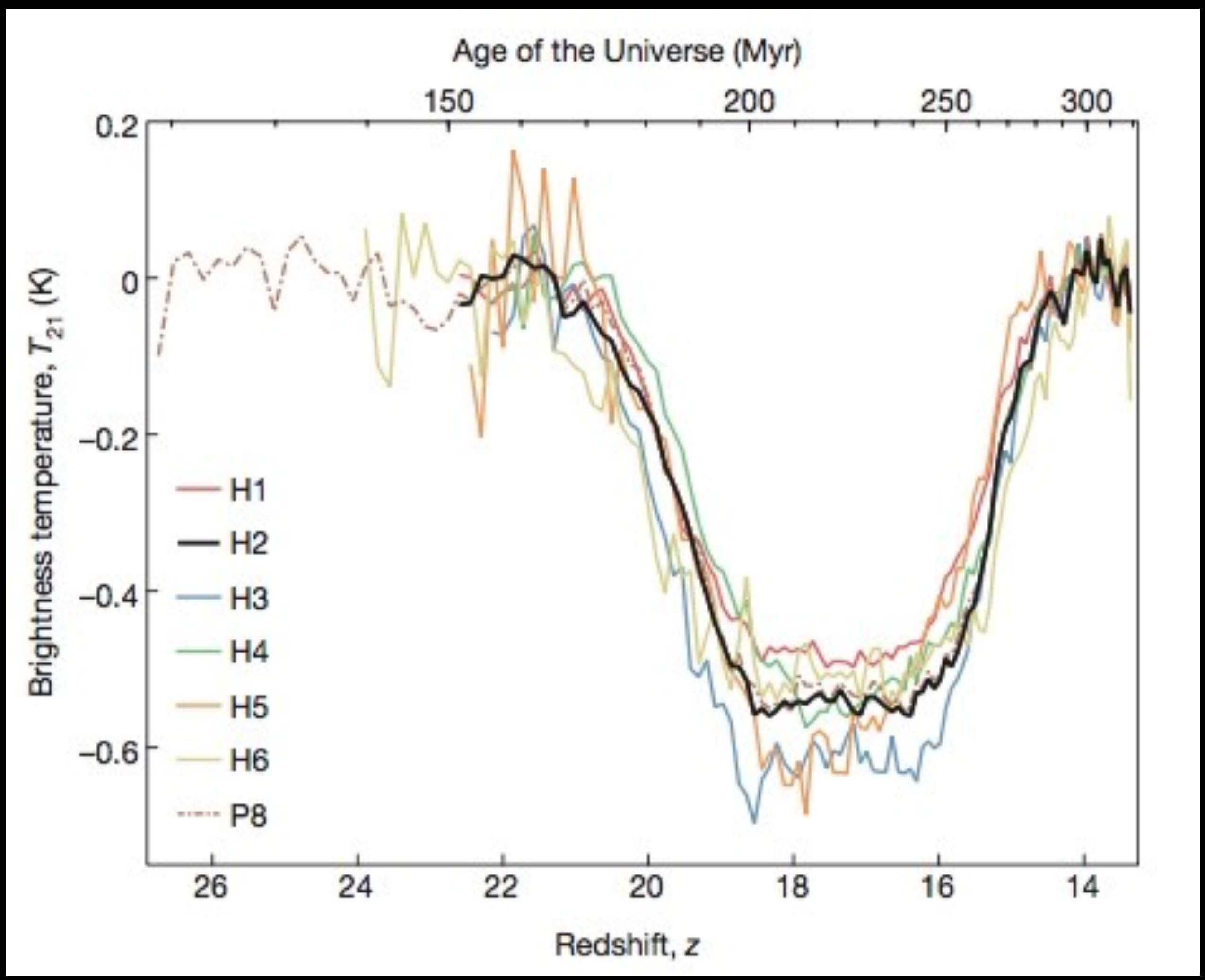


Bulbul et al. 2014

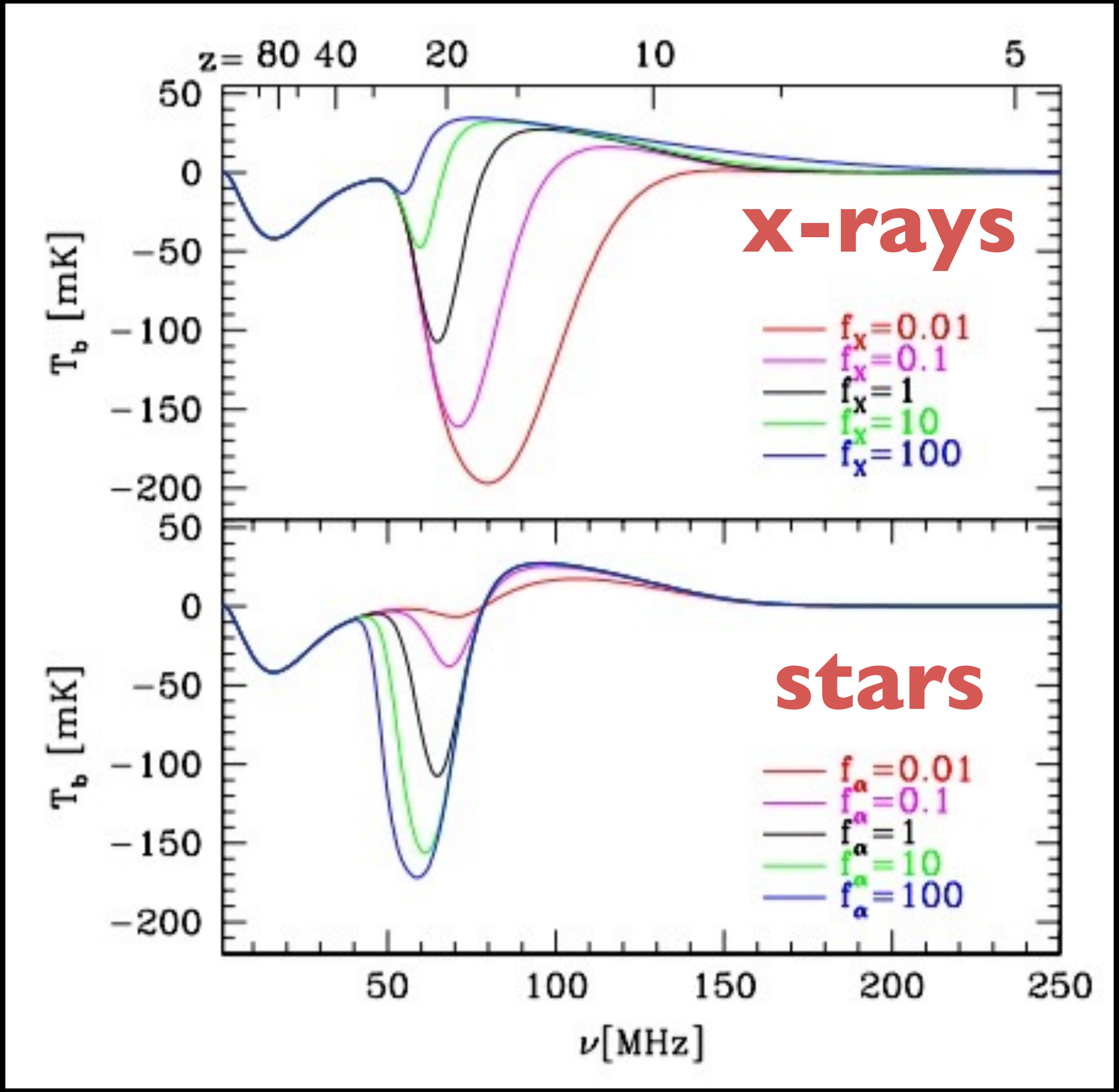
... but maybe line contamination

Scattering?

Super-cold neutral hydrogen at high redshift



Bowman et al. 2018

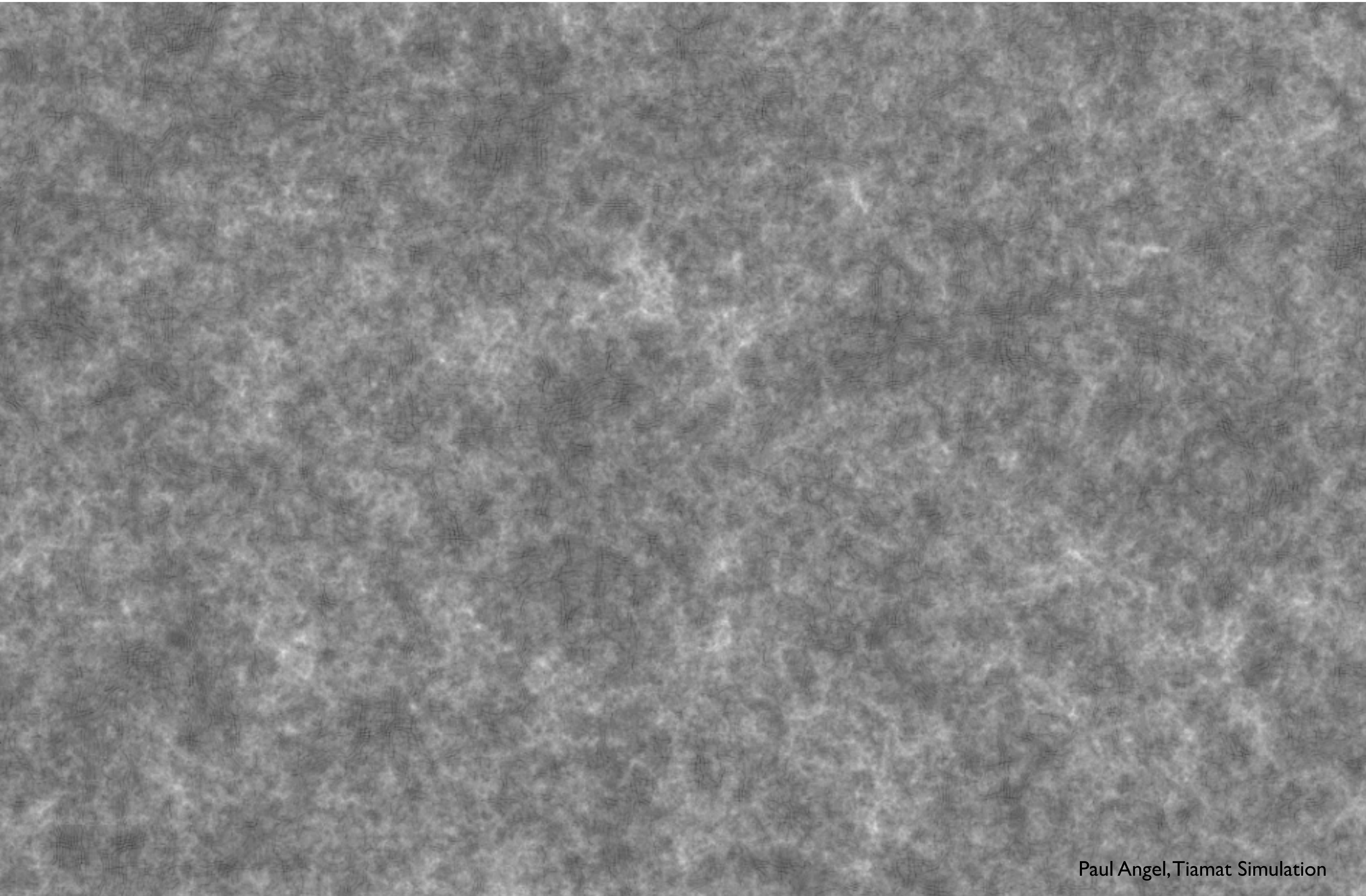


Pritchard & Loeb 2010

… but maybe a foreground subtraction problem

The Cosmic Frontier

Dark Matter: Cosmology

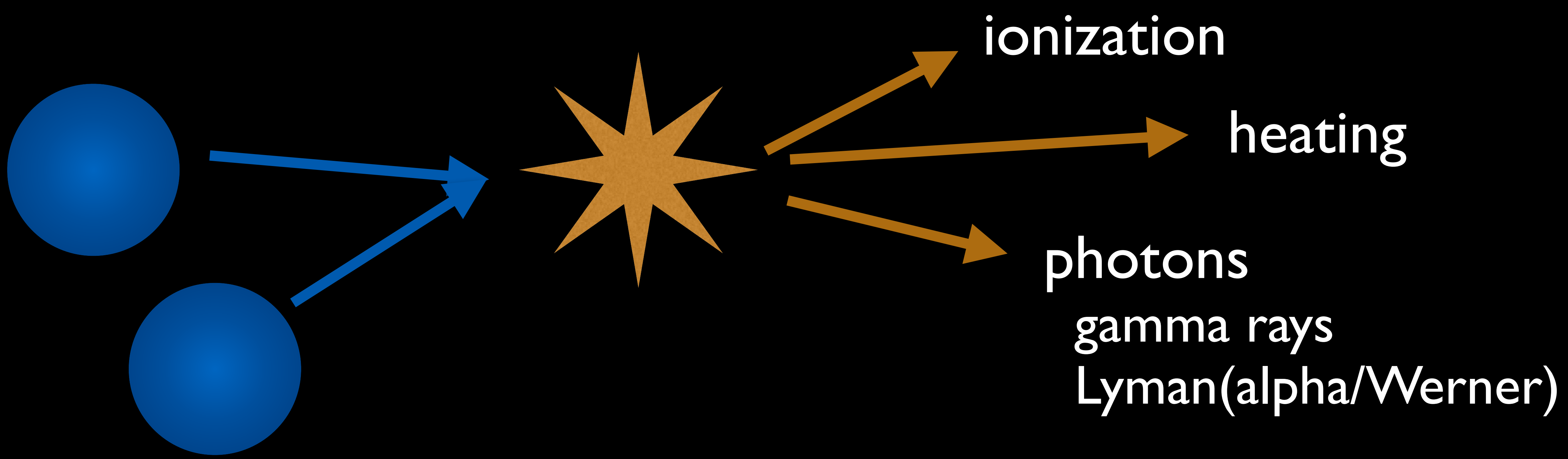


Paul Angel, Tiamat Simulation

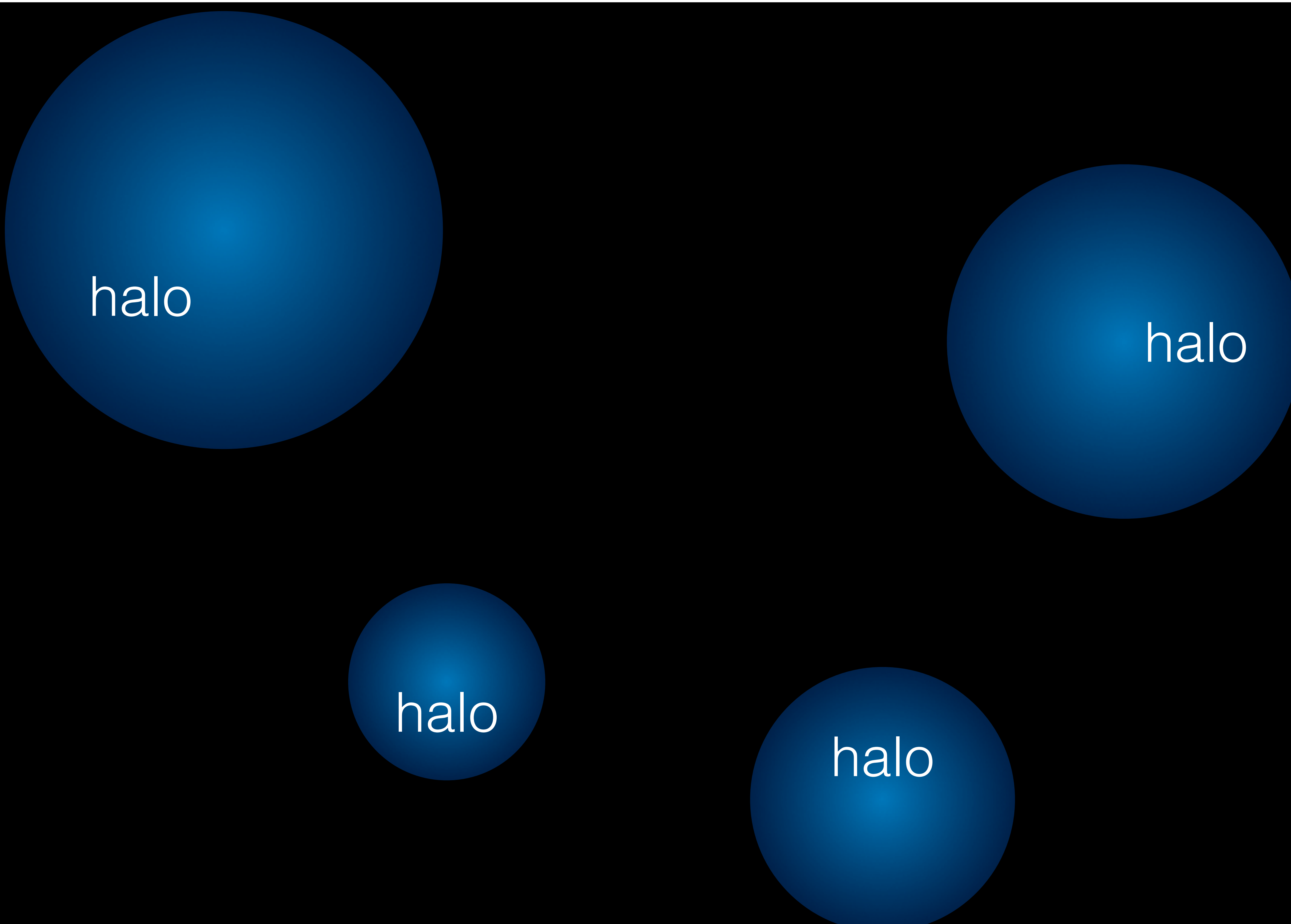
Impact of Dark Matter Annihilation

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



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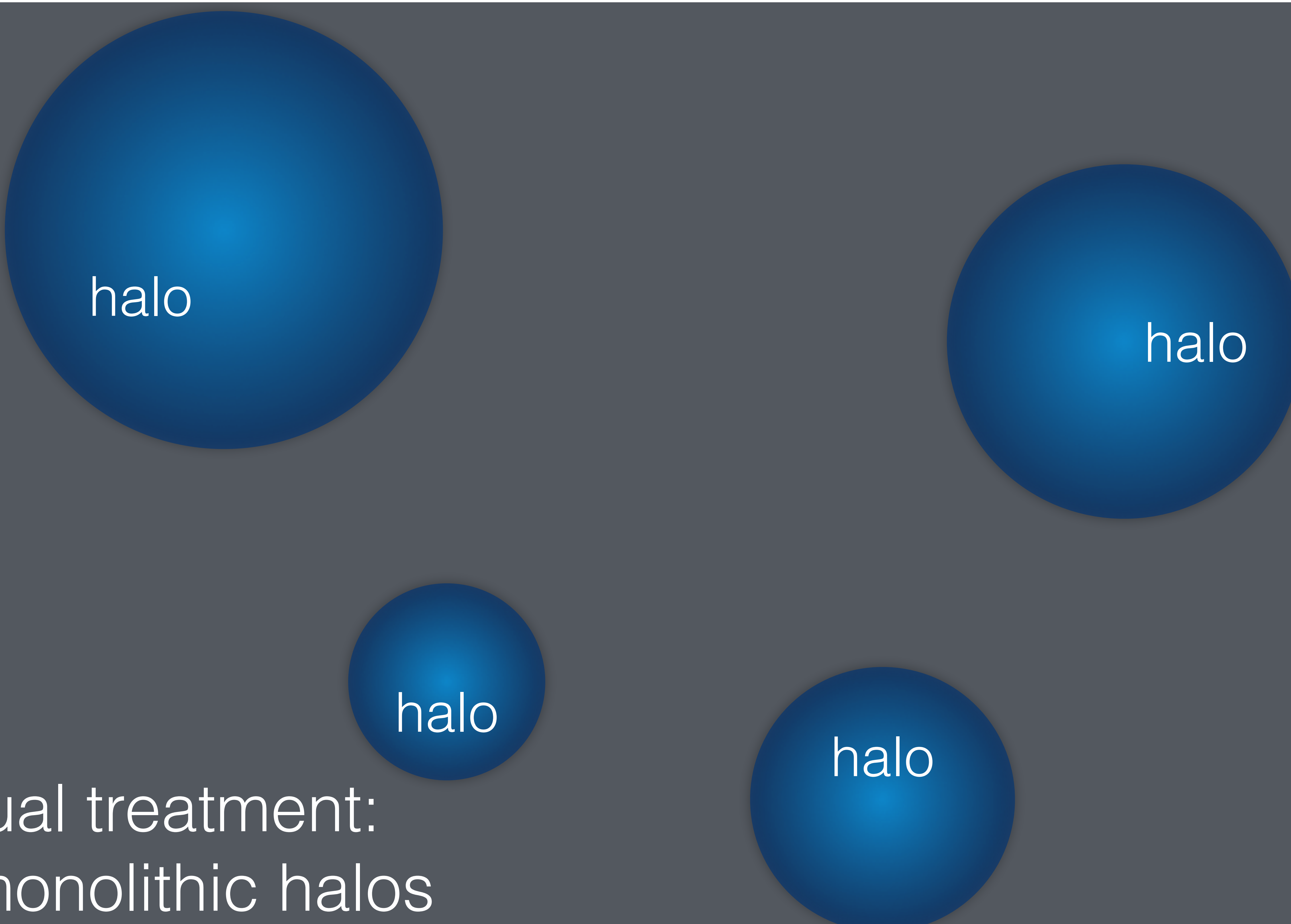
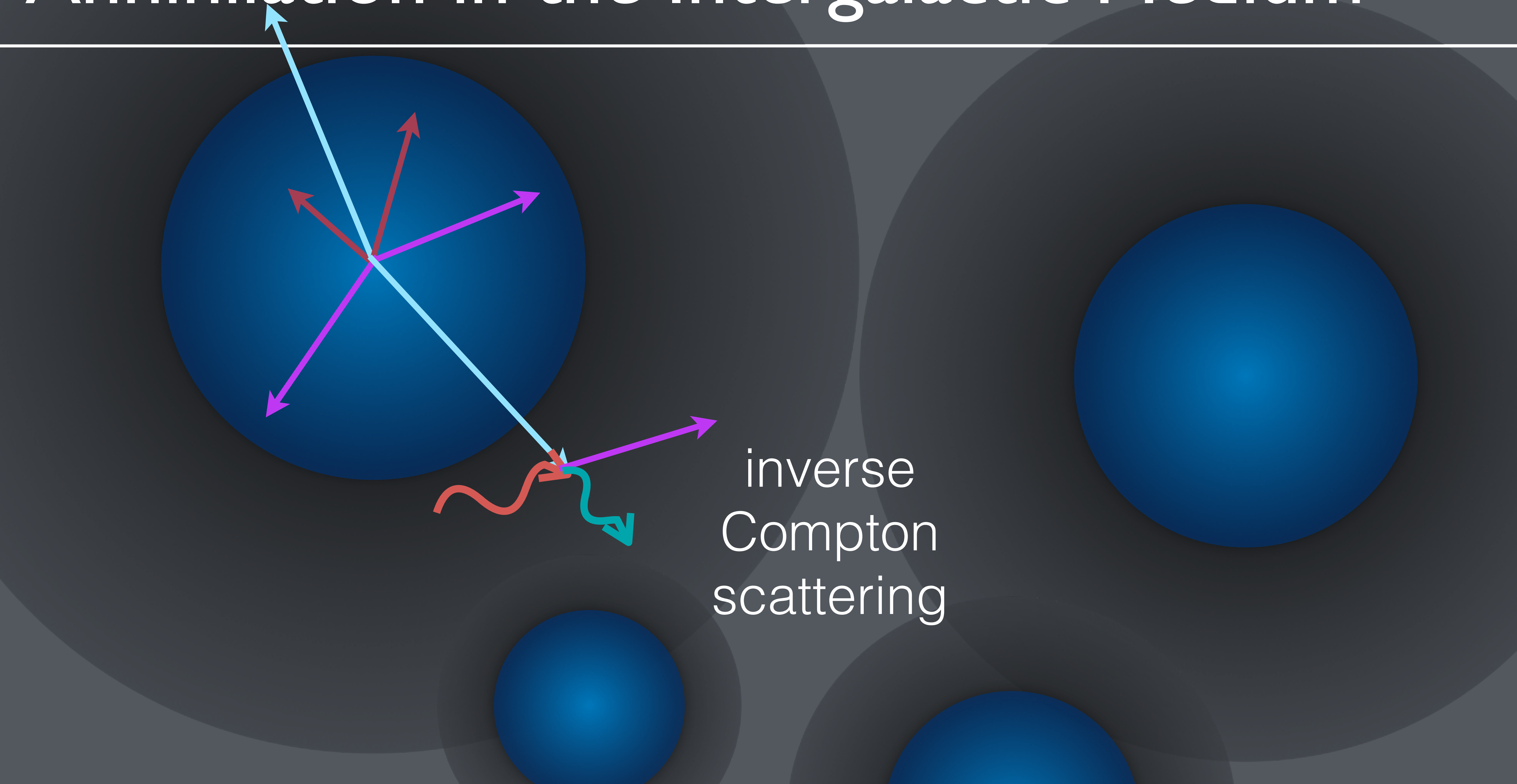


Usual treatment:

- monolithic halos
- immediate uniform energy deposition

Annihilation in the Intergalactic Medium

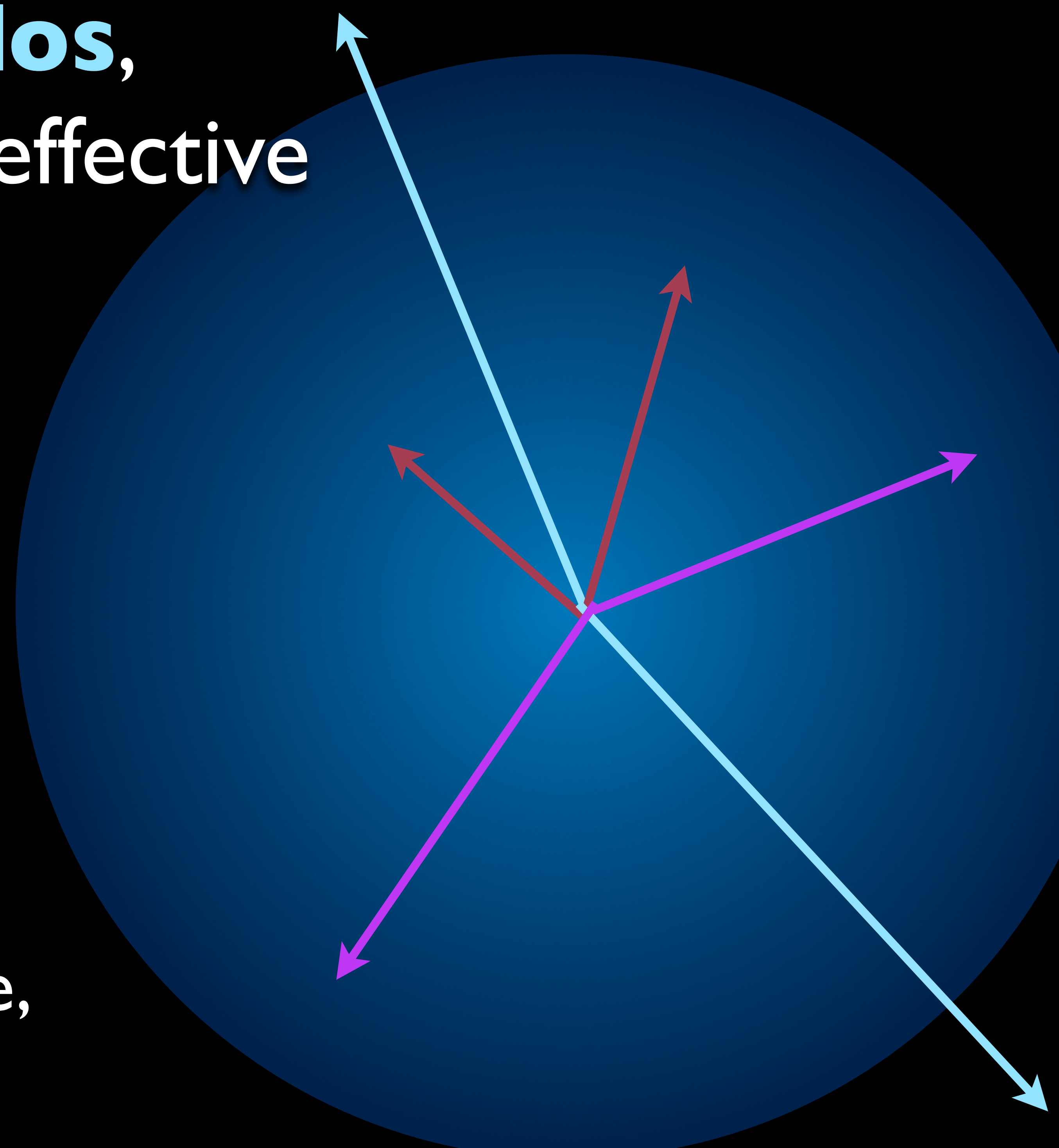


Better:

- 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?

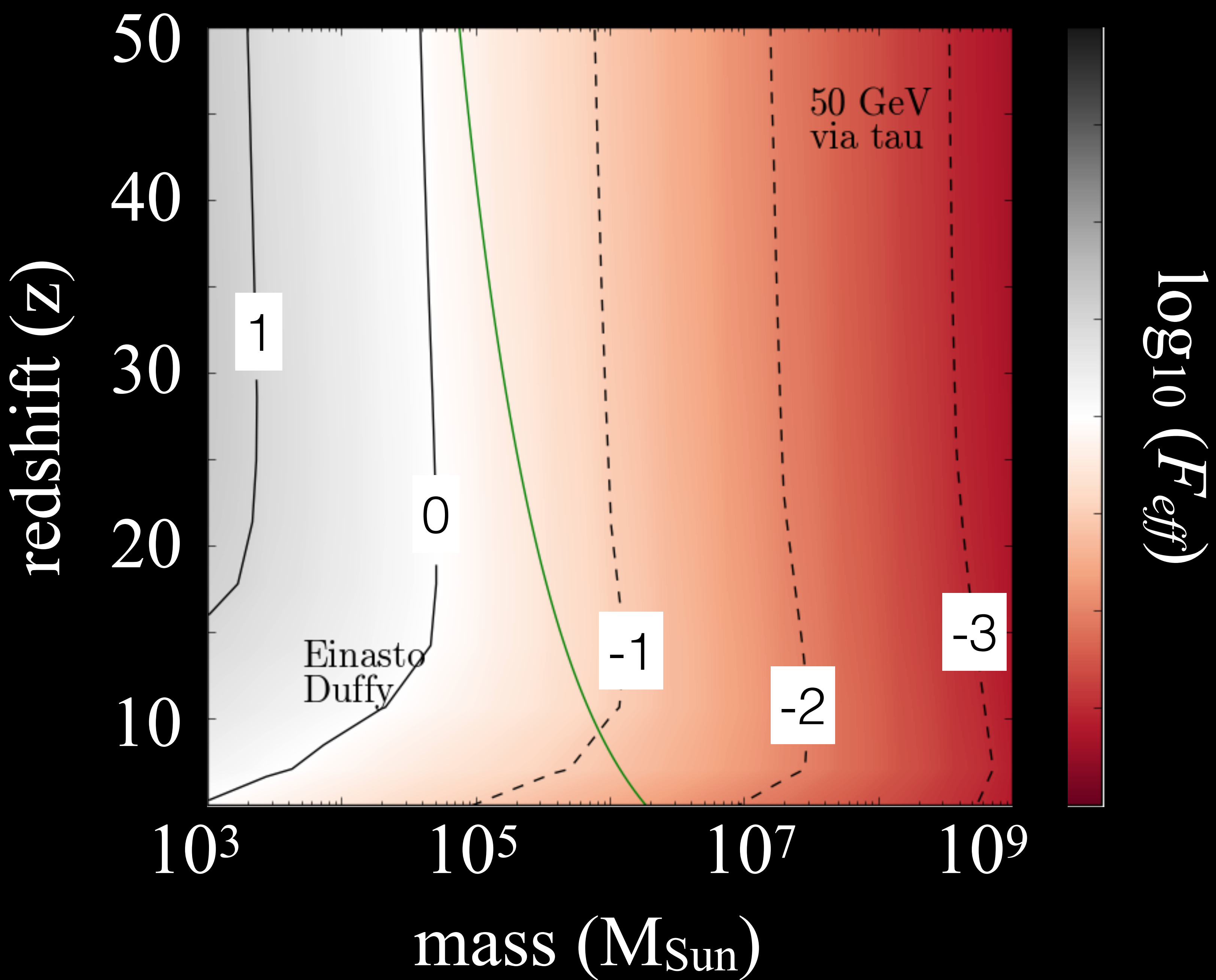


PYTHIA code: dark matter annihilation events

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]

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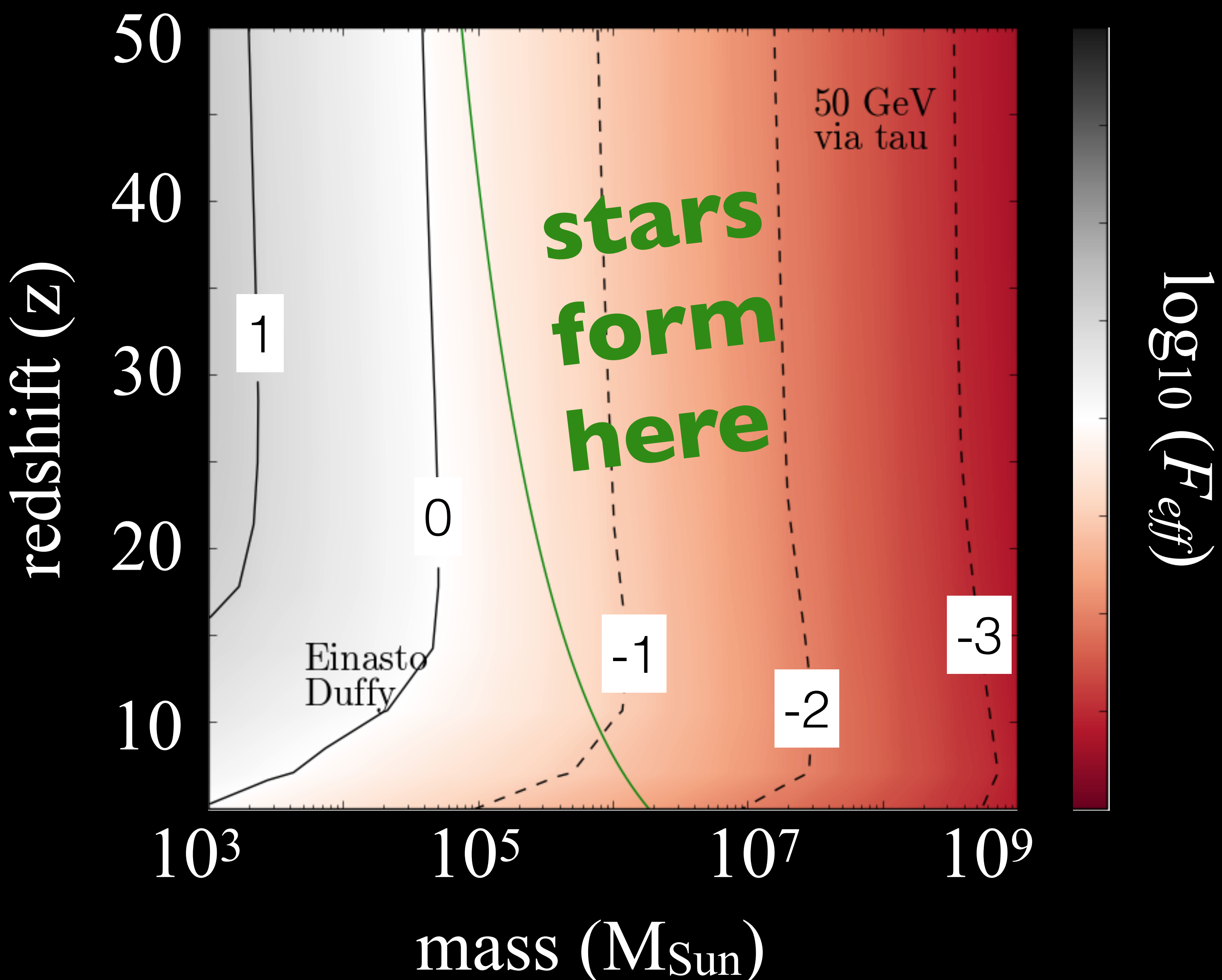

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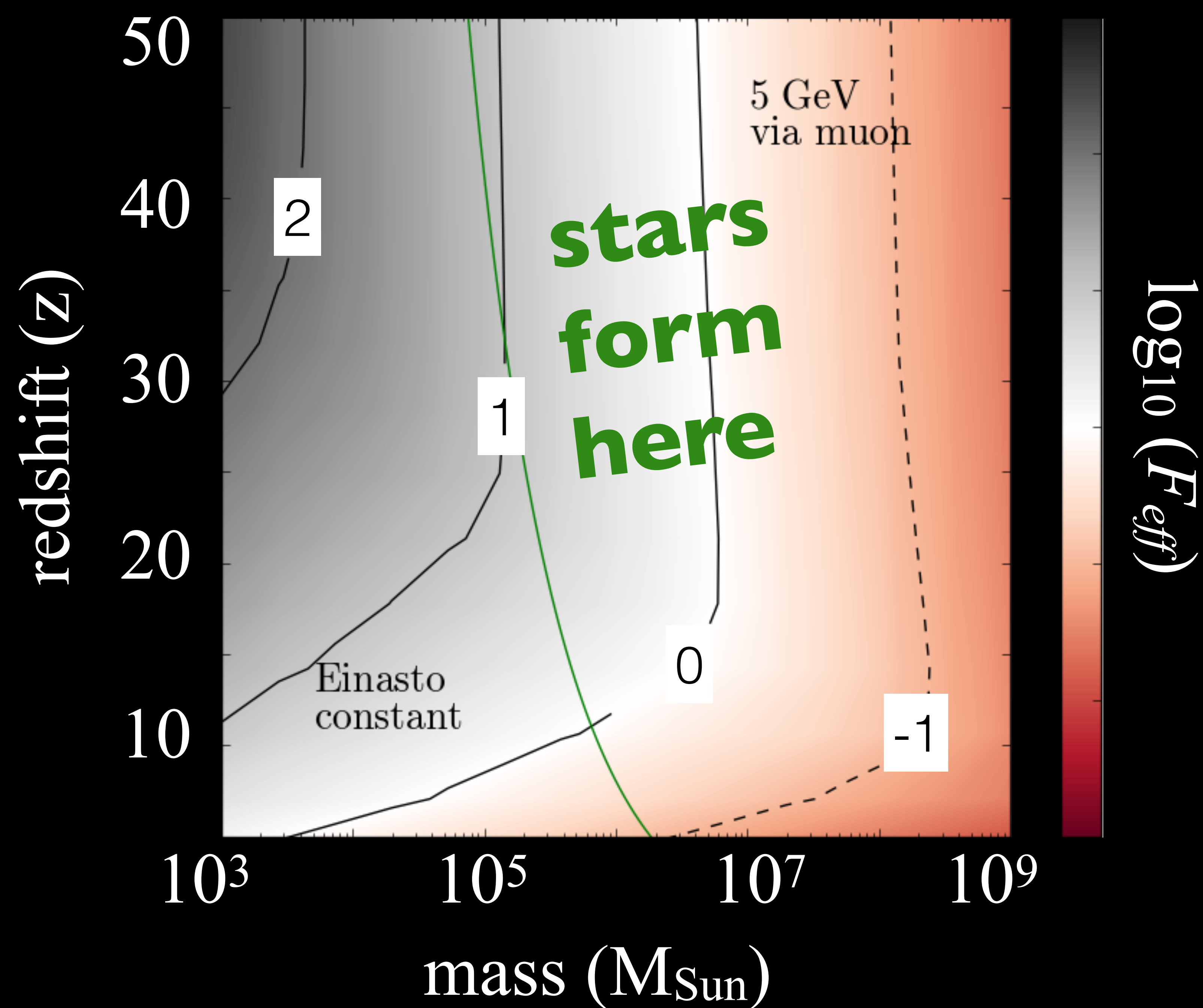

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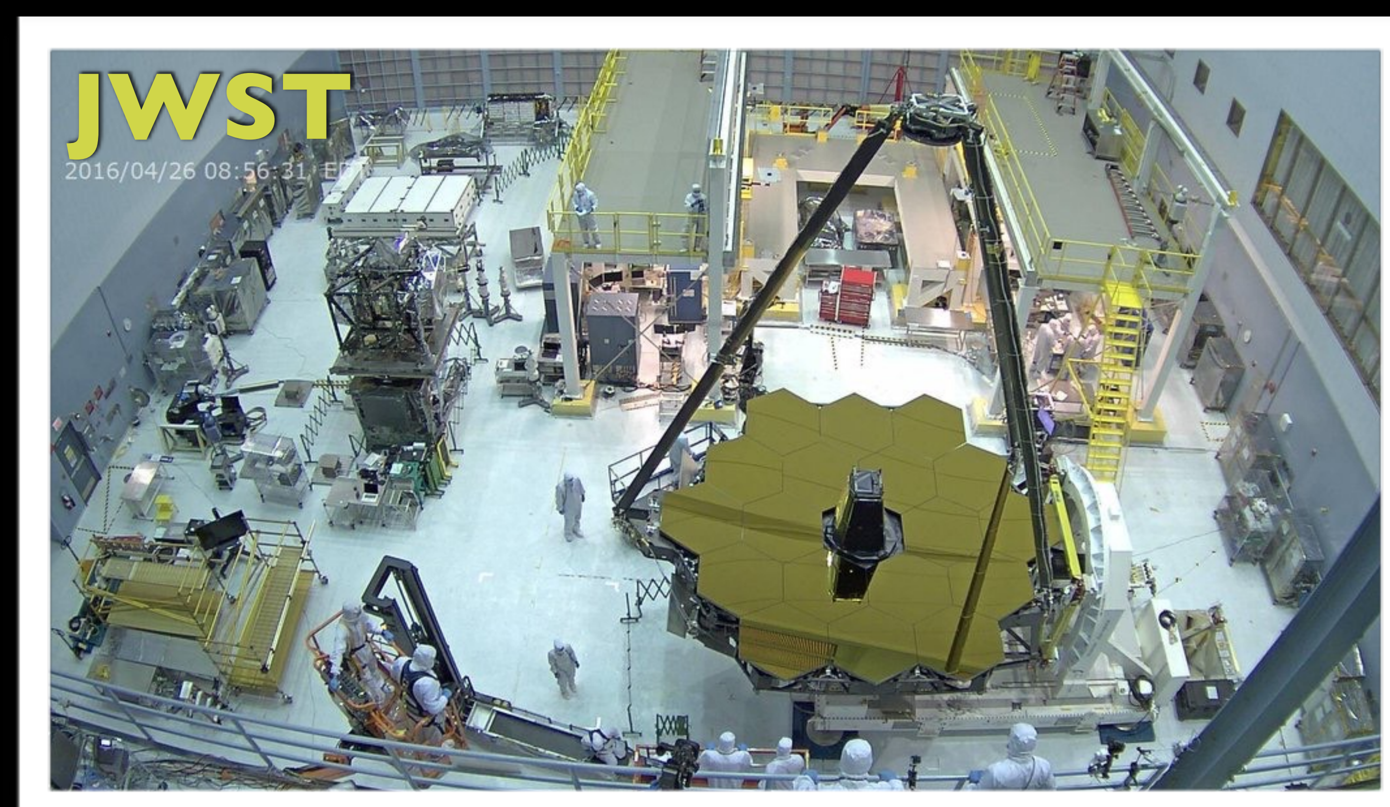
+ Schon, Mack+ 2018, MNRAS [arxiv: 1706.04327]

Probing Cosmic Dawn

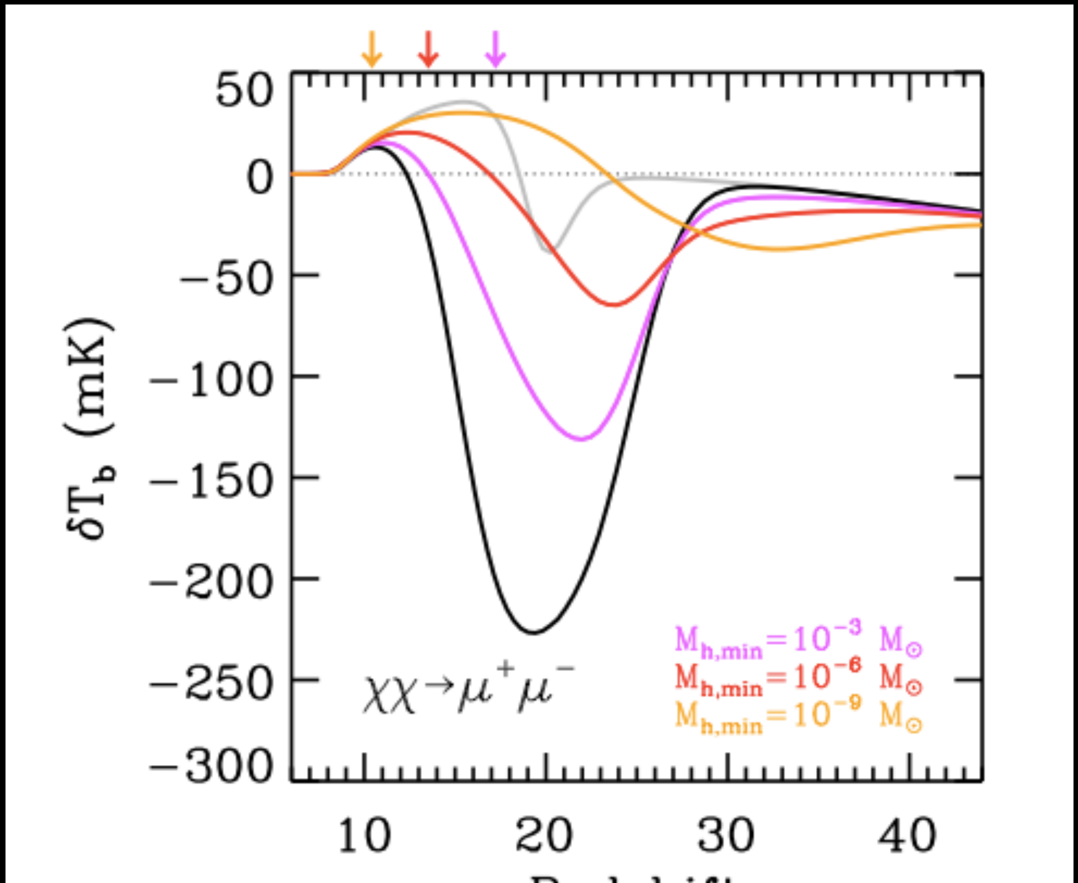
Djorgovski et al., Caltech

current instruments

next decade

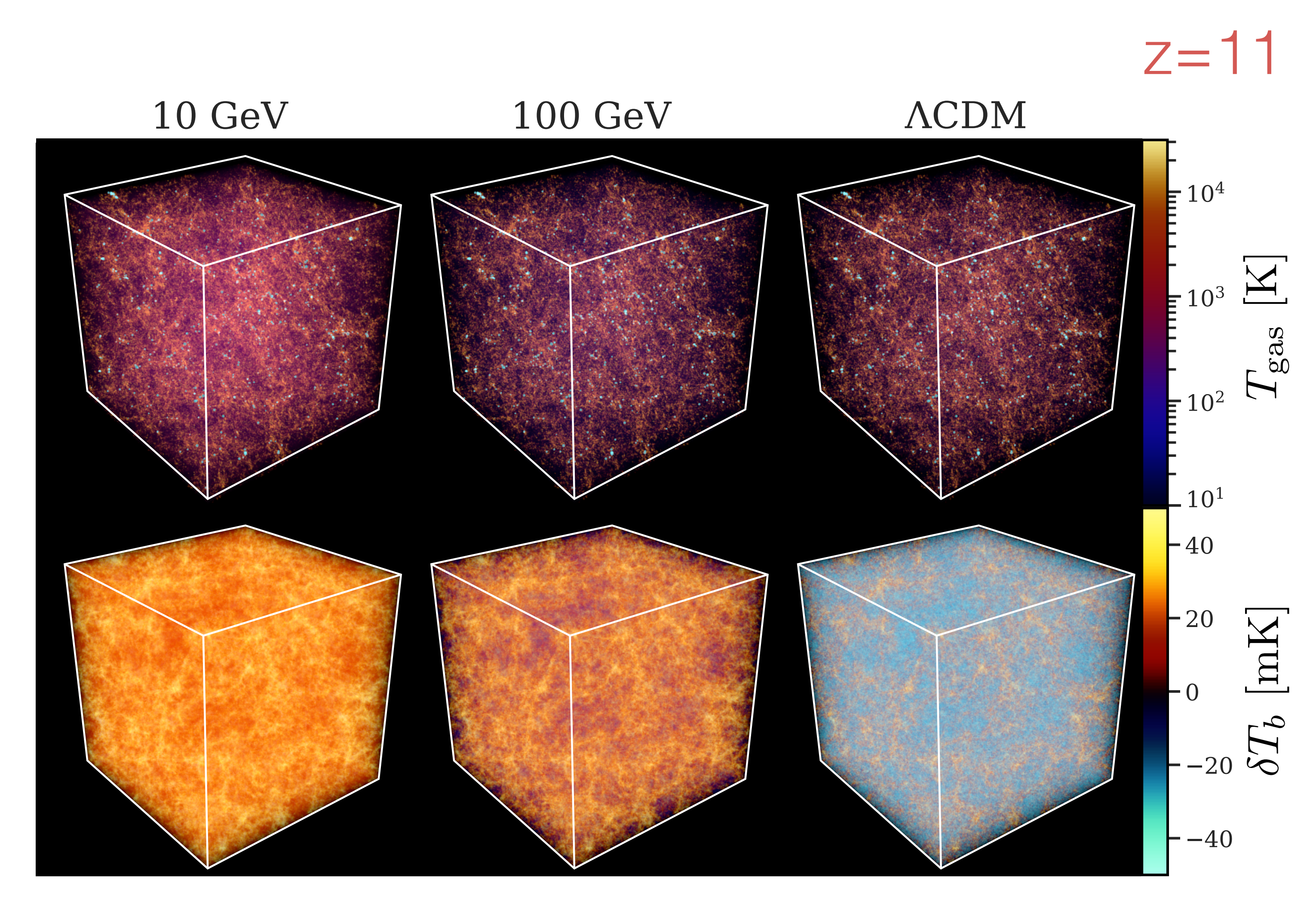


Dark Matter & 21cm



Evoli et al. 2014

List, Elahi and Lewis 2020



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

(and even dominate heating at certain redshifts)

DM+Hydro simulations needed to trace the impact of DM annihilation on galactic and intergalactic gas

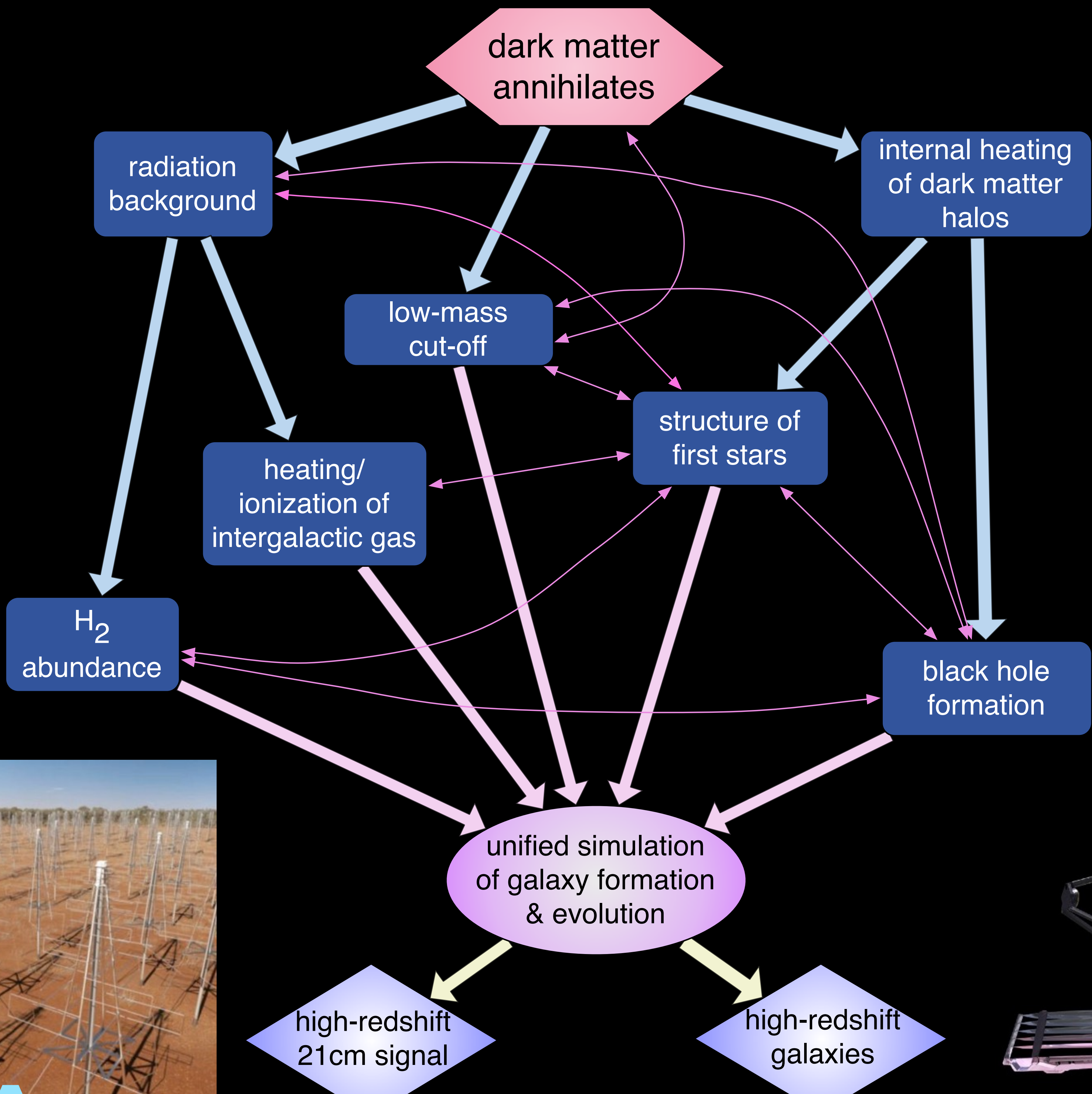


Image credit: Swinburne/ ICRAR/Cambridge/ASTRON

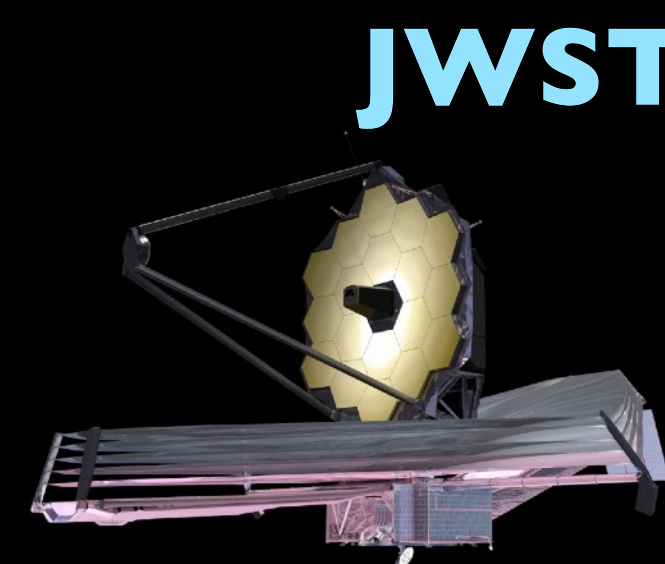


Image credit: NASA

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

end