Dark Matter in the Cosmic Context

Katie Mack

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(soon: North Carolina State University)

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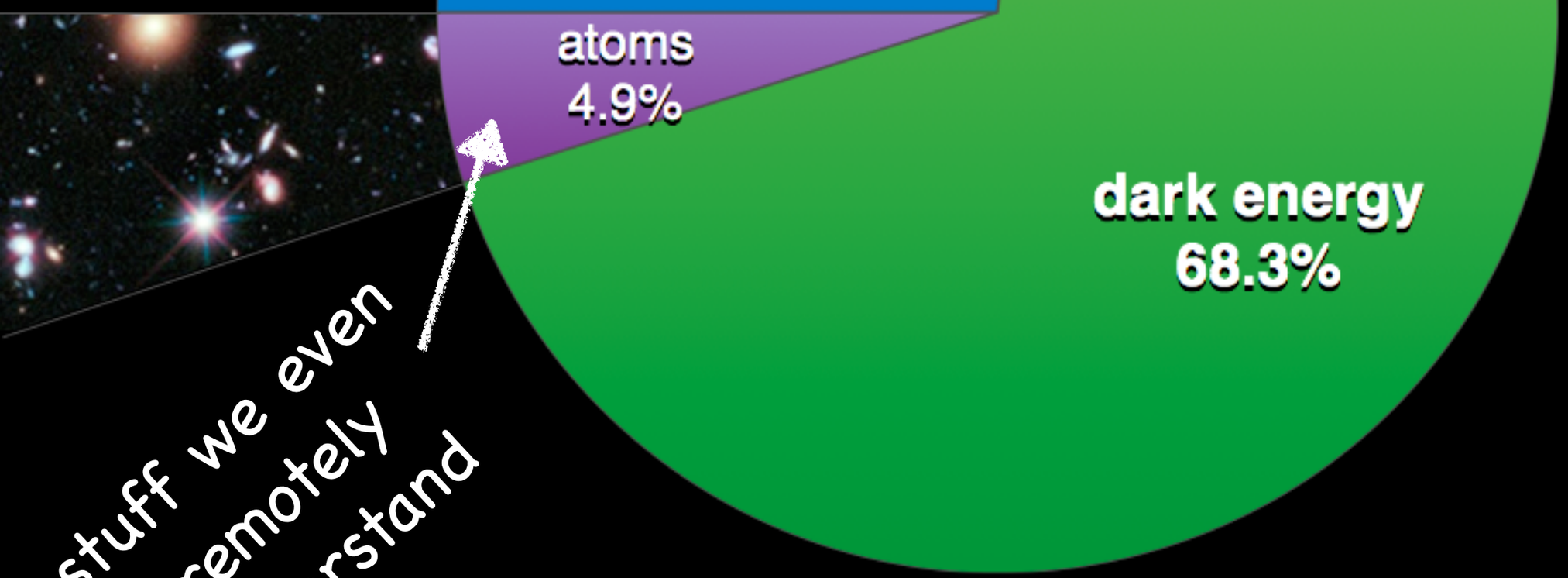
: @AstroKatie

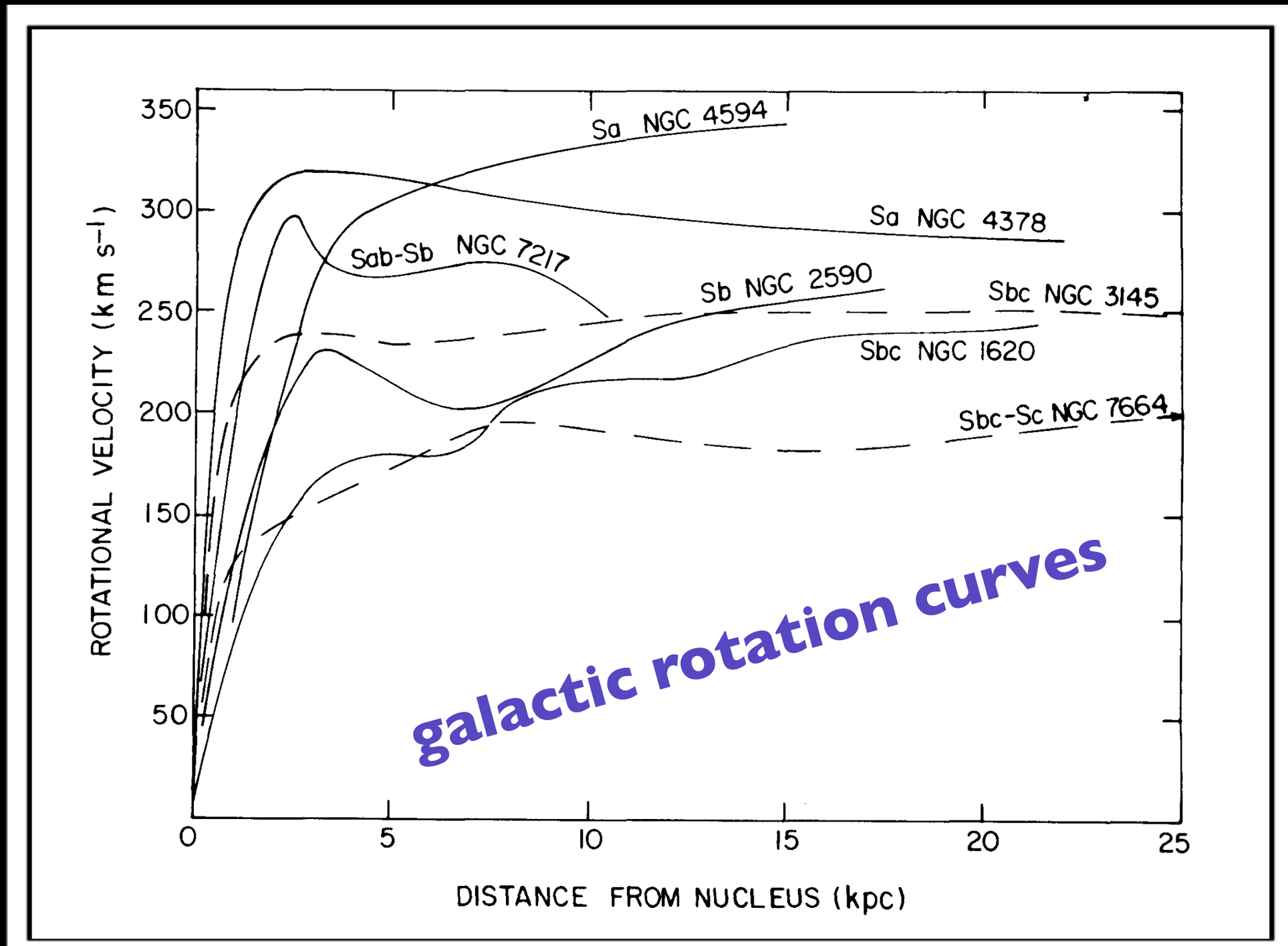

dark matter
26.8%
atoms
4.9%
dark energy
68.3%
stuff we even remotely understand

Dark Matter

Image: dark matter: K. Mack; Andromeda Galaxy: GALEX, JPL-Caltech, NASA

Evidence and Properties

massive



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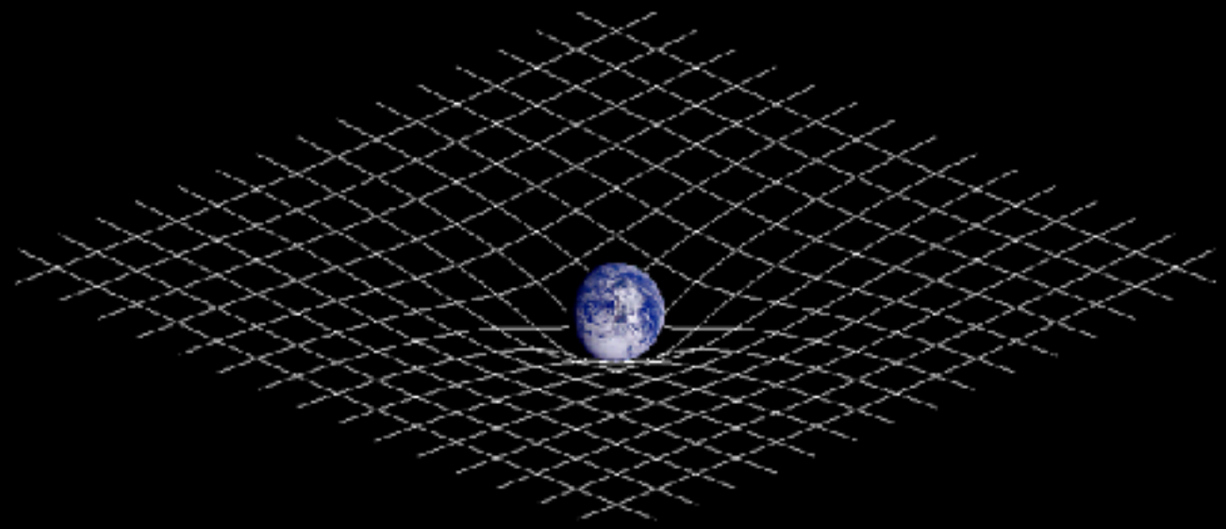


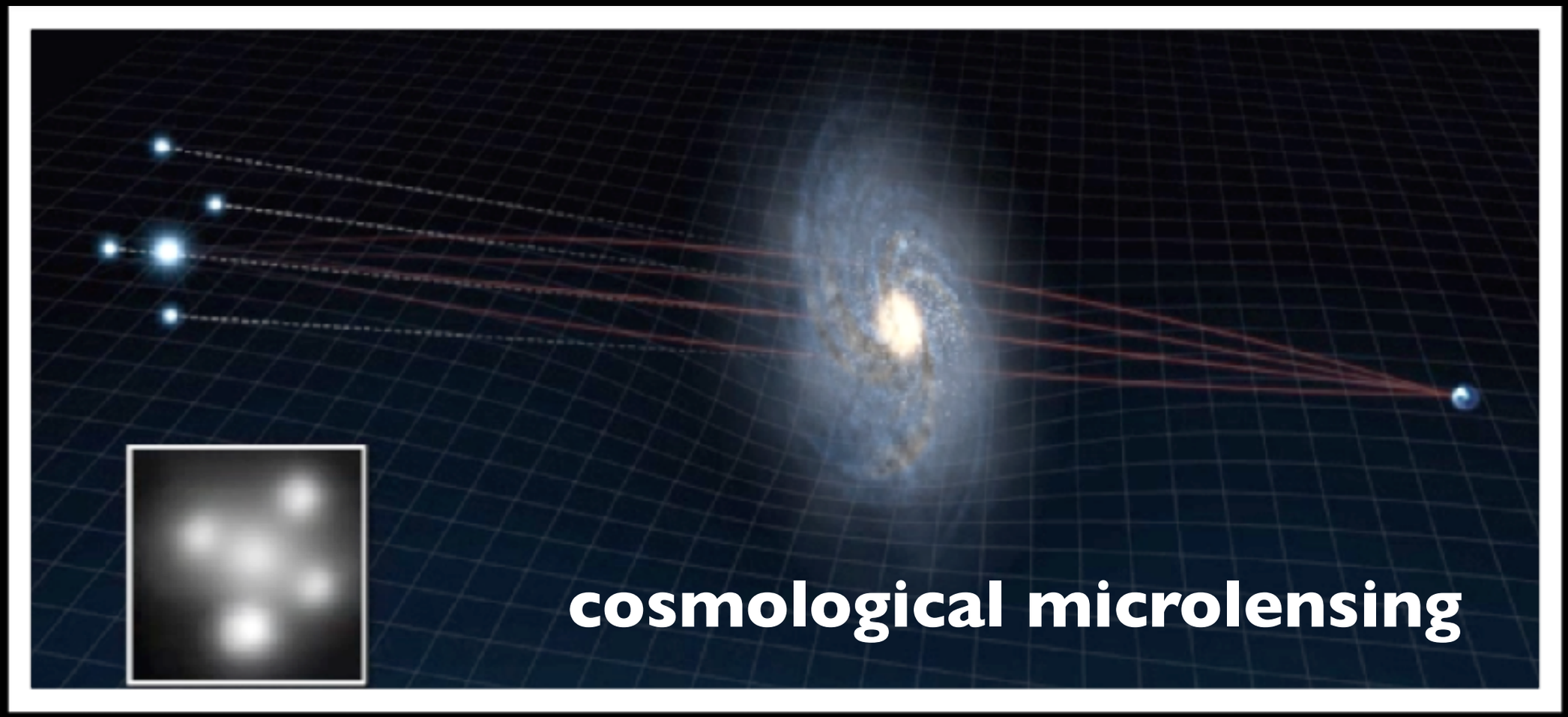
ubiquitous

Evidence and Properties

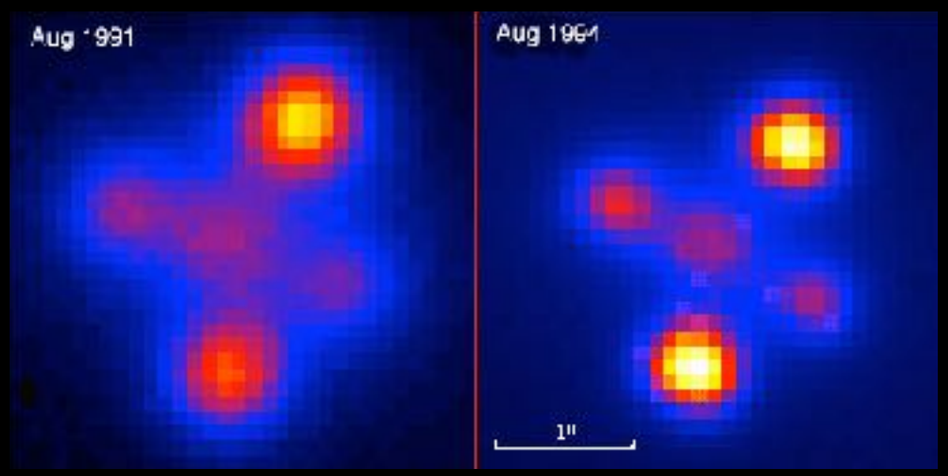
massive

ubiquitous

smooth



Lewis & Irwin 1996



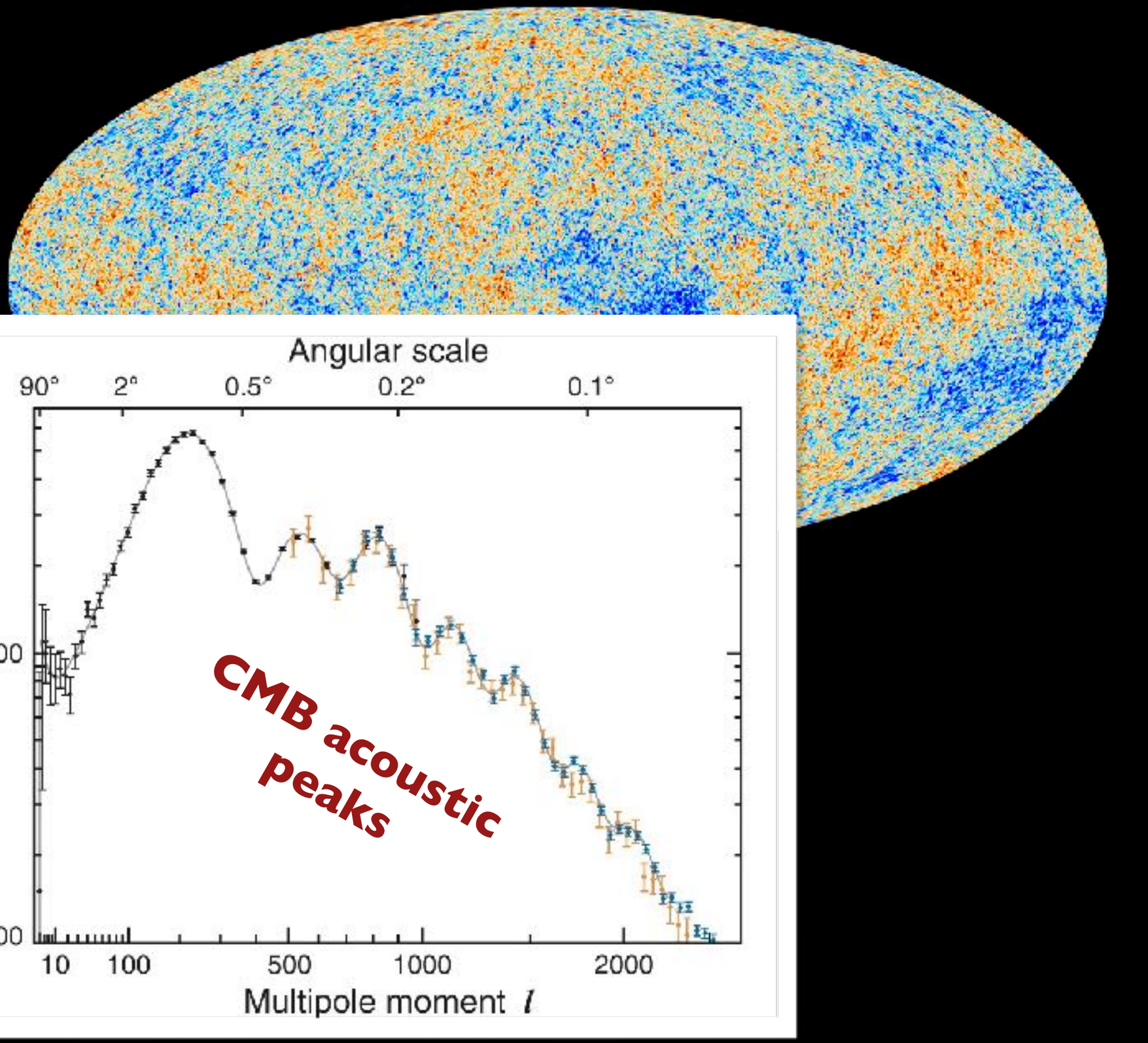
Evidence and Properties

massive

ubiquitous

smooth

collisionless



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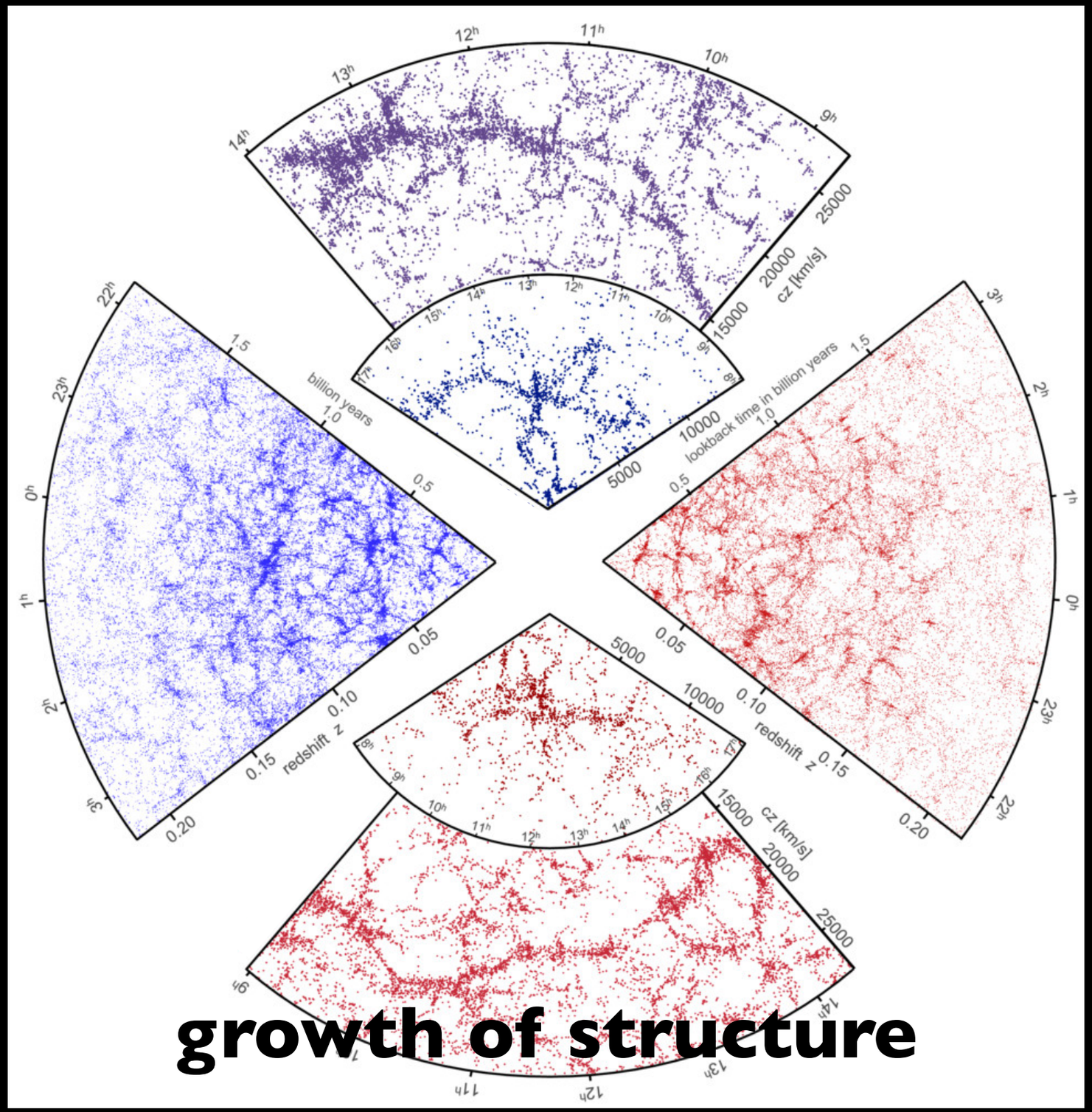


growth of structure

Evidence and Properties

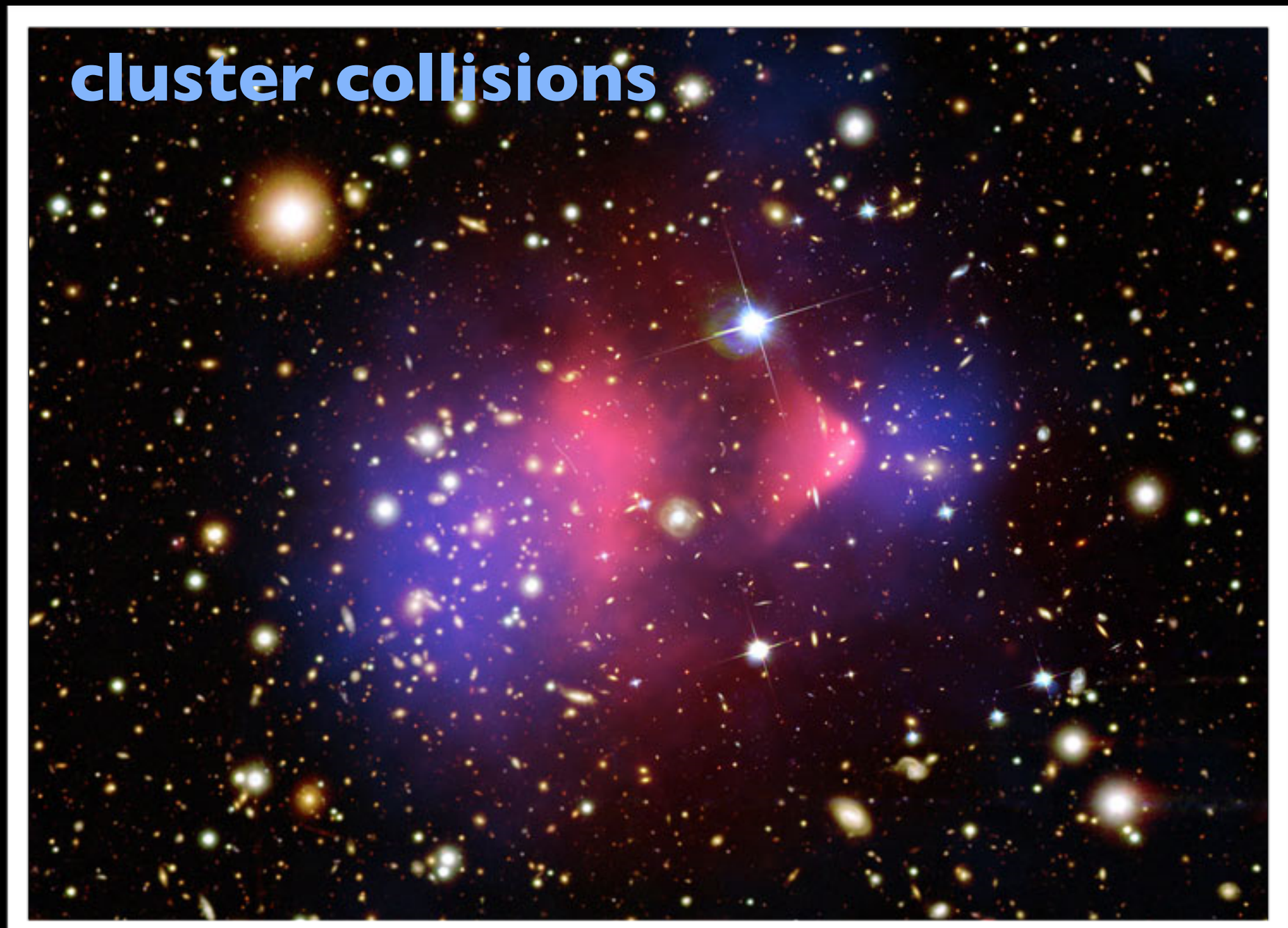
massive

ubiquitous

smooth

collisionless

new component

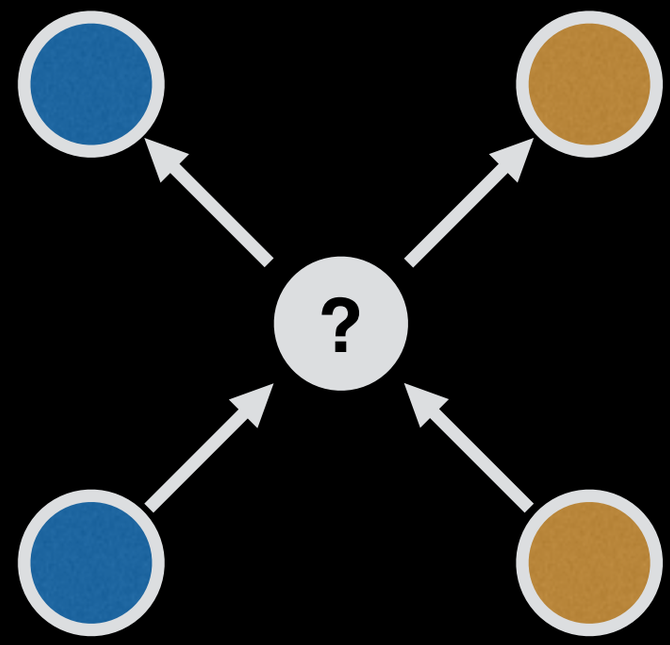


Candidates

- **W**eakly **I**nteracting **M**assive **P**articles (a.k.a., WIMPs)
  - Something not included in the Standard Model of Particle Physics
    - Annihilating (e.g., SUSY neutralino WIMP)
    - Decaying (e.g., axino)
    - Warm (WDM) (e.g., sterile neutrino)
    - Self-interacting (SIDM) (particle + dark sector force)
    - Axion (e.g., QCD axion / string axion)
    - MACHO (e.g., primordial black holes)

Annihilating WIMPS

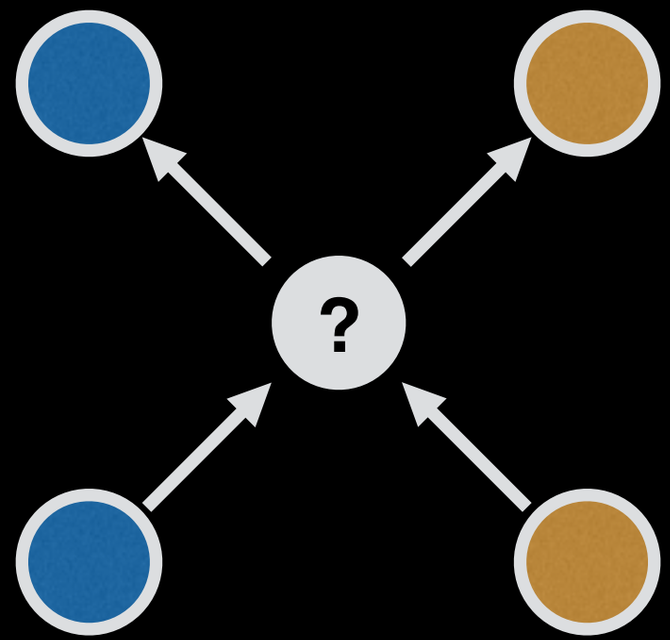
Key detection signature:
WIMP annihilation



Why **annihilating** dark matter?

- Good candidates in *supersymmetry* (e.g. neutralino), *Kaluza-Klein theory* (e.g. B^1)
- Early thermal equilibrium and freeze-out gives natural production mechanism

Dark Matter: Indirect Detection



- signature: cosmic rays, gamma rays, neutrinos (annihilation products)

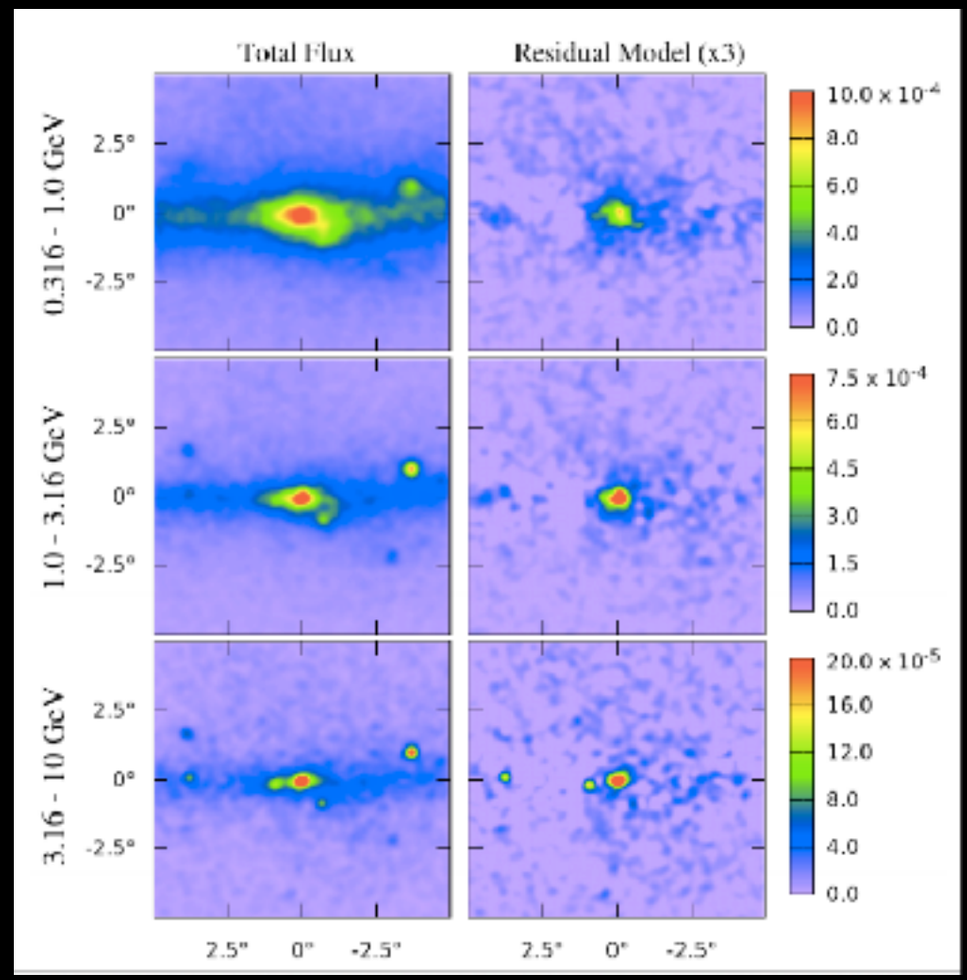
Gamma Rays

Gamma-ray excess in Galactic Center at 1-3 GeV

31-40 GeV WIMP annihilation?

In favor: **spatial distribution** looks plausible; fairly **simple WIMP model,** possible new hints seen in Andromeda

Against: Galactic Center is **messy**; **complicated analysis**; statistics favor **point sources** (Lee et al. 2015)



Daylan et al. 2014

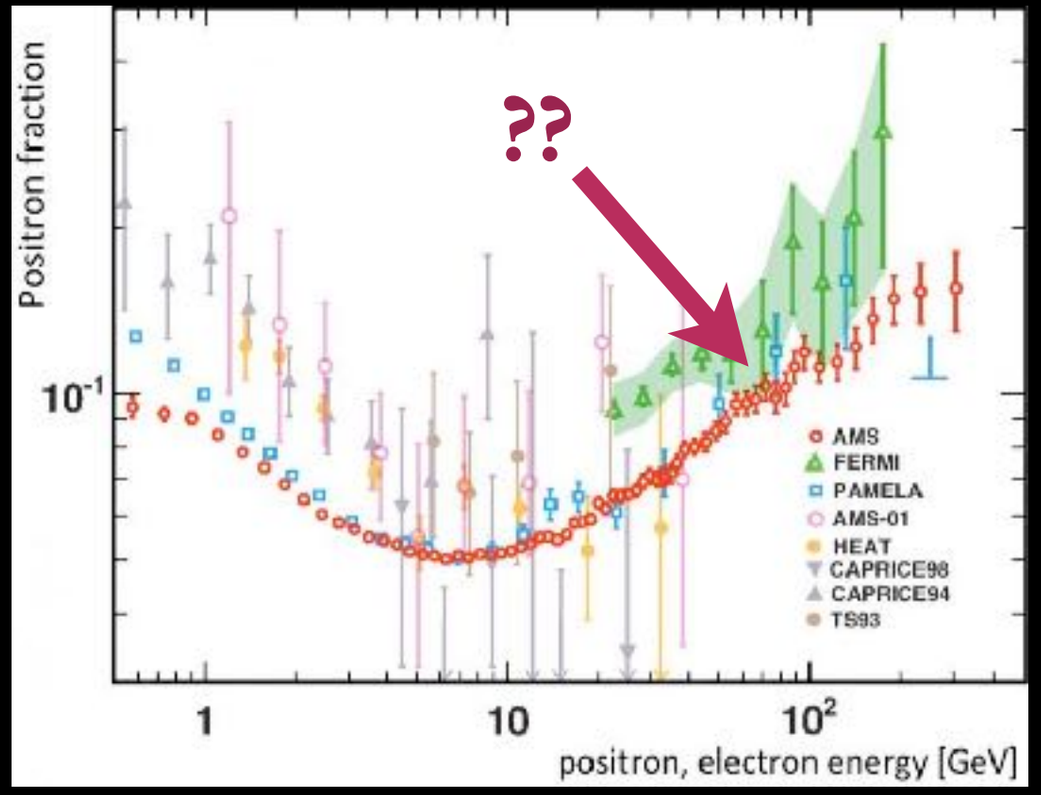
Cosmic Rays

Image credit: PAMELA Collaboration

Image credit: NASA

PAMELA and the **AMS instrument** (and several others) saw an excess of positrons in their measurements -- could it be dark matter annihilation?

3 TeV DM with **high cross-section** proposed as explanation



AMS Collaboration, 2013

Cosmic Rays

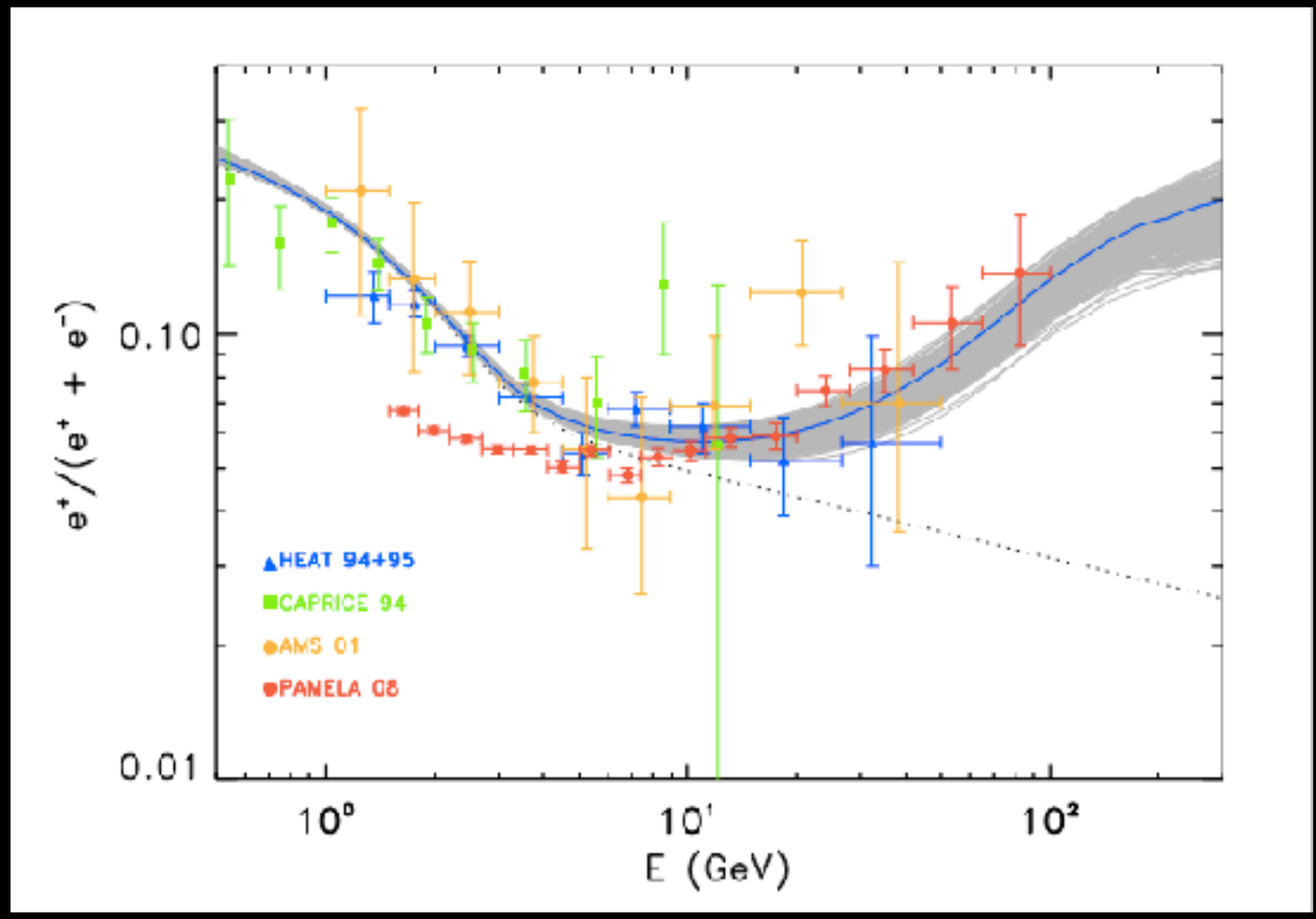
Image credit: PAMELA Collaboration

Image credit: NASA

But: **pulsars** also make electron-positron pairs

Limited **directional information**

A couple of nearby pulsars could produce entire signal

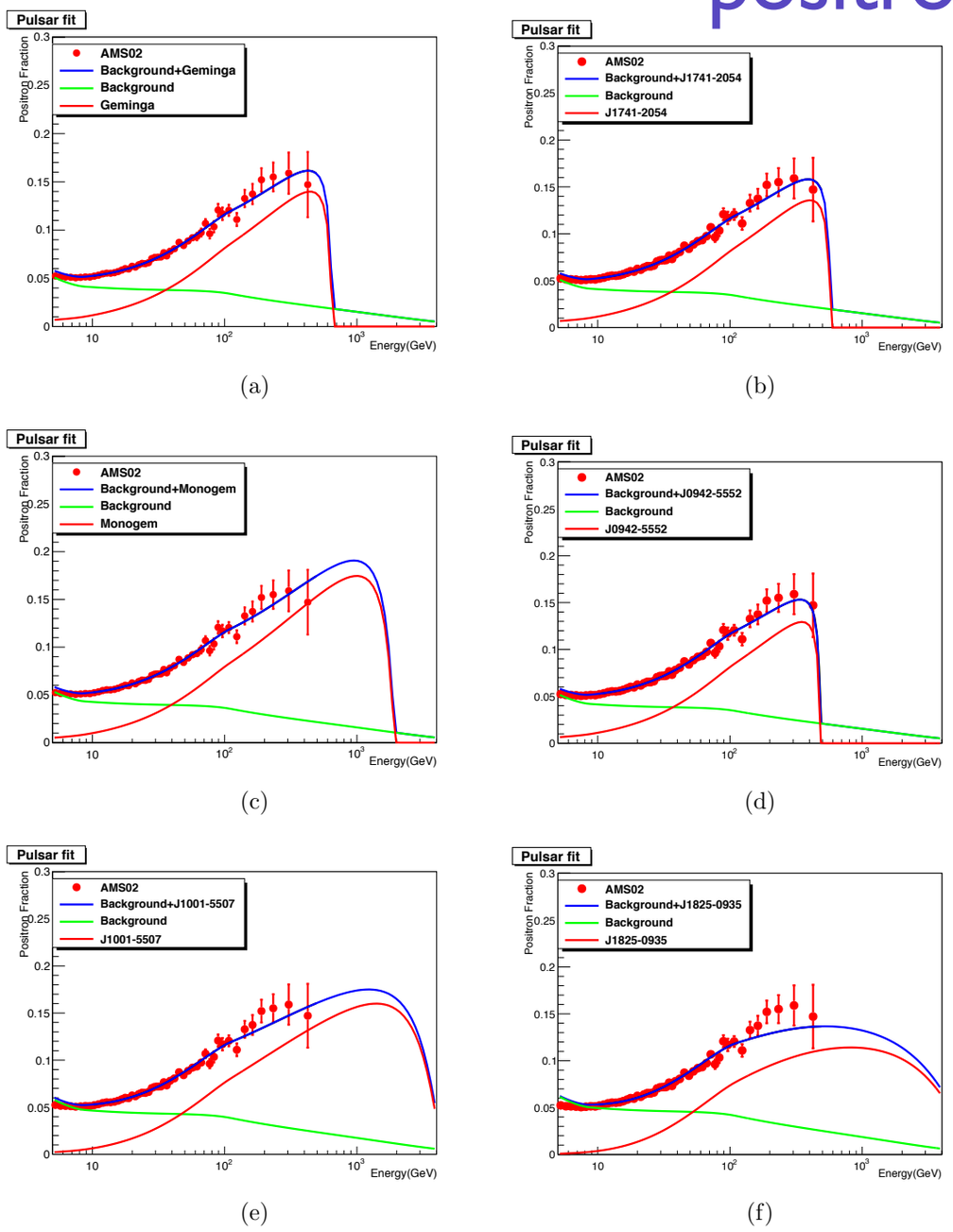


Grasso et al. 2009

Cosmic Rays

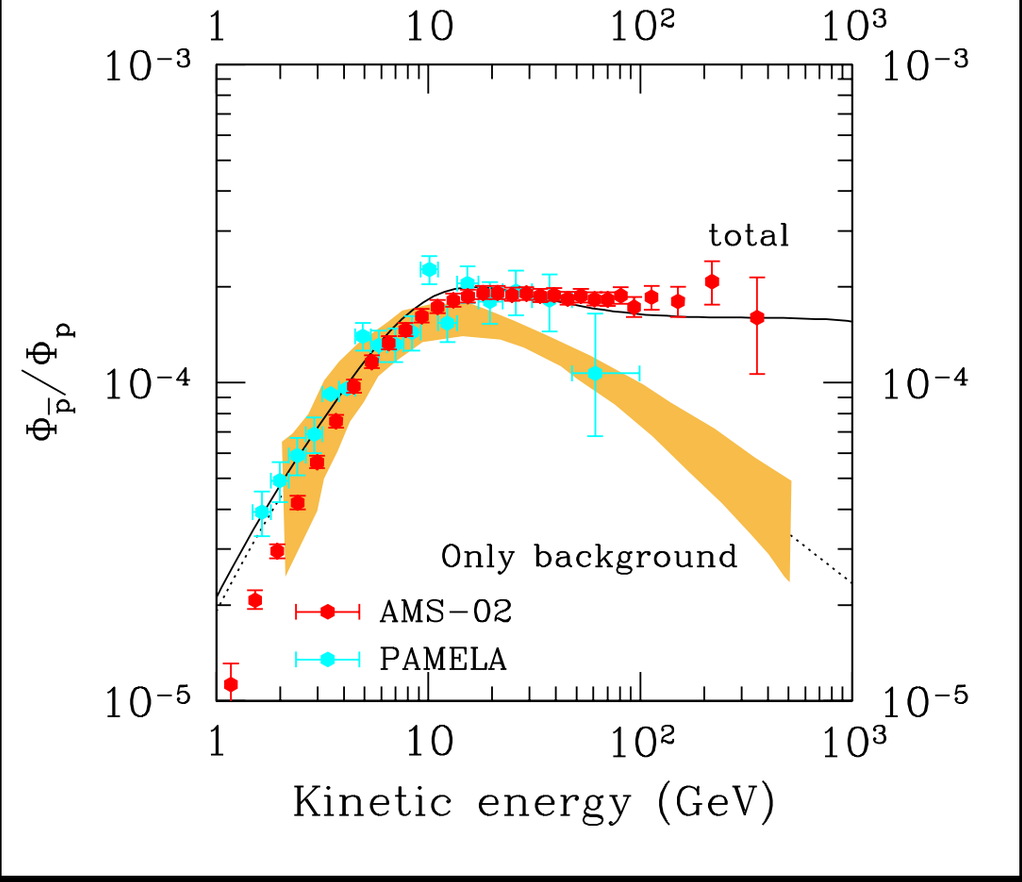
Image credit: NASA

positrons



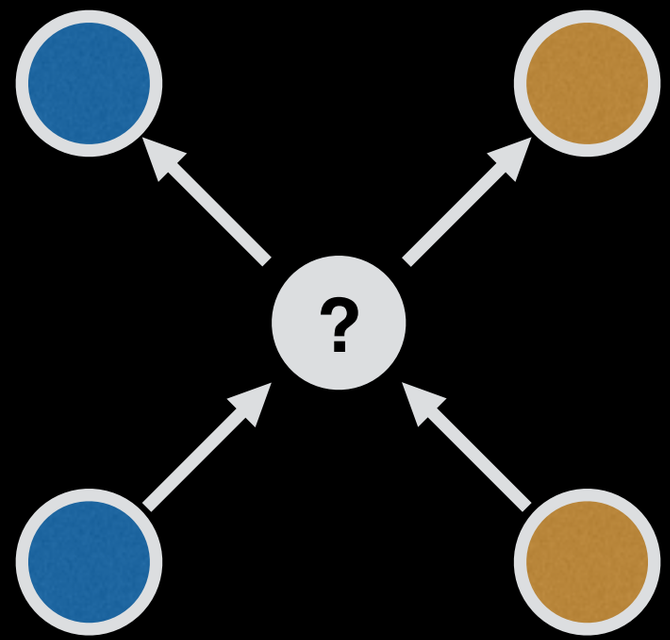
Feng & Zhang 2015

anti-protons



Kohri et al. 2015

Dark Matter: Indirect Detection



- signature: cosmic rays, gamma rays, neutrinos (annihilation products)
- results: inconclusive
- the future: giant cosmic ray array (CTA), high-resolution gamma-ray astronomy

Dark Matter: Direct Detection

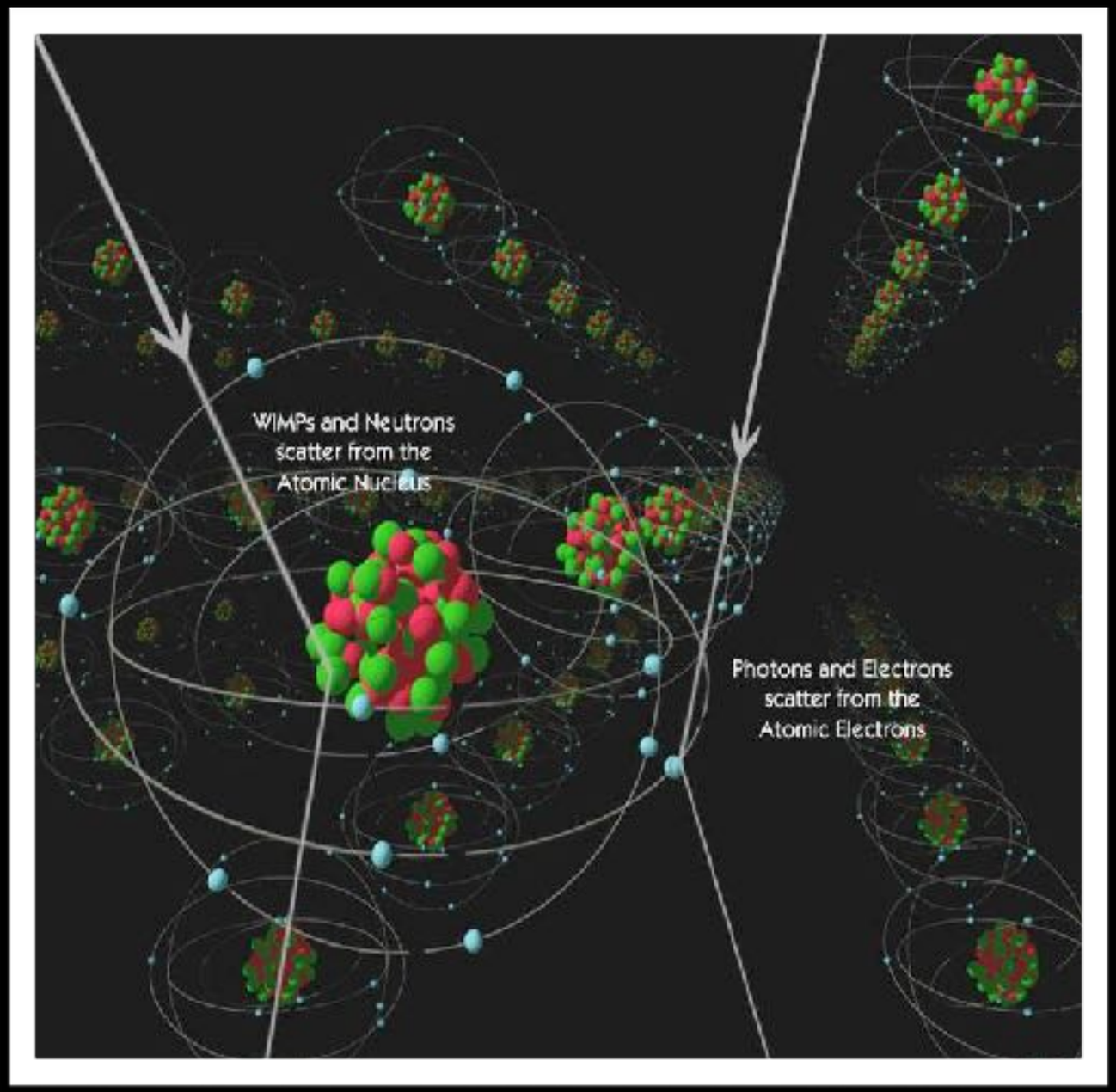
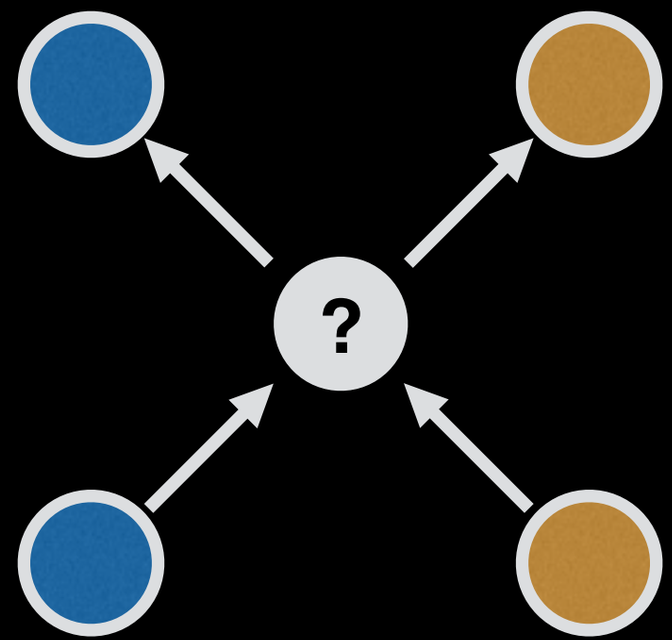
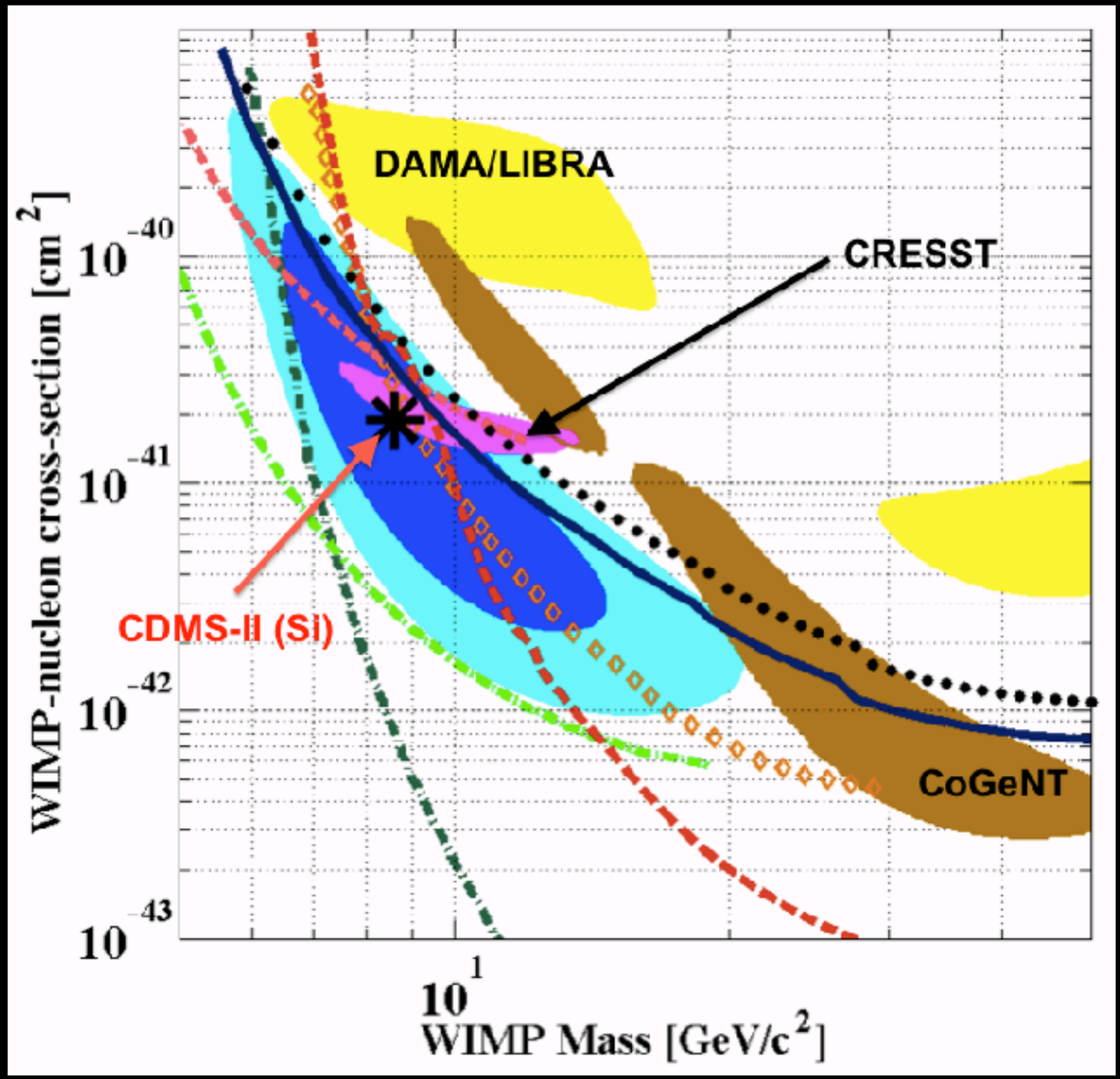


Image credit: UC Berkeley



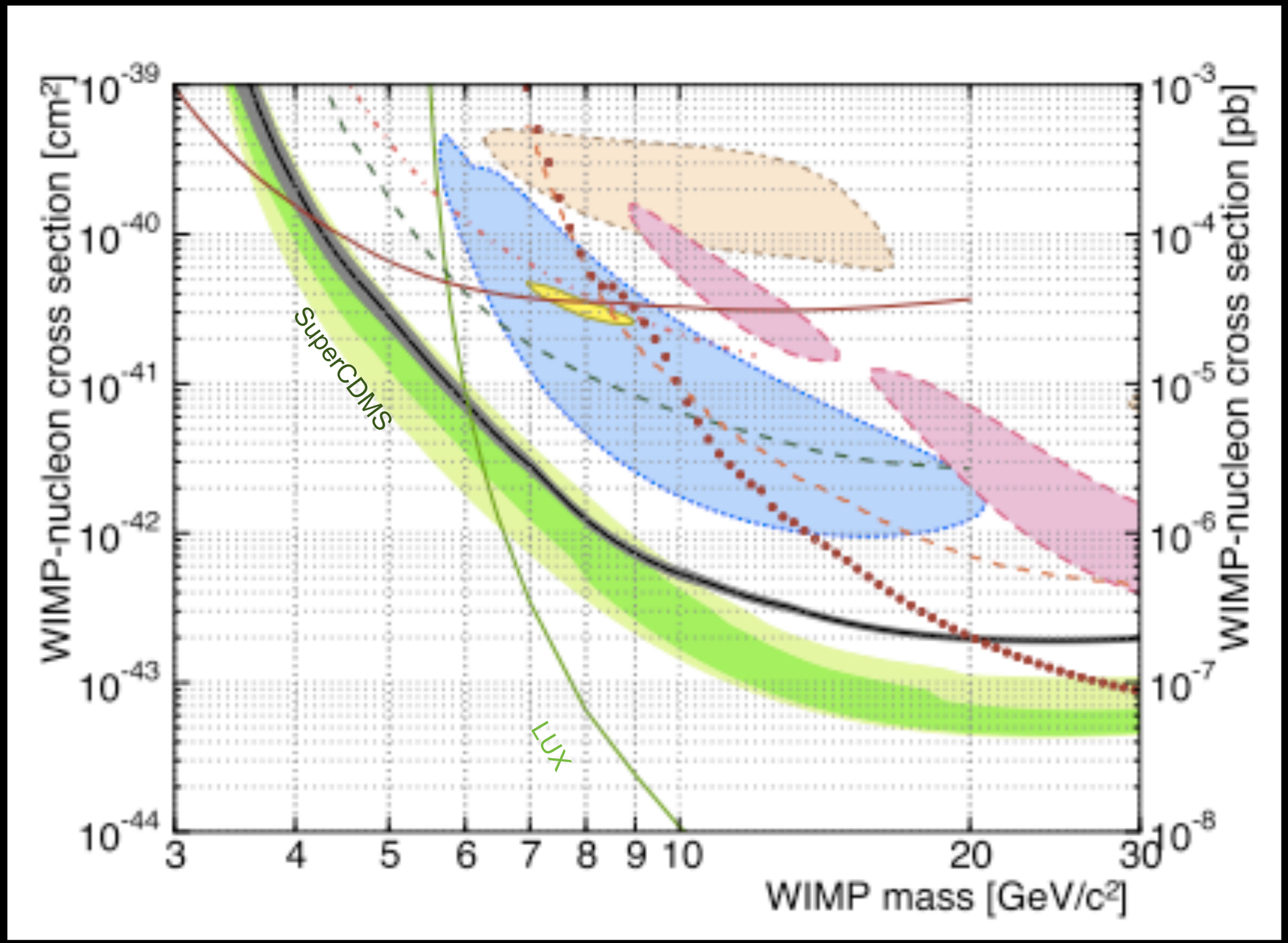
- signature: nuclear recoil

Direct Detection



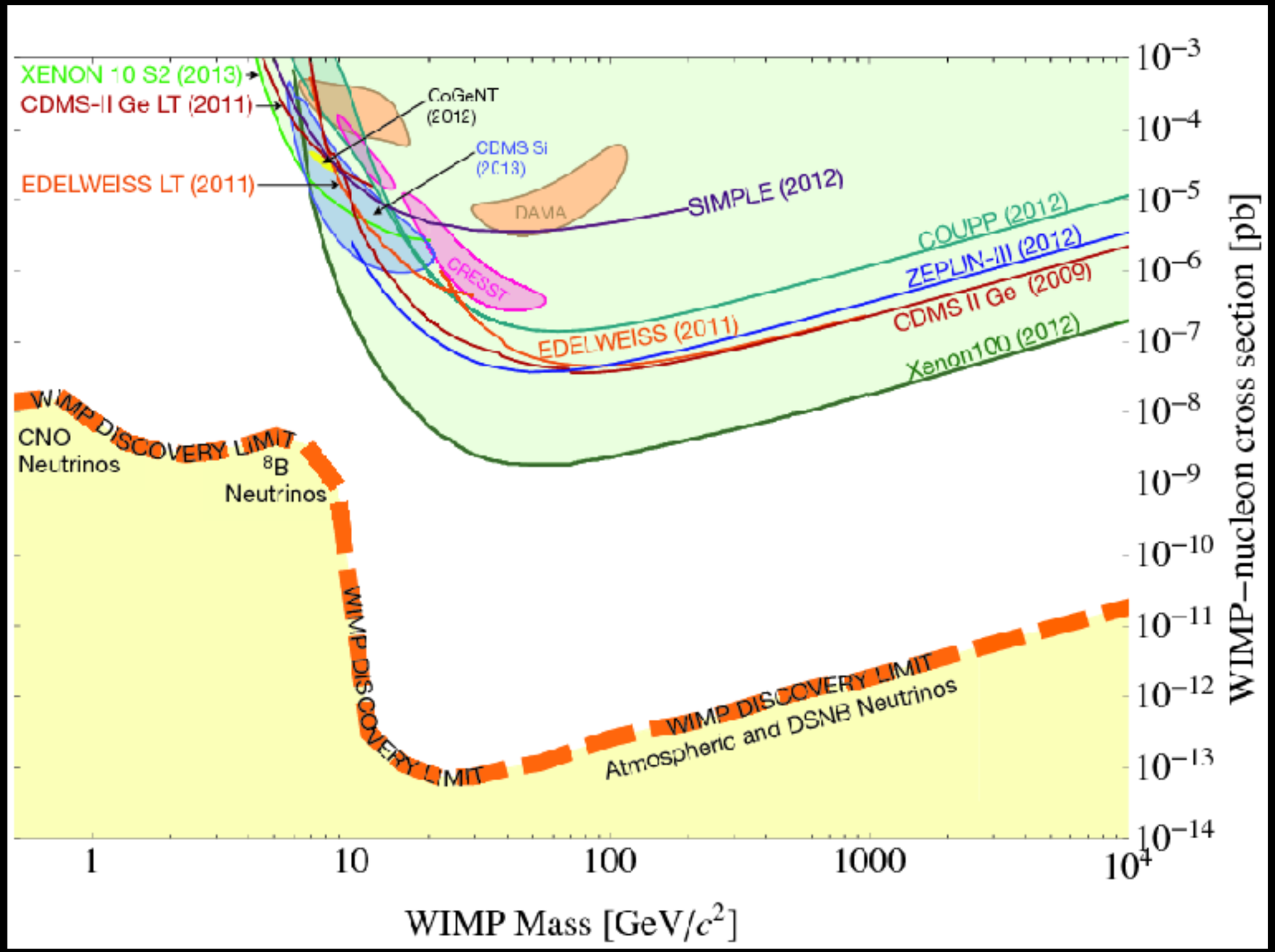
CDMS Collaboration, 2013

Direct Detection



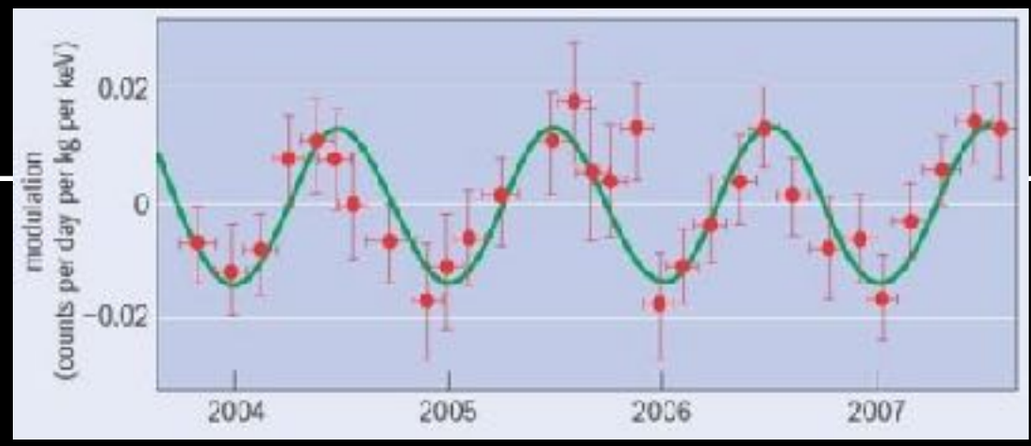
SuperCDMS Collaboration, 2014

Neutrino Wall

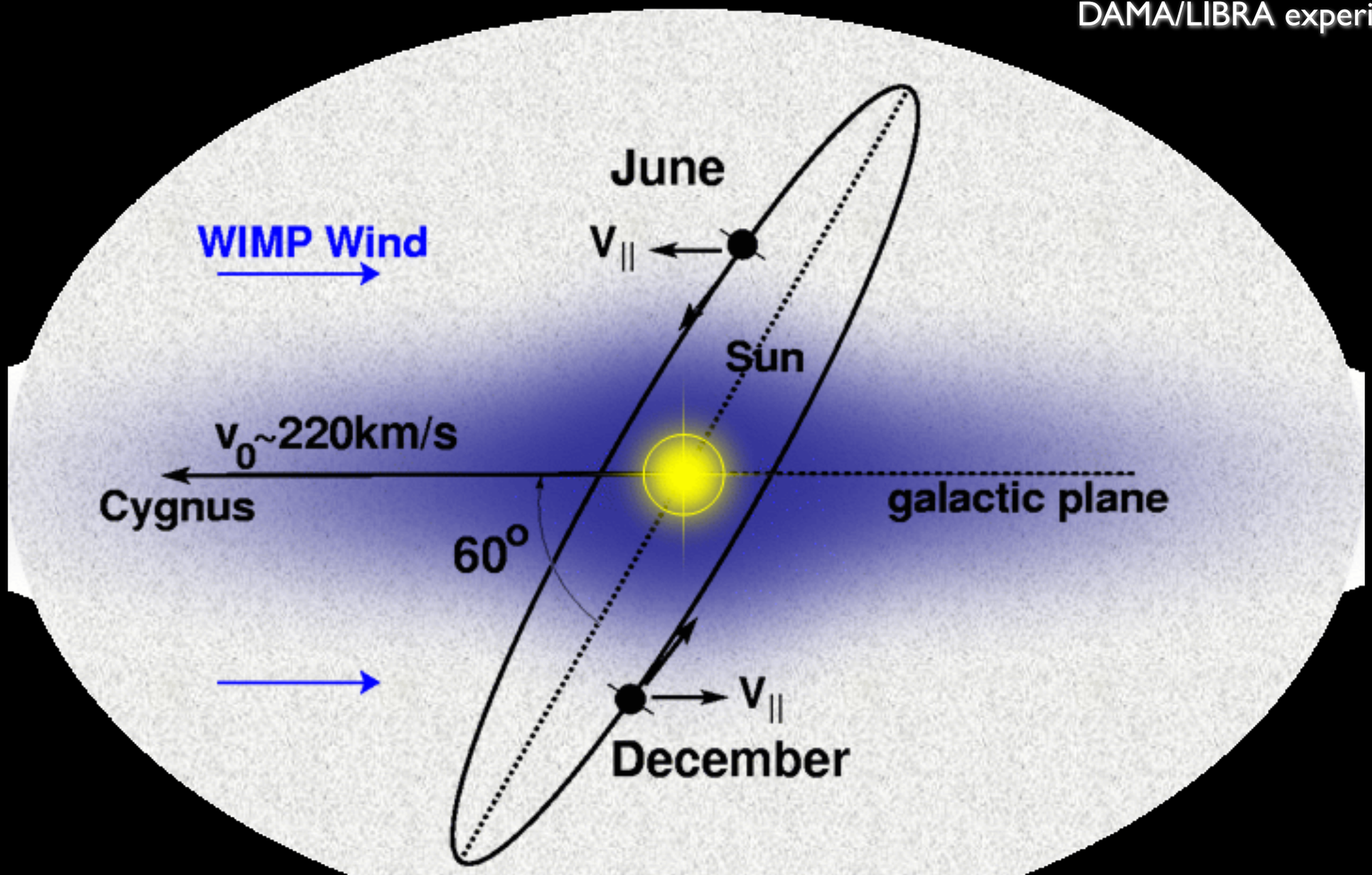


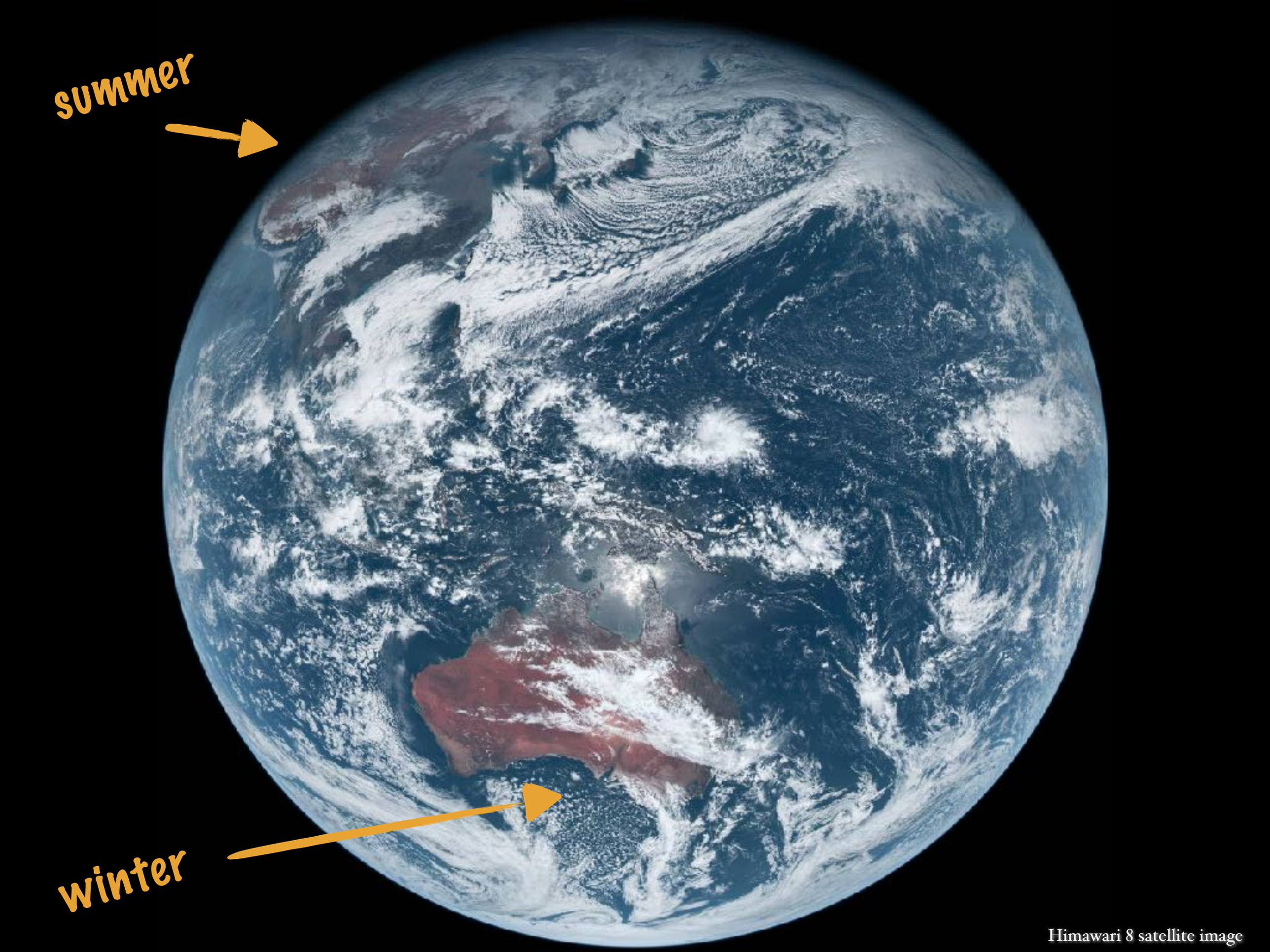
Billard et al. 2013

Annual Modulation



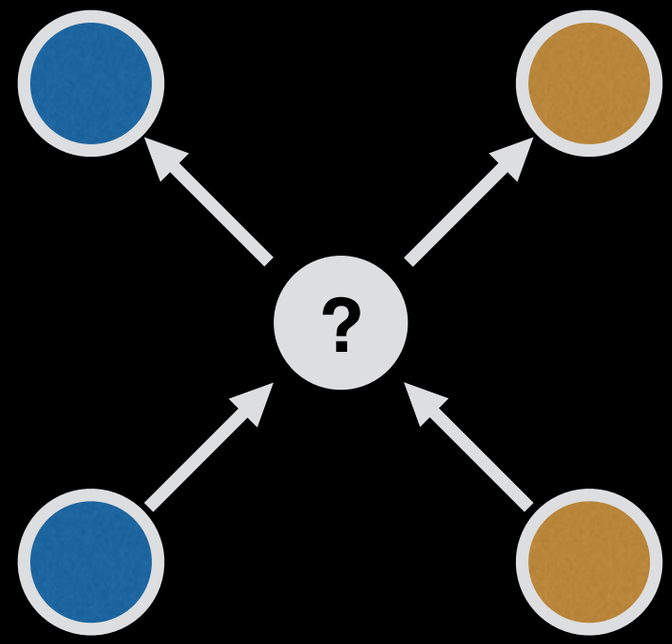
DAMA/LIBRA experiment results





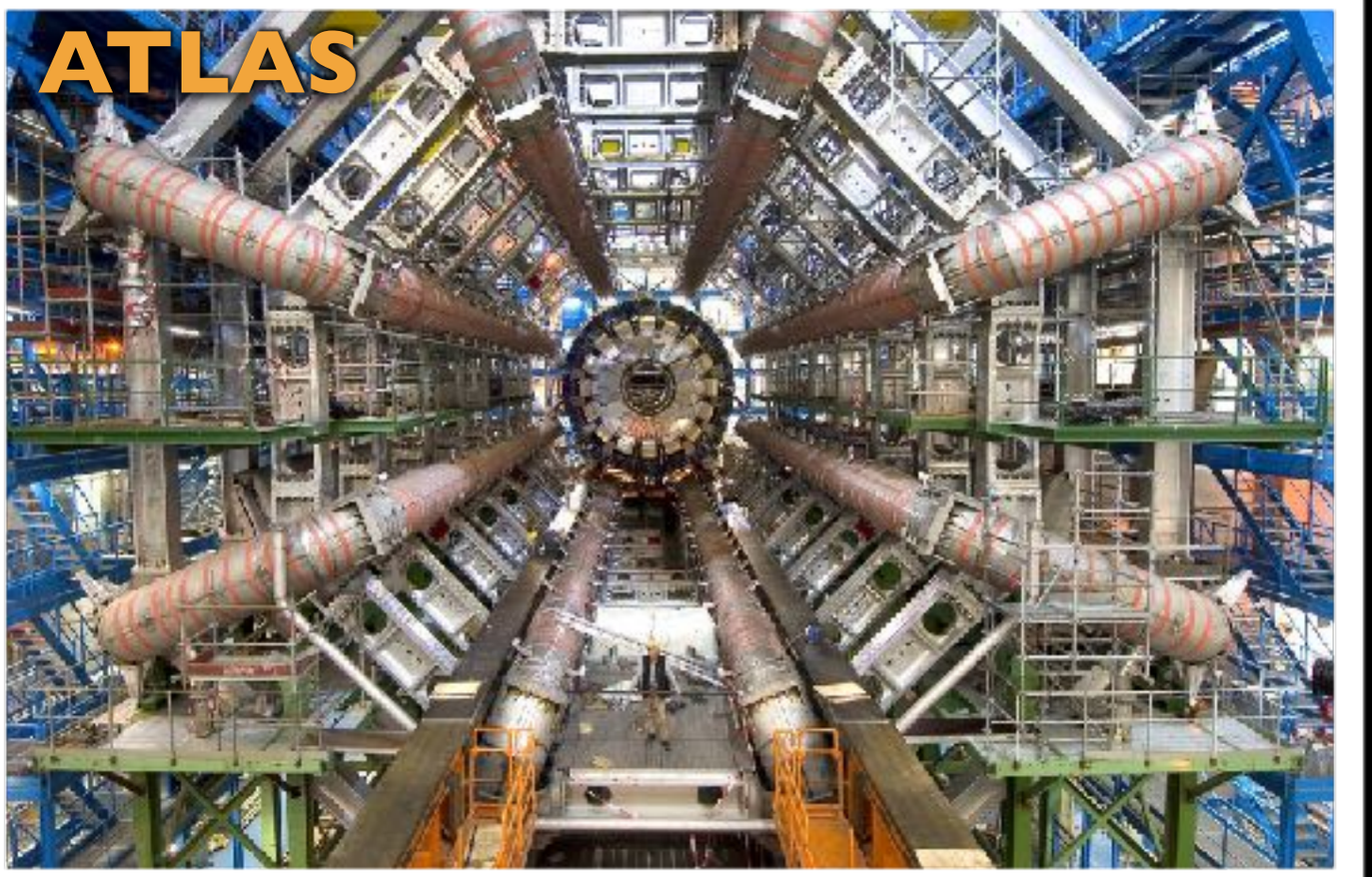
Himawari 8 satellite image

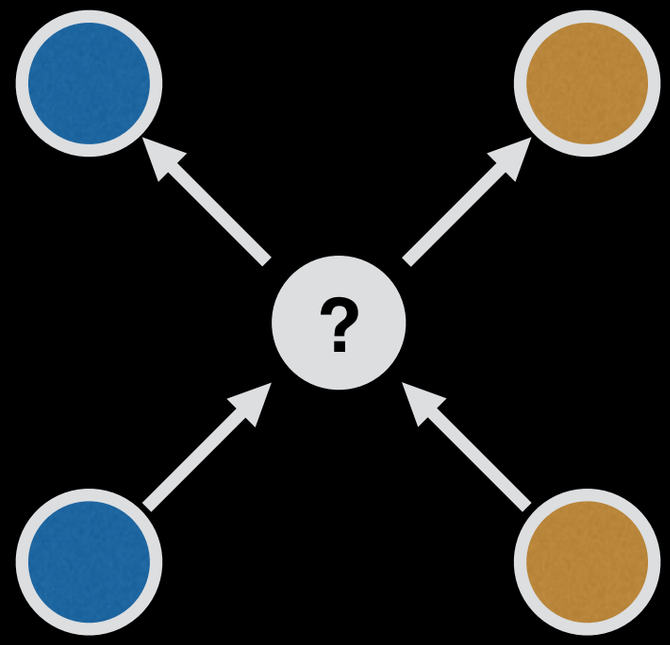
Dark Matter: Direct Detection



- signature: nuclear recoil
- results: inconclusive
- the future: SABRE, directional detection (see: CYGNUS project)

Dark Matter: Production





- signature: missing energy
- results: no signal (yet)
- the future: more LHC data, future colliders

Cosmological DM Signatures

- Density field
  - angular dependence of 21cm power spectrum
  - lensing (CMB, LSS)
- **Energy injection (annihilation, decay)**
- Structure formation
  - velocity offset between dark matter & baryons
- **Small-scale structure and bias (warm dark matter)**
- Radio counterparts (axions, annihilation)

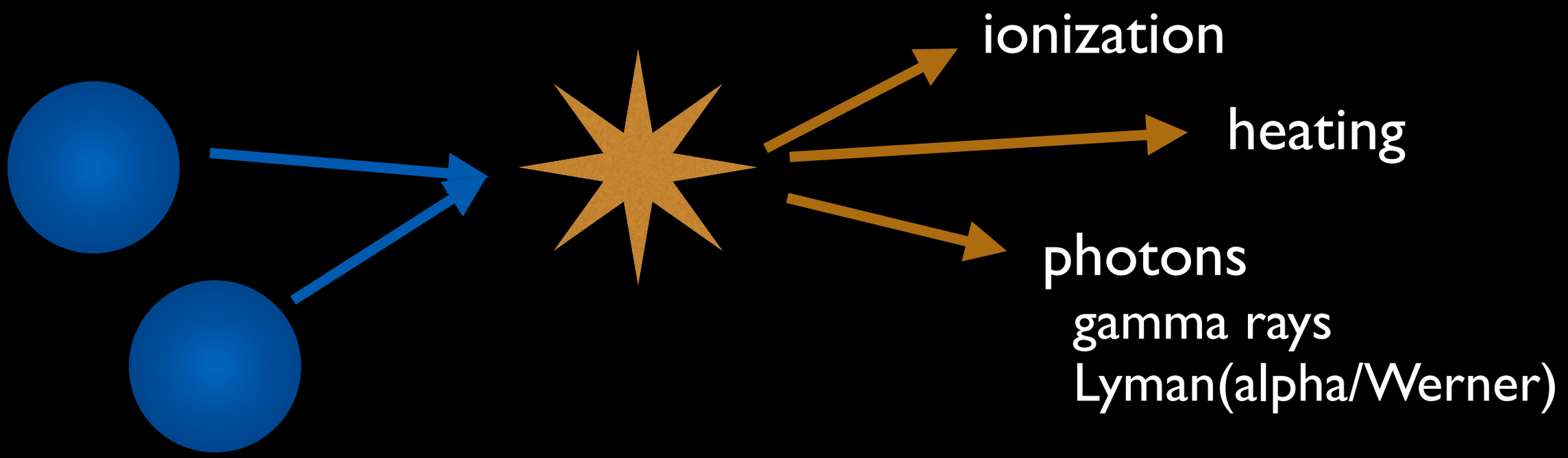
Dark Matter: Cosmology

Paul Angel, Tiamat Simulation

Annihilation "Feedback"

Major unanswered question:

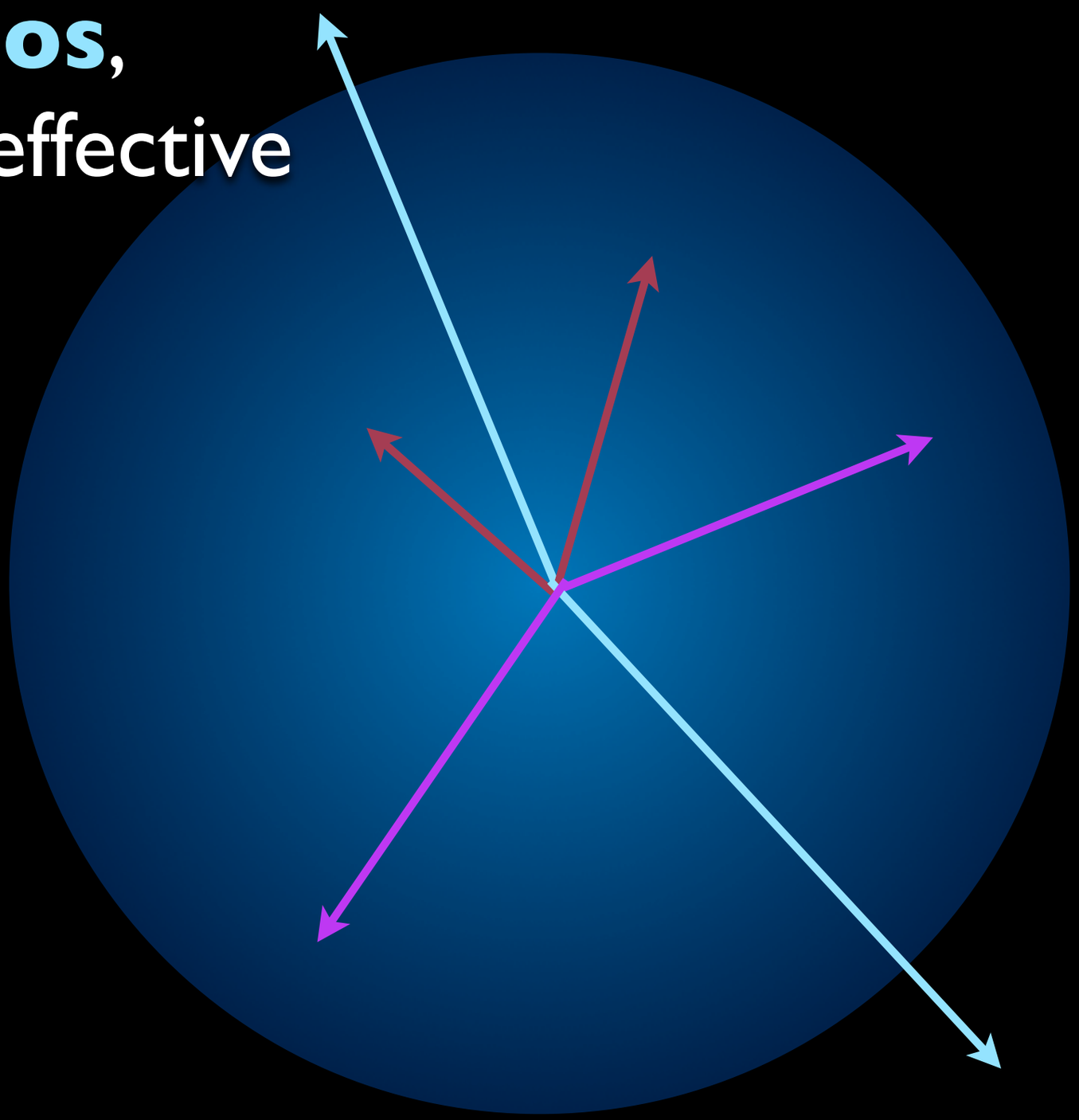
If dark matter **annihilates** across all of cosmic time, **how does it affect the first stars and galaxies?**



Annihilation Feedback on Halo Gas

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

Sarah Schon,
very-soon-to-be-PhD



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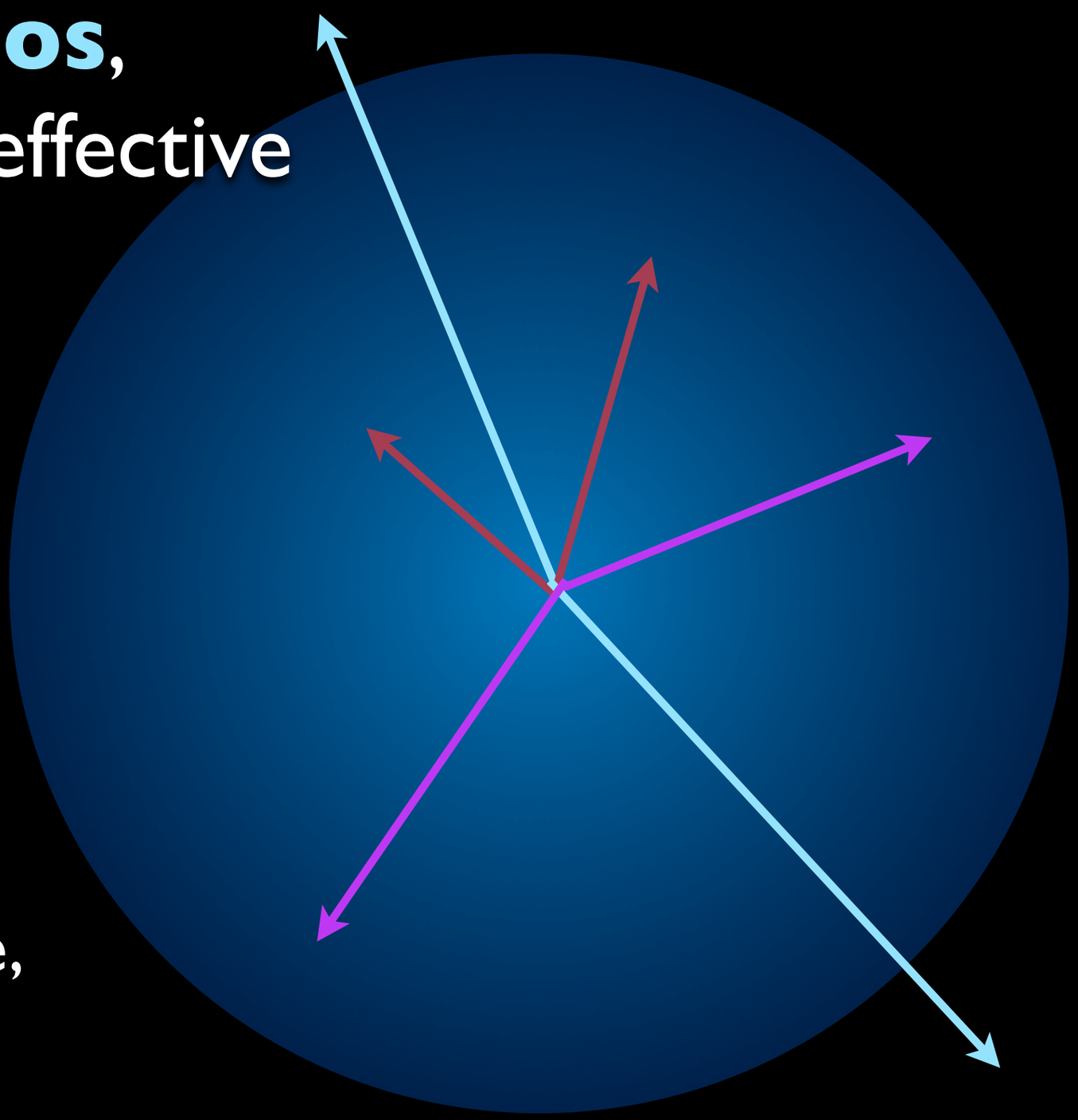
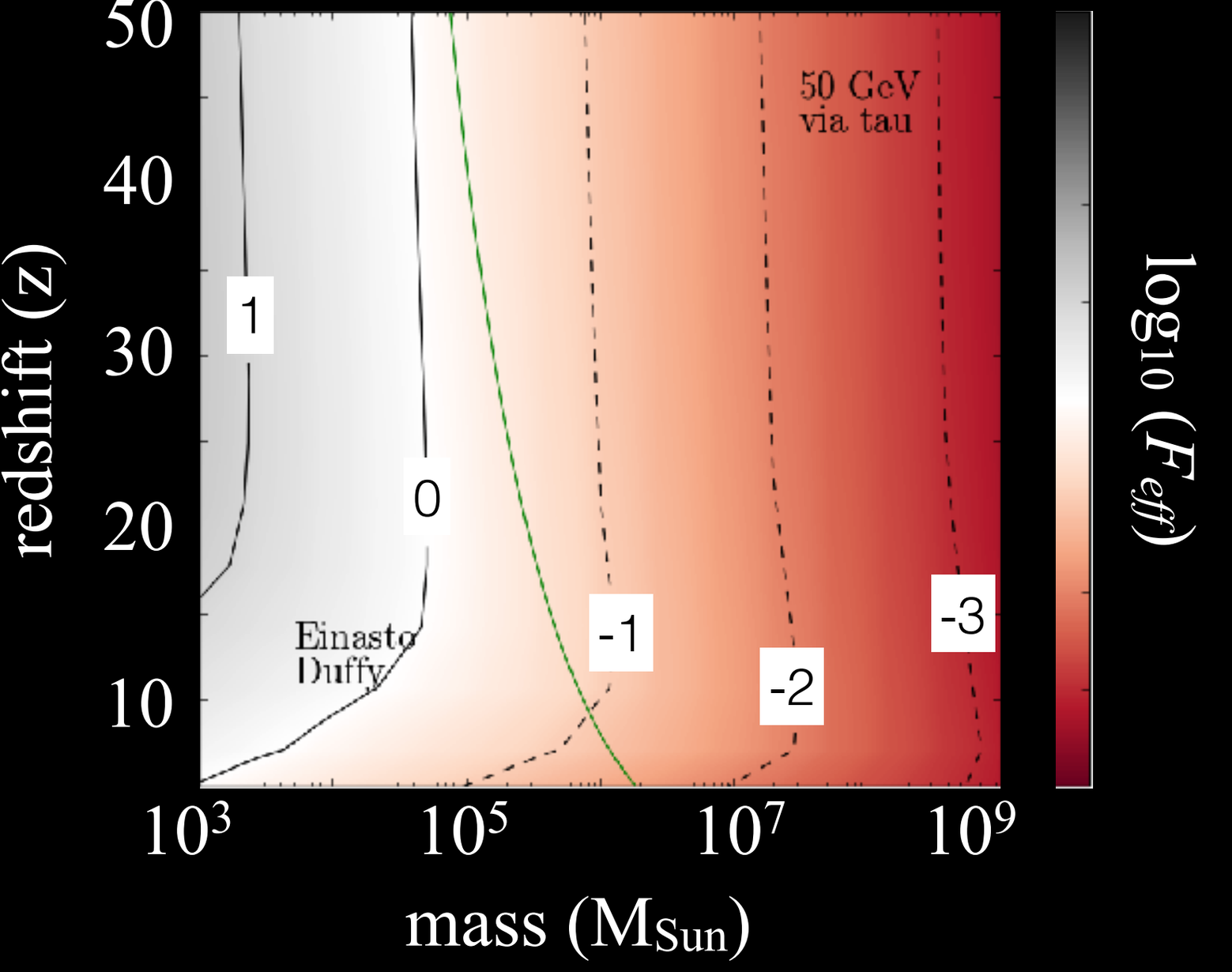


PYTHIA code: dark matter annihilation events

MEDEA2 code: energy transfer to baryons

Halo models: density profile, mass-concentration

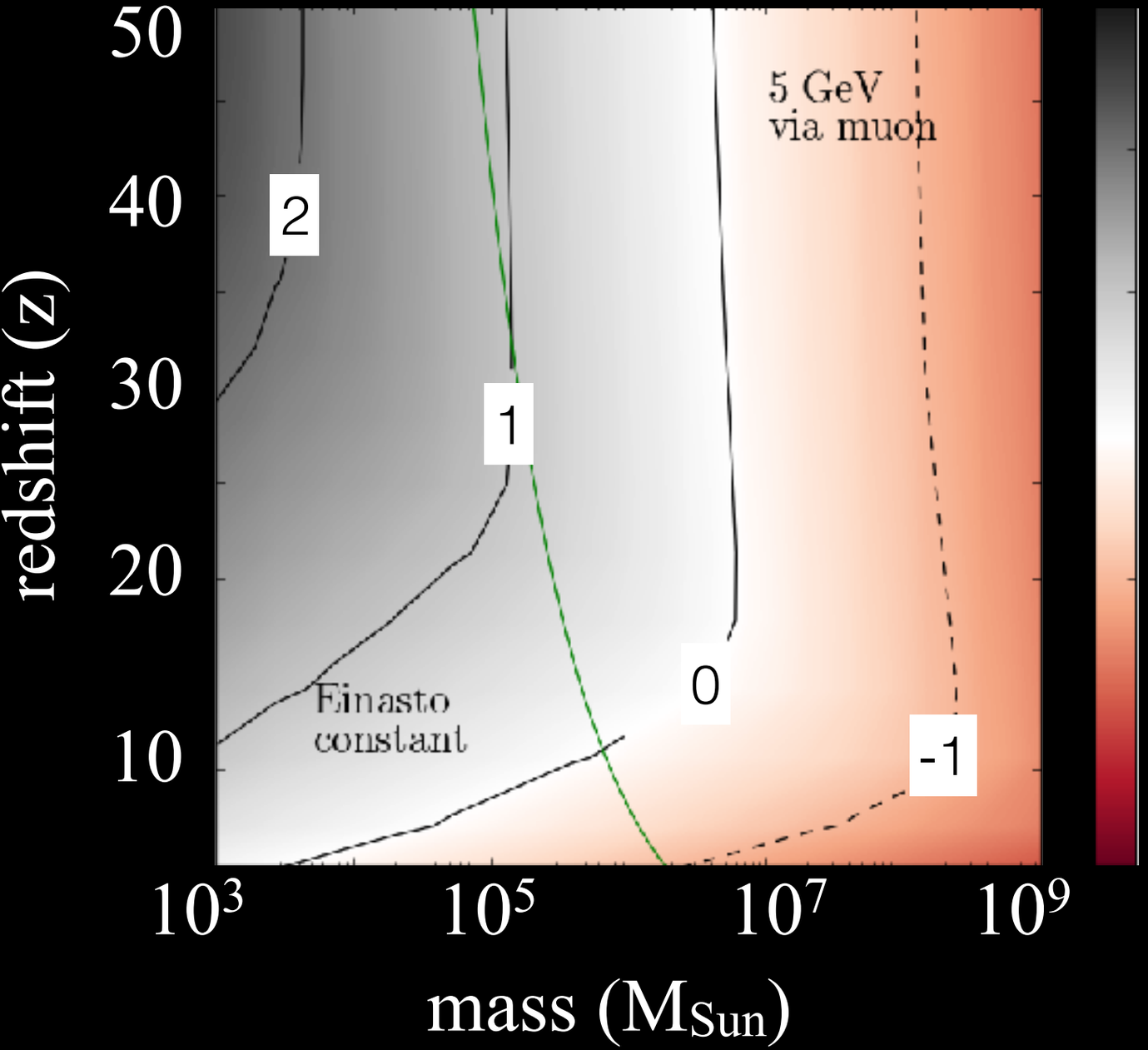
Annihilation Feedback on Halo Gas



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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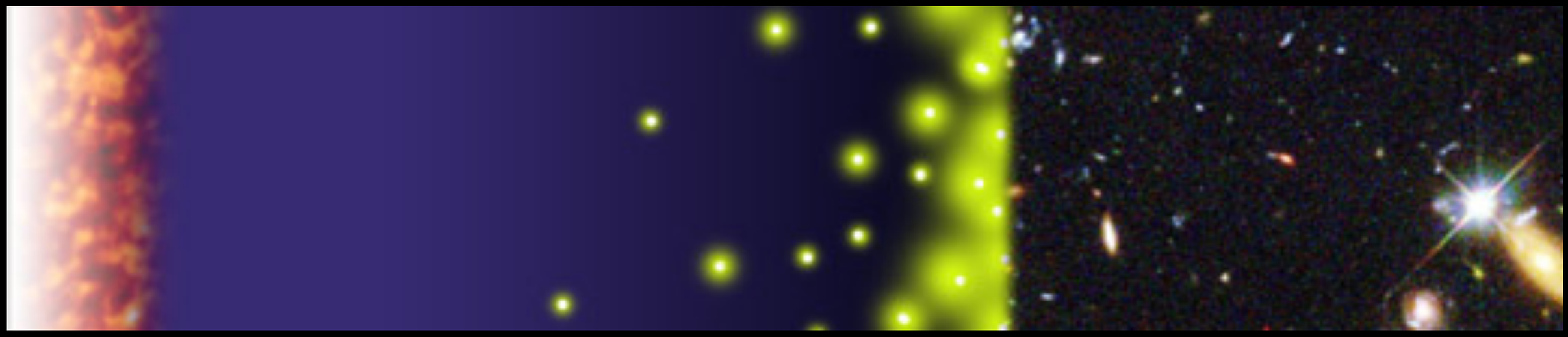
Probing "Cosmic Dawn"



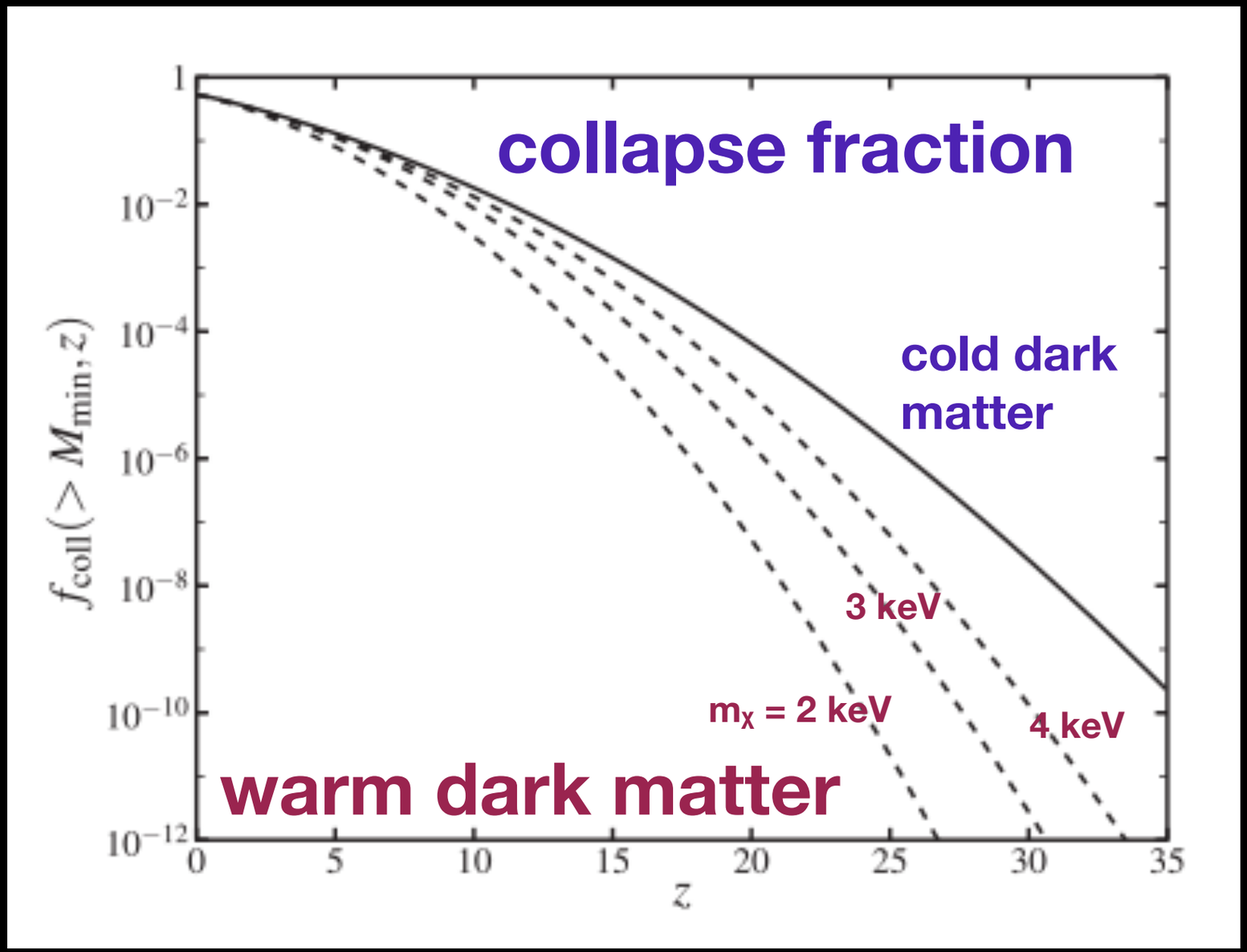
Djorgovski et al., Caltech

current instruments

next decade

Small-Scale Structure

Sitwell et al. 2014

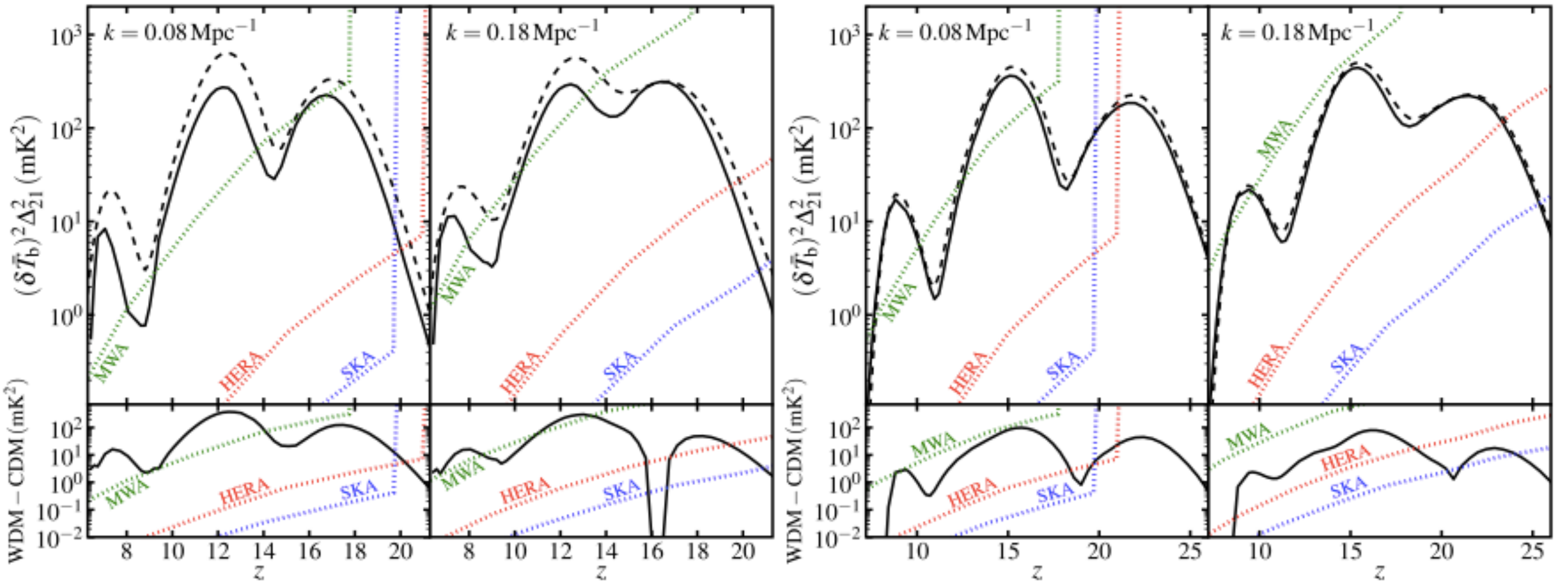


warm dark matter free-streams out of density peaks

cut-off in small-scale power spectrum

Small-Scale Structure

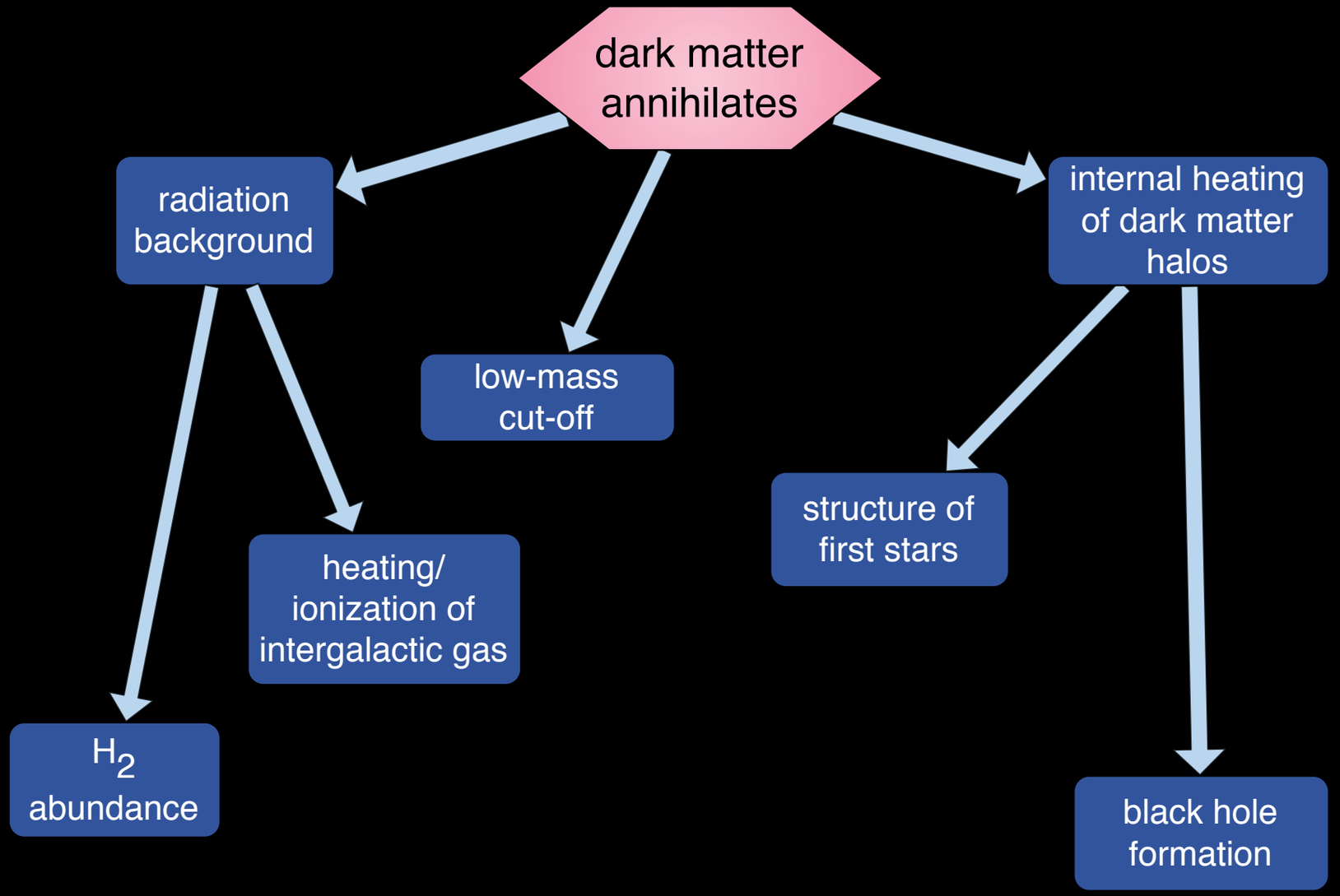
Sitwell et al. 2014

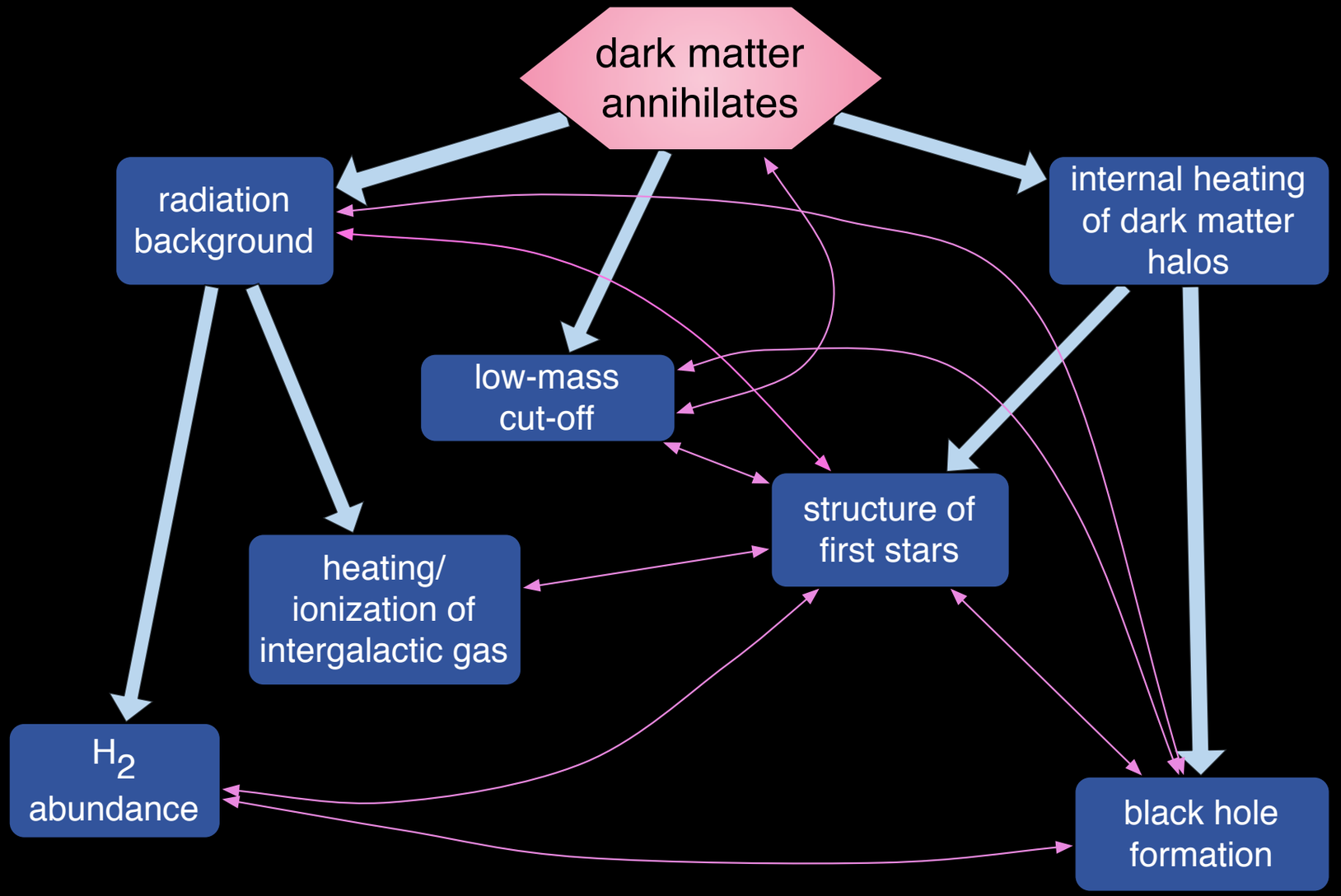


m_χ = 2 keV

4 keV

dark matter
annihilates


dark matter annihilates
radiation background
low-mass cut-off
internal heating of dark matter halos
heating/ ionization of intergalactic gas
structure of first stars
H_2 abundance
black hole formation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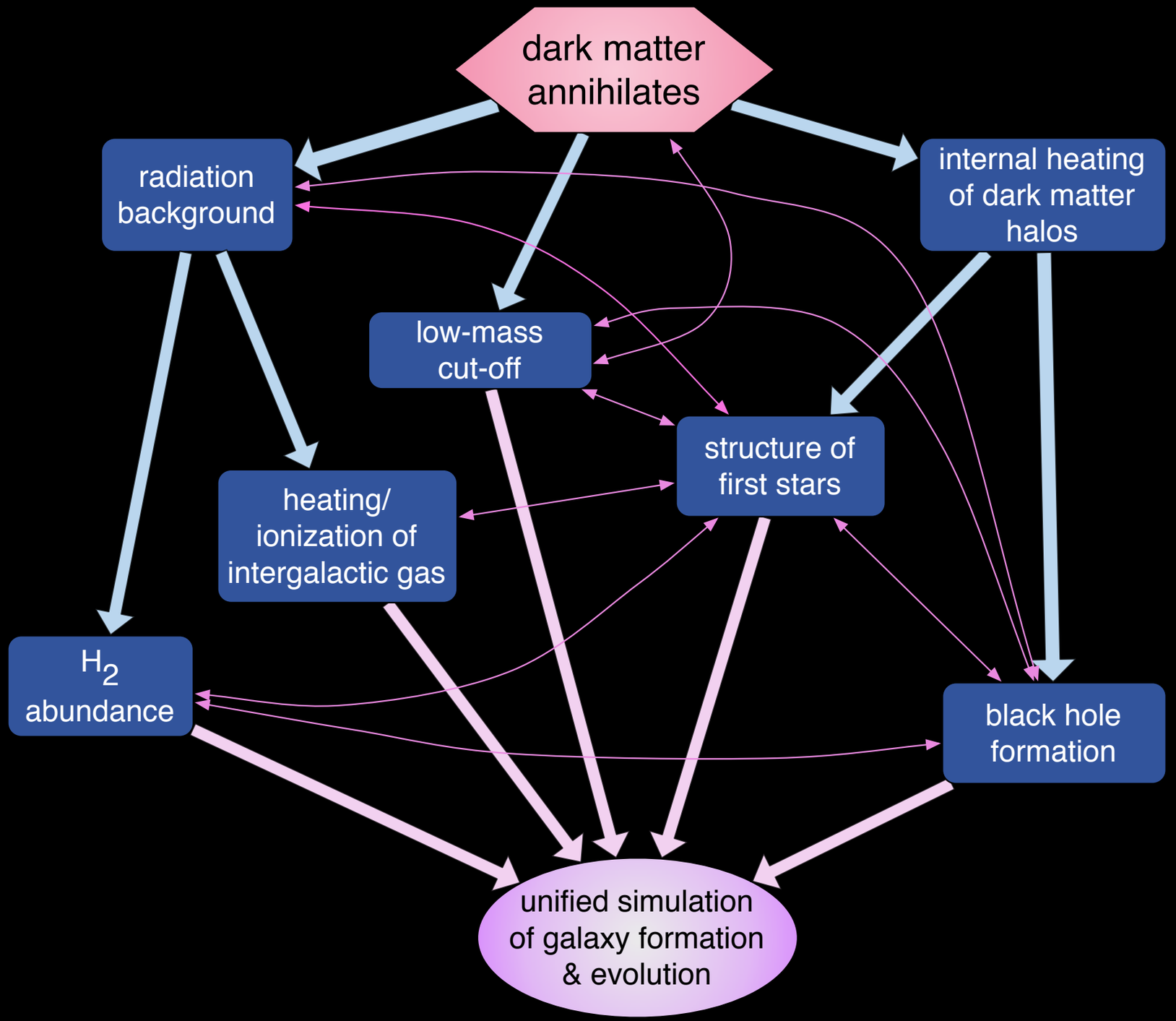
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high-redshift 21cm signal
high-redshift galaxies

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high-redshift 21cm signal

high-redshift galaxies

Image credit: Swinburne/ ICRAR/Cambridge/ASTRON

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Image credit: Swinburne/ ICRAR/Cambridge/ASTRON

JWST

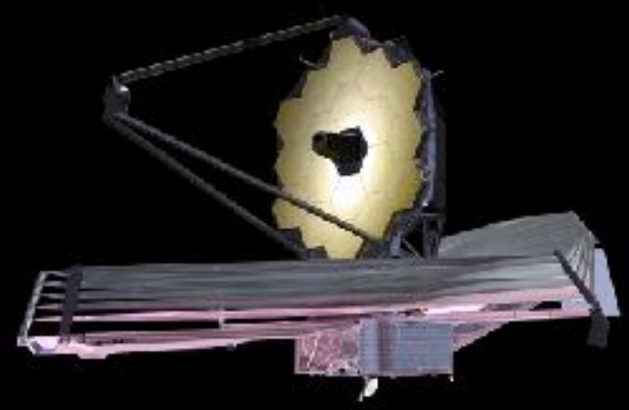


Image credit: NASA

Take-Home Messages

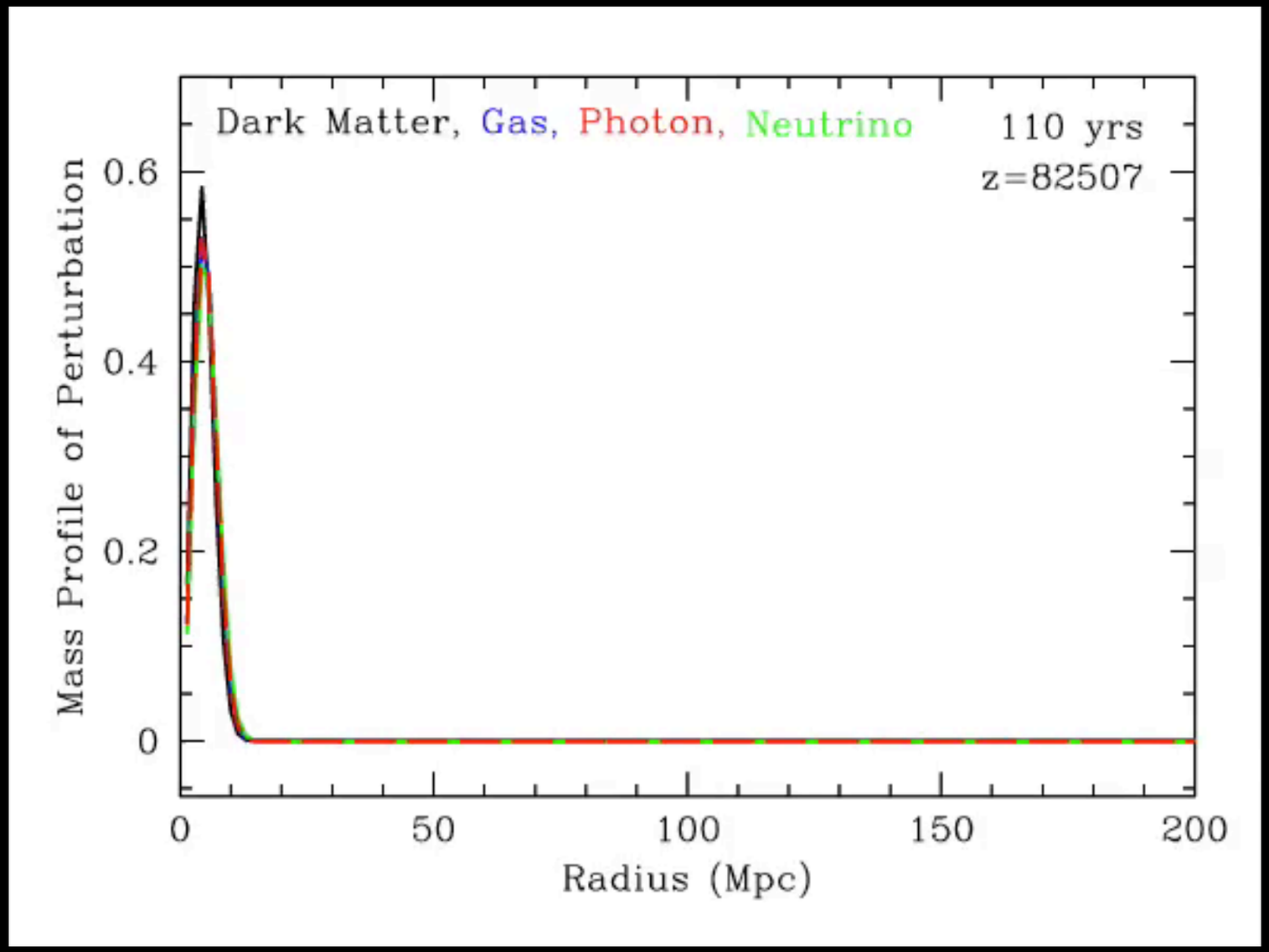
- The **fundamental nature** **of dark matter** is still a mystery (but we are getting clues)
- To identify dark matter from astrophysics, we need **multi-messenger signals** and a solid understanding of **astrophysical foregrounds**
- Future surveys can probe the **particle physics of dark matter** and produce a more consistent picture of cosmology

end

bonus slides

Velocity Offsets

Tseliakhovich & Hirata 2010
McQuinn & O'Leary 2012
Fialkov et al. 2014
Ali-Haimoud et al. 2014



animation by Daniel Eisenstein

Velocity Offsets

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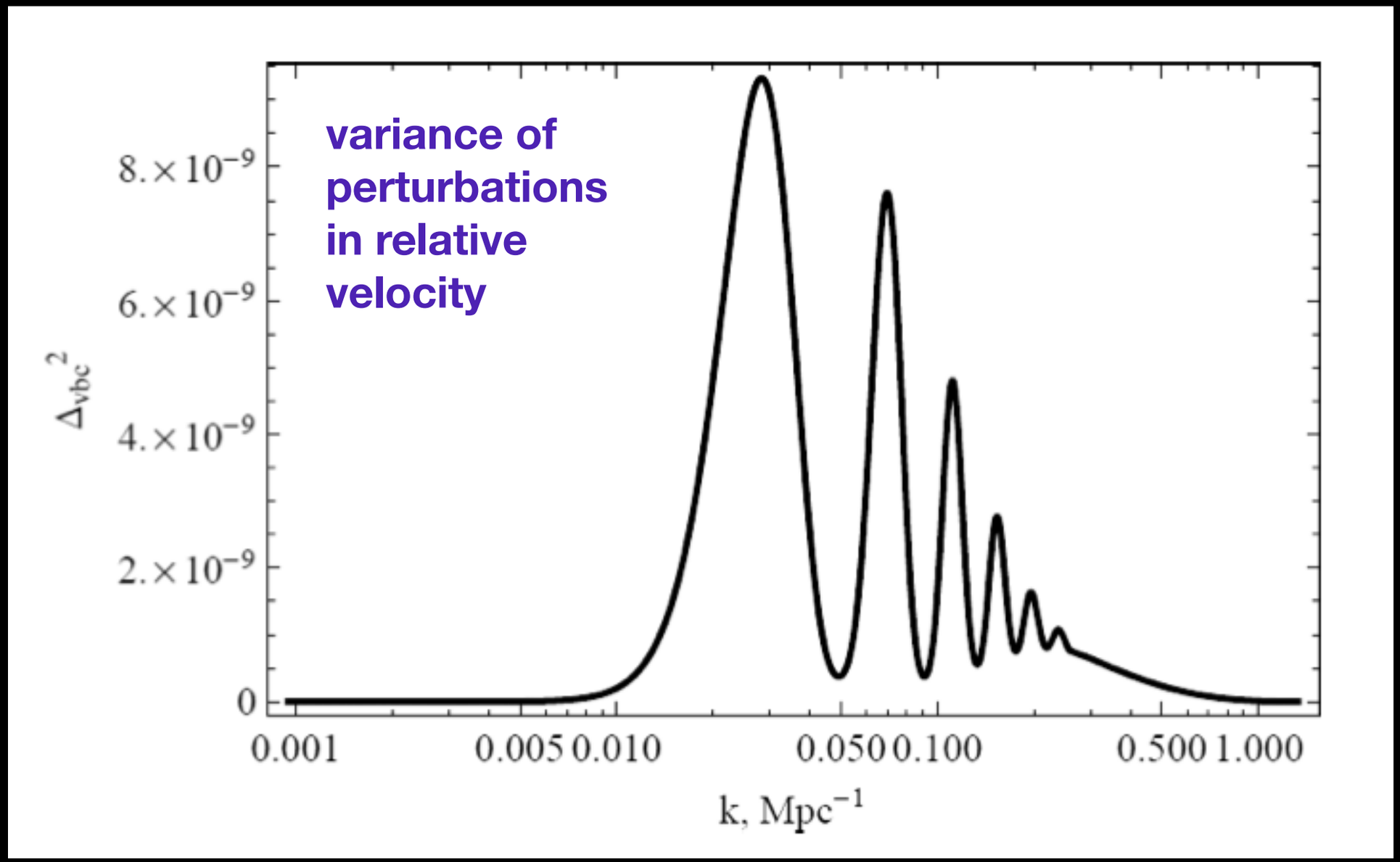

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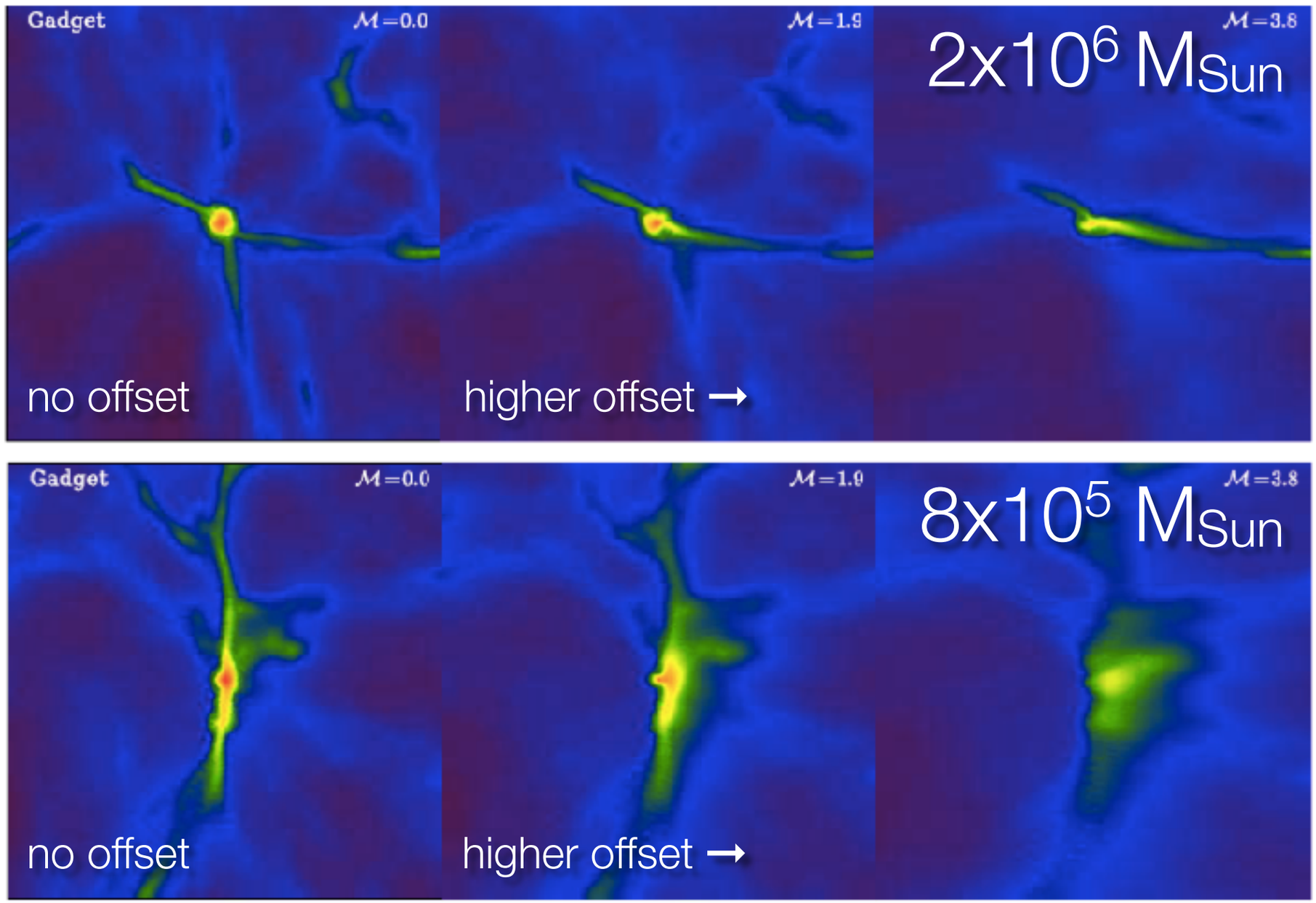

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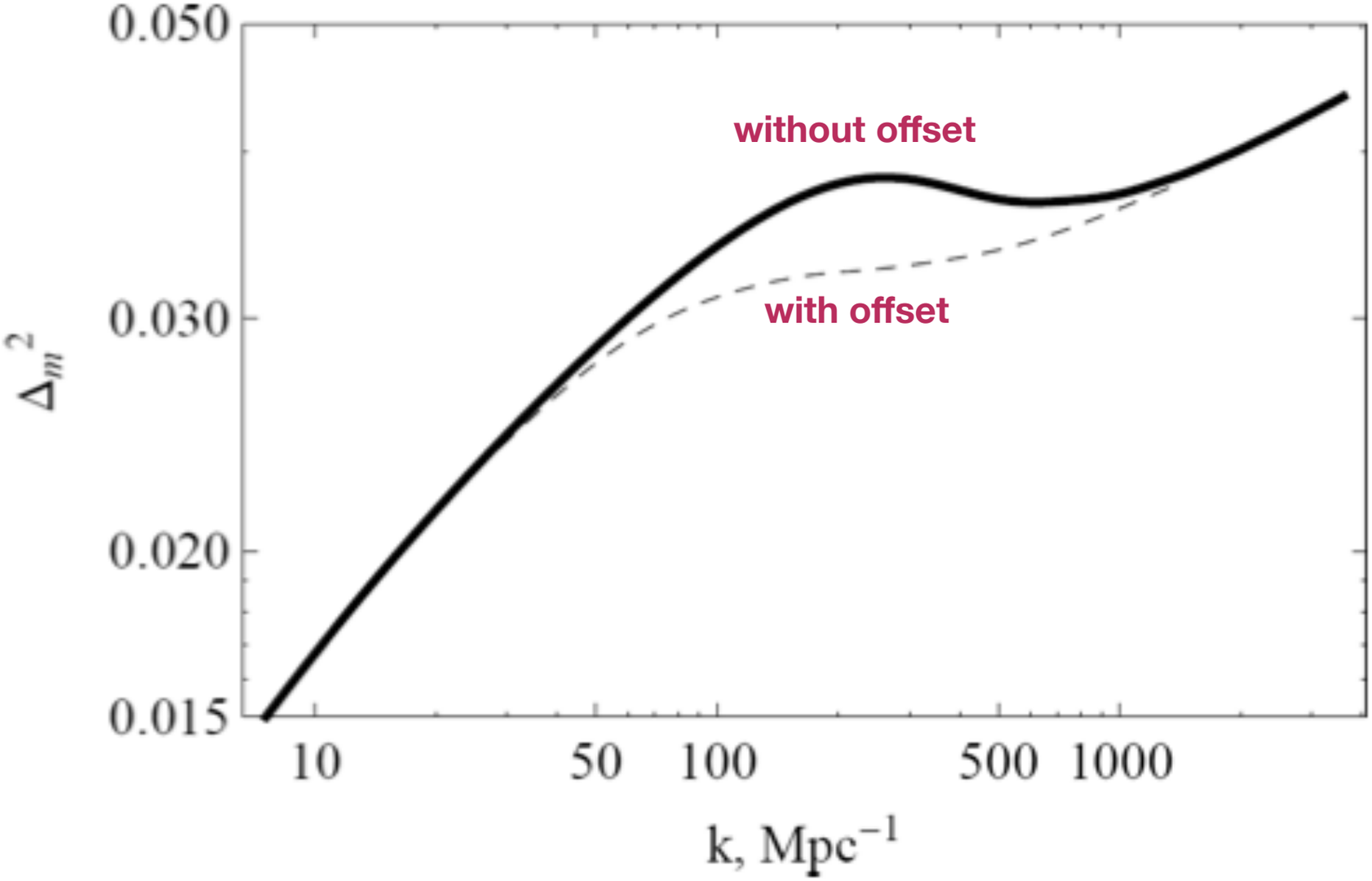

linear matter power spectrum

Velocity Offsets

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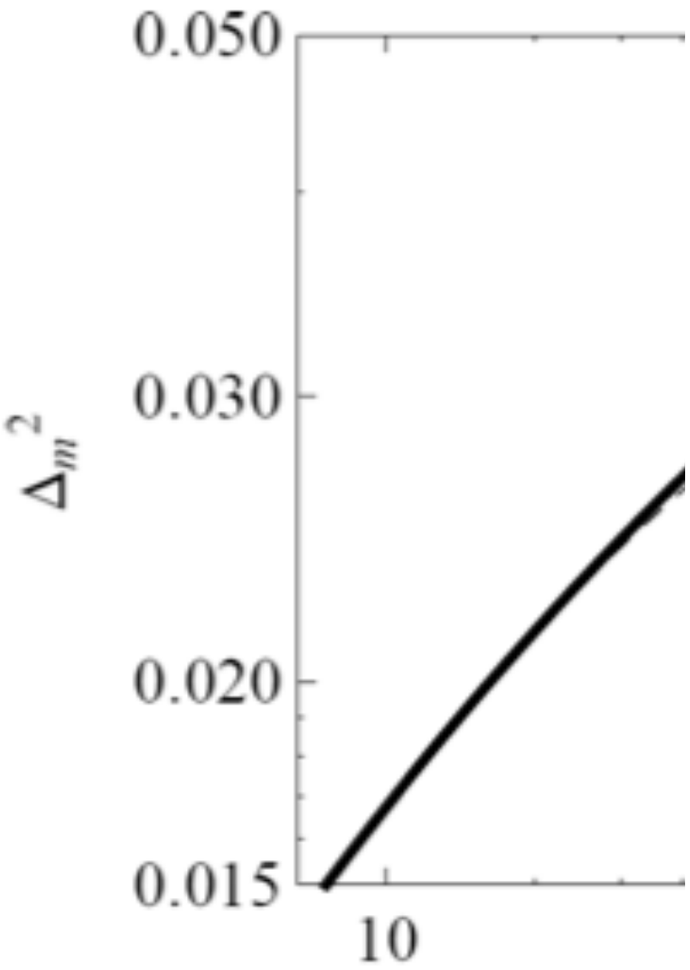
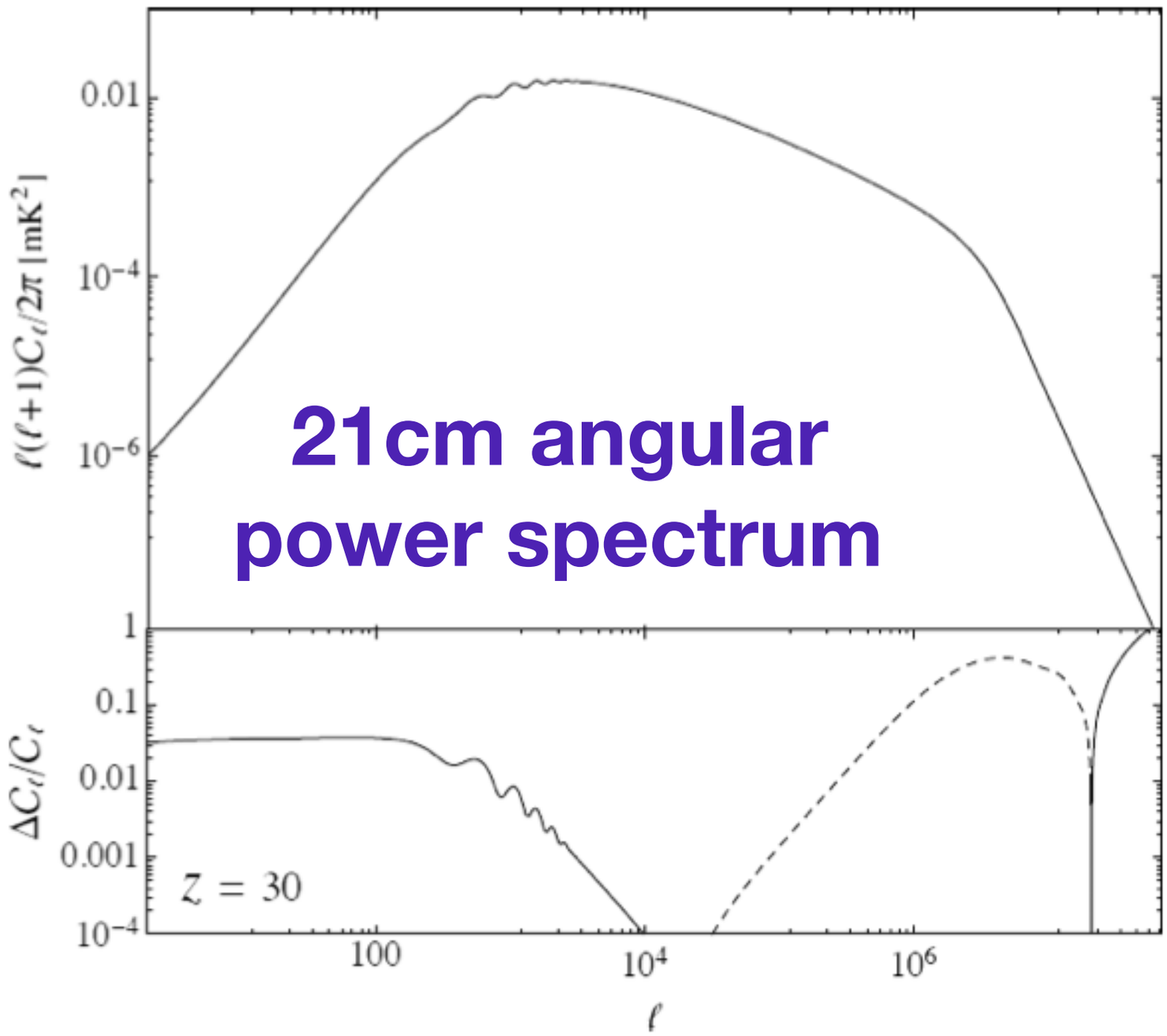


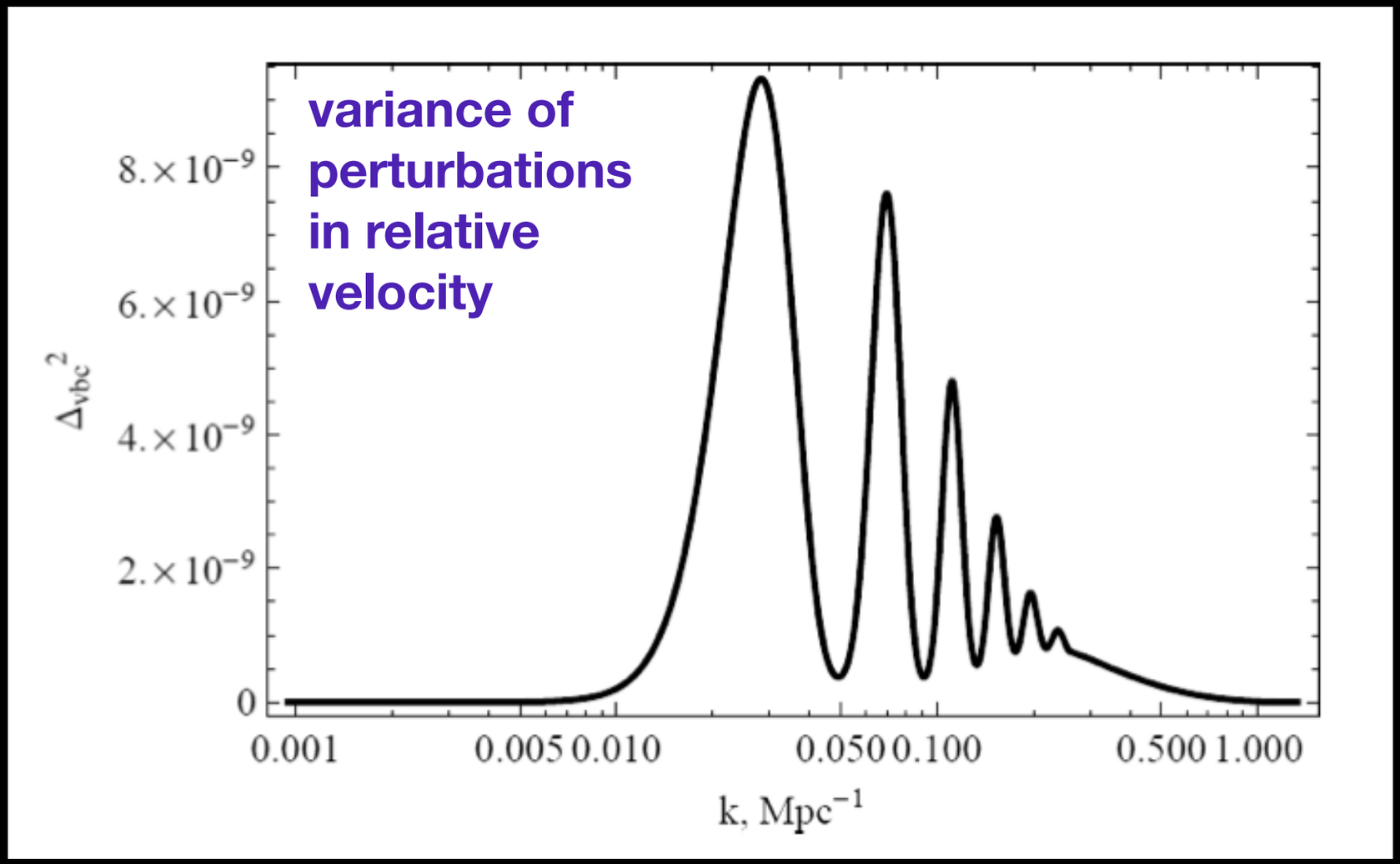
linear matter p



21cm angular power spectrum

Velocity Offsets

Tseliakhovich & Hirata 2010
McQuinn & O'Leary 2012
Fialkov et al. 2014
Ali-Haimoud et al. 2014
Marsh 2015



Velocity Offsets

Tseliakhovich & Hirata 2010
McQuinn & O'Leary 2012
Fialkov et al. 2014
Ali-Haimoud et al. 2014
Marsh 2015