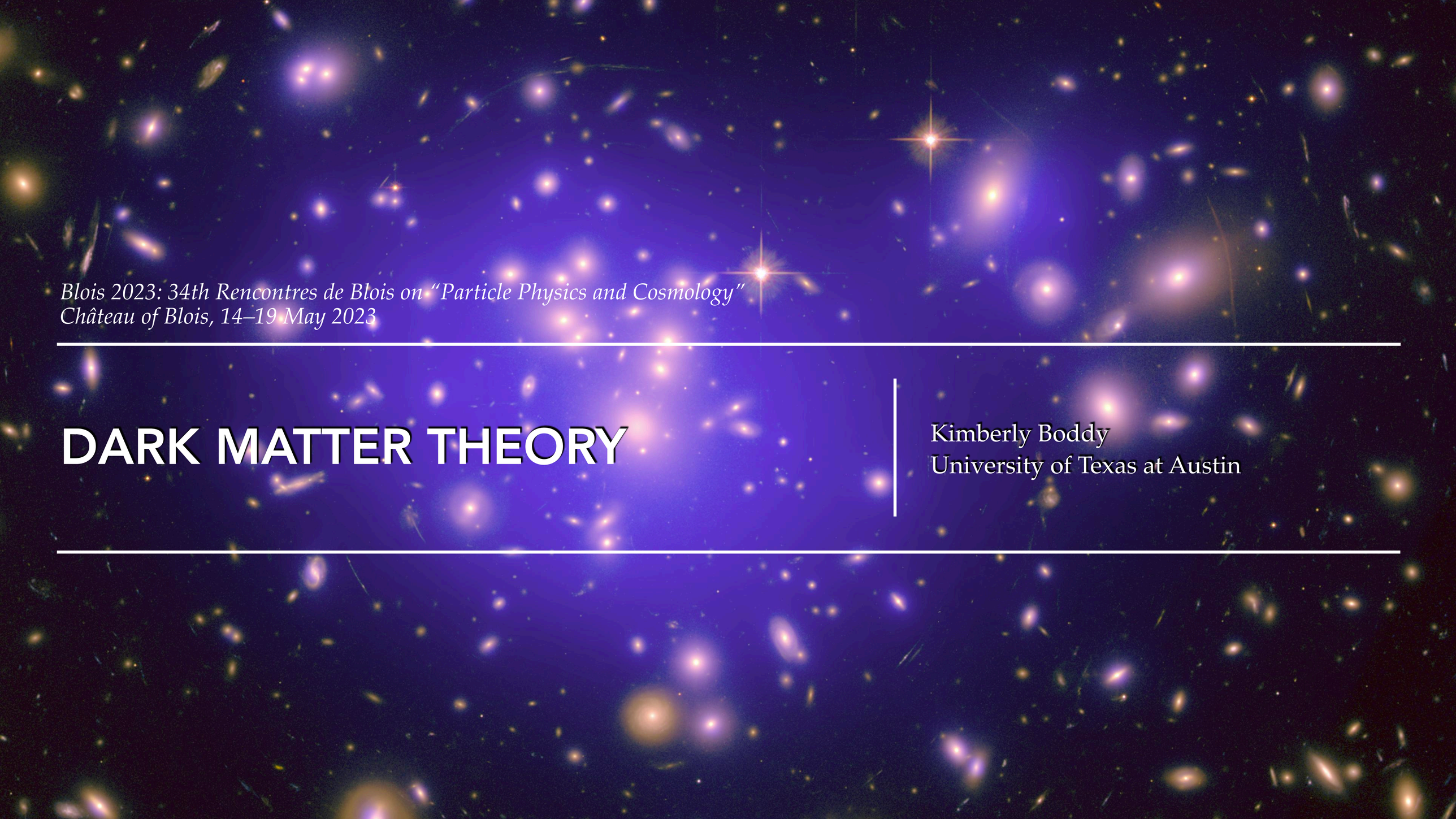


Blois 2023: 34th Rencontres de Blois on "Particle Physics and Cosmology"
Château of Blois, 14–19 May 2023

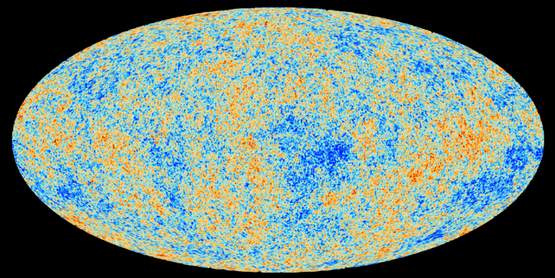
DARK MATTER THEORY

Kimberly Boddy
University of Texas at Austin

General Properties of Dark Matter

General Properties of Dark Matter

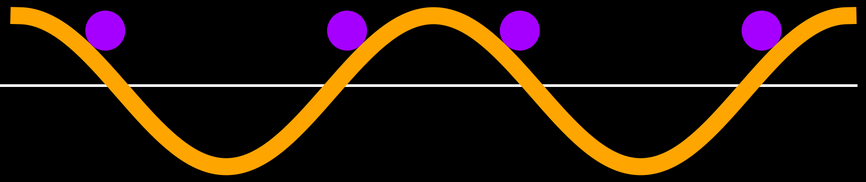
- From cosmic microwave background (CMB) anisotropies:



ΛCDM

Universe today is about
- 68% dark energy
- 5% baryons
- 27% dark matter (cold, collisionless)

General Properties of Dark Matter



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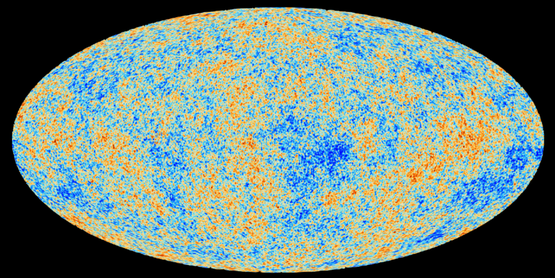

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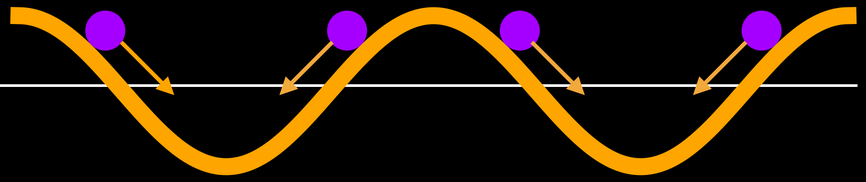

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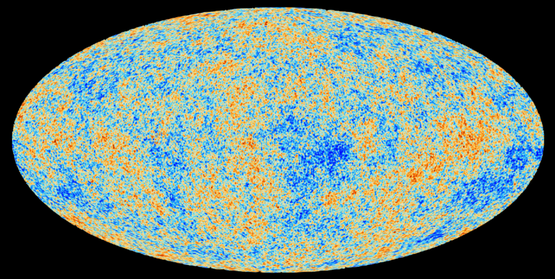

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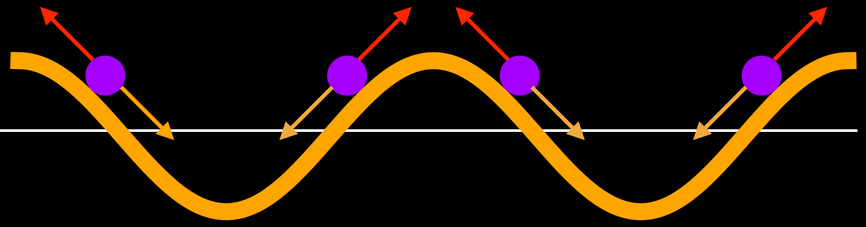

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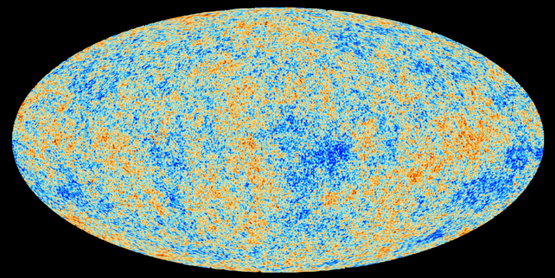

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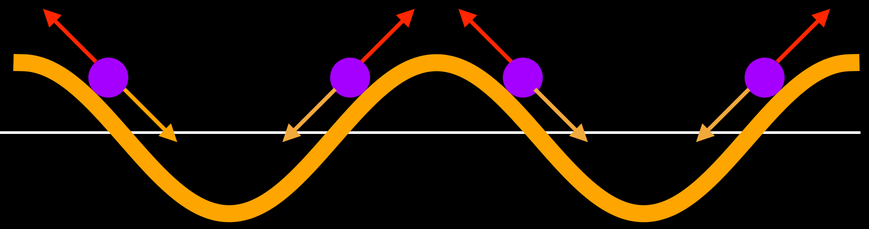

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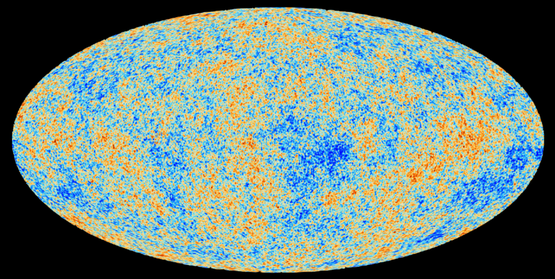

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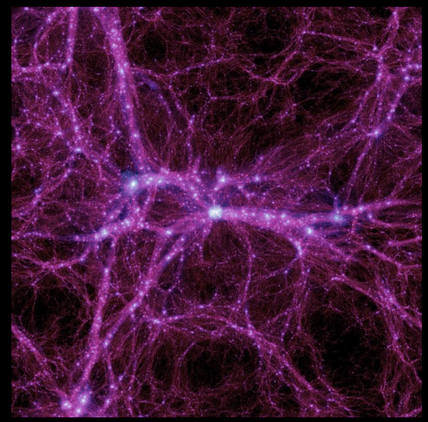

Boylan-Kolchin+ (2009)

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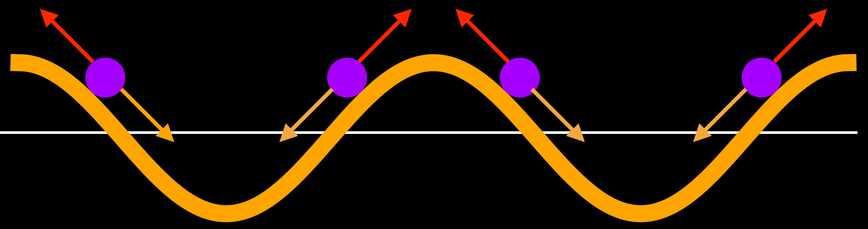

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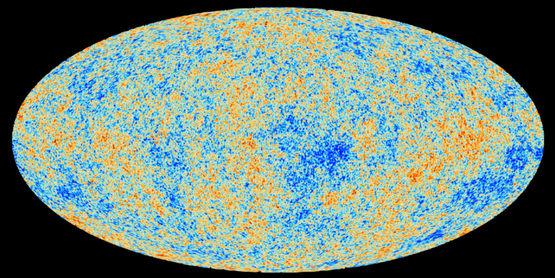

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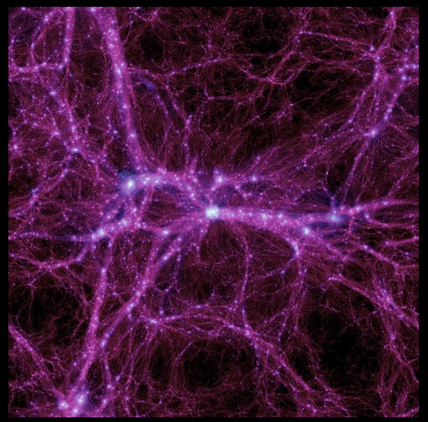
  → study structure formation with N-body simulations
- Dark matter forms self-gravitating halos that host galaxies



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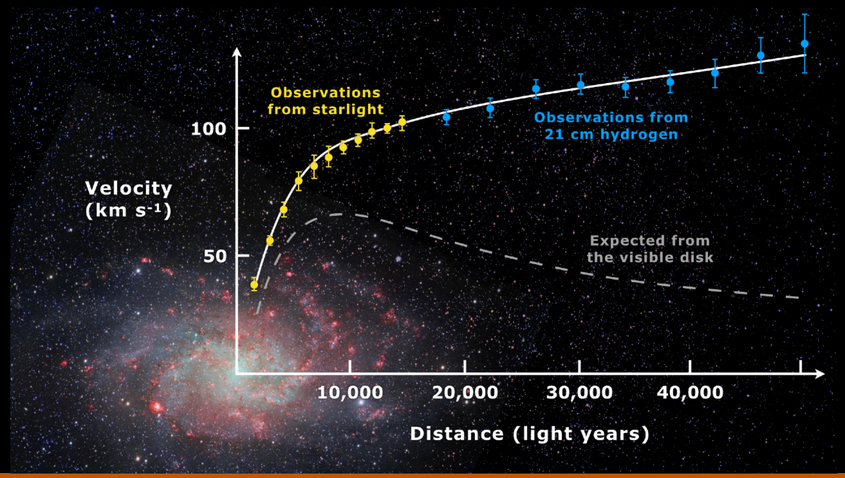
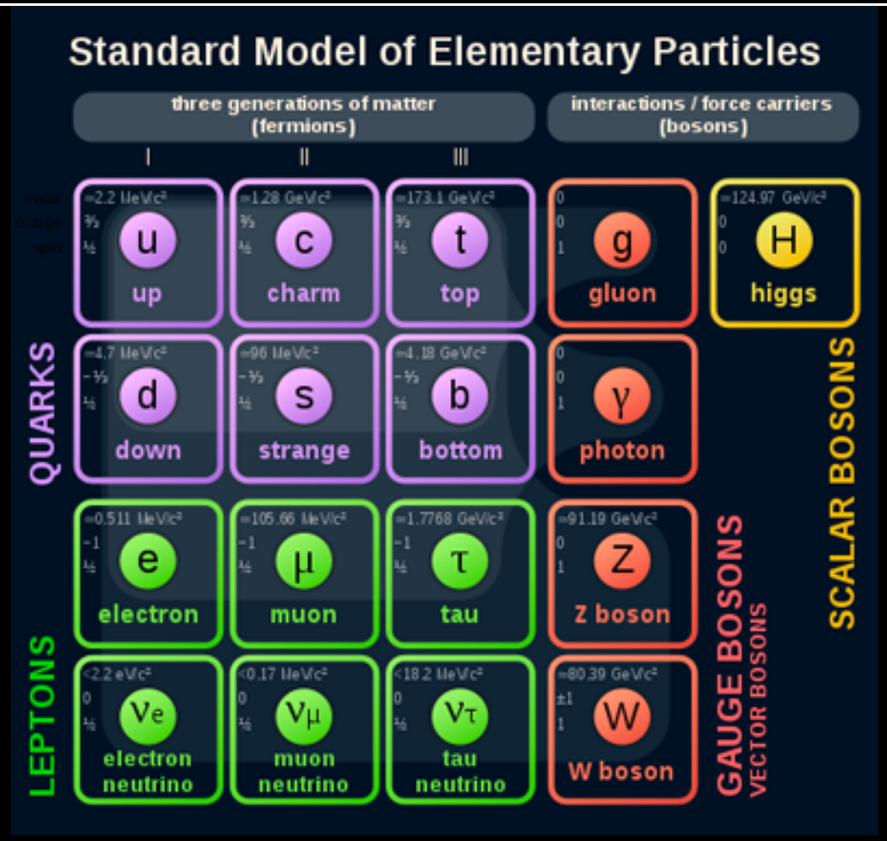


Credit: NASA, ESA, J. Lotz and HFF Team (STScI)

What is the particle nature of dark matter?



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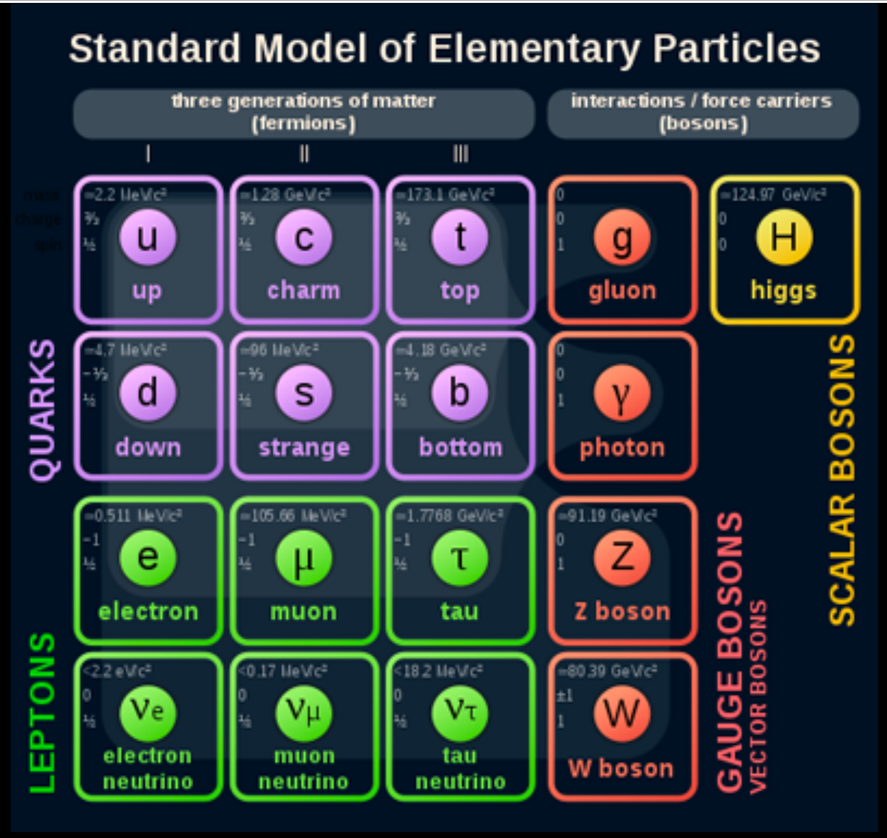
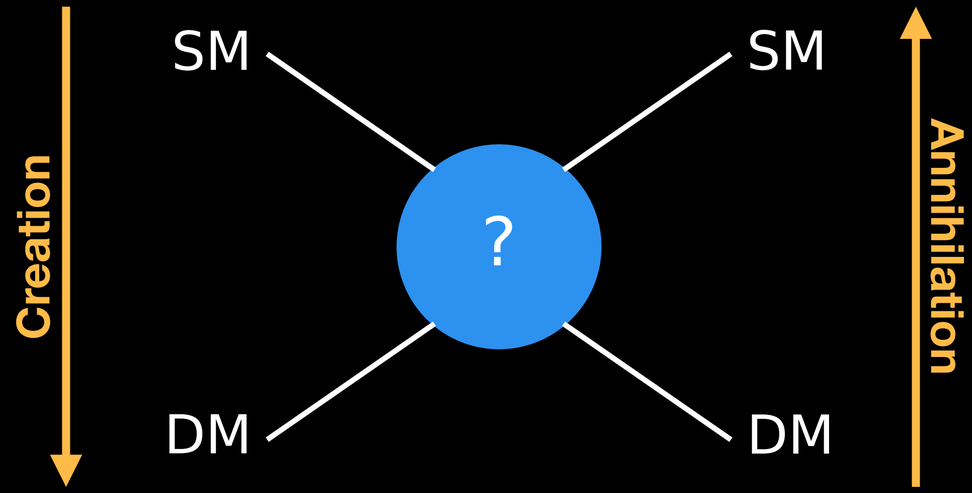




assume $\langle \sigma v \rangle \sim \frac{\pi \alpha^2}{m^2}$

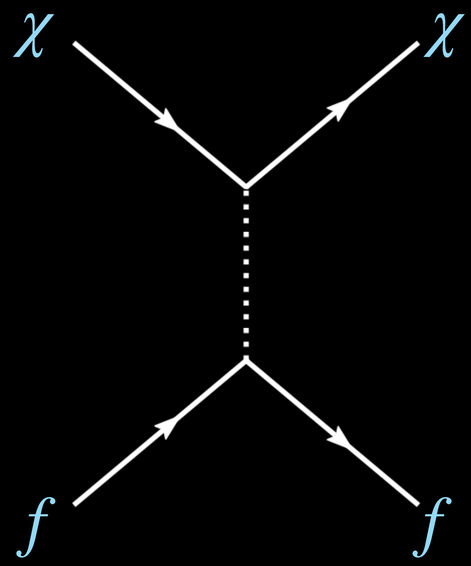
match observed abundance for thermal freeze-out of weak-scale particles (WIMP miracle)

Dark matter could be lightest supersymmetric particle in MSSM framework

WIMP Searches

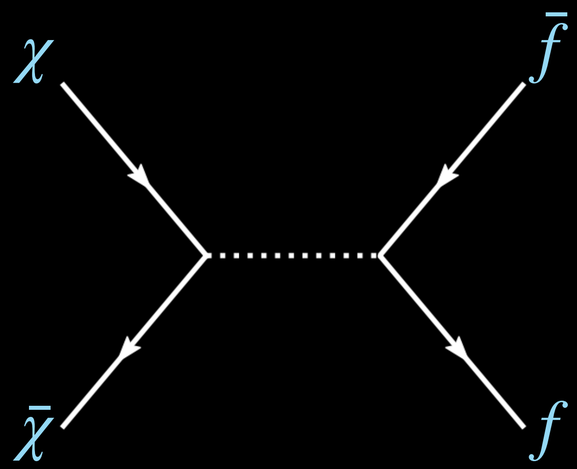
- Dedicated searches of WIMPs through interactions with Standard Model via:

direct detection



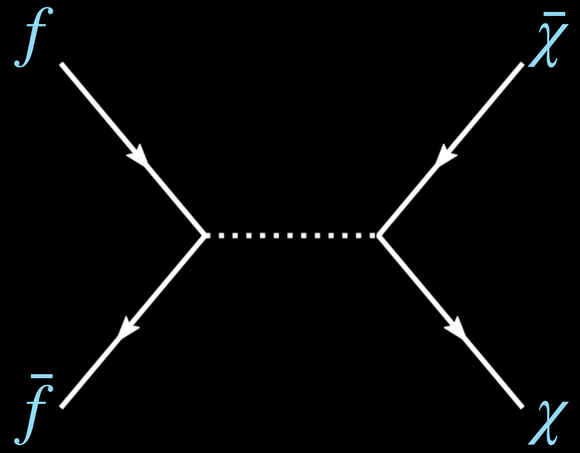
See plenary talks by Peter Sorensen, Enectali Figueroa-Feliciano

indirect detection



See plenary talks by Francesca Calore, Emmanuel Moulin

production at colliders



See plenary talks by Rebeca Gonzalez Suarez, Swagata Mukherjee, Marianna Liberatore

- But landscape of possibilities is much broader

Standard WIMP Assumptions (and Examples of How to Break Them)

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- single, point-like or fundamental particle
  composite particle; complex dark sector with multiple new particles/forces

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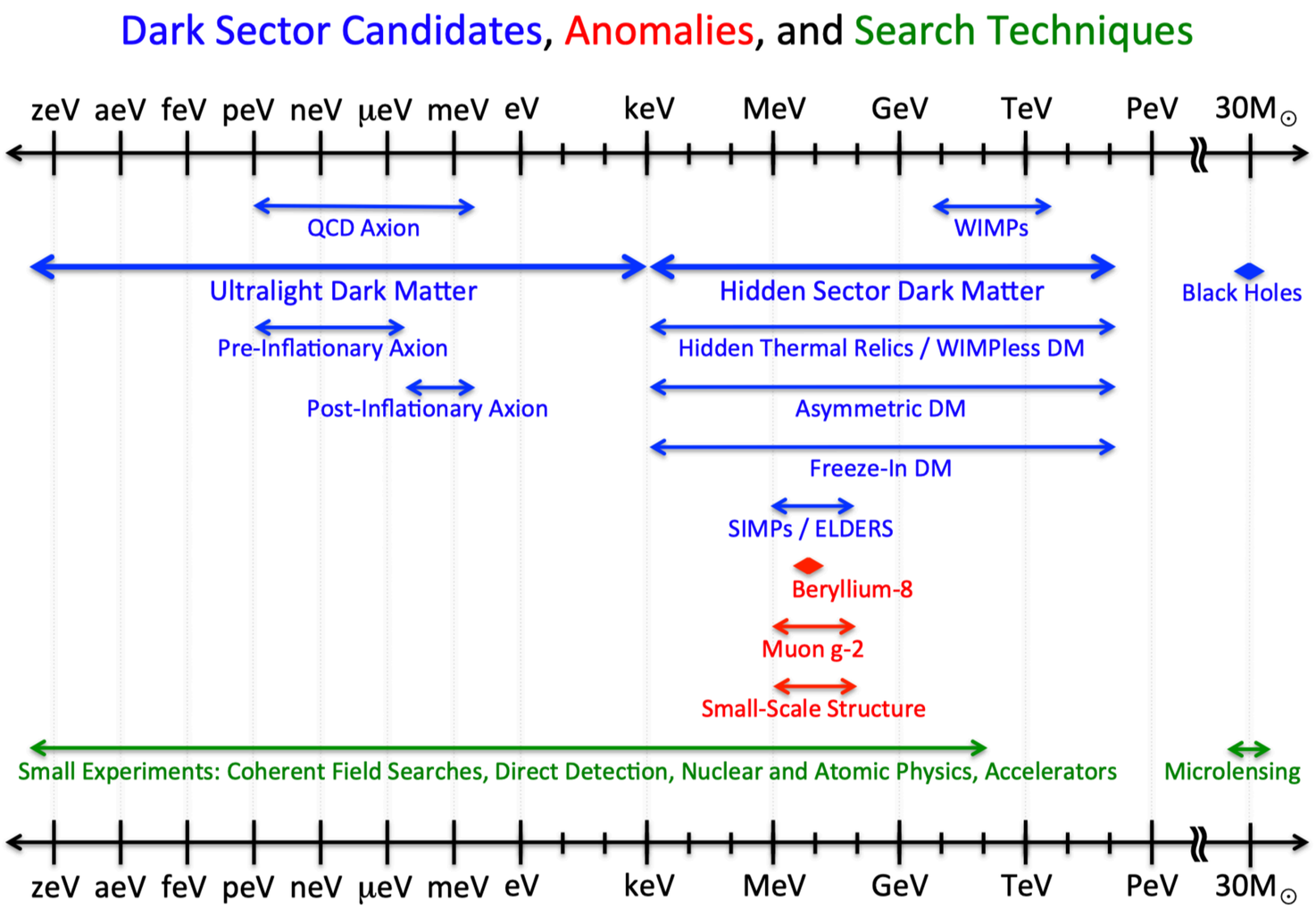
  different freeze-out scenario; freeze-in; asymmetric dark matter
- interacts with Standard Model
  "nightmare scenario": dark sector may be secluded

Mass Range of Possibilities

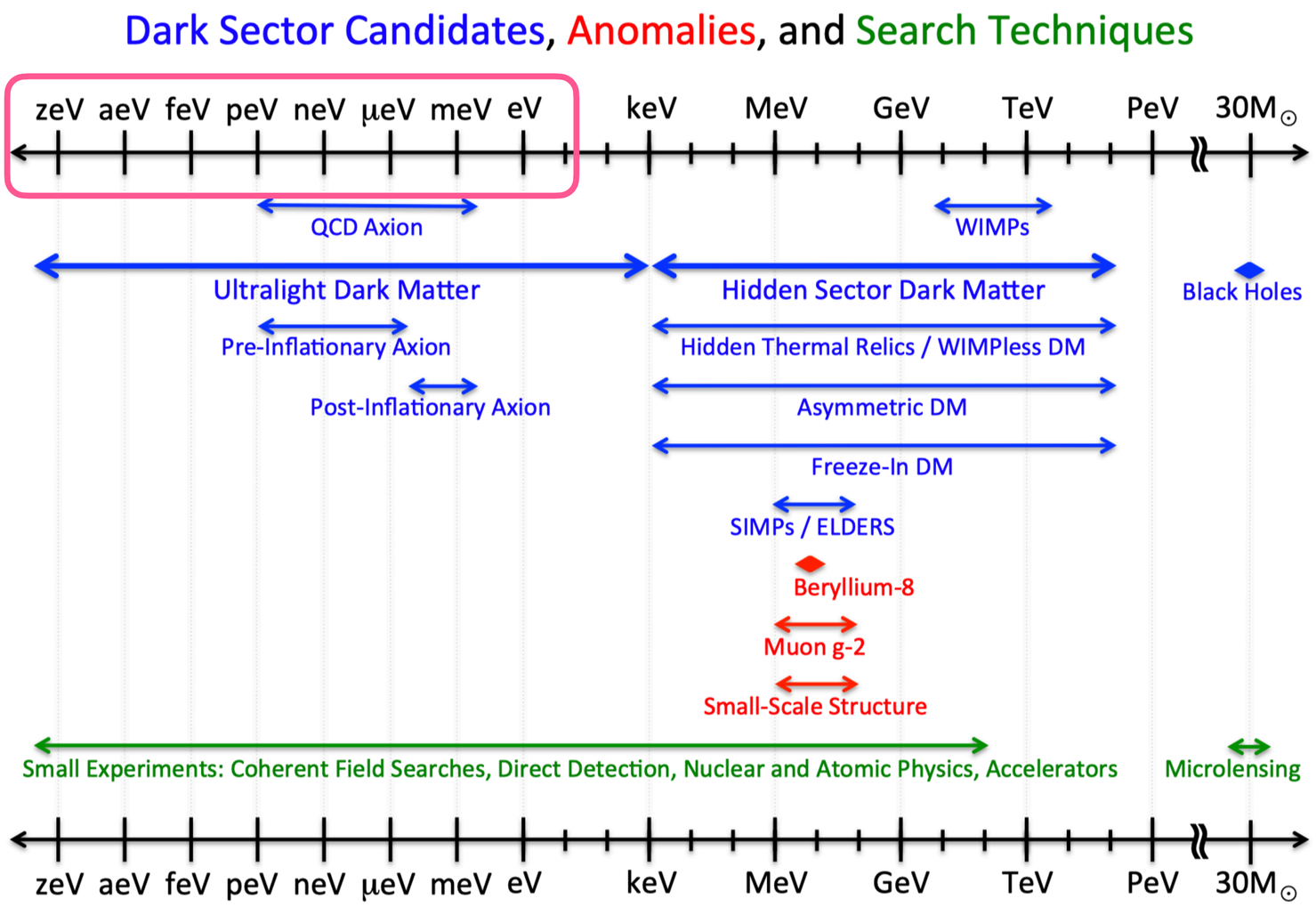


US Cosmic Visions: New Ideas in Dark Matter (1707.04591)

Mass Range of Possibilities

"wave-like" ultralight boson, axion, ALP

See plenary talks by Asher Berlin, Christopher McCabe



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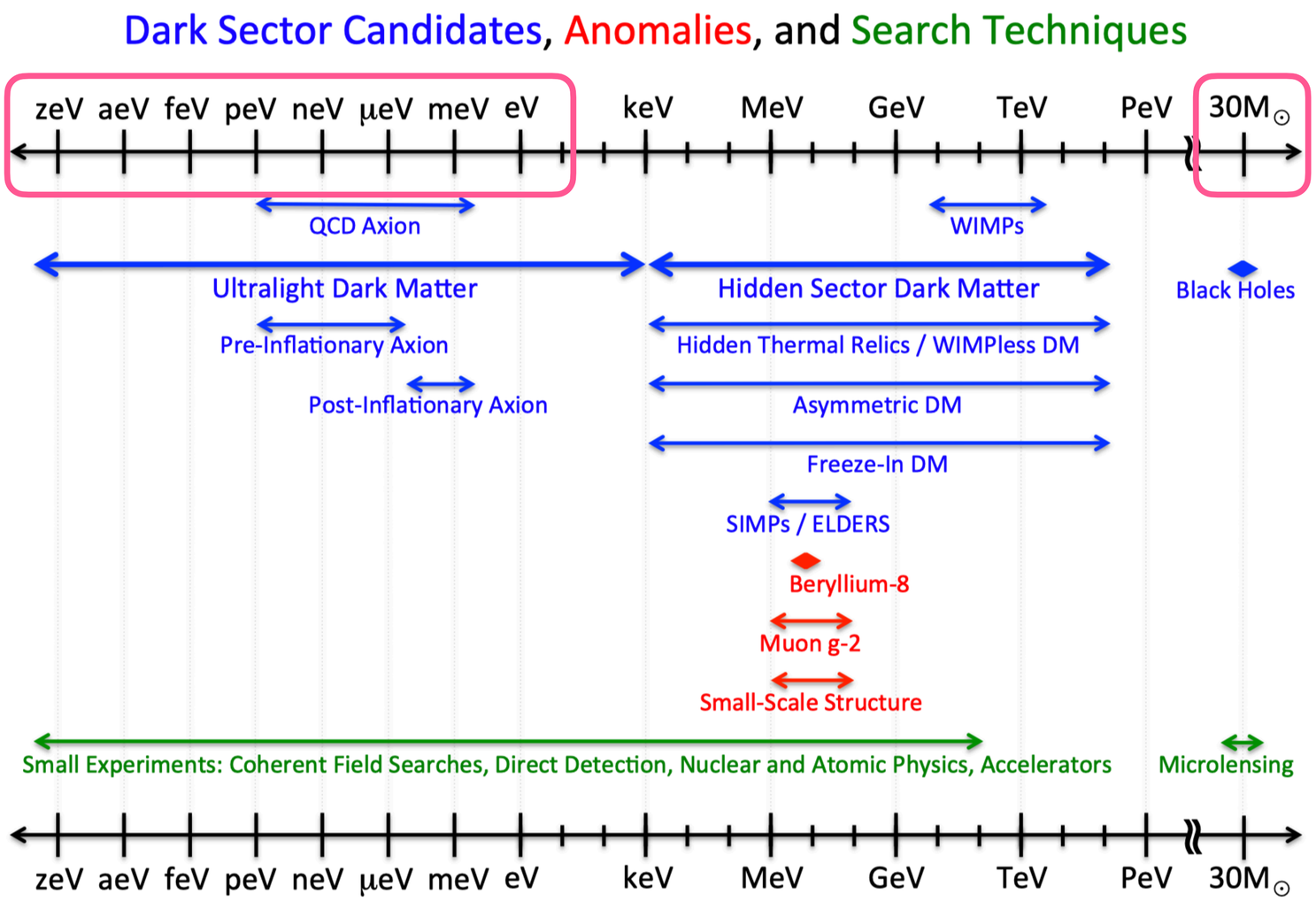

primordial black holes

US Cosmic Visions: New Ideas in Dark Matter (1707.04591)

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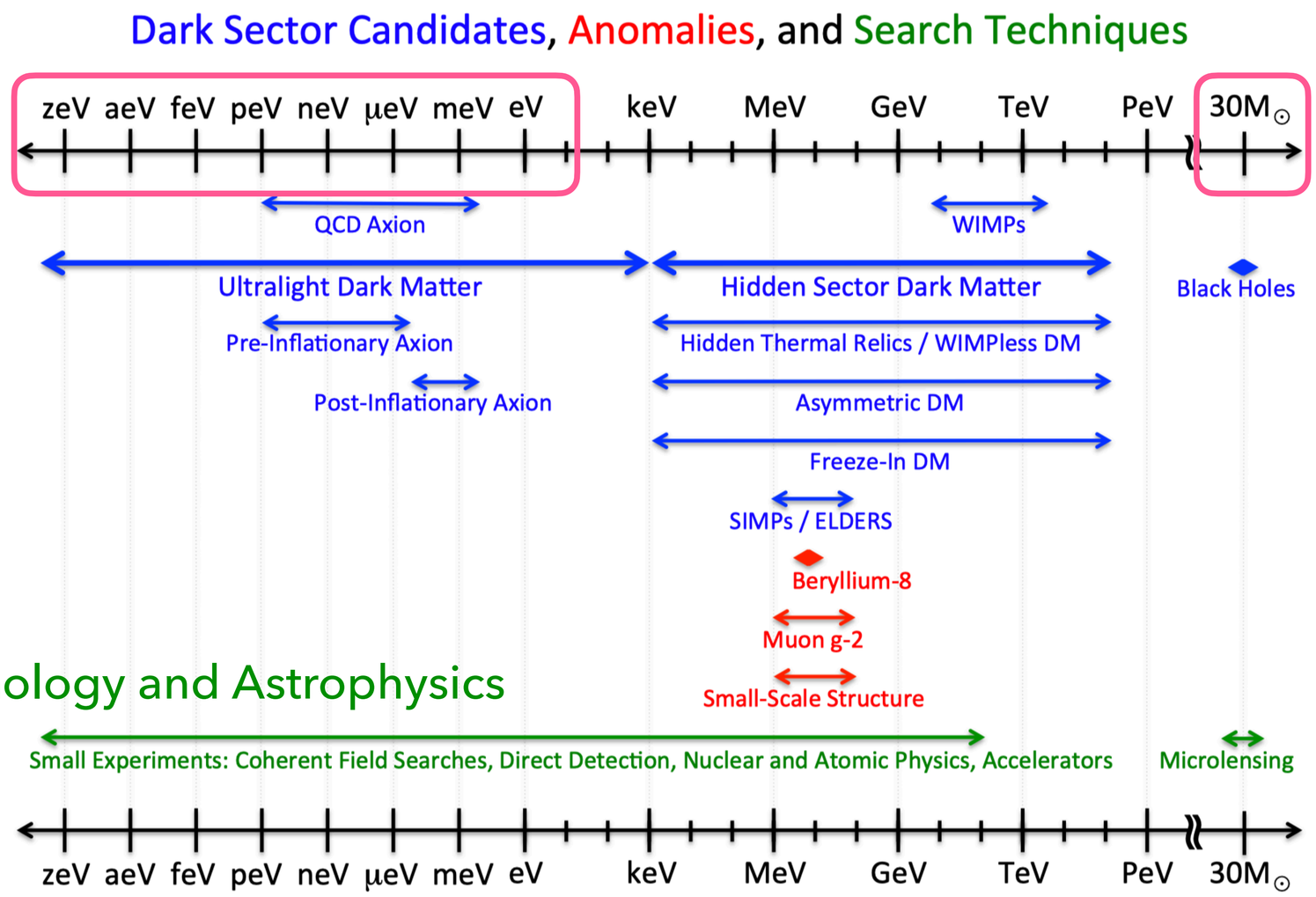
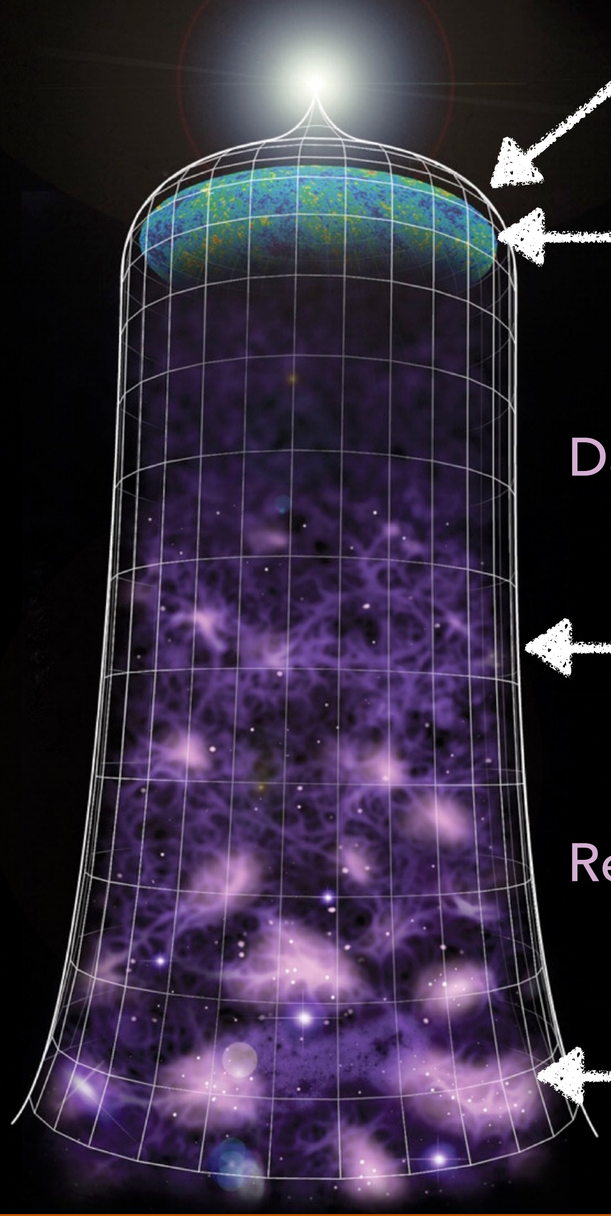


See plenary talks by Asher Berlin, Christopher McCabe

See plenary talk by Camille Bonvin

US Cosmic Visions: New Ideas in Dark Matter (1707.04591)

Cosmic History



Time

Redshift

$$z \equiv \frac{\lambda_{\rm obs} - \lambda_{\rm emit}}{\lambda_{\rm emit}}$$

BBN

CMB

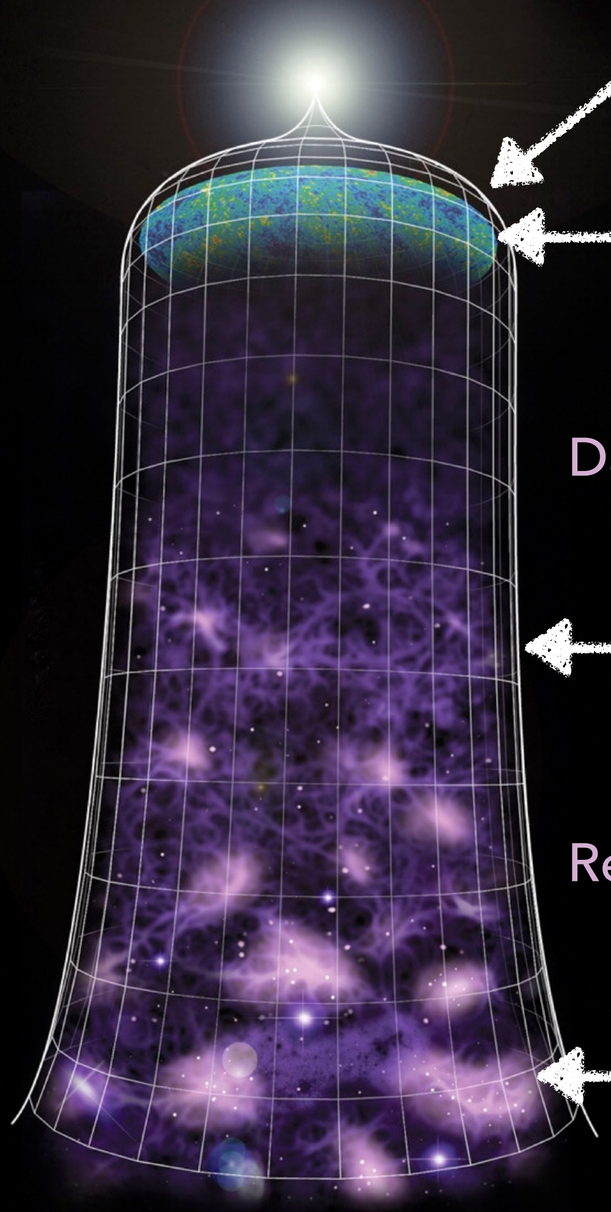
Dark Ages*

Cosmic Dawn*

Reionization

Galaxy Surveys and LSS

Cosmic History



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$$z \equiv \frac{\lambda_{\rm obs} - \lambda_{\rm emit}}{\lambda_{\rm emit}}$$

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Dark Ages*

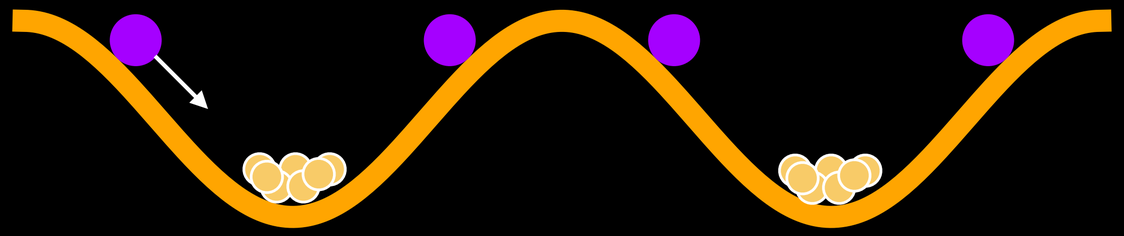
Cosmic Dawn*

Reionization

Galaxy Surveys and LSS

- Dark matter (dark sector) properties and/or interactions can affect structure formation (and thus star/galaxy formation)
- Observed large-scale structure well-described by ΛCDM
- More flexibility at small scales

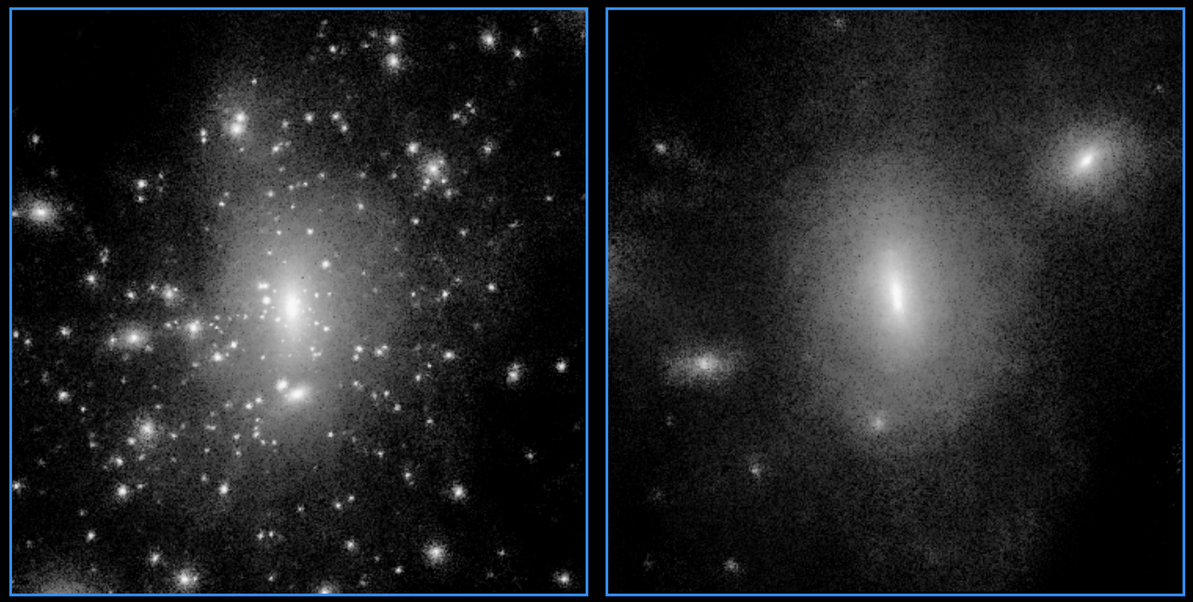
Example: Small-Scale Suppression



In early Universe, interactions wash out small, weakly-bound structures

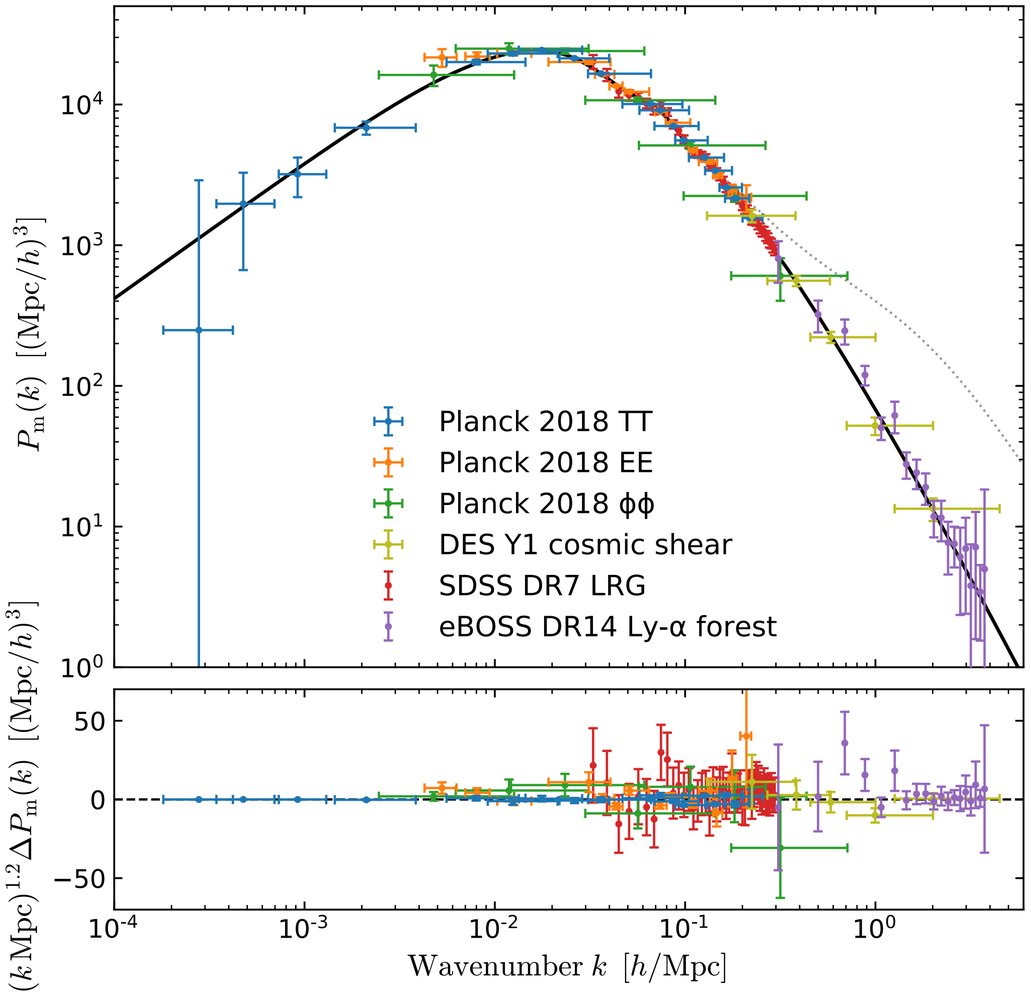
Particle POV: transfer of energy & momentum
Fluid POV: induce drag force

Washed out density perturbations do not exist to collapse and form small-scale structures



Moore+ (MNRAS, 1999)

Matter Power Spectrum: Small-Scale Modifications



Chabanier+ (MNRAS 2019)

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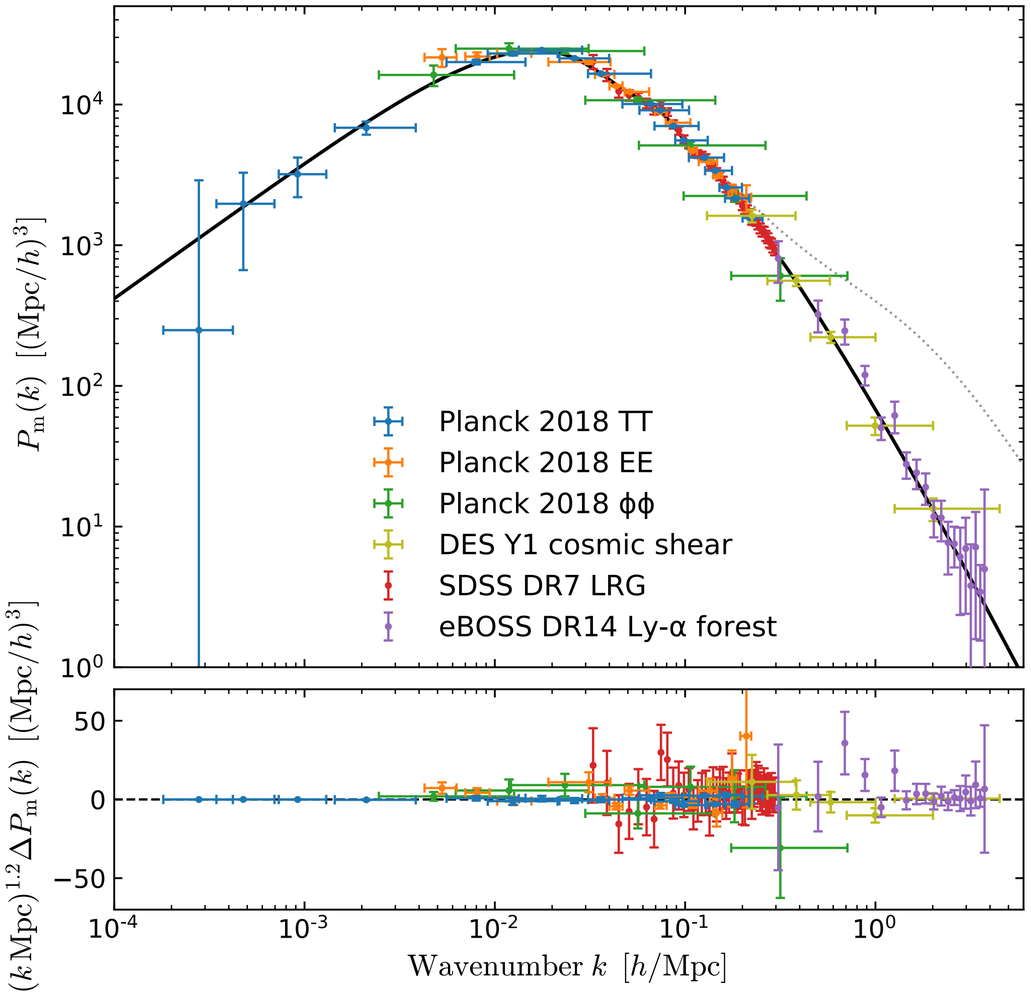
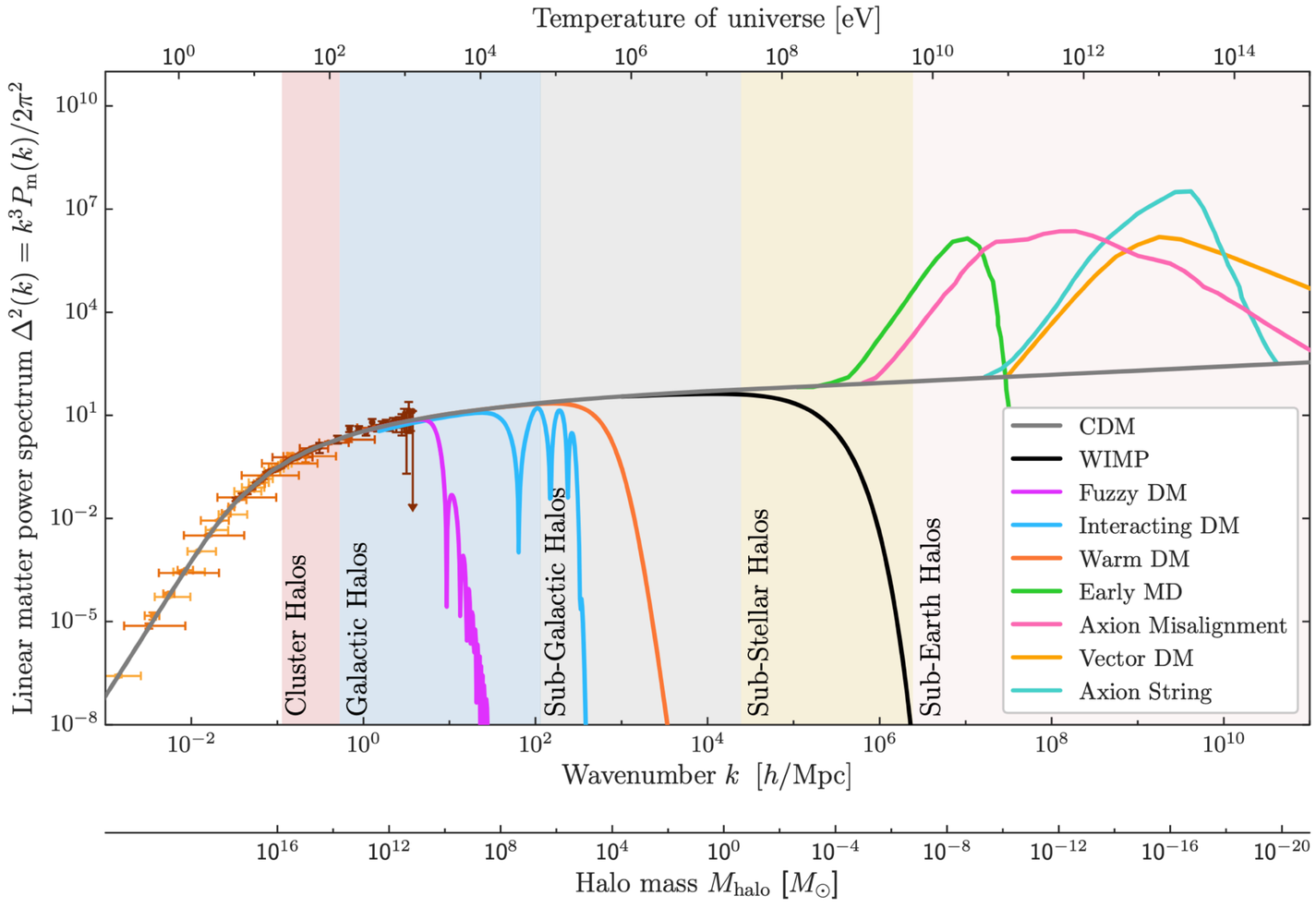
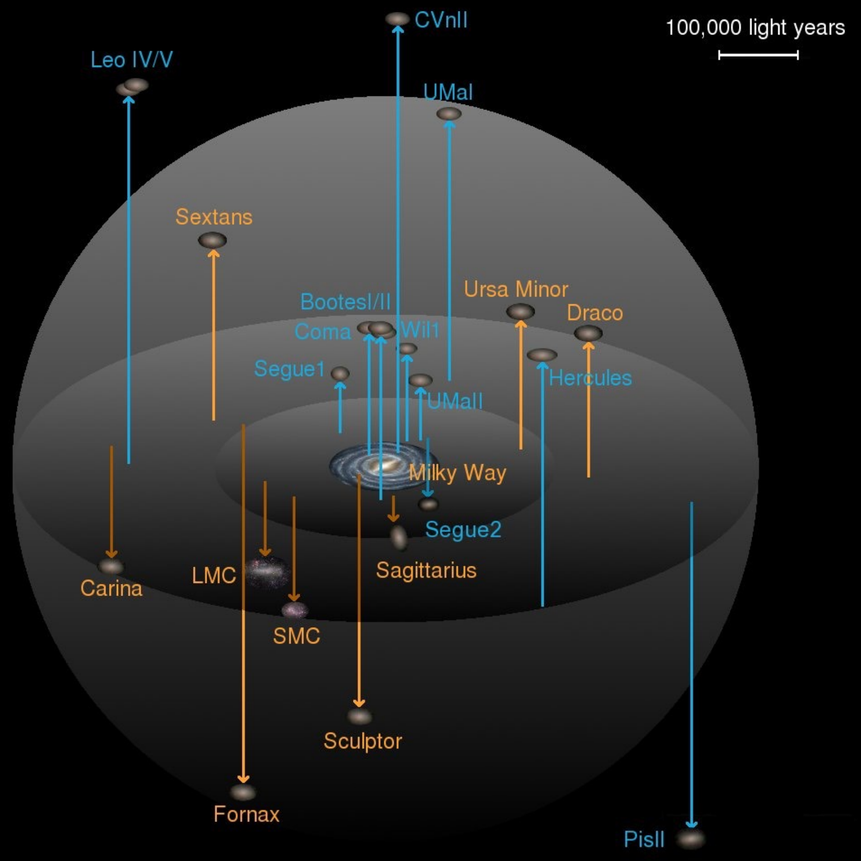




Chabanier+ (MNRAS 2019)

Snowmass 2021 Cosmic Frontier: Dark Matter Physics from Halo Measurements
Bechtol, Birrer, Cyr-Racine, Schutz+ (2203.07354)

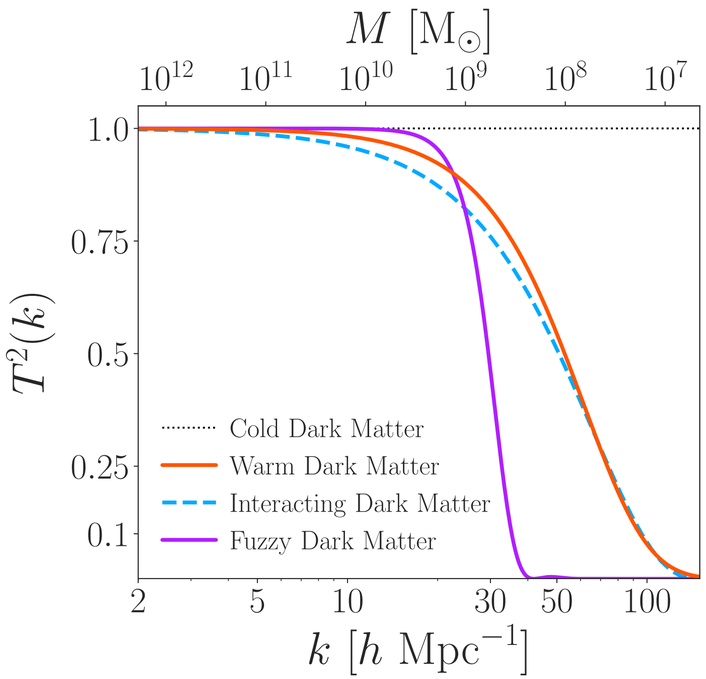
Milky Way Satellites

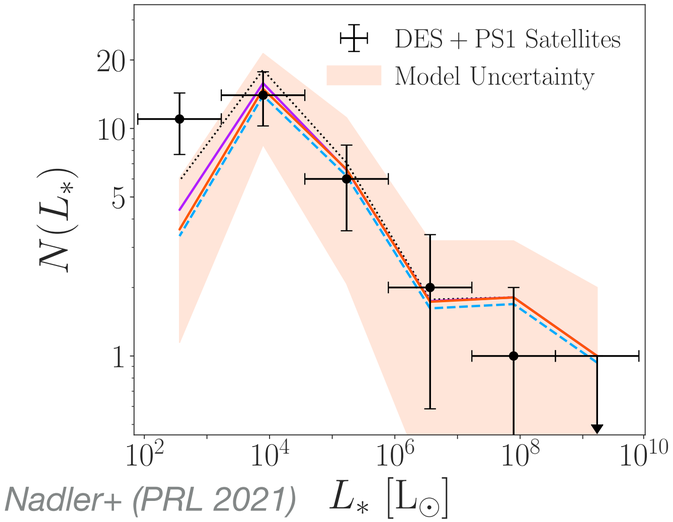


DES and Pan-STARRS1 identified dwarfs

Classic dwarfs
SDSS-identified dwarfs

Small-Scale Structure Suppression





DES Collaboration, Nadler+ (PRL 2021)

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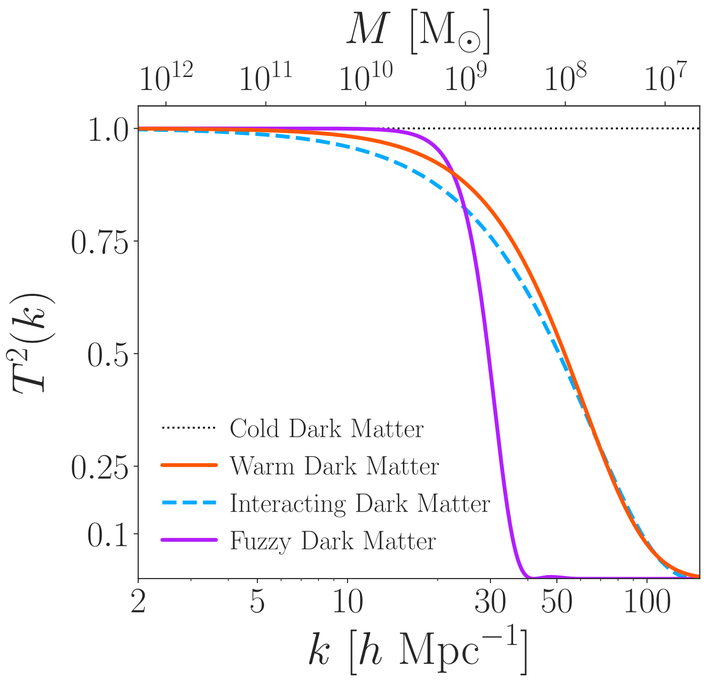

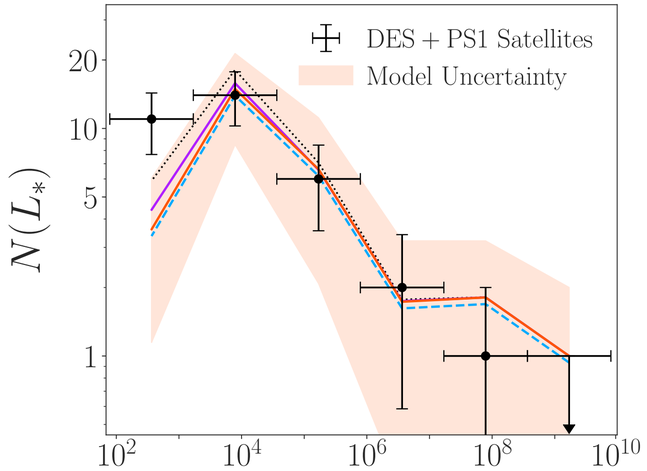

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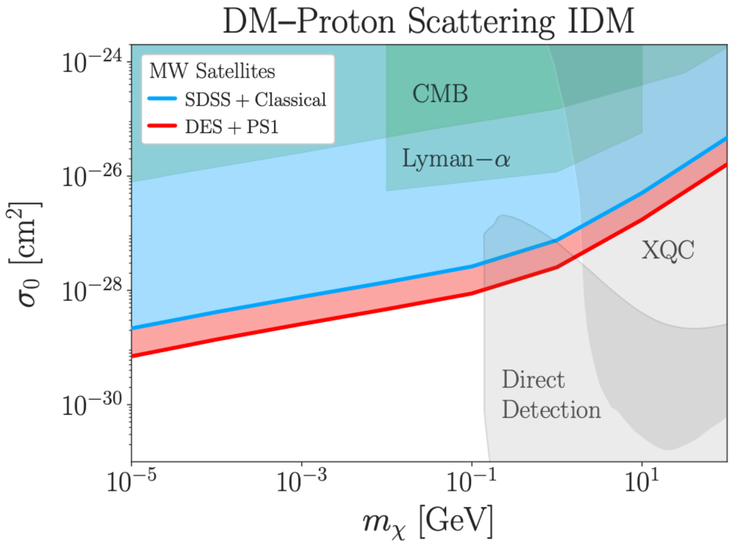

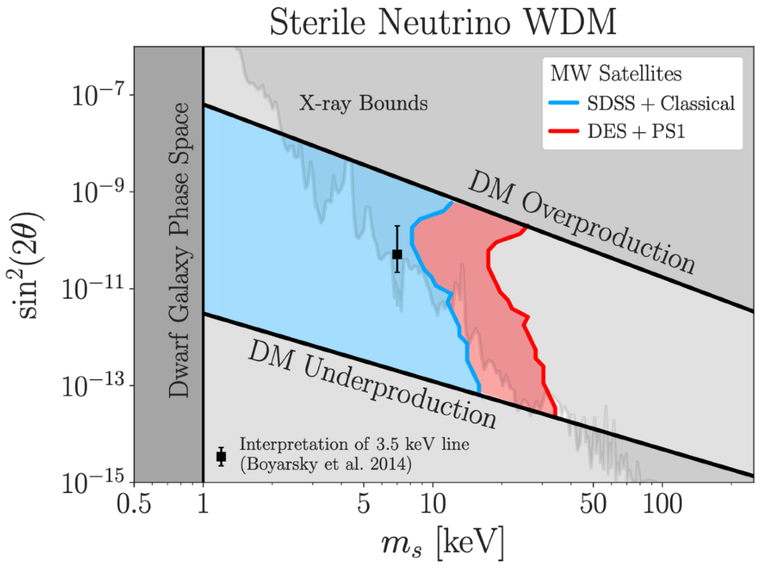

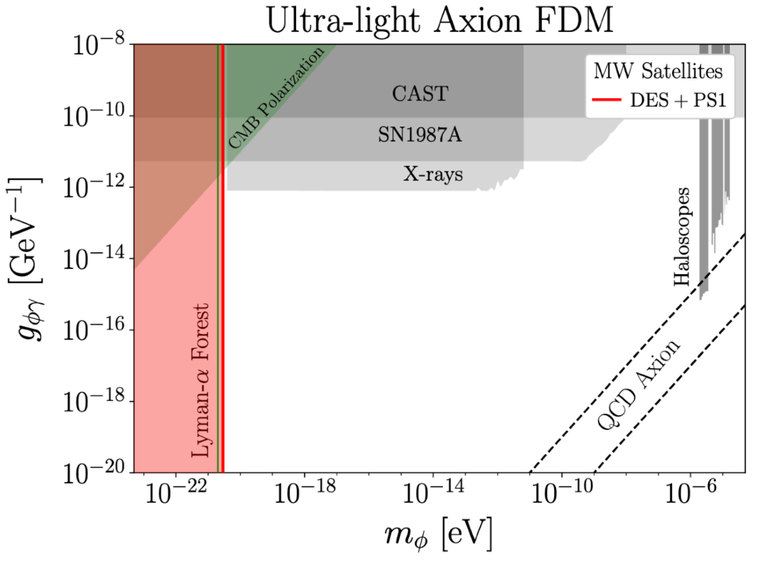

CMB constraints: KB, Gluscevic (PRD 2018); Gluscevic, KB (PRL 2018)

Cosmology with Hidden Dark Sector

Cosmology with Hidden Dark Sector

- Light mediators contribute to $N_{\rm eff}$

$$\rho_{\rm rad} = \rho_\gamma \left[1 + \frac{7}{8} \left(\frac{4}{11} \right)^{4/3} N_{\rm eff} \right]$$

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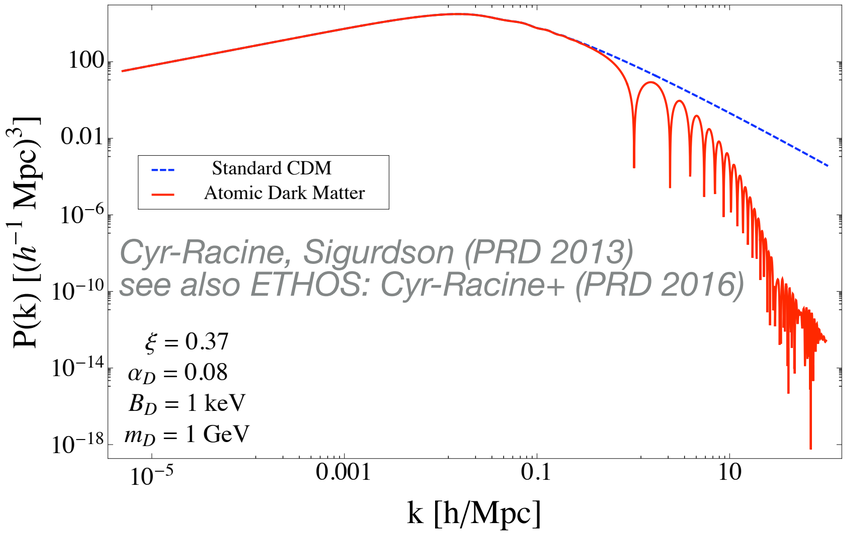

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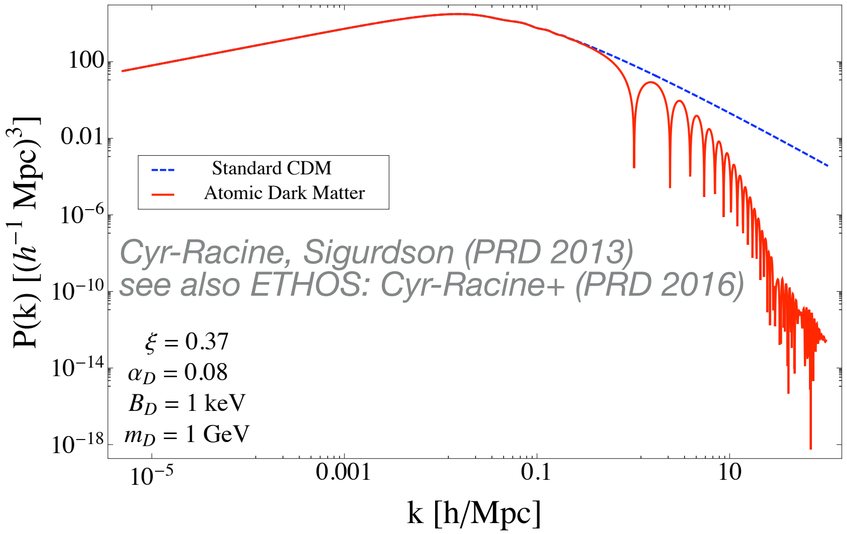
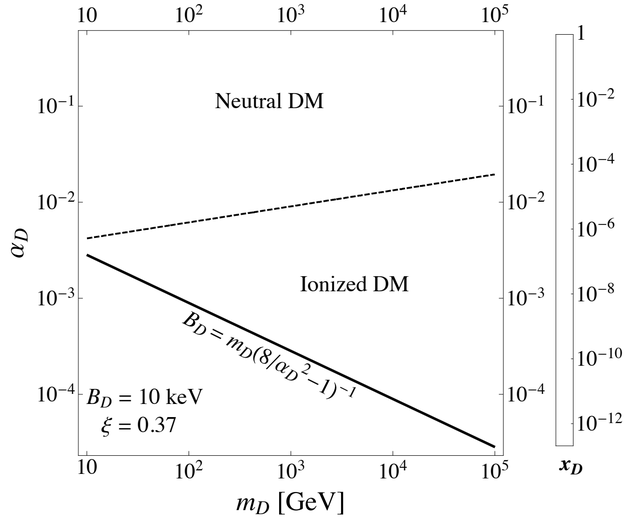
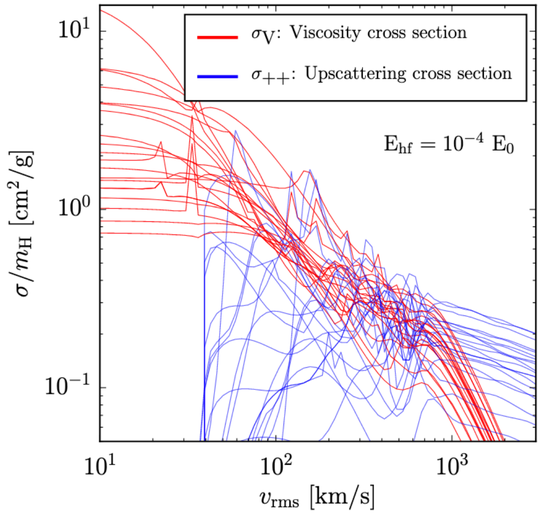


- Composite dark matter (e.g. atomic, nuclear) permits different pheno in early & late Universe



Cyr-Racine, Sigurdson (PRD 2013)



KB, Kaplinghat, Kwa, Peter (PRD 2016)

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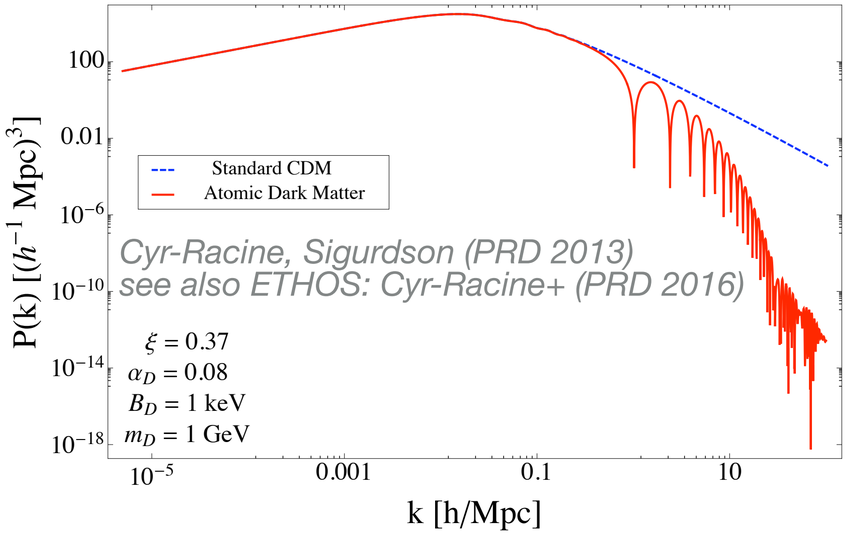
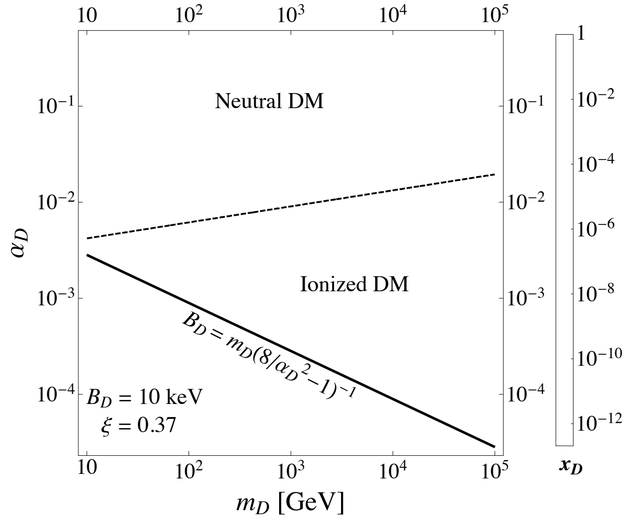
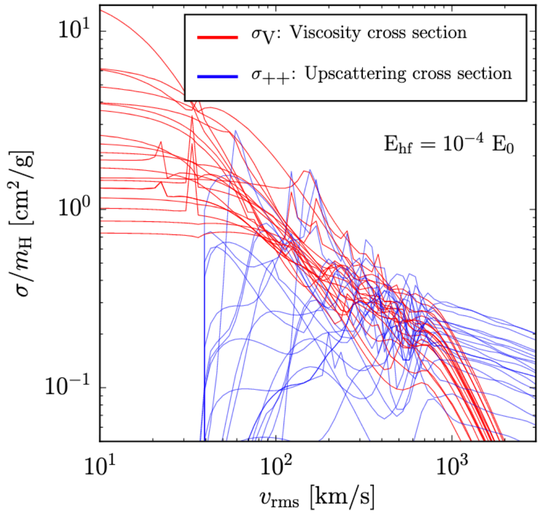


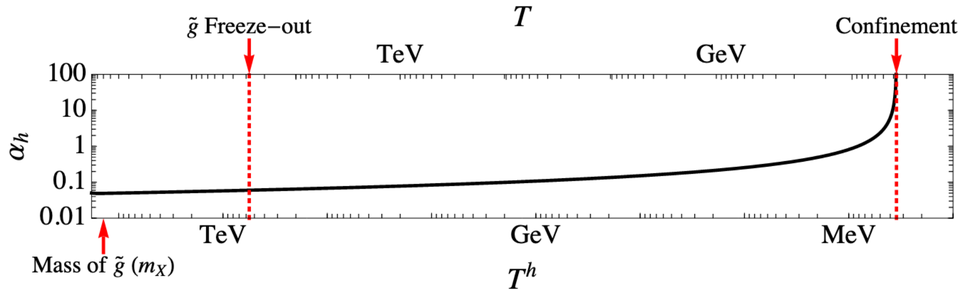
- Composite dark matter (e.g. atomic, nuclear) permits different pheno in early & late Universe



Cyr-Racine, Sigurdson (PRD 2013)



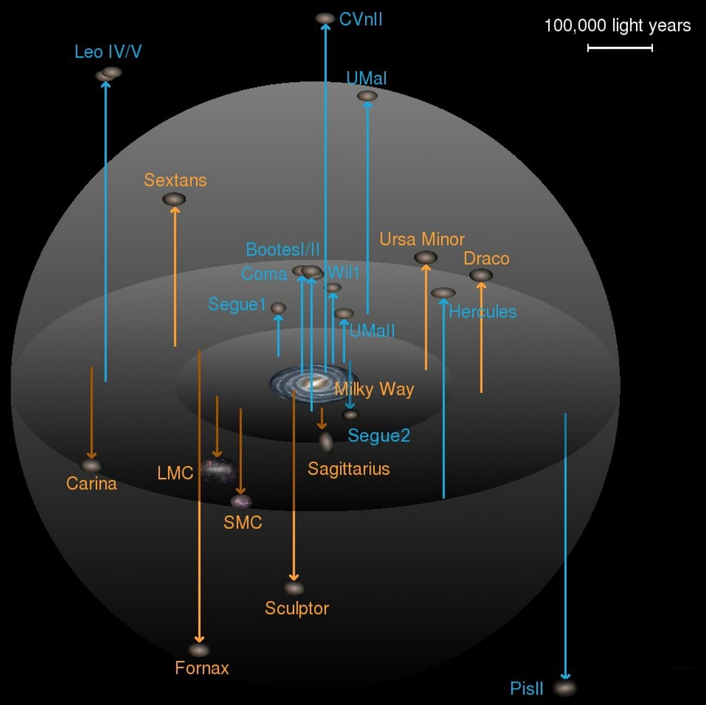
KB, Kaplinghat, Kwa, Peter (PRD 2016)



KB, Feng, Kaplinghat, Tait (PRD 2014)

Small-Scale Structure Puzzles

Dwarf Spheroidals



Low-Surface Brightness (LSB)

Clusters

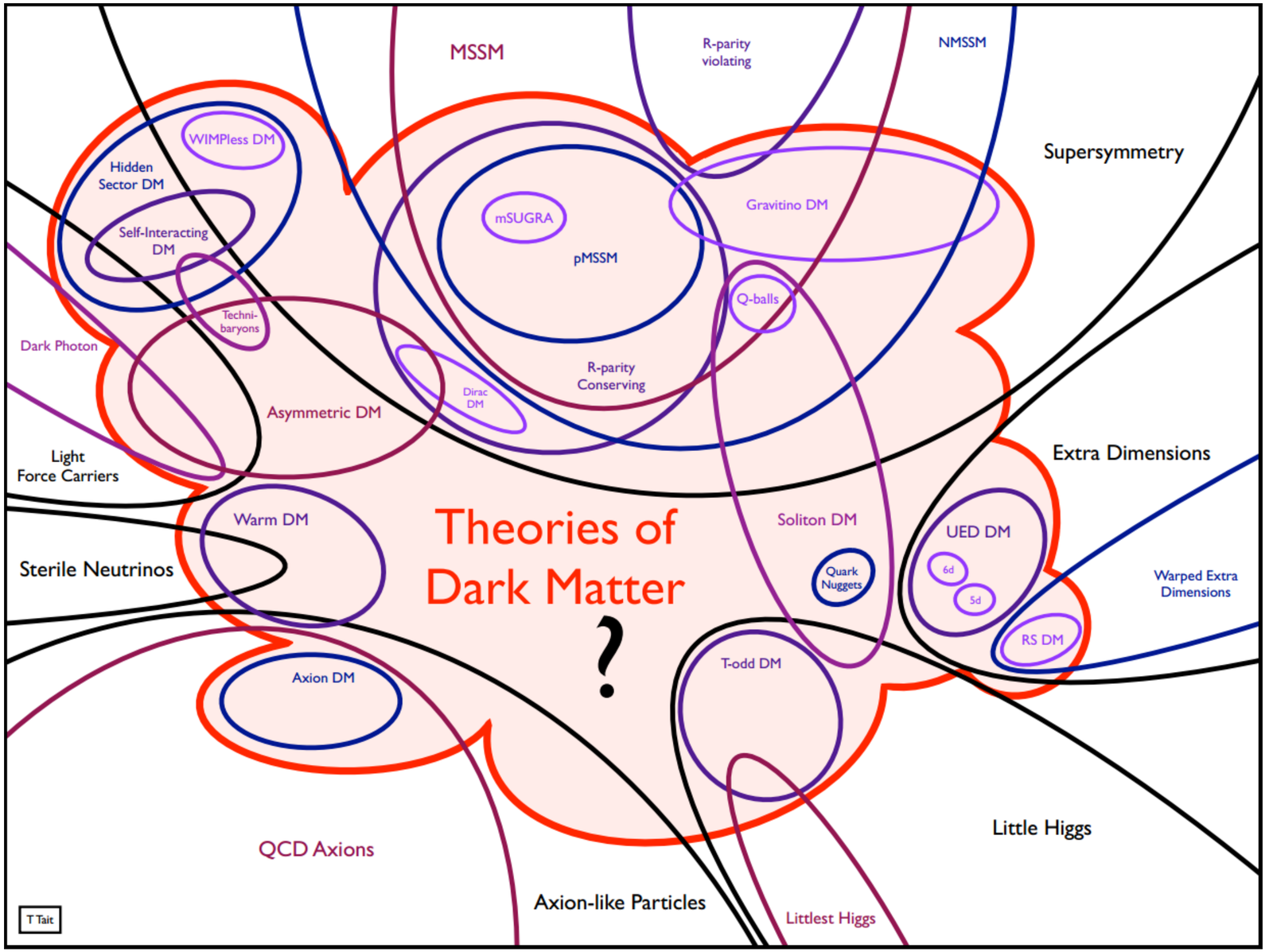
Puzzles (possible discrepancies between simulation and observation) arise in various systems: ~~missing satellites~~, core-cusp, too-big-to-fail, diversity

Attempt to address with SIDM

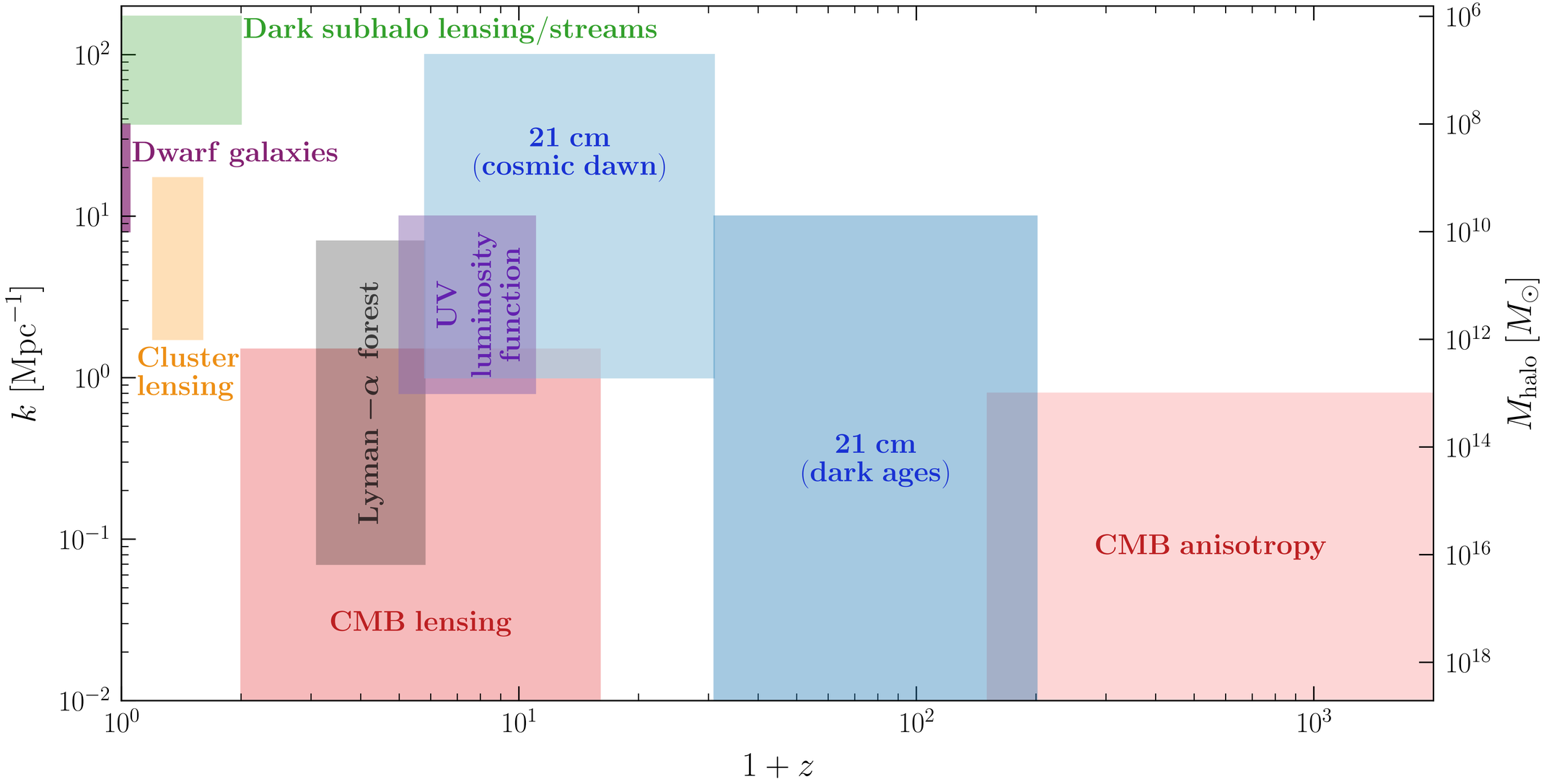
Spergel, Steinhardt (PRL 2000)

Dark Matter Self-Interactions and Small Scale Structure: Tulin, Yu (Phys Rept 2018)
Astrophysical Tests of Dark Matter Self-Interactions: Adhikari, Arka, Boddy+ (2207.10638)

Web of Dark Matter Theories



Complementarity



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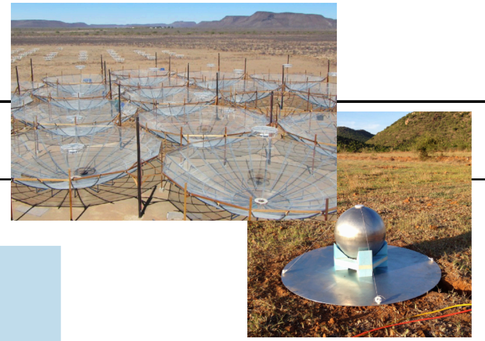
Complementarity



Dark subhalo lensing/streams

Dwarf galaxies

Cluster lensing

21 cm (cosmic dawn)

Lyman $-\alpha$ forest

UV luminosity function

CMB lensing

21 cm (dark ages)

CMB anisotropy

k [Mpc^{-1}]

10^{2}

10^{1}

10^{0}

10^{-2}

10^{0} 10^{1} 10^{2} 10^{3}

$1+z$

10^{6} 10^{8} 10^{10} 10^{12} 10^{14} 10^{16}

$M_{\rm halo}$ $[M_\odot]$

LSST DM white paper 1902.01055

& CMB-S4

Snowmass 2021 Theory Frontier: Astrophysical and Cosmological Probes of Dark Matter (2203.06380)