Cosmological Probes of Dark Matter Interactions

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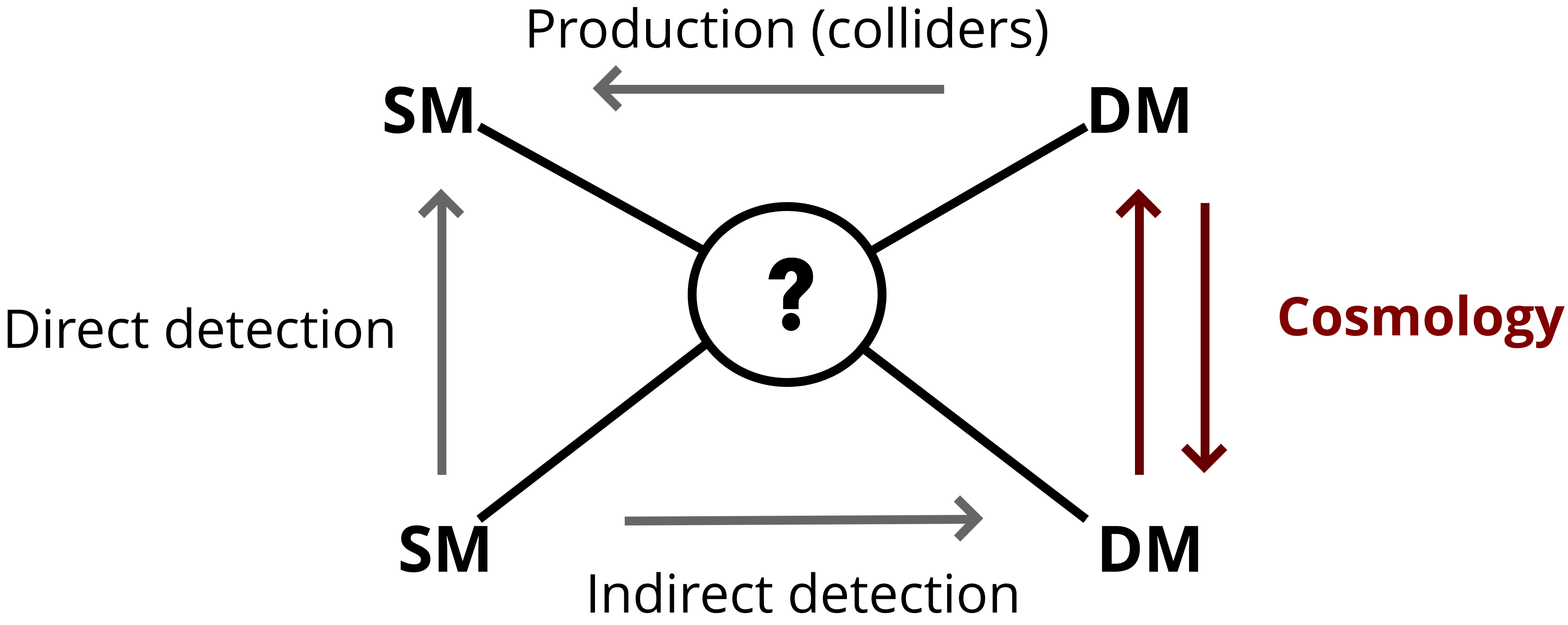
Princeton / USC

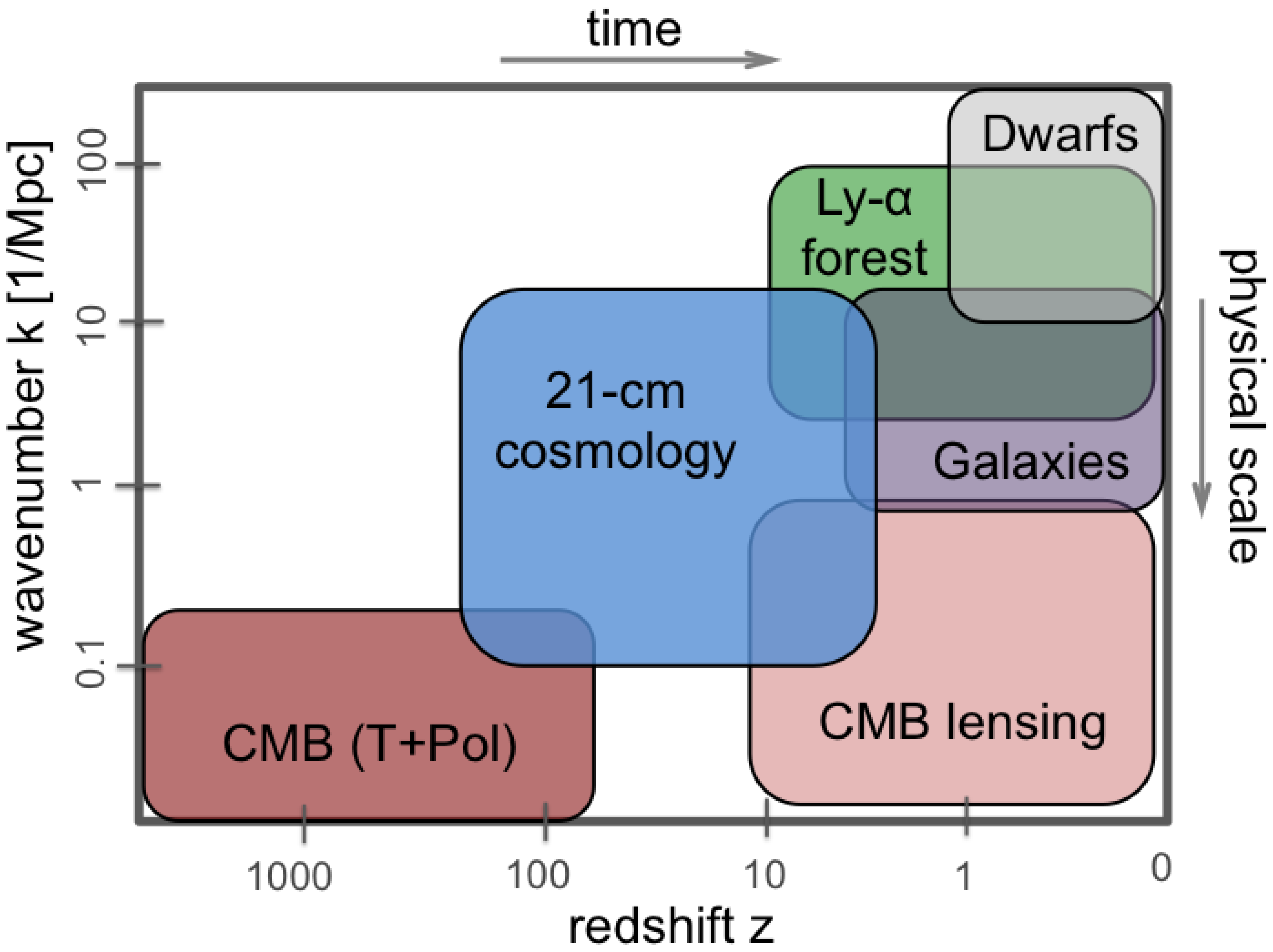
New Directions in the Search for Light Dark Matter Particles

Fermilab/KICP (Jun 7, 2019)

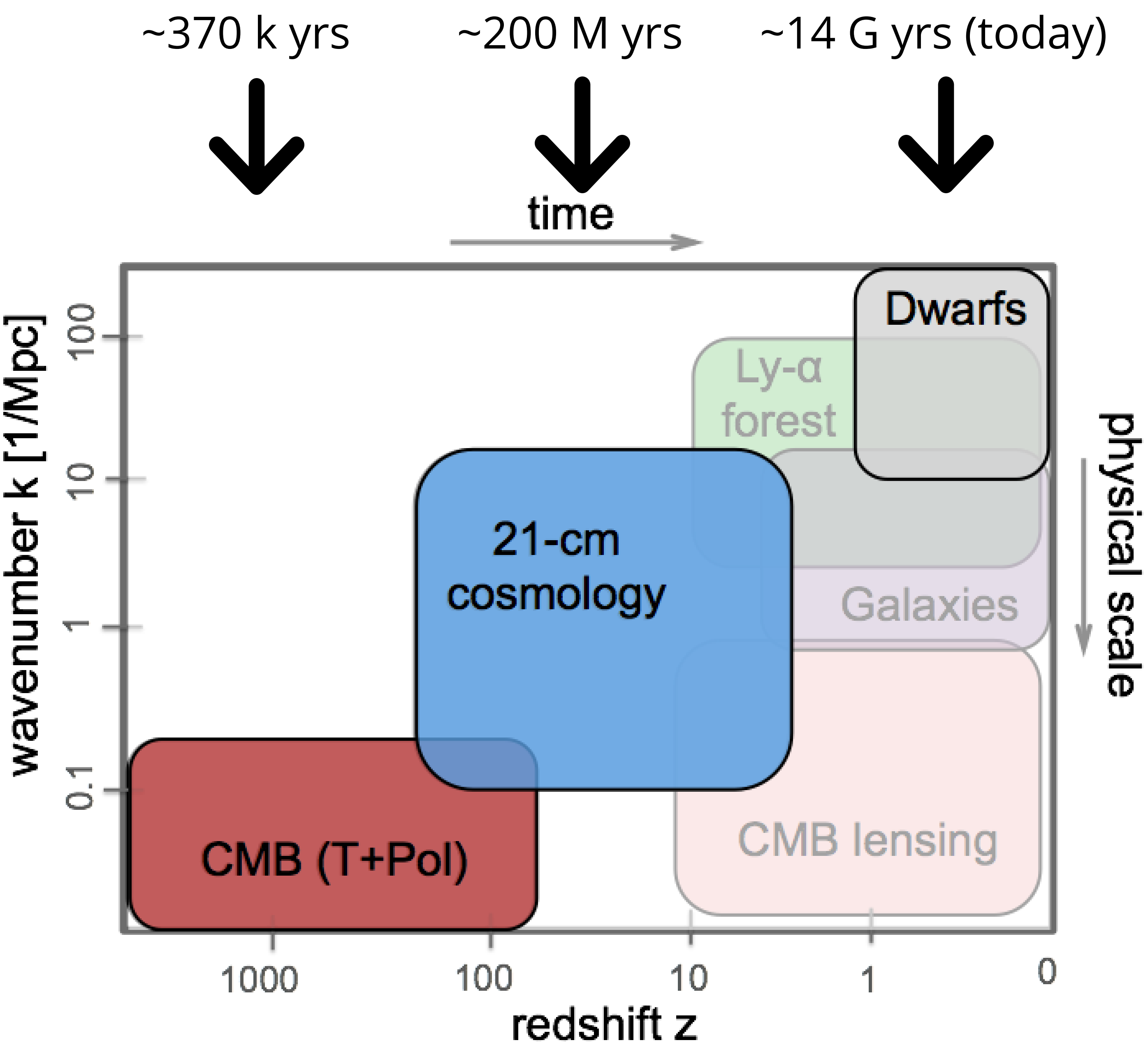
Cosmological direct detection



Observables



VG et al, Astro2020 (2019)



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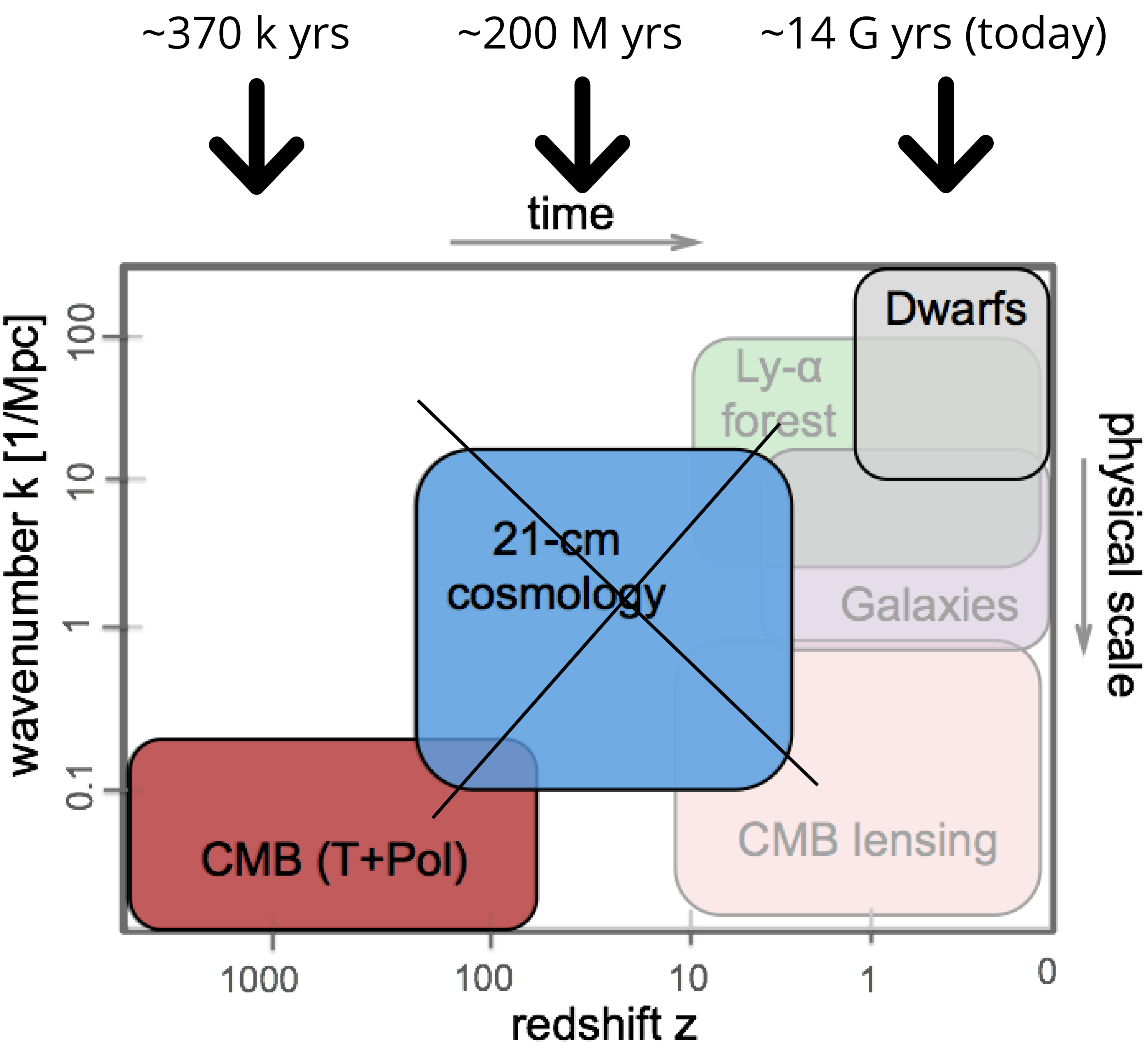
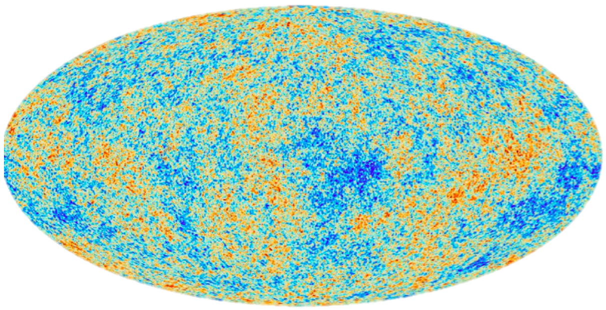
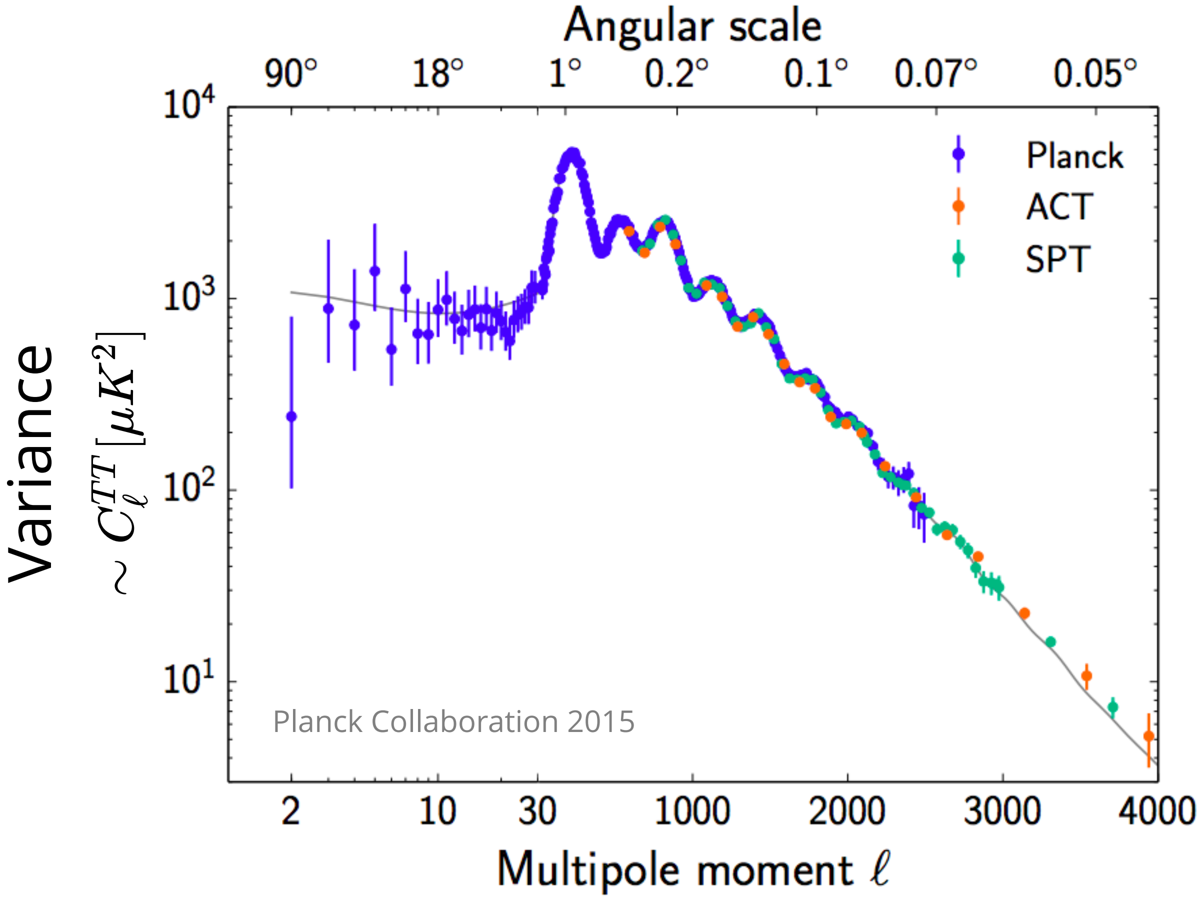


VG et al, Astro2020 (2019)

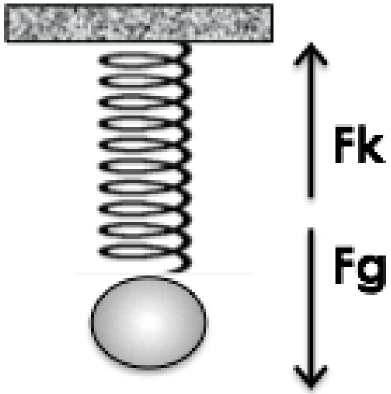
CMB power spectrum





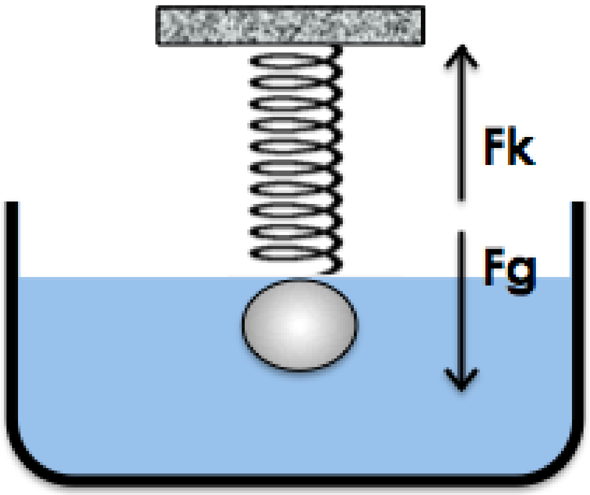
CMB with DM-baryon scattering

fluids + gravity = baryonic acoustic oscillations



CMB with DM-baryon scattering

fluids + gravity **+ drag** = **damped** baryonic acoustic oscillations



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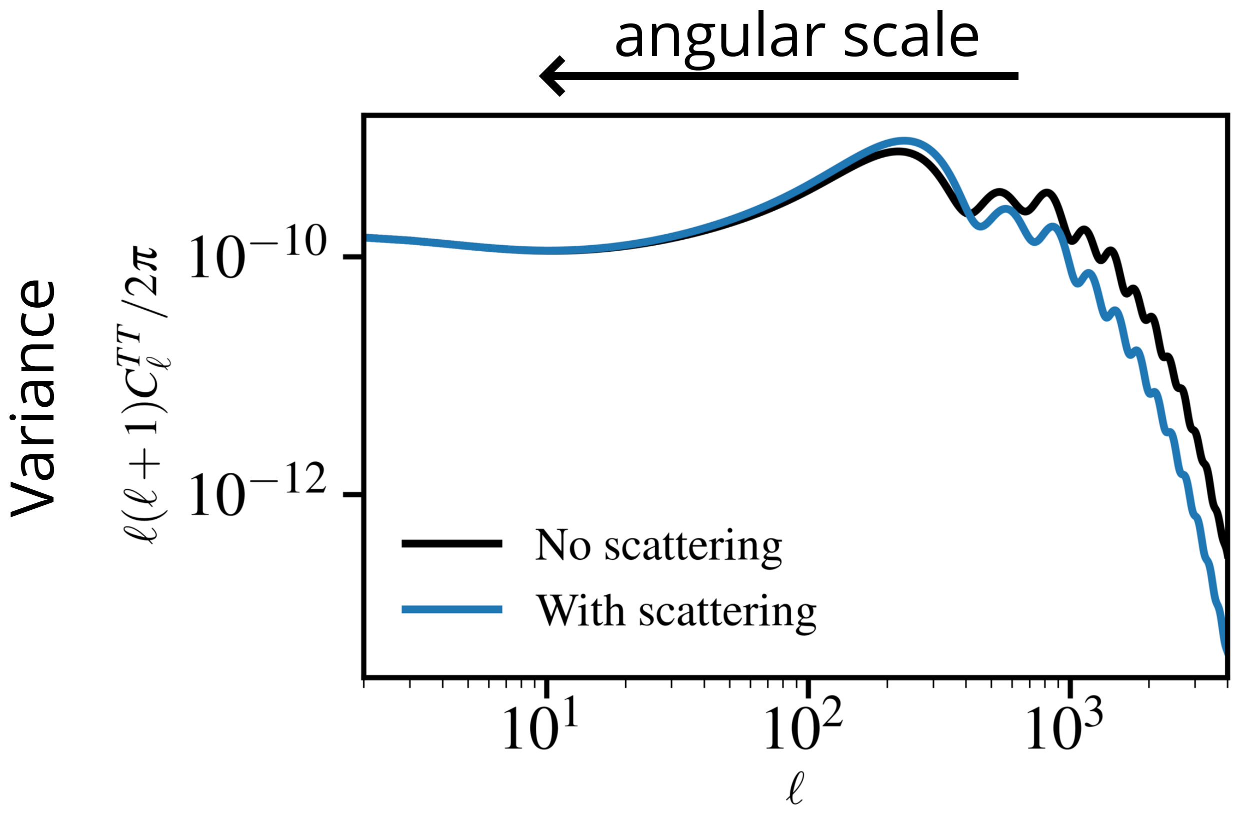
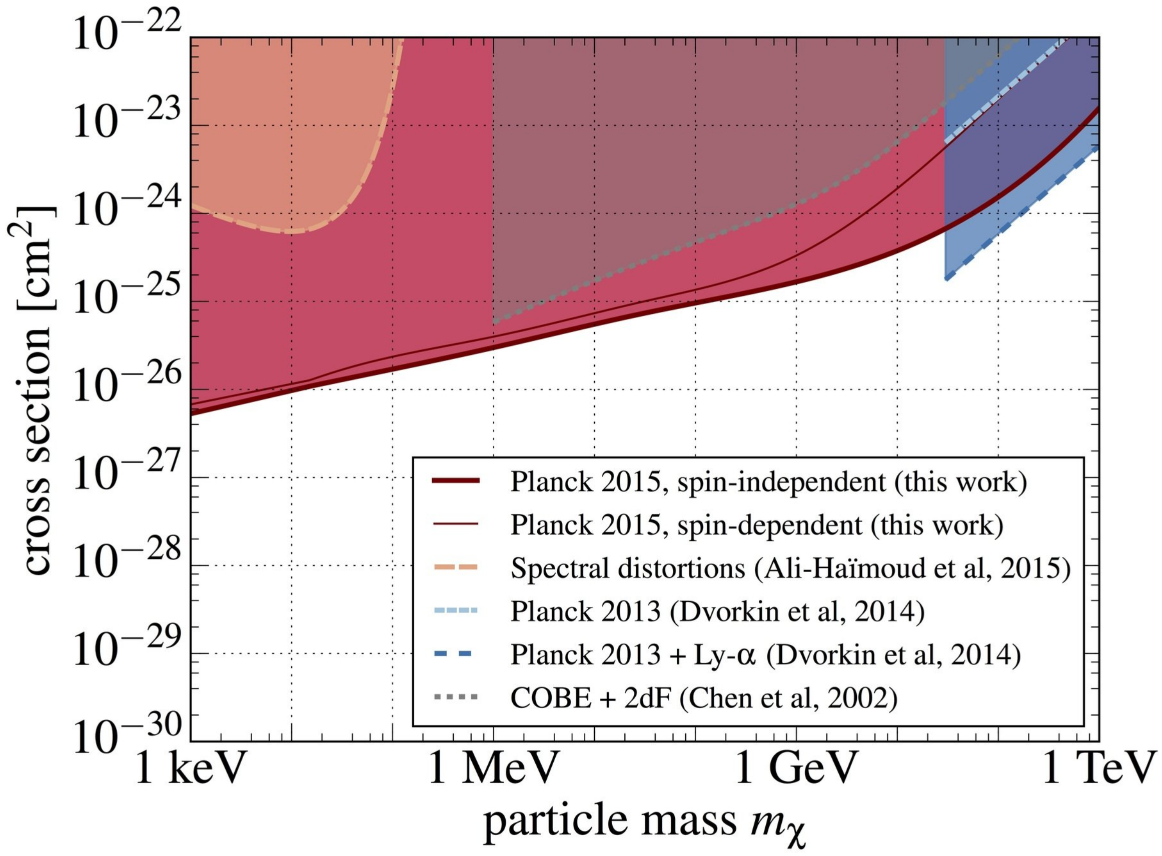


Planck limits on DM-proton scattering

[velocity-independent spin-independent interaction]

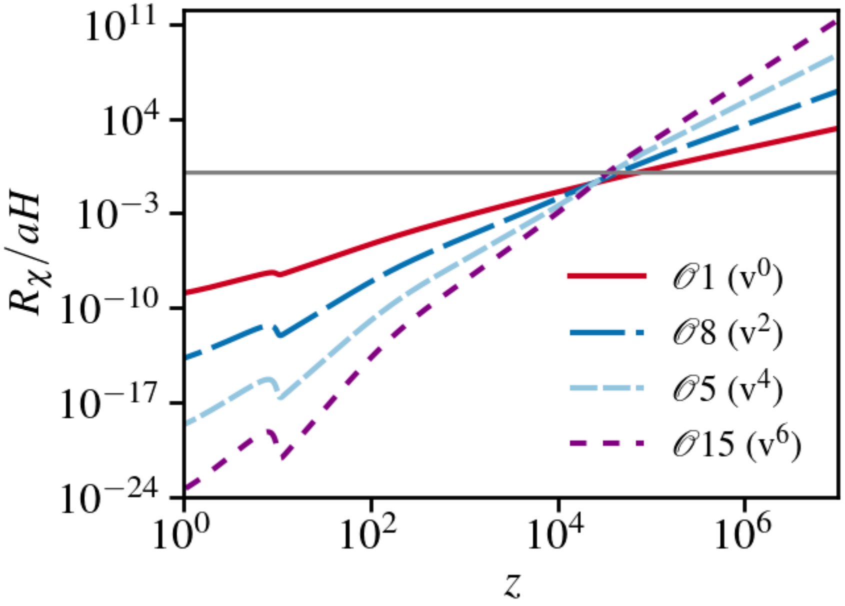


VG and Boddy, PRL (2018)

See also: Boehm+ (2002), Chen+ (2002), Dubovsky+ (2004), Sigurdson+ (2004), Dvorkin+ (2014).

And beyond...

momentum-transfer rate



time

Boddy and VG (2018)

momentum-transfer cross section

momentum-transfer rate

$$\sigma_{MT}(v^n) \longrightarrow R_\chi$$

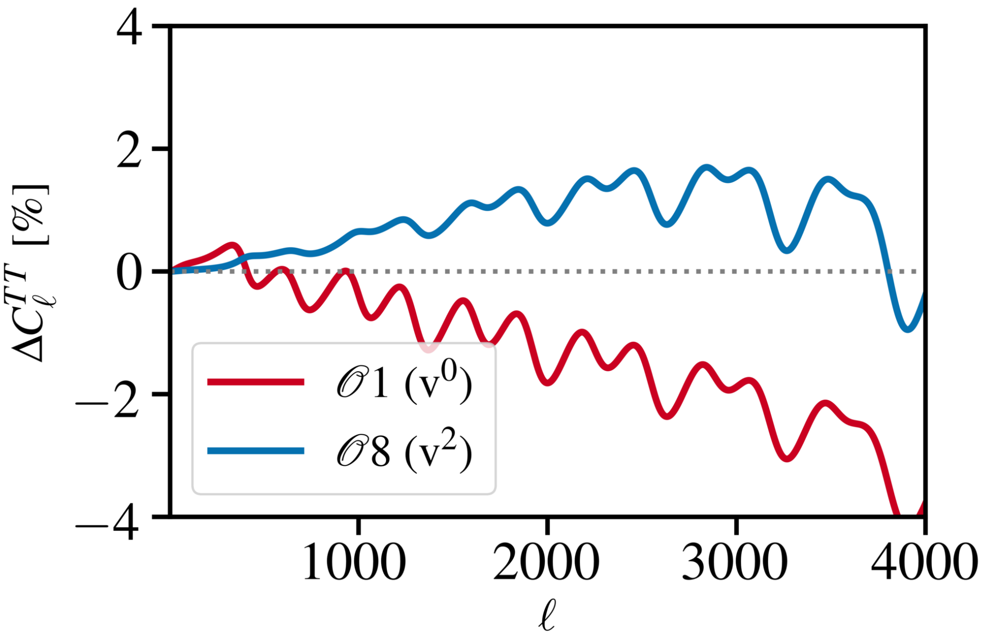
momentum dependance of the interaction operator

Interaction physics in cosmological context

operator **signal**

$$\mathcal{O}_i \longrightarrow C_\ell(m_\chi, c_i)$$

signal shape

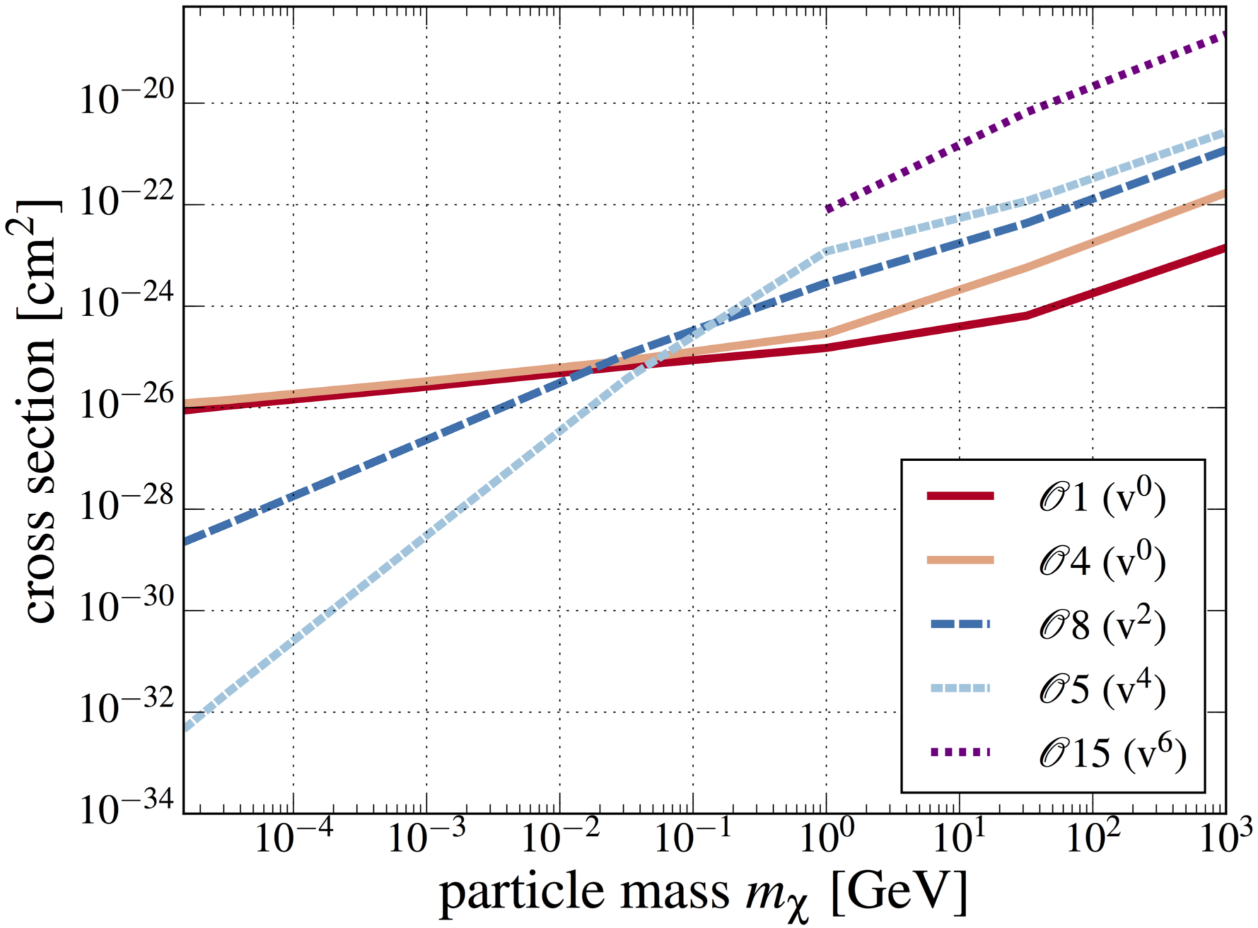


angular scale

Fan et al, 2010; Fitzpatrick et al, 2012; Anand et al, 2013

Boddy and VG (2018)

CMB limits on DM EFT



Boddy and VG (2018)

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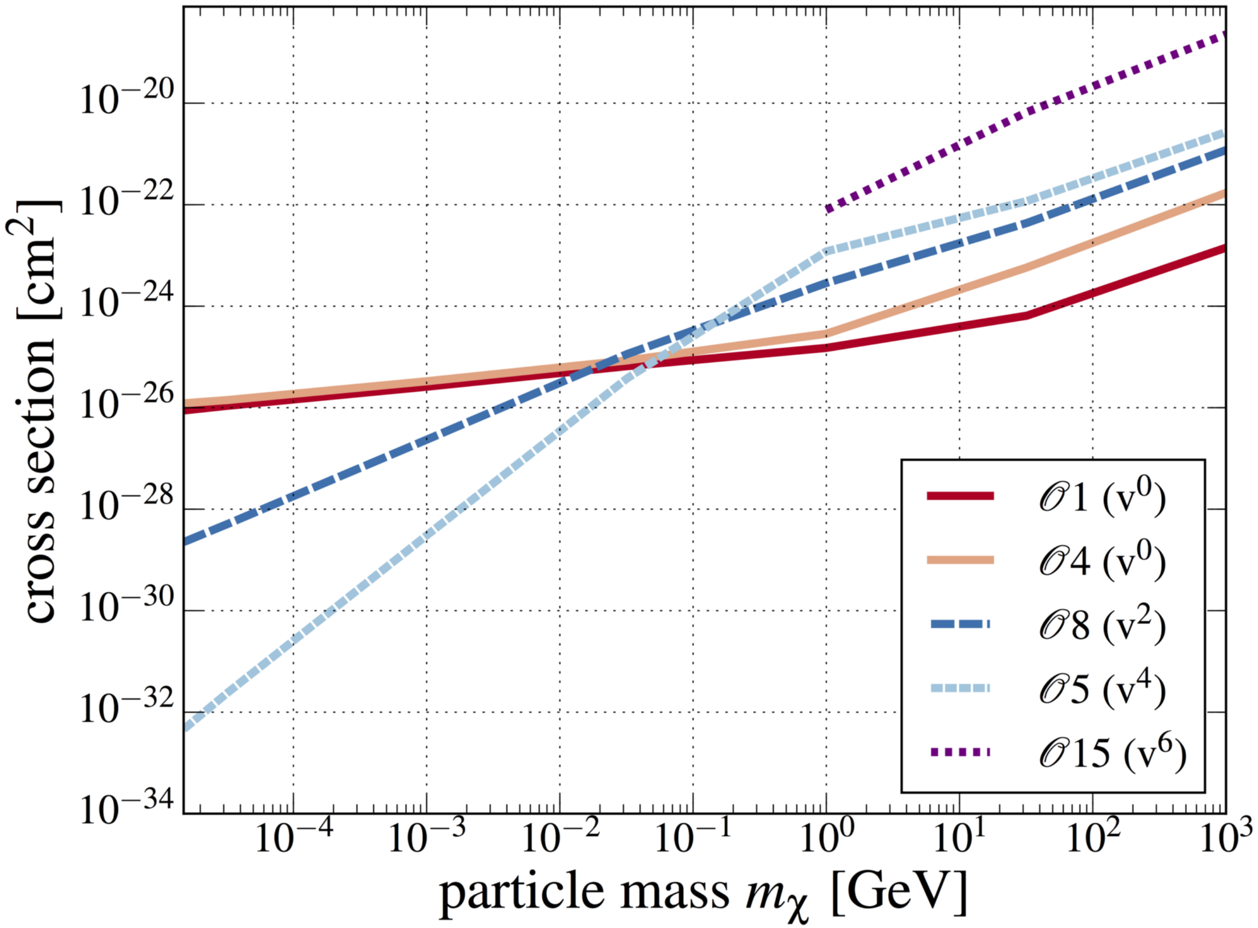
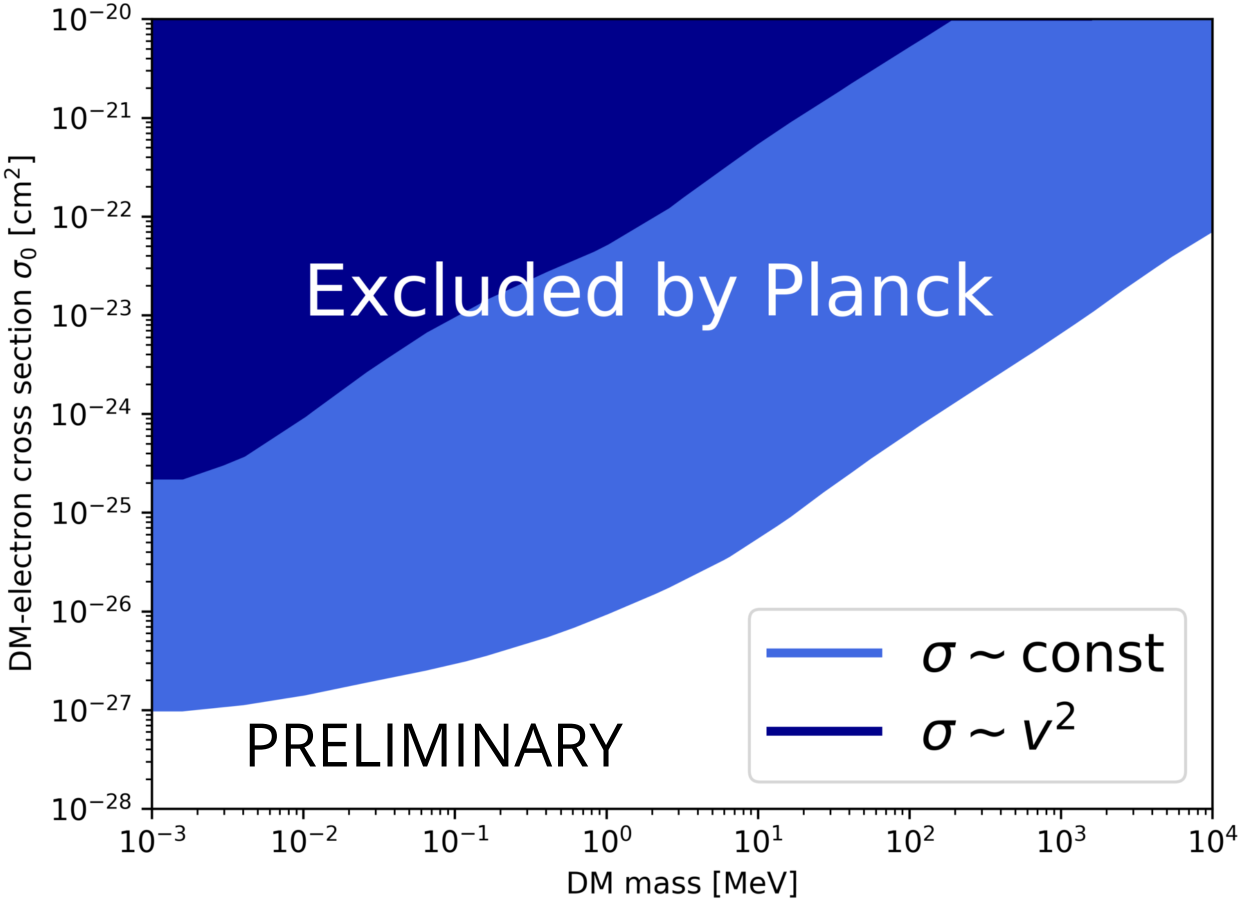


Age of the Universe ~1000 years:

less than 1 in 100 000 scatterings is with DM.

Boddy and VG (2018)

Planck limits on DM-electron scattering



Boddy and VG, in prep. (2019)

Next-generation ground-based CMB observatories

=> high resolution measurements.

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Proposed: CMB-S4

Next-generation ground-based CMB observatories

=> high resolution measurements.

Proposed: CMB-S4

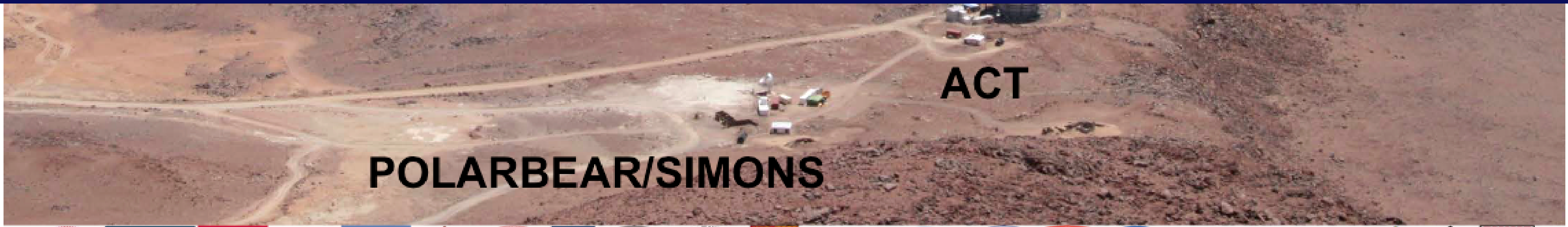
Funded: Simons Observatory

The Simons Observatory

ALMA

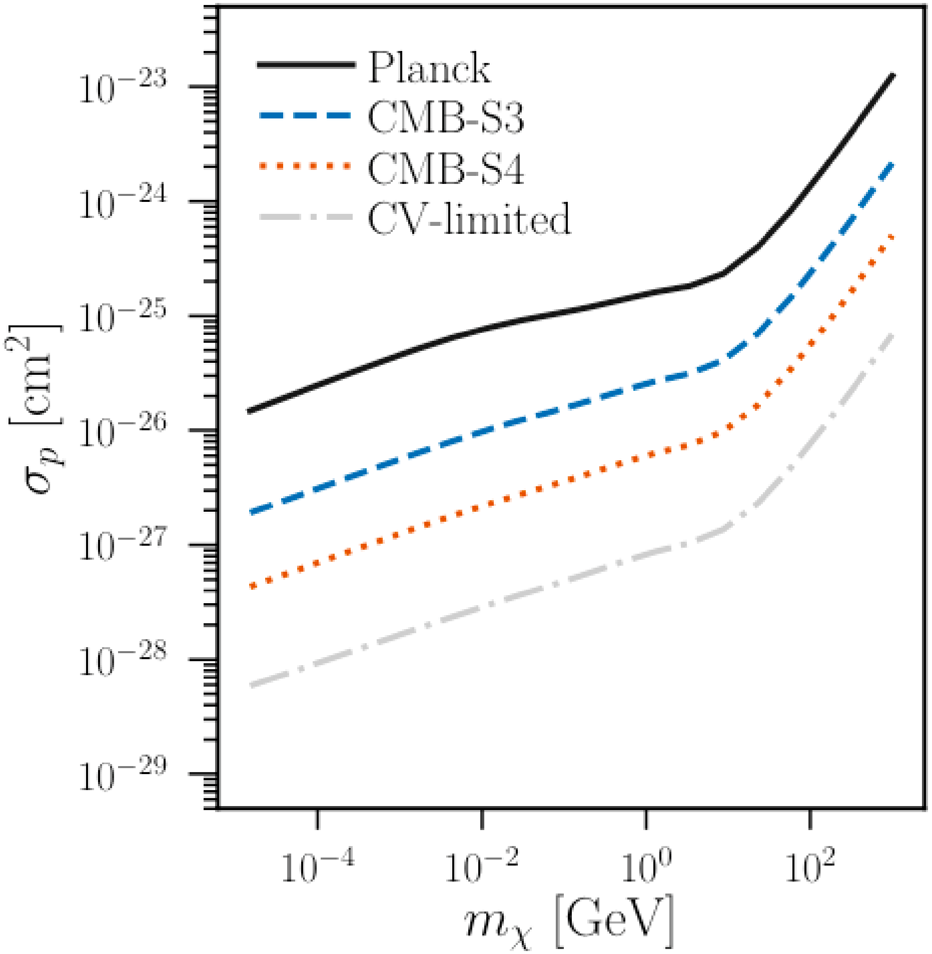
- A five year $45M+ program to advance technology and infrastructure in preparation for CMB-S4.
- Will eventually lead to the merging of the ACT and POLARBEAR/Simons Array projects.
- Tentative plans include:
  - Major site infrastructure
  - New telescopes with space for more future telescopes.
  - CMB-S4 class receivers with partially filled focal planes.

The Simons Observatory



Forecasts

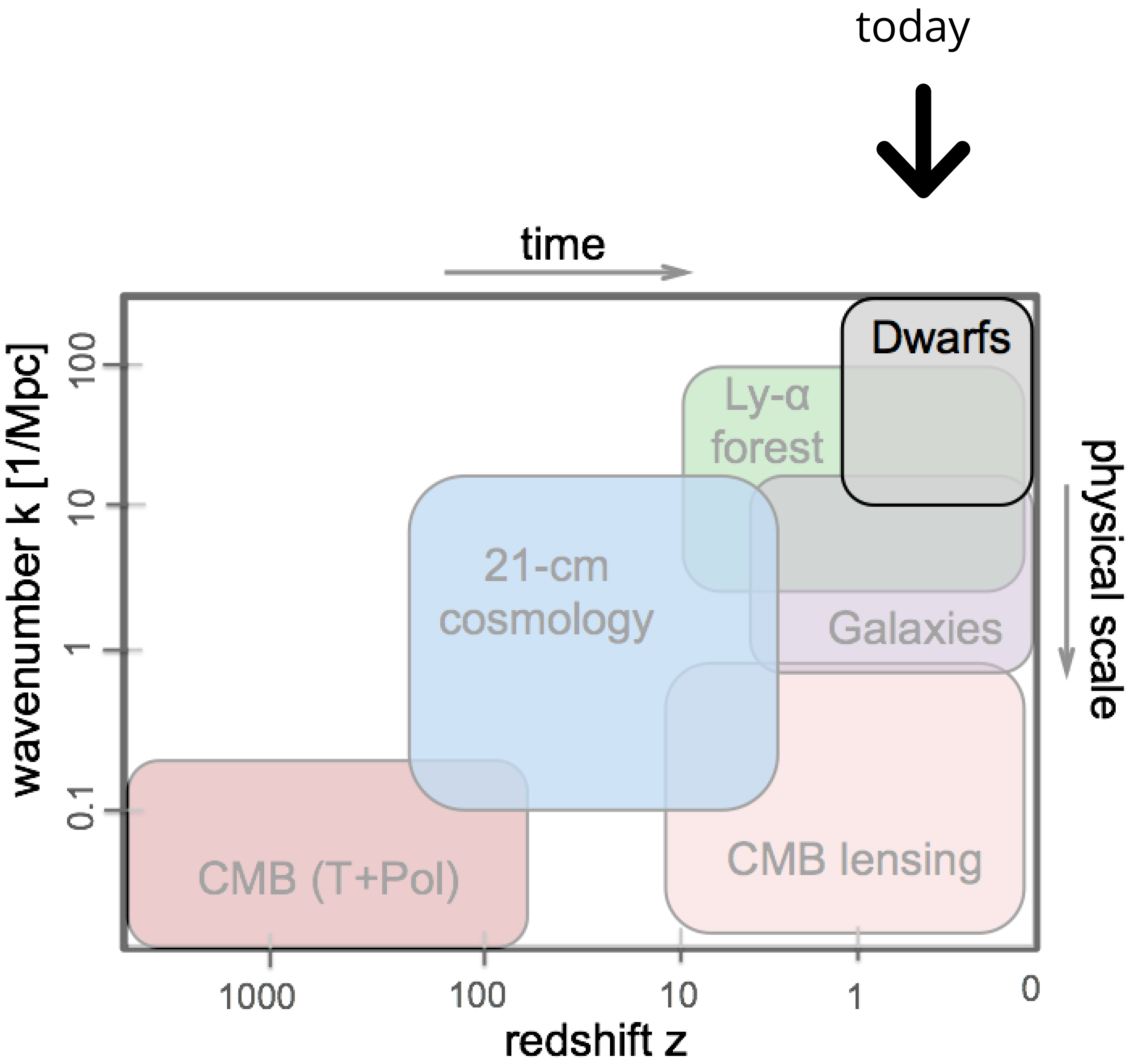
velocity-independent scattering



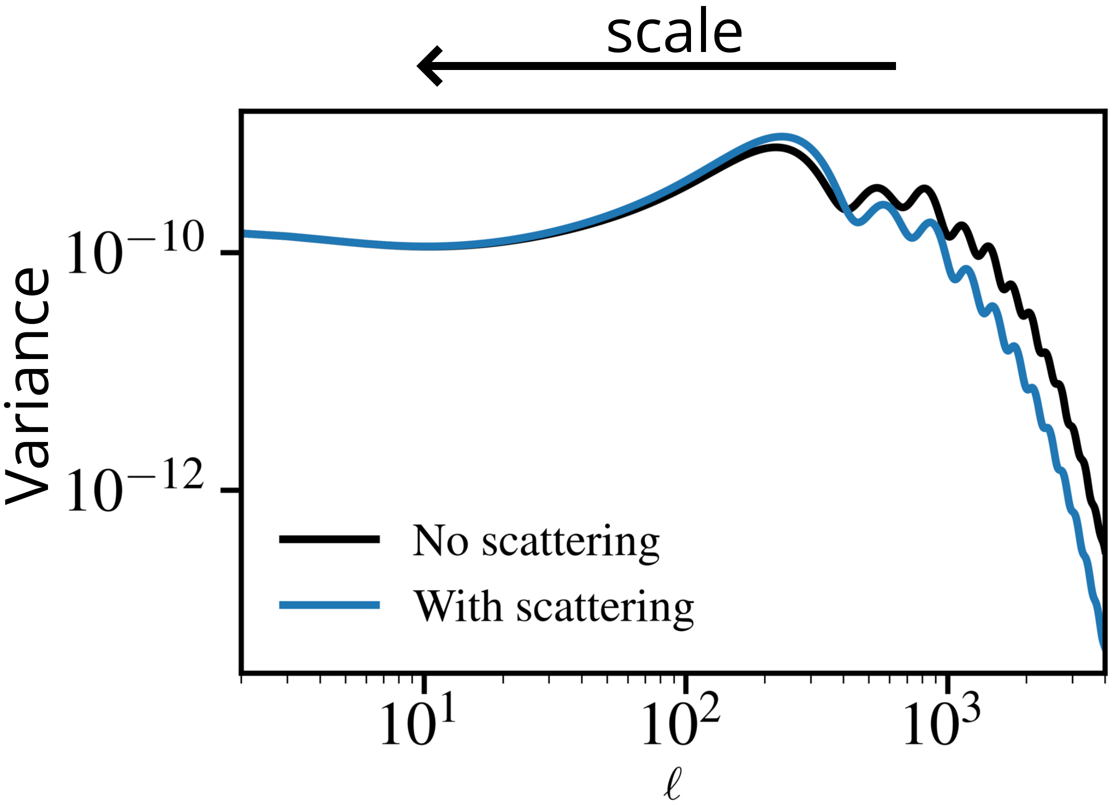
DM interactions do NOT look like other science targets, given well-measured CMB lensing.

Li, VG, + (2018)

See also: SO collaboration science goals [1808.07445]


today
time
Dwarfs
Ly-α
forest
21-cm
cosmology
Galaxies
CMB (T+Pol)
CMB lensing
wavenumber k [1/Mpc]
100
10
1
0.1
physical scale
1000
100
10
1
0
redshift z

Dark matter interactions suppress structure on small scales.



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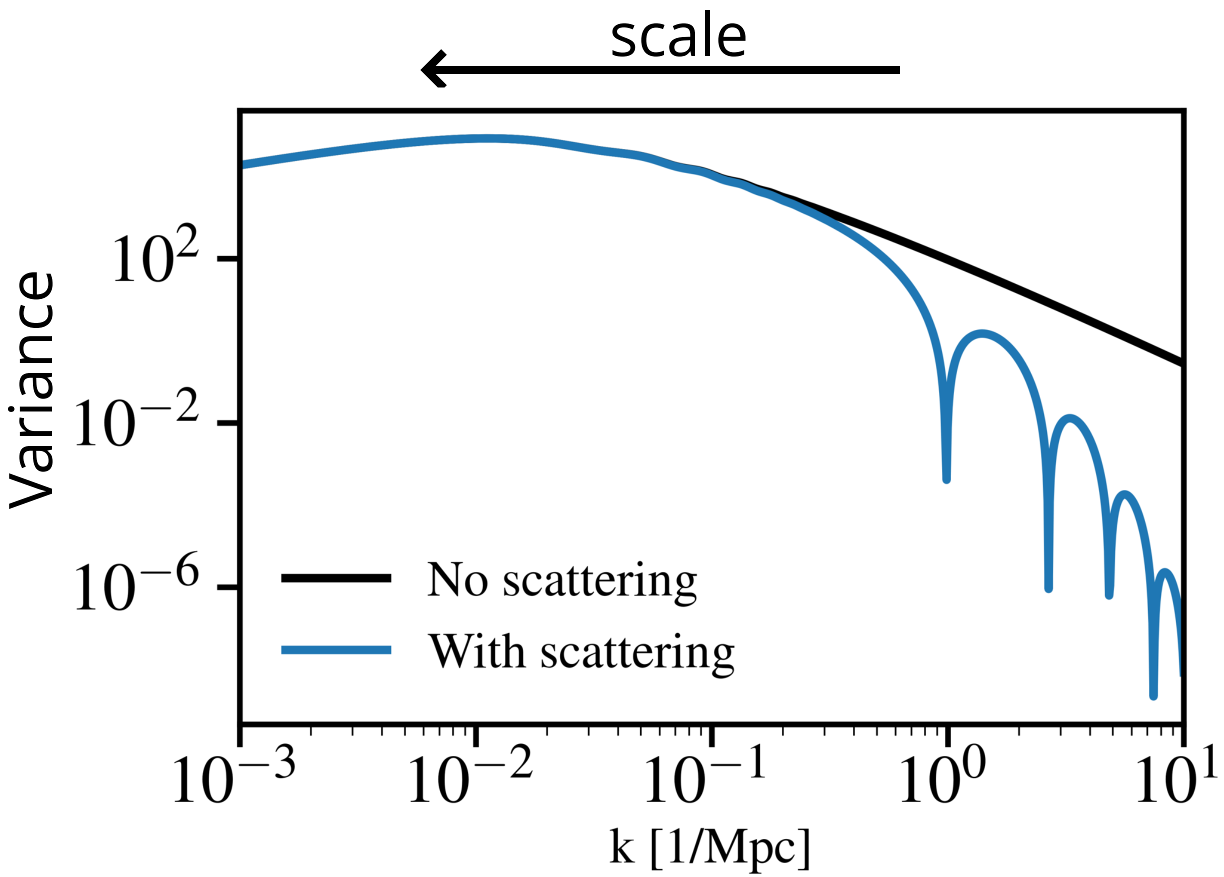
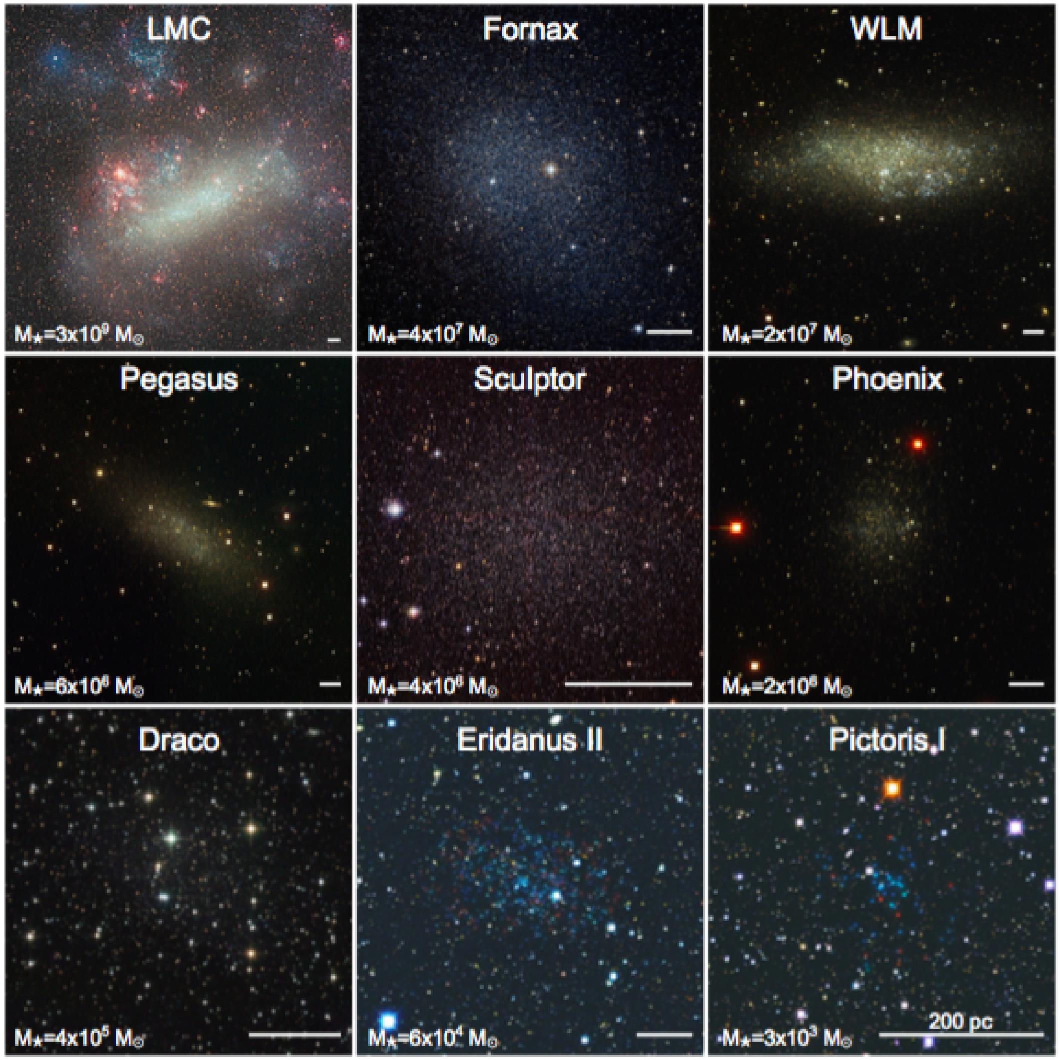


Near-field cosmology

Galaxy surveys: **SDSS, DES;** Upcoming: **LSST,DESI,...**



Bullock and Boylan-Kolchin (2017)

Near-field cosmology

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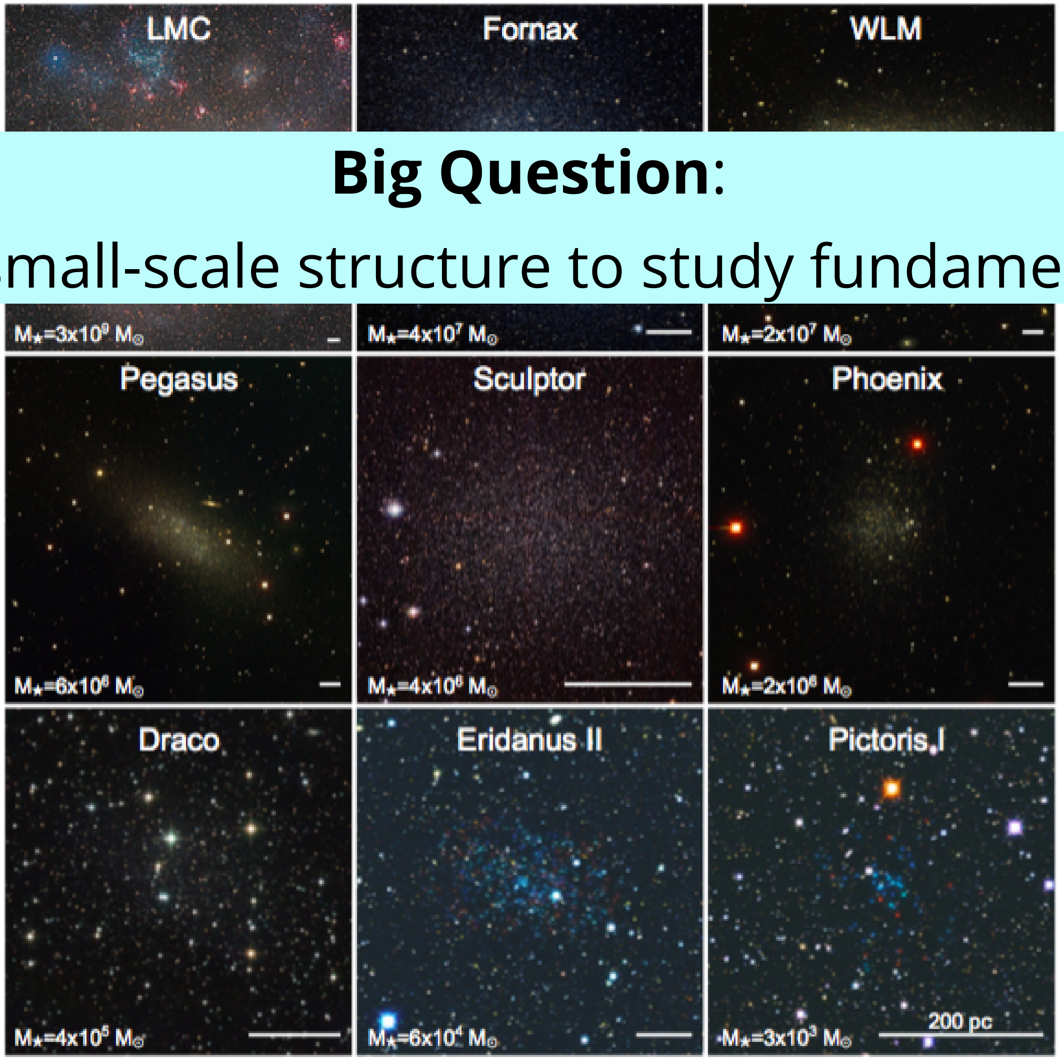


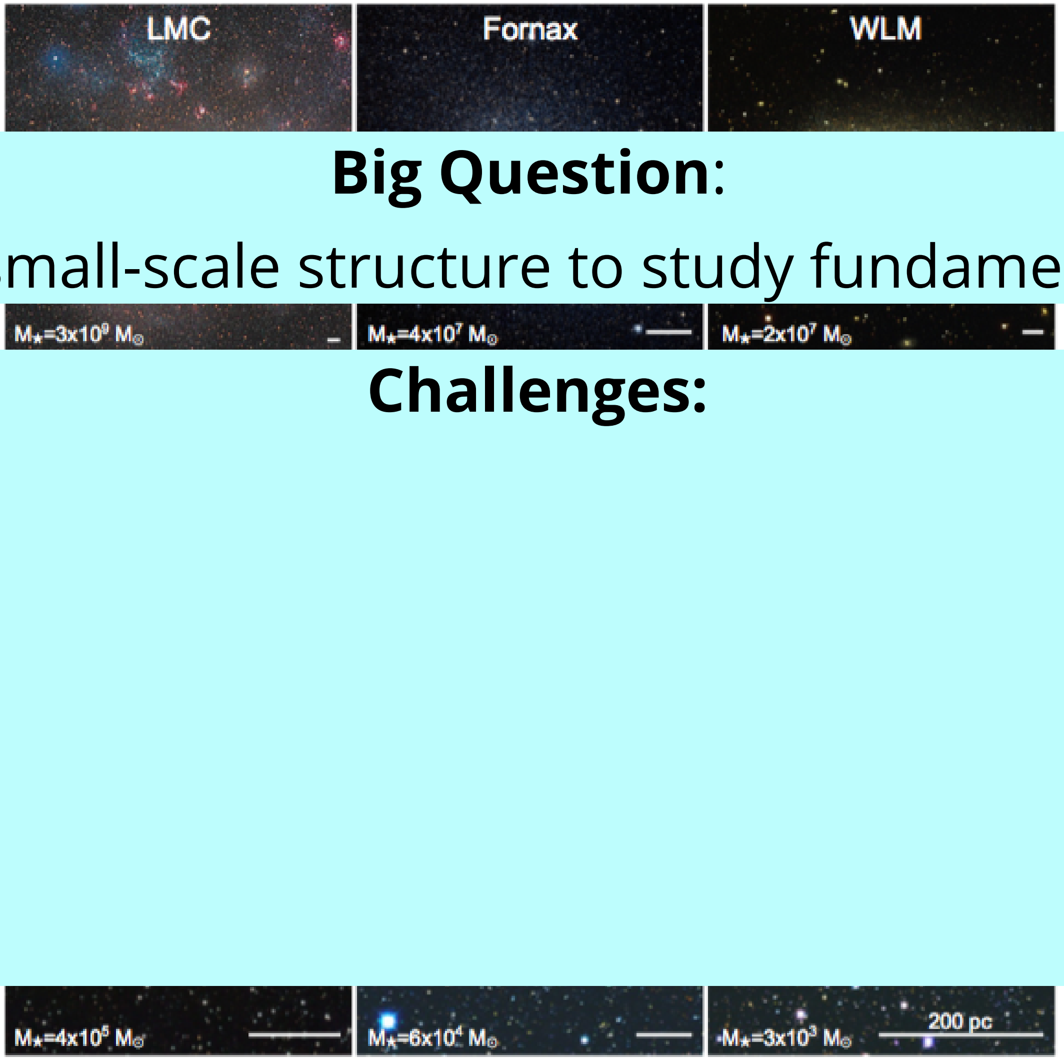
Big Question:

Can we use small-scale structure to study fundamental physics?

Bullock and Boylan-Kolchin (2017)

Near-field cosmology

Galaxy surveys: **SDSS, DES;** Upcoming: **LSST,DESI,...**



Big Question:

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Challenges:

Bullock and Boylan-Kolchin (2017)

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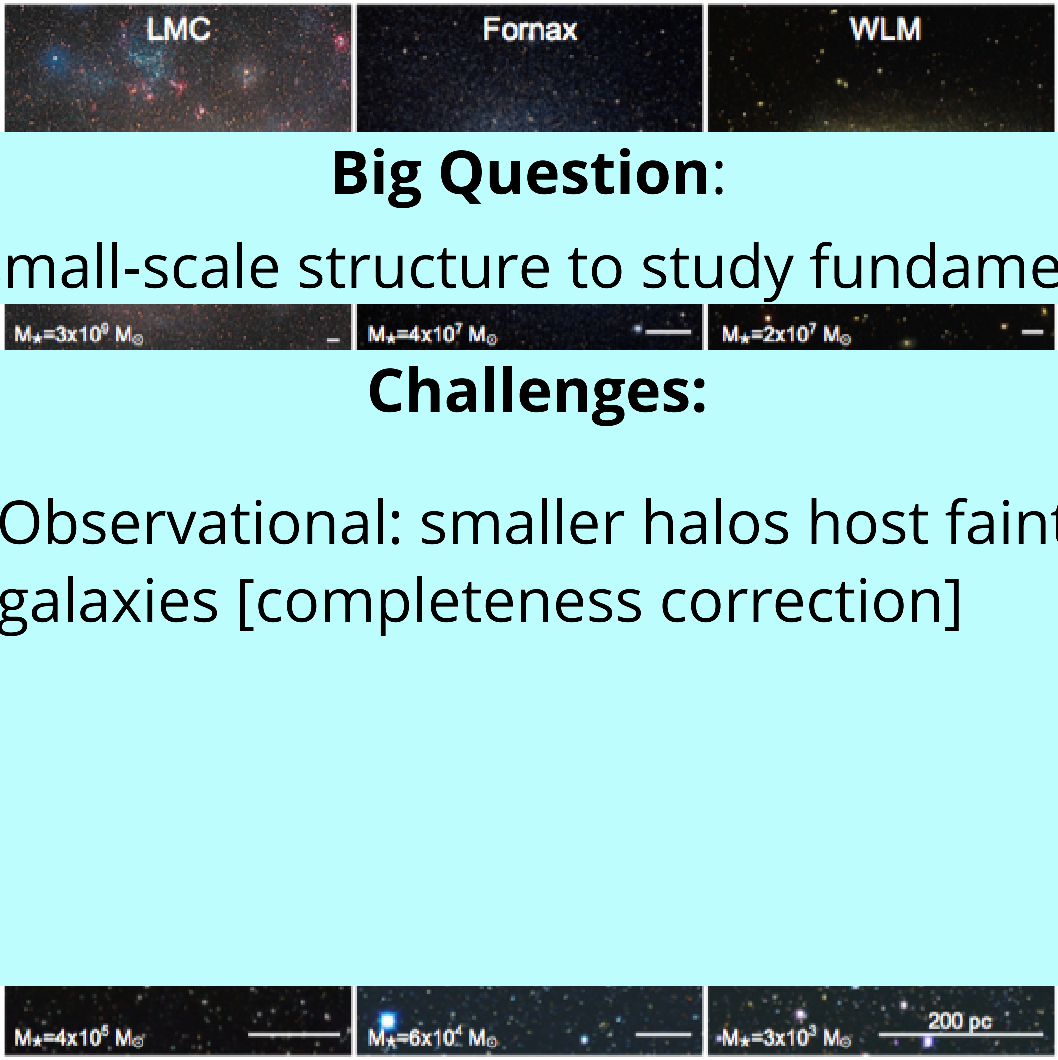


Big Question:

Can we use small-scale structure to study fundamental physics?

Challenges:

- Observational: smaller halos host fainter galaxies [completeness correction]

Bullock and Boylan-Kolchin (2017)

Near-field cosmology

Galaxy surveys: **SDSS, DES;** Upcoming: **LSST,DESI,...**

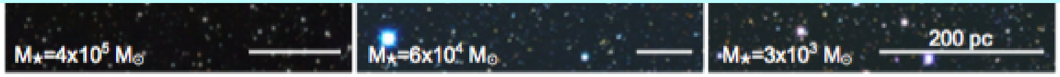
Big Question:

Can we use small-scale structure to study fundamental physics?

Challenges:

- Observational: smaller halos host fainter galaxies [completeness correction]

- Theoretical: baryonic physics and non-linear evolution [galaxy-halo connection]



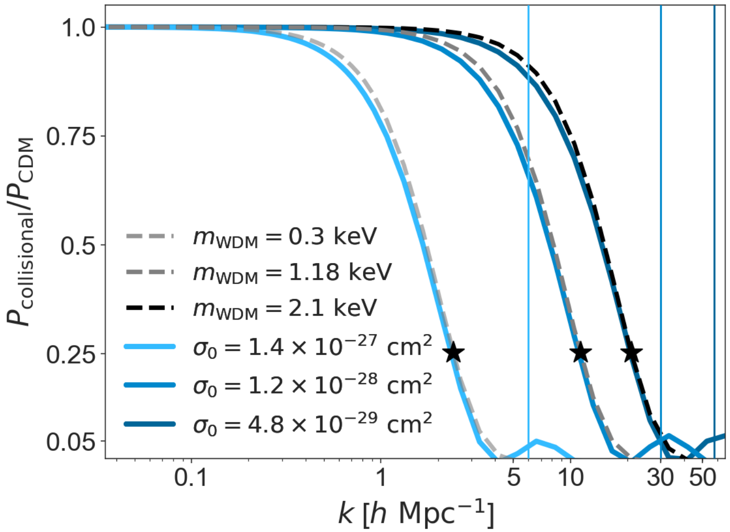
Bullock and Boylan-Kolchin (2017)

Near-field cosmology: Analytic estimate

decoupling redshift: $z_{crit}(\sigma_0, m_\chi)$

Horizon size $\longrightarrow$ $k_{crit}(\sigma_0, m_\chi)$ $\longrightarrow$ proxy for halo mass

$\sim 10^8 M_{\rm sun}$



Nadler, VG,+ (ApJ Letters 2019;)

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Horizon size $\longrightarrow$ $k_{crit}(\sigma_0, m_\chi)$ $\longrightarrow$ proxy for halo mass

$\sim 10^8 M_{\rm sun}$

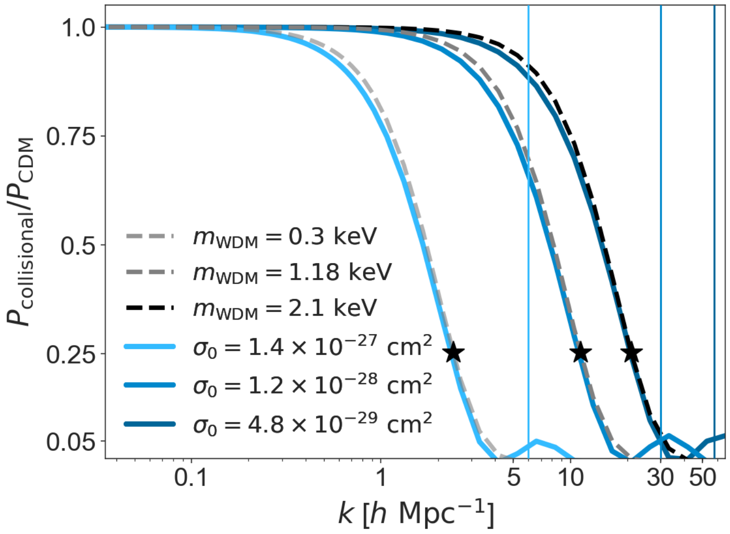
Population of Milky Way satellite galaxies

=>

no lack of structure

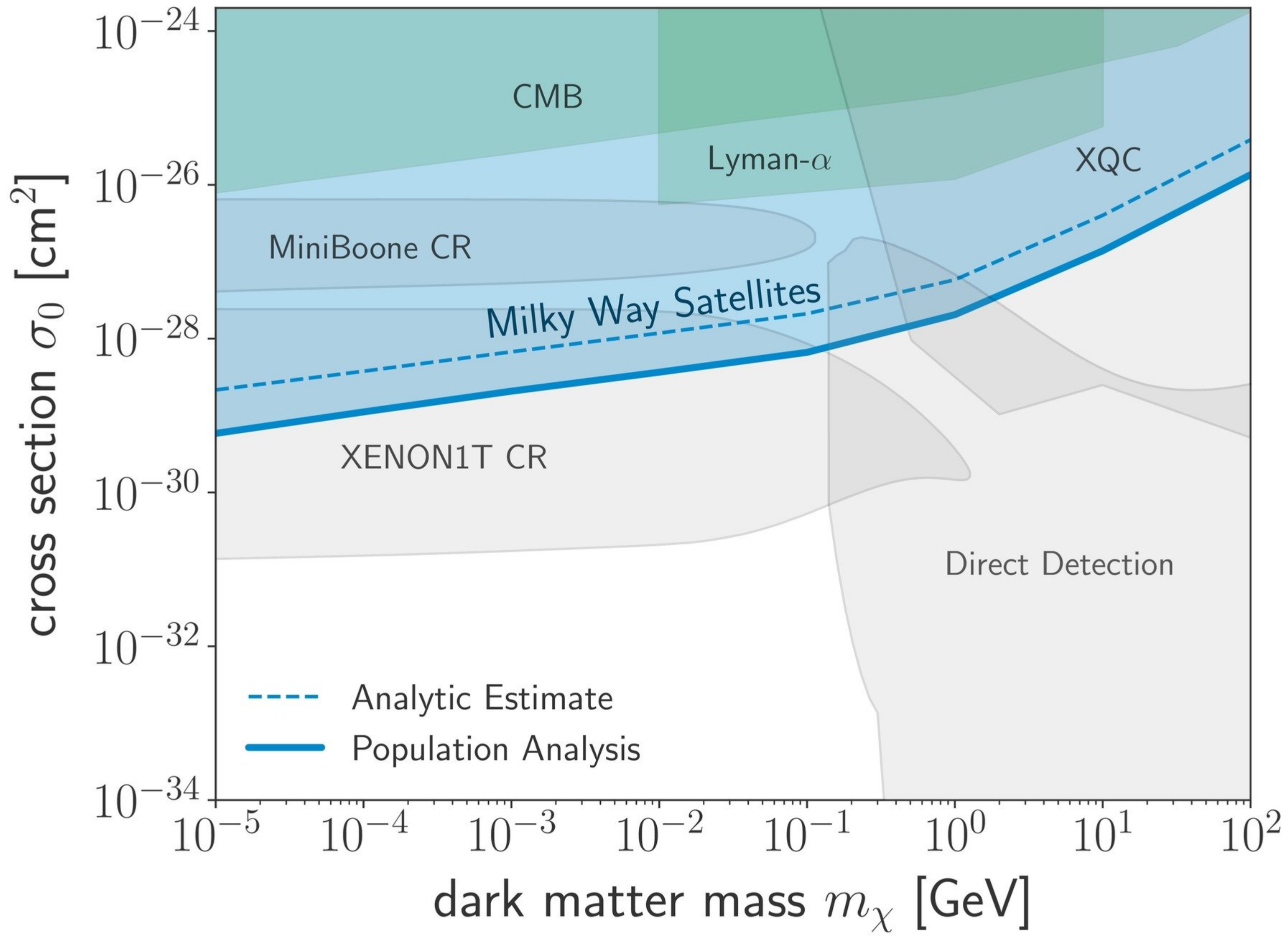
=>

limits on DM scattering.



Nadler, VG,+ (ApJ Letters 2019;)

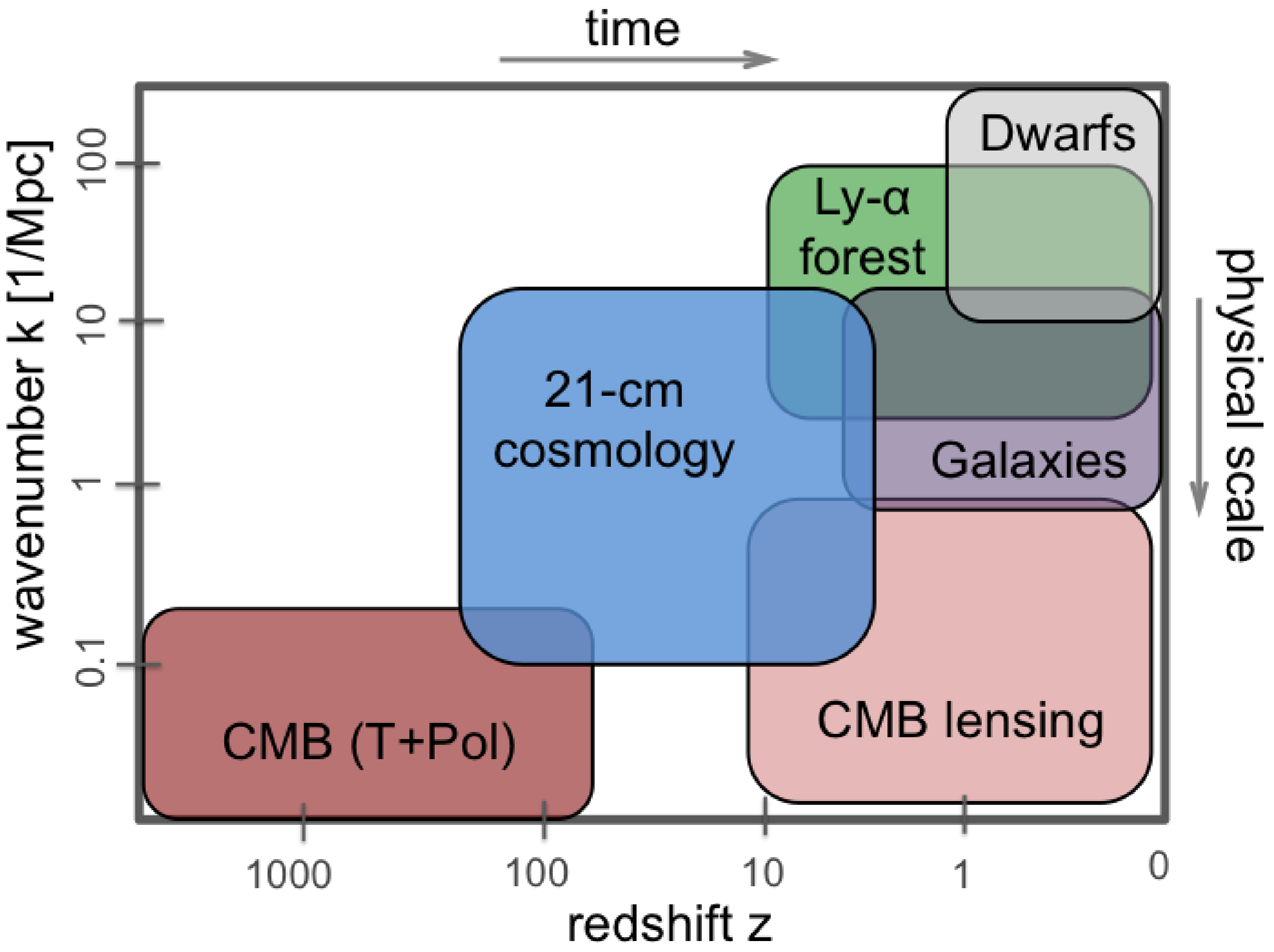
Near-field cosmology: Probabilistic inference



Nadler, VG,+ (ApJ Letters 2019;)

Promise: 3 orders of magnitude better than Planck.

Broader scope



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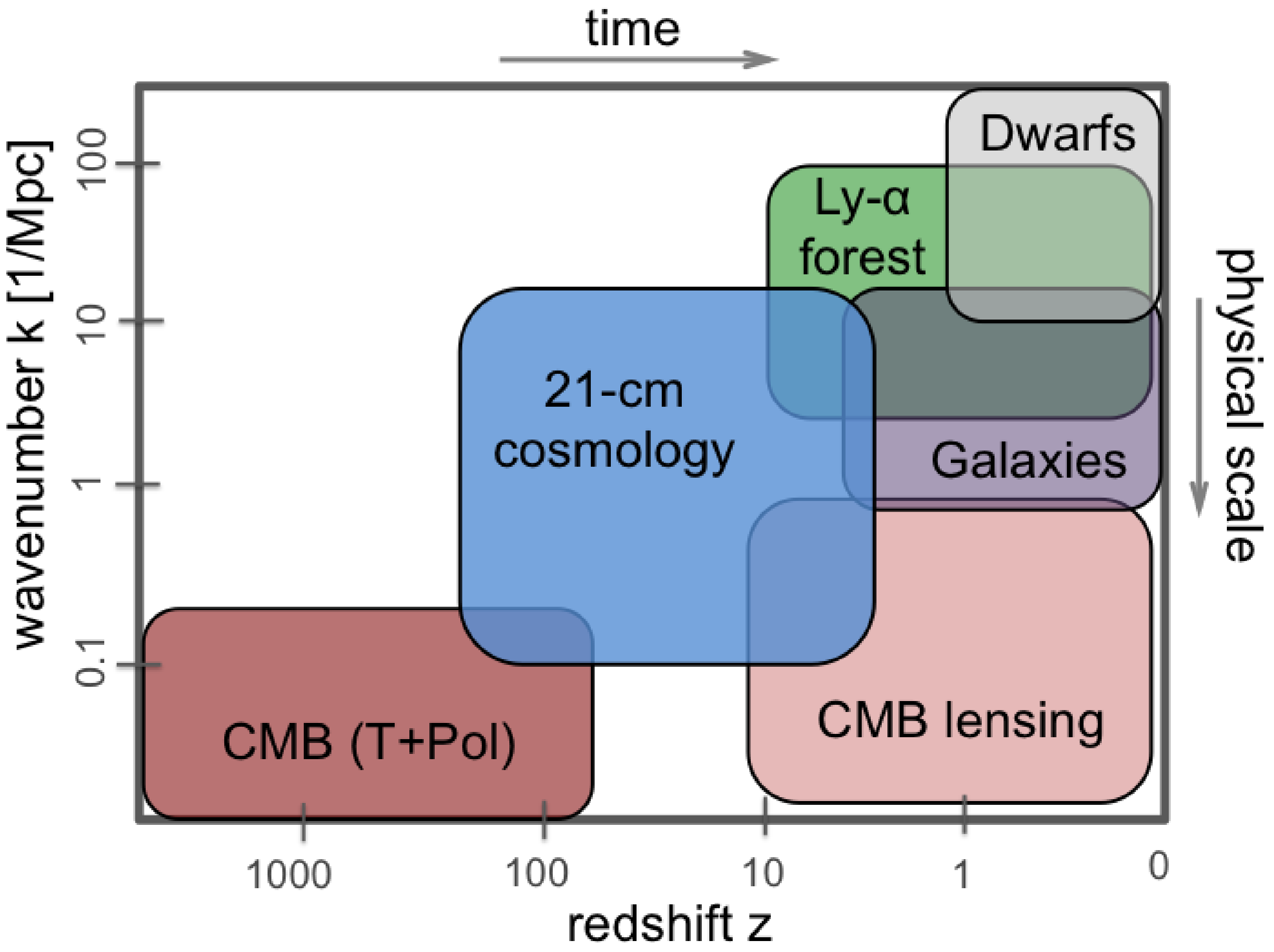

Lots of data coming: Simons Observatory, CMB-S4, LSST, DESI, HERA, SKA, EDGES, SARAS, DD experiments,...

Towards the future

Astro2020 Science White Paper

Cosmological Probes of Dark Matter Interactions: The Next Decade

Thematic area: Cosmology and Fundamental Physics.

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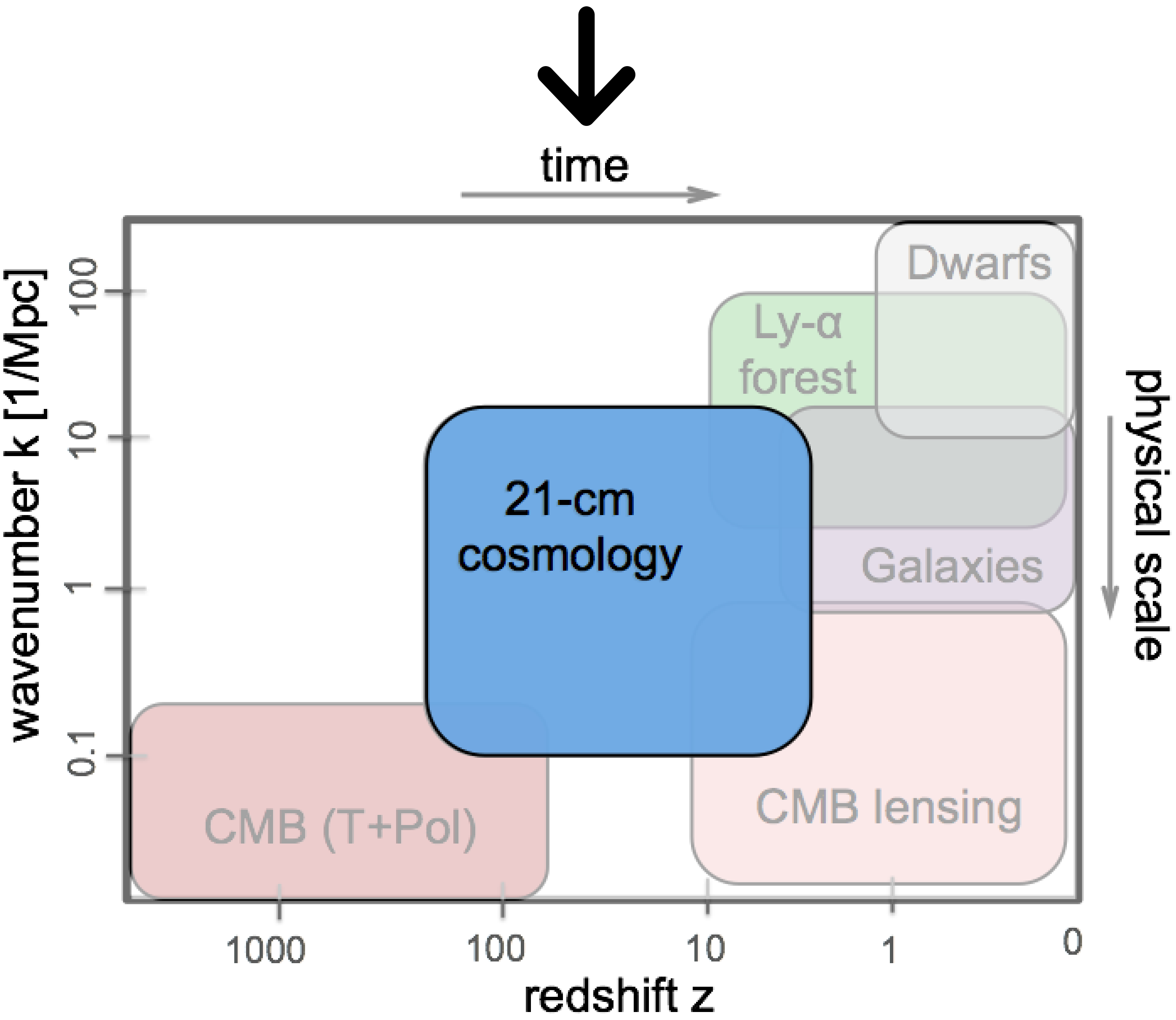
Endorsers: The full list of names is available at:
https://github.com/veragluscevic/Astro2020-DM-Cosmology-Endorsers

Abstract

Cosmological observations offer unique and robust avenues for probing the fundamental nature of dark matter particles—they broadly test a range of compelling theoretical scenarios, often surpassing or complementing the reach of terrestrial and other experiments. We discuss observational and theoretical advancements that will play a pivotal role in realizing a strong program of cosmological searches for the identity of dark matter in the coming decade. Specifically, we focus on measurements of the cosmic-microwave-background anisotropy and spectral distortions, and tracers of structure (such as the Lyman-α forest, galaxies, and the cosmological 21-cm signal).

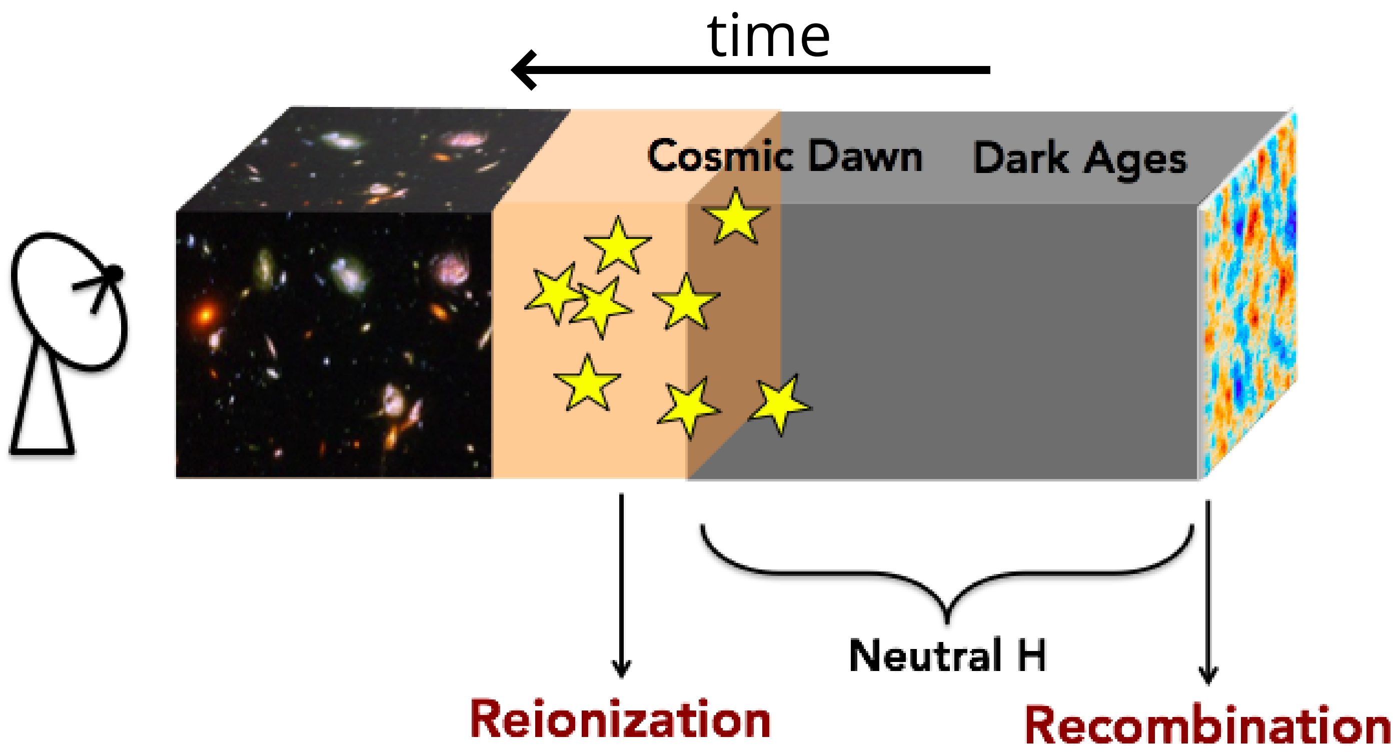
1

~200 M yrs



time
Dwarfs
Ly-α
forest
21-cm
cosmology
Galaxies
CMB lensing
CMB (T+Pol)
wavenumber k [1/Mpc]
100
10
1
0.1
physical scale
1000
100
10
1
0
redshift z

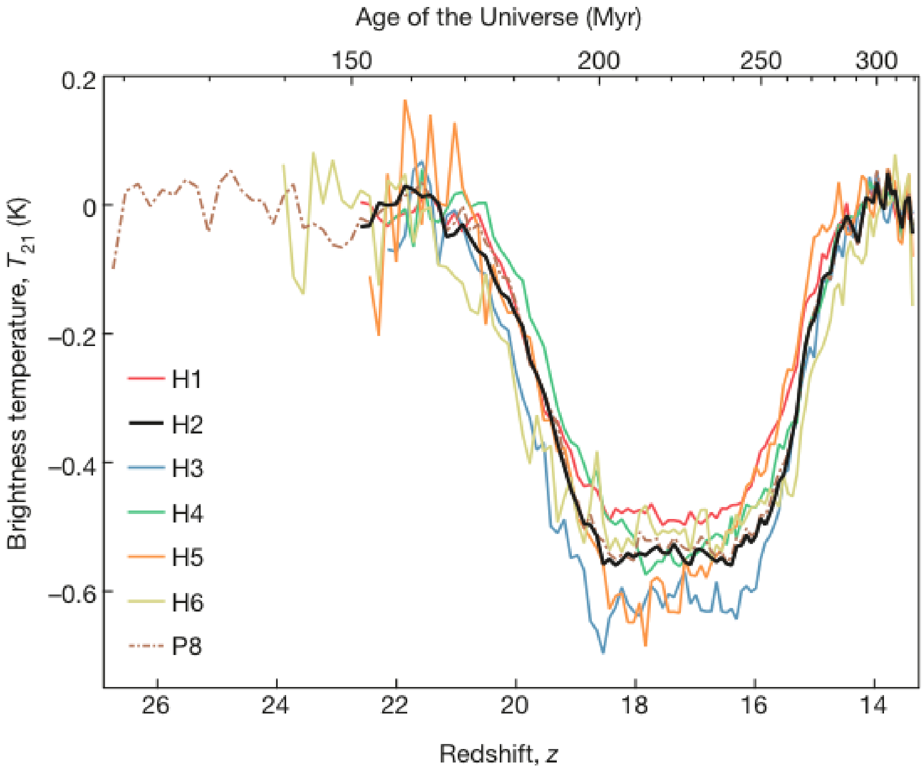
21-cm cosmology



Case study: EDGES

[<u>E</u>xperiment to <u>D</u>etect the <u>G</u>lobal <u>E</u>poch of reionization <u>S</u>ignature]

Bowman, + (2018).



Case study: EDGES

[Experiment to Detect the Global Epoch of reionization Signature]

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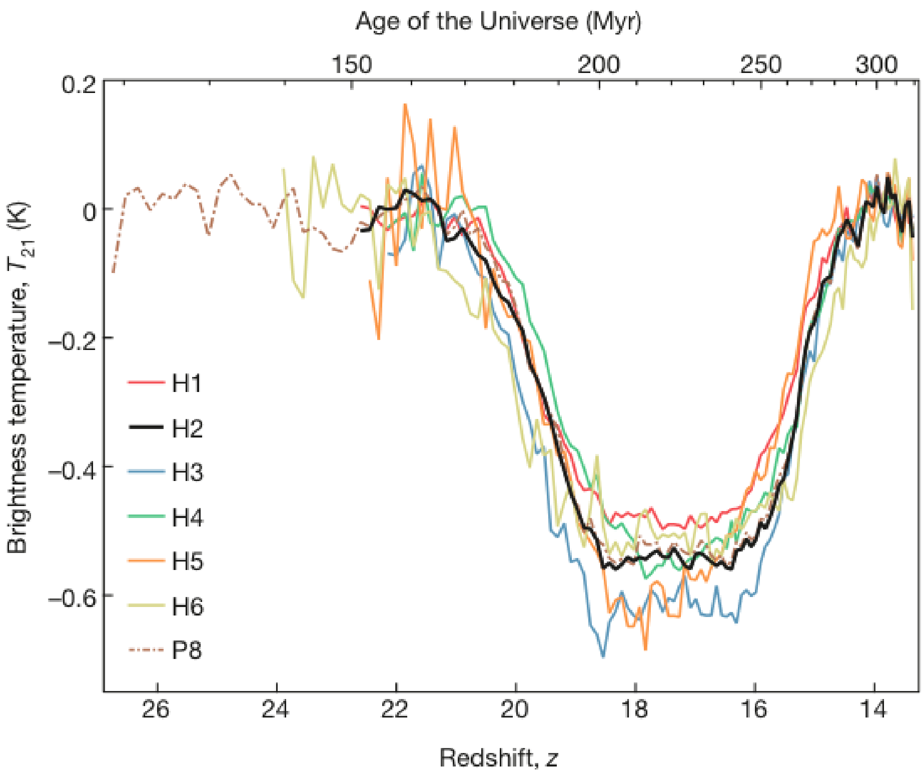

NB: Is it in the sky? Is it cosmological?

Case study: EDGES

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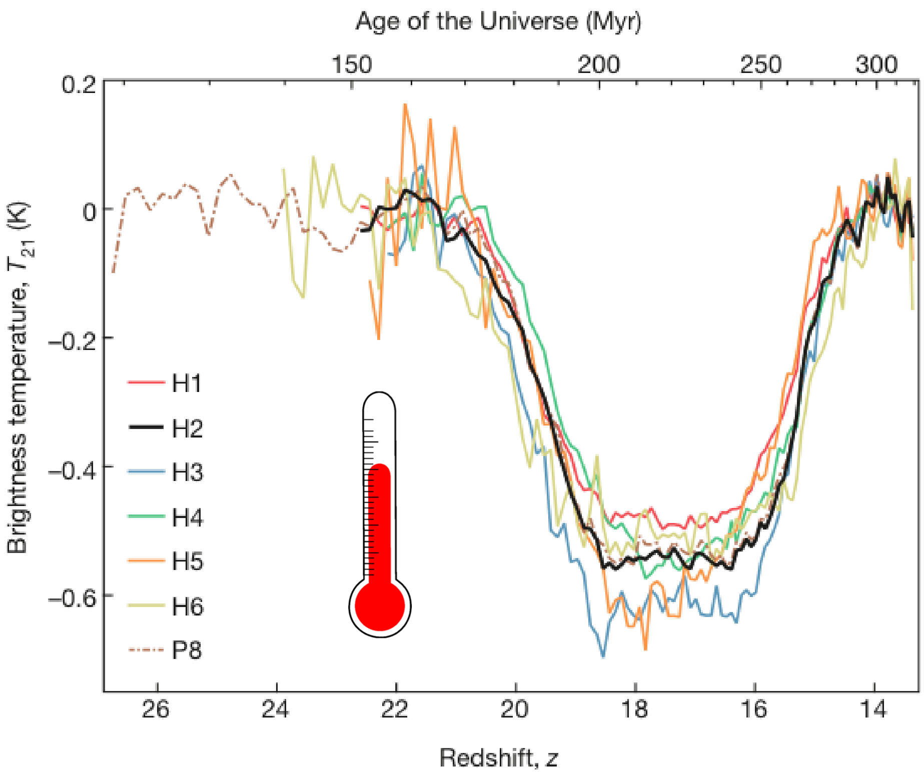

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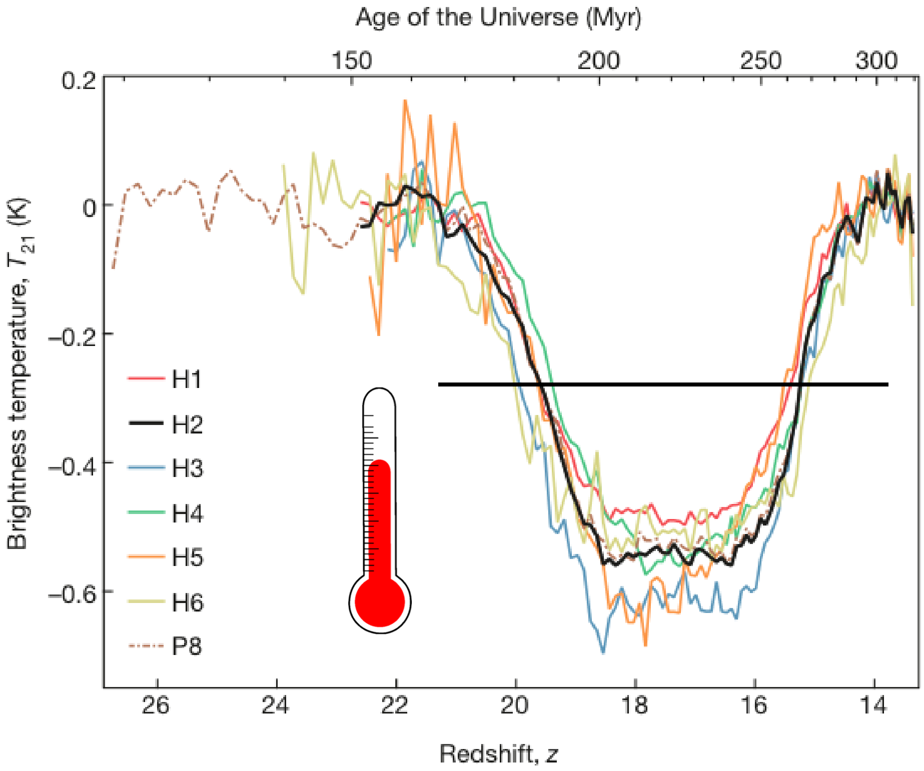

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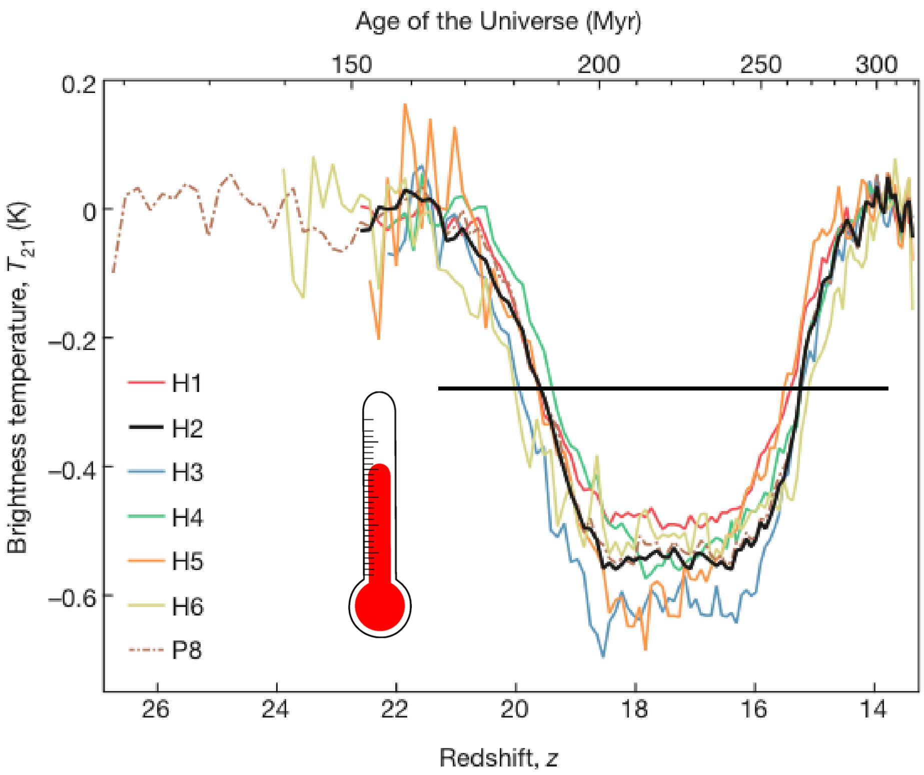
Case study: EDGES

Bowman, + (2018) and Barkana (2018); see also: Munoz, + (2016)



Baryons are cold!

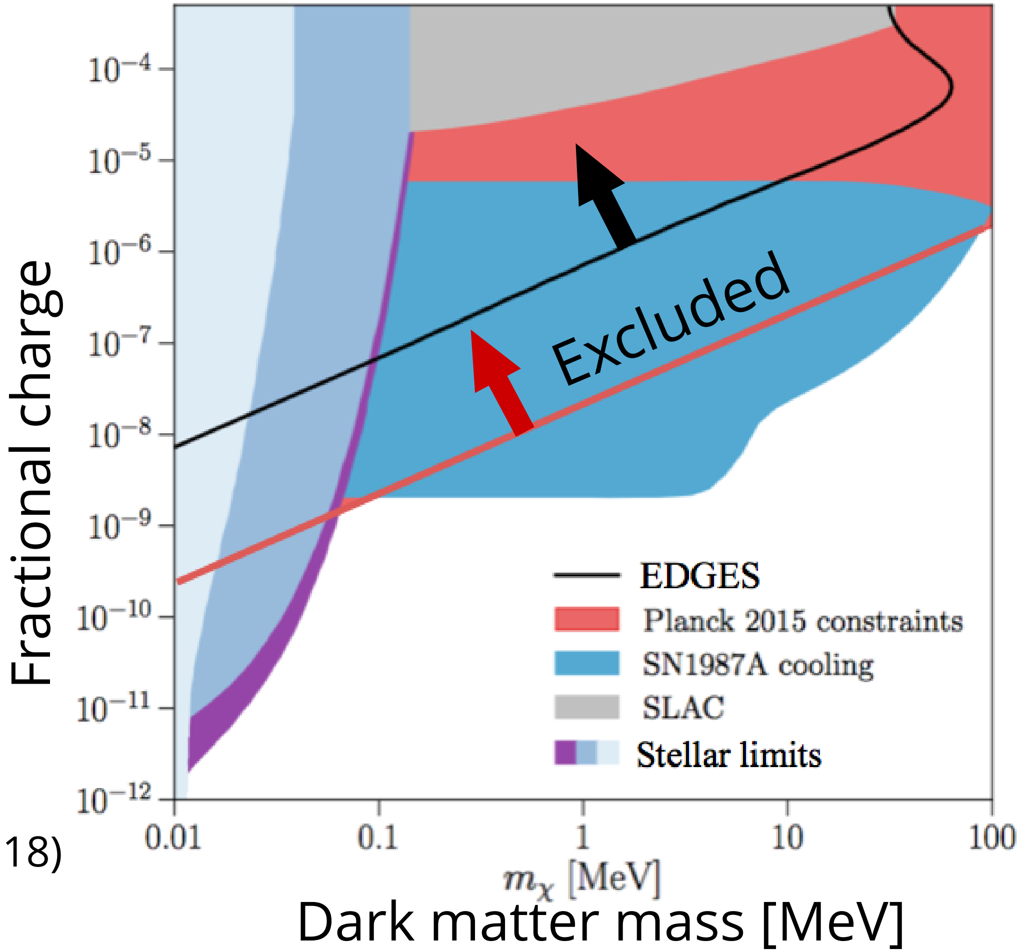
Dark matter-baryon interactions?!

Millicharge: $\sigma \sim v^{-4}$

What does CMB have to say?

Planck limits on millicharge

$$\sigma(v) \sim v^{-4}$$

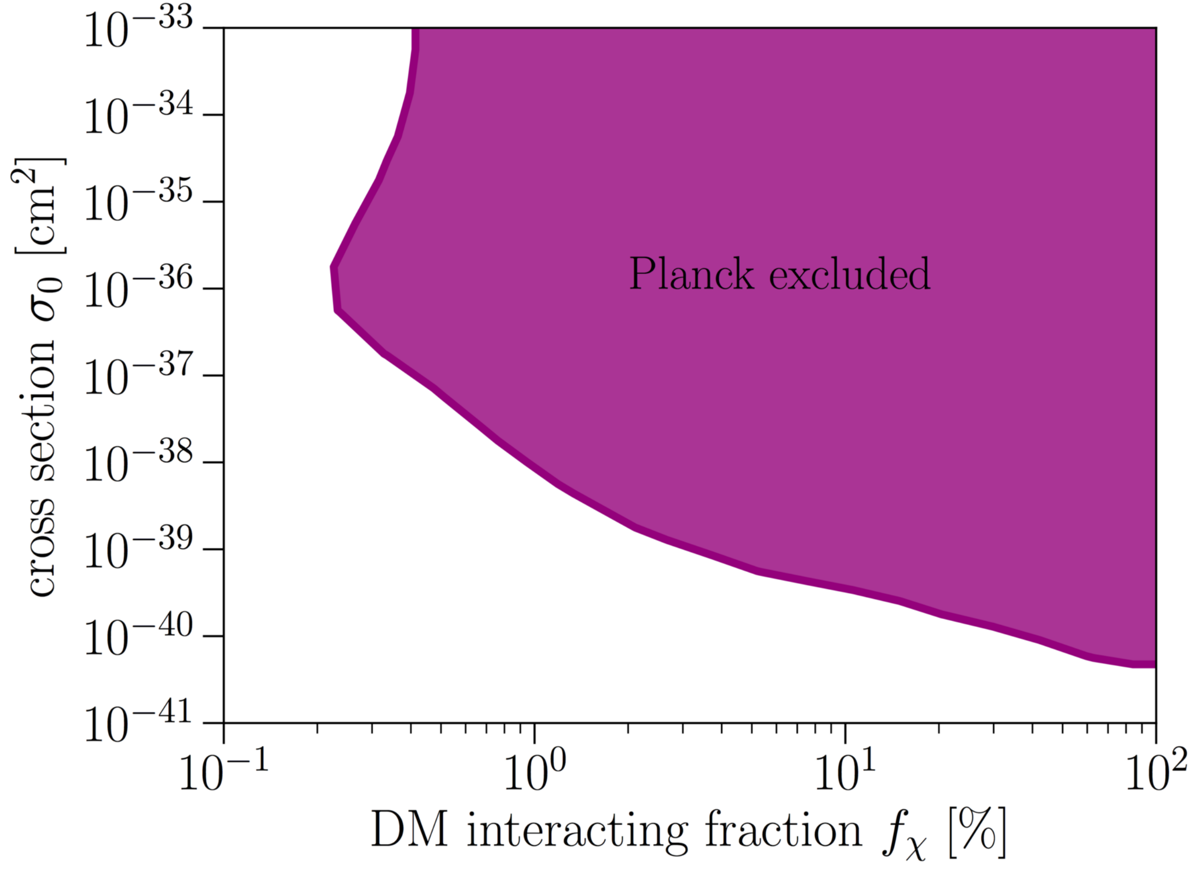


Boddy, VG, + (2018)

Kovetz, Poulin, VG, + (2018)

See also: Xu, + (2018); Slatyer, + (2018); Wu, + (2018); Dvorkin, + (2014).

Limits on interacting DM sub-component



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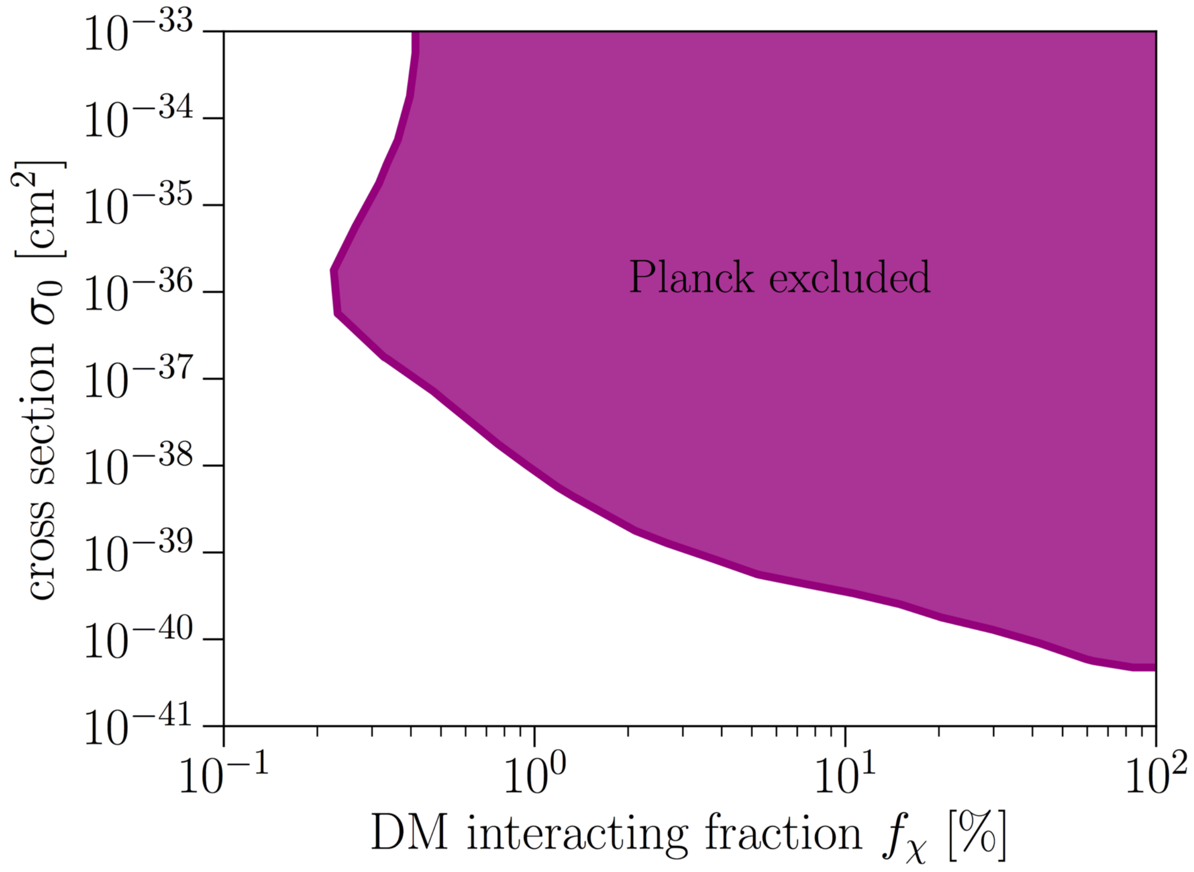

EDGES signal is inconsistent with Planck, if more than 0.5% of DM is millicharged.

Boddy, VG, + (2018).

Cosmological probes are already very sensitive.

Comprehensive analyses are essential to establish a discovery.