Cosmological probes of dark matter interactions

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LSST Dark Matter Workshop

Chicago (August 5, 2019)
Cosmic direct detection

Production (colliders)

Direct detection

Indirect detection

SM

DM

Cosmology
Astrophysics
DM-baryon scattering in the early universe

fluids + gravity = baryonic acoustic oscillations
DM-baryon scattering in the early universe

fluids + gravity + drag = damped baryonic acoustic oscillations
Dark matter interactions suppress structure on small scales.
Dark matter interactions suppress structure on small scales.
Observables

VG+, Astro2020 (2019)

arxiv:1903.05140
CMB power spectrum

\[ C_{\ell} \sim [\mu K] \]

Planck Collaboration 2015

Actpol Collaboration 2016

Angular scale

Multipole moment \( \ell \)

Planck
ACT
SPT

Planck Collaboration 2015
Planck limits on DM-proton scattering
[velocity-independent spin-independent interaction]

VG and Boddy, PRL (2018)

Planck limits on DM-proton scattering

[velocity-independent spin-independent interaction]

VG and Boddy, PRL (2018)

And beyond...
Interactions in cosmological context

momentum-transfer rate

\[ \sigma_{MT}(v^n) \rightarrow R_\chi \]

momentum-transfer cross section

momentum-transfer rate

time

Boddy and VG (2018)

see also: Sigurdson+ (2002), Dvorkin+ (2014), etc.
Interactions in cosmological context

\[ \mathcal{O}_i \rightarrow C_\ell(m_\chi, c_i) \]

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

Boddy and VG (2018)
Planck limits on EFT

![Graph showing cross section vs. particle mass](graph.png)

Boddy and VG (2018)
Age of the Universe $\sim 1000$ years: less than 1 in 100 000 scatterings is with DM.

Planck limits on EFT

Boddy and VG (2018)
Planck limits on DM-electron scattering

Excluded by Planck

PRELIMINARY

\( \sigma \sim \text{const} \)

\( \sigma \sim v^2 \)

Boddy and VG, in prep. (2019)
Planck limits on millicharge

\[ \sigma (\nu) \sim \nu^{-4} \]

Boddy, VG, + (2018)
Kovetz, Poulin, VG, + (2018)

See also: Xu, + (2018); Slatyer, + (2018); Wu, + (2018); Dvorkin, + (2014).
Planck limits on dipole DM

Excluded

PRELIMINARY

Plot by Daniel Pfeffer

Pfeffer, Boddy, Poulin, VG (in prep.)
Limits on interacting sub-component

Limits on interacting sub-component

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

Next-generation ground-based CMB observatories => high resolution measurements.
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CMB-S4 (proposed) and Simons Observatory
Next-generation CMB: Forecasts

velocity-independent scattering

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

Li, VG, + (2018)

See also 1808.07445
Dark matter interactions suppress structure on small scales.
Dark matter interactions **suppress structure on small scales.**
Near-field cosmology

Many more with galaxy surveys like LSST

Bullock and Boylan-Kolchin (2017)

c.f. Ethan's talk on Wednesday
Population of smallest galaxies in Milky Way's orbit \Rightarrow no lack of structure on corresponding scales \Rightarrow limits on DM scattering.


vel-independent scattering: 3 OOM better than Planck.

c.f. Ethan's talk on Wednesday

Limits from Milky Way Satellites

Work in progress

- Limits on other scattering models
- Simulations in interacting cosmologies
- Projections for LSST etc.
- Understand degeneracies in DM modeling space
- Understand modeling systematics
Broader scope

21-cm cosmology

Dwarfs

Ly-α forest

Galaxies

CMB (T+Pol)

CMB lensing

physical scale

time

wavenumber k [1/Mpc]

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

- CMB already probes new parameter space and new paradigms; near-field cosmology is messier, but very promising [e.g. satellites].
- **LSST/VRO and other data sets in next decade will be goldmine for tests of new physics.**
- **Key for discovery:** comprehensive searches and joint analyses.
- **To-address:** non-linearities in non-standard cosmologies, frameworks for joint analyses of multiple observables, assessment of limitations and degeneracies in new data sets.

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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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).