Trends/Themes in Cosmology and Particle Astrophysics

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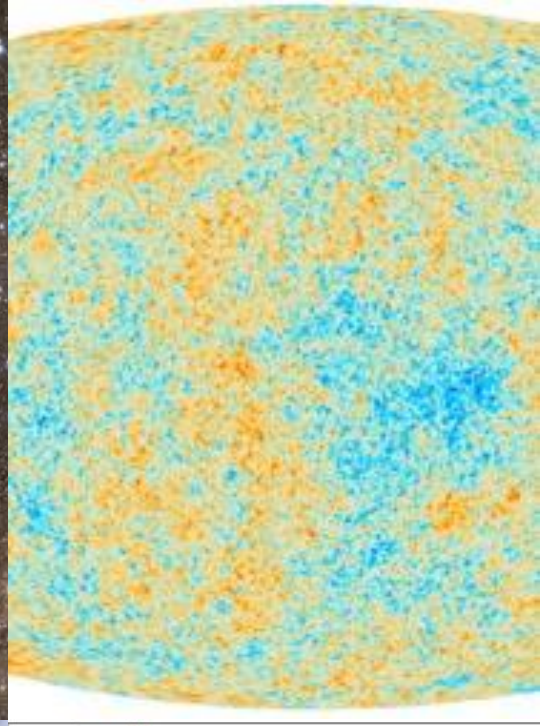
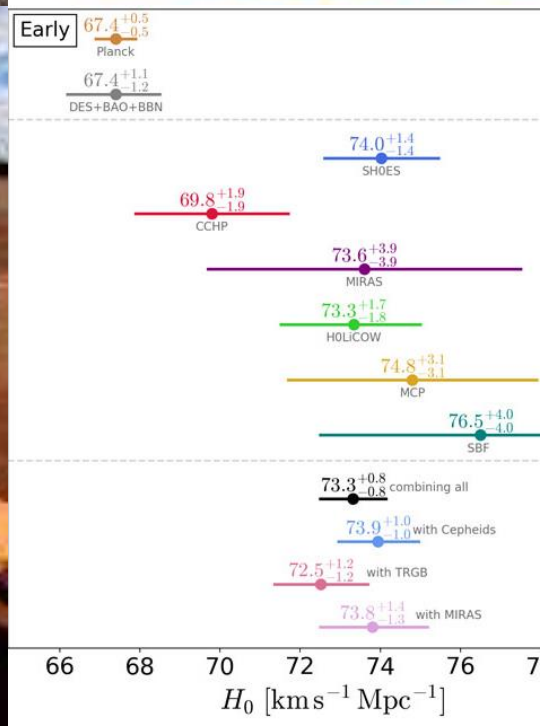




Topics

- Dark matter
- Dark energy / Hubble tension
- Inflation
- Gravitational-wave cosmology

Dark Matter 2009

- WIMPS
- Peccei-Quinn Axions
- Everything else

Dark-matter 2019

Some current frontrunners

- Ultra-low-mass fields (fuzzy DM, ultra-light axions)
- Hidden-sector DM (Higgs or photon)
- sub-GeV DM
- primordial black holes

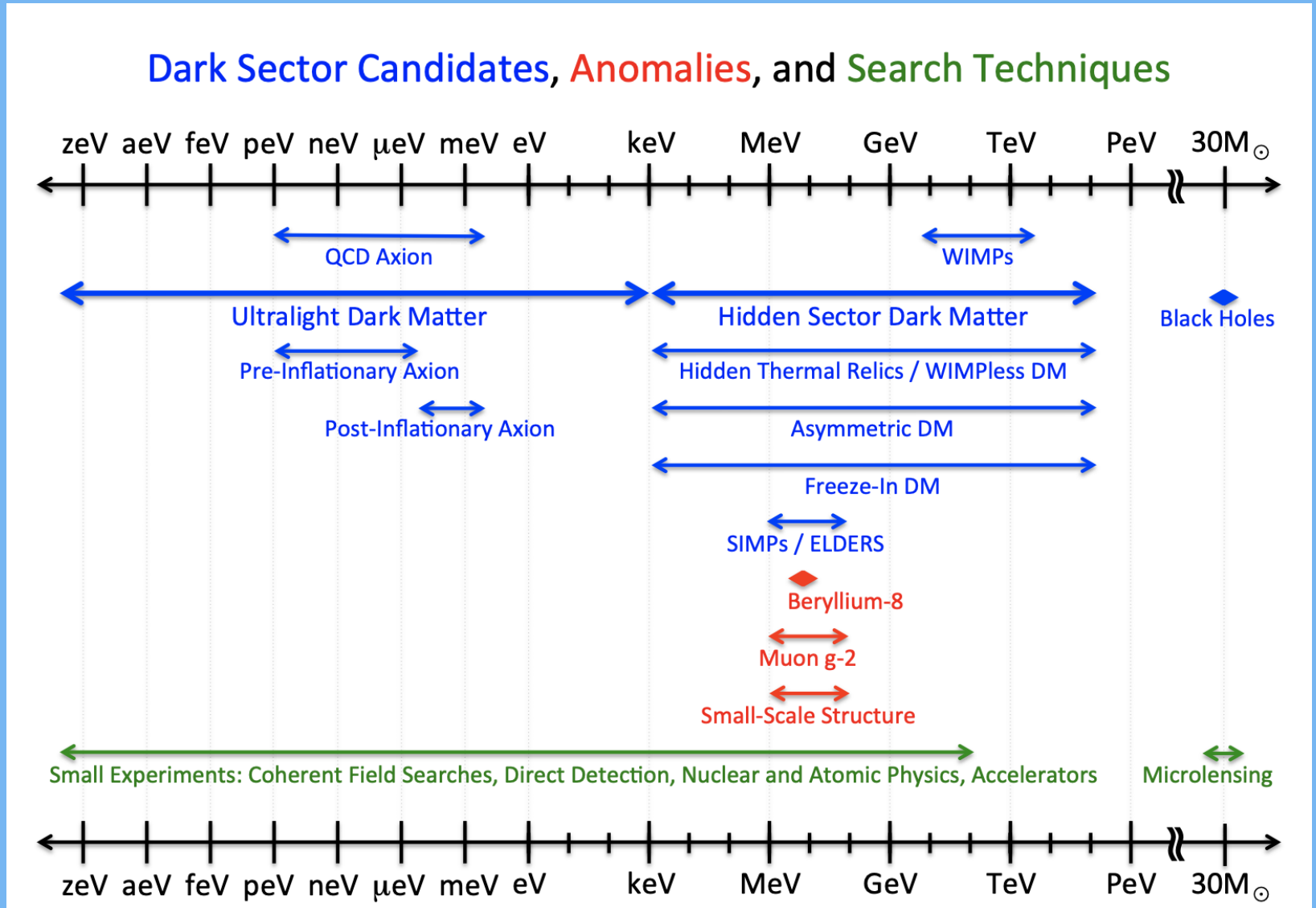
High Energy Physics - Phenomenology

US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report

Marco Battaglieri, Alberto Belloni, Aaron Chou, Priscilla Cushman, Bertrand Echenard, Rouven Essig, Juan Estrada, Jonathan L. Feng, Brenna Flaugher, Patrick J. Fox, Peter Graham, Carter Hall, Roni Harnik, JoAnne Hewett, Joseph Incandela, Eder Izaguirre, Daniel McKinsey, Matthew Pyle, Natalie Roe, Gray Rybka, Pierre Sikivie, Tim M. P. Tait, Natalia Toro, Richard Van De Water, Neal Weiner, Kathryn Zurek, Eric Adelberger, Andrei Afanasev, Derbin Alexander, James Alexander, Vasile Cristian Antochi, David Mark Asner, Howard Baer, Dipanwita Banerjee, Elisabetta Baracchini, Phillip Barbeau, Joshua Barrow, Noemie Bastidon, James Battat, Stephen Benson, Asher Berlin, Mark Bird, Nikita Blinov, Kimberly K. Boddy, Mariangela Bondi, Walter M. Bonivento, Mark Boulay, James Boyce, Maxime Brodeur, Leah Broussard, Ranny Budnik, Philip Bunting, Marc Caffee, Sabato Stefano Caiazza, Sheldon Campbell, Tongtong Cao, Gianpaolo Carosi, Massimo Carpinelli, Gianluca Cavoto, Andrea Celentano, Jae Hyeok Chang, Swapan Chattopadhyay, Alvaro Chavarria, Chien-Yi Chen, Kenneth Clark, John Clarke, Owen Colegrove, Jonathon Coleman, David Cooke, Robert Cooper, Michael Crisler, Paolo Crivelli, Francesco D'Eramo, Domenico D'Urso, Eric Dahl, William Dawson, Marzio De Napoli, Raffaella De Vita, Patrick DeNiverville, Stephen Derenzo, Antonia Di Crescenzo, Emanuele Di Marco, Keith R. Dienes, Milind Diwan, Dongwi Handiipondola Dongwi, Alex Drlica-Wagner, Sebastian Ellis, Anthony Chigbo Ezeribe, Glennys Farrar, Francesc Ferrer, Enectali Figueroa-Feliciano, Alessandra Filippi, Giuliana Fiorillo, Bartosz Fornal, Arne Freyberger, Claudia Frugiuele, Cristian Galbiati, Iftah Galon, Susan Gardner, Andrew Geraci et al. (151 additional authors not shown)

(Submitted on 14 Jul 2017)

Proliferation of novel searches for novel candidates

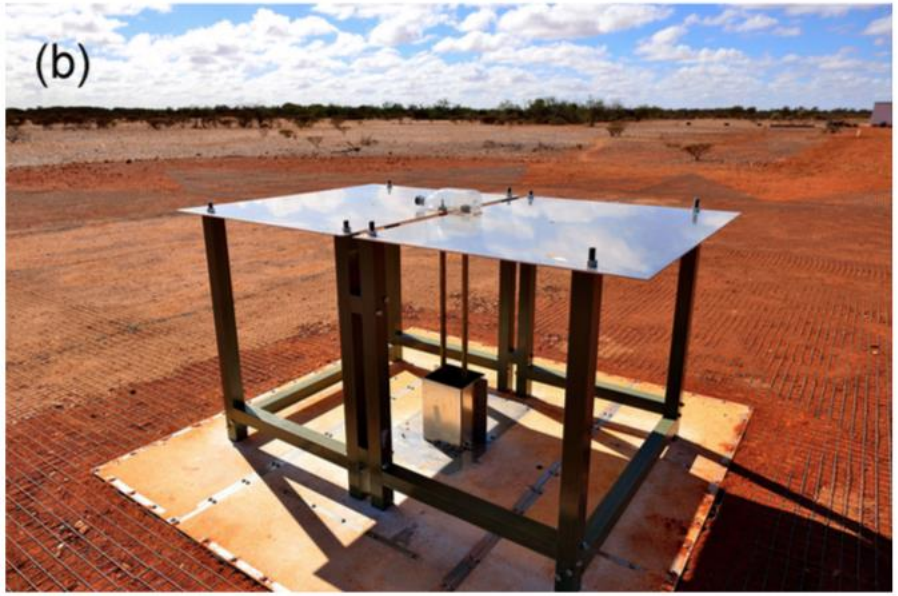


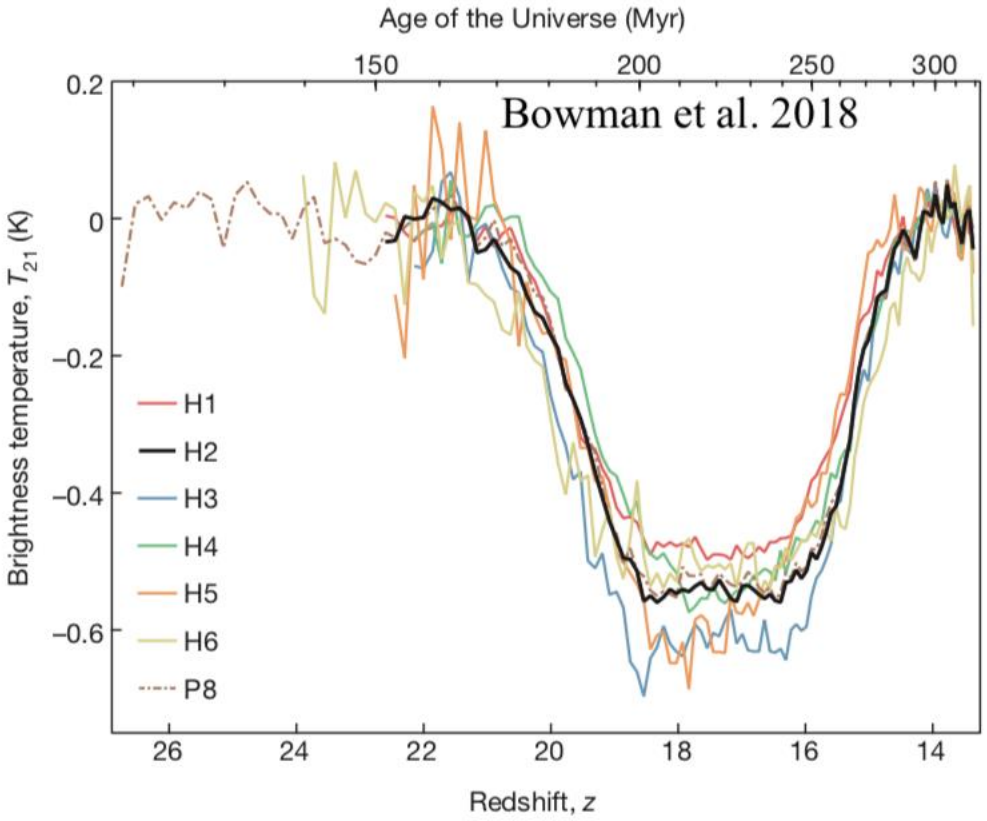
- Beam dumps
- Torsion balances
- AC neutron EDM
- Correlated magnetometers
- DM-electron scattering
- DM-nucleon scattering
- High-Q cavities
- Atom interferometry
- Astrophysics: annihilation/decay lines, dynamics, neutrinos/gammas/CRs…..

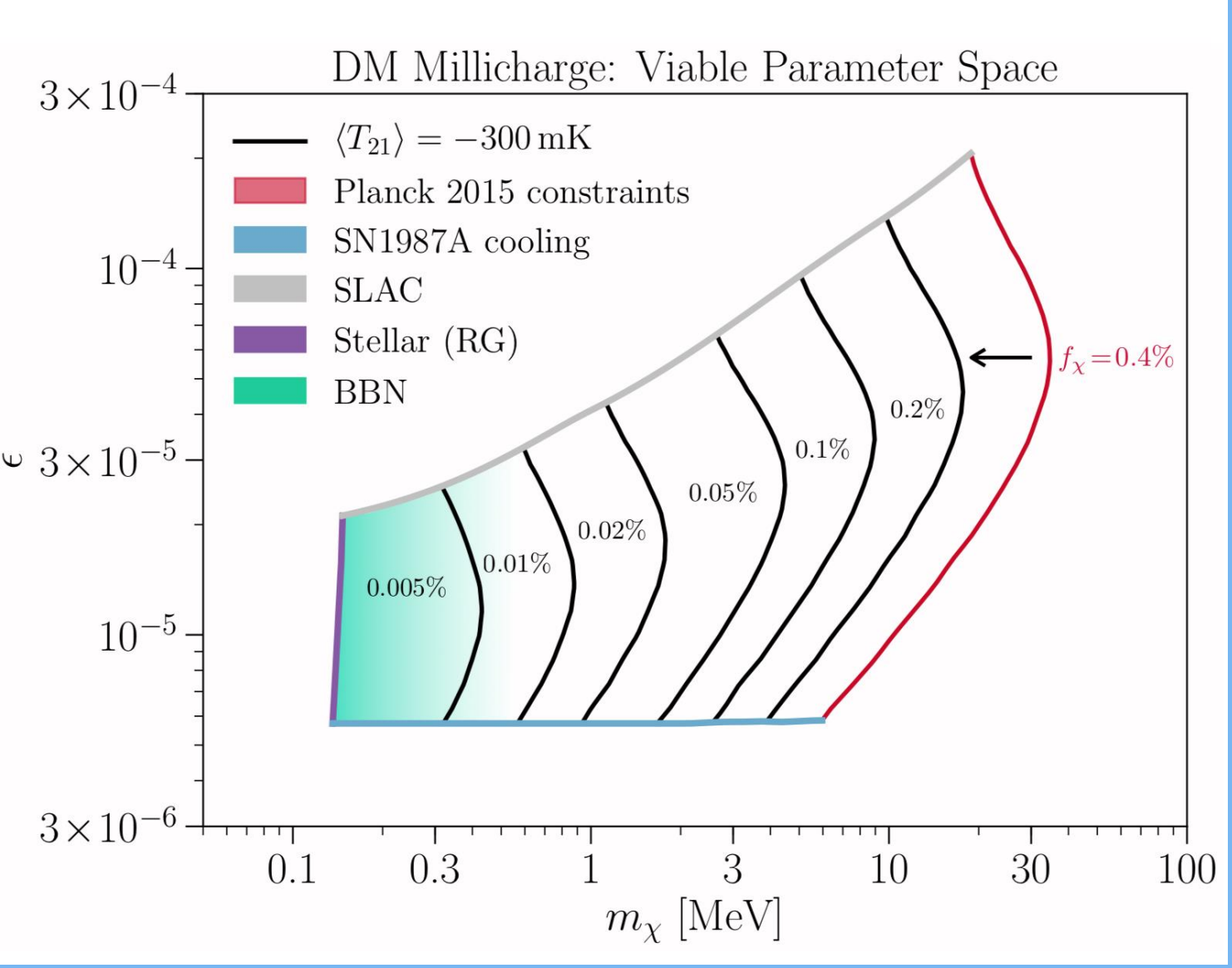
Baryon—DM interactions from cosmic dawn?

(EDGES: Bowman et al. Nature 2018; Barkana, Nature 2018, based on Munoz et al 2015, based on Dvorkin et al. 2013)

February 2018







Mill-charged—DM explanation very tightly constrained

(Boddy et al., 2018; Kovetz et al., 2018….

then “ruled out”---Creque-Sarbinowski et al. 2019)

Dark energy: Why does the vacuum weigh?

- Quintessence?
- Alternative gravity
  - f(R)?
  - Gauss-bonet?
  - Massive?
  - Braneworlds?
- Strange neutrino interactions?
- Phantom energy?
- Landscape?
- Or is that just the way it is?

Avenues

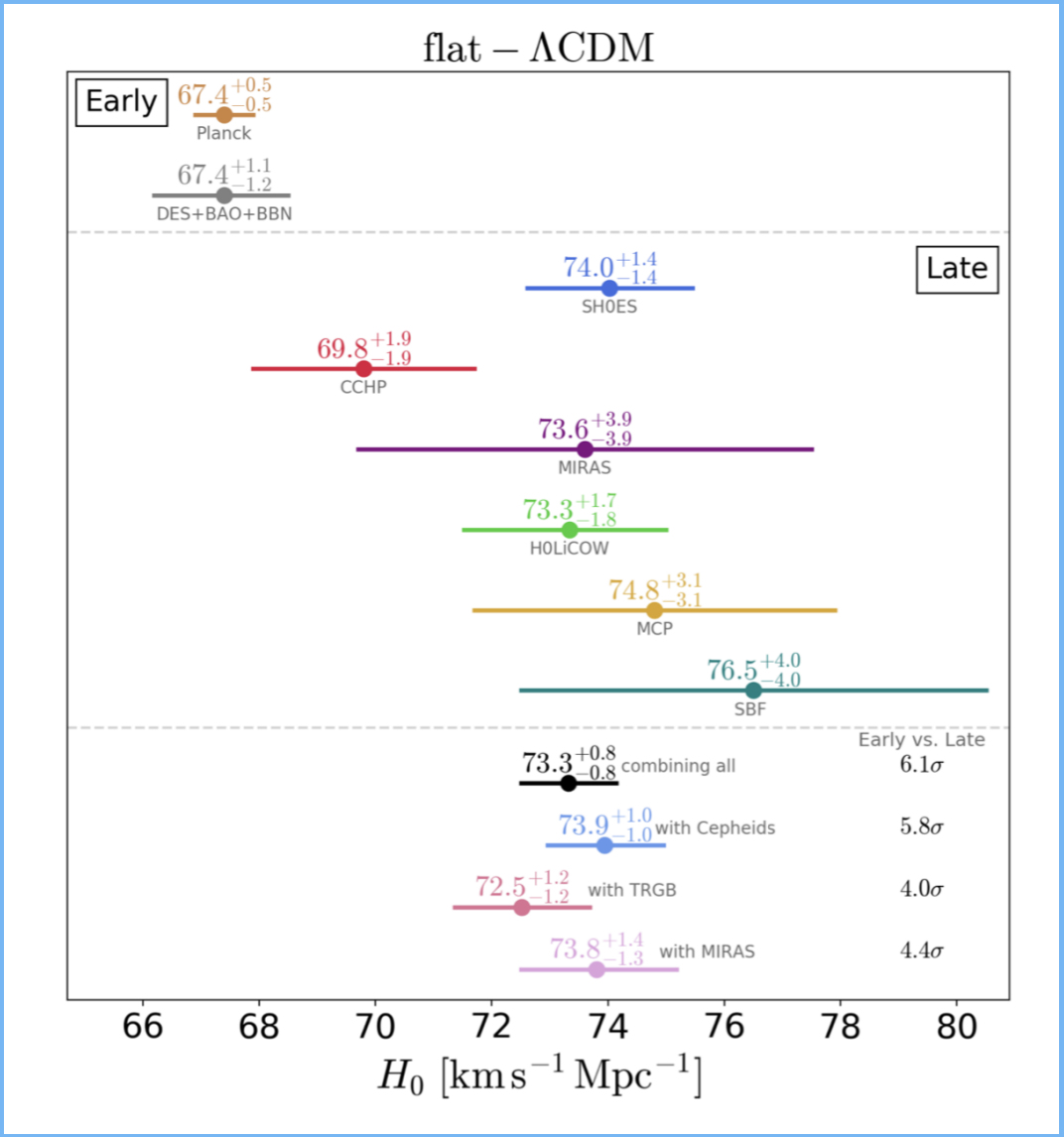
- Supernovae, CMB, BAO, galaxy clustering, Alcock-Paczynski, redshift-space distortions, weak lensing, galaxy-galaxy lensing….
- New probe: cross-correlation of galaxy surveys with kinematic Sunyaev-Zeldovich
- Tools
  - Galaxy surveys (DES, Subaru-PFS, Hypersuprime, DESI, Euclid, WFIRST, LSST)
  - CMB: ACT, SPT, Simons Observatory, CMB-S4…

The physics

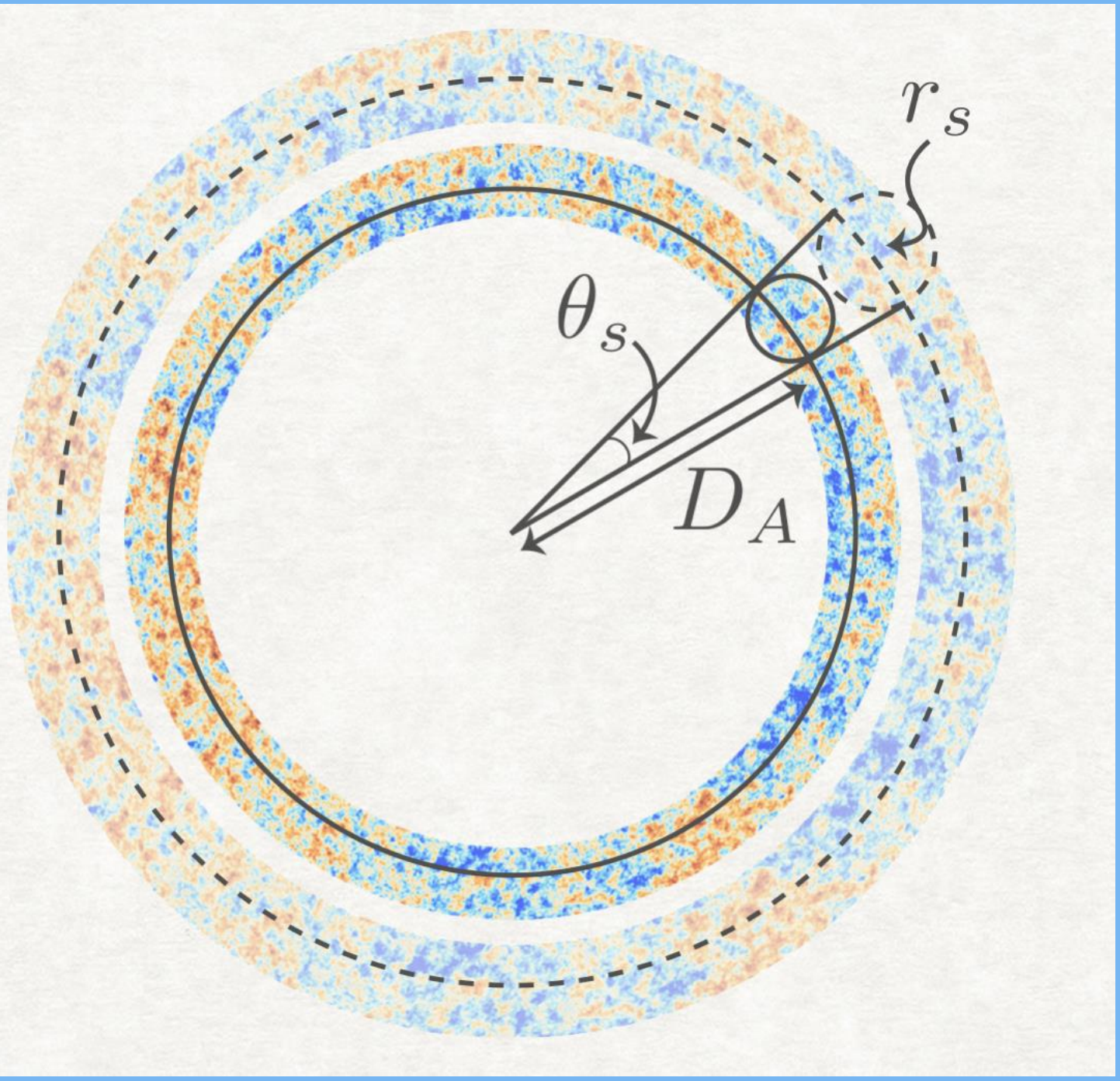
- Expansion history

- Cosmic Eddington experiment: Use gravitational lensing to check spacetime metric around galaxies

Problems with LambdaCDM? Hubble tension?



Verde, Treu, & Riess 2019


r_s
θ_s
D_A

Late-time solutions

- Modify late-time expansion history to reduce comoving distance to surface of last scatter
- Induce inconsistency with baryon acoustic oscillations (these seem consistent with CMB oscillations)

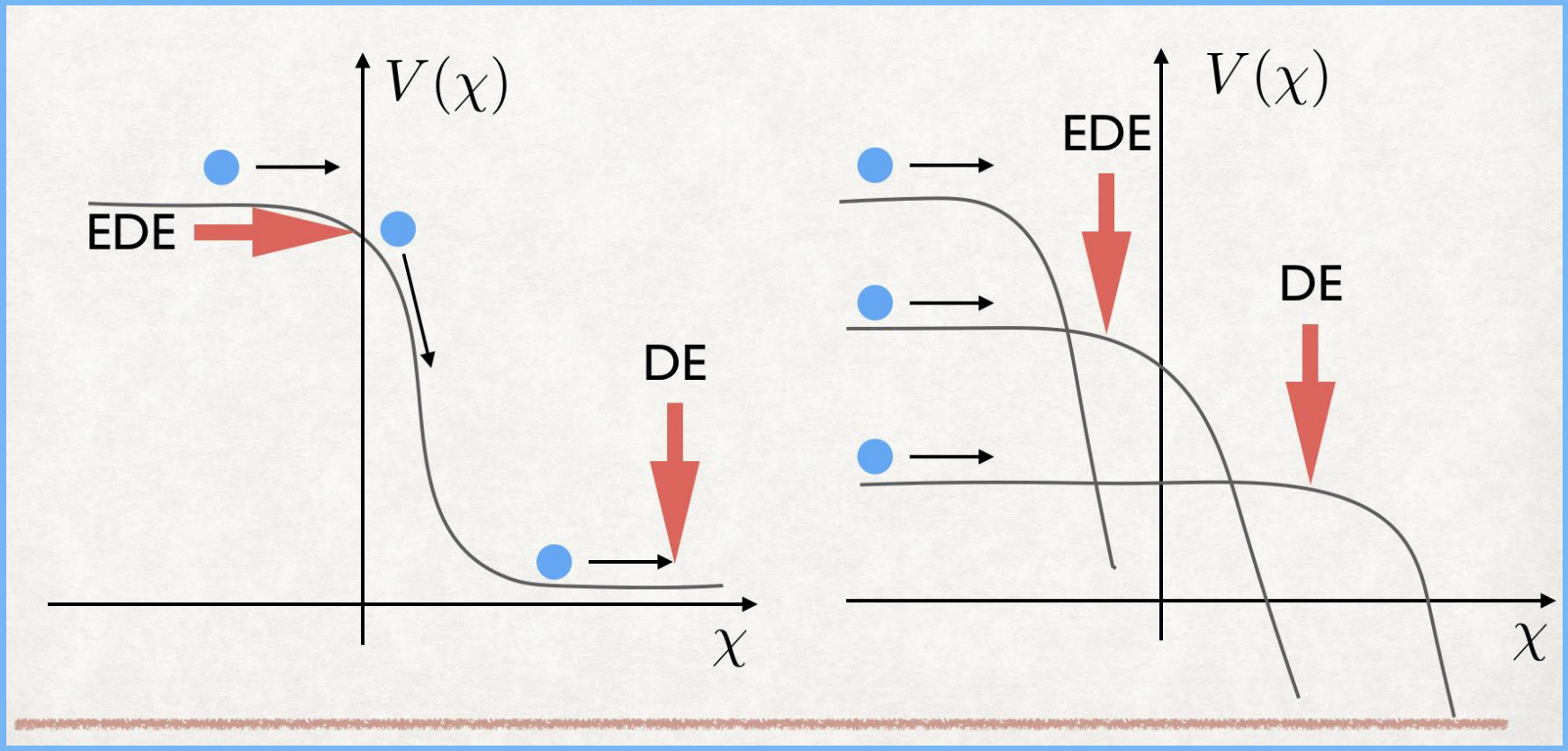
Early-time solution

- Reduce sound horizon
- Does not mess with BAO
- E.g., increase N_{eff} (but induces tension with small-scale CMB?) or early dark energy (Poulin, Smith, Karwal, MK 2018)

Recurring periods of DE domination?

e.g. Dodelson et al, astro-ph/0002360, Griest, astro-ph/0202052, MK, Pradler, Walker, 1409.0549

Oscillating dark energy? String axiverse?



What is the physics responsible for inflation?

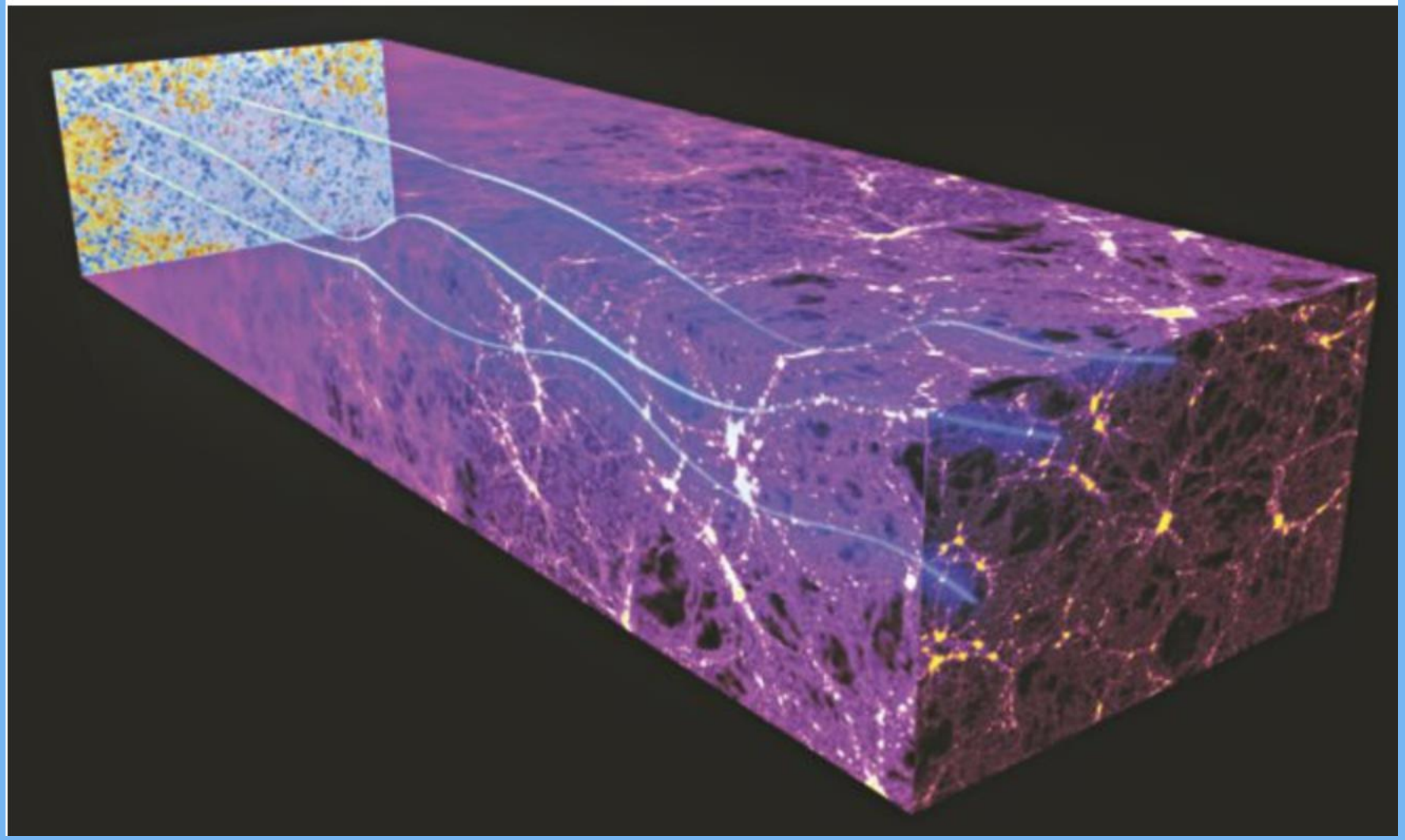
- Natural, chaotic, supersymmetric, supergravity, axion, hilltop, SSB, multi-field, supernatural, new, old, ghost, helical-phase, quintessential, galileon, quartic, locked, stochastic, solid, k-flation, power-law, eternal, inflection-point, Higgs, warm, WIMPflation, two-field, critical-Higgs, gaugeflation, BSI, Gauss-Bonnet, Brans-Dicke, f(R), Starobinsky, attractor, ALP, brane,

Avenues

- Scalar spectral index, non-gaussianity, isocurvature contributions (galaxy surveys, 21-cm, CMB)
- CMB polarization B modes from inflationary gravitational waves

Progress in B modes since P5

- Upper limit to r reduced by ~3 (to r<0.06; now from null B-mode searches)
- Deeper maps and more sensitivity
- Progress in de-lensing science
- Simons Observatory, CMB-S4, LiteBird coalescing

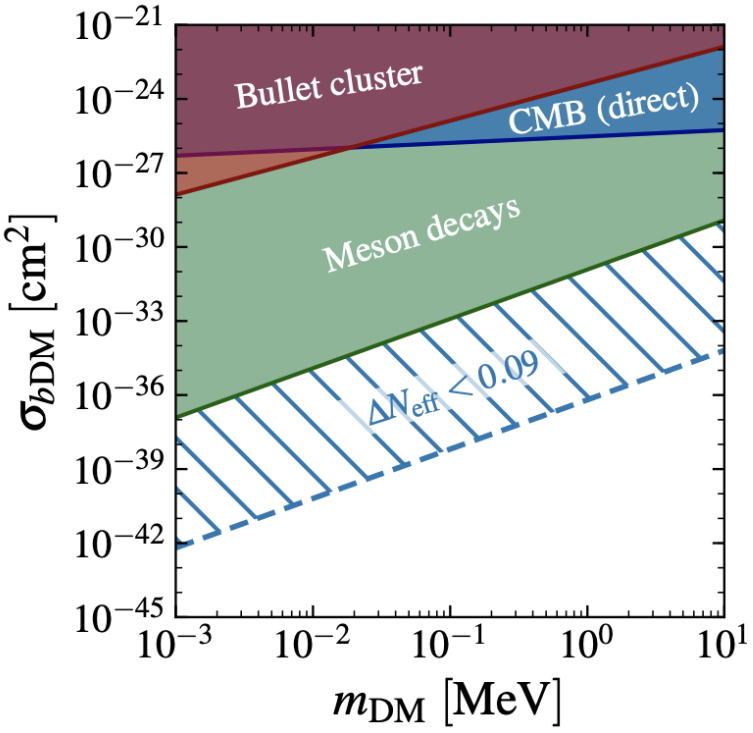


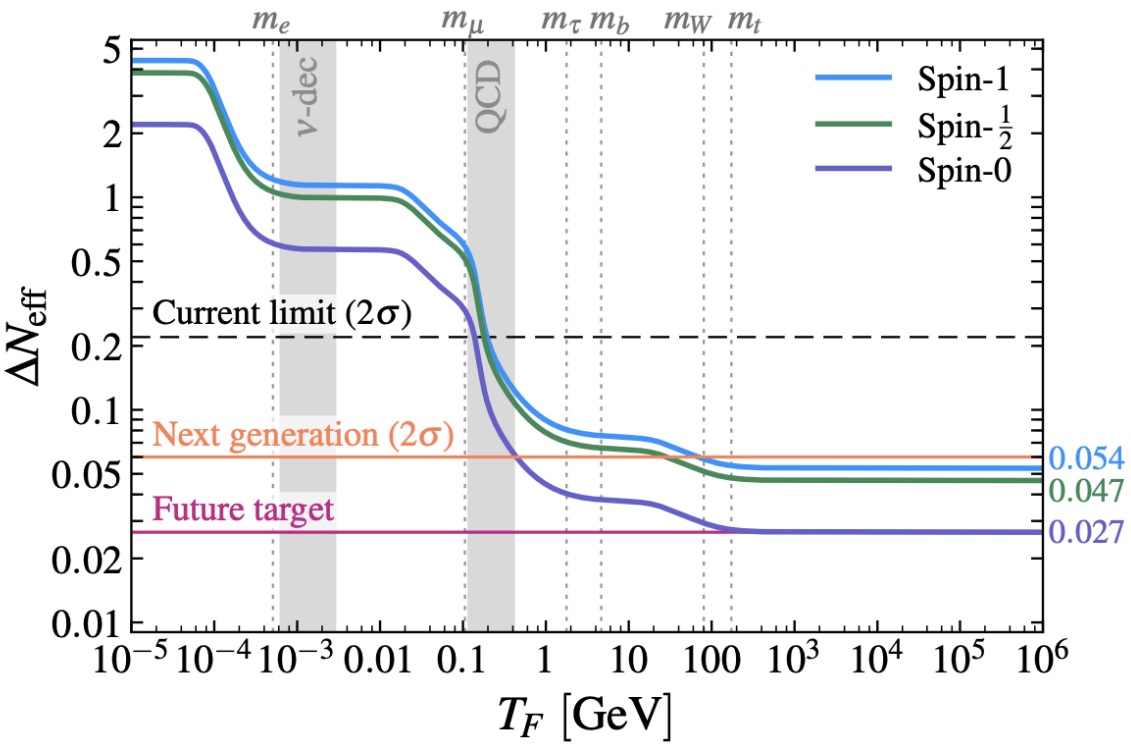
Gravitational lensing → B modes + characteristic departures from non-Gaussianity

Neutrino cosmology

- Galaxy/CMB measurements also aim to determine neutrino-mass hierarchy in ~5-10 years (current: sum neutrino masses <0.2-0.4 eV) and seek N_{eff} to ~0.02
- Broad program required: Mass scale from small scales, but optical-depth degeneracy must be broken by large-angle CMB

New light degrees of freedom





Gravitational waves and cosmology

- New ”standard siren” for H0, expansion history
- Tests of strong-field gravity, modified-gravity theories (including those relevant to cosmic acceleration)
- Exotica: DM-related? Stochastic backgrounds from early-U phase transitions? Firewalls?

Theorist wish list

- DM: broaden range of searches; independent check of EDGES
- DE/physical cosmology:
  - maintain current track with expansion history and cosmic Eddington tests
  - Understand Hubble tension
- Inflation:
  - B modes to r~0.001,
  - non-gaussianity to f_{nl}~1
  - scalar spectral index and isocurvature?
- Neutrinos:
  - Distinguish inverted/normal hierarchy
  - Light degrees of freedom to ~0.02
- Gravitational waves: new tool for cosmology?