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

- Axion
- Sterile neutrino
- ALP
- UED
- KK particle
- Dark photon
- Inflaton
- PBH
- Gravitino
- Q-tip
- Soliton
- MACHO
- Axion star
- Lost socks
- WIMP
- ULF
- KK particle
- Dirac neutrino
- Q-ball
- Hidden sector
- Majorana neutrino
- Fuzzy
- Millicharged DM
Some current frontrunners

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


(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?
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-bonnet?
  - 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
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 $N_{\text{eff}}$ (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, multifield, supernatural, new, old, ghost, helical-phase, quintessential, galileon, quartic, locked, stochastic, solid, k-inflation, 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 $\sim 3$ (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 $\rightarrow$ 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 $N_{\text{eff}}$ 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 \( r \sim 0.001 \),
  – non-gaussianity to \( f_{\text{nl}} \sim 1 \)
  – scalar spectral index and isocurvature?
• **Neutrinos:**
  – Distinguish inverted/normal hierarchy
  – Light degrees of freedom to \( \sim 0.02 \)
• **Gravitational waves**: new tool for cosmology?