Cosmology Connecting Dark Energy and Colliders

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Quiz

- Which of the following would you bet for the assertion of radiation dominance of the universe for 100 MeV < T < 100 GeV?

a) < $10 b) $100 c) $1000 d) more

Why Thermal Freeze-out

- CMB temperature + plausible/measurable particle physics + hot enough early universe (T>100 GeV) ⇒ Ω_M

cosmology

$$\Omega_M h^2 \propto \left(\frac{T}{m_\chi x_F}\right)^3 \left(\frac{m_\chi H_F}{\langle \sigma_A v \rangle}\right)$$

Weak cosmo

Particle physics
(electroweak scale)

~1/20 with log dependence on $H_F, \langle \sigma_A v \rangle, m_\chi$

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e.g. In standard cosmology, mass cancels

$$\Omega_M h^2 \propto \left(\frac{T}{m_\chi x_F}\right)^3 \left(\frac{m_\chi (x_F m_\chi)^2 / M_p}{\langle \sigma_A v \rangle}\right)$$

Scenario

- Focus: Standard thermal WIMP freeze-out, but cosmology is nonstandard.
- Suppose: collider measurement

Cosmological data
indirect detection
direct detection
astrophysics

$$\Omega_{\chi\, coll\ \ usual} > \Omega_{\chi\, astro}$$

Dilution mechanisms

a) Entropy release (e.g. Thermal infl, late decay)
b) Scalar-tensor gravity
c) More severe modifications of gravity

$$\Omega_{\chi\, coll\ \ usual} < \Omega_{\chi\, astro}$$

Enhancement mechanisms

a) Extra contribution to H
b) Scalar-tensor grav. (hep-ph/0302159)
c) More severe modifications to grav
d) More DM candidates (perhaps too weakly interacting for collider measure)

What can change H in standard gravity during freeze out?

- Exotic component in the stress tensor
  - Extra gas of radiation or matter $a^{-4,-3}$
  - Extra scalar field energy: potential a^{0}
    kinetic a^{-6}
- Scalar field KE domination: kination domination

[Salati 02, Kamionkowski & Turner 90]

  - Minimal: light scalar field can exist because of DE
  - Avoid any hint of conflict with standard BBN
  - Gives us a way to **probe DE sector through colliders** since colliders can probe DM whose freezeout properties are influenced by DE.

A Large Class of Models

Kination domination scenario:

DE sector $$L_{DE} = \sum_i \frac{1}{2}\dot{\phi}_i^2 - V(\{\phi_j\})$$

$$\rho_{\phi DE} \sim \sum_i \frac{1}{2}\dot{\phi}_i^2$$ during DM freeze-out

$$H^2 = \frac{1}{3M_p^2}\left(\rho_{\phi DE} + \rho_R\right) \quad > \quad H^2_{usual} = \frac{1}{3M_p^2}\left(\rho_{\phi DE} + \rho_R\right)$$

DM phenomenology characterized by 1 parameter:

$$\eta_\phi \equiv \left(\frac{\rho_\phi}{\rho_\gamma}\right)_{BBN} \quad \leq 1$$ BBN

A Surprising Signature

Surprise: Can be ruled out almost model independently if primordial CMB B-modes are observed.

Assumptions:

1) There is only one period of inflation.
2) RH related fields lighter than H exist at the end of inflation.

Reasoning leading to the bound:

1) The minimum radiation temperature at the end of inflation is the dS horizon temperature.
2) Horizon temperature depends on the energy density during inflation: V

   V $\Rightarrow$ V dependent lower bound on ρ_γ
3) The maximum kination energy density is also determined by V

   V $\Rightarrow$ V dependent upper bound on ρ_ϕ
4) Within the foreseeable future, measurement of primordial gravity wave induced B mode requires $V > V_{min}$
5) Hence, measurement of primordial B-mode gives an upper bound on $\eta_\phi \equiv \left(\frac{\rho_\phi}{\rho_\gamma}\right)_{BBN}$

$$\eta_\phi \ll 10^{-8}$$

6) 1% enhancement of Ω_M from the usual scenario requires $\eta_\phi > 10^{-8}$

Signatures

- There will be a discrepancy between cosmology and colliders.
- Can be ruled out almost model independently if primordial CMB B-modes are observed.
- Shift in the peak of the electroweak phase transition gravity wave spectrum possibly measured by LISA and LIGO
- Higgs bound for electroweak baryogenesis can be shifted by order 20%.
- Positron excess explanation through DM annihilation improved through this scenario.
- Leptogenesis will need to be resonant because of low T_{RH}
- Residual annihilation effects of DM will be affected

Conclusion

- There is exciting prospects for probing cosmology with colliders through DM physics. e.g. Measurements may yield $\Omega_{\chi\, coll\ \ usual} < \Omega_{\chi\, astro}$
- Such discrepancies can be enhanced by a period of kination domination.
- Minimality makes it natural to use quintessence (especially if w > -1 is confirmed): DE ⇔ colliders
- Large class of models can be ruled out by future CMB experiments
- Correlated signatures can support the scenario.

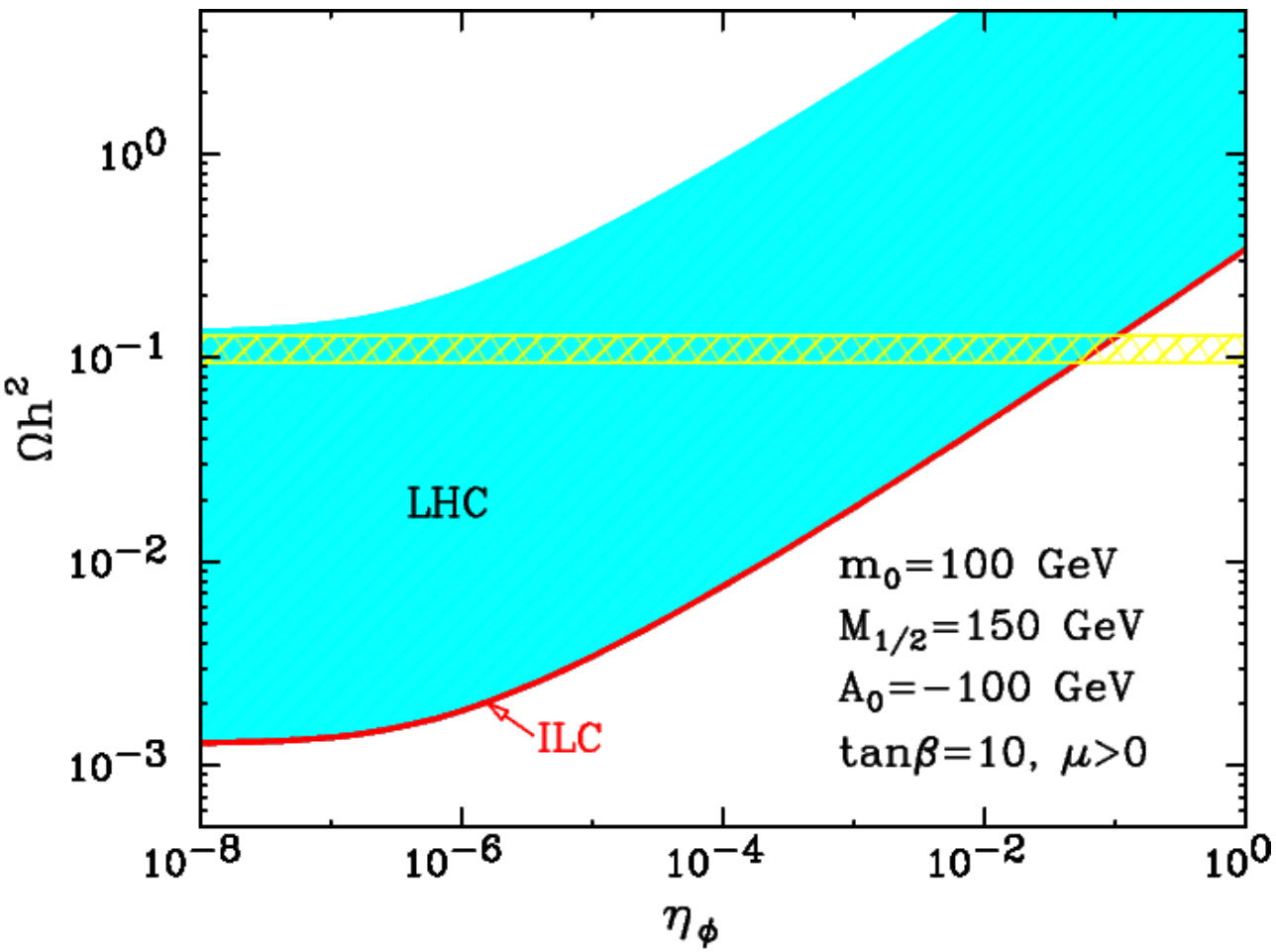
Connecting DE and DM To Do List

- Comparative studies with other mechanisms for mismatching collider and cosmology.
- Compute detailed gravity wave spectrum arising from electroweak phase transition within this context.
- Compute Higgs mass bound shift associated with quint. effects.
- Study resonant leptogenesis possibilities.
- Residual annihilation BBN effects.
- Effects on cosmic string network evolution and signatures.

CONNECTING LHC, ILC, AND QUINTESSENCE

(w/ Everett, Kong, Matchev)

- ILC can measure quintessence!



This example: LHC/LC's SPS1a (or Peskin et al's LCC1 study point) except with fermion mass shifted lower

Reason for ILC's Improvement: Higgs resonance

Other regions are not as dramatic, but qualitatively similar.