Constraining Inflationary Dark Matter in the Luminogenesis Model

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Luminogenesis Model

- Dark matter: comprises about 27% of our universe.
- What if all matter originated as dark matter?
- Luminogenesis model (P.H. Frampton and P.Q. Hung, `arXiv:1309.1723[hep-ph]`; P.H. Frampton and P.Q. Hung, Phys. Lett. **B675**, 411 (2009), `arXiv:0903.0358[hep-ph]`)

Luminogenesis Model

- $SU(3)_C \times SU(6) \times U(1)_Y \rightarrow SU(3)_C \times SU(4)_{DM} \times SU(2)_L \times U(1)_Y \times U(1)_{DM}$
- $SU(4)_{DM}$: DM gauge group
- DM: fermionic, color singlet
- mirror fermions
- DM hadrons

Inflationary Dark Matter

- DUT ("Dark Unified Theory") symmetry breaks at the end of inflation ($SU(6) \rightarrow SU(4)_{DM} \times U(1)_{DM} \times SU(2)_L$).
- Inflaton decays into dark matter, while decay into luminous matter is suppressed at tree level.
- Dark matter decays into luminous matter via "luminogenesis."

Luminogenesis

- Asymmetry in dark matter assumed: $n_\chi - n_{\bar{\chi}} \neq 0$
- DM decays to luminous matter, which mainly decays to radiation, and mirror matter. Almost all mirror fermions decay to standard fermions.
- Rate of conversion dependent on coupling in the Lagrangian: luminogenesis scale M_{lum}. Freeze-out happens at high scale, before BBN.
- The lepton asymmetry can be transferred as baryon asymmetry via the sphaleron process.

Some Attractive Features of this Model

- Self-coupling DM: it could explain the apparent lack of dwarf galaxies ("missing satellite problem") and the lack of observed dark-matter cusps near the centers of galaxies (both seen in N-body simulations).
- Typical GUT models predict the decay of the proton, which has never been observed. This model is consistent with the non-observation of proton decay: has no luminous matter above M_{lum}, so it's inappropriate to extrapolate SM gauge couplings in RG flow involving only luminous matter states above T_{lum}.

DM Mass from RG Flow and Inflation Constraints

- The mass scale of the DM particle is approximately equal to the confinement scale of its gauge group $SU(4)_{DM}$, just as the mass of a quark comes mainly from the $SU(3)$ confinement scale.
- $SU(2)$ and $SU(4)$ unified at DUT scale
- Can run $SU(2)$ from known electroweak scale to DUT scale, then run $SU(4)$ down to confinement scale
- Then we have our DM mass.

RG Flow

- The one-loop β-function equation for $SU(N)$ (ignoring the negligible term for the contribution due to scalar fields):
  $\frac{d\alpha}{d\ln\mu} \equiv \beta(\alpha) = -\left[\frac{11}{3}N - \frac{2}{3}T_{F_R}n_{f_R} - \frac{2}{3}T_{F_L}n_{f_L}\right]\frac{\alpha^2}{2\pi}$
- $\beta_2(\alpha_2) = -(\frac{11}{3}\cdot 2 - \frac{1}{3}\cdot 12 - \frac{1}{3}\cdot 12)\frac{\alpha_2^2}{2\pi} = \frac{2}{3}\frac{\alpha_2^2}{2\pi}$
- $\beta_4(\alpha_4) = -(\frac{11}{3}\cdot 4 - \frac{1}{3}\cdot 12 - \frac{1}{3}\cdot 12)\frac{\alpha_4^2}{2\pi} = -\frac{20}{3}\frac{\alpha_4^2}{2\pi}$
- Solving the β-function equation for $SU(4)$:
  $\alpha_4(\mu)^{-1} = \alpha_4(\mu_{DUT})^{-1} + \frac{10}{3\pi}\ln\frac{\mu}{\mu_{DUT}}$
- $\alpha_4(\mu_{DUT}) = \alpha_2(\mu_{DUT})$
- So solving the β-function equation for $SU(2)_L$, evaluating at μ_{DUT}:
  $\alpha_2(\mu_{DUT})^{-1} = \alpha_2(\mu_{EW})^{-1} - \frac{1}{3\pi}\ln\frac{\mu_{DUT}}{\mu_{EW}}$
- $\mu_{EW} = 246$ GeV, $\alpha_2(\mu_{EW}) \approx 0.03$

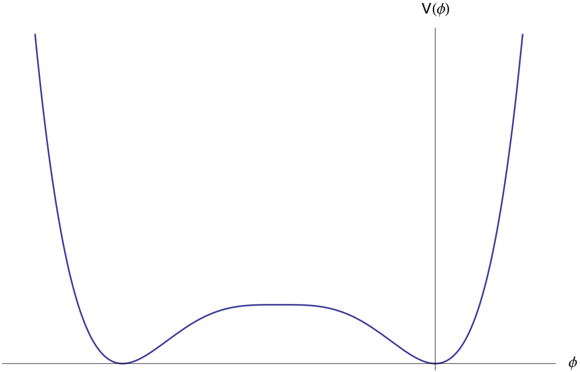
DM Mass

- Combining expressions for $SU(2)$ and $SU(4) \rightarrow \mu = \exp\left[\frac{3\pi(\alpha_2(\mu_{EW}) - \alpha_4(\mu))}{10\ \alpha_2(\mu_{EW})\ \alpha_4(\mu)}\right] \mu_{DUT}^{11/10}\ \mu_{EW}^{-1/10}$
- So we say that $\mu = \mu_{DM}$ when $\alpha_4 \sim 1$

DM and Inflation Constraints

- The DUT scale is equal to the scale of the true vacuum in the inflation potential.
- choose generic symmetry-breaking inflation potential
- get DUT scale from constraints on inflation from results from cosmological probes

Symmetry-Breaking Potential



$$V(\phi) = A(\phi + v)^4 \left[\ln \frac{(\phi+v)^2}{v^2} - \frac{1}{2}\right] + \frac{Av^4}{2}$$

$$v = \mu_{DUT}$$

BICEP2 Constraint

- Tensor-scalar ratio: $r = 0.20^{+0.07}_{-0.05}$
- Generically, large-field inflation: $\frac{\Delta\phi}{M_{Pl}} = \int_{N_{end}}^{N_\star} dN' \sqrt{\frac{r}{8}} \approx \mathcal{O}(1) \left(\frac{r}{0.01}\right)^{1/2}$
- Result still speculative, needs confirmation; alternative explanations exist
- If we accept BICEP2's result, adjustments to vanilla inflation must be made for small-field inflation to survive. (e.g., running of r).

Constraints

- Sayantan Choudhury and Anupam Mazumdar, `arXiv:1403.5549[hep-th]`
- Planck+WMAP9+high L+BICEP2 (at pivot scale $k_\star = 0.002\ \mathrm{Mpc}^{-1}$):
  $r = 0.20^{+0.07}_{-0.05}$
  $\ln(10^{10}\mathcal{P}_S) = 3.089^{+0.024}_{-0.027}$
  $n_s = 0.9600 \pm 0.0071$
  $\alpha_S \equiv \frac{dn_S}{d(\ln k)} = -0.022 \pm 0.010$
  $\kappa_S \equiv \frac{d^2 n_S}{d(\ln k)^2} = 0.020^{+0.016}_{-0.015}$

Breaking Symmetry

- With these constraints, for a sub-Planckian field: $0.066 \leq \frac{\Delta\phi}{M_{Pl}} \leq 0.092$, where $\Delta\phi = |\phi_e - \phi_\star|$.
- These are obtained in a model-independent way using slow-roll parameters.

  One can construct a symmetry-breaking potential that fits the constraints at pivot scale.

  Generally, the symmetry-breaking scale, as in a Coleman-Weinberg-type model, is the change in the field: $v = \mu_{DUT} \sim \Delta\phi = |\phi_e - \phi_i|$.
- So a lower bound: $0.066 \leq \frac{\mu_{DUT}}{M_{Pl}} \leq 0.092 \rightarrow 1.0 \times 10^7 \text{ GeV} \leq \mu_{DM}$
- There is an ongoing discussion on arXiv about this result. We do not take sides on this. We simply point out: generally, cosmological constraints imply high μ_{DUT}, and therefore high μ_{DM}

Summary and Conclusion

- DUT: $SU(3)_C \times SU(6) \times U(1)_Y \rightarrow$ $SU(3)_C \times SU(4)_{DM} \times U(1)_{DM} \times SU(2)_L \times U(1)_Y$
- This DUT symmetry broken when inflaton slips into true vacuum.
- Constrain true vacuum energy scale, $v = \mu_{DUT}$, from inflation constraints
- Run $SU(4)_{DM}$ coupling back to confinement scale → DM mass
- Investigation of reheating details, DM decay, etc. Paper still in progress.
- There are cosmic neutrino and positron data from IceCube and AMS, for example, that may suggest dark matter of the TeV scale or higher, so the possibility of heavy dark matter should be investigated thoroughly.