A Summary on DM/DE and Cosmology

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CC is still viable, but $w<1$ seems preferred

Horndeski theory [Tsujikawa]

Quintessence
Quintessential axions, DES [Soares-Santos]

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Chiral fields at GUT scale
SU(5), SU(7) GUTs
Heterotic string [Gross]

CP violation
Baryogenesis, Leptogenesis

Horndeski theory [Tsujikawa]

Quintessence
Quintessential axions, DES [Soares-Santos]

WIMP
[Penning, Boehm, Gondolo, Serfass, Wulf]

BCM
Axions [Gondolo]
All these must be discussed in the evolving Universe:
“Model” is a working example. Even though the design is fantastic, without a model example, some will say that it is a religion. Efforts to find a working model is our job toward THEORY/FRAMEWORK.
Gravity waves—observed [Video] and hoped looked even for (pseudoscalar) inflation [Dombcke]

DES experiment, in Chile, is trying to see DE [Soares-Santos]
DE/Cosmology: Inflation ideas from string: Natural inflation, aligned inflation, and axion monodromy, to understand large $f_A$ from $f_i$ values smaller than $M_P$.

[Shiu]
The fine-tuning problem of the SM: Introduced SUSY/SUGRA, and fine-tuning degrees, even a few percent [Tata]. But, it is in the SUGRA theory.

However, if we had a theory of soft-parameters that predicted \( A_0 = -1.6m_0 \) and \( m_{H_u}^2 = 1.64m_0^2 \) and \( m_{1/2} \approx 0.4m_0 \), this underlying theory would not be fine-tuned. We do not have such a theory today!!!!

<table>
<thead>
<tr>
<th>Correlation</th>
<th>( \Delta_{BG} )</th>
</tr>
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<tbody>
<tr>
<td>None</td>
<td>3168</td>
</tr>
<tr>
<td>( A_0 = -1.6m_0, \ m_{H_u}^2 = 1.64m_0^2 )</td>
<td>257</td>
</tr>
<tr>
<td>( m_{1/2} = 0.4m_0 )</td>
<td>15.4</td>
</tr>
<tr>
<td>( \Delta_{EW} )</td>
<td>11.3</td>
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Intrinsically, there exists a much more serious fine-tuning here. The gravitino mass is defined with CC=0. In any SUGRA model discussing MSSM and NMSSM assumes this fine-tuning.

Devils’ (Weinberg, Witten, Gross, ...) question:

Isn’t it a fine-tuning of order 1 out of $10^{120}$ ?
• In SUGRA, the cosmological constant (CC) needs to vanish in the true vacuum:

$$\langle V \rangle = |\langle F \rangle|^2 - 3 e^{\langle K \rangle} |\langle W \rangle|^2 \overset{!}{=} 0$$

• E.g., in the Polonyi model, constant in the superpotential: $w \rightarrow w_0 = (2 - \sqrt{3}) \mu^2$. 

[Schmidt]
Should we solve the CC problem first, before discussing the electroweak fine-tuning problem?

These two problems are in the same theory.
Can there be an example, or at least a hope for a solution of the CC problem?

Keep an eye on: Maybe, Hawking’s probability argument in Euclidian quantum gravity can be an understanding toward the CC problem [Baum (1983); Hawking (1984). See, also, Duff (1989), Wu(2008)]. Immediately required strategy is a set-up for a parameter for the variable CC in SUGRA.

Nobody has presented an argument so far in SUGRA.
For PQ, Barr-Seckel, Kamionkowski-MarchRussel, Holdom et al. Exclude terms up to dim 8.

The example of acc symm.
“Example” must be a working one.
Discrete symmetry
Family number is not a symmetry of Lagrangian like charge.

Family unification and gauge forces are unified into a simple group. Not a direct product of (Gauge group) x (Family group): a real unification of all forces.
In UGUTFs, after Higgsing, we want to have 3 left-handed families,

\[
\begin{align*}
(\nu_e)_L & , (\nu_\mu)_L & , (\nu_\tau)_L , \\
(u)_L & , (c)_L & , (t)_L \\
(d)_L & , (s)_L & , (b)_L
\end{align*}
\]

and

\[
\sin^2 \theta_W = \frac{3}{8}
\]
This was one good reason for having considered SUSY.
With a possible success of unification with gravity
Effective models with SM spectrum plus singlets

[Gondolo] tried for WIMP.
Summarized by Weinberg operator: 
[13.08.1979, Received]

\[ \ell L H_u N_R \]

gives \( \nu \) mass

Kim-Nilles SUSY operator: 
[24.11.1983, Received]

\[ \frac{S_1 S_2 H_u H_d}{M} \]

gives TeV scale \( \mu \) term

We neglected \( S H_u H_d \) since the VEV of \( S \) at intermediate scale is too large for SU(2) breaking.

Realized in seesaw: 
Minkowski [13.04.1977, Published], 
Yanagida [13-14 Feb 79, Conf. talk]

Realized in string comp.: 
Many papers, \( \ldots \)

\[ S_1 H_u X_{\text{doublet}} , \quad S_2 H_d X'_{\text{doublet}} , \quad \bar{Q}_L Q_R S_1, \ldots \]
Do we really need RENORMALIZABLE ONES at present low energy world?
For effective neutrino mass and mu term, these are sufficient. But, for cosmological effects, the underlying models are needed.

\[ \frac{1}{M} \ell \ell H_u H_u \]
gives $\nu$ mass

\[ \frac{1}{M} S_1 S_2 H_u H_d \]
gives TeV scale $\mu$ term

Definition of symmetries:
Example:

Definition of ONE global symmetry with a sufficiently high dimensional operator

Constructed so that there is no QCD anomaly
A sufficiently high dimensional operator def: next order term is very small! $10^{-47}$ GeV$^4$.

Magic of discrete symmetry.

$Z(10_R)$ example.

The rolling has not started yet, CC: [Tsujikawa]
Beyond SM
Neutrinoless double-beta decay:

$$|m| < 0.061 - 0.165 \text{ eV} \quad [\text{Lubashevskiy}]$$

MEG decay:

$$\text{BR}(\mu^+ \to e^+ \gamma < 4.2 \times 10^{-13}) \quad [\text{Signorelli}]$$

If neutrino magnetic moment(s) observed:

Current terrestrial limit [J-M Frere]:

$$|\mu_{\nu_e}| < 2.9 \times 10^{-11} \mu_B,$$

$$|\mu_{\nu_\mu}| < 6.8 \times 10^{-10} \mu_B,$$

$$|\mu_{\nu_\tau}| < 3.9 \times 10^{-7} \mu_B.$$
WIMP

Indirect

Direct (Cosmological effect [Boehm])

Collider [Penning]

Axion

(Cosmological effect [Gondolo])
Allowed if an approximate global symmetry is PQ.

from superstring: only possible with MI axion removed.

\[ \sin^2 \theta_W = \frac{e^2}{g_2} = \frac{\text{Tr} T_3^2}{\text{Tr} (Q_{em})^2} = \frac{1/2}{3a^2 + 1 + \sum_i b_i^2} \]
If technicolor worked, we are satisfied because the framework (theory) is simple. Complexity of calculation is of human problem.
In this sense, models with MINIMAL something is not compelling.

It works only if the framework is consistent.
But an example in the other way:

Fermi’s beta decay with 34 couplings.
In early 1957, Marshak and Sudarshan noted that V-A structure of weak interaction could explain all but four crucial experiments, and suggested that these four experiments should be redone.

Reduced the number 34 to one \( G_F \). It succeeded because the framework was consistent, and we all follow the SM, succeeding this V-A theory.

Are there another one coupling theory in the market?:

Out of many possible BCM, axion is simple: one parameter the decay constant \( f_a \) because of the anomaly and the Adler-Bardeen theorem.
Poll on Science of CC
Let us aim high at the framework level.

But there must be working examples with this framework.

To prove working examples, exp and th must go together.