Some things I don't like about

Asymmetric Dark Matter

(I think most of you heard the thorough review of Nuria Rius at Lyon)

Sacha Davidson + Martin Elmer
IPN de Lyon/CNRS
arXiv:1208.0551

1. intro: recall some motivating numbers: $\Omega_{cdm} \simeq 5\Omega_b$
2. I don't think that numerology is convincing because...
   - the WIMP miracle
   - Sakharov conditions for an asymmetry

   $\Rightarrow$ Sacha's alternate numerology
3. forget naturalness/numerology:there is a baryon asym, could it give a DM asym?
   - DM an electroweak doublet
   - (why it doesn't work) the other way round? BAU from the WIMP miracle?
4. comments

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1. intro: recall some motivating numbers: $\Omega_{cdm} \simeq 5\Omega_b$
2. I don't think that numerology is convincing because...
   - the WIMP miracle ... freeze-out relic abundance for any particle in TE
   - Sakharov cdns for an asym...complex...CPV when intctns violatg otherwise-conserved Q # go out of TE

   $\Rightarrow$ Sacha's alternate numerology
3. forget naturalness/numerology:there is a baryon asym, could it give a DM asym?
   - DM an electroweak doublet
   - (why it doesn't work) the other way round? BAU from the WIMP miracle?
4. comments on consequences of a DM asym (know nada)

introductory numbers

Densities "today":

$$\begin{aligned}
\Omega_{baryon} \simeq 0.05 &\propto m_p n_p \qquad \text{data}: n_{\bar{p}} \to 0 \quad :(\\
\Omega_{CDM} \simeq 0.27 &\propto m_\chi (n_\chi + n_{\overline{\chi}}) \\
\Omega_\nu = &\propto \overline{m_\nu}(n_\nu + n_{\bar{\nu}}) = \\
\Omega_\gamma = &\propto \rho_\gamma = \frac{\pi^2 T_0^4}{15} \\
\Omega_\Lambda \simeq 0.68 &\propto ?
\end{aligned}$$

$(h^2 = 2?)$
PLANCK

Why a DM Asymmetry?

1. numerology: $\Omega_{cdm} \simeq 5\Omega_b$ (more credible if $m_{DM} \simeq 5$ GeV, $\Rightarrow (n_\chi + n_{\overline{\chi}}) \simeq n_p$)

2. *Model-building Bonanza!* even more freedom than baryogenesis models, can invent the particle, no p decay bds

Recall...the usual stories

We all know the WIMP miracle

particle χ in TE, with $\sigma_{ann}(\chi\bar{\chi} \to SM)$, freezes out at $T < m_\chi$:

$$\Gamma_{ann} \simeq \sigma_{ann}(n_\chi + n_{\bar{\chi}}) \sim H$$

relic abundance normalised to entropy density s:

$$\eta_{te} \equiv \frac{n_\chi + n_{\bar{\chi}}}{s} \sim \frac{H}{\sigma_{ann} s} \propto \frac{T^2}{m_{pl}\sigma T^3} \sim \frac{1}{m_{pl}\sigma m_\chi}$$

$\Rightarrow$ predicts

$$\Omega_{CDM} \approx \frac{\alpha G_F}{\sigma_{ann}}$$

for all/any m_χ!
$\Rightarrow$ need χ interactive enough to be in TE
$\Rightarrow$ $\not{\text{TE}}$ provided by U expansion

...get right observable(=relic density) "for all/any" masses

The baryon density

relic abundance from freeze-out: $\Omega_{b+\bar{b}} \sim \alpha G_F m_p^2 \ll 10^{-7}$
and "no" observational traces of primordial anti-matter

$\Rightarrow$ **make a Baryon Asymmetry of the Universe (BAU)**

Never lose track of the Sakharov conditions:

1. $\not{\mathrm{B}}$: a Lagrangian that only slightly violates a (global) quantum number
2. $\not{\mathrm{C}}\not{\mathrm{P}}$: CPV in interactions that do-not-conserve the global quantum number
3. $\not{\mathrm{T}}\not{\mathrm{E}}$: departure from thermal equilibrium

$\Leftrightarrow$ if interactions that violate an otherwise-conserved quantum # have $\not{\mathrm{C}}\not{\mathrm{P}}$ when they go out of equilibrium, an asym is produced....
In practise:

$\not{\mathrm{C}}\not{\mathrm{P}} \propto$ loop, and many couplings (who can partially cancel in ratio)

$$\frac{(n_b - n_{\bar{b}})}{s} \propto \varepsilon_{cp} \ \eta_{te}$$

$\eta_{te} \propto$ (# parents decaying out of $\not{\mathrm{T}}\not{\mathrm{E}}$)/s

$H \sim \Gamma_{ID} = \Gamma exp\{-M/T\}$

$\eta_{te} \propto \frac{1}{g_*} exp\{-M/T\} \sim \frac{H}{g_* \Gamma} ...$

$$\propto 10^{-2} \frac{\lambda^{2+x}}{8\pi} \frac{M}{\lambda'^n m_{pl}} \lesssim 10^{-4} \frac{M}{\lambda'^n m_{pl}}$$

$\Rightarrow$ generating an asym as large as for protons is *DIFFICULT*

Sacha's numerology for $\Omega_{cdm} \sim \Omega_b$

Suppose the BAU arises due to $\not{\mathrm{T}}\mathrm{E}$, $\not{\mathrm{C}}\mathrm{P}$ decay of ψ (via cpling λ, has mass M):

$$\eta_{te} \equiv \frac{n_\psi \text{who decay out of TE}}{s} \simeq \frac{1}{g_*} \min\left\{1, \frac{H}{\Gamma}\right\}\Big|_{T=M} \simeq \frac{1}{g_*} \frac{C\sqrt{g_*} M^2}{m_{pl}} \frac{8\pi}{\lambda^2 M} \propto \frac{M}{\lambda^2}$$

Suppose DM from the WIMP miracle, $\sigma_{ann} = g^4/(4\pi m_\chi^2)$:

$$\eta_{te} \equiv \frac{n_\chi + n_{\bar{\chi}}}{s} \simeq \frac{H}{\sigma s}\Big|_{T=m_\chi/20} \simeq \frac{C\sqrt{g_*} m_\chi^2}{m_{pl}} \frac{4\pi m_\chi^2}{g^4 g_* m_\chi^3} \propto \frac{m_\chi}{g^4}$$

$$\frac{n_p}{n_\chi + n_{\bar{\chi}}} \simeq \epsilon \frac{M}{m_\chi}$$

the "natural scale" for $m_\chi \sim m_W$

the "natural size" for $\epsilon \lesssim 10^{-4} \to 10^{-7}$

the "natural scale" for M is...far away...flavour scale? GUT scale?

so $n_p \sim (n_\chi + n_{\bar{\chi}})$ if $\epsilon \sim m_\chi/M$

introductory numbers

Densities "today":

$$\Omega_{baryon} \simeq 0.05 \quad \propto \quad m_p n_p \qquad \text{data} : n_{\bar{p}} \to 0 \quad : ($$

$$\Omega_{CDM} \simeq 0.27 \quad \propto \quad m_\chi (n_\chi + n_{\overline{\chi}})$$

$(h^2 = 2?)$
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Why a DM Asymmetry?

1. numerology: $\Omega_{cdm} \simeq 5\Omega_b$ (more credible if $m_{DM} \simeq 5$ GeV, $\Rightarrow (n_\chi + n_{\overline{\chi}}) \simeq n_p$)

2. *Model-building Bonanza!* even more freedom than baryogenesis models, can invent the particle, no p decay bds

3. forget naturaless: work with what we know — baryon asym has to be generated, ? make a DM asym in the same process?

4. pheno: if $n_{\overline{\chi}} \neq n_\chi$, what signatures?

Linked generation of Dark Matter and baryon asymmetries

1. attribute a global quantum number to DM

2. generate a primordial asym in the SM and/or dark sectors

3. (if neccessary, add a mechanism for sharing the asym)

4. ensure that the symmetric relic abundance (sym + asym) of DM is correct (challenge for 5 GeV DM)

Raidal,Sannino,Strumia

Notice that...(an idea that works)

- if an asymmetry (to be the BAU) is generated prior to the EW Phase Transition...
- then the asym is distributed among particles in chem equilibrium

  ($\Gamma > H$ for gauge, Yukawas, strong+EW sphalerons)
- At the EPT, the EW sphalerons turn off...
- ...if DM is an doublet fermion, an asym freezes in?

1. if DM asym as big as the baryon asym, need $m_\chi \sim 5$ GeV? (maybe would have seen a 5 GeV EW doublet???)

2. Or... for $m_\chi \gg T_{EPT}$,

$$n_\chi - n_{\bar{\chi}} \sim \exp\left\{-\frac{m}{T_{EPT}}\right\} n_b$$

choose $m_\chi (\sim$ TeV) such that $m_\chi \exp\{-m_\chi/T_{ept}\} \sim 5 m_p$ to get

$$m_\chi (n_\chi - n_{\bar{\chi}}) \sim 5 m_p n_p$$

? Start from WIMP miracle, and obtain BAU? (an idea that does not want to work)

Randall ETAL
SD+Elmer

...rather than giving up the WIMP miracle and linking Ω_{DM} to the random Ω_b...

Suppose the WIMP miracle gives CDM.
Then, is $\Omega_{DM} \sim \Omega_b$ because the BAU is generated in $\mathcal{CP}$ interactions of WIMPs?

Tis difficult

$$\frac{n_b - n_{\bar{b}}}{s} \propto \epsilon_{cp}\eta_{te} \ , \quad \text{so if} \quad \eta_{te} \simeq \frac{n_\chi + n_{\bar{\chi}}}{s} \propto \frac{\Omega_{cdm}}{m_\chi} \quad \Rightarrow \quad \Omega_b \propto \frac{m_p}{m_\chi}\epsilon_{cp}\Omega_{cdm}$$

Comments...

The WIMP miracle is generic: any particle species in equilibrium freezes out.

The "WIMP miracle" has expecdictions: it hints that DM has weak interactions, and motivates $\rightarrow$ direct detection
$\rightarrow$ indirect detection
$\rightarrow$ collider production?

But observed is $\Omega_{cdm} \sim m_\chi(n_\chi + n_{\bar{\chi}})$. Its possible that $n_\chi \gg n_{\bar{\chi}}$...
$\Rightarrow$ **1**: no indirect detection?
$\Rightarrow$ **2**: unclear if χ interacts with detectors or protons
$\rightarrow$ if was in TE, need efficient annihilation to obtain $n_\chi \gg n_{\bar{\chi}}$:)
$\rightarrow$ if produced by decays of NP, maybe hardly talk to SM? :(

If WIMPS ever in trouble with data, ADM has more free parameters :)

if B asym originates prior tp EPT There are asyms in the plasma prior to the EPT. So some DM candidates who freezes out prior to the EPT, automatically have an asym.
If its not automatic...can add new particles and interactions to ensure that they do...

We know asym generation works for the baryons. Why not an independent asym generation mechanism for the DM?