Inflato-Natural Leptogenesis: Leptogenesis in Chromo-Natural Inflation and Gauge-Flation

based on arXiv:1208.2807 with M. M. Sheikh-Jabbari

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BARYON ASYMMETRY

- There is no evidence for anti-baryons in our universe, at least as far as we can see in our surroundings.
- Question: Why is so? Why are baryons favored over anti-baryons?

Baryon Asymmetry

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- Question: Why is so? Why are baryons favored over anti-baryons?
- There are far more photons in our universe than baryons: $\eta \approx 5 \times 10^{-10}$.
- Question: Why is so? Why are photons so much favored?

BARYON ASYMMETRY

- Possible conclusion: The universe started from *almost* equal number of quarks and anti-quarks.
- But there was a tiny asymmetry:

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- With $n_q = 10^9$ and $n_{\bar{q}} = 10^9 - 1$, the result of $q\bar{q} \to \gamma\gamma$ will be one quark among 2×10^9 photons with no anti-quarks left. This gives the desired value $\eta \approx 5 \times 10^{-10}$.

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- Historically not appealing to people.
- Inflation washes out asymmetric initial conditions.
- Need dynamical baryon asymmetry generation: Baryogenesis.

Sakharov Conditions (1967)

Three necessary conditions for dynamical generation of baryon asymmetry from symmetric initial conditions:

- Baryon number violation.
- C and CP violation.
- Departure from equilibrium.

THE MECHANISMS

- Even within the standard model all of Sakharov conditions are satisfied (no need for beyond SM).
- SM can also transfer an asymmetry generated in the lepton number to one in the baryon number (baryogenesis via leptogenesis).
- But SM baryogenesis doesn't seem to be effective. Need beyond SM, and there are plenty of them.

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- SM can also transfer an asymmetry generated in the lepton number to one in the baryon number (baryogenesis via leptogenesis).
- But SM baryogenesis doesn't seem to be effective. Need beyond SM, and there are plenty of them.
- These 'conventional' scenarios take place after inflation.
- Gravi-leptogenesis is a mechanism to generate lepton asymmetry during inflation.

Inflation

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- Should last for at least ~ 60 e-foldings to solve problems of cosmology.
- Dilutes all primordial relics, including baryon asymmetry.
- It's sufficient to have (almost) constant energy density:

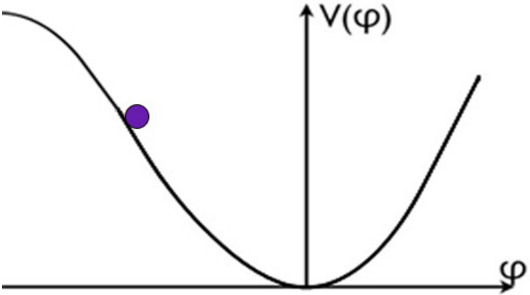
$$3H^2 = \rho \Longrightarrow a \sim e^{Ht}$$

- During inflation the Hubble parameter H is almost constant:

$$\epsilon = -\frac{\dot{H}}{H^2} \ll 1, \qquad \eta = \frac{\ddot{H}}{2H\dot{H}} \ll 1.$$

INFLATION

Inflation can be achieved by a scalar field (inflaton) slowly rolling down a flat potential. Once the inflaton reaches the end of the plateau it begins to oscillate and inflation ends, transferring its energy to the (SM/GUT) particles and leading to the standard radiation dominated era of cosmology.



CHROMO-NATURAL INFLATION

[Adshead, Wyman, arXiv:1202.2366]

- Ingredients: metric, non-abelian ($SU(2)$) gauge field, and axion, with the action:

$$\mathcal{L} = \frac{1}{2}R - \frac{1}{4}\mathrm{tr}F^2 - \frac{1}{2}(\partial\chi)^2 + \frac{\lambda}{8f}\chi\mathrm{tr}F\tilde{F} - \mu^4\left(1 + \cos\frac{\chi}{f}\right).$$

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- Along the inflationary trajectory:

$$A^a_\mu = \begin{cases} 0 & \mu = 0, \\ a\psi\delta^a_i & \mu = i. \end{cases}$$

and ψ is a scalar under rotations.

Chromo-Natural Inflation

- In addition, ψ and χ are interlocked and effectively act as one degree of freedom:

$$\sin\frac{\chi}{f} \approx \frac{3g\lambda}{\mu^4} H\psi^3,$$

both of which roll slowly:

$$\frac{\dot{\chi}}{H\chi}, \frac{\dot{\psi}}{H\psi} \ll 1.$$

- Finally:

$$3H^2 \approx \mu^4 \left(1 + \cos\frac{\chi}{f}\right).$$

CHROMO-NATURAL INFLATION

Two extreme regimes:

- Small axion ($\chi/f \ll \pi$):

$$\lambda = 200, \quad g = 2\times 10^{-6},$$
$$f = 10^{-2}, \quad \mu^2 = 10^{-7}, \qquad H \simeq 8\times 10^{-8}.$$

- Large axion ($\chi/f \approx \pi$):

$$\lambda = 2\times 10^{4}, \quad g = 10^{-3},$$
$$f = 10^{-2}, \qquad \mu^2 = 1.6\times 10^{-3}, \quad H \simeq 3.3\times 10^{-5}.$$

(coincides with gauge-flation)

[Maleknejad, Sheikh-Jabbari, arXiv:1102.1513 and 1102.1932]

Gravitational Chiral Anomaly

- The lepton number current

$$J_\ell^\mu = \bar{\ell}_i \gamma^\mu \ell_i + \bar{\nu}_i \gamma^\mu \nu_i$$

is anomalous:

$$\partial_\mu J_\ell^\mu = \frac{n_L - n_R}{16\pi^2} R\tilde{R},$$

where

$$R\tilde{R} = \frac{1}{2} \epsilon^{\alpha\beta\gamma\delta} R_{\alpha\beta\rho\sigma} R_{\gamma\delta}{}^{\rho\sigma}.$$

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- In usual applications spacetime is flat and the RHS is zero.
- It also vanishes on the inflationary (or any FRW) background since it is parity symmetric. Not promising.

[Alexander, Peskin, Sheikh-Jabbari, hep-th/0403069]

- However, $R\tilde{R}$ can receive a nonzero contribution at the level of perturbations if the inflaton field is a pseudo-scalar and relays P violation to metric perturbations h via a coupling

$$\frac{\mathcal{N}}{16\pi^2}\frac{\chi}{\mathcal{F}}R\tilde{R}.$$

Motivated by string theory: $\mathcal{N} \sim 10^3$–10^4 and $\mathcal{F}$ is the string scale satisfying the hierarchy:

$$\mu \lesssim f, \Lambda \lesssim \mathcal{F} \lesssim 1,$$

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with Λ being the gravitational cutoff.
- Therefore the same agent that drives inflation (and hence washes out asymmetries) is responsible for the generation of the lepton number asymmetry.
- This is how gravi-leptogenesis overcomes the standard argument/lore mentioned earlier.

- The term $\chi R\tilde{R}$ in the action modifies the gravity wave equation:

$$\Box h_L = -2i\frac{\Theta}{a}\dot{h}_L',$$

where

$$\Theta \simeq -\frac{\mathcal{N}\epsilon}{2\pi^2}H^2\frac{f}{\mathcal{F}}\tan\frac{\chi}{f}.$$

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- Plugging h_L and h_R into the anomaly equation and computing $\int J_\ell^0\sqrt{g}d^3x$ one finds:

$$n = \frac{1}{72\pi^4}\frac{\Lambda^6}{H}|\Theta|.$$

The amount of asymmetry is controlled by Θ.

- To obtain the produced baryon-to-photon ratio we also need to compute the entropy, which depends on the reheating model.
- We can parameterize reheating by its efficiency σ:

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- Put together:

$$\frac{n}{s} = 3 \times 10^{-6} g_*^{-1/4} \sigma^{-3/4} \mathcal{N} \epsilon H^{-1/2} \Lambda^6 \frac{f}{\mathcal{F}} \left| \tan \frac{\chi}{f} \right| .$$

Results

- We want to get $n/s \sim 10^{-10}$ with $g_* \sim 10^2$, $\mathcal{N} \sim 10^3$, and $\sigma \sim 10^{-20}$.
- Small axion:
  - For both $\mathcal{F} = 1$ and $\mathcal{F} = \Lambda$ we get $\Lambda \sim \mu \sim 10^{15}$ GeV.
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  - Good! A single cutoff works for both axion and gravity theory.
- Large axion:
  - For both $\mathcal{F} = 1$ and $\mathcal{F} = \Lambda$ we get $\Lambda \sim 10^{15}$ GeV.
  - But now $\mu \sim 10^{17}$ GeV.
  - Still fine since $H \ll \Lambda$.

A Simpler Possibility?

- Both chromo-natural inflation and gauge-flation have built-in chiral gravitons, even without the additional term $\chi R\tilde{R}$.

  [Adshead, Martinec, Wyman, arXiv:1301.2598]
- So maybe the model is rich enough in itself to account for leptogenesis without ad hoc modifications.
- Actual calculations needed; but doesn't look promising.

Summary

- Gravi-leptogenesis is applied to chromo-natural inflation and to gauge-flation.
- The models are capable of producing the observed baryon asymmetry with reasonable choices of parameters.
- The situation is a little bit better for the small axion case.
- The intrinsic capacity of the models to generate asymmetry needs to be studied.