Out of Equilibrium Baryogenesis with Gravitino Dark Matter

Giorgio Arcadi
Georg-August Universität Göttingen

Based on
G.A., L. Covi and M. Nardecchia
(to appear on PRD)
plus
work in preparation

PEOPLE

invisibles
neutrinos, dark matter & dark energy physics

OUTLINE OF THE TALK

General idea: Contemporary production of DM and baryon asymmetry from decay of a mother particle.

Embedding on Supersymmetric scenario: Wimp(like) mother particle and gravitino DM.

Concrete realization.

BARYOGENESIS AND SUPERWIMP MECHANISM

Baryon asymmetry and DM relic density generated by out-of-equilibrium decay of a same mother particle.

$$\Omega_{\Delta B} = \frac{m_p}{m_\chi} \epsilon_{\rm CP} BR\left(\chi \to \not{B}\right) \Omega_\chi^{\tau \to \infty}$$

Small parameter

$$\Omega_{\rm DM} = \frac{m_{\rm DM}}{m_\chi} BR\left(\chi \to DM + \text{anything}\right) \Omega_\chi^{\tau \to \infty}$$

Small parameter

$$\frac{\Omega_{\Delta B}}{\Omega_{\rm DM}}=\frac{m_p}{m_{\rm DM}}\epsilon_{\rm CP}\frac{BR\left(\chi\rightarrow \not{B}\right)}{BR\left(\chi\rightarrow DM+\mbox{anything}\right)}$$

The ratio between the Baryon and DM relic density is independent from the abundance of the mother particle.

The correct value can be achieved through a suitable choice of the parameters of the underlying particle theory.

Simple Example: The correct value can be realized with BR into DM of the order of the CP-asymmetry and DM mass close to the one of the proton.

BARYOGENESIS WITH GRAVITINO DM

A rather natural playground for this scenario are RPV SUSY scenarios with gravitino DM.

Gravitino is stable on cosmological scales even in presence of B(L)-violating couplings.

Superpartners decay with a Planck suppresed rate:

$$\Gamma\left(\tilde{X}_i \rightarrow \tilde{G} + X_i\right) = \frac{1}{48\pi} \frac{m_{\tilde{X}_i}^5}{m_{3/2}^2 M_{\rm Pl}^2}$$

The branching ratio of decay into DM can easily achieve the desired suppression.

IMPLEMENTATION IN LOW ENERGY BARYOGENESIS

An interesting possibility for the mother state is a metastable WIMP-like particle.

Baryon asymmetry and DM produced by late decay after conventional freeze-out

→ Abundance of the mother particle tightly related to the parameters of the particle framework.

↓

The production of the baryon asymmetry and of the DM can occur at TeV scale temperatures or even below.

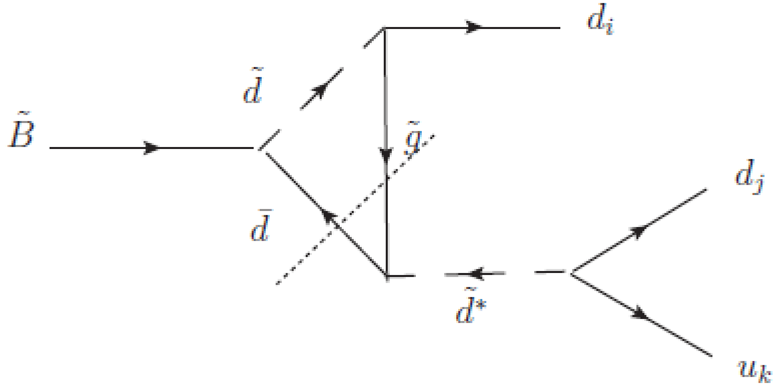
↓

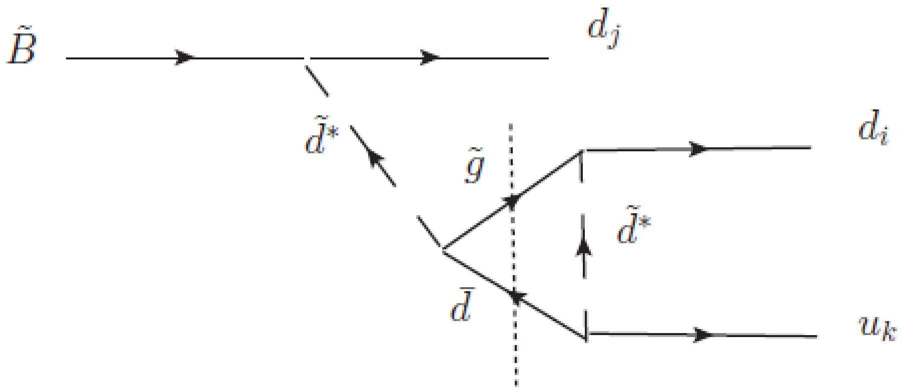
Wash-out processes not effective.(Y. Cui and R. Sundrum, 1212.2973)

Case of study: Split-Susy like scenario, arXiv:1309.2952

Direct Baryogenesis through $\lambda'' U^c D^c D^c$

$$m_{\tilde{g}} < m_{\tilde{B}} \ll m_{\tilde{d}} = m_0$$





Present only with flavor violation

Baryon asymmetry enhanced in case of a non trivial flavor structure

Illustrative scenario:no flavor violation

$$\Gamma\left(\tilde{B}\to udd+\overline{u}\overline{d}\overline{d}\right)=\frac{\lambda^2 g_1^2 N_{\rm RPV}}{768\pi^3}\frac{m_{\tilde{B}}^5}{m_0^4}$$

$$\Gamma\left(\tilde{B}\to \tilde{g}f\overline{f}\right)=\frac{\left(g_1 g_3 Q_f\right)^2 N_{\rm RPC}}{256\pi^3}\frac{m_{\tilde{B}}^5}{m_0^4}$$

→

$$\epsilon_{\rm CP}=\frac{8}{3}Im\left[e^{i\phi}\right]\frac{m_{\tilde{B}}m_{\tilde{g}}}{m_0^2}\alpha_s\left(1+\frac{2\pi N_{\rm RPC}\alpha_s}{N_{\rm RPV}\lambda^2}\right)^{-1}$$

Baryon Asymmetry

$$\Gamma\left(\tilde{B}\to\tilde{G}+X\right)=\frac{1}{48\pi}\frac{m_{\tilde{B}}^5}{m_{3/2}^2 M_{\rm Pl}^2}$$

→ DM generation

$$Br\left(\tilde{B}\to\tilde{G}+X\right)\approx 5.7\times 10^{-10}\left(1+\frac{N_{\rm RPV}\lambda^2}{\pi N_{\rm RPC}\alpha_s}\right)^{-1}\left(\frac{m_{3/2}}{1{\rm GeV}}\right)^{-2}\left(\frac{m_0}{10^6{\rm GeV}}\right)^4$$

→ Suppressed branching ratio. Does not influence generation of baryon asymmetry.

$$\Omega_{\Delta B} \approx 3.3 \times 10^{-2} \frac{x_{\rm f.o.}}{A(x_{\rm f.o.})} \left(\frac{m_{\tilde{B}}}{1\rm TeV}\right) \left(\frac{m_{\tilde{g}}}{m_{\tilde{B}}}\right) \left(\frac{\mu}{10^{3/2} m_0}\right)^2 \left(\frac{\lambda^2 N_{\rm RPV}}{\pi N_{\rm RPC} \alpha_s}\right) \left(1 + \frac{\lambda^2 N_{\rm RPV}}{\pi N_{\rm RPC} \alpha_s}\right)^{-1}$$

$$\Omega_{3/2}^{\rm SW} \approx 2.34 \times 10^{-3} \left(\frac{\mu}{10^{3/2} m_0}\right)^2 \left(\frac{m_0}{10^6 \rm GeV}\right)^6 \left(\frac{m_{\tilde{B}}}{1\rm TeV}\right)^{-1} \left(\frac{m_{3/2}}{1\rm GeV}\right)^{-1} \frac{x_{\rm f.o.}}{A(x_{\rm f.o.})} \left(1 + \frac{N_{\rm RPV} \lambda^2}{\pi N_{\rm RPC}}\right)^{-1}$$

$$\frac{\Omega_{\Delta B}}{\Omega_{DM}} \approx 3.3\, \xi \left(\frac{\lambda}{0.1}\right)^2 \left(\frac{m_{3/2}}{m_p}\right) \left(\frac{m_{\tilde{g}}}{m_{\tilde{B}}}\right) \left(\frac{m_{\tilde{B}}}{1\rm TeV}\right)^2 \left(\frac{m_0}{10^6 \rm GeV}\right)^{-6}$$

Limitation of the computations:

Effects of annihilations

Chemical decoupling of the Bino

Other production mechanisms of the gravitino

Two other production mechanisms for gravitino.

Thermal scatterings: gravitino density determined by gaugino masses and reheating temperature.
(Strumia et al 2007,Olechowski et al 2009)

Freeze-in: production from superpartners while still in equilibrium. (Cheung et al 2011)

$$\Omega_{3/2}^{\rm FIMP} = \frac{1.09 \times 10^{27}}{g_*^{3/2}} m_{3/2} \sum_i g_i \frac{\Gamma_i}{m_i^2} \longrightarrow \Gamma_i \propto m_i^5$$

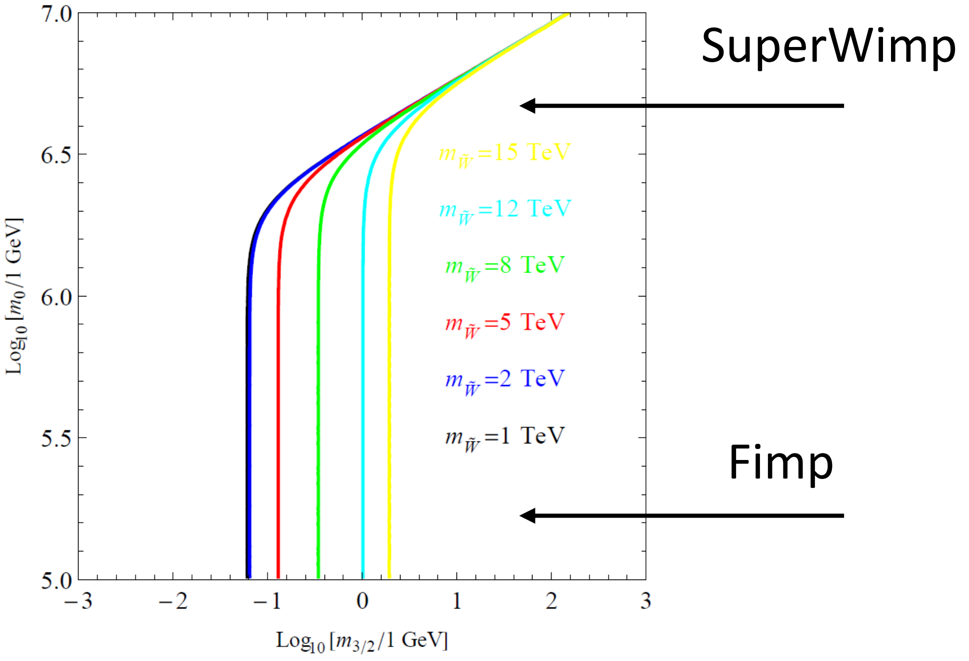
DM overproduced by the decays of the scalars

We can suppress dangerous contributions by setting $T_{\rm RH} < m_0$

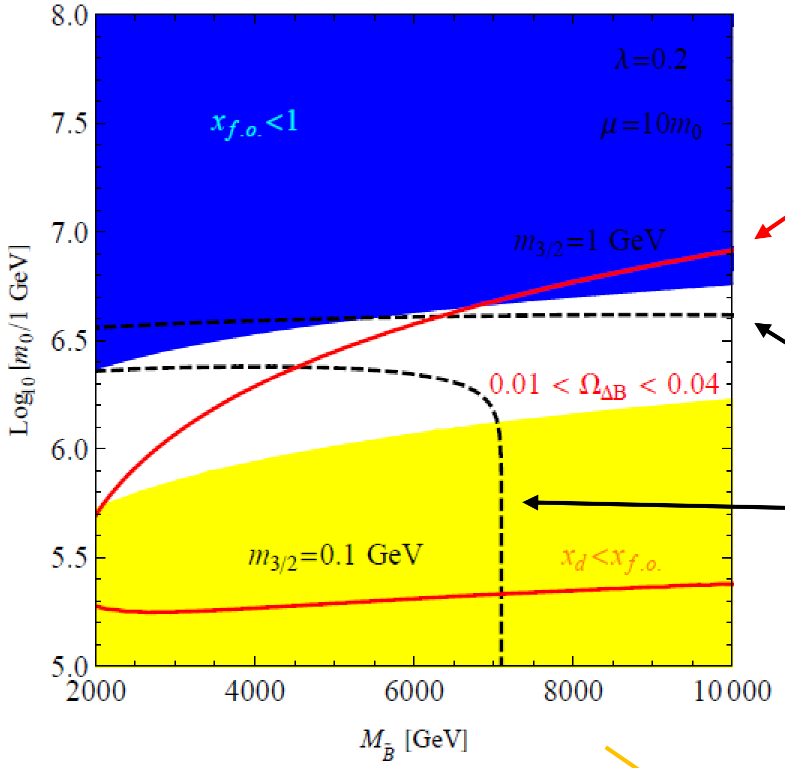
Freeze-in production from gauginos not suppressed

$$\Omega_{3/2}^{\rm FI} \approx 7 \times 10^{-4} \left(\frac{m_{\tilde{B}}}{1{\rm TeV}}\right)^3 \left(\frac{m_{3/2}}{1{\rm GeV}}\right)^{-1} \left[1 + 3\left(\frac{m_{\tilde{W}}}{m_{\tilde{B}}}\right)^3 + 8\left(\frac{m_{\tilde{g}}}{m_{\tilde{B}}}\right)^3\right]$$

$$\frac{\Omega_{3/2}^{\rm SW}}{\Omega_{3/2}^{FI}} \approx 0.1 \left(1 + \frac{N_{\rm RPV}\lambda^2}{\pi N_{\rm RPC}\alpha_s}\right)^{-1} \left(\frac{m_{\tilde{B}}}{1{\rm TeV}}\right)^{-4} \left(\frac{\mu}{m_0}\right)^2 \left(\frac{m_0}{10^6{\rm GeV}}\right)^6$$
$$\times \frac{x_{\rm f.o.}}{\left[A(x_{\rm f.o}) + 7.19 \times 10^{-2} \left(\frac{\lambda}{0.1}\right)^2 \frac{m_{\tilde{B}}^2}{m_0^2} \left(\frac{\mu}{m_0}\right)^2 B(x_{f.o})\right]} \frac{1}{\left[1 + 3\left(\frac{m_{\tilde{W}}}{m_{\tilde{B}}}\right)^3 + 8\left(\frac{m_{\tilde{g}}}{m_{\tilde{B}}}\right)^3\right]}$$



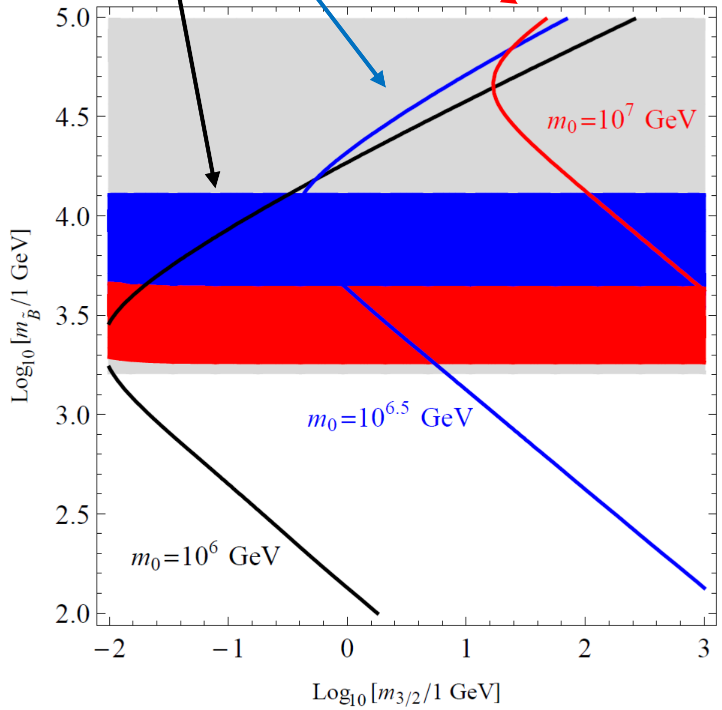
Relativistic decoupling of the Bino



$$0.01 \leq \Omega_{\Delta B} \leq 0.04$$

$$\Omega_{\rm DM} h^2 \approx 0.11$$

$$\frac{\Omega_{\Delta B}}{\Omega_{\rm DM}} \sim 0.2$$



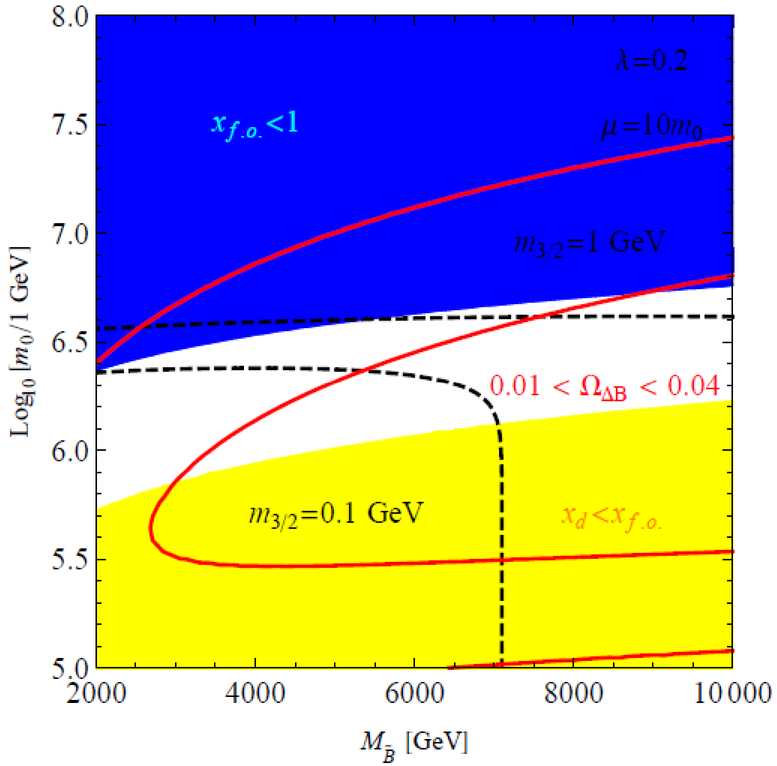
Time scales of annihilation and decay comparable.
Effects of annihilation should be taken into account

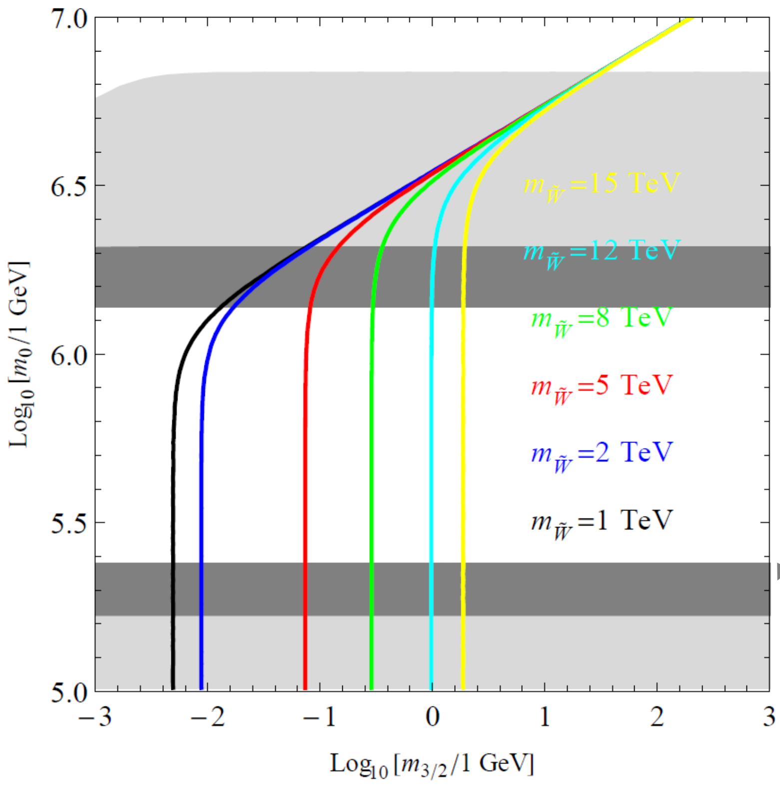
Second example: Left-right mixing.

Asymmetry increased in case of left-right mixing

$$\epsilon_{\rm CP} = \frac{16}{15} Im\left[e^{i\phi}\right]\left(\frac{m_{\tilde{t}_1}^2 v^2 X_t^2}{\left(m_{\tilde{t}_1}^2 + v|X_t|\right)^3} + \frac{5}{2}\frac{m_{\tilde{g}}}{m_{\tilde{B}}}\right)\frac{m_{\tilde{B}}^2}{m_0^2}\alpha_s\left(1 + \frac{2\pi N_{\rm RPC}\alpha_s}{N_{\rm RPV}\lambda^2}\right)^{-1}$$

$X_t \sim m_t \mu$





$0.03 \lesssim \Omega_{\Delta B} \lesssim 0.04$

$0.01 \lesssim \Omega_{\Delta B} \lesssim 0.03$

DETECTION PROSPECTS

$$\Gamma_{3/2} = N_c \frac{\lambda^2}{6144\pi^3} \frac{m_{3/2}^7}{m_0^4 M_{\rm Pl}^2} \longrightarrow \tau_{3/2} \approx \frac{7.4}{N_c} \times 10^{43}{\rm s} \left(\frac{\lambda}{0.1}\right)^{-2} \left(\frac{m_0}{10^6 {\rm GeV}}\right)^4 \left(\frac{m_{3/2}}{1 {\rm GeV}}\right)^{-7}$$

Decay rate of the gravitino higly suppressed by the scalar mass scale; beyond the reach of current and next future detectors.

SUSY spectrum beyond the reach of the LHC apart possibly the gluino.

$$c\tau_{\tilde{g}} \approx \frac{14.1}{N_c} {\rm cm} \left(\frac{\lambda}{0.1}\right)^{-2} \left(\frac{m_0}{10^6 {\rm GeV}}\right)^4 \left(\frac{m_{\tilde{g}}}{1 {\rm TeV}}\right)^{-5}$$

Rather long-lived gluino → Displaced vertex or even detector stable.

CONCLUSIONS AND PROSPECTS

Common production from decay is an intriguing possibility for the contemporary solution of the Baryogenesis and DM puzzles.

An intersting realization can be achieved form the decay of a metastable WIMP-like state in SUSY models with gravitino DM.

Prospects and Improvements

More systematic study.

Implementation of proper numerical treatment.