

Heavy Gravitino and Split SUSY in the Light of BICEP2

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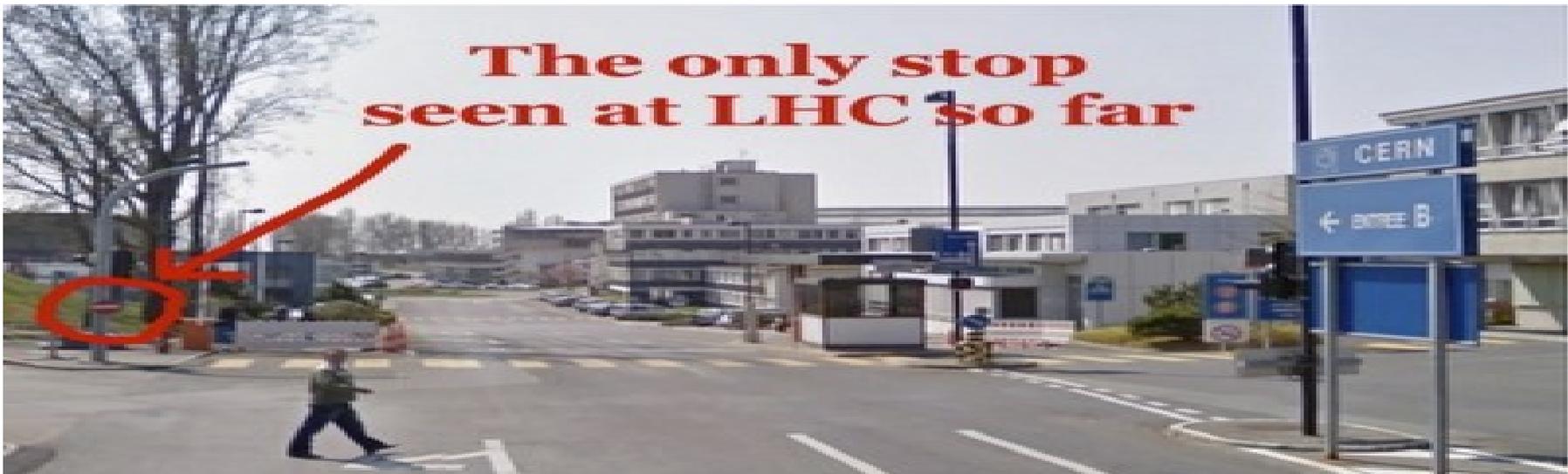


Work done with **JiJi Fan**, **Bithika Jain**
[arXiv:1404.1914]

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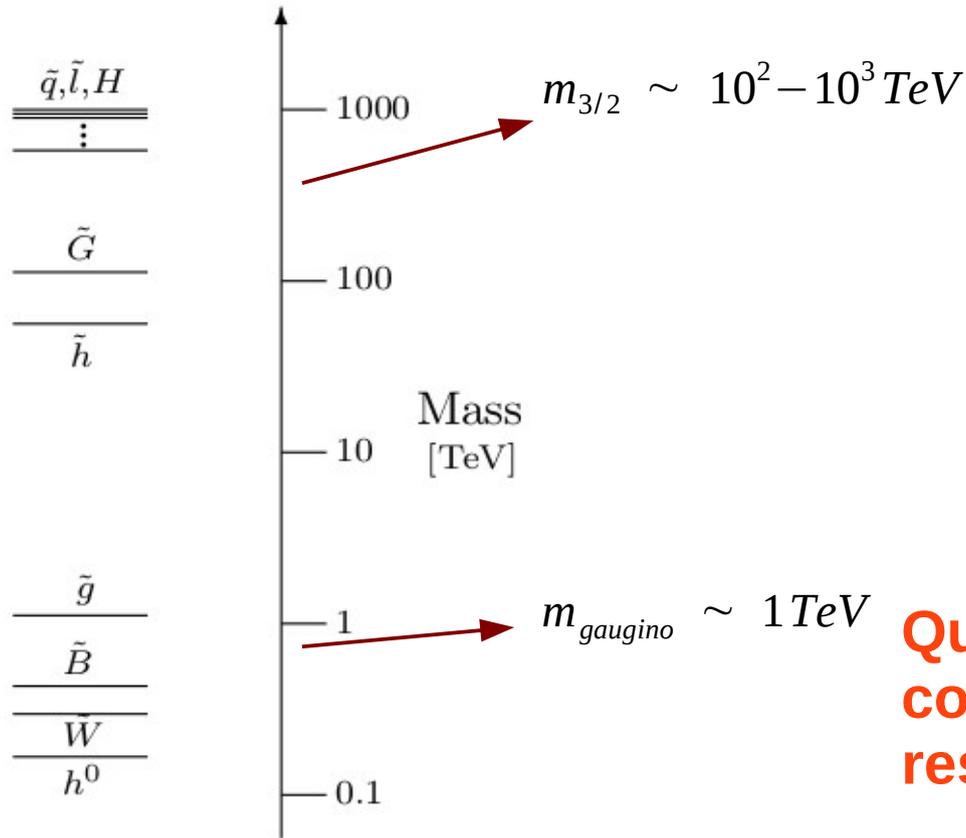
Motivation

- SUSY is still a favorite BSM physics framework
 - Current status of the experiments at the LHC



- Tension between data and low scale SUSY (naturalness)
- Alternative route \longrightarrow High-scale fine tuned SUSY: Split SUSY*
 - *Wells, Arkani-Hamed & Dimopoulos, Giudice & Romanino
- Virtues: Amelioration of CP and SUSY flavor problems, gauge coupling unification, natural DM candidate !

Motivation



→ Irreducible non-thermal contribution to DM abundance

→ Indirect DM searches sets strong bounds on the model parameters (if DM is Wino)

Question: Is this scenario compatible with recent BICEP2 result ?

Guidice et.al. ,[arXiv:hep-ph/9810442]
Randall & Sundrum [arxiv:hep-th/9810155]

Hall et.al. , [arXiv:hep-ph/1210.2395]
Arvanitaki et.al., [arXiv:hep-ph/1210.0555]

Gravitino Relic Abundance

- Main contribution:

- Scattering of MSSM particles* in the post-inflationary plasma

$$\Omega_{3/2}^{UV} h^2 \simeq 5.1 \times 10^{-2} \left(\frac{m_{3/2}}{1 \text{ TeV}} \right) \left(\frac{T_R}{10^9 \text{ GeV}} \right)$$

- Other contributions:

→ “Freeze-in”**

→ Decays of Inflaton***

*Pradler & Steffen , [arXiv:hep-ph/0612291],
*Rychkov & Strumia , [arXiv: hep-ph/0701104]
**Hall et.al , [arXiv: hep-ph/0911.1120]]

- Total : $\Omega_{3/2}^T h^2 = \Omega_{3/2}^{UV} h^2 + \dots$

***Kallosh et.al., [arXiv:hep-th/9907124]
Kawasaki et.al., [arXiv:hep-ph/0603265]

Wino Relic Abundance

→ Ineffective annihilations: $(10 \text{ TeV} < m_{3/2} < 10^4 \text{ TeV})$

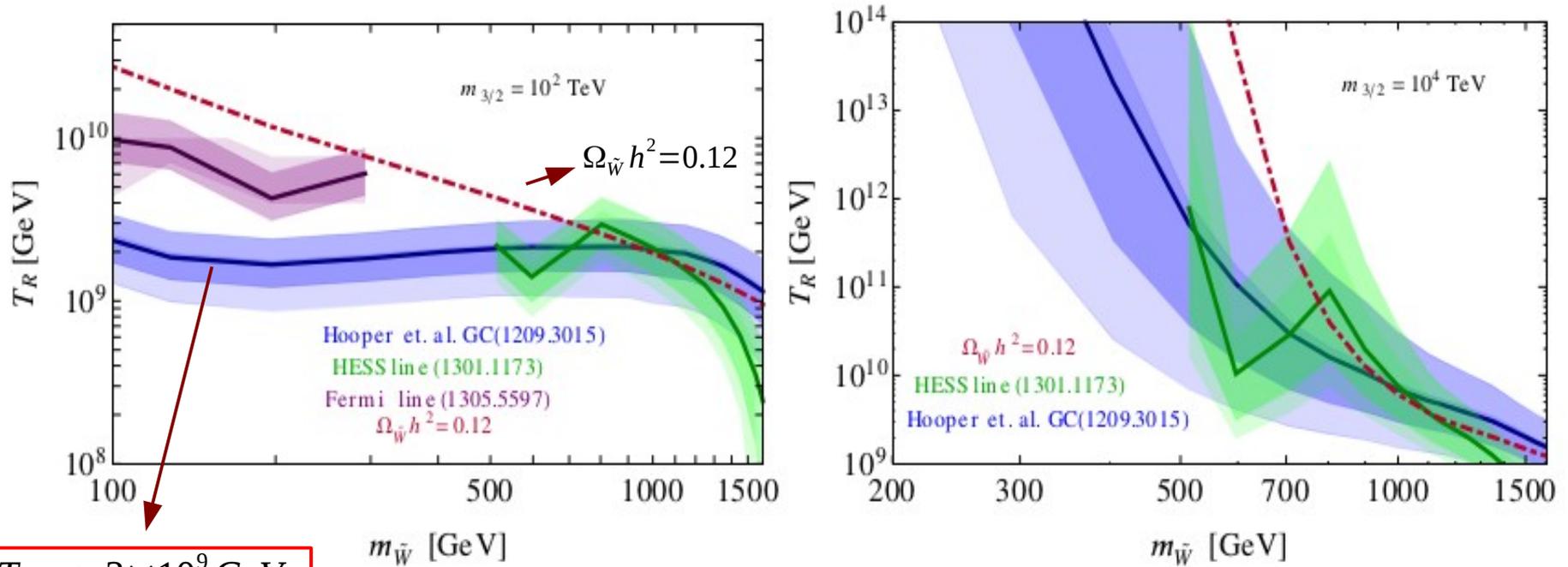
$$\begin{aligned} \Omega_{\tilde{W}}^{(no-ann)} h^2 &\simeq \frac{m_{\tilde{W}}}{m_{3/2}} \left[\Omega_{3/2}^{UV} h^2 + \dots \right] \\ &\simeq 0.12 \left(\frac{m_{\tilde{W}}}{1 \text{ TeV}} \right) \left[\frac{T_R}{2 \times 10^9 \text{ GeV}} + \dots \right] \rightarrow \text{Independent on } m_{3/2} \end{aligned}$$

→ Effective annihilations: $(m_{3/2} > 10^4 \text{ TeV})$

$$\Omega_{\tilde{W}}^{(ann)} h^2 \simeq 0.12 \left(\frac{75.75}{g_{eff}} \right)^{1/4} \left(\frac{m_{\tilde{W}}}{1 \text{ TeV}} \right) \left(\frac{1.2 \times 10^{-7} \text{ GeV}}{\langle \sigma v \rangle} \right) \left(\frac{m_{3/2}}{10^4 \text{ TeV}} \right)^{-3/2}$$

→ $T_R < 2 \times 10^9 \text{ GeV} \left(\frac{1 \text{ TeV}}{m_{\tilde{W}}} \right)$

Indirect detection constraints



$$T_R < 3 \times 10^9 \text{ GeV}$$

- Photon continuum : $\tilde{W}^0 \tilde{W}^0 \longrightarrow w^+ w^-$
- Gamma ray lines : $\tilde{W}^0 \tilde{W}^0 \longrightarrow \gamma \gamma \ (\gamma Z)$

Cohen et.al. , [arXiv:1307.4082]
Fan & Reece, [arXiv:1307.4400]

Assuming,
NFW with $\rho(r_{sun}) = 0.29 - 0.54 \text{ GeV cm}^{-3}$
Einasto with $\rho(r_{sun}) = 0.25 - 0.48 \text{ GeV cm}^{-3}$ centered at $\rho(r_{sun}) = 0.4 \text{ GeV cm}^{-3}$

Implications of BICEP2

- Discovery of B-modes:

$$V \approx (2 \times 10^{16} \text{ GeV})^4 \left(\frac{r}{0.1} \right) \quad \frac{\Delta \varphi}{M_{pl}} \approx 6.7 \left(\frac{N_{cmb}}{60} \right) \sqrt{\frac{r}{0.1}}$$

- Large field models with super-planckian excursions preferred! Lyth, [arXiv:9606387]

A crude estimate on the mass of the inflaton

$$m_{\varphi}^2 \sim \frac{V}{(\Delta \varphi)^2} \approx (2 \times 10^{13} \text{ GeV})^2$$

Implications of BICEP2

- Reheating temperature in the light of BICEP2:

$$T_R \approx \sqrt{\Gamma_\varphi M_{pl}}$$

- Simplest possible decay rate through a yukawa coupling:

$$\Gamma_\varphi = \frac{y^2}{8\pi} m_\varphi \longrightarrow T_R \approx 10^{11} \text{ GeV} \left(\frac{y}{10^{-3}} \right) \sqrt{\frac{m_\varphi}{10^{13} \text{ GeV}}}$$

- Or Inflaton will always decay through Planck-suppressed operators:

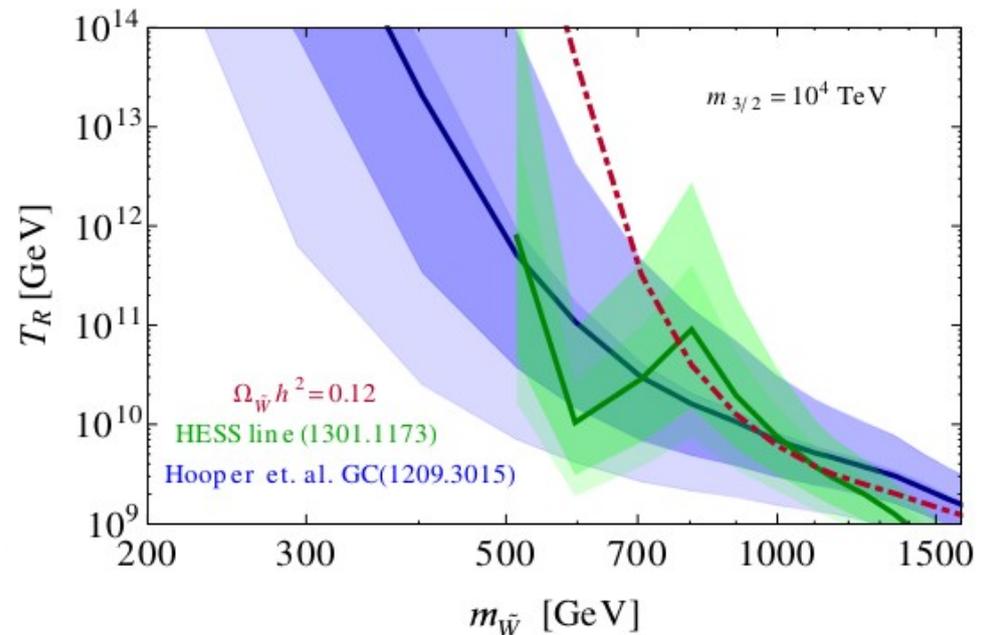
$$\Gamma_\varphi = c \frac{m_\varphi^3}{M_{pl}^2} \longrightarrow T_R \approx 5 \times 10^9 \text{ GeV} \sqrt{c} \left(\frac{m_\varphi}{10^{13} \text{ GeV}} \right)$$

BICEP2 prefers reheating temperature T_R at or above 10^9 GeV !!

Conclusions & Outlook

- Mini-Split SUSY with a heavy unstable gravitino (@PeV scale) requires $T_R < 10^9 \text{ GeV}$ to avoid overproduction of DM from the gravitino decay.
- On the other hand, BICEP2 result prefers high scale inflation with $T_R > 10^9 \text{ GeV}$, **in other words it favors a larger splitting between gravitino and gaugino!!**

Mild tension between simple Mini-Split scenario and BICEP2 !!!



THANK YOU!

Cheat Sheet

$$m_{\text{scalar}} \sim m_{3/2}, \quad m_{\text{gaugino}} \sim \frac{\beta}{4\pi} m_{3/2}$$

Mini-Split

$$\Gamma_{3/2} \approx 2.0 \times 10^{-23} \text{ GeV} \left(\frac{N_G}{12} \right) \left(\frac{m_{3/2}}{100 \text{ TeV}} \right)^3$$

Gravitino Decay Rate

$$\Omega_{3/2}^{FI} h^2 \approx 1.1 \times 10^{-2} \left(\frac{100 \text{ TeV}}{m_{3/2}} \right) \sum_i g_i \left(\frac{m_i}{1000 \text{ TeV}} \right)^3.$$

Freeze-in contribution

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE_\gamma} \int_{\text{ROI}} \rho(r)^2 d\Omega ds$$

Photon flux

$$m_{3/2} \approx \frac{W_0}{M_p^2} \approx \frac{|F_X|}{\sqrt{3} M_p}$$

$$\int d^2\theta d^2\bar{\theta} \frac{X^\dagger X W W_\alpha W^\alpha}{M_*^6} \longrightarrow m_{1/2} \gtrsim \frac{|F_X|^2 W_0}{M_p^6} \approx \frac{3m_{3/2}^3}{M_p^2}$$

Cheat Sheet

