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Light Gravitino DM: Hubble tension and the LHC

Lei Wu (武雷)

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In collaboration with: Y. Gu, M. Khlopov, J. M. Yang and B. Zhu;

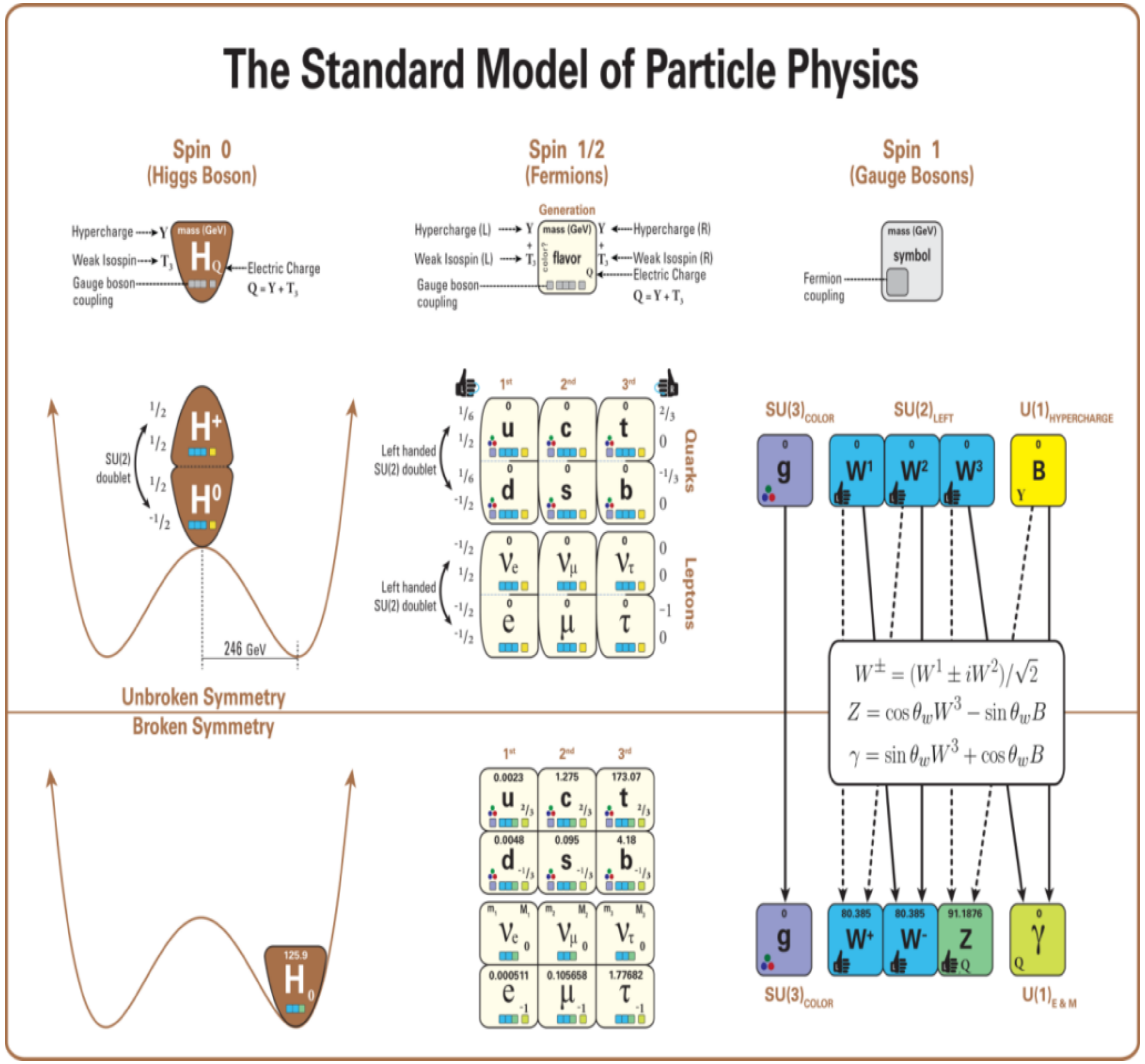
Outline

1. SUSY DM: WIMP and Super-WIMP

2. keV Gravitino DM, Hubble tension and LHC

3. Conclusions

1. SUSY DM: WIMP and Super-WIMP

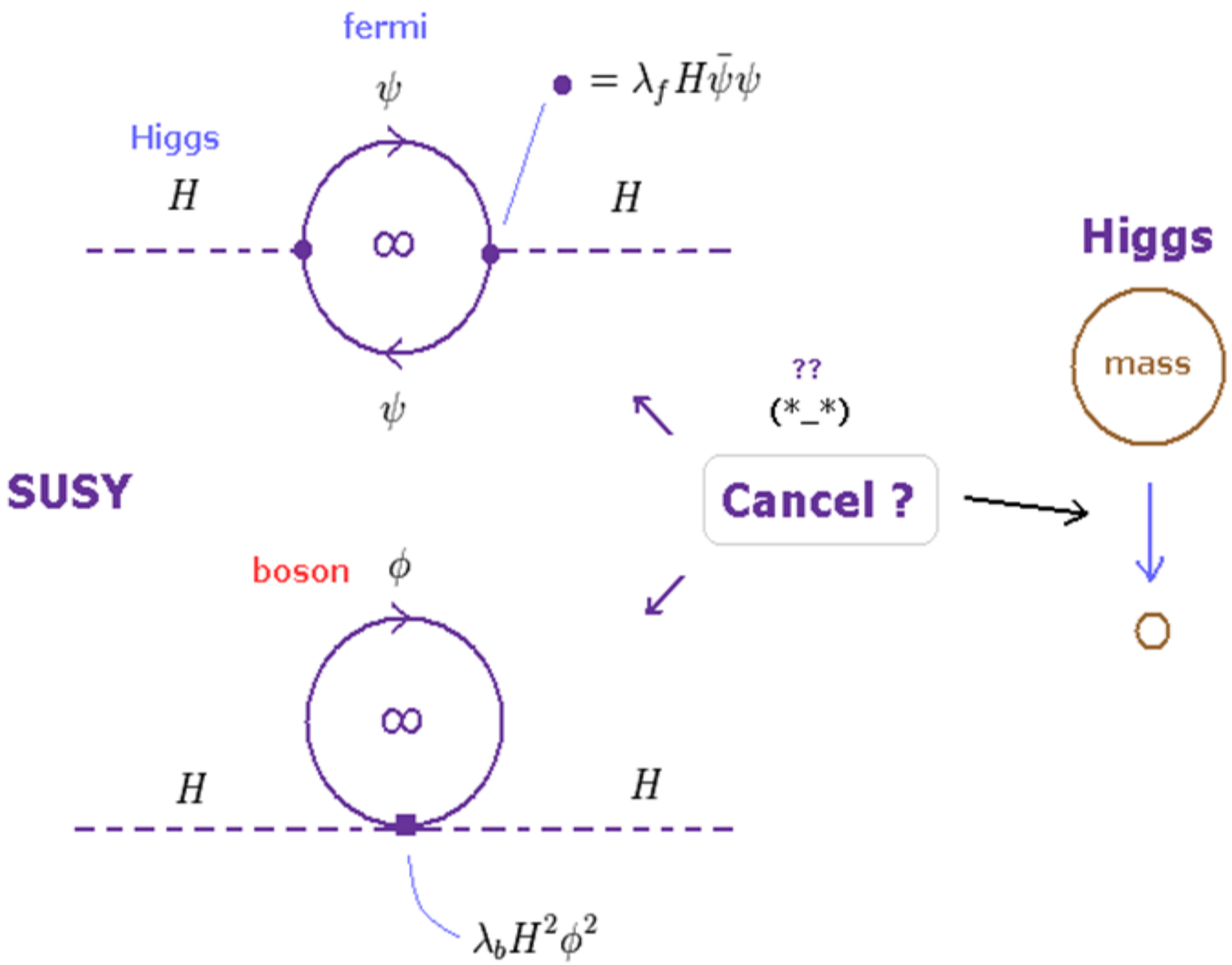


Origin of Mass ?

Nature of Dark Matter ?

Mater-antimatter asymmetry ?

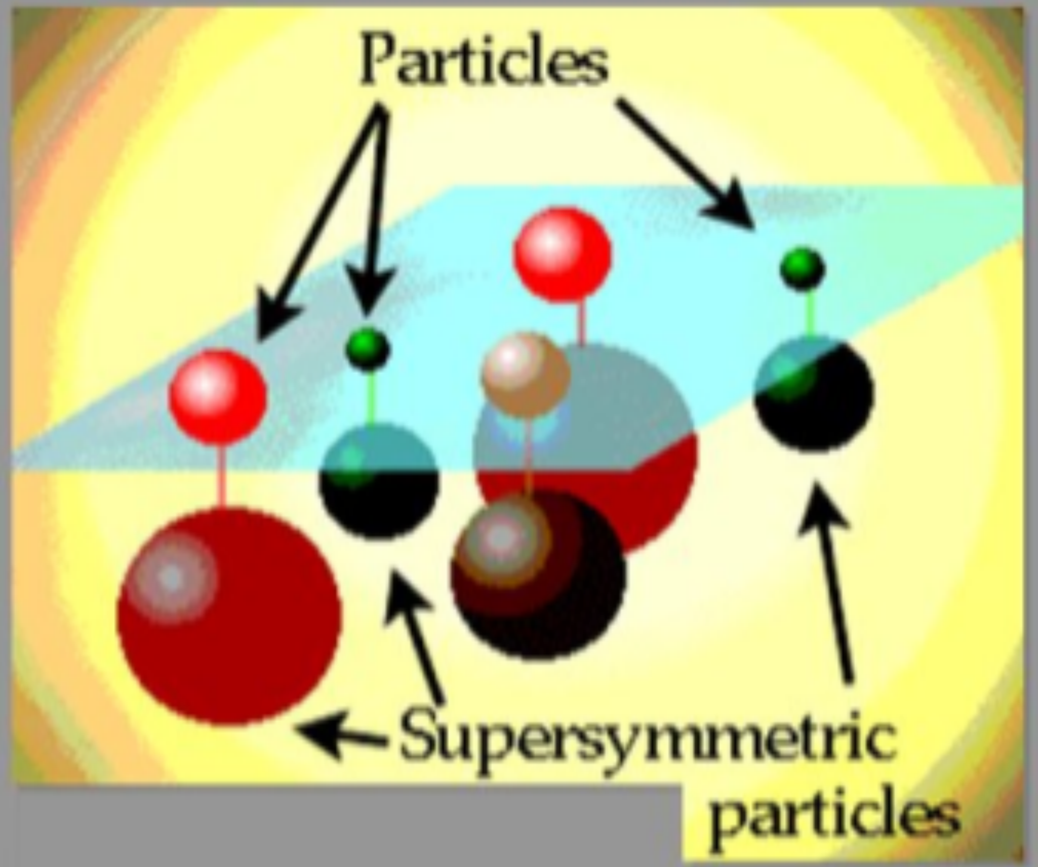
Naturalness (TeV Physics)



Dark Matter

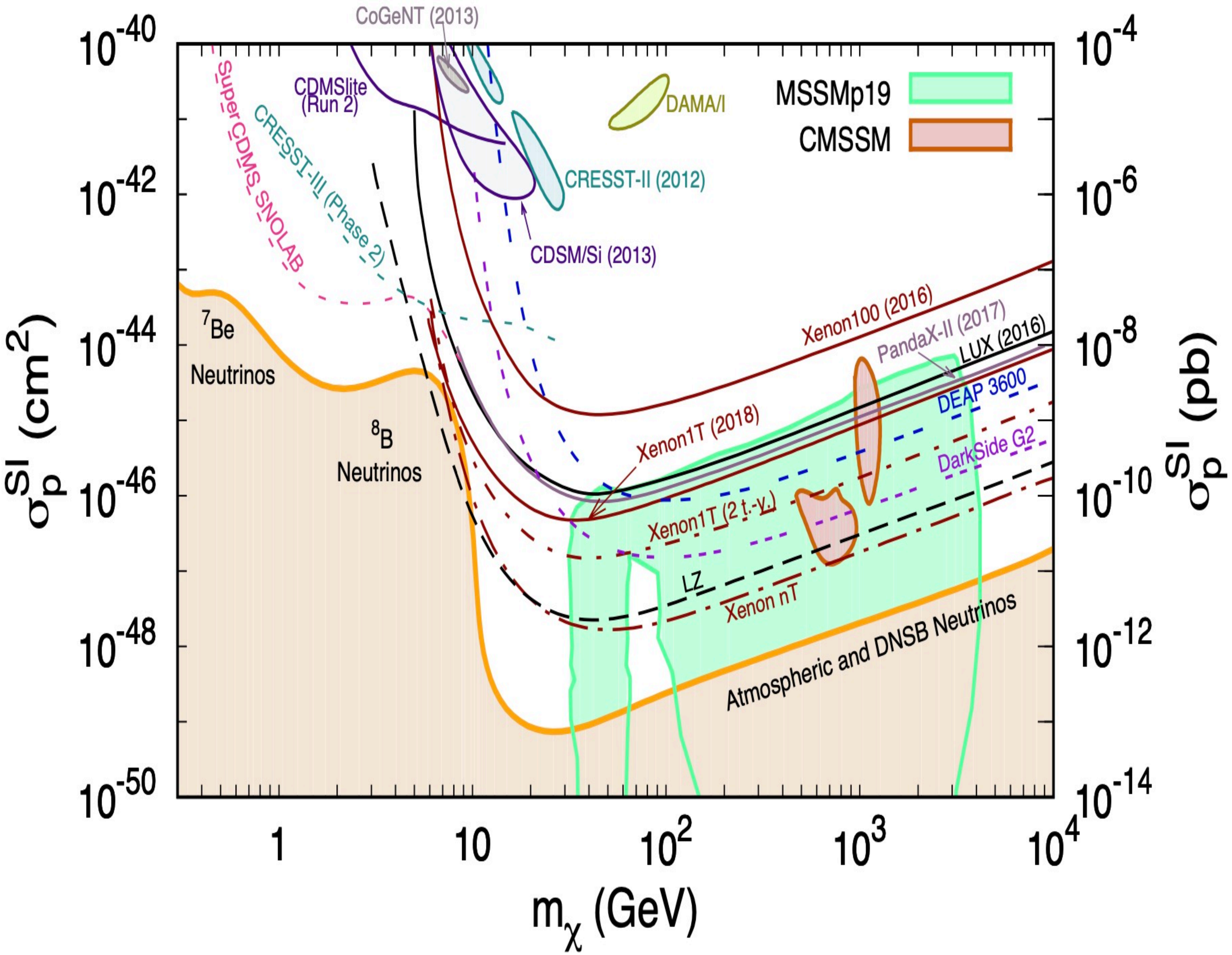
Supersymmetric Dark Matter

- R-parity must be introduced in supersymmetry to prevent rapid proton decay
- Another consequence of R-parity is that superpartners can only be created and destroyed in pairs, making the lightest supersymmetric particle (LSP) stable



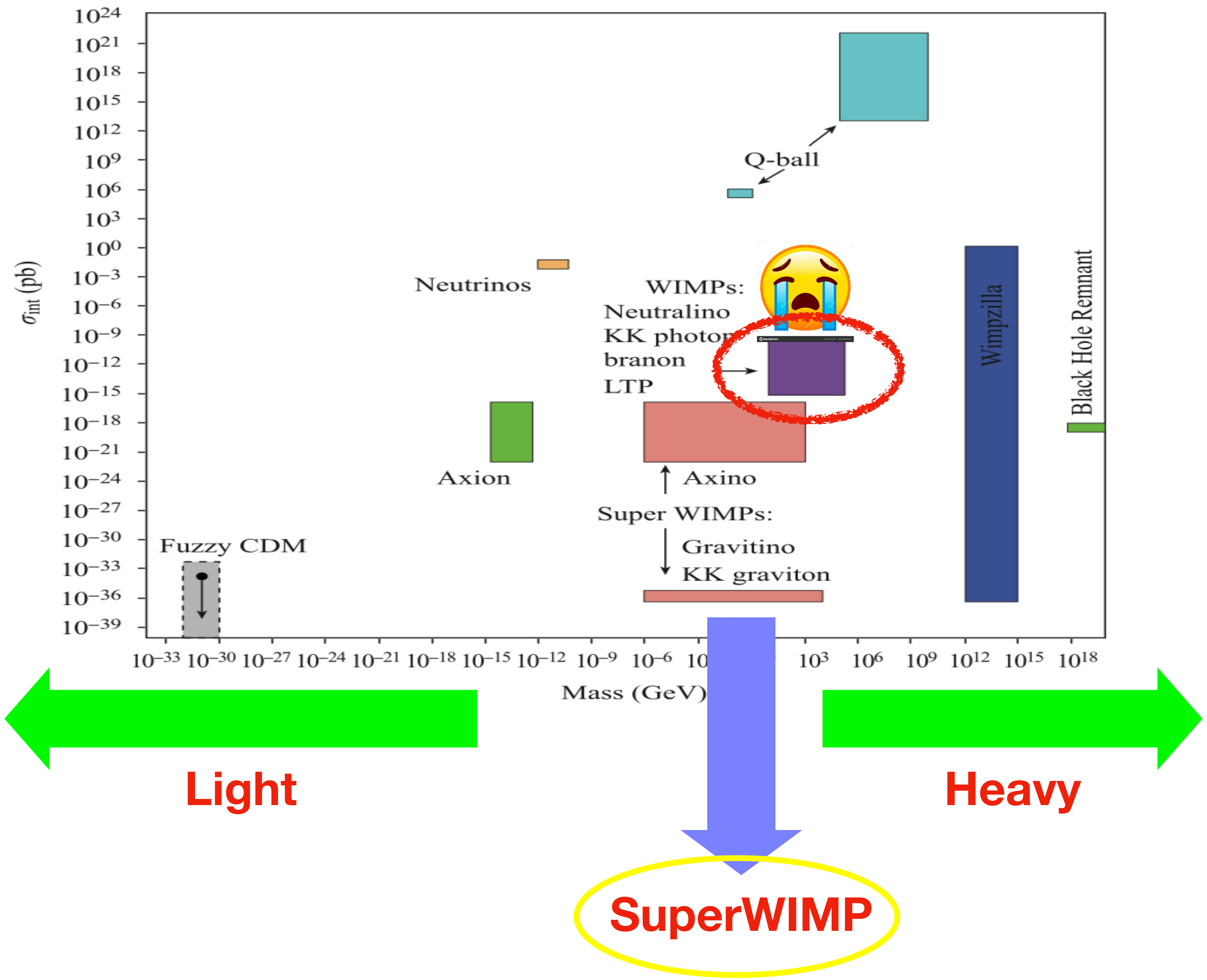
- Possible WIMP candidates from supersymmetry include: $\tilde{\gamma}, \tilde{Z}, \tilde{h}, \tilde{H}$ ← 4 Neutralinos; $\tilde{\nu}$ ← 3 Sneutrinos
- **Possible non-WIMP candidates:** **gravitino, axino**

Roszkowski et. al, 1707.06277



Possibilities:

1. Coannihilation
2. Blind Spot
3. ……



Multi-messenger Era:

DD, IDD, LHC

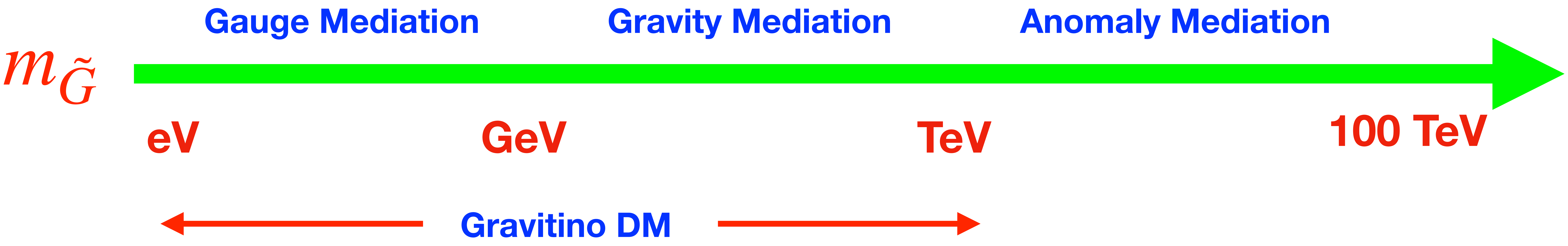
telescope, radar, pulsar timing, GW

cavity, atomic clock, quantum sensor

2. keV Gravitino, Hubble tension and LHC

Gravitino

- Local SUSY transformation
- Spin 3/2 Majorana field
- Coupling ~ $1/M_{PL}$, no signals in Direct Detection
- Mass (SUSY breaking mechanism):



Gravitino problem

Pagels and Primack 1982

LSP $n_{g_{3/2}} m_{g_{3/2}} + n_\nu \sum m_\nu \leq \rho_{\max}$ ➡ $m_{\tilde{G}} < \mathcal{O}(1)$ **KeV**

Low SUSY breaking scale: $m_{\tilde{G}} \sim F^2/M_{PL}$

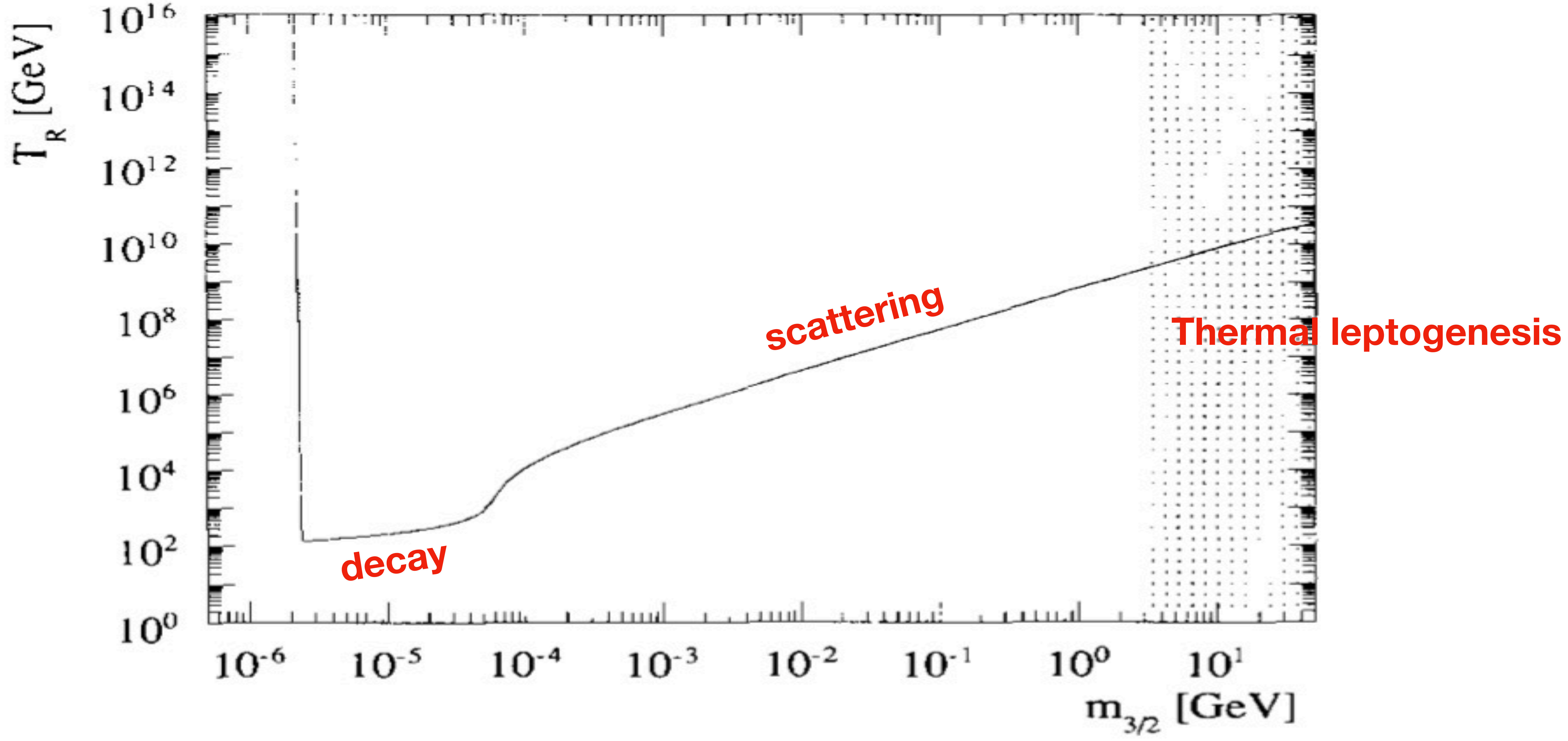
Weinberg 1982

NLSP $\tau(\tilde{G} \to \gamma \tilde{B})$ ➡ $m_{\tilde{G}} > \mathcal{O}(10^4)$ **GeV**

$m_{\tilde{G}} > 1$ **keV ?** → **Yes** → **Low Reheating Temperature T_R**

Moroi, Murayama, Humaguchi 1993

$$\frac{dn_{3/2}}{dt} + 3Hn_{3/2} = \langle \Sigma_{tot} v_{rel} \rangle n_{rad}^2 + \sum_i n_i \langle \Gamma_i \rangle$$



Can we do better?

Gauge Mediation

$$W = S\Phi_M\overline{\Phi}_M + \Delta W(S, Z_i)$$

(non-) renormalizable couplings
(superpotential,Kahler function)

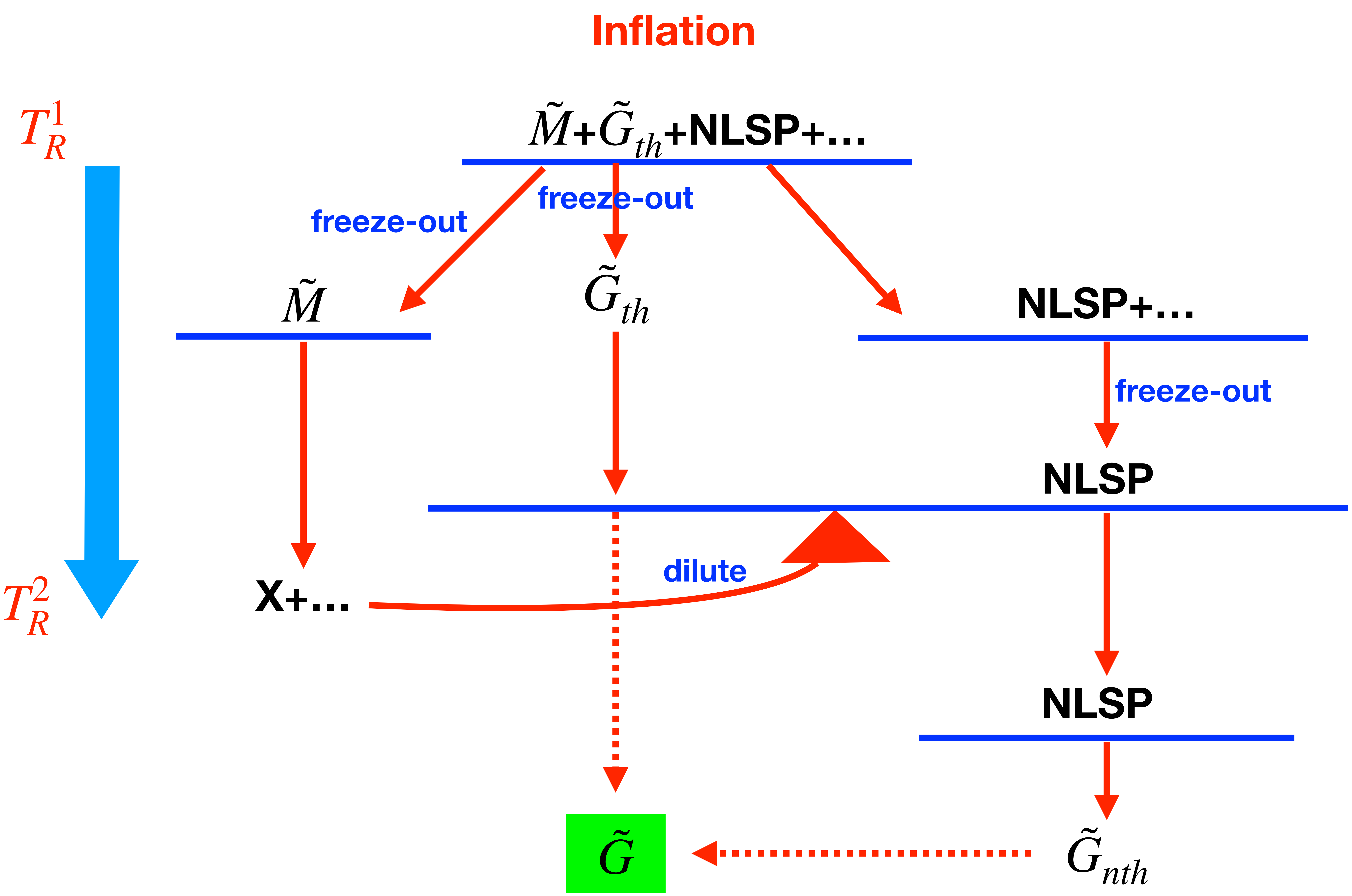
decay

E. Baltz and H. Murayama 2001

M. Fuji and T. Yanagida 2002

extra entropy production, then dilute gravitino abundance

Cosmological scenario of light Gravitino DM



Constraints-1: relic density

$$0.075 < \Omega_{3/2}h^2 < 0.126$$

$$\Omega_{3/2}h^2 = \frac{1}{D_m}(\Omega_{3/2}^{\mathrm{TP}}h^2 + \Omega_{3/2}^{\mathrm{NTP}}h^2)$$

$$\Omega_{3/2}^{\mathrm{TP}}h^2 \simeq 5.0 \times \left(\frac{m_{3/2}}{10\mathrm{keV}}\right)\left(\frac{230}{g_*(T_f)}\right)$$

$$\Omega_{3/2}^{\mathrm{NTP}}h^2 = m_{3/2}Y_{\tilde{B}}(T_0)\, s(T_0)\, h^2/\rho_c = \frac{m_{3/2}}{m_{\tilde{B}}}\Omega_{\tilde{B}}h^2$$

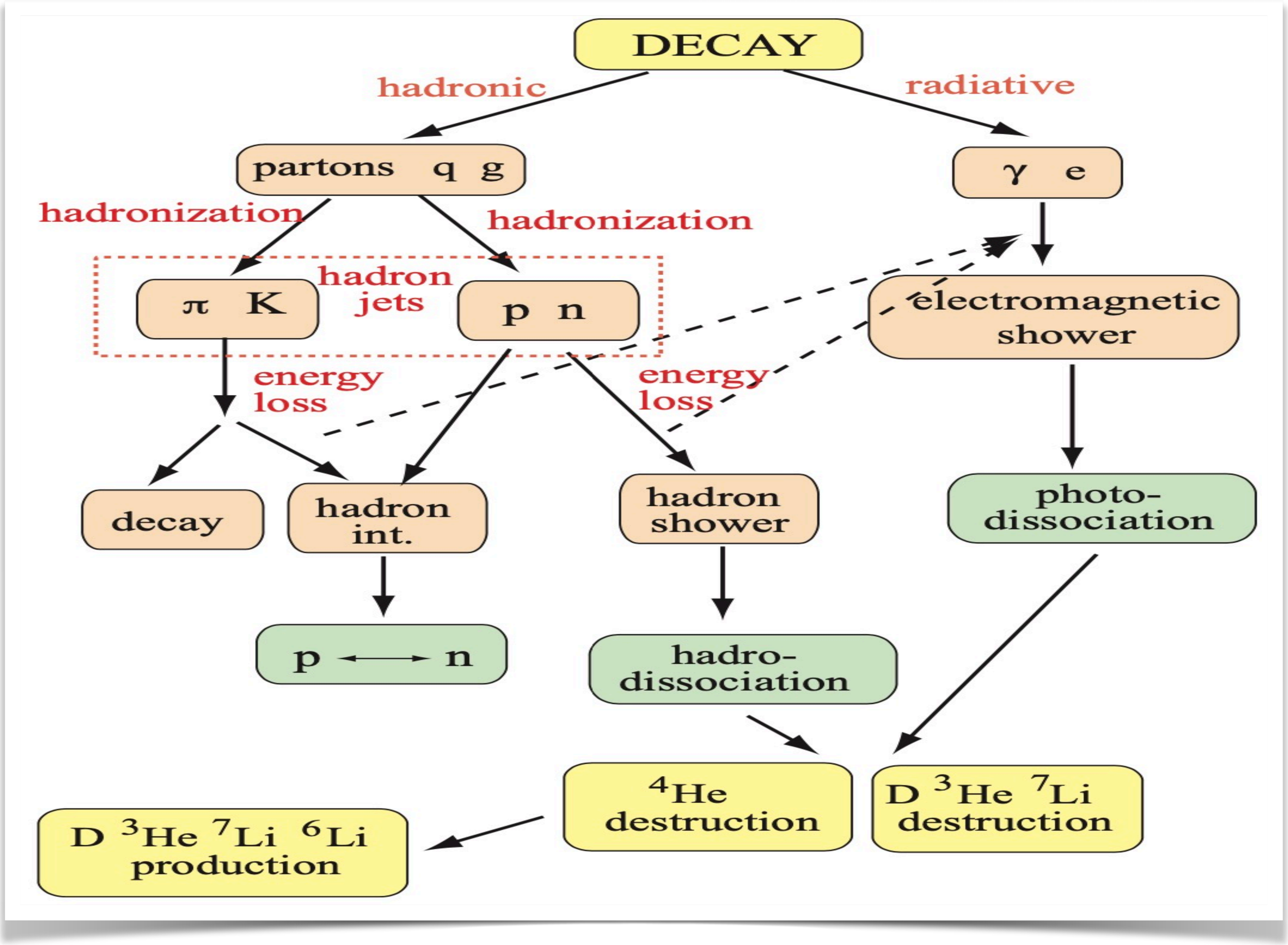
$$\Omega_{\tilde{B}}h^2 = (1.3 \times 10^{-2})\left(\frac{m_{m_{\tilde{e_R}}}}{100GeV}\right)^2 \frac{(1+r)^4}{r(1+r^2)}\left(1 + 0.07\log\frac{\sqrt{r}100GeV}{m_{\tilde{e_R}}}\right)$$

$$D_m = \frac{4/3 M_m Y_m}{(90/g_*\pi^2)^{1/4}\sqrt{\Gamma_m M_P}}$$

Constraints-2: BBN

$$\tau_{\tilde{B}} \simeq \frac{48\pi M_P^2}{\cos^2\theta_W}\left(\frac{m_{3/2}^2}{m_{\tilde{B}}^5}\right)$$

$$\tau < 10^4\mathrm{s}$$



Constraints-3: free streaming length

$\lambda_{FS} < 1$ **Mpc**

$$\lambda_{\rm FS} = \int_{\tau}^{t_{\rm eq}} \frac{v_{3/2}(t)}{a(t)} dt = \frac{2t_{\rm eq}}{a_{\rm eq}^2} \int_{a_\tau}^{a_{\rm eq}} v_{3/2}(a) da$$

$$\lambda_{\rm FS} \simeq 0.6 {\rm Mpc} \times \left(\frac{m_{\tilde{B}}}{10 m_{3/2}} \right) \left(\frac{\tau}{10^4 {\rm sec}} \right)^{1/2} \times \left[1 + 0.1 \log \left(\frac{10 m_{3/2}}{m_{\tilde{B}}} \left(\frac{10^4 {\rm sec}}{\tau} \right)^{1/2} \right) \right]$$

Constraints-4: LSS and CMB

$$exp(-4.9f) > 0.95 \quad \Rightarrow \quad f < 0.01$$

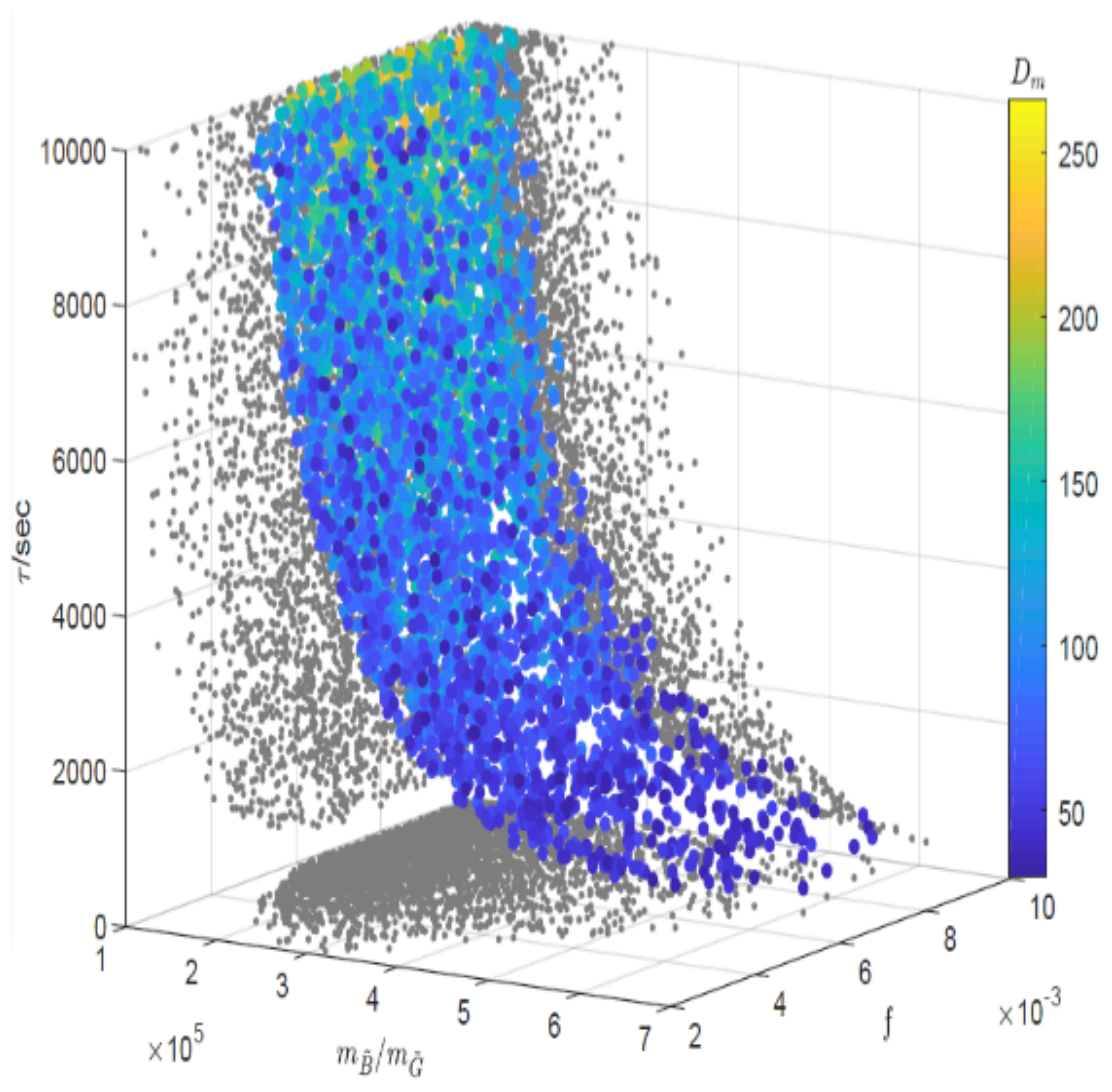
Constraints-5: velocity

Thermal:

$$\langle v_0 \rangle \approx 0.018 \mathrm{kms}^{-1} \left(g_{\star,\mathrm{dec}}/230\right)^{-1/3} \left(m/1\mathrm{keV}\right)^{-1} \left(1/D_m\right)^{1/3}$$

Non-thermal:

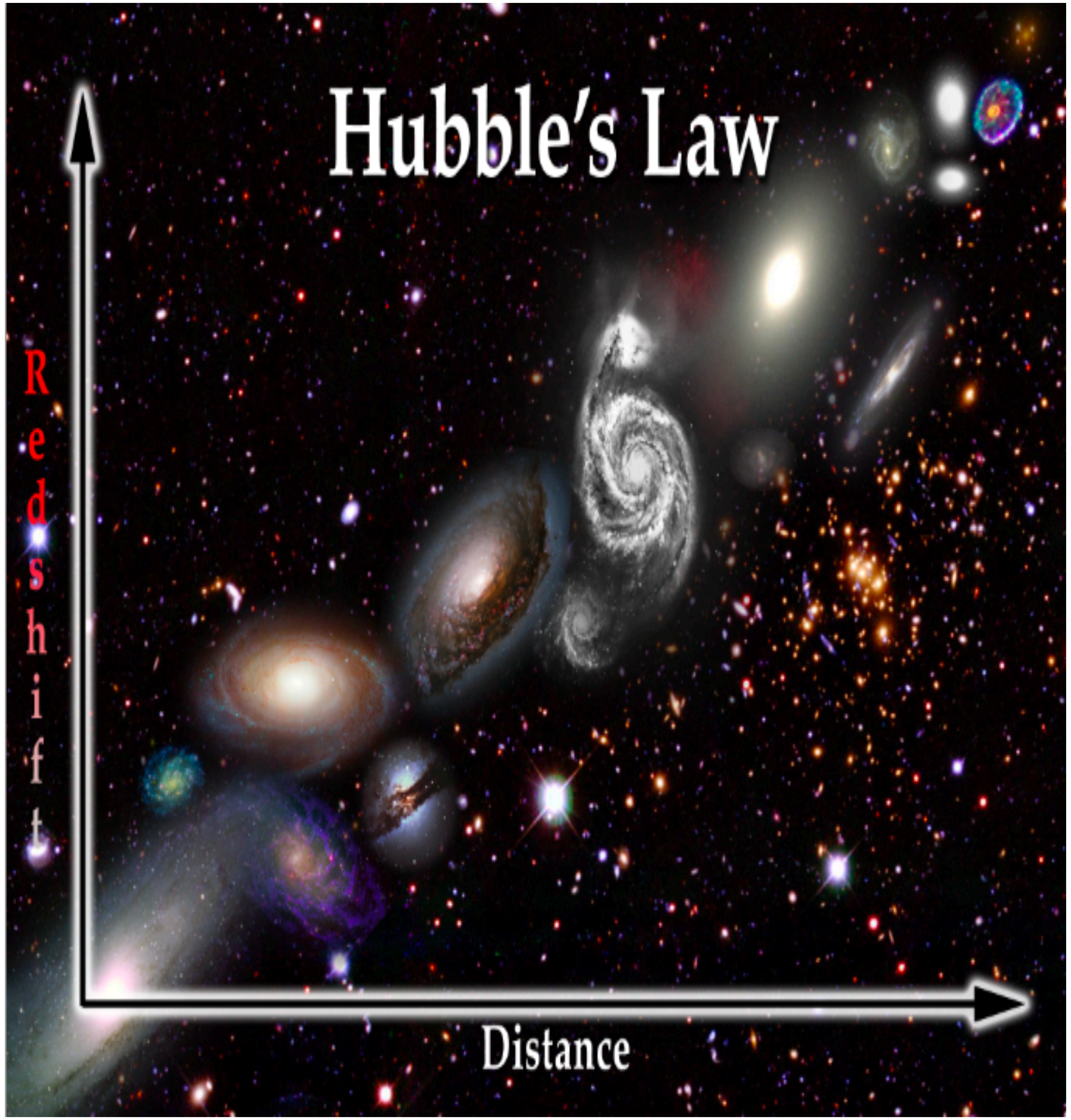
$$\langle v_0 \rangle \approx (M/2m_{3/2})(3.91/g_{\star,\mathrm{dec}})^{1/3}(T_0/T_{\mathrm{dec}})$$



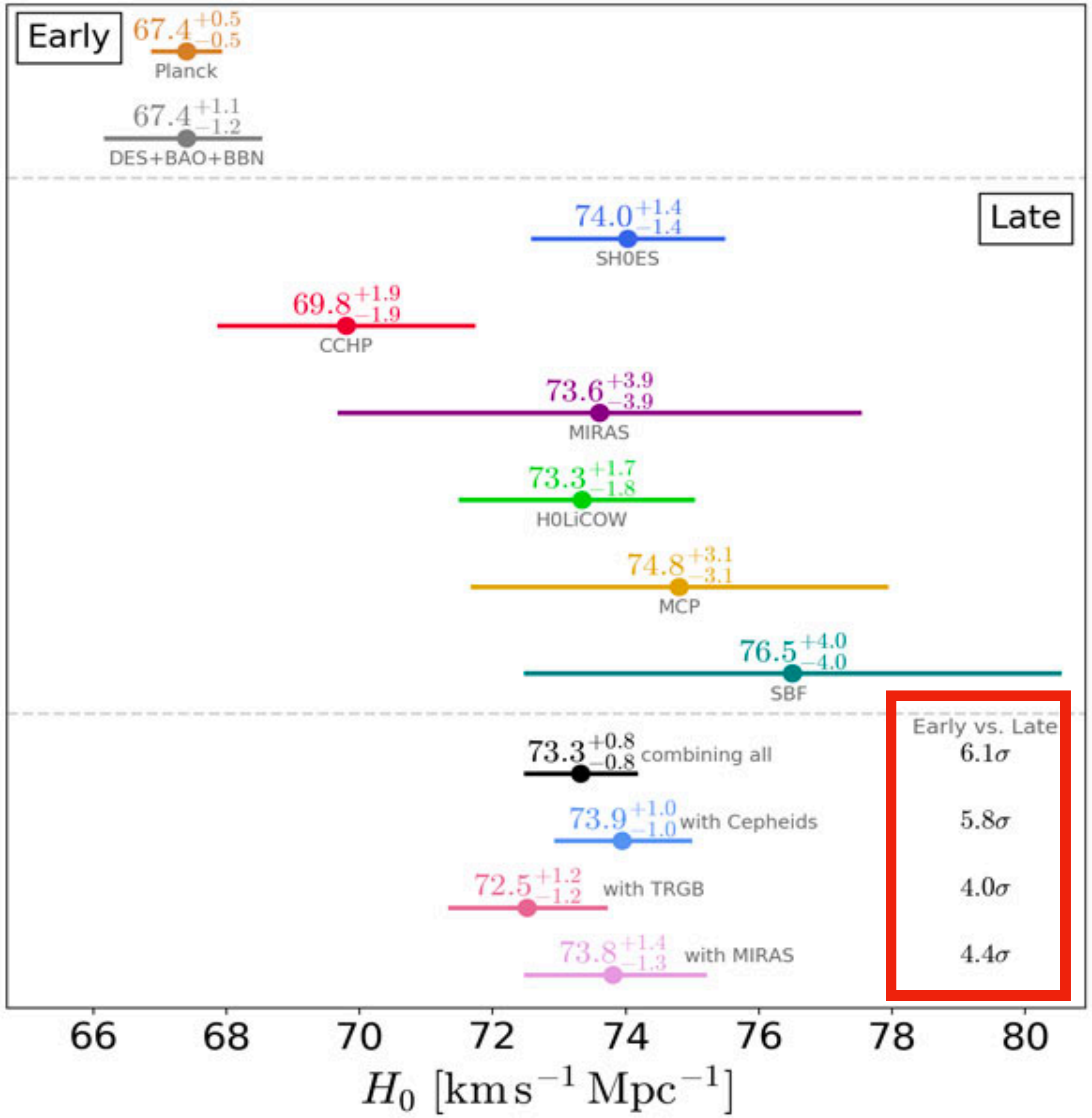
Dilution factor: 29-266

Fraction of non-thermal DM: < 10^{-3}

$m_{\tilde{B}}$ **~ 1 GeV,** $m_{\tilde{G}}$ **~ 10 keV**



Question of Expansion Rate of Universe



Verde, Treu and Riess, 2019

Increasing effective neutrino species, ΔN_{eff}

Hooper et al, 2011

If DM particle is sufficiently light, it may mimic an additional neutrino species.

$$\chi' \rightarrow \chi + \gamma$$

$$\Delta N_{\rm eff} = f \times (\gamma_\chi - 1)/0.16$$

reduce

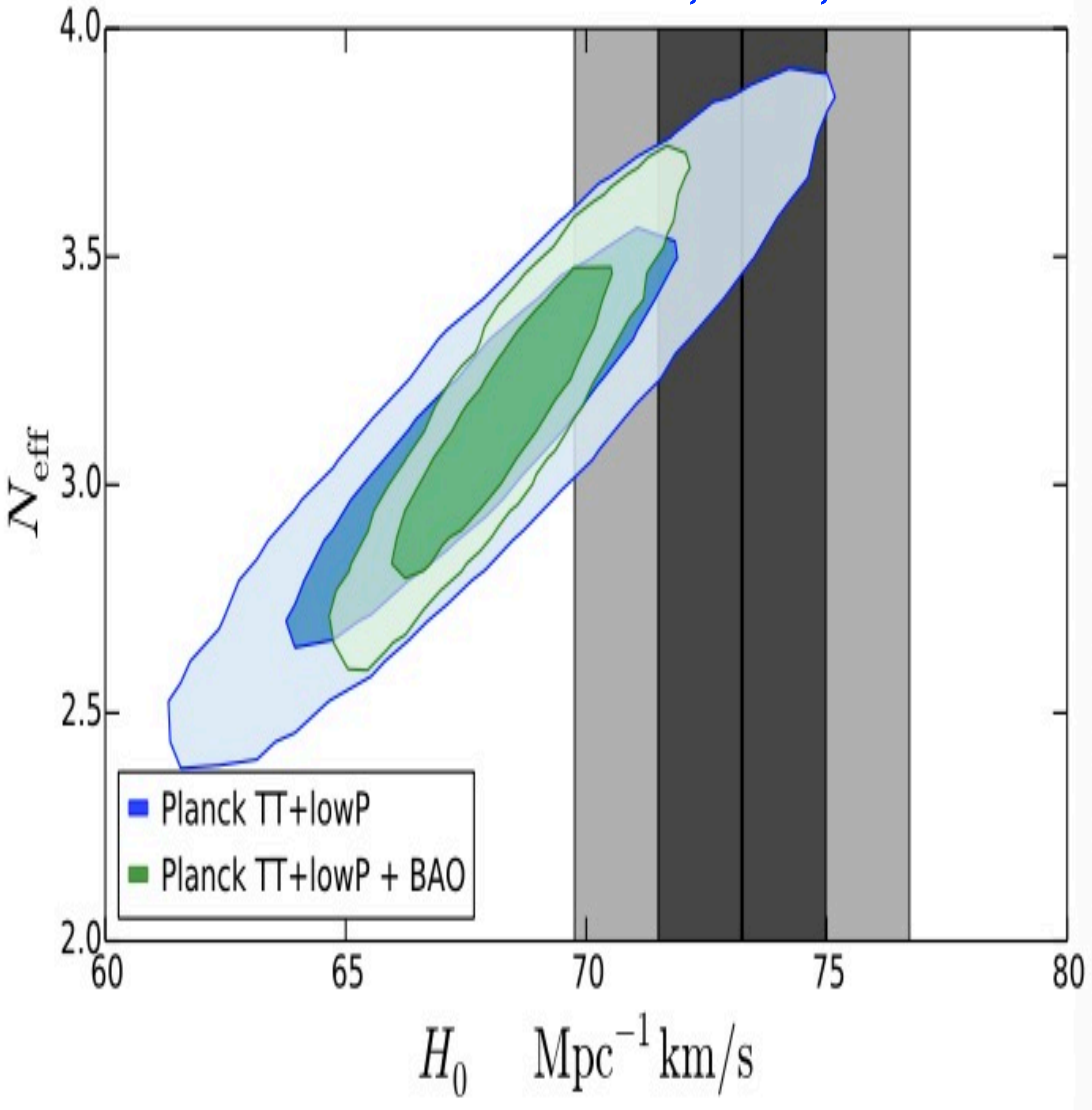
sound horizon

angular position of the acoustic peak

$$\theta_s = \frac{r_s}{D_A}$$

angular diameter distance to the last scattering surface

Bernal, Verde, Riess 2016

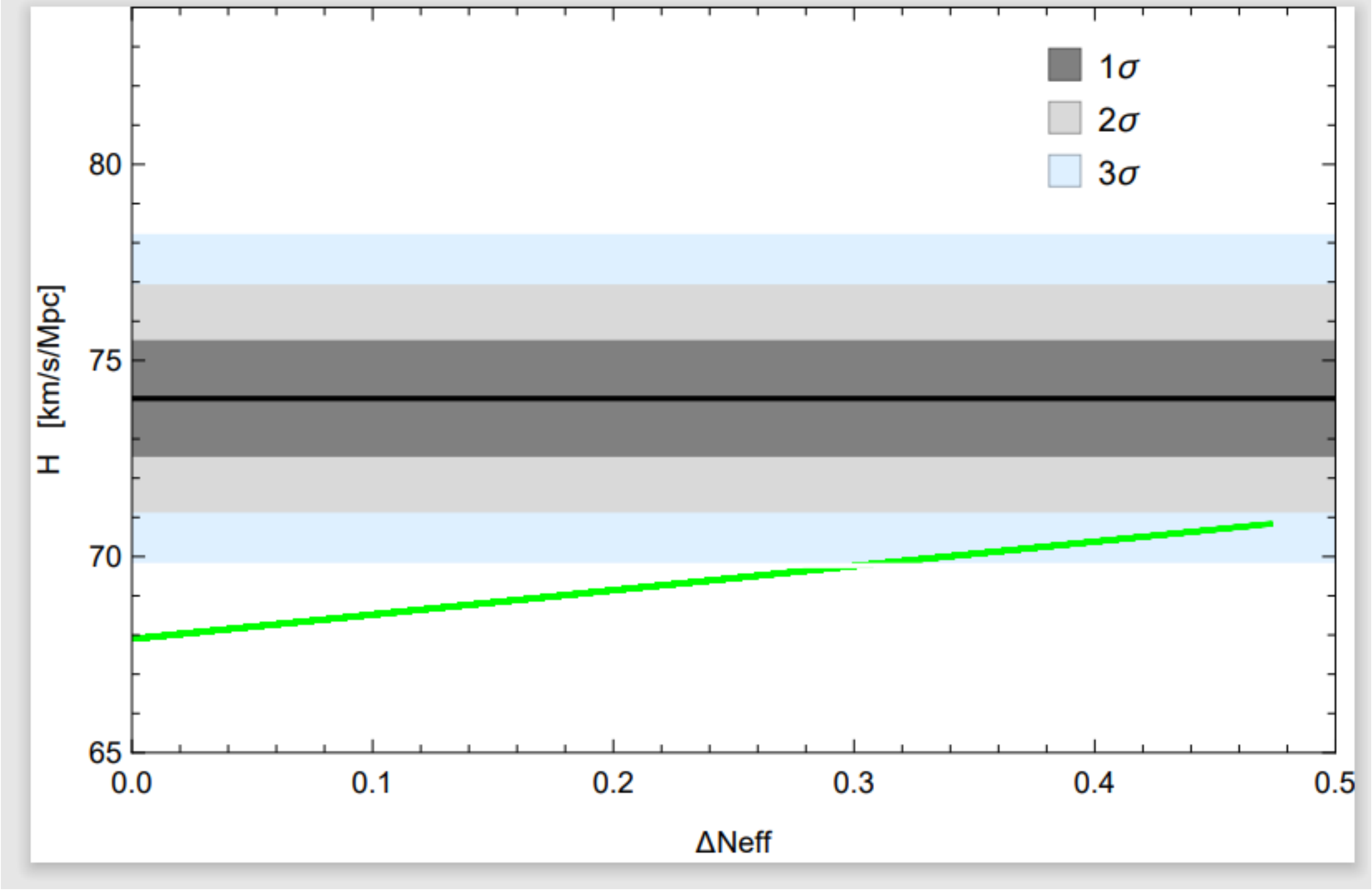


Non-thermal production of gravitino as Dark Radiation

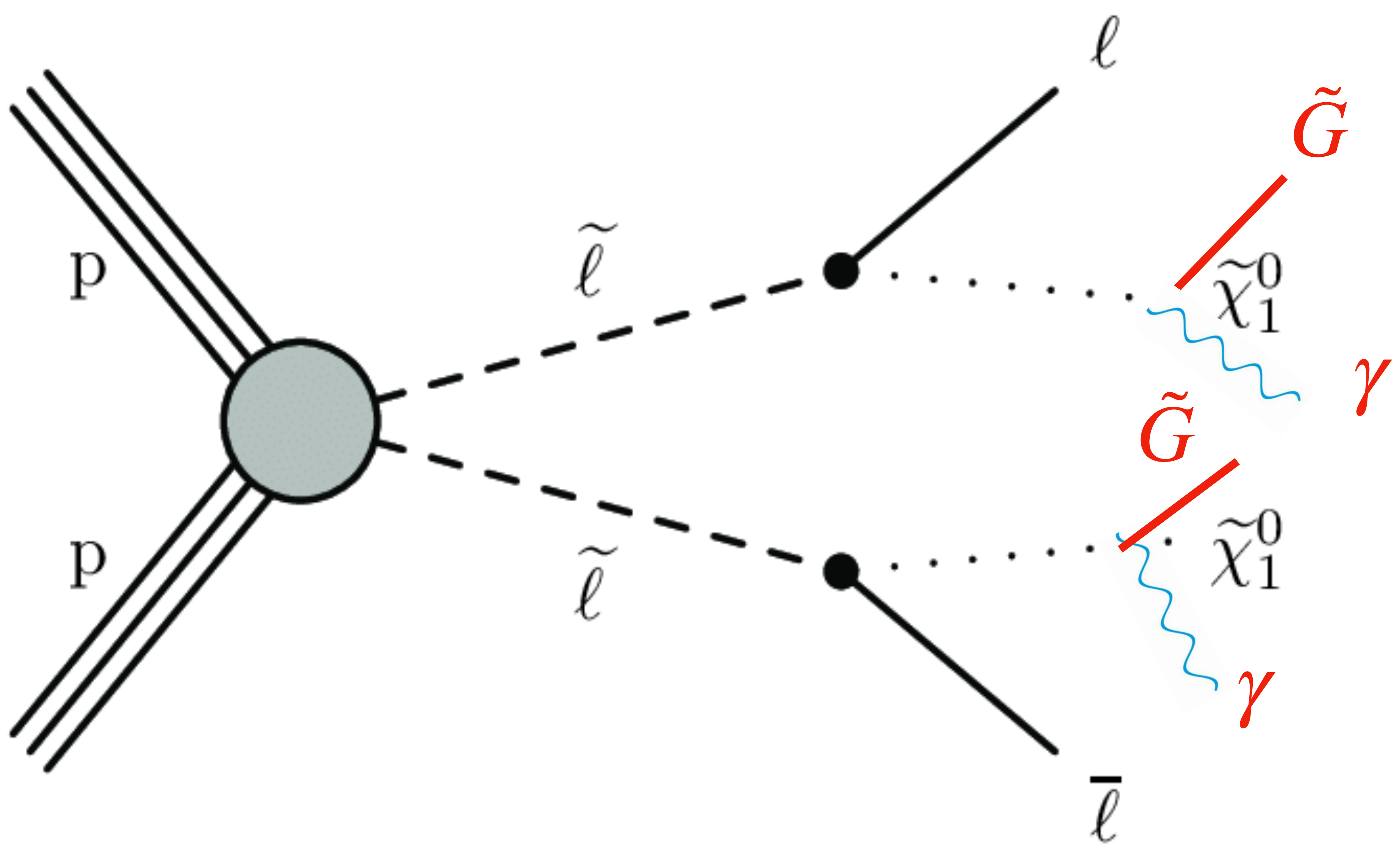
$$\tilde{\chi}_1^0 \to \tilde{G}\gamma$$

$$\gamma_{\tilde{G}}(t) = \sqrt{1 + \frac{(m_{\tilde{B}}^2 - m_{\tilde{G}}^2)^2}{4m_{\tilde{B}}^2 m_{\tilde{G}}^2} \cdot \frac{\tau}{t}}$$

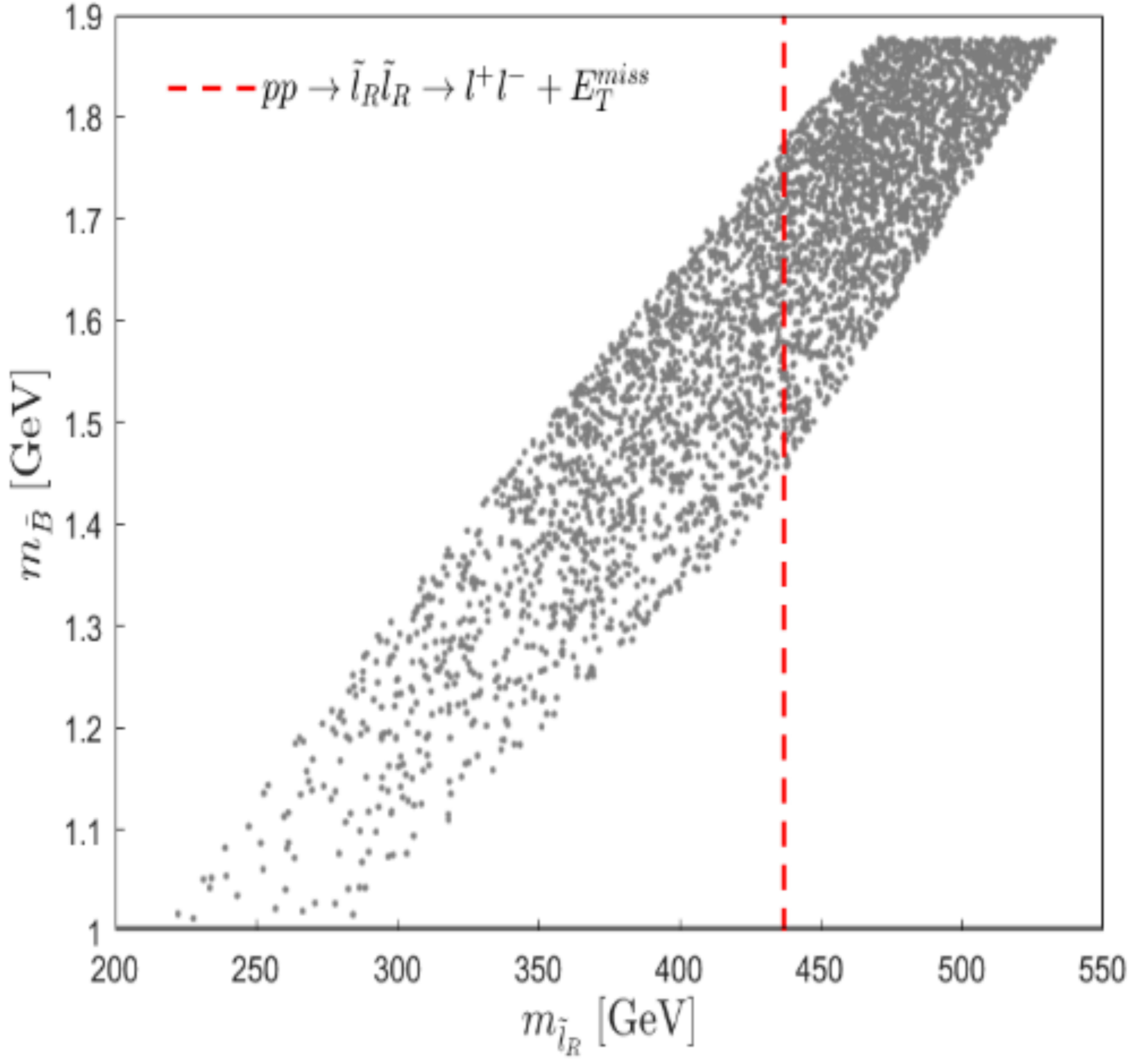
$$\Delta N_{eff} = f \times (\gamma_{\tilde{G}} - 1)/0.16$$



Slepton pair

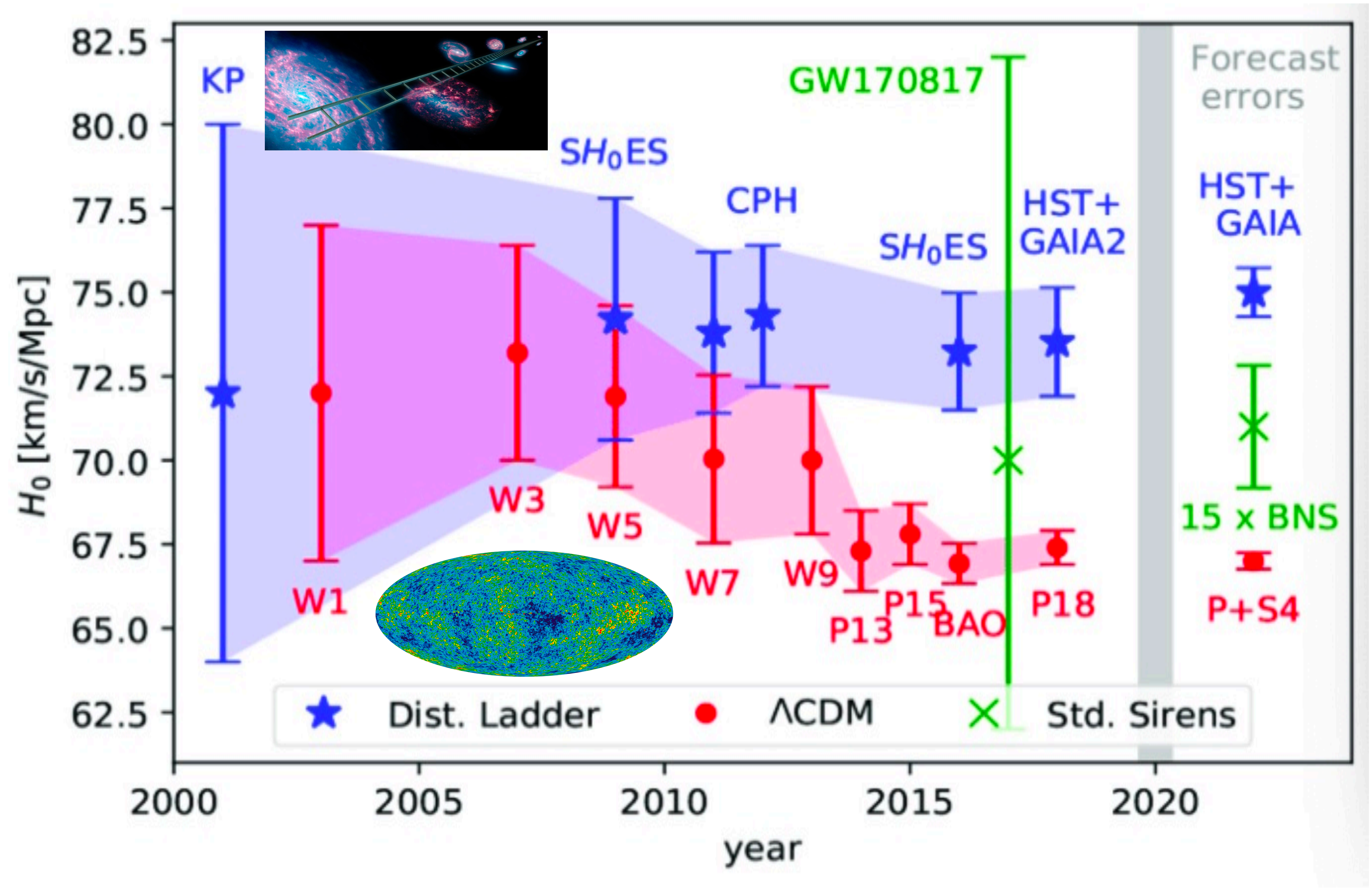


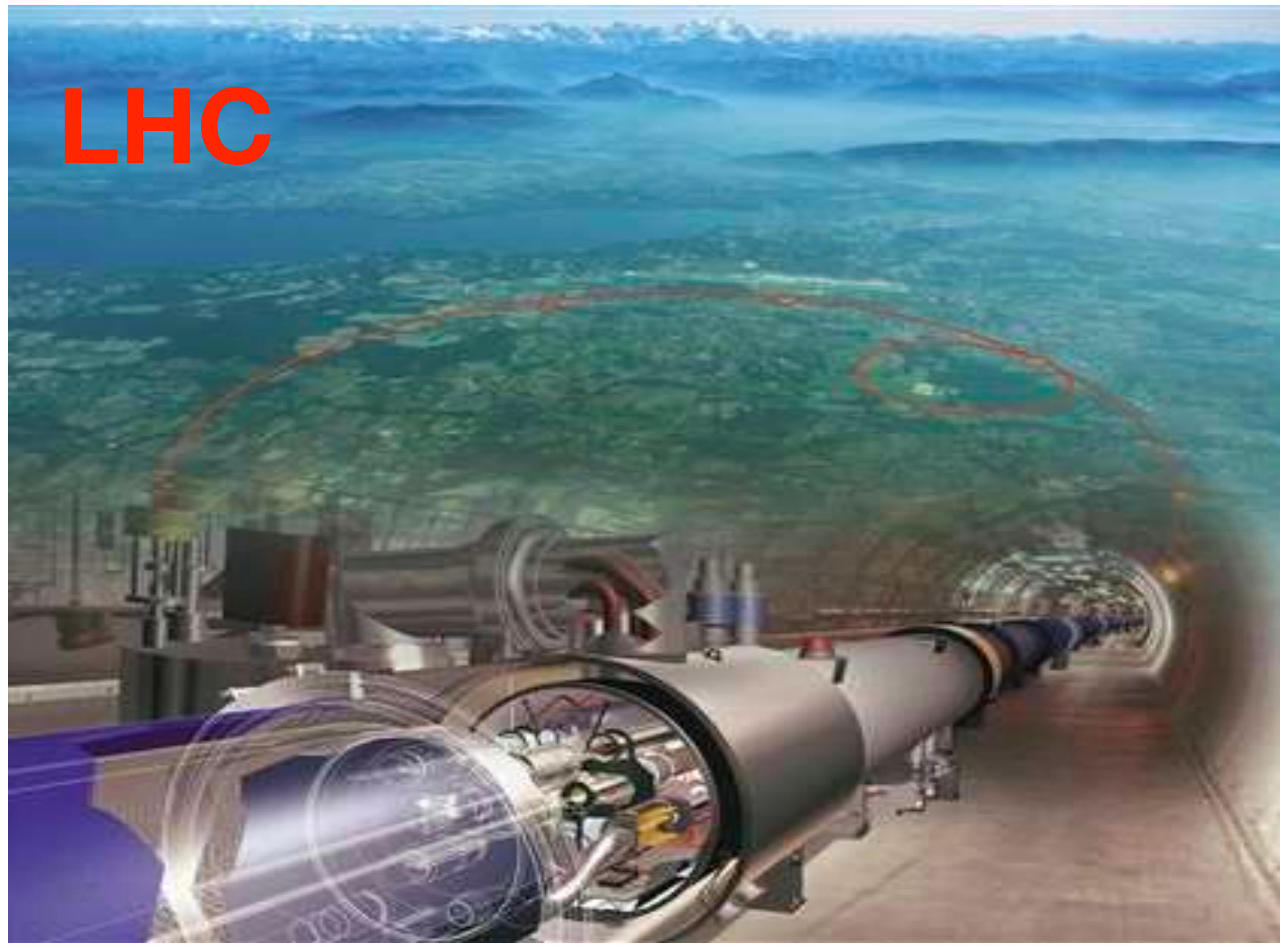
LHC can test it !!!



13 TeV LHC with a luminosity of $\mathcal{L} = 139$ fb^{-1}

3. Conclusions





1. **Hubble tension may be a big challenge for standard LCDM.**

2. **Cold+Warm DM, such as gravitino, may solve this problem.**

3. **LHC can play a complementary role of testing such a solution.**


Thanks!
Welcome to Nanjing!
马蜂窝

$$T_f^{\tilde{G}} \simeq 1\text{TeV} \, (\frac{g_*}{230})^{1/2} \, (\frac{m_{3/2}}{10\text{KeV}})^2 \, (\frac{1\text{TeV}}{m_{\tilde{g}}})$$

$$T_{dec}^{\tilde{B}} \sim \frac{m_{\tilde{B}}}{20}$$

$$T_{dec}^{\tilde{M}} \sim \frac{10}{\pi^2 g_*}^{1/4} \sqrt{\Gamma_{\tilde{M}} m_{PL}}$$

$T_R < T_f^{\tilde{G}}$

$$\Omega_{3/2}^{\rm FI}h^2 = 2\cdot 10^{-4}\left(\frac{m_{3/2}}{1\mathrm{GeV}}\right)^{-1}\left[0.6\left(\frac{M_3}{10^3\mathrm{GeV}}\right)^3\right.$$
$$\left.+2.4\left(\frac{M_3}{10^3\mathrm{GeV}}\right)^2\left(\frac{T_R}{10^5\mathrm{GeV}}\right)\right]$$
$$+\,2\left(\frac{m_{3/2}}{1\mathrm{GeV}}\right)^{-1}\left[3\left(\frac{M_3}{10^3\mathrm{GeV}}\right)^4\left(\frac{M_m}{10^5\mathrm{GeV}}\right)^{-1}\right.$$
$$\left.+0.2\left(\frac{M_3}{10^3\mathrm{GeV}}\right)^2\left(\frac{M_m}{10^5\mathrm{GeV}}\right)\right]$$

$$\delta K = \lambda \Phi_m \bar{5} \tag{13}$$

where λ is an $\mathcal{O}(1)$ parameter from the naturalness criteria, and $\bar{5}$ stands for matter fields in the SM. In terms of Kahler transformation, this interaction can be reinterpreted as additional interaction in superpotential,

$$\delta W = \lambda m_{3/2} \Phi_m \bar{5} \tag{14}$$

Assuming that only gauge interaction plays a crucial role, the decay width of messenger is approximately given by [55],

$$\Gamma_m = \frac{g^2}{16\pi} \left(\frac{m_{3/2}}{\sqrt{2} M_m} \right)^2 M_m. \tag{15}$$

At the matter-radiation equality, the energy density per neutrino species is approximately equal to 16% of the energy density of CDM.

This implies that the non-thermal gravitino dark matter that has a kinetic energy equivalent to 1.16 can be regarded as an additional neutrino species.)

an extra radiation density

$$\rho_R^{\rm extra} = f \times \rho_{3/2} \times (\gamma_{3/2} - 1)$$