Gravitino cold dark matter
in
gauge mediated supersymmetry breaking

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Gauge mediated supersymmetry breaking

e.g. Dine, Fischler, Srednicki 81; Dimopoulos & Raby 81; Dine & Fischler 82; Alvarez-Gaumé, Claudson, Wise 82; Dine & Nelson 93; Dine, Nelson, Shirman 95; Dine, Nelson, Nir, Shirman 96; Giudice & Rattazzi 99

- GMSB : transmission of SUSY from secluded sector to visible sector via gauge interactions thanks to messengers fields

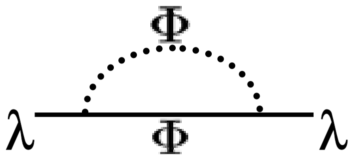
- simple model : superpotential $W \supset S\,\Phi\,\overline{\Phi}$

  S spurion; Φ, $\overline{\Phi}$ messengers charged under *SU(3)xSU(2)xU(1)*

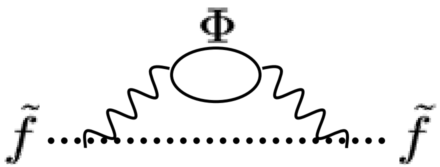
1. dynamics in secluded sector gives $\langle S \rangle \neq 0, \quad F_S \neq 0$
2. $\Rightarrow$ mass splitting in messengers multiplet:

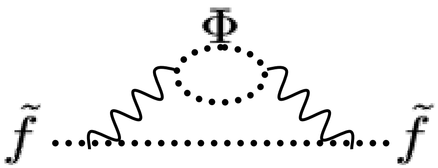
   boson mass: $\tilde{M}^2 = \langle S \rangle^2 \pm F_S$

   fermion mass: $M = \langle S \rangle$
3. induced soft masses in visible sector by radiative corrections:



gauginos: $\tilde{m}_{1/2} \sim \frac{\alpha}{4\pi} \frac{F_S}{\langle S \rangle}$





squarks,sleptons: $\tilde{m}_0^2 \sim \left(\frac{\alpha}{4\pi} \frac{F_S}{\langle S \rangle} \right)^2$

4. $F_S \sim 100\,\mathrm{TeV}\,\langle S \rangle \Longrightarrow \tilde{m}_{1/2} \sim \tilde{m}_0 \sim 1\,\mathrm{TeV}$

Dark matter in GMSB models

Dimopoulos, Giudice, Pomarol 96

- Mass spectrum:

  messengers: $M_X\,(\approx \langle S\rangle\,) \sim 10^5 - 10^{13}\,\mathrm{GeV}$

  spartners: NLSP generically bino or stau

  LSP: gravitino $m_{3/2} = \dfrac{F_S + \sum_i F_i}{\sqrt{3}m_{\rm Pl}} \sim 1\,\mathrm{eV} - 1\,\mathrm{GeV}$

- Dark matter:
  - secluded sector: possible candidate but no constraint
  - messenger sector: messenger number conserved $(W \supset S\Phi\bar{\Phi})$
    $\Rightarrow$ lightest messenger X is stable : dark matter candidate ?

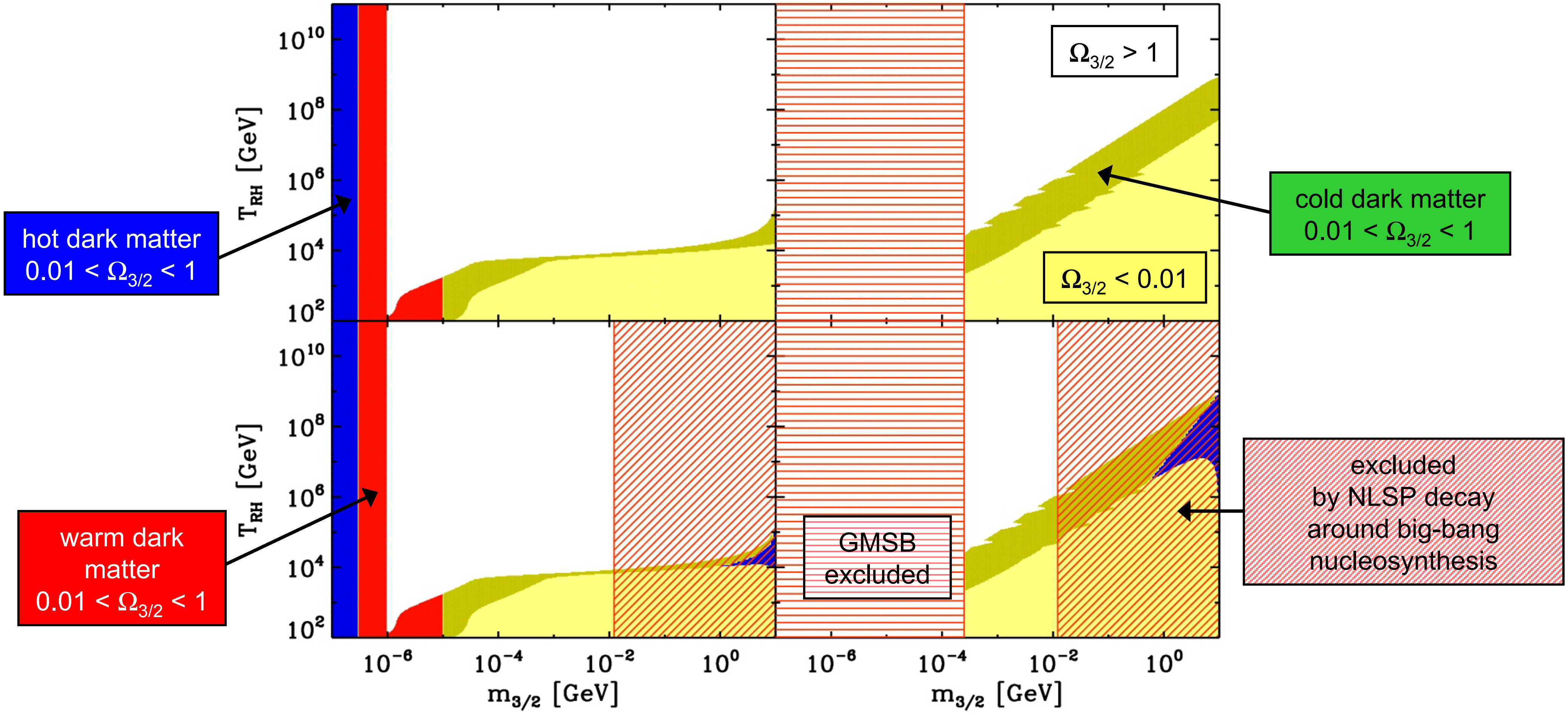
    in SU(5), $\Omega_X h^2 \sim 1$ if $M_X \sim 10$ - 30 TeV,
    in SO(10), too large relic abundance: messengers must decay !
  - gravitino: light gravitino interacts mainly through goldstino component: e.g., $\Omega_{3/2}\,h^2 > 1$ unless post-inflationary reheating temperature very low.
    (Moroi, Murayama, Yamaguchi 93; Choi, Hwang, Kim, Lee 99)

    But cosmological role of messengers fields ?
    (Baltz, Murayama 03, Fujii & Yanagida 02)

Gravitino abundance in $T_{RH} - m_{3/2}$ plane

- Calculation: integrate Boltzmann equation for gravitino abundance including sparticles and messengers scatterings and decay contributions. (Choi, Hwang, Kim, Lee 99)

- Example: messengers decay before dominating the total energy density
  $M_X = 10^5$ GeV (left), 10^{10} GeV (right); NLSP = stau (top), bino (bottom)

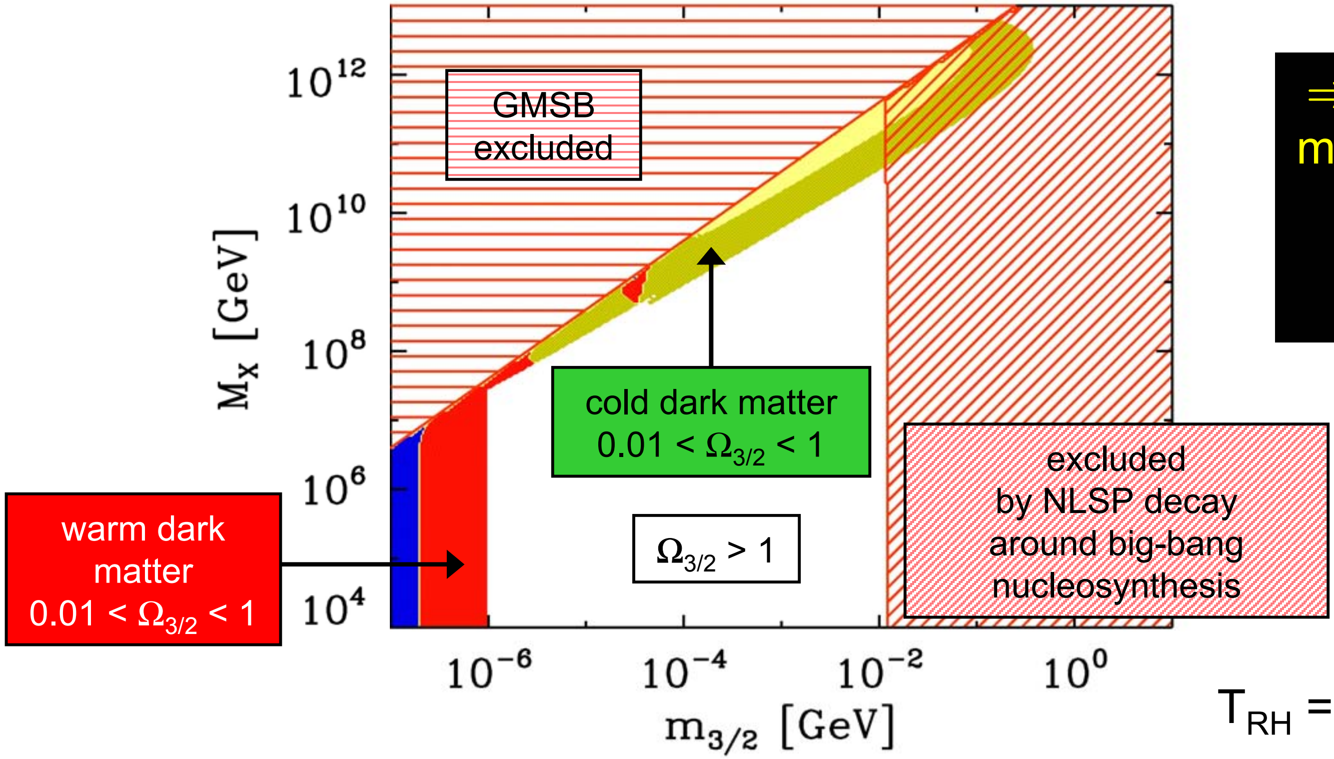


Gravitino abundance in $M_X - m_{3/2}$ plane for high T_{RH}

- <u>messenger decay:</u> cosmology requires that the lightest messenger decays; phenomenology requires that tree level messenger–matter coupling is suppressed …
  if X dominates the energy density before decaying (before BBN!), a second reheating occurs and the pre-produced gravitino abundance is diluted

- <u>Example:</u> renormalizable messenger – matter interaction in Kahler: $K \supset \mathbf{5}_{\rm mess}\overline{\mathbf{5}}_{\rm matt}$

  Fujii & Yanagida 02



$\Rightarrow$ gravitino CDM in *SU(5)*
$m_{3/2} \sim$ MeV, $M_X \sim 10^{10}$ GeV

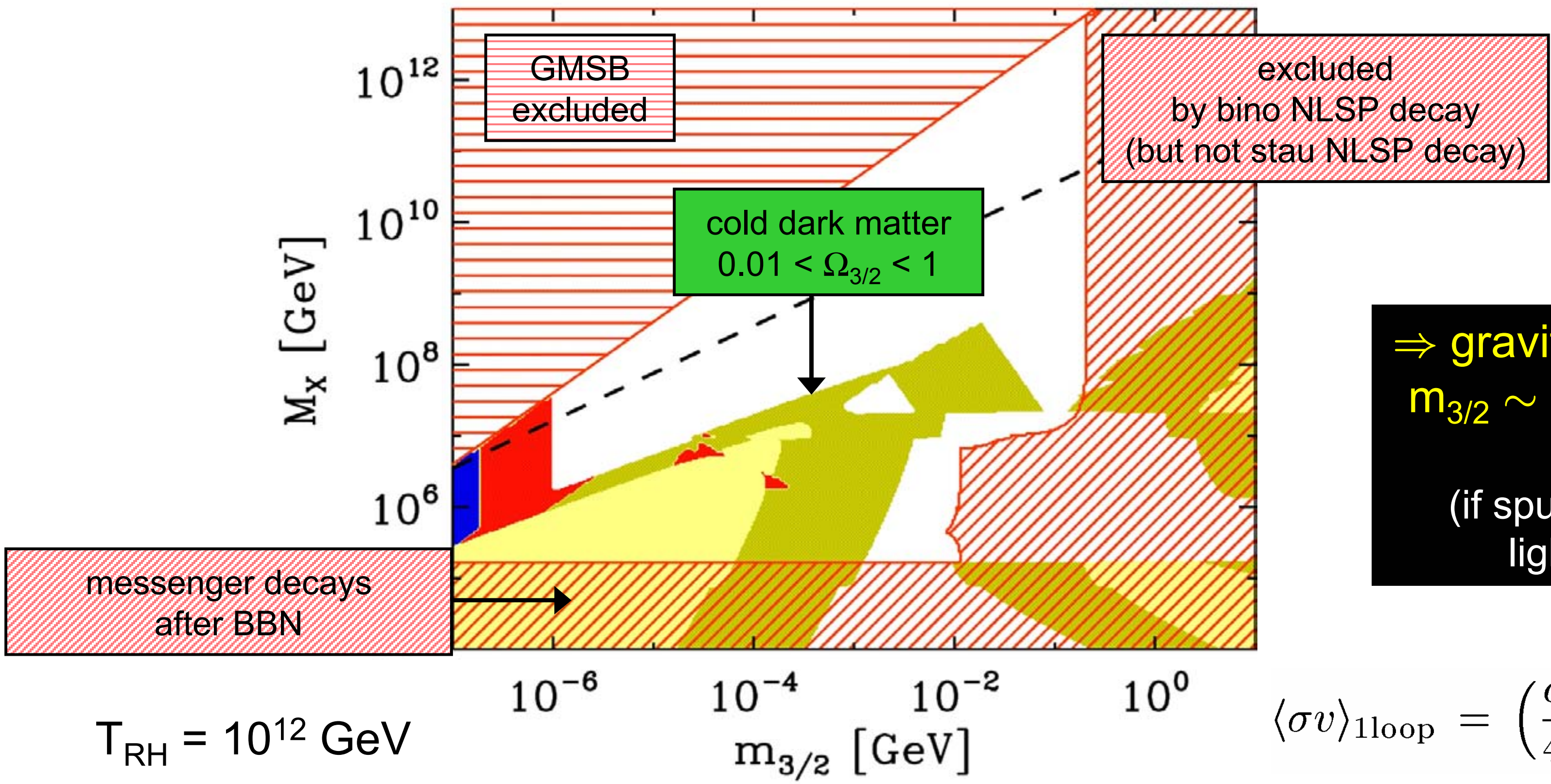
(if spurion is lighter than lightest messenger)

$T_{RH} = 10^{12}$ GeV

Gravitino abundance in $M_X - m_{3/2}$ plane for *SO(10)*

M.L., Jedamzik, Moultaka 05

- in *SO(10)*: lightest messenger is SM singlet boson: it annihilates through:
  GUT suppressed tree level diagrams,
  or at one loop,
  or at tree level into a pair of goldstinos.
  Its relic abundance is higher than that for *SU(5)*, hence it easily comes to dominate the energy density.
- decay width: generic non-renormalizable messenger-matter coupling: $\Gamma_X \sim \frac{f}{16\pi}\frac{M_X^3}{m_{Pl}^2}$



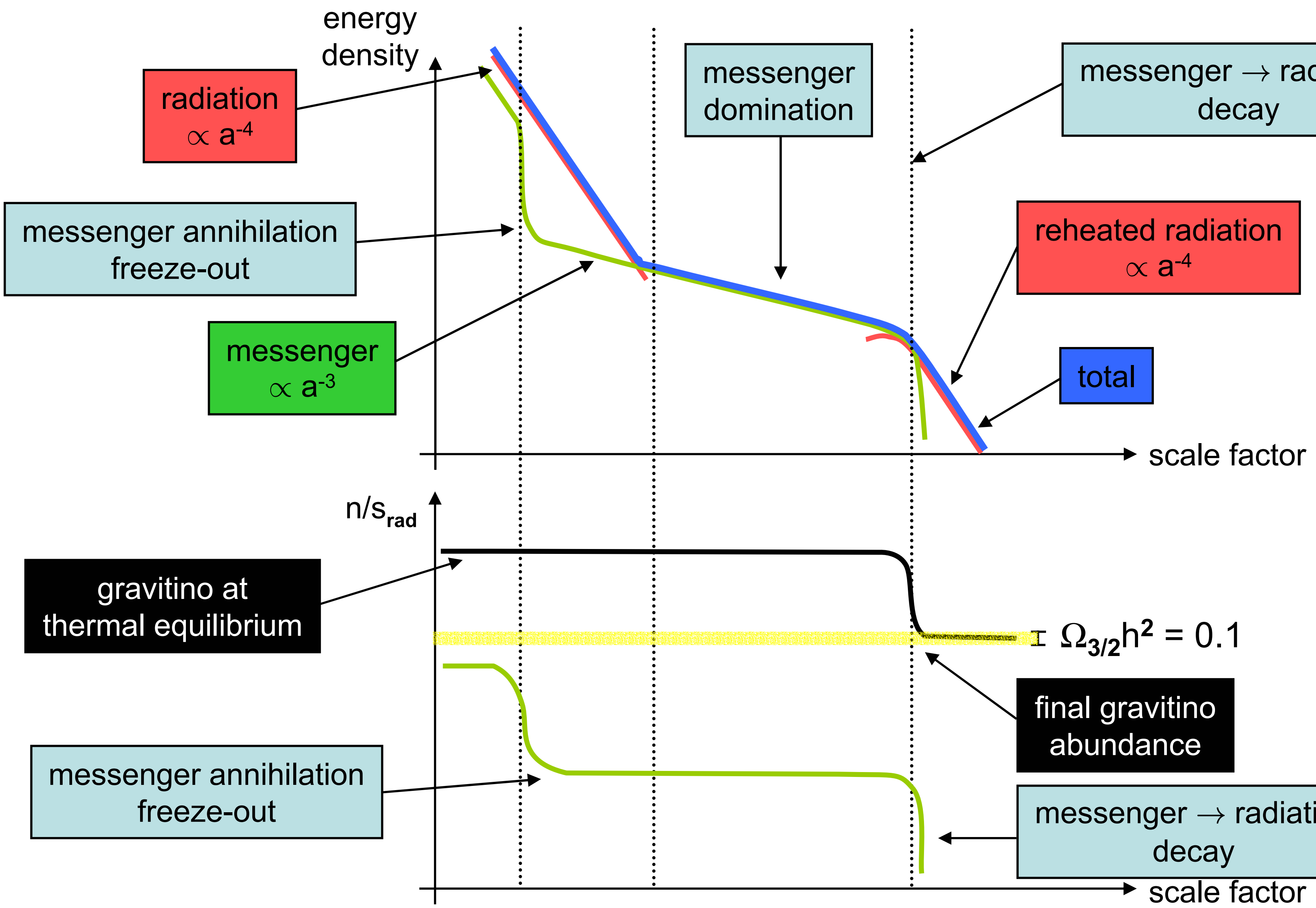
$T_{RH} = 10^{12}$ GeV

$\Rightarrow$ gravitino CDM in *SO(10)*
$m_{3/2} \sim$ MeV, $M_X \sim 10^6$ GeV

(if spurion is heavier than lightest messenger)

$$\langle\sigma v\rangle_{1\mathrm{loop}} = \left(\frac{\alpha_3}{4\pi}\right)^4 \frac{1}{M_X^2}, \qquad f = 0.05$$

Cosmological evolution with late-decaying messenger



$\Omega_{3/2}\, h^2 \sim$ thermal equilibrium value / amount of entropy production

$\Rightarrow$ depends on : relic messenger abundance and decay width ($\leftarrow$ couplings)

Summary + conclusions ...

- Gravitino LSP can be cold dark matter in GMSB scenarios :
  - if reheating temperature tuned: $T_{\rm RH} \approx \min\left[10^8 m_{3/2}\left(\frac{M_3}{1\,{\rm TeV}}\right)^{-2},\ \frac{M_X}{10}\right]$
  - or high T_{RH} ($\rightarrow$ leptogenesis !) + late messenger decay due to suppressed messenger number violating couplings to matter :
    - for *SU(5)*, only specific couplings
    - for *SO(10)*, generic non-renormalizable couplings

$$m_{3/2} \sim 10 \text{ keV} \rightarrow 10 \text{ MeV}$$

- Note :
  - in GMSB, the gravitino abundance is mostly determined by T_{RH} or by couplings between the lightest messenger and matter: it is relatively insensitive to other model parameters…
  - in gravity mediated scenarios, a gravitino LSP can be dark matter but its abundance is determined either by T_{RH} or by NLSP decay; in the latter case, gravitino dark matter is warm in a large part of parameter space…

    (Cembranos, Feng, Rajaraman, Takayama 05; Kaplinghat 05; Jedamzik, M.L., Moultaka 05)