Supersymmetric dark matter with low reheating temperature

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We examine a scenario in which the reheating temperature T_R after inflation is comparable to, or lower than, the freeze out temperature of ordinary WIMPs. In this case the relic abundance of dark matter (DM) is reduced, thus relaxing the impact of the usually strong constraint coming from the requirement that the Universe does not overclose.

In case of neutralino DM we often find dramatic departures from the usually considered regime of high T_R, with important implications for direct detection dark matter searches. For gravitino as a DM candidate we derive lower limits on T_R that depend on the gravitino mass and the nature of the lightest ordinary superpartner. Similar analysis for axino DM alleviates an effective upper limit on its mass.

low T_R $\Rightarrow$ correct $\Omega_\chi h^2$ for wide range of masses and interesting constraints for EWIMPs

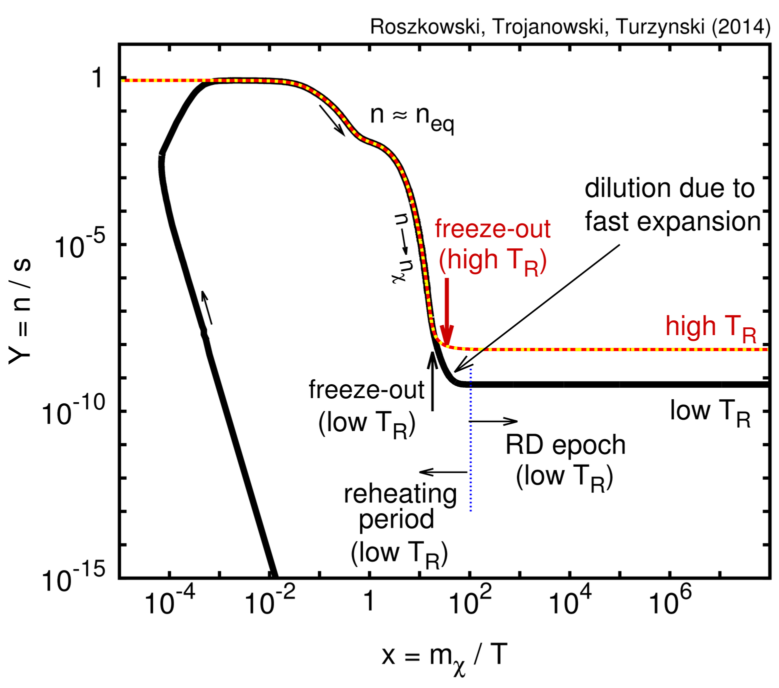
Dark matter relic density for low T_R

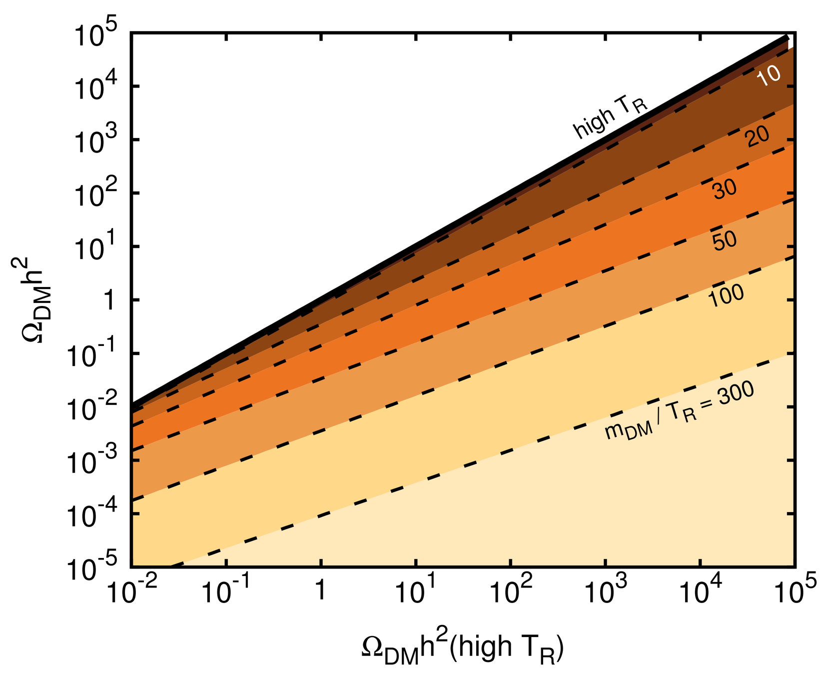
In scenarios with non-instantaneous **reheating** after a period of cosmological inflation the temperature of the Universe can grow above the initial temperature in the radiation dominated epoch which is close to T_R. It happens in the reheating period, *i.e.*, before the radiation dominated epoch.

- The Universe in the reheating period expands faster than in the radiation dominated epoch. Hence the DM freeze-out occurs earlier (for higher T), but …
- … between the dark matter freeze-out and the end of the reheating period the DM is effectively diluted away

$$\Omega_\chi h^2(\text{low } T_R) \sim \left(\frac{T_R}{T_{\text{fo}}}\right)^3 \Omega_\chi h^2(\text{high } T_R) \qquad \text{and} \quad T_{\text{fo}} > T_R.$$

- DM relic abundance may be additionally supplied by the direct/cascade decays of the inflaton field.

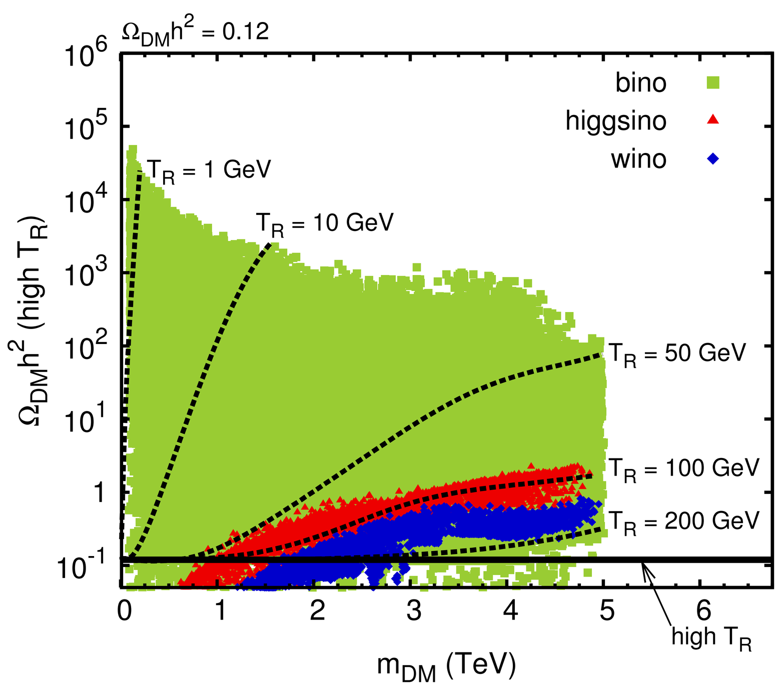


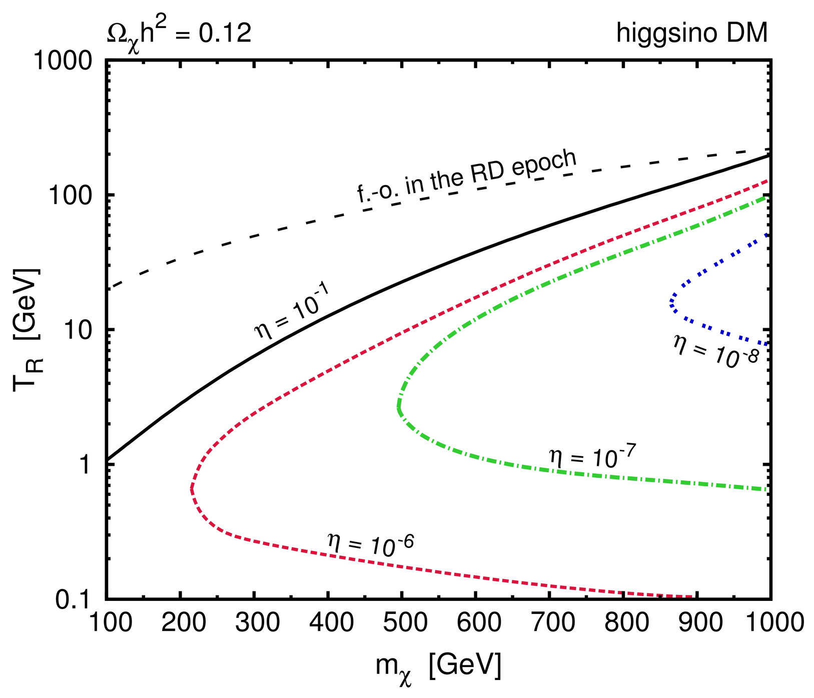


A) Neutralino DM with low T_R

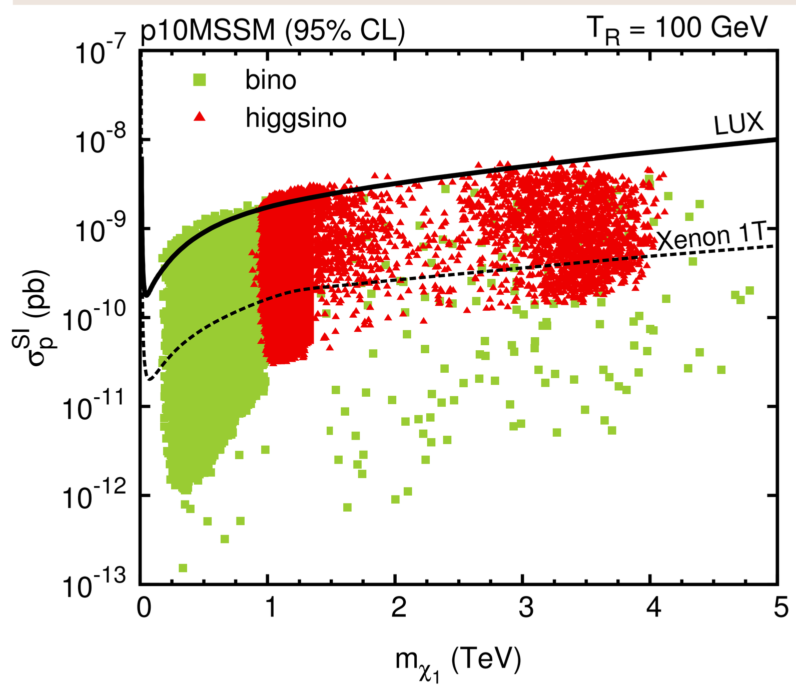
- **Correct DM relic density** for wide range of masses w/o any specific mass patterns
- If direct/cascade decays of the inflaton field to DM are efficient ($\eta > 0$), its relic density can be increased to the experimental value for light higgsinos or winos.

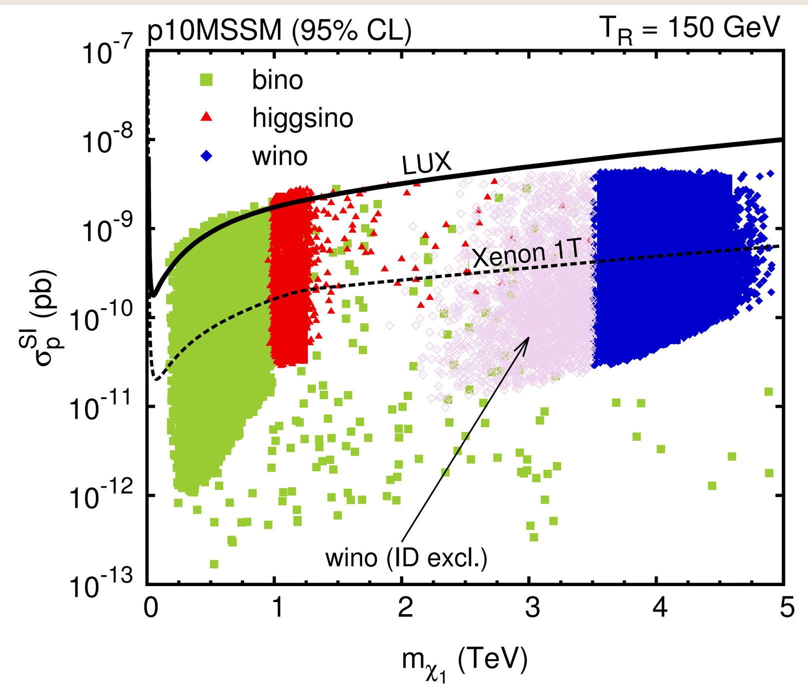
$\eta = b\,\frac{100\,\text{TeV}}{m_\phi}$ with b – average number of DM particles produced per inflaton ϕ decay.





- heavy higgsino DM is still **testable in DM direct detection experiments**
- wino DM can escape exclusion from current DM indirect detection experiments, but will be **testable in the future**





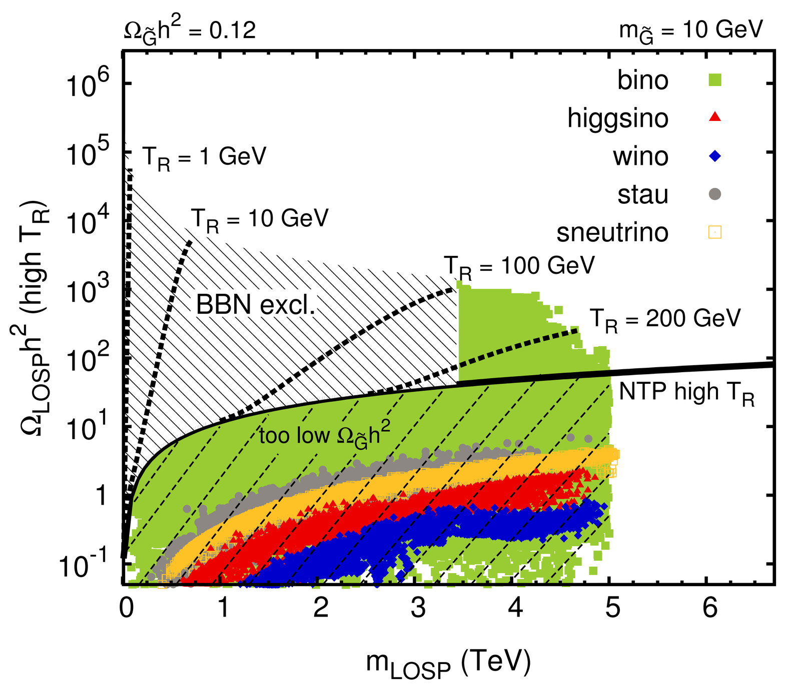
B) Gravitino DM with low T_R

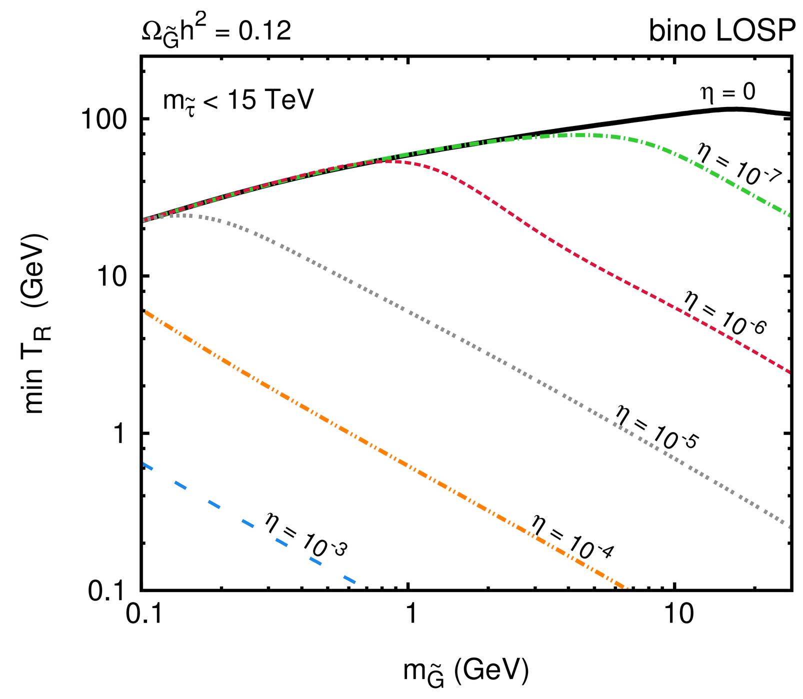
- Relic density of gravitinos for low T_R is determined by non-thermal production (NTP) in late-time decays of the next-to-LSP to gravitino $\tilde{G}$.

$$\Omega_{\tilde{G}} h^2 \simeq \Omega_{\tilde{G}}^{\text{NTP}} h^2 = \frac{m_{\tilde{G}}}{m_{\text{NLSP}}}\,\Omega_{\text{NLSP}} h^2,$$

$\Omega_{\text{NLSP}} h^2$ is calculated in the low T_R regime as if the next-to-LSP was a DM candidate.

- Combination of relic density and Big Bang Nucleosynthesis (BBN) constraints leads to an **effective lower limit on the reheating temperature T_R**



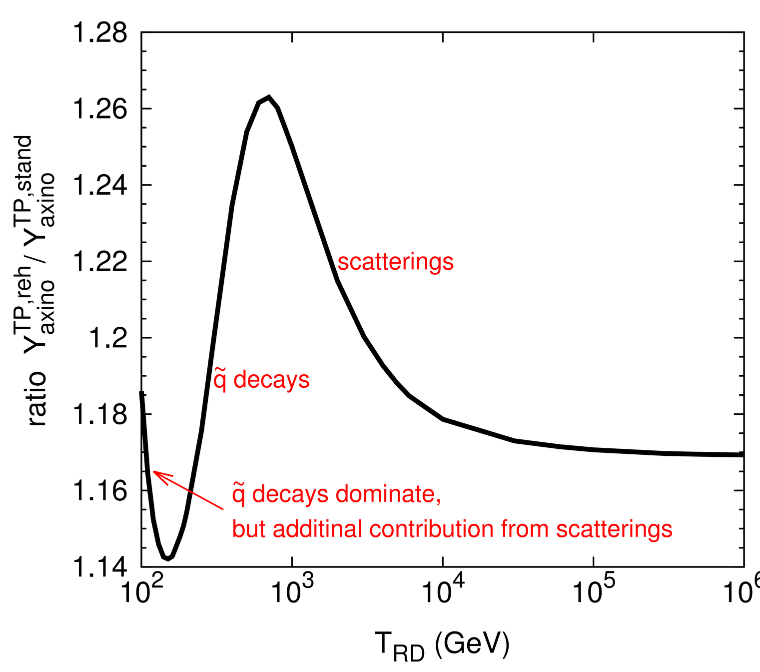


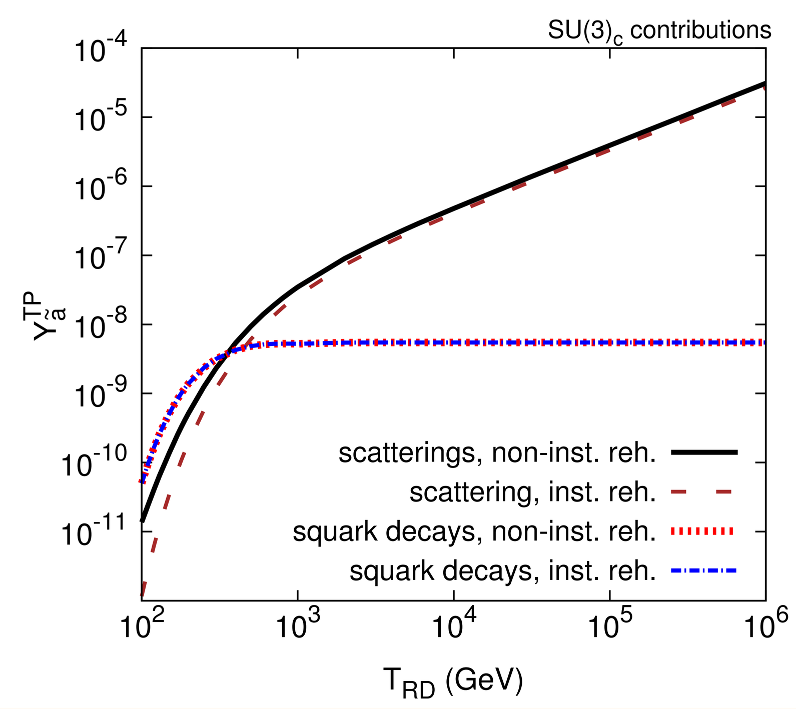
C) Axino DM with low T_R

- Non-thermal production analogous to the gravitino DM case
- Thermal production (TP) of axinos for low T_R is also non-negligible

$$\Omega_{\tilde{a}} h^2 = \Omega_{\tilde{a}}^{\text{NTP}} h^2 + \Omega_{\tilde{a}}^{\text{TP}} h^2$$

- When non-instantaneous reheating is taken into account TP is modified with respect to the standard result since T can be large in the reheating period.





- NTP of axinos is suppressed for sufficiently low T_R
- for higgsino/wino or slepton LOSP one obtains an effective lower limit on T_R
- BBN may severely constrain the low T_R scenario in the bino LOSP case