LARGEST TEMPERATURE OF THE RADIATION ERA AND ITS IMPLICATIONS:

- PARTICLE RELIC ABUNDANCE
- ν AS WARM DARK MATTER

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Particle relic abundance calculations are robust, i.e. do not depend on initial conditions

THERMAL EQUILIBRIUM

$$H \sim \frac{T^2}{M_{Pl}}$$

⇓

MICROPHYSICS

freeze-out when $\Gamma_A = H$

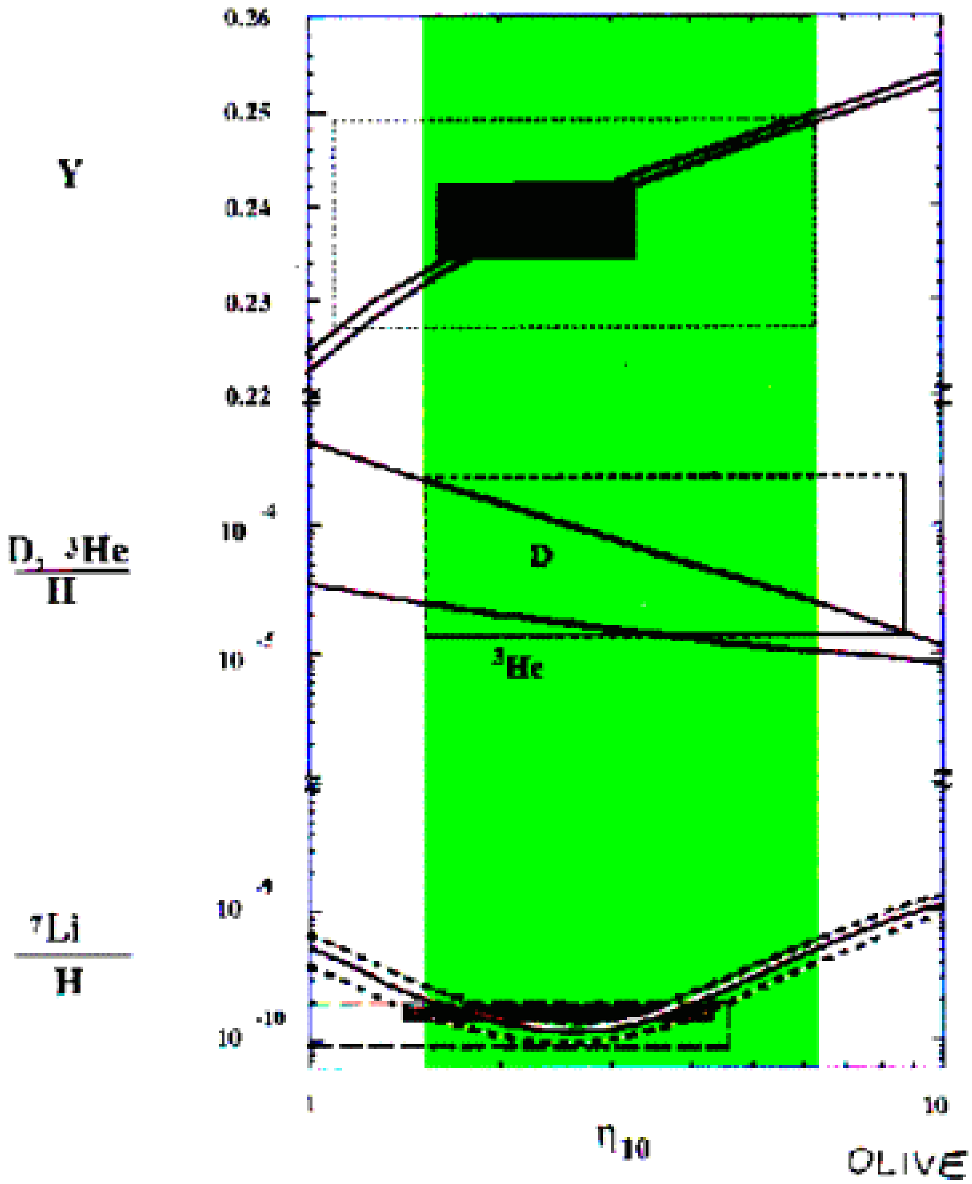
⇓

$$n_x \simeq \frac{\text{GeV}}{T_F} \frac{\text{nb}}{\langle \sigma v \rangle} 10^{-11} \text{ cm}^{-3}$$

Is thermal eq. a safe assumption?

What is the highest temperature of the radiation epoch T_{RH}?

BIG-BANG NUCLEOSYNTHESIS



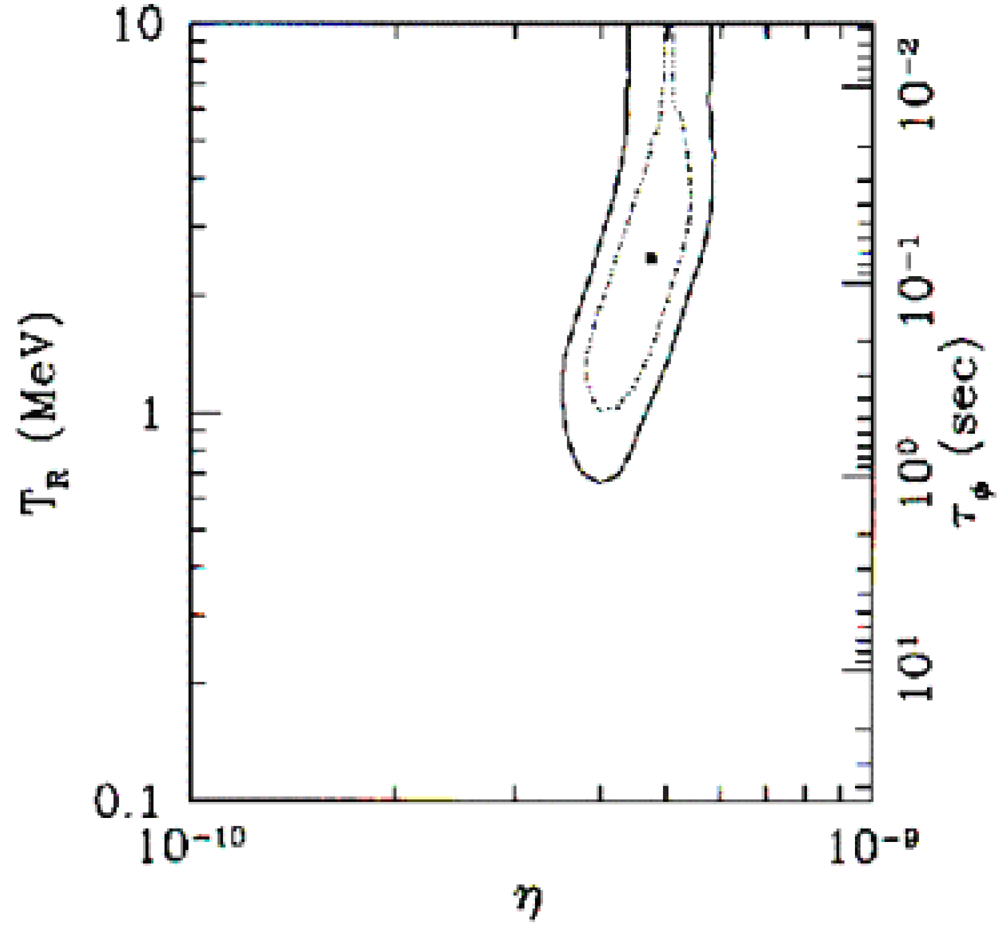


FIG. 8. Contours of the confidence level in (η, T_R) plane. The inner (outer) curve is 68% (95%) C.L. The filled square denotes the best fit point. The right vertical axis denotes the lifetime which corresponds to T_R.

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No support from observations for $T_{RH} \gg$ MeV

Recent theoretical considerations suggest low T_{RH}

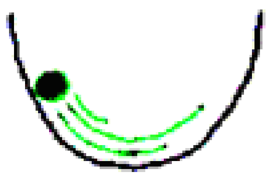
- non-thermal production of gravitinos and moduli in certain inflationary schemes require T_{RH} as low as 100 GeV

- theories with large extra dimensions require T_{RH} in the range MeV - GeV to avoid graviton emission in bulk.

Study the case in which T_{RH} is of the order of the characteristic temperature of the physical process

DYNAMICS OF REHEATING

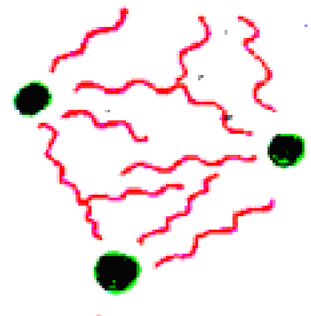
Sudden approximation:



ρ_ϕ

at inflaton decay time

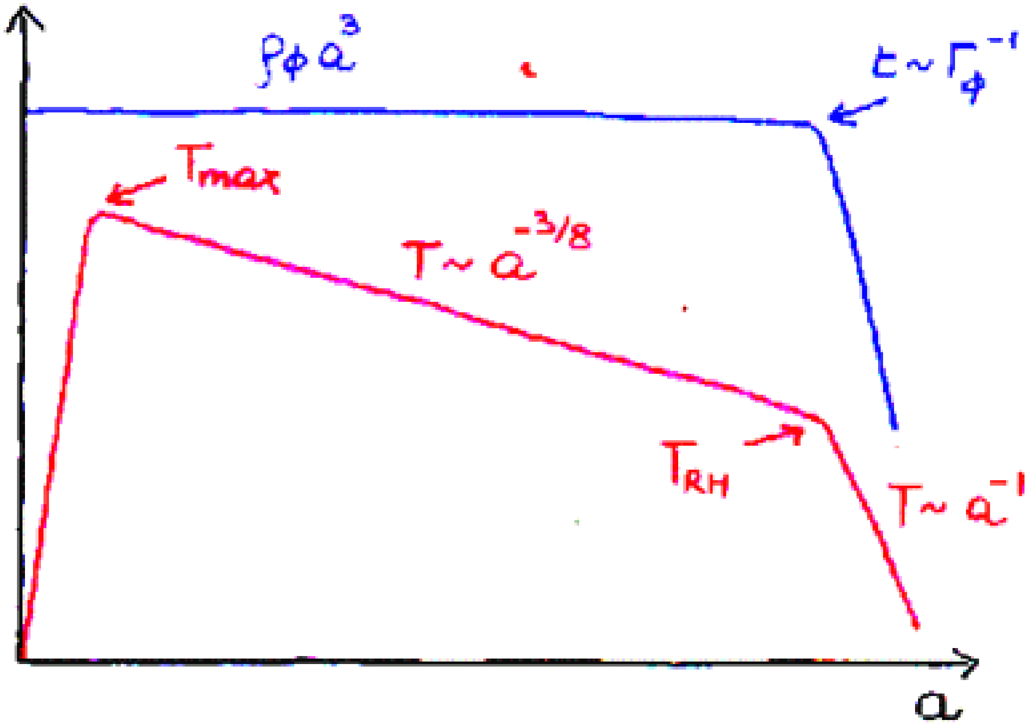
$$t^{-1} = \Gamma_\phi$$
$$\parallel$$
$$H = \sqrt{\frac{8\pi}{3M_p^2}\rho_\phi}$$



$$\rho_R = \pi^2 \frac{g_*}{30} T^4$$

$$\rho_\phi = \rho_R \quad \Rightarrow \quad T_{RH}^2 = \sqrt{\frac{45}{4\pi^3 g_*}}\,\Gamma_\phi M_p$$

- Reheating is not an instantaneous process
- T_{RH} is not the largest temperature
- The Universe has an unusual expansion phase



- T_{max} is the largest temperature

$$\frac{T_{max}}{T_{RH}} \simeq 4 \times 10^5 \left(\frac{H_I}{\text{TeV}}\right)^{1/4} \left(\frac{\text{MeV}}{T_{RH}}\right)^{1/2}$$

- Universe has a pre-reheating phase with fast expansion

$$T \sim a^{-3/8} \qquad H \sim \frac{T^4}{T_{RH}^2 M_P}$$

- For $t > \Gamma_\phi^{-1}$, usual radiation-dominated phase

$$T \sim a^{-1} \qquad H \sim \frac{T^2}{M_P}$$

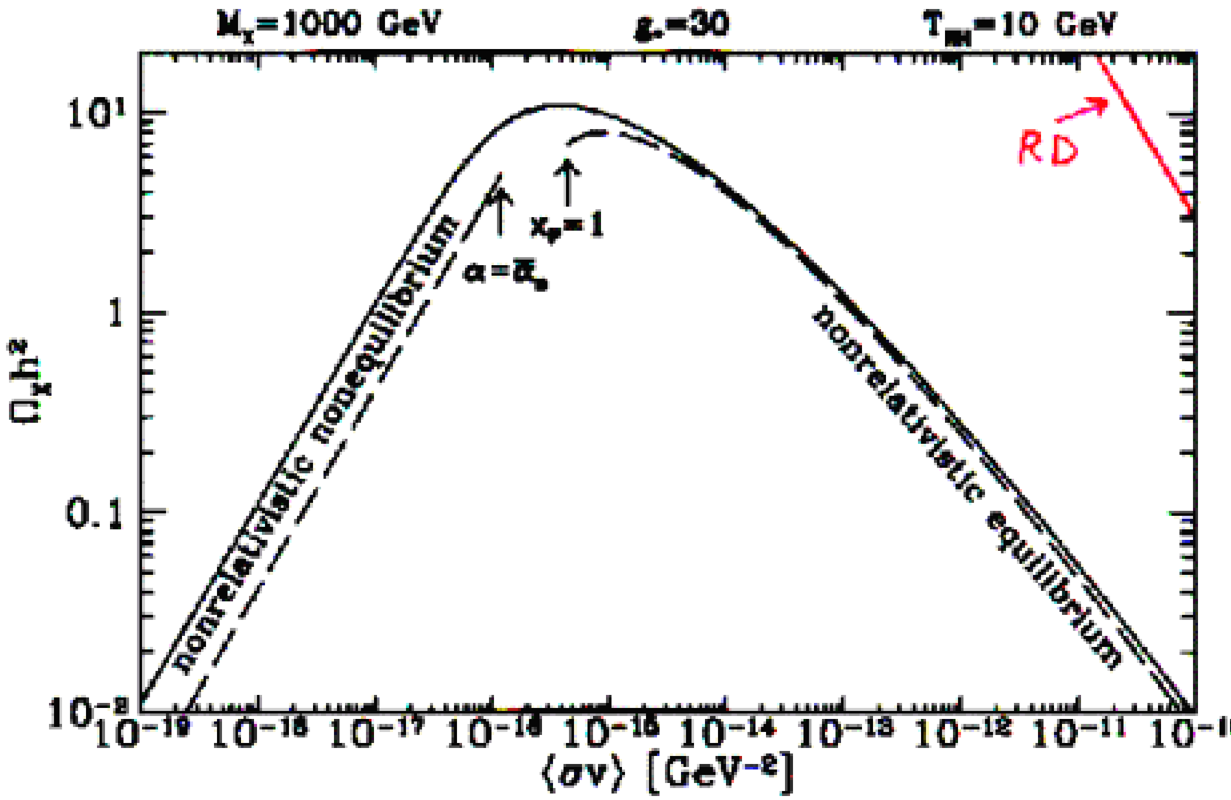
$\sigma < \sigma_c \qquad \Omega_X h^2 \simeq 10^{25} \dfrac{T_{RH}^7}{M_X^5}\, \sigma$

$\sigma > \sigma_c \qquad \Omega_X h^2 \simeq 10^{-11} \dfrac{T_{RH}^3 M_X}{\sigma\, T_F^4}$

$\sigma_c \simeq 10^{-18} M_X / T_{RH}^2$ all units in GeV

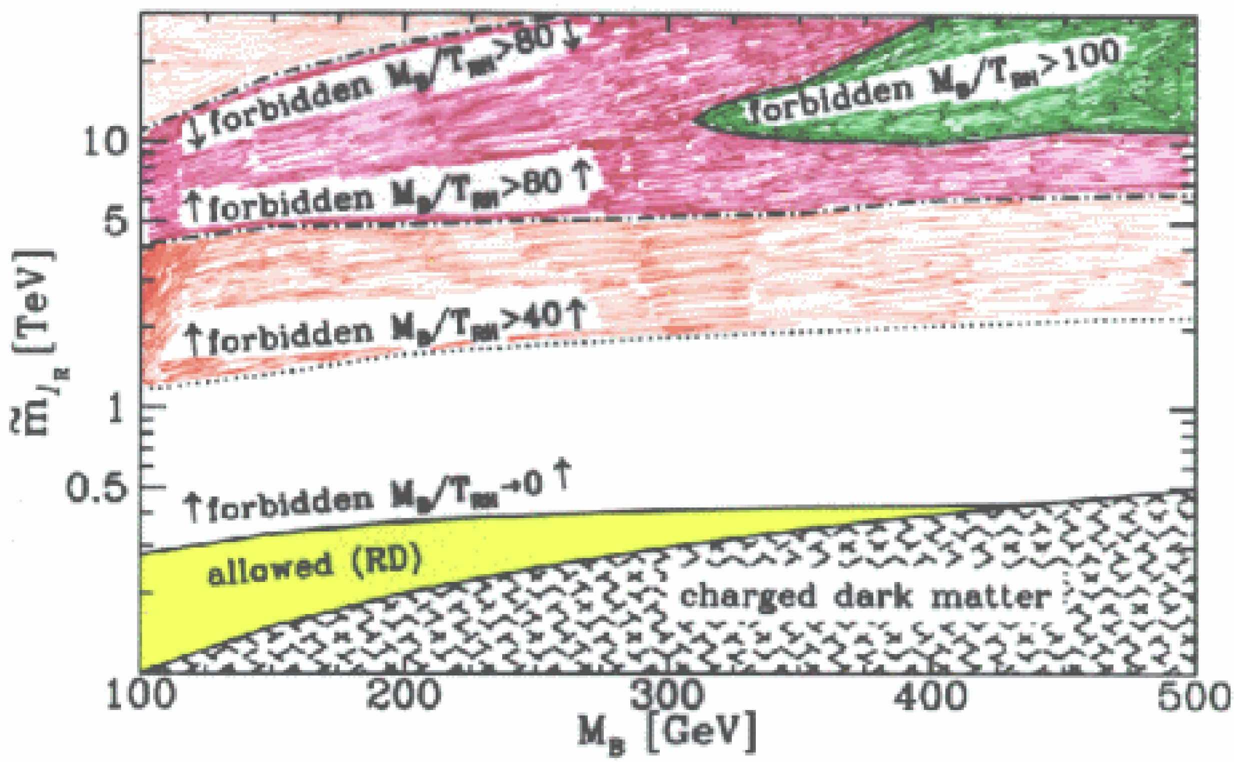
If it decouples during RD phase

$$\Omega_X h^2 \simeq 10^{-11} \frac{M_X}{\sigma T_F}$$

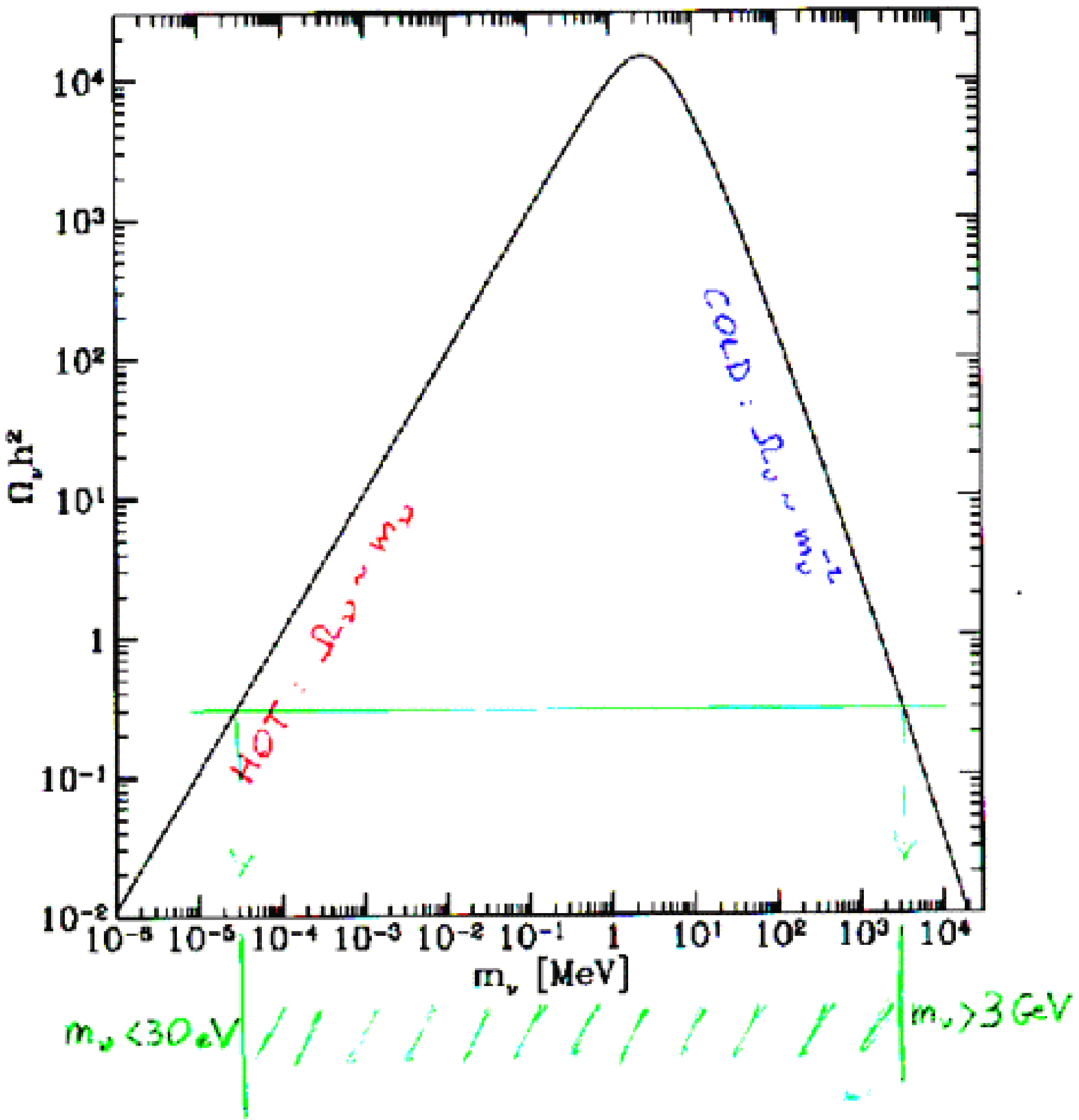


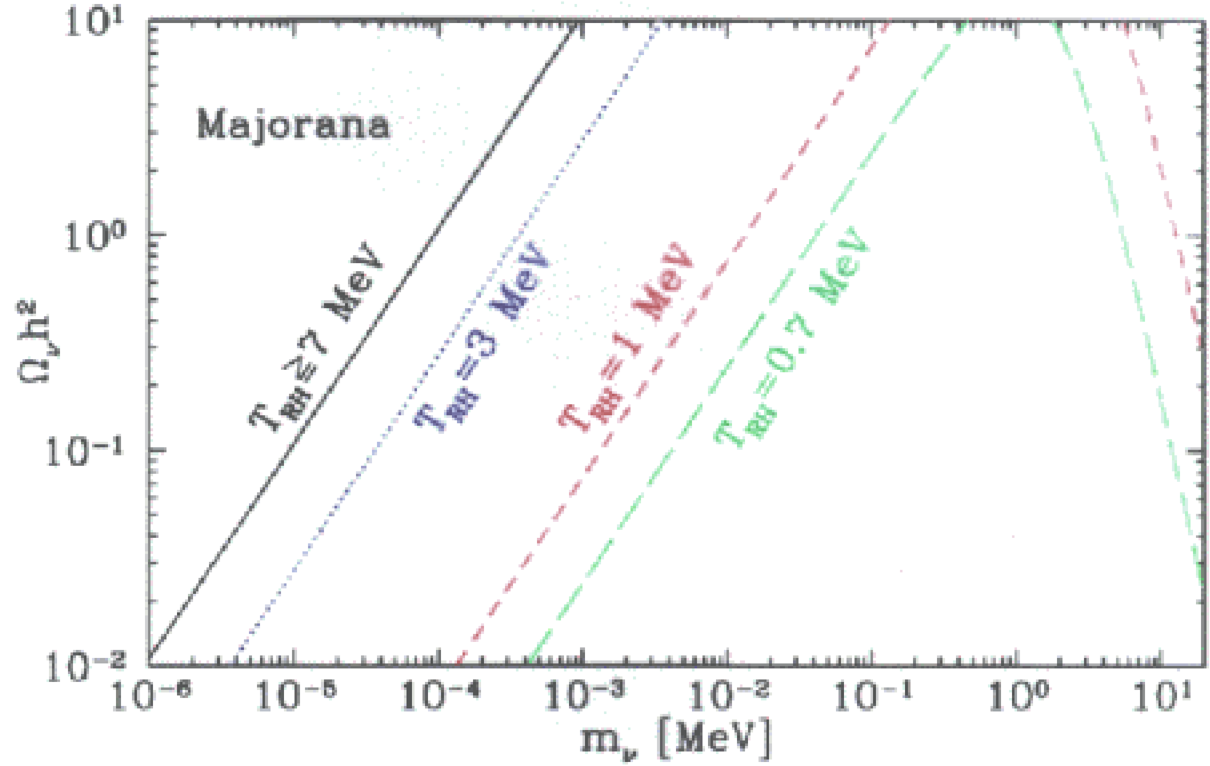
Supersymmetric DM abundances are modified if

$$T_{RH} < T_F \simeq \frac{M_{susy}}{20}$$



LEE-WEINBERG BOUND





Majorana
$T_{RH} \gtrsim 7$ MeV
$T_{RH}=3$ MeV
$T_{RH}=1$ MeV
$T_{RH}=0.7$ MeV
$\Omega_\nu h^2$
m_ν [MeV]

$$\Omega_{\nu_\mu} = \Omega_{\nu_\tau} = 0.3 \left(\frac{0.65}{h}\right)^2 \frac{m_\nu}{\text{KeV}} \left(\frac{T_{RH}}{0.8\text{ MeV}}\right)^3$$

For $T_{RH} \sim$ MeV, $m_\nu \sim$ KeV allowed

$\Rightarrow$ ν as warm DM ?

ΛCDM cosmology successful at large scales

Difficulties at small scales ?

Cured by WDM ?

Smoothing scale

$$R_S \simeq 0.3 \left(\frac{\Omega_{WDM}}{0.3}\right)^{0.15} \left(\frac{h}{0.65}\right)^{1.3} \left(\frac{\text{KeV}}{m}\right)^{1.15} \text{Mpc}$$

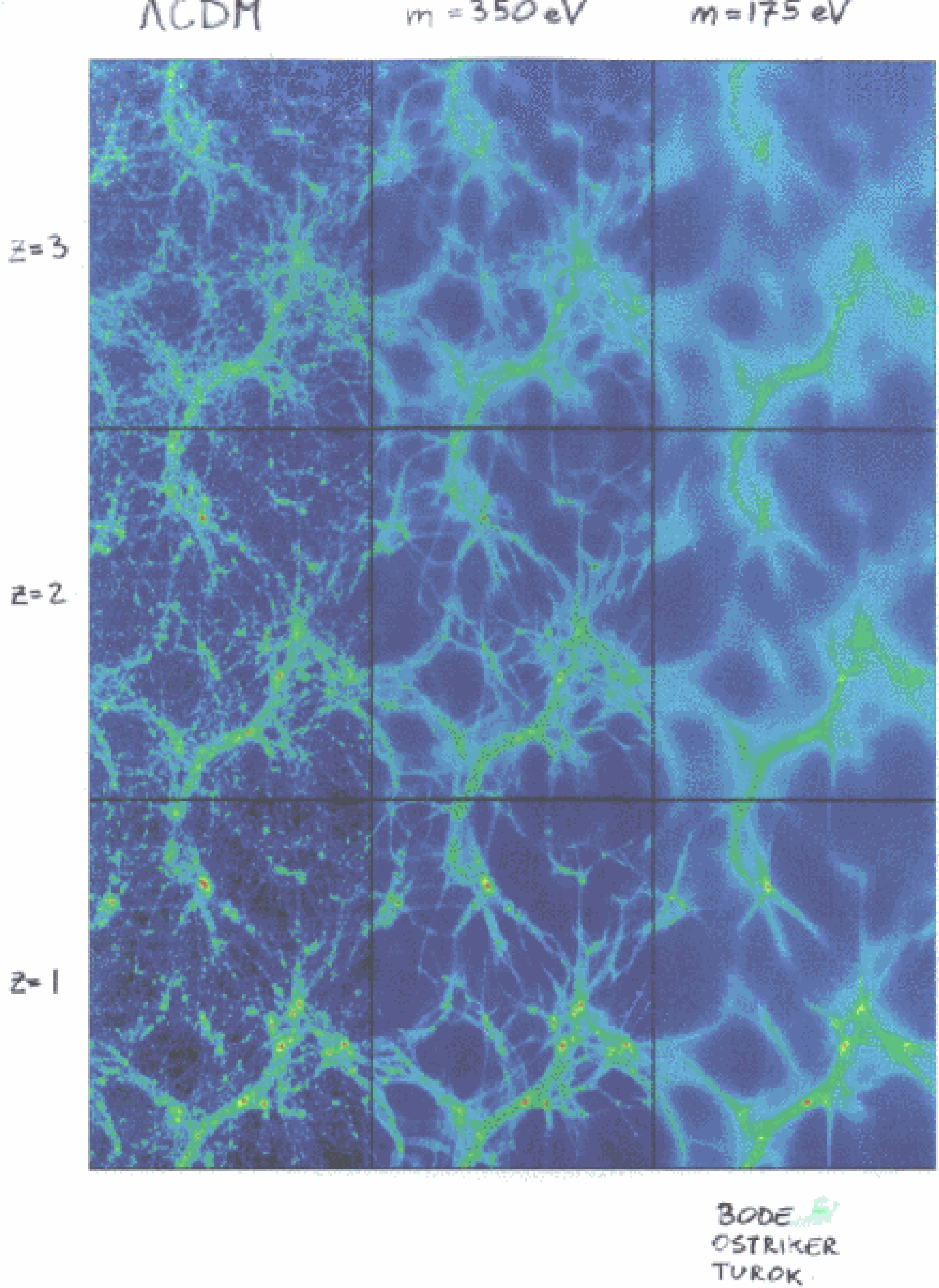
- low-mass halos

CDM 500 satellites of Milky Way with mass $\gtrsim 10^8 M_\odot$

2000-3000 " " local group ~ 1.5 Mpc

Obs: 11 dwarf galaxies MW

36 " " LG


ΛCDM
m = 350 eV
m = 175 eV
z = 3
z = 2
z = 1
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- Cusps in halos ?

WDM reduces both core radius and core density

- Obs : faint galaxies distribution seems correlated with bright galaxies

ΛCDM : low-mass halos fill the gaps of large-mass halos

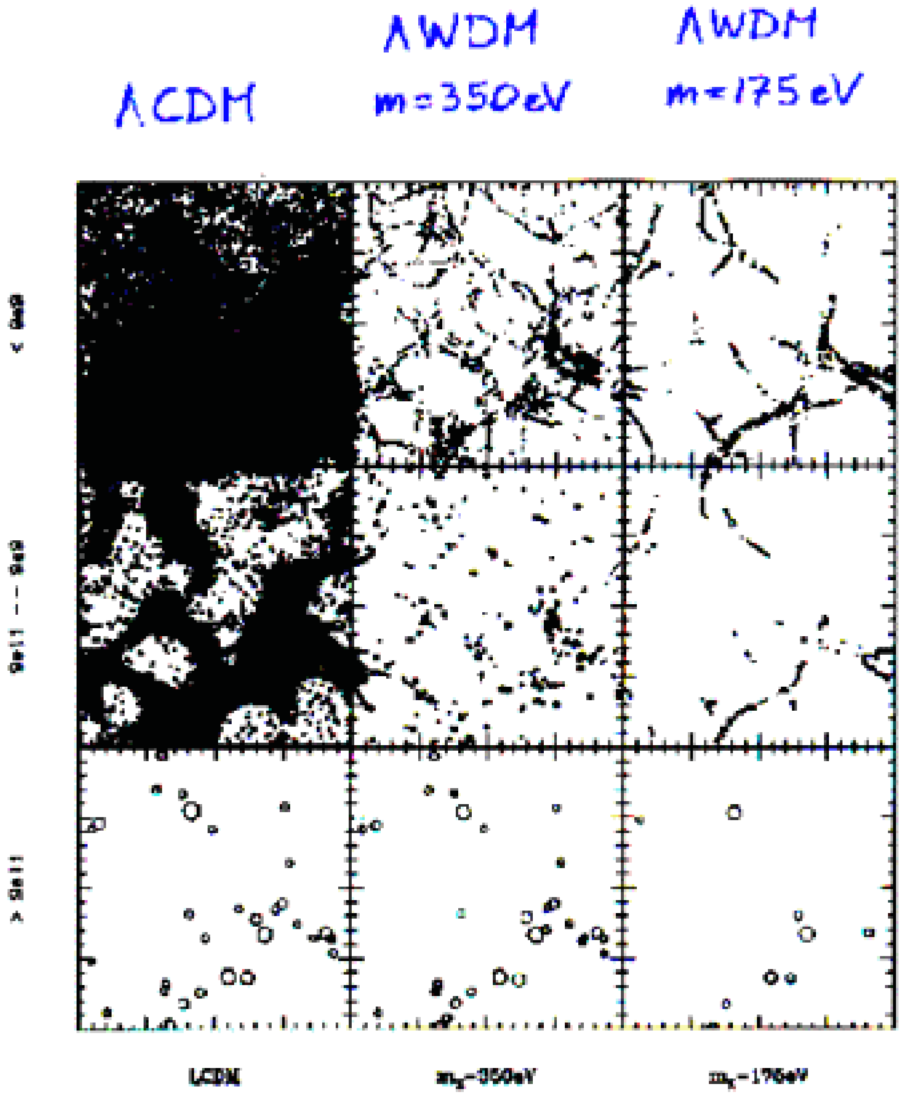

FIG. 5. Position of gravitationally bound halos at redshift $Z = 1$, corresponding to the top row of Figure (4). Bottom to top: high ($M_{200} > 9 \times 10^{9} h^{-1} M_{\odot}$), intermediate ($9 \times 10^{8} h^{-1} M_{\odot} < M_{200} < 9 \times 10^{9} h^{-1} M_{\odot}$), and low mass ($9 \times 10^{7} h^{-1} M_{\odot} < M_{200} < 9 \times 10^{8} h^{-1} M_{\odot}$) halos. Left to right: ΛCDM, $m_X = 350$ eV and $m_X = 175$ ΛWDM. The radius of each circle is r_{200}. In WDM, the formation of low mass objects is in a filament-like structure connecting higher mass halos. Note the almost complete absence of small halos outside these regions, while the highest mass halos (bottom row) are quite similar to LCDM.

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CONCLUSIONS

- We have no observational evidence that $T_{RH} \gtrsim$ MeV
- If T_{RH} comparable to characteristic temperature of physical process, standard predictions are modified
- Relic density calculations depend on T_{RH}
- Supersymmetric particle density can be reduced
- ν can become a WDM candidate