Local density of relic neutrinos with minimal mass

Based on arXiv:1706.09850, in collaboration
with P F. de Salas, J. Lesgourgues and S. Gariazzo

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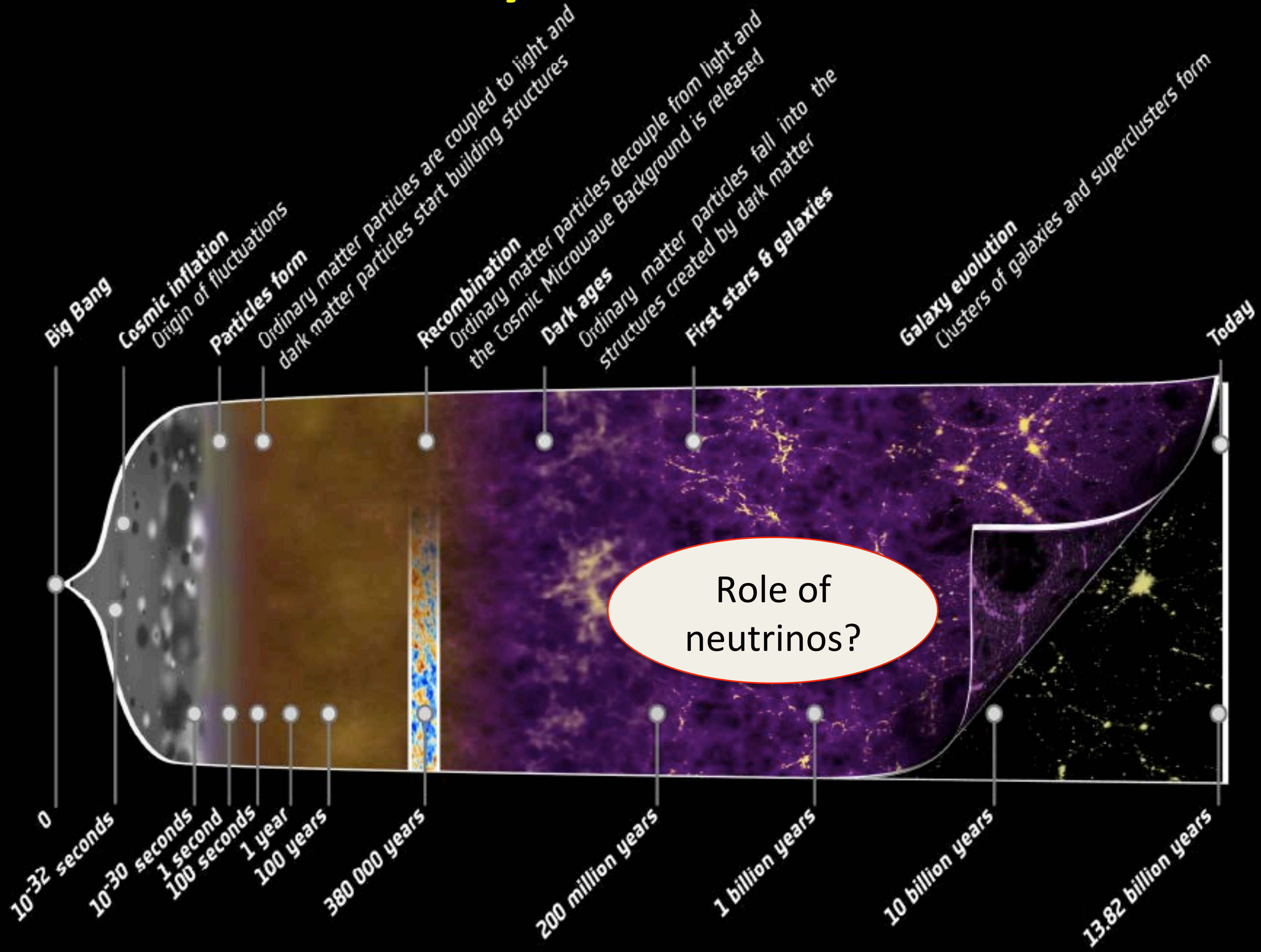
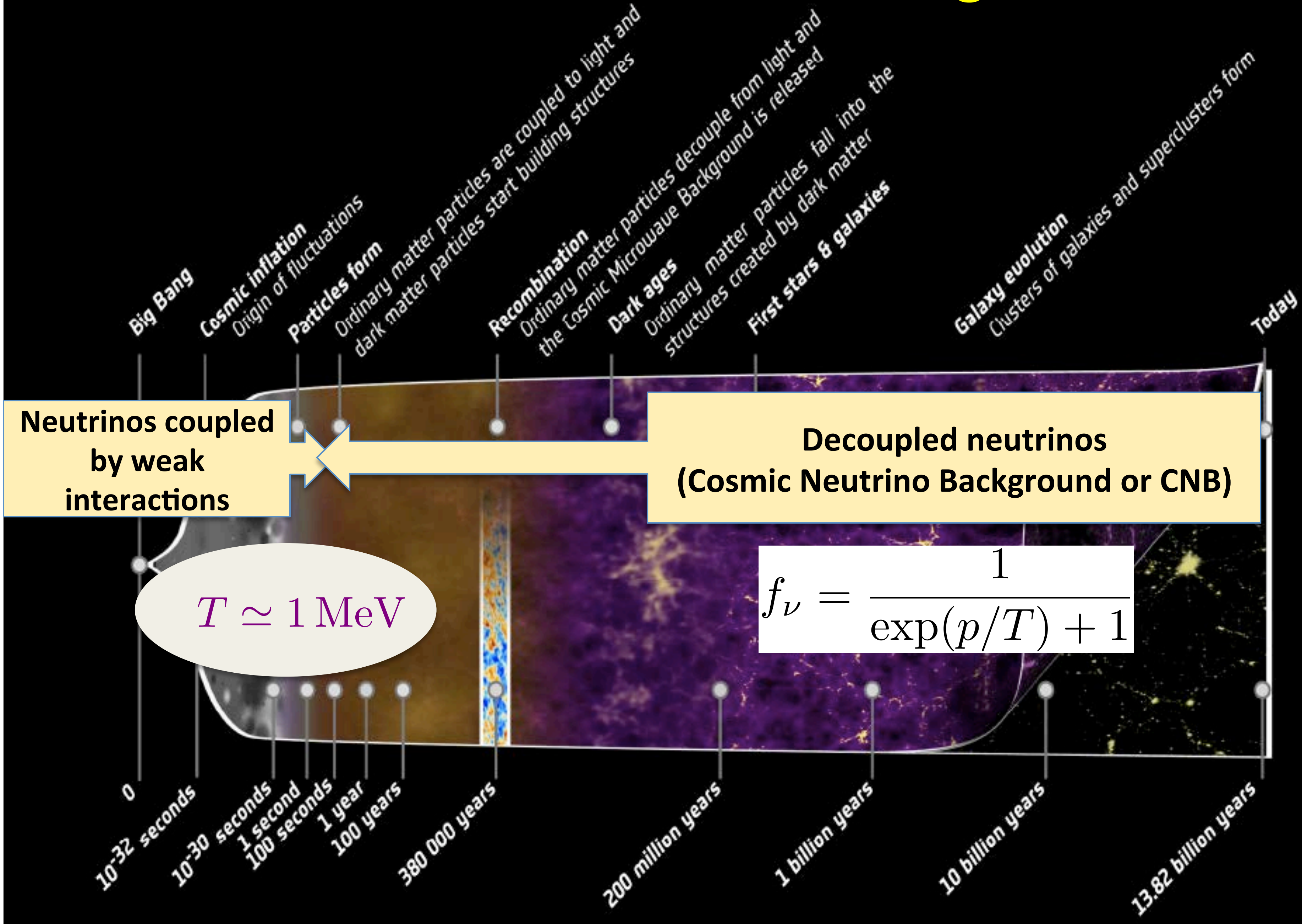
History of the Universe



Role of neutrinos?

The Cosmic Neutrino Background



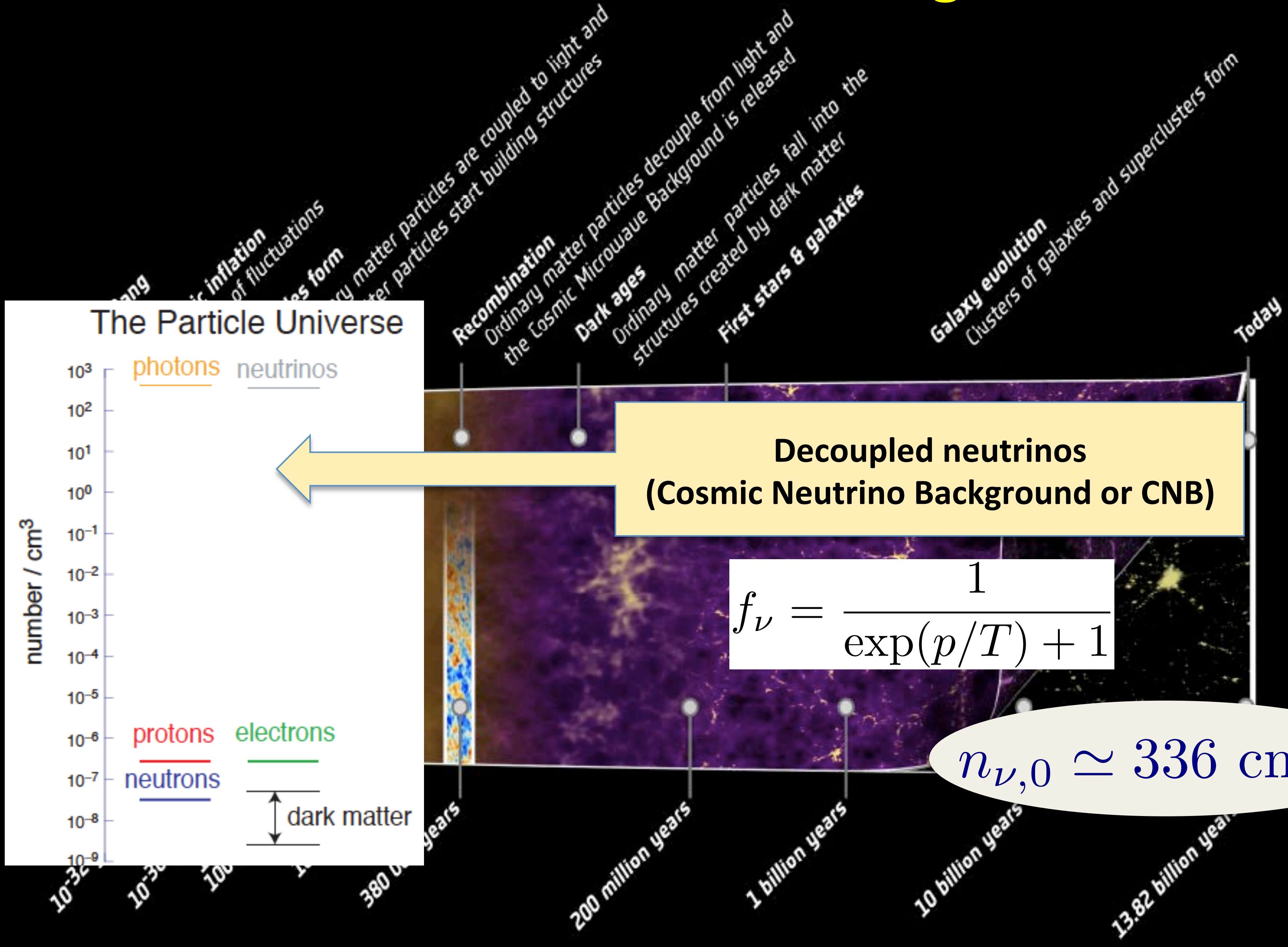
Neutrinos coupled by weak interactions

Decoupled neutrinos
(Cosmic Neutrino Background or CNB)

$T \simeq 1\,\mathrm{MeV}$

$$f_\nu = \frac{1}{\exp(p/T)+1}$$

The Cosmic Neutrino Background

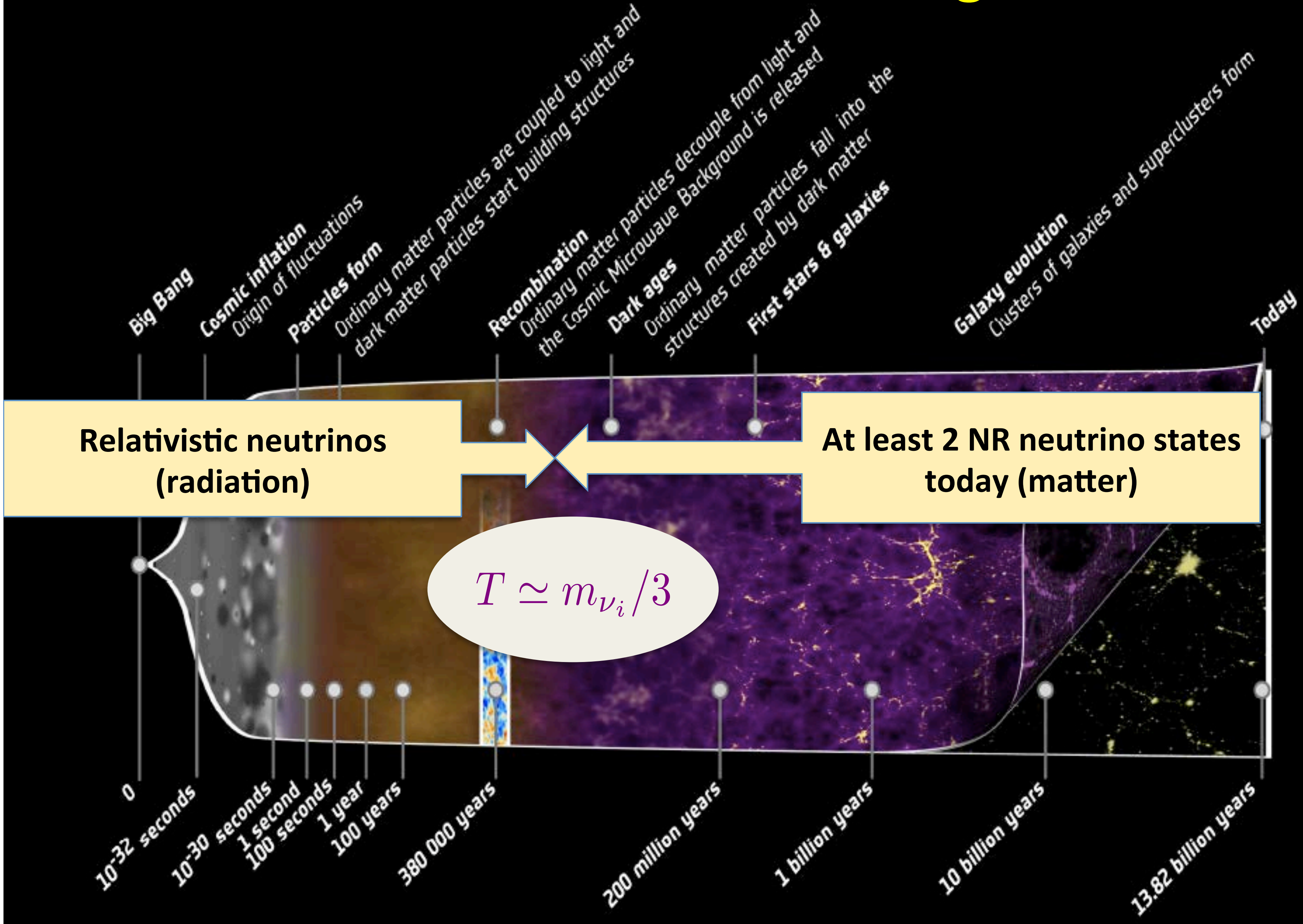


Decoupled neutrinos
(Cosmic Neutrino Background or CNB)

$$f_\nu = \frac{1}{\exp(p/T)+1}$$

$$n_{\nu,0} \simeq 336\ \mathrm{cm}^{-3}$$

The Cosmic Neutrino Background

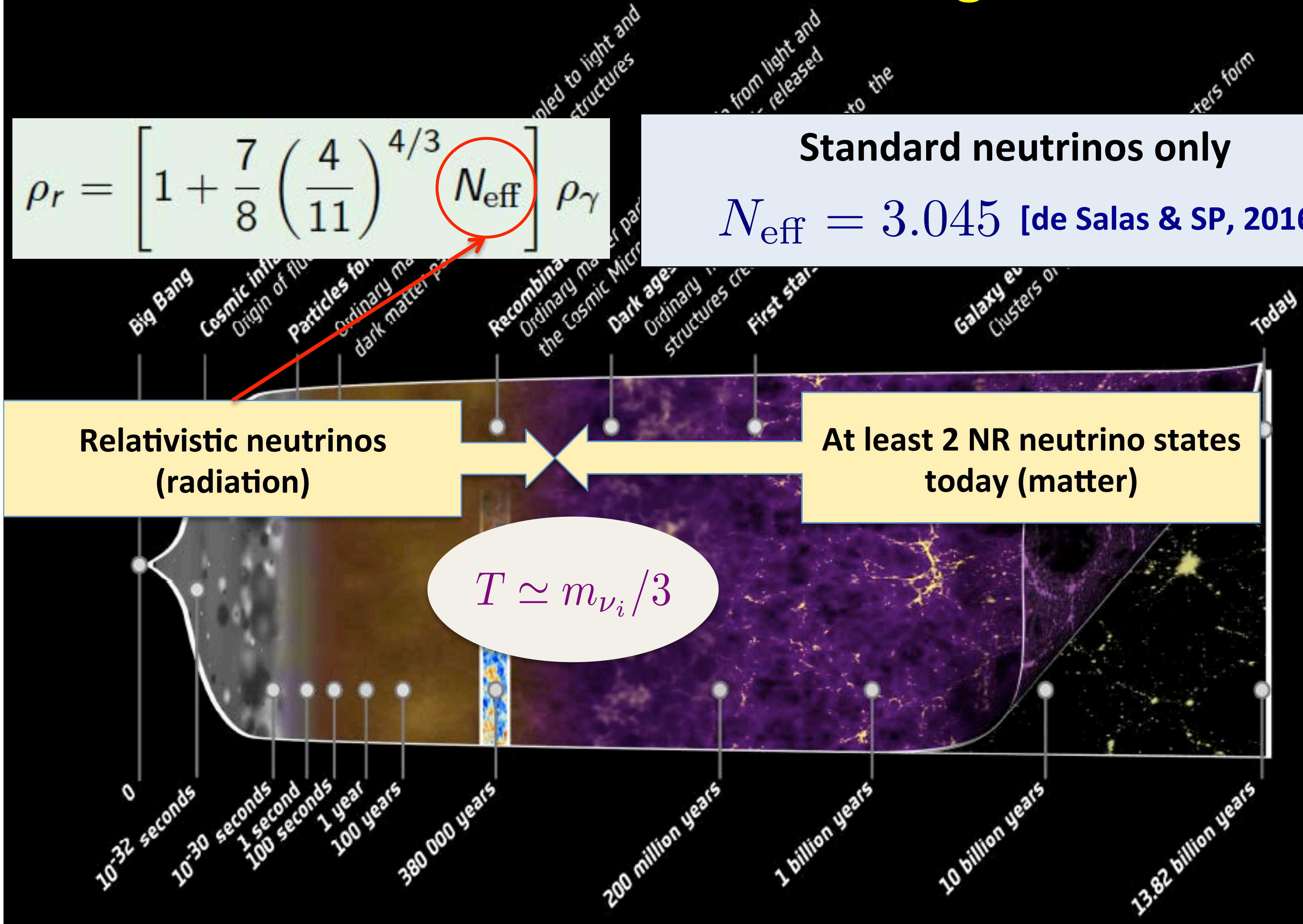


Relativistic neutrinos (radiation)

At least 2 NR neutrino states today (matter)

$$T \simeq m_{\nu_i}/3$$

The Cosmic Neutrino Background



$$\rho_r = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right]\rho_\gamma$$

Standard neutrinos only

$N_{\rm eff} = 3.045$ **[de Salas & SP, 2016]**

Relativistic neutrinos (radiation)

At least 2 NR neutrino states today (matter)

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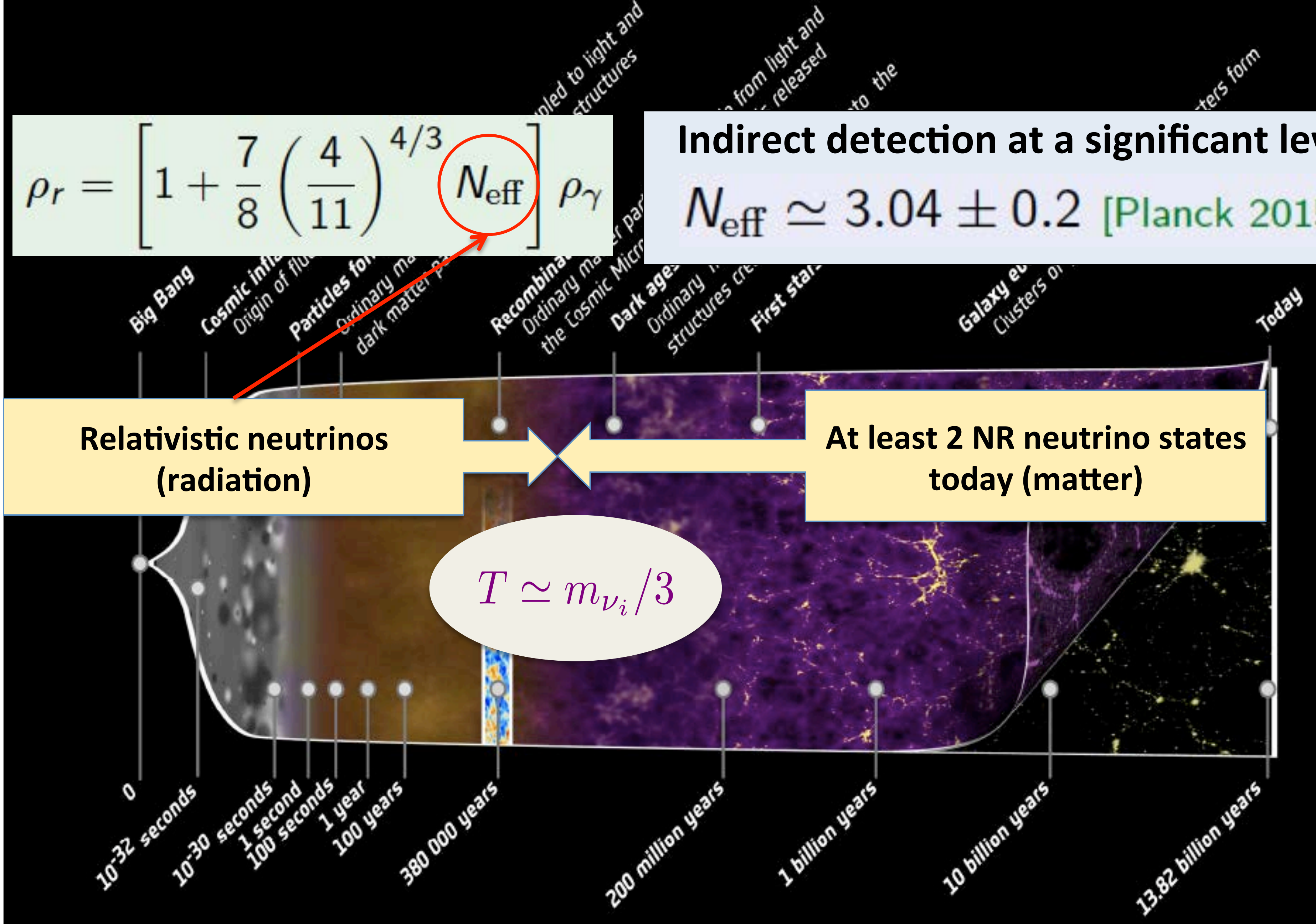
The Cosmic Neutrino Background

$$\rho_r = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} \boxed{N_{\mathrm{eff}}}\right] \rho_\gamma$$

Indirect detection at a significant level

$$N_{\mathrm{eff}} \simeq 3.04 \pm 0.2 \text{ [Planck 2015]}$$



Relativistic neutrinos (radiation)

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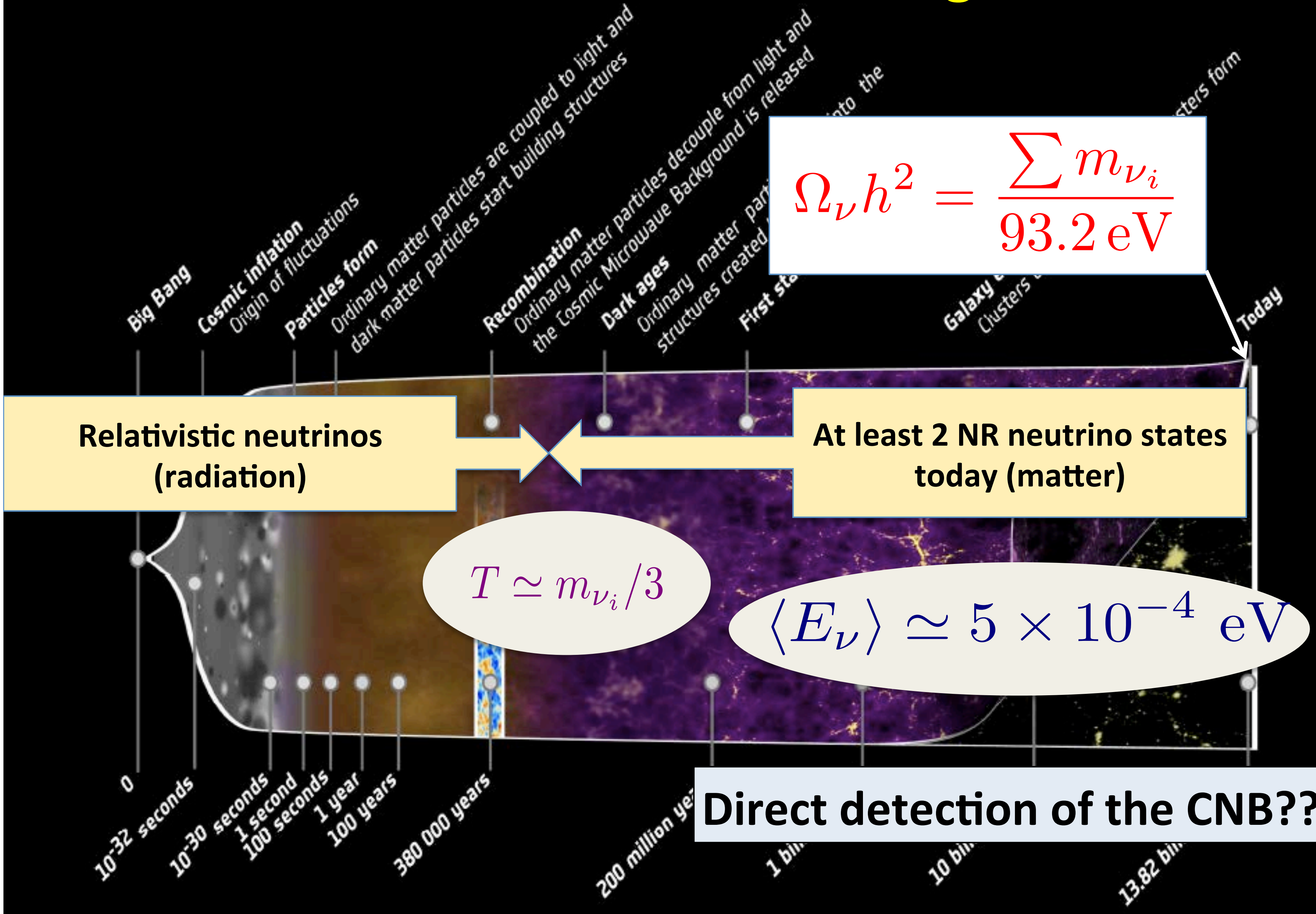


$$\Omega_\nu h^2 = \frac{\sum m_{\nu_i}}{93.2\,\mathrm{eV}}$$

Relativistic neutrinos (radiation)

At least 2 NR neutrino states today (matter)

$$T \simeq m_{\nu_i}/3$$

$$\langle E_\nu \rangle \simeq 5 \times 10^{-4}\ \mathrm{eV}$$

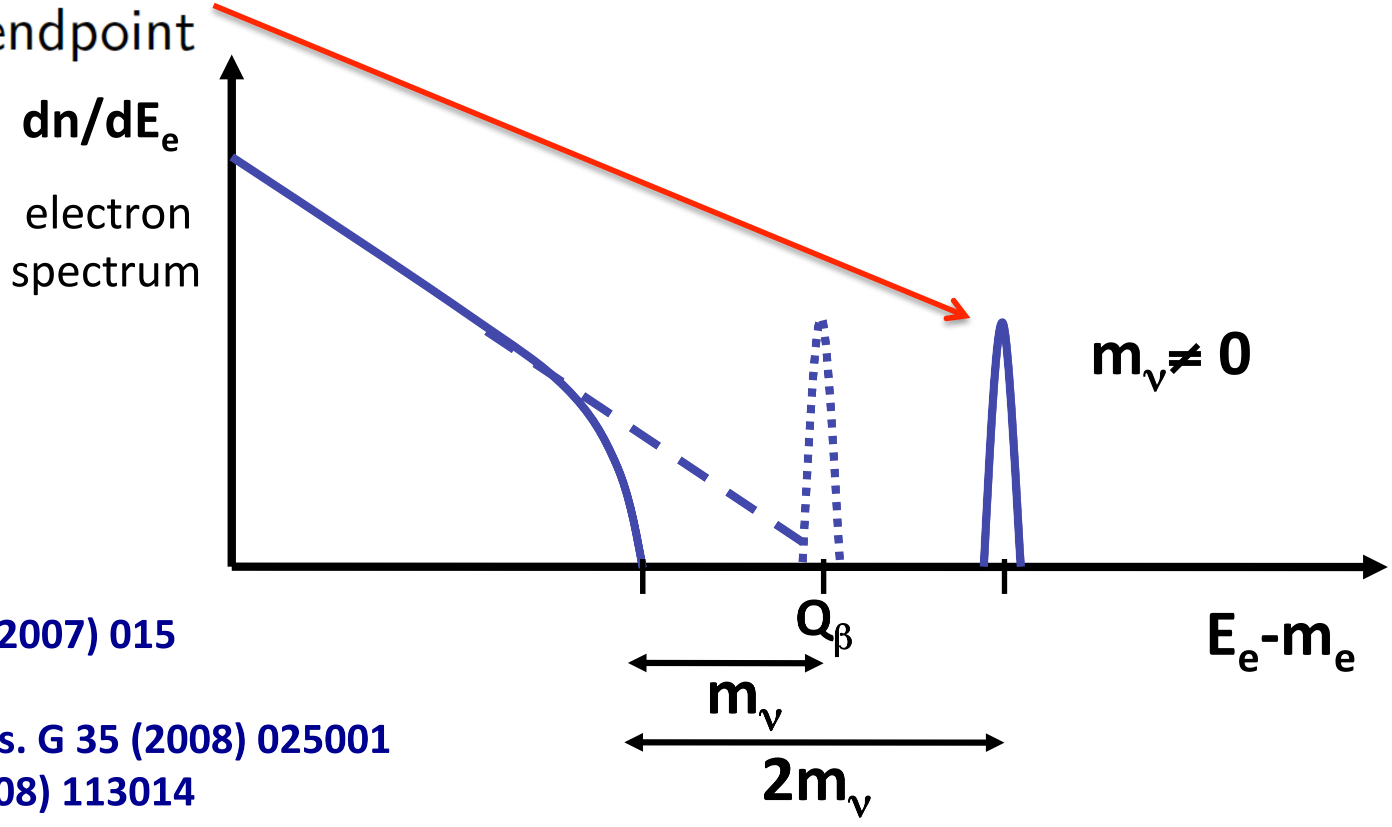
Direct detection of the CNB??

Direct detection of massive relic neutrinos

A process without energy threshold is necessary

[Weinberg, 1962]: neutrino capture in β–decaying nuclei

signal is a peak at $2m_\nu$
above β–decay endpoint



Cocco et al, JCAP 06 (2007) 015
see also:
Lazauskas et al, J.Phys. G 35 (2008) 025001
Blennow, PRD 77 (2008) 113014

Direct detection of massive relic neutrinos

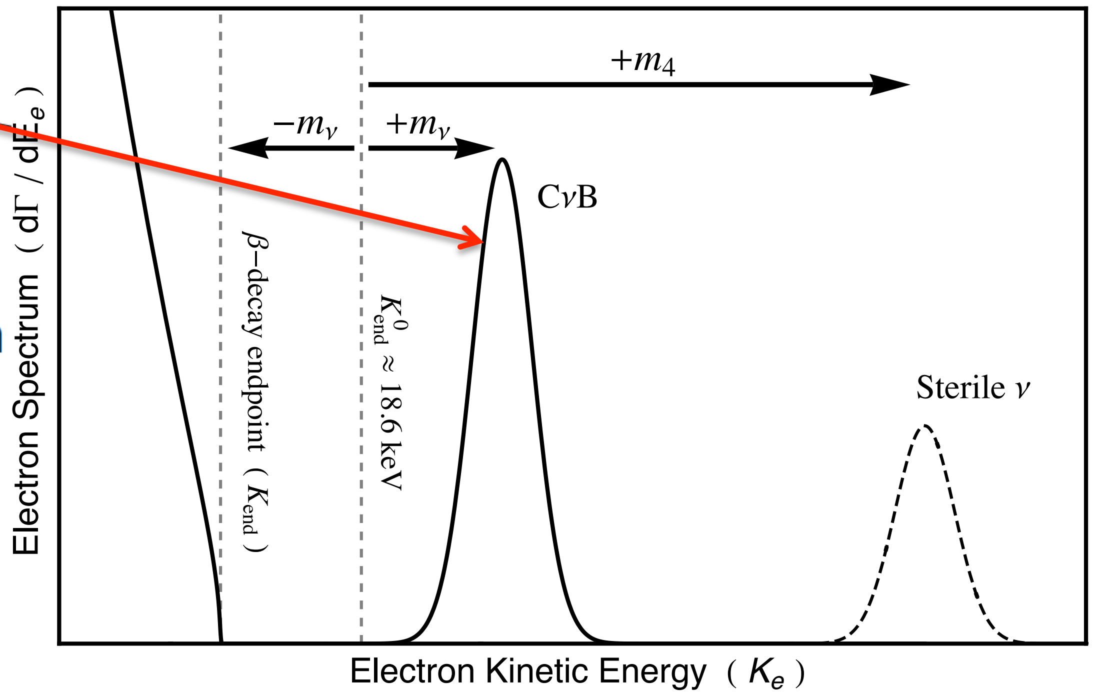
A process without energy threshold is necessary

[Weinberg, 1962]: neutrino capture in β–decaying nuclei

signal is a peak at $2m_\nu$ above β–decay endpoint

only with a lot of material

need a very good energy resolution



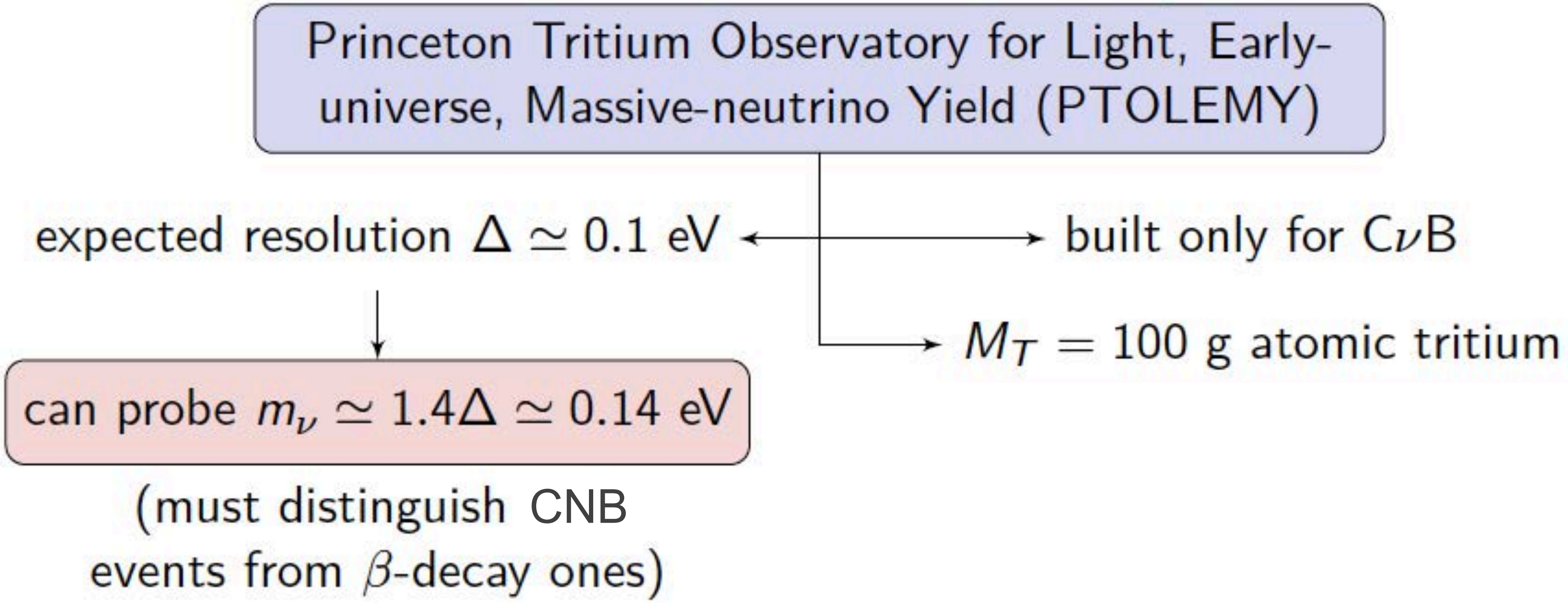
Long et al, JCAP 08 (2014) 038

Good candidate: tritium

(low Q–value) + (good availability of ^{3}H) + (high cross section of $\nu +^3 \mathrm{H} \to^3 \mathrm{He} + e^-$)

Direct detection of massive relic neutrinos

Long et al, JCAP 08 (2014) 038
Betts et al arXiv:1307.4738



Princeton Tritium Observatory for Light, Early-universe, Massive-neutrino Yield (PTOLEMY)

expected resolution $\Delta \simeq 0.1$ eV

built only for CνB

$M_T = 100$ g atomic tritium

can probe $m_\nu \simeq 1.4\Delta \simeq 0.14$ eV

(must distinguish CNB events from β-decay ones)

$$\Gamma_{\mathrm{C}\nu\mathrm{B}} = \sum_{i=1}^{3} |U_{ei}|^2 [n_i(\nu_{h_R}) + n_i(\nu_{h_L})]\, N_T\, \bar{\sigma}$$

N_T number of ^{3}H nuclei in a sample of mass M_T $\bar{\sigma} = \simeq 3.834 \times 10^{-45}$ cm^2 n_i number density of neutrino i

$$\Gamma^{M}_{\mathrm{C}\nu\mathrm{B}} = 2\Gamma^{D}_{\mathrm{C}\nu\mathrm{B}}$$

Direct detection of massive relic neutrinos

Long et al, JCAP 08 (2014) 038
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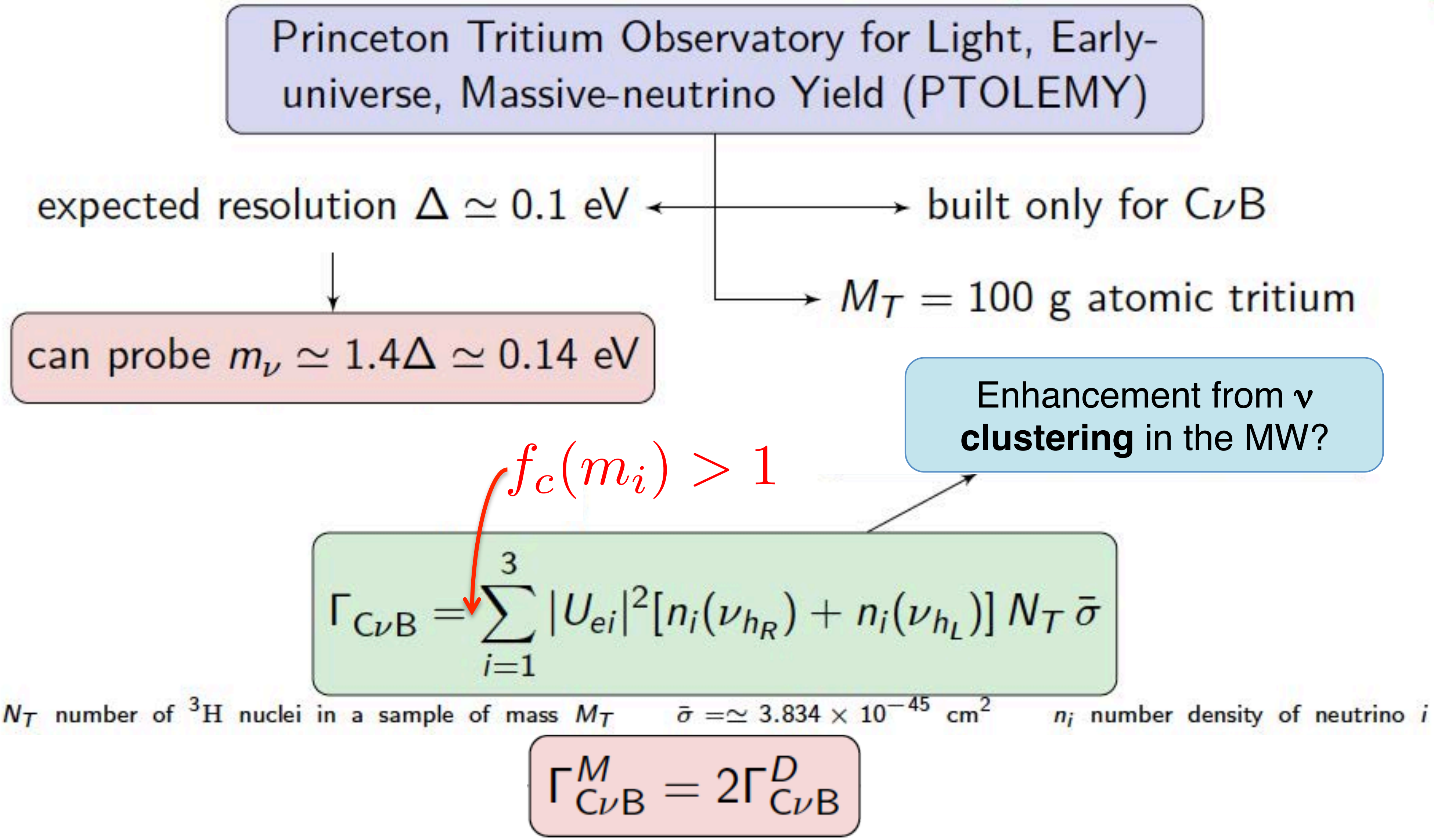

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Enhancement from ν **clustering** in the MW?

$$f_c(m_i) > 1$$

$$\Gamma_{\mathrm{C}\nu\mathrm{B}} = \sum_{i=1}^{3} |U_{ei}|^2 [n_i(\nu_{h_R}) + n_i(\nu_{h_L})]\, N_T\, \bar{\sigma}$$

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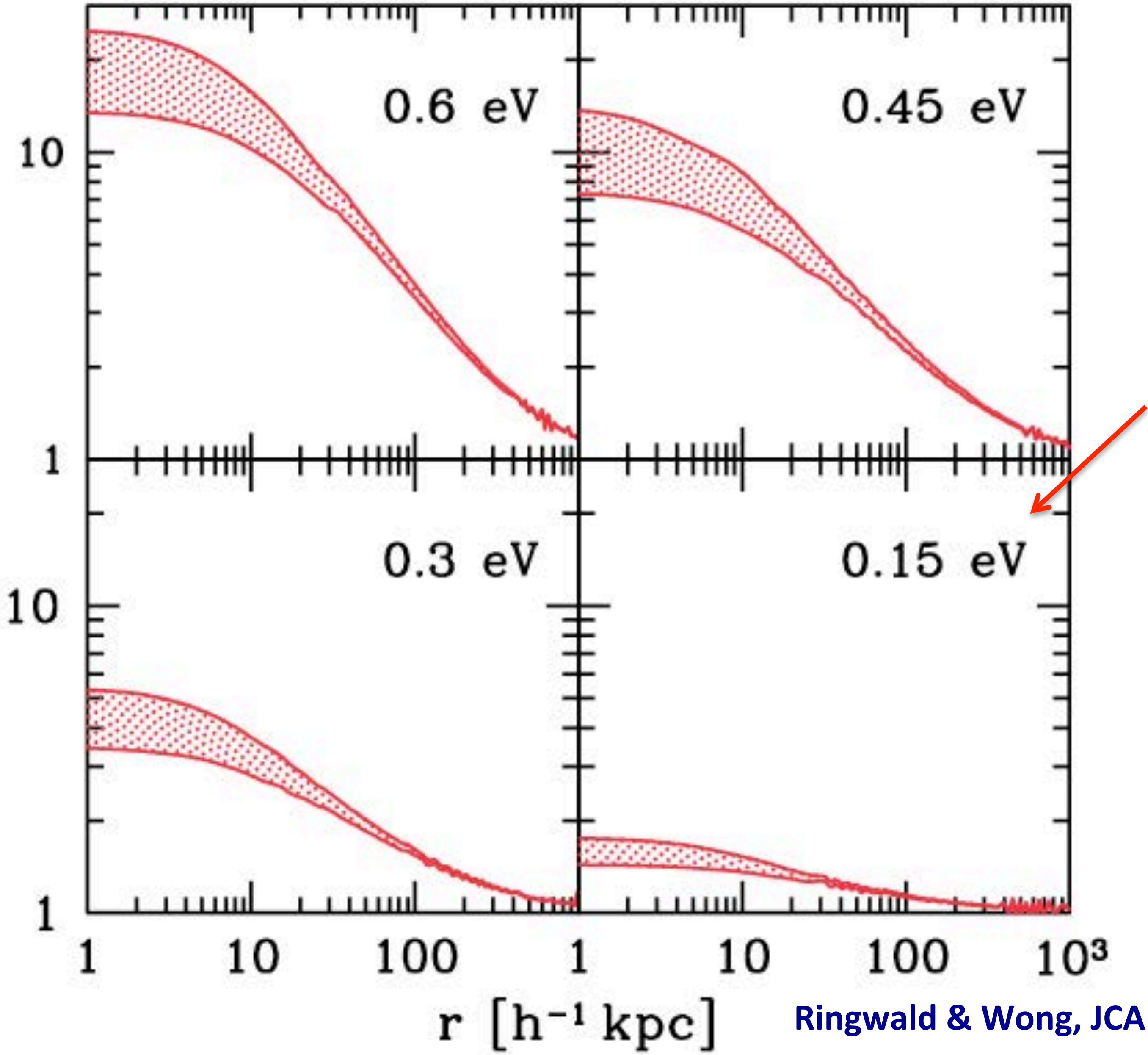
$$\Gamma^{M}_{\mathrm{C}\nu\mathrm{B}} = 2\Gamma^{D}_{\mathrm{C}\nu\mathrm{B}}$$

Relic neutrino clustering in the Milky Way

clustering factor $f_c(m_i)$



neutrino mass

Ringwald & Wong, JCAP 12 (2004) 005

Relic neutrino clustering in the Milky Way

To calculate the clustering factor we use the

N-1-body simulation technique (Ringwald & Wong 2004)

Assumptions:

- νs are independent
- only gravitational interactions
- νs do not influence matter evolution ($\rho_\nu \ll \rho_{\mathrm{DM}}$)

N-one-body= N × single ν simulations

→ each ν evolved from initial conditions at $z = 3$

→ spherical symmetry, coordinates $(r,\ \theta,\ p_r,\ l)$

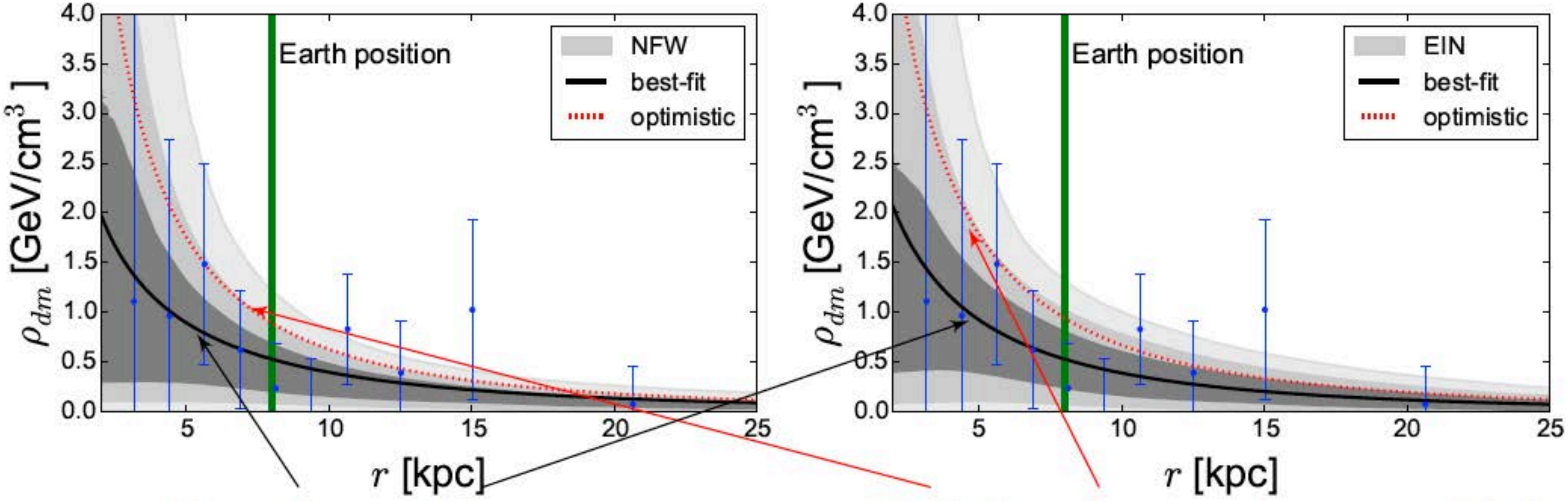
→ need $\underline{\rho_{\mathrm{matter}}(z) = \rho_{\mathrm{DM}}(z) + \rho_{\mathrm{baryon}}(z)}$

Dark matter: profiles today

NFW profile:

Einasto (EIN) profile:

$$\mathcal{N}_{\rm NFW}\left(\frac{r}{r_s}\right)^{-\gamma}\left(1+\frac{r}{r_s}\right)^{-3+\gamma} = \boxed{\rho_{\rm DM}(r)} = \mathcal{N}_{\rm Ein}\,\exp\left\{-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^{\alpha}-1\right)\right\}$$



Best-fit profiles

optimistic: close to 2σ upper limits

fit of data points from [Pato & Iocco, 2015]

de Salas, Gariazzo, Lesgourgues, SP, arXiv:1706.09850

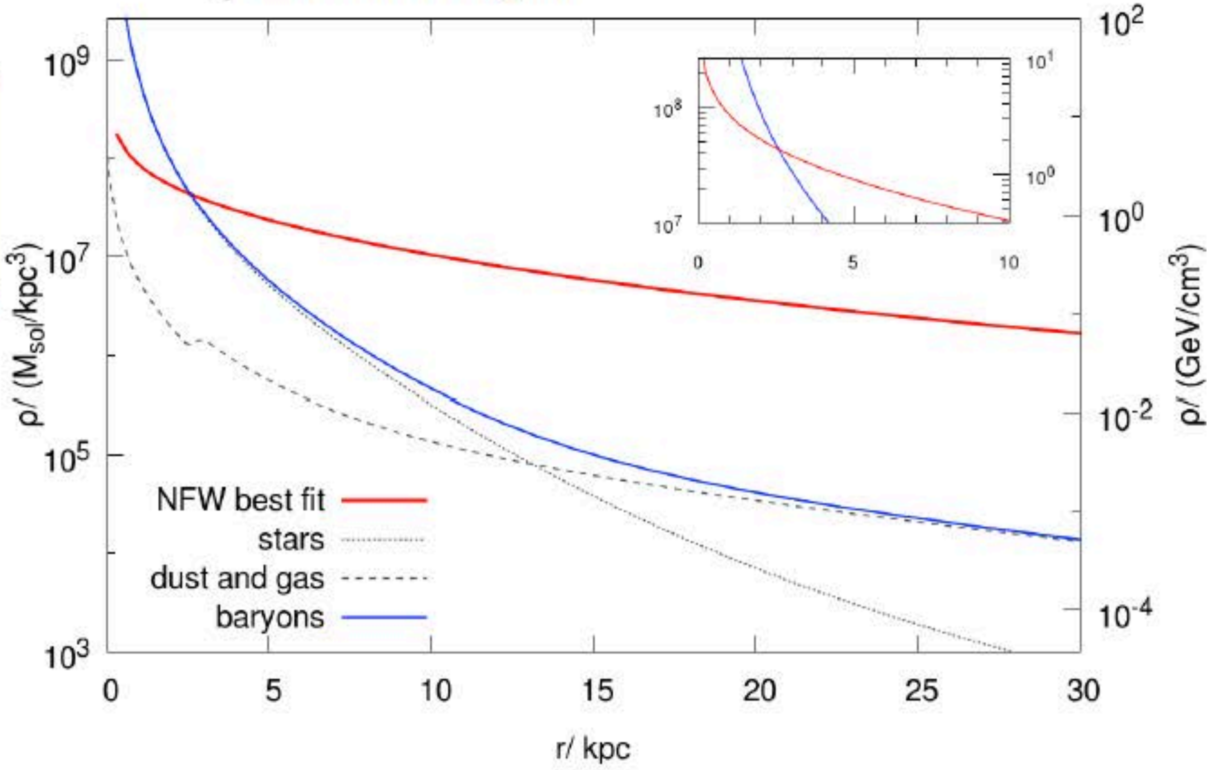
Baryon content of our galaxy: complex structure

e.g. [Pato et al., 2015]:
70 different baryonic models

7 models for the bulge
×
5 for the disc
×
2 for the gas

[Misiriotis et al., 2006]:
5 independent
components

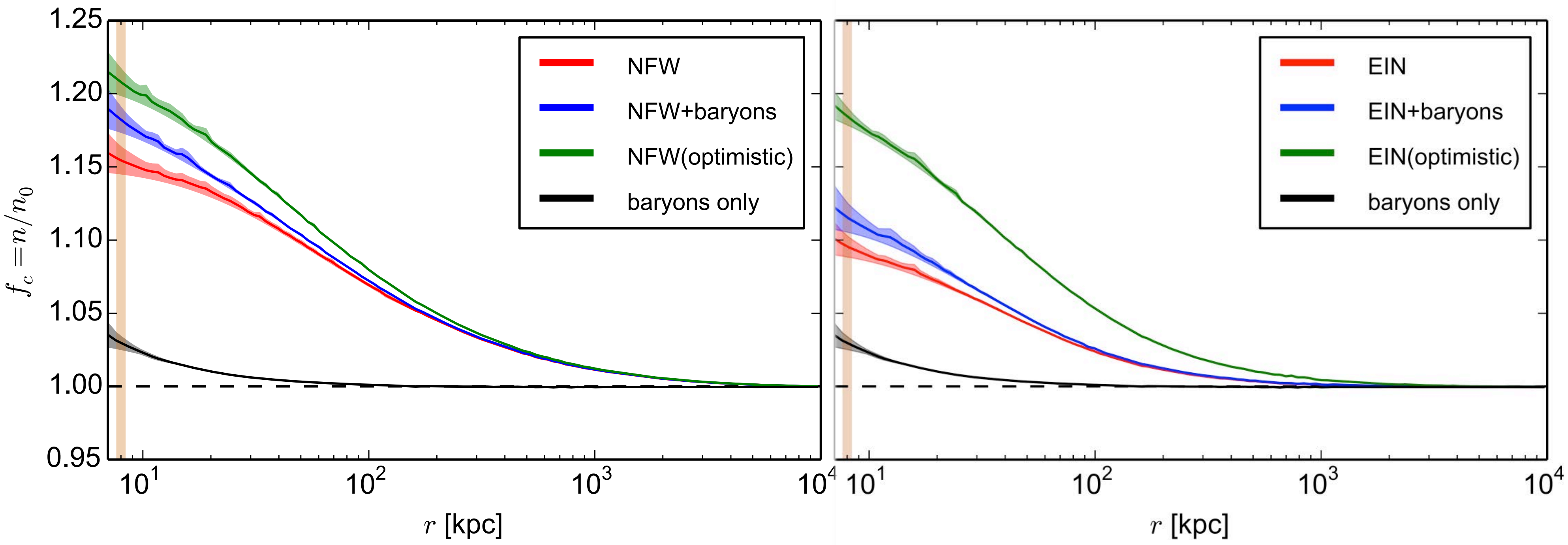
- warm dust
- cold dust
- stars
- atomic H gas
- molecular H gas

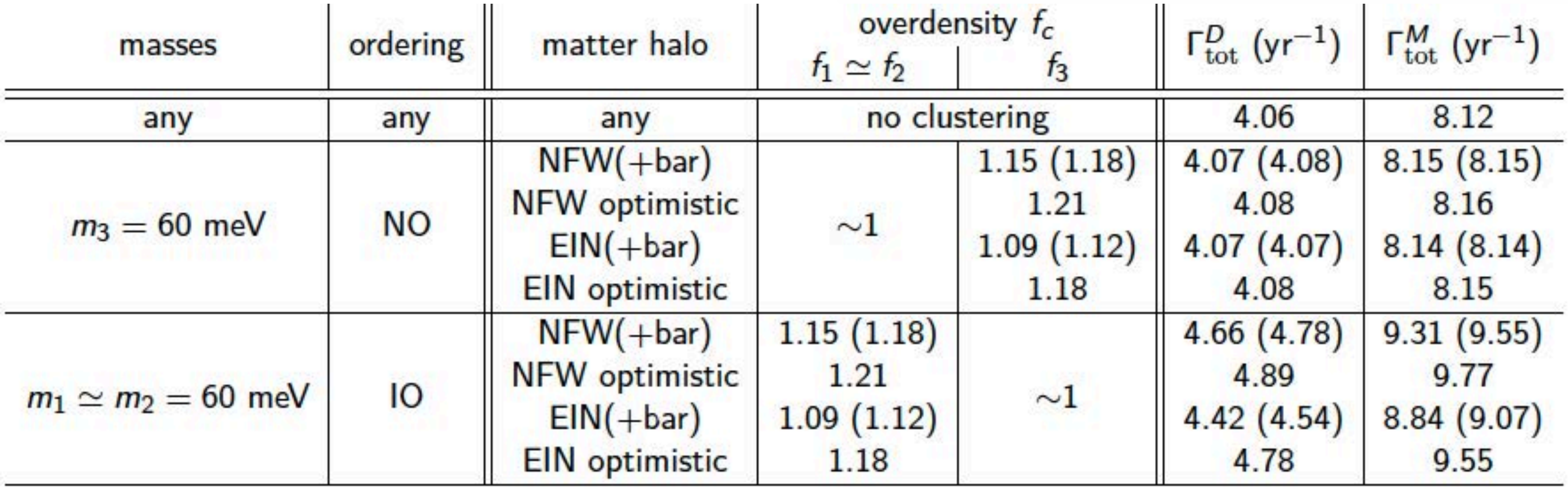


our case: [Misiriotis et al., 2006], spherically symmetrized

de Salas, Gariazzo, Lesgourgues, SP, arXiv:1706.09850

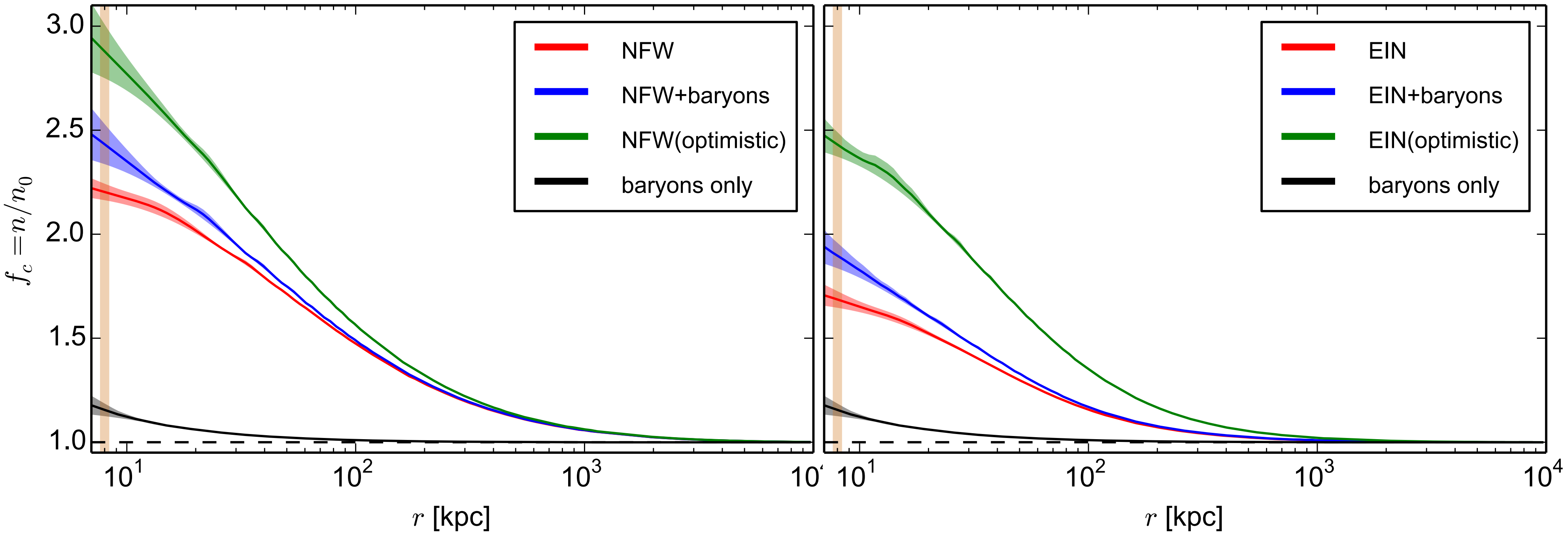
Local neutrino clustering for a 60 meV mass





masses	ordering	matter halo	overdensity f_c $f_1 \simeq f_2$	f_3	Γ^D_{tot} (yr^{-1})	Γ^M_{tot} (yr^{-1})
any	any	any	no clustering		4.06	8.12
$m_3 = 60$ meV	NO	NFW(+bar)	$\sim$1	1.15 (1.18)	4.07 (4.08)	8.15 (8.15)
		NFW optimistic		1.21	4.08	8.16
		EIN(+bar)		1.09 (1.12)	4.07 (4.07)	8.14 (8.14)
		EIN optimistic		1.18	4.08	8.15
$m_1 \simeq m_2 = 60$ meV	IO	NFW(+bar)	1.15 (1.18)	$\sim$1	4.66 (4.78)	9.31 (9.55)
		NFW optimistic	1.21		4.89	9.77
		EIN(+bar)	1.09 (1.12)		4.42 (4.54)	8.84 (9.07)
		EIN optimistic	1.18		4.78	9.55

Local neutrino clustering for a 150 meV mass



matter halo	overdensity f_c $f_1 \simeq f_2 \simeq f_3$	$\Gamma^{D}_{\mathrm{tot}}$ (yr^{-1})	$\Gamma^{M}_{\mathrm{tot}}$ (yr^{-1})
any	no clustering	4.06	8.12
NFW(+bar)	2.18 (2.44)	8.8 (9.9)	17.7 (19.8)
NFW optimistic	2.88	11.7	23.4
EIN(+bar)	1.68 (1.87)	6.8 (7.6)	13.6 (15.1)
EIN optimistic	2.43	9.9	19.7

no ordering dependence: $m_1 \simeq m_2 \simeq m_3 \Longrightarrow f_1 \simeq f_2 \simeq f_3$

Conclusions

✓ Cosmological relic neutrinos predicted but **not directly detected** (strong indirect evidence via **N_{eff}**). A future detector rate depends on **massive neutrino clustering** in the local matter distribution

✓ We used the N-one-body method to calculate the **relic neutrino density in the Milky Way** (requires knowledge of DM and baryonic profiles and their evolution)

✓ We find **local overdensities** from 10-20 % (**60 meV**) to 170-300 % (**150 meV**). **Enhanced event rates** at a PTOLEMY-like experiment