Thermalisation of Light Sterile Neutrinos
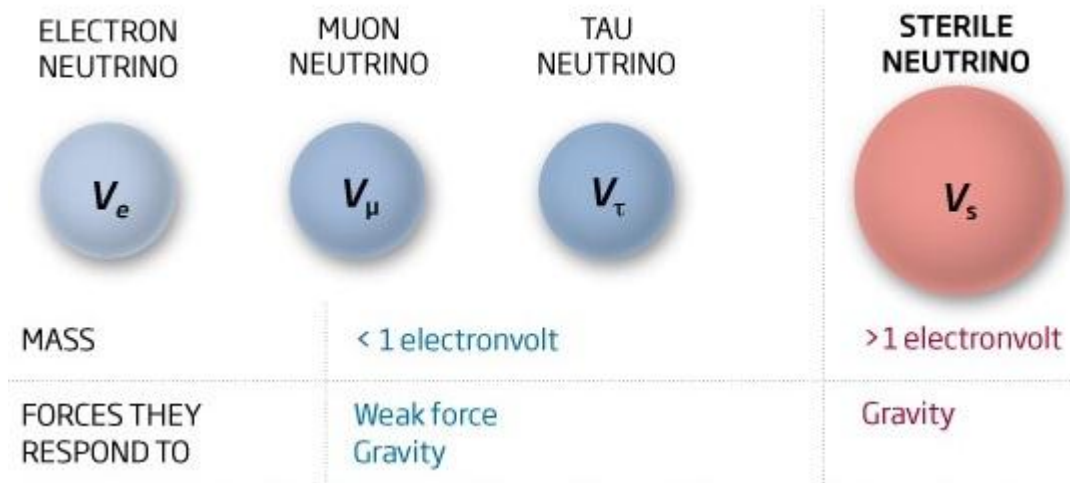
Thomas Tram

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Paper: arXiv:1204.5861
Colaborators: Irene Tamborra and Steen Hannestad

What is a sterile neutrino?

|	ELECTRON NEUTRINO	MUON NEUTRINO	TAU NEUTRINO	STERILE NEUTRINO
	V_e	V_μ	V_τ	V_s
MASS		< 1 electronvolt		>1 electronvolt
FORCES THEY RESPOND TO		Weak force Gravity		Gravity

- No Standard Model interaction
- Non-zero mixing angle with an active neutrino
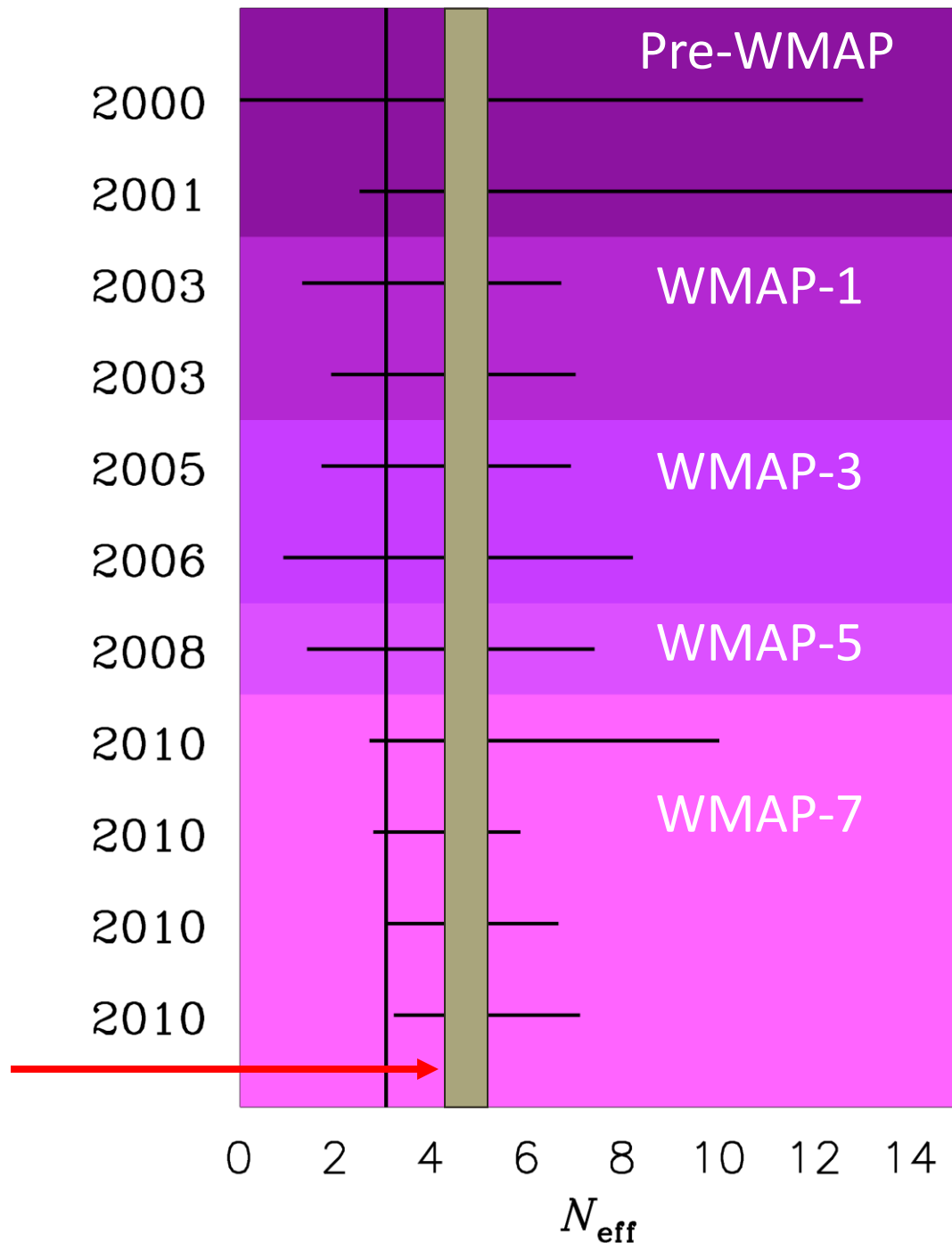- Mass?

How to thermalise a sterile neutrino?

- Propagation and measurement!

- Rate: $\Gamma_{\nu_s} = \frac{1}{2}\sin^2(2\theta_s)\left(\frac{\Delta_0}{\Delta_m}\right)^2 \Gamma_\nu$

- Resonances in the medium: $\Delta_m \to 0 \left(\text{IH}\ \frac{\text{and}}{\text{or}}\ L \neq 0\right)$
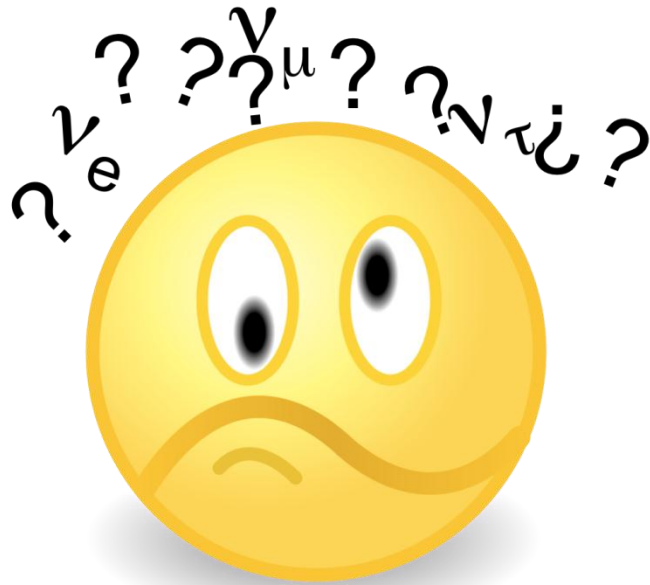
TIME EVOLUTION OF THE 95% BOUND ON N_ν

(Remember LEP: 3 active light neutrinos.)

ESTIMATED PLANCK SENSITIVITY

Credit: Steen Hannestad

Motivation: Neutrino anomalies

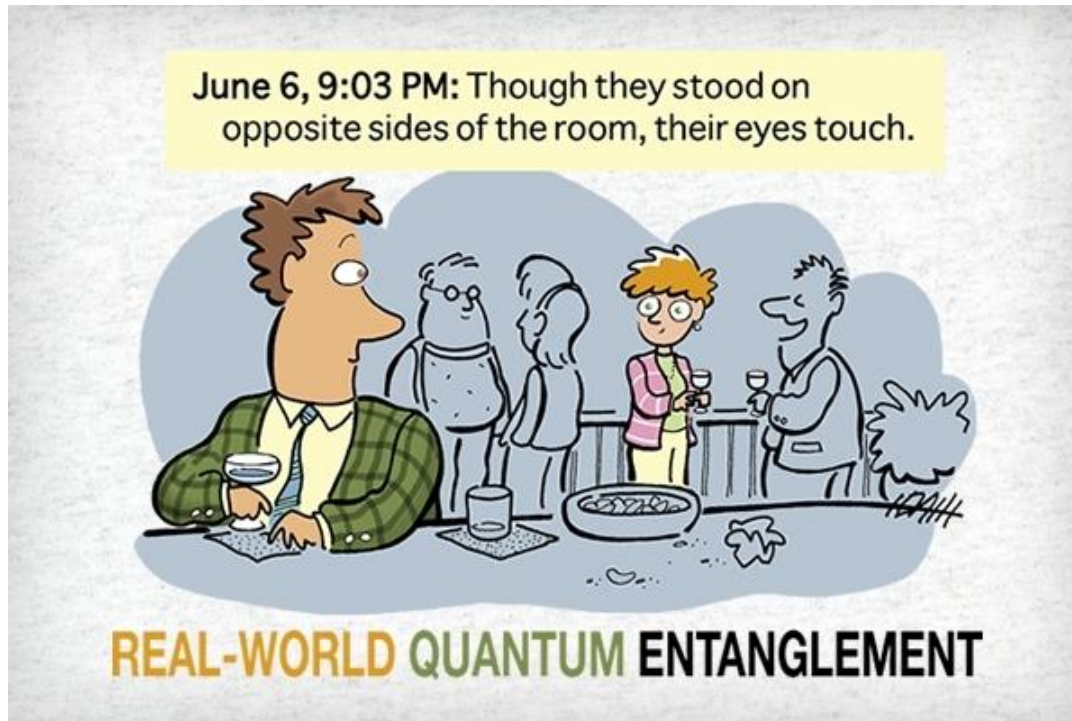| Experiment	What do they measure?	Estimate of significance
Nuclear reactors (ILL, Bugey, Gösgen…)	A small deficit in the $\bar{\nu}_e$ flux from ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu fission.	2.5σ (Mention et. al.: 1101.2755)
Galium detectors (SAGE and GALLEX)	A small deficit in the the ν_e-flux from ^{51}Cr and ^{37}Ar decay.	3.0σ (Giunti and Laveder: 1006.3244)
Short baseline oscillation experiments (LSND and MiniBooNE)	$\bar{\nu}_\mu - \bar{\nu}_e$ and $\nu_\mu - \nu_e$ oscillations.	$3.8\sigma + 0\sigma + 3.0\sigma +? \sigma$ (1007.1150 + …)
Big Bang Nucleosynthesis (BBN)	Amount of radiation at T=1 MeV	Consistent with 0 or 1 fully thermalised neutrino.
Cosmic Microwave Background (WMAP + ACT/SPT + BAO + H_0)	Amount of radiation at recombination	$1.5\sigma - 2.5\sigma$ (1009.0866 + …)

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$$\delta m_s^2 \sim 1\, eV^2$$

1+1 approximation

- 2 level system: 2x2 density matrix
- Hermitian and unitary: Expand in Pauli matrices..

$$\rho = \begin{bmatrix} \text{active} & \text{(entanglement)} \\ \text{(entanglement)} & \text{sterile} \end{bmatrix}$$

June 6, 9:03 PM: Though they stood on opposite sides of the room, their eyes touch.

REAL-WORLD QUANTUM ENTANGLEMENT

Quantum Kinetic Equations

- Density matrices using Bloch-vectors:

$$\rho = \frac{1}{2}f_0(P_0 + \boldsymbol{P}\cdot\sigma)$$

$$\bar{\rho} = \frac{1}{2}f_0(\overline{P_0} + \overline{\boldsymbol{P}}\cdot\sigma)$$

- Equations of motion:

$$\dot{\boldsymbol{P}} = \boldsymbol{V}\times\boldsymbol{P} - D\boldsymbol{P_T} + \dot{P_0}\hat{\boldsymbol{z}}$$

$$\dot{P_0} = \Gamma\left[\frac{f_{eq}}{f_0} - \frac{1}{2}(P_0 + P_z)\right]$$

Sigl & Raffelt 1993

Numerics (!)

- Vastly separated time scales: Hubble expansion, relaxation, oscillations… → Stiffness
- $8 \times \text{res} \sim 10^3$ equations → sparse methods needed
- Parameter space spans several order of magnitudes
- ndf15 and RADAU5: state of the art
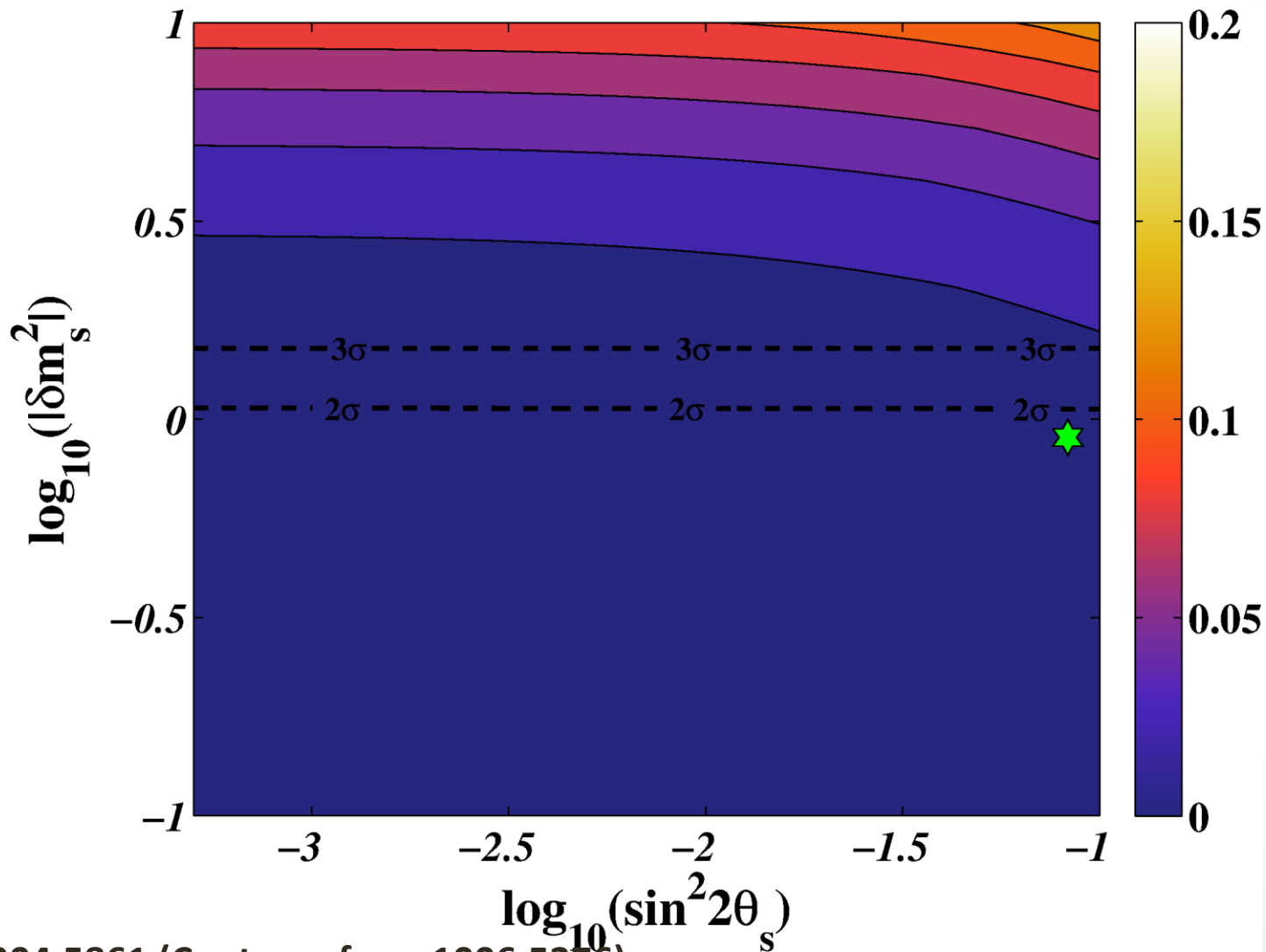- LASAGNA: Lepton Asymmetric Sterile-Active Grid Neutrino Analyser
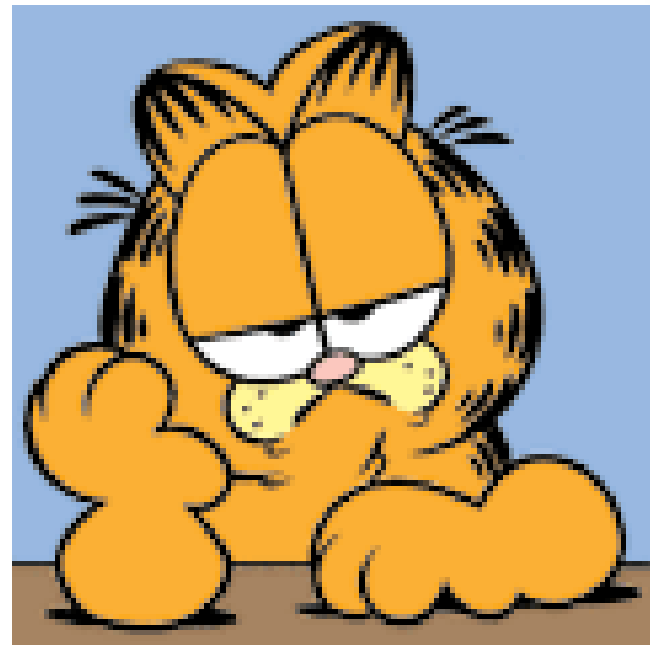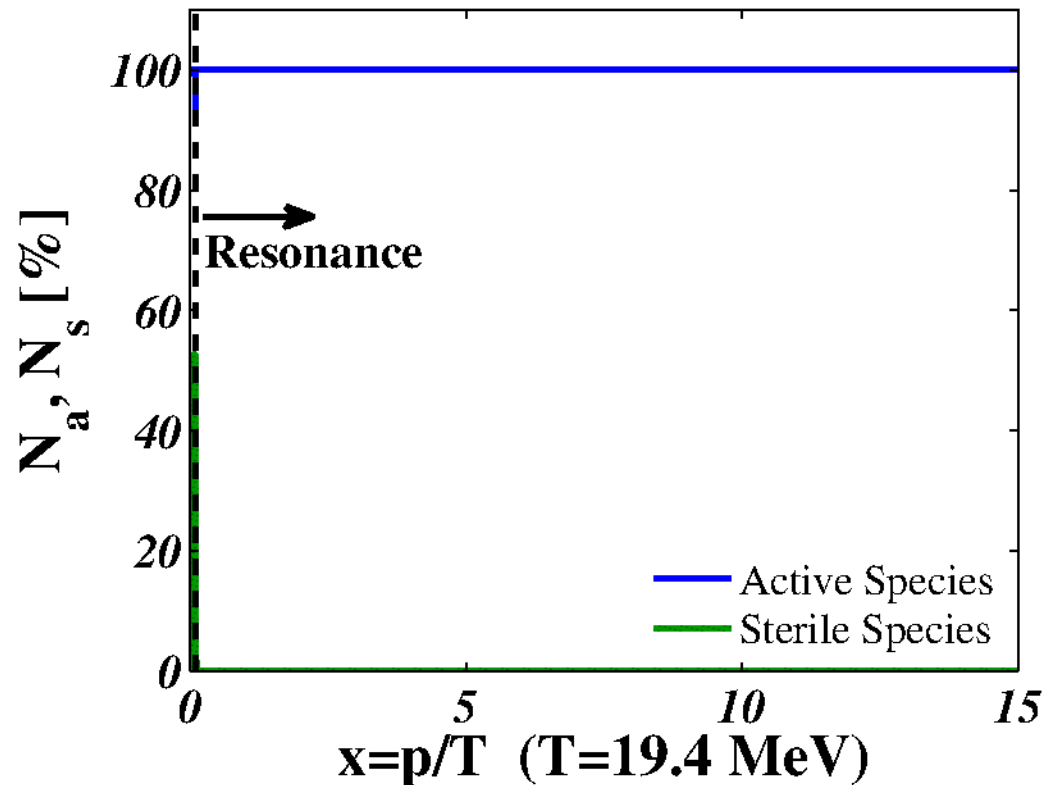
$\delta \mathrm{N_{eff}}$ for $\delta m_s^2 > 0, L = 0$
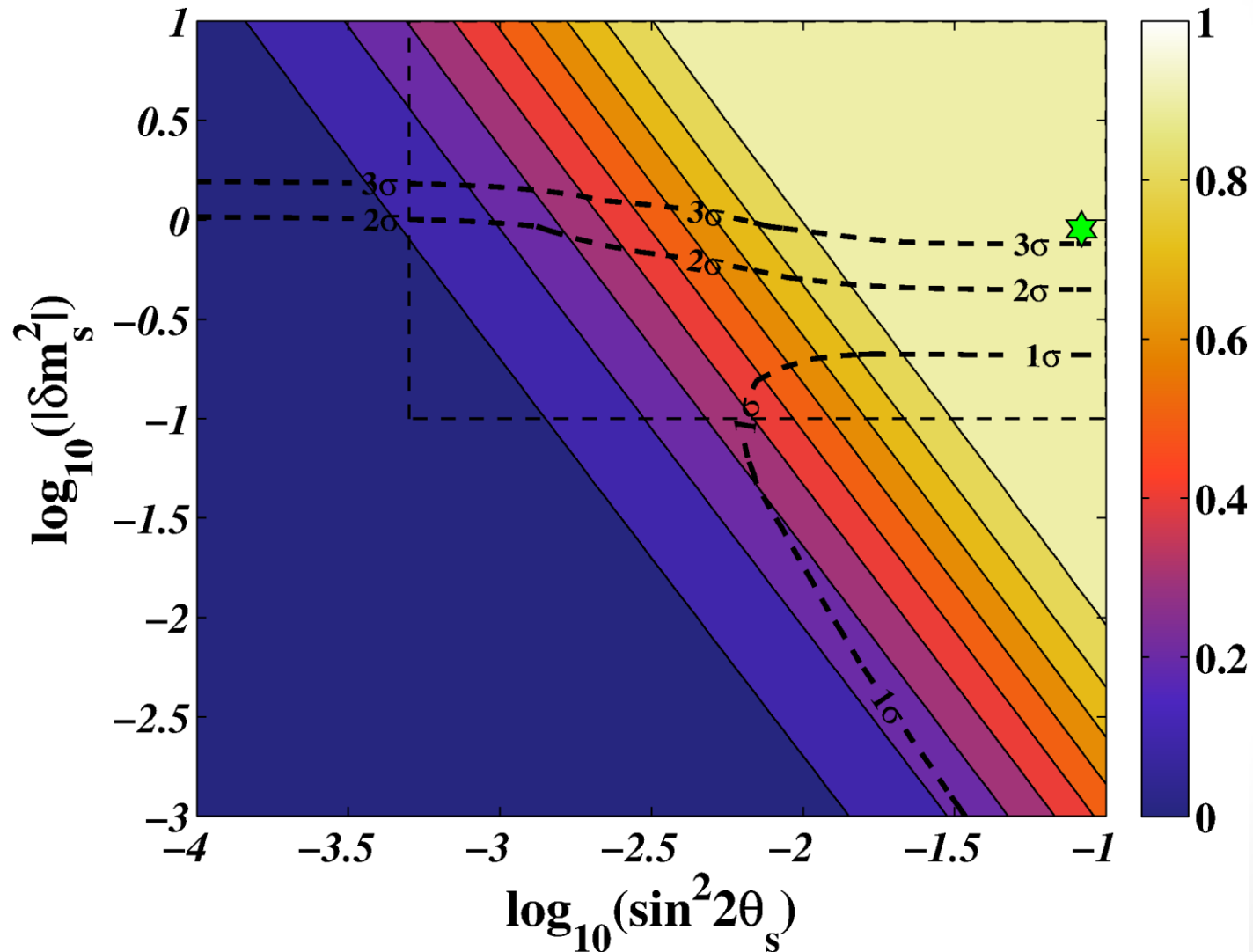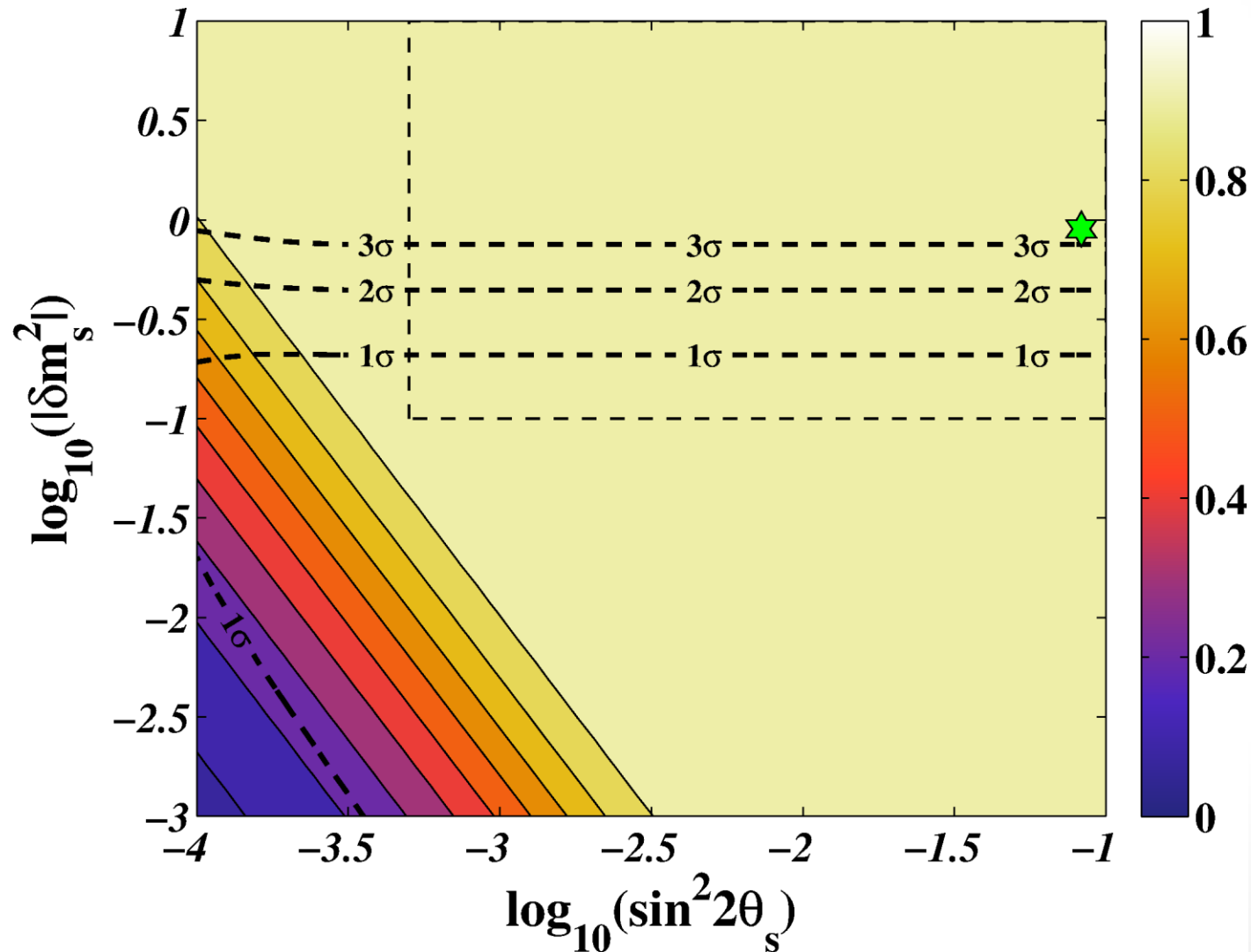
δN_{eff} for $\delta m_s^2 < 0, L = 0$

δN_{eff} for $\delta m_s^2 > 0, L = 10^{-2}$

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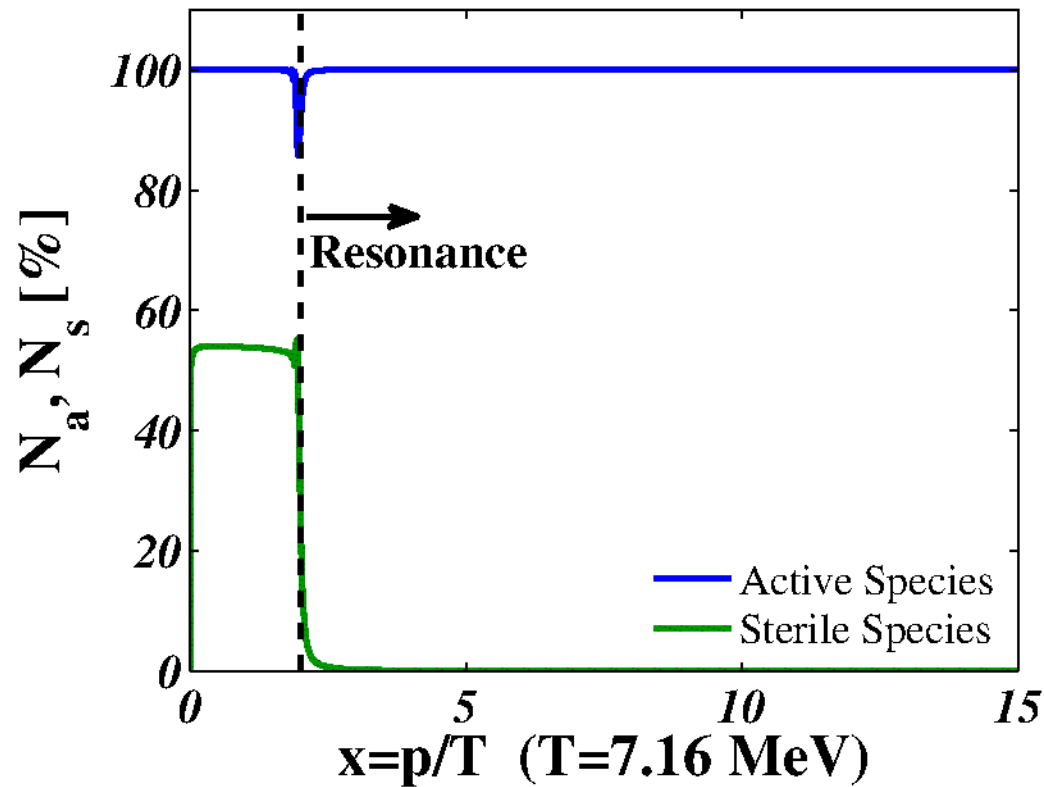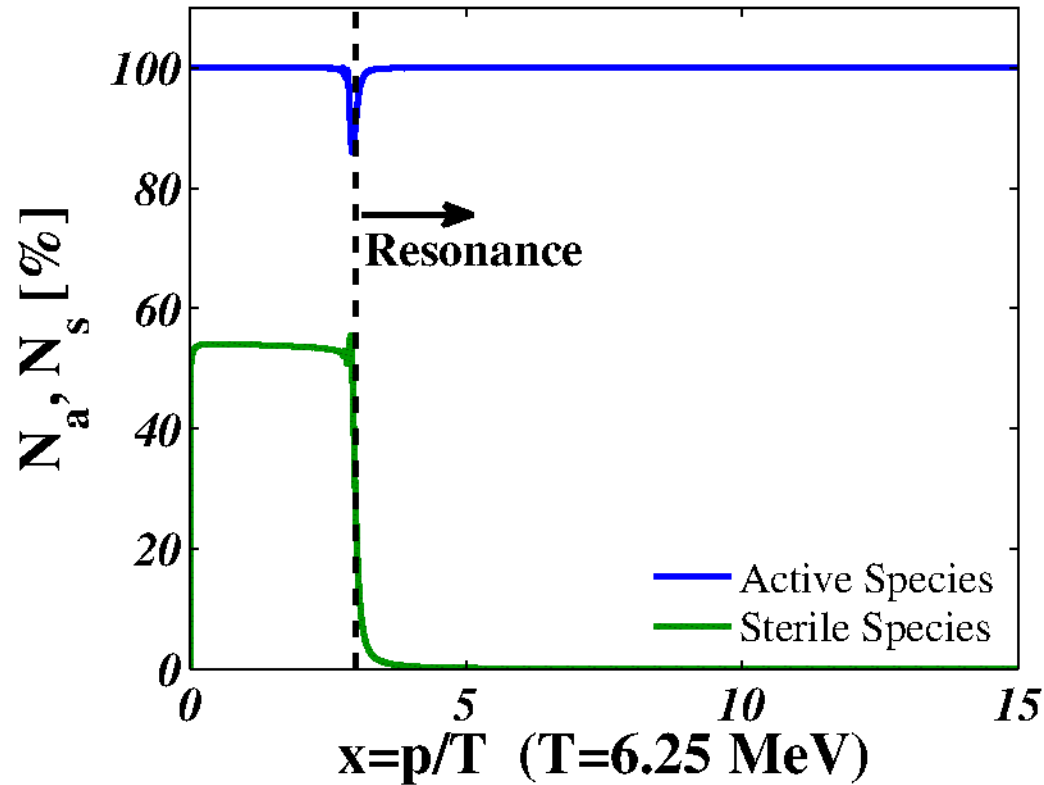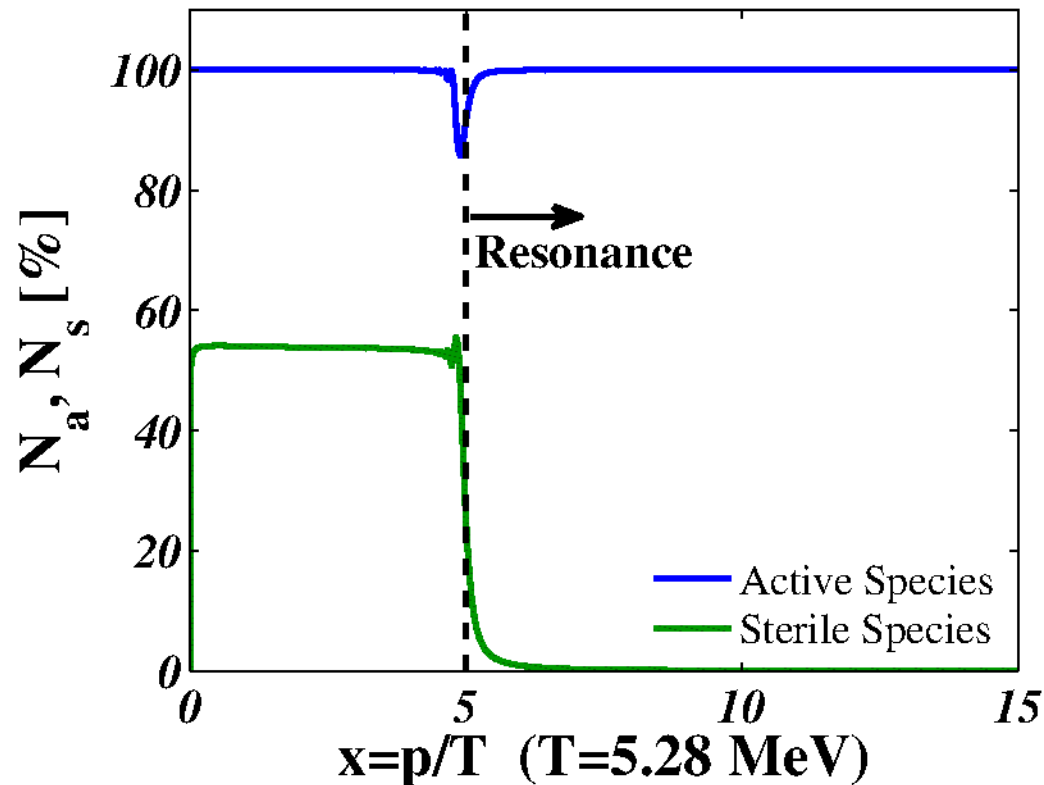# Thermalisation cartoon
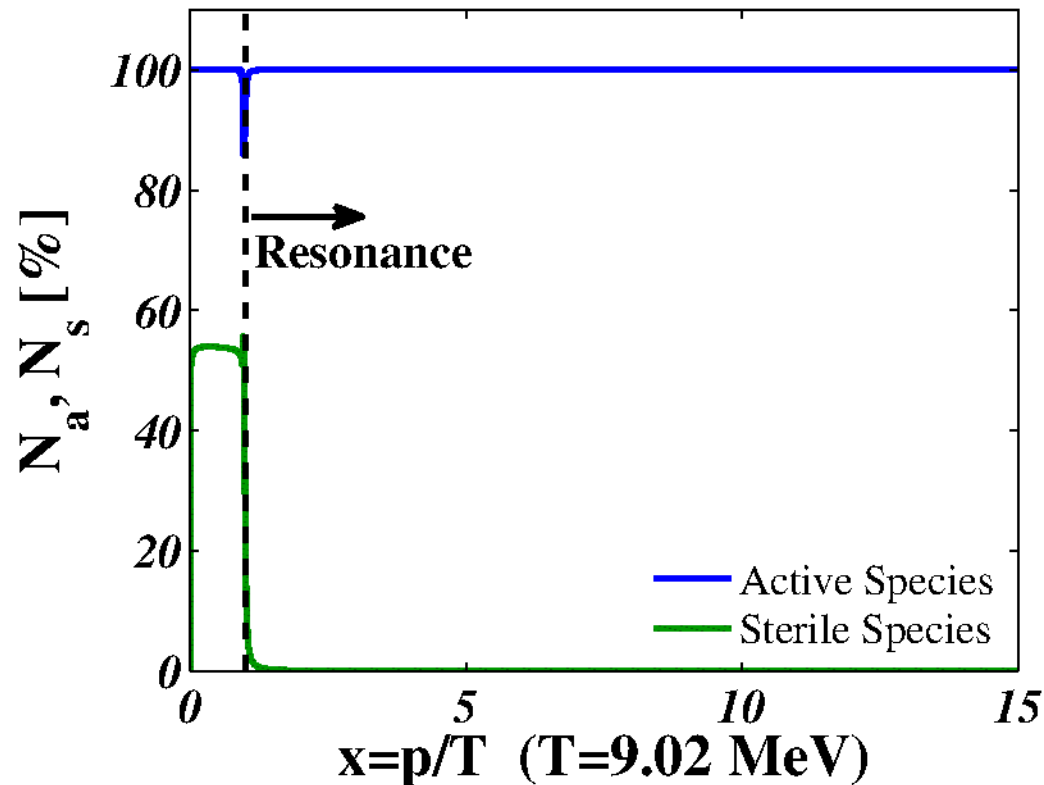
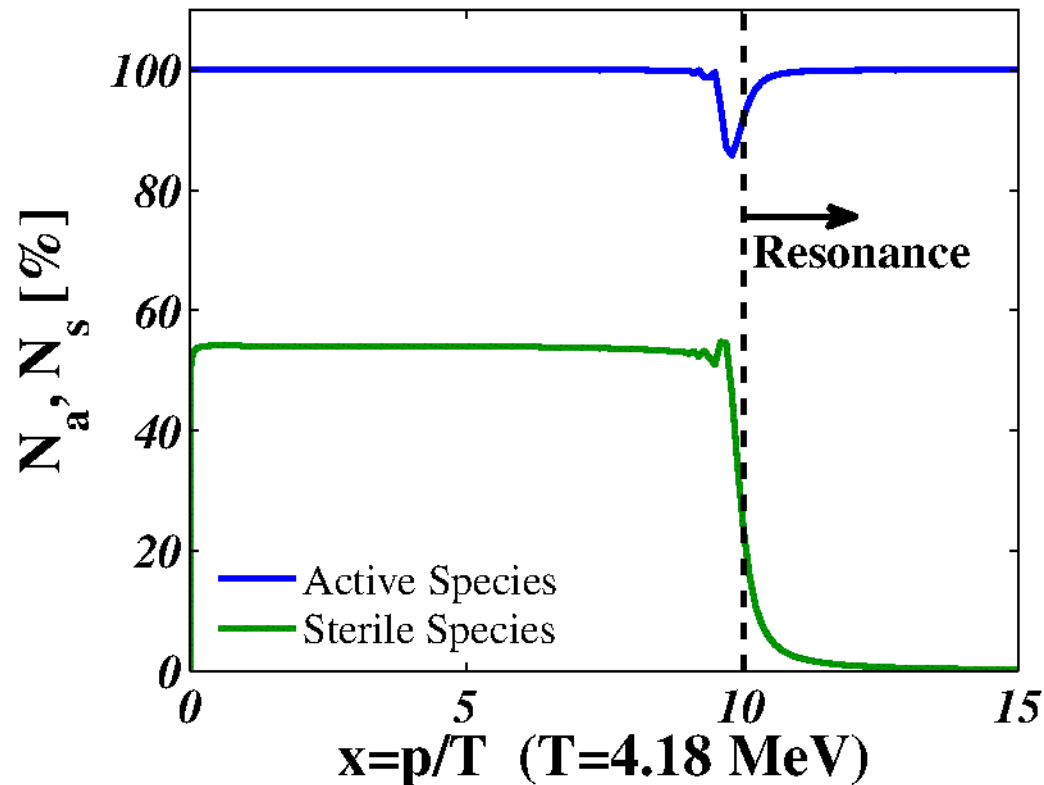# Thermalisation cartoon

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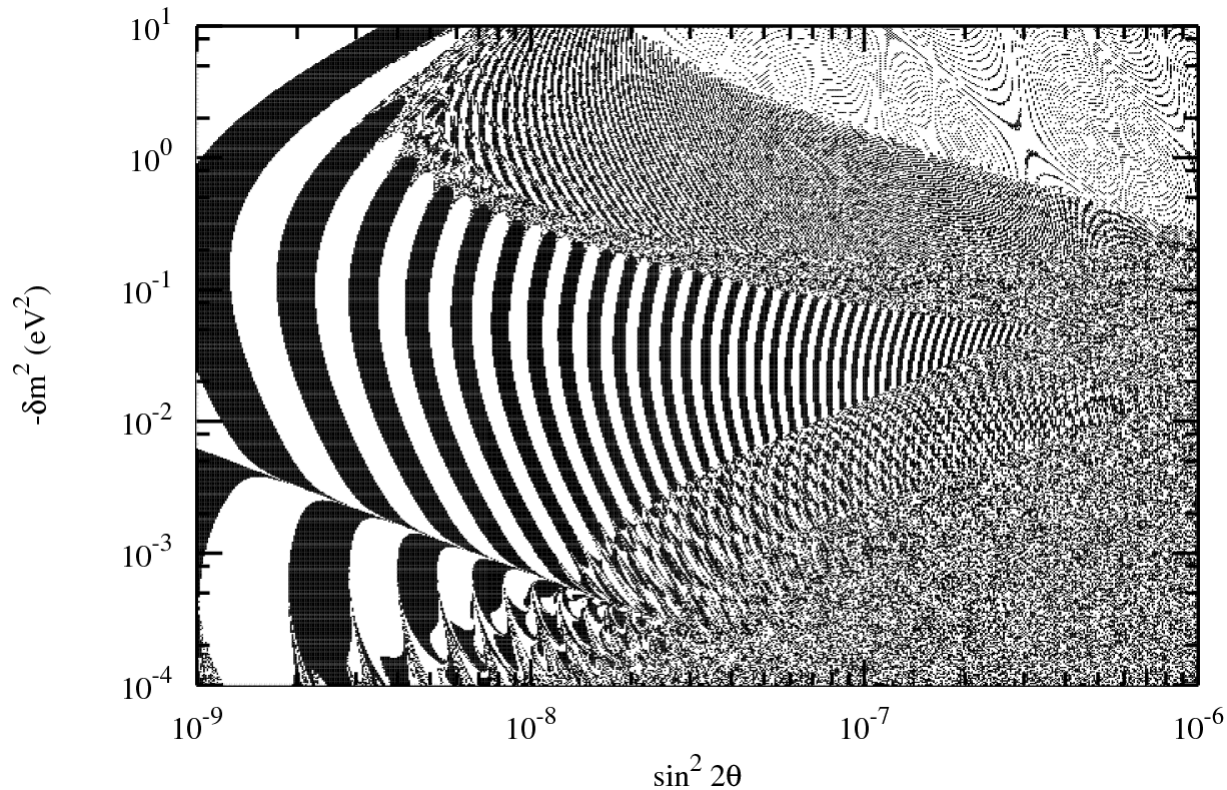# Thermalisation cartoon

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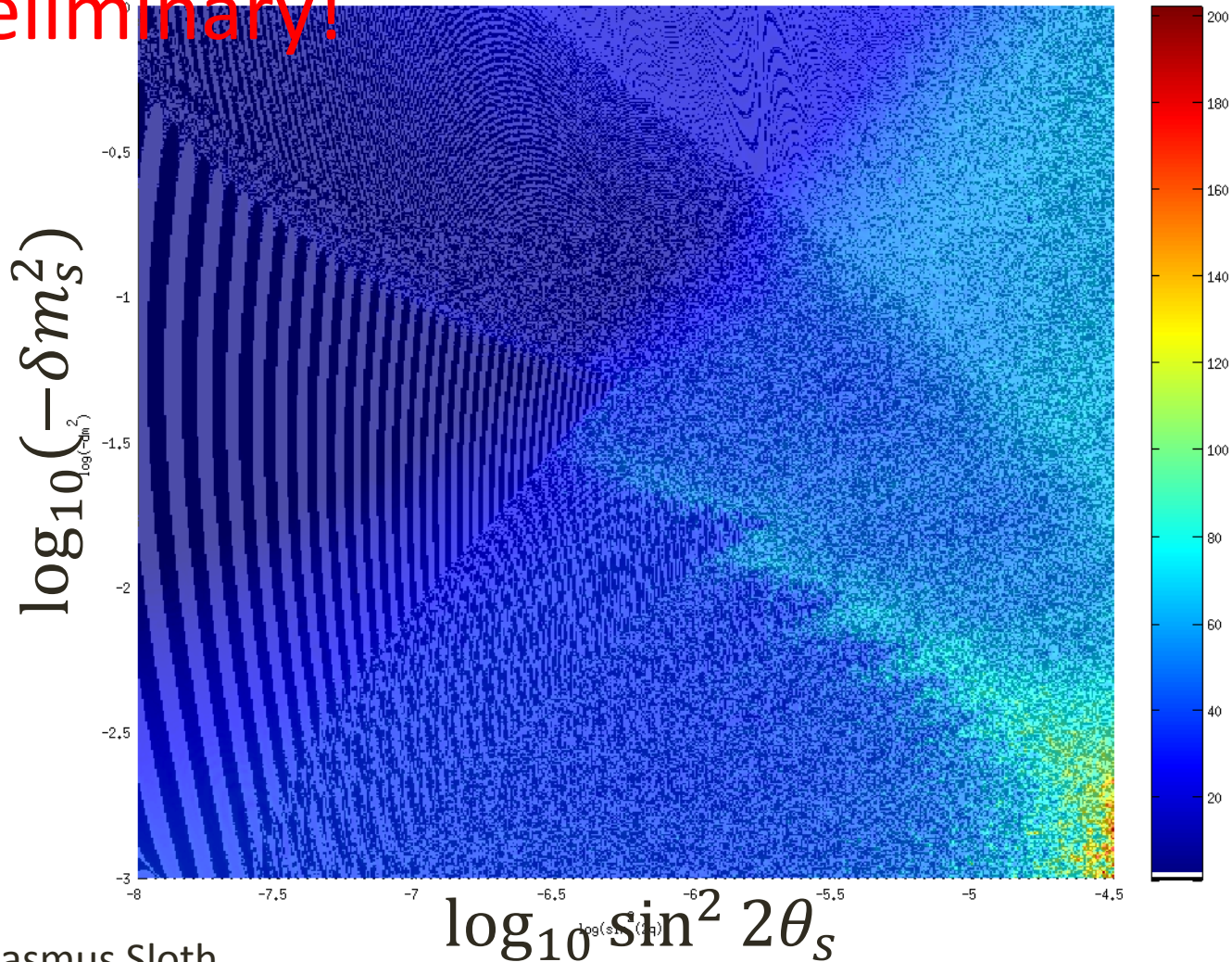
Open questions/future

- Effect of ν_e distribution function distortion on BBN
- Make LASAGNA public
- Chaotic lepton number in inverted hierarchy? (in progress)

hep-ph/9906452 and 0807.0456

Information loss in QRE

Preliminary!

Credit: Rasmus Sloth

The End

Thank you for your attention!