Light right-handed neutrinos: why not?

R. Barbieri

"Neutrinos in Venice"
February 7-10, 2006

+ an incursion in cosmology

B, Hall, Oliver, Strumia
Amendola, B

The standard answer: the seesaw bans them

(no evidence for them - see below)

Appealing theory or physical reality?

" The typical lifetime of a new trend in high energy physics and cosmology nowadays is about 5 to 10 years. If it survived for a longer time, the chances are that it will be with us for quite a while"

(Linde)

The Standard Model, emended to include neutrino masses

$$\mathcal{L}^{(\nu-mass)} = L_i \lambda^{\nu}_{ij} N_j v + N_i M_{ij} N_j$$

$$\mathcal{L}^{(\nu-mass)} = (\nu^T N^T) \begin{pmatrix} 0 & \lambda v \\ \lambda v & M \end{pmatrix} \begin{pmatrix} \nu \\ N \end{pmatrix}$$

with ν, N each 3-vectors and λ, M 3x3 matrices

3 alternatives for the light neutrinos:

1 - 3 light Majorana neu's (M large)

2 - 3 light Dirac neu's (M = 0)

3 - from 4 to 6 mixed states (M small but non-zero)

(every N carrying a factor ~ $(G_N/G_F)^{1/2}$ with all masses otherwise maximal)

An incursion in cosmology: The accelerated expansion of the universe

$\Lambda \approx (3 \cdot 10^{-3} eV)^4$ perhaps anthropically "explained"

or

$\Lambda = 0$ (why?) $\oplus$ $\delta\Lambda_{eff}$ perhaps a quintessence

Is there a "calculable" microscopic model of quintessence where

$$\delta\Lambda_{eff} = O(m_\nu^4)$$

(e.g. $m_\phi \leq H_0 \approx 10^{-33} eV$)

Quintessence as a PGB in neutrino flavour physics

$$V = V_0[\cos(\phi/f) + 1] \qquad \begin{matrix} V_0 \approx m_\nu^4 \\ f \approx M_{Pl} \end{matrix} \qquad \Rightarrow\ m_\phi^2 = \frac{V_0}{f^2} \approx H_0^2$$

$$\mathcal{L}_Y = N^T \lambda \phi N + h L^T \lambda^D N + V(\phi)$$

with λ, ϕ, λ^D matrices in flavour space: $6\ \phi_{ij}$

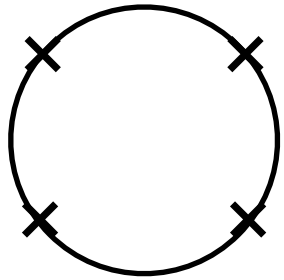
an approximate $U(1)^6 \rightarrow \emptyset$

an exact $U(1)^3 \rightarrow \emptyset$

$\Rightarrow$ 6 -3 = 3 PGB's

Calculating the DE potential

the leading term



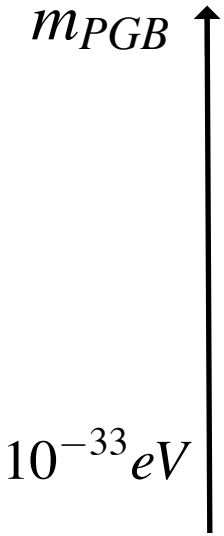
$$V \approx \frac{1}{32\pi^2} Tr\left[MM^\dagger MM^\dagger \ln\frac{\Lambda^2}{MM^\dagger}\right]$$

$$< \phi_{ij} >= f_{ij} \qquad M_{ij} = \lambda_{ij} f_{ij} e^{iG_{ij}/f_{ij}}$$

$$V(G) = \mu^4 \cos(G/f) \qquad \mu^4 = O(M^4)$$

Quadratic terms in M irrelevant

More than one PGB: DE and *DM?*



ϕ_3

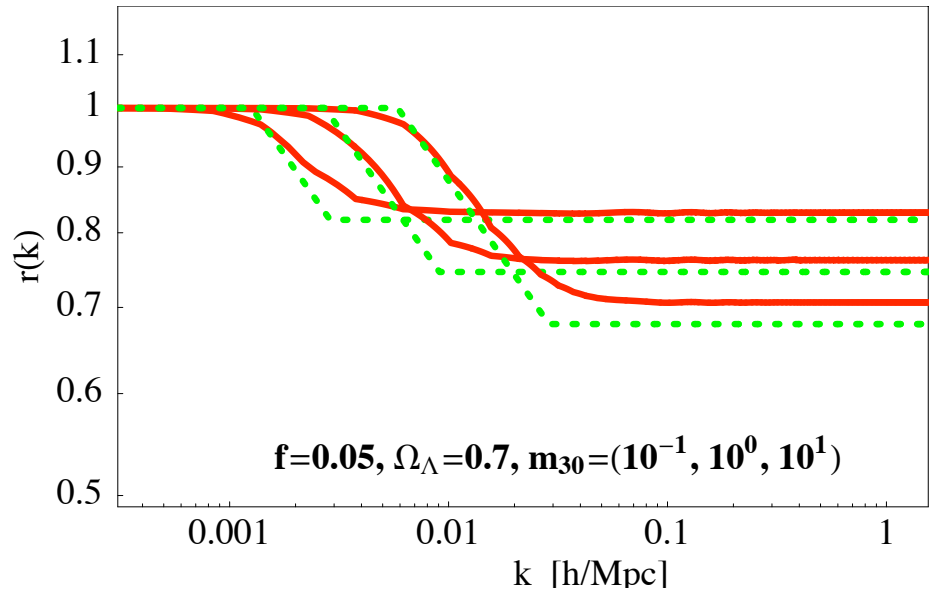
ϕ_2

ϕ_1

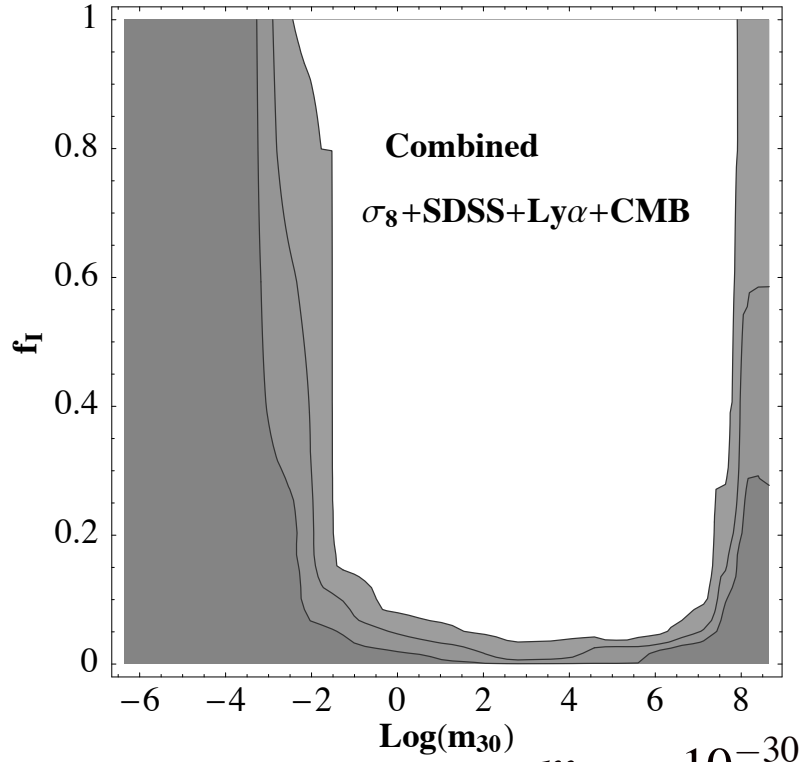
$\}$ $\Leftarrow$ DM? (as an axion)

only if $m_{2,3} \geq 10^{-23} eV$

$\Leftarrow$ DE



(~ degenerate with massive neutrinos)



$m_{30} = 10^{-30}\ eV$

Back to the 6 light neutrinos

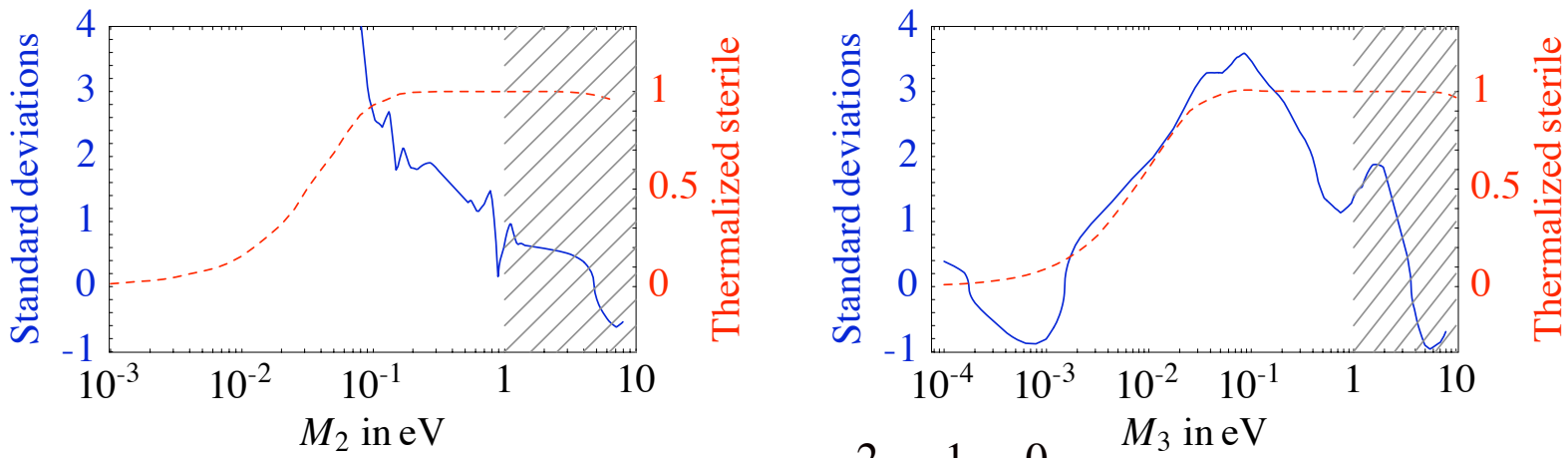
1. Aren't we seeing only two oscillation frequencies?

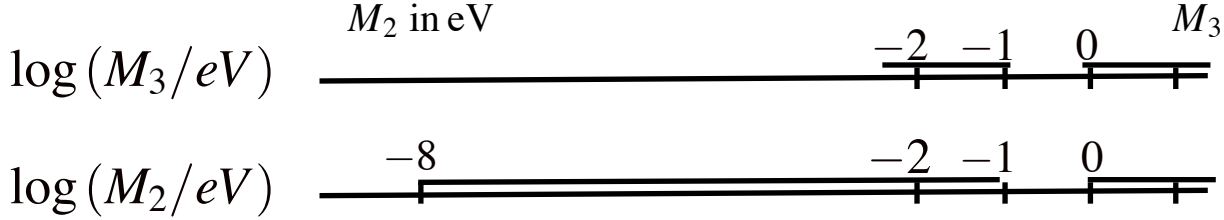
2. What about the constraints from BBN, CMB, LSS?

An illustrative case (simple enough)

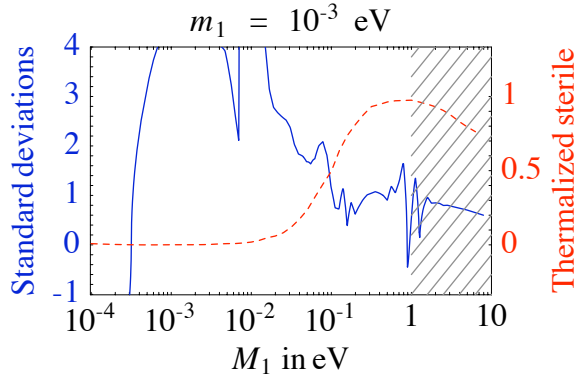
$$\mathcal{L} = \frac{g}{\sqrt{2}}\bar{\nu} V \gamma_\mu e W_\mu + \nu^T m_d N + N^T M_d N$$

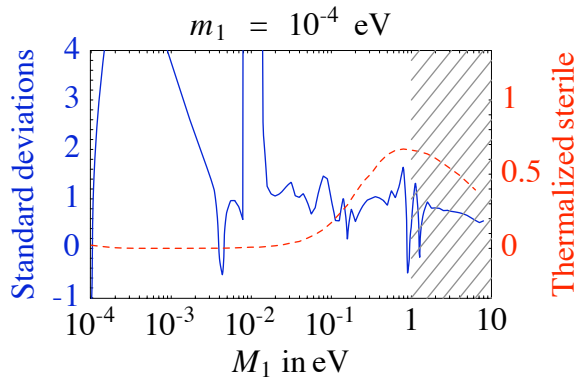
(in general $N^T U^T M_d U N$)

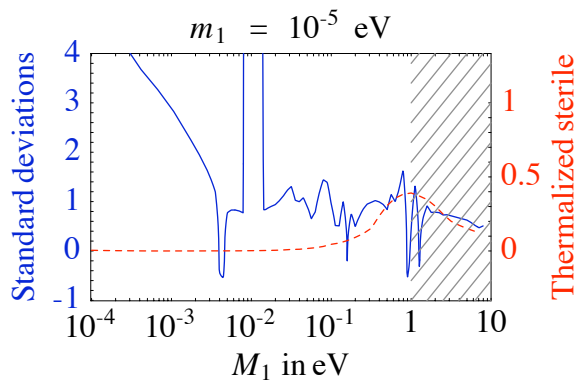


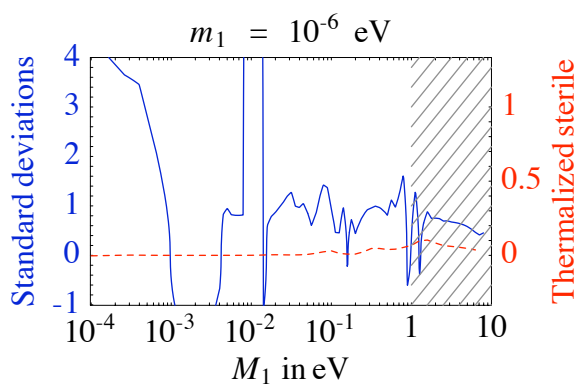


M_1 largely undetermined since m_1 unknown

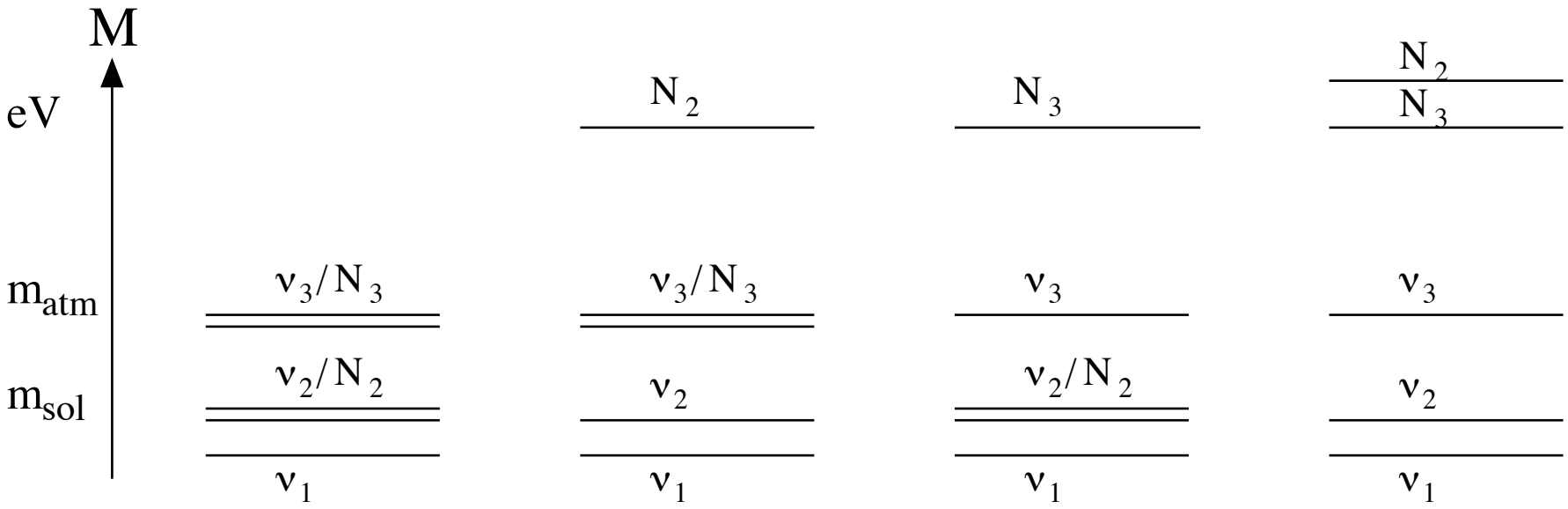

m_1 = 10^{-3} eV
Standard deviations
Thermalized sterile
4
3
2
1
0
-1
1
0.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
M_1 in eV


m_1 = 10^{-4} eV
Standard deviations
Thermalized sterile
4
3
2
1
0
-1
1
0.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
M_1 in eV


m_1 = 10^{-5} eV
Standard deviations
Thermalized sterile
4
3
2
1
0
-1
1
0.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
M_1 in eV


m_1 = 10^{-6} eV
Standard deviations
Thermalized sterile
4
3
2
1
0
-1
1
0.5
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
M_1 in eV

4 possible spectra



Case 0 | Case 1a | Case 1b | Case 2

$\Delta N_\nu \approx 0$ | $\Delta N_\nu \approx 1$ | $\Delta N_\nu \approx 1$ | $\Delta N_\nu \approx 2$

N_1 ~ unconstrained (warm DM if in the keV region?)

Shaposhnikov et al

Signals of light ν_R*'s*

Oscillation exp.s

$\Rightarrow$ $M_2 \approx 0.3\ eV$ by reactors: $\bar{\nu}_e$ disappearance at ~ 10 m

$\Rightarrow$ $M_3 \approx 0.3\ eV$ by atmospheric and beam experiments

$\Rightarrow$ $M_3 \approx 10^{-3 \div 2}\ eV$ by long-baseline and atmospheric exp.s

$\Rightarrow$ very small $M_{1,2,3}$ { MSW effects in the sun and in supernovae
vacuum oscillations in neu-telescopes

$\Rightarrow$ the LSND anomaly?

Cosmology

$\Rightarrow$ ΔN_ν (decoupling) by CMB measurements ($\Delta N_\nu \approx 0.1$!?)

$\Rightarrow$ $M_{2,3} \approx 0.3\ eV$ by LSS/CMB measurements ($m_\nu \approx 0.05\ eV$!?)

The dichotomy in particle physics

$\Rightarrow$ 1. A coherent grand picture, developed in late 70's / 80's

Unification, supersymmetry

Pros	Contras
gauge unification	No proton decay
size of neu-masses	No susy particles
	No flavour effects
	No Higgs

YET!

$\Rightarrow$ 2. Anything else (reasonable enough)

It should not be the theorists who decide among 1 and 2