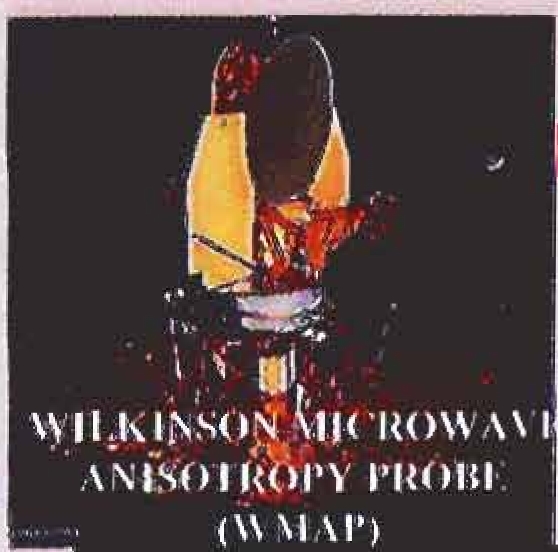
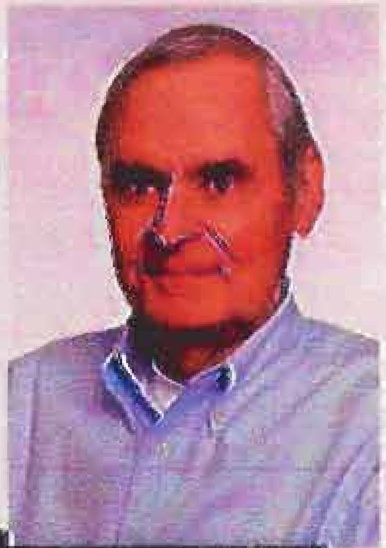
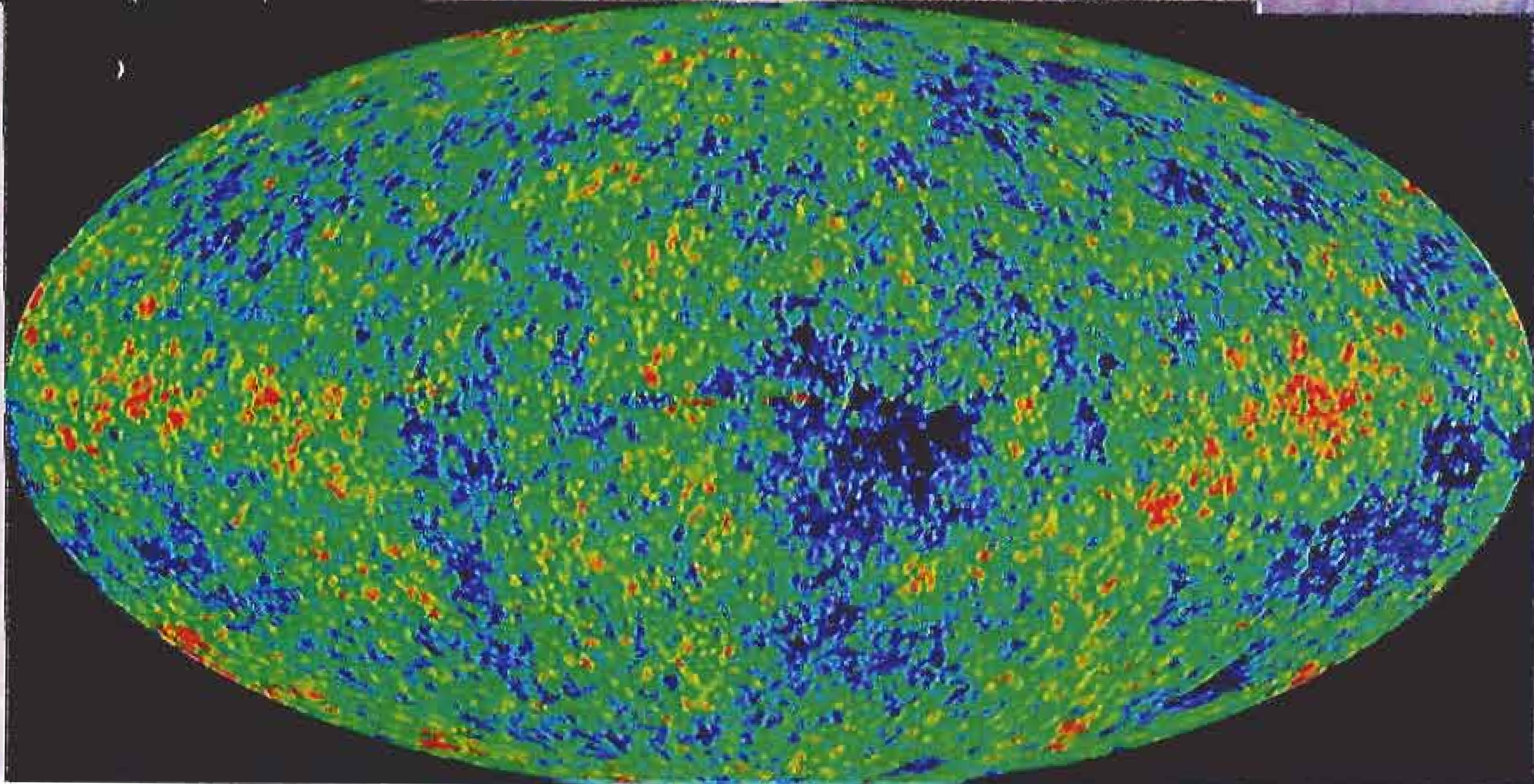


MAP OF THE UNIVERSE AT A SIMPLER TIME (400,000 YRS)





(Turner

Sneutrino Inflation

original suggestion:

Murayama + Suzuki + Yanagida + Yokoyama: '93, '94

our revival:

J.E. + Raidal + Yanagida: hep-ph/0303242

further exploration:

Chankowski + J.E. + Pokorski + Raidal + Turzynski:
hep-ph/0403nnn

1 - Summary of inflation

e.g. $V = \frac{1}{2} m^2 \phi^2$ fits WMAP

2 - Generic seesaw model

18 parameters $\Rightarrow \nu$, LFV, leptogenesis

3 - Could the inflaton be a sneutrino?

mass ✓ gravitino problem $\Rightarrow$ non-thermal leptogenesis

4 - Exploration of LFV

$\mu \to e\gamma$ near limit, $\tau \to \mu\gamma$ further away?

I - Basic Idea of Inflation

At some early epoch, energy density may have been dominated by $\simeq$ constant term:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G_N \rho}{3} - \frac{k}{a^2} \quad : \quad \rho = V \leftarrow \text{constant}$$

⊛

⇒ epoch of exponential expansion:

$$a = a_i \exp(Ht) \quad : \quad H = \sqrt{\frac{8\pi G_N}{3} V}$$

⇒ Horizon

expanded exponentially

all observable Universe within pre-inflationary horizon ⇒ homogeneity could have been established

"real" horizon $\gg$ "apparent" horizon

$$a_i e^{H\tau} \gg a_H = c t_0$$

requires $\gtrsim 60$ e-foldings

Flatness

$-k/a^2$ term negligible

but perturbations ⇒ $|\Omega - 1| \sim 10^{-5}$

Entropy

Universe very big

Monopoles

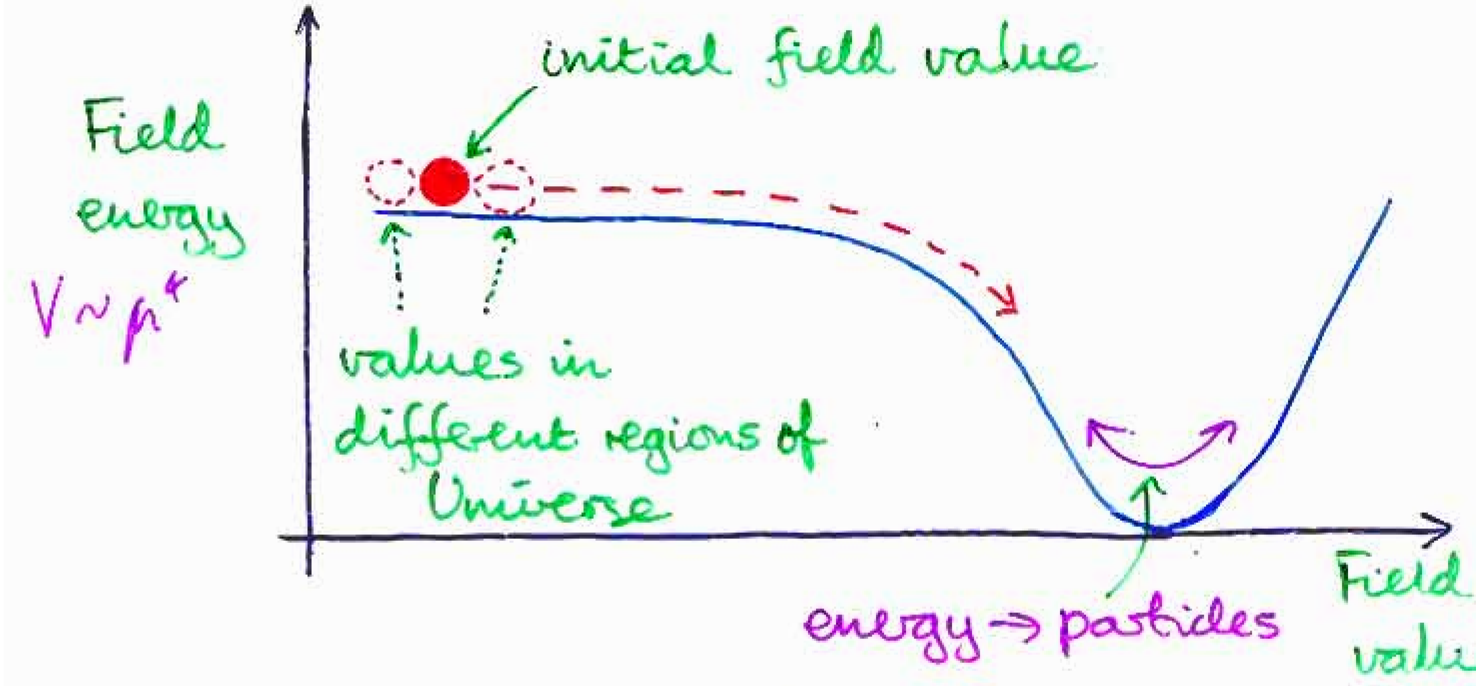
closest one beyond CMB

Density Perturbations

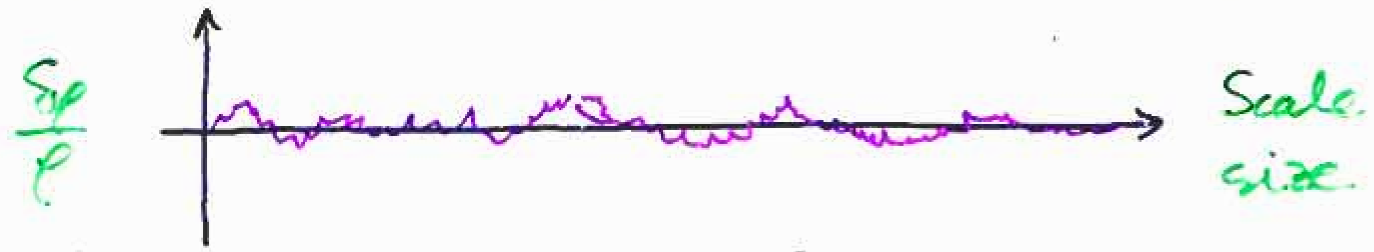
GUT Higgs?
"

quantum/thermal fluctuations in scalar field

⇒ different parts of Universe expand differently



⇒ Gaussian random field of perturbations



similar magnitudes at different scale sizes

wanted by astrophysicists (Harrison, Zeldovich)

magnitude ⇔ value of field energy

$$\left(\frac{\delta T}{T}\right) \sim \frac{\delta\varphi}{\varphi} \propto \mu^2 \cdot G_N$$

consistent with COBE data $\quad \delta T/T \sim 10^{-5}$

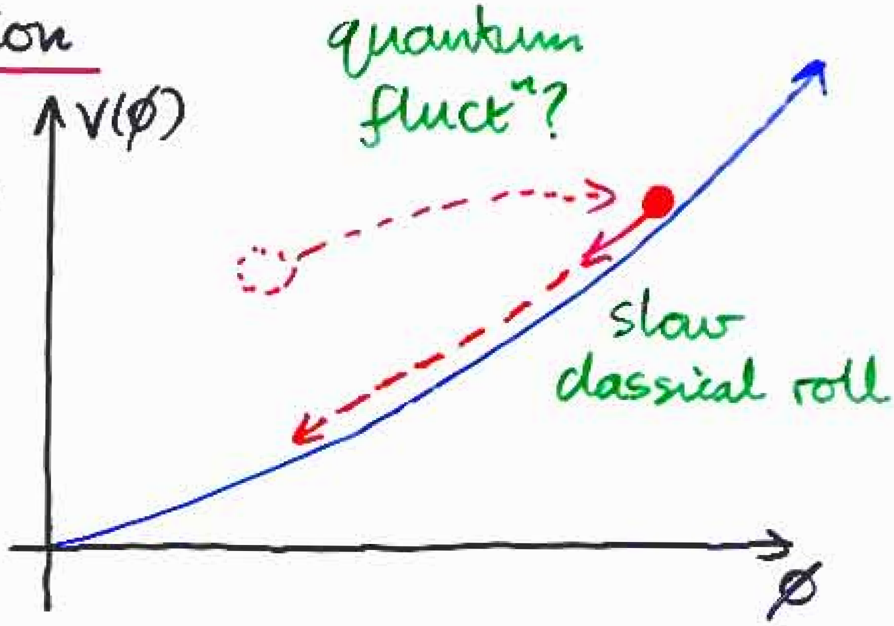
$$\boxed{\mu \sim 10^{16}\ \mathrm{GeV} : \text{GUT energy?}}$$

Chaotic Inflation

- monotonic potential

$V \sim \phi^n$ or $e^{\alpha\phi}$

field theory: $n=2,4$? string?



- roll slowly down from some large initial value:

$$\cancel{\ddot{\phi}}_{\to 0} + 3H\dot{\phi} + V' = 0$$

- slow-roll conditions

$$\epsilon = \frac{m_P^2}{16\pi}\left(\frac{V'}{V}\right)^2, \quad \hat{\eta} = \frac{m_P^2}{8\pi}\frac{V''}{V} \ll 1$$

- expansion factor (# of e-foldings)

$$N = \frac{2\sqrt{\pi}}{m_P}\int_{\phi_{initial}}^{\phi_{final}} \frac{d\phi}{\sqrt{\epsilon}} \qquad e^N : N = \int H dt$$

required amount for comoving scale k:

$$N(k) = 62 - \ln\frac{k}{a_0 H_0} - \ln\frac{10^{16}\,\mathrm{GeV}}{V_k^{1/4}} + \ln\frac{V_k^{1/4}}{V_{exit}^{1/4}} - \frac{1}{3}\ln\frac{V_{exit}^{1/4}}{\rho_{Reheat}^{1/4}}$$

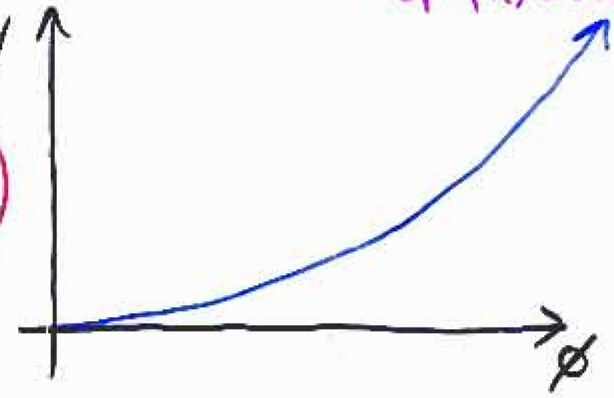
$\simeq 50$ to 70

- different 'bubbles' may have different $\phi_{initial}$

quantum fluctuations?

(J.E. + Raidal + Yanagida: hep-ph/0303242

Toy Model



$$V = \frac{1}{2} m^2 \phi^2 \leftarrow \text{e.g. } \tilde{N}$$

$$V' = m^2 \phi, \quad V'' = m^2$$

slow-roll parameters: $\epsilon = \frac{2 m_{Pl}^2}{\phi^2} = \eta$ $\quad m_{Pl} \equiv (8\pi G_N)^{-\frac{1}{2}} \simeq 2.4 \times 10^{18}$ GeV

COBE normalization:

$$(1.94 \times 10^{-5}) = \sqrt{\frac{1}{75\pi m_{Pl}^6} \frac{V^3}{V'^2}}$$

magnitude of potential:

$$V^{1/4} = 0.027\, \epsilon^{1/4} m_{Pl} \quad < \text{Planck scale}$$

in simple model: $\phi \sqrt{m} \simeq 0.04 \times m_{Pl}^{3/2}$

need about 60 e-folds of expansion:

$$N = 2\pi G_N \phi^2 \simeq 60 \quad \Rightarrow \quad \phi^2 \simeq 240\, m_{Pl}^2$$

somewhat > Planck scale

inflaton mass: $m \simeq \frac{(0.04)^2 m_{Pl}^3}{\phi^2} \simeq \boxed{1.8 \times 10^{13} \text{ GeV}}$

spectral index: $n_s = 1 + 2\eta - 4\epsilon \simeq 1 - \frac{8 m_{Pl}^2}{\phi^2} \simeq \boxed{0.96}$

tensor mode: $\simeq 16\epsilon \simeq \boxed{0.16} \leftarrow$ only monomial compatible with WMAP?

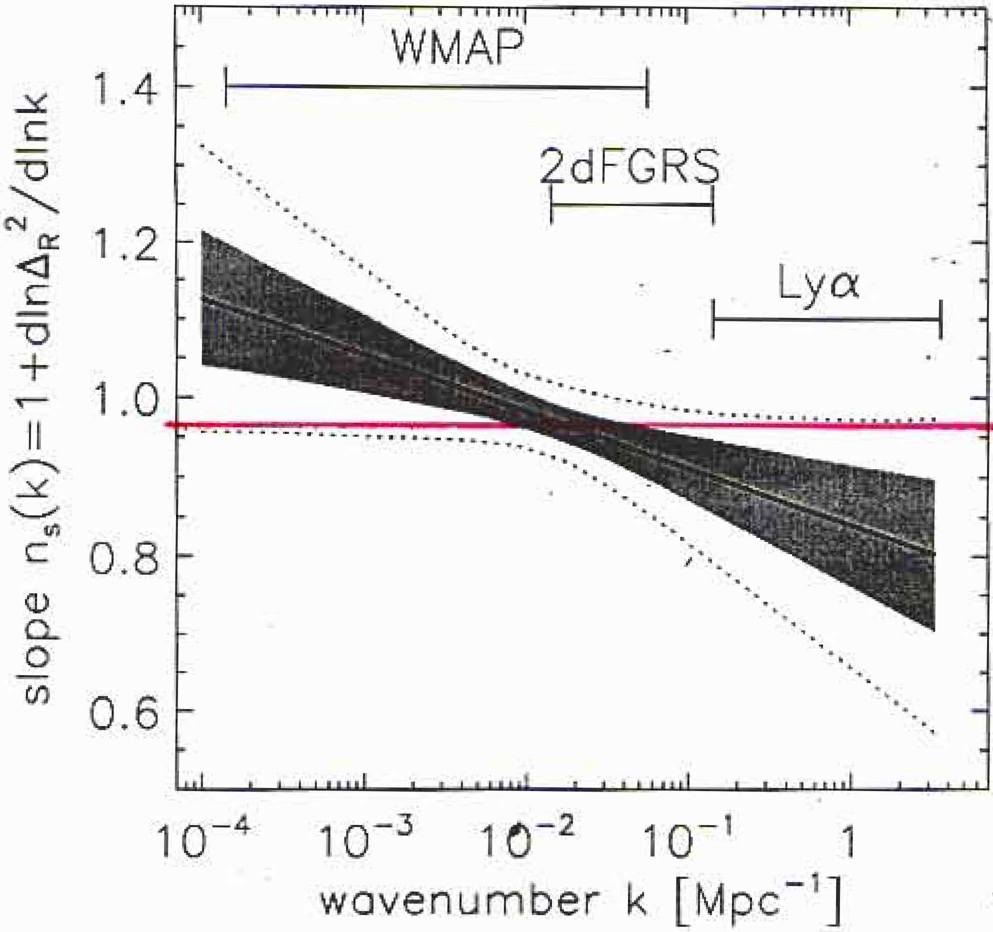
($V \sim \phi^4$ excluded by $\sim 3\sigma$)

Spectral Index from WMAP + 2dFGRS + Lyman α

combination prefers scale dependence in spectral index

BUT consistent with constant spectral index

$n_s \sim 1.0 \leftarrow$ Harrison-Zeldovich



constant spectral index from $V = \frac{1}{2}m^2\phi^2$

as expected for sneutrino

Fig. 2.— This figure shows n_s as a function of k for the *WMAP*ext+2dFGRS+Lyman α data. The mean (solid line) and the 68% (shaded area) and 95% (dashed lines) intervals are shown. The scales probed by *WMAP*, 2dFGRS and Lyman α are indicated on the figure.

(WMAP

Constraints from WMAP et al
on inflation observables

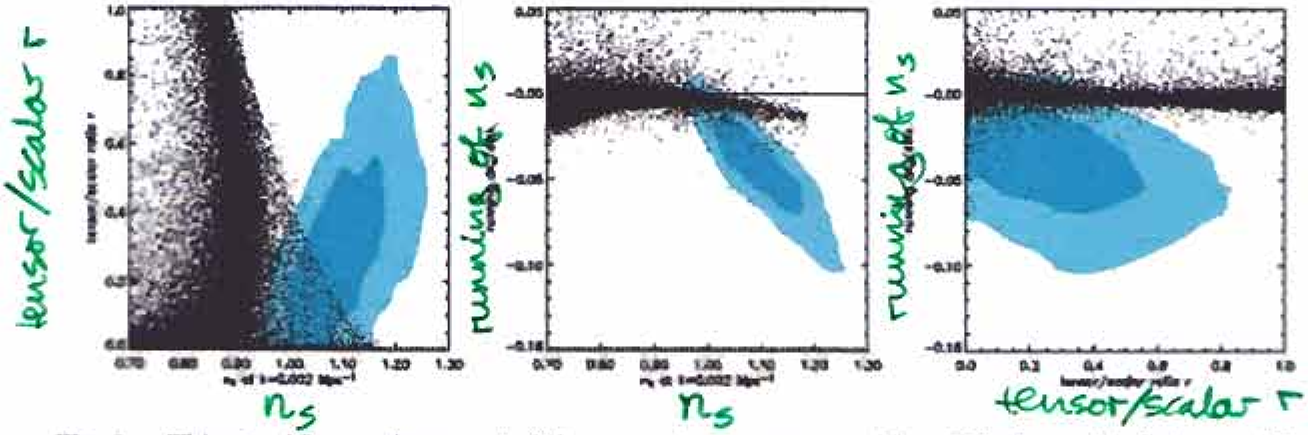


Fig. 3.— This set of figures shows part of the parameter space spanned by viable slow roll inflation models, with the *WMAP*ext+2dFGRS+Lyman α 68% confidence region shown in dark blue and the 95% confidence region shown in light blue.

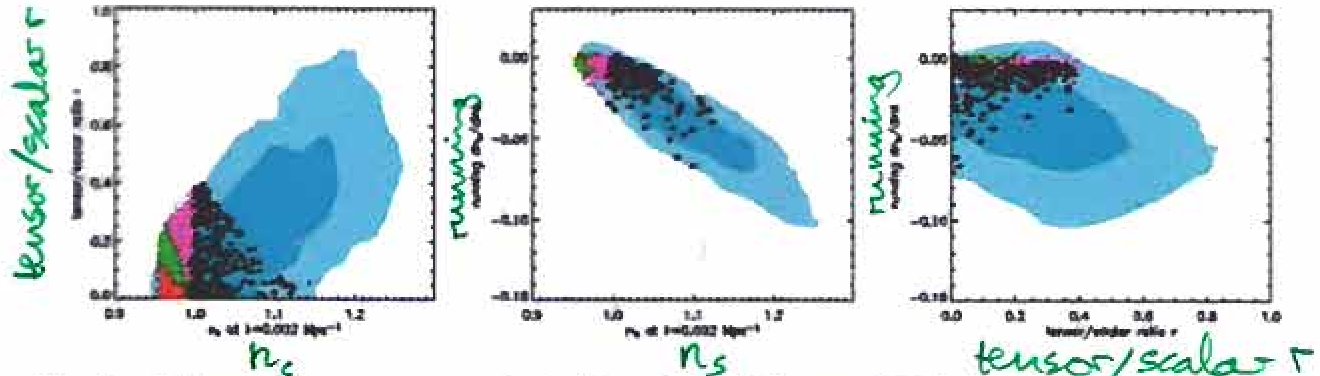


Fig. 4.— This set of figures compares the fits from the *WMAP*ext+2dFGRS+Lyα data to the predictions of specific classes of physically motivated inflation models. The color coding shows model classes referred to in the text: (A) red, (B) green, (C) magenta, (D) black. The dark and light blue regions are the joint 1-σ and 2-σ regions for the *WMAP*ext+2dFGRS+Lyman α data. We show only Monte Carlo models that are consistent with 2-σ regions in all panels. This figure does not imply that the models not plotted are ruled out.

2-Generic GUT Seesaw Model

no new gauge int^{us} needed

$$(\nu_L, \nu_0) \begin{pmatrix} 0 & m_D \\ m_D^T & M_M \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_0 \end{pmatrix}$$

Dirac mass $= O(m_q, m_l)$

singlet ✓

Majorana mass

diagonalization:

$$m_\nu = m_D \frac{1}{M_M} m_D^T \quad \ll m_{q,l} \text{ if } M_M \gg m_W$$

each mass matrix in flavour space

flavour diagonalization:

$$V_{MNS} = V_l V_\nu^\dagger$$

diagonalize l_L $\quad \nu_L \leftarrow m_D \frac{1}{M} m_D^T$

different structure from quark mixing

$$V_{CKM} = V_d V_u^\dagger \leftarrow m_q$$

ν mixing might be very different from q

U(1) models? $\begin{pmatrix} \epsilon^m & \epsilon^q & \epsilon^p \\ \epsilon^{q'} & \epsilon^r & \epsilon^s \\ \epsilon^{p'} & \epsilon^{s'} & \epsilon^t \end{pmatrix}$ GUTs? extra dimensions?

non-Abelian flavour symmetry?

Neutrino Mixing Matrix

(Maki + Nakagawa + Sakata

$$U_{MNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

charged lepton flavours →

mass eigenstates ← eigenvalues?

CPX

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmospheric ν oscill^{ns} — for the future — solar ν oscill^{ns}

CPX

$$+\ 2 \text{ Majorana phases } \begin{pmatrix} e^{i\phi_1} & 0 & 0 \\ 0 & e^{i\phi_2} & 0 \\ 0 & 0 & 1 \end{pmatrix} \text{ measurable in double-}\beta\text{ decay}$$

CP-Violating Observable

$$P(\nu_e \to \nu_\mu) - P(\bar{\nu}_e \to \bar{\nu}_\mu)$$

$$= 16\, s_{12} c_{12} s_{13} c_{13}^2 s_{23} c_{23} \sin\delta$$

$$\times \sin\left(\frac{\Delta m_{12}^2}{4E} L\right) \sin\left(\frac{\Delta m_{13}^2}{4E} L\right) \sin\left(\frac{\Delta m_{23}^2}{4E} L\right)$$

possible only if

Δm_{12}^2, s_{12} large enough: LMA ← established

θ_{13} large enough

↑ we need to know!

Window on leptogenesis?

Beyond the Neutrino Sector

Parameter Counting in Seesaw Model

$$\mathcal{L}_\nu = (Y_\nu)_{ij} H \bar{N}_i \begin{pmatrix} \nu \\ L \end{pmatrix}_j + \frac{1}{2} \bar{N}_i \mathcal{M}_{ij} \bar{N}_j$$

(Casas + Ibarra

physical parameters = 18

$$\underbrace{3m_\nu + \underbrace{(\delta, \phi_1, \phi_2)}_{CP\times} + \theta_{12,23,13}}_{9 \text{ `observable' @ low energies}} + \underbrace{3M_\nu + \overbrace{3\alpha_H + 3\underbrace{\beta_H}_{CP\times}}^{\text{matrix } R}}_{9 \text{ heavy sector}}$$

4 'known'

+ renormalization of susy $\times$

Total of 6 CP-violating parameters

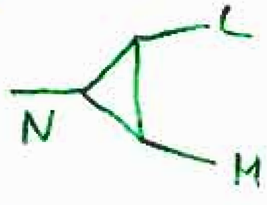
MNS phase + 2 Majorana phases ← $\beta\beta_{0\nu}$

3 extra phases control leptogenesis

Origin of baryon asymmetry?

$$\Gamma(N \to L + H) \neq \Gamma(N \to \bar{L} + H) \quad ?$$

possible via 1-loop CP$\times$ diagrams



Lepton asymmetry → baryon asymmetry

via non-perturbative electroweak interactions

hpt

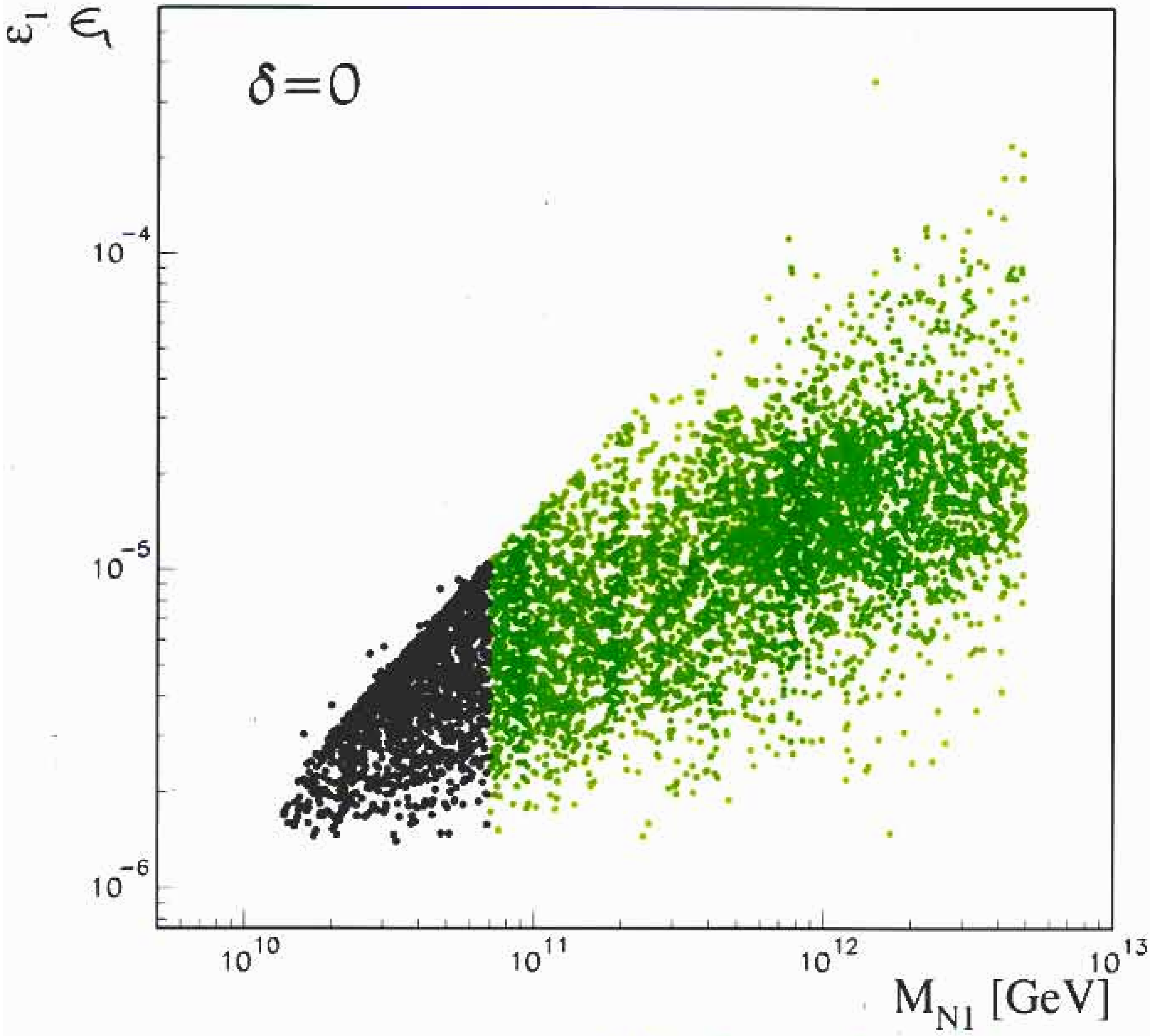
in minimal supersymmetric seesaw model

Leptogenesis Asymmetry

without CP violation in ν oscillations

in decays of heavy neutrinos

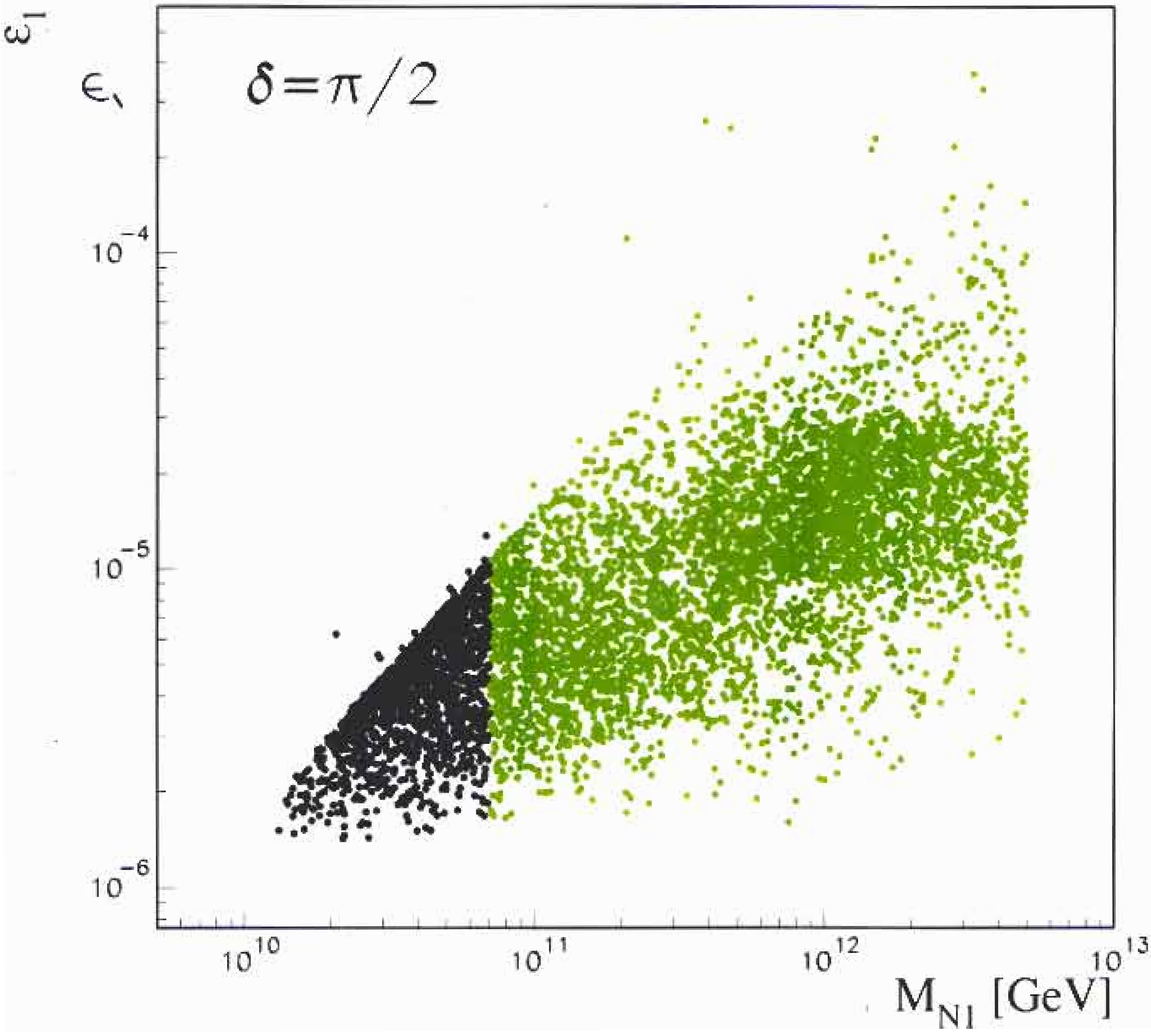
$\Delta L \propto$ ϵ_1



(J.E. + Raidal: hep-ph/0206174

with CP violation in ν oscillations

ΔL ∝



Seesaw Parametrization

(S.E. + Hisano + Lola + Raidal)

diagonalize masses of charged leptons:

$$(Y_e)_{ij} = Y^D_{e_i}\,\delta_{ij}$$

and heavy neutrinos:

$$\mathcal{M}_{ij} = \mathcal{M}^D_i\,\delta_{ij} \qquad \text{3 masses}$$

parametrize Y_ν:

$$Y_\nu = Z^* Y^D_{\nu_k} X^\dagger$$

X: cf CKM matrix — 1 phase, 3 angles

$Y^D_{\nu_k}$: real, diagonal — 3 evalues

$$Z = P_1\,\bar{Z}\,P_2$$

$\bar{Z}$: cf CKM matrix — 1 phase, 3 angles

$$P_{1,2} = \mathrm{diag}(e^{i\theta_{1,3}}, e^{i\theta_{2,4}}, 1)$$

4 phases

leptogenesis $\quad \propto Y_\nu Y_\nu^\dagger = P_1^* \bar{Z}^* (Y_\nu^D)^2 \bar{Z}^T P_1$

3 phases, 3 angles

leading renormalization of sparticle masses

if N_i degenerate $\quad \propto Y_\nu^\dagger Y_\nu = X (Y_\nu^D)^2 X^\dagger$

1 phase, 3 angles

if N_i non-degenerate: 3 phases

assuming universality @ input (Sugra/GUT) scale

Renormalization of soft susy X parameters

$$(\delta m^2_{\tilde{L}})_{ij} \ni -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger Y_\nu)_{ij} \ln\left(\frac{M_{GUT}}{M_N}\right)$$

$$(\delta A_e)_{ij} \ni -\frac{1}{8\pi^2} A_0 Y_{e_i} (Y_\nu^\dagger Y_\nu)_{ij} \ln\left(\frac{M_{GUT}}{M_N}\right)$$

in leading-log approximation: degenerate

$$M_{N_i} \ll M_{GUT}$$

single 'Jarlskog' invariant

$$J_{\tilde{L}} = \mathrm{Im}\left[(m^2_{\tilde{L}})_{12}(m^2_{\tilde{L}})_{23}(m^2_{\tilde{L}})_{31}\right] \qquad \text{1 phase}$$

additional contribution for non-degenerate N_i

$$(\tilde{\delta} m^2_{\tilde{L}})_{ij} \simeq -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger L Y_\nu)_{ij} \; : \; L \equiv \ln\frac{M_N}{M_{N_i}}\delta_{ij}$$

where $M_N = \sqrt[3]{M_{N_1} M_{N_2} M_{N_3}}$

contains matrix factor

$$Y^\dagger L Y = X Y^D P_2 Z^T L Z^* P_2^* Y^D X^\dagger$$

introduces dependence on phases in $Z\, P_2$

not P_1

now a total of 3 phases

(EHLR

3- Could the Inflaton be a Sneutrino?

(Murayama + Suzuki + Yanagida + Yokoyama: 1993, 1994)

need massive scalar $m \sim 10^{10} - 10^{15}$ GeV

without gauge interactions ($\rightarrow$ potential $\neq$ flat)

sounds like heavy singlet sneutrino $\tilde{N}$

mass in correct range

need not have gauge interactions ($\times$ SO(10)?)

tailor-made for leptogenesis?

if so, inflation $\leftrightarrow$ rest of physics

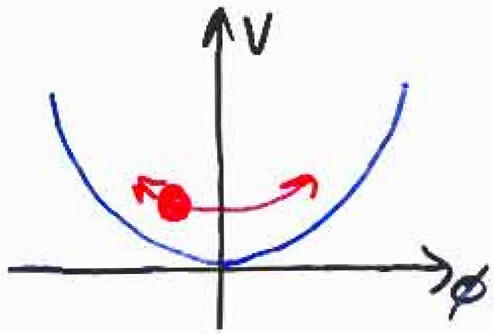
can calculate baryon density via leptogenesis in inflaton decay

Predictions for lepton flavour violation

$\mu \to e\gamma$, $\tau \to \mu\gamma$, ...

(J.E + Raidal + Yanagida hep-ph/0303242

Following Inflation



ends when $H \sim m$

field then oscillates about minimum

energy density $\simeq$ non-relativistic matter

$$\rho_\phi \simeq \rho_{\text{initial}} \left(\frac{a_{\text{initial}}}{a} \right)^3$$

inflaton decays when $H \sim \Gamma_\phi$

inflaton decay rate

decay products thermalize rapidly $\Rightarrow$ reheating

$$\rho_{\text{Reheating}} \simeq \rho_\phi$$

reheating temperature:

$$n\, T_{RH}^4 \simeq \left(\frac{g_\phi^2}{8\pi} m_\phi \right)^2 m_{Pl}^2$$

$$T_{RH} \lesssim 10^{14}\,\text{GeV}$$

want low T_{RH} to suppress relic gravitinos?

$\Rightarrow$ approximate decoupling

(ERY

Gravitino Problem

Case A): $\tilde{G}$ not lightest sparticle (= neutralino χ)

$$\tau_{\tilde{G}\to\chi\gamma} \simeq 3\times10^{8}\,s \times \left(\frac{100\,GeV}{m_{\tilde{G}}}\right)^{3}$$

constraint on relic $\tilde{G}$ abundance from light element abundances (photo-dissociation, ...)

for $\tau \sim 10^{8}s$: $$Y_{\tilde{G}} \equiv \frac{n_{\tilde{G}}}{n_{\gamma}} < 5\times10^{-14}\times\left(\frac{100\,GeV}{m_{\tilde{G}}}\right)$$

(J.E. + Gelmini + Lopez + Nanopoulos + Sarkar (Kawasaki (+ Kohri) + Moroi (Cyburt + J.E. + Fields + Olive: 2003

compare with thermal production

$$Y_{\tilde{G}} \gtrsim 10^{-11}\times\left(\frac{T_{RH}}{10^{10}\,GeV}\right)$$

reheating temperature after inflation

(Bolz + Brandenburg + Buchmüller)

$\Rightarrow$ strong constraint

$$T_{RH} < \text{few}\times10^{7}\,GeV$$

(CEFO

more stringent if hadronic gravitino decays are important

(Kawasaki + Kohri + Moroi: astro-ph/0402490

Case B) : $\tilde{G}$ is lightest sparticle

venerable history (J.E. + Kim + Nanopoulos : '84 ⋮ Fujii + Yanagida : 2002

relic abundance from

- decays of next-to-lightest sparticle (NSP = $\chi, \tilde{\tau}$?)
- primordial production (e.g. thermal

NSP lifetime typically

$$\tau_{NSP} \sim 10^4 \text{ to } 10^8 s$$

recycle previous constraint on unstable relics:

$$\Omega^0_{NSP} \lesssim 10^{-2} \Omega_B h^2$$

(J.E. + Olive + Santoso + Spanos : Dec.'03

density it would have had, if not decayed, to be compared with standard $\Omega_{LSP} h^2 \sim 5 \Omega_B h^2$

⇒ important constraint on NSP parameters

Relic $\tilde{G}$ density from primordial thermal prod^n:

$$\Omega_{\tilde{G}} h^2 \lesssim 0.1 : \quad Y_{\tilde{G}} > 10^{-11} \times \left(\frac{T_{RH}}{10^{10} GeV} \right)$$

$$\Rightarrow \quad T_R \lesssim 10^{10} GeV \times \left(\frac{100\, GeV}{m_{\tilde{G}}} \right)$$

Gravitino Dark Matter?

allowed domains for CMSSM parameters

$m_{\tilde{G}} = 10$ GeV

100 GeV

Scalar mass ↑

→ gaugino mass

allowed by BBN, CMB

$0.2 m_0$

m_0

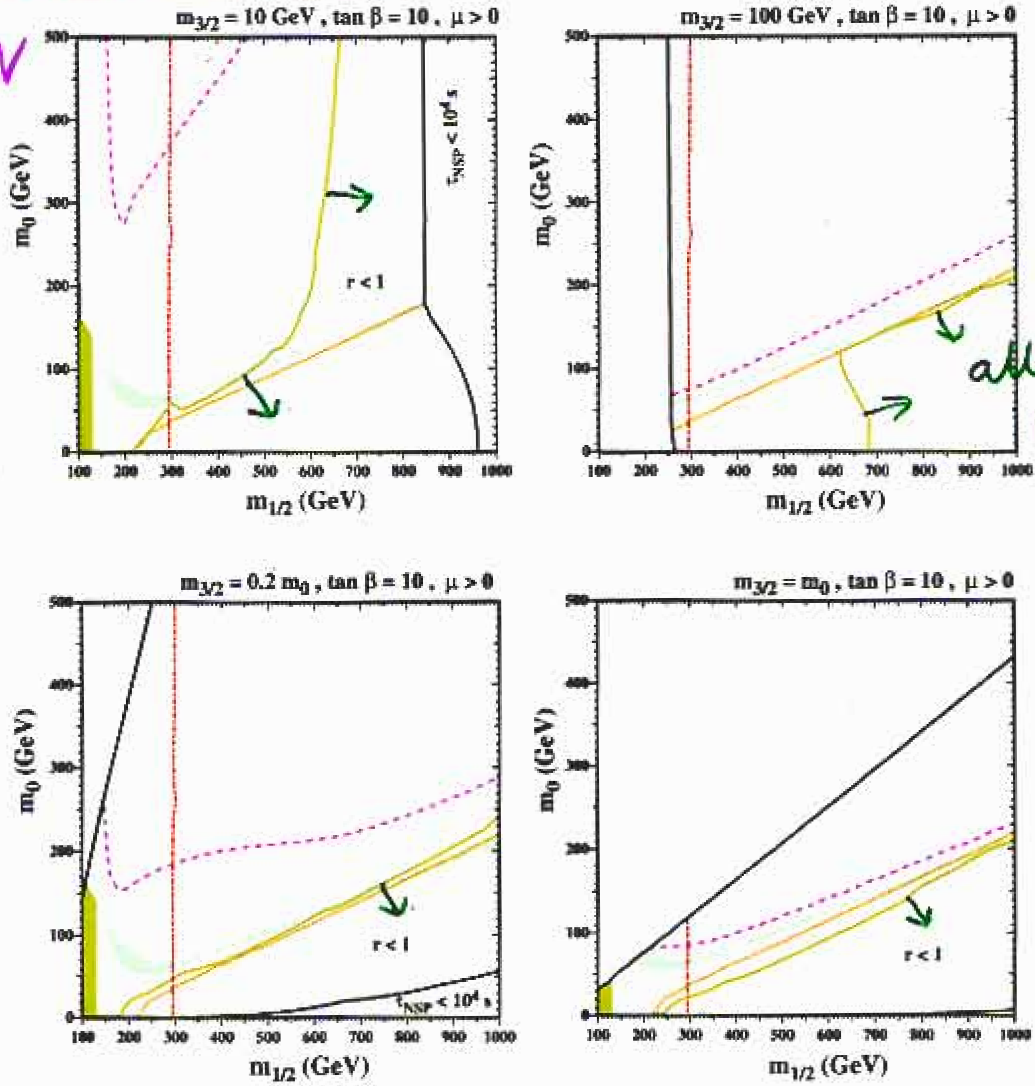
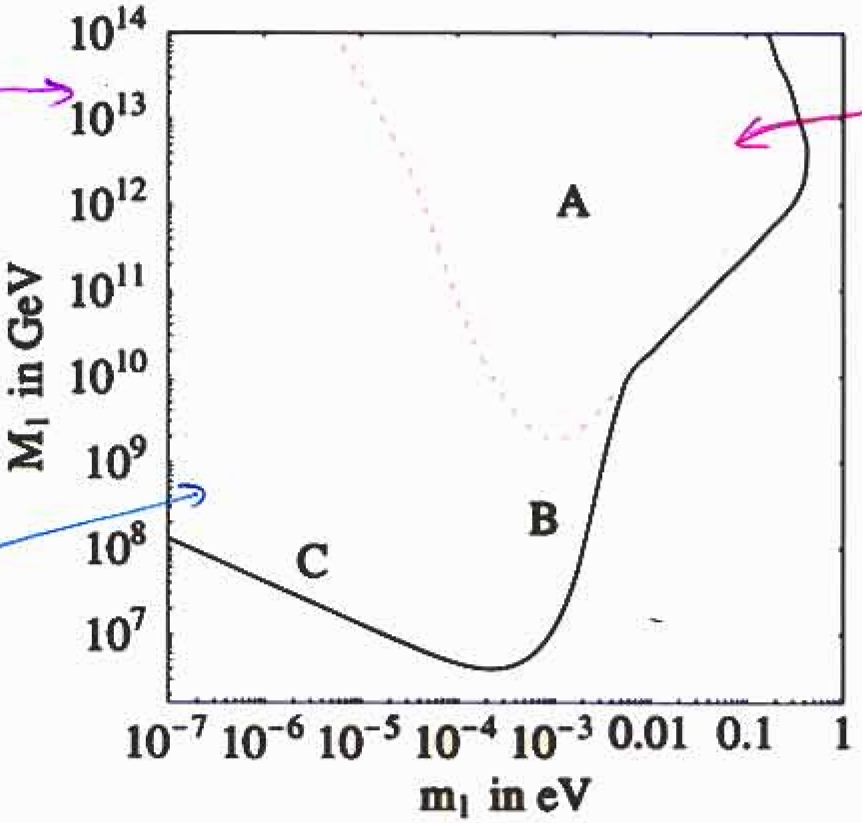


Figure 1: *The $(m_{1/2}, m_0)$ planes for $\tan\beta = 10, \mu > 0$ and the choices (a) $m_{3/2} = 10$ GeV, (b) $m_{3/2} = 100$ GeV, (c) $m_{3/2} = 0.2 m_0$ and (d) $m_{3/2} = m_0$. In each panel, we show $m_h = 114$ GeV calculated using* FeynHiggs *[24], as a near-vertical (red) dot-dashed line, the region excluded by $b \to s\gamma$ is darkly shaded (green), and the region where the NSP density before decay lies in the range $0.094 < \Omega^0_{NSP} h^2 < 0.129$ is lightly shaded (turquoise). The (purple) dashed line is the contour where gravitinos produced in NSP decay have $\Omega_{3/2} h^2 = 0.129$, and the grey (khaki) solid line ($r = 1$) is the constraint on NSP decays provided by Big-Bang nucleosynthesis and CMB observations. The contour where $m_\chi = m_{\tilde{\tau}_1}$ is shown as a (red) diagonal dotted line. Panels (a) and (c) show as a black solid line the contour beyond which $\tau_{NSP} < 10^4$ s, the case not considered here. Panels (b), (c), and (d) show black lines to whose left the gravitino is no longer the LSP.*

(J.E.+Olive+Santoso+Spanos
Dec. '03

Possibilities for Leptogenesis



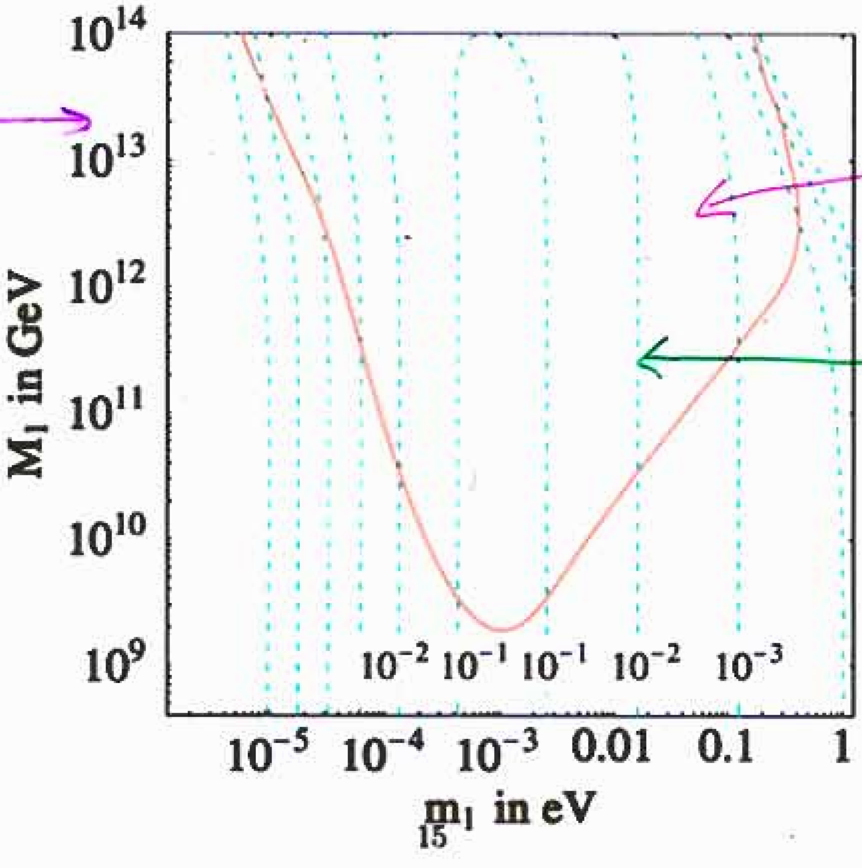


Figure 1: *Left: Lower bound (solid curve) on M_{N_1} as a function of $\tilde{m}_1$ for $Y_B > 7.8 \times 10^{-11}$, assuming a maximal CP asymmetry $\epsilon_1^{max}(M_{N_1})$. Successful leptogenesis is possible in the area above the solid curve. In the area bounded by the red dashed curve, leptogenesis is entirely thermal. Right: The dashed lines are isocontours of the efficiency parameter $\eta = 10^{-1,-2,-3,-4}$: they have meaning only inside the solid curve, which bounds the region where leptogenesis is*

(J.E. + Raidal + Yanagida: hep-ph/0303242

Possibilities for Leptogenesis

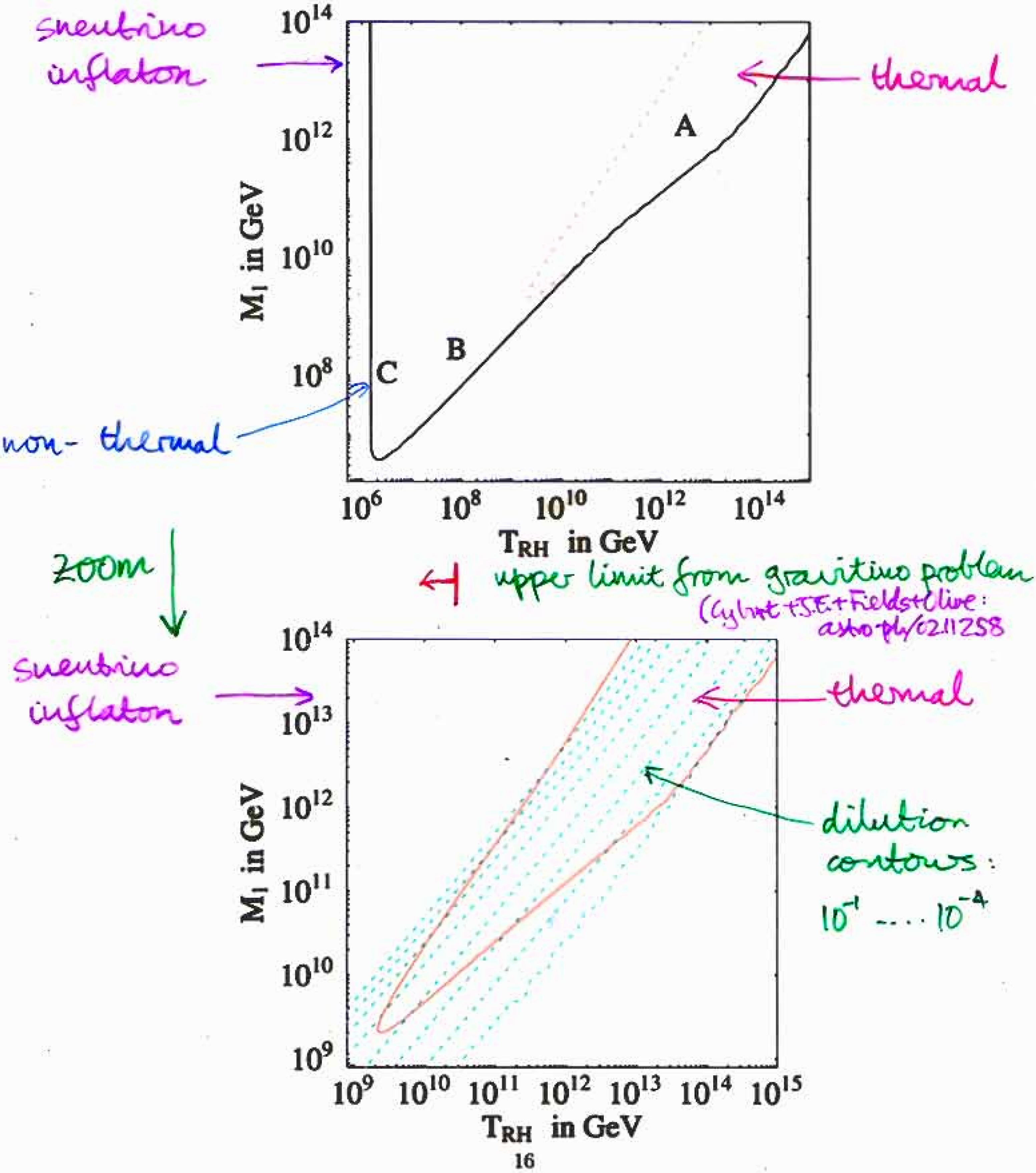


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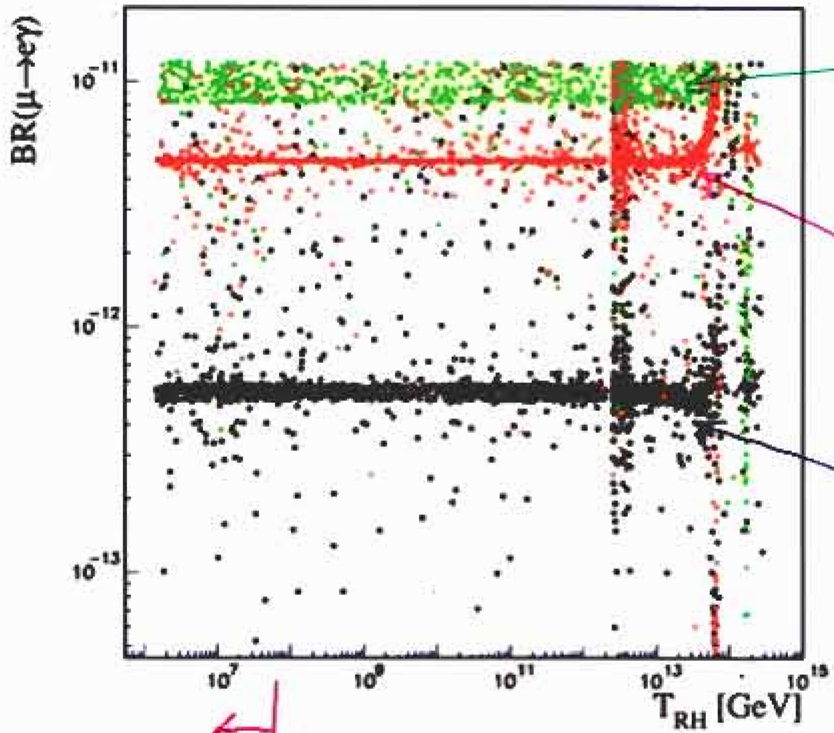
Figure 2: *Left: The solid curve bounds the region allowed for leptogenesis in the* (T_{RH}, M_{N_1}) *plane, again obtained assuming* $Y_B > 7.8 \times 10^{-11}$ *and the maximal CP asymmetry* $\epsilon_1^{max}(M_{N_1})$*. In the area bounded by the red dashed curve leptogenesis is entirely thermal. Right: The dashed lines are isocontours of the efficiency parameter* $\eta = 10^{-1,-2,-3,-4}$*: they have meaning only inside the solid curve, which bounds the region where leptogenesis is thermal.*

(J.E.+Raidal+Yanagida: hep-ph/0303242

Lepton Flavour Violation

assuming sneutrino inflation, leptogenesis

$\mu \to e\gamma$



$\sin\theta_{13} = 0.1$
$M_2 = 10^{14}$ GeV
$M_3 = 5\times10^{14}$ GeV

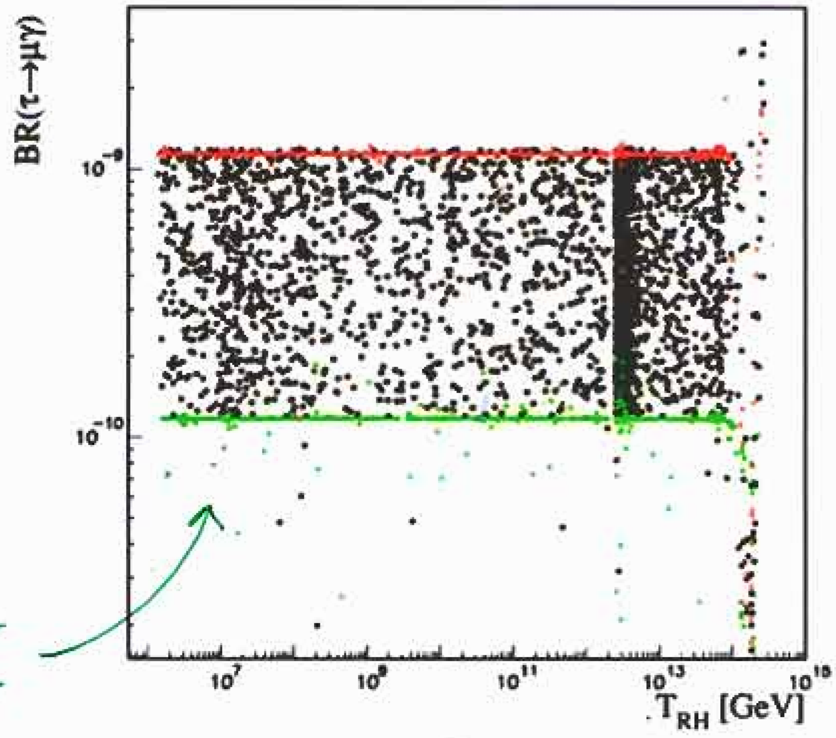
$\sin\theta_{13} \sim 0$
$M_2 = 5\times10^{14}$ GeV
$M_3 = 5\times10^{15}$ GeV

$\sin\theta_{13} = 0.0$
$M_2 = 10^{14}$ GeV
$5\times10^{14} < M_3 <$
5×10^{15} GeV

$\tan\beta = 10$,
$m_{1/2} = 800$ GeV,
$m_0 = 170$ GeV,
$\mu > 0$

upper limit from gravitino problem
(Cyburt+JE+Fields+Olive: astro-ph/0211258

$\tau \to \mu\gamma$



reheating temperature may be low

Figure 3: *Calculations of $BR(\mu \to e\gamma)$ and $BR(\tau \to \mu\gamma)$ on left and right panels, respectively. Black points correspond to $\sin\theta_{13} = 0.0$, $M_2 = 10^{14}$ GeV, and 5×10^{14} GeV $< M_3 < 5 \times 10^{15}$ GeV. Red points correspond to $\sin\theta_{13} = 0.0$, $M_2 = 5 \times 10^{14}$ GeV, and $M_3 = 5 \times 10^{15}$ GeV, while green points correspond to $\sin\theta_{13} = 0.1$, $M_2 = 10^{14}$ GeV, and $M_3 = 5 \times 10^{14}$ GeV.*

(J.E.+Raidal+Yanagida: hep-ph/0303242

4-Exploring LFV with Decoupling

$$Y_\nu \propto M_N^{1/2}\, \Omega\, U_\nu$$ ⇐ ν physics

?

assume:

$$m_{\nu_1} \ll m_{\nu_2} < m_{\nu_3}$$
$$M_1 \le M_2 < M_3$$

Majorana phases

$$U_\nu = \begin{pmatrix} c_{12} & s_{12} & s_{13}e^{-i\delta} \\ -\frac{s_{12}}{\sqrt{2}}+\dots & \frac{c_{12}}{\sqrt{2}}+\dots & \frac{1}{\sqrt{2}} \\ \frac{s_{12}}{\sqrt{2}}+\dots & -\frac{c_{12}}{\sqrt{2}}+\dots & \frac{1}{\sqrt{2}} \end{pmatrix} \cdot \mathrm{diag}(e^{i\phi_1}, e^{i\phi_2}, 1)$$

$s_{12}^2 = 0.315$ →

two options: a) $s_{13} = 0$ or b) $s_{13} = 0.1$, $\delta = \frac{\pi}{2}$

Assume (approximate) 1⊕2 $\boxed{\text{decoupling}}$ of Ω

$\boxed{\text{motivated}}$ by inflation:

$$T_{RH} \propto \sqrt{(Y_\nu Y_\nu^\dagger)_{AA}} \quad \propto \sum_B |\Omega_{AB}|^2 m_{\nu_B}$$

$$\Omega \simeq \begin{pmatrix} 1 & 0 & 0 \\ 0 & z & p \\ 0 & \mp p & \pm z \end{pmatrix}, \begin{pmatrix} 0 & z & p \\ 1 & 0 & 0 \\ 0 & \mp p & \pm z \end{pmatrix}, \begin{pmatrix} 0 & z & p \\ 0 & \pm p & \mp z \\ 1 & 0 & 0 \end{pmatrix}$$

also $\boxed{\text{suggested}}$ by some flavour theories

(Chankowski + J.E. + Pokorski + Raidal + Turzyński

Predictions for LFV Decays

(CEPRT

To a good approximation:

$$B(l_A \to l_B \gamma) \propto |\tilde{m}^2_{L_{AB}}|^2$$

given by RGE: in single-insertion approximation:

$$\tilde{m}^2_{L_{AB}} \propto \sum_C (Y_\nu^{CA})^* \Delta t_C (Y_\nu^{CB})$$

$$\Delta t_C \to \ln(M_X/M_C)$$

qualitative: we use full one-loop RGE

$\boxed{\tau \to \mu\gamma}$ in first decoupling pattern

$$\tilde{m}^2_{L_{32}} \propto \Delta t_3 \times \Big[U_\nu^{33} U_\nu^{23*} (|z|^2 + S|1-z|^2) + R^2 U_\nu^{32} U_\nu^{22*} (S|1-z|^2 + |z|^2)$$
$$+ R\, U_\nu^{33} U_\nu^{22*} (S z\sqrt{1-z^2} - z^* \sqrt{1-z^2}) + R\, U_\nu^{32} U_\nu^{23*} (S z^* \sqrt{1-z^2} - z\sqrt{1-z^2})^* \Big]$$

where $R = \sqrt{m_{\nu_2}/m_{\nu_3}} \sim 0.41$, $S = M_2 \Delta t_2 / M_3 \Delta t_3$

almost independent of M_1, M_2, ϕ_2 if $M_1 < M_2 \ll M_3$:

choose $M_1 = 2 \times 10^{13}$ GeV, $M_2 = 3 \times 10^{13}$ GeV, $M_3 = 5 \times 10^{14}$ GeV

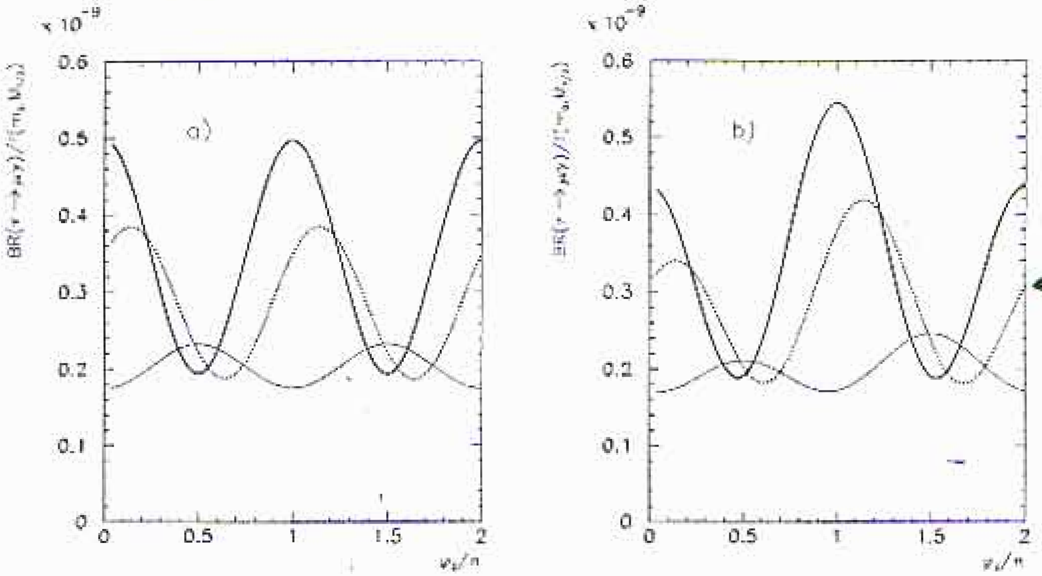
↑ sneutrino inflation

$BR(\tau \to \mu\gamma) > 10^{-9}$ is possible, but ....

what about $BR(\mu \to e\gamma)$?

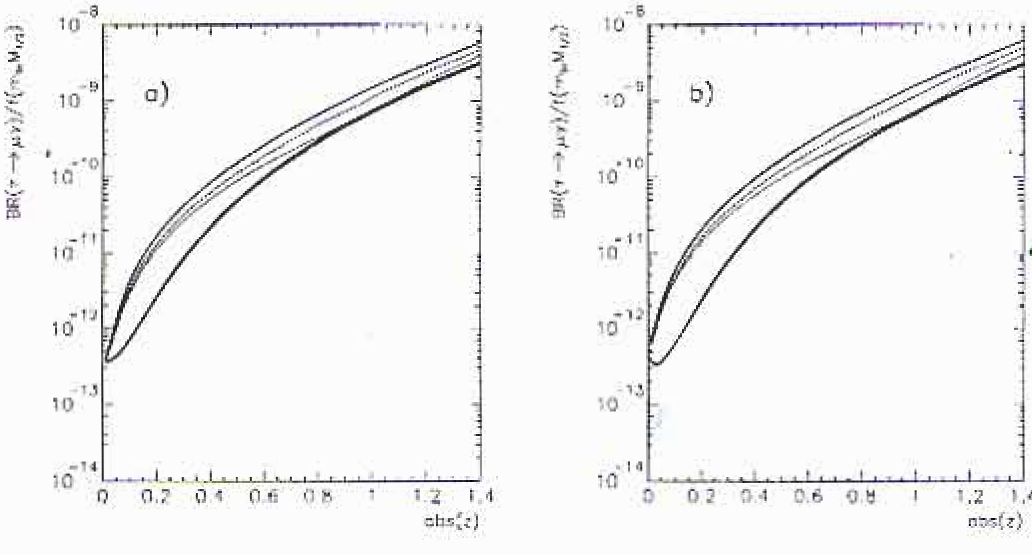
BR($\tau \to \mu\gamma$)

$U_2^{13} = 0$ $\qquad$ $U_2^{13} = 0.1 e^{-i\pi/2}$



dependence on ϕ_2

Figure 2: $BR(\tau \to \mu\gamma)/f(m_0, M_{1/2})$ as a function of ϕ_2 for the choice of the remaining phases described in Table 1, $|z|^2 = 1/2$, $\tan\beta = 10$ and $A_0 = 0$. Dotted, dashed and solid lines correspond to $\arg z = 0, \pi/4, \pi/2$, respectively.



dependence on z

Figure 3: The extremal values of $BR(\tau \to \mu\gamma)/f(m_0, M_{1/2})$ as a function of $|z|$ for the choice of the parameters described in Table 1, $\tan\beta = 10$ and $A_0 = 0$. Dotted, dashed and solid lines correspond to $\arg z = 0, \pi/4, \pi/2$, respectively.

(CEPRT

$\boxed{BR(\mu \to e\gamma)}$

(CEPRT

$$\tilde{m}^2_{L_{21}} \propto \Delta t_3 \times \Big[R\, U_\nu^{23} U_\nu^{12*} \left(S z \sqrt{1-z^2}^* - z^* \sqrt{1-z^2} \right) + R^2 U_\nu^{22} U_\nu^{12*} \left(S|z|^2 + |1-z^2| \right) + \underbrace{U_\nu^{23} U_\nu^{13*} \left(|z|^2 + S|1-z^2| \right)}_{\text{small}} \Big]$$

- stronger dependence on ϕ_2
- possible cancellation for particular values of z

$$BR(\mu \to e\gamma) \gtrsim 10^{-13}$$

- below present experimental limit

$$BR(\mu \to e\gamma) \lesssim 1.2 \times 10^{-11}$$ only for special z

- these generally $\Rightarrow$ $BR(\tau \to \mu\gamma) < 10^{-9}$

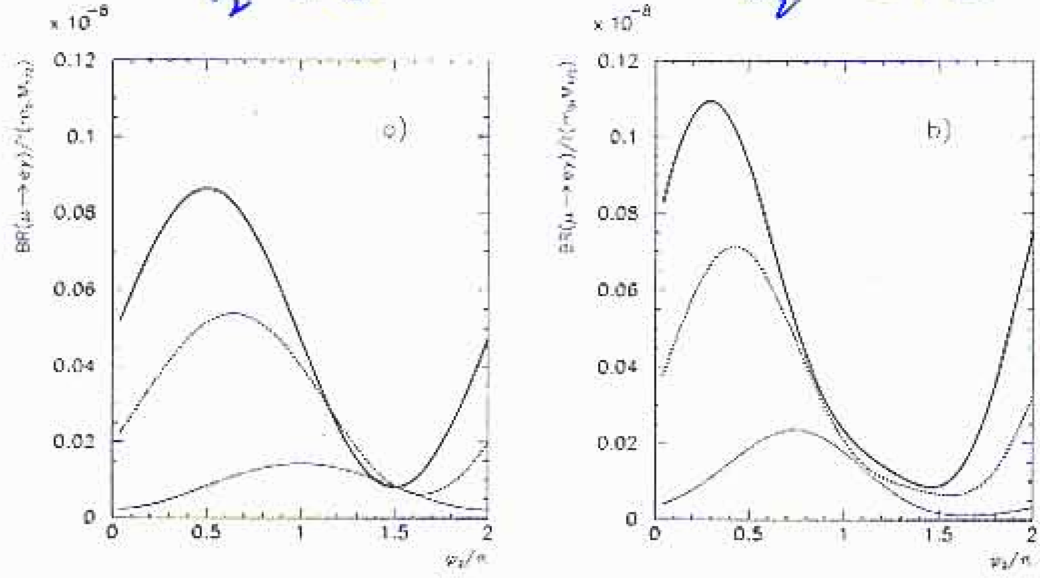
unobservable?

$\boxed{BR(\tau \to e\gamma)}$

- opposite dependence on ϕ_2
- generally smaller than $BR(\tau \to \mu\gamma)$

$BR(\mu \to e\gamma)$

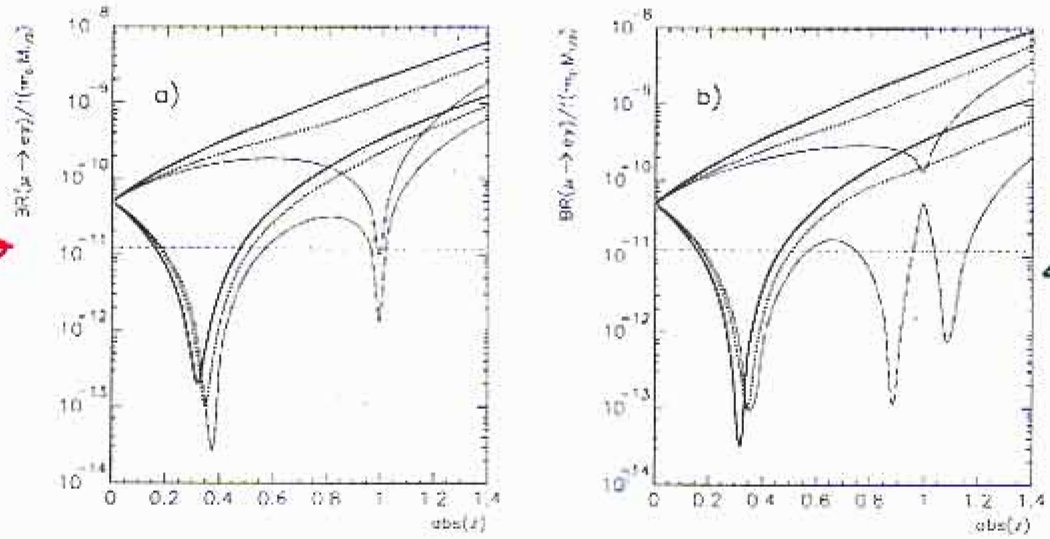
$U_2^{13} = 0$ $\qquad$ $U_2^{13} = 0.1\, e^{-i\pi/2}$



stronger dependence on ϕ_2

Figure 4: $BR(\mu \to e\gamma)/f(m_0, M_{1/2})$ as a function of ϕ_2 for the choice of the remaining phases described in Table 1, $|z|^2 = 1/2$, $\tan\beta = 10$ and $A_0 = 0$. Dotted, dashed and solid lines correspond to $\arg z = 0, \pi/4, \pi/2$, respectively.

limit



dependence on z

Figure 5: Extremal values of $BR(\mu \to e\gamma)$ as a function of $|z|$ for the choice of the parameters described in Table 1, $\tan\beta = 10$ and $A_0 = 0$. Dotted, dashed and solid lines correspond to $\arg z = 0$, $\pi/4$ and $\pi/2$, respectively.

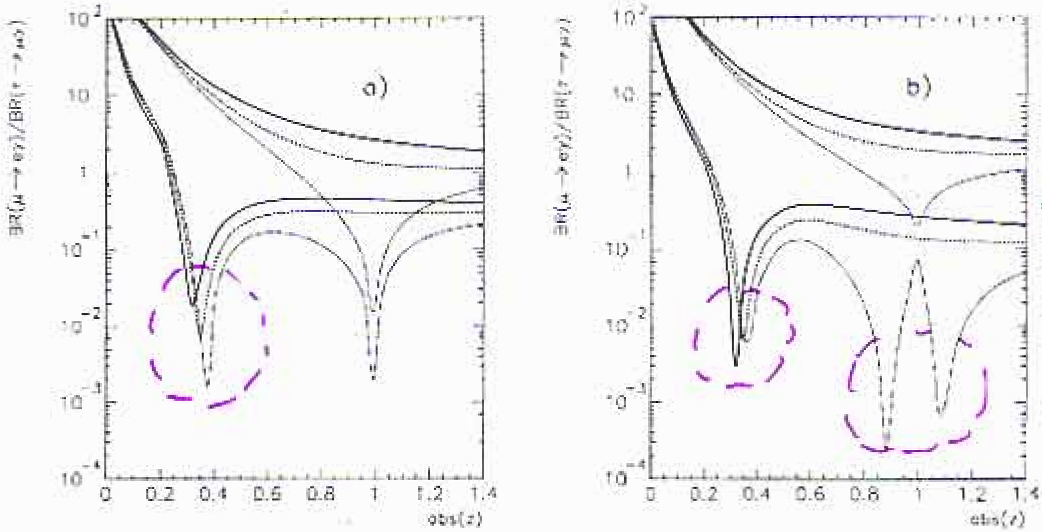
$BR(\mu \to e\gamma) \gtrsim 10^{-13}$

Prediction < experimental limit only for special values of z

(CEPRT

$BR(\mu \to e\gamma)/BR(\tau \to \mu\gamma)$

$U_2^{13} = 0$ $\qquad$ $U_2^{13} = 0.1\,e^{-i\pi/2}$

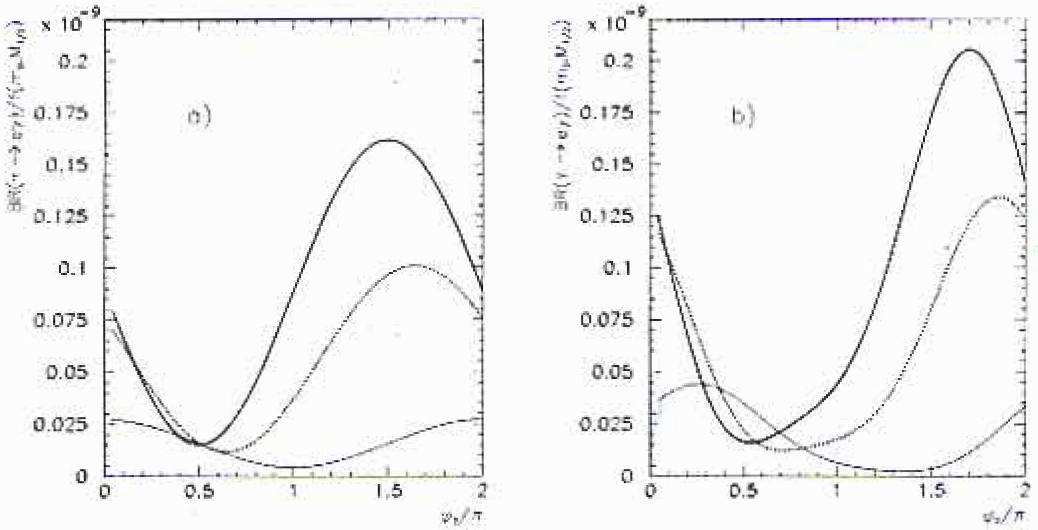


← dependence on z

few cases where $BR(\tau \to \mu\gamma) \gtrsim 10^{-9}$

Figure 6: Extremal values of $BR(\mu \to e\gamma)/BR(\tau \to \mu\gamma)$ as a function of $|z|$ for the choice of the parameters described in Table 1. Dotted, dashed and solid lines correspond to $\arg z = 0$, $\pi/4$ and $\pi/2$, respectively.

$BR(\tau \to e\gamma)$



← dependence on ϕ_2

Figure 7: $BR(\tau \to e\gamma)$ as a function of ϕ_2 for the choice of the remaining phases described in Table 1, $|z|^2 = 1/2$, $\tan\beta = 10$ and $A_0 = 0$. Dotted, dashed and solid lines correspond to $\arg z = 0$, $\pi/4$ and $\pi/2$, respectively.

(CGPRT

$BR(\tau \to e\gamma) / BR(\tau \to \mu\gamma)$

$U_2^{13} = 0$ $\qquad$ $U_2^{13} = 0.1 e^{-i\pi/2}$

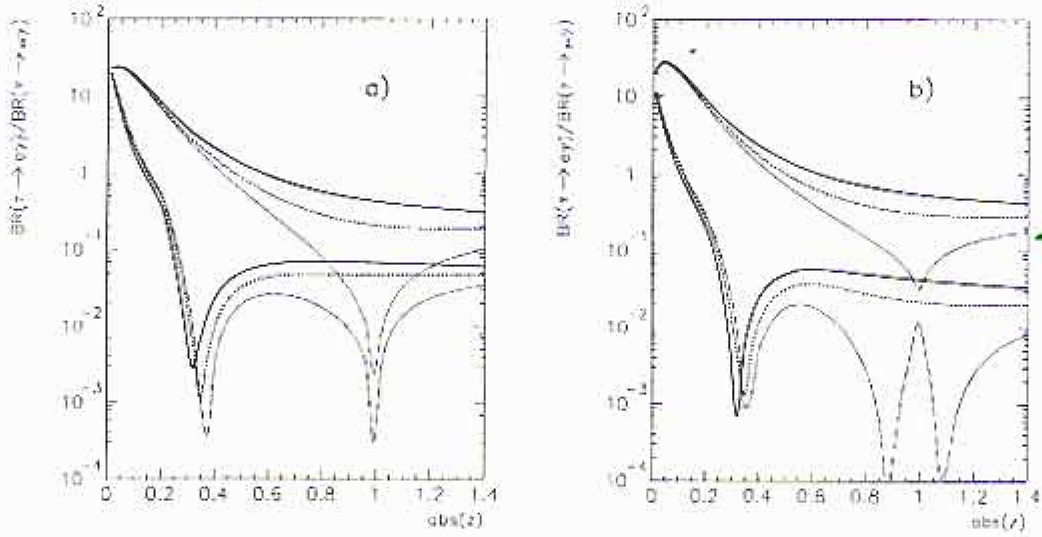


Figure 8: The extremal values of $BR(\tau \to e\gamma)/BR(\tau \to \mu\gamma)$ as a function of $|z|$ for the choice of the parameters described in Table 1, $\tan\beta = 10$ and $A_0 = 0$. Dotted, dashed and solid lines correspond to $\arg z = 0$, $\pi/4$ and $\pi/2$, respectively.

$BR(\mu \to e\gamma)$ minimal values, varying M_2/M_3

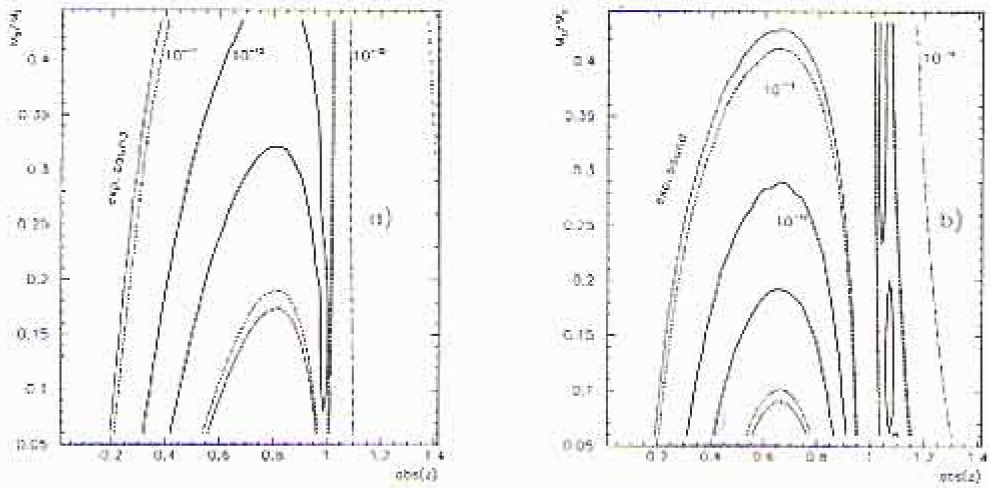


Figure 9: Contour plot of the minimal values of $BR(\mu \to e\gamma)/f(m_0, M_{1/2})$ as a function of $|z|$ and M_2/M_3 for the choice of the parameters described in Table 1, $\tan\beta = 10$, $A_0 = 0$ and $\arg z = 0$.

(CEPRT

Motiv:

"We are all made of stars"

astrophysical/cosmological nucleosynthesis?

Here:

"We are all made of neutrinos"

leptogenesis? inflation?

"The rest is made of neutralinos"

LHC? direct detection?