VARIOUS REALIZATIONS OF LEPTOGENESIS AND NEUTRINO MASS CONSTRAINTS

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PLAN:
- THE 3 BASIC INGREDIENTS OF LEPTOGENESIS
- THE NEUTRINO MASS CONSTRAINTS IN THE STANDARD SEESAW MODEL
- OTHER (THERMAL) LEPTOGENESIS MODELS

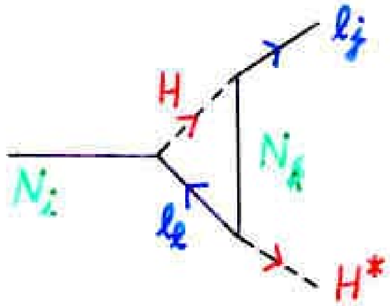
THE 3 INGREDIENTS OF LEPTOGENESIS

• 1) CP ASYMMETRY: (AVERAGED ΔL PRODUCED PER N_i DECAY)

$$\varepsilon_{N_i} = \frac{\Gamma(N_i \to \ell_j H^*) - \Gamma(N_i \to \bar{\ell}_j H)}{\Gamma^{TOT}_{N_i}}$$

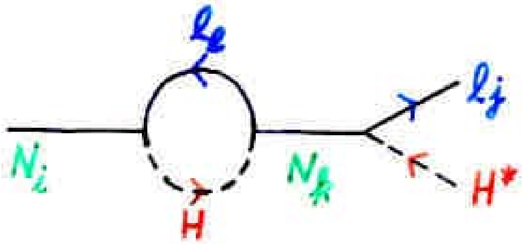
FROM 2 DIAGRAMS:

• VERTEX:



FUKUGITA-YANAGIDA 86

• SELF-ENERGY:



LIU, SEGRÉ 93
COVI ET AL 96
FLANZ ET AL 96

$$\Rightarrow \varepsilon_{N_i} = \frac{1}{8\pi} \sum_k \frac{\mathrm{Im}[(Y_\nu Y_\nu^\dagger)^2_{ik}]}{\sum_j |Y_{\nu ij}|^2} \cdot \frac{M_{N_k}}{M_{N_i}} \cdot$$

$$\left[1 - \left(1 + \frac{M^2_{N_k}}{M^2_{N_i}}\right) \log\left(1 + \frac{M^2_{N_i}}{M^2_{N_k}}\right) + \frac{M^2_{N_i}}{M^2_{N_i} - M^2_{N_k}} \right]$$

VERTEX SELF-ENERGY

• 2) THE EFFICIENCY FACTOR : (DUE TO WASHOUT)

$$\frac{n_L}{s} = \frac{\varepsilon_{N_i}}{\underset{\sim 100}{g_*}} \cdot \underline{\underline{\eta}}$$

→ IF N_i DECAYS OUT-OF-EQUILIBRIUM : $\eta = 1$

→ IF N_i DECAYS IN EQUILIBRIUM : $\eta \ll 1$

⇒ OUT-OF-EQUILIBRIUM CONDITIONS :

- DECAY : $\Gamma_{N_i} \lesssim H\,(T = M_{N_i})$
- $\Delta L = 1$ SCATTERINGS : $N_i + \ell_j^- \to H^- \to \bar{t} + b, \ldots$
- $\Delta L = 2$ SCATTERINGS : $\ell_j + H^* \to N_i \to \bar{\ell}_k + H, \ldots$

MUST BE SLOW % H

- ...

⇒ TO BE PUT IN THE BOLTZMANN EQUAT° TO CALCULATE THE EVOLUTION OF THE L ASYM. % T. (⇒ TO GET η).

• 3) THE $L \to B$ SPHALERON CONVERSION : $\left.\frac{n_B}{s}\right|_{FIN} \sim \frac{1}{3} \left.\frac{n_L}{s}\right|_{INIT.}$

B+L ANOMALY (VIA INSTANTONS)

THE ν MASS CONSTRAINTS

- m_ν CONSTRAINT ON THE SIZE OF WASHOUT: ALWAYS APPLIES

$$\underline{\frac{\Gamma_{N_i}}{H} \geqslant \frac{m_{\nu_1}}{(10^{-3}\,eV)}} \Leftarrow$$

BUT NO WASHOUT REQUIRES THAT: $\frac{\Gamma_{N_i}}{H} \lesssim 1$!

$$\Rightarrow \begin{cases} \text{IF } m_{\nu_1} > 10^{-3}\,eV \Rightarrow \text{WASHOUT IS THERE} \\ \text{IF } m_{\nu_1} \nearrow \Rightarrow \text{WASHOUT} \nearrow \end{cases}$$

- m_ν CONSTRAINT ON THE SIZE OF CP ASYMMETRY:

NOT ALWAYS THERE : DEPENDS ON THE N_i MASS SPECTRUM :
- VERY HIERARCHICAL: $M_{N_{2,3}} \ggg M_{N_1}$
- HIERARCHICAL: $M_{N_{2,3}} \sim 10\text{-}100\, M_{N_1}$
- QUASI-DEGENERATE: $M_{N_1} \sim M_{N_2} (\sim M_{N_3})$

VERY HIERARCHICAL N_i CASE : $M_{N_{2,3}} \ggg M_{N_1}$

ONLY ε_{N_1} IS ⚠ FOR LEPTOGENESIS :

$$\varepsilon_{N_1} \leq \frac{3}{8\pi} M_{N_1} \frac{1}{v^2} \frac{\Delta m^2_{ATM}}{m_{\nu_3} + m_{\nu_1}}$$

HAMAGUSHI ET AL 03
DAVIDSON, IBARRA 03
(+BUCHMÜLLER ET AL 03,
T. H. 02)

$\Downarrow$ $\qquad$ $\Downarrow$

ε_{N_1} DECREASES WHEN $M_{N_1} \downarrow$ $\qquad$ ε_{N_1} DECREASES WHEN $m_{\nu_{1,2,3}} \uparrow$

$\Downarrow$ $\qquad$ $\Downarrow$

$$\underline{M_{N_1} \gtrsim 4 \cdot 10^8 \, GeV} \qquad \underline{m_{\nu_3} \lesssim (0.12 - 0.15) \, eV}$$

(IBIDEM, ↗)

BUCHMÜLLER, DI BARI, PLÜMACHER 02, 03
GIUDICE, NOTARI, RAIDAL, RIOTTO, STRUMIA 03

T. H., LIN, NOTARI, PAPUCCI, STRUMIA 03

HIERARCHICAL N_i CASE : $M_{N_{2,3}} \sim 10\text{-}100\, M_{N_1}$

RESULTS E.G. SAME AS FOR VERY HIERARCHICAL CASE

BUT NOT ALWAYS:

$$\varepsilon_{N_1} \leq \frac{3}{8\pi} M_{N_1} \frac{1}{v^2} \frac{\Delta m^2_{ATM}}{m_{\nu_3} + m_{\nu_1}} + \underbrace{\frac{M^2_{N_1}}{M^2_{N_{2,3}}}}_{\text{SMALL}} \cdot C$$

T.H., LIN, NOTARI, PAPUCCI, STRUMIA 03

CAN BE LARGE:

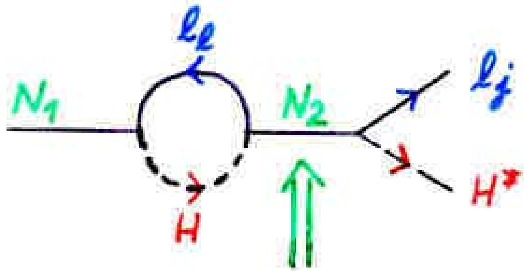
- NOT $\downarrow$ WHEN $m_\nu \uparrow$
- NOT $= 0$ FOR $m_{\nu_1} = m_{\nu_2} = m_{\nu_3}$.

$\Rightarrow$ FOR EXAMPLE $m_{\nu_3} \sim 0.5$ eV OR $M_{N_1} \sim 10^6$ GeV ARE COMPATIBLE WITH SUCCESSFUL LEPTOGENESIS FOR SPECIAL CONFIGURATIONS OF YUKAWA'S.

QUASI-DEGENERATE N_i CASE : $M_{N_1} \sim M_{N_2}$

IF $M_{N_1} \sim M_{N_2}$ => RESONANCE EFFECT :

M. FLANZ ET AL. 96
A. PILAFTSIS 98
PILAFTSIS, UNDERWOOD 03
T.H., LIN, NOTARI, PAPUCCI, STRUMIA 03



$$\sim \frac{1}{\underbrace{M_{N_1}^2 - M_{N_2}^2 + i M_{N_2} \Gamma_{N_2}}}$$

HUGE RESONANCE PEAK IF $M_{N_1} \sim M_{N_2}$

(BECAUSE E.G. $\Gamma_{N_i} \lll M_{N_i}$)

=> NO MORE $\left\{\begin{array}{l} m_\nu \\ M_{N_i} \end{array}\right.$ CONSTRAINT ON ε_{N_i} : $\underline{\varepsilon_{N_i} < 1/2}$

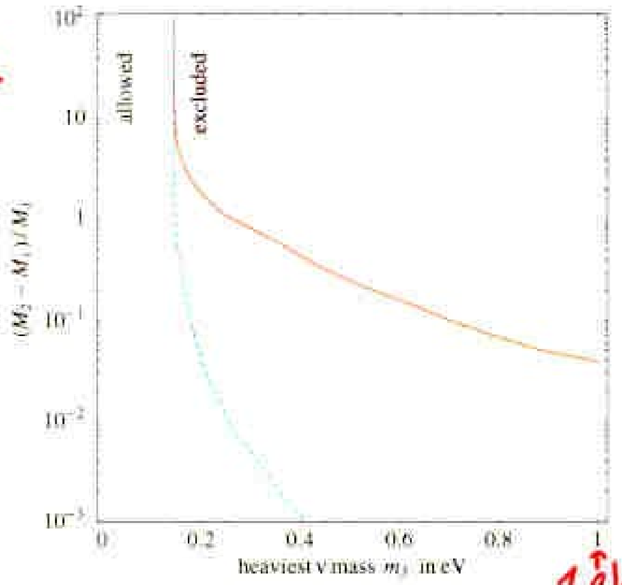
=> NO MORE LOWER LIMIT ON M_{N_1} FOR SUCCESSFUL LEPTOG. EXCEPT FOR $L \to B$ CONVERSION => $\underline{\underline{M_{N_1} \gtrsim 1\ \text{TeV}}}$

=> MUCH LARGER UPPER LIMIT ON m_{ν_i}

$\Rightarrow$ RESULTS FOR m_{ν_3} UPPER BOUND IN FULL GENERALITY:

T.H., LIN, NOTARI, PAPUCCI, STRUMIA 03

$$\frac{M_{N_2}-M_{N_1}}{M_{N_1}}$$



1 eV

m_{ν_3}

$\Rightarrow$ A DEGENERACY $(M_{N_2}-M_{N_1})/M_{N_1} \sim 4\cdot 10^{-2}$ ALLOWS ALREADY SUCCESSFUL LEPTOGENESIS WITH $m_{\nu_3} \sim 1\,eV$!

N.B.: IF $m_{\nu_3} \gtrsim 0.1\,eV$, ν DATA TELLS US THAT THE LIGHT ν ARE QUASI-DEGENERATE ANYWAY. TO EXPLAIN SUCH A LIGHT ν SPECTRUM IT IS E.G. EASIER TO START WITH QUASI-DEGENERATE N_i'S.

$\Rightarrow$ QUASI-DEGENER. N_i: BOUND ON m_{ν_3} FULLY RELEVANT!!

RESULTS FOR m_{ν_3} IN THE "MOST REALISTIC" CASE

TO EXPLAIN $M_{N_1} \sim M_{N_2} \sim M_{N_3}$: A $SO(3)$ SYMMETRY BETWEEN THE N_i

↳ WE EXPECT E.G.:

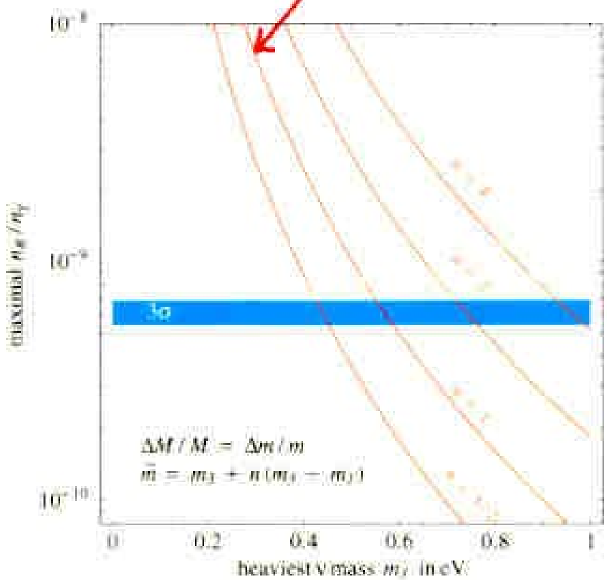
$$\frac{M_{N_2}-M_{N_1}}{M_{N_1}} \sim \frac{\tilde{m}_2-\tilde{m}_1}{\tilde{m}_1} \sim \frac{m_{\nu_2}-m_{\nu_1}}{m_{\nu_1}} \sim \frac{\Delta m^2_{sol}}{2\, m^2_{\nu_1}} \sim 5 \cdot 10^{-5} \left(\frac{eV}{m_{\nu_1}}\right)^2$$

$$\frac{M_{N_3}-M_{N_2}}{M_{N_2}} \sim \frac{\tilde{m}_3-\tilde{m}_2}{\tilde{m}_2} \sim \frac{m_{\nu_3}-m_{\nu_2}}{m_{\nu_2}} \sim \frac{\Delta m^2_{ATM}}{2\, m^2_{\nu_2}} \sim 10^{-3} \left(\frac{eV}{m_{\nu_2}}\right)^2$$

WITH: $m_{\nu_1} \leq \tilde{m}_i \lesssim m_{\nu_3}$ ← GIVES EXTRA SUPPRESSION OF THE ASYMMETRY

⇒ RESULTS:

$(n_B/n_\gamma)^{MAX}$

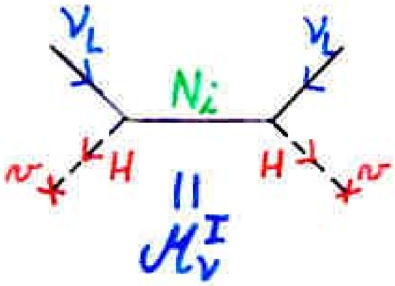
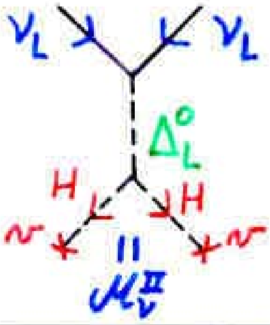
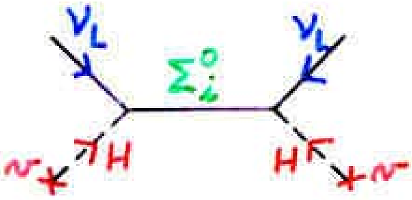


← $(n_B/n_\gamma)^{EXP}$

m_{ν_3}

⇒ $m_{\nu_3} < 0.6\ eV$ ← "MOST REALISTIC" BOUND

SEESAW MODELS

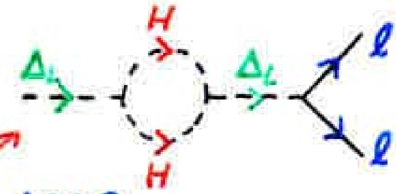
TYPE OF SEESAW	ν MASS DIAGRAMS	GUT MOTIVATION
3 RIGHT-HANDED N_i "TYPE 1 SEESAW"		VERY NATURAL IN SO(10) (WITH NON-RENORM. INTER. TO INDUCE THE M_{N_i})
1 SCALAR $SU(2)_L$ TRIPLET Δ_L "TYPE 2 SEESAW"		LESS NATURAL
3 FERMION $SU(2)_L$ TRIPLETS Σ_i "TYPE 3 SEESAW" ← ?		LESS NATURAL
$3N_i + 1\Delta_L$ "TYPE 1" + "TYPE 2"	$\mathcal{M}_\nu = \mathcal{M}_\nu^{I} + \mathcal{M}_\nu^{II}$	VERY NATURAL IN SO(10) (WITH RENOR. INTER. WITH H_{126})
$2\Delta_L : \Delta_{L_{1,2}}$	$\mathcal{M}_\nu = \mathcal{M}_{\nu_1}^{II} + \mathcal{M}_{\nu_2}^{II}$	LESS NATURAL
$3N_i$ + EXTRA SINGLET FERMIONS S_i	$\mathcal{M}_\nu = \mathcal{M}_{\nu_N}^{I} + \mathcal{M}_{\nu_S}^{I}$	POSSIBLE IN SO(10) (WITH S_i = SO(10) SINGLETS AND $H_{\overline{16}}$)

LEPTOGENESIS WITH A SINGLE SCALAR TRIPLET

DOESN'T WORK!

DIAGRAMS HAVE NO $\cancel{CP}$ AT ONE LOOP

AND TOO SUPPRESSED AT 2 LOOPS



⇐ MAGG, WETTERICH 80
LAZARIDES, SHAFI, WETTERICH 81
MOHAPATRA, SENJANOVIC 81
WETTERICH 81, ...

⇐ FOOT, LEW, HE, JOSHI 89
MA 98; MA, ROY 02, ...

⇐ MOHAPATRA, SENJANOVIC 81; BABU, MOHAPATRA 92;
BAJC, SENJANOVIC, VISSANI 03
GOH, MOHAPATRA, NG 03, ...

⇐ MA, SARKAR 98

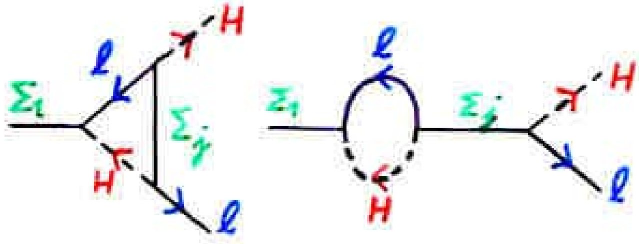
⇐ MOHAPATRA, VALLE 86
BARR 03; ALBRIGHT, BARR 03

LEPTOGENESIS WITH FERMION TRIPLETS Σ_i

T.H., LIN, NOTARI, PAPUCCI,
STRUMIA 03

↳ SIMILAR TO THE TYPE I CASE:

- SIMILAR DIAGRAMS:



- SIMILAR ASYMMETRY:

$$\varepsilon_{\Sigma_1} = \frac{M_1}{M_j}\frac{\Gamma_j}{M_j}\frac{\mathrm{Im}\left[(Y_\nu Y_\nu^\dagger)^2_{1j}\right]}{|Y_\nu Y_\nu^\dagger|_{11}\,|Y_\nu Y_\nu^\dagger|_{jj}}$$

$$\cdot\left\{\frac{M_j^2}{M_1^2}\left[\left(1+\frac{M_j^2}{M_1^2}\right)\log\left(1+\frac{M_1^2}{M_j^2}\right)-1\right]-\frac{M_j^2}{M_j^2-M_1^2}\right\}$$

WITH HOWEVER ONE DIFFERENCE: GAUGE SCATTERINGS: $\Sigma_i^+ + \Sigma_i^- \to W^+ + W^-, \ldots$

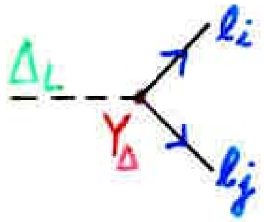
⇒ MASS BOUNDS SLIGHTLY MORE STRINGENT:

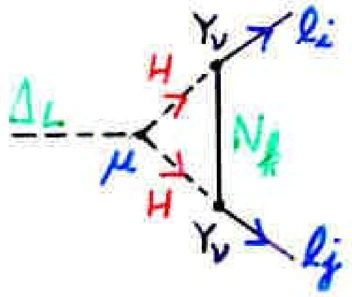
- WITH HIERARCHICAL Σ_i:
  - $M_{\Sigma_1} \gtrsim 1.5 \cdot 10^{10}$ GeV
  - $m_{\nu_3} \lesssim 0.12$ eV

- WITH QUASI-DEGENERATE Σ_i: E.G. $M_{\Sigma_1} > \sim(10-100)$ TeV

LEPTOGENESIS WITH $3N_i$ AND $1\Delta_L$ (SO(10), L-R MODEL)

- CASE $M_{\Delta_L} << M_{N_1}$: LEPTOGENESIS FROM $\Delta_L \to \ell\ell$





O'DONNELL, U. SARKAR 94

$$\Rightarrow \varepsilon_{\Delta_L} = \frac{1}{8\pi} \sum_k M_{N_k} \frac{Im\,[Y^*_{\nu ki} Y^*_{\nu kj} Y_{\Delta ij} \mu^*]}{|Y_{\Delta pq}|^2 + |\mu|^2} \cdot \log\left(1 + \frac{M_\Delta^2}{M_{N_k}^2}\right)$$

T.H., G. SENJANOVIC 03

$\Rightarrow$ LEPTOGENESIS FINE WITH 4 ≠ % STANDARD N_i LEPTOG.:

- GAUGE SCATTERINGS: $\Delta_L + \Delta_L \to W^+ + W^-, \ldots$
- NO SELF-ENERGY DIAGRAM $\Rightarrow$ NO RESONANCE
- IF $\mathcal{M}_\nu^I \uparrow$, $\varepsilon_{\Delta_L} \uparrow$
- IF $\mathcal{M}_\nu^I \uparrow$ WASHOUT DOESN'T INCREASE

$\Rightarrow$ IF $\mathcal{M}_\nu^I \uparrow$ LEPTOGENESIS $\uparrow$!!

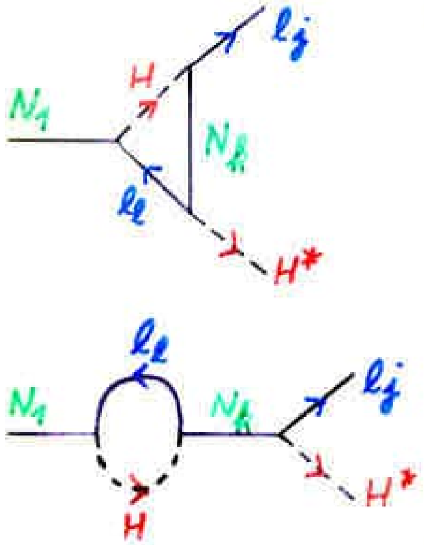
$\Rightarrow$ NO MORE RELEVANT UPPER BOUND ON m_ν !

$\Rightarrow$ $M_\Delta > \sim 10^{10}$ GeV $\leftarrow$ FOR SUCCESSFUL LEPTOGENESIS

$\hookrightarrow$ FOR $m_\nu^{MAX} \sim \sqrt{\Delta m^2_{ATM.}}$ (AND M_Δ FEW TIMES LESS IF $m_\nu^{MAX} > \sqrt{\Delta m^2_{ATM.}}$)

- CASE $M_{N_1} << M_{\Delta_L}$: LEPTOGENESIS FROM $N_1 \to \ell + H^*$ FROM

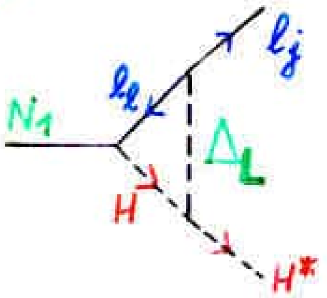
USUAL DIAGRAMS :



$$\varepsilon_{N_1} = \frac{3}{16\pi} \frac{M_{N_1}}{v^2} \frac{\mathrm{Im}\left[Y_{\nu_{1j}} Y_{\nu_{1\ell}} (\mathcal{M}_\nu^{I})_{j\ell}\right]}{|Y_{\nu_{1k}}|^2}$$

(FOR $M_{N_1} << M_{N_{2,3}}$)

AND THE ADDITIONAL DIAGRAM:



$$\varepsilon^{\Delta}_{N_1} = \frac{3}{16\pi} \frac{M_{N_1}}{v^2} \frac{\mathrm{Im}\left[Y_{\nu_{1j}} Y_{\nu_{1\ell}} (\mathcal{M}_\nu^{II})_{j\ell}\right]}{|Y_{\nu_{1k}}|^2}$$

O'DONNELL, U. SARKAR 94
LAZARIDES, SHAFI 98

T.H., SENJANOVIC 03
ANTUSCH, KING 04

$\Rightarrow$ TYPE 1 AND 2 CONTRIBUTIONS TO LEPTOG. $\propto$ RESPECTIVE $\mathcal{M}_\nu$

$\Rightarrow$ TYPE 2 E.G. DOMINATES LEPTOGEN. IF IT DOMINATES $\mathcal{M}_\nu$ AND TRIPLET DIAGRAM CAN LEAD TO LEPTOGEN. EASILY

$\Rightarrow$ IF $\mathcal{M}_\nu^{I}$ SMALL, INCREASING $\mathcal{M}_\nu^{II}$ LEADS TO LARGER $\varepsilon^{\Delta}_{N_1}$ WITH NO WASHOUT ! $\Rightarrow$ NO MORE m_ν UPPER BOUND

T.H., G. SENJANOVIC 03 $\Rightarrow$ $M_{N_1} \gtrsim 4 \cdot 10^8$ GeV $\leftarrow$ FOR $\begin{cases} m_\nu^{MAX} \sim \sqrt{\Delta m^2_{ATM}} \\ M_{N_1} << M_{N_{2,3}} \end{cases}$

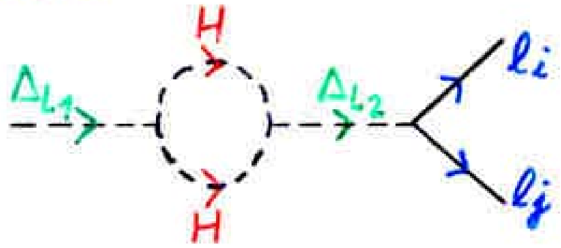
$\to$ M_{N_1} A FEW TIMES LESS IF $m_\nu^{MAX} > \sqrt{\Delta m^2_{ATM}}$

$\to$ TRUE ALSO FOR $\mathcal{M}_\nu^{I}$ LARGER $\leftarrow$ ANTUSCH, KING

LEPTOGENESIS WITH 2 OR MORE Δ_L

↳ SUCCESSFUL LEPTOGENESIS EASY (IN AGREEMENT WITH ν DATA)

FROM:



E. MA, U. SARKAR 98
T.H., E. MA, U. SARKAR 01

⇒ REQUIRES: • $M_{\Delta_{L_1}} > \sim 10^{10}$ GeV IF $M_{\Delta_{L_1}} \ll M_{\Delta_{L_2}}$

• $M_{\Delta_{L_1}} > \sim (10-100)$ TeV IF $M_{\Delta_{L_1}} - M_{\Delta_{L_2}} \sim \Gamma_{\Delta_{L_2}}$

⇒ NO RELEVANT UPPER BOUND ON m_ν.

LEPTOGENESIS WITH $3N_i$ AND EXTRA SINGLETS S_i

POSSIBLE IN SO(10) WITH SO(10) SINGLETS S_i AND $H_{\overline{16}}$

=> N_i AND S_i SOURCES OF ν MASSES (MULTIPLE SEESAW)

BARR 03; ALBRIGHT, BARR 03

=> LEPTOGENESIS SUCCESSFUL EASILY FROM DIAGRAMS SAME AS WITH TYPE 1 (WITH N AND S)

$\Downarrow$

GIVE MORE FREEDOM

$\Downarrow$

NO MORE m_ν UPPER BOUND HERE TOO

LEPTOGENESIS IN RADIATIVE MODELS OF m_ν

↳ m_ν FROM LOOP DIAGRAMS WITH EXTRA TeV PARTICLES

↳ MORE TESTABLE

- SUSY WITH $\cancel{R}$:

SEE E.G. VALLE ET AL., ...

↳ m_ν FROM: $W^{\cancel{R},\cancel{L}}_{MSSM} = \mu_i L_i H_2 + \lambda_{ijk} L_i L_j e^c_k + \lambda'_{ijk} L_i Q_j d^c_k$

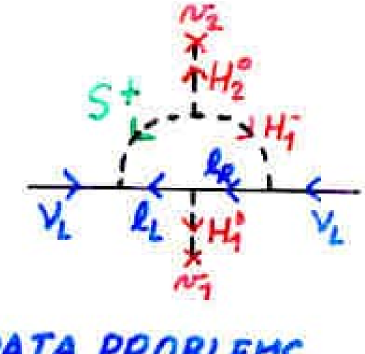
BILINEAR — TRILINEAR

↳ 2 BIG PROBLEMS FOR LEPTOGENESIS:

MA, RAIDAL, SARKAR 99
T.H., MA, SARKAR 00

- NO SINGLETS OF $SU(2)_L \times U(1)$ ⇒ GAUGE SCATTERINGS WASHOUT ALWAYS TREMANDOUS AT $T \sim$ TeV WHERE $H \sim \text{TeV}^2/M_{Pl}$ IS TINY
- NO RESONANT EFFECT

- ZEE MODEL : EXTRA SINGLET S^+: $m_\nu \sim$



T.H., 02

↳ SAME LEPTOG. PROBLEMS AS WITH $\cancel{R}$ + ν DATA PROBLEMS

↳ CAN BE CURED WITH EXTRA TeV N_i ⇒ 3 BODY DECAY LEPTOGENESIS

- **SEESAW EXTENDED MSSM : MSSM WITH 3 $N_i - \tilde{N}_i$**

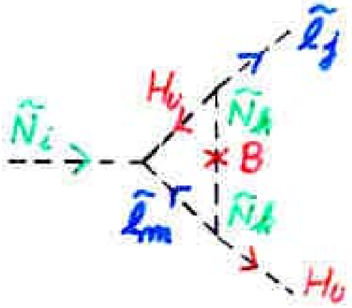
↳ OFFERS AN INTERESTING LOW SCALE LEPTOGENESIS ALTERNATIVE IF $M_{\tilde{N}_i} \sim 1-10$ TeV ← LOW B-L SCALE

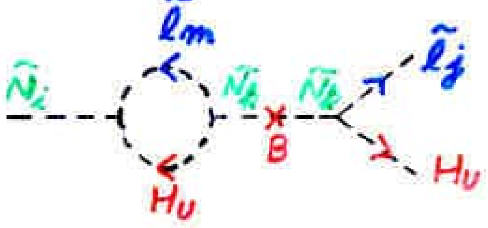
↳ $\mathcal{L}_{SOFT} \ni B_{ij} \tilde{N}_i \tilde{N}_j + A_{ij} \tilde{L}_i H_U \tilde{N}_j$

$\Uparrow$ $\tilde{N}_i$ $\Delta L=2$ EQUIVALENT OF N_i $\Delta L=2$ MAJORANA MASS TERM

$\Uparrow$ EQUIVALENT OF YUKAWA $N_i L H$ TERMS BUT FOR $\tilde{N}_i$

⇒ SIMILAR DIAGRAMS WITH $\tilde{N}_i$ INSTEAD OF N_i :





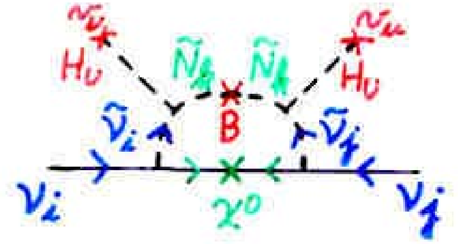
L. BOUBEKEUR, T.H., G. SENJANOVIC 04

$$\Rightarrow \quad \varepsilon_{\tilde{N}_i} \simeq -\frac{3}{8\pi} \frac{1}{M^2_{\tilde{N}_k}} \frac{1}{|A_{ji}|^2} \cdot Im\left[A_{mi} A_{ji} A^*_{mk} A^*_{jk} \frac{B_i}{M^2_{\tilde{N}_i}} \frac{B^*_k}{M^2_{\tilde{N}_k}}\right] \ldots$$

⇒ LEPTOGENESIS (ASYMMETRY + WASHOUT) SUCCESSFUL IF:

$$\left.\begin{array}{l} \bullet\ A_{jk} \sim 10^{-3} M_{\tilde{N}_k} \\ \bullet\ A_{ji} \sim 10^{-7} M_{\tilde{N}_i} \end{array}\right\} \Rightarrow \text{REQUIRES FLAVOR HIERARCHY OF } A_{jk}$$

MOREOVER: THE VALUES OF A_{ij} AND B_k LEADING TO SUCCESSFUL LEPTOGENESIS ALSO LEAD TO $m_\nu^{MAX} \sim (0.1-1)\,eV$ RADIATIVELY:



$\Rightarrow$ LOW SCALE TESTABLE MODEL OF BOTH ν MASSES AND LEPTOGENESIS FROM SAME INTERACTIONS

SUMMARY

- BESIDE THE USUAL N_i SEESAW MODEL THERE ARE QUITE A FEW ALTERNATIVES FOR ν MASSES AND LEPTOGENESIS, SEESAW OR EVEN RADIATIVE

- THE MASS BOUNDS ON ν AND OTHER PARTICLES INVOLVED ARE QUITE SENSITIVE TO THE ASSUMPTIONS MADE (MASS SPECTRUM...) AND TO THE MODEL CONSIDERED.