THEORETICAL IMPLICATIONS OF RECENT NEUTRINO DISCOVERIES

X

R. N. MOHAPATRA
INT WORKSHOP '99.

1. ν'S: DATA AND CONSTRAINTS.

2. 3 ν'S VRS. 3+1 ν'S

3. SEE-SAW, SUPERSYM. LEFT-RIGHT MODEL AND ν-MASSES

4. STERILE ν'S: MIRROR MATTER OR E_6-MATTER?

5. ARE MACHOS MADE OF MIRROR MATTER?

NOTATION

- ν'S $\equiv$ 2-COMPONENT SPINORS
- ν'S ARE MAJORANA PARTICLES.

Ex. 2 ν'S (ν_1, ν_2)

GENERAL MASS MATRIX : $\begin{pmatrix} A & C \\ C & B \end{pmatrix}$

SPECIAL CASES : (i) $A, B \ll C$ (PSEUDO-DIRAC)

(ii) $A = B = 0$ (DIRAC) $L(\nu_1) = -L(\nu_2)$

- COUNTING THE # OF ν'S :

N_ν = # OF 2-COMPONENT ν'S.

EXPERIMENTAL CONSTRAINTS ON $\mathcal{M}_\nu$

(i) SOLAR ν_e DEFICIT

4 EXPTS., NO ASTROPHYS. RESOLUTION.

$\Rightarrow$ $\nu_e \to \nu_x$ OSCILLATION

- **MSW** SOLN. (SMALL ANGLE). $x = \mu, \tau, s$
  $\Delta m^2_{\nu_e \nu_x} \simeq (5-7) \times 10^{-6}\ eV^2$ ↓
  $\sin^2 2\theta \simeq .003 - .015$
- LARGE ANGLE: $x = \mu, \tau$
  $\Delta m^2_{\nu_e \nu_\mu} \simeq 10^{-4} - 10^{-5}\ eV^2$ ↑
  $\sin^2 2\theta \simeq .8 - 1$
- VACUUM: $\Delta m^2 \simeq 10^{-10}\ eV^2$ ↑

(ii) ATMOSPHERIC ν_μ - DEFICIT

$\frac{\#\nu_\mu}{\#\nu_e} = 2$; ISOTROPIC EXPECTED

ZENITH ANGLE DEPENDENCE OBSERVED

$\Rightarrow$ $\nu_\mu \to \nu_x$ OSCILLATION !!

$\Delta m^2_{\nu_\mu \nu_e} \simeq (2-6) \times 10^{-3}\ eV^2$ SUPER-K

$\sin^2 2\theta \simeq .84 - 1$ ~~$\nu_\mu \to \nu_e$~~

$\nu_\mu \to \nu_\tau$ ↑ $\nu_\mu \to \nu_s$ ↓

(iii) LSND

OBSERVED e - EXCESS IN BOTH DAR AND DIF.

•• HARD TO UNDERSTAND AS $\mu^+ \to e^+ \bar{\nu}_e \nu_\mu$ DUE TO M-$\bar{M}$ ($\Delta(L+L) = 4$)

UPPER LIMIT (HERCZEG '97; BERGMANN, GROSSMAN '98)

$\Rightarrow \bar{\nu}_\mu \to \bar{\nu}_e$ OSCILLATION.

$\Delta m^2 \sim .2 - 10\ eV^2$

KARMEN 8 events - (DREXLIN, BEYOND 99 JUNE 99)

(BOONE ...)

THREE $\Delta m^2_{ij} \equiv m_i^2 - m_j^2$ DIFFERENT

$\Rightarrow$ AT LEAST 4 ν's

LEP-SLC $\Rightarrow N_\nu = 3 \Rightarrow \nu_s$.

(OTHER REASONS FOR ν_s : r-PROCESS NUC SYNTH, PULSAR VELOCITY)

iv) HOT DARK MATTER : (??)

IF SUPER-K IS $\nu_\mu - \nu_\tau$

$\Rightarrow \Omega_\nu \geq 0.002$

LSND ≥ 0.008

STRUCTURE WITH ΛCHDM $\Rightarrow \Sigma m_\nu \approx 1\ eV$??
(PRIMACK)

v) $\beta\beta_{0\nu}$ DECAY : (HEIDELBERG - MOSCOW) KLAPDOR et. al.

$$\langle m_\nu \rangle \leq .2\ eV - .4\ eV$$

$$\langle m_\nu \rangle = \sum_i U_{ei}^2\, m_{\nu_i} \equiv m_{\nu_e \nu_e}.$$

vi) CHOOZ

$$|U_{ei}|^2 \leq .05$$

FOR $\Delta m_{1i}^2 > 10^{-3}\ eV^2$

v) BIG BANG NUCLEOSYNTHESIS:

OLIVE, THOMAS '98
SARKAR REV.

$$N_\nu < 3.2 - 4 \quad (\text{EVEN } 5.3)$$

- DEPENDS ON He^4 ABUNDANCE, D. FROM QSO etc.

HAS IMPLICATIONS FOR MODELS WITH STERILE ν's:

$$\Rightarrow \quad |U_{\nu_s \nu_i}|^2 \lesssim 10^{-4} \qquad i = e, \mu, \tau$$

$$(\text{FOR } \Delta m^2_\nu \gtrsim eV^2).$$

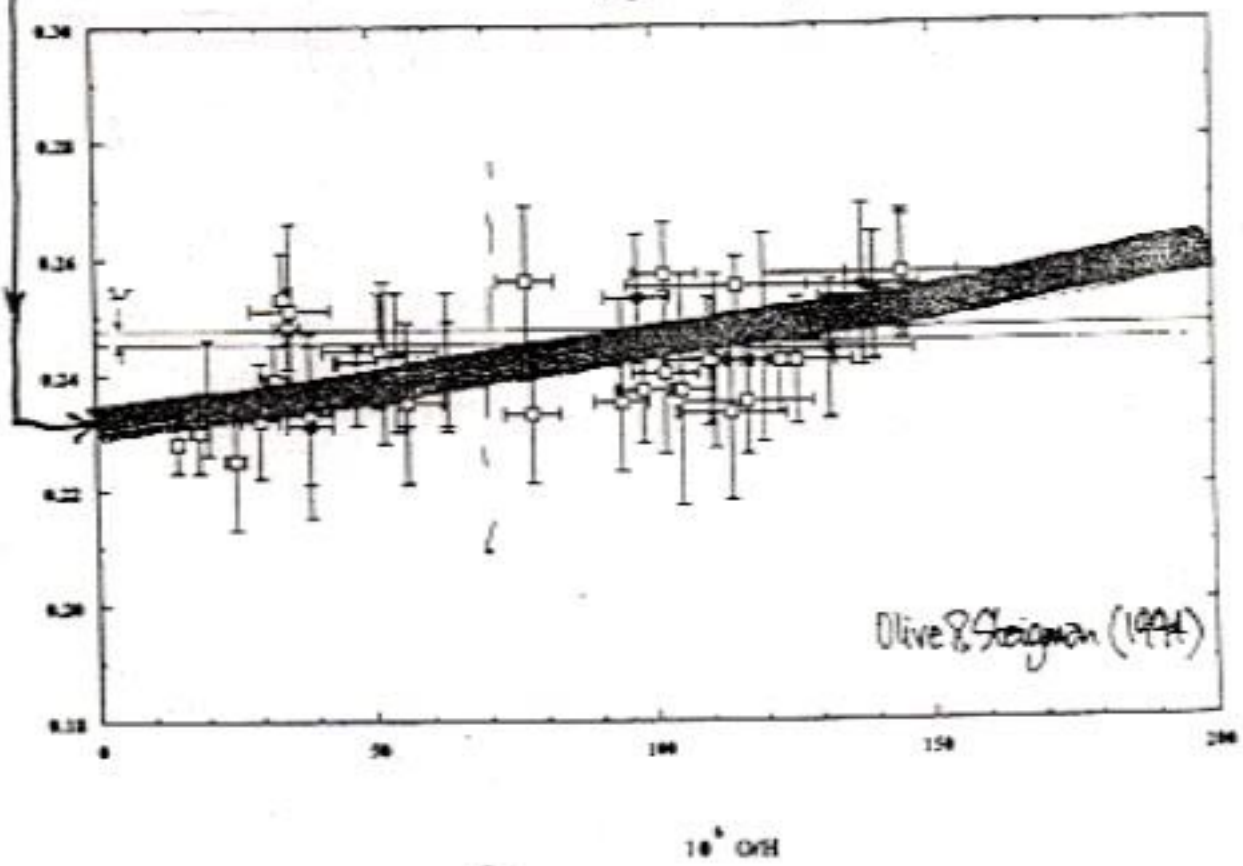
WAYS TO AVOID BOUND:

CHEM. POT. μ_ν SIGNIFICANT !!

$\nu_i - \nu_s$ OSCILLATION AS A POSSIBLE ORIGIN (FOOT, VOLKAS)

$Y_p = 0.232 \pm 0.003 \pm \Delta Y_{\text{systematic}}$

0.004	Skillman (priv. comm.)
0.005	Walker; Pagel; Olive & Steigman
0.006	Quantified here
0.015	Copi, Turner & Schramm



10^5 D/H

IMPLICATION FOR MASS PATTERNS:

1. $\nu_\odot + \nu_{ATM}$.

2. $\nu_\odot + \nu_{ATM}$ + HDM

CALDWELL, R.N.M '93

3. $\nu_\odot + \nu_{ATM}$ + LSND

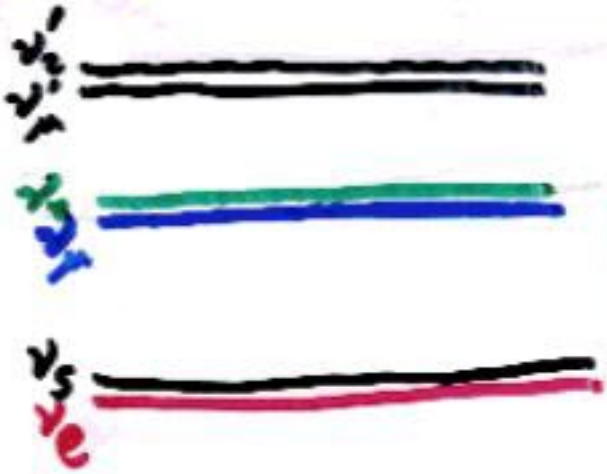
eV

SMA, 10^{-3} eV

CALDWELL, R.N.M '93
PELTONIEMI, VALLE '93.

GENERALIZATION TO THE MORE SYMMETRIC 6-ν SCHEMES:

(6-I)



ATM. $\nu_\mu \rightarrow$

SOLAR $\nu_e \rightarrow \nu_s$

BEREZHIANI, R.N.M '95

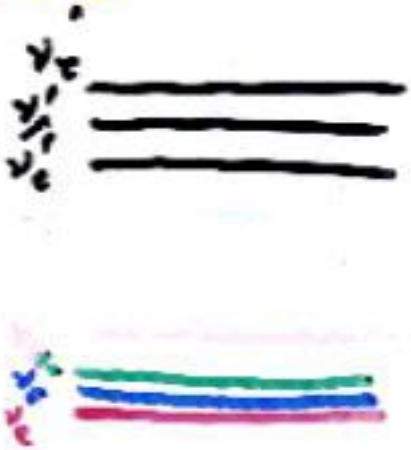
(6-II)

ATMOS. $\nu_\mu \rightarrow \nu_s'$

SOLAR $\nu_e \rightarrow \nu_e'$: VO

FOOT-VOLKAS '95

(6-III)



LSND INDIRECT.

BALATENKIN, FETTER, FULLER, MCGLAUGHLIN

⇒ BILENKY, GIUNTI, GRIMUS '96-99.
(V. BARGER'S TALK)

TESTING THE DEGENERATE ν- SCENARIO WITH $\beta\beta_{0\nu}$-DECAY + SOLAR ν'S : (ASSUME ~~LSND~~)

$$\langle m_\nu \rangle_{\beta\beta} = \sum_i U_{ei}^2 m_{\nu_i} \lesssim .2 - .4 \text{ eV}$$

FOR $m_{\nu_i} \simeq m_0 \gtrsim$ eV + CHOOZ

$$\Rightarrow U_{e1} \simeq U_{e2} \simeq \frac{1}{\sqrt{2}}$$

$\Rightarrow$ • ν_0 SOLN : MAXIMAL MIXING

OR

• $\beta\beta_{0\nu}$ WILL TELL US ABOUT THE UNIVERSE (i.e. REDUCE HDM COMPONENT).

e.g. MSW SMA $\Rightarrow \Omega_\nu \lesssim 1.6\%$

(FURTHER DISCUSSION, SEE KAYSER et. al. '99 BARGER et. al., VISSANI '96, '99; BILENKY et al. '98)

TESTS OF ν_s:

(i) SOLAR VIA $\nu_e \leftrightarrow \nu_s$: (A)

SNO: NEUTRAL CURRENT OBS. IMPORTANT.

$$\frac{\Phi_{cc}}{\Phi_{NC}} \simeq 1 \qquad \nu_e \to \nu_s$$

$$\simeq \frac{1}{2} \qquad \nu_e \to \nu_{\mu,\tau}.$$

(ii) ATMOSPHERIC $\nu_\mu \to \nu_s$: (B)

a. MATTER EFFECT AND $\left.\frac{U}{D}\right|_{P.C.}$

AT $\Delta m^2 = 3\times10^{-3}\,eV^2$, $\frac{U}{D} = .72$ EXPECTED

$= 0.50 \pm 0.12 \pm 0.01$ OBS.

b. $R\left(\frac{\pi^0}{e}\right) = \frac{(\pi^0/e)_{OBS}}{(\pi^0/e)_{MC}\cdot R}$ $= 1$ $X=\tau$

$= .67$ $X=s$

$$: R\left(\frac{\pi^0}{e}\right) = 1.11 \pm 0.06 \pm 0.02 \pm 0.26$$

(FAVORS $X=\tau$ AT 2σ)

SUPPOSE LSND CONFIRMED -
SNO FINDS $\nu_e \to \nu_{\mu,\tau}$ IN NC DATA.

⇒ ONLY ONE OSCILLATION SCENARIO WORKS:

HOWEVER BILENKY, GRIMUS, GIUNTI, SCHNETZ

⇒ INCONSISTENT WITH ATMOS. + CDHS + BUGEY (90%)

K2K, SUPER-K WILL DECIDE THIS

⇒ MUST ENTERTAIN DECAY SCENARIO FOR LSND !!

(ANOMALOUS μ-DECAY ??)

TWO CHALLENGES FOR THEORY :

1. $m_{\nu_{e,\mu,\tau}} \neq 0$ AND $\ll m_{l,q}$?

2. WHAT IS ν_s

AND HOW TO UNDERSTAND "ULTRALIGHTNESS OF ITS BEING" ?

• m_ν IN THE STANDARD MODEL:

$$SU(2)_L \times U(1)_Y .$$

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \qquad u_R \qquad d_R$$

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \qquad e_R$$

- B-L EXACT $\qquad T_\nu (B-L) G_i^2 = 0.$
- NO ν_R

$$\Rightarrow m_\nu = 0 .$$

PLANCK SCALE EFFECTS MAY BREAK ALL GLOBAL SYM.

$\Rightarrow \sim LHLH/M_{Pl} \Rightarrow m_{\nu_e} \sim 10^{-6}$ eV TOO SMALL !!

(WEINBERG '79)

• SIMPLEST KIND OF NEW PHYSICS

STD MODEL + ν_R

↓ ANOMALY EQN. $\mathrm{Tr}\,(B-L)^3 = 0$

⇒ LEFT-RIGHT SYM. THEORY

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

$$\vec{W}_L \qquad \vec{W}_R \qquad B$$

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix} \overset{P}{\longleftrightarrow} \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \overset{P}{\longleftrightarrow} \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$$

i) WEAK INT. CONSERVE PARITY

ii) QUARK-LEPTON SYM.

PUZZLES:

i) WHY WEAK INT. VIOLATE P AT LOW ENERGIES ?

ii) WHY $m_{\nu_e} \neq m_{q,e}$?

SYMMETRY BREAKING:

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_c$$

$$M_\nu = \begin{pmatrix} 0 & 0 \\ 0 & f v_R \end{pmatrix}$$

$$\downarrow \quad \langle \Delta_R(1,3,+2) \rangle \neq 0$$

$$SU(2)_L \times U(1)_Y \times SU(3)_c$$

$$M_\nu = \begin{pmatrix} 0 & m_{\nu D} \\ m_{\nu D} & f v_R \end{pmatrix}$$

$$\downarrow \quad \langle \phi(2,2,0) \rangle \neq 0$$

$$U(1)_{em} \times SU(3)_c$$

- $v_R \gg \langle \phi \rangle \Rightarrow$ LOW ENERGY WEAK INT. V-A TYPE.
- SEE-SAW FOR m_ν:

$$m_\nu \simeq \frac{m_{\nu D}^2}{f v_R} \ll m_{e,u,d}.$$

Gell-Mann, Ramond, Slansky
Yanagida; R.N.M., Senjanović '79.

TYPE II SEESAW

NEW.

I

$$m_{\nu_i} = f_i v_L - \frac{m_{\ell_i}^2}{f v_R}$$

WITH $v_L \sim \frac{\kappa_{WK}^2}{v_R}$

- TYPE I VRS TYPE II IN MODEL BUILDING:

I $\Rightarrow$ $m_{\nu_e} \ll m_{\nu_\mu} \ll m_{\nu_\tau}$

II $\Rightarrow$ NON-HIERARCHICAL ($f_i \sim 1$)

- TYPE II VALID IN MOST GUT MODELS.

MORE IMPORTANT:

m_ν PROBES THE SCALE OF W_R (PARITY BREAKING)

e.g.

SOLAR $\Rightarrow$ $m_{\nu_\mu} \sim 10^{-3}$ eV

ATMOS. $m_{\nu_\tau} \sim 10^{-1} - 10^{-2}$ eV

(IF $m_{\nu_e} \ll m_{\nu_\mu} \ll m_{\nu_\tau}$)

$\Rightarrow M_{W_R} \sim 10^{11} - 10^{12}$ GeV

CAN WE PREDICT DETAILS ? ($\frac{3}{6}$ m_ν; mixings)

$$M_\nu \simeq - M_D^T M_N^{-1} M_D$$

$M_D = ?$ 9 - PARAMETERS

$M_N = ?$ 6 - PARAMETERS.

BARYOGENESIS $\Rightarrow$ $M_{13}^N \simeq 0$; M_{12}^N SMALL; (5-PARAM.)

(GOLDBERG'S TALK)

HIGHER UNIFICATION HELPS !!

(i) $SO(10)$ $\Rightarrow$ Quark-Lepton unif.

$\Rightarrow$ $M_D \sim M_u$; M_N - ARBITRARY

5 INPUTS $\rightarrow$ 6 OUT PUTS.

SPECIFIC MINIMAL MODEL
(BABU, R.N.M '93)

M_D DETERMINED
$\Rightarrow$ ALL m_ν, MIXINGS PREDICTED !!
(RULED OUT BY ATMOS. DATA).

(ii) SUPERSYM. LEFT-RIGHT MODEL:
(BABU, DUTTA, RNM '92)

PREDICTS $M_D = M_\ell \cdot c$

5 - INPUTS $\Rightarrow$ 6 OUTPUTS.

(i) + (ii) PREDICT $\tau \rightarrow \mu\gamma$ AND $\mu \rightarrow e\gamma$!!

MODELS TESTABLE !!

SEE-SAW IN LR HAS OTHER ADVANTAGES

~~R_p, $\not{CP}$~~ BIG EMBARASSMENTS OF MSSM :

$$QLd^c,\ u^c d^c d^c,\ LLe^c$$

$$\Rightarrow\ \tau_p < \text{sec.}\quad \text{etc.}$$

LR + SUSY :

$$Q\quad Q^c\quad ,(L, L^c)$$

$$\Phi\ (2,2,0)$$

$$\Delta_L, \bar{\Delta}_L ; \Delta_R, \bar{\Delta}_R$$

$$W = Q\Phi Q^c,\ L\Phi L^c,\ LL\Delta + L^c L^c \Delta_R$$

- R-PARITY AUTOMATIC :
- SOLVES SUSY CP PROBLEM !!

CAN WE EVER TEST SUCH A HIGH SCALE FOR RIGHT-HANDED CURRENTS?

SOME POSSIBILITIES:

i) LEPTON FLAVOR VIOLATION:

a) Q-L UNIFICATION ($SU(4)_c, SO(10), \ldots$)

$\Rightarrow B(\mu \to e\gamma) \gtrsim 10^{-14}$

BARBIERI, HALL, STRUMIA; GOLDBERG, GOMEZ; DUTTA, DUONG, KEITH; ...

b) Q-L NON UNIFIC.

$B(\mu \to e\gamma) \lesssim 10^{-14}$

$B(\tau \to \mu\gamma) \simeq 10^{-8}$

(BABU, DUTTA, R.N.M)

ii) FOR SO(10), MODEL DEPENDENT SIGNATURES IN PROTON DECAY

(BABU, PATI, WILCZEK)

iii) TYPE II SEE SAW $\Rightarrow m_\nu \sim eV$'s

$\beta\beta_{0\nu}$, H^3-DECAY etc.

HOW DOES ν_s FIT INTO THE BIG GUT PICTURE ?

- WHY IS ν_s SO LIGHT ?
  (eV - milli-eV)

- ONLY SYMMETRIES CAN PROTECT MASSES FROM BEING LARGE (e.g. $m_e, m_q, \ldots$)

$\Rightarrow \nu_s \Rightarrow$ NEW SYMMETRIES BEYOND $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

COULD ν_S BE AN INDICATION OF E_6-GUT ?

(MA '96)

CHACKO, R.N.M. '99

$27 \supset 16 + 10 + 1$

ν_S ?

5 NEUTRAL FERMIONS:

$(\nu_L, \nu_R, \nu_S, \nu_E, \bar{\nu}_E)$

ASSUME $E_6 \xrightarrow[M.]{} G_{STD}$.

SEESAW:

TREE:

	$\nu_L^{1/2}$	ν_S°	ν_R°	$\nu_E^{1/2}$	$\bar{\nu}_E^{1/2}$
$\nu_L^{1/2}$	0	0	m_D	μ	0
ν_S°	0	0	0	m_1	m_2
ν_R°	m_D	0	M_0	0	0
$\nu_E^{1/2}$	μ	m_1	0	0	M_1
$\bar{\nu}_E^{1/2}$	0	m_2	0	M_1	0

$\Rightarrow M_0 \Leftarrow 27_m \times 27_m \times 351'_H$ OR $(27)^2(\overline{27})^2/M$

DIFFERENCE BETWEEN μ AND $m_{D,1,2}$

$m_{D,1,2} \propto \lambda_i$ (Yukawa Coupling)

$\propto m_{\ell_i}$

μ ARBITRARY $\sim V_{WK}$.

SEESAW

$$\begin{array}{c} \\ \nu \\ \nu_S \end{array} \begin{array}{c} \begin{array}{cc} \nu & \nu_S \end{array} \\ \begin{pmatrix} \frac{m_D^2}{M} & \frac{m_D \mu}{M} \\ \frac{m_D \mu}{M} & \frac{m_1 m_2}{M} \end{pmatrix} \end{array}$$

(i) $\Rightarrow$ $m_D \mu \gg m_D^2$ $\Rightarrow$ ν_i-ν_{S_i} FORM PSEUDO-DIRAC PAIR FOR EACH GEN.

$\Rightarrow$ BOTH $\nu_{ATM.}$ & $\nu_\odot$ USE MAXIMAL MIXING.

(ii) $\Delta m^2_{\nu_i \nu_{S_i}} \propto \lambda_i^3$

$\Rightarrow$ $\Delta m^2_{SOLAR} = \left(\frac{m_e}{m_\mu}\right)^3 \Delta m^2_{ATM} \approx 10^{-10} eV^2$

- A NATURAL EXPLANATION OF VO SOLUTION FOR SOLAR ν'S;
- NATURAL EXPLANATION OF MAXIMAL MIXING FOR ν_{ATM}.

TESTABLE!!

THE STERILE NEUTRINO

IDEA: ν_s: A PARTICLE FROM THE MIRROR UNIVERSE

- OLD IDEA — LEE, YANG; NISHIJIMA } 60's. KOBZAREV, OKUN, ZELDOVICH

- REENERGIZED BY SUPERSTRINGS:

  $E_8 \times E_8'$

  OR TWO SETS OF D-BRANES, M-THEORY etc.

MIRROR UNIVERSE

THEORY OF THE STERILE NEUTRINO:

×

(BEREZHIANI, R.N.M. '95)
FOOT, VOLKAS '95

OUR WORLD	MIRROR WORLD
$W^{\pm}, Z, \gamma, \ldots$	$W^{\pm\prime}, Z', \gamma', \ldots$
$u, d, e, \nu \ldots$	$u', d', e', \nu', \ldots$

SCALE ASYMMETRY:

$$m_{W'} \simeq 30\, m_W$$

$$m_{q',l'} \simeq 30\, m_{q,l} \quad (l' \neq \nu')$$

ν_e, ν_μ, ν_τ $\qquad$ $\nu_e', \nu_\mu', \nu_\tau'$

$B-L \Rightarrow m_{\nu_i} = 0$ $\qquad$ $B'-L' \Rightarrow m_{\nu_i'} = 0$.

THE TWO WORLDS COMMUNICATE ONLY GRAVITATIONALLY !!

GRAVITY ALSO BREAKS GLOBAL B-L.

$\Rightarrow$ ν - MASSES & MIXINGS:

$$\frac{(LH)^2}{M_{Pl}}, \quad \frac{LH \cdot L'H'}{M_{Pl}}, \quad \frac{(L'H')^2}{M_{Pl}} \Rightarrow \frac{m_{\nu'}}{m_\nu} = \frac{V'^2_{WK}}{V^2_{WK}}.$$

MSW SOLN. $\Rightarrow$ $\langle H' \rangle / \langle H \rangle \simeq \zeta$

$$\frac{V^2_{WK}}{M_{Pl}} \begin{pmatrix} & \nu_e & \nu_s \\ & 1 & \zeta \\ & \zeta & \lambda\zeta^2 \end{pmatrix}$$

(i) $\lambda \sim 1$; $\zeta \sim 30$ $\Rightarrow$ MSW SMALL ANGLE

(ii) $\lambda \sim \frac{1}{10}$, $\zeta \sim 10\text{-}15$ $\Rightarrow$ VACUUM OSC.

ν_μ, ν_τ MASSES ARISE FROM GUT PHYSICS :

$$m_{\nu_\mu, \nu_\tau} \sim .1 - 2 \text{ eV}$$

$$m_{\nu'_\mu, \nu'_\tau} \sim .1 - 1 \text{ keV}$$

$\nu_{\mu',\tau'}$ VERY WEAKLY MIXED WITH $\nu_{\mu,\tau}$:

SINCE : $\theta_{\nu\nu'_{\mu,\tau}} \sim \dfrac{\delta_{\nu\nu'}}{m_{\nu'}} \lesssim 10^{-5}$

GOOD FOR NUCLEOSYNTHESIS.

QUESTIONS

(i) BBN CONSTRAINT

$\epsilon = 10^{-3}$ $\Rightarrow$ $\nu_e', \nu_\mu', \nu_\tau'$ DECOUPLE ABOVE $T \gtrsim 200$ MeV

$\Rightarrow$ $\delta N_\nu \approx .3$.

$\gamma' + e^+ e^-$ ' ANNIHILATION

POSTULATE ASYMMETRIC INFLATION.

KOLB, SECKEL, TURNER '85

HODGES '85

BEREZHIANI, DOLGOV, R.N.M. '95

(ii) WHAT IS THE MIRROR UNIVERSE LIKE ?

$\Lambda'_{QCD} = ?$

$\Lambda'_{QCD} \simeq 30\, \Lambda_{QCD}$ R.N.M., TEPLITZ '98

$\frac{B'}{B} \sim 30 \Rightarrow B' \simeq 240\,MeV$

e.g. $m_{p'} \sim 30\,GeV$

$m_{n'} \sim 30.1\,GeV$

- $\frac{n_{B'}}{n_B} \sim \frac{1}{10}$ (ASYM. INFLATION)

$\rho_{B'} \simeq 3\rho_B \Rightarrow \Omega_{B'} + \Omega_B \simeq .3$

$\Rightarrow$ MIRROR BARYON CAN BE CDM.

$\Omega_{TOT} = \Omega_m + \Omega_\Lambda = 1.$

$.3 + .7$

TESTING THE MIRROR UNIVERSE IDEA

⇒ MIRROR GLOBS ;

MICROLENSING ..
MACHO, EROS, OGLE

A POSSIBLE CRISIS ?

C. ALCOCK et. al. $M_{MACHO} = (.5\ ^{+0.3}_{-0.2})M_\odot$

ARE THEY SENILE WHITE DWARFS ?

⇒ LONGER t_U , GENERALLY HARD TO ACCOMODATE ... (FIELDS, FREESE, GRAFF '98)
- CARBON PROBLEM ...
$\Omega_{MACHO} \approx \Omega_B$

⇒ MACHOS ARE MIRROR BLACK HOLES:

WHY ? SCALING LAWS FOR STARS:

$$m_{e'} = \zeta\, m_e$$

$$m_{p'} = \zeta\, m_p$$

HOW DO STELLAR PARAMETERS CHANGE ?

1. $$M^{\odot'}_{max}(\text{MIRROR}) = A\,\frac{M_{Pl}^3}{m_{p'}^2} = \zeta^{-2} M^{\odot}_{max.}$$

$$M^{\odot}_{max} \sim (70 - 100)\, M_\odot$$

$$\Rightarrow \zeta \sim 15, \qquad M^{\odot'}_{max} \sim \tfrac{1}{2} M_\odot$$

($\approx$ MACHO MASS)

2. **MAIN SEQUENCE LIFE TIME :**

$$t_{MS} \sim \frac{0.1\, M}{L}$$

$$L \sim 4\pi R^2 \sigma_{SB} T_s^4$$

T_s = SURFACE TEMP.

COMPARING STERILE ν MODELS:

	$N_\nu^{TOT.}$ IN BBN	TESTS
E_6	6	$\nu_\odot$: $\nu_e \to \nu_{se}$ VO ν_{ATM} : $\nu_\mu \to \nu_{sM}$
SYM. MIRROR MODEL (FV) ($v_{WK} = v'_{WK}$ $\Lambda_{QCD} = \Lambda'_{QCD}$)	9.2 (MUST GENERATE $\mu_\nu^{CHEM.}$)	» + DUPLICATE UNIVERSE.
ASYM. MIRROR MODEL (BM) ($v_{WK} \simeq v'_{WK}/20$ $\Lambda_{QCD} \simeq \Lambda'_{QCD}/20$)	6.2 (SOLVED BY ASYM. INFLATION)	$\nu_\odot$: SMA MSW OR LMA MSW(?) $\nu_{ATM.}$ $\nu_\mu \to \nu_\tau$ + PROVIDES DARK MATTER MACHO's ⋮

CONCLUSION

0. $m_\nu \neq 0 \Rightarrow \nu_R \Rightarrow$ LEFT-RIGHT SYM. OF NATURE.

1. SOLAR, ATMOSPHERIC AND LSND RESULTS CANNOT BE UNDERSTOOD SIMULTANEOUSLY WITHOUT A "STERILE" NEUTRINO : (ν_s)

2. THERE MAY BE OTHER HINTS FOR ν_s FROM ASTROPHYSICS
   (SN NUCLEOSYNTHESIS, PULSAR VELOCITY, ...)

3. E_6 THEORY FOR $\nu_s \Rightarrow$ VO FOR SOLAR, ...

4. A PLAUSIBLE THEORY IS THE MIRROR UNIVERSE THEORY:

5. COULD MIRROR BARYONS BE CDM?
   COULD MACHOS BE MIRROR STARS?