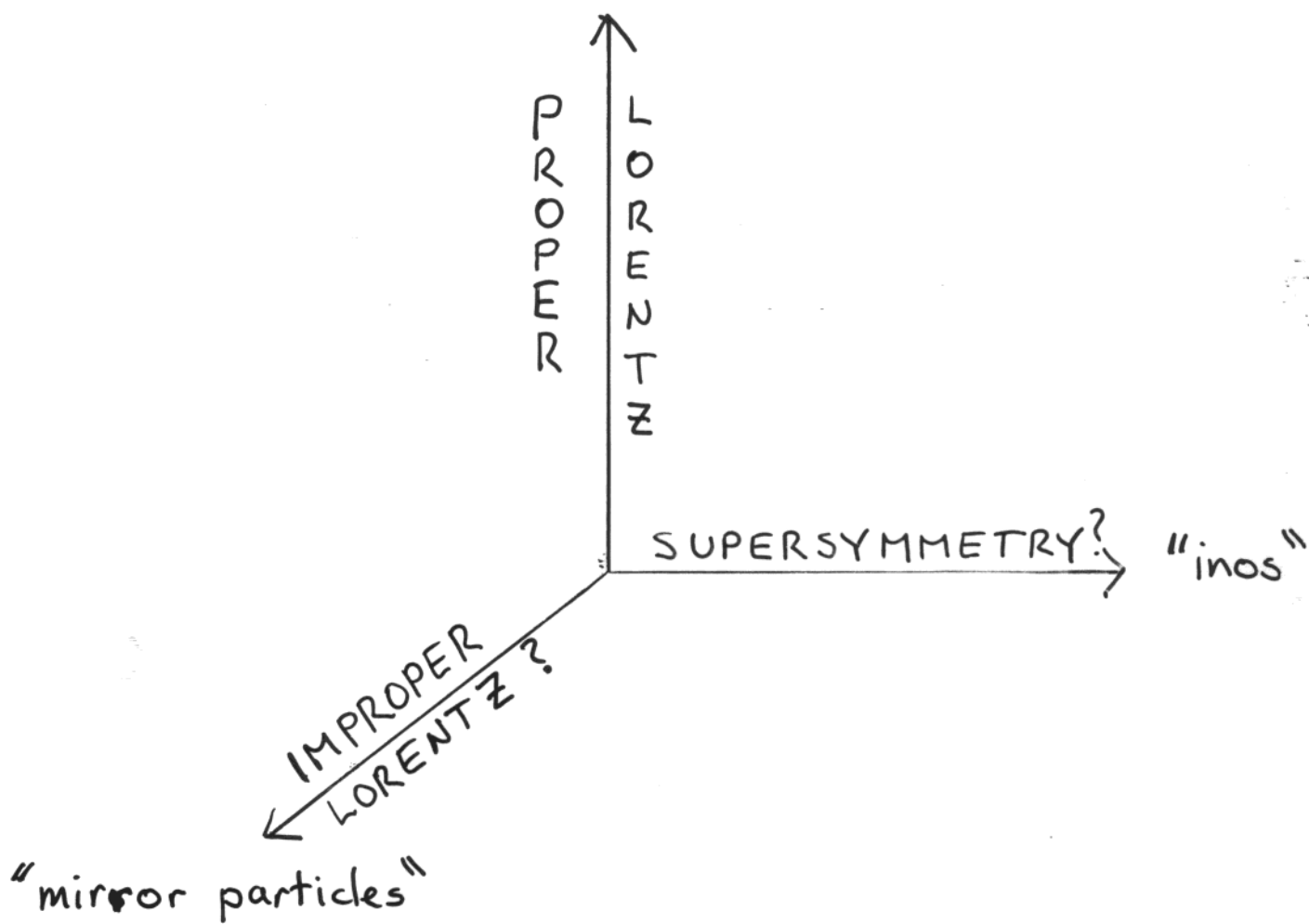# Neutrino Physics and the Mirror World

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1. Exact Improper Lorentz Group

2. Mirror Neutrinos: Phenomenology

3. Cosmology – BBN

4. Conclusion

1. EXACT IMPROPER LORENTZ GROUP

PROPER LORENTZ

SUPERSYMMETRY? → "inos"

IMPROPER LORENTZ ?

"mirror particles"

The red route offers a
solution to all of the ν anomalies
via ordinary – mirror ν oscillations
(LSND $\nu_e - \bar{\nu}_\mu$ of course)
in a cosmologically consistent way.

Take parity non-invariant Lagrangian,
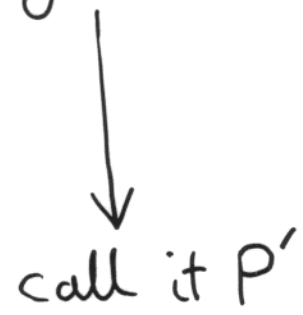
$$\mathcal{L}_1$$

with gauge group G & reps. R,

ADD

its parity transform

$$\mathcal{L}_2$$

with isomorphic gauge group G' &
same reps. R.

Then $\mathcal{L}_1 + \mathcal{L}_2$ new parity-invariant
$G \otimes G'$ gauge theory.

call it P'

$$\mathcal{L} = \mathcal{L}_1 + \mathcal{L}_2 + \mathcal{L}_{int}$$

non-gravitational P invariant interactions between ordinary and mirror sectors.

Very important to test the idea.

Responsible for solar and atmospheric ν anomalies ??

Note: define T' via $CPT = P'T'$

⟹ T' also an invariance

⟹ Full improper Lorentz Group
(Foot, Lew, RV - 1990)

Lee & Yang; Kobzarev, Okun & Pomeranchuk; Glashow; Berezhiani & Mohapatra (broken P') & others...

2. MIRROR NEUTRINOS: PHENOMENOLOGY

Extend $(\text{Minimal SM}) + (\text{Minimal SM})'$

by introducing nonzero ν mass.

$$\nu_e \longleftrightarrow \nu_e'$$

$$\nu_\mu \longleftrightarrow \nu_\mu'$$

$$\nu_\tau \longleftrightarrow \nu_\tau'$$

$$P'$$

MNS

Take inter-family/mixing to be small:

- like quark sector

- LSND

<u>model-independent</u> <u>result</u>:

If MNS mixing $= 0$, then

$$\nu_{\alpha \pm} = \frac{\nu_\alpha \pm \nu_\alpha'}{\sqrt{2}}$$

are the mass eigenstates (states of definite Parity).

$$\begin{pmatrix} \nu_\alpha \\ \nu_\alpha' \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \nu_{\alpha+} \\ \nu_{\alpha-} \end{pmatrix}$$

" maximal $\nu_\alpha - \nu_\alpha'$ mixing "

Remarkably, the atmospheric ν results point to ν_μ being maximally mixed with something, PERHAPS ν_μ' ?

explicit model?

Need reason for ordinary ν's to be so light — see-saw mechanism is simple, plausible, generic possibility.

Then, by Exact Parity, the same mechanism operates in mirror world.

Note: $m_{\nu_{\alpha+}} \neq m_{\nu_{\alpha-}}$ in general

$$\Rightarrow \quad \Delta m_\alpha^2 = \left| m_{\nu_{\alpha+}}^2 - m_{\nu_{\alpha-}}^2 \right| \neq 0$$

is a free parameter

The Exact Parity Model is, in part, an explicit theory of light, effectively sterile, neutrinos which are pairwise maximally-mixed with ordinary neutrinos.

Atmospheric anomaly:

EPM $\Rightarrow$ due to $\nu_\mu \longrightarrow \nu'_\mu$

- mixing angle predicted and correct

- Δm^2_μ free; constrained to

  be $\sim 10^{-3} - 10^{-2}$ eV^2

  (Foot; Foot & RV)

Vital experimental issue:

$$\nu_\mu \longrightarrow \nu_\tau \quad \text{or} \quad \nu_\mu \longrightarrow \nu_s \, (\overset{?}{=} \nu'_\mu) \, ?$$

(Akhmedov, Lipari & Lusignoli
Liu & Smirnov)

Super K: neutral current vs.
charged current

$\frac{\pi^\circ}{e}$ ratio

π° up-down asymmetry

(Diwan & Goldhaber)

Solar anomaly:

Outcome depends on parameter space region.

A) Interfamily mixing small; not in MSW region

$\nu_e \rightarrow \nu_e'$ maximal oscillations:

"just-so" for $\Delta m_e^2 \sim 10^{-11}, 10^{-10}\, eV^2$

or

averaged for $\Delta m_e^2 \gg 10^{-10}\, eV^2$

$\Rightarrow$ energy-independent 50% flux reduction

(Foot, Lew, RV)

B) $\nu_e \rightarrow \nu_e'$ + MSW interfamily transitions

(RV, Wong)
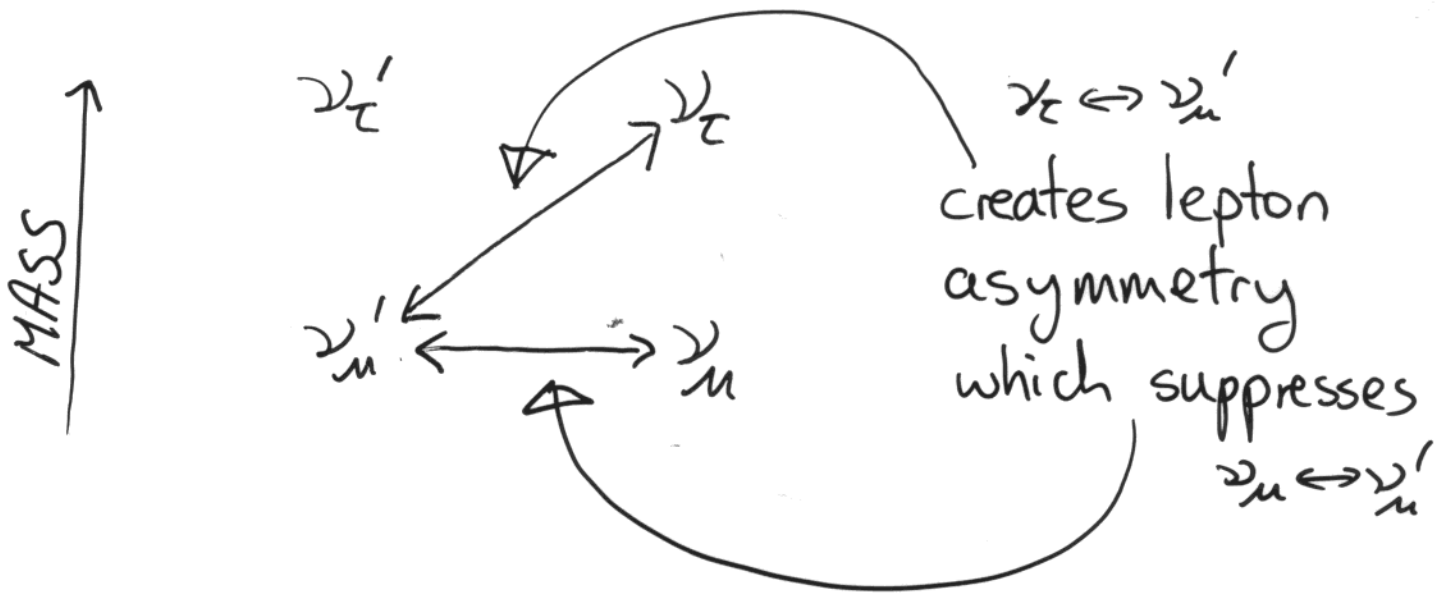
c) MSW interfamily only (not attractive in this context)

(RV + Wong, similar to Liu & Smirnov)

LSND anomaly:

Trivially accounted for through $\nu_e - \nu_\mu$ mixing in appropriate parameter space region

(Foot & RV)

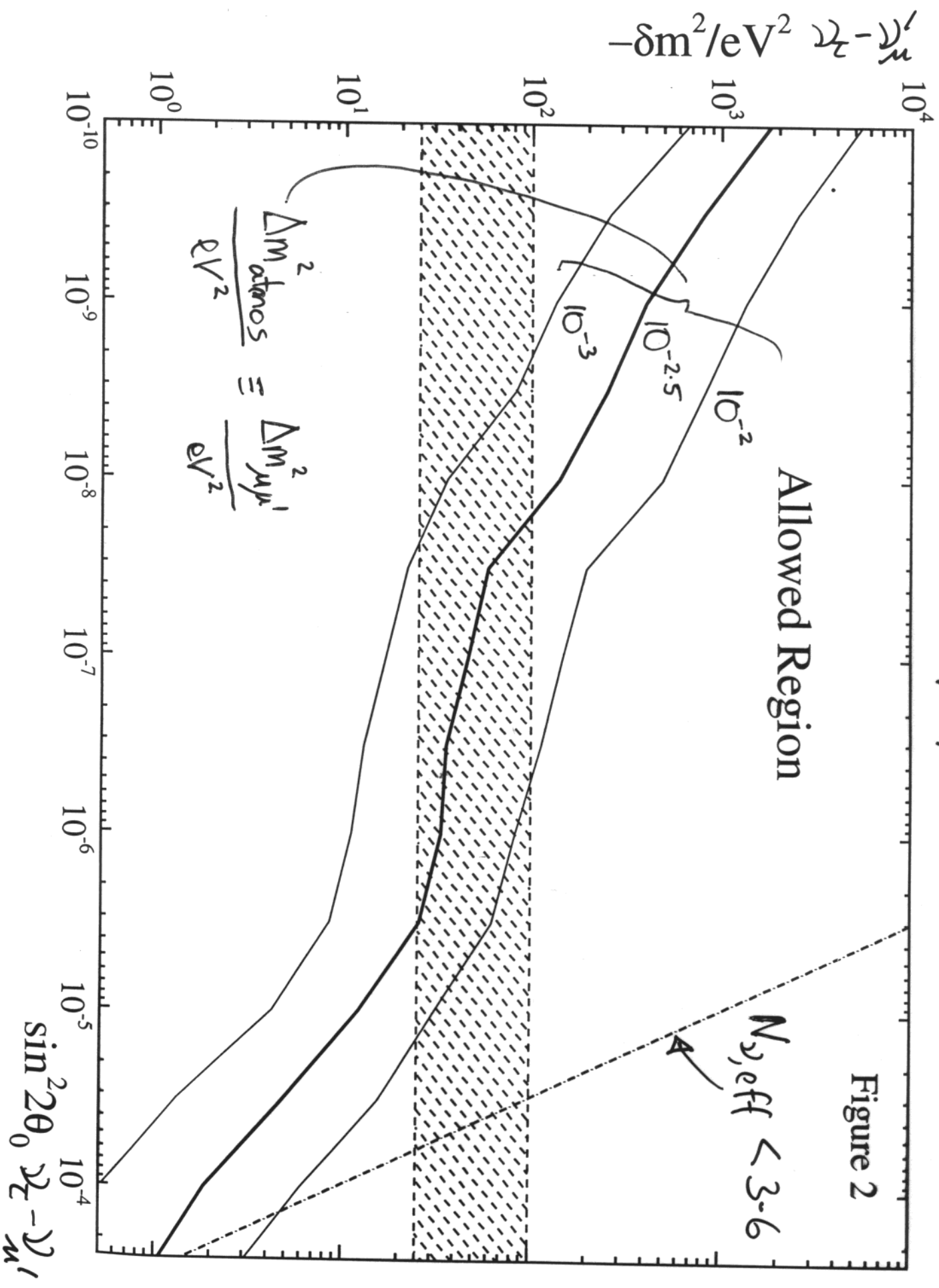# 3. COSMOLOGY - BBN

ν_τ'

ν_τ

ν_μ' $\longleftrightarrow$ ν_μ

$\nu_\tau \Longleftrightarrow \nu_\mu'$
creates lepton asymmetry which suppresses $\nu_\mu \Longleftrightarrow \nu_\mu'$

MASS

(Foot & RV, in preparation)

Foot f RV, in preparation

Figure 2

$$\frac{\Delta m^2_{atmos}}{eV^2} \equiv \frac{\Delta m^2_{\mu\mu'}}{eV^2}$$

Allowed Region

$N_{\nu, eff} < 3-6$

$-\delta m^2/eV^2$

$\sin^2 2\theta_0$

4. CONCLUSIONS

- EPM is an explicit theory of three light, effectively sterile, neutrinos

- Atmospheric anomaly: $\nu_\mu \longrightarrow \nu_\mu'$
  maximal mixing predicted

  $\longrightarrow$ need NC measurement

- Solar anomaly: A) $\nu_e \longrightarrow \nu_e'$ maximal mixing
  just-so or averaged

  $\longrightarrow$ SNO NC
  $\longrightarrow$ check greater mid-energy suppression
  (Iodine, Borexino)
  $\longrightarrow$ seasonal variation or not
  $\longrightarrow$ high E SK events ??
  $\longrightarrow$ composition of low E flux (HERON etc.)
  B) $\nu_e \longrightarrow \nu_e'$ + MSW

- Interesting cosmology: $\nu\bar\nu$ asymmetry, BBN, mirror stars as MACHOs, HDM, MAP & PLANCK