Neutrino Stream Summary Talk

theory + $\beta\beta_{0\nu}$ - Ray Volkas

experiment - J J Gomez

THEORY

We would like to understand:

* how ν's fit into our understanding of fundamental particle interactions (SM or extension thereof)

  FLAVOUR PROBLEM

* consequences of ν mass, mixing, oscillations for astrophysics

  SN EXPLOSION DYNAMICS

  HEAVY ELEMENT NUCLEOSYNTHESIS

  ν ASTRONOMY

* same for cosmology

  BIG BANG NUCLEOSYNTHESIS

  LARGE SCALE STRUCTURE

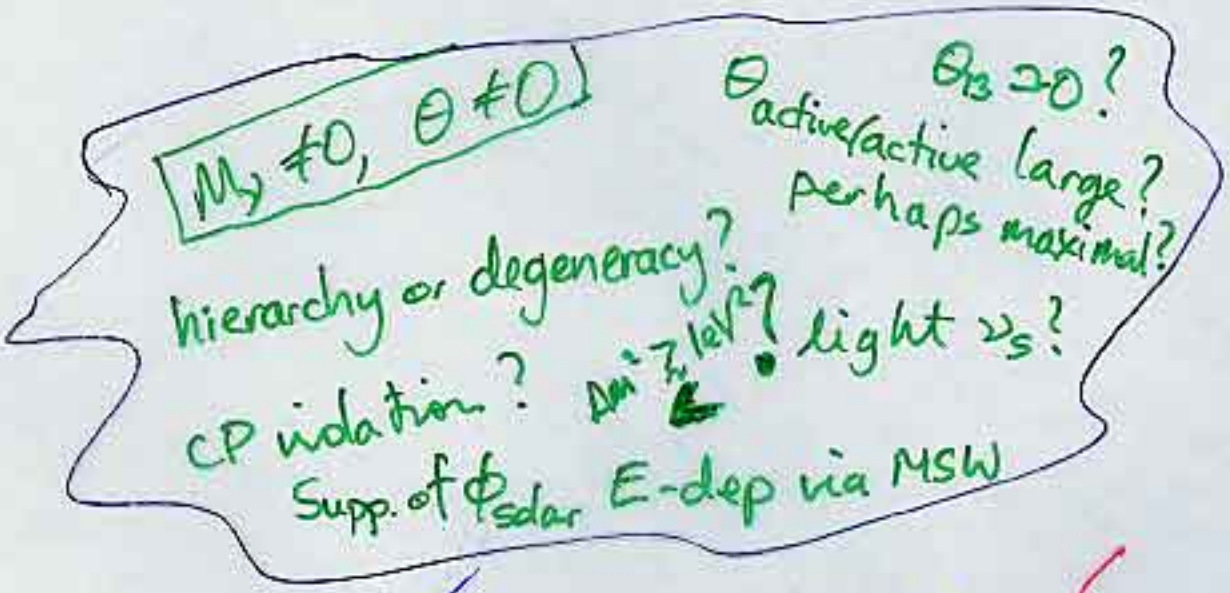
  CMBR IMPRINTS?

  LEPTOGENESIS

Flavour Problem

Theorists need to know what they have to explain

→ more & better experiments!



ν_s ✗

ν_s ✓

What are the masses & mixing angles?

WHY ν_s, and why is it (are they?) light?

THEORY OF FLAVOUR

astro + cosmo

Is there a light ν_s ?

- MINI BOONE [Conrad]
- MORE/DIFFERENT SNO DATA [Robertson]
- LBL CHECK OF $\nu_\mu \to \nu_\tau$

We wait and see.

In the meantime ...

"Fully sterile" ν_s – singlet under all gauge groups known & unknown – $M\overline{(\nu_s)^c}\,\nu_s$ bare term – M can be anything, not necessarily small.

"Weakly sterile" ν_s – G_{SM} singlet – $G_{>SM}$ non-singlet

- GUTs etc, M_{ν_s} is large
- mirror matter models, $m_{\nu'} \sim m_\nu$, hence light [Mohapatra talk]

Note: $G_{mirror} = G_{SM} \otimes G'_{SM}$,

so Origin of $\nu_s \leftrightarrow$ Increased symmetry

[Mohapatra]

By the way, discovery of ν_s (ν_s's) would be like discovery of charm or tau $\rightarrow$ new fundamental d.o.f.('s)

ν parameters & the Flavour Problem

* ν's are special: neutral & light

see-saw mechanism connects these two peculiarities:

$$\begin{bmatrix} \bar{\nu}_L & \overline{(\nu_R)^c} \end{bmatrix} \begin{bmatrix} 0 & m_{EW} \\ m_{EW} & M \end{bmatrix} \begin{bmatrix} (\nu_L)^c \\ \nu_R \end{bmatrix}$$

L conserving

L-violating

$M \gg m \Rightarrow$

$m_{\nu,light} \simeq \frac{m_{EW}^2}{M}$

If correct, then M is a new and very high energy scale in nature e.g. many people like GUTs,
[Wetterich, Shafi talks]

but smaller SM extensions such as LR sym. models also possible
[Mohapatra]

$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$ $\begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$ ← new d.o.f.

$SU(2)_L$ $SU(2)_R$

$M \sim M_{GUT}, M_{LR}$, etc.

Increased symmetry again!

* ν's have large angle mixing

- ATM ν $\Rightarrow$ $\sin^2 2\theta_{atm} \simeq 1$ [SK]
- undistorted ^8B spectrum
  $\Rightarrow$ $\sin^2 2\theta_{solar}$ large [SK+SNO]

$\rightarrow$ very different from quark sector

WHY?

$$M_{\nu,\,light} \simeq - m_{EW} M_R^{-1} m_{EW}^T$$

c.f. $m_{quark} = m_{EW}$

looks different!

[Wetterich]

(also "induced triplet" contribution possible for ν's)

If only it was $\nu_e \to \nu_s$
$\nu_\mu \to \nu_s'$

then the mirror matter model (Melbourne version) would have provided an elegant explanation for pairwise maximal mixing

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

I'll keep it in my back pocket!

back to main story:

* Is there a predictive theory that simultaneously explains the quark & lepton flavour data? [Wetterich]
* Are new symmetries involved? [Mohapatra, Wetterich]
* Something more radical? [Shafi]
* Is there leptonic CP? [Kayser, Yasuda]

* Is the "default option" [Ellis] —

○ near bimaximal mixing [Mohapatra]

$$U = \begin{pmatrix} c & s & \text{small} \\ \frac{s}{\sqrt{2}} & -\frac{c}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{s}{\sqrt{2}} & -\frac{c}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{pmatrix}$$

correct?

Some important issues:

○ * Is $\theta_{atm} = \frac{\pi}{4}$ exactly or not? [Para, Casper, Zuchelli]

if YES → look for symmetry

if NO → well...

$\sim \theta_{quark}$

$\sin^2 2\theta = 1 - \varepsilon$ [Wetterich]

○ * Exact (e.g. Melb. mirror matter)

versus

Spontaneously broken (e.g. gauged horizontal syms.) [Wetterich]

versus

○ Approximate (e.g. $L_e \mp L_\mu - L_\tau$) [Mohapatra]

All the above have historical precedents:

- Exact → $SU(3)_c \otimes U(1)_Q$
- Spon. br. → $SU(2)_L \otimes U(1)_Y$
- Approx. → $SU(3)$, etc.

Gell-Mann – Neeman

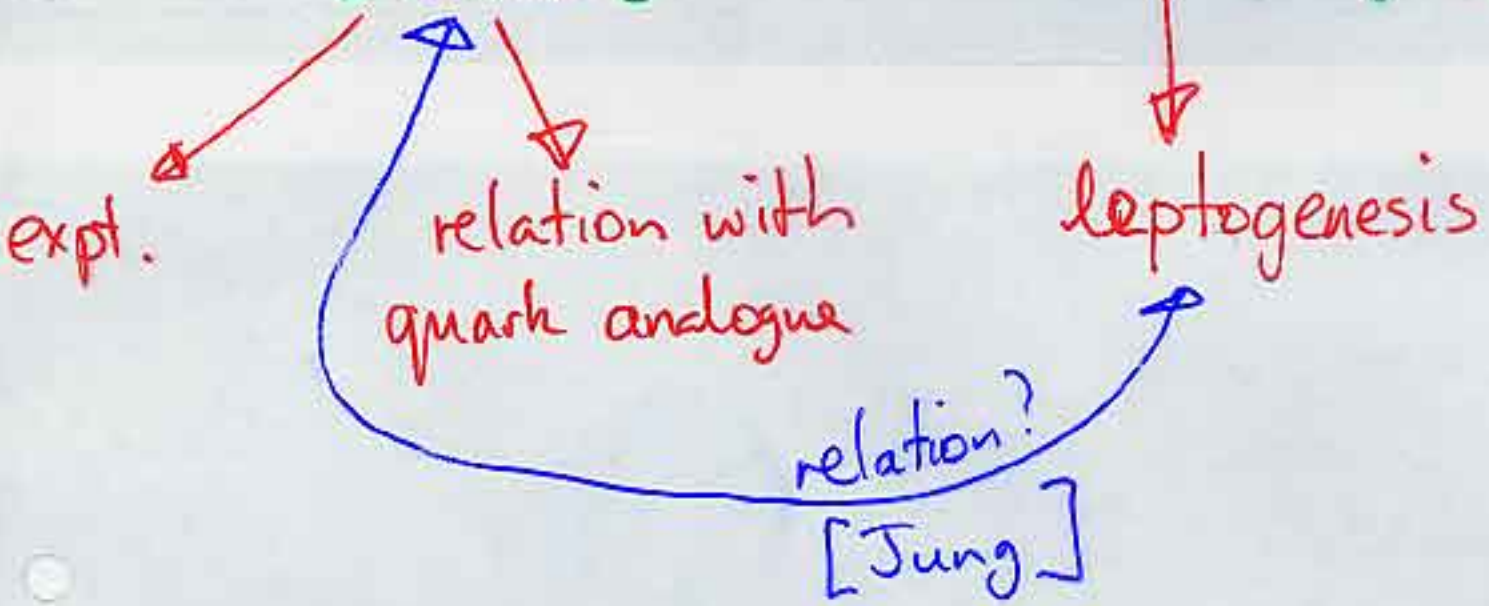
* θ_{13} & connection b/w solar & atmospheric solutions

[e.g. $\theta_{13} \sim \Delta m^2_{SUN} / \Delta m^2_{ATM}$, Mohaptra]

* CP violation?

MNSP phase, Majorana phases

[Yasuda] [Kayser]



* Dirac or Majorana? and Absolute Scale?

usual see-saw ⇒ Majorana

dominant theoretical prejudice

But, Dirac certainly possible

→ modified see-saw

→ extra dimensions [Shafi]

experimental test : $\beta\beta_{0\nu}$ [Vogel]

$M_\nu \sim \sqrt{\Delta m^2_{ATM}} \sim 0.05$ eV established

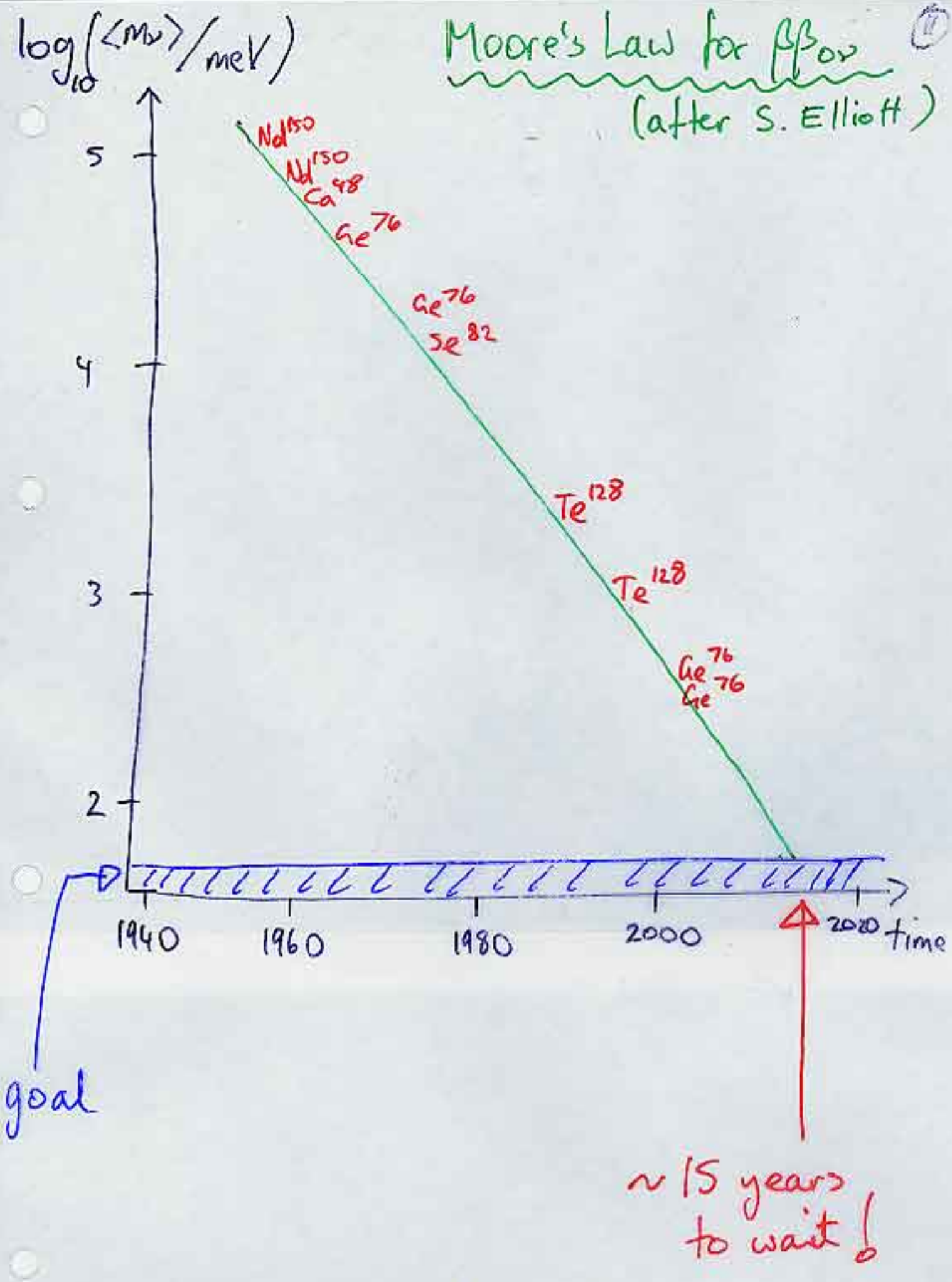
Can $\beta\beta_{0\nu}$ reach this sensitivity?

$(Z, A) \rightarrow (Z+2, A) + 2e^-$

$\Delta L = 2$ process

Moore's Law for $\beta\beta_{0\nu}$

(after S. Elliott)



$$\langle m_\nu \rangle \equiv \sum_i |U_{ei}|^2 m_i e^{2i\delta_{ei}}$$

go to 1 ton sources.

Many proposed experiments:

CAMEO, CANDLES, CUORE, EXO, GEM, GENIUS, GSO, Majorana, MOON

Something like the required sensitivity seems possible.

[Recent Klapdor-Kleingrothaus, Dietz, Harney, Krivosheina paper — majority opinion is that several important questions about the analysis require answers unavailable in the present paper.]

CONCLUSIONS

- Settle degree of freedom identification
  $\nu_s \longleftrightarrow$ mirror matter ?

- Is $\sin^2 2\theta_{ATM} = 1$ or merely large?
  $\theta_{13} = ?$ CP ?

- Flavour Problem & Symmetry
  Exact
  Spontaneously broken ??
  Approximate
  → echo of something more fundamental

- Reason for hope re $\beta\beta_{0\nu}$