Happy Birthday Keh-Fei



• I wish you to be as rich as the golden pig

Gold	Venus
Wood	Jupiter
Water	Mercury
Fire	Mars
Earth	Saturn



 $\frac{10 \times 12}{2} = 60$ 1 A
2 B
3 C

• And live as long as the turtle



The Strange World of Neutrino Mixing

C.S. Lam

McGill and UBC

CSL, hep-ph/0104116, Phys. Lett. B507 (2001) 214 CSL, hep-ph/0606220, Phys. Lett. B640 (2006) 260 CSL, hep-ph/0611017, Phys. Rev. D74 (2006) 113004 CSL, ? Quark Mixing is small

Neutrino Mixing is large

Is Nature trying to tell us that neutrino is special?

Neutrino

Fogli et al. Harrison, Perkins, Scott

Solar
$$s_1^2 = 0.314 (1_{-0.18}^{+0.18})$$

atmospheric $s_2^2 = 0.44 (1_{-0.22}^{+0.41})$
reactor $s_3^2 = 0.9_{-0.9}^{+2.3}$
 $V_1 \quad V_2 \quad V_3$
 $V_e \quad V_e \quad U = \frac{1}{\sqrt{6}} \begin{pmatrix} 2 & \sqrt{2} & 0 \\ -1 & \sqrt{2} & \sqrt{3} \\ -1 & \sqrt{2} & -\sqrt{3} \end{pmatrix}$

• T

Tri-bimaximal mixing

$$M_e = \text{diagonal}$$

 $M_v = U^T m_v U$



Just like many other ancient civilizations

There was a big flood in China more than 4,000 years ago

before the first dynasty: Xia





Yu, Luo River, circa 2100 BCE



The original 2-3 and magic symmetries

They Are Symmetries

$$\boldsymbol{v} = \begin{pmatrix} \boldsymbol{v}_e \\ \boldsymbol{v}_\mu \\ \boldsymbol{v}_\tau \end{pmatrix} \qquad \boldsymbol{H} = \boldsymbol{v}^T \boldsymbol{M}_v \boldsymbol{v}$$

 $V_e \leftrightarrow V_{\tau}$

Magic symmetry

$$v_e \rightarrow (v_e - 2v_\mu - 2v_\tau)/3$$
$$v_\mu \rightarrow (v_\mu - 2v_\tau - 2v_e)/3$$
$$v_\tau \rightarrow (v_\tau - 2v_e - 2v_\mu)/3$$



But Badly Broken Horizontal Symmetries

$$e = \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix} \quad V = \begin{pmatrix} V_e \\ V_\mu \\ V_\tau \end{pmatrix}$$

 $H = v^T M_v v + e^{\dagger} M_e e$



$$M_{\nu} = \begin{pmatrix} & & V_{\mu} & V_{\tau} \\ & & & & \\ & & & \\ & & & \\ & & & \\ & & & & \\ & & & \\ & & &$$

So what is it trying to tell us?



$$\vec{v}_{1} = (f_{0}s_{0} - \frac{1}{3}\delta_{00}\vec{f}\cdot\vec{s})\sqrt{\frac{3}{2}}$$

$$\vec{v}_{2} = \vec{f}\cdot\vec{s}/\sqrt{3}$$

$$\vec{v}_{3} = i(\vec{f}\times\vec{s})_{0}/\sqrt{2}$$

$$M = v^{T}M_{v}v$$

$$= \tilde{m}_{1}\tilde{v}_{1}^{2} + \tilde{m}_{2}\tilde{v}_{2}^{2} + \tilde{m}_{3}\tilde{v}_{3}^{2}$$

$$M = f_{-}s_{+}$$

$$(f_{\alpha} f_{\beta}) = n\delta_{\alpha+\beta,0}$$

$$\vec{v}_{\alpha} = n\delta_{\alpha+\beta,0}$$

$$\vec{v}_{\alpha}$$

$$m_i = \tilde{m}_i s_0^2$$

speculation:
$$s_0^2$$
 is cosmological
and is related to the dark energy

Neutrino mass comes from dark energy. Dark energy is like a Higgs condensate (to neutrinos alone).

Neutrino masses become heavier with time. Astrophysical tests?

Neutrinos provide some negative pressure



 $s_0^2 = \Omega_{DF}(t)$

Neutrino energy could be the dark energy because $\rho = n(m_1 + m_2 + m_3), \ n \propto a^{-3}$

 $\tilde{m}_i = \alpha_i (\rho_{crit}(t))^{1/4}$

Neutrino mass purely cosmological in origin m_i fixed if $s_0^2 = \Omega_{DE}(t)^{1/4}$. O(meV) masses.

Conclusion



- Is the turtle symmetry accidental, or something deep?
- Is the turtle symmetry caused by a nu-spin?
- Does the neutrino mass vary with cosmology?
- Only precision experiments can tell.

