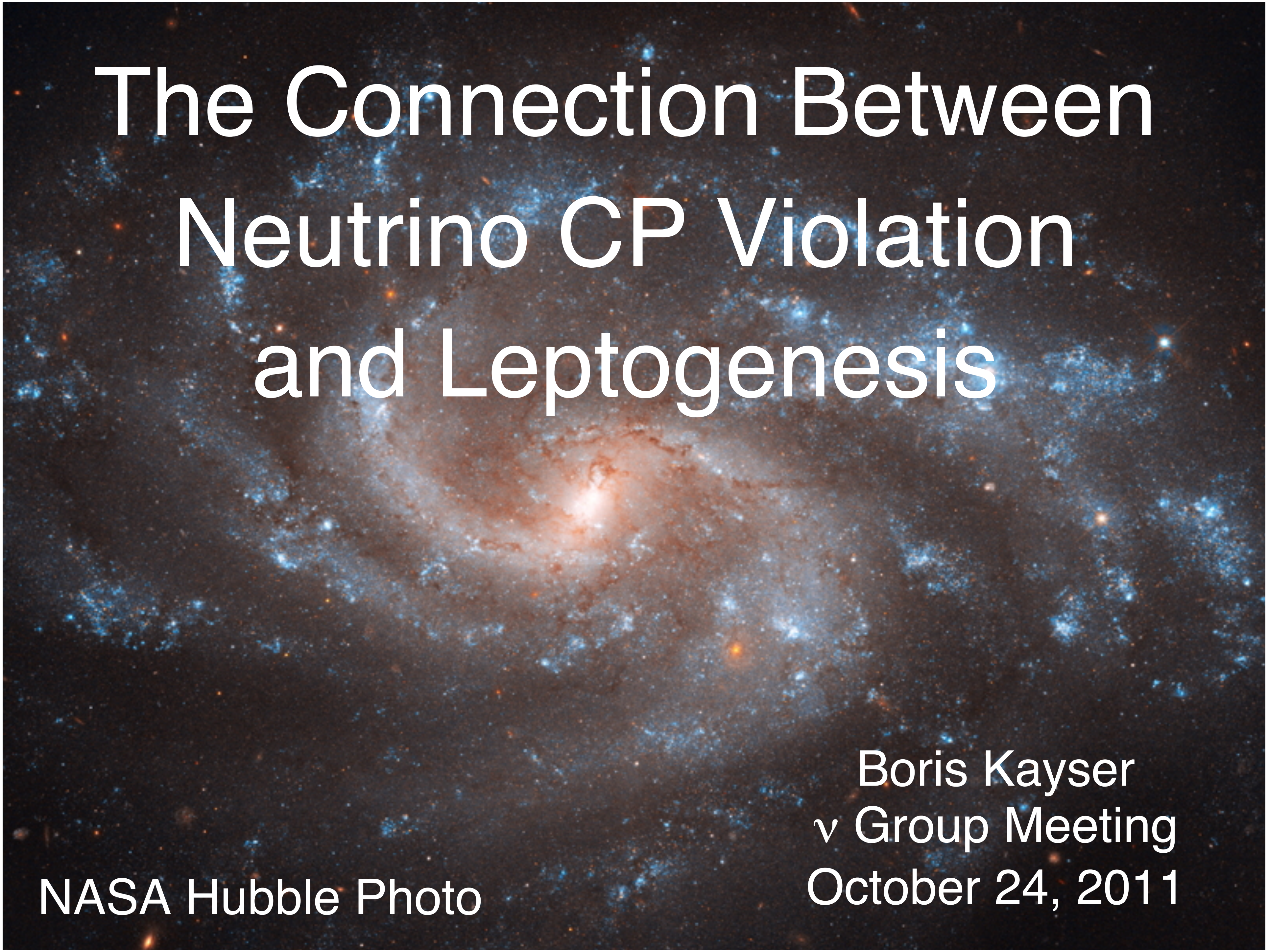
The Connection Between Neutrino CP Violation and Leptogenesis



NASA Hubble Photo

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ν Group Meeting
October 24, 2011

A major motivation to look for $\cancel{CP}$ in neutrino oscillation:

Its observation would make **leptogenesis** more plausible.

Leptogenesis

Explains the baryon-antibaryon asymmetry of the universe by CP-violating heavy neutrino decays.

SM lepton

Heavy ($m_N > 10^9$ GeV) Majorana neutrino

SM Higgs

$$\Gamma\left(N \rightarrow \ell^- + H^+\right) \neq \Gamma\left(N \rightarrow \ell^+ + H^-\right)$$

This $\cancel{CP}$ creates a ***lepton-antilepton*** asymmetry.

The SM Sphaleron process converts part of this asymmetry into the observed ***baryon-antibaryon*** asymmetry.

Leptogenesis is an outgrowth of the **See-Saw** theory of why neutrinos are so light.

The straightforward (type-I) See-Saw theory adds to the SM Lagrangian just —

Majorana masses

SM lepton doublet

$$\mathcal{L}_{\text{new}} = -\frac{1}{2}\sum_i m_{N_i} N_i^2 \quad + \sum_{\substack{\alpha=e,\mu,\tau \\ i=1,2,3}} y_{\alpha i}\left[\overline{\nu}_\alpha \overline{H^0} - \overline{\ell}_\alpha H^-\right] N_i + h.c.$$

SM Higgs doublet

Yukawa coupling matrix

$\cancel{CP}$ in N decays comes from $\cancel{CP}$ phases in y.

Number of leptonic parameters in the See-Saw picture: 21

Number of these parameters that can be measured without producing the heavy neutrinos N: 12

Since 21 > 12, laboratory measurements today cannot pin down what happened in the early universe.

Can there be $\cancel{CP}$ in ν oscillation but no leptogenesis? Yes.

Can there be leptogenesis but no $\cancel{CP}$ in ν oscillation? Yes.

Is either of these possibilities likely? ***NO!***

An Argument

(BK, arXiv:1012.4469)

The See-Saw Relation

Leptonic mixing matrix

Heavy N mass eigenvalues

$$U M_\nu U^T = -v^2 \left(y\, M_N^{-1} y^T \right)$$

Light ν mass eigenvalues

The Higgs vev, a real number

$$\left(\underbrace{U M_\nu U^T}_{\text{Outputs}} = -v^2 \underbrace{\left(y\, M_N^{-1} y^T \right)}_{\text{Inputs, in } \mathcal{L}} \right)$$

Through ***U***, the phases in ***y*** lead to $\cancel{CP}$ in light neutrino oscillation.

$$P(\overset{(-)}{\nu}_\alpha \rightarrow \overset{(-)}{\nu}_\beta) =$$

e, μ, or τ

Distance

$$= \delta_{\alpha\beta} - 4 \sum_{i>j} \Re(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin^2(\Delta m^2_{ij} \frac{L}{4E})$$

$$\overset{+}{\scriptstyle(-)}2 \sum_{i>j} \Im(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin(\Delta m^2_{ij} \frac{L}{2E})$$

Neutrino (Mass)^2 splitting

Energy

Generically, leptogenesis and light-neutrino $\cancel{CP}$ imply each other.

If all N_i masses > 10^{12} GeV, then the phases that drive leptogenesis are independent of those in U.

However, supersymmetry suggests that the lightest N_i must have mass ~ 10^9 GeV.

Then $\cancel{CP}$ phases in U, which produce $\cancel{CP}$ in ν oscillation, and influence the rate for neutrinoless double beta decay, lead also to a baryon-antibaryon asymmetry.

(Casas, Ibarra; Kohri, Moroi, Yotsuyanagi; Abada, Davidson, Ibarra, Josse-Michaux, Losada, Nardi, Nir, Racker, Riotto, Roulet; Pascoli, Petcov, Riotto, Rodejohann)

Summary

Generically, leptogenesis and light-neutrino ~~CP~~ do imply each other.