Searching for new physics in the flavor composition of high-energy astrophysical neutrinos

Mauricio Bustamante

Fellow @ Center for Cosmology and AstroParticle Physics, The Ohio State University

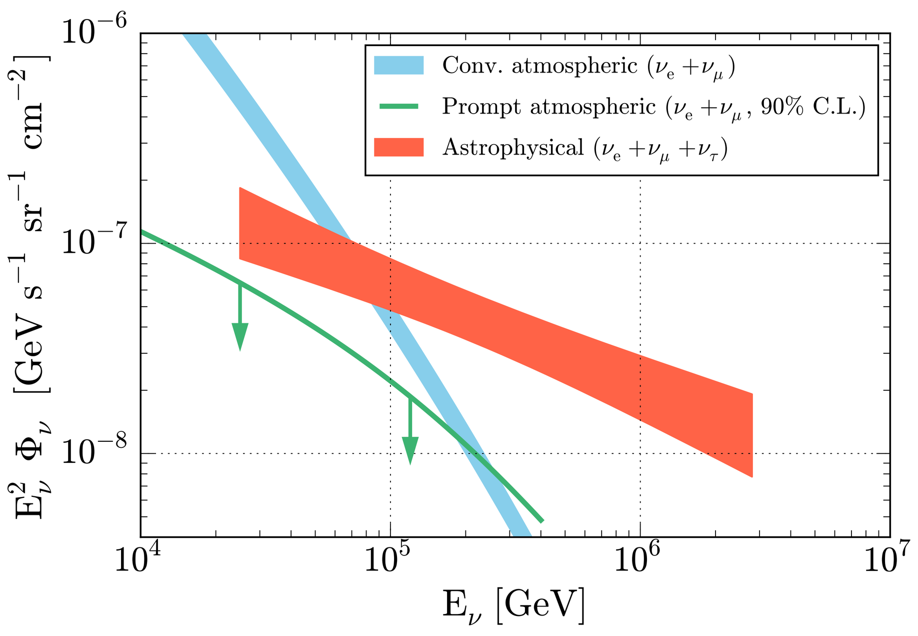
CCAPP

The Ohio State University

At a glance

- High-energy astrophysical neutrinos are a novel arena to look for new physics
- Extreme neutrino energies (∼ PeV) and propagated distances (∼ Gpc)
- The flavor composition of the neutrino flux — how much of each flavor is in it — is particularly sensitive to new physics
- Powerful tests can be performed with current and upcoming neutrino data

IceCube: high-energy astrophysical neutrinos [1]



- IceCube detects light from neutrino-nucleon interactions
- Diffuse flux $\propto E^{-2.5}$
- Likely extraglactic origin
- **Showers:** mainly from ν_e and ν_τ charged-current interactions
- **Tracks:** from ν_μ and some ν_τ charged-current interactions

Flavor composition is inferred from the number of showers and tracks

Why look for new physics here?

1 — The highest neutrino energies observed: 25 TeV — 2 PeV

- Most energetic man-made neutrino: ∼ 350 GeV
- Can probe new physics suppressed by higher energy scales

2 — The longest propagation distances: few Gpc

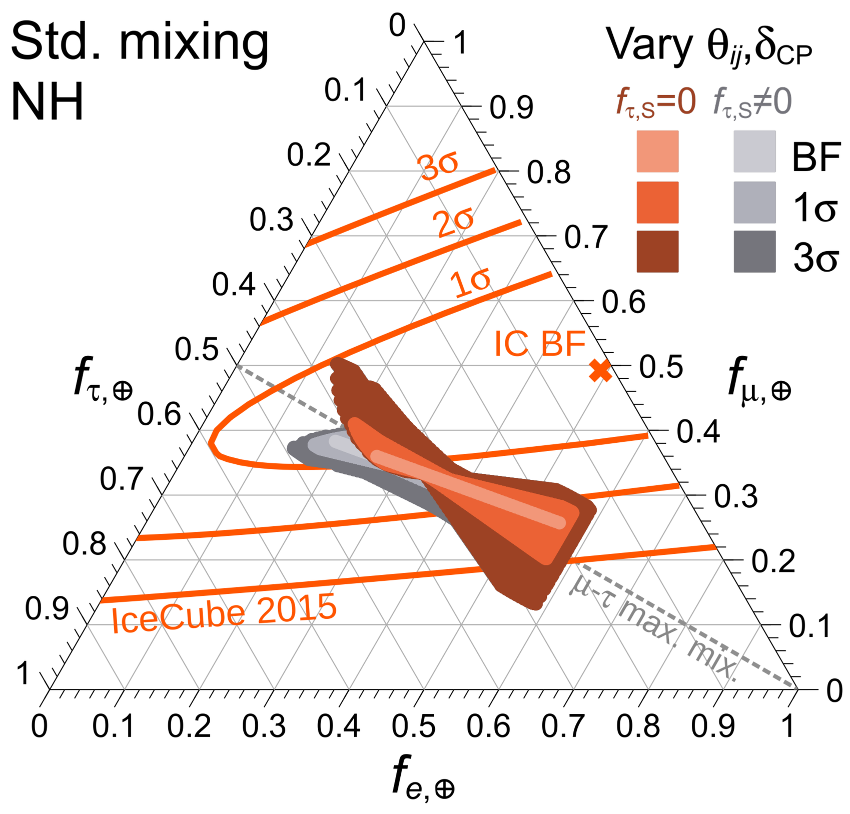
- Most potential extragalactic sources are around $z \approx 1$, or L = few Gpc
- Tiny new-physics effects made detectable by accumulation

Flavor composition at Earth — with standard mixing [2]

Generate the allowed region by varying:

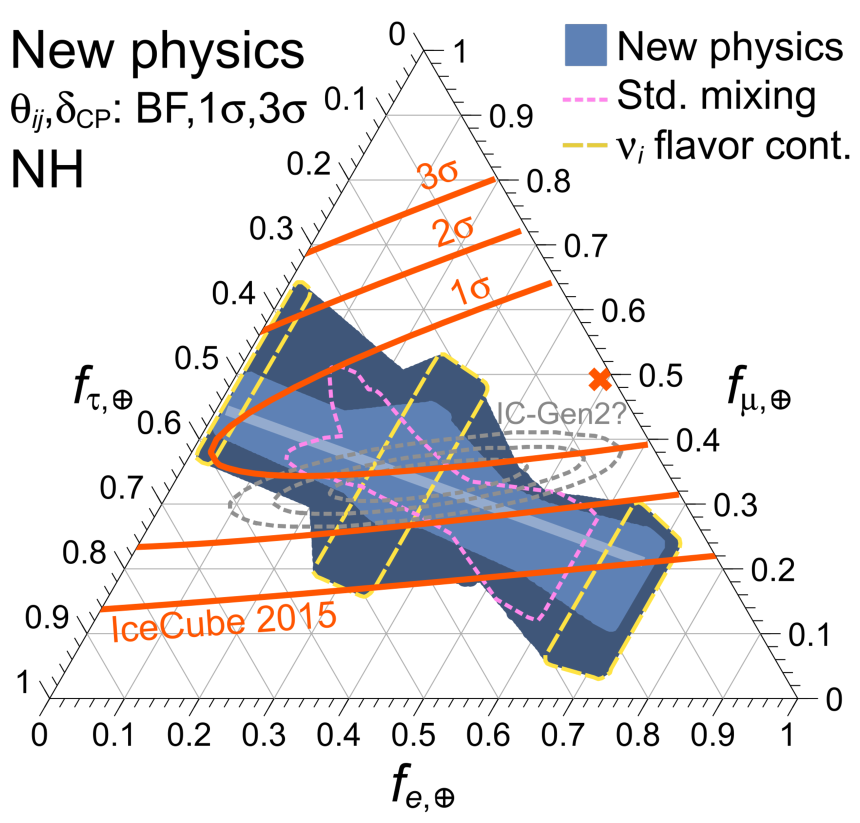
- All flavor compositions at sources
- Mixing parameters within uncertainties

- ∼ 10% of the triangle
- Outside this region: new physics
- Region will shrink with smaller particle-physics uncertainties
- Contours will shrink with more ν data and better flavor-tagging



Flavor composition at Earth — with new physics [2]

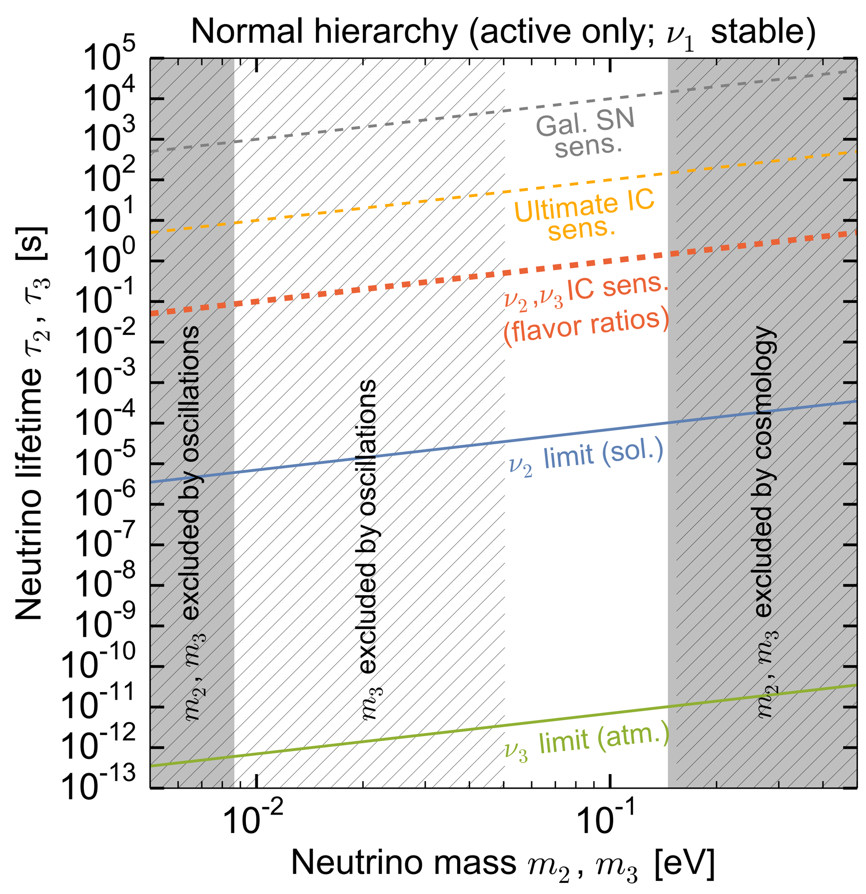
- Blue: class of new physics models that change the proportion of mass eigenstates ν_1, ν_2, ν_3 in the flux
- *E.g.*, ν decay, secret ν interactions
- Flavor composition: superposition of flavor content of eigenstates
- ∼ 25% of the triangle
- Outside this region: models that change the mixing parameters (*e.g.*, Lorentz, CPT violation [3])



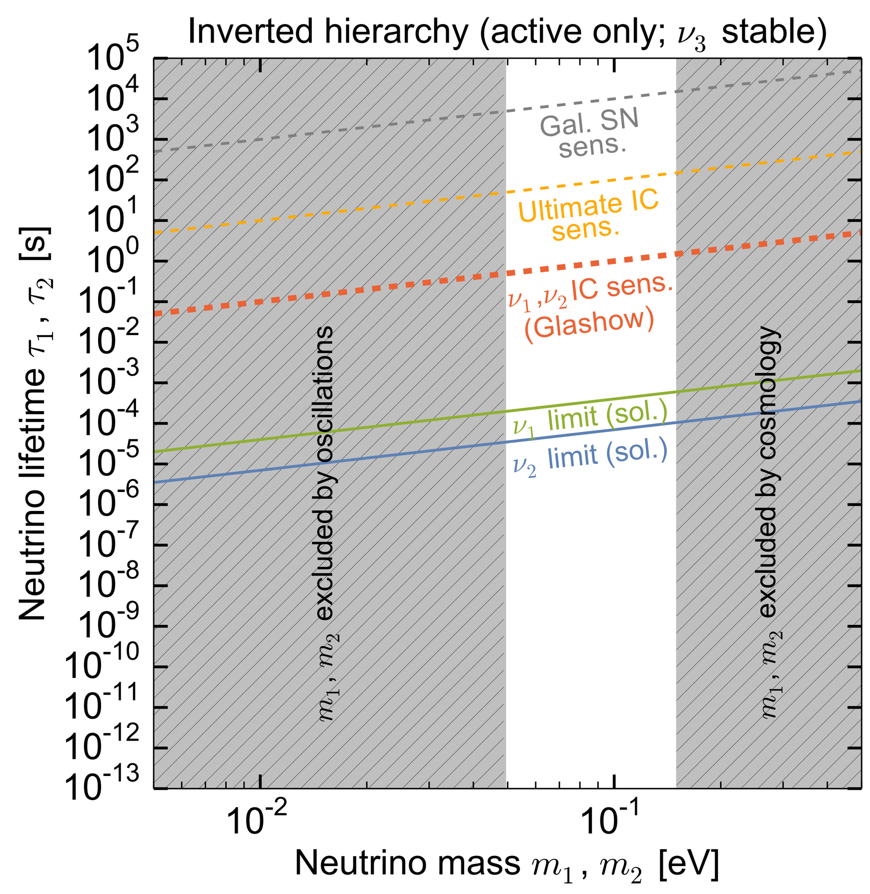
Testing neutrino decay with incomplete information [4,5]

If neutrinos are unstable, heavier eigenstates could decay to the lightest one

$\nu_2, \nu_3 \to \nu_1$

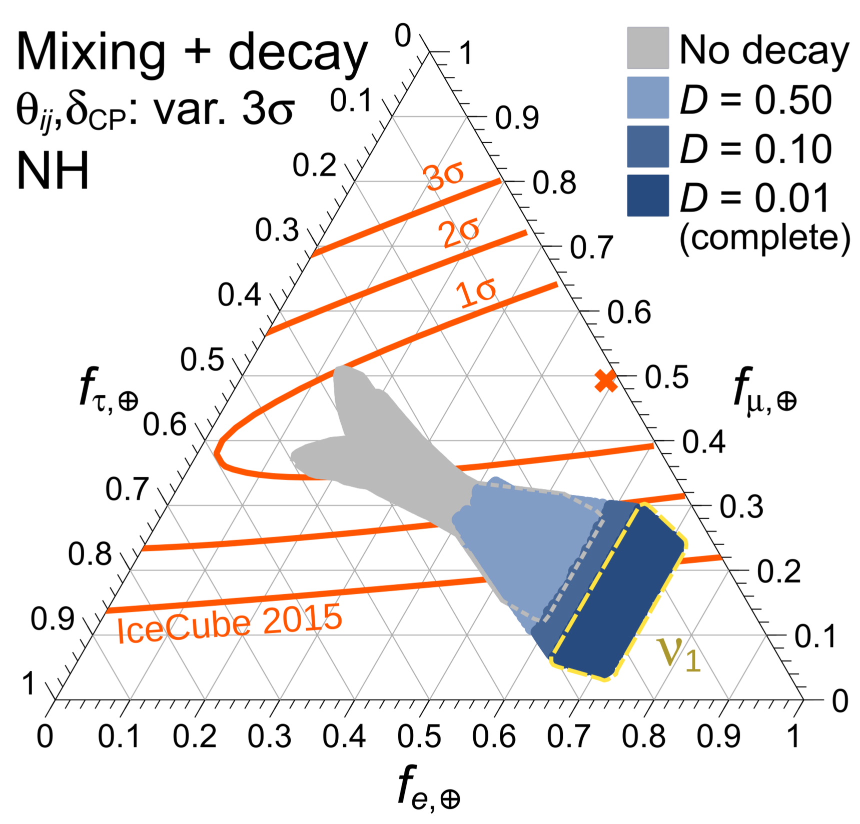


$\nu_1, \nu_2 \to \nu_3$



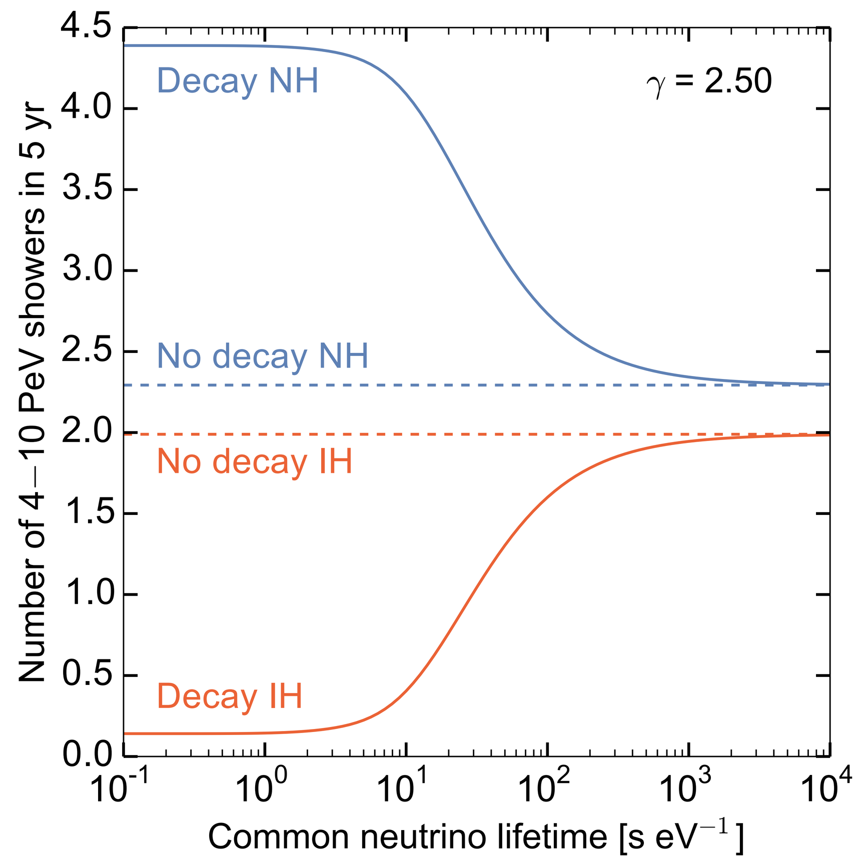
Complete decay: all unstable ν's decay before reaching Earth — the flavor composition equals the flavor content of ν_1 (NH) or ν_3 (IH)

Test with flavor composition:



Current data disfavors NH complete decay at $\gtrsim 2\sigma$

Test with high-energy showers:



Observation of one 4–10 PeV shower would disfavor IH complete decay

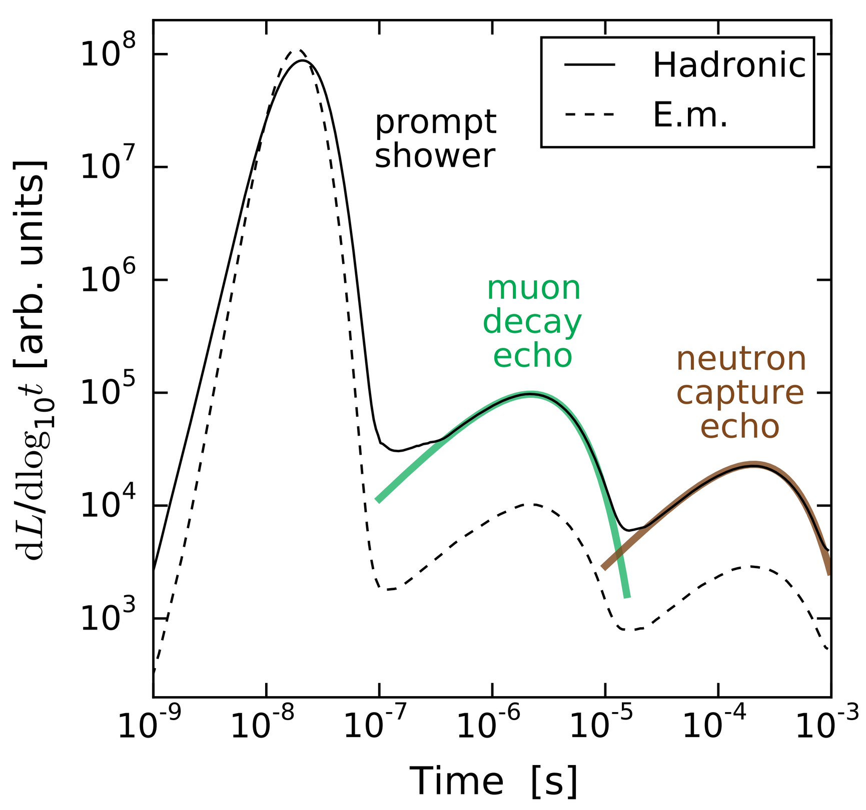
Either method reaches a sensitivity of $\tau \gtrsim 10$ s (m/eV)

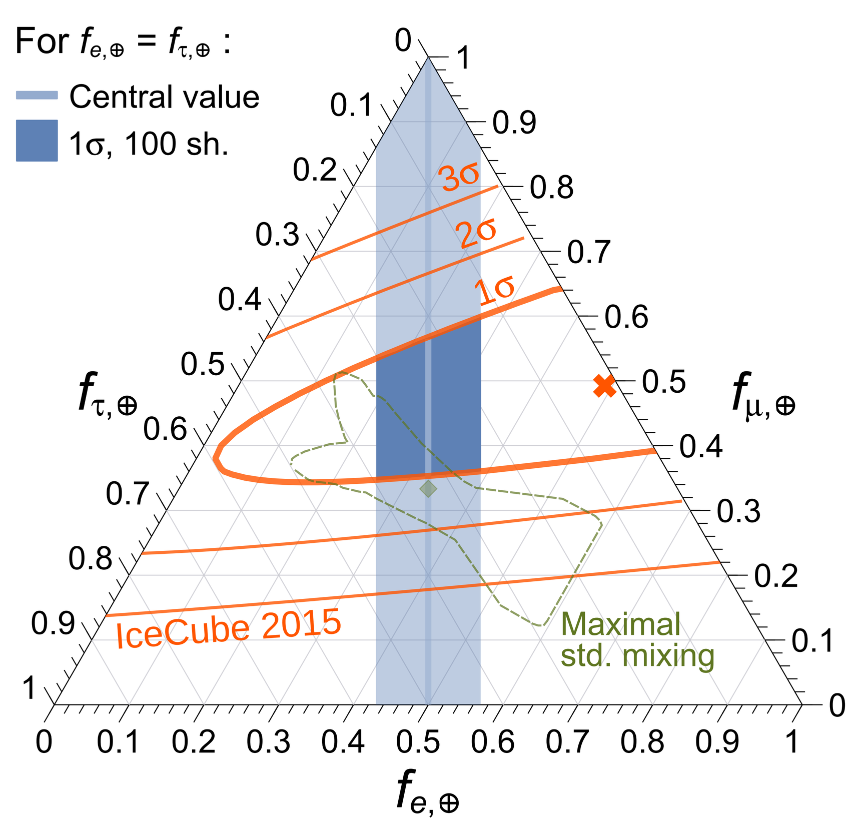
Improving flavor measurement in neutrino telescopes [6]

How to distinguish showers made by ν_e and ν_τ charged-current interactions?

- Detect delayed light ("echoes") from muon decays and neutron captures
- Hadronic showers have stronger echoes than e.m. showers

- ν_e showers: mostly e.m. — faint echoes
- ν_τ showers: mostly hadronic — strong echoes





With 100 showers, echoes improve flavor measurement by ∼ 10

Conclusion

IceCube provides tests of new physics via flavor composition, in spite of uncertainties in neutrino properties, source properties, and detection difficulties

Selected references

[1] IceCube Collaboration, *A combined maximum-likelihood analysis of the high-energy astrophysical neutrino flux measured with IceCube*, ApJ 809, 98 (2015) [1507.03991]

[2] M. Bustamante, J.F. Beacom, and W. Winter, *Theoretically palatable flavor combinations of astrophysical neutrinos*, PRL 115, 161302 (2015) [1506.02645]

[3] C.A. Argüelles, T. Katori, and J. Salvadó, *New physics in astrophysical neutrino flavor*, PRL 115, 161303 (2015) [1506.02043]

[4] P. Baerwald, M. Bustamante, and W. Winter, *Neutrino decays over cosmological distances and the implications for neutrino telescopes*, JCAP 1210, 020 (2012) [1208.4600]

[5] M. Bustamante, J.F. Beacom, and K. Murase, *Testing decay of astrophysical neutrinos with incomplete information*, In preparation

[6] S.W. Li, M. Bustamante, and J.F. Beacom, *Echo technique to distinguish flavors of astrophysical neutrinos*, [1606.06290]

www.physics.ohio-state.edu/∼bustamanteramirez.1/ bustamanteramirez.1@osu.edu

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