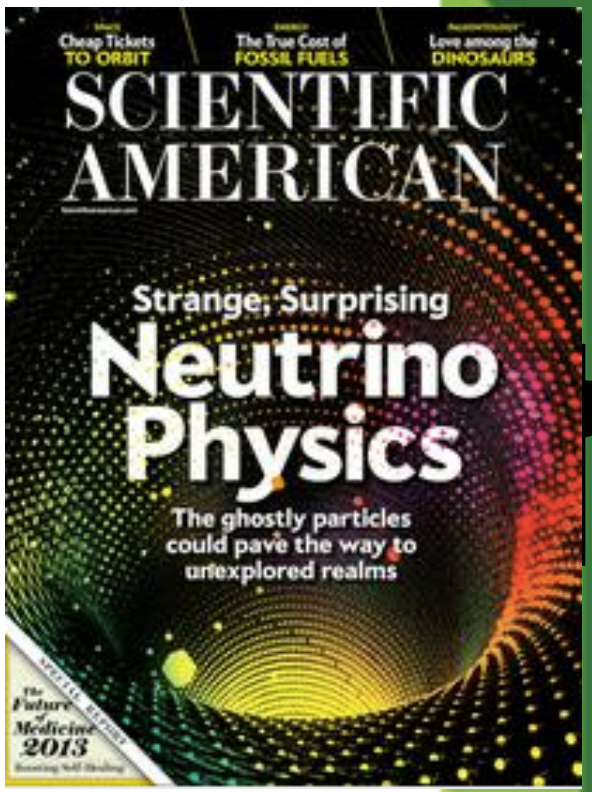
Message from Neutrinos to Snowmass 2013



André de Gouvêa, Kevin Pitts, Kate Scholberg, Sam Zeller

ANL, April 2013

Neutrino Subgroups

- **Nu1: Neutrino Oscillations and the Three-Flavor Paradigm**
  subgroup conveners: Mary Bishai, Karsten Heeger, Patrick Huber

- **Nu2: The Nature of the Neutrino: Majorana vs. Dirac**
  subgroup conveners: Steve Elliott, Lisa Kaufman

- **Nu3: Absolute Neutrino Mass**
  subgroup conveners: Hamish Robertson, Ben Monreal

- **Nu4: Neutrino Interactions**
  subgroup conveners: Jorge Morfin, Rex Tayloe

- **Nu5: Anomalies and New Physics**
  subgroup conveners: Boris Kayser, Jon Link

- **Nu6: Astrophysical and Cosmological Neutrinos**
  subgroup conveners: Kara Hoffman, Cecilia Lunardini, Nikolai Tolich

- **Nu7: Neutrinos and Society**
  subgroup conveners: Jose Alonso, Adam Bernstein

Ongoing work: gathering input from community & synthesizing

`http://www.snowmass2013.org/tiki-index.php?page=Neutrinos`

83 one-page whitepapers received

- March 6-7: premeeting at SLAC, presentation of ideas and discussions
- Mid-April: first draft of neutrino working group document circulated to community for feedback
- April 23- May 1: first community comment period
- April 25-27: Intensity Frontier Workshop at ANL, chance for feedback and discussion
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- May 21-June 15: second community comment period
- July 1: third draft of document circulated to community for feedback

first drafts posted: see twiki

we are here

Because we just had a workshop in March full of talks, for this meeting's parallel sessions we had *only discussions*

(except one talk with physics news since the SLAC meeting)

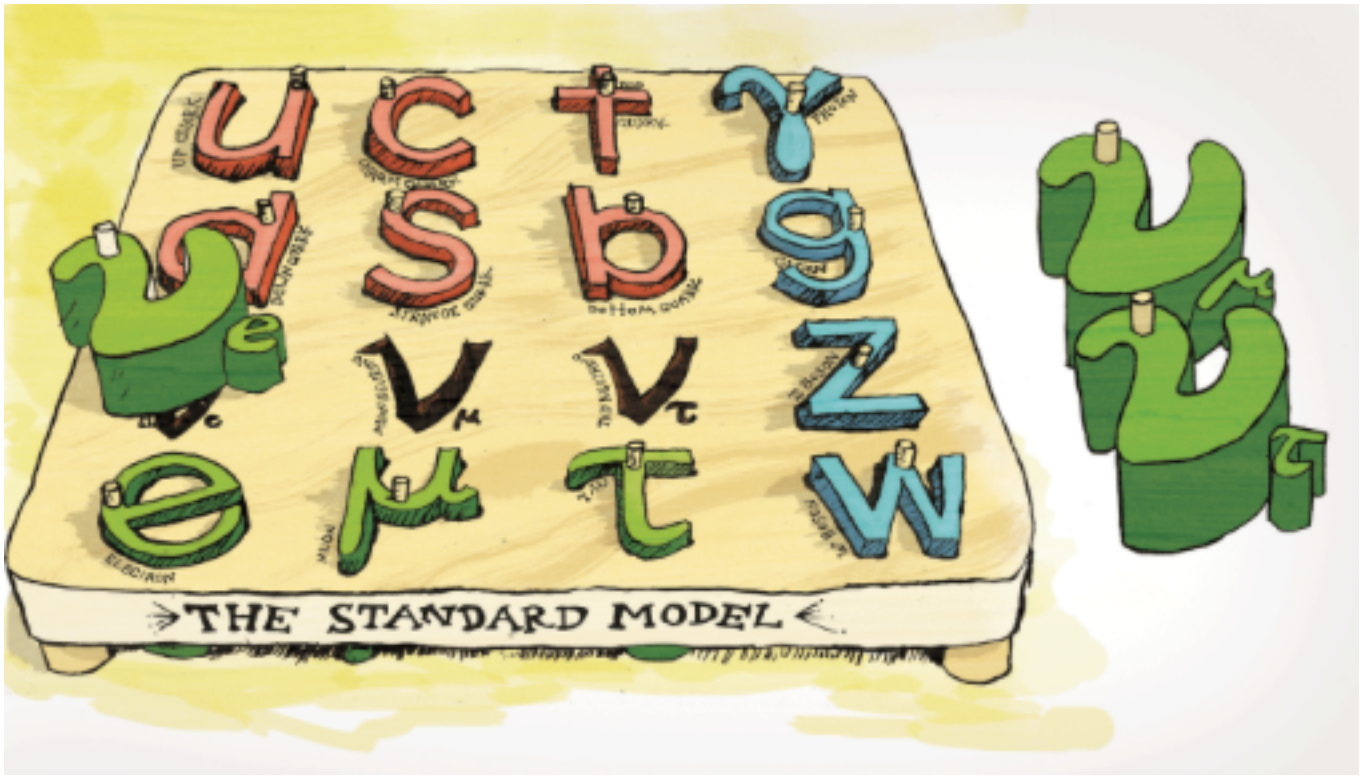
Special thanks to note-takers & runners!

Roberto Acciarri
Jonathan Asaadi
Xuebing Bu
Ben Carls
Mike Cooke
Maury Goodman
Debbie Harris
Glenn Horton-Smith
Bryce Littlejohn
Sarah Lockwitz
Mike Kirby
Mike Kordosky
Camillo Mariani
Jim Maloney
Jyotsna Osta
David Webber
Tingjun Yang
Eric Zimmerman

Neutrino physics has been *tremendously successful* over the past two decades...

We now have a pretty robust, simple 3-flavor neutrino paradigm, describing most of the data

Still unknown:
what is the absolute mass scale?
are neutrinos Majorana or Dirac?



Symmetry

What do we *not* know about three-flavor oscillations?

	Free Fluxes + RSBL	
	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	$0.302^{+0.013}_{-0.012}$	$0.267 \to 0.344$
$\theta_{12}/^\circ$	$33.36^{+0.81}_{-0.78}$	$31.09 \to 35.89$
$\sin^2\theta_{23}$	$0.413^{+0.037}_{-0.025} \oplus 0.594^{+0.021}_{-0.022}$	$0.342 \to 0.667$
$\theta_{23}/^\circ$	$40.0^{+2.1}_{-1.5} \oplus 50.4^{+1.3}_{-1.3}$	$35.8 \to 54.8$
$\sin^2\theta_{13}$	$0.0227^{+0.0023}_{-0.0024}$	$0.0156 \to 0.0299$
$\theta_{13}/^\circ$	$8.66^{+0.44}_{-0.46}$	$7.19 \to 9.96$
$\delta_{CP}/^\circ$	300^{+66}_{-138}	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.50^{+0.18}_{-0.19}$	$7.00 \to 8.09$
$\frac{\Delta m^2_{31}}{10^{-3}\ \mathrm{eV}^2}$ (N)	$+2.473^{+0.070}_{-0.067}$	$+2.276 \to +2.695$
$\frac{\Delta m^2_{32}}{10^{-3}\ \mathrm{eV}^2}$ (I)	$-2.427^{+0.042}_{-0.065}$	$-2.649 \to -2.242$

Is θ_{23} non-negligibly greater or smaller than 45 deg?

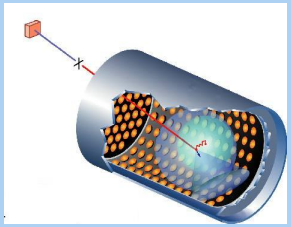
basically unknown

sign of Δm^2 unknown (ordering of masses)

Outstanding 'anomalies'

LSND @ LANL (~30 MeV, 30 m)

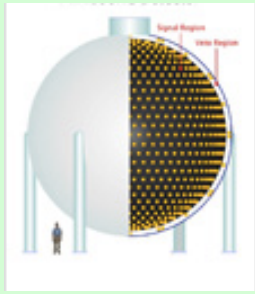
Excess of $\overline{\nu}_e$ interpreted as $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$



➔ $\Delta m^2 \sim 1\ eV^2$: inconsistent with 3 ν masses

MiniBooNE @ FNAL (ν,$\overline{\nu}$ ~1 GeV, 0.5 km)

- unexplained >3 σ excess for E < 475 MeV in neutrinos
  (inconsistent w/ LSND oscillation)
- no excess for E > 475 MeV in neutrinos
  (inconsistent w/ LSND oscillation)
- small excess for E < 475 MeV in antineutrinos
  (~consistent with neutrinos)
- small excess for E > 475 MeV in antineutrinos
  (consistent w/ LSND)
- for E>200 MeV, both nu and nubar consistent with LSND



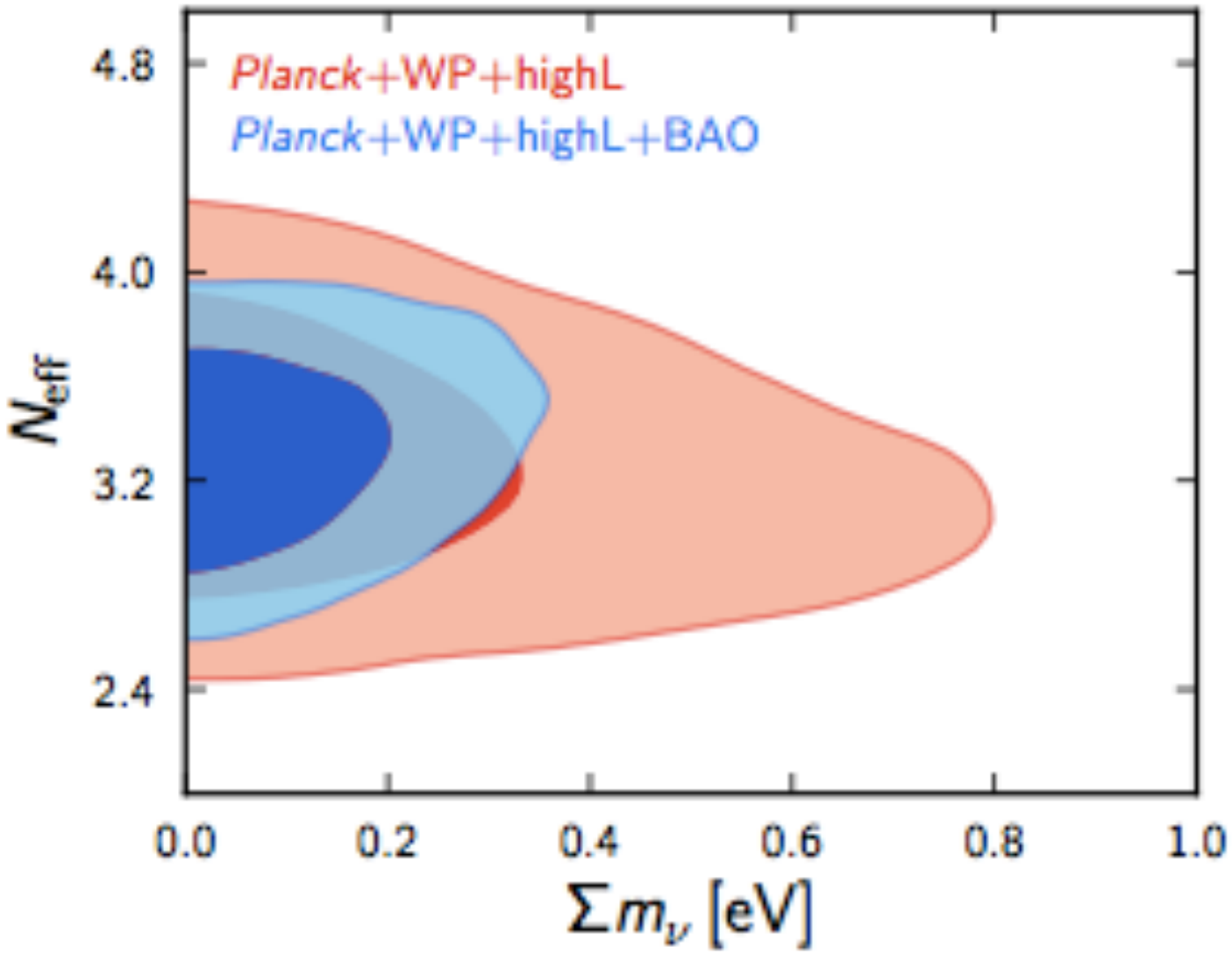
????

more data needed

Also: possible deficits of reactor $\overline{\nu}_e$ ('reactor anomaly')
and source ν_e ('gallium anomaly')

Sterile neutrinos?? (i.e. no normal weak interactions)
Some theoretical motivations for this, both from particle physics & astrophysics. **Or some other new physics??**

Information about neutrinos from Planck



Talk by Sudeep Das

Panel Discussion Topics

Overall Neutrino Physics Strategy

US Strategy Part I

Neutrino Theory Needs

Inter-Frontier Connections

Neutrinos and Society

US Strategy Part II

International Coordination

- comments from panelists and audience in response to specific questions
- not always consensus, or answers, but in the following, we will try to capture some of the most commonly expressed ideas (not comprehensive!)

Overall neutrino physics strategy

Moderator: Boris Kayser

Panelists: F. Halzen, K. Lande, W. Louis, W. Marciano, S. Parke, R. Patterson, R. Plunkett, J. Rosner

- **What are the most important neutrino physics goals?**
- **How well do we need to know the standard neutrino sector parameters?**
- **What is the relative importance of testing the 3-flavor paradigm and exploring anomalies?**
- **How do we frame a convincing and accurate narrative regarding the importance of the PMNS phase for understanding the lepton/baryon asymmetry of the Universe?**

- we don’t have full answers to all these yet... working on it!
- along with the Higgs, the neutrino is the one type of particle we don’t understand well yet
- we do have a clear list of questions, and good experimental ideas for getting the answers
- especially important physics questions:
  - CP violation
  - 0νbbdk (lepton number violation)
- exploring existing anomalies should not be ignored (we are “blessed, not plagued”)

US strategy, part 1: LBNE

Moderator: Patrick Huber
Panelists: Chris Mauger, Mark Messier, Jennifer Raaf, Gina Rameika, Bob Svododa, Robert Wilson

- **How will LBNE test the 3-flavor paradigm in the context of a long-term program? What are other alternatives?**
- **How important is the breadth of the program?**
- **What aspect of LBNE does the the community value most? Underground, near detector, more target mass?**

- **getting LBNE underground is scientifically important and critical**
- **breadth of program is very important**
- **depth & near detector make LBNE attractive to international partners**

ISOUPS 2013 (International Symposium: Opportunities in Underground Physics for Snowmass)

24-27 May 2013 *Asilomar, California*

Neutrino theory needs

Moderator: André de Gouvêa

Panelists: K.S. Babu, B. Balantekin, P. Huber, J. Link, H. Gallagher, J. Morfin, H. Lee

- **What is the role of neutrino theory?**
- **What are the most pressing questions for neutrino theory today?**
- **How do we increase the number of nuclear phenomenologists and attract them to join the neutrino theory and experimental effort?**
- **What should be the size of the neutrino theory community?**
- **If we need to grow the neutrino community, how can we do it?**

- need more neutrino theorists
- need theorists who can calculate (not just speculate) and interface with experimentalists
- need theorists who can connect between frontiers, and with nuclear physics (neutrino interactions)

Meeting of neutrino theorists on May 20 at FNAL to discuss concrete initiatives (contact André de Gouvêa)

Inter-Frontier Connections

Moderator: Yuri Gershtein

Panelists: D. Cowen, R. Henning, B. McKeown, A. Piepke, M. Ramsey-Musolf, R. Roser, J. Yoo

- **How do we communicate the importance of neutrino physics to the other Frontiers?**
- **How do we ensure that "stovepiping" of funding within/between Frontiers doesn't limit opportunities for science?**
- **How can we mitigate "stovepiping" within/between HEP and NP (DOE and NSF) that can limit opportunities for science?**
- **How can we exploit opportunities at the interfaces between the Frontiers?**
- **How can we exploit connections with nuclear physics?**

- **we are *particle physicists*, not neutrino physicists**
- **neutrinos naturally cross many boundaries**
- **funding issues have been solved in the past; need constructive solutions in collaboration with agencies**

Neutrinos and society

Moderator: Adam Bernstein

Panelists: E. Blucher, Z. Djurcic, G. Horton-Smith, J. Klein, R. Lanza, K. van Bibber, H. White

- **How do we communicate the importance of fundamental and applied neutrino physics to Congress and the public?**
- **What synergies exist between fundamental neutrino physics and proposed applications of neutrinos in other fields?**
- **How can the community best take advantage of these synergies?**
- **What training is useful for scientists to facilitate these synergies?**
- **What technologies – accelerators, detectors– arising directly from neutrino physics are relevant in fields beyond fundamental science?**

- **getting the message out matters**
- **synergies between fundamental physics and applications are a "gift dropped in the lap of the neutrino community", e.g. nonproliferation & short baseline oscillations**
- **synergies with industry, spin-offs**
- **need to pay attention to other agencies (e.g. NNSA) to tap connections**

US strategy, part 2: experiments at different scales

Moderator: Kate Scholberg
Panelists: S. Brice, A. Bross, A. Connolly, J. Conrad, J. Formaggio, G. Gratta, K. McFarland, P. Mumm

- **Do we need a robust program of experiments at different scales?**
- **What are the opportunities for smaller projects?**
- **How do we ensure that new ideas can find fertile ground?**
- **What should be the strategy beyond the next decade?**

- general consensus that different scales (time, money...) are desirable; breadth and diversity matter
- high risk acceptable for smaller projects; need to be nimble
- smaller projects good for training
- initiatives for “incubation” of new ideas?

International coordination

Moderator: Sam Zeller

Panelists: F. di Lodovico, T. Ekelöf, M. Goodman, S. Kettell, Y. Kim, Y.K. Kim, K. Long, S. Mishra, H. da Motta, N. Smith, M. Yokoyama

- **What are the opportunities for international participation in U.S. neutrino experiments?**
- **What are the opportunities for U.S. participation in neutrino physics experiments abroad?**
- **How can we optimize the global program?**

- many opportunities for collaboration in the US (notably, LBNE)
- international partners will be full scientific partners
- follow-through is important
- many opportunities abroad
  (Japan, Europe, Canada, Korea, India, China, S. America,..)
- no consensus on meaning of "optimization"
  (how important is complementarity?)

Next steps:

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Subgroup conveners are working on synthesizing input for coherent physics case, story for opportunities and plans
(difficult due to diversity of neutrino physics!)

Further feedback: email if-neutrino-conveners@fnal.gov
(This reaches all Nu1-Nu7 conveners)

explain it in 60 seconds

Neutrino physics has been *tremendously successful* over the past two decades... we have clear paths forward for building on this success

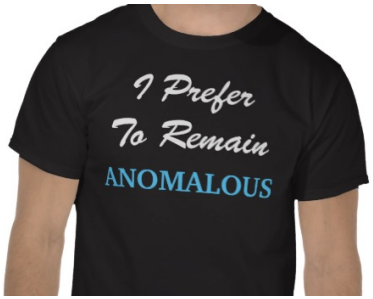
We now have a pretty robust, simple 3-flavor neutrino paradigm, describing most of the data

Still a few unknown parameters in this picture, notably mass hierarchy & CP δ, but clear steps to take

➔need to push on the paradigm w/ precision measurements

... and plenty of long-term ideas, smaller experiment ideas

Anomalies are still out there... they may or may not go away.



Final thoughts on the message for Snowmass

Yuval's talk on first day:

"Once you find an entrance, there will be an explosion in some direction that will carry on for decades"

That's happened for neutrinos!

We can build a world-class neutrino program along three lines:

- long-baseline oscillations
- neutrinoless double beta decay
- smaller experiments to search for new physics

Breadth, and connections between Frontiers, are important