

Neutrino Working Group Updates

Tomás Gonzalo

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GAMBIT XVI

Active WG Members

- **Tomas Gonzalo** (current convenor, stepping down after f2f)
- **Wilf Shorrock** (current convenor)
- **Michele Lucente** (next convenor after f2f)
- Anders Kvellestad
- Chien Lin
- Are Raklev
- Mark Ross-Lonergan
- Roberto Ruiz de Austri
- Martin White
- *Yoshi Uchida (external collaborator)*
- *Pedro Machado (external collaborator)*
- *Stephen Parker (external collaborator)*

Activities of the Neutrino WG

- Anything to do with neutrinos
- Past projects
 - Right-handed neutrinos

A Frequentist Analysis of Three Right-Handed Neutrinos with GAMBIT

Marcin Chruszacek^{1,2}, Marco Drewes³, Tomás E. Gonzalo^{4,5}, Julia Harz⁶,
 Suraj Krishnamurthy^{6,4}, Christoph Weniger⁶

[*Eur.Phys.J.C* 80 (2020) 6, 569, [arXiv:1908.02302](https://arxiv.org/abs/1908.02302)]

- Cosmological neutrinos

Strengthening the bound on the mass of the lightest neutrino with terrestrial and cosmological experiments

The GAMBIT Cosmology Workgroup: Patrick Stöcker,^{1,*} Csaba Balázs,² Sanjay Bloor,^{3,4} Torsten Bringmann,⁵ Tomás E. Gonzalo,^{6,7,8} Will Handley,^{6,7,8} Selim Hotini,⁴ Cullan Howlett,^{9,1} Felix Kühlhofer,¹ Janina J. Renk,^{3,4,9,1} Pat Scott,^{3,4,1} Aaron C. Vincent,^{10,11,12} and Martin White¹³

[*Phys.Rev.D* 103 (2021) 12, 123508, [arXiv:2009.03287](https://arxiv.org/abs/2009.03287)]

- Ongoing projects
 - Neutrino 3-flavour oscillation
 - Non-unitary mixing matrix



Neutrino Oscillations with GAMBIT

Tomás E. Gonzalo^{1,a}, Anders Kvellestad², Chien Lin^{3,b}, Michele Lucente⁴,
Roberto Ruiz de Austri⁵, Pat Scott⁶, Wilf Shorrock^{7,c}, Yoshi Uchida³,
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⁶ Quantum Brilliance Pty Ltd, The Australian National University, Daley Road, Acton ACT 2601, Australia

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⁸ ARC Centre of Excellence for Dark Matter Particle Physics & CSSM, Department of Physics, University of Adelaide, Adelaide, SA 5005

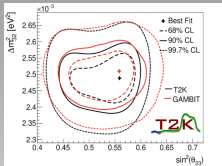
Received: date / Accepted: date

- 3-flavour neutrino oscillations global fit
- Old topic, already 3 groups with long expertise, but
 - first ever open-source neutrino global fit software
 - detailed reproduction of the experiments, without “fudging” data
 - proper treatment of systematic uncertainties

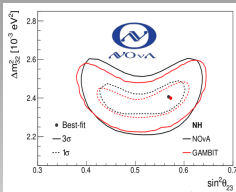
Neutrino Oscillations

- 8 experiments implemented and validated

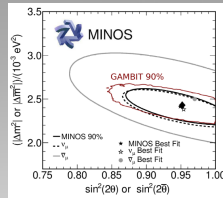
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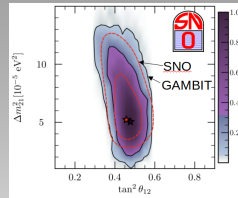
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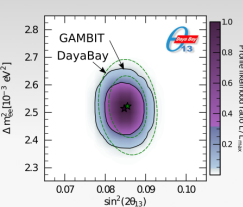
MINOS



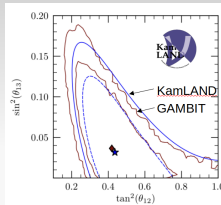
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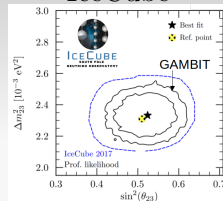
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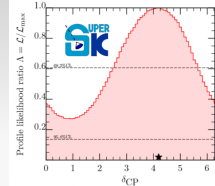
KamLAND



IceCube

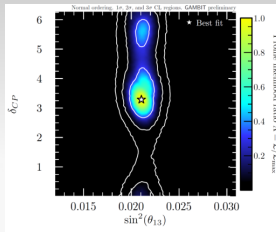
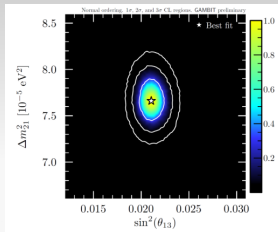
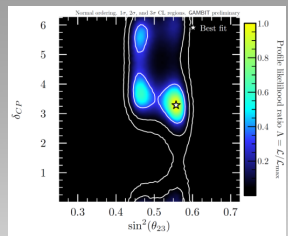
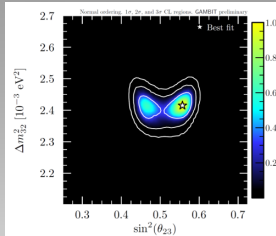
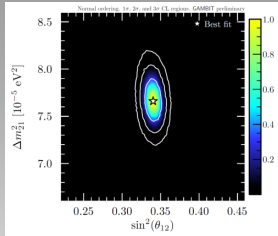


SuperK



Neutrino Oscillations

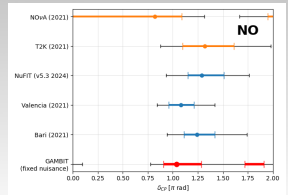
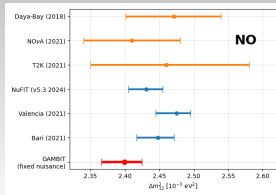
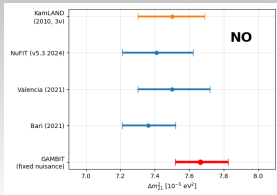
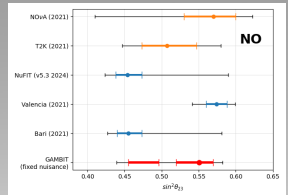
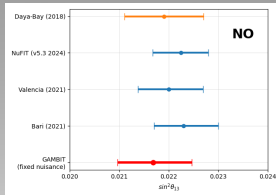
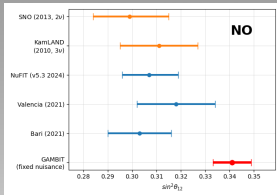
- Results from no-systematics scan (NO)



Normal ordering ($\pm 1\sigma$)	
θ_{12} [$^\circ$]	35.7 ± 0.5
θ_{13} [$^\circ$]	8.34 ± 0.25
θ_{23} [$^\circ$]	$48.3^{+1.0}_{-1.4}$
$\sin^2 \theta_{12}$	0.340 ± 0.009
$\sin^2 \theta_{13}$	$0.0211^{+0.0013}_{-0.0012}$
$\sin^2 \theta_{23}$	$0.557^{+0.013}_{-0.024}$
Δm_{21}^2 [10^{-5} eV 2]	$7.66^{+0.15}_{-0.14}$
Δm_{32}^2 [10^{-3} eV 2]	2.41 ± 0.03
δ_{CP} [$^\circ$ / π rad]	$188^{+27}_{-23} / 1.05^{+0.15}_{-0.13}$

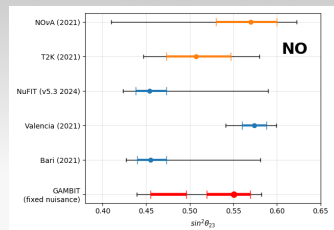
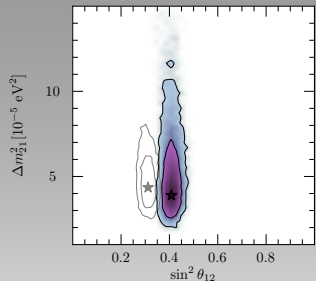
Neutrino Oscillations

- Results from no-systematics scan (NO)



Neutrino Oscillations

- Still some physics issues to resolve
 - θ_{12} larger than in other studies
 - ↪ dependence on Solar Models
 - ↪ 2005 vs 2016, high vs low metallicity
 - preference for high θ_{23} solution
 - ↪ other collabs prefer low θ_{23} solution
 - ↪ missing recent SuperK results
- Computational problems
 - 50+ nuisance parameters
 - ↪ partial solution with gaussian priors of varying width
 - ↪ PCA analysis of systematics
 - Slow likelihoods (SNO, IceCube)
 - ↪ Pre-sample and train NN
 - LUMI has been down for a while



Non-unitarity

- Non-unitary PMNS matrix can (maybe) explain some of the oscillation anomalies in LNSD and MiniBoone
- Can use (most of) the existing infrastructure from vanilla oscillations
 - Needs upgrade of oscillation codes to depend on matrix elements, no mixing angles
 - Remove assumptions of max probability for neutral current
 - New experiments: OPERA and other short-baseline
- Lead by Michele Lucente, with Mark Ross, Pedro Machado, Steven Parke
 - Need more manpower to code experiments