neutrinos and new physics

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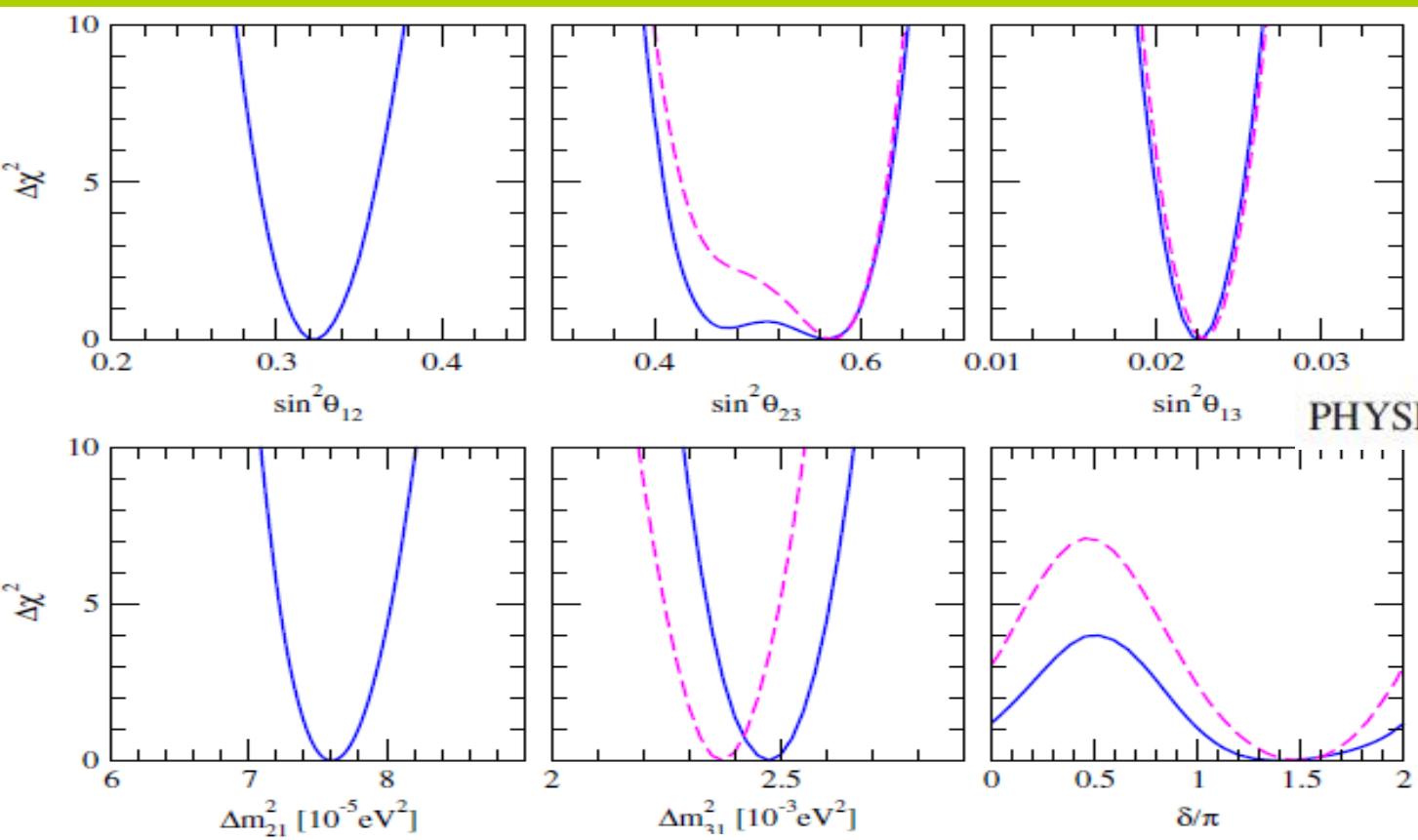
CERN-EPFL-Korea Theory Institute "New Physics at the Intensity Frontier"

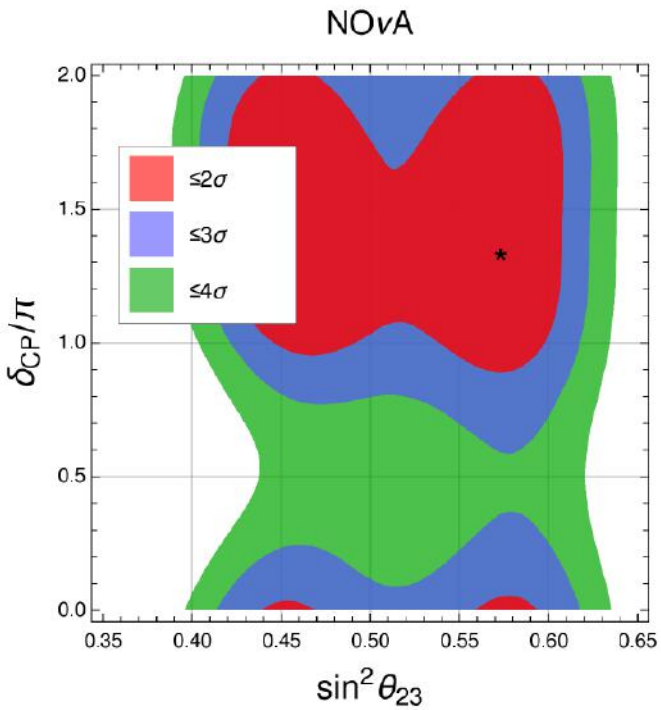


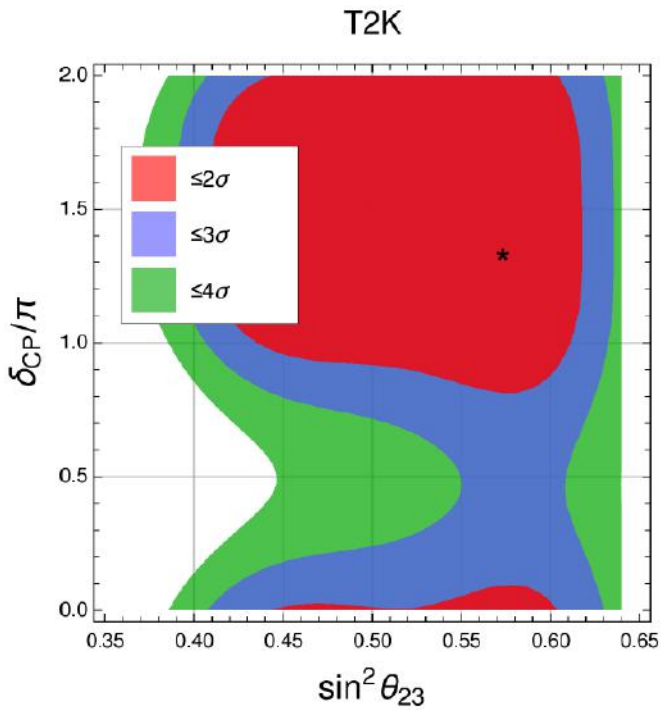
PHYSICAL REVIEW D **90**, 093006 (2014)

Oscillations Status & prospects

θ_{23} and δ_{CP}

1702.03160





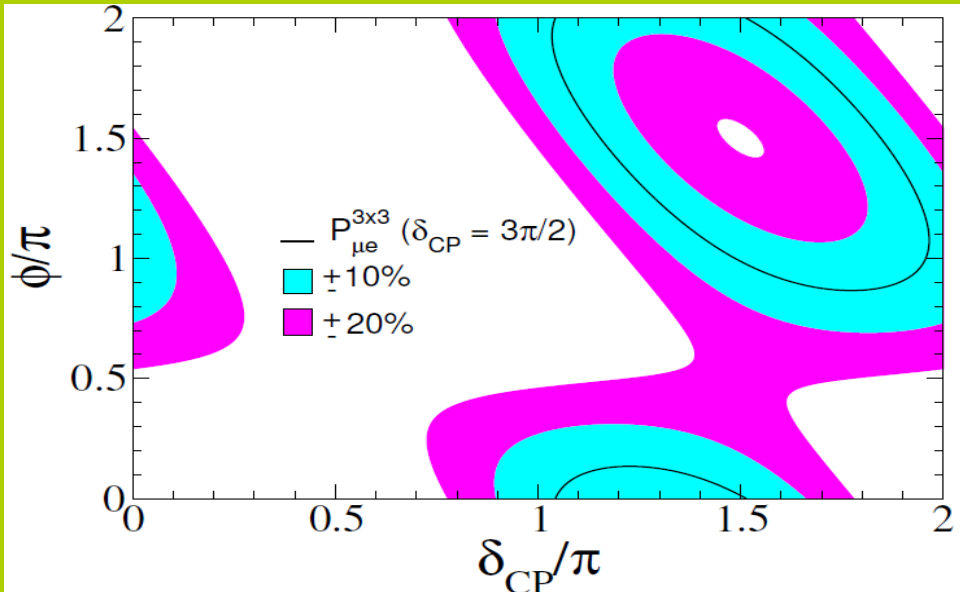
Neutrino oscillations with...

PLB199, 432 (1987)
PhysRevD.92.053009

$$\begin{pmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} U$$

$$\alpha_{11}^2 \geq 0.989\,, \quad \alpha_{22}^2 \geq 0.999\,, \quad |\alpha_{21}|^2 \leq 6.6 \times 10^{-4}$$

non-unitary lepton mixing



O.G. Miranda, J.W.F. Valle / Nuclear Physics B 908 (2016) 436–455

PRL **117,** 061804 (2016) PHYSICAL REVIEW LETTERS week ending 5 AUGUST 2016

New Ambiguity in Probing *CP* Violation in Neutrino Oscillations

O. G. Miranda,[1,*] M. Tórtola,[2,†] and J. W. F. Valle[2,‡]

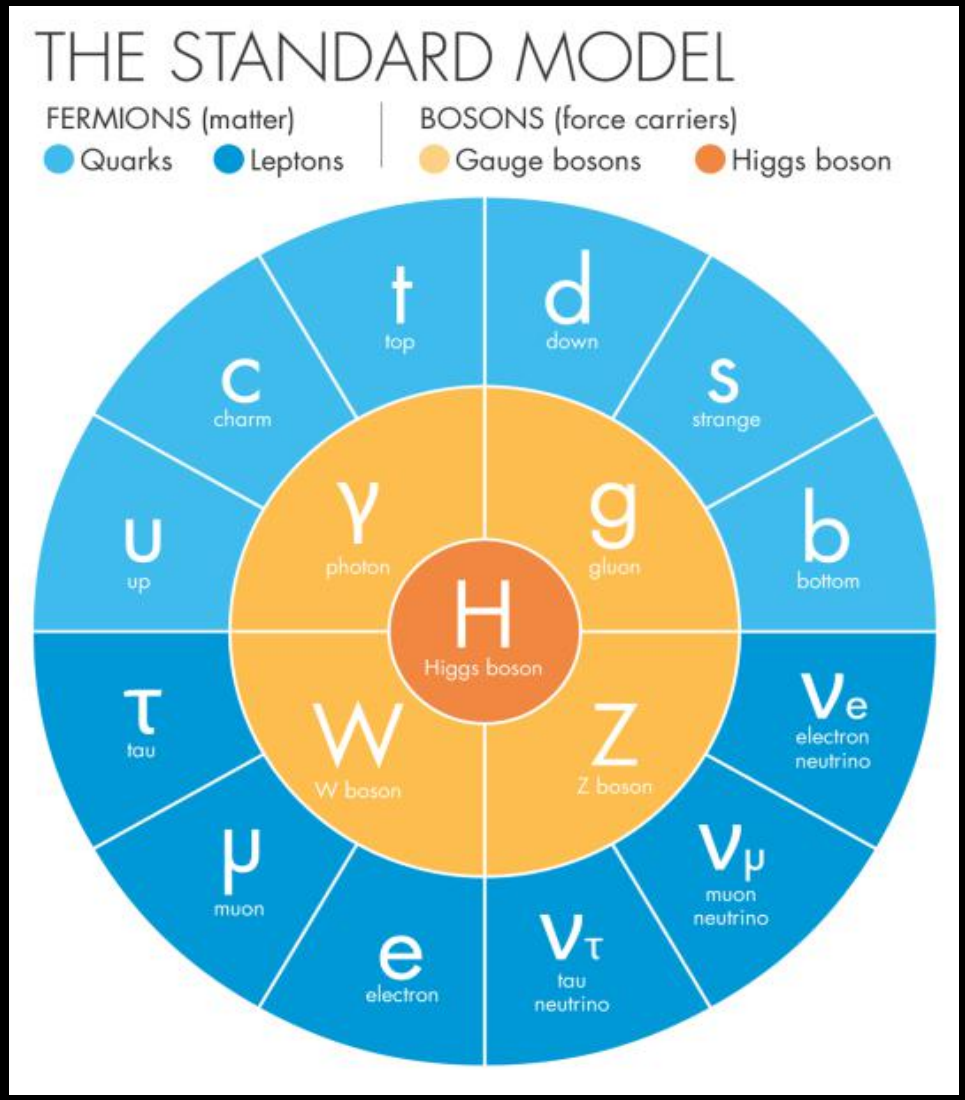
PHYSICAL REVIEW D **95,** 033005 (2017)

Measuring the leptonic *CP* phase in neutrino oscillations with nonunitary mixing

Shao-Feng Ge,[1,*] Pedro Pasquini,[2,3,†] M. Tórtola,[2,‡] and J. W. F. Valle[2,§]

CP confusion

However exciting ...



Higgs not the last brick !

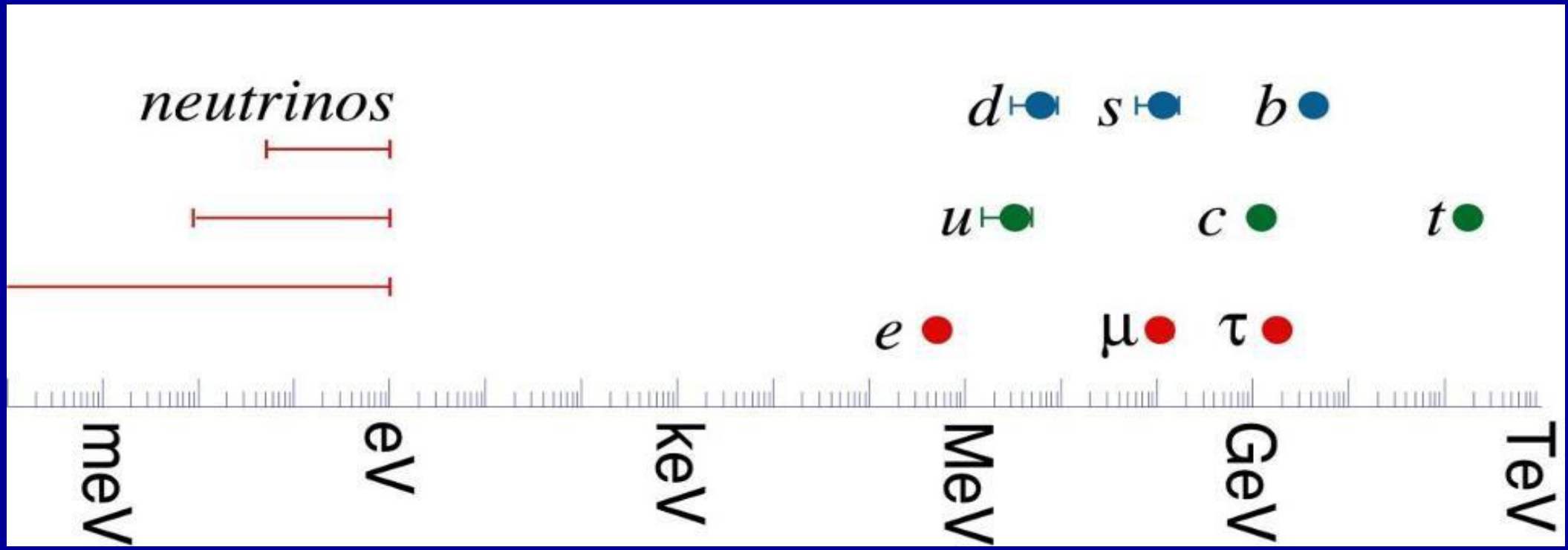
Standard model

does not explain

- Anomalies,
- unification,
- consistency of SSB,
- Gravity
- Flavor

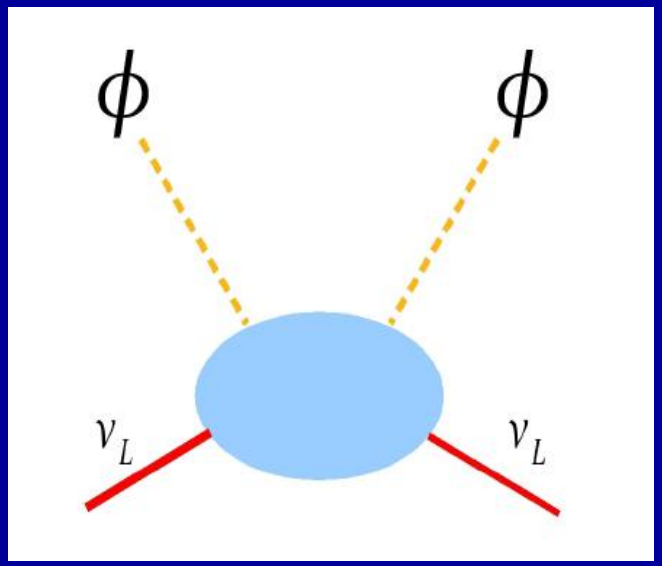
Neutrino mass ...
nor cosmo:

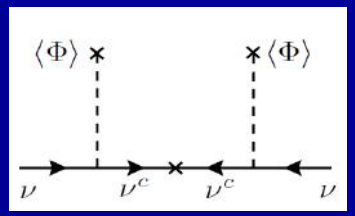
dark matter, inflation,
LG, dark energy



Why tiny neutrino masses

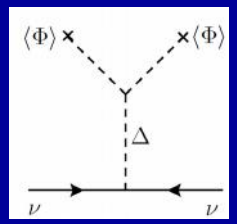
The origin of neutrino mass





TYPE I

Minkowski 77
Gellman Ramond Slansky 80
Glashow, Yanagida 79
Mohapatra Senjanovic 80
Lazarides Shafi Weterrich 81
Schechter-Valle, 80 & 82



TYPE II

Schechter-Valle 80/82

Seesaw

$$v_3 v_1 \sim v_2{}^2$$

MECHANISM

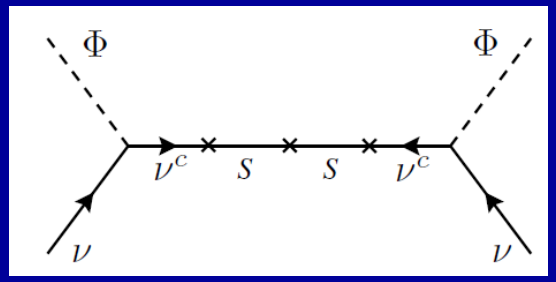
SCALE

FLAVOR STRUCTURE

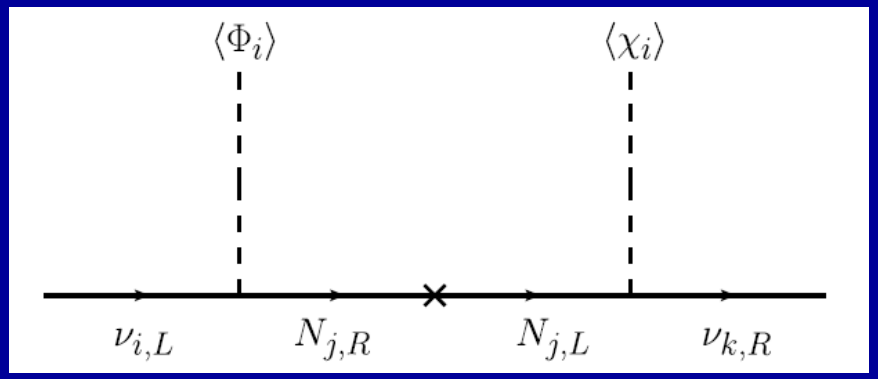
Any number of messengers

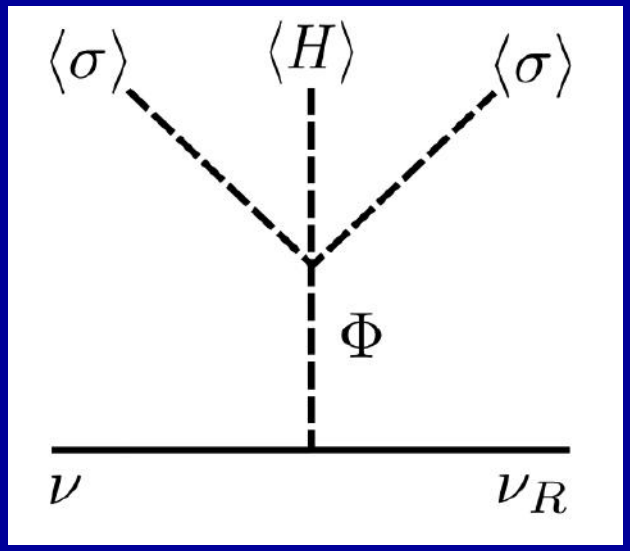
LOW-SCALE SEESAW

Mohapatra-Valle 86
Akhmedov et al PRD53 (1996) 2752
Malinsky et al PRL95(2005)161801
Bazzocchi et al, PRD81 (2010) 051701



seesaw mechanism for Dirac neutrinos





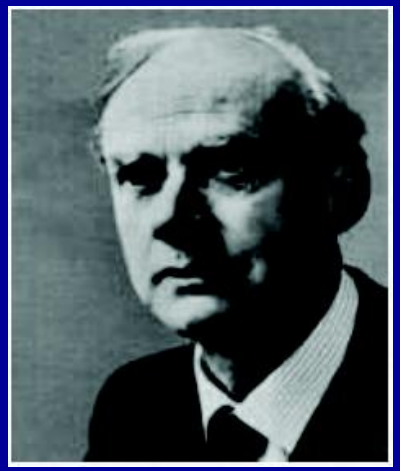
Phys.Lett. B761 (2016) 431-436

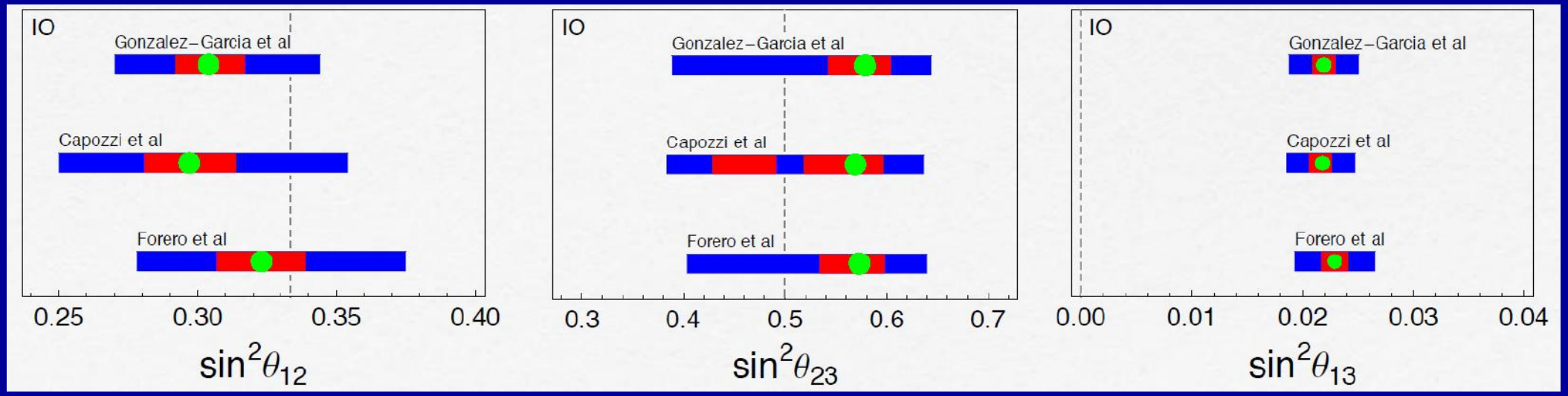
Phys.Lett. B767 (2017) 209-213

Phys.Lett. B762 (2016) 162-165

Phys.Rev. D94 (2016) 033012

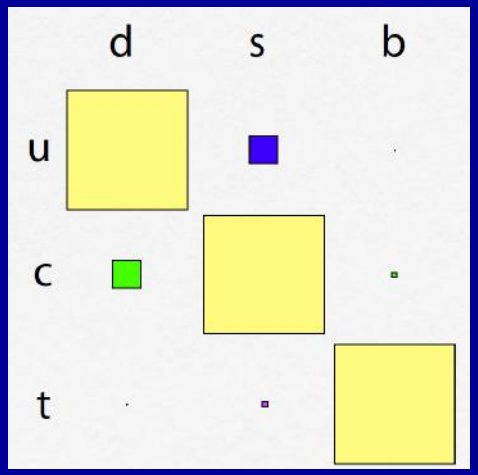
spont U(1) violation...



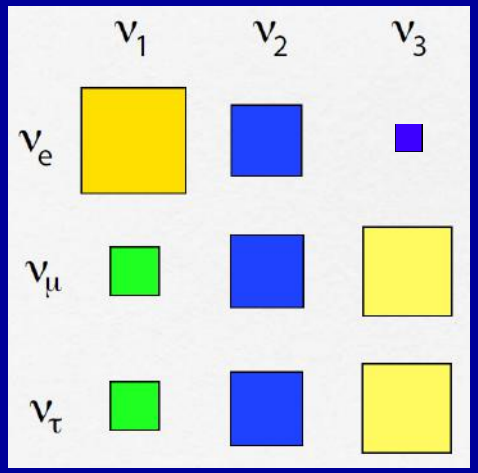


Phys.Lett. B748 (2015) 1-4

Phys.Rev. D86 (2012) 051301



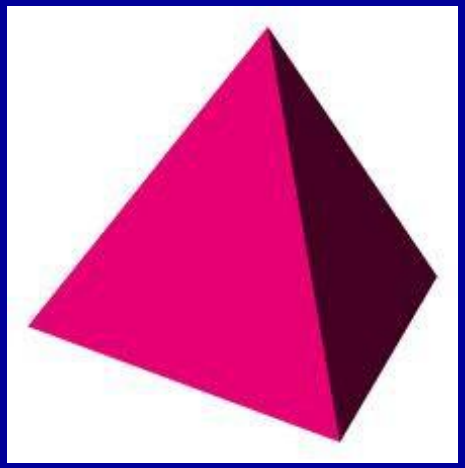
vs



Quarks & lepton masses & mixings...

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$$
$$e_R \qquad \mu_R \qquad \tau_R$$
$$\begin{pmatrix} u \\ d \end{pmatrix}_L \quad \begin{pmatrix} c \\ s \end{pmatrix}_L \quad \begin{pmatrix} t \\ b \end{pmatrix}_L$$
$$u_R \qquad c_R \qquad t_R$$
$$d_R \qquad s_R \qquad b_R$$

Flavor Symmetry

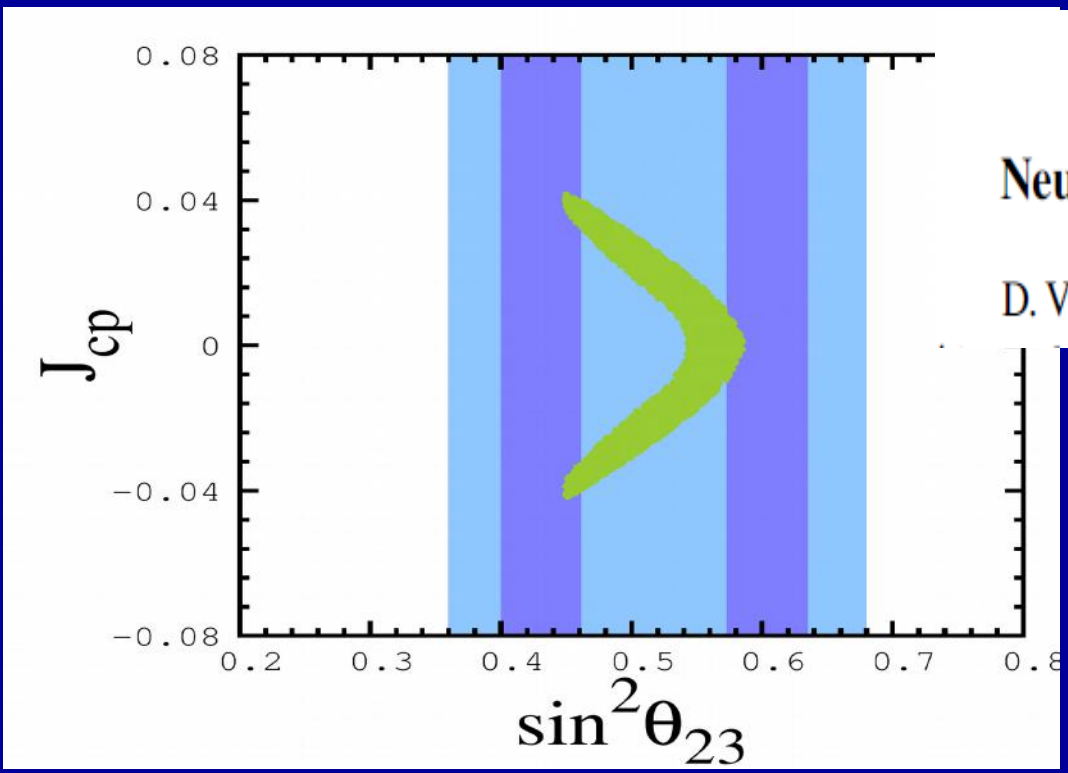


A4

Babu-Ma-Valle PLB552 (2003) 207
Hirsch et al PRD69 (2004) 093006

$$\sin^2\theta_{23} = 0.5$$

$$\sin^2\theta_{13} = 0$$



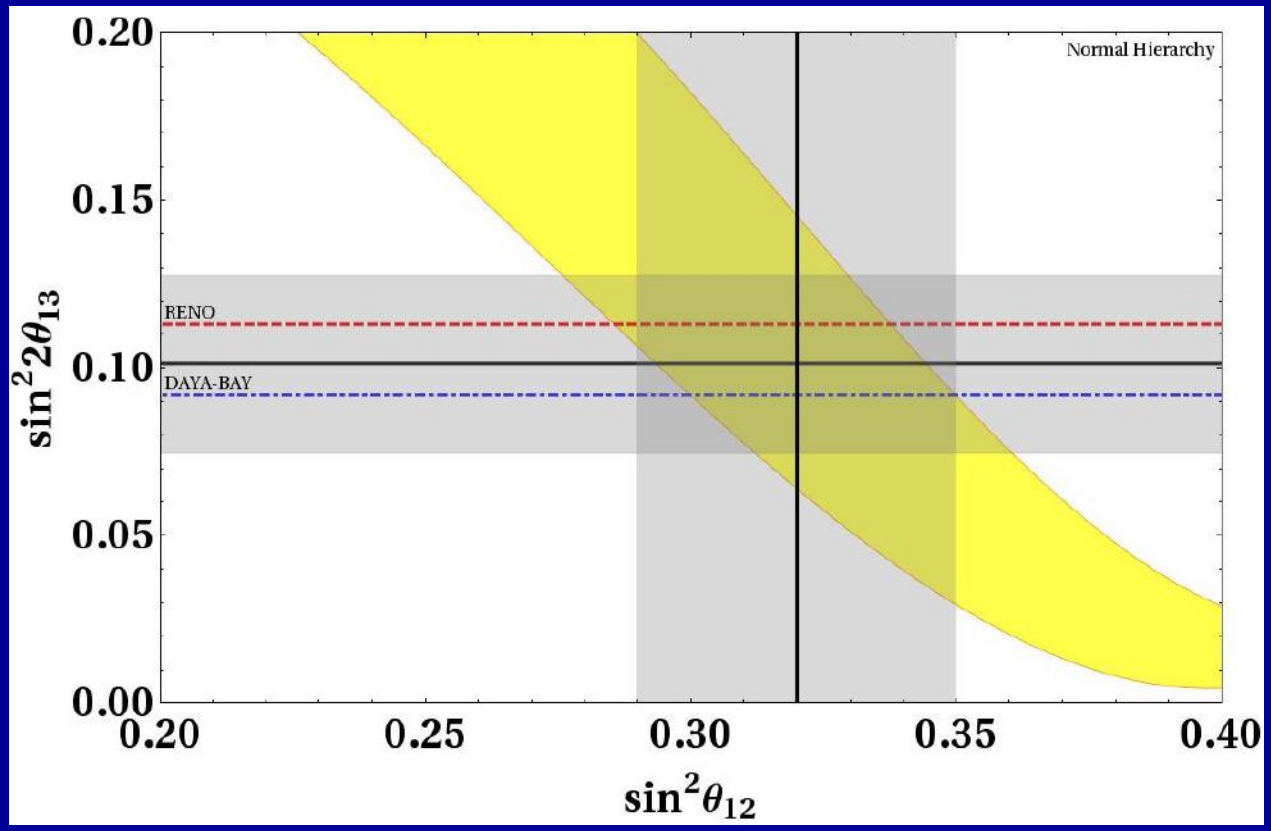
PHYSICAL REVIEW D 88, 016003 (2013)

Neutrino mixing with revamped A_4 flavor symmetry

D. V. Forero,[1,2,*] S. Morisi,[3,†] J. C. Romão,[1,‡] and J. W. F. Valle[2,§]

Flavor correlations

Boucenna et al
PhysRevD.86.073008



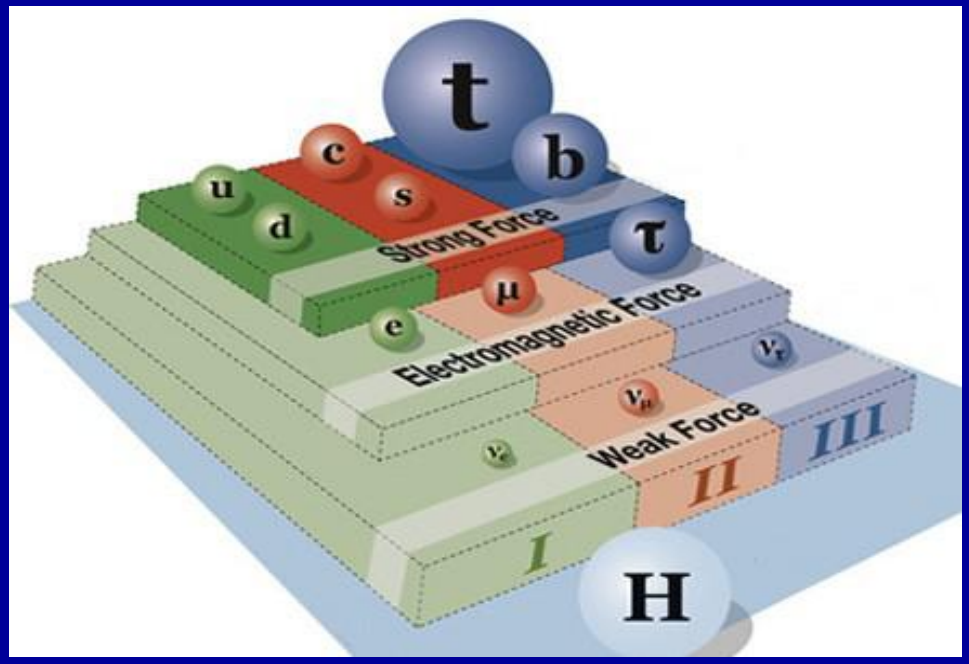
P Chen et al
Phys.Lett. B753 (2016) 644-652
Phys.Rev. D94 (2016) no.3, 033002

Residual CP symmetry approach

Can neutrinos shed light on charged fermion masses?

Flavor dependent b-tau unification

$$\frac{m_\tau}{\sqrt{m_e m_\mu}} \approx \frac{m_b}{\sqrt{m_d m_s}}$$



Morisi et al Phys.Rev. D84 (2011) 036003

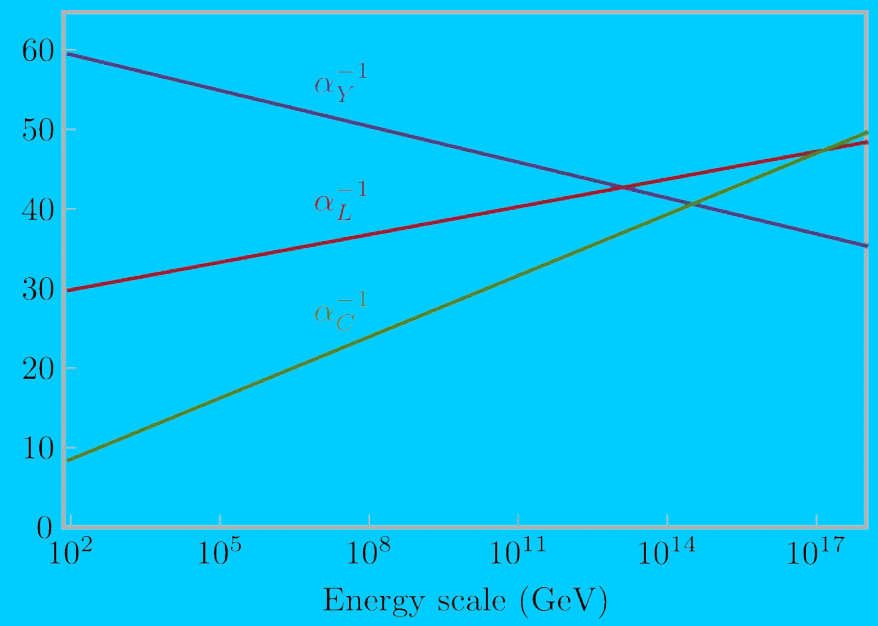
King et al Phys. Lett. B 724 (2013) 68

Morisi et al Phys.Rev. D88 (2013) 036001

Bonilla et al Phys.Lett. B742 (2015) 99

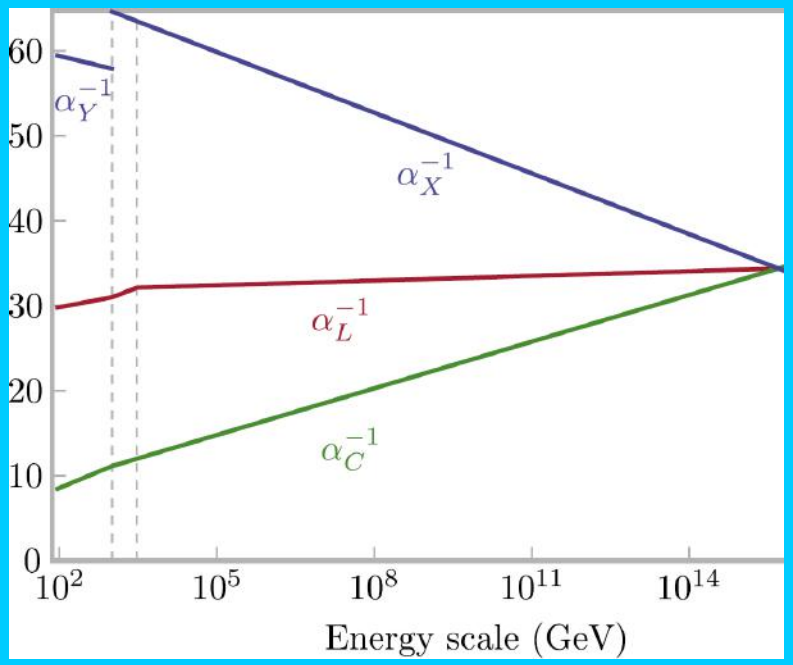
standard model

a near miss ...



What makes the gauge couplings unify? SUSY-GUT

But ... p decay, super-particles ...



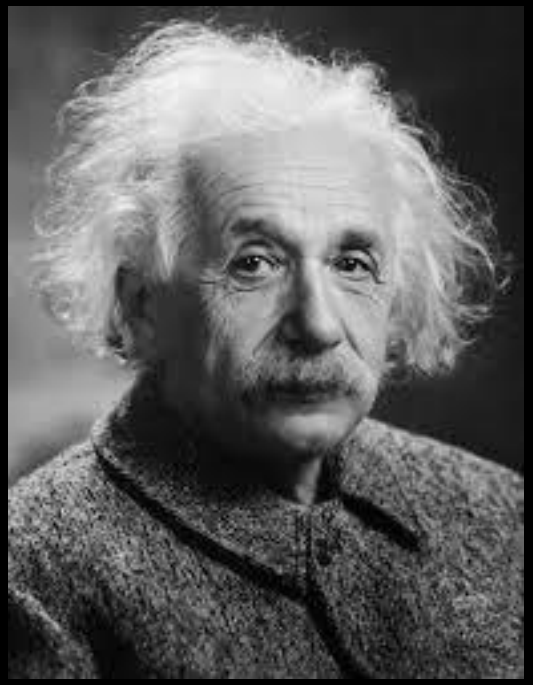
neutrinos & unification

The physics responsible for gauge coupling unification may also induce neutrino masses

Boucenna et al Phys. Rev. D 91, 031702 (2015)

Deppisch et al Phys.Lett. B762 (2016) 432

including Gravity



neutrinos in the theory of everything

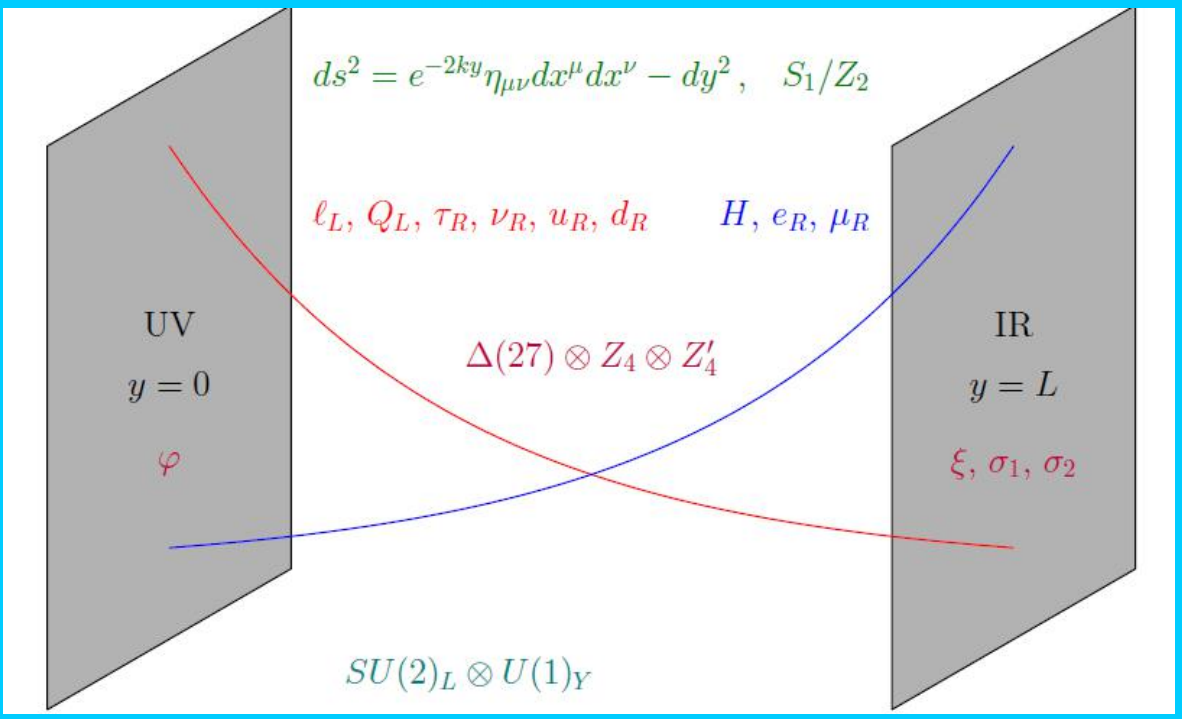
: Chen et al arXiv:1509.06683
JHEP01(2016)007

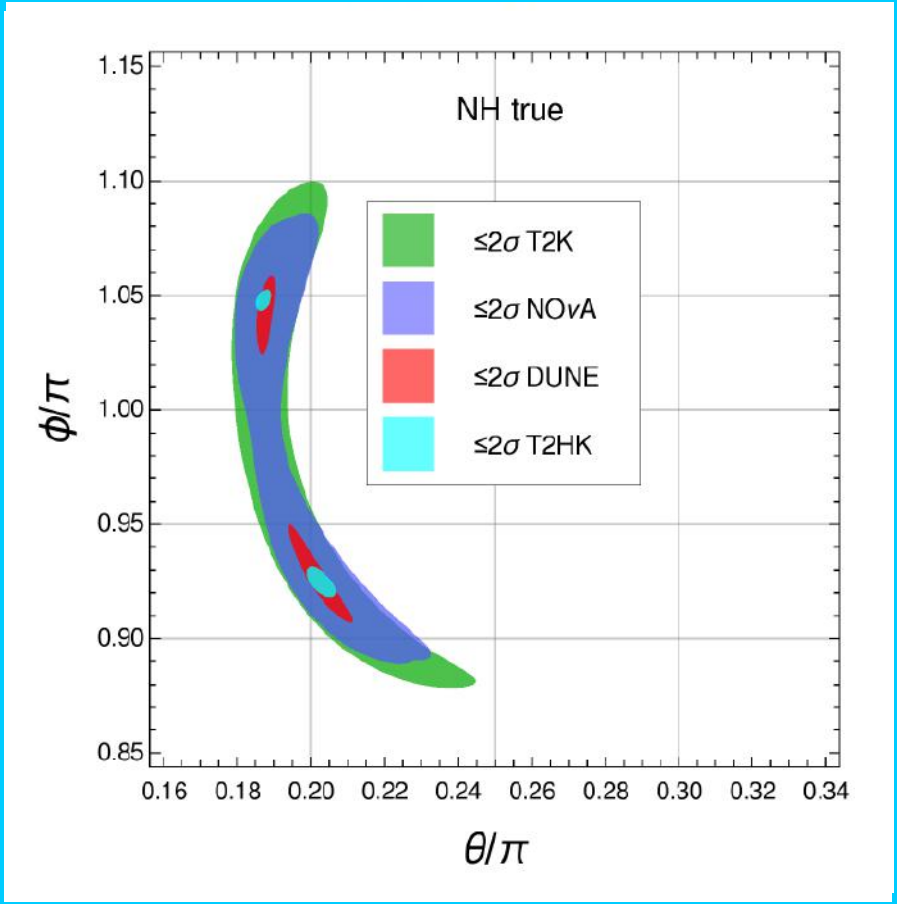
Addazi et al

Phys.Lett. B759 (2016) 471-478

Warped standard model

: Chen et al arXiv:1509.06683
JHEP01(2016)007





masses explained by bulk parameter choices

mixings

$$\sin^2\theta_{12} = \frac{1}{2 - \sin 2\theta_\nu \cos\phi_\nu}$$

$$\sin^2\theta_{13} = \frac{1}{3}(1 + \sin 2\theta_\nu \cos\phi_\nu)$$

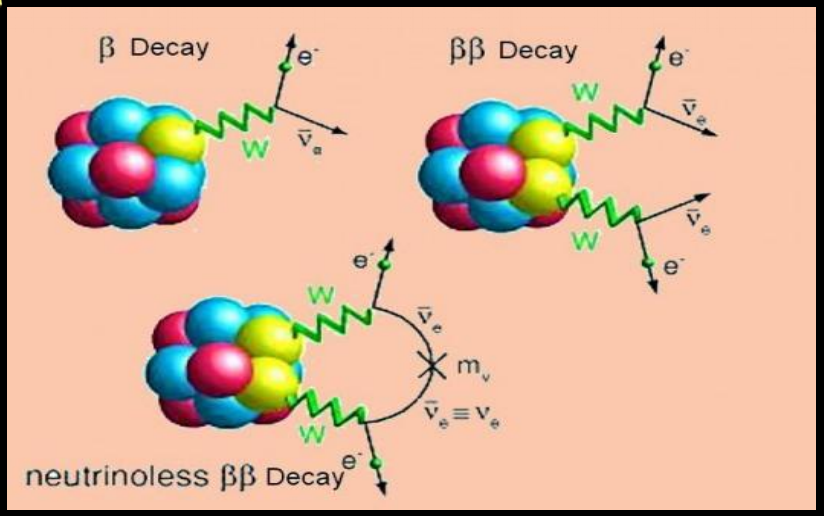
$$\sin^2\theta_{23} = \frac{1 - \sin 2\theta_\nu \sin(\pi/6 - \phi_\nu)}{2 - \sin 2\theta_\nu \cos\phi_\nu}$$

$$J_{CP} = -\frac{1}{6\sqrt{3}}\cos 2\theta_\nu$$

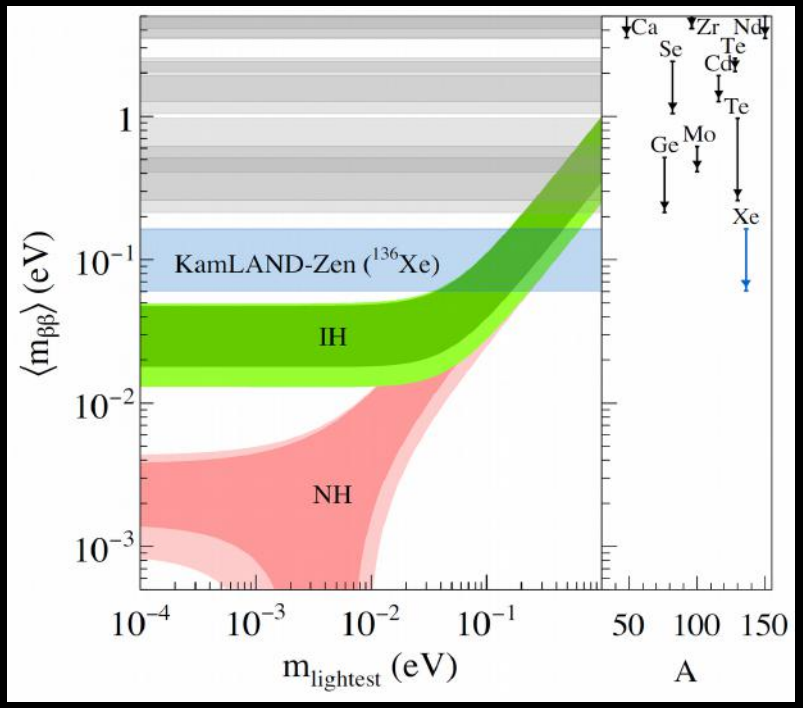
http://arxiv.org/abs/arXiv:1610.05962
https://arxiv.org/abs/1702.03160

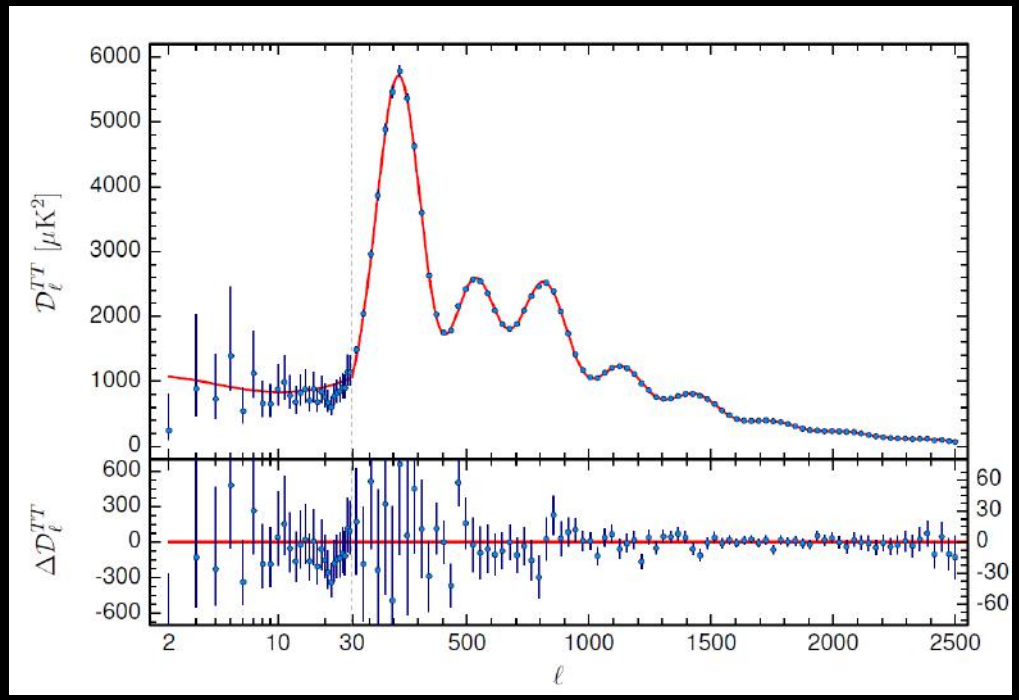
predictions for neutrino oscillations

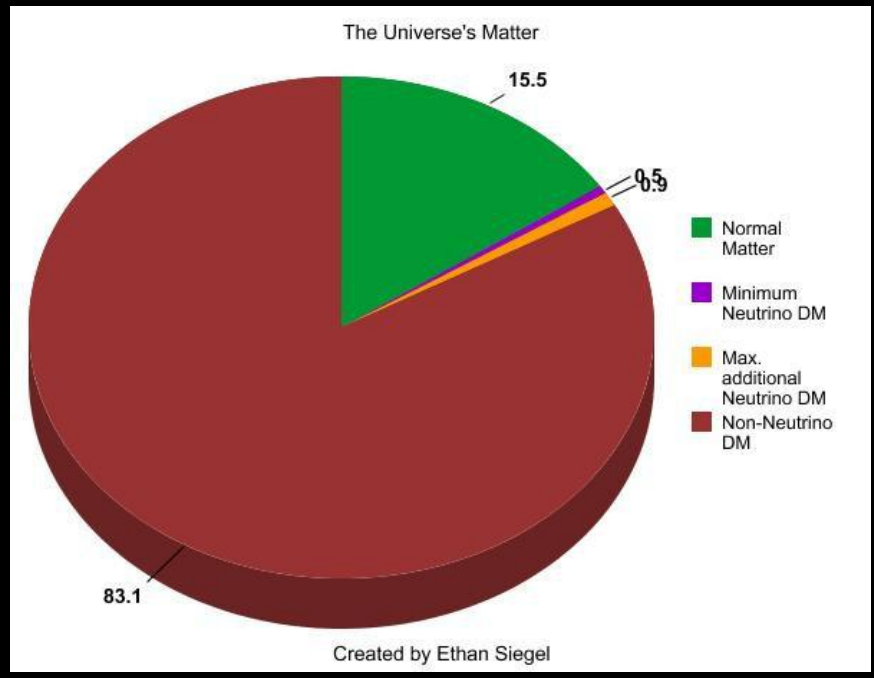
probing neutrino mass scale



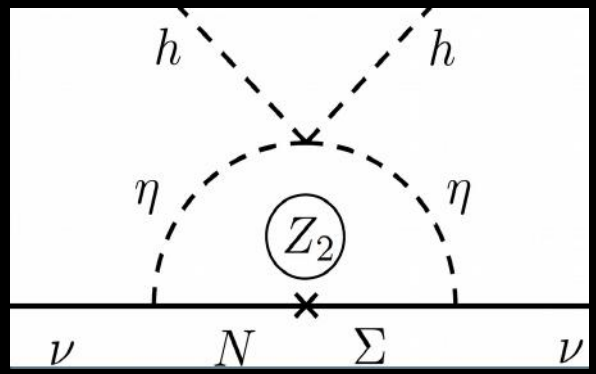
A.S. Barabash arXiv:1104.2714








even if neutrinos form only
tiny DM fraction
they can hold the key
to Dark matter problem



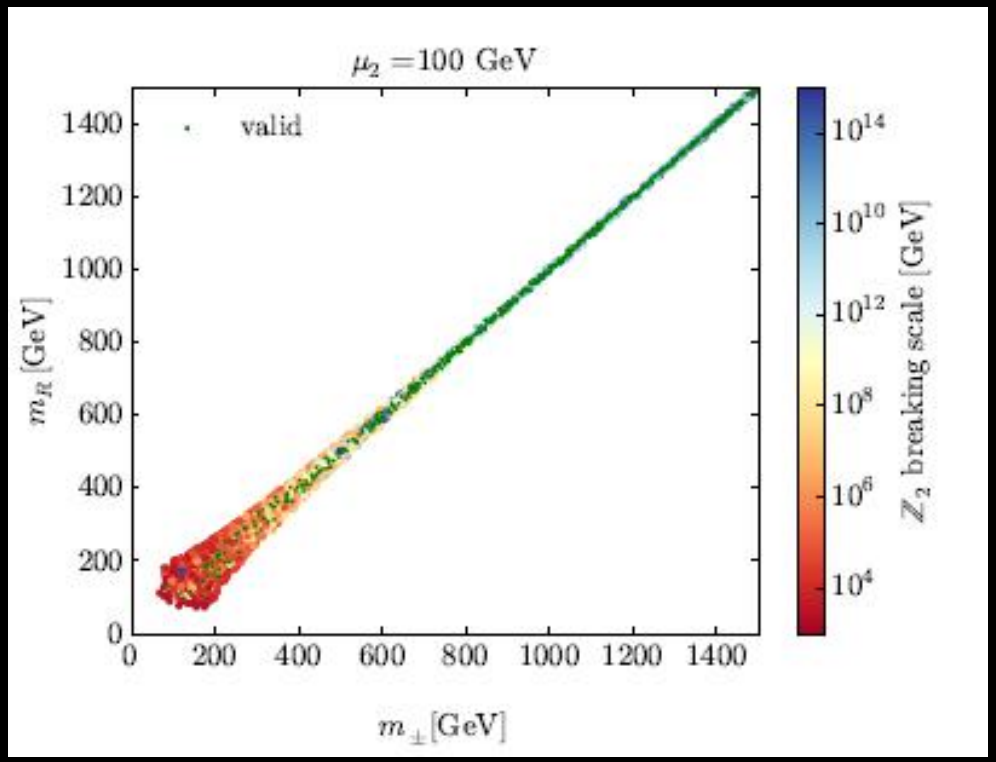
scotogenic dark matter

E Ma, Hirsch et al JHEP 1310 (2013) 149

	Standard Model			Fermions		Scalars	
	L	e	ϕ	Σ	N	η	Ω
Generations	3	3	1	1	1	1	1
$SU(2)_L$	2	1	2	3	1	2	3
$U(1)_Y$	-1/2	-1	1/2	0	0	1/2	0
$\mathbb{Z}_2$	+	+	+	−	−	−	+

WIMP dark Matter as radiative neutrino mass messenger

Merle et al JHEP 1607 (2016) 013

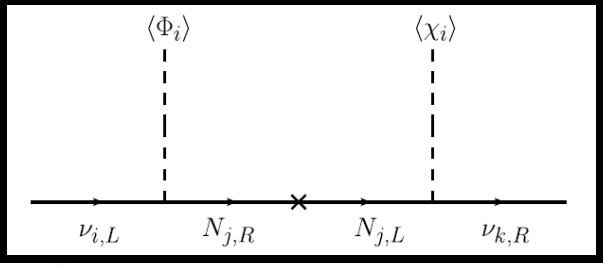


Either scalar or fermion messenger :

“susy dm” without susy

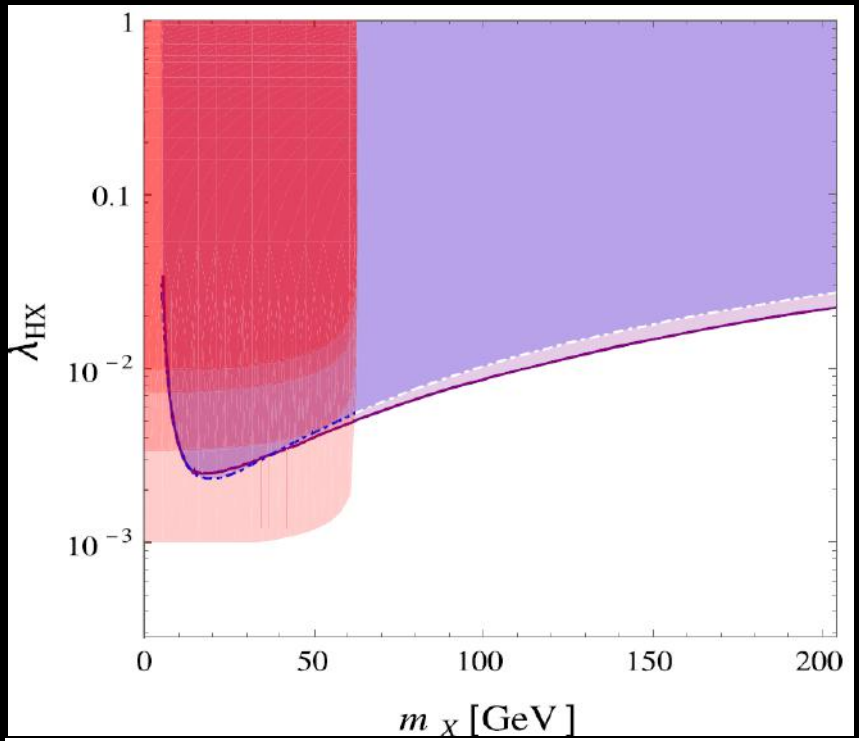
Fields	Z_4	Z_2	Fields	Z_4	Z_2
$\bar{L}_{i,L}$	$\mathbf{z}^3$	$\mathbf{1}$	$\nu_{i,R}$	$\mathbf{z}$	$-\mathbf{1}$
$l_{i,R}$	$\mathbf{z}$	$\mathbf{1}$	$\bar{N}_{i,L}$	$\mathbf{z}^3$	$\mathbf{1}$
$N_{i,R}$	$\mathbf{z}$	$\mathbf{1}$			
Φ	$\mathbf{1}$	$\mathbf{1}$	χ	$\mathbf{1}$	$-\mathbf{1}$
ζ	$\mathbf{z}$	$\mathbf{1}$	η	$\mathbf{z}^2$	$\mathbf{1}$

Chiulia et al Phys.Lett. B767 (2017) 209
Phys.Lett. B761 (2016) 431



DM Stability from Diracness

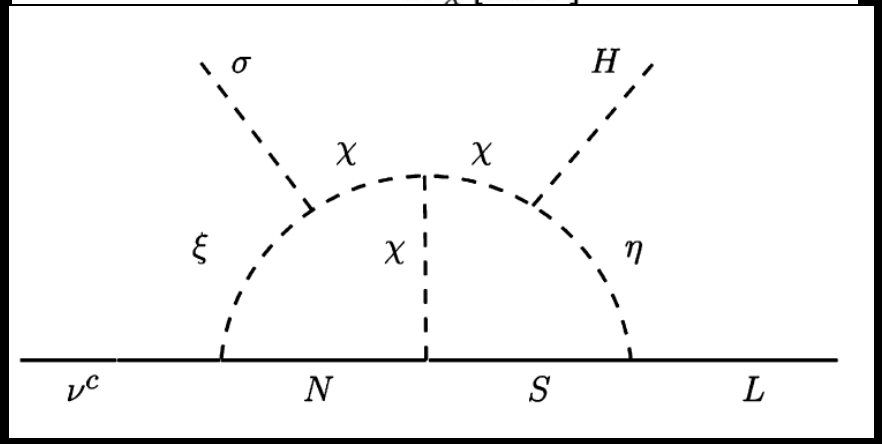
non susy wimp



C. Bonilla et al. / Physics Letters B 762 (2016) 214–218

Table 1
Relevant particle content and quantum numbers of the model.

	$\bar{L}$	ν^c	H	η	N	S	σ	ξ	χ
$SU(2)_L$	2	1	2	2	1	1	1	1	1
$U(1)_D$	-1	3	0	0	-1	1	2	-2	0
Z_3^{DM}	1	1	1	α	α	α	1	α^2	α
Z_3	ω	ω^2	1	1	ω	ω^2	1	1	1

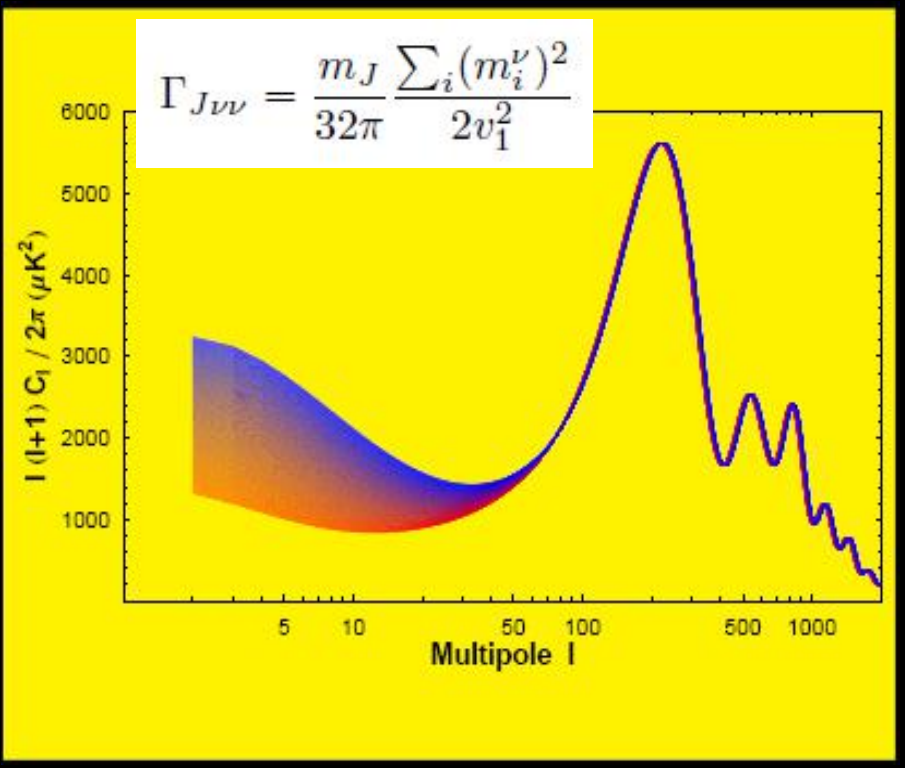


dark matter majorons

Berezinsky, Valle PLB318 (1993) 360

Consistency with CMB

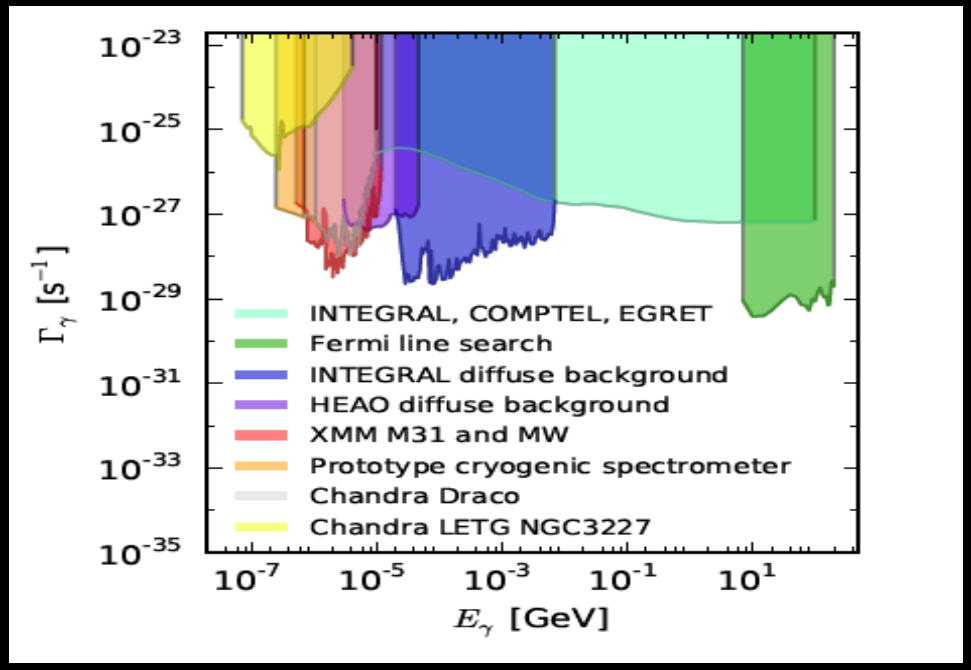
Lattanzi & Valle, PRL99 (2007) 121301



Bazzocchi & al JCAP 0808 (2008) 013

Esteves et al, PRD 82, 073008 (2010)

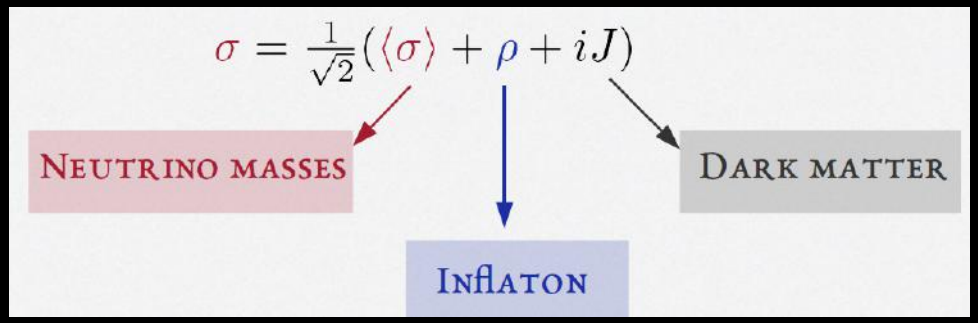
$J \to \gamma\gamma$



Lattanzi et al PRD88 (2013) 063528

majoron dark matter & seesaw inflation

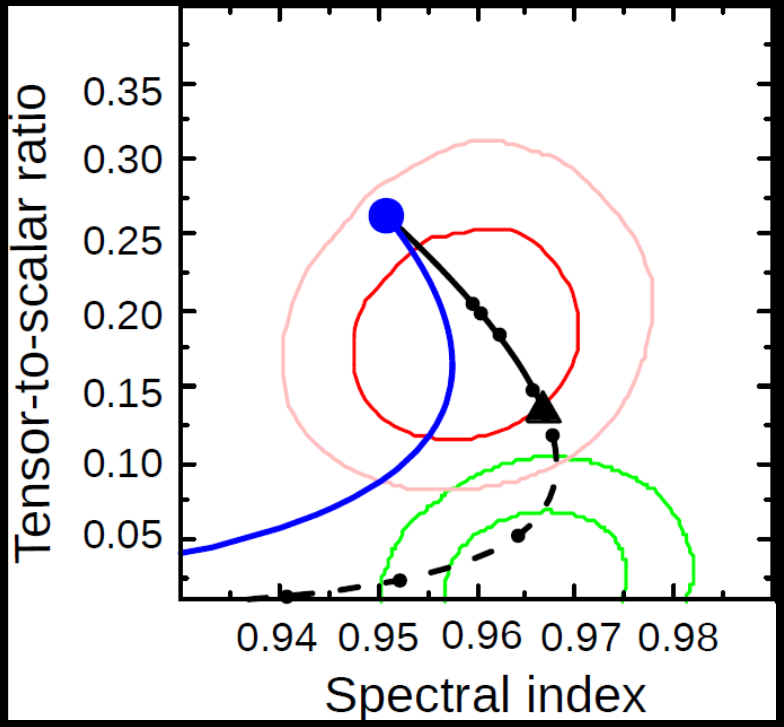
Boucenna, Morisi, Shafi, Valle
PRD90 (2014) 055023

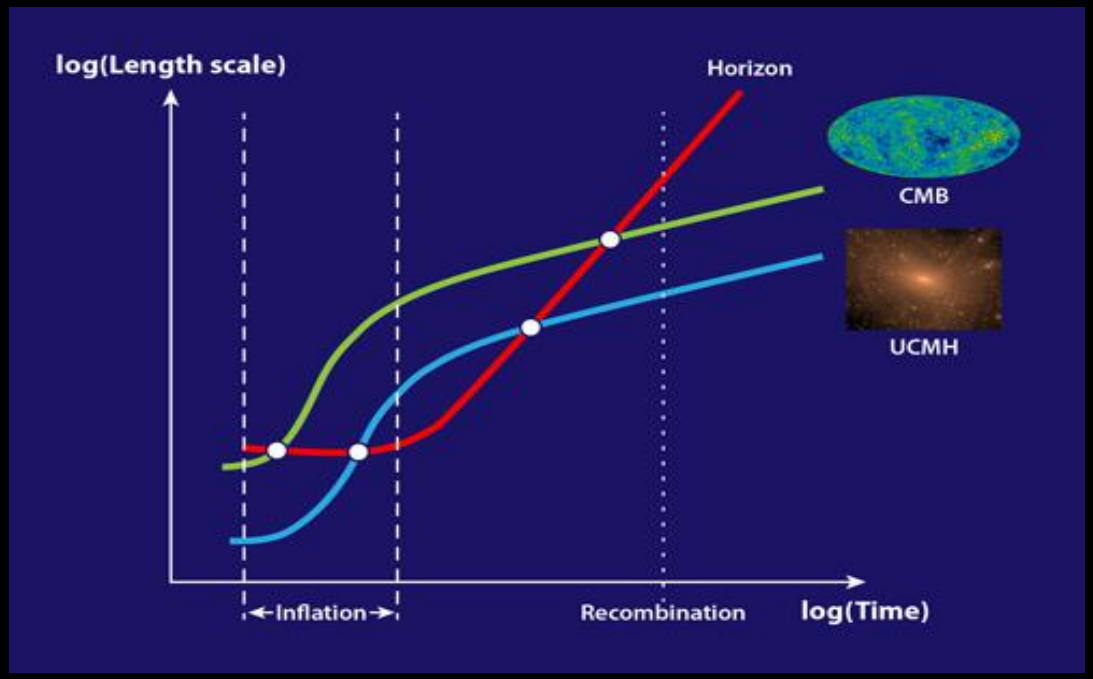


type-I seesaw **Leptogenesis**

Aristizabal et al JCAP 1407 (2014) 052

Quartic versus Higgs Inflation





http://arxiv.org/pdf/1502.00612v1

DARK MATTER FROM FLAVOR SYMMETRY

- *Accidental ?*

Lavoura, Morisi, JV JHEP 1302(2013) 118

- *unbroken subgroup*

Boucenna, et al JHEP 1105 (2011) 037
Hirsch, et al Phys.Rev. D82 (2010) 116003

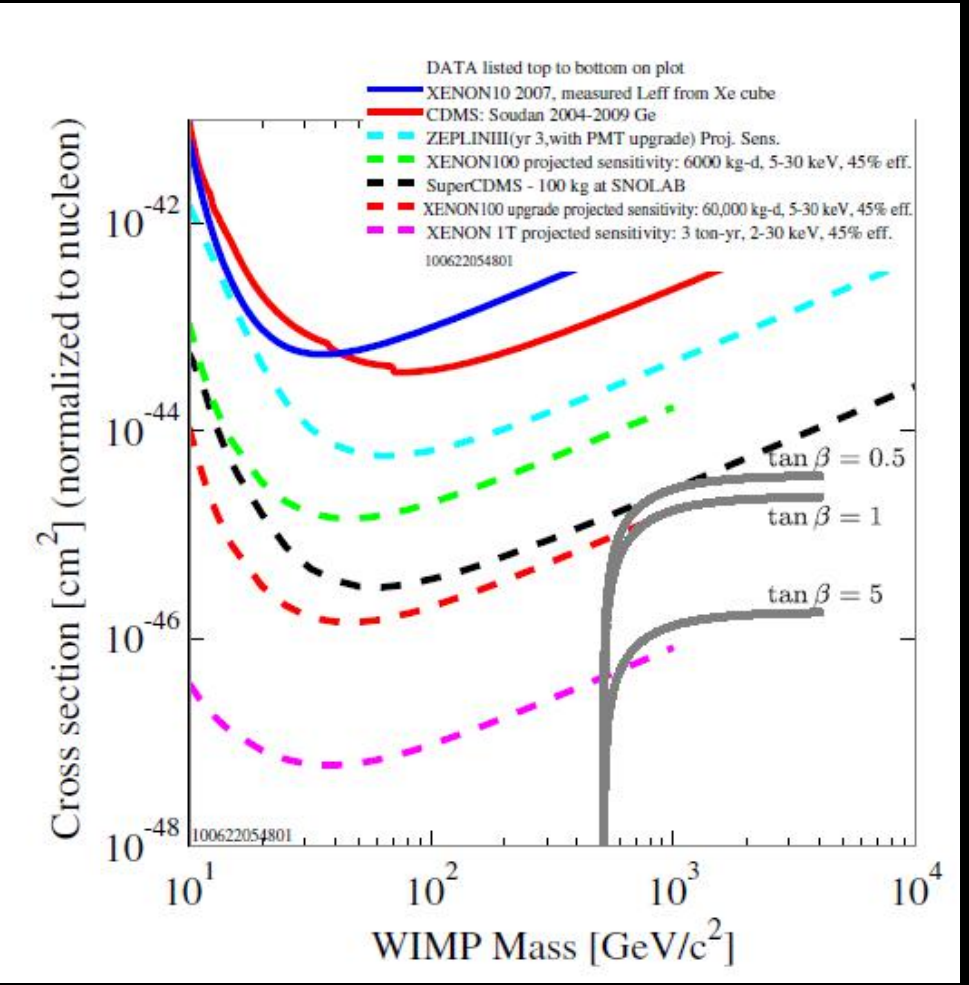
A4

many choices

Z2 PARITY

more possibilities

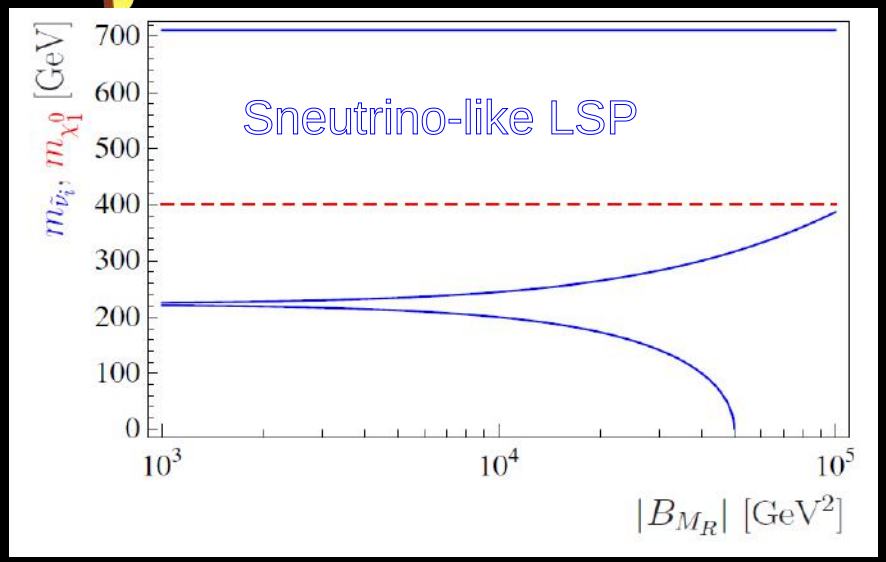
HIGGS PORTAL
DIRECT DETECTION



susy wimp dark matter

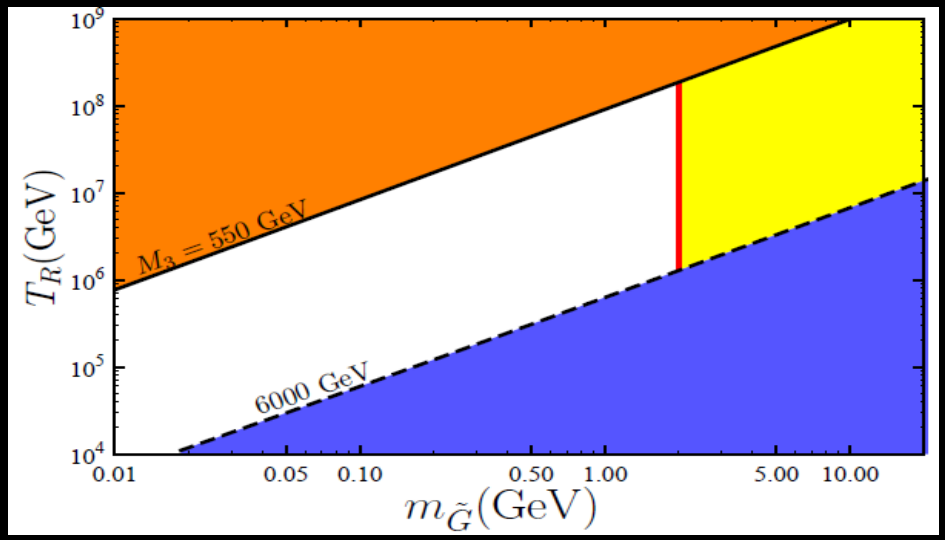
Arina et al PRL101 (2008) 161802
Bazzocchi, Cerdeno, Munoz, J.V., PRD81 (2010) 051701

De Romeri, Hirsch, JHEP 1212 (2012) 106



susy inverse seesaw ...

Restrepo et al PRD85 (2012) 023523



decaying Gravitino dark matter

doubly suppressed decays

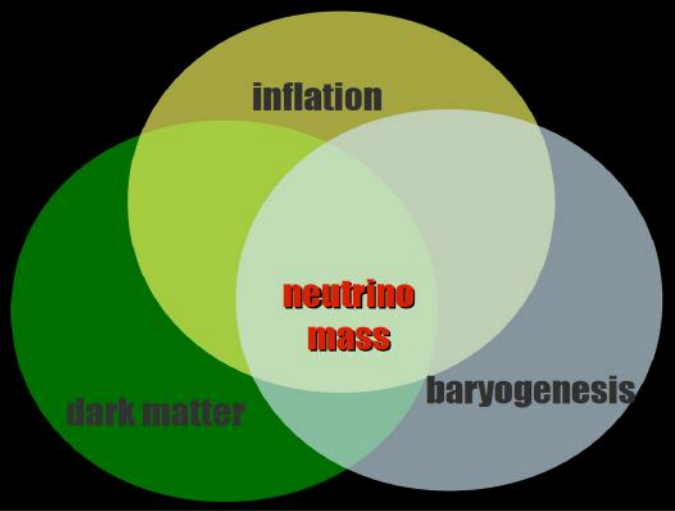
$$\Gamma = \Gamma(\tilde{G} \to \sum_i \nu_i \gamma) \simeq \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{\tilde{G}}^3}{M_P^2}$$

chosen to fit neutrino osc. data

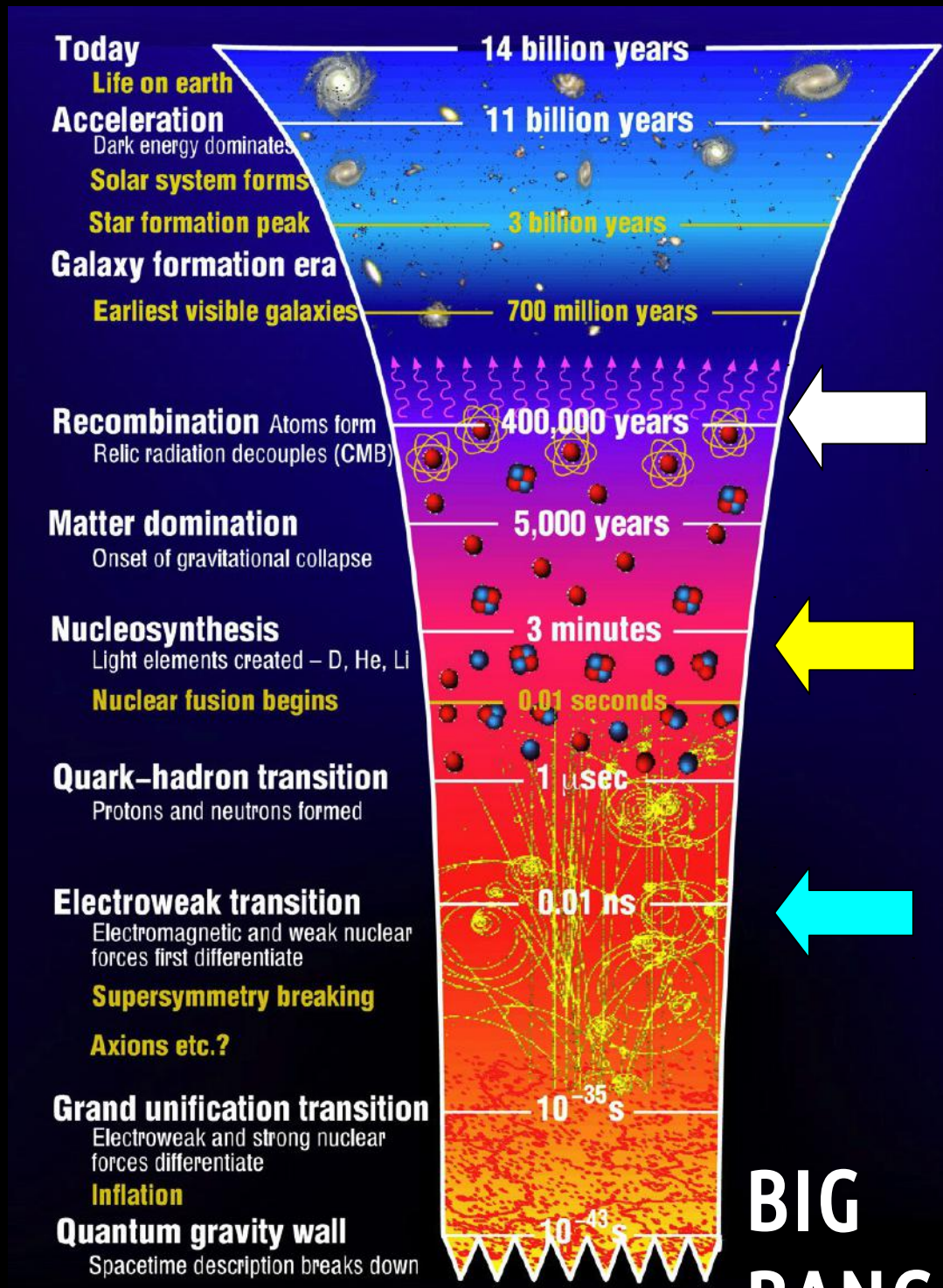
conclusions

A most ubiquitous particle ...

neutrinos may explain WDM or CDM through an emergent theory ...



new features and phenomena



BIG BANG

new phenomena

status and prospects of neutrino oscillations

octant and CP violation sensitivity & predictions from flavor models

heavy and light sterile neutrinos and seesaw mechanism,

effects at High intensity and new long baseline experiments,

wimp dark matter : susy & non-susy

non-wimp dark matter :

majoron dark matter & CMB ... X-ray gamma lines

Gravitino dark matter ... GeV gamma + neutrino lines

Thank you

Neutrinos in High Energy and Astroparticle Physics

Jose Wagner Furtado Valle, Jorge Romao

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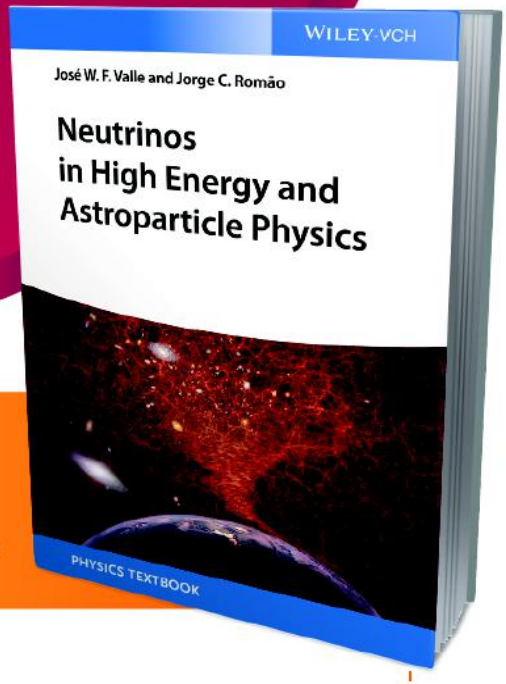

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