U(1)' for neutrino mass, dark matter, stability of the electroweak scale

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On a model building approach to neutrino mass and dark matter with U(1)' gauge symmetry and Coleman-Weinberg mechanism

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Issues in the SM

- Gravity
- Neutrino mass
- Dark matter, Baryon asymmetry of the Universe
- Gauge hierarchy
- Strong CP
- Fermion masses and mixing
- QCD dynamics

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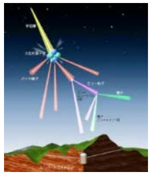
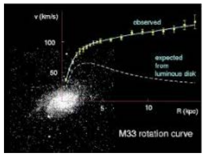
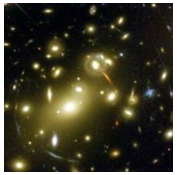
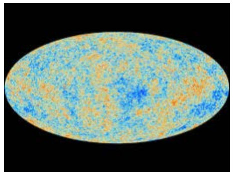
Relatively easy (but compelling)

Neutrino mass, dark matter









Hidden sector ?

Gauge singlet fermion is one of the most attractive possibilities

Minimal extensions

νMSM — SM+ 3 νR — Asaka,Blanchet,Shaposhinikov, 2005

$U(1)_{B-L}$ with Z_2 — SM + 3 νR + 1 scalar — Okada, Seto, 2010

Radiative seesaw (with ν_R) — SM + n νR + m scalars — Krauss, Nasri,Trodden, 2003
Ma, 2006
Aoki, Kanemura,Seto, 2009
…

Discrete (global) symmetries for the stability of DM

→ Gauge symmetry
(The simplest example is U(1)')

Classical scale invariance and Higgs mass

Bardeen, 1995

No fine-tuning in the SM itself if

- Λ^2 is canceled by the counter terms
- No new scale exists between EW and Planck

$$\Theta^\mu_\mu\big|_{classical} = 2m^2\overline{H}H$$

$$\Theta^\mu_\mu\big|_{one\,loop} = 2\Delta m^2\overline{H}H + \sum_i \beta_{\lambda_i} O_i$$

$$\Delta m^2 \sim m^2 \cdot X,\ \text{not}\ \Lambda^2 \cdot X$$

"EW symmetry breaking via Coleman-Weinberg"

(An incomplete list of) related works

Hempfling,1996;Dias,2006;Meissner,Nicolai,2007; Chang,Ng,Wu,2007; Foot,Kobakhidze,McDomald,Volkas,2007;Iso,Okada,Orikasa 2009; Holthausen,Lindner,Schmidt,,2010;Nunneley,Pilaftsis,2010; Hur,Ko,2011;Ishiwata,2012;Englert,Jaeckel,Khoze,Spannowsky,2013;Hambye,Strumia,2013;Marques,Tavares,Schmaltz,Skiba,2013;Carone,Ramos,2013;Farzinnia,He,Ren,2013;Antipin,Mojaza,Sannino,2013;Hill,2014;Kubo,Lim,Lindner,2014…

Can U(1)' kill``three birds" ?

- Smallness of the neutrino masses
- Stability of dark matter
- Fine tuning in the Higgs mass via Coleman-Weinberg mech.

Address the compelling issues such as neutrino masses, dark matter, (and baryon asymmetry) by the physics up to TeV scale, with the same footing as the SM (the gauge principle)

U(1)' for the neutrino mass and DM

e.g., U(1)' acting on three gauge singlet fermions

Lindner, Schmidt, AW 2013

	ν_{R_1}	ν_{R_2}	ν_{R_3}
$U(1)'$	0	q	$-q$

Unique possibility
for anomaly cancellation
for three vR

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Usual Type I seesaw

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Radiative correction

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Usual Type I seesaw

Radiative correction

	ν_{R_1}	ν_{R_2}	ν_{R_3}	η	ϕ	ξ
$SU(2)\times U(1)_Y$	$(1,0)$	$(1,0)$	$(1,0)$	$(\mathbf{2},1/2)$	$(1,0)$	$(1,0)$
$U(1)'$	0	q	$-q$	q	$2q$	q

η : so-called inert doublet $\langle\eta\rangle = 0$

ϕ : breaks U(1)' by VEV $\langle\phi\rangle \sim 1$ TeV

ξ : plays a role in the loop correction $\langle\xi\rangle = 0$

U(1)' for the neutrino mass and DM

$$\mathcal{L} = y_{1\alpha}\nu_{R_1}^\dagger L_\alpha \Phi + y_{2\alpha}\nu_{R_2}^\dagger L_\alpha \eta + \frac{1}{2}(\nu_{R_1}^{\mathrm{T}}, \nu_{R_2}^{\mathrm{T}}, \nu_{R_3}^{\mathrm{T}}) \begin{pmatrix} M_1 & g_{12}\xi^* & g_{13}\xi \\ g_{12}\xi^* & g_1\phi^* & \widetilde{M}_2 \\ g_{13}\xi & \widetilde{M}_2 & g_2\phi \end{pmatrix} \begin{pmatrix} \epsilon\,\nu_{R_1} \\ \epsilon\,\nu_{R_2} \\ \epsilon\,\nu_{R_3} \end{pmatrix} + \text{h.c.},$$

Mass eigenstates

$$\begin{pmatrix} N_2 \\ N_3 \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_{R_2} \\ \nu_{R_3} \end{pmatrix}$$

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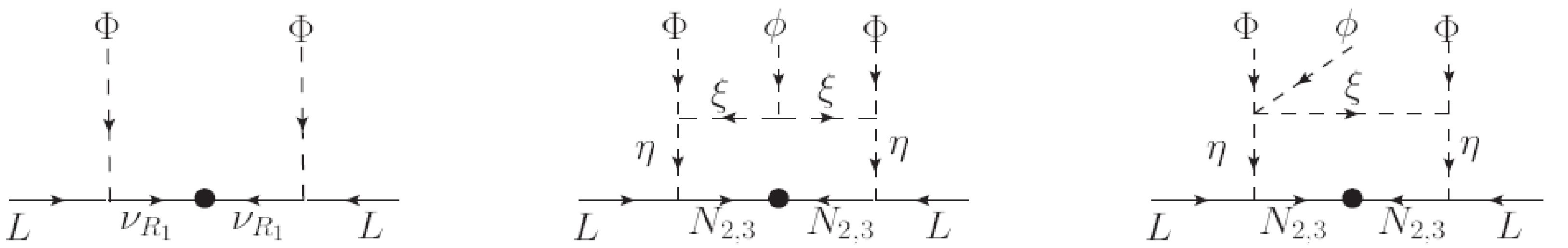
Neutrino mass and mixing



$$(\mathcal{M}_\nu^{\rm tree})_{\alpha\beta} \simeq y_{1\alpha} y_{1\beta} \frac{v^2}{M_1} \qquad (\mathcal{M}_\nu^{\rm rad})_{\alpha\beta} \simeq y_{2\alpha} y_{2\beta} \left(\frac{1}{16\pi^2} \frac{v^2}{M_{2,3}} \frac{\langle \phi \rangle}{M_*} \right)$$

Normal hierarchy (m_1=0 , m_2 < m_3) is natural

An illustrative fit

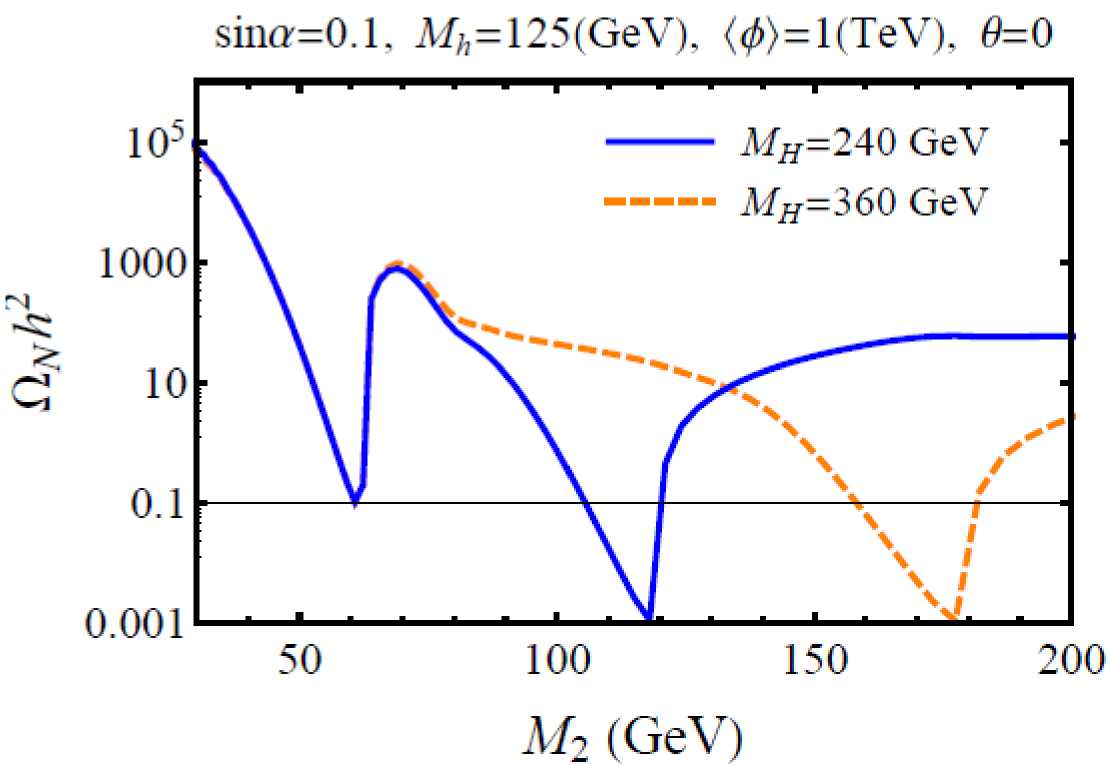
$$y_{2\alpha} = (U_{\alpha 2})\, y_2, \qquad y_{1\alpha} = (U_{\alpha 3})\, y_1,$$

$$M_{2,3} = 100\,\text{GeV},\ M_1 = M_\eta = \langle \phi \rangle = 1\,\text{TeV and } M_* = 10\,\text{TeV}$$

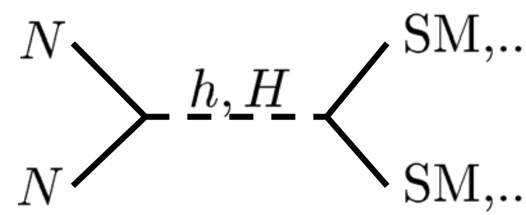
➡ $y_2 \approx 3 \times 10^{-5}$ and $y_1 \approx 1 \times 10^{-6}$

Relic density

s-channel exchange of scalars and Z’



$\sin\alpha = 0.1,\ M_h = 125\,\mathrm{GeV},\ \langle\phi\rangle = 1\,\mathrm{TeV},\ \theta = 0$



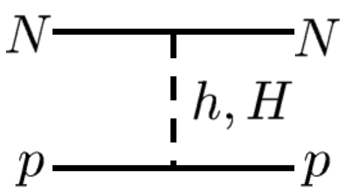
So-called Higgs portal

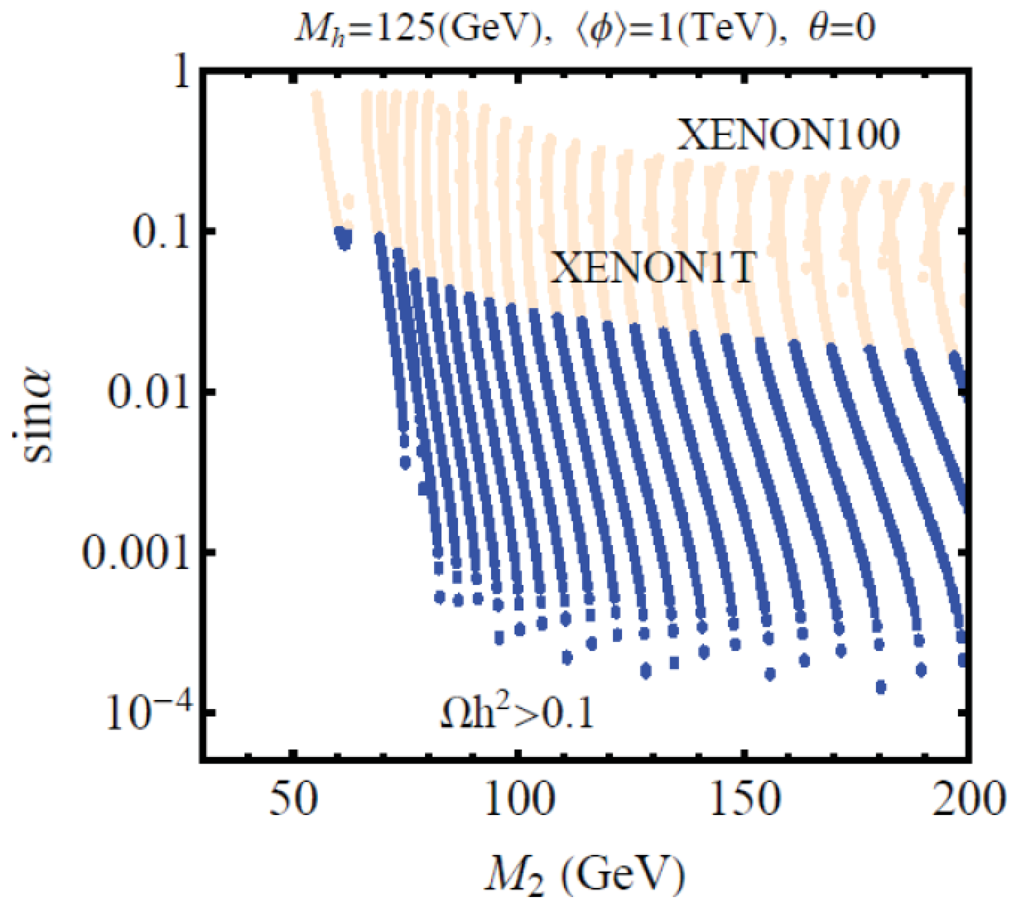
$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \Phi_R \\ \phi_R \end{pmatrix}$$

Correct relic density needs $2M_2 \simeq M_{h,H}$

Z’ contribution is small

Direct Detection





M_H is varied from 150 GeV to 500 GeV

$$M_h = 125\,\text{GeV},\ \langle\phi\rangle = 1\,\text{TeV},\ \theta = 0$$

Higgs and Z’

● Higgs-SM coupling and invisible decay width

・Higgs couplings are suppressed by cosα

EW precision & Higgs data
⇒ c_v = [0.98,1.08] @ 95%CL
Falkowski, Riva, Urbano,2013

$$\sin\alpha \lesssim 0.2$$

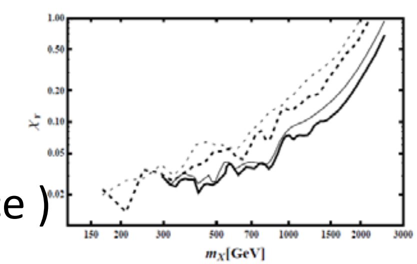
・If DM mass is smaller than $M_h/2$ ・・・ B_{inv} < few percent

A global fit of ATLAS,CMS, andTevatron
B_{inv} < 24 % Belanger et. al. 2013

● Z’ boson

・η is charged under both $U(1)_Y$ and U(1)’
⇒ Kinetic mixing is generated radiatively (～10^{-3})

K < 0.03 for 10 GeV < Mz’ < 1 TeV (by ATLAS, CMS, EW precision)
K < 0.003 for 1 GeV < Mz’ < 10 GeV (by $e^+e^- \rightarrow \gamma\, l^+ l^-$ with Y resonance)
See for instance, Jaeckel, Jankowiak, Spannowsky 2013



Scale invariant extension

A straightforward idea is …

Mass parameters ⇒ a singlet scalar

	ν_{R_1}	ν_{R_2}	ν_{R_3}	η	ϕ	ξ	X
$SU(2)\times U(1)_Y$	$(1,0)$	$(1,0)$	$(1,0)$	$(\mathbf{2},1/2)$	$(1,0)$	$(1,0)$	$(1,0)$
$U(1)'$	0	q	$-q$	q	$2q$	q	0

ϕ is charged under $U(1)'$ ⇒ gets VEV by Coleman-Weinberg

If only $H^\dagger H\phi^*\phi$ and $X^\dagger X\phi^*\phi$ have negative couplings

$$\langle\phi\rangle\sim 1\,\mathrm{TeV},\ \langle H\rangle\sim 100\,\mathrm{GeV},\ \langle X\rangle\sim 1\,\mathrm{TeV},\ \langle\eta\rangle=\langle\xi\rangle=0$$

Scale invariant extension

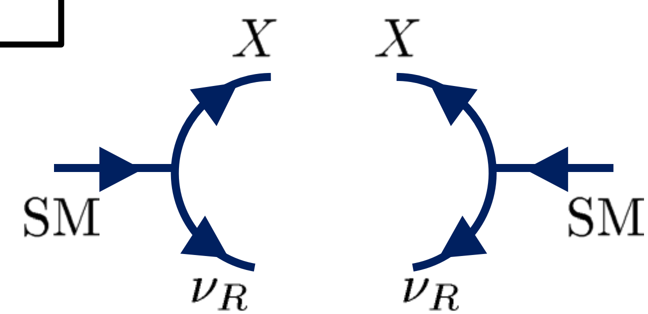
Can we kick out the gauge-singlet fields entirely ?

→ Looks like it's not easy .....

We start with a gauge singlet fermion charged under U(1)'

$$\nu_R\,(\text{SM lepton})\,X$$
$$q \qquad\qquad -q$$

- Two chirality flippings are needed



But then

3-points

$\nu_R \nu_R \phi$ (q q $-2q$) : Dimensionless ○

$X X \phi^*$: Dimensionful ×

4-points $X X Y Y$

Summary

● Can U(1)’ gauge symmetry account for neutrino mass, dark matter, (Coleman-Weinberg) EWSB ?

- Two of them are OK.
- (it seems) accommodating the third one needs some trick