FImP Miracle of Sterile Neutrino by Scale Invariance

Zhaofeng Kang, KIAS, 28.01.2015

Joint Winter Conference on Particle Physics,
String and Cosmology

YongPyong-High1 2015

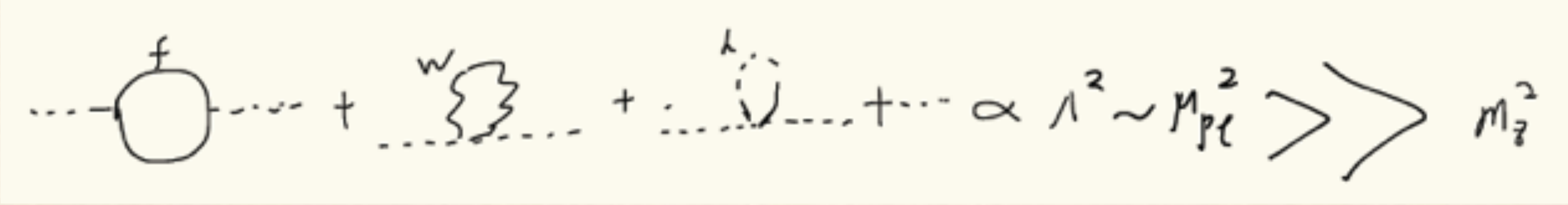
Outline

- Three leading new physics
- Scale invariant νMSM
- Conclusions

Three leading new physics

- Theoretically: gauge hierarchy problem

  Why does electro-weak (EW) scale exist facing $M_{\rm pl}$?



  Solutions: supersymmetry, composite,…, scale invariance?

- Phenomenologically: nonzero neutrino masses & the existence of dark matter (DM)

  Adding right-handed neutrinos (RHNs) & neutral stable particle

Three leading new physics

- Address them in an unified framework?

SUSY: solving gauge hierarchy problem & offering LSP as DM candidate. However, it is not a theory of neutrino

*v*MSM: DM is the keV scale RHN, unifying RHN and DM!!! But it can not address the hierarchy problem

- Their dark matter is beautiful

Dark matter is predicted instead of added!
Stability of DM is not required but accident!
Correct relic density is via a miracle, for LSP being WMIP…

Scale invariant *v*MSM (*v*SISM)

- *v*MSM version 1.0

T. Asaka, S. Blanchet and M. Shaposhnikov, Phys. Lett. B 631 (2005) 151.

*v*MSM=SM+RHNs=the canonical seesaw with very low seesaw scale

$$\mathcal{L}_{\nu\mathrm{MSM}} = \mathcal{L}_{\mathrm{MSM}} + \bar{N}_I i\partial_\mu\gamma^\mu N_I - F_{\alpha I}\,\bar{L}_\alpha N_I \Phi - \frac{M_I}{2}\,\bar{N}_I^c N_I + \mathrm{h.c.}\,,$$

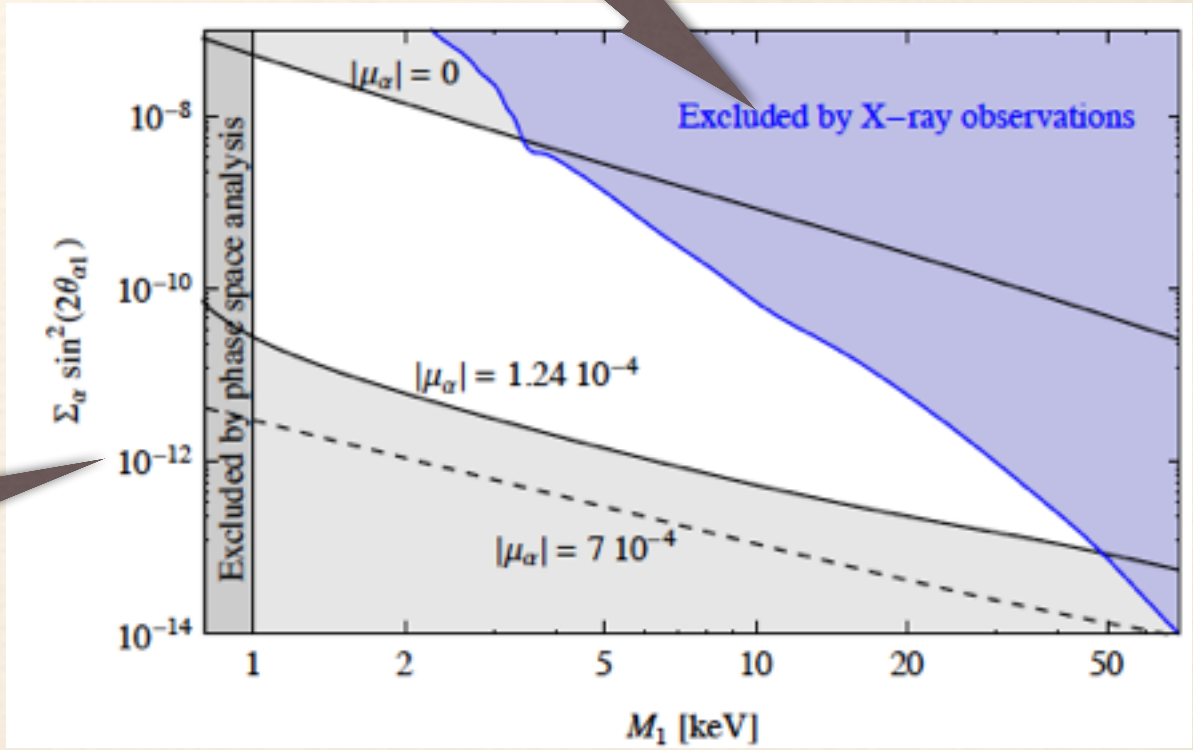
Accidental stability of the lightest RHN, N_1: $\Gamma_{N_1\to\nu\gamma} \simeq \frac{9G_F^2\alpha M_1^5}{256\pi^4} \times \sin^2\theta_1,$

Prediction: *X*-ray line——3.5keV line?

Relic density: sterile-active neutrino oscillation with(out) resonant effect

Lyman-alpha bound

production is problematic



Scale invariant *ν*MSM (*ν*SISM)

- *ν*MSM version 2.0

*ν*MSM 2.0=*ν*MSM 1.0 with classical SI (no massive couplings)

$$\mathcal{L} = \frac{\lambda_1}{2}|H|^4 + \frac{\lambda_2}{2}|S|^4 + \lambda_3|H|^2|S|^2 + \lambda_4|H|^2\left(S^2 + S^{*2}\right) + \lambda_5|S|^2\left(S^2 + S^{*2}\right) + \frac{\lambda_6}{2}\left(S^4 + S^{*4}\right) + \left(\frac{\lambda_{sn}}{2} S N^2 + y_N \bar{\ell} H N + c.c.\right).$$

SI demands singlets with VEVs to give Majorana masses of RHNs; One complex singlet is required to accommodate Higgs phenomenology

similar singlet was introduced before, but only here it is a result of symmetry, namely in the sprite of naturalness

No need of any global symmetry, but here imposing CP-invariance in the Higgs sector in order to reduce parameters

Scale invariant *v*MSM (*v*SISM)

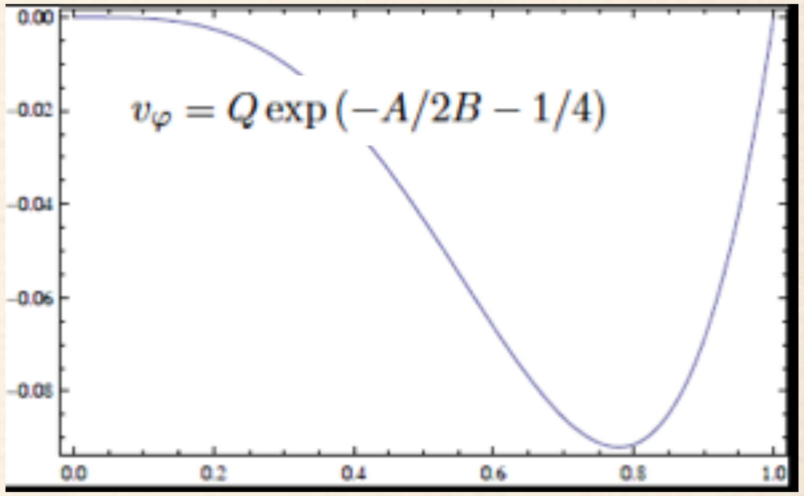
S. Coleman and E. Weinberg, Phys. Rev. D 7, 1888 (1973).

- SI spontaneously breaking: origin of VEVs

SI is anomaly, so a scaleless theory can break SI!

$$V_{\rm eff} = A\phi_{\rm cl}^4 + B\phi_{\rm cl}^4 \ln\frac{\phi_{\rm cl}^2}{Q^2},$$

$$A = \frac{\lambda}{8} + \frac{1}{64\pi^2}\sum_P n_P g_P^4\left(-A_P + \ln g_P^2\right),$$
$$B = \frac{1}{64\pi^2}\sum_P n_P g_P^4,$$



The prediction of a light Higgs state $m_\phi^2 = 8B\langle\phi_{\rm cl}\rangle^2$

Heavy top makes B<0, so SM can not be SI. But extension by S works!

$$S = \frac{J + i6}{\sqrt{2}}$$

$$V(J,6,\lambda) = \frac{\lambda_J}{4!}J^4 + \frac{\lambda_6}{4!}6^4 + \frac{\lambda_\lambda}{4!}\lambda^4 + \frac{\lambda_{J6}}{4}J^2 6^2 + \frac{\lambda_{\lambda J}}{4}\lambda^2 J^2 + \frac{\lambda_{\lambda 6}}{4}\lambda^2 6^2$$

3-d classical field space, using the Gilderner-Weinberg approach

PGSB of SI is dominated by singlet with largest VEV~TeV, with mass around 100 GeV

Scale invariant νMSM (νSISM)

- FImP (keV FIMP) miracle

EWSB favors singlets with VEVs~TeV, thus a keV RHN means

$$\frac{1}{2}\lambda_i S N^2 \xrightarrow{S=\frac{1}{\sqrt{2}}(\langle s\rangle + s)} \begin{cases} M_N = \lambda\langle s\rangle \Rightarrow \lambda = \frac{M_N}{\langle s\rangle} \sim 10^{-8} \\ \frac{1}{2\sqrt{2}}\lambda \cdot s N^2 \end{cases}$$

At the same time, RHN gains a feeble interaction, which is too weak to thermalize it. However, it is just at the correct order to freeze-in RHN:

$$\Omega_{\rm DM}h^2 = 0.11 \times \sum_{H_a=\mathcal{P},H_2} \left(\frac{m_{\rm DM}}{10\,{\rm keV}}\right)^3 \left(\frac{\rm TeV}{v_J}\right)^2 \left(\frac{100\,{\rm GeV}}{m_{H_a}}\right) \left(\frac{10^3}{g_*^S\sqrt{g_*^\rho}}\right),$$

By scale invariance, RHN mass and dynamics accounting for relic density share the same origin——FImP miracle

Scale invariant νMSM (νSISM)

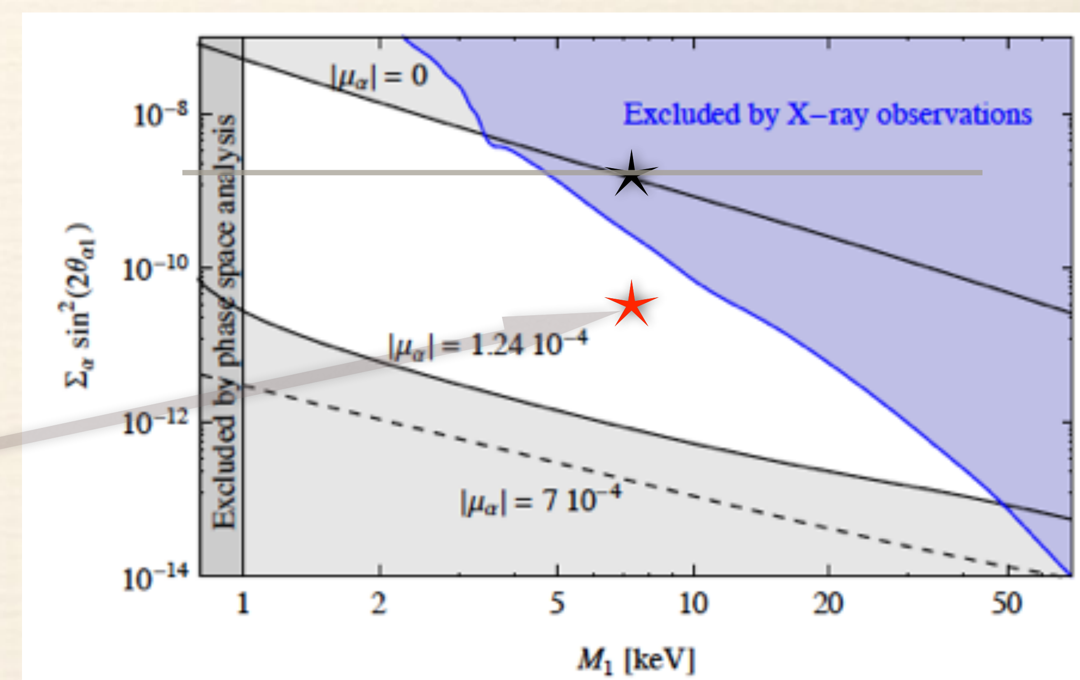
- FImP miracle shines in the *X*-ray line?

The *X*-ray line at 3.5 keV reported this year is explained by RHN

$$\Gamma_{\nu\gamma} \simeq 1.62 \times 10^{-28} s^{-1} \left(\frac{\sin^2 2\theta}{7 \times 10^{-11}} \right) \left(\frac{m_{\tilde{X}}}{7\mathrm{keV}} \right)^5$$

But it has been excluded for RHN with conventional productions, even for resonant production which has been excluded by Lyman-alpha bound

A. Merle and A. Schneider, arXiv:1409.6311



The RHN from freeze-in with colder spectrum thus being favored!

Conclusions

- νSISM is a good example to address three leading new physics in an unified framework

- The lightest RHN here is predicted to be an accidental DM, with FImP miracle

Thanks…