Majoron dark matter from a spontaneous inverse seesaw model

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In collaboration with N. Rojas and F. Gonzales-Canales – arxiv:1703.03416

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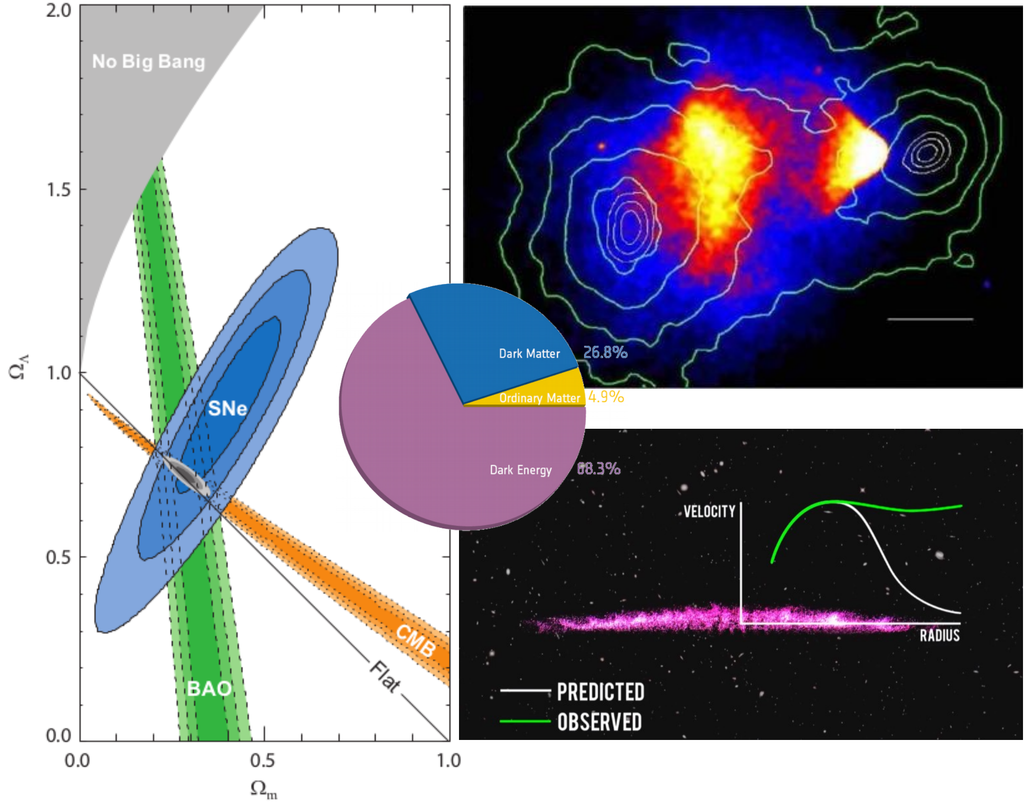
Motivation

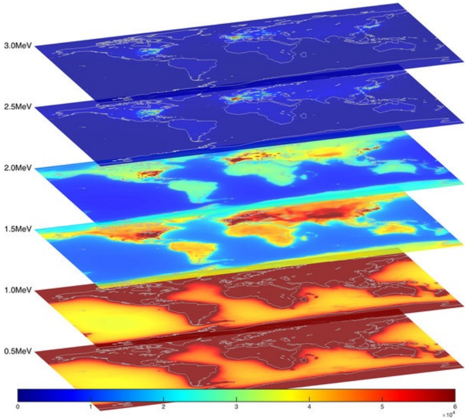
Majoron DM models provide a tantalizing connection between Dark Matter and Neutrinos



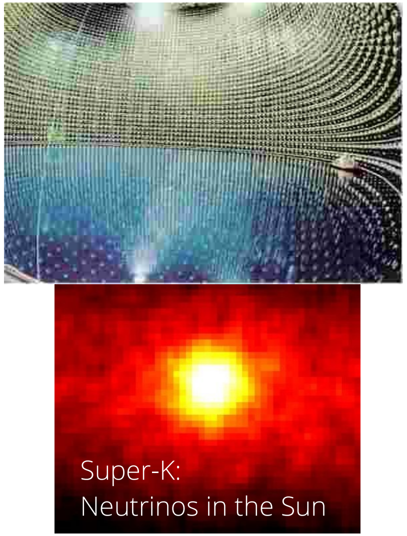
This talk


You are Here
Neutrino mass
and the majoron
Spontaneous
Inverse SeeSaw
Majoron DM
Phenomenology
Conclusions

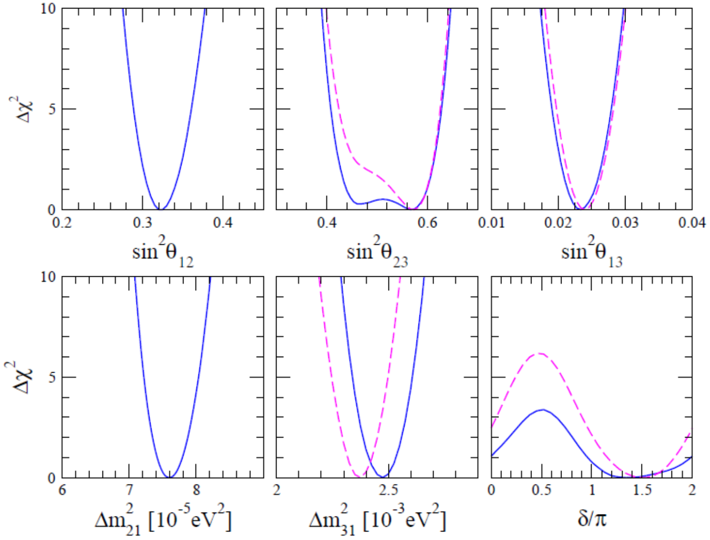
Neutrinos



AGM2015: Antineutrino Global Map 2015



Forero, Tortola and Valle PRD 90 (2014) 093006



The SM predicts zero neutrino mass

Beyond SM physics is required to explain

mass spectrum and mixing angles

Neutrino mass mechanisms

A large fraction of the models uses the 5-dim Weinberg operator to generate majorana neutrino masses

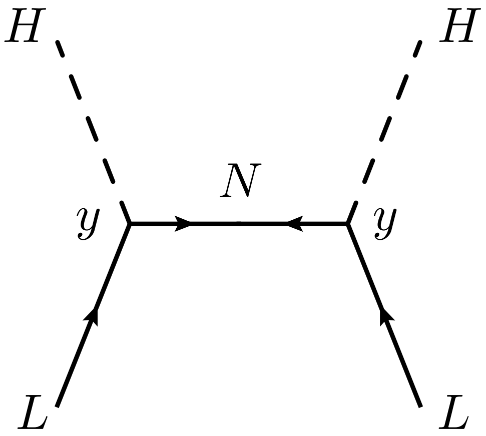
$$\mathcal{O}_{5ij} \propto (L_i H)^T (L_j H)$$

This operator breaks lepton number in 2 units

Neutrino mass mechanisms

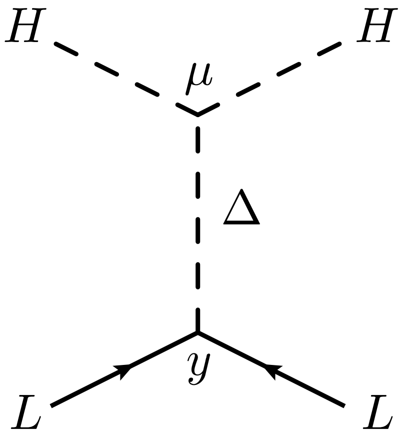
The commonly known schemes are see-saw mechanisms

Type-I



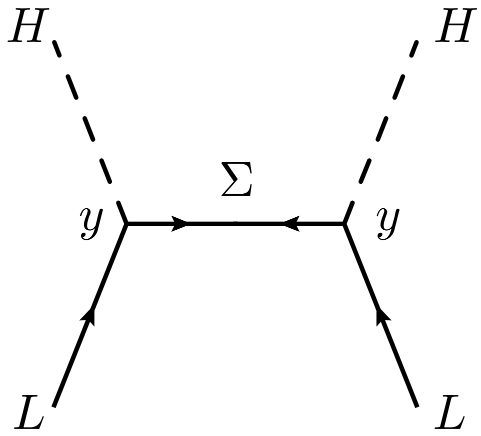
$$m_\nu \propto \frac{v^2 y^2}{M_N}$$

Type-II



$$m_\nu \propto \frac{v^2 y \mu}{M_\Delta^2}$$

Type-III



$$m_\nu \propto \frac{v^2 y^2}{M_\Sigma}$$

Neutrino mass mechanisms

The commonly known schemes are see-saw mechanisms

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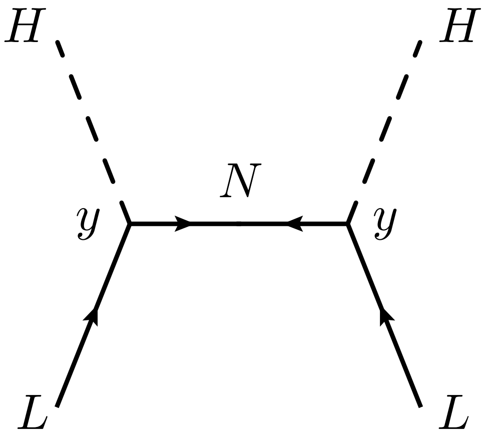

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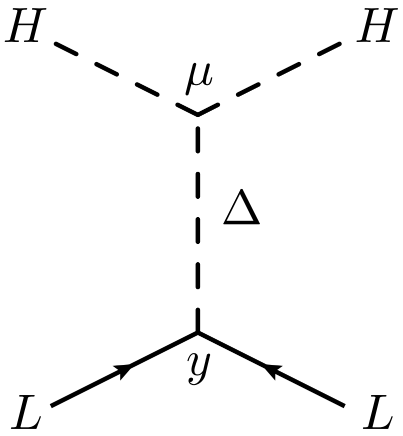

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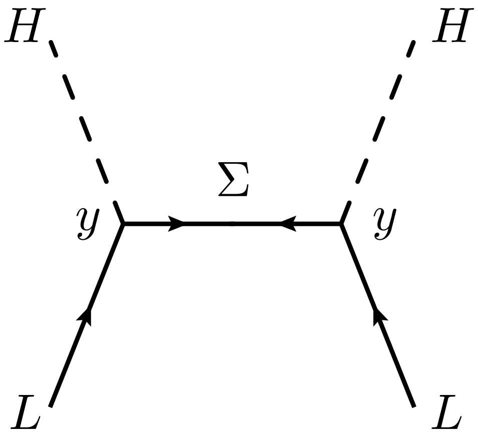
Type-III

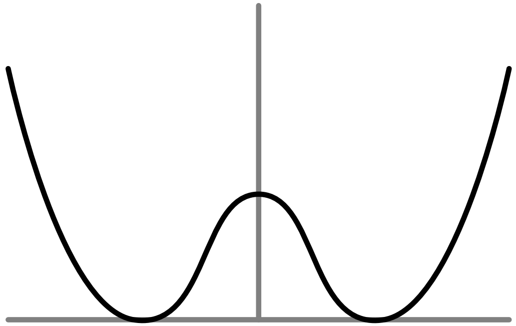


$$m_\nu \propto \frac{v^2 y^2}{M_\Sigma}$$

Enters the Majoron

The Type-I seesaw can be generated by the spontaneous breaking of the U(1) lepton number symmetry

$$S = \frac{v_S + \sigma + iJ}{\sqrt{2}}$$



$$\mathcal{L} \supset -y_L \overline{L} H N^c - \frac{y_S}{2} S \overline{N^c} N + h.c.$$

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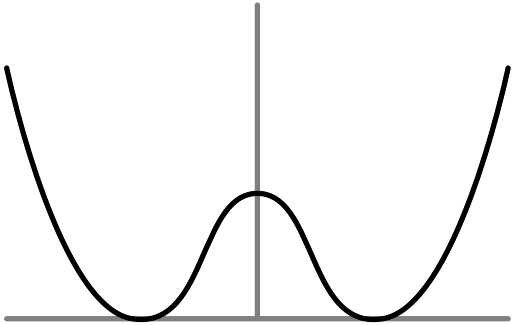

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-1 0 1 2 -1 -1

Enters the Majoron

$$m_D = \frac{y_L v_H}{\sqrt{2}}$$

$$M_N = \frac{y_S v_S}{\sqrt{2}}$$

After the SSB, we get the Type-I seesaw

$$\mathcal{L} \supset -m_D \bar{\nu}_{\rm L} N^c - \frac{M_N}{2} \overline{N^c} N + h.c.$$

and 2 scalars: σ and J

$$m_\sigma \simeq v_S \qquad m_J = 0$$

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After the SSB, we get the Type-I seesaw

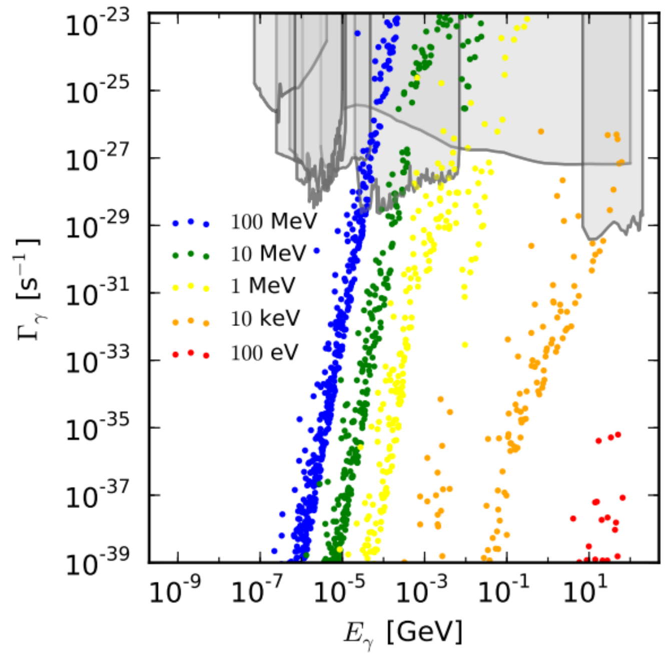
$$\mathcal{L} \supset -m_D \bar{\nu}_{\rm L} N^c - \frac{M_N}{2} \overline{N^c} N + h.c.$$

and 2 scalars: σ and J ← DM candidate

$$m_\sigma \simeq v_S \qquad m_J = 0$$

Majoron as DM (pros)

- Neutral
- Weakly coupled to the SM
- Long lived



Details in arxiv:1406.0004

$$\Gamma_{J\to\nu\nu} = \frac{m_J}{32\pi}\frac{\sum_i (m_i^\nu)^2}{2v_1^2} \qquad \Gamma_{J\to\gamma\gamma} = \frac{\alpha^2 m_J^3}{64\pi^3}\left|\sum_f N_f Q_f^2 \frac{2v_3^2}{v_2^2 v_1}(-2T_3^f)\frac{m_J^2}{12 m_f^2}\right|^2$$

Majoron as DM (cons)

$$m_J = 0 \quad !!!!$$

... but global symmetries are not protected under gravity effects

Therefore

$$m_J \neq 0$$

... and the majoron DM is just a pseudo Nambu-Goldstone boson

Majoron as DM (our fixing)

What defines a majoron DM?

- It is a (pseudo)scalar
- It is part of the neutrino mass mechanism
- Its signature is the decay into neutrinos
- It is massive

~~Spontaneous~~ Inverse seesaw

The standard inverse seesaw

$$\mu \ll m_D \ll M$$

$$\mathcal{L} = -\frac{1}{2} n_L^T C \mathcal{M} n_L + h.c.$$

$$\mathcal{M} = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M \\ 0 & M^T & \mu \end{pmatrix}$$

$$n_L^T = (\nu_L, N_1^c, N_2)$$

~~Spontaneous~~ Inverse seesaw

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Lepton number violating term

~~Spontaneous~~ Inverse seesaw

The standard inverse seesaw

$$\mu \ll m_D \ll M$$

Active neutrinos

$$m_\nu = \left(\frac{m_D}{M}\right)^2 \mu$$

Heavy neutrinos

$$m_{\mathcal{N}'} = M - \frac{m_D^2}{M} + \frac{\mu}{2}$$

$$m_{\mathcal{N}} = M - \frac{m_D^2}{M} - \frac{\mu}{2}$$

~~Spontaneous~~ Inverse seesaw

The standard inverse seesaw

$$\mu \ll m_D \ll M$$

Some numerology:

$$M \sim 100\,\mathrm{TeV} \quad m_D \sim 10\,\mathrm{GeV} \quad \mu \sim 10\,\mathrm{MeV}$$

$$m_\nu \sim 0.1\,\mathrm{eV}$$

$$\alpha = \frac{\mu}{M} \sim 10^{-7}$$

Spontaneous Inverse seesaw

To generate the inverse seesaw scheme we need to add 2 complex scalars

$$\mathcal{L} = -y_L \bar{L} H N_1^c - y_S S^\dagger \overline{N_2} N_1^c - \frac{y_X}{2} X^\dagger \overline{N_2^c} N_2 + h.c.$$

$$m_D = \frac{y_L v_h}{\sqrt{2}}\,,\ M = \frac{y_S v_S}{\sqrt{2}}\,, \text{and}\ \mu = \frac{y_X v_X}{\sqrt{2}}$$

Spontaneous Inverse seesaw

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$$v_S > 50 \text{ TeV} \qquad v_X > 5 \text{ MeV}$$

Spontaneous Inverse seesaw

But the charge assignments do not follow the typical one of the ISS

	L	N_1	N_2	S	X
$SU(2)_L$	2	1	1	1	1
$U(1)_Y$	1/2	0	0	0	0
$U(1)_l$	1	-1	x	$1-x$	$2x$

$$x = 3/5$$

$$\mathcal{L} = -y_L \bar{L} H N_1^c - y_S S^\dagger \overline{N_2} N_1^c - \frac{y_X}{2} X^\dagger \overline{N_2^c} N_2 + h.c.$$

Scalar potential

$$\omega = \frac{v_X}{v_S}$$

The assignment fixes the potential

$$V_{\text{scalar}} = V_{XS} + V_{HXS} + V_I$$

$$V_I = \lambda_{\text{cp}} e^{i\delta} X S^{\dagger 3} + h.c.$$

$$S = \frac{v_S e^{i\theta} + \sigma_S + i\chi_S}{\sqrt{2}} \qquad X = \frac{v_X e^{i\tau} + \sigma_X + i\chi_X}{\sqrt{2}}$$

The tadpole equations relate the CP phases: $\tau = 3\theta - \delta - \pi$

Mass spectrum

$$\omega = \frac{v_X}{v_S}$$

Now we have 5 spin-0 fields: 4 related to L breaking
1 related to EW breaking

ζ_1 ζ_2 ζ_3 ζ_4 ζ_5

ζ_5 → higgs-like

ζ_1 → Massless

ζ_2 →

$$M_J^2 = \frac{v_S^2}{2\omega}\lambda_{\rm cp}(1+9\omega^2)$$

ζ_3, ζ_4 → Heavy scalars

$$M^2_{\zeta_{3,4}} \sim \mathcal{O}(v_S^2)$$

Majoron DM stability

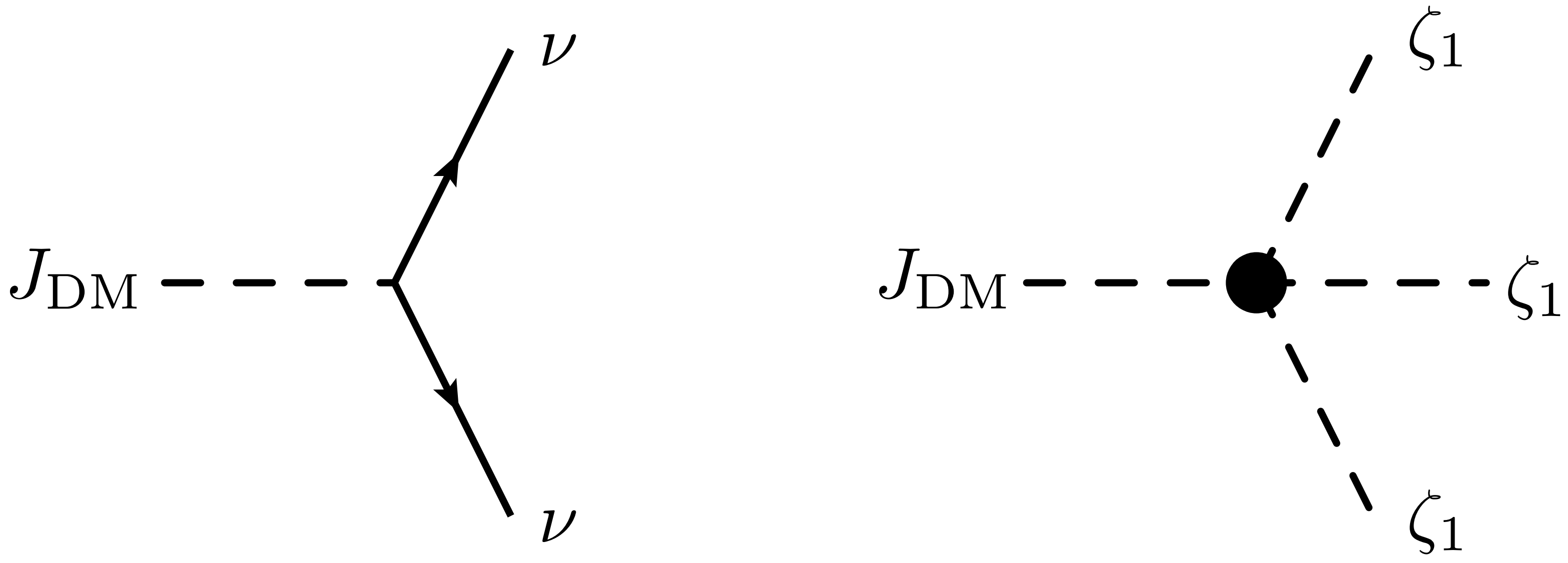
The only candidate is the lightest massive scalar i.e. $\zeta_2 = J_{\rm DM}$

We still has to satisfy the stability condition:

$$\Gamma_{\rm DM} < 10^{-52}\,{\rm GeV}$$

Decay modes

There are potentially dangerous decay modes:



Decay into neutrinos

$$\alpha = \frac{\mu}{M} \sim 10^{-7}$$

The decay rate vanishes for:

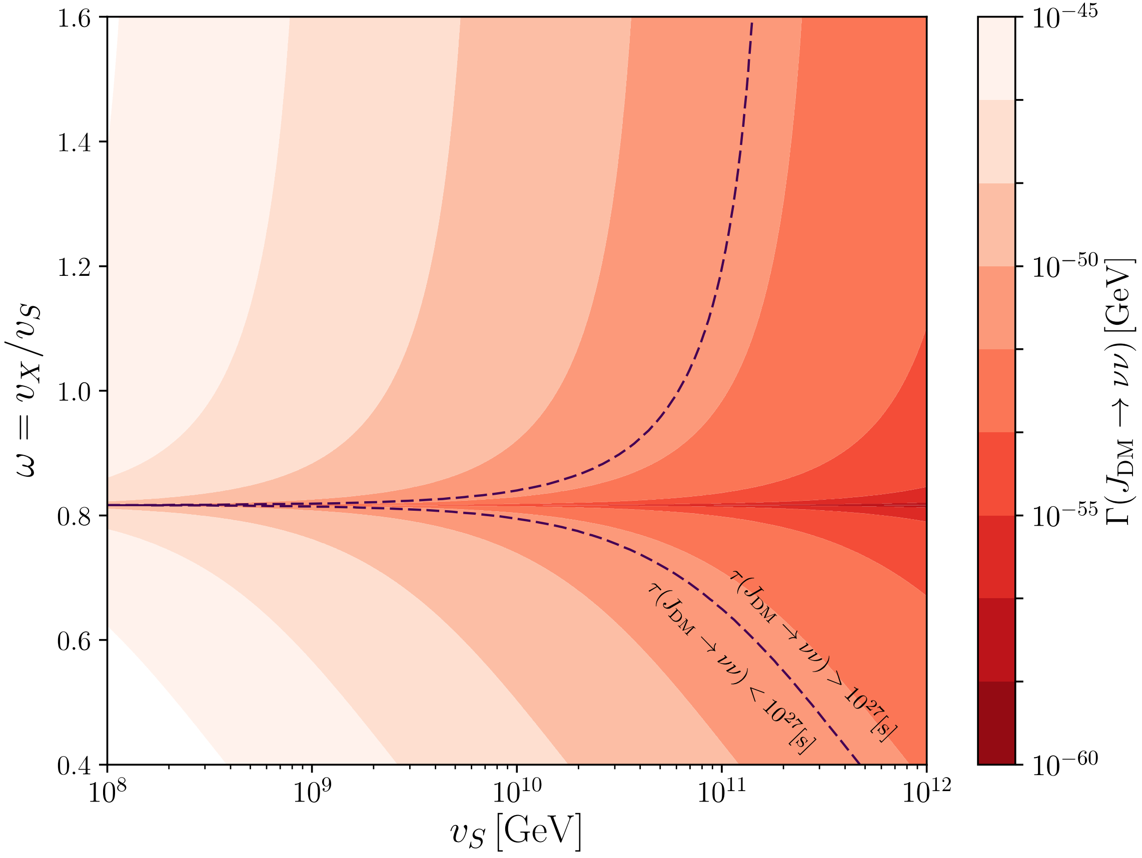
$$\omega_0 = \sqrt{2/3}$$

$$\Gamma_\nu = \Gamma_{0\nu}(\omega_0)\, 4\alpha^2$$

$$\Gamma_{0\nu}(\omega_0) \simeq 10^{-40}\,\mathrm{GeV}\left(\frac{m_\nu}{0.1\,\mathrm{eV}}\right)^2\left(\frac{M_J}{1\,\mathrm{keV}}\right)\left(\frac{v_S}{100\,\mathrm{TeV}}\right)^{-2}$$

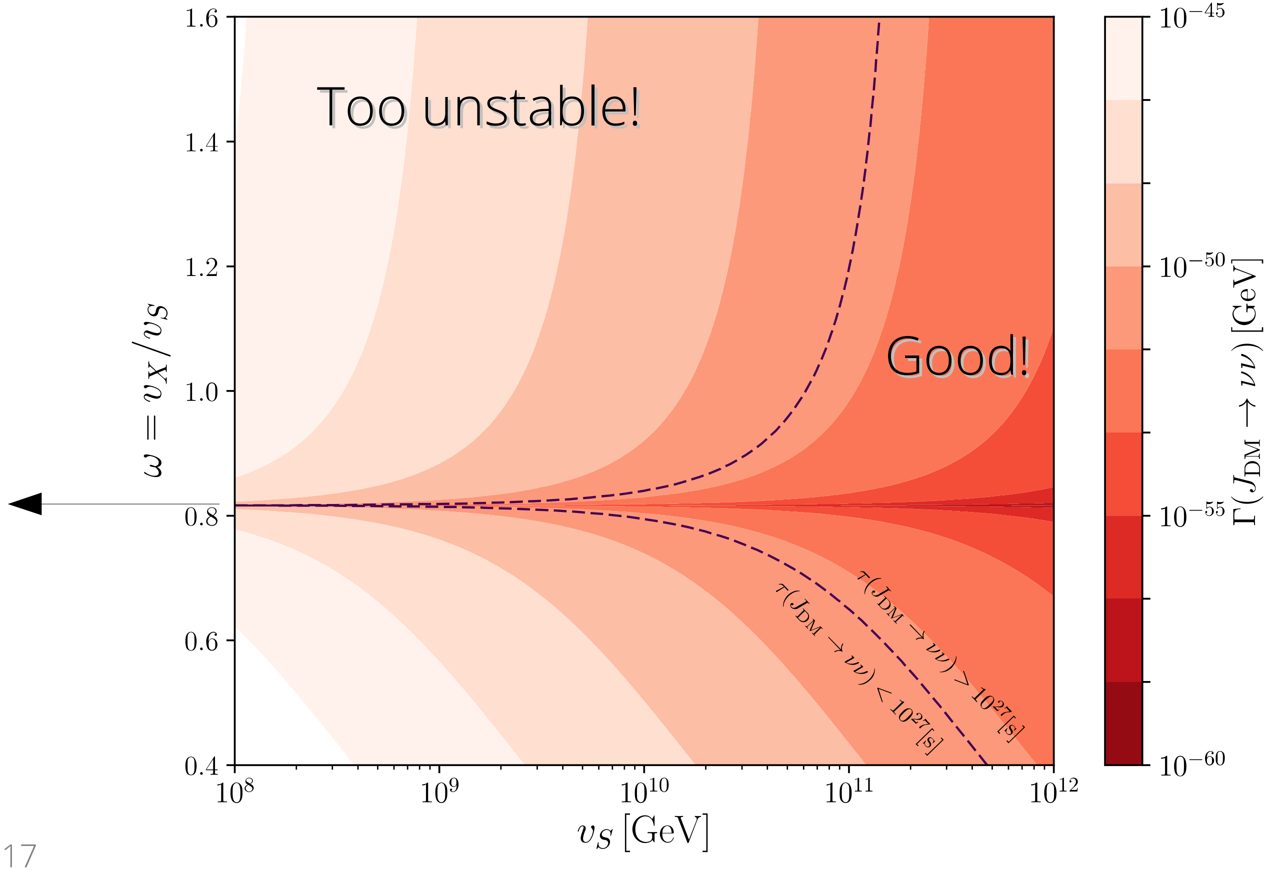
Decay into neutrinos

$J_{\mathrm{DM}} \to \nu\nu$



Decay into neutrinos

$$J_{\rm DM} \to \nu\nu$$



$$\omega = \sqrt{\frac{2}{3}}$$

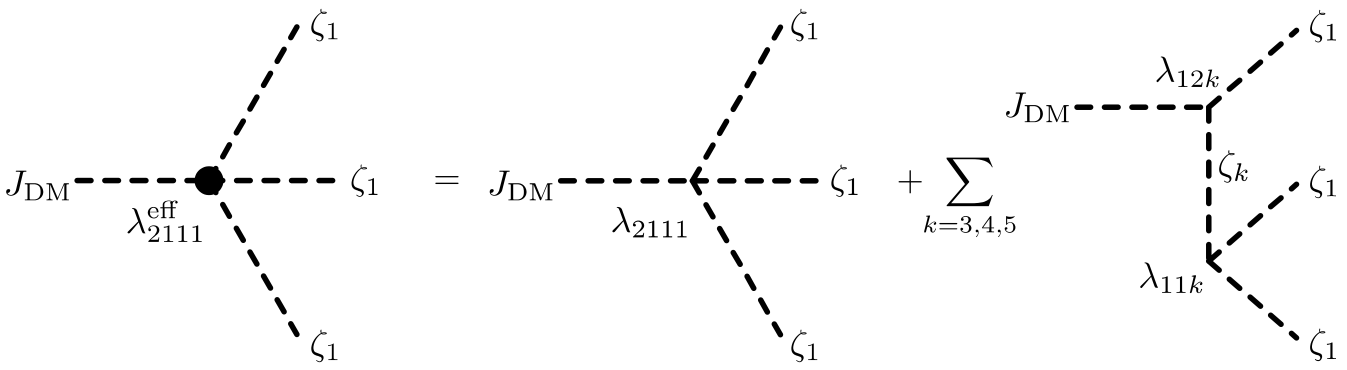
Stability thanks to vev alignment

Decay into scalars

$J_{\rm DM} \to \zeta's$

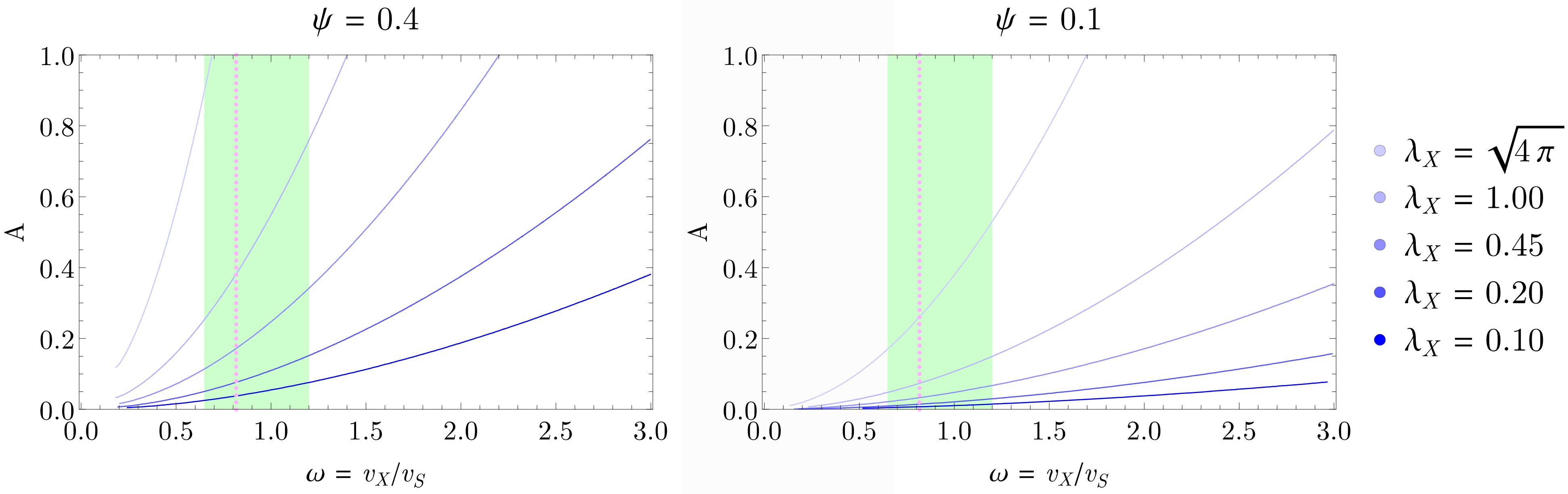
Without a protective symmetry, this channel is not suppressed

However we can find the parameter space where the mode vanishes



Decay into scalars

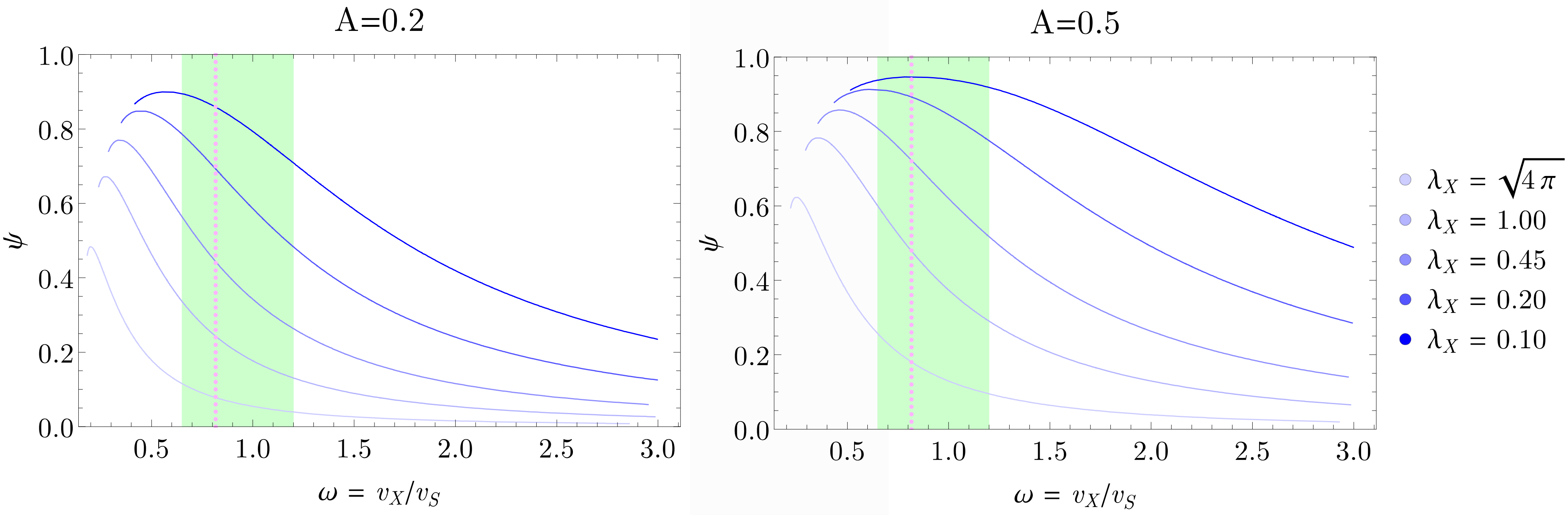
$J_{\mathrm{DM}} \to \zeta'\mathrm{s}$



The interplay of different diagrams allows to vanish the decay mode

Decay into scalars

$J_{\rm DM} \to \zeta' {\rm s}$



There is a whole volume that satisfy this condition

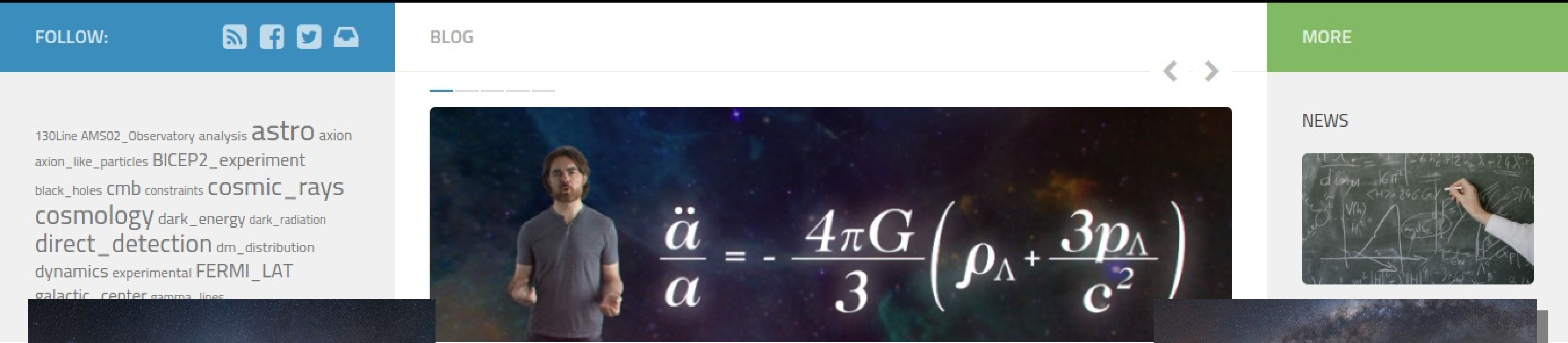
Conclusions

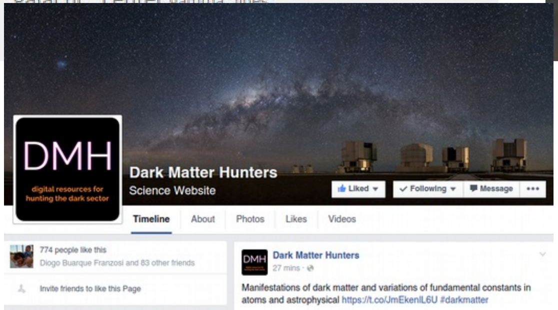
- The spontaneous inverse seesaw provides a well suited majoron DM candidate
- Our majoron DM is phenomenologically equivalent to the PNGB one
- The vev alignment has a relevent role in the DM stability

Dark Matter Hunters

Digital resources for hunting the dark sector

www.dmhunters.org





Daily digest of papers about

Dark Matter and related topics

1127

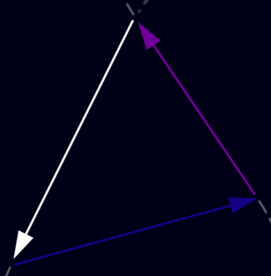
2420

lawphysics

Latin American Webinars on Physics

Sum Rules for Flavour Parameters

Martin Spinrath, NCTS (Taiwan)



Host: Joel Jones
Wednesday 3 May 2017 15:00 UTC

09:00 Colorado - 10:00 Mexico City, Lima, Bogotá - 11:00 New York - 12:00 Santiago, São Paulo, Buenos Aires - 16:00 London - 17:00 Brussels

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Thanks!

Extras

Charge assignments

5 possible models

	L	N_1	N_2	S	X
$n=1$	1	-1	$1/7$	$6/7$	$2/7$
$n=2$	1	-1	$1/3$	$2/3$	$2/3$
$n=3$	1	-1	$3/5$	$2/5$	$6/5$

m+n = 4

$$V_{\rm I} = \lambda_{\rm cp} e^{i\delta} X^m S^{\dagger n}$$

m+n = 3

	L	N_1	N_2	S	X
$n=1$	1	-1	$1/5$	$4/5$	$2/5$
$n=2$	1	-1	$1/2$	$1/2$	1

The rest of the scalar potential

$$V_{SX} = -\mu_S^2 |S|^2 + \frac{\lambda_S}{4} |S|^4 - \mu_X^2 |X|^2 + \frac{\lambda_X}{4} |X|^4 + \lambda_5 |S|^2 |X|^2 + V_{\mathrm{I}}$$

$$V_{\mathrm{HSX}} = -\mu_H^2 H^\dagger H + \frac{\lambda_H}{4}(H^\dagger H)^2 + \lambda_{HS} |S|^2 H^\dagger H + \lambda_{HX} |X|^2 H^\dagger H$$

Mass spectrum

$$m_h^2 \simeq \frac{v_h^2}{2} \left\{ \frac{\lambda_H}{2} + 2 \left(\frac{\lambda_{HX}^2 \lambda_S + \lambda_{HS}^2 \lambda_X - 4\lambda_5 \lambda_{HS} \lambda_{HX}}{4\lambda_5^2 - \lambda_S \lambda_X} \right) \right\}$$

$$M_{\zeta_3}^2 \simeq \frac{v_S^2}{2} \left(\frac{-A + A\psi + 2\lambda_X \omega \psi}{2\psi} \right)$$

$$M_{\zeta_4}^2 \simeq \frac{v_S^2}{2} \left(\frac{A + A\psi + 2\lambda_X \omega \psi}{2\psi} \right)$$

$$\lambda_S = A + \lambda_X \omega^2$$

$$\lambda_5 = -A \left(\frac{\sqrt{1 - \psi^2}}{4\,\omega\,\psi} \right)$$

Numerology

Parameter	Value
M	100 TeV
μ	10 MeV
m_D	10 GeV
v_S	10^8 – 10^{12} GeV
ω	0.4 – 1.6

$$\lambda_{\rm cp} \simeq \frac{M_J^2}{v_S^2} < 10^{-22}$$