



Neutrinos and its possible connection with DM

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The SM is complete LHC



The SM is complete LHC

Terra cognita and terra incognita



The SM is complete LHC

Terra cognita and terra incognita



Standard Model & Physics BSM

Infinite possibilities

H. Murayama



- Many of these extensions were proposed to address some unsolved questions of the SM: hierarchy problem, generation and flavour problem
- Others simply to explain some deviations of the SM, top forward backward asymmetry, $\mu \rightarrow e\gamma$, $h \rightarrow \gamma\gamma$, non universal lepton decays, DM, etc...

BSM searches

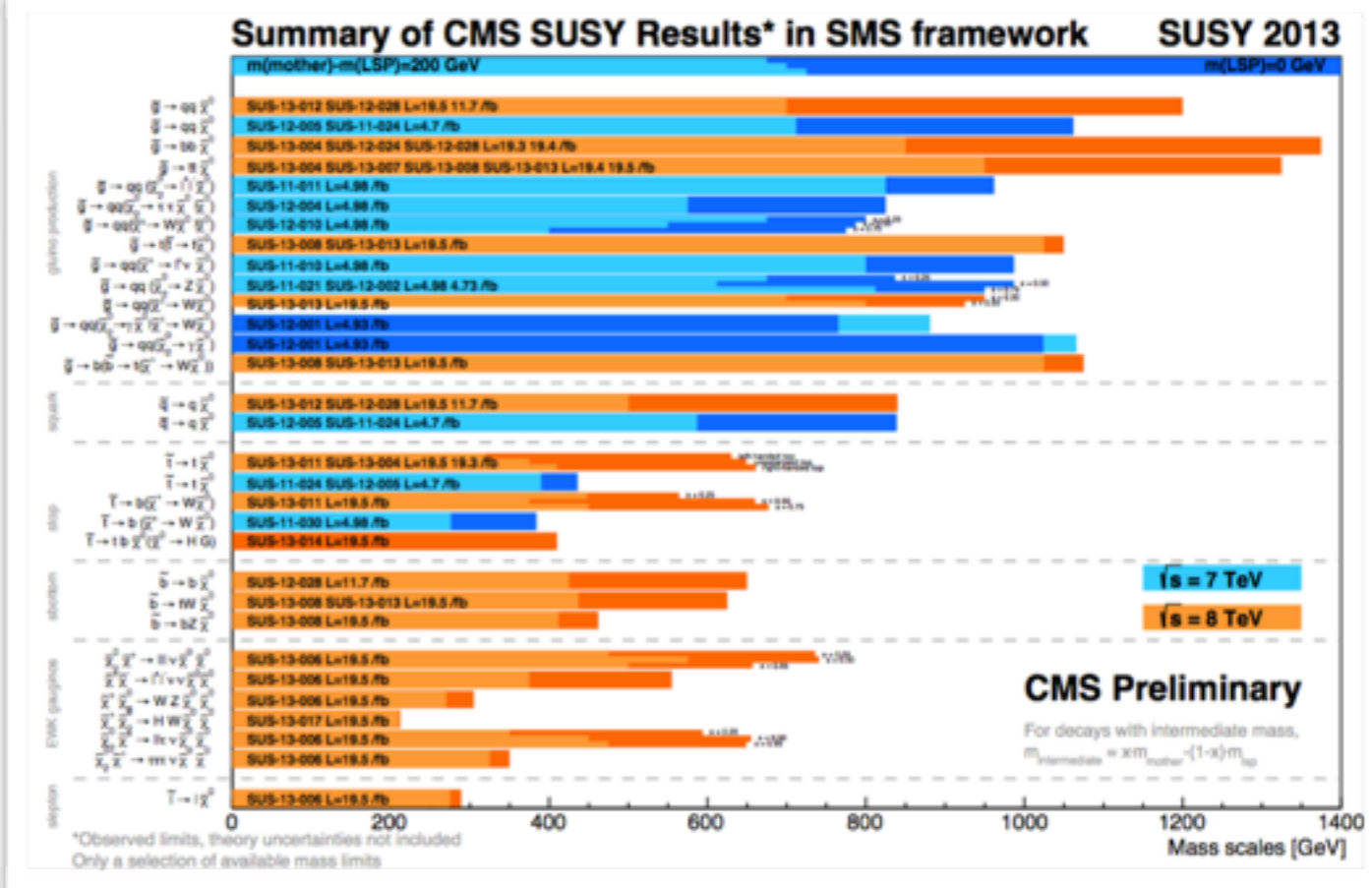
Nothing yet!!!

ATLAS Exotics Searches* - 95% CL Exclusion
Status: April 2014

ATLAS Preliminary
 $\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ TeV}$

Model	f, γ	Jets	E_T^{miss}	$\mathcal{L}(\text{exotic})$	Mass limit	Reference
ADD $G_{\mu\nu} + \mu/\eta$	-	1-2	Yes	4.7	M_{pl} 4.37 TeV	1210.4491
ADD non-resonant $\ell\ell\gamma\gamma$	2y or 2e, μ	-	-	4.7	M_{pl} 4.18 TeV	1211.1150
ADD GBH $\rightarrow \ell\ell$	1 e, μ	1	-	20.3	M_{pl} 3.2 TeV	1211.2086
ADD BH high M_{th}	2 e, μ (SS)	-	-	20.3	M_{pl} 3.7 TeV	1208.4075
ADD BH high Σp_T	2 e, μ	2-3	-	20.3	M_{pl} 6.2 TeV	ATLAS CONF 2014-016
RS1 $G_{\mu\nu} \rightarrow \ell\ell$	2 e, μ	-	-	20.3	$G_{\mu\nu}$ mass 2.47 TeV	ATLAS CONF 2013-017
RS1 $G_{\mu\nu} \rightarrow ZZ \rightarrow 4\ell$	2 or 4 e, μ	2	-	1.0	$G_{\mu\nu}$ mass 945 GeV	1209.0718
RS1 $G_{\mu\nu} \rightarrow WW \rightarrow \ell\nu\ell$	2 e, μ	-	Yes	4.7	$G_{\mu\nu}$ mass 1.23 TeV	1208.2880
Bulk RS $G_{\mu\nu} \rightarrow H\nu \rightarrow \ell\ell\nu\ell$	-	4-5	-	19.5	$G_{\mu\nu}$ mass 990-710 GeV	ATLAS CONF 2014-005
Bulk RS $G_{\mu\nu} \rightarrow \ell\ell$	1 e, μ 2-1 b, 2-1 τ	Yes	14.3		$G_{\mu\nu}$ mass 3.5-2.2 TeV	ATLAS CONF 2013-052
S^1/Z_2 ED	2 e, μ	-	-	5.0	$M_{\text{KK}} \times R^{-1}$ 4.71 TeV	1209.2525
UED	2y	-	Yes	4.8	Compact scale R^{-1} 1.41 TeV	ATLAS CONF 2012-012
SIM $Z' \rightarrow \ell\ell$	2 e, μ	-	-	20.3	Z' mass 2.88 TeV	ATLAS CONF 2013-017
SIM $Z' \rightarrow \nu\nu$	2 e	-	-	19.5	Z' mass 1.3 TeV	ATLAS CONF 2013-086
SIM $W' \rightarrow \ell\nu$	1 e, μ	-	Yes	20.3	W' mass 3.28 TeV	ATLAS CONF 2014-017
EGM $W' \rightarrow WZ \rightarrow \ell\nu\ell\nu$	3 e, μ	-	Yes	20.3	W' mass 1.32 TeV	ATLAS CONF 2014-015
LRSM $W'_2 \rightarrow \ell\bar{\ell}$	1 e, μ 2 b, 2-1 τ	Yes	14.3		W' mass 1.88 TeV	ATLAS CONF 2013-052
Cl $\mu\mu\mu$	-	2	-	4.8	κ 7.8 TeV	1210.1718
Cl $\mu\mu\tau$	2 e, μ	-	-	5.0	κ 13.3 TeV	1211.1150
Cl $\mu\tau\tau$	2 e, μ (SS) 2-1 b, 2-1 τ	Yes	14.3		κ 3.3 TeV	ATLAS CONF 2013-051
EFT D5 operator	-	1-2	Yes	10.5	M_{pl} 721 GeV	ATLAS CONF 2012-147
EFT D6 operator	-	1-2, 1-1	Yes	20.3	M_{pl} 2.4 TeV	1209.4017
Scalar LQ 1 st gen	2 e 2-2	-	-	1.0	LQ mass 560 GeV	$\beta = 1$ 1112.4629
Scalar LQ 2 nd gen	2 e, 2-2	-	-	1.0	LQ mass 560 GeV	$\beta = 1$ 1203.3172
Scalar LQ 3 rd gen	1 e, μ , 1 τ 1 b, 1 τ	-	-	4.7	LQ mass 524 GeV	$\beta = 1$ 1205.3526
Vector-like quark $TT \rightarrow Hb + X$	1 e, μ 2-2 b, 2-2 τ	Yes	14.3		T mass 790 GeV	ATLAS CONF 2013-018
Vector-like quark $TT \rightarrow Wb + X$	1 e, μ 2-1 b, 2-2 τ	Yes	14.3		T mass 810 GeV	ATLAS CONF 2013-080
Vector-like quark $BB \rightarrow Zb + X$	2 e, μ 2-2 b	-	-	14.3	B mass 725 GeV	ATLAS CONF 2013-056
Vector-like quark $BB \rightarrow W\tau + X$	2 e, μ (SS) 2-1 b, 2-1 τ	Yes	14.3		B mass 720 GeV	ATLAS CONF 2013-051
Excited quark $q^* \rightarrow q\gamma$	1y 1	-	-	20.3	q^* mass 3.5 TeV	1209.3230
Excited quark $q^* \rightarrow qg$	-	2	-	13.0	q^* mass 3.84 TeV	ATLAS CONF 2012-148
Excited quark $q^* \rightarrow W\ell$	1 or 2 e, μ 1 b, 2 or 1 τ	Yes	4.7		q^* mass 870 GeV	1201.1383
Excited lepton $\ell^* \rightarrow \ell\gamma$	2 e, μ , 1 τ	-	-	13.0	ℓ^* mass 2.2 TeV	1205.1264
LRSM Majorana ν	2 e, μ 2	-	-	2.1	N^0 mass 1.5 TeV	1205.5420
Type III Seesaw	2 e, μ	-	-	5.8	N^0 mass 295 GeV	ATLAS CONF 2013-019
Higgs triplet $H^{++} \rightarrow \ell\ell$	2 e, μ (SS)	-	-	4.7	H^{++} mass 409 GeV	1210.3270
Multi-charged particles	-	-	-	4.4	Multi-charged particle mass 480 GeV	1201.3272
Magnetic monopoles	-	-	-	2.0	Monopole mass 362 GeV	1207.8411

*A selection of the available mass limits are shown in blue or green to show



Only limits!!!
(and possible hints)

Outline

- **Introduction**

 - The SM

- **Neutrino physics**

 - SeeSaw Mechanism

- **Extensions of the SM**

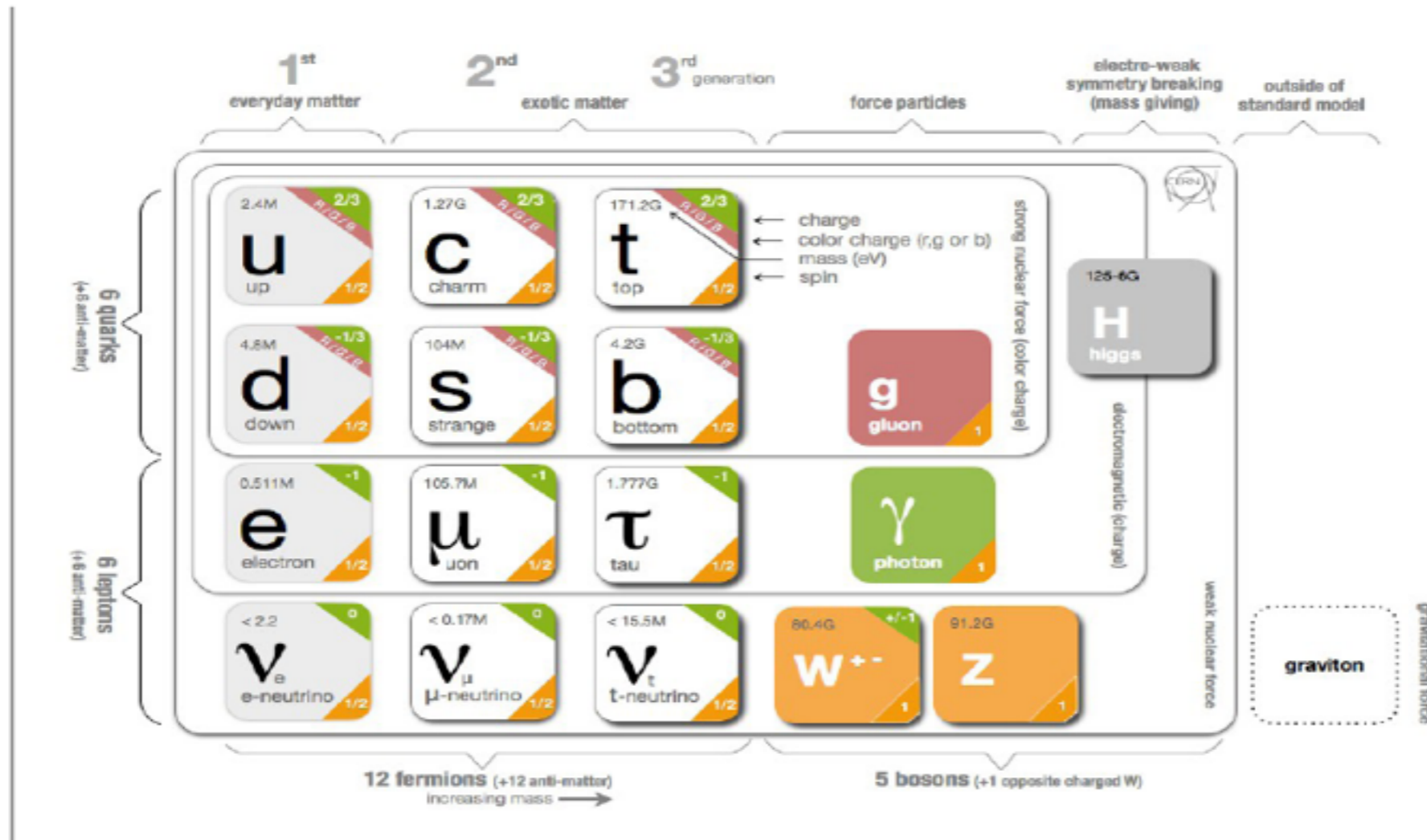
 - Using neutrinos

- **Conclusions**

The SM

$$SU_c(3) \times SU_L(2) \times U_Y(1)$$

“Mendeleev periodic table” for high energy physics



The SM



Fundación príncipe de Asturias



Cern Higgs Discovery

The SM

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\Psi} \not{D} \Psi + h.c. + \Psi_L \not{Y}_u \Psi_R \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$
$$V(\phi) = \frac{m_\phi^2}{4v^2} (|\phi|^2 - v^2)^2$$



Cern Higgs Discovery

What about
neutrino masses?

DM?
BAU?

etc...



Fundación príncipe de Asturias



The SM

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\Psi} \not{D} \Psi + h.c. + \Psi_L \not{Y}_u \Psi_R \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$
$$V(\phi) = \frac{m_\phi^2}{4v^2} (|\phi|^2 - v^2)^2$$



Cern Higgs Discovery



Fundación príncipe de Asturias



with flavor?



What about
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DM?

BAU?

etc...

Evidence of Physics BSM

☞ LHC put constraints only in PBSM

☞ Neutrino masses * (In the SM L is not violated)

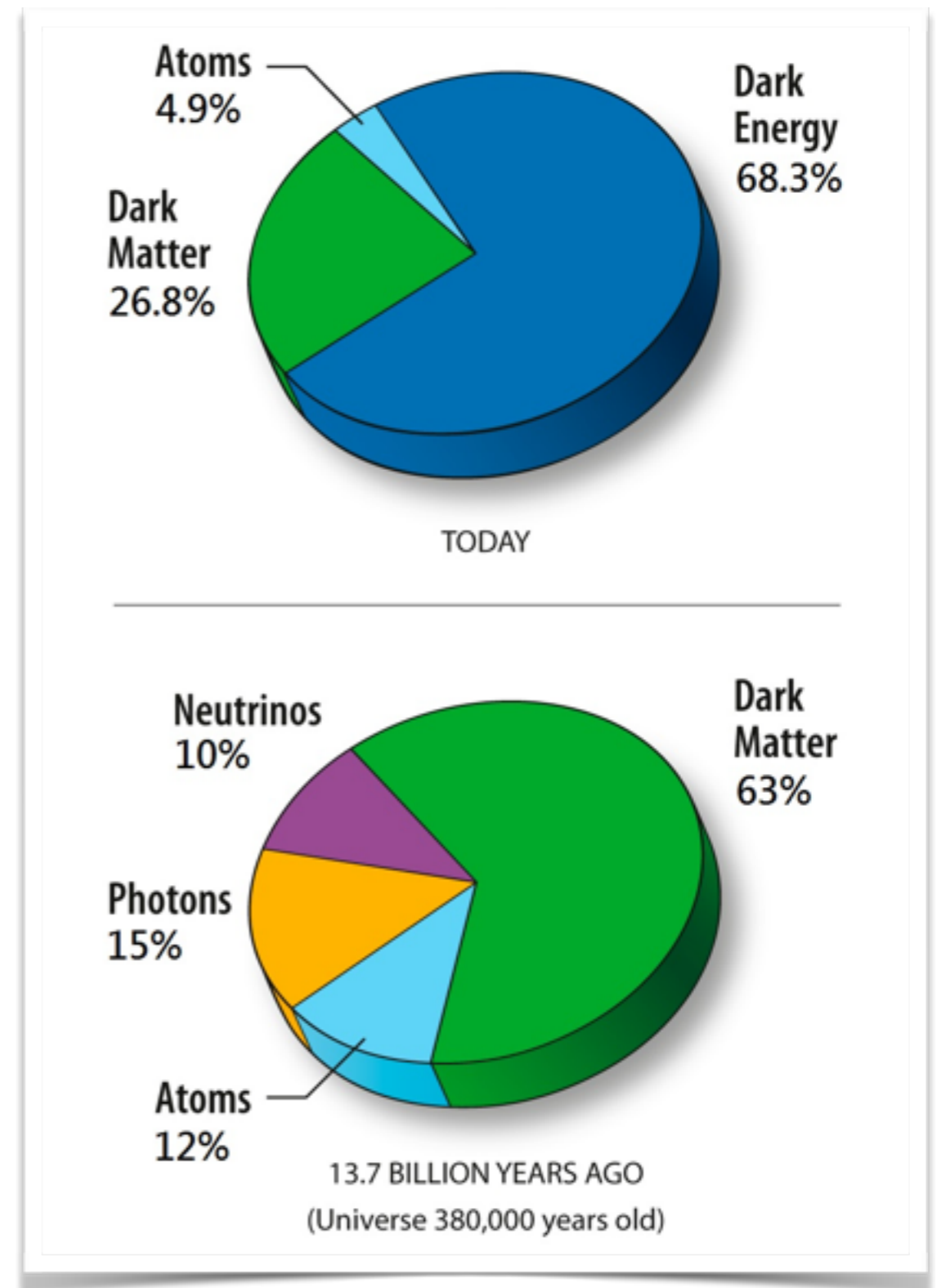
☞ Cosmology: Dark Matter, Baryon Asymmetry, Dark Energy ...

☞ Some theoretical aspects like hierarchy problem

☞ something else? LHC? rare decays ...

Jose's talk

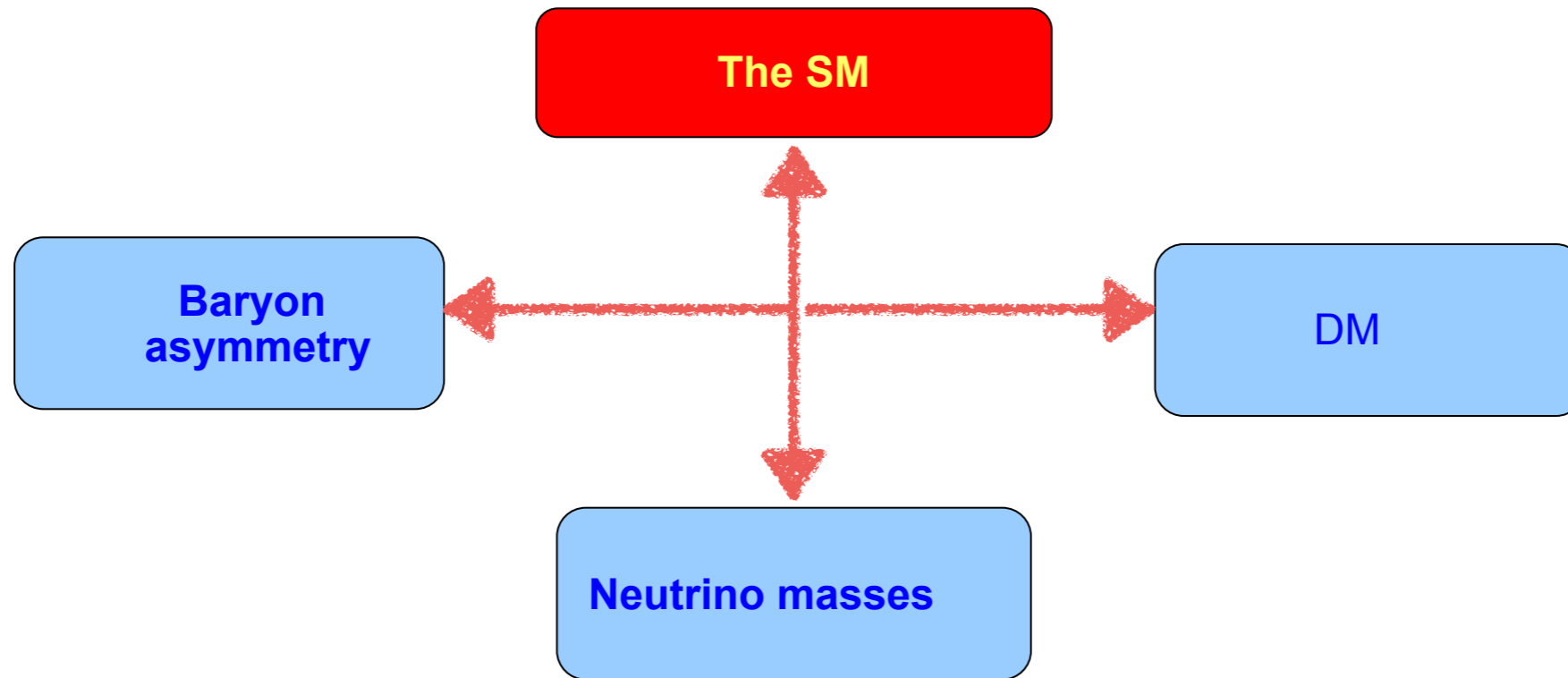
Eric's talk



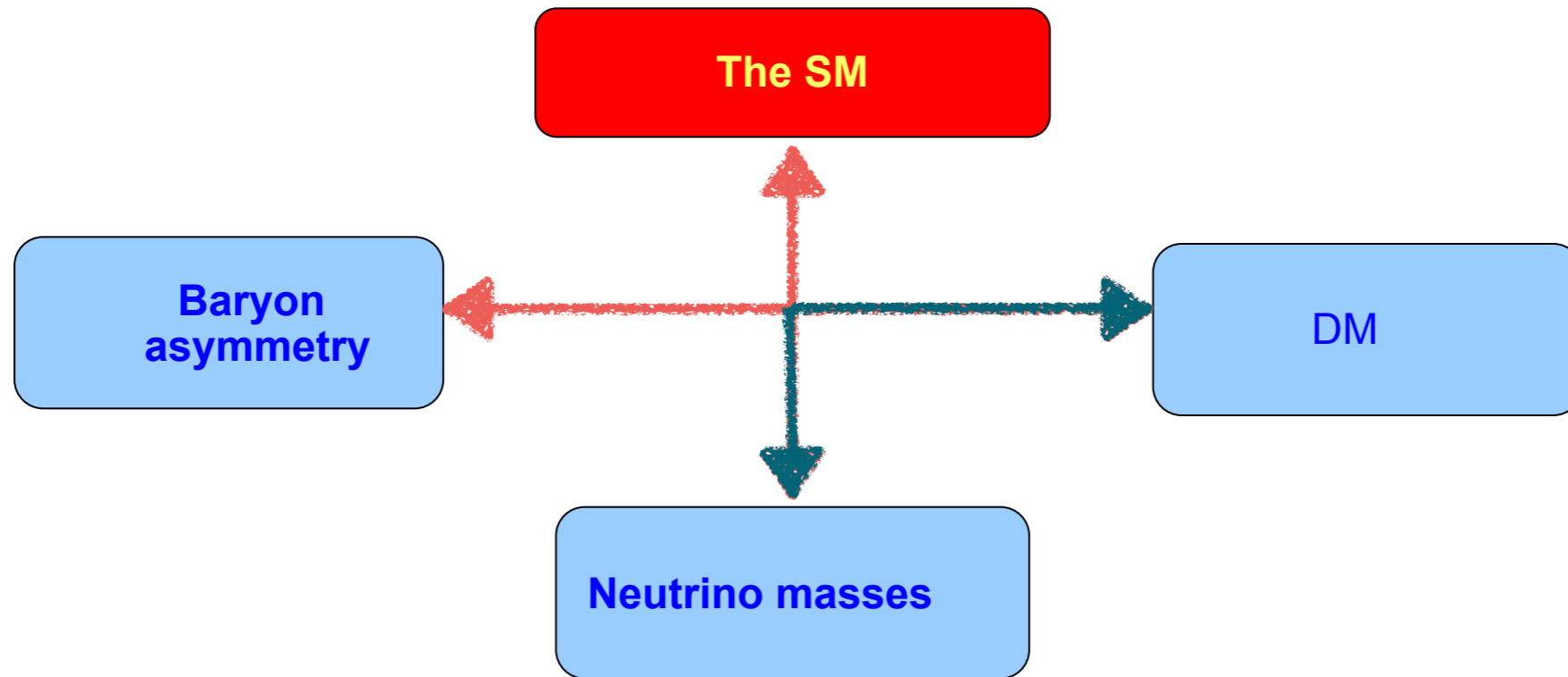
How to connect neutrino physics with DM?

The SM

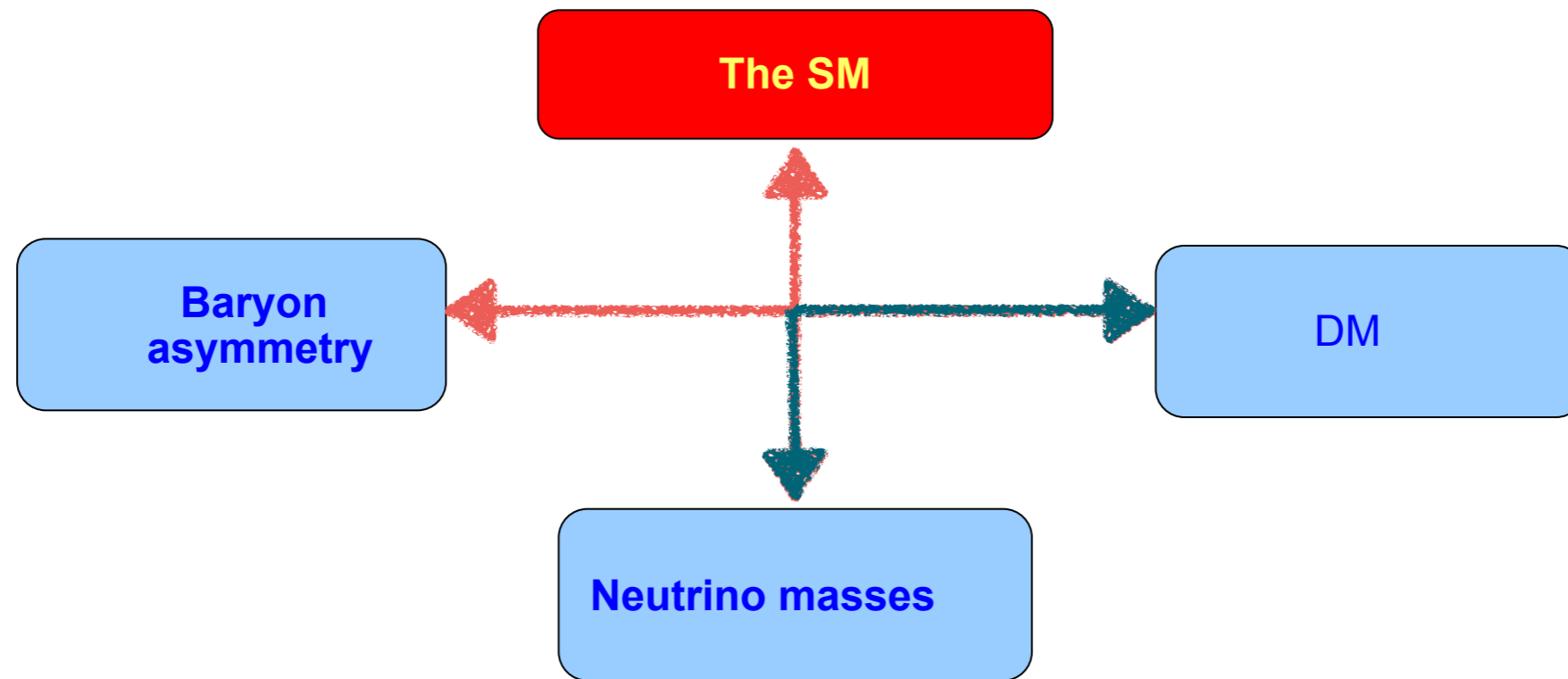
How to connect neutrino physics with DM?



How to connect neutrino physics with DM?



How to connect neutrino physics with DM?



Majoron

Inert+Loops

DDM

Loops with higher Higgs representations

KeV sterile neutrinos

etc...

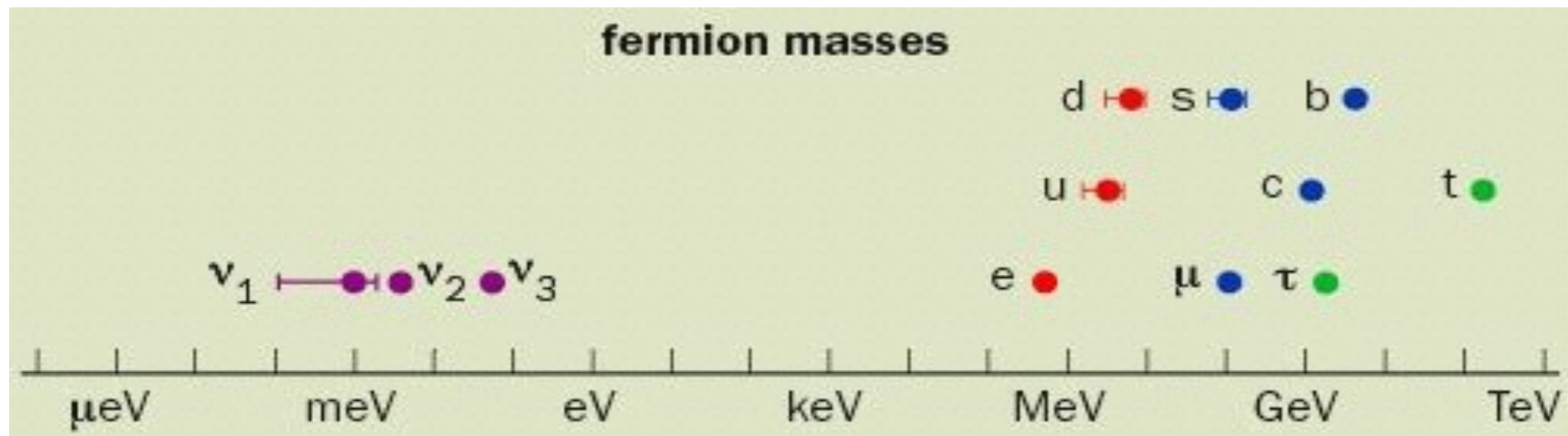
If Dirac

Can be either

If Dirac

Can be either

- If we impose Lepton number then the neutrinos are Dirac particles just like quarks and charged leptons



- many orders of magnitude

$$m_\nu \ll m_e \ll m_t$$

$$Y_{\nu_e} : Y_e : Y_t$$

The Yukawa couplings
are very different

$$< 10^{-11} : 10^{-6} : 1$$

Majorana Neutrinos

If we allow L to be violated?

Majorana Neutrinos

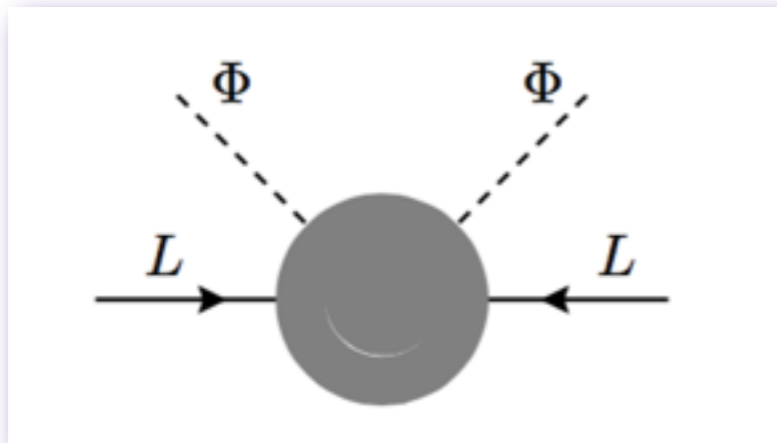
If we allow L to be violated?

-  The simplest effective source of Majorana neutrino masses dim 5 Weinberg operator

Majorana Neutrinos

If we allow L to be violated?

- The simplest effective source of Majorana neutrino masses dim 5 Weinberg operator



Weinberg, S. (1980)

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda} \mathcal{L}_5$$

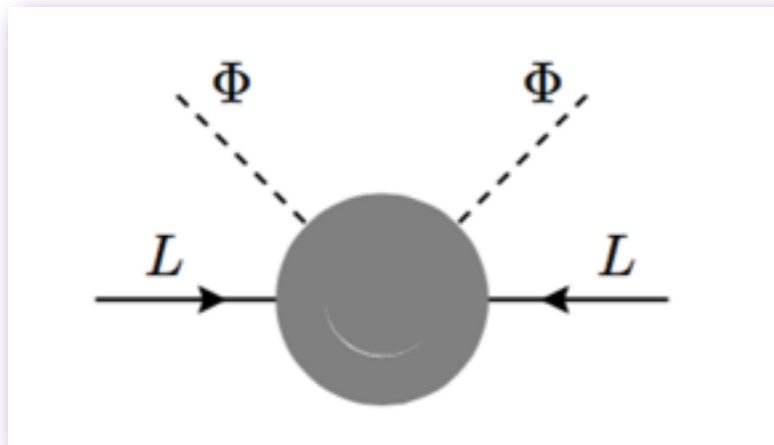
$$\mathcal{L}_5 = LL\Phi\Phi$$

$$\Delta L = 2$$

Majorana Neutrinos

If we allow L to be violated?

- The simplest effective source of Majorana neutrino masses dim 5 Weinberg operator



Weinberg, S. (1980)

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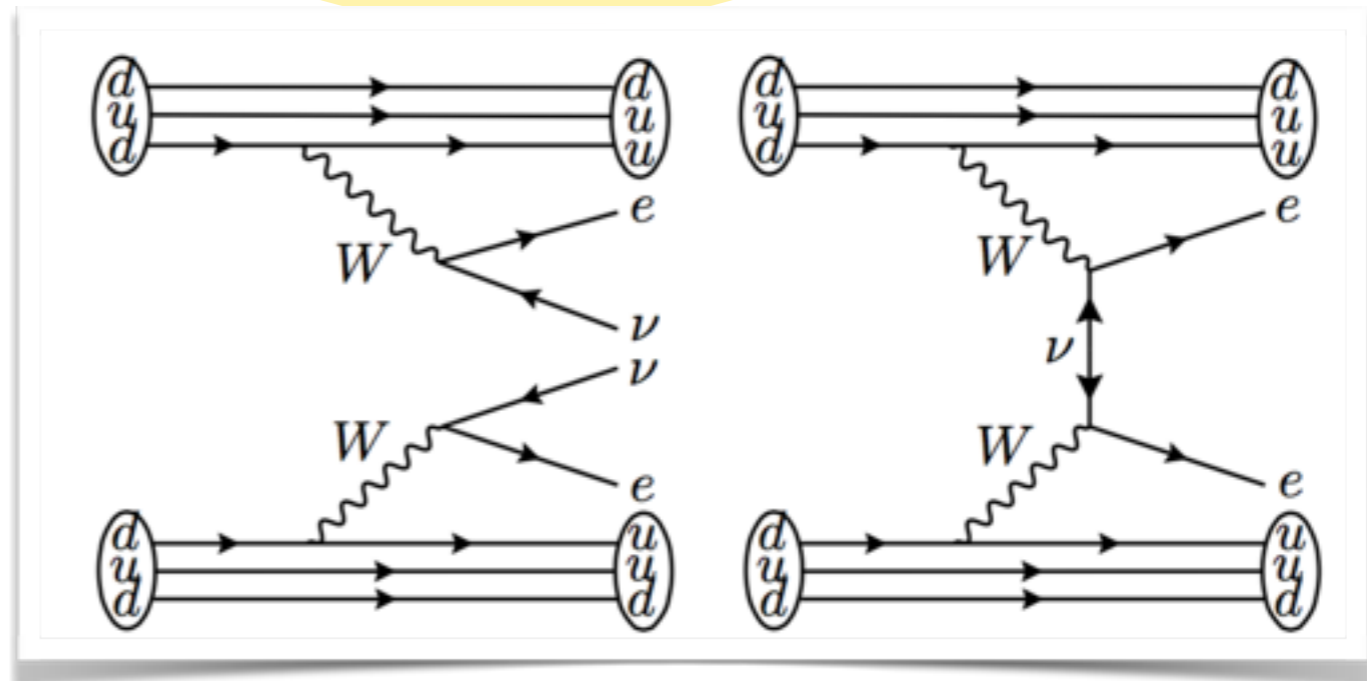
$$\mathcal{L}_5 = LL\Phi\Phi$$

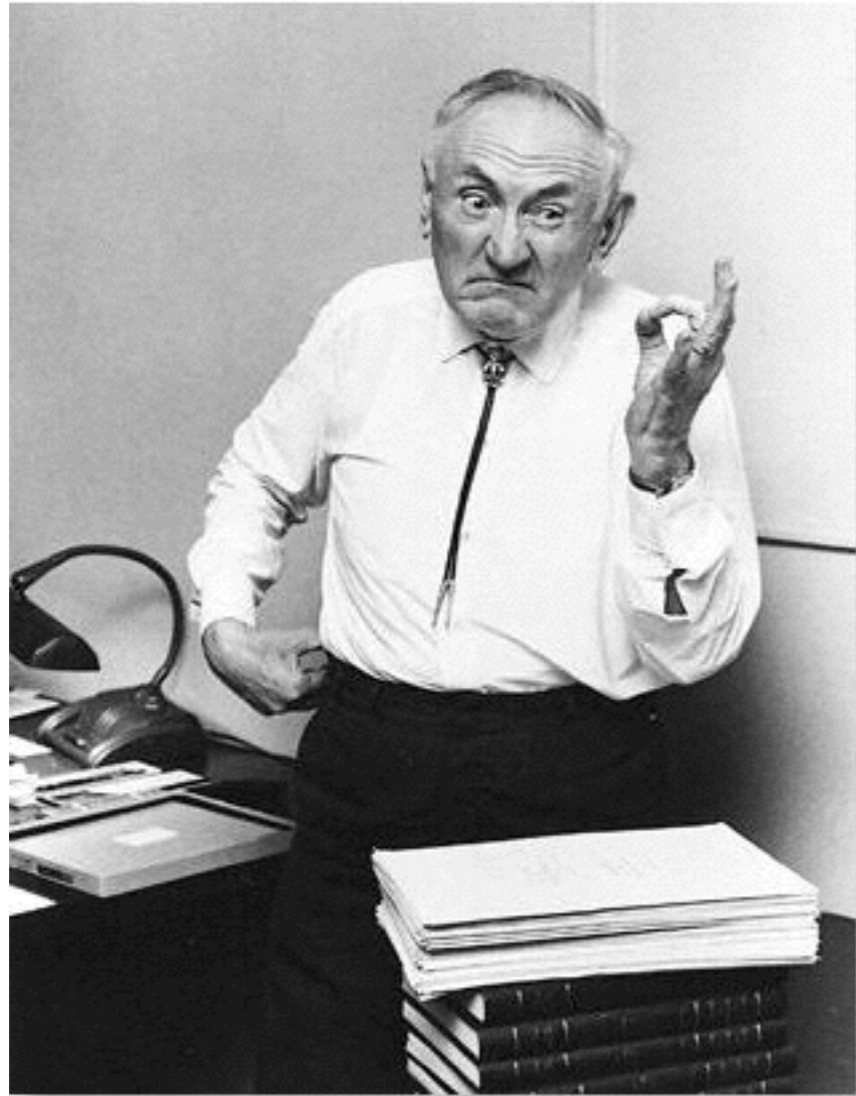
$$\Delta L = 2$$



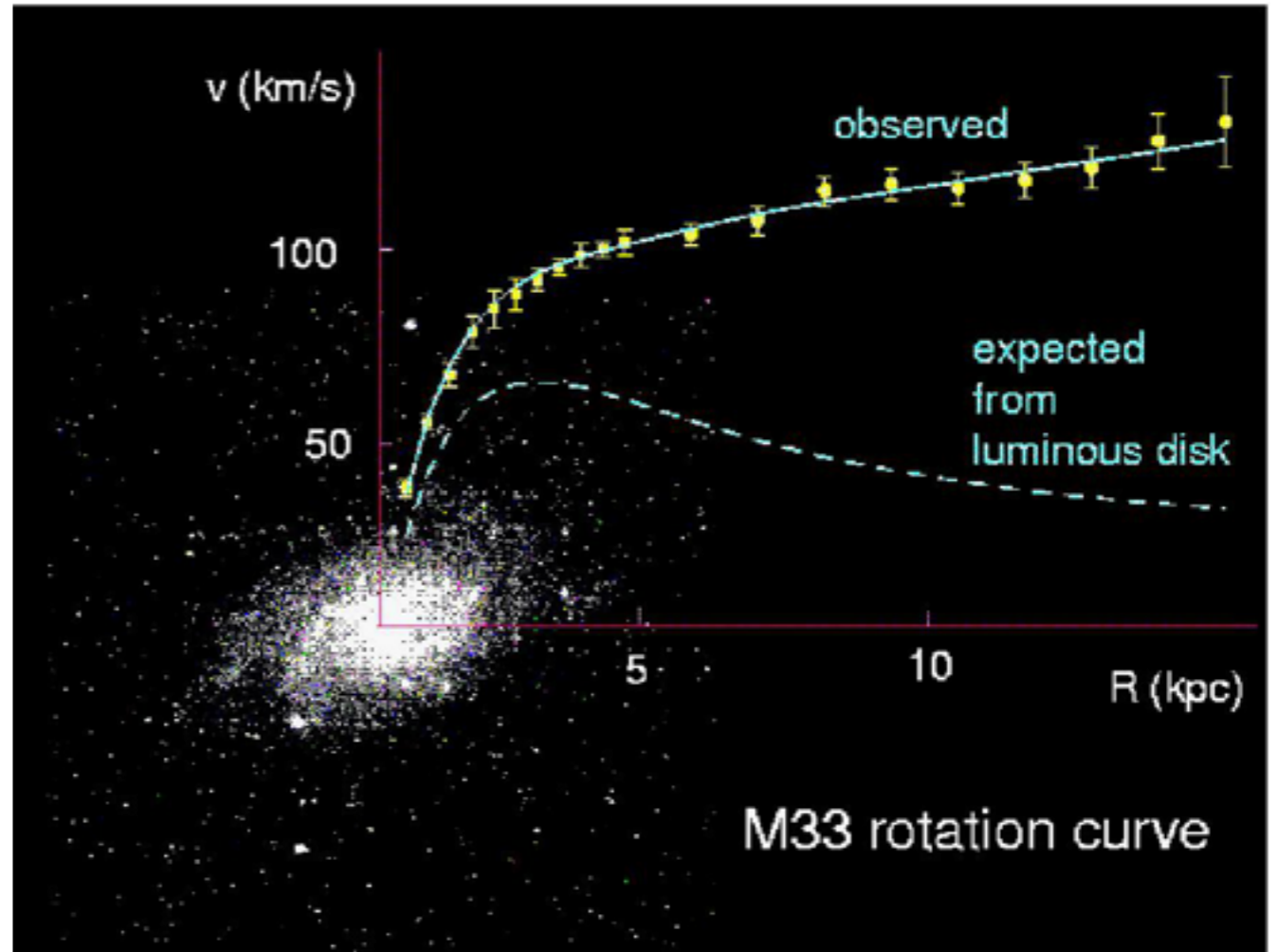
- Implications?

$$0\nu\beta\beta$$





Zwicky 1933



M33 rotation curve



M33 rotation curve

Dark Matter

DM evidence

Not only in the clusters of galaxies



Vera Rubin
70's

Velocidad de las estrellas
en la galaxia andromeda

ROTATION OF THE ANDROMEDA NEBULA FROM A SPECTROSCOPIC SURVEY OF EMISSION REGIONS*

VERA C. RUBIN† AND W. KENT FORD, JR.†

Department of Terrestrial Magnetism, Carnegie Institution of Washington and Lowell Observatory, and Kitt Peak National Observatory‡

Received 1960 July 7; revised 1960 August 31

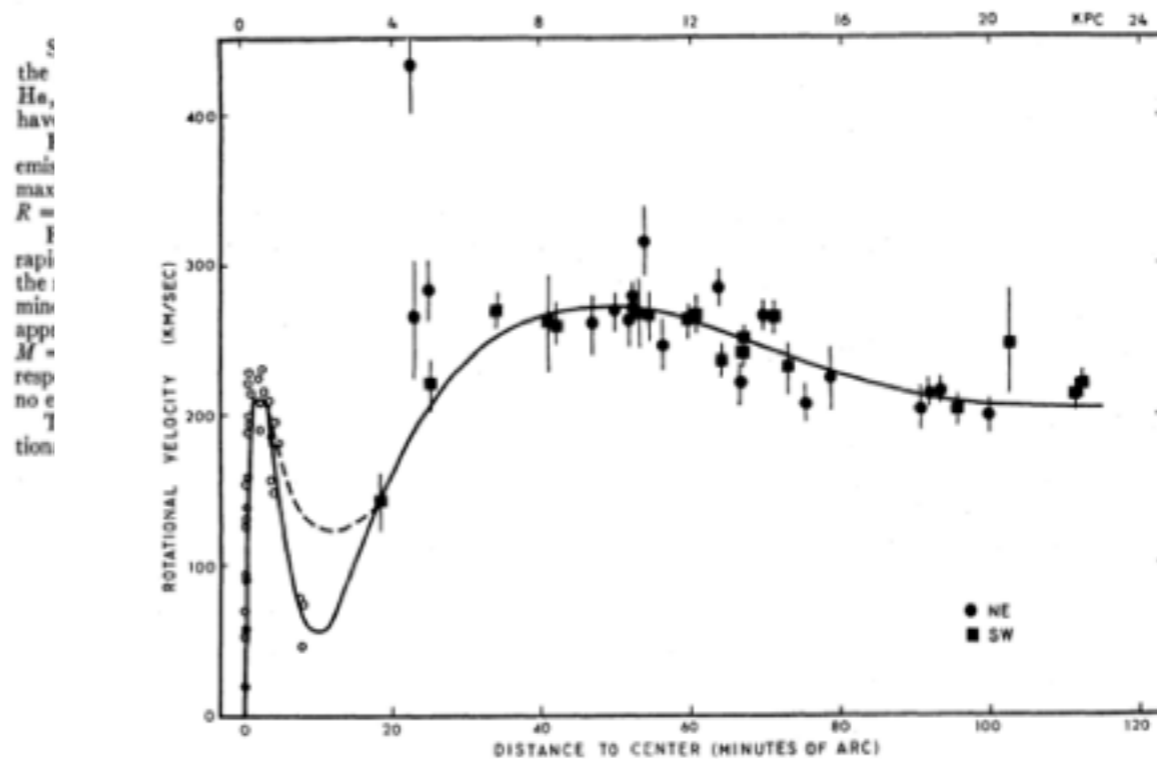
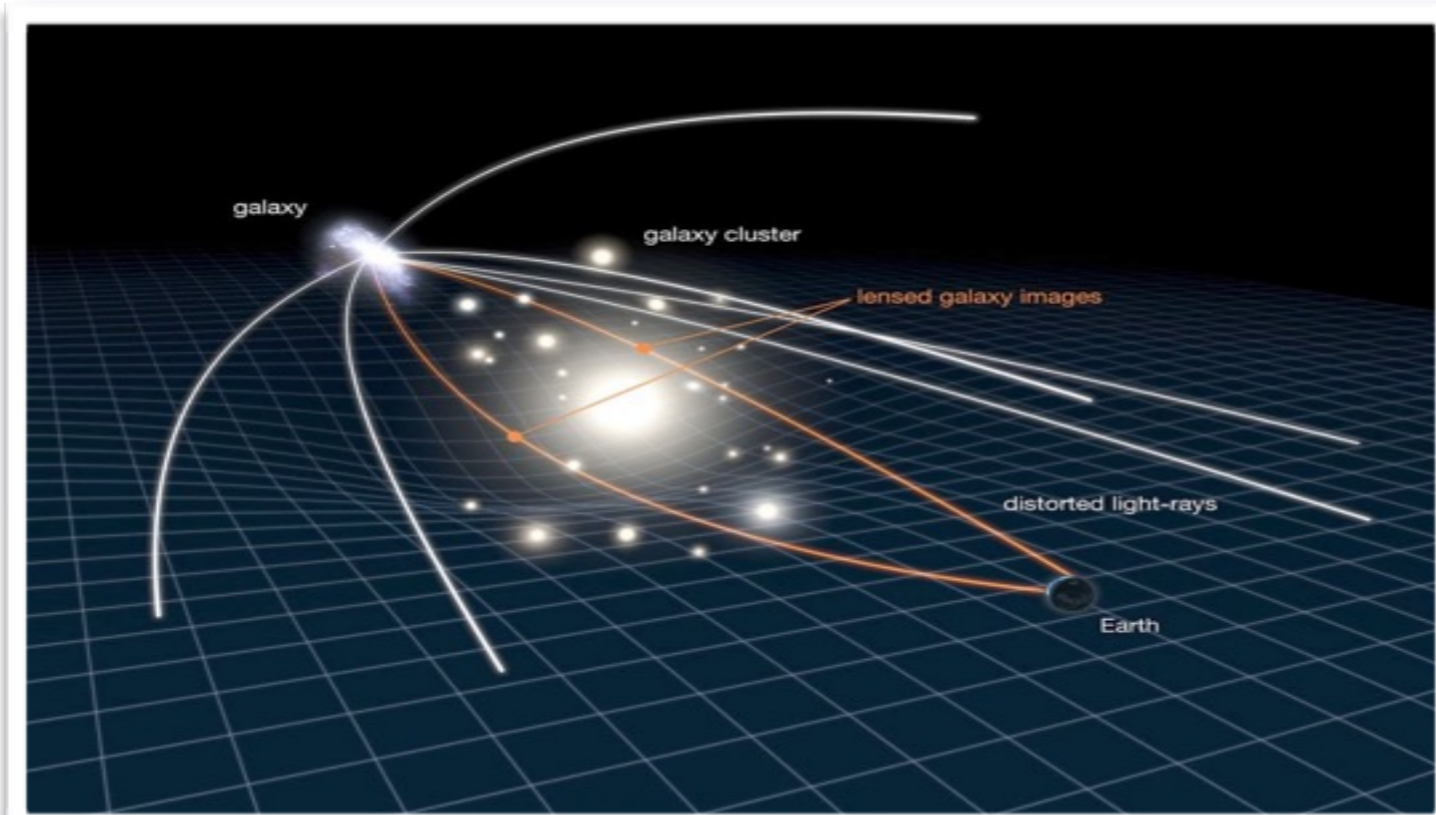
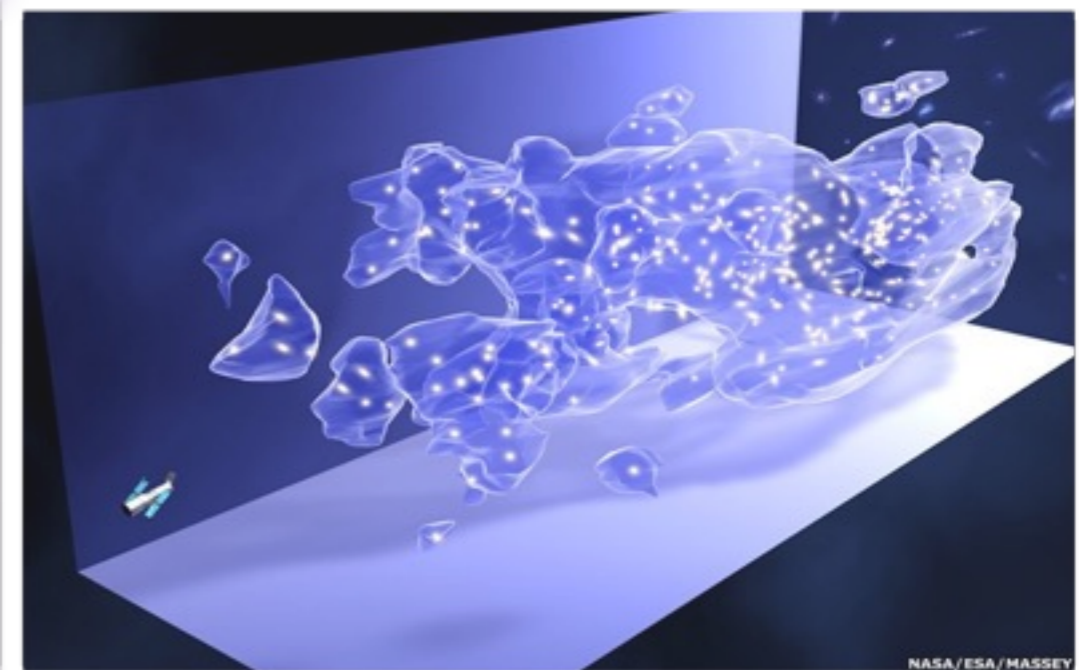
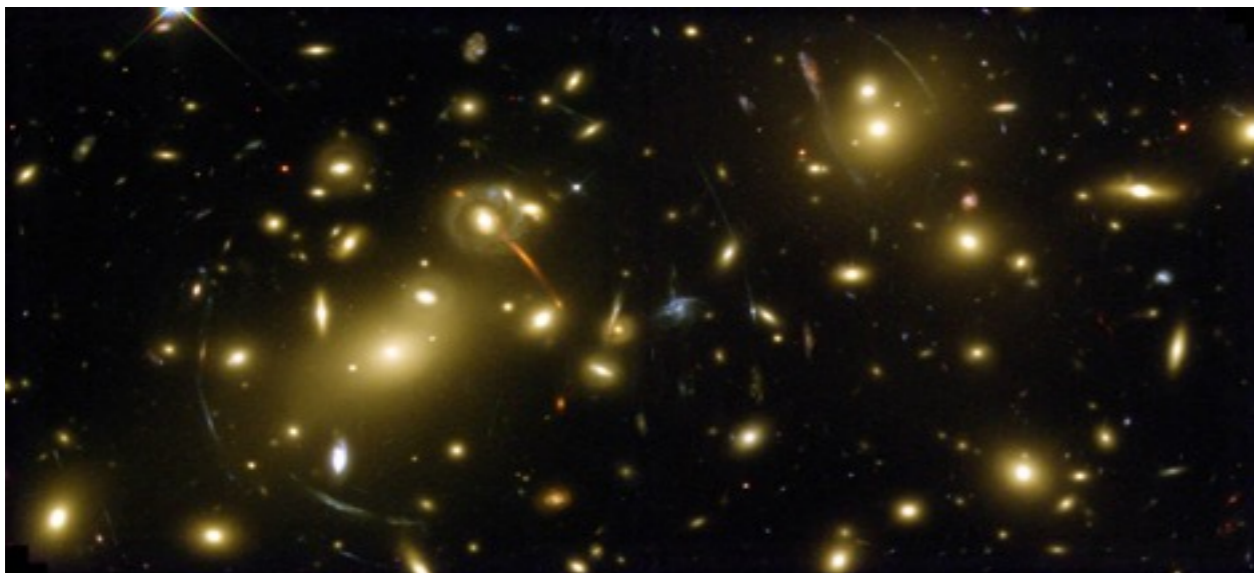
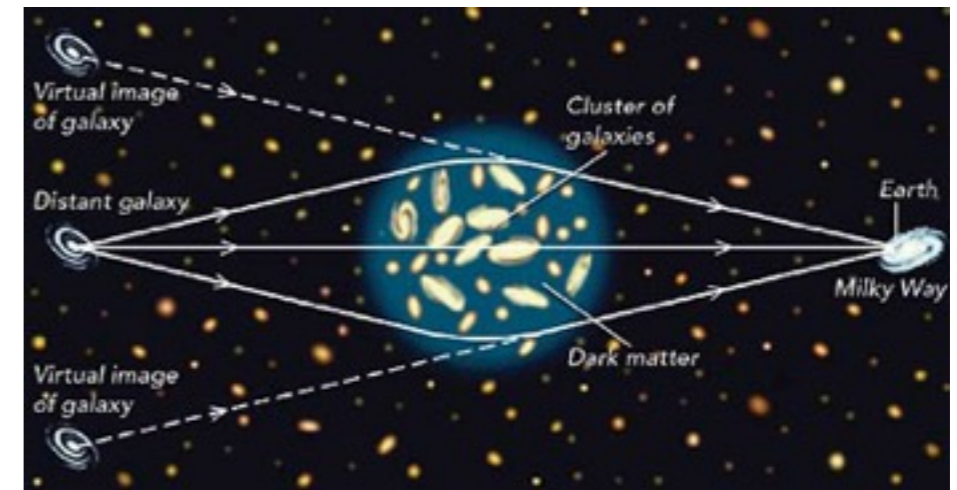


FIG. 9.—Rotational velocities for OB associations in M31, as a function of distance from the center. *Solid curve*, adopted rotation curve based on the velocities shown in Fig. 4. For $R \leq 12'$, curve is fifth-order polynomial; for $R > 12'$, curve is fourth-order polynomial required to remain approximately flat near $R = 120'$. *Dashed curve* near $R = 10'$ is a second rotation curve with higher inner minimum.

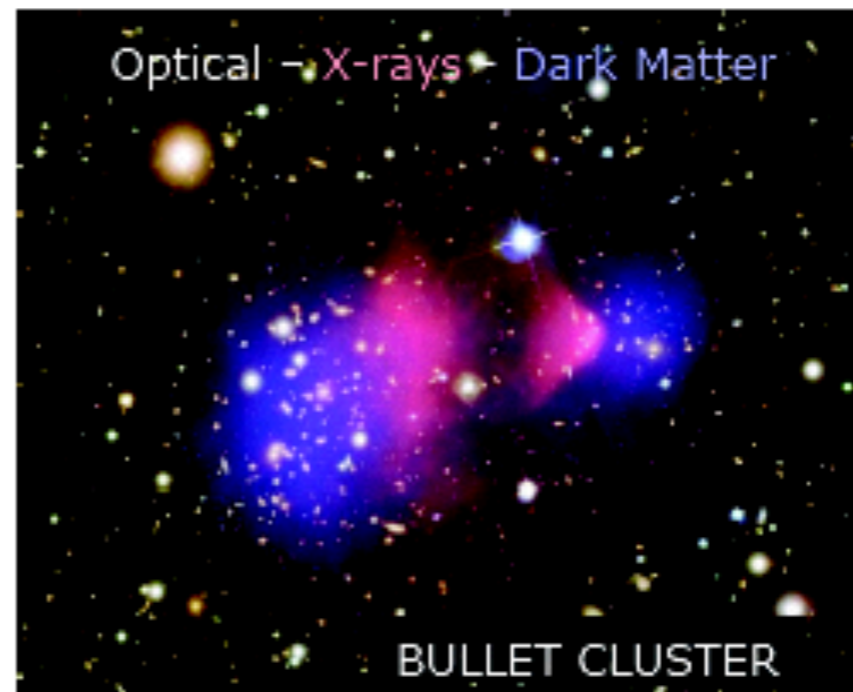
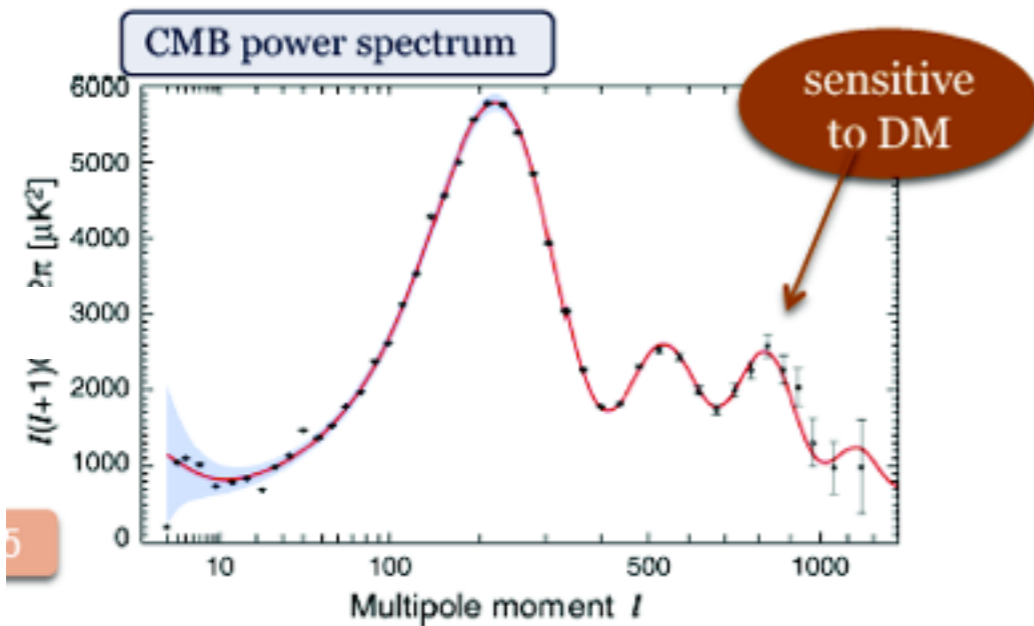
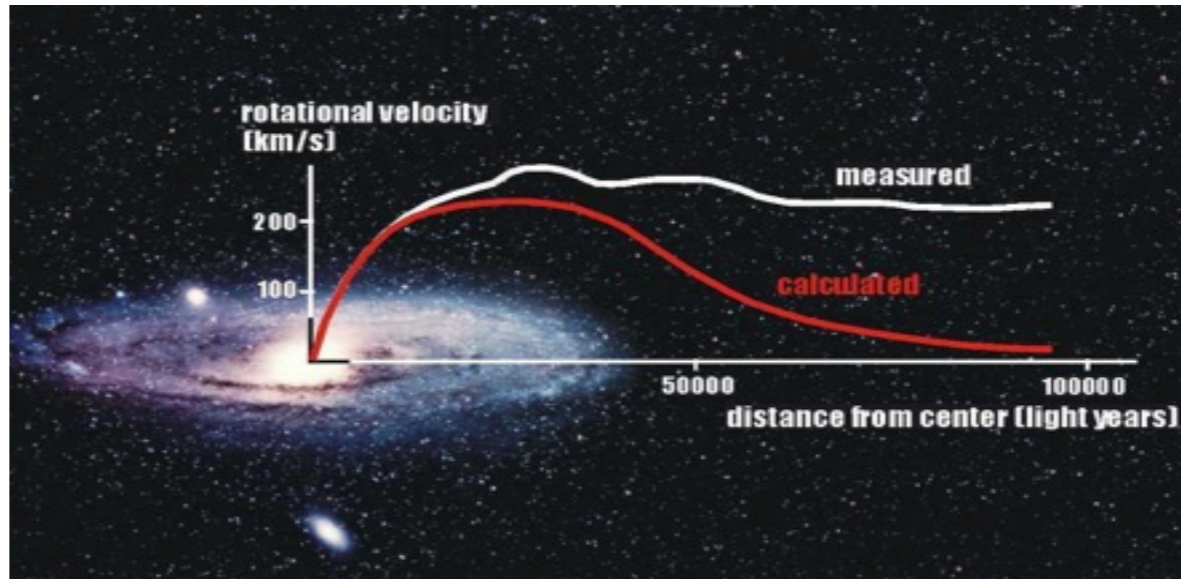
DM evidence



Gravitational lensing



- Rotational curves
- Clusters of galaxies
- CMB anisotropies
- BBN
- ...



Bradac et al,
ApJ 652 (2006) 937

See one of Eric's Talks

Inventory of matter in the universe



Stars
Stellar gas
Gas

DM

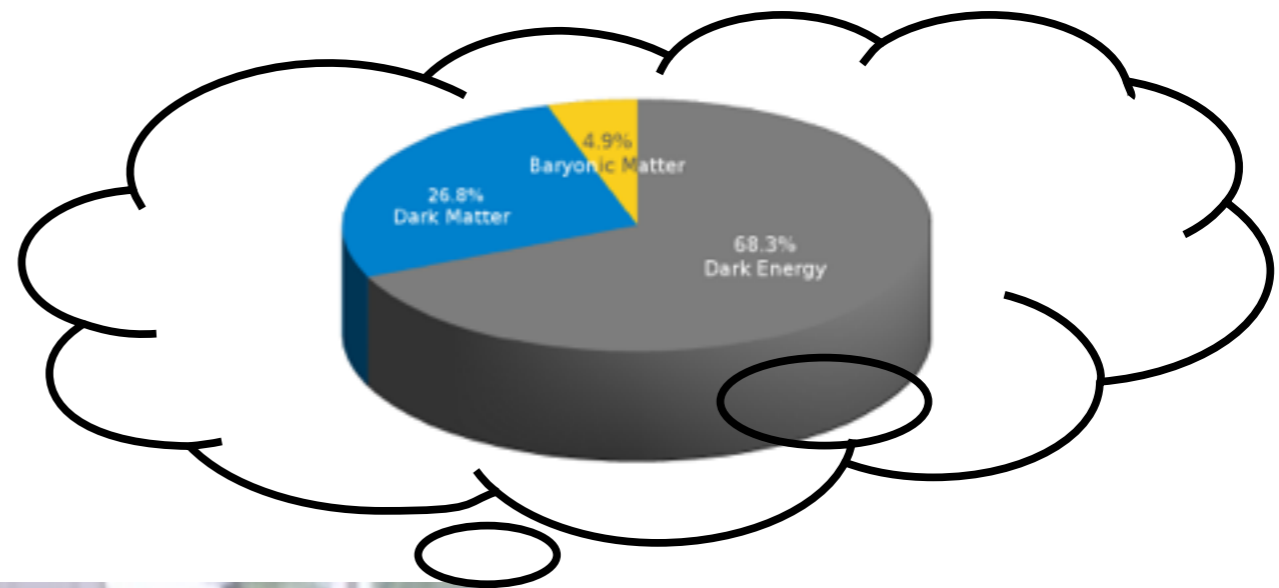
baryonic
matter

Non baryonic
matter

What do we “know” about DM?

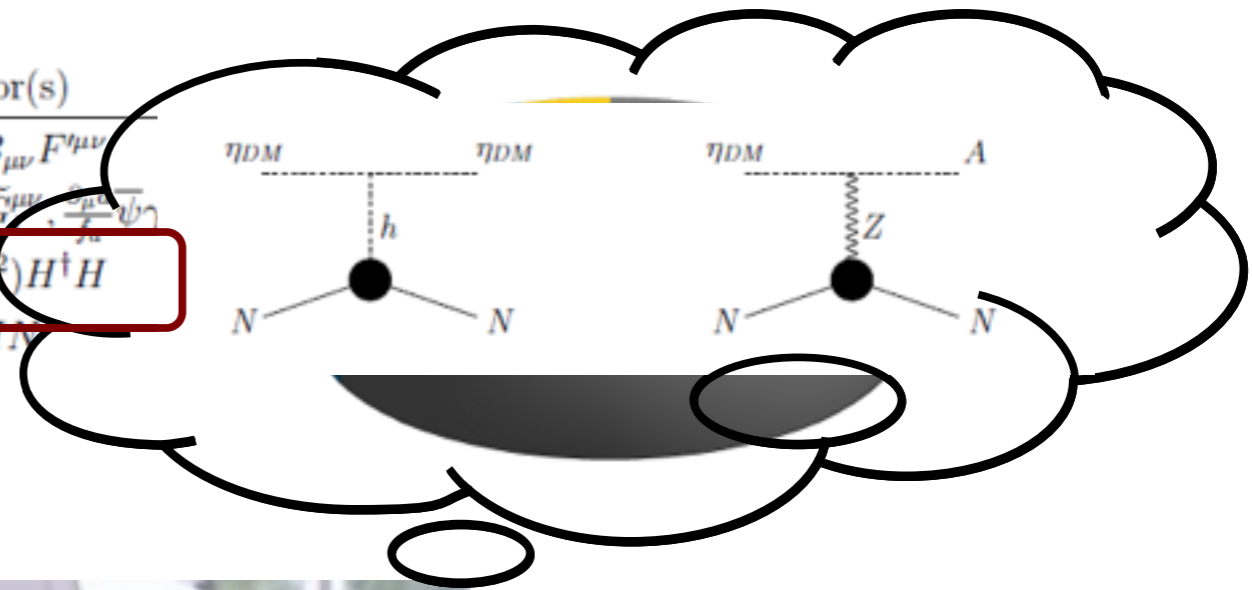
- **Long lived (Stable)**
- **DM** cosmological abundance extracted from observations
- **DM** is cold (or warm)
- **Electrically neutral**
- **DM-DM** and **DM-SM** interactions constrained by observations

DM puzzle



DM puzzle

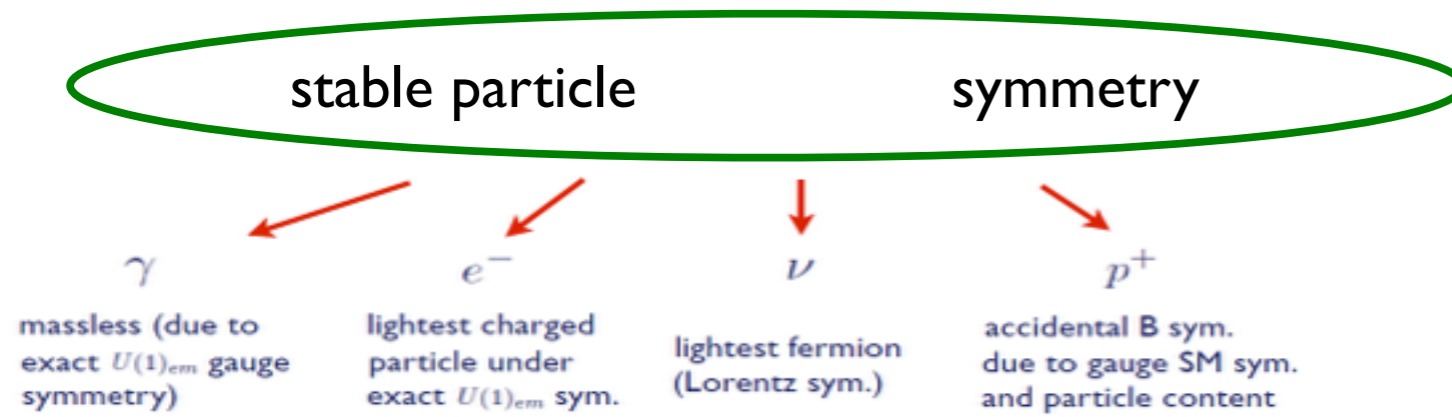
Portal	Particles	Operator(s)
"Vector"	Dark photons	$-\frac{\epsilon}{2 \cos \theta_W} B_{\mu\nu} F^{\mu\nu}$
"Axion"	Pseudoscalars	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}, \frac{a}{f_a} G_{\mu\nu} \tilde{G}^{\mu\nu}, \frac{a}{f_a} \bar{\psi} \gamma_5 \psi$
"Higgs"	Dark scalars	$(\mu S + \lambda S^2) H^\dagger H$
"Neutrino"	Sterile neutrinos	$y_N L H N$



Higgs Portal
Direct detection

One simple Idea for DM

Inert scalar DM

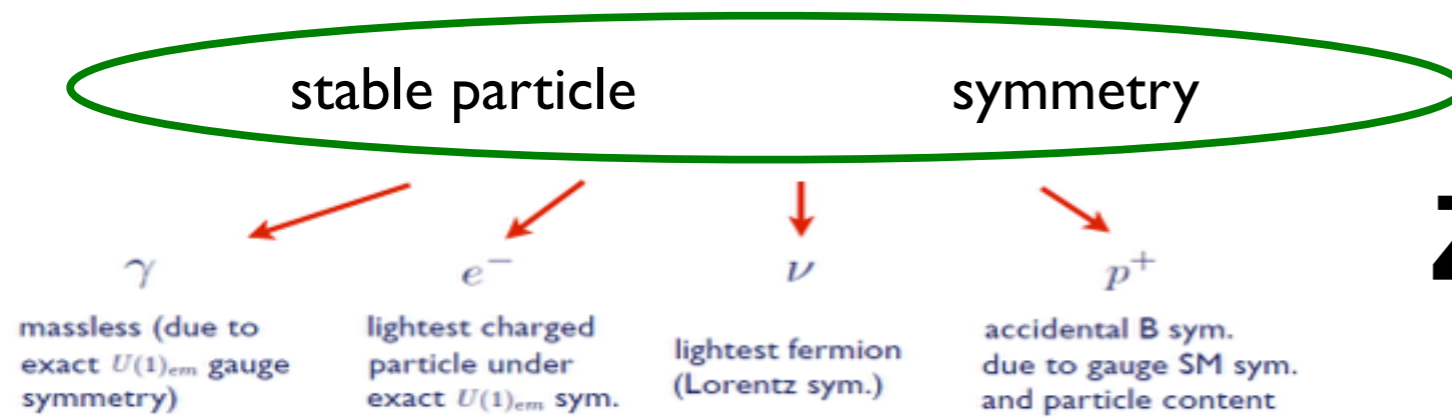


One simple Idea for DM

Inert scalar DM

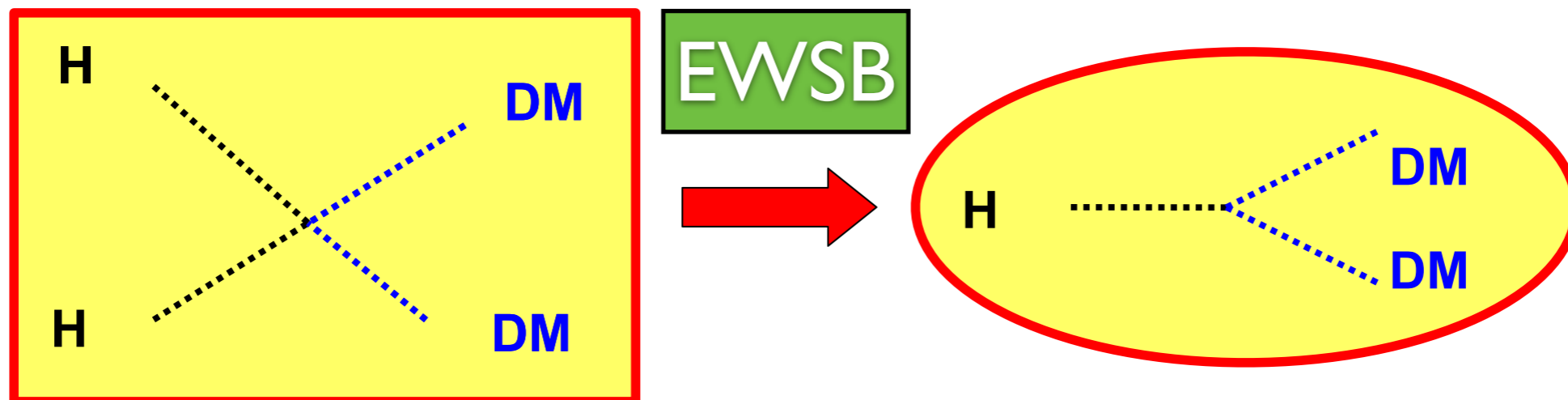
Deshpande and Ma (1978)

SM + scalar



Z_2 + -

$$\lambda_3 |H_1|^2 |H_2|^2 + \lambda_4 |H_1^\dagger H_2|^2 + \frac{\lambda_5}{2} [(H_1^\dagger H_2)^2 + h.c.]$$

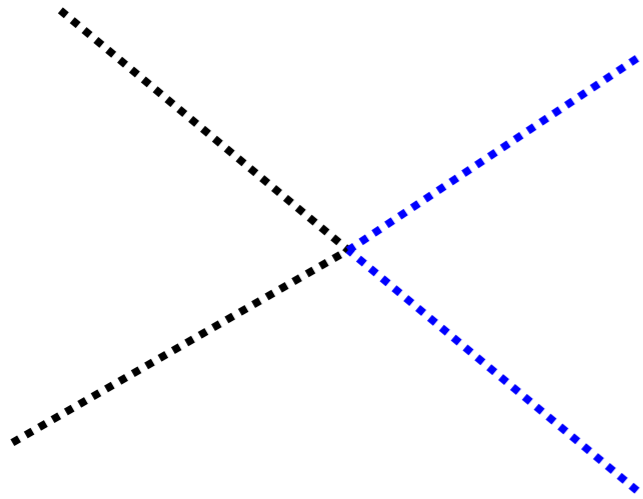


Higgs portal

Neutrino masses in the Inert DM?

L **H** **N** **η**

Z_2 **+** **-**



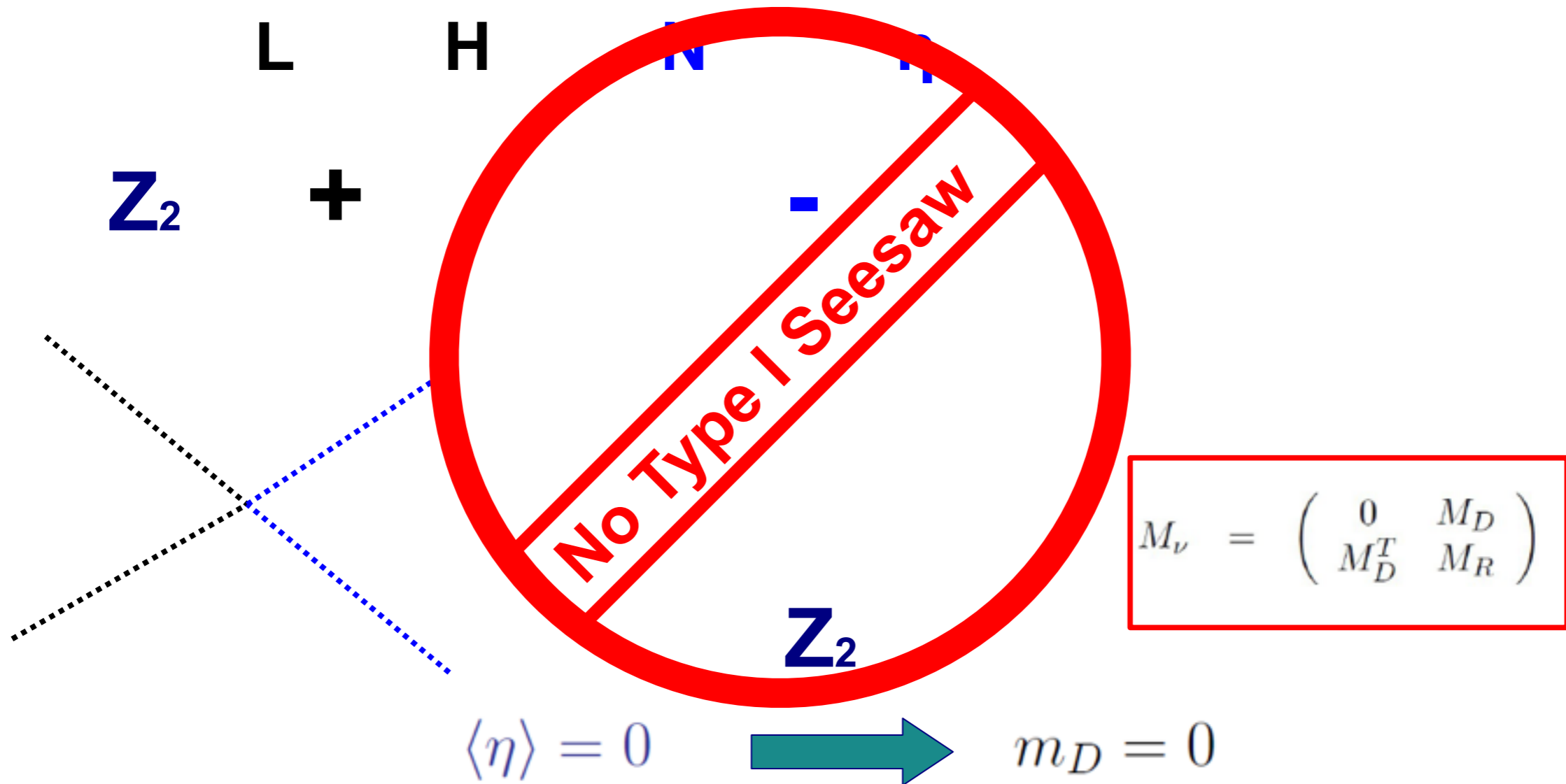
$$\langle \eta \rangle = 0$$



$$m_D = 0$$

Z_2

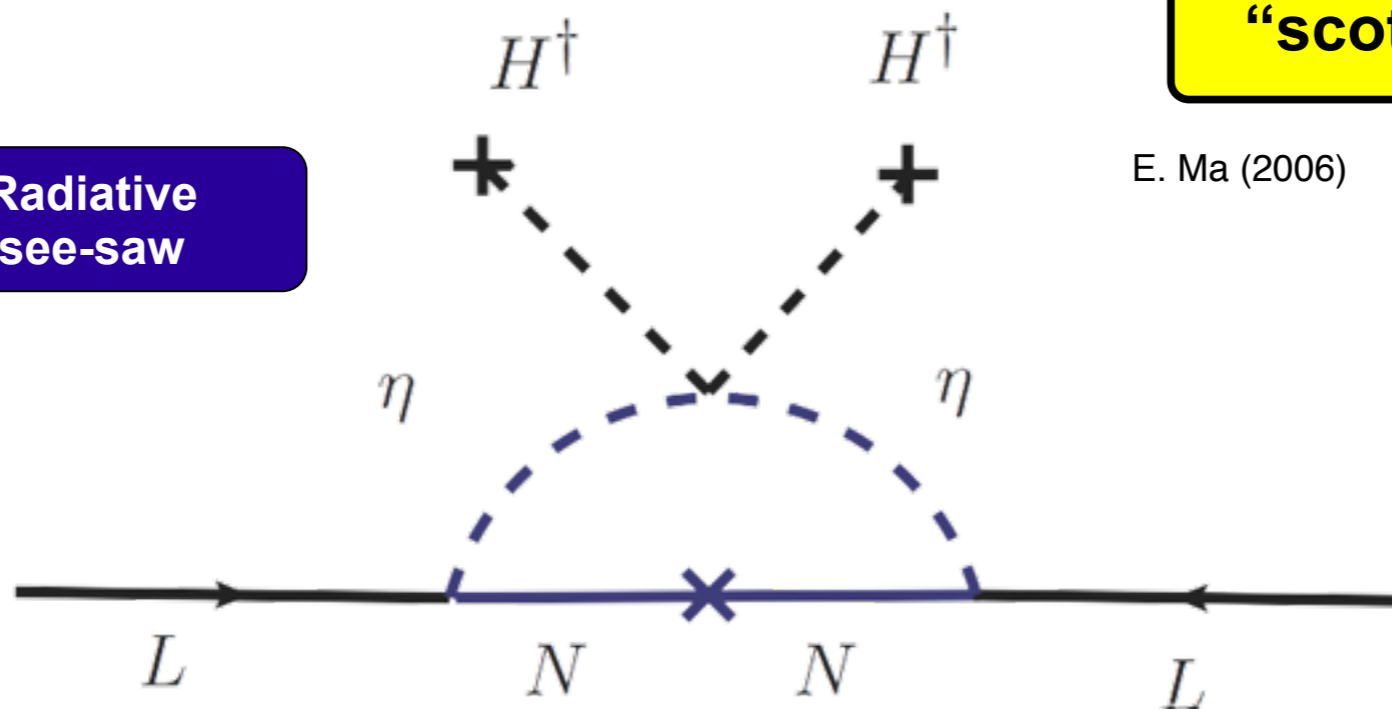
Neutrino masses in the Inert DM?



Neutrino masses in the inert DM

A. Zee (1980)

Radiative
see-saw



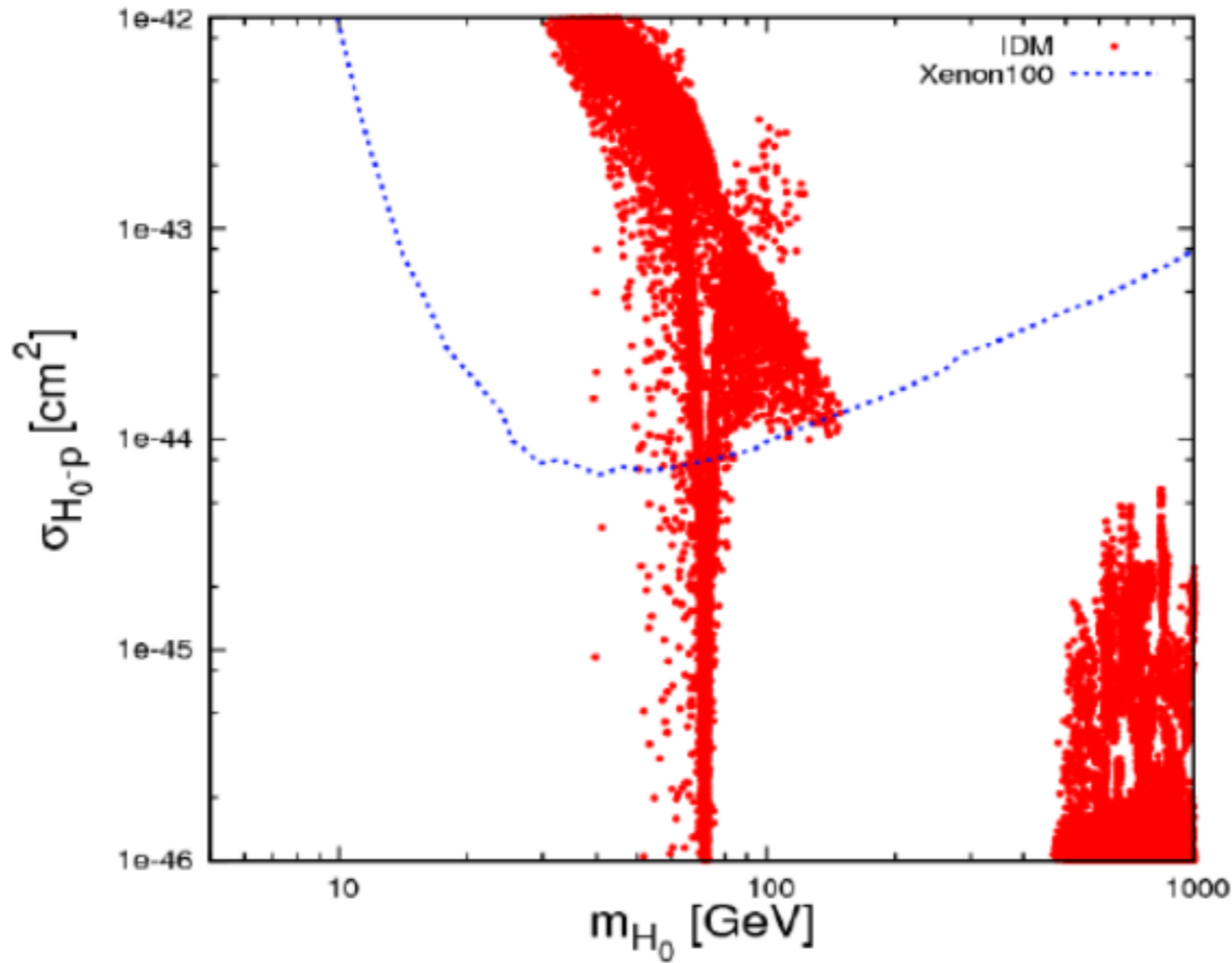
“scotogenic”

E. Ma (2006)

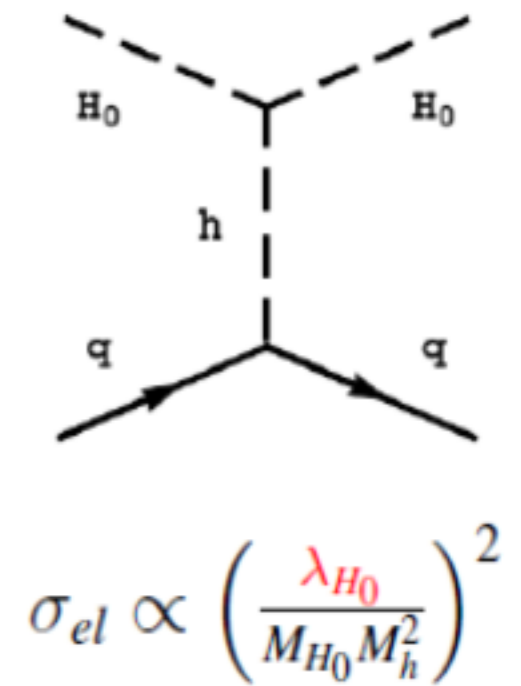
If $M_k^2 \gg m_0^2$, then

$$(\mathcal{M}_\nu)_{ij} = \frac{\lambda_5 v^2}{8\pi^2} \sum_k \frac{h_{ik} h_{jk}}{M_k} \left[\ln \frac{M_k^2}{m_0^2} - 1 \right]$$

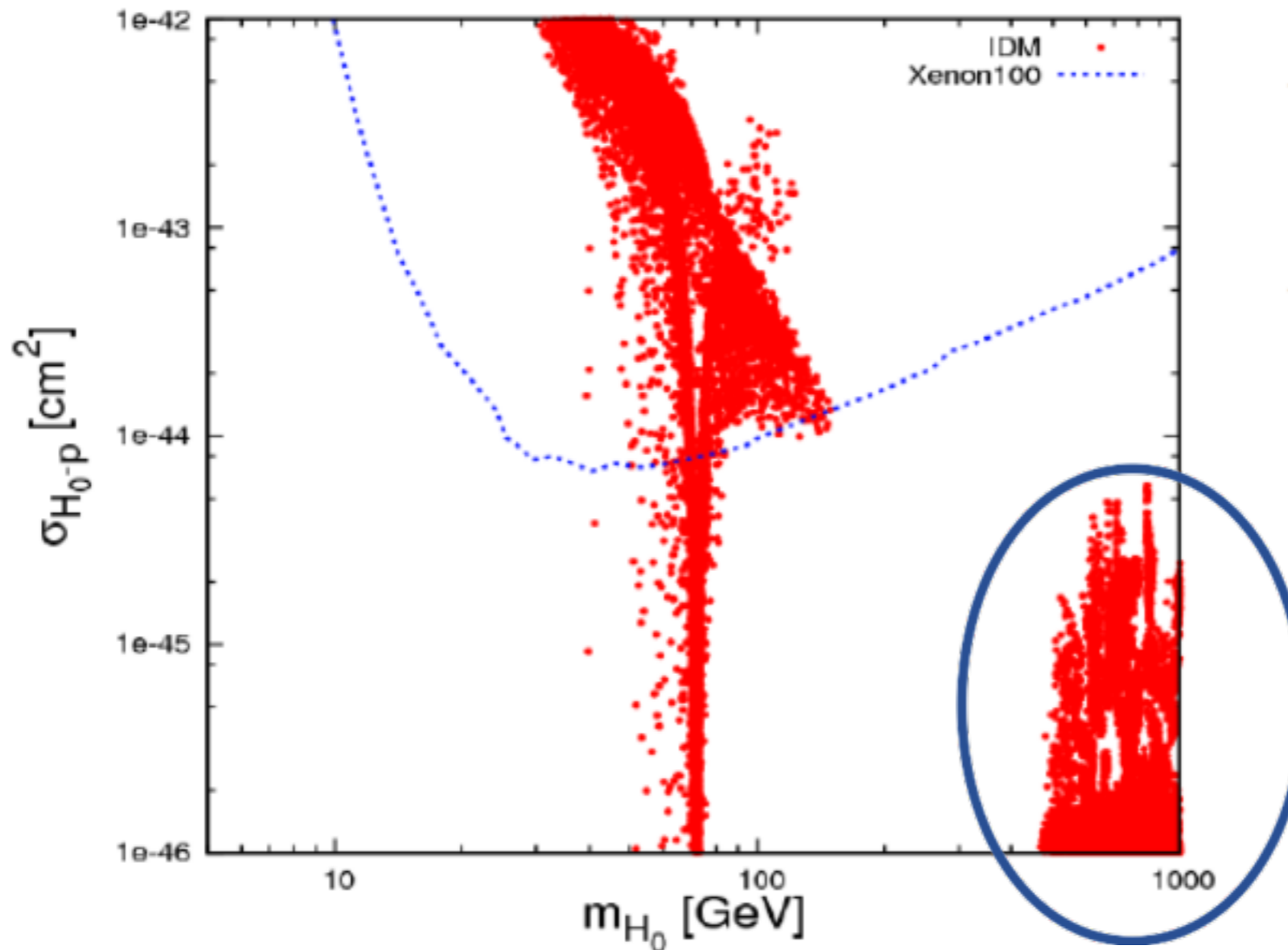
Direct Detection



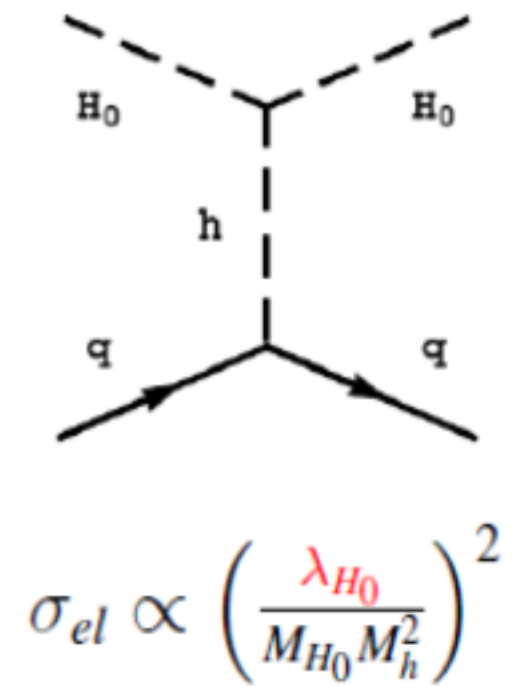
result of a scan giving rise to $0.09 < \Omega_{H_0} h^2 < 0.13$



Direct Detection



result of a scan giving rise to $0.09 < \Omega_{H_0} h^2 < 0.13$



High mass regime

Other Possibilities

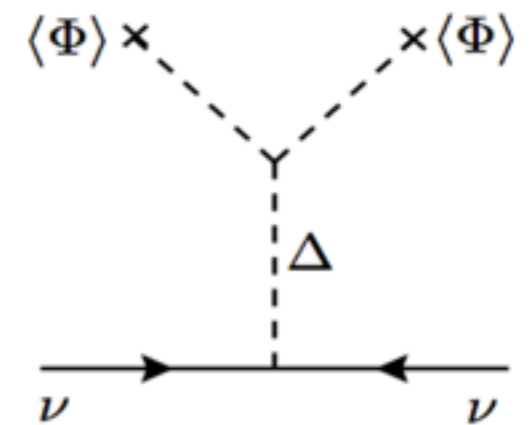
with higher representations

$$2 \otimes 2 = 1 + 3$$

type II seesaw

$$L\Delta L$$

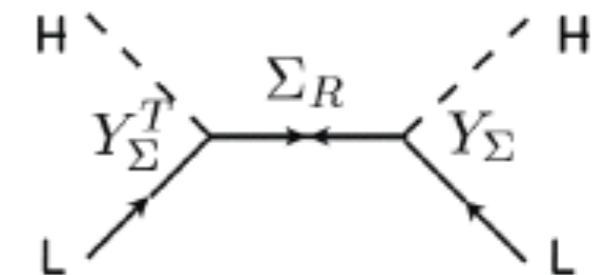
$$2 \otimes 3 \otimes 2$$



type III seesaw

$$LH\Sigma$$

$$2 \otimes 3 \otimes 2$$



Type III

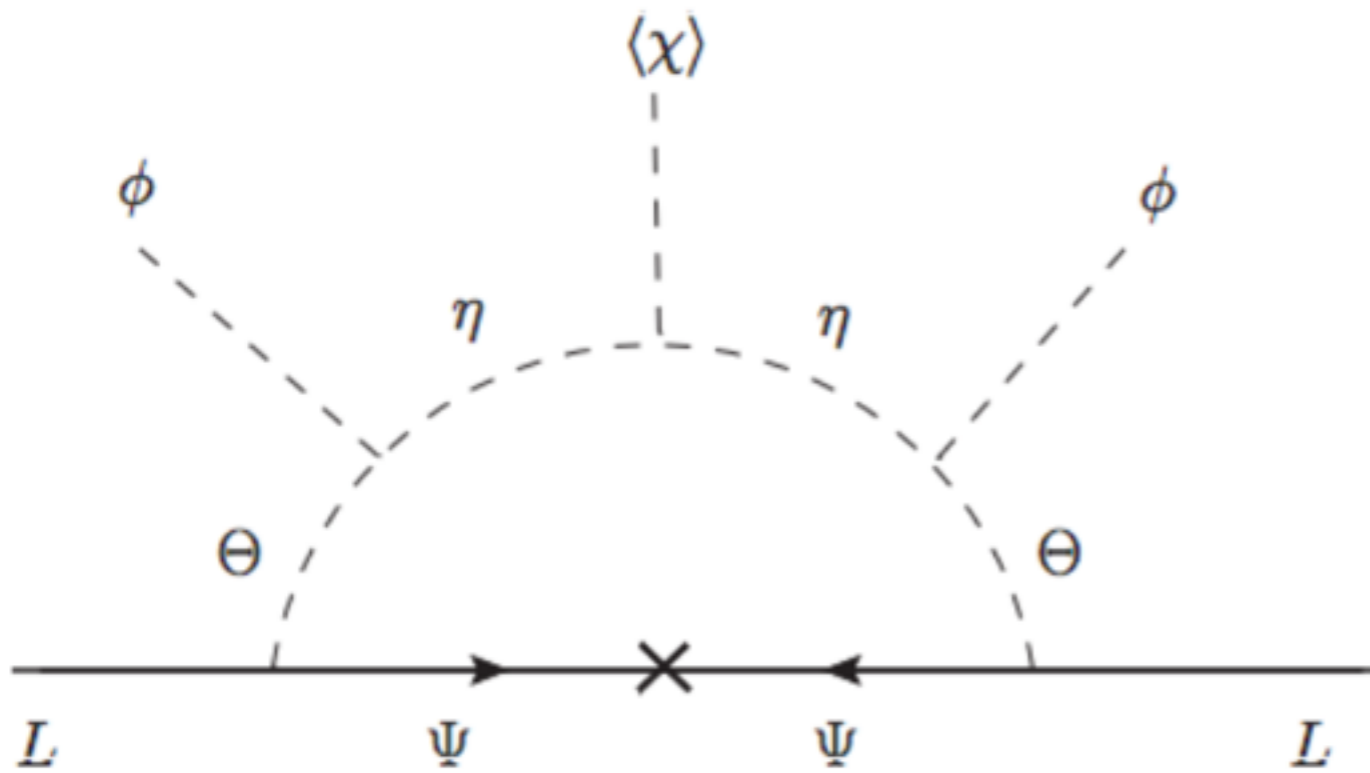
Neutrino masses from higher dim Higgses

Aranda, EP (2015)

- **Imposing the condition rho parameter 1 at tree level**

$$\rho = \frac{\sum_{\phi} [j_{\phi}(j_{\phi} + 1) - Y_{\phi}^2] v_{\phi}^2}{\sum_{\phi} 2Y_{\phi}^2 v_{\phi}^2}$$

- **the minimal is a septet with Y=2**
- **What do we need for this to contribute to Neutrino masses?**
- **What are the conditions?**



$$2 \times 2 = 1 + 3$$

$$3 \times 2 = 2 + 4$$

$$3 \times 3 = 1 + 3 + 5$$

$$4 \times 2 = 3 + 5$$

$$4 \times 3 = 2 + 4 + 6$$

$$4 \times 4 = 1 + 3 + 5 + 7$$

$$5 \times 2 = 4 + 6$$

$$5 \times 3 = 3 + 5 + 7$$

$$5 \times 4 = 2 + 4 + 6 + 8$$

$$5 \times 5 = 1 + 3 + 5 + 7 + 9$$

$$6 \times 2 = 5 + 7$$

$$6 \times 3 = 4 + 6 + 8$$

$$6 \times 4 = 3 + 5 + 7 + 9$$

$$6 \times 5 = 2 + 4 + 6 + 8 + 10$$

$$6 \times 6 = 1 + 3 + 5 + 7 + 9 + 11$$

$$7 \times 2 = 6 + 8$$

$$7 \times 3 = 5 + 7 + 9$$

$$7 \times 4 = 4 + 6 + 8 + 10$$

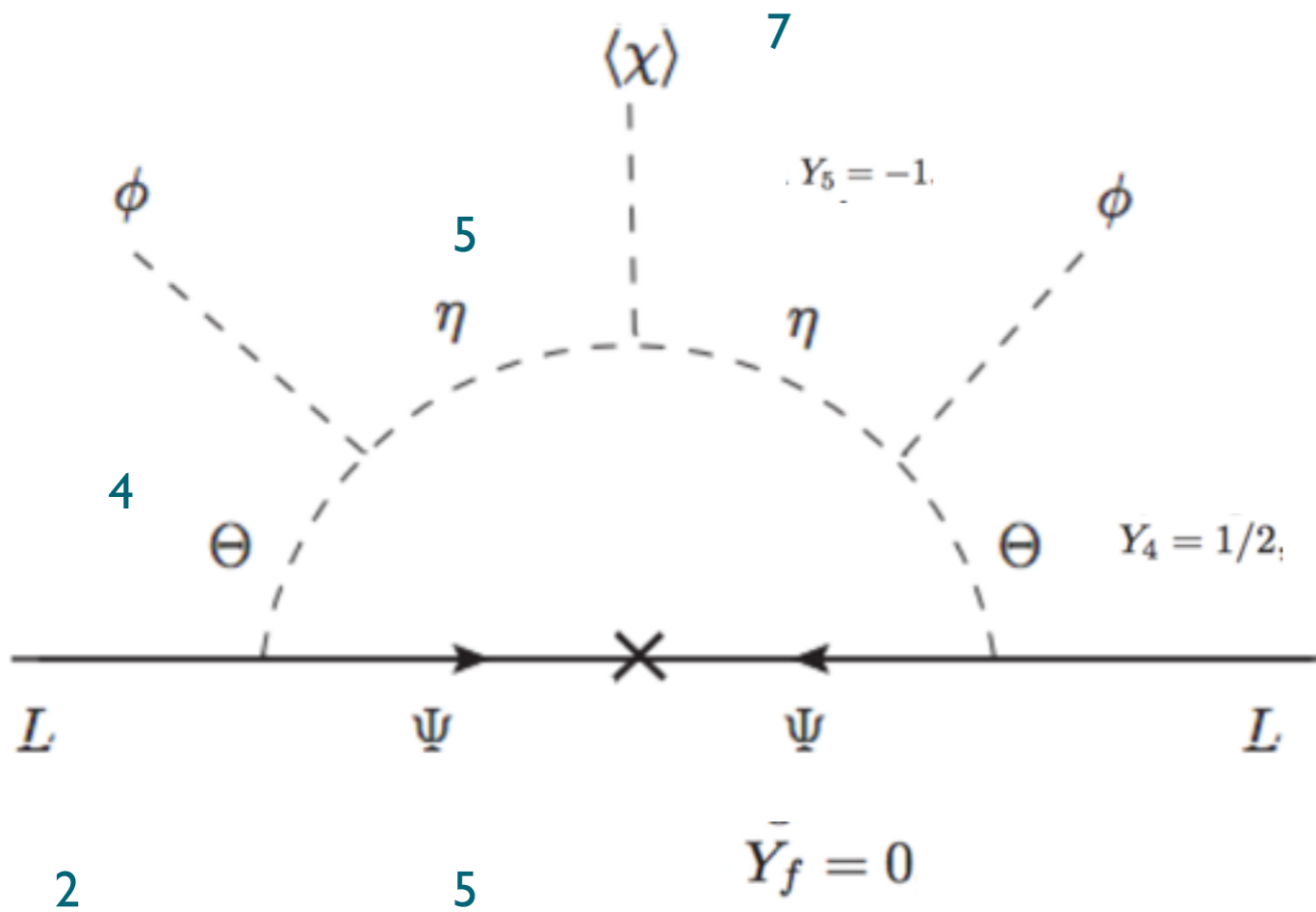
$$7 \times 5 = 3 + 5 + 7 + 9 + 11$$

$$7 \times 6 = 2 + 4 + 6 + 8 + 10 + 12$$

$$7 \times 7 = 1 + 3 + 5 + 7 + 9 + 11 + 13$$

How to generate neutrino masses?

Aranda, EP (2015)



fermionic SU(2) 5-plet Ψ

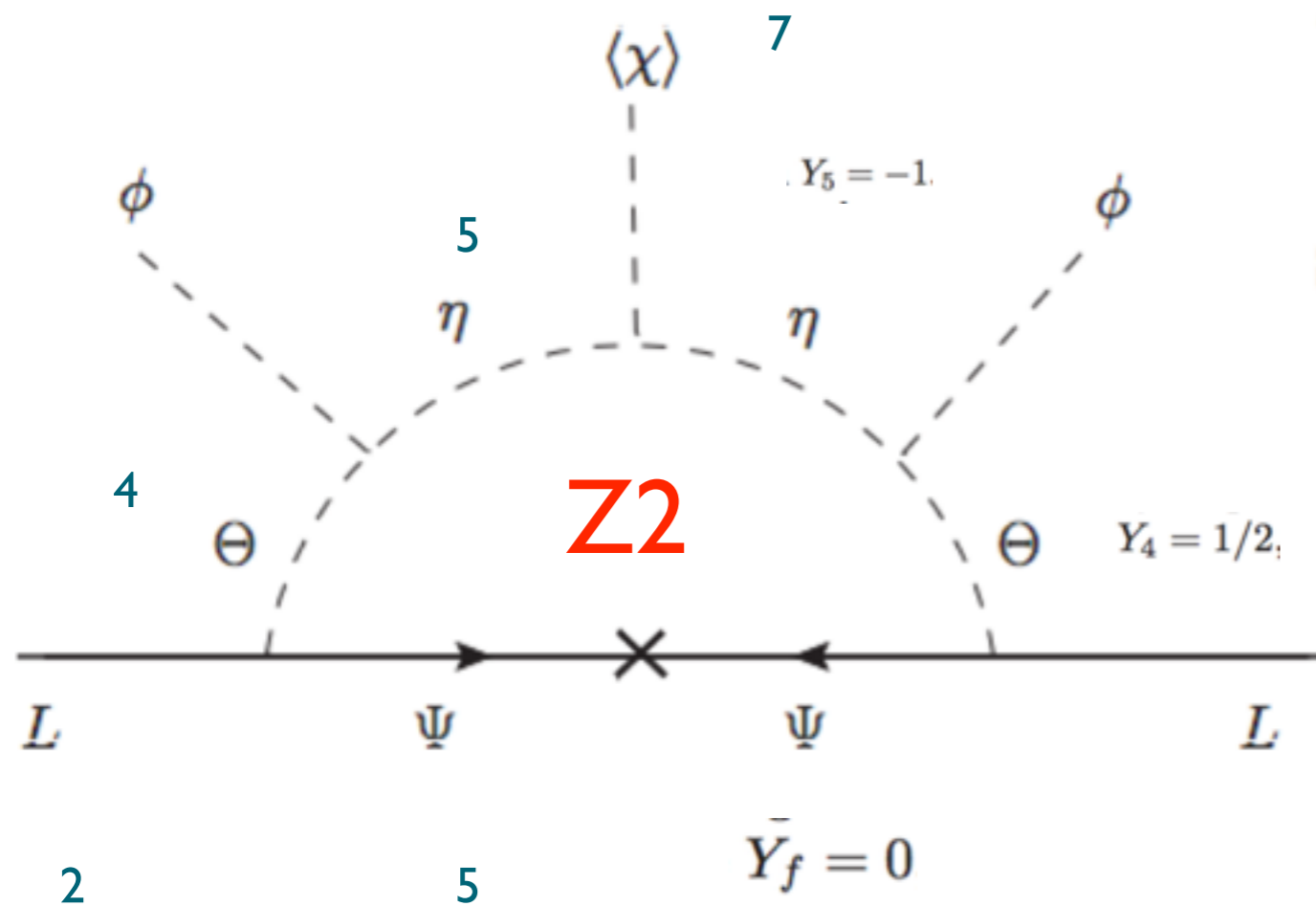
scalars in the quartet (Θ)

and quintet (η)

$$LL\phi\phi\tilde{\chi}$$

How to generate neutrino masses?

Aranda, EP (2015)



fermionic SU(2) 5-plet Ψ ,

scalars in the quartet (Θ)

and quintet (η)

$$LL\phi\phi\tilde{\chi}$$

In order to preserve the tree level rho parameter we must impose a Z_2 symmetry, in such a way the neutral components of the scalar fields remain vevless

Discrete Dark Matter Introduction

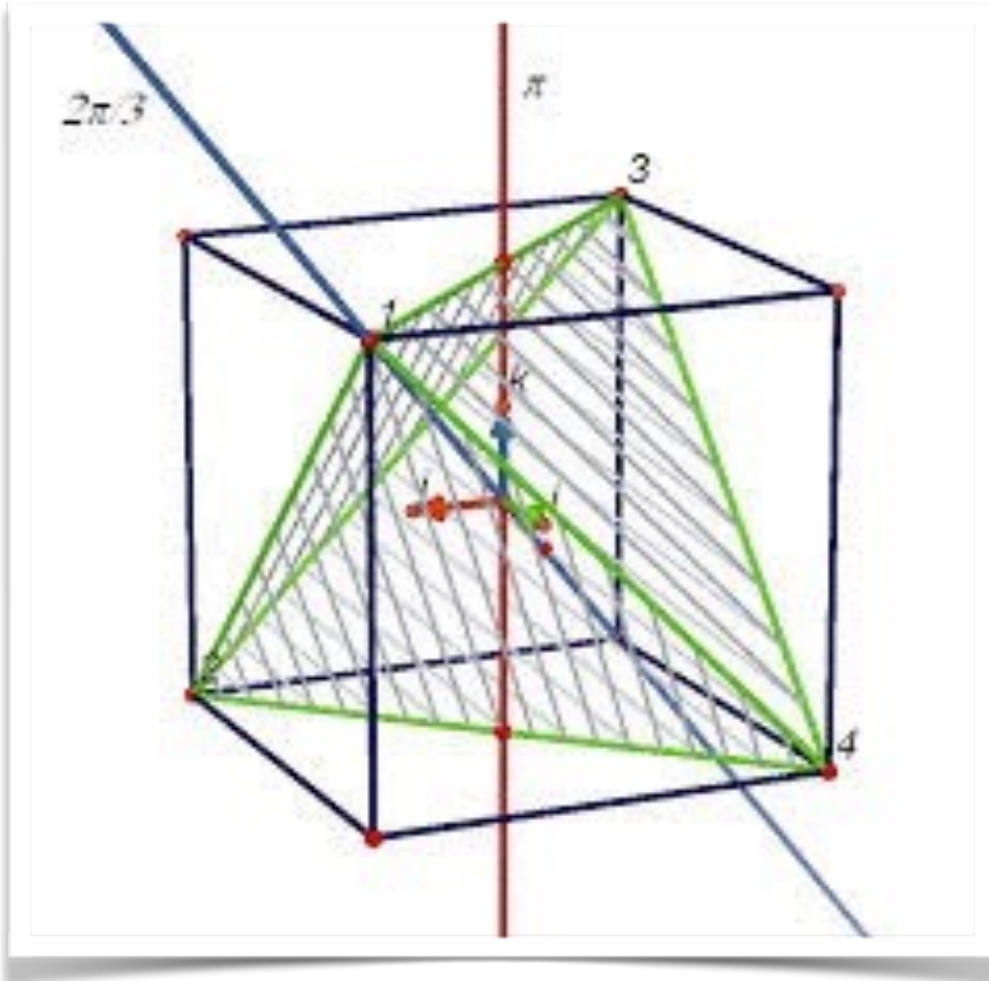
A flavor group

Non-Abelian

Very popular because it was
useful
reproduce the **TBM** mixing

Babu-Ma-Valle
and
Altarelli-Feruglio

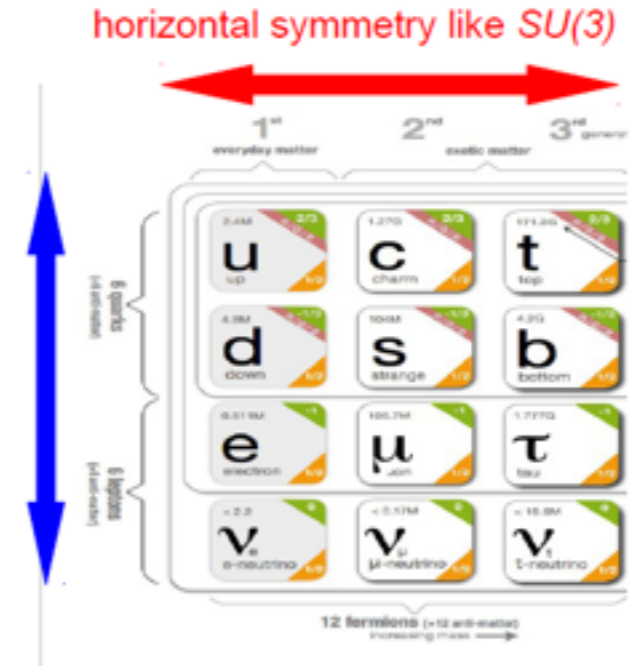
A₄ even permutations
4 objects



Frampton and Kephart, PRD64 (01)

order	groups
6	$S_3 \equiv D_3$
8	$D_4, Q = Q_4$
10	D_5
<u>12</u>	$D_6, Q_6, T \equiv A_4$
14	D_7
16	$D_8, Q_8, Z_2 \times D_4, Z_2 \times Q$
18	$D_9, Z_3 \times D_3$
20	D_{10}, Q_{10}
22	D_{11}
24	$D_{12}, Q_{12}, Z_2 \times D_6, Z_2 \times Q_6, Z_2 \times T, Z_3 \times D_4, Z_3 \times Q, Z_4 \times D_3, S_4$
26	D_{13}
28	D_{14}, Q_{14}
30	$D_{15}, D_5 \times Z_3, D_3 \times Z_5$

vertical gauge symmetry



horizontal symmetry like $SU(3)$ - triplets

Abelian, non-abelian
continuous, discrete,
global, local

Flavor Symmetries (Horizontal)

An example: A4

Ma and Rajasekaran 2001
Babu, Ma, Valle 2003
Altarelli, Feruglio 2005

...

The generators are :

S and T

$$S^2 = T^3 = (ST)^3 = \mathcal{I}.$$

1, 1', 1'' and 3

1	$S = 1$	$T = 1$
1'	$S = 1$	$T = e^{i4\pi/3} \equiv \omega^2$
1''	$S = 1$	$T = e^{i2\pi/3} \equiv \omega$

$$S = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \quad T = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

Z_2

Z_3

A4 and TBM

$$\langle \phi \rangle = (1, 1, 1)$$

$$\langle \phi' \rangle = (1, 0, 0)$$

Z_3

Z_2

Altarelli Feruglio (2005)

M_l

M_ν

$$m = \begin{pmatrix} x & y & y \\ y & x+v & y-v \\ y & y-v & x+v \end{pmatrix}$$

A4 completely broken

$$V_{lep} = U_l^+ \quad U_\nu = TBM$$

Large neutrino mixing

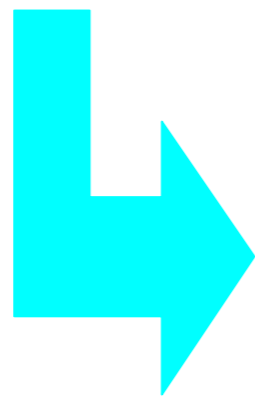


$\phi \neq \phi'$
Misalignment

We have symmetries (stability)?

Z3 in the charged sector

Z2 in the neutrino sector



TBM



Hirsch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)

We have symmetries (stability)?

Z3 in the ~~charged~~ sector

Z2 in the neutrino sector

stabilize the DM



~~TBM~~



Hirsch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)

We have symmetries (stability)?

Z2 in the charged sector **Z2** in the neutrino sector

stabilize the DM



Hirsch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)

1, 1', 1''

3

The simplest model

SM + 3 Higgs SU(2) doublets , 4 right handed neutrinos

Hirsch, Morisi, Peinado and Valle
Phys. Rev. D 82, 116003 (2010)

	L_e	L_μ	L_τ	l_e^c	l_μ^c	l_τ^c	N_T	N_4	H	η
$SU(2)$	2	2	2	1	1	1	1	1	2	2
A_4	1	1'	1''	1	1''	1'	3	1	1	3

$$\begin{aligned}
 1 \times 1_i &= 1_i \\
 1' \times 1'' &= 1 \\
 1' \times 1' &= 1'' \\
 1'' \times 1'' &= 1'
 \end{aligned}$$

Z_3

Charged leptons
diagonal

The simplest model

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	L_e	L_μ	L_τ	l_e^c	l_μ^c	l_τ^c	N_T	N_4	H	η
$SU(2)$	2	2	2	1	1	1	1	1	2	2
A_4	1	1'	1''	1	1''	1'	3	1	1	3

$$\langle \eta_{2,3}^0 \rangle = 0$$

$$\langle \eta \rangle \sim (1, 0, 0)$$

$$\langle \eta_1^0 \rangle = v_\eta$$

$$\langle H^0 \rangle = v_h$$

$$m_D = \begin{pmatrix} x_1 & 0 & 0 & y_1 \\ x_2 & 0 & 0 & 0 \\ x_3 & 0 & 0 & 0 \end{pmatrix}$$

$$M_R = \text{diag}(M_1, M_1, M_1, M_2)$$

Neutrino masses in the model

Scaling matrix,
Rodejohan and Mohapatra

$$\begin{pmatrix} y^2 & ab & ac \\ ab & b^2 & bc \\ ac & bc & c^2 \end{pmatrix}$$



$$m_3 = 0$$

$$\begin{pmatrix} 0 \\ -c/b \\ 1 \end{pmatrix}$$

Inverse mass Hierarchy

$$\left\{ m_{ee} \sim 0.03 - 0.05 \text{ eV} \right\}$$

Neutrino masses in the model

Scaling matrix,
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$$m_3 = 0 \quad \begin{pmatrix} 0 \\ -c/b \\ 1 \end{pmatrix}$$

$\sin^2 \theta_{13}/10^{-2}$ (NH)

2.34 ± 0.20

1.95–2.74

1.77–2.94

Inverse mass Hierarchy

$$\left\{ m_{ee} \sim 0.03 - 0.05 \text{ eV} \right\}$$

Reactor mixing angle?

	L_e	L_μ	L_τ	l_e^c	l_μ^c	l_τ^c	N_T	N_4	N_5	H	η	ϕ
$SU(2)$	2	2	2	1	1	1	1	1	1	2	2	1
A_4	1	1'	1''	1	1''	1'	3	1	1'	1	3	3

Charged leptons
diagonal

Now the FS will be
broken
At the see-saw scale

$$V_{lep} = U_l^+ U_\nu$$

The A4 breaking

$$\langle H^0 \rangle = v_h \neq 0, \quad \langle \eta_1^0 \rangle = v_\eta \neq 0 \quad \langle \eta_{2,3}^0 \rangle = 0. \quad \langle \phi_1 \rangle = v_\phi \neq 0 \quad \langle \phi_{2,3} \rangle = 0$$

$$\begin{array}{c} \eta \\ \phi \end{array} \quad (1,0,0)$$

$$m_\nu = -m_{D_{3 \times 5}} M_{R_{5 \times 5}}^{-1} m_{D_{3 \times 5}}^T \equiv \begin{pmatrix} a & 0 & b \\ 0 & 0 & c \\ b & c & d \end{pmatrix}$$

Two zero-textures
B3

Frampton, Glashow, Marfatia
Phys.Lett. B536 (2002) 79-82

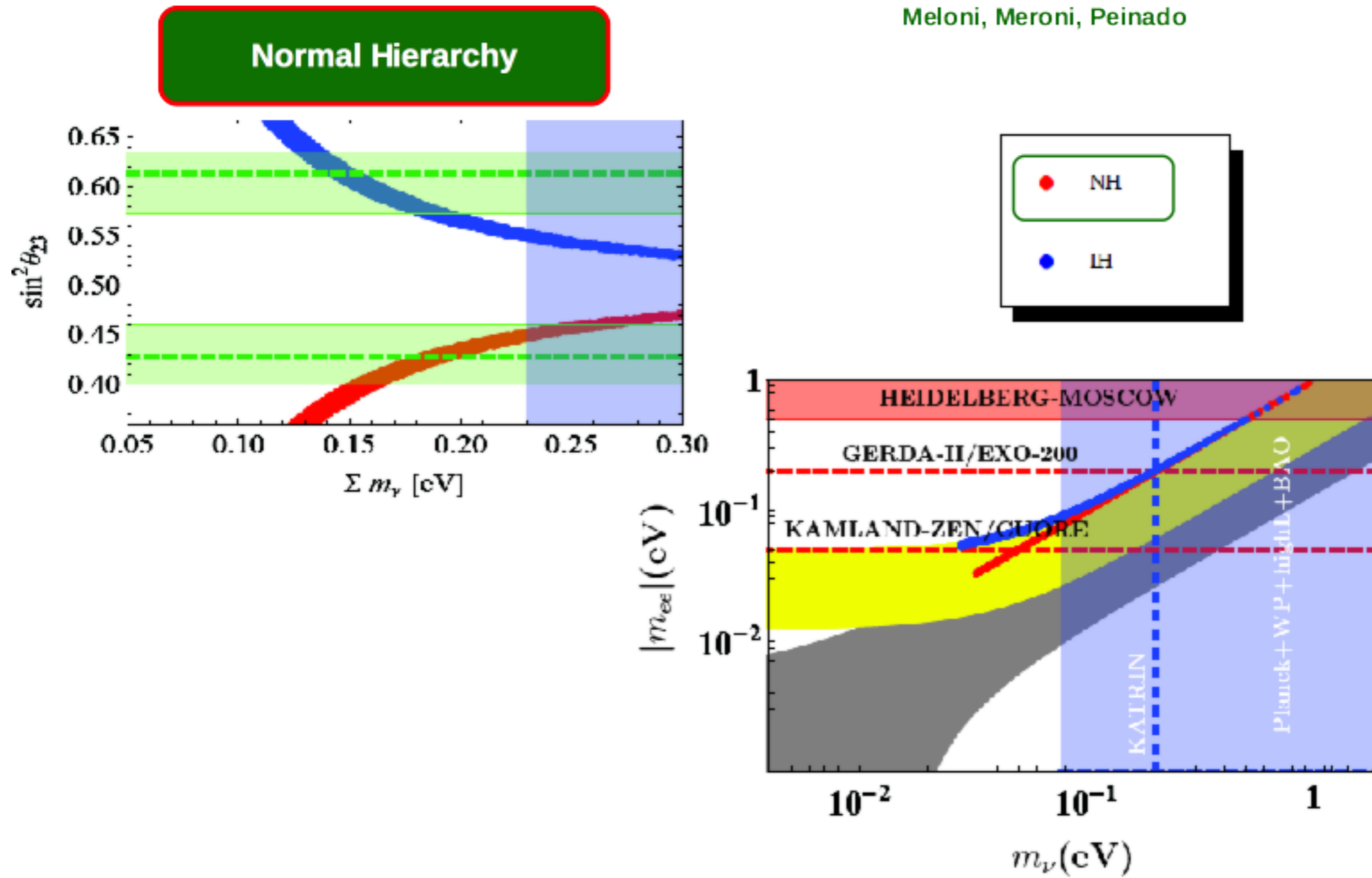
Merle, Rodejohann
Phys.Rev. D73 (2006) 073012

Ludl, Morisi, EP
Nucl.Phys. B857 (2012) 411-423

Meloni, Meroni, EP
Phys.Rev. D89 (2014) 5, 053009

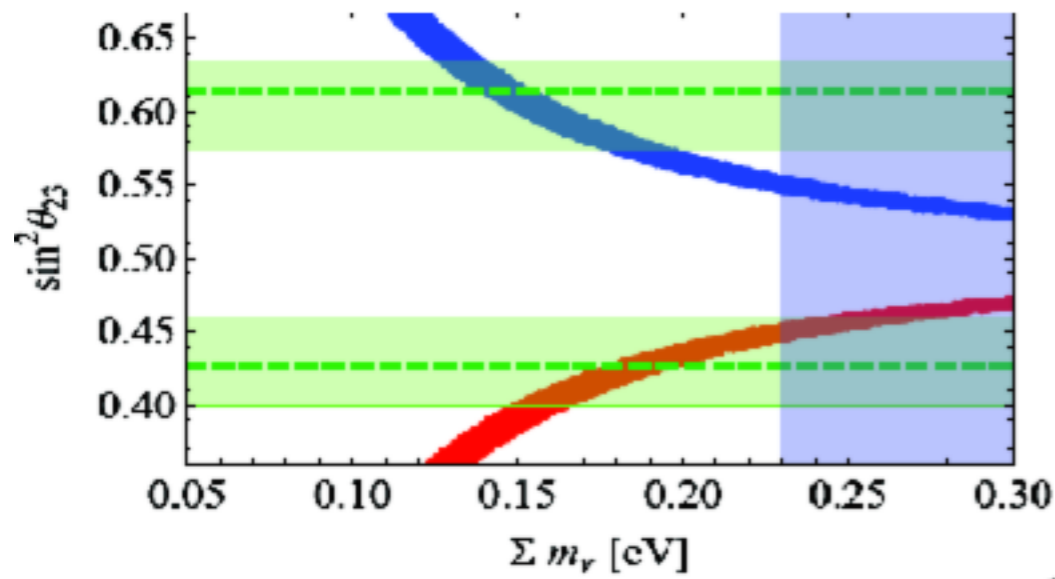
Normal spectrum

Meloni, Meroni, Peinado



Normal spectrum

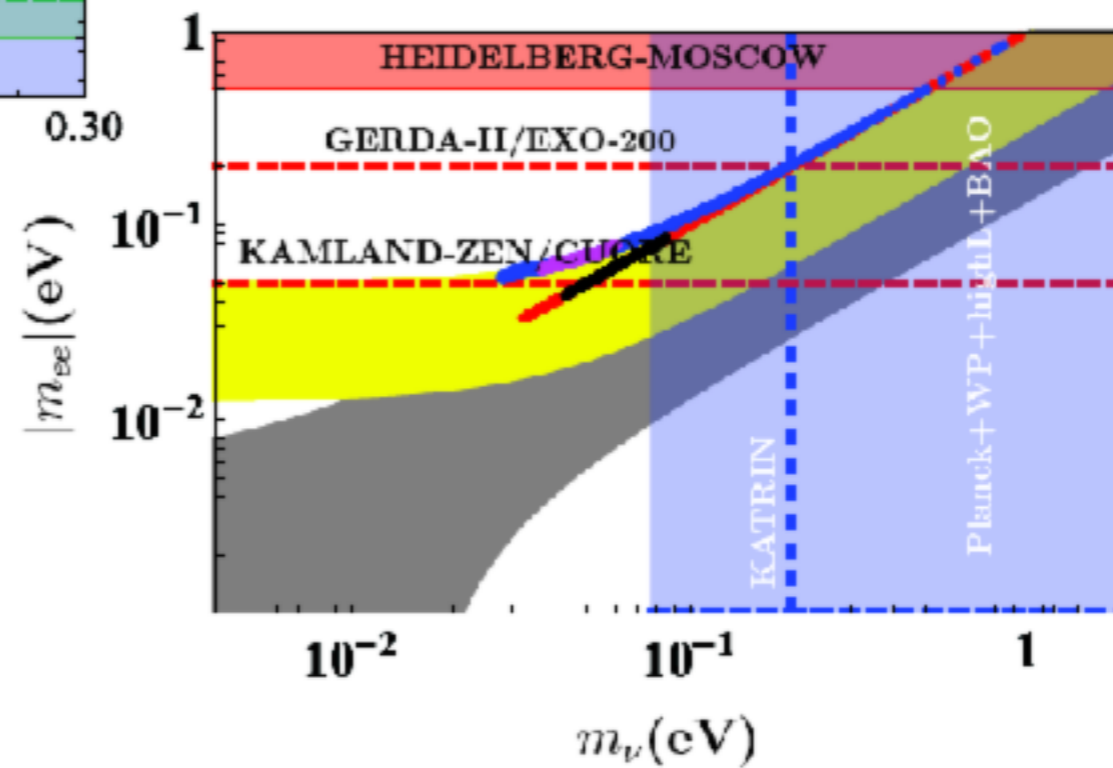
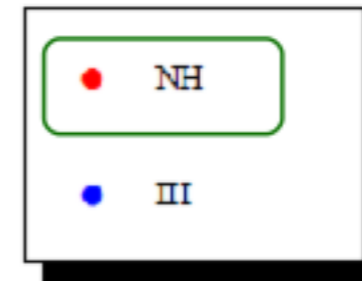
Normal Hierarchy



Could be excluded soon!!!

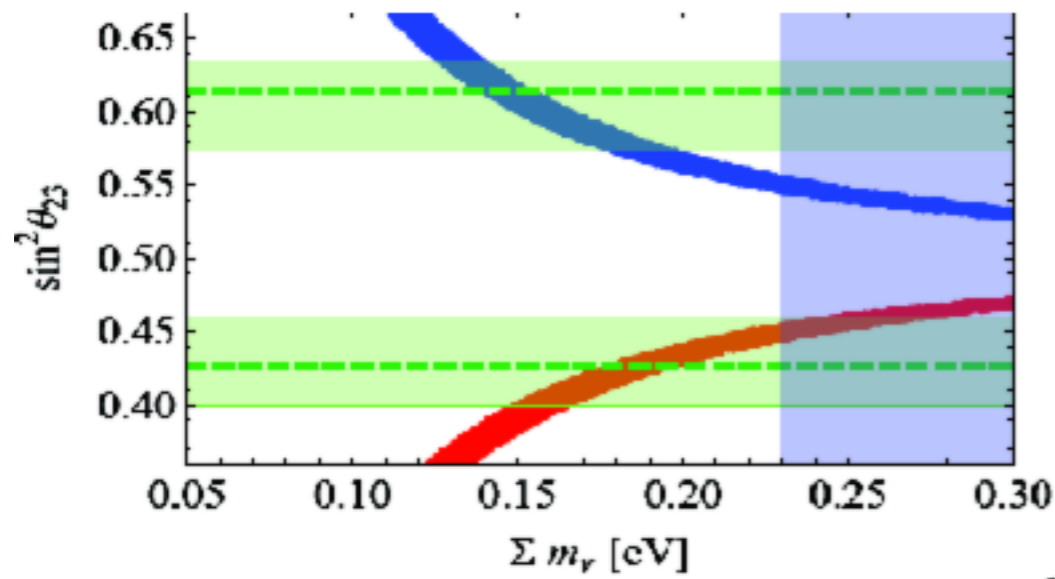
:)

Peinado, in progress...



Inverted spectrum

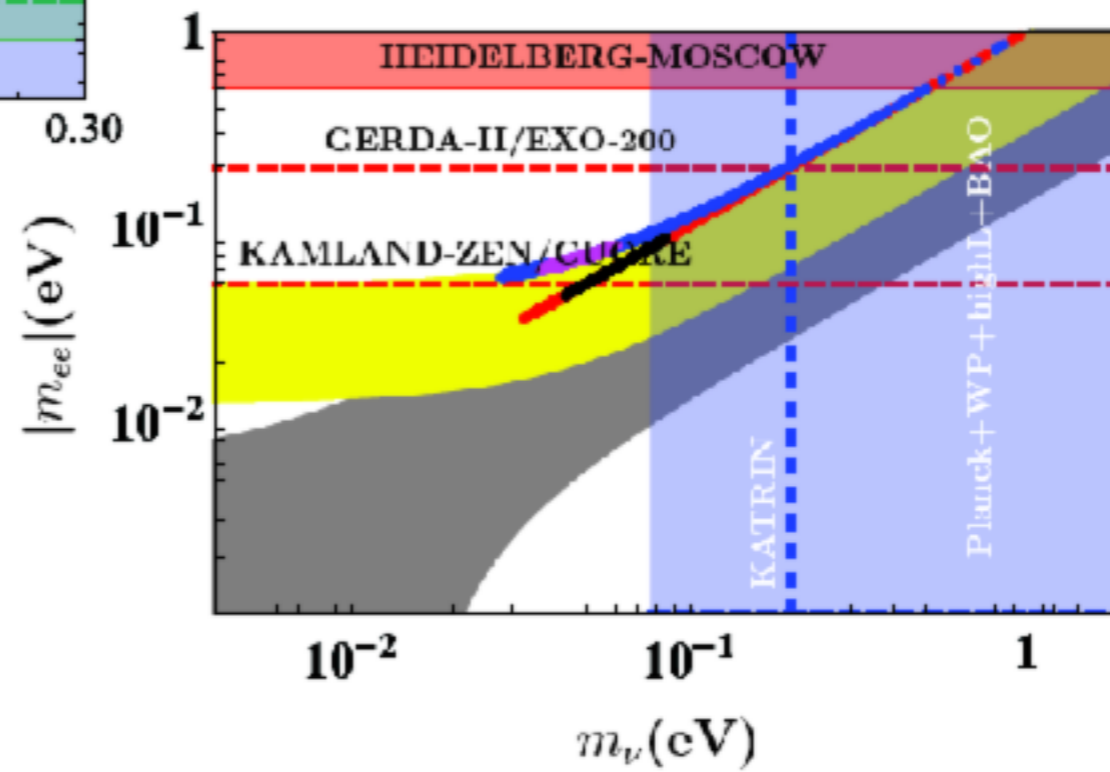
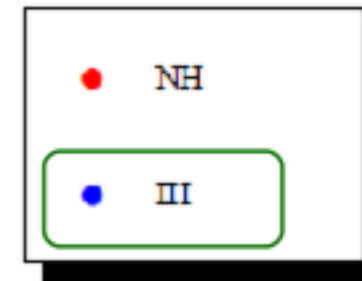
Inverted Hierarchy









Could be excluded soon!!!

:)

Peinado, in progress...



Conclusions

-  **We have evidence of “physics beyond the SM”**
-  **It is interesting to find scenarios where some of them have a common explanation**
-  **neutrino physics is a nice “portal to PBSM”**
-  **DM stability and neutrino physics can be related**
-  **Neutrino and BAU also related**
-  **why not neutrinos - DM - BAU**



**Thank you very much for your
attention**