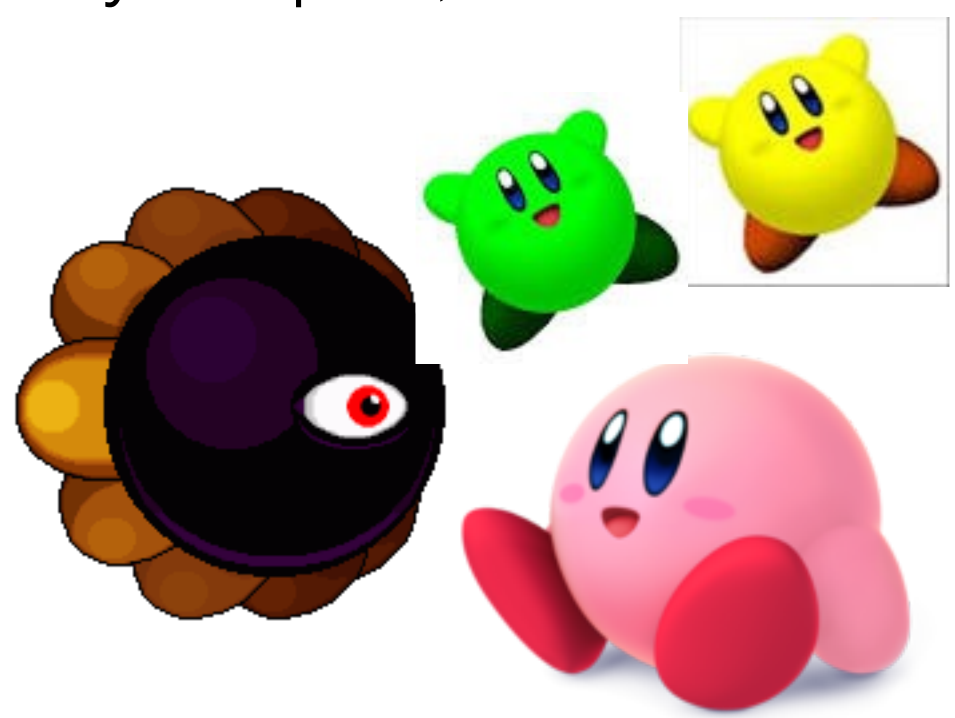
ν -Dark matter interactions

with Bridget Bertoni, Seyda Ipek, David McKeen

arXiv:1412.3113,
JHEP 1504 (2015) 170



Large Dark matter-ν interaction

- ➡ reduces small-scale structure
- ➡ solves “missing satellite” problem
- ➡ experimentally viable
- ➡ simple, renormalizable model
- ➡ implies “non-standard” ν matter effect

Dark Matter

Discovered! See talks by Steigman, Azabajian…

From recent Particle Physics Project Prioritization Panel (P5) Report

"There are many well-motivated ideas for what dark matter could be. These include weakly interacting massive particles (WIMPs), gravitinos, axions, sterile neutrinos, asymmetric dark matter, and hidden sector dark matter. The masses and interaction strengths of these candidates span many orders of magnitude, and, of course, the dark matter could be composed of more than one type of particle."

How to theoretically progress?

- Top down inspiration? (WIMP, axion)
- Effective field theory bottom up?
- Decoupling--Many more models of fundamental physics than low energy parameters, low energy physics always underconstraining

Clues?
Great match between simulation and observation, except:

"missing satellites"
"too big to fail"
"core vs cusp"

Warning! Some (or all?) of these problems might be solved by properly including effects of baryons (esp. supernovae) in simulations!

see e.g. Pontzen and Governato, arXiv:1106.0499, “How supernova feedback turns dark matter cusps into cores”

Phenomenological, not derived from first principles focus of this talk

“Missing satellites”

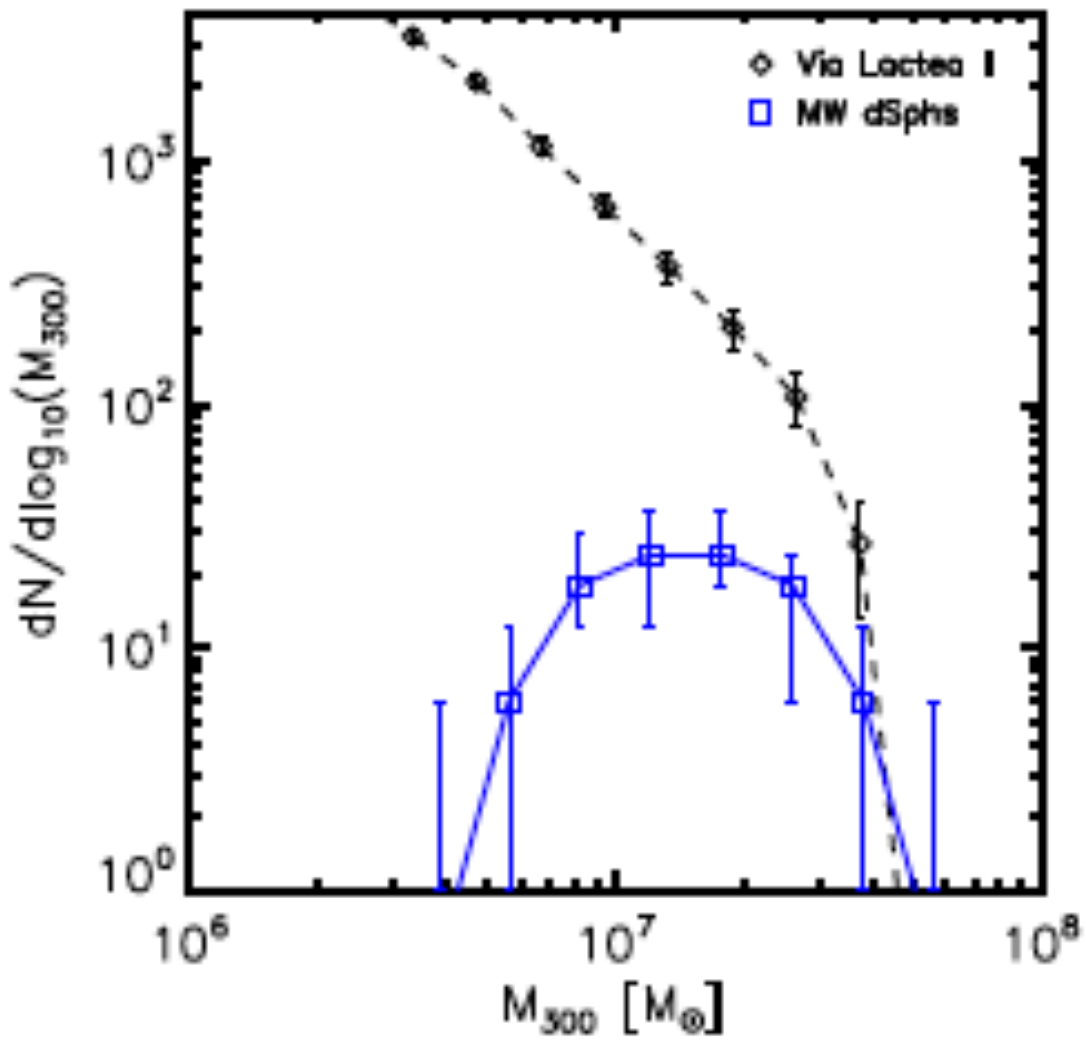


Fig. 1.6. Mass function for $M_{300} = M(< 300pc)$ for MW dSph satellites and dark subhalos in the Via Lactea II simulation within a radius of 400 kpc. The short-dashed curve is the subhalo mass function from the simulation. The solid curve is the median of the observed satellite mass function. The error bars on the observed mass function represent the upper and lower limits on the number of configurations that occur with a 98% of the time (from Wolf et al., in preparation). Note that the mismatch is about ~ 1 order of magnitude at $M_{300} \simeq 10^7 M_\odot$, and that it grows significantly towards lower masses.

Simulation predicts MANY more dwarf satellites than observed

James Bullock, arXiv:1009.4505

suppressed structure formation below $\sim 10^8$ solar masses?

Suggested Resolution

“baryonic” (failure to form stars, supernovae feedback)

warm dark matter (velocity dispersion too high to form small structures)

Strongly self-interacting dark matter

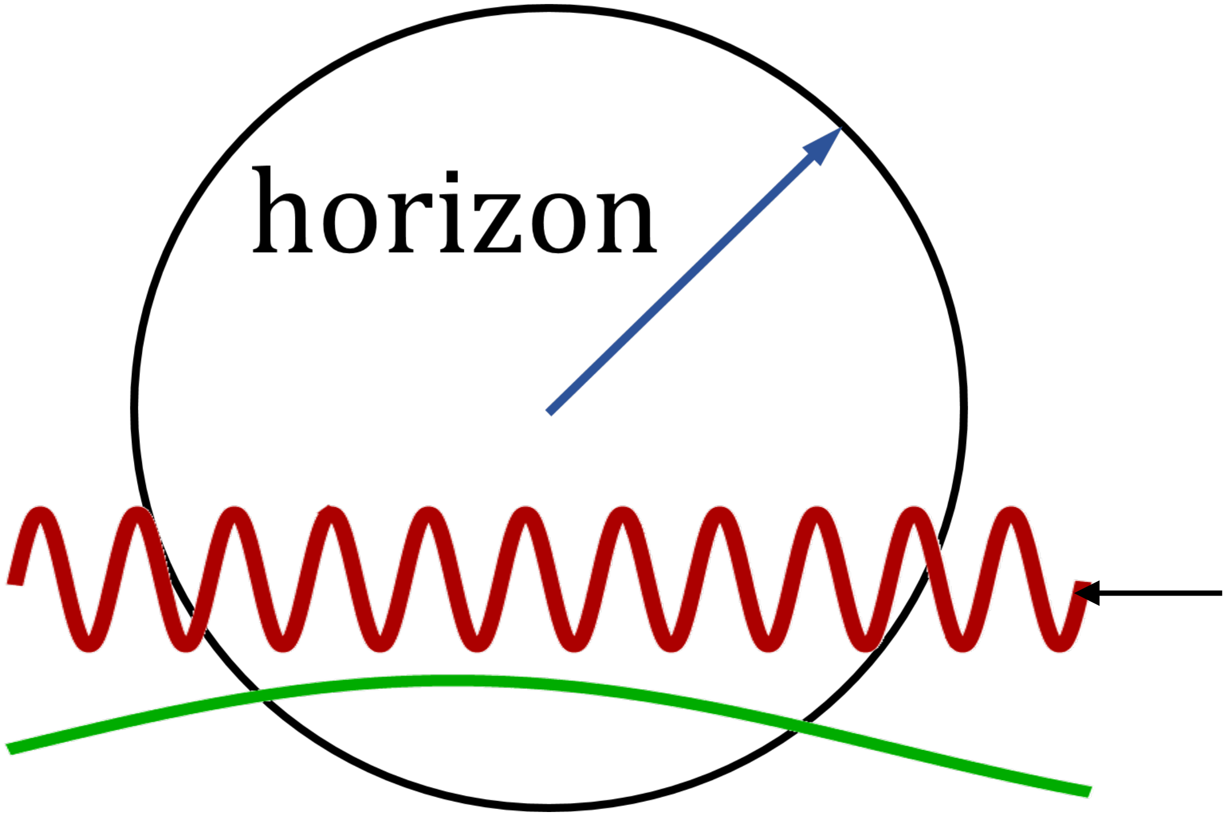
substantial v-dark matter interaction

Kinetic decoupling of Dark Matter from relativistic stuff and structure formation

Structure Formation and Dark Matter couplings

- Chemical decoupling first (freezeout, or asymmetric dark matter)

- Kinetic decoupling at temperature T_d



$T > T_d$

small scale perturbations coupled to ν's oscillate, don't grow

M_{ao}: suppressed structure

Loeb & Zaldarriaga, astro-ph/0504112

$$M_{\rm ao} \approx \rho_{DM} \frac{4\pi}{3} H_d^{-3} \approx 2 \times 10^8 M_\odot \sqrt{\frac{3.4}{g_{\rm eff}}} \left(\frac{\rm keV}{T_d}\right)^3$$

larger coupling=lower T_d= larger M_{ao}

$T < T_d$

- DM perturbations can grow due to gravity
- DM has velocity dispersion, also damps small scale structure due to free streaming (Green, Hofmann & Schwarz, astro-ph/0503387)

For $T_{\rm d} \lesssim 100 \text{ keV} \left(\frac{m_\chi}{10 \text{ MeV}}\right)$

M_{ao} dominates

$$\Sigma$$

- kinetic decoupling of Dark Matter at ~keV suppresses structure below ~ 10^8 solar masses
- consistent with observations

- DM ν interaction via dim 6 operator at scale Λ
- $\sigma \sim T_d^2/\Lambda^4$
- momentum transfer /scattering $\sim T_d$
- need $N \sim M_\chi/T_d$ scatterings per Hubble time

$$T_d \sim \text{keV} \left(\frac{g_{\text{eff}}}{3.4}\right)^{1/8} \left(\frac{M_\chi}{10\ \text{MeV}}\right)^{1/4} \left(\frac{\Lambda}{60\ \text{MeV}}\right)$$

Light Dark Matter, New ν physics at ~10 MeV

- Can this be consistent with particle experiment?

SURE, just use the neutrino portal

What is a 'portal' ???

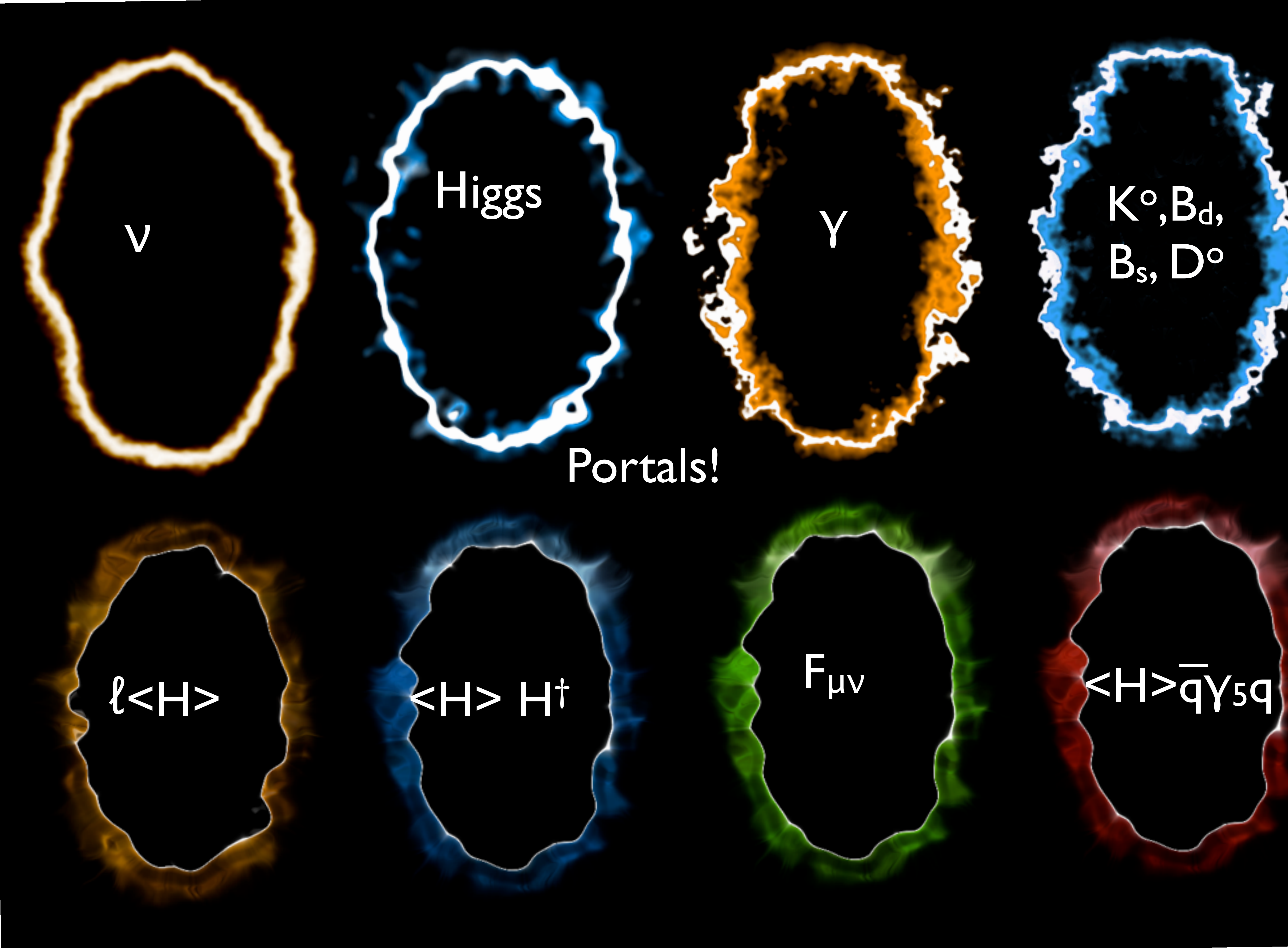
- in science fiction and virtual 'reality': a useful short cut to another sector.

- in particle theory???

- Two ingredients

1. Dimensional analysis: possibility of a marginal or relevant operator in an effective theory which connects two sectors
2. A long lived particle associated with the operator which can take advantage of the connection to oscillate or decay into the hidden sector

   - Portal is most effective if can mix with a particle of the hidden sector


ν
Higgs
γ
K^o, B_d,
B_s, D^o
Portals!
ℓ<H>
<H> $H^\dagger$
$F_{\mu\nu}$
<H>$\bar{q}\gamma_5 q$

Model

$$\mathcal{L} \supset -m_{ij}\frac{H^2}{v^2}\ell_i\ell_j - MN_1N_2 - \lambda_i N_1 H\ell_i - y_1\phi^* N_1\chi - y_2\phi N_2\chi$$

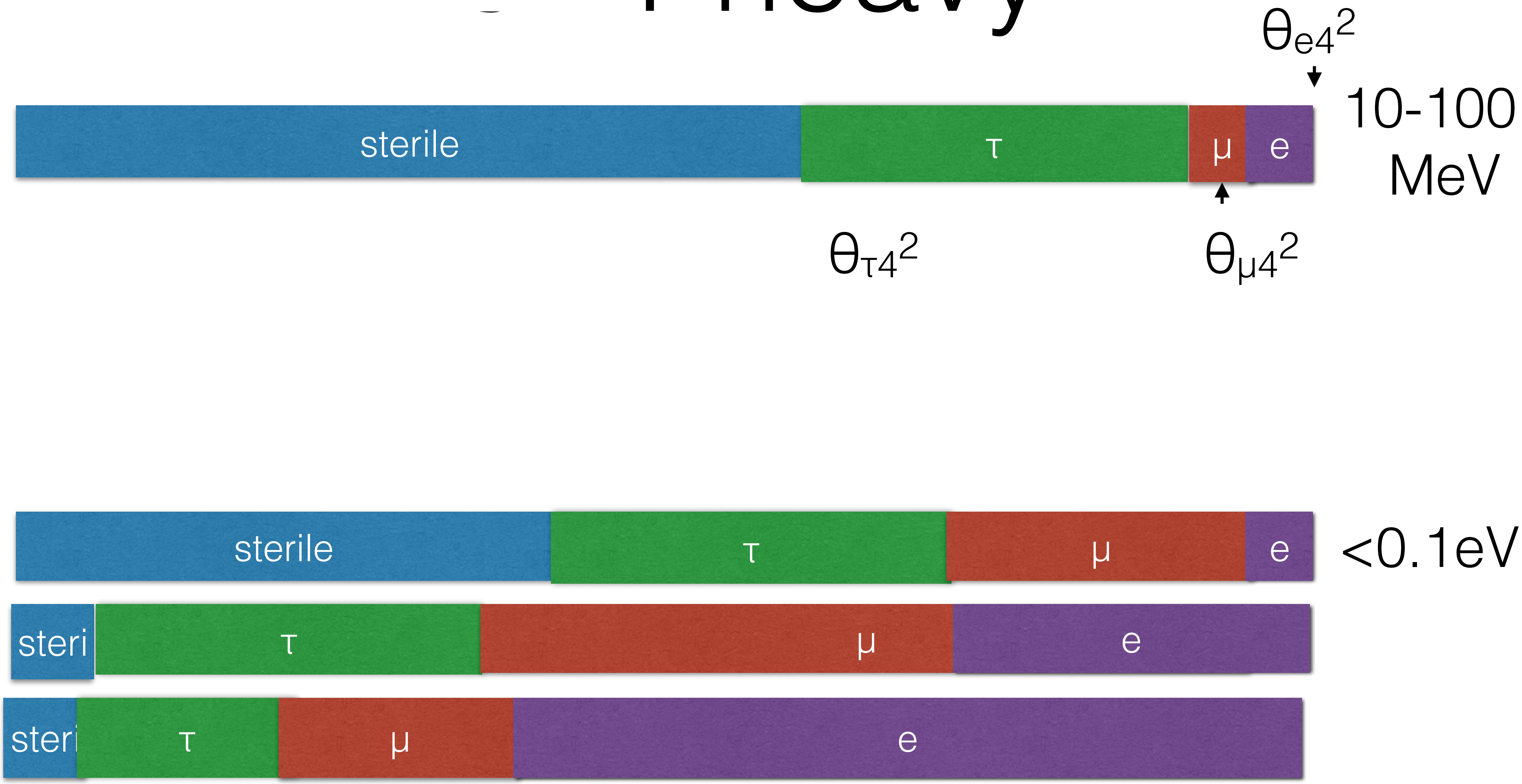
- first term gives tiny Majorana neutrino masses
- last four terms conserve lepton number
- mass matrix from first three terms:

$$\begin{pmatrix} m_{ij} & \lambda_j v & 0 \\ \lambda_i v & 0 & M \\ 0 & M & 0 \end{pmatrix}.$$

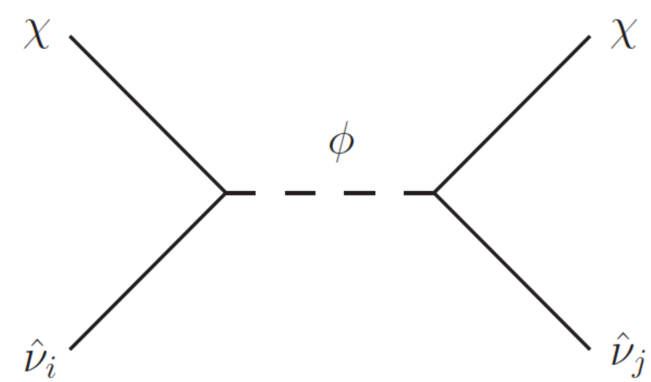
- 3 very light Majorana ν's, mass from first term
- 1 heavy (~10 MeV) Dirac ν, mass $\sqrt{M^2 + \sum_i \lambda_i^2 v^2}$
- 4x4 ν mixing matrix

$$\nu_i = U_{ij}\hat{\nu}_j,$$

$\nu_i = U_{ij}\hat{\nu}_j$, 1 heavy



Missing satellite problem



$$T_d \sim \text{keV} \left(\frac{g_{\text{eff}}}{3.4}\right)^{1/8} \left(\frac{M_\chi}{10\ \text{MeV}}\right)^{1/4} \left(\frac{\Lambda}{60\ \text{MeV}}\right)$$

$$\Lambda \sim \sqrt{m_\phi^2 - m_\chi^2}/g$$

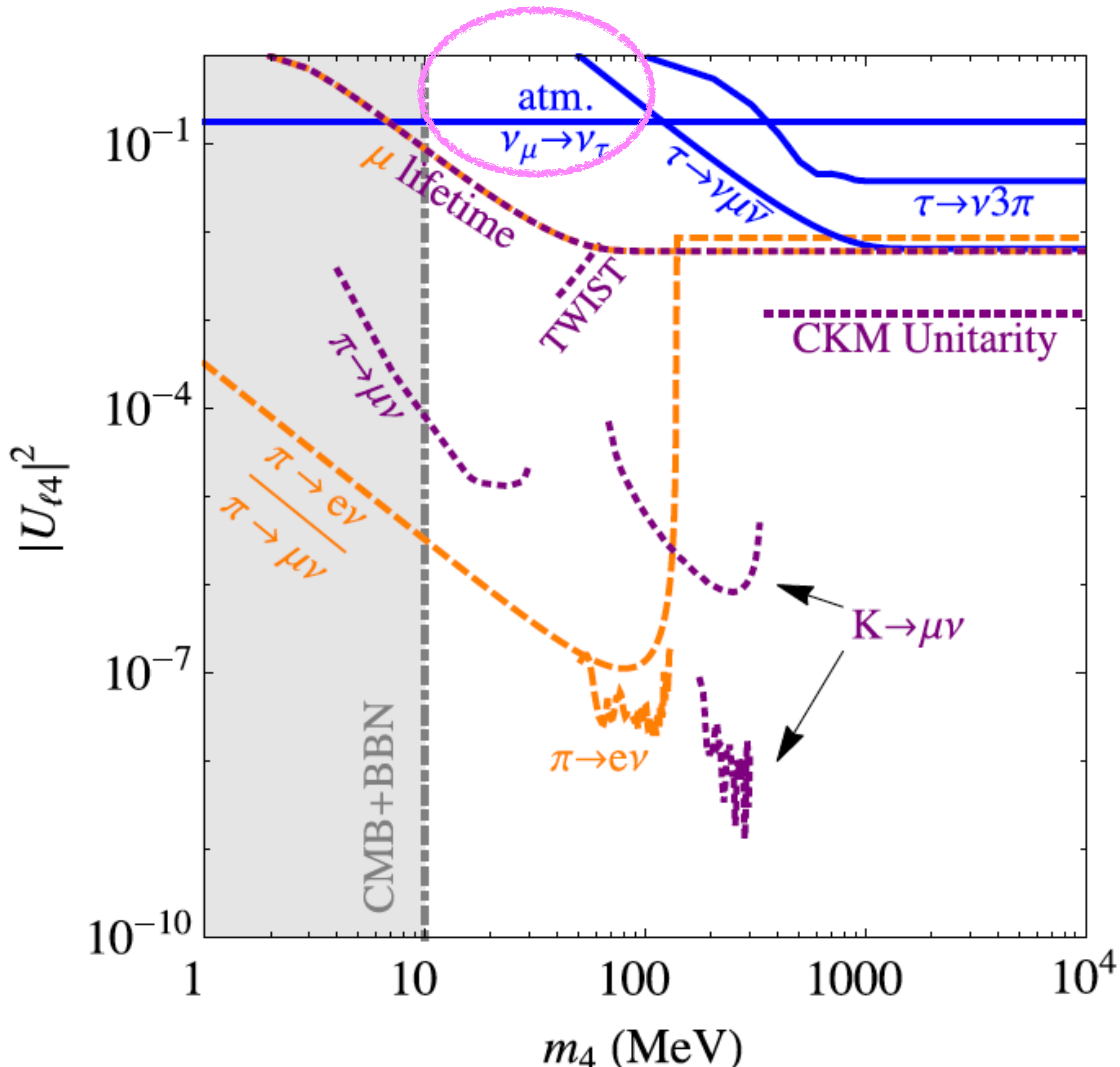
$$g \equiv y_2 \sqrt{|U_{e4}|^2 + |U_{\mu 4}|^2 + |U_{\tau 4}|^2}$$

- to address missing satellite problem, want DM mass~ 10 MeV, $|U_{e4}|^2 + |U_{\mu 4}|^2 + |U_{\tau 4}|^2$ >~.1

Constraints on mixing with heavy ν

- $\mu \to e\gamma$
- μ lifetime, energy spectrum
- $\pi, K \to l\, \nu_4$
- visible ν_4 decays
- BBN (heavier than 10 MeV)
- SN1987A (heavier than 10 MeV)
- τ lifetime, decays

Constraints



Non Standard ν interactions

- flavor oscillations impacted by sterile component of light ν mass eigenstates

- neutral current of active neutrinos gives non standard matter effect

- equivalent NSI parameter:

$$\epsilon_{ii} = \frac{U_{i4}^2}{6}$$

- look for $\varepsilon_{\tau\tau}$

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