Dark Matter Horizons

Scalar Dark Matter, Neutrino Masse, and the IceCube Experiment

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Outline

Introduction

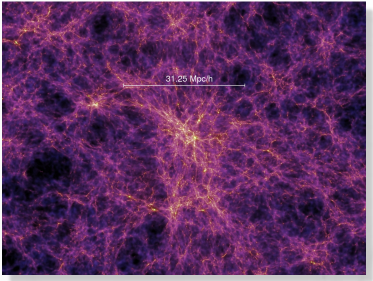
What are the current problems?

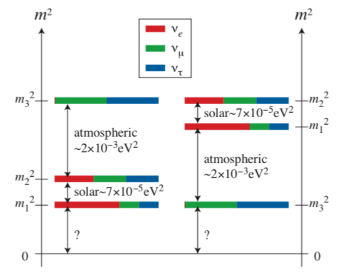
There are three main issues that currently face Cosmology and Particle Physics;

1. The nature of **Dark Matter**,
2. The appearance of a small but non-zero **neutrino mass**,
3. Why there are more baryons than antibaryons, **baryogenesis**.

Which ones are we considering?

We focus on the first two issues; having a viable **Dark Matter** candidate, as well as radiatively generating a small **neutrino mass**. We want to link them in an *effective field theory*.





How will we test it?

We will test it using data from the **IceCube Neutrino Observatory**, located at the South Pole.

The Model

An Effective Aside

We can classify a Quantum Field Theory into two types; **effective** or **UV complete**. An **effective field theory** is only valid up to some high energy scale Λ. Importantly;

- They can only be used up to the energy scale Λ, not at some higher energy
- They can be derived from a fully UV complete theory by integrating out the high mass fields
- The Lagrangian describing the theory need not respect all the **symmetries** of the UV complete theory

Particle Content

We keep all the Standard Model particles, but introduce two new particles;

1. A **scalar field**, δ, which can be real or complex
2. Two or more massive **right-handed neutrinos** N_R^i

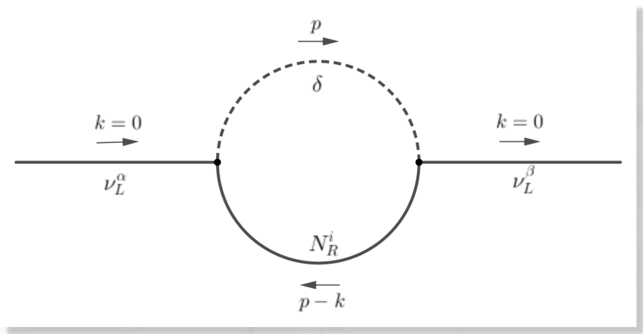
There is an additional $\mathbb{Z}_2$ symmetry under which only the new dark sector is charged. This **stabilises** the lightest particle in the spectrum, which we choose to be a scalar.

Lagrangian and Neutrino Mass

The Lagrangian contains all the mass terms, as well as the interaction with the Standard Model neutrinos;

$$\mathcal{L}_{int} = \sum_{\ell} g_{i\ell} \delta \bar{N}_R^i \nu_L^\ell + \text{h.c.}$$

This generates neutrino mass via diagrams such as;



Where do the constraints come from?

There are a number of different ways this model is constrained depending on whether the scalar δ is real or complex;

1. **Real Dark Matter:** Dark matter annihilation along with neutrino mass constraints restrict both the massses and the couplings;

$$\mathcal{O}(1\,\mathrm{MeV}) \lesssim m_\delta < m_N \lesssim 10\,\mathrm{MeV}, \quad 3 \times 10^{-4} \lesssim g_{i\ell} \lesssim 10^{-3}$$

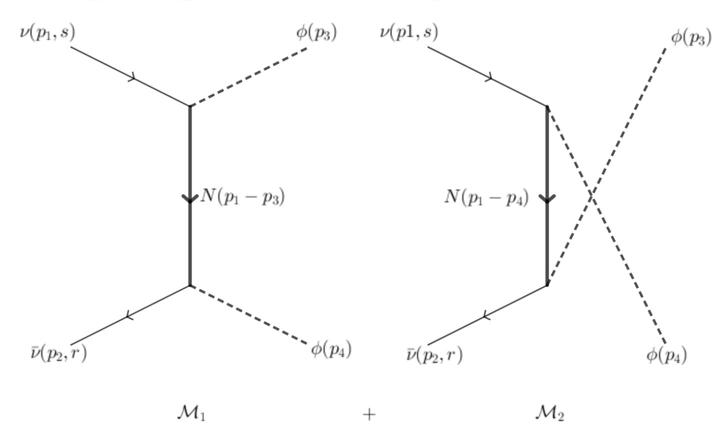
2. **Complex Dark Matter:** The couplings are now constrained by *light meson decay*, with an additional, less important, constraint on the mass splitting from dark matter cross section

$$g_{ie} \lesssim 3 \times 10^{-3}, \quad g_{i\mu} \lesssim 10^{-2}, \quad g_{i\tau} \lesssim 3 \times 10^{-1}$$

Method

The Interaction

Within the model, the following process is allowed;



The Mean Free Path

Once we have the cross section, σ, we can calculate the mean free path;

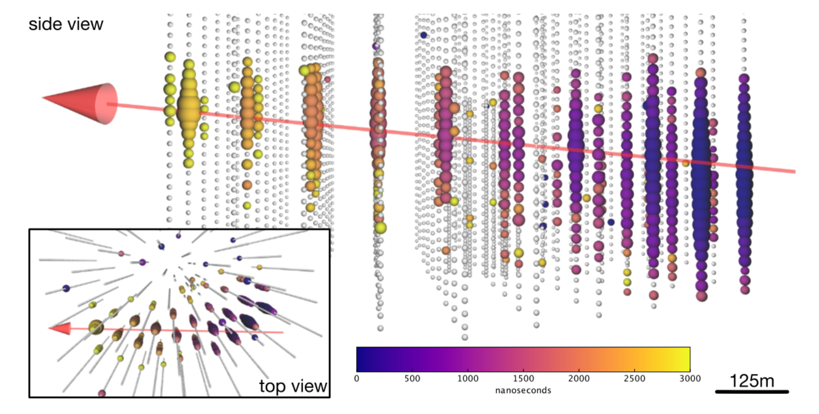
$$\ell^{-1} = \sum_i n_{X_i} \sigma(\nu_\mu X_i \to Y_i)$$

If this is **less** than the distance to a source of neutrinos for given parameter values, then we can constrain those parameters.

IceCube and TXS 0506+056

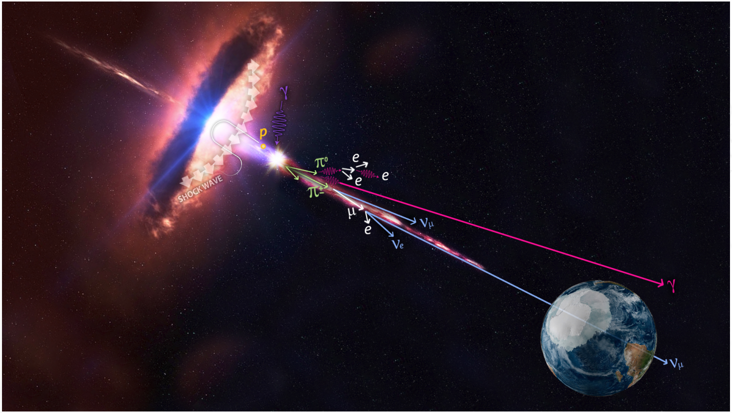
How does IceCube detect neutrinos?

IceCube is a Cherenkov detector. We see the light emitted by the muons travelling through the ice. From this we reconstruct the **neutrino energy** and **trajectory**.



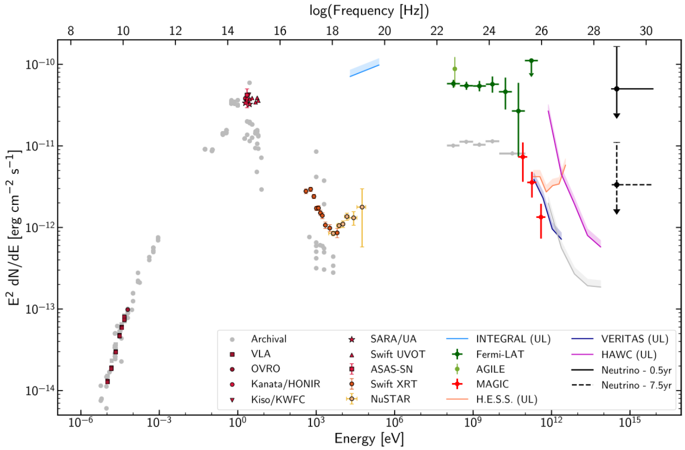
The Blazar TXS 0506+056

We are interested in a source of high energy neutrinos at a comoving distance of $d_L = 1.3\,\text{Gpc}$. Multimessenger observations suggest that the source is likely the γ-ray blazar TXS 0506+056.



22^{nd} September 2017

On the 22^{nd} September 2017, IceCube announced the detection of a 290 TeV neutrino which they believe to be from TXS 0506+056. This is the event we use to constrain the model.



Results and Conclusions

Preliminary Results

We are yet to properly include the **neutrino masses**, or the **PMNS mixing** yet, but these are the results so far;