Sterile Neutrinos and Their Significance

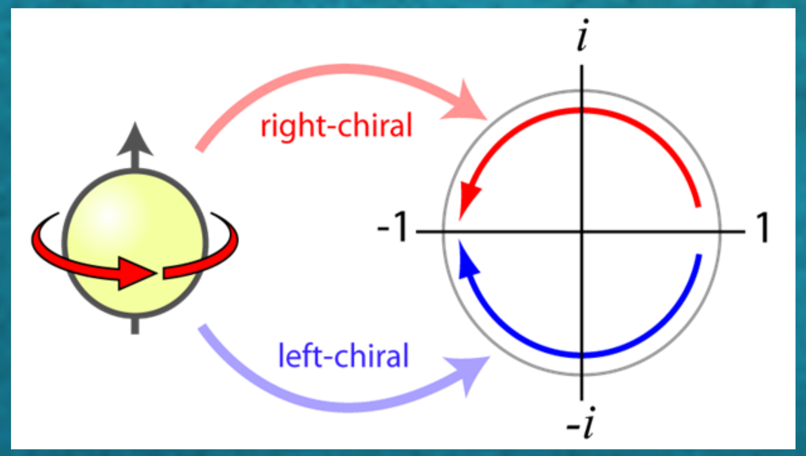
Bryan Burgos, Johns Hopkins University, 4 Aug. 2015

ABSTRACT

During the past six weeks, I have spent time researching about hypothetical particles known as sterile neutrinos. With help from teachers and the web, I have expanded my understanding of the nature of sterile neutrinos and particle physics. I've found data and studies testing the existence of sterile neutrinos. Sterile neutrinos are an important area to study because they are a gateway to a realm of unexplored physics.

INTRODUCTION- WHAT ARE STERILE NEUTRINOS?

Sterile neutrinos are hypothetical particles that would extend the Standard Model. They are right-chiral, meaning they only interact through gravity among the four fundamental interactions, which makes them incredibly hard to detect. However, they interact through the Yukawa interaction with leptons and Higgs bosons. Sterile neutrinos could be majorana particles since they do not interact with any of the four gauge bosons (W, Z, gluon, photon). Proving the existence of sterile neutrinos could explain things like neutrinoless double beta decay and the composition of dark matter, and could lead to further discoveries.



KEY TERMS

Chirality - a property that determines how a particle's quantum mechanical function changes in the complex plane when it is rotated (illustrated above). This affects the phase shift of the wave function when the quantum number changes. Chirality also determines whether the particle can interact through the weak interaction - right-chiral particles cannot.

Yukawa Interaction - an interaction between a scalar field and a Dirac field such that the potential is roughly equal to the product of the g-factor, the particle's inverse wave function, the Higgs field, and the particle's wave function.

Majorana Particle - A particle that is its own antiparticle.

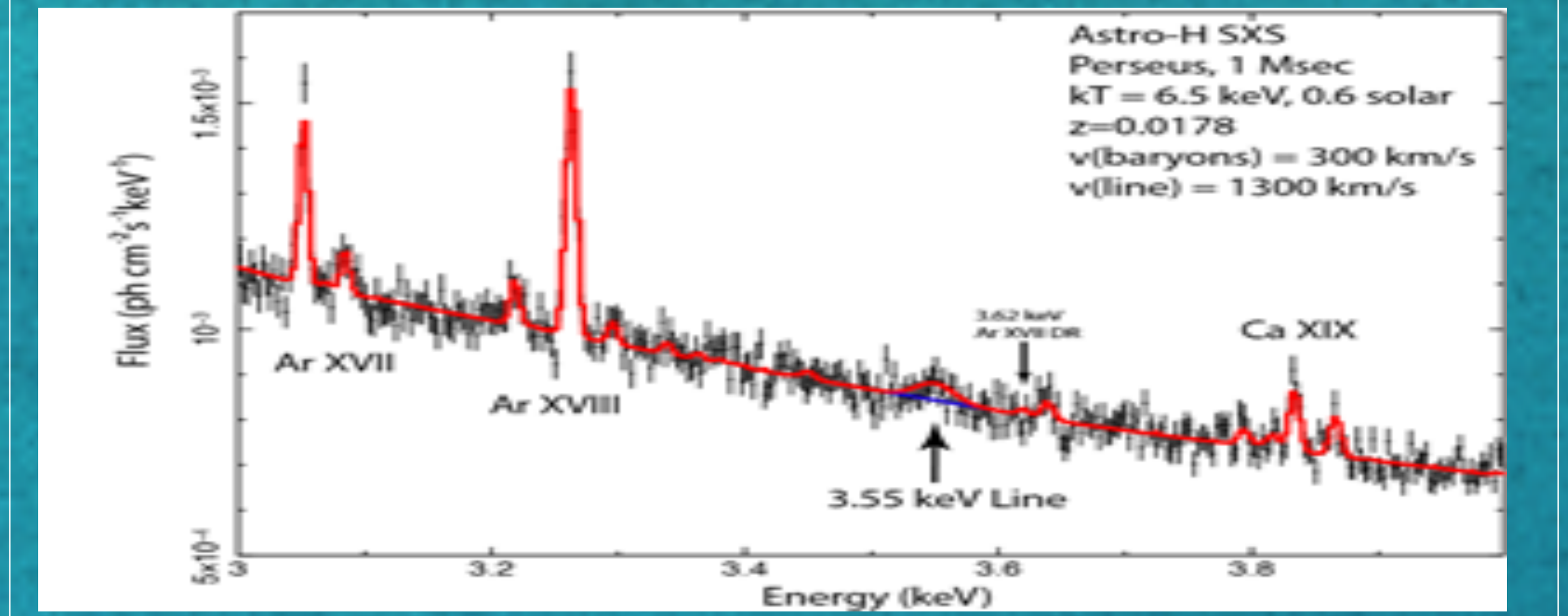
See-saw Mechanism - Hypothetical model which allows for a particle to oscillate between two different states of mass - one very light, one very heavy

nuMSM (NEUTRIINO MINIMAL STANDARD MODEL)

Most theories I came across were forms of the Neutrino Minimal Standard Model. This theory introduces three sterile neutrinos to the fundamental particles - two of very heavy masses for neutrinos (around 1 GeV), and one of a smaller mass (around 7 keV). Through the see-saw mechanism, these neutrinos can oscillate between two different states of mass, meaning there are six different neutrino fields in total. The presence of these neutrino fields would explain properties of dark matter galaxies, baryogenesis,, and neutrinoless double beta decay, among other mysteries.

STERILE NEUTRINOS AS DARK MATTER

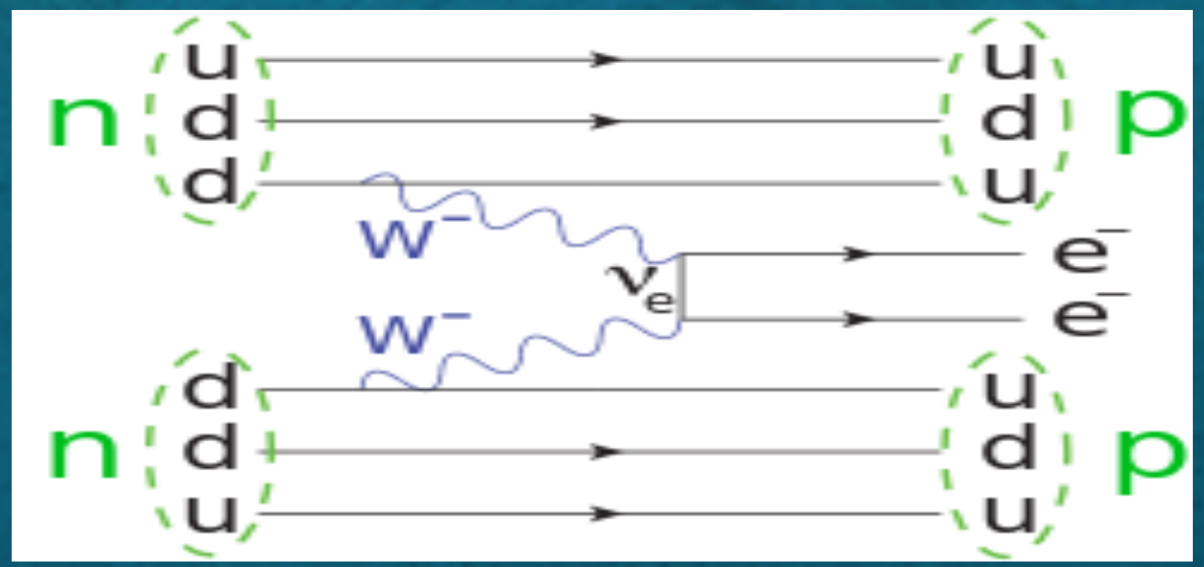
Sterile neutrinos have been hypothesized to make up dark matter galaxies and clusters. This is because the lightness of neutrinos makes them too "hot" - or too fast to form a galaxy. On the other hand, since sterile neutrinos are supposedly heavier, they are potential candidates for the material that forms the dense structures of dark galaxies.



A study by Esra Bulbul and colleagues found a 3.5 keV x-ray signal in the Perseus cluster which could be interpreted as an emission from a decaying sterile neutrino (a sterile neutrino decay should emit an x-ray photon). However, this could be a false alarm, as Bulbul claimed "significant modelling uncertainties" in the data (shown above).

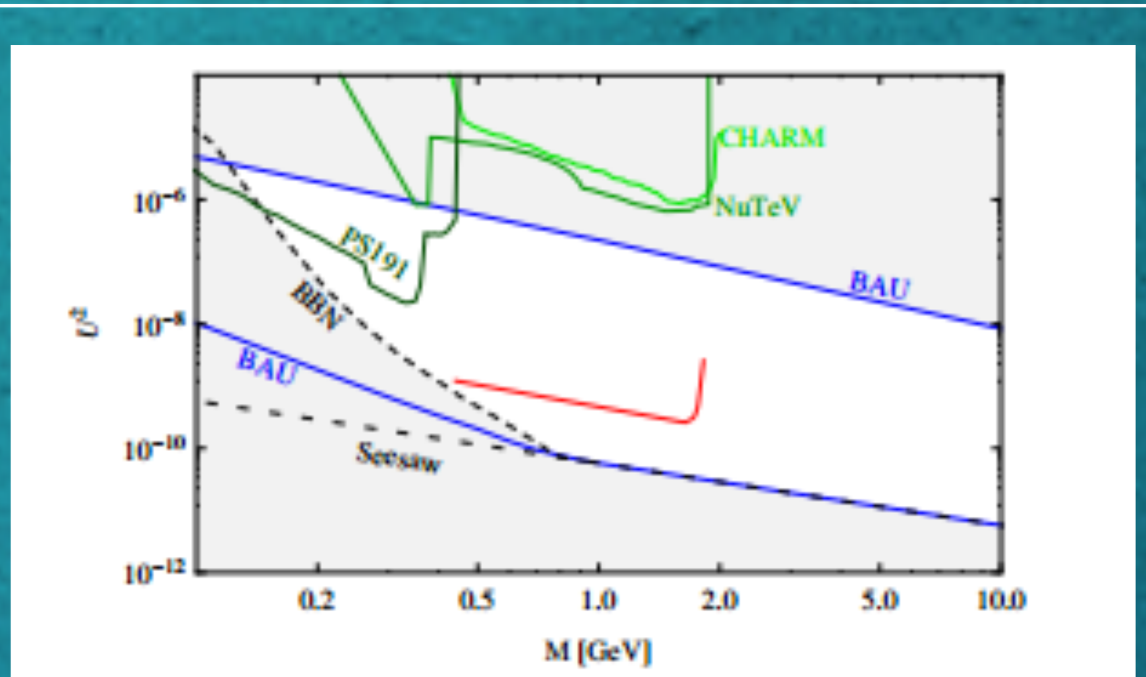
NEUTRINOLESS DOUBLE BETA DECAY

Neutrinoless double beta decay is a hypothetical form of beta decay where no neutrinos are emitted as a decay product. Usually, a neutrino or antineutrino is created as a product of beta decay, but if sterile neutrinos were to be made instead, in a double beta decay (where two nucleons change instead of one), they would annihilate each other. This can only be possible for sterile neutrinos because they could be majorana particles, while none of the fermions currently in the Standard Model can be majorana particles because they interact with the four known force carrier bosons. (Illustrated below)



BARYOGENESIS

Baryogenesis is a term for the cause of the imbalance of matter and antimatter. Baryogenesis could come from sterile neutrinos oscillating between states of mass via the see-saw mechanism. According to a publication by S.N. Gninenko, sterile neutrinos responsible for baryogenesis can only exist in a certain range of mass, below 2 GeV (the mass of certain charm mesons). In a possible experiment modelled by Gninenko, an array of detectors



kilometers long would be required to detect the signals that may verify the existence of sterile neutrinos responsible for baryogenesis. (Mass range shown above, in white area)

CONCLUSION

By researching sterile neutrinos, I believe that finding out more about them and verifying their existence would help answer many of the questions we have in the fields of particle physics and cosmology. Confirming their existence would make the Standard Model more complete in explaining the laws of nature, and learning that they do not exist would not answer our questions, but would help us get closer to the right path. In my efforts to understand this complex subject matter, I increased my understanding of particle physics and quantum mechanics. While I might not have provided the best or most accurate explanations for these subjects, I put it in my own words and interpretations, and I think I got a lot out of that.

ACKNOWLEDGEMENTS

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