In my project, I will investigate the characteristics of neutron stars and their important insights for our models of quantum physics. Firstly, what is a neutron star? It is a star that was on the cusp of becoming a black hole but wasn’t massive enough. Every star starts out as a stellar nebula that coalesces into an average or massive star. After millions or billions of years, they form red giants or red supergiants. These giants quickly undergo an explosion, either a nova or supernova that leaves behind a remnant. The nature of this remnant depends on the mass of the star. If the star was small, a white dwarf would be left. If the star was medium sized, a neutron star is left. Or, if the star was big, a black hole would form.

Why do we care about neutron stars? Neutron stars are the densest objects in the universe so they are used as a place for scientists to study microphysics at densities not currently sustainable on Earth. Physicists study where current models become uncertain to create better models and predictions. At the densities of neutron stars, quantum dynamics models diverge in what they predict. This is why neutron stars are of special importance to microphysicists and how studying neutron stars affects models of quantum dynamics.

Neutron stars have a so-called Equation of State (EOS) which relates the thermodynamic variables of the star. Generally, the Equation of State of neutron stars relates the pressure and density. The importance of the neutron star EOS is that the mass and radius of the neutron star can be derived from it. If we know the true neutron star EOS, then we can predict the minimum and maximum mass and the exact relationship between the radius and mass.

By using mass and radius observations of neutron stars, we can find the true neutron star EOS from a list of possible EOSs. To do this, we use Bayesian statistics to inference how likely a possible EOS is based on the data we obtain. This was done in a paper [1] using observations from the Neutron-star Interior Composition Explorer (NICER) [2] and the Laser Interferometer Gravitational-wave Observatory (LIGO) [3]. I plan to reproduce the findings from this paper and expand on it with new data.

Currently, my program inputs mass and radius curves corresponding to each neutron star EOS and calculates the probability of each, therefore giving the probabilities of each neutron star EOS. Next, I will write a program to solve the Tolman-Volkoff-Oppenheimer equations [4] which are used to convert EOSs into mass-radius curves. This will allow me to generate the mass-radius curves myself.

My program yields results identical to those shown in the paper [1], verifying my code and the paper. Next, I will assess how likely new observations are based on current knowledge. This will show if there is experimental error in the new methodology. Afterwards, I will expand on my project, possibly using different assumptions or initial EOSs.

Works cited:
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[4] Tolman-Oppenheimer-Volkoff (TOV) Stars Aaron Smith December 4, 2012

[5] Somasundaram, Rahul, and Ingo Tews . “Inference of Microscopic Nuclear Interactions and the Equation of State from Multimessenger Astrophysics.” *Nuclear Theory in the Age of Multimessenger Astronomy*, by Omar Benhar, 2385 NW Executive Center Drive, Suite 320, Boca Raton FL 33431, CRC Press, 2024.