Using Rotation Curves to Assess the Viability of Warm and Cold Dark Matter Profiles

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Dark Matter is currently one of the most studied and mysterious topics of modern day astronomy. According to the theory of dark matter only 5% of the combined mass-energy content of the universe is made up of ordinary baryonic matter, such as the sun, stars and planets, which we see every day (We can combine mass and energy into one number by using Einstein's famous equation $E=mc^2$). Another 26% of this mass-energy content can be attributed to dark matter, with the remaining 69% being attributed to the even more mysterious dark energy. Dark matter is matter that has mass and a gravitational field, but gives off no light, heat or radiation, hence 'dark' matter. This makes it extremely difficult for us to detect, and we haven't yet been able to observe it directly, however luckily there are ways for us to detect it in a more indirect manner.

Dark matter is usually found in 'halos' around galaxies. Using different techniques we are able to measure the velocity of stars at different distances from the centre of a galaxy. From standard Newtonian physics we can predict that the velocity of the stars should rise sharply and peak, before slowing down as they get further from the galactic centre, as shown by the dotted line in figure 1. However, what we actually observe is that the curve we see flattens out, and the stars travel at more or less the same speed throughout the entire galaxy. The only way to resolve this without re-defining our understanding of Newtonian physics is to assume that there must be some extra mass that is invisible, and interacting with the galaxy, causing the observed rotation curve.By making measurements of the masses of the stars, gas and the velocity of the stars we can predict distribution of dark matter throughout a galaxy. For example in figure 2 we have the velocity contributions of different components of a galaxy. We can then use a mathematical model based on the mass of the dark matter halo and the concentration, which represents how concentrated the mass is towards the centre, to find which of these two values best fit the data.

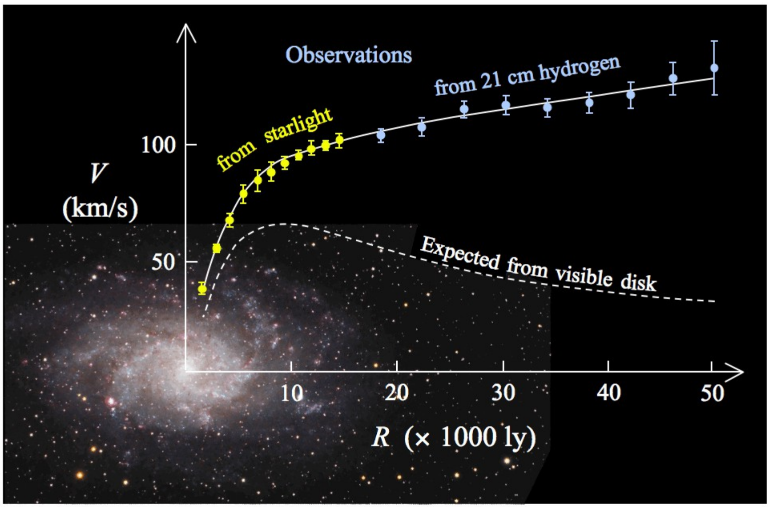

Figure 1 - Diagram Illustrating the observed rotation curve of M33 (Andromeda), and the expected curve using only baryonic matter. Public domain image taken from https://en.wikipedia.org/wiki/Galaxy_rotation_curve

During our project we compared five of these mathematical models and tried to assess which one produced the best results. The main models we were looking to assess were those using 'warm' dark matter, so we could compare them to the other models which used 'cold' dark matter. These warm and cold labels don't refer to the temperature, but the velocity that the particles were travelling during the very early stages of the universe, before galaxies had formed.

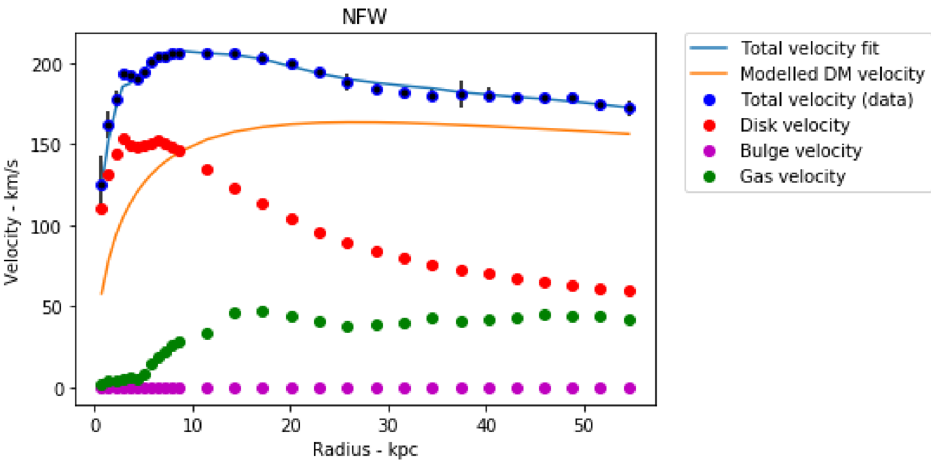

Figure 2 - The rotation curve of the NGC5055 galaxy using the NFW dark matter halo model.

Cold dark matter is the main model used today, however when looking at dwarf galaxies with very low masses the cold dark matter model tends not to work as well. Warm dark matter models are roughly the same as cold dark matter ones at high masses, but they start to differ when we look at dwarf galaxies, as the warm dark matter models suggest a lower concentration than cold dark matter, potentially solving the problem that cold dark matter has. We have used various different methods to compare the warm and cold dark matter models and try to find out if warm dark matter could be a viable alternative to cold dark matter.

We found that warm dark matter performed as well, or almost as well as cold dark matter in most of the methods we used, and in particular we found that when we imposed restrictions on all the models, based on the theoretical values for halo mass and concentration that we expect to get, the warm dark matter models fit the curves better than the cold dark matter ones, especially in galaxies with very low masses. However in the sample of 127 galaxies that we looked at only 20 had what could be considered 'low mass' dark matter halos according to our simulation. Since this sample size is so small it makes it very difficult to conclude decisively whether warm dark matter is could be an improvement over cold dark matter.