Comparing The Luminous Mass Fraction to Dark Matter Halo Mass in AGN and non-AGN Spiral Galaxies

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Why do some galaxies form stars efficiently and others don't? Theorists predict that there is a distinct relationship between the star-forming efficiency of a galaxy and its dark matter halo mass, which reaches a peak around 10^{12} solar masses. Galaxies within this peak zone can have some variation amongst themselves, with a prominent difference being the presence of an Active Galactic Nucleus (AGN). AGN are caused by super-massive black holes accreting gas and dust from the disc of the galaxy, releasing massive amounts of energy. This project revolves around 1) confirming the star-formation to dark matter halo relationship and 2) determining if the presence of an Active Galactic Nucleus changes this relationship. We found that indeed stellar mass fraction is directly related to dark matter halo mass, and that AGN may increase the stellar mass fraction at a given halo mass.

Background

To approach our question, we first need to understand what galaxies form stars well and why. Spiral galaxies, like the one shown in Figure 1 A, are very good at forming stars. It has been predicted that a galaxies ability to form stars is directly related to the size of the **dark matter halo** it occupies. Dark matter makes up the vast majority of the mass of any given galaxy, but it is impossible to observe because it doesn't emit light. Only by measuring the velocity at which galaxies rotate around their center can we determine how much mass we cannot see. Figure 1 B illustrates how a typical spiral galaxy sits within its dark matter halo.

All galaxies contain a black hole at their centers. Some galaxies' black holes are accreting matter from the galaxy's disc, releasing massive amounts of energy in the process. This is called an **Active Galactic Nucleus (AGN),** and our goal was to see how AGN affect star-formation efficiency.

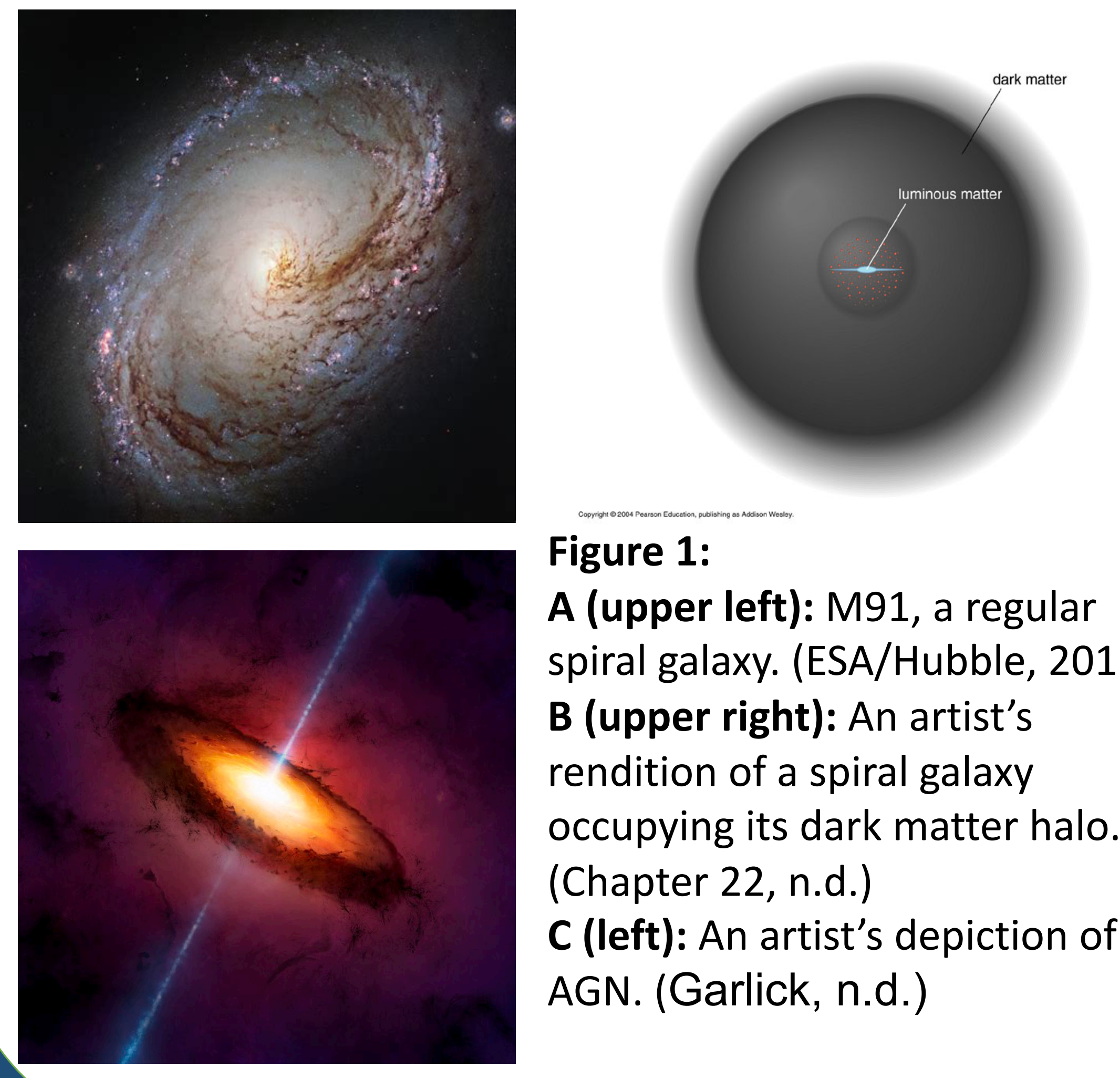

Figure 1:
A (upper left): M91, a regular spiral galaxy. (ESA/Hubble, 2015)
B (upper right): An artist's rendition of a spiral galaxy occupying its dark matter halo. (Chapter 22, n.d.)
C (left): An artist's depiction of an AGN. (Garlick, n.d.)

References:
Behroozi, P. S., Wechsler, R. H., & Conroy, C.. (2013), ApJ. 770, 57.
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Garlick, M. Artwork Of An Active Galactic Nucleus by Mark Garlick. (n.d.). https://pixels.com/featured/1-artwork-of-an-active-galactic-nucleus-mark-garlick.html
Somerville, R. S., et. al. (2018). MNRAS. 473, 2714.

Data Collection

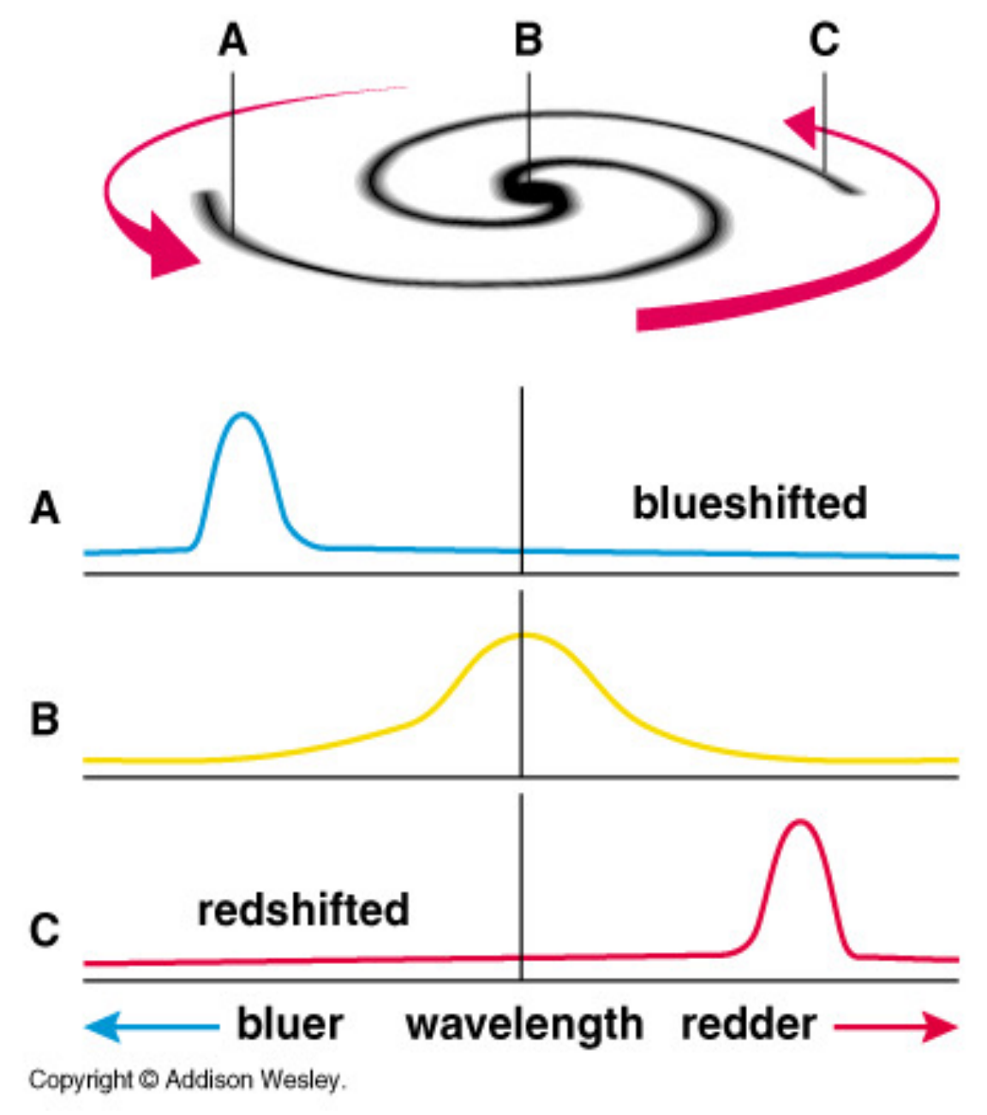

Figure 5: A diagram showing the Doppler Effect.

We chose to look at five regular spirals and five AGN to answer our question. We took two different types of data, **spectral** and **photometric**, taking advantage of a couple of well-known physical effects and processes. To determine the rotational velocity of each galaxy, we used the **Doppler Effect**. This can be used to measure the rotational velocity of a galaxy as the approaching and receding sides compresses or lengthen the light waves differently. This shift in wavelength is seen when taking **spectral** data. The relative shift in unique wavelengths emitted by gas and dust can tell us the velocity that the galaxy is rotating. By taking spectral data of a sample of ten galaxies, we could obtain their rotational velocities by comparing the Doppler shifts on either side of the galaxy's disc.

The other type of data we took was **photometric data.** This refers to images of galaxies, as shown in Figure 7, that are used to determine the amount of light that we received from each galaxy. These images were also used to find the **half-light radius** of each galaxy. This radius is defined as the distance from the center at which half of the galaxy's light is contained.

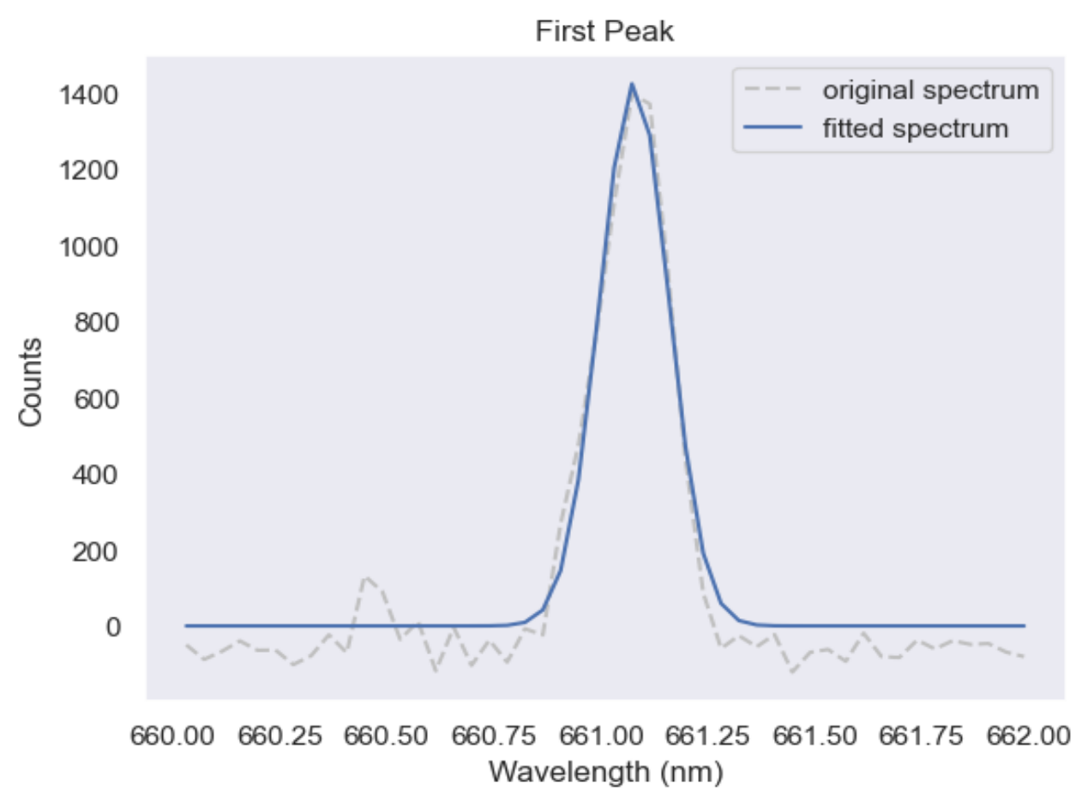

Figure 6 : An emission line in the spectra of NGC 5673

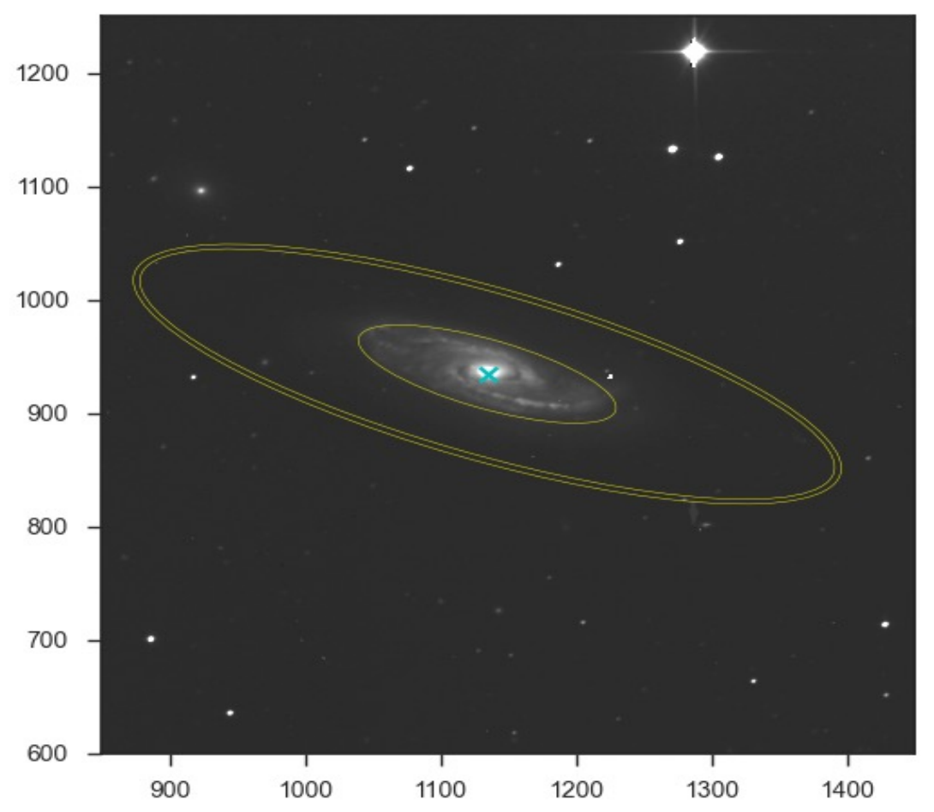

Figure 7: An image of NGC5899, one of the galaxies in our sample.

Methodology

We first calculated the radii of the dark matter halo for each galaxy, using a conversion between half-light radius and dark matter halo radius found by Sommerville et. al. (2018).

We then found the number of solar masses required to produce the light we observe from each galaxy, under the assumption that each star in a galaxy is approximately the luminosity of the Sun.

Next, we found the **dark matter halo mass** calculated through the formula $M = \frac{V^2R}{G}$, which is derived from the circular velocity formula. The velocity (V) we obtained from the spectral data, and the halo radius (R) from the photometric data as described previously. This mass was compared to the **stellar mass fraction,** or the stellar mass component derived from the photometric data divided by the dark matter halo mass for each galaxy. Our results can be seen in Figure 8.

NGC 1376, *ESA*

Results

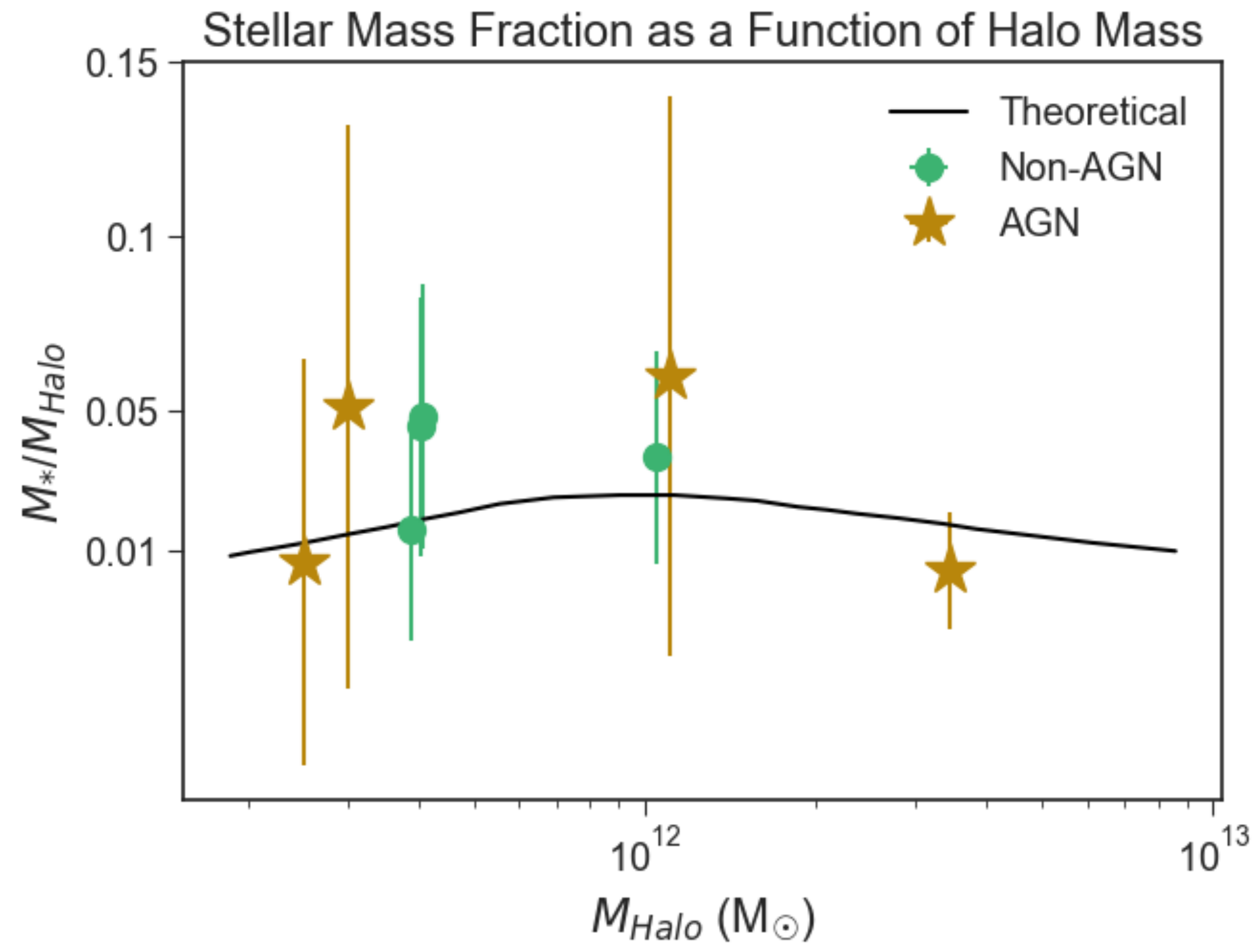

Figure 8: Our resulting plot, showing the stellar mass fraction of eight galaxies, four being regular spirals and four being AGN.

We confirmed the theoretical relationship between stellar mass fraction and dark matter halo mass, with the peak of stellar mass fraction being at a halo mass of roughly 10^{12} solar masses. This matches theoretical predictions (Behroozi et. al. 2013), as the peak stellar mass fraction is within 1 and 5%. There does not appear to be a significant difference between our AGN and non-AGN samples. However, the error bars on these points are too large to make any definitive conclusions about how AGN affect the amount of stellar mass in a galaxy.