Modelling Self-Interacting Dark matter in the Milky Way

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Introduction & Motivation

Dark matter comprises approximately 85% of the matter in our universe, and yet remains relatively poorly understood. Cold dark matter (CDM) serves as a widely accepted framework for modeling dark matter. According to CDM, dark matter consists of heavy, low-velocity particles that interact only through gravity, without interactions among themselves or other forms of matter.

Self-interacting dark matter (SIDM) is a proposed alternative to CDM, and is the focus of this project. While similar to CDM, SIDM introduces the concept of dark matter interacting with itself through a new force, distinct from gravity.

While CDM has been very successful in explaining many observations, the model often fails on smaller scales. A notable issue with CDM is the core-cusp problem; the steep "cusp"-like density profile CDM predicts in the centers of dark matter halos, is in contrast to observations of dwarf galaxies, which show a constant density "core" in this region.

SIDM generally shows the same large-scale behavior as CDM, but offers the possibility of resolving some of the small scale discrepancies associated with CDM. In the case of the core-cusp problem, SIDM's self interactions thermalize the inner region of galaxies, allowing the DM to redistribute into a constant density core.

Objectives

Question

What shape are SIDM halos, and how do they compare to observational data?

Motivation

Baryonic matter is often treated as spherical when calculating the densities of SIDM halos, even though baryons have significant deviations from spherical symmetry. Therefore, it would be valuable to know the true shape of an SIDM halo, taking the proper shape of baryonic matter into account.

Objective

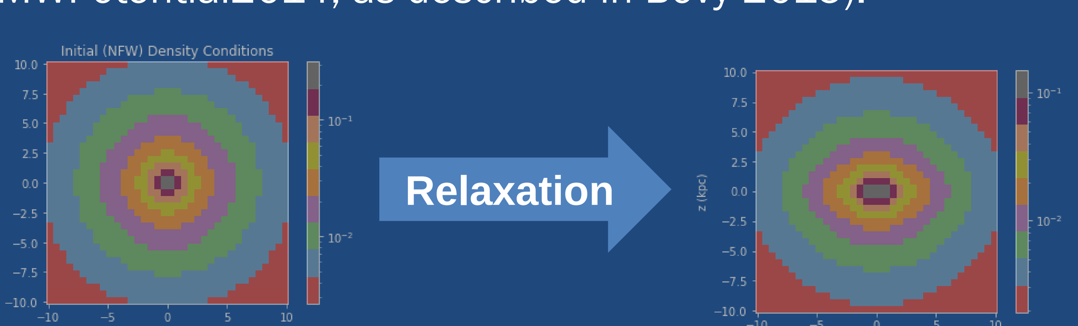
The goal of this project is to determine the shapes and radial profiles of SIDM halos, and compare them to observations.

Methods

For both the spherical and axis-symmetric cases, we numerically solved the Jeans equation for the gravitational potential (and therefore for the density).

For the spherical profiles, the equation simply reduces to a non-linear ODE.

For the axis-symmetric profile, this gives a partial differential equation. We used the relaxation method to solve this equation, with the boundary/initial conditions being an NFW profile fitted to the Milky Way (MWPotential2014, as described in Bovy 2015).



Figures 1 & 2: The initial NFW density conditions (left), and the final results after relaxation (right)

Results

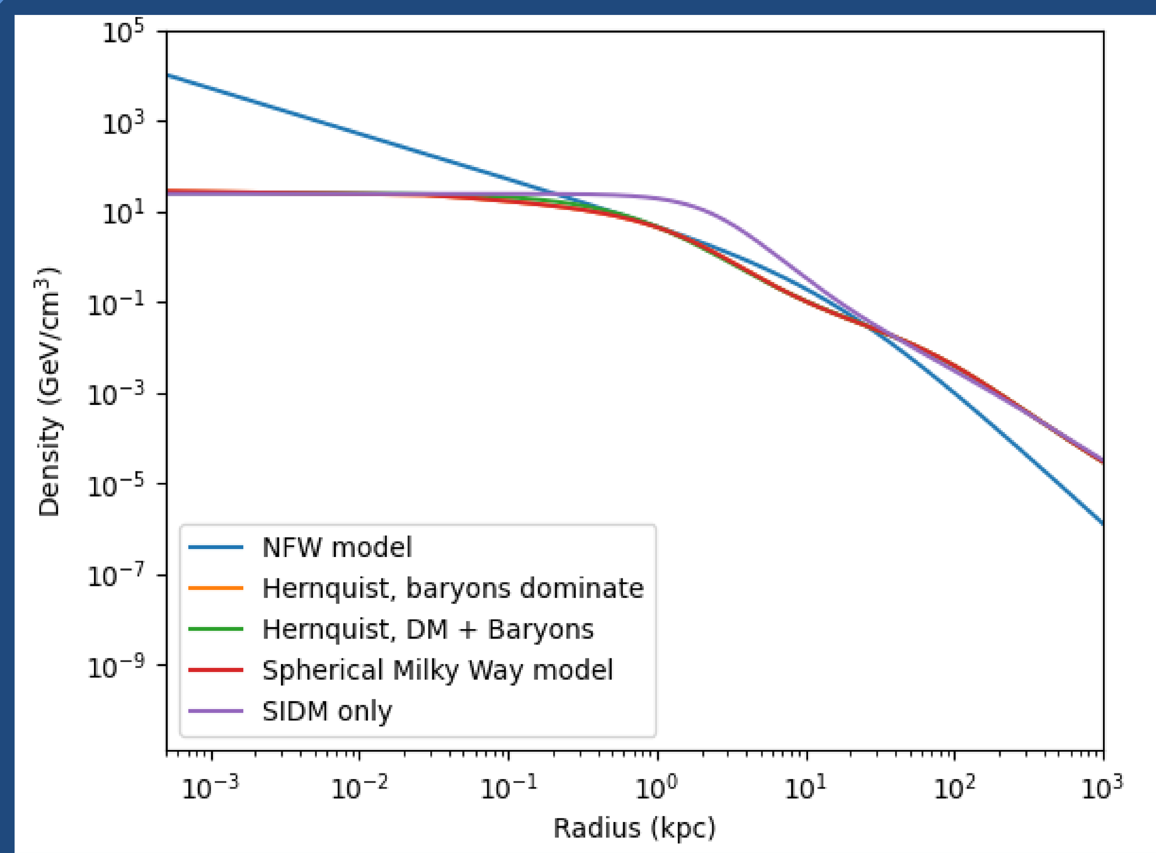


Figure 3: The densities of the various spherically symmetric models, in units of GeV/pc^3. Spherical Milky Way model takes uses the spherical enclosed mass of MWPotential2014 presented in Bovy 2015 as the baryonic potential

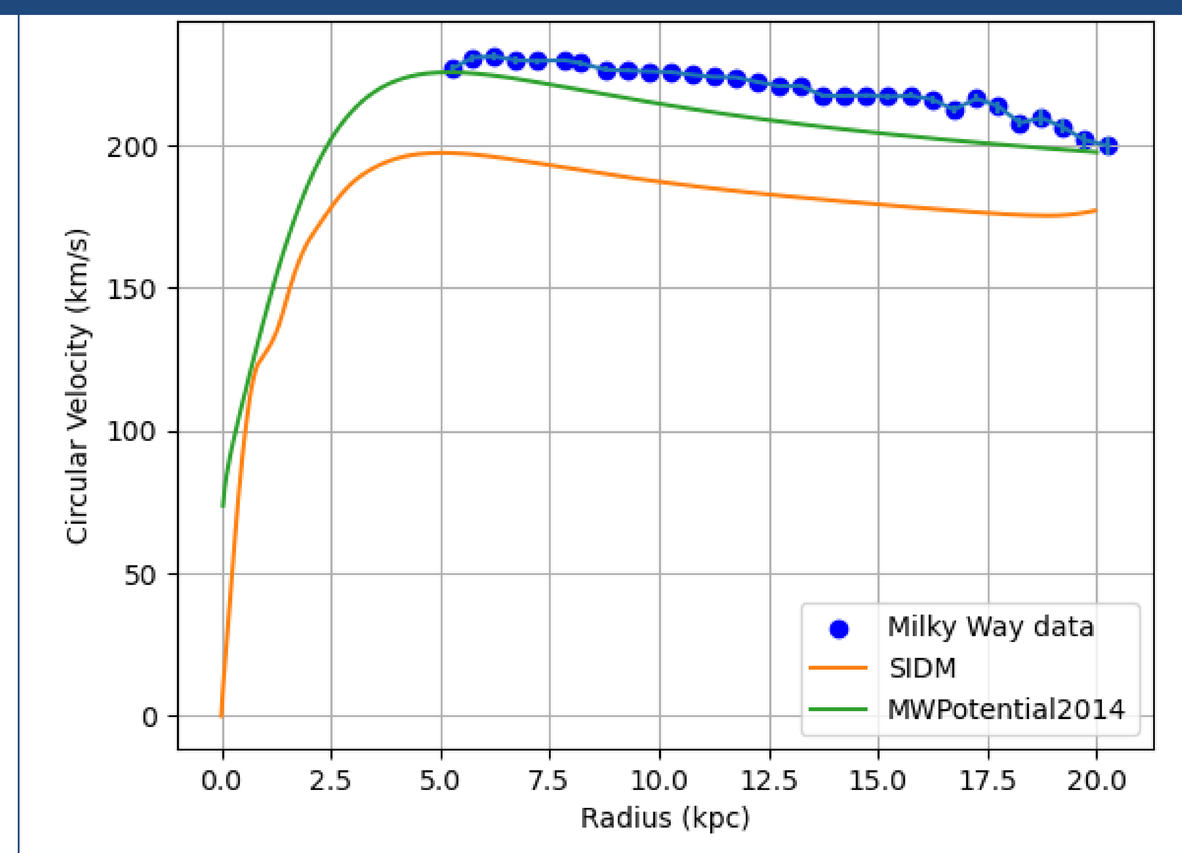


Figure 5: The circular velocity of the profile shown in Figure 4 (orange), that of a NFW model (MWPotential2014) fitted to Milky Way (green), and observational data of the Milky Way from Eilers et. al. 2019 (blue).

Model	Core Radius
Hernquist model, Baryons dominate	0.358 kpc
Hernquist Model, DM + Baryons	0.345 kpc
Spherical Milky Way Model, DM + Baryons	0.162 kpc
SIDM only	1.38 kpc

Table 1: Core sizes of the various spherically symmetric models

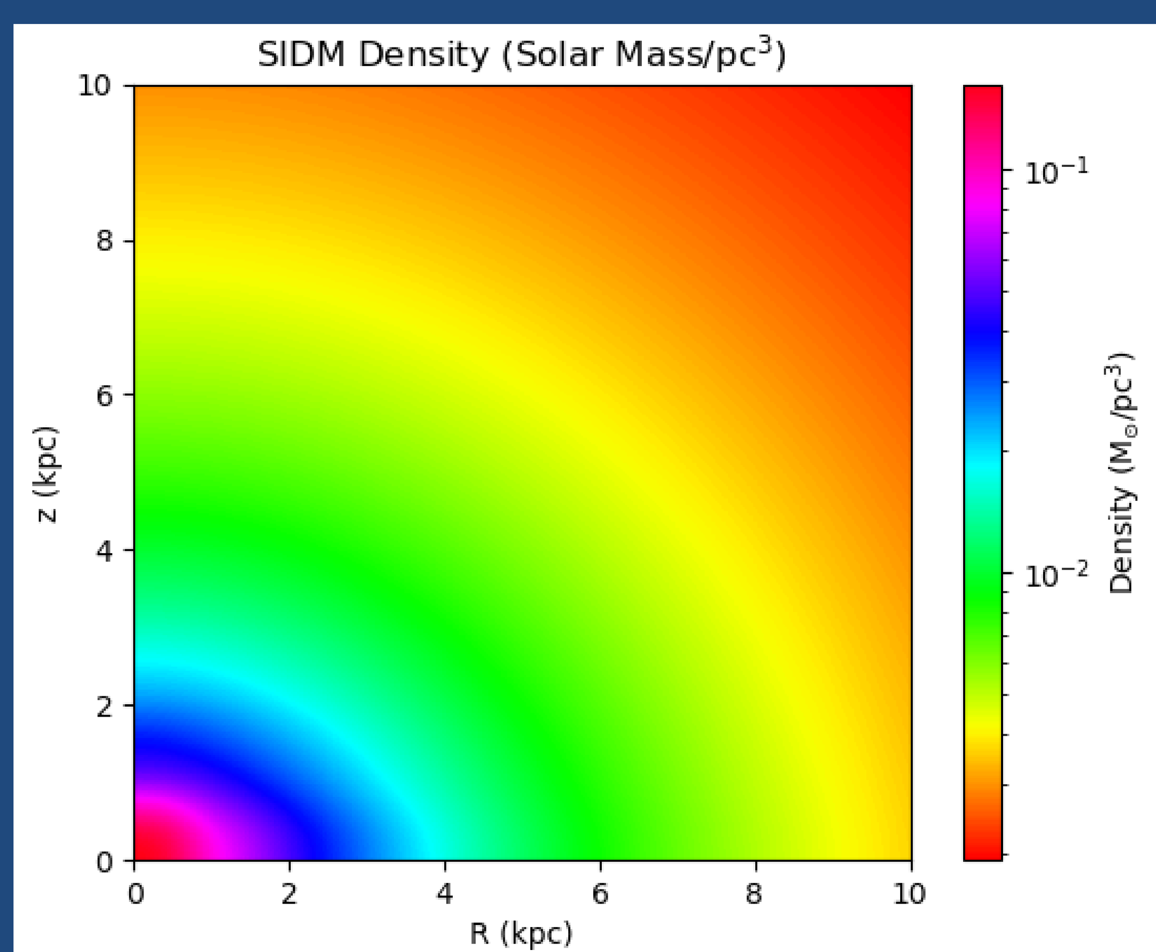


Figure 4: Density of the SIDM halo, assuming a Milky Way potential, as a function of the cylindrical coordinates R and z.

Details

- Core size is defined as the radial point at which the density falls to half that of the central density

Main Results

- The presence of baryons greatly shrinks the size of the core; the DM being significant in the potential additionally decreases the size of the core
- Near the core, the SIDM profile is significantly non-spherical, and is stretched in the radial direction
    - This occurs due to the influence of the baryons, which have a similar flattened shape
- The SIDM profile has a worse fit to the observed velocity curve of the Milky Way than the model using an NFW profile from Bovy 2015

Conclusions and Next Steps

- The SIDM halo takes on a shape which appears to be a mixture of the spherical NFW halo, and the flattened baryon distribution of the galaxy
- The presence of baryons greatly decreases the size of the core, compared to the SIDM only model
- However, the SIDM halo has a worse fit to the observed circular velocity of the Milky Way than the existing NFW model
- In future, an exploration of the parameter space may help to find a reasonable model which could more accurately fit the Milky Way data
- Additionally, different types of galaxies could be used to investigate how other potentials might affect the shape of SIDM halos, and the size of their cores

References

- Jo Bovy 2015 *ApJS* 216 29
- Anna-Christina Eilers *et al* 2019 *ApJ* 871 120
- Manoj Kaplinghat *et al* 2014 *Phys. Rev. Lett.* 113.021302
- Photo Credit: ESA & NASA