# Missing Satellites No Longer Missing?


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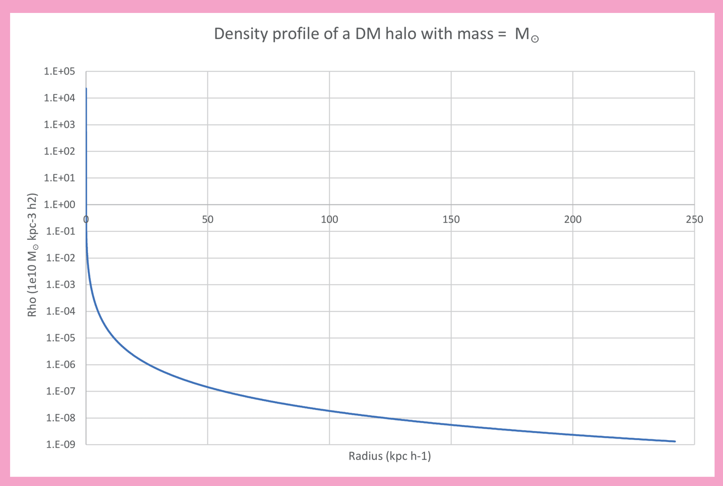
## Introduction

The well-accepted Lambda-Cold-Dark-Matter (CDM) model wins a Nobel Prize in 2020, helps explain most of the cosmological problems and thus is currently the most successful model to study DM behaviour. Nevertheless, this successful model is not flawless, the most well-known Navarro-Frenk-White (NFW) mass profile for a DM halo used in CDM model, blows up when approaching the centre of the halos. This infinite central density leads to the commonly known core-cusp problem, and also fails to match the observational rotation curve in galactic centres.

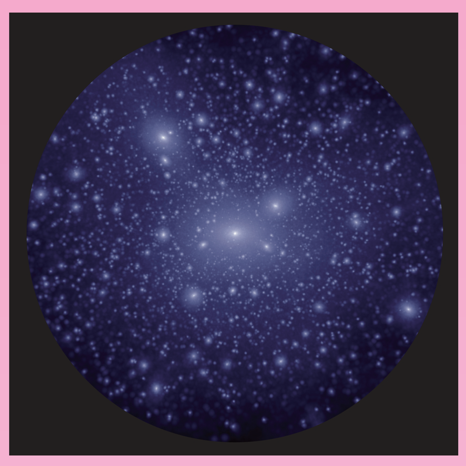
In view of the flaws, fine modifications of CDM have been proposed. Prof. M.C. Chu raised the plausibility of the decaying DM (DDM) model to resolve the flaws, DDM allows the slow-moving DM particles to decay once with two parameters (recoil velocity $V_k$, half-life $\tau$), this helps suppress the central singularity. Other models like self-interacting DM (SIDM) are also proposed, and the one we are working on contains degeneracy pressure at the central region which depends on one parameter, the particle mass $m_{particle}$.



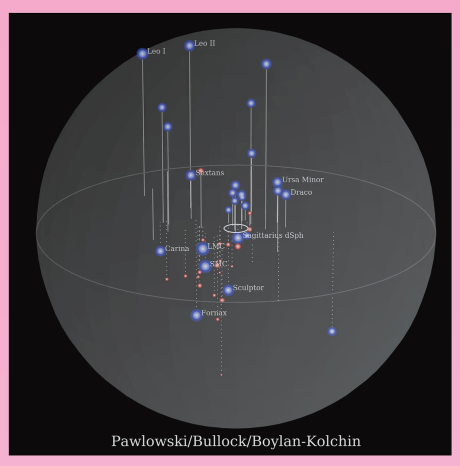

CDM Halo Density Profile

## Missing Satellite Problem

Missing satellite problem (MSP) refers to the number of observed satellite galaxies not matching the prediction from the N-body simulation of DM halos using CDM. Since CDM is a well-developed model with high credibility, there should exist a reason that the amount of observed satellite galaxies is greatly less than the prediction. In this project, DDM is used to simulate and test if it reasonably explains the deviations.



CDM Simulation




Observation

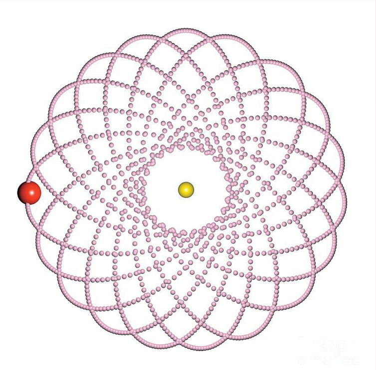
(Bullock and Boylan-Kolchin, 2017)

## Motivation

As DDM decays and raises the energy of the DM particle, some may even escape the halo, causing the halo to shrink in size. Some large subhalos can decay to a small but visible one, some can decay to become an invisible one, and some can even be destroyed due to decaying. Therefore, decaying may account for the massive decrease in the counts of subhalos from hundreds expected to around 60 observed. Most importantly, there is a preferred range of parameter sets to solve other independent problems, which is $V_k$: 20-40 km s$^{-1}$, $\tau$: 3-7 Gyr. It will be very promising if the parameter sets usable to solve the MSP are close to or even overlapping with the preferred range.

## Semi-core Code

The DDM model has been well-constructed with Semi-core code for simulation, and the results agree well with N-body simulation with short computational time. Semi-core code makes use of two fundamental assumptions: spherically symmetry and no surrounding disturbance from other DM halos. The code involves two processes: decay, by simply adding an extra energy ($V_k^2/2$) and turning the circular orbits to rosettes; adiabatic expansion (Chen and Chu, 2021), letting the orbits expand due to the decrease in enclosed mass. Undergoing the evolution for 16 time steps, the halo slowly evolved and became a decayed one. This code has great advantages in speed and efficiency which allows us to massively simulate the dark matter subhalos around the Milky Way.



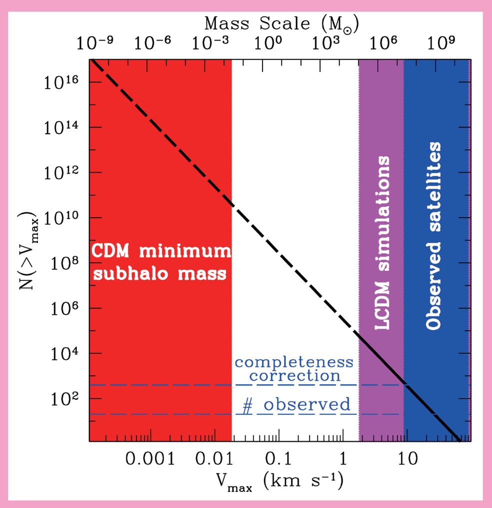
(Russell Kightley, 2014)

## Method

$$M_{sub} = 3.4 \times 10^7 M_\odot (V_{max}/10\ km\ s^{-1})^{3.5}$$

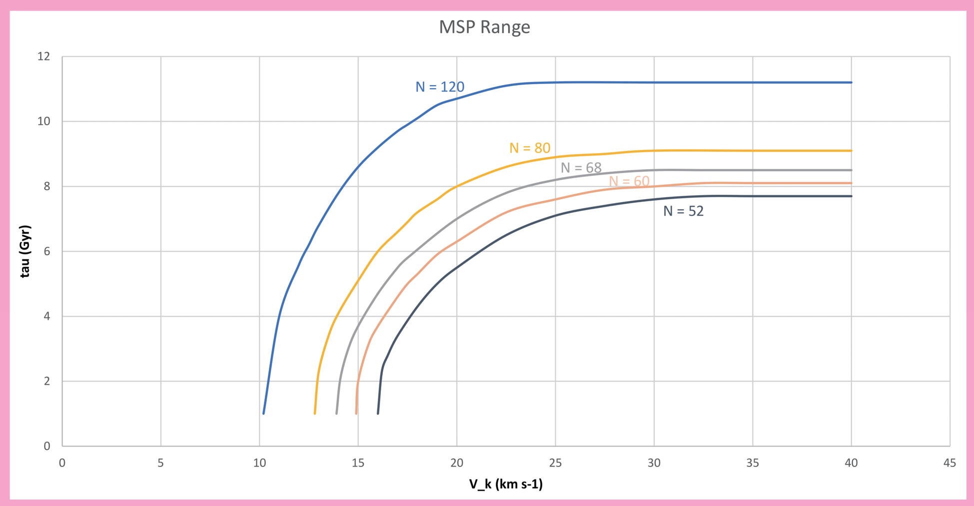
$$N(> V_{max}) \simeq 0.15 (V_{max}/V_h)^{-2.94}$$

As there are only 60 subhalos currently observable, by considering observational error and our limited resolving power, it is considered satisfactory if the number of observational subhalos after decay is constrained between 52 - 120. Making use of the two equations shown above, one can figure out the corresponding subhalo masses before decaying.

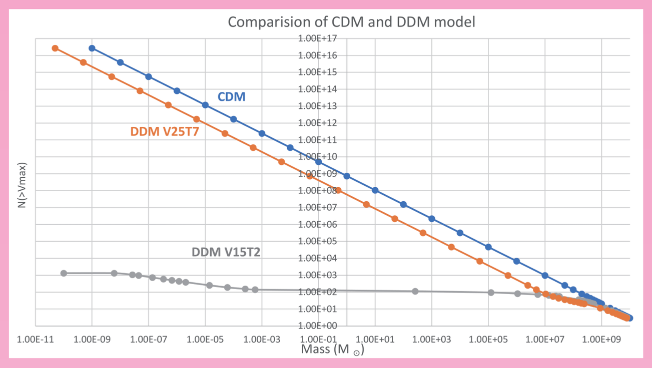



(Bullock, 2010)

## Result

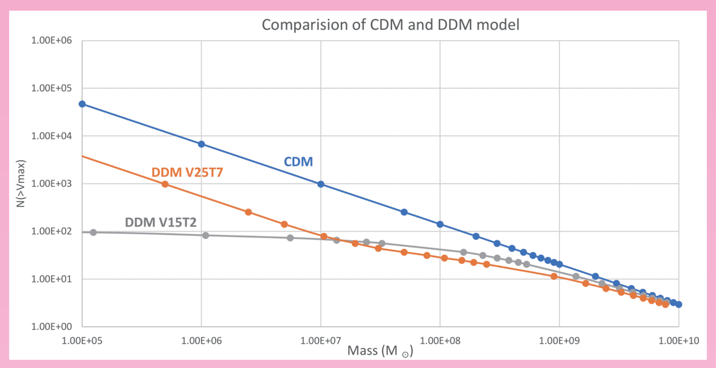



From the graph above, a belt is illustrated to show the range of possible combinations of $V_k$ and $\tau$ to narrow down the vast number of subhalo to around 60. The belt is quite promising as it is close to the preferred range from fitting dwarf galaxy rotation curves.




The left graph shows that when $\tau$ is comparable to the age of the universe (14 Gyr), the low mass halos tend to have a specific portion (0.0495 for V25T7) of initial mass compared to CDM. However, when $\tau$ is small enough compared to 14, the low mass halos tend to vanish.

The right graph shows that a larger $V_k$ in DDM represents a relatively lower number of high mass halos, while not really affecting the number of very large subhalos. Besides, the amount of observable halos (around M > 2.35E+7 $M_\odot$) is satisfying in order of magnitude.




## Discussion

The belt is slightly overlapping with the preferred range from other resolved problems, so DDM is quite successful in solving MSP also and raising the credibility of DDM. Although the belt is only overlapping to a small extent, it is accountable as there exist errors in defining visible satellite galaxies (or their corresponding subhalo). This tiny difference in the definition of visible satellite halo propagates and causes the range to shift vertically in a great extension. Therefore, the band can potentially match much better with the preferred one.

## Other Suggested Solutions

It is suggested that some dwarf galaxies are ultra-faint that they are not visible to us. There are not many stars formed in the galaxies due to feedback that keeps cold gas from forming stars which can be caused by supernova explosions, stellar wind, etc. (Khullar, 2018). Hence, there may actually exist such a number of galaxies predicted by the CDM while we are unable to observe them by telescope.

Another approach is that the low mass subhalos could have been destroyed by external events. For instance, tidal stripping or energy from supernova explosions. Supernova feedback in satellites can reduce the density of dark matter in these systems, while the presence of a baryonic disk can enhance the degree of tidal stripping that takes place (Brooks et al., 2013). The cumulation of these effects could destroy most of the low mass subhalos, reducing the number of visible halos to be comparable with the CDM prediction.