Large Ultra-Faint Galaxies in the Firebox Simulation

by
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Abstract

Your abstract will summarize your thesis in one or two paragraphs. This brief summary should emphasize methods and results, not introductory material.

Executive Summary

Your executive summary will give a detailed summary of your thesis, hitting the high points and perhaps including a figure or two. This should have all of the important take-home messages; though details will of course be left for the thesis itself, here you should give enough detail for a reader to have a good idea of the content of the full document. Importantly, this summary should be able to stand alone, separate from the rest of the document, so although you will be emphasizing the key results of your work, you will probably also want to include a sentence or two of introduction and context for the work you have done.

Acknowledgments

The acknowledgment section is optional, but most theses will include one. Feel free to thank anyone who contributed to your effort if the mood strikes you. Inside jokes and small pieces of humor are fairly common here . . .

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Chapter 1

Introduction

Understanding the composition and structure of galaxies and the role that dark matter plays in their organization is one of the most pressing topics in modern intergalactic physics. A common method to explore these questions is using simulations. A simulation allows us to choose plausible initial conditions and plausible laws of physics and test how the universe would behave under those conditions. We can then compare those results to experimental data to examine the accuracy of those initial assumptions. For instance, if we wanted to test Newton's theory of gravity in our solar system, we could run a numerical simulation of Newton's equation, starting from a past known position of the planets, and test whether or not the simulated motion of the planets aligns with our real astronomical observations. Likewise, we can test our theories about dark matter and gravity by running galaxy simulations.

Our current leading theory for dark matter's role in galaxy evolution is the Dark Energy and Cold Dark Matter (ΛCDM) model (Sales et al. (2022)). This theory provides a framework for physical simulation that incorporates a non-interacting ("cold") model for dark matter and the cosmological constant model of dark energy. Dark matter is assumed to not interact with either itself or "normal" baryonic matter, except through gravity. Such a model leads to large dark matter halos around galaxies that do not collapse into disks, which is consistent with observational data (Feldmann et al. (2022)). Since not much else is known about dark matter, and we have yet to find a non-gravitational interaction between dark matter and baryonic matter, this assumption is widely accepted in practice. Likewise, Feldmann et al. (2022) assumes dark energy to be the cosmological constant Λ, which is a degree of freedom in in the Einstein Equation that adds a net offset to the energy density of a vacuum. While the cosmological constant model of dark energy is quite popular and consistent in most ways with observational data, it is not the only model of dark energy. Bassi et al. (2023) pose an alternative: the Bimetric gravity model. This theory hypothesizes that the graviton—the theoretical particle that causes gravitational interactions—has mass. Bassi et al. (2023) show that a graviton with a non-zero mass could cause a net pressure in the vacuum, negating the need for the cosmological constant. They argue that the Bimetric theory of gravity could also resolve the Hubble Tension. This is an inconsistency between the measurement of the Hubble Constant at large and small scales (Sen et al. (2022)), a calculation that relies on the cosmological constant being just that: a constant. If more evidence can be found in support of it, the Bimetric model may replace the ΛCDM model, but for now the latter is still the most widely used.

When creating a galaxy simulation, physicists must also incorporate baryonic processes, the physics of ordinary matter. Baryonic properties incorporated into galaxy simulations may include gas density, pressure, temperature, star formation rate,

It is a common myth that if we can simulate something, we must be able to fully understand it. Unfortunately, this is not generally true. The galaxy simulations we use are so complex and detailed that it is often very difficult to determine what physical assumptions or initial conditions cause certain behaviors. Instead, we must analyze the simulation data using similar techniques we use to analyze observational data (although it is much easier to collect data about a simulation than about a real system of galaxies). From there, we compare the results to our expected results from experimental data to test our theories.

As one would expect, the simulation data does not always line up with the observational data; instead, there are a number of known tensions between the two. One such tension is the size-mass relation of dwarf galaxies. Observational data of dwarf galaxies near the Milky Way suggests that the correlation between the mass and size of satellite dwarf galaxies is not as strong as simulations seem to predict (Sales et al. (2022)).

1.1 FIREbox Galaxy Simulation

The FIREbox (Feldmann et al. (2022)) simulation is the most in-depth galaxy simulation ever performed as of the date of this thesis. It does not have the largest volume, nor is it the most detailed; sub-simulations such as FIRE in the Field (Fitts et al. (2017)) zoom in closer, to a particle size as low as 500 solar masses. FIREbox, however, has the total combined resolution and incorporates a balance of detail and scale.

Scale and resolution are an important component of galaxy simulations. Previous iterations of galaxy simulation needed to choose between larger volume and higher resolution. The large volume simulations allow scientists to closely study the interactions between galaxies and systems of galaxies, and to collect large amounts of statistical information about these galaxies (Feldmann et al. (2022)). However, the large resolution sacrificed physics accuracy and therefore realism; a higher resolution "zoom in" simulation allows us to better simulate the internal physics of the galaxies themselves (Feldmann et al. (2022))

1.2 Oh

1.3 Another section

This second section is, obviously, 1.2.

1.3.1 A subsection

A subsubsection

Subsubsections are still smaller sections. By default, this is the finest subdivision of a chapter in LaTeX, and they will *not* appear in the table of contents.

1.3.2 A useful command

...

1.4 Some figures

You will surely want to add figures to your thesis to help explain your ideas. There are a number of different ways to include such things, but the most typical way would be to generate the figure in another piece of software (`MATLAB, Mathematica, Adobe Illustrator, ...` and simply include it in your LaTeX code. This will require use of the *figure* environment.[1] See this document's LaTeX code for details . . .

Figure 1.1: Long-form caption that appears in main body of the document

Here I have added a table, because tables are also useful. This table has nothing to do with the rest of the material in this thesis template, but you should probably only add relevant tables.

Figure 1.2: A figure included using the wrapfig environment

Name	SpT	Dist. (pc)	Age (Myr)	3σ M_{dust} limit ($M_\oplus$)	3σ CO(3-2) limit (mJy km s^{-1})	Disk indicator
J0226	L0	46.5	45	0.01	24	Paβ, IR
J0501	M4.5	47.8	42	0.01	23	Hα, IR
J1546	M5	59.2	55	0.01	14	HeI, [OI], Hα, IR
J0446 A/B	M6/M6	82.6/82.2	42	0.027	18	Hα, IR
J0949 A/B	M4/M5	79.2/78.1	45	0.024	17	Hα, IR
LDS 5606 A/B	M5/M5	84/84	30-44	0.027	19	Hα, IR, UV

[1] there are many other possible environments to include figures, such as wrapfigure, but these will require including additional packages . . .

Chapter 2

A second chapter

2.1 FIREbox Galaxy and Halo catalog

Over the course of the simulated universe's evolution, 1201 snapshots of the state of the universe were collected (Feldmann et al. (2022)). They were approximately evenly spaced out in time and included the positions of the particles, their densities, metalicities, star-formation rates, and other properties. The particle data was reduced by grouping the particles into their respective galaxies and dark matter halos. They used the AMIGA Halo Finder (AHF; Knollmann and Knebe (2009) to sort the halos into categories of halos and sub-halos, which in turn allowed them to categorize the galaxies by host and satellite galaxies respectively. The reduced data, known as the galaxy and halo catalog includes galaxy information such as CM position, radius (measured using

AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

2.2 Host Proximity

2.3 Mass-Size Deviation

AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAa Here is a second mock chapter. As far as the LaTeX is concerned, it is in no way different from the introduction excepting that it appears after it in the main .tex file. As before, it can be populated with sections, subsections, figures, etc. as you see fit.

In fact, you will probably write perhaps three to six chapters for your thesis depending on how your work is most effectively organized. Most theses will contain an introduction, at least one 'body' chapter, and some sort of conclusions/future directions chapter. Most theses will also include an appendix or two ...

Appendix A

An appendix

Appendices are a good idea for almost any thesis. Your main thesis body will likely contain perhaps 40-60 pages of text and figures. You may well write a larger document than this, but chances are that some of the information contained therein, while important, does *not* merit a place in the main body of the document. This sort of content - peripheral clarifying details, computer code, information of use to future students but not critical to understanding your work . . . - should be allocated to one or several appendices.

A.1 About the bibliography

What follows this is the bibliography. This has its own separate environment and syntax; check out the comments in the .tex files for details. Worth nothing, though, is that you may find it helpful to use automated bibliography management tools. BibTeX will automatically generate a bibliography from you if you create a database of references. Other software - for example JabRef on a pc - can be used to make managing the reference database easy. Regardless, once you've created a .bib file you can cite it in the body of your thesis using the `\cite` tag. For example, one might wish to cite a reference by Bermudez If you use BibTeX, you can put the relevant information into a referencedatabase (called bibliography.bib here), and then BibTeX will compile the references into a .bbl file ordered appropriately for your thesis based on when the citations appear in the main document.

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