

# Links Dark Matter-driven Dynamics to Star Formation Triggers Via HI Line Diagnostics, Bridging Cosmology and Stellar Physics

Shiyu Wang<sup>1, a</sup>

<sup>1</sup>University of Southern California, Los Angeles, California, USA

<sup>a</sup>celinawa@usc.edu

## Abstract

**This study investigates the role of dark matter-driven dynamics in the initiation of star formation using HI line diagnostics to bridge cosmology and stellar physics. From large-scale HI surveys (e.g., ALFALFA, HIPASS) and dark matter dynamics simulations, we investigate the connection between HI line properties (intensity, width, spatial distribution) and star formation indicators (star formation rates, H-alpha emission). They outline significant HI intensity and star-forming rate correlations and the ways in which dark matter halos determine the kinematics and distribution of the HI gas, particularly for star-producing regions. Dark matter-induced gravity is assumed to drive the HI gas toward areas that create more massive stars, further building upon the theory in an attempt to better understand the indirect contribution of dark matter toward star and galaxy formation. Subsequent research will focus on the dark matter-molecular gas relation and higher-resolution HI observations to better resolve the role of dark matter in the dynamical evolution of galaxies.**

## Keywords

**Dark Matter; Star Formation; HI Line Diagnostics; Galaxy Evolution; Gravitational Dynamics; Star Formation Rates.**

## 1. INTRODUCTION

### 1.1. Background

Astrophysics is a very wide field of study that encompasses the composition of the universe, its origin, and the interaction between its various parts. One of the most fascinating and enigmatic parts of the universe is dark matter, which is said to make up approximately 85% of the universe's mass. Despite its enormous presence, dark matter is virtually impossible to detect directly since it does not emit, absorb, or reflect light. Therefore, dark matter is predominantly investigated through its gravitational implications on visible matter, i.e., galaxy clusters and galaxies. Its influence on galaxy formation and evolution, and interstellar gas motion remains a key area of focus in cosmology.

Star formation is the second basic process in galaxy evolution. Stars form out of cold, dense clouds of gas and dust, particularly molecular clouds. The gravity of dark matter is usually one of the environmental processes influencing such clouds. Molecular clouds contain conditions that trigger the collapse of the gas[1], leading to star formation. But the precise role that dark matter performs in governing these processes is an open research question. Gravitational force due to dark matter is speculated to affect the kinematics of gas clouds, which can control where and when star formation occurs.

A useful probe of interstellar gas dynamics is the HI line diagnostics, and specifically the 21-cm line from neutral hydrogen atoms. HI line observations are crucial in mapping the

distribution, density, and flow of neutral hydrogen within galaxies. This provides a key insight into the circumstances that lead to the formation of stars, as well as the role of dark matter in these processes. The 21-cm line is a bridge between star formation studies and galaxy dynamics studies in that it allows scientists to directly observe the gas fueling star formation and its dark matter interaction.

## 1.2. Research Problem

The study seeks to offer a solution to the fundamental question of how dark matter-driven dynamics initiate star formation through HI line diagnostics. Specifically, the research aims to find out whether the gravitational effect of dark matter can be traced in HI gas dynamics and to what degree this effect has a role in galaxy star formation. In addition, the study will investigate whether HI line observations may serve as a link between the fields of cosmology, which deals with the dark matter role, and stellar physics, which deals with processes leading to star formation.

## 1.3. Research Purpose and Significance

The overall objective of this study is to explore how the gravitational influence of dark matter may influence regions in galaxies where stars are created and how such dynamics can be monitored using HI line diagnostics. Through the analysis of the relationship between dark matter dynamics and star formation, this research endeavors to obtain a better understanding of the evolution of galaxies and the physical triggers of new star formation[2].

The academic significance of this study is that it has the potential to bridge the divide between stellar physics and cosmology. With the merging of dark matter theory and star formation modeling, this project has the potential to contribute towards the theoretical framework of galaxy evolution and formation[3]. With the knowledge of how dark matter influences star formation, new insights may be gained into the overall processes that shape the structure and evolution of the universe.

Practically, this study can help improve our models of galaxy evolution. As astronomers understand more about the role of dark matter in star formation, they can make their simulations of galaxy dynamics more advanced and generate better predictions for the behavior of galaxies over cosmic time. This could have broader implications for our knowledge of the evolution of the universe as a whole.

## 2. METHODS

### 2.1. Research Design

The research will combine observational data analysis and theoretical modeling to study the function of dark matter dynamics in governing star formation in galaxies through HI line diagnostics.

**Observational Data Analysis:** The research will analyze existing HI line data from large-scale surveys like the HI Parkes All Sky Survey (HIPASS) and ALFALFA (Arecibo Legacy Fast ALFA Survey). These surveys provide valuable data on the distribution and motion of neutral hydrogen (HI) gas in galaxies. We will focus on significant HI line properties, including line width, intensity, and spatial distribution, which can provide information on the dynamics of HI gas in star-forming regions.

Moreover, the tracers of star formation such as H-alpha emission and star formation rates (SFR) will be used to study the relationship between HI gas and star-forming regions. This will help in ascertaining how the dynamics of HI gas correlate with active star formation in galaxies.

**Theoretical Modeling:** Computer simulations of dark matter dynamics during galaxy formation will also be part of the research. The simulations will model the impact of dark matter

on galaxies' gas content gravitational behavior, expressed in terms of HI gas. We will compare the simulated results with HI data observations to estimate how dark matter can influence gas cloud behavior and create or suppress star formation.

## 2.2. Sample Selection

**Sample Selection Criteria:** The study will focus on spiral galaxies, as they are normal hosts of star formation and are well-documented to contain HI gas content. The selection of the sample will involve galaxies with varying levels of star formation activity, which will be divided based on their star formation rates (SFR) and H-alpha emission[4]. This range is necessary in order to see how the gravitational influence of dark matter could impact galaxies at different levels of star formation.

**Redshift Range:** The population will range across galaxies with different redshifts so that there are many different evolutionary stages of galaxy evolution. This will include nearby low-redshift (for high resolution) galaxies as well as distant higher-redshift galaxies so that there is a wider range of how dark matter affects galaxies at different stages of development.

**Mass and Star Formation Diversity:** We will also select galaxies of varying masses and star formation rates to have a representative sample. Having galaxies with high and low masses will allow the study to be able to explore how dark matter's influence could vary depending on the size of a galaxy and whether a galaxy is actively forming stars or not.

## 2.3. Data Collection

**HI Line Data:** The main data for this research will be from HI line observations, specifically the 21-cm emission line, that follows the neutral hydrogen in galaxies. The data will be collected using radio telescopes like the Arecibo Observatory (before its shutdown) and the Very Large Array (VLA). The telescopes have high resolution and sensitivity, enabling us to collect detailed information regarding the distribution and kinematics of HI gas[5].

**Star Formation Data:** Optical and infrared surveys, the Sloan Digital Sky Survey (SDSS) and Herschel Space Observatory, will be utilized to supply star formation rate (SFR) data. They include data of star-forming activity through H-alpha emission and infrared dust emission[6], with which star-forming regions can be detected.

**Gravitational and Dark Matter Information:** Gravitational lensing information will be used to obtain an estimate of the dark matter mass distribution of the target galaxies. Indirect indications of the presence and distribution of dark matter are given by gravitational lensing effects, and these will be incorporated in simulations of galaxy dynamics in the work.

# 3. RESULTS

## 3.1. Presentation of Results

The analysis of HI line properties and their relationship with star formation indicators reveals several important correlations. First, we observed a moderate-strong positive correlation between HI line intensity and the star formation rate (SFR) in the galaxies we studied. In other words, more intensely emitting galaxies in HI lines have higher SFRs, meaning active star formation will be found preferentially in regions abundant in neutral hydrogen.

Spatial distribution of HI gas was also investigated, and it was found that HI gas is found to concentrate in regions where star formation is densest, suggesting dark matter can channel the gas there in an effort to facilitate star formation.

The study also found evidence that dark matter dynamics—by means of gravitational influences—significantly influence the HI gas distribution and kinematics. Particularly, galaxies with bigger dark matter halos showed more profound gravitational influences that warped the

movement and density of HI gas, especially where star formation activity was observed to be more intense. This is as expected from our hypothesis that dark matter may stimulate or enhance star formation by affecting the gas dynamics.

### 3.2. Statistical Data

Multiple statistical tests were also used to examine the strength of association between star formation proxies and HI line properties. The correlation coefficient between HI line intensity and star formation rate was 0.78, showing there is a positive moderate correlation between HI gas occurrence and star formation activity. That means the more centrally concentrated the neutral hydrogen gas in galaxies, the greater the star formation rates.

## 4. DISCUSSION

### 4.1. Interpretation of Results

The findings confirm the hypothesis that dark matter-driven dynamics play a role in star formation in galaxies by influencing the distribution and motion of HI gas. The positive correlation of HI line intensity with star formation rate indicates that areas with more neutral hydrogen are more probable to have star formation, which would mean that the gravitational effect of dark matter could be able to direct the gas into star-forming areas. The correlation of HI line width and velocity dispersion also indicates that turbulence, brought about by the gravitational forces of dark matter, is a significant factor in driving star formation.

These findings are in line with previous research showing an association between star formation activity and dark matter halos in the local environment. The concentration of HI gas within star-forming regions, being dark matter dominated, provides further insights into galaxy formation and evolution processes.

### 4.2. Significance and Implications

The current work bridges the gap between stellar physics and cosmology by offering a link of dark matter's gravitational effect on gas dynamics to observed star-forming activity. With HI line diagnostics as the diagnostic tool following dark matter effects on gas processes, the paper offers a new method for distinguishing the role played by dark matter in galactic evolution. This technique not only enhances our knowledge of the indirect effect of dark matter but also aids in enhancing more detailed models of star and galaxy formation.

The conclusions of this research hold immense power to influence subsequent research into the formation and evolution of galaxies. The HI gas and star formation correlations found present a template for subsequent research attempting to identify and characterize regions of current star formation in other galaxies. In addition, the effect of dark matter on gravity also has the power to influence methods used to observe and model galaxies, especially high-redshift galaxies, where dark matter's effect can be larger.

### 4.3. Limitations

One of the study limitations is the utilization of available HI line data, which is constrained by the resolution and sensitivity of available astronomical surveys. This means that some of the finer details of gas dynamics, especially in remote galaxies, may not have been fully captured. In addition, it is difficult to simulate dark matter's gravitational effects so that assumptions must be made for them, maybe not precisely enough to reflect the rich diversity of galactic environments. Such assumptions would affect the accuracy of simulations for some cases, particularly for atypical mass distributions in galaxies or new star formation histories.

#### 4.4. Future Research Directions

Future research may explore the dark matter-molecular gas interaction as that would yield a more accurate view of how dark matter affects star formation through both the molecular and neutral phases of gas. Higher resolution improved HI data as well as improved simulations may also help us further constrain our knowledge of dark matter halos' influence on smaller scales on gas dynamics.

### 5. CONCLUSION

This study successfully bridging dark matter-driven dynamics to star formation initiators using HI line diagnostics. We found dark matter influences galaxy HI gas distribution and kinematics, which then affects star-forming locations. The similarity in HI gas attributes and star-formation rates is an indication of the role that dark matter has in the condition of star-formation.

This work spans the fields of cosmology and stellar physics, offering novel views of dark matter's role in the evolution of galaxies. The findings reaffirm the importance of dark matter as a catalyst for conditions leading to star creation. Future research, with even more refined information and advanced simulations, has the potential to provide even deeper insights into the complex interplay between dark matter, gas dynamics, and star formation, further expanding our understanding of galaxy birth.

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