The Star Formation Law in Dwarf Galaxies

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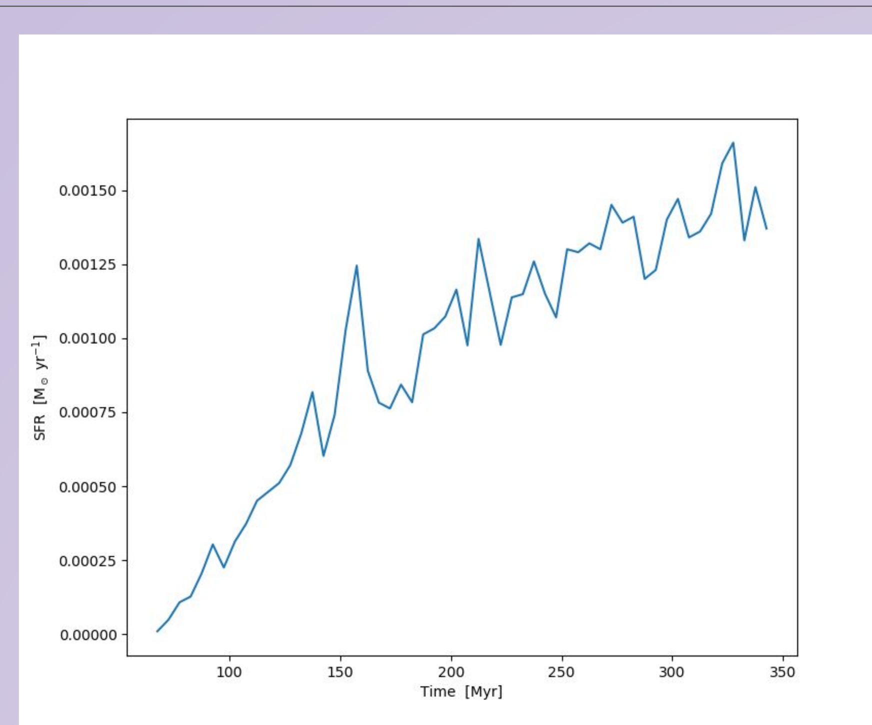
Background

Advantages of Studying Dwarf Galaxies

- Excellent laboratories to study the Interstellar Medium (ISM)
  - High gas to dust ratio
  - Low metallicities
  - Significant response to minor changes in thermodynamic conditions due to small size.
- Low density regime unexplored in star formation law

Advantages of Numerical Simulations

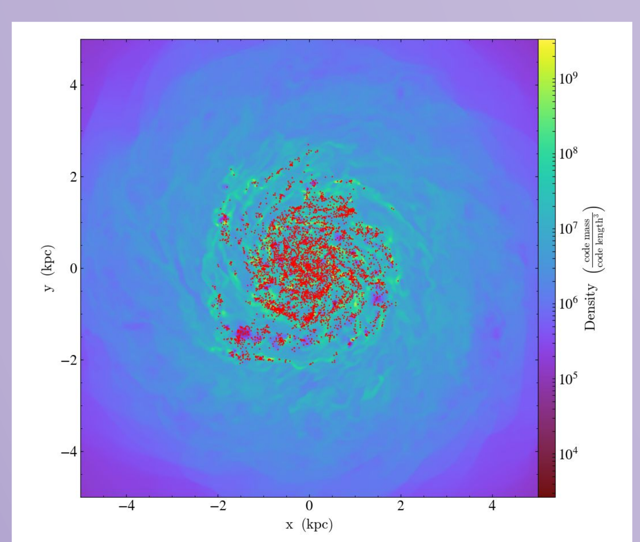
- Dwarfs relatively easy to simulate
- Dwarfs difficult to observe due to low luminosity, low mass, small size
- Control over physical conditions



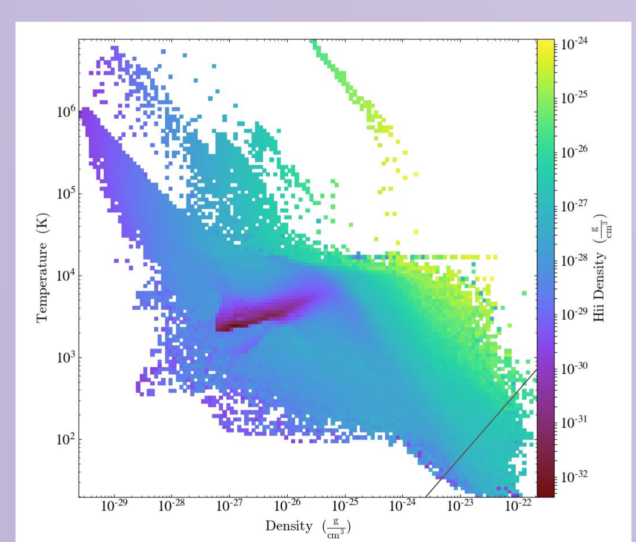
The star formation rate throughout most of the runtime of the simulated galaxy. The amount of star formation is much lower and the rate is slower than larger star forming galaxies.

Blue compact dwarf galaxy, *NGC 5253* (ESA/Hubble & NASA, 2012). Blue compact dwarfs are known to exhibit periodic bursts of high star formation.

The Kennicutt-Schmidt Law established a near linear relation between ISM density and star formation, based on observed galaxies: $\Sigma_{SFR} \propto (\Sigma_{Gas})^{1.4}$ where Σ represents surface density (Kennicutt, 1998). Due to the lack of observable dwarfs, though, it is unclear whether this relation holds for low densities. Furthermore, evidence from nearby dwarfs show irregular patterns of star formation, often occurring in periods of concentrated bursts. There has been debate on what dominates star formation regulation in these systems: supernovae (SNe) feedback or photoelectric (PE) heating.



A projection plot of the gas in the simulation, at a certain snapshot. In red are star particles.



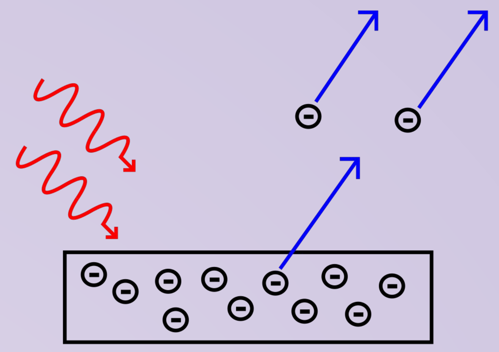
A phase diagram of the gas at a certain snapshot. The black line represents the jeans mass. Gas below this threshold would collapse and form stars.

The Simulation & Methodology

The high-resolution simulation used in this project was generated using the Adaptive Mesh Refinement (AMR) code, Enzo. It includes both photoelectric heating and supernovae driven feedback.
The simulation was analyzed in ~100 pc² patches, in which the total gas mass and total number of newly formed star particles were summed and divided by the patch area to obtain values for Σ_{Gas} and Σ_{SFR}.

Candidates

- **Ostriker, Mckee, & Leroy (2010)**
  - Top Down (Galaxy scale)
  - PE dominated



(Wikimedia Commons, 2007)

- **Krumholz (2013)**
  - Bottom-up (Cloud scale)
  - PE dominated

Orion Molecular Cloud(NASA, 2010)

- **Faucher-Giguere (2013)**
  - Top-down (Galaxy scale)
  - SN dominated

SN Remnant G299 (NASA, 2015)

Results

After iterating over patches all throughout the galaxy at several snapshots, the arrays of Σ_{Gas} and corresponding Σ_{SFR} values were plotted, as shown in **Figure 1**. **Figure 2** shows the same data, in conjunction with the values predicted by the analytic models of *Ostriker (2010), Faucher-Giguere (2013) and Krumholz (2013)*. No model fits exactly with the simulation, though they all fall within a reasonable range. We see that *Ostriker* and *Fauchere-Giguere* overestimate the values, implying that their top-down approach ignores a suppressive dependence on molecular gas. The *Krumholz* model does account for molecular gas dependence, though it does not agree as well with the simulation as the other models. While the Ostriker model's emphasis on galaxy scale processes and photoelectric heating as the dominant regulating factors appears to agree most with the results, it is clear that the star formation law must incorporate complex physics from cloud scale processes as well.

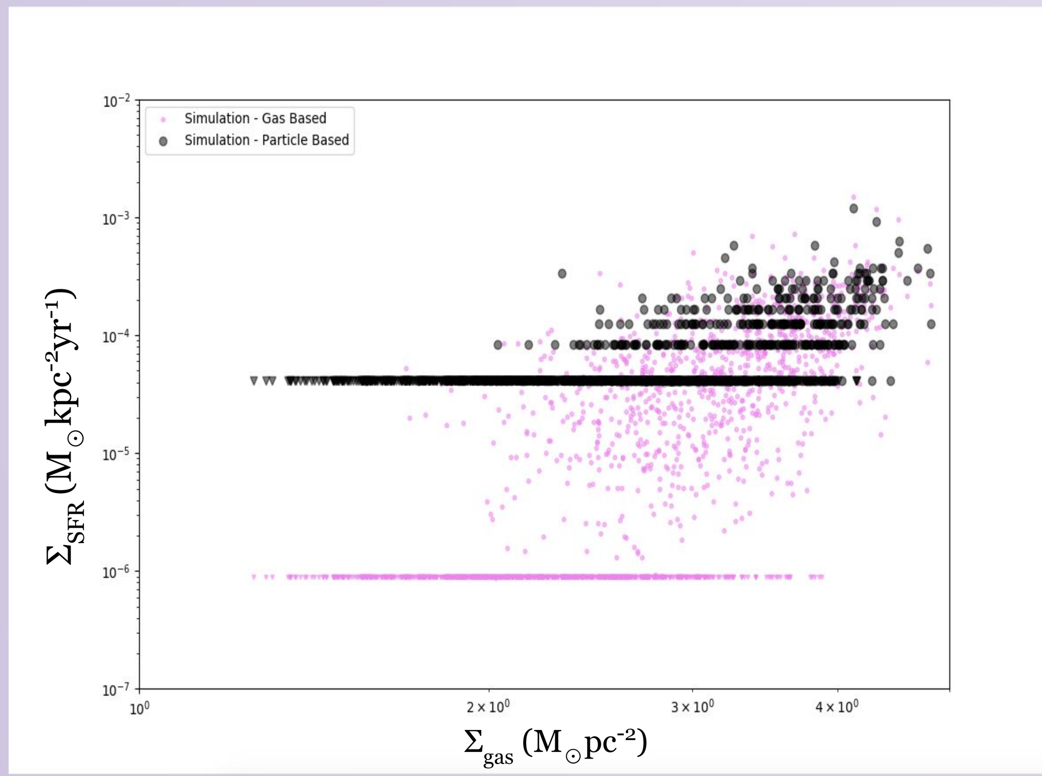


Figure 1 The Σ_{SFR} - Σ_{Gas} relation of the simulated galaxy. The black represents the particle based calculation of Σ_{SFR} determined by the quantity of star particles in a patch. The pink represents the expected Σ_{SFR} based on the gas characteristics at that instant.

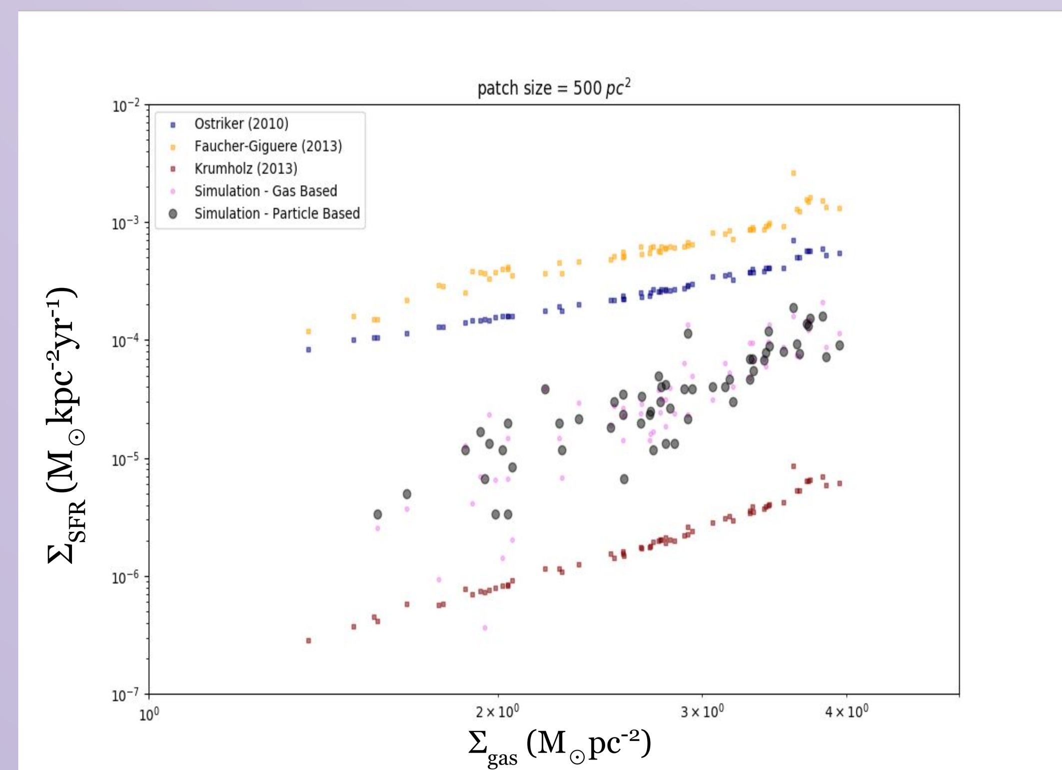


Figure 3 The same analysis as Figure 2 instead using patches of 500 pc².

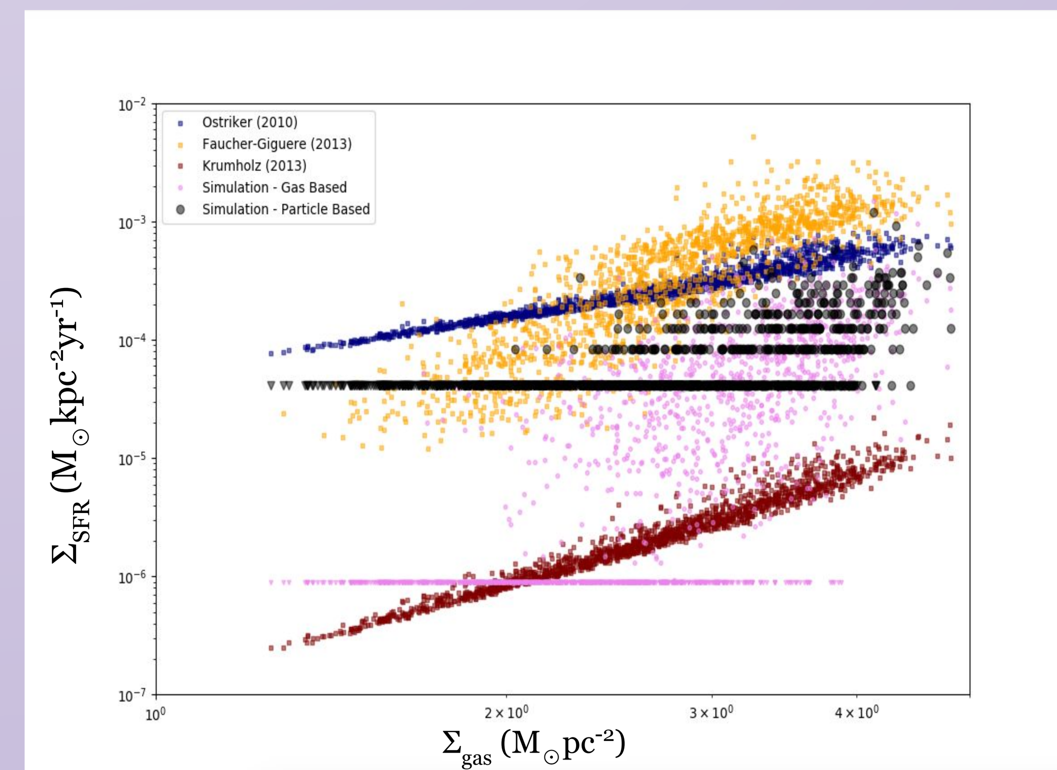
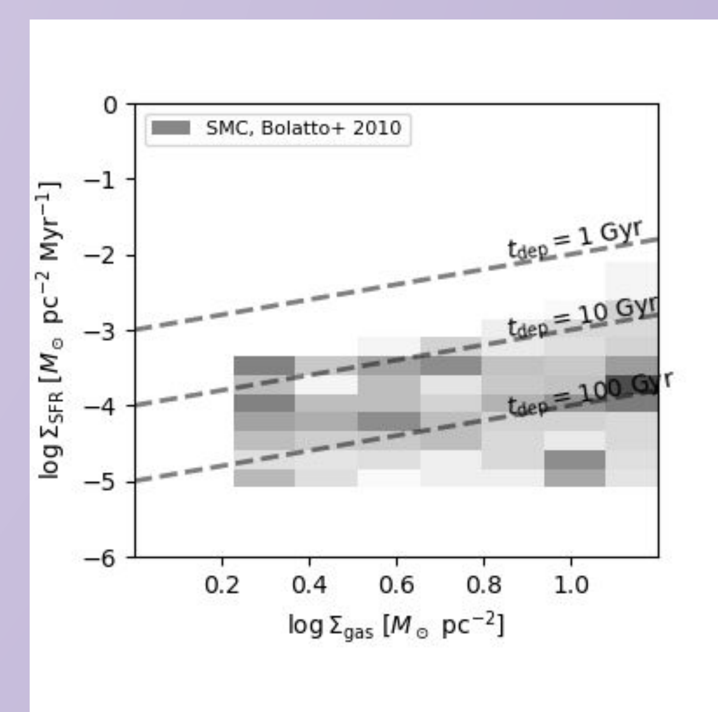


Figure 2 The data from Figure 1 overlayed with the predicted values for Σ_{SFR} based on each of the proposed analytic models.

Future Work

We will investigate further into the specifics of each analytic model and reapply them to the simulations. This will consist mainly of finding more precise values for certain physical parameters, including warm gas fraction, thermal pressure, etc. Additionally, we will compare these results to observational data from nearby dwarfs such as the Large and Small Magellanic Clouds, which will reveal the accuracy of both the simulation and the analytic models in recreating the circumstances of real systems. We will also analyze other simulations with varying conditions, isolating SNe or PE feedback to examine their impacts individually.



The star formation law in the Small Magellanic Cloud, using data from Alberto Bolatto (2010). The dashed lines show constant depletion times τ_{dep}=1, 10, and 100 Gyr.

References

Bolatto, Alberto D., et al. "The State Of The Gas And The Relation Between Gas And Star Formation At Low Metallicity: The Small Magellanic Cloud." *The Astrophysical Journal*, vol. 741, no. 1, 2011, p. 12., doi:10.1088/0004-637x/741/1/12.

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