Simulating supernovae driven outflows in dwarf galaxies

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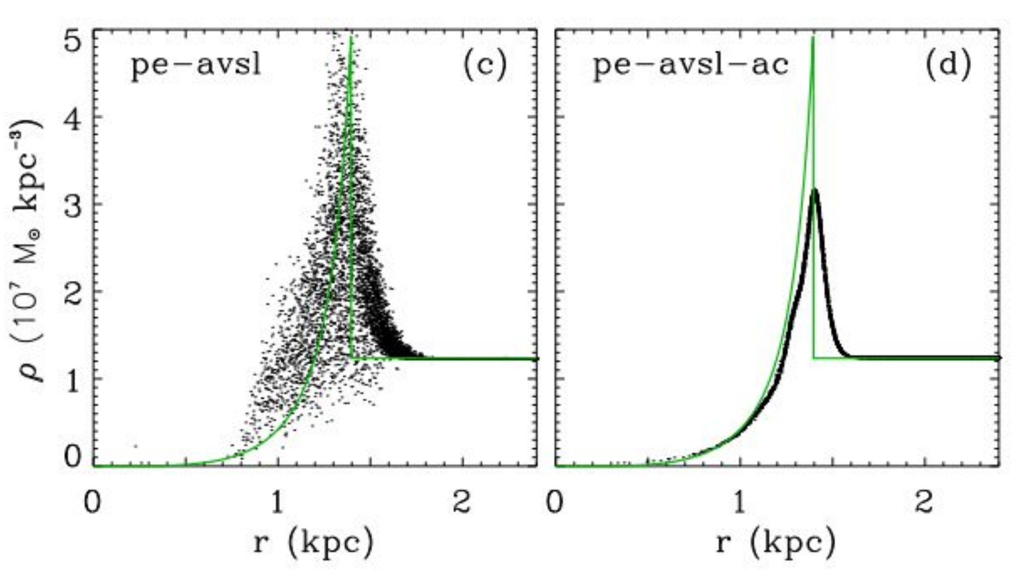
Introduction

Galactic outflows are a phenomena in which gas from the interstellar medium (ISM) is blown out of a galaxy in a wind-like fashion. It has been observed in several galaxies, such as in M82, pictured below. Outflows are a key ingredient in large scale, cosmological simulations, as they are necessary to produce correct galactic morphologies. However, outflows are still only partially understood, since it is difficult to directly observe them. It is commonly accepted that supernovae are the main drivers of outflows, and we have created simulations accordingly to study the behavior of the ISM and outflows due to stellar activity. The project at hand is intended to further our understanding of the nature and origin of galactic outflows. We place focus on dwarf galaxies because of their shallow potential wells and smaller physical scale, allowing simulations to be resolved in more detail, even so far as to resolve individual supernova, which cannot be done in larger galactic simulations.

This image of galaxy M82 is one of the most notable depictions of galactic outflows. Superimposed on top of the visible light image of the galaxy is the image of hydrogen gas outflows (in red). However, due to the larger mass of M82, it is contended that an Active Galactic Nucleus is a source of outflows, instead of just supernovae. This could not be the case in dwarf galaxies, like those being simulated in this project. (NASA, 2006).

Methods

The simulations analyzed in this project were created using the Gadget-3 code (Springel, 2005). The simulations account for self-gravity, non-equilibrium chemistry and cooling, shielding from interstellar radiation field, and hydrodynamics, solved by the smooth-particle hydrodynamics (SPH) method (Hu, 2017). They follow the galaxies' evolution over one billion years, with a period of initial turbulence input at the beginning of its lifespan. Star formation occurs when a gas particle's mass exceeds its Jean's Mass, and is thus converted into a smaller, collisionless star particle. Supernovae occurs in star particles over 8 solar masses, after a period of about 10 Myr. Two simulations were analyzed for this project, only differing in artificial conduction, which determines the local operation of the rate of thermal conduction. Once these simulations were created, they were analyzed using python to extract necessary information, in particular, the star formation rate and the outflow rate, which is the mass flux (product of the mass and speed of the gas) through the threshold of z=±2 kpc from the galaxy.



This figure, taken from Hu et al. 2014, compares the radial density profiles of a sedov explosion in two different simulations. The left figure does not include artificial conduction, whereas the right figure does. Including AC clearly reduces much of the noise (in black) and produces results much closer to the analytic solution (in green).

Results

The data gathered shows the relation between stellar activity and outflows. In Figure 2a, stellar formation can be seen to begin at around 0.05 Gyr, and according to Figure 2b, outflows begin shortly after that (ignoring the first spike in outflows caused by initial turbulence), corresponding to the first supernovae. Also, it is clear that star formation rate is unaffected by the change in diffusion coefficient, since the star formation process is independent of the thermal conduction. However, the galaxy with the smaller diffusion coefficient produced significantly stronger and faster outflows per the same rate of star formation (and subsequently supernovae). This, however, is not an indication of efficient outflows, but rather of numerical artifacts. Low artificial conduction allows fluid instabilities to form quicker, and so shocks are not able to be correctly resolved and particle penetration ensues. As artificial conduction increases, instabilities are increasingly suppressed, which corrects shock behavior and prevents overblown outflows.

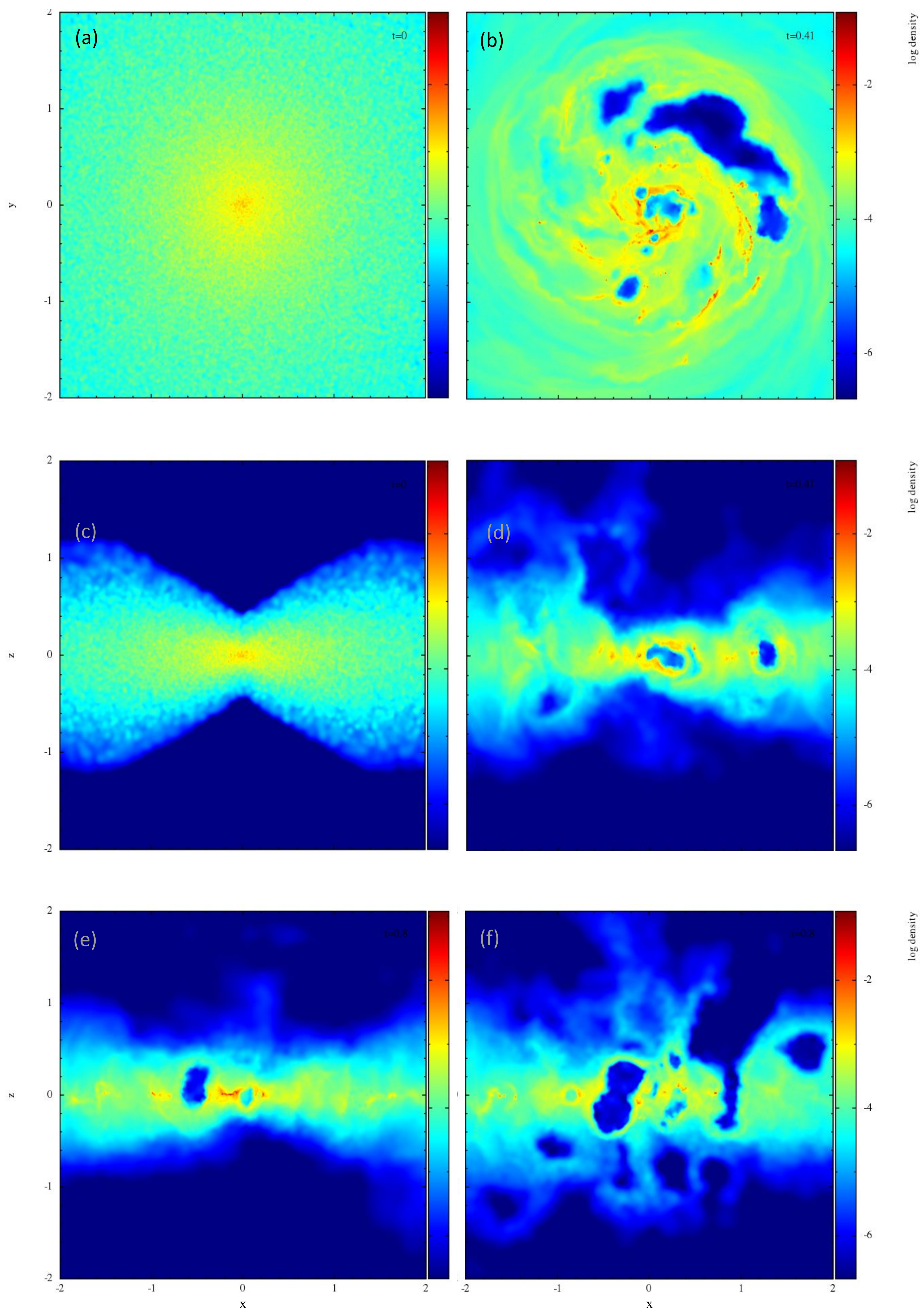


Figure 1: The gas behavior of one simulated galaxy. (a) and (c), respectively, show the face-on and edge on views of the galaxy at t = 0 Gyr, before the initial turbulence occurs. (b) and (d) show the face-on and edge on view of the galaxy at t = 0.41 Gyr. In (b) and (d), a supernova site can be seen, indicated by the round clearing of gas. In (d), the gas jutting out perpendicular to the plane of the galaxy can be seen, which become outflows. (e) is the same simulation after 0.8 Gyr, compared to (f), which is another simulation after the same amount of time, but with a lower diffusion coefficient.

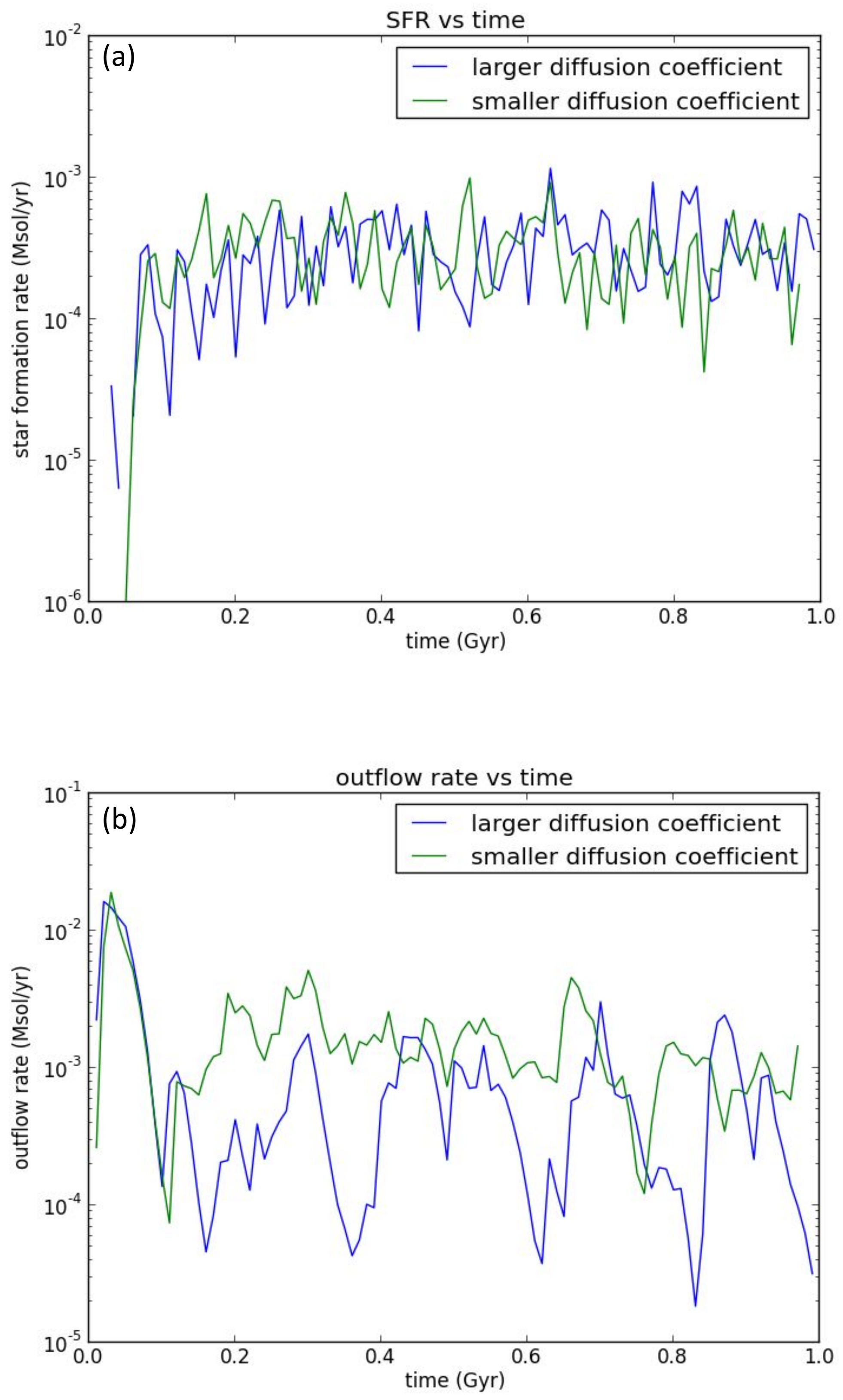


Figure 2: The star formation and outflow rate of both simulated galaxies. The larger diffusion coefficient is 1.0, whereas the smaller diffusion coefficient is 0.1.

Conclusions and Future Work

From this project, we learn the importance of implementing the correct amount of artificial conduction. This is just one aspect of a simulation, but knowing this will help future simulations be more accurate. Further work may follow a similar path – analyzing the effects of altering certain physical properties, such as cooling or gravity, will help us determine the accuracy of our simulations. As this work progresses, we will come closer to creating simulations that are accurate to nature, which will allow us to correctly study the behavior of outflows and ISM behavior in all types of galaxies.

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