National Aeronautics and Space Administration

Bridging the gap: observations and theory of star formation meet on large and small scales

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Program: Strategic Initiative

OBJECTIVES

The objective of this task is to provide a link between the results of numerical simulations of galactic evolution and observations of tracers of galactic interstellar medium and star formation over a large range of spatial scales. The following points summarize the goals of this task:

1) Incorporate a treatment of chemistry and radiative transfer into numerical simulations produced as part of the FIRE collaboration (Hopkins et al. 2014) to generate predicted intensities of several key tracers of the interstellar medium and star formation activity, such as [CII], [OI], [NII], HI, CO, and HI spectral lines, FIR/NIR/optical/UV continuum, and X-rays. The FIRE project has developed cosmological simulations of galaxy formation that directly resolve the interstellar medium of individual galaxies while capturing their cosmological environment, which will allow us to probe the observables in a wide range of representative galaxy types over the whole of cosmic history.

2) Compare the simulated observations with existing full maps of galaxies in different tracers of their interstellar gas and star formation rate to test these models, as well as to test the fidelity of observations in tracing a specific phase of the interstellar medium. In particular, we will focus on comparing simulated [CII] emission with observations of the galaxy M51 (nearby giant spiral galaxy with active star formation), which are currently being completed with the SOFIA telescope (Figure1; Pineda et al. 2019, in preparation).

3) Create a catalog of simulated galaxies over a wide range of physical conditions and different tracers that will be released as a data product in a public repository. This catalog can be used to design future surveys with the current and next generation of observatories such as the Origins Space Telescope (OST), which is being studied by NASA for consideration by the 2020 Decadal Survey, and SPICA, which is being studied by ESA and could have a JPL contribution.

APPROACH AND RESULTS

During FY19, Mr. Orr completed the requisites to obtain his PhD at Caltech based in part on the tasks in this initiative. He worked on adapting a non-equilibrium chemistry code, CHIMES, which produces equilibrium chemical abundances in resolved maps of the simulated FIRE galaxies and created a simulated galaxies database with the FIRE simulation. This database allowed us to probe the physics involved in producing the conditions that govern chemical equilibrium in the simulations on kiloparsec scales.

We advised Mathew Orr on how to test the incorporation of, and optimize, the chemistry and thermal balance in the simulations. We have found that including a proper treatment of the cooling for temperatures below 3000K (relevant for the neutral ISM) is imperative for an accurate forward modeling of the observables, and that an optimized compact chemistry is needed to minimize computational demands. While it does not affect the galaxies dynamically, the thermal balance does affect the structure of the phases of the ISM (ionized medium, cold neutral medium and warm neutral medium), which are where most of the observables originate.

Mathew Orr has developed a pipeline to generate preliminary simulated spectral cube of the [CII], CO, and H and H_2 masses (Figure 2). We advised him on the conversion of emission from simulated galaxies into a format that is usable for comparison with observations.

We also incorporated radiative transfer in the simulations so that the distribution of C^+ and CO can be converted into images of the observable [CII] fine structure and CO rotational transitions. We advised Mathew Orr on radiative transfer issues in the estimation of emission from simulated galaxies (e.g. considering the effects of overlapping clouds along the line of sight).

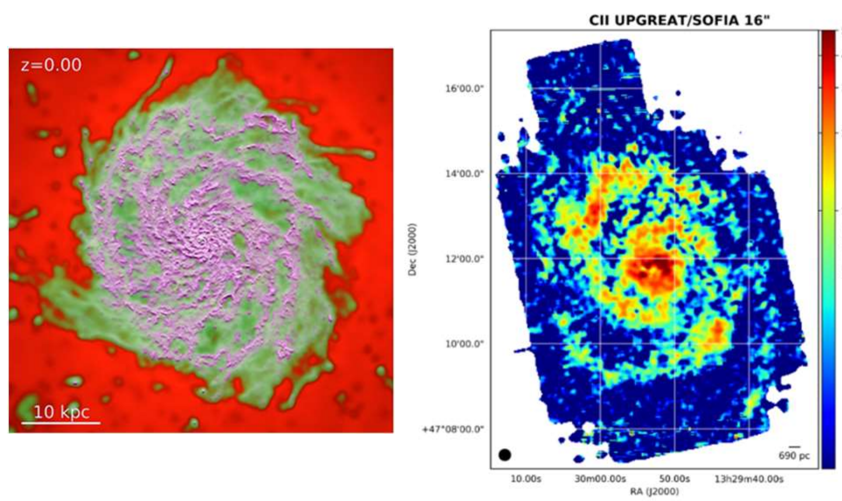

Figure 1: The combination of detailed numerical simulations of galaxies with state-of-the art observations has the potential to generate new insight in the field of galaxy evolution through cosmic time and to motivate specific technological and mission requirements. (left) We show a simulated galaxy generated as part of the FIRE simulations (Hopkins et. al 2014). These simulations are one of most detailed numerical simulations available studying physical processes over scales ranging from cosmological to that of individual, star forming, giant molecular clouds. Such theoretical results can be compared with new observations such as those shown in the right panel showing the first velocity-resolved image of the entire M51 galaxy in the [CII] 158μm line being observed using the SOFIA airborne observatory (Pineda et al. 2019).

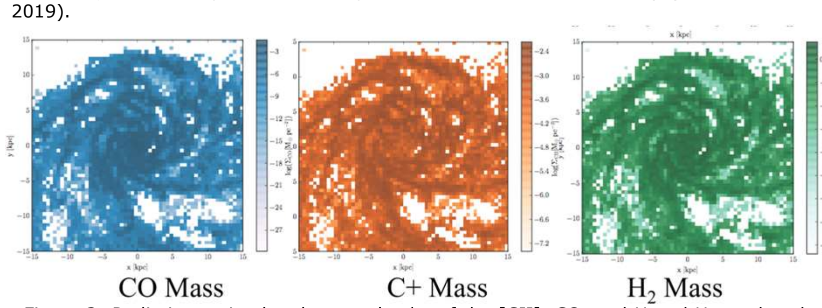

Figure 2: Preliminary simulated spectral cube of the [CII], CO, and H and H_2 produced using a pipeline developed in the first year of this task (Orr 2019 PhD Thesis). We are in the process of implementing radiative transfer calculations that will be used to convert these maps into images of the emission that can be compared with observations.

SIGNIFICANCE OF RESULTS

The capability to produce spectral line and continuum intensities from simulated galaxies will be of critical importance for future missions that will either be capable of mapping entire galaxies at high spatial resolution (e.g. OST, LUVOIR, SPICA), or interpreting the emission of galaxies on large scales. It will also help us to identify observations that will have the most impact, testing models of galaxy evolution and constraining the underlying physics of uncertain processes such as micro-scale plasma physics (e.g. the roles of dust and magnetic fields in astrochemistry or the details of how individual supernovae couple to the inter-stellar medium). These outputs will also be used to justify proposals and current and future missions.

This project has strengthened collaborative research between JPL and Caltech by combining expertise in theory and observations. Our team included a Caltech graduate student, Dr. Mathew Orr, and we had regular meetings at JPL and Caltech, thus ensuring regular communication between JPL and Caltech

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