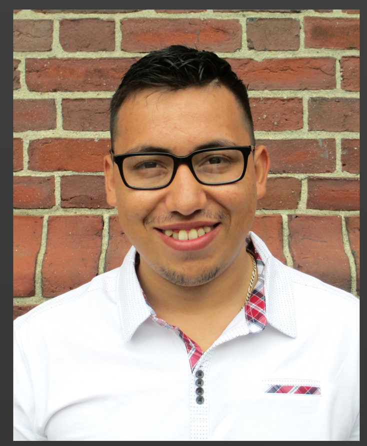

Kinematic Characteristics of Galaxy Mergers in FIRE

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Introduction

Galaxy mergers are believed to play a fundamental role in triggering starbursts (Sanders & Mirabel 1996) and active galactic nuclei (Canalizo & Stockton 2000). To study these processes, hydrodynamic numerical simulations have been employed for many years (Barnes & Hernquist 1996, Moreno et al. 2015). However, due to lack of sufficiently large observational samples, galaxy kinematics have not been utilized in depth in our understanding of mergers. In this work we use the "Feedback in Realistic Environments" (FIRE) model (Hopkins et al. 2014) to simulate merging galaxies and investigate their kinematic structure (Figure 1).

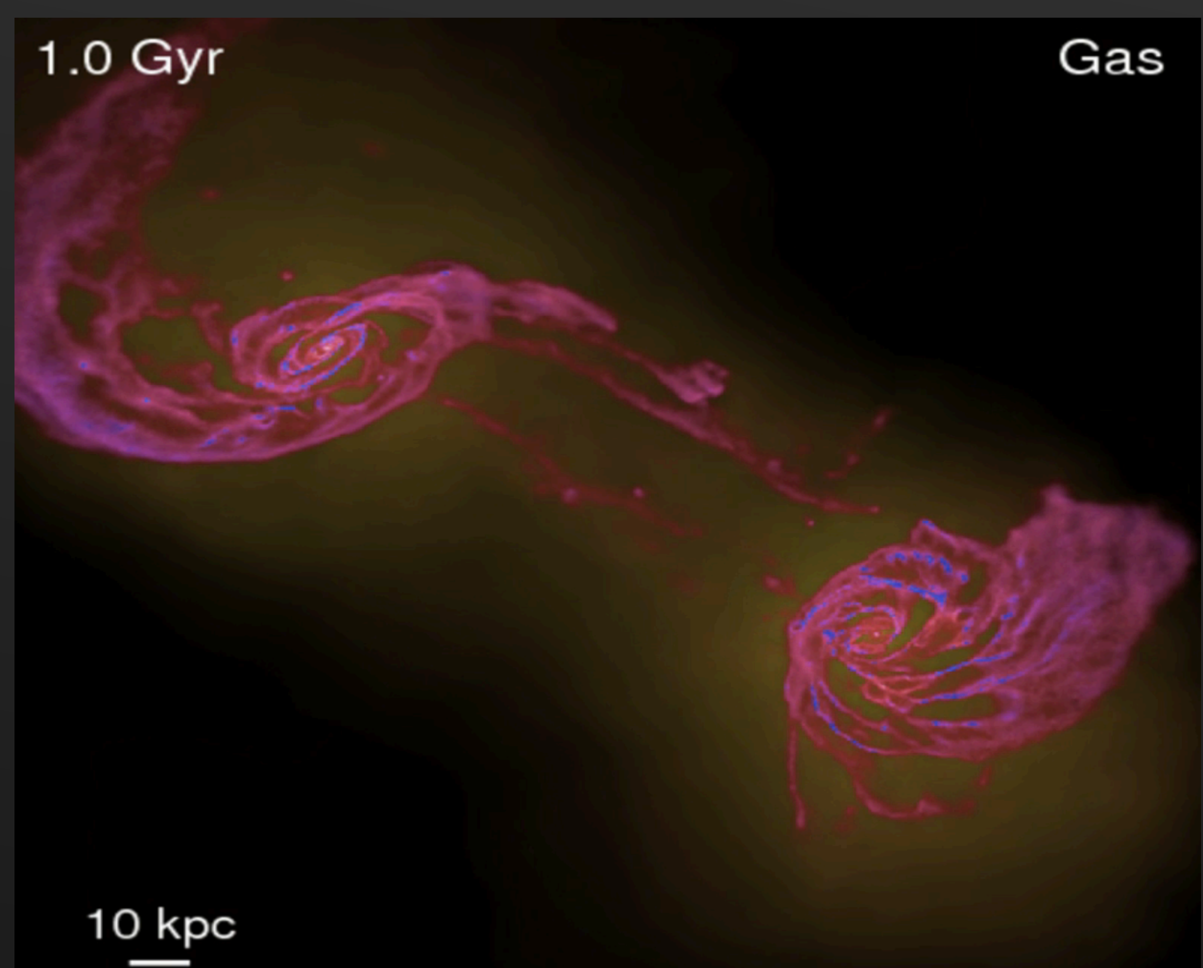

Figure 1. Multiphase gas structure in a galaxy merger simulated with the FIRE model. Yellow, magenta and blue colors indicate hot, warm-ionized and cold-molecular gas.

The central goal of this project is to construct the first framework for extracting kinematic information from galaxy merger simulations.

Observational Motivation

With the advent of Integral Field Spectroscopic (IFS) Surveys, we can now analyze kinematic maps for large galaxy samples. The first such sample was created using the Calar Alto Legacy Integral Field Area (CALIFA) survey (Barrera-Ballesteros et al., 2015), which includes 103 interacting galaxies. Figure 2 shows two galaxy pairs from this survey (left hand panels). For the galaxies enclosed in hexagons, stellar density (central panels) and kinematic maps (right hand panels) are included.

These authors report the following interesting finding: for a given interacting galaxy, a significant misalignment is seen between the visual semi-major axis (white segments) and its projected kinematic axis (black segments). This misalignment is not found in galaxies in isolation.

Our galaxy-kinematics framework will be ideal to understand the image/kinematic misalignment seen in observed galaxy mergers.

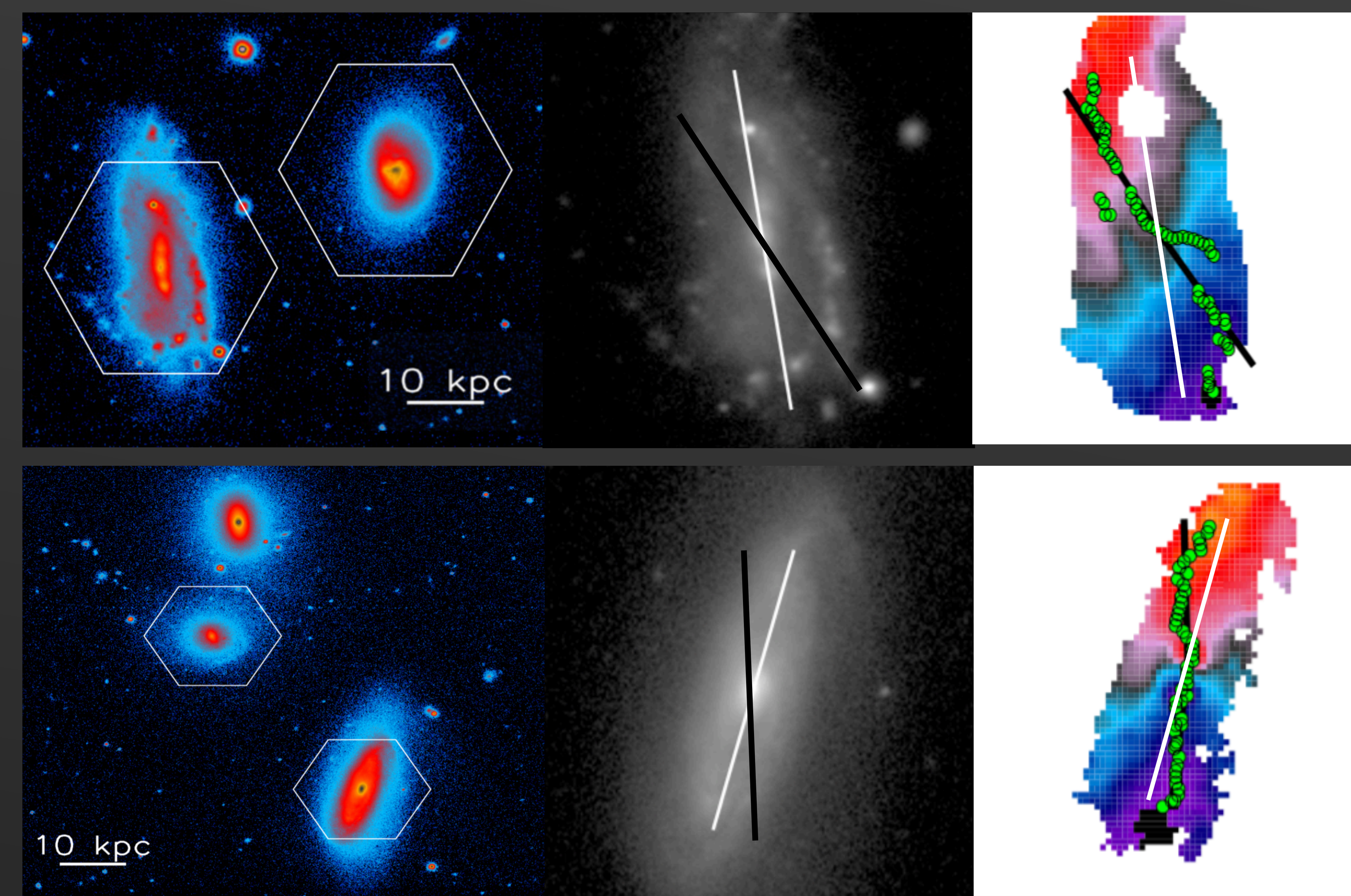

Figure 2. Image/kinematic misalignments. ***Left Panels:*** Interacting galaxies selected from the Sloan Digital Sky Survey (http://www.sdss.org). Hexagons correspond to CALIFA's field of view. ***Center Panels:*** Stellar images in the r-band. Best-fitted semi-major axes indicated by white segments. ***Right Panels:*** Line-of-sight velocity maps. Best-fitted projected rotational accesses indicated by black segments.

Results: Kinematic Maps

We employ the FIRE model to simulate galaxy mergers. Unlike older models, FIRE resolves the formation of Giant Molecular Clouds. Explicit treatment of feedback processes – including radiation pressure, stellar winds, photoionization and supernovae explosions – regulate star formation. It employs GIZMO, a modern mesh-free hydro solver (Hopkins 2015).

We constructed modules to map and analyze the internal structure of galaxies in galaxy merger simulations with FIRE (Figure 3).

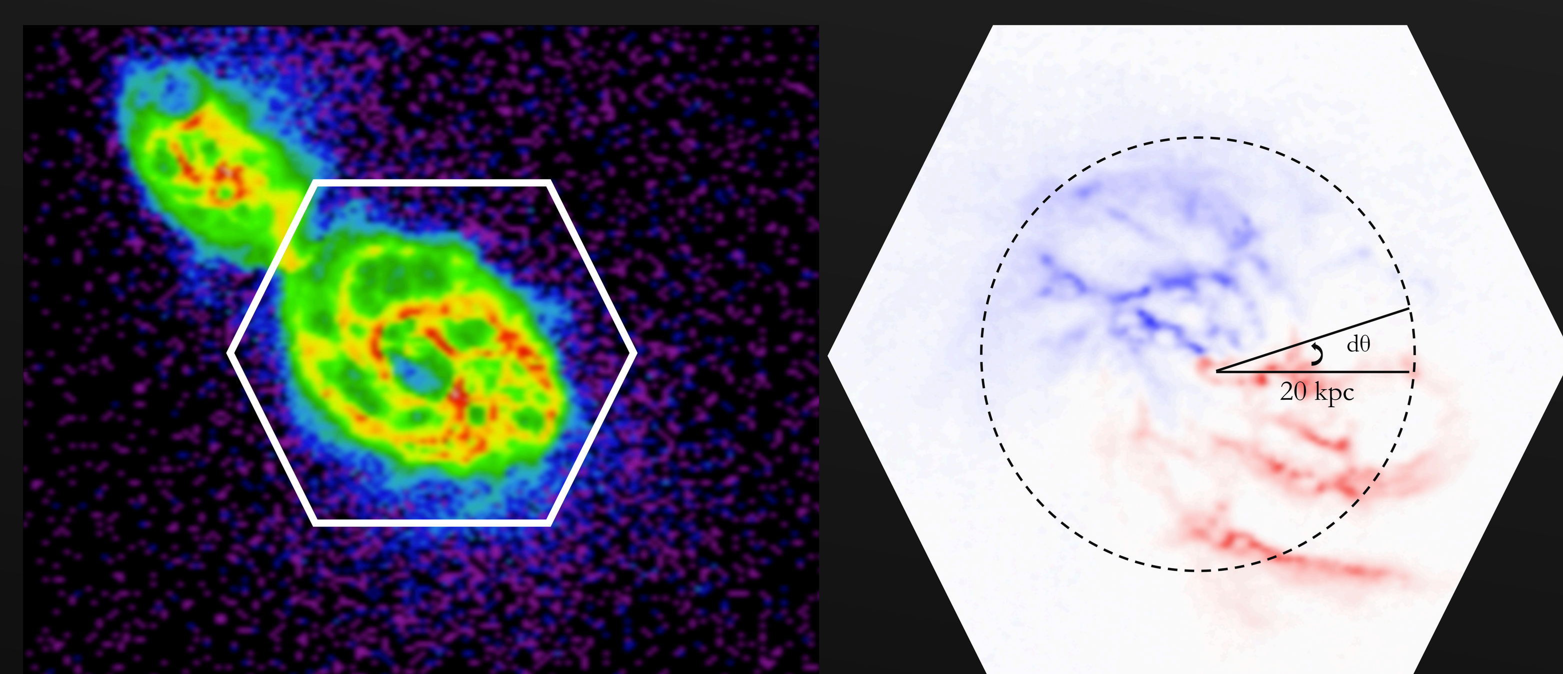

Figure 3. Mapping simulated merging galaxies. ***Left Panel:*** Gas surface density for two FIRE interacting galaxies. White hexagon encloses target galaxy of interest. ***Right Panel:*** Gas Kinematic map for target galaxy. Blue and red pixels correspond to blueshifted and redshifted gas parcels. Circle of 20-kpc radius is used to calculate angular profiles and the kinematic axis of rotation (Figure 4).

Results: Angular Profiles

Our framework allows us to construct angular profiles. Figure 4 shows an example of this for one of our mergers. Profiles are expected to vary as a function of time and orientation. The angle at which the profile equals zero corresponds to the kinematic axis of rotation.

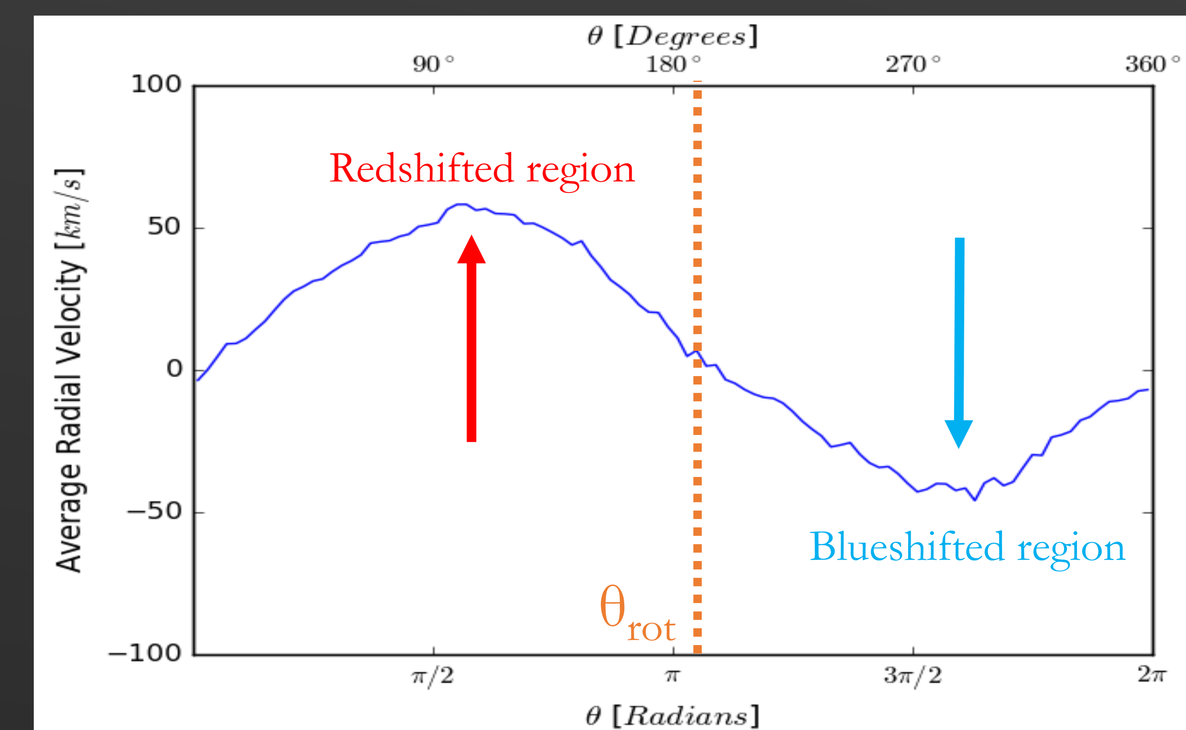

Figure 4. Angular profile: average line-of-sight velocity per unit angle (blue curve) for gas parcels in a simulated galaxy merger. Arrows indicate blue(red)-shifted portions of the target galaxy. Orange vertical dotted line denotes the rotational axis.

Angular profiles allow us to the determine the kinematic axis of rotation in our galaxy merger simulations.

Future Work

With this kinematic framework, we plan to take the following steps:

- Determine the behavior of the kinematic axis for various time snapshots, orientations, and orbital merger configurations.
- Create synthetic images and determine their visual semi-major axes.
- Investigate if simulations are consistent with CALIFA observations: if visual and kinematic axes misalign in interacting galaxies.
- Expand our modules for studies employing higher-order kinematic statistics, as in Bloom et al. (2017) with the SAMI survey.

FINAL GOAL: To use galaxy merger simulations to investigate what causes the misalignment of visual and kinematic axes in interacting galaxies, as observed by the CALIFA survey.

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