Star Formation Rate Indicators in FIRE Galaxy Formation Simulations

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Introduction

Theoretical models of galaxy formation over the past years enabled a better understanding of current large scale galaxy surveys. Instruments like the Galaxy Evolution Explorer (GALEX), the Spitzer Space Telescope, Herschel Observatory, and the Hubble Space Telescope allow astronomers to gather more information about the star formation rates (SFRs) of galaxies (Kennicutt & Evans 2012). With simple assumptions about the star formation histories (SFHs) of galaxies, SFR indicators have been calibrated with the goal to identify newly formed stars (Calzetti+2013). Recent simulations show that some of these assumptions may not be well motivated -- specifically that star formation can be more time variable (burstier) than previously thought.

The central goal of this project is to use the self-consistent SFHs realized in the FIRE simulation to quantify differences between observationally-inferred SFRs. We use different indicators and true SFRs, as a function of galaxy mass and redshift to also predict time scales that specific SFR indicators are averaged over .

Star Formation Rate Indicators

The SFR indicators we are interested are Far Ultra Violet (FUV) and Recombination lines, (Hα). Hα emissions are exclusive to hot massive stars and trace stars formed in the past 10 Myr. FUV light probes older and less massive stellar populations formed over the past 100 Myr , see Figure 1. We calculate SFRs via Hα and FUV in order to mimic observations.

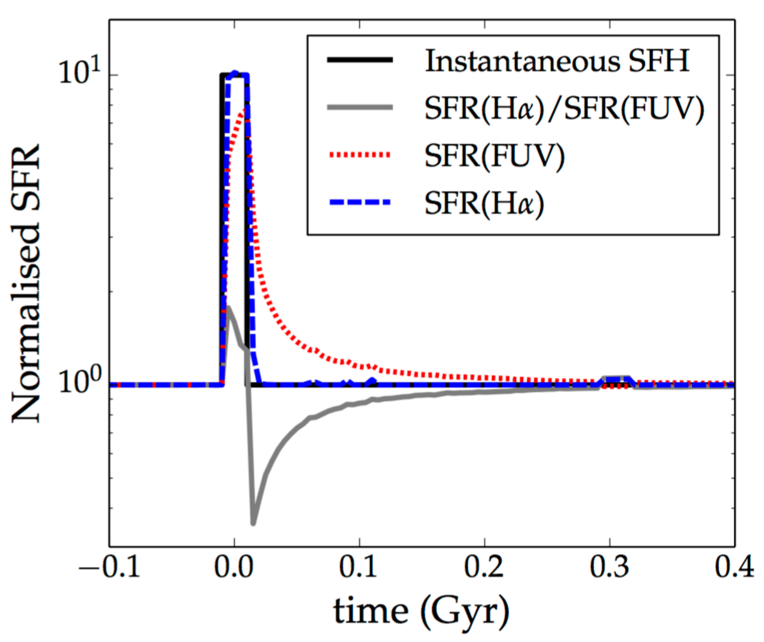

Figure 1. *The solid black line is the normalized SFH of a 20 Myr burst, the dotted red line is the response of the FUV indicator and the dotted blue line is the response of the Hα indicator. The solid grey line is the ratio of the SFR derived by the indicators which is sensitive to the galaxy's bursty SFH (Sparre+2017).*

***SFR(FUV)* is calculated using a GALEX-FUV filter on the stellar continuum flux calculations. The *SFR(Hα)* indicator is assumed to be proportional to the flux of ionizing photons.**

FIRE

The Feedback In Realistic Environments (FIRE) simulations are cosmological simulations of galaxy formation that explore the role of stellar feedback. The FIRE simulation resolved the formation of giant molecular clouds. Explicit treatment of feedback processes – including radiation pressure, stellar winds, photoionization and supernovae explosions – regulate star formation. It also employed GIZMO, a modern mesh-free hydro solver (Hopkins+2014).

In this work we employ FIRE-2 (Hopkins+2017), an updated numerical implementation of FIRE-1 physics for the GIZMO code.

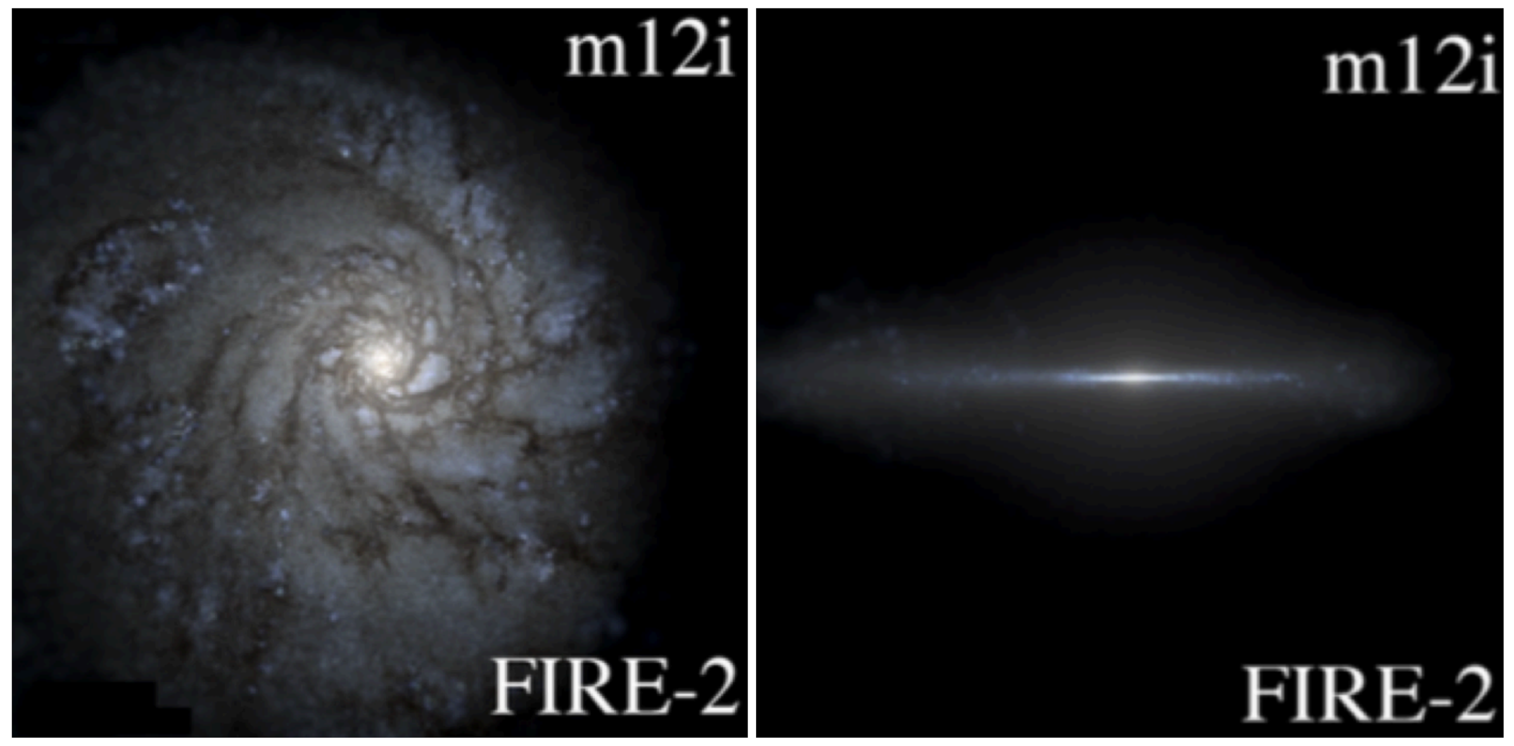

Figure 2. *Stellar light attenuated by dust in simulated Milky Way Mass-Like Galaxy known as m12i.* ***Left:*** *Face-on projection,* ***Right:*** *Edge-on projection.*

Bursty Star Formation Histories

Observations as well as galaxy formation simulation reveal that star formation occurs in burst. The FIRE simulations predicts that the SFR of galaxies tend to be bursty at higher redshifts (Muratov+2015, FG-2017). Observations like: Shivaei+2015, Guo+2016, and Shimakawa+2017 also suggest bursty star formation. Our project is motivated by the common assumption made when calibrating SFR indicators. It is assumed that the SFR of galaxies remains constant for a period of time which as shown in recent observations and simulations that may not be the case.

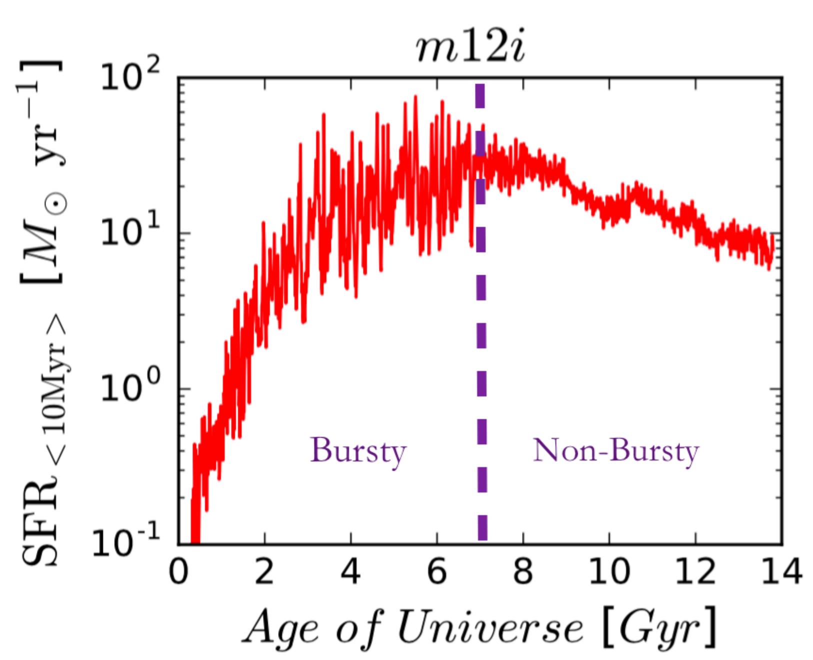

Figure 3. *10 Myr boxcar average SFH of the Milky Way mass-like galaxy -- m12i. We define the bursty SFH of m12i to be at z ≳ 0.7 and the non-bursty regime at z ≲ 0.7.*

We calculate the SFRs derived by *FUV* light *and Hα* emissions in the bursty and non-bursty regimes (Figure 3) and compare to the true SFRs in the simulation, see Figure 4.

Results

We average the true SFR of our simulated galaxy over different time scales in order to match the physics of what the observational indicator is doing, see Figure 4. The scatter in these plots will decrease at an average time scale that most accurately resembles what the indicator is doing. To determine the scatter we determine a best fit line through our SFR data set and calculate the root mean square (RMS) relative error. In Figure 5 we analyze the scatter at the different averaged time scales for the Hα and FUV indicators.

In plots like Figure 4 we are interested in their scatter. A plot with the least scatter implies that our averaged time scale most accurately resembles the observational indicator.

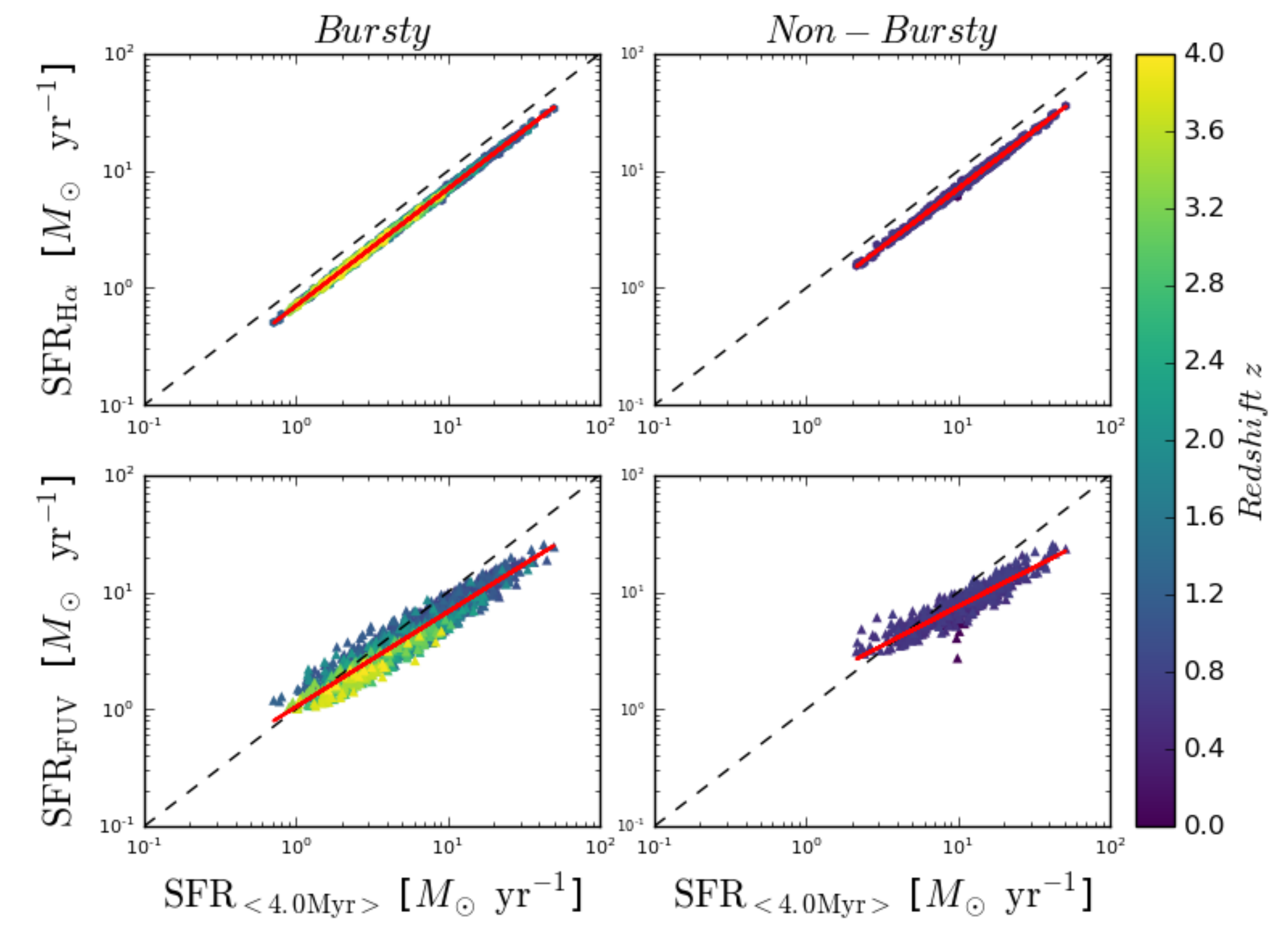

Figure 4. *These scatter plots are for the m12i simulation. Each point was generated by binning the ages of the stars in the simulation. SFR(Hα) (1st row), SFR(FUV) (2nd row) vs $SFR_{<4Myr>}$ are separated in Bursty (left) and Non-Bursty (right) regimes. The black dashed line is a one-to-one line and the solid red line is a best fit line between SFR derived by the indicators and the true SFR in our simulation.*

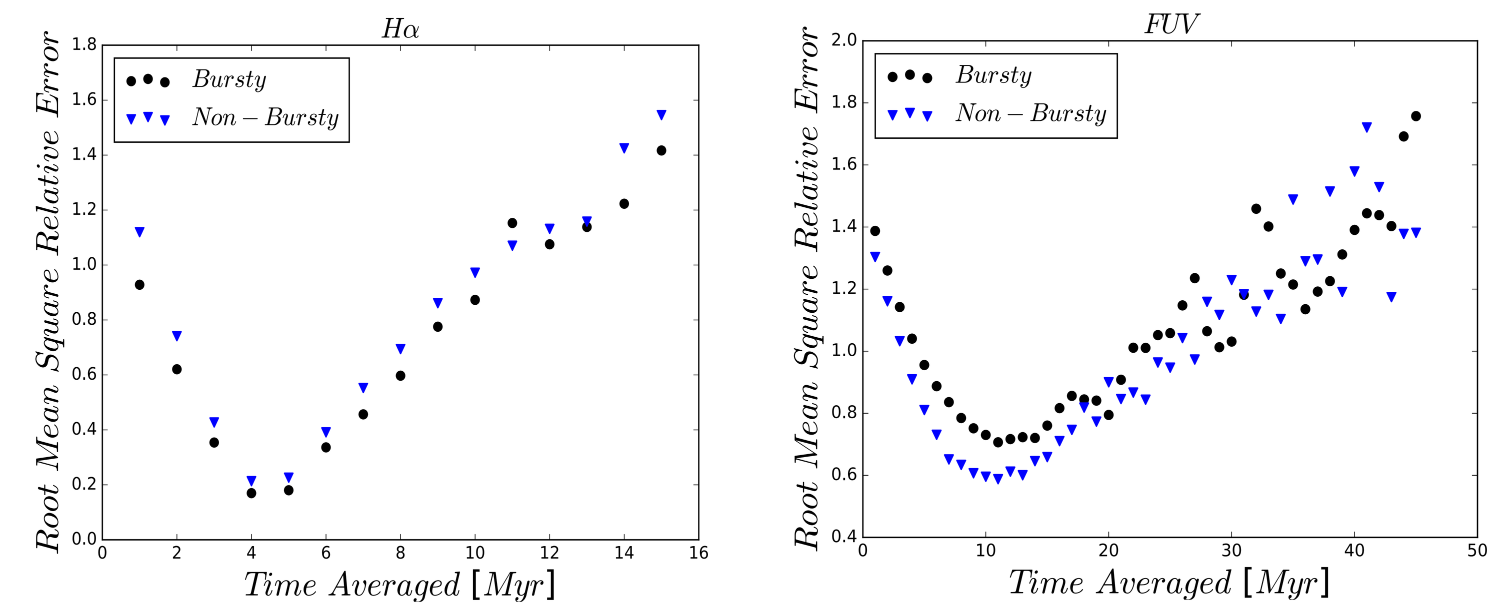

Figure 5. *RMS Relative Error (R.E.) vs Time Averaged: black circles correspond to RMS R.E in the bursty regime and blue triangles correspond to the RMS R.E. in the non-bursty regime.*

We analyze the RMS relative errors of scatter for the *Hα* and *FUV* indicators and find that the best-fit timescales derived by these indicators do not depend significantly on whether the SFR is bursty. Best-fitting timescales of about 4 Myr for *Hα* and about 10 Myr for *FUV* in both the time-steady and bursty regimes.

Future Work

- Investigate how different indicators depend on different mass galaxies and what timescales do they probe.

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