THE POPULATIONS OF STAR FORMING AND QUIESCENT GALAXIES IN LARGE-SCALE COSMOLOGICAL SIMULATIONS

TJITSKE STARKENBURG
POSTDOCTORAL FELLOW
CIERA, NORTHWESTERN UNIVERSITY

AND THE IQ-COLLABORATORY
Observationally, a dichotomy in galaxy colors, structure, environment, and other properties is observed to correlate with the presence or absence of star formation.

Theoretically, galaxies that decrease or stop star formation can be studied in detail, as well as their environment.

We need apples-to-apples comparisons
Observationally, a dichotomy in galaxy colors, structure, environment, and other properties is observed to correlate with the presence or absence of star formation.

But there are many different observational tracers used, at high/low mass galaxies, green valley/“really” quiescent populations, high/low redshift.

Theoretically, galaxies that decrease or stop star formation can be studied in detail, as well as their environment.

Different simulations with different underlying models, can produce “different” quiescent populations and quenching pathways.

We need apples-to-apples comparisons.
the Isolated and Quiescent galaxies (IQ) - Collaboratory*

Simulators (sort-of): Tjitske Starkenburg (PI; Northwestern), Shy Genel (CCA), Chris Hayward (CCA), Rachel Somerville (CCA), Ariyeh Maller (CUNY), Ena Choi (KIAS), Romeel Davé (ROE), Alyson Brooks (Rutgers), Mika Rafieferantsoa (UWC), Andrew Emerick (Carnegie), Daniel Angles-Alcazar (CCA/UConn), Greg Bryan (Columbia), Stephanie Tonnesen (CCA), Anna Wright (Rutgers)

Observers (sort-of): Chang Hoon Hahn (Princeton), Jeremy Tinker (NYU), John Moustakas (Sienna), Viraj Pandya (UCSC), Claire Dickey (Yale), Marla Geha (Yale), Kartheik Iyer (Dunlap), Nityasri Mandyam (NYU), Mary Putman (Columbia)

*Yes, it is a real word
the Isolated and Quiescent galaxies (IQ) - Collaboratory*


Simulations: Illustris (Vogelsberger+2014; Genel+2014), EAGLE (Schaye+2015; Crain+2015), MUFASA (Dave+2016), Santa Cruz semi-analytical model (Somerville+2015), TNG100 (Pillepich+2018; Weinberger+2018), SIMBA (Dave+2019)

iqcollaboratory.github.io

*Yes, it is a real word
THE POPULATIONS OF STAR FORMING AND QUENCHED GALAXIES

A LOOK AT DIFFERENT SIMULATIONS: THE STAR FORMATION SEQUENCE

Very similar slope across all simulations, but also a factor of 5 (0.7 dex) discrepancy over the whole stellar mass range. This seems in some tension with earlier results (Genel+2014, Somerville & Dave 2014, Furlong+2015, Sparre+2015, Schaye+2015, Dave+2016, Bluck+2016, …).

Most of the discrepancy is purely due to using one and the same definition across all simulations.
A LOOK AT DIFFERENT SIMULATIONS: THE HIGH-\(z\) STAR FORMATION SEQUENCE

Very good agreement between simulations in particular at higher redshift, with overall good agreement with CANDELS data (Iyer+2018, 2019)

Choi, TKS & the IQ-collaboratory in prep.
A LOOK AT DIFFERENT SIMULATIONS: THE HIGH-Z STAR FORMATION SEQUENCE

Very good agreement between simulations in particular at higher redshift, with overall good agreement with CANDELS data (Iyer+2018,2019)

Quiescent fractions based on distance from the star-forming sequence are quite different, and show different trends with stellar mass and with redshift

Choi, TKS & the IQ-collaboratory in prep.
comparing the simulations to observation without forward modeling the measurements is not an apples-to-apples comparison.

Build Synthetic Galaxy Spectra and Photometry

- **FSPS**: Flexible Stellar Population Synthesis (Conroy+09, Conroy&Gunn2010, Conroy+2014)
- Use identical input from all simulations, and consistent assumptions
- Include noise and limits consistent with observational surveys to compare to
- Remeasure colors and spectral indices and compare one-to-one to observations
Dust is crucial but very challenging. 
(Jonsson+2006, Rocha+2008, Baes+2011, 
Natale+2015, Hayward+2015, Hou+2017, 
Rodrigues-Gomez+2019, Nelson+2019, 
Trayford+2020, Salim+2020, 
Narayanan+2020, Baes+2020, and more)

We use color-magnitude diagrams to infer an empirical dust model, and then can learn the required dust-gas-metallicity relations required in the simulations by the inferred model.

Hahn, TKS & the IQ-collaboratory in prep.
Dust is crucial but very challenging.

We use color-magnitude diagrams to infer an empirical dust model, and then can learn the required dust-gas-metallicity relations required in the simulations by the inferred model.

Hahn, TKS & the IQ-collaboratory in prep.
We build full synthetic SDSS spectra, including finite signal-to-noise, incompleteness, and limited position and velocity information.

We follow Geha+2012 in selecting low-mass quiescent galaxies based on Dn4000 and HaEW, and compare.
We follow Geha+2012 (black) in selecting low-mass quiescent galaxies based on Dn4000 and HaEW, and compare.

All simulations have too many low-mass quiescent galaxies, but in varying numbers. Resolution effects are important, but appear not to be the full story.

See also Trayford+2015,2017; Donnari+2019, 2020a,b
Now we have this amazing space to explore:

Multi-dimensional in tracers, in theoretical models, in galaxies masses and other properties, in dust models, .....

TKS & the IQ-collaboratory in prep.
**CONCLUSIONS**

- The **IQ (Isolated and Quiescent galaxies) collaboratory** aims to better understand and constrain the quenching processes. However, we first need to do *apples-to-apples* comparisons between simulations and observations and define quiescence consistently.

- At $z=0$ the **star-forming sequence** is comparable between simulations but shows a factor 5 discrepancy in normalization (*Hahn*+2019). At higher redshifts the star-forming sequence in simulations seems to agree much better, and agree with observations. **Quiescent fractions** however, are diverse (*Choi*+in prep.).

- We build **synthetic galaxy spectra** to compare “observations” for all galaxies, and remeasure spectral indices, lines, bands, and derived parameters. **Dust modeling is crucial** and different dust models can change results for different simulations (*Starkenburg*+in prep.). We are inferring a **dust empirical model** (*Hahn*+in prep.).

- When fully forward modeling the SDSS spectroscopic survey, **low-mass galaxy quiescent fractions** in simulations tend to be higher than observed (*Geha*+2012). Differences between simulations may be connected to diverse star formation histories (*Dickey*+in prep.).