Growing a Galaxy:

Exploring Merger and Accretion History with Galactic Archaeology

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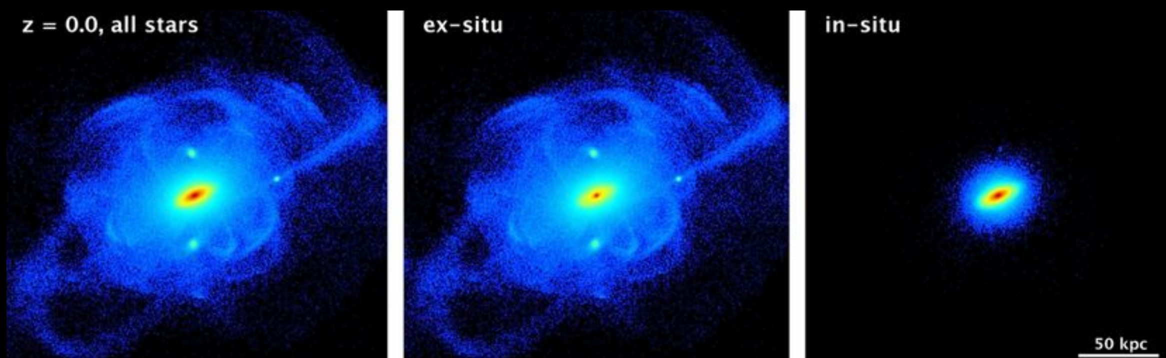
Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration.

Galaxies are ancient structures in space. The oldest known galaxies were born only 400 million years after the Big Bang (*Oesch, et al. 2016*). But all change drastically throughout their lifetimes.

One major contributor to galaxy growth is mergers. This can come in the form of minor mergers, causing little to no disruption; or major mergers, causing huge disruption (see image right, antennae galaxies undergoing major merger).

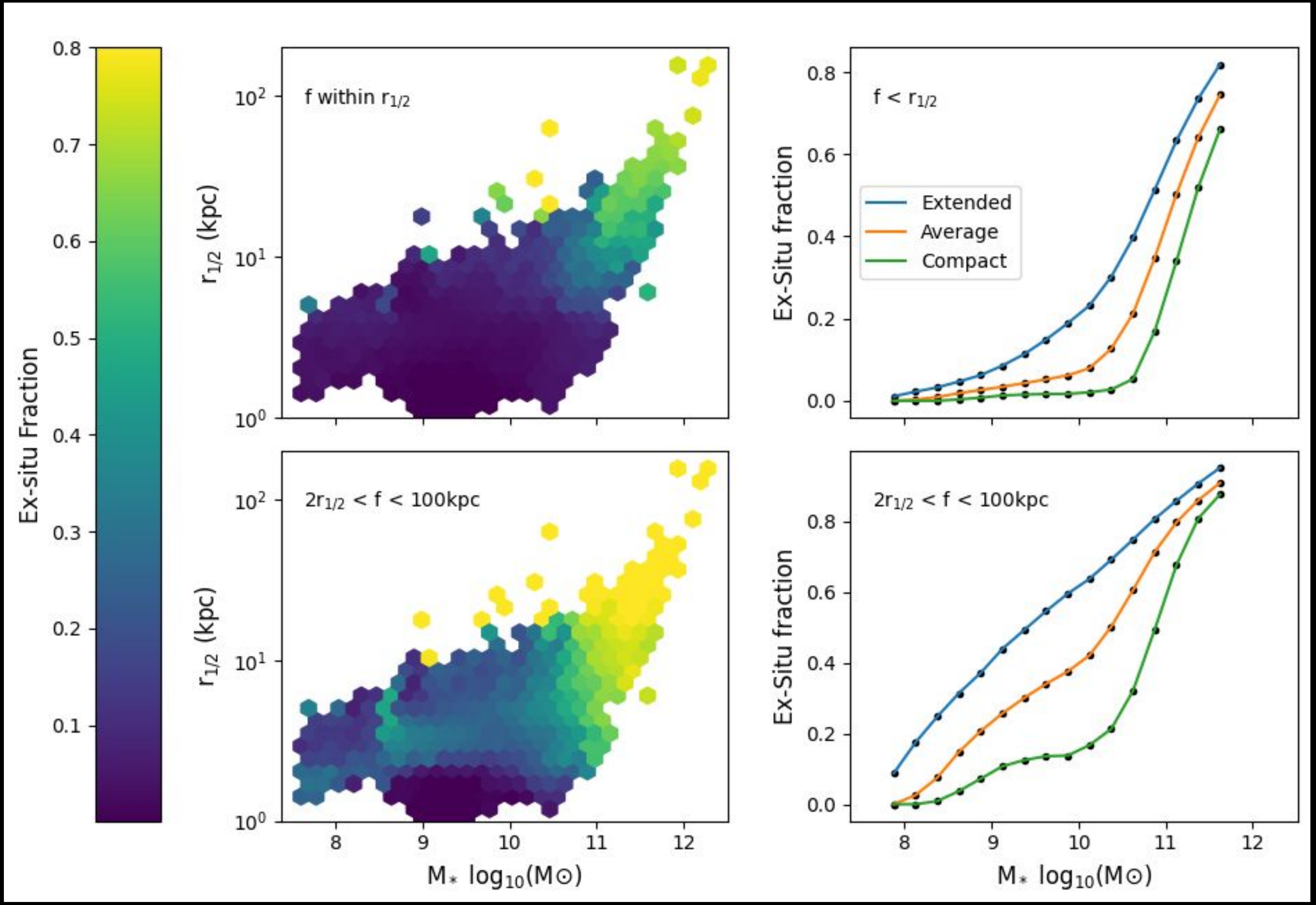


A. Pillepich et al, 2015

Both simulations of galaxy formation, and observational techniques have suggested an ‘inside out’ method of galaxy growth. This occurs where galaxies are initially formed of only their own stars (in-situ stars), but soon gain the majority of new stars though mergers (ex-situ stars).

Simulated Galaxy Growth

Simulations show that galaxies experience many mergers throughout their lifetimes (*Rodriguez-Gomez et al. 2016*). As shown in *Davison et al, 2020*, large galaxies in the EAGLE simulation are composed mostly of ex-situ stars. Remarkably, the largest galaxies studied ($M_\star > 1\times10^{12}$ $M_\odot$) contained 90% ex-situ stars.



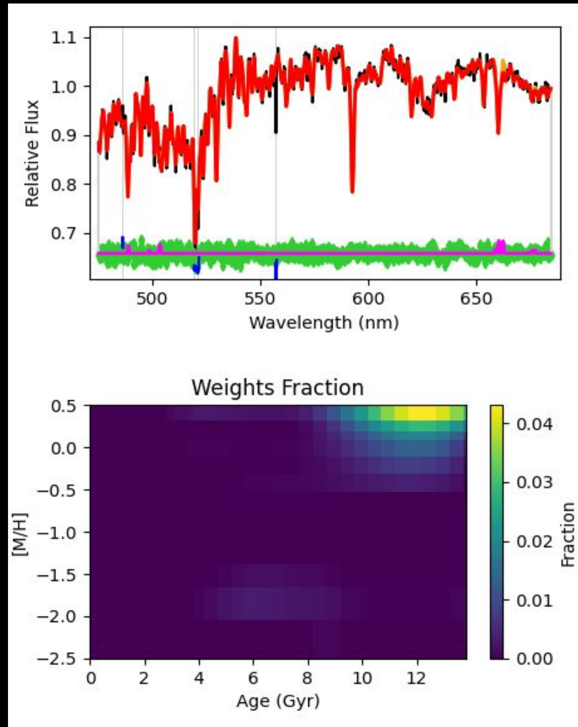
As shown in the Figure, the ex-situ fraction of galaxies depends not only on galaxy mass, but also on galaxy radius. We also see that extended galaxies show higher ex-situ fractions than their lower mass counterparts at fixed mass.

The top two panels of the Figure show only the inner regions of the galaxies (less than the half mass radius, $r_{1/2}$). When we compare this to the lower two panels which show the outer regions of the galaxies ($>2r_{1/2}$), we see there are far more ex-situ stars on the outskirts of the galaxies. This is indicative of mergers depositing material on the outer regions of galaxies, increasing their radius, and increasing the overall ex-situ fraction.

Observational Techniques

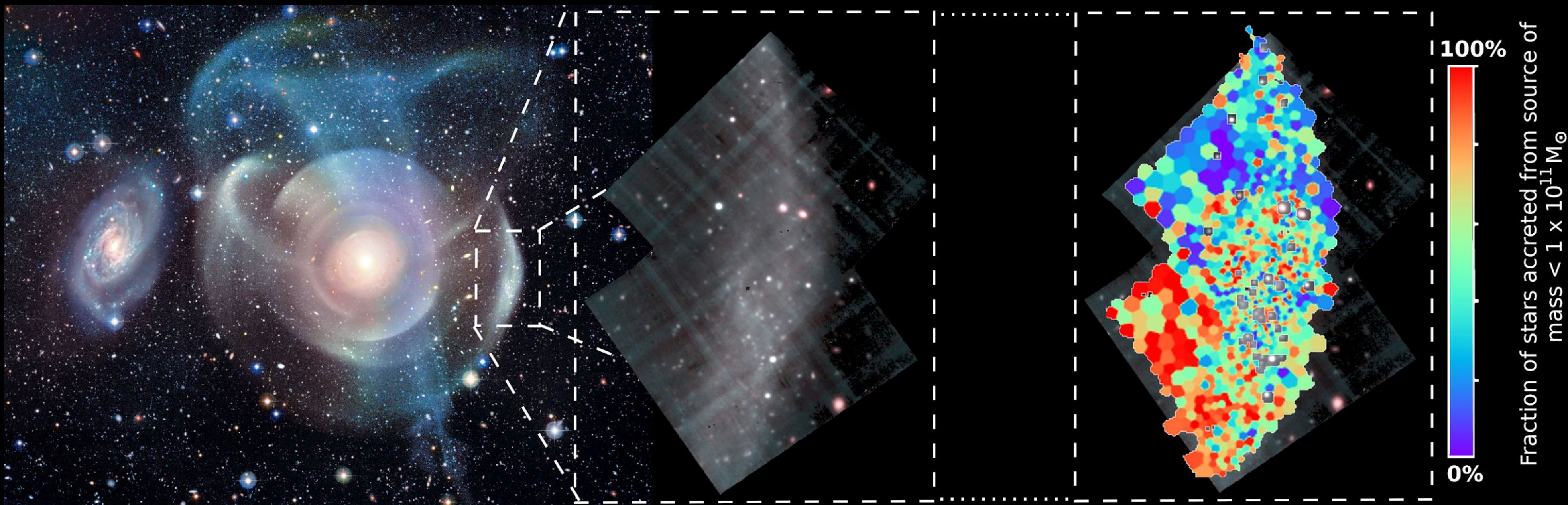
In observational astronomy, unlike in simulated instances, we must extract the histories of galaxies using only the information contained within their current structure and light.

By using full spectral fitting we can begin exploring the histories of galaxies. Contained within the spectrum of every galaxy is the combined light of all the emission, from stars, gas and active galactic nuclei. We can use software such as ppxf (*Cappellari 2017*) to calculate the combinations of different types of stars necessary to reproduce a galaxy spectrum.



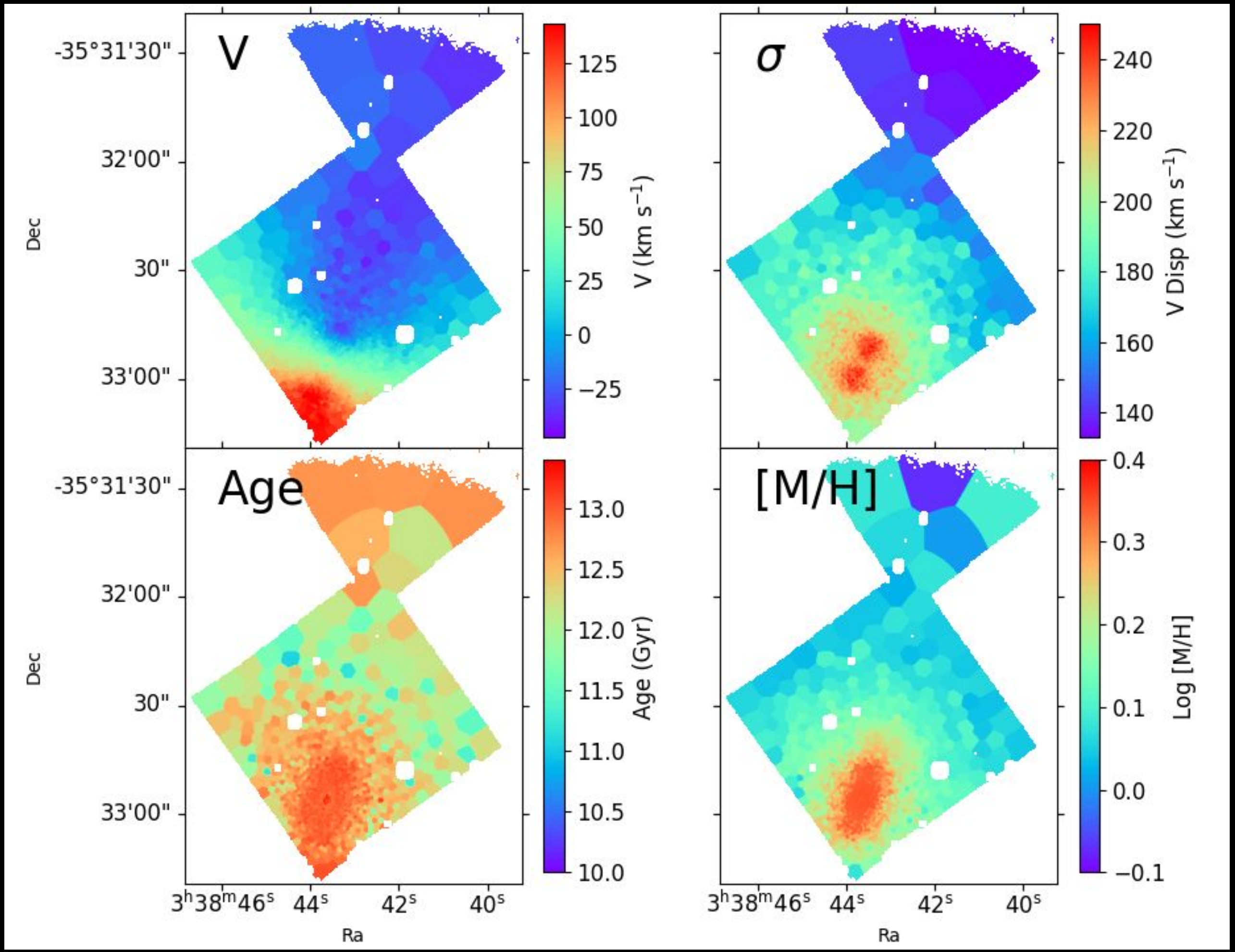
Galaxies follow well understood rules on the increase in metal content according to time and galaxy mass. As such, we can measure the amount of stars which are not following the expected relation. Any such stars are designated as ‘ex-situ’.

As in the Figure below, we can build spatial maps which show areas with high fractions of ex-situ stars, and areas where the stars are largely in-situ



MUSE observations

We have begun to apply our technique of full spectral fitting and ex-situ fraction identification to MUSE data cubes. The MUSE (Multi Unit Spectroscopic Explorer) is an Integral Field Unit Spectrograph, and provides spectral data across large spatial regions, at high resolutions. This means it is ideal for studying spectroscopically derived properties, such as ex-situ fraction. Some properties are shown below for NGC 1404.



As seen in the plot below, we are able to pull features from the spectrum via full spectral fitting, and examine these properties spatially. We are using these data to find trends in ex-situ fraction for a sample of galaxies.

Once the method has been refined, the next task will be to extend the analysis to a large number of galaxies. We expect to sample widely across the galaxy mass size plane, granting us insights into trends with galaxy mass and size. Further investigation will explore trends with galactocentric radius. Work is ongoing.

Cappellari, M. MNRAS 466.1 (2017): 798-811

Davison, T., et al. "An EAGLE's view of ex situ galaxy growth." MNRAS 497.1 (2020): 81-93

Oesch, P. A., et al. ApJ, 819.2 (2016): 129

Pillepich, A., Madau, P., and Mayer, L., ApJ 799.2 (2015): 184

Rodriguez-Gomez, V., et al. MNRAS, 458.3 (2016): 2371-2390