Relating Morphological Asymmetry and Large-scale Environment to Star formation and Gas Accretion in Galaxies

Hassen Yesuf (Kavli IPMU/KIAA)

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Why do galaxies have different star formation rate?

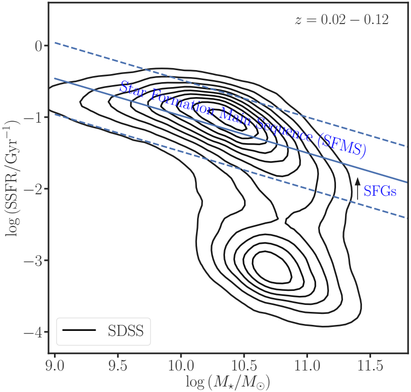
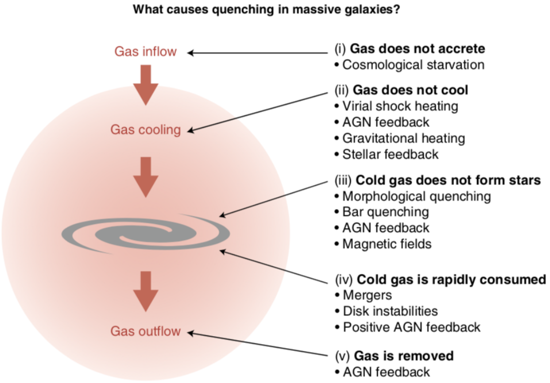


Figure: Stellar mass and SSFR of SDSS galaxies at redshift $z = 0.02 - 0.12$.

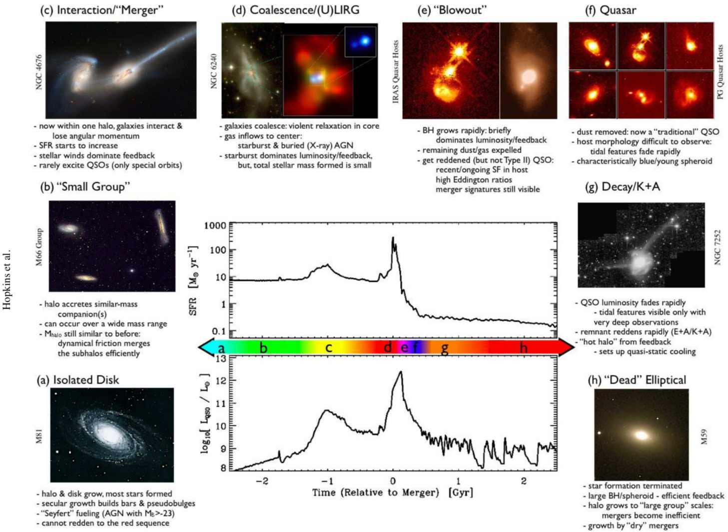
Gas is fundamental and processes that regulate gas affect star formation



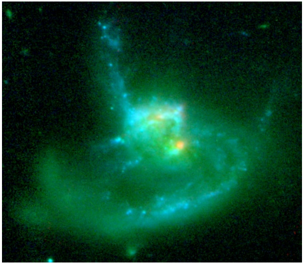
Schematic diagram listing the plausible quenching mechanisms.

Figure: From Man & Belli NatA 2018

Galaxy merger-driven evolution of galaxies



What are starbursts (SB) ?



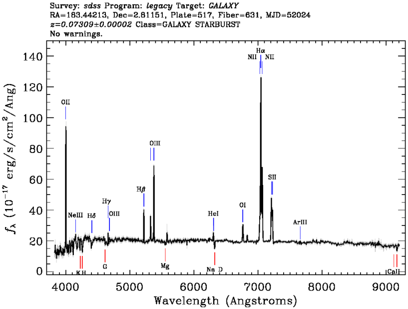
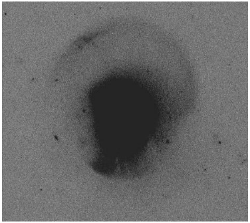
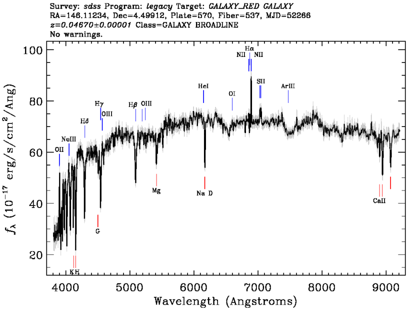


Figure: **Left:** HST B,I,H composite image **Right:** SDSS spectra

What are (quenched) post-starbursts (QPSB) ?

- Weak O II Hα emission: low ongoing star formation rates
- Strong Balmer absorption (Hδ, Hγ,Hβ): high recent star formation





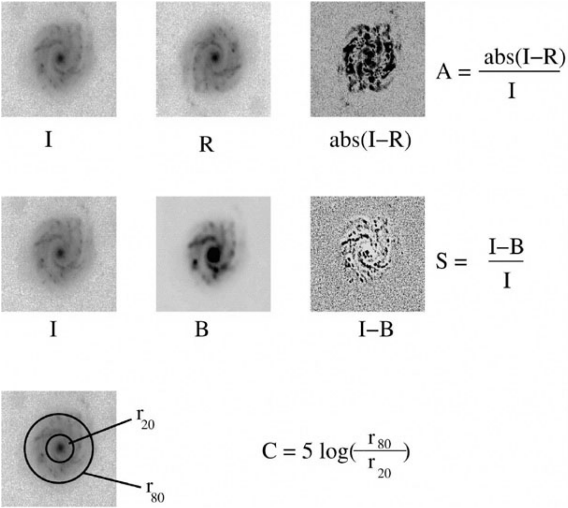
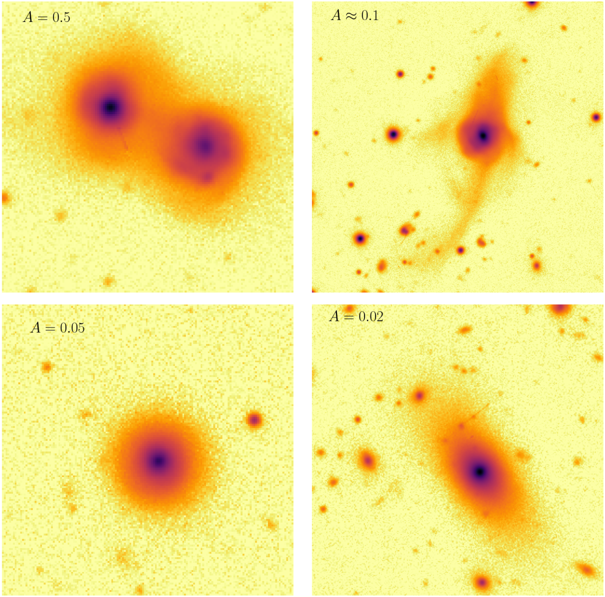
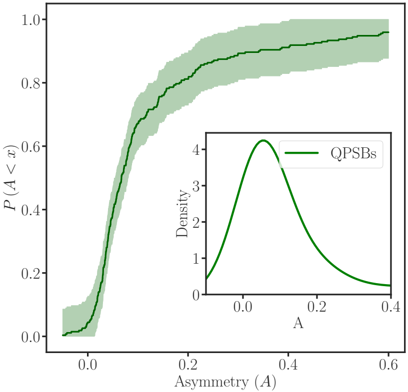


Figure: A graphical representation of how the concentration (C), asymmetry (A), clumpiness (S) are measured on an example nearby galaxy (Conselice 2003).

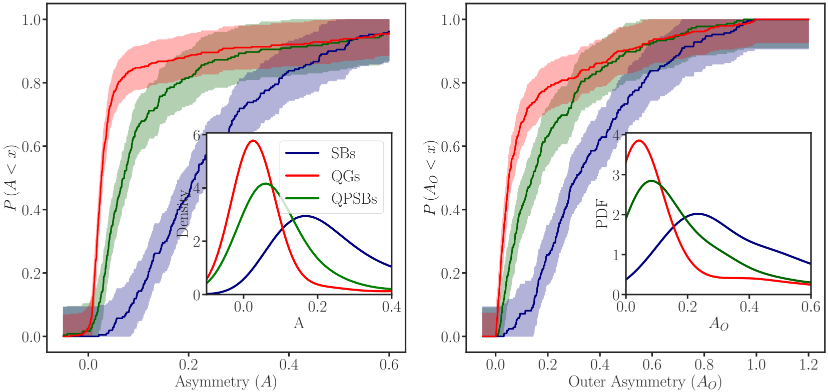
Example Post-starburst Galaxies from Subaru HSC Survey



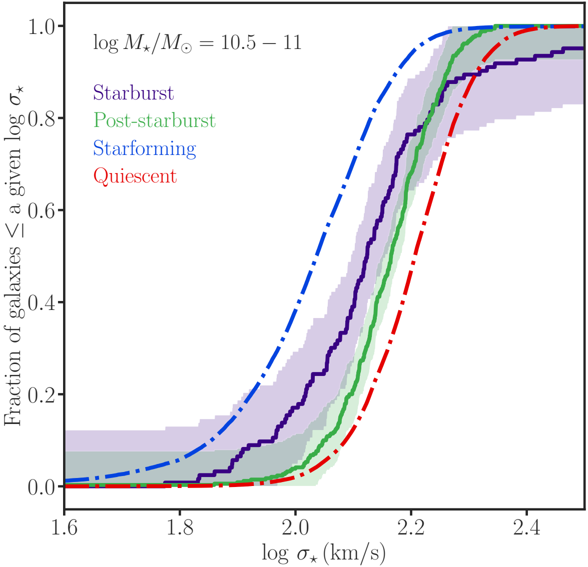
About half of post-starburst galaxies are disturbed, supporting the merger picture.



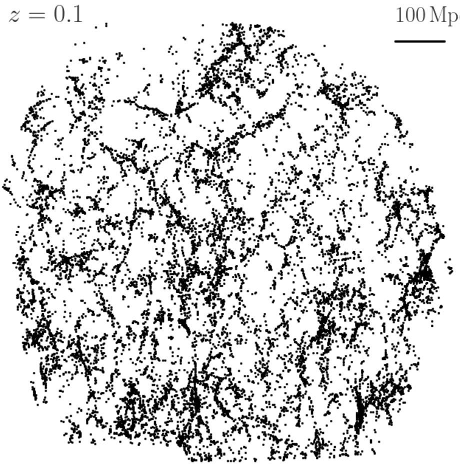
Asymmetries of PSBs are intermediate between starbursts and quiescent galaxies.



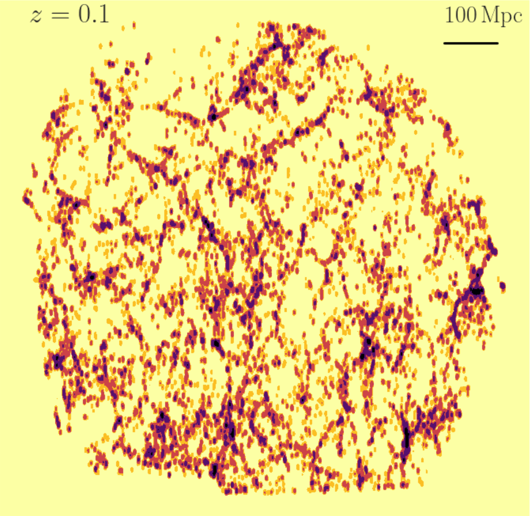
Starburst and post-starburst galaxies have higher velocity dispersion compared to normal star-forming galaxies



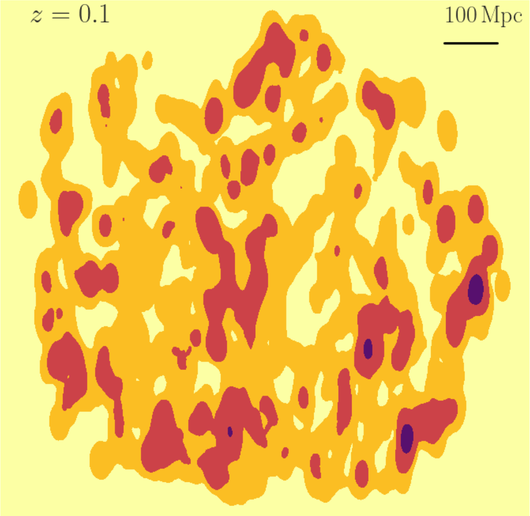
Large-scale structure: galaxies are not distributed randomly on the sky



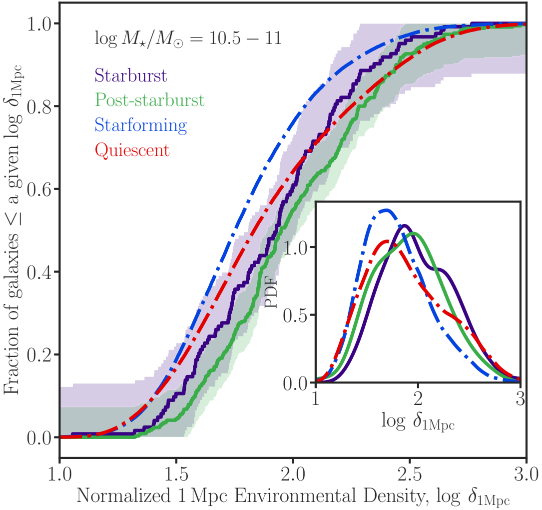
Mass density of galaxies smoothed by 1 h^{-1} Mpc



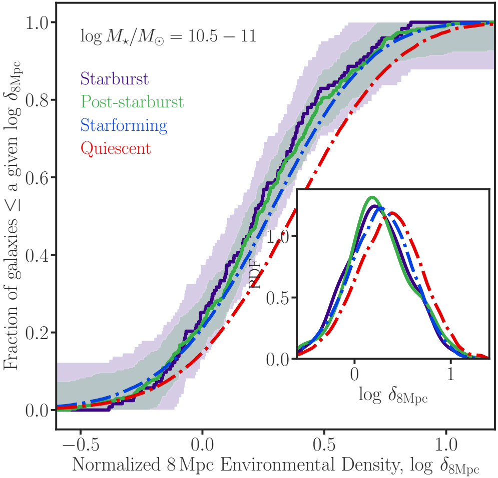
Mass density of galaxies smoothed by 8 h^{-1} Mpc



At 1 h^{-1} Mpc scale, the environmental density of starbursts and post-starbursts are different



At 8 h^{-1} Mpc scale, the environmental densities of starbursts and post-starbursts are similar to that star-forming galaxies



The AGN Horizon cosmological simulation

- Cosmic gas accretion and galaxy mergers determine galaxy morphology; Without black hole feedback galaxies reform discs.

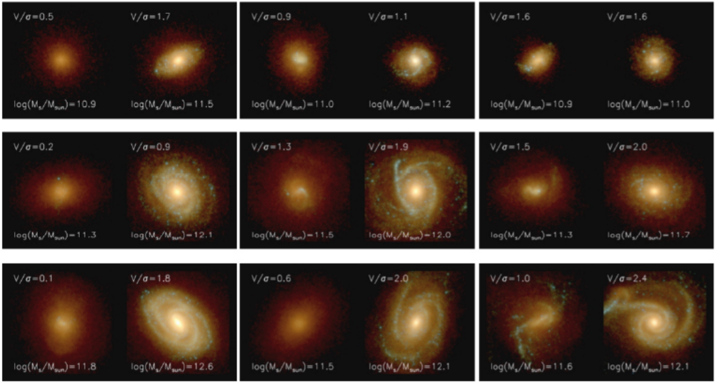
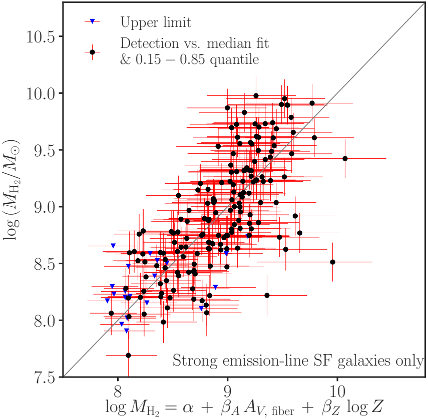


Figure: Column 1, 3 & 5 with BH feedback; Column 2, 4 & 6 with NO BH feedback (Dubois et al. 2016)

Dirt-cheap gas scaling relation using dust absorption & metallicity (Yesuf & Ho 2019, ApJ, 884, 177).



- Use dust absorption $(\mathrm{H}\alpha/\mathrm{H}\beta) \propto \Sigma_{dust}$ as proxy
- $M_{\mathrm{dust}}/M_{\mathrm{gas}} \approx [0.001, 1]\%$ depending on Z
- Z depends on $M_\star$ and R

Figure: *Scaling relations among molecular gas mass ($M_{\mathrm{H_2}}$), A_V, gas-phase metallicity (Z)*

Some die filthy rich: The diverse molecular gas contents of post-starburst galaxies (Yesuf & Ho 2020, ApJ, 900, 107)

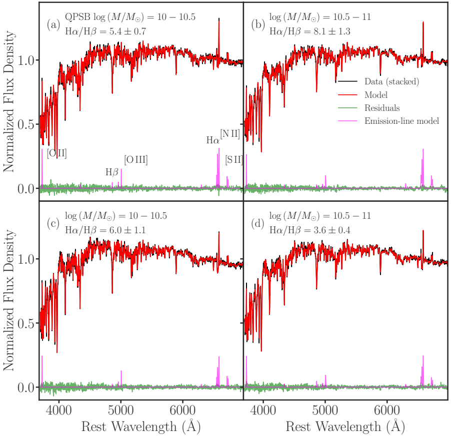


Figure: Example stacked spectra (black) of subsamples of PSBs with low-SNR ($1 - 3\,\sigma$) $H\alpha/H\beta$ ratios.

- by subdividing into low and high $M_\star$
- by subdividing into: poorly measured $H\alpha/H\beta$ ($< 1\sigma$), and marginally measured ($1 - 3\,\sigma$) high, medium and low $H\alpha/H\beta$
- by using WISE mid-IR 12μm flux to 4.6μm flux ratios

Stacked and individual analysis combined

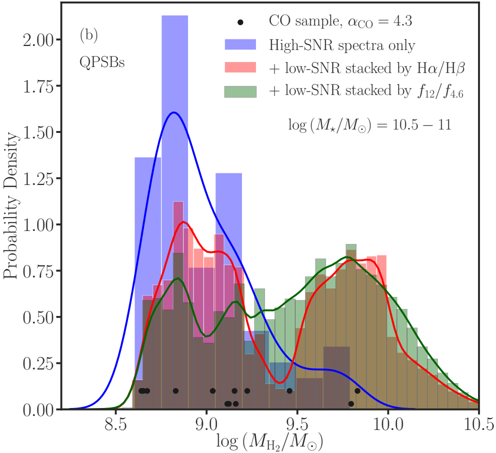
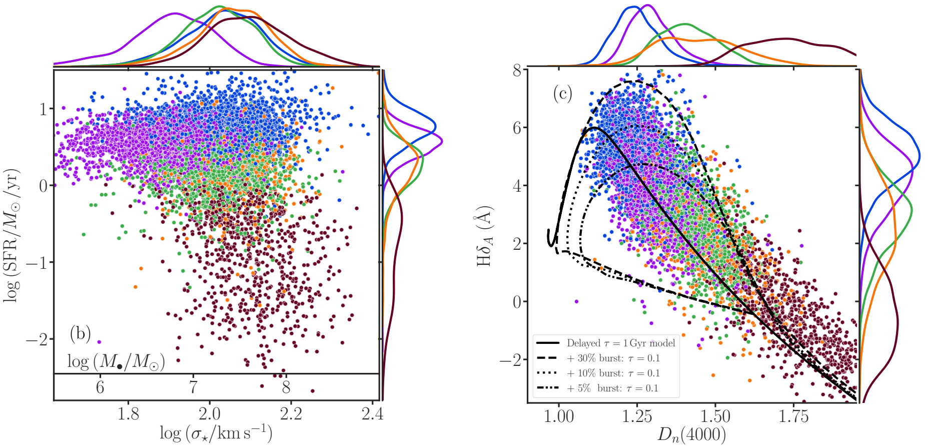


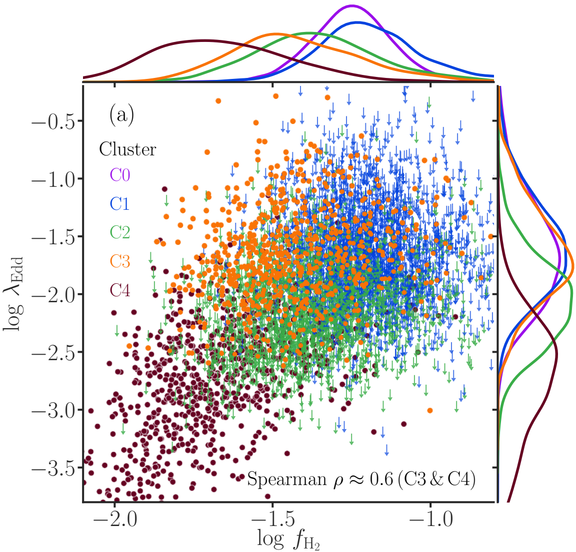
Figure: QPSBs have a wide range of $H\alpha/H\beta$ ratios and molecular gas fractions that overlap with the typical gas fractions of star-forming or quiescent galaxies: $H\alpha/H\beta \approx 3 - 8$ and $f_{H_2} \approx 1\% - 20\%$ with median $f_{H_2} \approx 4\% - 6\%$, which correspond to $M_{H_2} \approx (1-3) \times 10^9\, M_\odot$. (**?**)

Gas content regulates the life cycle of star formation and black hole accretion (Yesuf & Ho 2020, ApJ, 901, 42)



Age sequence at constant $M_\star$ and morphology wherein gas content mediates SFR and AGN activity

Strong AGNs are gas-rich. AGNs do not impact cold gas in short periods of time.



Gas accretion onto galaxies affect metallicity and star formation rate.

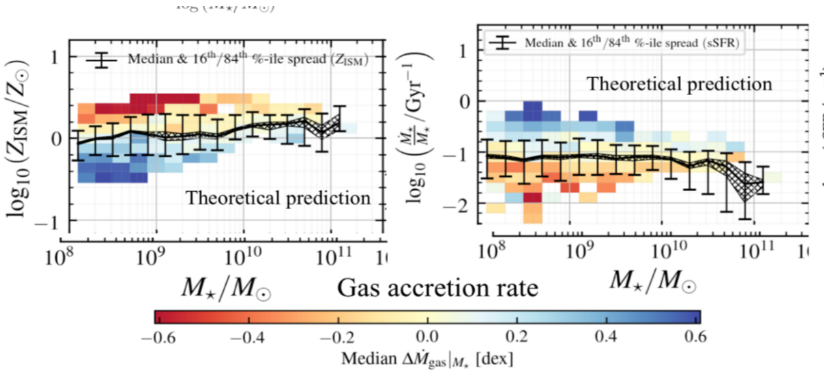
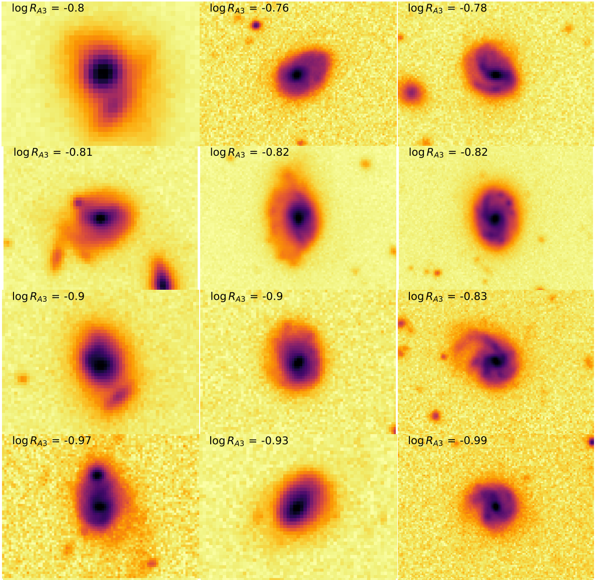


Figure: Elemental abudance (metallicty) and the specific star formation rate SSFR vs. stellar mass plane coloured by excess gas accretion efficiency (EAGLE; Wright et al. 2021).

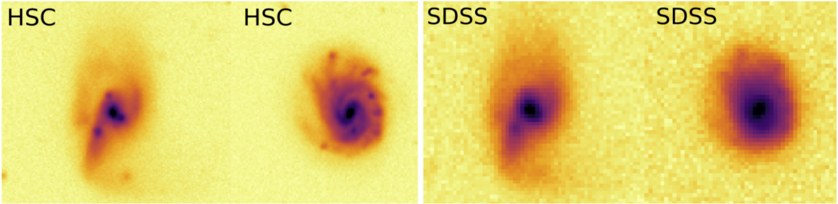
Observationally, which structural parameters best predict whether a galaxy is above or below the SFMS? (Yesuf, Ho, & Faber 2021, ApJ, in press, arXiv:2109.08882)

- We use the statistical framework of mutual information (MI) to rigorously quantify the inter-dependence among several structural variables and to rank their relevance to predicting SSFR, taking their inter-dependence into account.
- We use deep imaging data in SDSS Stripe 82 to study a large sample of galaxies. The Stripe 82 data improve the reliability of measurements of variables such as asymmetry (Bottrell et al. 2019).

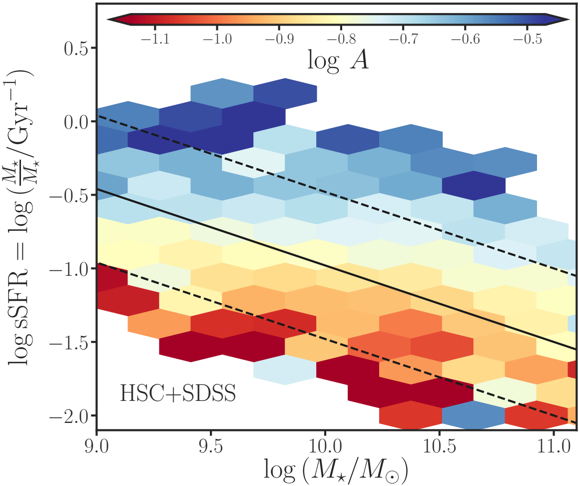
Asymmetries are due to mergers/interactions, lopsidedness, and asymmetric spiral arms in isolated galaxies.



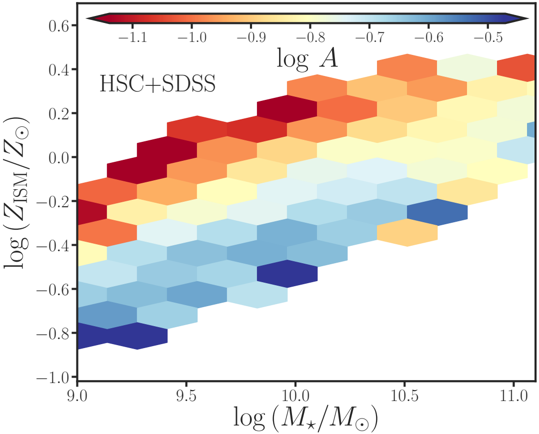
Comparing Subaru HSC with Sloan Digital Sky Survey (SDSS)



HSC data: the star formation is associated with asymmetry.



HSC data: Gas-phase metallicity depend on both stellar mass and asymmetry.



Summary

- After $M_{\star}$, morphological asymmetry is the most important predictor of variations in SSFR and metallicity.
- The correlation between asymmetry and star formation rate or metallicity is likely due to galaxy mergers and interactions as well as diffuse gas accretion.
- Mergers and interaction induces starbursts may explain half of post-starburst galaxies. The the morphology and environments of these two populations are broadly similar.
- Strong active black holes are gas-rich and do not impact cold gas (and star formation) in short periods of time

Visualizing trends of deviations from the mean SSFR

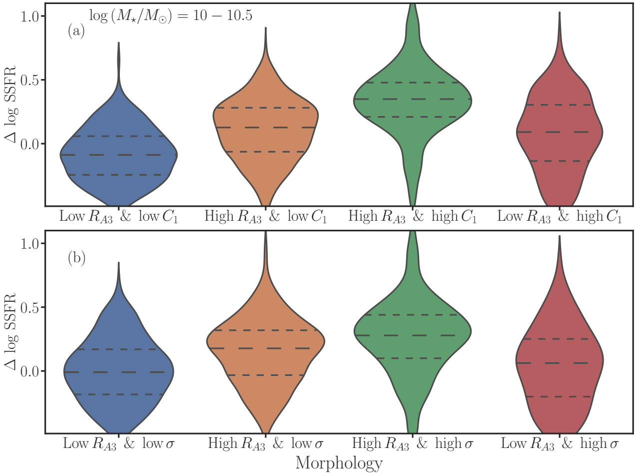


Figure: The distributions of $\Delta\,\mathrm{SSFR}$ for four sets of SFGs binned by R_{A3} and C_1 or σ. The violin plots show the kernel density estimates of the distributions and the dashed lines denote the median and quantiles of the distributions for each bin.

Visualizing average structural trends with SSFR