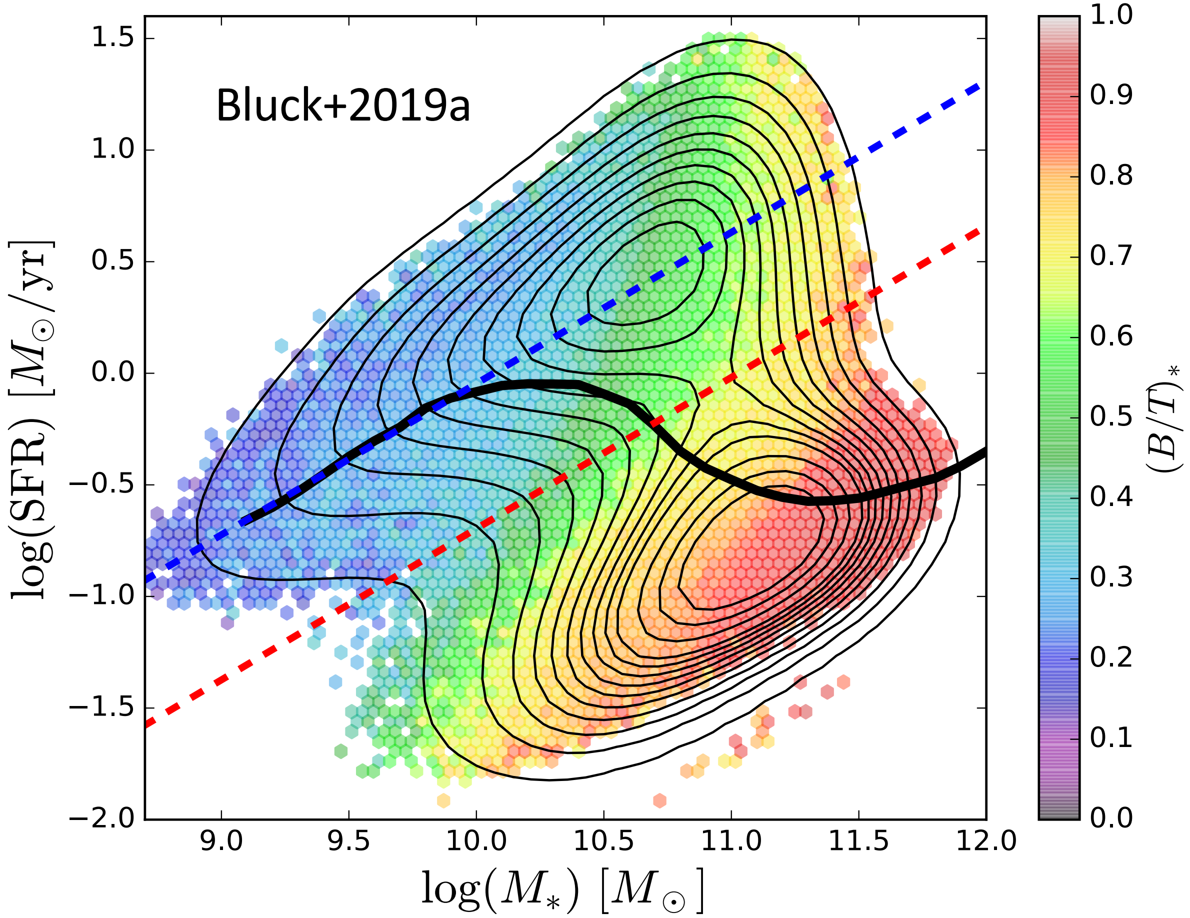
Are star formation & quenching governed by local, global or environmental phenomena?



UNIVERSITY OF CAMBRIDGE

Asa F. L. Bluck

University of Cambridge

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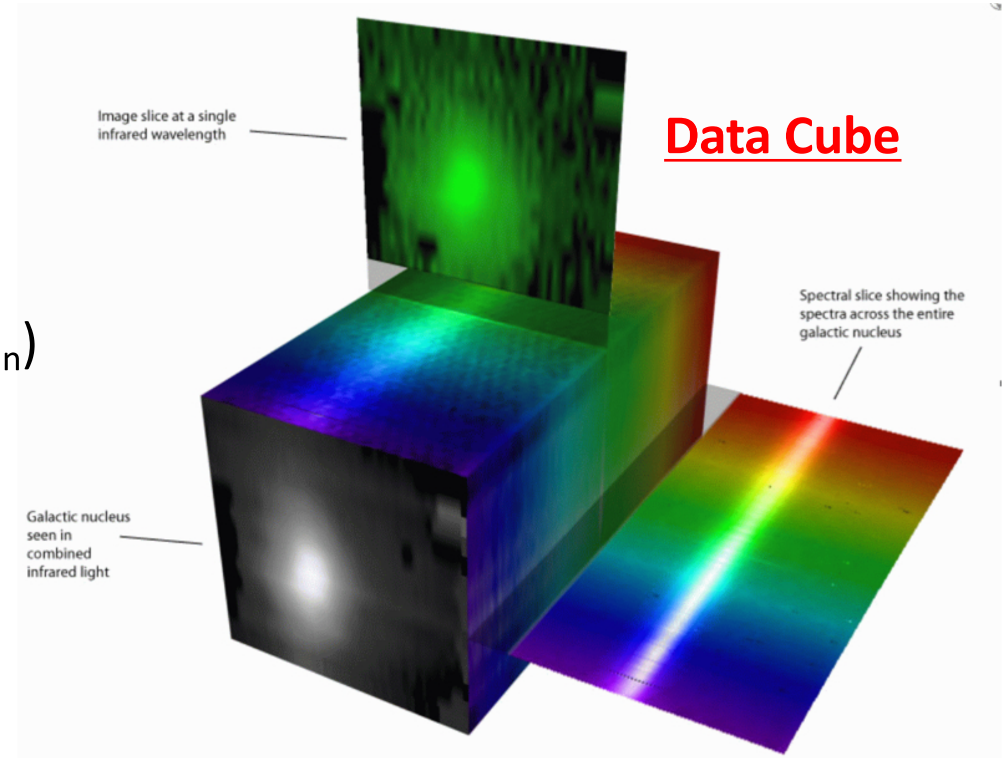
Collaborators: R. Maiolino, S. Ellison, S. Sanchez, J. Piotrowska, M. Thorp, H. Teimoorinia, K. Bundy

MaNGA IFU Survey – DR15 (Released Jan 2019)

The MaNGA Survey:

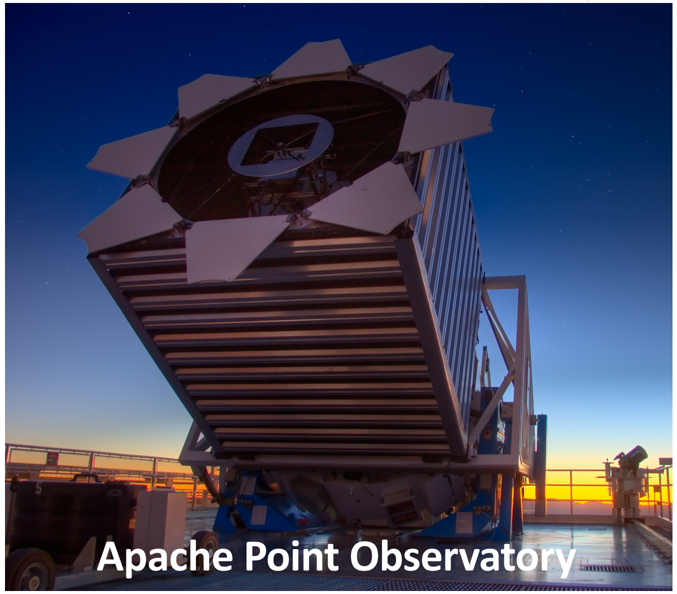
- SDSS IV Ongoing Large Program
- ~10,000 Local ($z < 0.1$) Galaxies Observed with IFU Spectroscopy
- Flat Mass Distribution ($10^9 – 10^{11.5} M_{sun}$)
- 3600 – 10000 A Spectral Range ($R = 2000$)
- ~1kpc Spatial Resolution (0.5 arcsec)
- Largest IFU Survey to date!



Pipe3D DR15 VAC:

- ~4500 Galaxies Observed
- ~10 Million Spectra Analysed:
  - Emission Line Strengths (Flux & EW)
  - Absorption Lines & Spectral Indices
  - Kinematics (V_{los}, σ_{los})
  - SSP Fitting Parameters: stellar mass densities, stellar ages$_{L,M}$, stellar metallicities, SFHs…

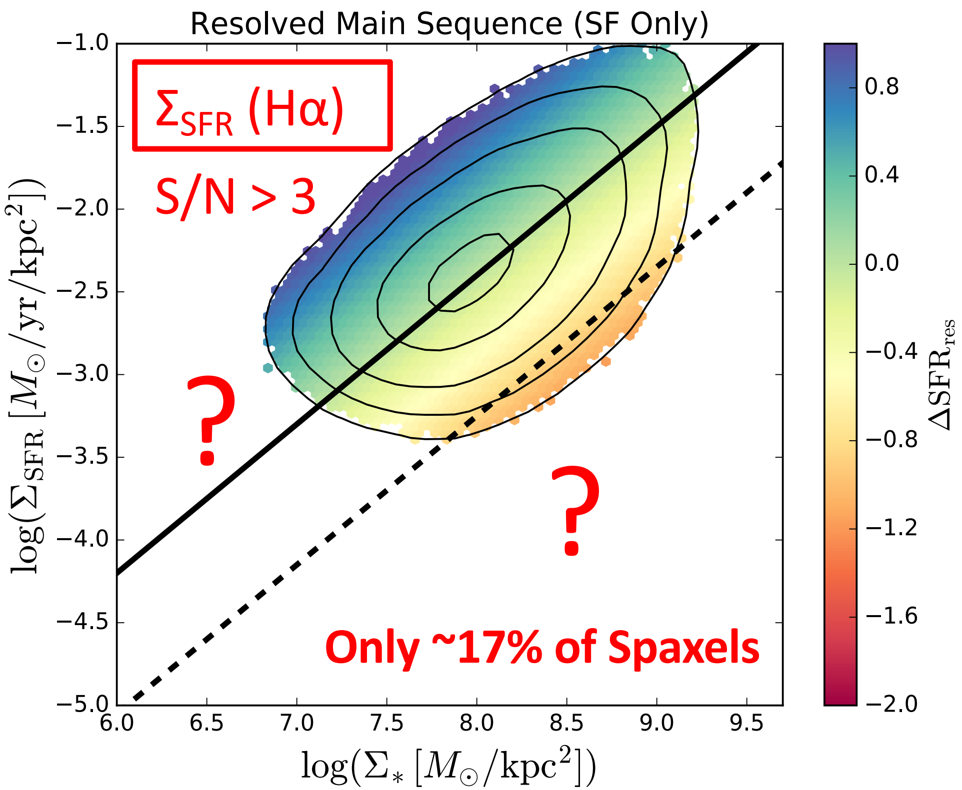
Bundy et al. (2015); Sanchez et al. (2016a,b)

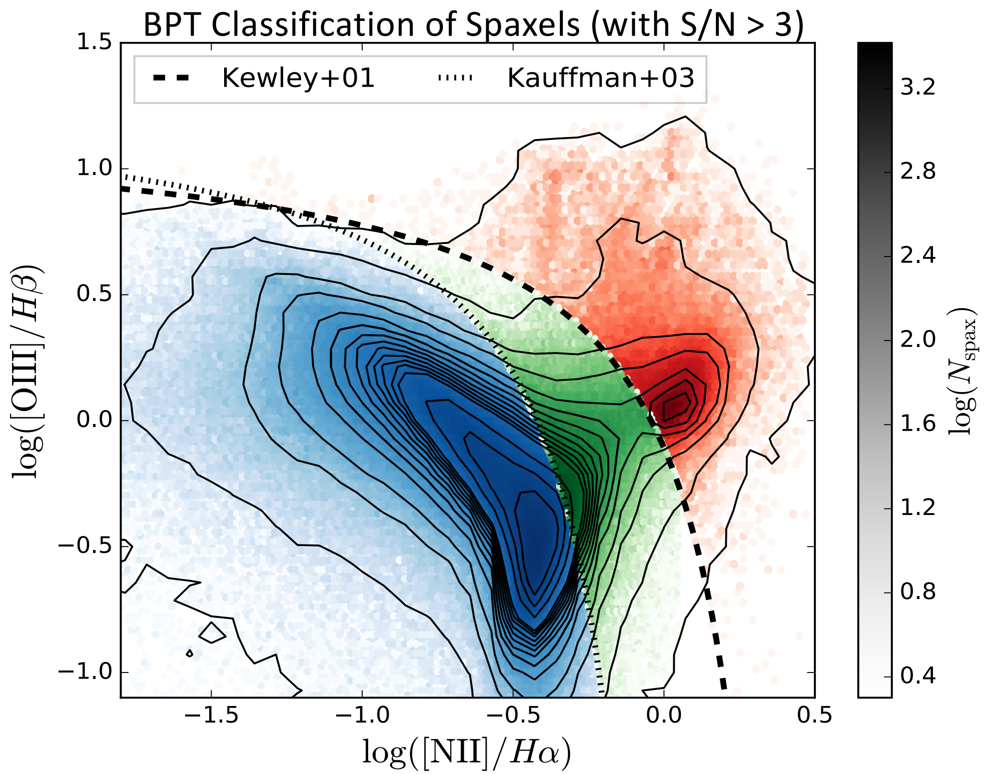


Resolved SF Main Sequence in MaNGA

Note: using public Pipe3D intermediate data-products for SDSS DR15

(see Sanchez et al. 2016a,b)



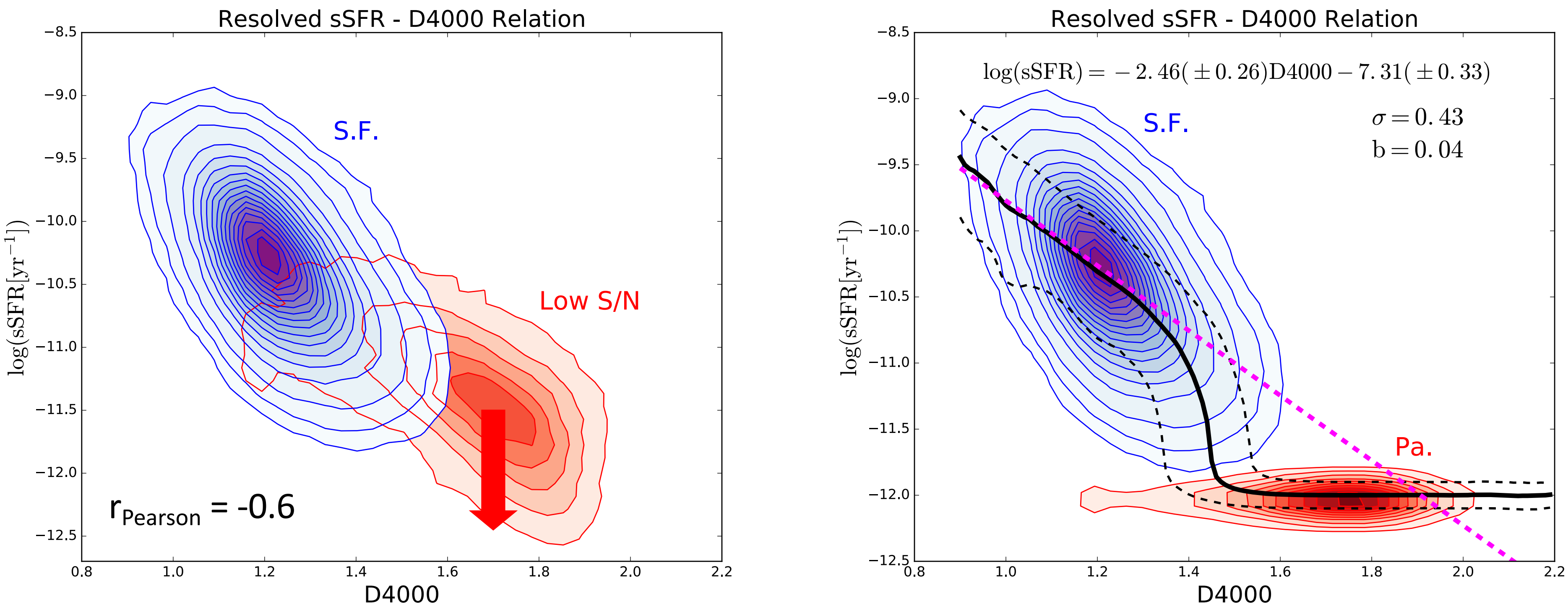


"reliable, but highly incomplete/ biased"

-> Catastrophic if goal is to study the quenching process

Estimating SFRs for Lineless and Non-SF Spaxels

Inspired by Brinchmann et al. (2004) SDSS Approach



1. The low S/N spaxels are well separated from star forming spaxels in D4000
   - ➢ motivates the use of the D4000 spectral index to ‘classify’ spaxels

2. There is a reasonably tight correlation between D4000 – sSFR for SF spaxels
   - ➢ motivates its use to estimate SFR densities for AGN, COMP and LI(N)ER

3. D4000 is measured at 5σ in > 99% of spaxel binnings -> **completeness** ☺

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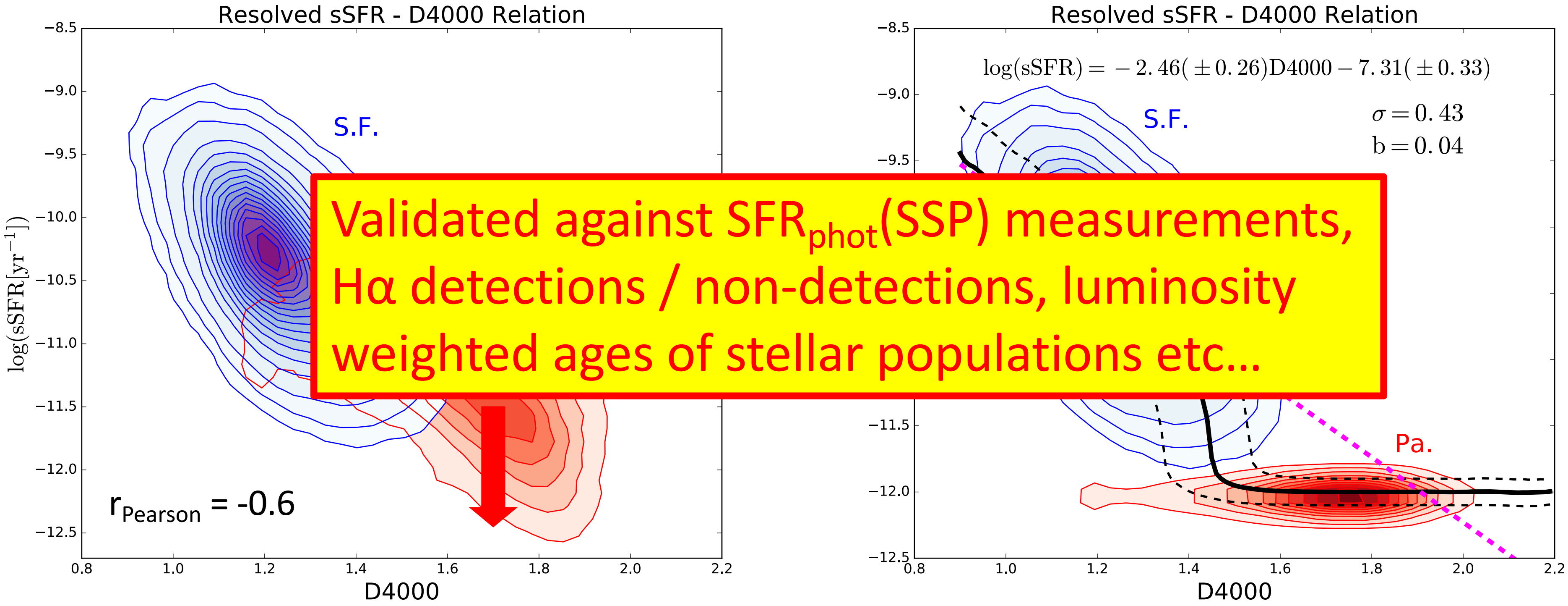

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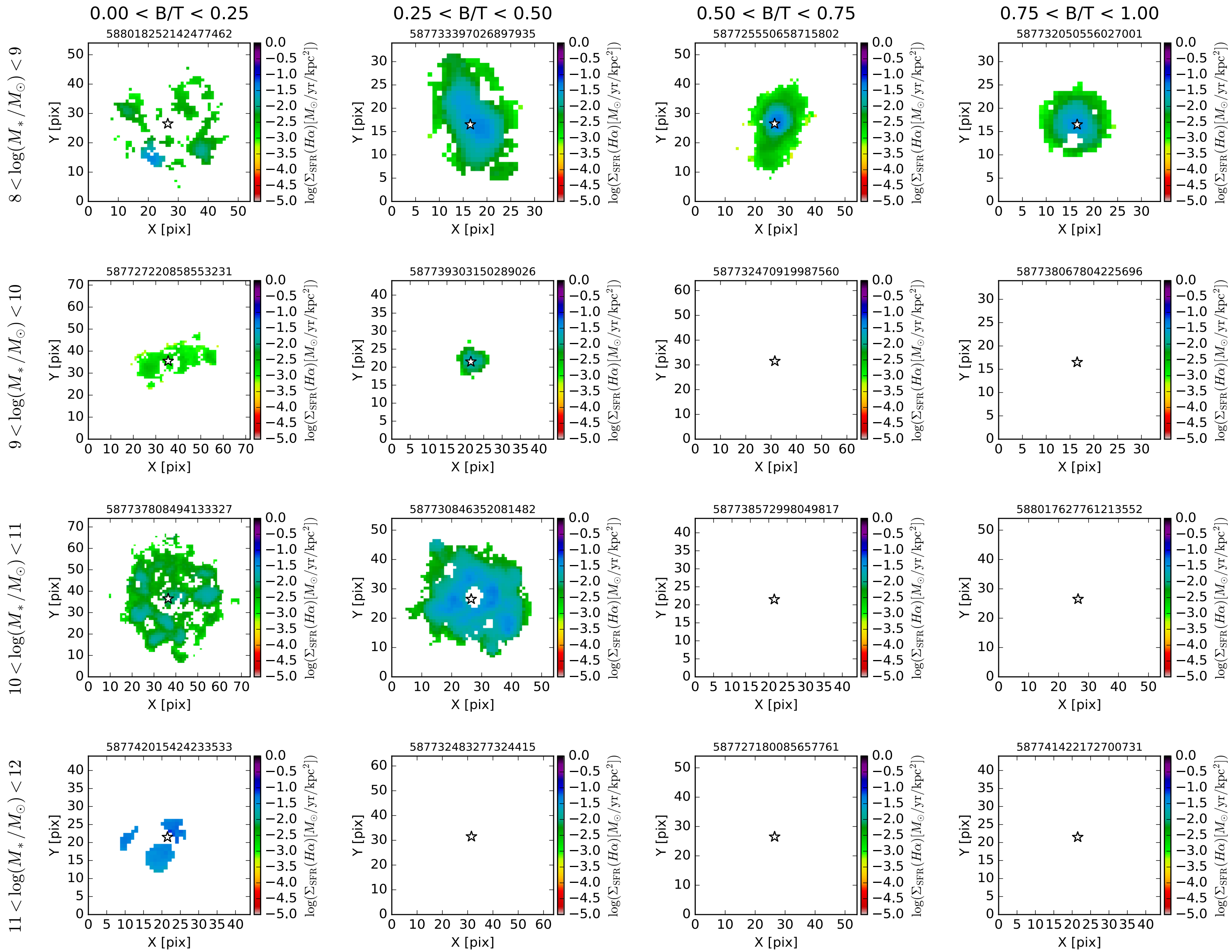
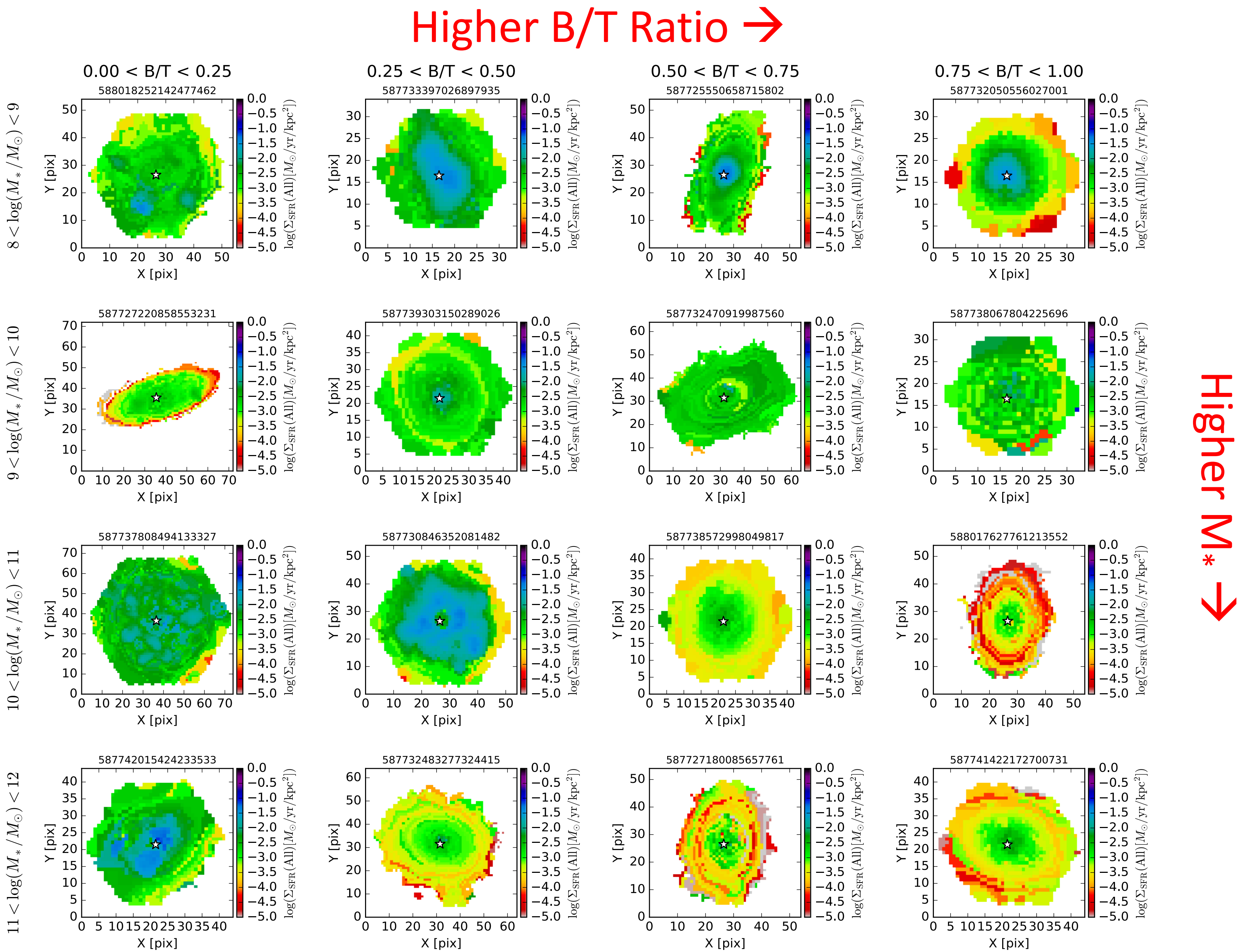
SFR Maps for BPT SF-Only Sample

Higher B/T Ratio →

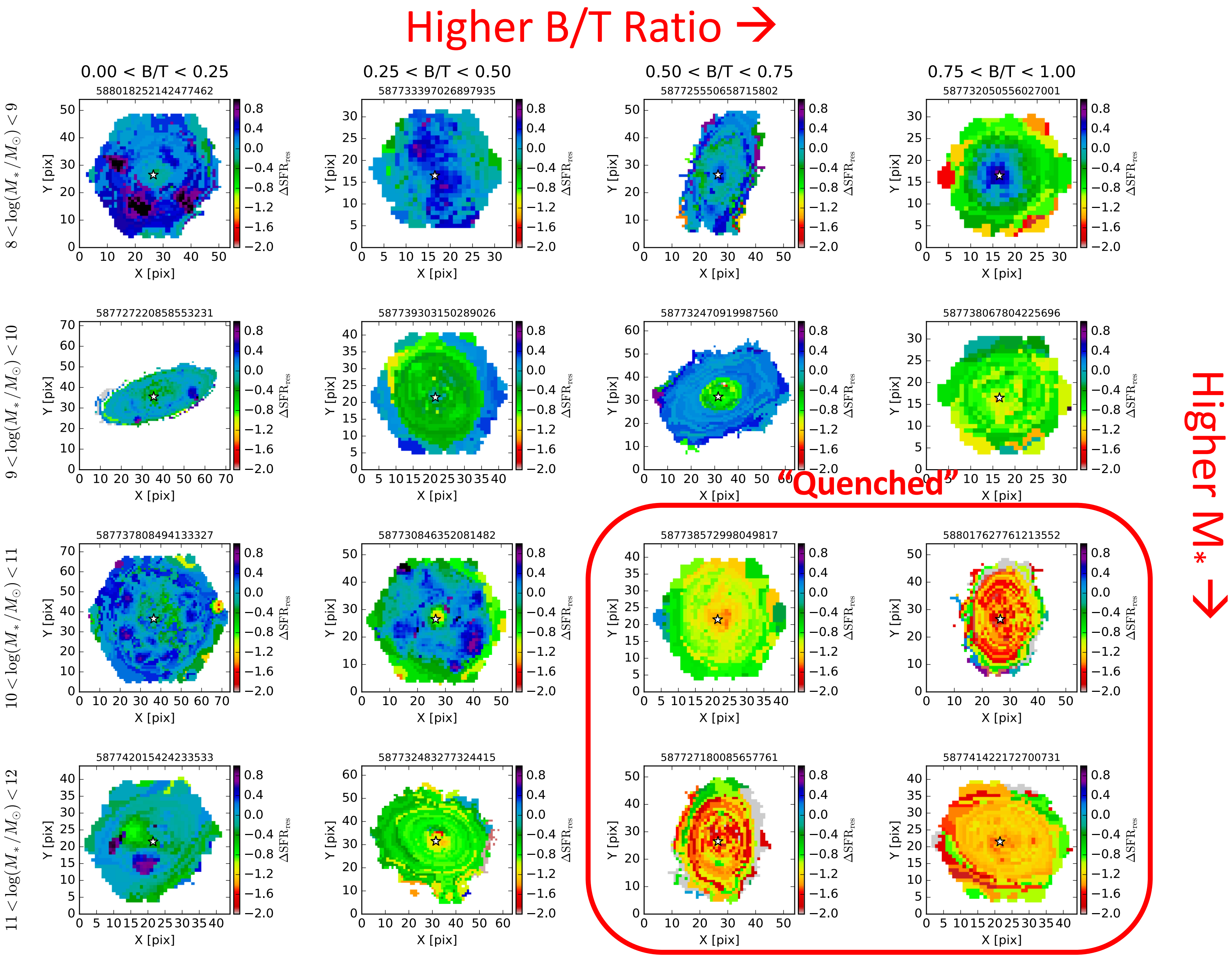


Higher M* →

SFR Maps for Full Sample (Quenched & All-SF)

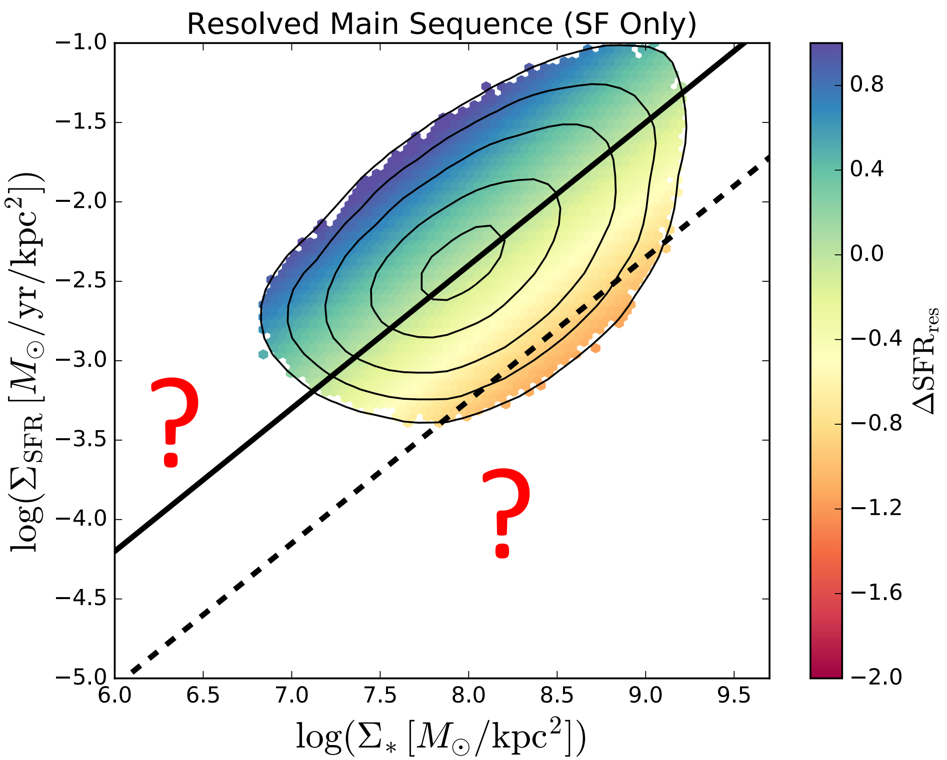


ΔSFR Maps for Full Sample



The Complete Resolved Main Sequence

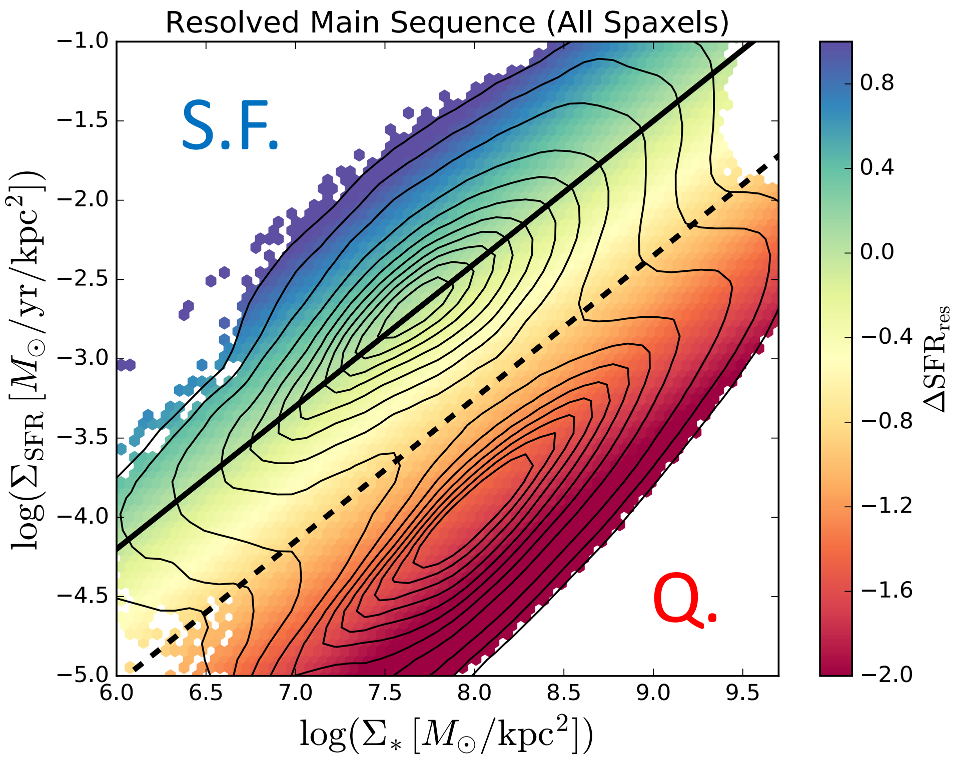
Only ~17% of Spaxels



Σ_{SFR} (Hα)

"reliable, but highly incomplete/ biased"

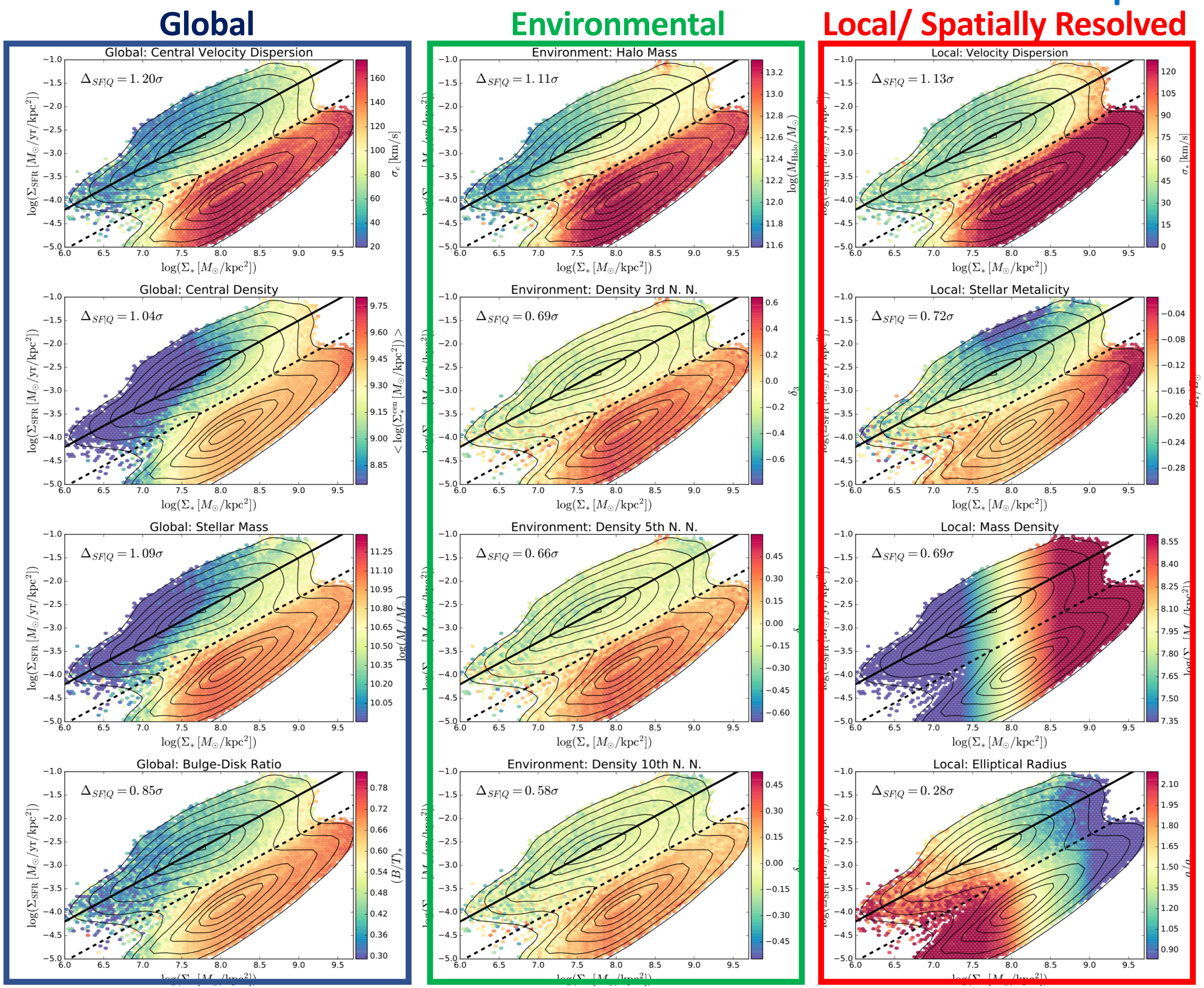
All ~100% of Spaxels



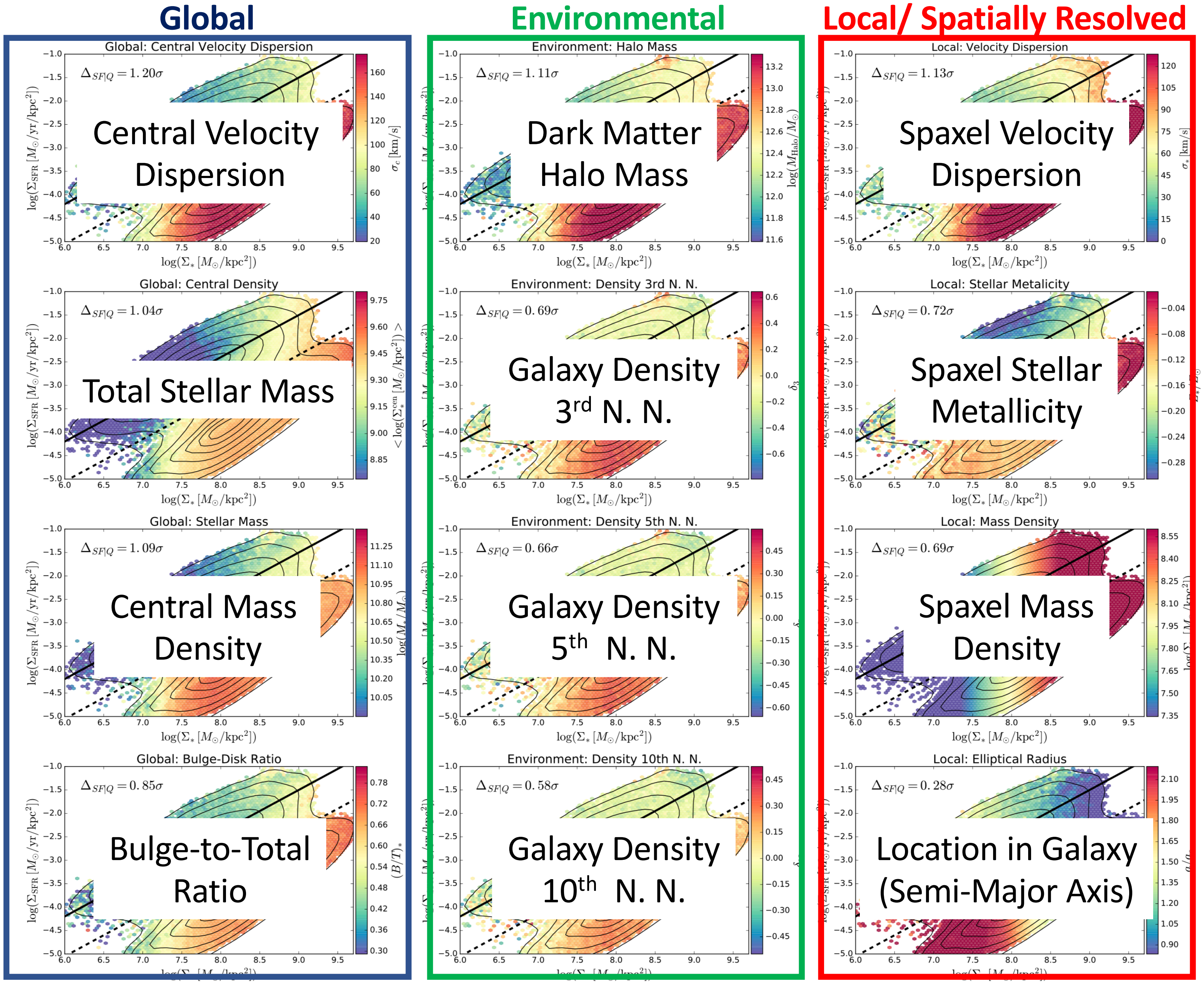
Σ_{SFR} (Hα | D4000)

"complete/ unbiased, but more uncertain"

Variation of Parameters Across Resolved Main Sequence

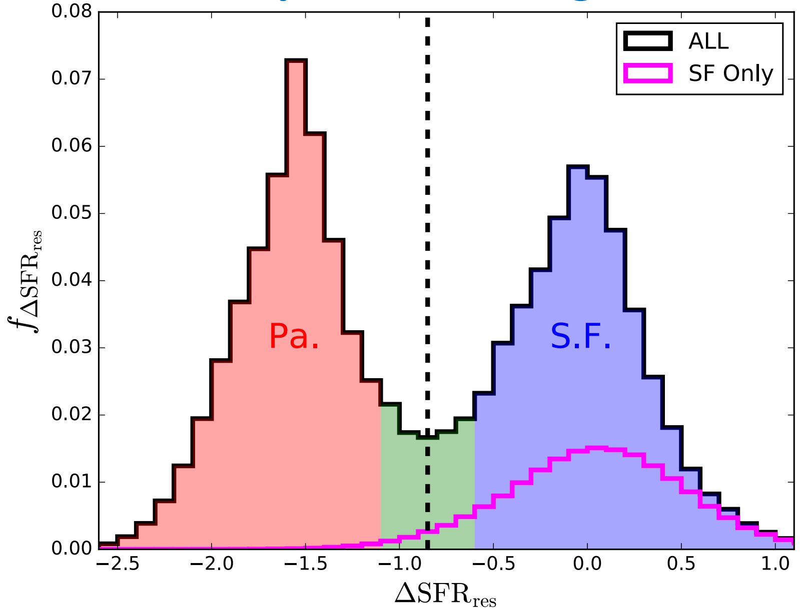


Variation of Parameters Across Resolved Main Sequence

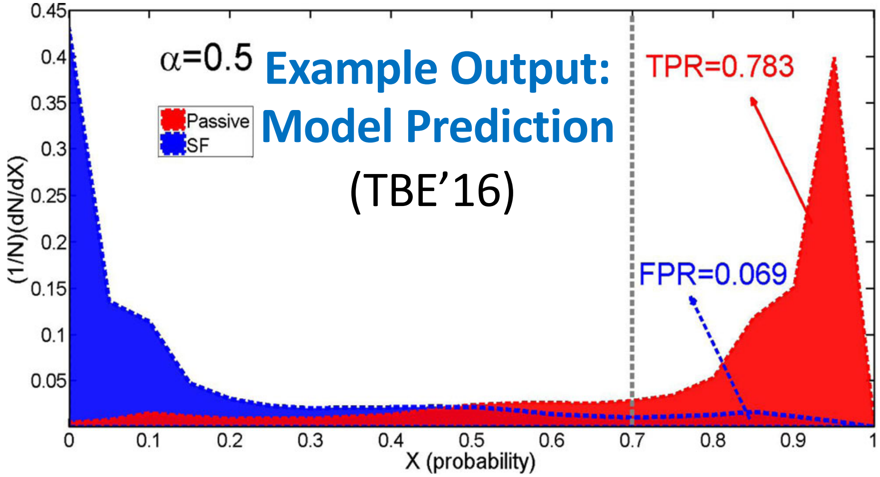


Artificial Neural Network Analysis:
Predicting Quenched Spaxels & Resolved SFR Densities

Input for Training:



Example Output: Model Prediction (TBE'16)



Quenching:

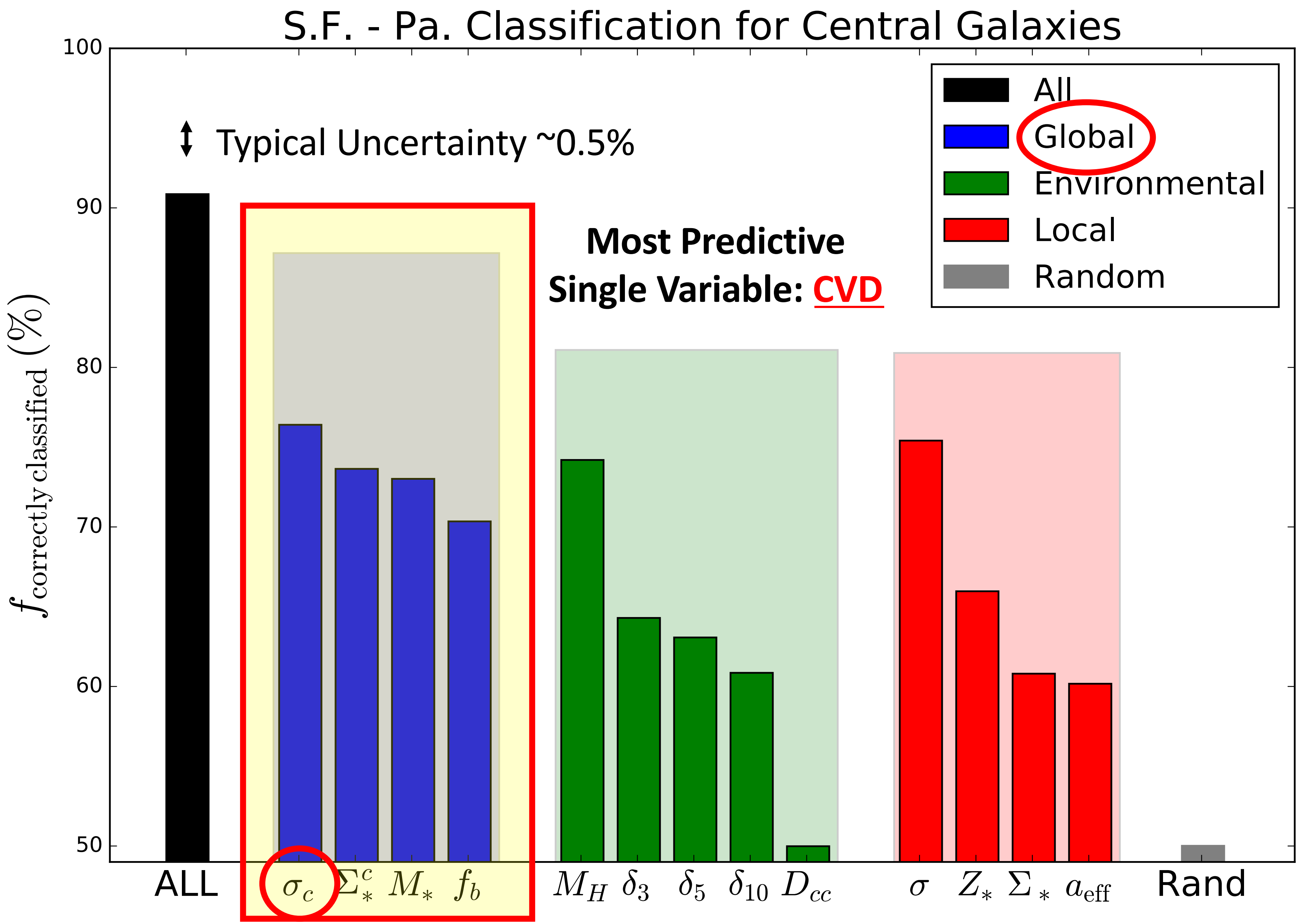
1) Identify which parameters, and groups of parameters, are particularly effective at predicting whether spaxels will be star forming or quenched:
"Classification"

Star Formation:

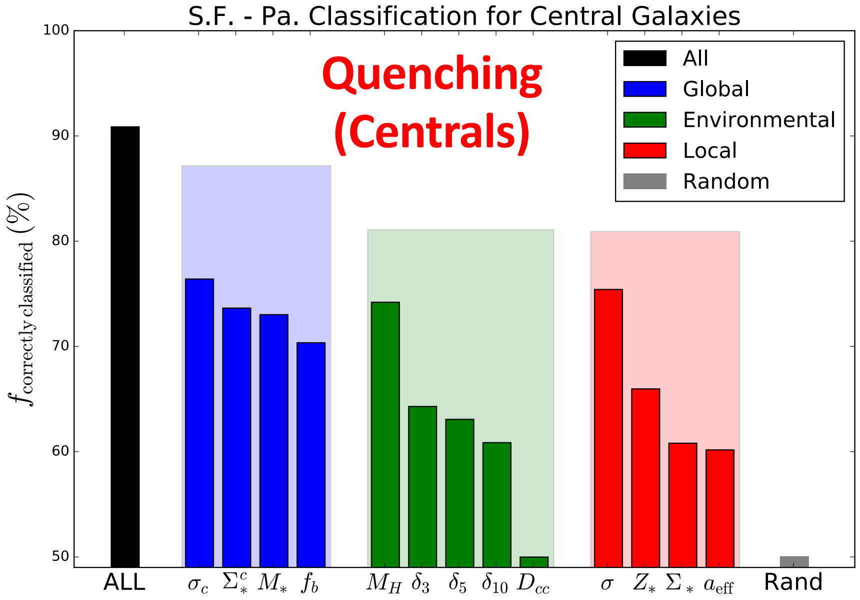
2) Identify which parameters, and groups of parameters, are particularly effective at predicting actual SFR surface densities in star forming spaxels:
"Regression"

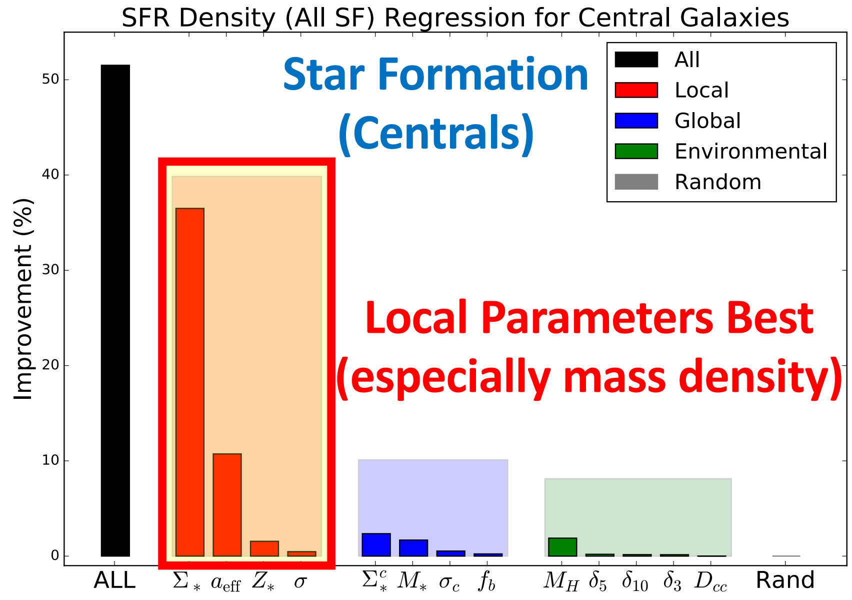
See also Teimoorinia, Bluck & Ellison (2016) & Bluck et al. (2019a) for similar ANN approaches

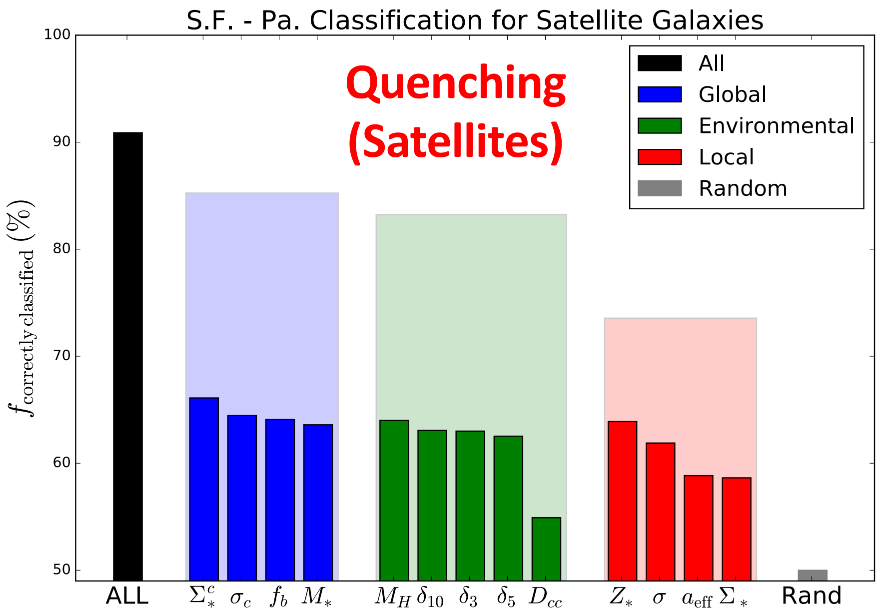
Machine Learning Results: Classifying Centrals

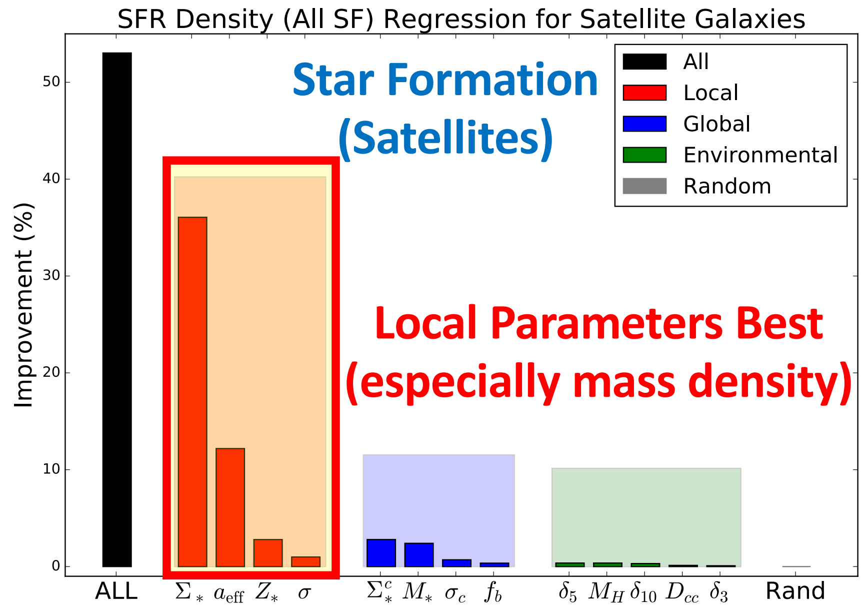


Machine Learning: Ranking of Parameters

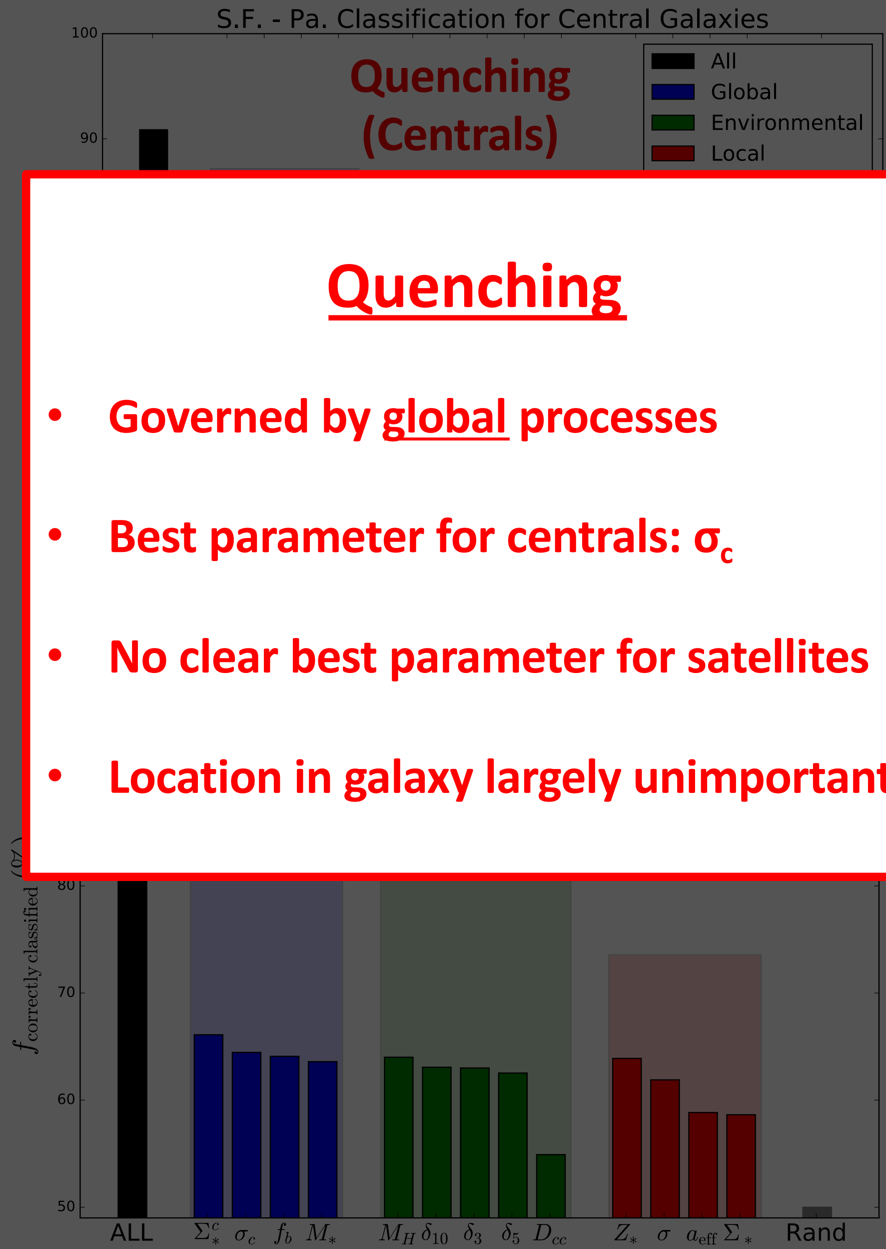


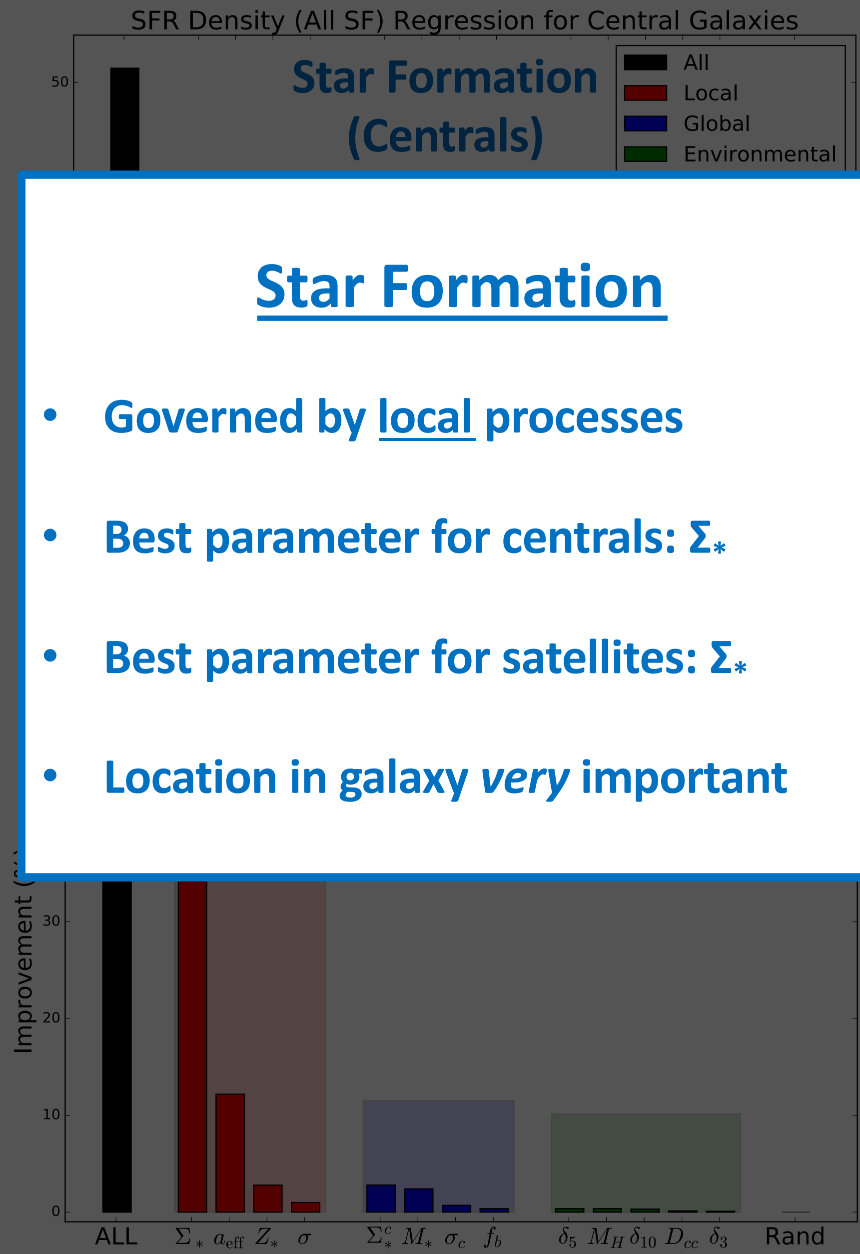






Machine Learning: Ranking of Parameters





Quenching

- Governed by global processes
- Best parameter for centrals: σ_c
- No clear best parameter for satellites
- Location in galaxy largely unimportant

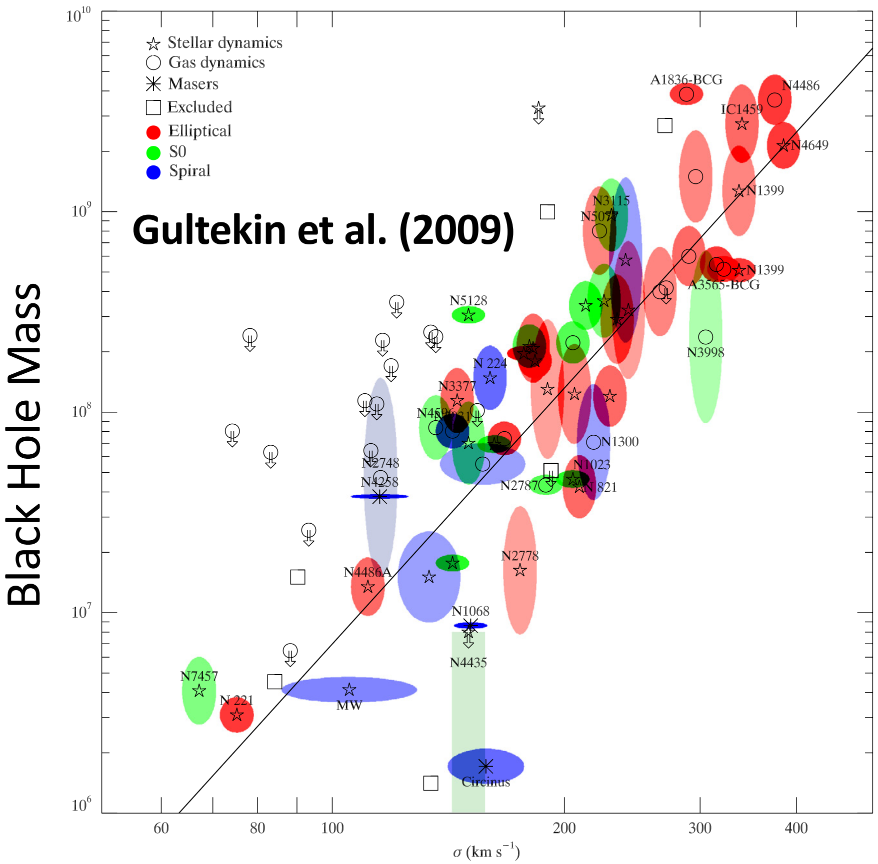
Star Formation

- Governed by local processes
- Best parameter for centrals: Σ_*
- Best parameter for satellites: Σ_*
- Location in galaxy *very* important

Black Hole Mass across the Resolved MS

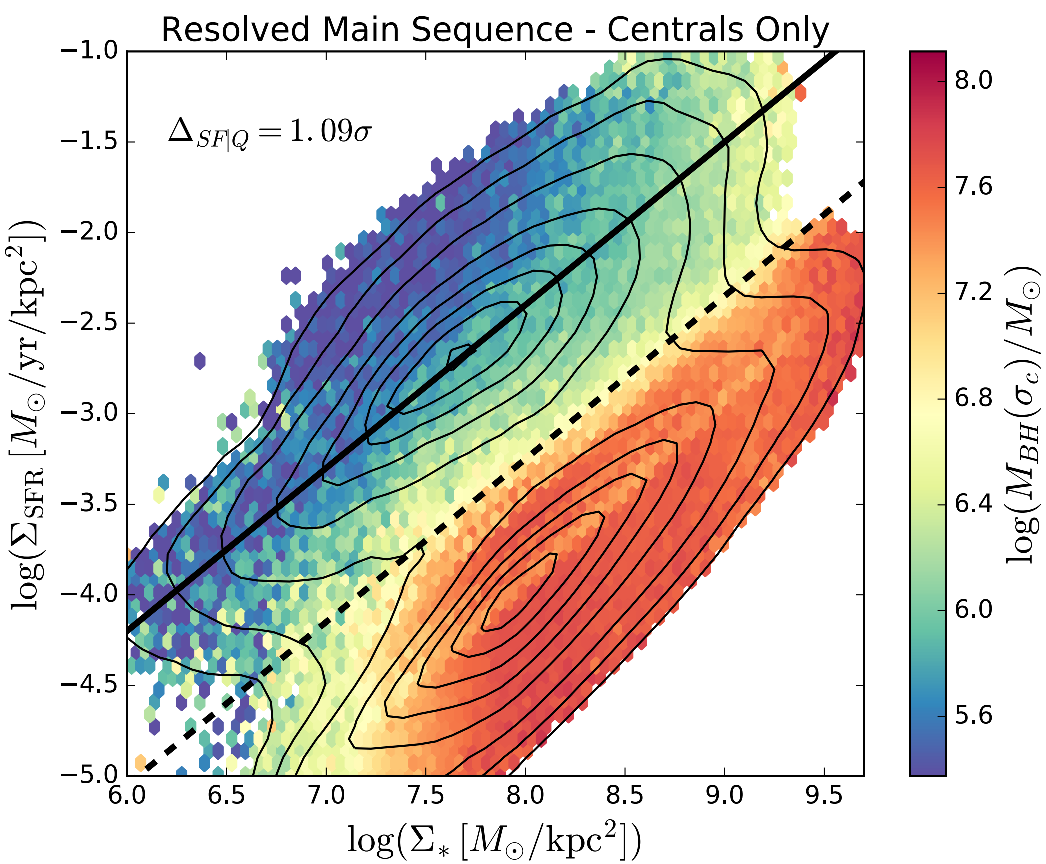
Note: Focusing on Centrals from now on…

$M - \sigma_c$ Relation



Central Velocity Dispersion

MaNGA DR15 - CENTRALS

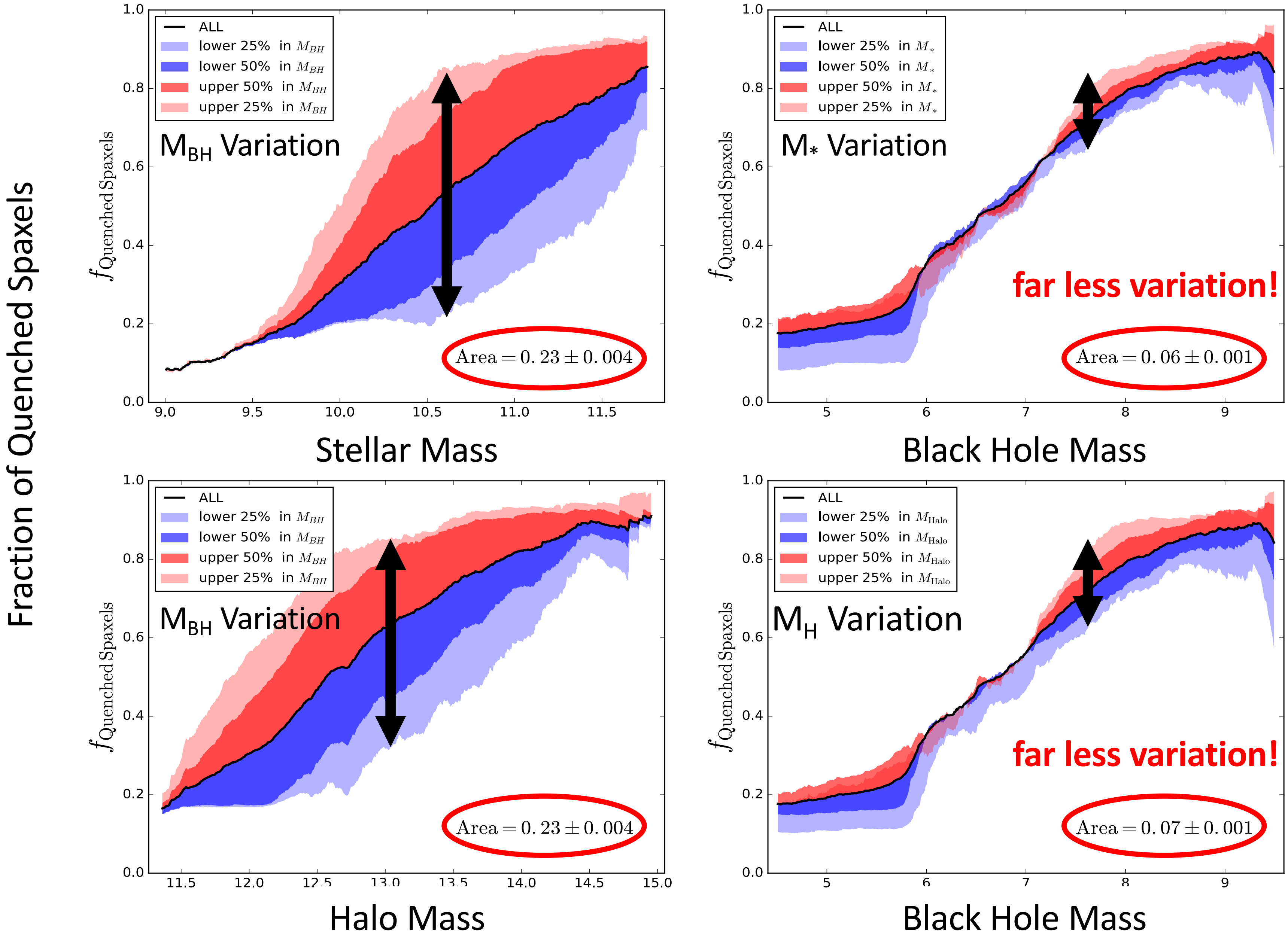


M_{BH} varies with *ΔSFR_{res} not Σ_**

<u>Key Result:</u> *Quenched spaxels reside in host galaxies harbouring high mass black holes*

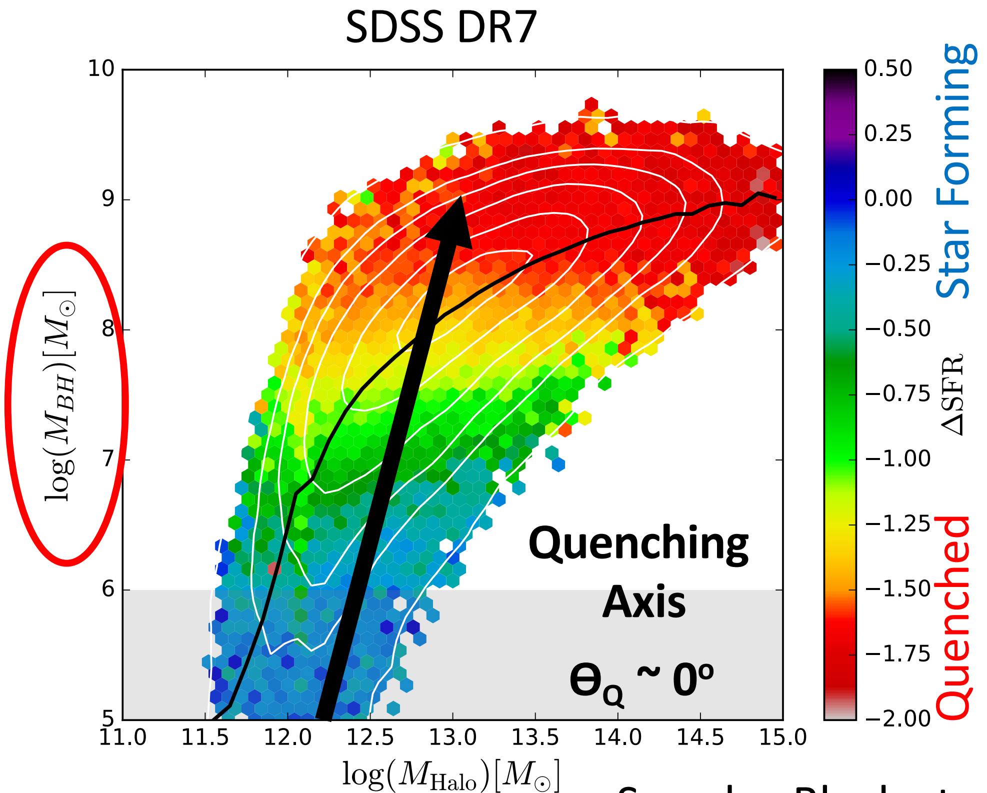
But, what's in a couple of per cent?

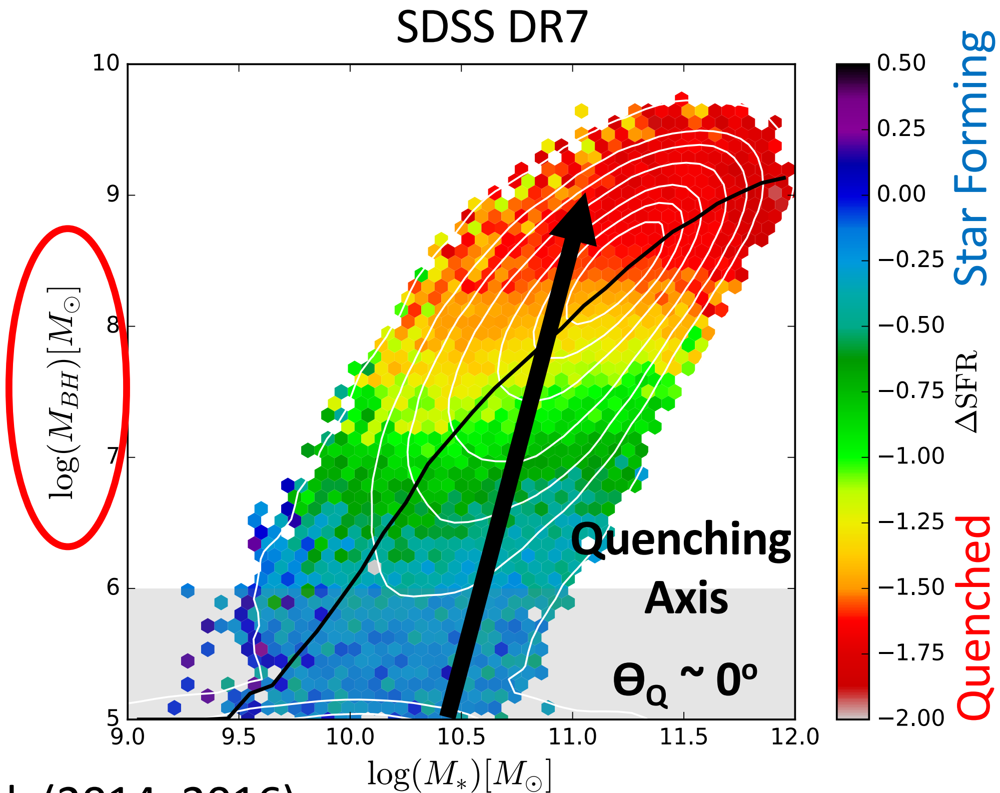
Comparing Stellar Mass, Halo Mass & Black Hole Mass



Comparison to Global Relations in the SDSS

'Mass Quenching' is 'Black Hole Mass Quenching'!





See also Bluck et al. (2014, 2016)

Key Idea – M_{BH} traces total integrated feedback energy from AGN

M_* traces total integrated feedback energy from SNe

M_{Halo} traces the gravitational potential, source of feedback from shocks

Conclusions

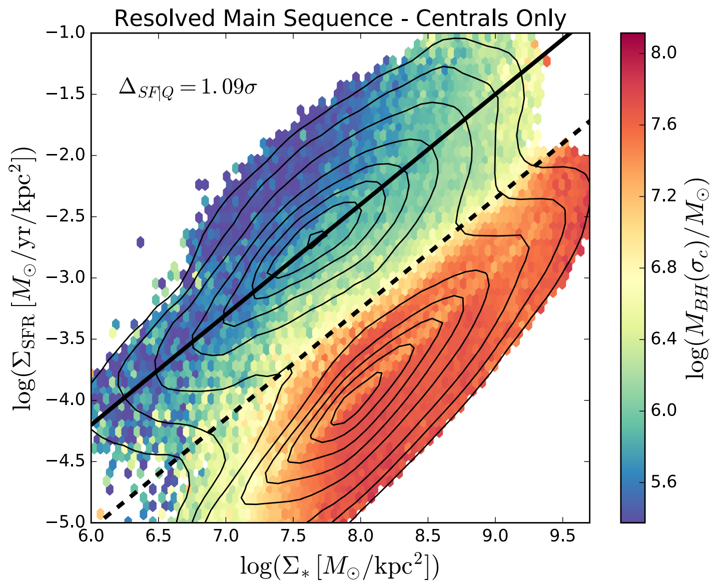
- Global parameters impact the quenching of spaxels more than local properties.
  Hence, **'quenching is a global process'**

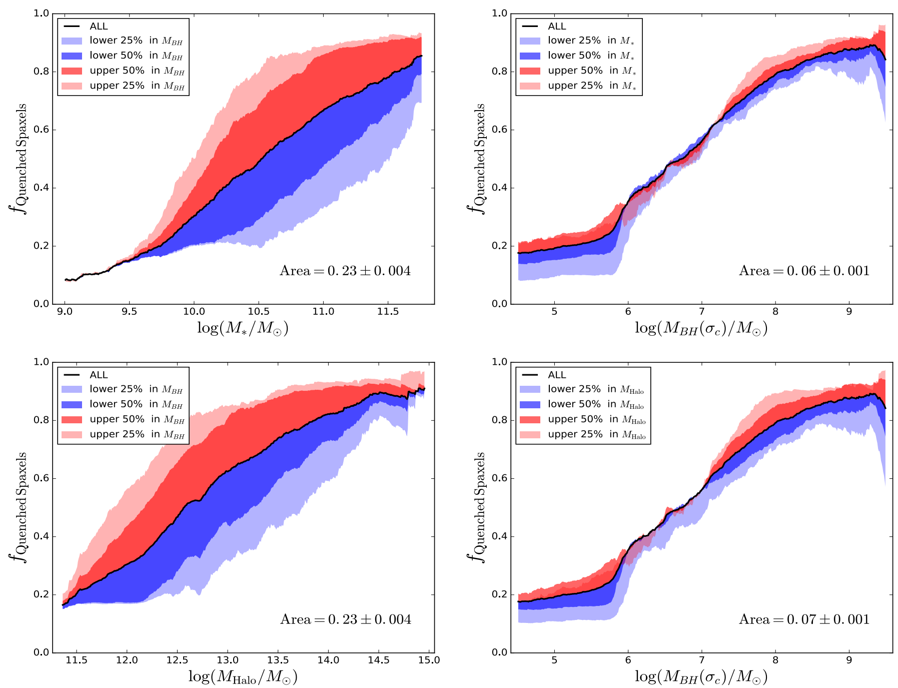
- But, local parameters impact the SFR Densities of SF spaxels more than global parameters.
  Hence, **'star formation is a local process'**

- **Supermassive Black Hole Mass is an excellent predictor of central galaxy quenching (consistent with AGN quenching predictions from Eagle & Illustris)**

→ AGN feedback is a *plausible* mechanism for central galaxy quenching

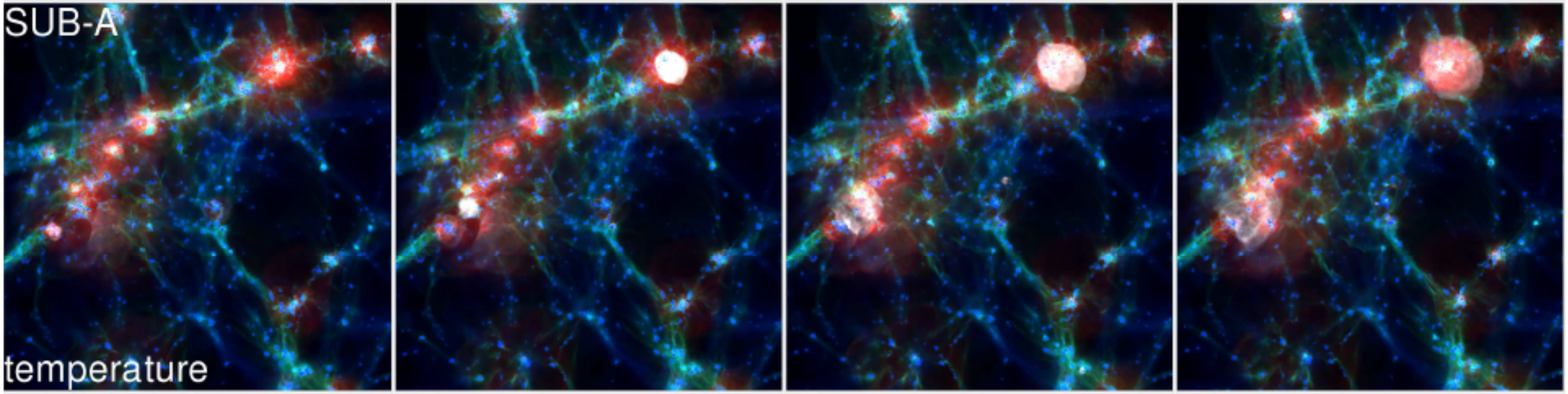
See Bluck et al. 2014, 2016, 2019a, 2019b & Teimoorinia, Bluck & Ellison 2016





A Theoretical Explanation:

"The General AGN Quenching Argument"



An Example – Illustris (Vogelsberger et al. 2014a,b)

1) $P_Q \propto f\,(W_Q - \phi_{act}) = f\,(\varepsilon E_{QM} - \phi_{act})$

2) $E_{BH} = \eta c2 \int \frac{dM_{BH}}{dt} dt \propto M_{BH}$ (Theory)

3) $M_{BH} = f\,(\sigma_c) \sim (\sigma_c)^{\alpha}$ (Observations)

$\therefore$ $P_Q = f\,(\sigma_c)$ $\{+ \xi_{halo} + \xi_{gas} + \ldots\}$

$$f_{Quench} \sim f\,(\sigma_c)$$

As observed!