Resolved Main Sequence in Local SFGs Following Two Star-Forming Scenarios

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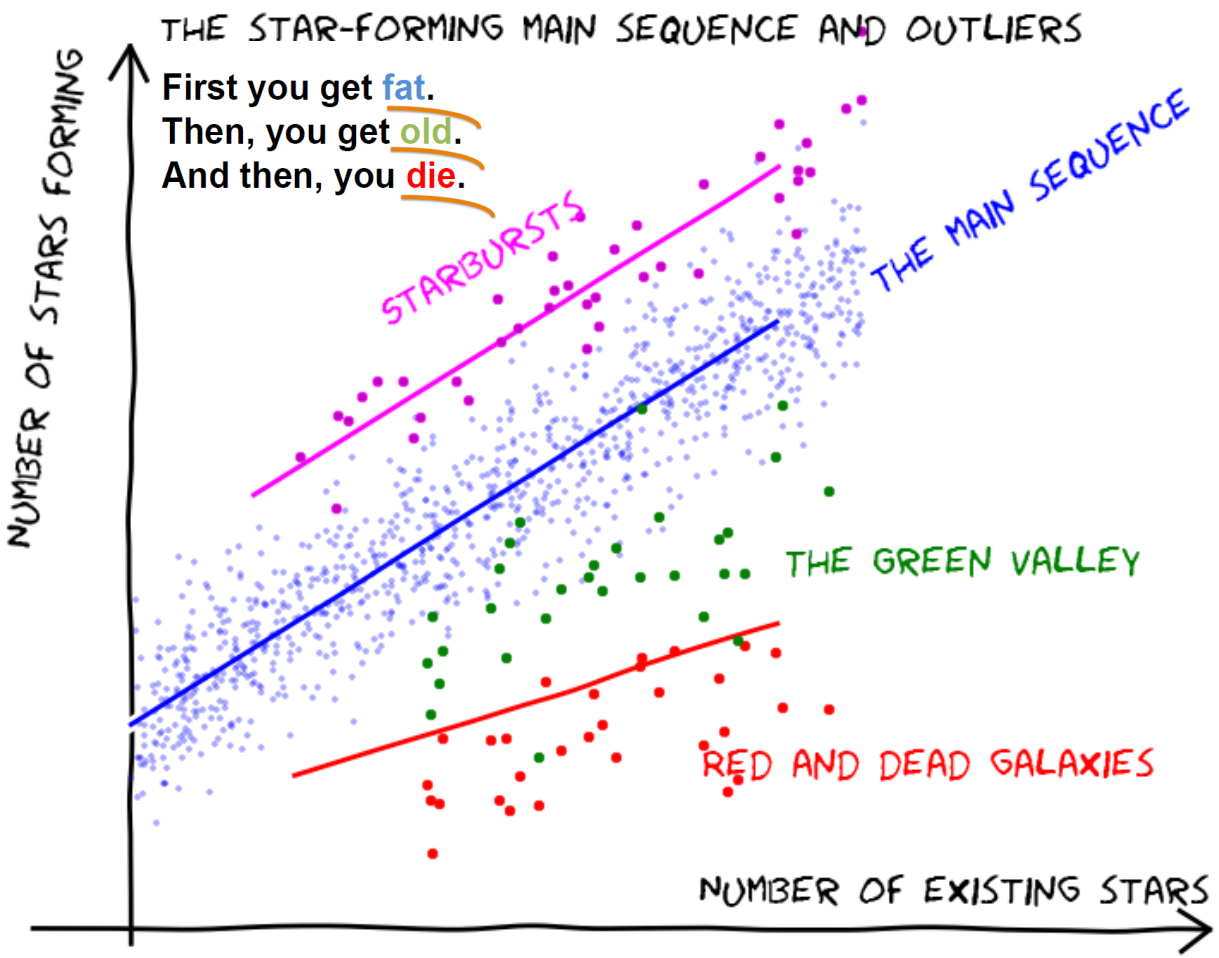
SFR : star formation rate

M_* : stellar mass

Introduction

■ Star-Forming Main Sequence (SFMS)



- One of the MOST FAMOUS relationships in extragalactic studies.
- The intensity of current star formation scales with its products over the cosmic time:

$$SFR \propto M_*^{\alpha}$$

- Holds from the local universe (Brinchmann et al. 2004; Salim et al. 2007) to the high-redshift one (Daddi et al. 2007; Noeske et al. 2007) with an evolution over the cosmic time.

■ Sub-Galactic Main Sequence (SGMS)

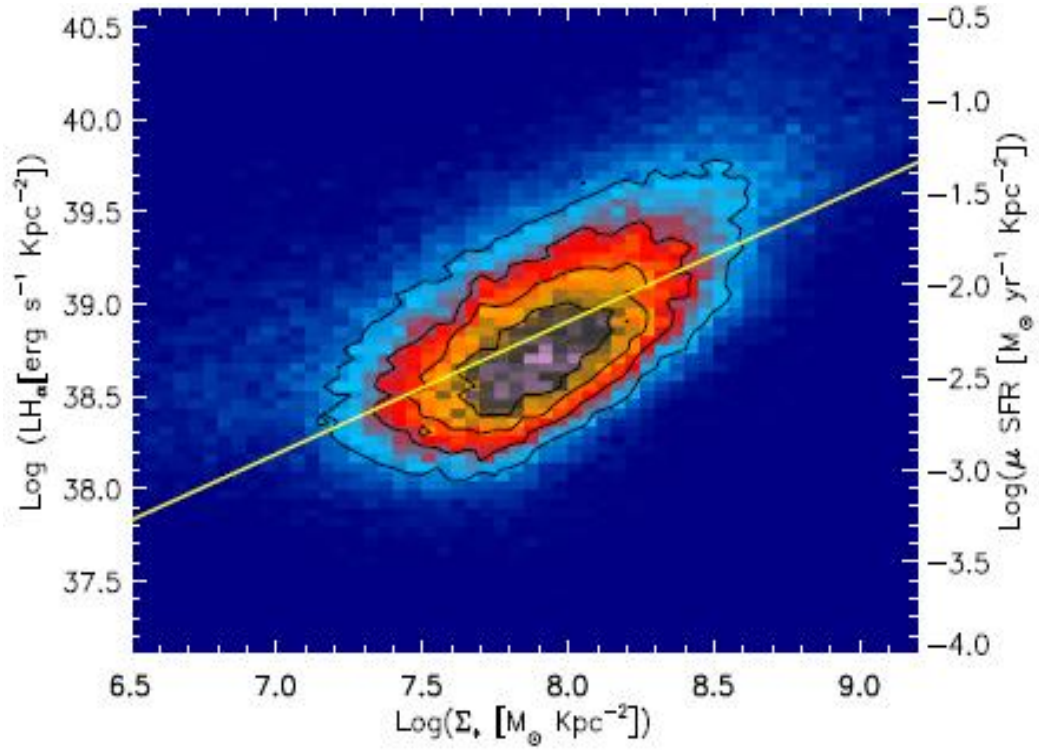
- It has been revealed only recently that **such correlation holds tightly on a spatially-resolved scale.**
- Associates the **surface density of star formation (Σ_{SFR})** and the **surface density of stellar mass (Σ_*)**
- *A more fundamental relation between local star-forming activities and the underlying stellar populations.*

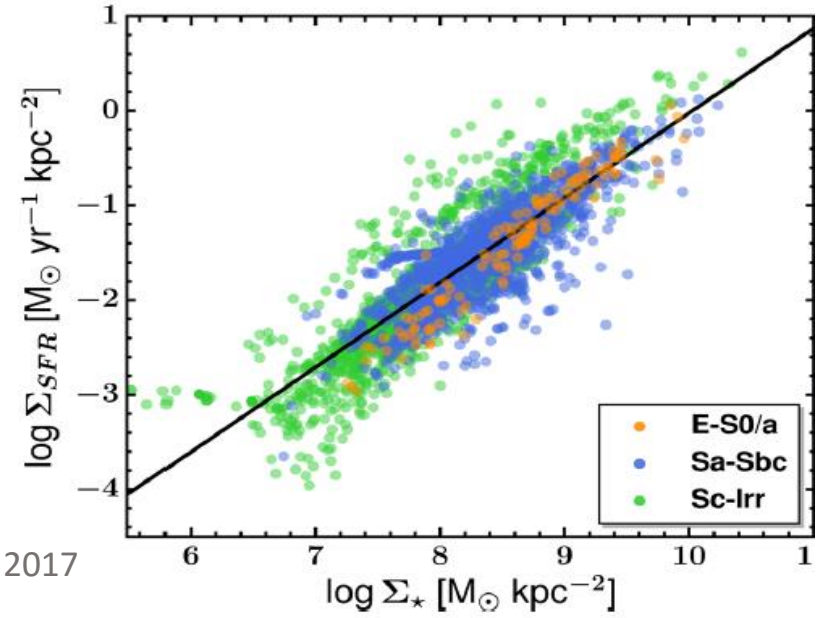
E.g. Wuyts et al. (2013) : CANDELS + 3D-HST

Cano-Diaz et al. (2016) : CALIFA IFS survey

Maragkoudakis et al. (2017) : IRAC Photometry

Abdurro'uf et al. (2017) : GALEX + SDSS



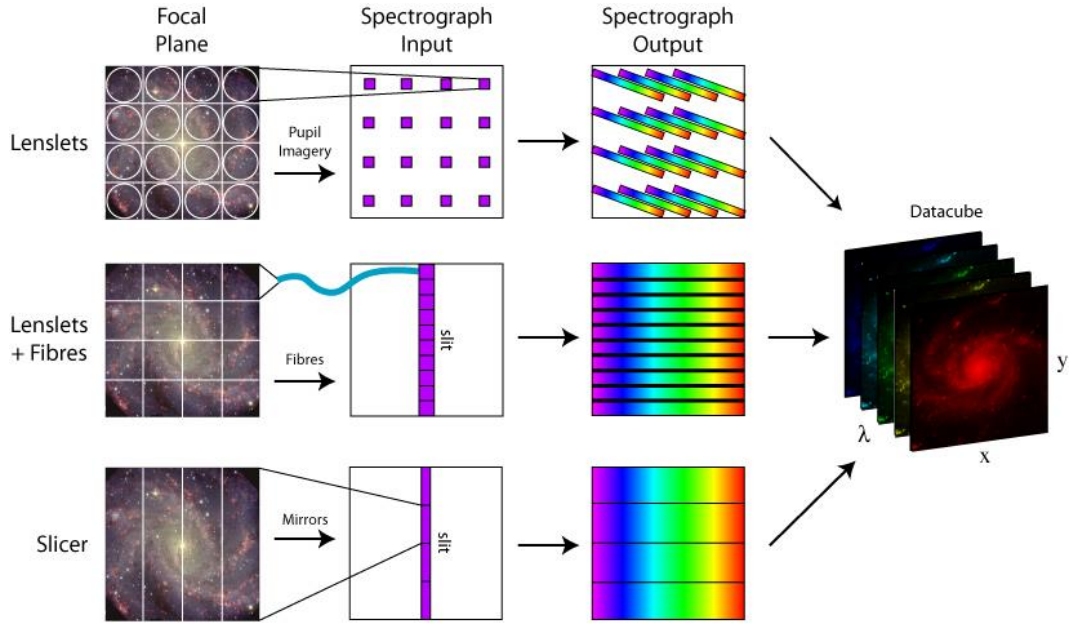


Up : Cano-Diaz et al. 2016

Down : Maragkoudakis et al. 2017

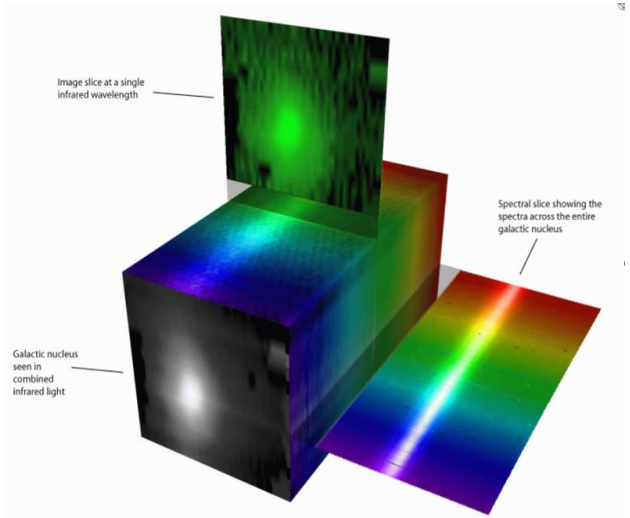
Integral Field Spectroscopy (IFS)

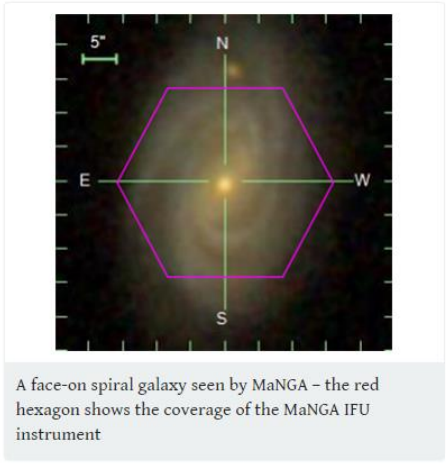
- Obtaining **two-dimensional spatially-resolved spectroscopic information** at the same time.
- E.g. CALIFA , MaNGA , SAMI , MUSE…...
- IFS is extraordinarily suitable to study **the SGMS** and give insights on the nature of local star forming activities.



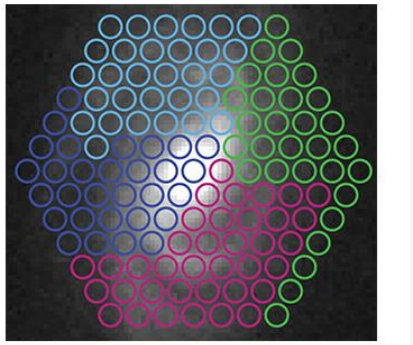
SDSS-IV MaNGA : high data quality

+ large statistical sample

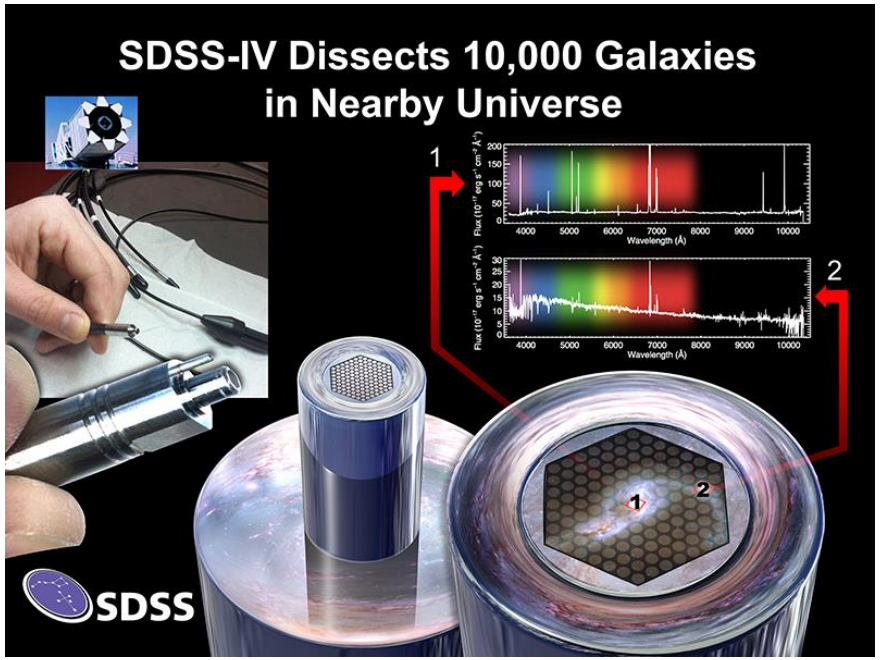




A face-on spiral galaxy seen by MaNGA – the red hexagon shows the coverage of the MaNGA IFU instrument

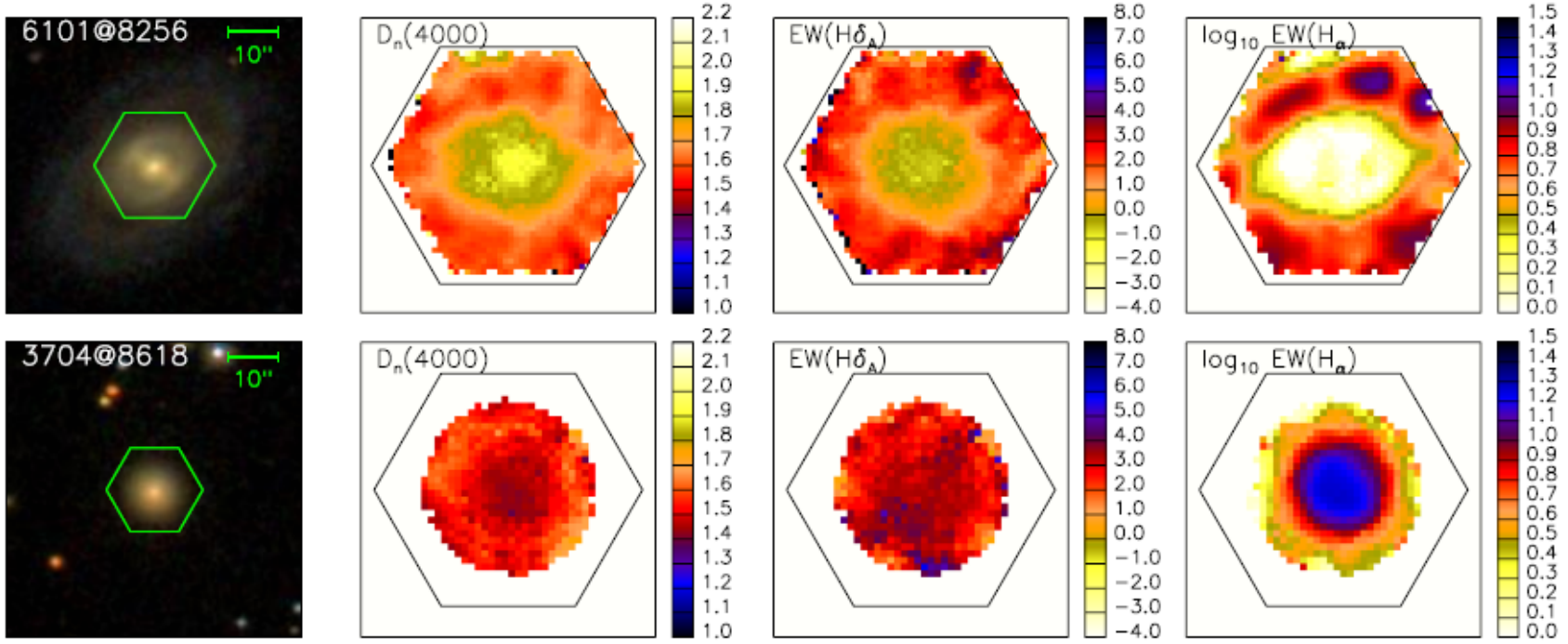


The same spiral galaxy, now showing circles for the individual IFU fibers



■ Two types of star-forming scenario *(mass assembly mode)*

- Recent studies have revealed that galaxies appear to assemble their stellar mass following two types of scenarios: (e.g. Pan et al. 2016, Ibarra-Medel et al. 2016, Goddard et al. 2017, Li et al. 2015, Perez et al. 2013)



'inside-out'

'outside-in'

- This two populations have prominent **distinctions in their properties**, e.g. galaxies following **'outside-in'** scenario have smaller size, larger concentration, and larger global gas-phase metallicity than those following **'Inside-out'** scenario (Wang et al. 2017).

☐ This work commits to answer:

1) whether sub-galactic regions in galaxies with different assembly modes present different behaviors (patterns) on the main sequence;

2) whether properties of their host galaxies modulate their local star formation to some extent.

- Throughout this work, we adopt a Chabrier (2003) IMF and a cosmology with $H_0 = 70$ km $s^{-1}Mpc^{-1}$, $\Omega_M = 0.3,\ \Omega_\Lambda = 0.7$.

SFG : star-forming galaxy

Data

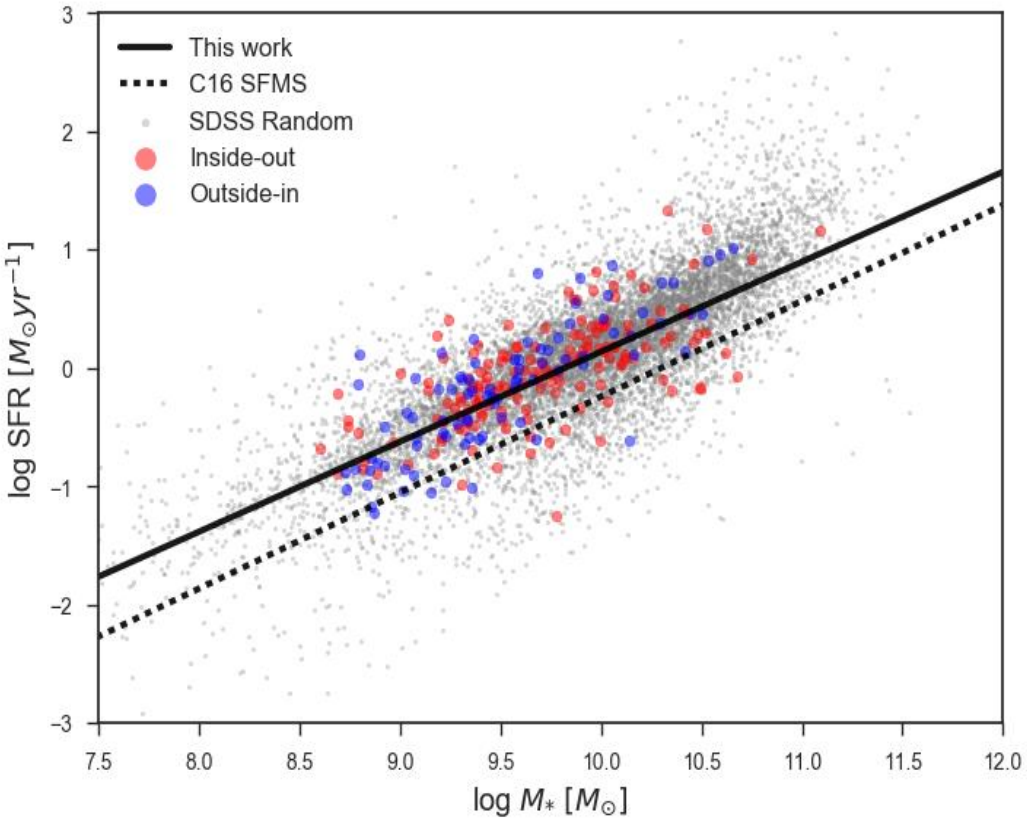
■ Galaxy sample

- **398 SFGs** from the SDSS-IV **MaNGA DR13** survey
- Selection based on *bptclass* from MPA-JHU catalog

  $8.3 < \log(M_*/M_\odot) < 11.1$; $-2.0 < \log(\mathrm{SFR}) < 1.3$

  $0.01 < z < 0.13$; $\bar{z} \cong 0.03$

- Inclination $< 60^o$ ⇨ $b\ /\ a > 0.5$



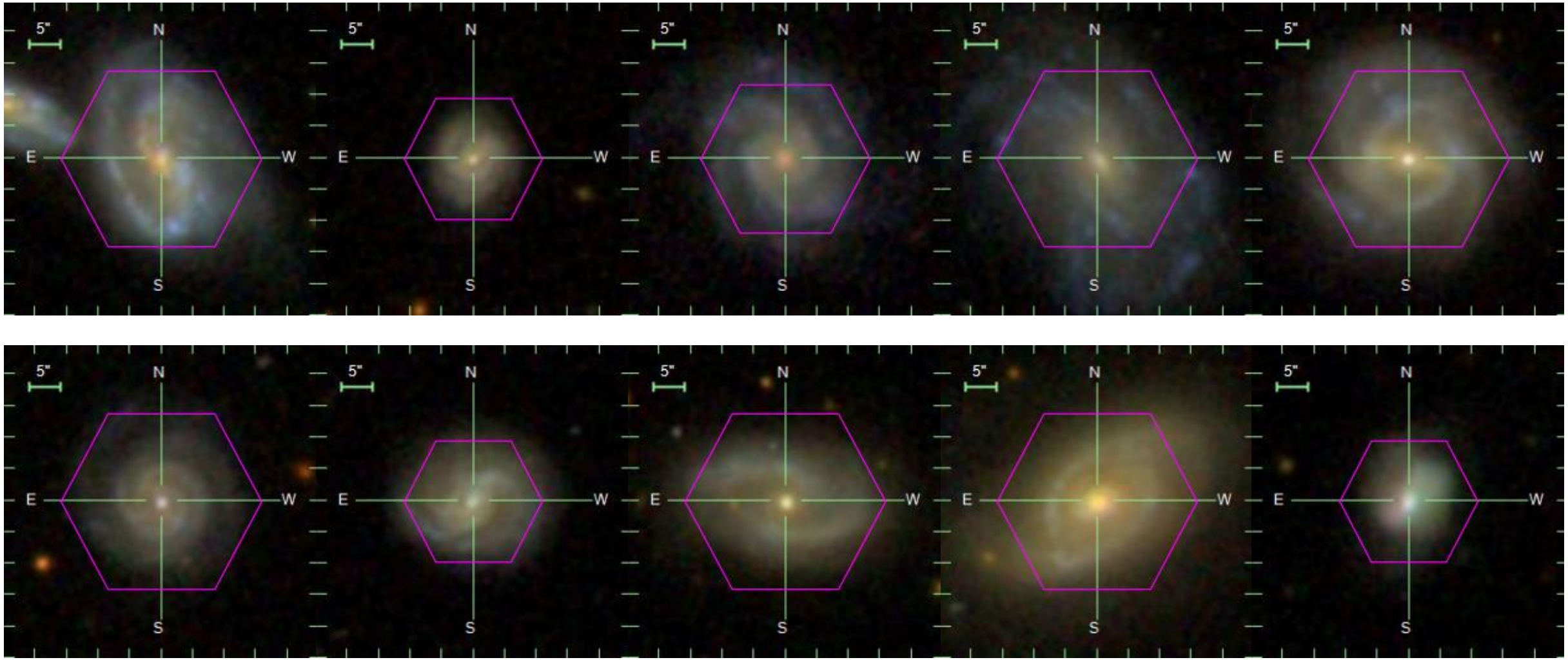
153 'inside-out' + 89 'outside-in'

- Classification based on information from spatially resolved 4000 Å break, $D_n(4000)$:

  'Outside-in' : $D_n(4000)_{1.5\,Re} > D_n(4000)_{center}$

  'Inside-out' : $D_n(4000)_{1.5\,Re} < D_n(4000)_{center}$

(See details in Wang 2017)



Up : ‘Inside-out’ galaxies

Down : ‘Outside-in’ galaxies

■ Continuum Reduction & Emission-line Fitting

STARLIGHT (Cid Fernandes et al. 2005) + **MPFIT** (Markwardt et al. 2009)

\+ **BC03 Library** (Bruzual & Charlot 2003)

■ Spaxels Extraction & Filtering

- Correction for dust attenuation using **Balmer decrements**
- SFR : **Kennicutt (2012) conversion (H_α tracer)**
- M_* : STARLIGHT results
- Divided by corresponding sky area derived from distance

  ➡ Σ_{SFR} and Σ_* in units of $\log(M_\odot\ yr^{-1}\ Kpc^{-2})$ and $\log(M_\odot\ Kpc^{-2})$

- Selection Criteria:

  1) SNR of H_α > 3 across field-of-view

  2) $EW(H_\alpha) > 6$ Å (Cid Fernandes et al. 2011)

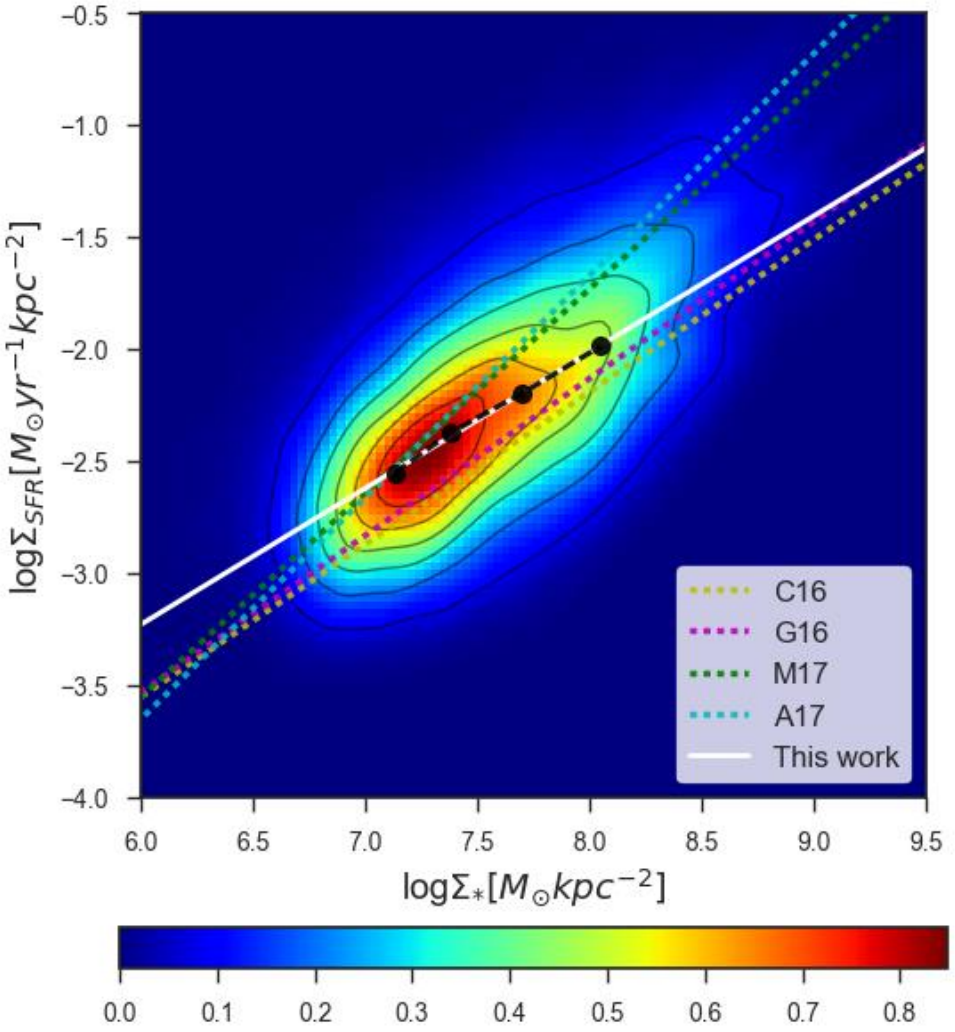
  3) BPT below Kauffmann (2003) limit

Excluding effects caused by AGNs/post-AGBs

- Assuming $(H_\alpha/H_\beta)_0 = 2.86$
- Calzetti (2000) extinction law
- Manually setting $E(B-V) = 0$ under conditions that $(H_\alpha/H_\beta) < 2.86$

Results

- Sub-Galactic Main Sequence in MaNGA



(Fig.2 in Liu et al. in prep.)

$$\log(\Sigma_{SFR}) = \alpha \log(\Sigma_*) + \beta$$

KDE (Kernel Density Estimation)

Black circles: modes at 20%/40%/60%/80% quantiles of Σ_* distribution

Count	184983
α	0.61
β	6.87
Scatter	0.38
Pearson's R	0.67

C16 : Cano-Di*á*z et al. 2016

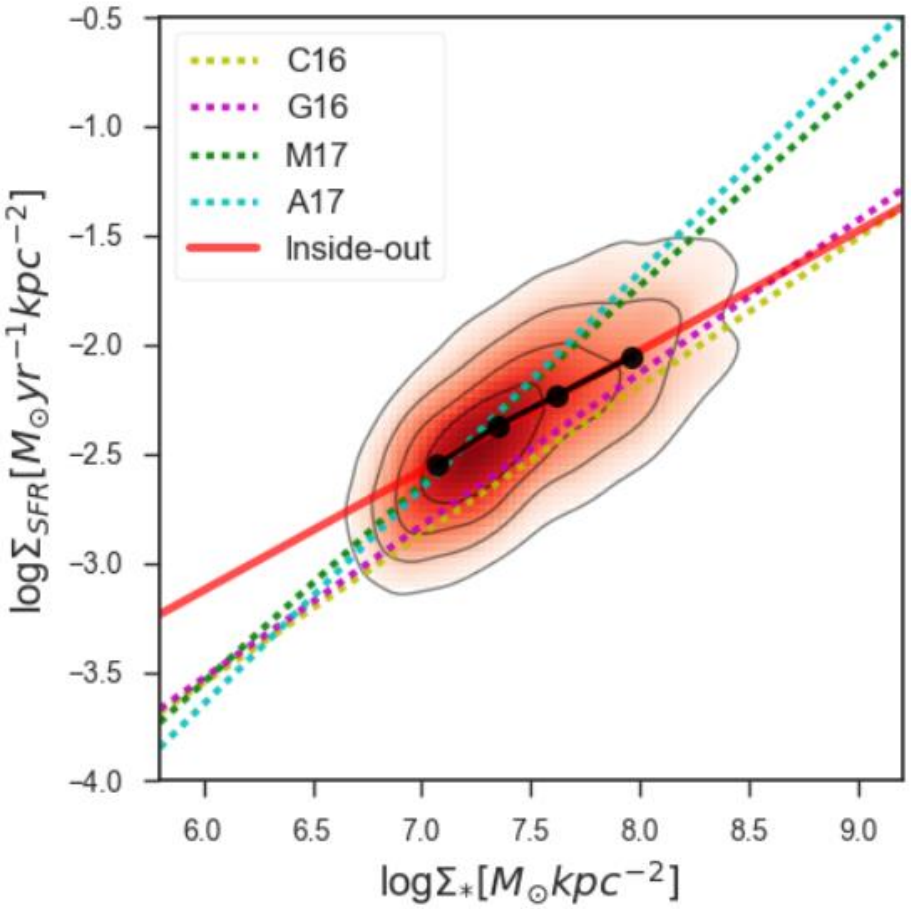
G16 : Gonz*á*lez et al. 2016

M17 : Maragkoudakis et al. 2017

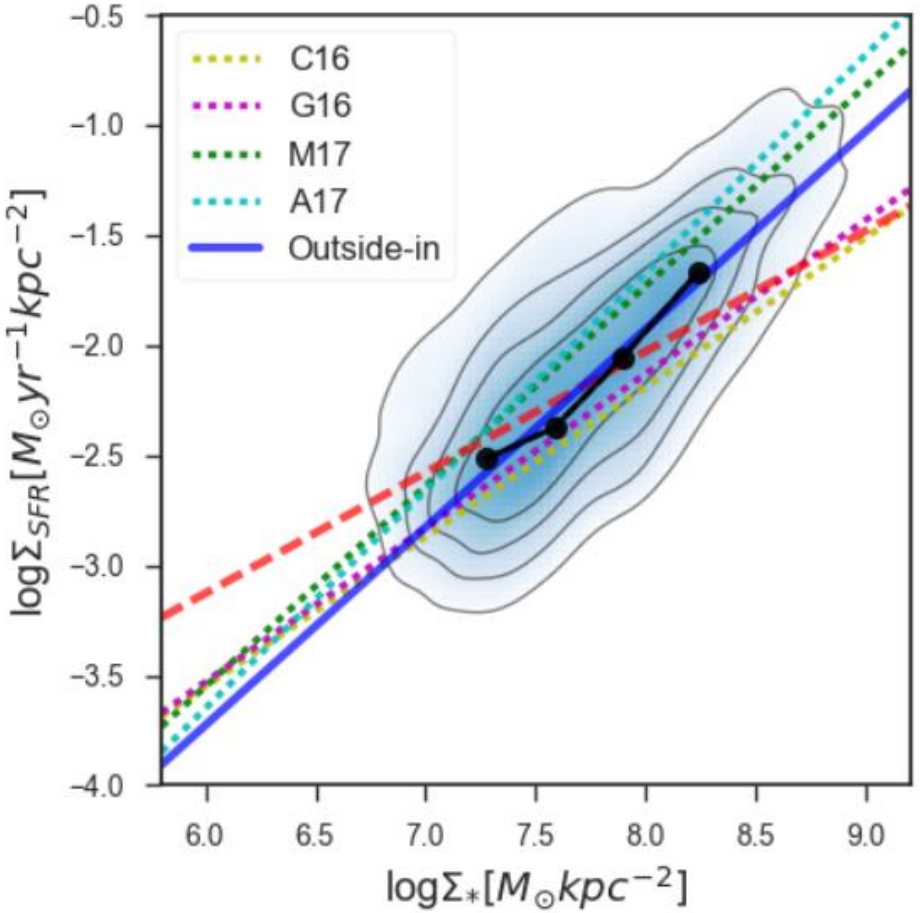
A17 : Abdurro'uf et al. 2017

■ SGMS in two star-forming scenarios

(Fig.3 in Liu et al. in prep. Left: Inside-out Right: Outside-in)

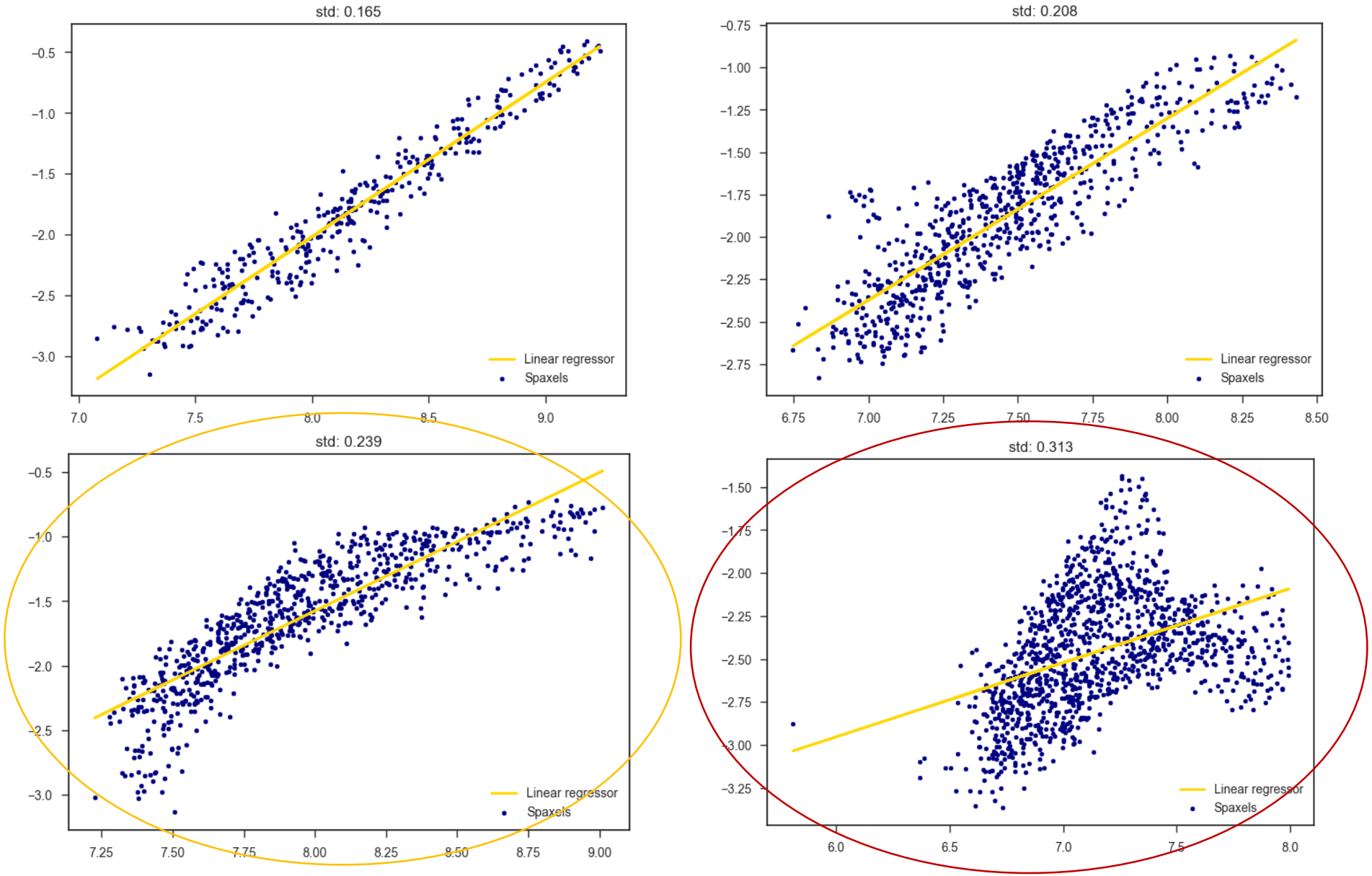


Count	141553
α	0.55
β	6.42
Scatter	0.36
Pearson's R	0.64



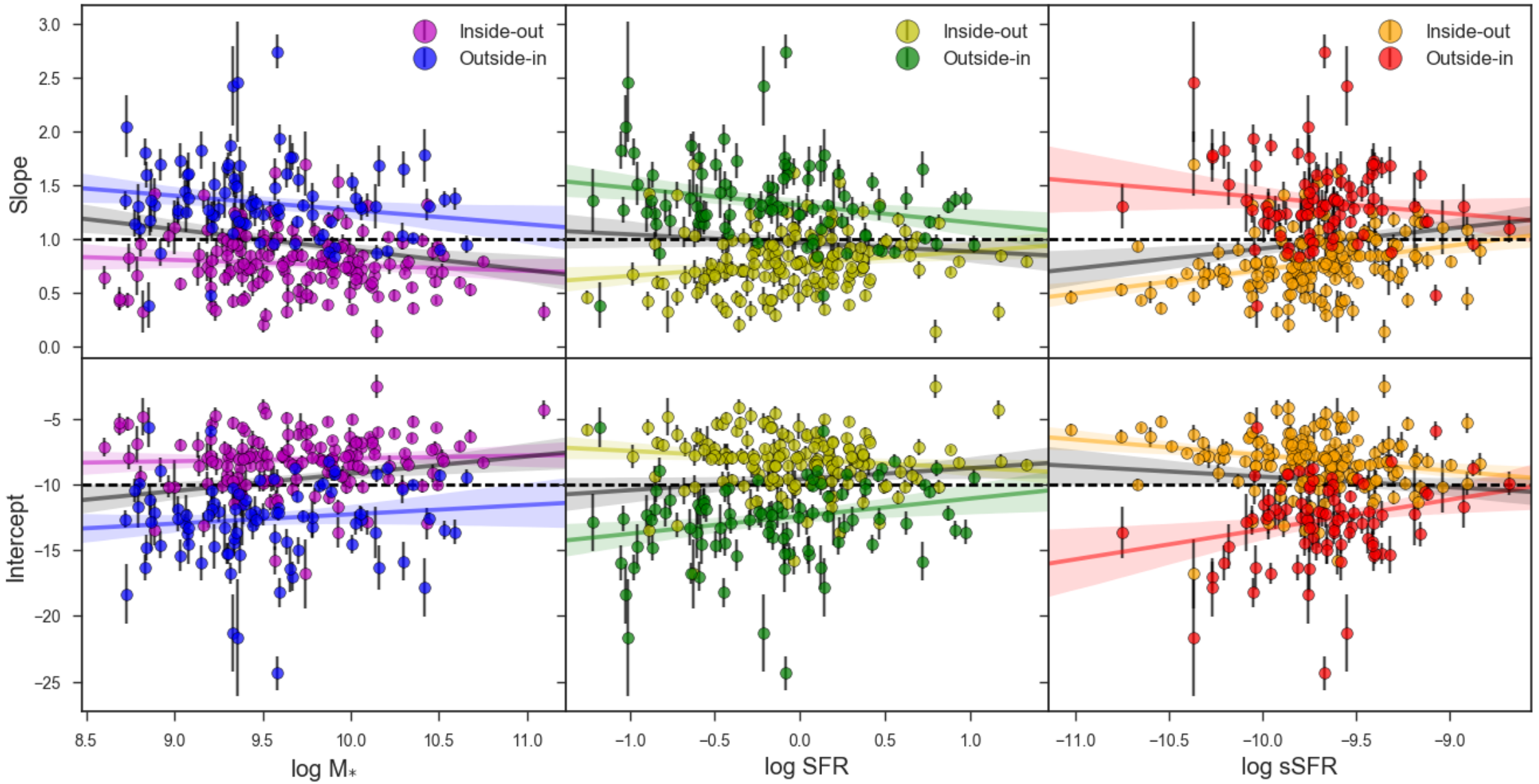
Count	43430
α	0.90
β	9.12
Scatter	0.42
Pearson's R	0.70

- SGMS within individual galaxies (G-by-G)



■ SGMS within individual galaxies

(Fig.4 in Liu et al. in prep.)



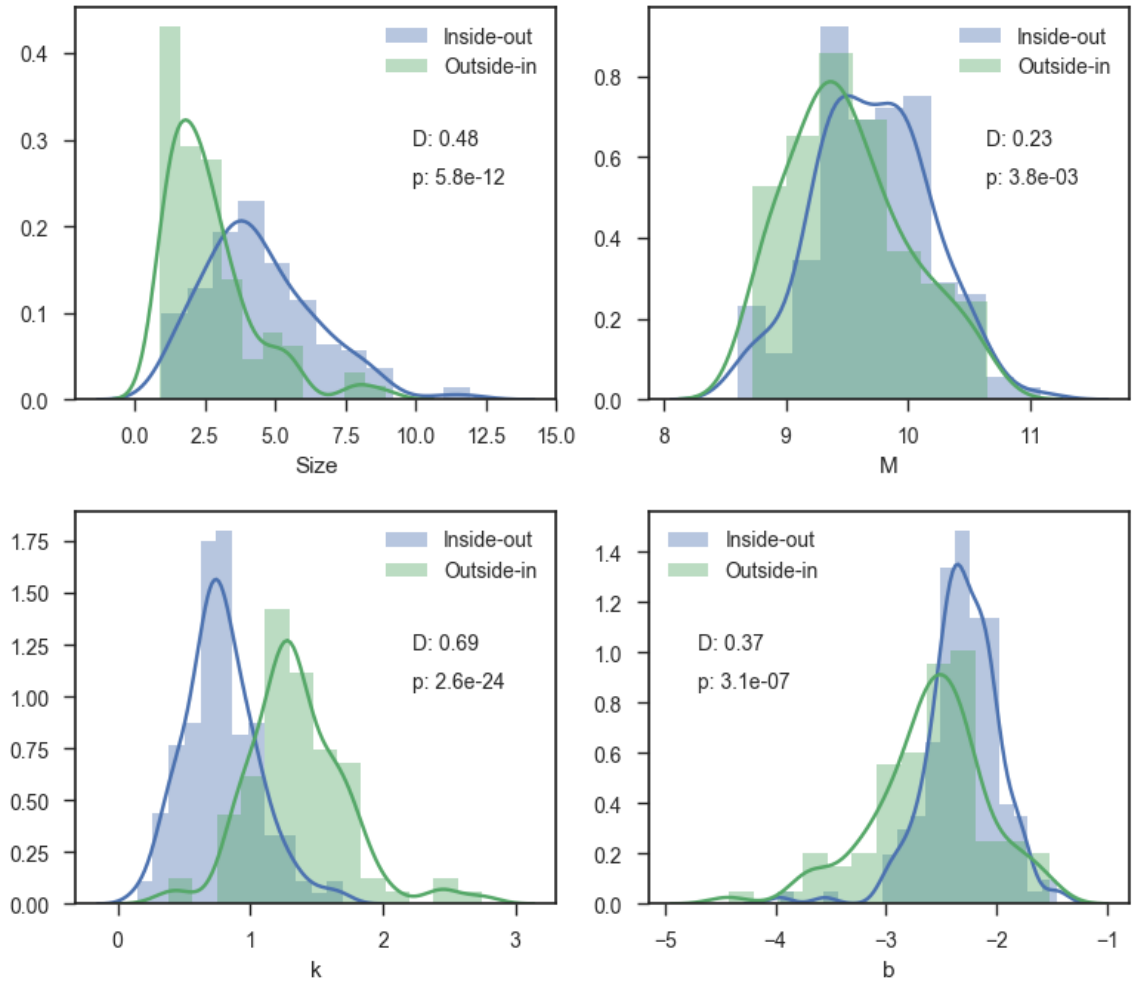
■ SGMS within individual galaxies

- **The two populations can be discriminated clearly:**

  'Outside-in' galaxies ➡ superlinear

  'Inside-out' galaxies ➡ sublinear

- Two-sample K-S test indicates difference in distributions with a significance level of 0.01



- **Their differences in correlations with global properties of galaxies become more clear:**

  ➢ For 'outside-in' galaxies,

  slope has a negative correlation with M and SFR of the galaxy while having large scatter with sSFR.

  ➢ For 'inside-out' galaxies,

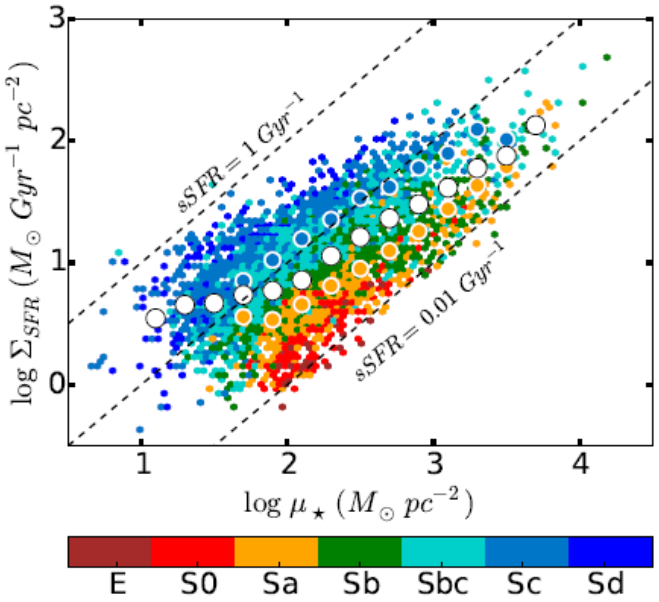
  no conspicuous trends with M but a slight positive correlation with SFR and sSFR.

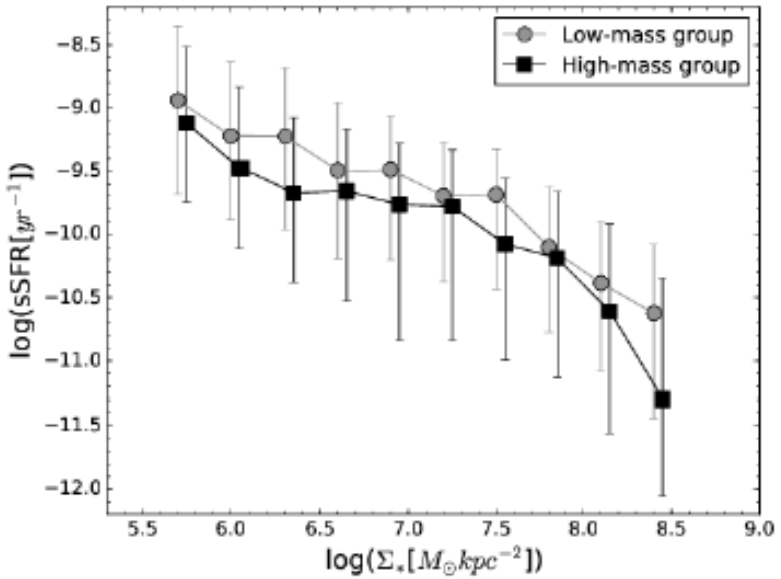
Discussion & Conclusion

- Due to the fact that star formation is a local self-regulated procedure, one would naturally infer that **sub-galactic relations are more fundamental than the integrated ones**.
- It turns out that **local ongoing star formation can be well tracked by its past harvests.**
- G16 ： a gradient along Hubble sequence in SGMS ⇨ **morphological dependence**

  C16 ： no dependence on M for the SGMS of the galaxy

  A17 ： more massive galaxies tend to have lower local sSFR than the less massive.





Left : Gonzalez et al. 2016

Right : Ab'duroff et al. 2017

■ Our results show that **the mass assembly mode of the galaxy leads to distinct behaviors on the SGMS panel :**

- Inside-out ： the local star formation traced is gentler in its sub-regions
- Outside-in ： the local SF traced by equivalent stellar mass is stronger

➢ According to Wang (2017), outside-in galaxies are likely in transitional phase from star-forming to quiescent

⇨ Transforming SFGs have stronger star-forming activities?

■ **Try another approach to study dependence of SGMS on integrated properties :**

By categorizing spaxels with regards to properties of host galaxies (e.g. strong-SF, low-massive and etc.)：