"AGN Feedback" or "Bulge Growth" ?

Exploring the Bent of SGMS in Inside-out Growing Galaxies

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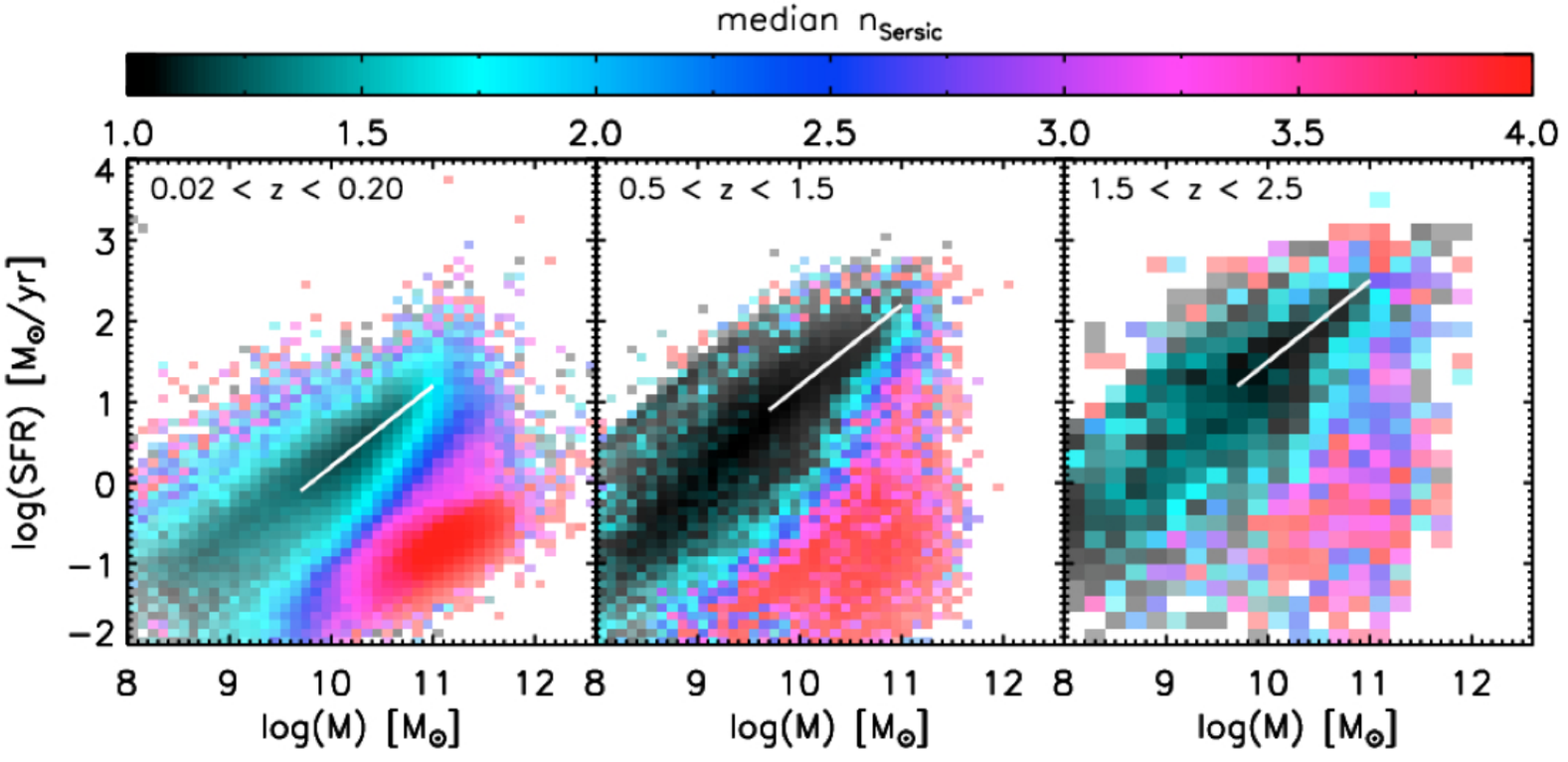
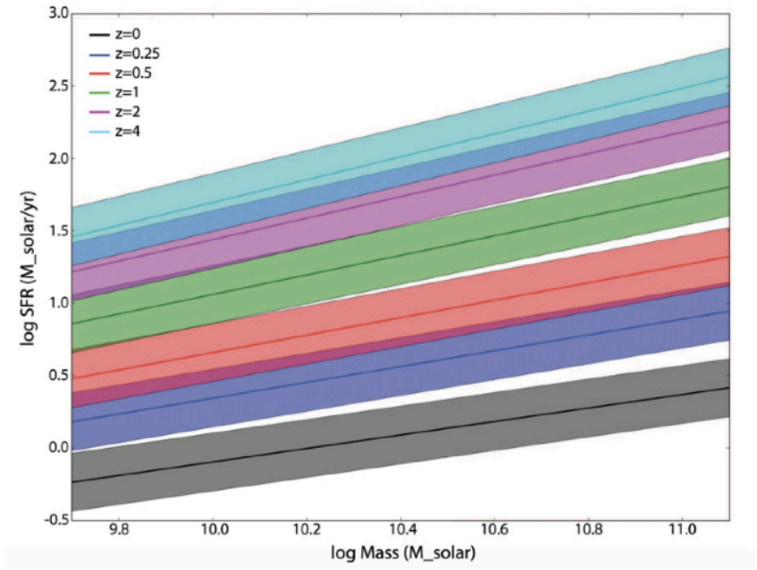
Introduction

Star-Forming Main Sequence (SFMS) : Correlation between the star formation rate (SFR) and the stellar mass (M*) for SFGs.

- One of the well-established relationships in galaxy formation and evolution
- Holds from the local universe (e.g. Brinchmann et al. 2004; Salim et al. 2007) to the high-redshift one (e.g. Daddi et al. 2007; Noeske et al. 2007; Elbaz et al. 2007)
- Evolved along with redshift (summarized in Speagle et al. 2014)



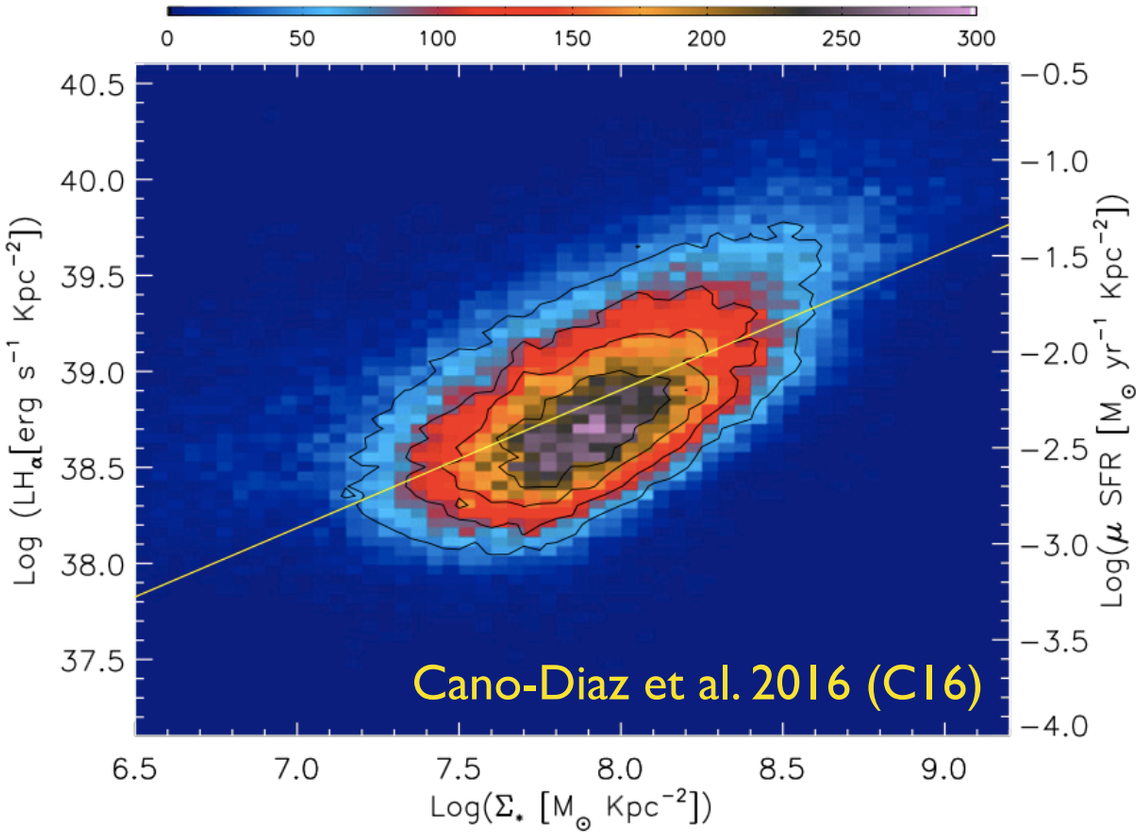
Wuyts et al. (2011)



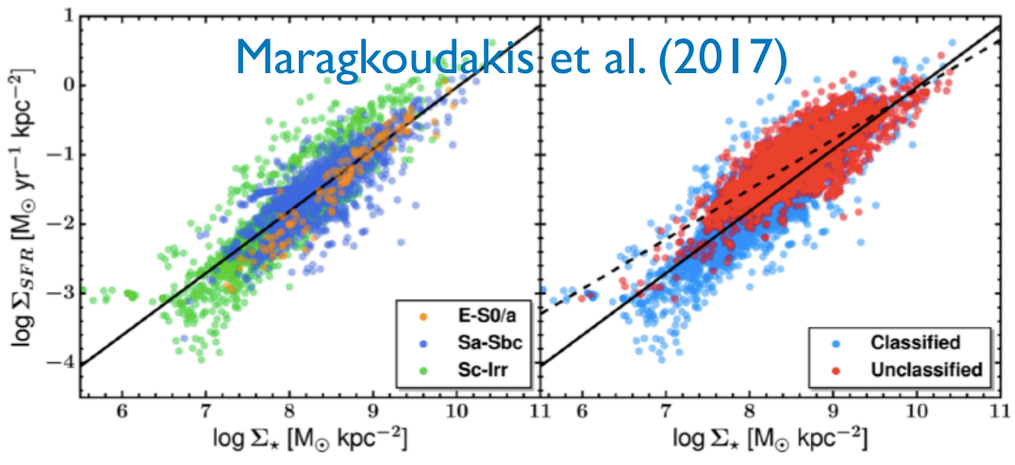
Speagle et al. (2014)

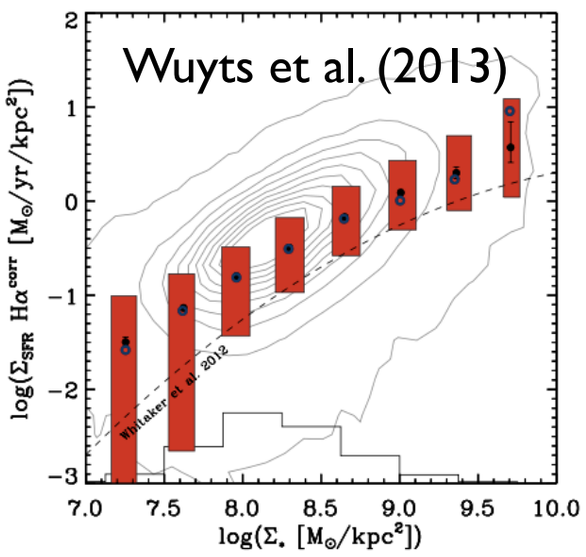
Sub-Galactic Main Sequence (SGMS) : Correlation between the surface density of SFR (Σ_{SFR}) and the surface density of stellar mass (Σ_{*}) for SFGs.

'Spatially-Resolved Star Formation Main Sequence'



- First reported in Sanchez et al. (2013).
- Also shown in Wuyts et al. (2013), Magdis et al. (2016), Cano-Diaz et al. (2016), Maragkoudakis et al. (2017), Abdurro'uf & Akiyama (2017) and Hsieh et al. (2017).





Slope : 0.7~1.0 **Scatter : 0.2 - 0.4**

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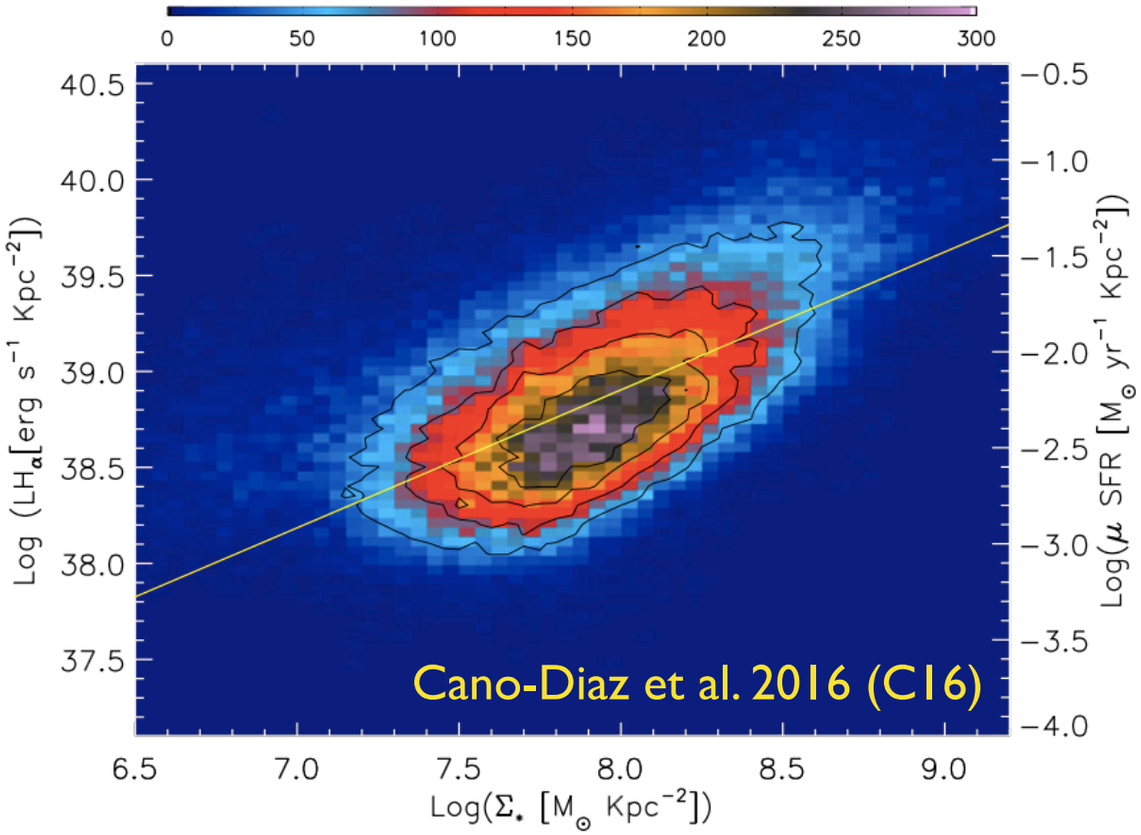

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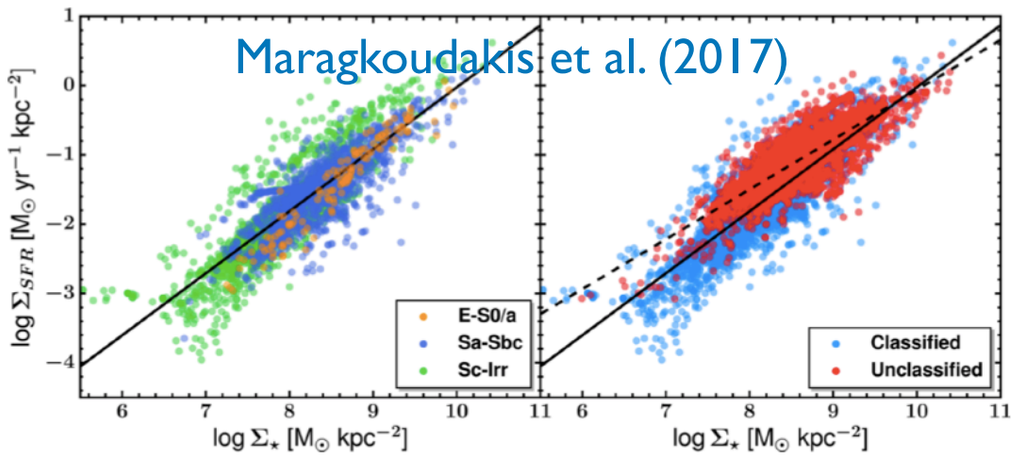

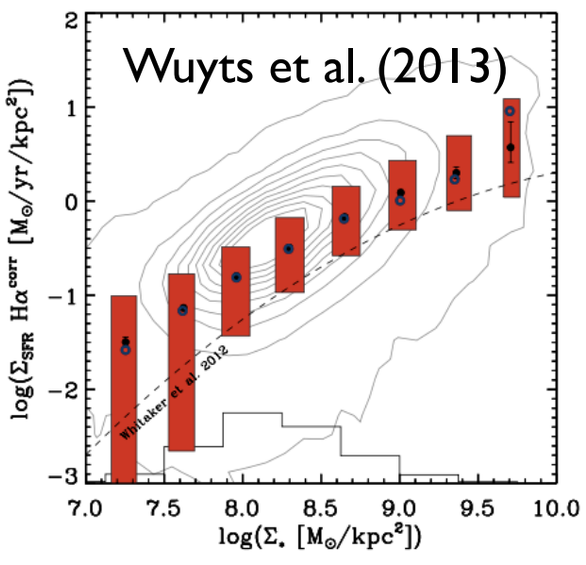

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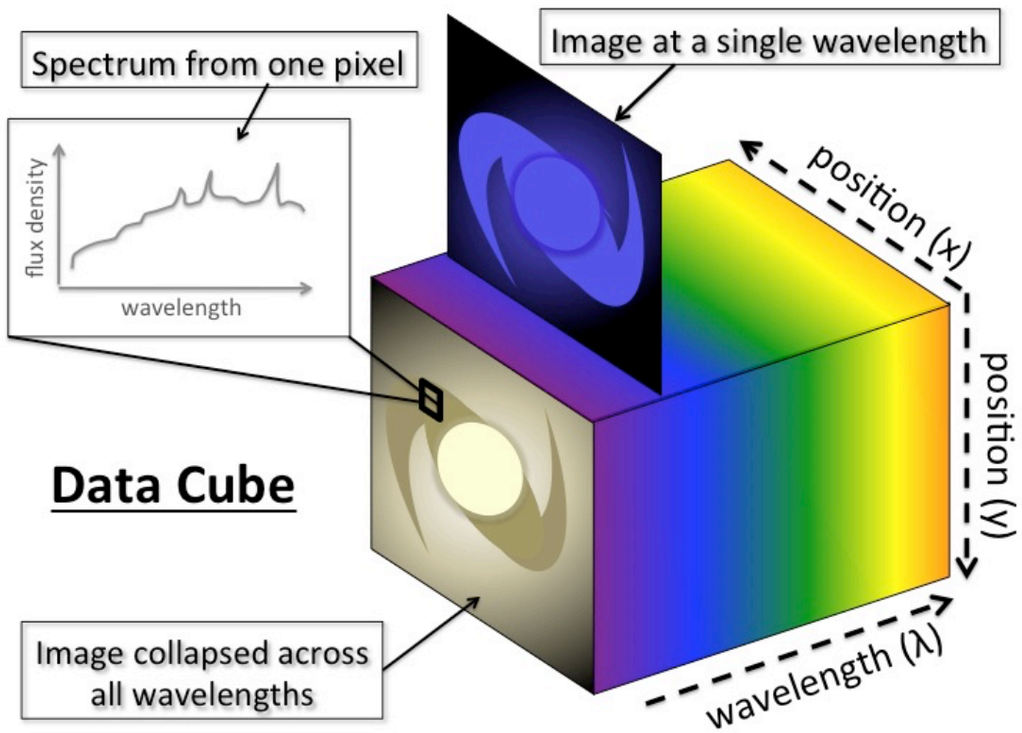
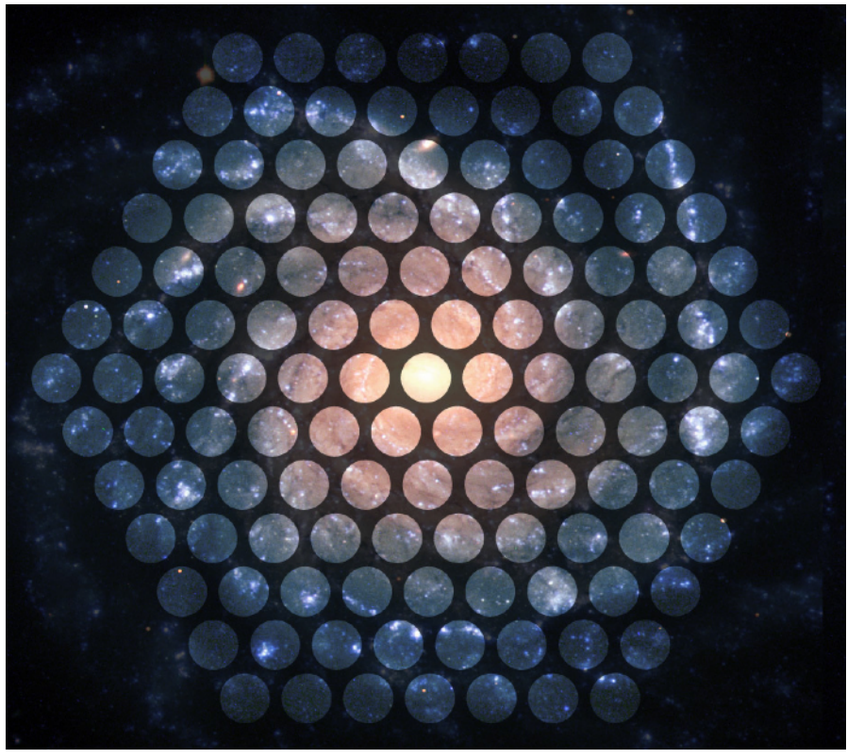
A more fundamental relation between local ongoing star-forming activities and the underlying stellar populations.

Integral Field Spectroscopy (IFS/IFU) : MaNGA, CALIFA, MUSE, SAMI……



Credit: Chris Harrison



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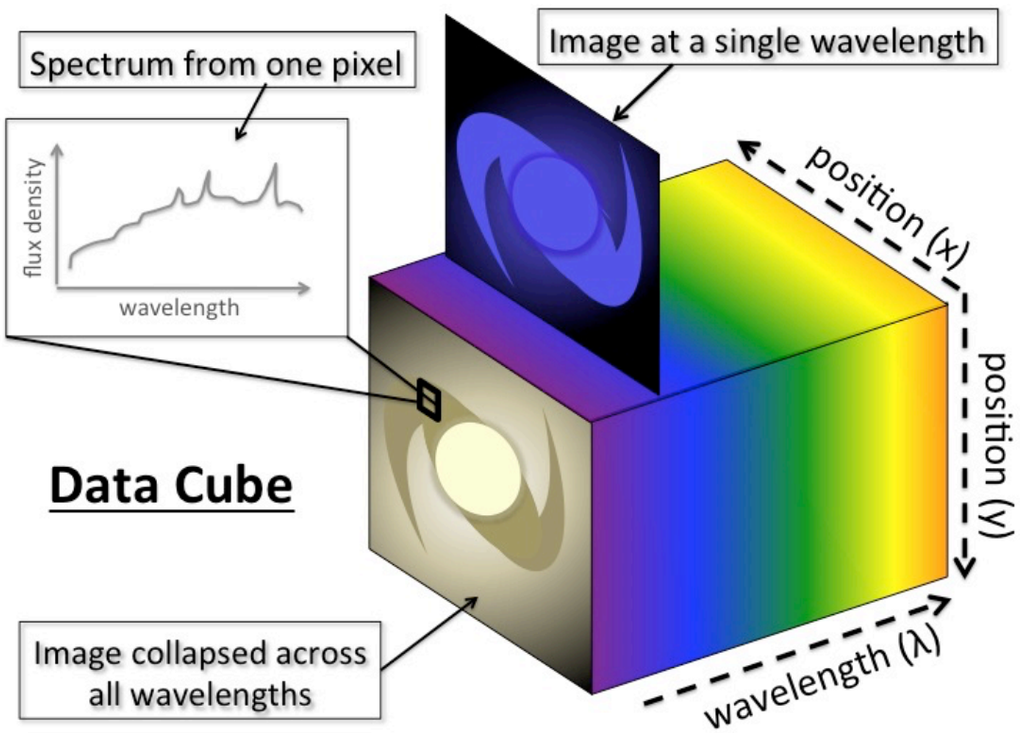

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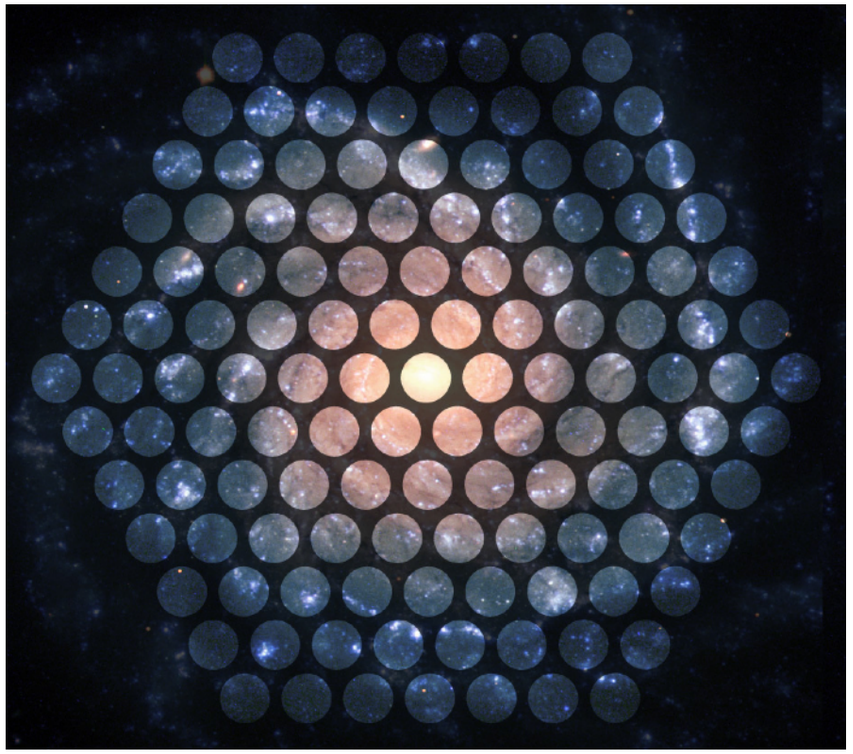

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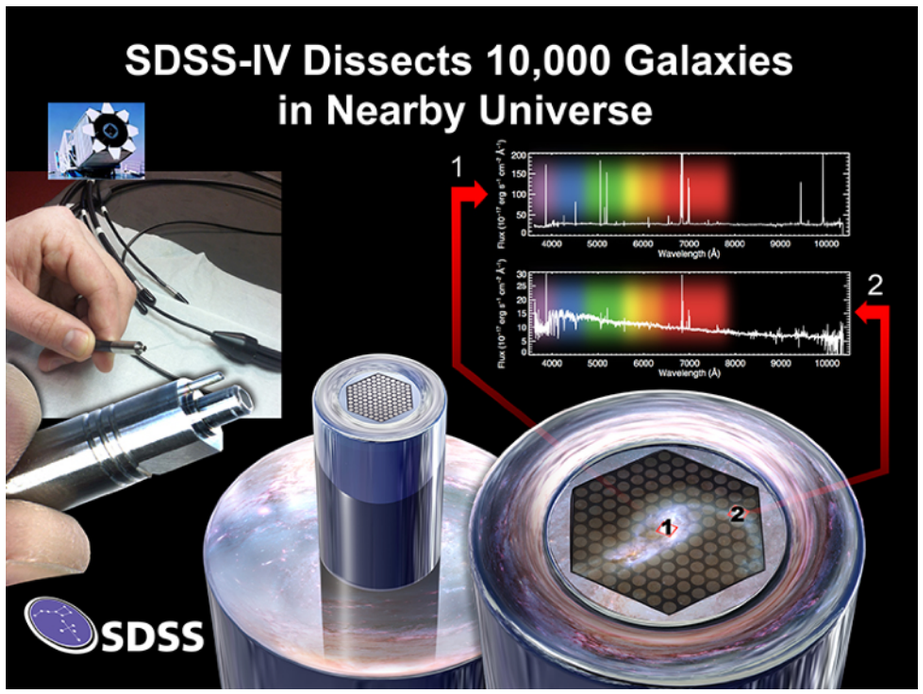
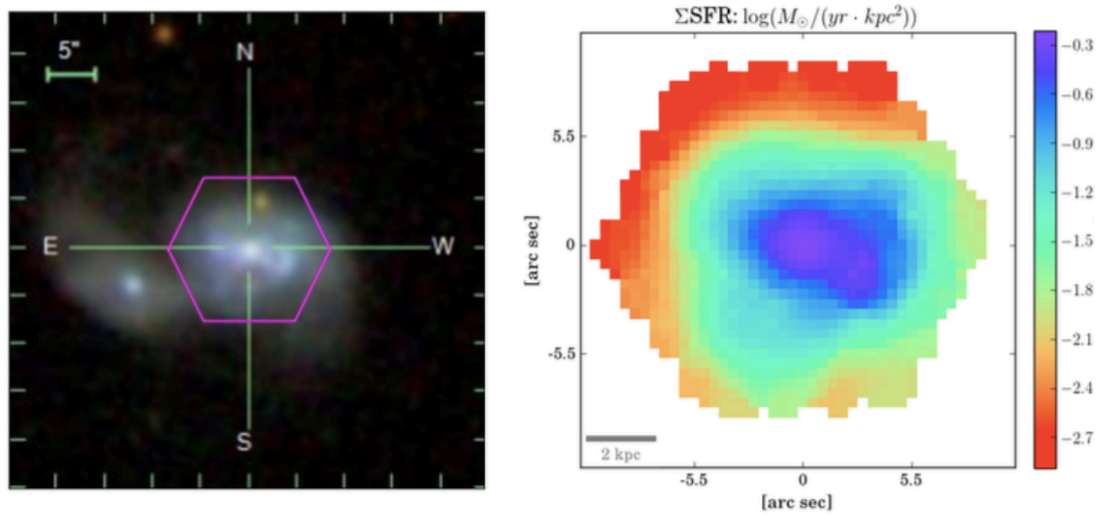


Credit: SDSS

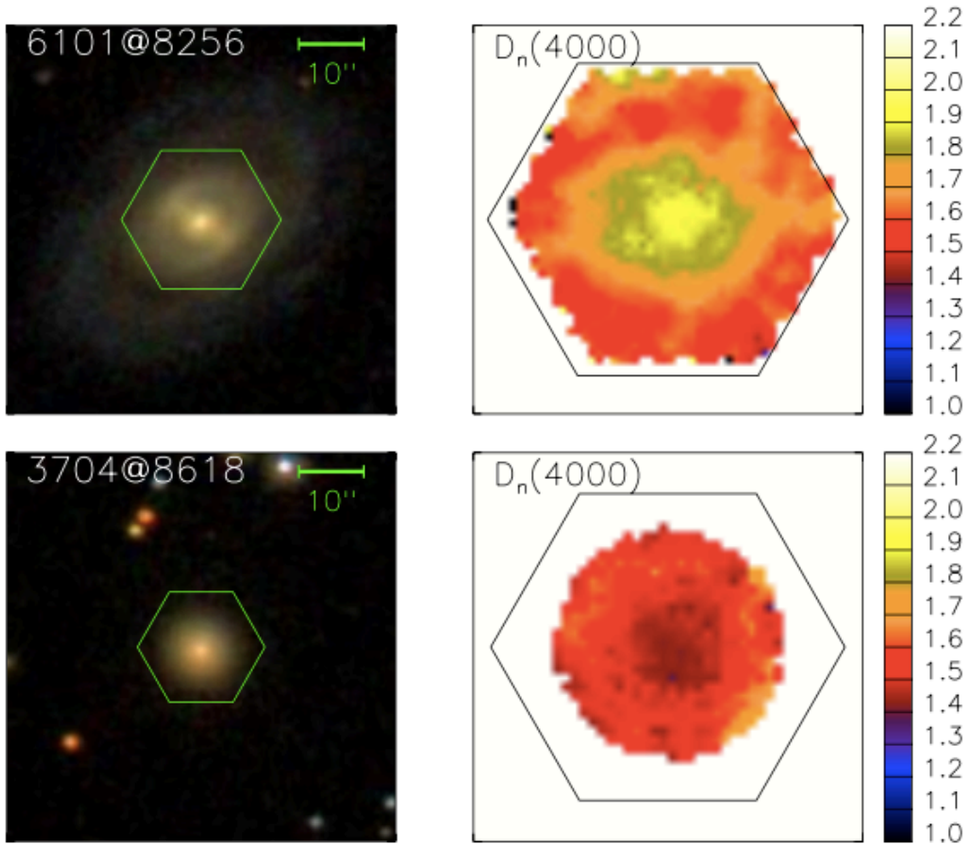


Ellison et al. (2017)

Single Fiber Measurement => Maps

Motivation

- With IFU data, galaxies can be divided into two populations according to their **assembly modes** (Perez et al. 2013; Pan et al. 2015; Ibarra-Medel et al. 2016; Goddard et al. 2017)
- Wang et al. (2017) used MaNGA to divide galaxies according to their recent assembly modes, and found the galaxies with recent 'outside-in' assembly modes have different properties.



Wang et al. (2017)

'Inside-out' galaxies

$D4000_{cen} > D4000_{1.5Re}$

IO-SFG

'Outside-in' galaxies

$D4000_{cen} > D4000_{1.5Re}$

OI-SFG

- We would like to know the processes of **star formation regulation** in these galaxies, e.g. their behaviors on SGMS.

Data Description:

- SDSS-IV MaNGA : ~2700 galaxies
- Data reduced by Pipe3D (Sanchez et al. 2016), publicly released (Sanchez et al. 2017).
- Salpeter (1955) IMF + Calzetti (2000) dust attenuation law
- Kennicutt (1998) conversion

Selection Criteria

- Face-on : b/a > 0.5
- SFG : NUV - r < 4
- Optical extension : Field-of-view > 2 Re
- SF Spaxel : Kewley et al. (2001) line on BPT + EW(Ha) > 6Å (Sanchez et al. 2017)
- S/N(Ha) > 3, S/N of other lines > 1

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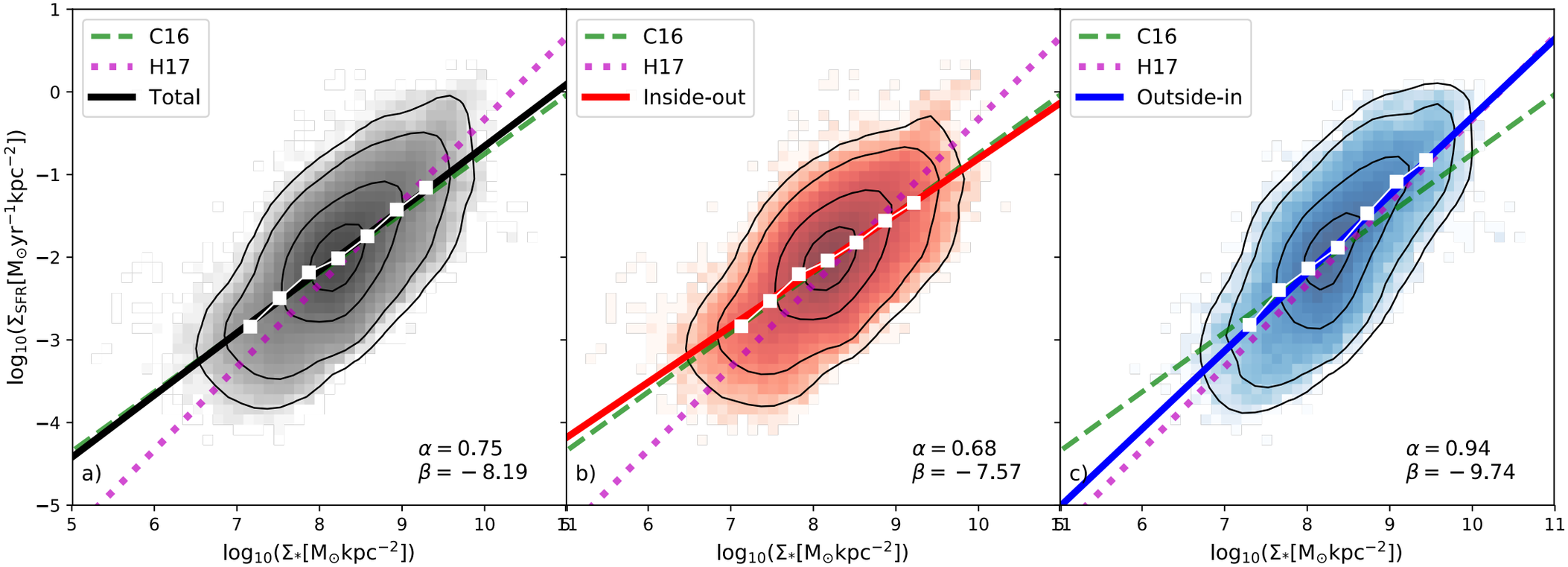
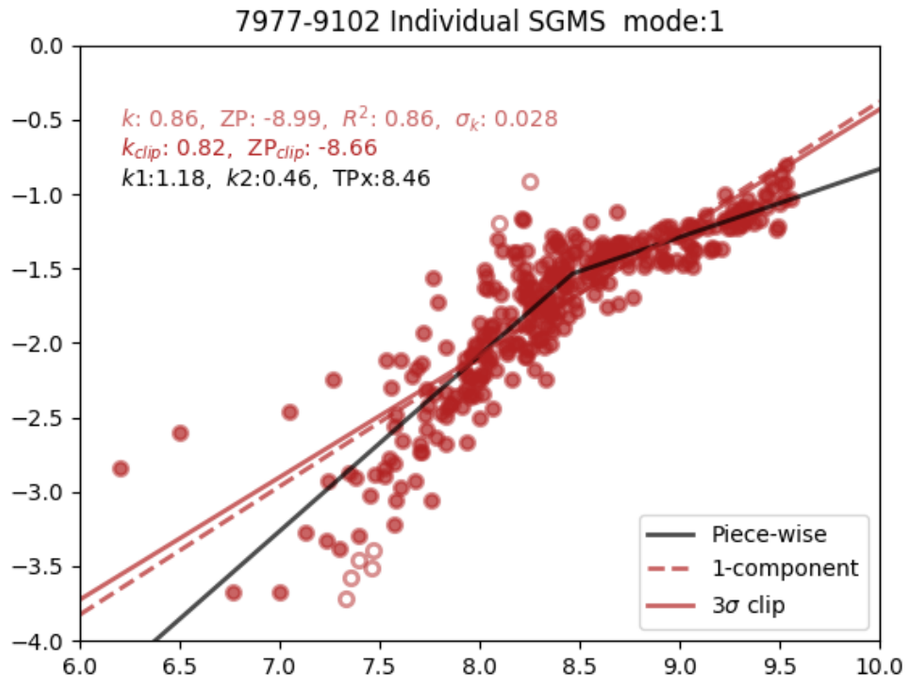
Fig 2 in Liu et al. (submitted to ApJ)

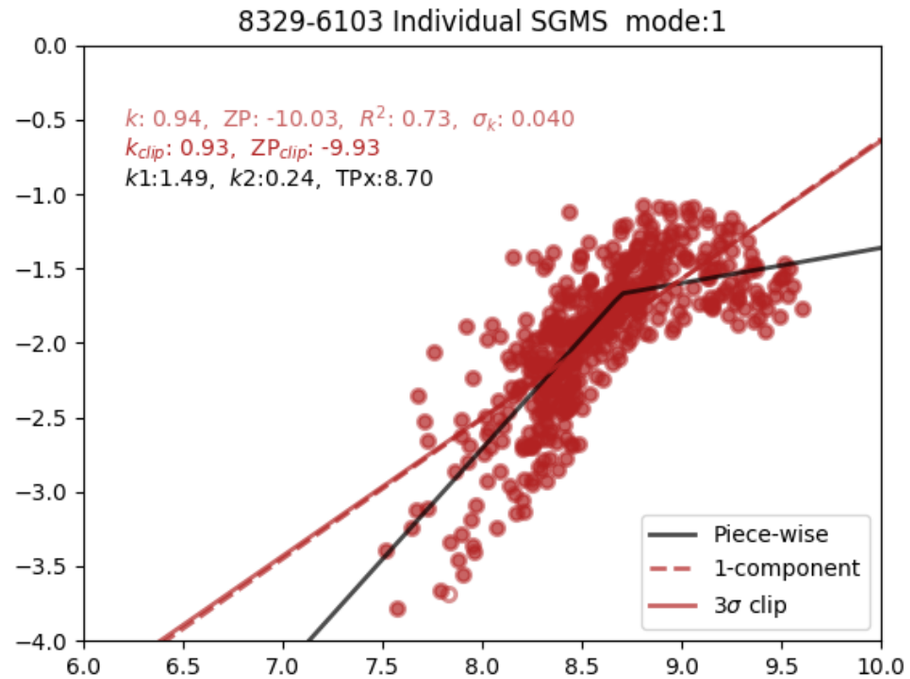


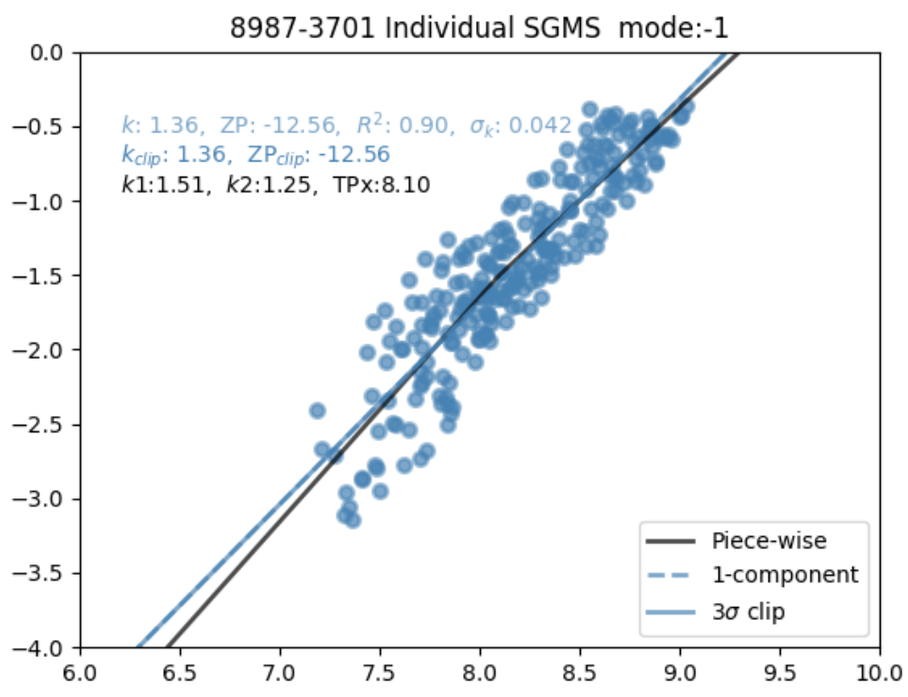
☆ SGMS in **outside-in** galaxies is **steeper** than **inside-out** galaxies.

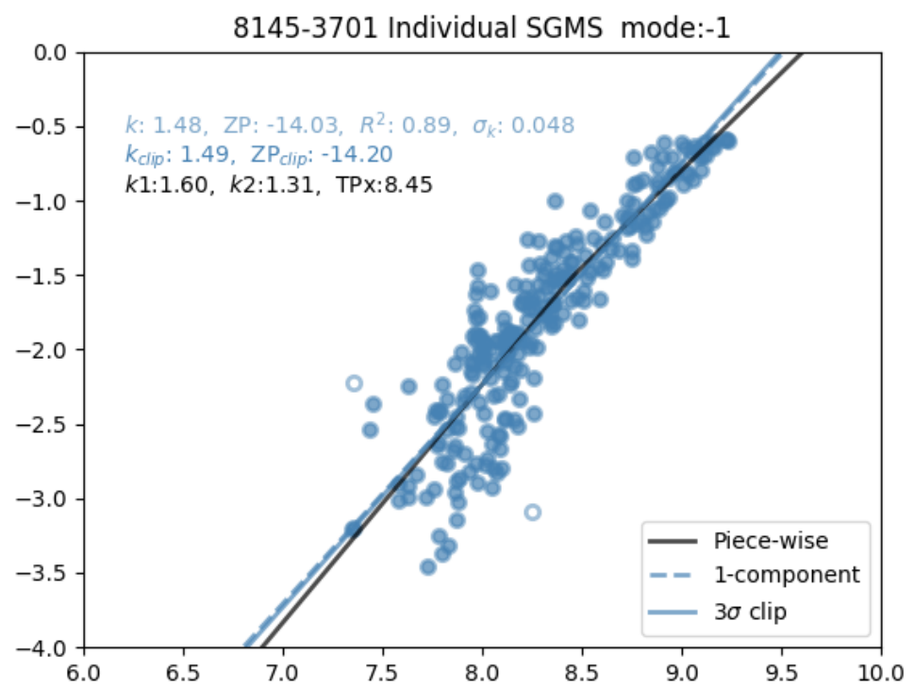
☆ This is largely caused by the high surface density (inner) regions.

From a Galaxy-by-Galaxy (G-by-G) view…





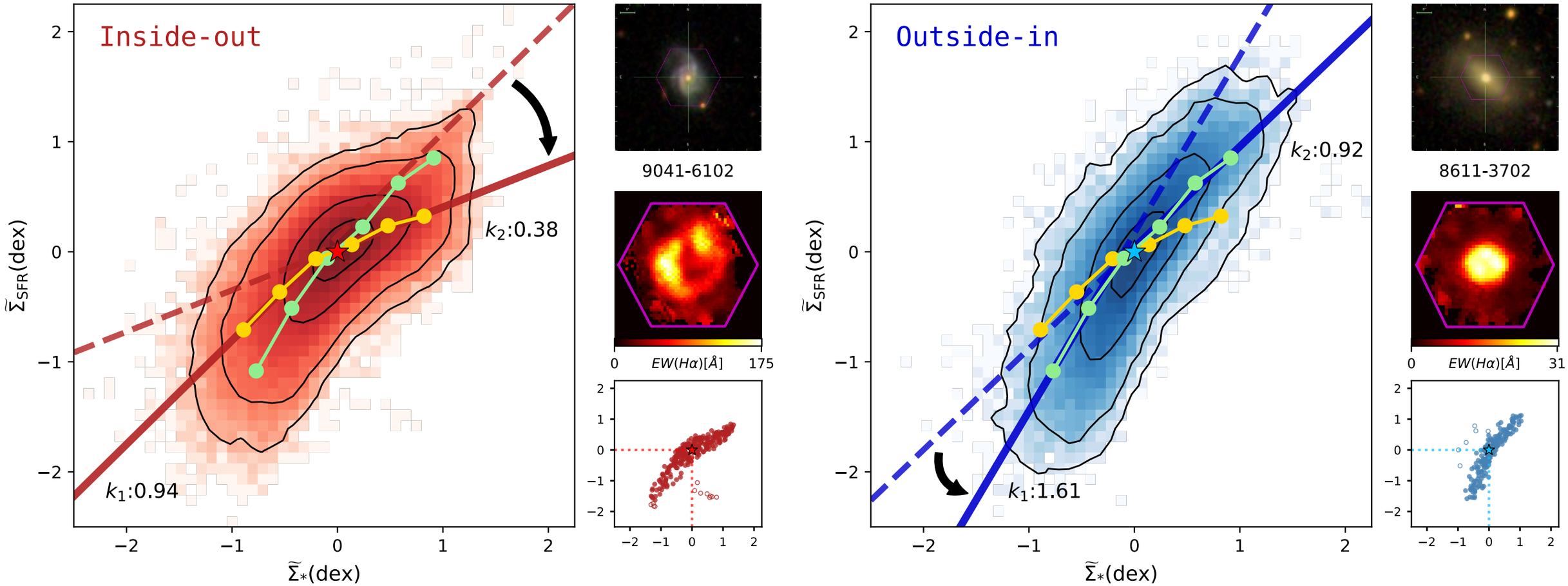




☆ Many G-by-G SGMS (especially in **inside-out** galaxies) show **turning points**.

➡ Possible cause of the smaller slope of the **inside-out** SGMS?

Fig 5 in Liu et al.



- ☆ We assumed the outer parts of **inside-out** SGMS and inner parts of **outside-in** SGMS (slope ~0.9) to be the **standard** SGMS without introducing extra physical processes.
- ☆ Clearly there is a **bent** in SGMS for **inside-out** galaxies.

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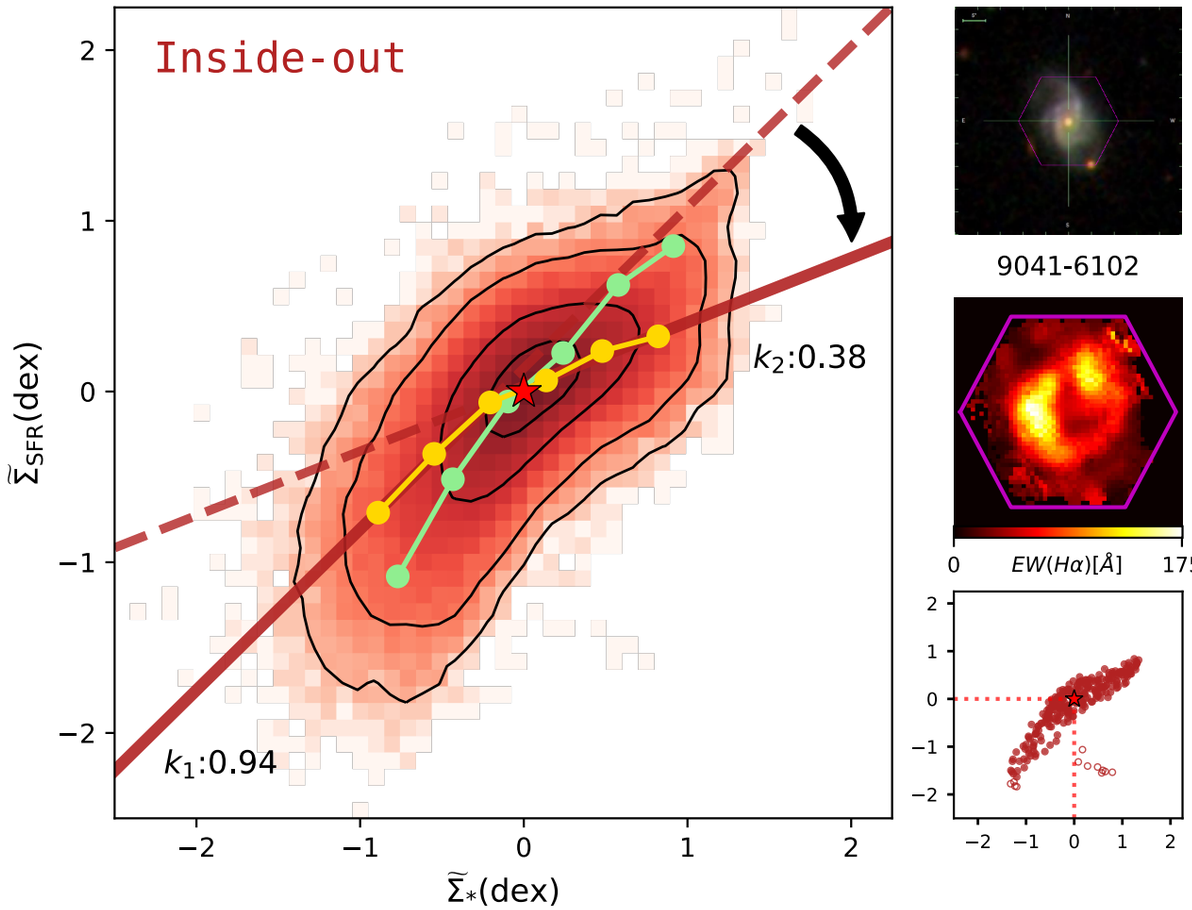

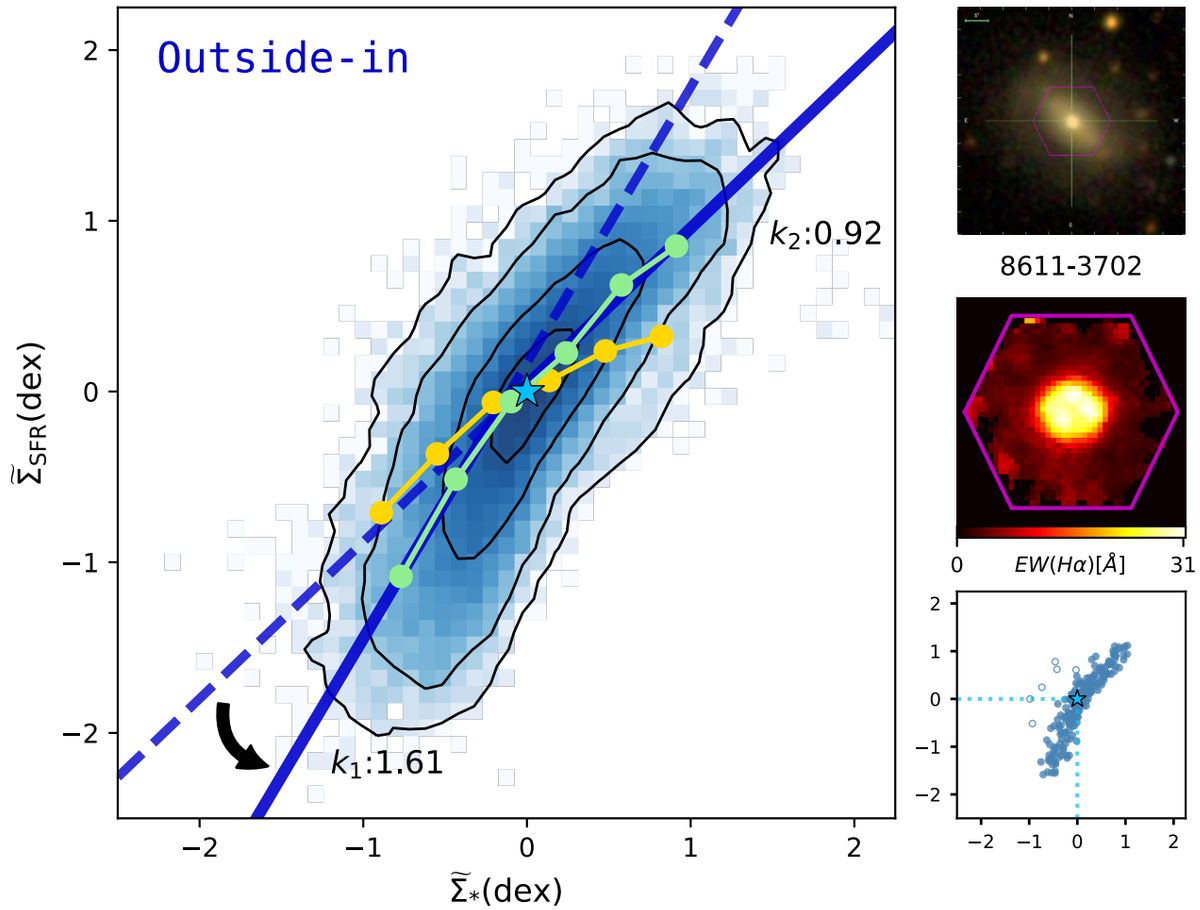

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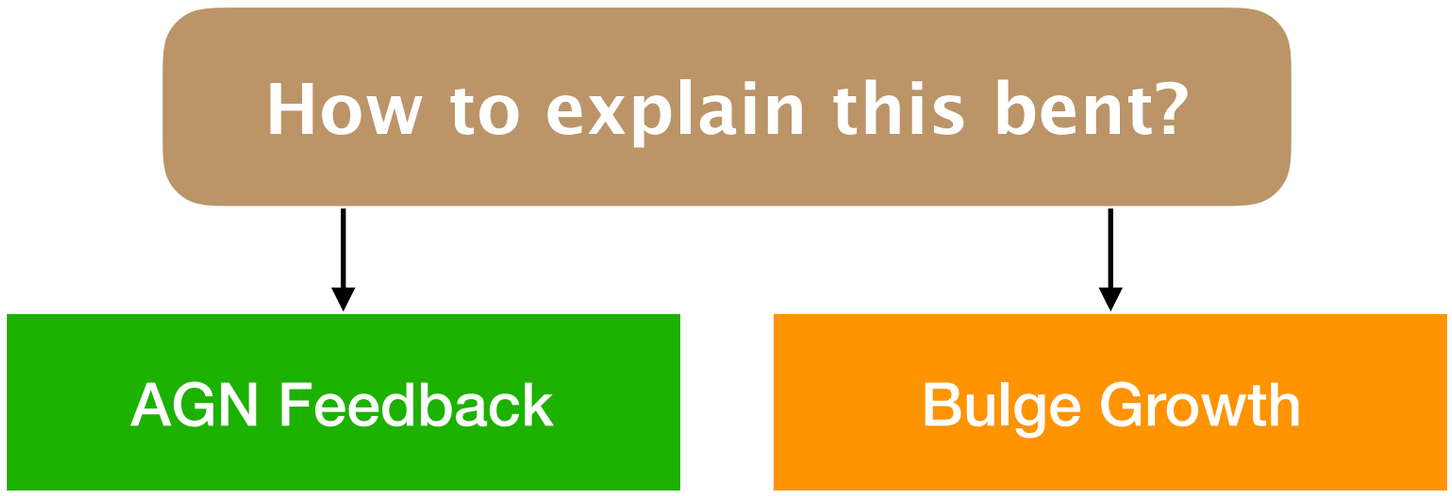
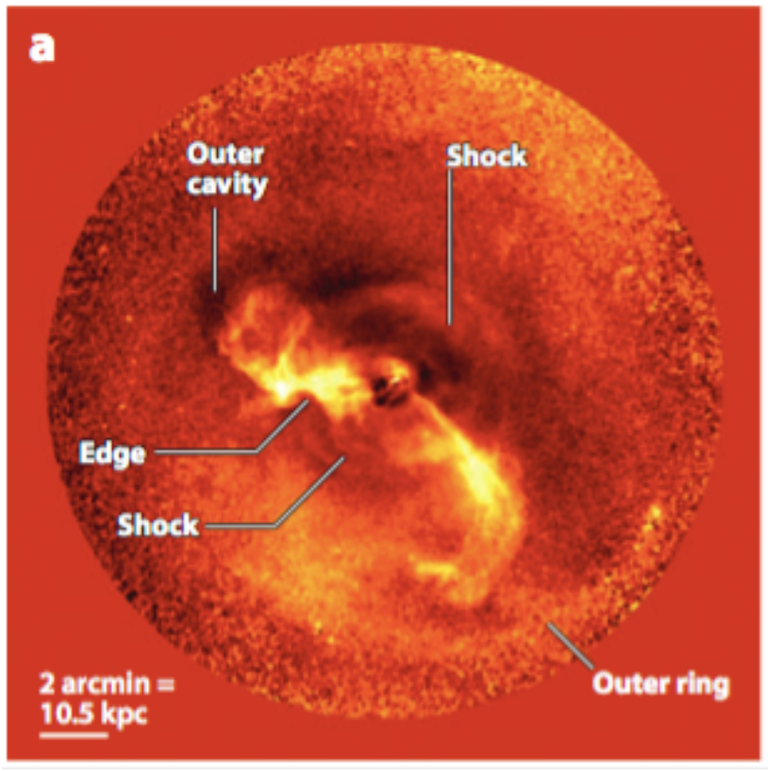


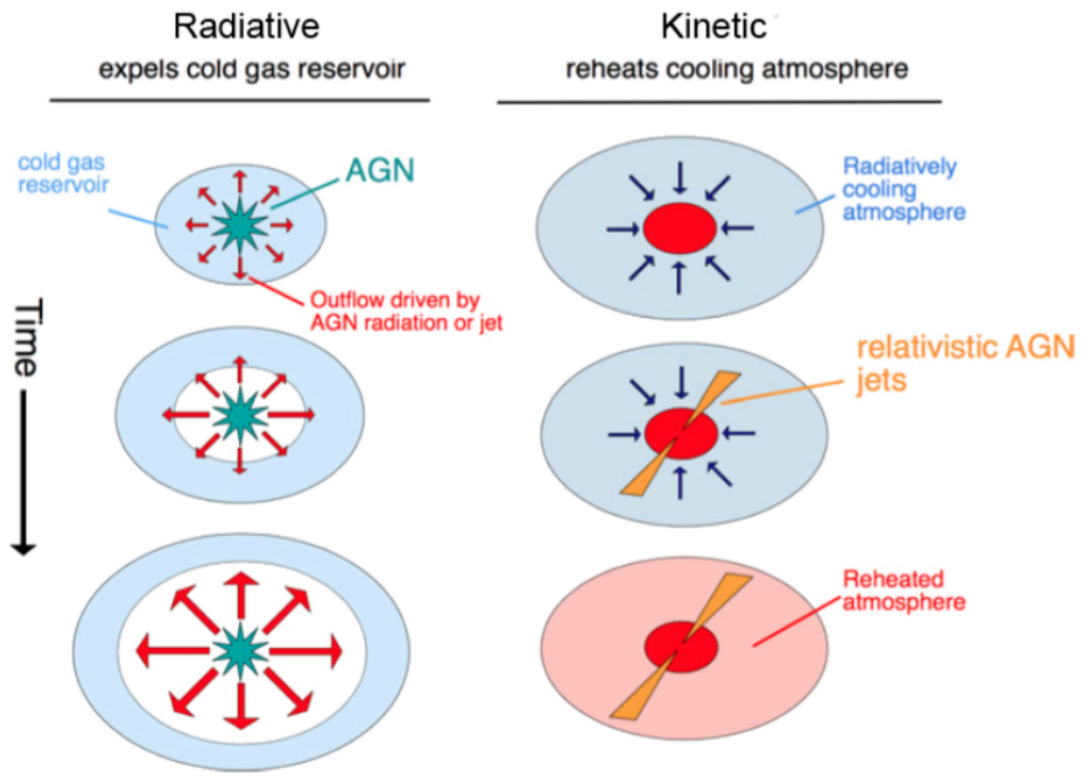
Exp 1 : AGN Feedback

- **AGN feedback** is closely related to the halting of star-formation (Oppenheimer et al. 2010; Page et al. 2012; Shimizu et al. 2015; Hopkins et al. 2016; Carniani et al. 2016).
- Also see recent work of Catalan-Torrecilla et al. (2017), Penny et al. (2017) using IFU data.

Forman et al. (2007)



ARAA by A.C. Fabian (2012)



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- AGN feedback is an important factor in galaxy **self-regulation**.

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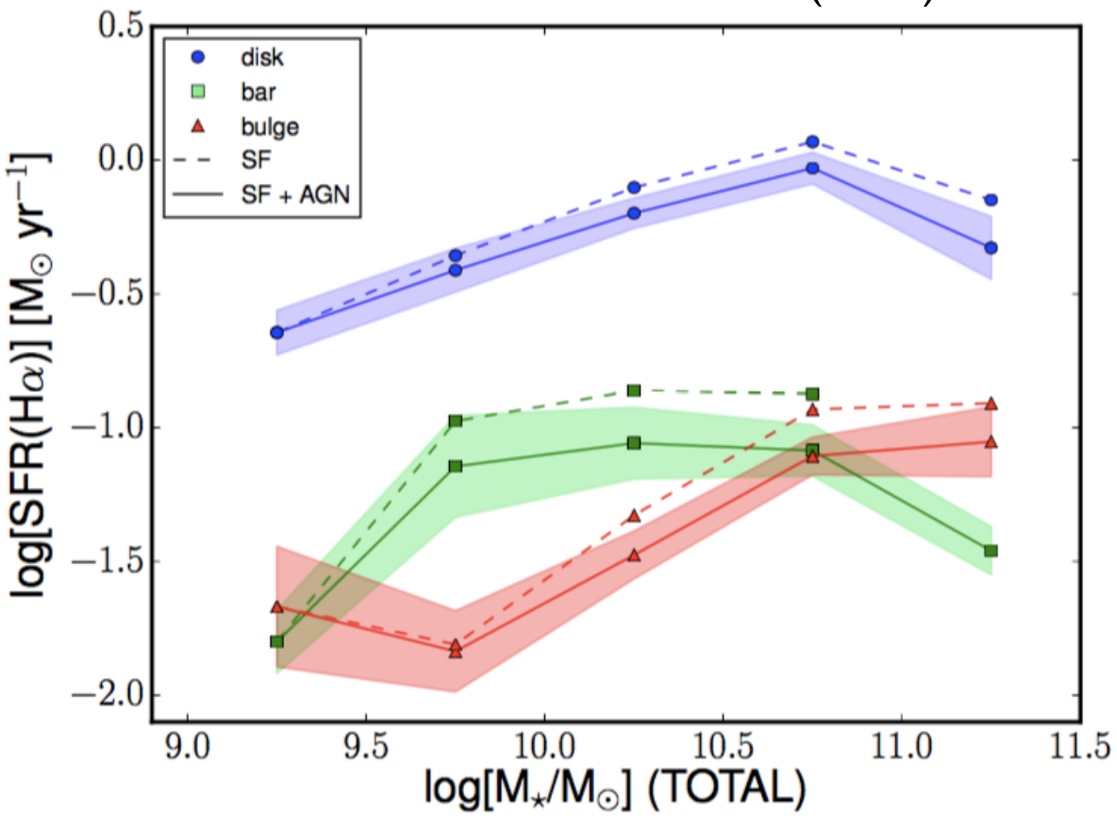
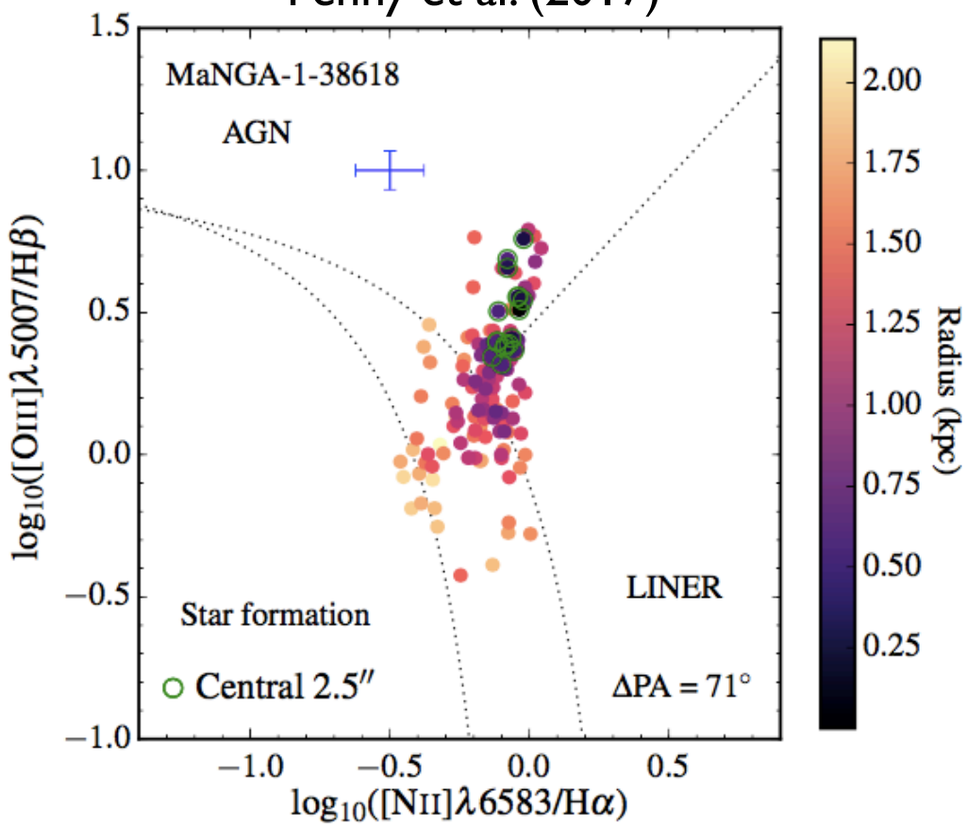


Penny et al. (2017)



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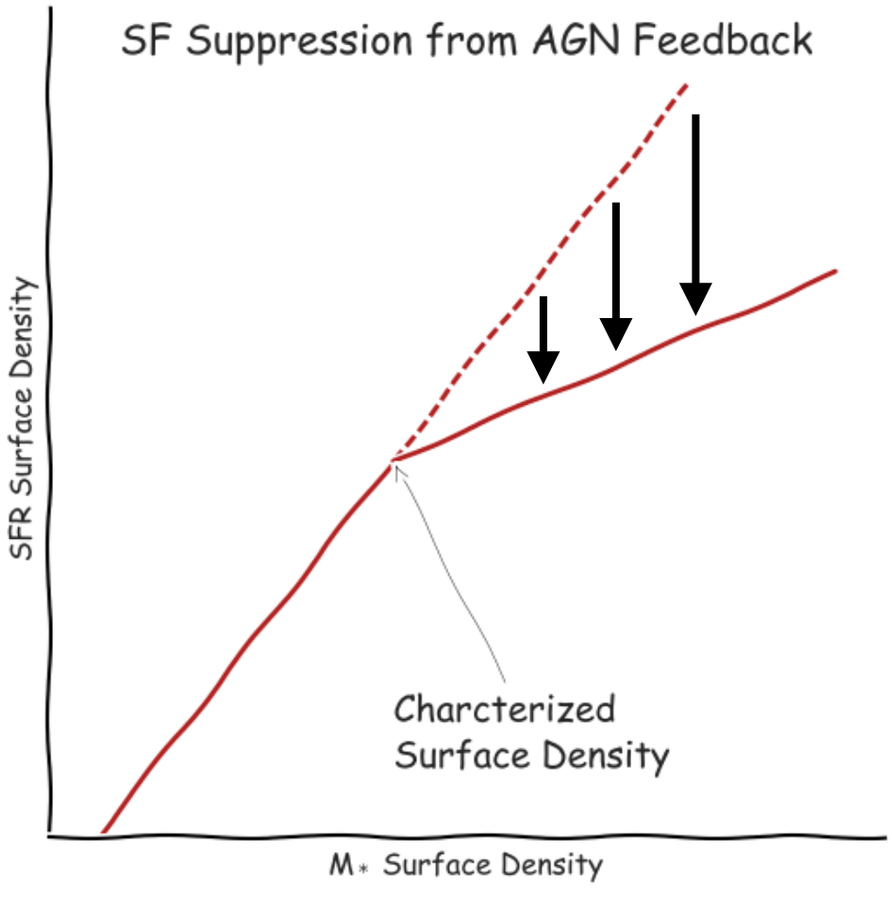

In this case the SFR at certain surface density is decreased because AGNs heat/blow away the SF material (cold gas). The closer to the AGN, the larger of suppression.

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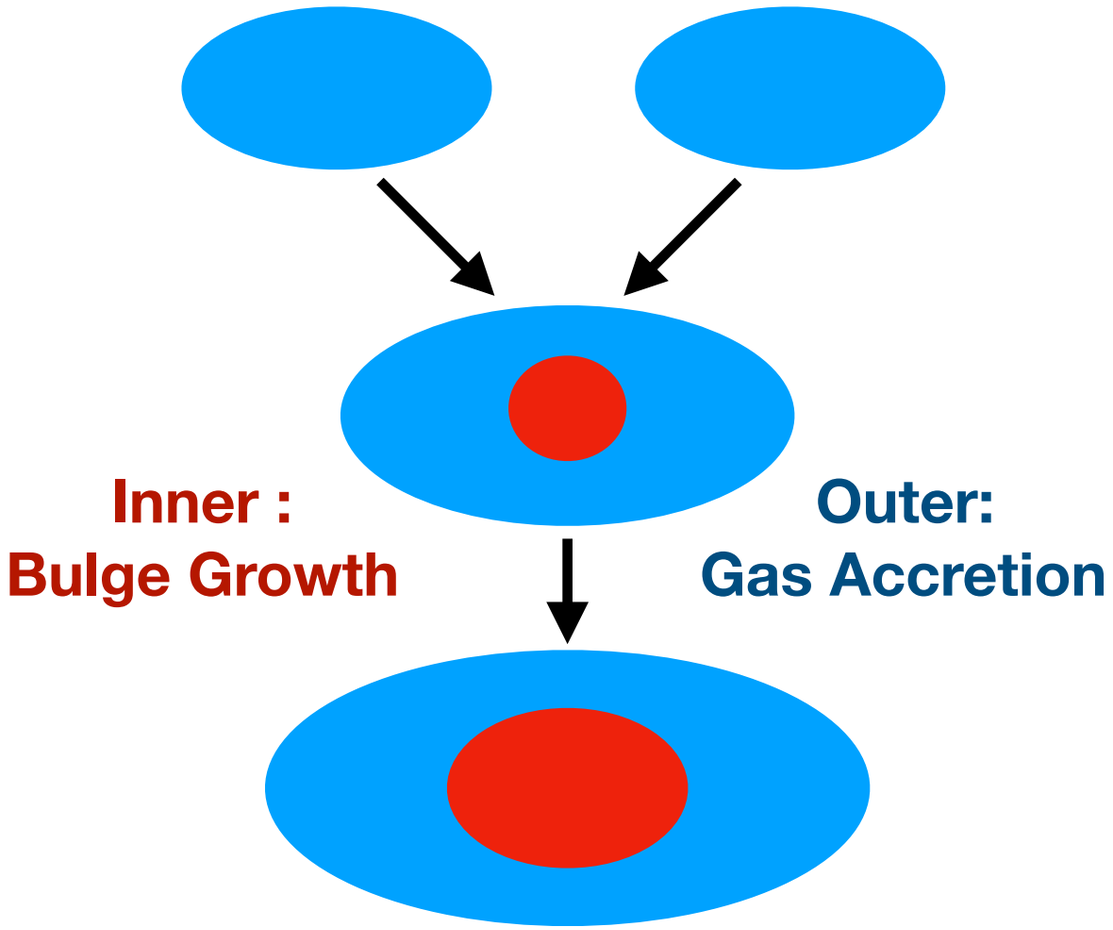
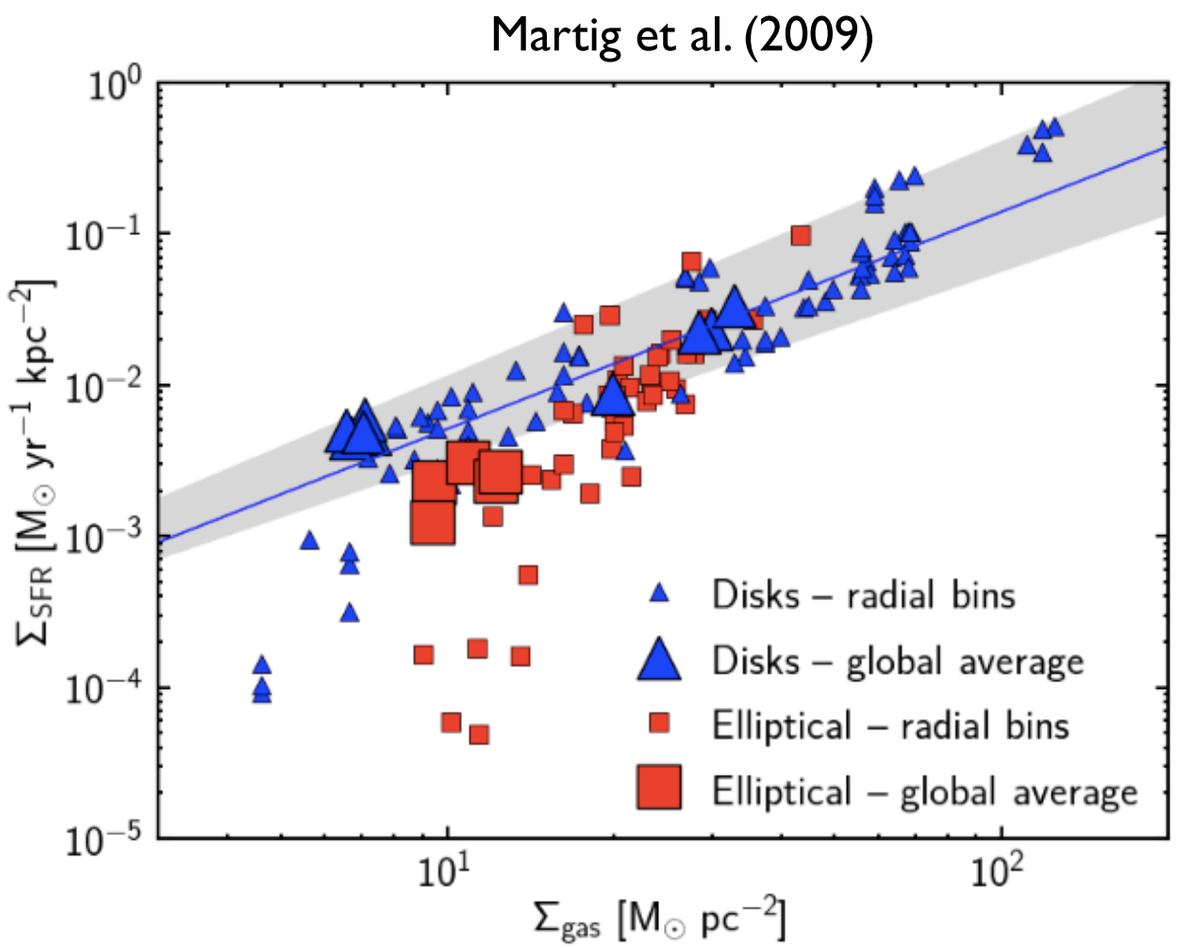
Exp 2 : Bulge Growth

- Cold gas resides in **disks**, where stars are formed.
- In galaxies with **classical bulges**, SFR in bulges is irrelevant of M_{bulge}.





- **Morphological Quenching** : bulge prevent clump fragmentation (Martig et al. 2009)
- The bulge could have been formed in early epoch by minor mergers or in-situ SF clump in-falling. In this case there is no need of gas heating / repelling.

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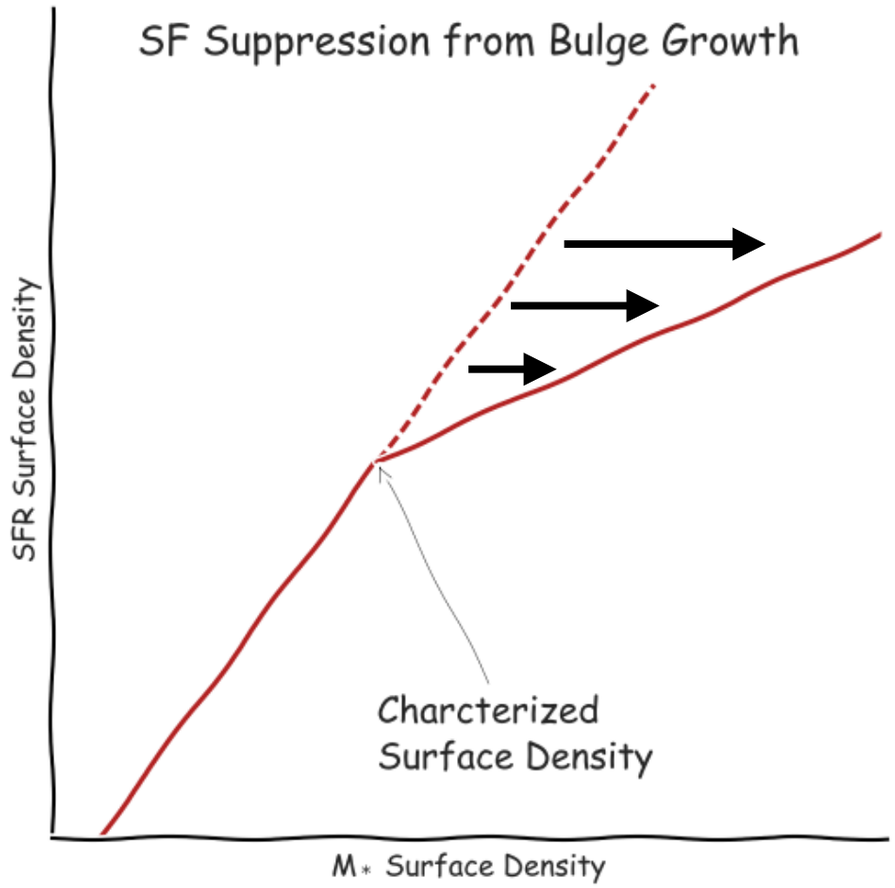

In this case the M_* at certain surface density is increased because of excessive mass, i.e. presence of bulge.

The closer to the center, the more significant of bulge.

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Science Goals

Key Questions

Can we figure out which factor is predominant?

Can we separate IO-SFG to tell the cause of the bent?

If caused by AGN Feedback, can we find
a way to quantify the amount of SF suppression?

If caused by AGN Feedback, can we find
relations between the amount of SF suppression and strength of AGN activity?

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Overall Scientific Importance

To Investigate the
Star Formation Regulation
Process in SFGs

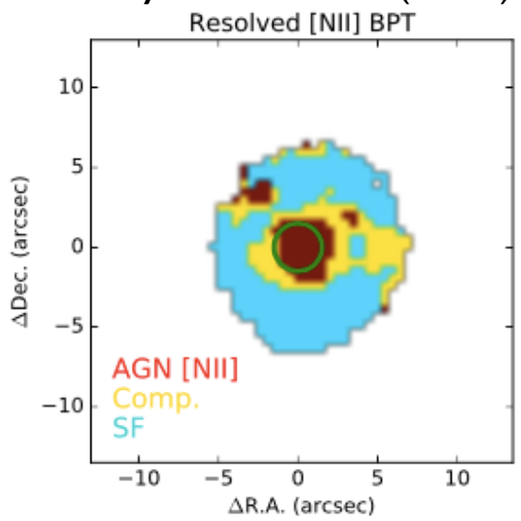
To Explore the
Role of AGN Feedback
in Galaxy Evolution

❑ What do we expect?

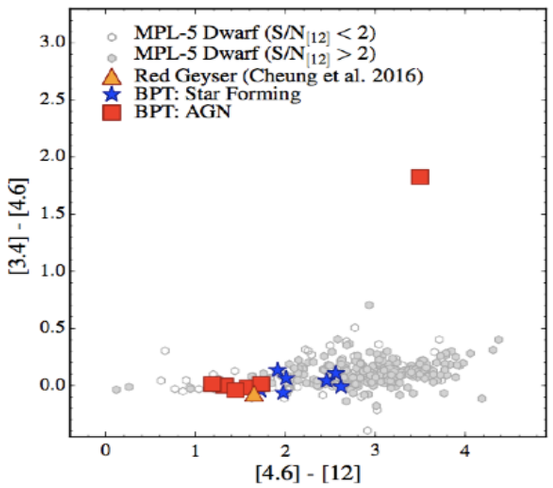
- In the **AGN Feedback** case

  1. Evidence of ongoing AGN activity:
     - Central line ionizations from AGN
     - Bluer in WISE [4.6] - [12] color in centers
     - AGN outflow (Wylezalek et al. 2017)
  2. Evidence of past AGN activity:
     - Deficiency of cold gas in central regions
     - And/or large gas v and sigma

Wylezalek et al. (2017)



Penny et al. (2017)



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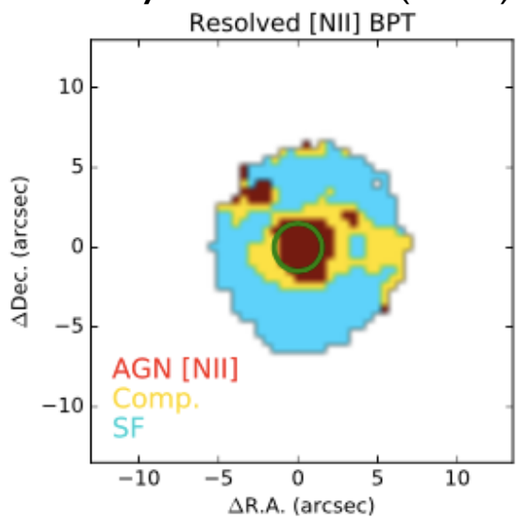
- In the **Bulge Growth** case

  1. In IO-SFG with a pseudo-bulge
     - A reservoir of cold gas still exist
     - 1-component profile, no bent (if no AGN)
  2. In IO-SFG with a classical bulge
     - A reservoir of cold gas still exist
     - 2-component profile, SGMS Bent <=> Bulge frat

Wylezalek et al. (2017)



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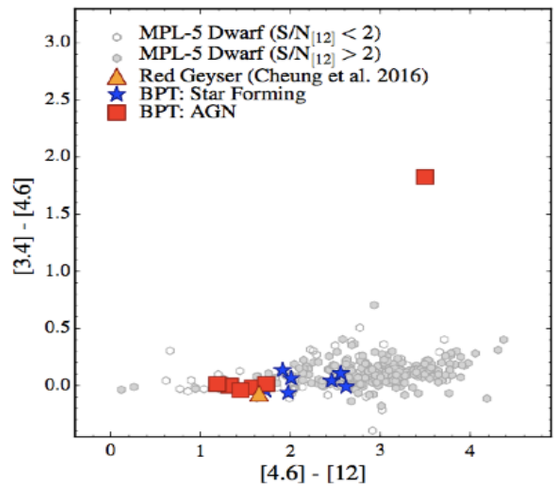

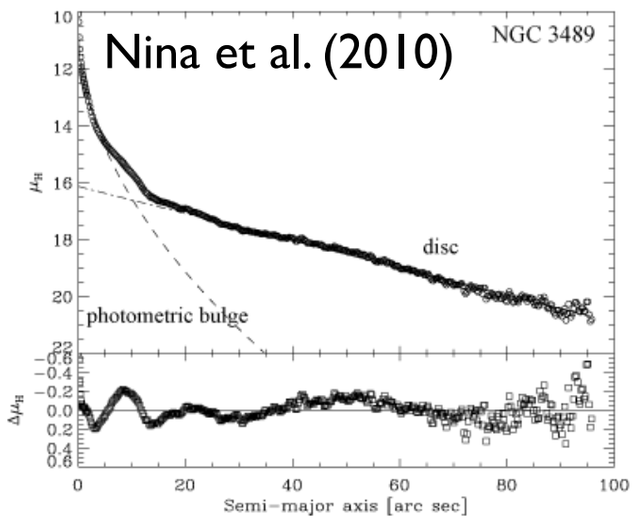

■ Proposed Research Activities

1. Exploring gas around AGN and compare with those without AGN

a. Check with the CALIFA data :

- The CALIFA-EDGE survey (Bolatto et al. 2017).
- How many of CALIFA IO-SFG contain AGN?
  - Of these galaxies, how many of them have gas data matched?
  - Of these galaxies, how many of them have evidence of SF suppression?

b. Crossmatch between COLD-GASS and MANGA:

- The GASS (GALEX-Arecibo-SDSS) survey (McClure-Griffiths et al. 2009)
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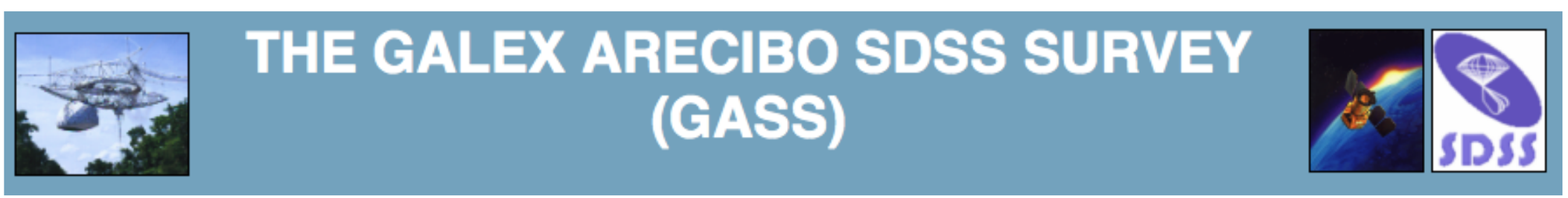

II. Quantifying the amount of SGMS Bent -> amount of SF suppression?

Method 1 : the slope of SGMS in each piece

$$\Delta\ Slope\ =\ Slope_{\ out}\ -\ Slope_{\ in}$$

Δ Slope ~ 0.6 averagely

Current fitting method is not satisfying

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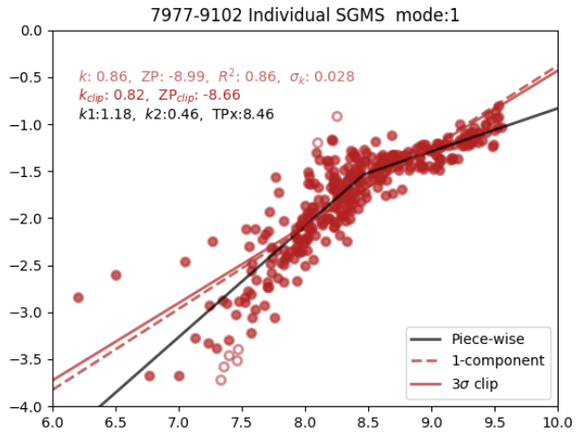

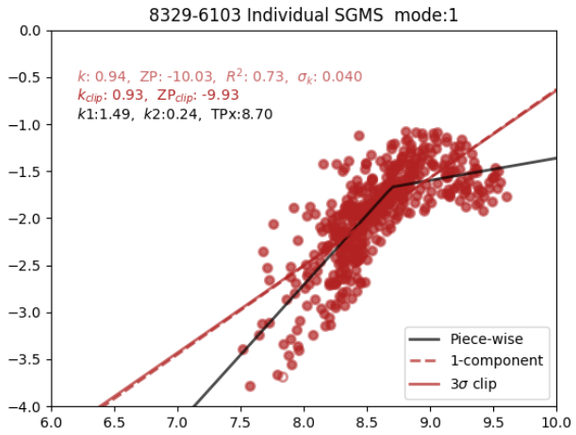

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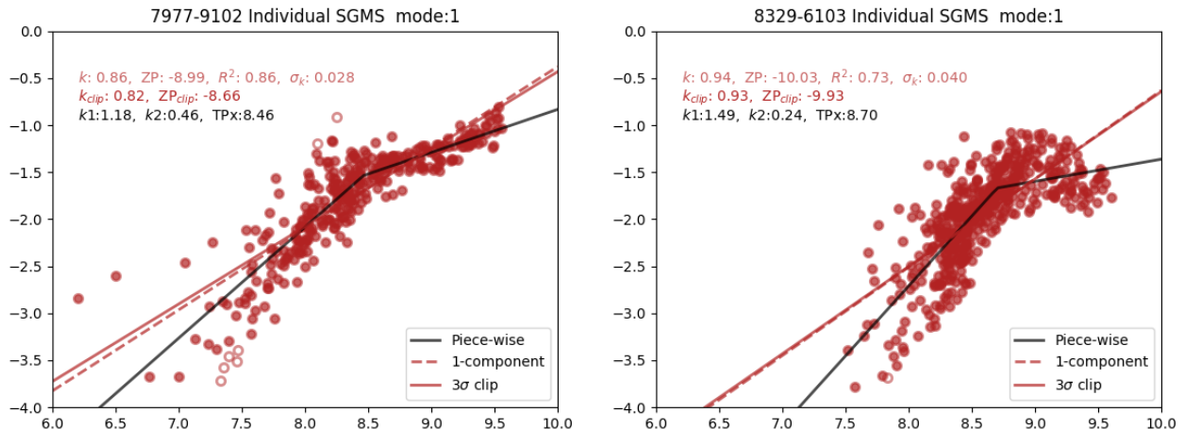
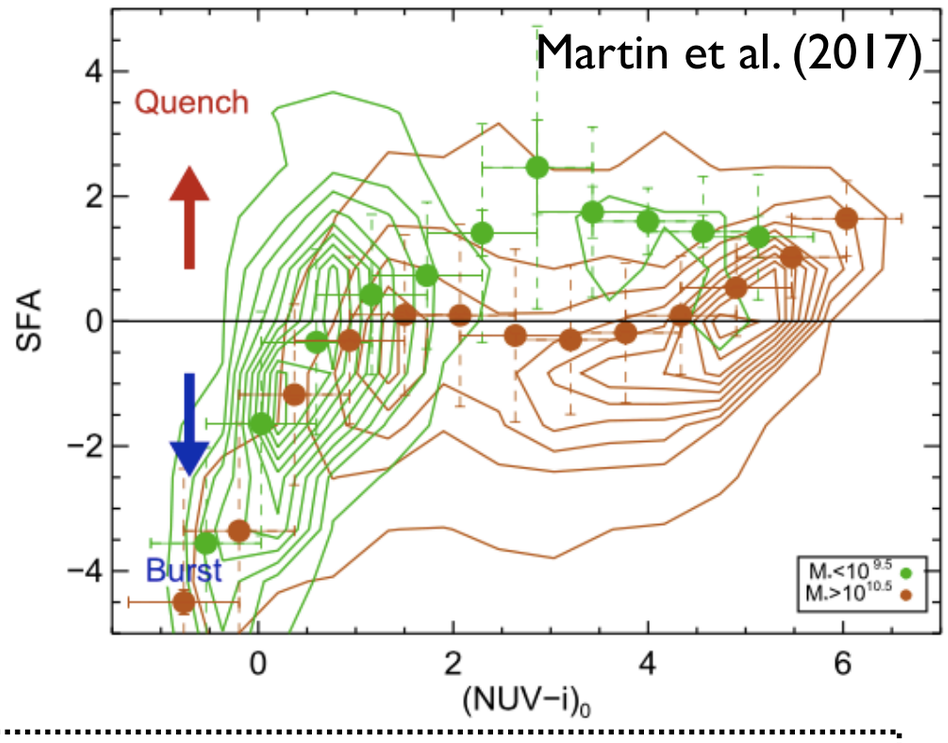


Method 2 : SF Acceleration (SFA) and SF Jerk (SFJ) (Martin et al. 2017)

- If AGN Feedback have impacts, SF is likely to shut down suddenly, so we can measure the suppression by measuring SFA and SFJ.
- SFA and SFJ can be derived using colors and spectra features.



Physical parameters are derived from

$$P_p(\text{est}) = \sum_{o=1}^{o=8} M_{o,p,d,z} O_o \qquad (2)$$

$$\begin{aligned} P_p(\text{est}) = {} & M_{1,p,d,z}(\text{FUV} - \text{NUV}) \\ & + M_{2,p,d,z}(\text{NUV} - u) + M_{3,p,d,z}(u - g) \\ & + M_{4,p,d,z}(g - r) + M_{5,p,d,z}(r - i) \\ & + M_{6,p,d,z} D_n(4000) + M_{7,p,d,z} H_{\delta A} \\ & + M_{8,p,d,z} M_i + \text{constant.} \end{aligned} \qquad (3)$$

III. Studying the relation between Bulge Growth and amount of SGMS Bent

- Are galaxies with pseudo-bulges suffer from SF suppression?
  - If so, they are likely to be caused by AGN feedback.
- How Bulge indicators (B/T, Σ_1, λ_R) relate with the SGMS Bent?
- Bulge-disk decomposition : How bulge profiles coincide with the bent in each galaxy?

B/T : L_{Bulge} / L_{Total} Σ_1 : Surface Density within 1 kpc λ_R : Rotational Spin

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IV. Studying the relation of AGN strength and amount of SF suppression

- Crossmatch with the WISE survey
  - Whether [4.6] - [12] color of AGN hosts are bluer?
- Is there anti-correlation between AGN strength / ionization and SF level?

  e.g. larger L_{IR} / ion parameter U => larger SF suppression.
- Is there correlation between AGN strength / ionization and gas motion randomness?

  e.g. larger L_{IR} / ion parameter U => higher gas velocity dispersion around them.
- BTW : Is there correlation between gas disturbance and SF deficiency?

  This is generally expected (When jet / wind hit the cold gas, they will heat, disturb the gas and ionize them) => Make a test.

IV. Possible observation / ongoing observation

- The key is the **cold gas reservoir** in these **IO-SFG**.
- However statistical data of gas is hard and expensive to obtain :

  low resolution, time-consuming, lack of equipment

Telescope available : CARMA, IRAM, JCMT…

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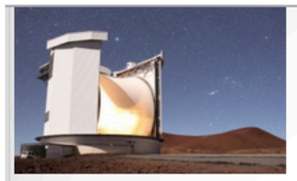
If I have money, I would participate in the ongoing collaboration.



JINGLE: the JCMT dust and gas In Nearby Galaxies Legacy Exploration

a new JCMT legacy survey

Ting Xiao
Shanghai Astronomical Observatory

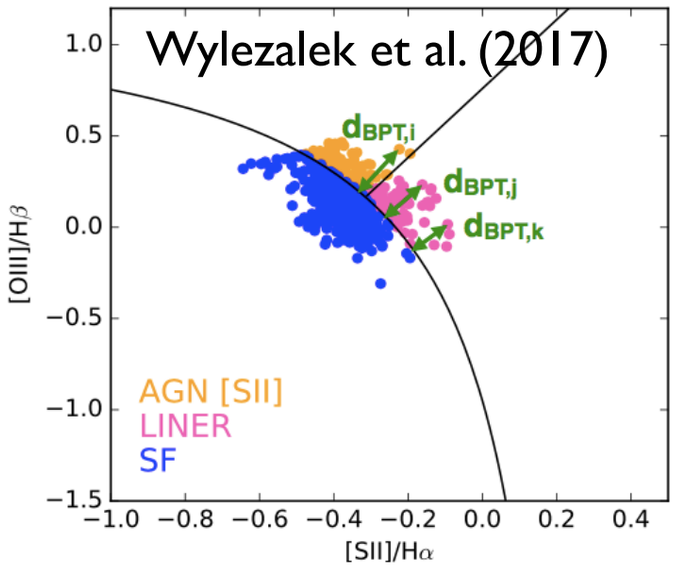
Pis:Amelie Saintonge (UCL), Christine Wilson (Mcmaster), Ting Xiao (SHAO)
Collaborators: Cheng Li (Tsinghua/SHAO), Yu Gao (PMO), Ho Seong Hwang (KIAS), Lihwai Lin (ASIAA), Yang Gao (SHAO), Ming Zhu (NAOC), and the JINGLE Team

MaNGA Collaboration Meeting @ Shanghai, 2016.11

Possible CO Follow-up of MaNGA

Cheng Li (SHAO), Martin Bureau (Oxford)

Initial Results



For each **IO-SFG** :

1. Measure its individual SGMS slope (OLS)
2. Measure the BPT Distance of its central regions

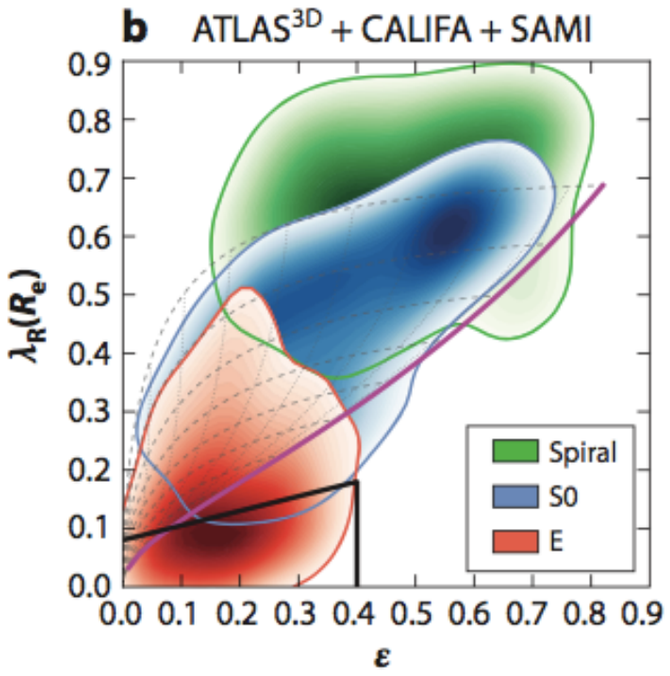
BPT Distance is defined as the distance to the Kauffmann (2003) line on BPT diagram

3. Measure its λ_R within the core radius

$$\lambda_R \equiv \frac{\langle R|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle} = \frac{\sum_{n=1}^{N} F_n R_n |V_n|}{\sum_{n=1}^{N} F_n R_n \sqrt{V_n^2+\sigma_n^2}},$$

As preliminary results, we use $\lambda_{1.5Re}$ measured in Sanchez et al. 2017 to indicate bulge growth.

ARAA by M. Cappellari (2016)



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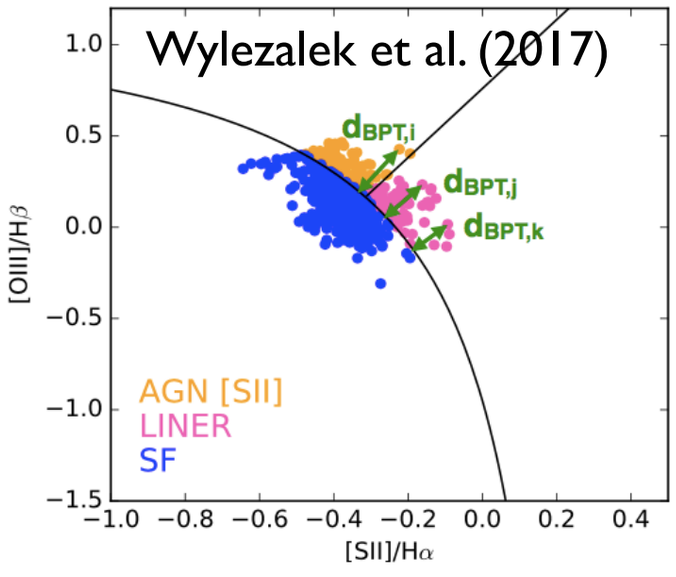

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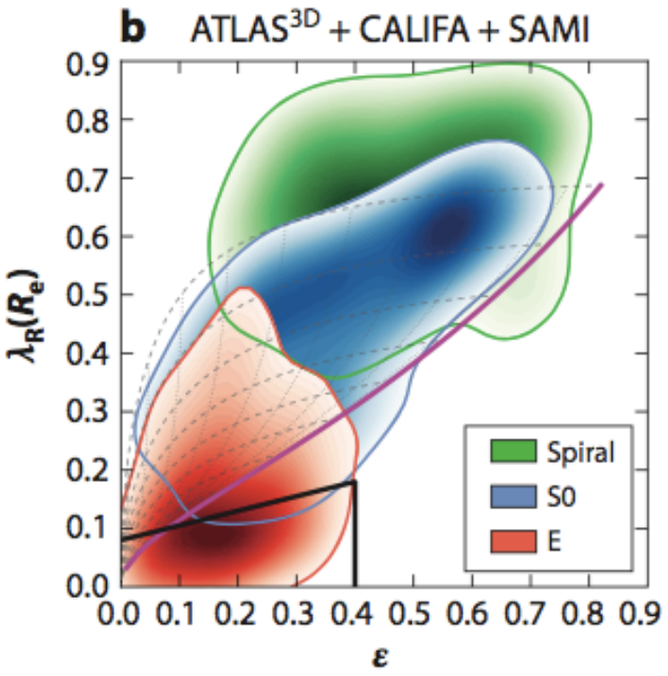

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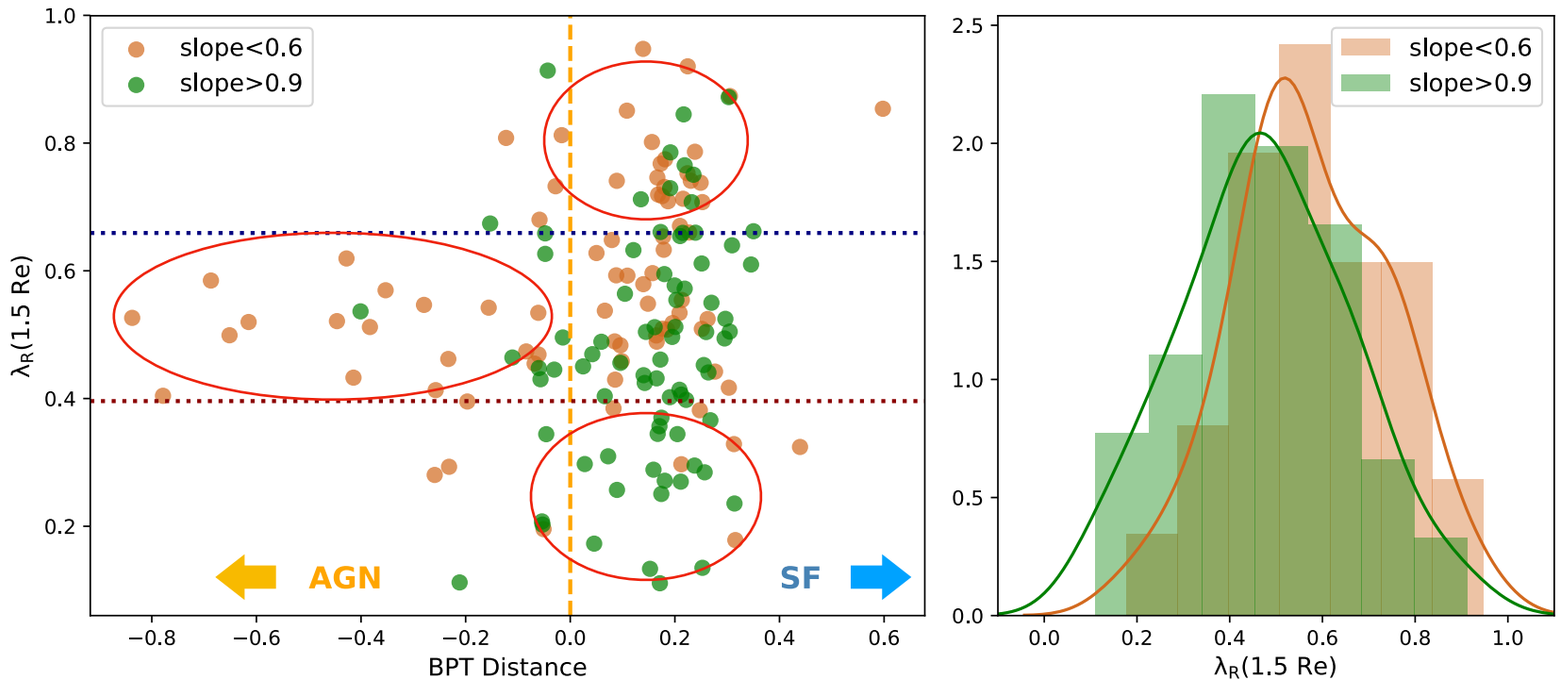

SUMMARY

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- ☆ Is it **AGN Feedback** or **Bulge Growth** ? (Or maybe both)
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