Dynamical Hotness, Star Formation Quenching and Growth of Supermassive Black Holes

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Outline

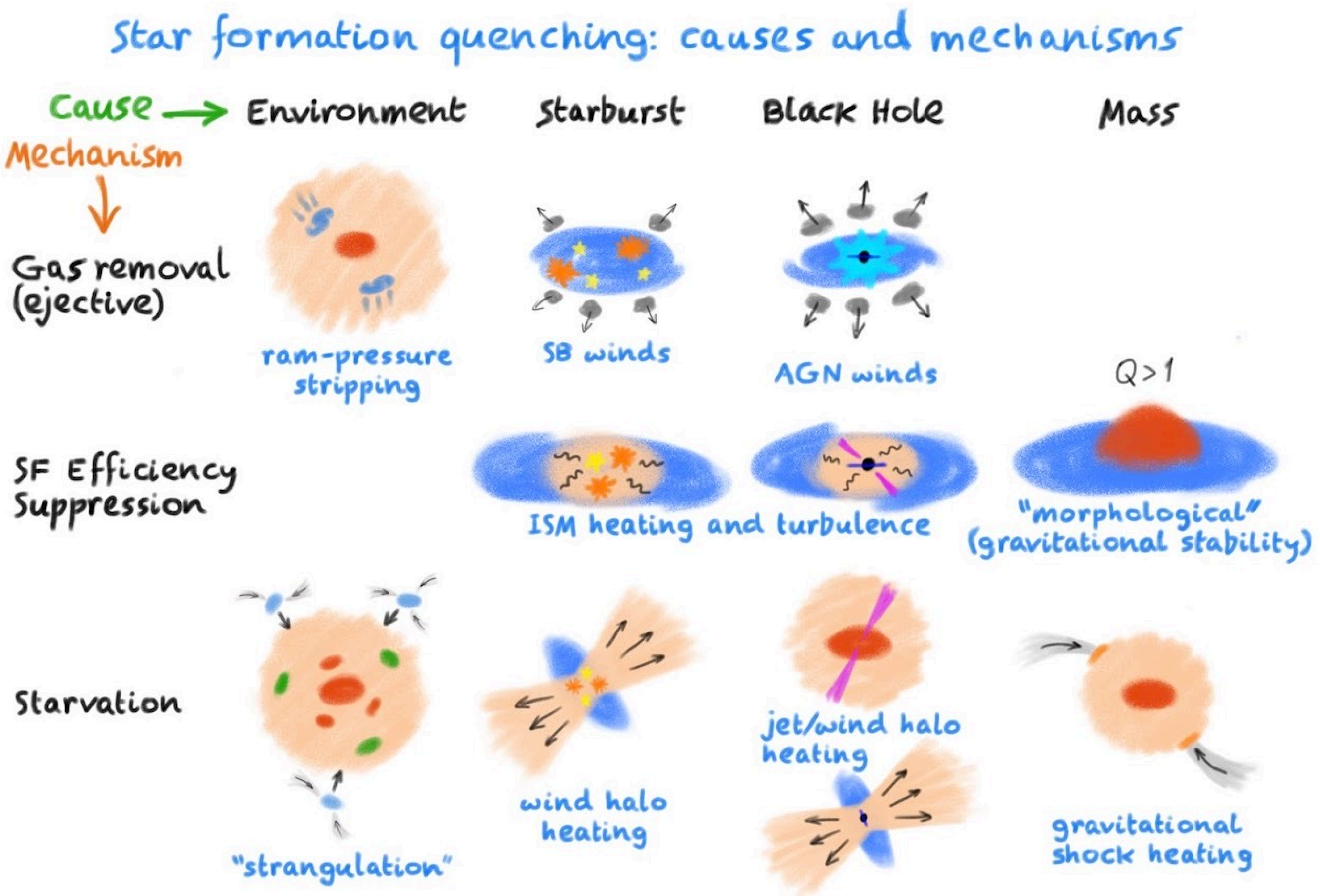
- **Background**:
  - Quenching mechanisms
  - Former studies
- **Observations**:
  - Central velocity dispersion versus quenching properties
  - Two-σ (central-outskirt velocity dispersion) diagram
  - Evolutionary tracks on two-σ diagram
- **Toy model** coevolution of SMBH and its host galaxy

Background

Quenching mechanisms:

Expel gas or heat gas or stabilize gas

- environmental processes
  - ram pressure stripping
  - tidal stripping
  - ……
- internal processes
  - SN feedback
  - AGN feedback
  - morphology quenching
  - ……



Credit: https://www.robertomaiolino.net/projects/quench

We focus on internal properties for massive galaxies.

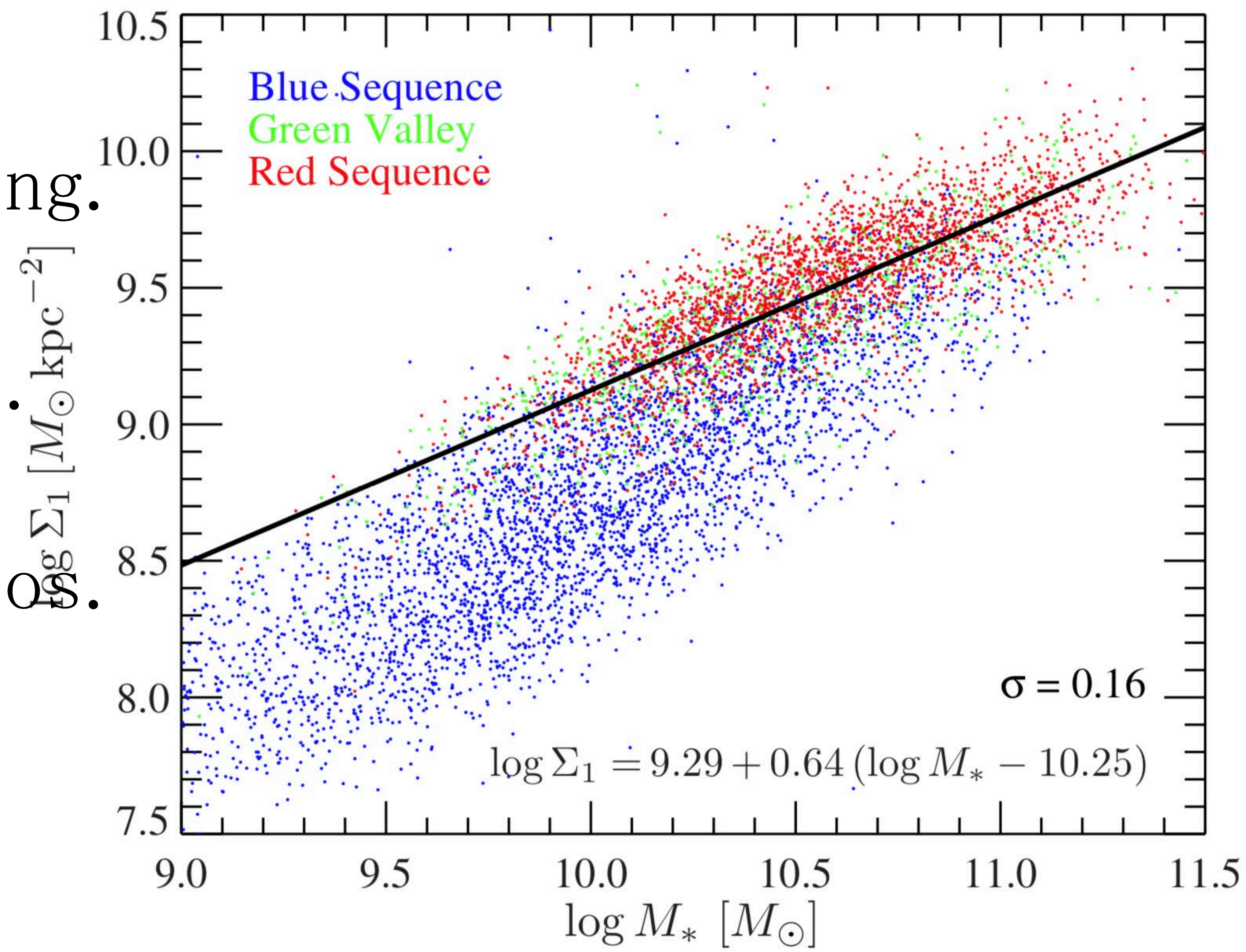
Internal property: Σ_1

Photometric observations:

Fang+2013: mass-dependent characteristic Σ_1 for quenching.

Barro+2017: characteristic Σ_1 extended to high redshift.

Chen+2020: characteristic Σ_1 linking SMBHs and host halos.



Fang+2013

Virialized system: Σ_1 correlates with σ_c strongly.

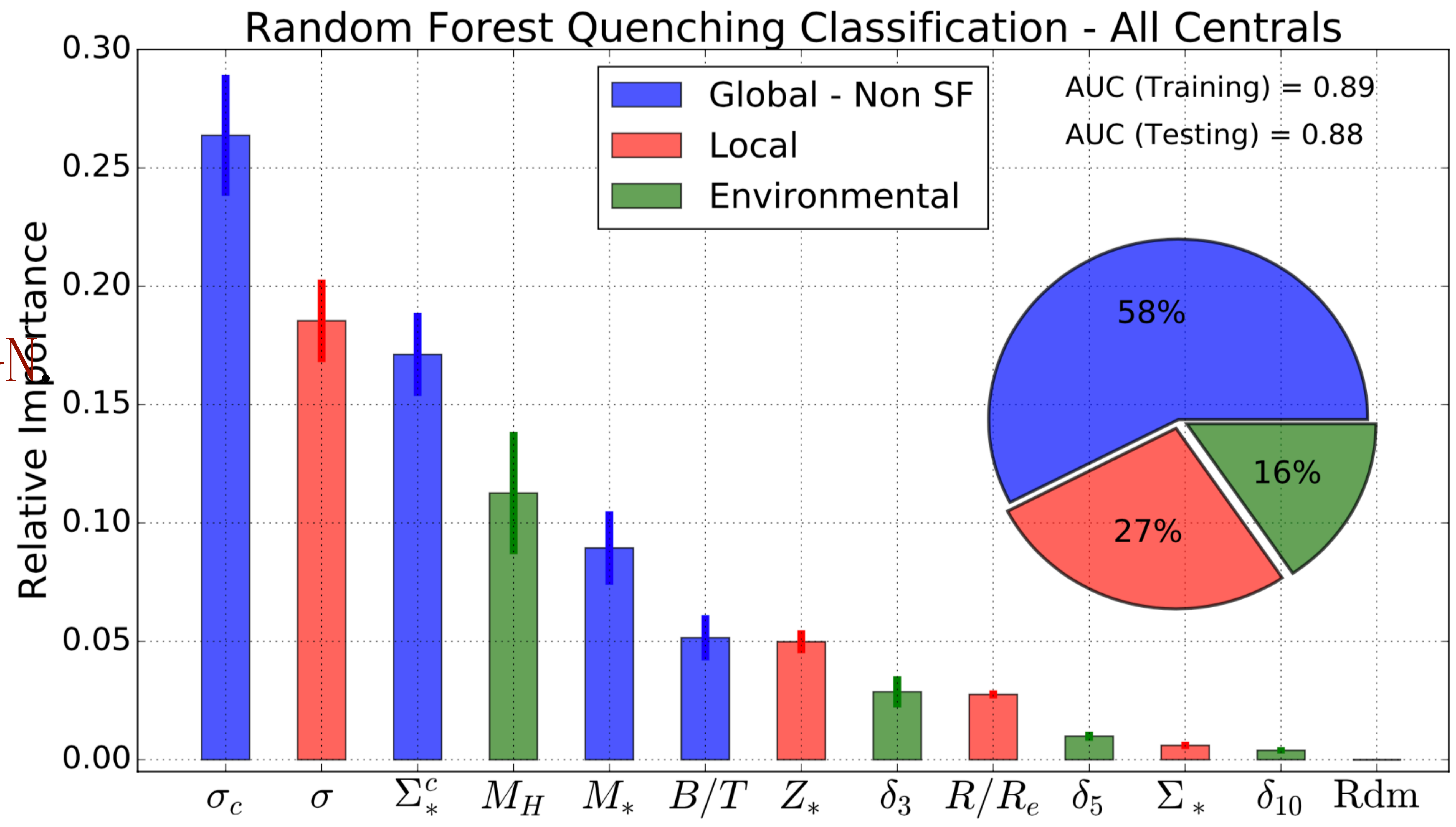
Internal property: σ

Spectroscopic observations:

Bluck+2020: MaNGA DR15, central velocity dispersion (σ_c) is the most predictive paramet
for quenching in central galaxies.

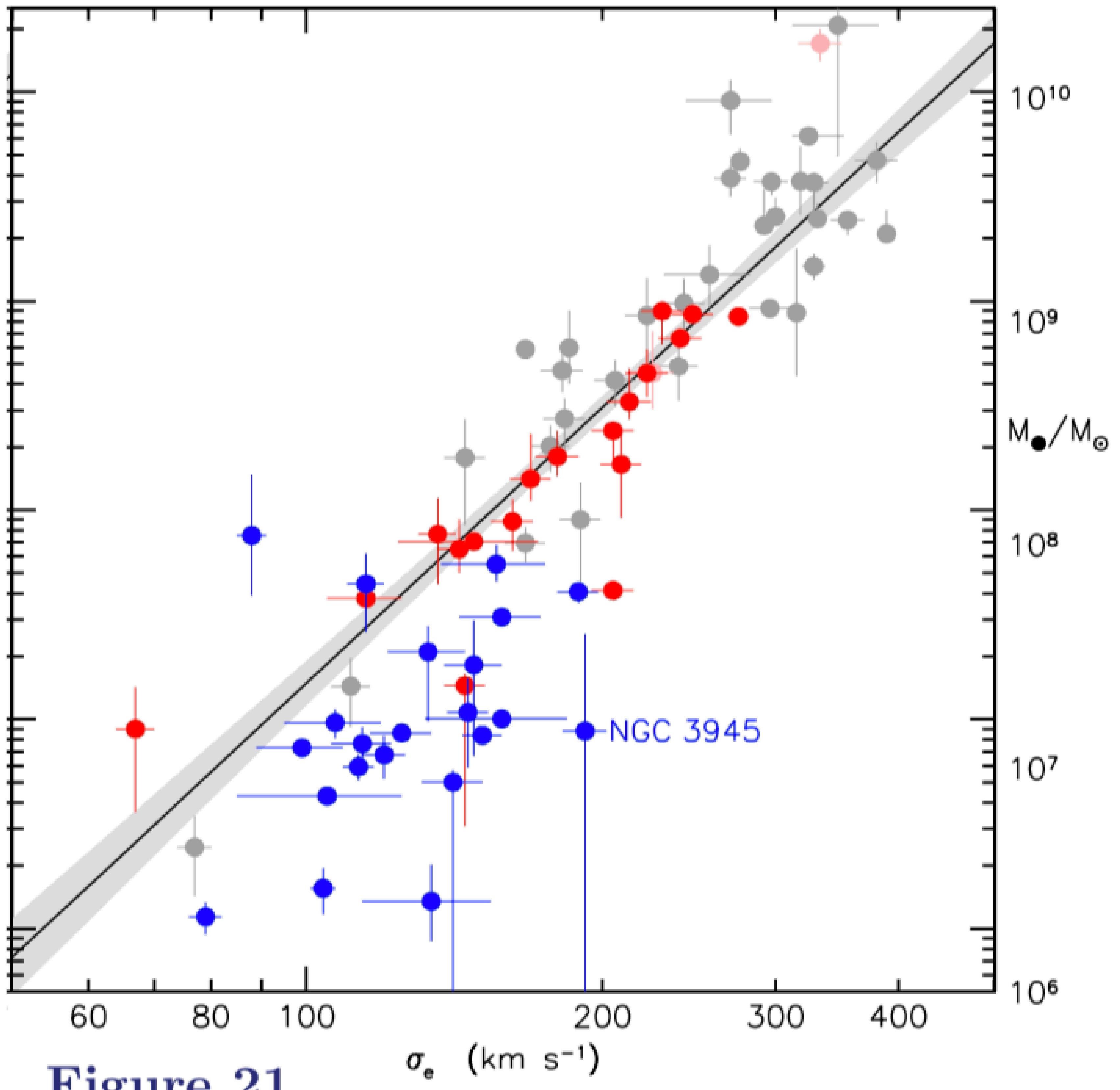
Dynamical hotness connects with quenching.

σ_c traces integrated energy released by AGN



Bluck+2020

SMBH scaling relations



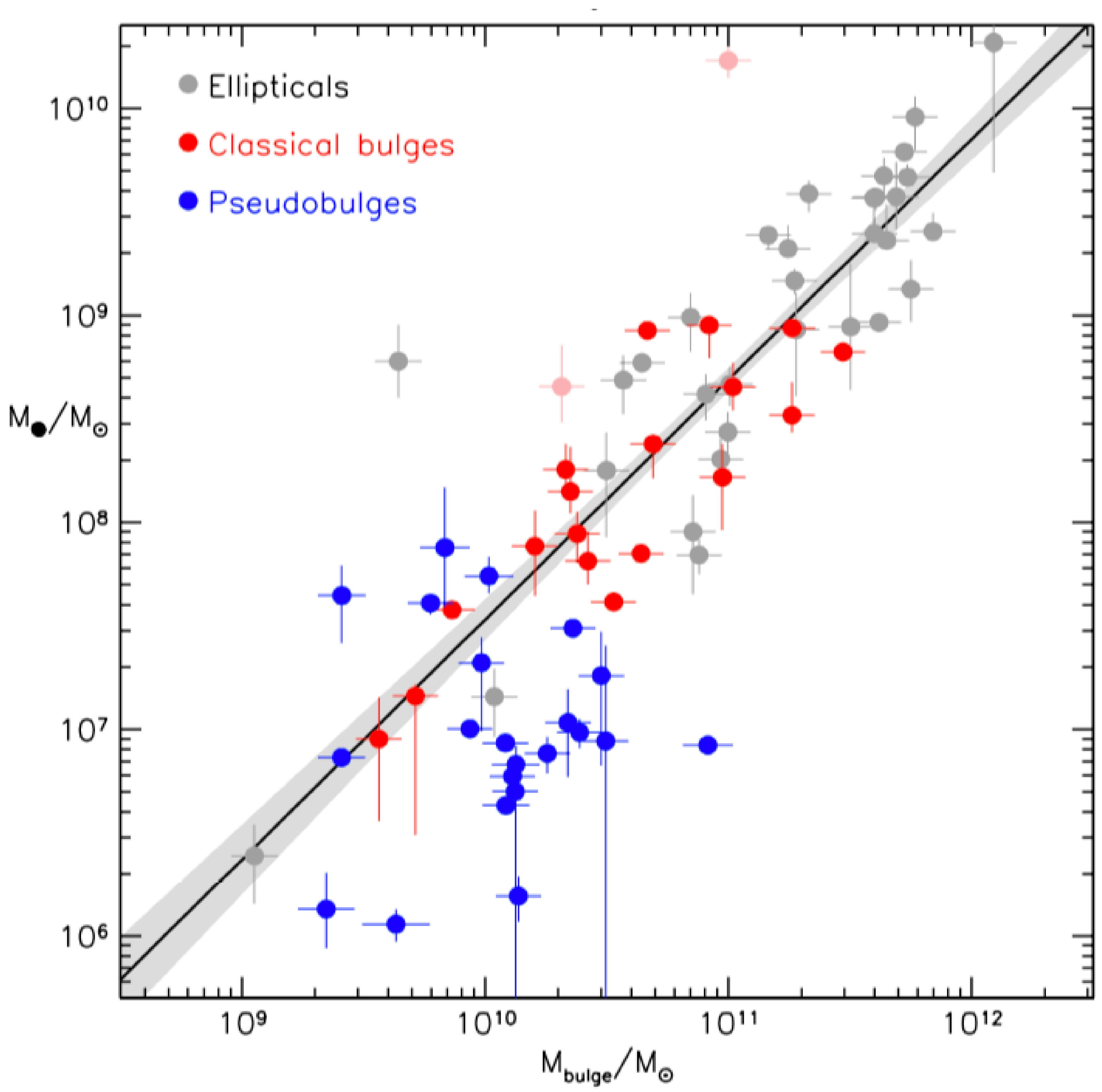
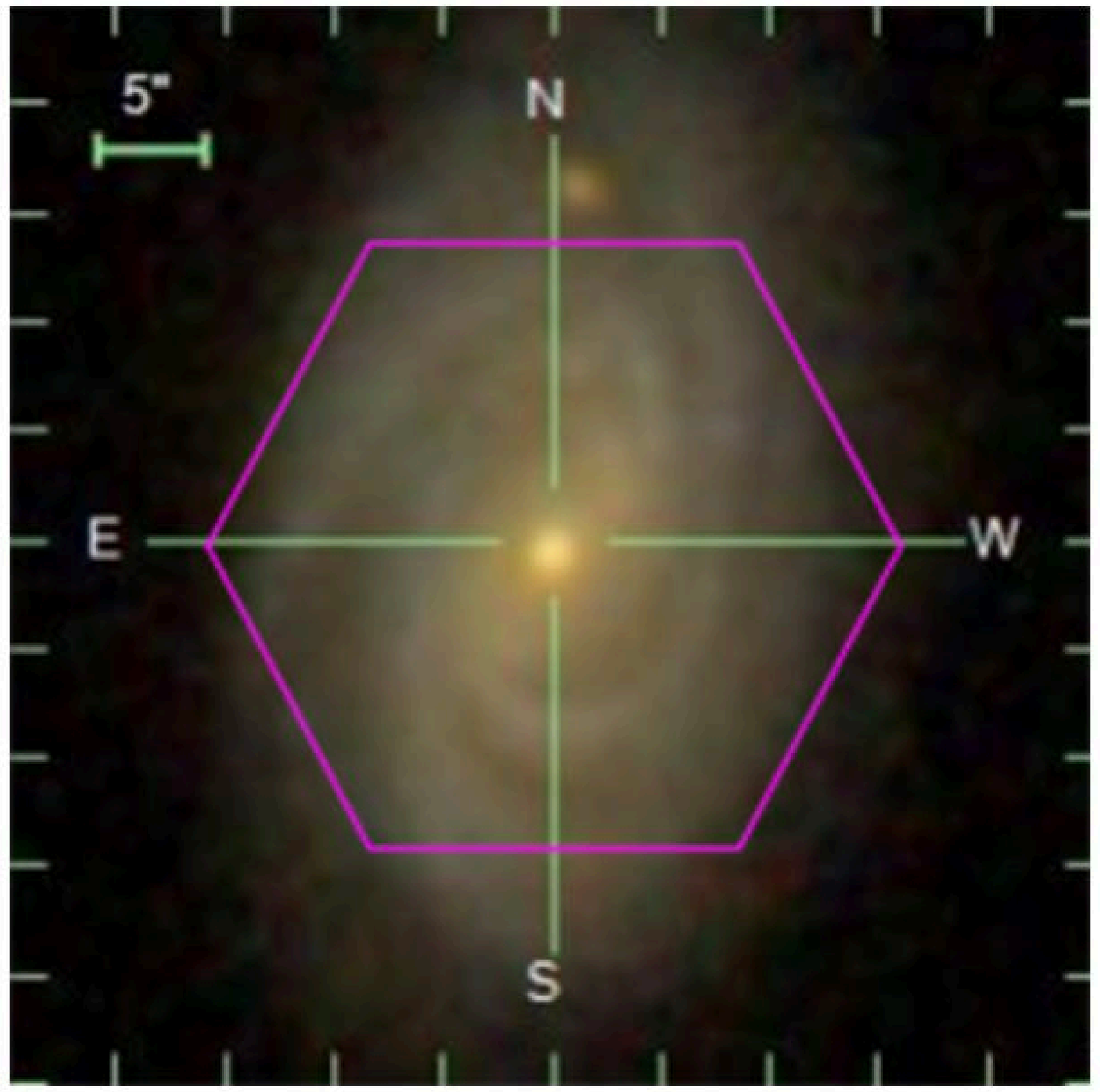


Figure 21

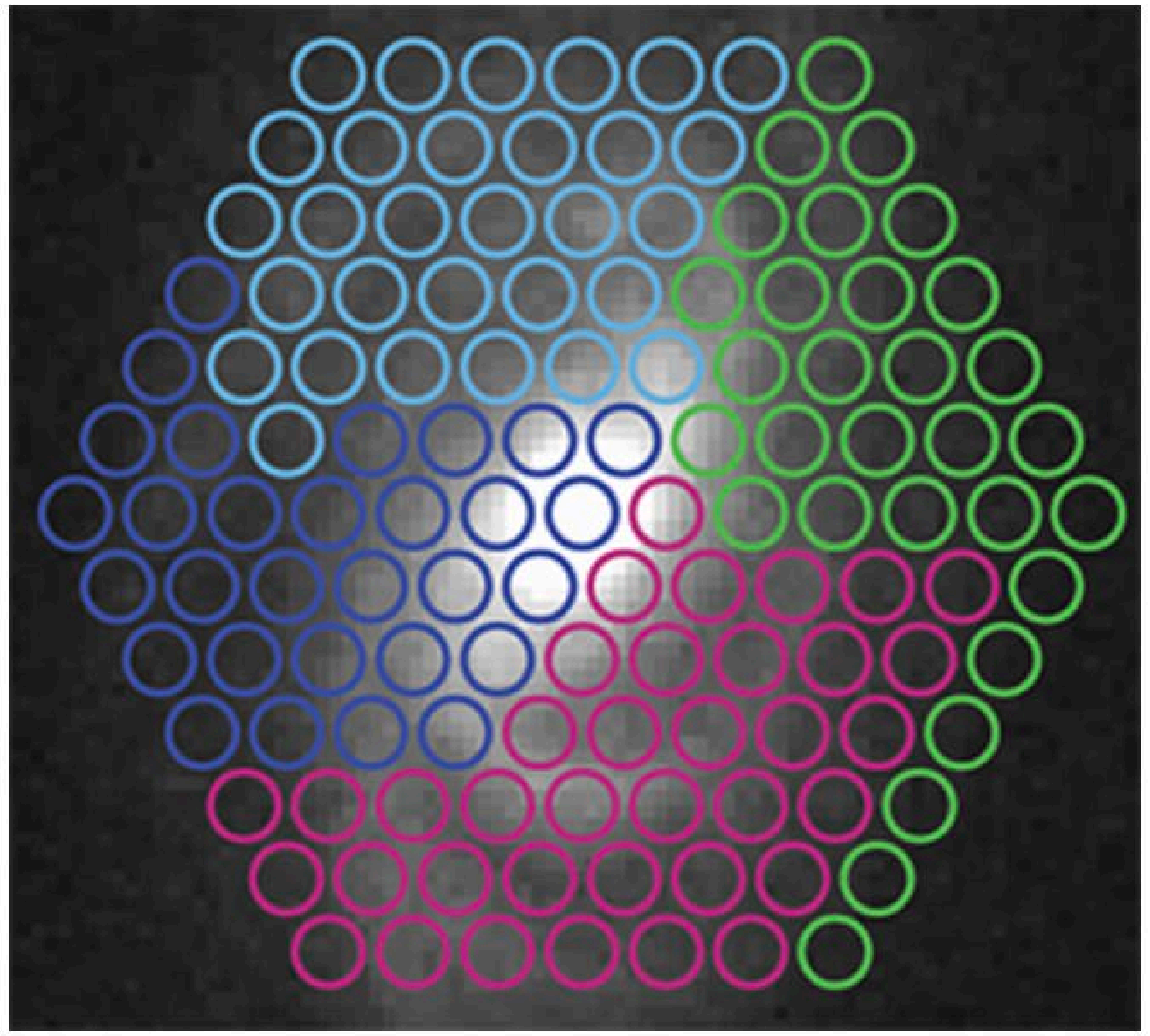
Kormendy & Ho 2013: $M_{\mathrm{BH}} - \sigma$ relation, $M_{\mathrm{BH}} - M_{\mathrm{bulge}}$ relation.

Coevolution of SMBH and its host galaxy.

DATA: MaNGA DR17



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

Credit: https://www.sdss4.org/dr17/manga/

Spatially resolved spectroscopic observations for ~10,000 local galaxies.

Dynamical information (σ), quenching information (D4000).

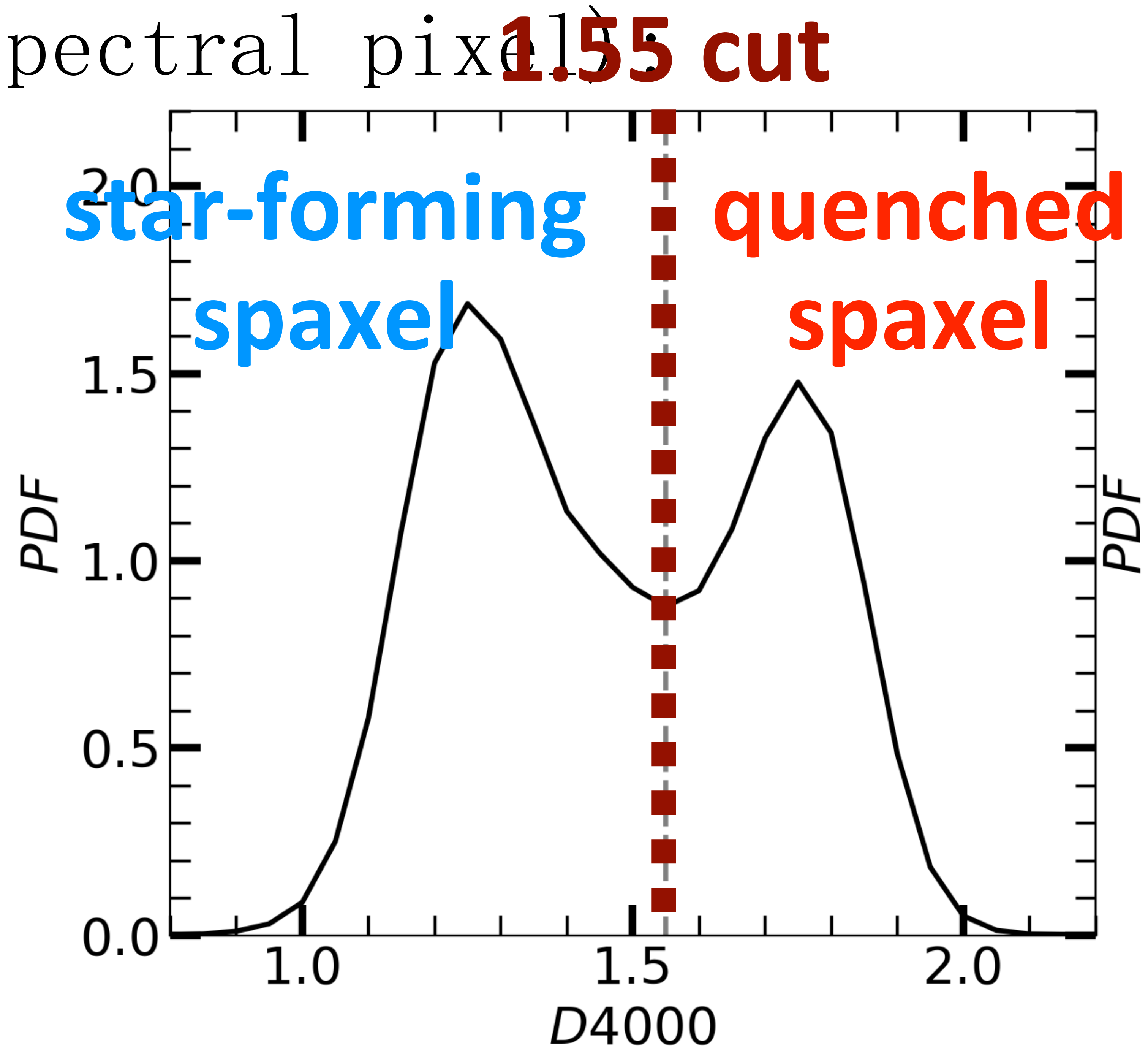
—> Our study: 5124 central galaxies (internal processes).

Star-Forming / Quenching Classification

Step1: Classification of spaxel (spectral pixel):

D4000 on spaxels within 1.5 R_e

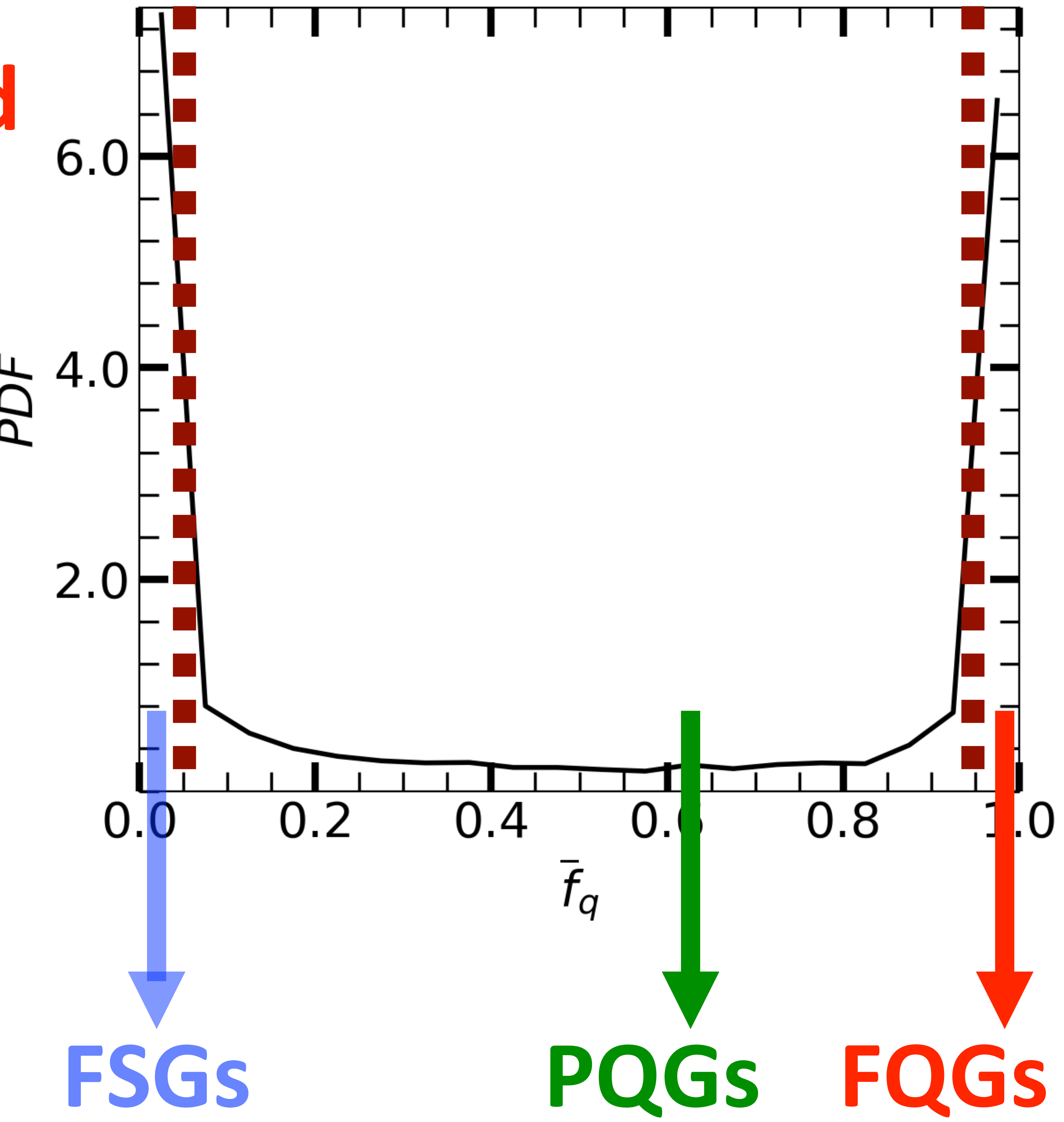
- **quenched**: D4000>1.55
- **star-forming**: D4000<=1.55



Step2: Classification of galaxy

$\bar{f}_q$ (mean quenched fraction within galaxies)

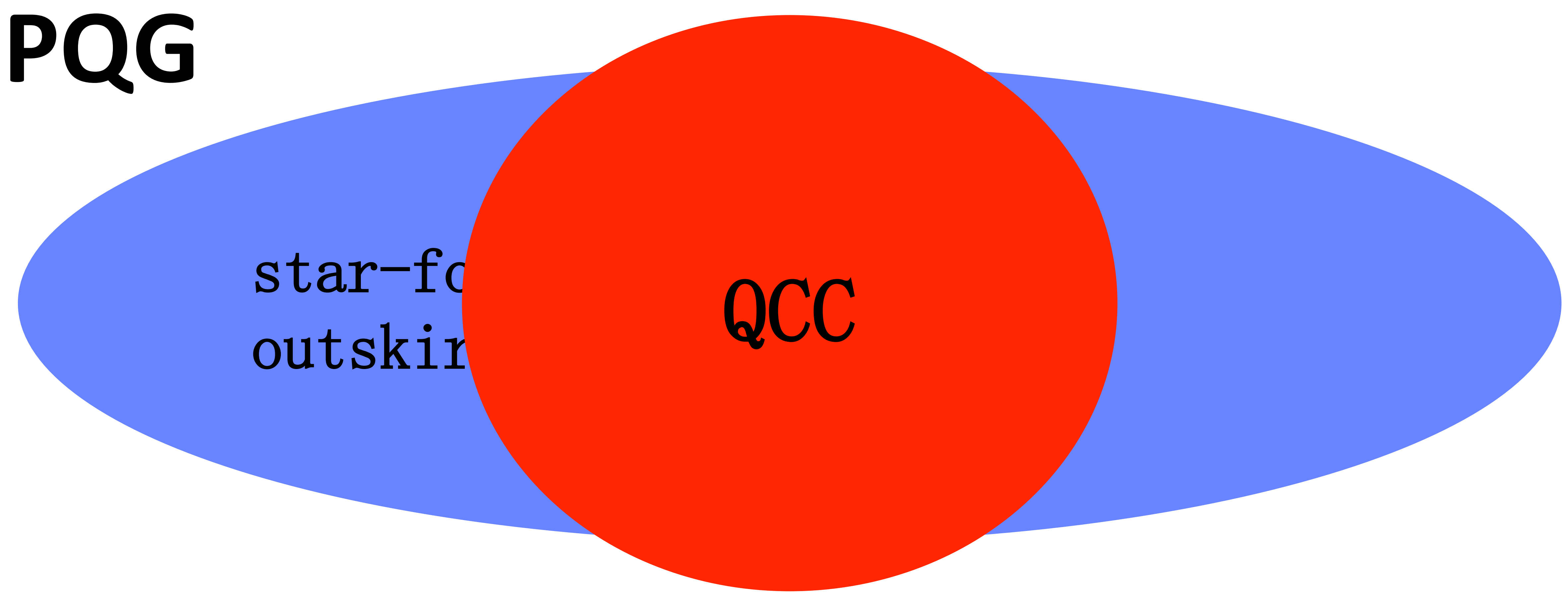
- Fully quenched galaxy (**FQGs**) : $\bar{f}_q > 0.95$
- Partially quenched galaxy (**PQGs**): $0.05 \le \bar{f}_q \le 0.95$
- Fully star forming galaxy (**FSGs**): $\bar{f}_q < 0.05$

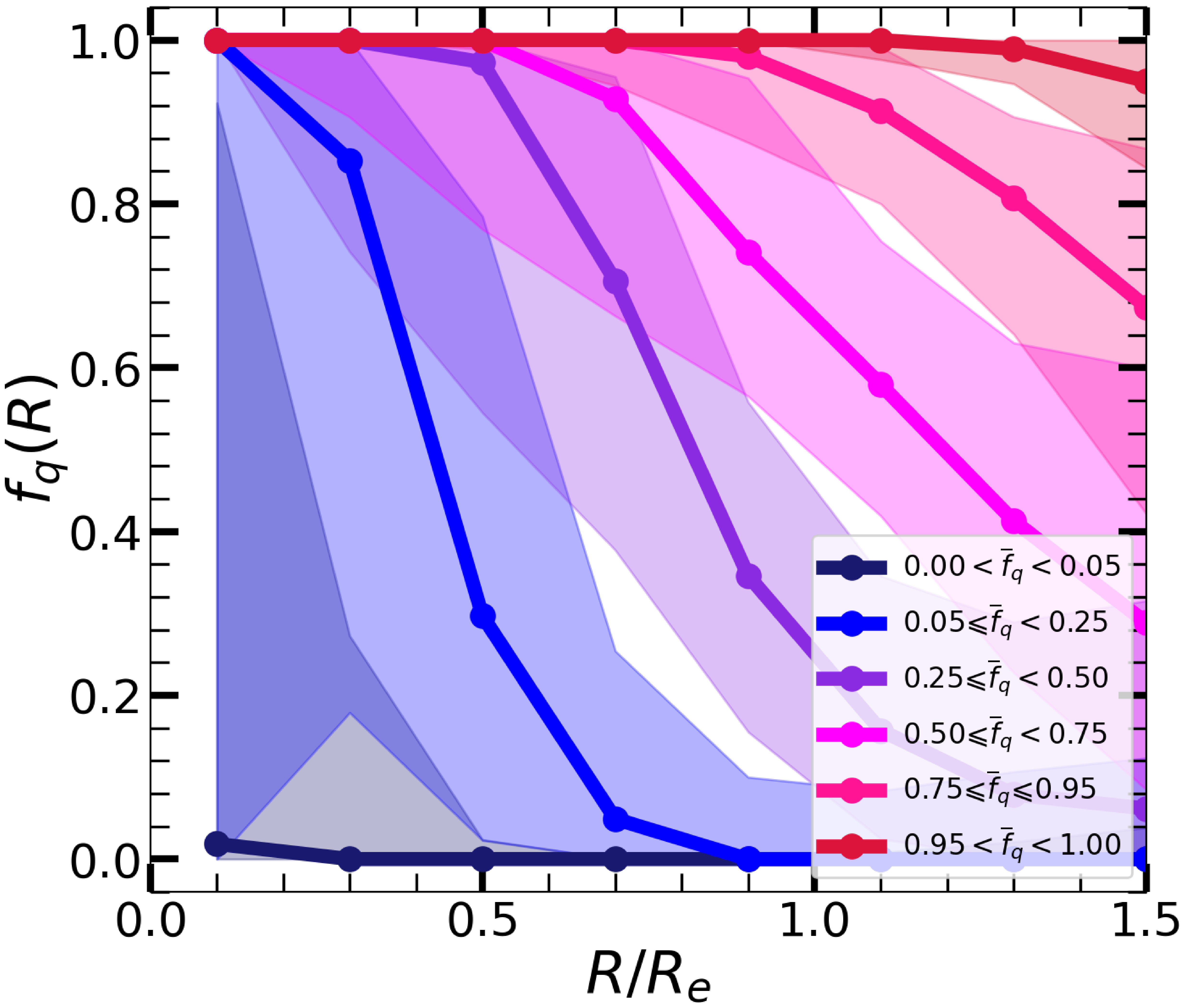


Identify QCC (quenched central core)

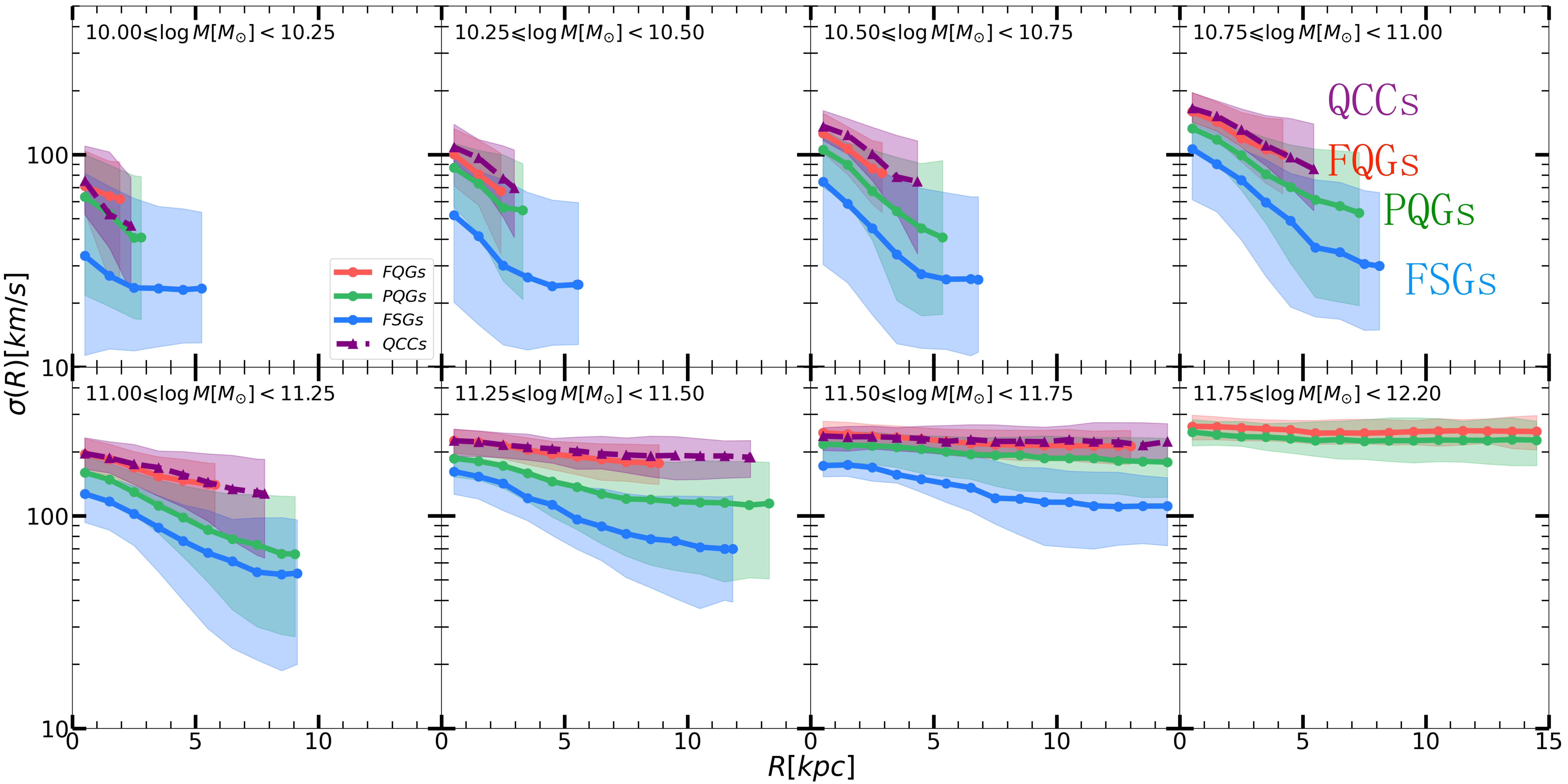
Inside-out quenching for galaxies.

QCC: $\bar{f}_{\rm q}(r < R_{\rm QCC}) = 0.95.$





velocity dispersion profiles



FQGs & QCCs: similar dynamical status, hottest, flat σ profiles, hot throughout the entire galaxies.

Dynamical hotness is important to quenching.

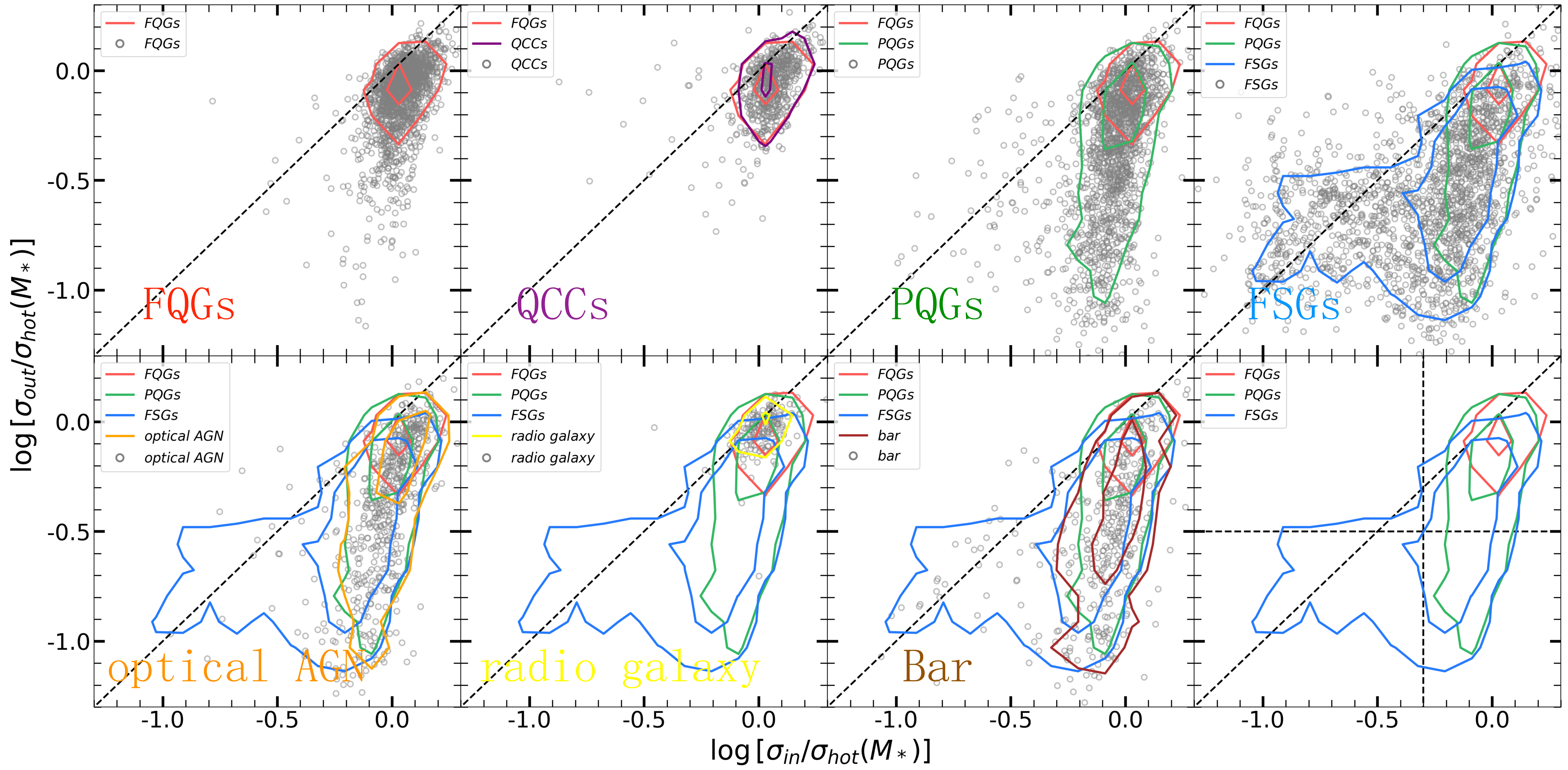
Defining of dynamical hotness

Scaling relation of dynamical hotness (SRDH: $\sigma_{\rm hot}(M_*)$):

fixed slope=0.3, amplitude from massive ($M_* > 10^{11.5} M_\odot$) ellipticals.

$\log\sigma/\sigma_{\rm hot}(M_*)$: distance to SRDH in $\sigma - M_*$ diagram.

Two-σ diagram

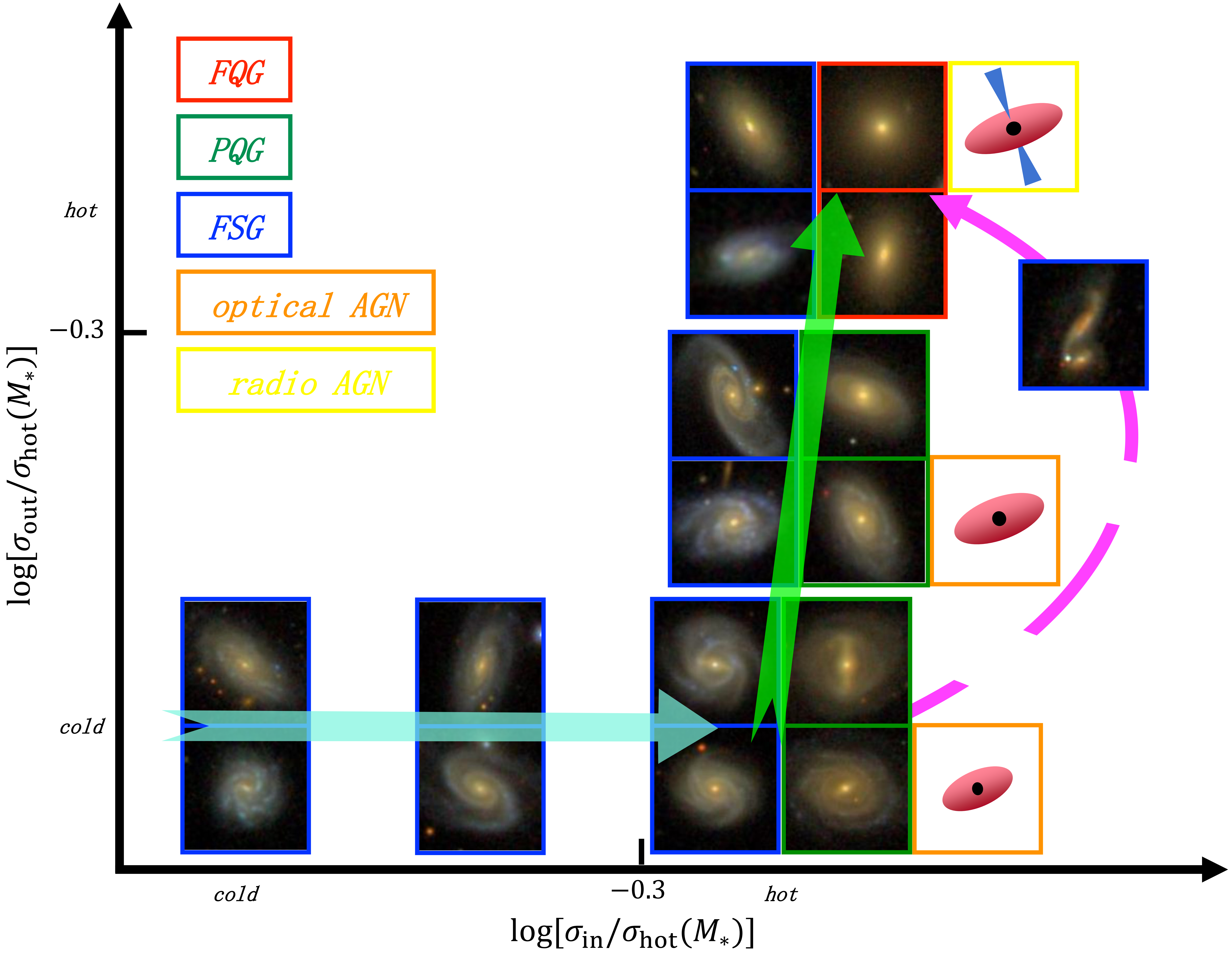


Different population can be well separated.

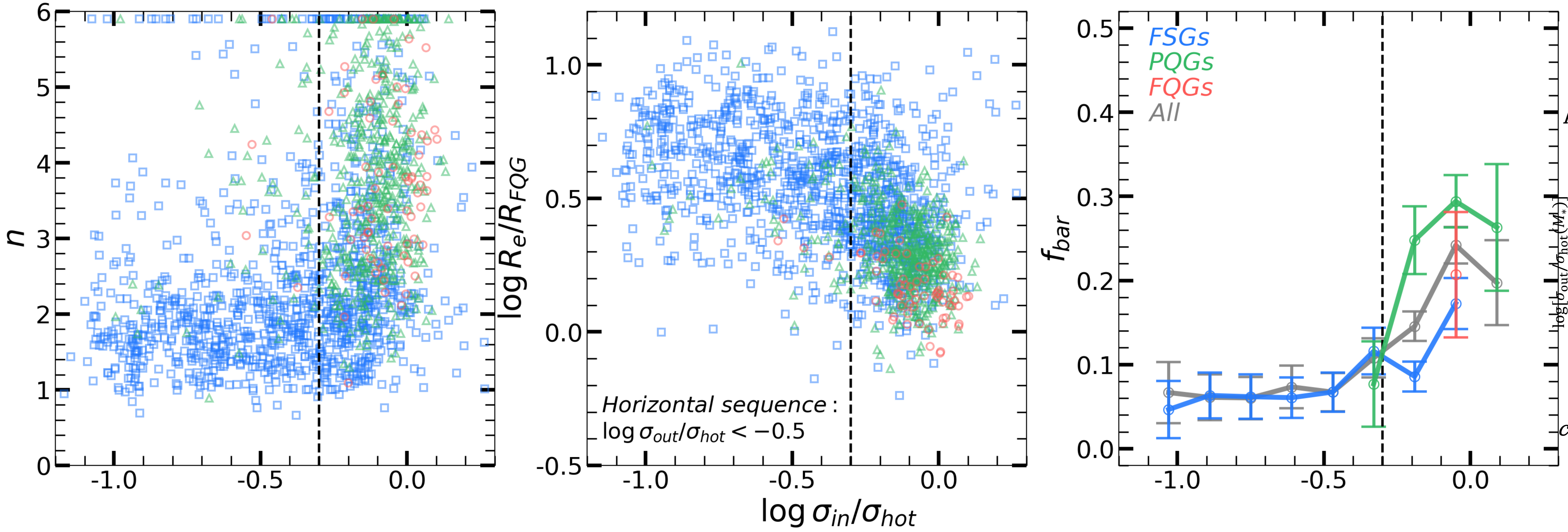
Hot region (upper right corner) + Horizontal and Vertical sequences.

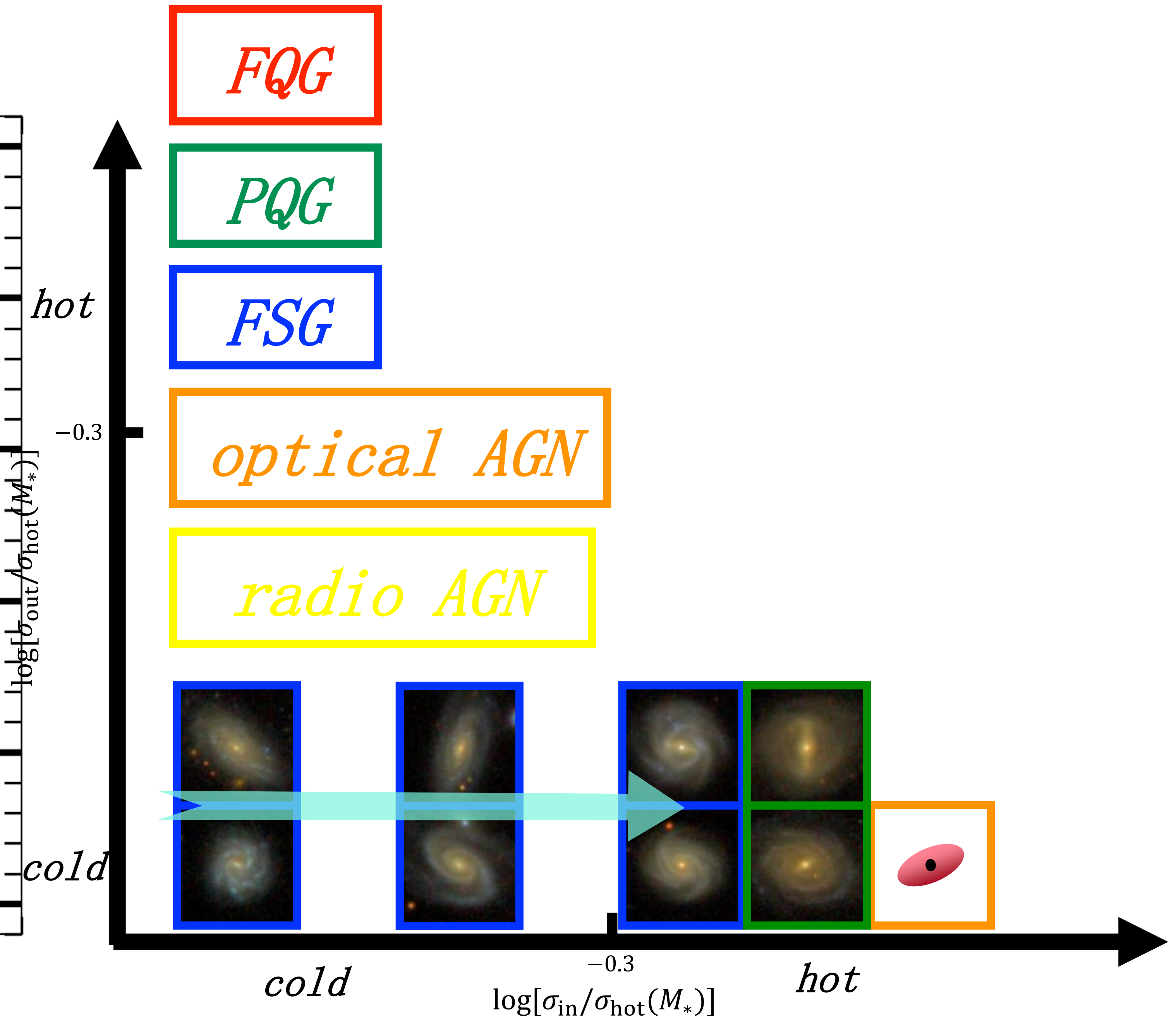
Optical AGNs and barred galaxies are located along vertical sequence. Radio galaxies are located at hot region.

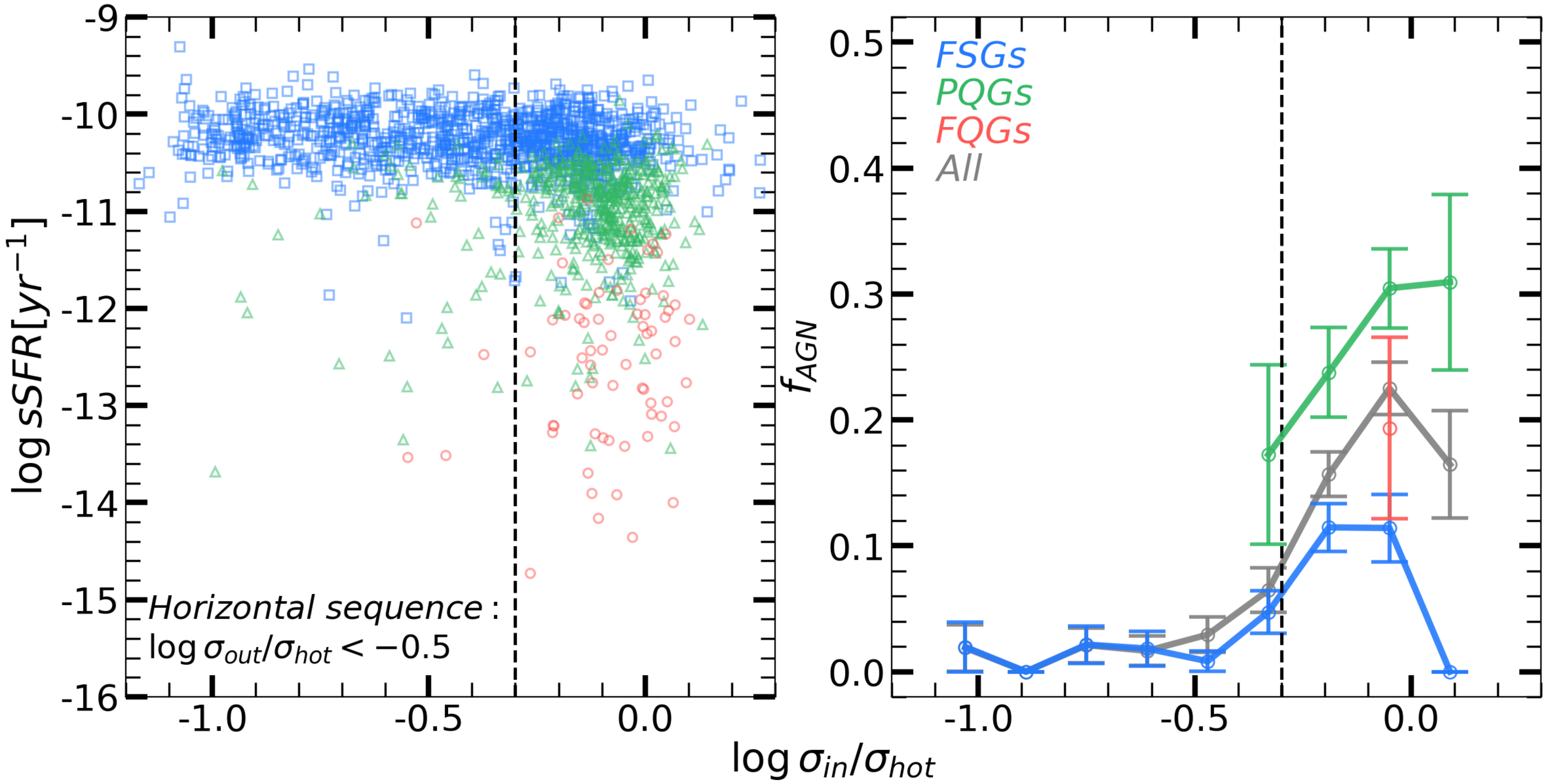
Evolution on 2-σ diagram



Horizontal sequence



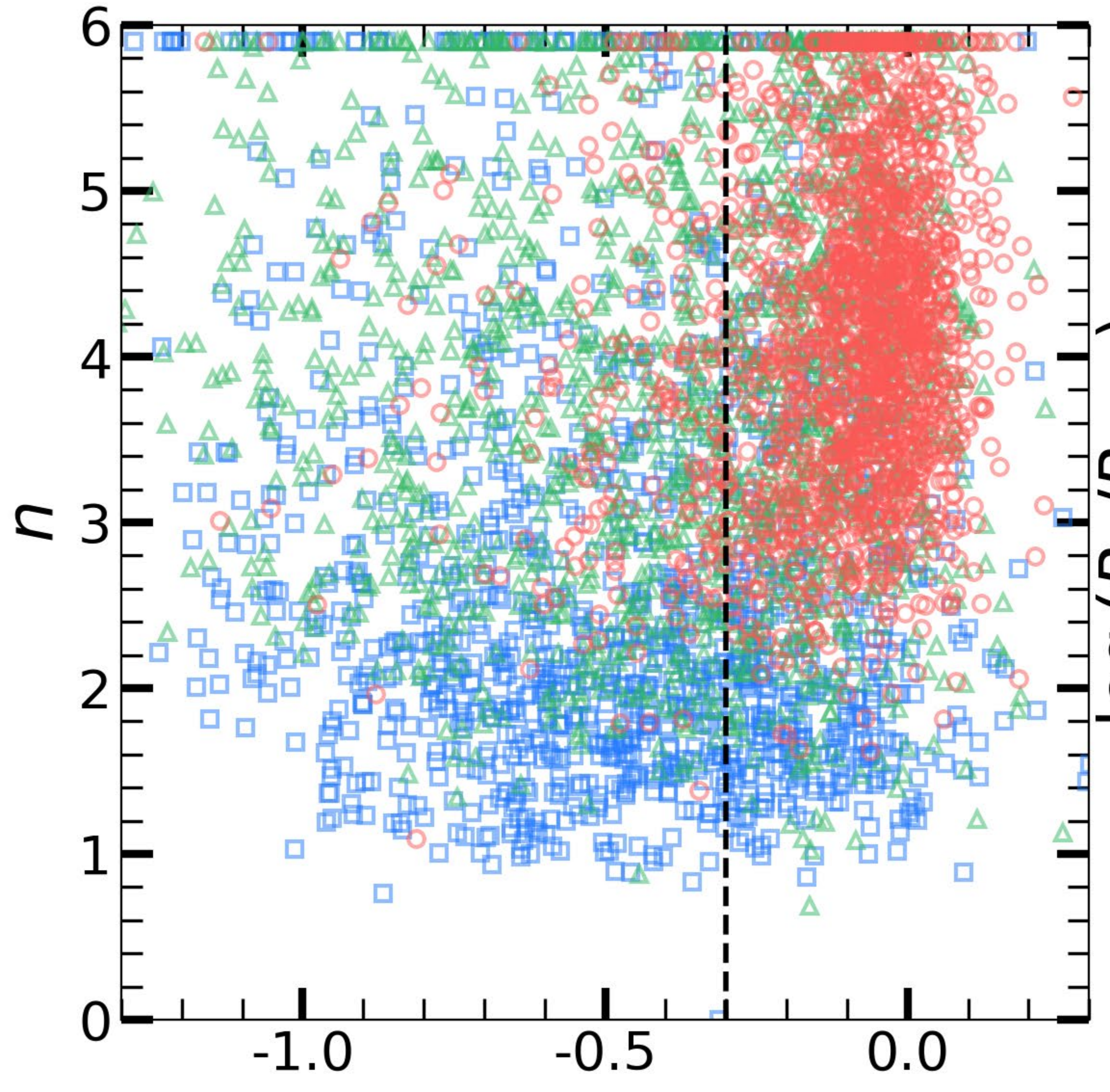


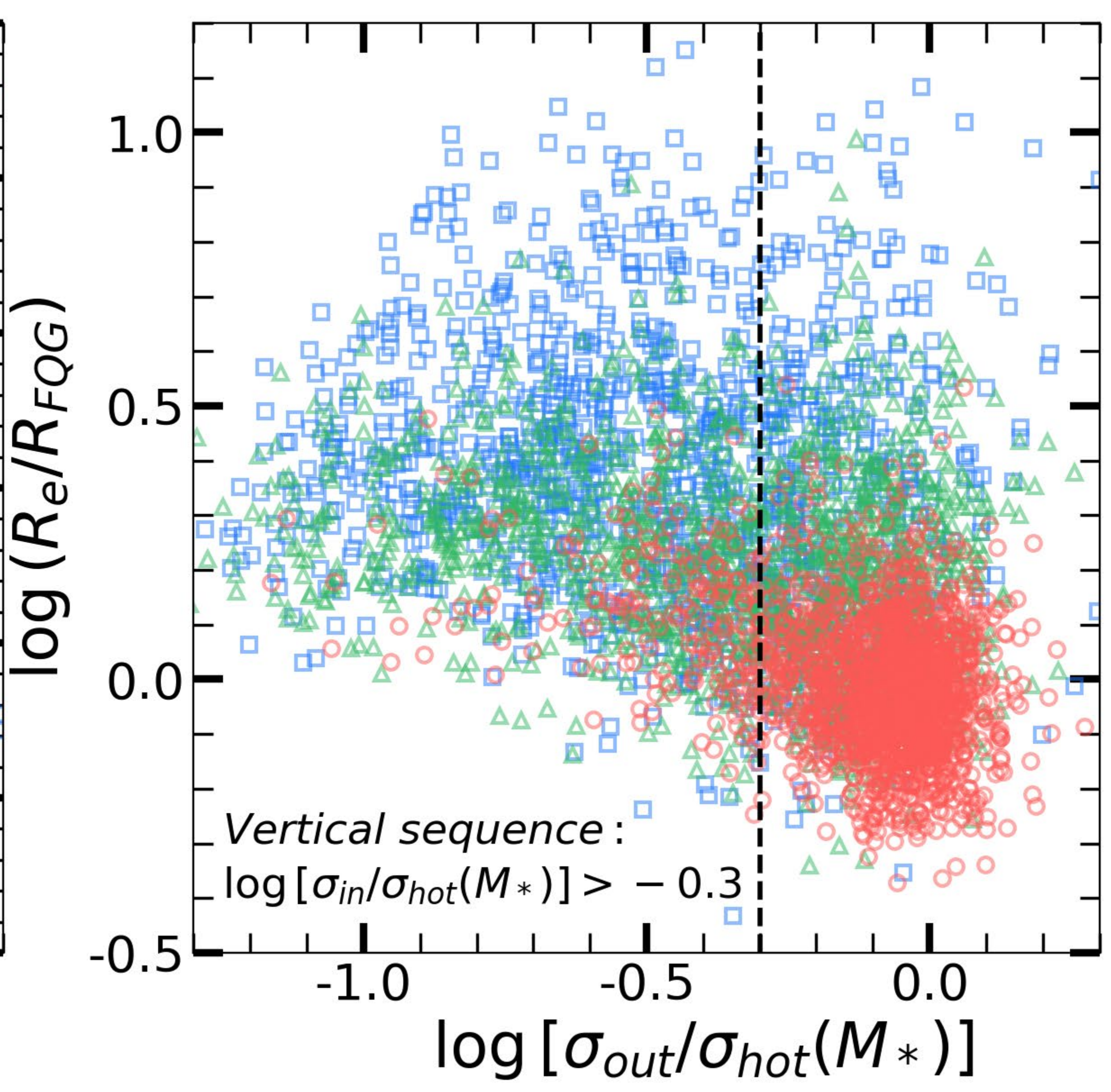


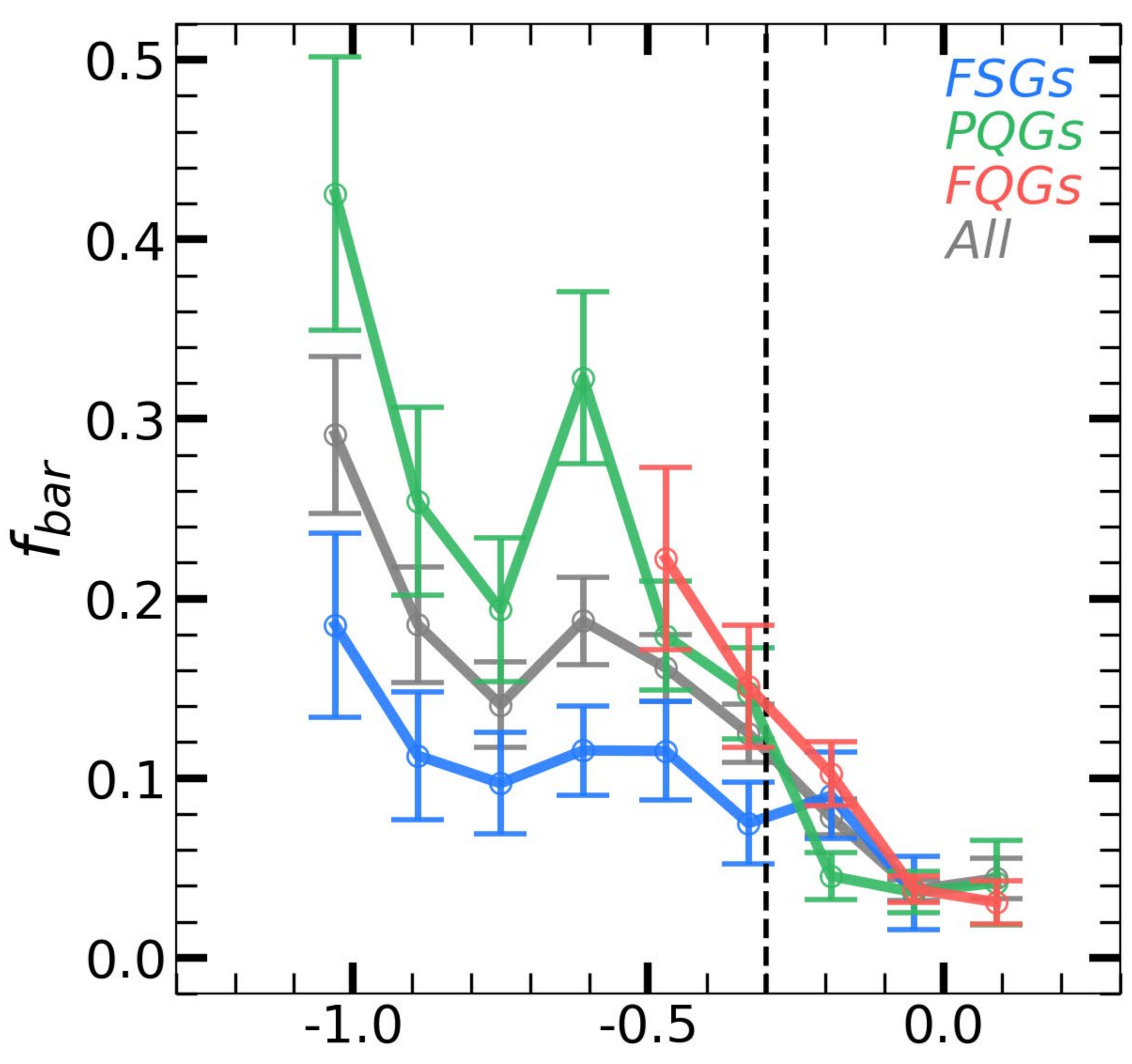
$\sigma_{\rm in}$ increases: disk-growth

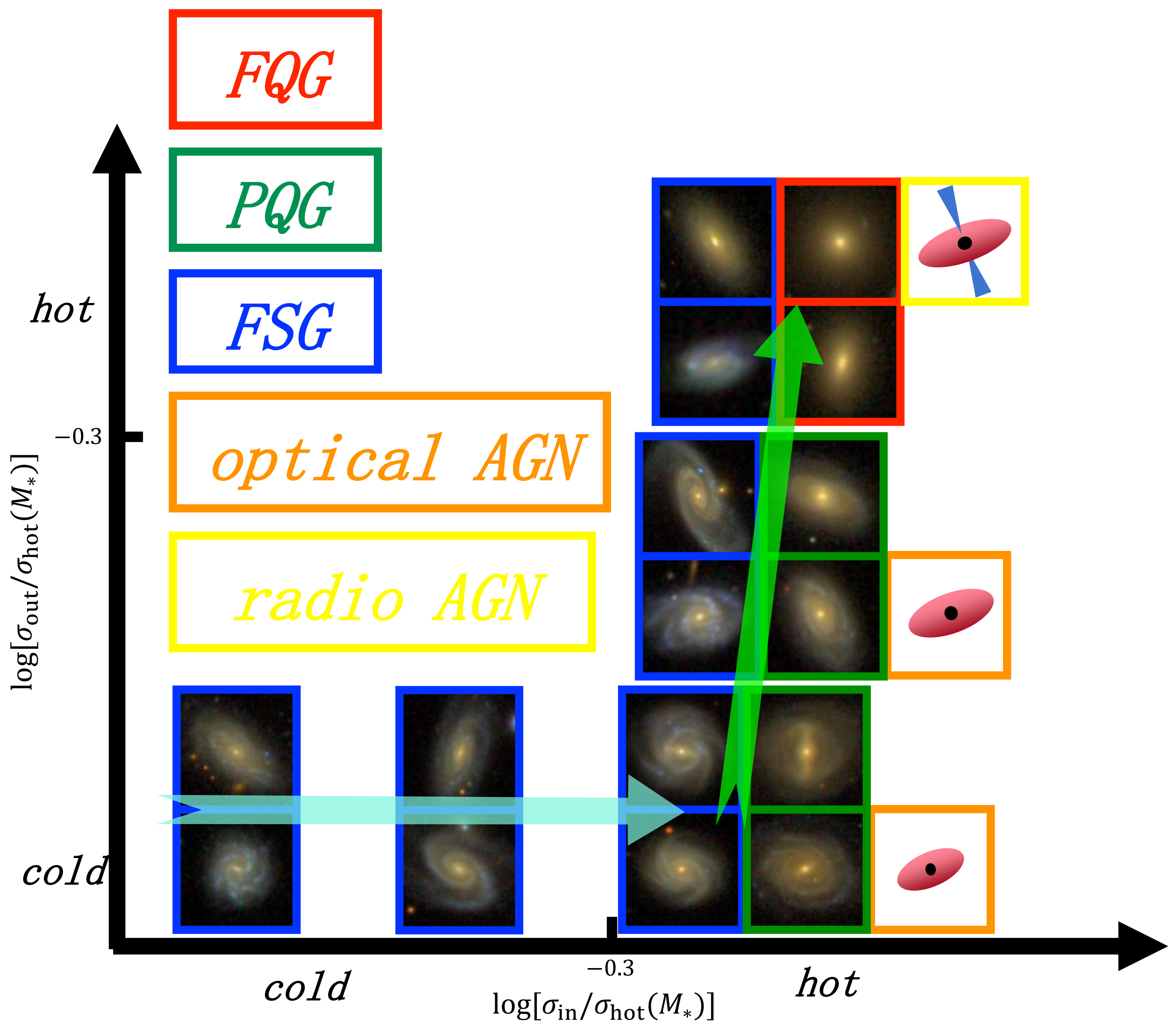
Once $\sigma_{\rm in} \approx 0.5\sigma_{\rm hot}(M_*)$: diverse morphology, size shrinks, barred galaxies, optical AGNs trigger, PQGs emerges (1st L-shape in sSFR-$\sigma_{\rm in}$ diagram) —> enter vertical sequence.

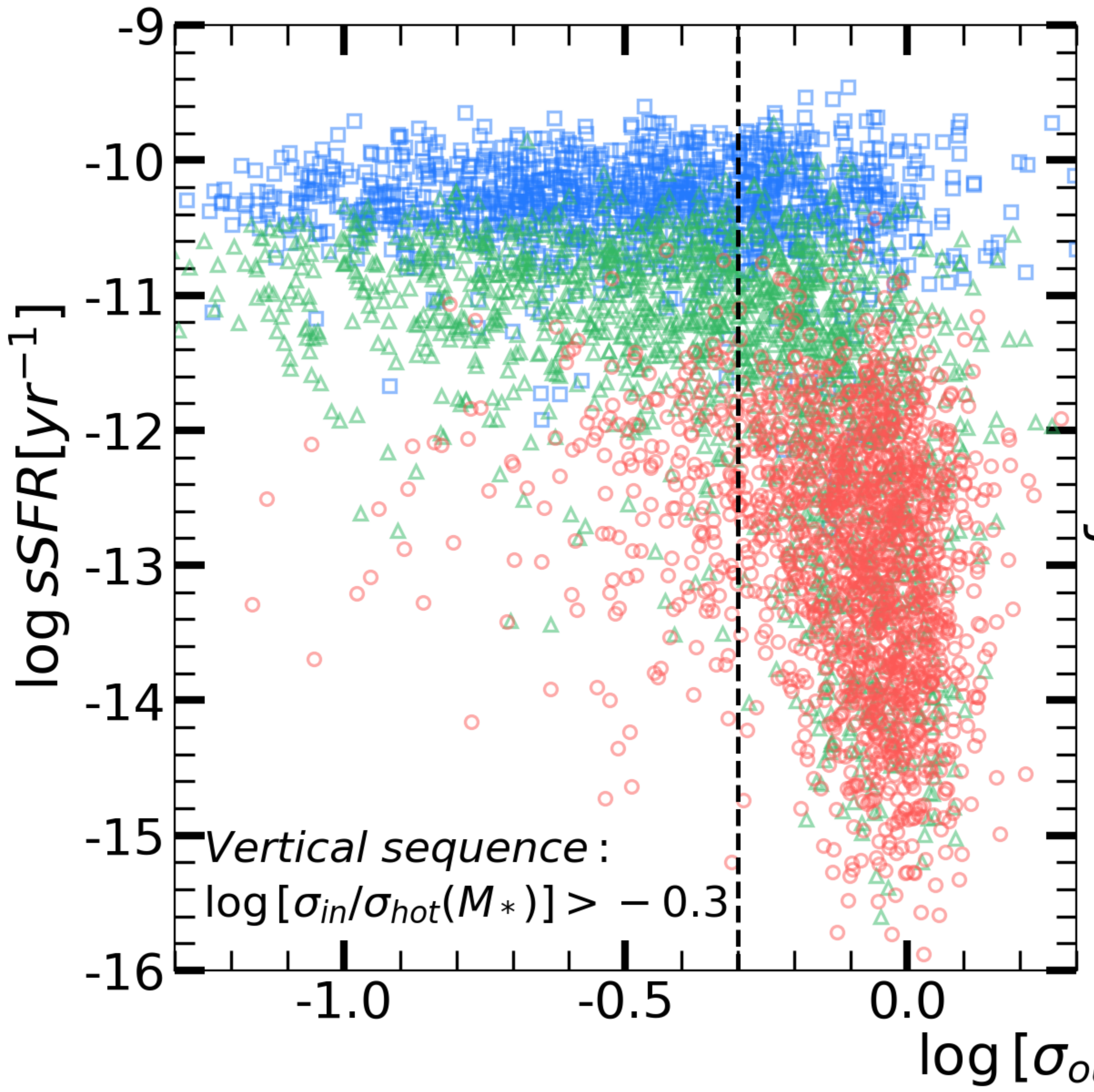
Vertical sequence

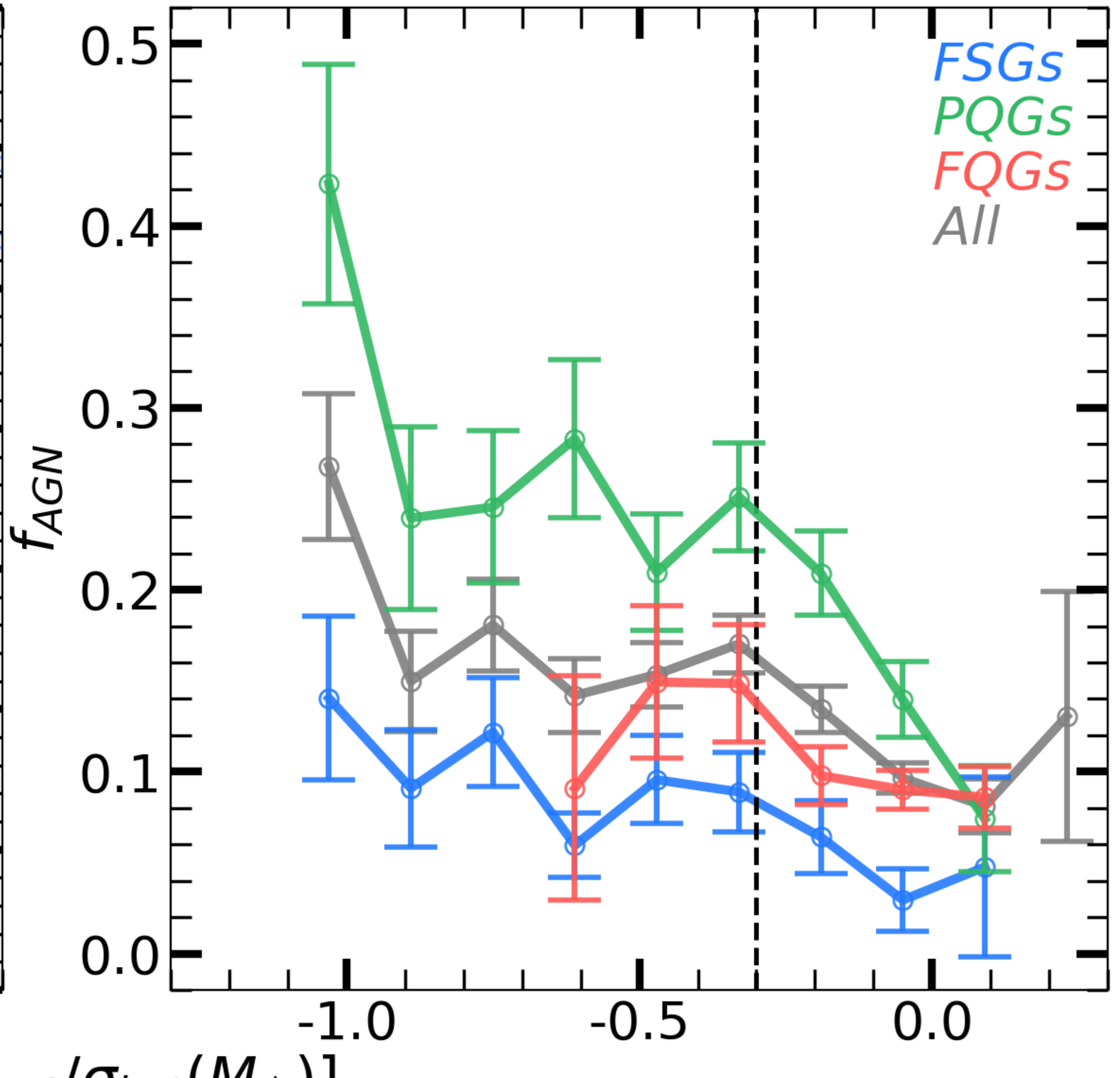








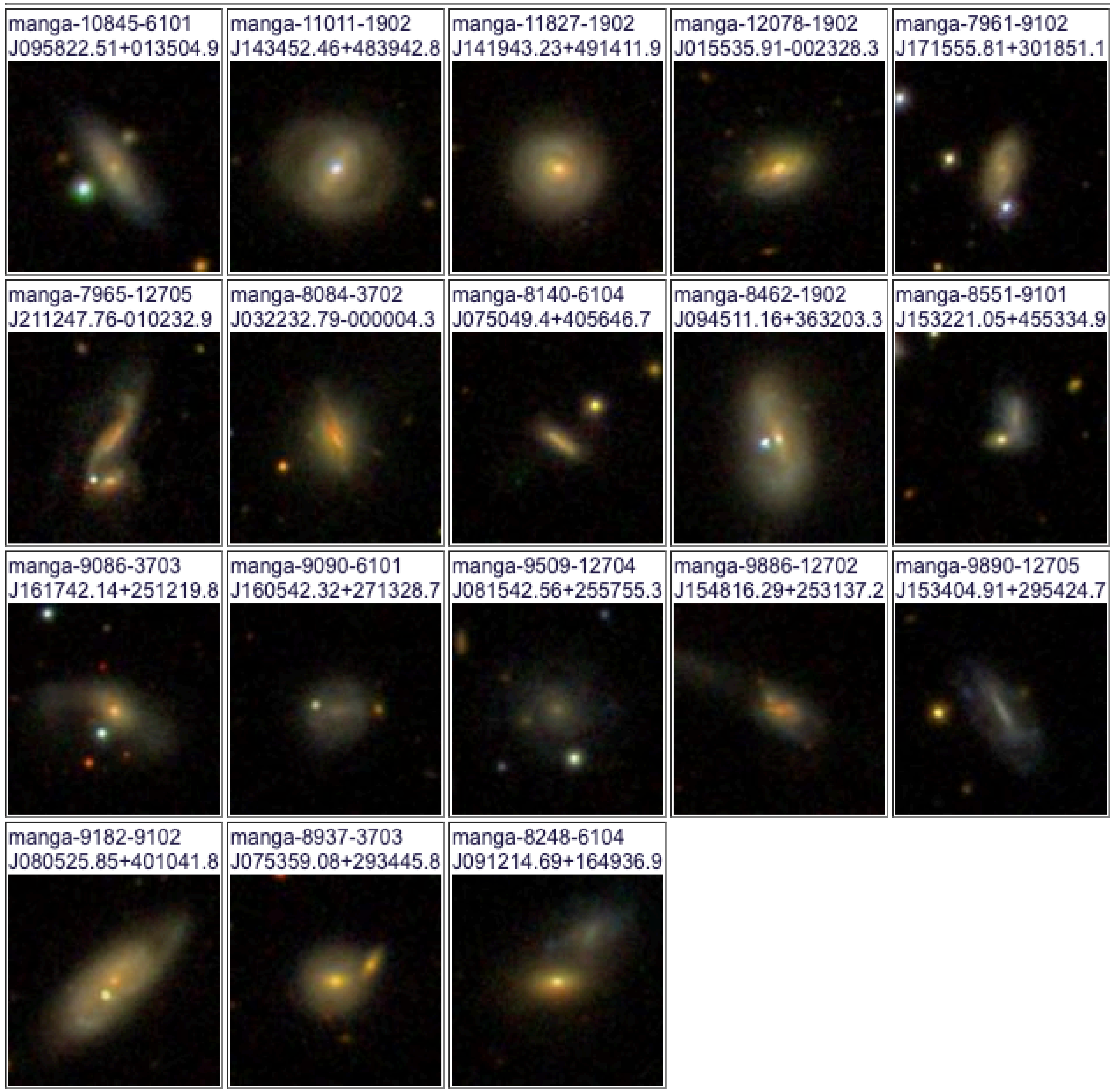


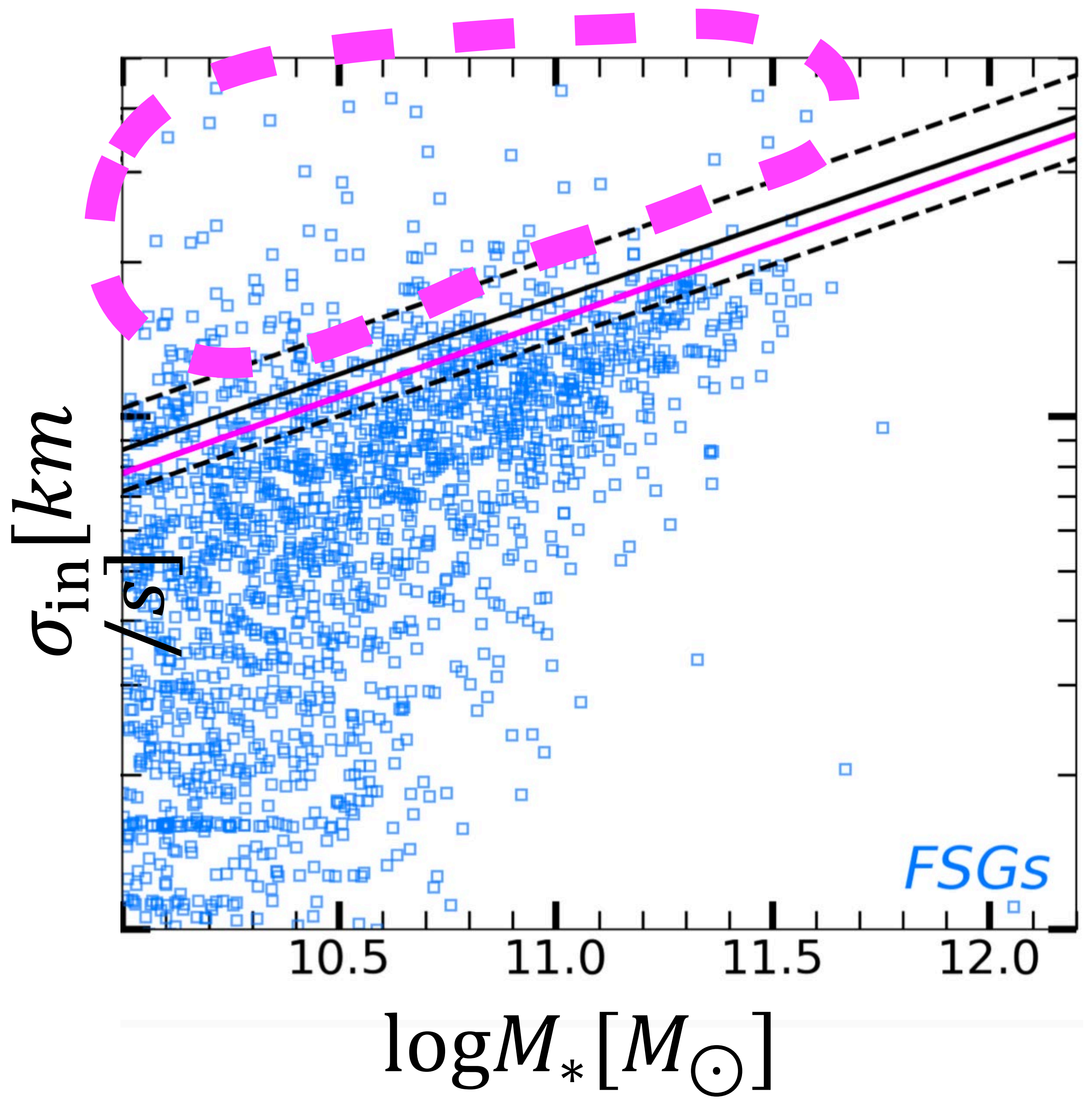


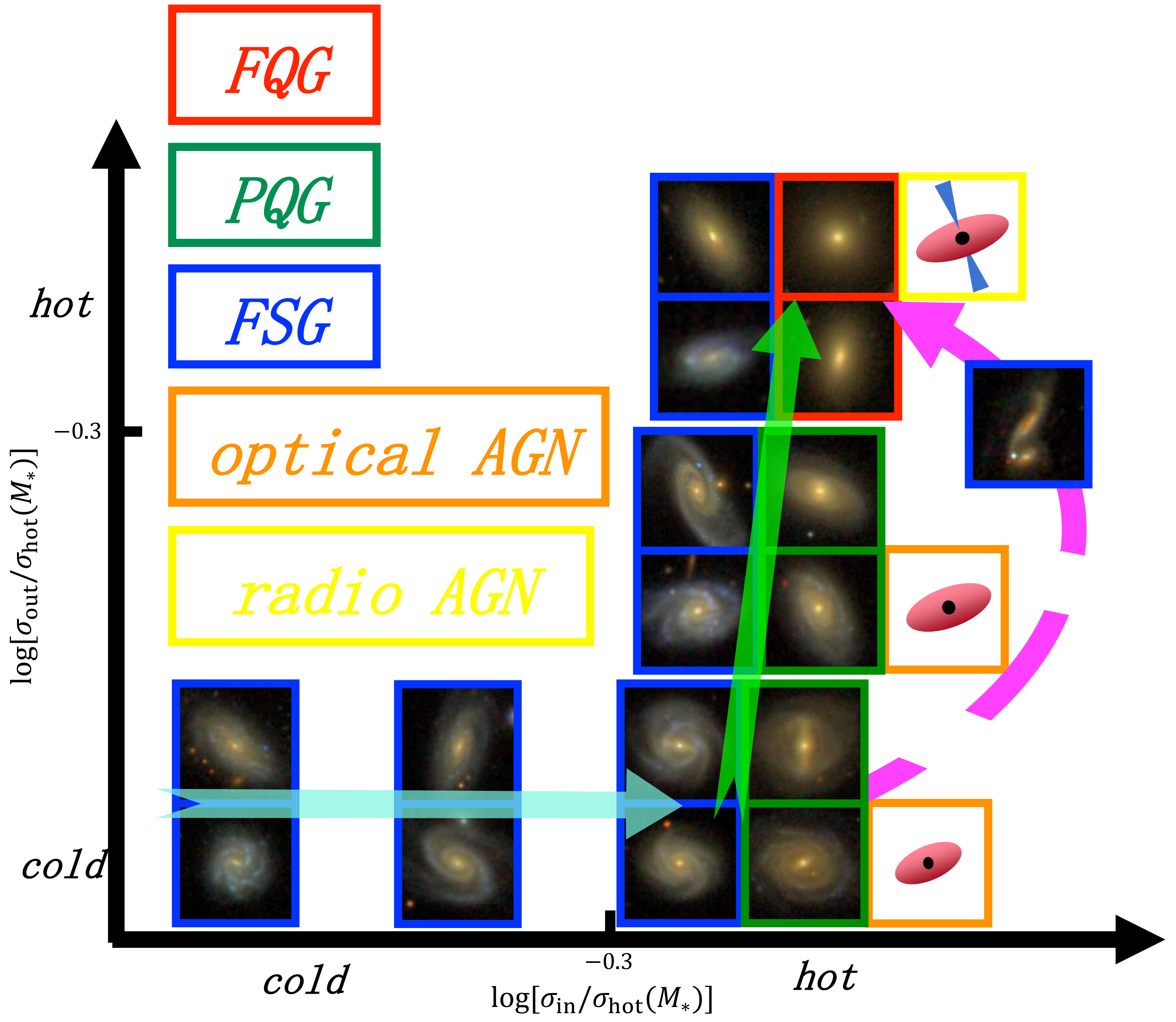
σ_{out} increases: diverse morphology, size shrinks,
f_{bar} decreases, f_{AGN} decreases.

Once $\sigma_{\mathrm{out}} \approx 0.5\sigma_{\mathrm{hot}}(M_*)$: radio AGNs trigger, FQGs emerges (2nd L-shape in sSFR-σ_{in} diagram) —> enter hot region.

Rapid jumps

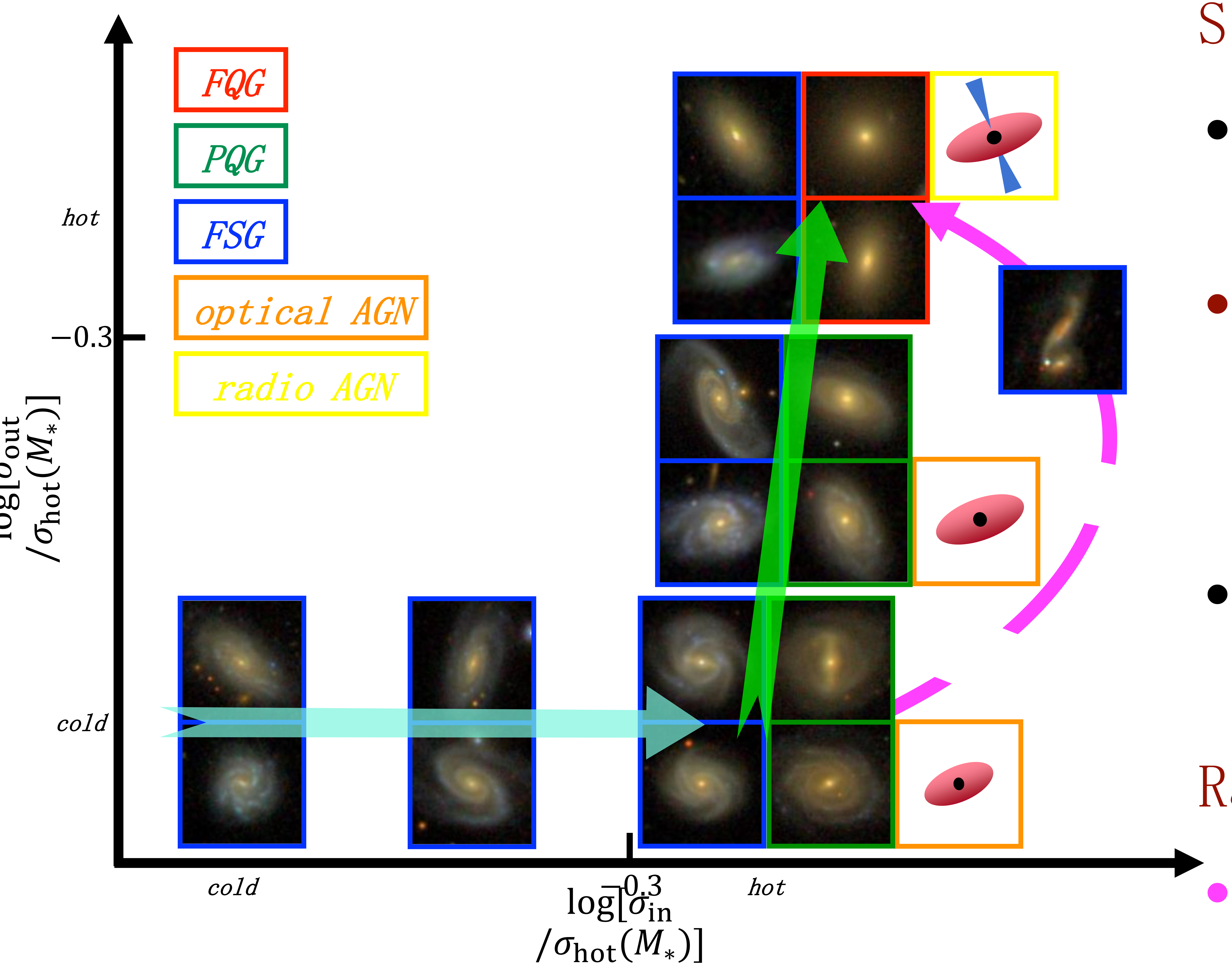






violent interaction: major mergers

Evolutionary path/jumps



Secular processes:

- Along horizontal sequence: gas accretion to form disk.
- Bar or minor interaction or minor mergers drive gas into center —> form stars, feed optical AGNs —> centrally quenched —> enter/along vertical sequence.
- Enter hot region: fully quenched, radio AGNs sustain quenching.

Rapid processes:

- Jumps: major mergers —> disturb star orbits, drive gas into center—> form new stars, trigger AGNs—> quench galaxy.

Toy Model—SMBH & host galaxy

Total energy released by SMBH: $E = \epsilon M_{\rm BH} c^2/(1-\epsilon)$, ϵ: mass-to-energy efficiency fo

Energy couples with ISM, expels or heats gas, ceases the star formation activity:

Expelled or heated gas mass: $M_{\rm gas} = \frac{f_{\rm cp}\epsilon M_{\rm BH} c^2}{1/2(1-\epsilon)v_{\rm esc}^2} = \frac{2\epsilon f_{\rm cp} M_{\rm BH} c^2}{(1-\epsilon)a^2\sigma_{\rm in}^2}$,

$f_{\rm cp}$: fraction of energy coupled with ISM, $v_{\rm esc}$: escaping speed for gas, $v_{\rm esc} = a\sigma_{\rm in}$.

SMBH mass: $M_{\rm BH} = \frac{(1-\epsilon)a^2 f_{\rm gas} M_* \sigma_{\rm in}^2}{2\epsilon f_{\rm cp} c^2} = \gamma M_* \sigma_{\rm in}^2$,

$f_{\rm gas}$: gas-to-star mass ratio, M_*: galaxy or object mass, $\gamma \equiv (1-\epsilon)a^2 f_{\rm gas}/2\epsilon f_{\rm cp} c^2$ (need to be calibrated).

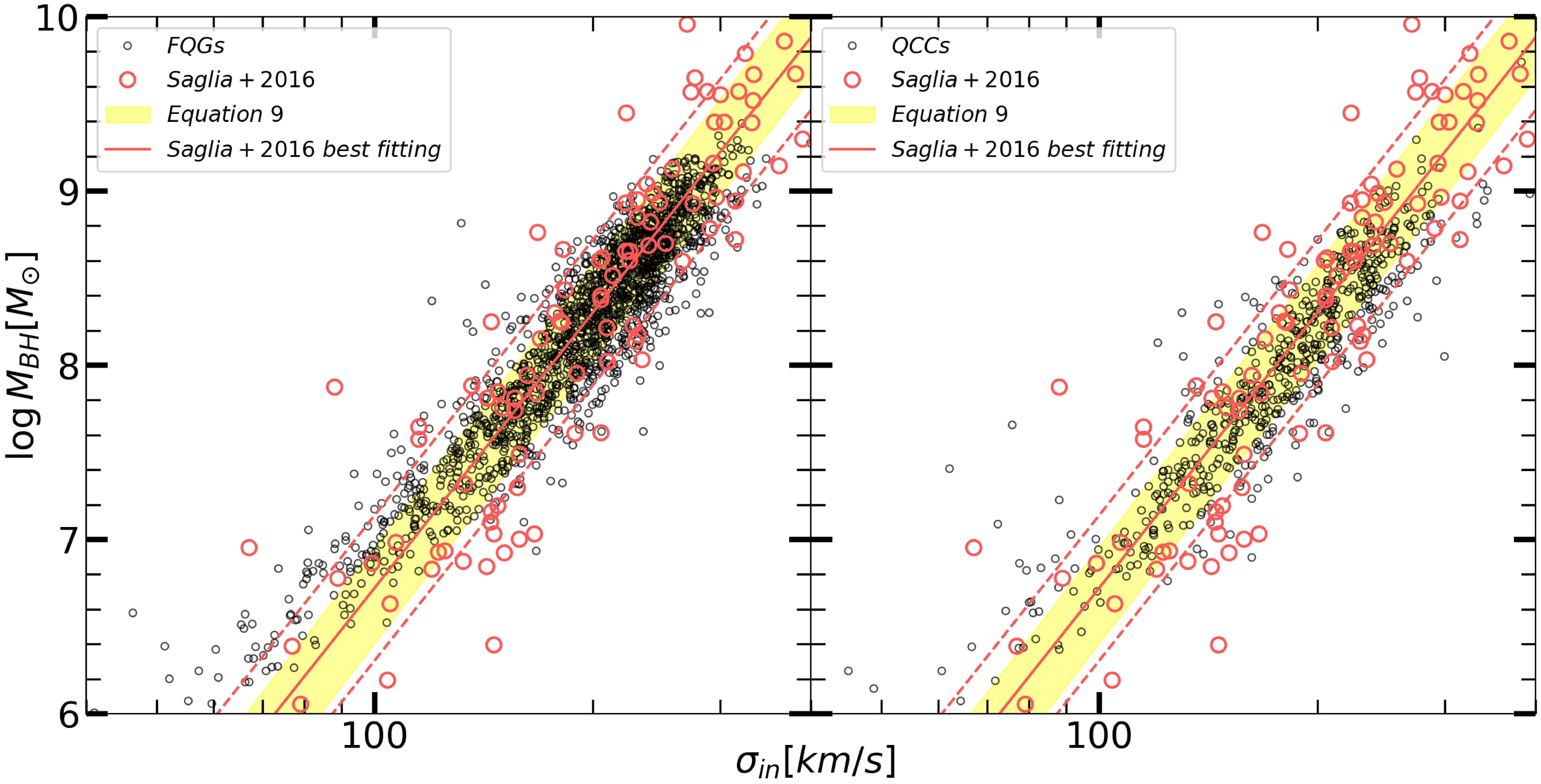
Assumption:

(1) Dynamically hot systems: AGN accretion and feedback are efficient.

(2) Fully quenched systems: balanced systems.

—> can be applied to FQGs and QCCs.

$M_{BH} - \sigma$ relation

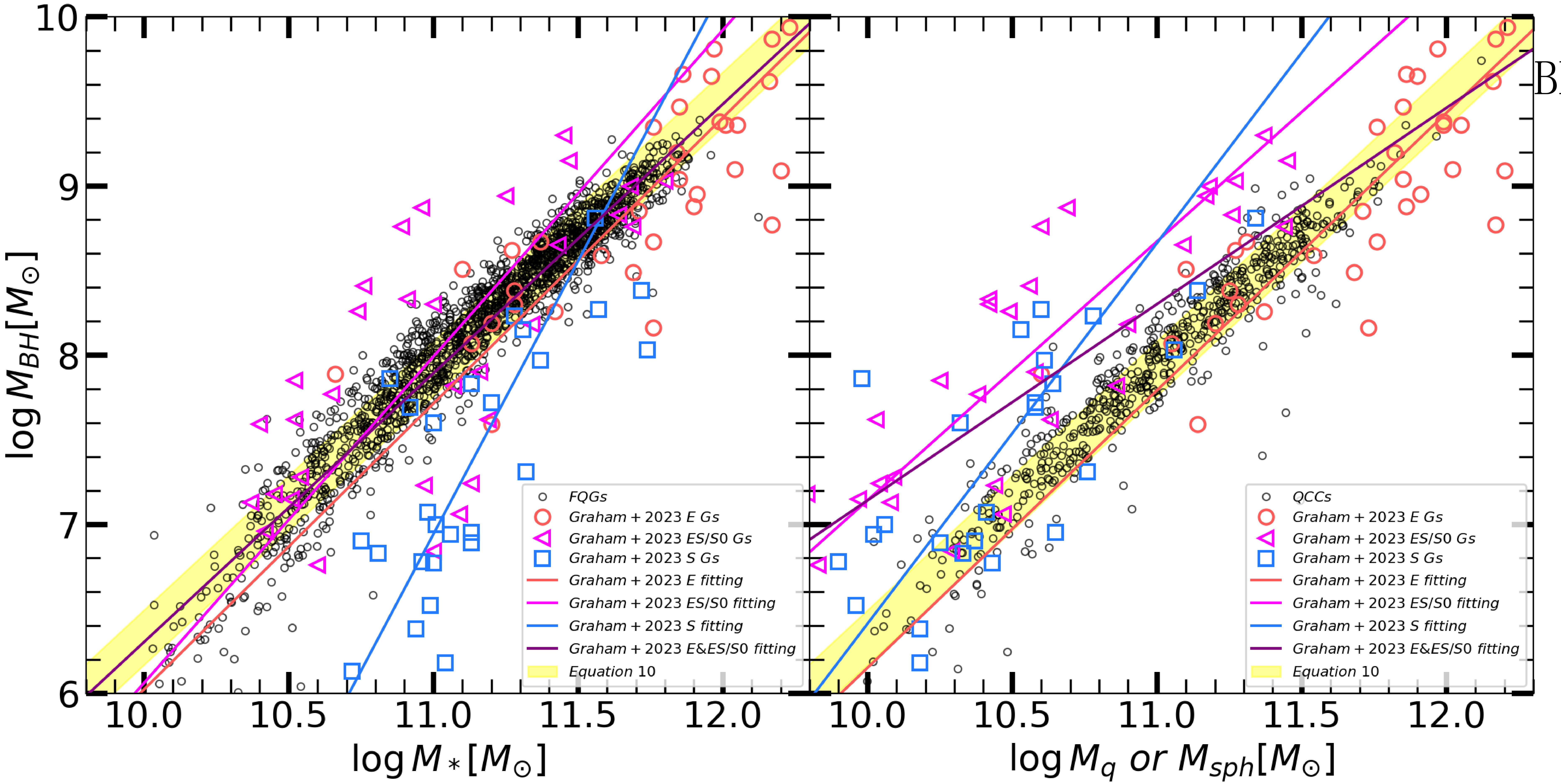


BH1 sample (Saglia+2016)

—> calibration of γ

FQGs and QCCs (Eq 9) follows the same trend (similar slope) described by BH1 sample whic are consistent with the former study different morphological types of galaxies follows similar $M_{BH} - \sigma_{in}$ relation.

$M_{\mathrm{BH}} - M$ relation



BH2 sample(Graham+2023)

$M_{\mathrm{BH}} - M_*$: FQGs follow the same trend as ETGs (purple line, E+ES/S0) in BH2 sample.

$M_{\mathrm{BH}} - M_{\mathrm{sph}}$: QCCs are similar as E (red line) at massive end, different from ES/S0 (p

low mass end—> QCCs are larger than bulges —> other dynamically hot and quenched components are needed (eg. dynamically hot inner stellar halo).

Main Points

- Dynamically hot objects or galaxies (QCCs & FQGs) can be effectively quenched.
- Two-σ diagram is powerful to separate different populations.
- Evolutionary tracks on Two-σ diagram: secular processes (bar-driven, minor interactions) and rapid processes (mergers).
- Toy model: coevolution of SMBHs and quenched objects or galaxies.

Q&A
Thanks！

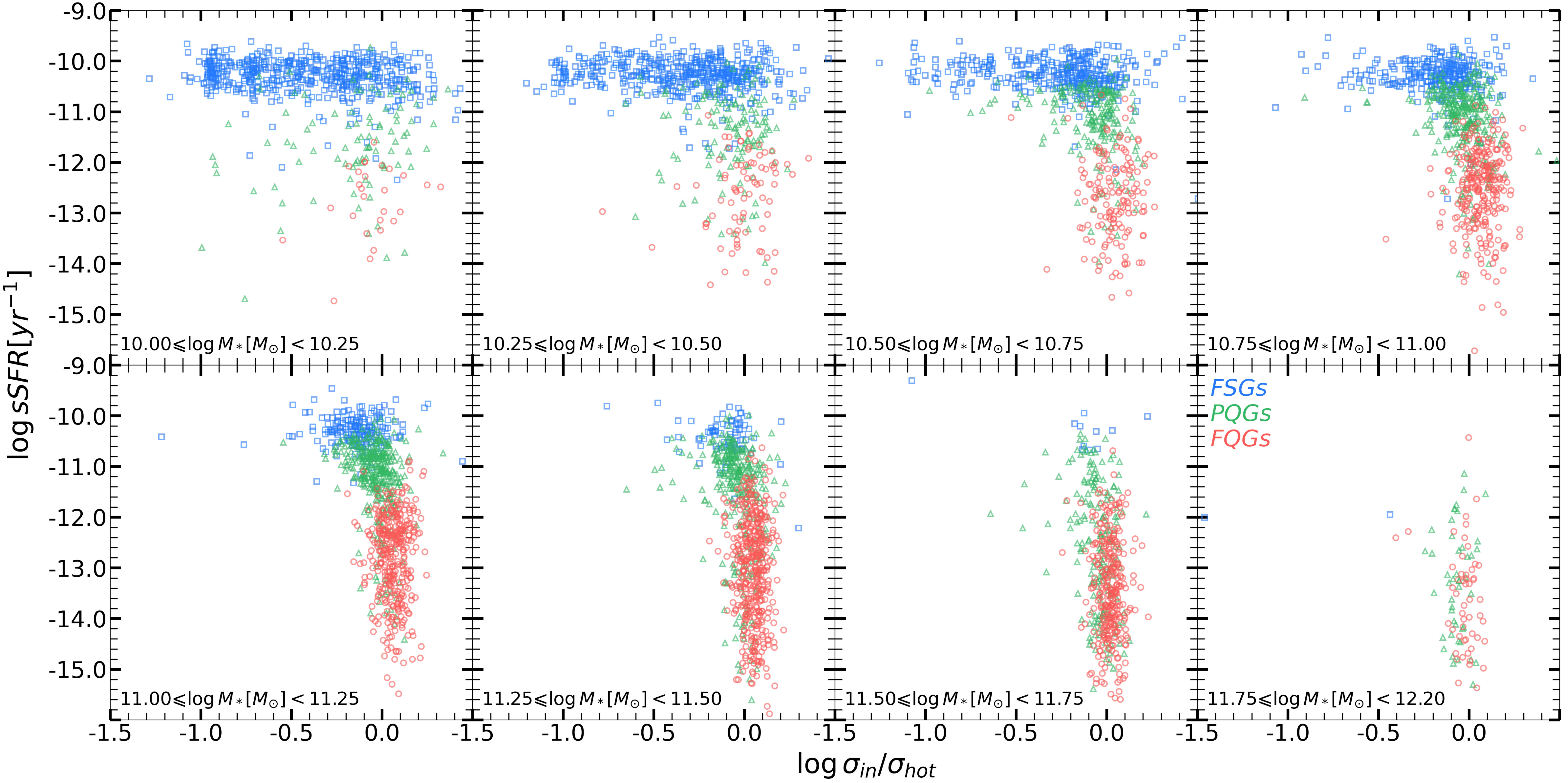
hotness and QGSR

FQGs: hottest, follow a tight relation. —> QGSR (quenched galaxy scaling relation)

QCCs

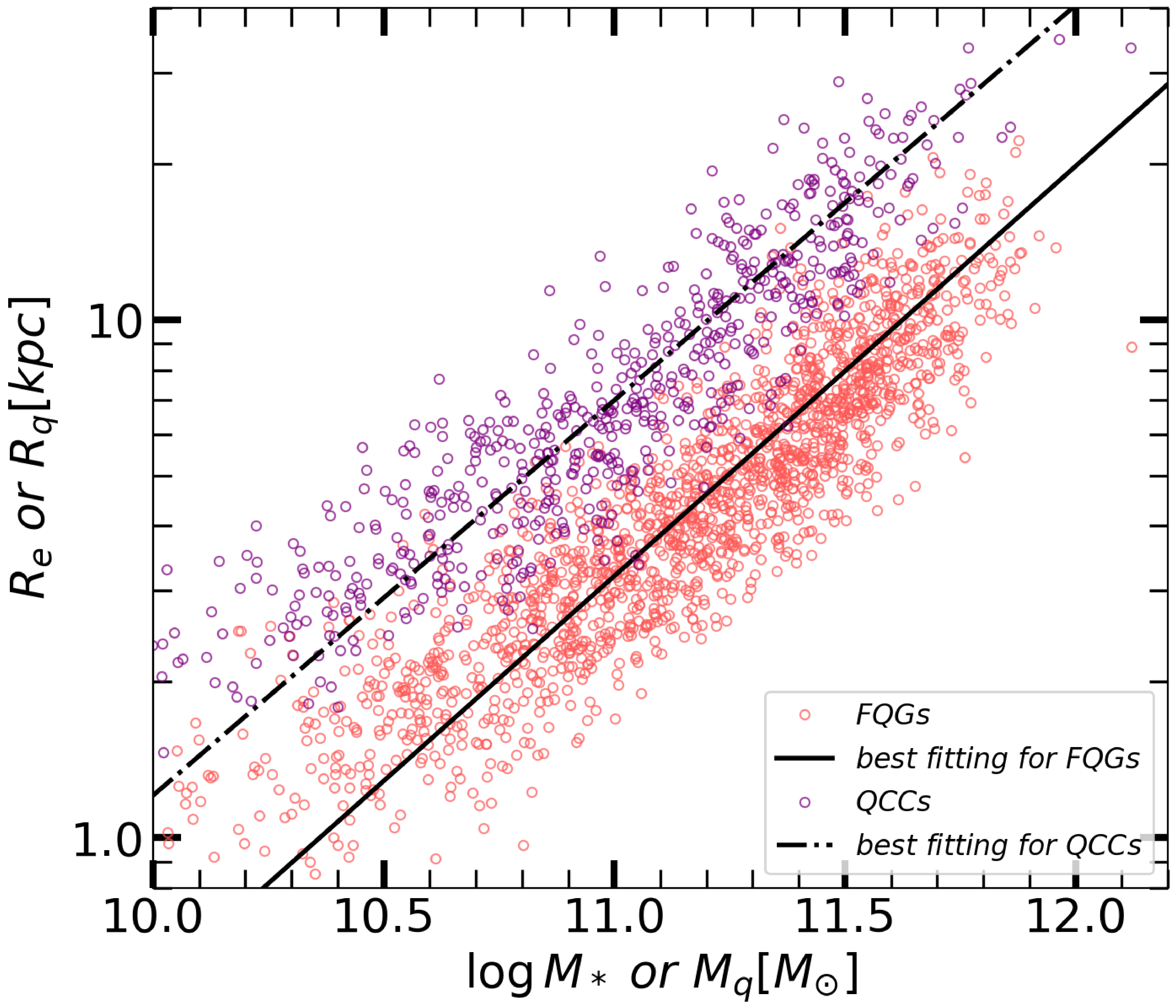
QCCs obey QGSR as FQGs do.

L-shape

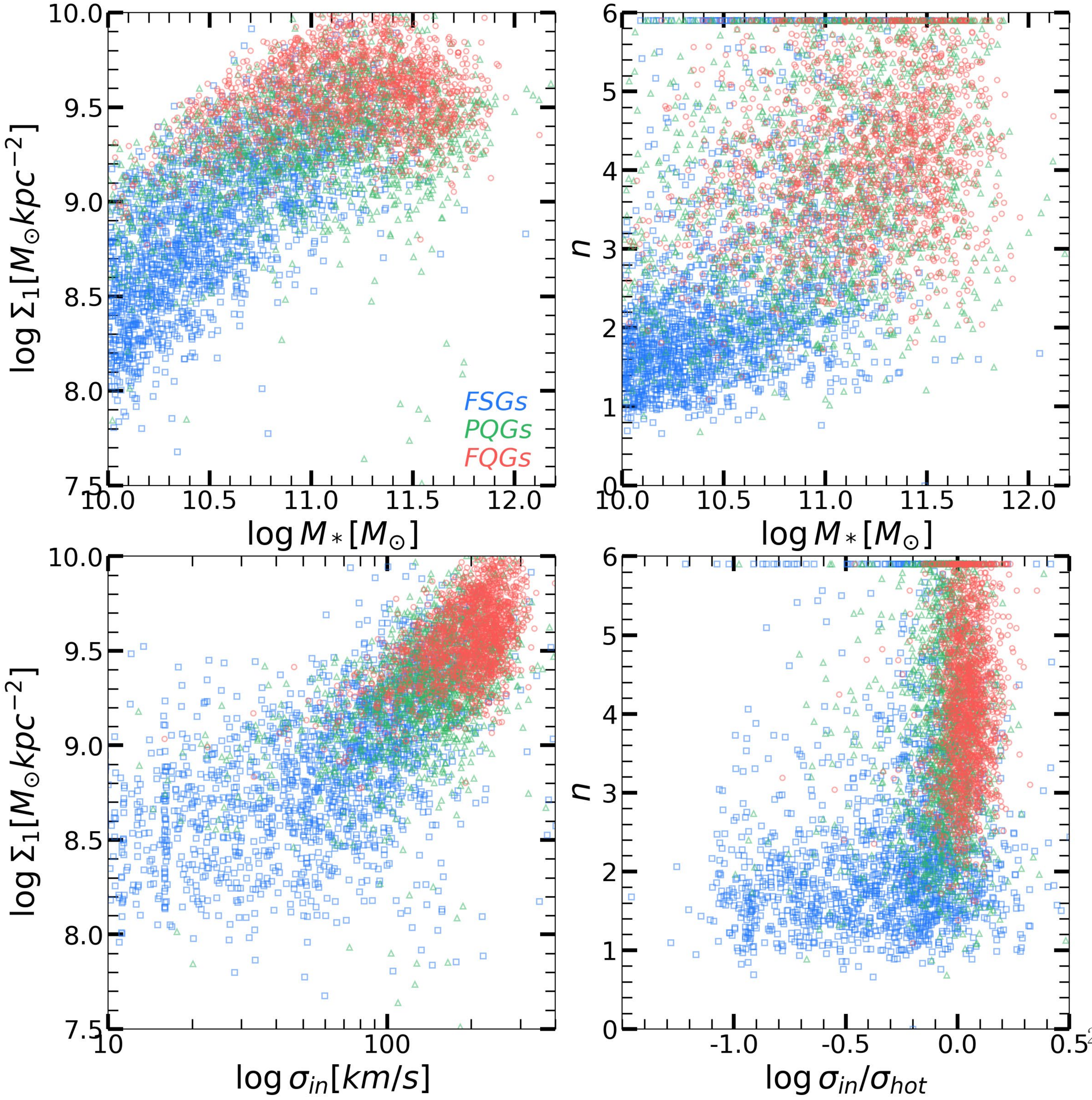


phase transition: σ_{in} reaches half of σ_{hot} ⟶ quenching emerges

Mass-Size relation



Other structural parameters



Two-σ digram for FSGs

Two-σ digram for PQGs

Two-σ digram for FQGs