FABER-JACKSON AND BLACK HOLE SCALING RELATIONS AND THEIR CONNECTION WITH STAR FORMATION QUENCHING

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Background:

galaxy structural properties: morphology, M_*, M_{sph}, Σ_1, σ_{c}

Faber-Jackson relation:
$M_* - \sigma_c$

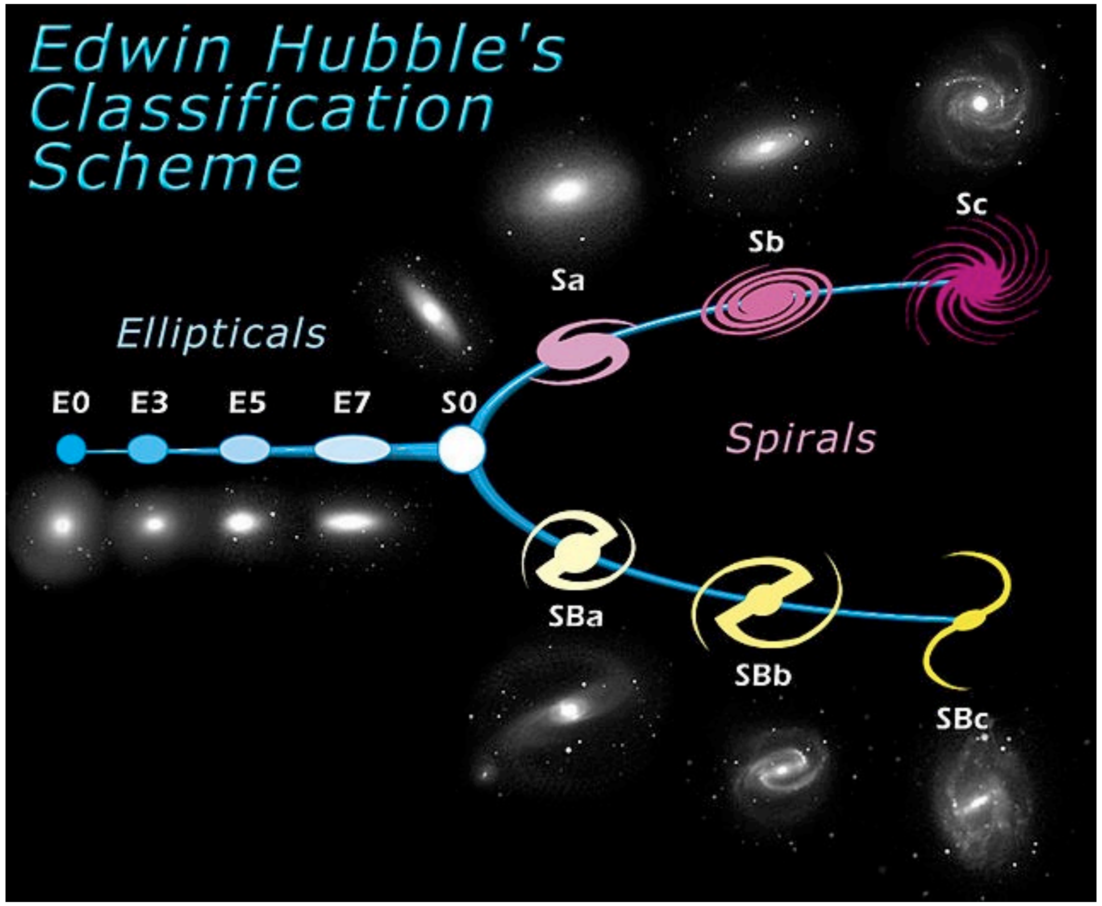
SMBH scaling relations:
$M_{\mathrm{BH}} - \sigma_{\mathrm{c}}$, $M_{\mathrm{BH}} - M_{\mathrm{sph}}$, $M_{\mathrm{BH}} - M_*$

galaxy quenching

quiescent galaxies tend to be:
massive, compact, denser cores,
higher central velocity dispersion

SMBHs

AGN feedback



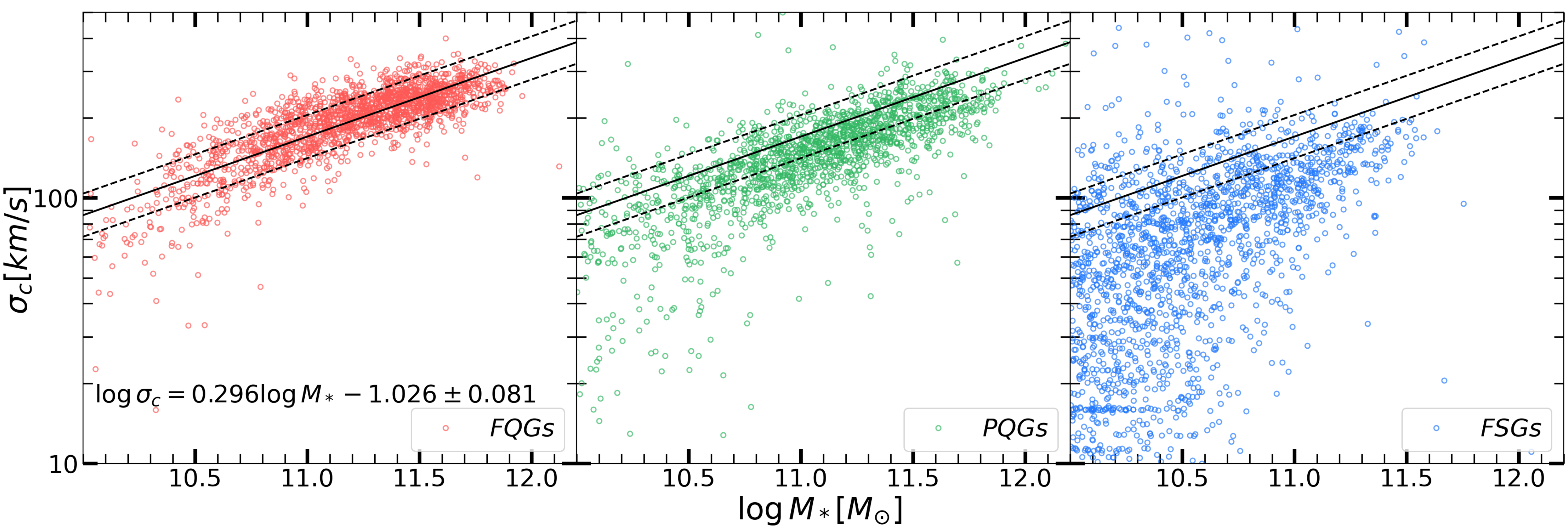
MaNGA: spatially resolved spectra data
central galaxies (internal quenching processes)

Observations:

based on spatially resolved D4000: D4000>1.55 —>quenched spaxel; <1.55—> SF spaxel
mean quenched fraction ($\bar{f}_{\rm q}$) within 1.5$R_{\rm e}$

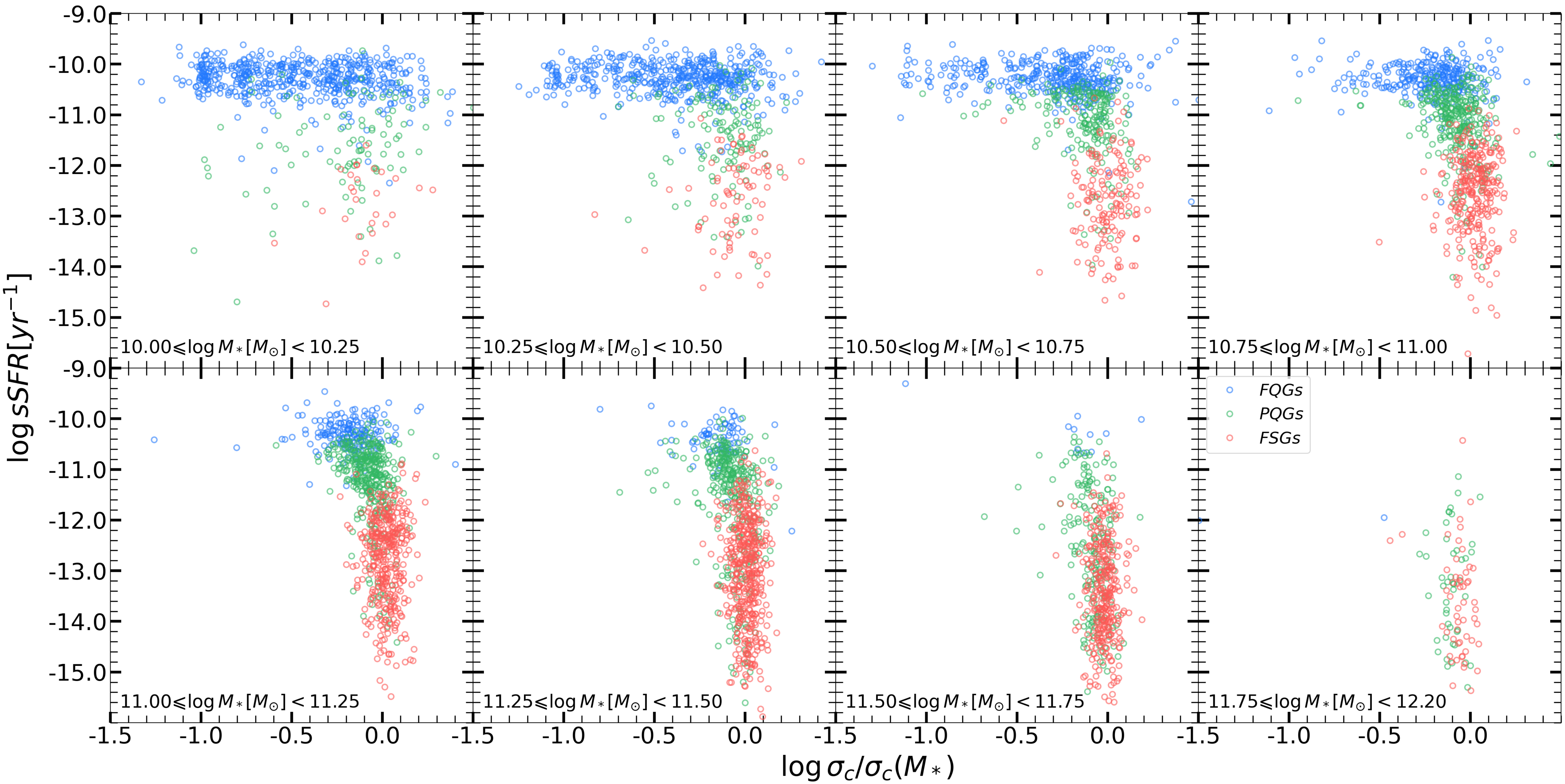
FQGs (fully quenched galaxies, red): $\bar{f}_{\rm q} > 0.95$
PQGs (partially quenched galaxies, green): $0.05 \leq \bar{f}_{\rm q} \leq 0.95$
FSGs (fully star-forming galaxies, blue): $\bar{f}_{\rm q} < 0.05$

FQGs: tight relation ($M_* \propto \sigma_{\rm c}^4$) —>Faber-Jackson relation



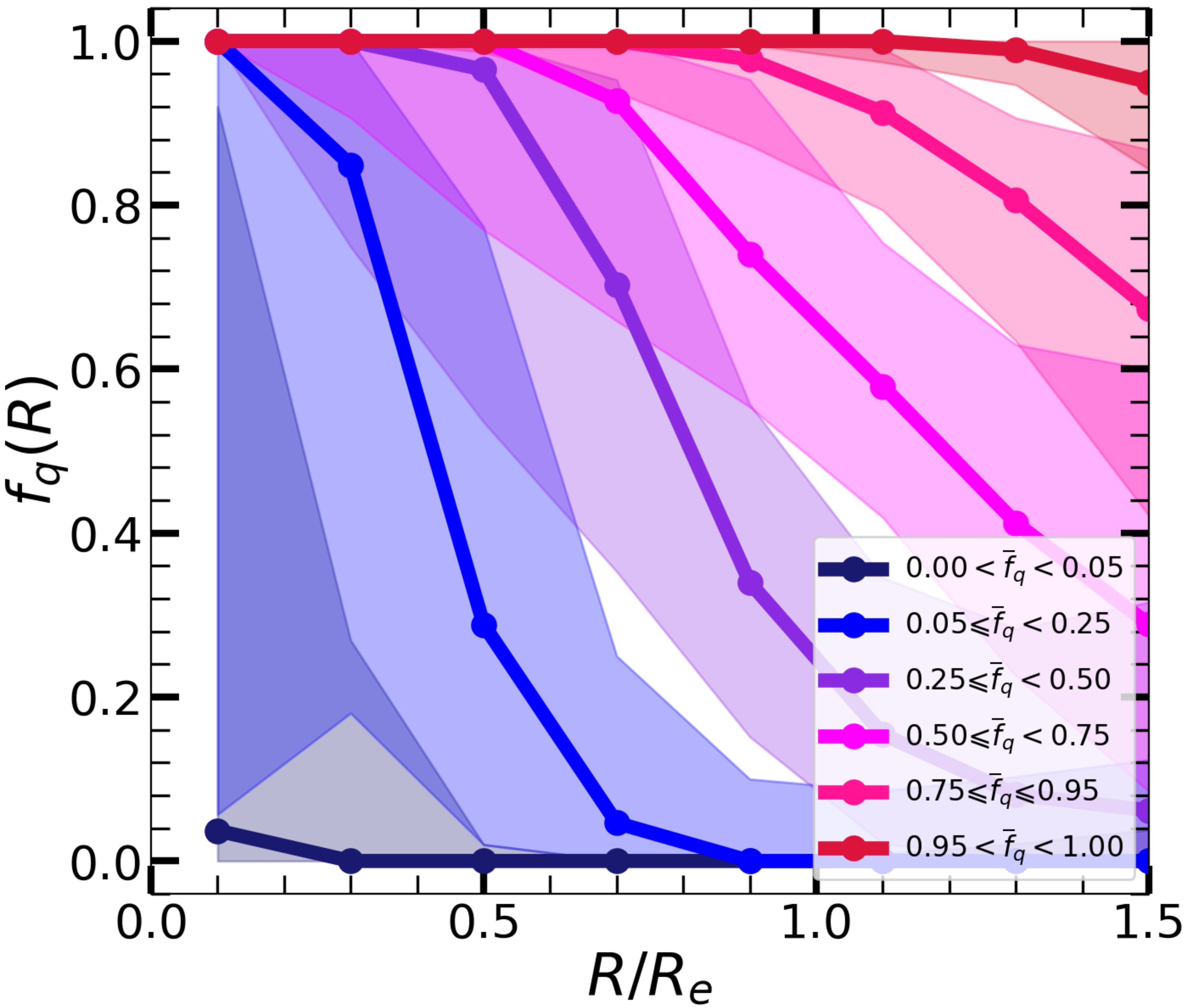
L-shape

$\sigma_{\rm c}(M_*)$: central velocity dispersion predicted from fitting FJ relation
$\log \sigma_{\rm c}/\sigma_{\rm c}(M_*)$: distance to FJ relation in $\sigma_{\rm c} - M_*$ diagram along y-axis ($\sigma_{\rm c}$ direction)



PQGs: quenching happens from inner to outer

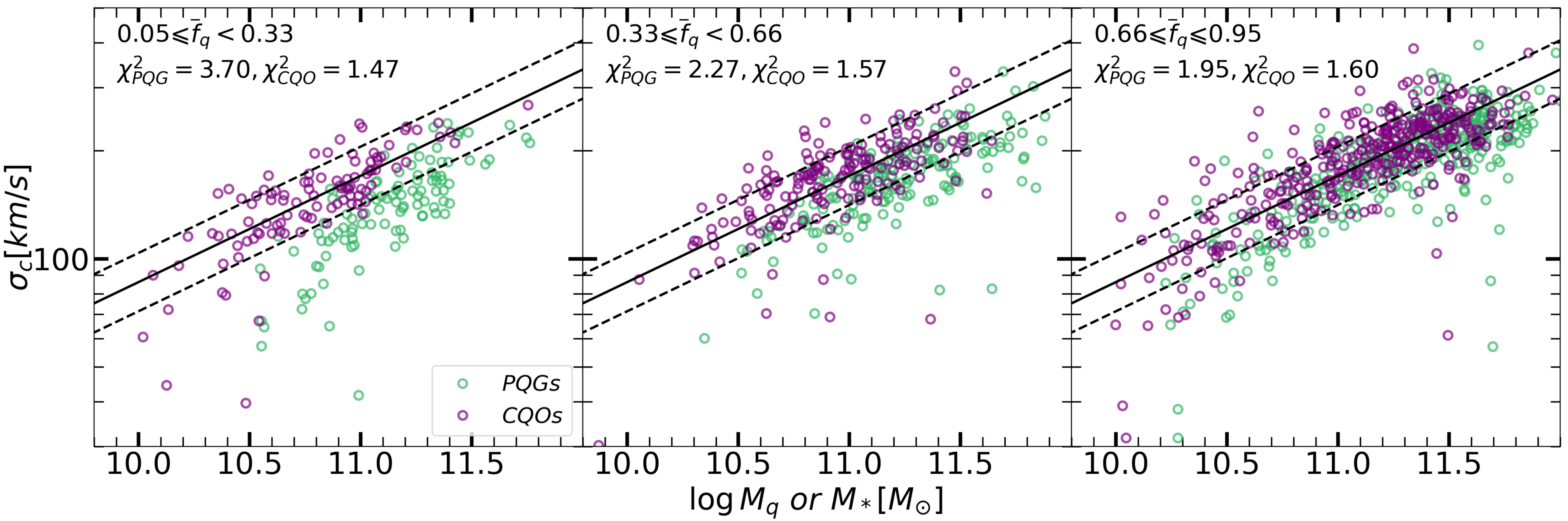
identify central quenched objects (CQOs)



$\sigma_\mathrm{c} - M_*$ diagram for PQGs: deviate from FJ relation

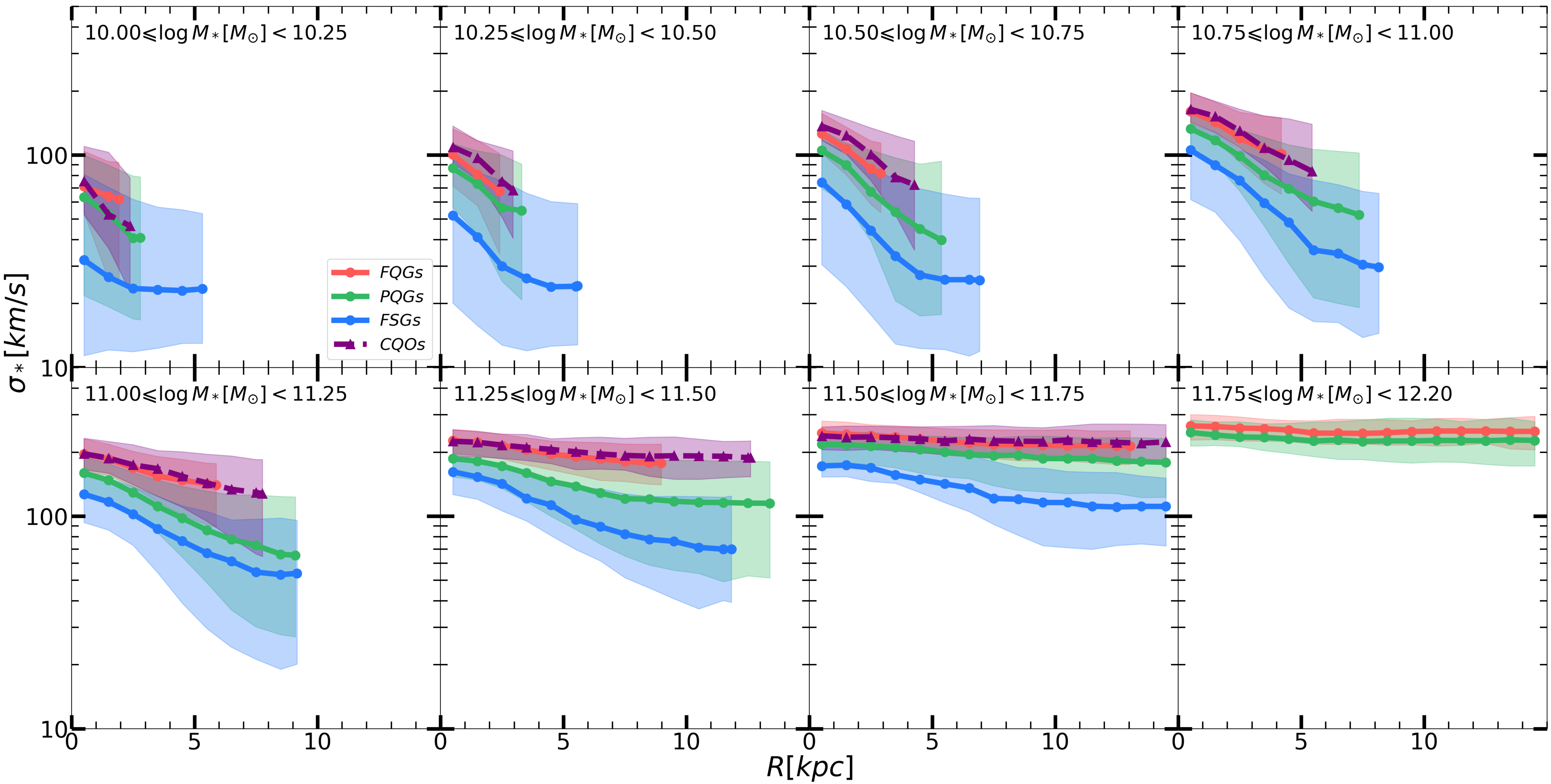
$\sigma_\mathrm{c} - M_\mathrm{q}$ diagram for CQOs identified in PQGs: lie within FJ relation

—> quenched systems (FQGs & CQOs) obey FJ relation



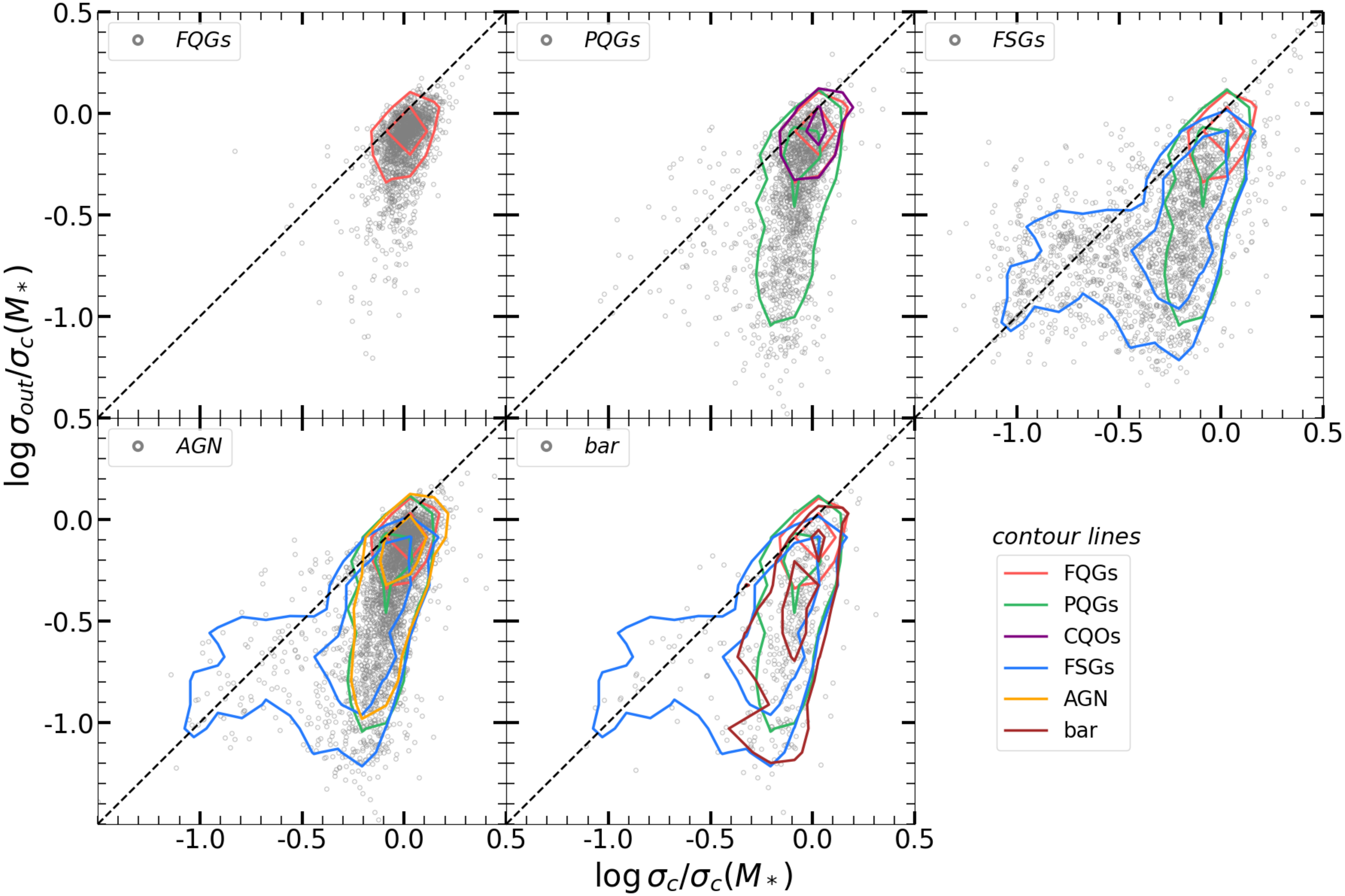
FSGs and PQGs: apparent gradients for σ_* profiles

FQGs and CQOs: similar, almost flat σ_* profiles —> dynamically hot from inner to outer



$2-\sigma$ diagram: distance to FJ relation for both σ_c and σ_{out} in $\sigma_c - M_*$ diagram

FQGs & CQOs: small region (both σ_c and σ_{out} obey FJ relation, a entire dynamically hot systems)
PQGs: vertical belt (dynamically hot central: eg. bulges, outskirts vary from cold to hot)
FSGs: vertical (similar as PQGs)+ horizontal branches (inner from cold to hot, cold outskirts)



Toy model:

energy released by BH accretion: $E_{\mathrm{a}} = \epsilon M_{\mathrm{BH}} c^2$, ϵ: mass-to-energy efficiency for BH

energy coupled with ISM, driven gas outside the host galaxies:

$$M_{\mathrm{gas}} = \frac{\epsilon f_{\mathrm{cp}} M_{\mathrm{BH}} c^2}{1/2 v_{\mathrm{esp}}^2} = \frac{2\epsilon f_{\mathrm{cp}} M_{\mathrm{BH}} c^2}{a^2 \sigma_{\mathrm{c}}^2}$$

f_{c}: fraction of energy coupled with ISM, v_{esp}: escaping speed for gas within galaxy

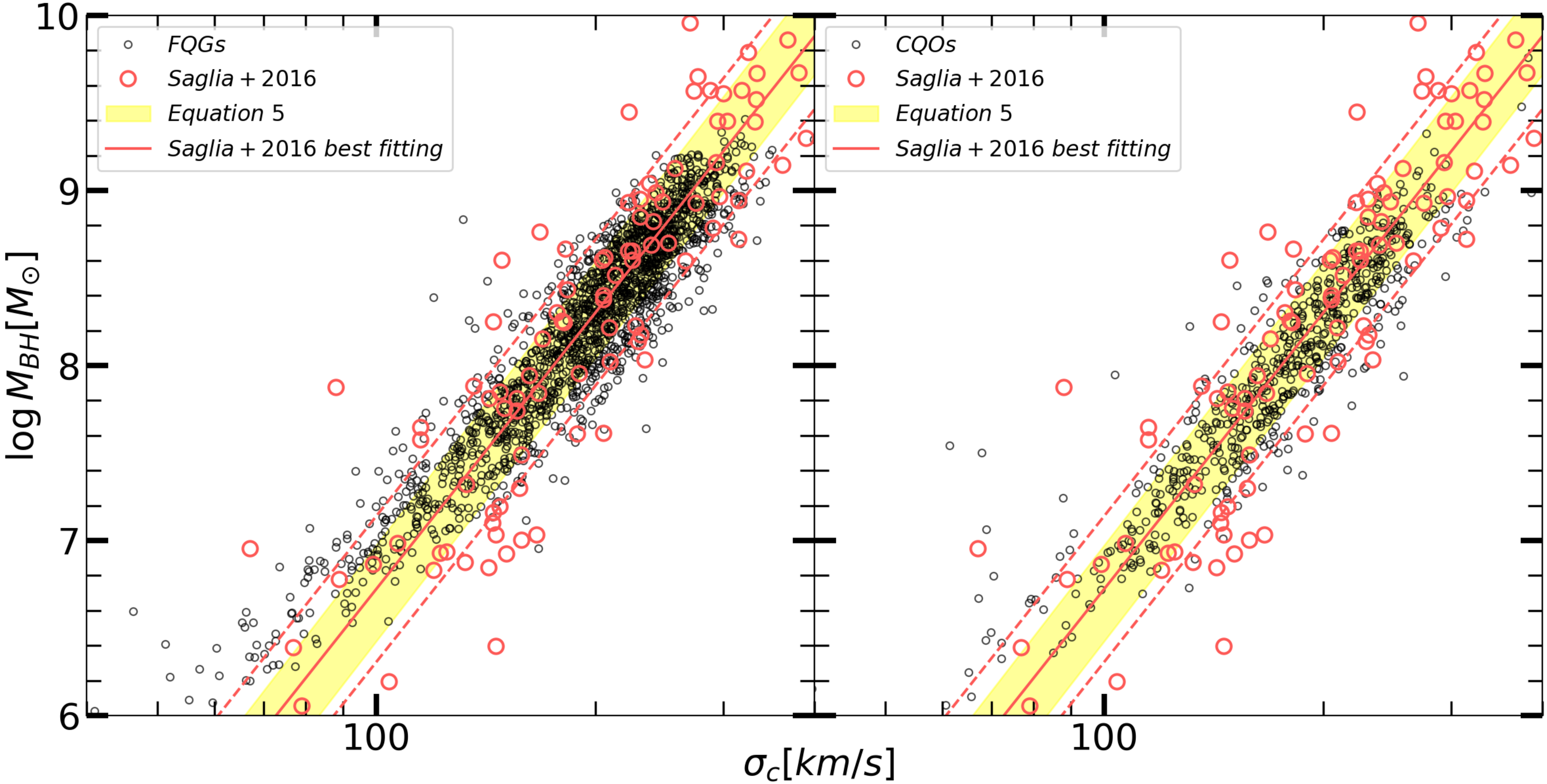
$v_{\mathrm{esp}} = a\sigma_{\mathrm{c}}$

$f_{\mathrm{e}} = M_{\mathrm{gas}}/M_*$: total fraction of gas expelled from galaxy

$M_{\mathrm{BH}} = \dfrac{a^2 f_{\mathrm{e}} M_* \sigma_{\mathrm{c}}^2}{2\epsilon f_{\mathrm{cp}} c^2} = \gamma M_* \sigma_{\mathrm{c}}^2,\ \gamma = a^2 f_{\mathrm{e}}/2\epsilon f_{\mathrm{cp}} c^2$: calibration parameter

assumptions:
dynamically hot systems: accretion and feedback is efficient (cold system: gas has large angular momentum)
—> apply in quenched systems: FQGs & CQOs

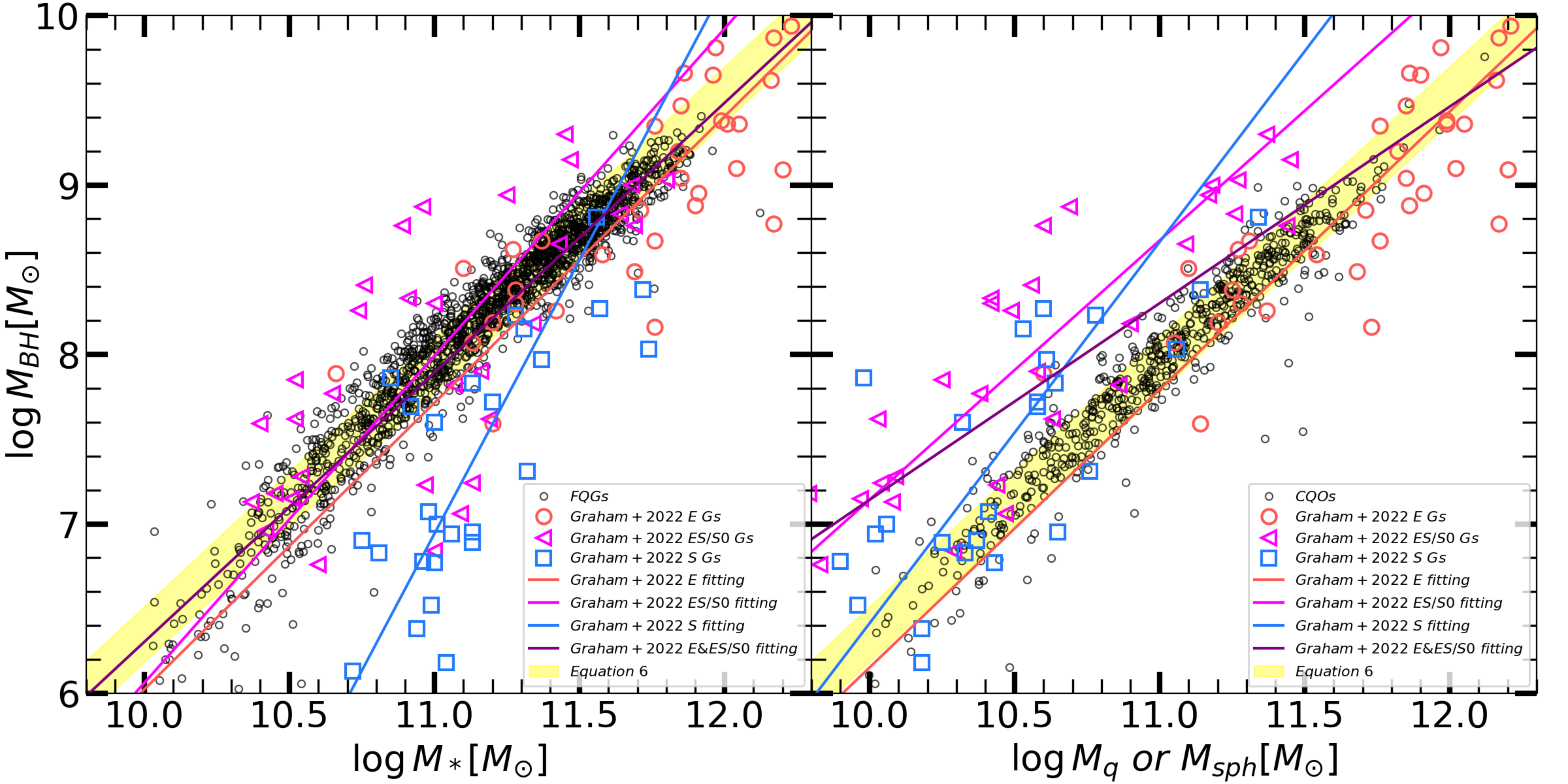
Saglia+2016: dynamical BH measurement —> calibrate our γ



Graham+2022: dynamical BH measurement

$M_{\mathrm{BH}} - M_{*}$: FQGs have good agreement with G22 E&ES/S0 (dynamically hot)

$M_{\mathrm{BH}} - M_{\mathrm{sph}}$: CQOs deviate from G22, our CQOs are different from traditional bulges

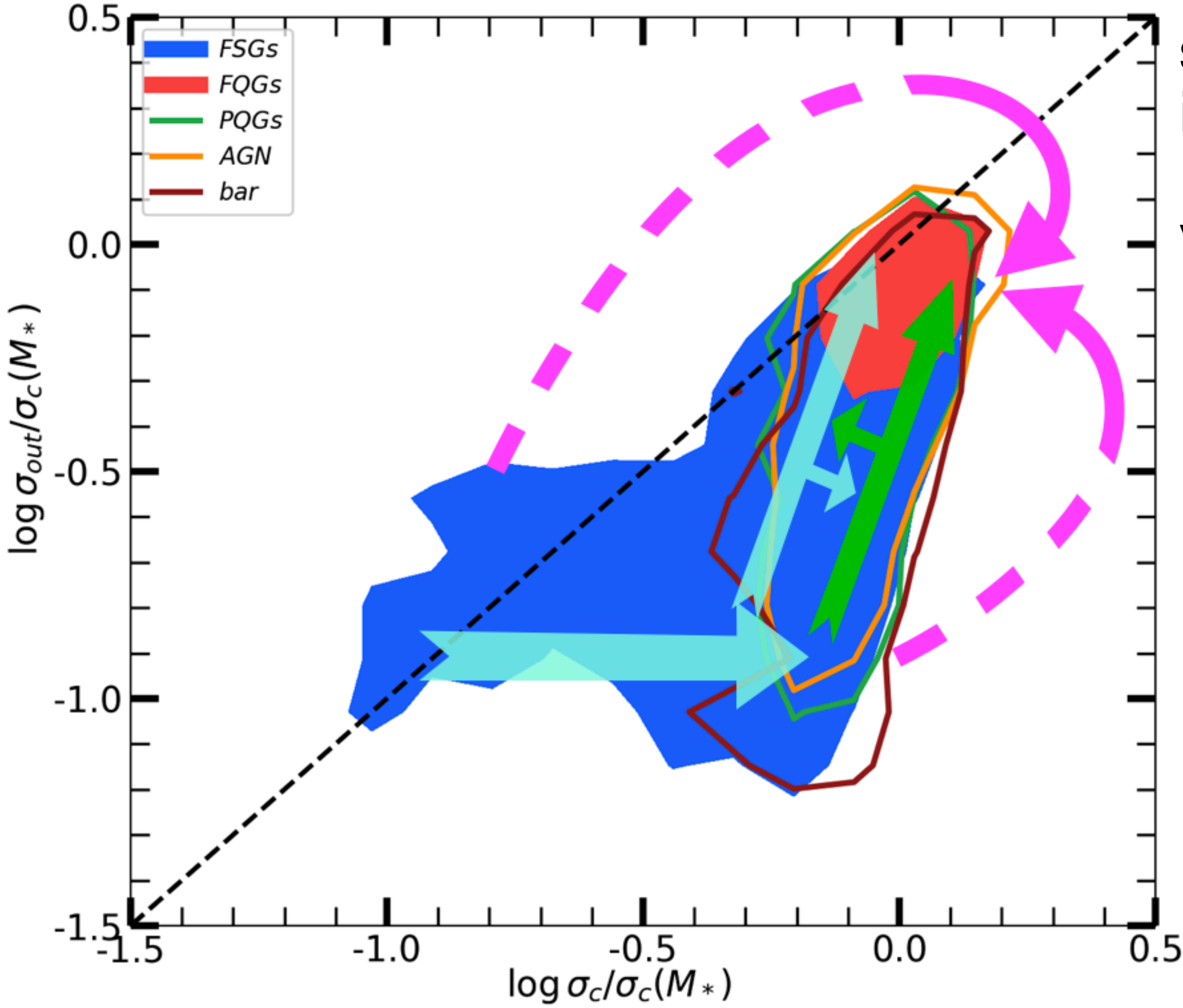


Evolutionary tracks:

FQGs: small region, both inner and outer are dynamically hot

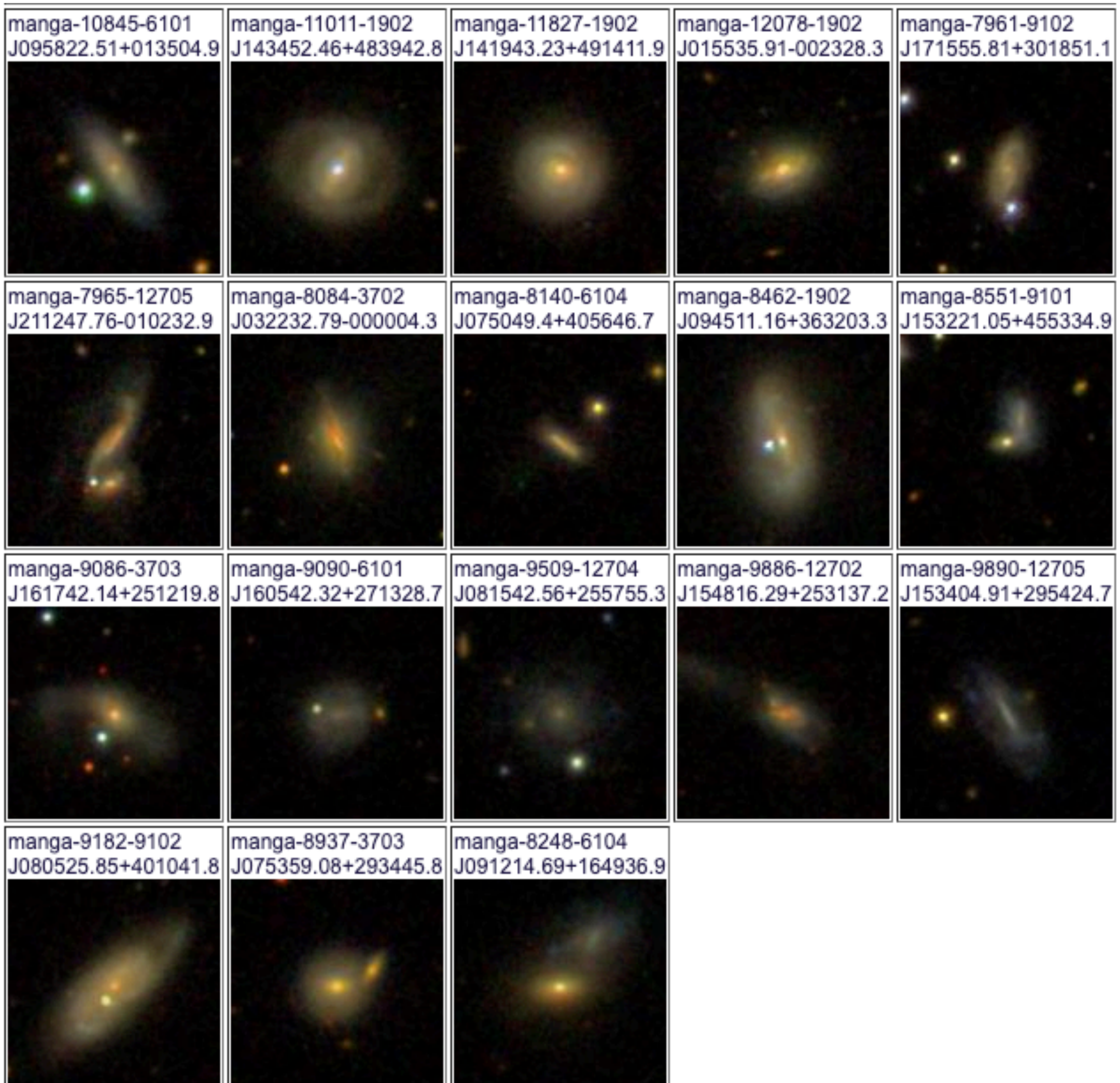
PQGs: vertical arrow, σ_c is large, σ_{out} increases

FSGs: horizontal arrow, σ_c increases, σ_{out} remains (central grows)
vertical arrow, σ_c is large, σ_{out} increases



secular processes: bar-driven, minor interaction

violent processes: major mergers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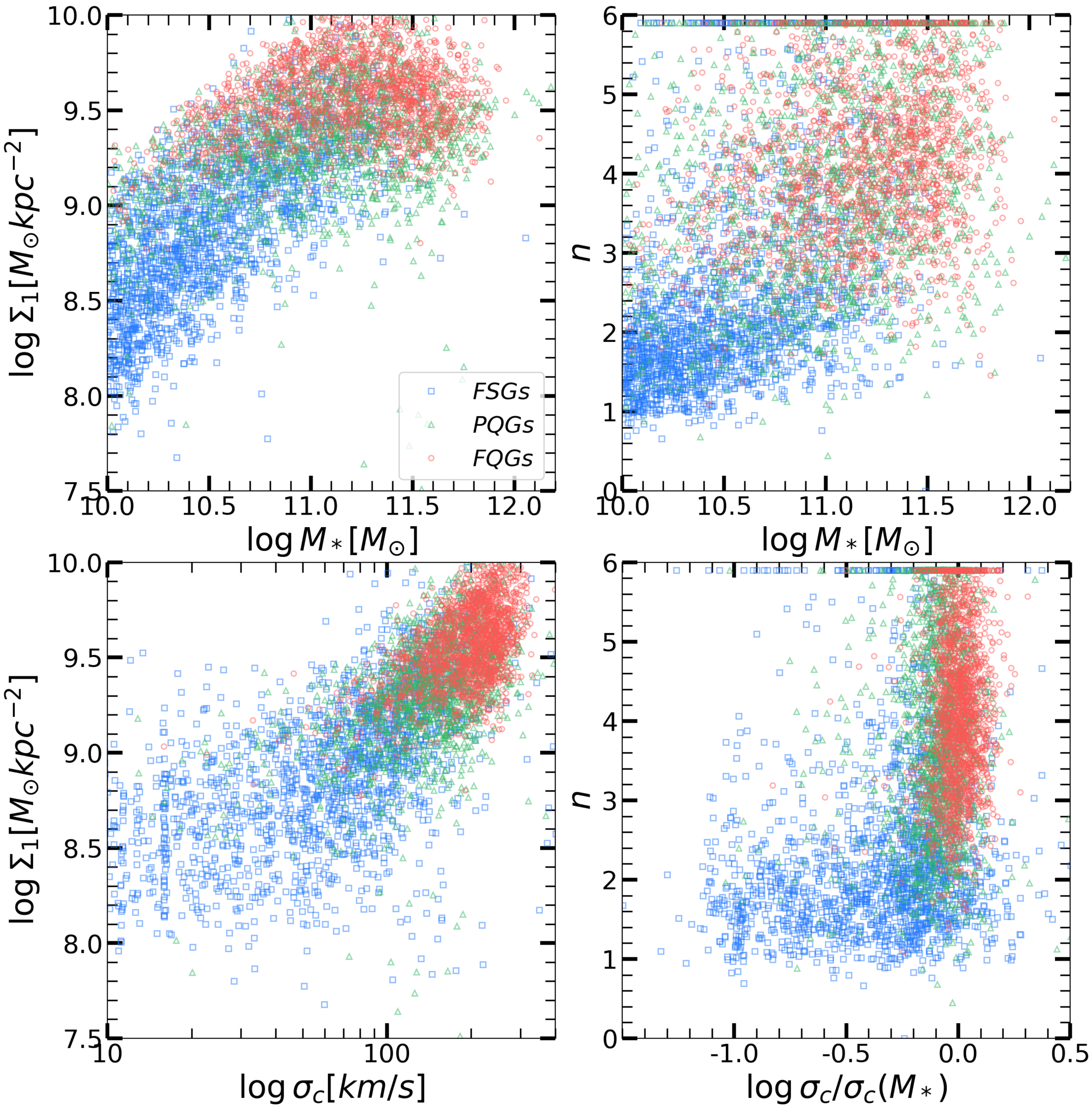
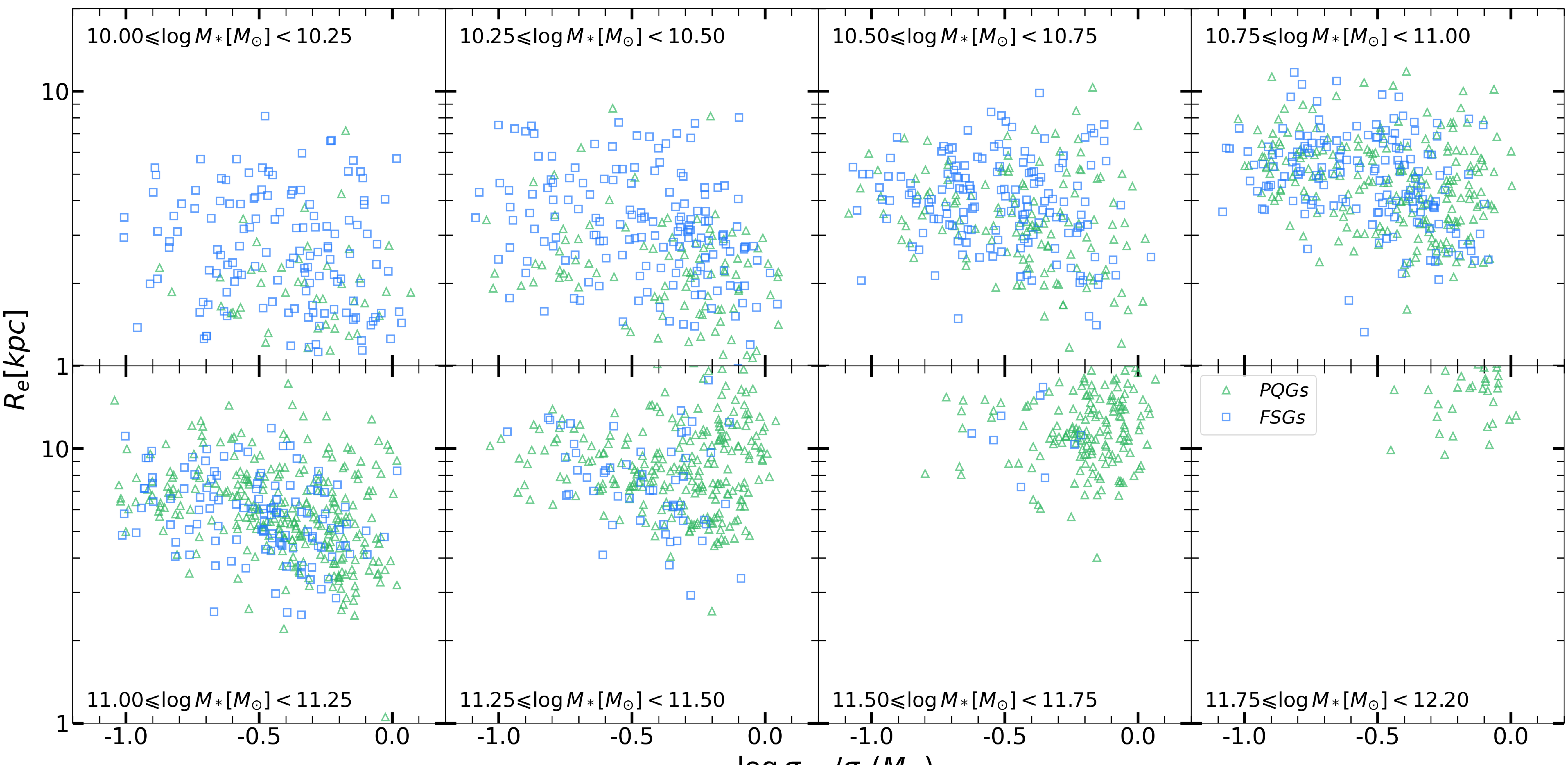
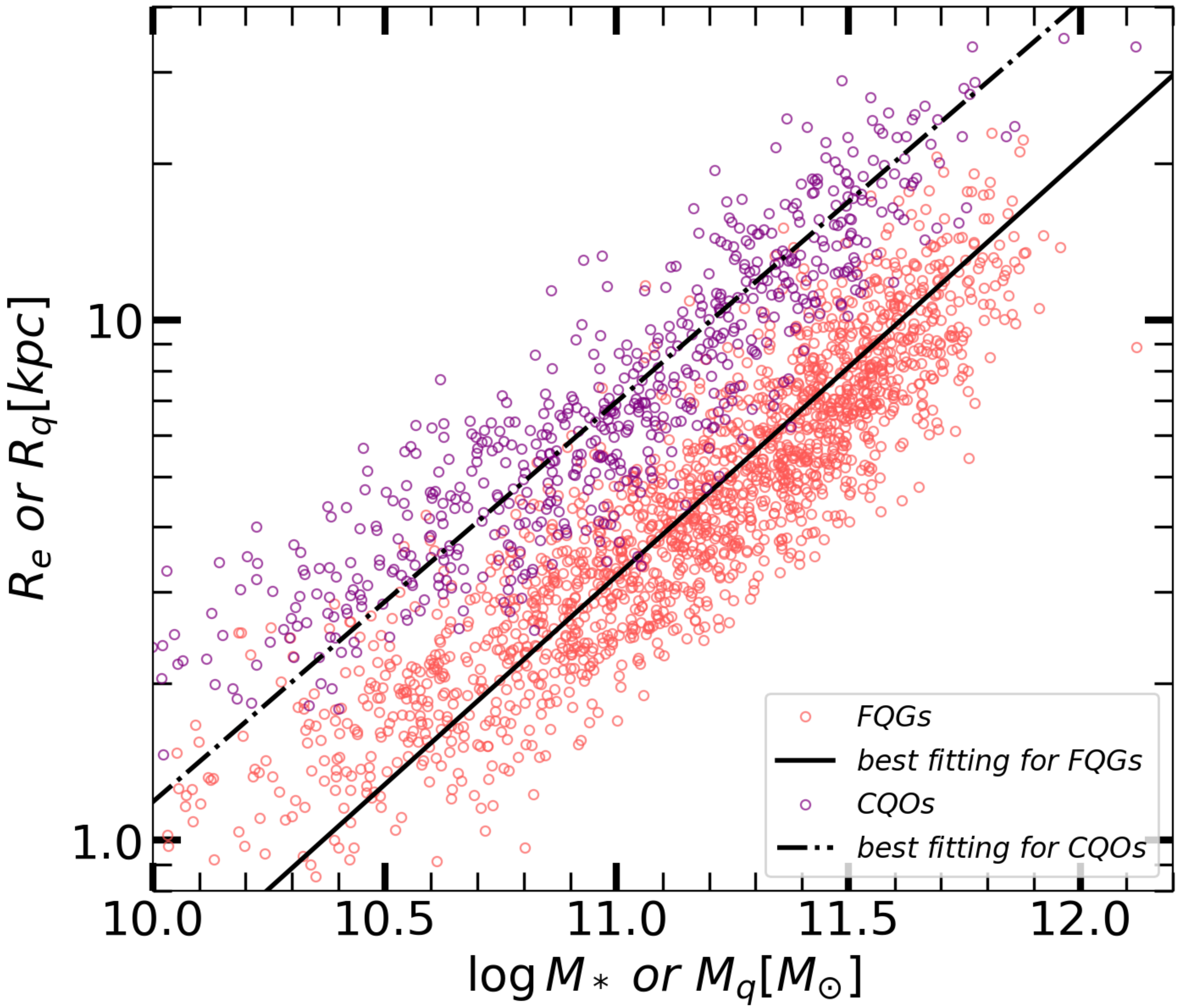


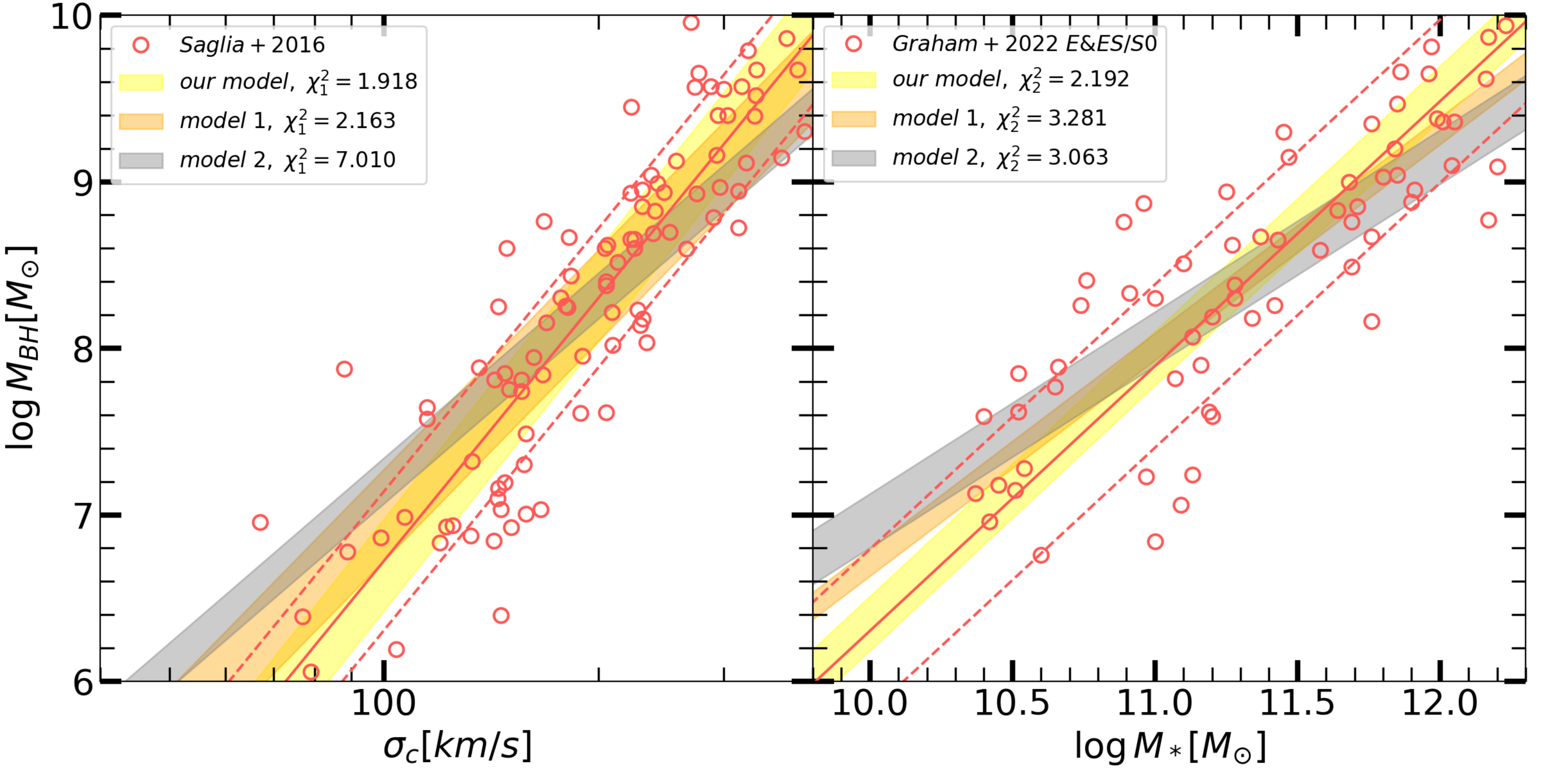
FSGs
PQGs
FQGs
log Σ1[M⊙kpc−2]
log M∗[M⊙]
n
log σc[km/s]
log σc/σc(M∗)



$10.00 \leqslant \log M_*[M_\odot] < 10.25$
$10.25 \leqslant \log M_*[M_\odot] < 10.50$
$10.50 \leqslant \log M_*[M_\odot] < 10.75$
$10.75 \leqslant \log M_*[M_\odot] < 11.00$
$11.00 \leqslant \log M_*[M_\odot] < 11.25$
$11.25 \leqslant \log M_*[M_\odot] < 11.50$
$11.50 \leqslant \log M_*[M_\odot] < 11.75$
$11.75 \leqslant \log M_*[M_\odot] < 12.20$
PQGs
FSGs
$R_e[kpc]$



10
1.0
10.0
10.5
11.0
11.5
12.0
$\log M_* \ or\ M_q [M_\odot]$
$R_e \ or\ R_q [kpc]$
FQGs
best fitting for FQGs
CQOs
best fitting for CQOs



Saglia + 2016
our model, $\chi_1^2 = 1.918$
model 1, $\chi_1^2 = 2.163$
model 2, $\chi_1^2 = 7.010$
Graham + 2022 E&ES/S0
our model, $\chi_2^2 = 2.192$
model 1, $\chi_2^2 = 3.281$
model 2, $\chi_2^2 = 3.063$
$\log M_{BH}[M_\odot]$
$\sigma_c[km/s]$
$\log M_*[M_\odot]$
10
9
8
7
6
100
10.0
10.5
11.0
11.5
12.0