The MASSIVE Galaxy Survey

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MASSIVE Survey Team

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MASSIVE-Gas: Tim Davis (Cardiffe), **Viraj Pandya** (Princeton)
MASSIVE-Xray: Andy Goulding (Princeton)

Survey paper	**Ma +**	**(2014, ApJ)**
Stellar pop gradients	**Greene +**	**(2015, ApJ)**
Molecular gas	**Davis +**	**(2016, MNRAS)**
Hot X-ray gas	**Goulding +**	**(2016, ApJ)**
Black hole mass	**Thomas +**	**(2016, Nature)**
Stellar kinematics	**Veale +**	**(2017a,b,c MNRAS)**
Warm Ionized gas	**Pandya +**	**(2017, ApJ)**
HST profiles	**(in prep)**	
Revised distances	**(in prep)**	

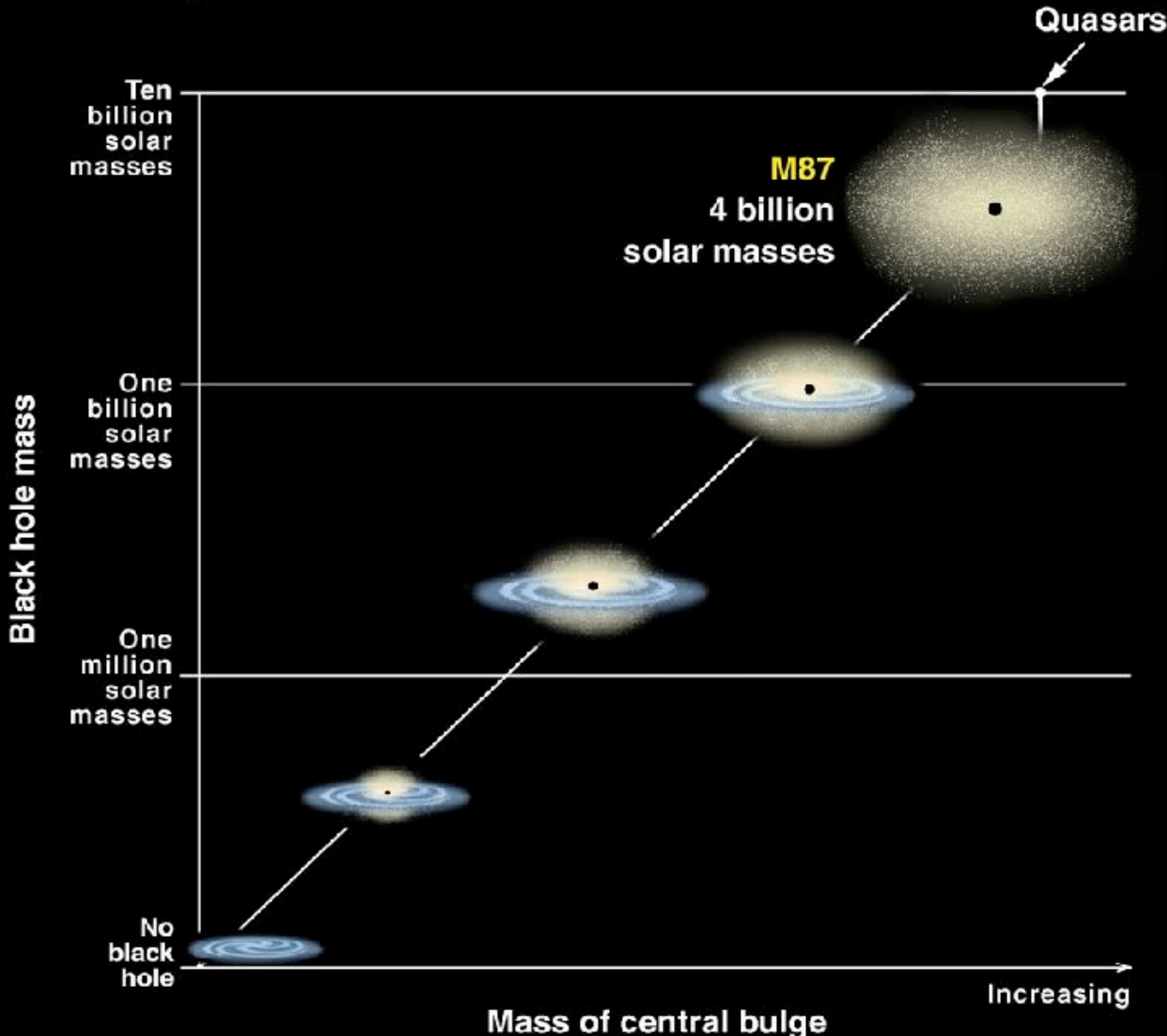
MASSIVE Galaxy Survey Plan

A volume-limited, integral field spectroscopic survey of the ~100 most massive early-type galaxies within ~100 Mpc

Also a wide-field photometric imaging survey

Plan: use spatially-resolved 2-d stellar kinematics to study structure and stellar content of massive early-type galaxies and their central black holes in the nearby universe

Correlation Between Black Hole Mass and Bulge Mass



MASSIVE Sample Selection

Stellar-mass selected (Ma et al. 2014)

$M_K < -25.3$ (2MASS XSC)

$M^* > 10^{11.5}\ M_{sun}$ ATLAS-3D: $M_K < -21.5$

Volume limited

D < 108 Mpc (2MASS Redshift Survey) ATLAS-3D: D < 42 Mpc

Includes Coma Cluster

Morphology (from Hyperleda)

~100 Early-type galaxies

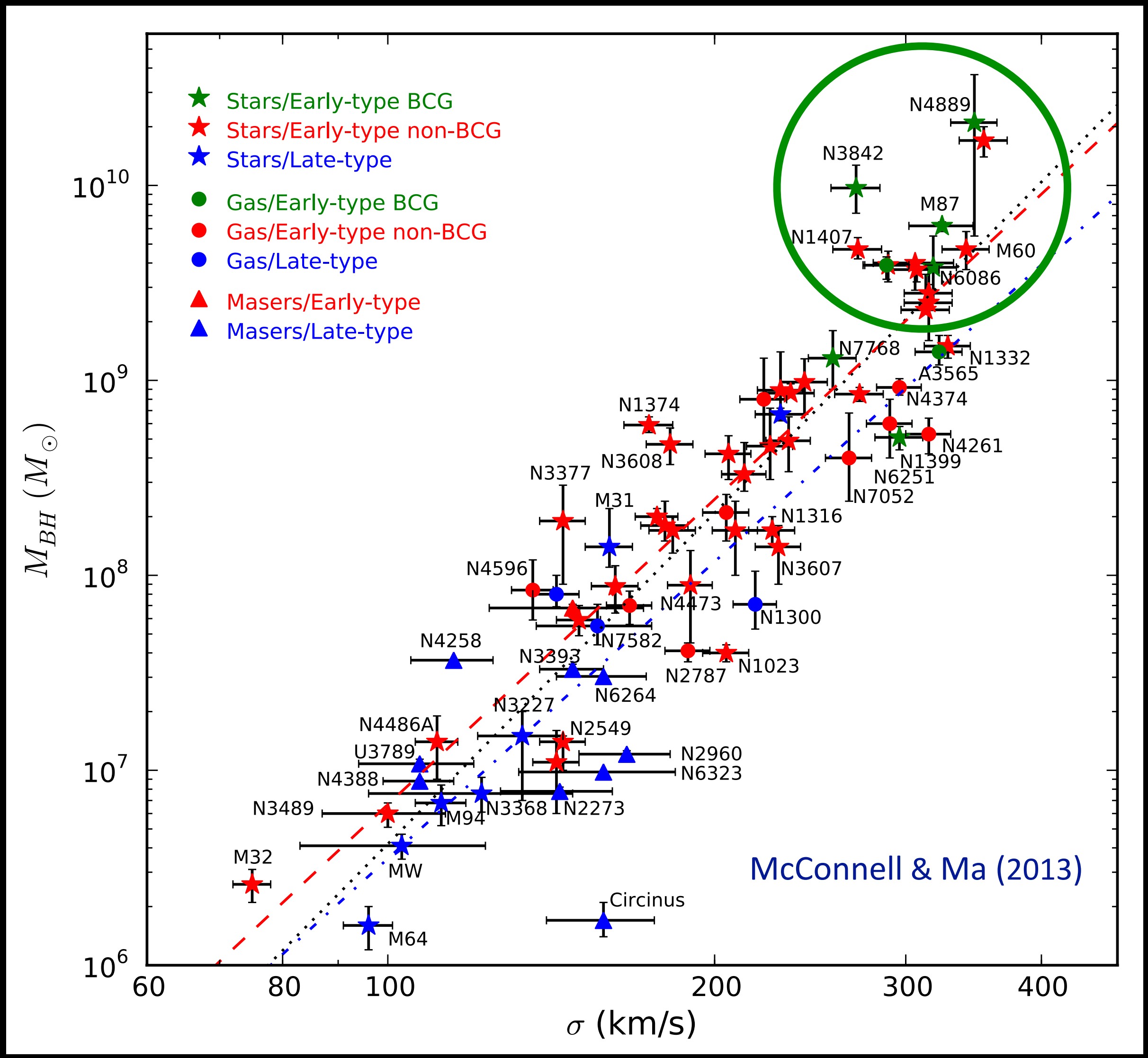
Mostly gEs; a handful of S0s

ATLAS-3D: mostly S0s, fast rotators

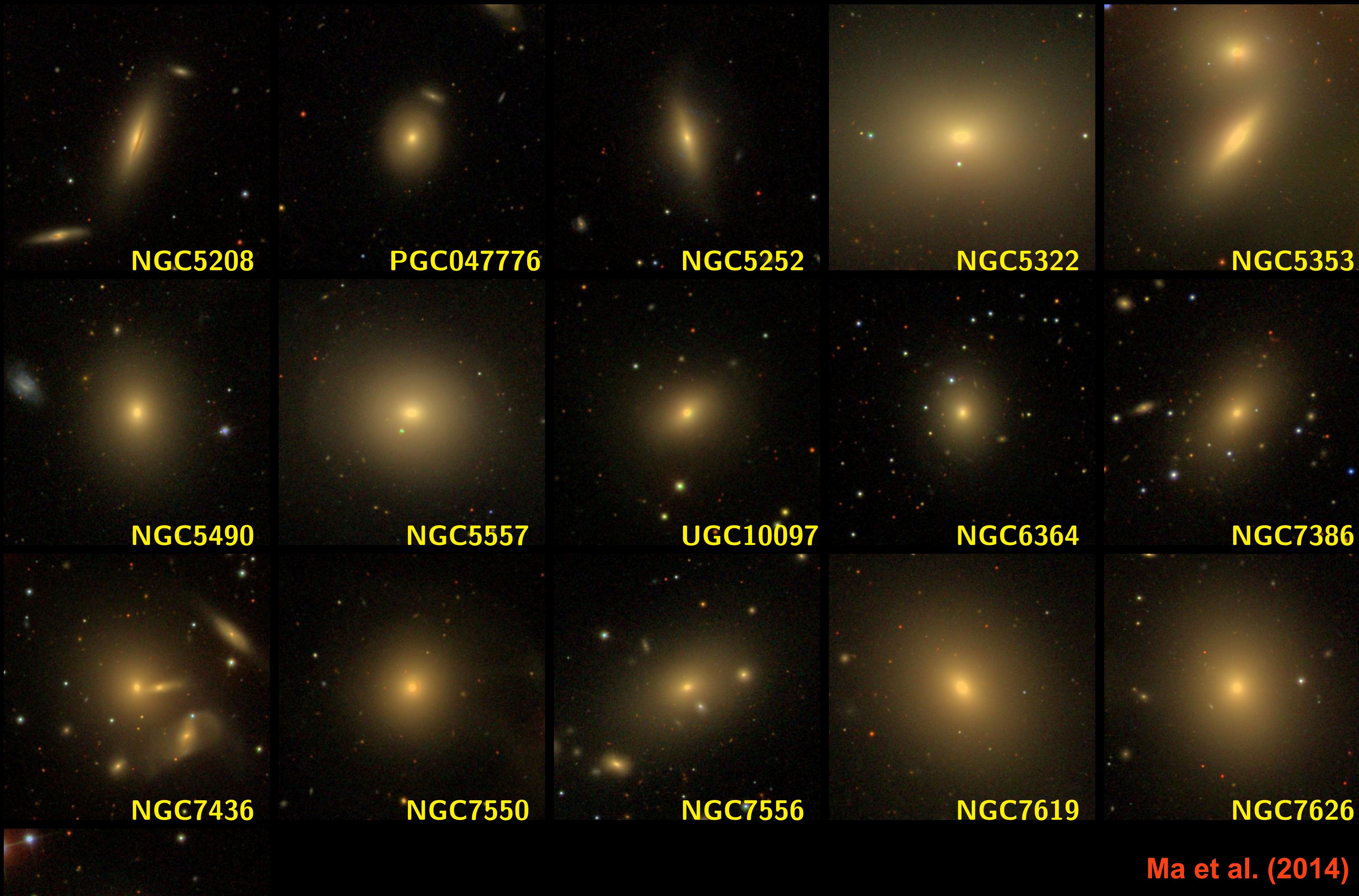
Additional criteria

Dec > −6 $A_V < 0.6$

and relatively "clean"



SDSS images of some MASSIVE galaxies



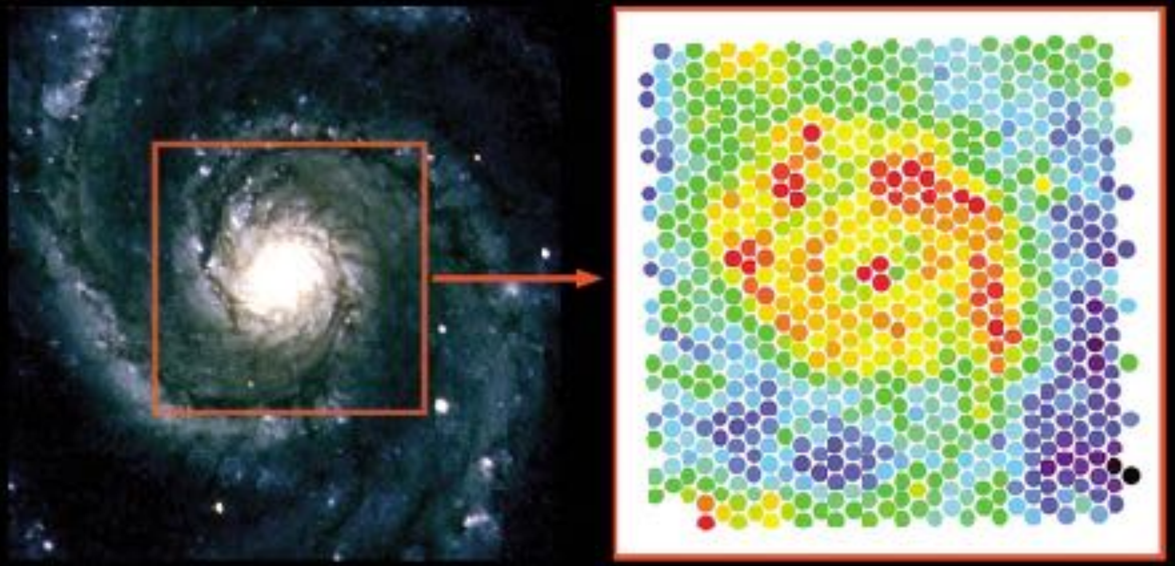
Ma et al. (2014)

MASSIVE Survey Observations

Idea: combine **wide-field** and **high-resolution** IFU data

Wide-field (107″×107″)

- **Mitchell IFU** McDonald 2.7m
- 246 fibers, each 4″
- 3600−5800 Å
- Out to ~2 R_e for >50% galaxies



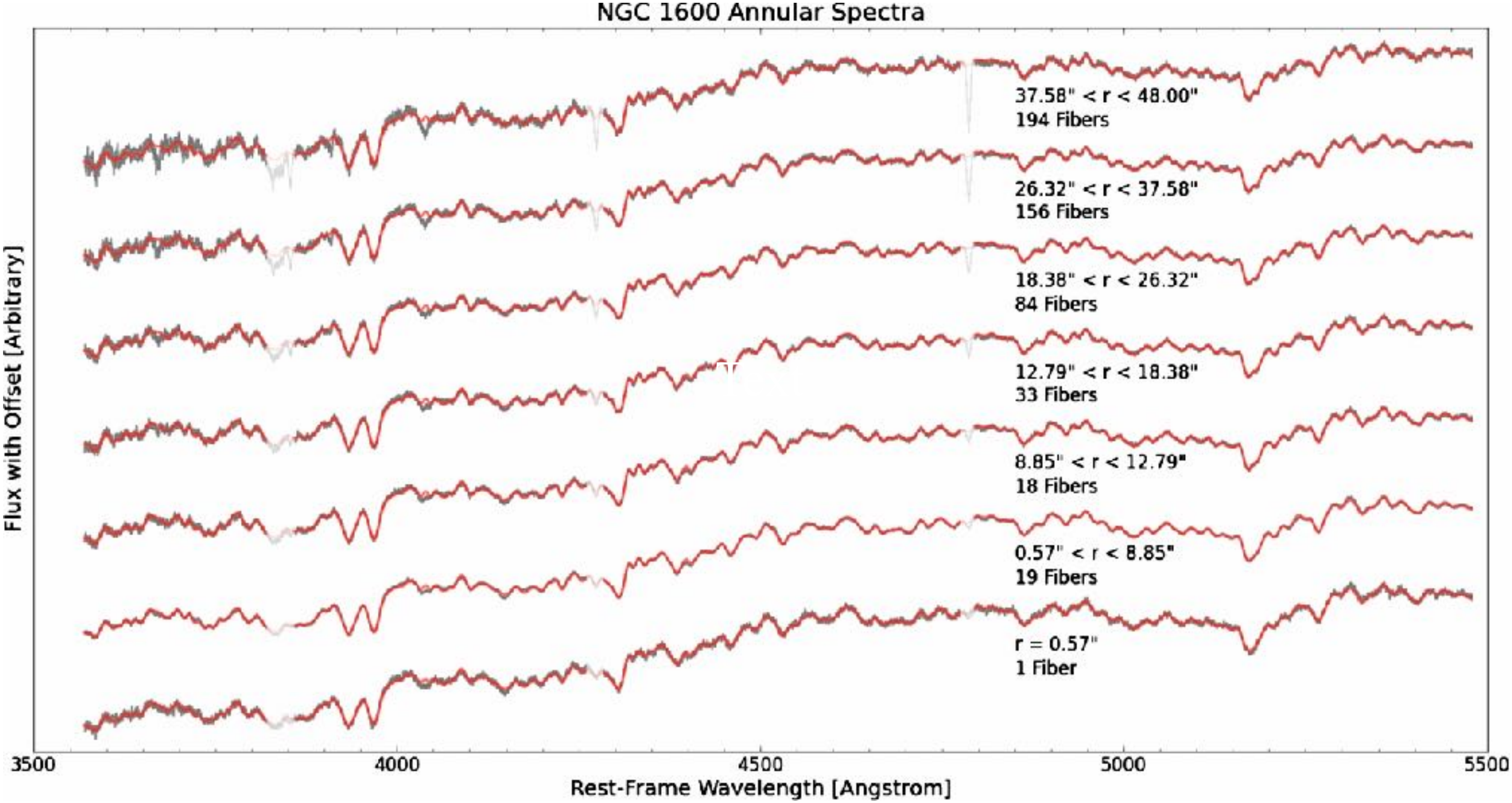
High-resolution (~0.1″ to 4″)

- **NIFS + AO** Gemini
- **GMOS N+S** Gemini

Photometry

- CFHT, HST, PanSTARRS

Example Mitchell IFU Spectra for NGC 1600

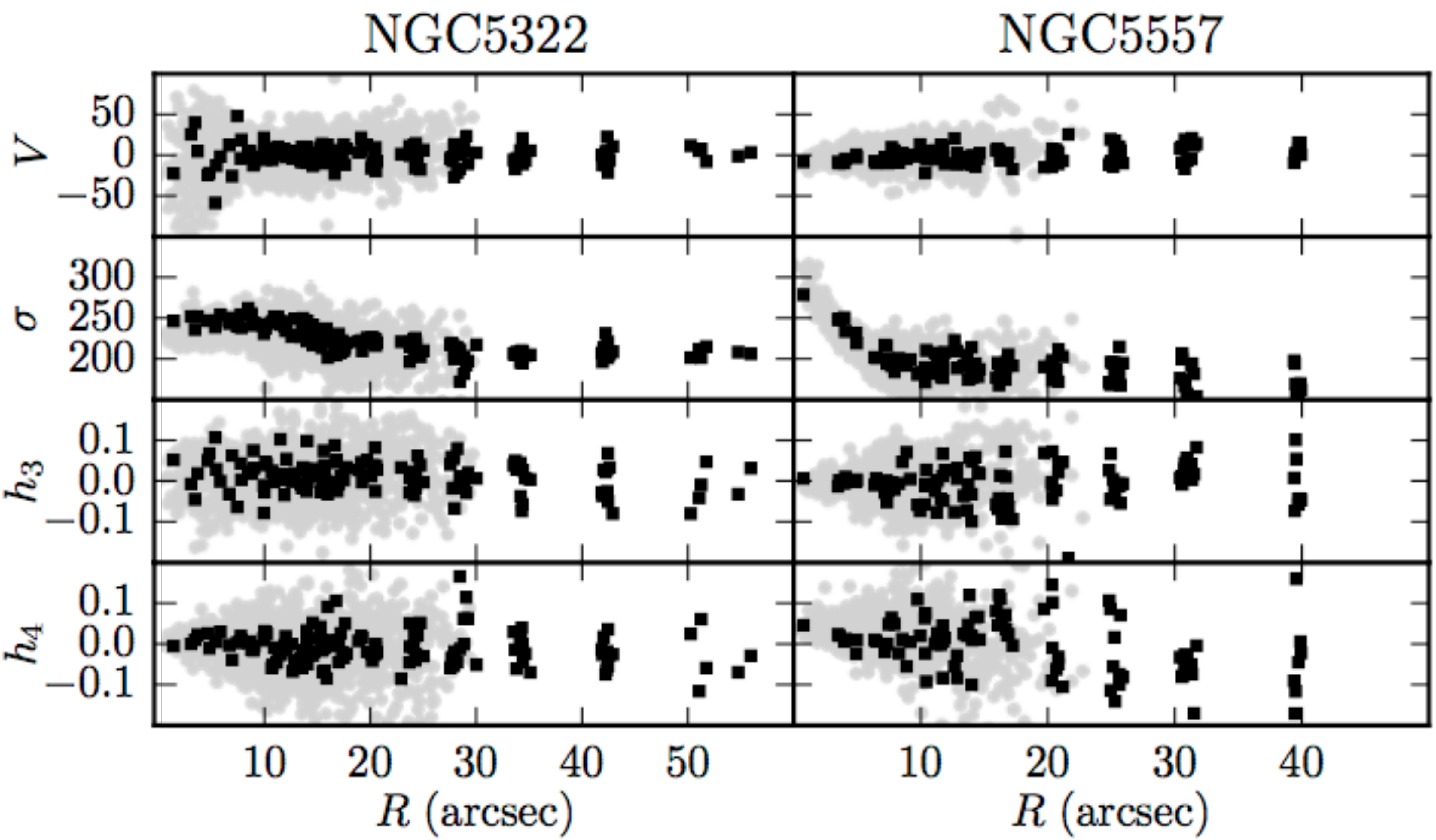


Black: data

Red: fits w/pPXF

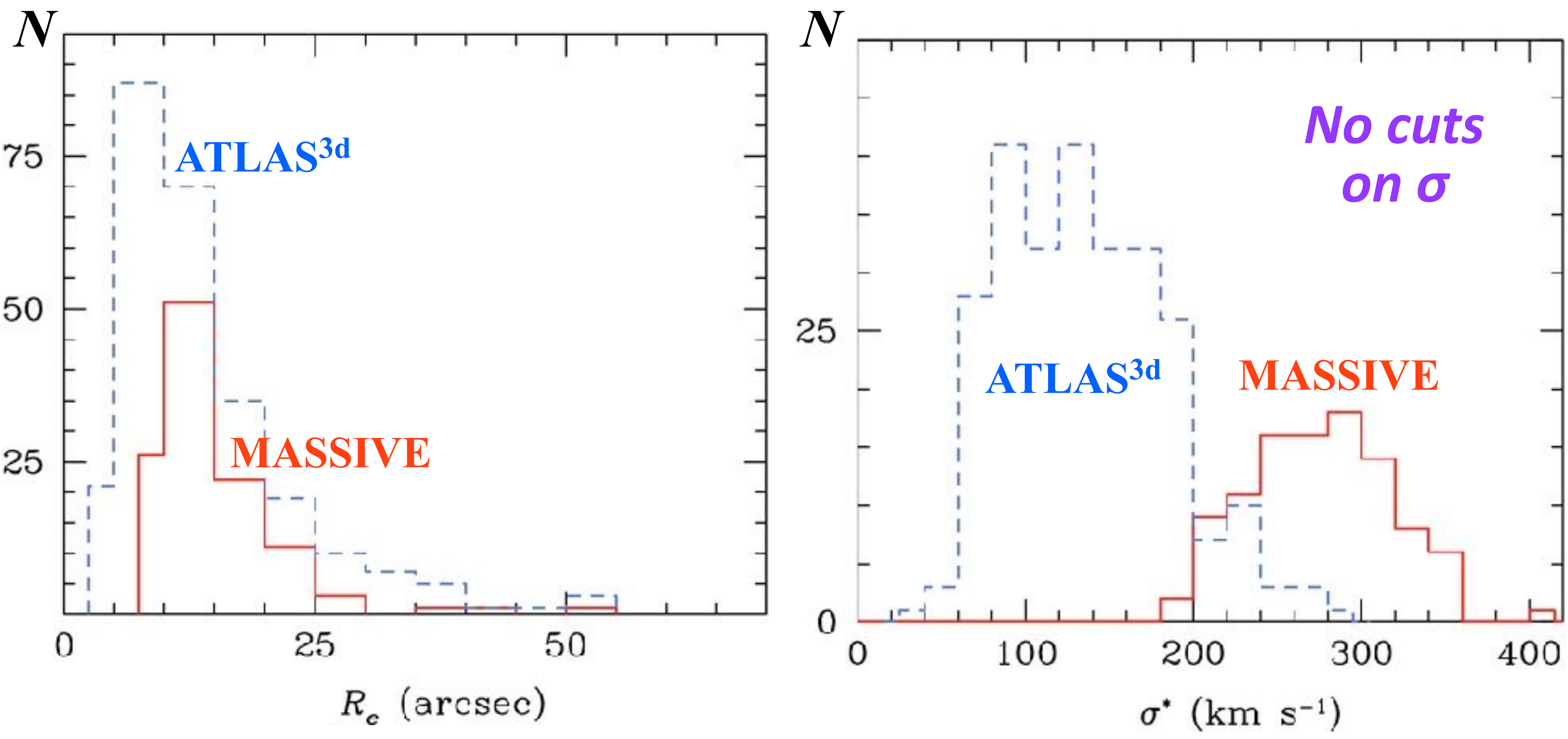
(Capellari & Emsellem 2004)

MASSIVE vs ATLAS^{3D} angular coverage for 2 galaxies in common

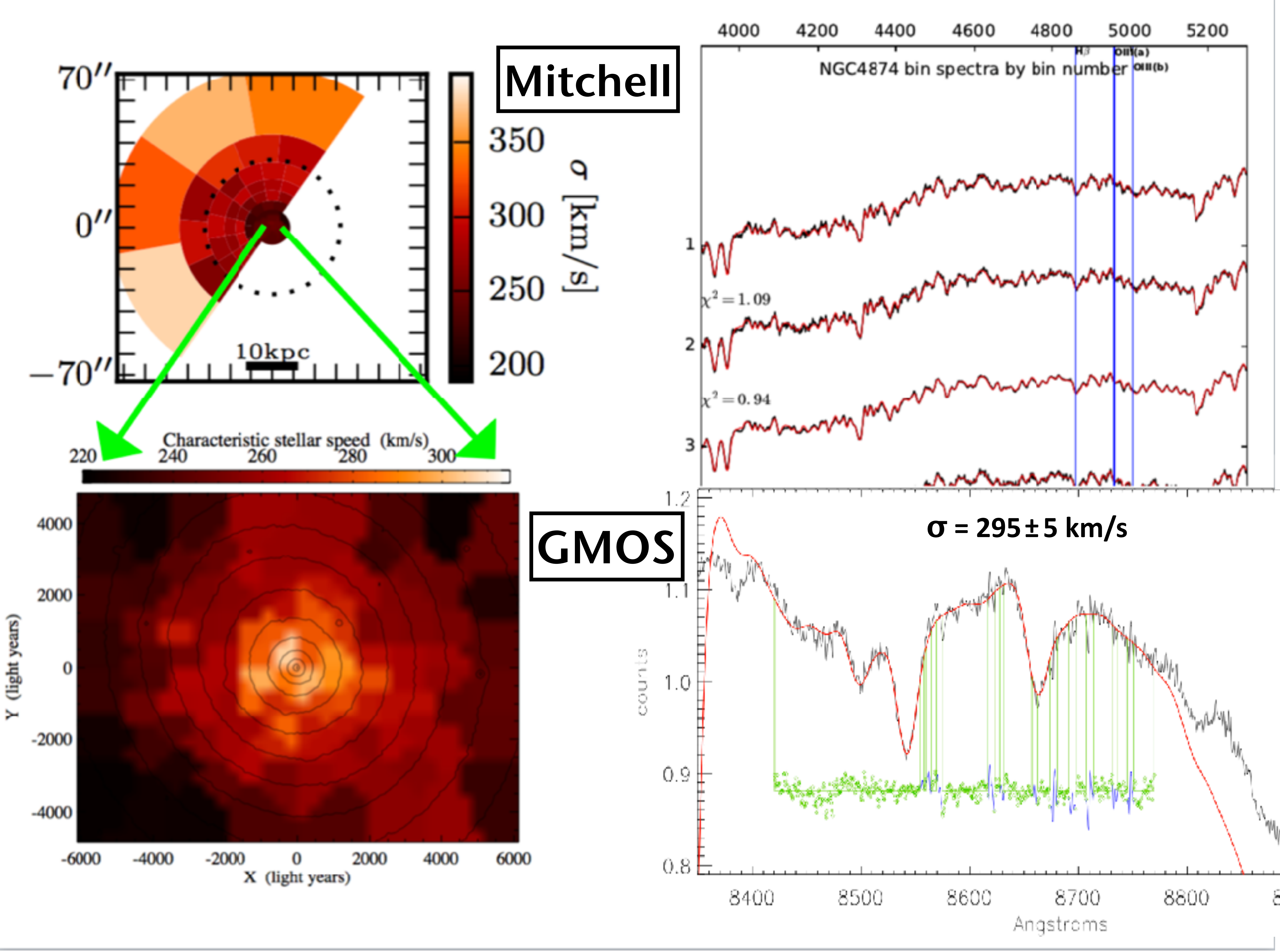


$$f(v) \propto \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(v-V)^2}{\sigma^2}} \left[1 + \sum_{m=3}^{n} h_m H_m\left(\frac{v-V}{\sigma}\right)\right], \qquad H_m(x) = \frac{1}{\sqrt{m!}} e^{x^2} \left(-\frac{1}{\sqrt{2}}\frac{\partial}{\partial x}\right)^m e^{-x^2}.$$

MASSIVE galaxies similar in angular size to ATLAS^{3D} sample galaxies; different in Stellar Velocity Dispersion

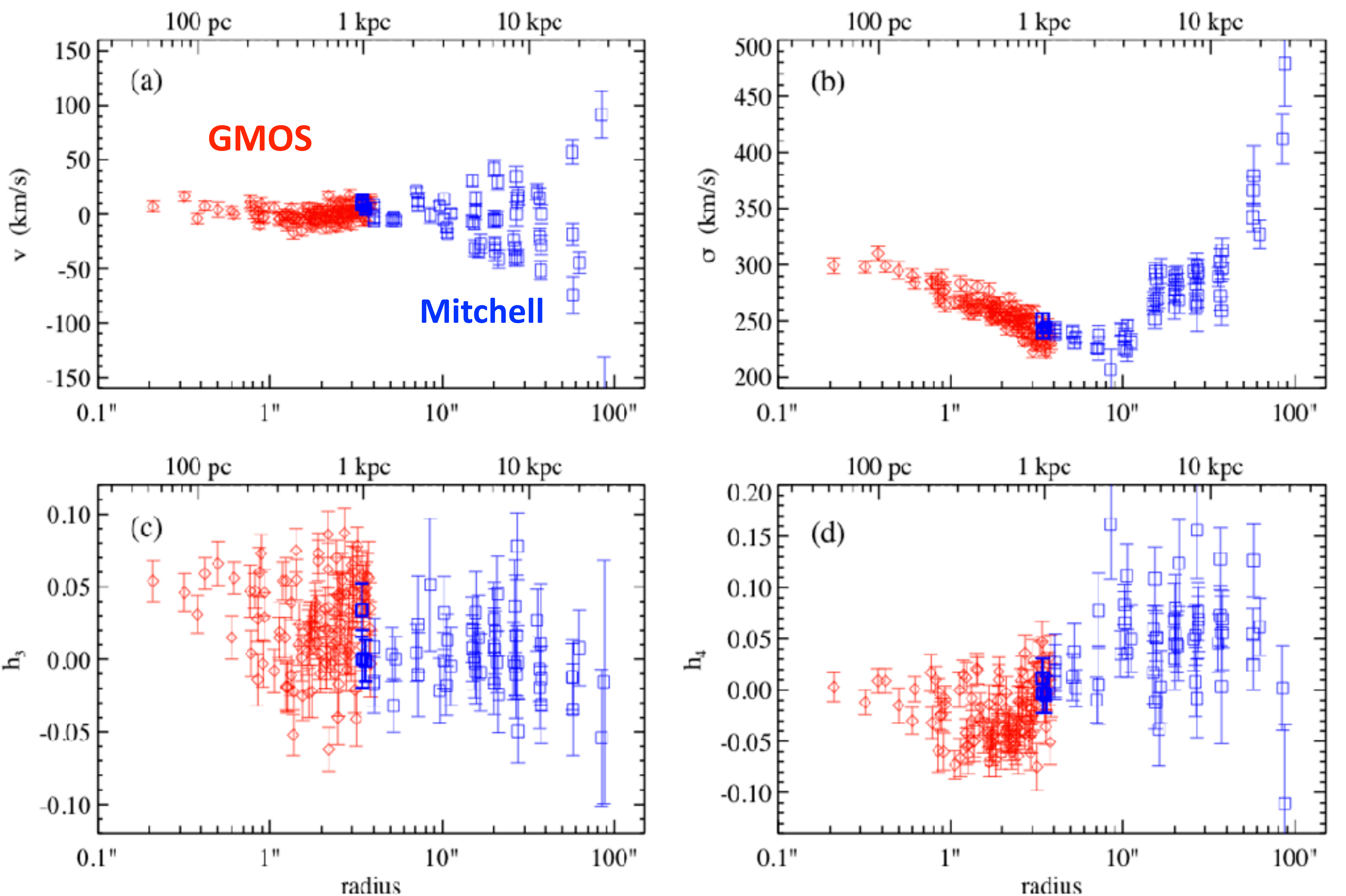


Ma et al. (2014)

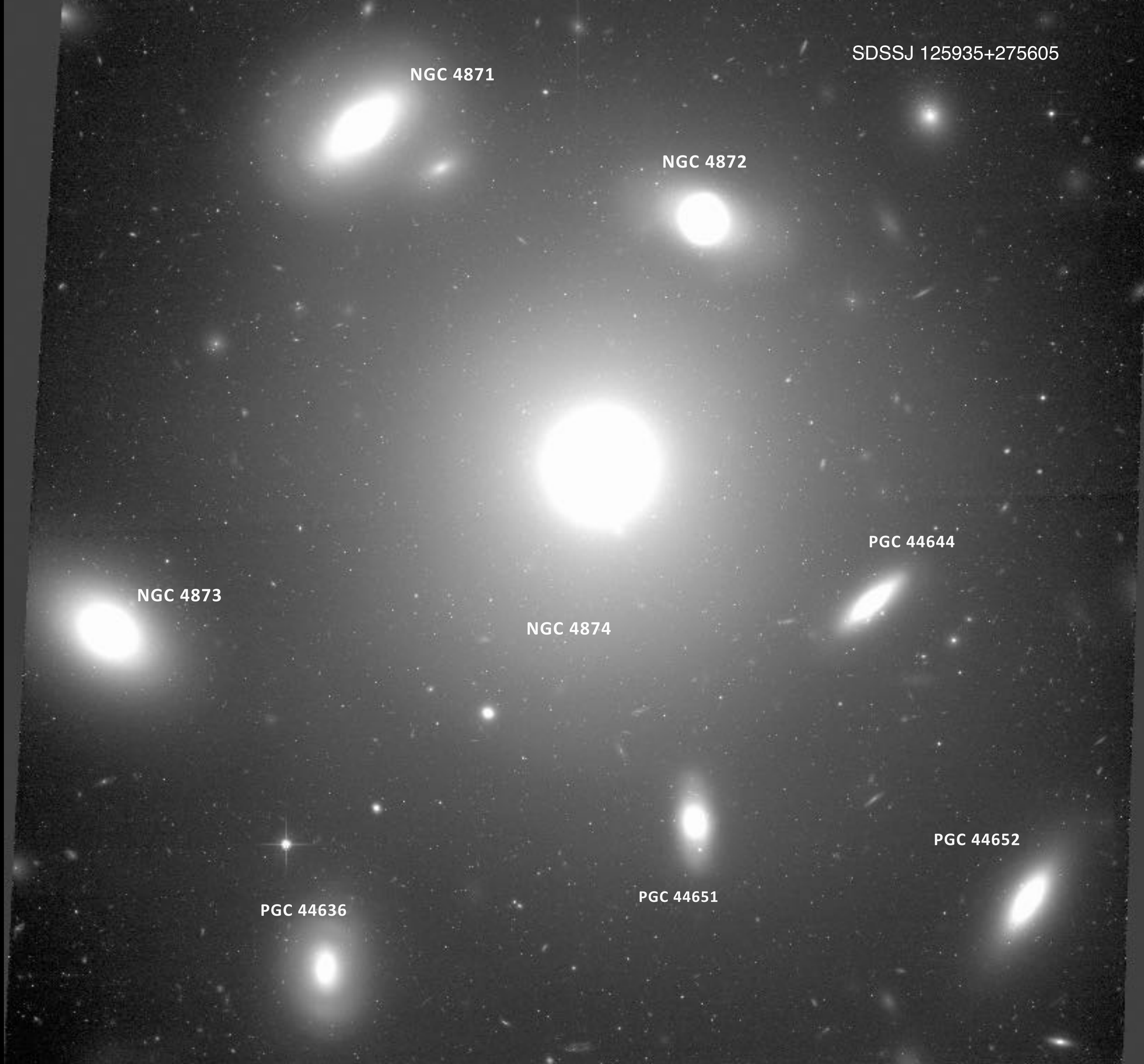


Mitchell
NGC4874 bin spectra by bin number
10kpc
σ [km/s]
$\chi^2=1.09$
$\chi^2=0.94$
Characteristic stellar speed (km/s)
Y (light years)
X (light years)
GMOS
σ = 295 ± 5 km/s
counts
Angstroms

NGC 4874

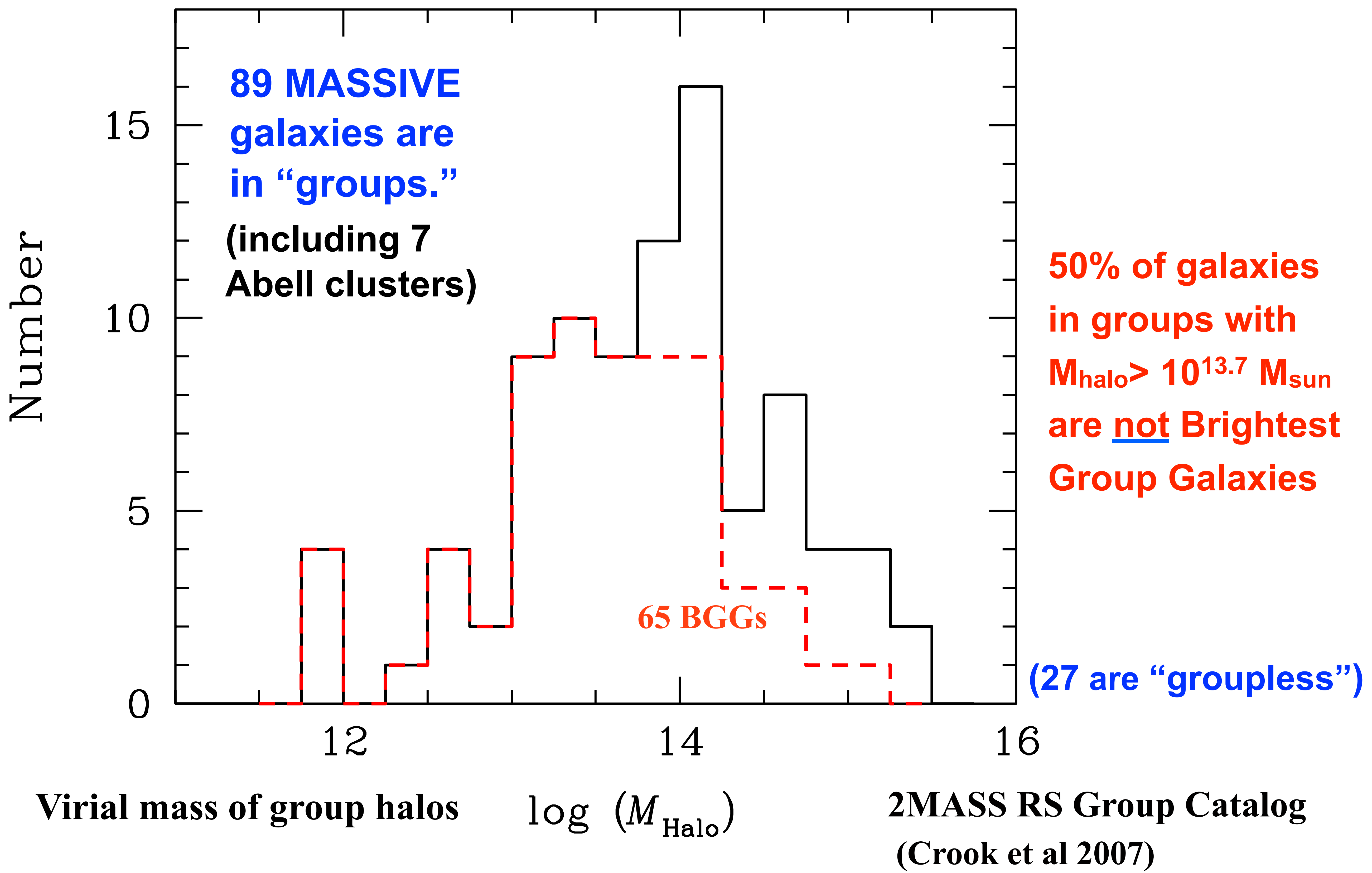


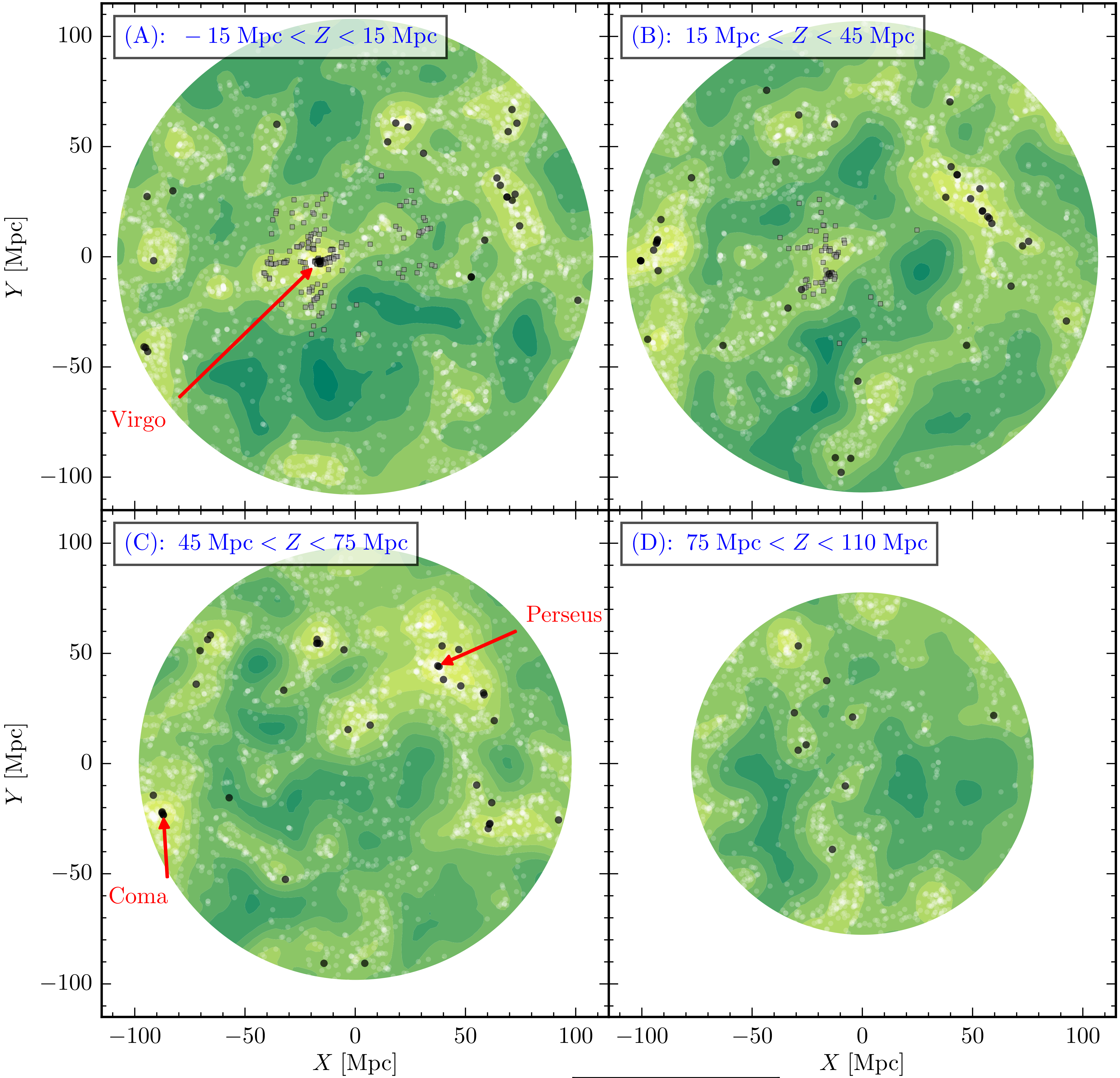
(in prep)



SDSSJ 125935+275605
NGC 4871
NGC 4872
PGC 44644
NGC 4873
NGC 4874
PGC 44652
PGC 44651
PGC 44636

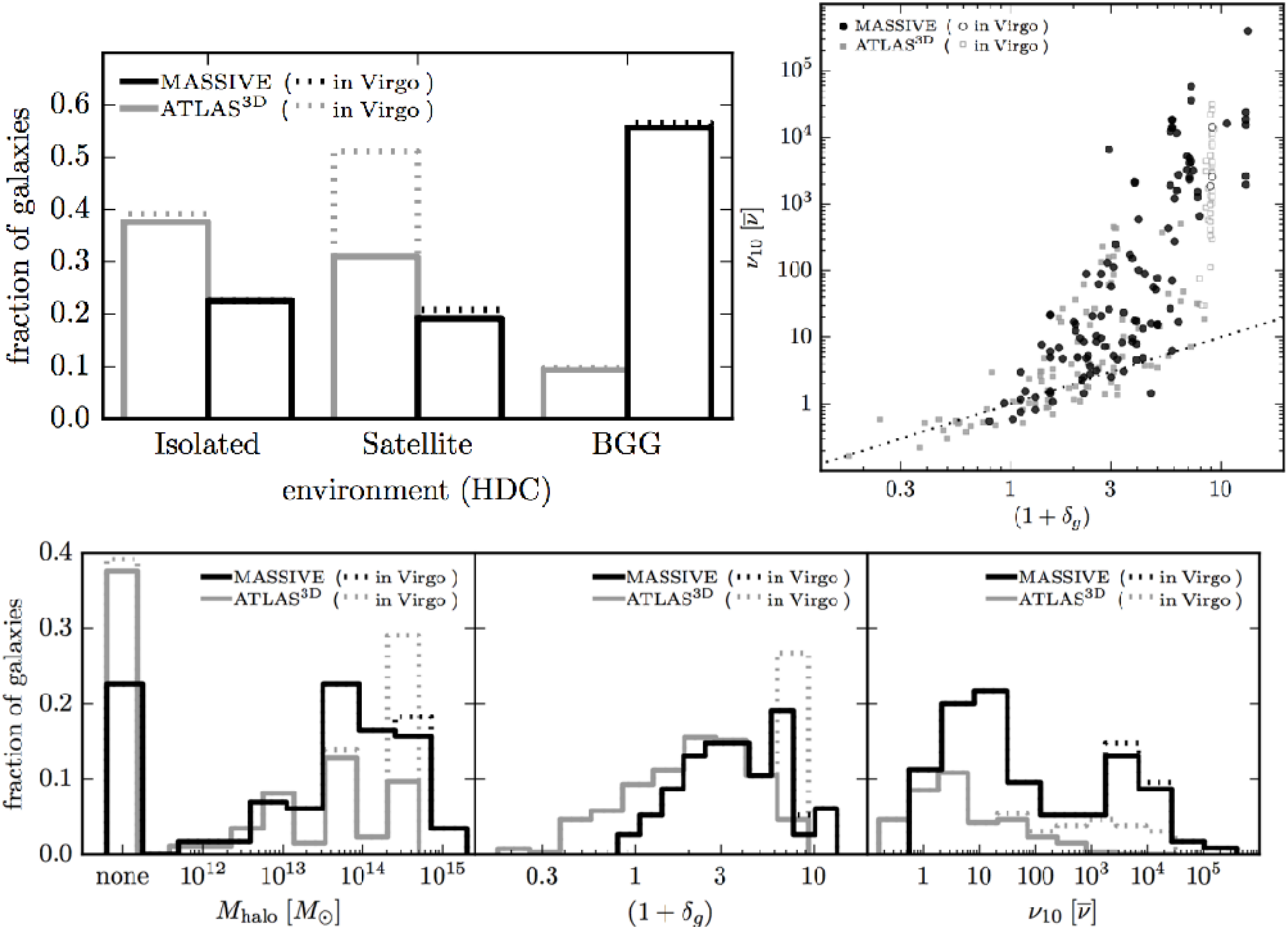
MASSIVE Sample Galaxy Environments





MASSIVE survey density field; colors indicate variation in $\boldsymbol{\nu}_{10}$. (Grey squares are ATLAS-3D galaxies.)

Veale et al. (2017b, MNRAS, in press)

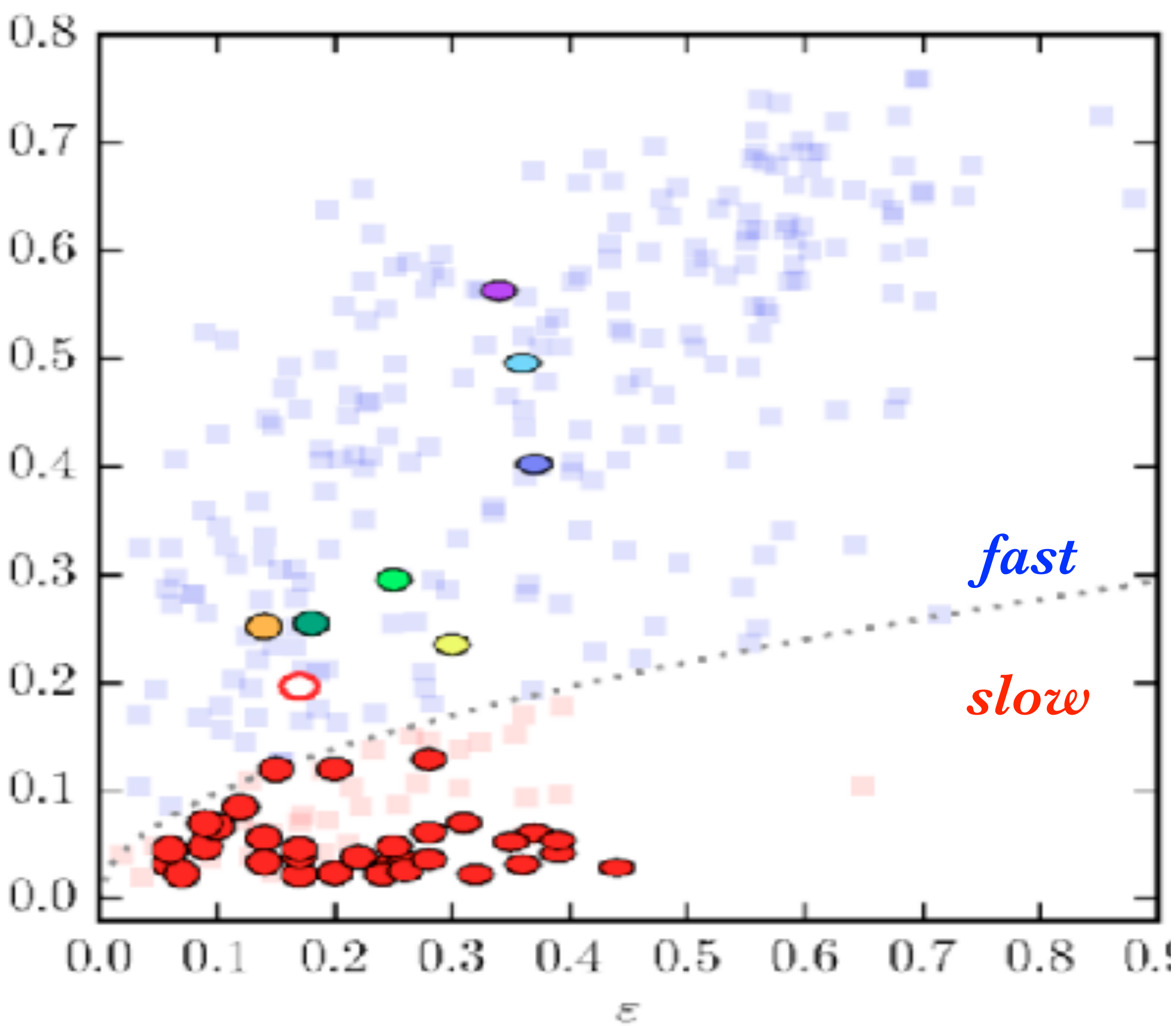


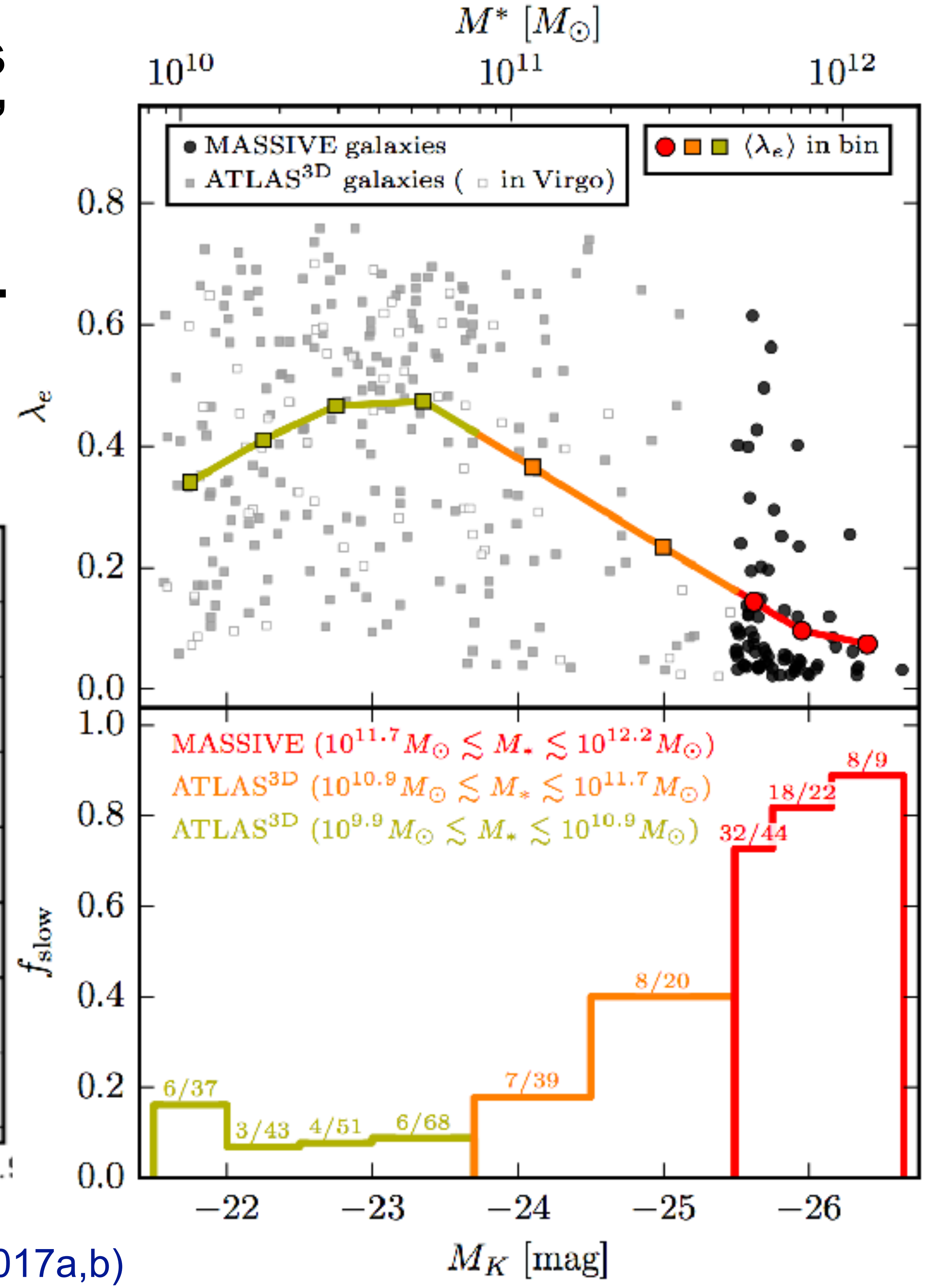
MASSIVE (in Virgo)
ATLAS3D (in Virgo)
fraction of galaxies
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Isolated
Satellite
BGG
environment (HDC)
MASSIVE (o in Virgo)
ATLAS3D (□ in Virgo)
ν_{10} [$\overline{\nu}$]
10^5
10^4
10^3
100
10
1
0.3
1
3
10
$(1+\delta_g)$
MASSIVE (in Virgo)
ATLAS3D (in Virgo)
fraction of galaxies
0.0
0.1
0.2
0.3
0.4
none
10^{12}
10^{13}
10^{14}
10^{15}
$M_{\rm halo}$ [$M_\odot$]
0.3
1
3
10
$(1+\delta_g)$
1
10
100
10^3
10^4
10^5
ν_{10} [$\overline{\nu}$]

MASSIVE Survey galaxies are mainly "slow rotators."

Spin parameter decreases and $f_{\rm slow}$ increases with M_K.

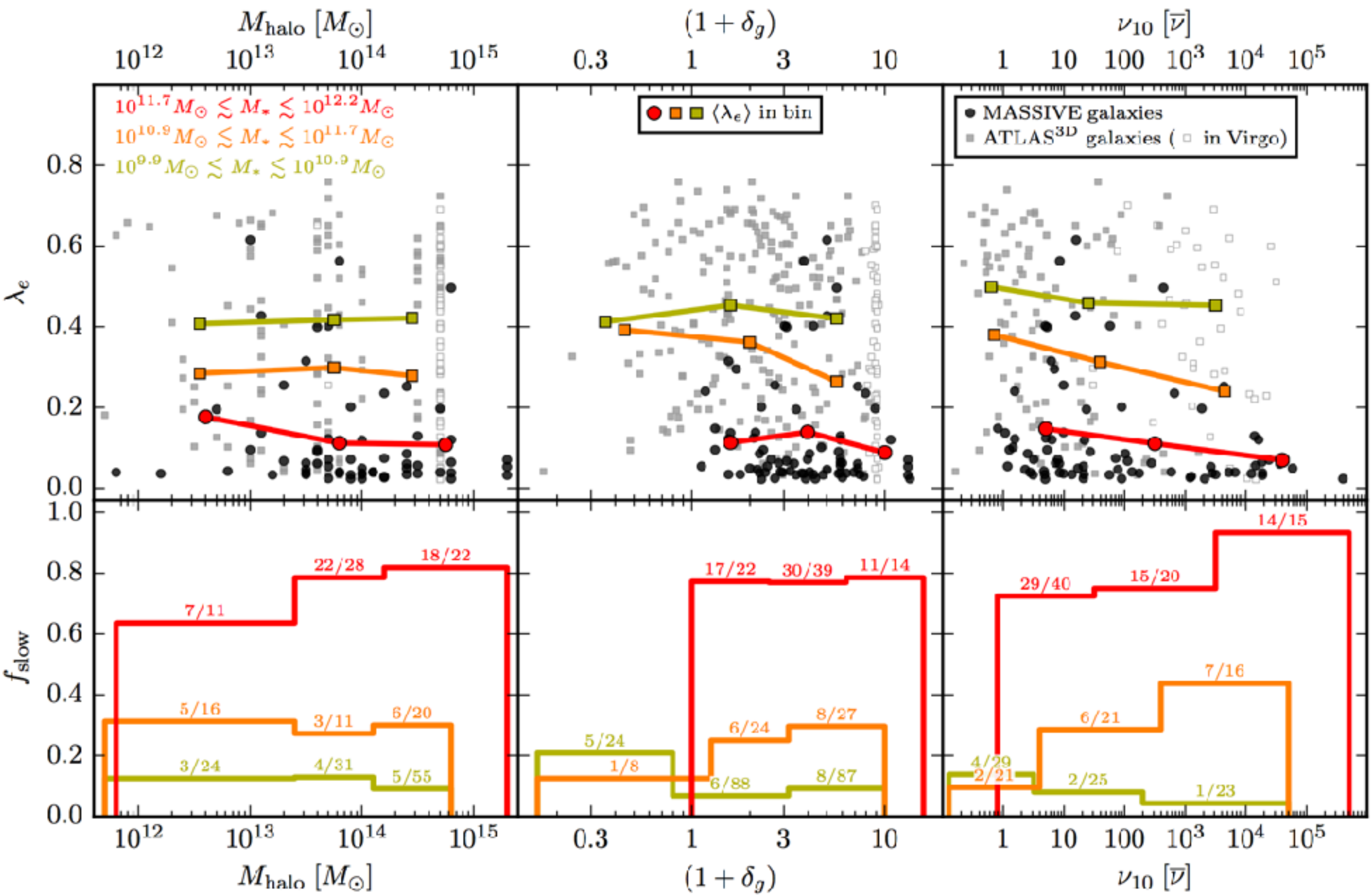
$$\lambda(<R) \equiv \frac{\langle R|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle}$$



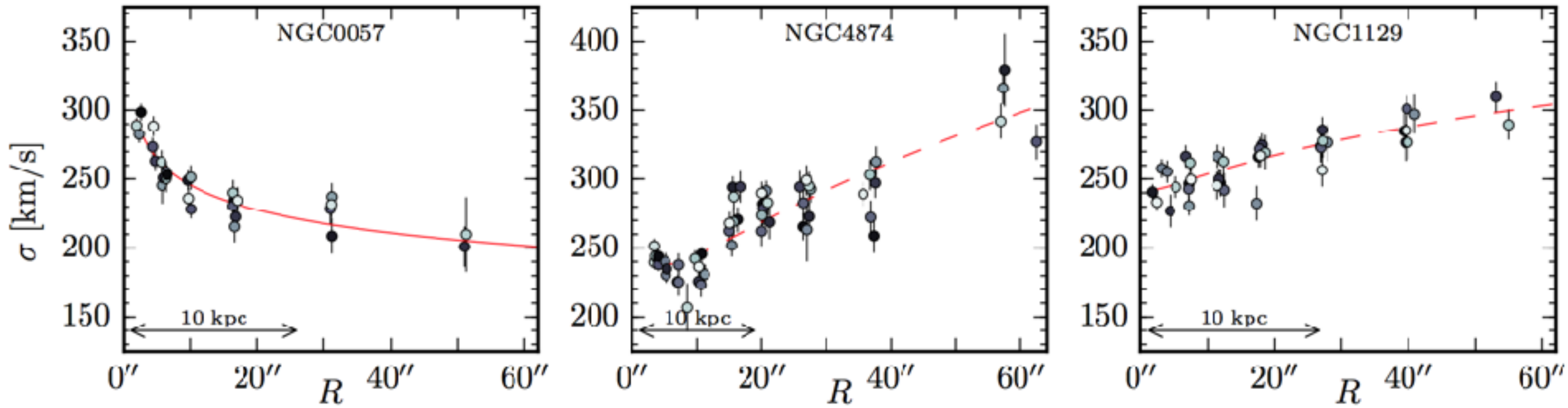


Veale et al. (2017a,b)

No significant fast/slow rotator trend with environment, after controlling for M_K



See Veale et al. (2017b, MNRAS) for detailed analysis.



Veale et al. (2017c, in prep)

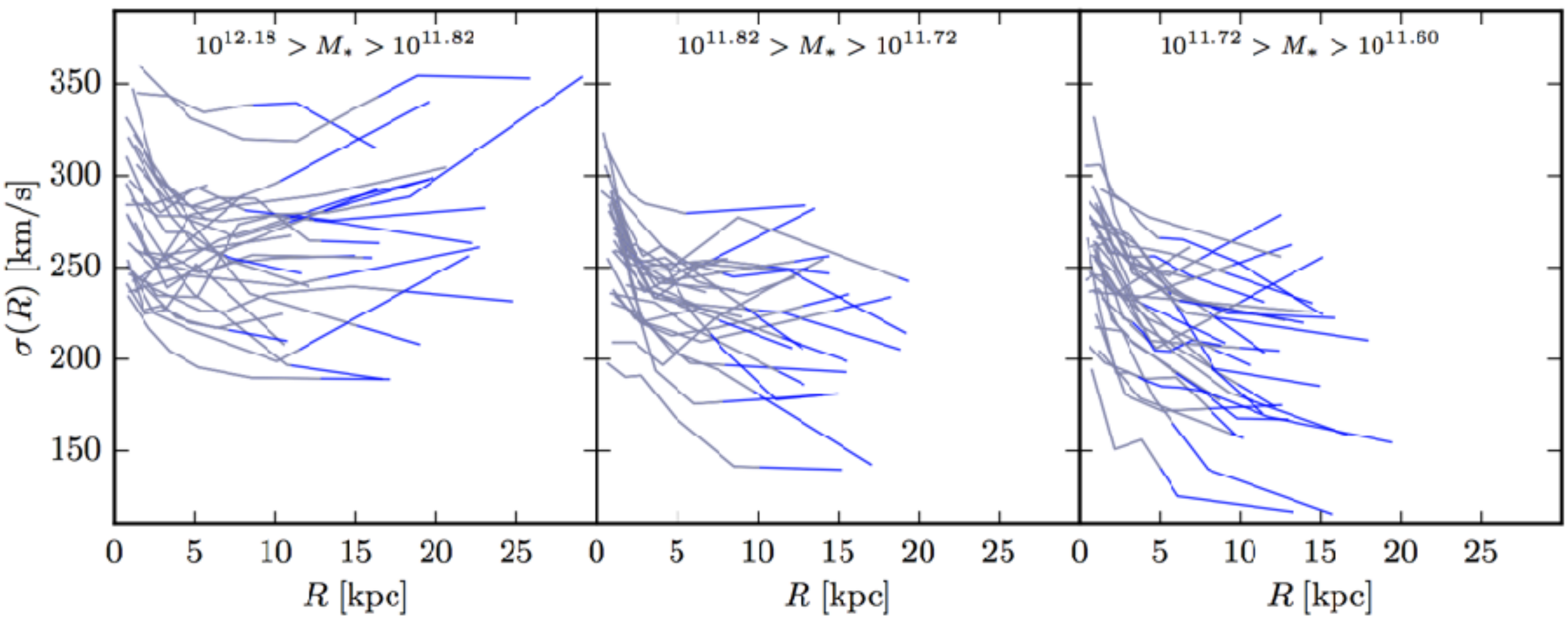
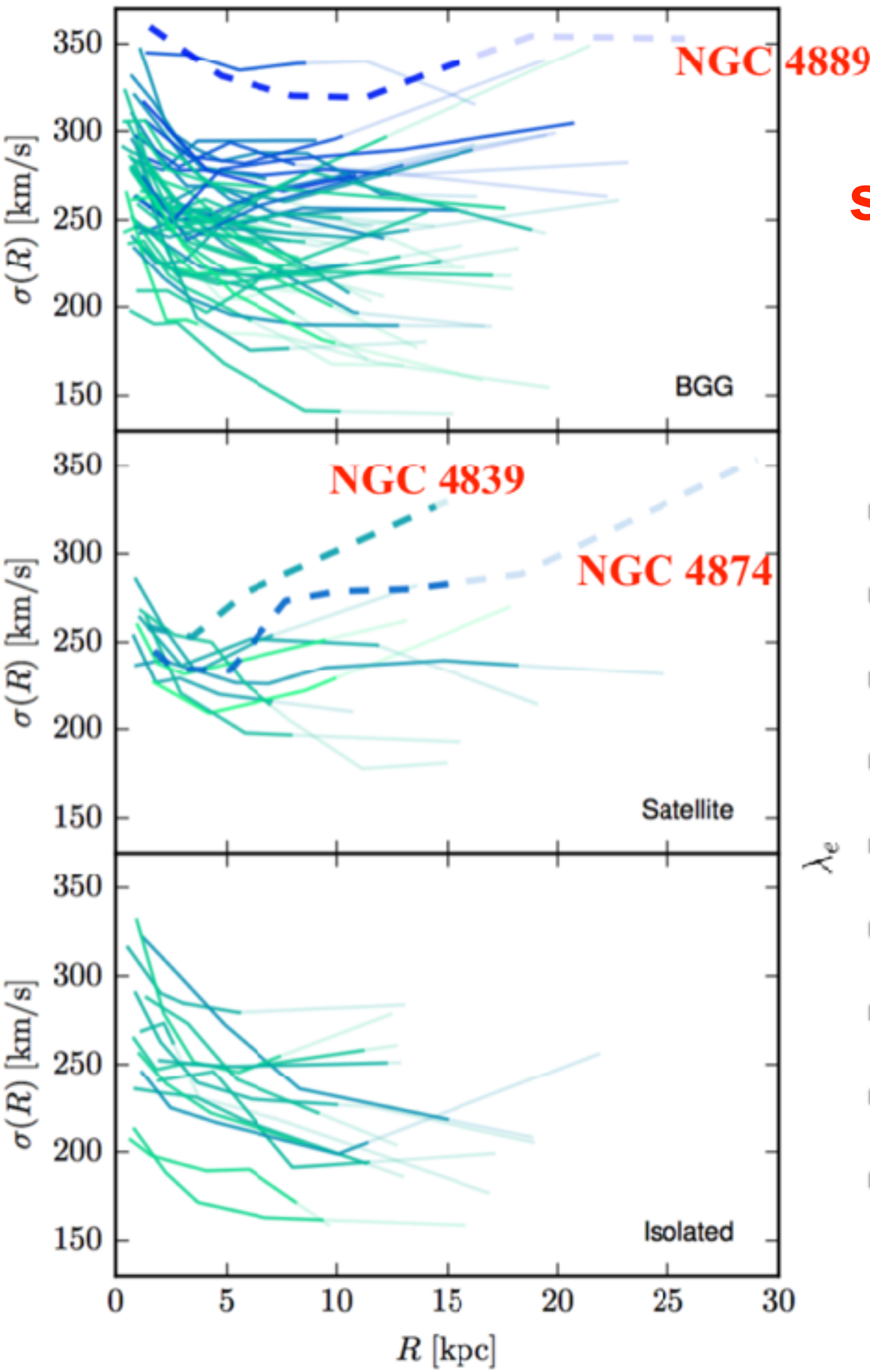
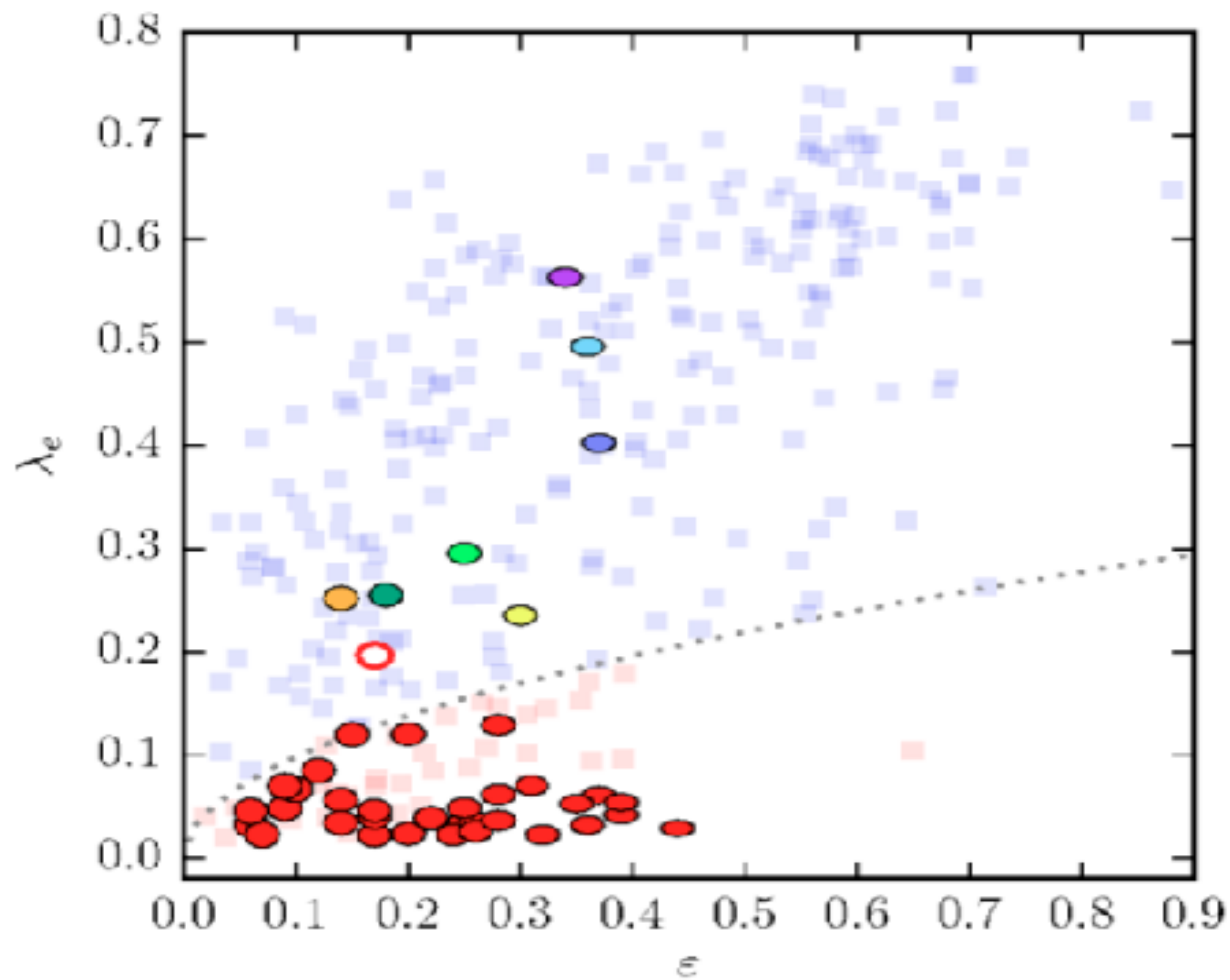


Figure 1. Dispersion profiles in bins of M_K. The 3 panels are arranged from high to low mass, in equal-number bins corresponding to $10^{12.18}M_\odot > M_* > 10^{11.82}M_\odot$ (left), $10^{11.82}M_\odot > M_* > 10^{11.72}M_\odot$ (center), and $10^{11.72}M_\odot > M_* > 10^{11.60}M_\odot$ (right). Each profile is blue at $R > R_e$. From left to right, overall σ becomes slightly lower, and more profiles are steeply falling.

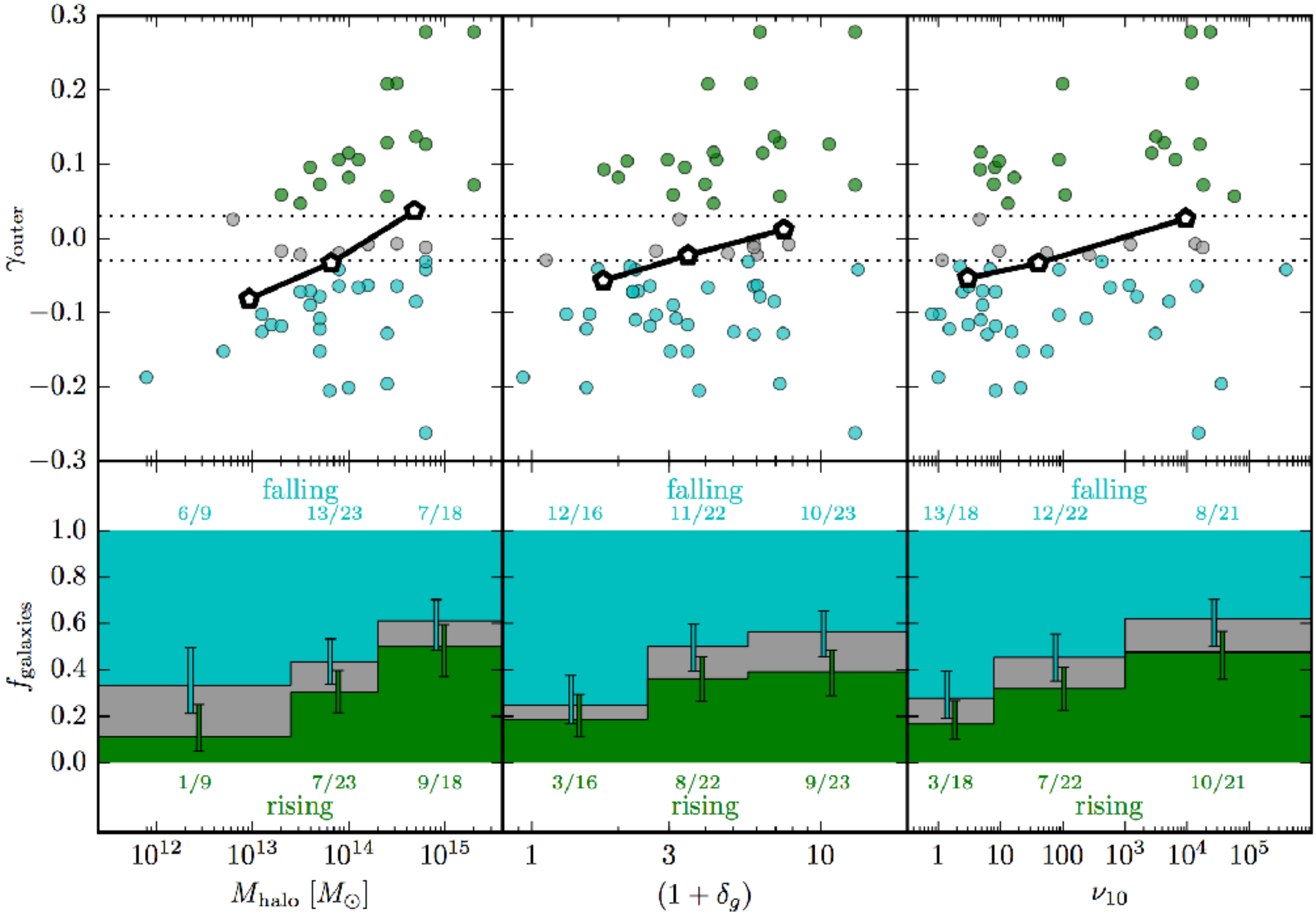


MASSIVE galaxies are mainly slow rotators, but with profiles that vary with environment.

$$\lambda(<R) \equiv \frac{\langle R|V|\rangle}{\langle R\sqrt{V^2+\sigma^2}\rangle}$$

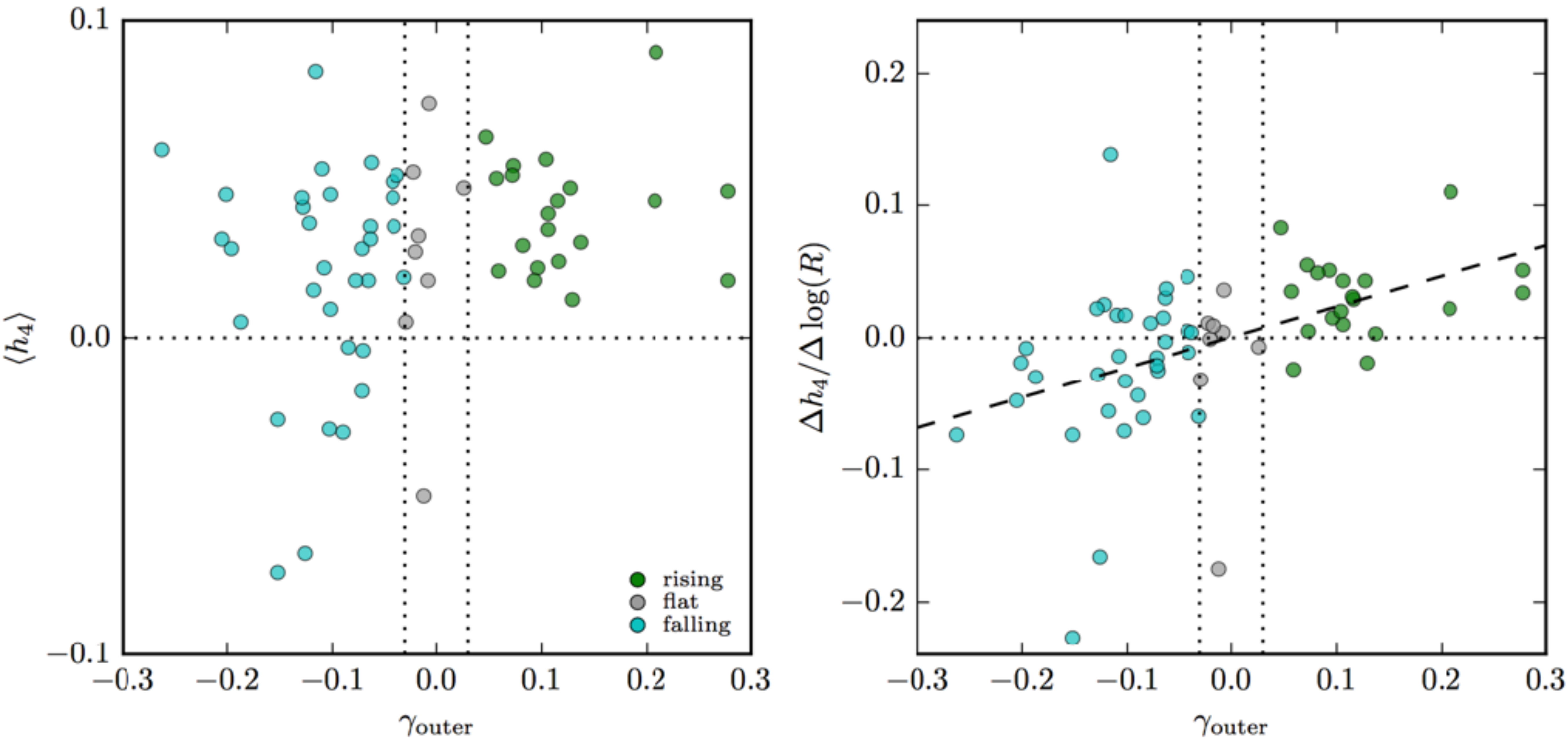


Veale et al. (2017a,c)



Veale et al. (2017c, in prep)

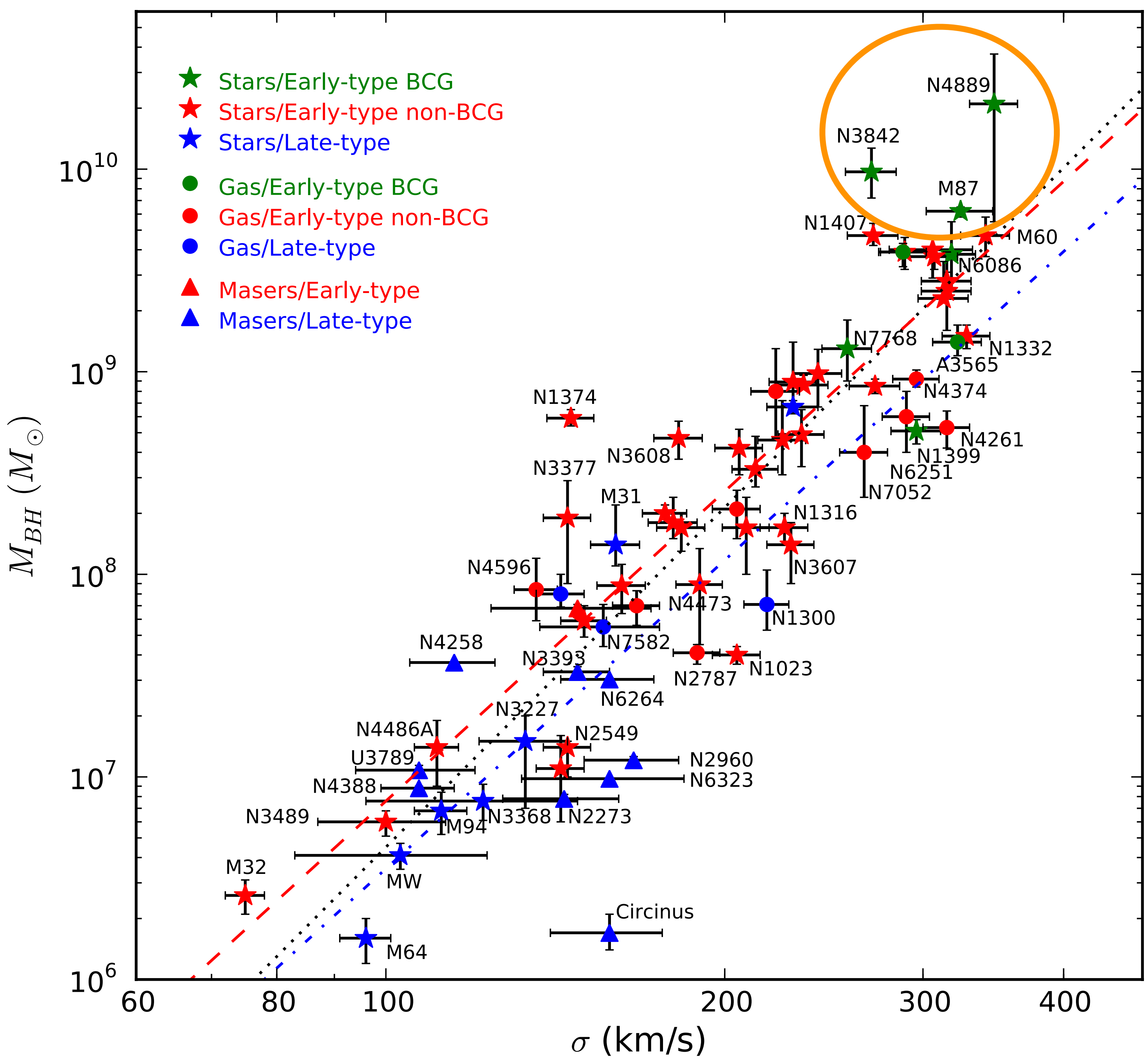
Rising dispersion profile correlates with h_4



Veale et al. (2017c, in prep)

M_{BH}-σ-*environment* relation?

M_{BH} - σ relation



McConnell & Ma (2013)

Very few BHs known with M_{BH} > ~6×10^9 M_{sun}

M87, cD of Virgo

6.2×10^9 M_{sun} (Gebhardt+ 2011)

3.3×10^9 M_{sun} (Walsh+ 2013)

NGC 3842, BCG of A1367

9.7×10^9 M_{sun} (McConnell+ 2011)

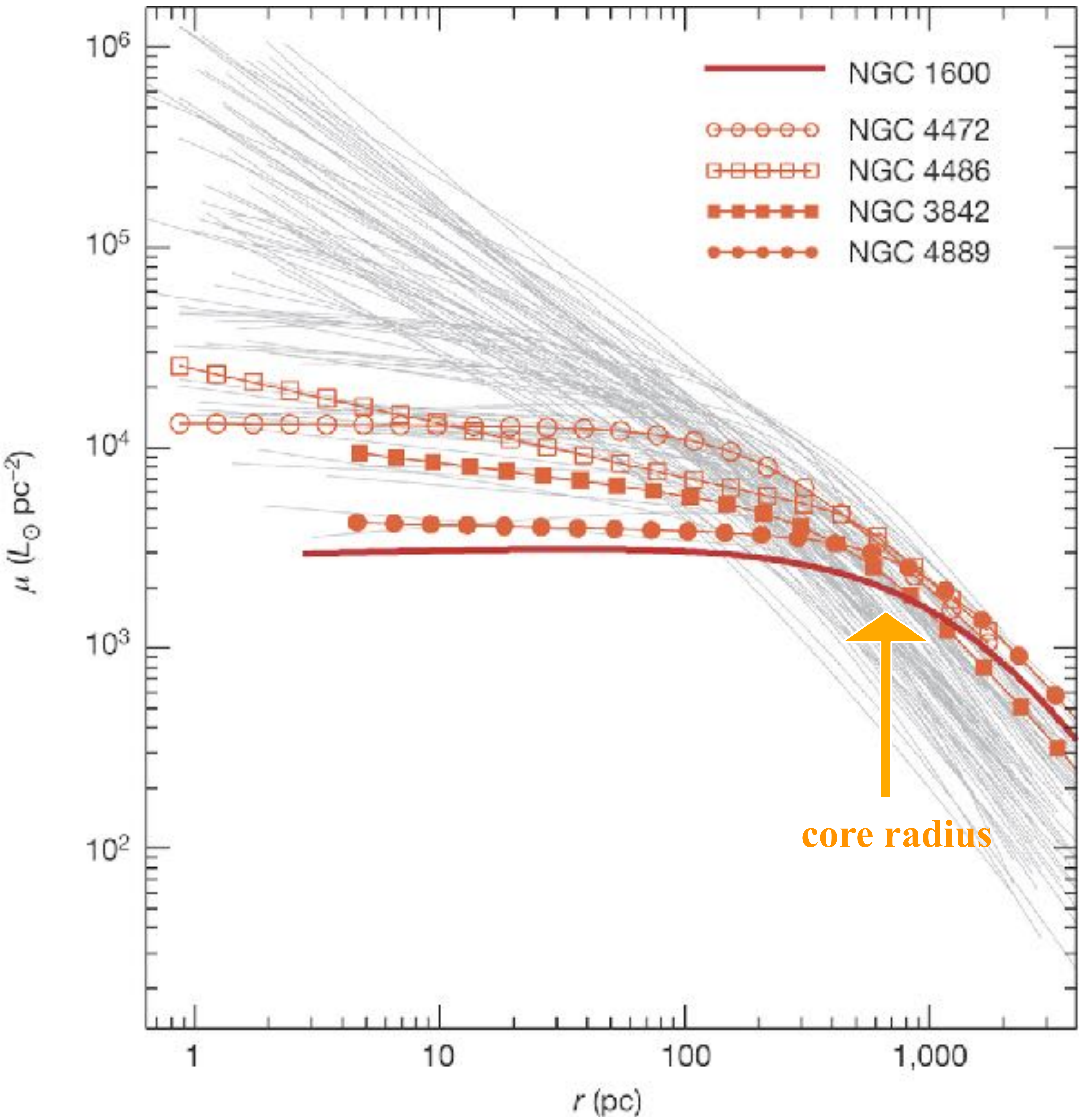
NGC 4889, BCG of Coma

~20×10^9 M_{sun} (McConnell+ 2011)

The most massive E's are rare and distant; also have flat, low-SB cores.

Thus, BHs require both high resolution & large apertures.

Supermassive BH Demographics



In addition to high σ's, hosts of the most massive BHs tend to have flat central profiles, or "cores."

In the **MASSIVE** sample, **NGC 1600** has flattest central profile, with a break radius $r_b \approx 0.7$ kpc.

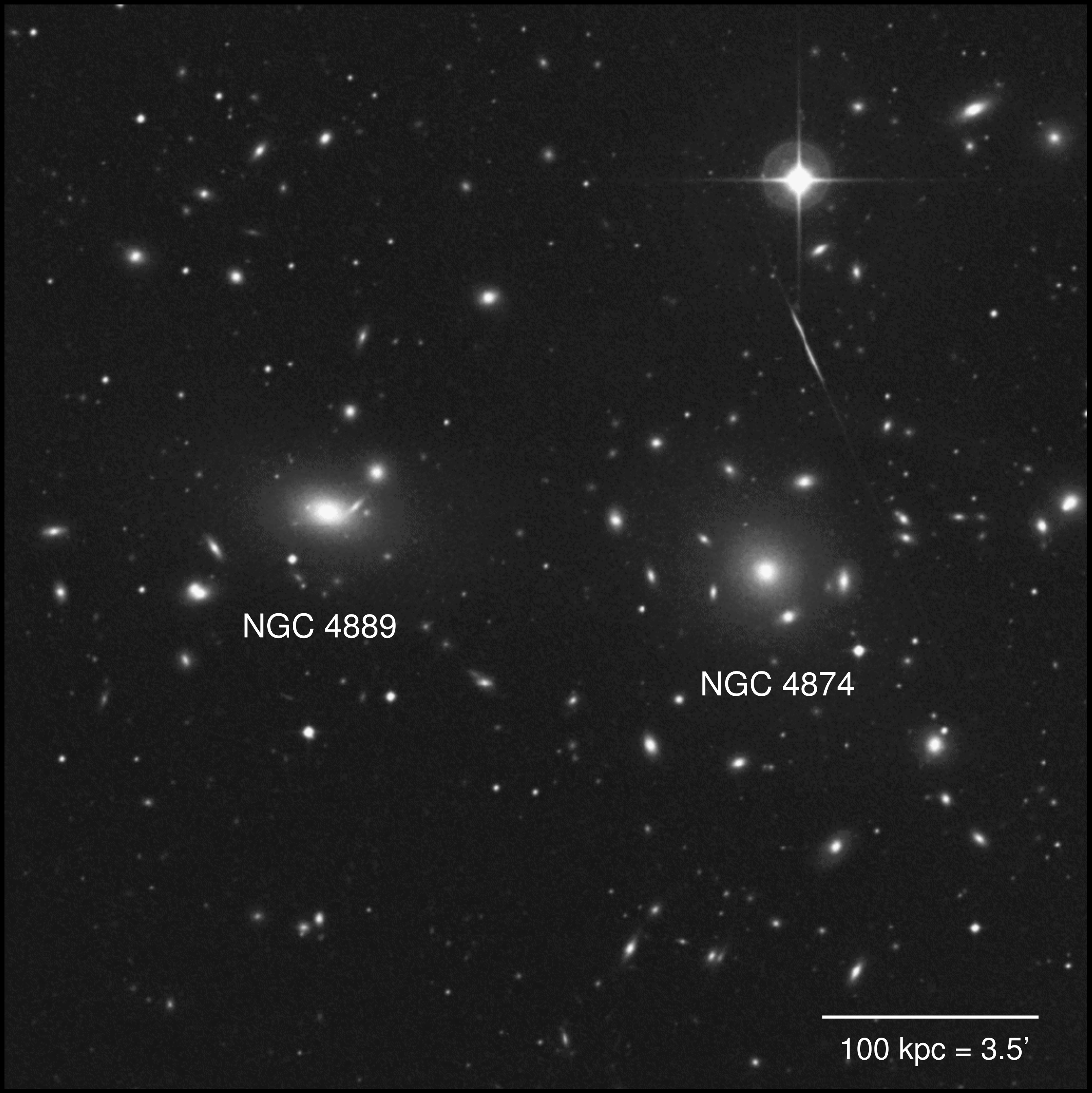
Unlike known hosts of ~10^{10} M_{sun}–ish BHs, **NGC 1600** resides in a small group (similar to the most luminous quasars), ***not in a rich cluster.***

Thomas+ 2016, Nature

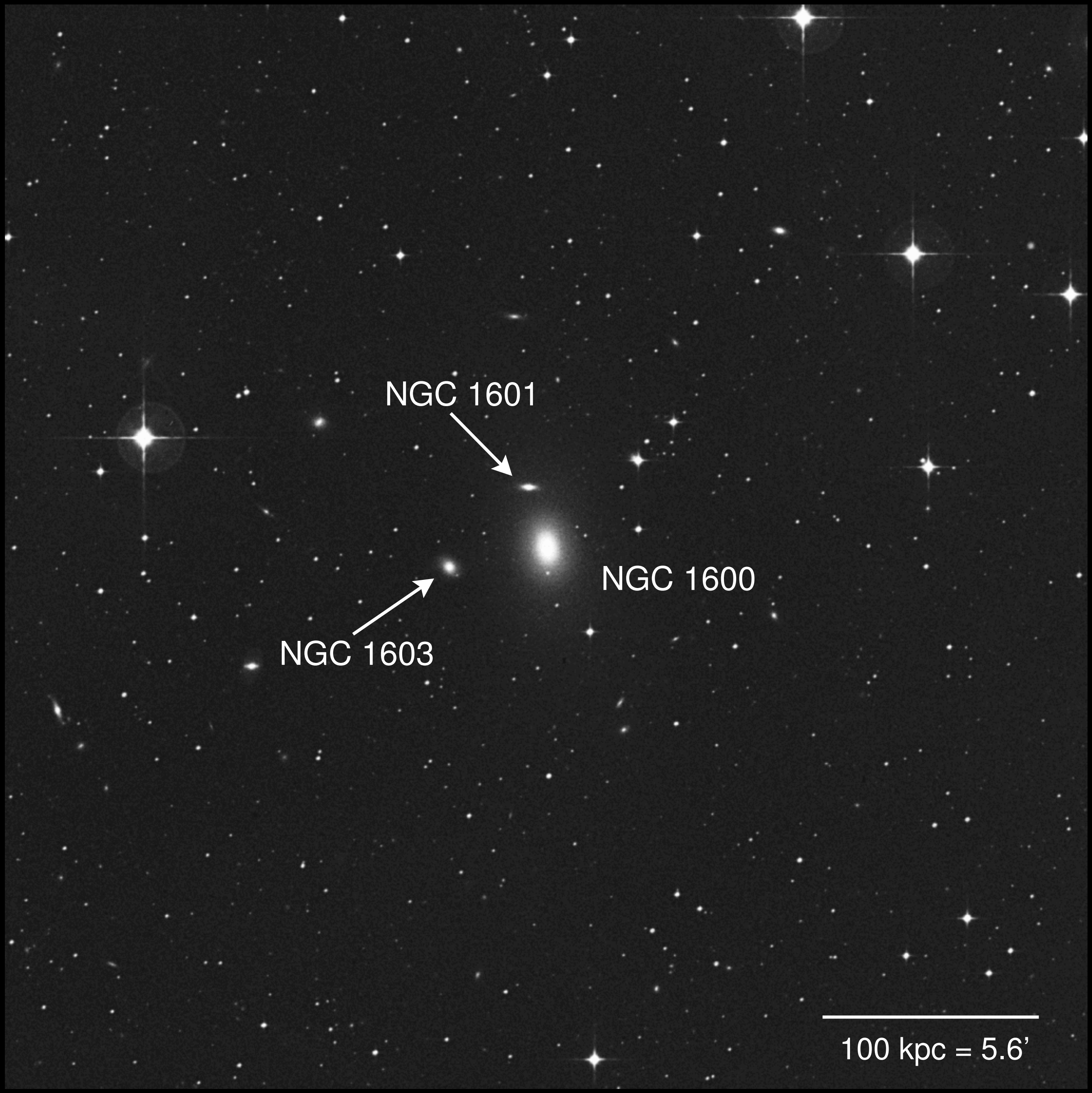
Thomas+ 2016, *Nature*

Contrasting Environments

Coma cluster



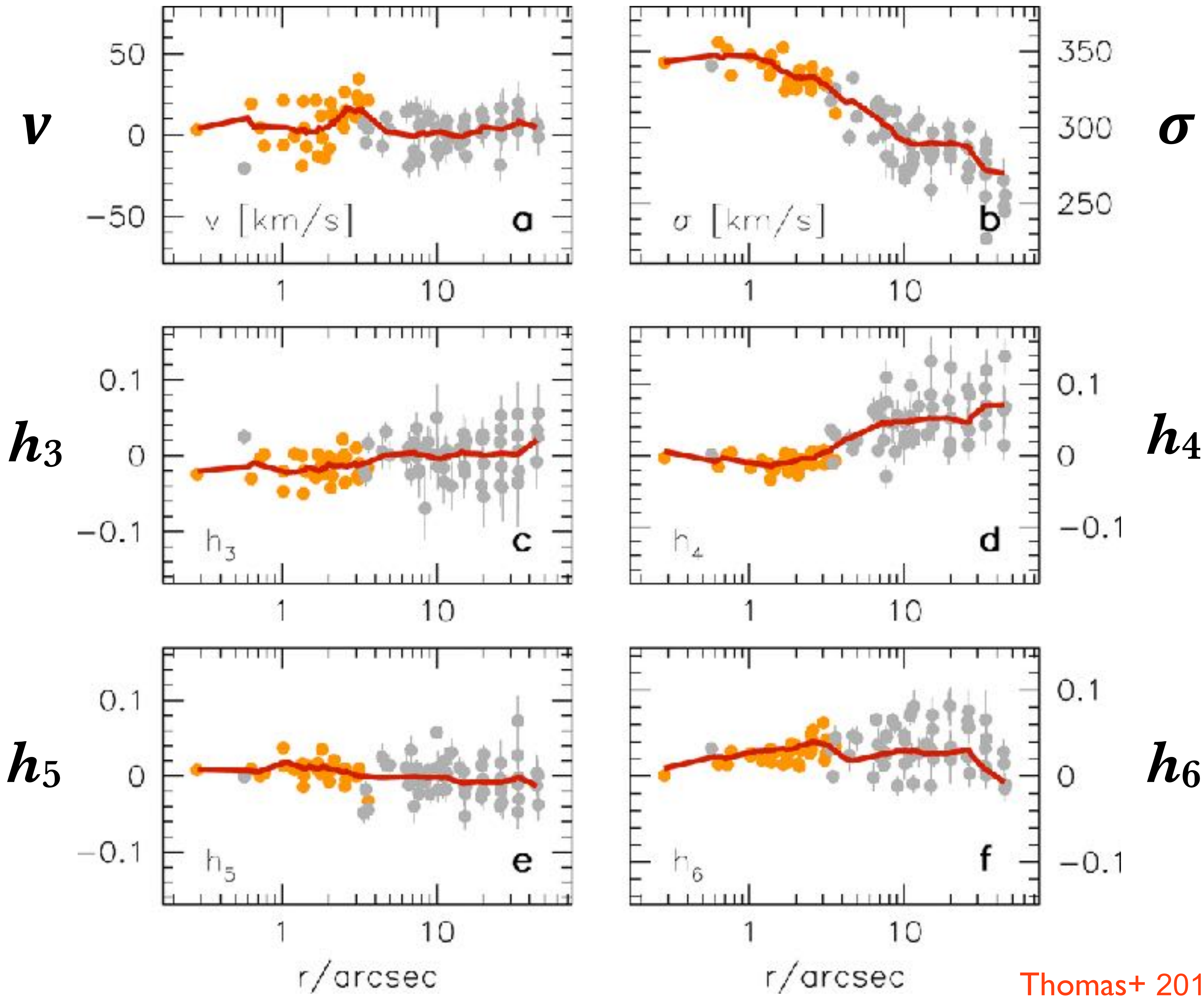
N1600 group



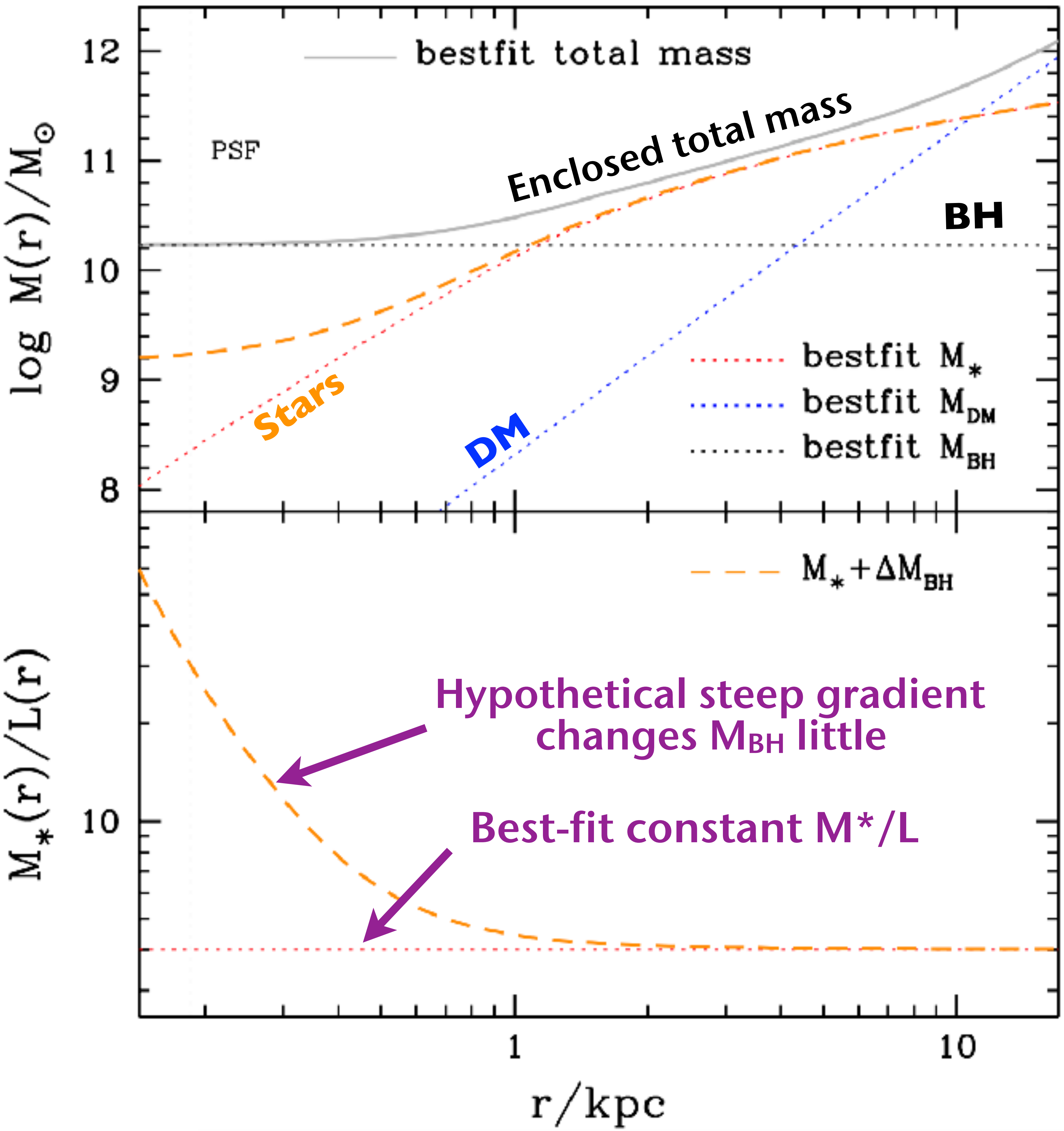
$M_{vir} = (1.4–2.7)\times10^{15}\ M_{sun}$
$L_X = 4\mathrm{x}10^{44}\ L_{sun}$
Rank 2 galaxy similar in L

$M_{vir} \sim 1.5\times10^{14}\ M_{sun}$
$L_X \sim$ 1000x lower
Rank 2 galaxy 6x fainter (fossil-like)

NGC 1600 Mitchell/VIRUS-P + GMOS IFU velocity data



Thomas+ 2016, Nature



Best-fit mass model

$M_{BH} = (17 \pm 2) \times 10^9 \, M_\odot$

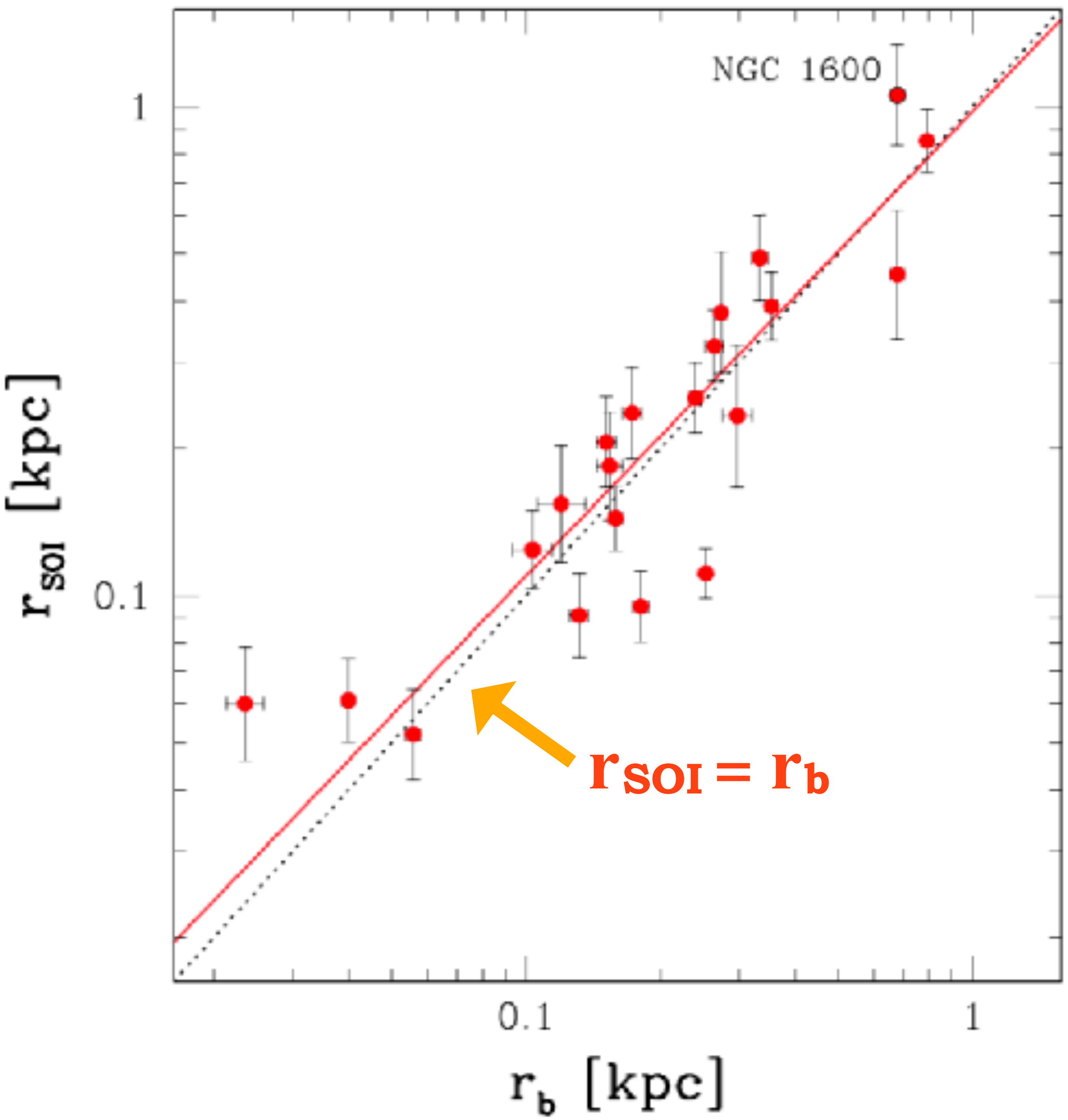
Best-fit stellar $M^*/L \approx 4$.

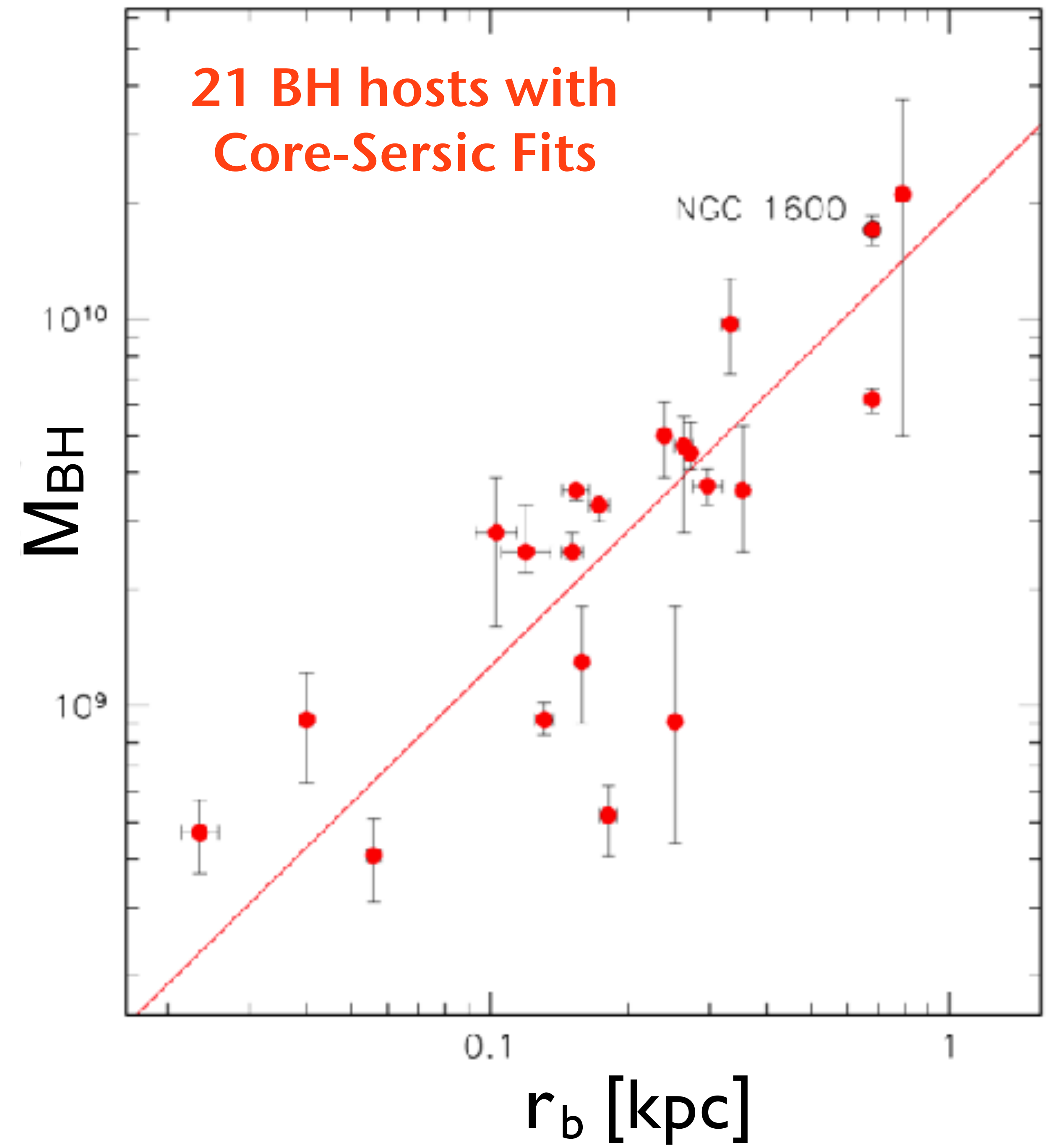
A hypothetical steep gradient in M^*/L lowers M_{BH} only ~10%.

Thomas et al. 2016, *Nature*

BH Scaling Relations for Cored Ellipticals

BH mass dominates within sphere of influence, r_{SOI}





Best-fit consistent with $r_{SOI} = r_b$, scatter ~0.17 dex;

r_b is a better predictor of M_{BH} than σ is.

Thomas+ (2016)

Summary

- Making MASSIVE progress on multiple fronts, targeting 100+ early-type galaxies with $\mathbf{M_\star > 10^{11.5}\,M_{sun}}$, $\boldsymbol{d} < 108$ Mpc.
- About 75% of the **wide-field IFU data** in hand; **deep wide-field IR** observations obtained for 90% of the galaxies, plus ongoing programs with **ALMA/IRAM**, **Chandra**, and **HST**.
- Specific angular momentum parameter $\boldsymbol{\lambda}$ & $f_{\mathbf{slow}}$ correlate only with stellar mass, but velocity dispersion profile **σ(R)** correlates with environment, even controlling for $\mathbf{M_\star}$.
- Correlation of $\boldsymbol{h_4}$ and **σ** profiles; thus, $\boldsymbol{h_4}$ with environment
- Molecular & ionized gas detected in many galaxies: **red ≠ dead**.
- NGC 1600 harbors **first >10^{10} M_{sun} BH outside a rich cluster,** consistent with environs of most luminous QSO at $z \approx 2$.
- ***More MASSIVE science to come!***