New measurements of the galaxy mass-spin relation

(Including a contribution from Roy)

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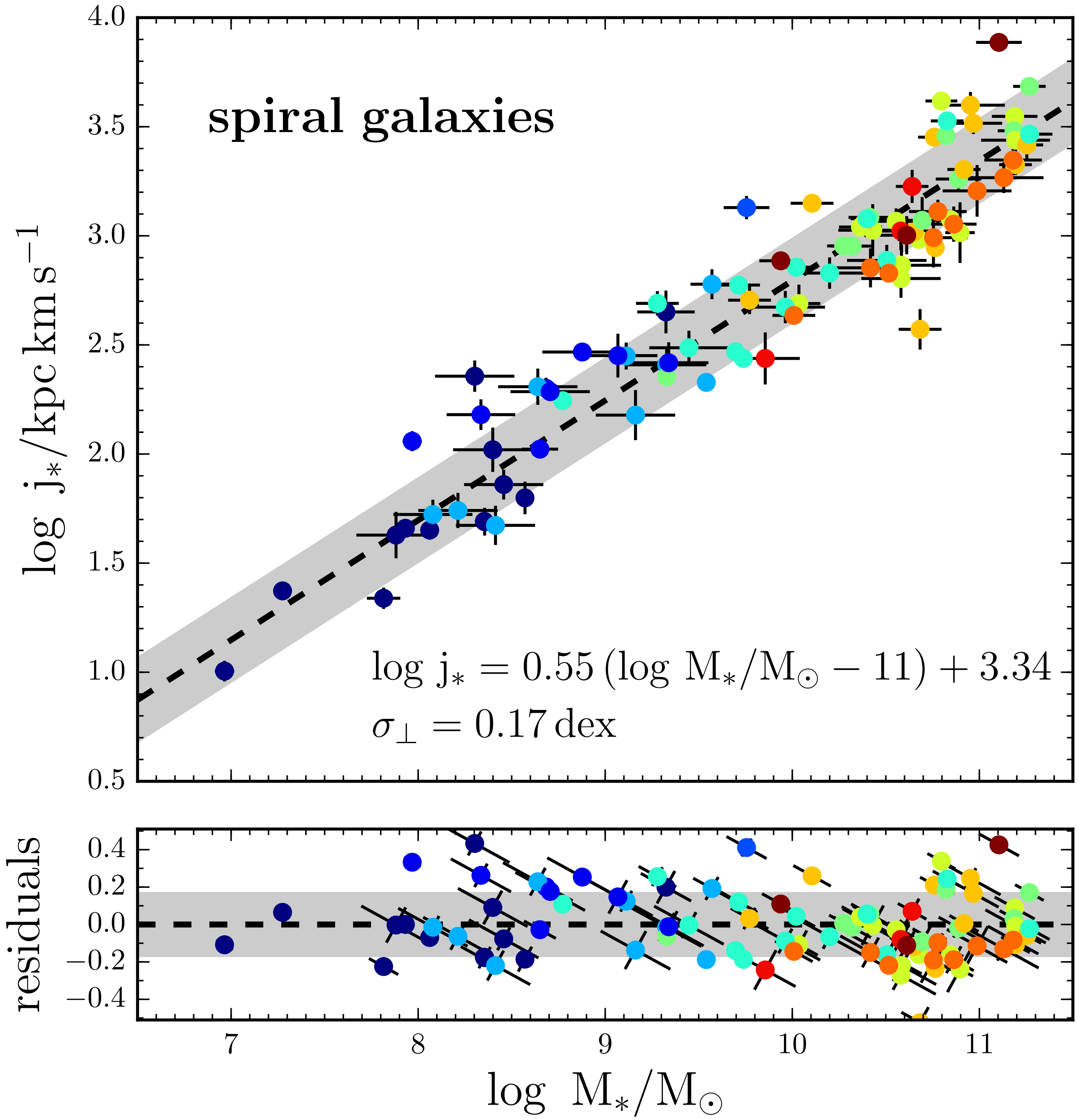
Introduction

The j-M relation

Posti+ 2018



- Connects a galaxy's mass with its specific angular momentum (total angular momentum per unit mass).
- $j_* = \beta M_*^\alpha$
- Power-law behavior indicates a systematic way in which galaxies acquire and conserve angular momentum.

Introduction

The j-M relation

- AM content is largely determined by interaction/merger history and feedback processes.
- It's a probe of the baryon cycle, and hence galaxy evolution.
- Validate predictions from tidal torque theory and hierarchical assembly models.
- Also a link between DM and observable properties.

Introduction

The j-M relation

- $$j_h = \frac{1.67 \times 10^3}{\sqrt{F_E}} \left(\frac{\lambda}{0.035}\right) \left(\frac{M_\mathrm{h}}{10^{12} M_\odot}\right)^{2/3} \quad \mathrm{kpc\ km/s}$$

- Considering $f_* \equiv M_*/M_\mathrm{h}$ and $f_j \equiv j_*/j_\mathrm{h}$, the specific angular momentum for the stars in a galaxy is:

$$j_* = \frac{77.4}{\sqrt{F_E}} \left(\frac{\lambda}{0.035}\right) f_j f_*^{-2/3} \left(\frac{M_*}{10^{10} M_\odot}\right)^{2/3} \quad \mathrm{kpc\ km/s}$$

Previous j⋆-M⋆ studies

Fall (1983)

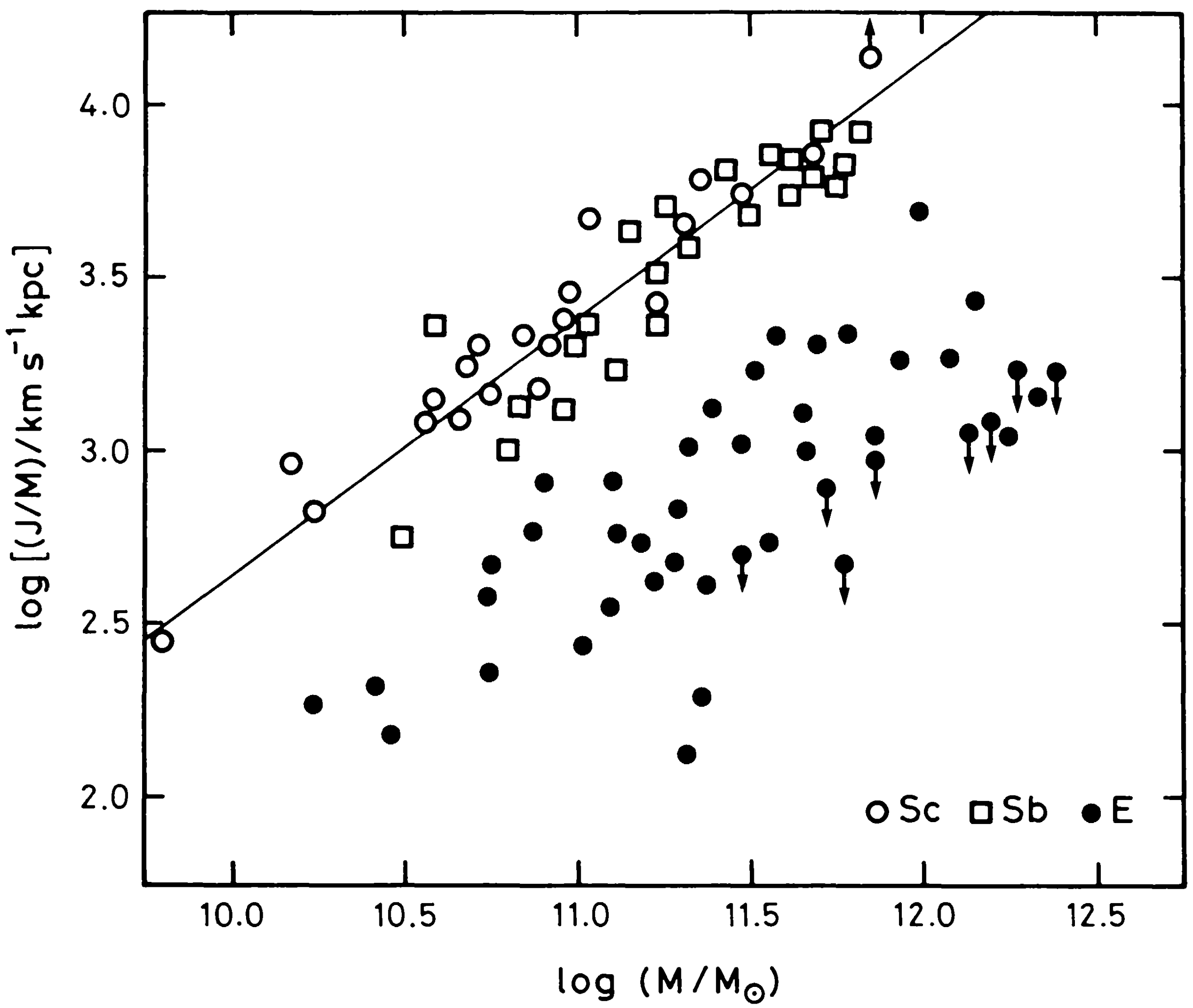


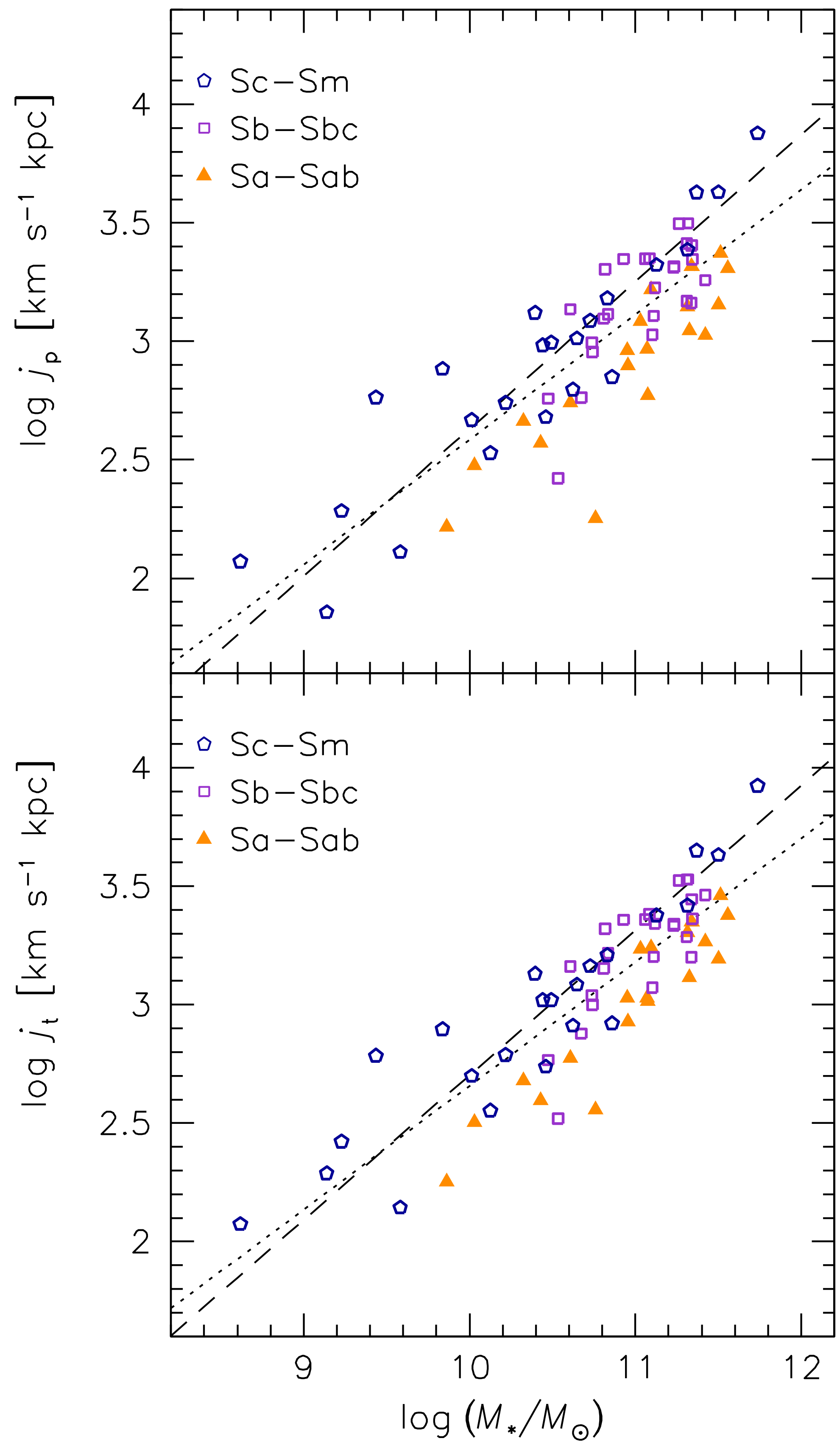
Figure 1. Specific angular momentum against luminous mass for galaxies of different morphological types. Spirals: $J/M = 2v_c\alpha^{-1}$ with $v_c = V(R_{25}^{ib})$ and $\alpha^{-1} = 0.32\ R_{25}^{ib}$; $M = (M/L)L(B_T^{ib})$ with $M/L = 3.0$ for Sb and $M/L = 1.5$ for Sc; data from Rubin et al. (1980, 1982). Ellipticals: $J/M = 2.5\ v_m\ r_e$ as appropriate for a de Vaucouleurs profile, a flat rotation curve and random orientations; $M = (M/L)L(B_T^b)$ with $M/L = 6.0$; data from Davies et al. (1982). A Hubble constant of 50 km s^{-1} Mpc^{-1} is adopted but the relative positions of points do not depend on this distance-scale.

- Spirals and ellipticals have $j_* = \beta M_*^\alpha$ with $\alpha \sim 0.6$.
- β varies by a factor ~5 between spirals and ellipticals.

Previous j⋆-M⋆ studies

Romanowsky & Fall (2012)

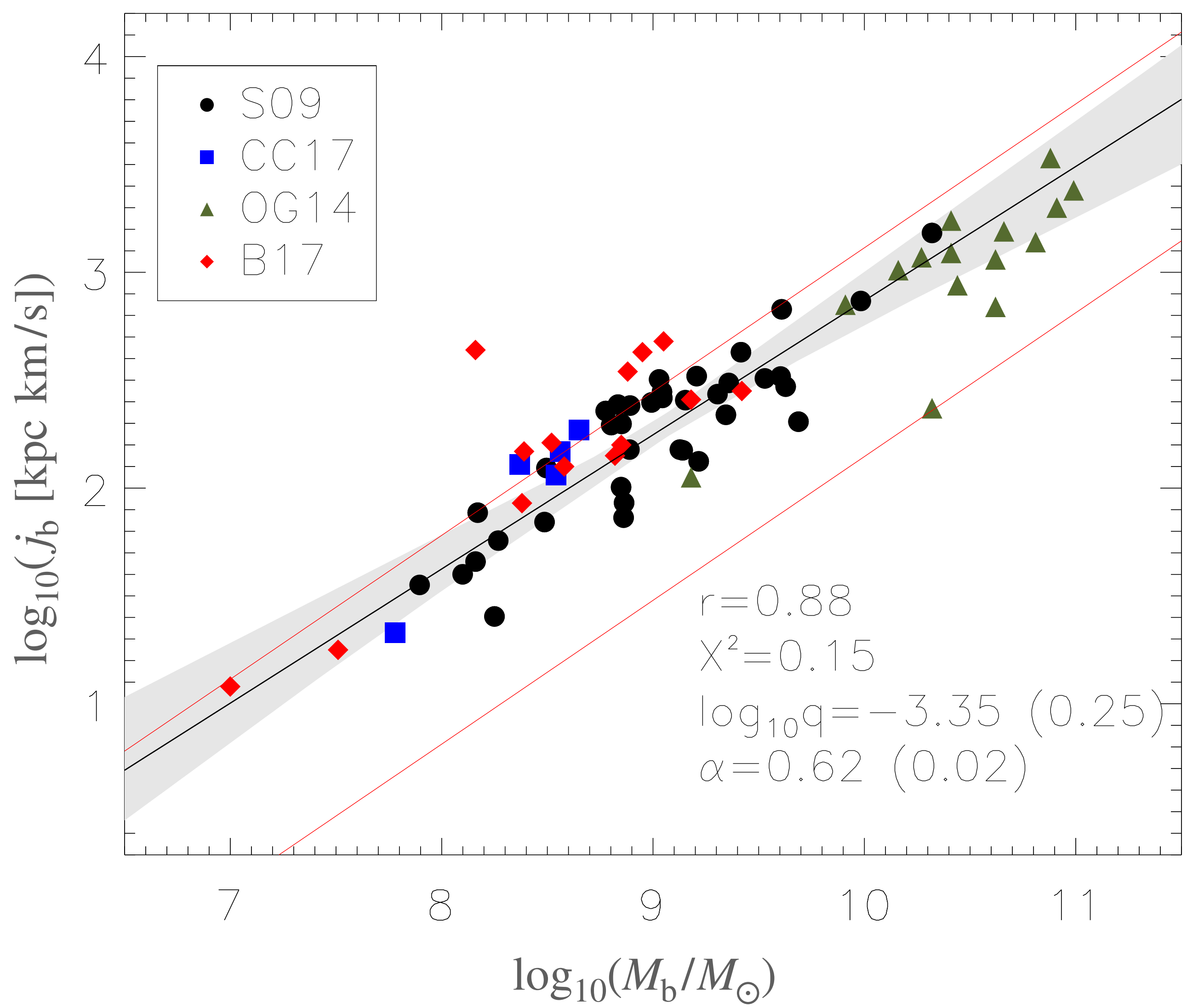
- Spirals and ellipticals follow parallel $j_* - M_*$ tracks with α~0.6 but with ellipticals containing ~3-4 times less j⋆
- Presented new methods of accurately estimating j_* using global observable quantities ($j_* \approx 2R_{\rm eff}V_{\rm c}$).



Previous j⋆-M⋆ studies

Elson (2017)

- Used 37 HI-rich galaxies from WHISP survey to study baryonic $j - M$ relation.
- Roughly doubled the number of gals with $M_\mathrm{b} < 10^{10} M_\odot$
- Found $\alpha = 0.62 \pm 0.02$.



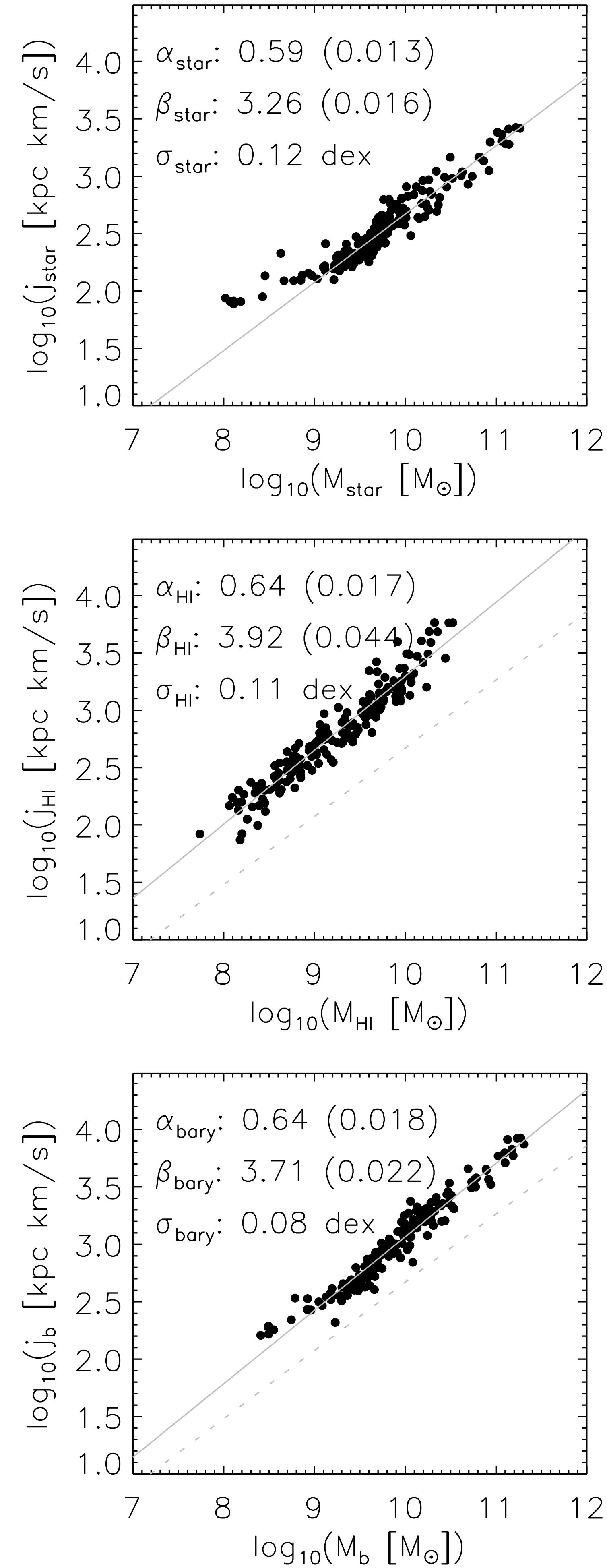
Roy’s contribution

- In ~2018, Roy asked how AM is transferred between the various mass components.
- Roy’s suggestion: maybe simulations could be used to figure it out.

Previous $j_\star$-$M_\star$ studies

Elson et al. (2023)

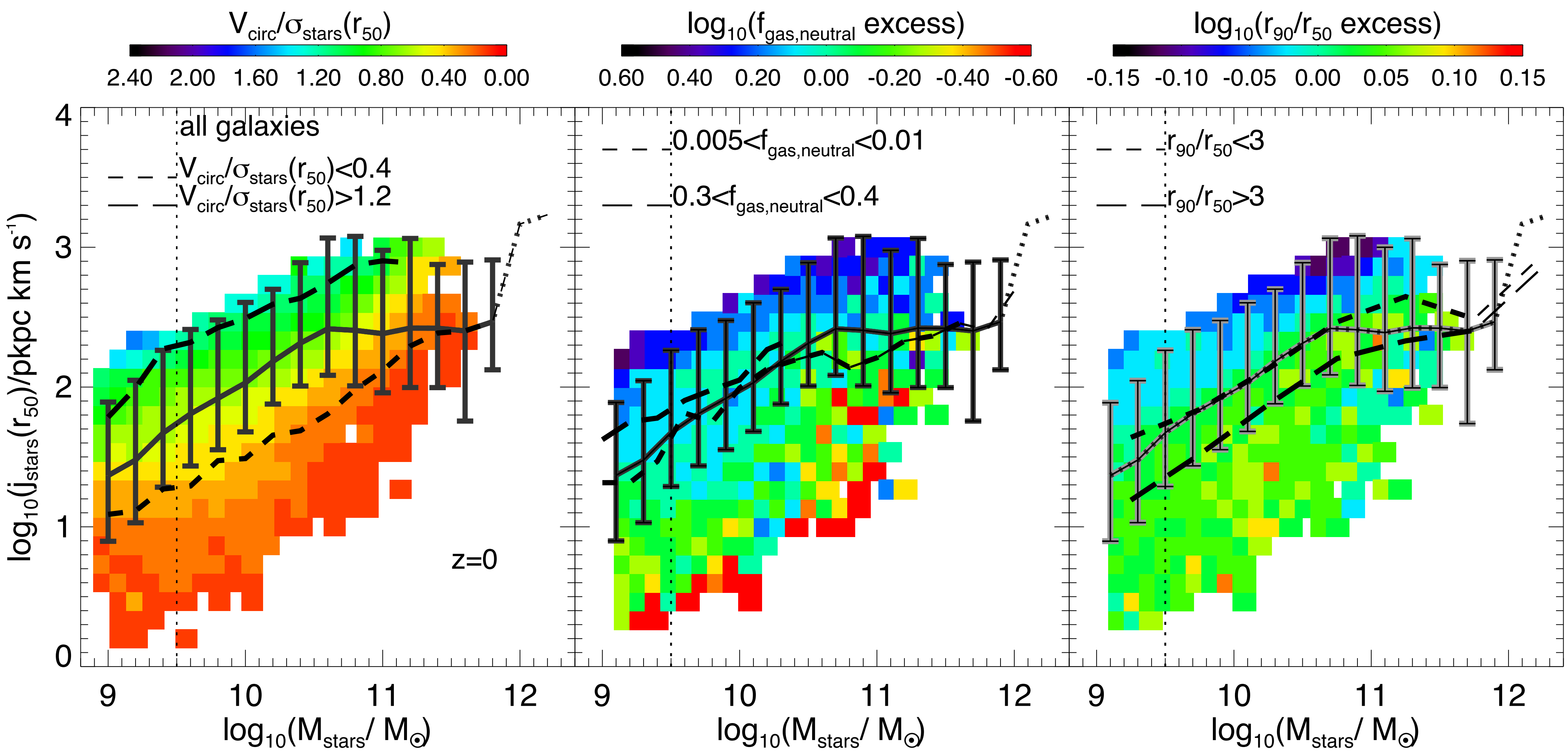
- Using Simba simulations: very tight $j - M$ relations for stars, HI and baryons.
- Scatter linked to HI content.
- Galaxies with higher/lower-than-average HI mass have higher/lower-than-average j_*.



Previous $j_\star$-$M_\star$ studies

Lagos et al. (2017)

- Lagos et al. (2017): $j_* - M_*$ scatter highly correlated with morphological proxies (gas fraction, stellar concentration, etc.)



Previous $j_\star$-$M_\star$ studies

Summary

- Most studies favour α in the range ~0.5 to 0.7, which is similar to the theoretical expectation of 2/3.
- Sample sizes are typically small and scatter in relations is oftentimes high (>0.2 dex).
- Several studies point to proxies of galaxy morphology playing a role in determining j_*.

What next?

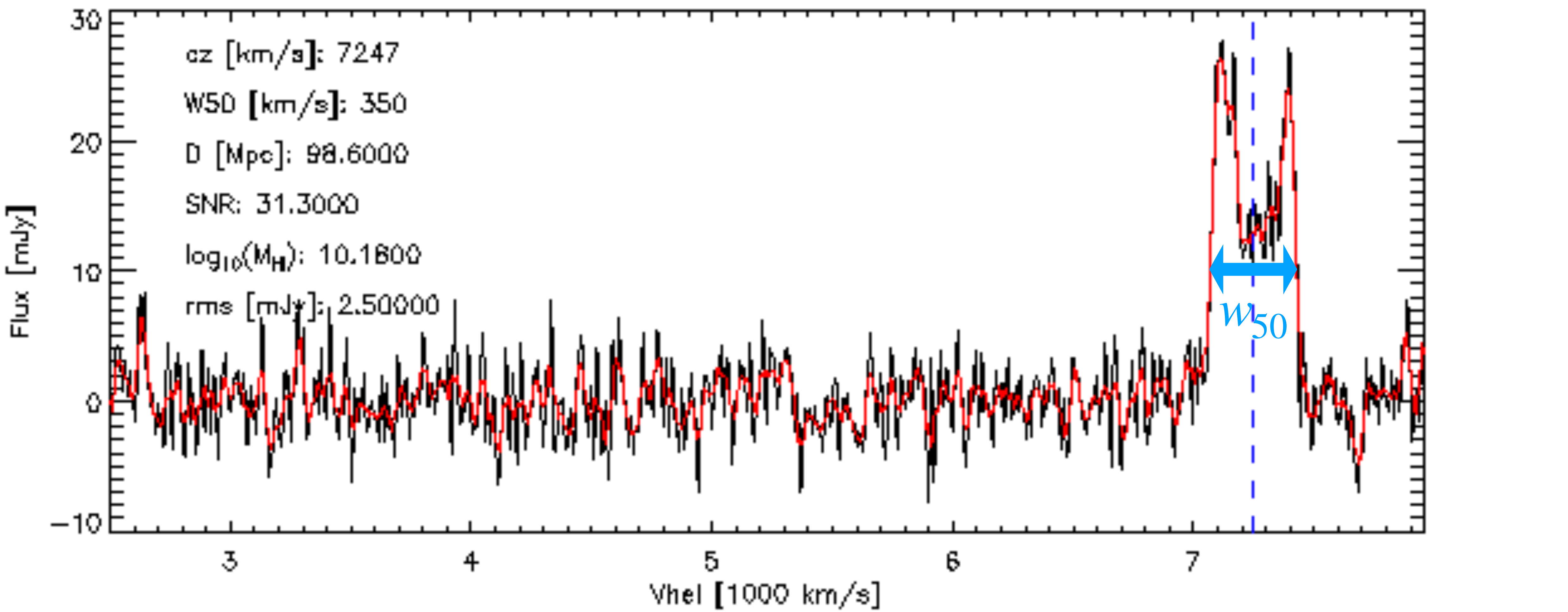
- Let's generate a new set of $j_\star$-$M_\star$ relations that are:
  - Based on large, statistically significant samples.
  - Have very low intrinsic scatter.
  - Consistent with the current best measurements of $j_\star$-$M_\star$, but which improve on them.
- To do this:
  - Used data from the Arecibo Legacy Fast ALFA (ALFALFA) Survey.

Measuring angular momentum

Approximation method

- v_c can be measured from the global HI profile:
  $w_{50} = 2\ v_c \times \sin i \rightarrow v_c = w_{50}/2 \sin i.$

- $j_* \approx 2\ v_c\ R_{\rm eff}/1.68 = \dfrac{w_{50}\ R_{\rm eff}}{1.68 \sin i}$



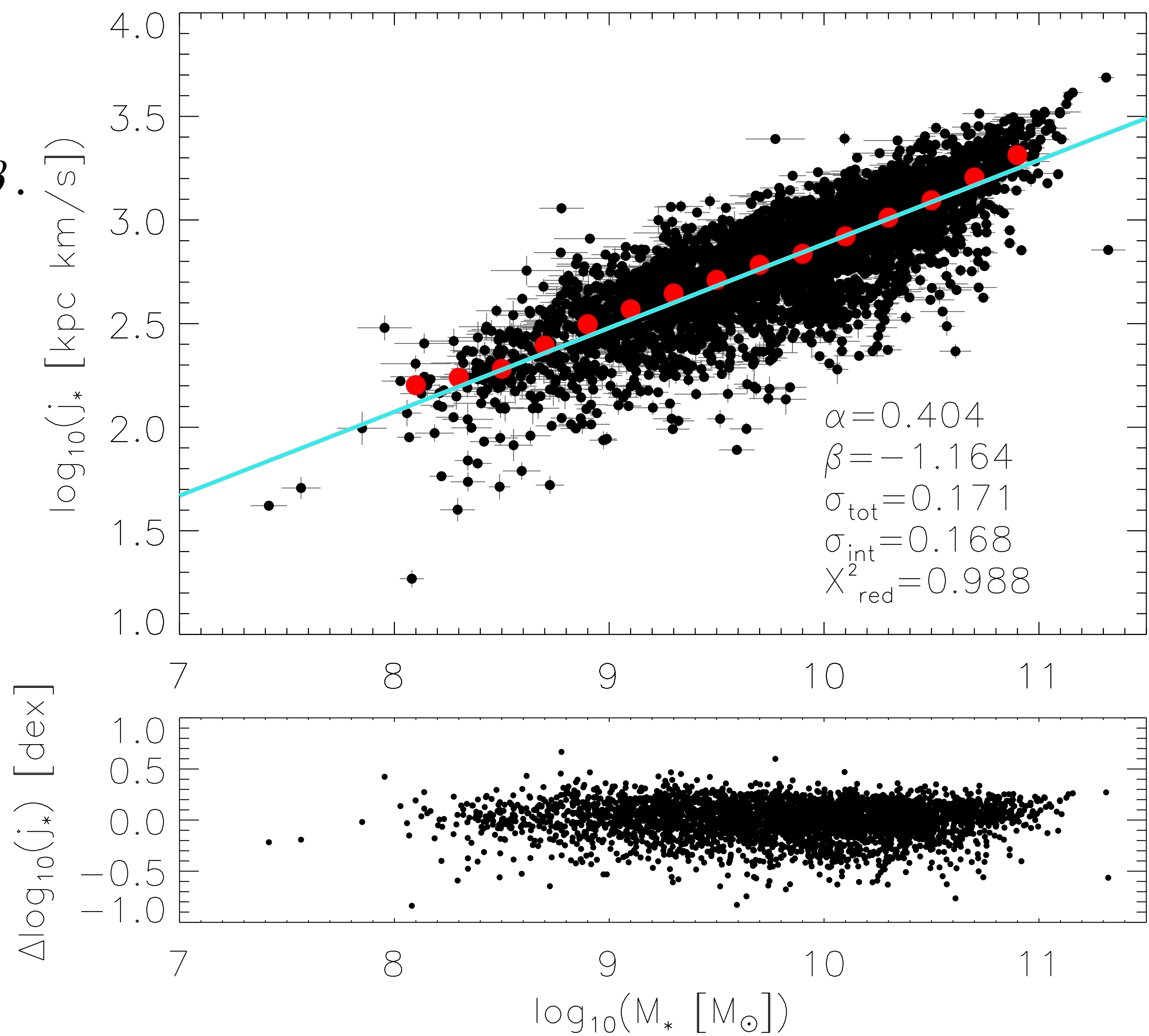
Results

Full sample (N=3607)

- Fit a power-law model

$$\log_{10}\left(\frac{j_*}{\mathrm{kpc\ km/s}}\right) = \alpha \log_{10}\left(\frac{M_*}{M_\odot}\right) + \beta\,.$$

- MPFITEXY IDL routine.
- $\alpha = 0.404 \pm 0.003$
- $\beta = -1.164 \pm 0.03$
- $\sigma_{\mathrm{int}} = 0.168\ \mathrm{dex}$
- N=3 607



Results

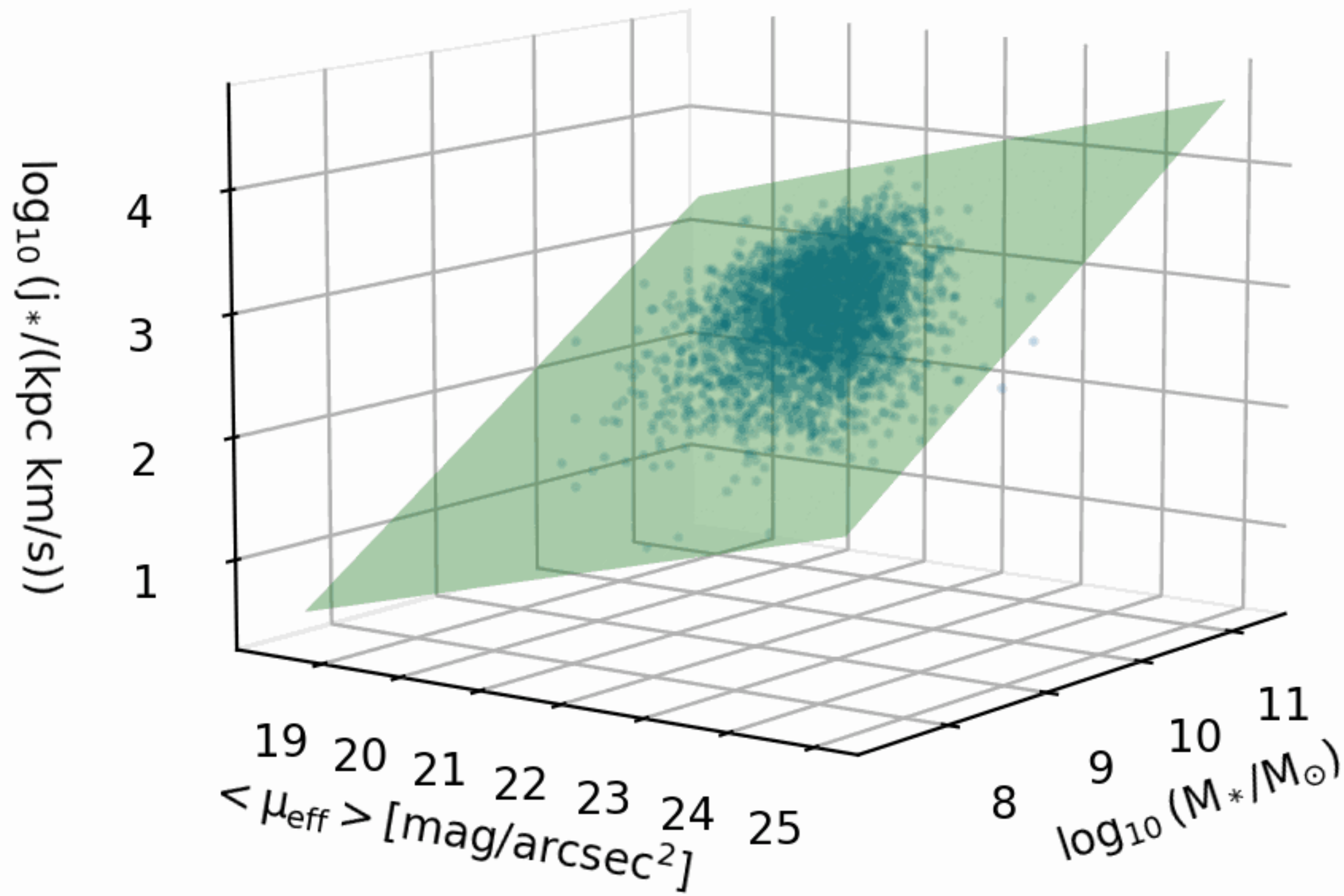
$< \mu_{\rm eff} >$ sub-samples

- Is there another galaxy parameter/property that strongly correlates with j_*?
- $j_* - M_*$ relation is known to be heavily dependent on galaxy morphology.
- The bulge-to-total mass ratio is strongly correlated.
- Idea: What about *I*-band effective surface brightness as a proxy for mass concentration?

Results

$< \mu_{\rm eff} >$ sub-samples

- First, fit a plane
  $$\log_{10}\left(\frac{j_*}{\rm kpc\ \ km/s}\right) = \alpha \log_{10}\left(\frac{M_*}{M_\odot}\right) + \beta\left(\frac{< \mu_{\rm eff} >}{\rm mag\ \ arcsec^2}\right) + \gamma$$
  to galaxies in $\log_{10} j_* - \log_{10} M_* - < \mu_{eff} >$ space.
- $\alpha = 0.589 \pm 0.002, \beta = 0.193 \pm 0.002$
- Standard deviation of residuals about this plane: 0.089 dex!!



log10 (j*/(kpc km/s))
1
2
3
4
19
20
21
22
23
24
25
< μeff > [mag/arcsec²]
8
9
10
11
log10 (M*/M⊙)

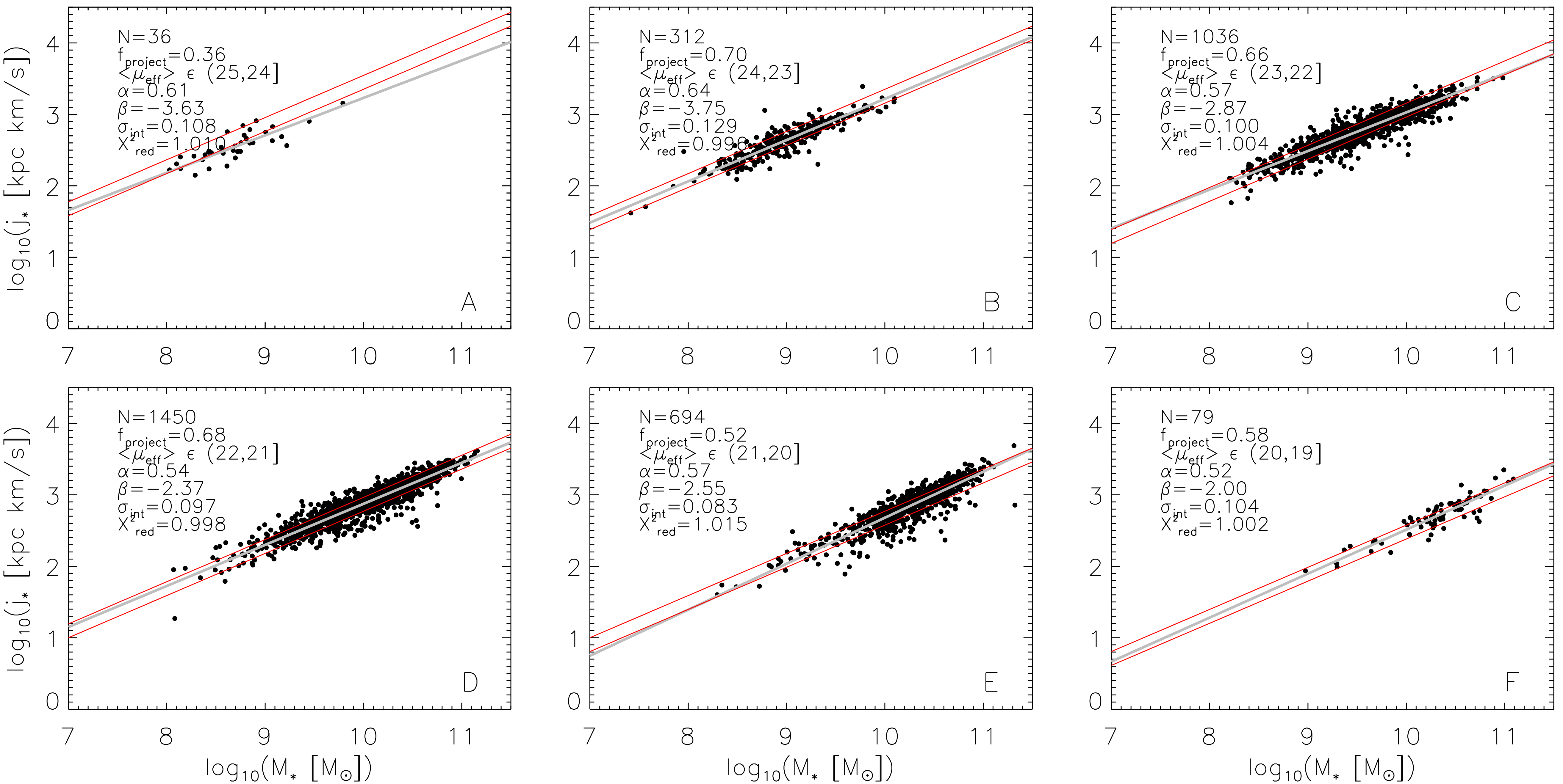
Results

$< \mu_{\rm eff} >$ sub-samples

- Now split ALFALFA galaxies into sub-samples delimited by $\langle \mu_{\rm eff} \rangle = \{25,\ 24,\ 23,\ 22,\ 21,\ 20,\ 19\}$ mag/arcsec^2 and check 2D $j_* - M_*$ relations.

Results

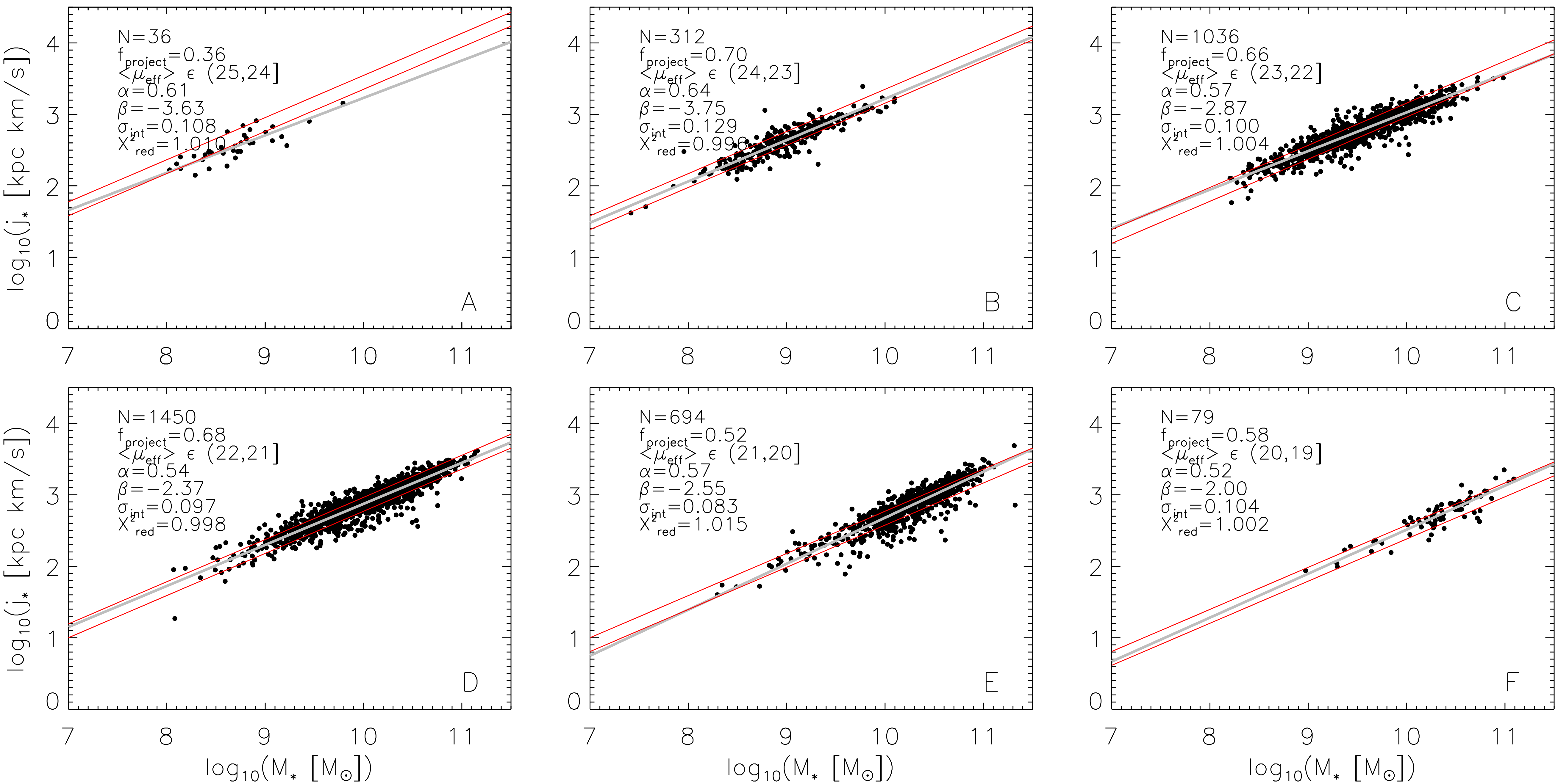
$< \mu_{\rm eff} >$ sub-samples



- Most of these relations are consistent with the $\alpha = 0.55 \pm 0.02$ result from Posti et al. (2018b).

Results

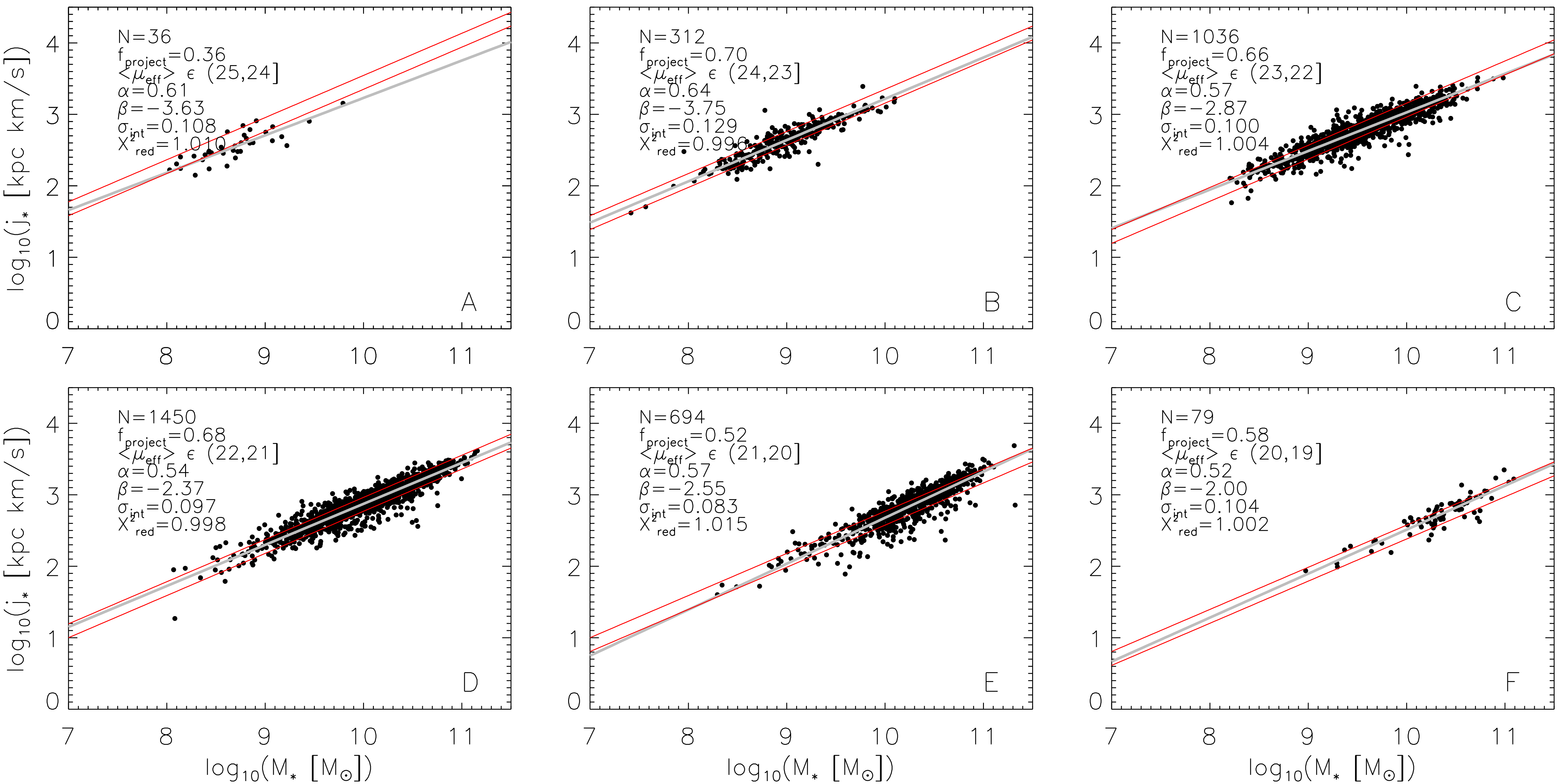
$<\mu_{\rm eff}>$ sub-samples



- 2D $j_* - M_*$ relations are the tightest ever measured. Intrinsic scatter $\lesssim 0.1$ dex for a large $<\mu_{\rm eff}>$ range.

Results

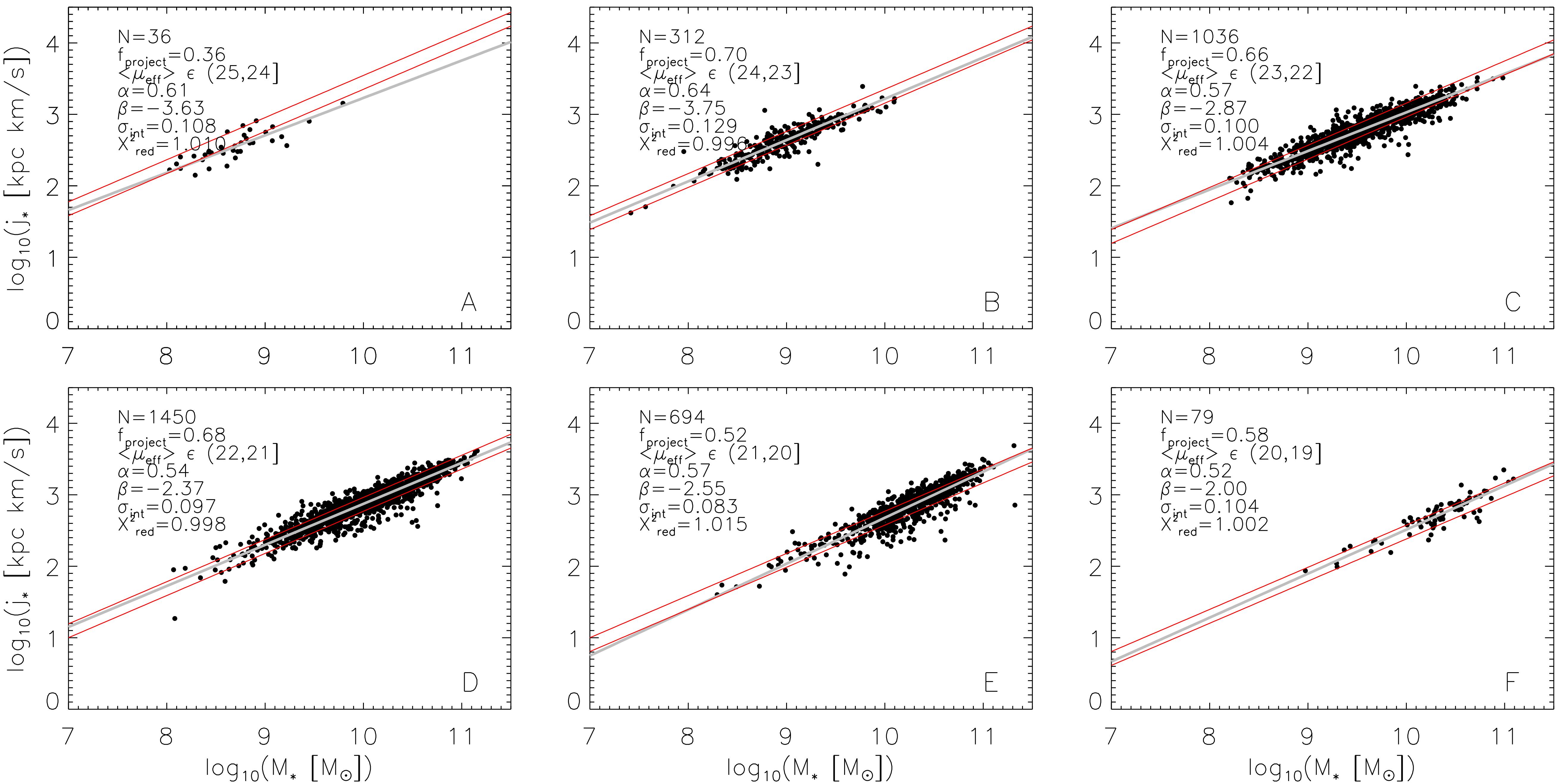
$<\mu_{\rm eff}>$ sub-samples



- 2D $j_* - M_*$ relations are based on the largest samples ever used (up to factor ~3 larger).

Results

$< \mu_{\rm eff} >$ sub-samples



- Results published as Elson (2023) - arXiv:2310.17916

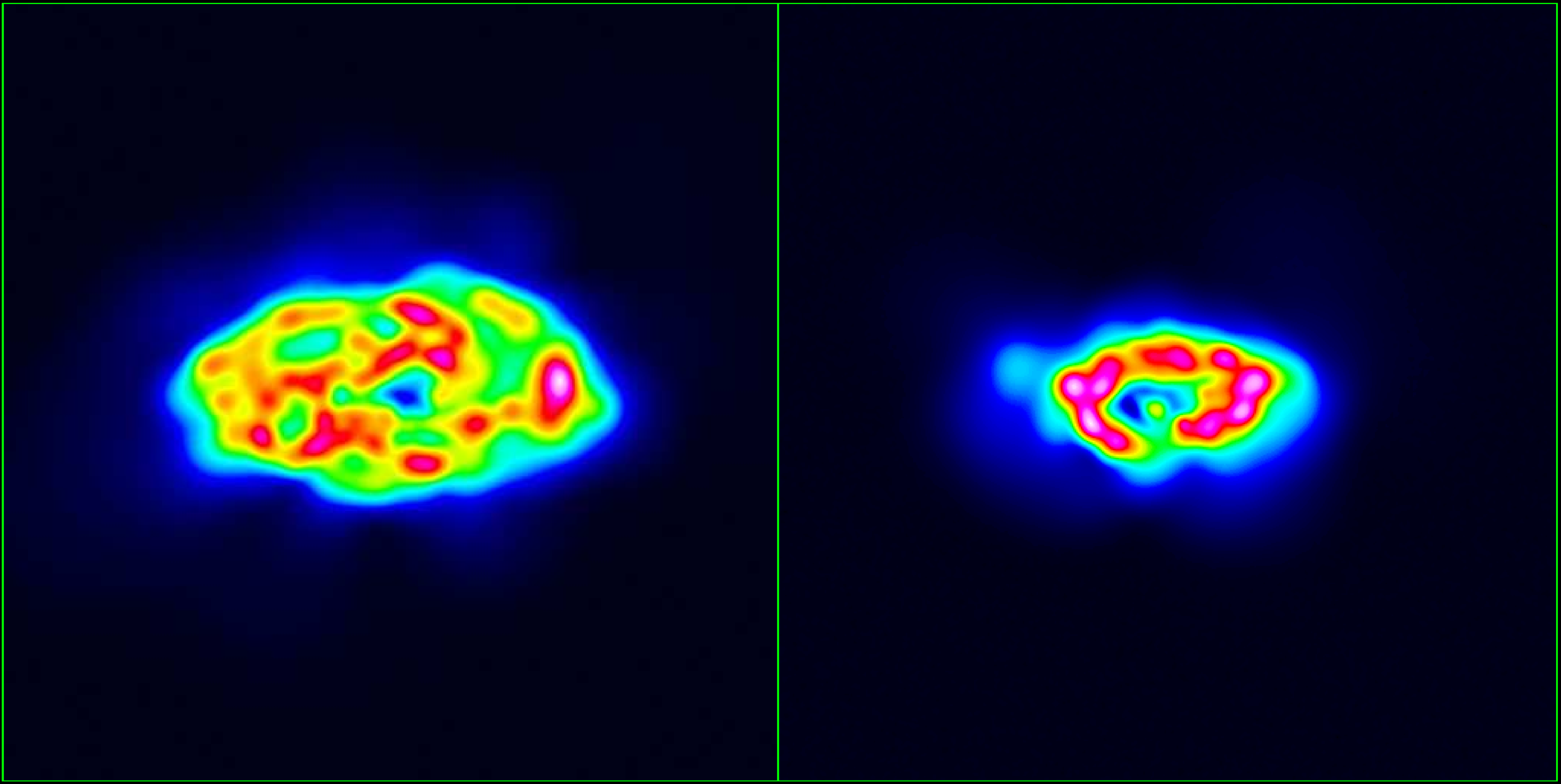
Part 2 (very quickly):

- Can the Simba sims be used to produce a more accurate measurement of the $\log_{10} j_* - \log_{10} M_* - \langle \mu_{\mathrm{eff}} \rangle$ relation?
- Answer: yes!
- Question: What useful things can be done with it?
- Answer: Easily estimate the stellar masses of real galaxies to within 0.1 to 0.2 dex!

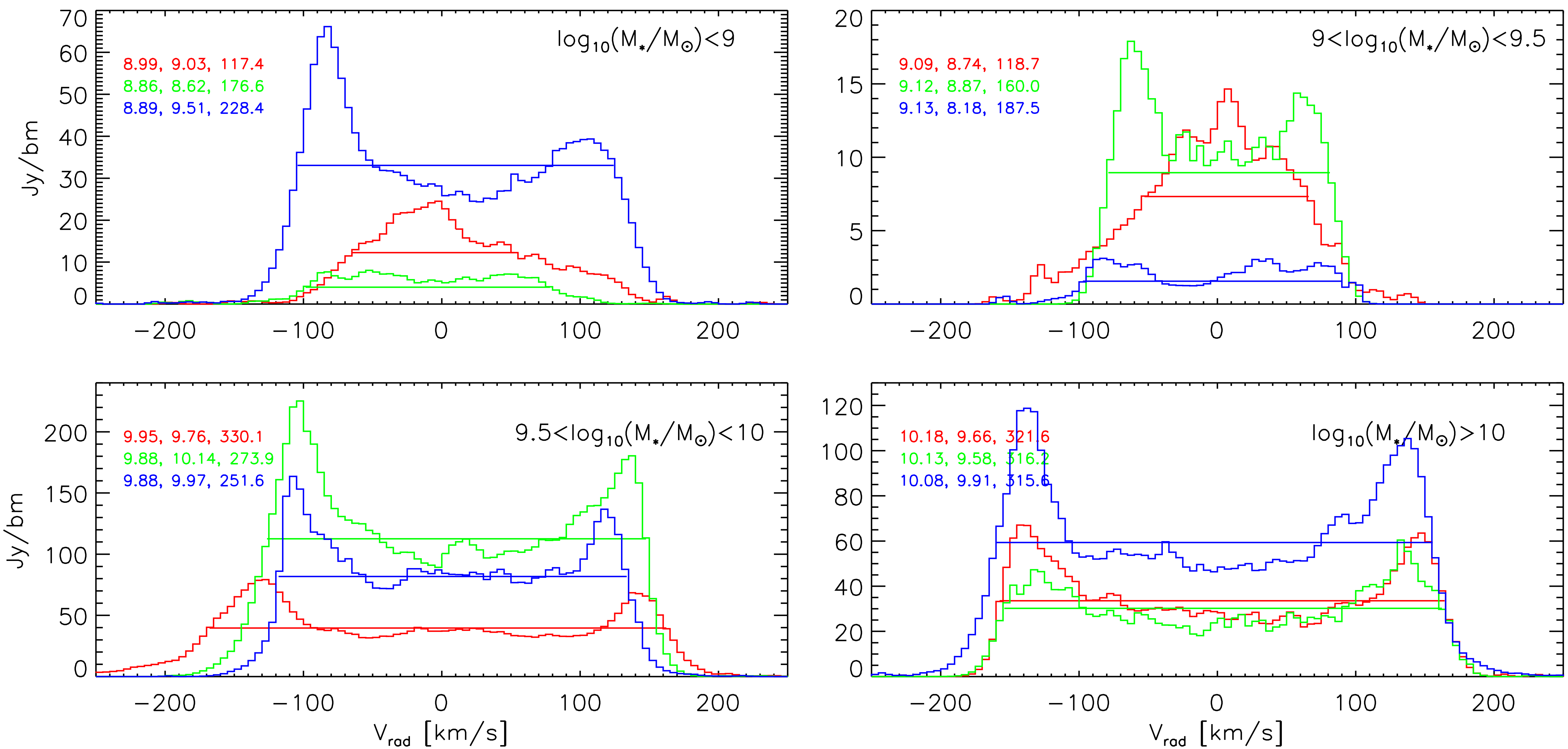
The Simba $j_* - M_* - \langle \mu_{\rm eff} \rangle$ relation

- Use the Simba m25n512_s50 z=0 snapshot.
- Select a suitable set of galaxies for which to measure $j_\star$
- Final sample: N=179

HI total intensity maps of 2 mock-observed Simba galaxies



HI spectra of mock-observed Simba galaxies



The Simba $j_* - M_* - \left\langle \mu_{\rm eff} \right\rangle$ relation

Results

- After also measuring $\left\langle \mu_{\rm eff} \right\rangle$ for each Simba galaxy, a 2D plane was fit to the galaxies in $\log_{10} j_* - \log_{10} M_* - < \mu_{eff} >$ space:

$$\log_{10}\left(\frac{j_*}{\rm kpc\ km/s}\right) = \alpha \log_{10}\left(\frac{M_*}{M_\odot}\right) + \beta\left(\frac{< \mu_{\rm eff} >}{\rm mag\ arcsec^2}\right) + \gamma$$

The Simba $j_* - M_* - \langle \mu_{\text{eff}} \rangle$ relation

Results

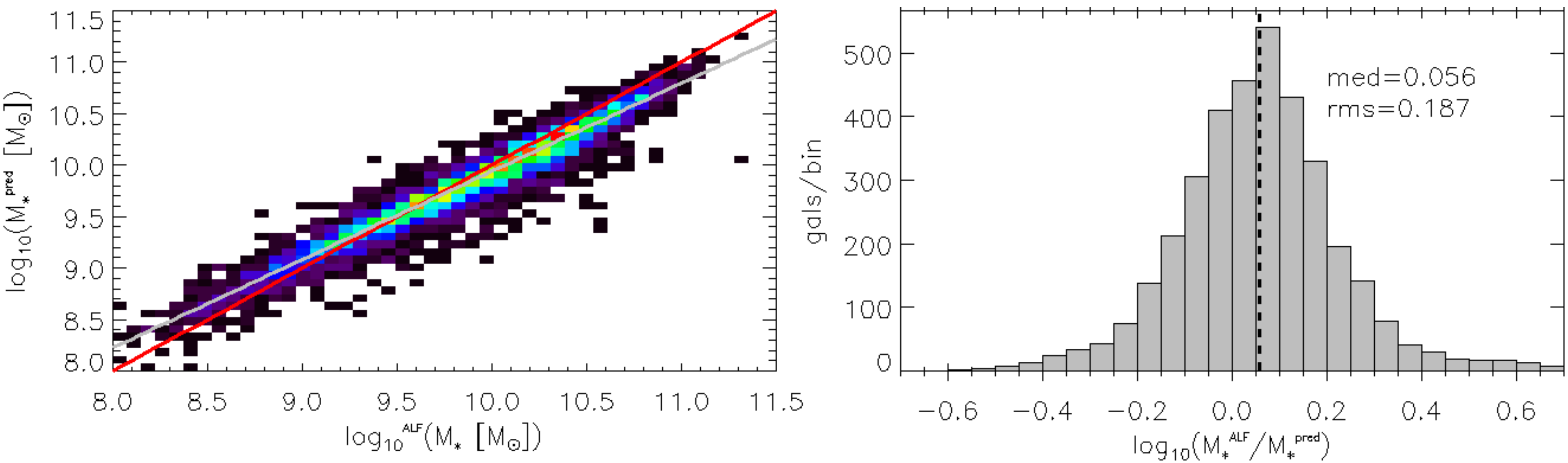
- Simba's planar relation fits much tighter.
- Has α very close to theortical expectation (2/3).
- The planar relation between $\log_{10} j_* - \log_{10} M_* - \langle \mu_{\text{eff}} \rangle$ is truly fundamental.

	α	**β**	**γ**	**σ**
Simba	0.694 (0.046)	0.190 (0.026)	-8.111 (1.009)	0.057 dex
ALFALFA	0.586 (0.002)	0.193 (0.002)	-7.198 (0.054)	0.089 dex

The Simba $j_* - M_* - \langle \mu_{\rm eff} \rangle$ relation

Predicting real stellar masses

- Use Simba $\log_{10} j_* - \log_{10} M_* - \langle \mu_{\rm eff} \rangle$ relation to predict M_* given j_* and $\langle \mu_{\rm eff} \rangle$ measurements.
- Results published as Elson (2024) - arXiv:2409.08076



Thank you.