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# *Translators of galaxy morphology indicators between observation and simulation*

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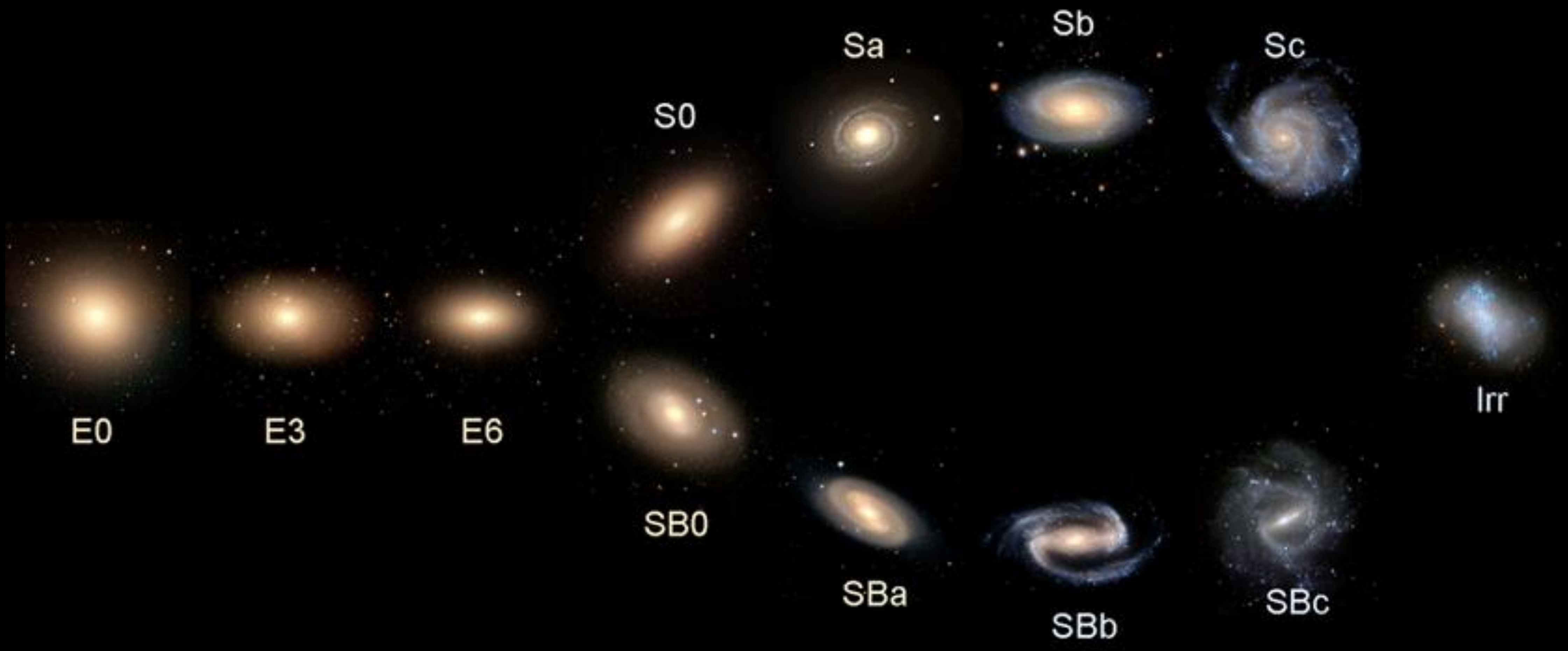
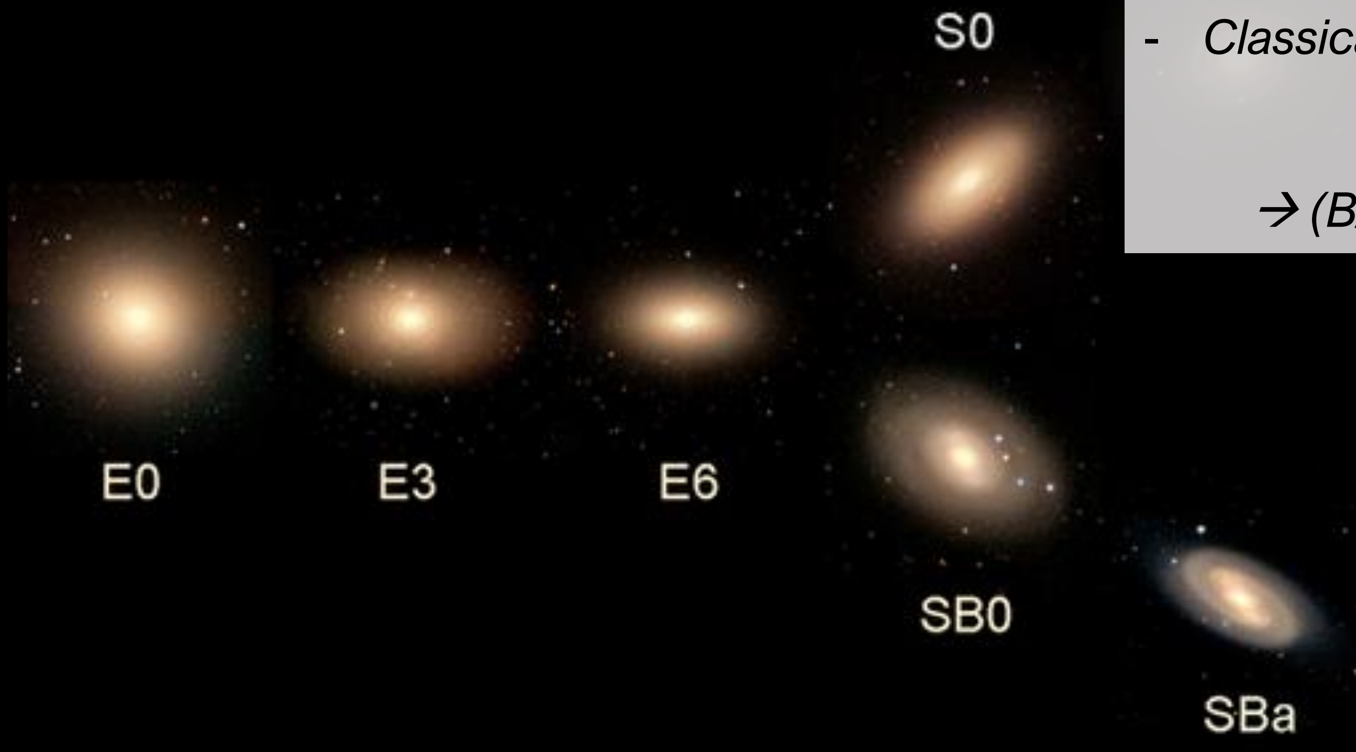
# Introduction




*Yin et al. (2014)*

# *Introduction*

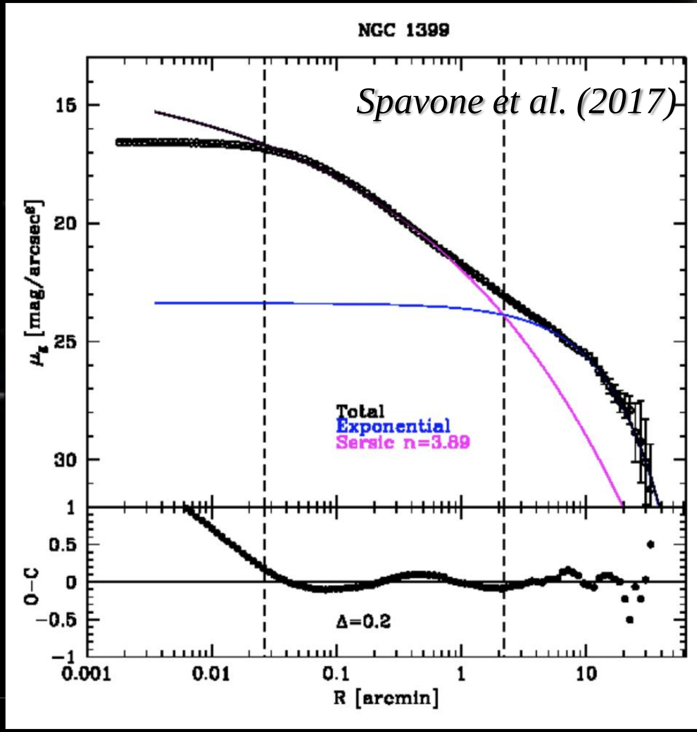



*Photometric Decomposition*

*Using profile fitting:*

- *Exponential disk*
- *Classical/pseudo-bulge*

*→ (B/T) or (D/T)*

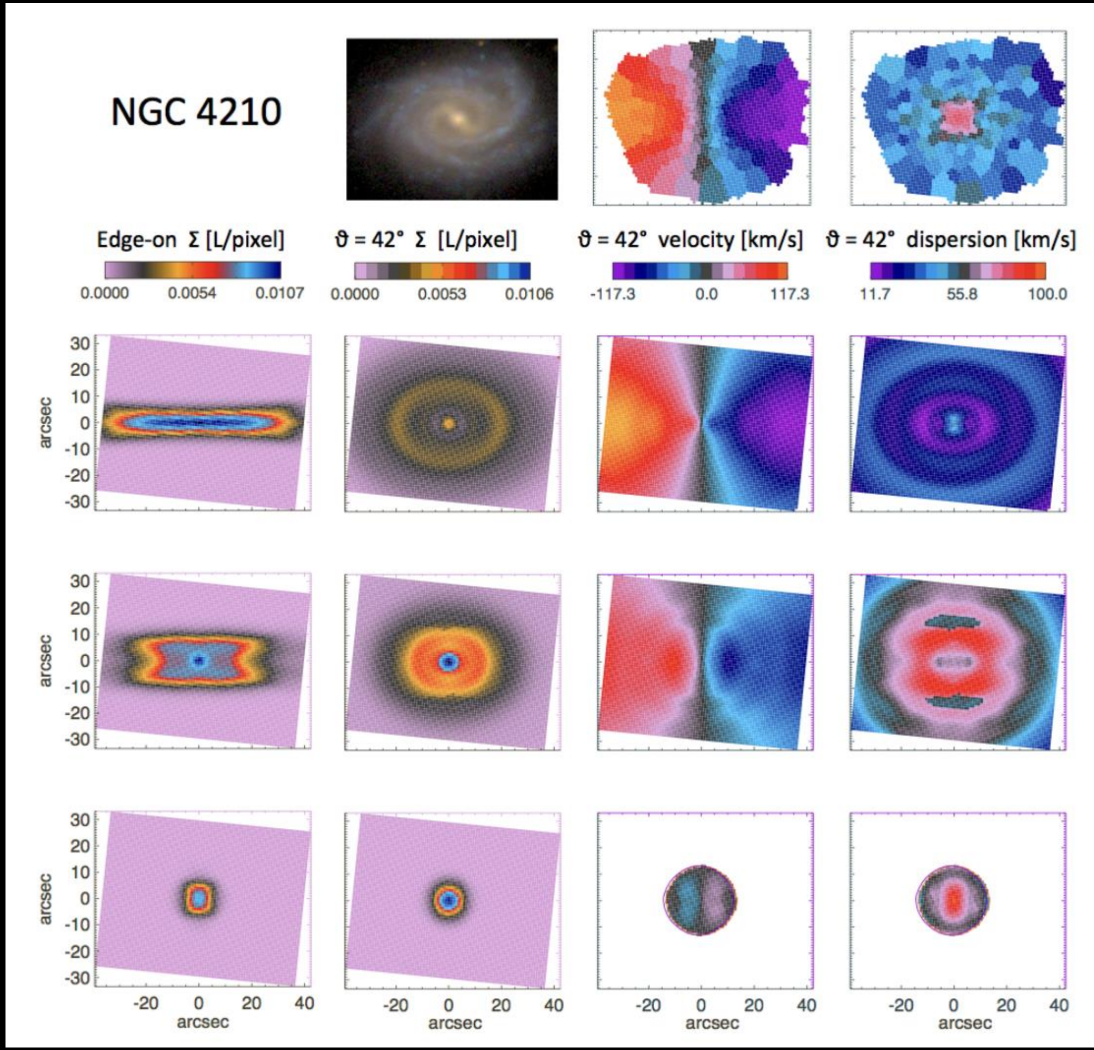



Yin et al. (2014)

# Introduction

**Spectroscopic Decomposition**

*w/ dynamical modeling*




Zhu et al. (2018)

**Photometric Decomposition**

*Using profile fitting:*

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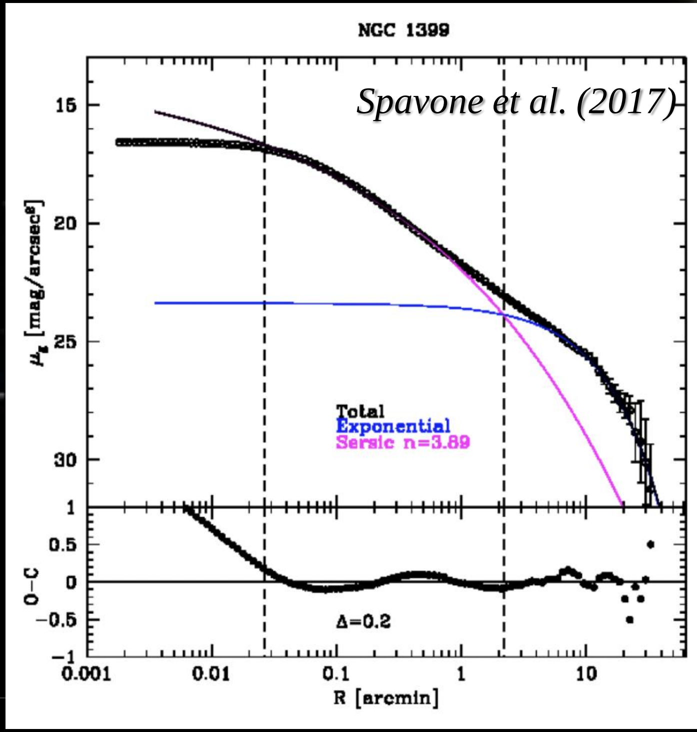
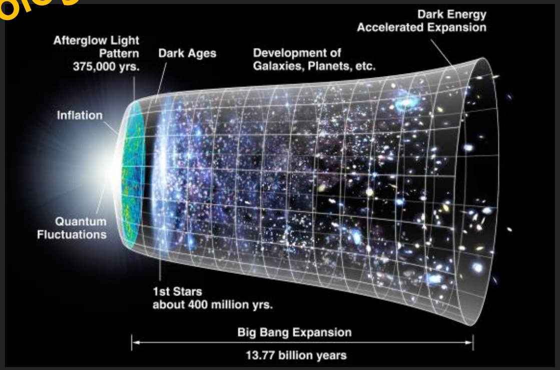



Yin et al. (2014)

*What about in numerical simulation?*

cosmology




AGN Feedback

https://www.nature.com/collections/dttrsdkjww

Input

Input

Input

Input

Input

Input

Stellar Feedback

Galaxy!



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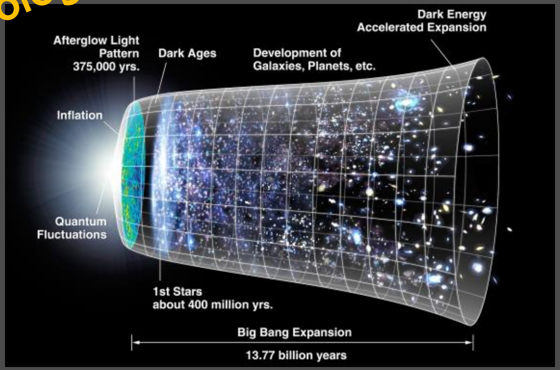
cosmology




AGN Feedback

Input

Input

Input

Input

Input

Input

Stellar Feedback

Galaxy!

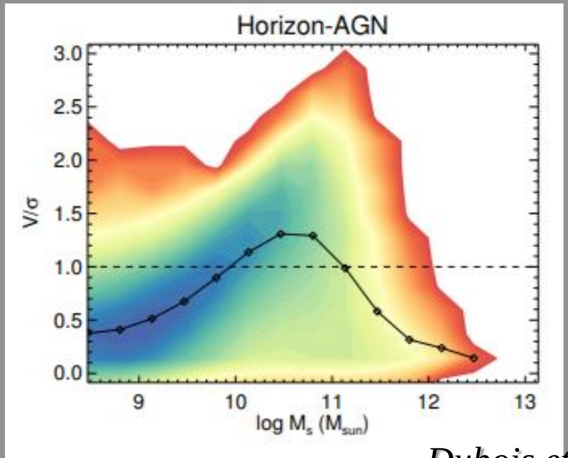
*How can we define the morphology of the simulated galaxy?*

# Introduction

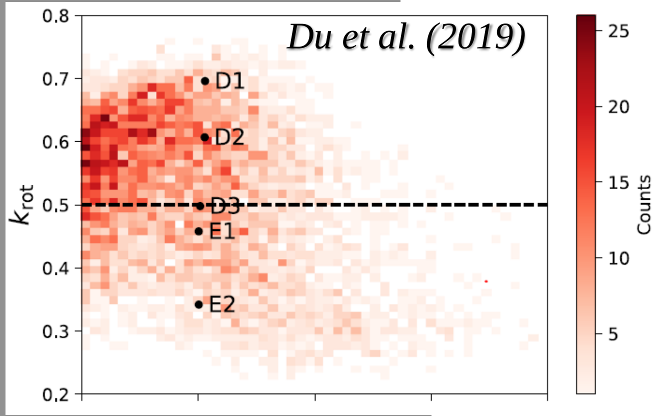
- We have (almost) every kinematic information of the particles!
  - $V/\sigma$
  - Kappa parameter ($\kappa_{rot}$)

$$\kappa_{\rm rot} = \frac{K_{\rm rot}}{K} = \frac{1}{K}\sum_i \frac{1}{2} m_i \left(\frac{j_{z,i}}{R_i}\right)^2$$

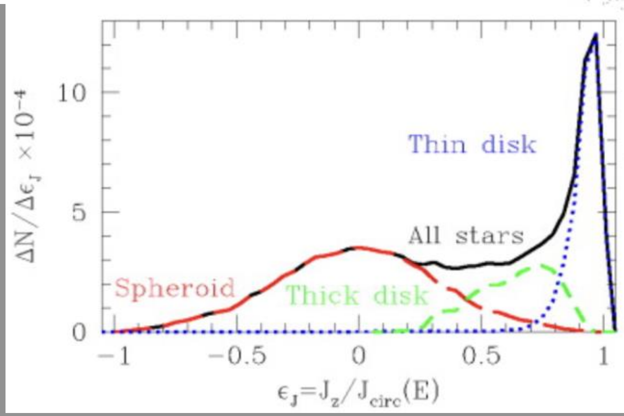
  - Circularity parameter ($\epsilon = j_z/j_{cir}$)




Dubois et al. (2016)




Abadi et al. (2003)



# Introduction

- We have (almost) every kinematic information:
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  - Circularity parameter ($\epsilon = j_z/j_{cir}$)

*How well*
*the visual or morphology classification t*
*races the kinematics of the galaxies?*

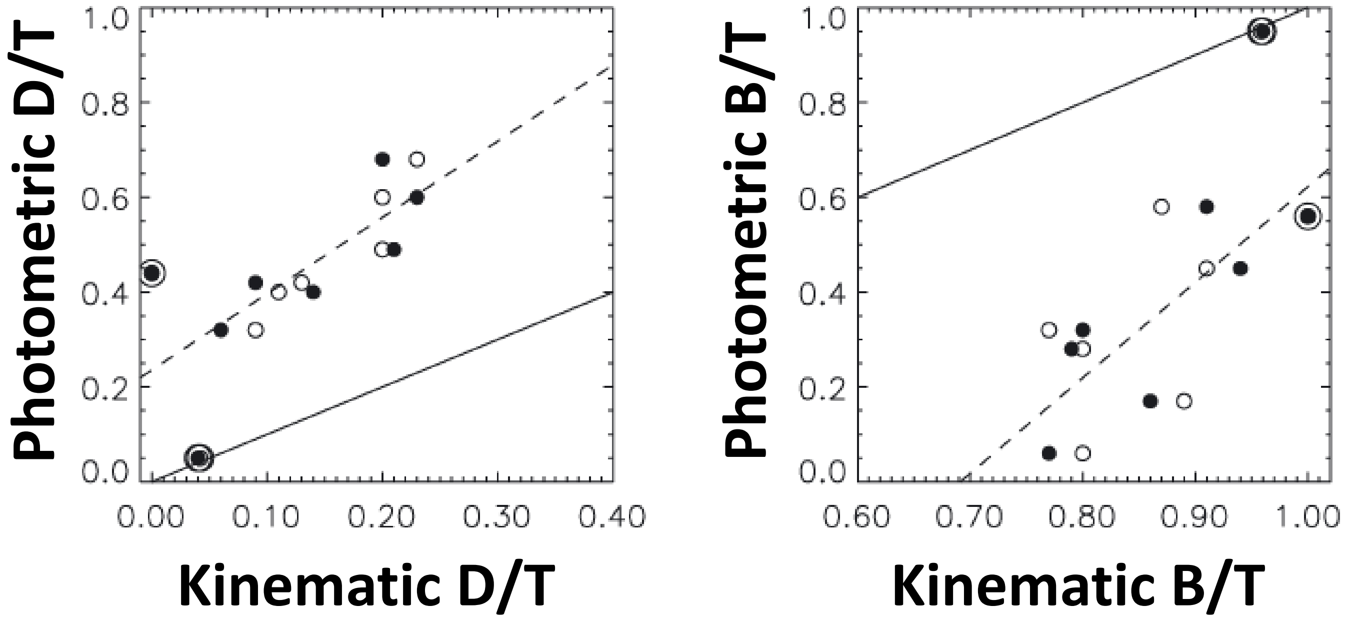
# *Introduction*

- In simulation, all the kinematic properties are available:
- In observation, especially for photometry,

***Indeed,***

**The comparison between kinematically & photometrically defined morphology:**

*Scannapieco et al. (2010)*



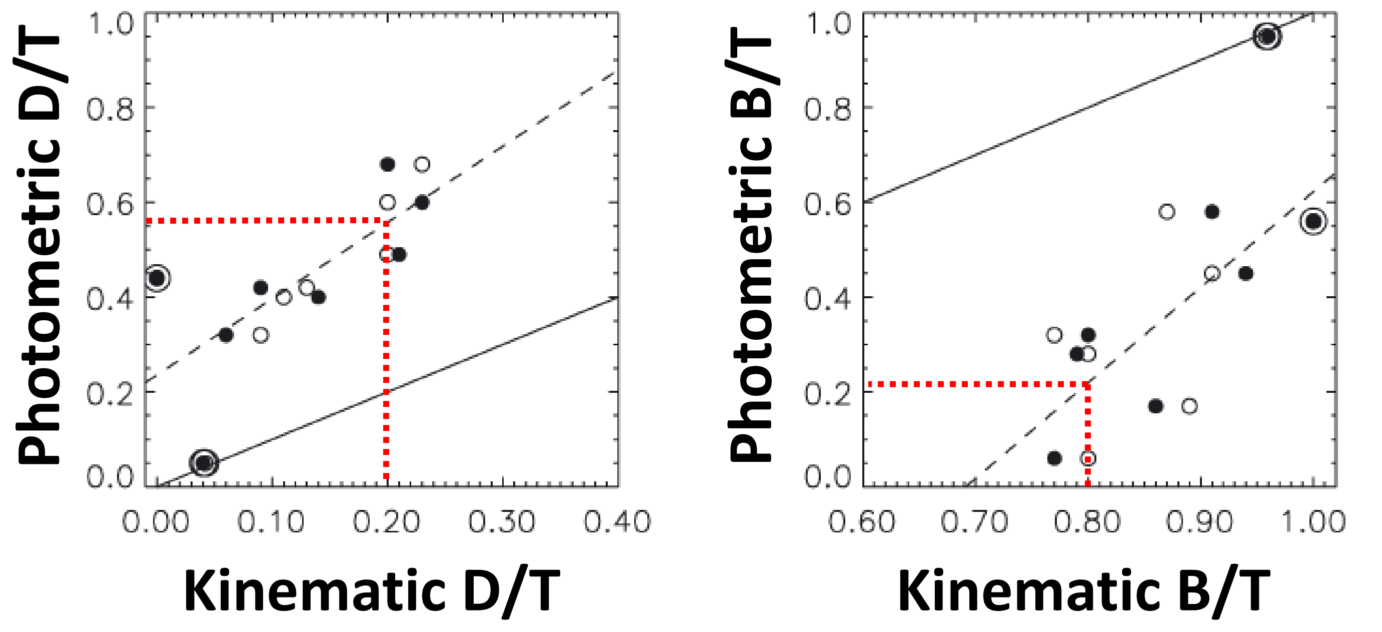
# Introduction

- In simulation, all the kinematic properties are available:
- In observation, especially for photometry,
  - Visual classification
- Kappa parameter (
- Circularity parame
- profile is widely used)
- ty can be derived (i.e., B/T or D/T)

***Indeed,***

**A huge discrepancy between the photometric D/T and the kinematic D/T:**

*Scannapieco et al. (2010)*



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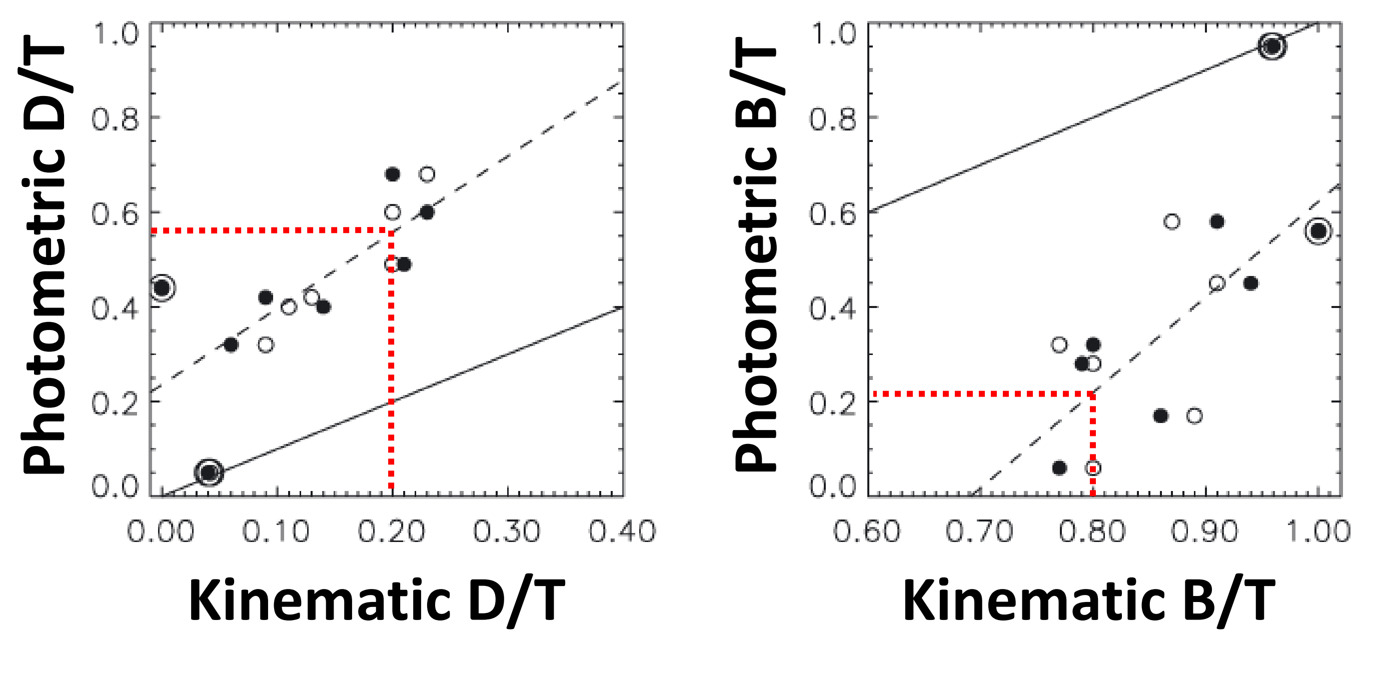


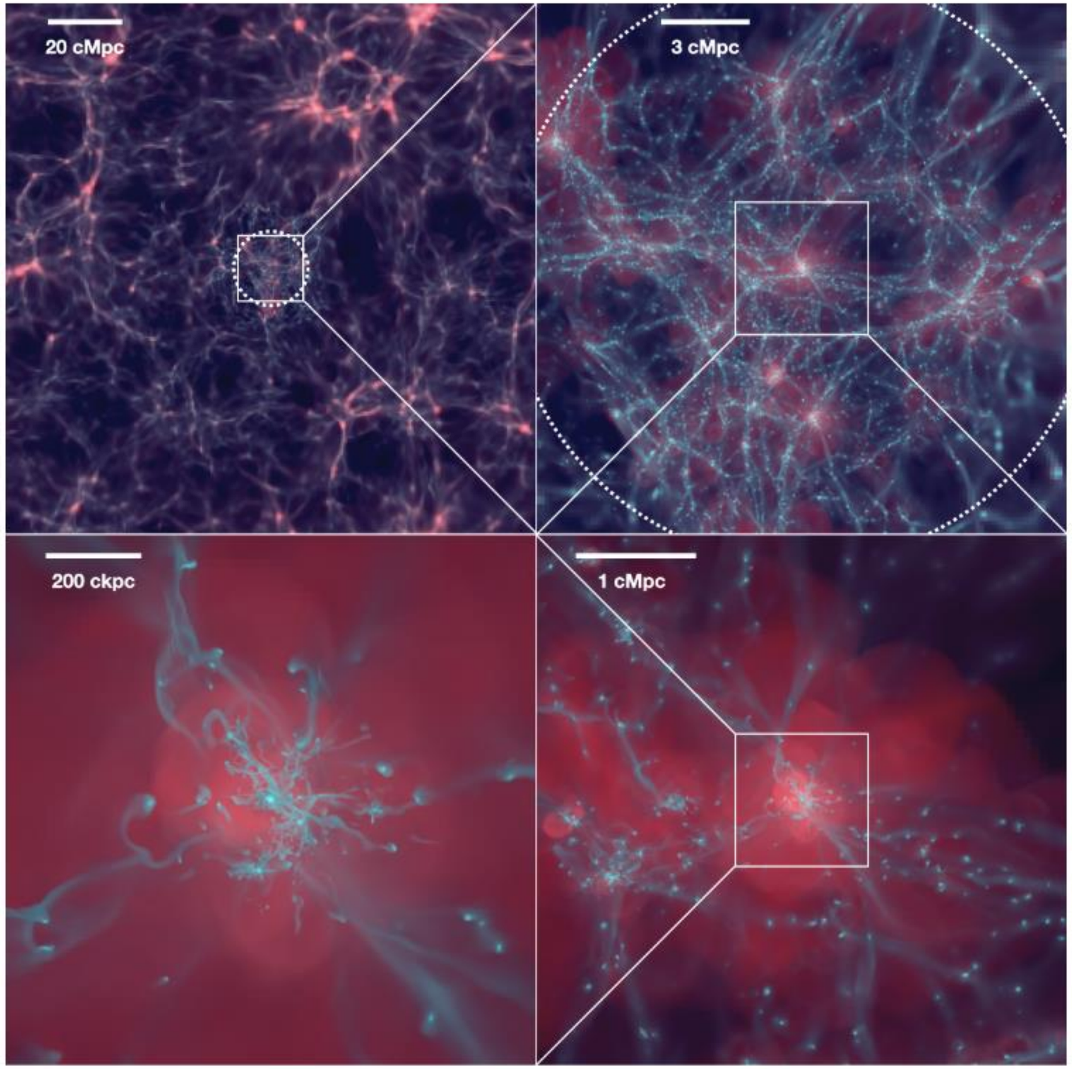

**for eight galaxies**
**w/ spatial res. ~ 1kpc**

**small sample size ☹**

# NewHorizon simulation

IAP-Oxford-Yonsei collaboration

- High resolution cosmological zoom-in simulation
- 10 Mpc radius sphere
  (214 galaxies > 1e9 $M_\odot$ at z ~ 0.17)
- Resolution :
  - $dx_{min}$ ~ 34 pc, $dm_{star}$ ~ 1e4 $M_\odot$, $dm_d$ ~ 1e6 $M_\odot$
- Including:
  - Radiative cooling & heating
  - Feedback from massive stars (Type II SN)
  - MBH formation
  - AGN Feedback (radio/quasar mode)

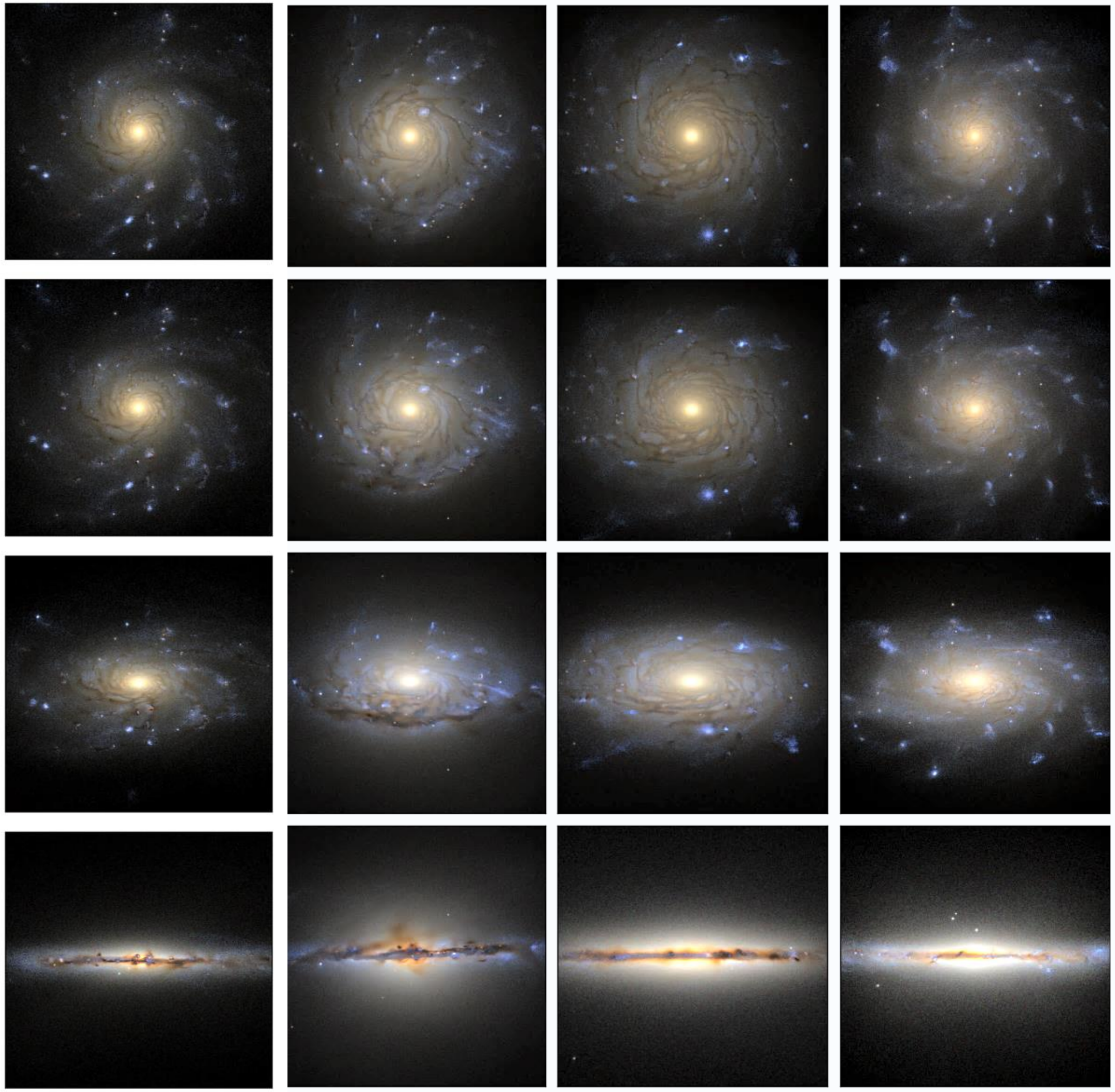



*Dubois et al. (2021) Fig.1*

# IllustrisTNG (
# $\Delta x \sim 300$ pc)

# IllustrisTNG ( $\Delta x \sim 300$ pc)


# NewHorizon ($\Delta x \sim 30$ pc)



# Methodology

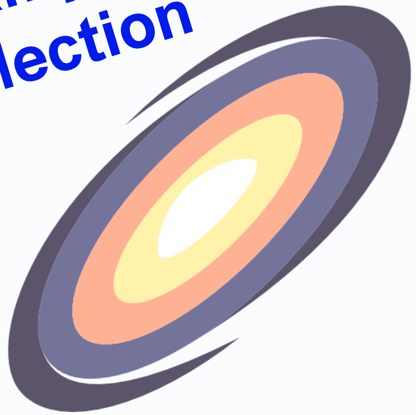
**Sample Selection** → 

- Photometric Decomposition
- Kinematic Decomposition
- Spectroscopic Parameter

→ **Result**

simple & straightforward

Sample Selection



Galaxy Sample

- $10^{9.5}\,[\mathrm{M}_\odot] < M_*$
- At 3 different redshift (0.70, 0.30, 0.17)
- Exclude irregular/interacting galaxies

# Methodology

Photometric Decomposition

Kinematic Decomposition

Spectroscopic Parameter

simple & straightforward

Result

## Galaxy Sample

- $10^{9.5}\ \mathrm{M}_\odot < M_*$
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  (0.70, 0.30, 0.17)
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## Photometric Decomposition

Mock imaging

Multi-component Sersic profile

Homepage

- We assumed that the gas cells with the temperature **T < 10,000 K** contain the dust mixture
- We assumed Zubko et al. (2004) dust model for calculation
- We used fixed **dust-to-metal** ratio as **0.3**
- We used adaptive scheme for the number of the photon packet

**BEFORE**

$$M_{\mathrm{dust}} = M_{\mathrm{cell}} \times Z \times f_{\mathrm{dust}}$$

$$8 \times 10^7 \times (M_{\mathrm{gal}} / 10^{10}\,\mathrm{M}_\odot)$$

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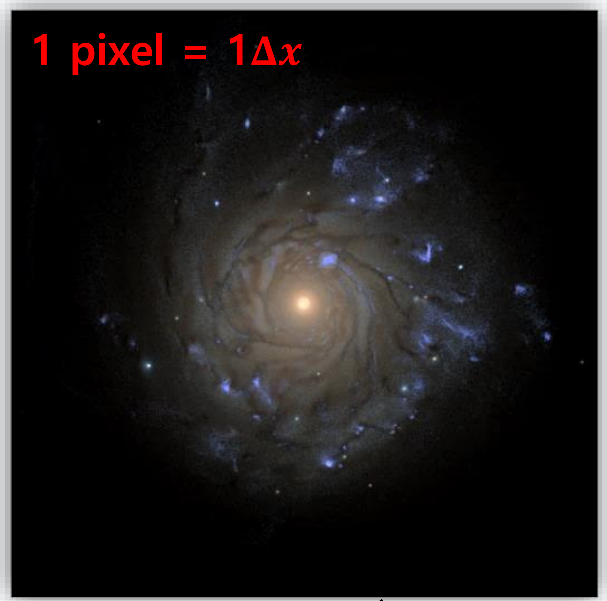
Mock imaging

Multi-component Sersic profile

Kinematic Decomposition

- The high res. Observation
- w/ negligible sky noise
- Face-on condition

Spectroscopic Parameter




**Galaxy Sample**

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**Photometric Decomposition**

Mock imaging

Multi-component Sersic profile

**Kinematic Decomposition**

**Spectroscopic Parameter**

using SDSS r-band luminosity

1-dimensional radial Σ profile

$1-4\ comp$ $Sérsic\ fitting$ using MCMC

$n_{disk} = 1$ (fixed)
$n_{extra} \in (0.5, 10]$
$1\,\Delta x < R < R_{90}$

Choose the optimal fitting by using Bayesian Information Criteria (BIC) value

$$BIC = -2\,Log\,\mathcal{L} + k\,Log\,N_{dat}$$

wellness of fitting    penalize term

$\mathcal{L}$ : likelihood of the fitting
$k$ : total parameter number
$N_{dat}$ : the number of the data point

## Galaxy Sample

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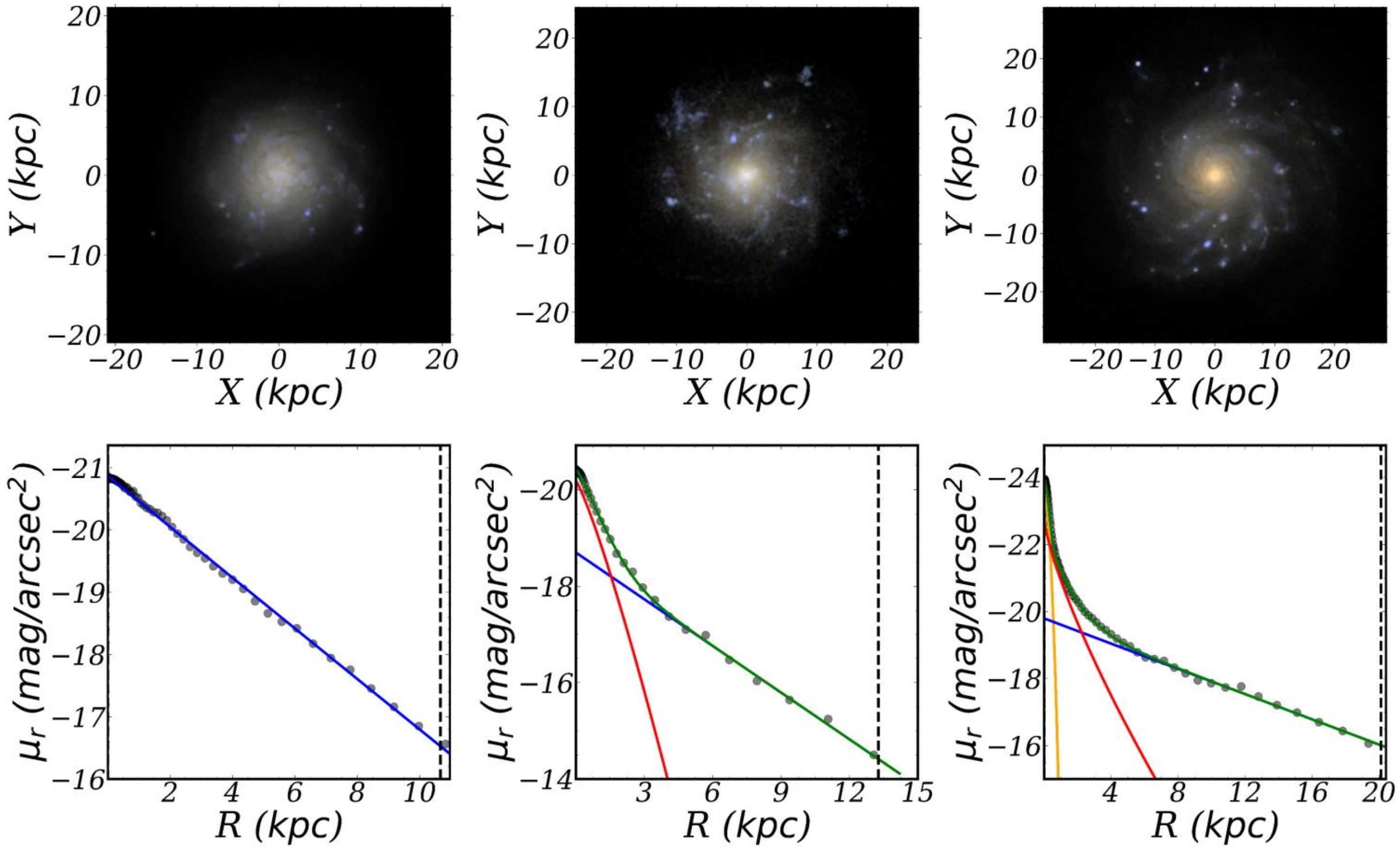


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**Photometric Decomposition**

Mock imaging

Multi-component Sersic profile

**Kinematic Decomposition**

3-dimensional phase-space

ML Clustering
(Gaussian Mixture Model; GMM)

**Spectroscopic Parameter**

1.

2.

3.

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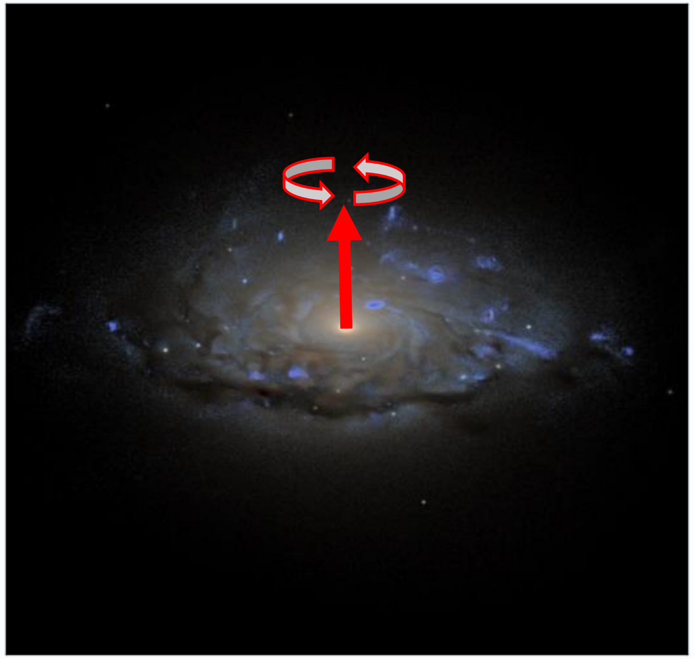

$j_z \,/\, j_{cir}(e)$

rotating component of the angular momentum

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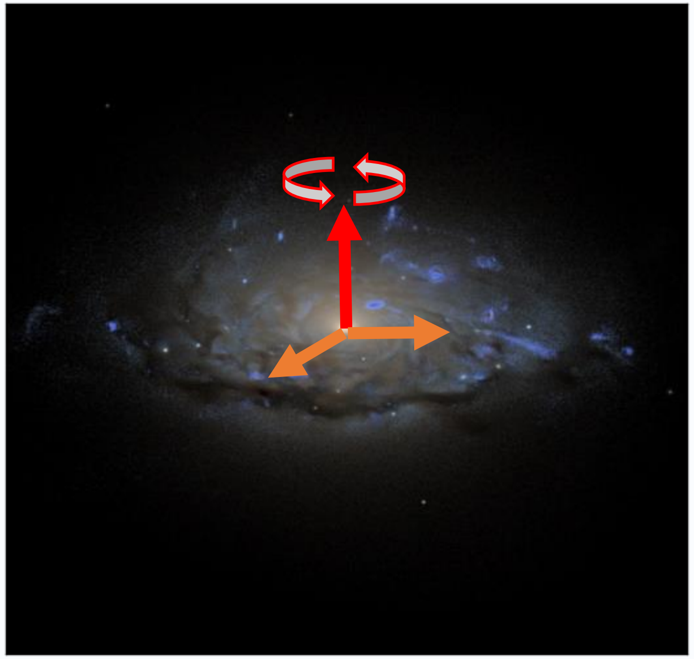

$j_z\,/\,j_{cir}(e)$ rotating component

$j_p\,/\,j_{cir}(e)$ remaining component of the angular momentum

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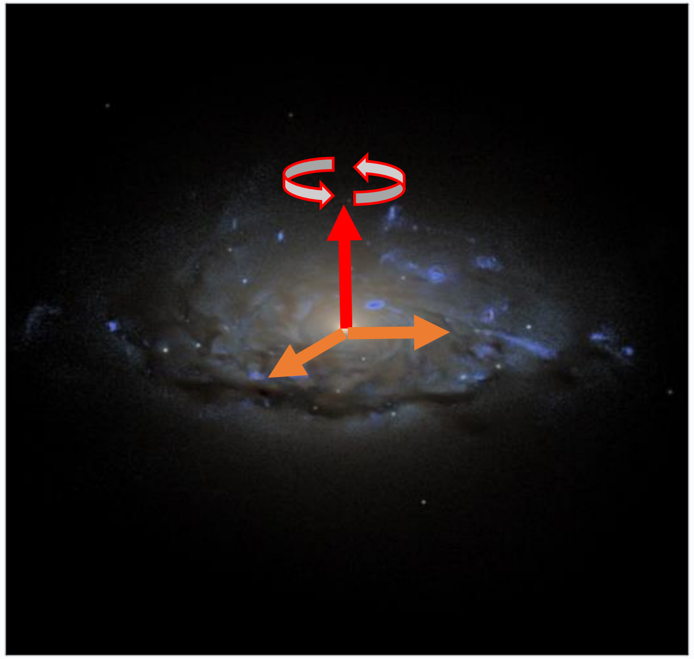

| | |
|---|---|
| $j_z\ /\ j_{cir}(e)$ | rotating component |
| $j_p\ /\ j_{cir}(e)$ | remaining component |
| $e\ /\ \lvert e_{max}\rvert$ | specific binding energy (KE+PE) |

## Galaxy Sample

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### Photometric Decomposition

Mock imaging

Multi-component Sersic profile

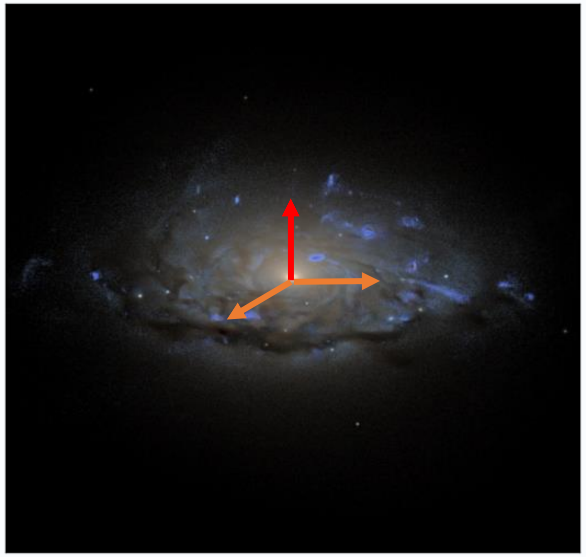
### Kinematic Decomposition

3-dimensional phase-space

ML Clustering

(Gaussian Mixture Model; **GMM**)

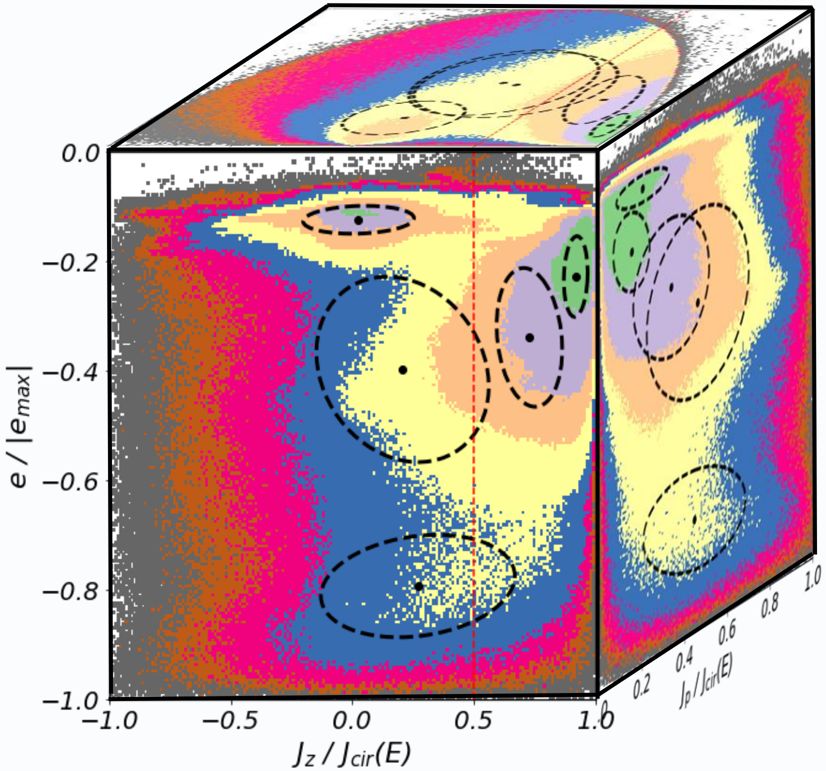
### Spectroscopic Parameter



$j_z \,/\, j_{cir}(e)$

$j_p \,/\, j_{cir}(e)$

$e \,/\, |e_{max}|$



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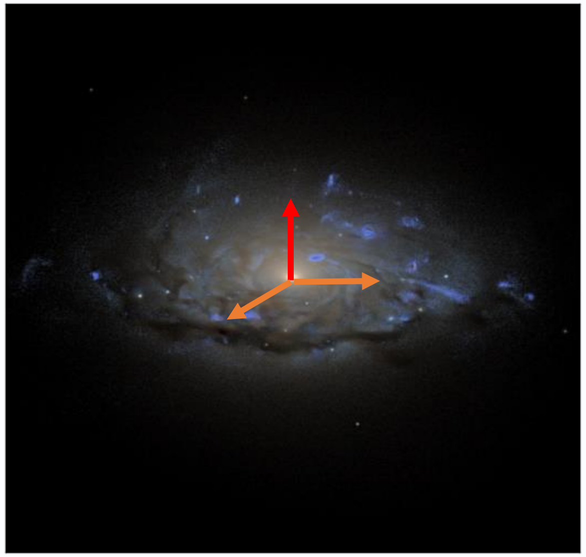

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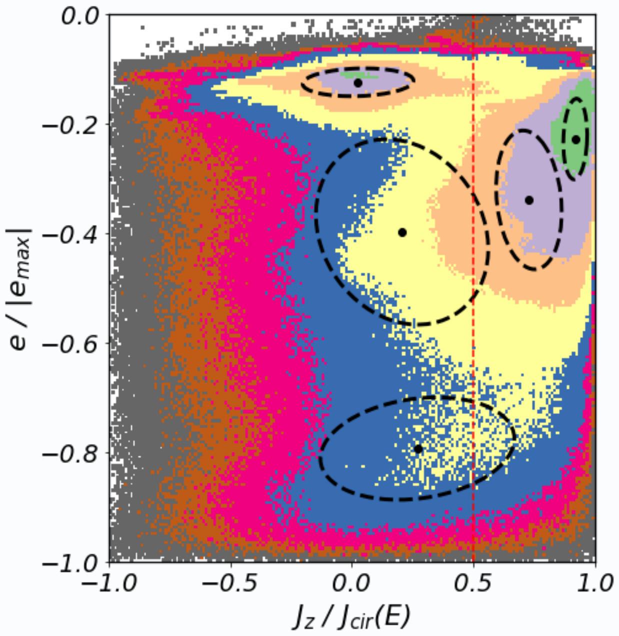
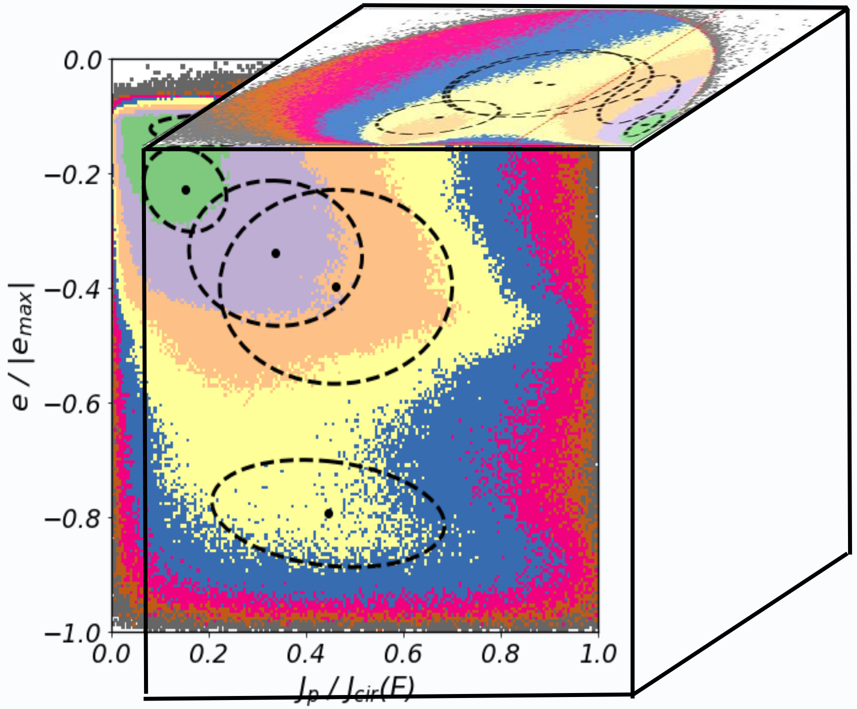


# Kinematic Decomposition

3-dimensional phase-space

$(J_z/J_{cir}(E),\ J_p/J_{cir}(E),\ E/|E_{max}|)$

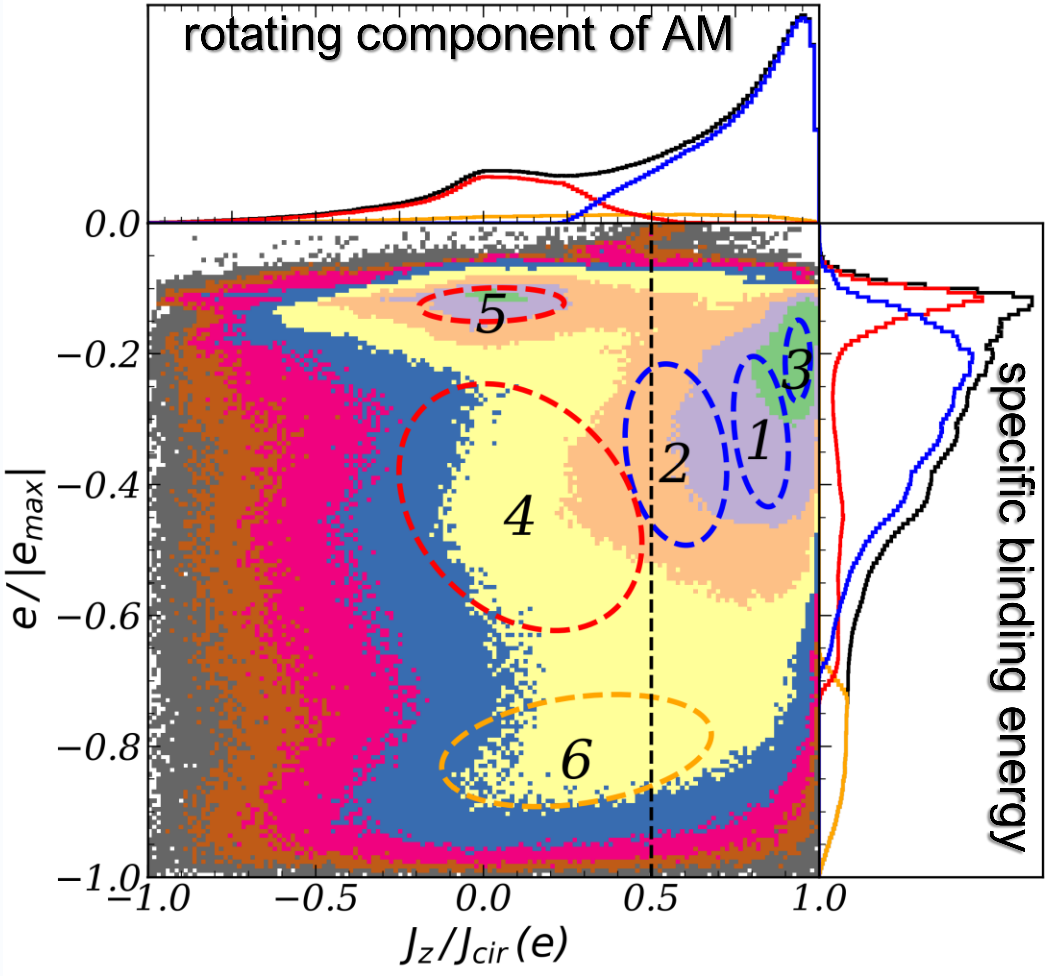
ML Clustering

(Gaussian Mixture Model; GMM)

- $N_{group} = 4 - 15$

  → we assume that **6** is the minimum value for successfully identifying the intrinsic structure of the galaxies.

  → $N_{group} = 6$



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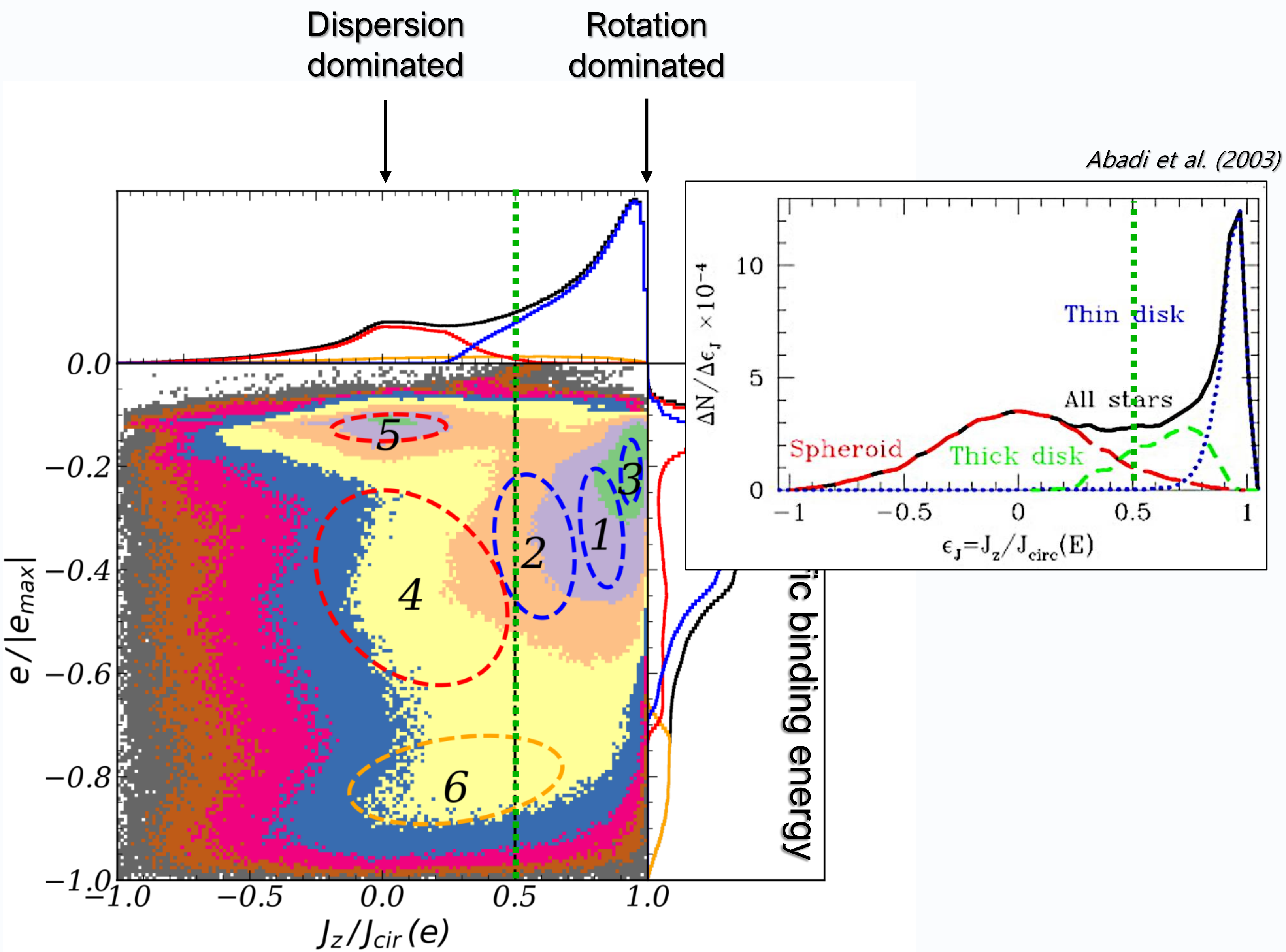


rotating component of AM



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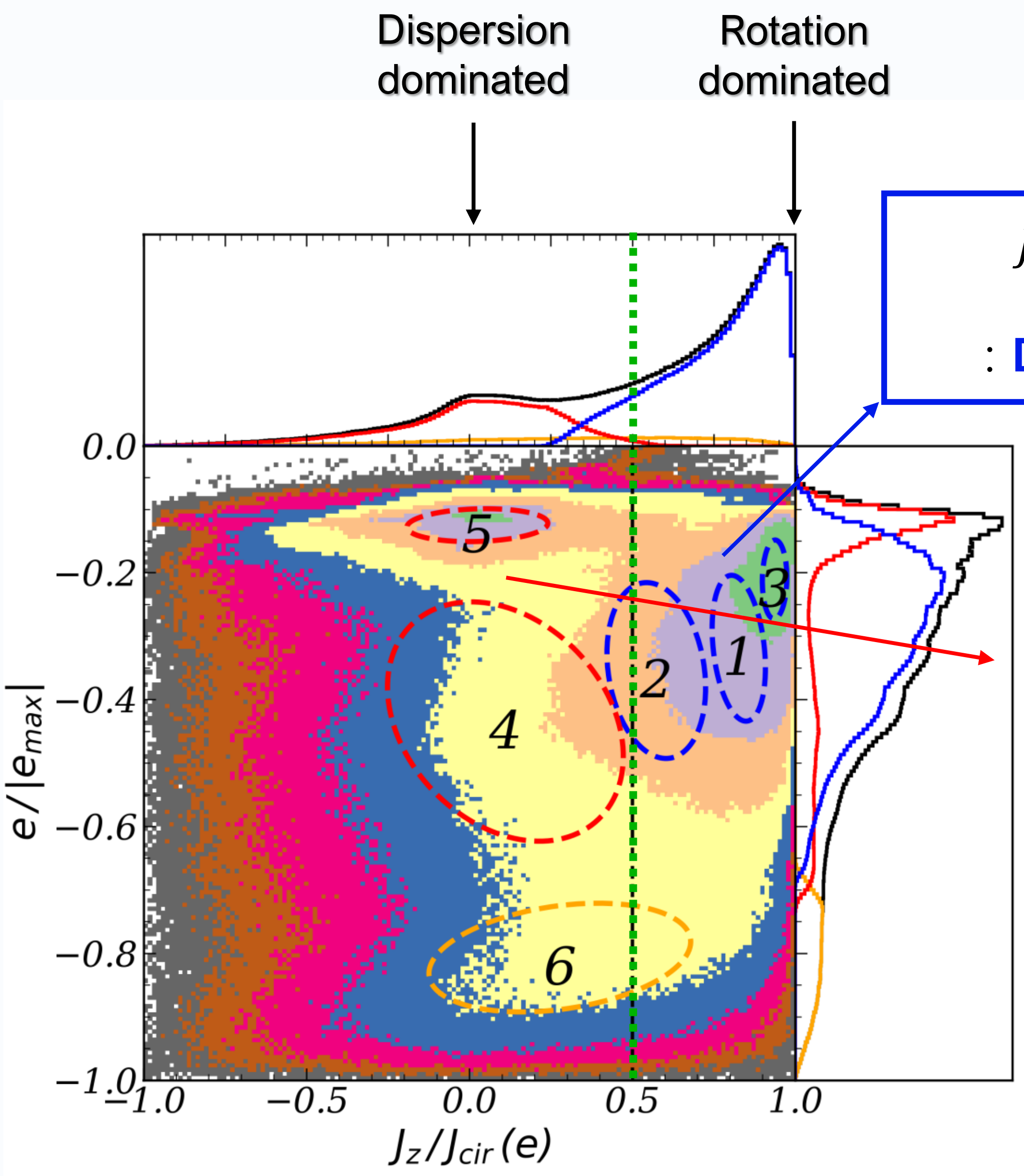


rotating component of AM

$J_z/J_{cir}(e) > 0.5$

: **Disk** component

$J_z/J_{cir}(e) < 0.5$

: **Spheroid**

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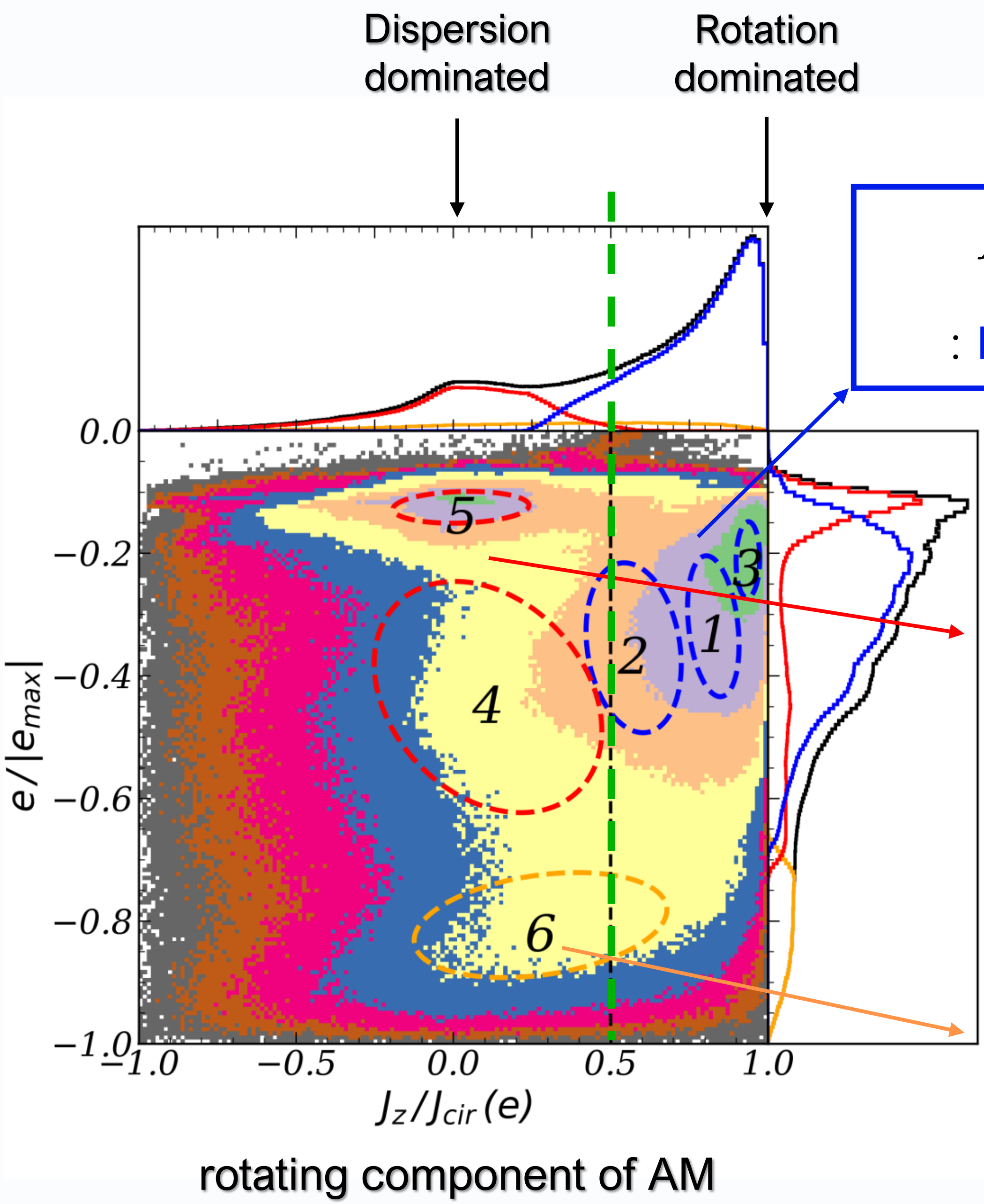


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: **Disk** component

$J_z/J_{cir}(e) < 0.5$

: **Spheroid**

$J_z/J_{cir}(e) < 0.5$

: **Spheroid, centrally (very much) concentrated**

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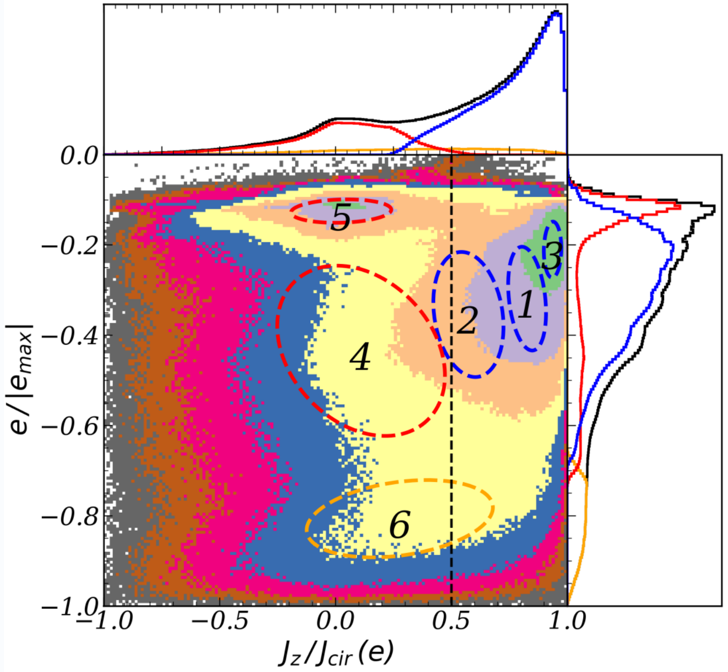


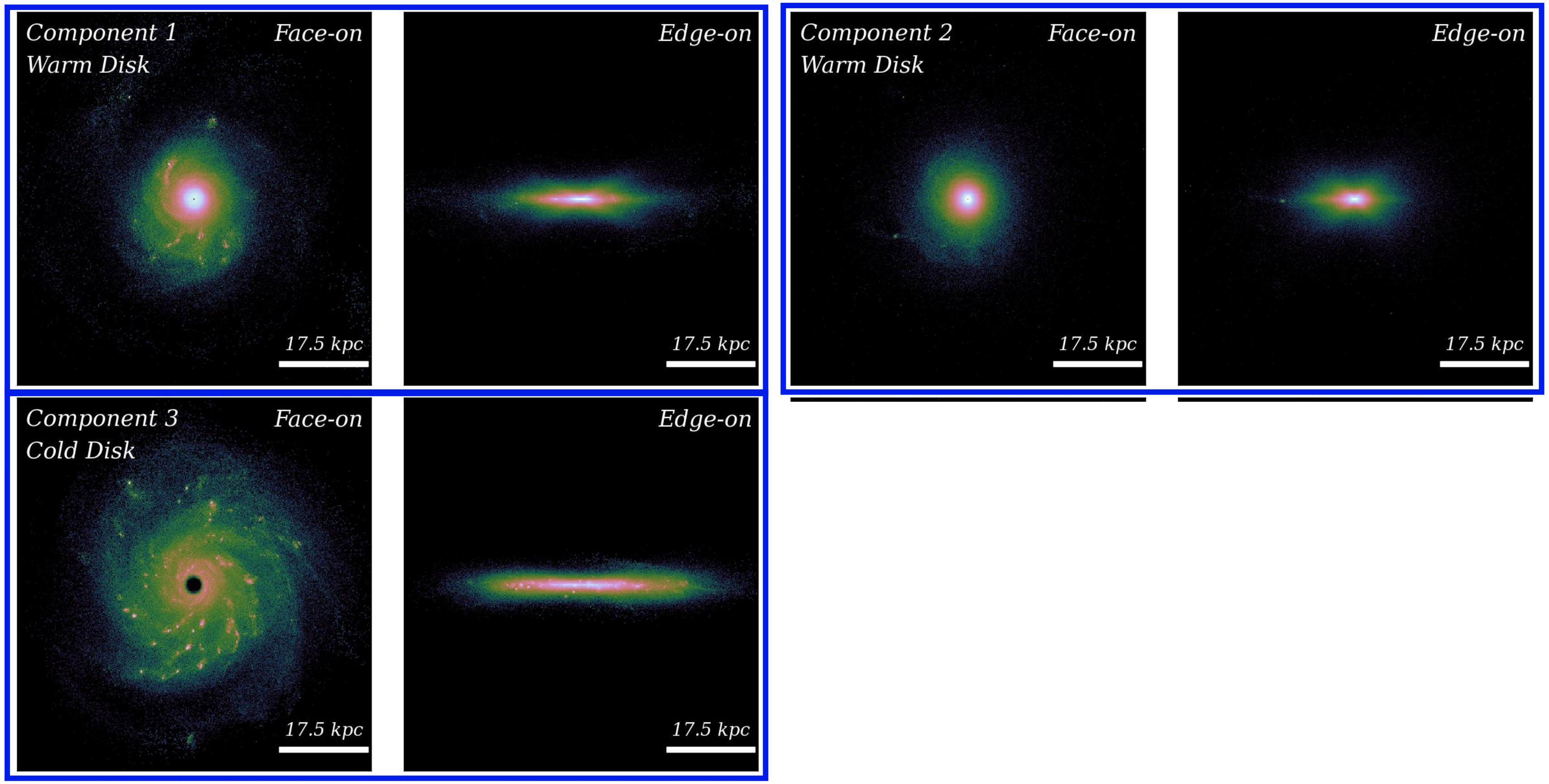

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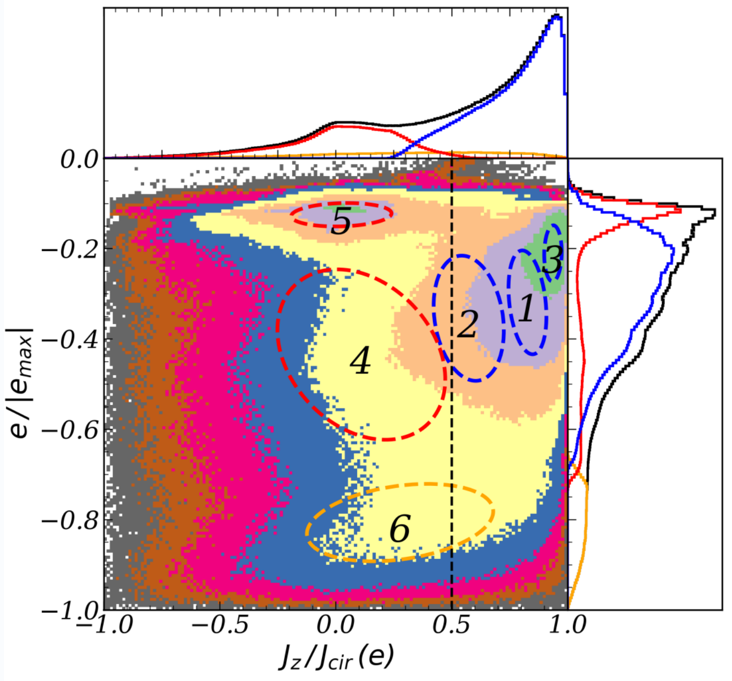


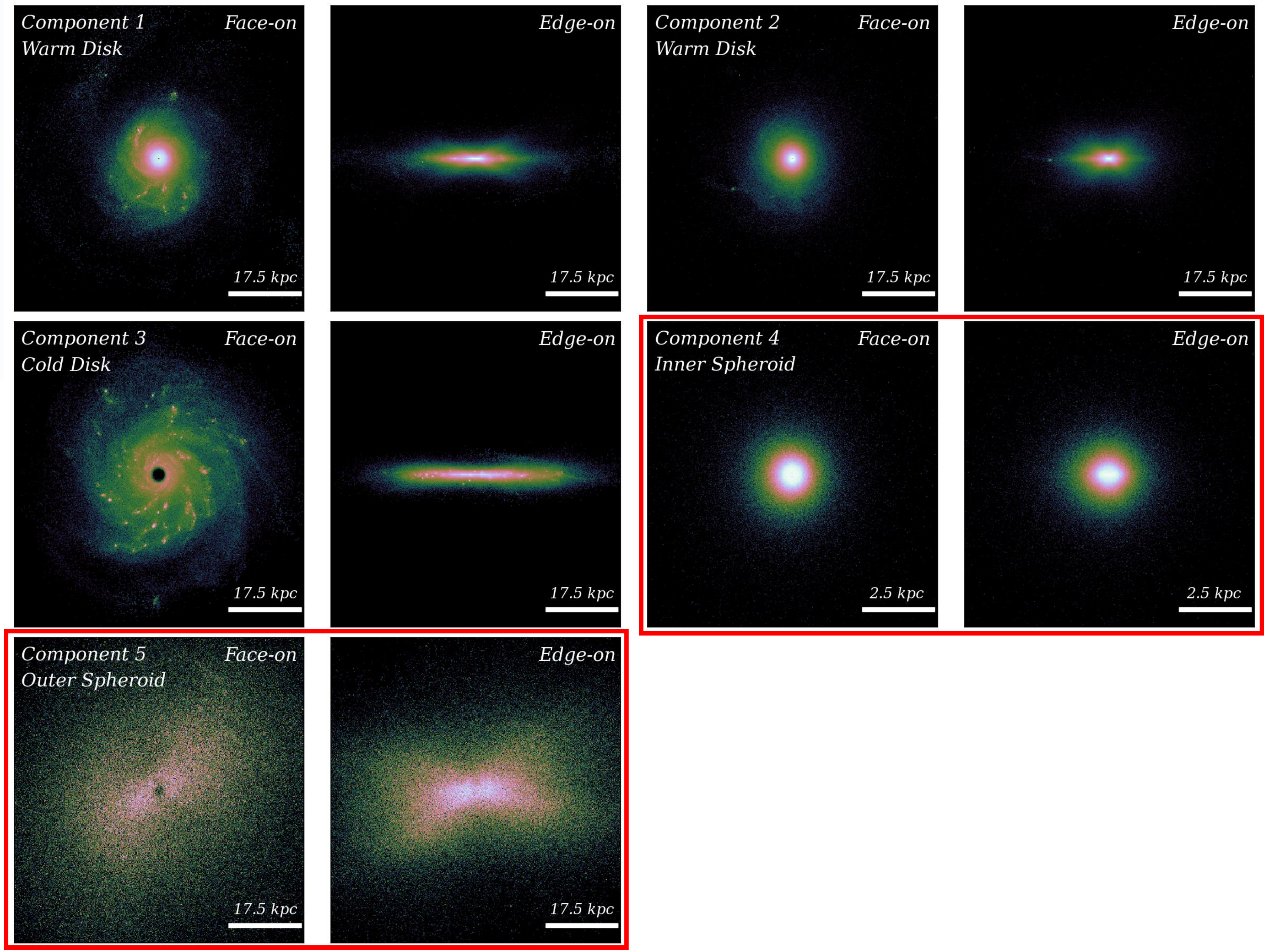

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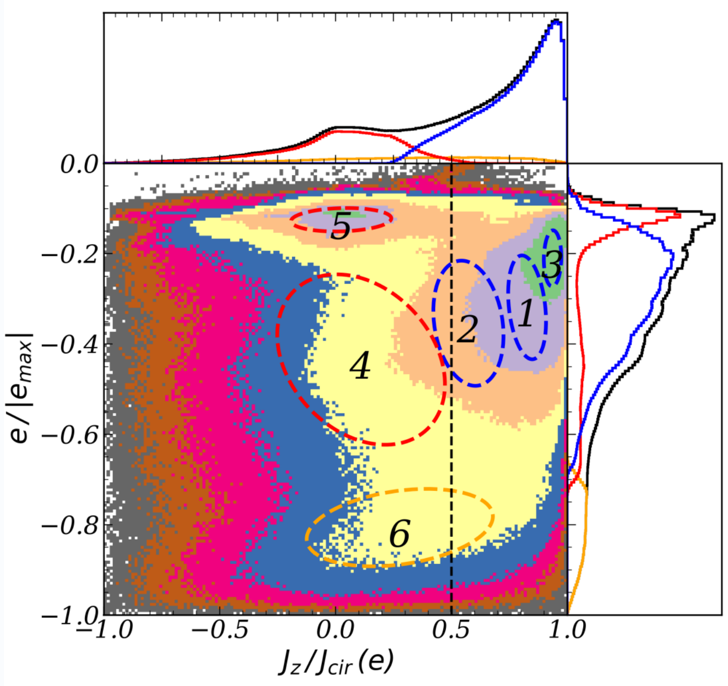
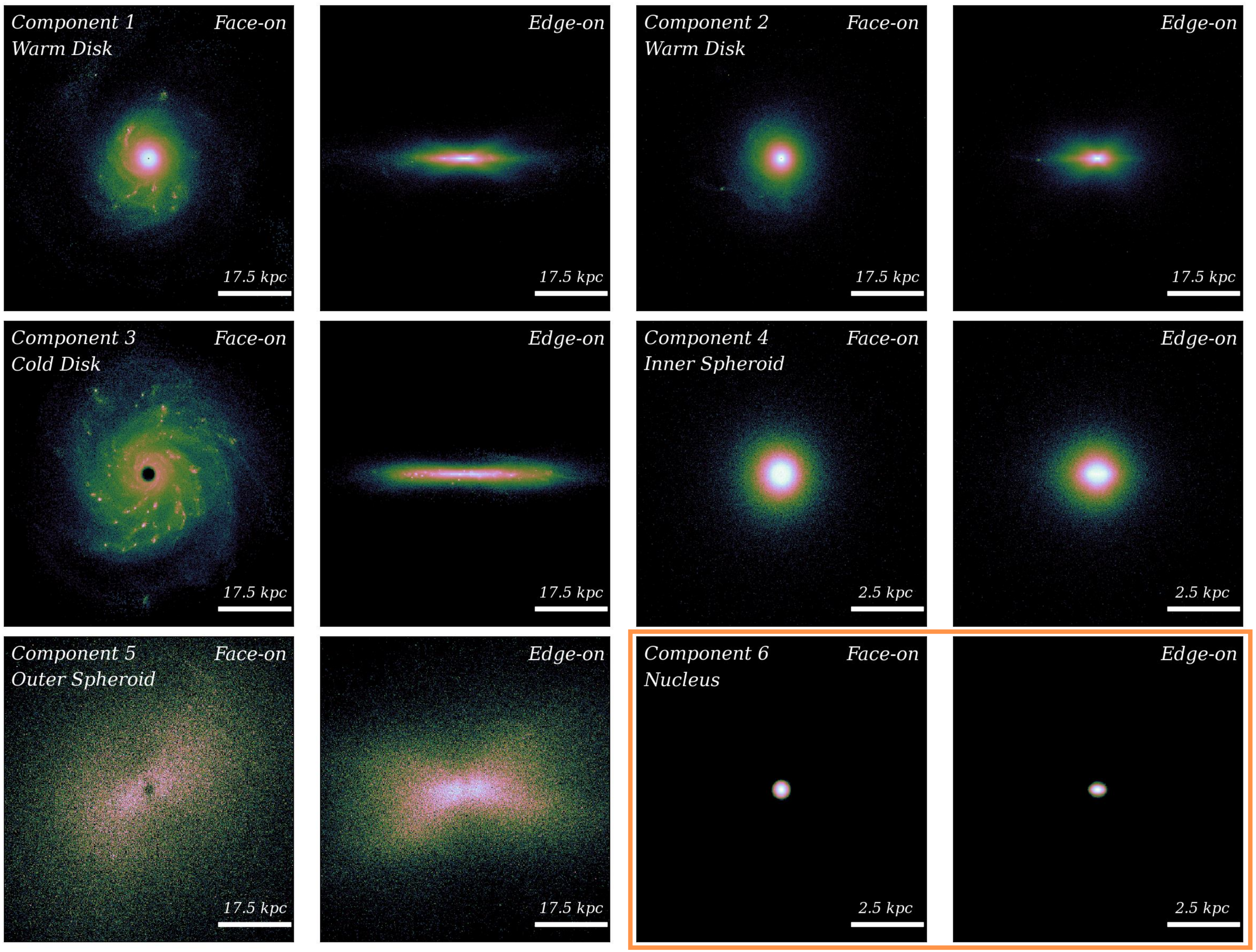
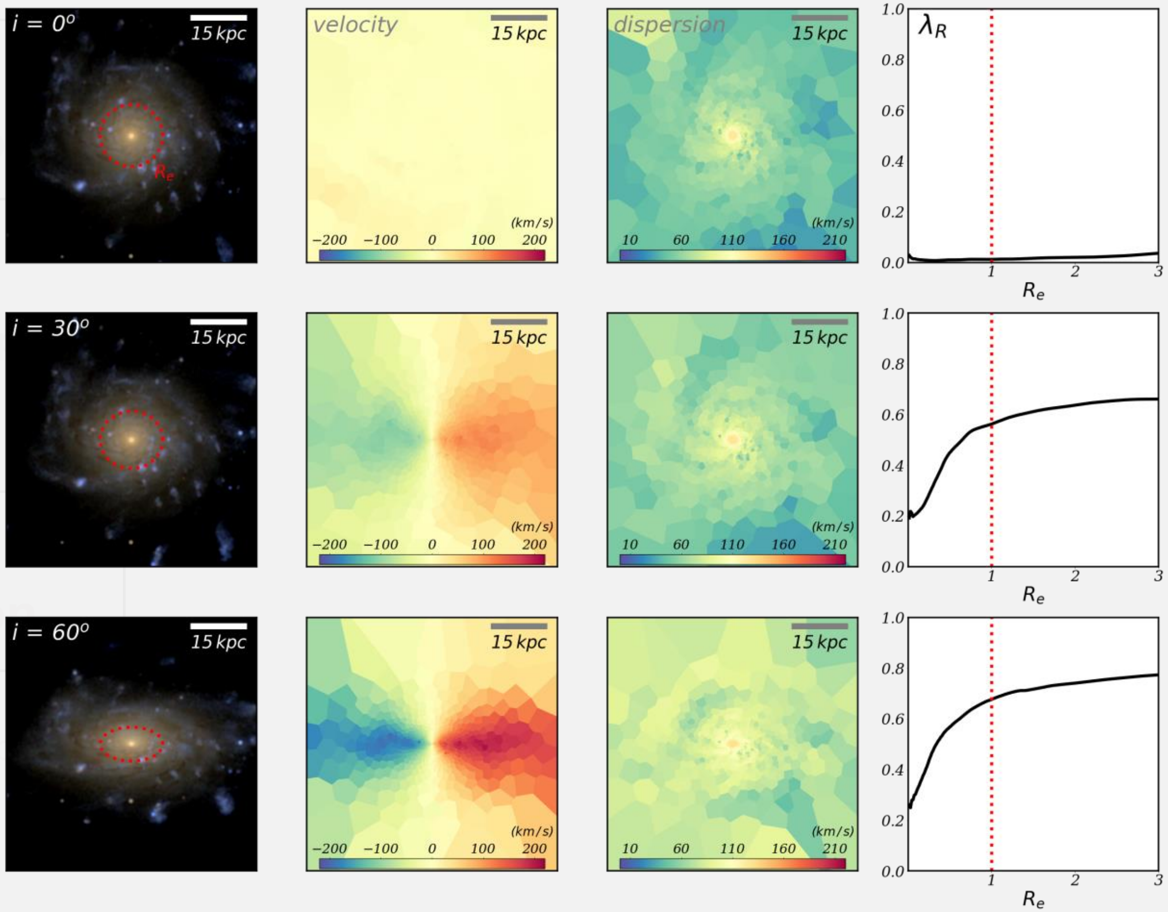


## Galaxy Sample

- $10^{9.5}\,\mathrm{M}_\odot < M_*$
- At 3 different redshift (0.70, 0.30, 0.17)
- Exclude irregular/interacting galaxies

- At least 5 stellar particles contained in 1 Voronoi cell
- Measured at 3 different inclination (30, 60, and 90 deg)
- Using the values at the effective radius ($R_{eff}$)




## Spectroscopic Parameter

Voronoi Tesselation

Spin Parameter

$$\lambda_R = \frac{\Sigma_i F_i R_i |V_i|}{\Sigma_i F_i R_i \sqrt{V_i^2 + \sigma_i^2}}$$

$$(V/\sigma)^2 = \frac{\Sigma_i F_i V_i^2}{\Sigma_i F_i \sigma_i^2}$$

# *Result*

*(finally!)*

**Photometric Decomposition**

Mock imaging

Multi-component Sersic profile

**Spectroscopic Parameter**

Voronoi Tesselation

Spin Parameter

**Kinematic Decomposition**

3-dimensional phase-space

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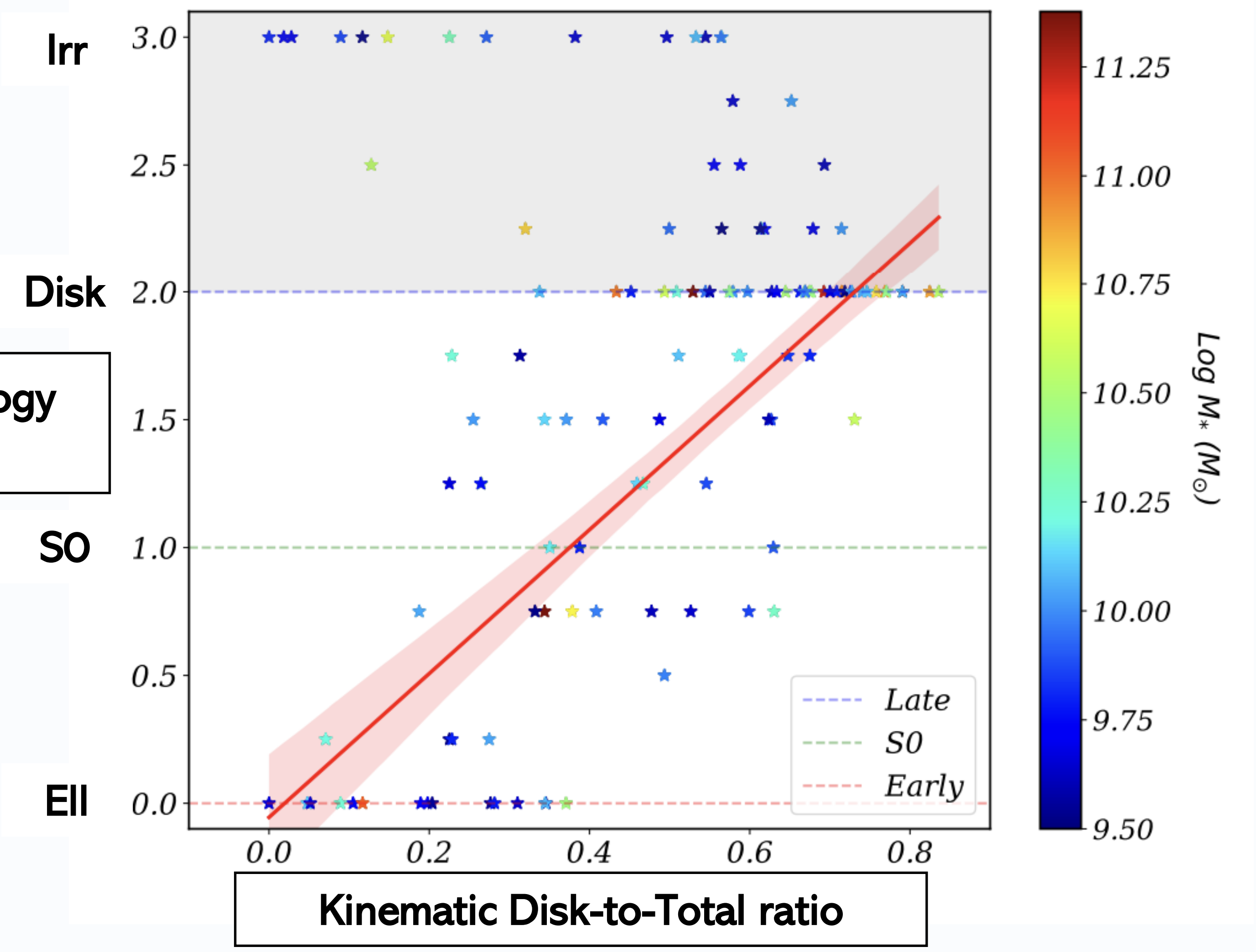



- Visual morphology?

  → Reasonably good correlation with the kinematically defined disk-to-total ratio

  (Pearson correlation coefficient $r \sim 0.8$)

Photometric Decompositio

Mock imaging

Multi-component Sersic

Spectroscopi Parameter

Voronoi Tesselatior

Spin Parameter

Kinematic Decompositio

3-dimensional phase-s

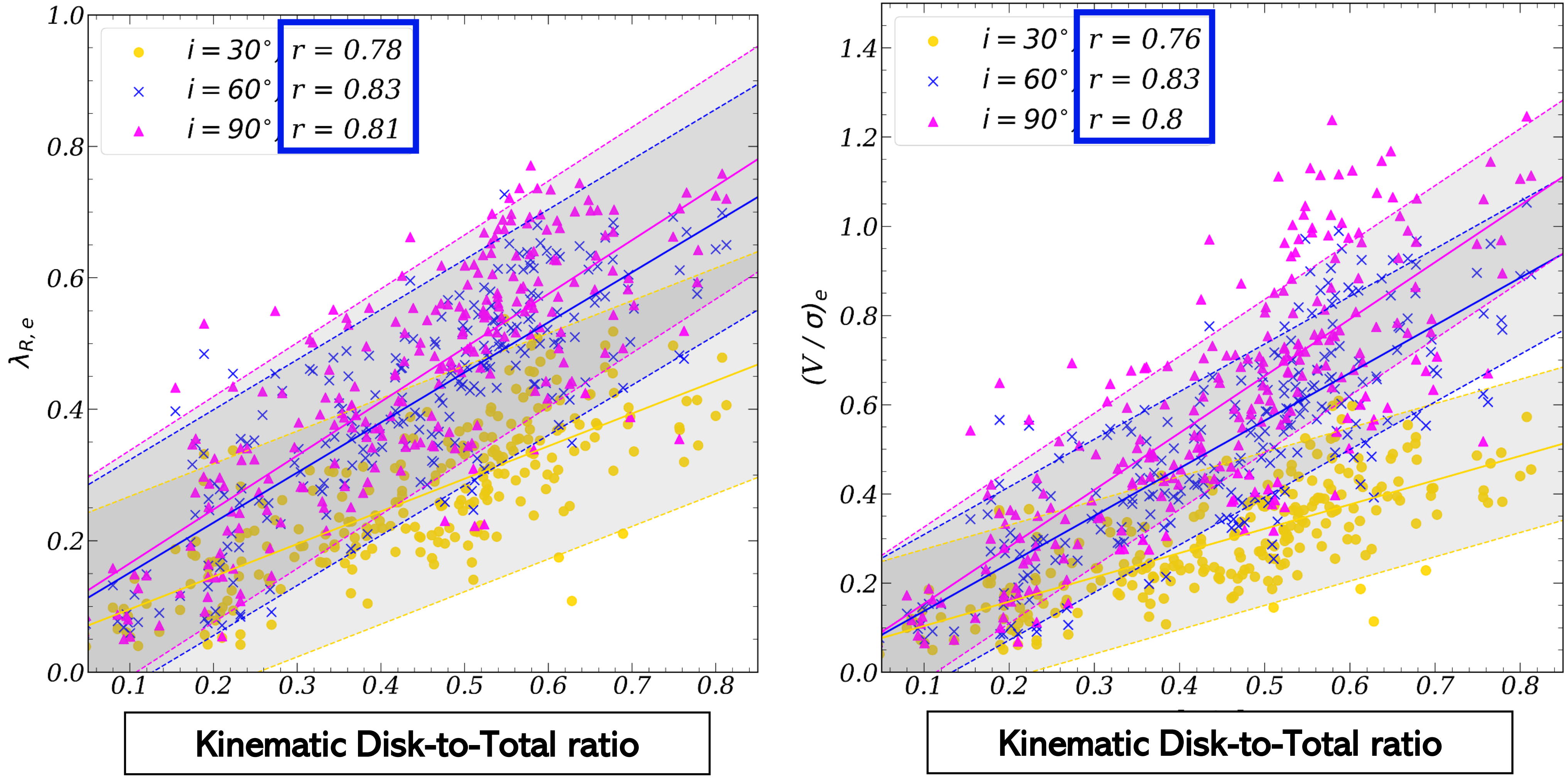
$(J_z/J_{cir}(E),\ J_p/J_{cir}(E),\ E/|E$

ML Clustering

(Gaussian Mixture Model;

The $\lambda_{R,e}$ spin parameter and $(V/\sigma)_e$

show a tight correlations with the kinematic Disk-to-Total ratio



**Photometr**
**Decomposit**

Mock imaging

Multi-component Sers

**Spectrosco**
**Paramete**

Voronoi Tesselat

Spin Paramete

**Kinemati**
**Decomposit**

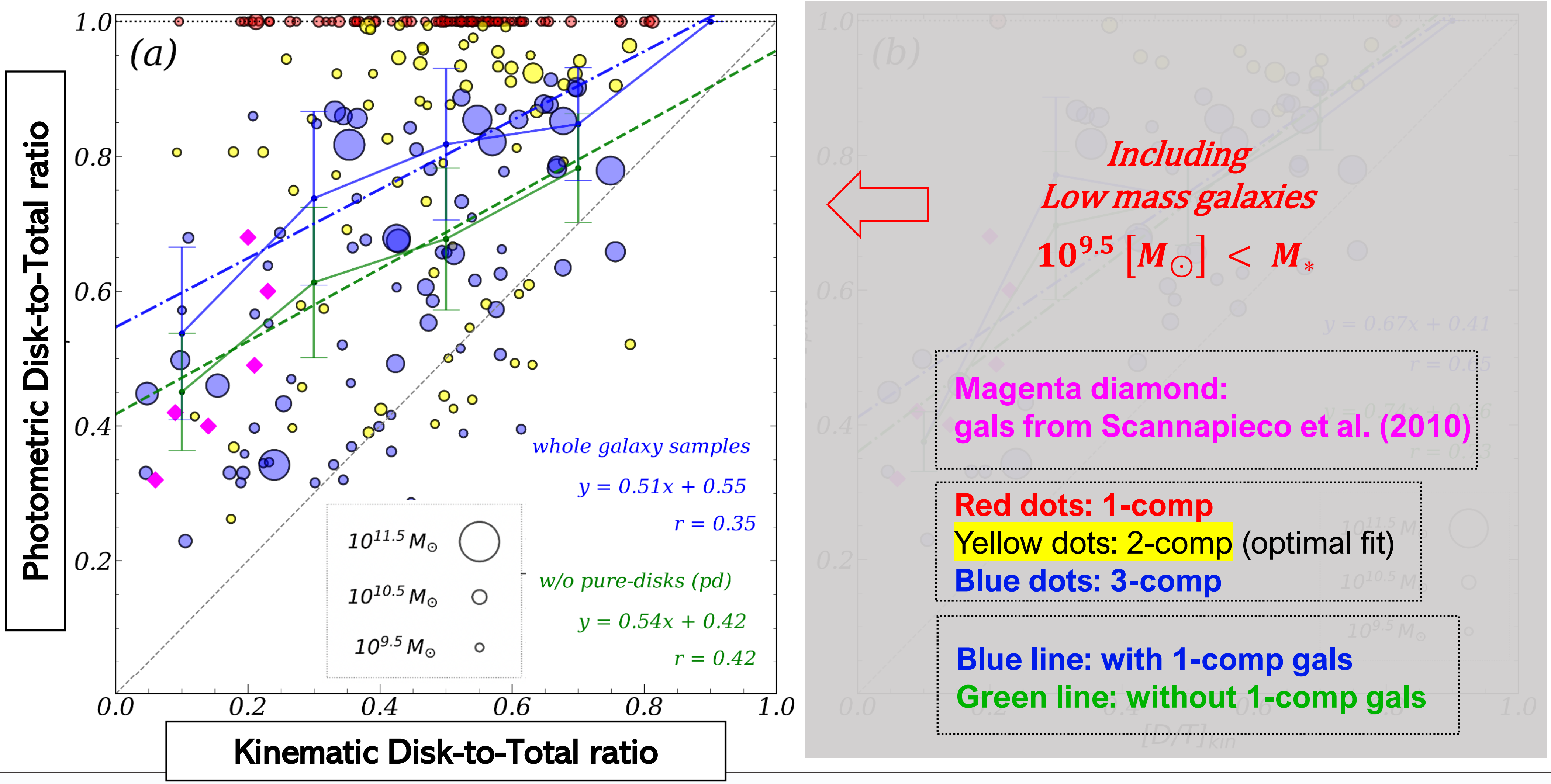
3-dimensional phase

$(J_z/J_{cir}(E),\ J_p/J_{cir}(E),$ I

ML Clustering

(Gaussian Mixture Moc

- We find there's a lot of single component-like (nearly exponential) galaxies
- Including low-mass galaxies, the correlation is mildly weak ($r = 0.35\ and\ 0.42$)



**Photometr**
**Decomposit**

Mock imaging

Multi-component Sers

**Spectrosco**
**Paramete**

Voronoi Tesselat

Spin Paramete

**Kinemati**
**Decomposit**

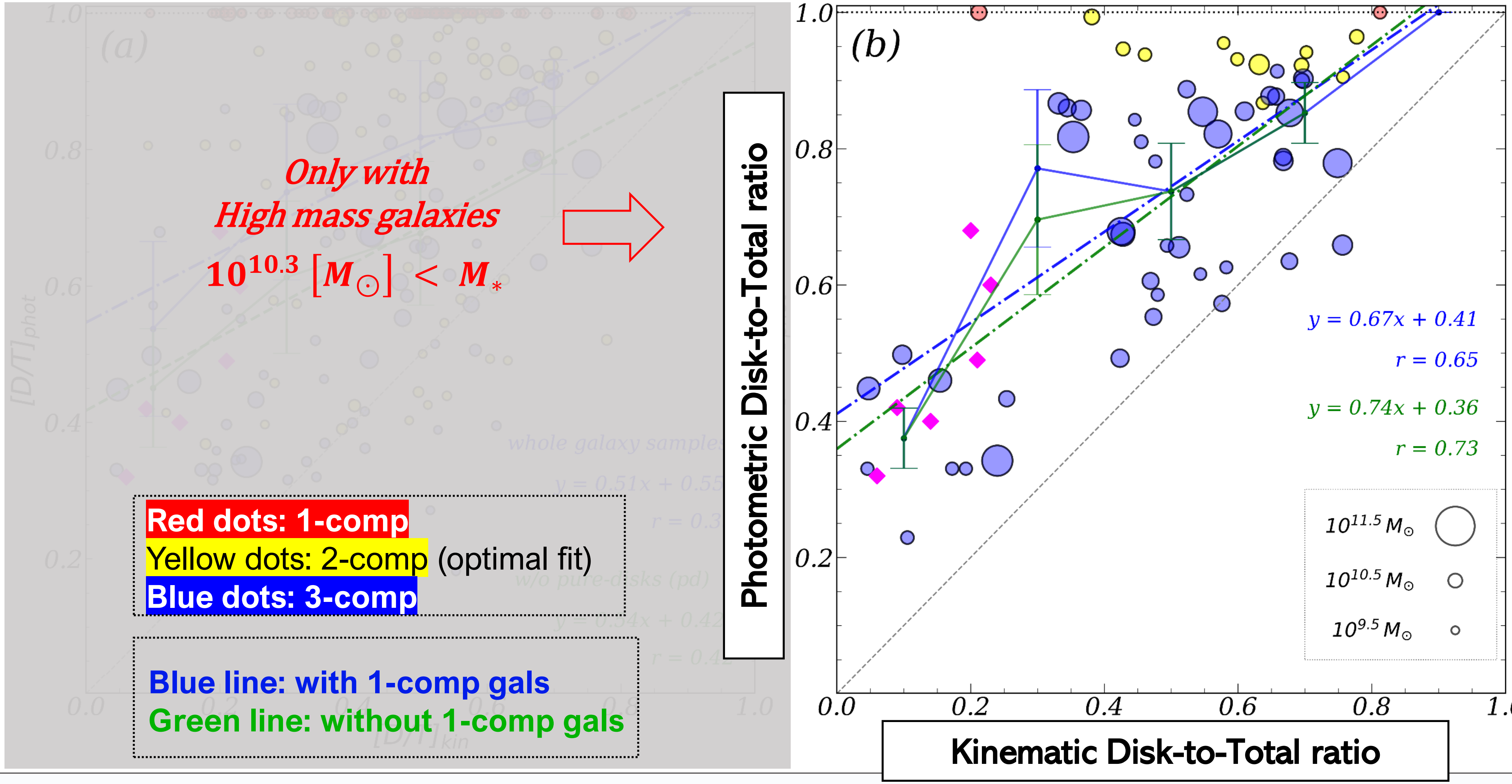
3-dimensional phase

$(J_z/J_{cir}(E),\ J_p/J_{cir}(E),$ E

ML Clustering

(Gaussian Mixture Moc

- Including low-mass galaxies, the correlation is mildly weak ($r = 0.35$ *and* $0.42$)
- Using only high-mass galaxies, the correlation is quite strong ($r = 0.65$ *and* $0.73$)

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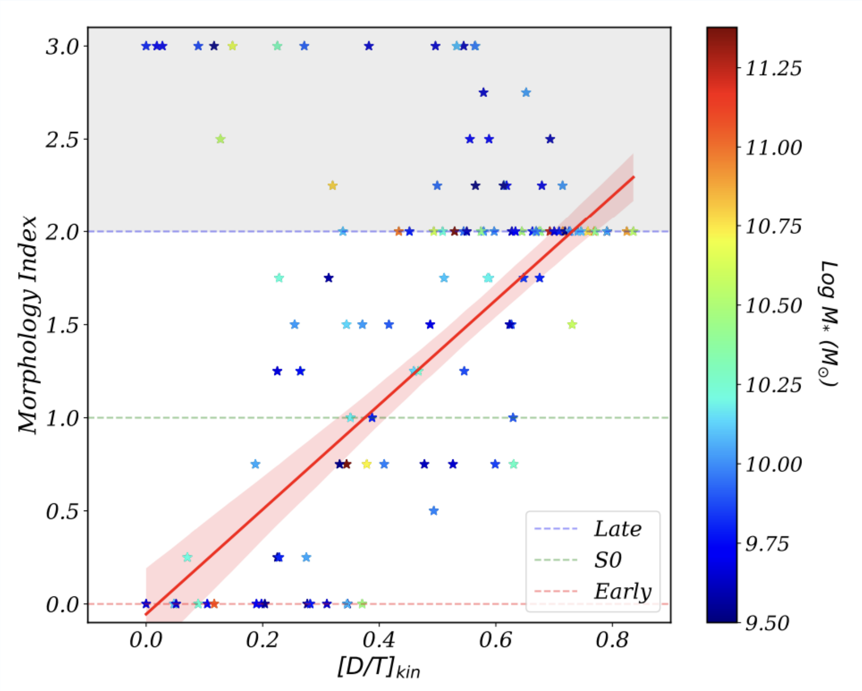
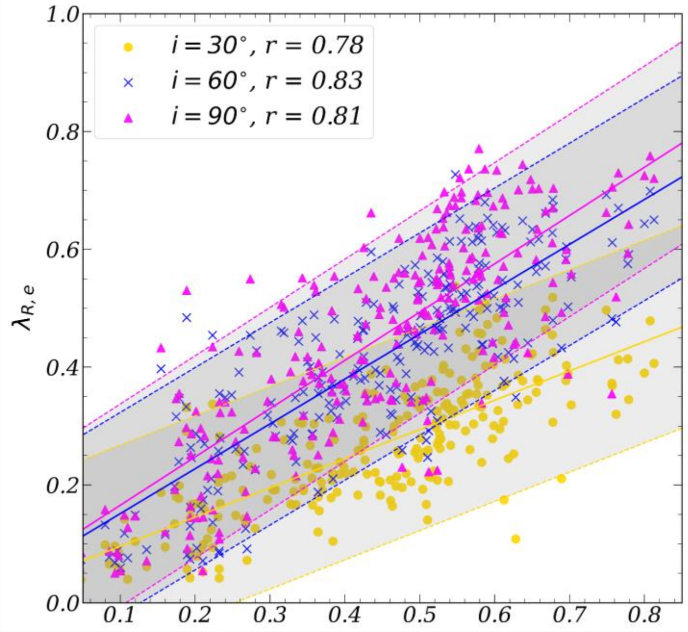
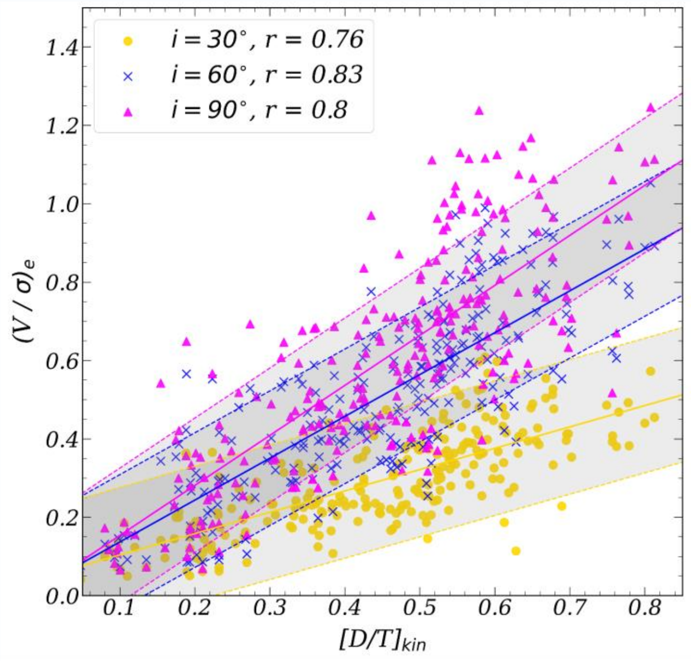
# Summary

- The kinematic disk-to-total ratio reasonably agrees with visual inspection
- The spectroscopic parameters exhibited tight correlations with the kinematic disk-to-total ra tio.
  - The $\lambda_R$ spin parameter indicated correlation coefficients in the range of 0.7–0.8, depend ing on the inclinations. Similarly-good correlations were found for V/σ.

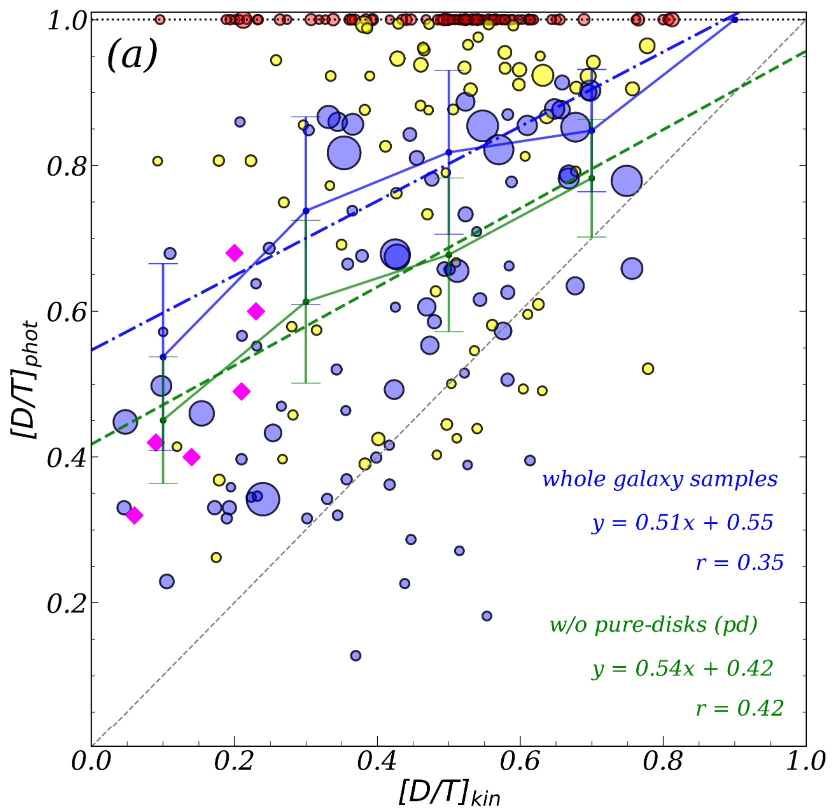


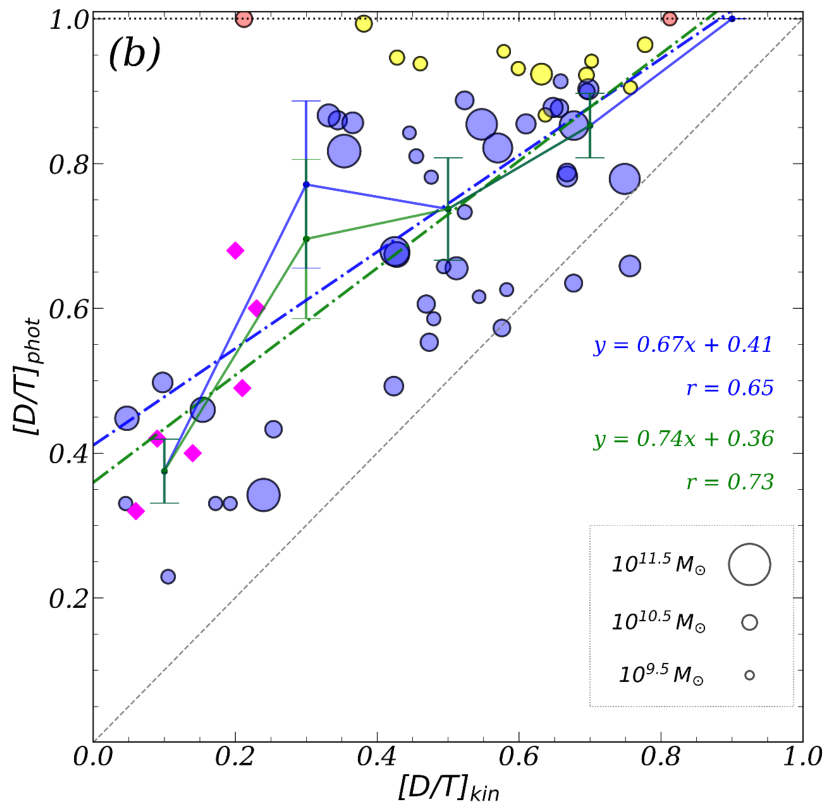



# Summary

- The photometric disk-to-total ratio showed a poor correlation with the kinematic ratio, and a substantial offset existed.
- The photometric decomposition failed to accurately recover the structural composition of g alaxies, which seemed more serious for low-mass galaxies that are often classified as pure disks.
- While the offsets did not change much, the correlation between the kinematic and photometric disk-to-total ratios became substantially stronger if we removed the low mass galaxies.



***Thank you!***



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