Evolution of Kinematic Properties of Early-Type Galaxies Investigated by Surface Photometry

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Outline

❶ Introduction

Kinematics of Early-Type Galaxies (ETGs)

❷ Relation between kinematics and surface brightness profiles

Local ETGs with IFS data

❸ Surface photometry at z~1 and 0

Cluster ETG samples at z~1 and 0

❹ Evolution of Kinematics from Surface photometry

Spin down of ETGs at z < 1

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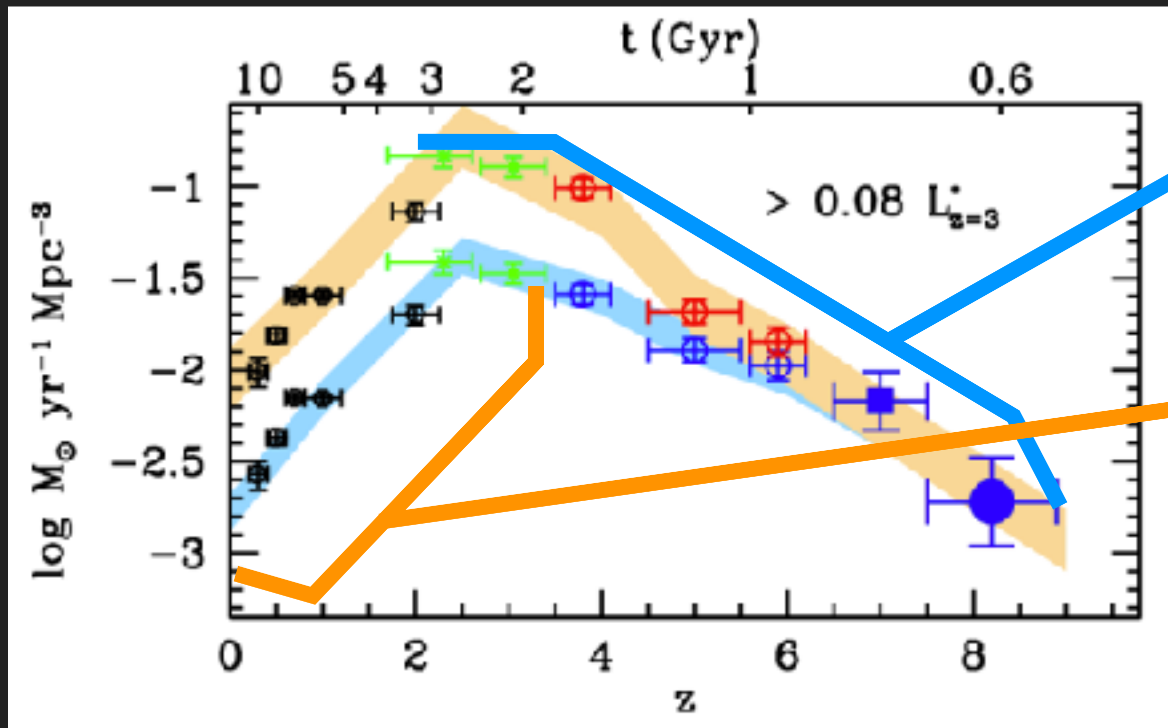
Galaxy Formation & Evolution



Cosmic Star Formation History; Bouwens+10

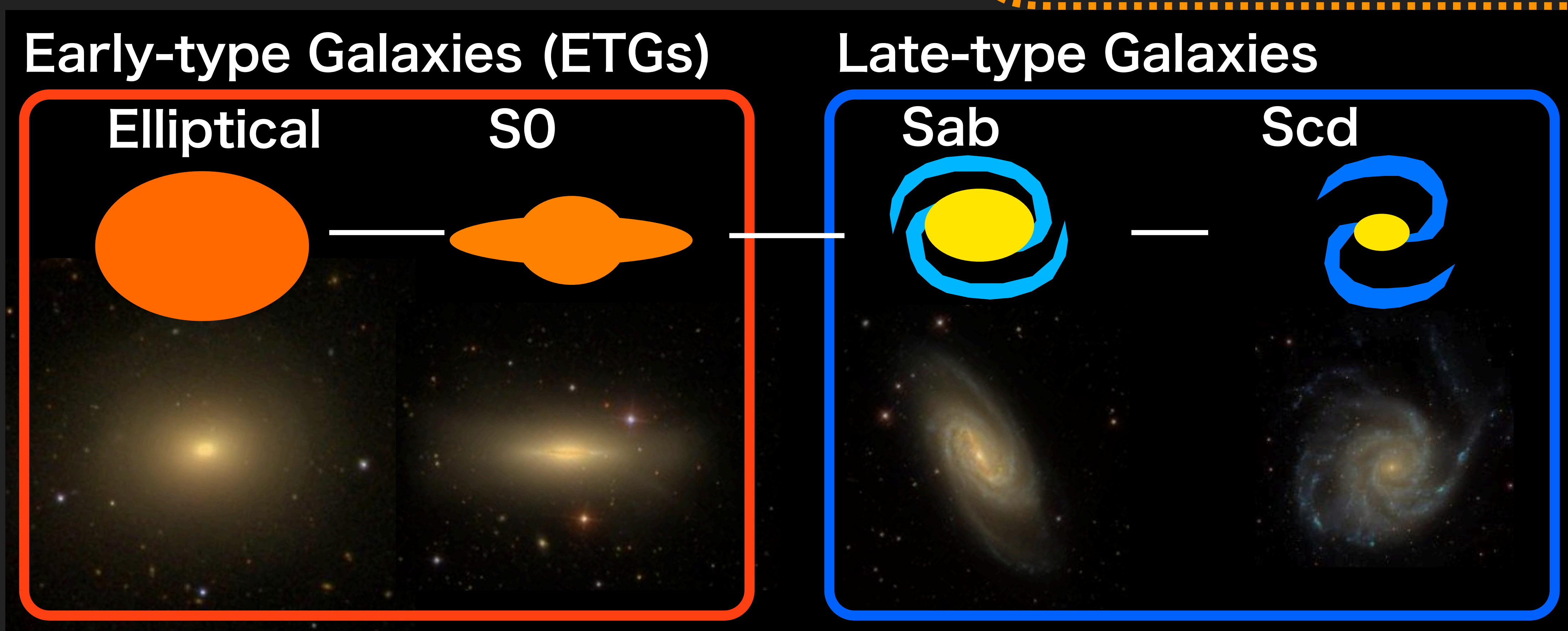
Before Quenching

Star-forming (SF) galaxies

After Quenching

Quiescent or Early-Type Galaxies

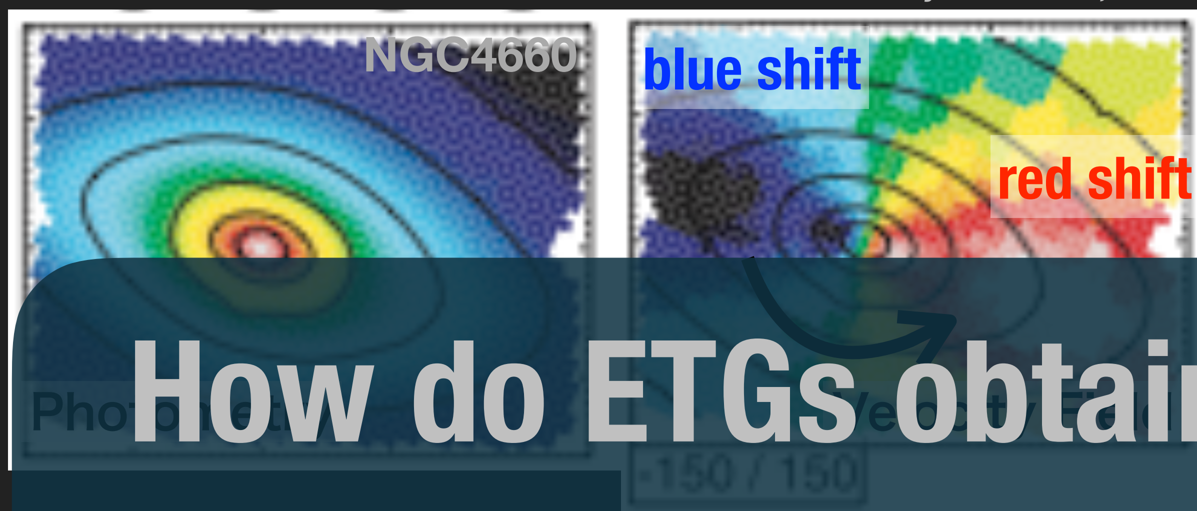
- Quenching of SF
- Mass & size growth
- EV of Morphology
- EV of Kinematics (spin-down)



Kinematics of ETGs by Integral Field Spectroscopy

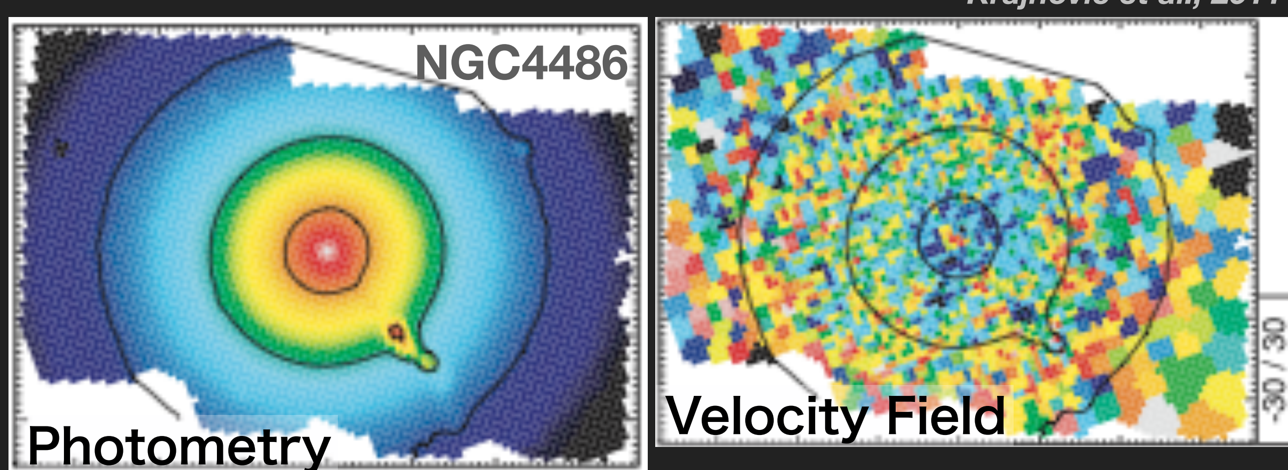
Fast v.s. Slow Rotators

Krajnovic et al., 2011



Rotation dominated

Krajnovic et al., 2011



Dispersion dominated
= slow rotators

degree of galaxy spin

Quantified with spin parameter λ

$$\lambda = \frac{\Sigma_{i=1}^{N} F_i R_i |V_i|}{\Sigma_{i=1}^{N} F_i R_i \sqrt{V_i^2 + \sigma_i^2}},$$

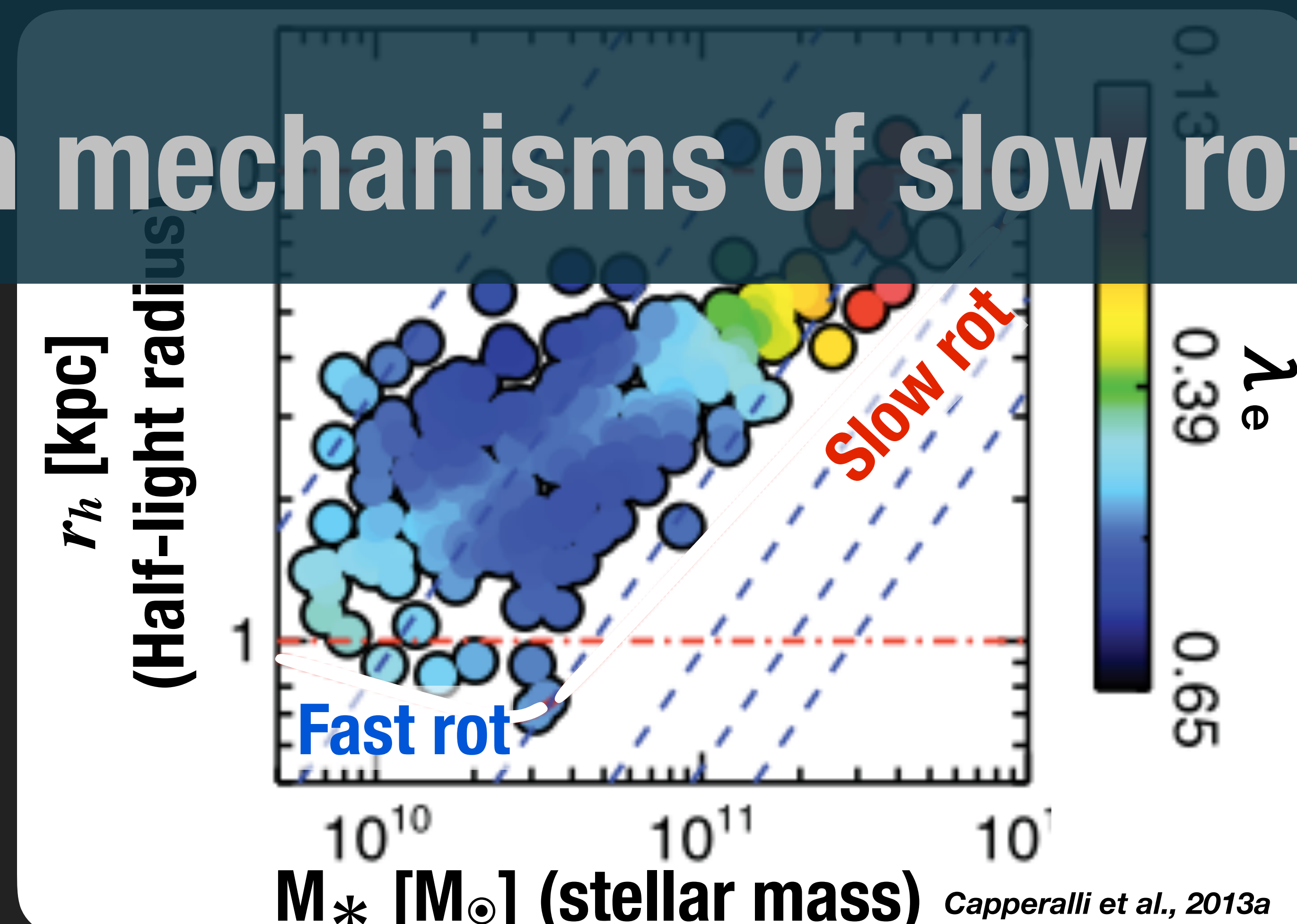
Emsellem et al., 2007

- i: i-th pixel
- F_i: flux
- R_i: galactocentric distance
- V_i: line-of-sight velocity
- σ_i: velocity dispersion

* λ < 0.3 : Slow Rot, λ>0.3 Fast Rot

How do ETGs obtain such kinematic properties?

What are the spin-down mechanisms of slow rots?



Capperalli et al., 2013a

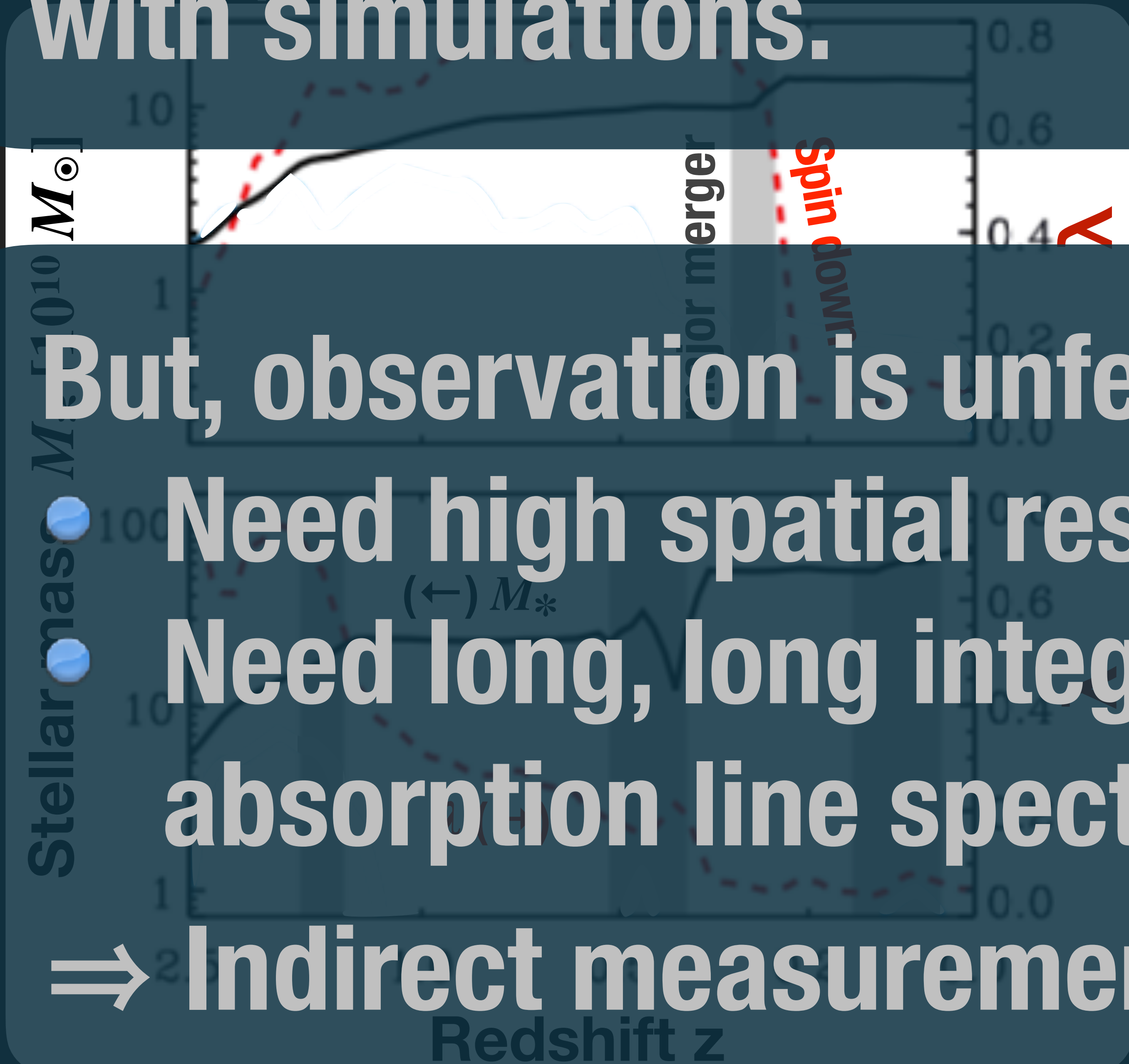
- Only massive end = Slow Rot

Latest Cosmological Simulations

- Spin-down history in a cosmological context
- Not perfect (e.g., different results between different simulations)

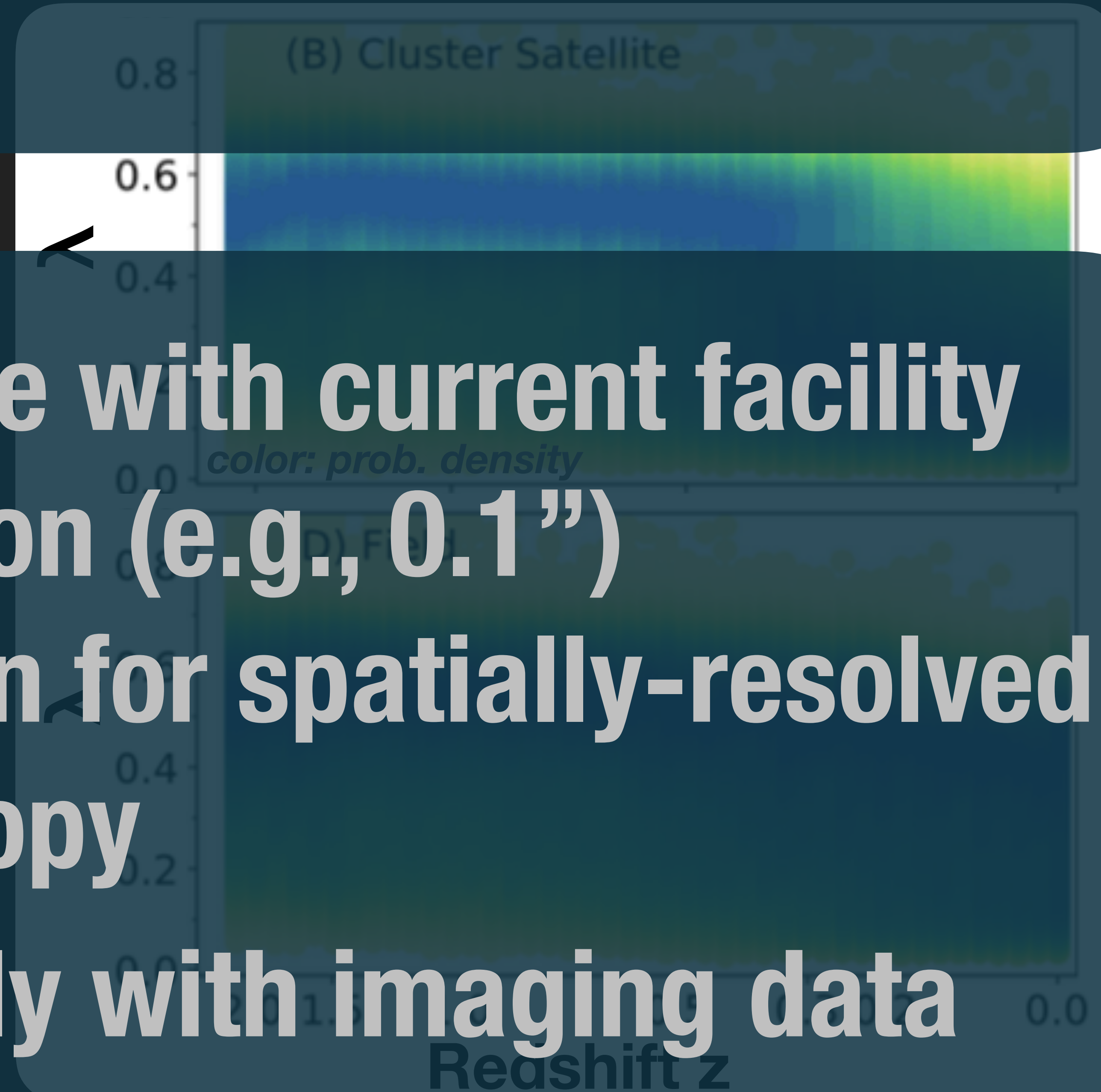
If we can observe kinematics (λ parameter) of high-redshift ETGs, the results can be compared with simulations.

Two examples from 15k simulated ETGs



Penoyre et al., 2017

Statistics with 3-5k simulated ETGs



Choi et al., 2018

But, observation is unfeasible with current facility

- Need high spatial resolution (e.g., 0.1”)
- Need long, long integration for spatially-resolved absorption line spectroscopy

⇒ Indirect measurement only with imaging data

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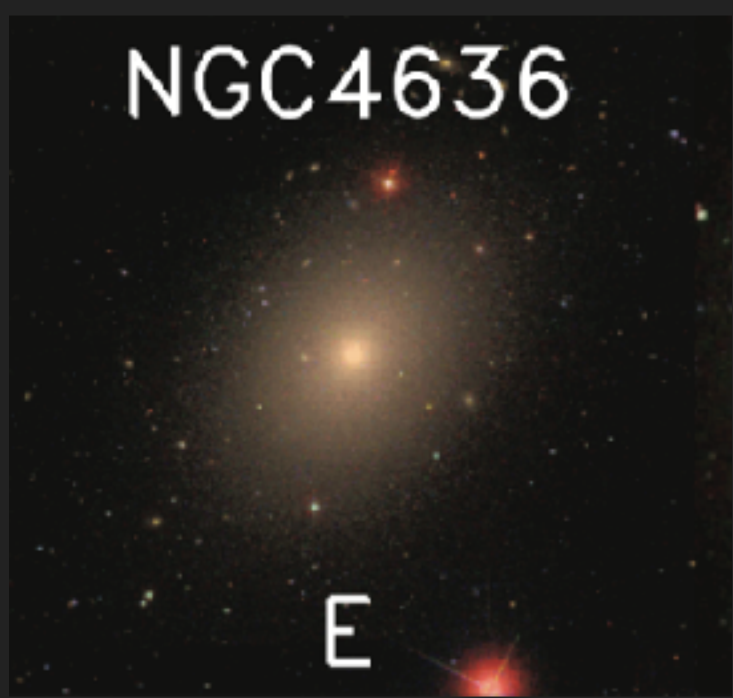
ATLAS^{3D} Data and Non-barred ETG Sample

ATLAS^{3D}: Volume-limited, mass complete IFS survey *(Cappellari et al., 2011)*

- D < 42 Mpc (Northern Hemisphere)
- $M_K < -21.5$ mag ($M_* > 6 \times 10^9 M_\odot$)
- Morphological selection by eye (absence of spiral arms)
  - 260 ETGs

Sample in this study: Non-barred ETGs with SDSS images

- No bar, ring, and shell ⇐ Inspected by ATLAS^{3D} team *(Krajnovic et al., 2011)*
- Galaxies with Sloan Digital Sky Survey (SDSS) Images
  - 166 ETGs

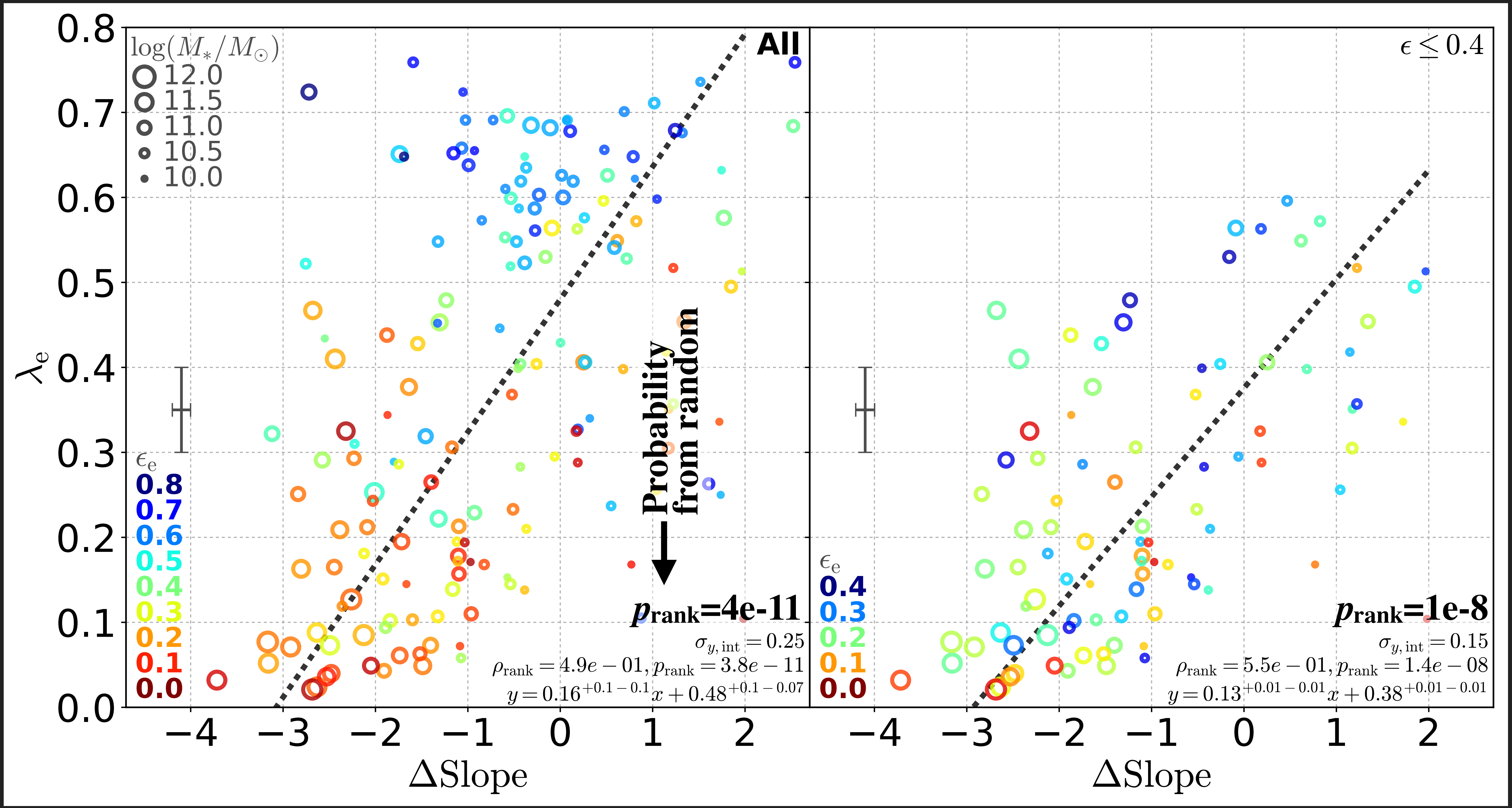


(Cappellari et al., 2011)

Examples of the non-barred ETG sample

Relation between ΔSlope and λ

Smaller ΔSlope (extended) → Smaller λ (slow rotators)



- Significant correlation revealed by rank correlation tests
- Best photometric parameter for kinematics (compared to, e.g., Sersic index)

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Early-type Galaxy Samples at z~1 and 0

Cluster ETG Sample: Easy to follow evolution from z~1 to 0

- Galaxies remain in the cluster once they fall in it
- Galaxy clusters: matching halo mass assuming mass evolution
- ETGs: assuming passive evolution to select z~0 descendants of z~1 ETGs

High-z Sample (z~1)

- 25 clusters at z=0.9-1.5 (z_{med}=1.2)
  (Dawson et al., 2009)
  $\log M_{200}/M_{\odot}$ = 14.2 - 14.9
- 692 ETGs with $\log(M_{*}/M_{\odot})>10$
  Selected by i, z color-mag diagram
  Quantitative morphological selection
- High-quality HST imaging (i, z)
  (Suzuki et al., 2012)
  PSF FWHM: 0.1 arcsec
  Integration time: >10k sec (z)

Low-

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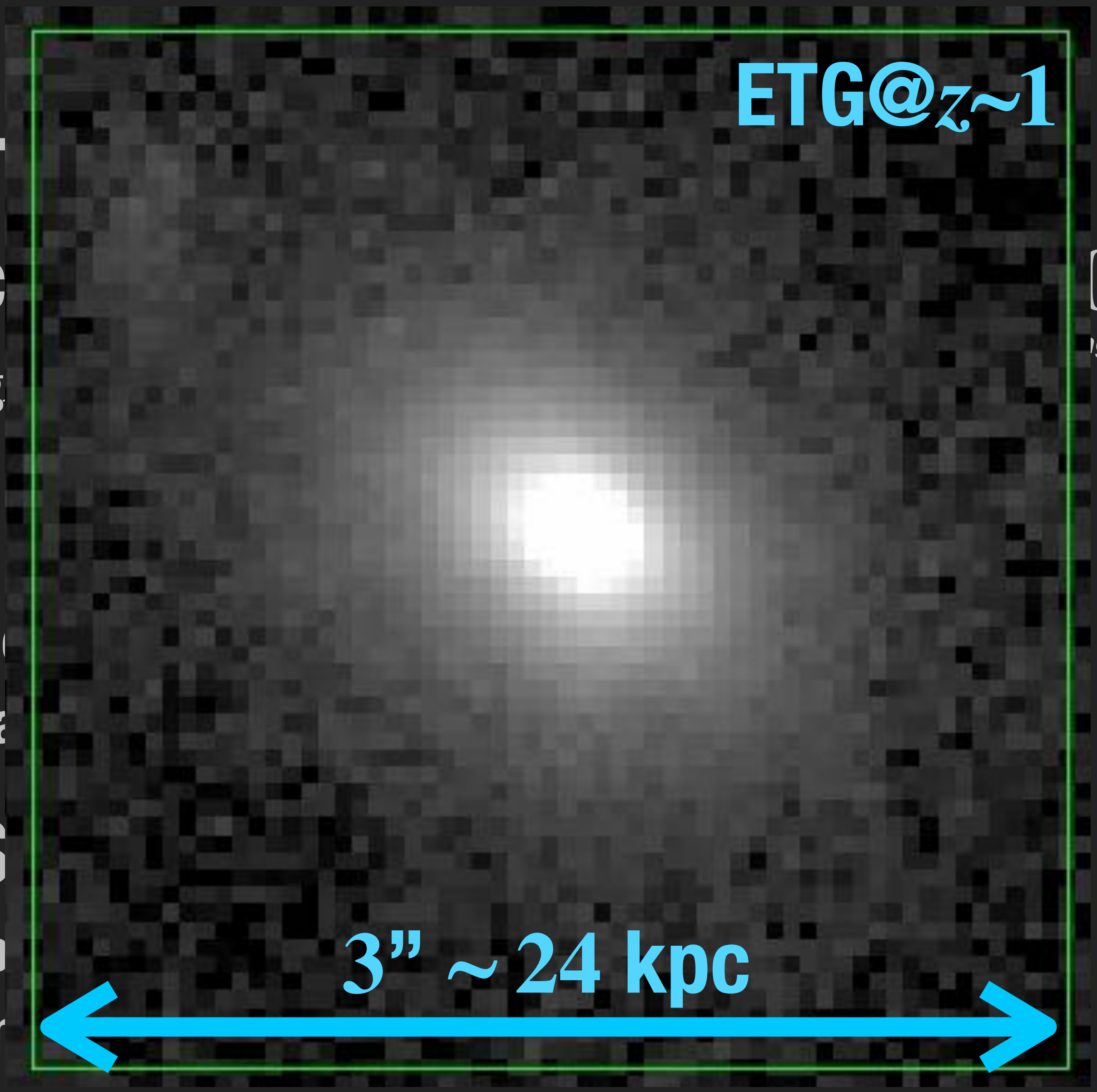
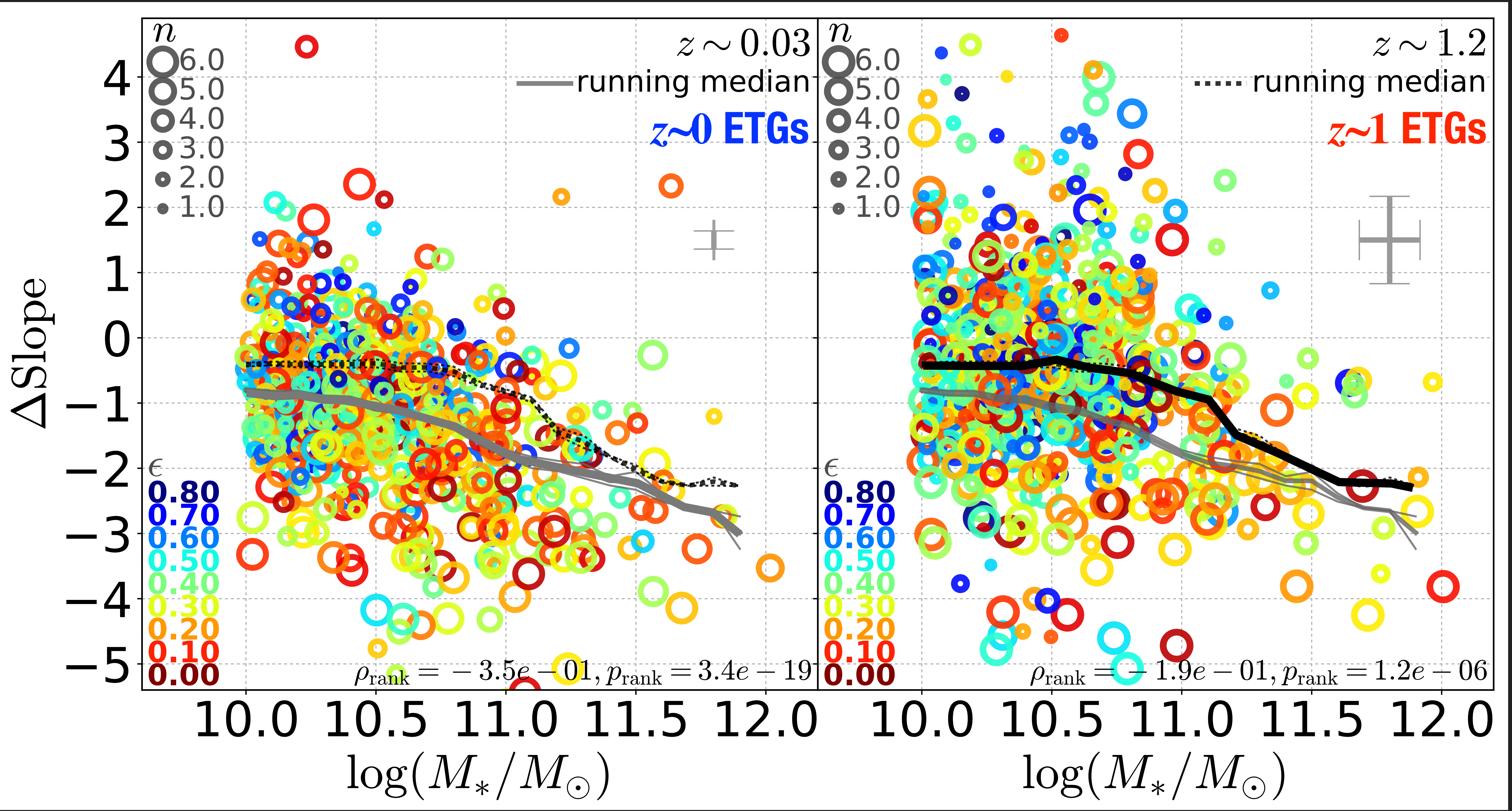


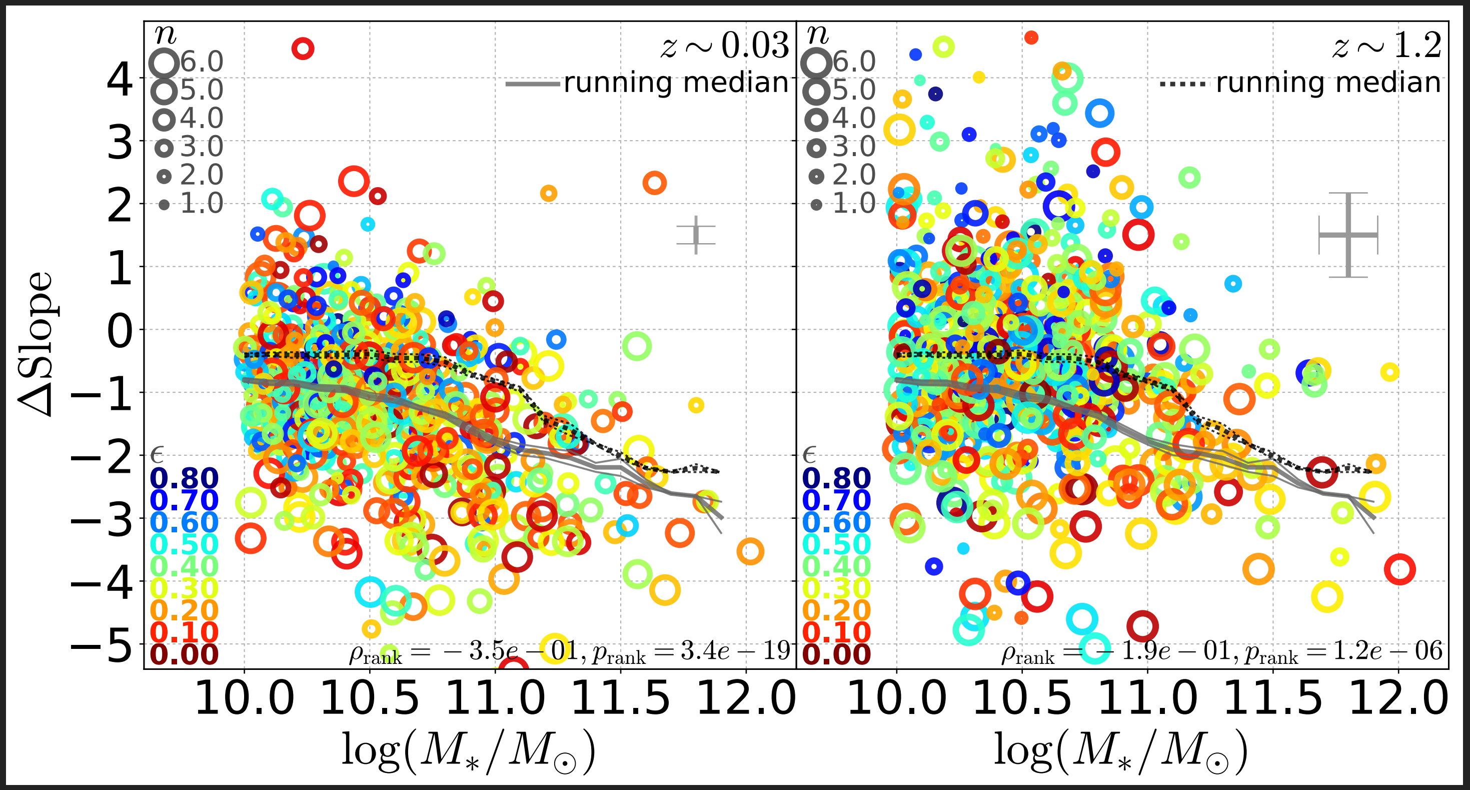
Mass Dependence of ΔSlope

- High-z (z~1) sample has larger ΔSlope (i.e., more truncated)

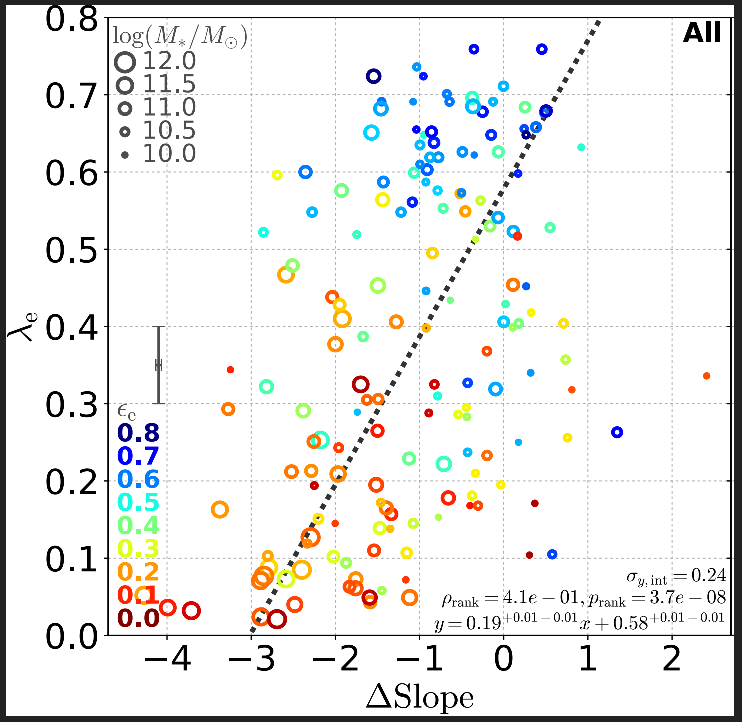


Evolution of Kinematic Properties of ETGs

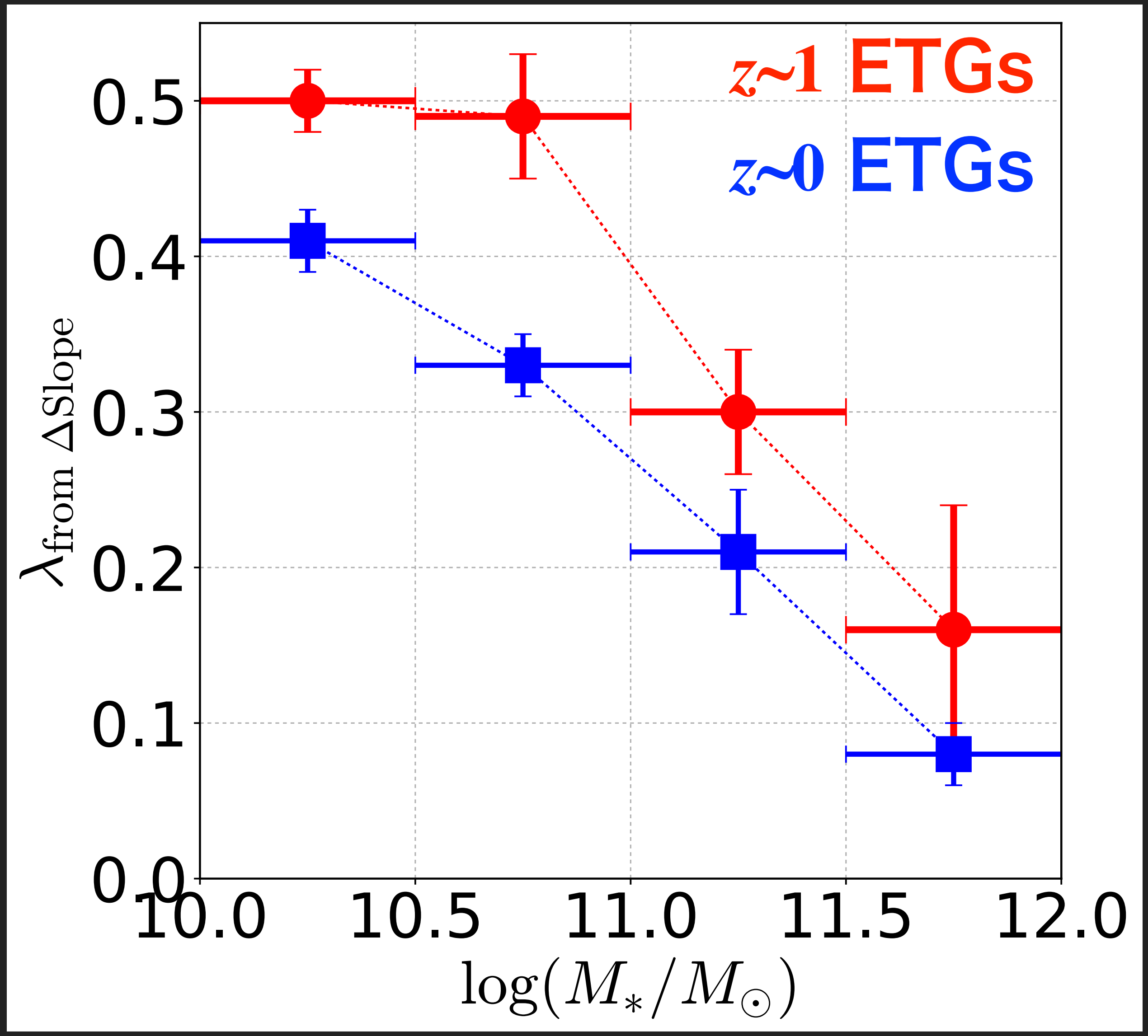
§3. ΔSlope of z~1 and 0 ETGs



§2. ΔSlope — λ relation



λ of z~1 and 0 ETGs



- **Spin down from z~1 to 0 by Δλ~0.05 - 0.15**

  (compared at a fixed stellar mass)

Summary

Section 2

- We investigate the relation between kinematics and surface brightness profile with a local ETG sample from IFS survey ATLAS^{3D}
- We introduce the **ΔSlope parameter,** and show that **ΔSlope is correlated with the spin parameter λ.**
- Slow Rotator tend to have ΔSlope<0 (extended), while Fast Rotator tend to have ΔSlope>0 (truncated)
- ΔSlope is measured from imaging data and can be applied to high-redshift ETGs

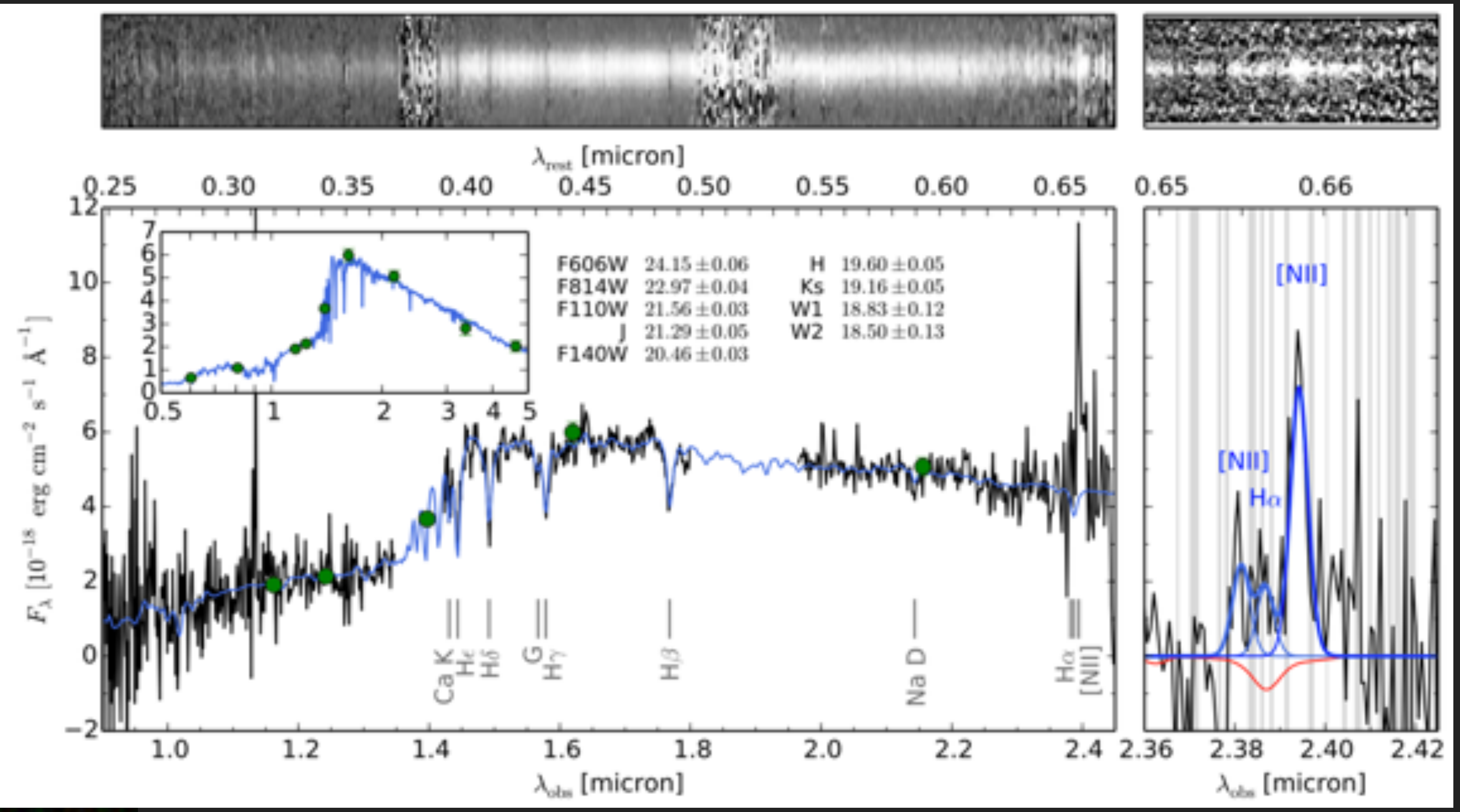
Section 3 and 4

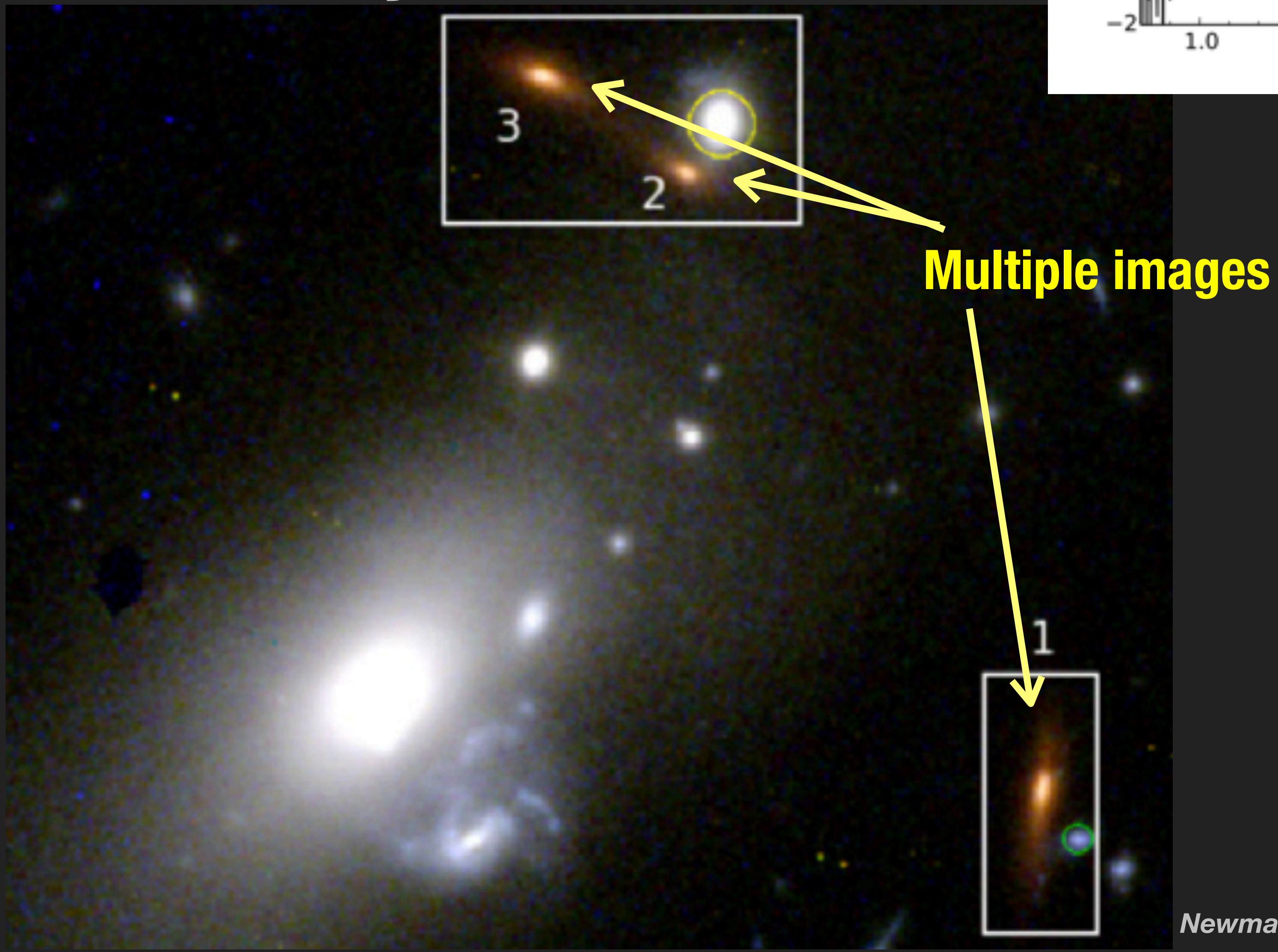
- We measure ΔSlope for large samples (>600) of ETGs at z~1 and 0
- **z~1 ETGs have larger ΔSlope**
- Assuming ΔSlope — λ relation, **ETGs experience spin down by Δλ ~ 0.05 - 0.15 from z~1 to 0.**

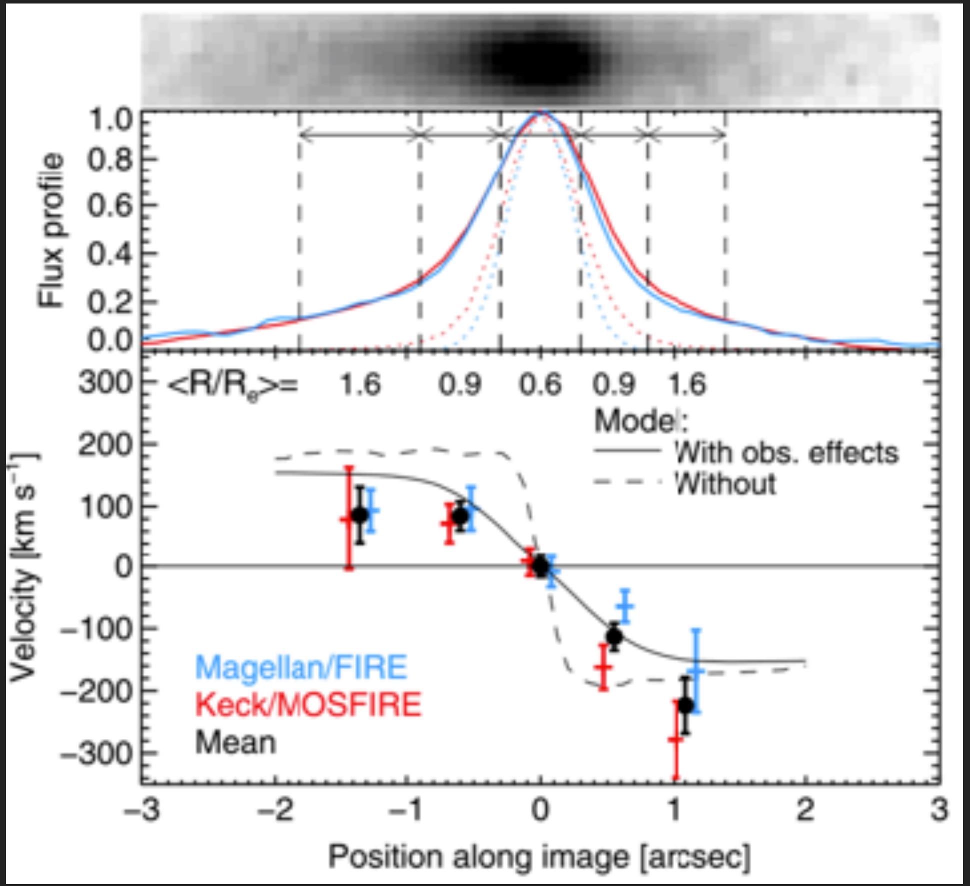
Kinematics of z > 2 Lensed ETGs

Lensed ETGs at z>2 provide opportunities for direct kinematic measurements

- One ETG per 10 clusters
  - a few hundred by HSC





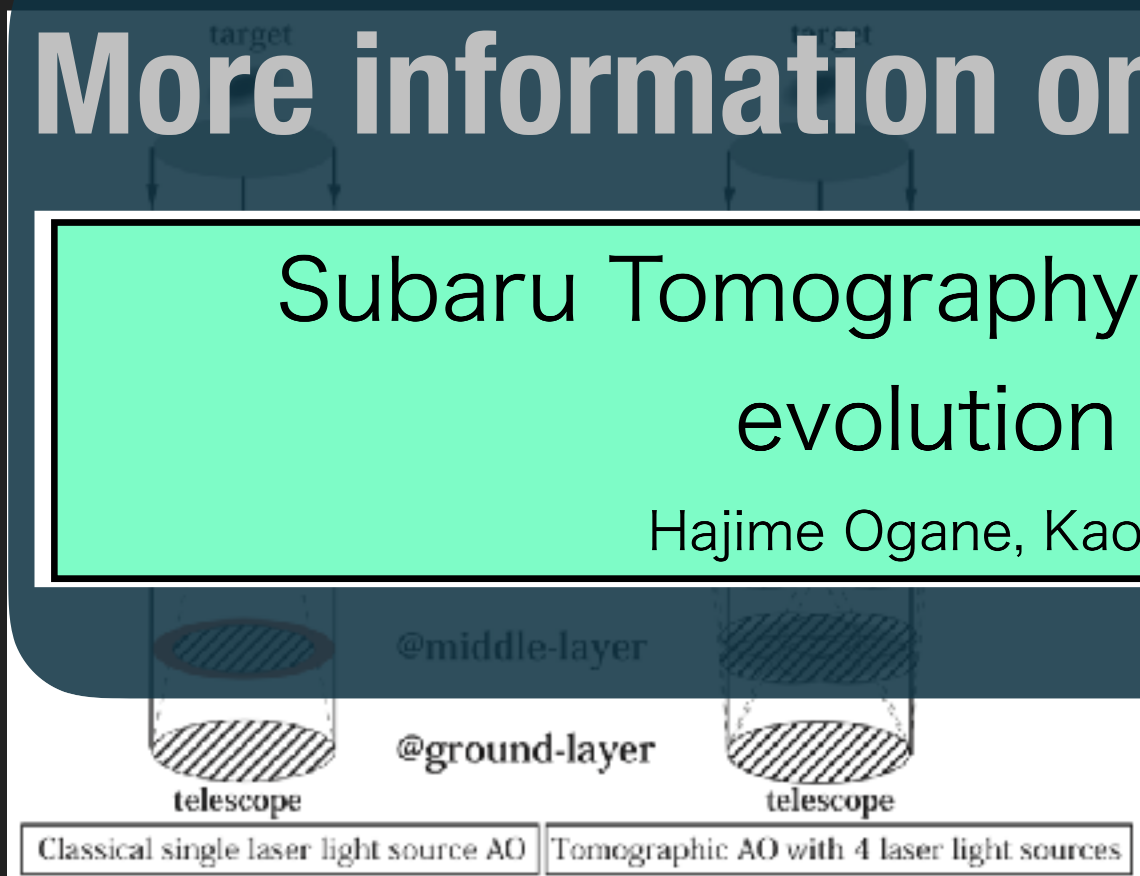


Newman et al., 2015

Direct observation of kinematics at z~1

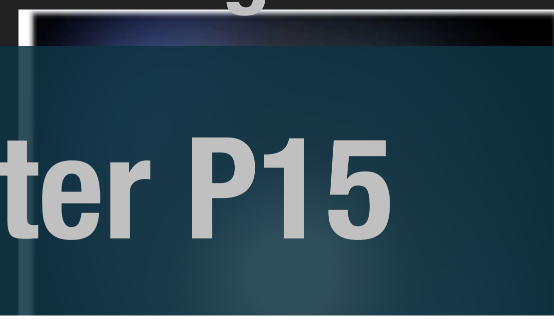
Overcome spatial resolution with laser tomographic AO on the Subaru telescope

Laser tomographic AO (LTAO)



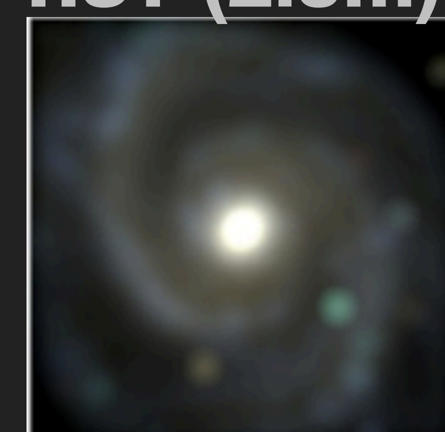
- Wavefront error correction for multiple turbulence layers
  - Diffraction limit in optical
    Spatial resolution = 0.02”

Seeing limited



w/ LTAO

HST (2.5m)



More information on the poster P15

Subaru Tomography Adaptive Optics to study cosmological evolution of galaxy internal structures

Hajime Ogane, Kaoru Omoto, Masayuki Akiyama (Tohoku University)

Galaxy evolution workshop
@Ehime University 2018/6/6-8

END