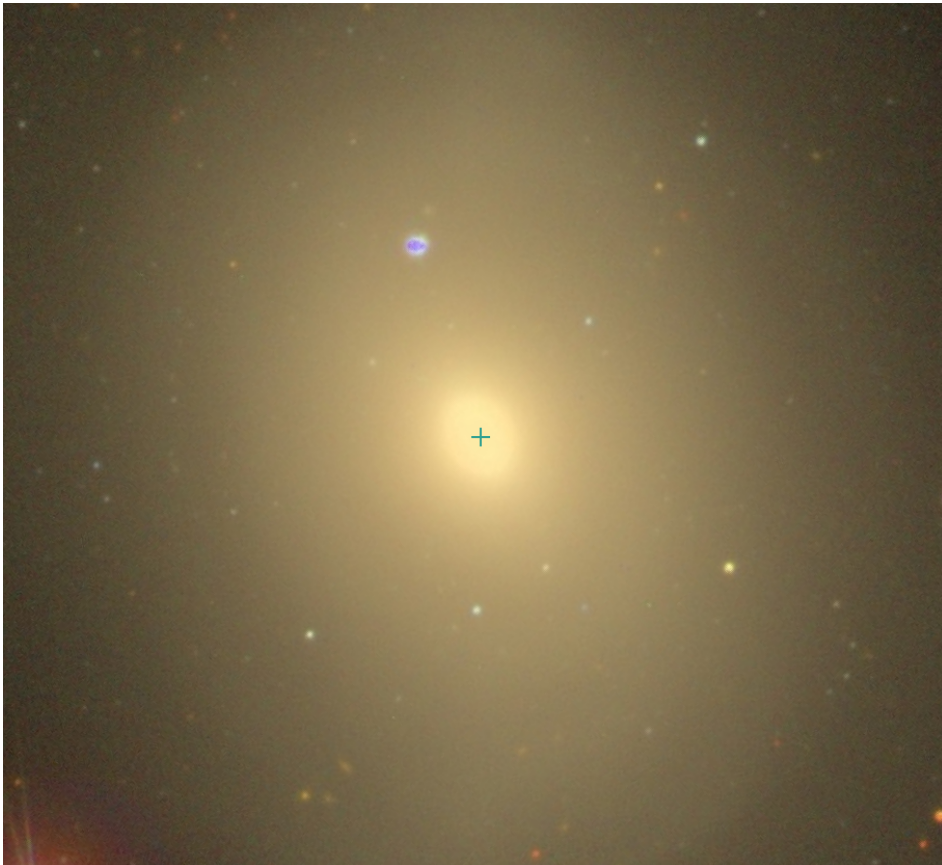


# Rotation of galaxies in Hydrodynamic Cluster Simulations



Hoseung Choi & Sukyoung Yi  
Yonsei University

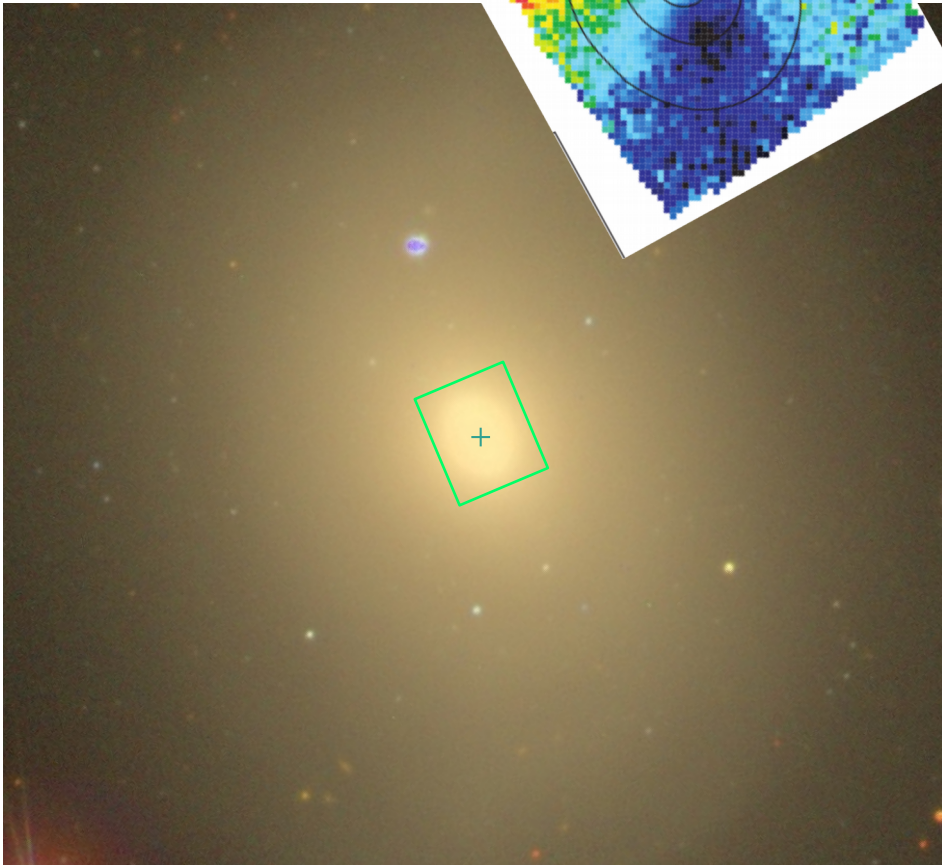
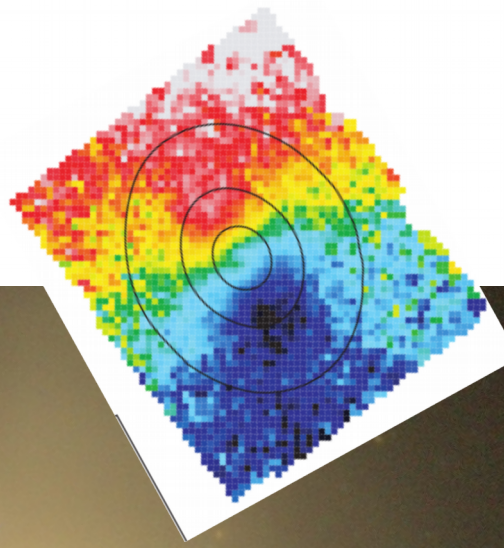
RAMSES User Meeting, Paris, Oct. 6, 2016



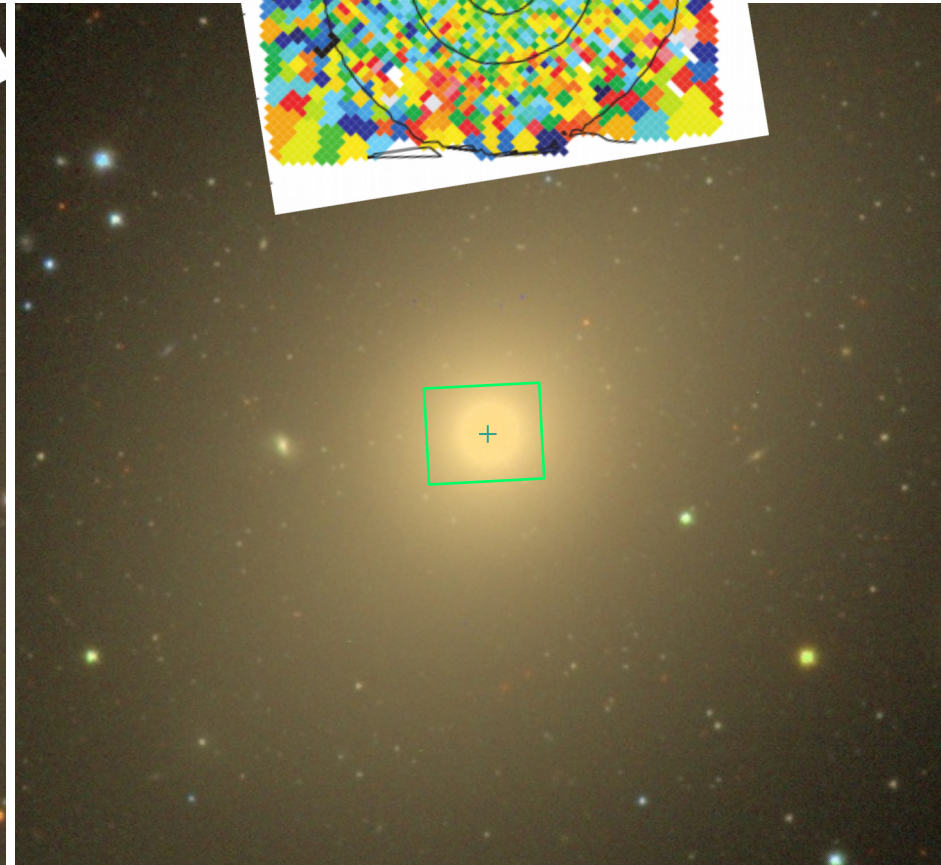
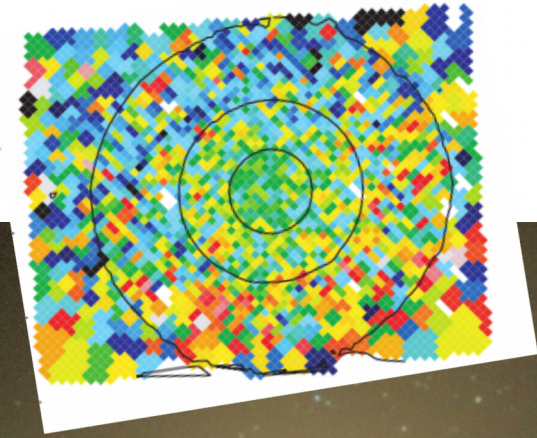
NGC4382



NGC4636

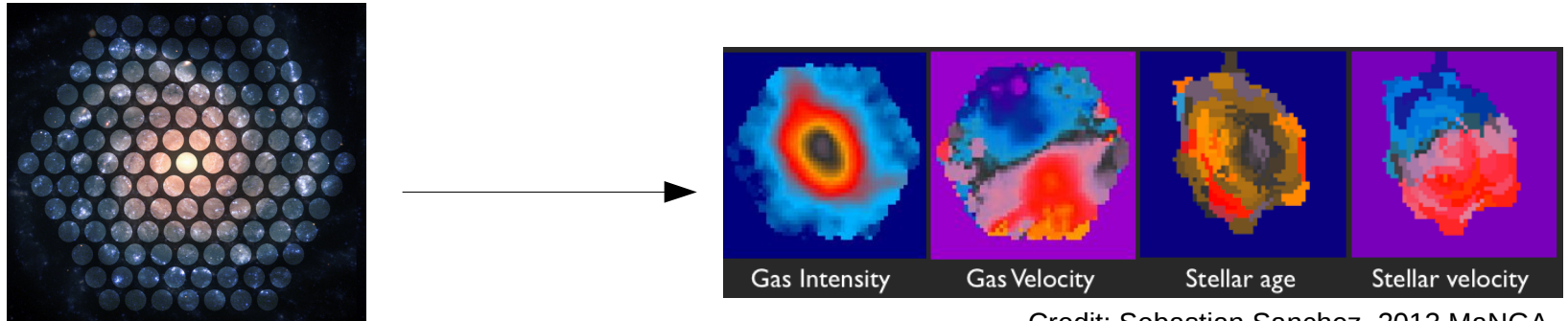


NGC4382

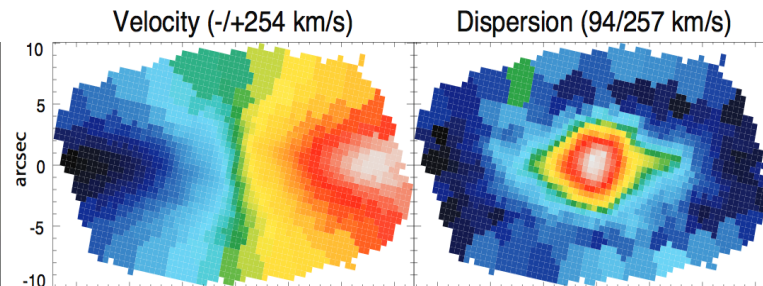


NGC4636

# IFU - Kinematics



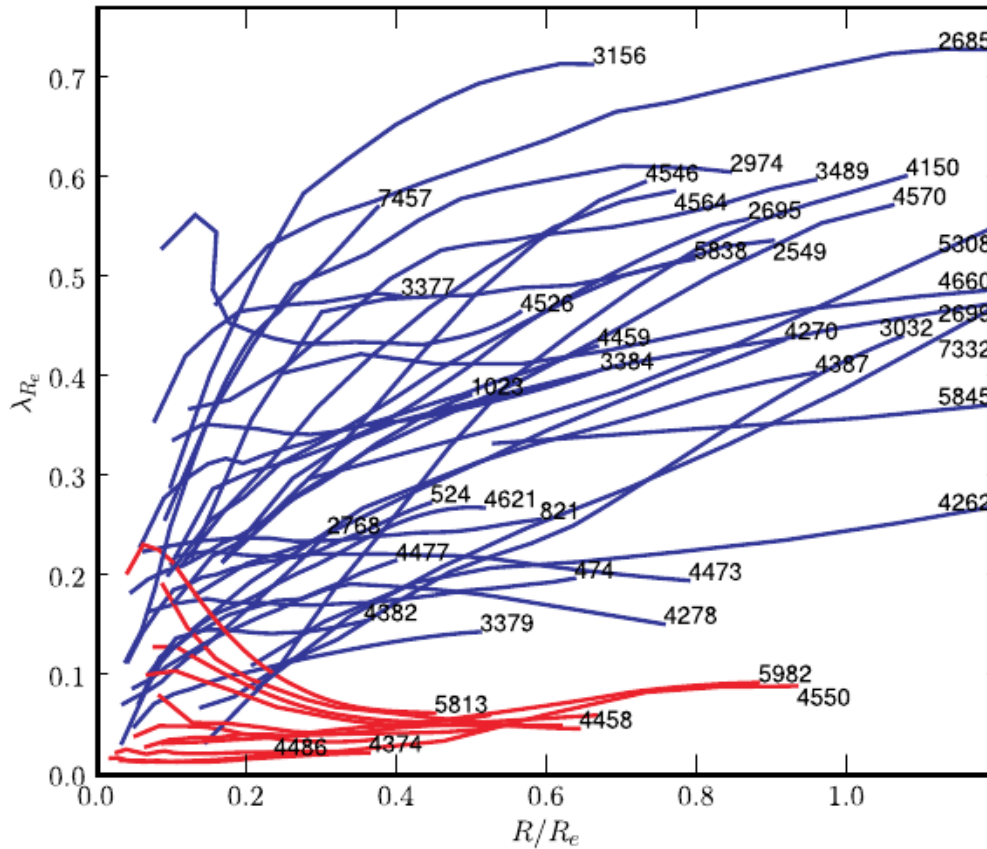
Credit: Sebastian Sanchez, 2013 MaNGA test run



$$\lambda_R \equiv \frac{\langle R |V| \rangle}{\langle R \sqrt{V^2 + \sigma^2} \rangle}$$

Rotation parameter  
(Emsellem + 07)

# Rotation matters

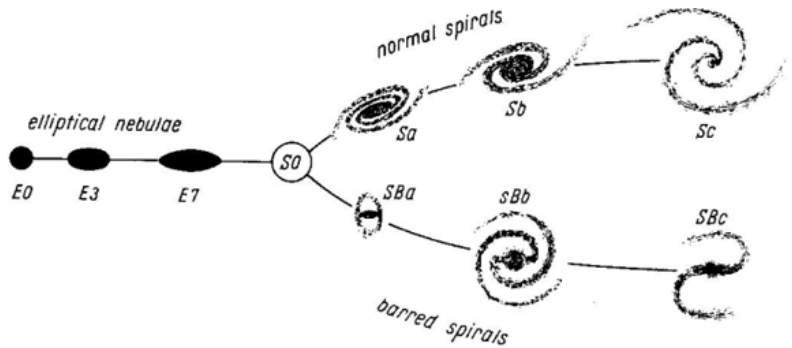


(Emsellem + 07, SAURON)

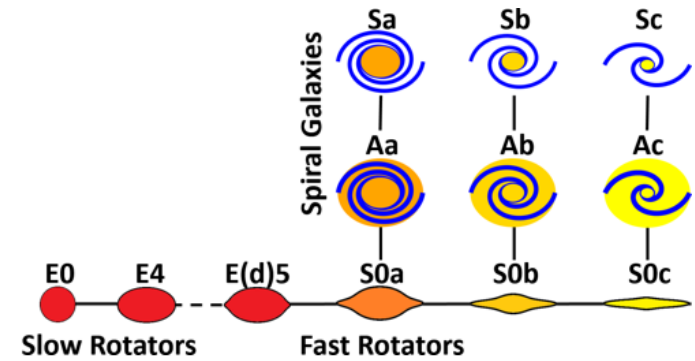
$$\lambda_R \equiv \frac{\langle R |V| \rangle}{\langle R \sqrt{V^2 + \sigma^2} \rangle}$$

Rotation parameter  
(Emsellem + 07)

# Rotation matters



Hubble (1936) tuning fork



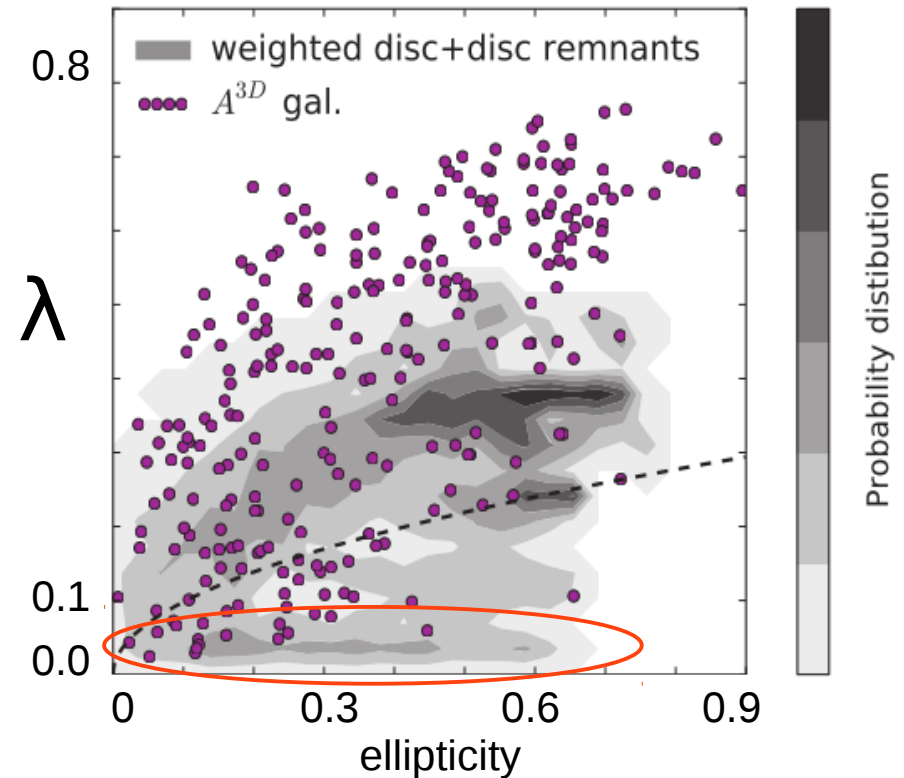
The ATLAS<sup>3D</sup> comb (2011)

SAURON, ATLAS3D, SAMI, SLUGGS, MASSIVE, MaNGA, Hectospec.....

Q: What determines the galaxy rotation?

# Theoretical studies

- 1:1 merger simulations
  - (Jesseit + 09, Bois +10 & 11, ...)
- 70 late-type binary mergers
- 200 projections
- Flat slow rotators



(Bois + 11)

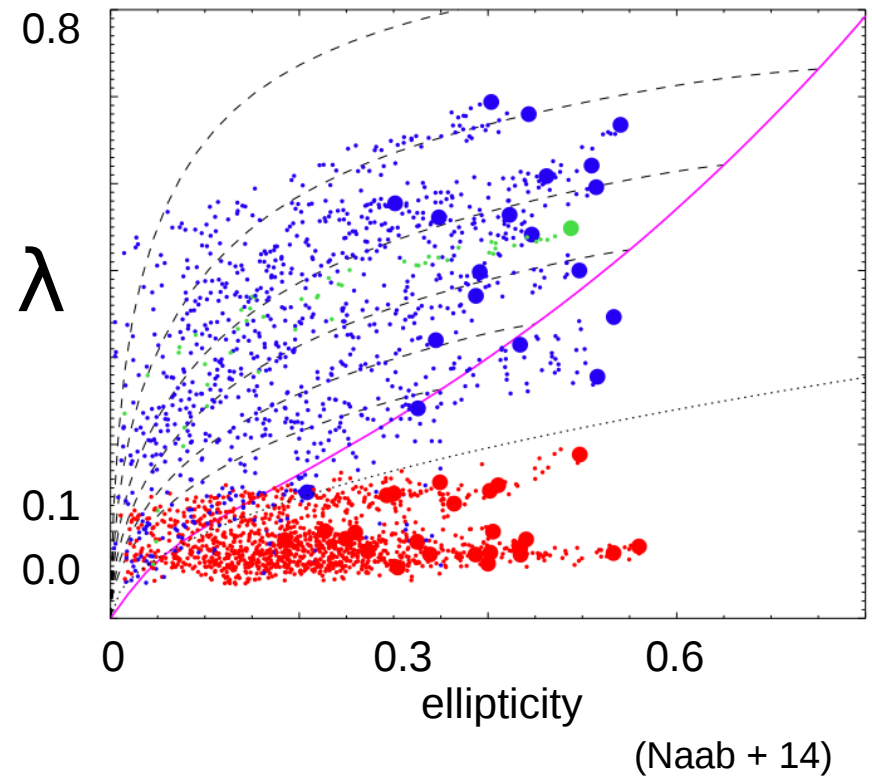
Need cosmological context.



# Theoretical studies

- SAM
  - (Khochofar + 11)
- Cosmological simulation
  - (Moody +14, Naab +14)
- **44 galaxies**
- **Many (minor) mergers**
- **Round slow rotators**

Larger sample is wanted.

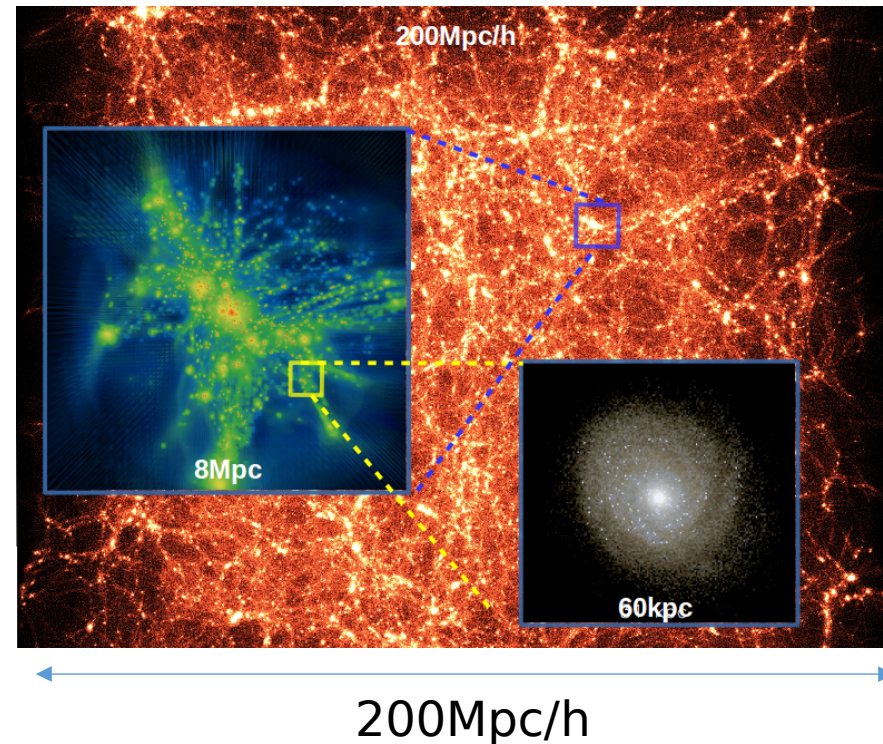


# This study...

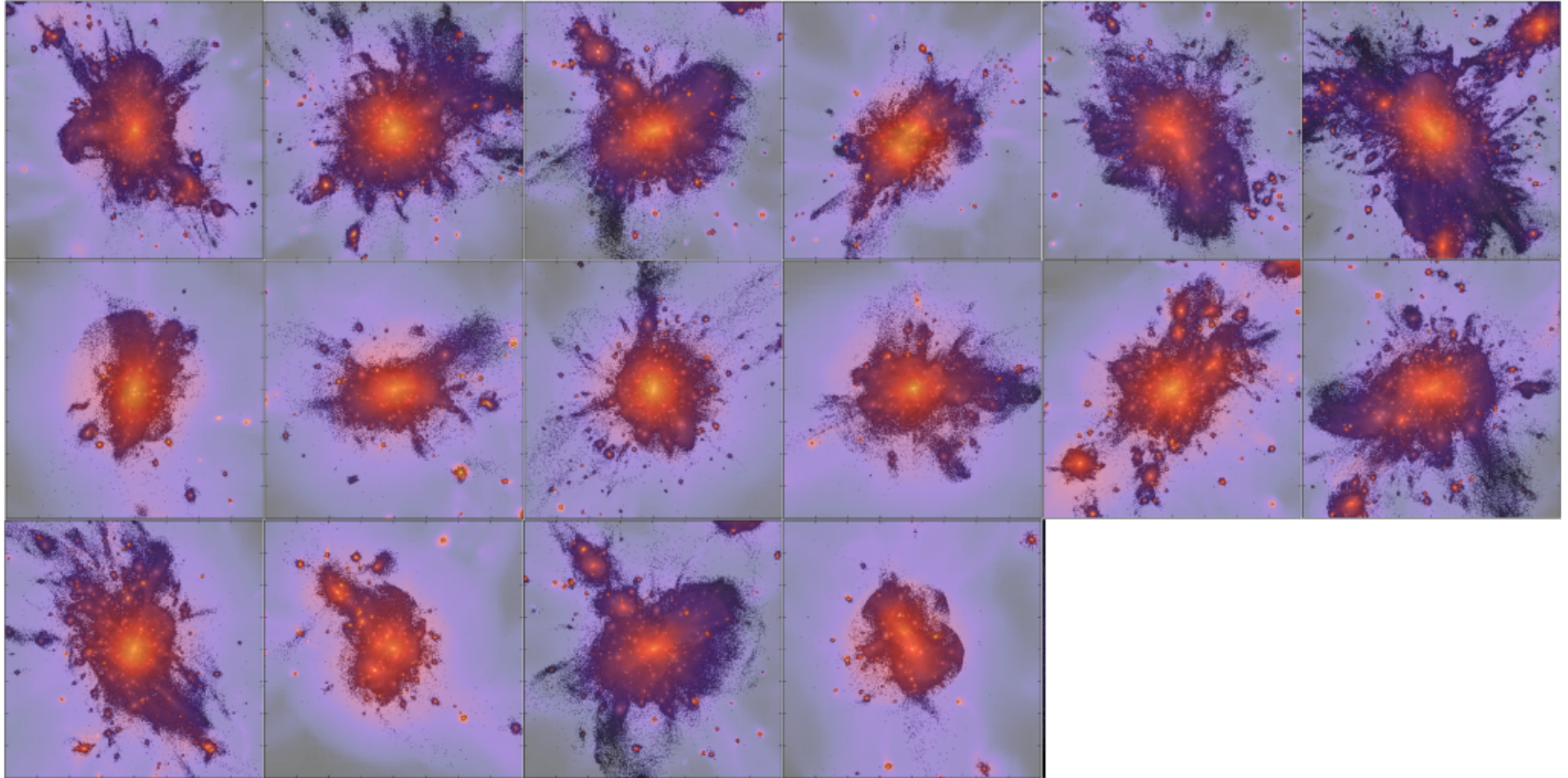
- Cosmological context
- Large sample of galaxies
- Evolution history of rotation
- Contribution of mergers

# Cluster zoom-in simulations

- RAMSES (AMR)
- Baryon physics
  - SF, SN, AGN (Dubois +12)
- 16 clusters in 200Mpc/h
- $10^{13.5} M_{\odot} < M_{\text{halo}} < 10^{15} M_{\odot}$
- $dx = 0.76 \text{kpc/h}$ 
  - Illustris, Eagle.

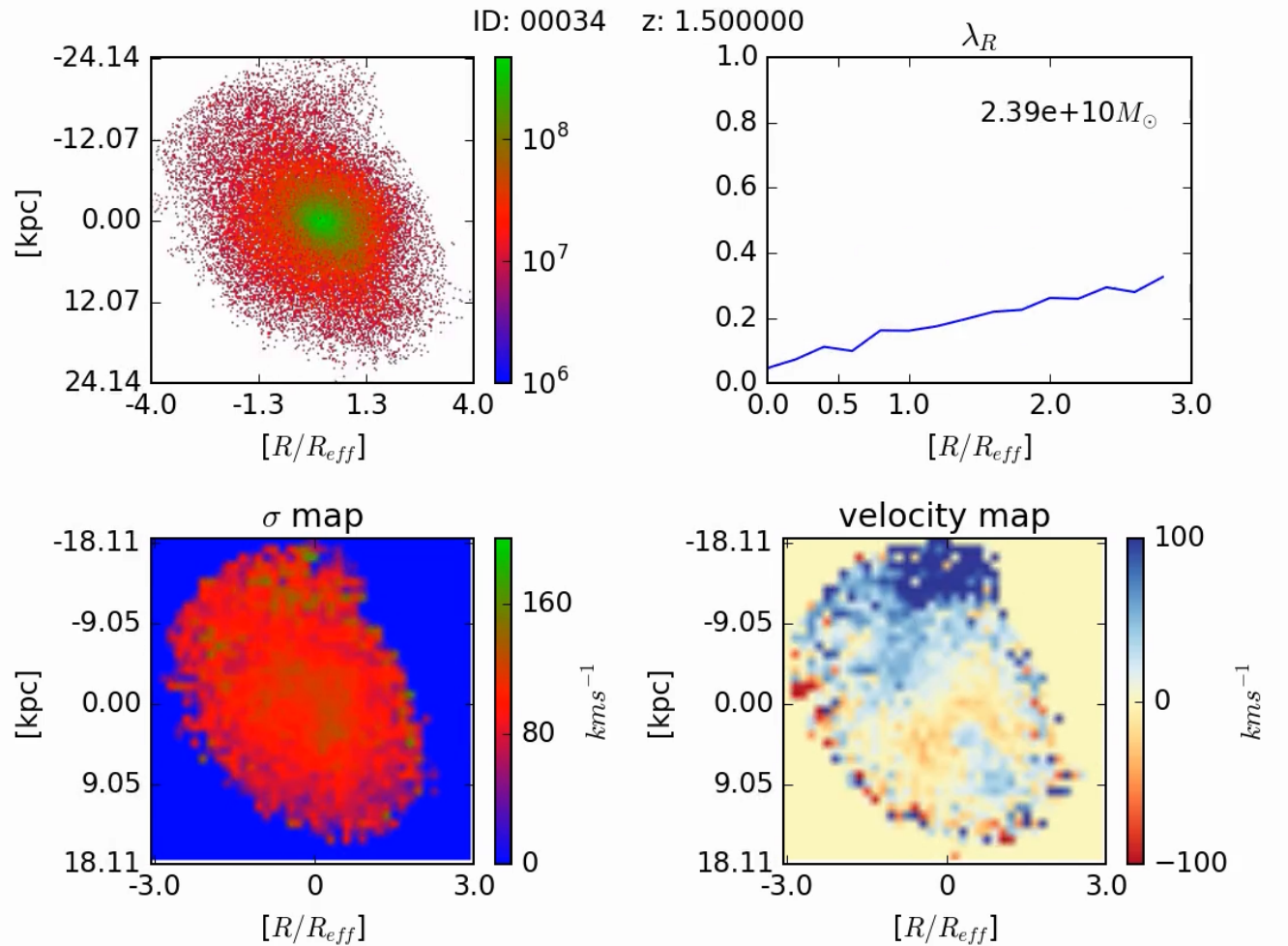


# 16 clusters

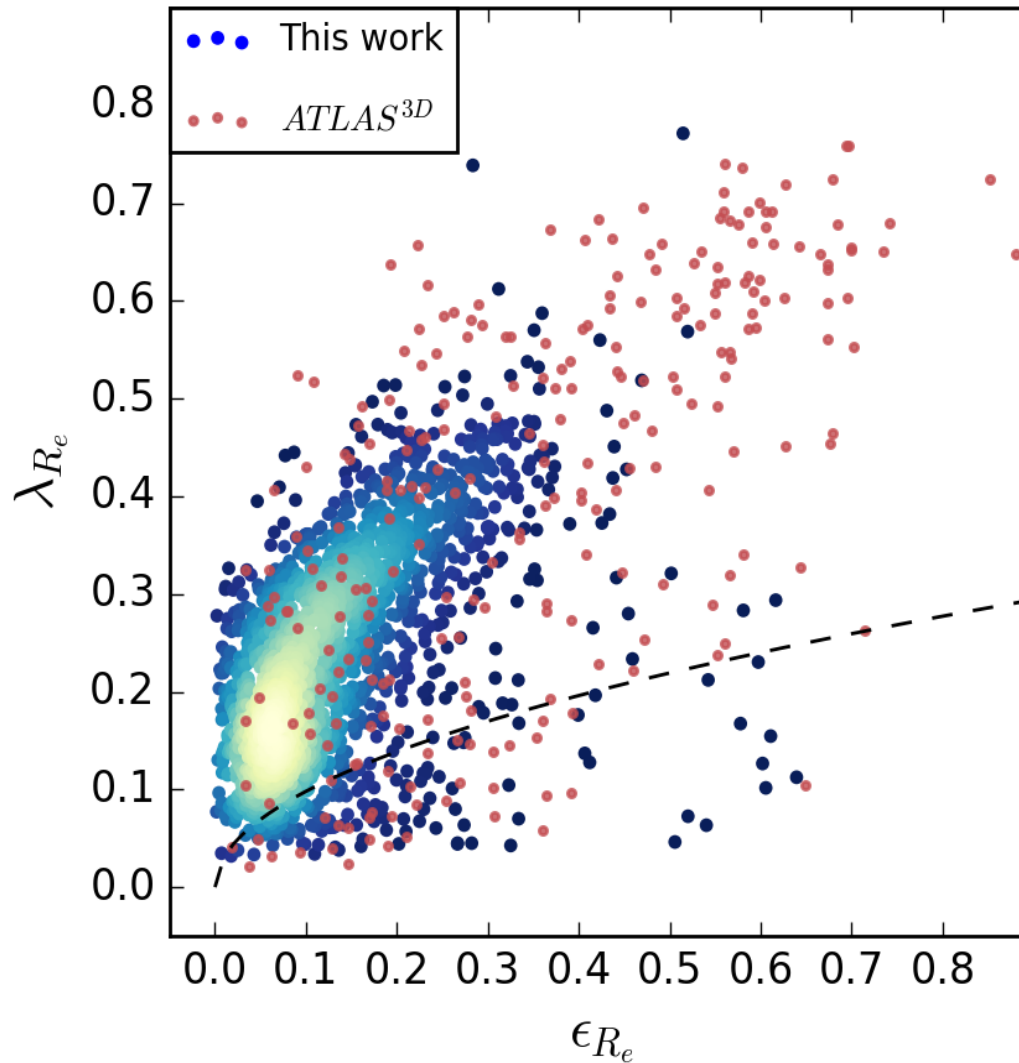


# Results

# Rotation parameter

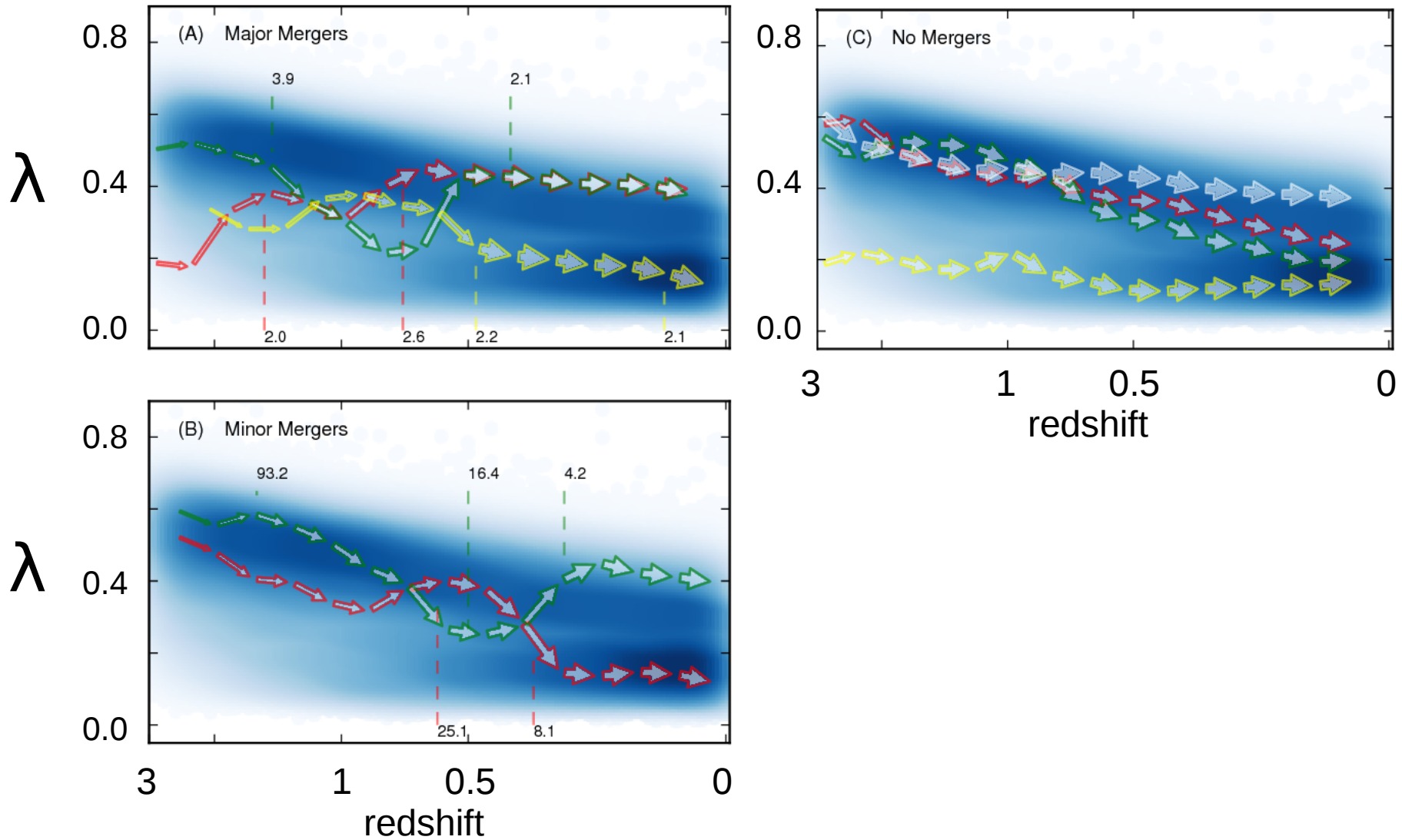


# Rotation parameter at z=0



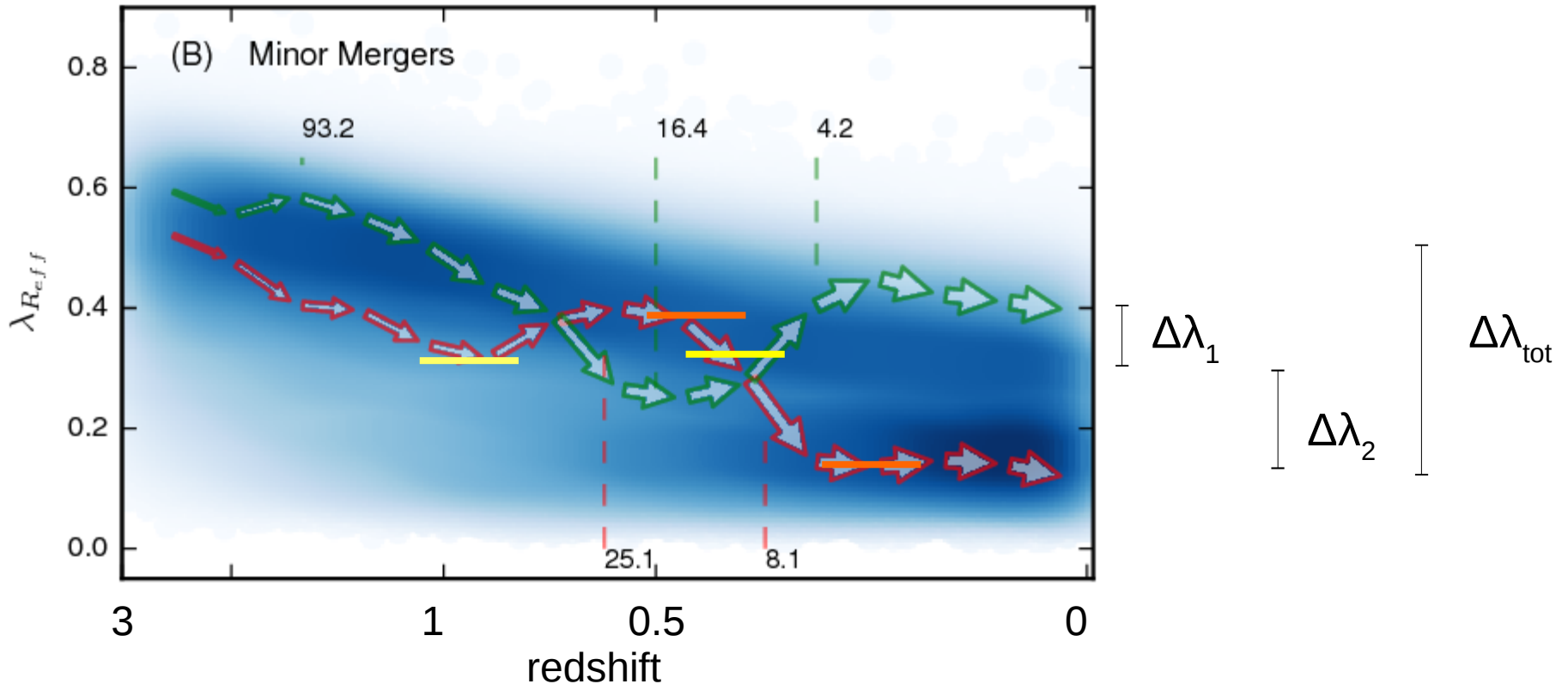
- 1Reff
- N = 1726

# Evolution history





# Measuring $\Delta\lambda$

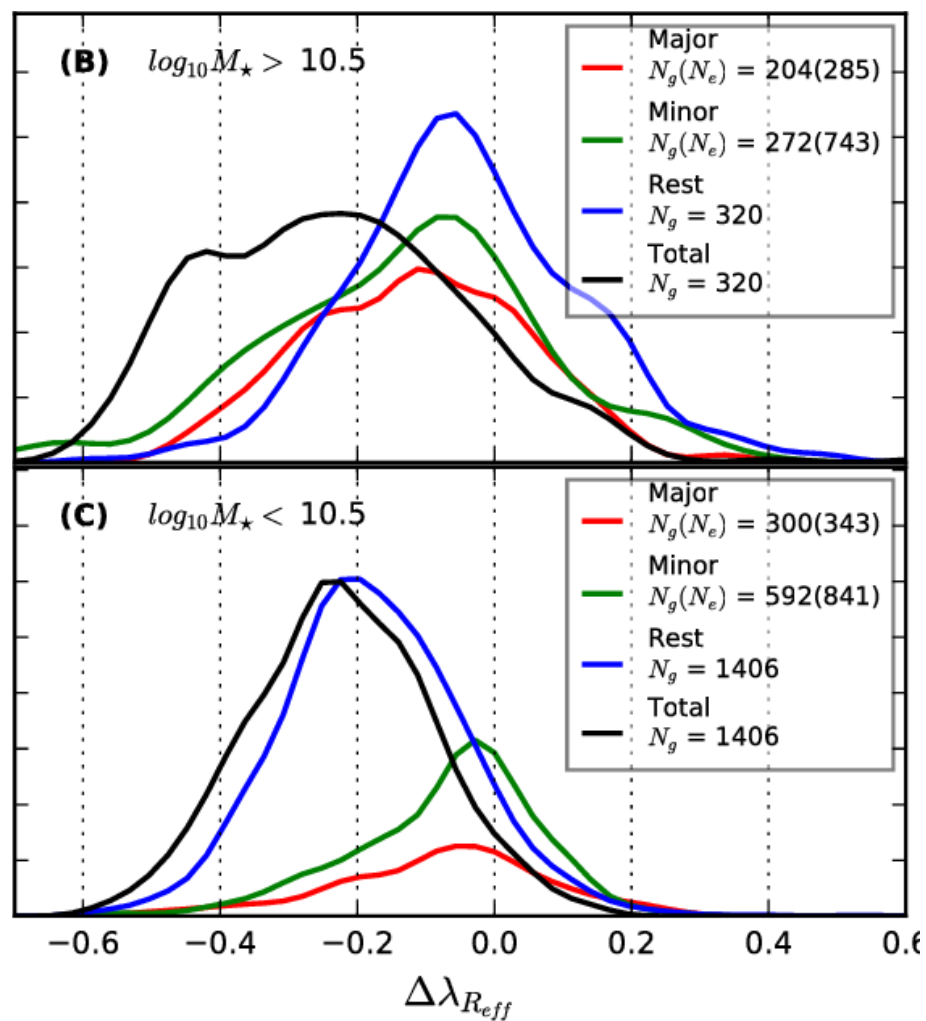
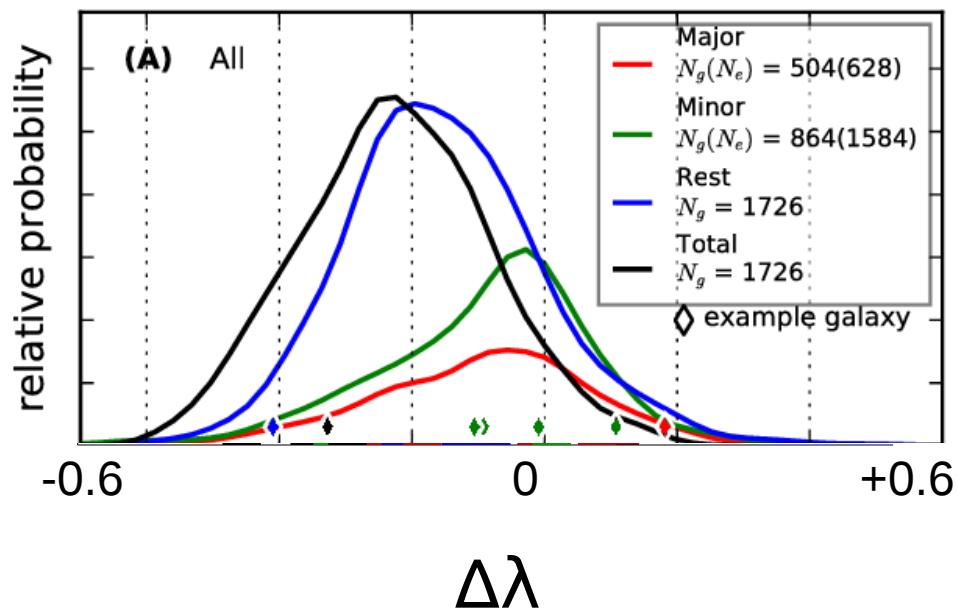


$$\Delta\lambda_{\text{tot}} = -0.4 = +0.15 - 0.25 - 0.3$$

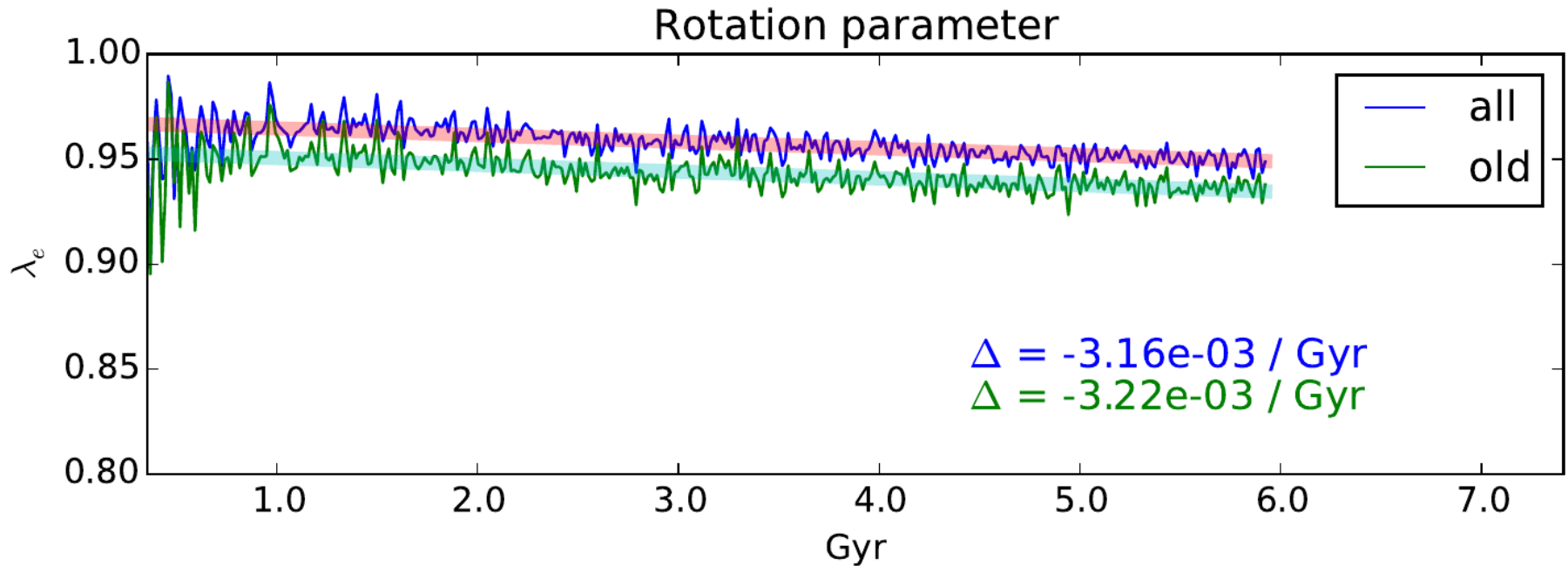
$(\Delta\lambda_1)$      $(\Delta\lambda_2)$      $\Delta\lambda_{\text{Rest}}$

# Major / minor / The rest

$$\Delta\lambda_{total} = \sum_i \Delta\lambda_{Major,i} + \sum_j \Delta\lambda_{minor,j} + \Delta\lambda_{Rest}$$



# Numerical effect?



- Isolated Sb galaxy
- 150, 300, 600pc resolution

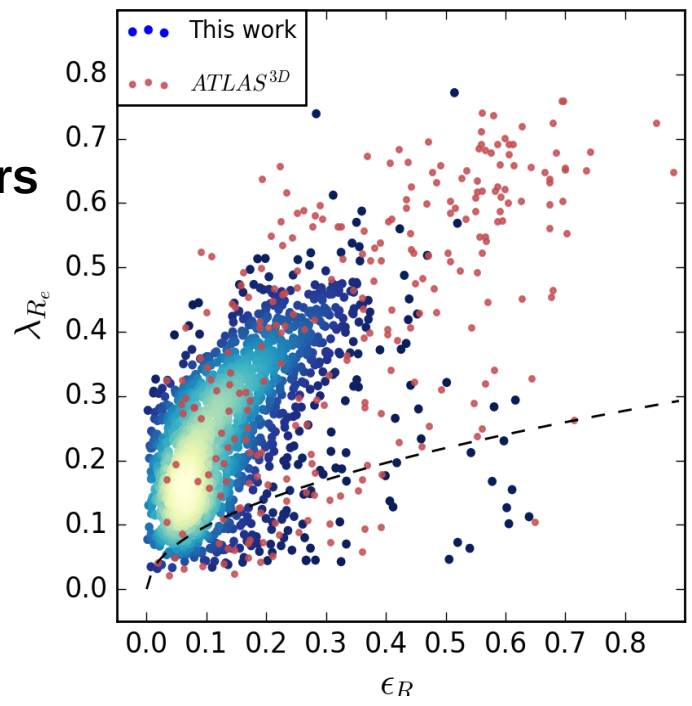
- Summary

- Large sample of simulated galaxies in dene region
- Continuous  $\lambda$  distribution
- Evolution towards slower rotation
  - Large galaxies ( $\sim 100$ )
    - Mergers are important
  - Small galaxies ( $\sim 1000$ )
    - dominated by **non-mergers!**

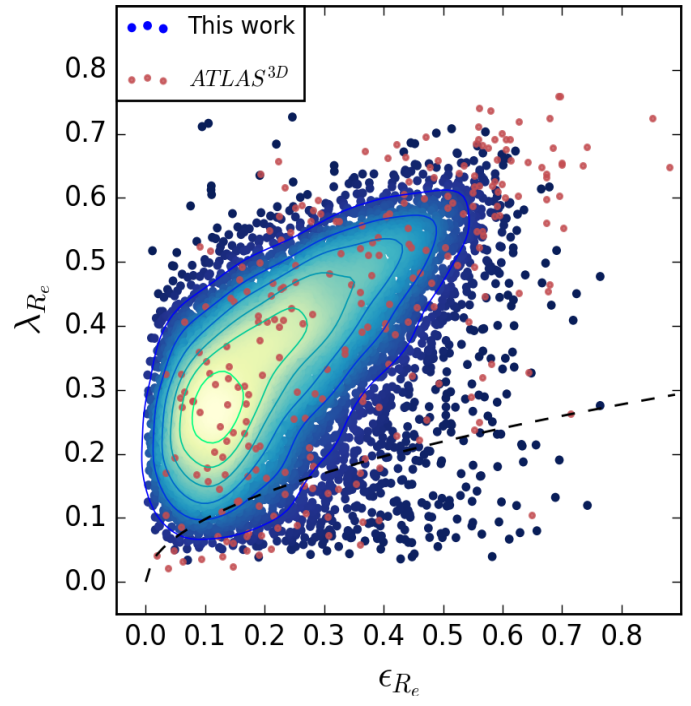
Submitted

What about field?

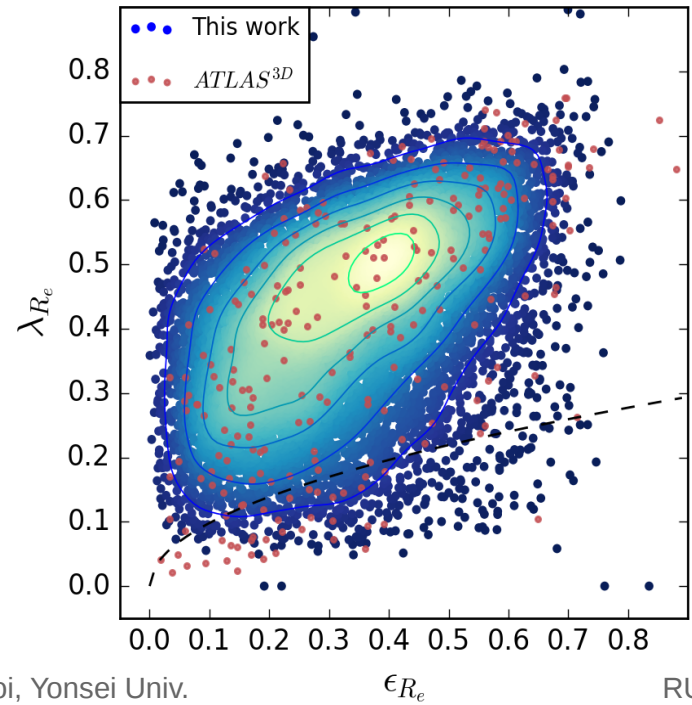
**z=0**  
**Clusters**



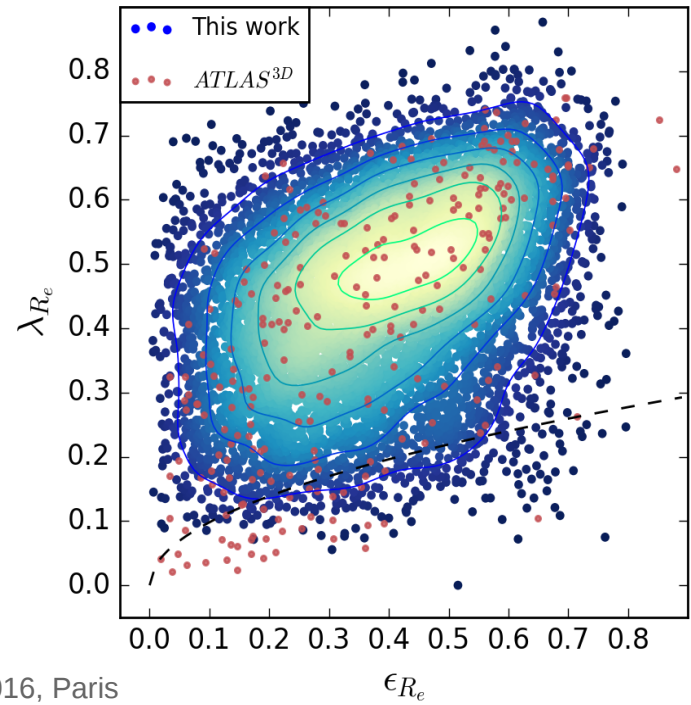
**z=1**



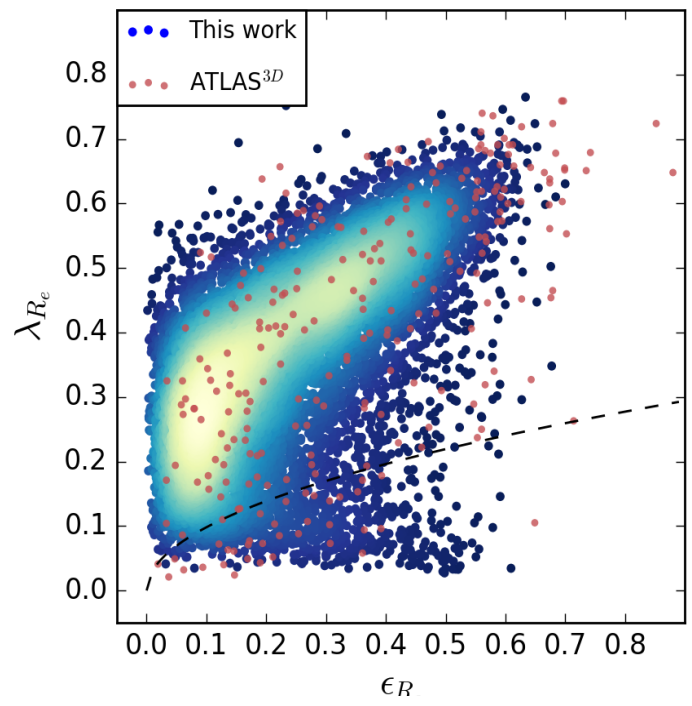
**z=2**



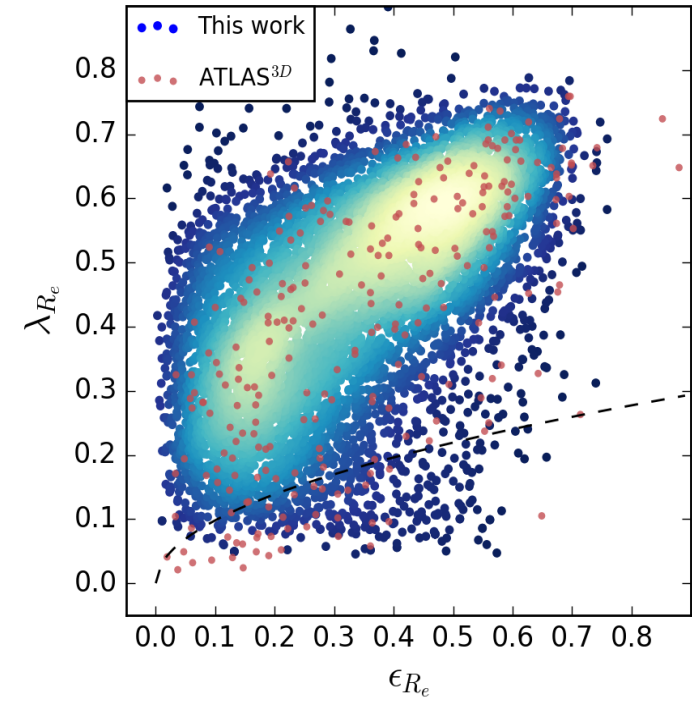
**z=3**



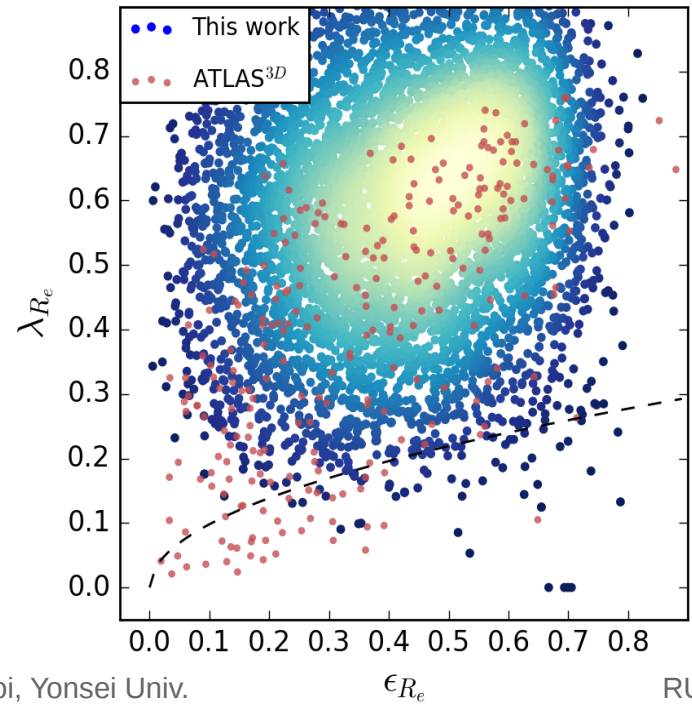
**z=0**  
**HAGN**



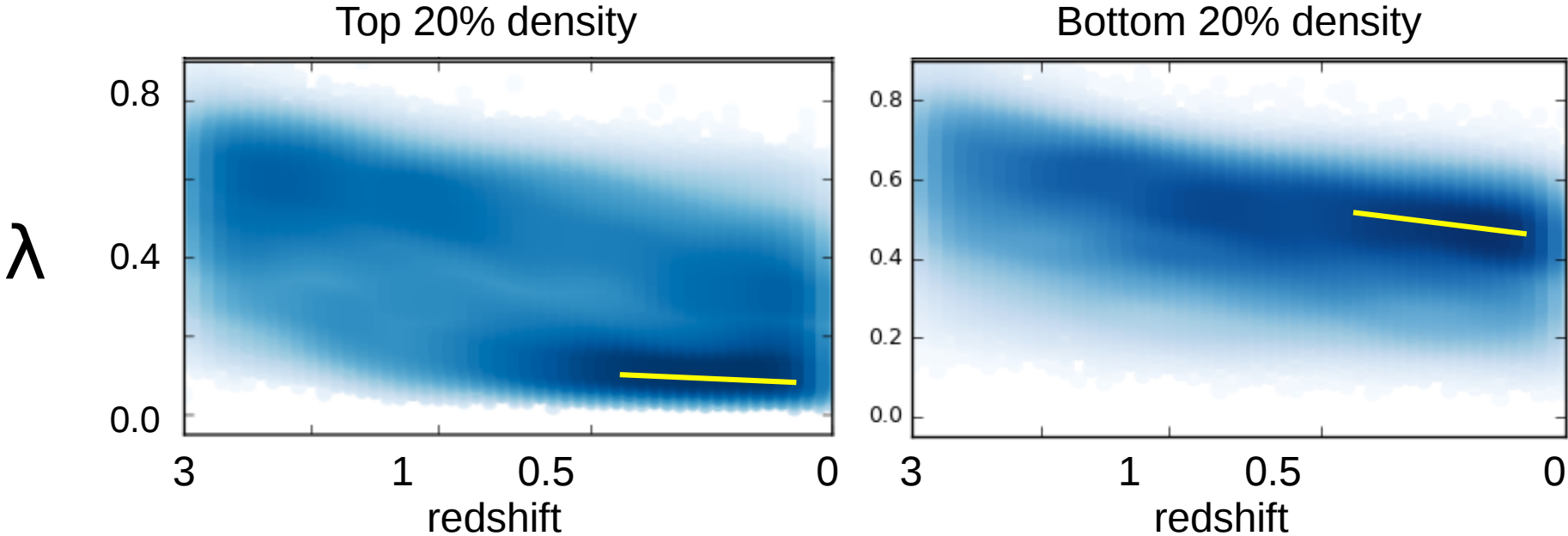
**z=1**



**z=2**



# Horizon-AGN





Thank you!