Thin and thick discs of spiral galaxies

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Snowflake

M101 ESA/NASA

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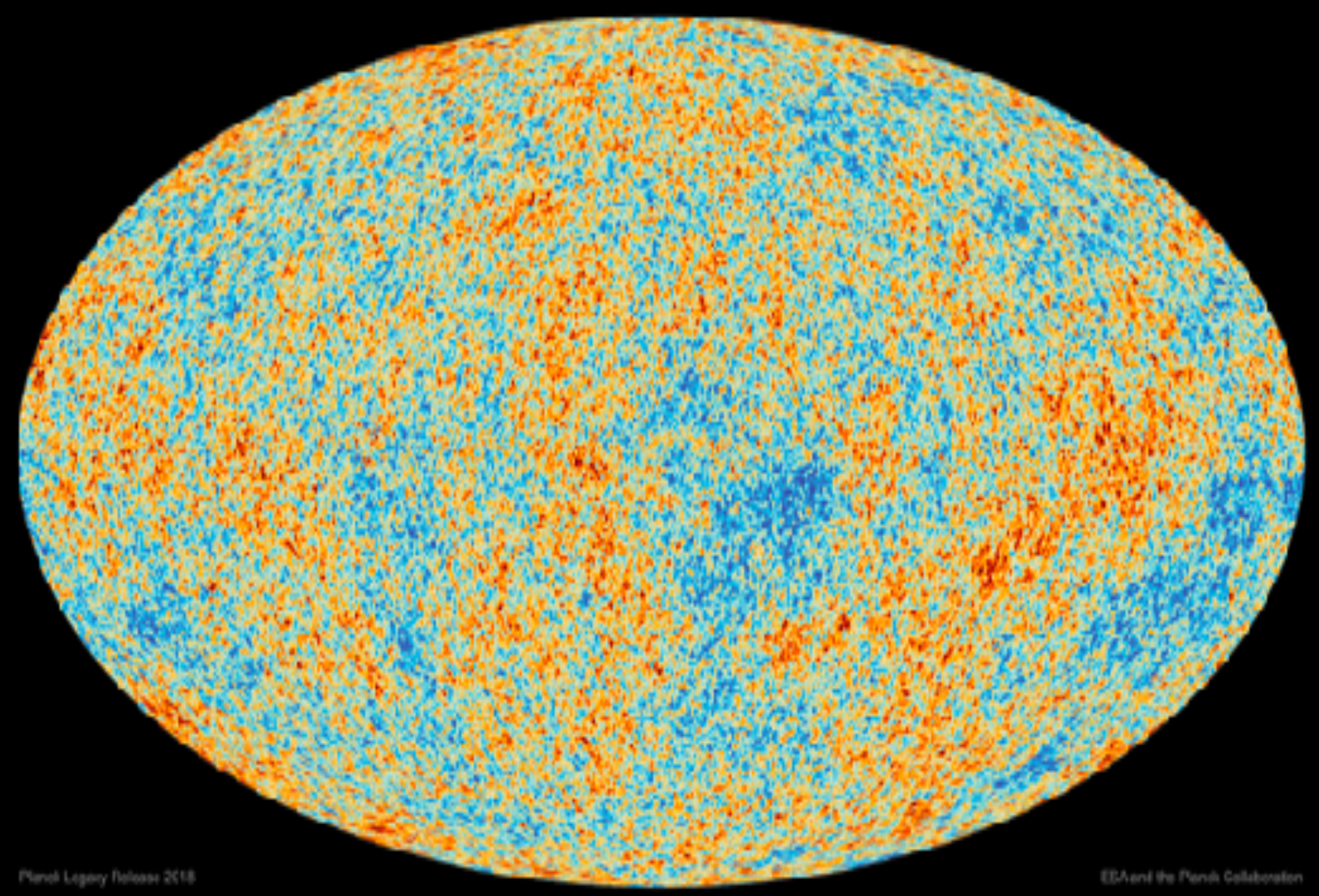
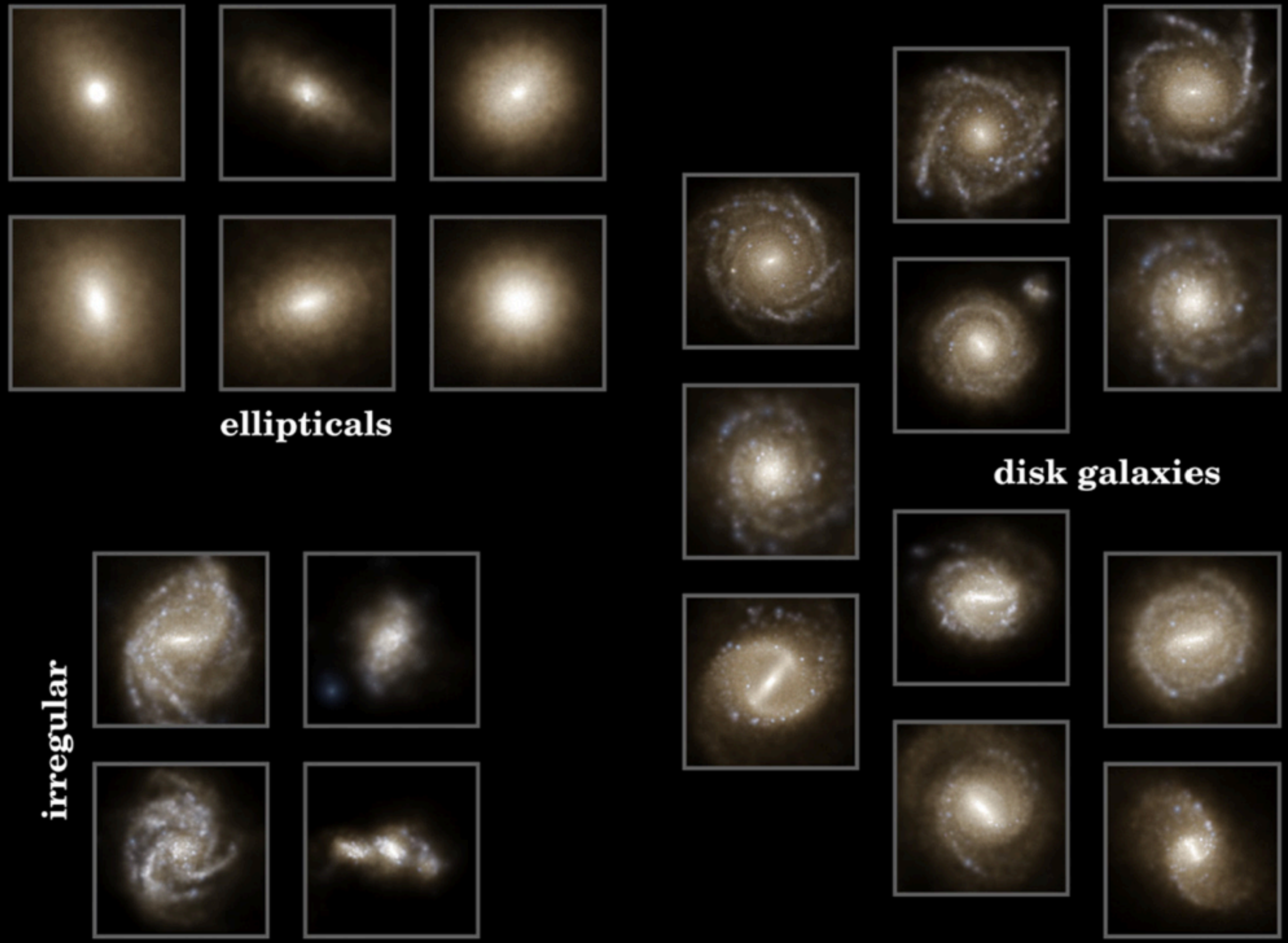
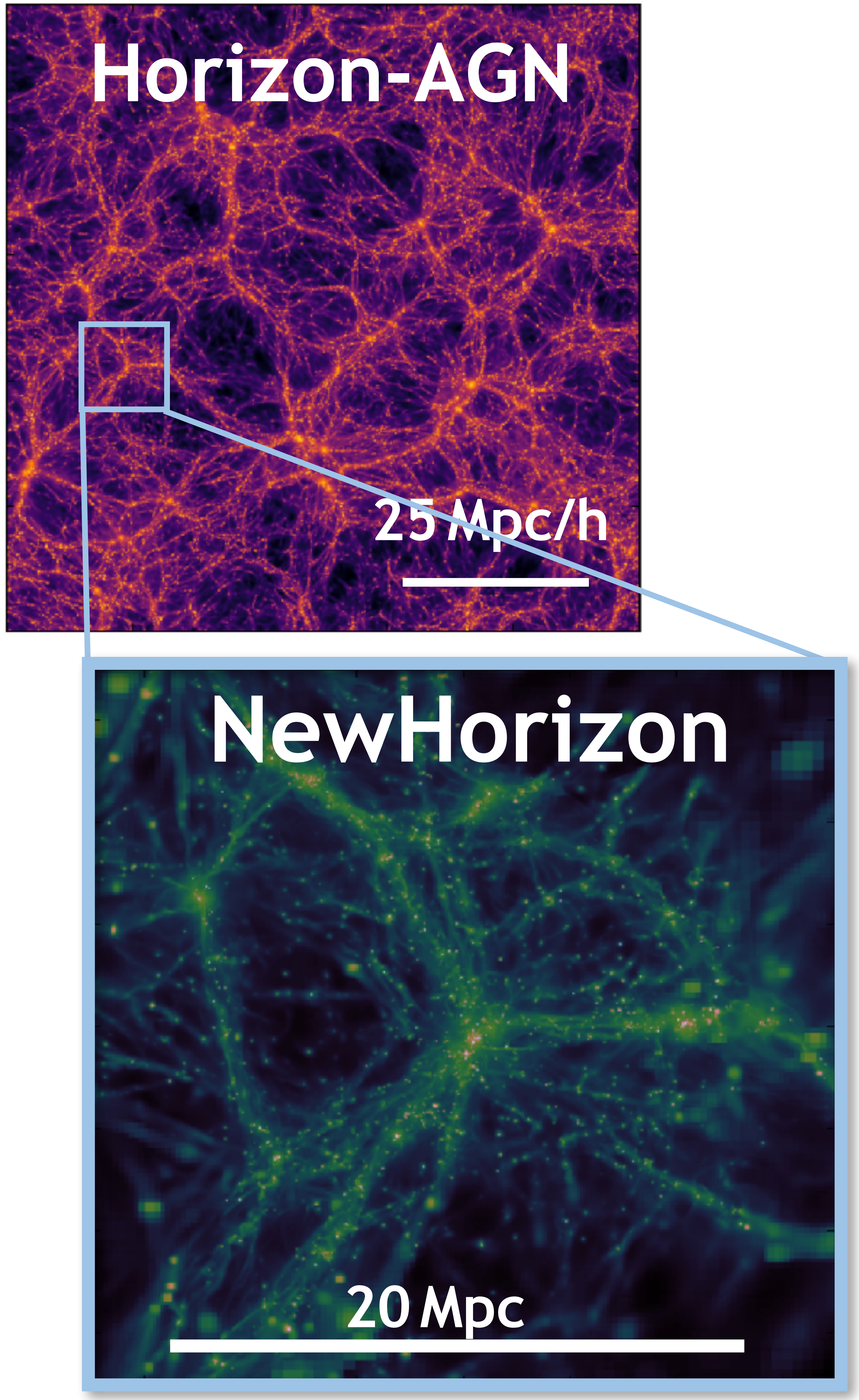
Numerical simulation of GF





Vogelsberger et al. 2014 (Illustris)

Thin discs



NewHorizon (Dubois et al. *2021, A&A*)

- Cosmological zoom-in simulation
- Medium-size (D ~ 20 Mpc) volume
- ~150 galaxies of $M_s > 1e9$
- Resolution: dx_best = 35 **pc**, dm_s~1e4, dm_{DM}~1e6
- Computing: 80 Mhr to reach z=0.17

NewHorizon2

- Resolution: dx_best = 70 **pc**, dm_s~2e4, dm_{DM}~1e6
- Chemical elements: H,D,C,N,O,Mg,Si,S,Fe

Cf. dx ~ 1 kpc (Eagle, Horizon-AGN, Illustris) 0.3 kpc (TNG50)

NewHorizon

Dubois et al. 2021

Field environment
Ramses
4800 cores
80 Mhr
D = 20 Mpc
dx > 34 pc
dm_star = 1e4
AGN & Stellar FB
1000 snapshots

DM
Hot gas
Stars

Credit: Jinsu Rhee

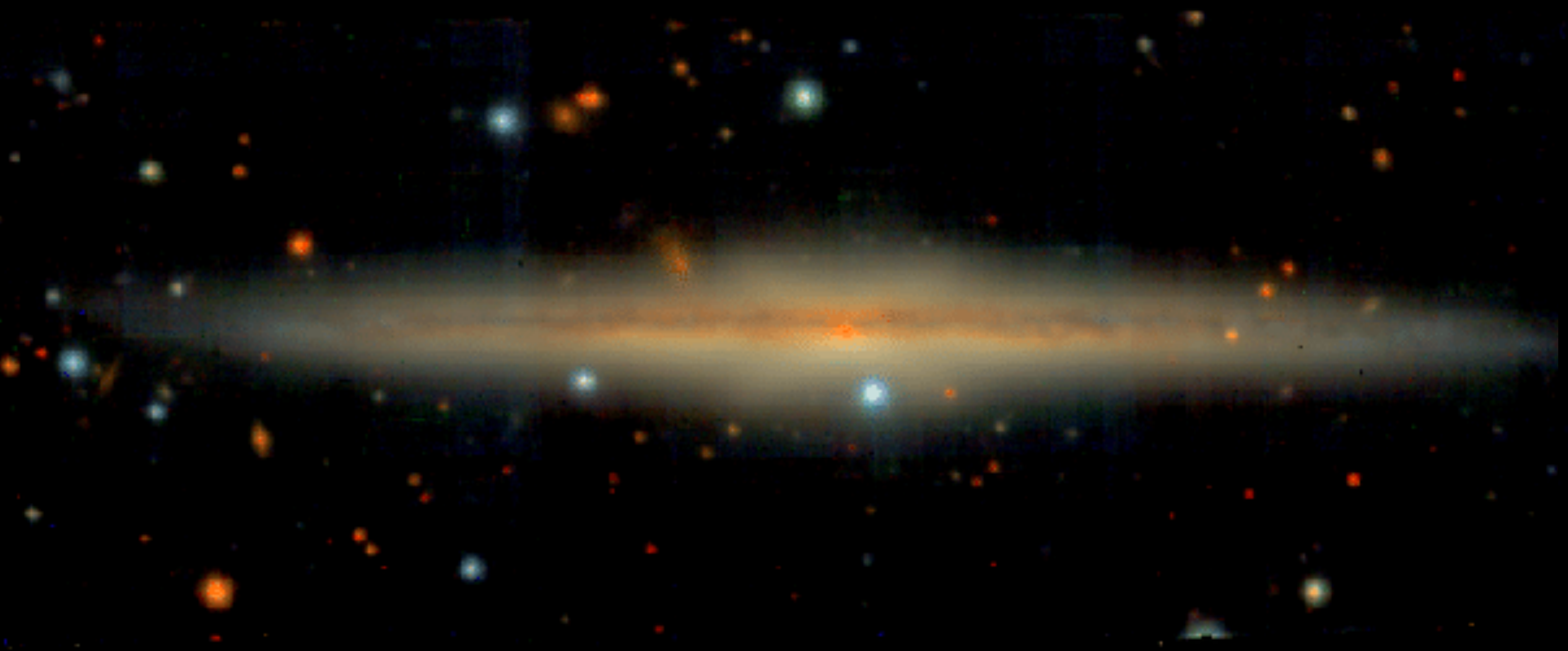
Disc formation

NH in SKIRT

NH: ID-1-867

Credit: JK Jang

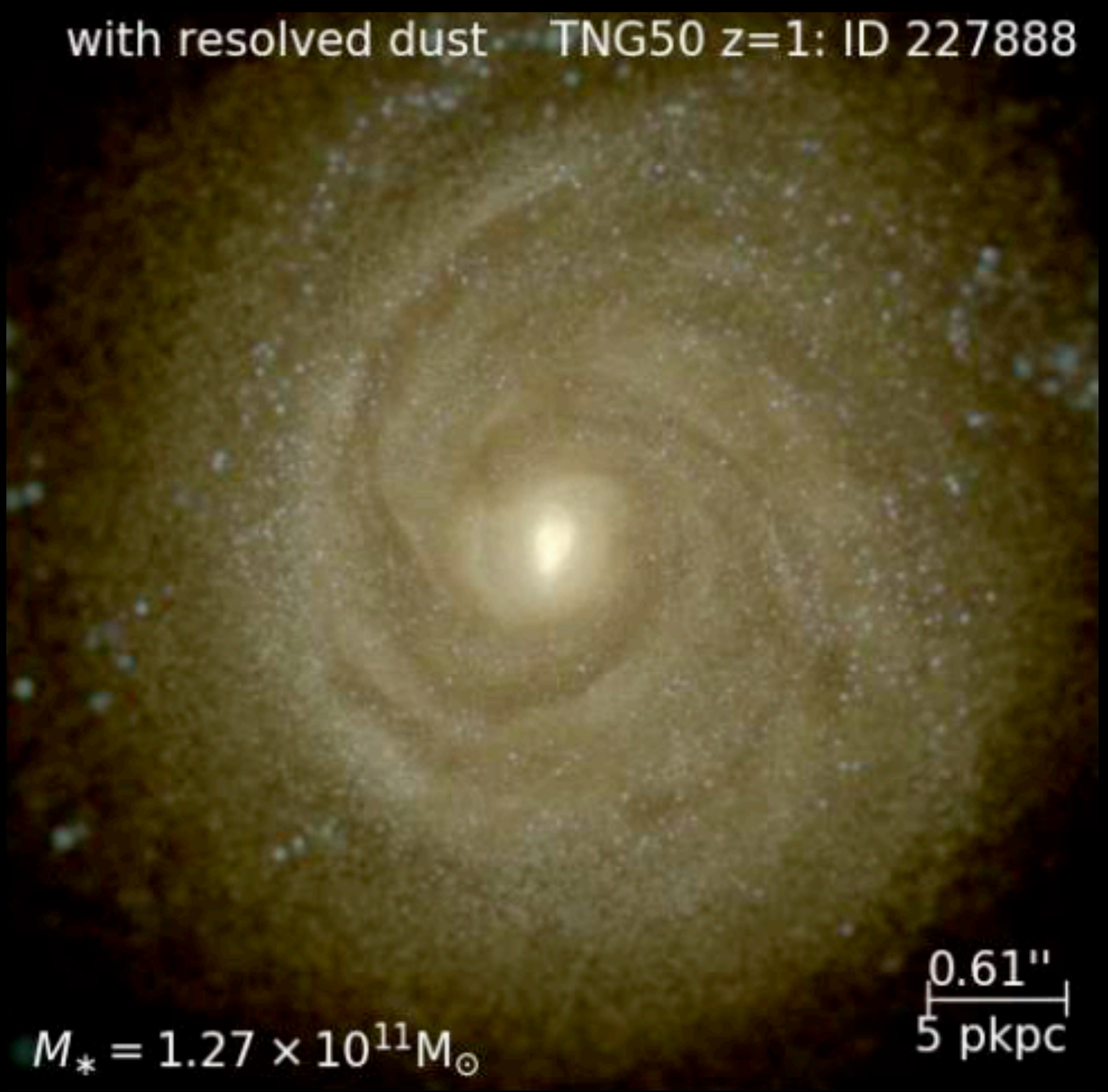
Observation

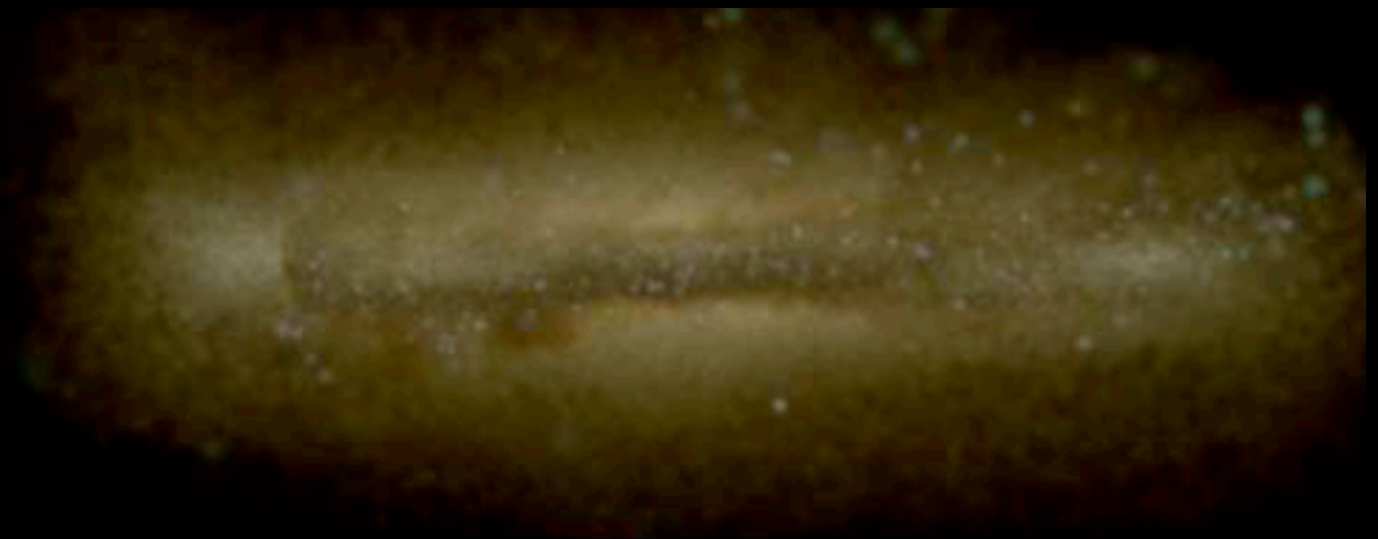


UGC 10738 (Scott et al. 2021)

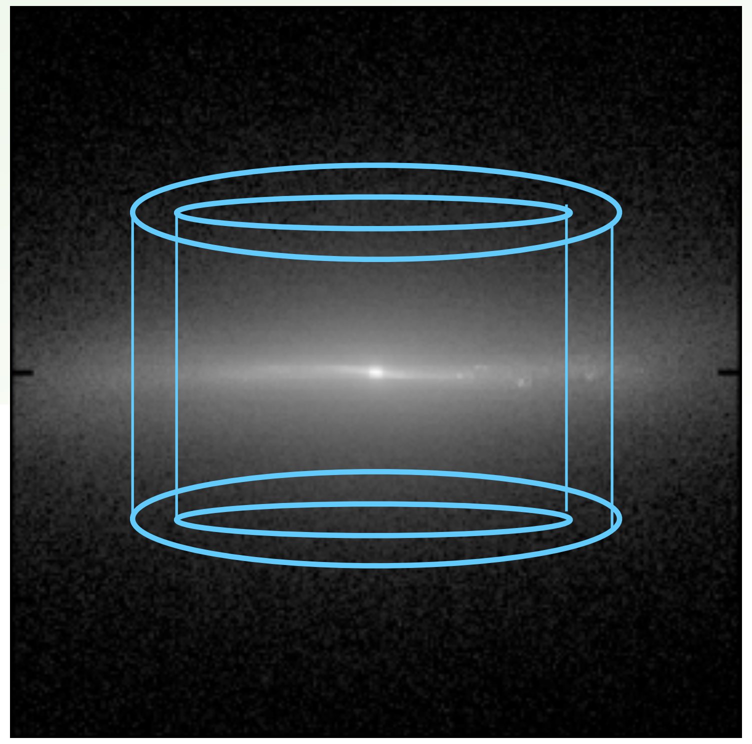
NewHorizon

TNG50



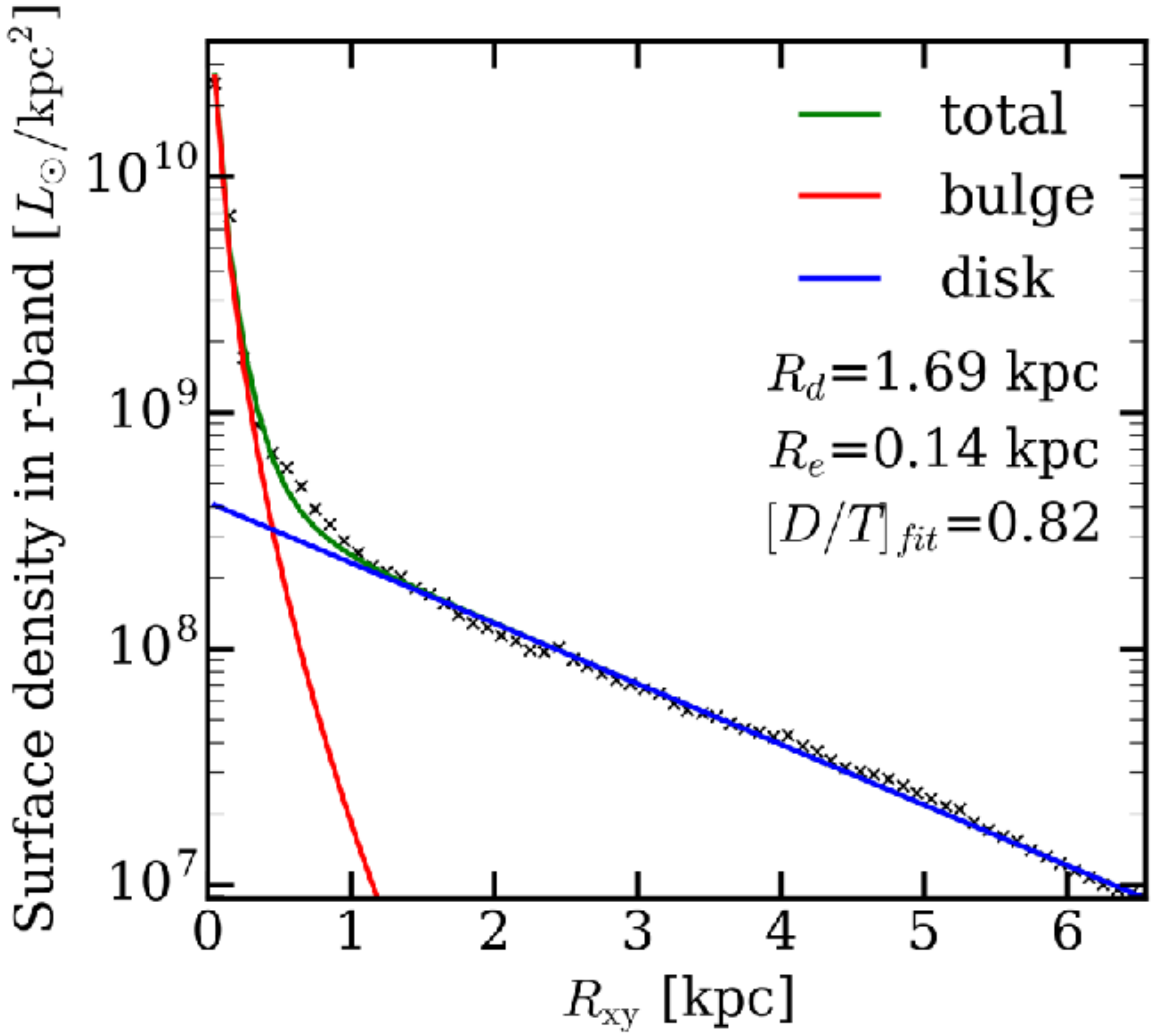


High-resolution allows profile fits



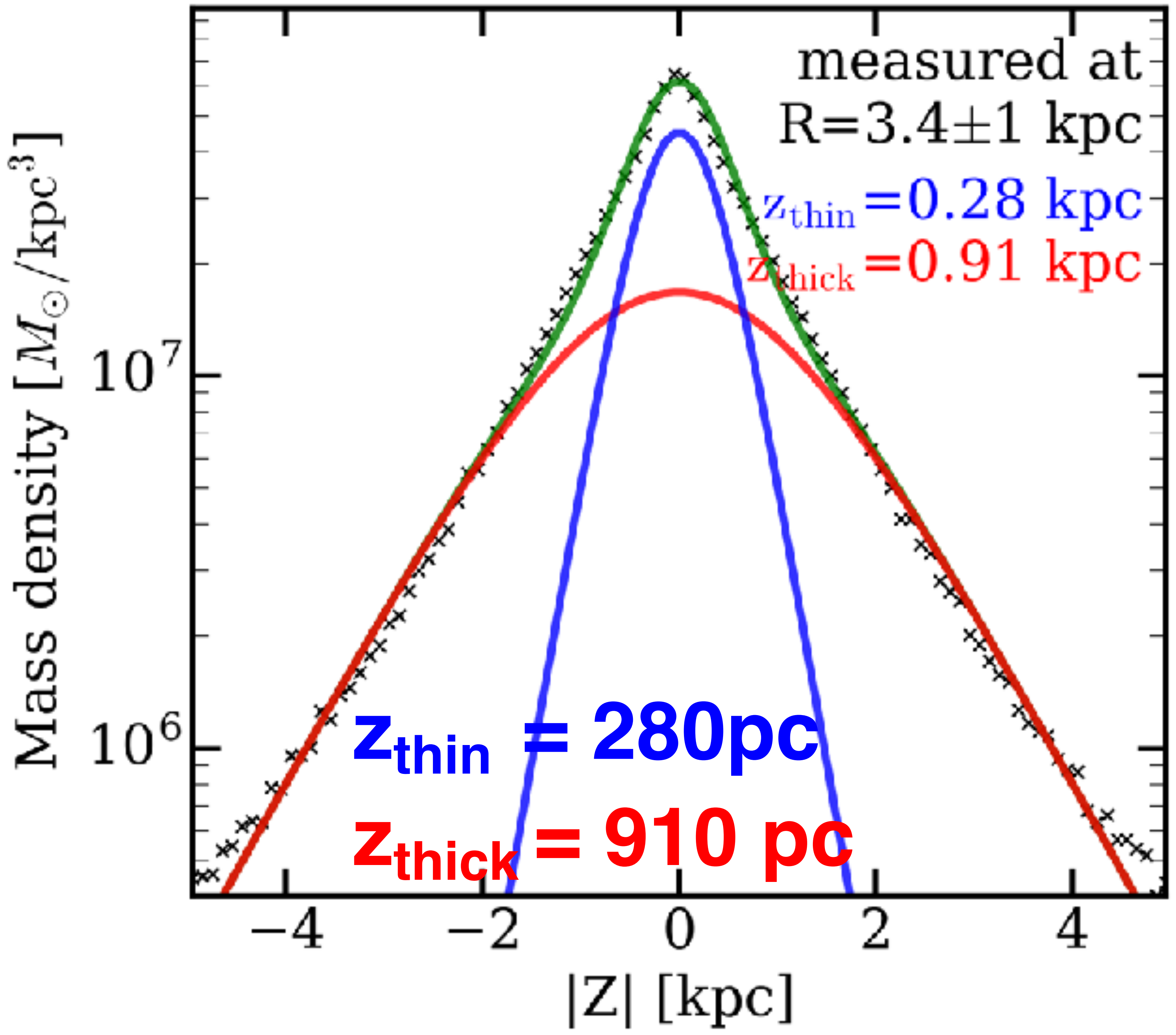
Radial Profile in r-band: Sersic + exponential disc

disk scale length: R_d = 1.7 kpc



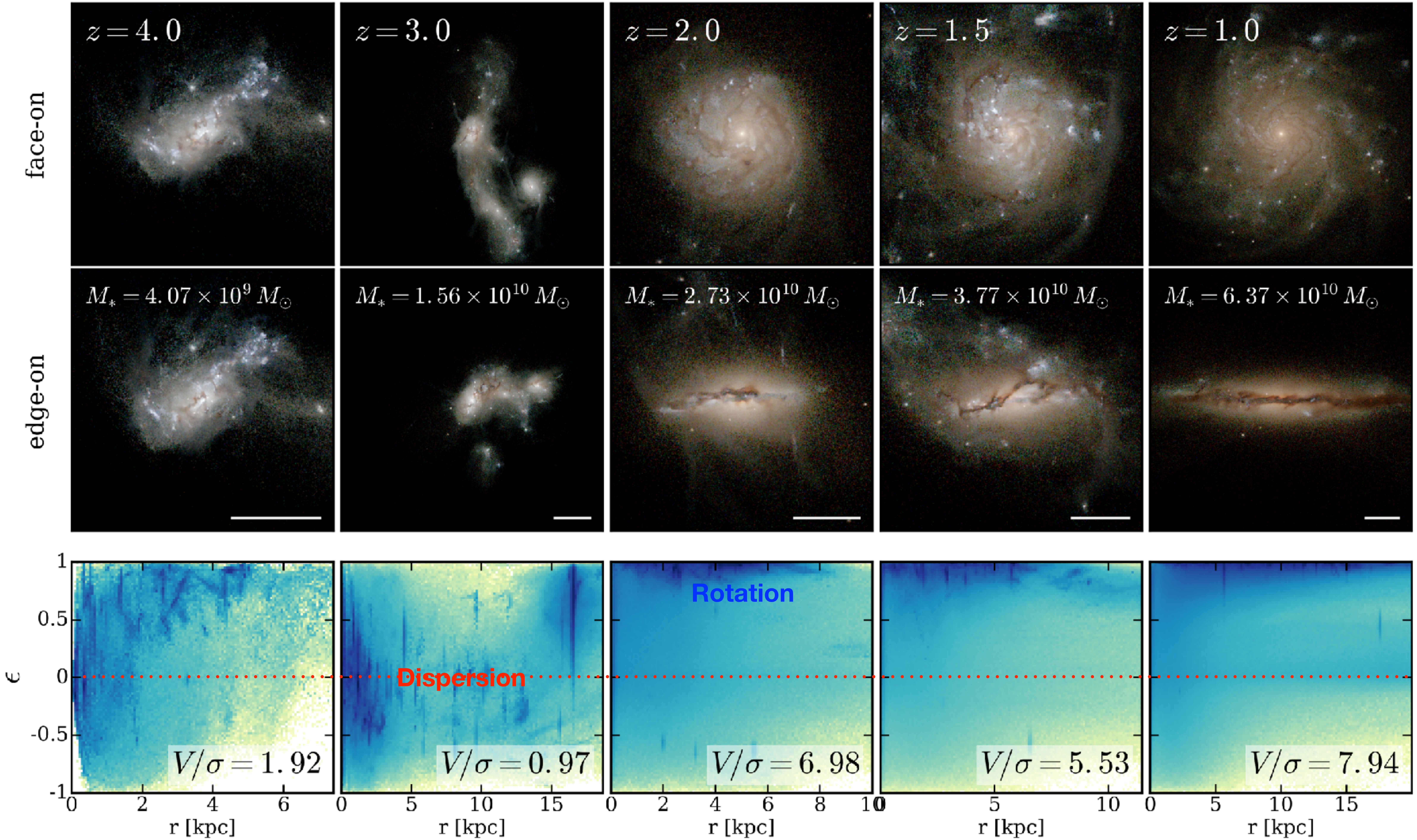
Vertical Profile

$$\rho(z) = \rho_{\rm thin}\ sech^2(z/2z_{\rm thin}) + \rho_{\rm thick}\ sech^2(z/2z_{\rm thick})$$



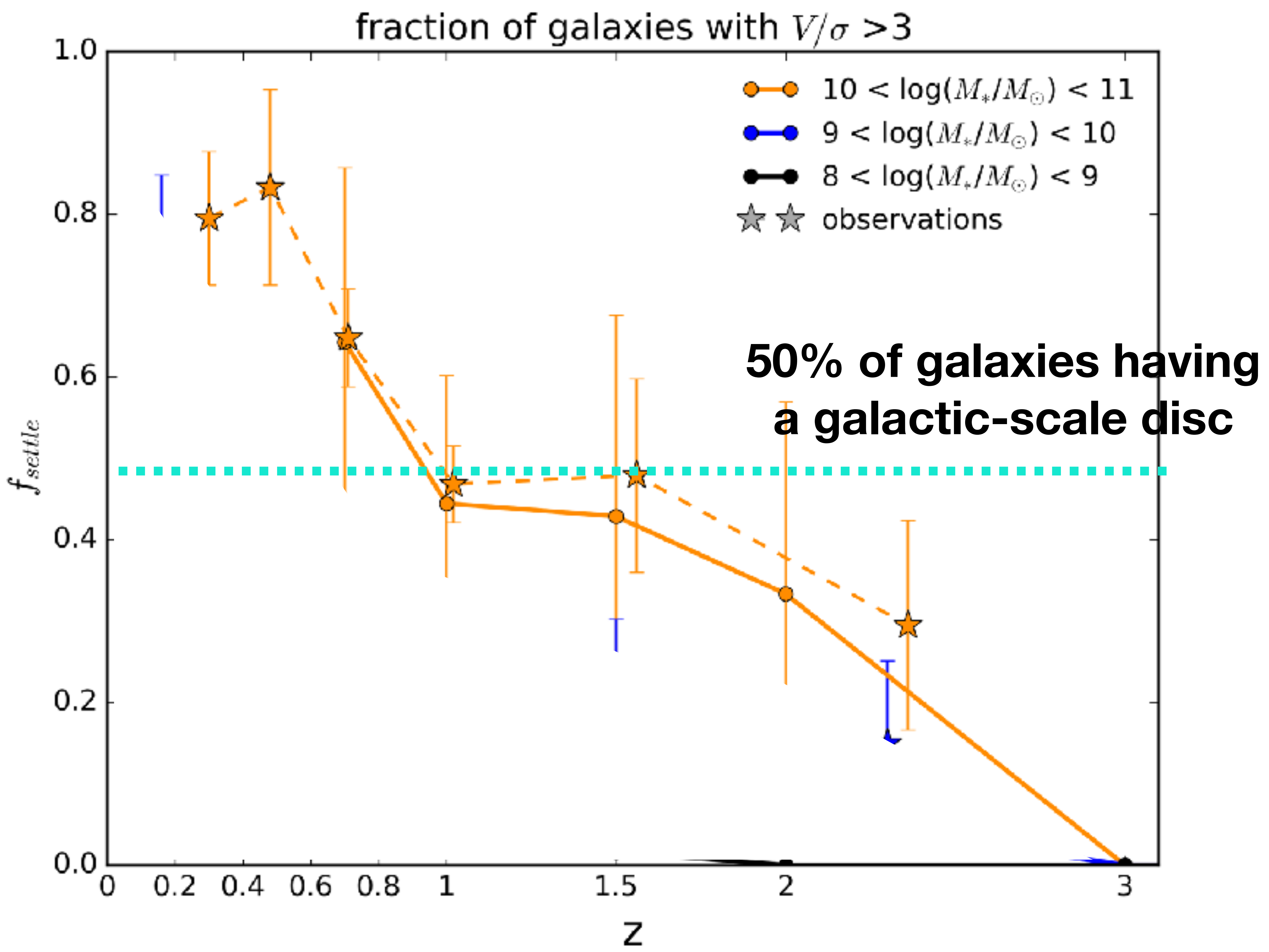
In the cylindrical region:

R_{xy} = 2 R_d = 3.4 ±1 kpc



face-on
edge-on
$z = 4.0$
$z = 3.0$
$z = 2.0$
$z = 1.5$
$z = 1.0$
$M_* = 4.07 \times 10^9 M_\odot$
$M_* = 1.56 \times 10^{10} M_\odot$
$M_* = 2.73 \times 10^{10} M_\odot$
$M_* = 3.77 \times 10^{10} M_\odot$
$M_* = 6.37 \times 10^{10} M_\odot$
Rotation
Dispersion
ϵ
$V/\sigma = 1.92$
$V/\sigma = 0.97$
$V/\sigma = 6.98$
$V/\sigma = 5.53$
$V/\sigma = 7.94$
r [kpc]

Epoch of disc settling?

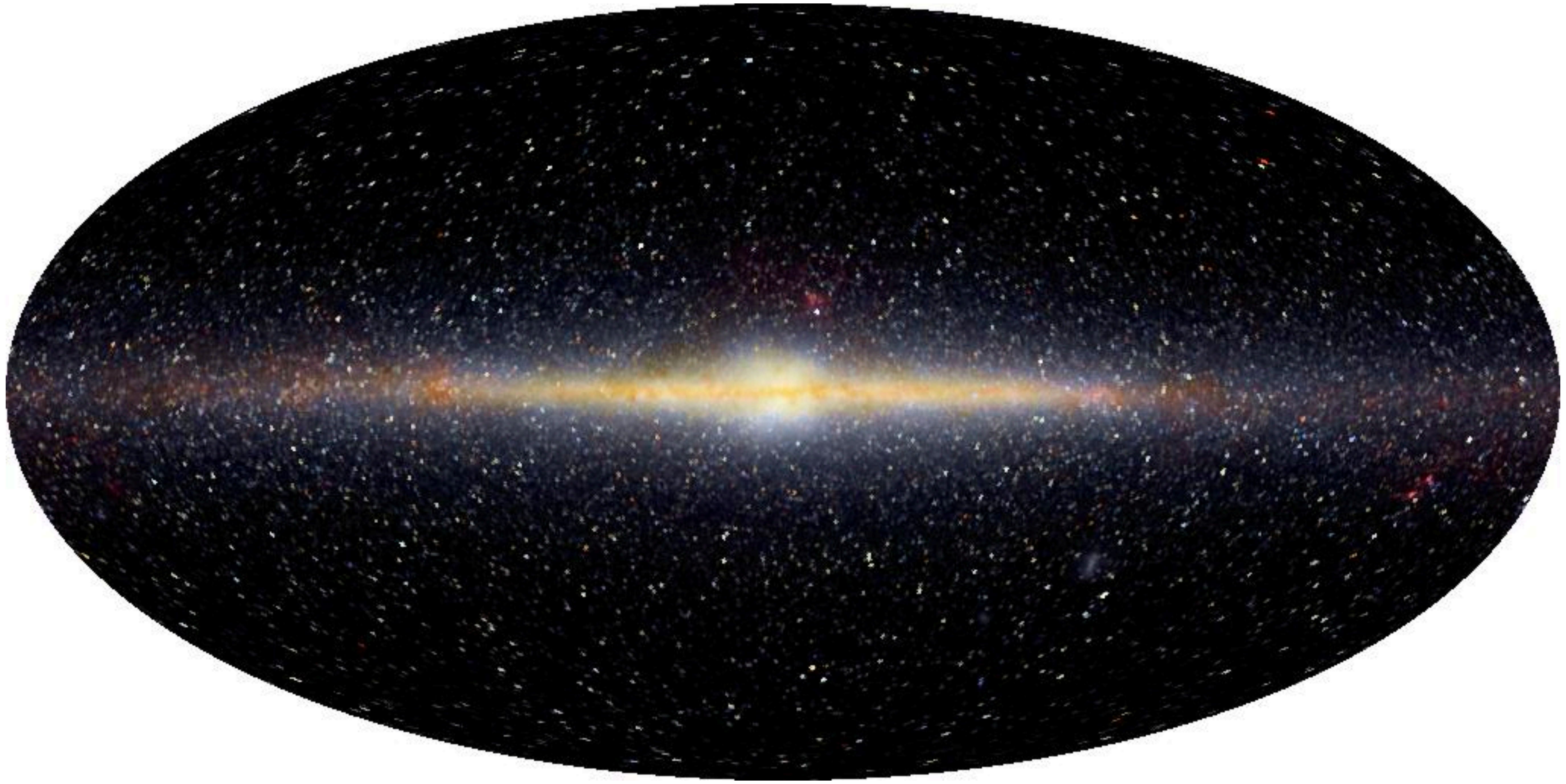


(See also Kassin+12; Simons+16; Johnson+18; El-Badry+18; Hung+19; Pillepich+19)

Conditions for disc settling?

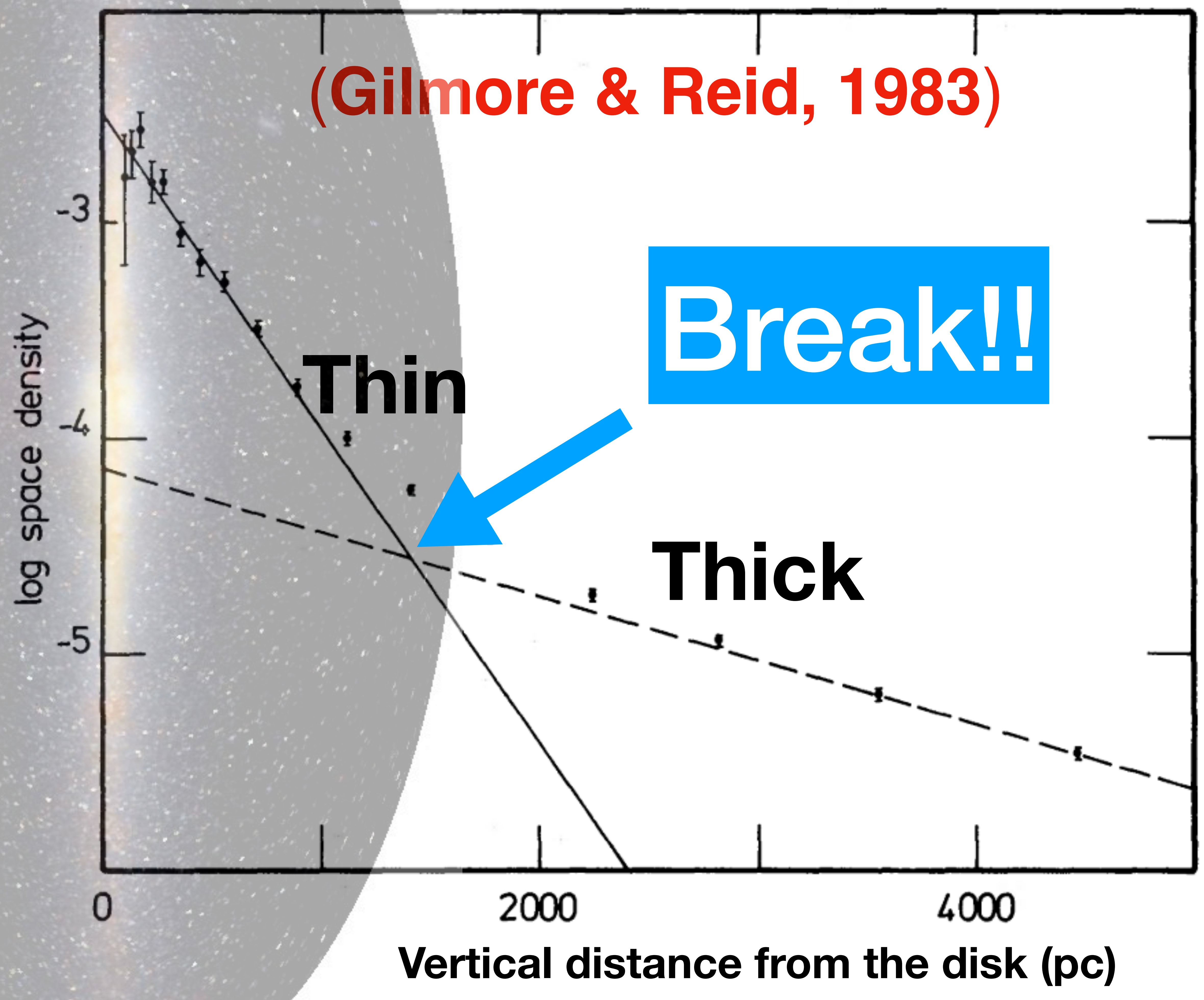
- galaxy should be massive having collected enough angular momentum from the cosmic web
- and reach a meta-stable Q=1 stage (Pichon’s talk)
- merger should not be frequent (external perturbation)
- too much stellar and BH feedback causes turbulence (internal perturbation)

Thick discs



Observation: Vertical profile requires 2 components?

Resolved star count in MW



- Photometric parallexes for ~12,500 stars brighter than I=18

- The density distribution for stars with **4<M_V<5** with distance from the Galactic plane

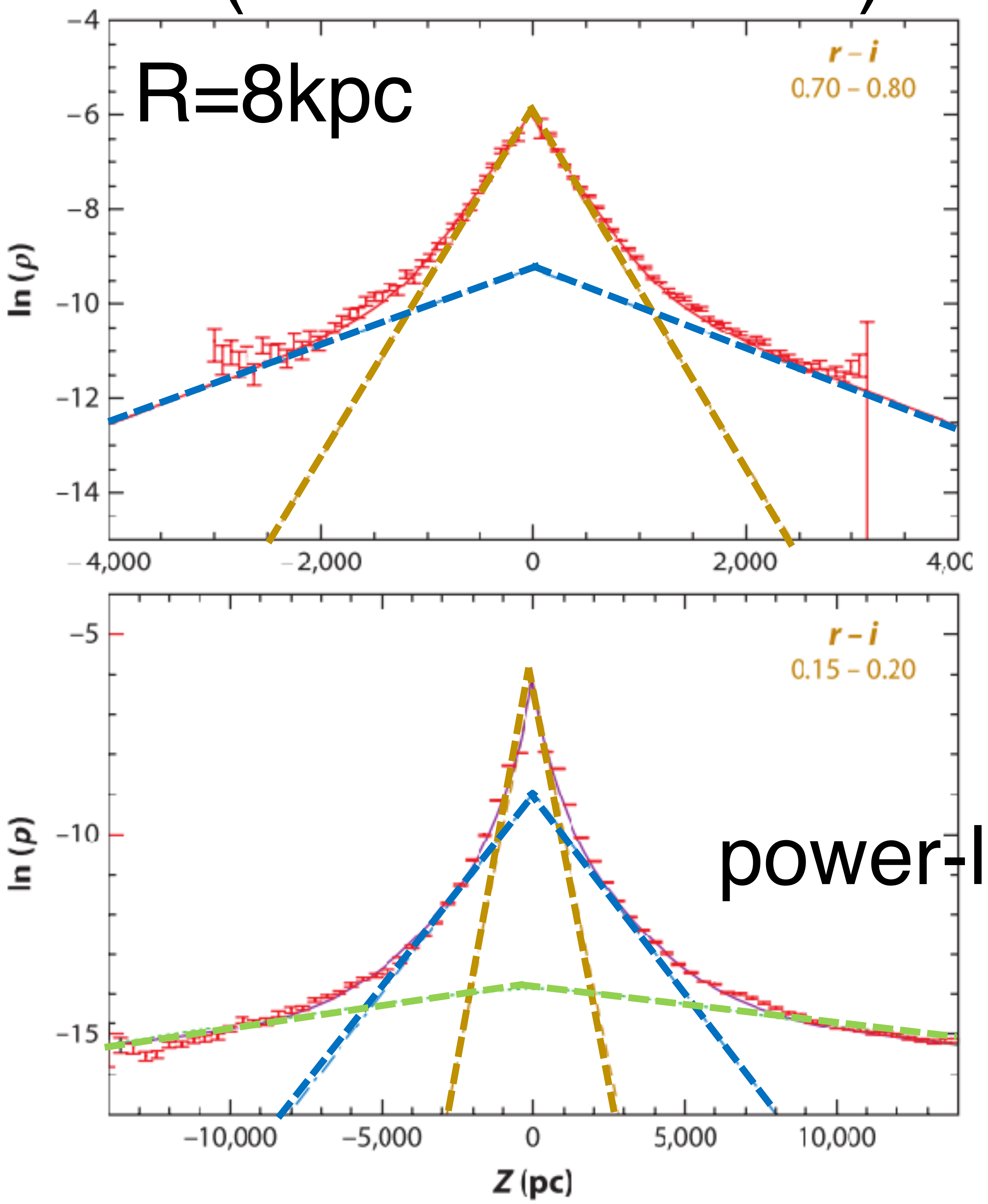
- **Exponential** fit **~ 300pc (thin)**
  ~1450pc (thick)

  Thick disk contains ~ 2% of stars in the solar neighborhood

Observation: sech² fit

SDSS survey to map 3D number density distribution in the Galaxy

(Juric et al. 2008)



270 pc

1200 pc

(f_{thick} ~ 4%)

power-law spherical halo

Vertical Profile functions

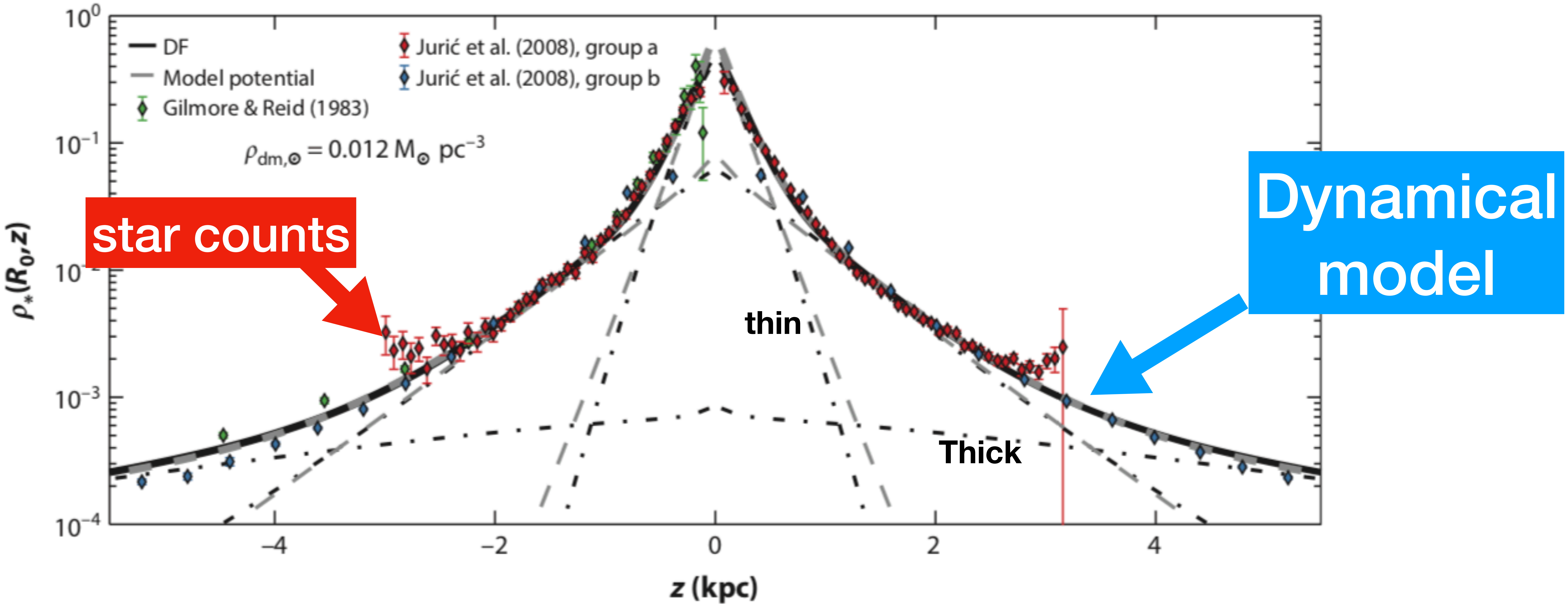
- Vertical density profile of a self-gravitating isothermal population, massive disc (**Spitzer 1942; Kruit & Searle 1981**)

$$\rho(z) = \rho_0 \; sech^2(z/z_0)$$

- can be approximated as an **exponential** with scale height of **$h_z = z_0/2$**

$$\rho(z) = \rho_0 \; exp(-z/h_z) \qquad (z>z_0)$$

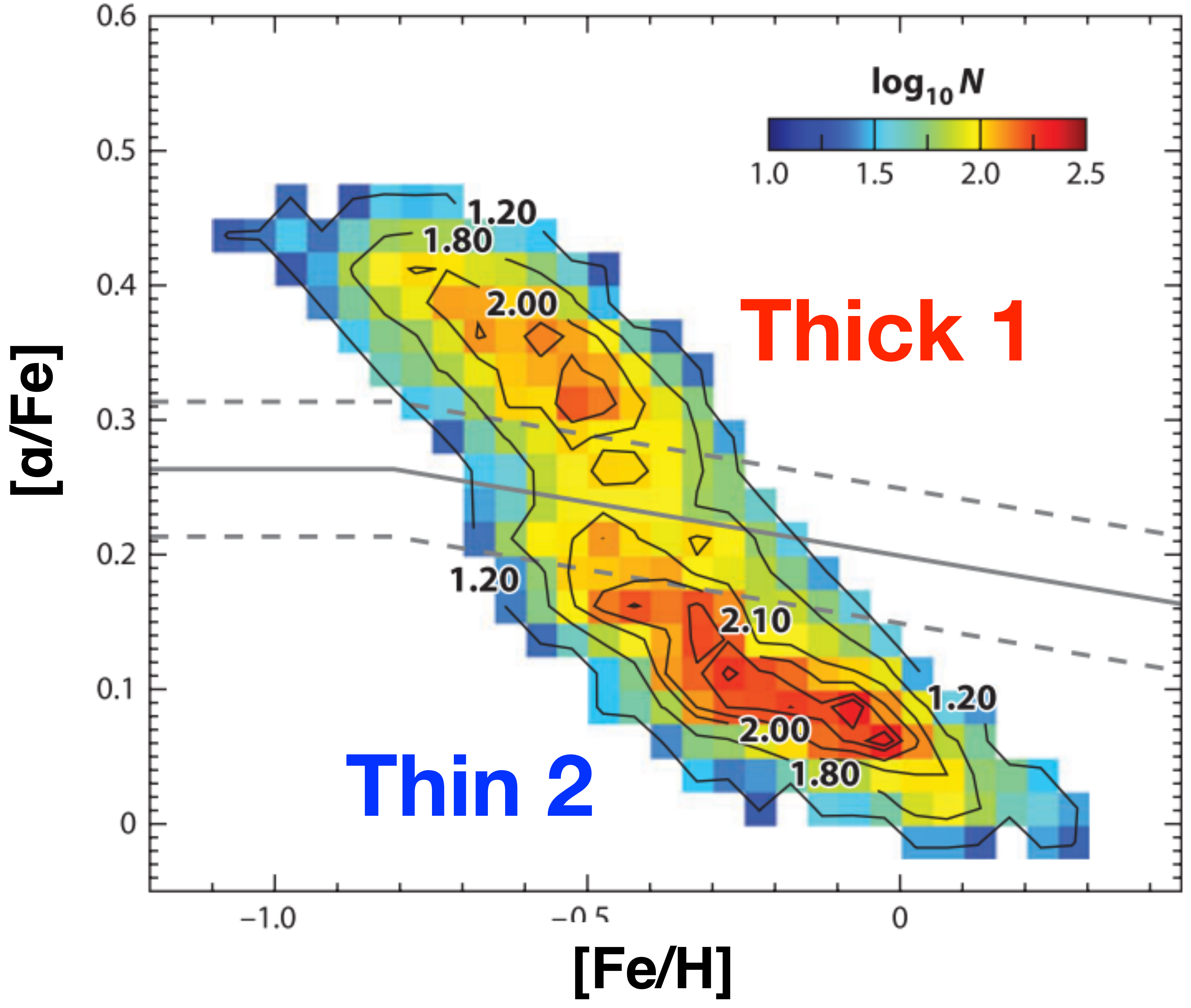
Observation: dynamical models on star counts

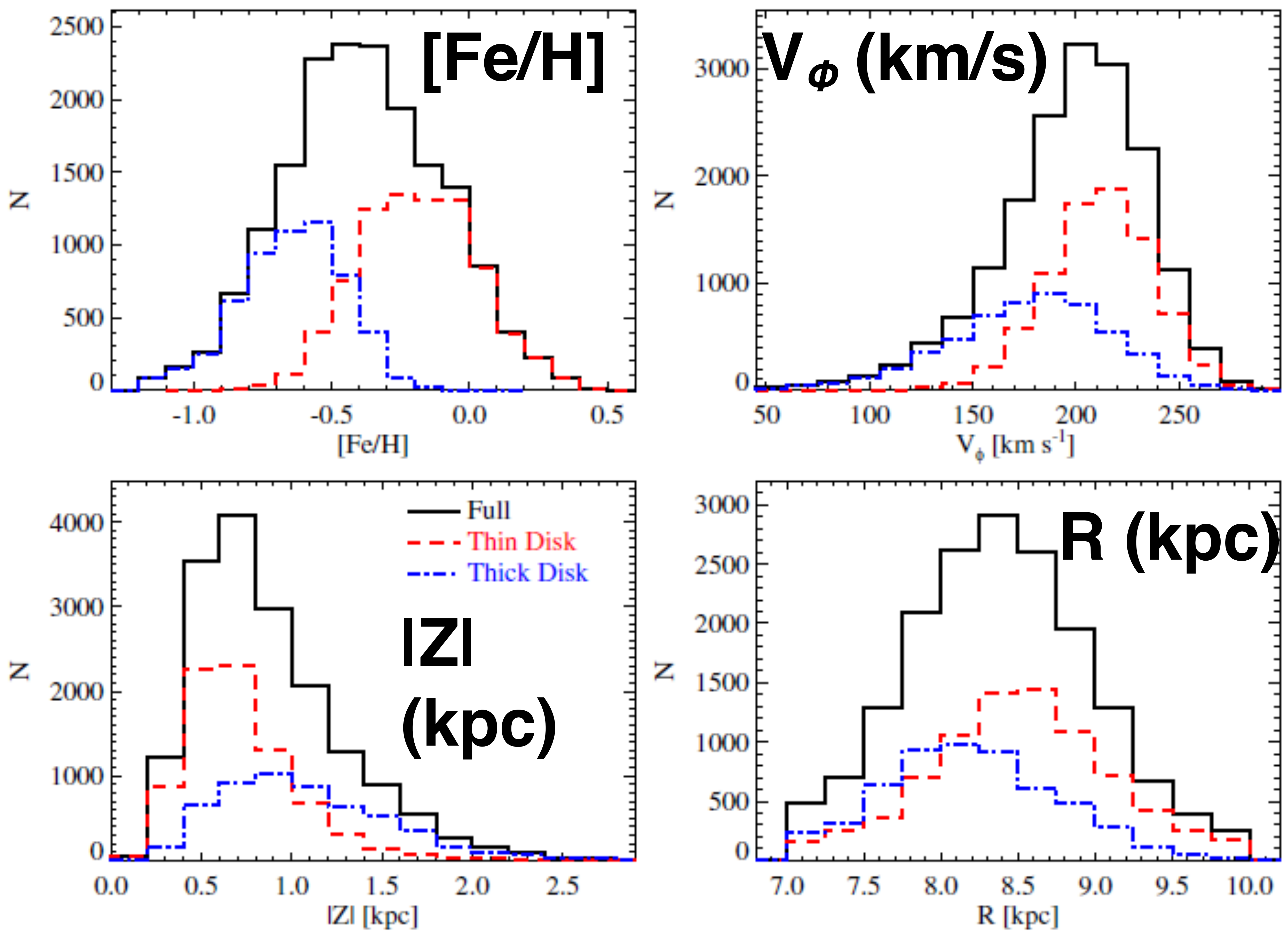


Bovy & Rix 2013; Bland-Hawthorn & Gerhard 2016 review thin:Thick=6:1

Observation: bimodality in [α/Fe]- [Fe/H], distinct origin?

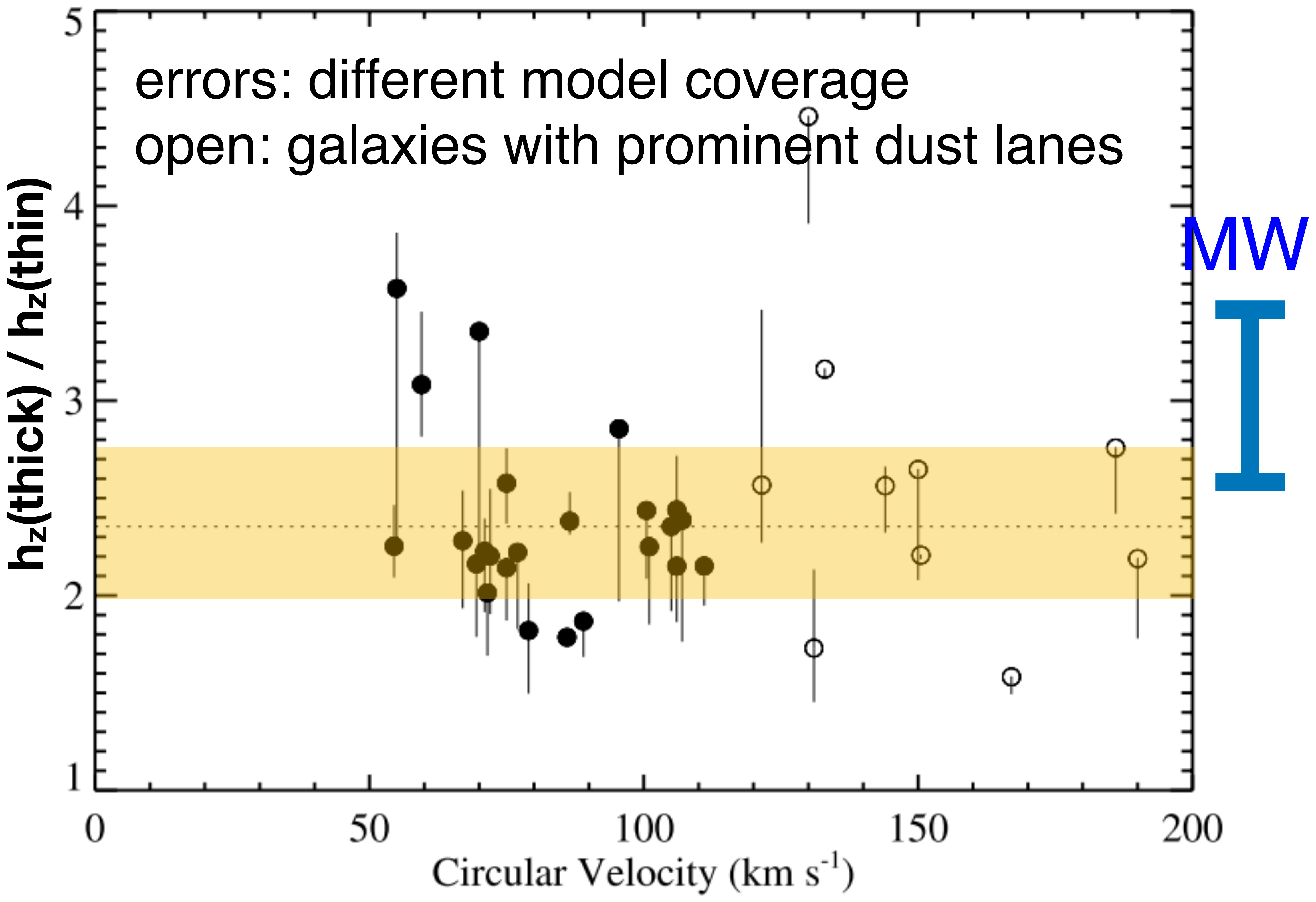
(**Lee et al. 2011**) ~17,000 G-type dwarfs

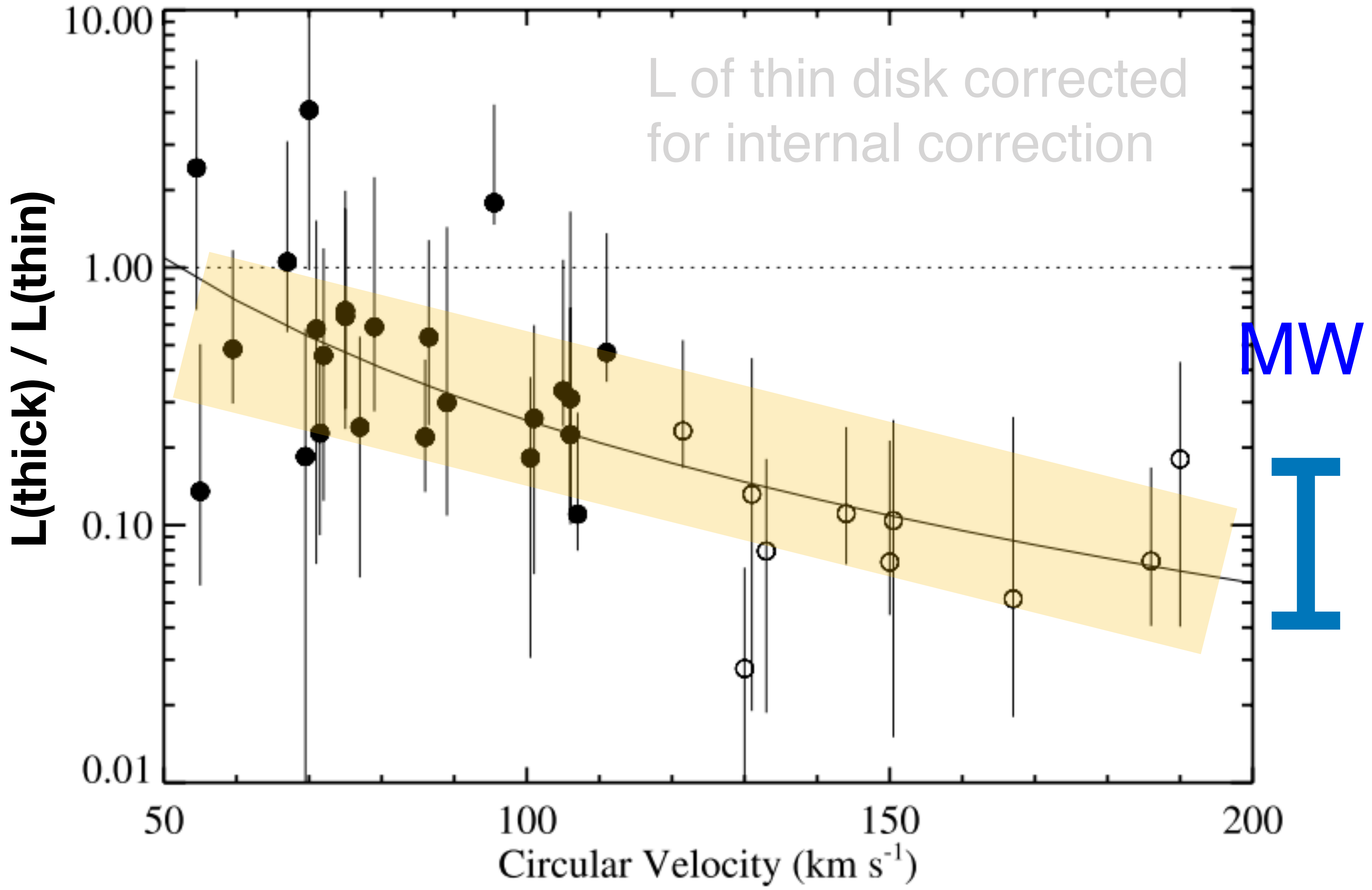




Observation: External galaxies: surface photometry

(Yoachim & Dalcanton 2006) **34** edge-on disk galaxies with a wide range of mass





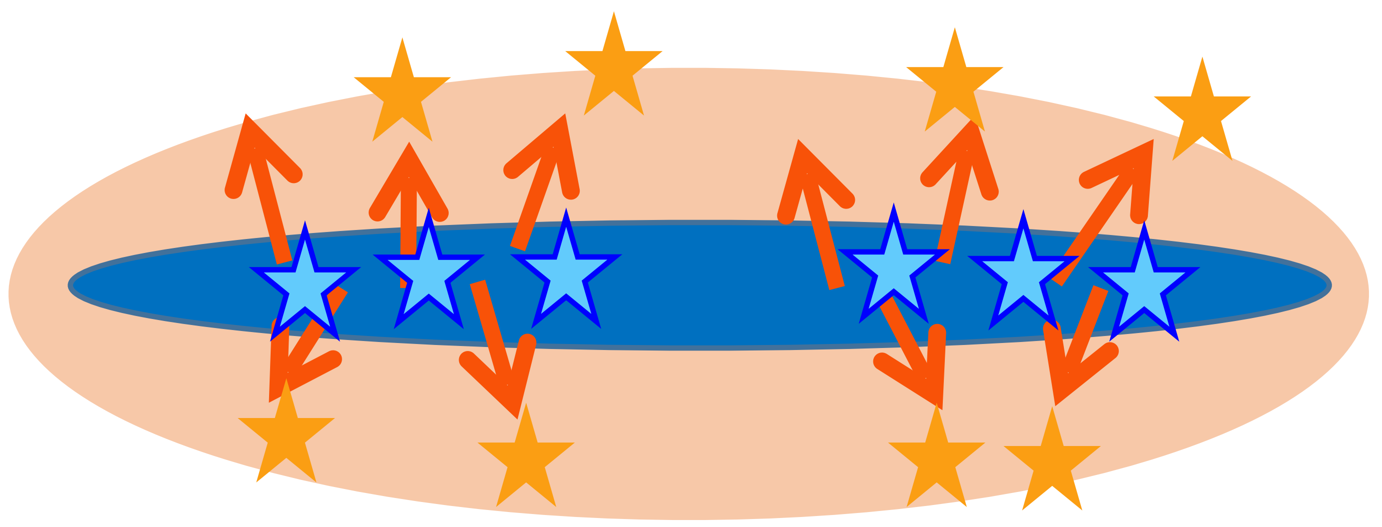
median value of the ratio of scale heights
z(thick)/z(thin) ~2.35

- **L_{thick}/L_{thin} = 0.25 (V_C/100km/s)$^{-2.1}$**
- M/L model (Bell & de Jong 2001) ➡ **M_{thick}/M_{thin}**

Formation scenarios of the thick disks

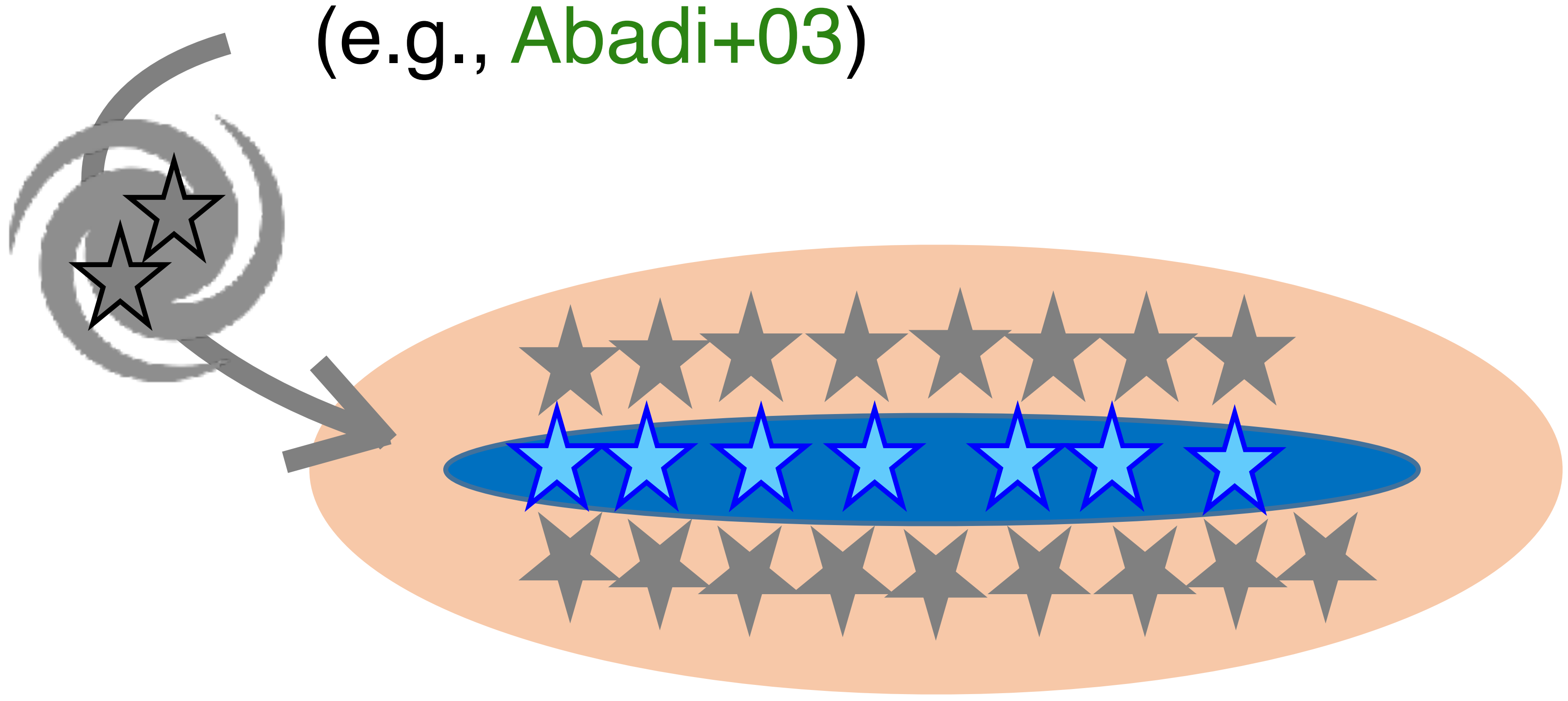
(1) Kinematic heating of a pre-exisiting disk

- minor mergers (e.g., Quinn+93; Kazantzidis+08)
- spiral arms/ bars (e.g., Sellwood & Carlberg 84)
- GMCs (e.g., Spitzer & Schwarzschild 1951)

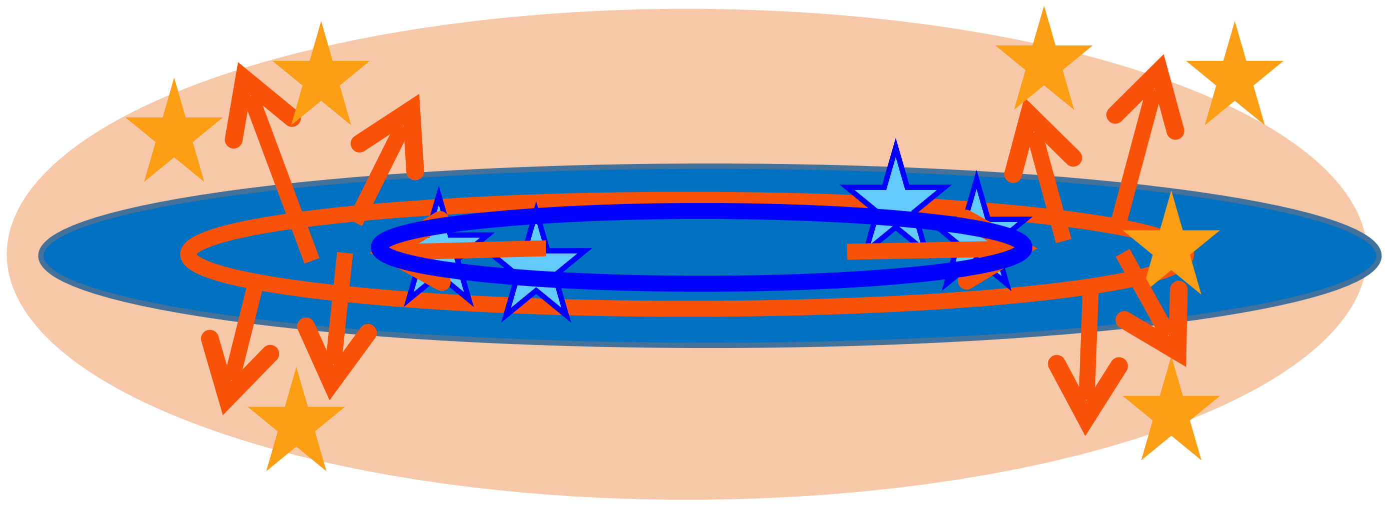


(2) Accretion from disrupted satellite galaxies

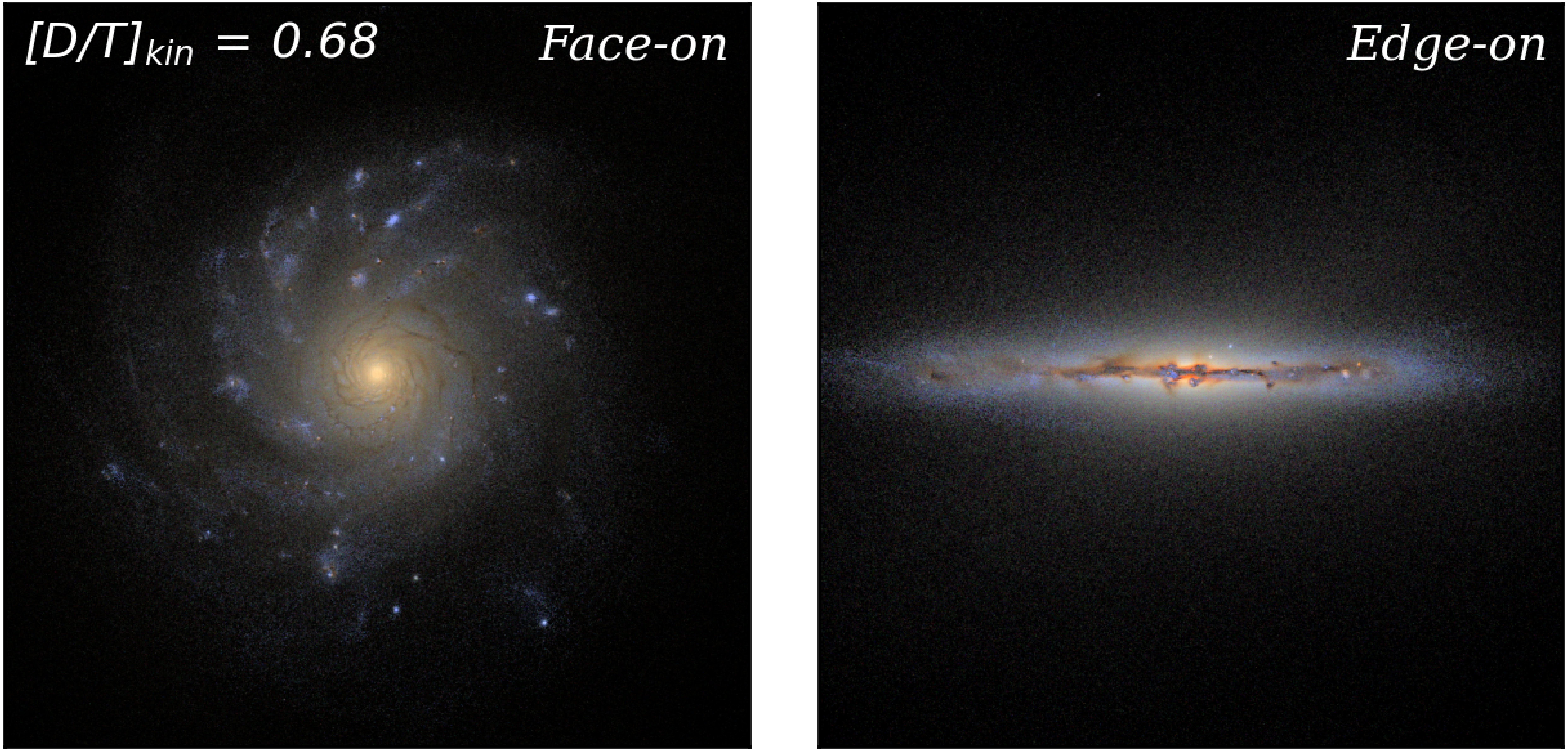
(e.g., Abadi+03)



(3) Radial Migration (e.g., Roskar et al. 2008)



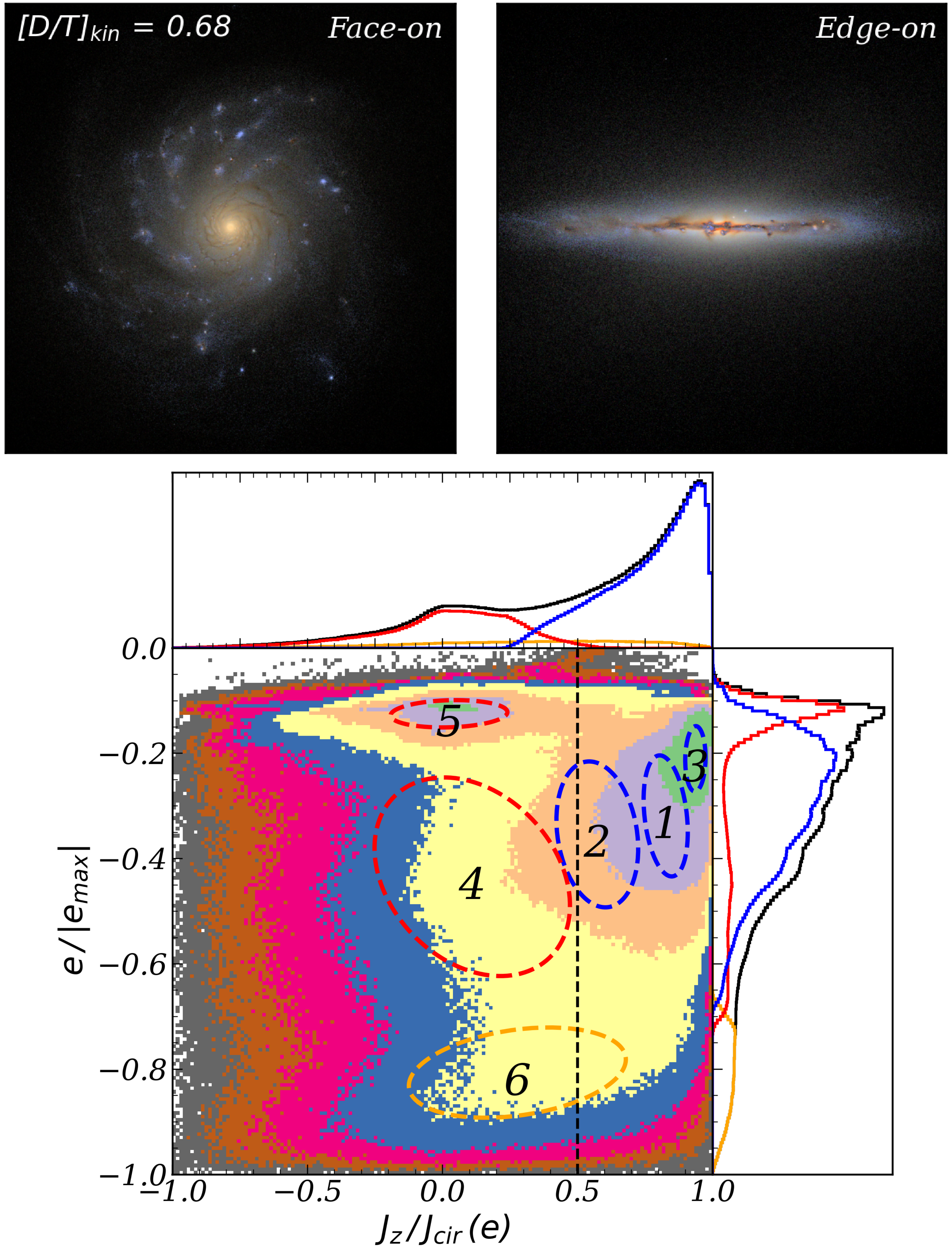
(4) In-situ SF triggered by gas-rich merger (e.g., Brook et al. 2004)

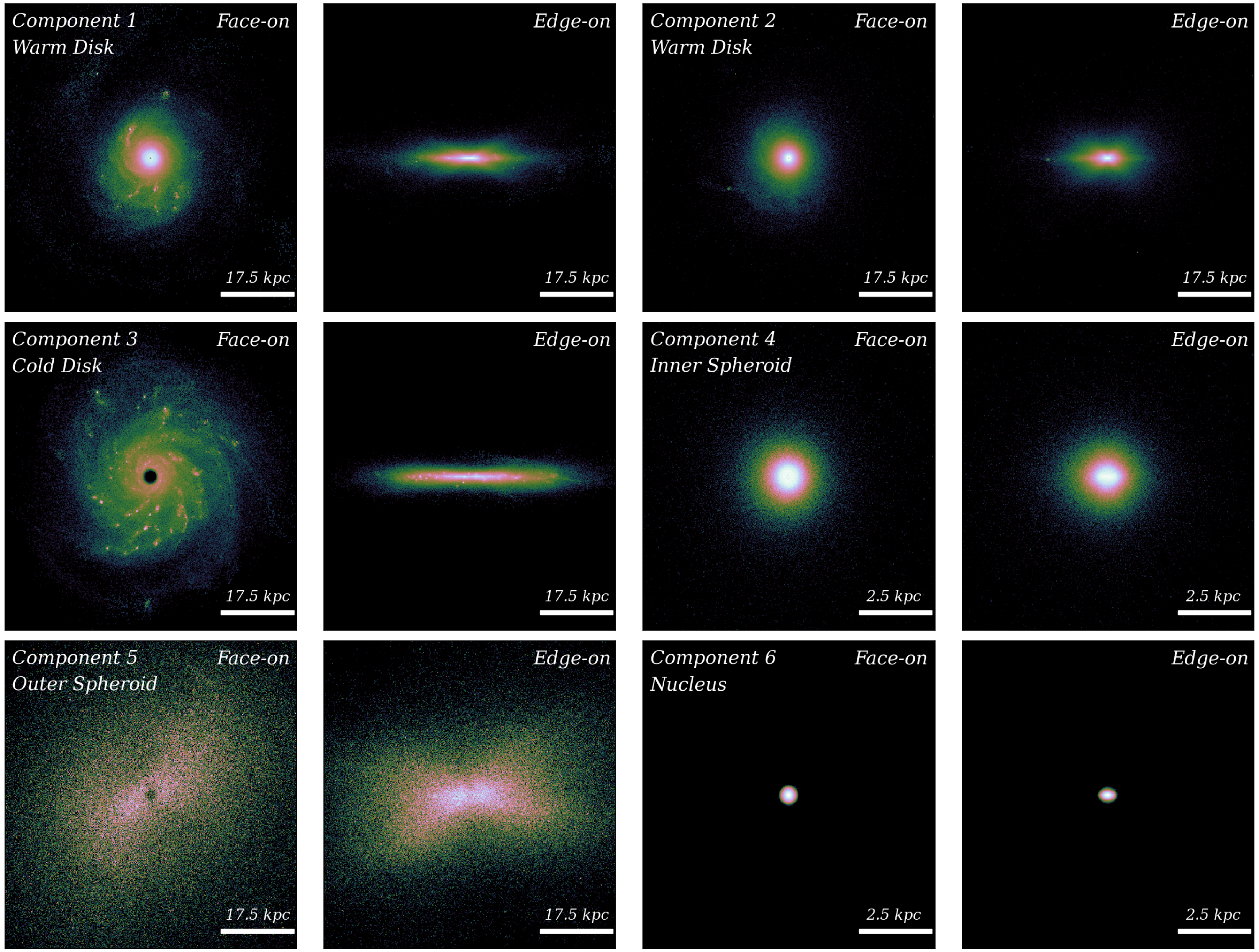


Do we see thick discs in high-res simulations?
What is the origin of thick disc?

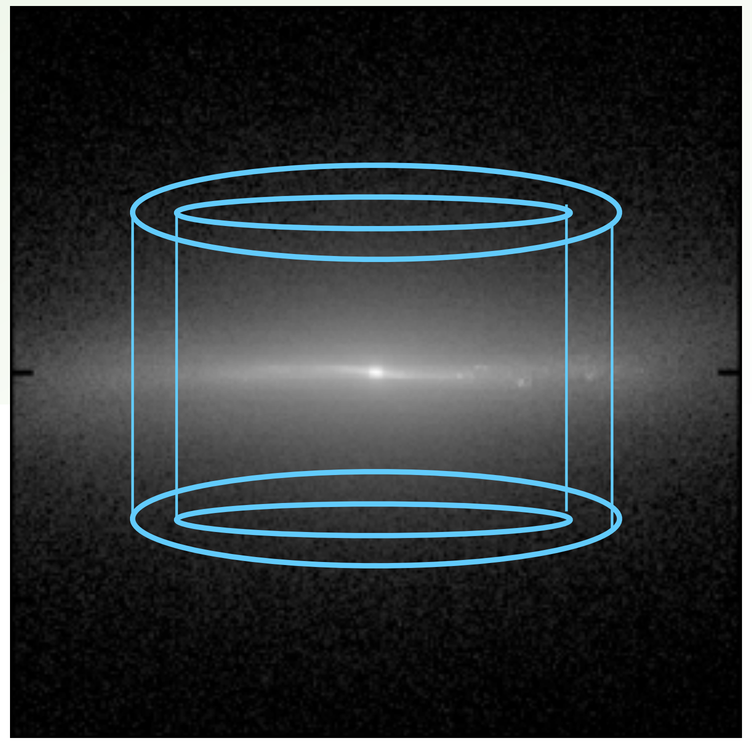
Gaussian Mixture Model on NH galaxies

(Jang et al. 2022, arXiv221100931J)





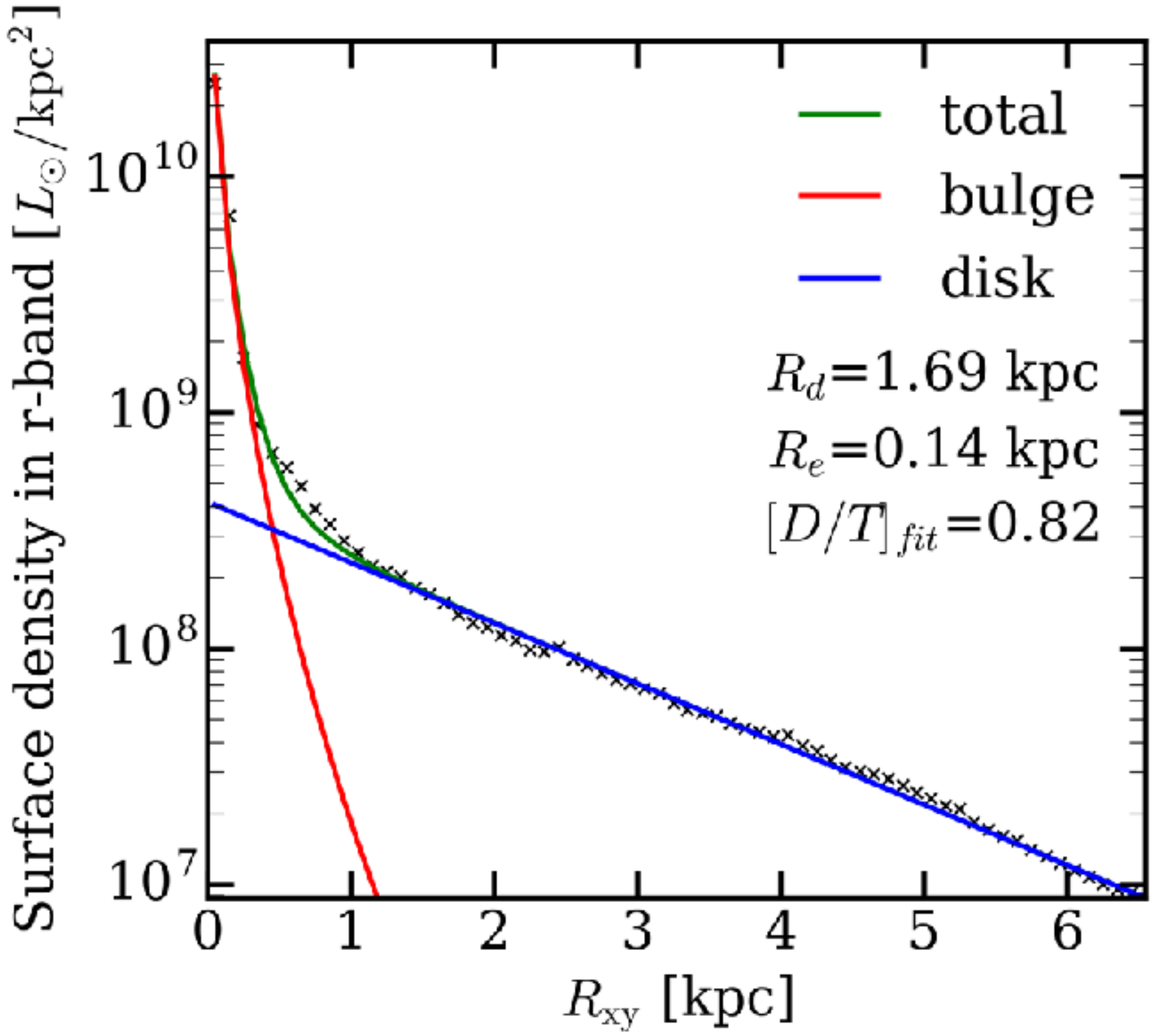
Radial & vertical profiles: two-component fits



Galactica

Radial Profile in r-band: Sersic + exponential disc

disk scale length: R_d = 1.7 kpc



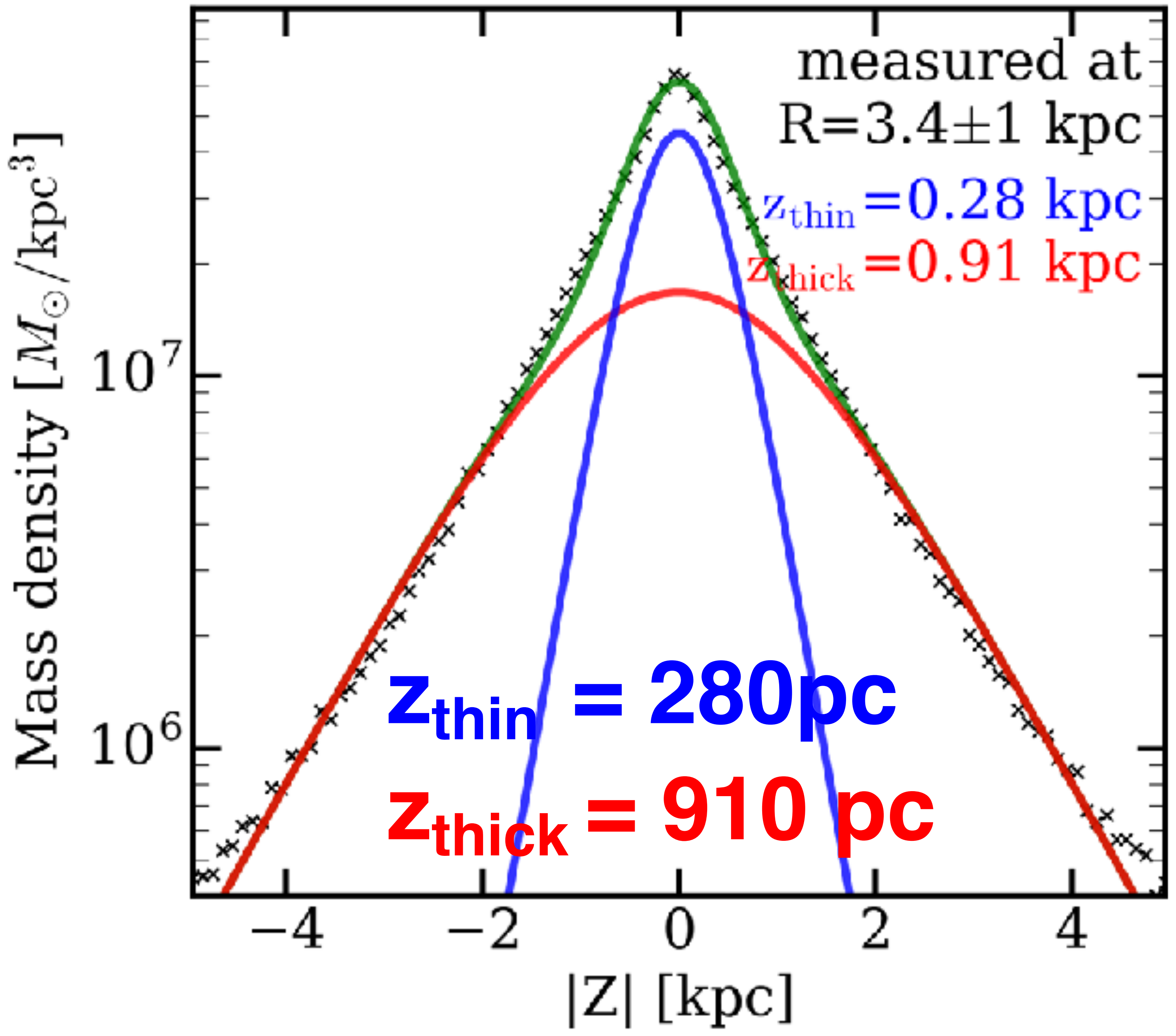
In the cylindrical region:

$R_{xy} = 2\ R_d = 3.4 \pm 1$ kpc

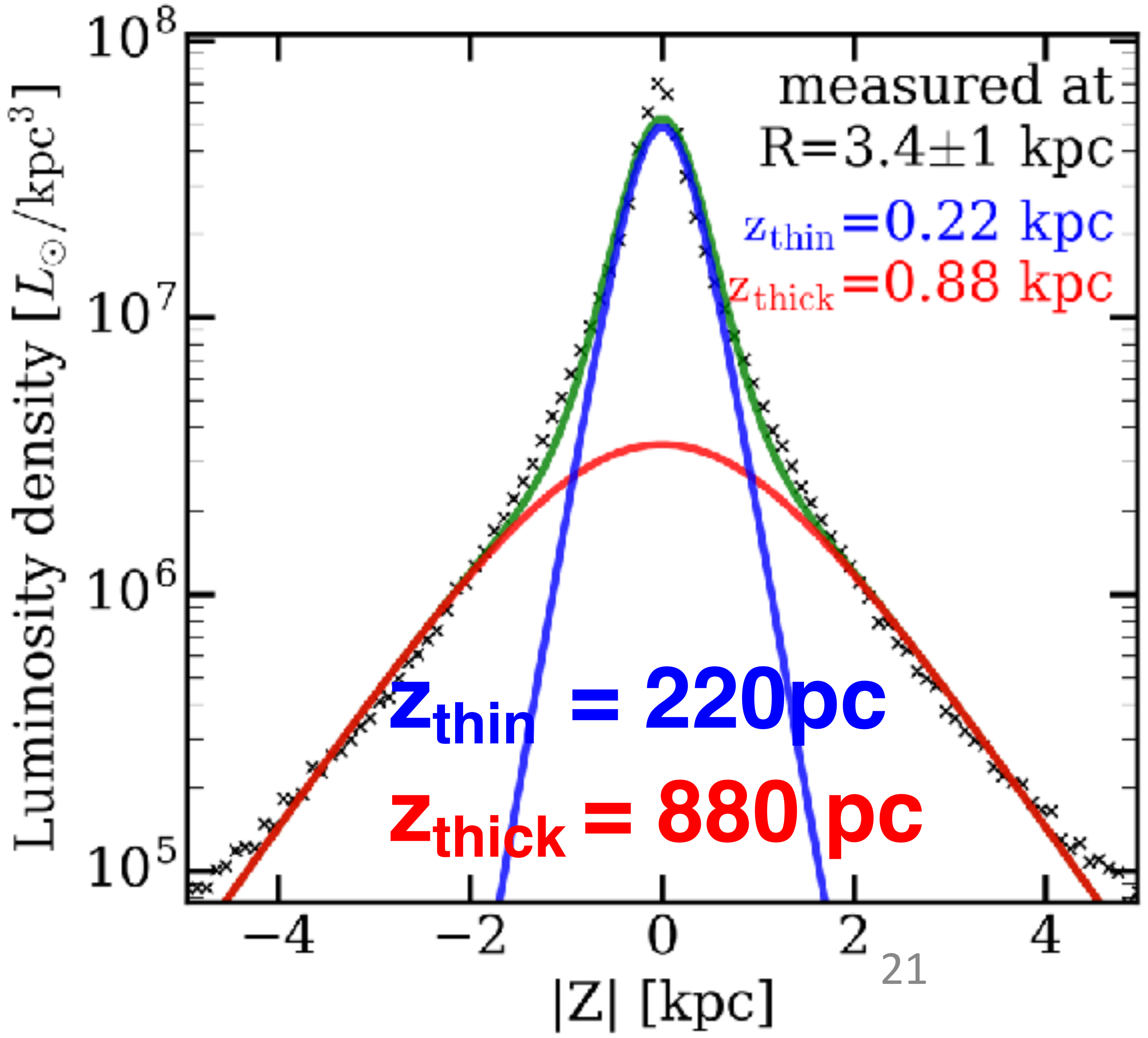
Vertical Profile:

$$\rho(z) = \rho_{\rm thin}\ sech^2(z/2z_{\rm thin}) + \rho_{\rm thick}\ sech^2(z/2z_{\rm thick})$$

in mass

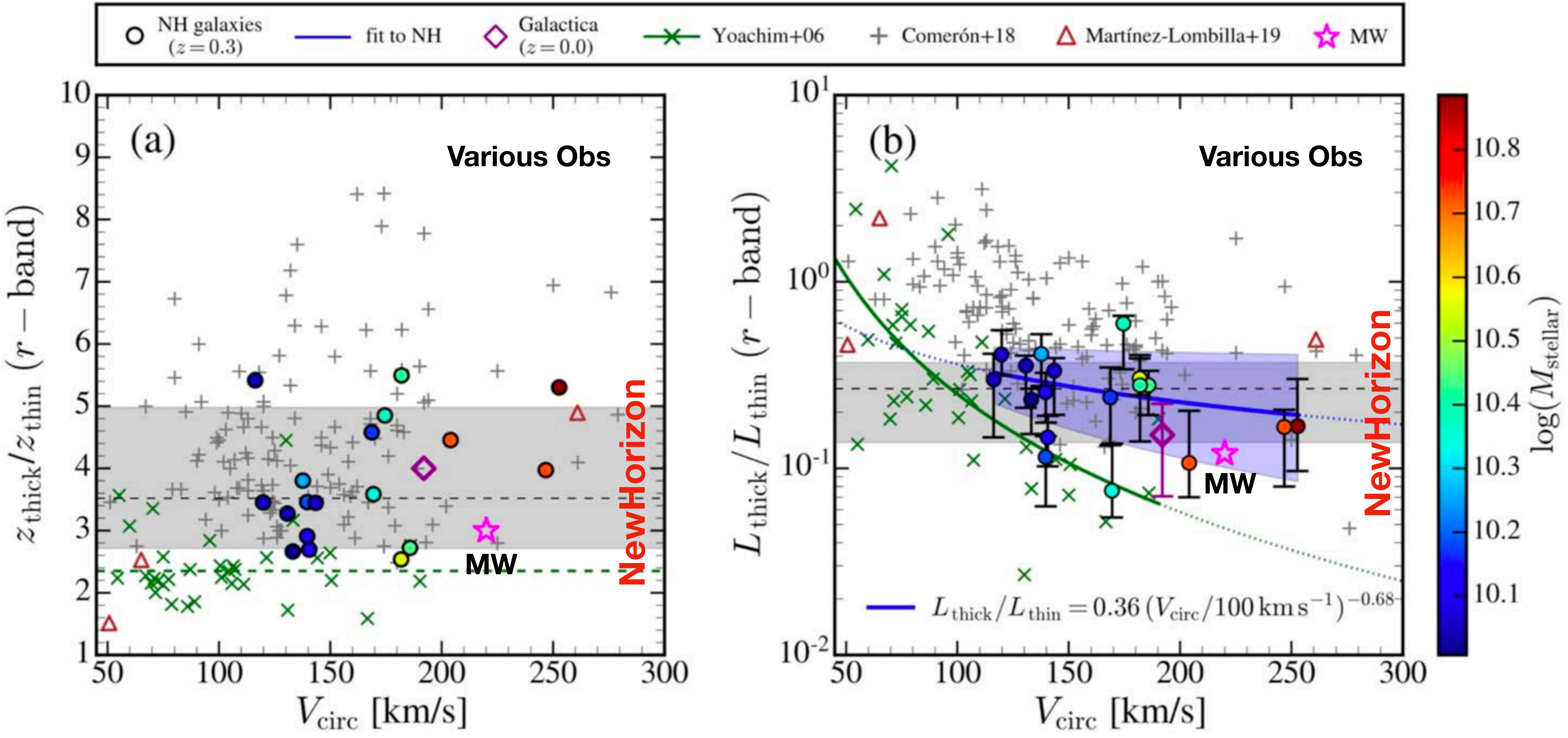


in r-band

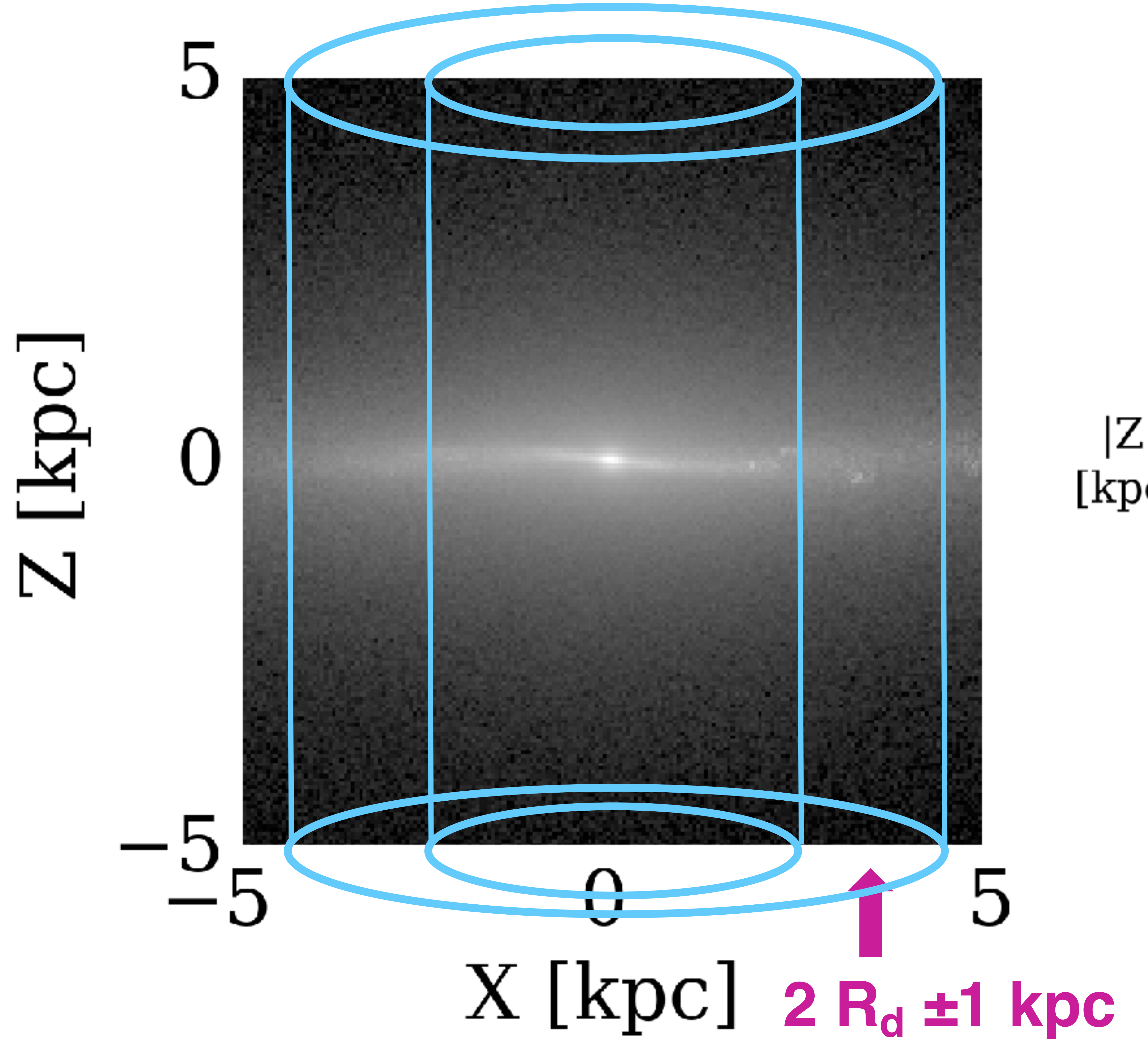


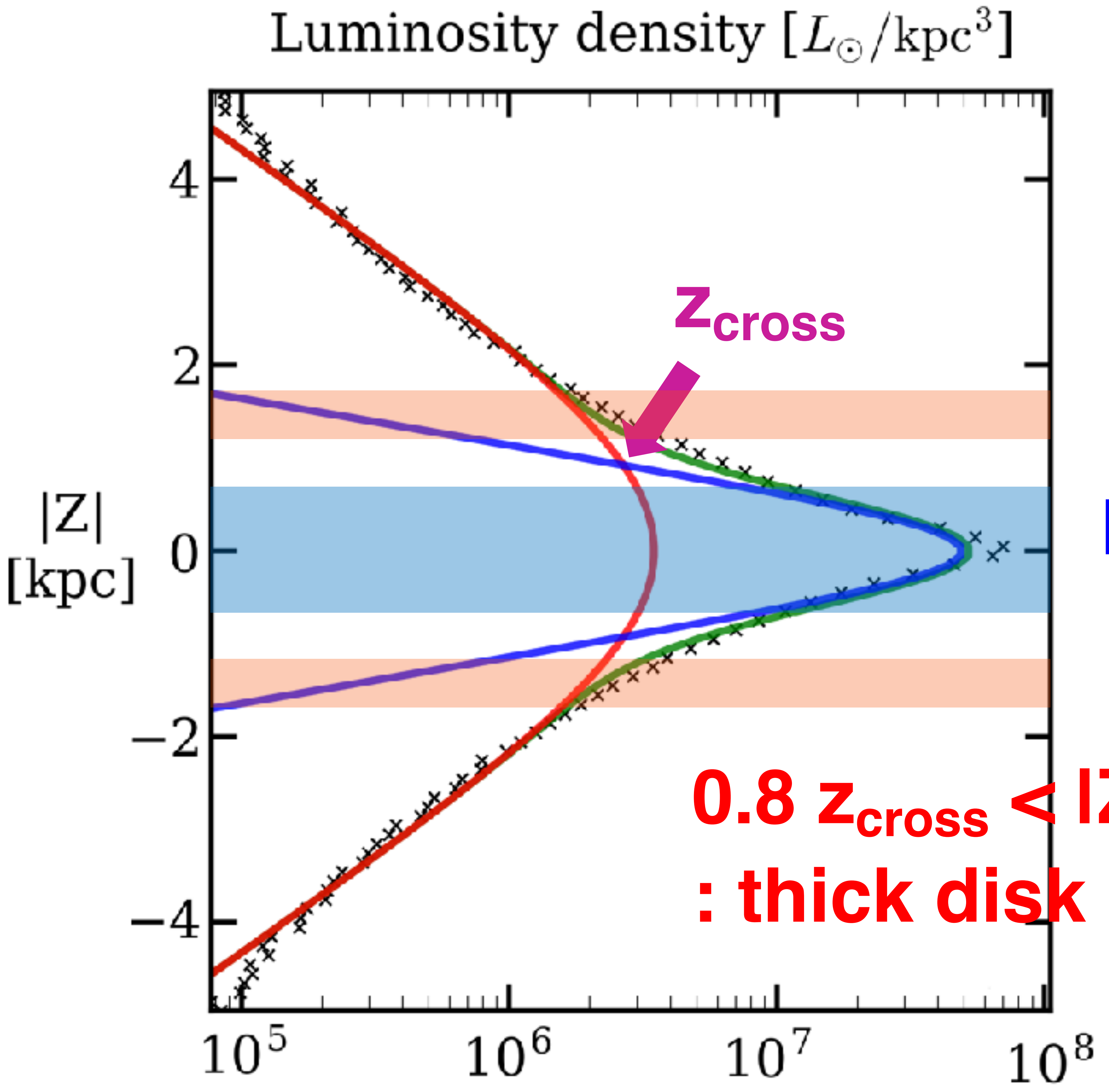
Thick disc fractions: scale height and luminosity

Park et al. 2021, ApJS, 254, 2



Spatial decomposition: thin and thick discs



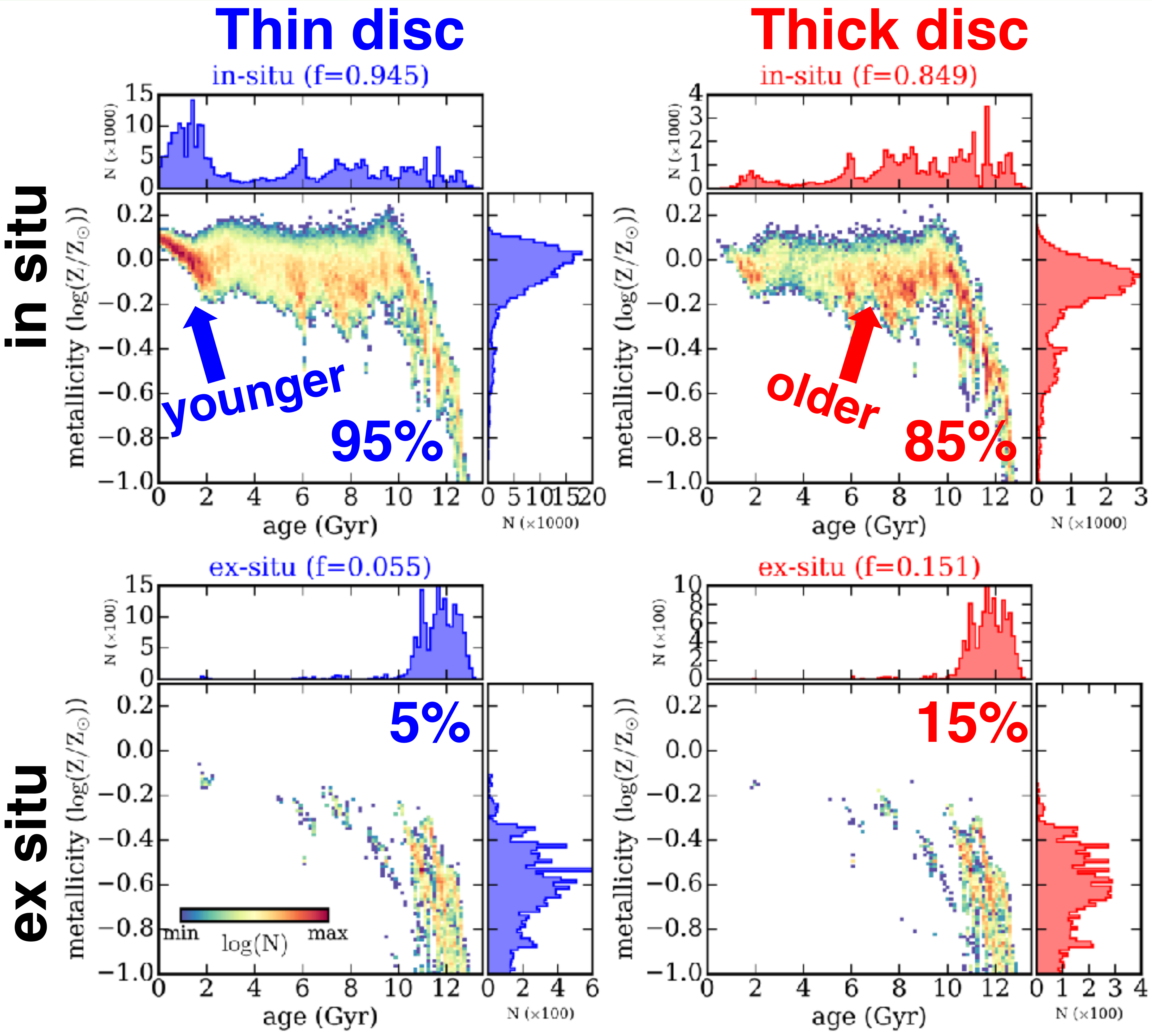


$|Z| < 0.8\ z_{cross}$
: thin disc

$0.8\ z_{cross} < |Z| < 2\ z_{thick}$
: thick disk

Thick disc: in situ formed, older, metal-poorer than thin disc (one galaxy)

Park et al. 2021, ApJS, 254, 2



- Galactica at z=0.0

	Thin	Thick
age	5.4 Gyr	9.7 Gyr
$\log(Z/Z_{sun})$	-0.05	-0.17
f_{exsitu}	0.06	0.15

- <18 NH galaxies> at z=0.3

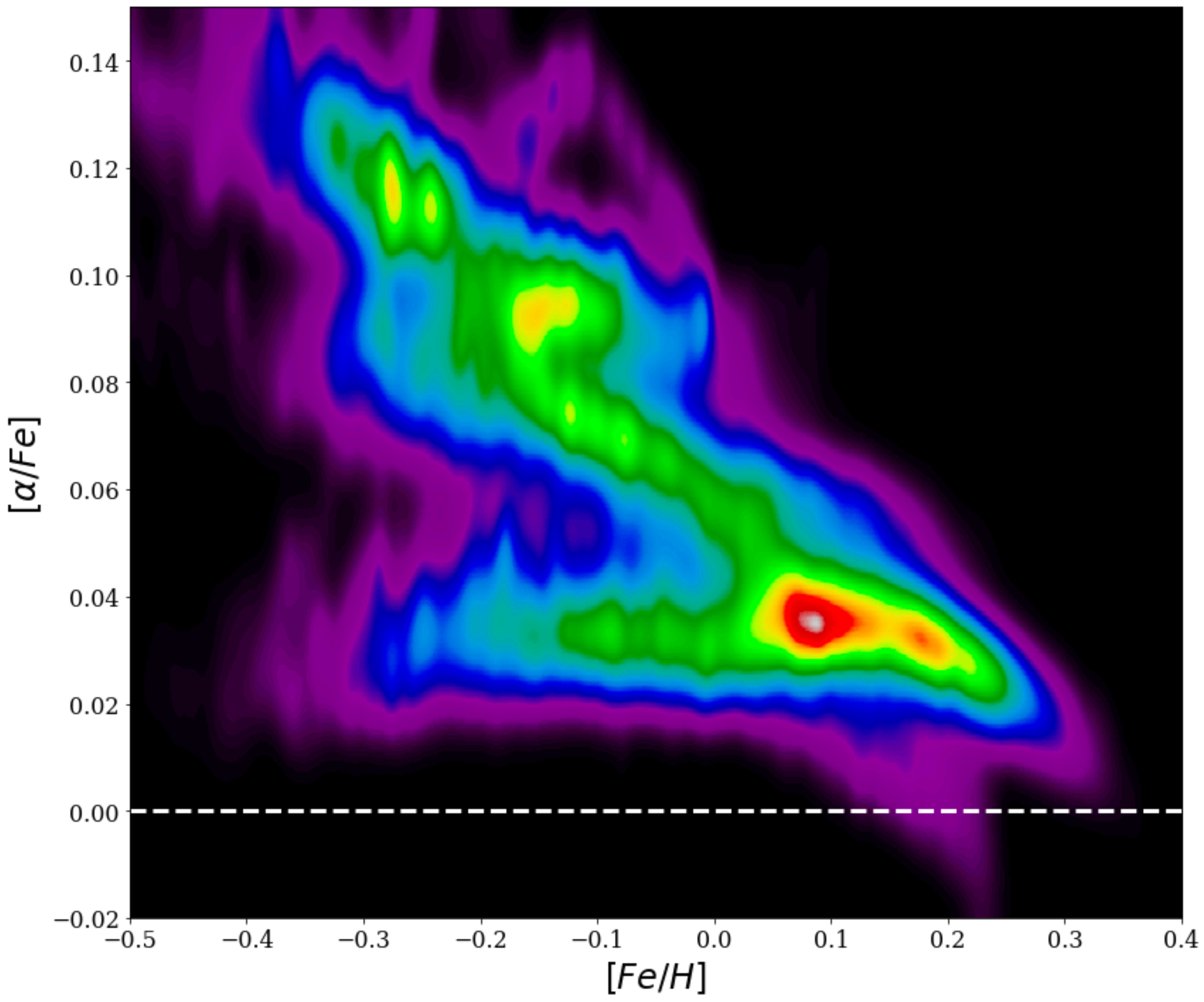
($t_{lookback}$~3.5Gyr)

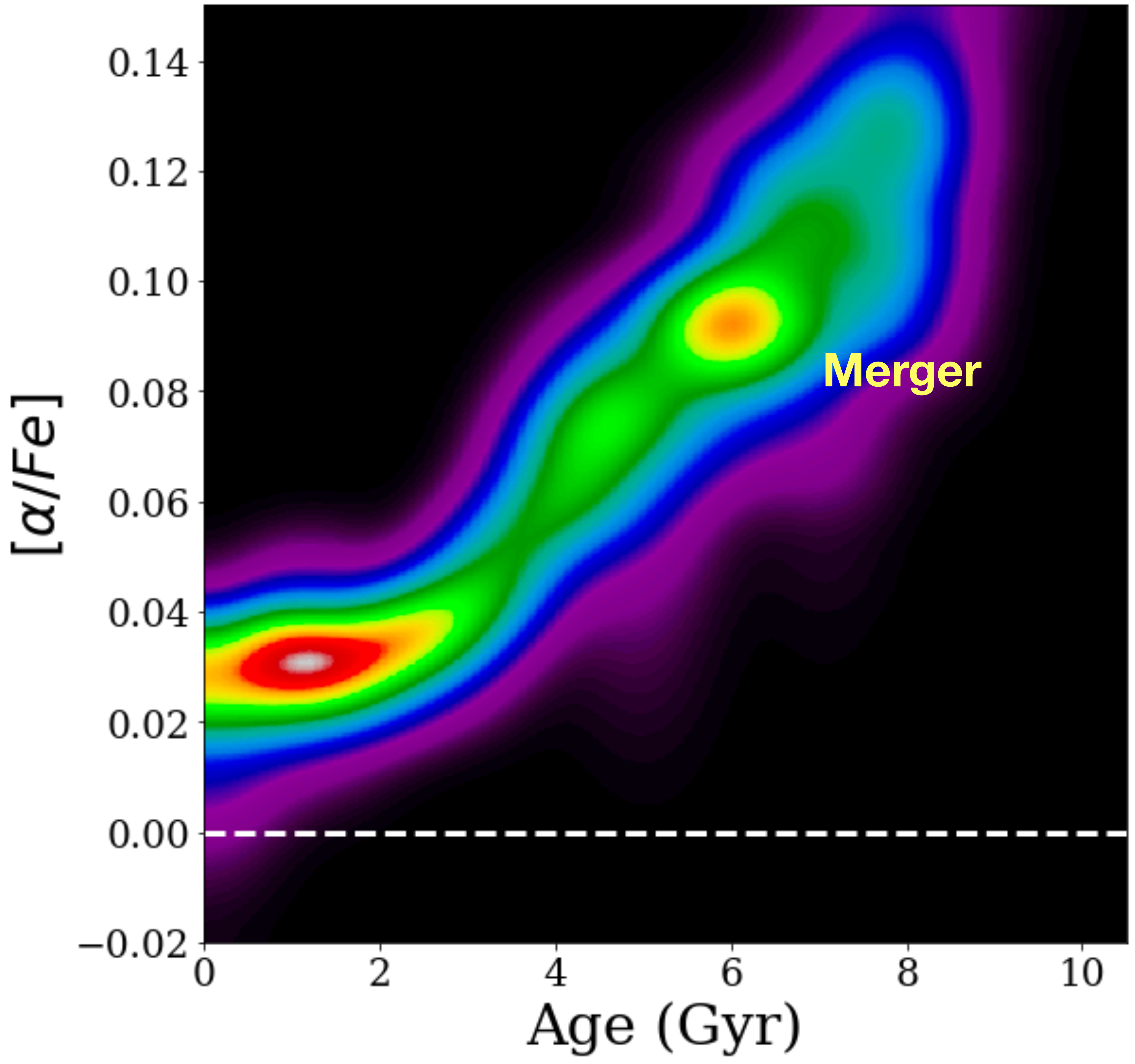
	Thin	Thick
age	4.0 Gyr	5.6 Gyr
$\log(Z/Z_{sun})$	-0.06	-0.22
f_{exsitu}	0.06	0.11

NH2: bimodal distribution in chemical properties like MW

NH2: dx=70 pc simulation with 9 chemical elements

C.f., NIHAO (Buck et al. 2019),
Auriga (Grand et al. 2020), Vintergatan (Agertz et al. 2021)



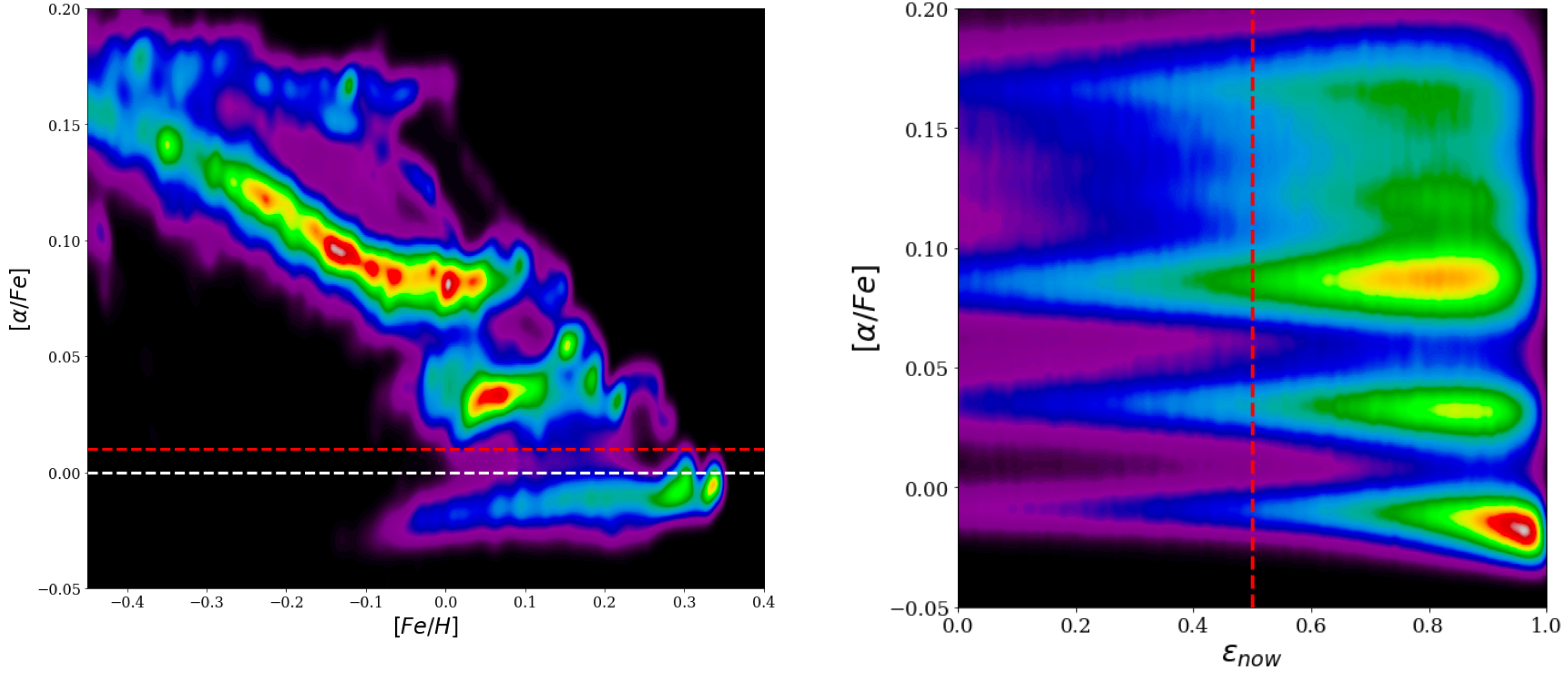


NH2: bimodal distribution in chemical properties like MW

NH2: dx=70 pc simulation with 9 chemical elements

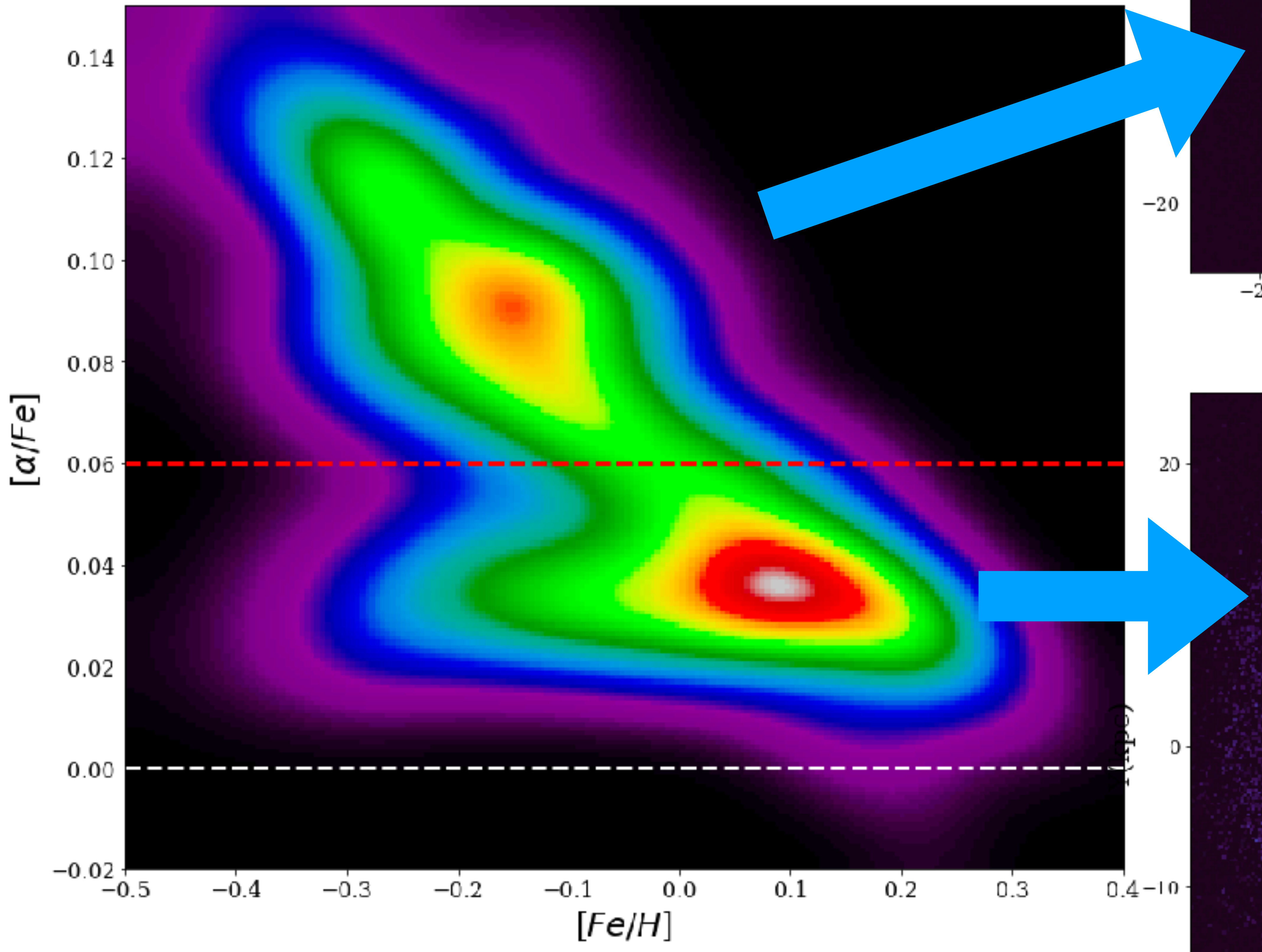
Consistent with Auriga (Grand et al. 2020)

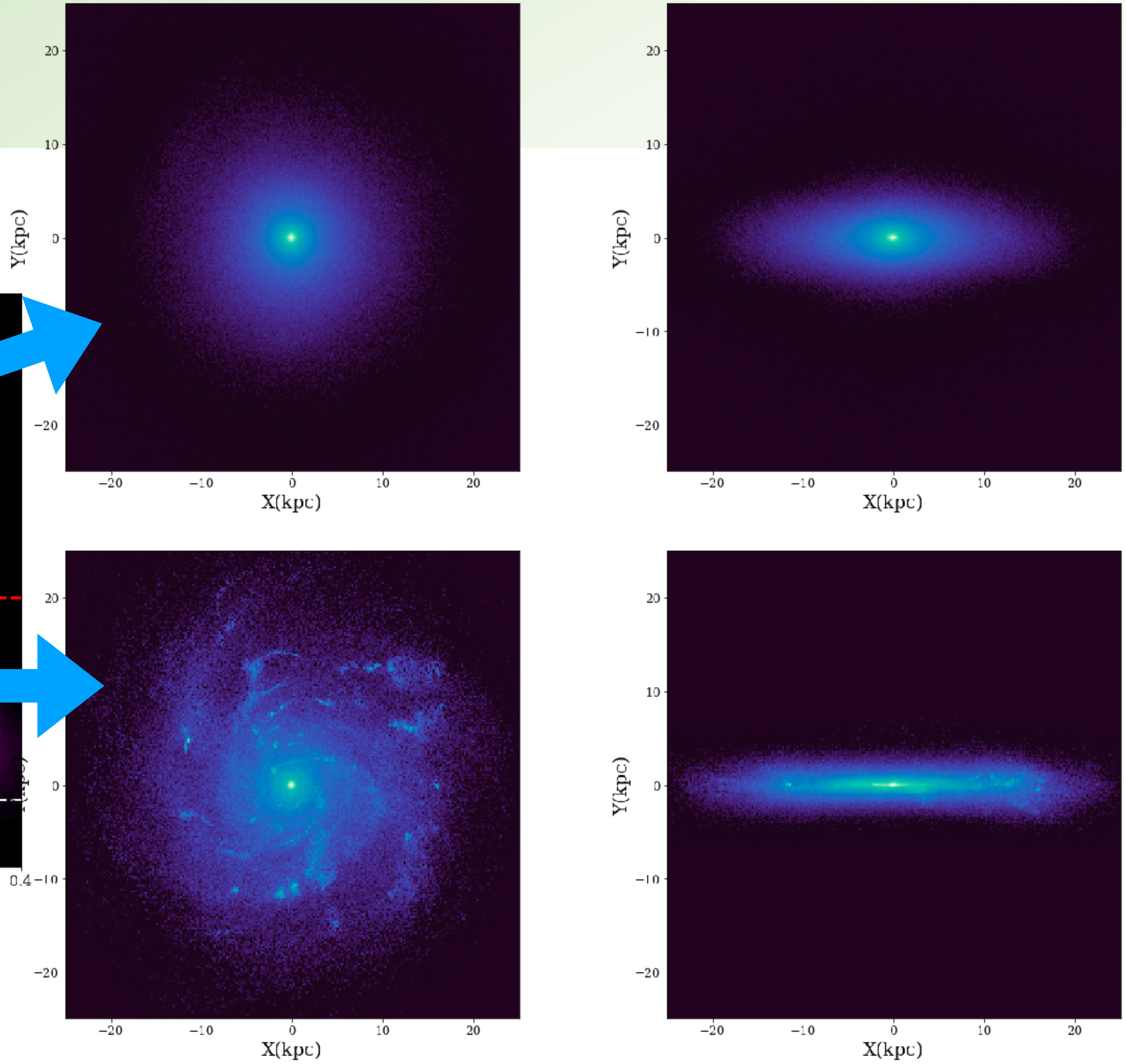
Varieties in chemical phase space distribution



NH2: [a/Fe] - morphology

Bimodal when smoothed

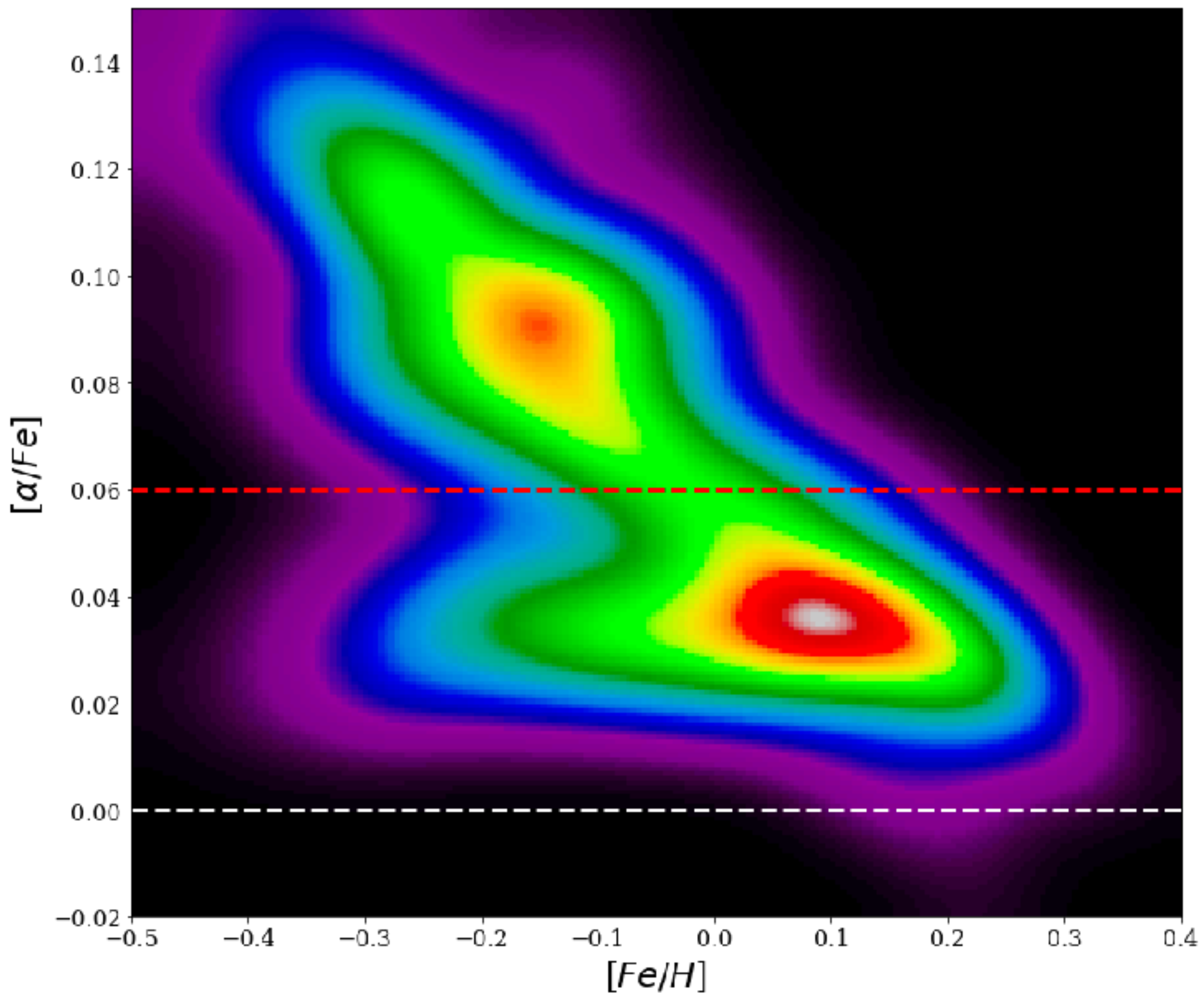




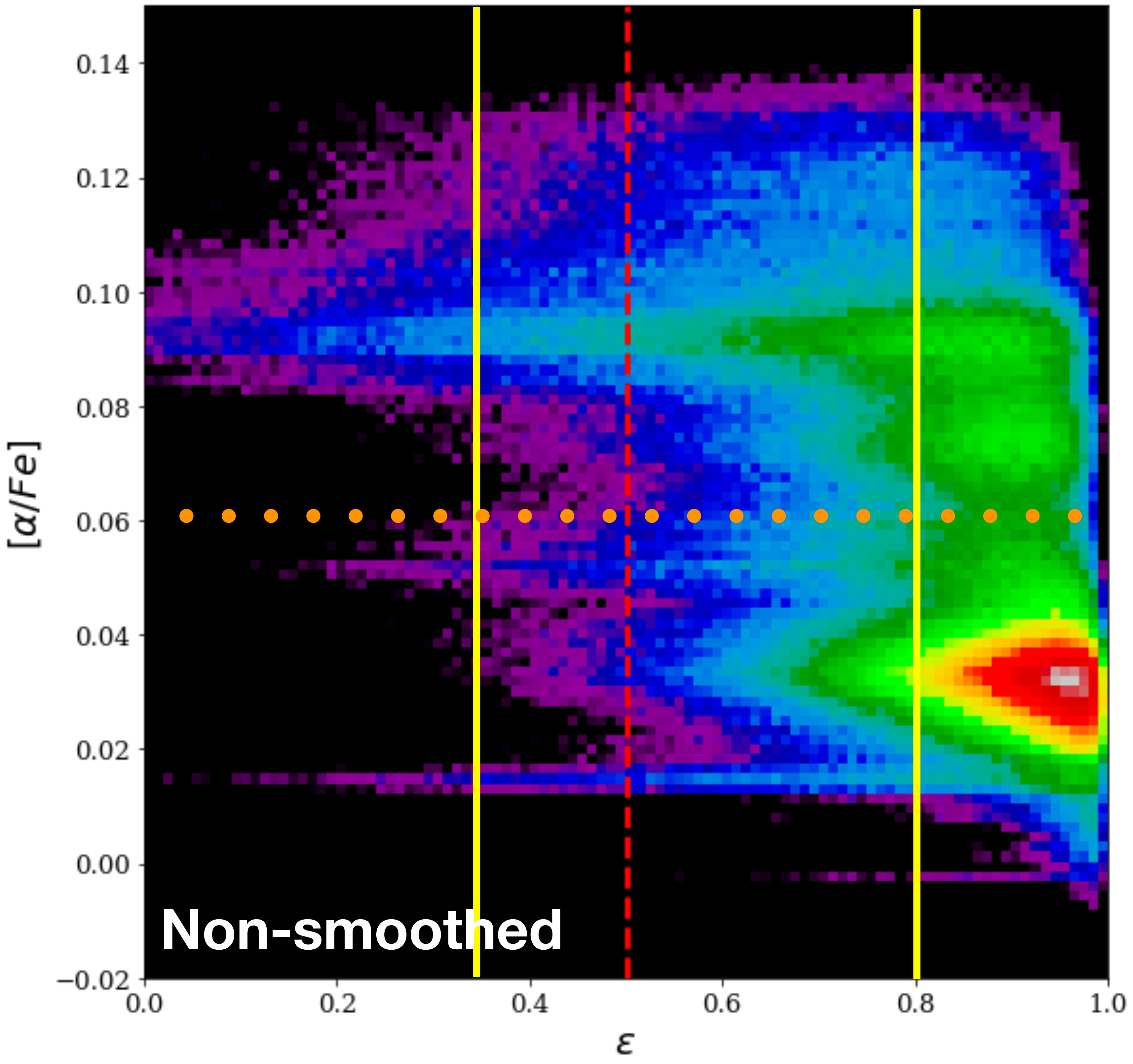
NH2: [a/Fe] - kinematics

High [a/Fe] includes
many thin-disc & spheroidal stars

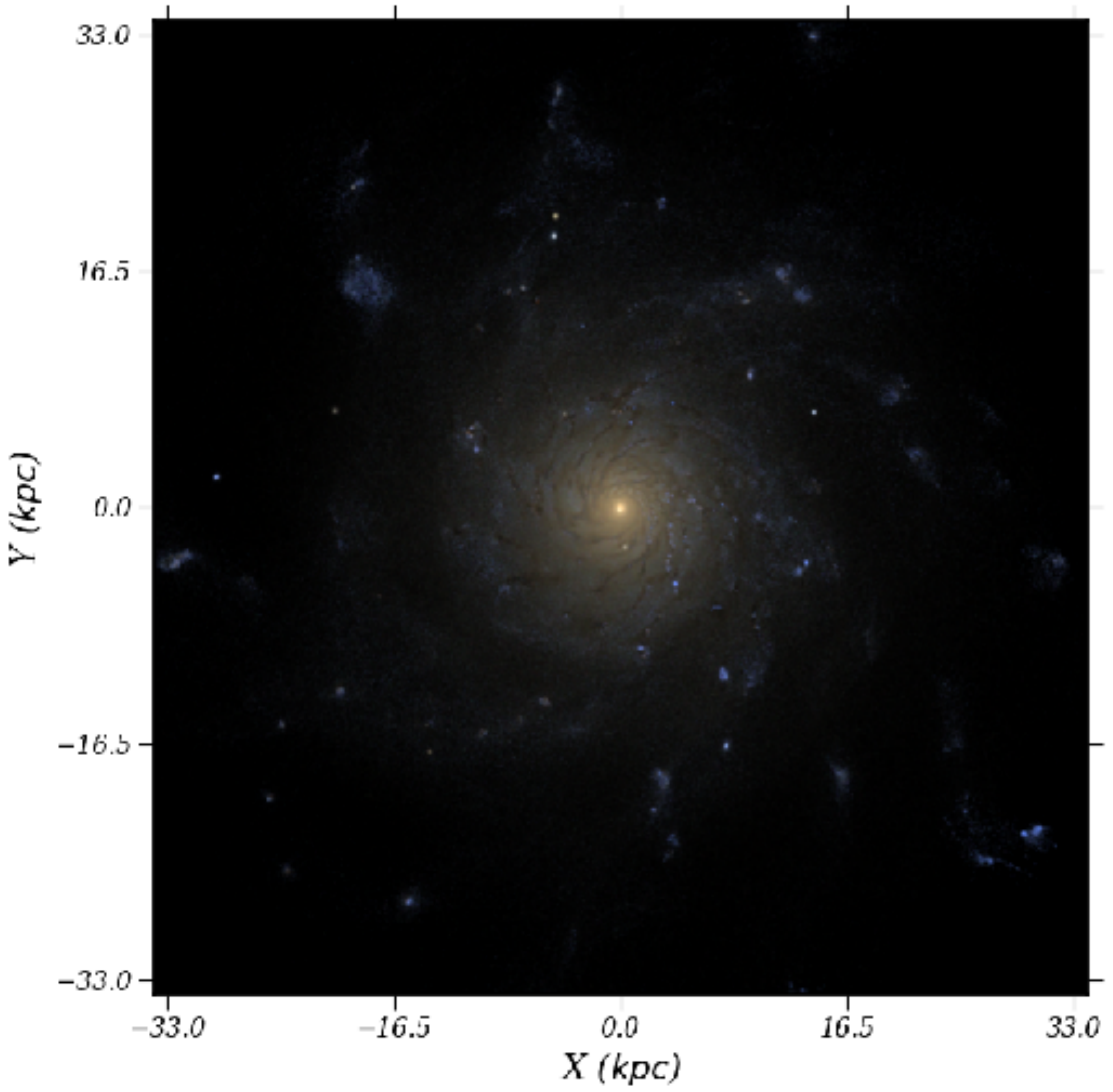
Bimodal when smoothed

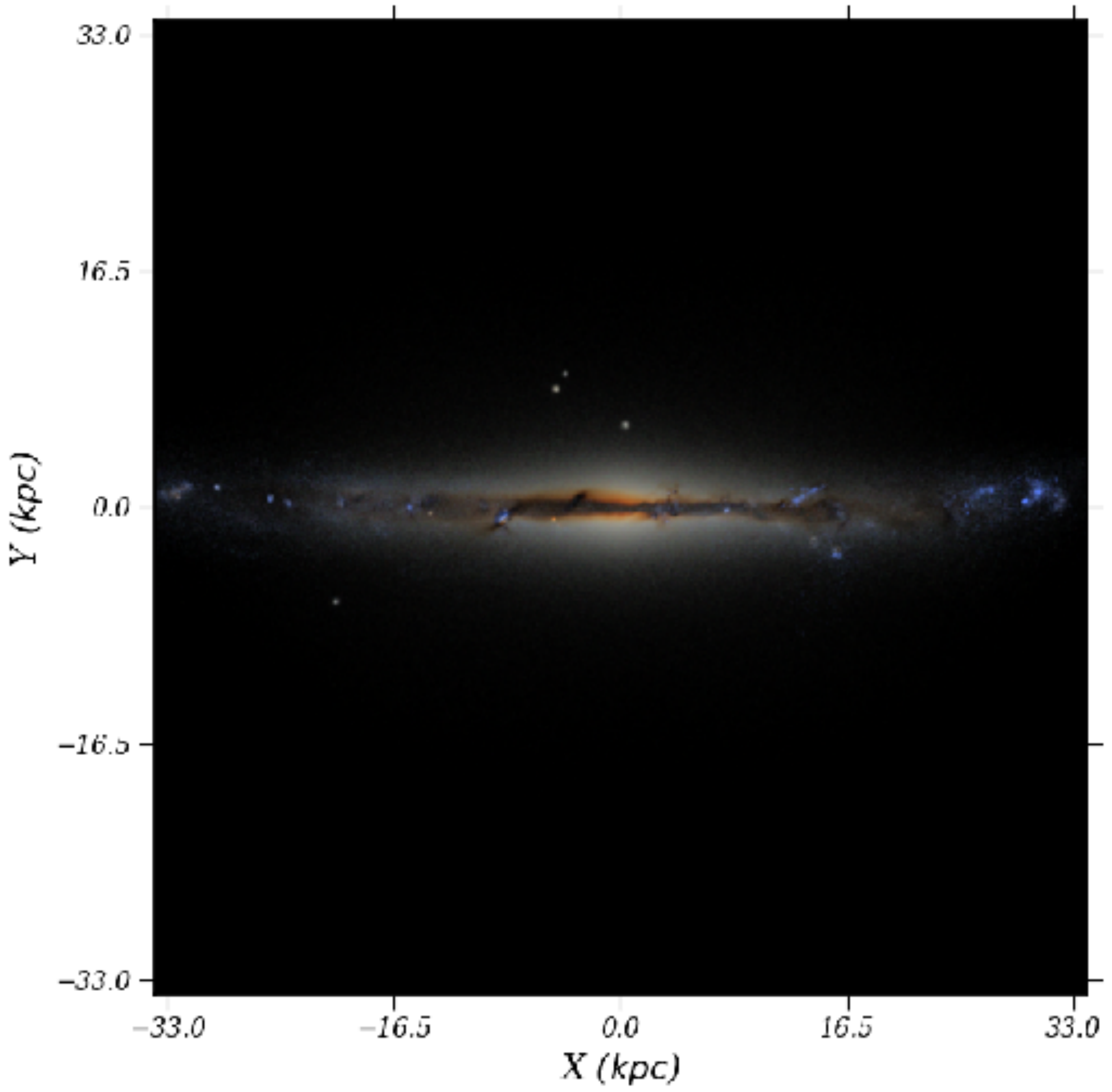


Dispersion ⟵ ⟶ Disc



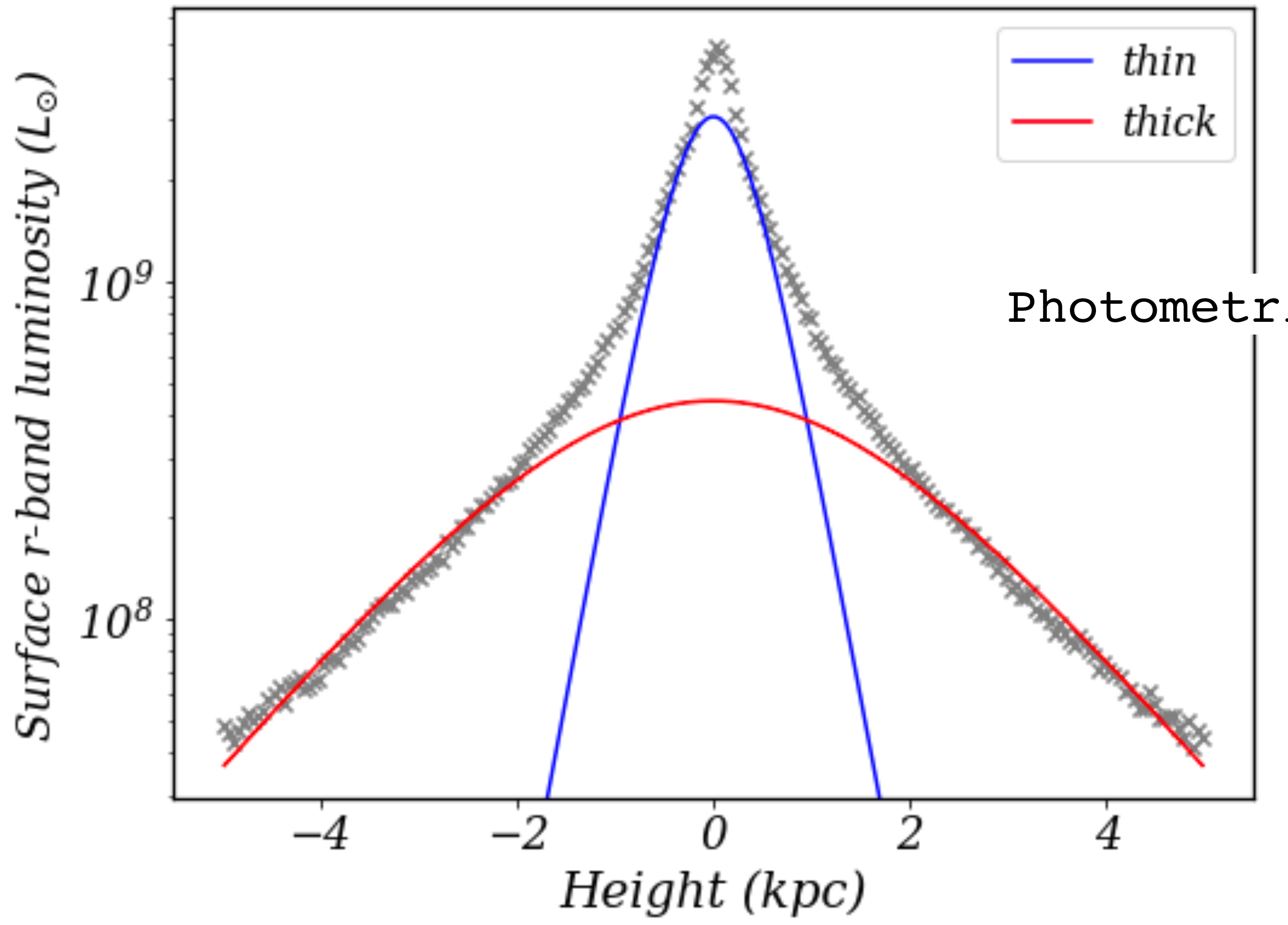
Dispersion Thick Thin



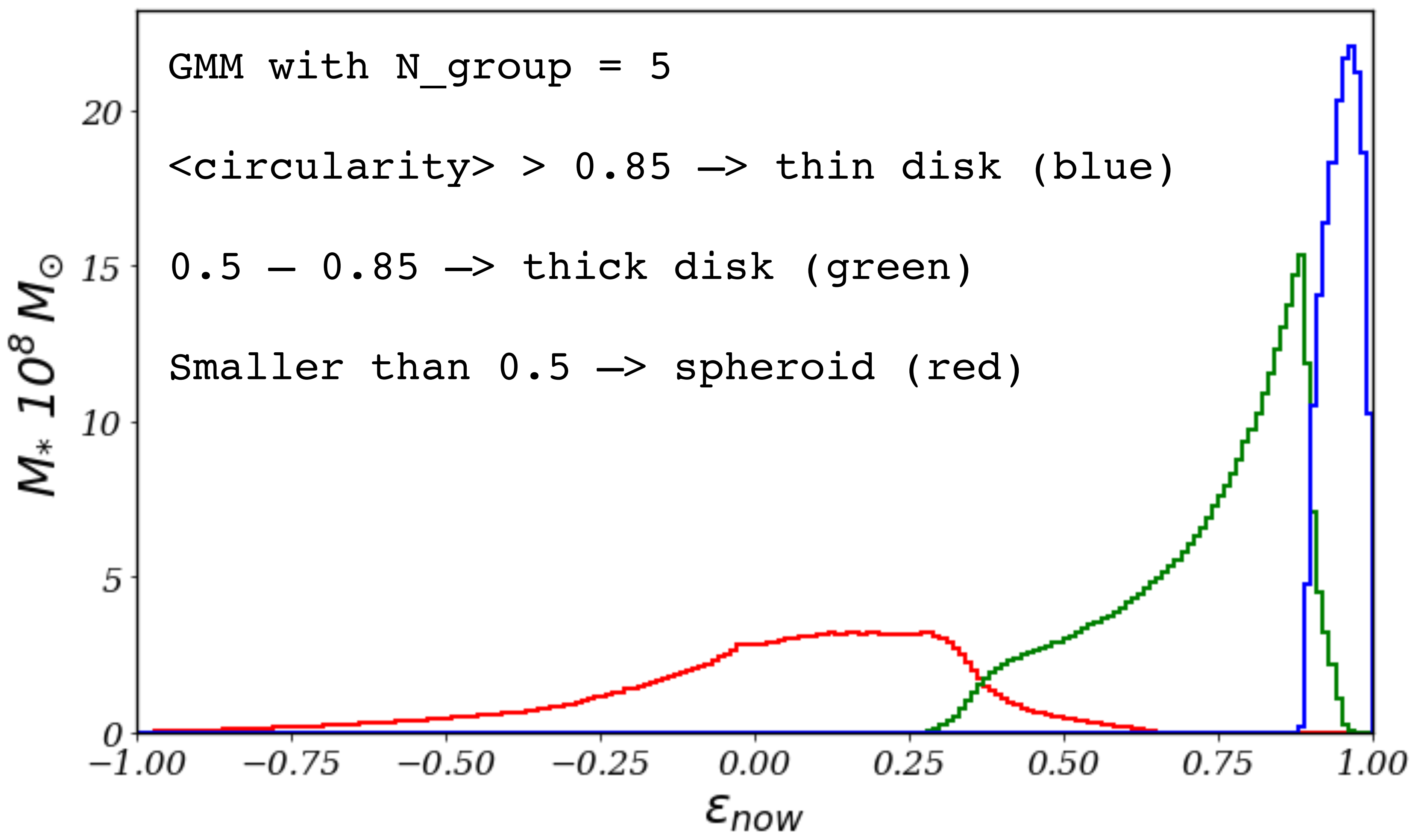


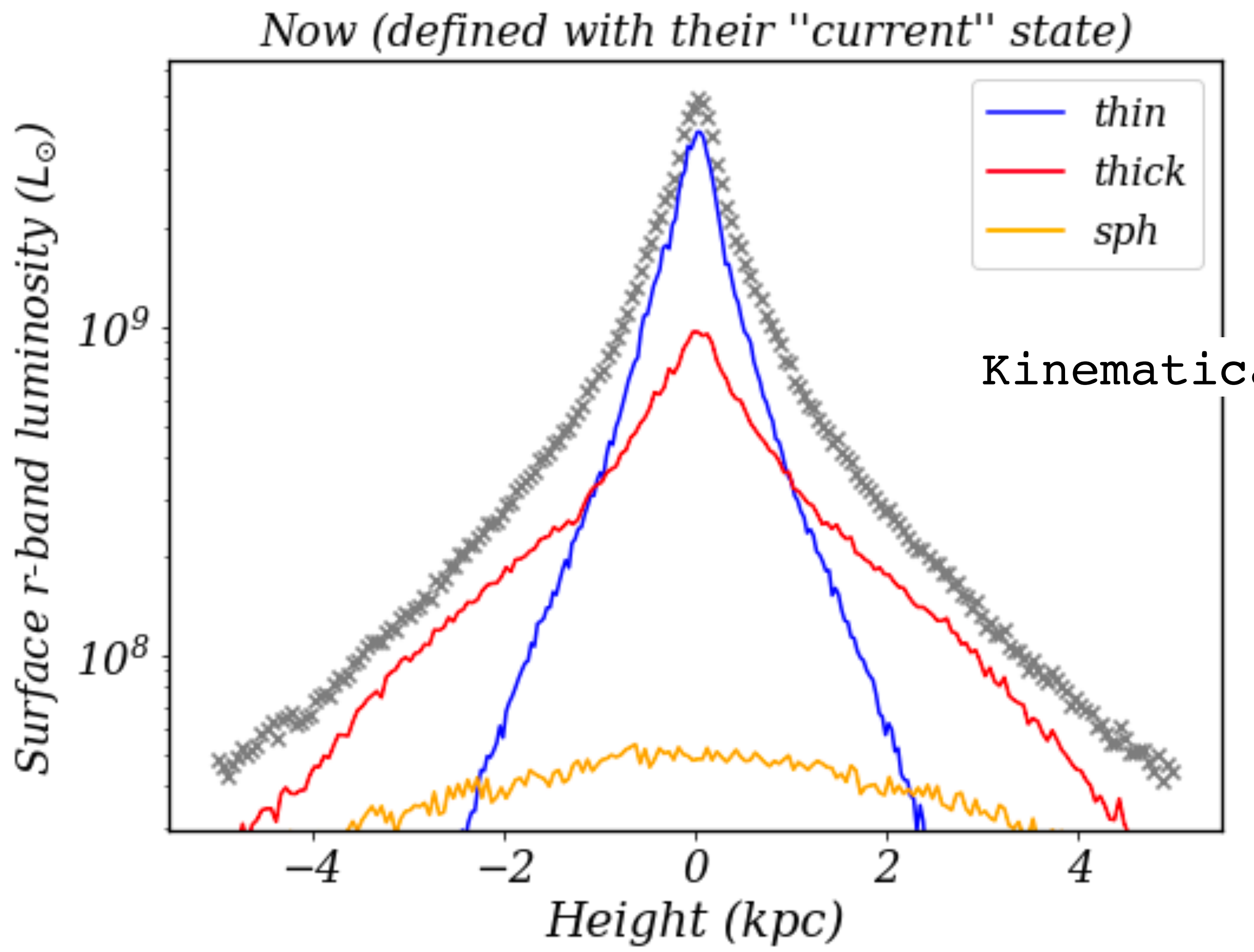
Measured at R_2d = 9 +- 1 (kpc)

thin disk's scale height : 0.28 (kpc)
thick disk's scale height : 1.3 (kpc)
z_cross : 0.95 (kpc)



Photometric 2-comp sech fit



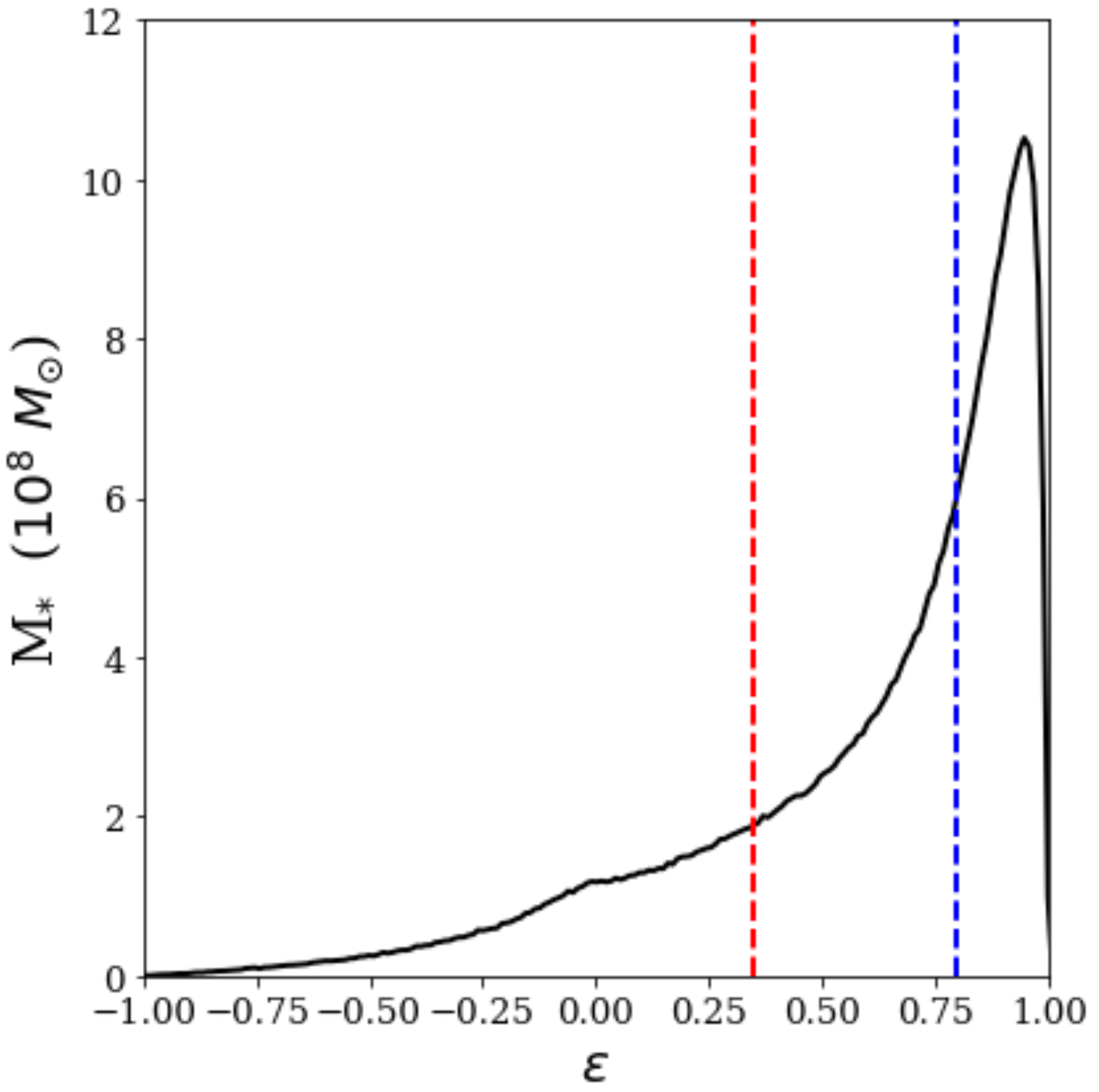


Kinematically classified

NH2: Kinematically-defined thin/thick discs

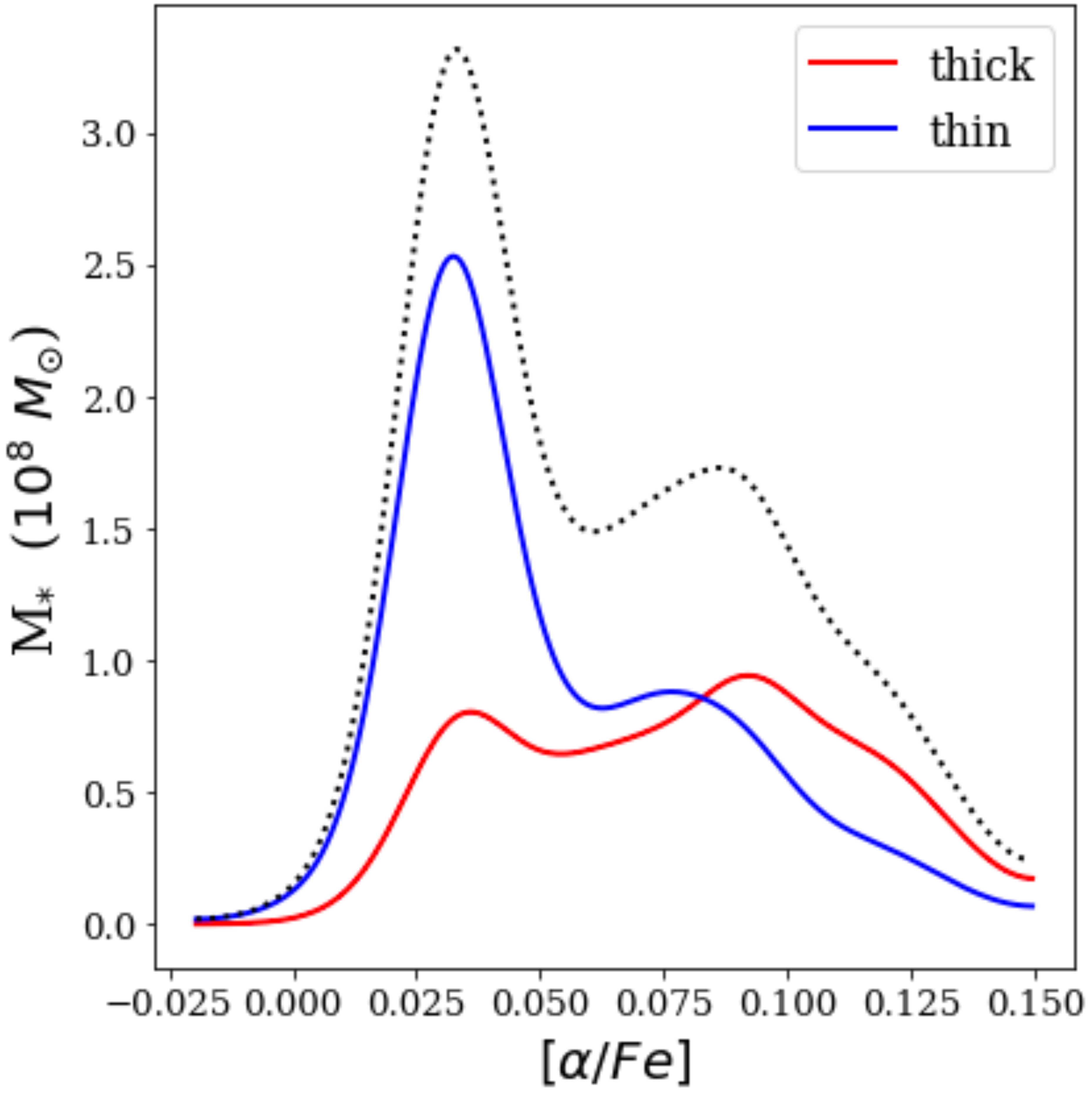
Measured — R_3d > 1 kpc

If we use these cuts



Present day circularity

“thick disc” has a wide range of [a/Fe].

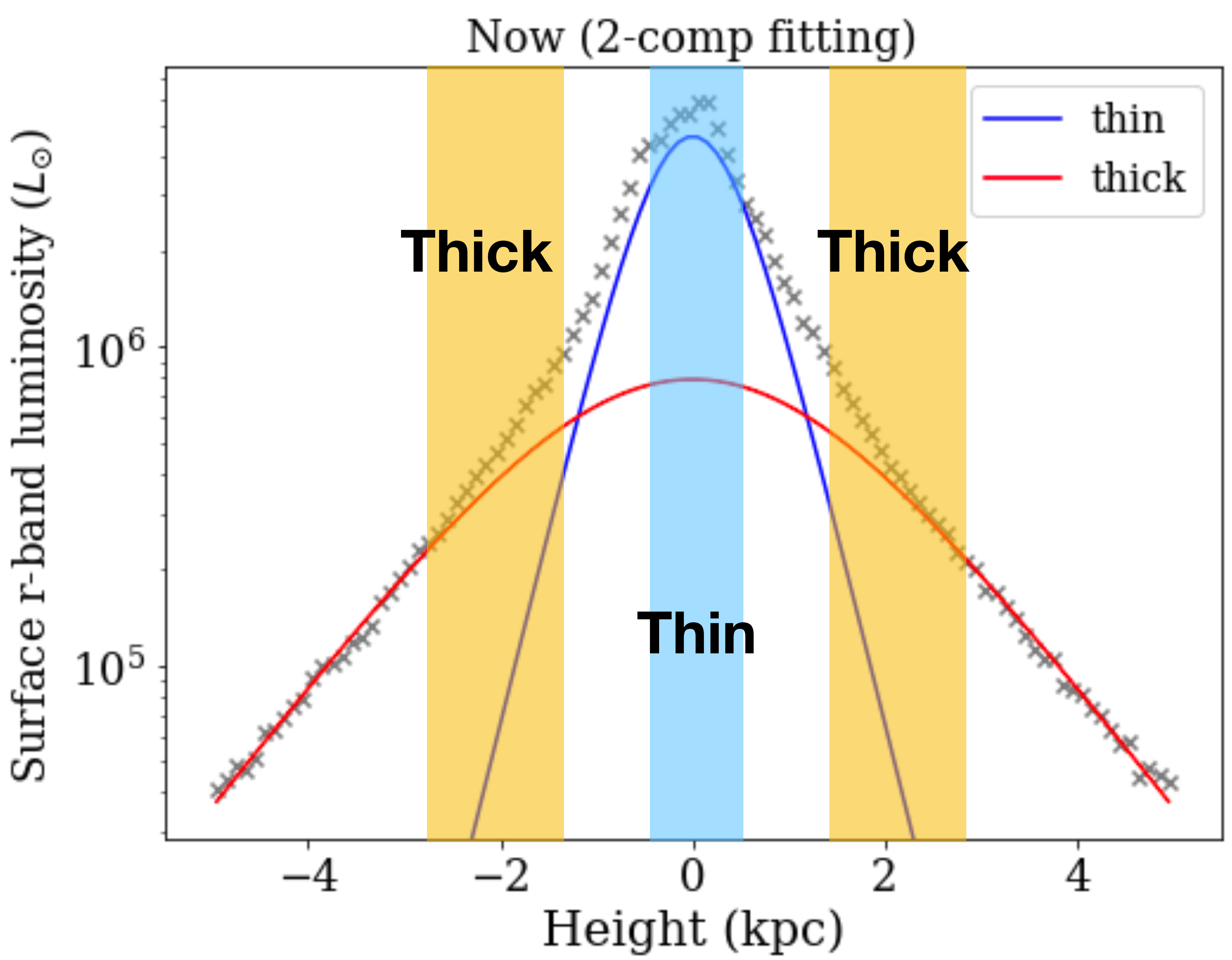


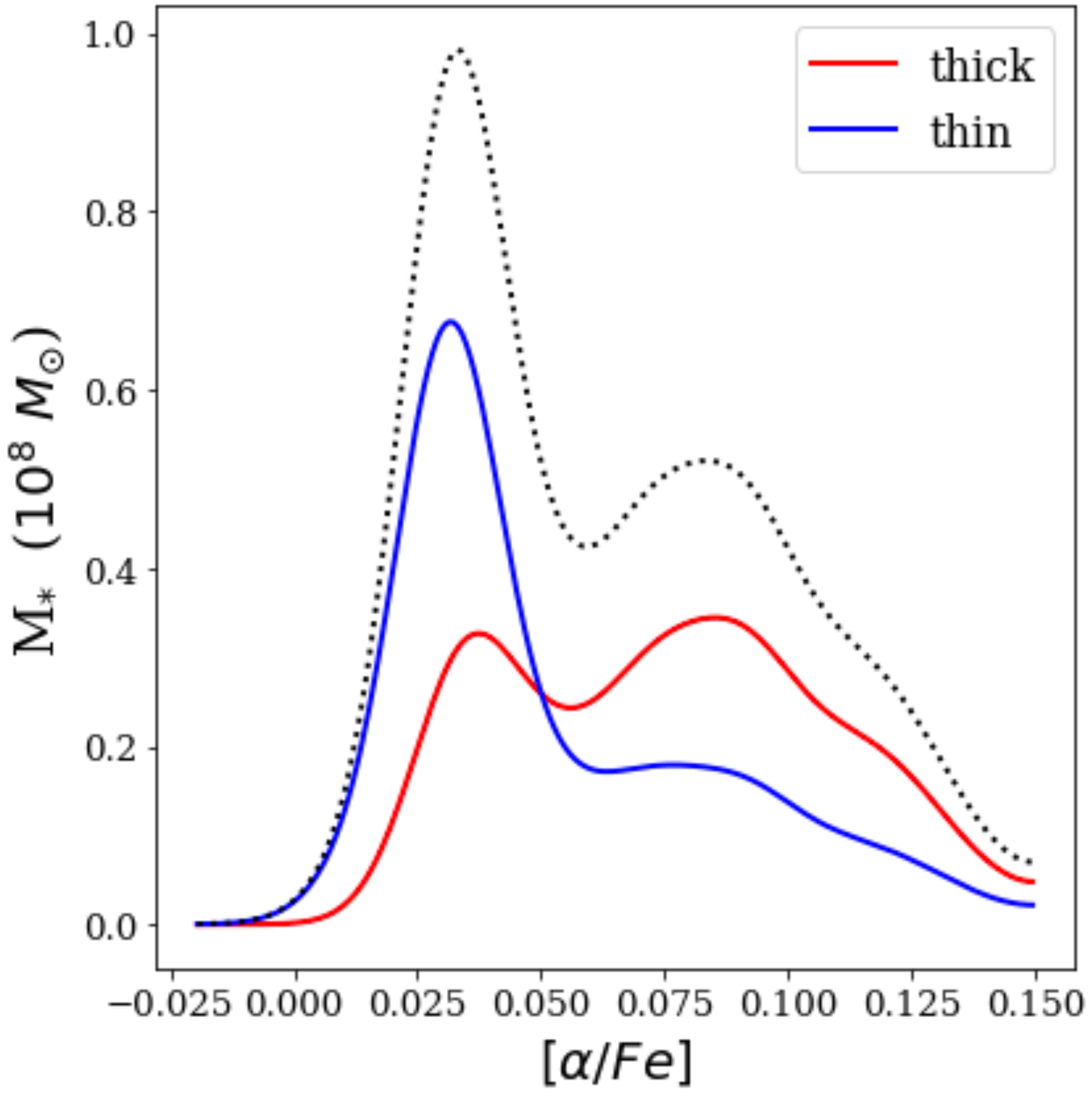
NH2: Spatially-defined thin/thick discs

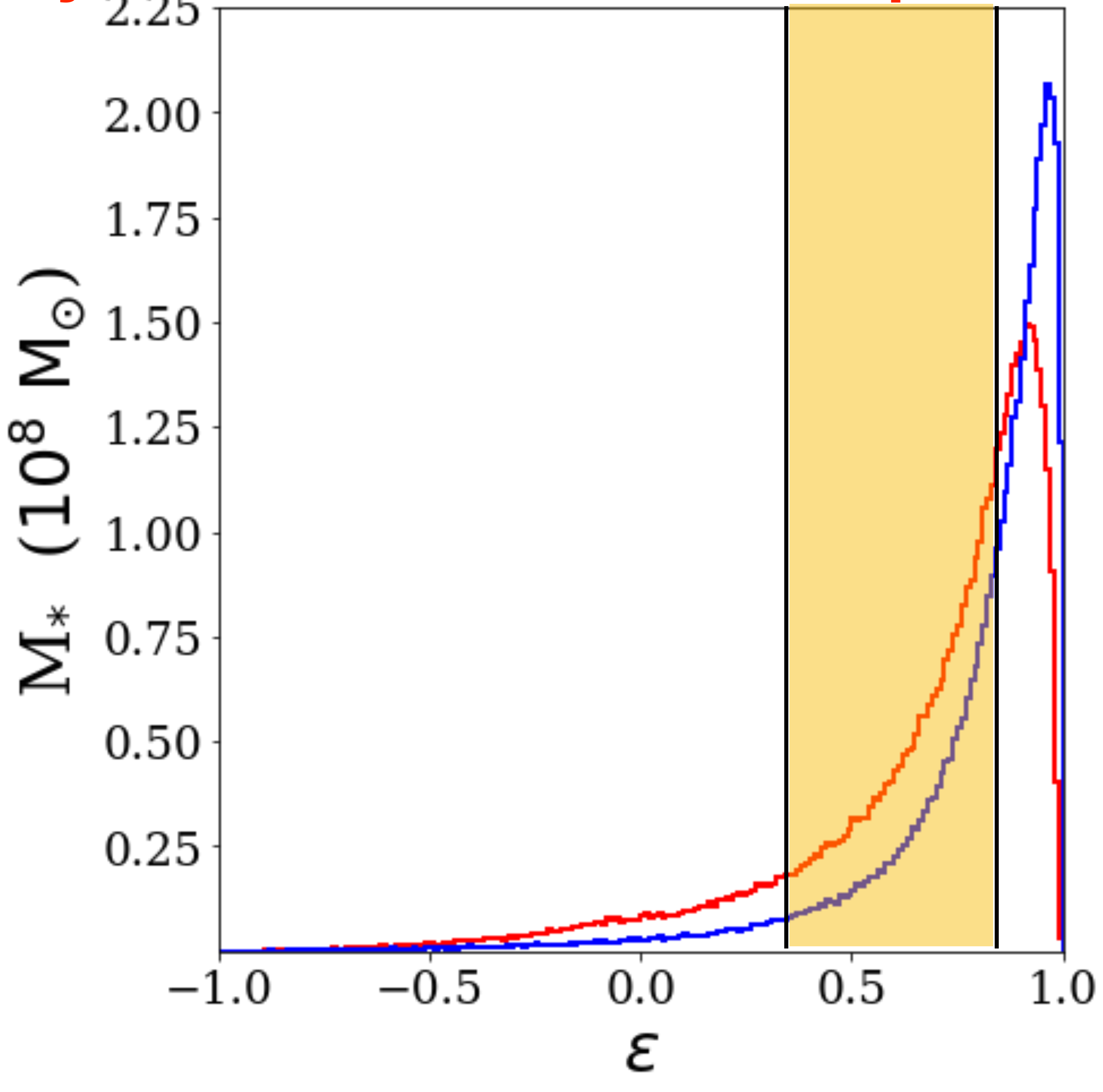
```
thin disk's scale height : 0.36 kpc
thick disk's scale height : 1.12 kpc
z_cross : 1.19 kpc

z_thick / z_thin : 3.16
```

```
thin_disk: |Z| < 1*z_thin
thick_disk: 1.2*z_thick < |Z| < 2.5*z_thick

Measured within 0.5*R_50 – 2.0*R_50
```

Spatial thick disc based on the surface bright fit does not fully tell us the kinematic composition.

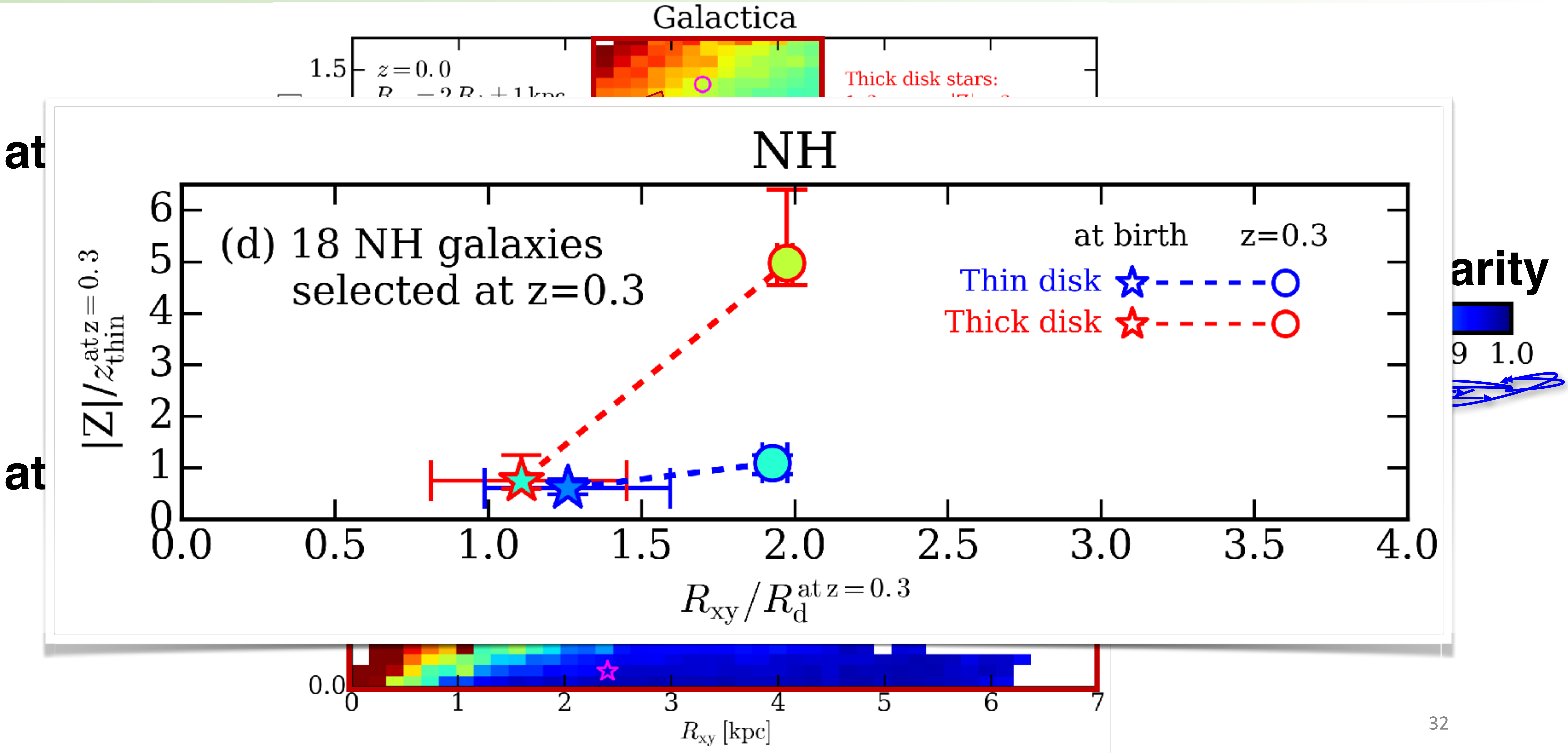






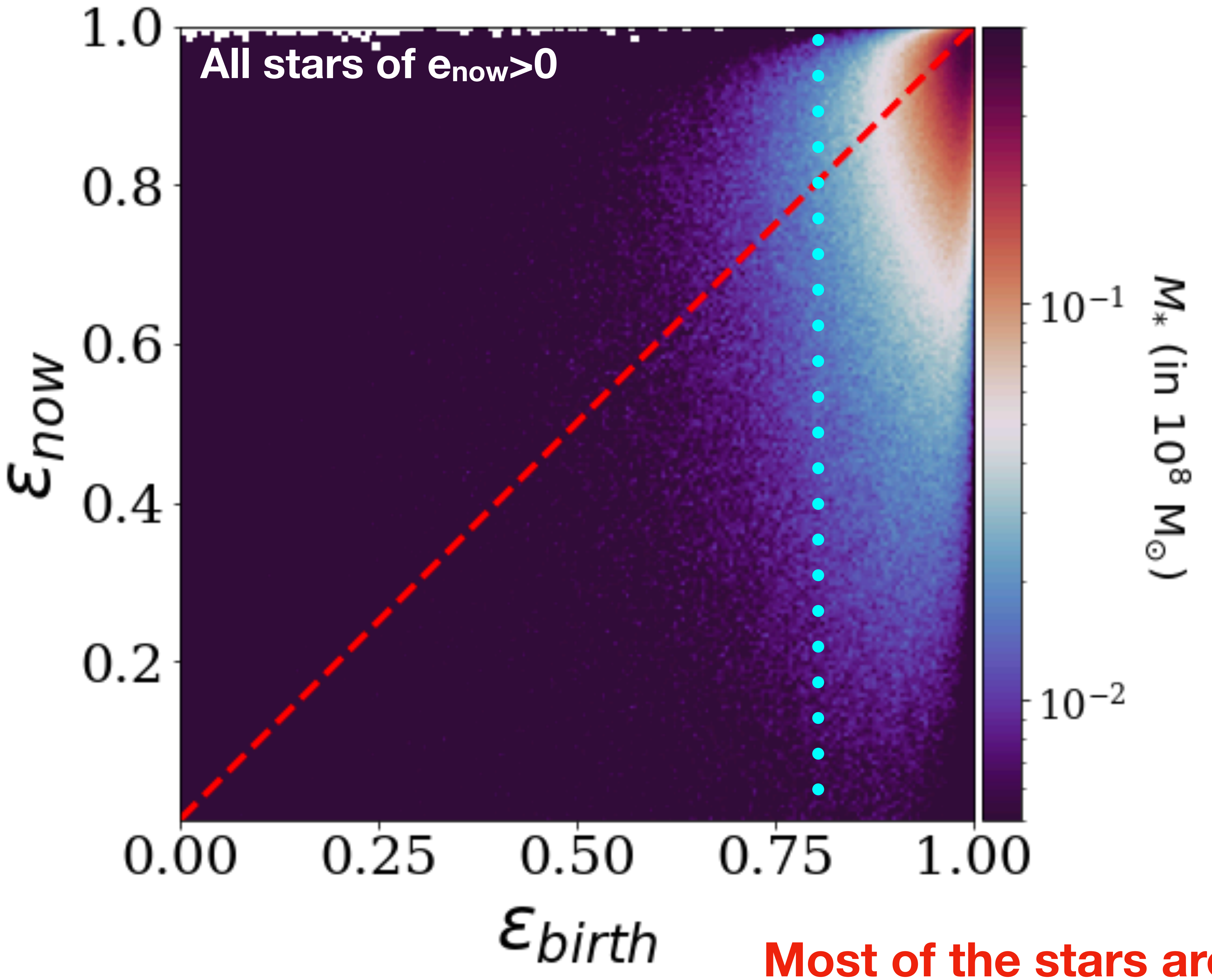
NH: Birth place of spatial thick disc stars

Park et al. 2021, ApJS, 254, 2



Cicularity change of disc stars: disc heating

Consistent with FIRE (Ma et al. 2019) and NIHAO (Buck et al. 2019)



Most of the stars are born on the thin disc and dynamically heated with time.

Summary

- Both thin and thick discs are well **reproduced as observed.**
- Thick disc stars: mostly **in situ** formed.
- Thick disc is mainly **a result of secular evolution**
  - Pre-existing stars get **dynamically heated**.
  - But a large variation between galaxies depending on SF and merger history.
- Thin and thick discs are **continuous** and reflect the SFH of the galaxy.
- Are there really two distinct discs?

Gaussian Mixture Models on NH