Thick discs of spiral galaxies

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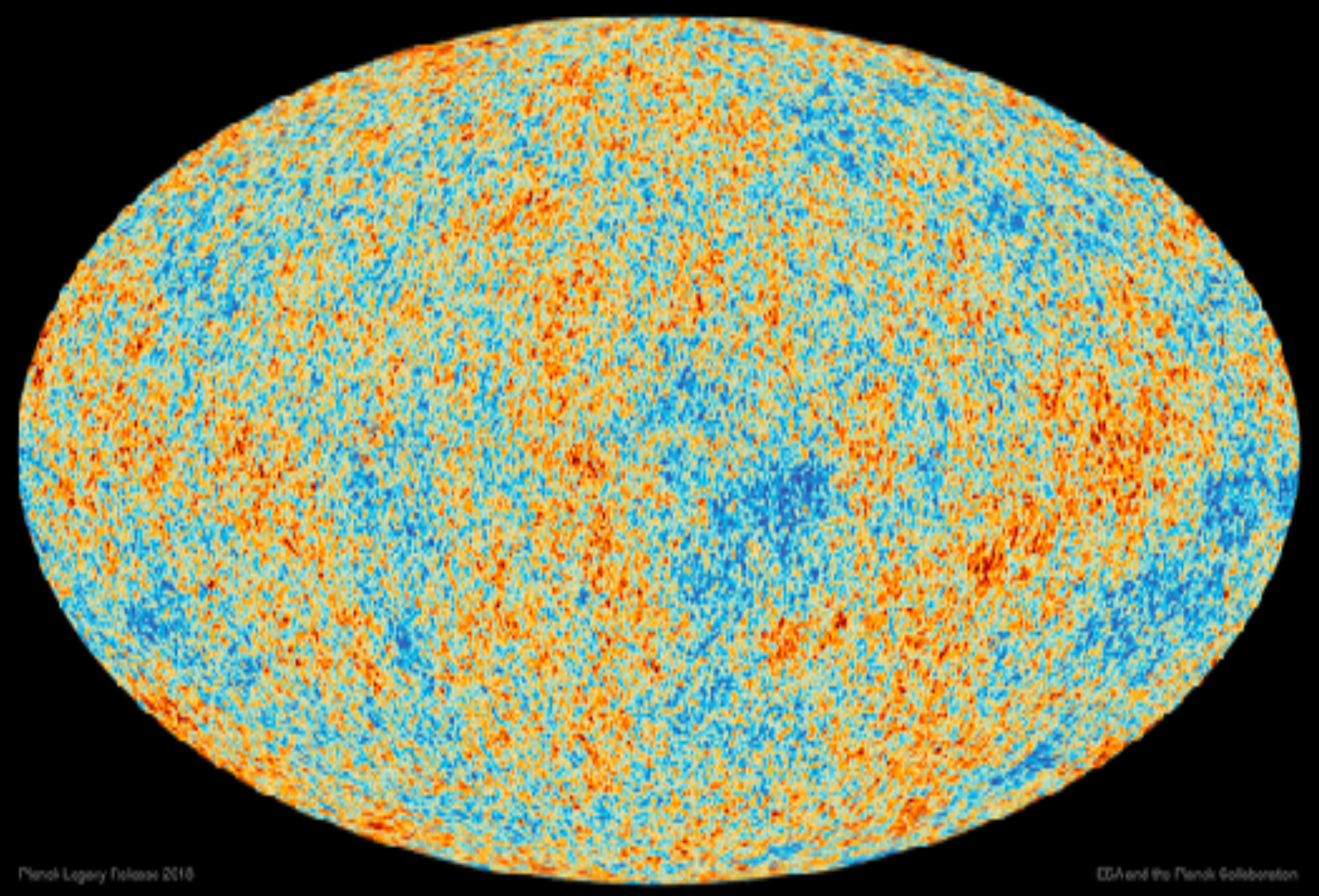
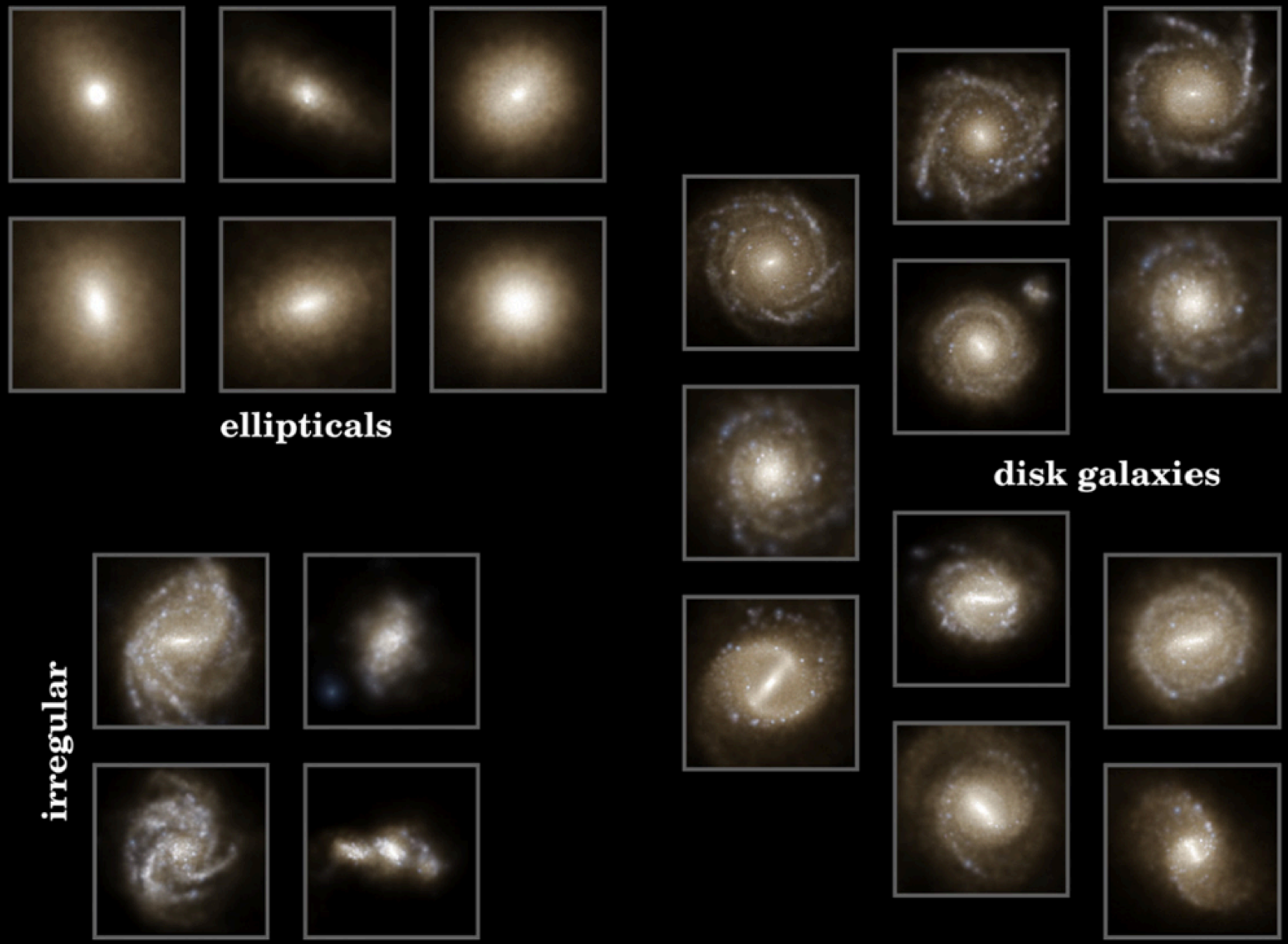
Numerical simulation of GF





Vogelsberger et al. 2014 (Illustris)

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

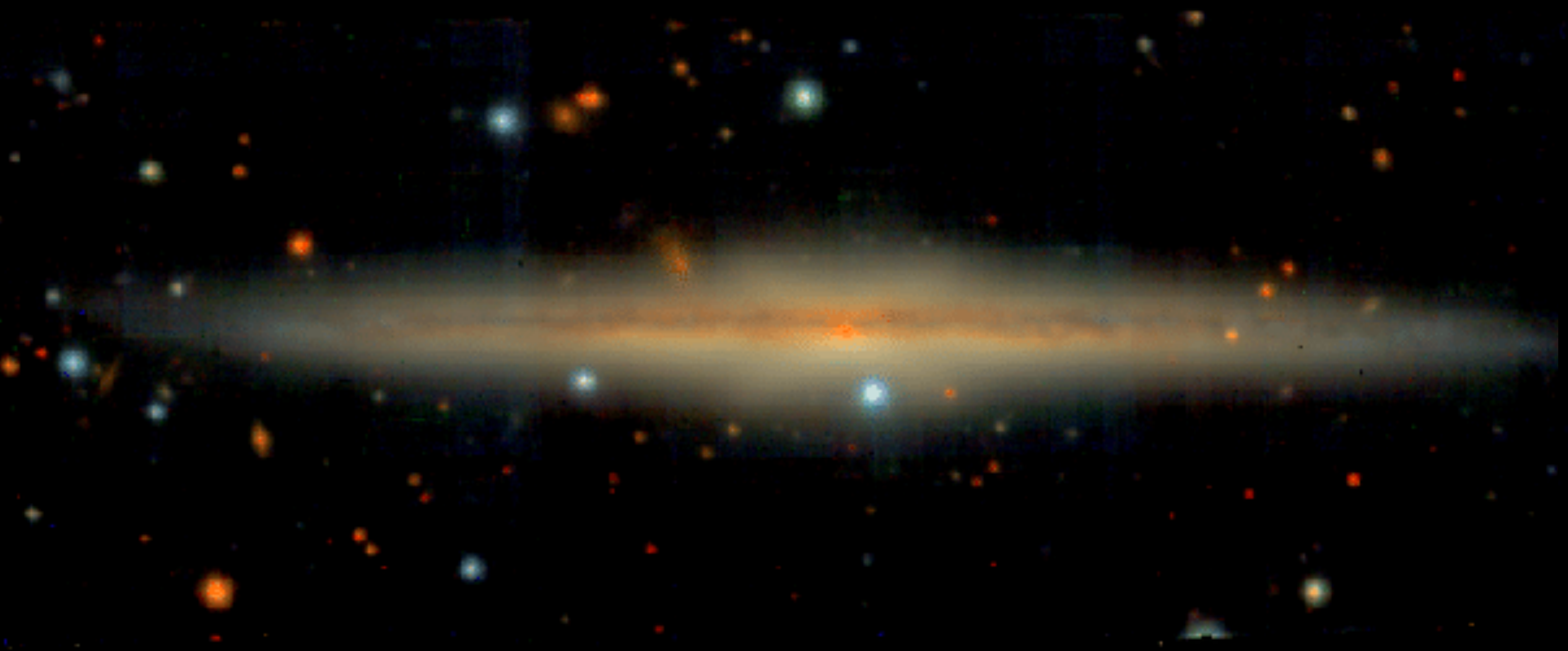
Credit: Jinsu Rhee

Disc formation
NH in SKIRT

NH: ID-1-867

Credit: JK Jang

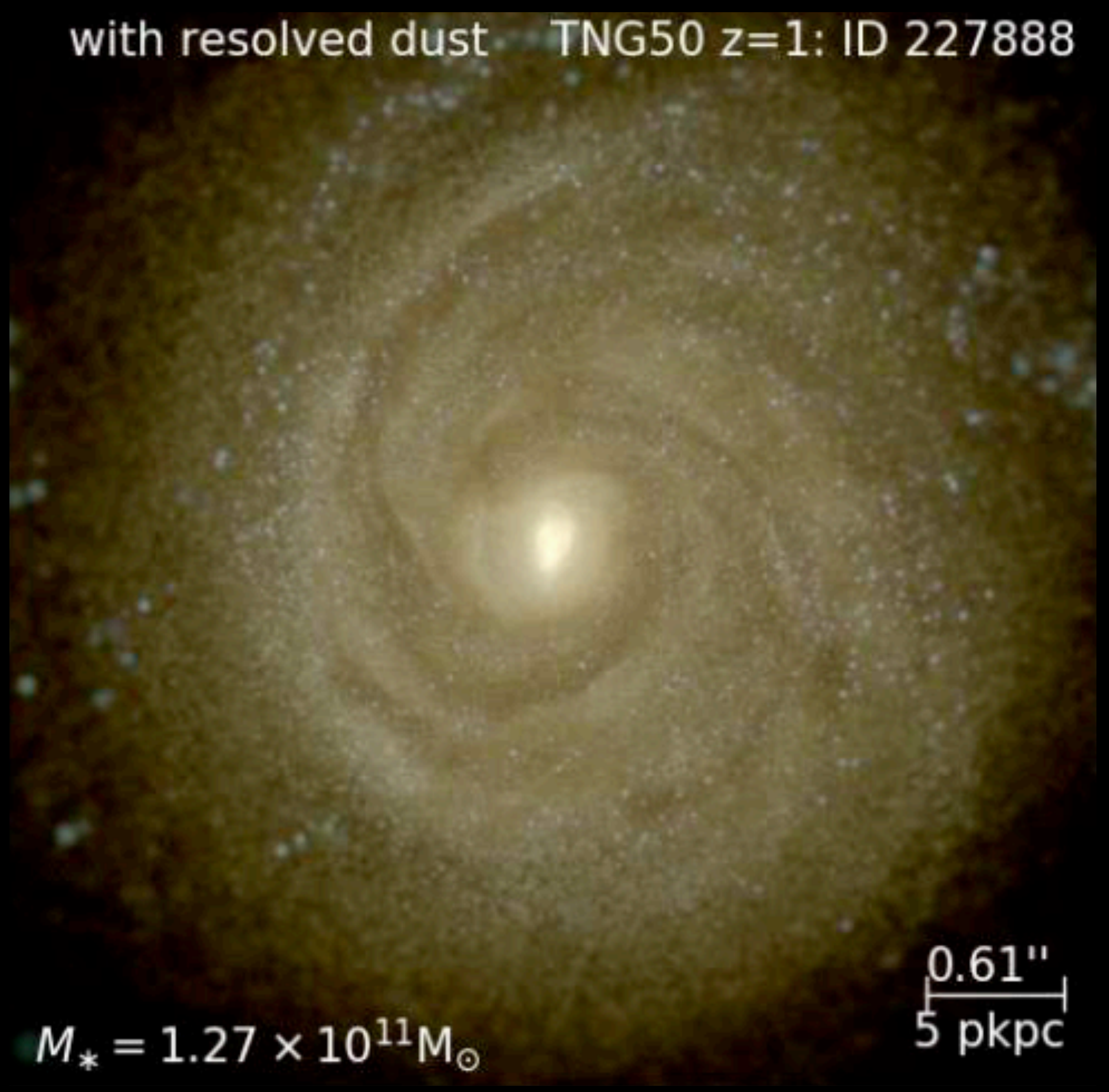
Observation

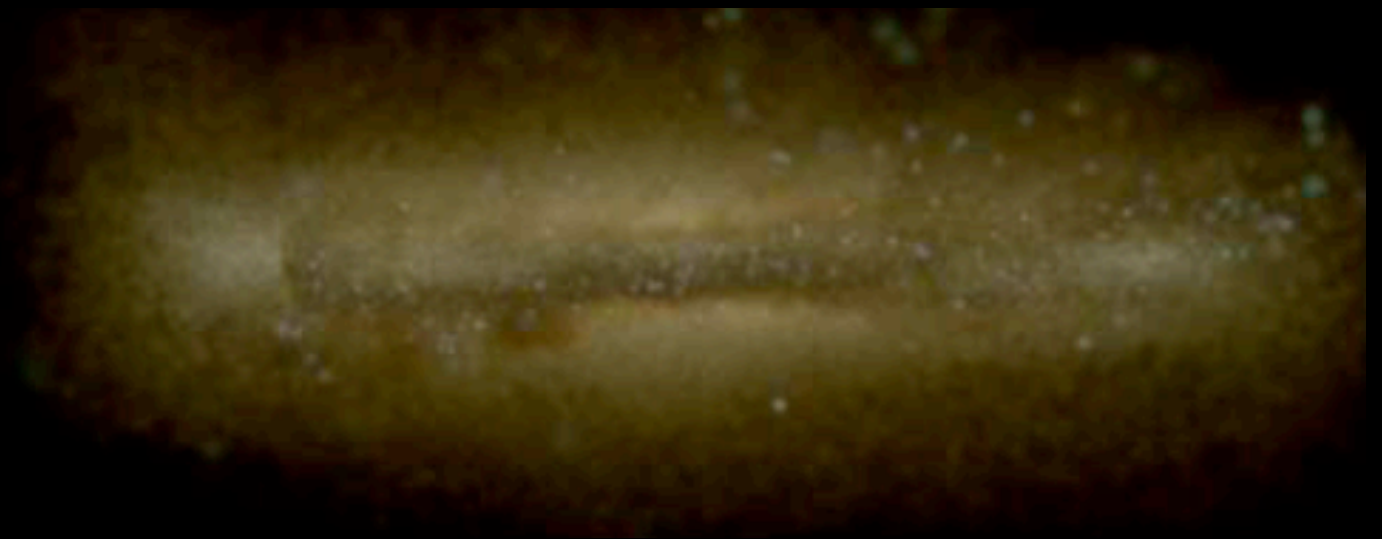


UGC 10738 (Scott et al. 2021)

NewHorizon

TNG50



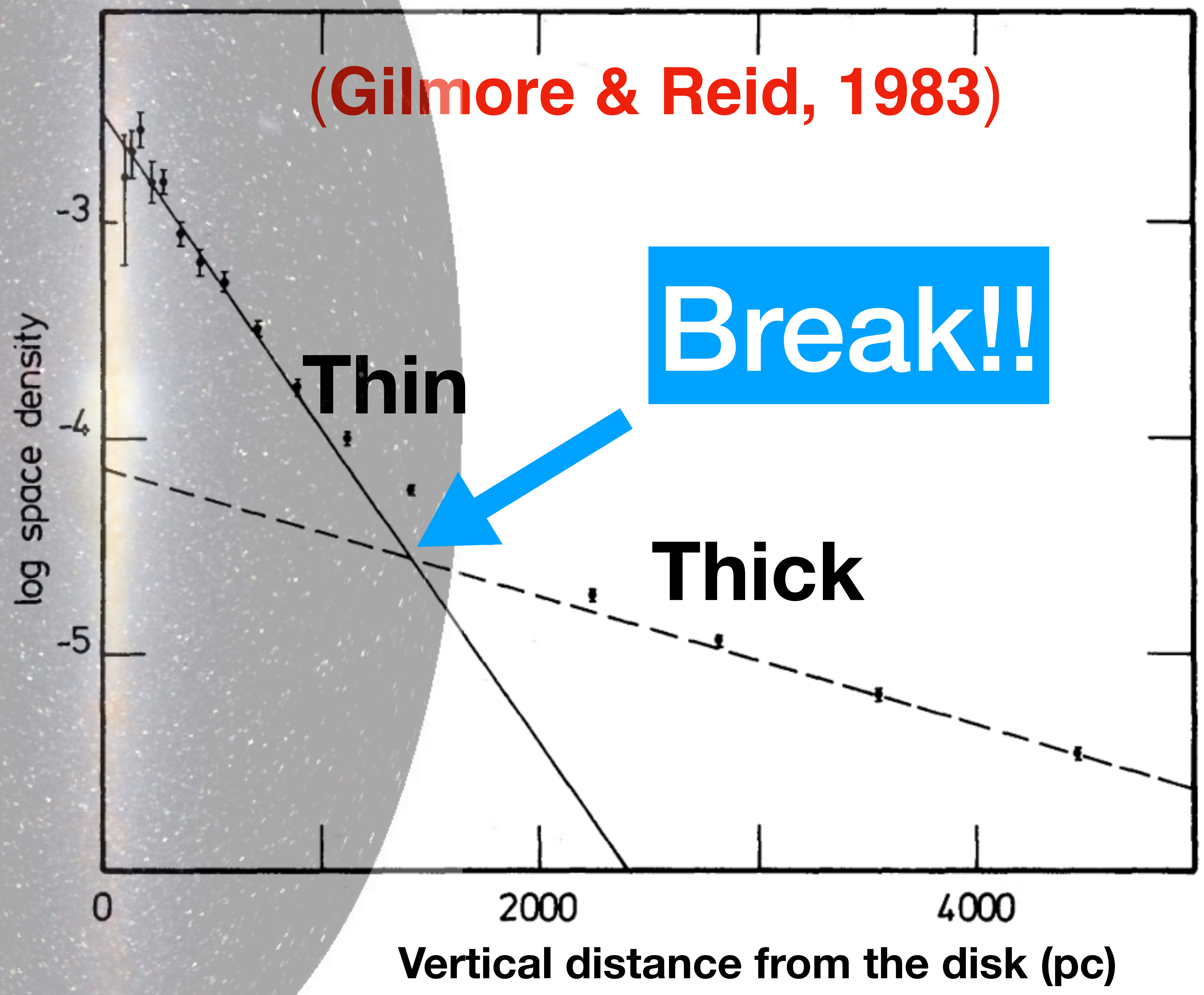


NH2

9 elements inc. O & Mg traced

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

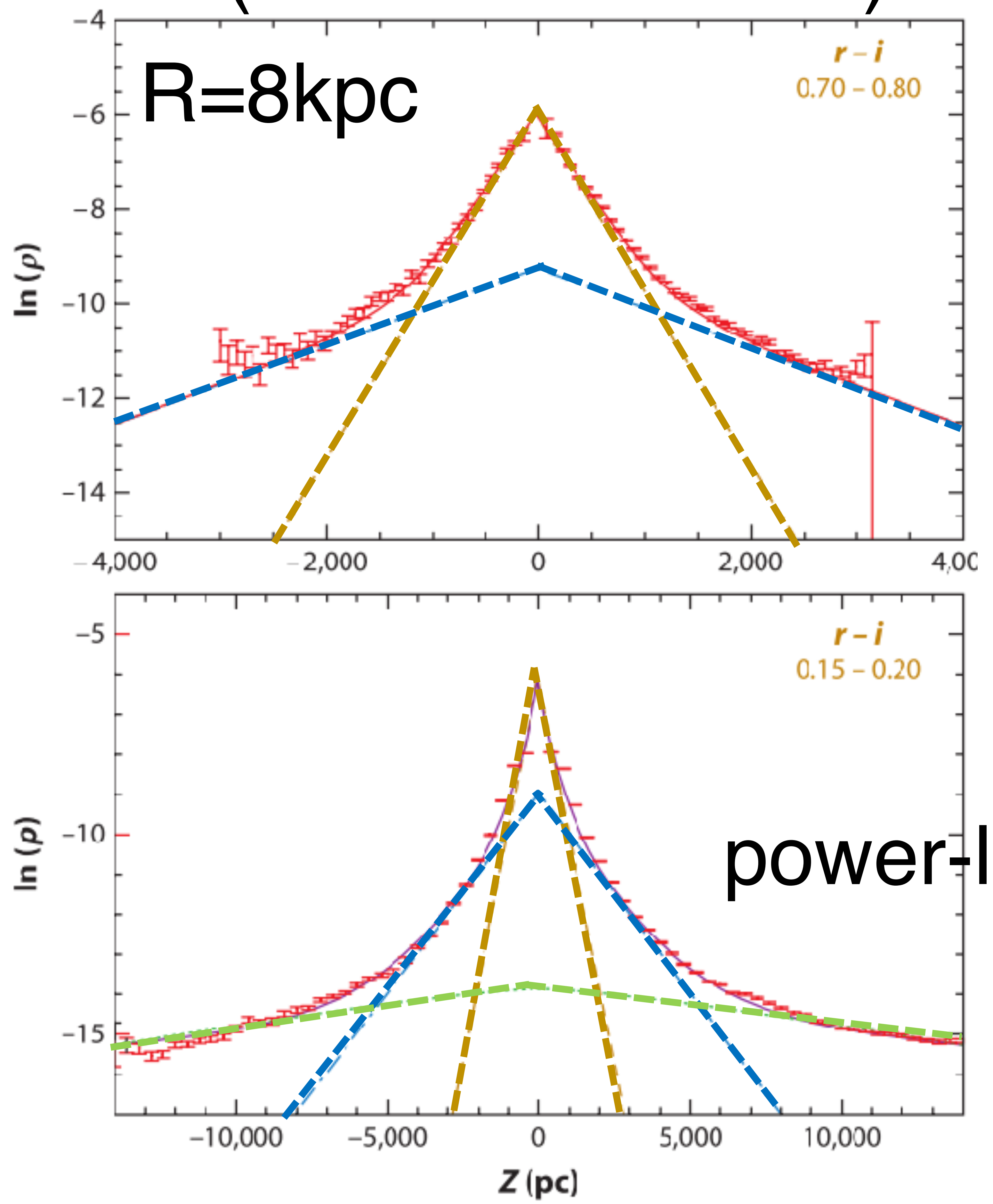
- **Exponential** fit **~ 300pc (thin)**
  ~1450pc (thick)

  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

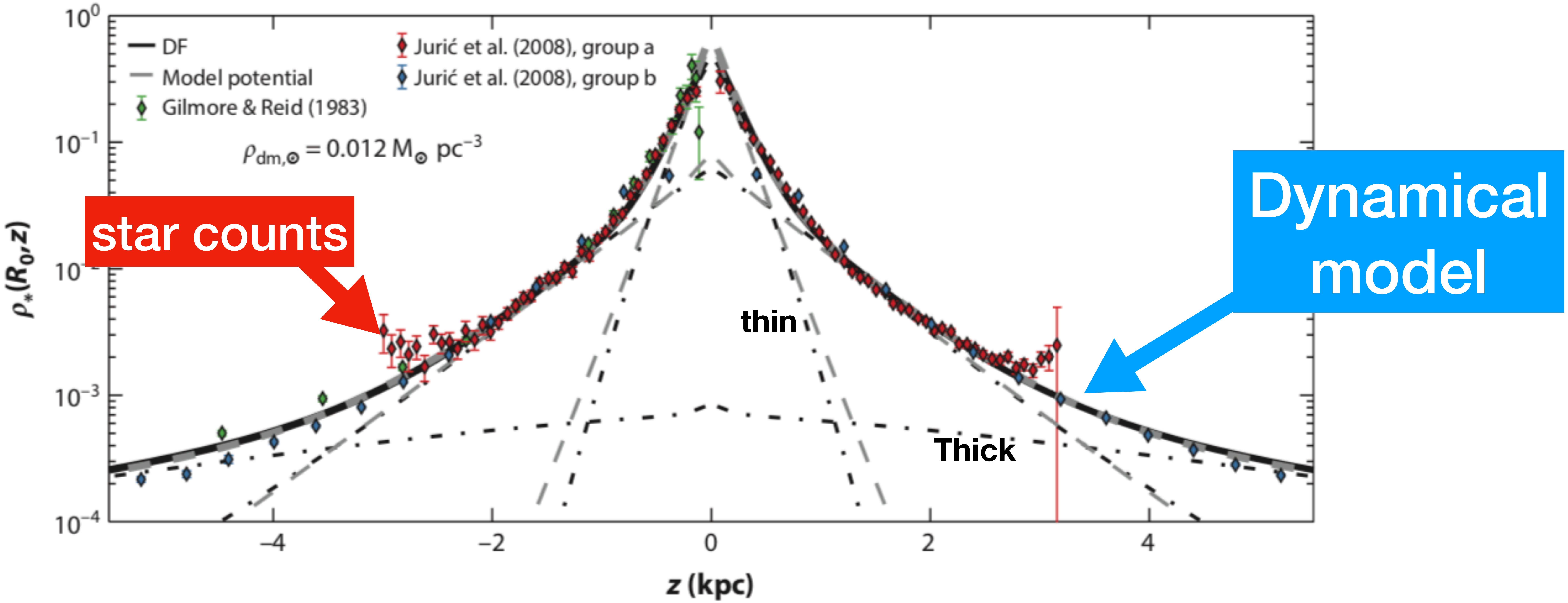
- Vertical density profile of a self-gravitating isothermal population, massive disc (Spitzer 1942; Kruit & Searle 1981)

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

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

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

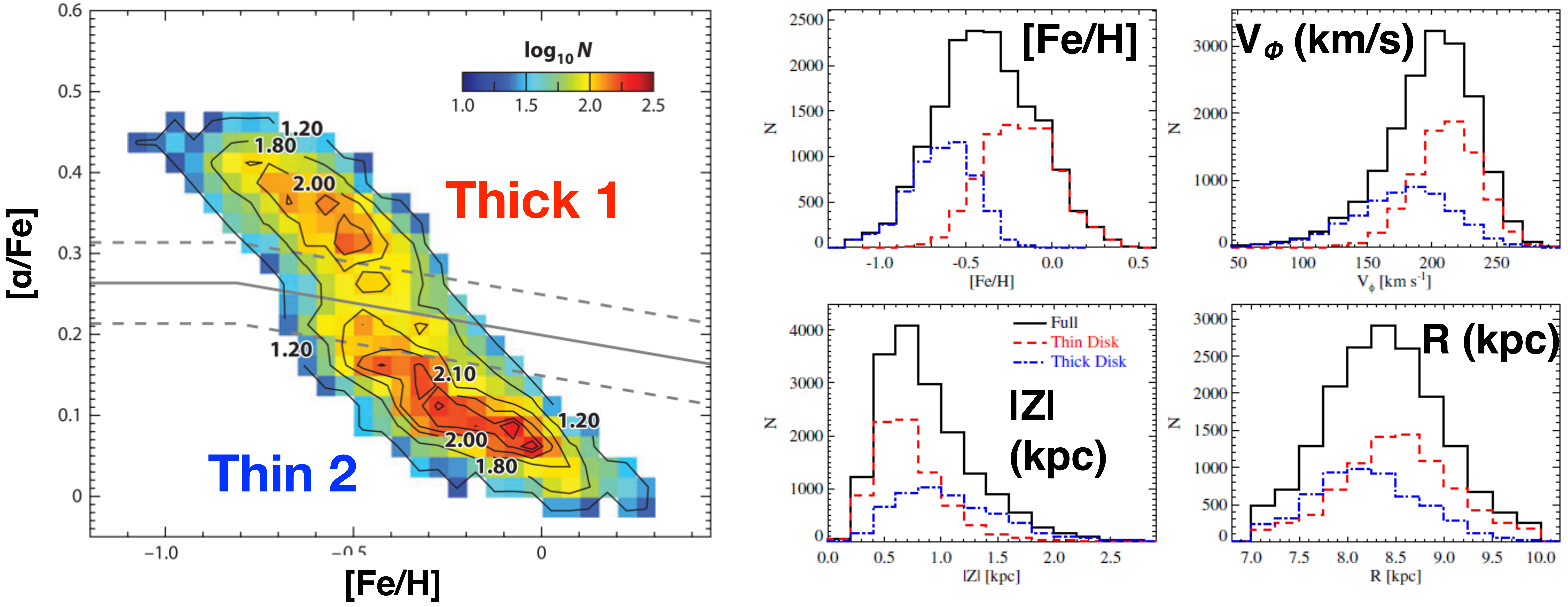
Observation: dynamical models on star counts



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

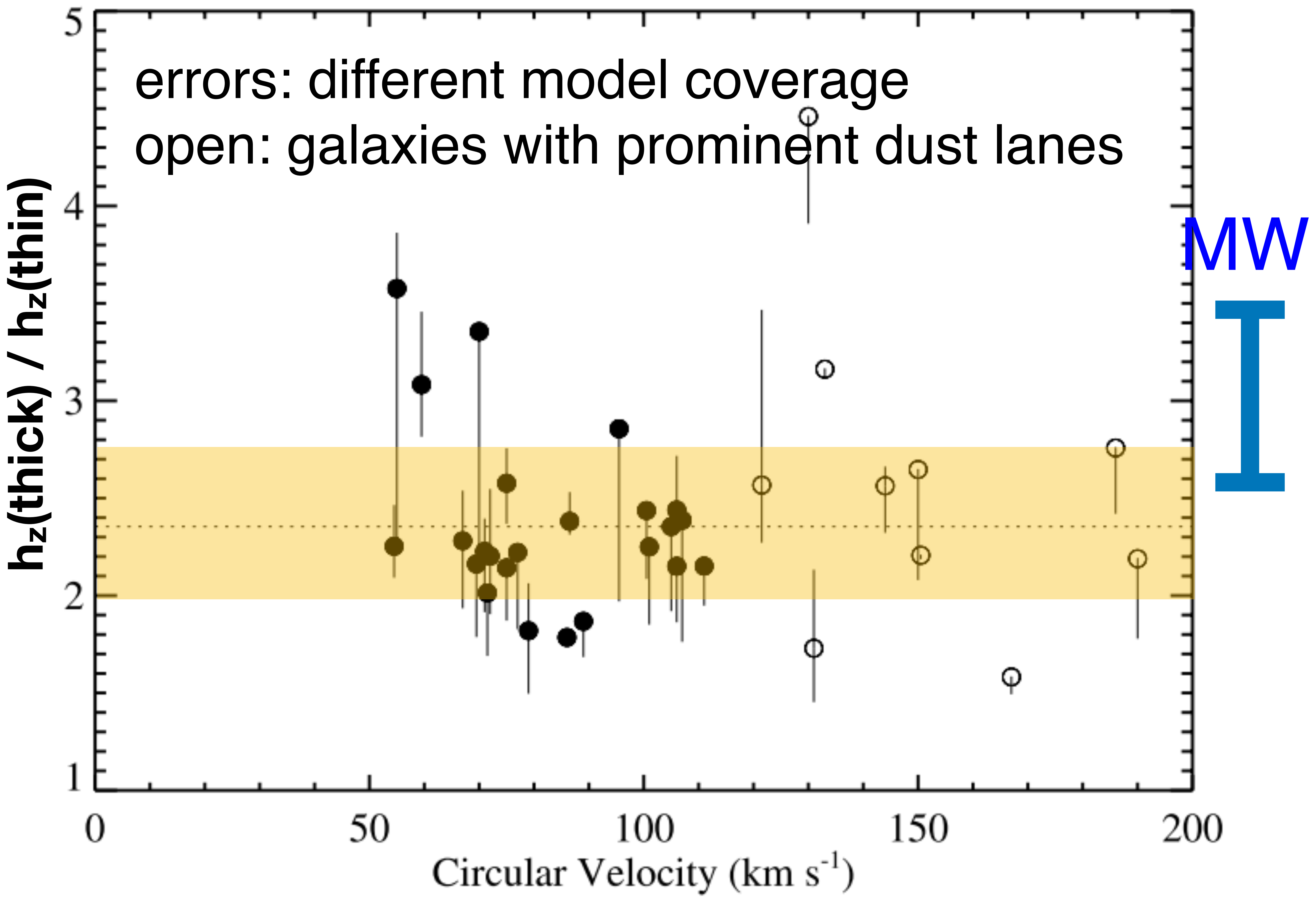
Observation: bimodality in [α/Fe]- [Fe/H], distinct origin?

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

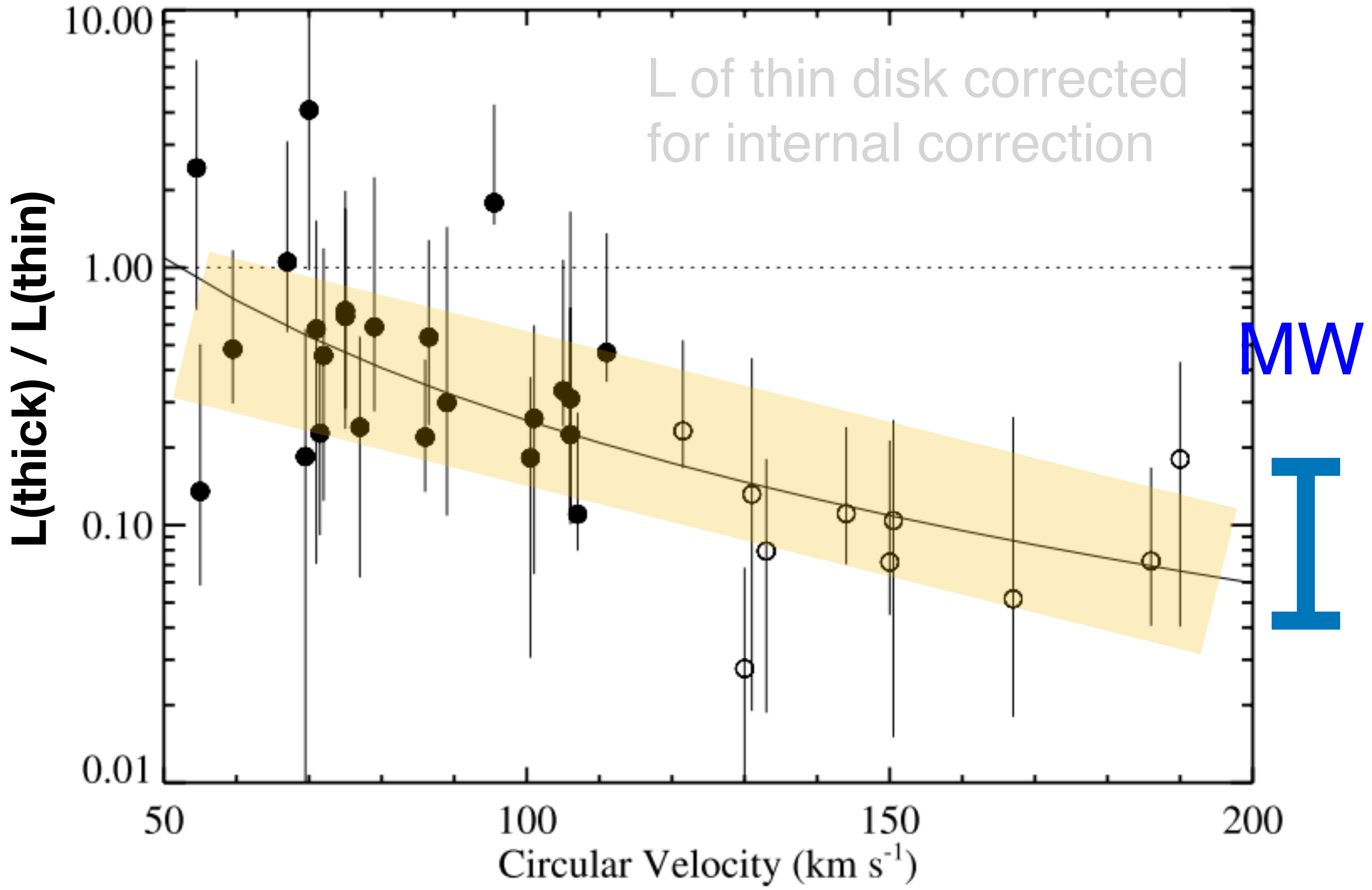


Observation: External galaxies: surface photometry

(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

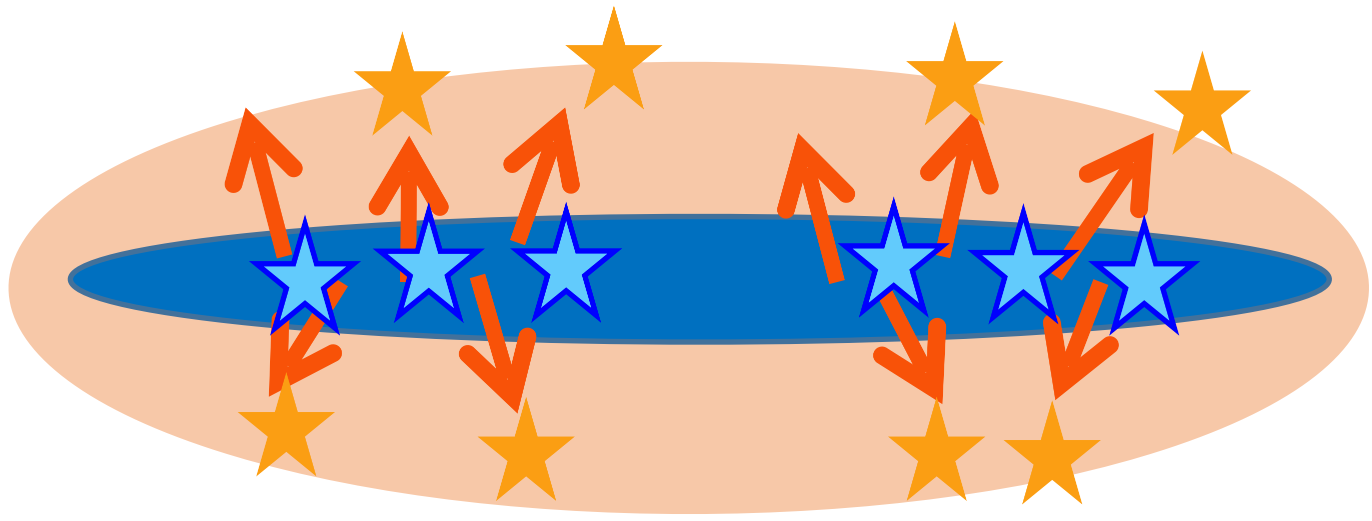


- L_{thick}/L_{thin} **= 0.25 (V_C/100km/s)$^{-2.1}$**
- M/L model (Bell & de Jong 2001) ➡ M_{thick}/M_{thin}

Formation scenarios of the thick disks

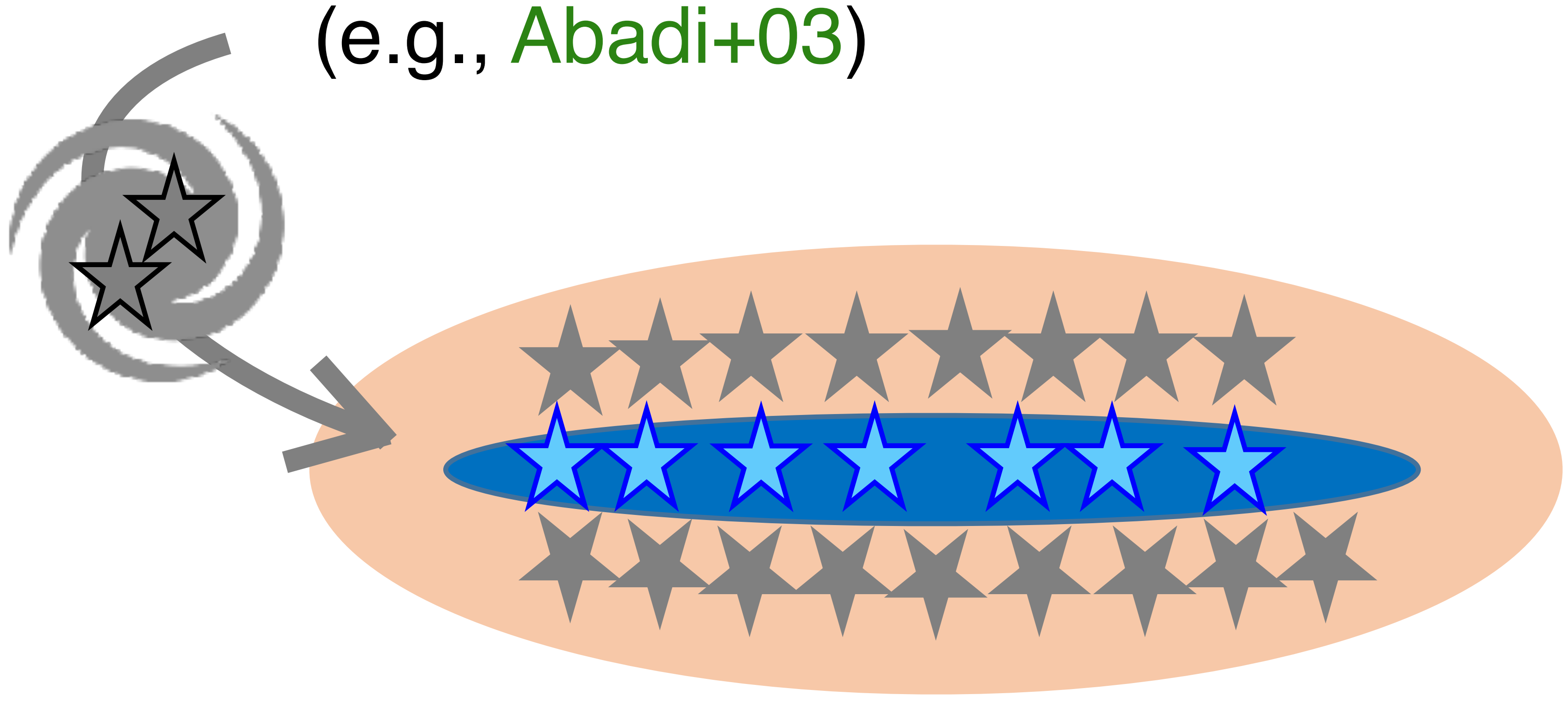
(1) Kinematic heating of a pre-exisiting disk

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

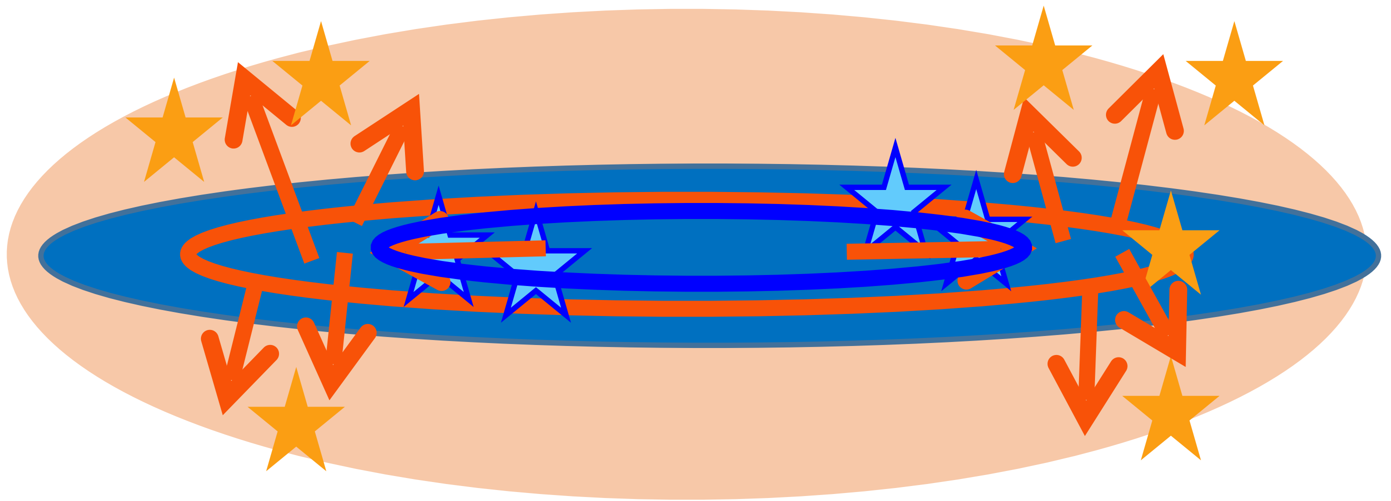


(2) Accretion from disrupted satellite galaxies

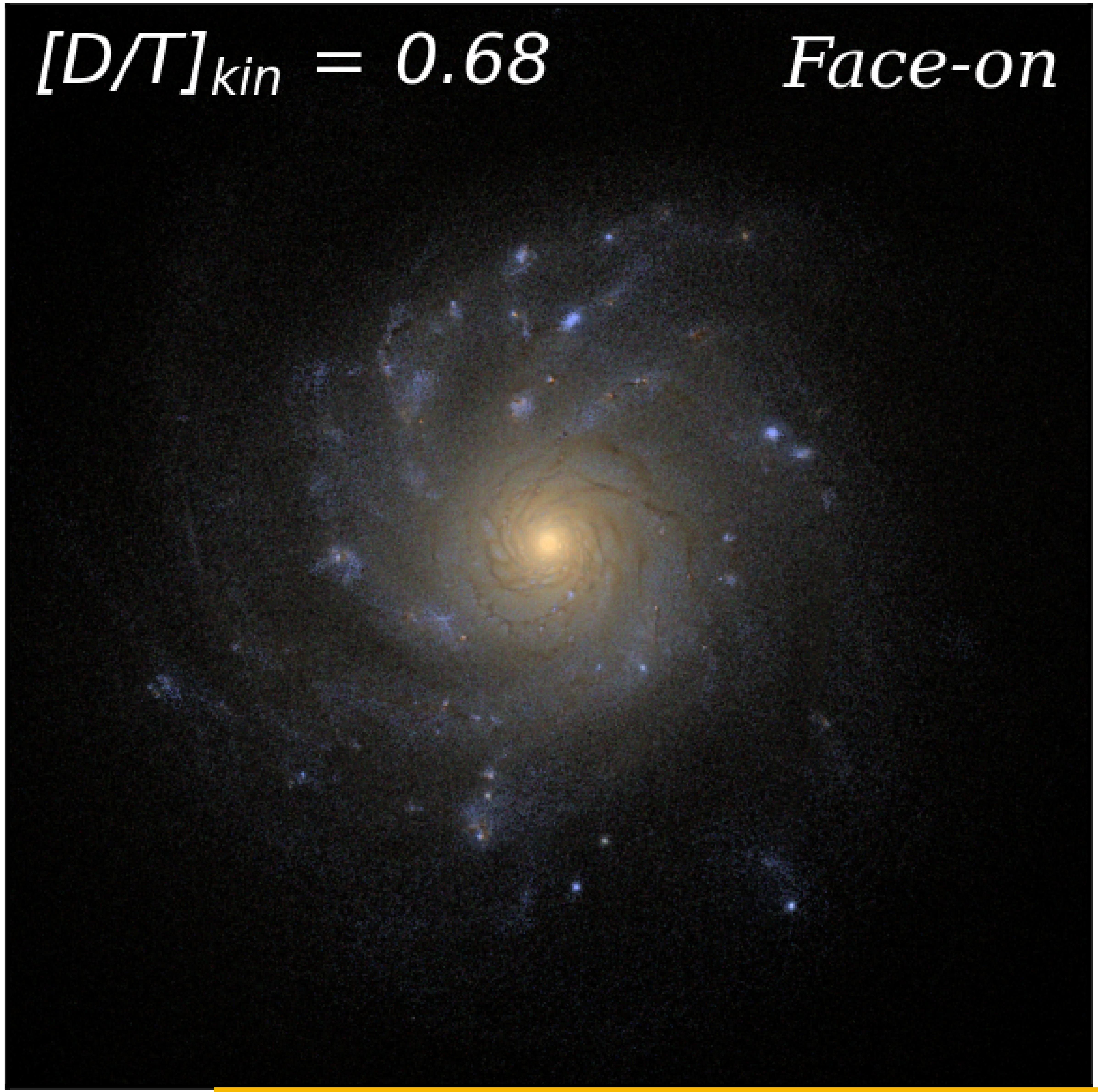
(e.g., Abadi+03)

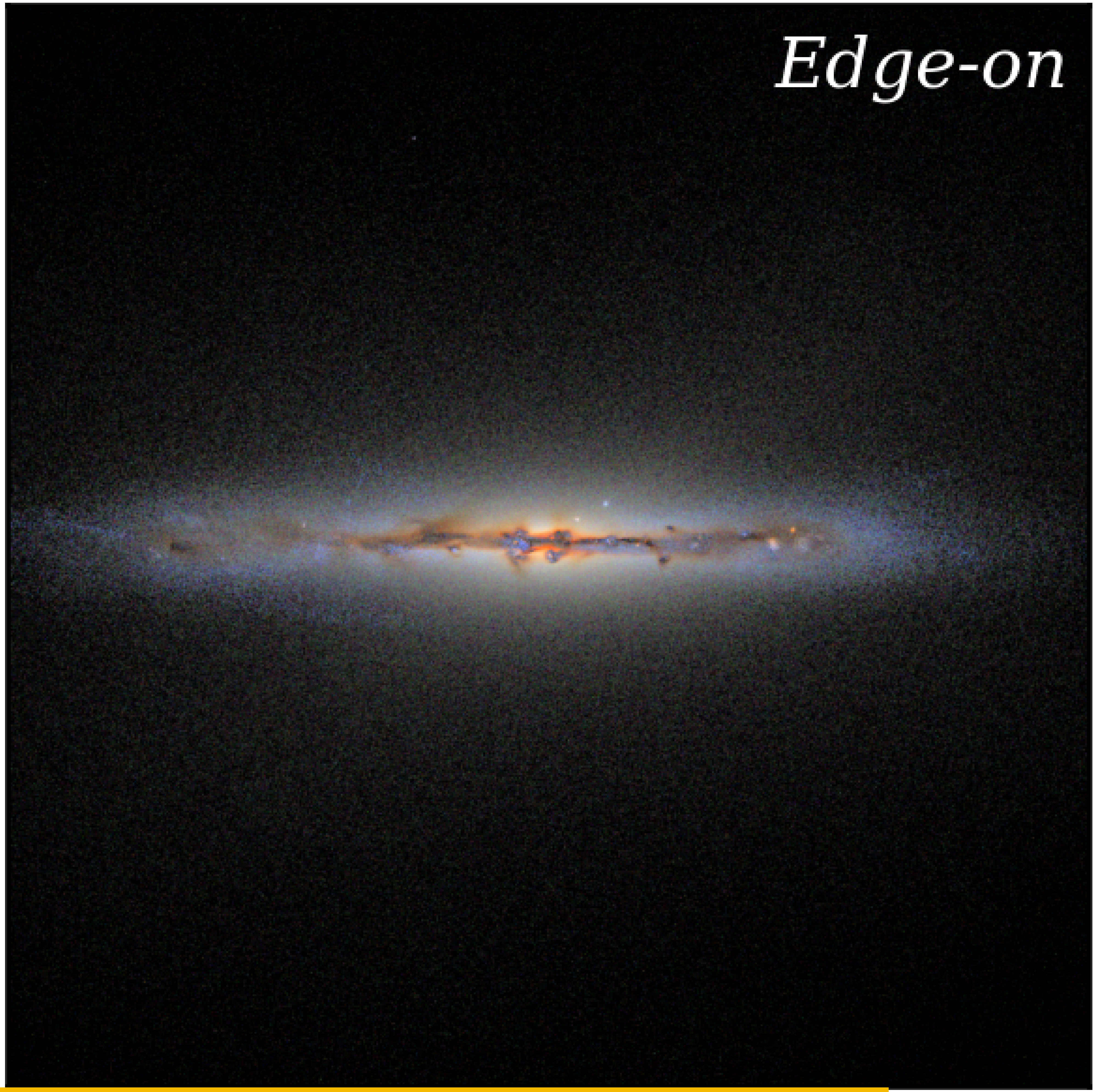


(3) Radial Migration (e.g., Roskar et al. 2008)



(4) In-situ SF triggered by gas-rich merger (e.g., Brook et al. 2004 Agertz & Renaud 2021)

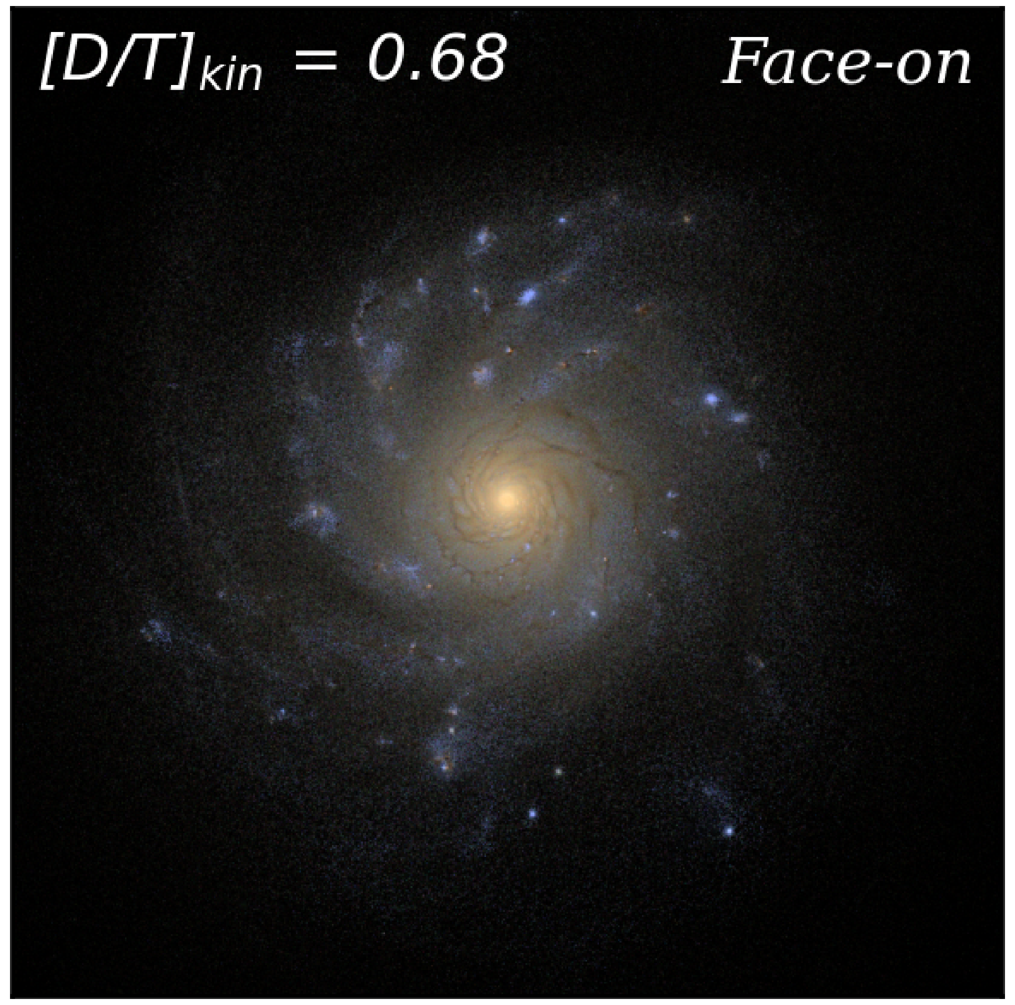


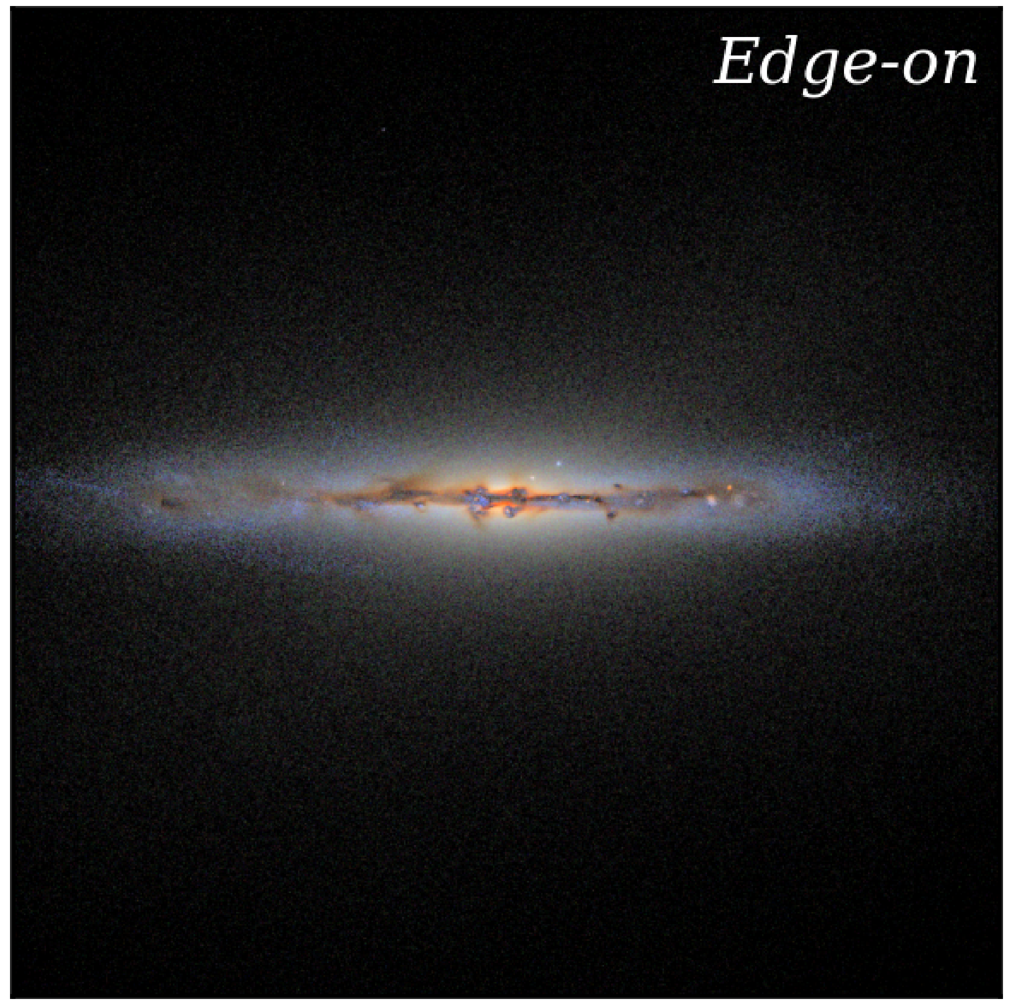


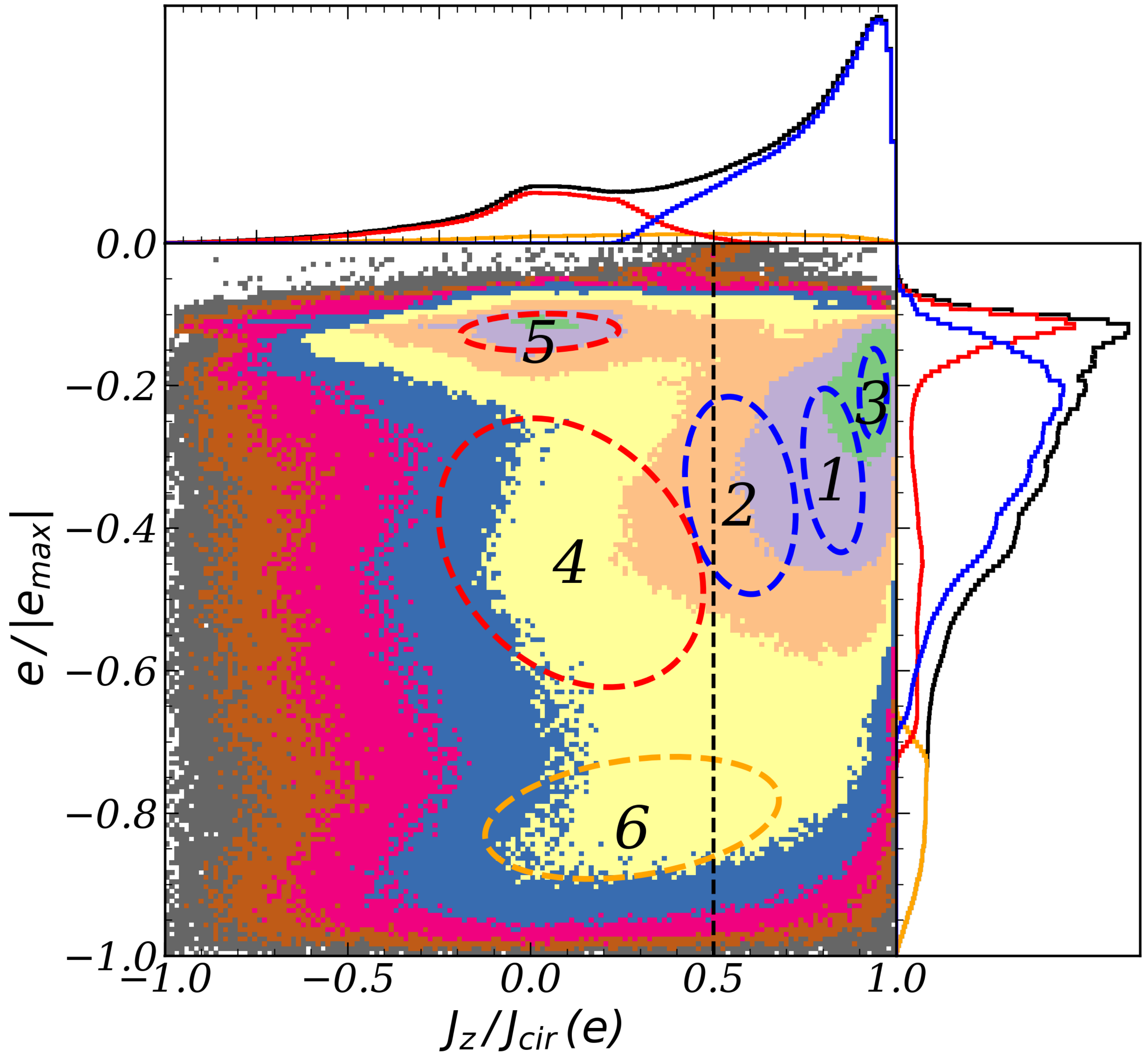
Do we see thick discs in high-res simulations?
What is the origin of thick disc?

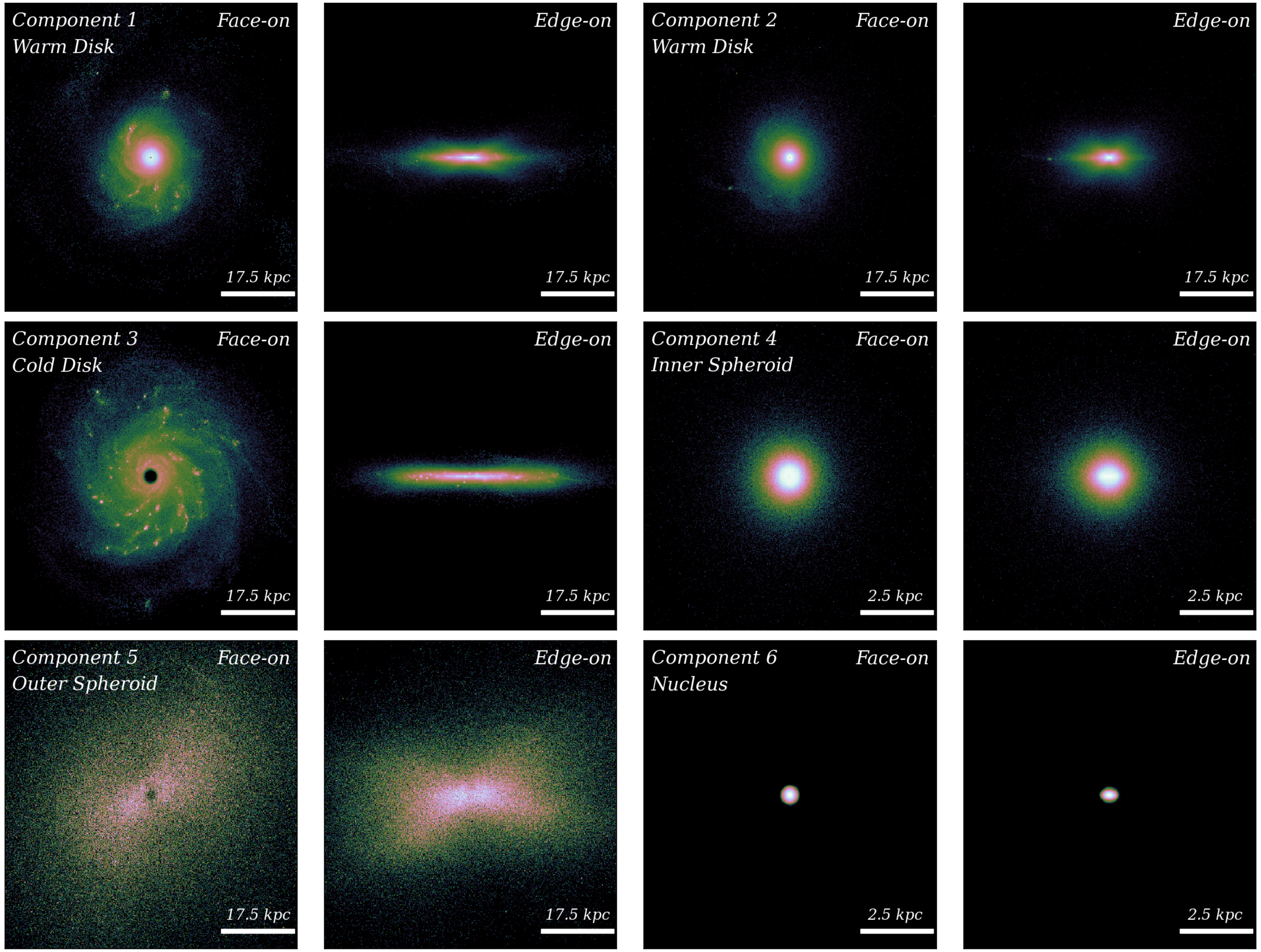
Gaussian Mixture Model on NH galaxies

(Jang et al. 2022, arXiv221100931J)

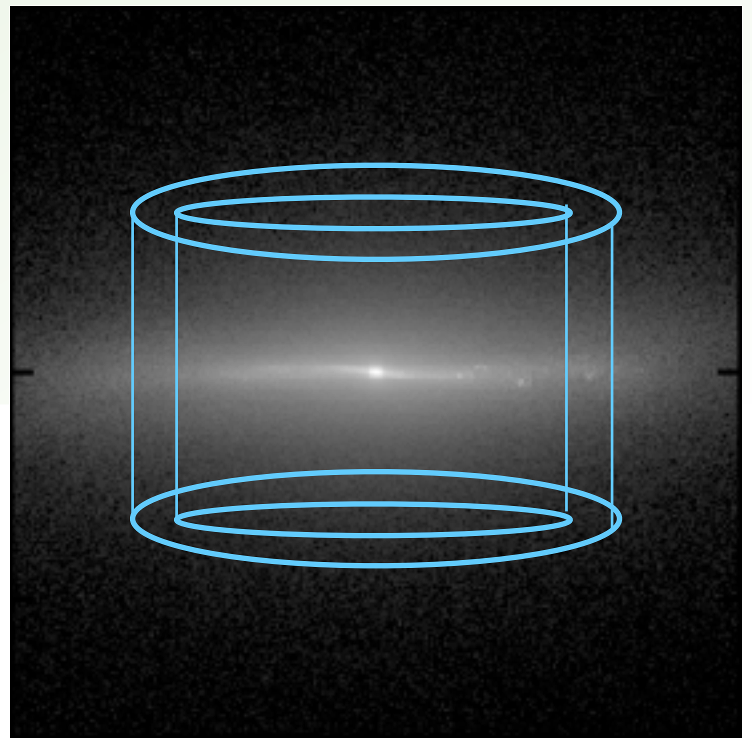








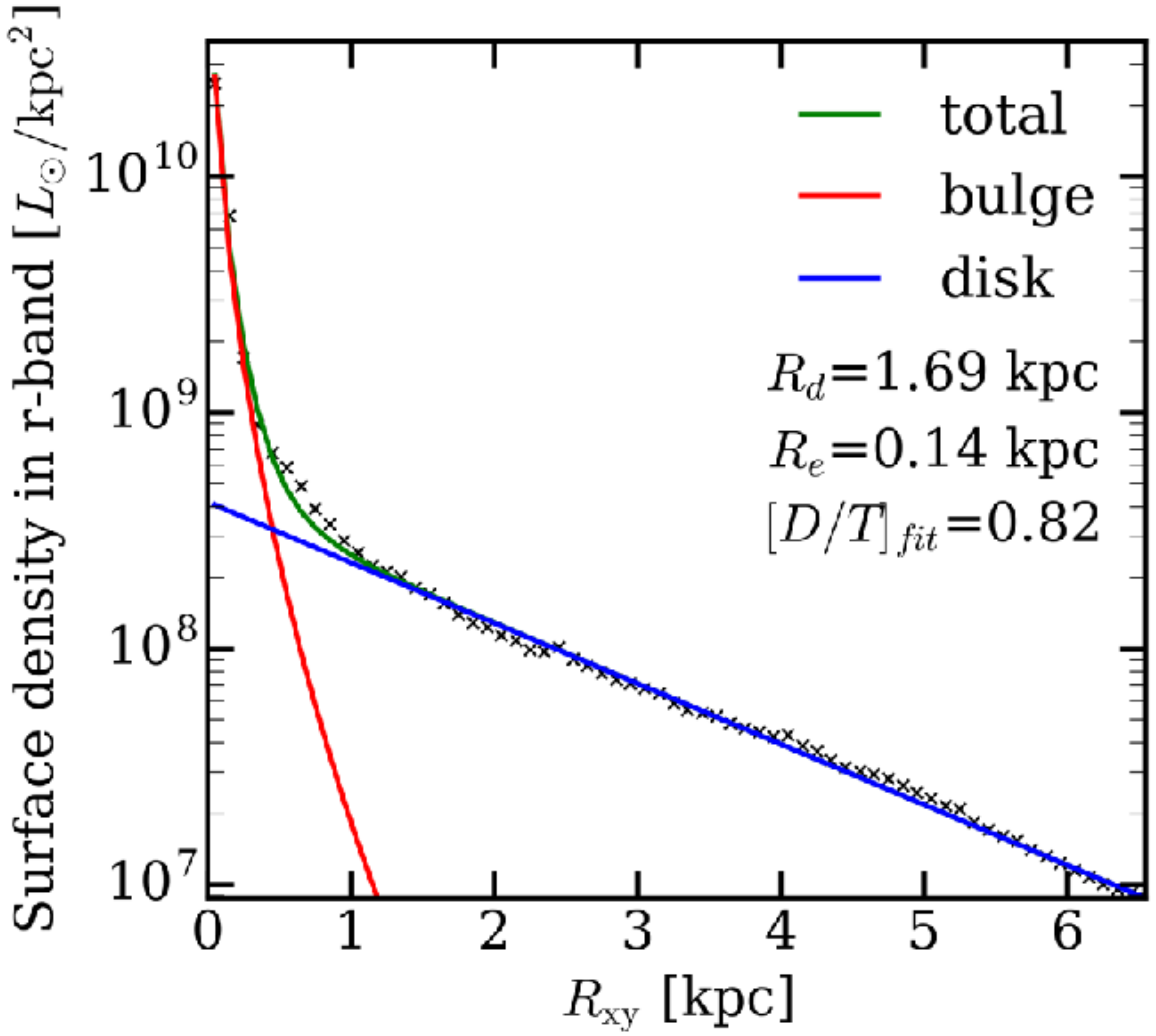
Radial & vertical profiles: two-component fits



Galactica

Radial Profile in r-band: Sersic + exponential disc

disk scale length: R_d = 1.7 kpc



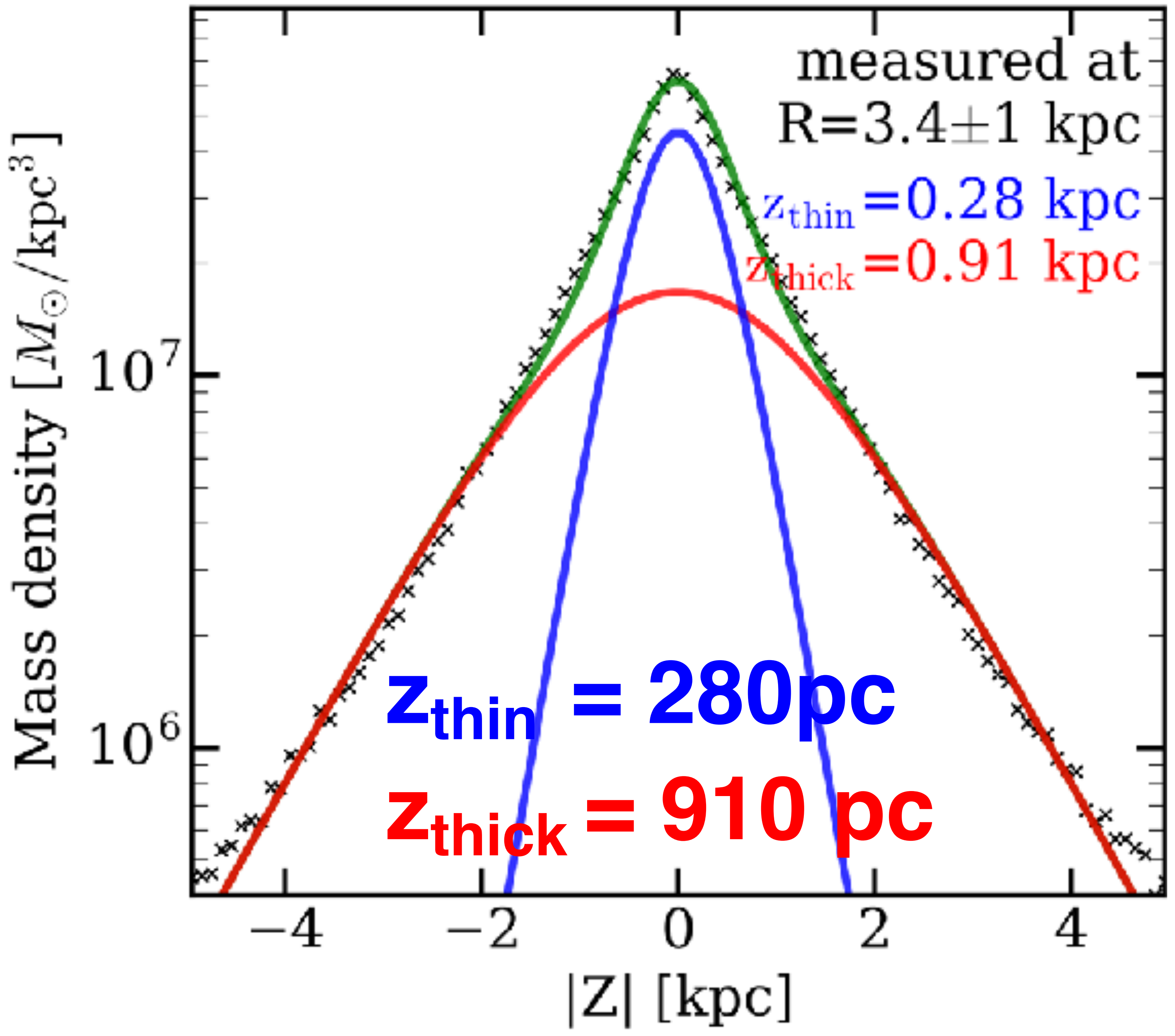
In the cylindrical region:

R_{xy} = 2 R_d = 3.4 ±1 kpc

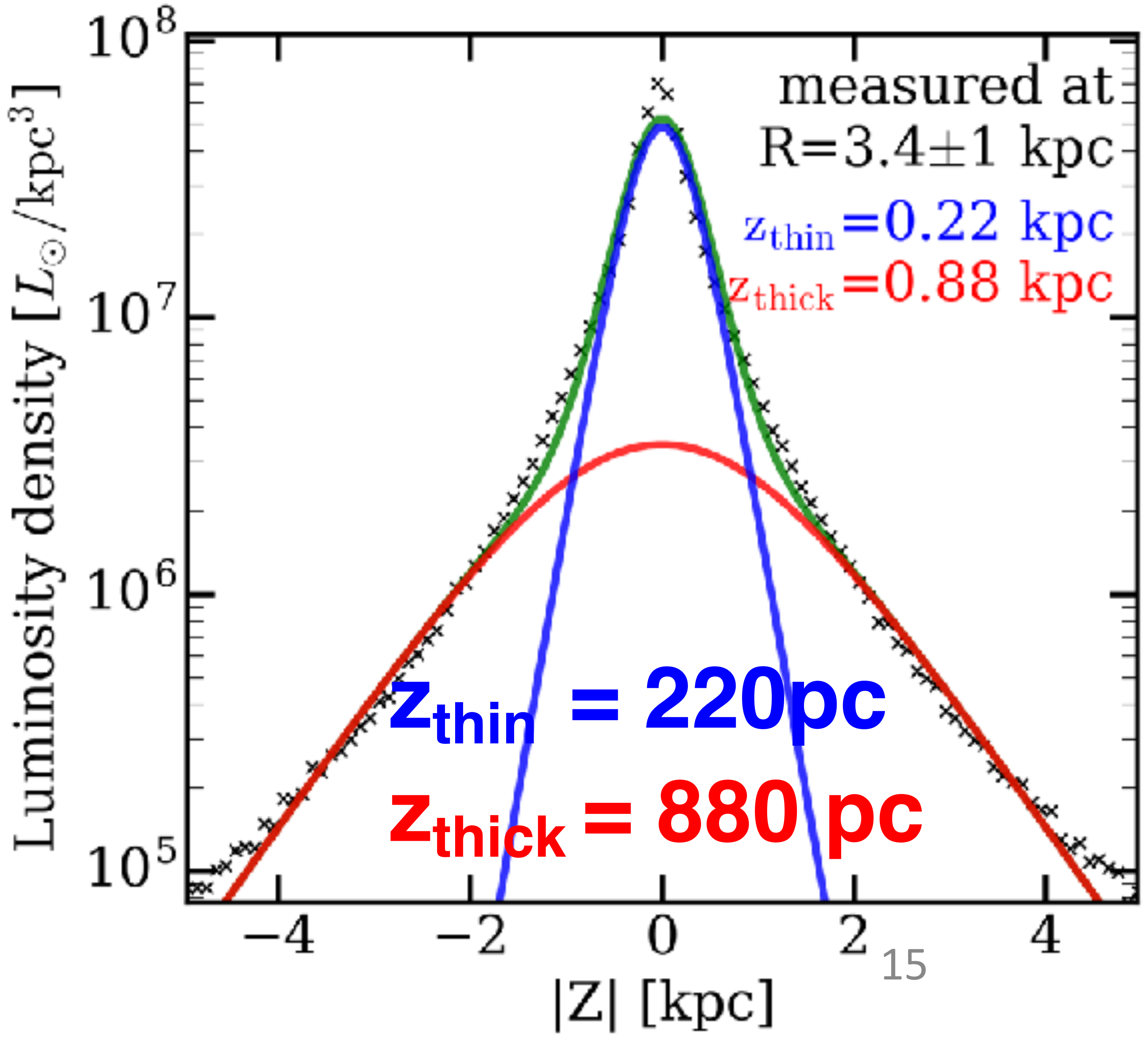
Vertical Profile:

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

in mass

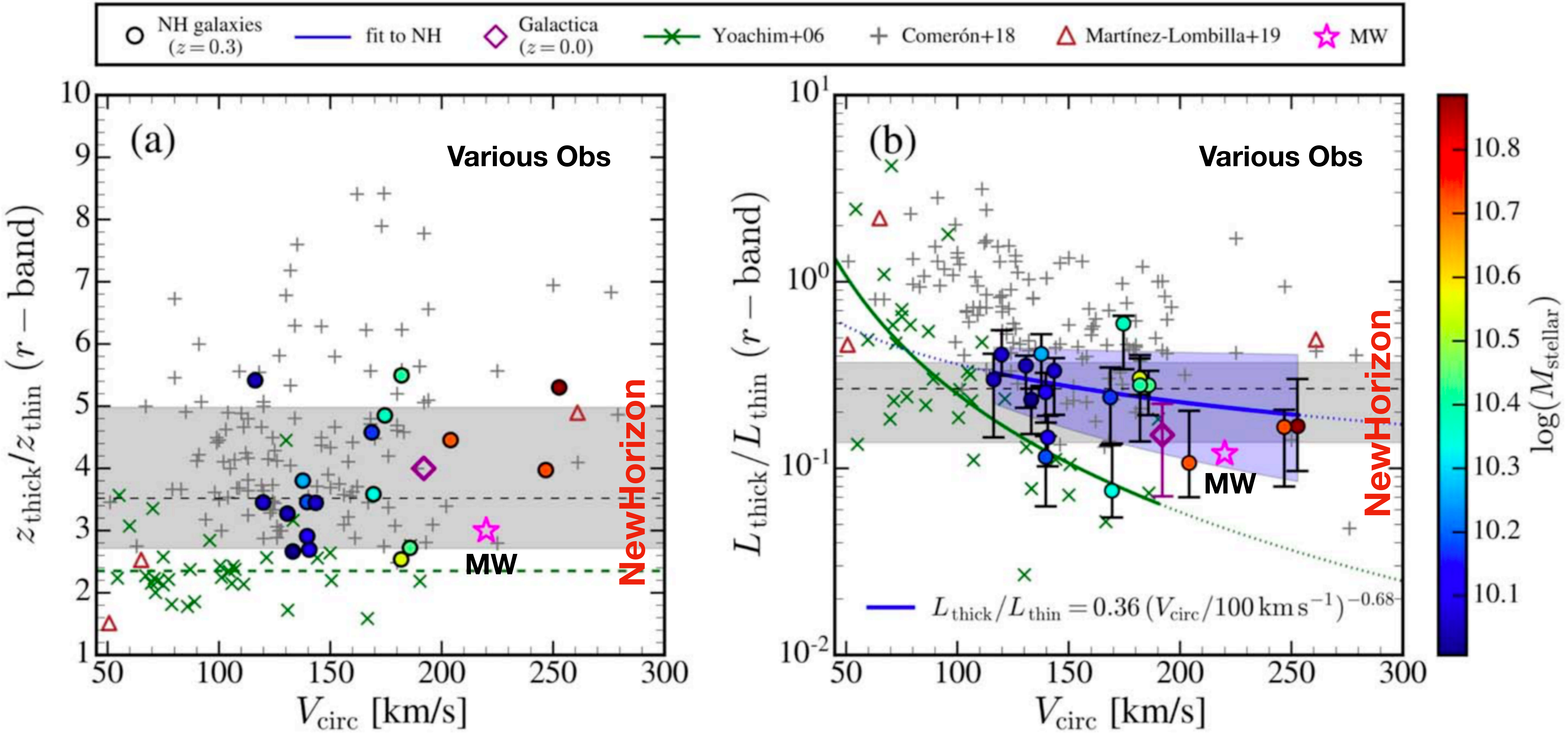


in r-band

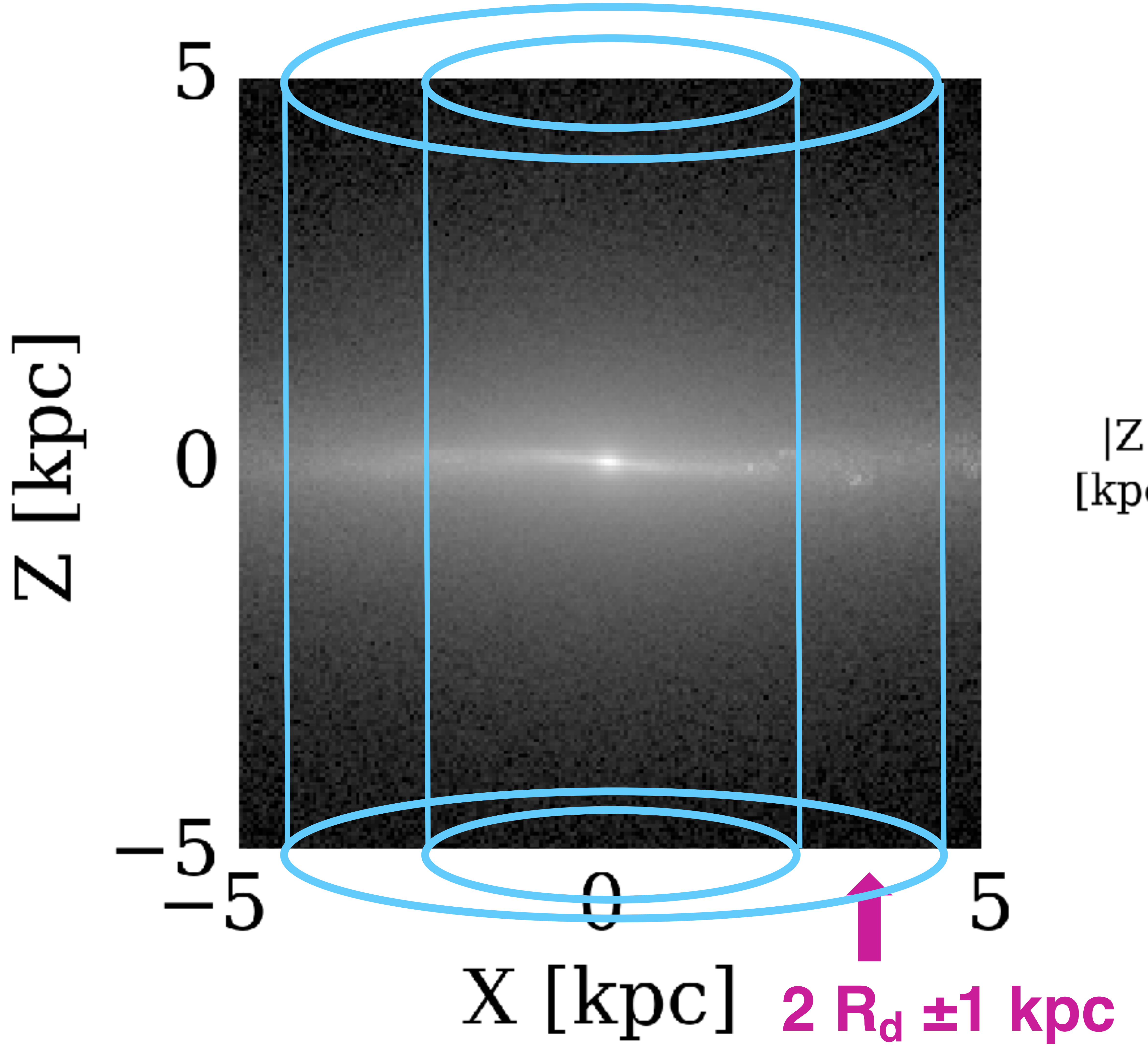


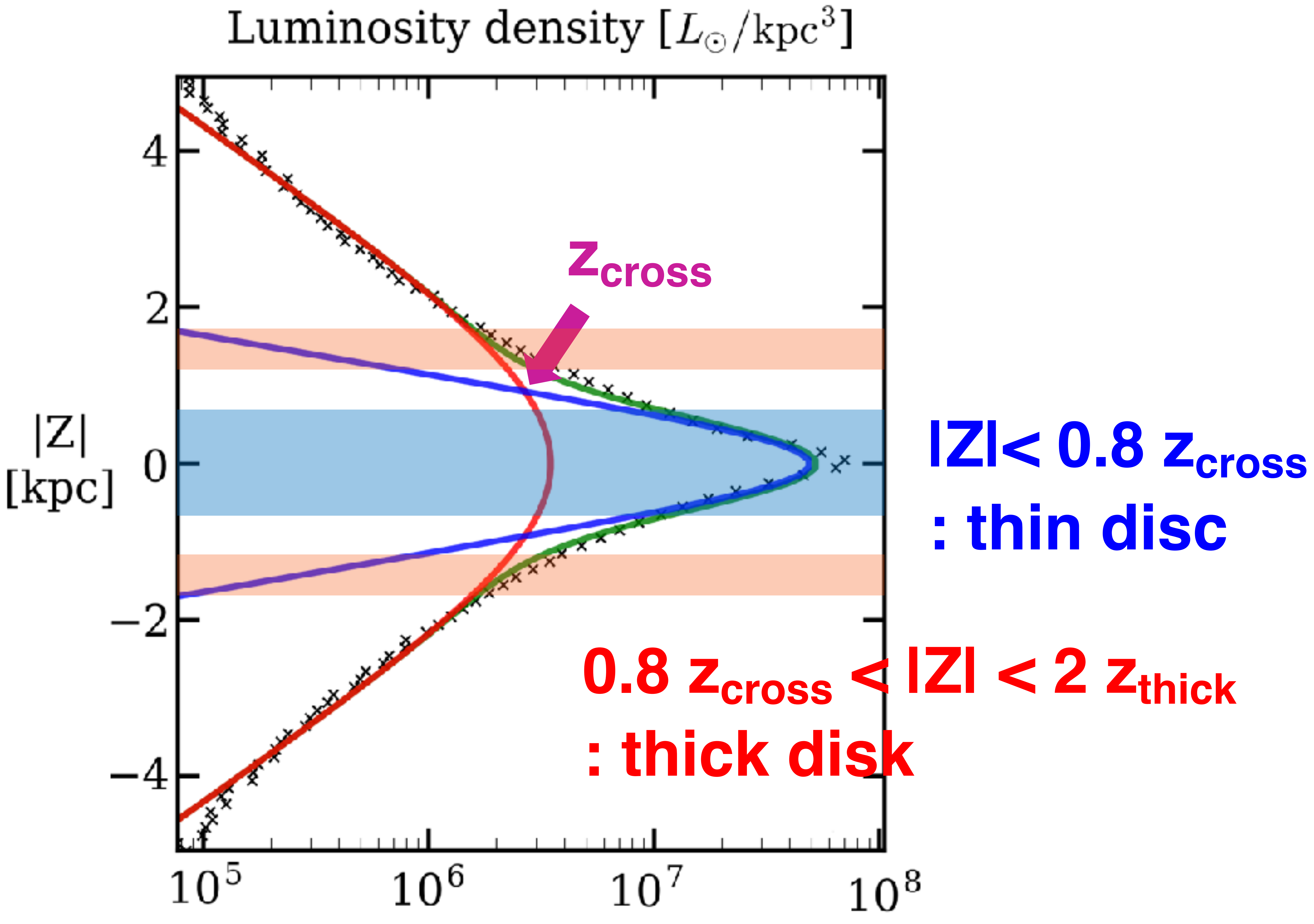
Park et al. 2021, ApJS, 254, 2

Thick disc fractions: scale height and luminosity



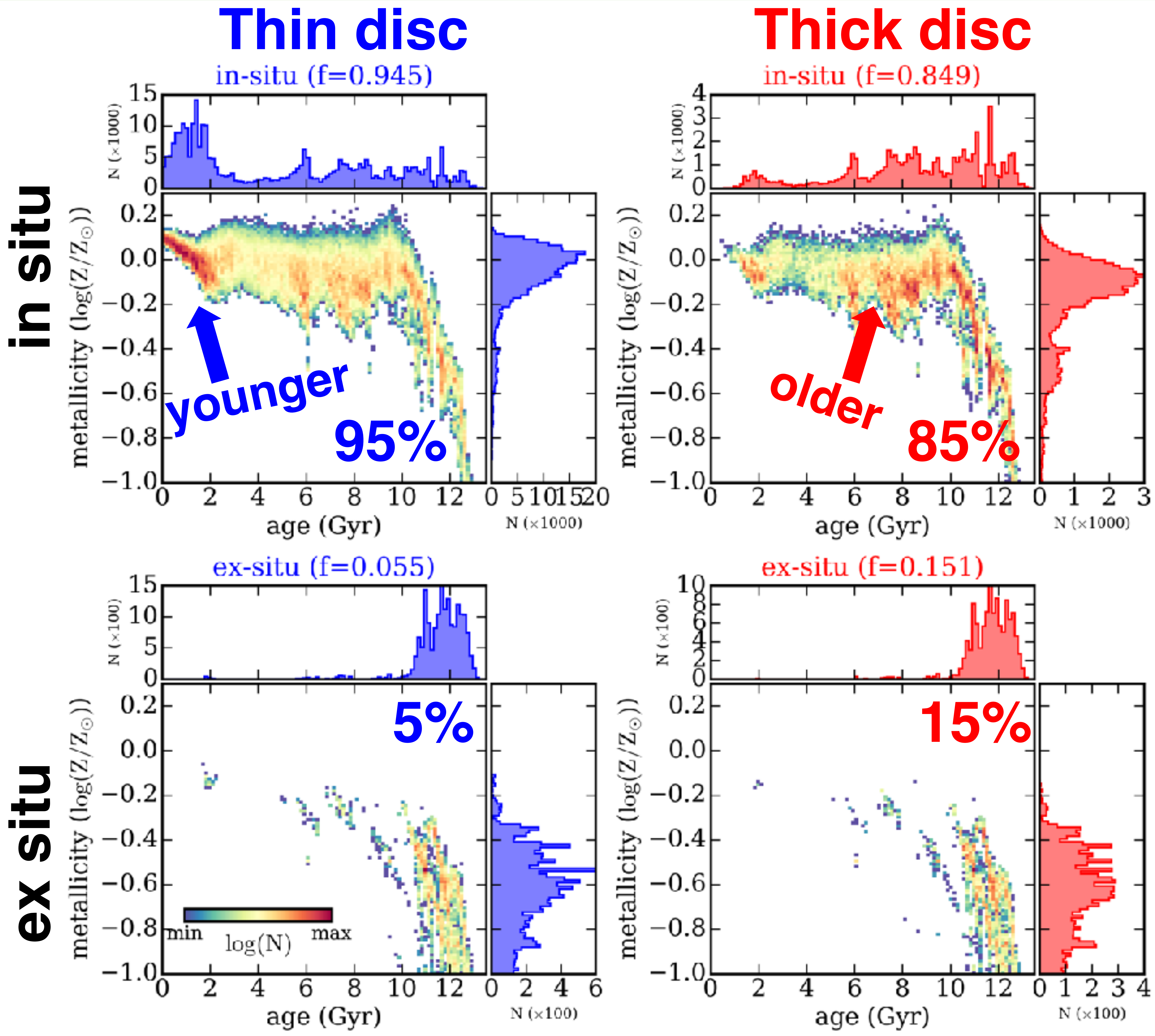
Spatial decomposition: thin and thick discs





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)

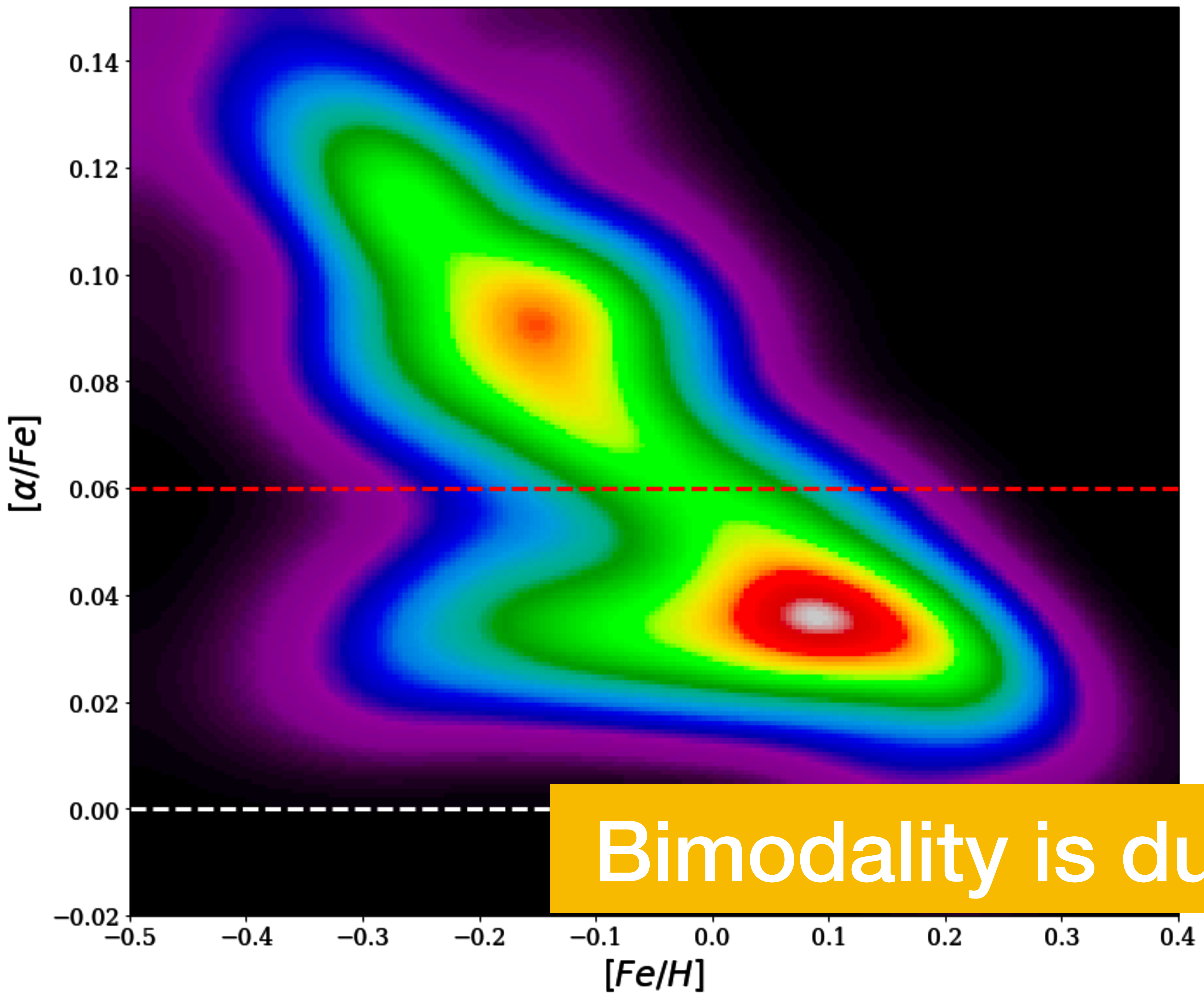
	Thin	Thick
age	4.0 Gyr	5.6 Gyr
$\log(Z/Z_{sun})$	-0.06	-0.22
f_{exsitu}	0.06	0.11

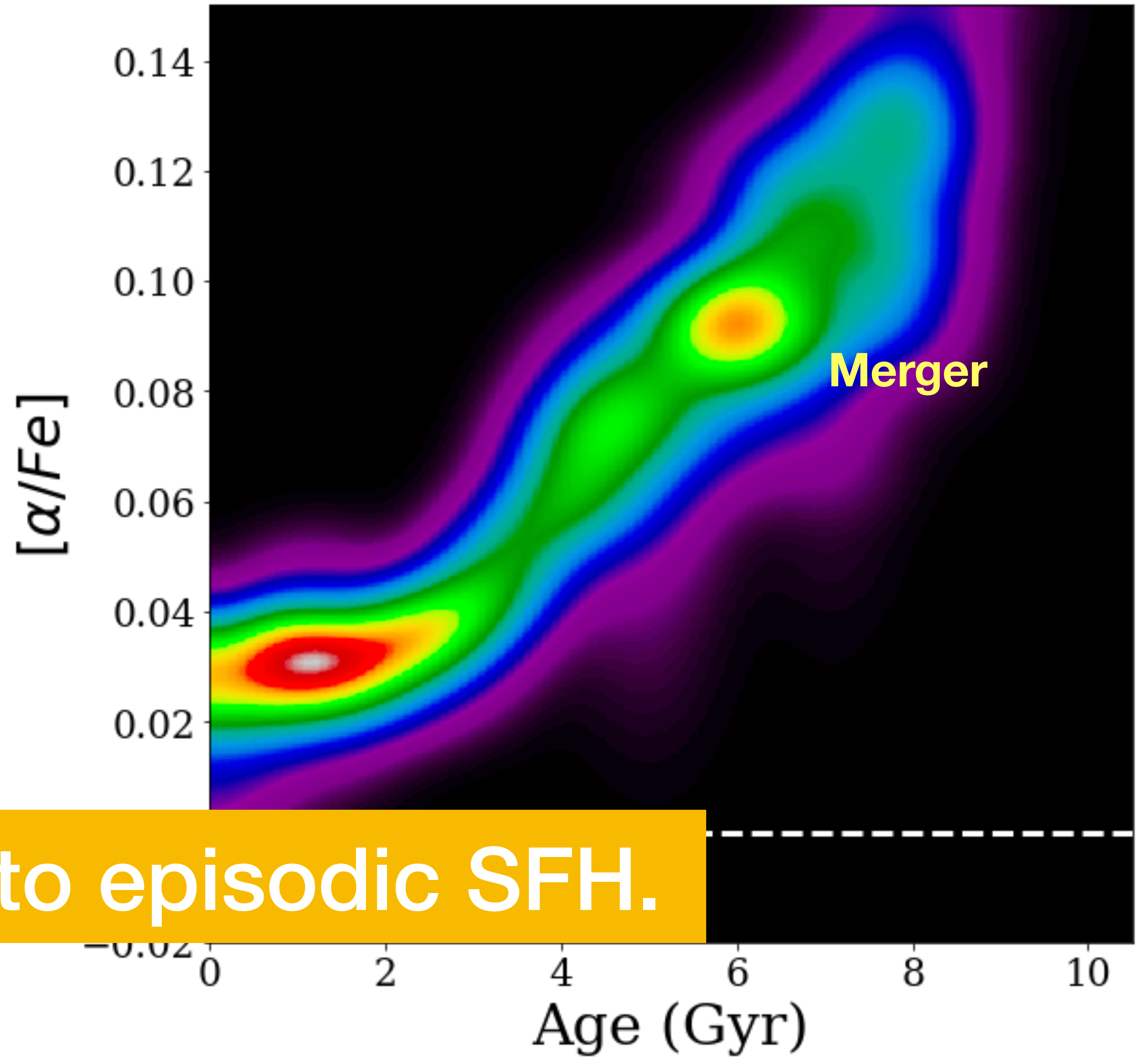
NH2: bimodal distribution in chemical properties like MW

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)

Bimodal when smoothed

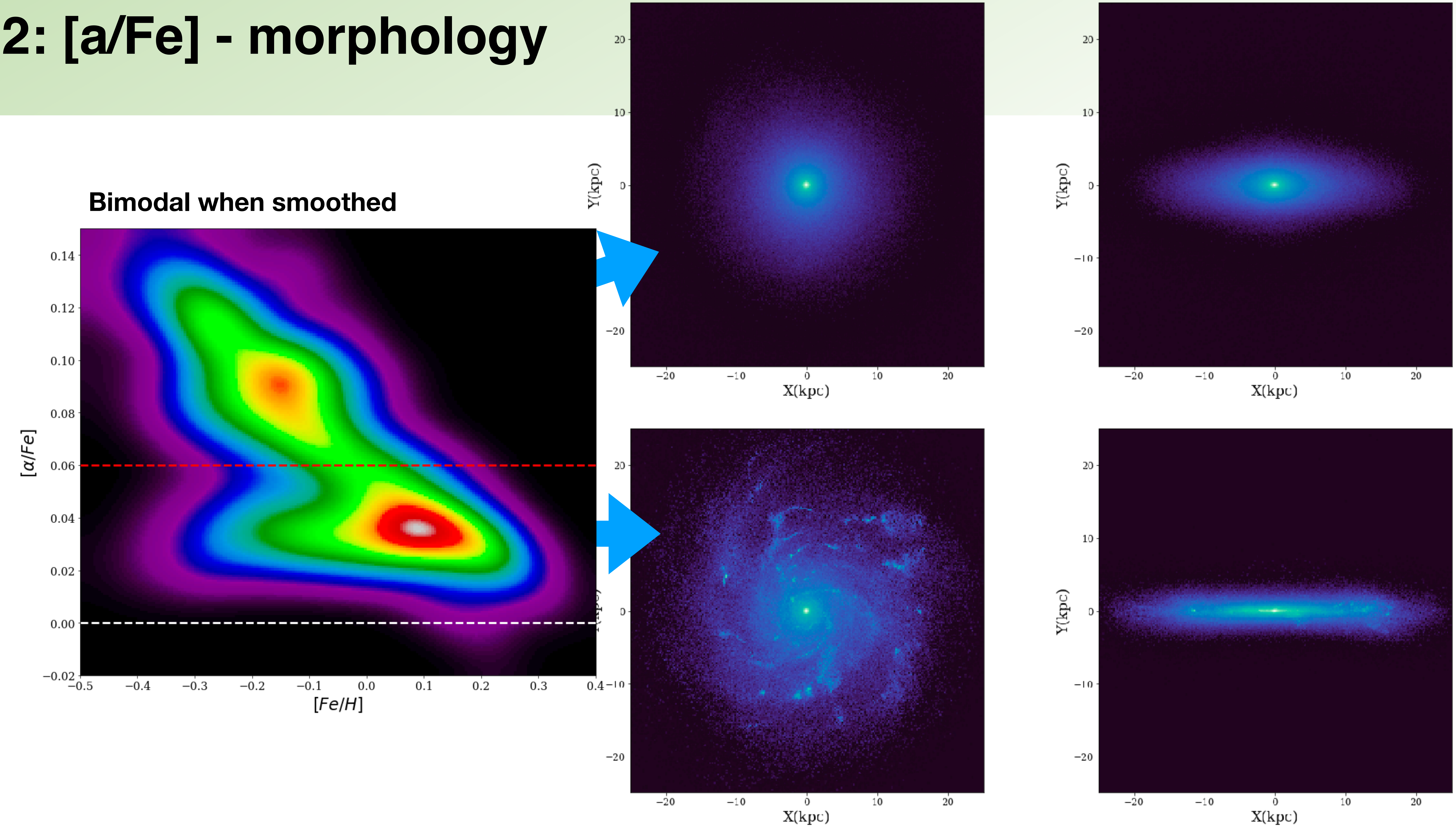




Bimodality is due to episodic SFH.

NH2: [a/Fe] - morphology

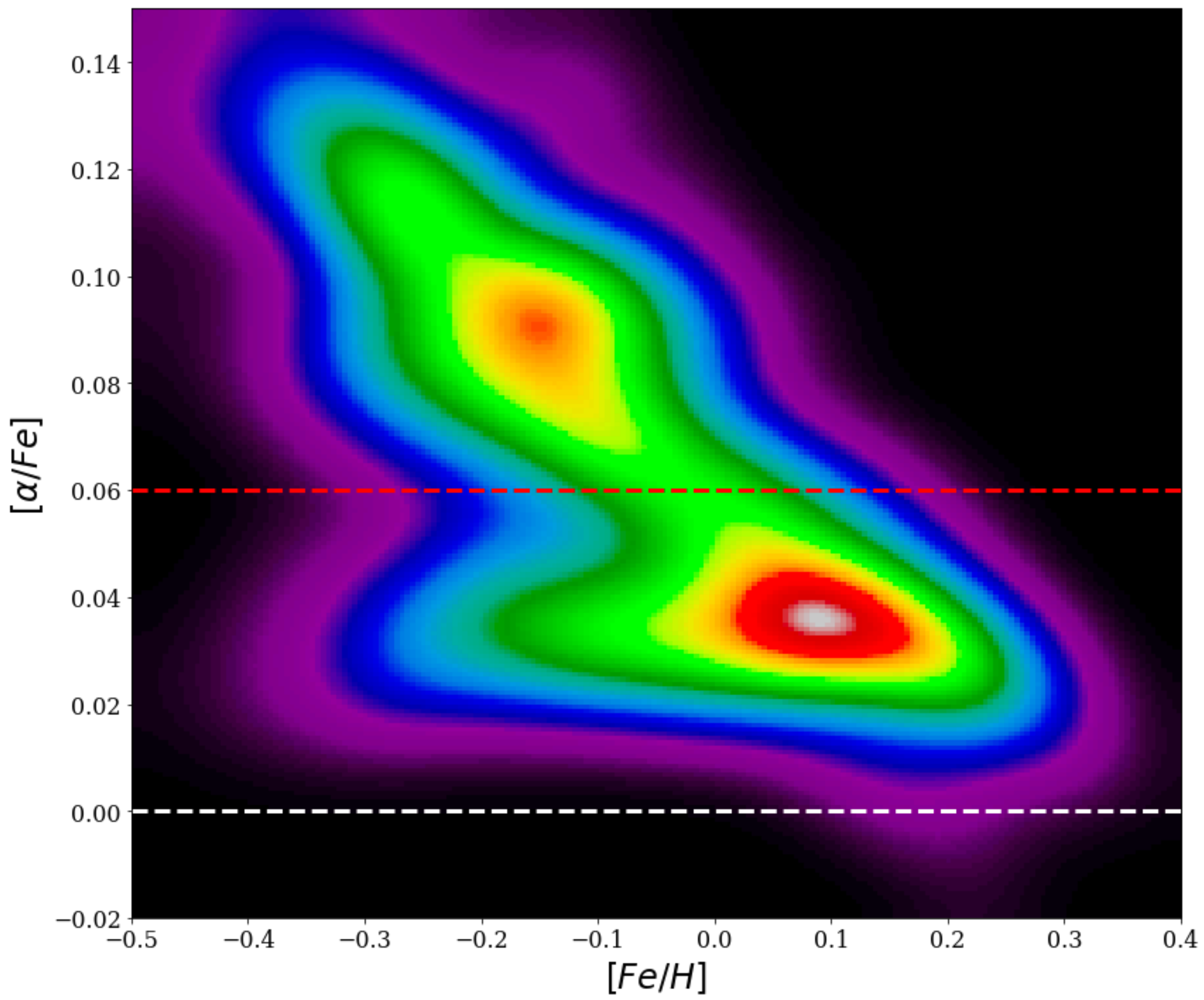
Bimodal when smoothed



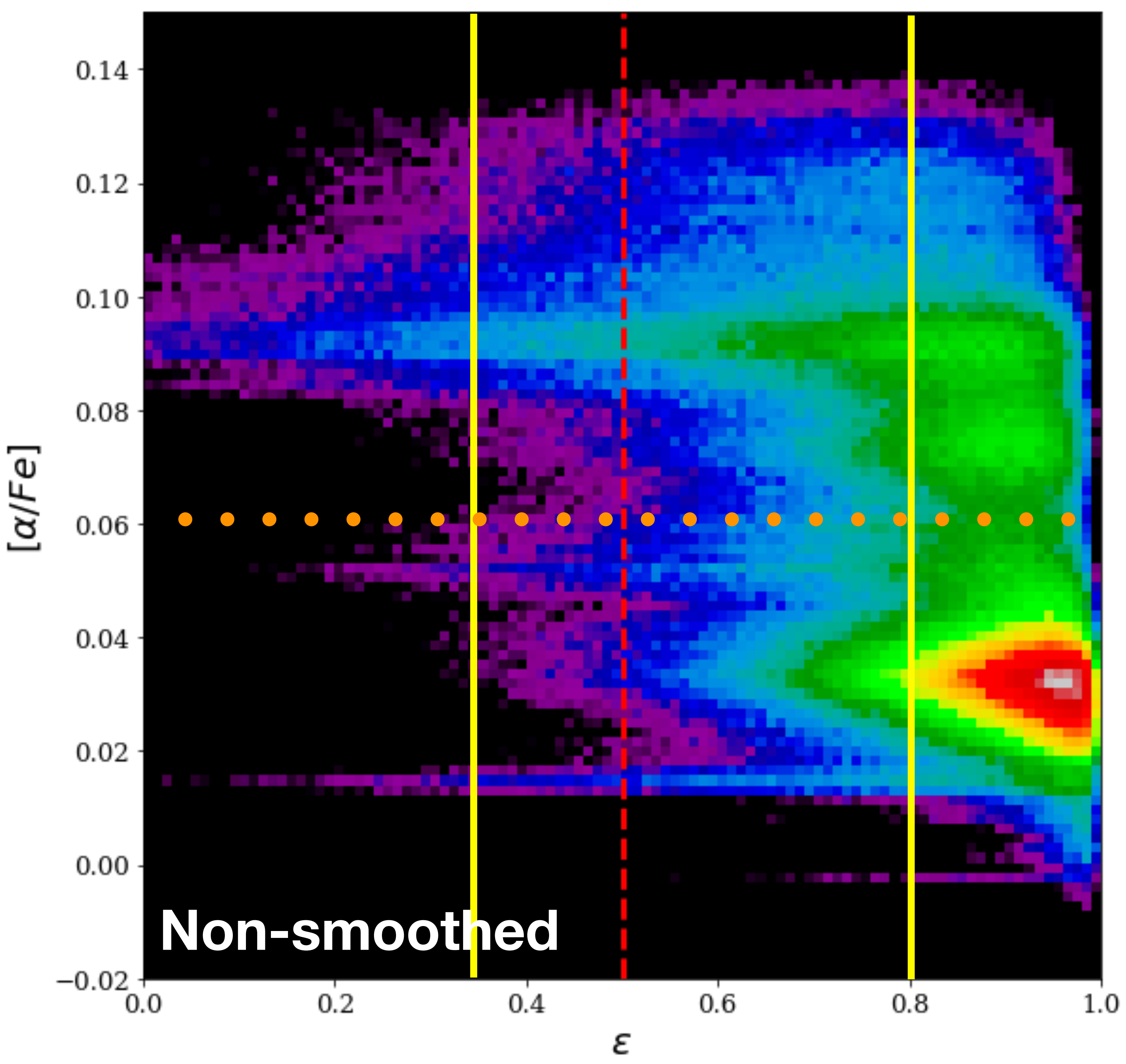
NH2: [a/Fe] - kinematics

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

Bimodal when smoothed



Dispersion ⟵ ⟶ Disc



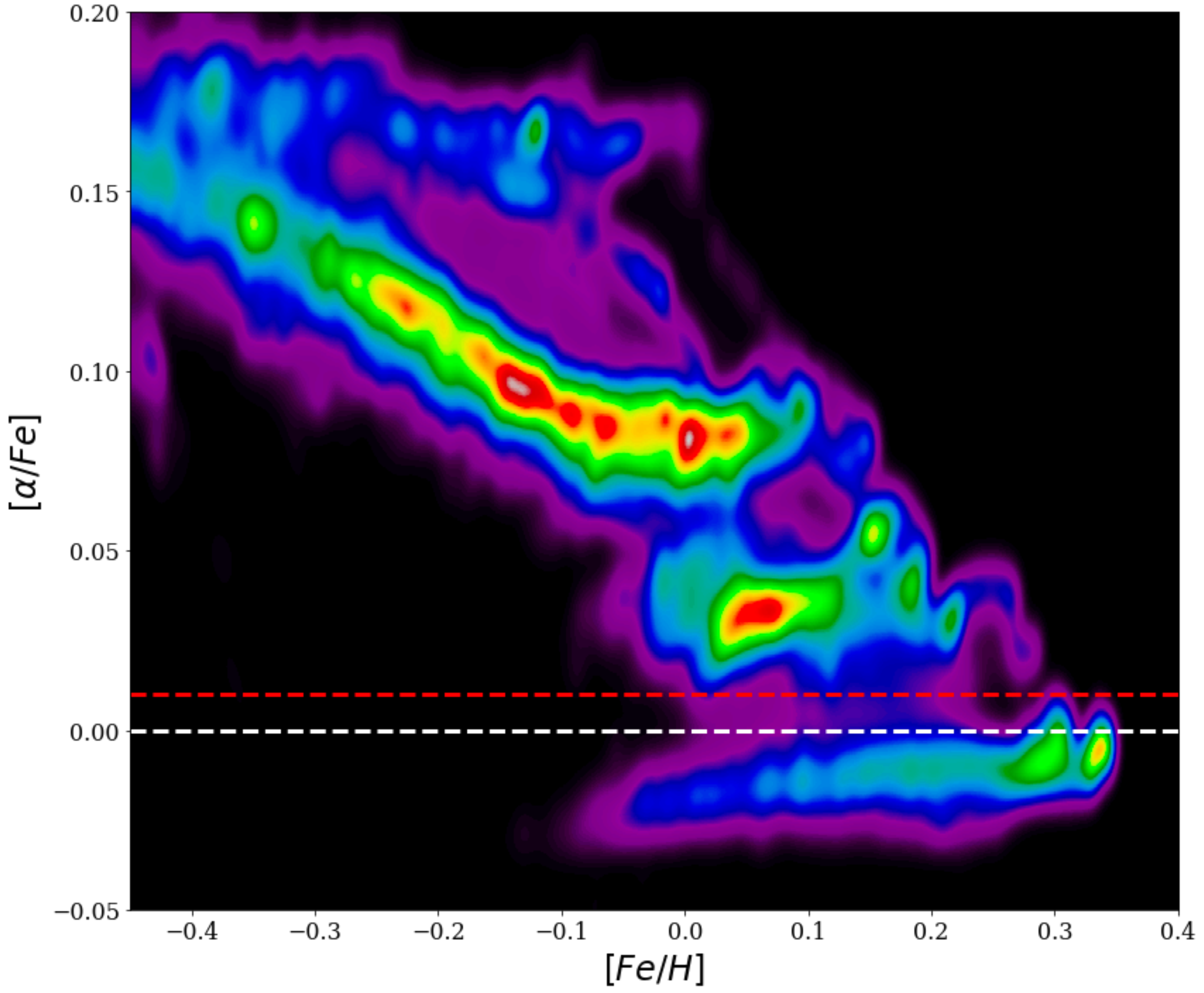
Bimodality does not necessarily mean thin and thick stars

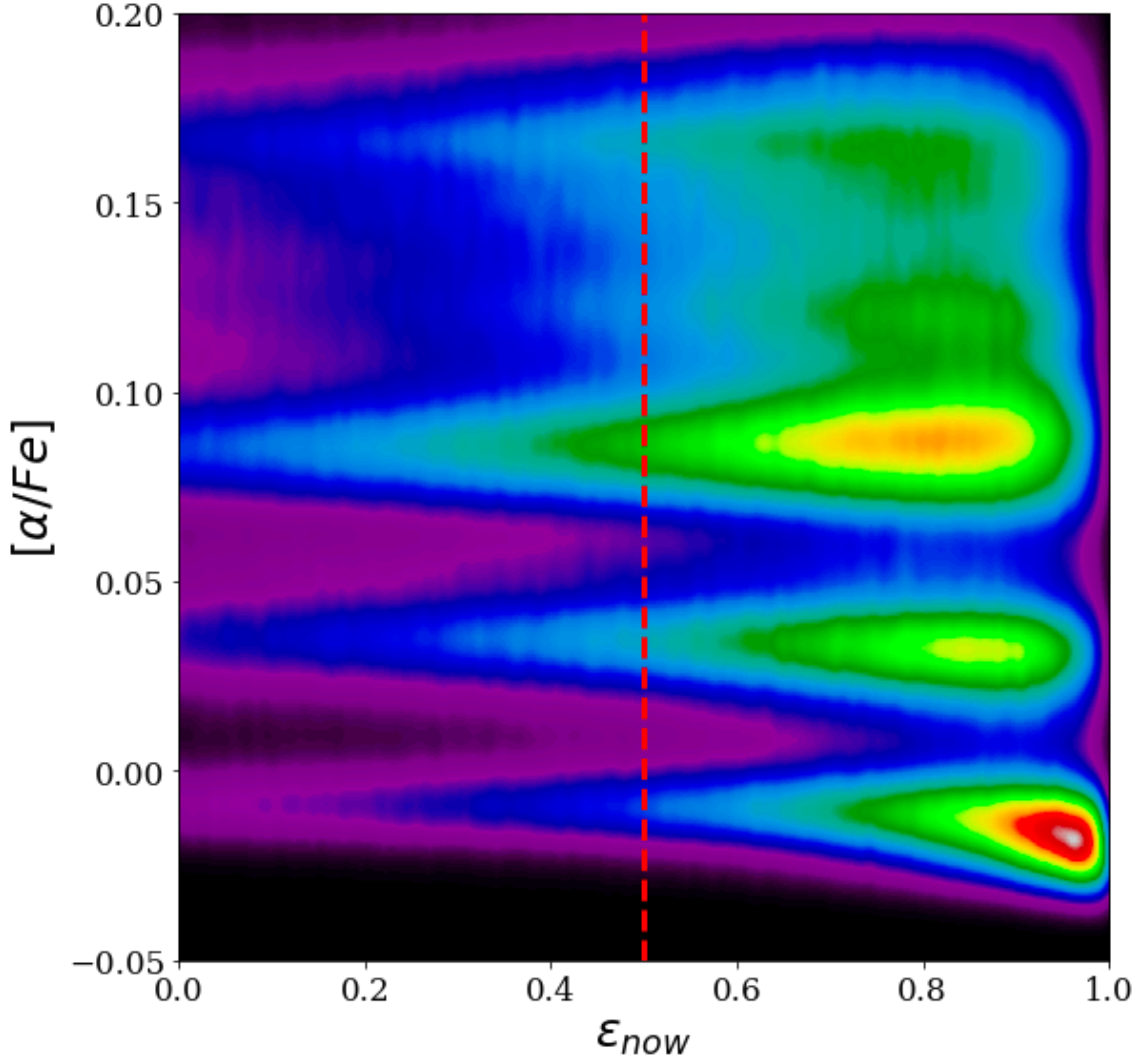
NH2: bimodal distribution in chemical properties like MW

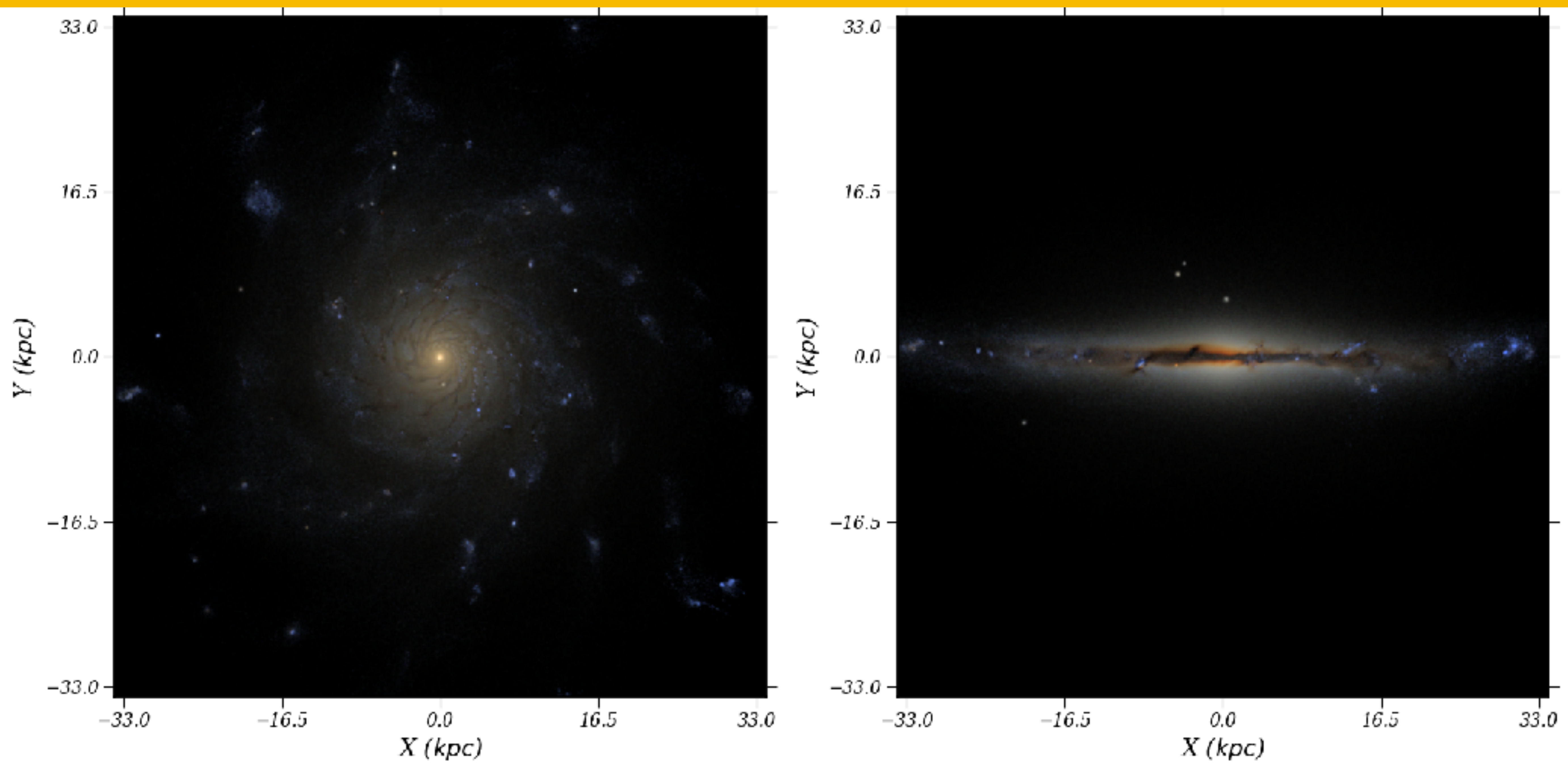
NH2: dx=70 pc simulation with 9 chemical elements

Consistent with Auriga (Grand et al. 2020)

Varieties in chemical phase space distribution

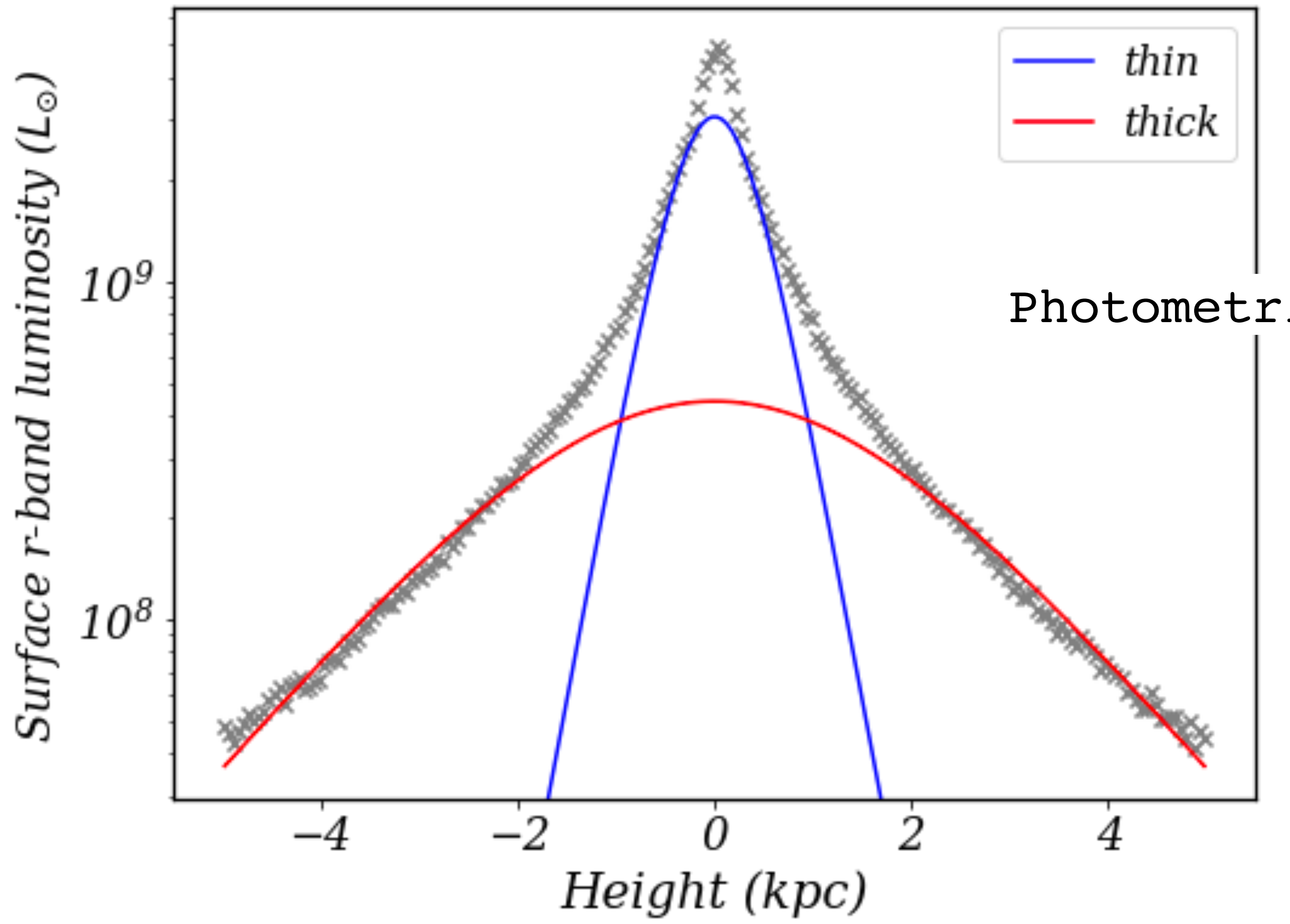




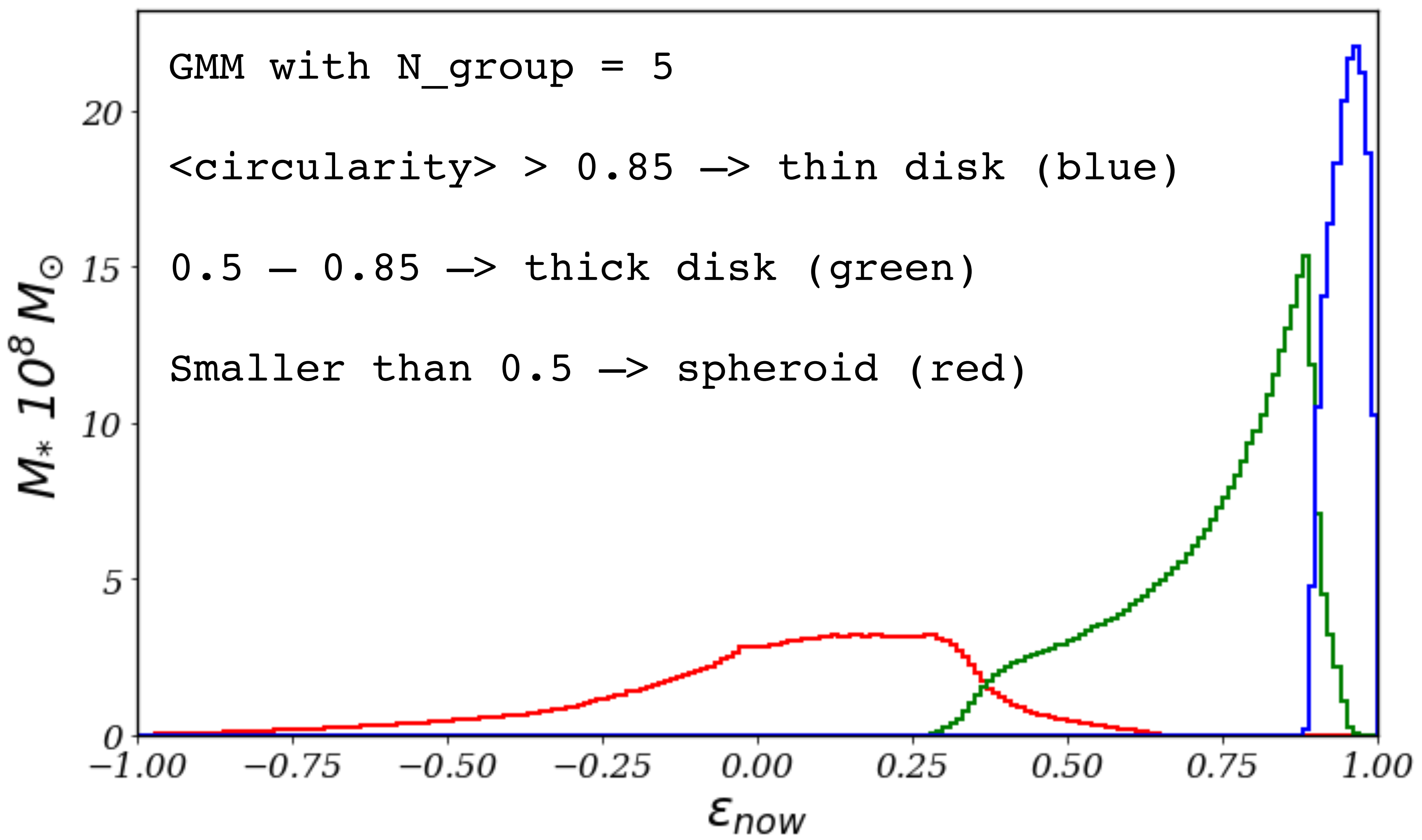


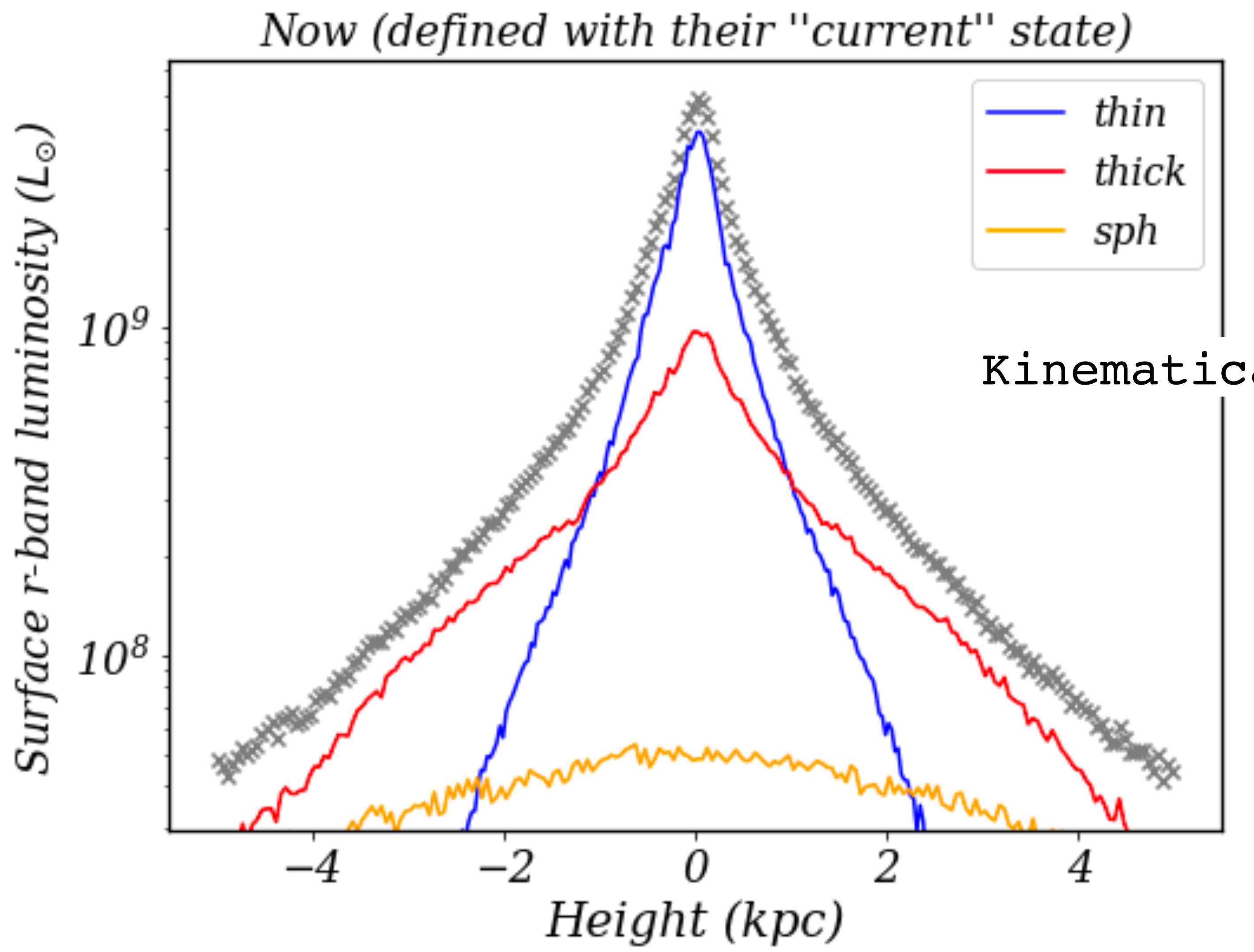
Measured at R_2d = 9 +- 1 (kpc)

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



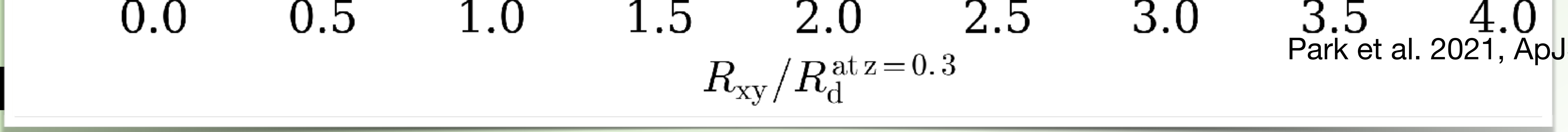
Photometric 2-comp sech fit





Kinematically classified

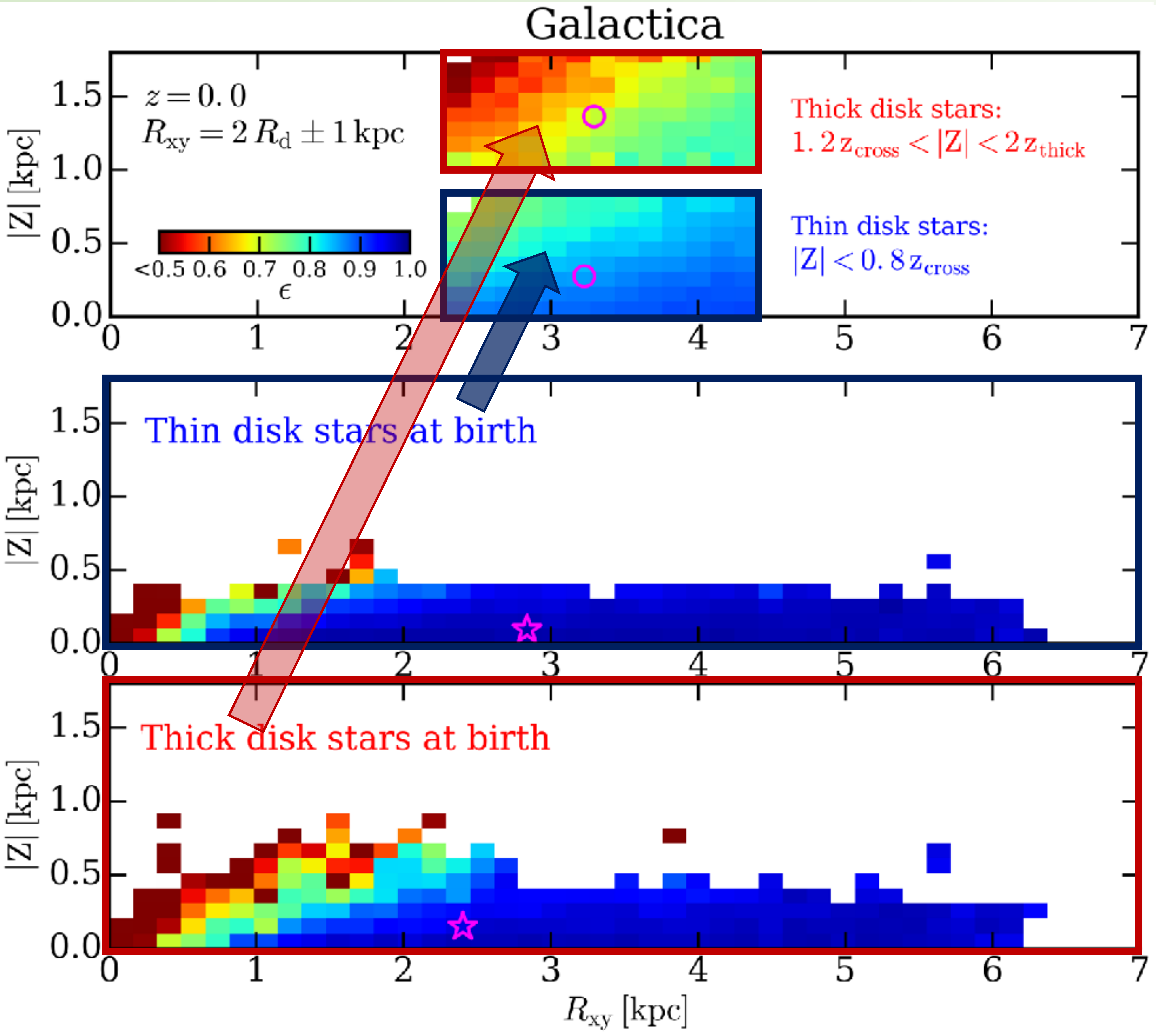
Park et al. 2021, ApJS, 254, 2



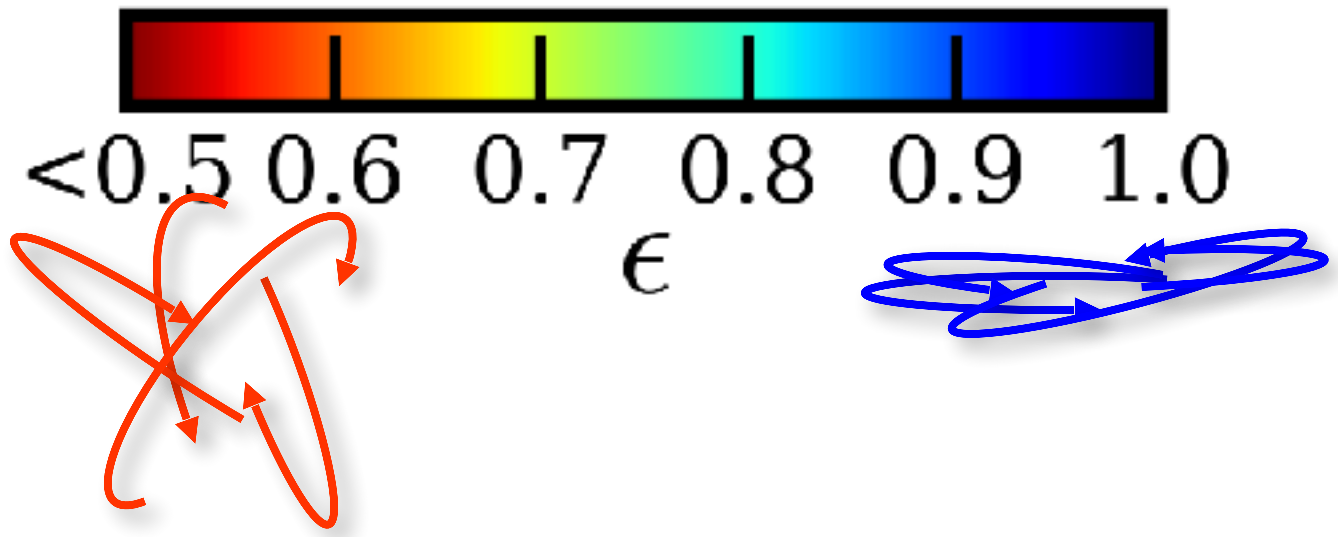
NH

at z=0.0

at birth!

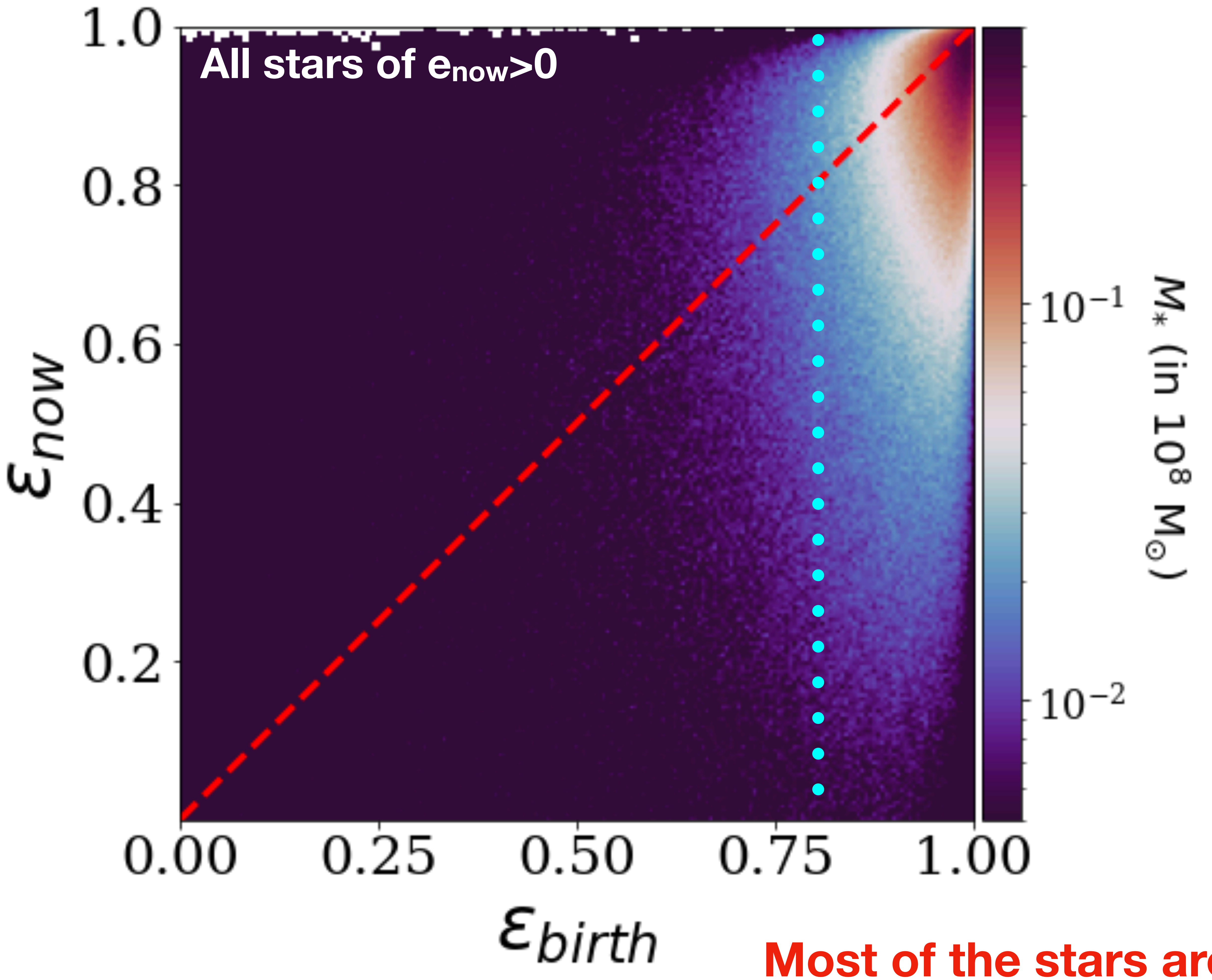


orbtial circularity



Cicularity change of disc stars: disc heating

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

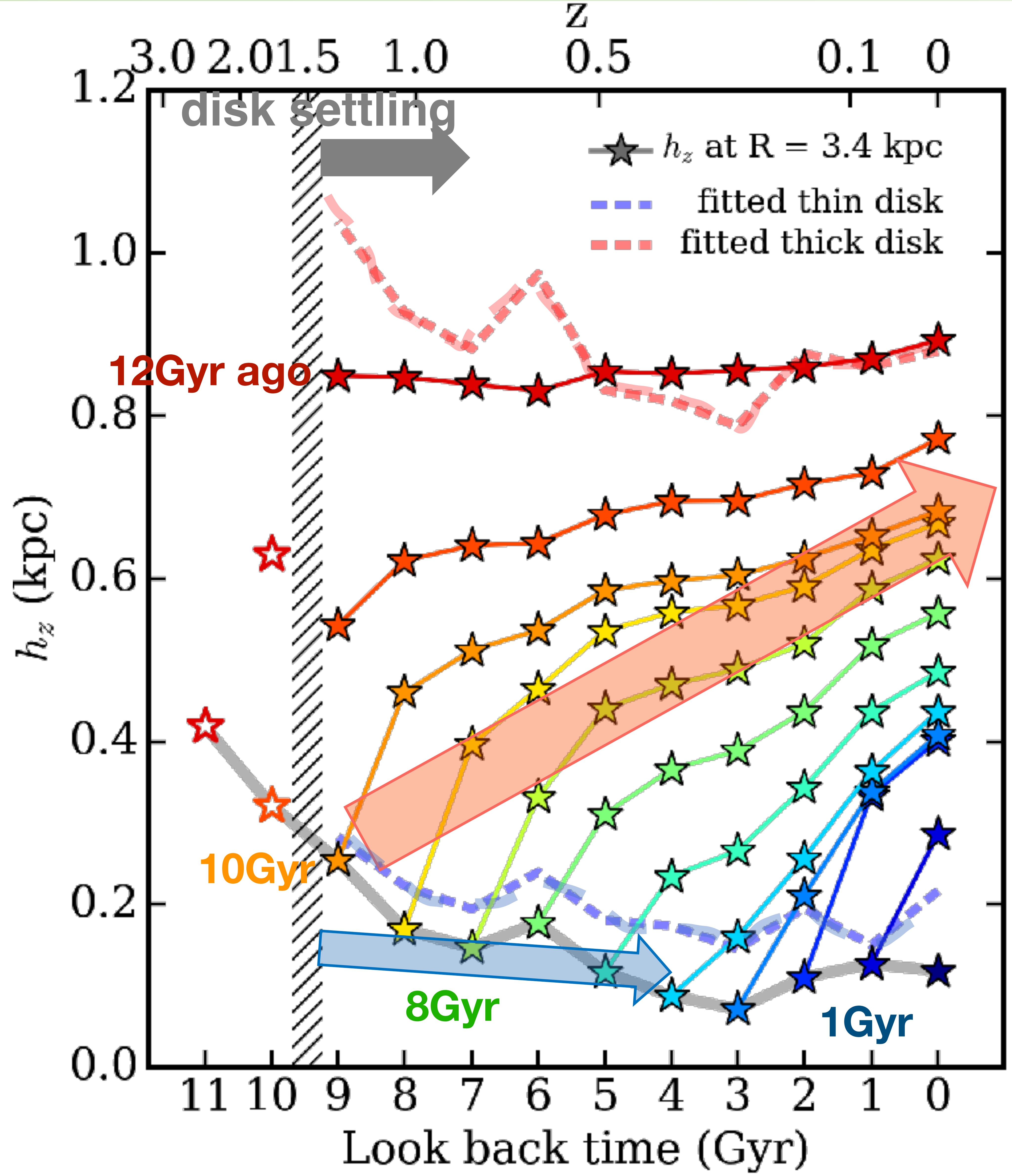


Most of the stars are born on the thin disc
and dynamically heated with time.

Park et al. 2021, ApJS, 254, 2

NH: Evolution of the vertical distribution (one galaxy)

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



Disc settling happened at z=1.5

Vertical scale height of thick disc almost constant

Stars formed on thin disc get heated: Disc heating

Vertical scale height of thin disc almost constant

New stars always form on a thin disc

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**
- [a/Fe] provides a guideline at best. Bimodality many/may not mean much.
- Thin and thick discs are **continuous** reflecting the SFH of the galaxy: A large variation between galaxies depending on SF and merger history.
- Are there really two distinct discs?

Gaussian Mixture Models on NH