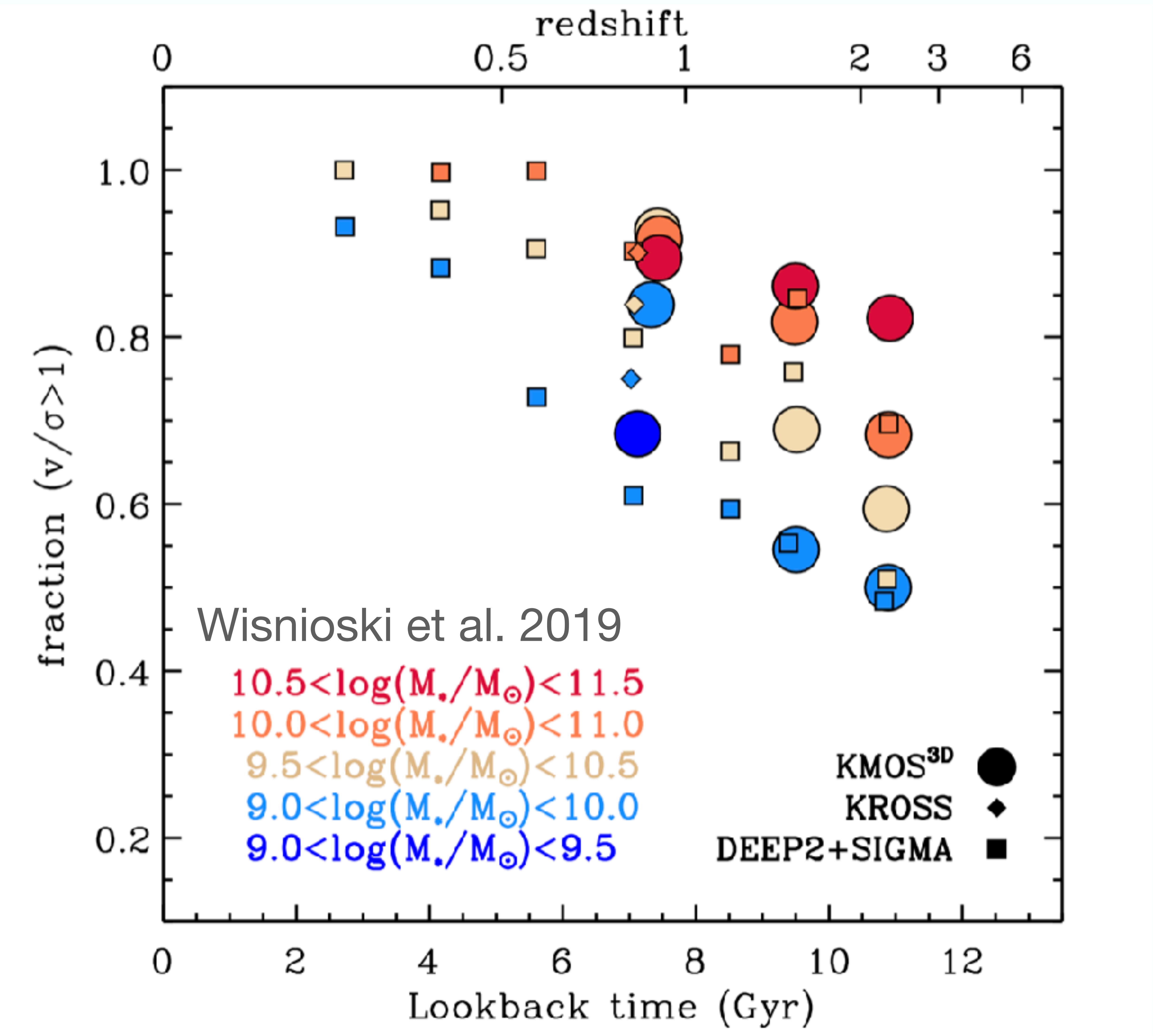
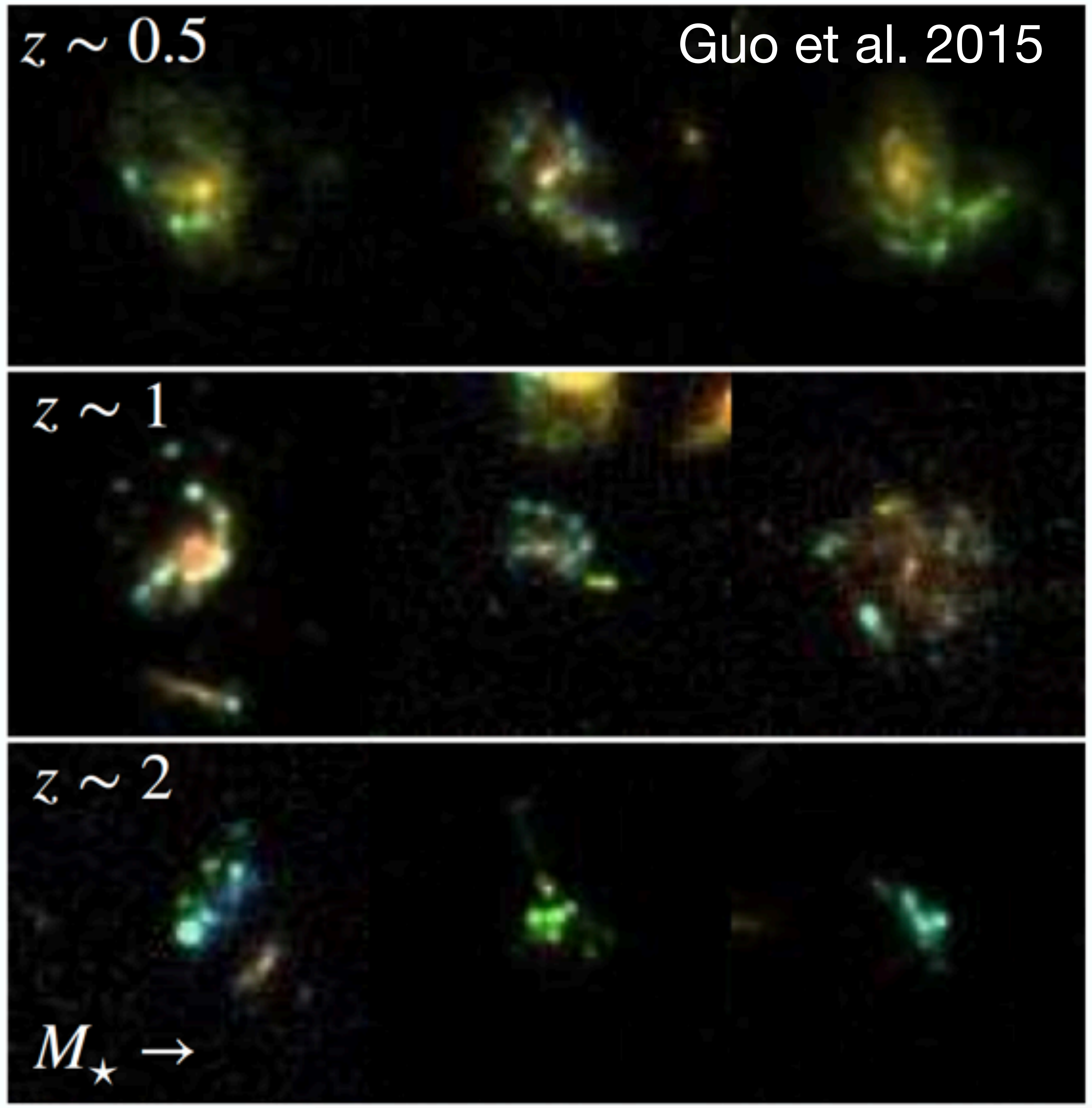
THE PHYSICS OF GALAXY DISK FORMATION

Image: Garrison-Kimmel et al. 2018

James Bullock (UC Irvine)





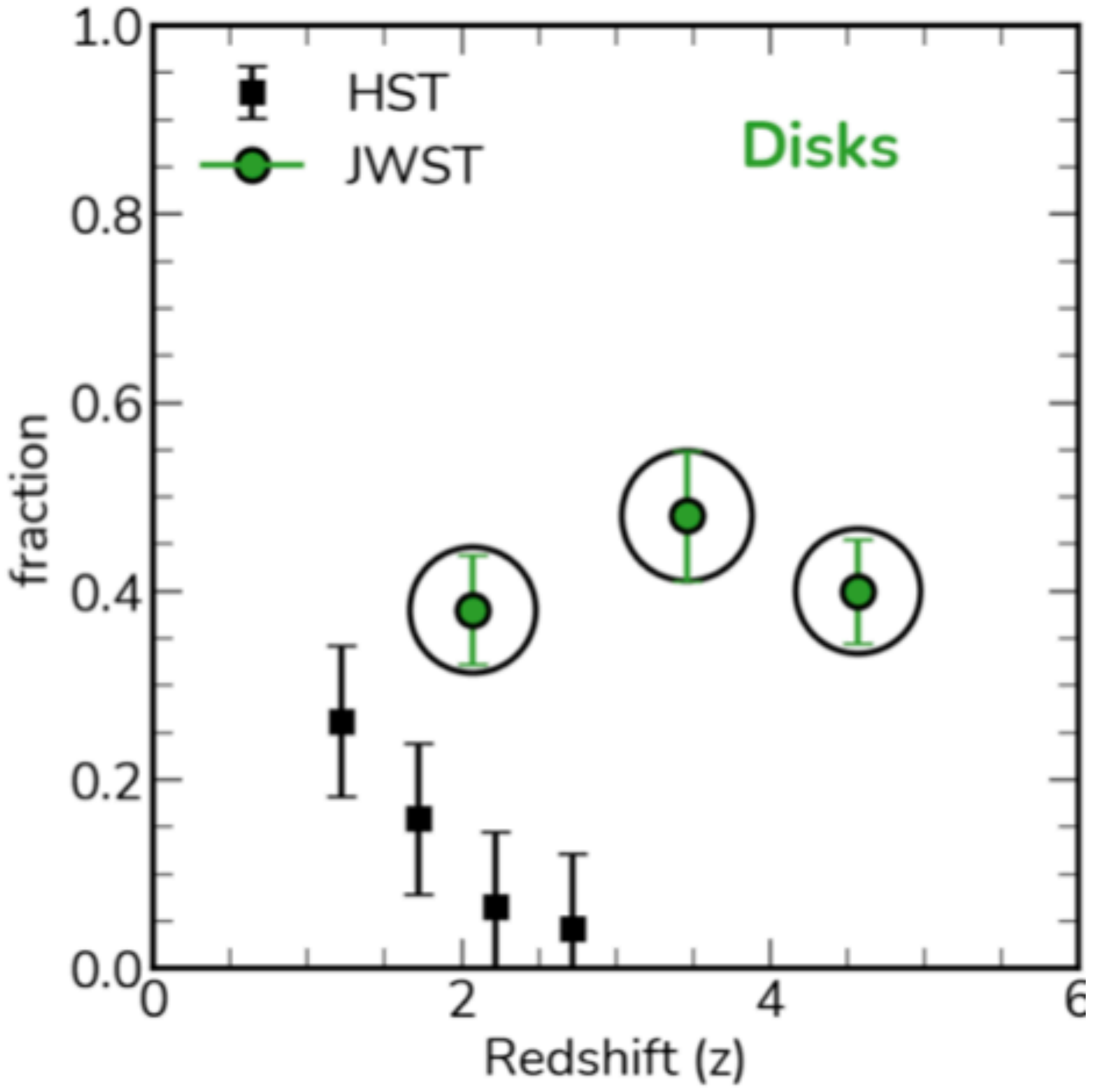
e.g. Elmegreen & Elmegreen 05; Oesch +10; Guo+15, Margalef-Bentabol +18; Whitney +21

Among star-forming galaxies:
More disks @ high mass & low z

High-z disks:
irregular & clumpy

JWST sees more high-z disk galaxies than expected ->Current ground-based IFS may underestimate V/σ?

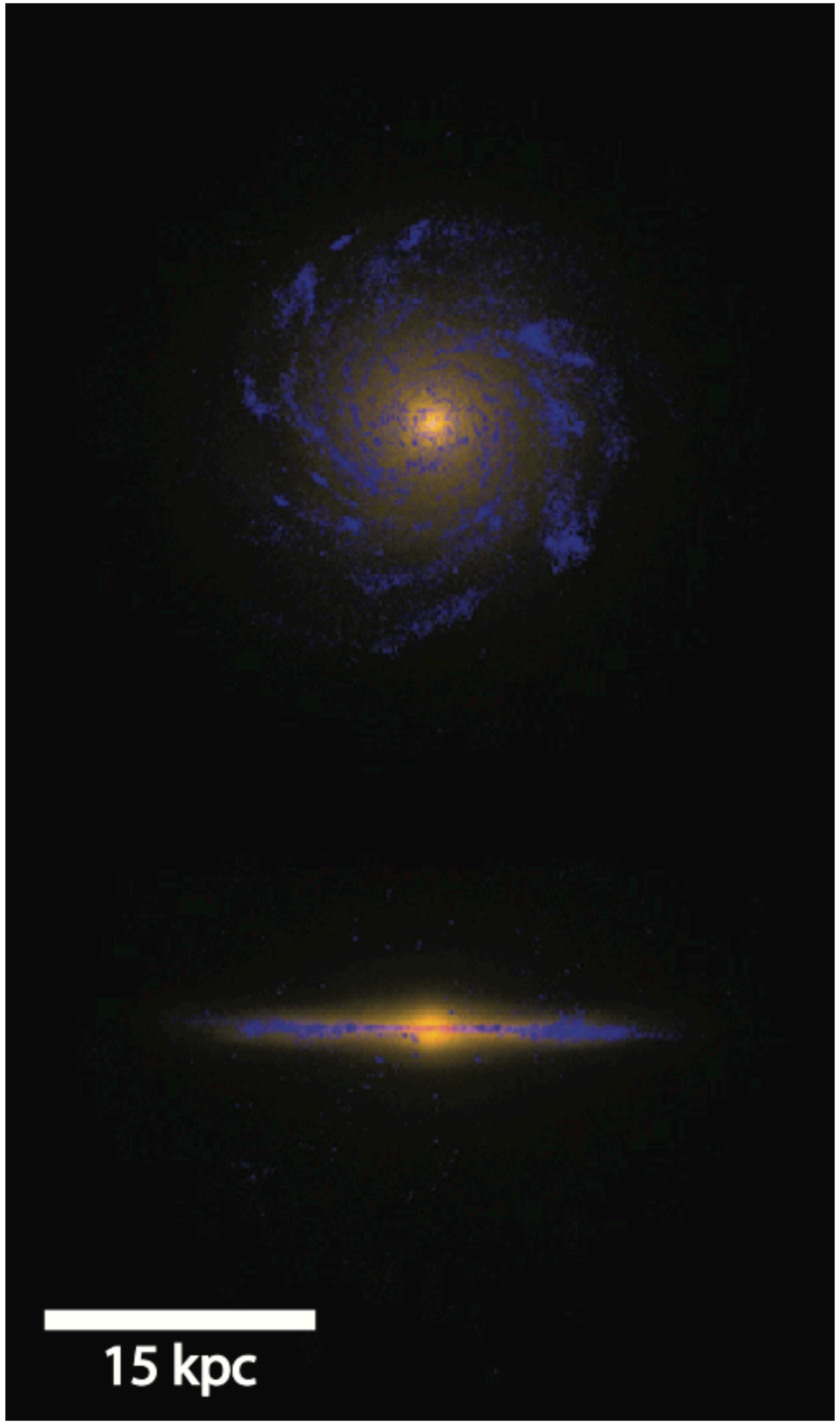
Ferreira et al. 2022



Also: Robertson et al 2022, Kartaltepe et al. 2022,Colin et al. 2022,Vega-Ferrero et al. 2023, …

Bold claim: Hard to say what it means… We really don't have a fully agreed-upon "physics-based" theory for disk formation.

Towards realistic disks in LCDM simulations



2011

The Astrophysical Journal, 742:76 (10pp), 2011 December 1
doi:10.1088/0004-637X/742/2/76

FORMING REALISTIC LATE-TYPE SPIRALS IN A ΛCDM UNIVERSE: THE ERIS SIMULATION

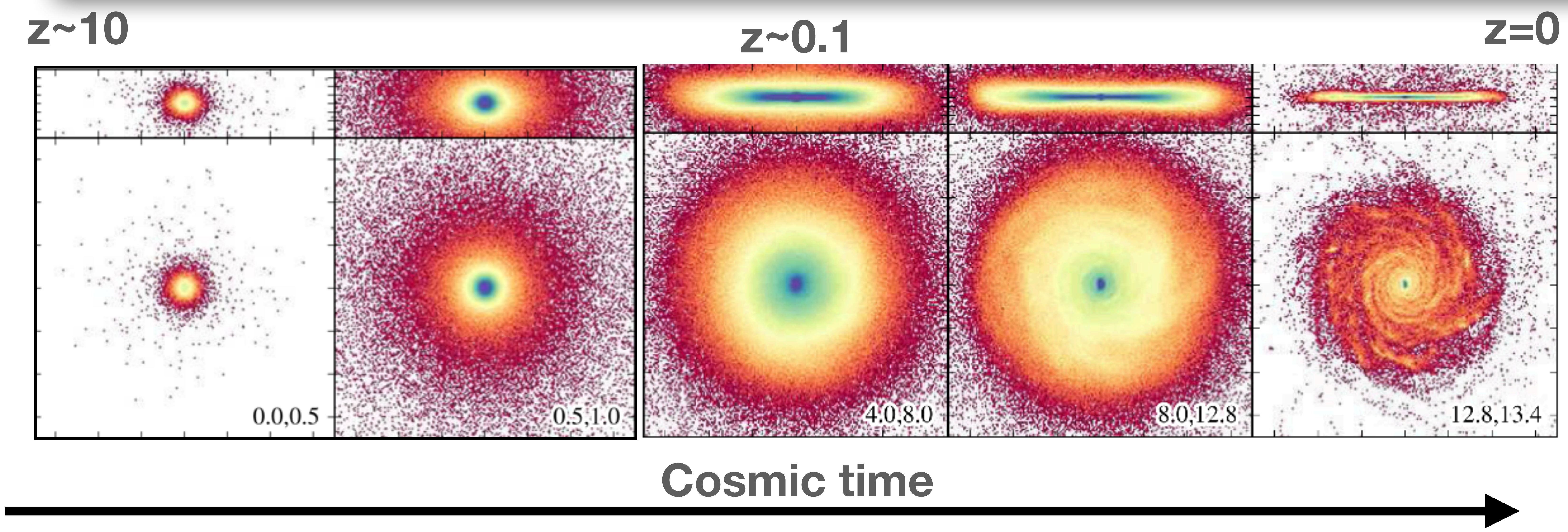
Javiera Guedes[1,2], Simone Callegari[3], Piero Madau[1], and Lucio Mayer[2,3]

2013

The Astrophysical Journal, 773:43 (19pp), 2013 August 10
doi:10.1088/0004-637X/773/1/43

INSIDE OUT AND UPSIDE DOWN: TRACING THE ASSEMBLY OF A SIMULATED DISK GALAXY USING MONO-AGE STELLAR POPULATIONS

Jonathan C. Bird[1,2,3,8], Stelios Kazantzidis[1,2], David H. Weinberg[1,2], Javiera Guedes[4], Simone Callegari[5], Lucio Mayer[6], and Piero Madau[7]



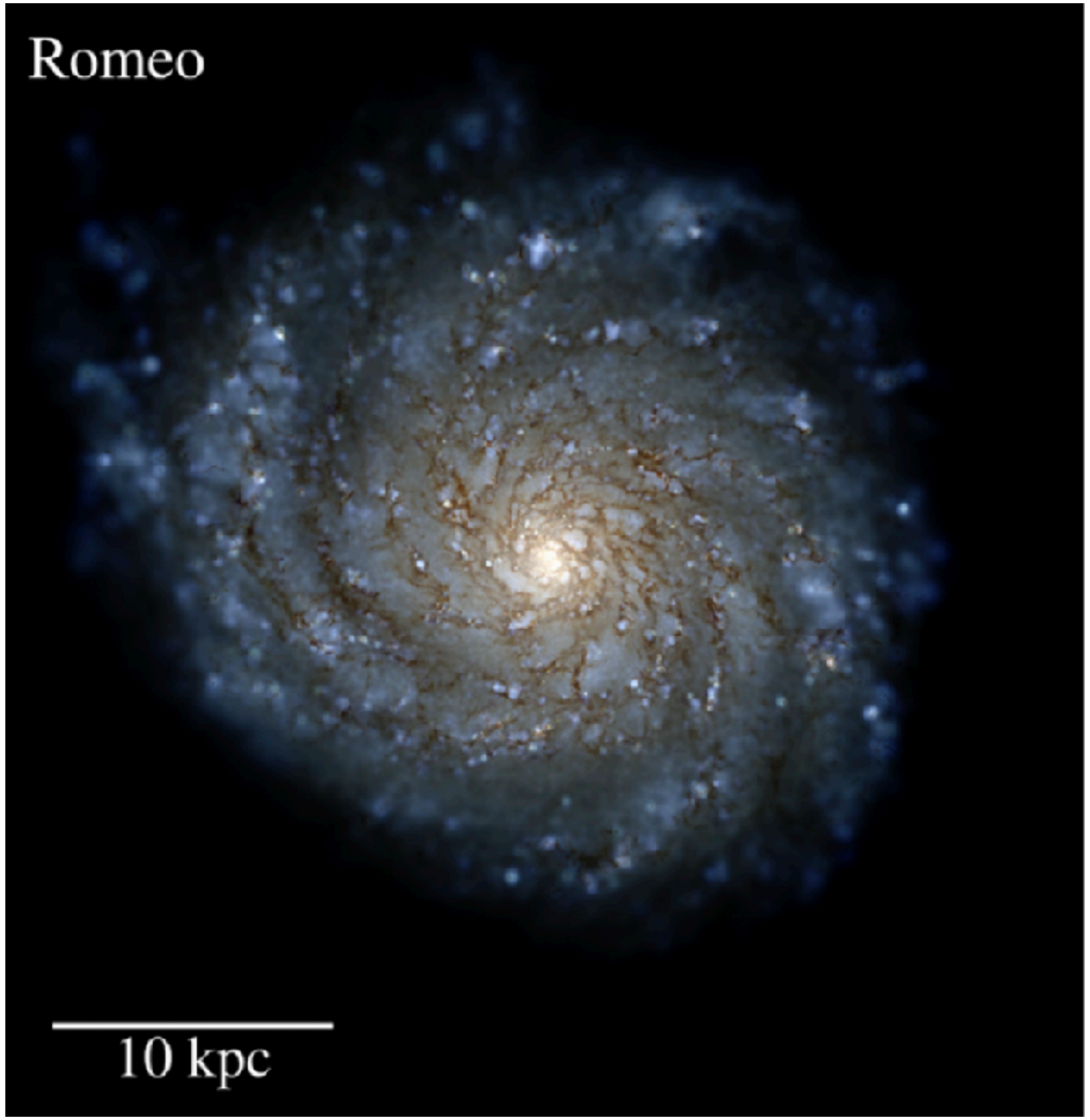
(See also Thacker & Couchman 2000; Governato et al. 2004; Robertson et al. 2006; Giuseppe et al. 2015…)

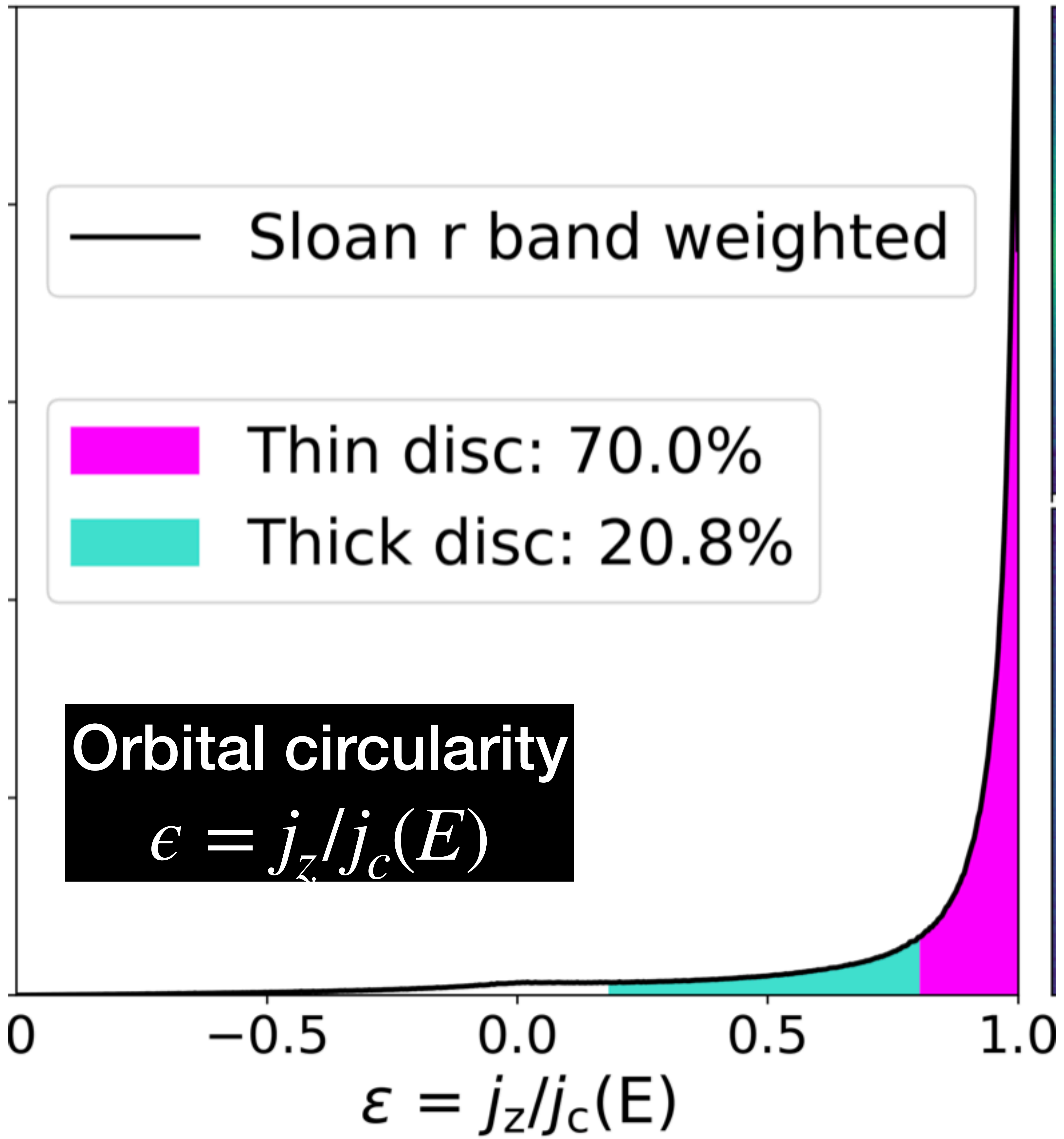
FIRE-2 Simulations of Milky-Way size galaxies

Feedback In Realistic Environments

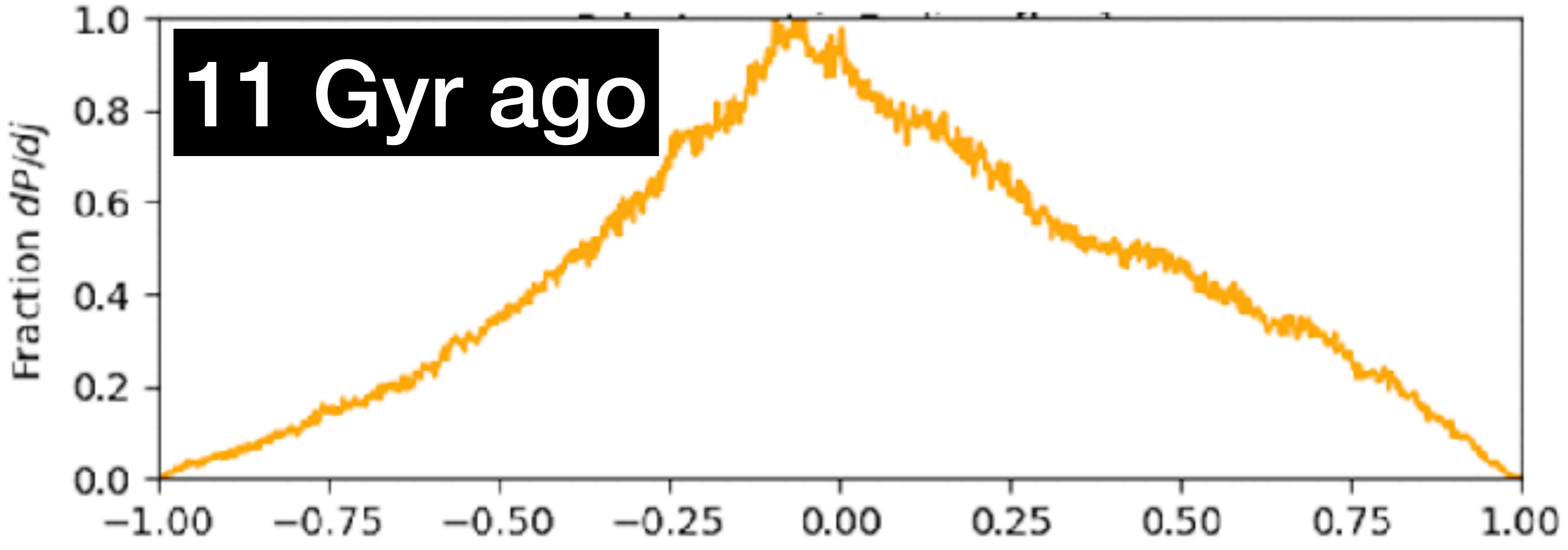
Image: Garrison-Kimmel et al. 2018

This disk is very thin at z=0



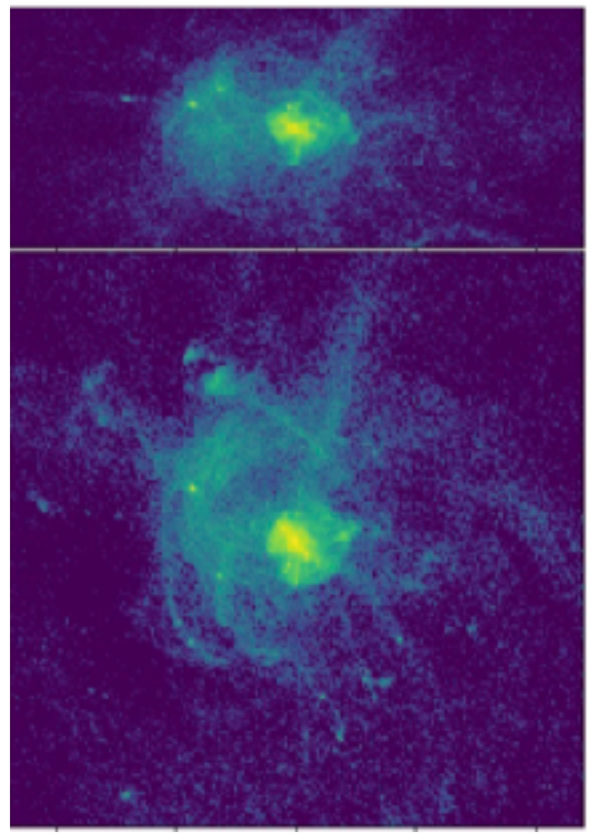


Orbits of young stars

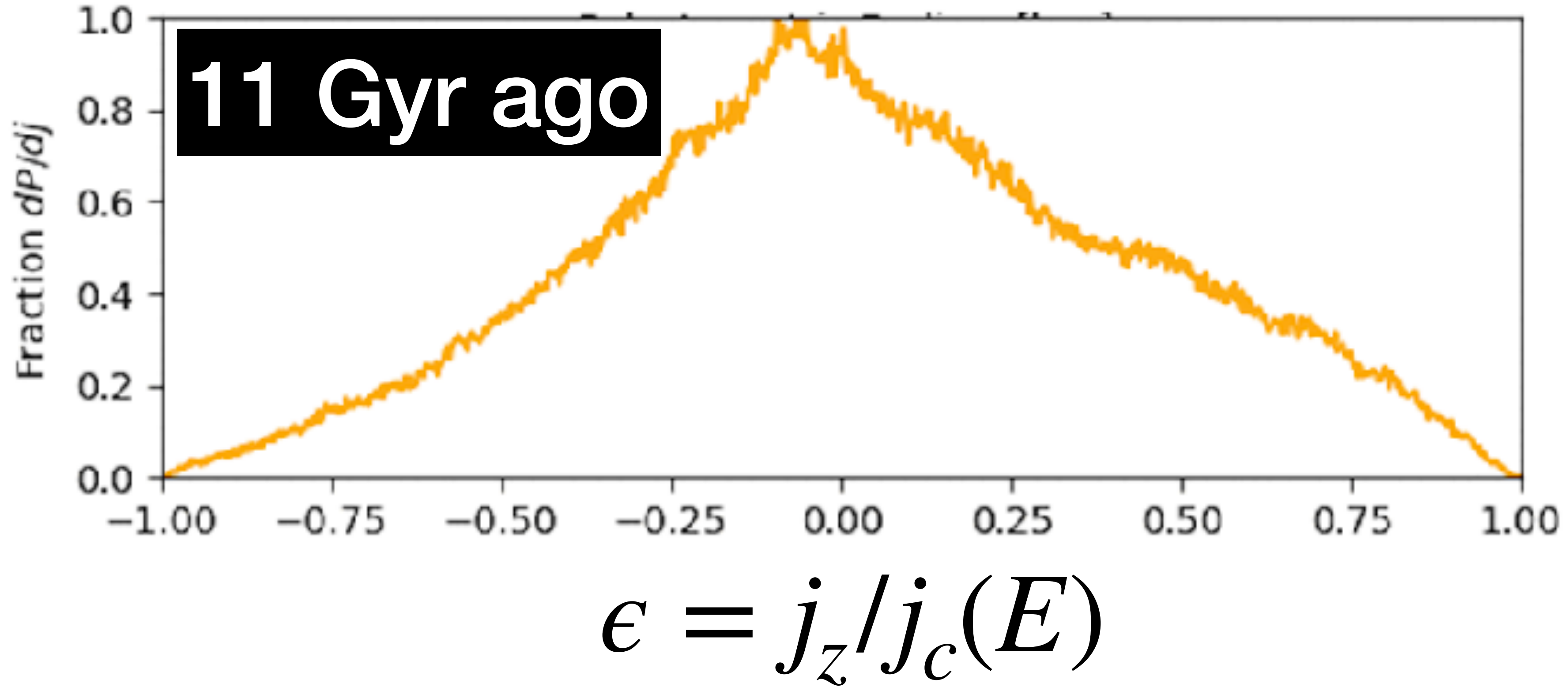


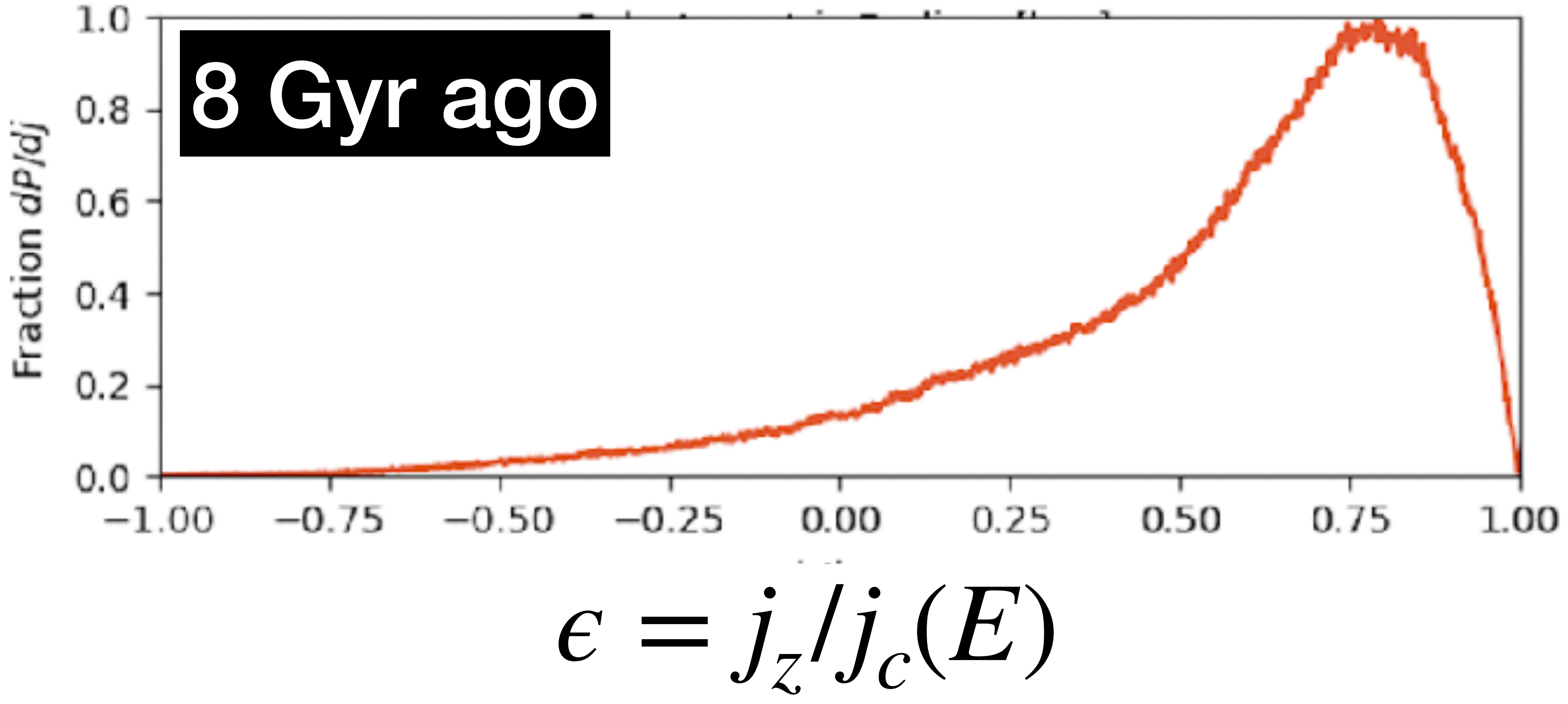
$\epsilon = j_z / j_c(E)$

Young stars

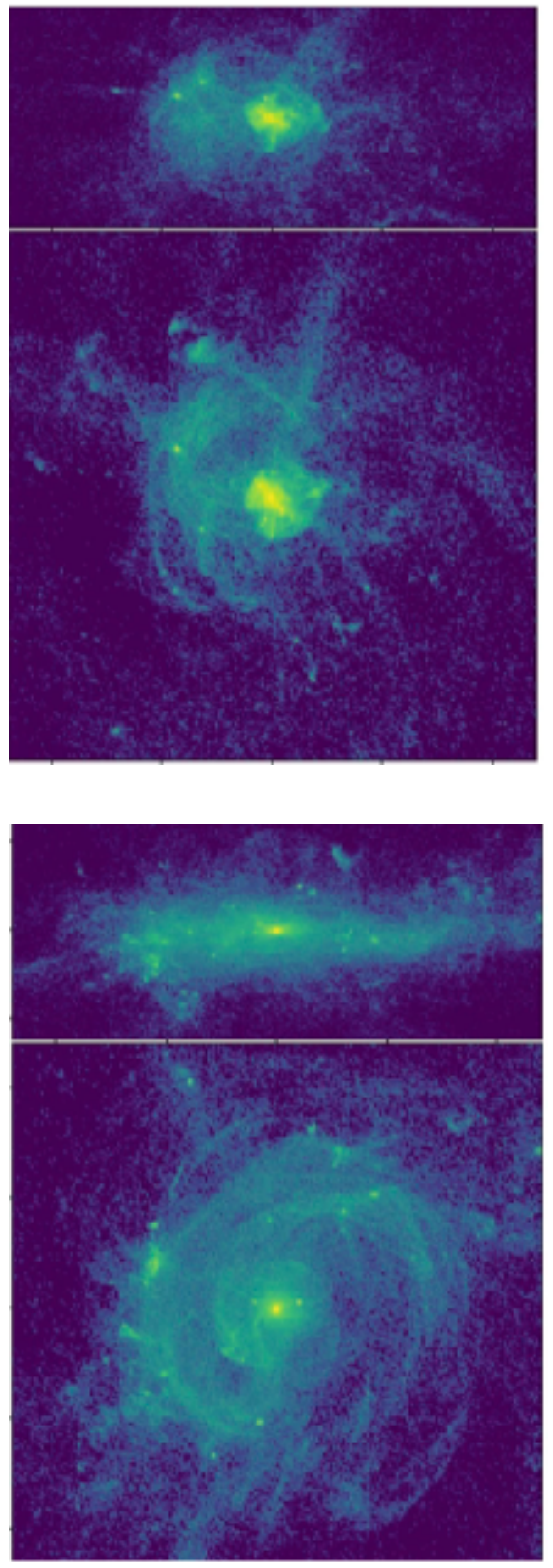


Orbits of young stars



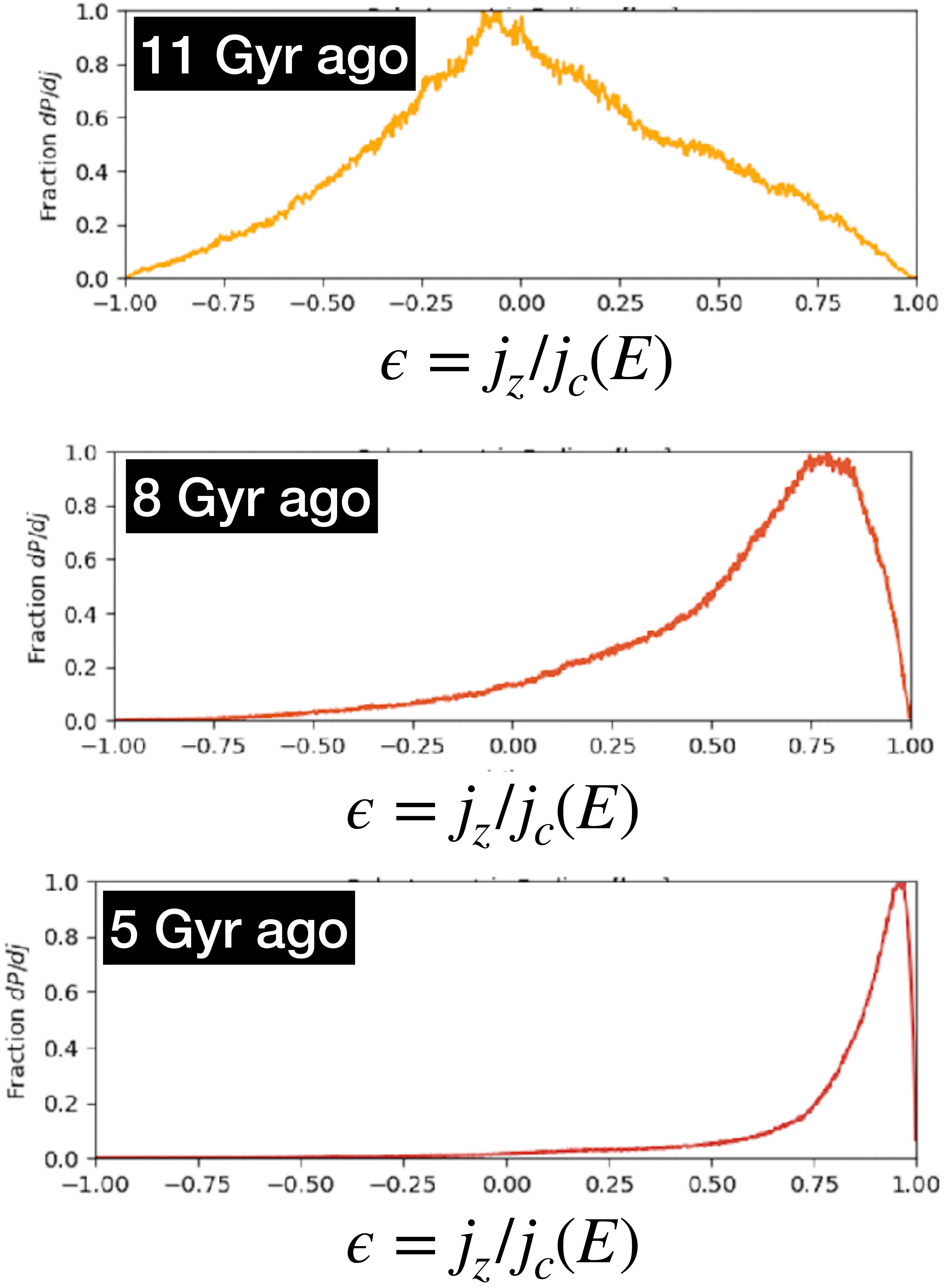


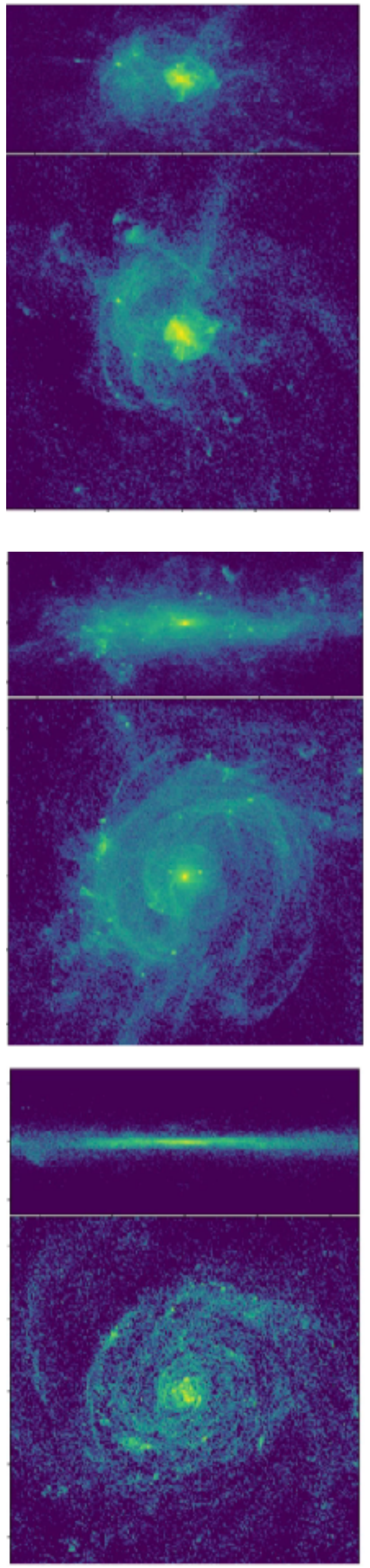
Young stars

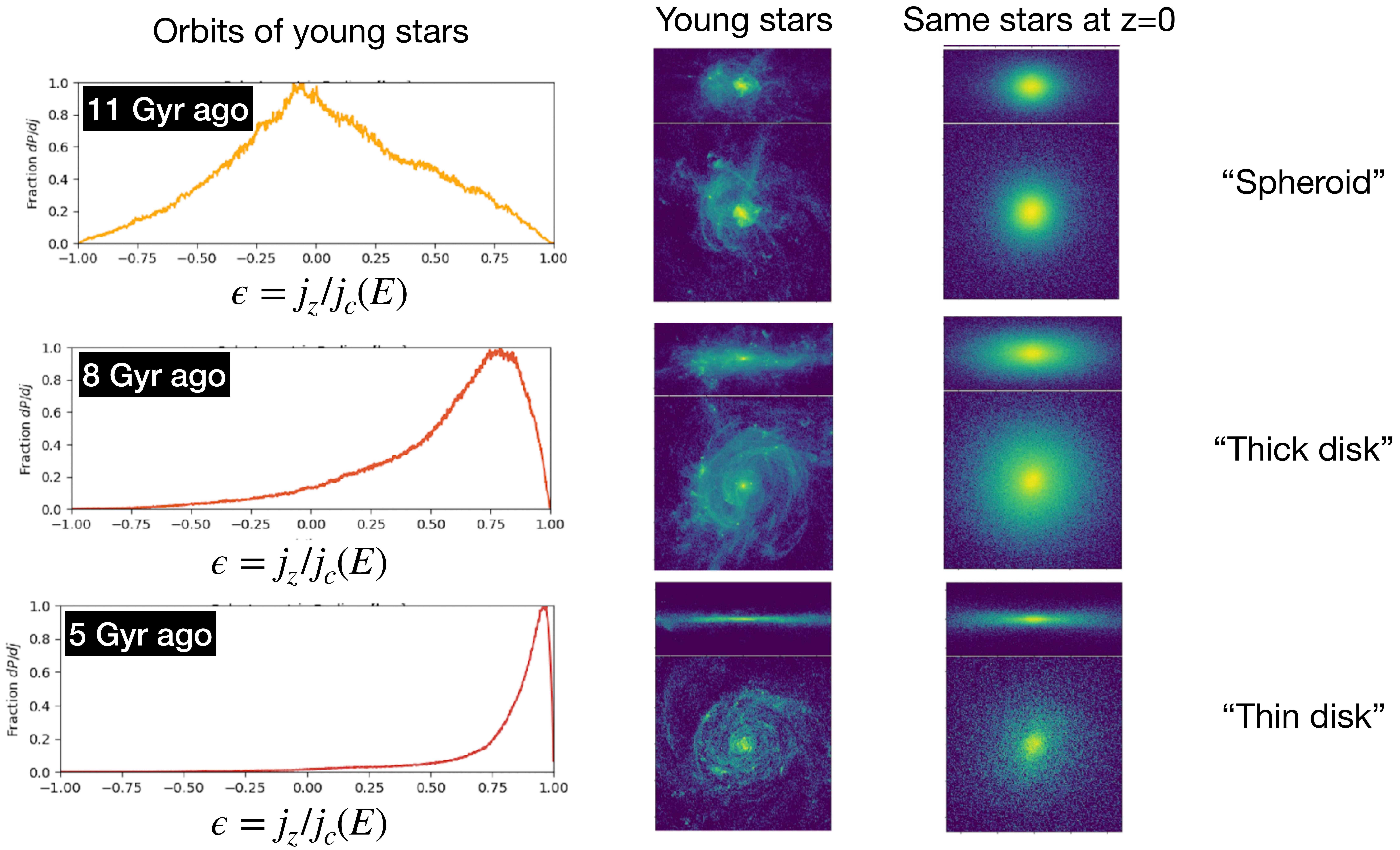


Orbits of young stars

Young stars

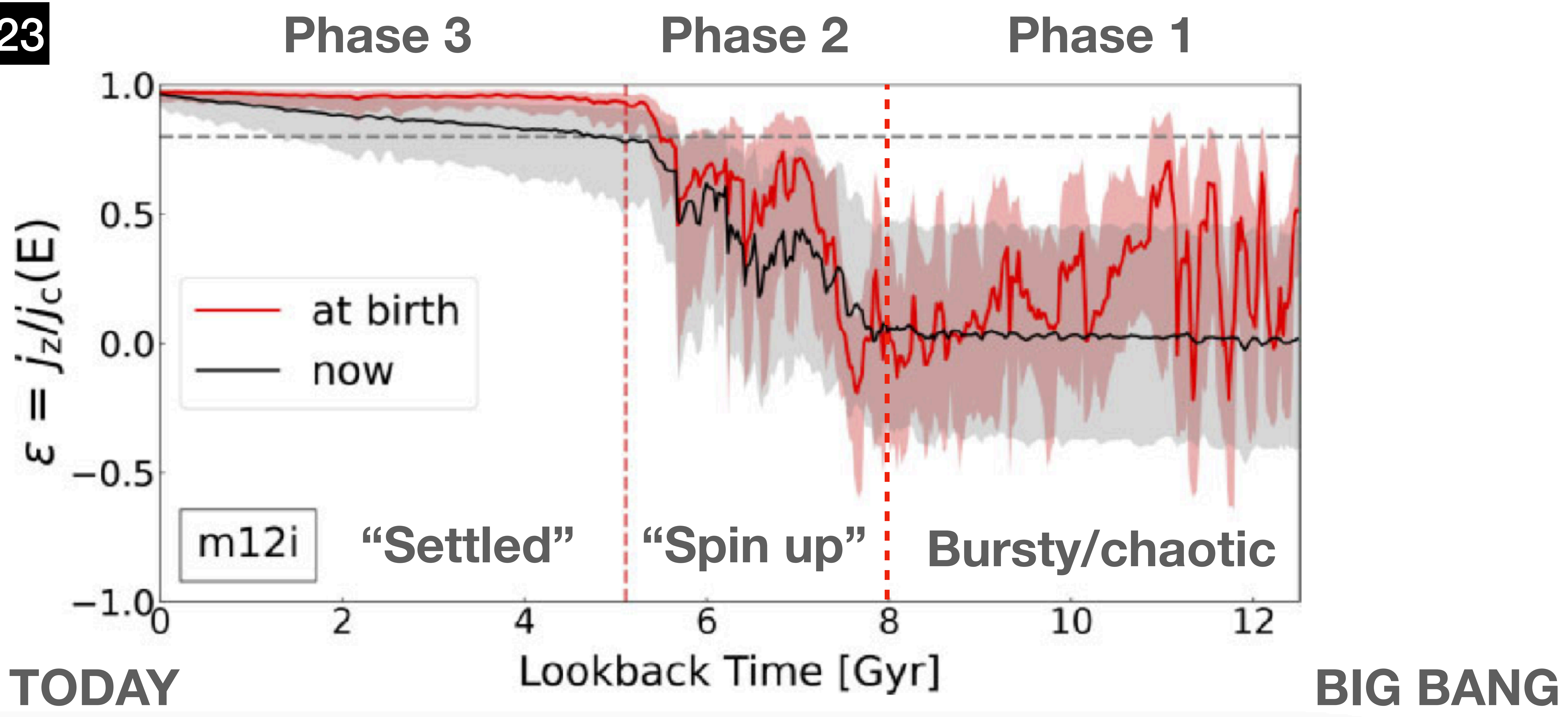





Orbits of young stars
Young stars
Same stars at z=0
11 Gyr ago
8 Gyr ago
5 Gyr ago
Fraction dP/dj
$\epsilon = j_z/j_c(E)$
"Spheroid"
"Thick disk"
"Thin disk"

3 Phases of Galaxy Disk Formation

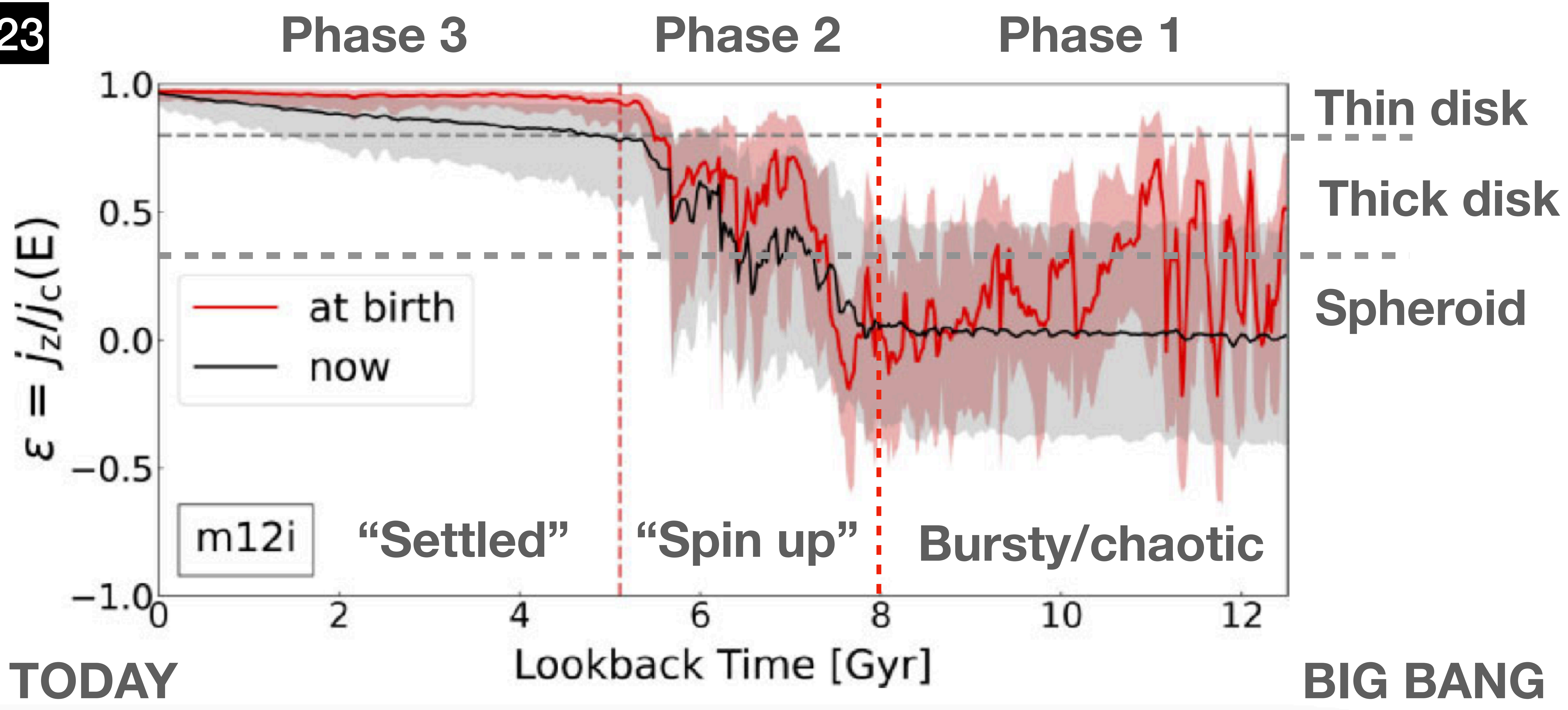
Yu+2023



See also Fiona McCluskey et al. 2023

3 Phases of Galaxy Disk Formation

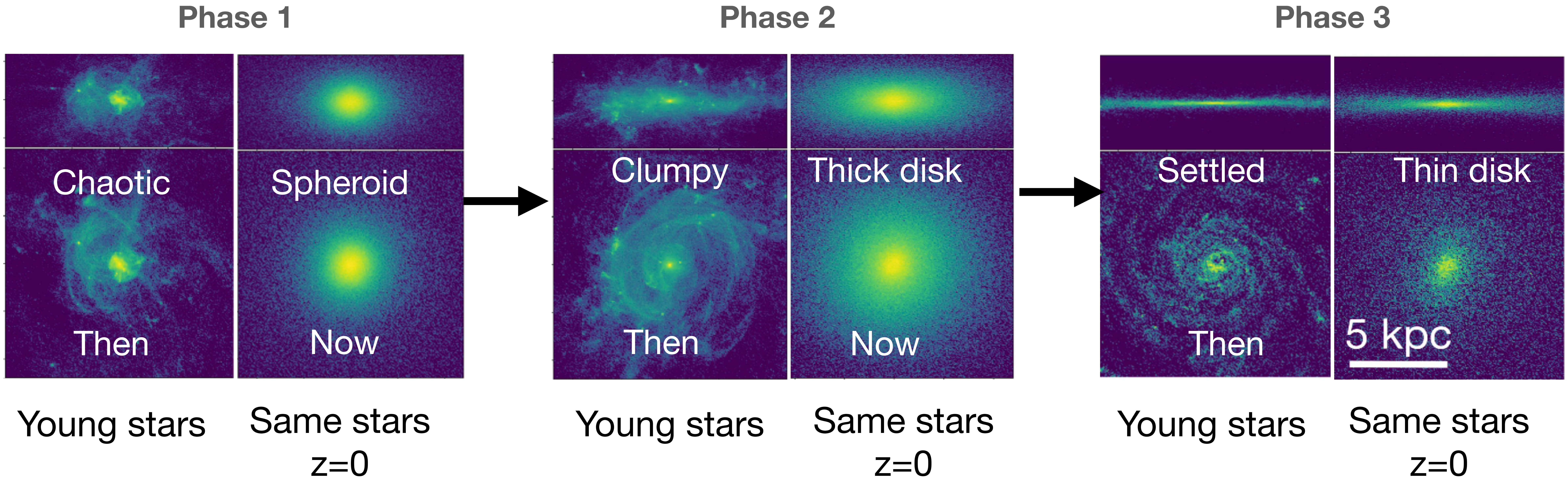
Yu+2023



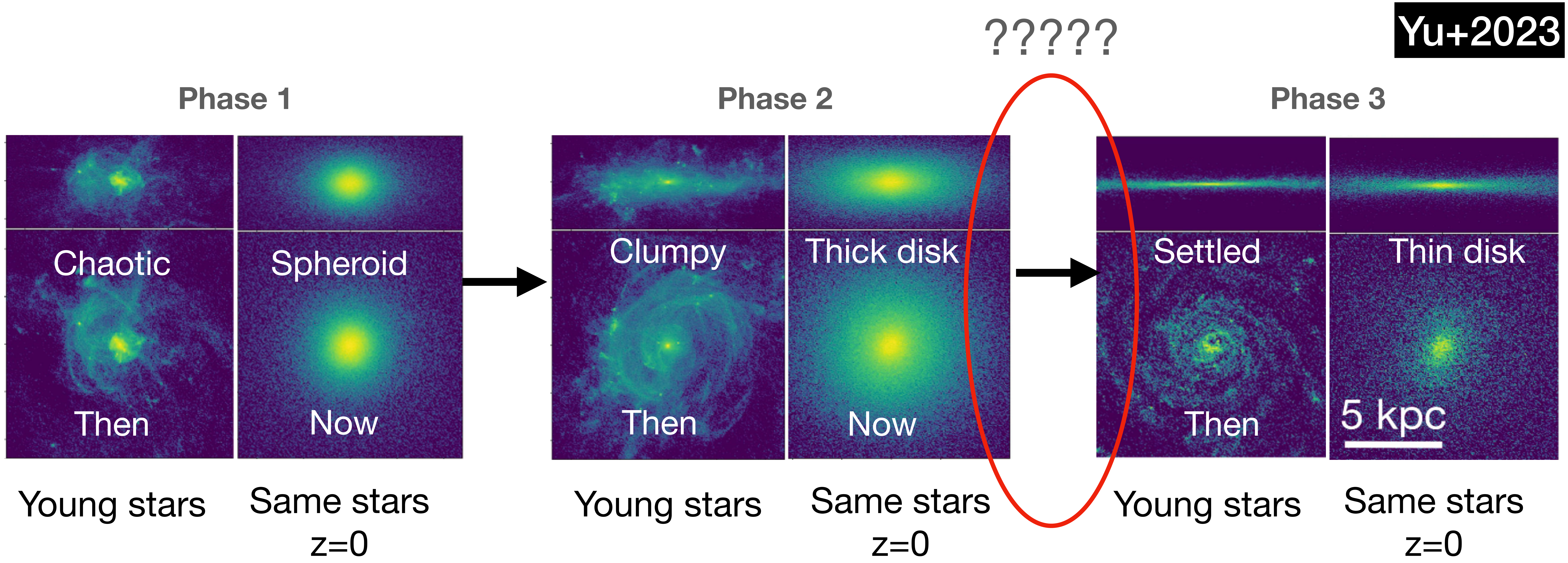
See also Fiona McCluskey et al. 2023

3 Phases of Galaxy Disk Formation

Yu+2023



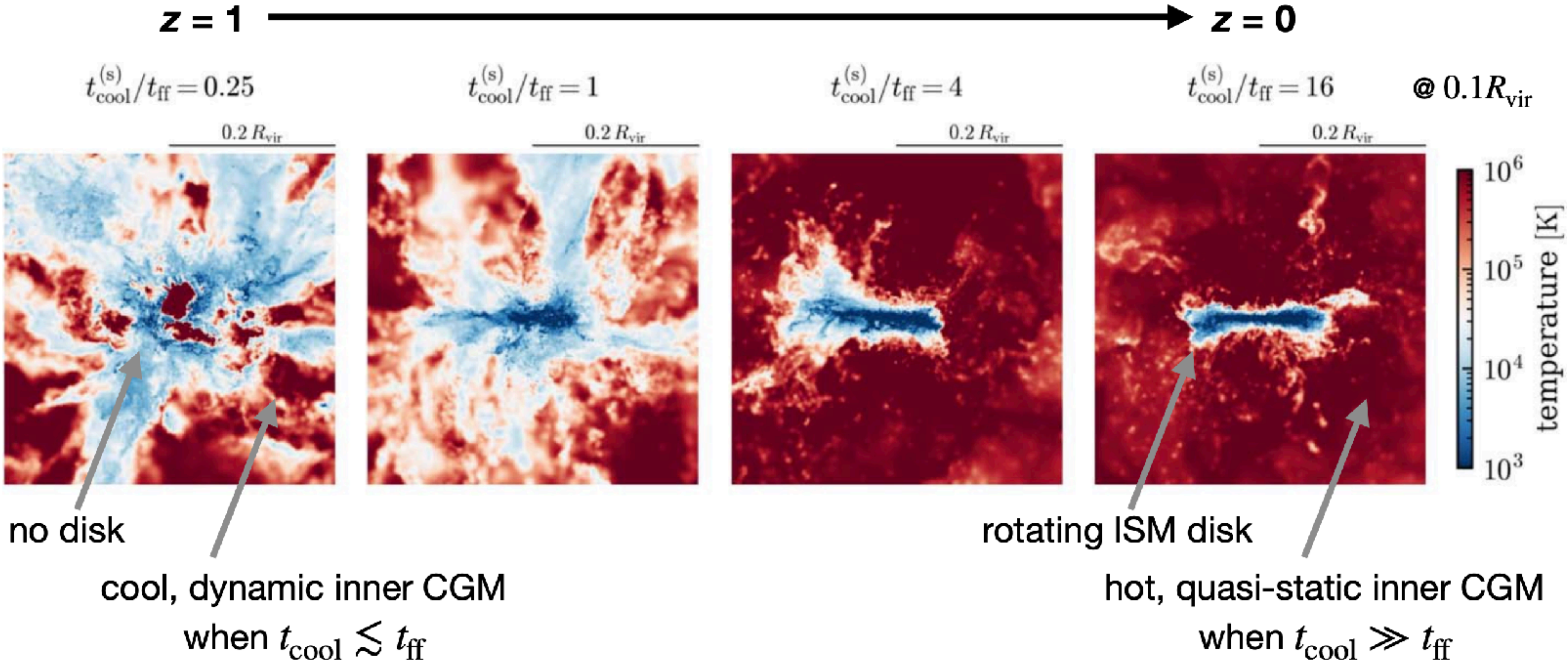
3 Phases of Galaxy Disk Formation



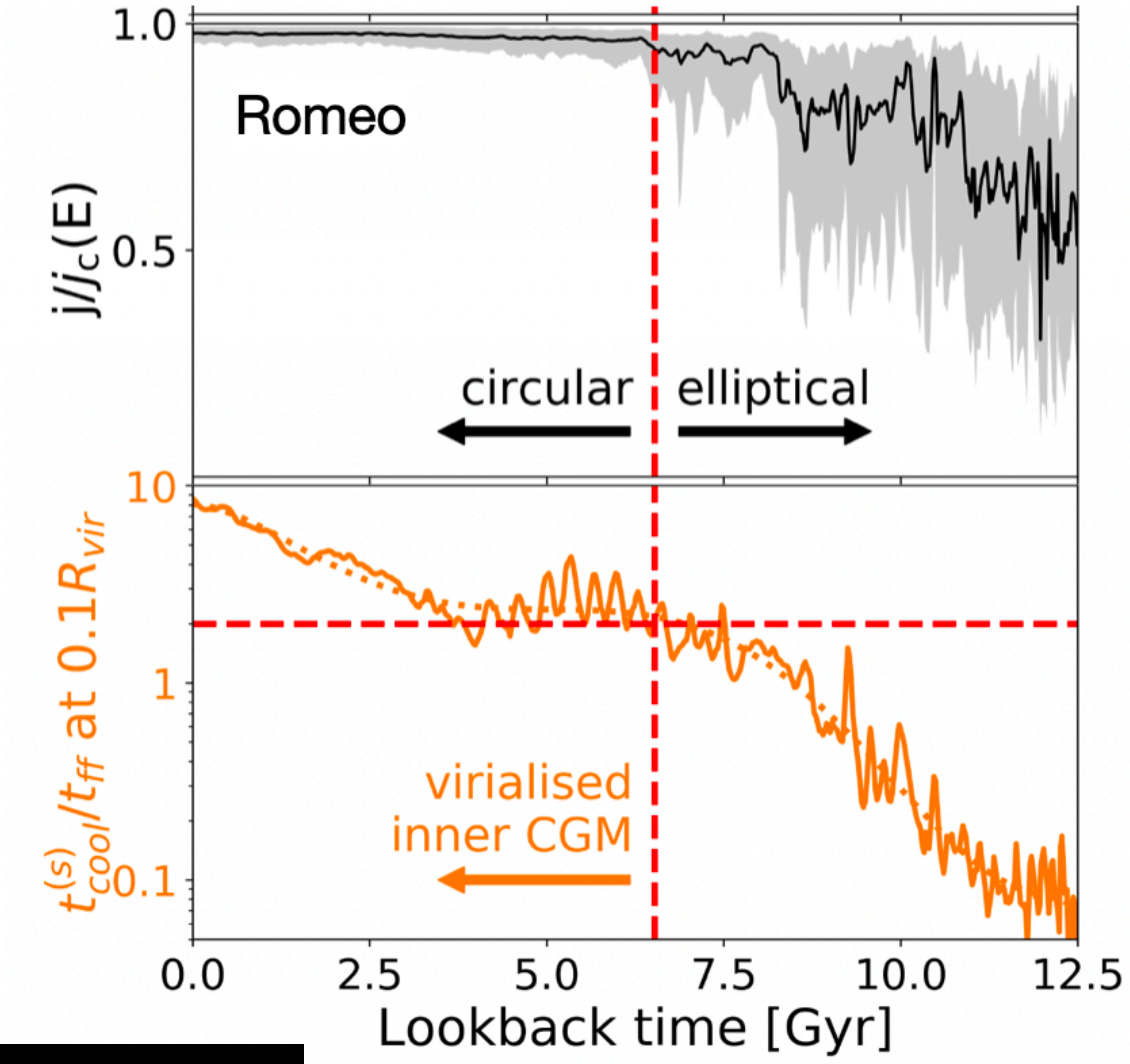
What causes 2—> 3 transition?

Stern+2021

Inner CGM virialization in *FIRE*



Cool inflows crash supersonically → **Gentle, coherent subsonic flows**



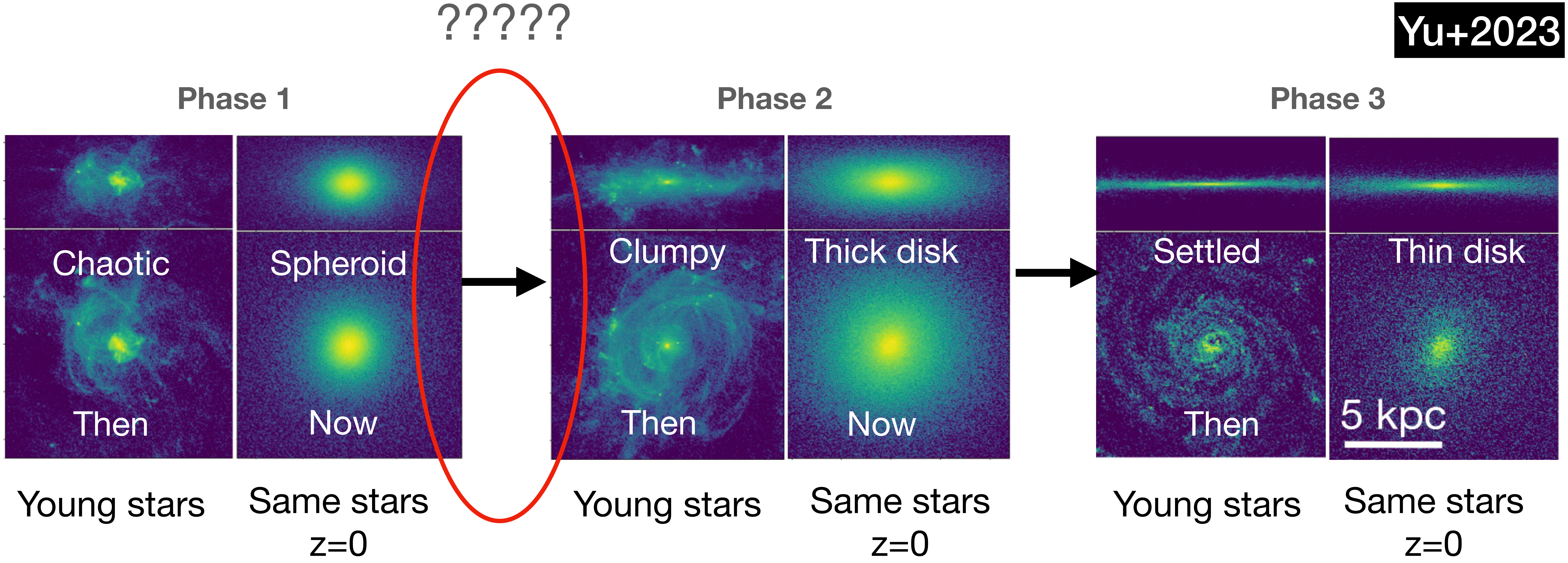
Yu+2023

*** Young-star orbits become VERY circular after inner CGM virializes**

<u>Why?</u> Hot (sub-sonic) accretion allows angular momentum to mix/align prior to entering the galaxy

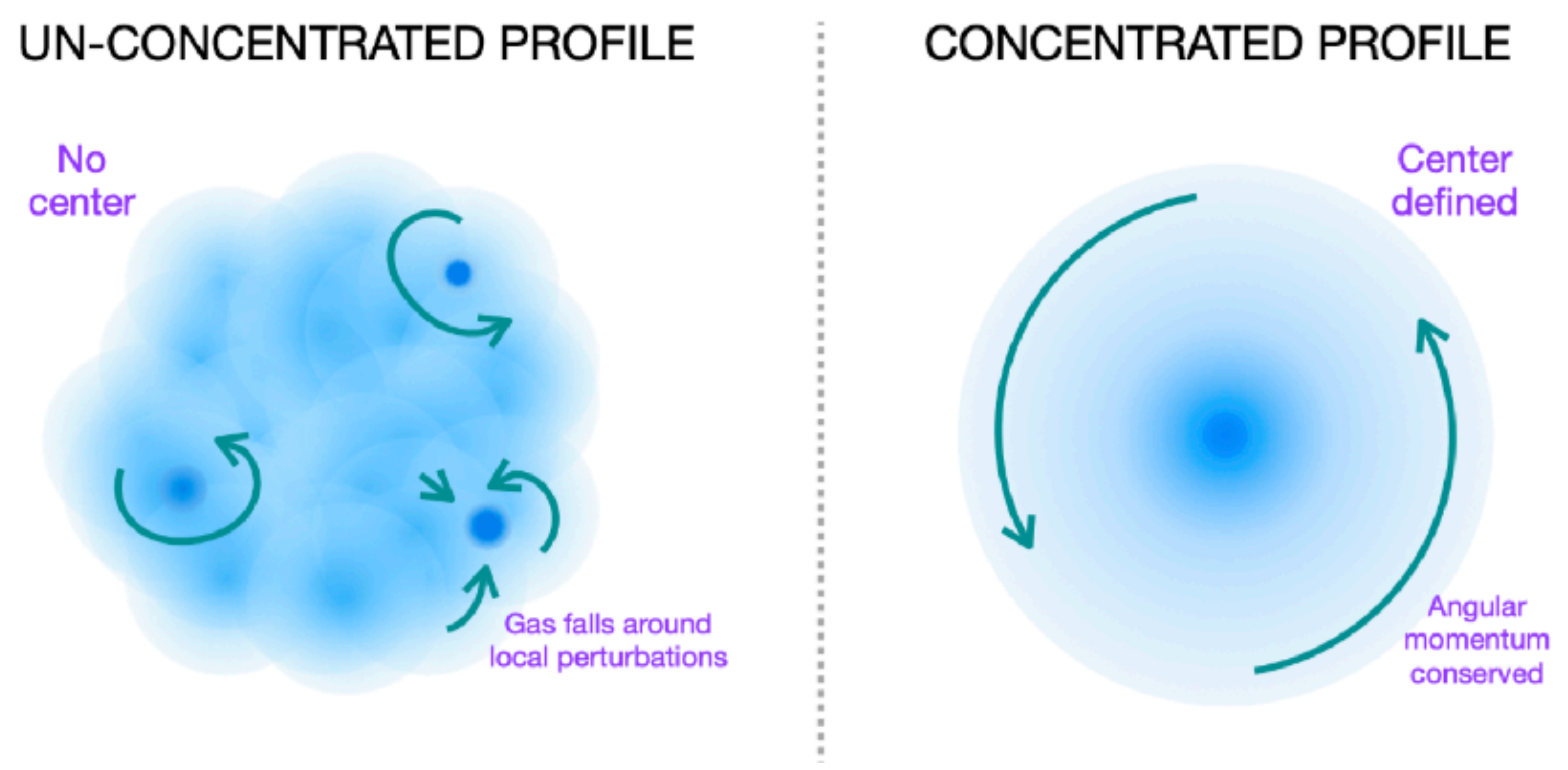
Hafen et al. 2022

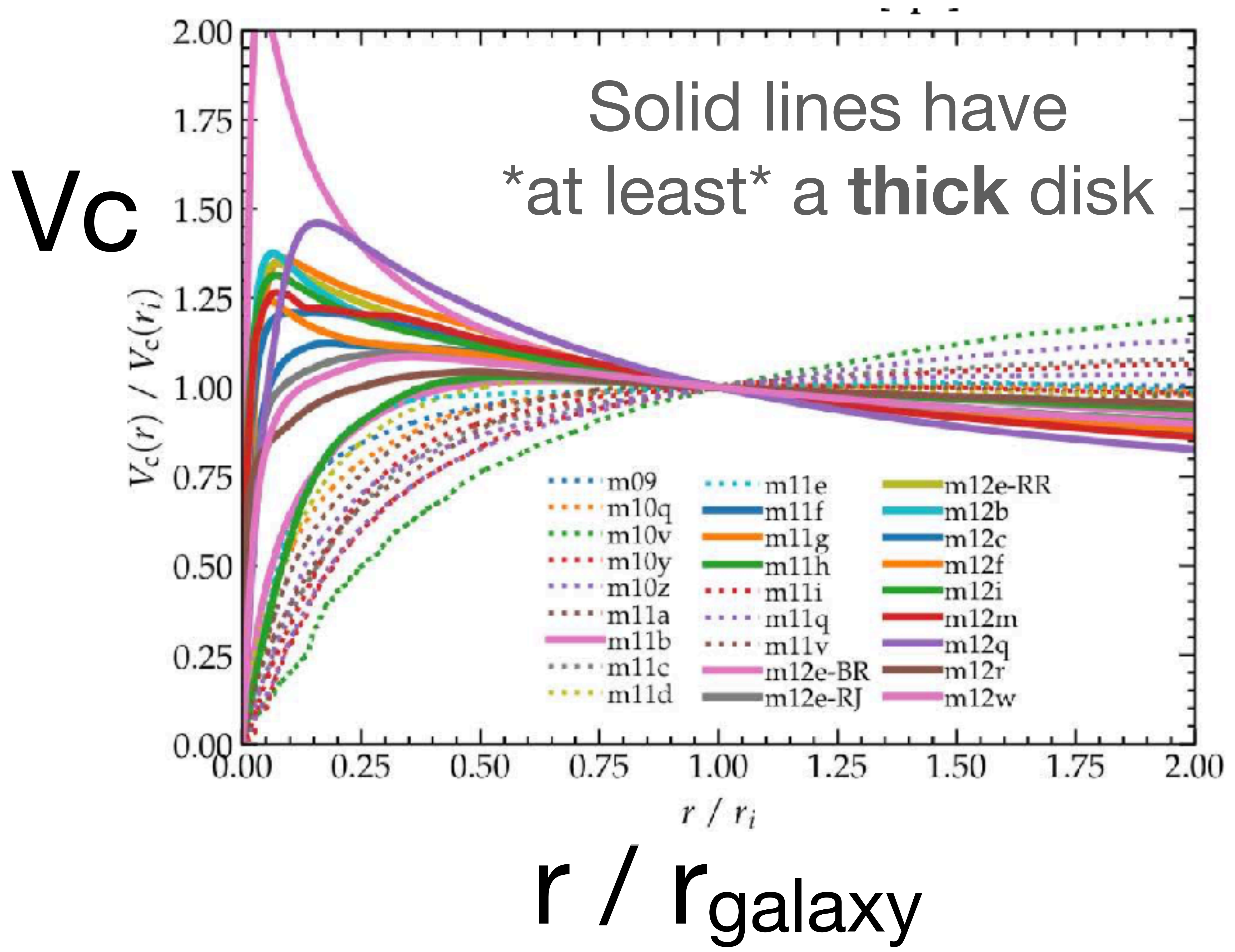
3 Phases of Galaxy Disk Formation



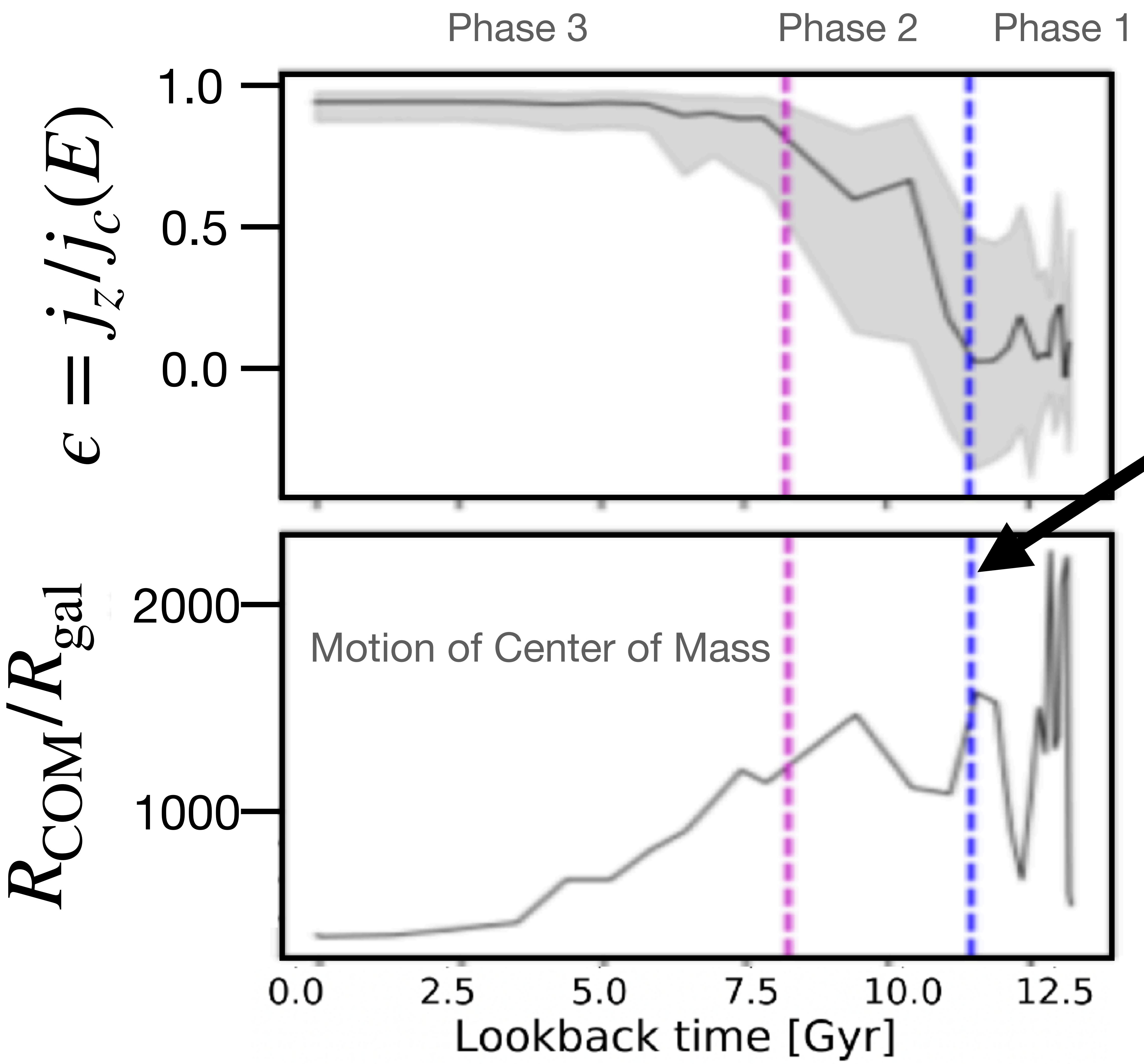
What causes 1 —> 2 transition?

Disk formation is promoted when the mass profile becomes sufficiently centrally-concentrated



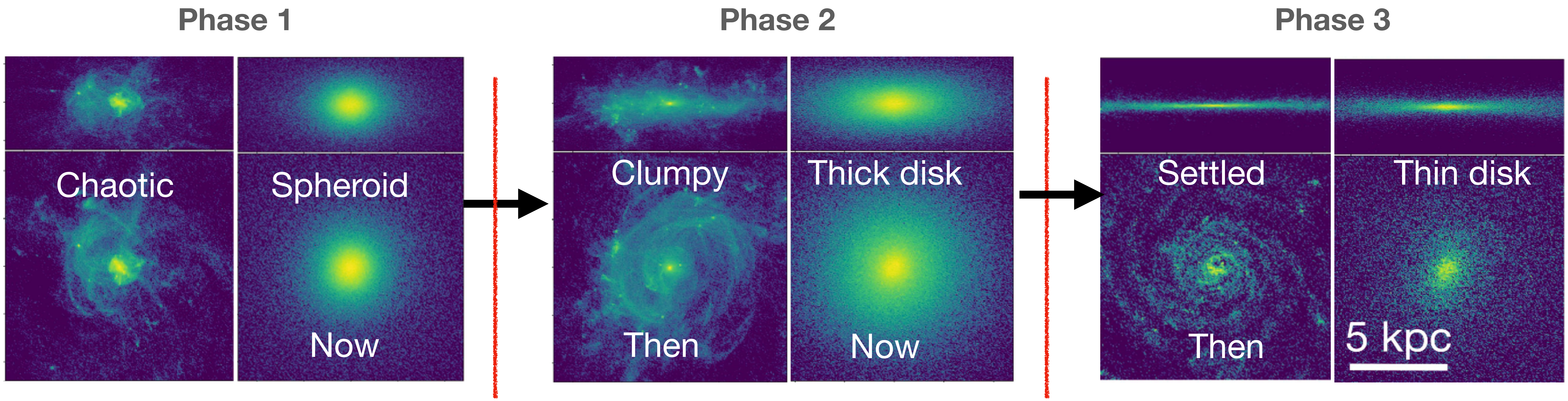


Hopkins+2023



Galaxy "spins up" only after it has a well-established center and concentrated potential.

Olti Myrtaj et al., in prep.



Center of mass is stable; Potential becomes concentrated?

Inner CGM virializes

3 phases of disk formation in FIRE-2

- Phase 1: Chaotic morphology, bursty star formation => spheroid orbits today
- Phase 2: Clumpy, puffy disk, bursty star formation => thick disk orbits today
- Phase 3: Thin, regular disk, steady star formation => (mostly) thin-disk orbits today
- **Thick disk "spin-up" phase enabled by centrally-concentrated potential?**
- **Thin disk "cool down" phase enabled by sub-sonic "hot mode" accretion**; angular momentum coherence