Hidden properties and dynamical evolution of a giant disk galaxy at z~3

Giada QUADRI (https://arxiv.org/abs/2605.04144)

In collaboration with:
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Outline

- Introduction
- Scientific questions
- Methods
- Results
- Implications
- Conclusions

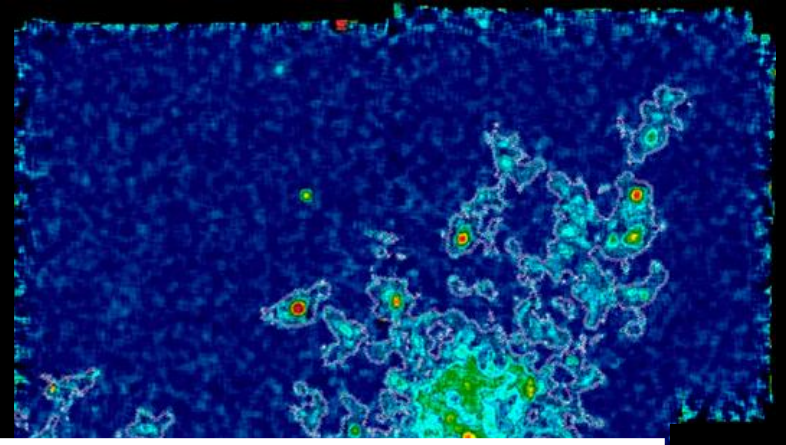
Introduction

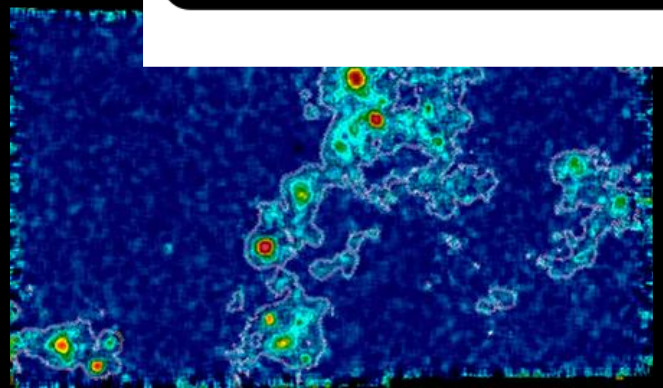
Observing the IGM and CGM in emission

The **MQN01** field at z~3 hosts one of the highest known concentration of galaxies and AGN

They are found to be connected by Cosmic Web filaments revealed via Lyα emission across 8 cMpc

This system is an **ideal laboratory** to study the assembly of the progenitors of today's most massive galaxies





Cantalupo et al. to be submitted

Introduction

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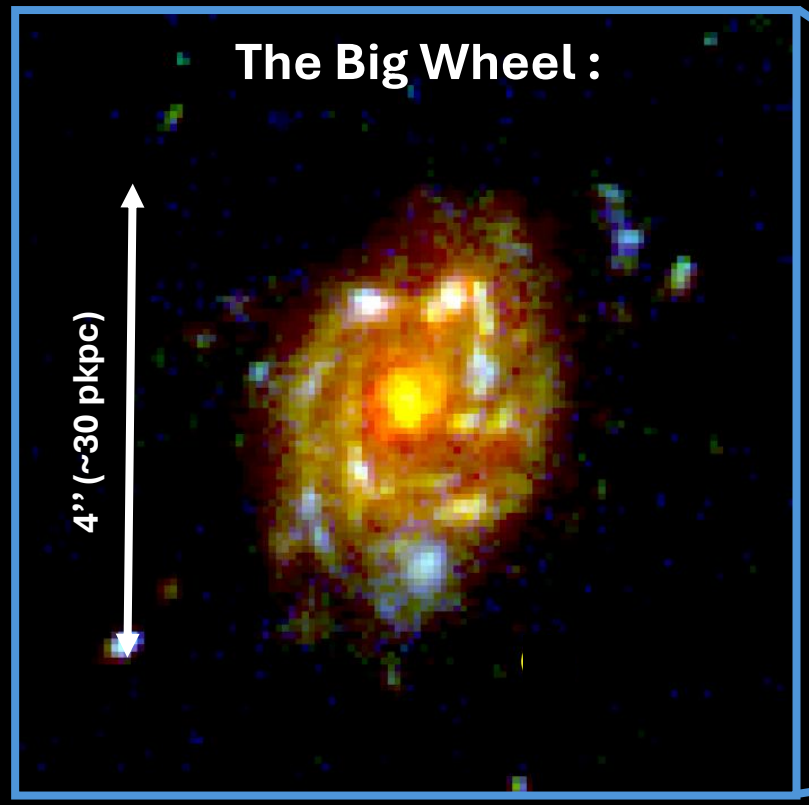
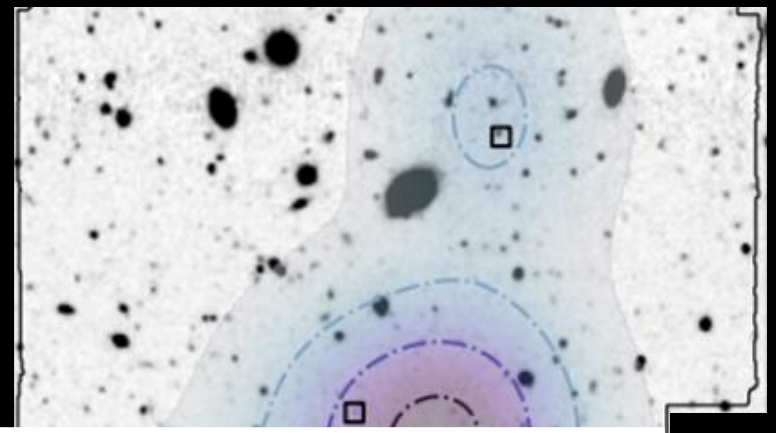
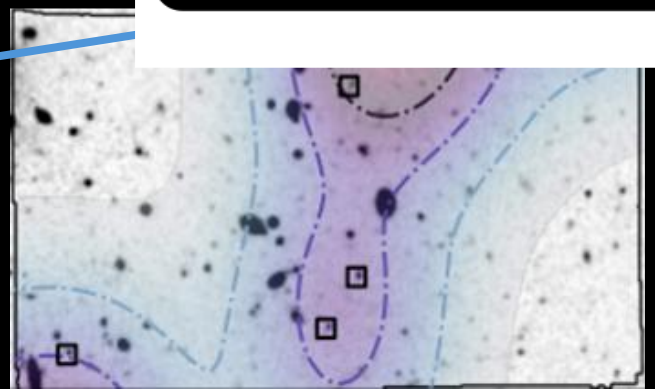
Introduction

The Big Wheel – A giant disk galaxy at z ~ 3.25



JWST reveals a giant spiral-like disk galaxy,
with a physical size of around 30 kpc





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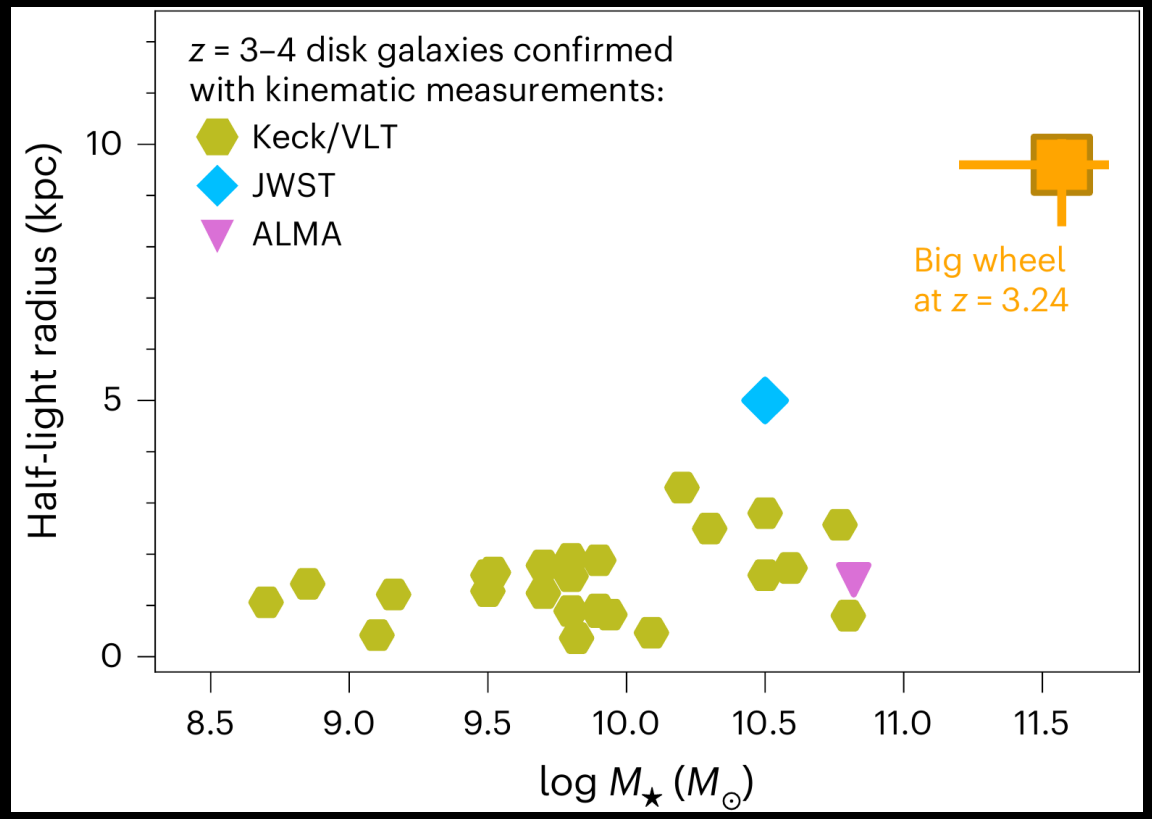
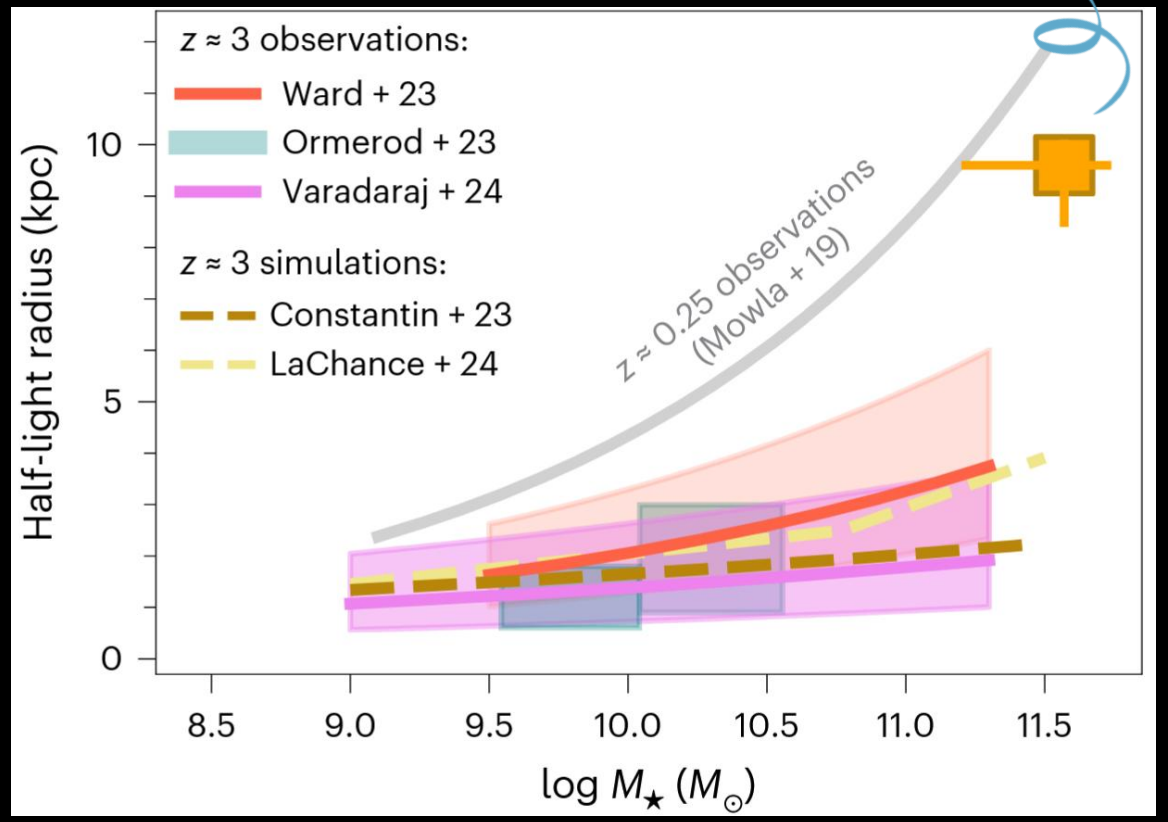
Introduction

The Big Wheel baryonic properties

The Big Wheel is consistent with **local** disk galaxies





Wang et al. 2025

$M_\star = 2.34 \times 10^{11}\ M_\odot$ $R_{\text{half-light}} = 9.6$ kpc $R_{\text{half-mass}} = 6.7$ kpc

Scientific questions

- *How **massive** is the **dark matter halo** of the Big Wheel?*

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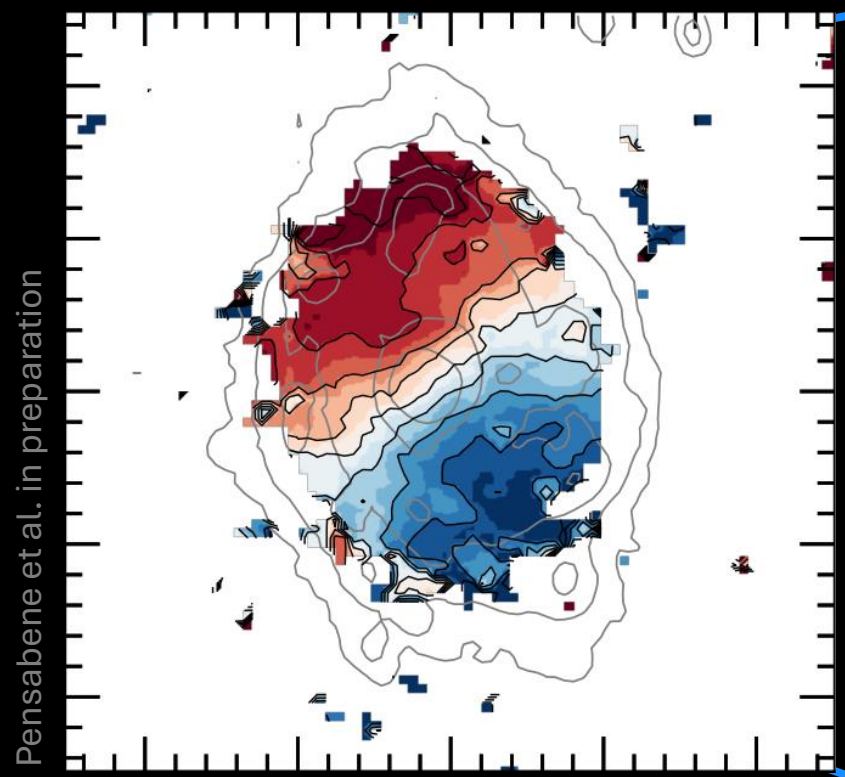
- *Which are the physical processes and events that led to its observed properties?*

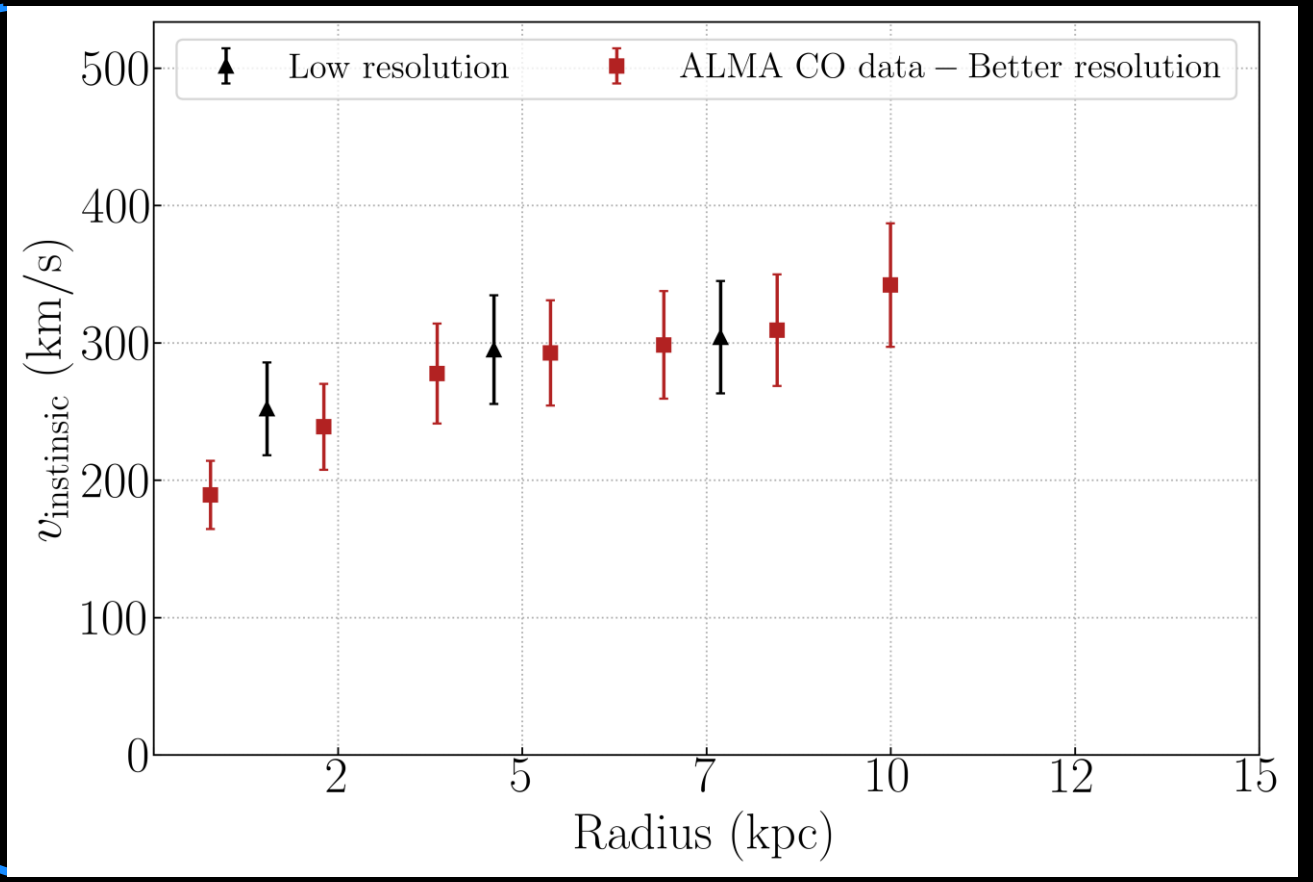
- *Is the disk stable or will it evolve into a different kind of object? What are the present-day counterparts of the Big Wheel?*

Kinematical observations



CO traces the cold gas
↓
reliable for the kinematics

Intrinsic rotation curve with respect to the galaxy inclination



Low-resolution data: 3 points extending up to 7 kpc
High-resolution data: 7 point extending up to 10 kpc

Methods: get M_{DM} through a Bayesian analysis

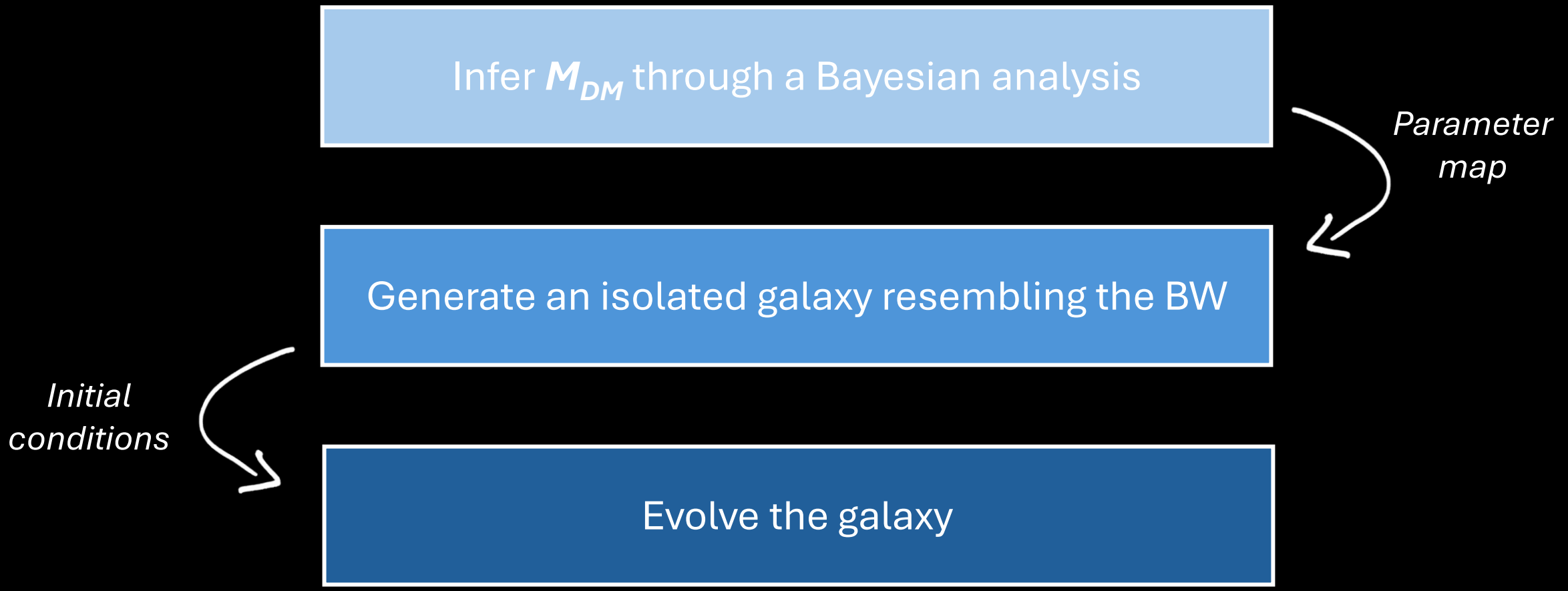
The rotation curve from ALMA CO is used as starting point for the mass decomposition

The set of priors used for the dynamical model is the following:

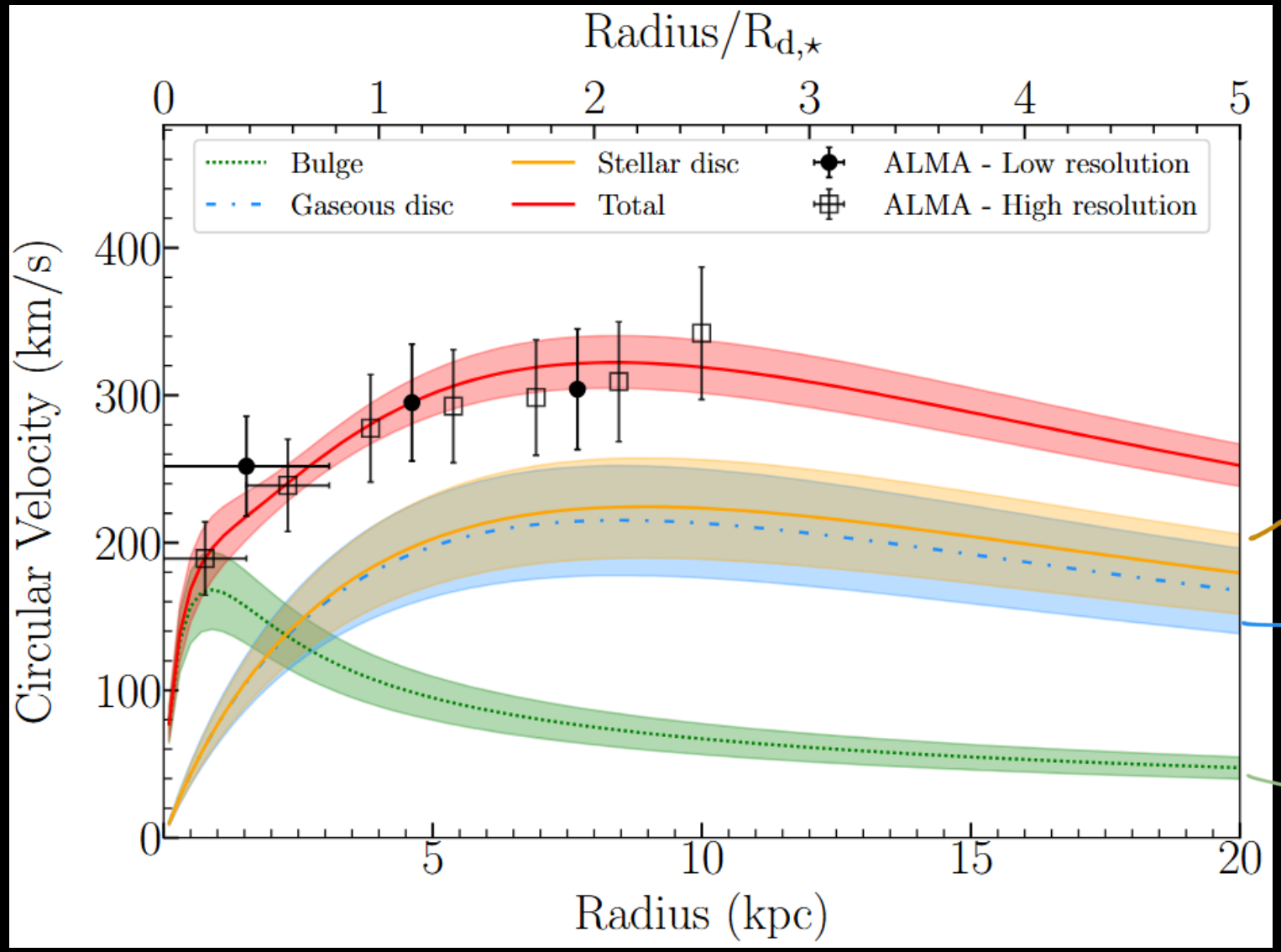
Parameter	Prior distribution	Range
$\log(f_{\rm bar})$	uniform	$[-4,\ \log(f_{\rm bar,c})]$ [a]
$\log(M_\star / M_\odot)$	gaussian	$11.37^{+0.20}_{-0.20}$
$\log(f_{\rm bulge})$	uniform	$[10^{-3},\ 0.18]$
$\alpha_{\rm CO}(M_\odot/{\rm K\,km\,s^{-1}\,pc^{-2}})$	uniform	[0.8, 4.3]
r_{41}	uniform	[0.2, 1]
$R_{d,\star}$ (kpc) [b]	lognormal	$3.75^{+0.48}_{-0.36}$
$R_{d,\rm gas}$ (kpc) [b]	lognormal	$3.75^{+0.48}_{-0.36}$
$R_{s,\rm bulge}$ (kpc)	uniform	[0.1, 1]

The missing parameters (like the **DM halo mass**) are determined through the kinematics.

Methods: characterising the Big Wheel



Is the baryonic mass sufficient to explain the v_{circ}?



We performed a dynamical model **without** DM halo component.

Stellar disc

$M_{\star,\,disk} = 1.4 \times 10^{11}\ M_{\odot}$

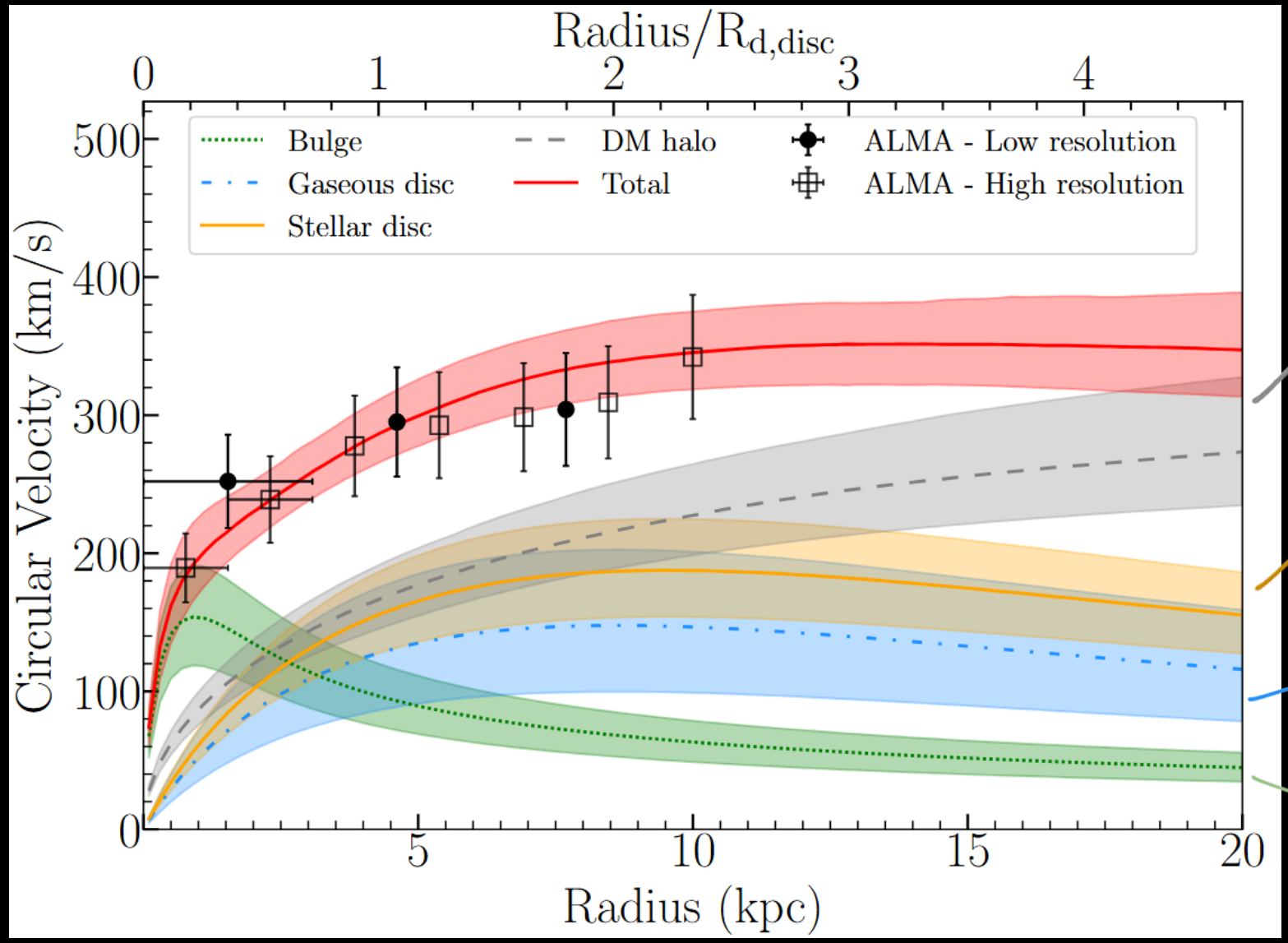
Gaseous disk

$M_{gas} = 8.1 \times 10^{10}\ M_{\odot}$

Stellar bulge

$M_{bulge} = 10^{10}\ M_{\odot}$

Results: get M_{DM} through a Bayesian analysis



The dynamical model with the DM halo component.

Dark matter halo

$M_{DM} = 1.3 \times 10^{12}\ M_\odot$

Stellar disc

$M_{\star,\,disk} = 9.1 \times 10^{10}\ M_\odot$

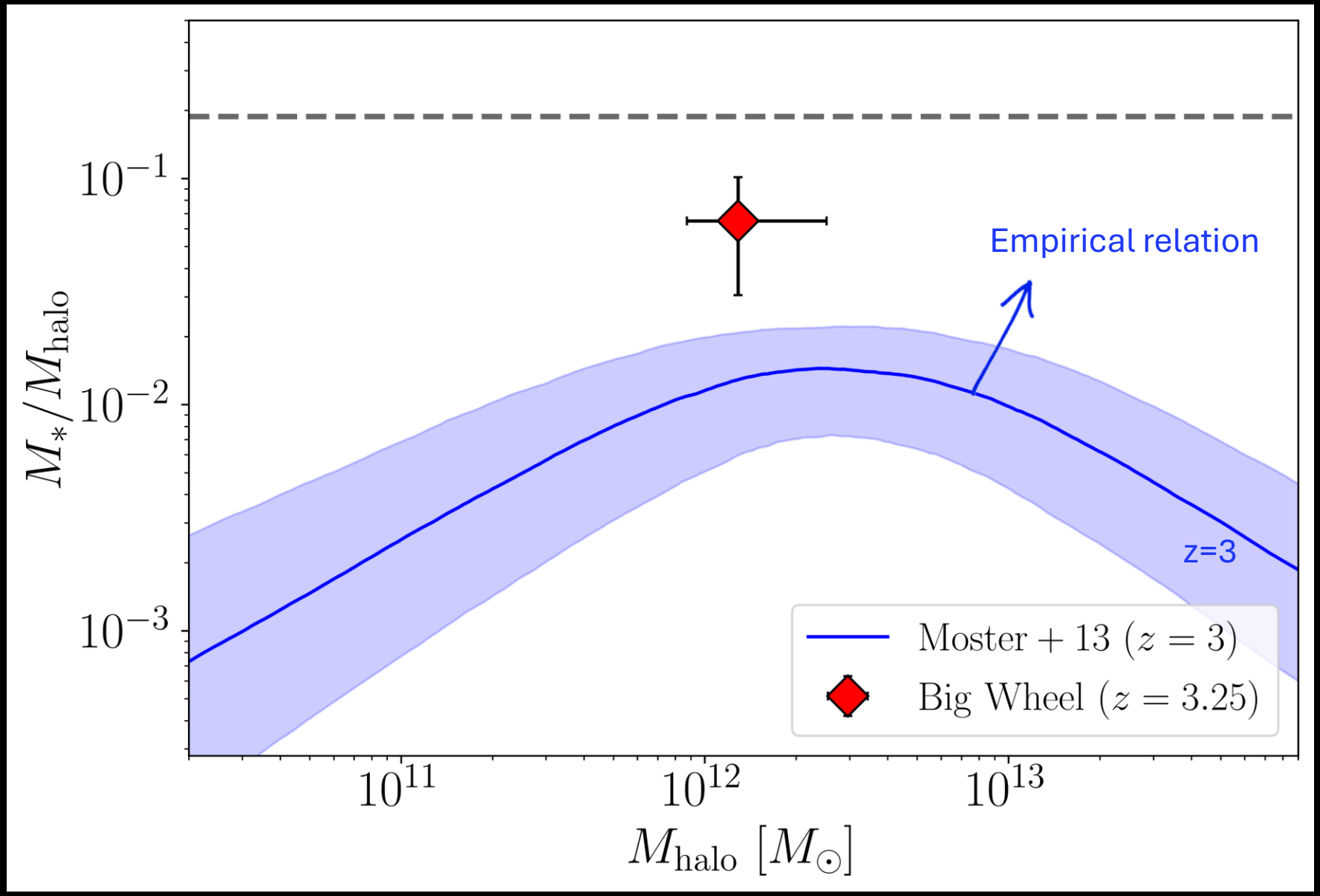
Gaseous disk

$M_{gas} = 5.8 \times 10^{10}\ M_\odot$

Stellar bulge

$M_{bul} = 8.5 \times 10^{9}\ M_\odot$

Results: stellar-to-halo-mass ratio



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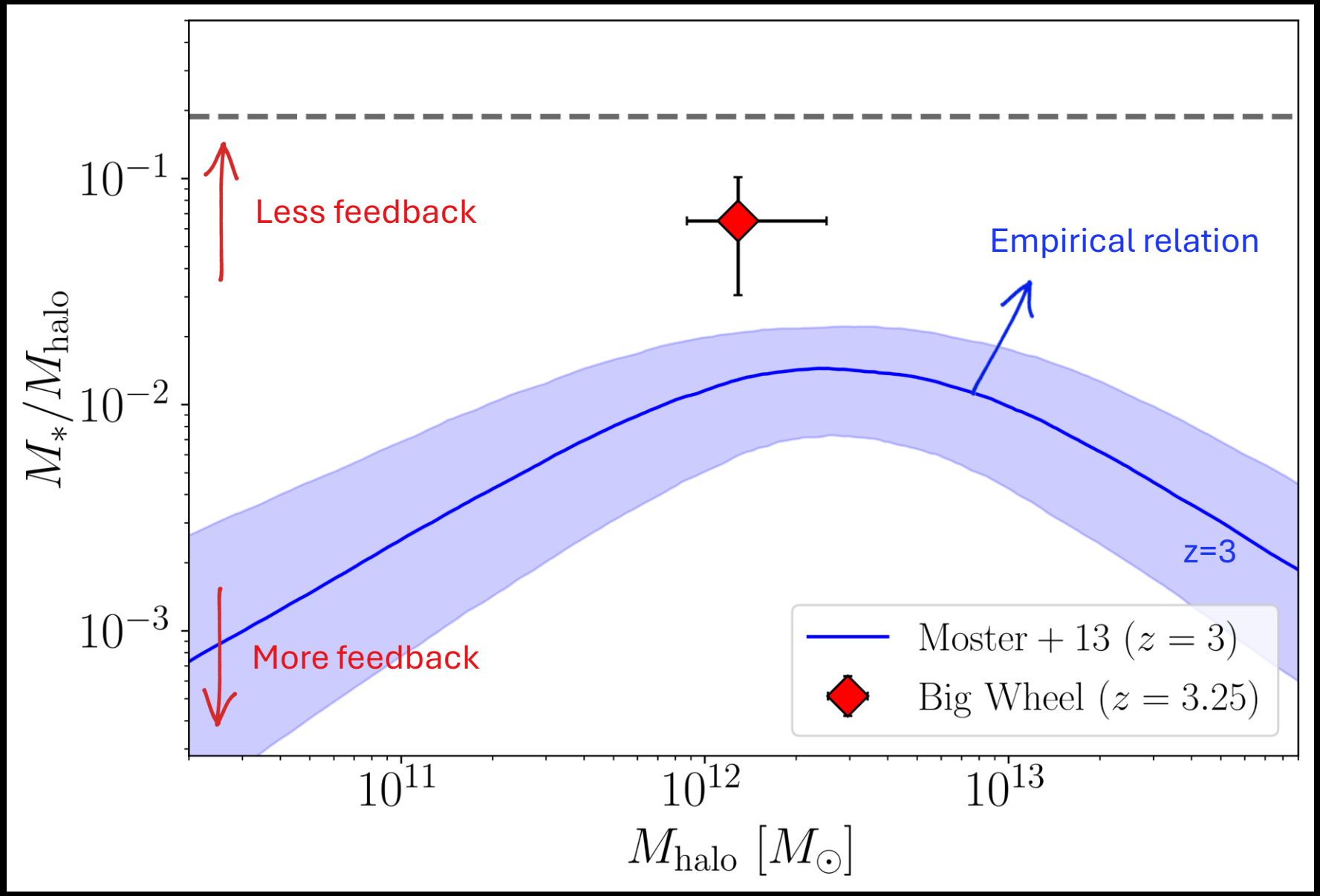

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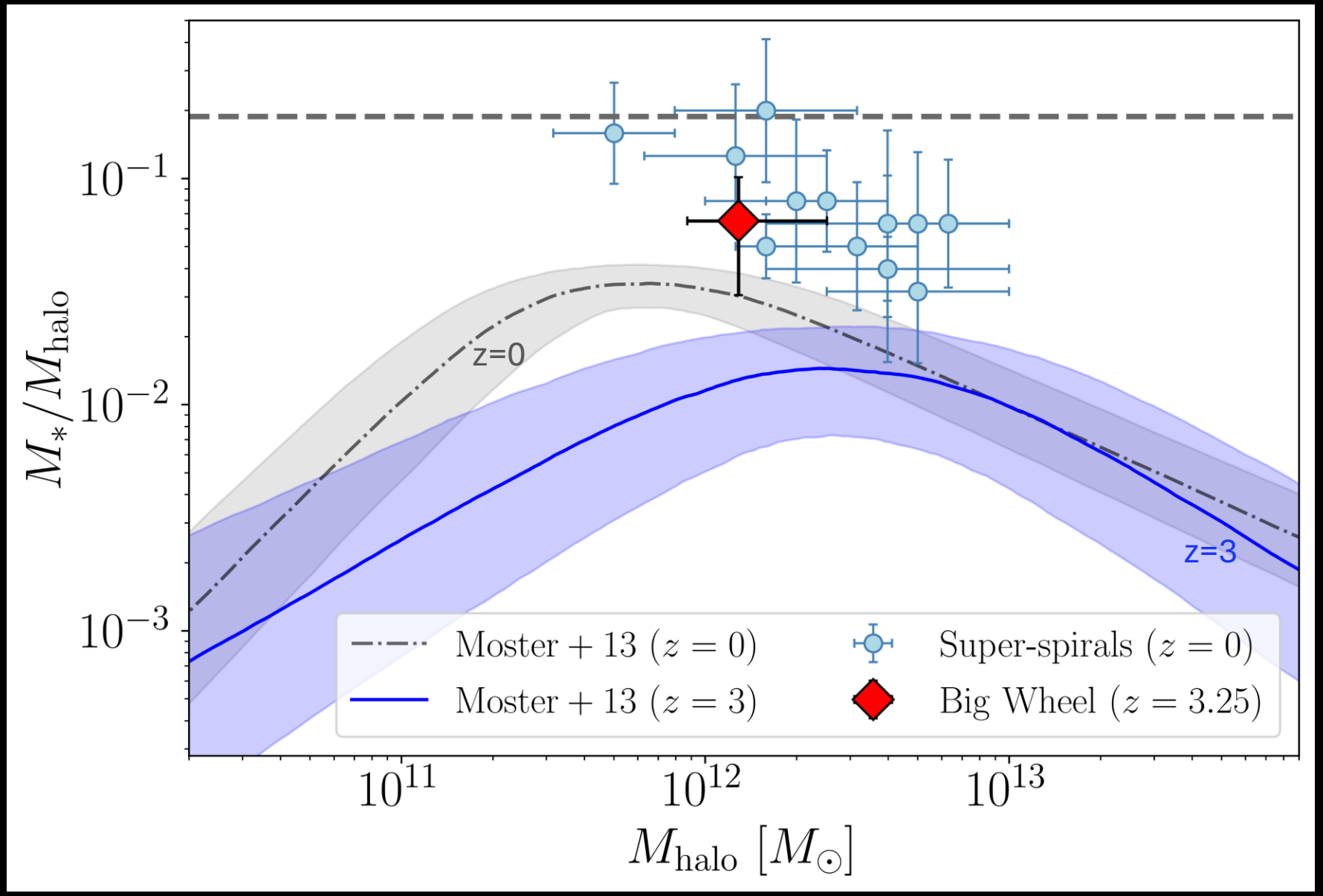

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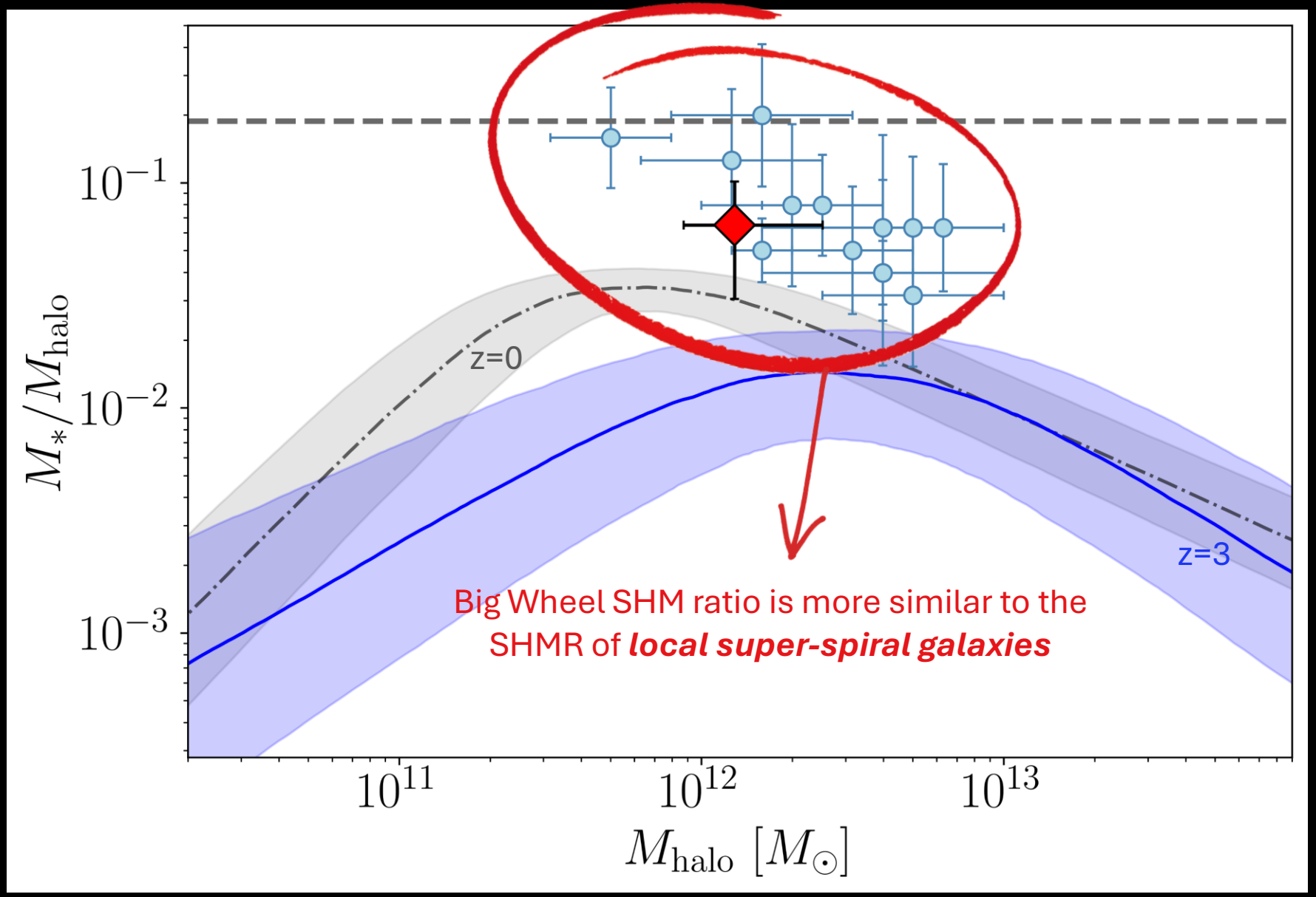
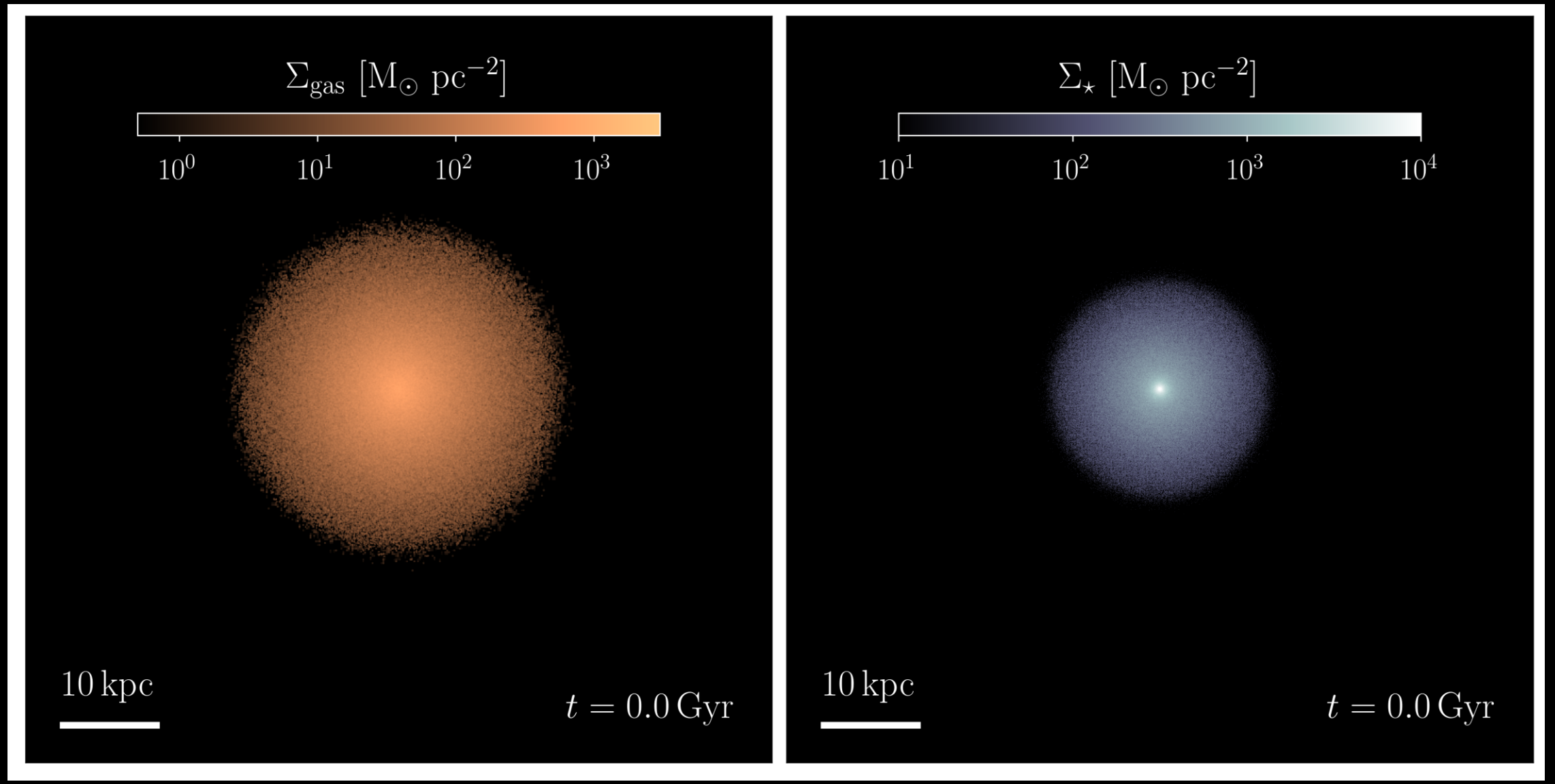


Results: global stability of the galaxy



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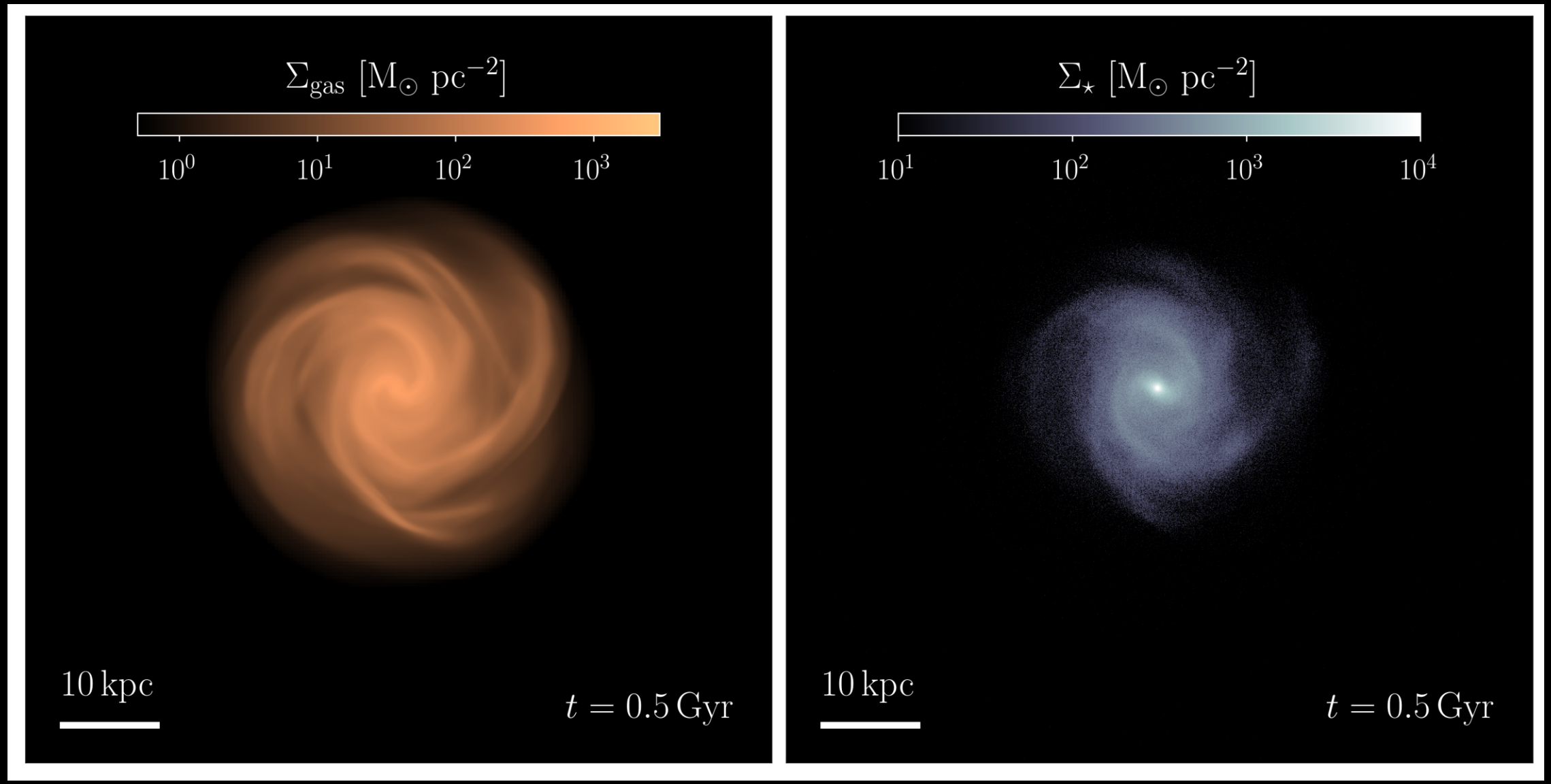

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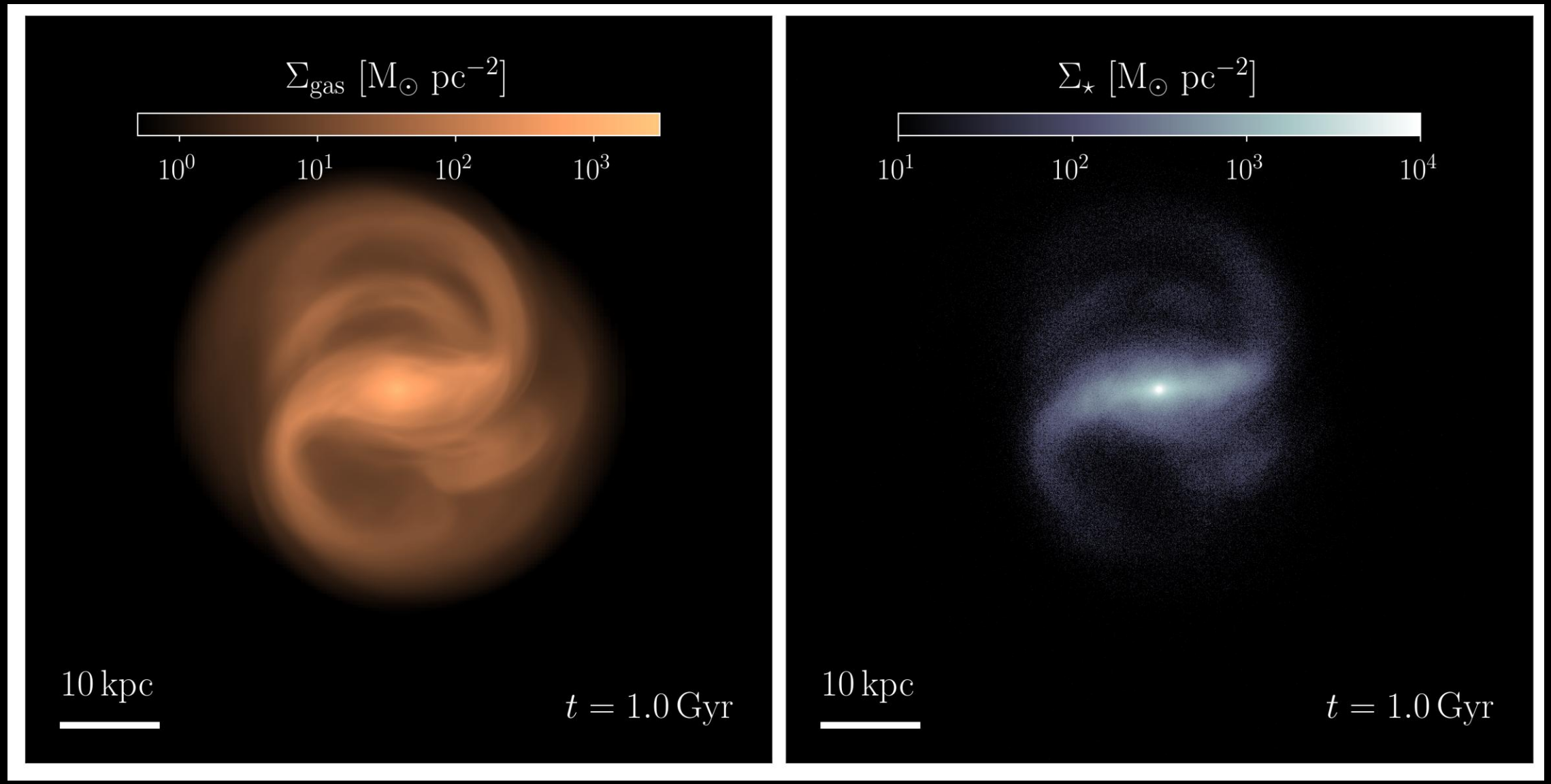

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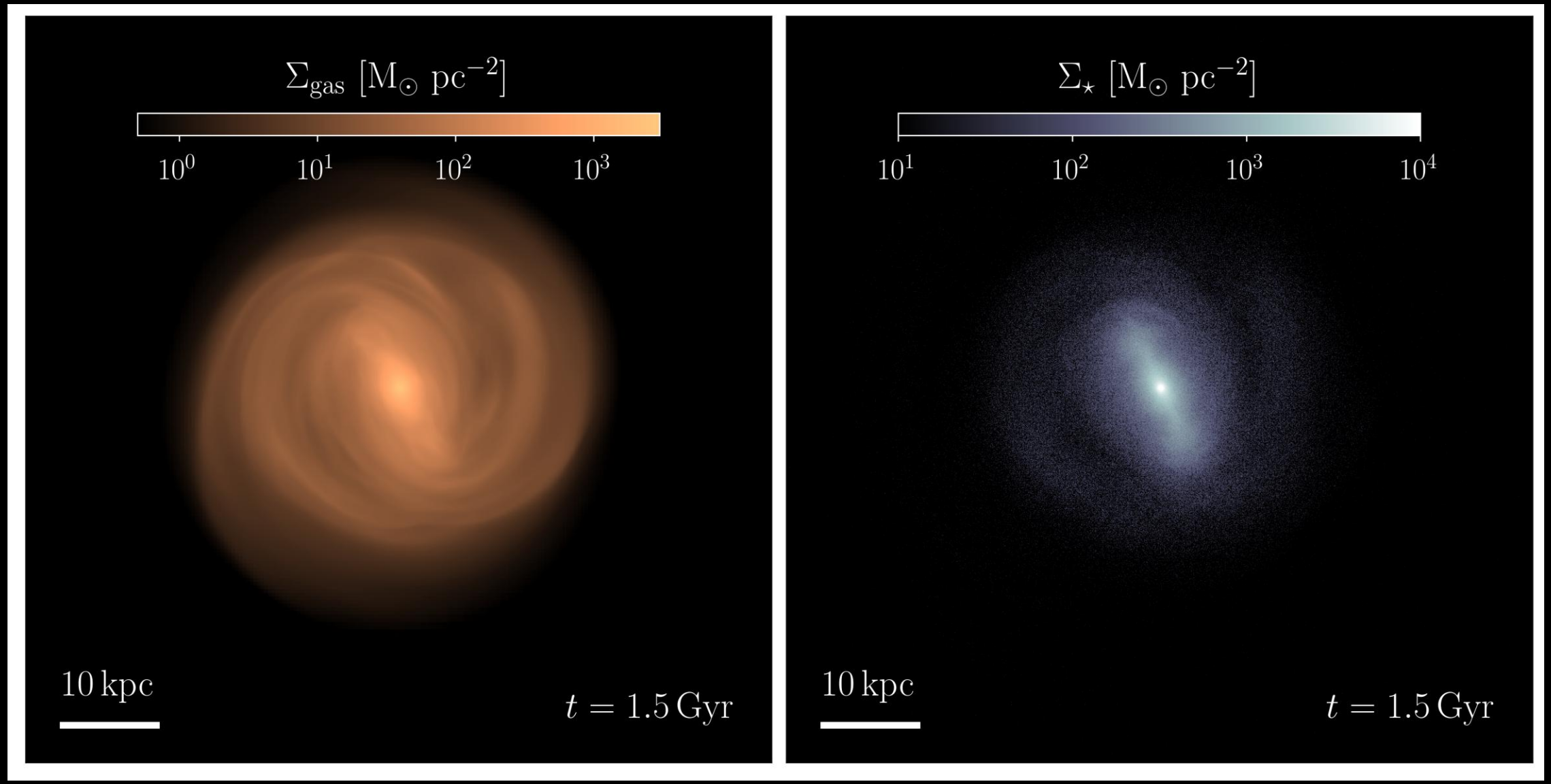

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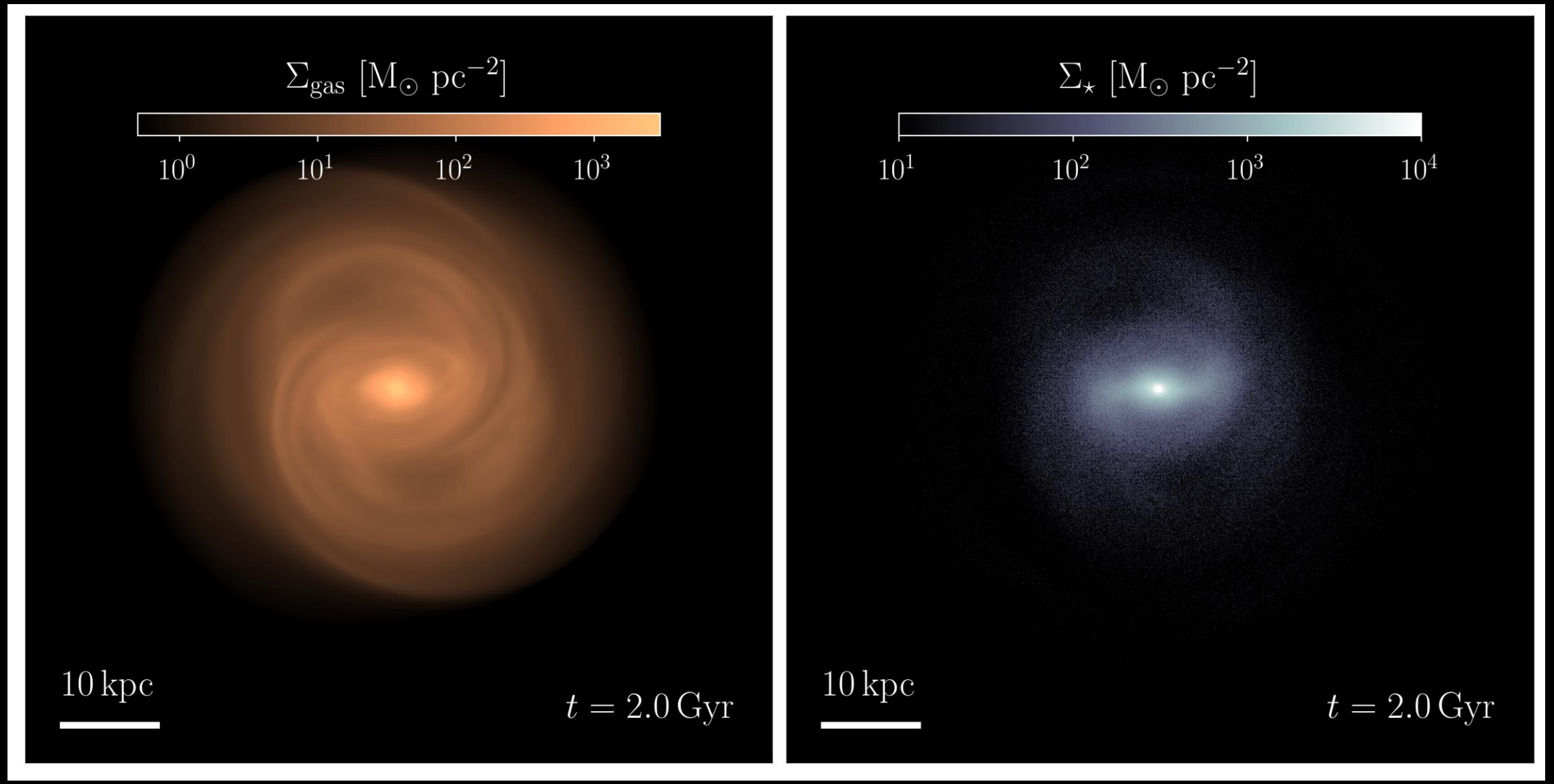

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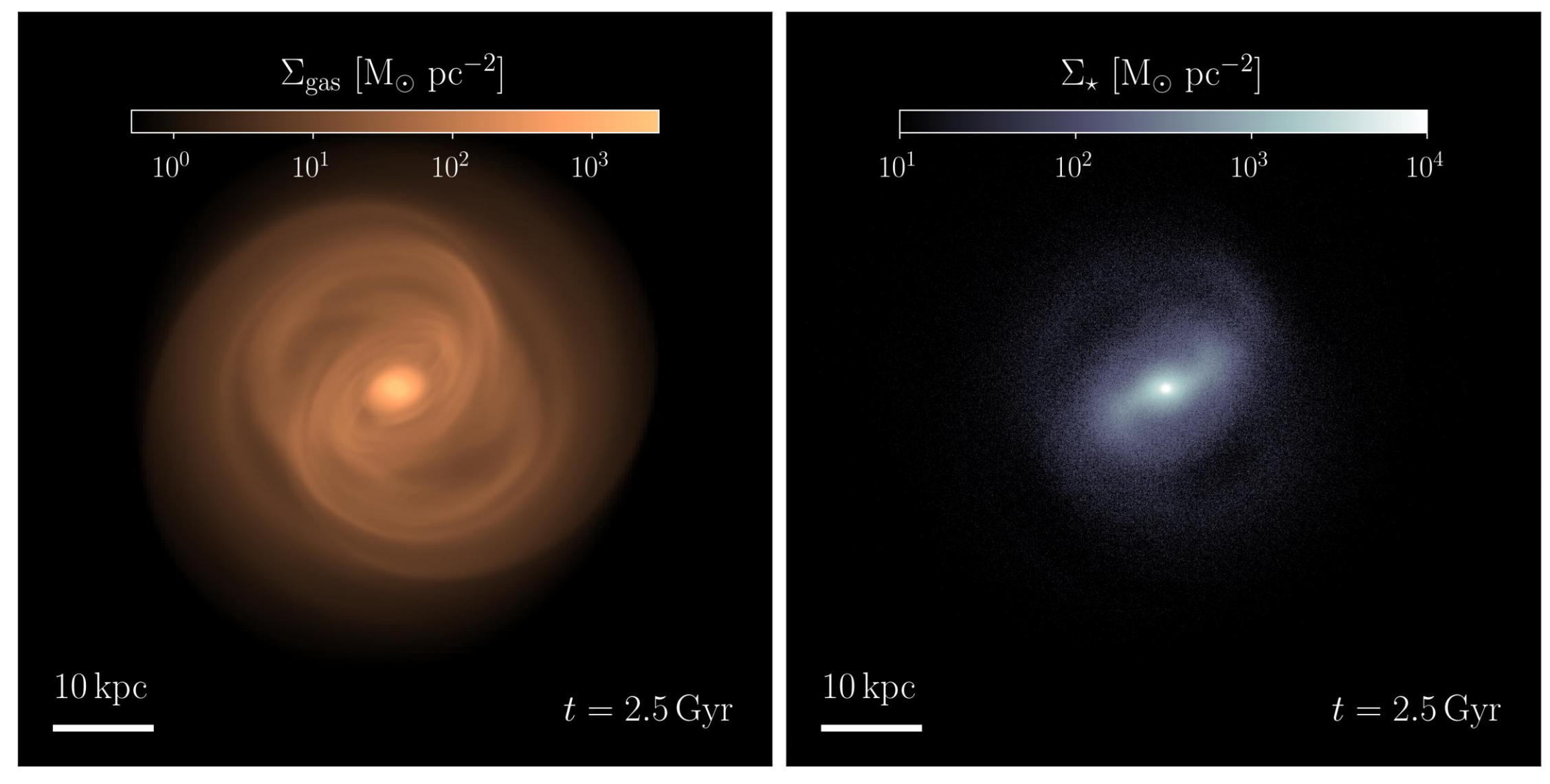

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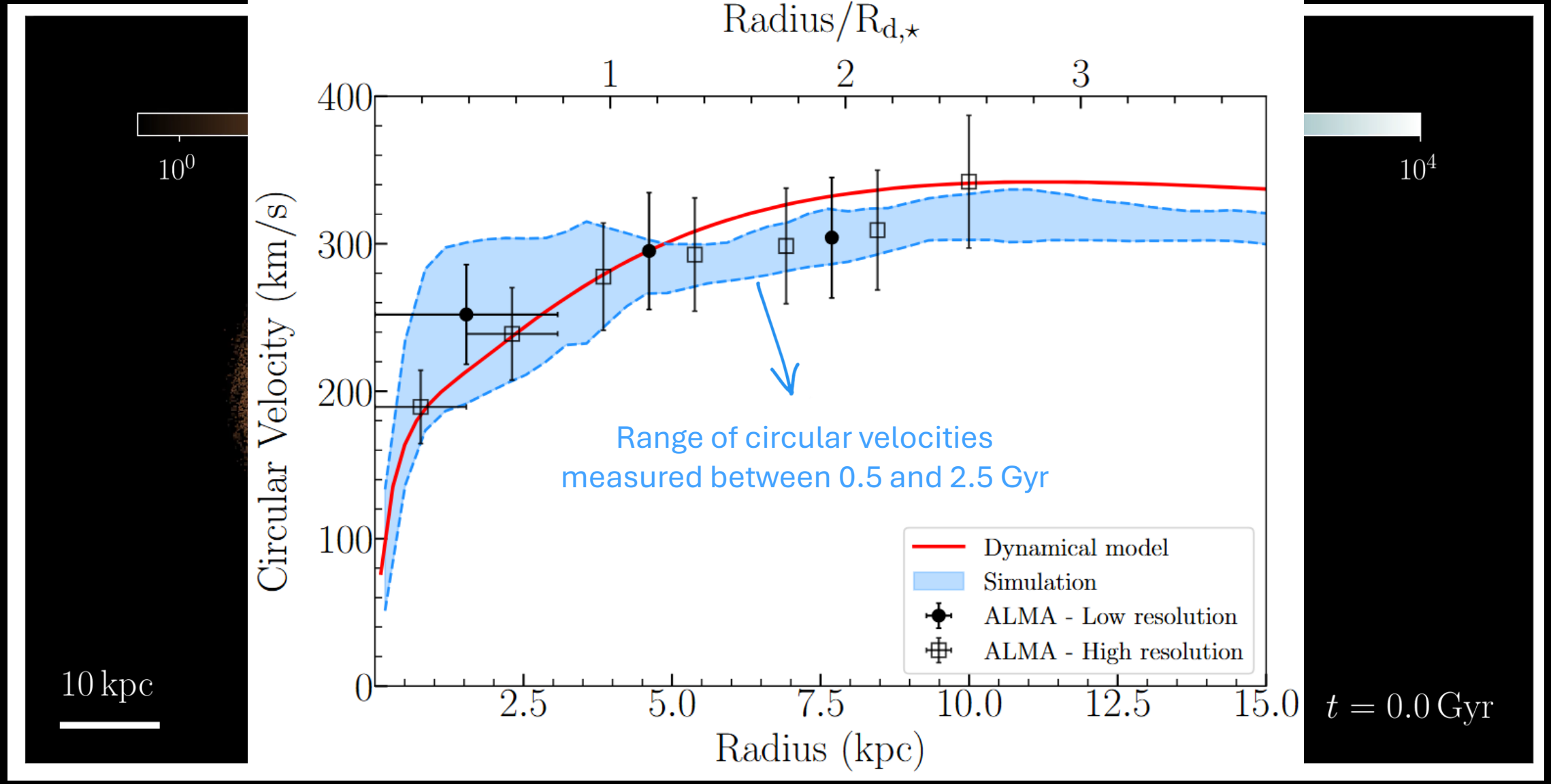

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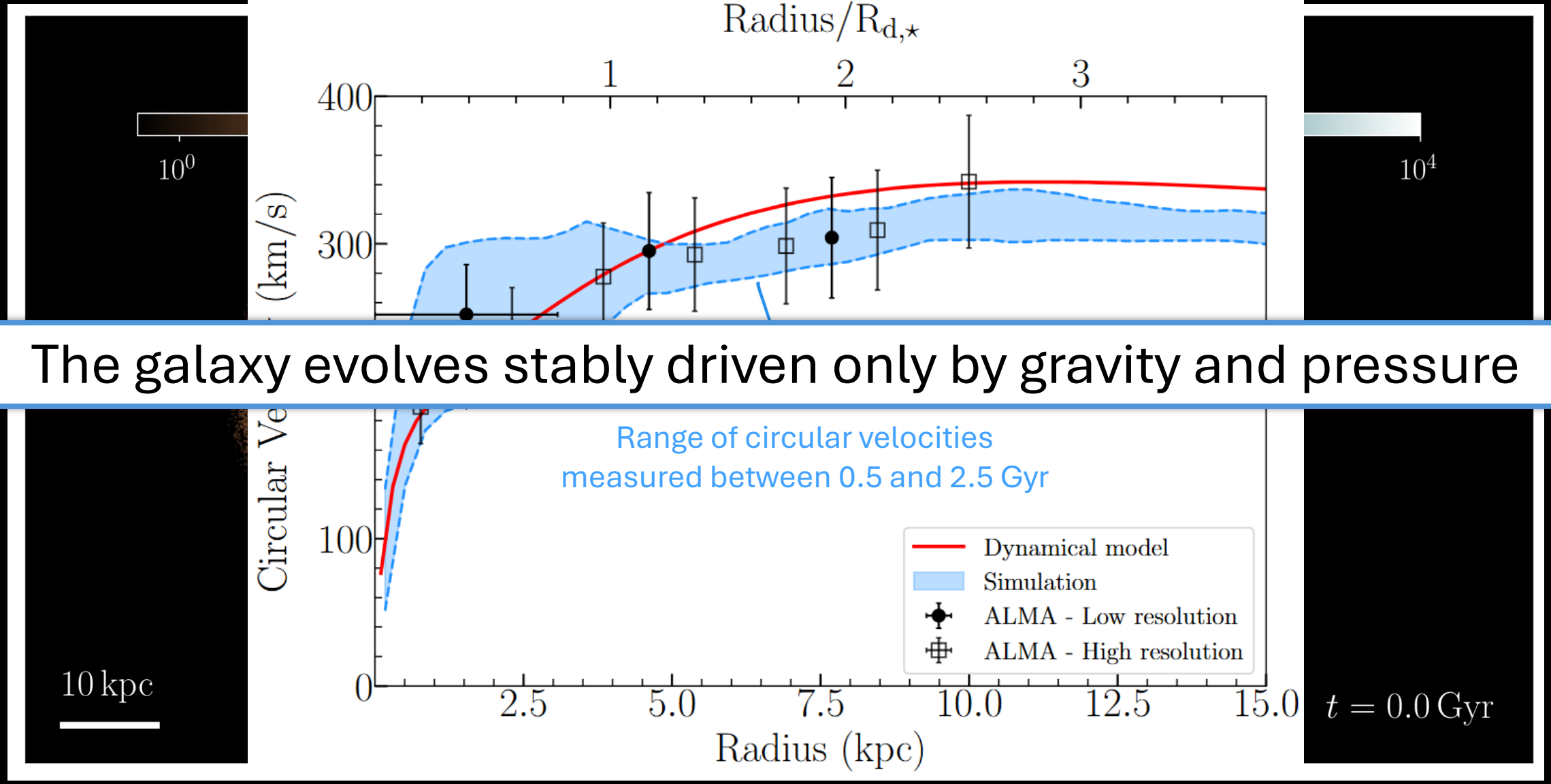
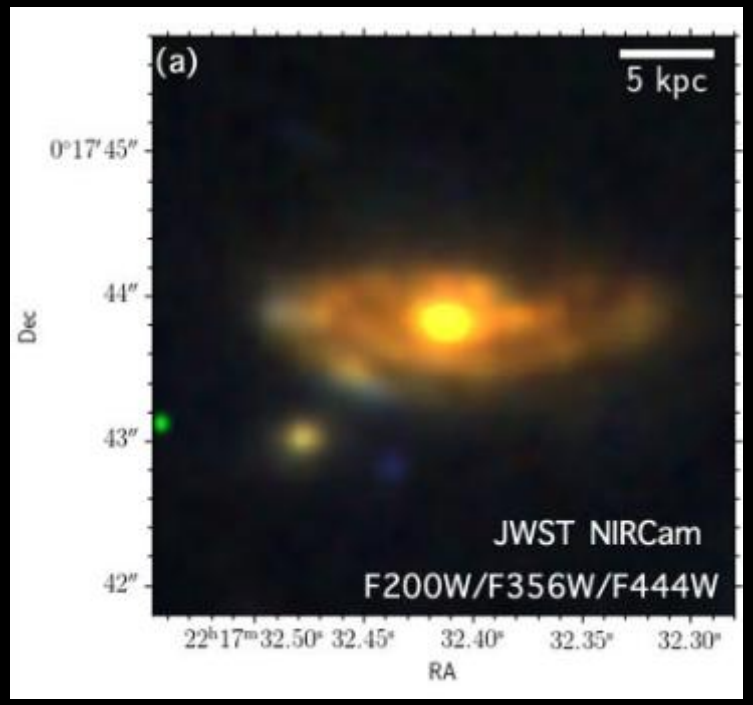


The galaxy evolves stably driven only by gravity and pressure

Is the Big Wheel alone?

A giant barred spiral starburst galaxy in the z = 3.1 SSA22 protocluster core



Umehata+ 2025

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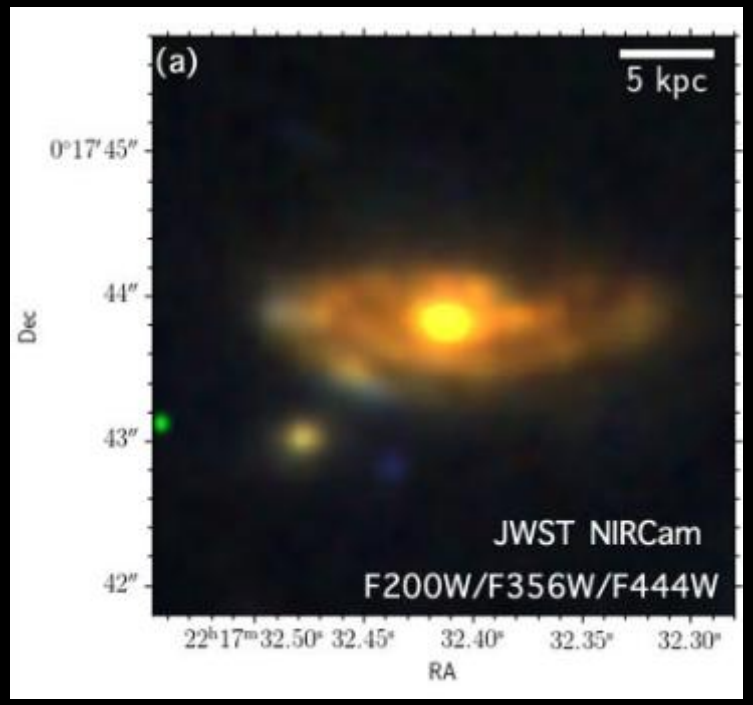

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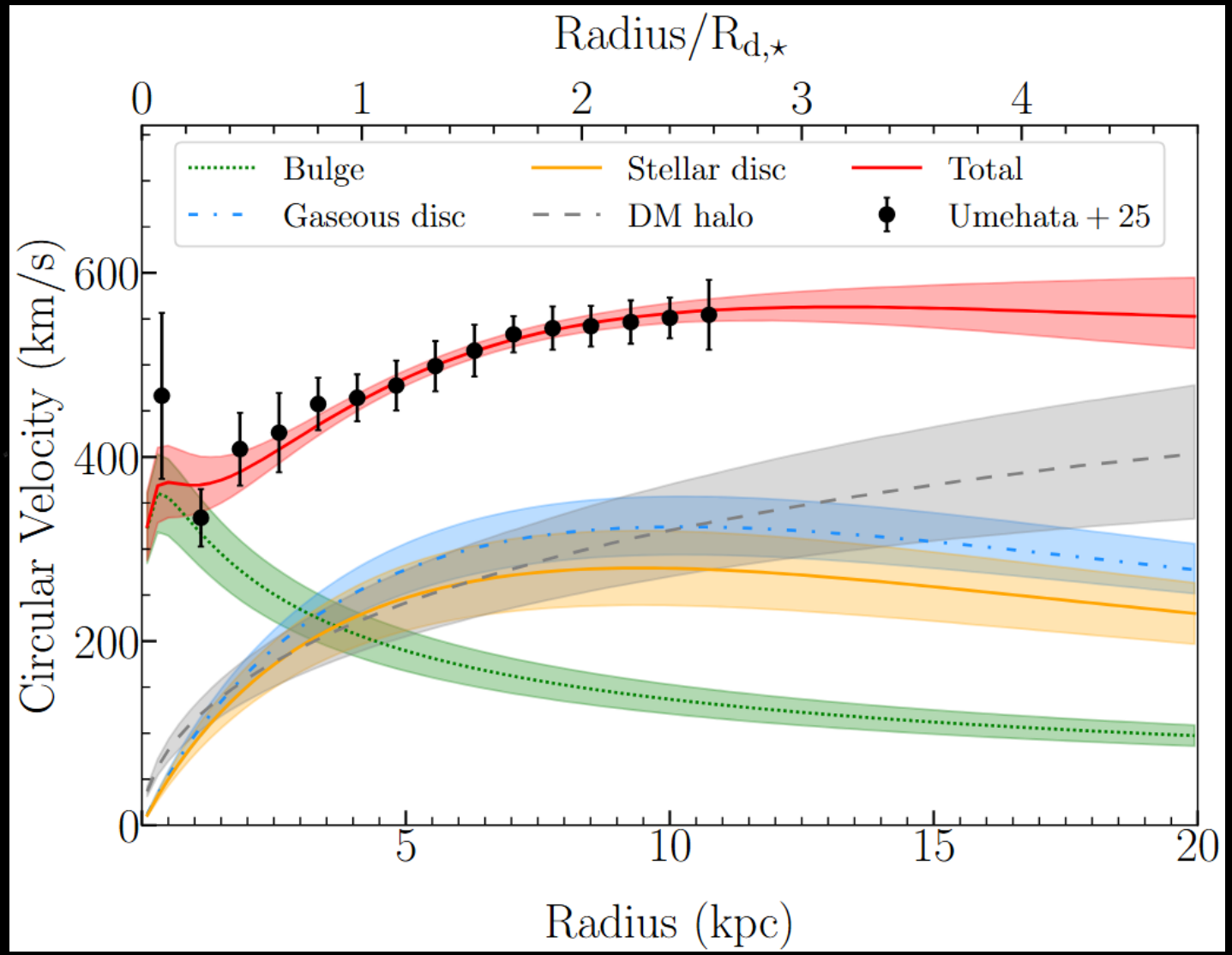

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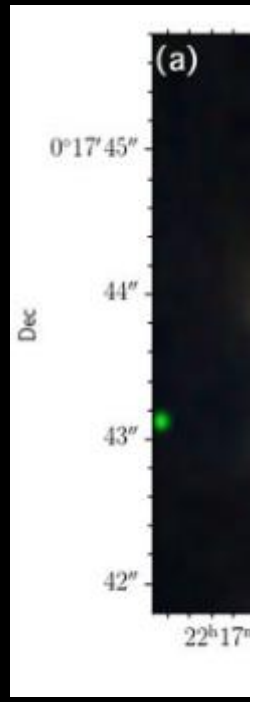

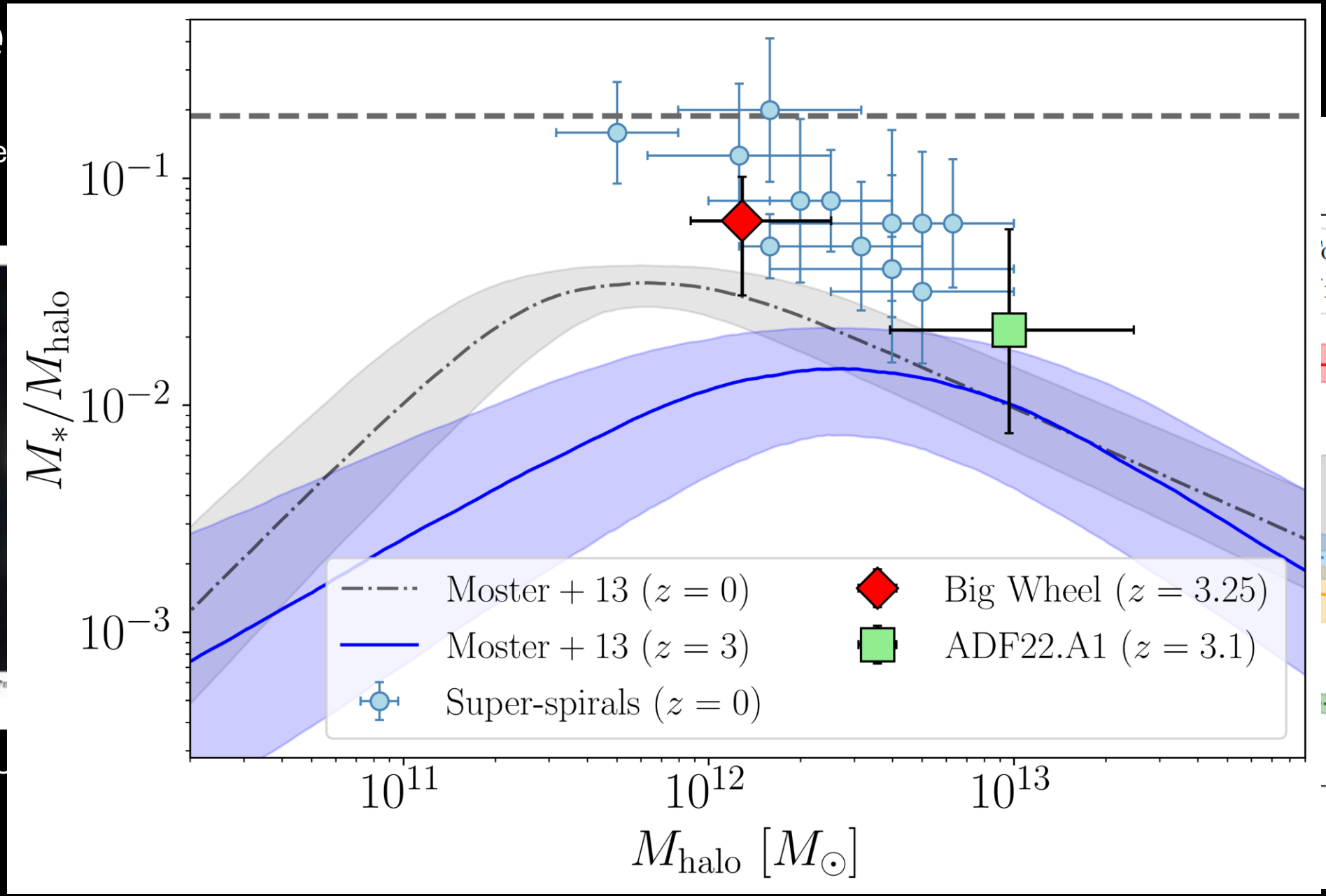

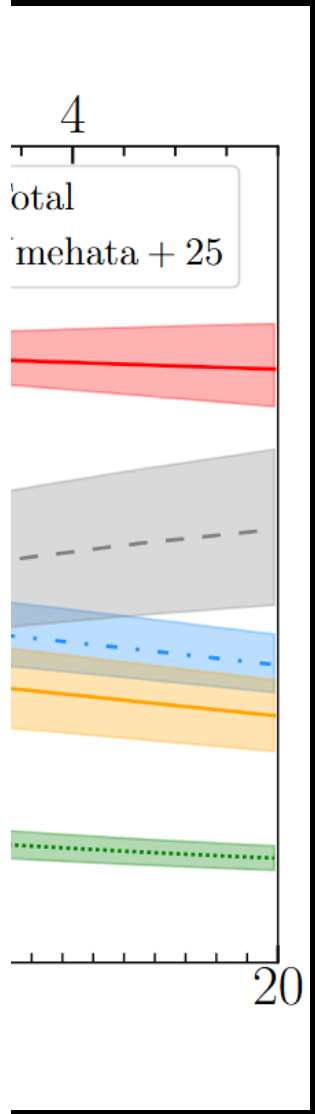

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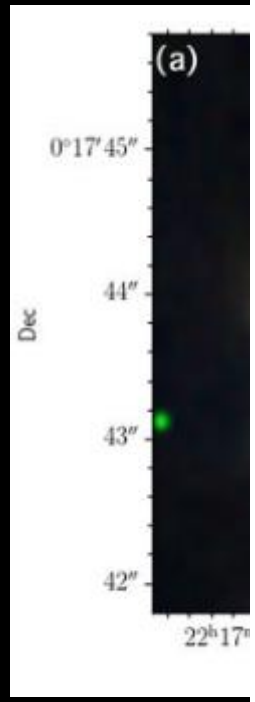

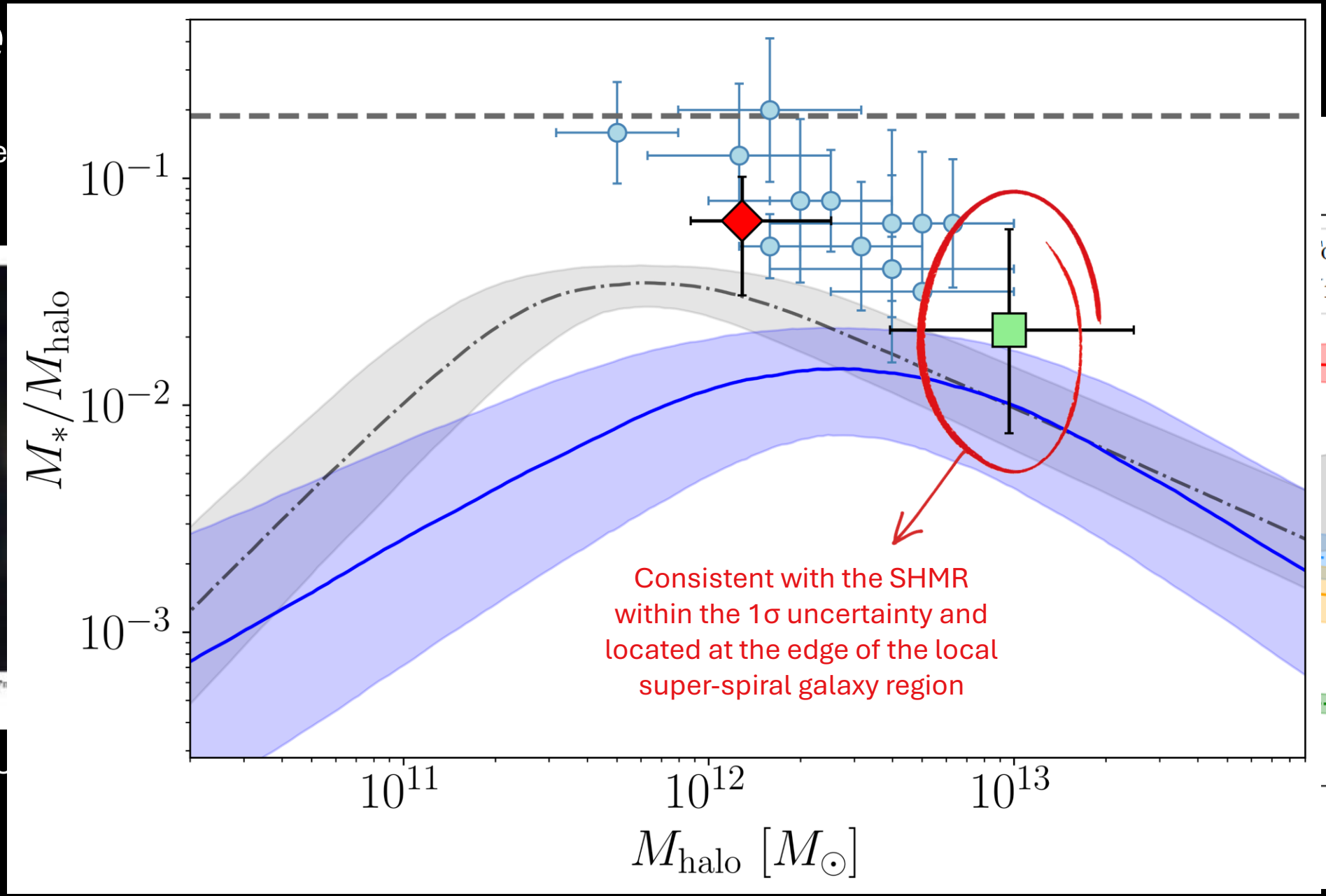

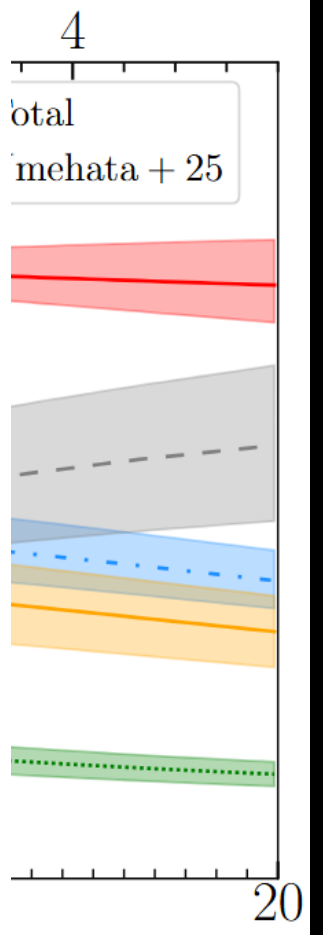

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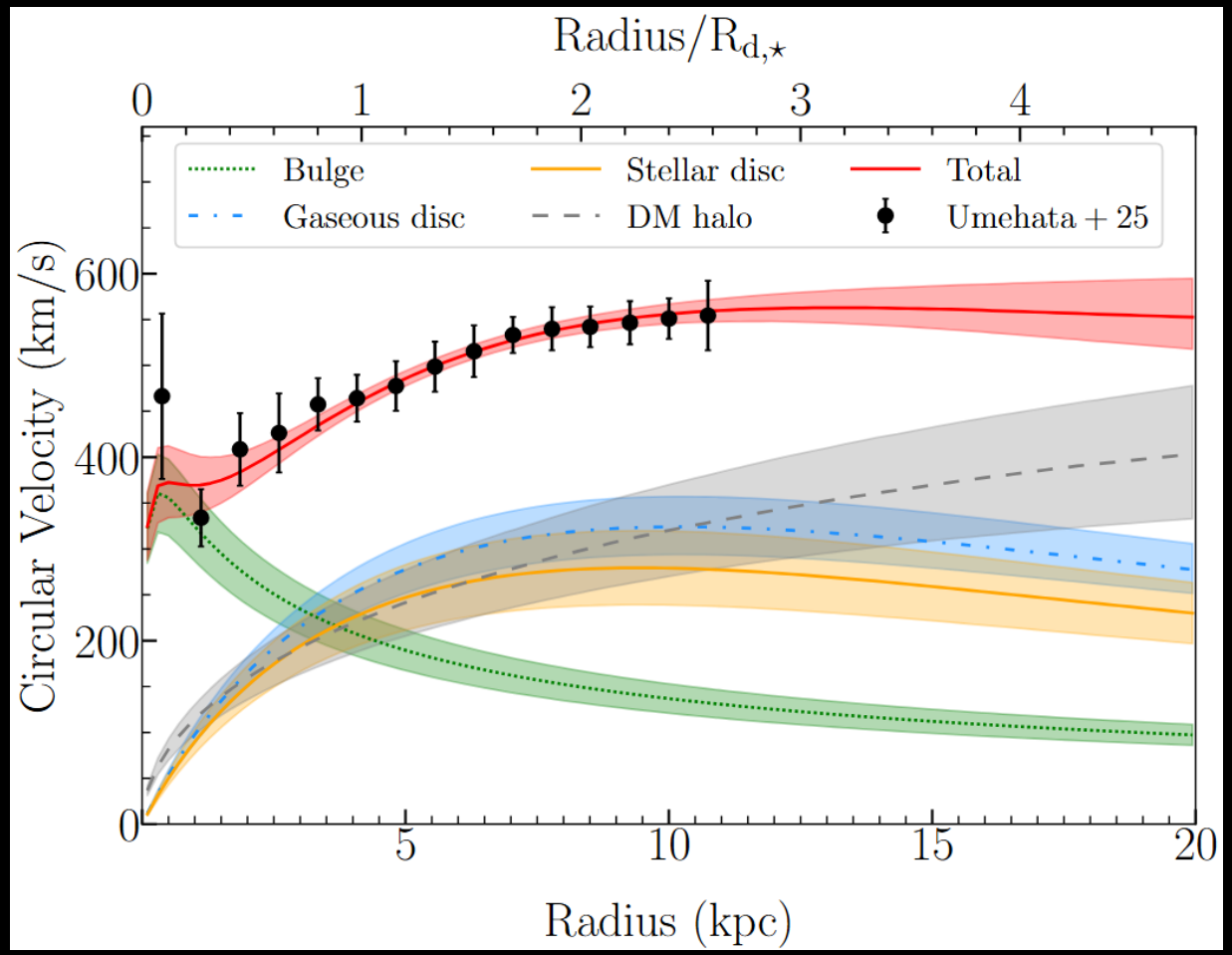
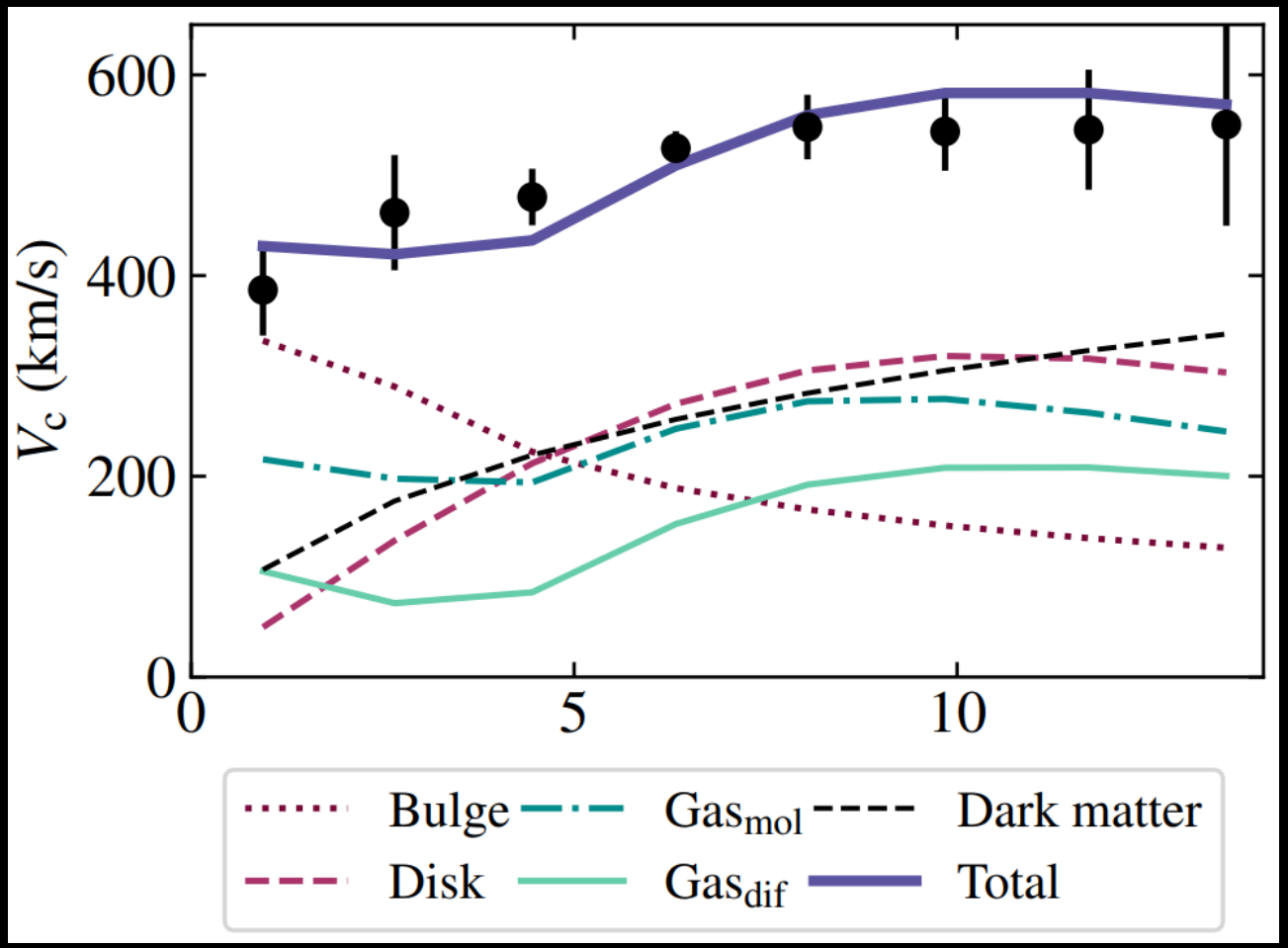


Our dynamical model based on the kinematical model in Umehata et al. 2025



Dynamical model by Rizzo et al. 2026 relying on a different kinematic derivation.

Implications

Big Wheel shares similar properties with local super-spiral galaxies: **SHM ratio** and **half-mass radius**

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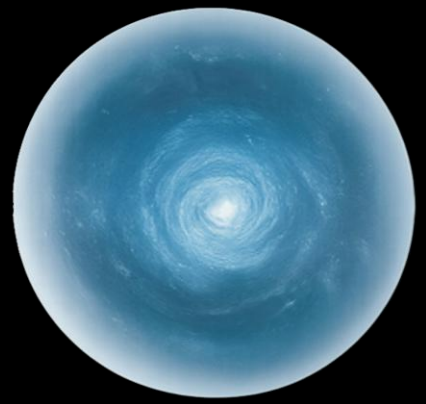
DM halo



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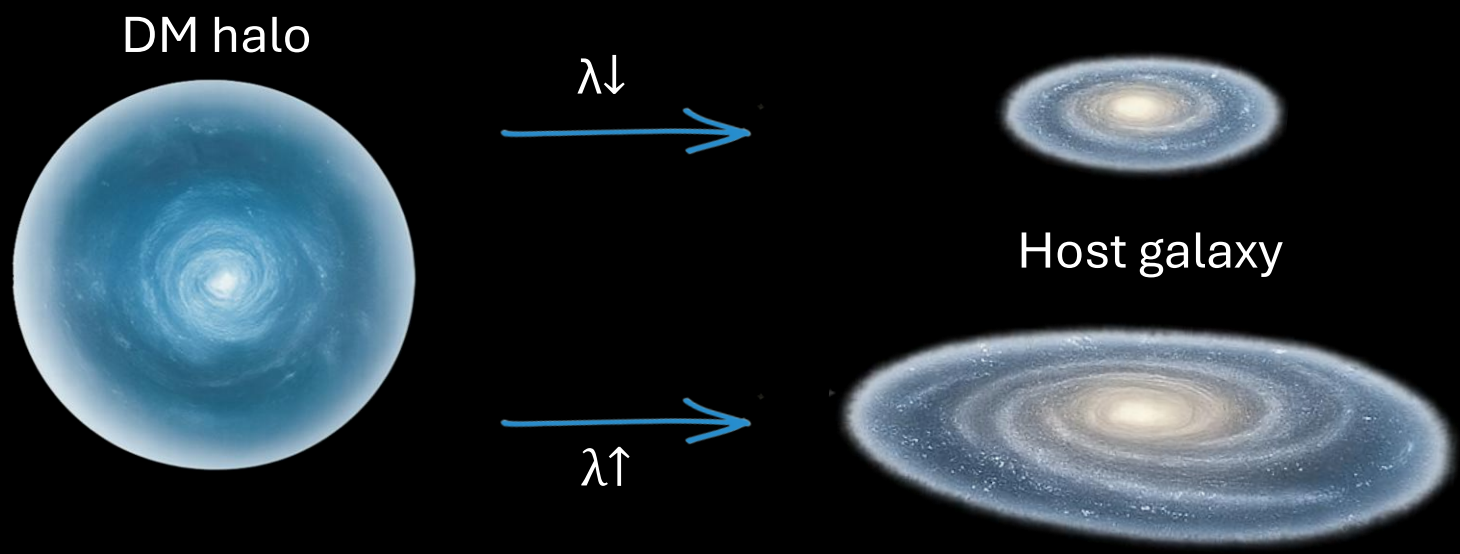

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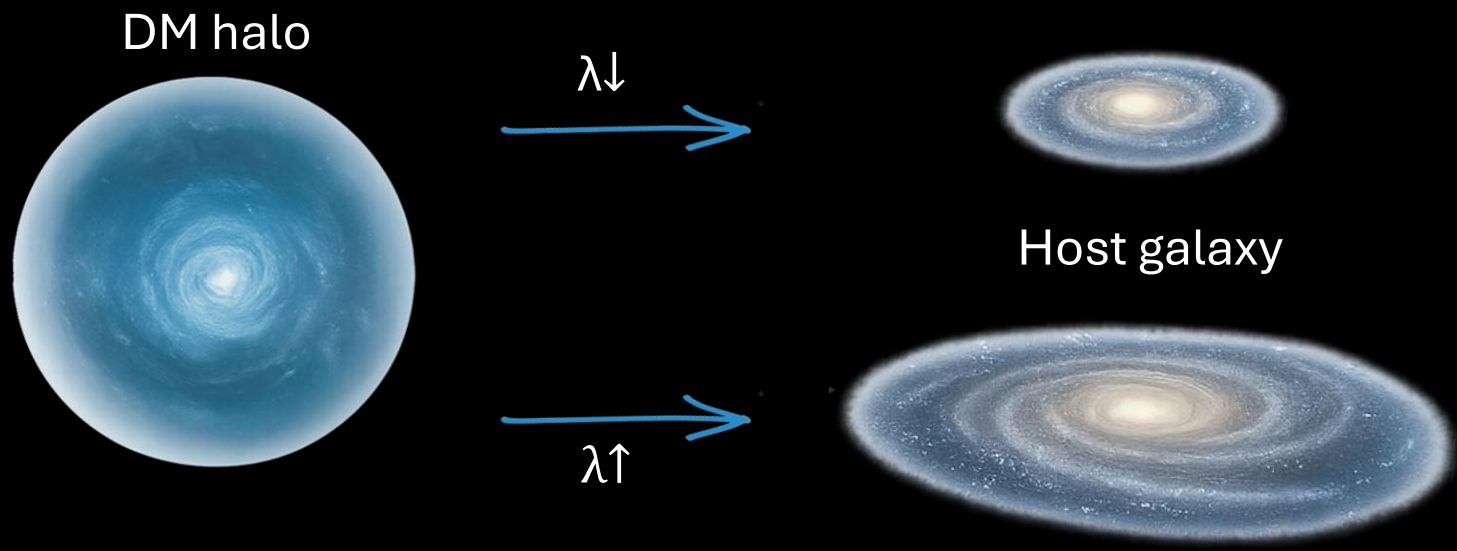
= 1

Mo et al. 1998;
Somerville & Primack 1999;
Cole et al. 2000

= 0.6

Dutton & van den Bosh 2012



Our estimates for the λ of the Big Wheel are ~**2-4 times** the expected value from N-body simulations.

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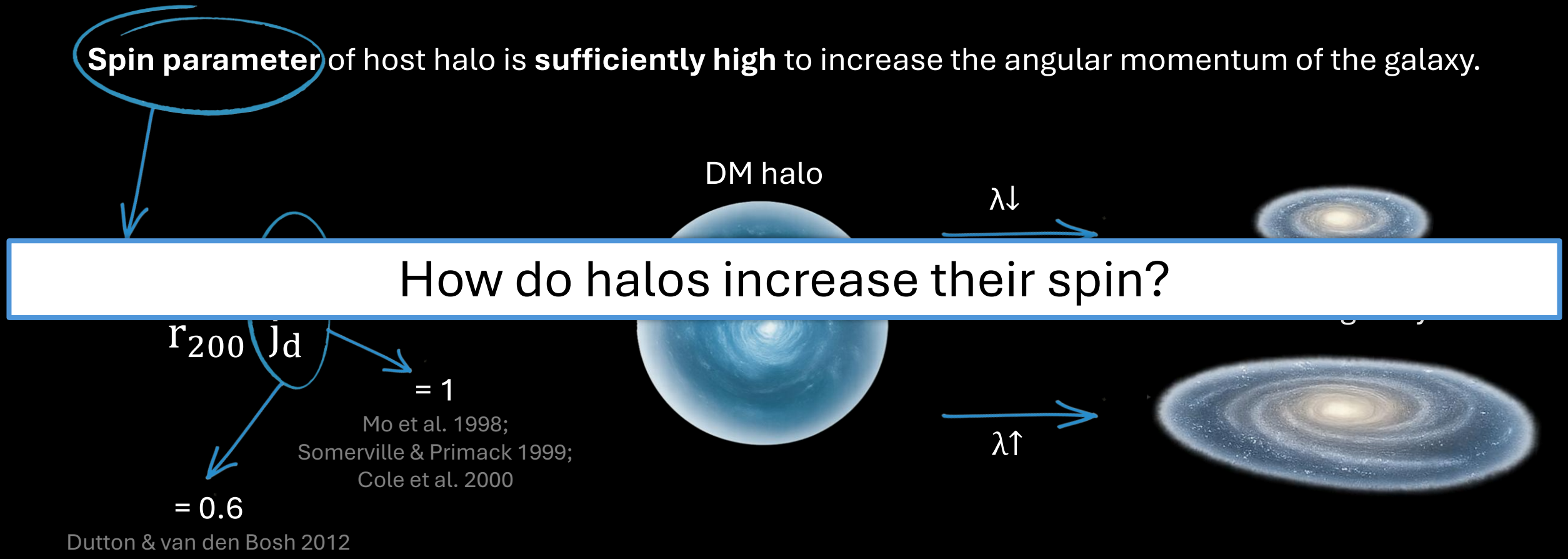

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Conclusions

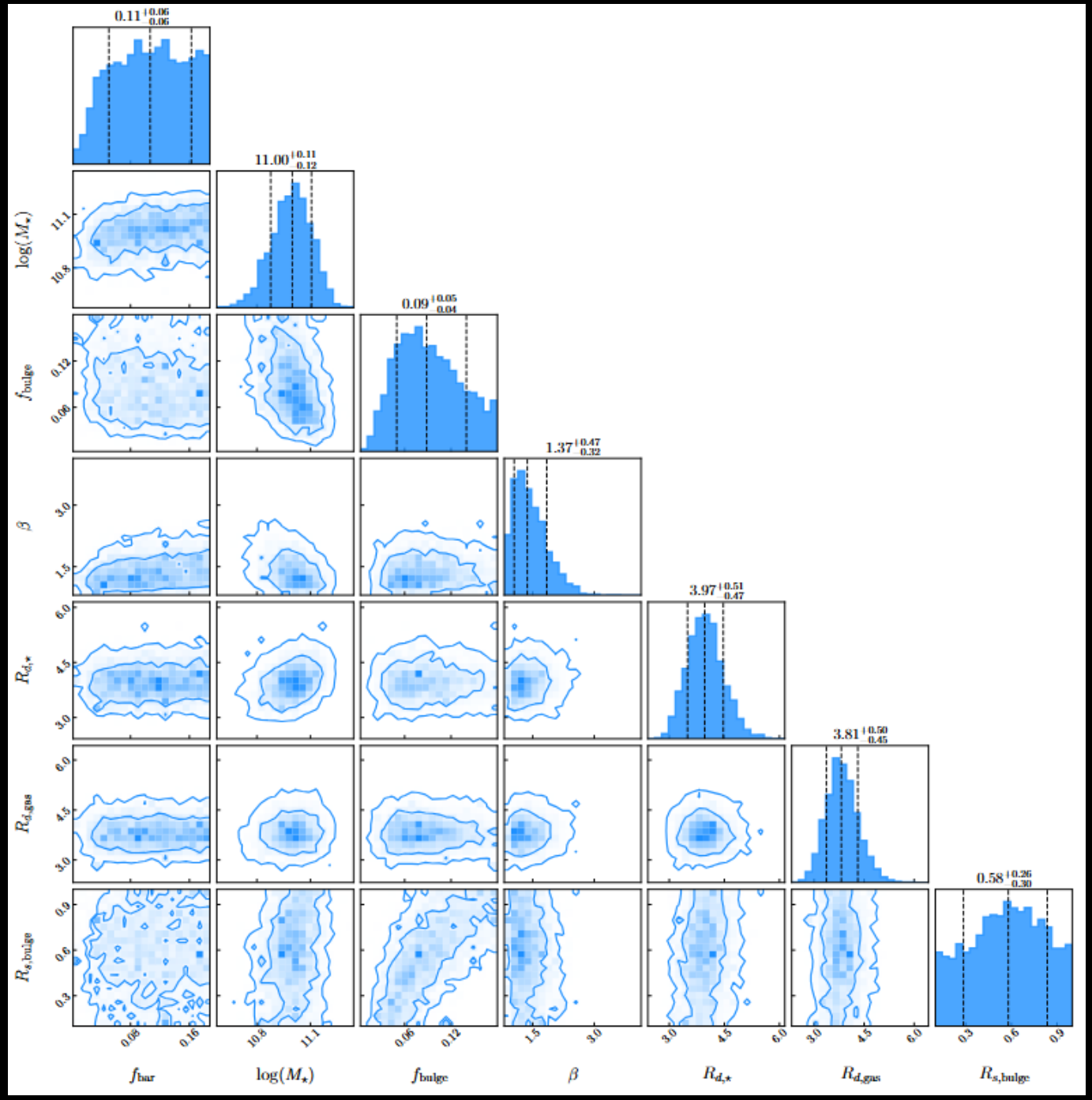
- We performed **dynamical modelling** to infer the **DM halo mass** and to provide further constraints on the baryonic components of the Big Wheel.
- The resulting **SHM ratio** is higher than expected for the galaxy population at z∼3 and **similar** to the value estimated for **local super-spiral galaxies**. This result suggests that the Big Wheel efficiently assemble its large stellar mass without strong feedback episodes.
- Studies on both the spin parameter of the Big Wheel's DM halo and its stellar-to-halo specific angular momentum ratio suggest that the **large spatial extent** can be **related** to a particularly **high halo spin**.
- The galaxy inferred from the dynamical model, once evolved in isolation and adiabatically, is **stable** against **gravitational instabilities**.

Thank you for your attention!

BACKUP SLIDES

Corner plot

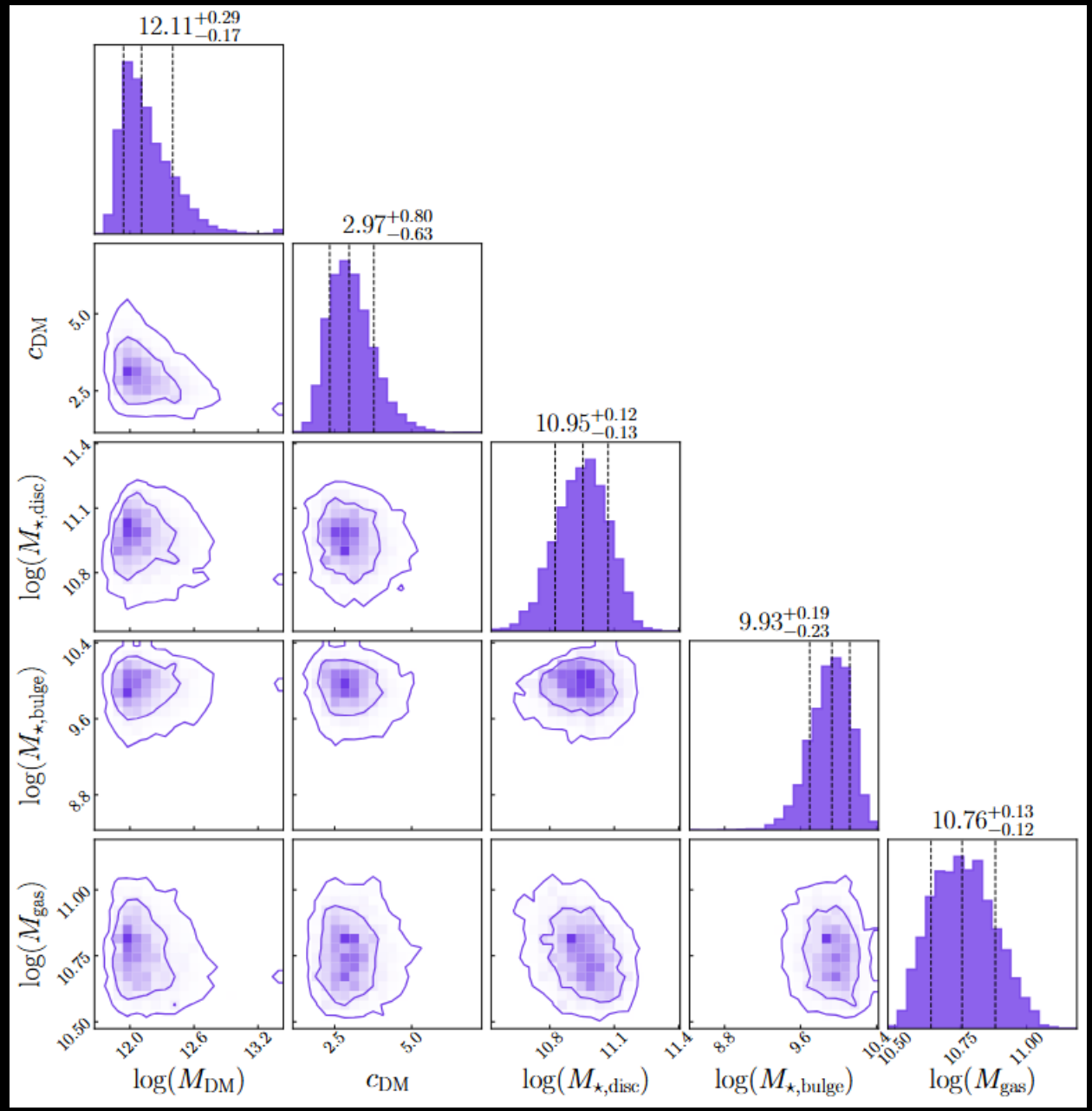
Best-fitting parameters	Posteriors
$f_{\rm bar}$	$0.11^{+0.06}_{-0.06}$
$\log(M_\star / M_\odot)$	$11.00^{+0.11}_{-0.12}$
$f_{\rm bulge}$	$0.09^{+0.05}_{-0.04}$
β ($M_\odot$/K km s^{-1} pc^{-2}) [a]	$1.37^{+0.47}_{-0.32}$
$R_{d,\star}$ (kpc)	$3.96^{+0.51}_{-0.47}$
$R_{d,\rm gas}$ (kpc)	$3.81^{+0.50}_{-0.44}$
$R_{s,\rm bulge}$ (kpc)	$0.58^{+0.26}_{-0.29}$



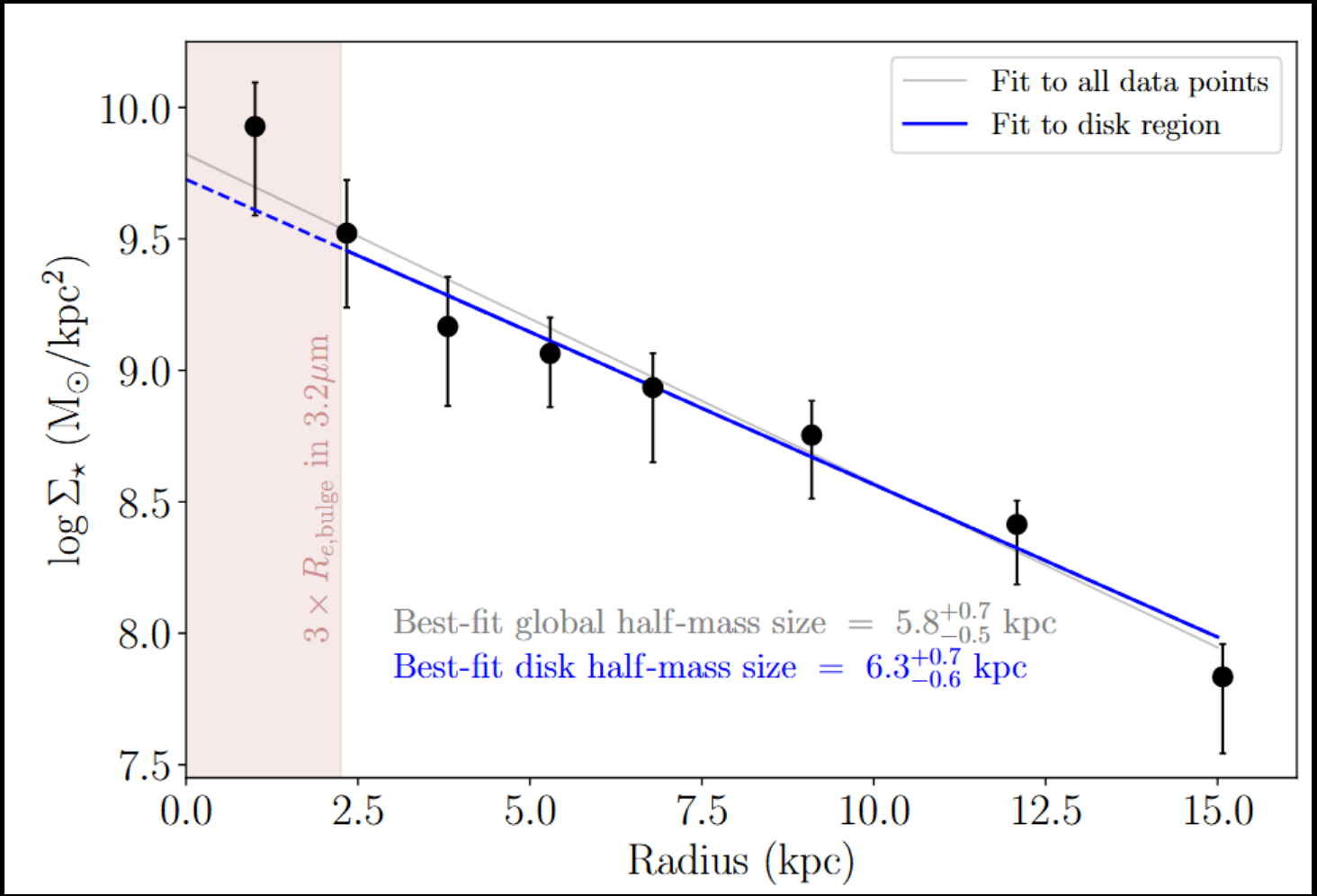
Corner plot

Derived parameters	Values
$\log(M_{DM}/M_\odot)$	$12.11^{+0.29}_{-0.17}$
c_{DM}	$2.97^{+0.80}_{-0.63}$
$\log(M_{\star,disc}/M_\odot)$	$10.95^{+0.12}_{-0.13}$
$\log(M_{\star,bulge}/M_\odot)$	$9.93^{+0.19}_{-0.23}$
$\log(M_{gas}/M_\odot)$	$10.76^{+0.13}_{-0.12}$

[a] $\beta = \alpha_{CO}/r_{41}$.



Refined SED fitting for the Big Wheel



SED fitting using ***finer radial bins***

↓

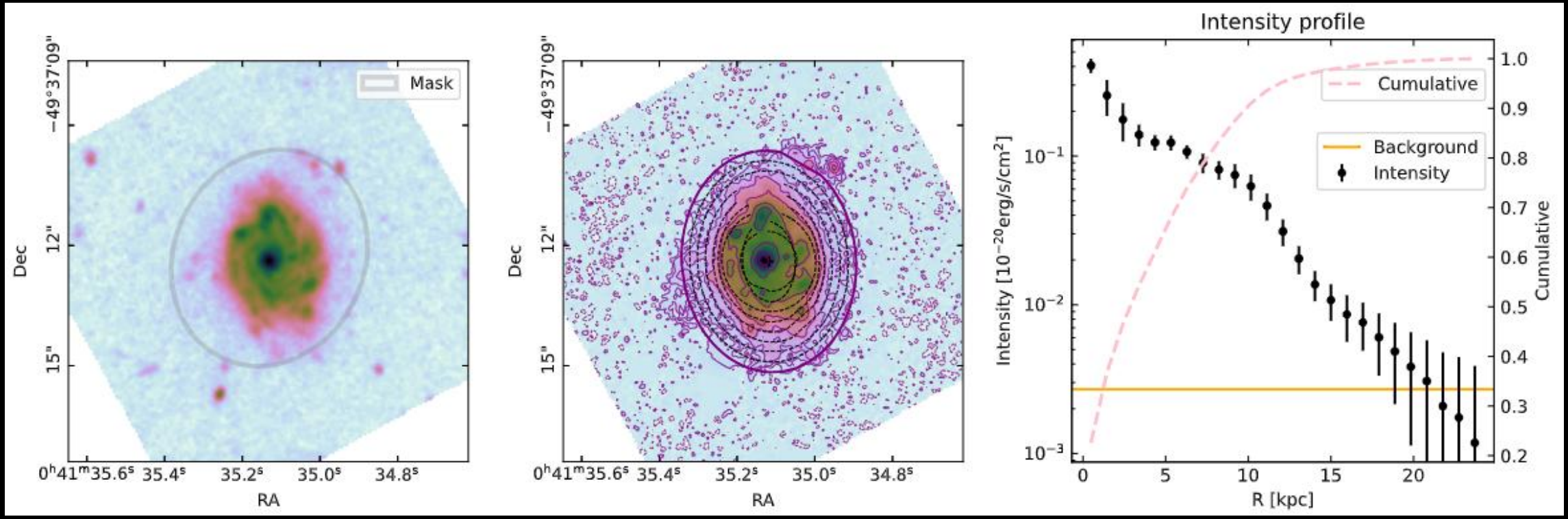
Bins of 1.5 kpc up to 7.5 kpc and 3 kpc up to 16.5 kpc

≠

Coarser binning of 2.25 kpc up to 6.75 kpc and 4.5 kpc up to 15.75 kpc

Stellar mass ***density profile*** closely ***follows*** an ***exponential*** distribution.

Photometry analysis



^{3D}Barolo analysis