



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



MAX-PLANCK-GESELLSCHAFT



Probing Galaxy Structures and Stellar Population Properties with MICADO & MORFEO:

Insights from ScopeSim simulations

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Natascha M. Förster Schreiber, Francesca Annibali, Carlotta Gruppioni, Carmelo Arcidiacono et al.

Where do we stand ahead of the ELT era?

Morphology studies across cosmic time

- ▶ Star-forming galaxies at $z \sim 1 - 3$ commonly ($\sim 70\%$) show disk/bulge structures despite being more clumpy, gas-rich, and turbulent than their local counterparts

[e.g. Förster Schreiber & Wuyts 2020, Tacconi+2020]

- ▶ Galaxy build-up may be driven by multiple mechanisms: e.g., clump migration, gravitational instabilities, gas inflows, compaction events, and angular momentum transport

[e.g. Genzel+2011, Dekel & Burkert 2014, Krumholz+2018, Guo+2018]

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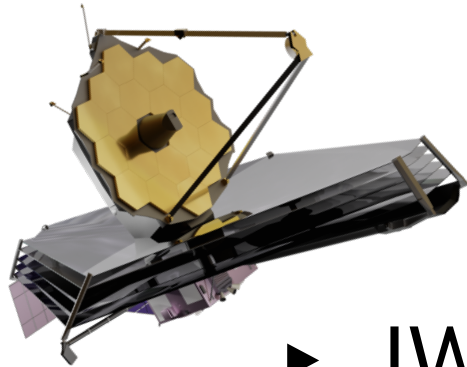
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- ▶ JWST is facilitating **clump studies** over larger unlensed (down to ~ 100 - 500 pc scales) and lensed (down to ~ 1 - 10 pc scales) galaxy samples across wide redshift ranges; however, the exact nature, survival, and role of clumps in galaxy assembly remain unclear

[e.g. Claeysens+2023,2025, Vanzella+2023, Kalita+2024,2025, Mercier+2026]

Where do we stand ahead of the ELT era?

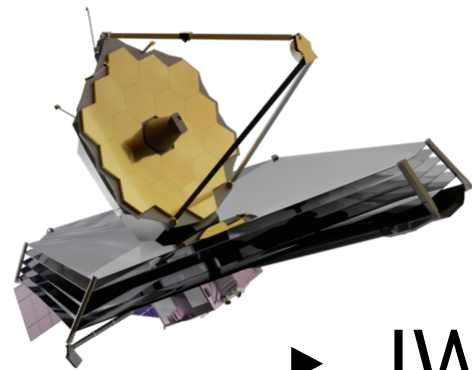
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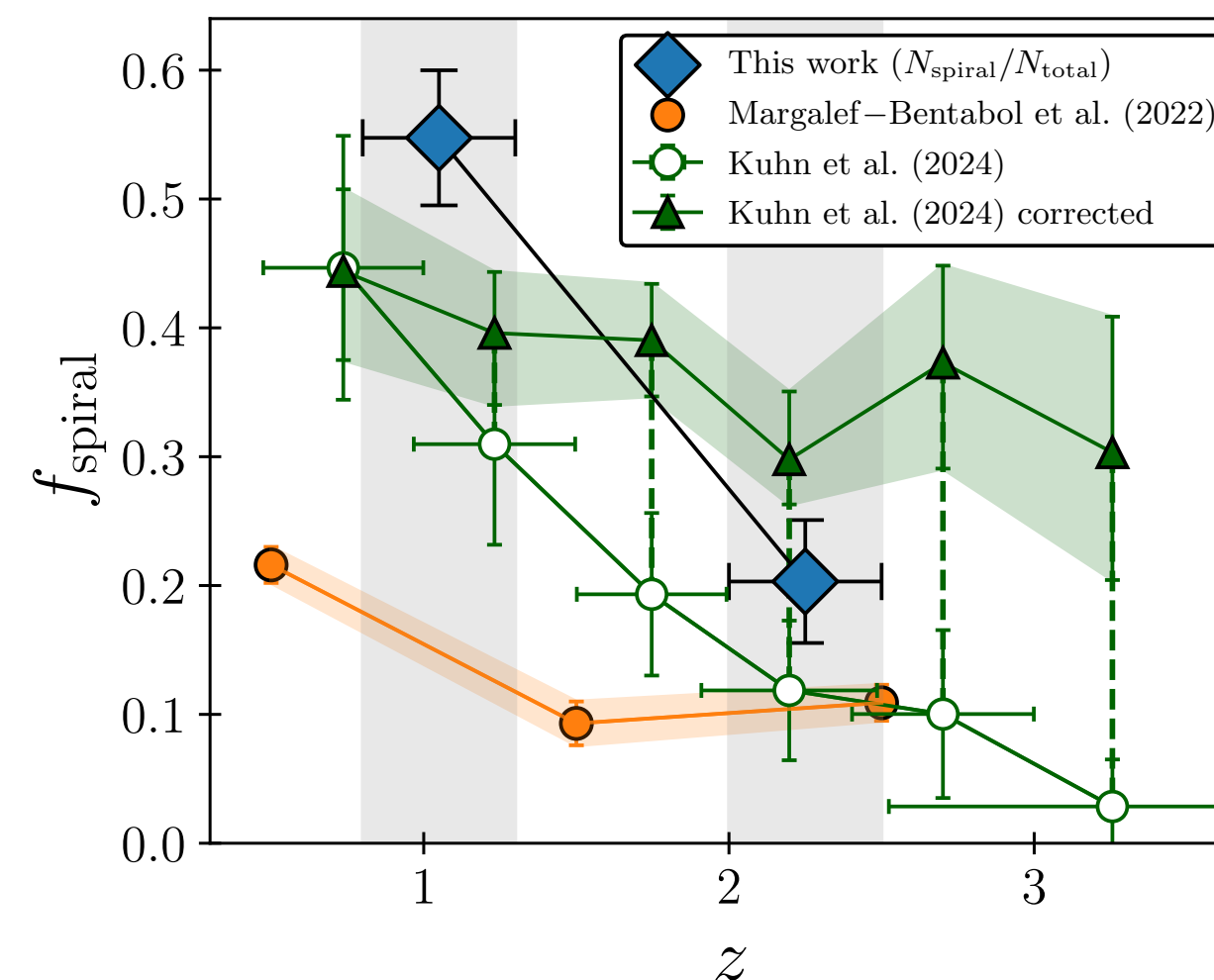
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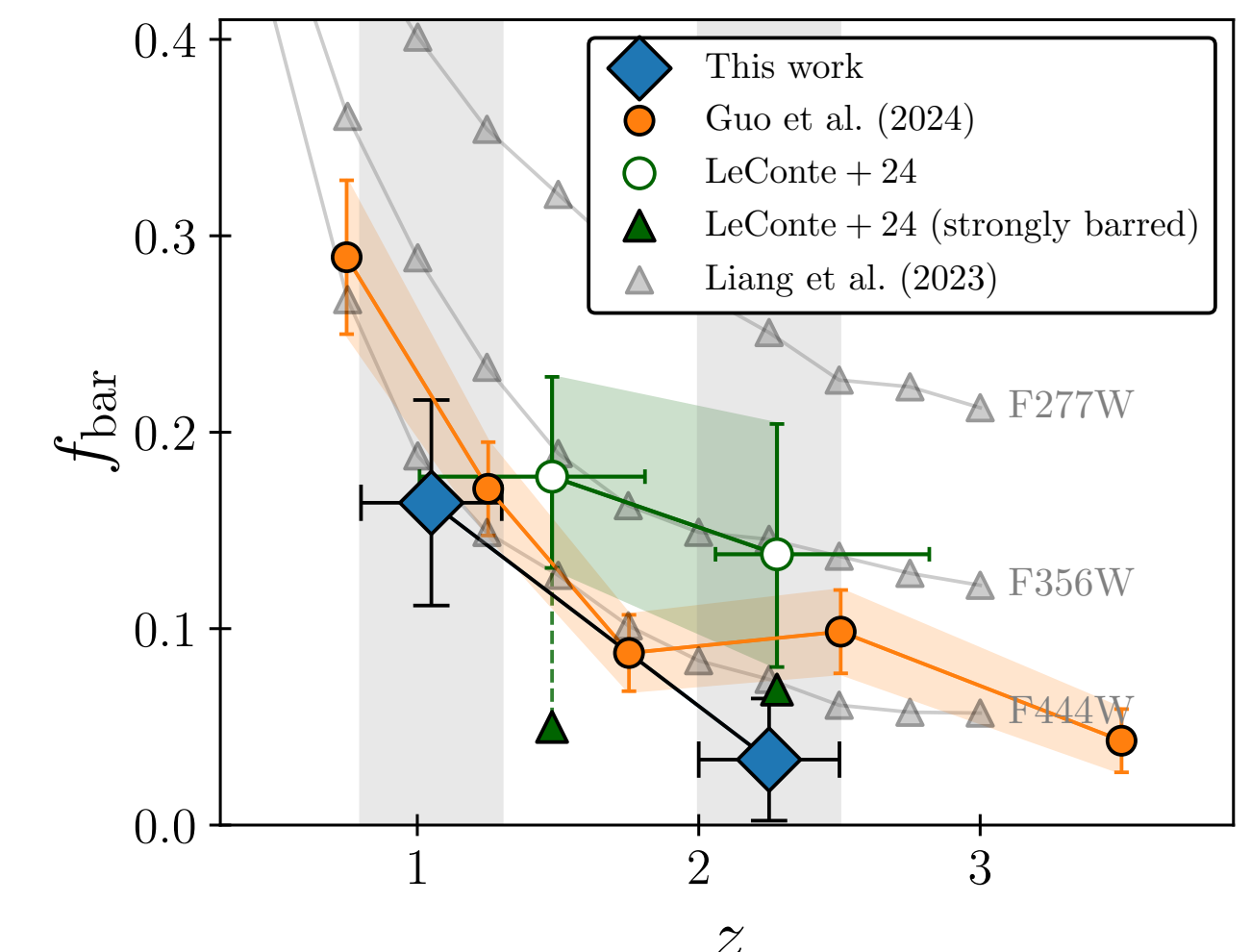


- ▶ JWST observations are uncovering significantly higher fractions of **non-axisymmetric features** (spiral arms and bars) out to $z \sim 2$ and beyond

[see also Costantin+2023, Le Conte+2024, Gerón+2025, Jain & Wadadekar 2025, Xiao+2025]



Espejo Salcedo+2025



Where do we stand ahead of the ELT era?

Morphology studies across cosmic time

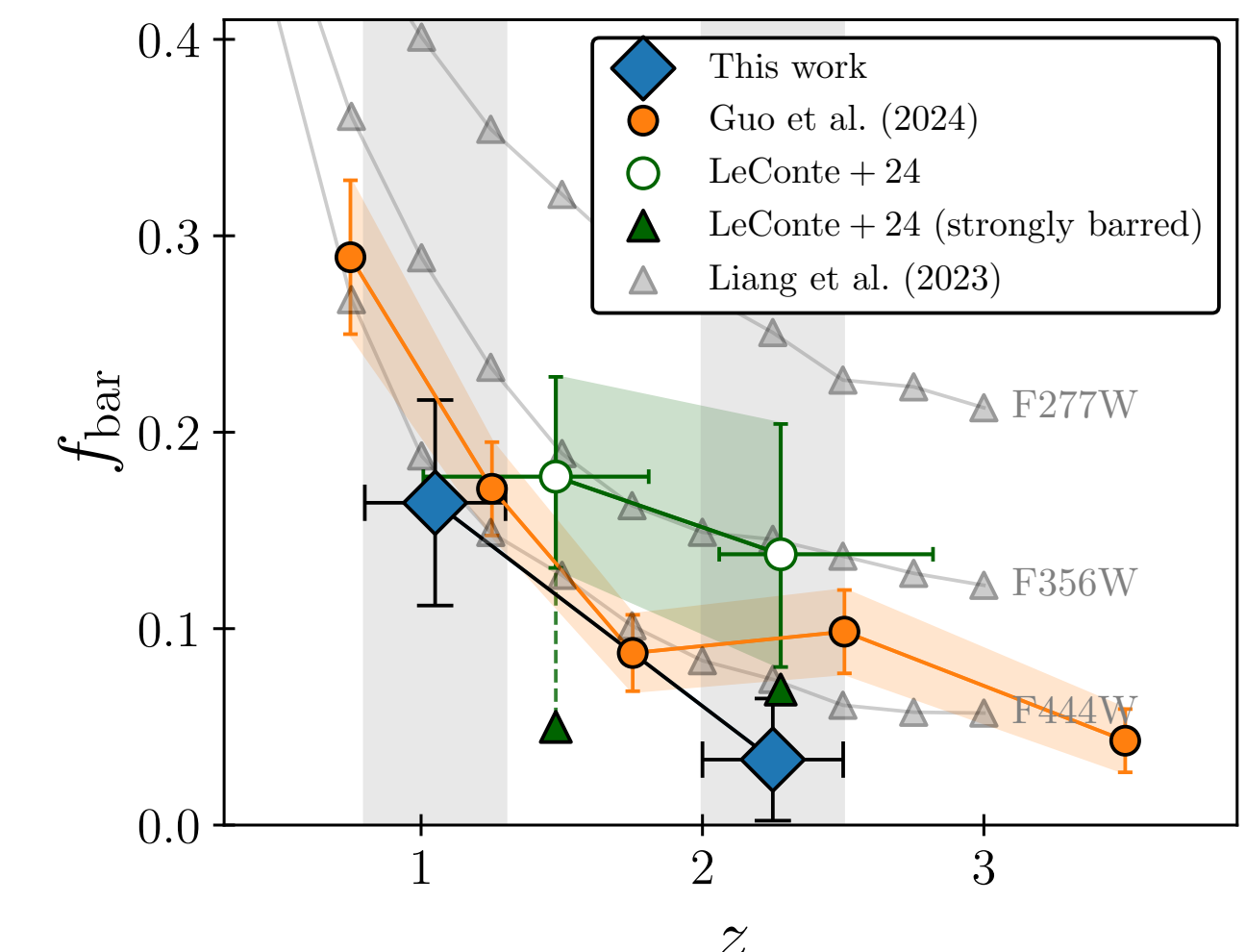
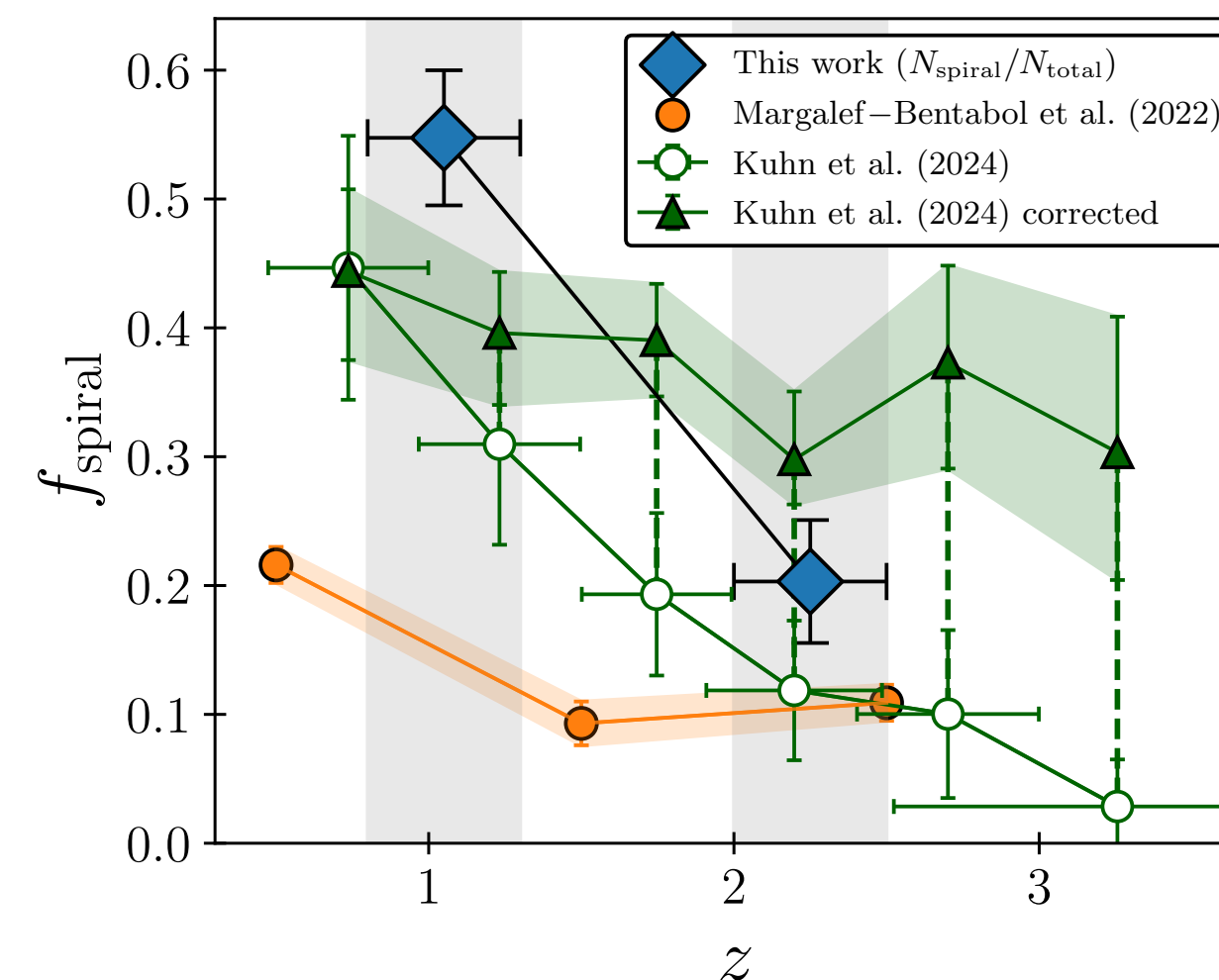
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- Observational challenges: surface brightness dimming, resolution limitations, and the expected evolution of galaxy and bar sizes
- **MICADO & MORFEO at the ELT:** improved spatial resolution in the NIR

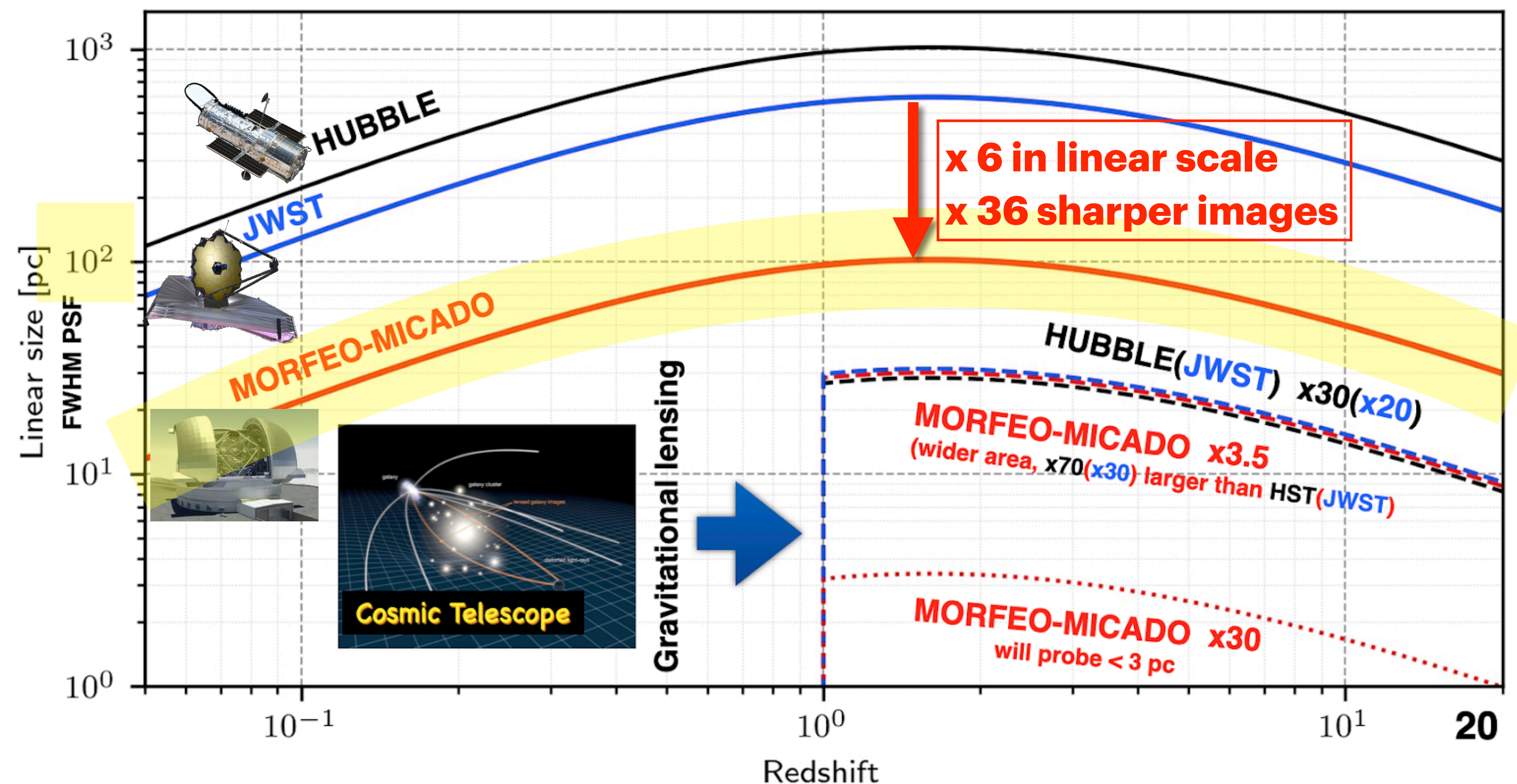


Espejo Salcedo+2025

What's next? MICADO & MORFEO at the ELT

Spatial resolution

- ▶ MICADO & MORFEO at the ELT will **resolve galaxies on $\leq 100\text{pc}$ scales everywhere** in the Universe
→ transform studies of morphologies and physics of galaxies across cosmic time



Credits:
MICADO&MORFEO
Science Teams

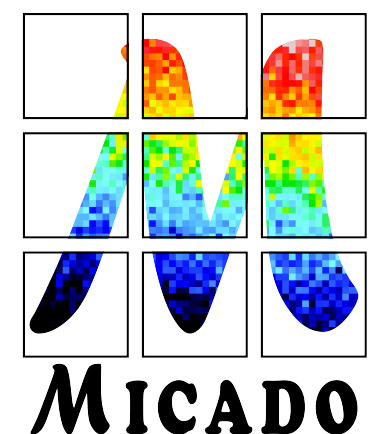
Setting up the stage...

Project goal and outline

Determine the detectability of morphological sub-structures, like bars, spiral arms or clumps, as a function of target properties (e.g. galaxy size, luminosity, redshift)

- Define a local reference sample of galaxies
- Generate a mock population of galaxies in different redshift bins, up to the cosmic noon, redshifting the properties of the local reference sample
- Generate PSFs for realistic NGS asterisms (TIPTOP algorithm)
- Run the ScopeSim code to simulate observations with MICADO & MORFEO
- Perform a post-processing analysis of the simulated MICADO & MORFEO images to quantitatively assess the expected performance

Scaloni+2026, in prep.



Reference sample

GAMA survey in the local Universe

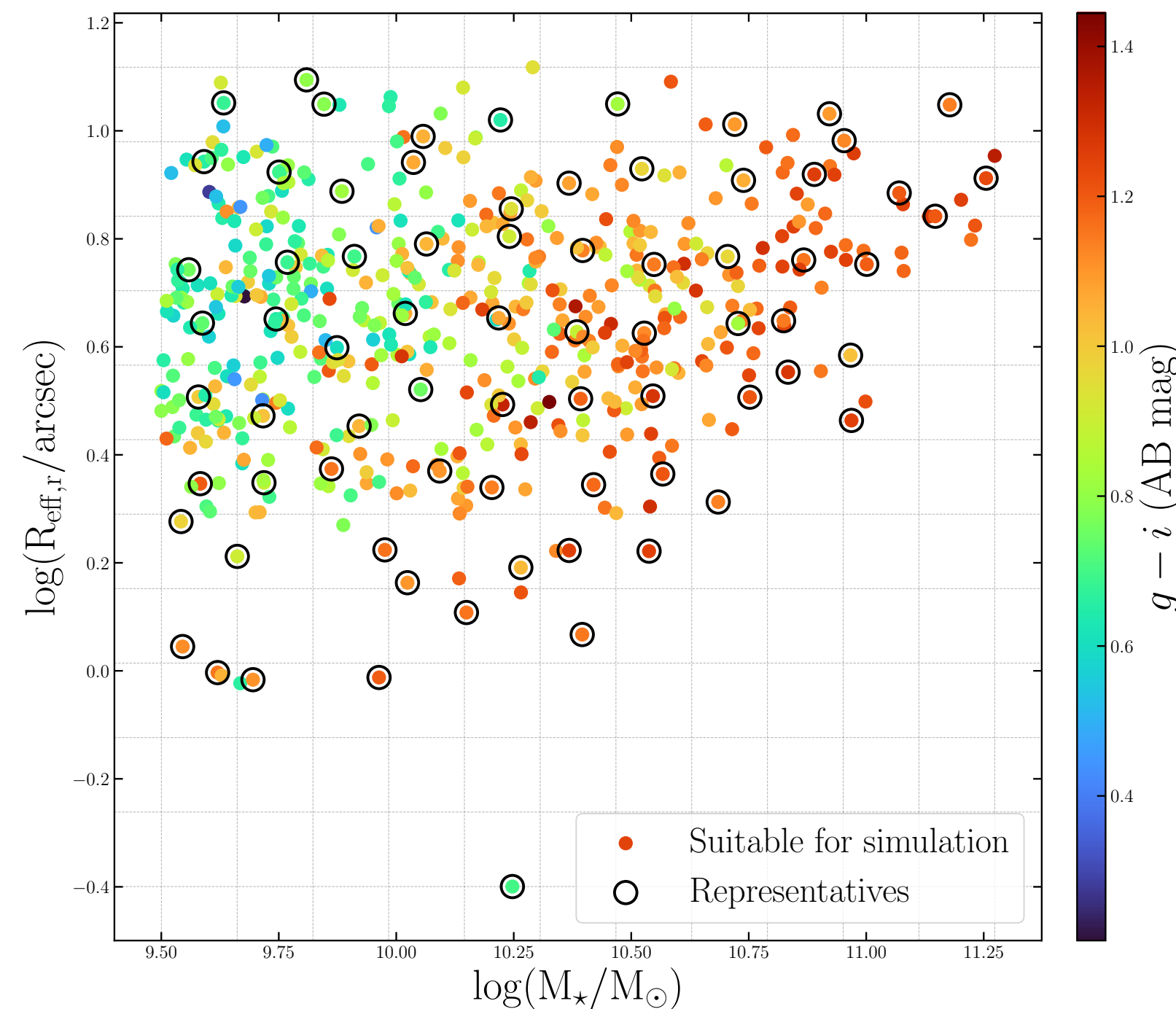
- Selection criteria:

- stellar mass $9.5 M_{\odot} < \log(M_{\star}) < 11.5 M_{\odot}$

- $z \leq 0.05$

- reliable R_{eff} and SED fitting

→ 545 local galaxies



→ 74 representative local galaxies

Redshifting properties

From the local Universe to intermediate redshifts

- 4 redshift bins: $[0.5, 1]$ - $[1, 1.5]$ - $[1.5, 2]$ - $[2, 2.5]$ $\longrightarrow$ midpoints: $z = 0.75, 1.25, 1.75, 2.25$
- Main properties to be redshifted: **fluxes** and **effective radii**
 - $\longrightarrow$ Available bands from GAMA: FUV, NUV (GALEX), u, g, r, i (KiDS), Z, Y, J, H, K (VIKING) and W1, W2 (WISE)
- MICADO wide bands: **I** (8500 Å), **J** (12500 Å), **H** (16350 Å), **K_s** (22000 Å)

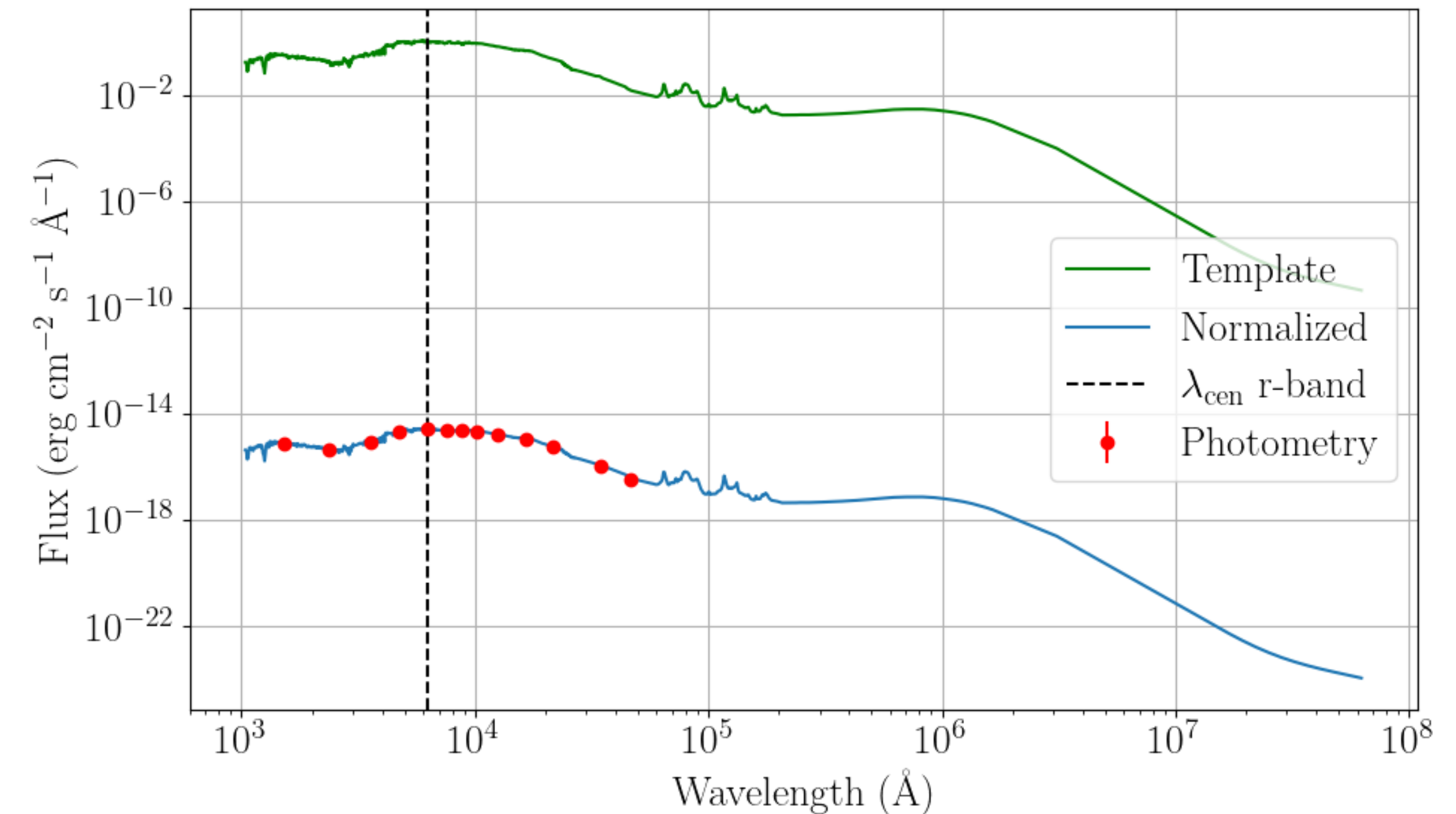
Retrieve galaxy properties at the corresponding rest-frame wavelengths for each redshift bin

Redshifting properties

Fluxes and effective radii

Fluxes:

- Spectra: SWIRE templates library [Polletta+07]
- Assign the best template according to the minimum χ^2
- Normalize the template to the observed fluxes (r-band)



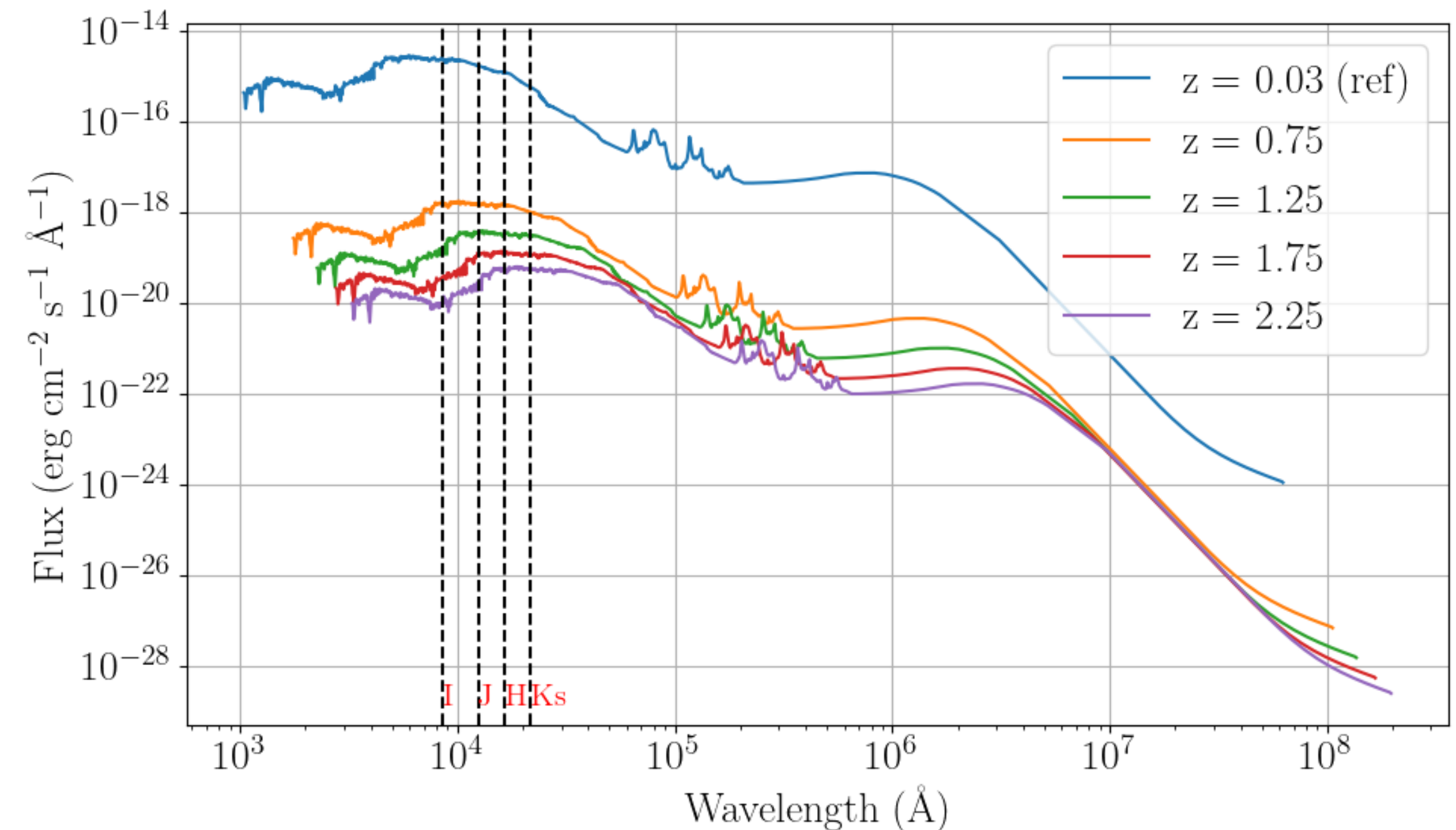
Redshifting properties

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- Apply the **cosmological dimming** effect
- Apply the **evolution of the intrinsic luminosity** to get the final observed fluxes in I, J, H, K_s bands

[Yu+23]



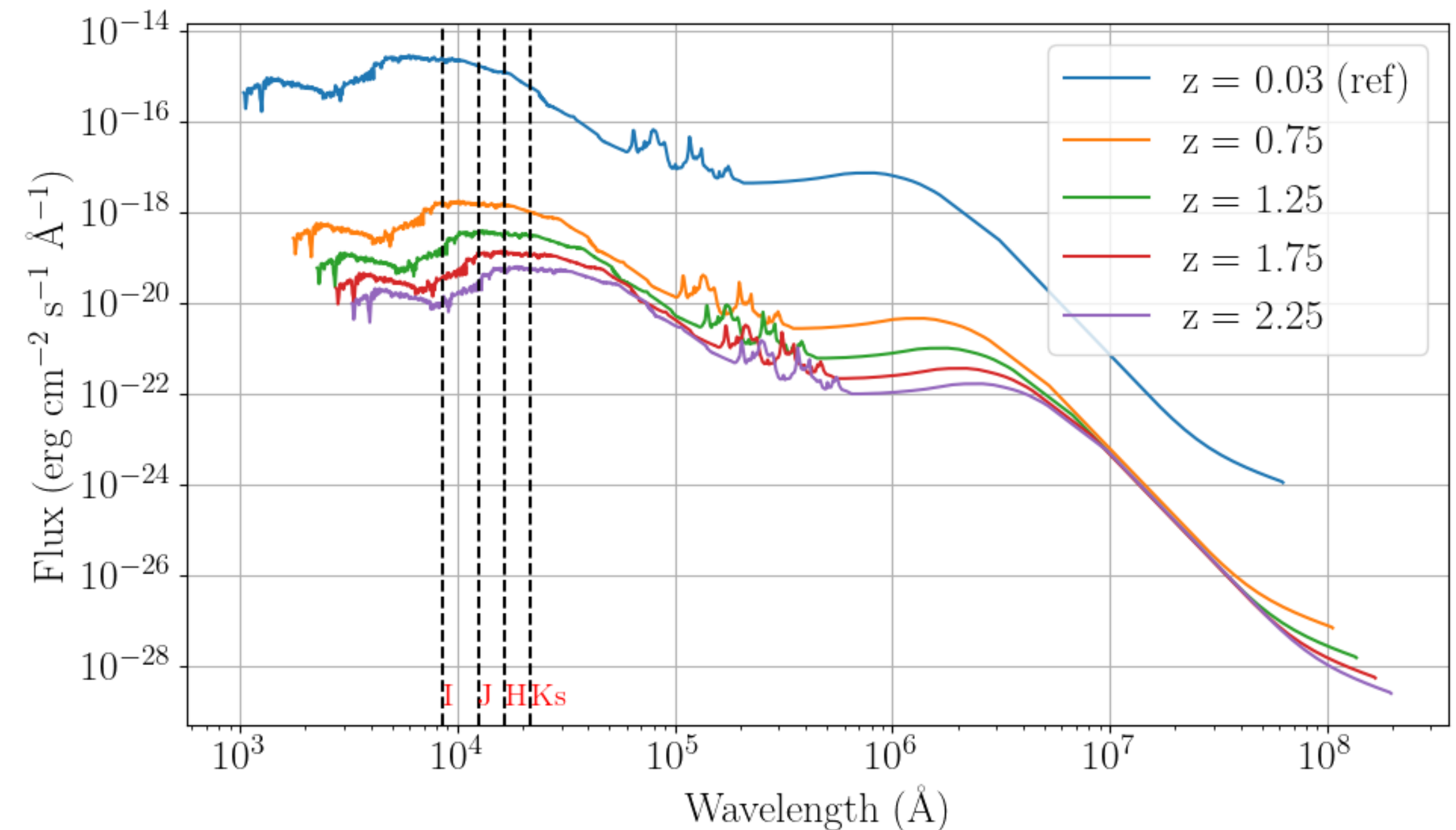
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[Yu+23]



Effective Radii:

- Apply the intrinsic size evolution [van der Wel et al. 2014], and compute angular sizes as a function of z

Parametric galaxy models with GALFIT

Morphological components

- ▶ A suite of galaxy models with **different morphologies** is generated for each pair of total flux and effective radius associated with a galaxy in the reference sample (as derived from the redshifting procedure for each z-bin and MICADO band)

Parametric galaxy models with GALFIT

Morphological components

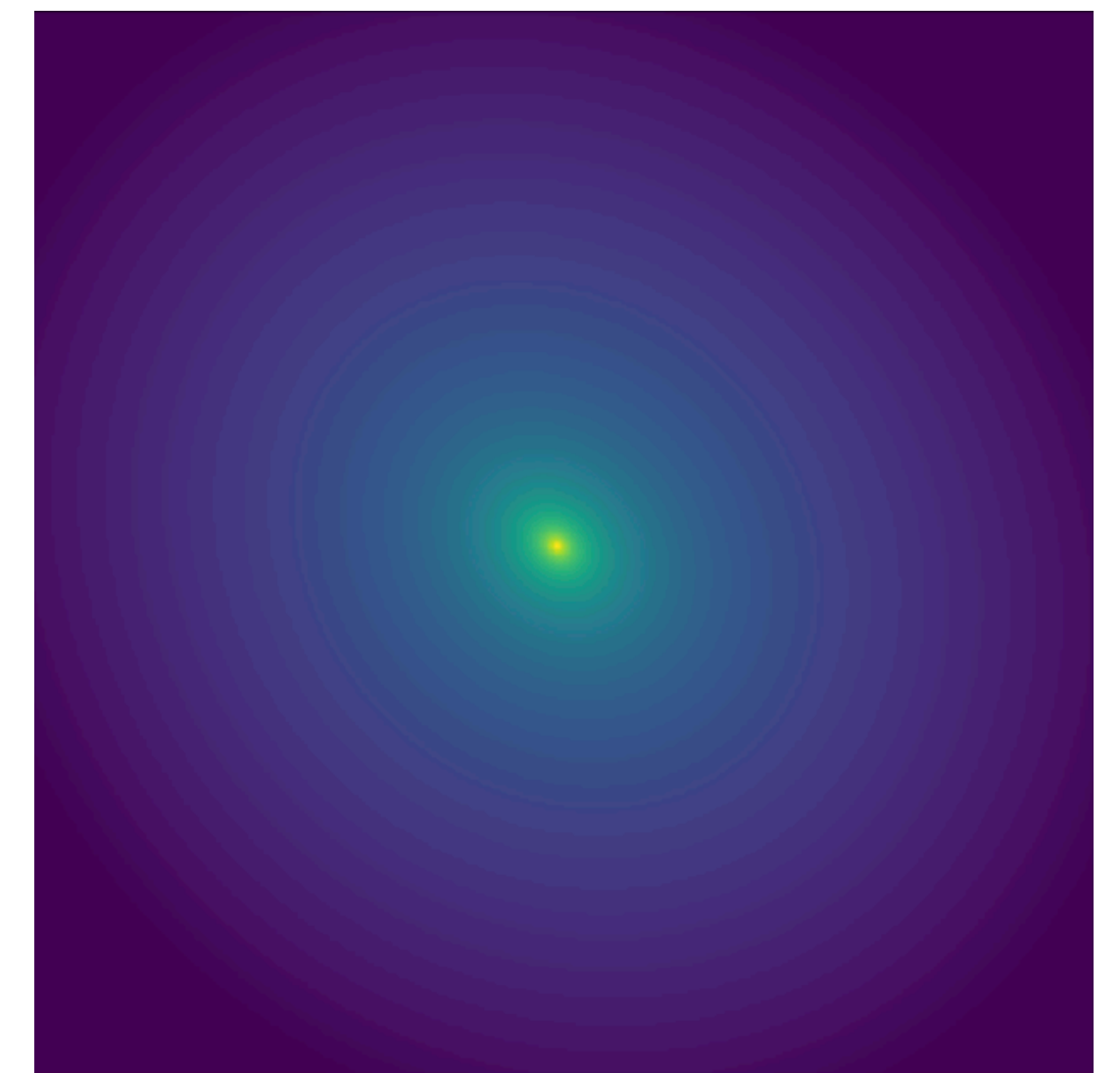
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Bulge and disk

B: Sérsic component, $n=4$, $q=0.8$

D: Sérsic component, $n=1$, $q=0.9$

$B/T=0.3 + D/T=0.7$



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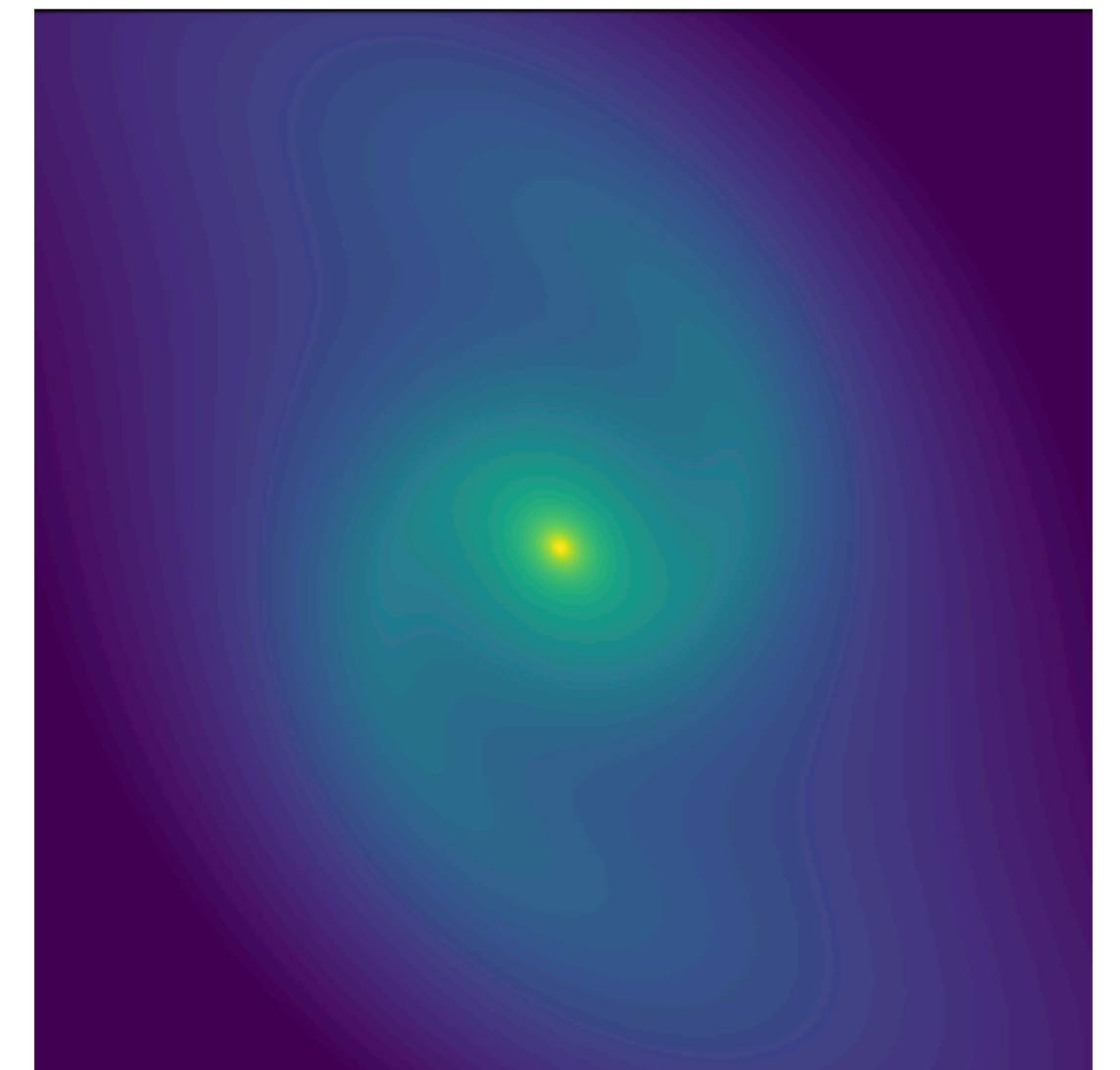
Bulge, disk and spiral arms

B: Sérsic component, $n=4$, $q=0.8$

D: Sérsic component, $n=1$, $q=0.9$

spirals arms: distorted Sérsic component ($r > r_{\text{out}}$: $\theta(r) \propto r^q$), $n=1$, $q=0.4$

$B/T=0.3 + D/T= 0.2 + \text{spirals}/T=0.5$



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Morphological components

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Bulge, disk, spiral arms and bar

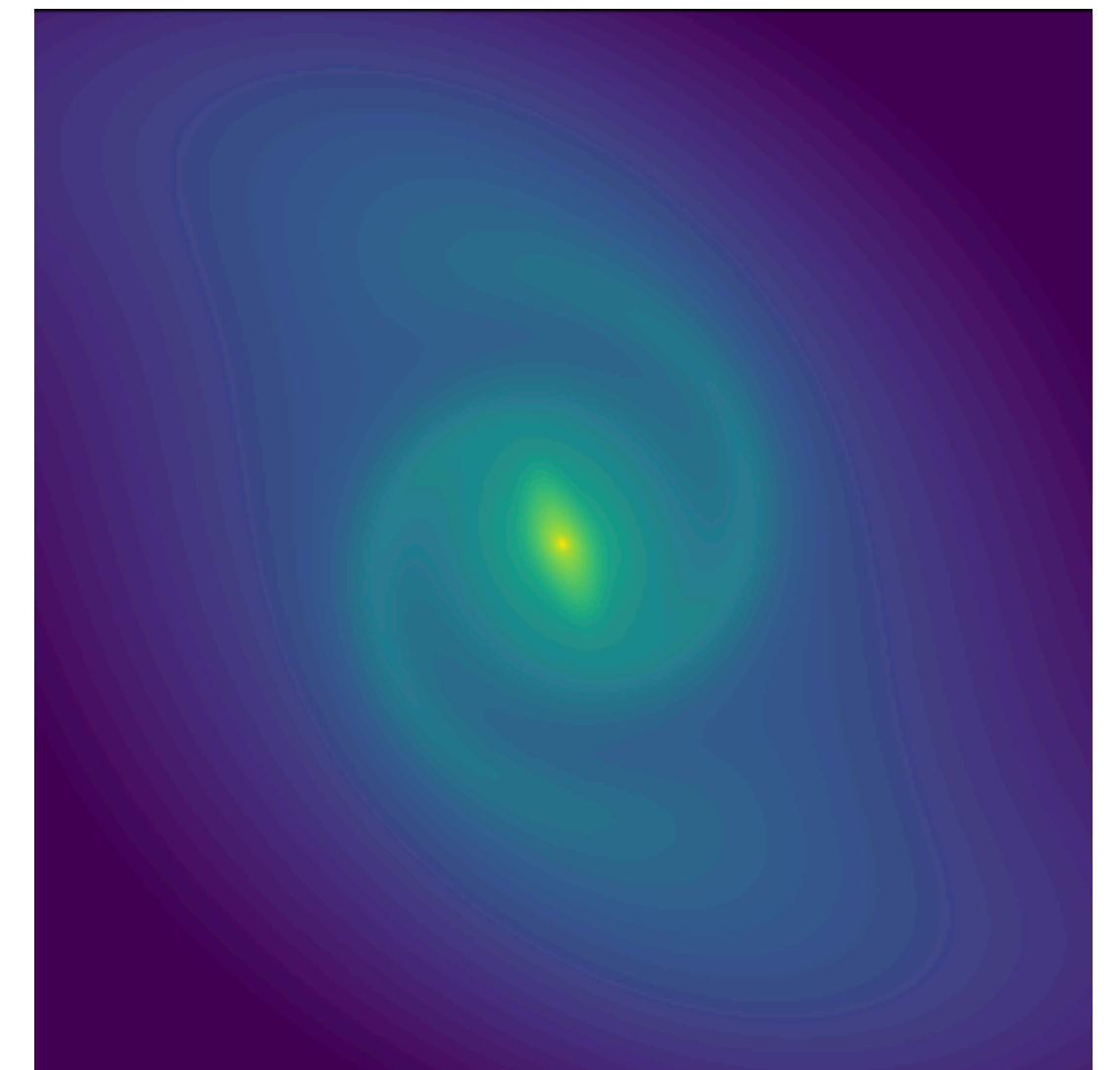
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bar: modified Ferrer profile, $\alpha=2.5$, $\beta=1.0$, $q=0.4$

$B/T=0.3 + D/T= 0.15 + \text{spirals}/T=0.4 + \text{bar}/T=0.15$



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Bulge, disk, spiral arms, bar and **clusters/small clumps**

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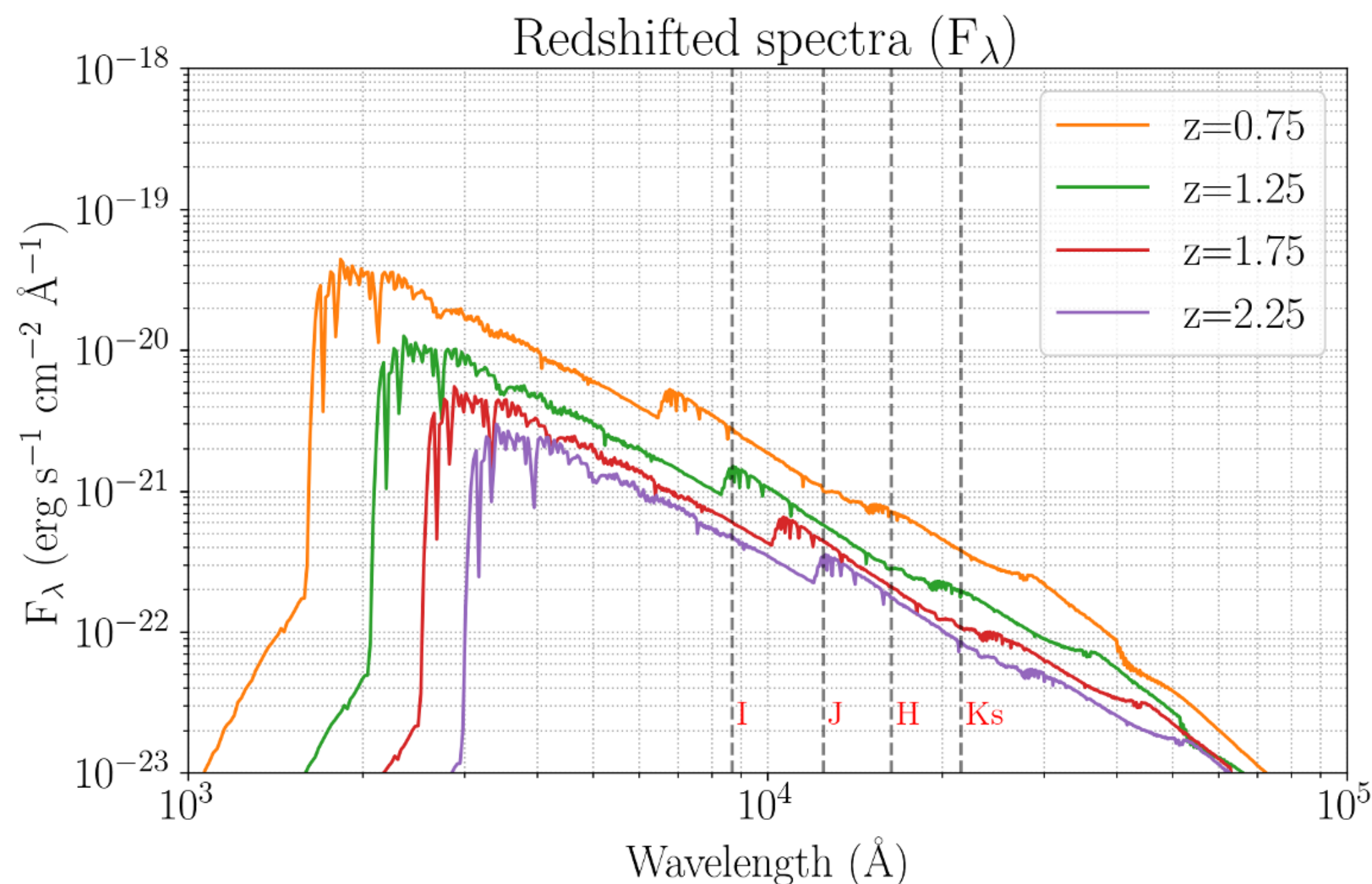
rescaled fractions in order to put ~ 10% of light in **clusters**: 2D gaussians

Parametric galaxy models with GALFIT

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Bulge, disk, spiral arms, bar and **clusters/small clumps**



SSP from *Starburst99* — 20Myr, $10^6 M_\odot$

Extract **M/L** at I, J, H, K_s bands from the redshifted spectra

Parametric galaxy models with GALFIT

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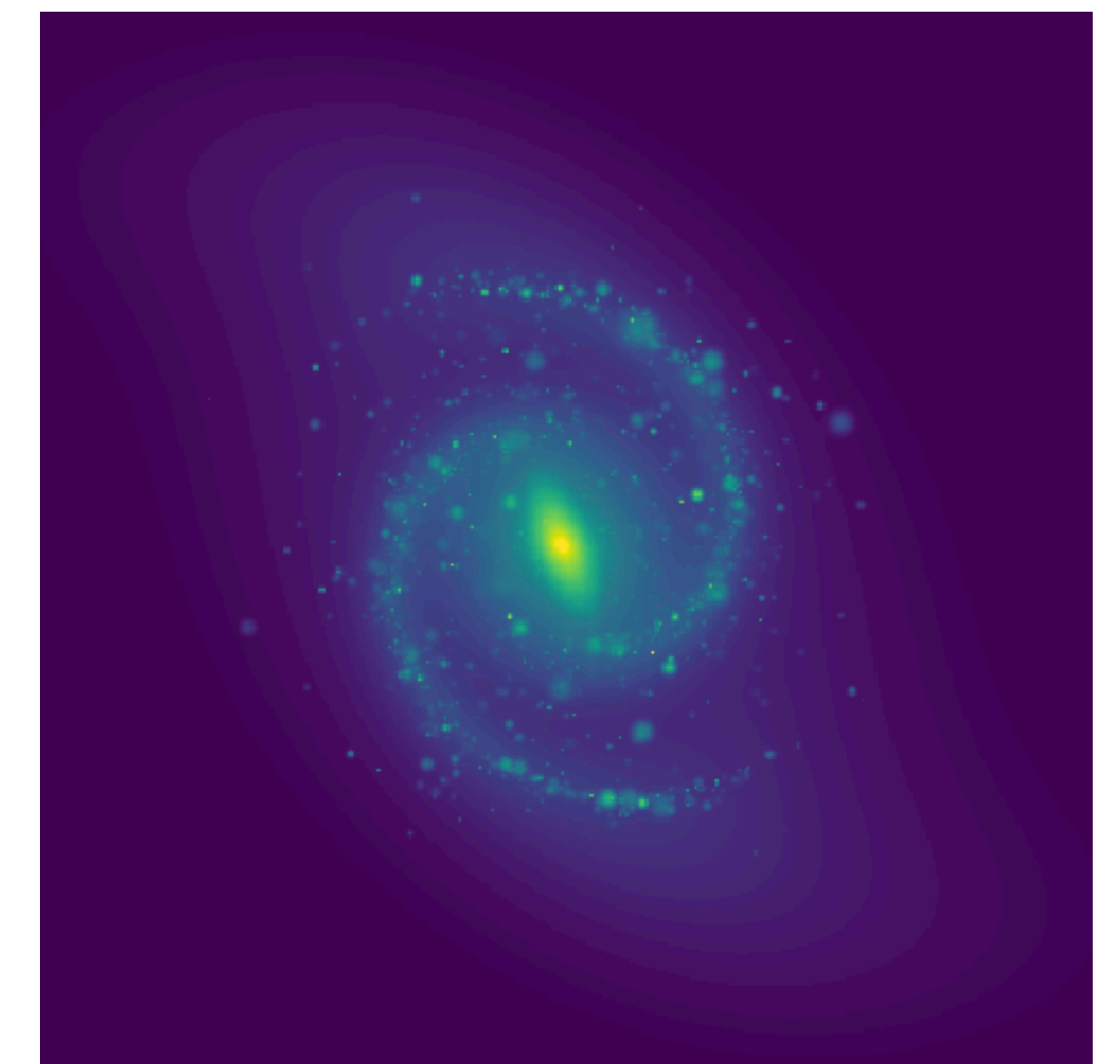
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rescaled fractions in order to put $\sim 10\%$ of light in **clusters**: 2D gaussians

- luminosities: $N \propto L^{-2}$

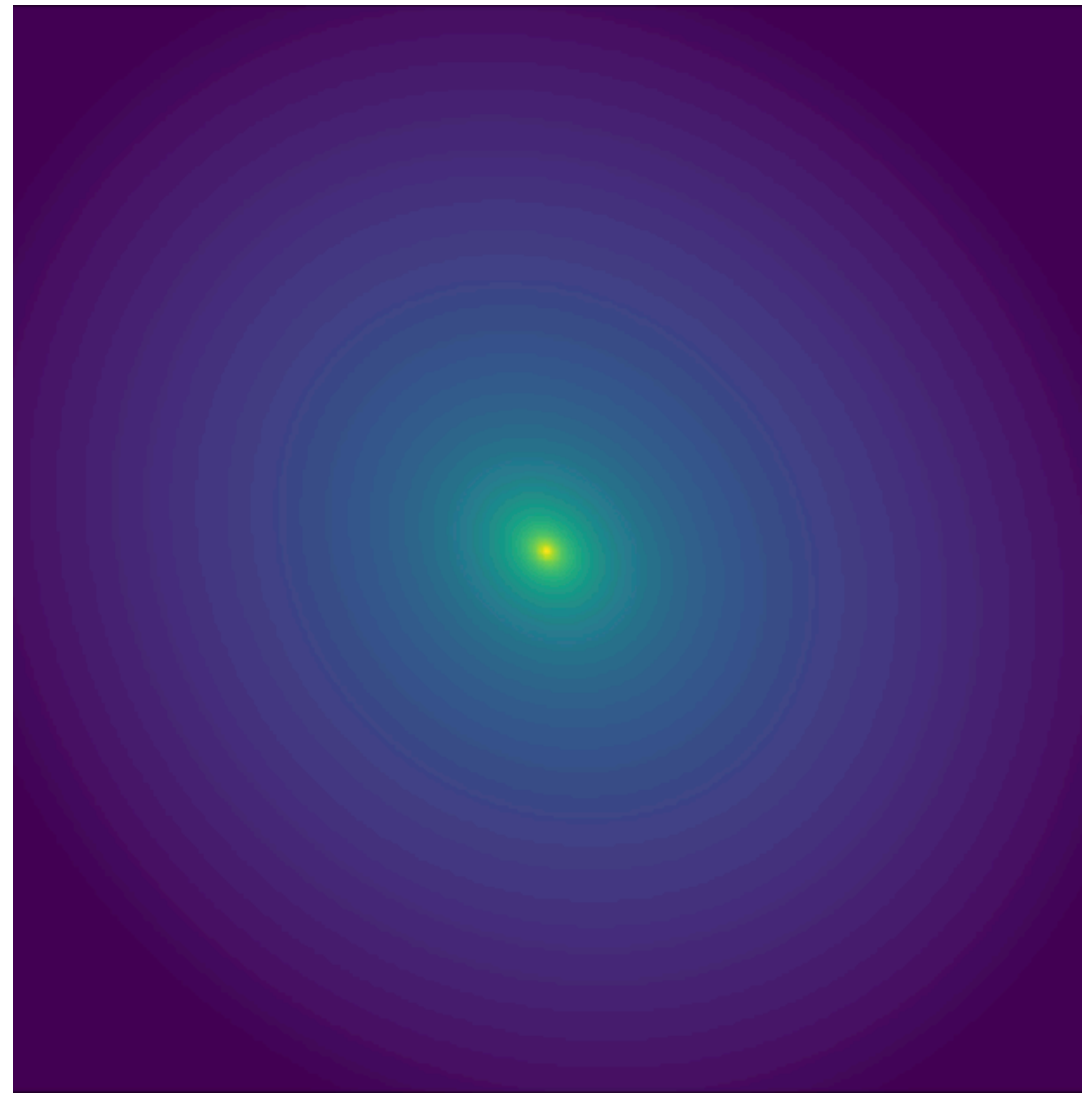
- stellar masses: $10^5 - 10^8 M_{\odot} \longrightarrow$ sizes: $\sim 5 - 100$ pc

[Claeyssens+23]

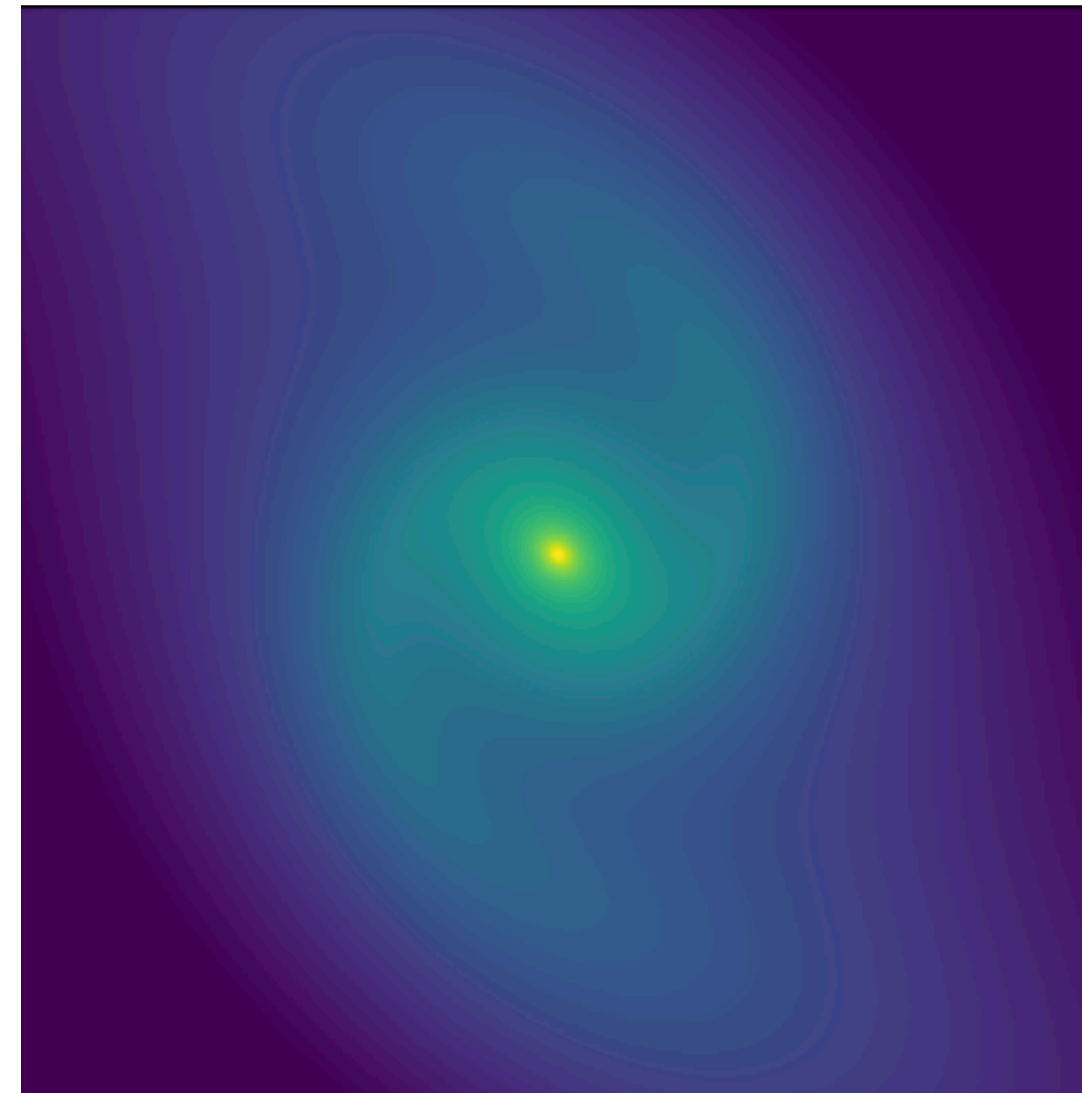


Parametric galaxy models with GALFIT

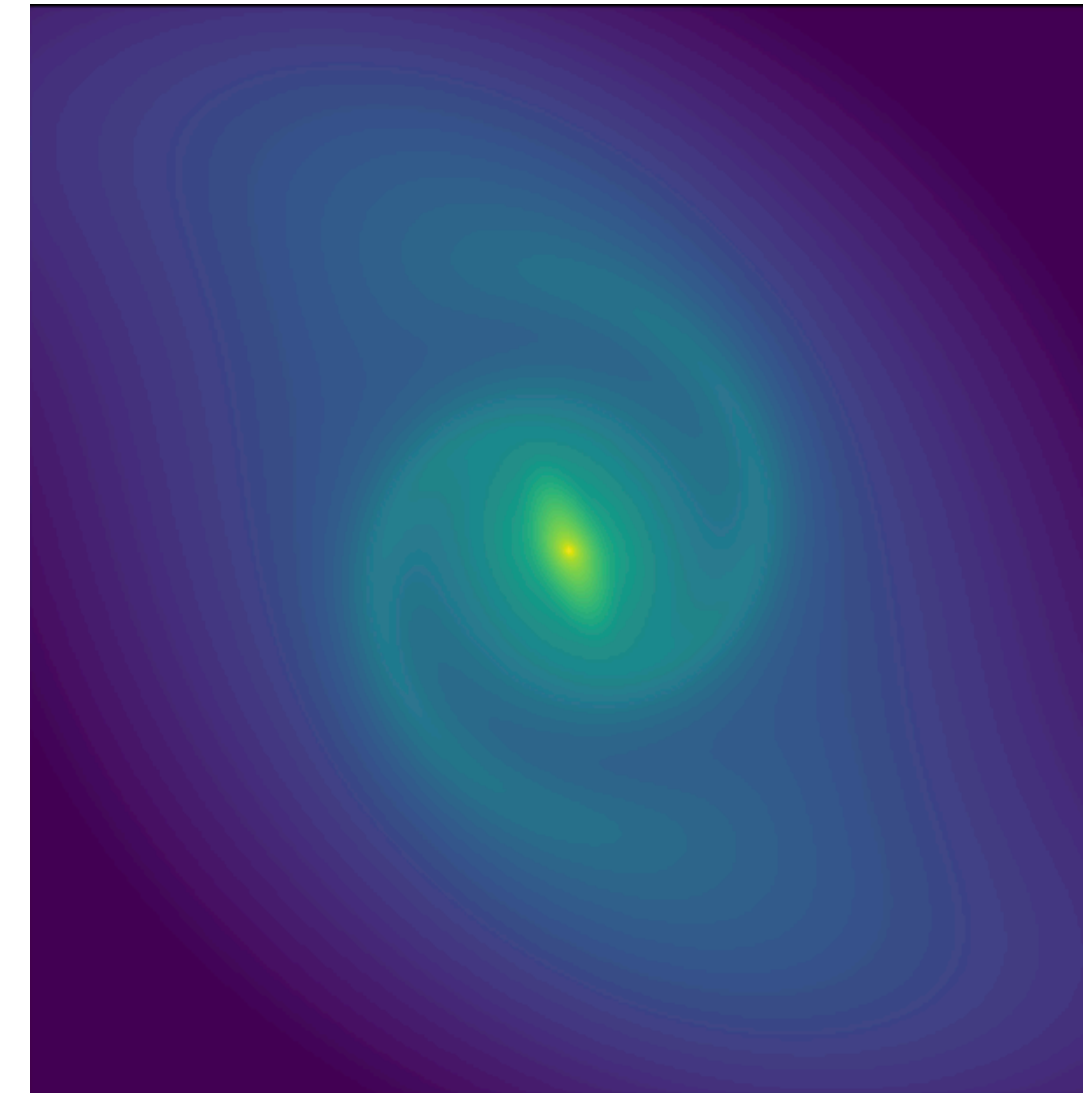
Overview



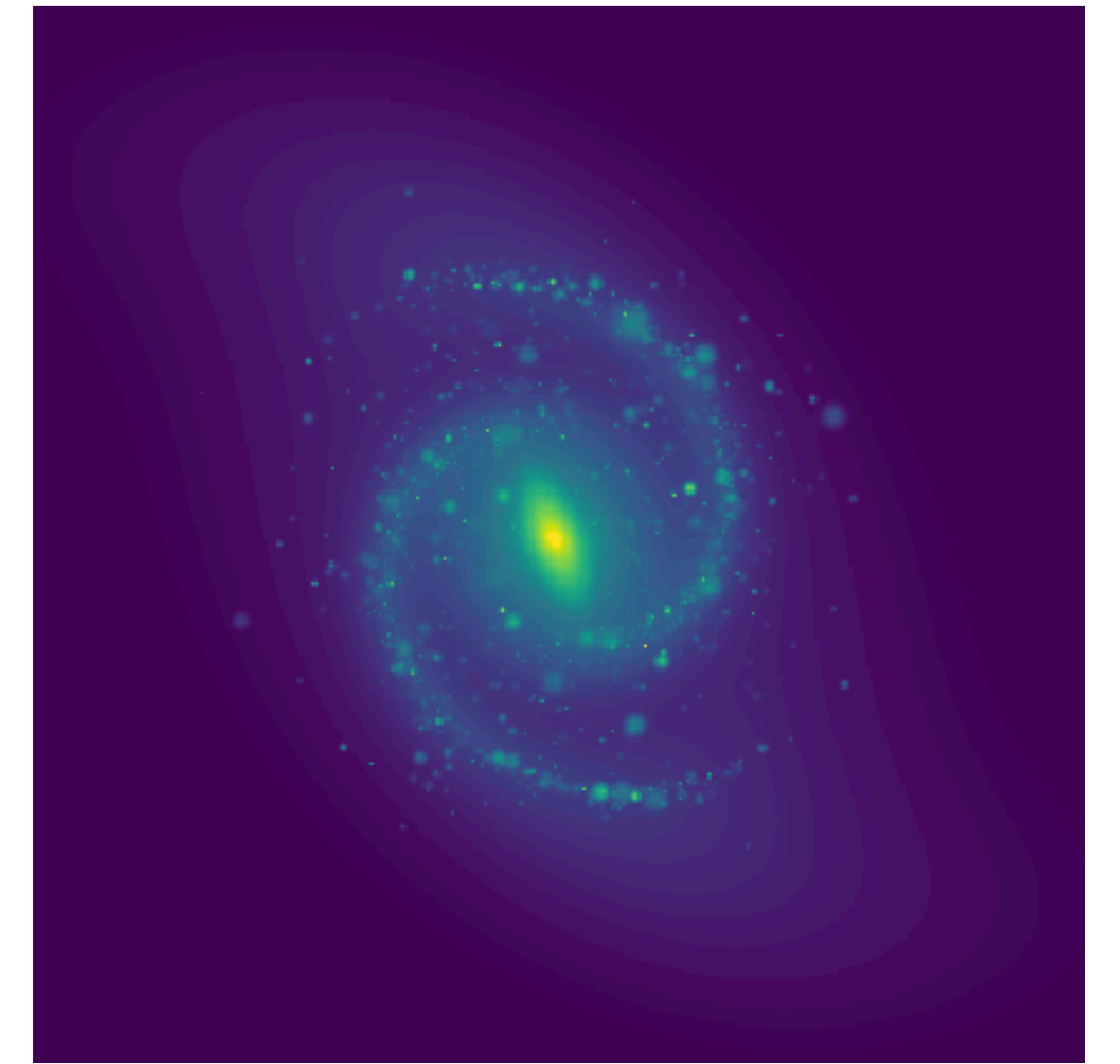
B+D
+clusters



B+D+spirals
+clusters



B+D+spirals+bar

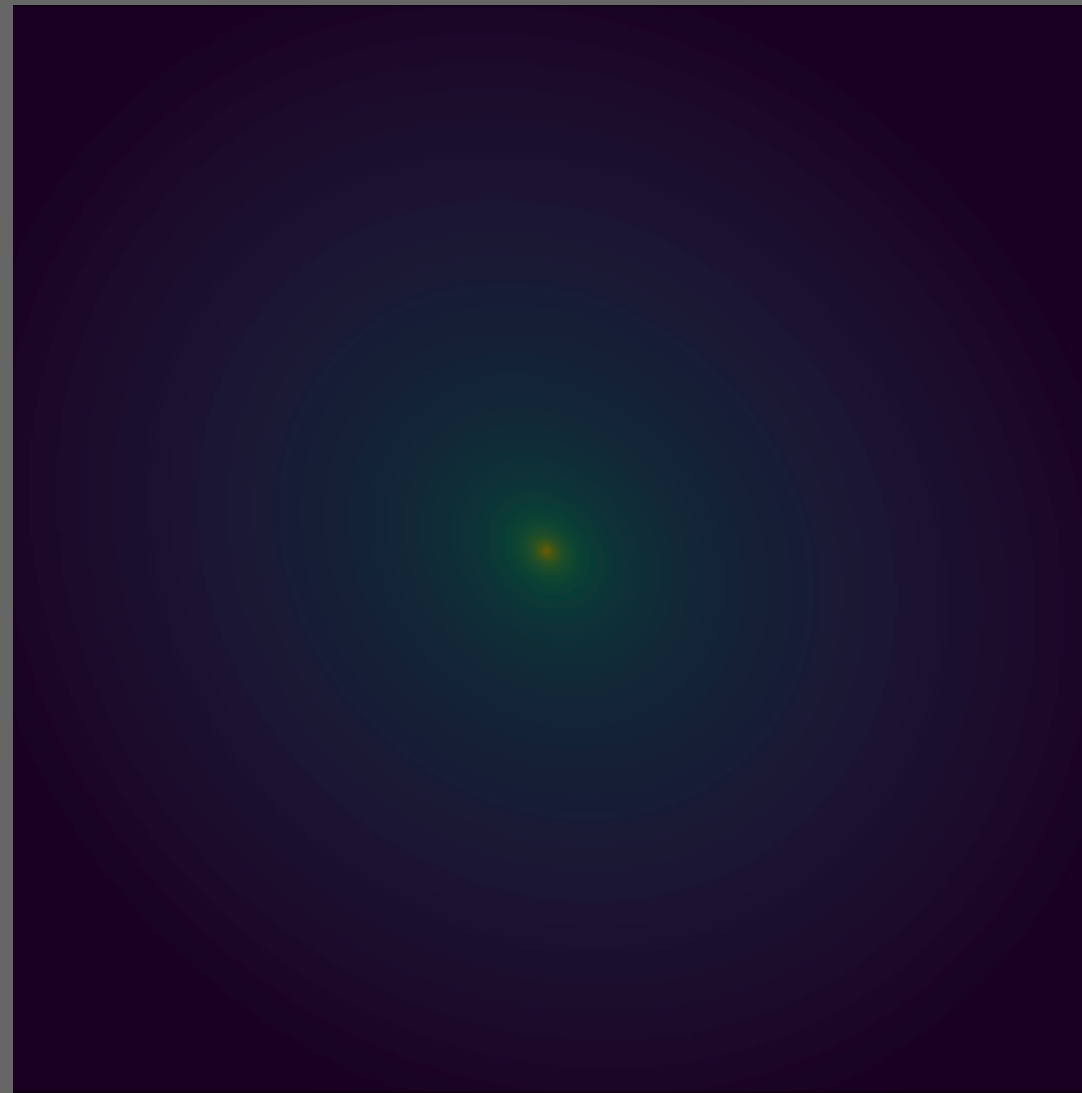


B+D+spirals+bar
+clusters

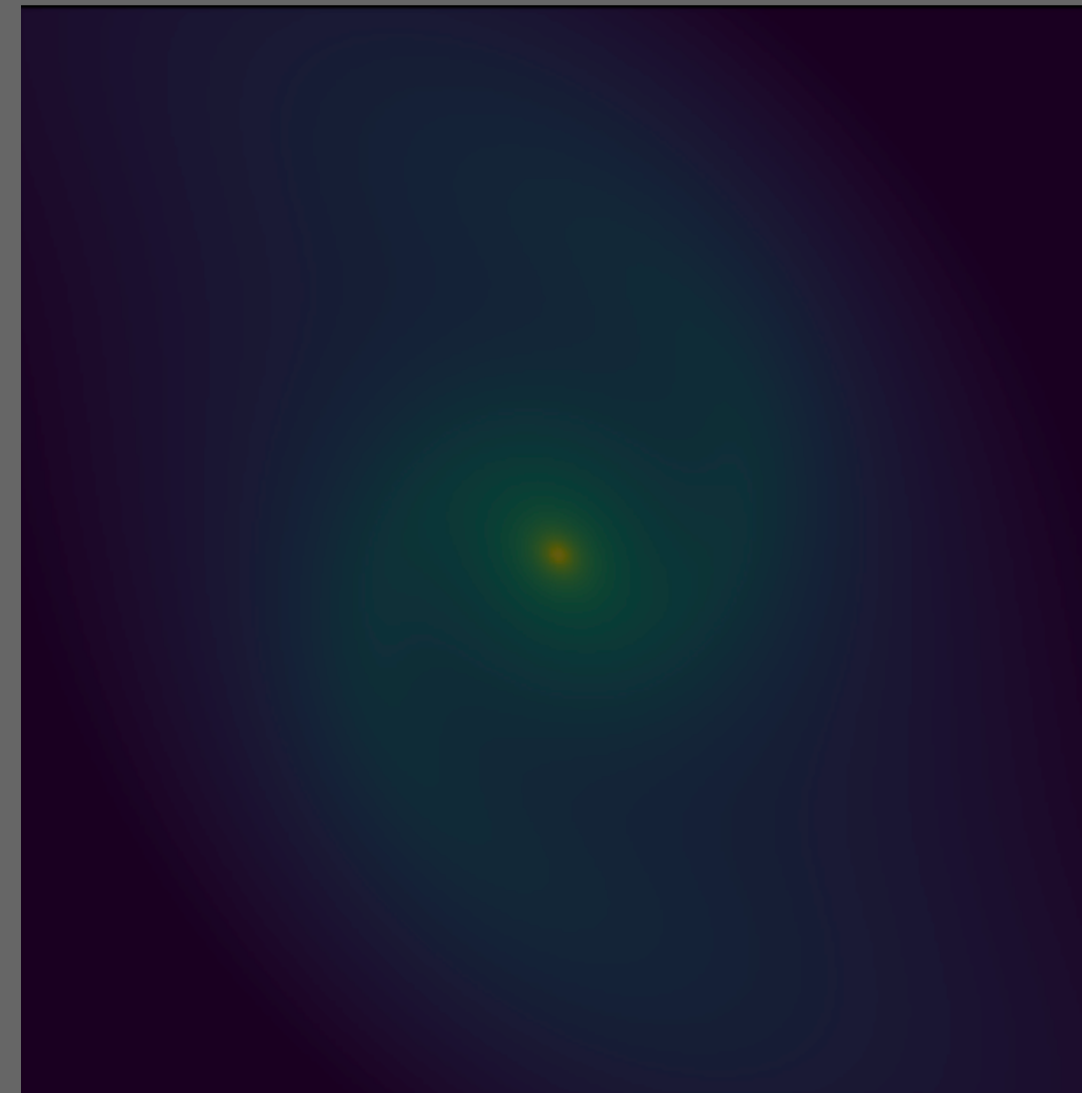
- Redistribute redshifted magnitudes and effective radii among the various components of each model

Parametric galaxy models with GALFIT

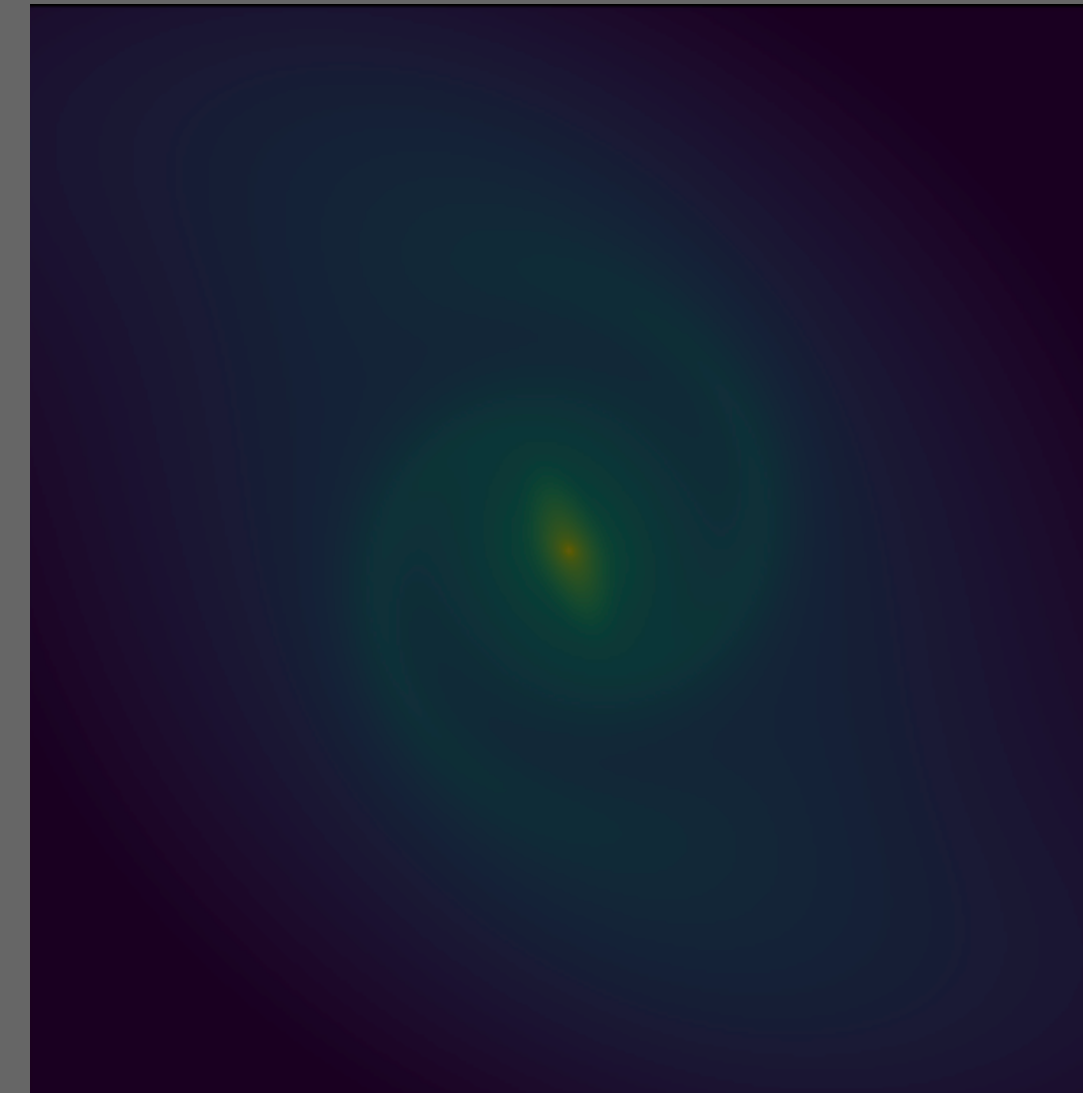
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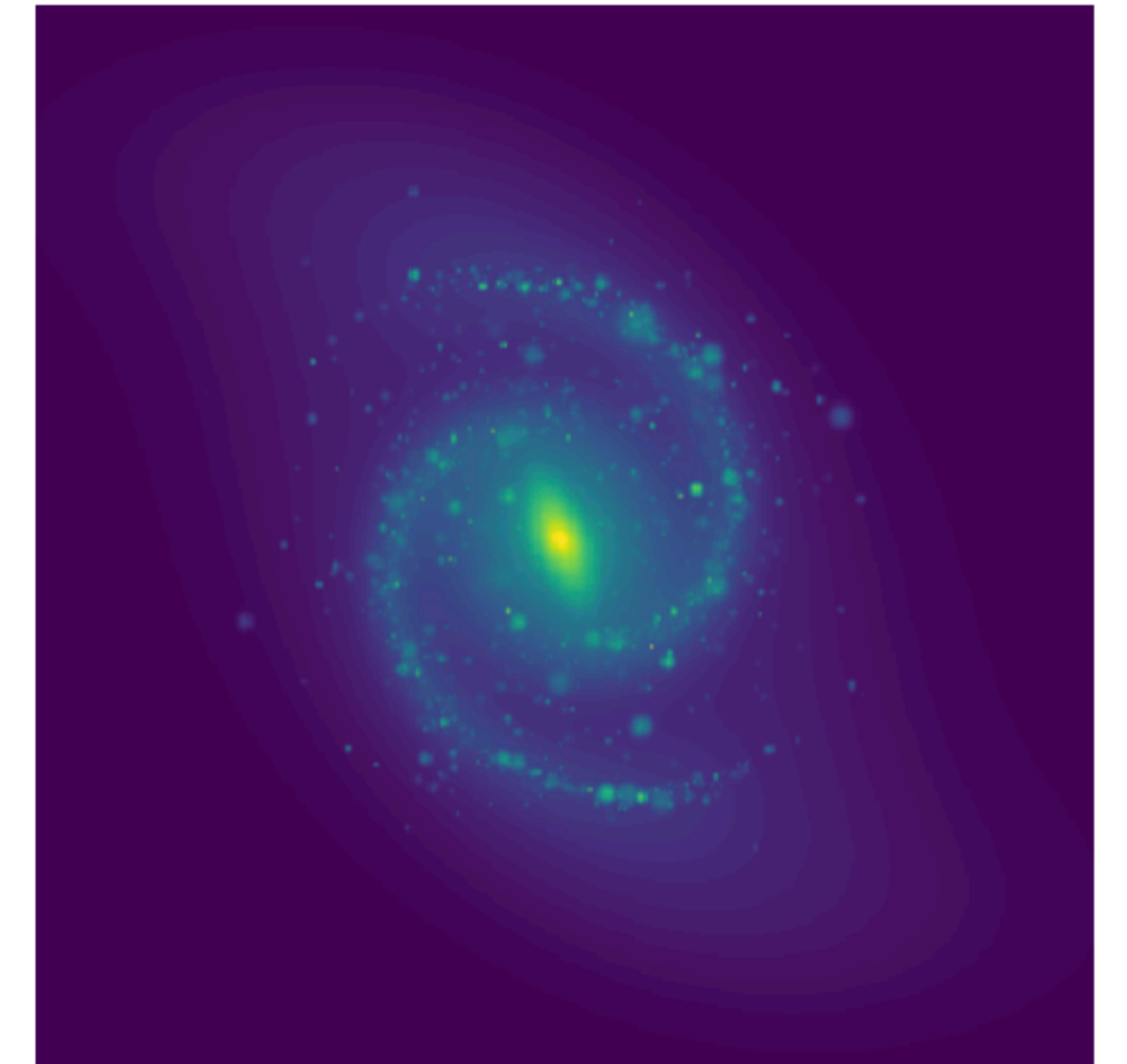
B+D
+clusters



B+D+spirals
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B+D+spirals+bar



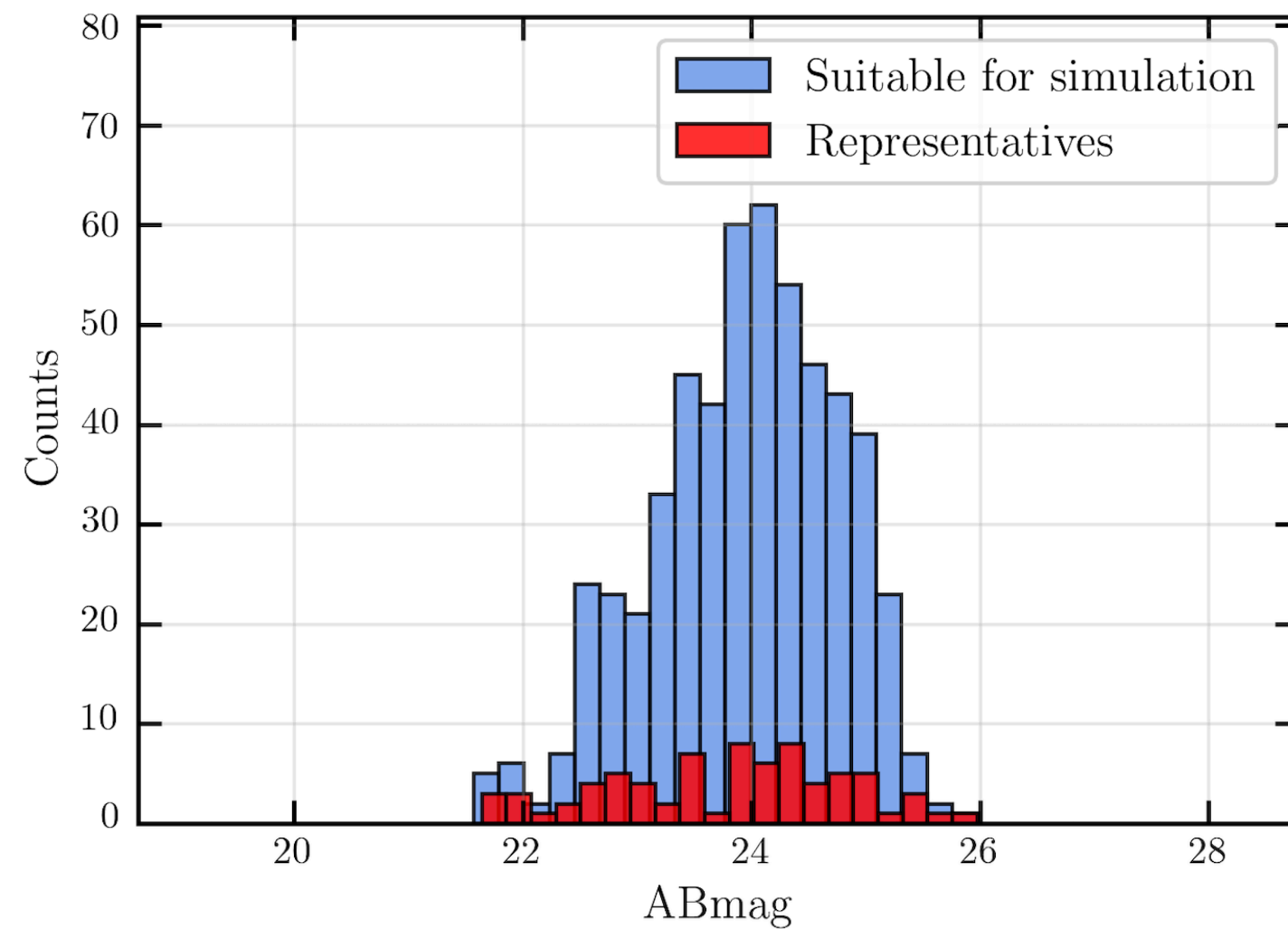
B+D+spirals+bar
+clusters

- Redistribute redshifted magnitudes and effective radii among the various components of each model

Consider the redshifted properties at $z=2.25$ in the K-band for 3 test cases

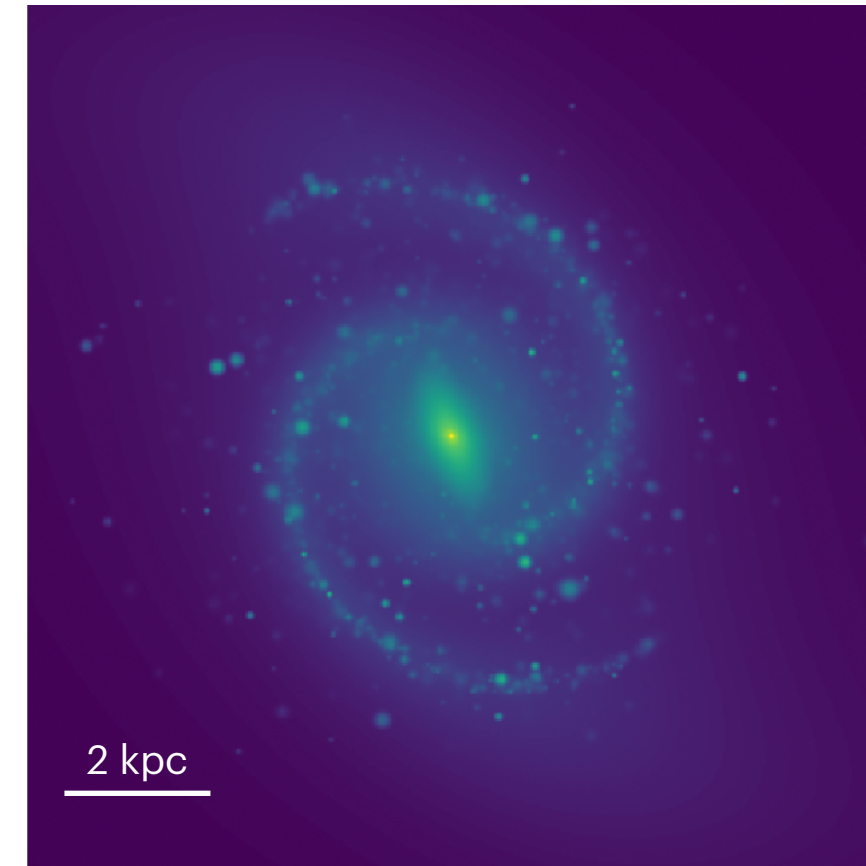
Selection of 3 test cases

K-band at $z=2.25$

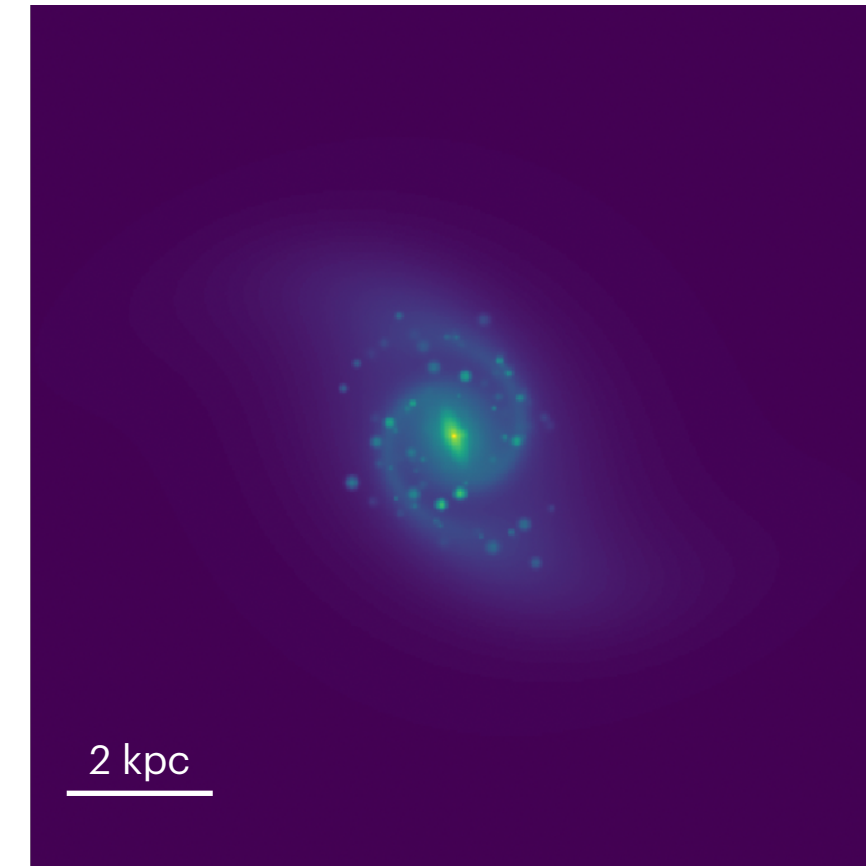


21.7 24.0 25.7

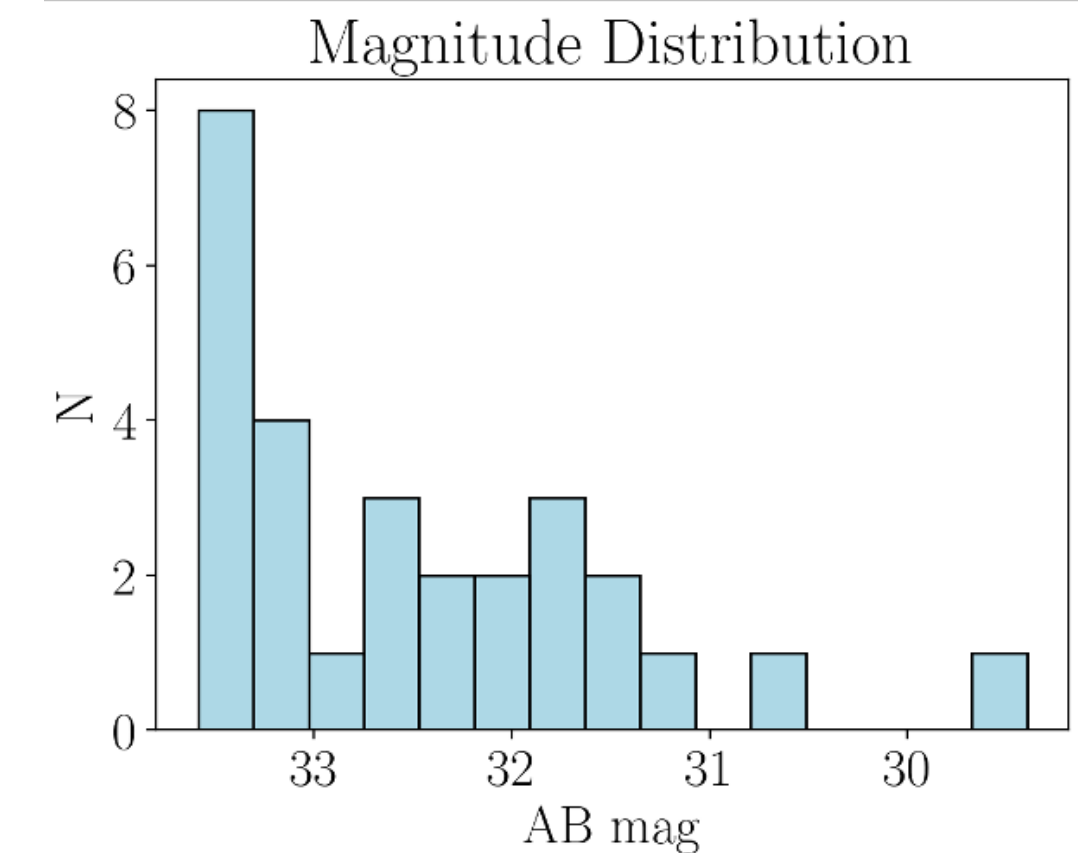
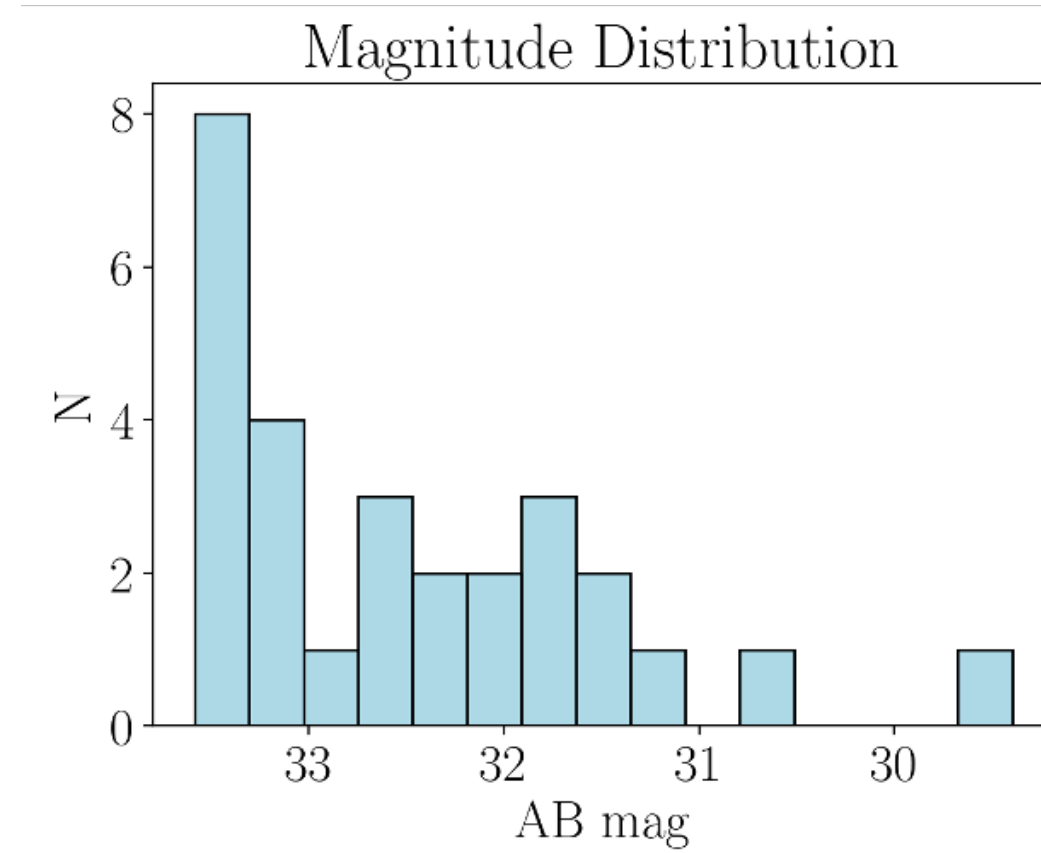
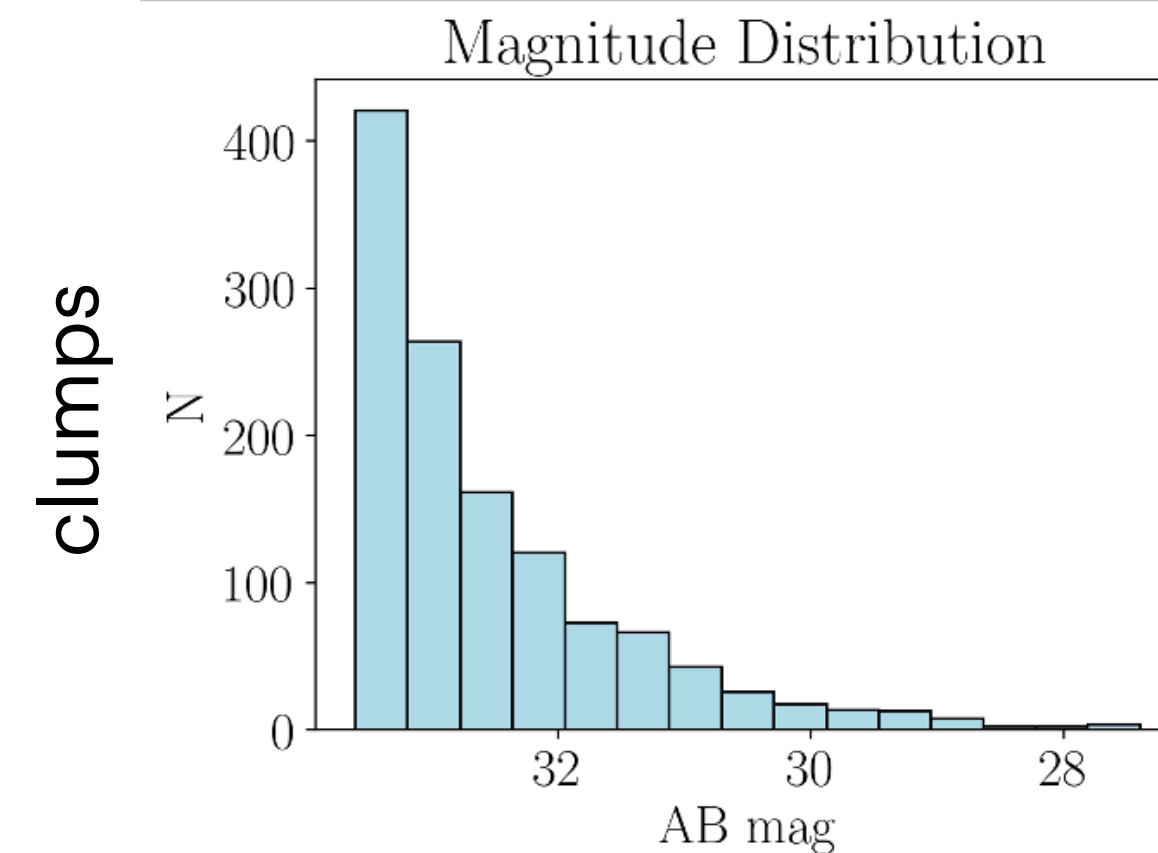
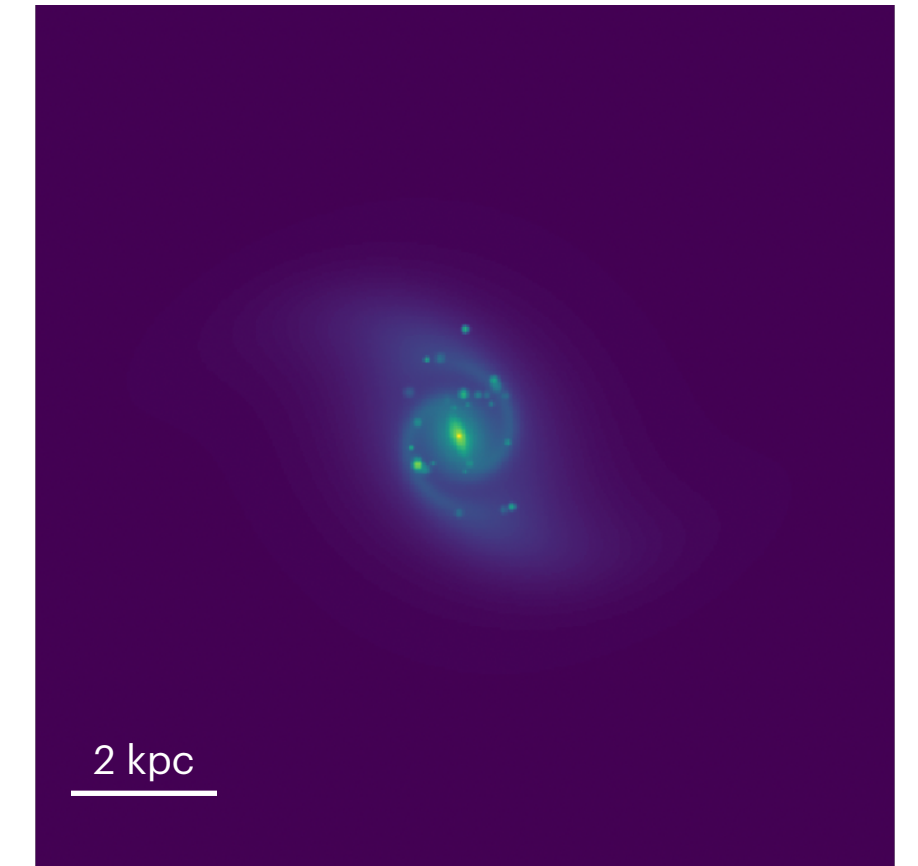
bright



median



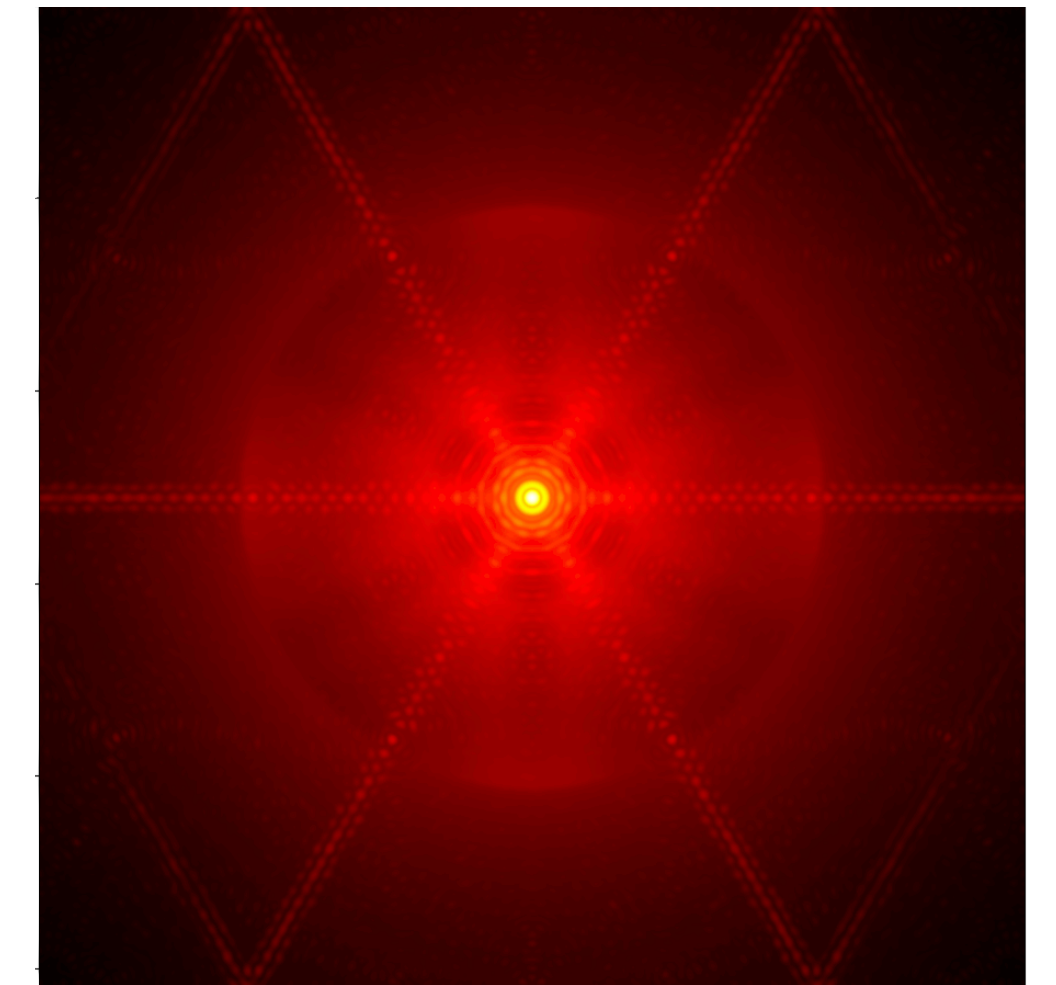
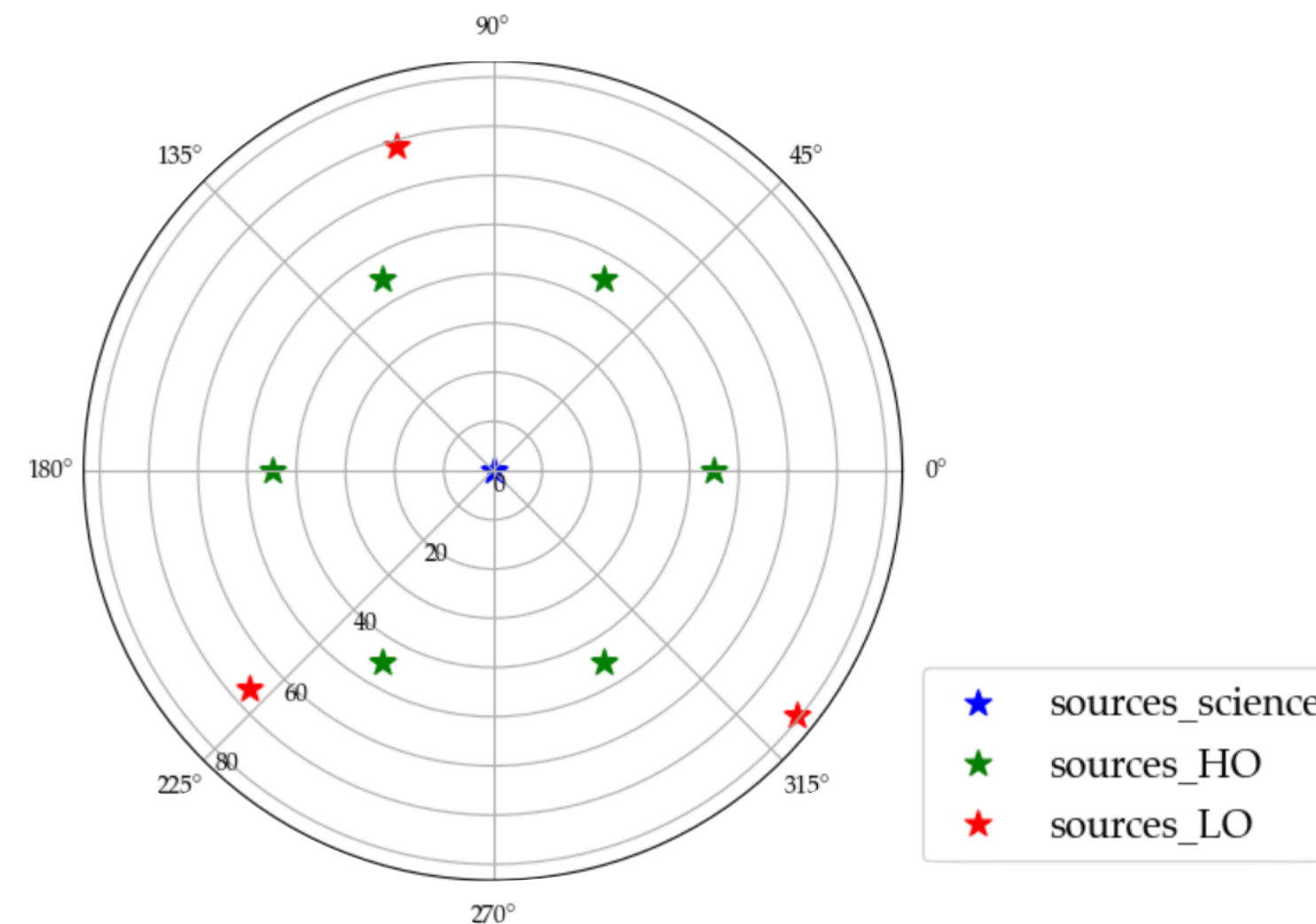
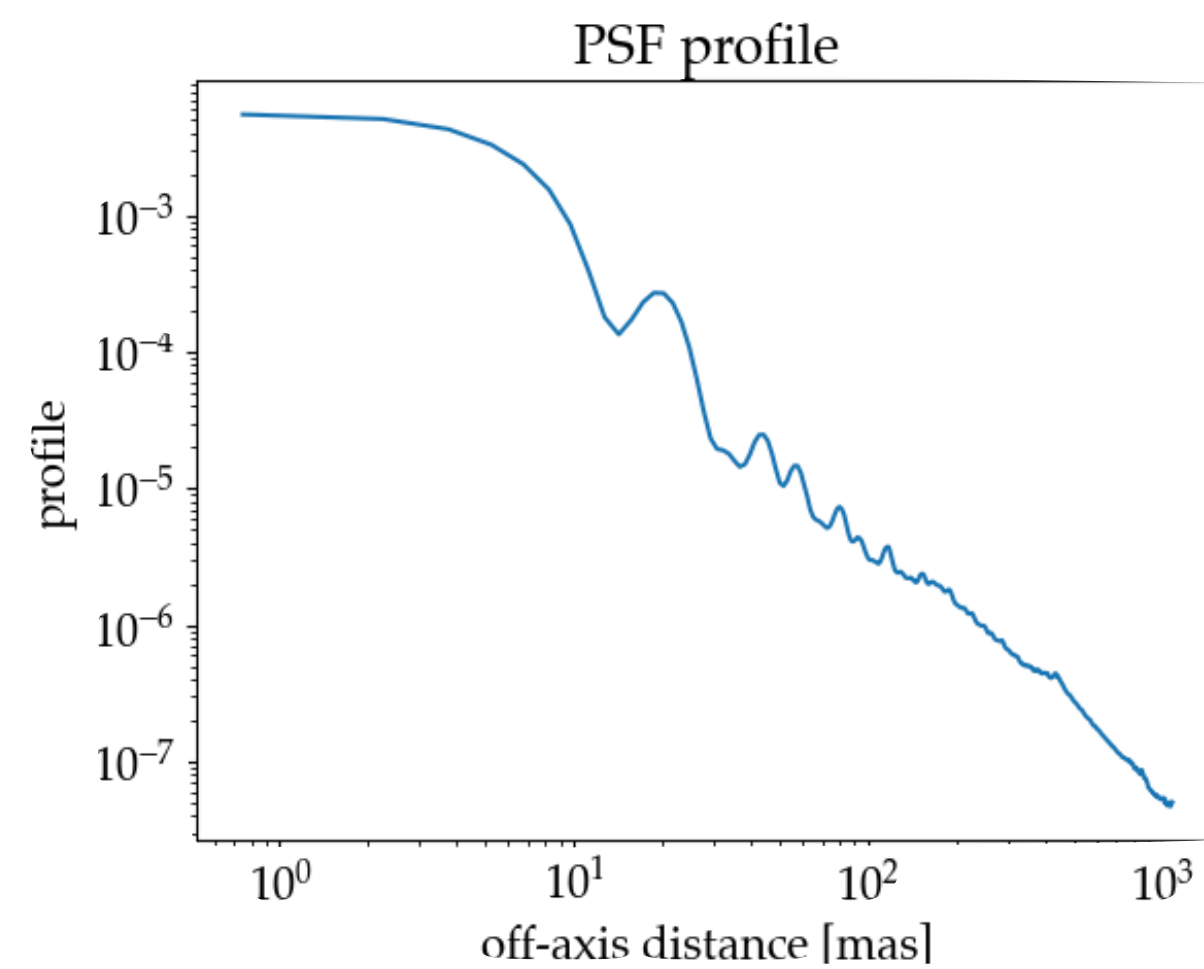
faint



TIPTOP

PSF simulation in the K band

- Compute the PSF in the K band, for a configuration of bright NGS stars



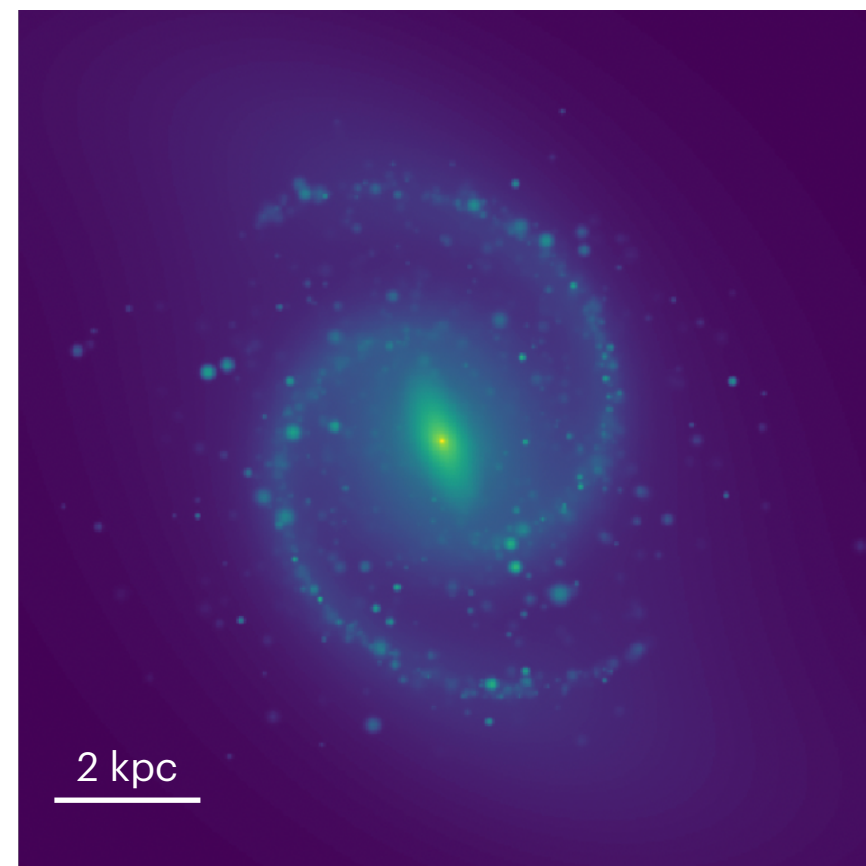
SR: 0.52

FWHM: 12.31 mas

ScopeSim simulations

Bright case

model

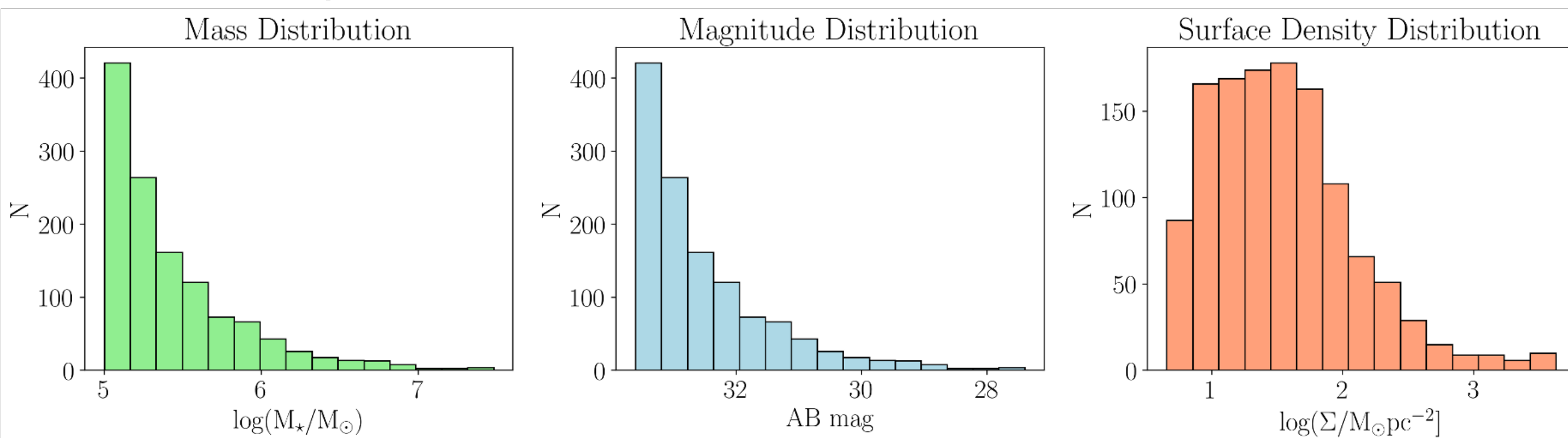


$z=2.25$

21.7 ABmag

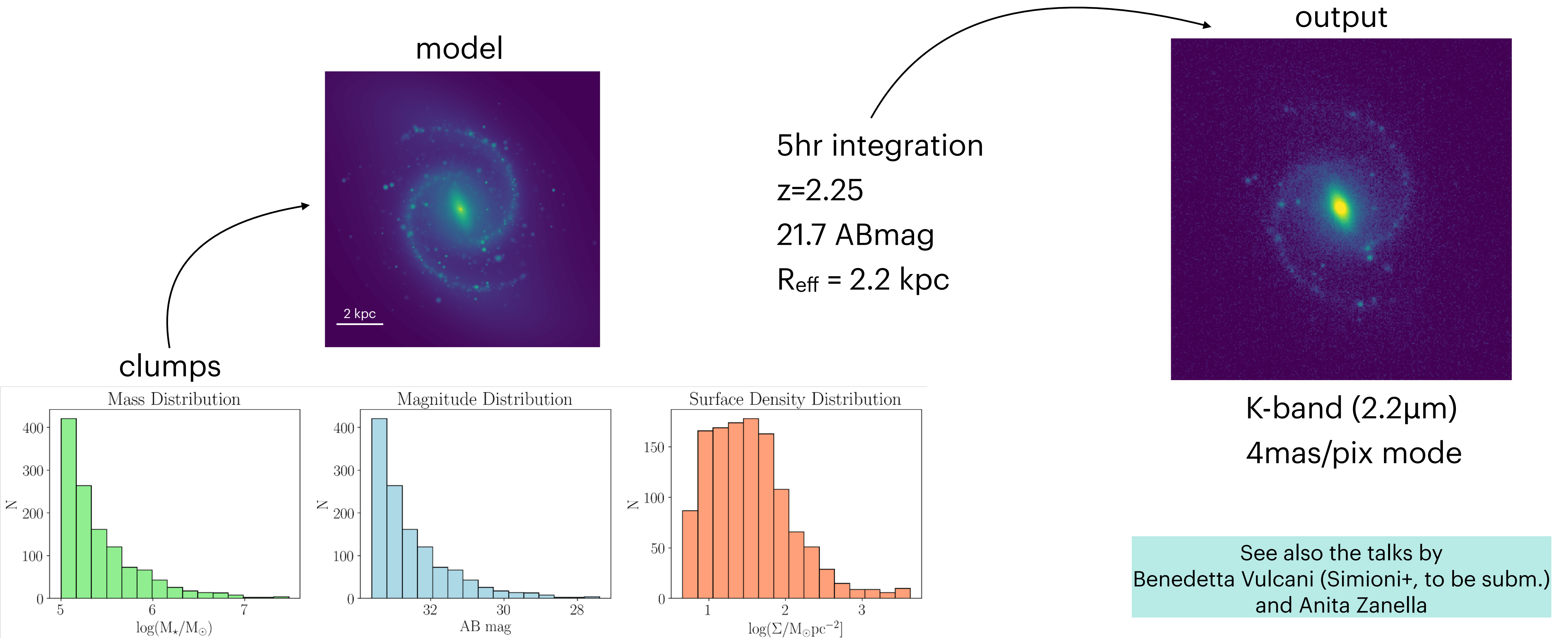
$R_{\text{eff}} = 2.2 \text{ kpc}$

clumps



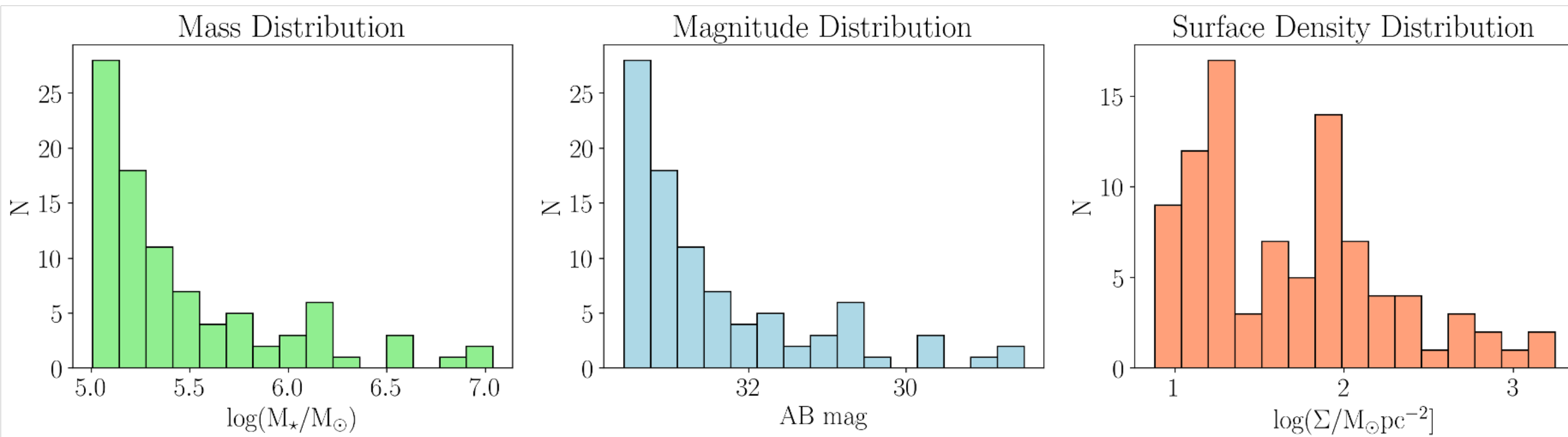
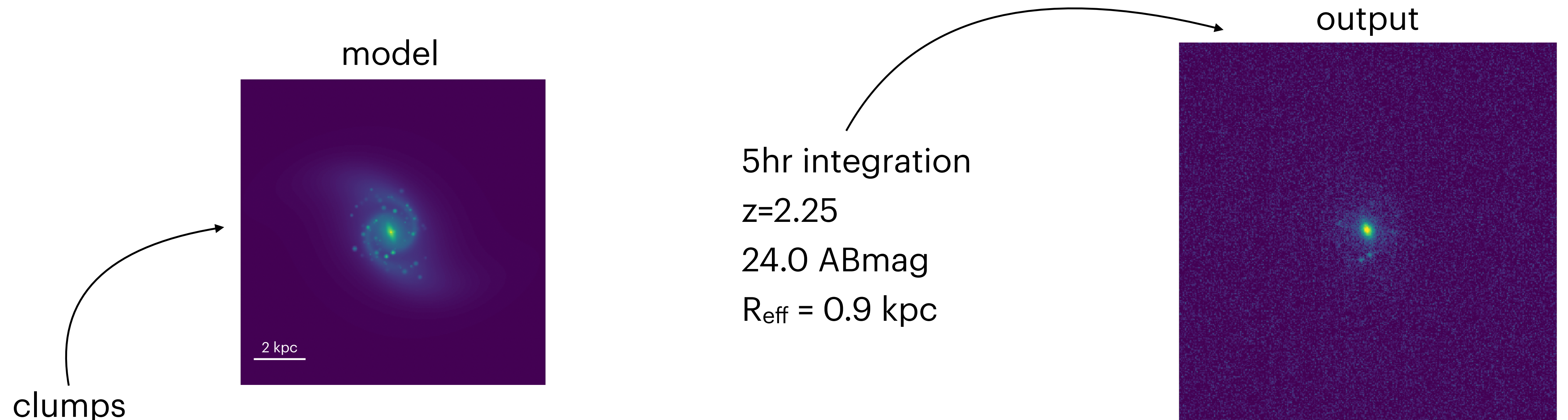
ScopeSim simulations

Bright case



ScopeSim simulations

Median case

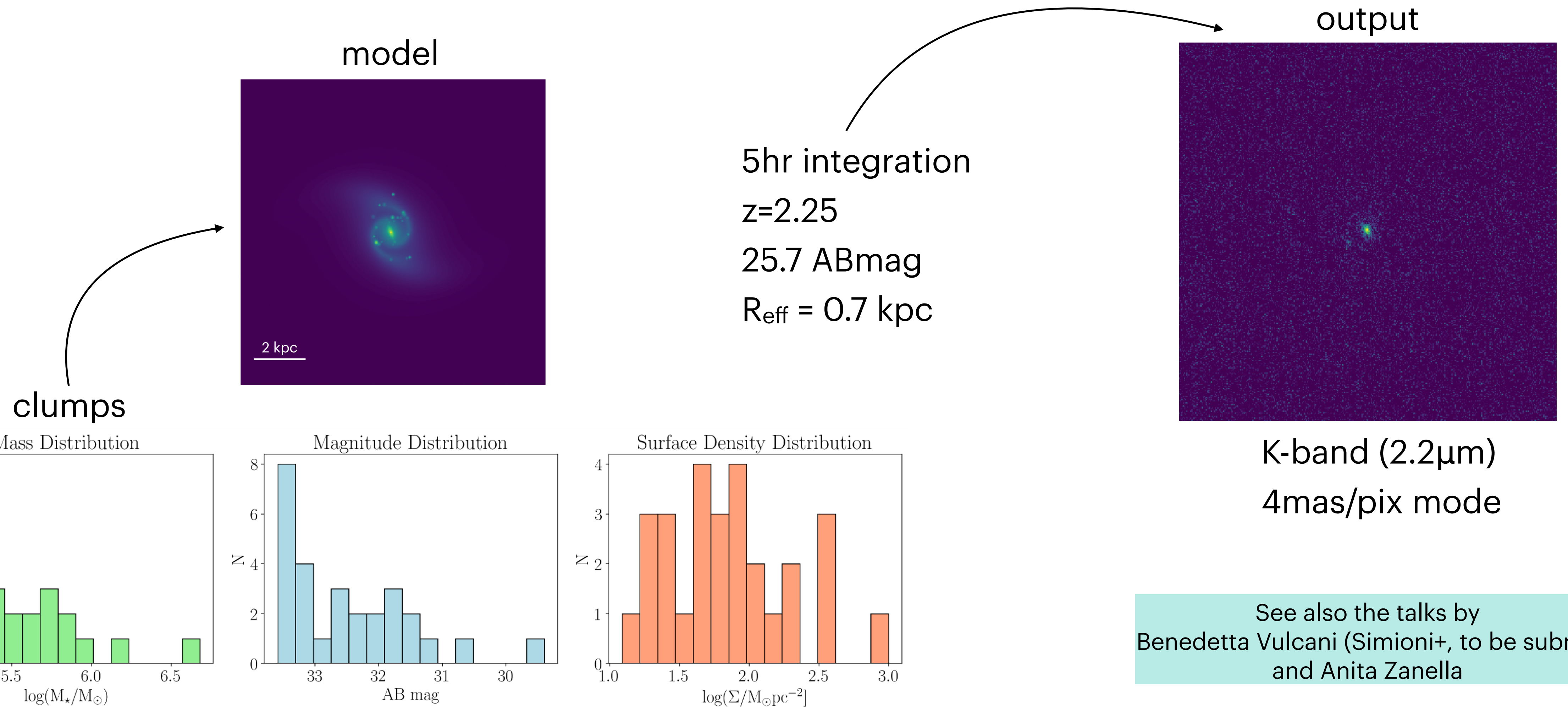


K-band ($2.2\mu\text{m}$)
4mas/pix mode

See also the talks by
Benedetta Vulcani (Simioni+, to be subm.)
and Anita Zanella

ScopeSim simulations

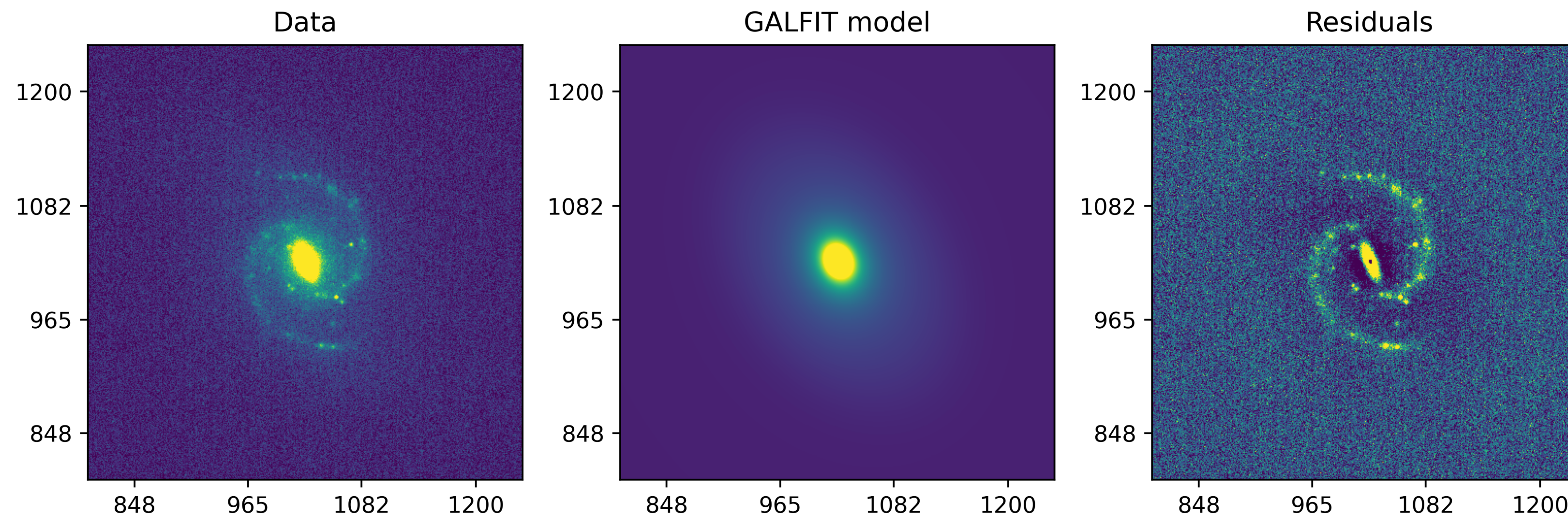
Faint case



Quantitative recovery

Post-processing of ScopeSim simulations

1. GALFIT fit: 1 or 2 Sérsic components

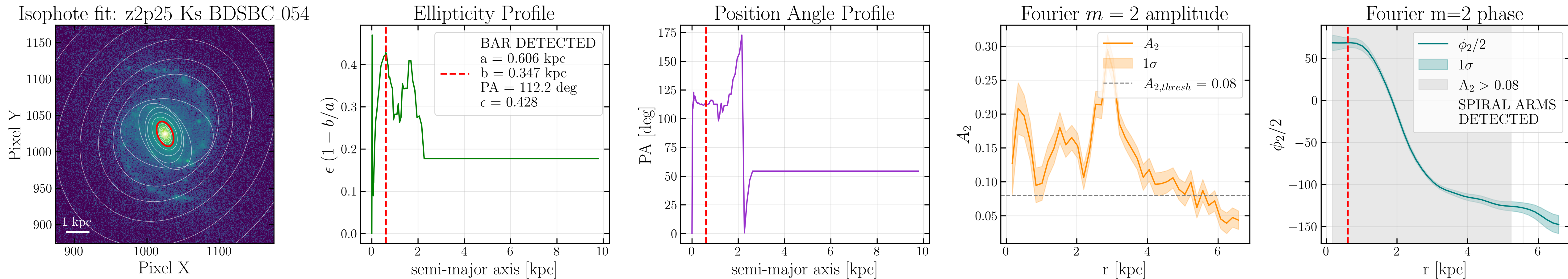


Disk and bulge components are detected in ~ **90%** of the cases

Quantitative recovery

Post-processing of ScopeSim simulations

1. GALFIT fit: 1 or 2 Sérsic components
2. Ellipse fitting & Fourier analysis: bar component and spiral arms detection



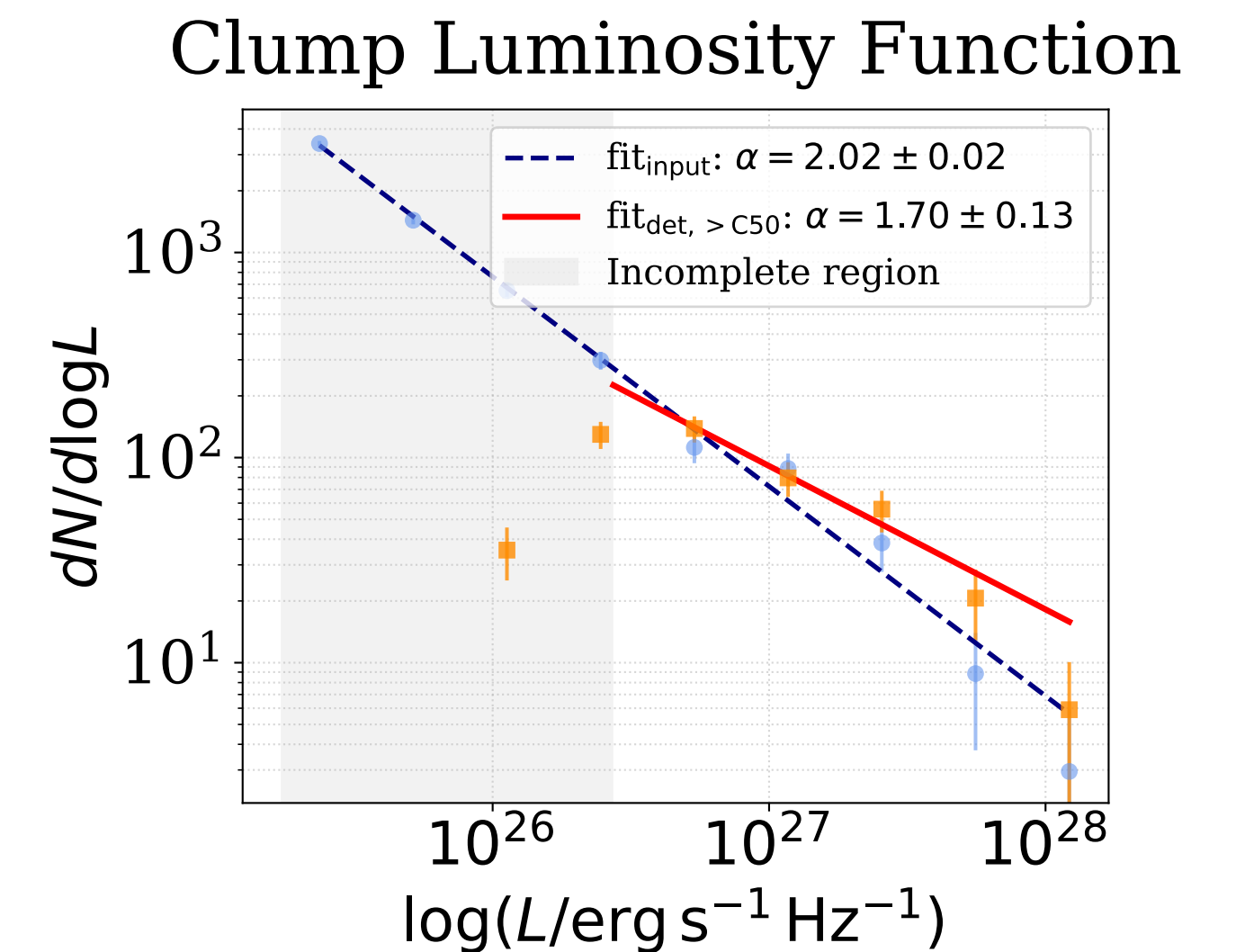
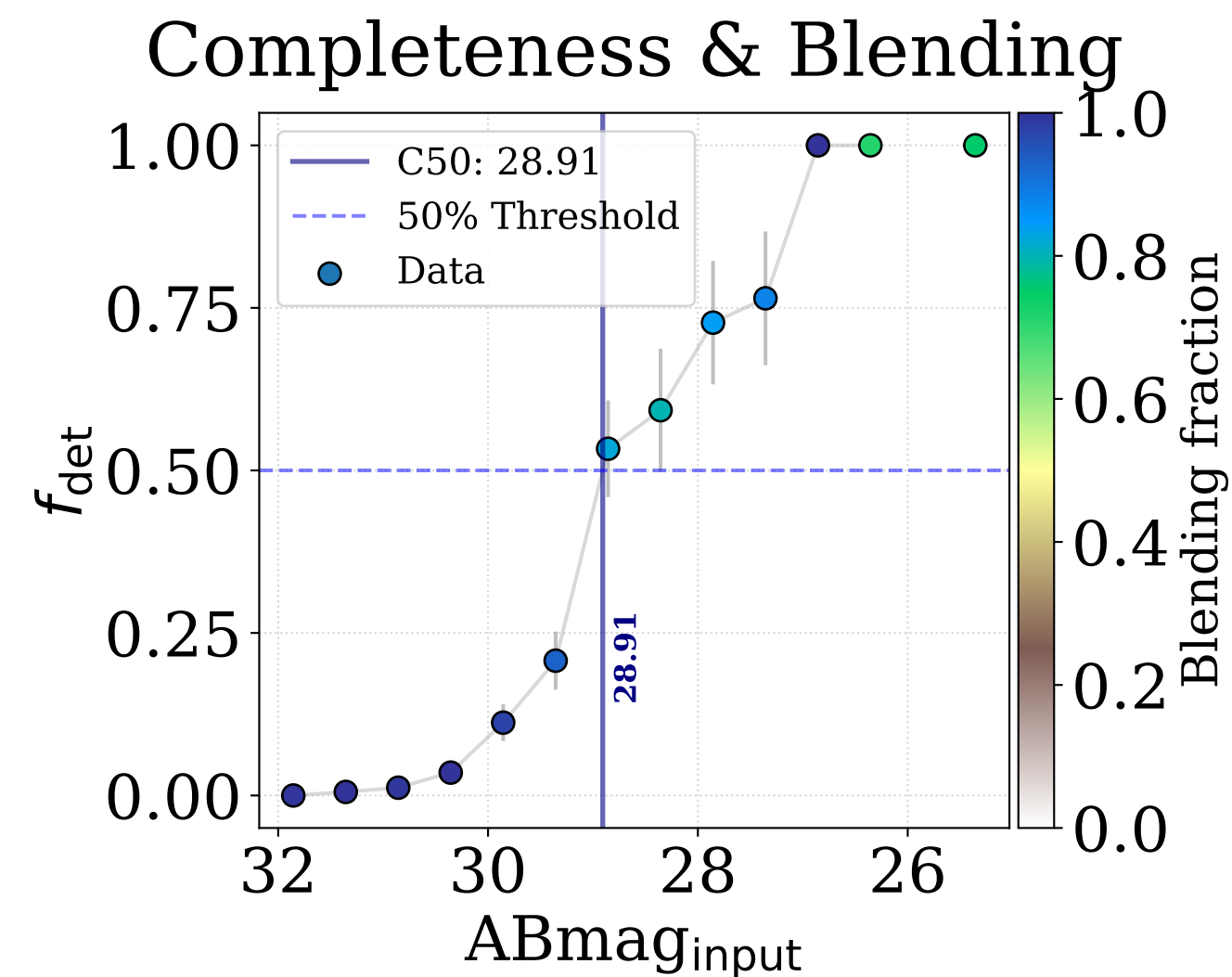
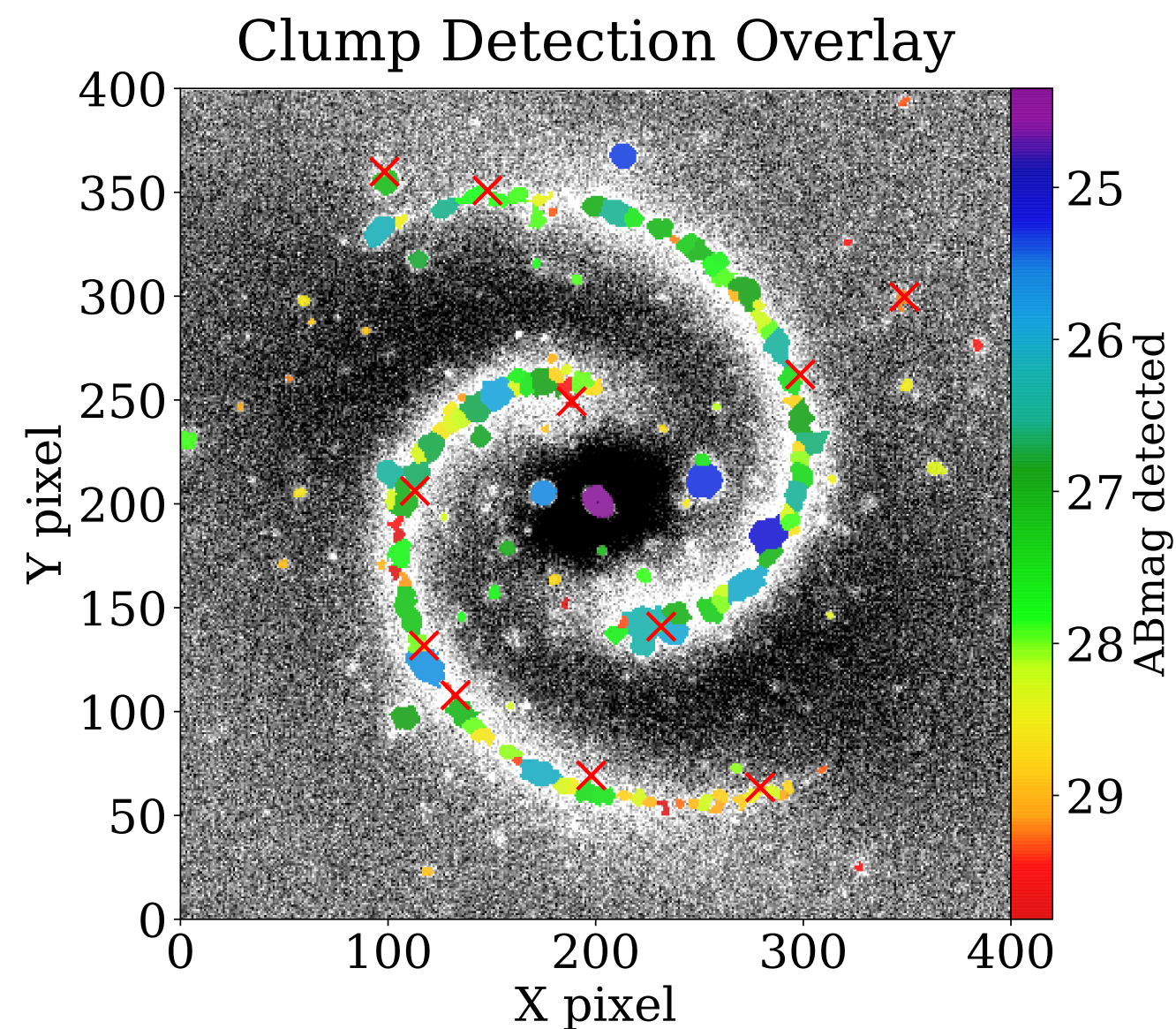
Non-axisymmetric features are identified in **> 40–50%** of galaxies down to $m_{\text{tot}} \sim \mathbf{23-24}$

Quantitative recovery

Post-processing of ScopeSim simulations

1. GALFIT fit: 1 or 2 Sérsic components
2. Ellipse fitting & Fourier analysis: bar component and spiral arms detection
3. Clumps identification: PyCupid module

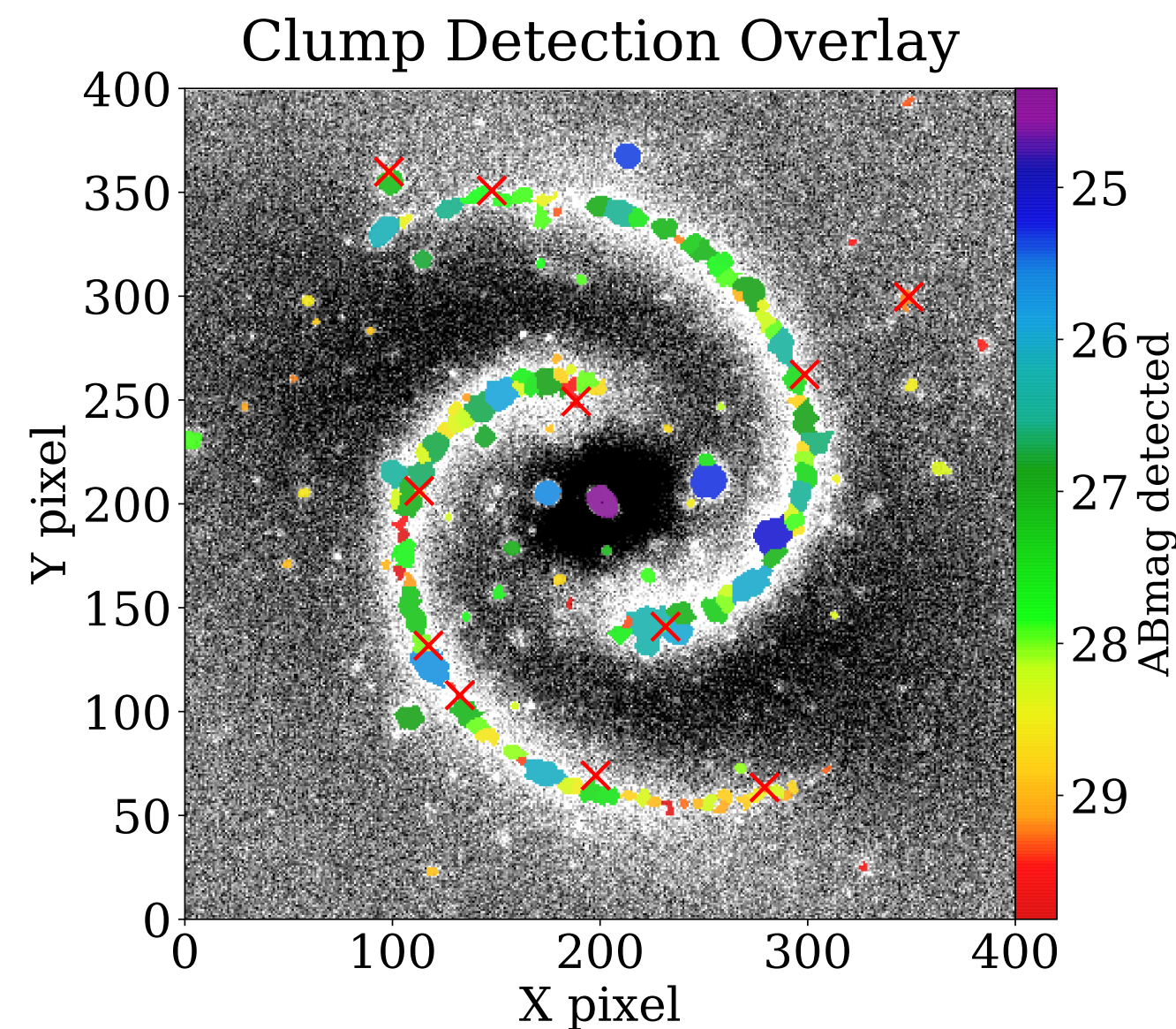
$z=0.75$
21.6 ABmag
 $R_{\text{eff}} = 1.8$ kpc



Quantitative recovery

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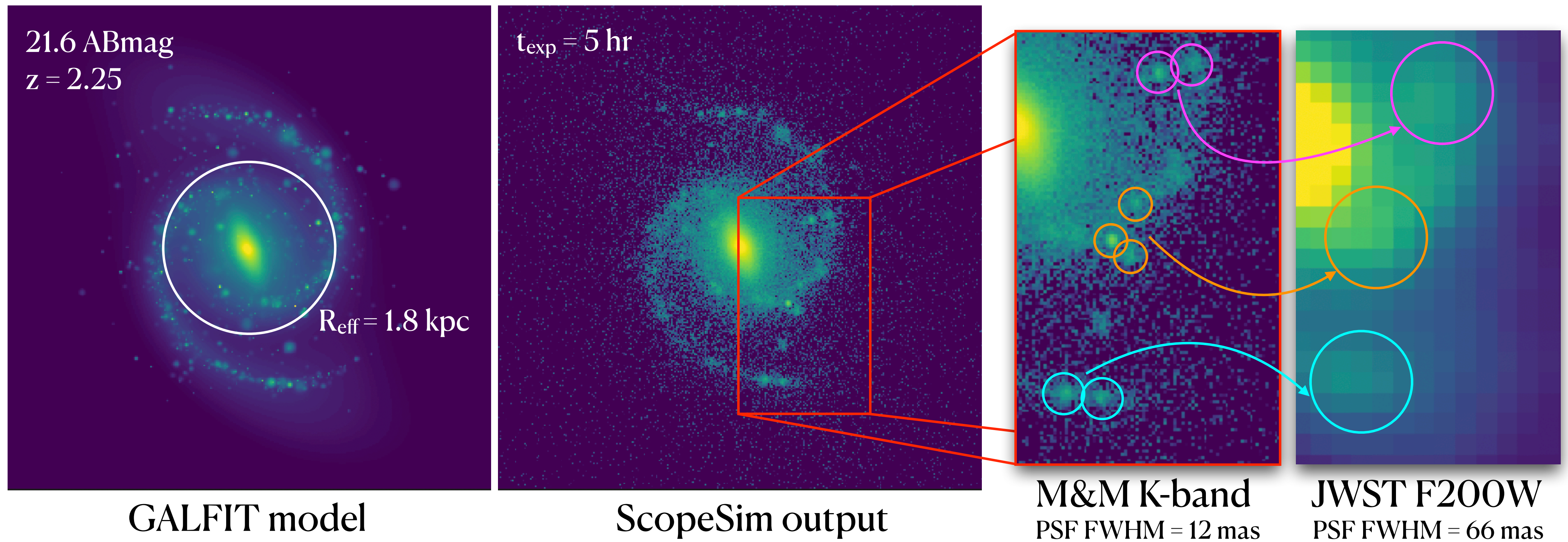
$z=0.75$
21.6 ABmag
 $R_{\text{eff}} = 1.8 \text{ kpc}$

We detect clusters/clumps with 50% completeness of **$m_{\text{AB}} \sim 29\text{--}30$** in the most sensitive J, H, K_s bands, and resolve them on physical scales of **$\sim 15\text{--}30 \text{ pc}$** across the explored redshift range

See also Benedetta Vulcani's talk
— Simioni et al., to be submitted

Comparison M&M vs JWST/NIRCam

- MICADO & MORFEO will allow a more effective deblending of closely spaced substructures compared to JWST



Thank you!