Probabilistic characterization of blending in Rubin/LSST: application to cluster lensing cosmology

Rubin/Euclid workshop, December 2024

Manon Ramel

Laboratoire de Physique Subatomique & Cosmologie

Supervisors : Cyrille Doux, Marine Kuna

LPSC GRENOBLE | MODANE

LSST Legacy Survey of Space and Time

LSST DESC Dark Energy Science Collaboration

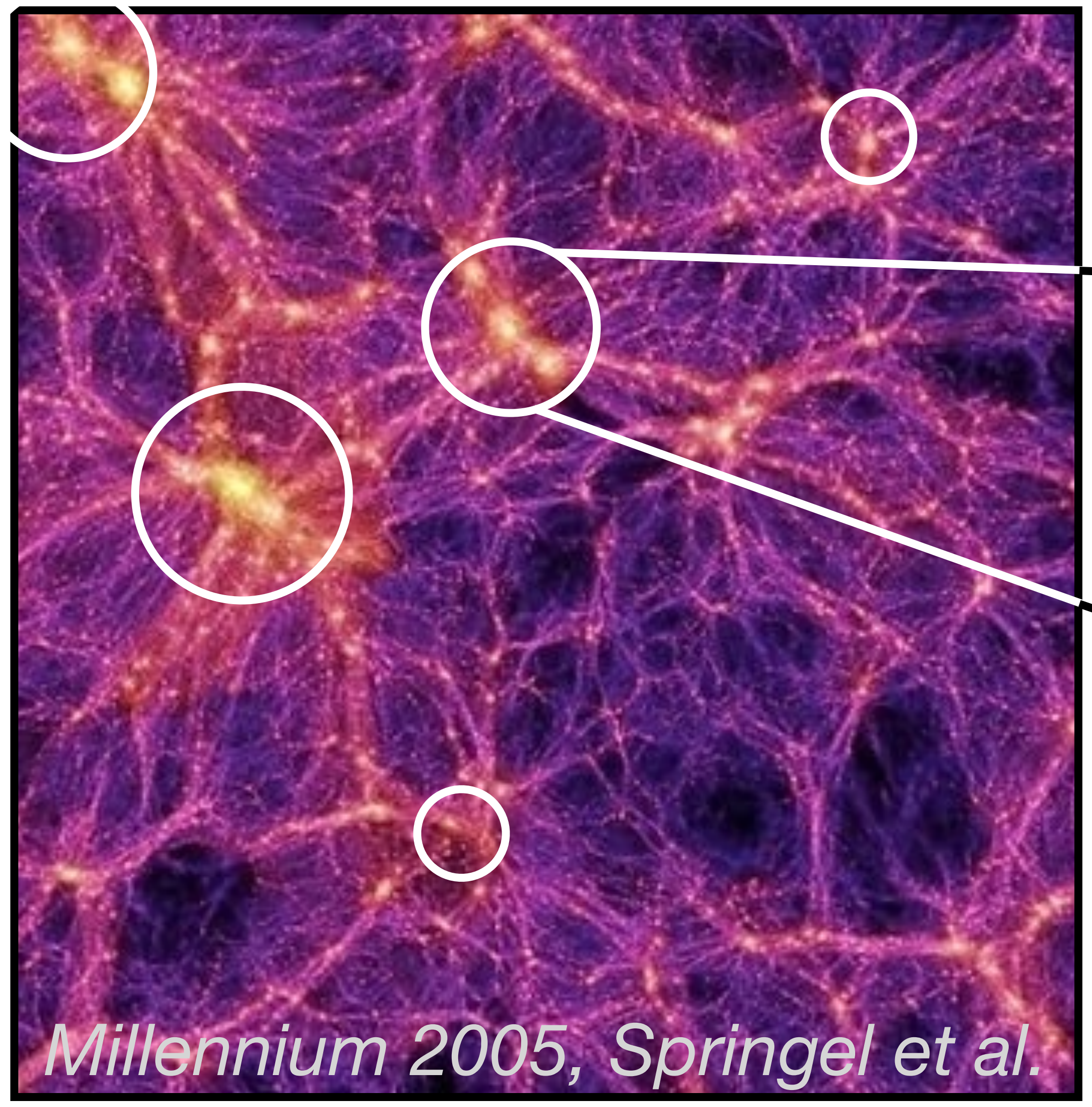
Cosmology with galaxy clusters

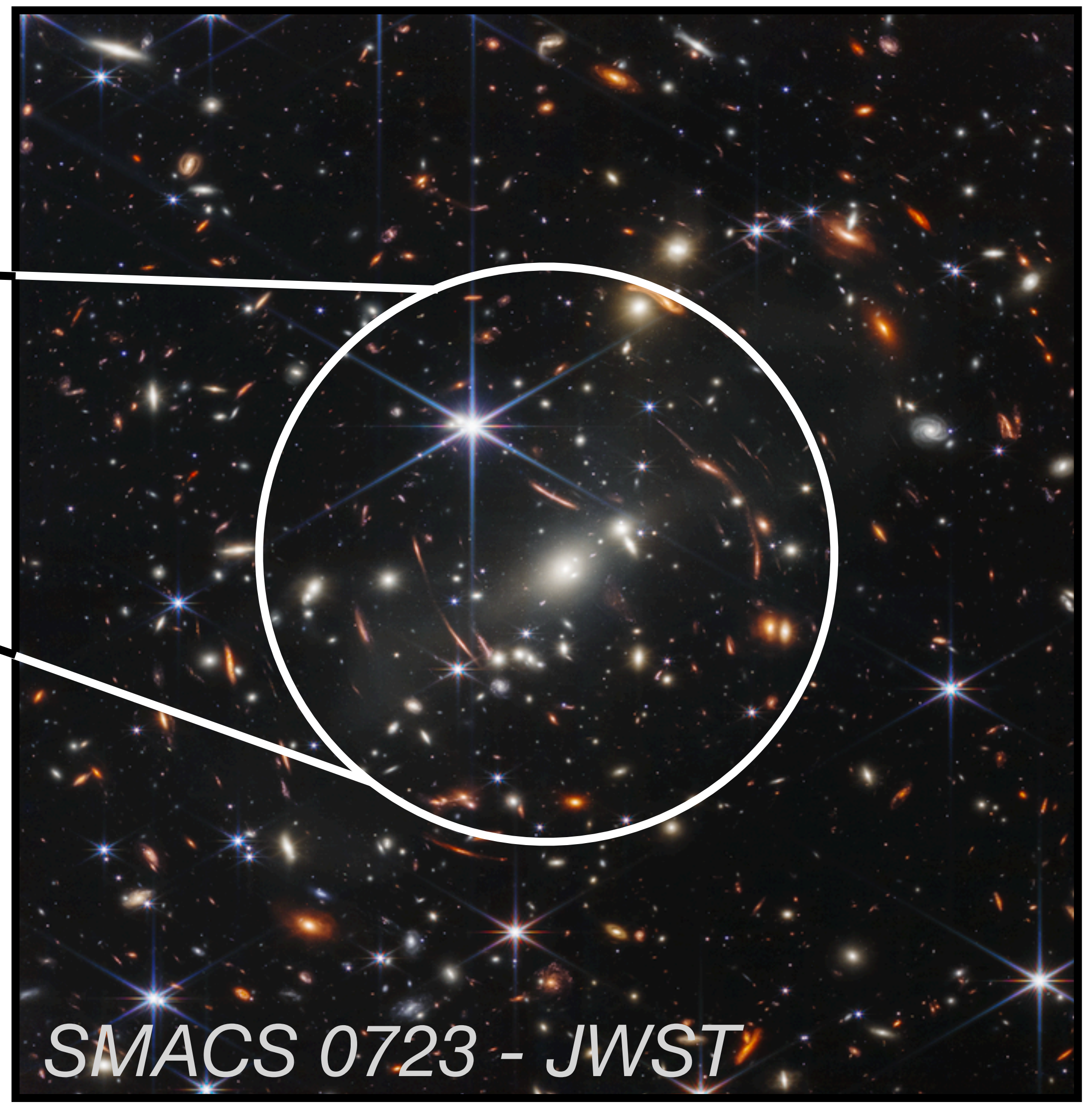
Largest gravitationally bound structures in the Universe

- 50 to 1000 galaxies
- $M > 10^{13.5} M_{\odot}$, $z < 3$

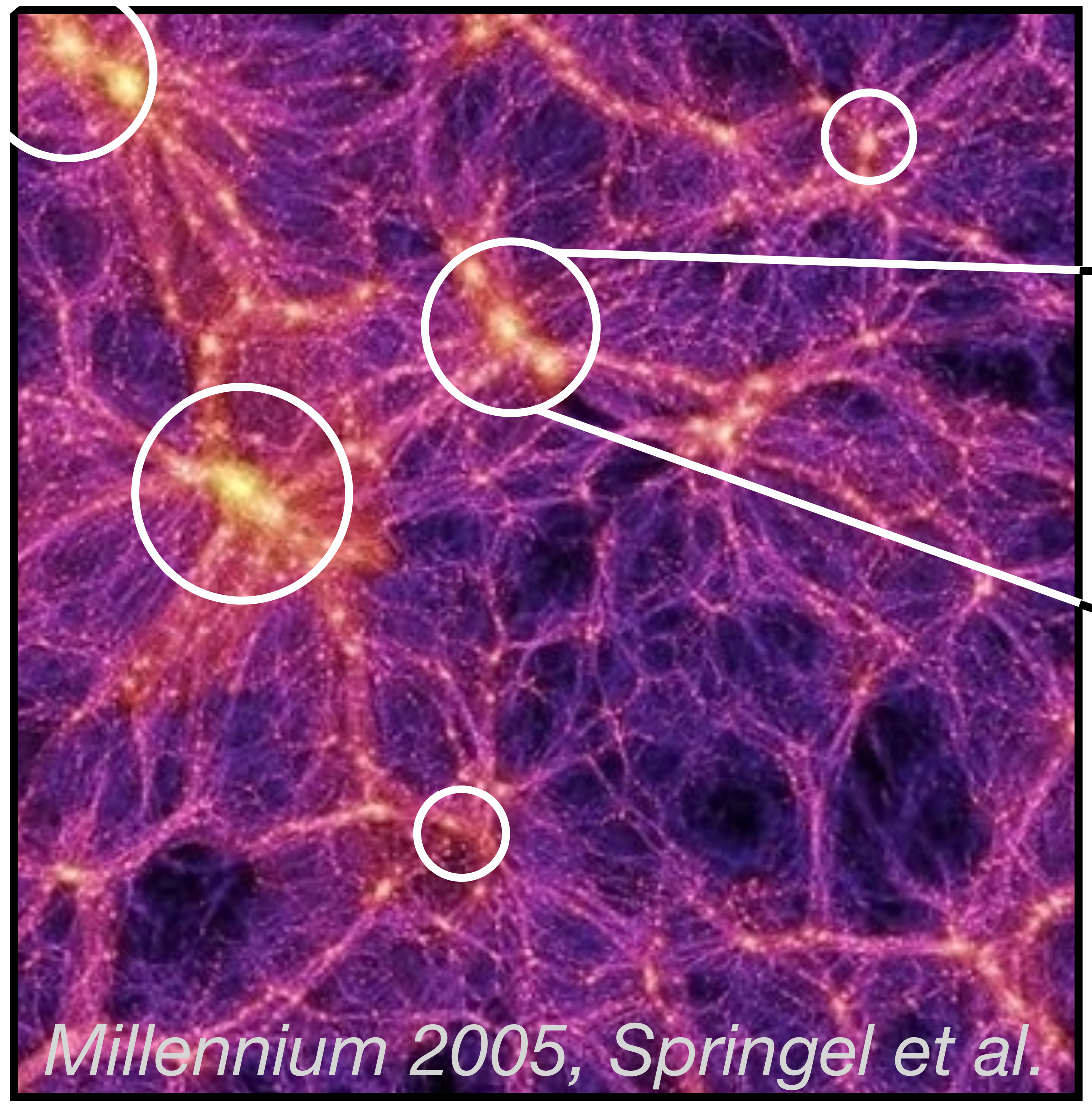
Tracers of the matter over-densities

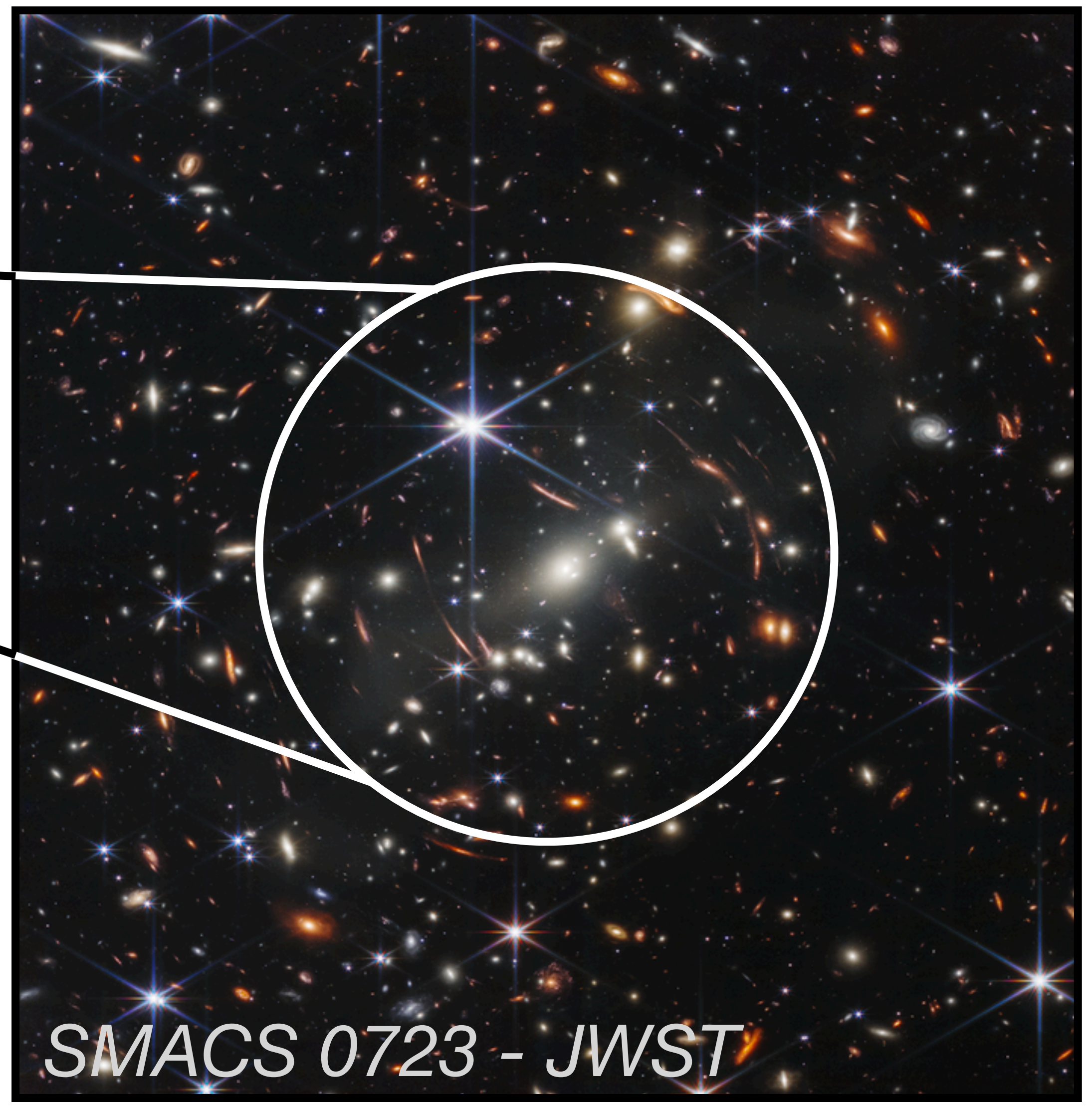
- Depend on cosmology





Cosmology with galaxy clusters





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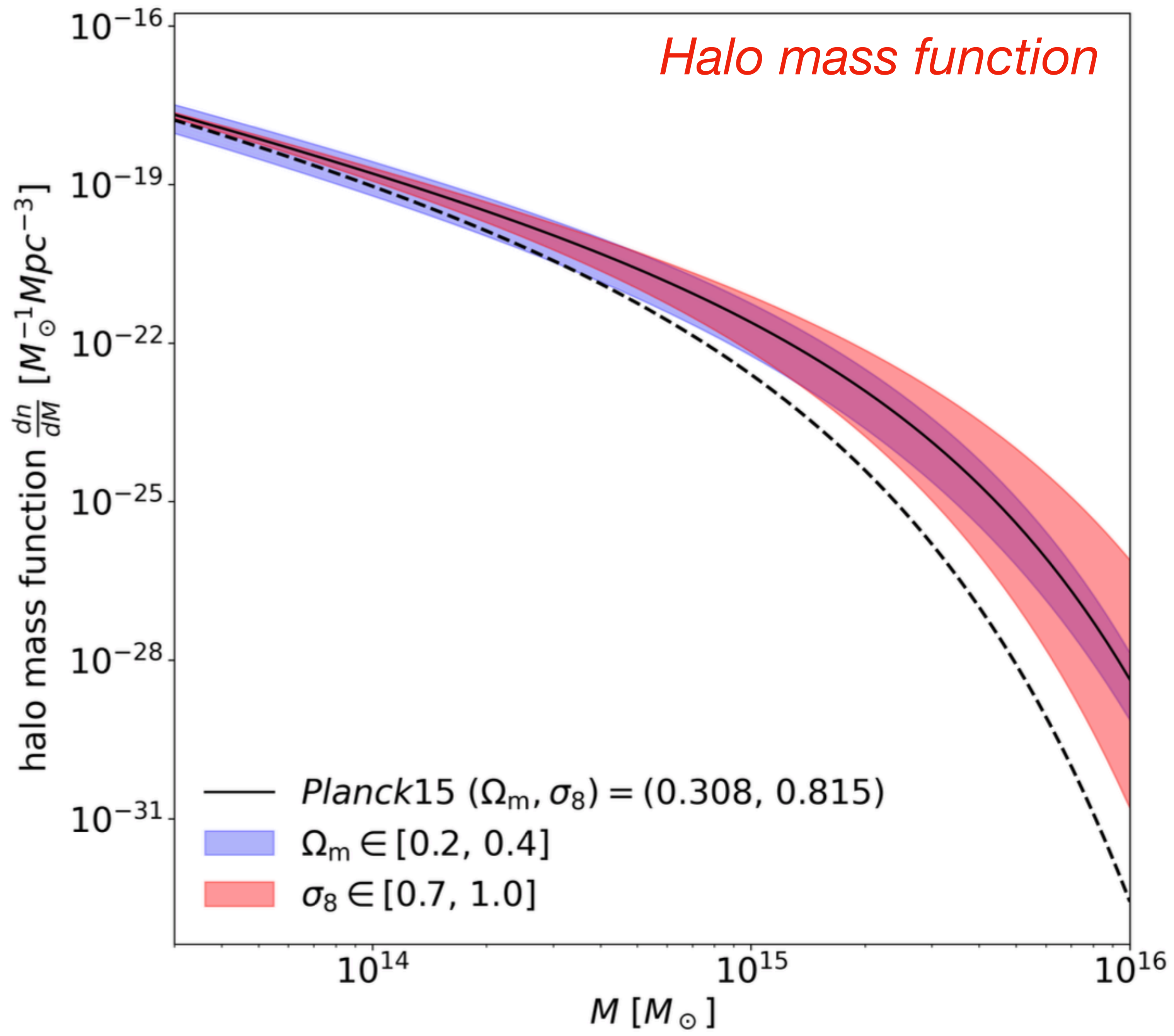
Counting per bins of mass and redshift

$$\frac{\partial^2 N_{th}}{dzdm} \propto \frac{dn(m,z)}{dm} \frac{d^2V(z)}{dzd\Omega}$$



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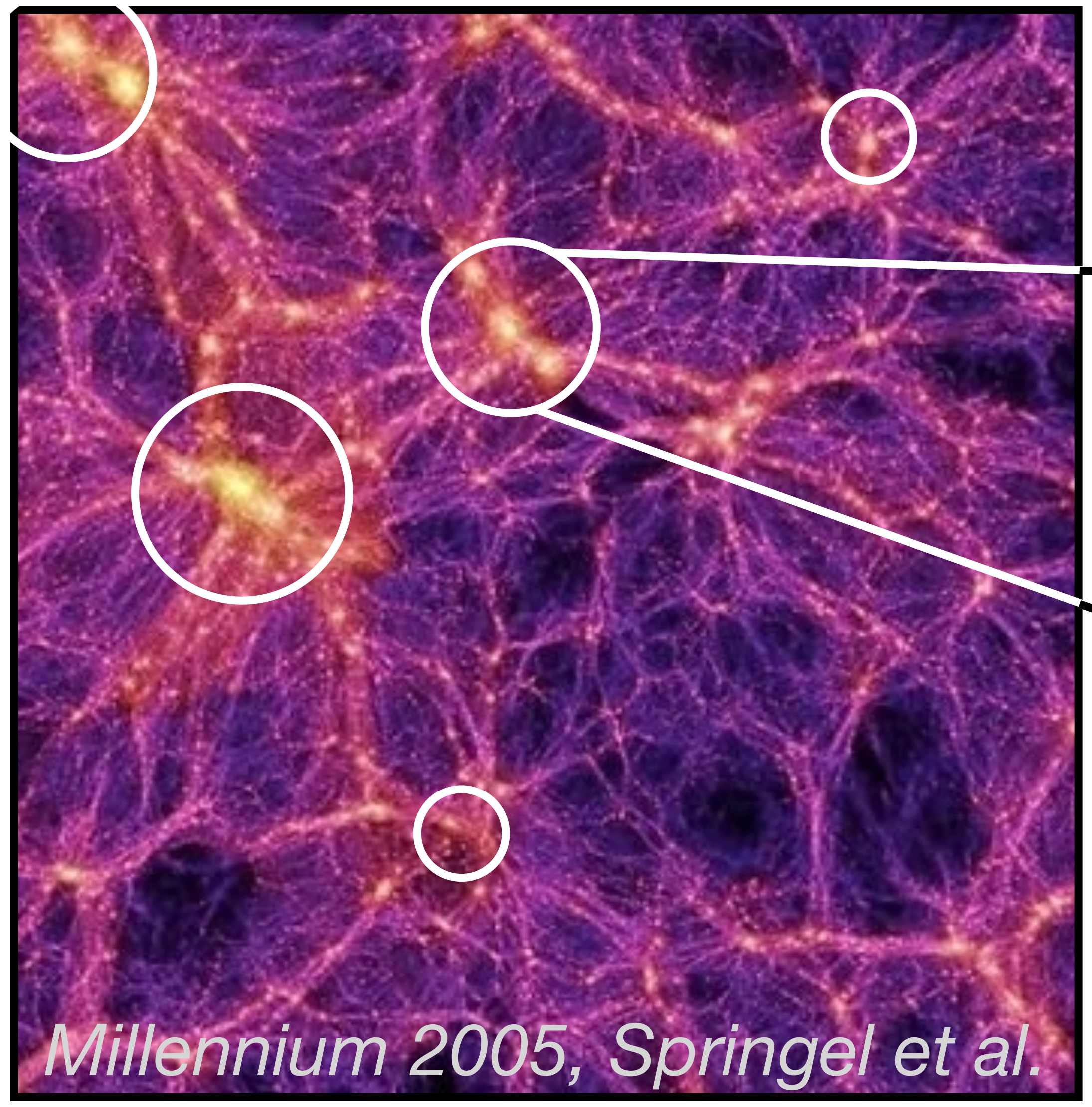

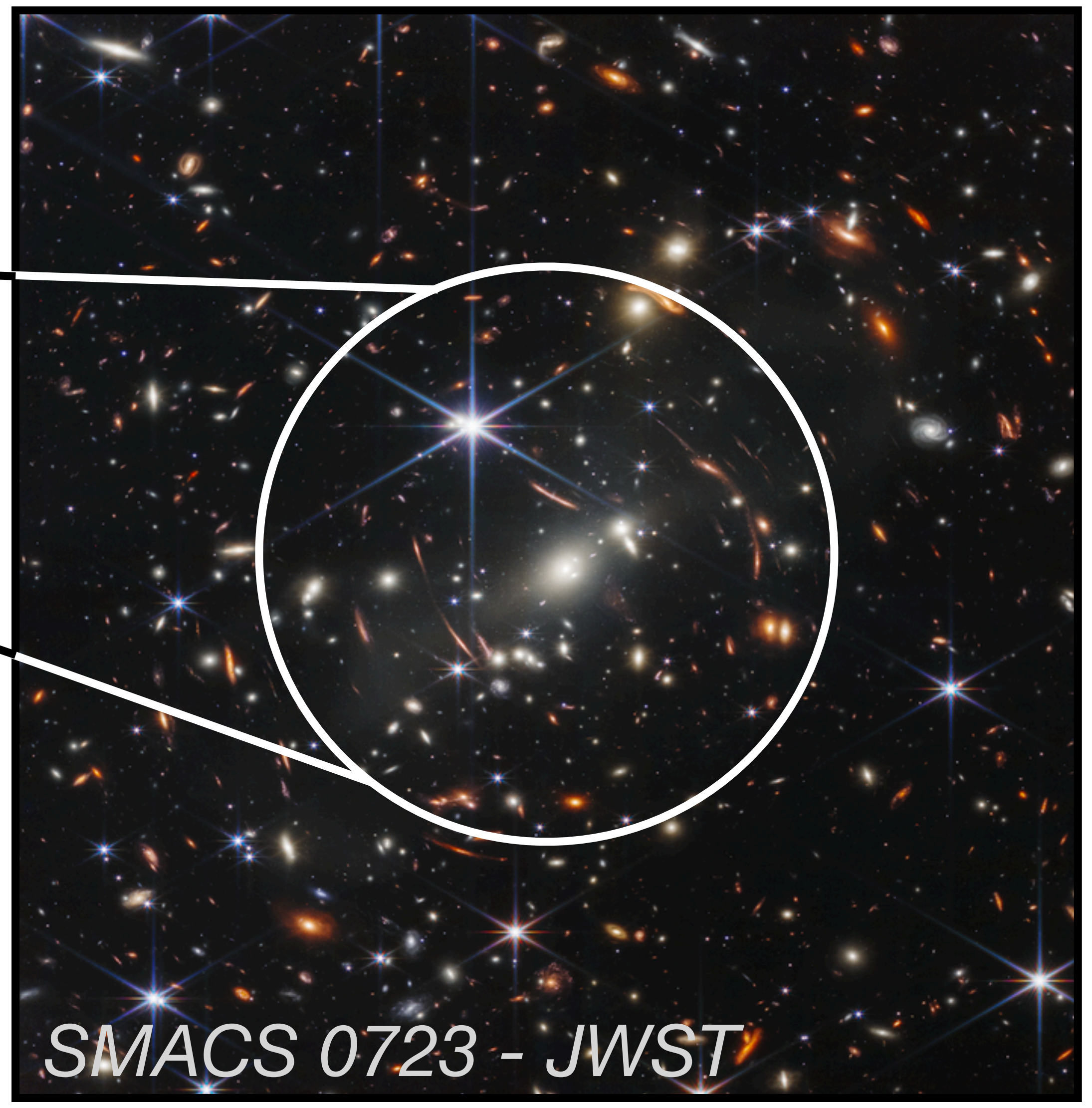

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proxys

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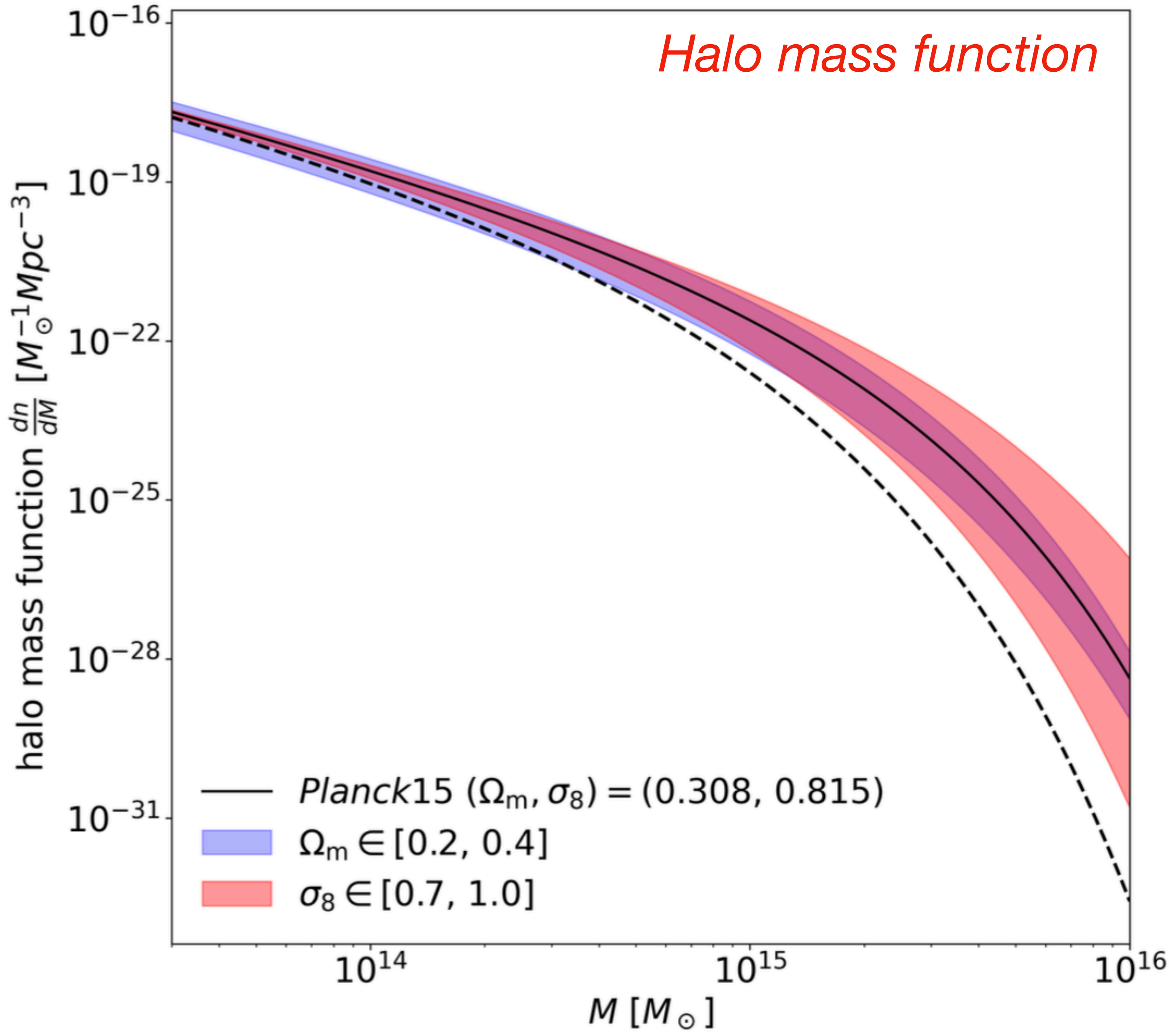

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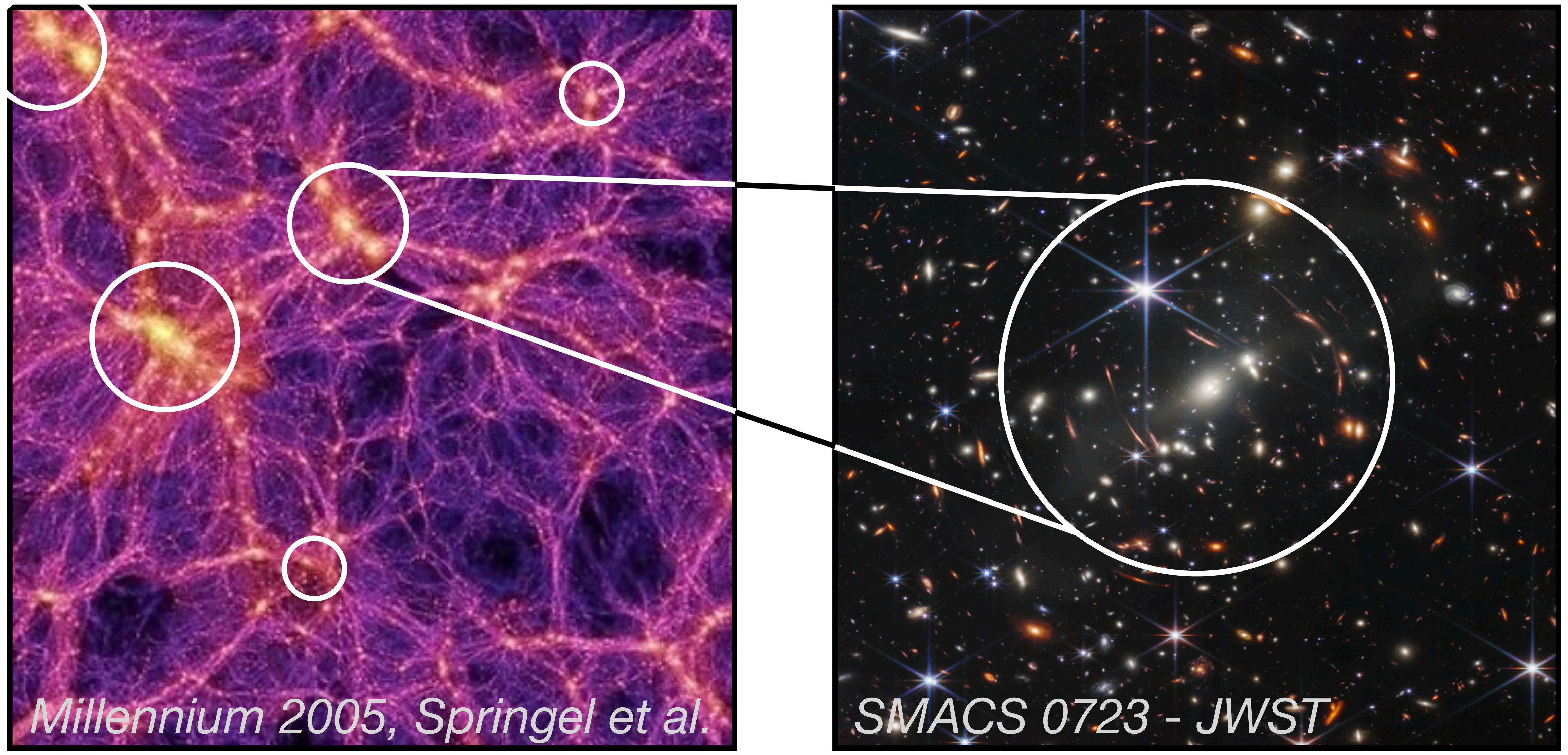

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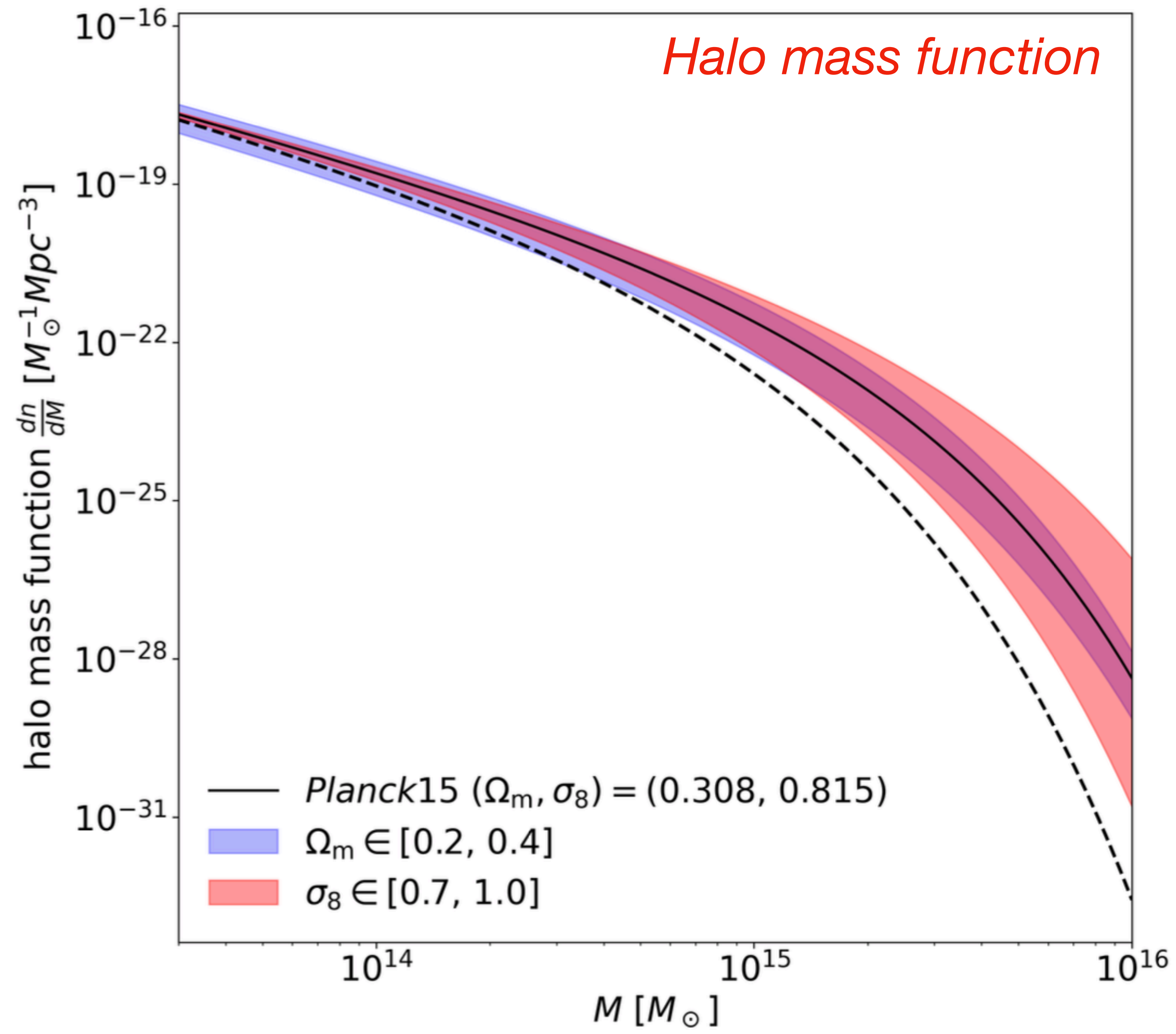
Richness
Number of member galaxies



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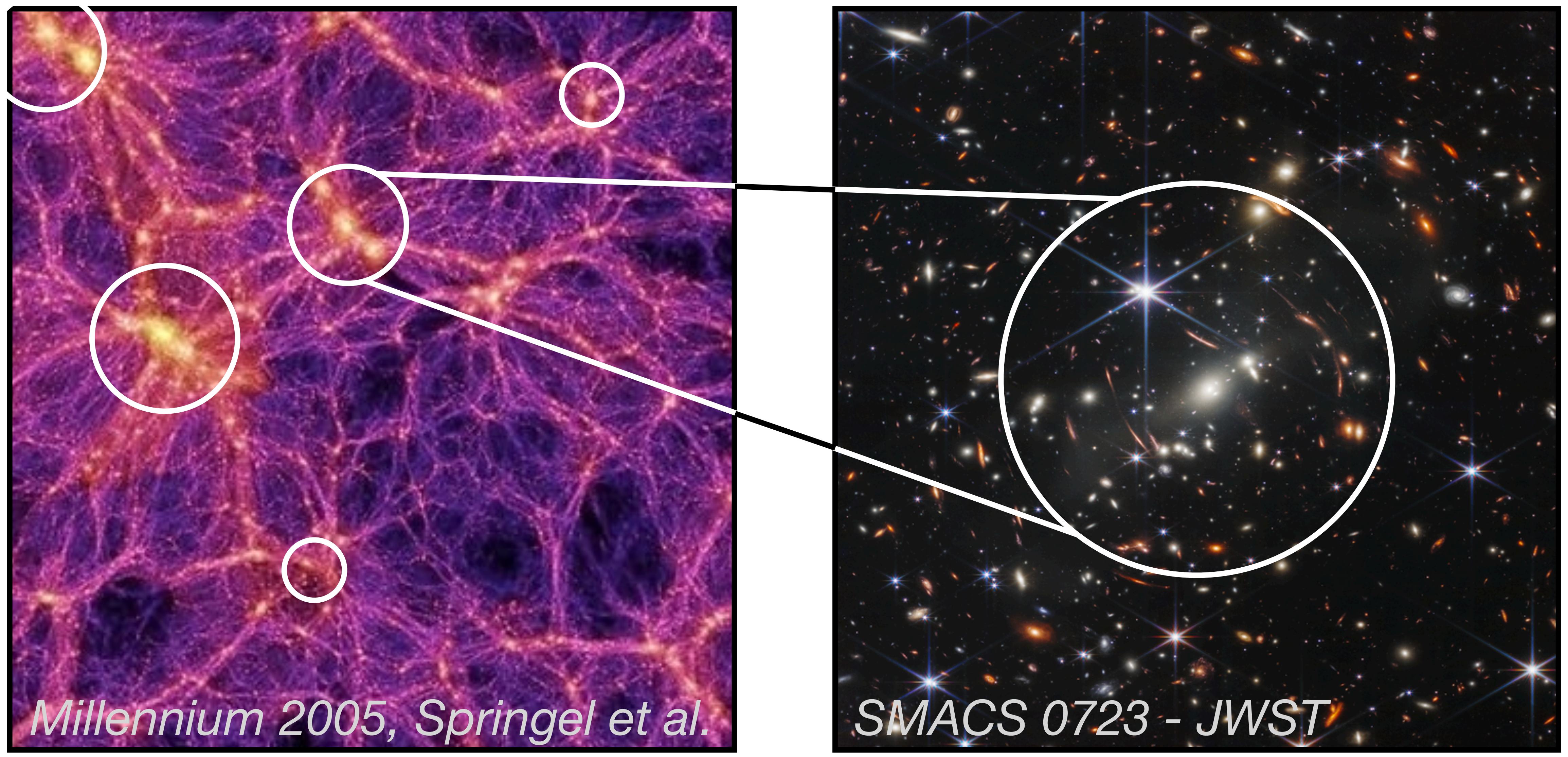

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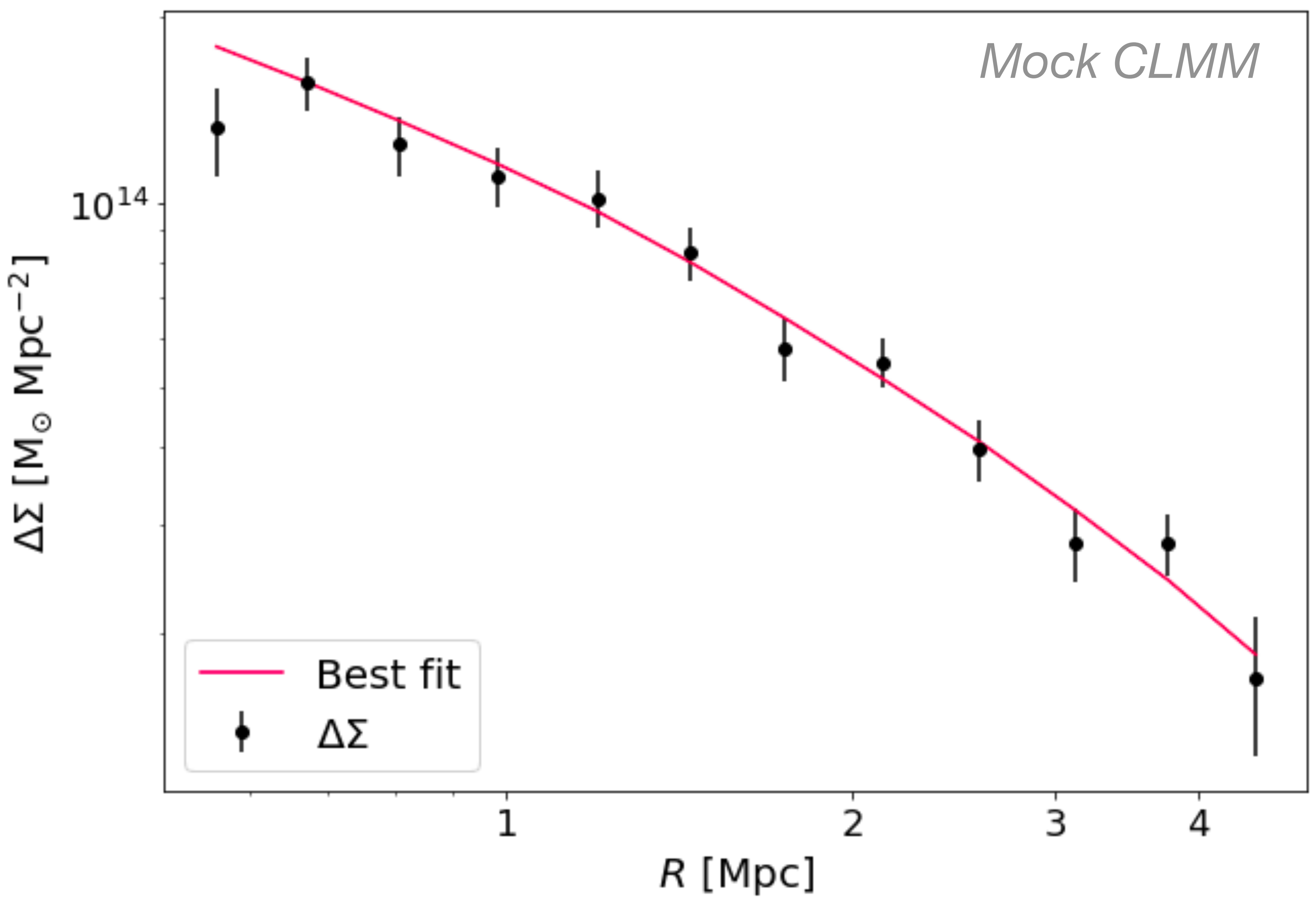
proxys

Richness
Number of member galaxies

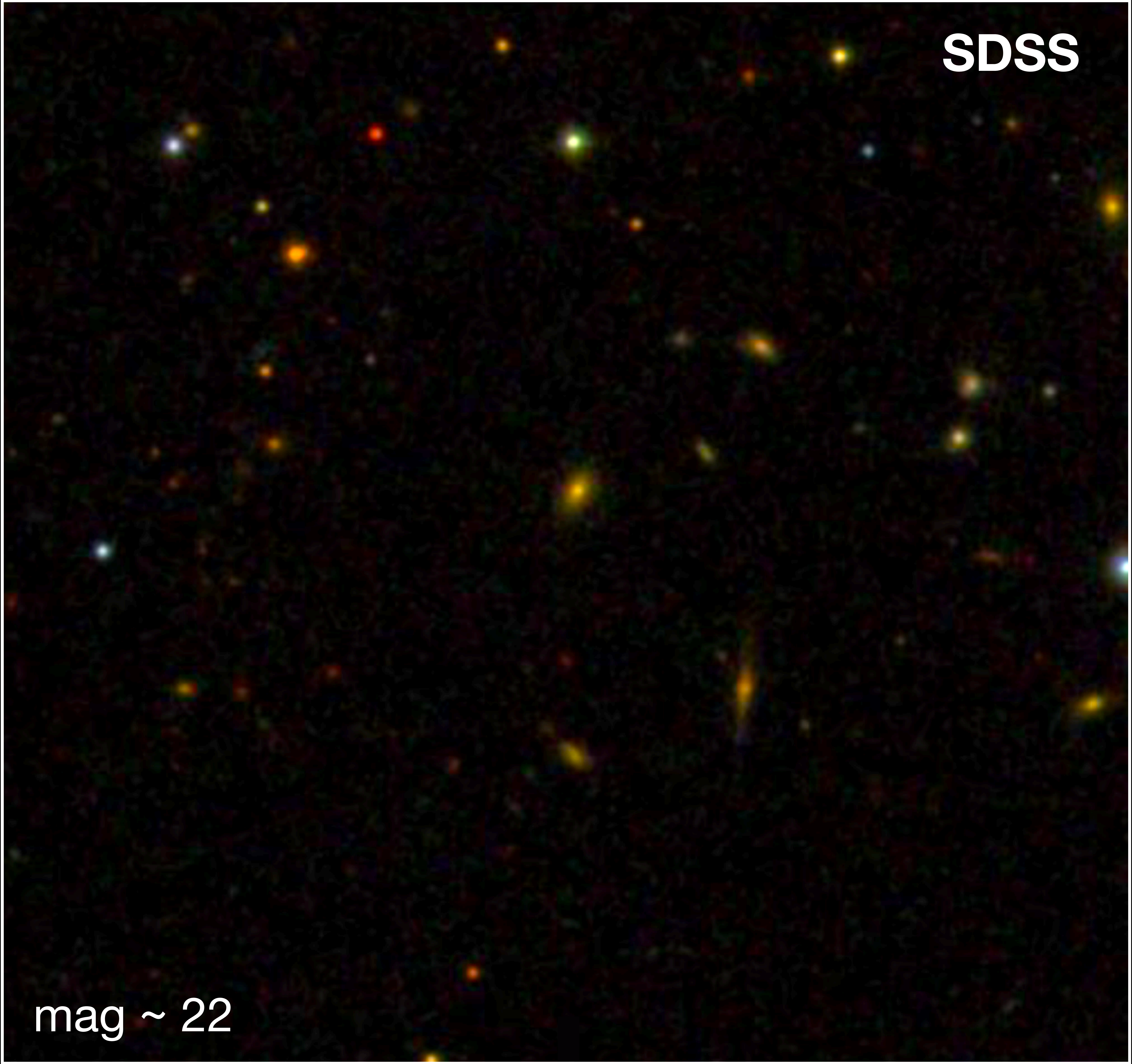
Weak gravitational lensing
Cluster lensing profiles



Blending

Superposition of galaxies due to:

- The **depth** of observation
- The **PSF size**



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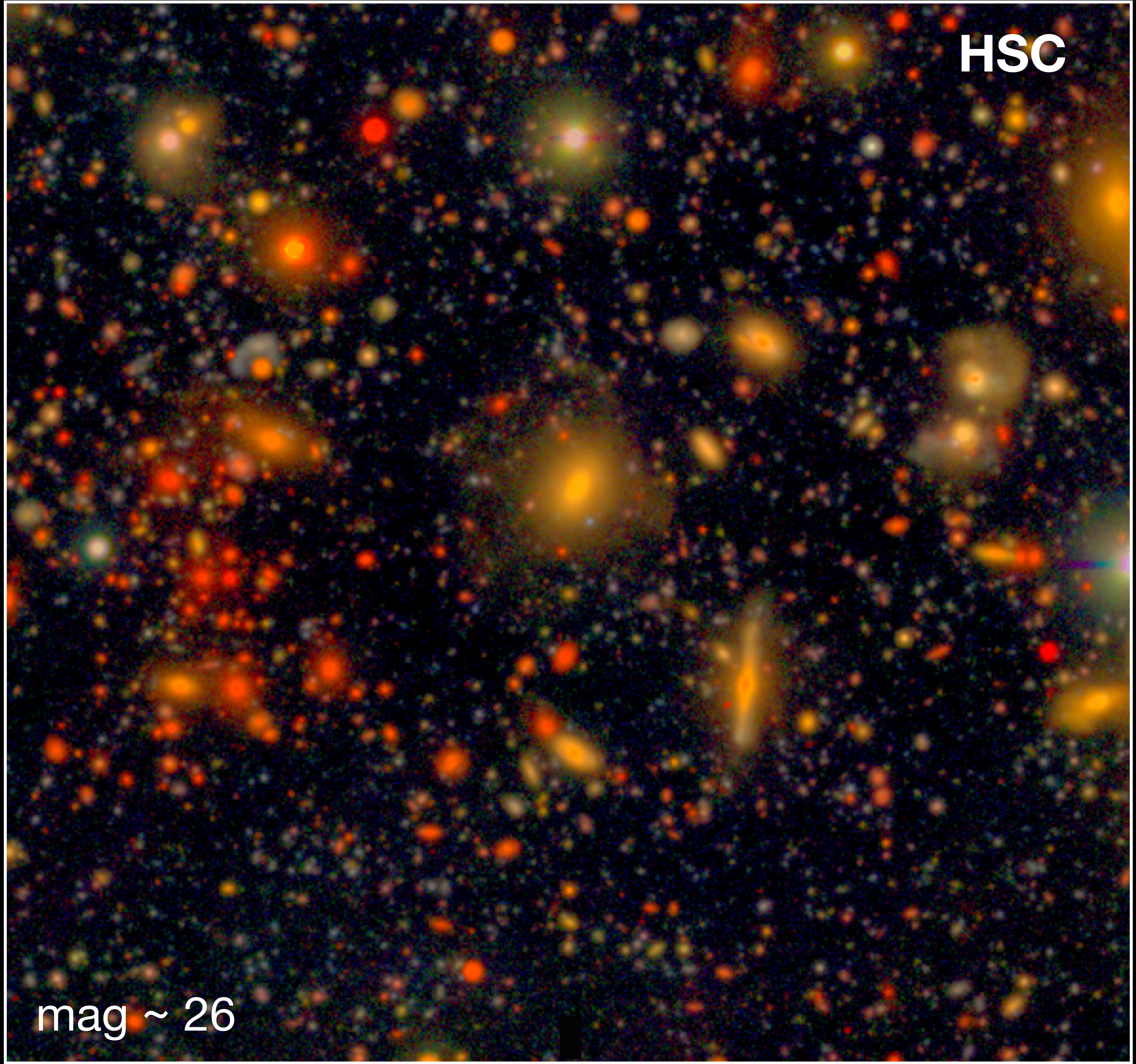

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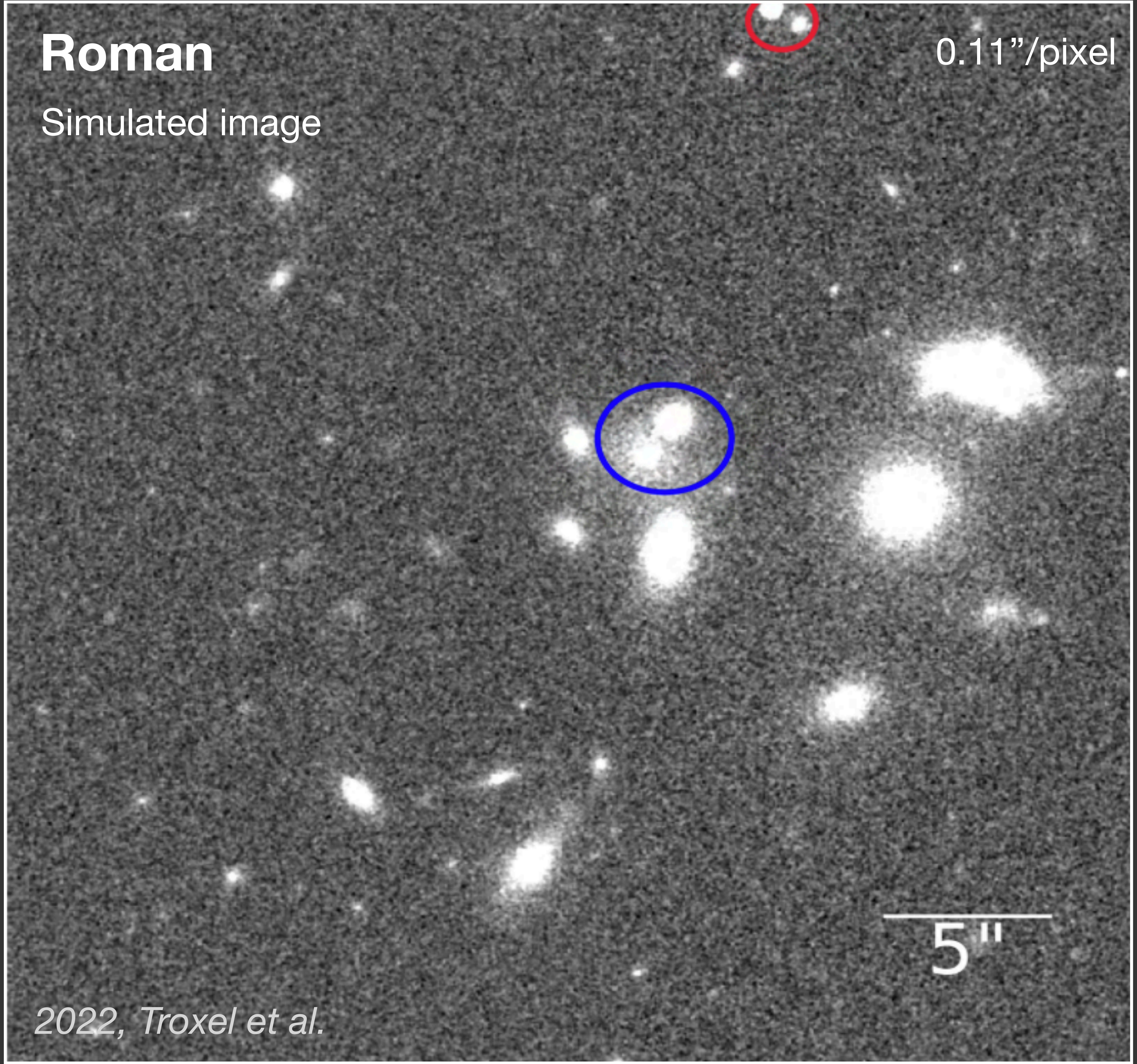

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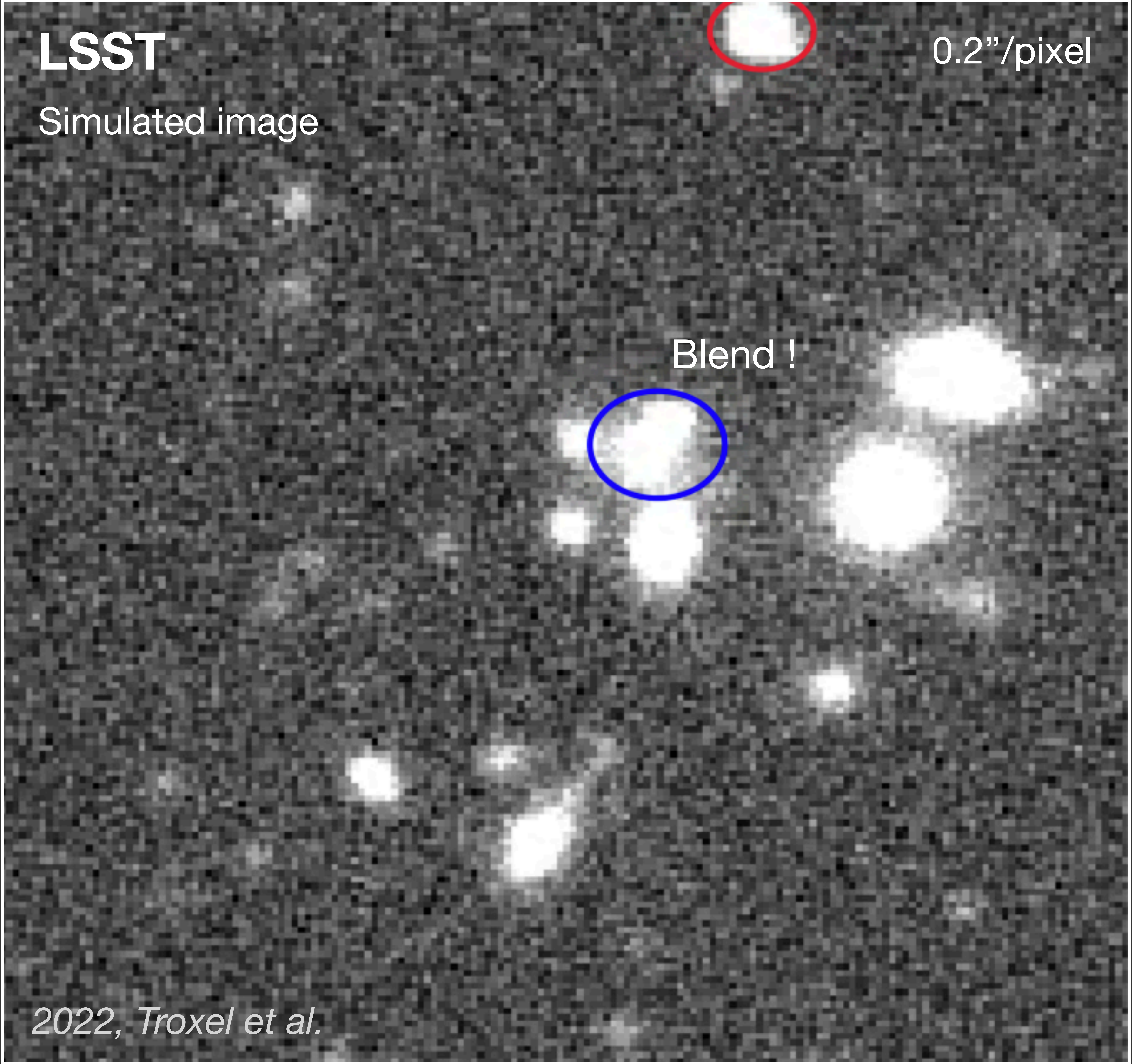
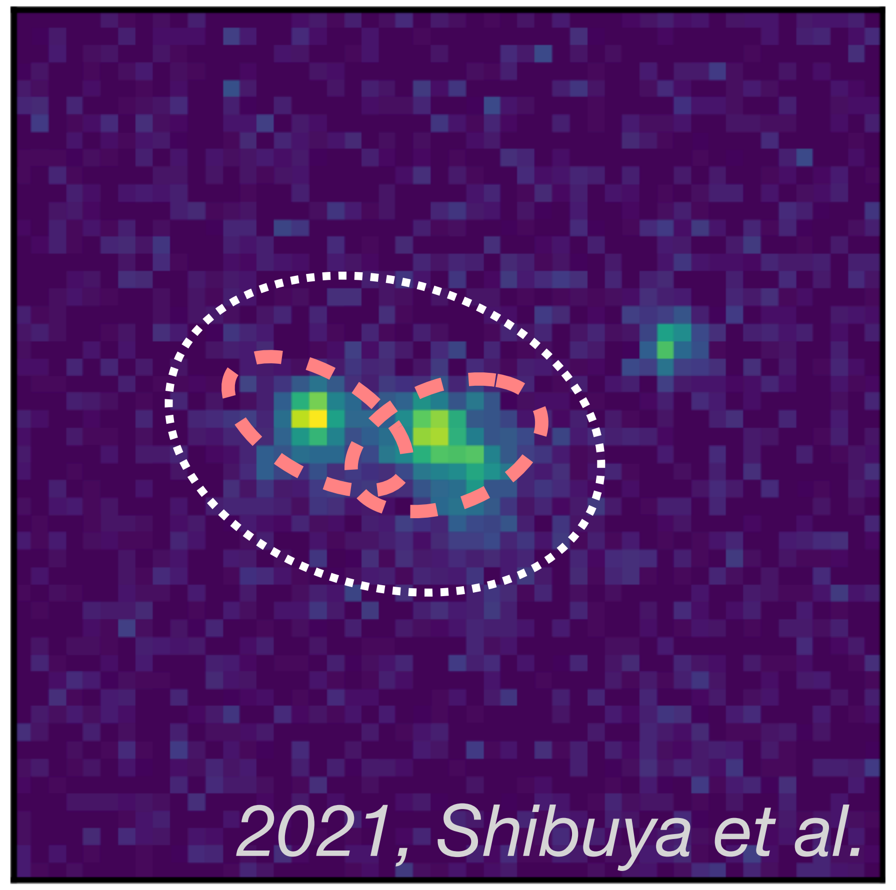


Recognized/unrecognized blends

Recognized blends

Hubble/ACS



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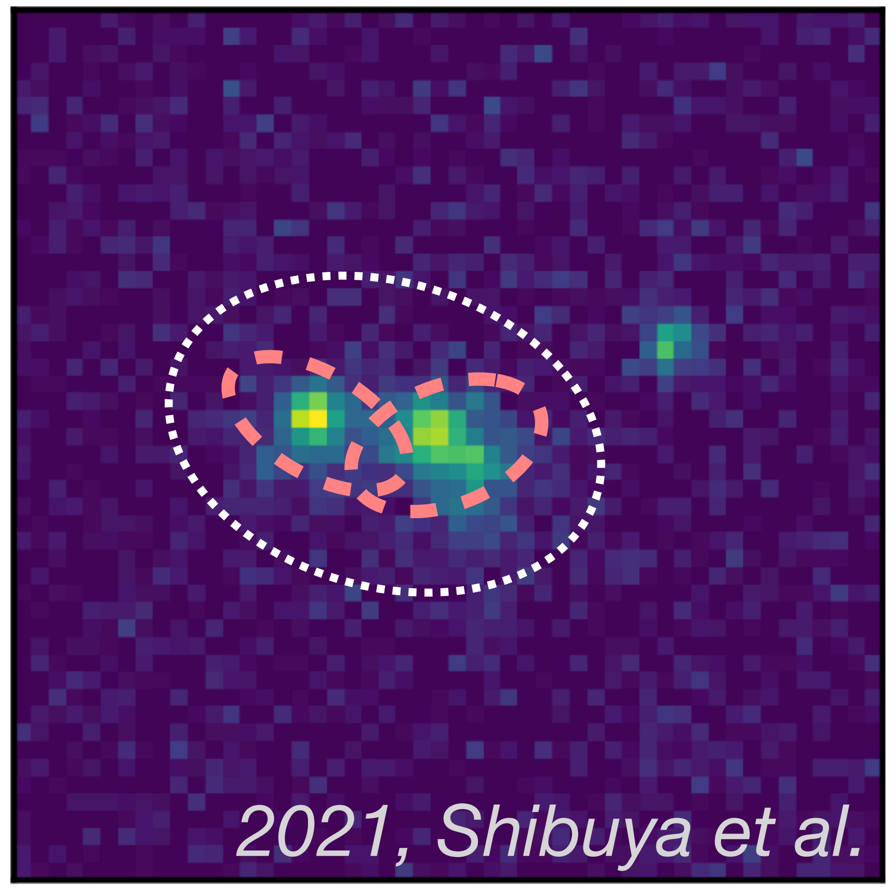
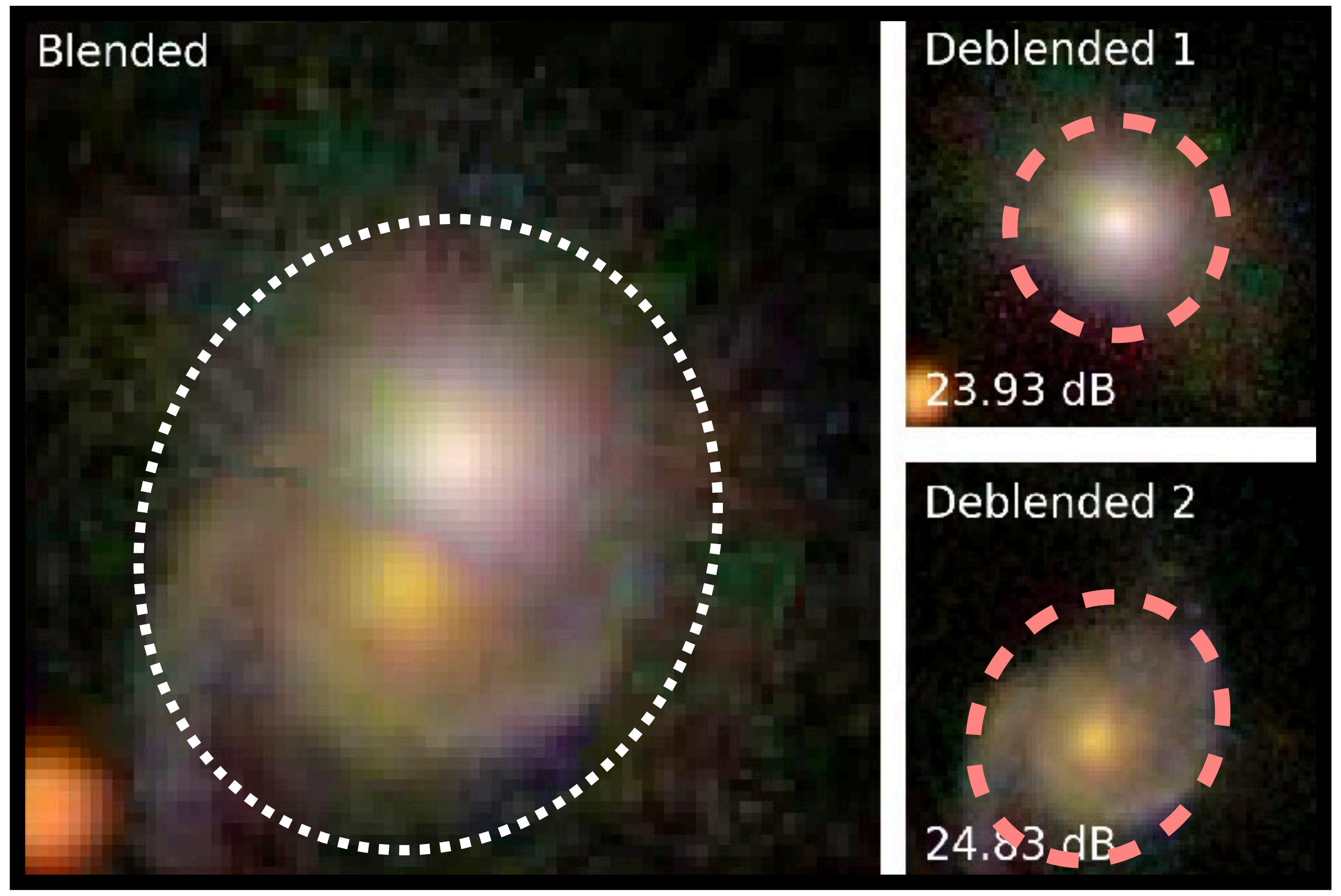


LSST deblender: **SCARLET**



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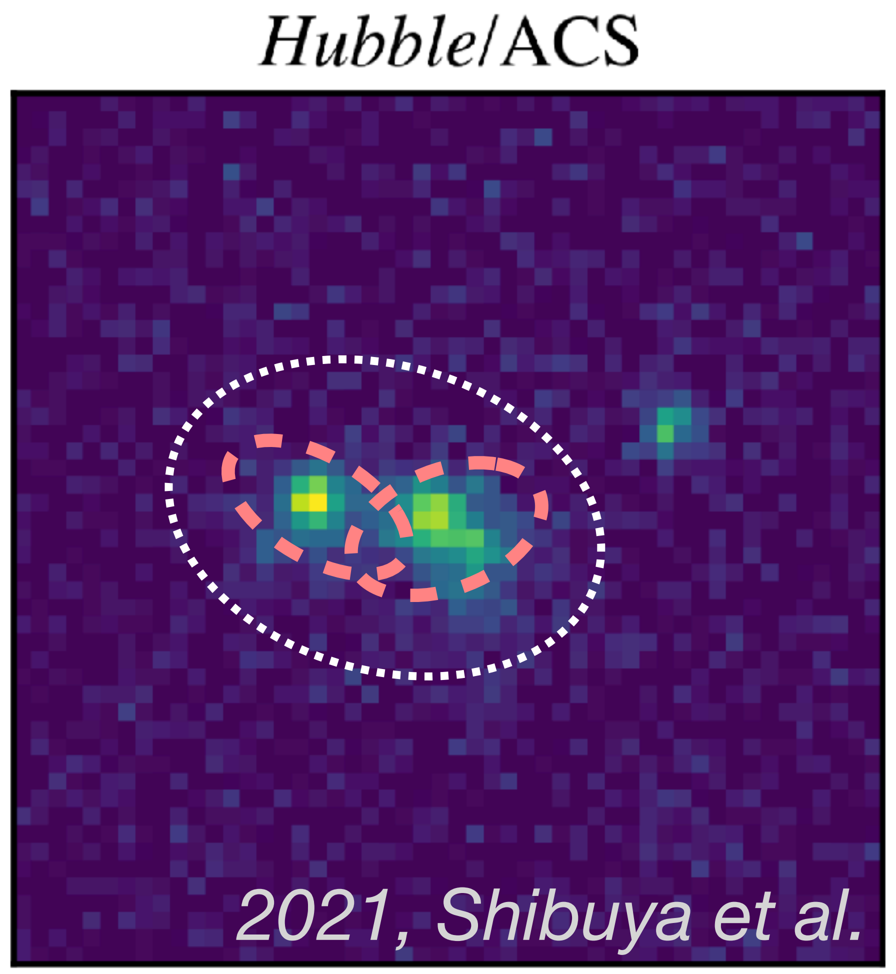

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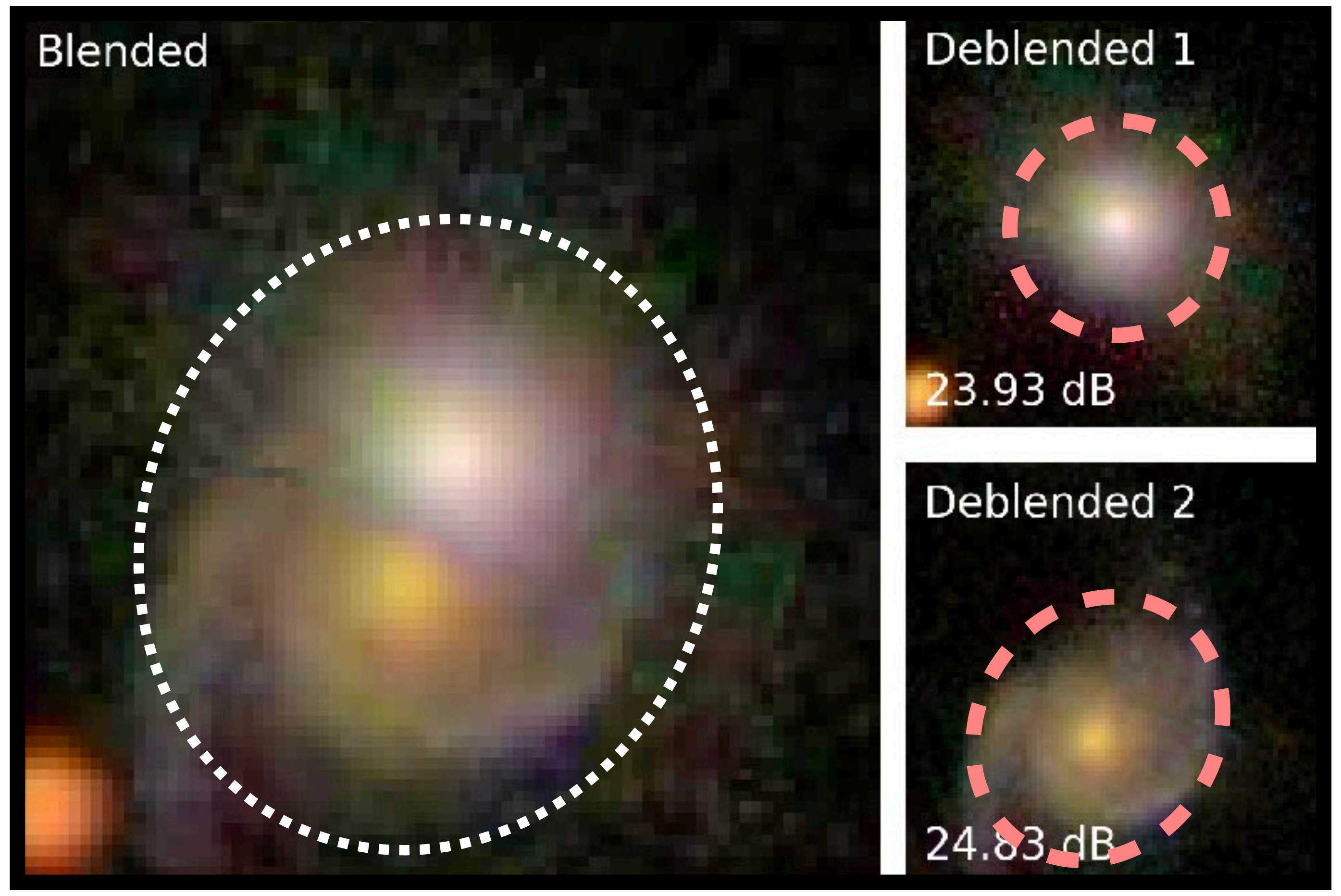

~40 %

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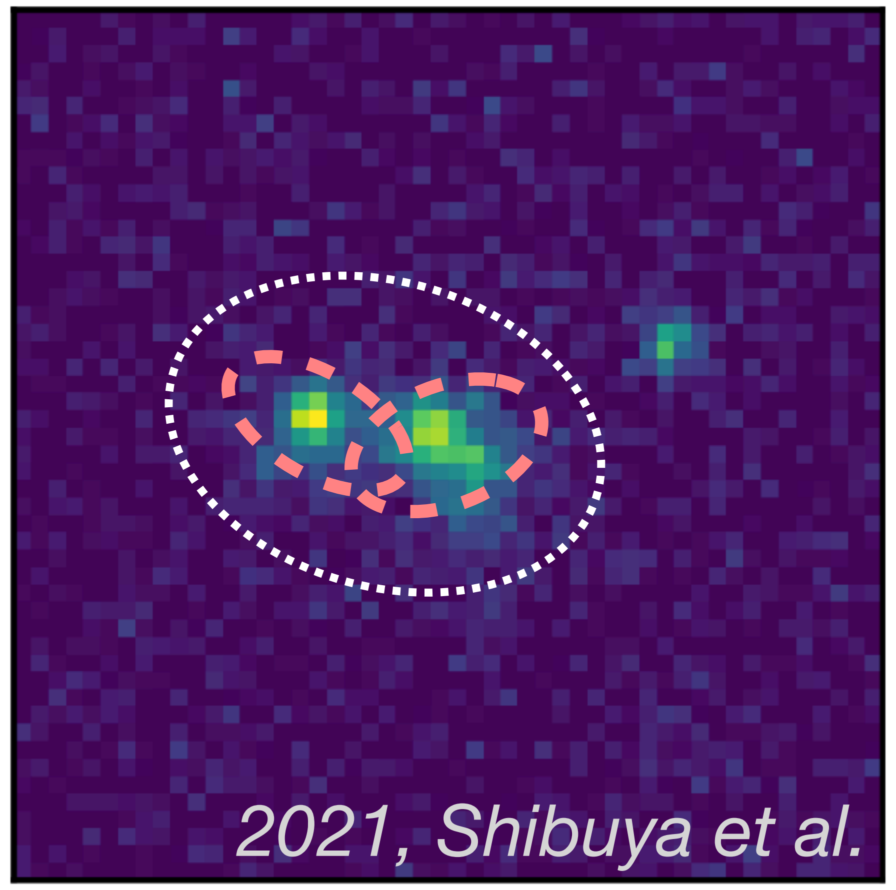

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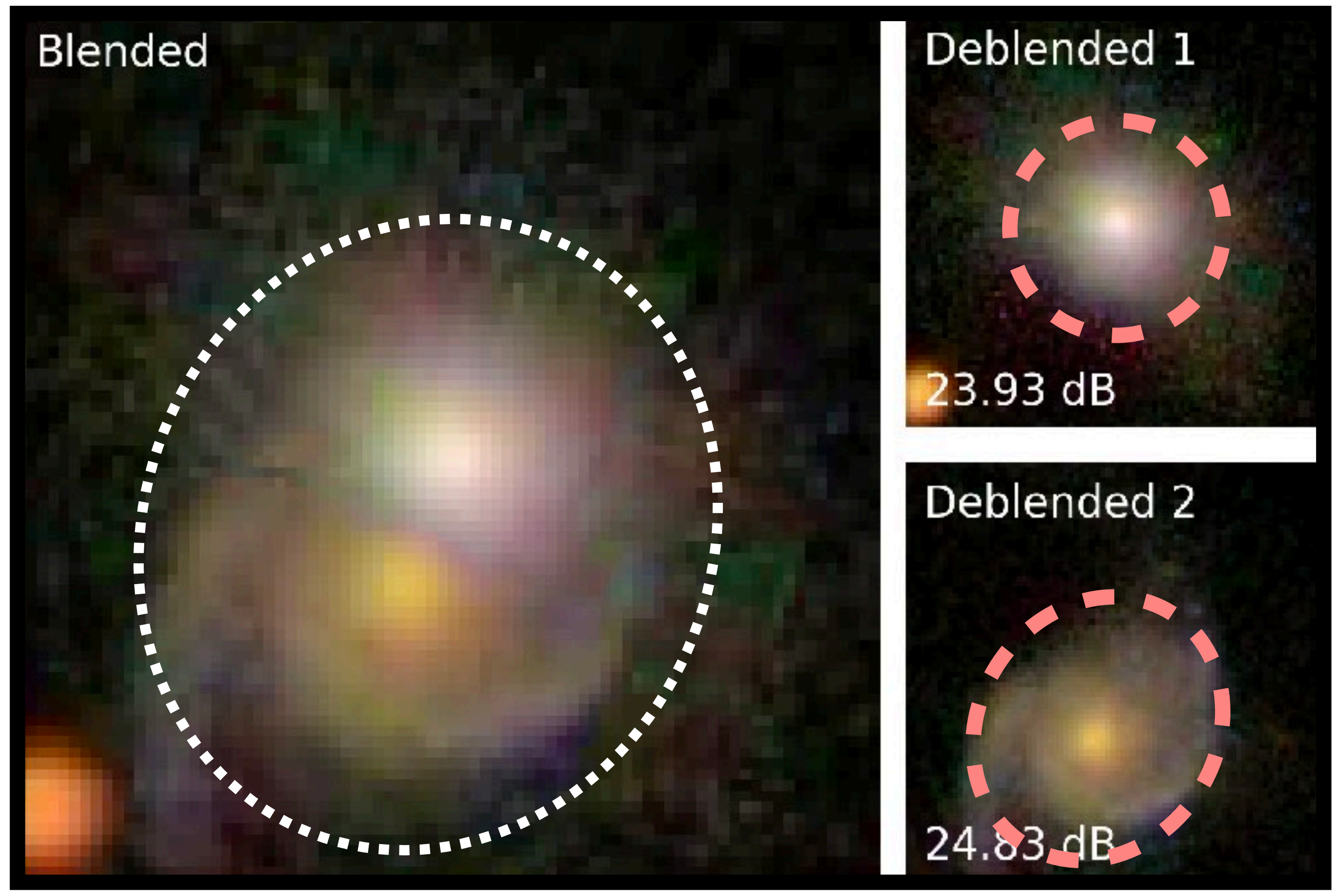

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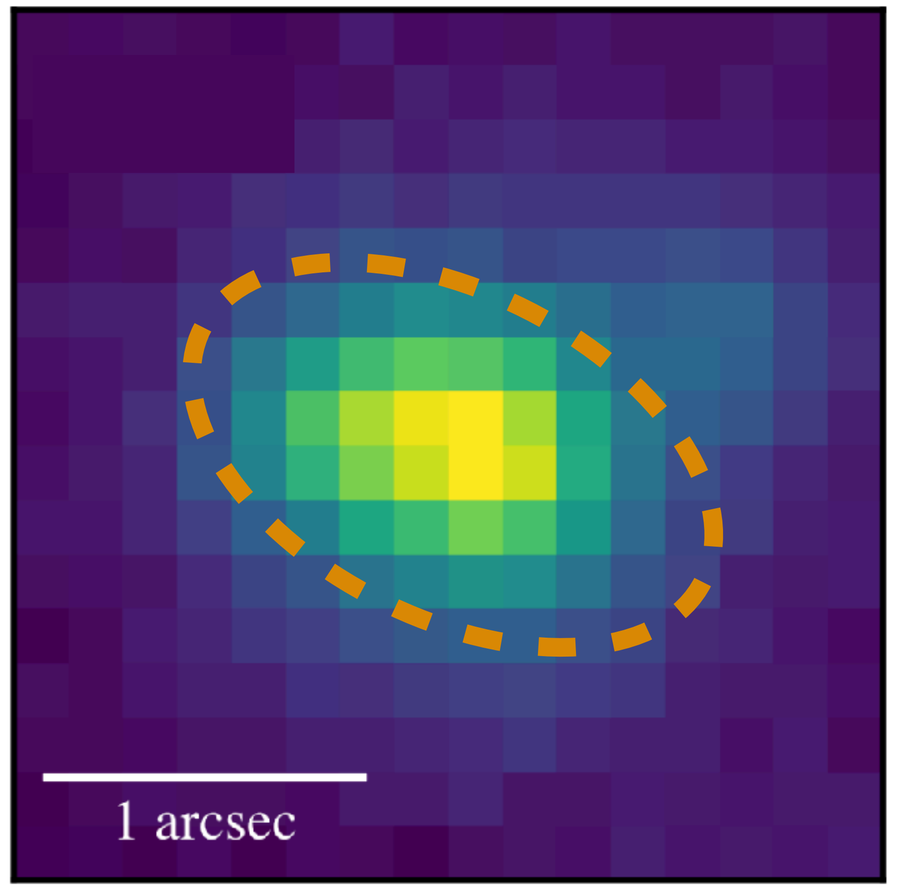
Unrecognized blends

Subaru/HSC



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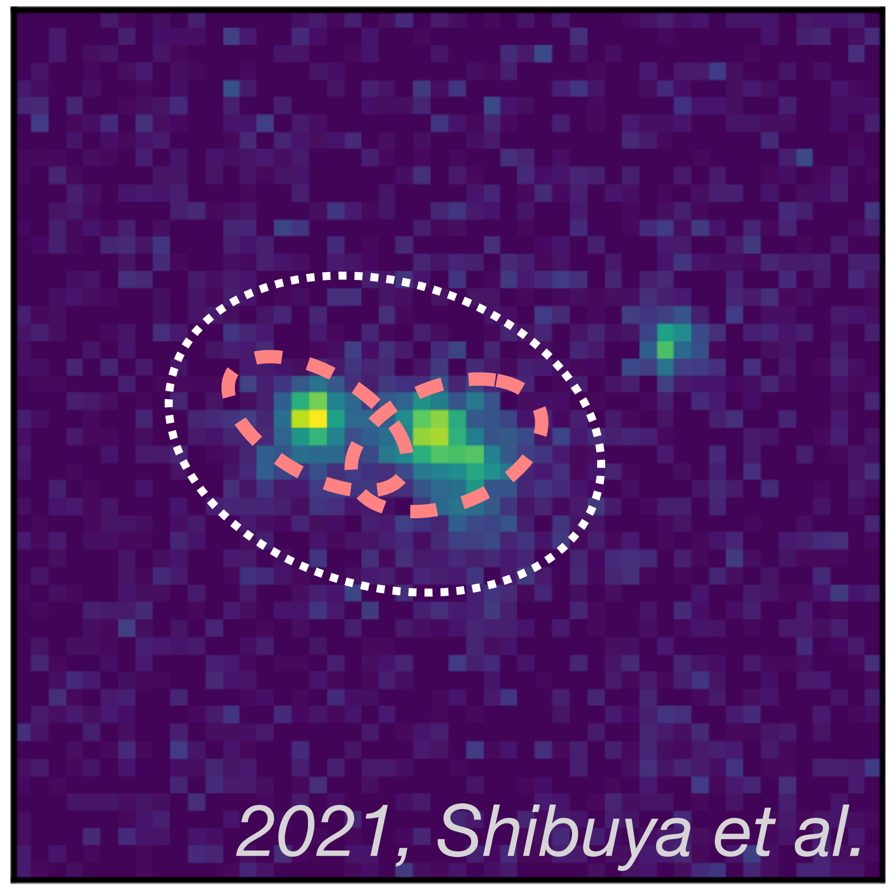

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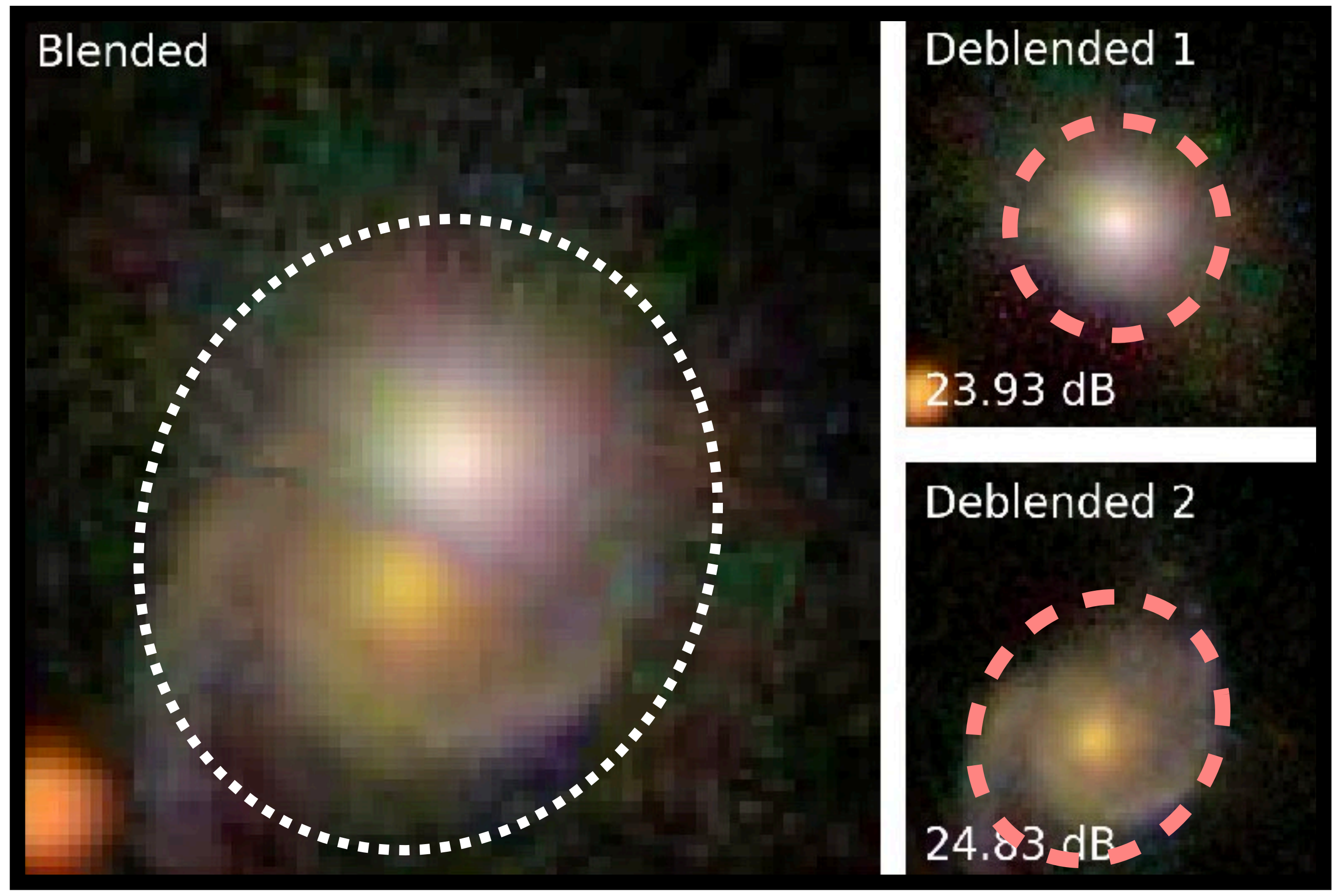

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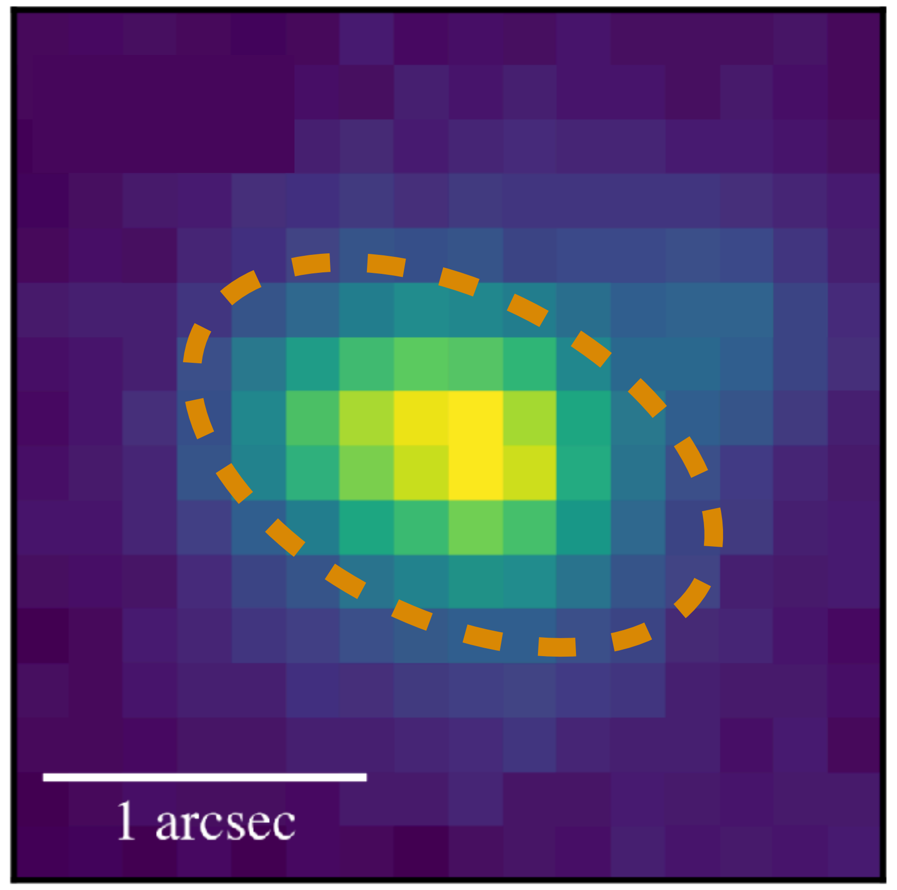


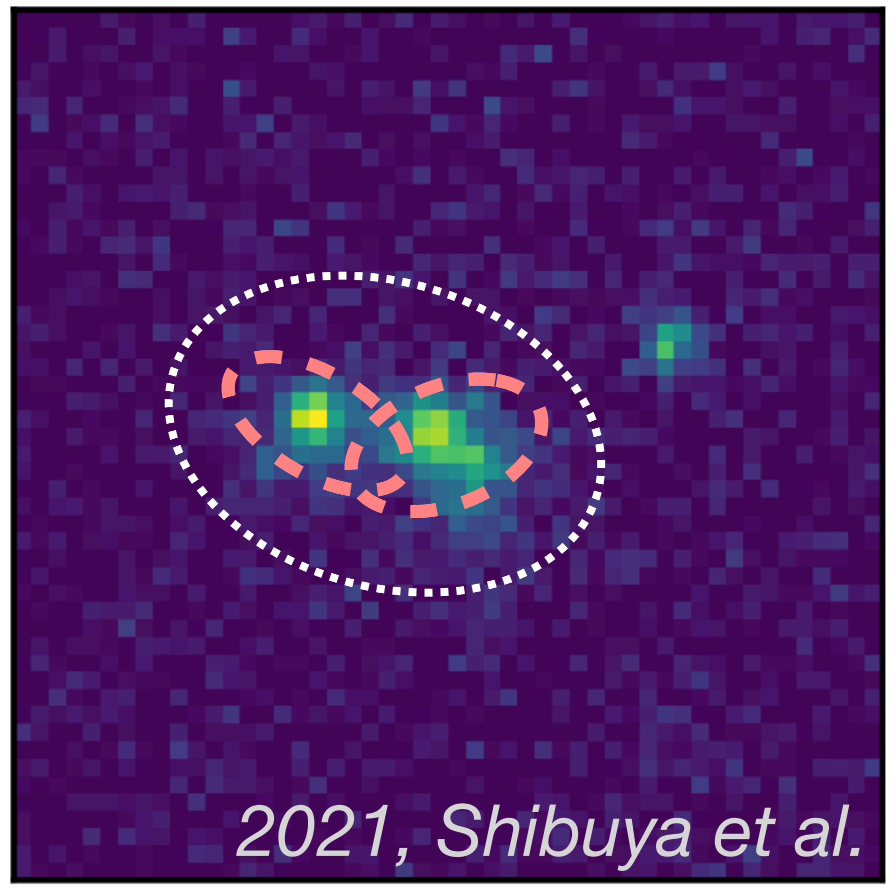
?

Recognized/unrecognized blends

* 2016, Dawson et al.
2022, Troxel et al.

Recognized blends

Hubble/ACS



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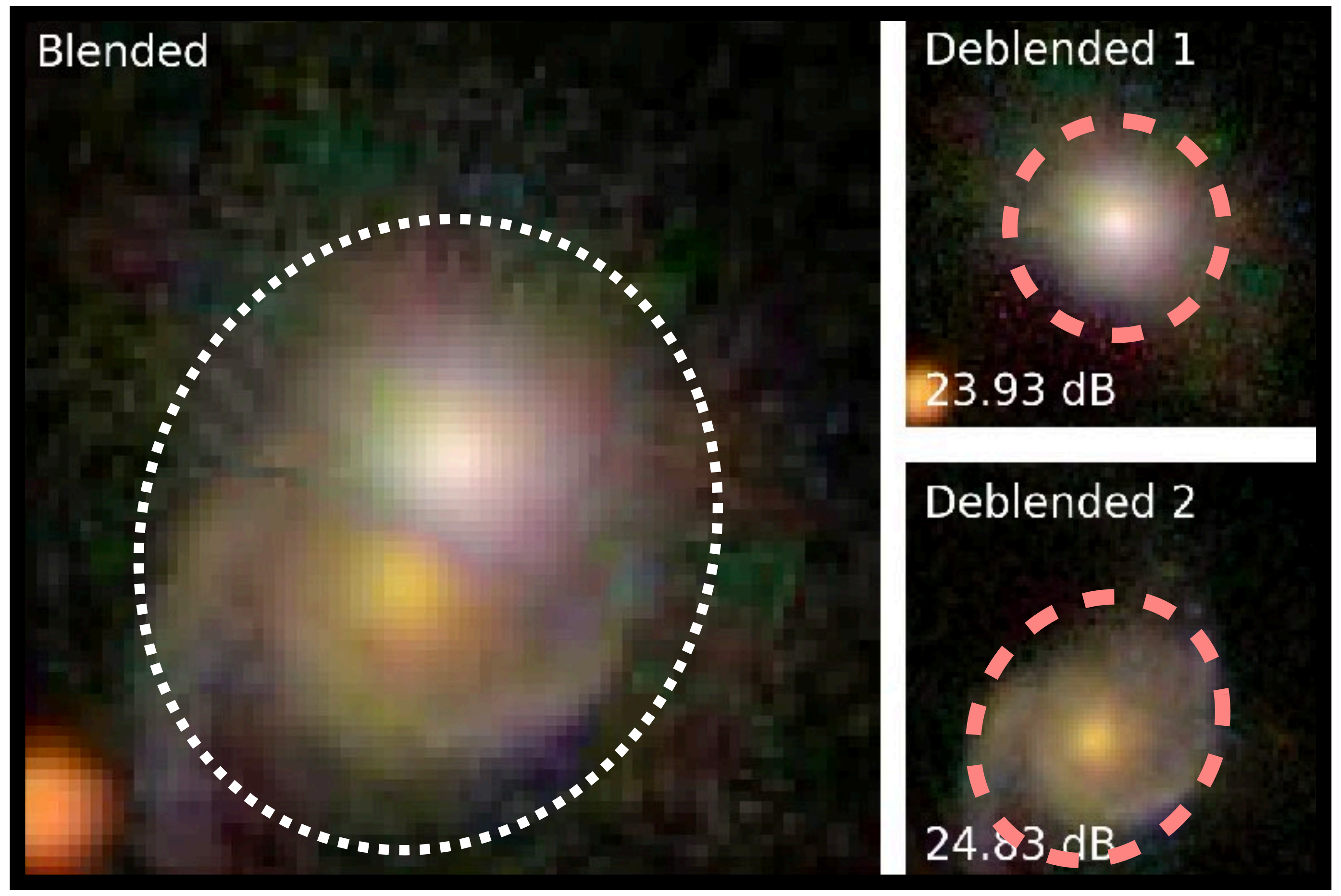
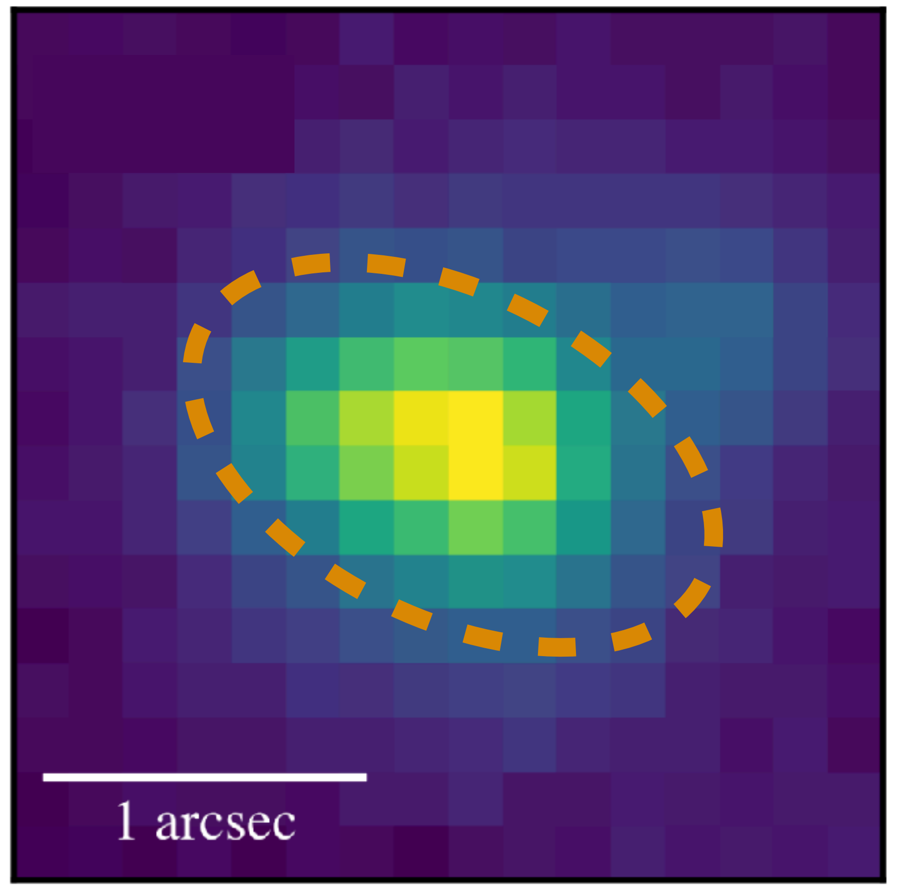


→ ~40 %

Unrecognized blends

Subaru/HSC



→ ? → ~14 - 20 %*

Scientific context

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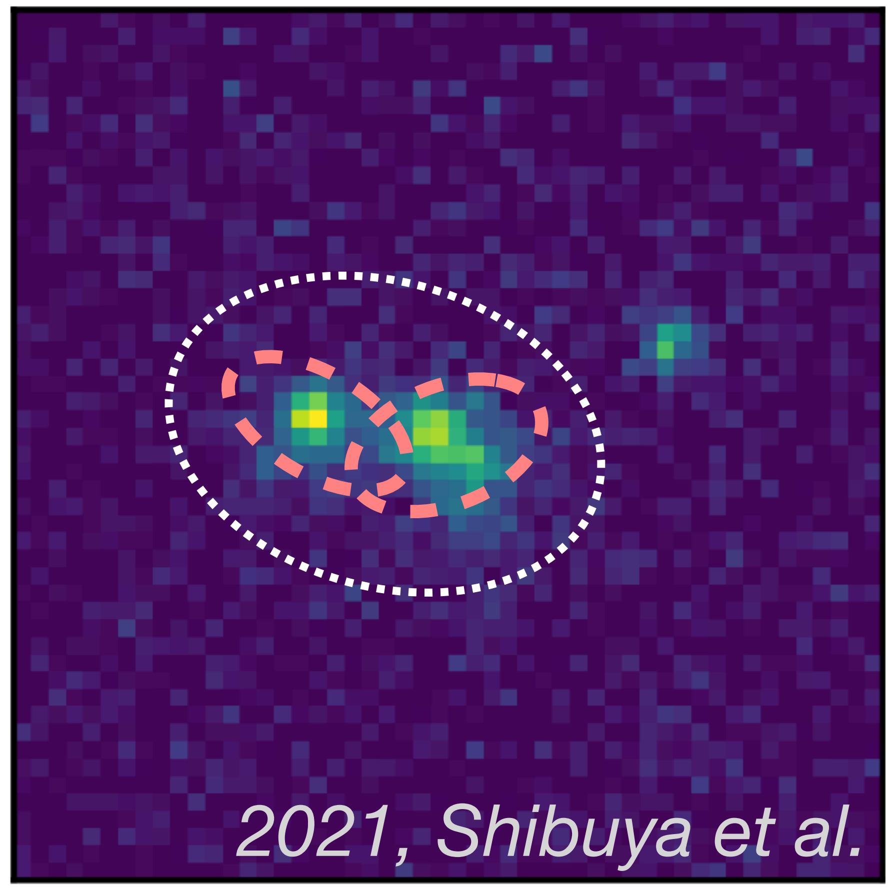

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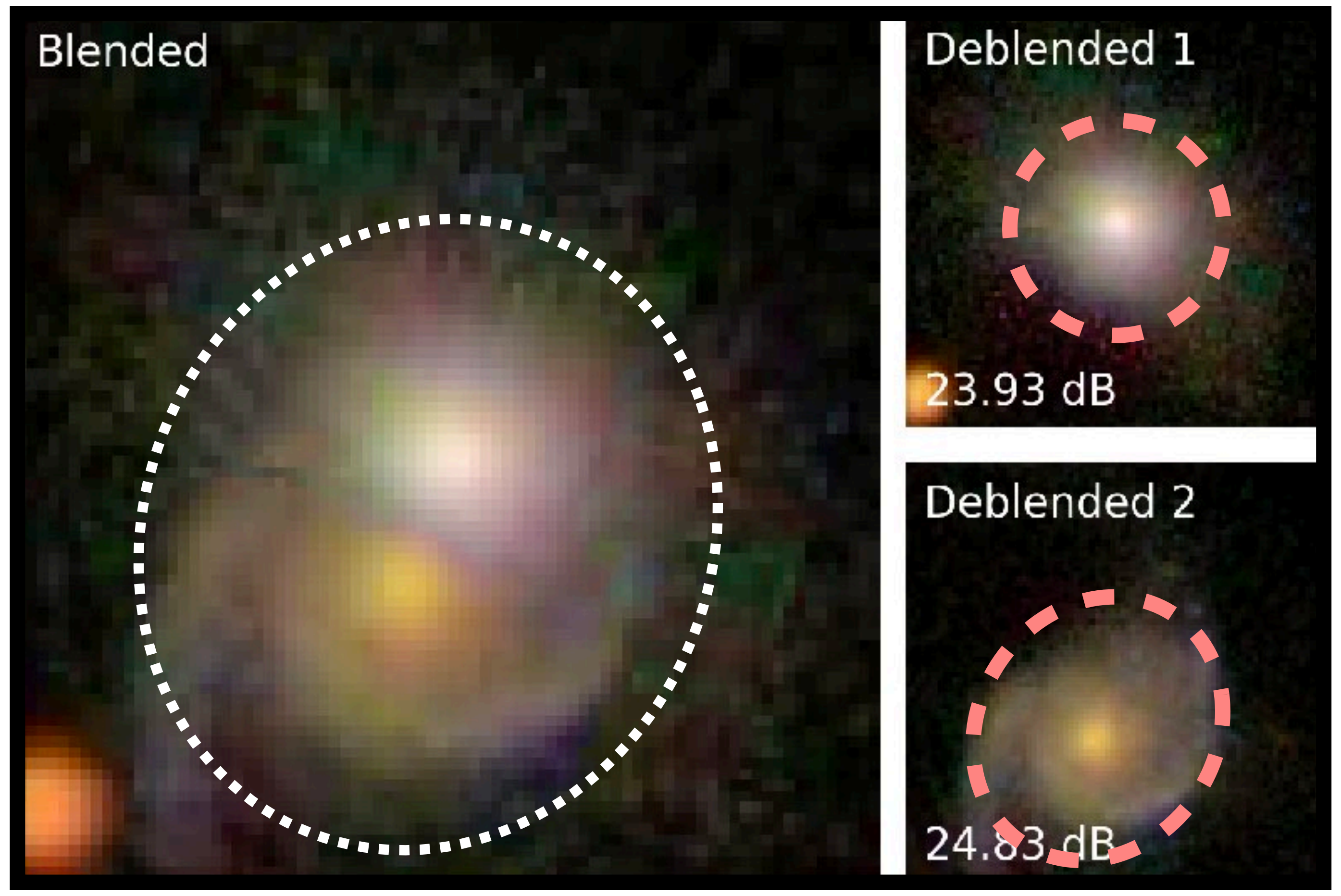
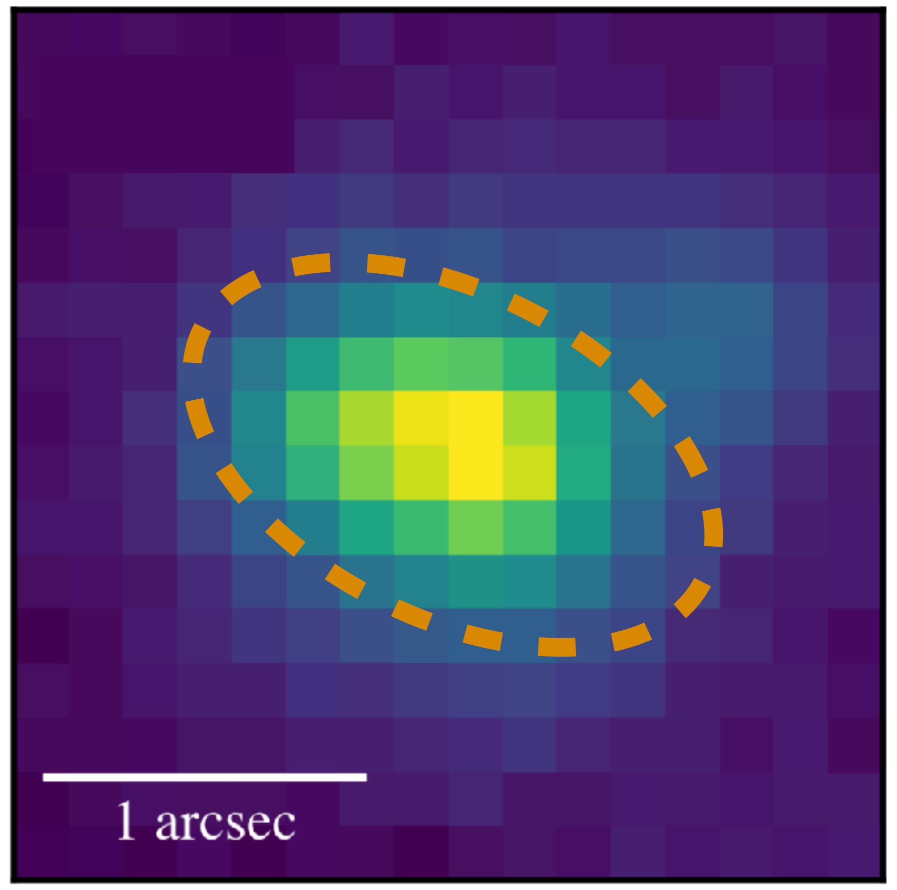


→ **~40 %**

Unrecognized blends

Subaru/HSC

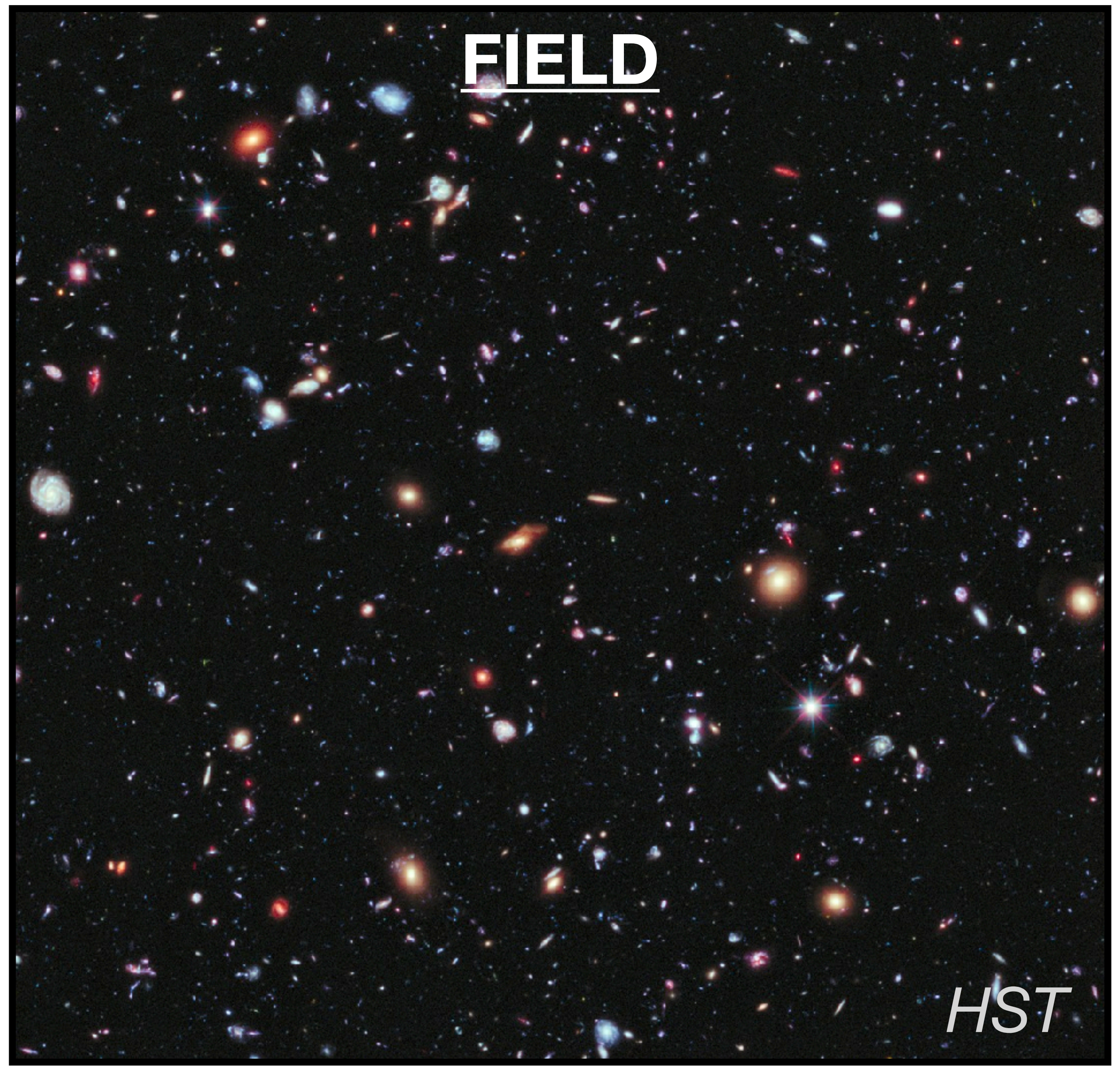


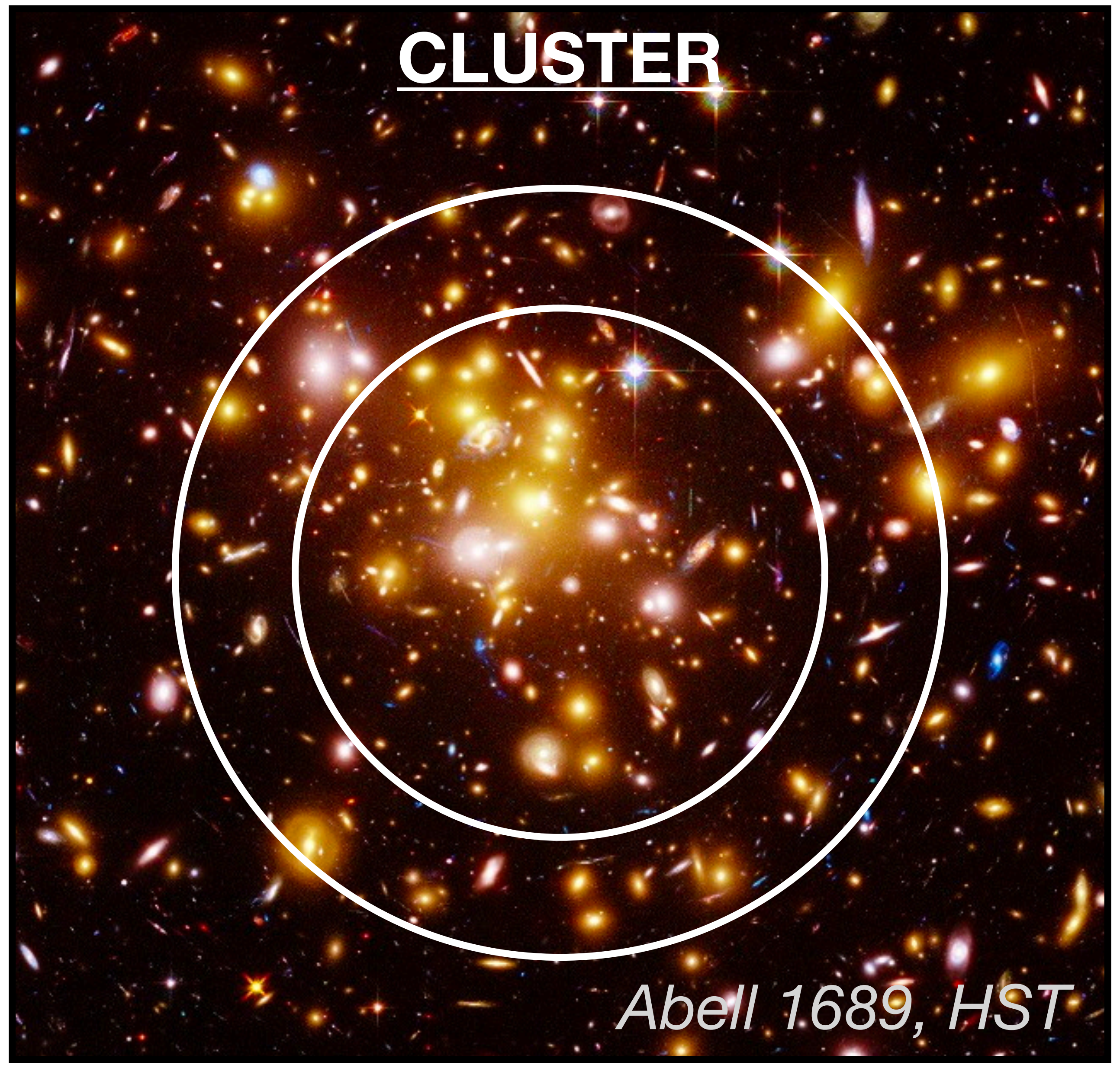
→ **?** → **~14 - 20 %***

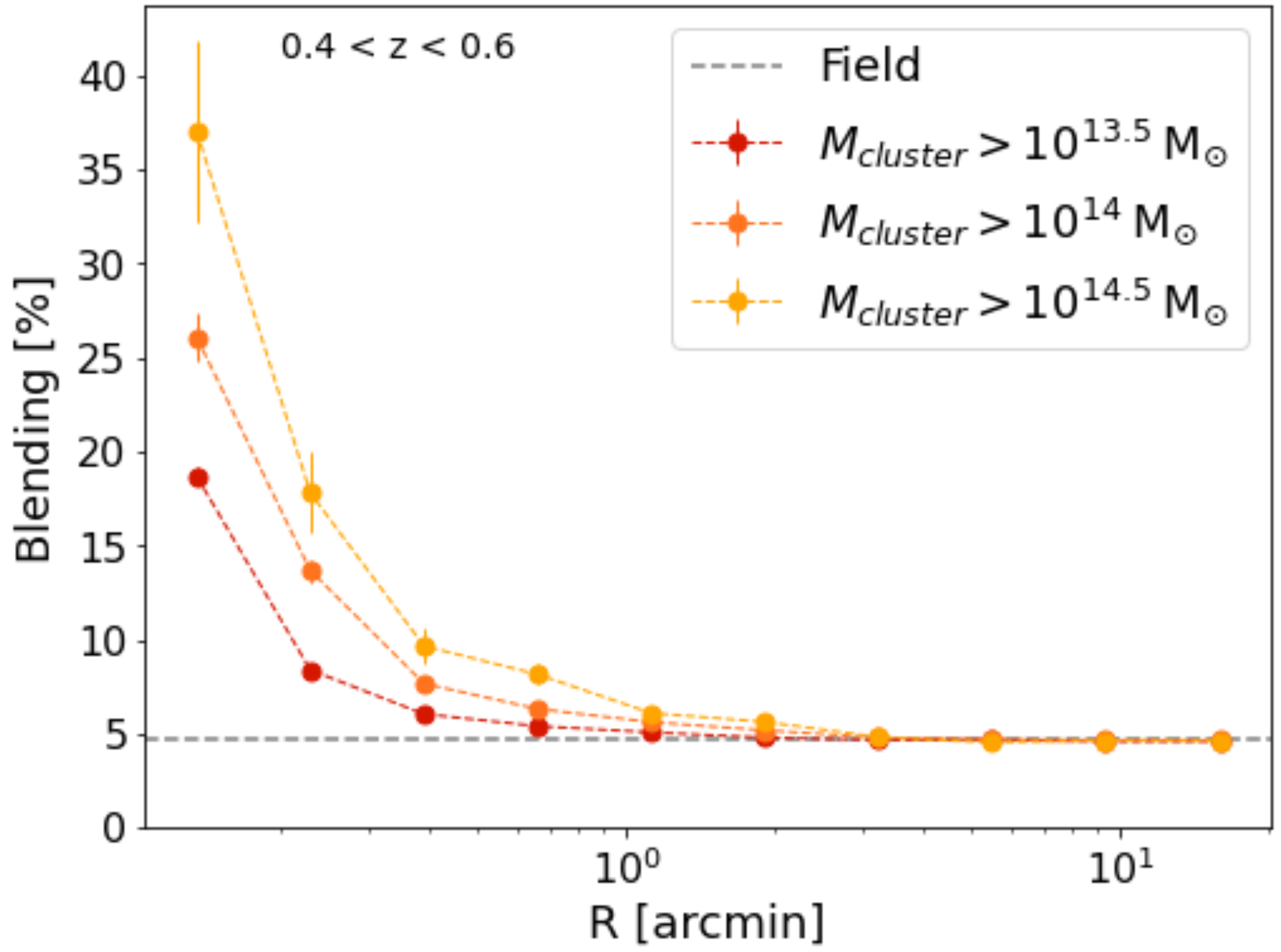
~ 60% of blends

- Detection
- Shapes
- Redshifts

Blending around galaxy clusters



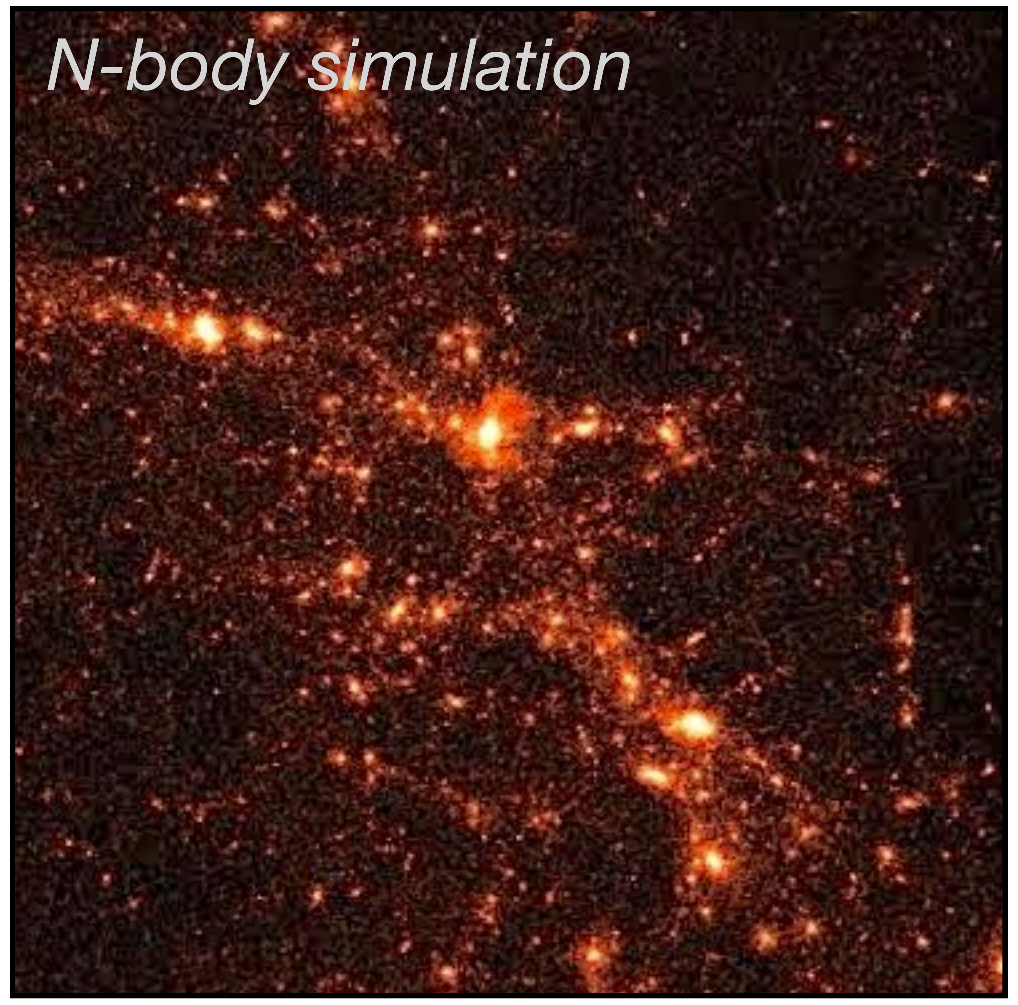




Blending in cluster fields ↔ WL profiles ↔ galaxy cluster masses ↔ cosmology

Identification of blends in LSST

Simulated catalogs

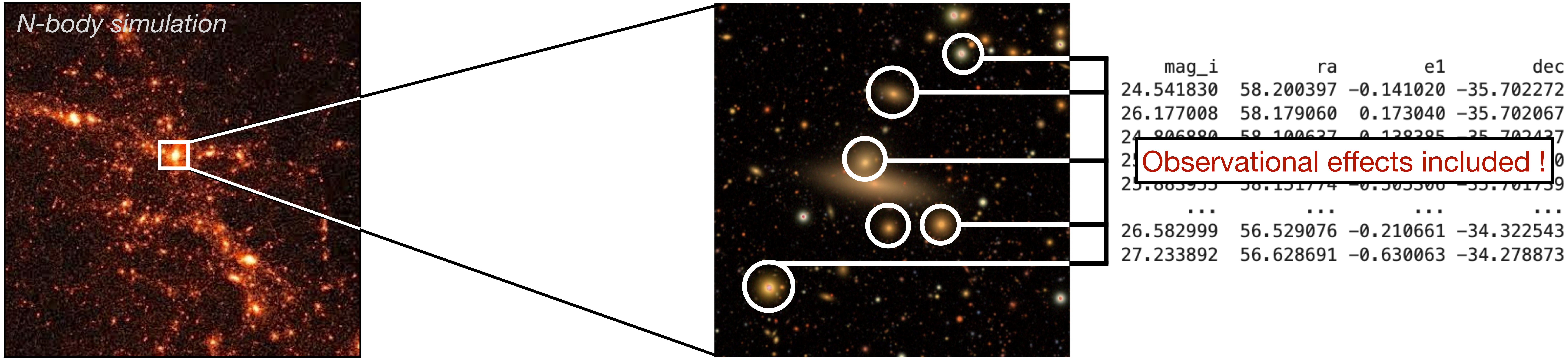


Outer Rim 2019, Heitmann et al.

cosmoDC2

- Reference for **galaxies** and dark matter haloes

Simulated catalogs



Outer Rim 2019, Heitmann et al.

DESC simulated image

cosmoDC2

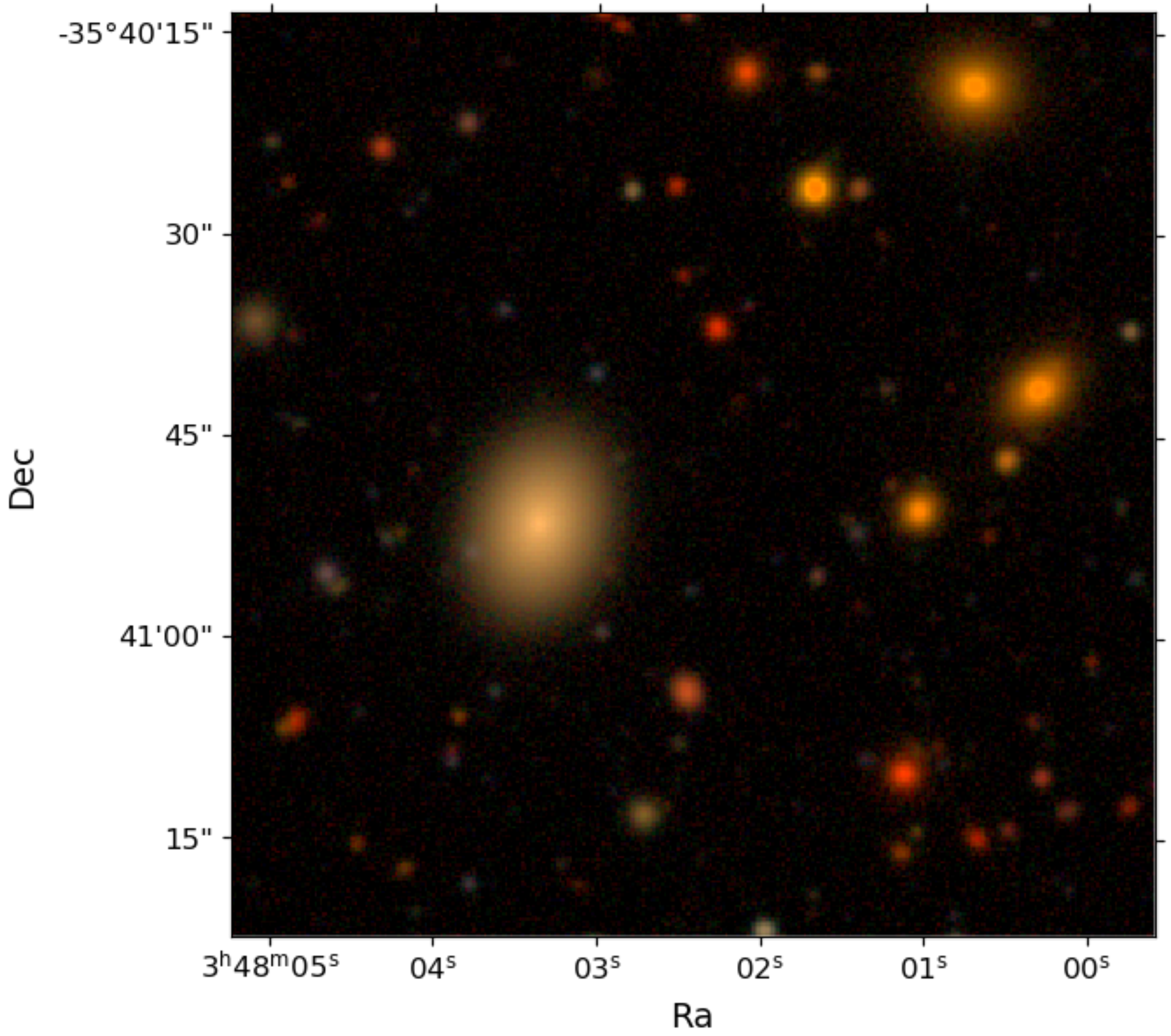
- Reference for **galaxies** and dark matter haloes

DC2object

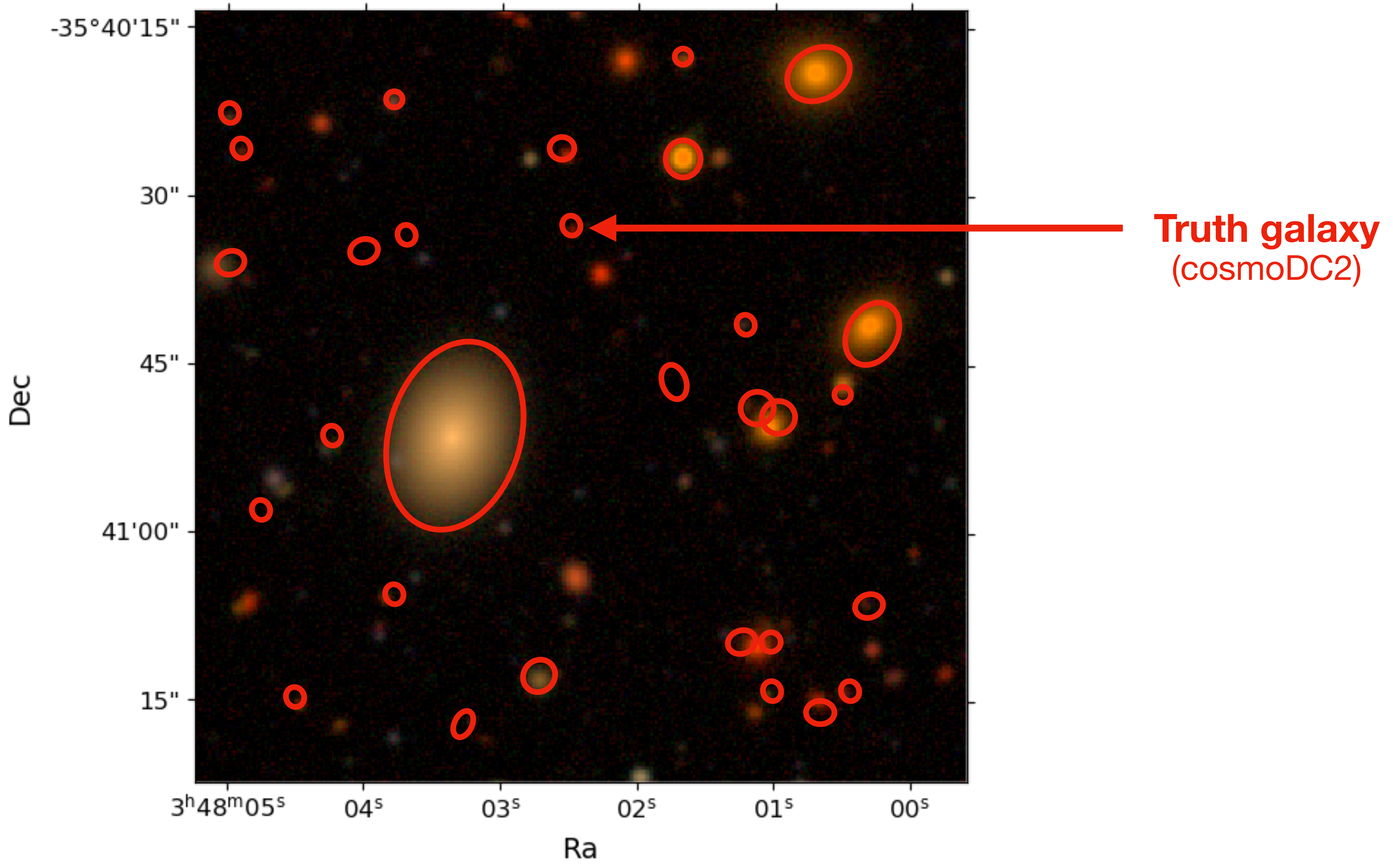
- Detected **objects** from realistic simulated images

Identification of blends through catalog matching

Blends in DC2 images



Blends in DC2 images



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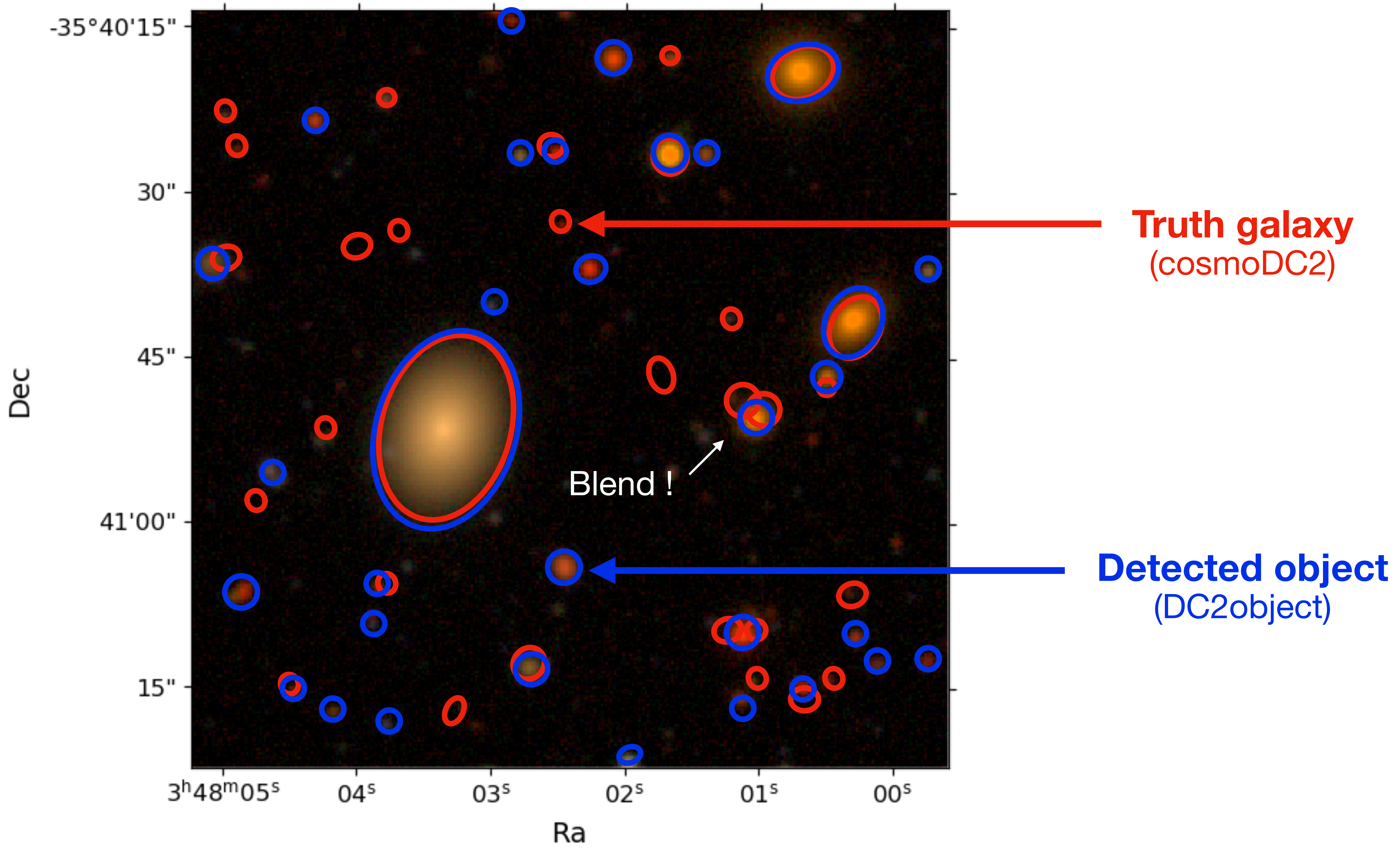
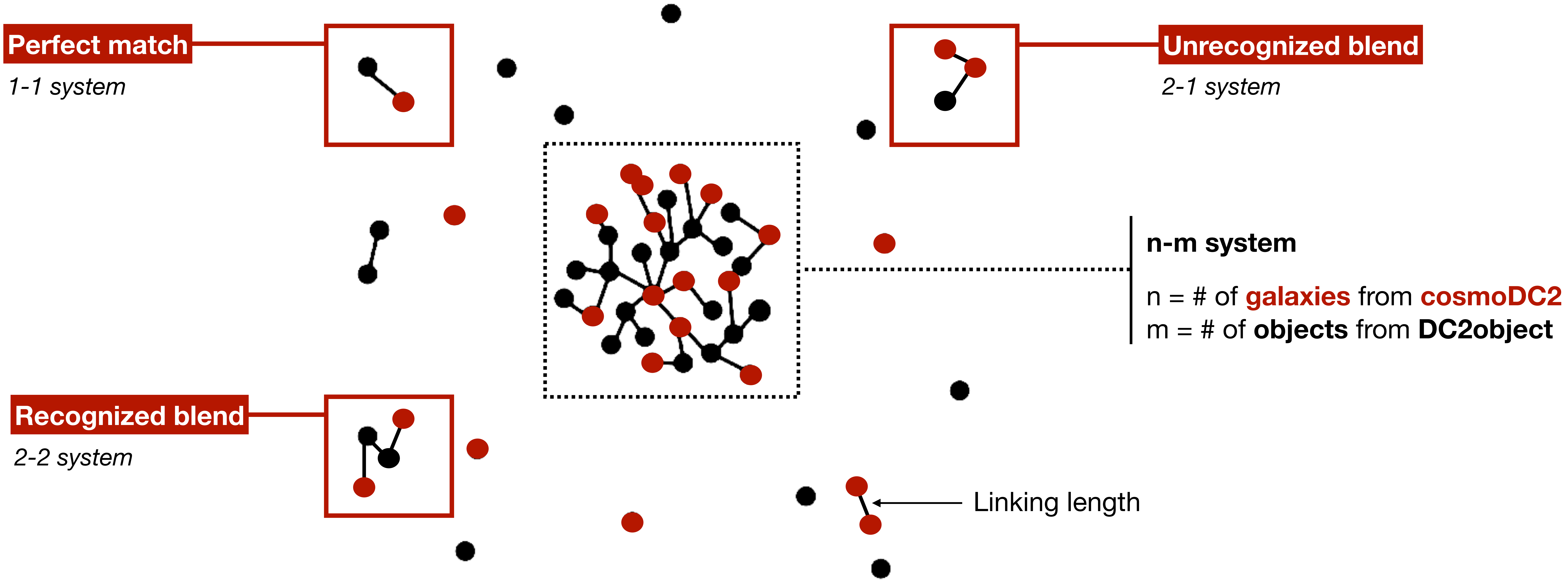


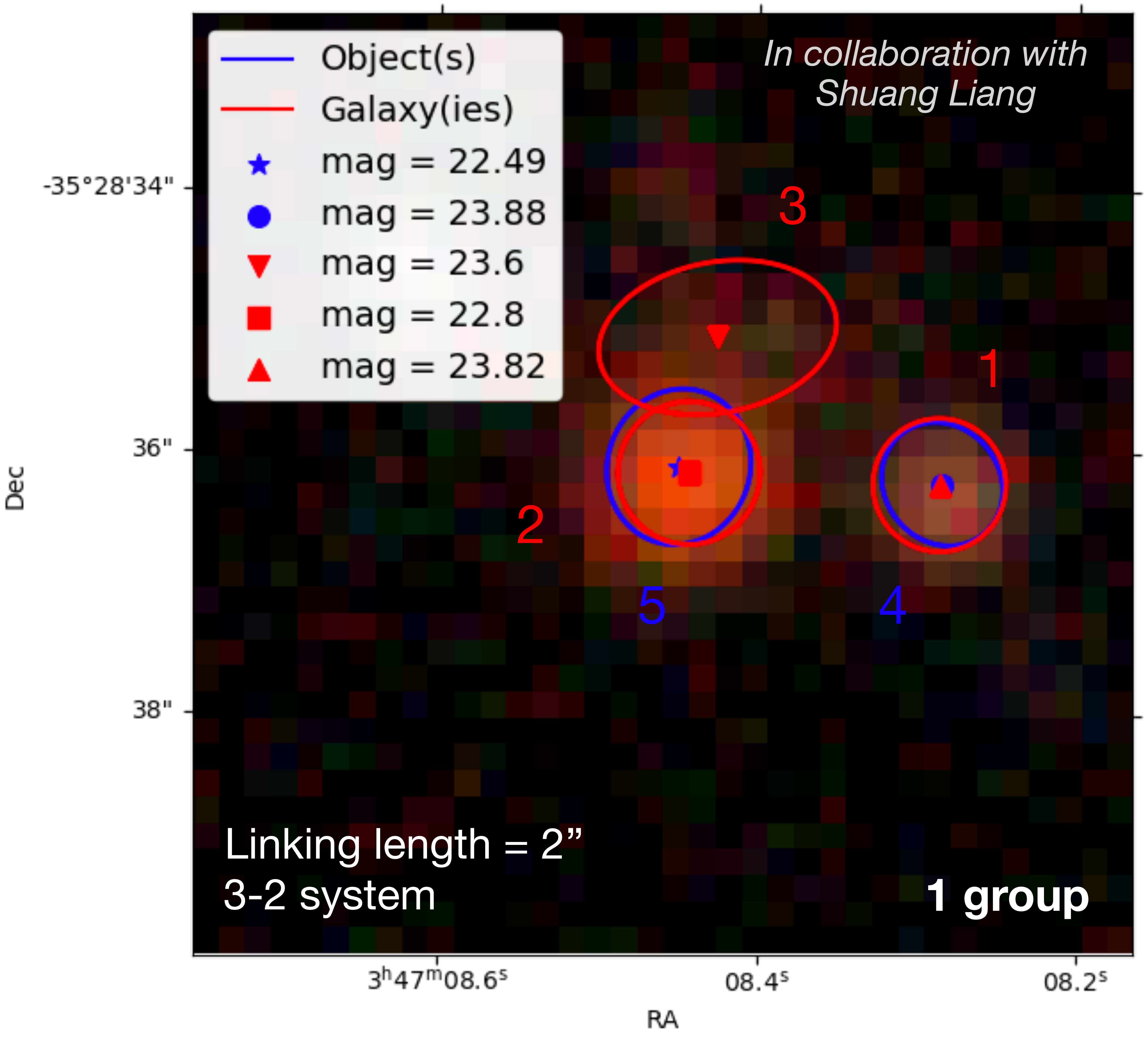
First attempt of matching

https://github.com/yymao/FoFCatalogMatching



Look at FoF groups

https://github.com/LSSTDESC/friendly
https://github.com/LSSTDESC/Cluster_Blending



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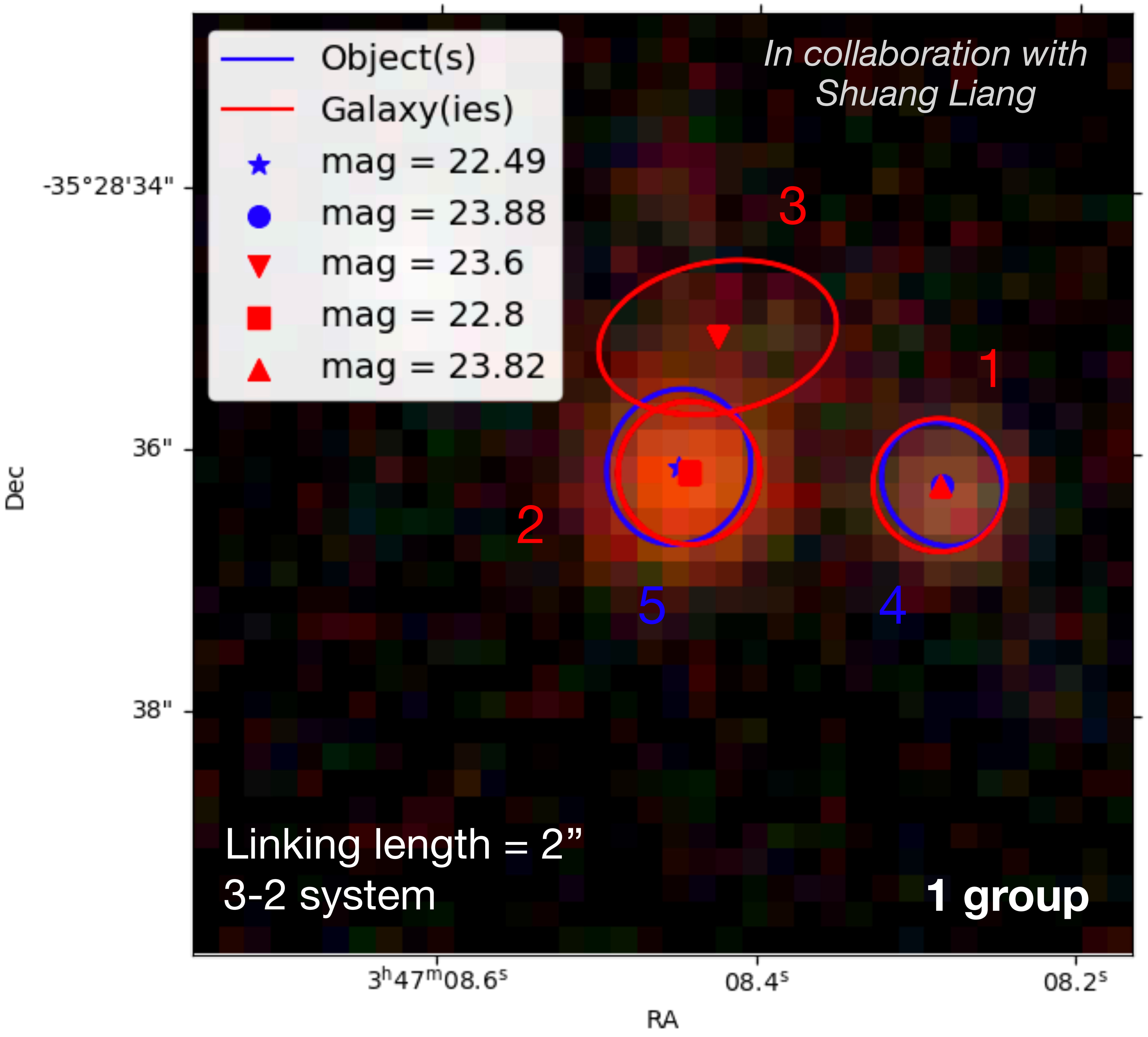

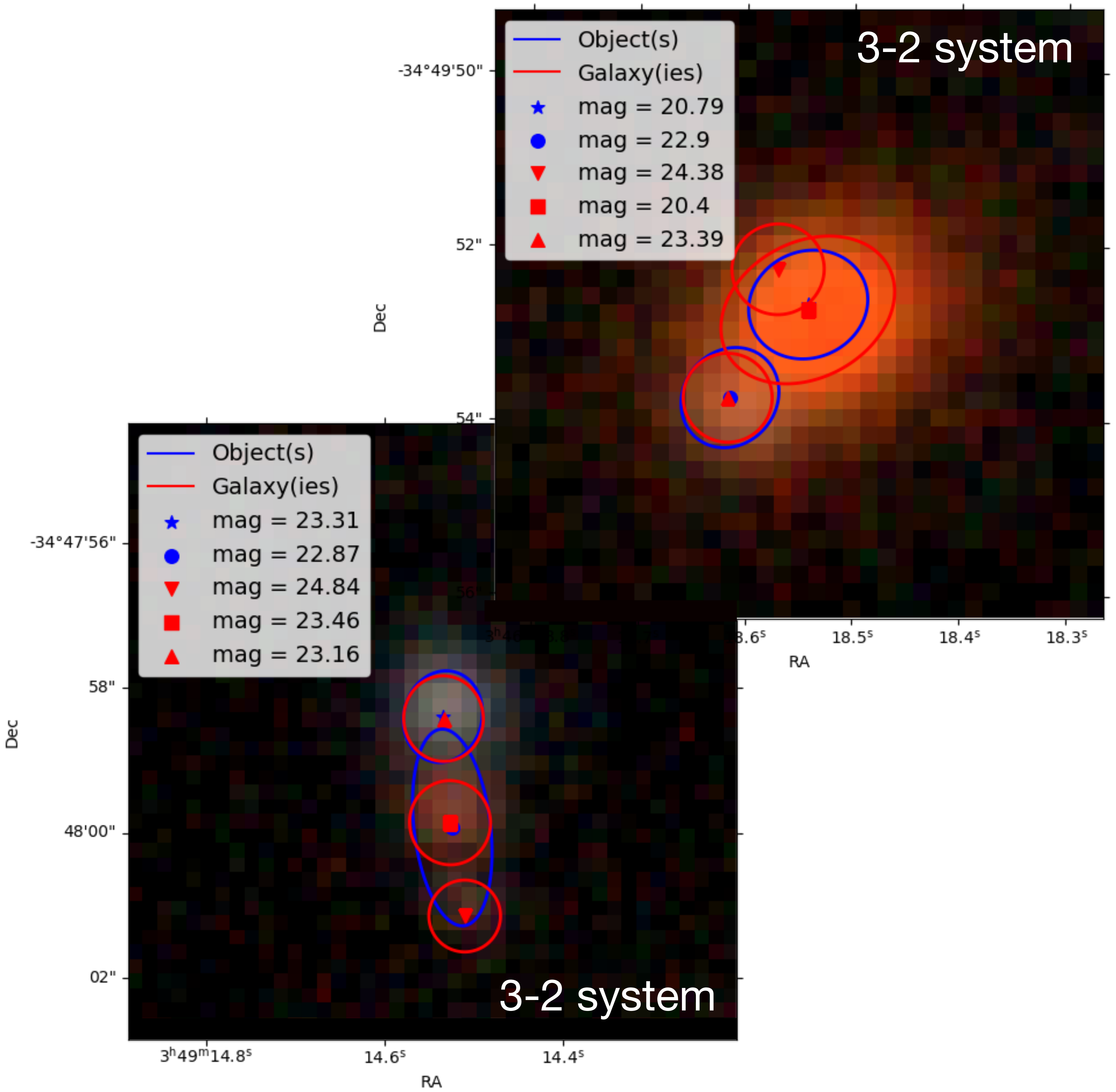

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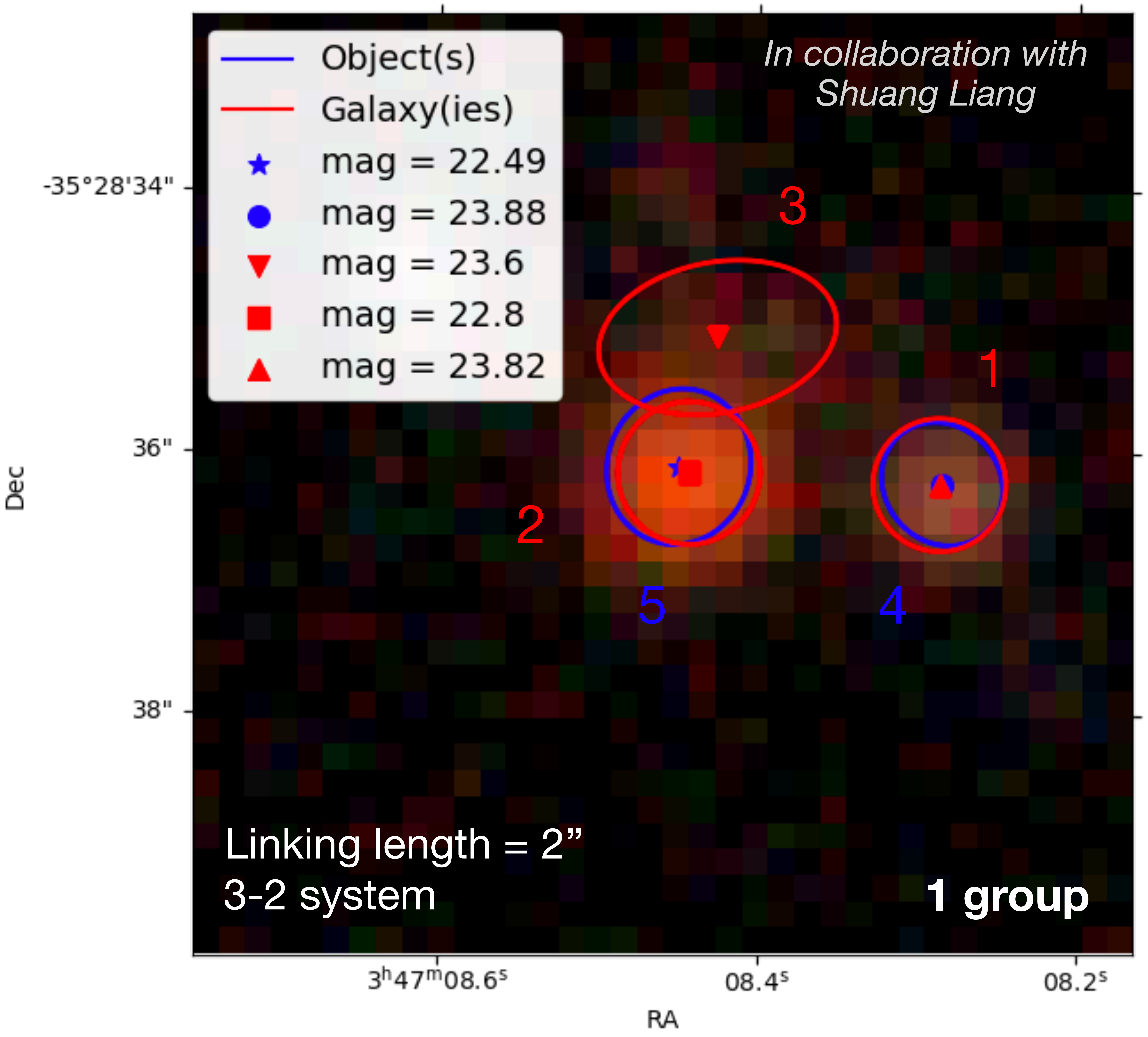
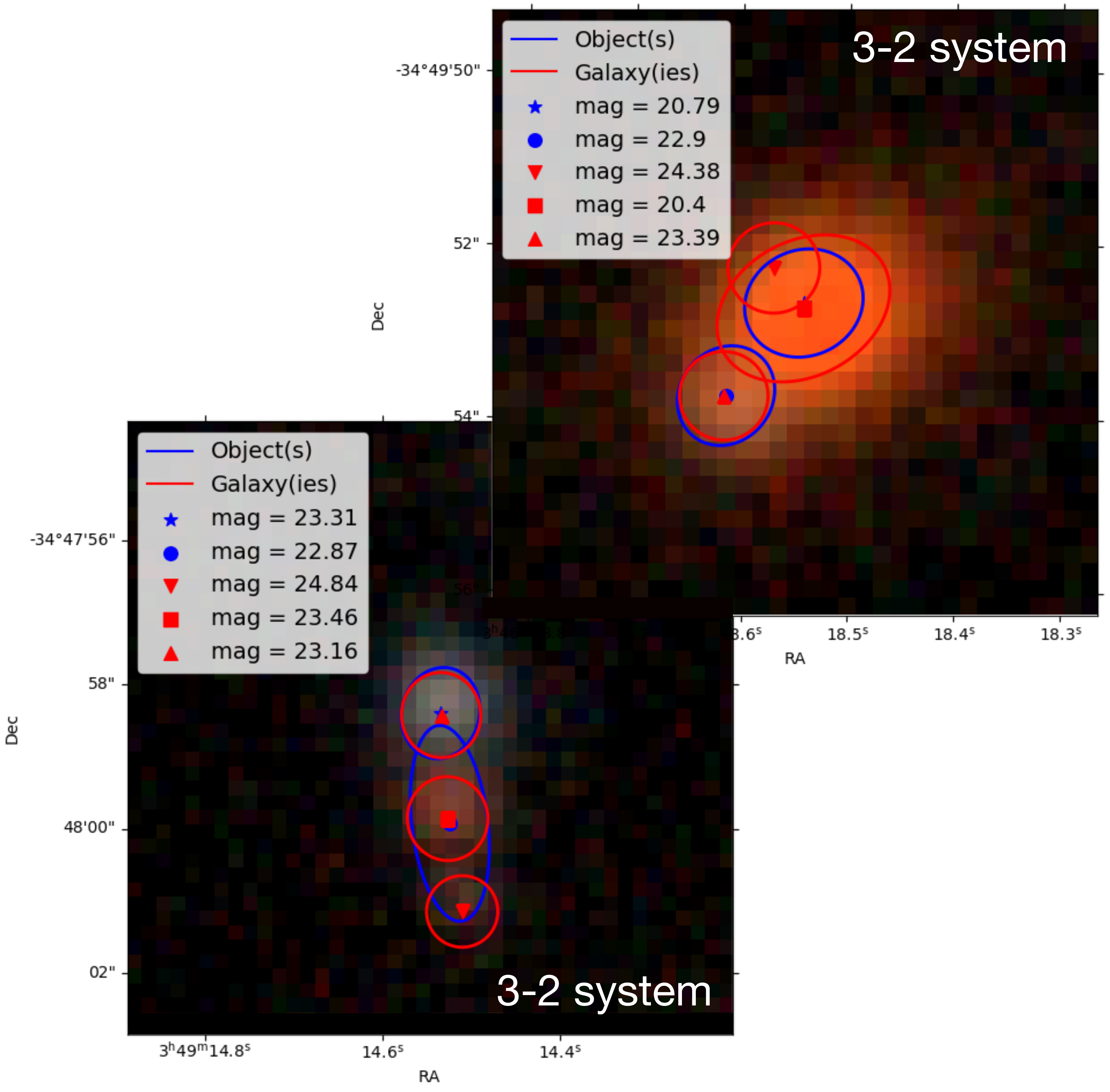
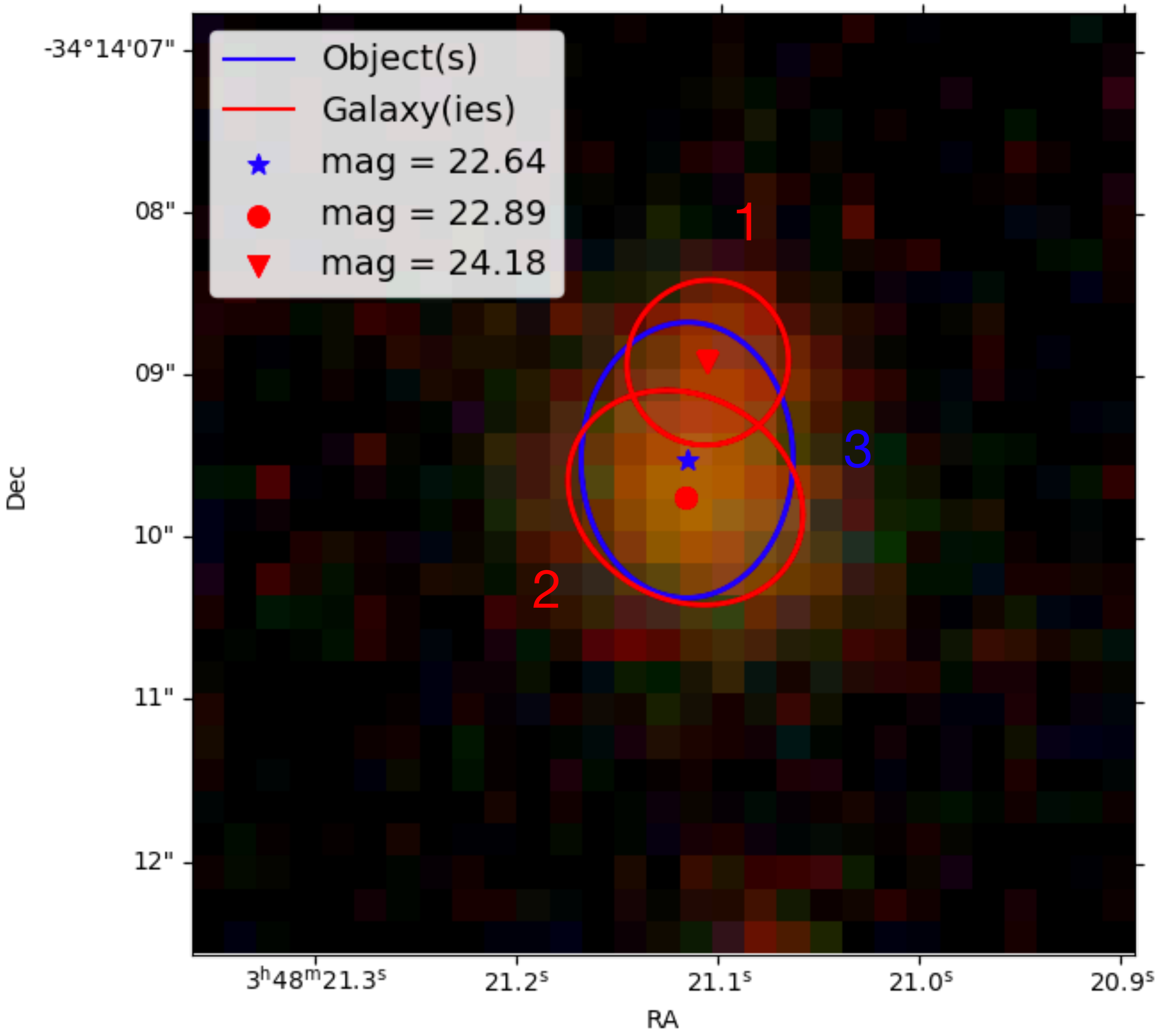




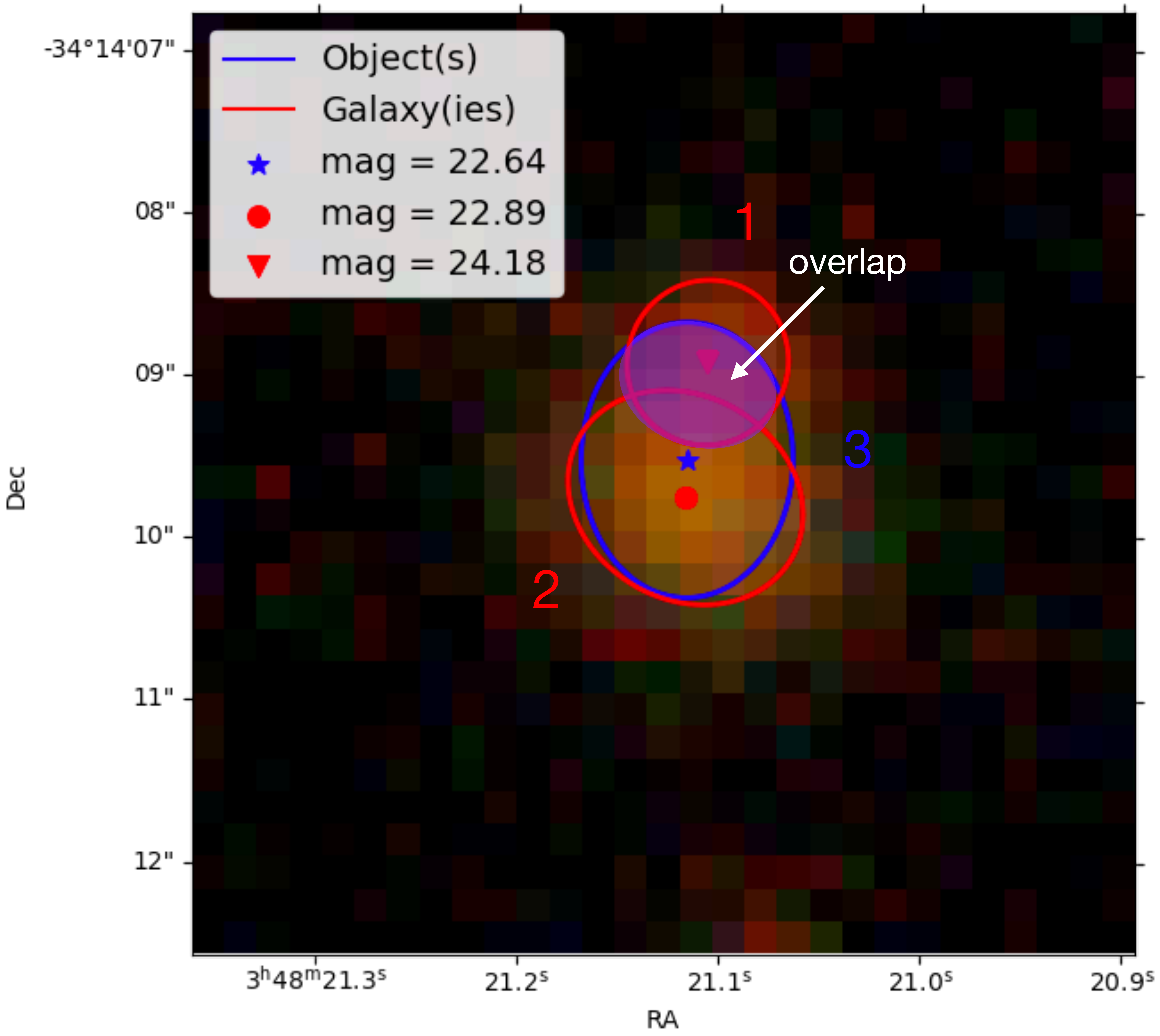
Need to account for position + shape + flux information

Blending as a matching ambiguity



Object-Galaxy matching probability

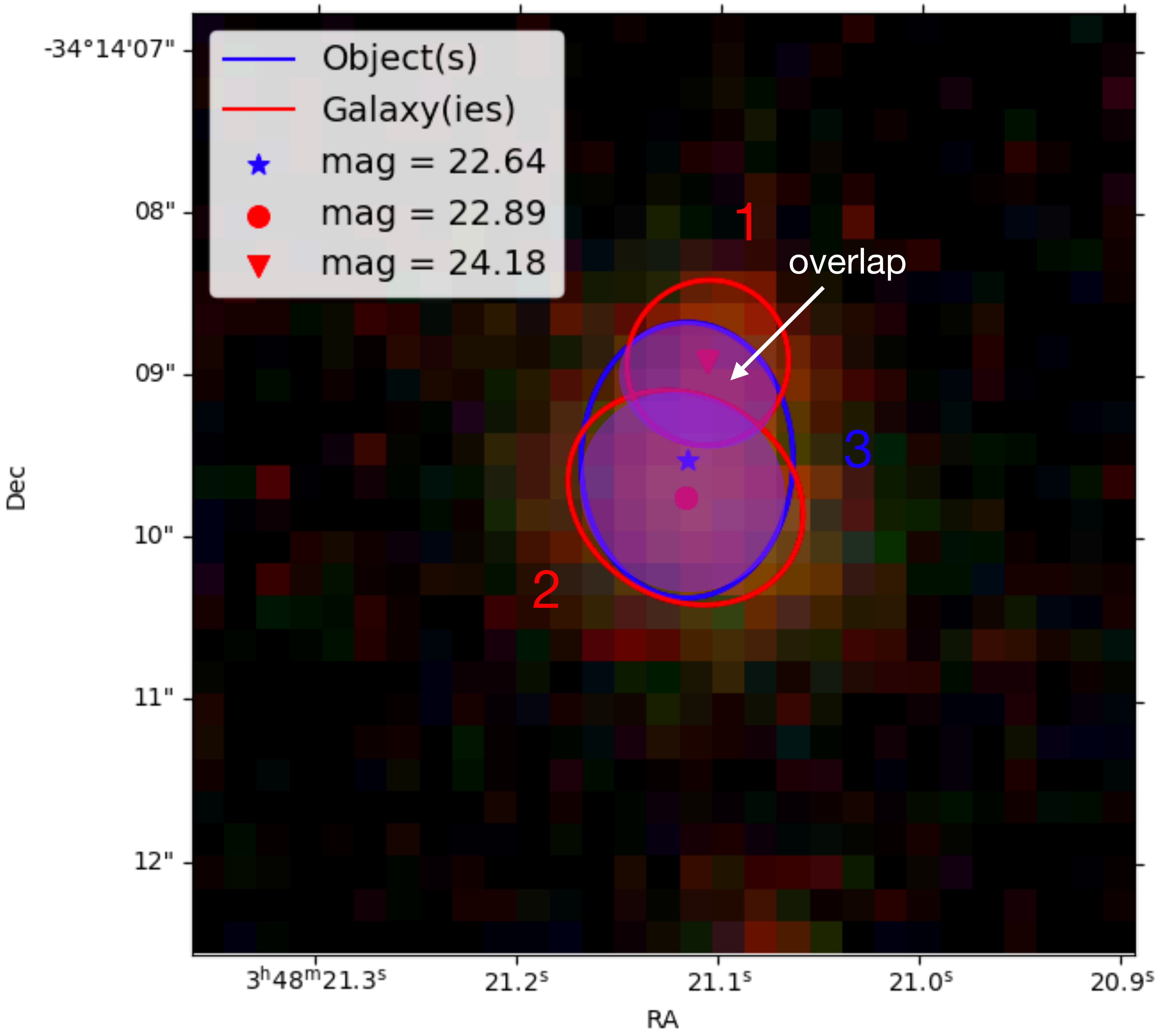
Blending as a matching ambiguity



Object-Galaxy matching probability

p ∝ overlap weighted by the difference in | magnitudes, colors

Blending as a matching ambiguity



Object-Galaxy matching probability

$p \propto$ overlap weighted by the difference in | magnitudes / colors

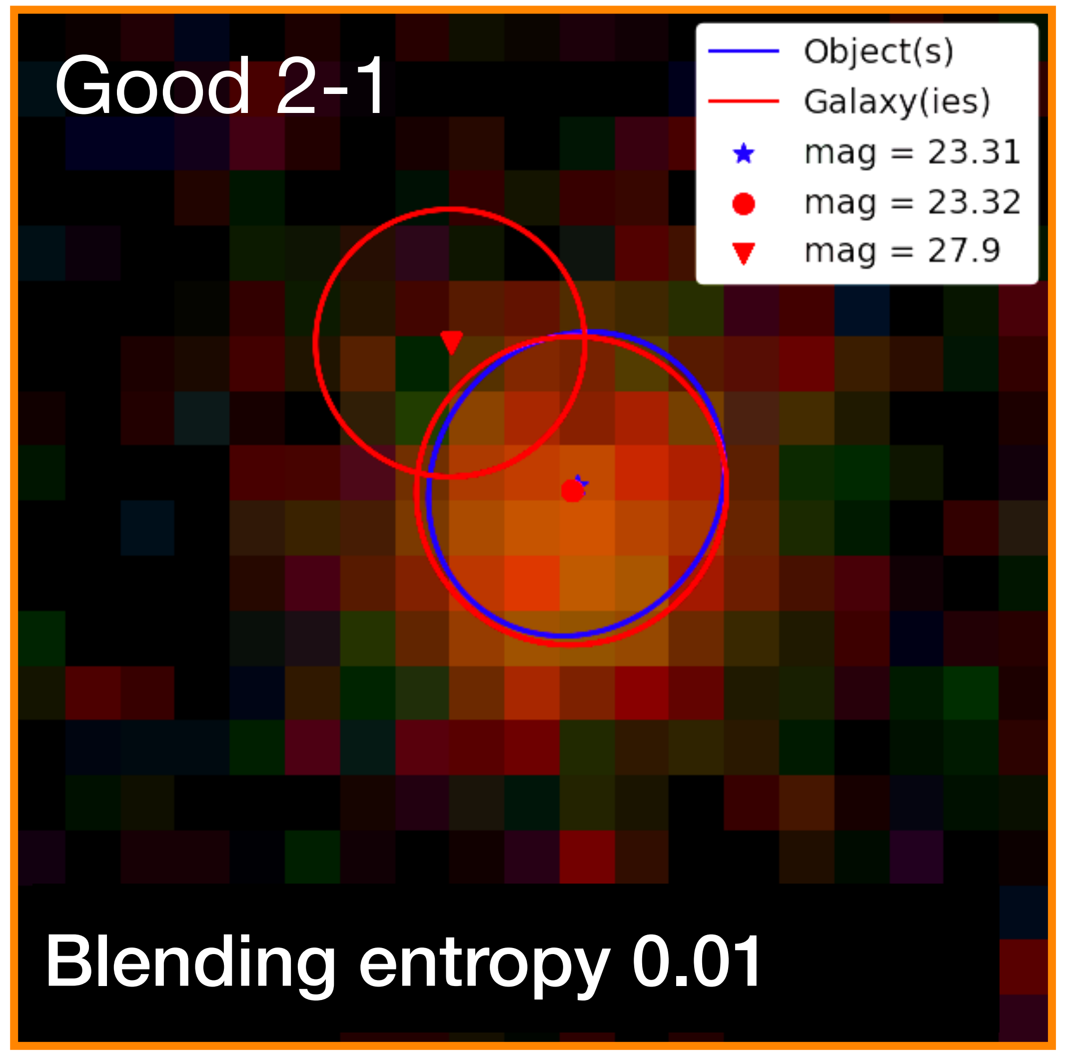
Blending entropy

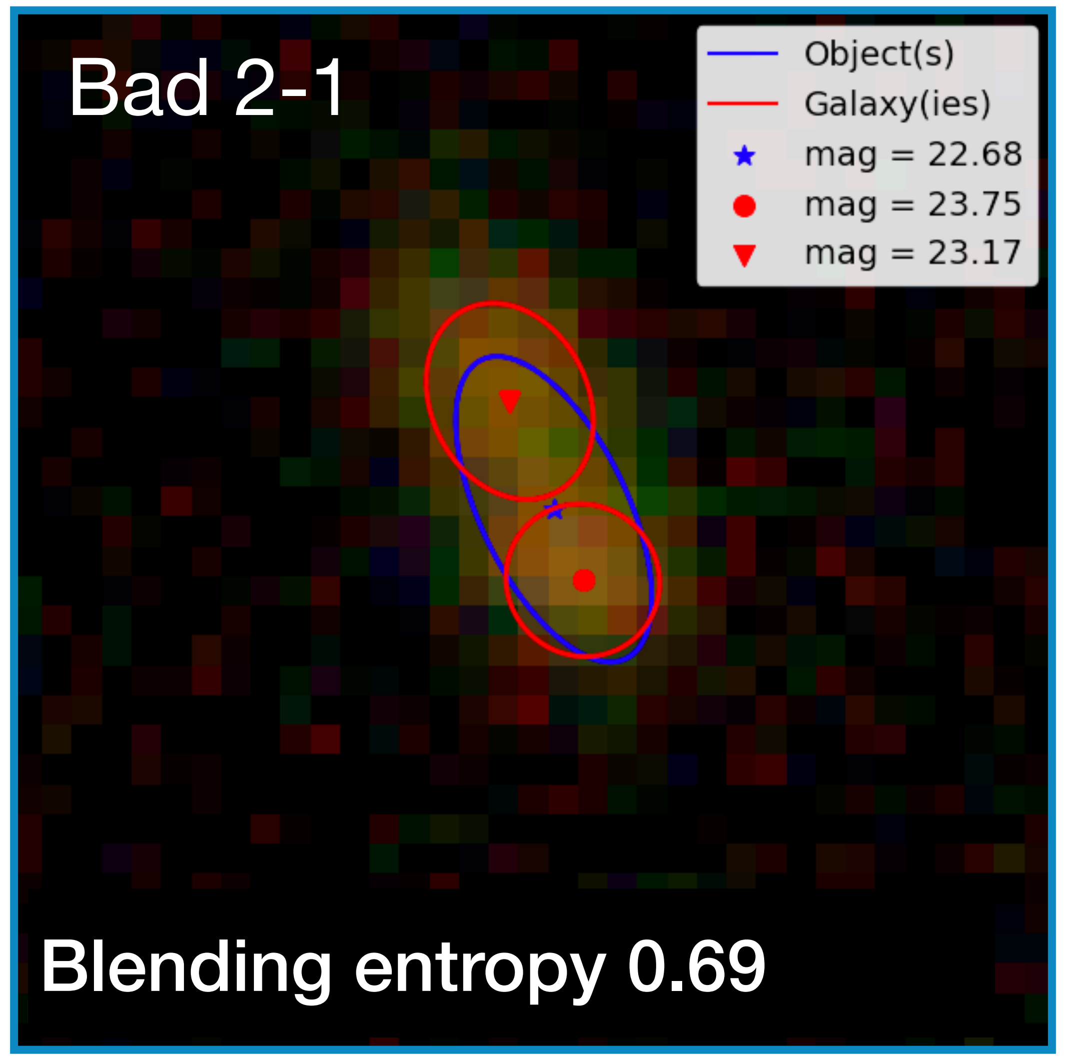
$$S_b = -\sum_{i \in gal} p_i \log p_i$$

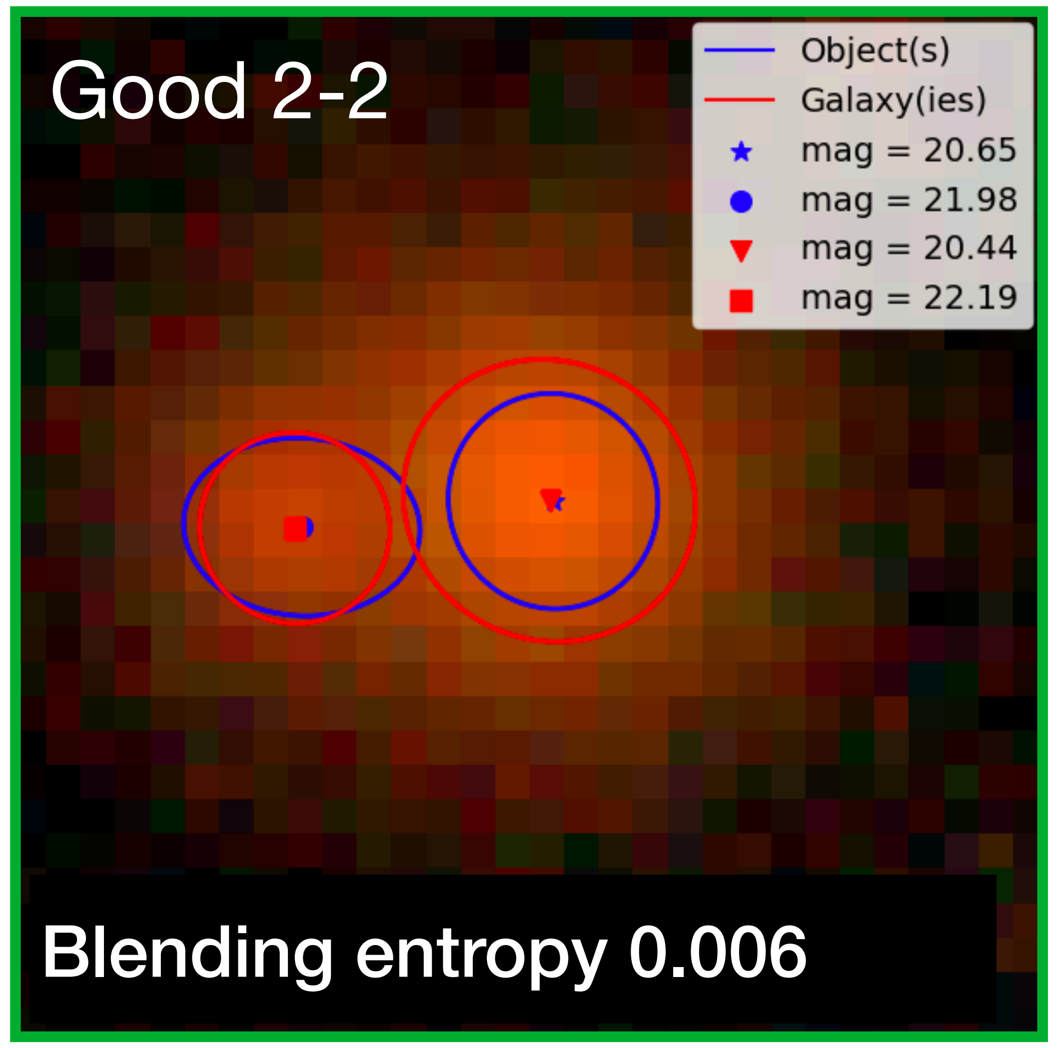
= score for each object

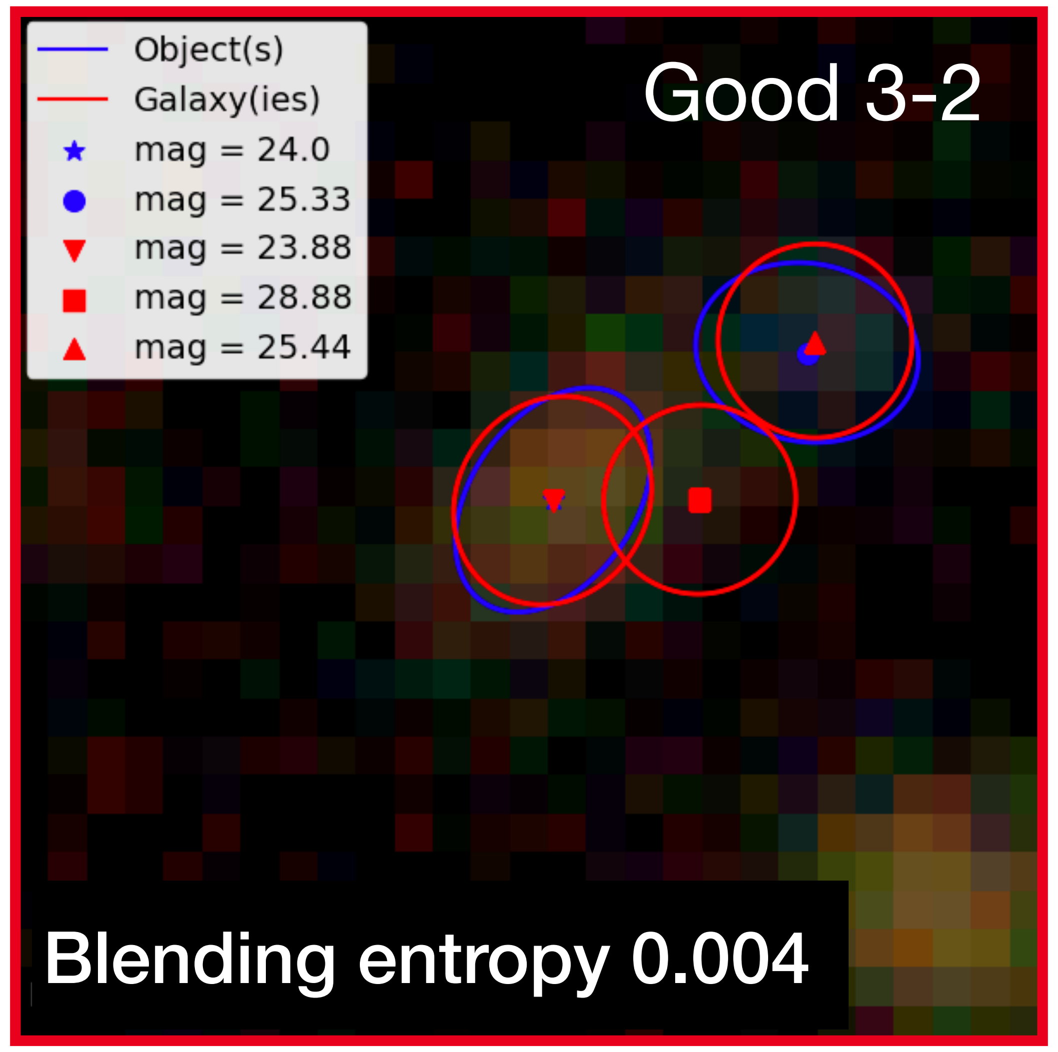
* $S_b = 0$ *for 1-1 systems*

S_b as discriminant of blended systems









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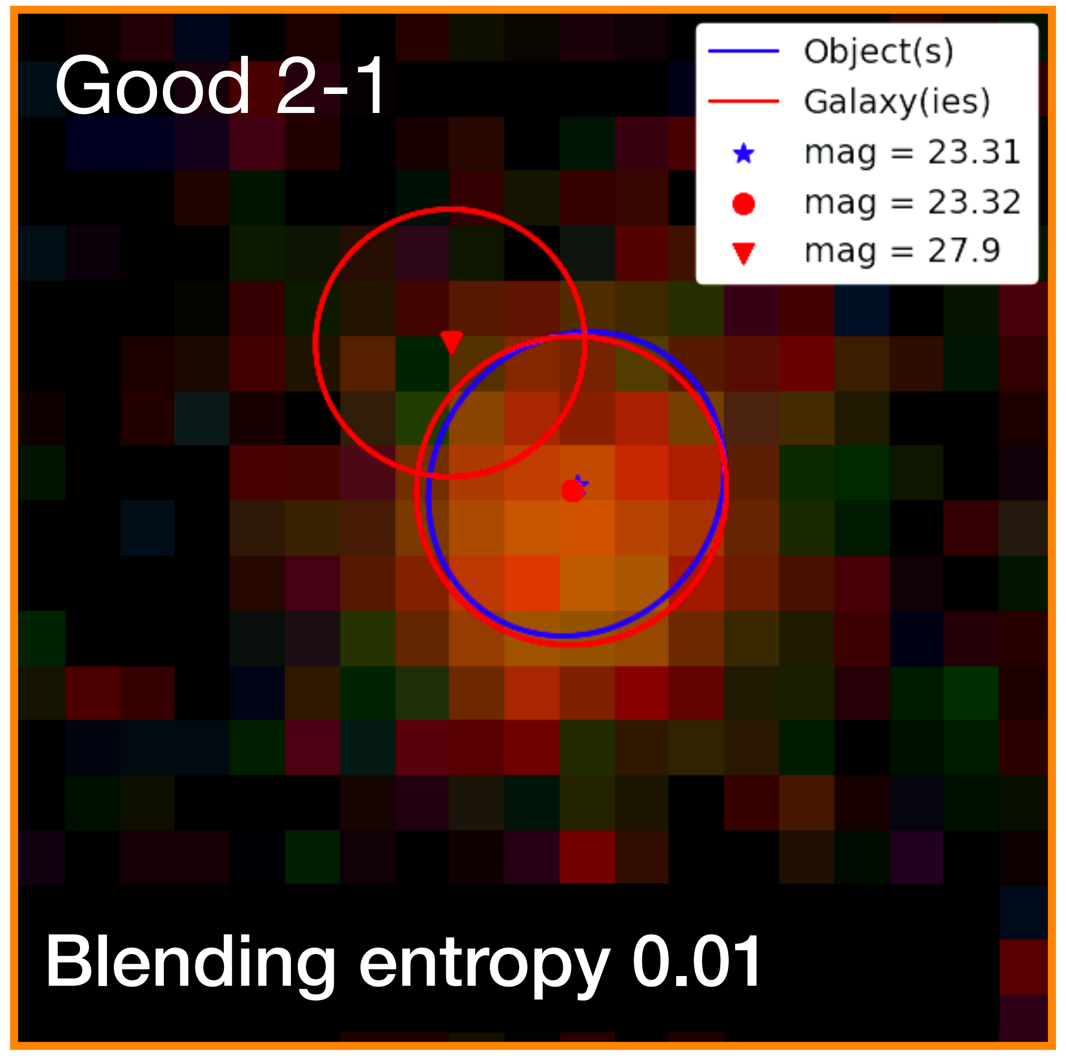

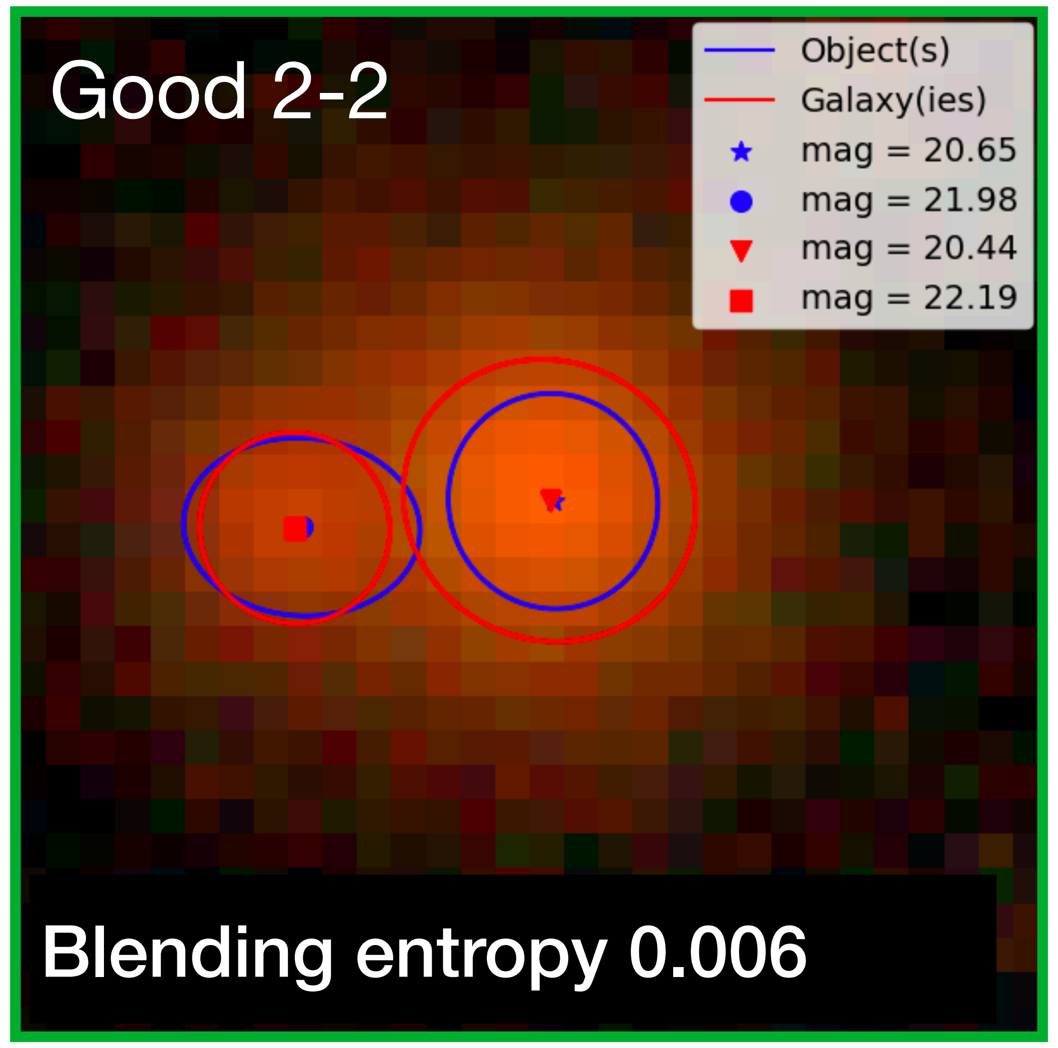

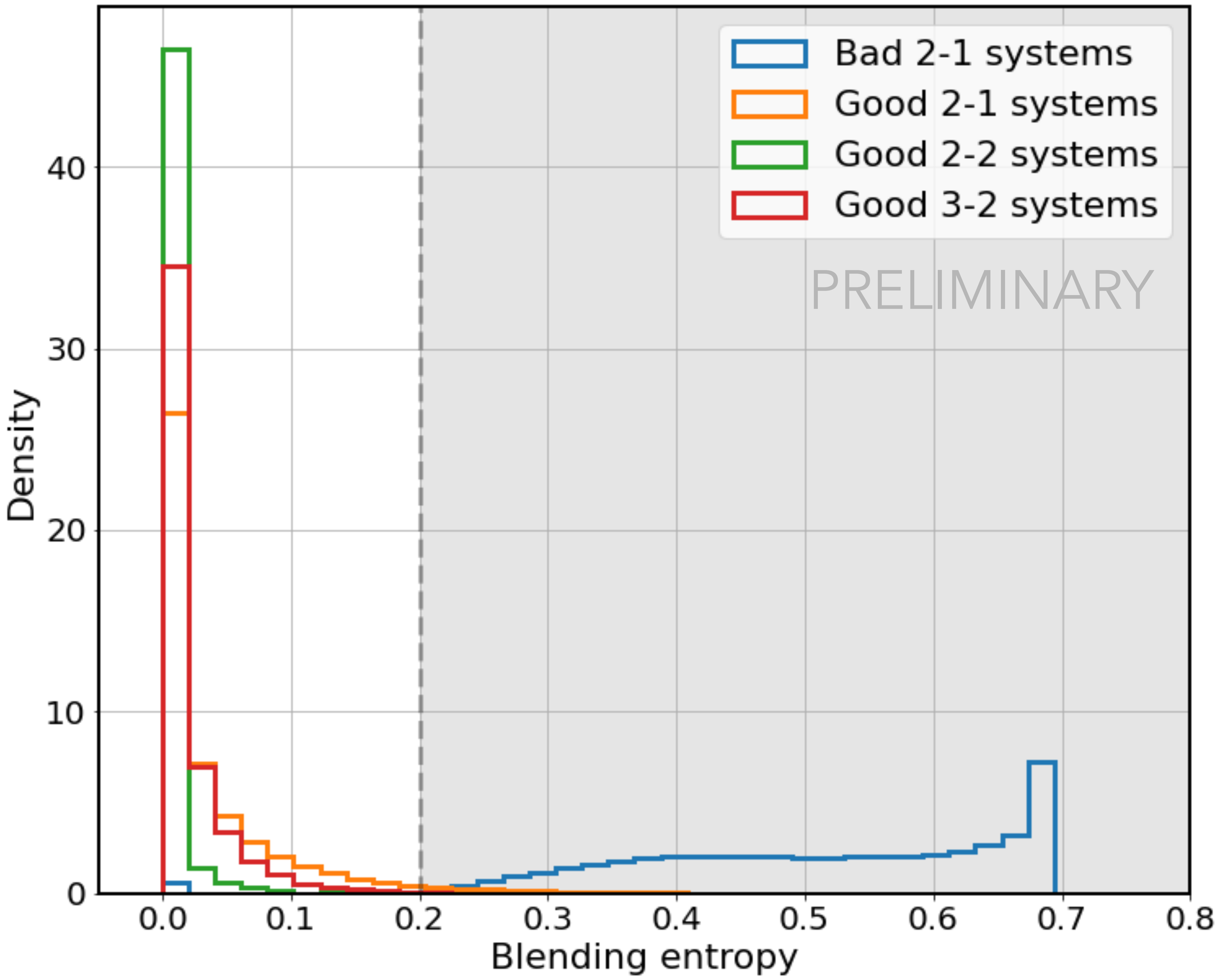

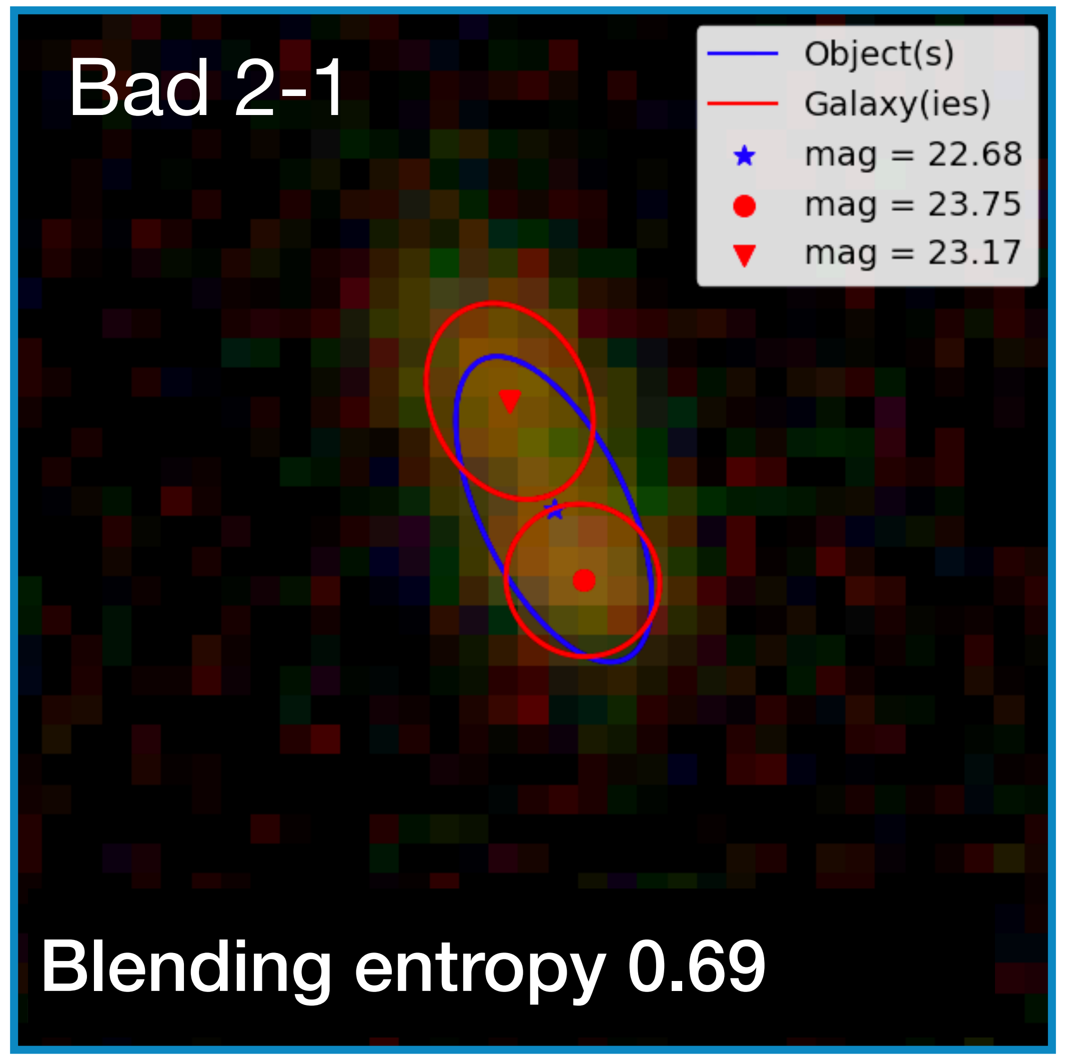

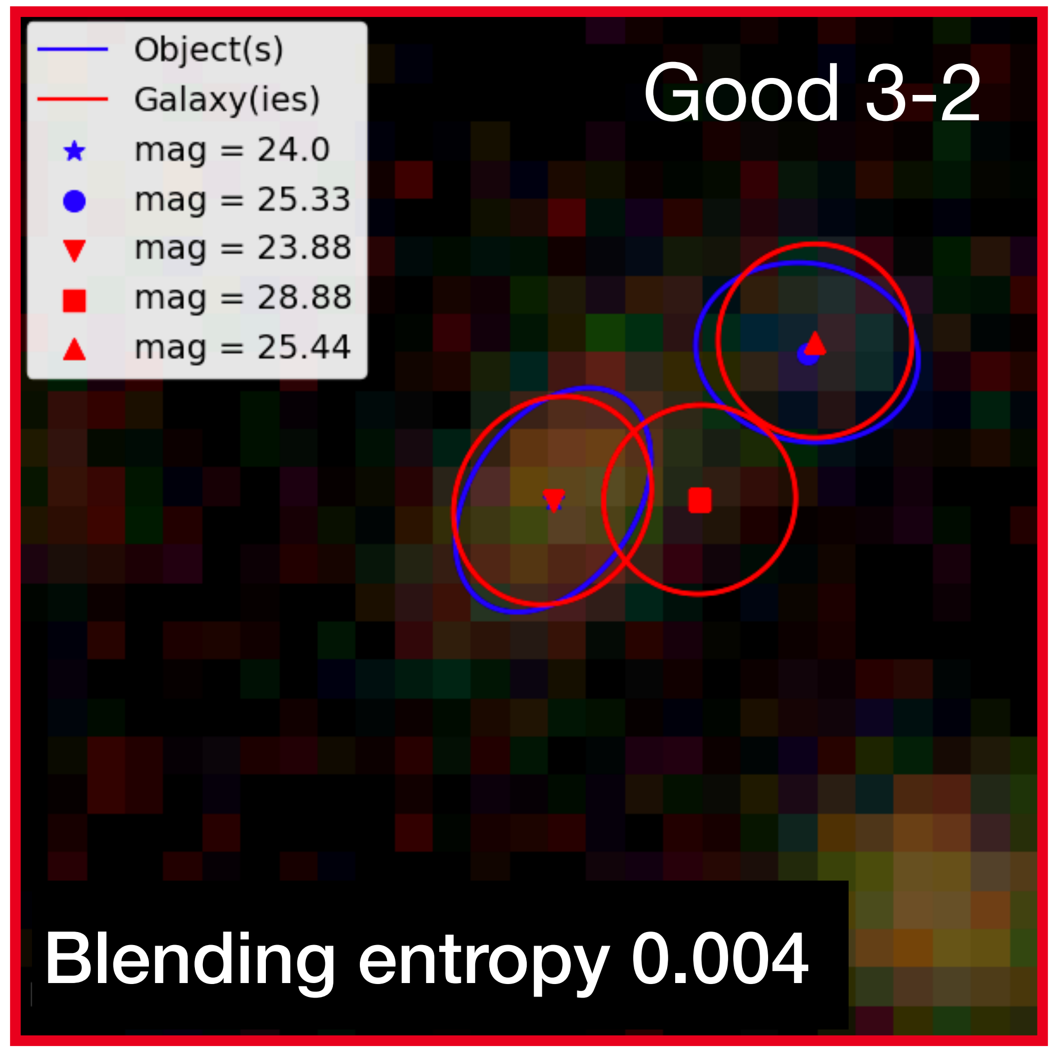

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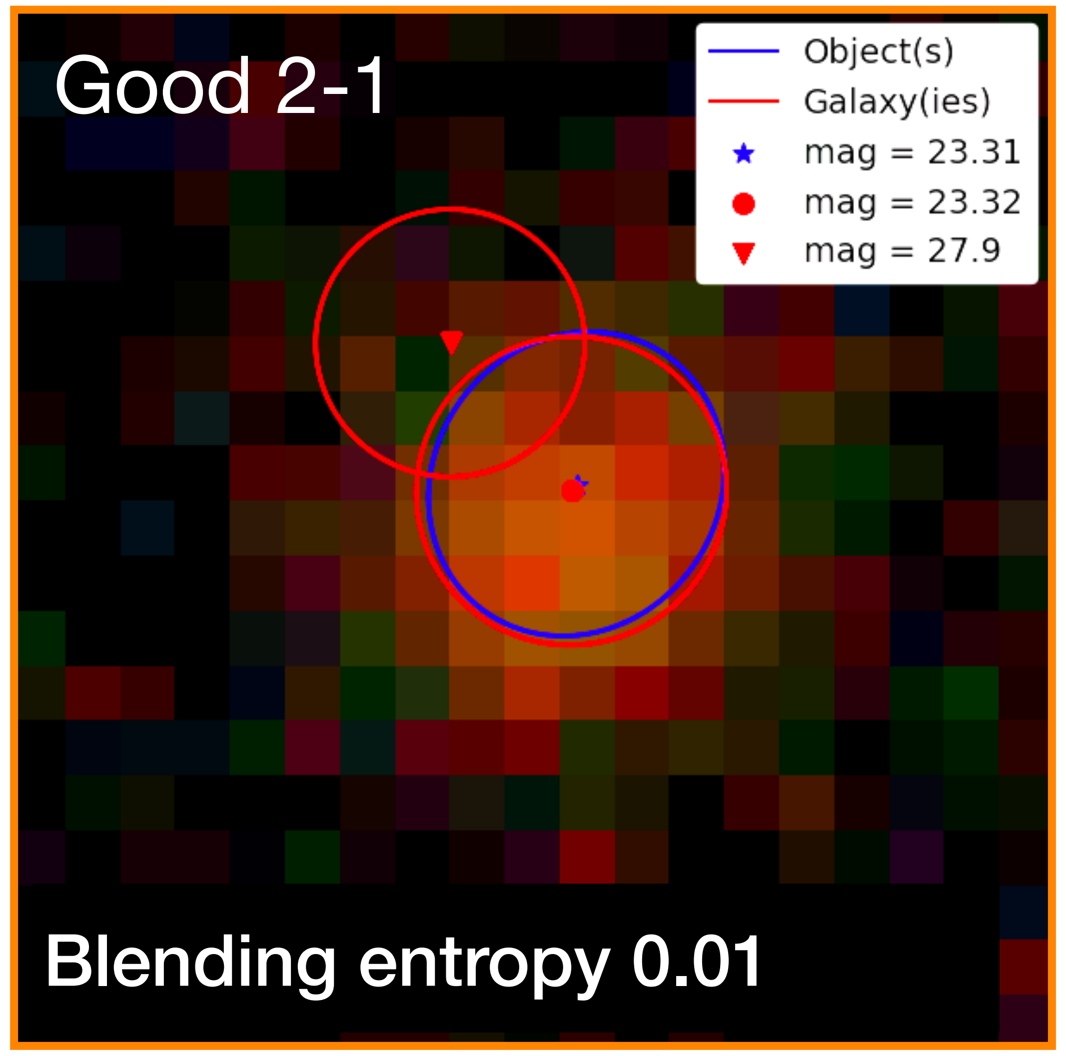
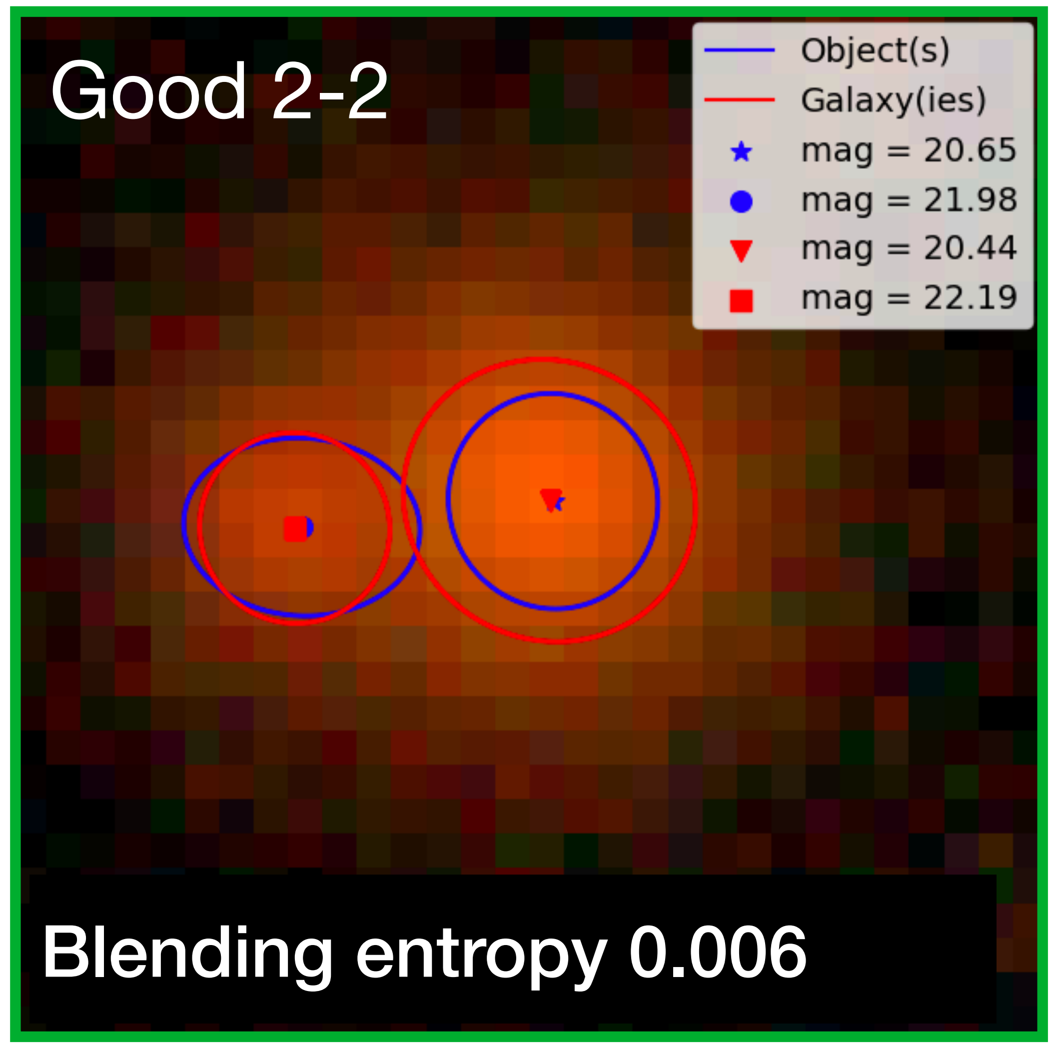
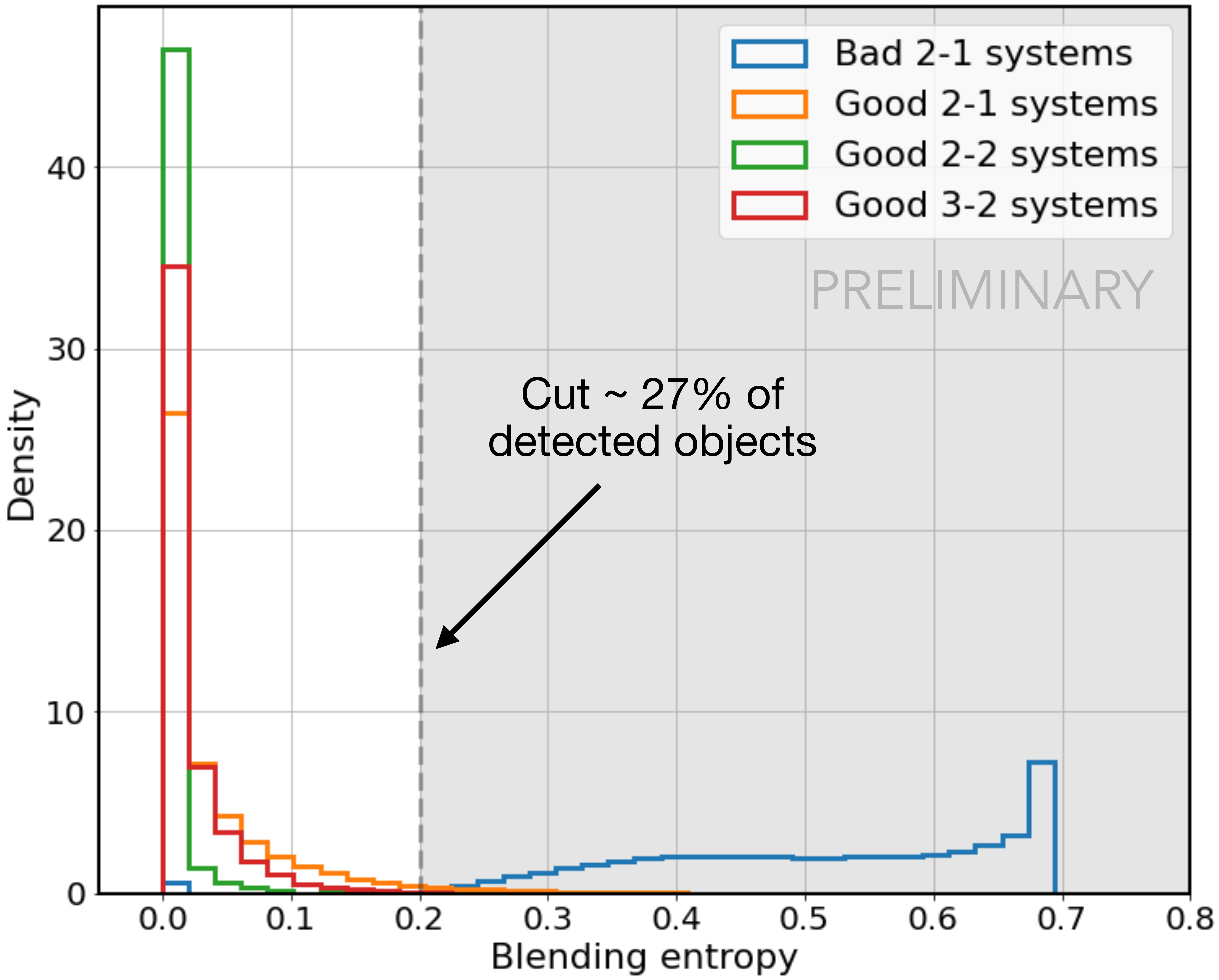
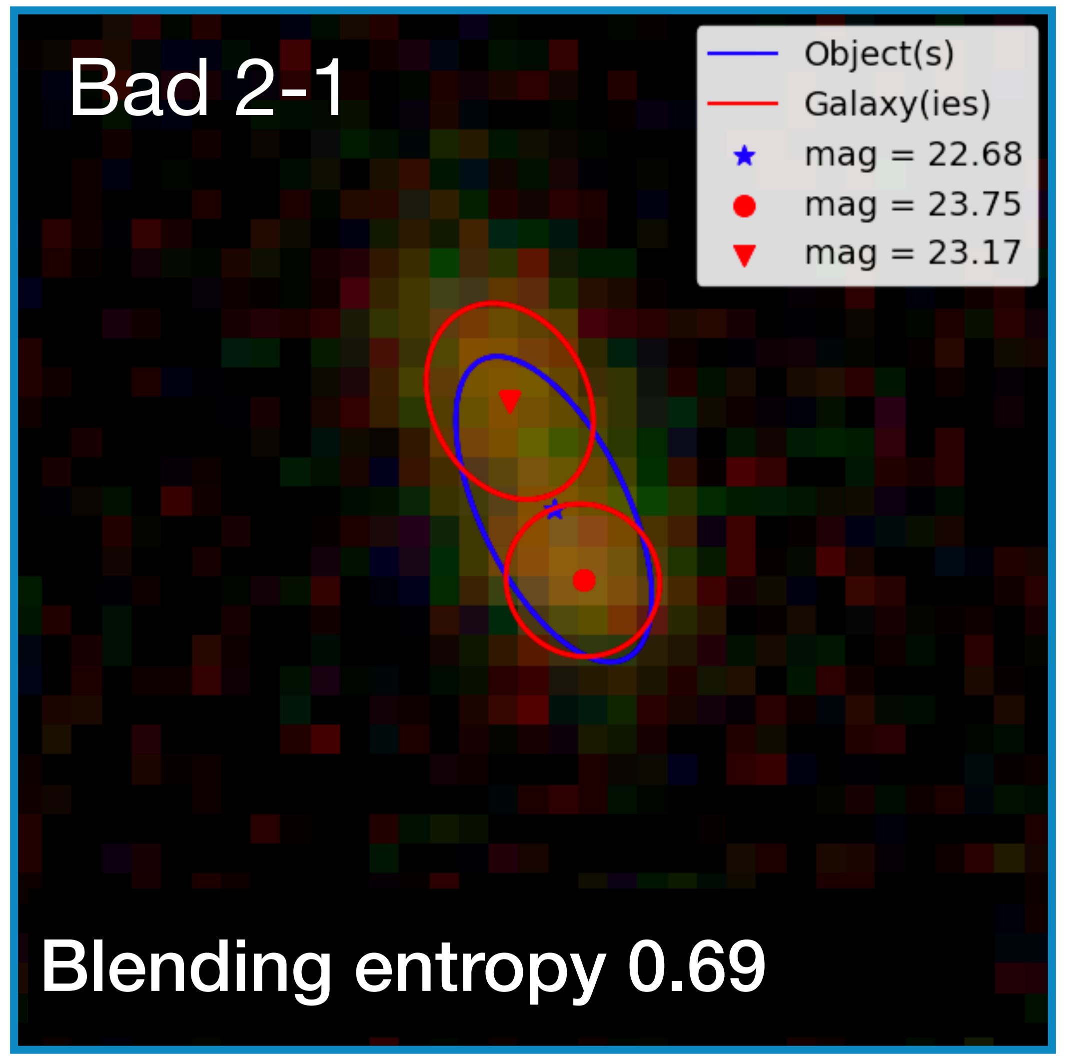
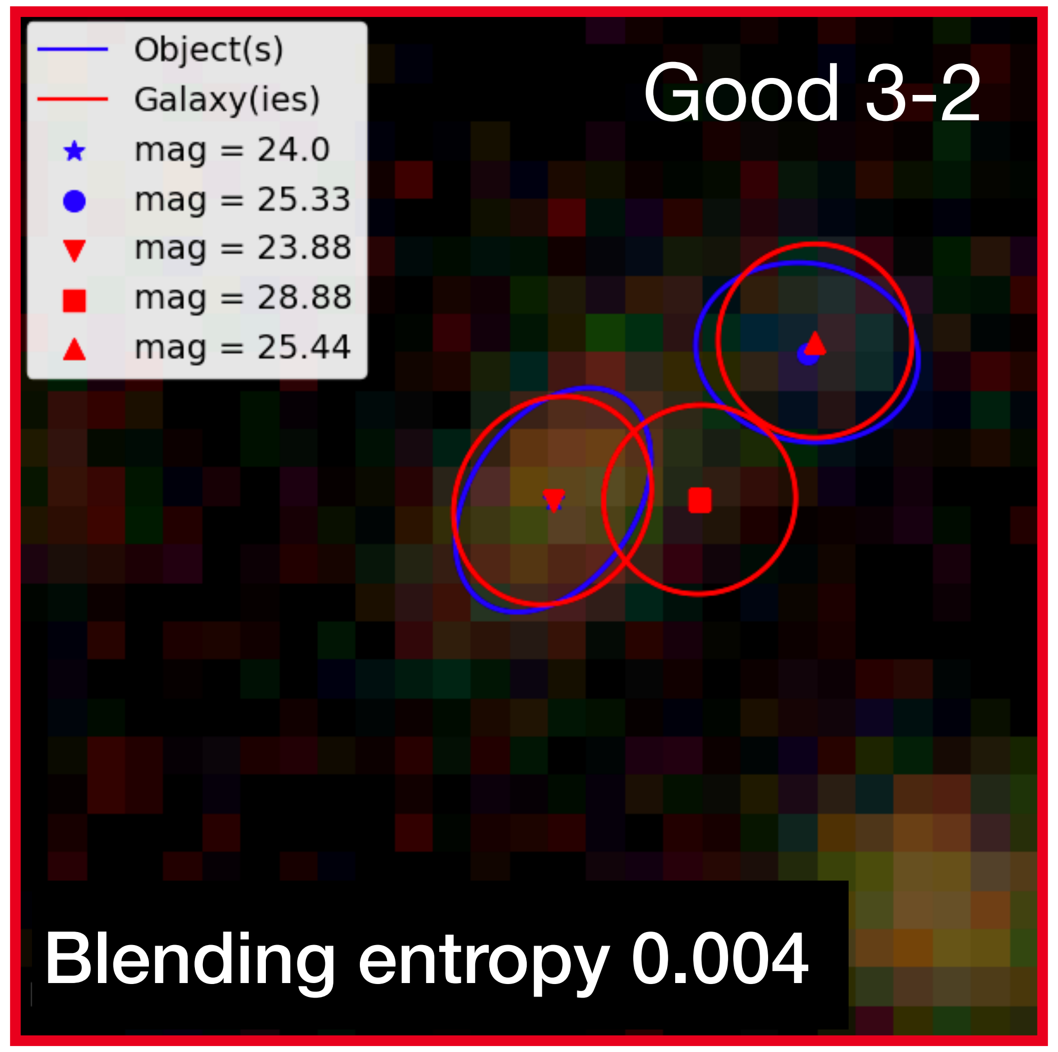




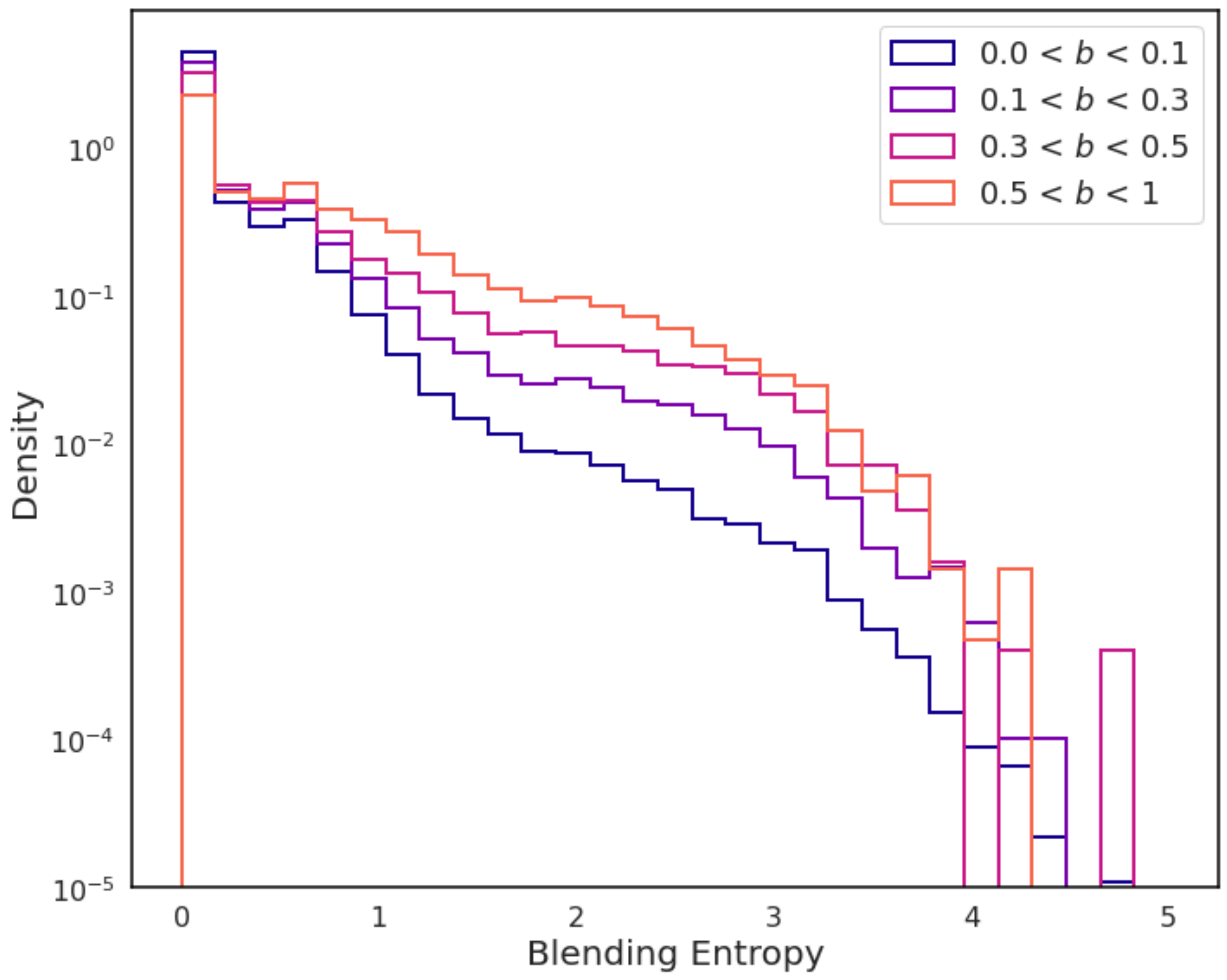




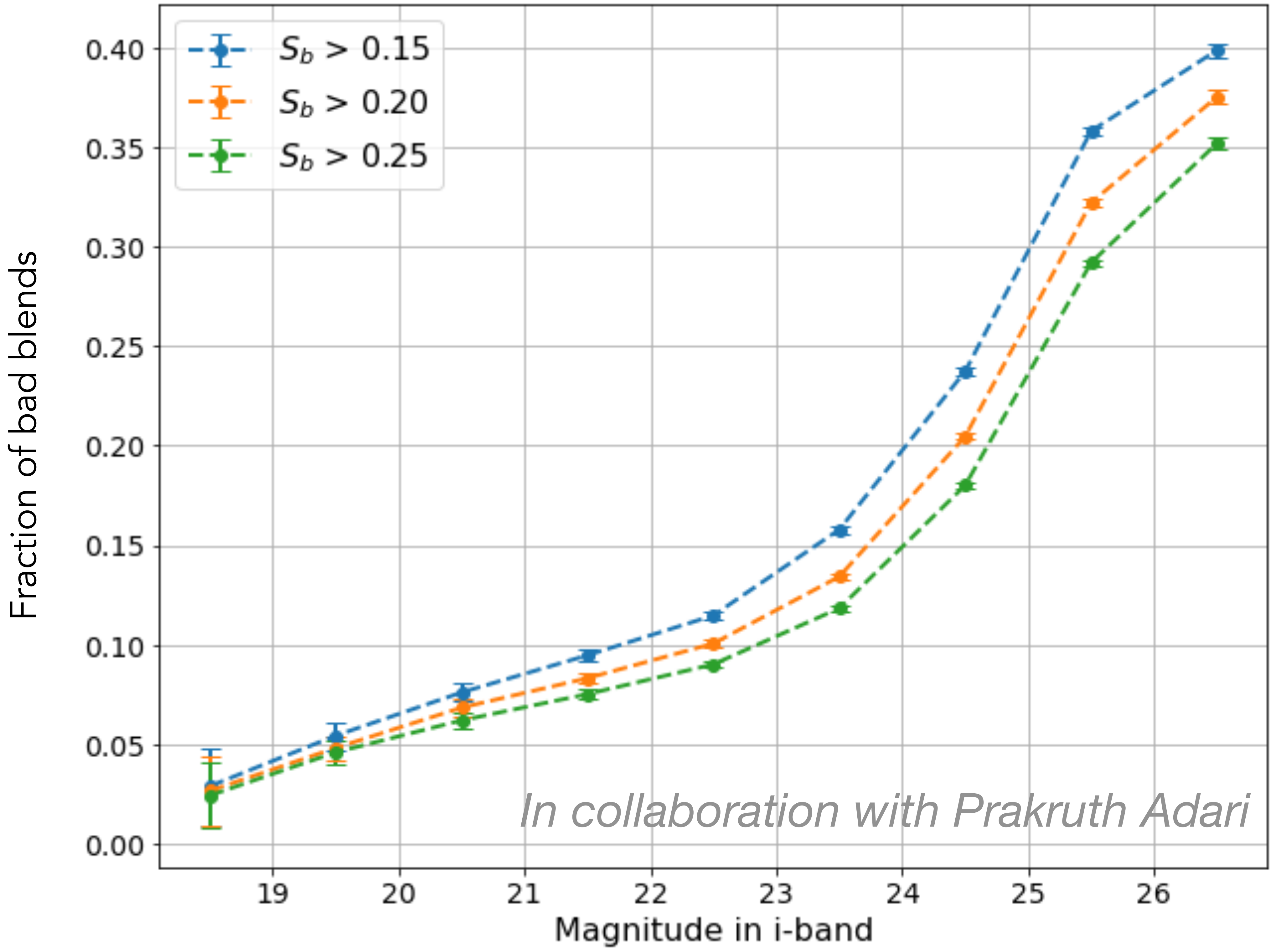


Blending entropy efficiency

Blending entropy vs. blendedness b



Fraction of *bad* blends increases with magnitude



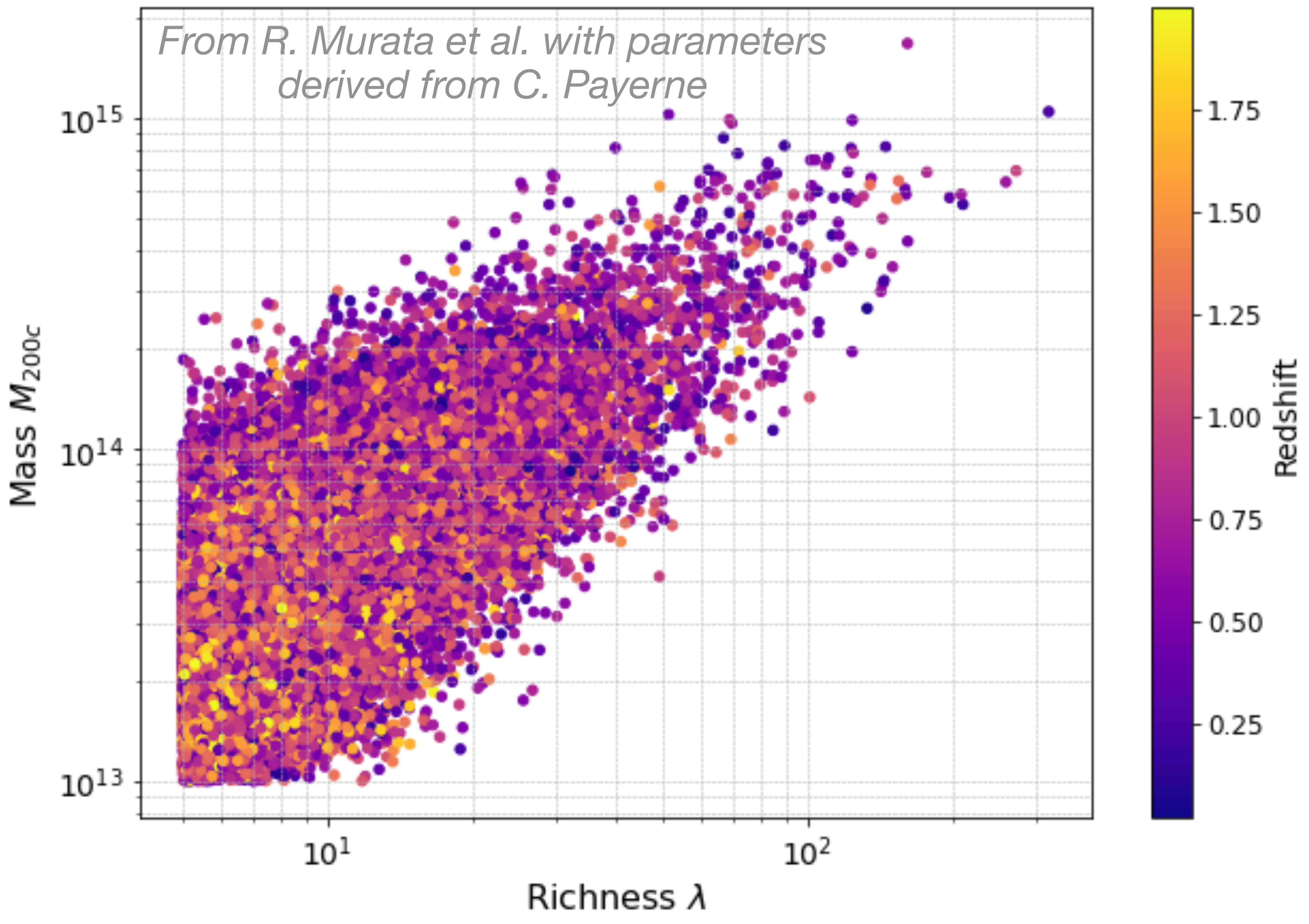
New efficient metric to characterize blended systems

Application to cluster cosmology

Framework

Set-up

- Lensing around DC2 **dark matter haloes**
  - No detection of galaxy clusters
- Sampling fiducial $M - \lambda$ relation

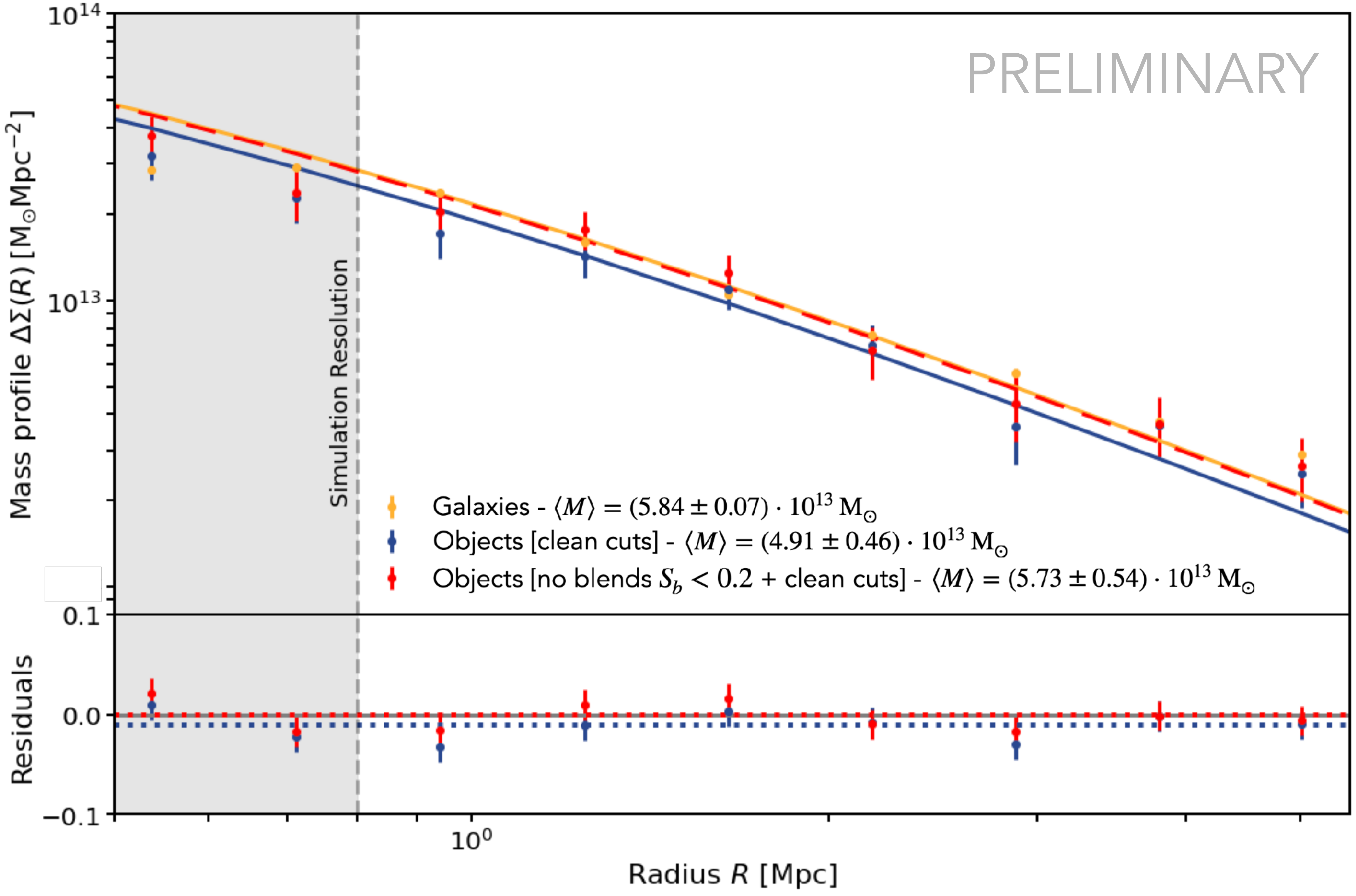


Goal

- Two observables per bins of richness and redshift
  - Haloes **number** and mean **mass**

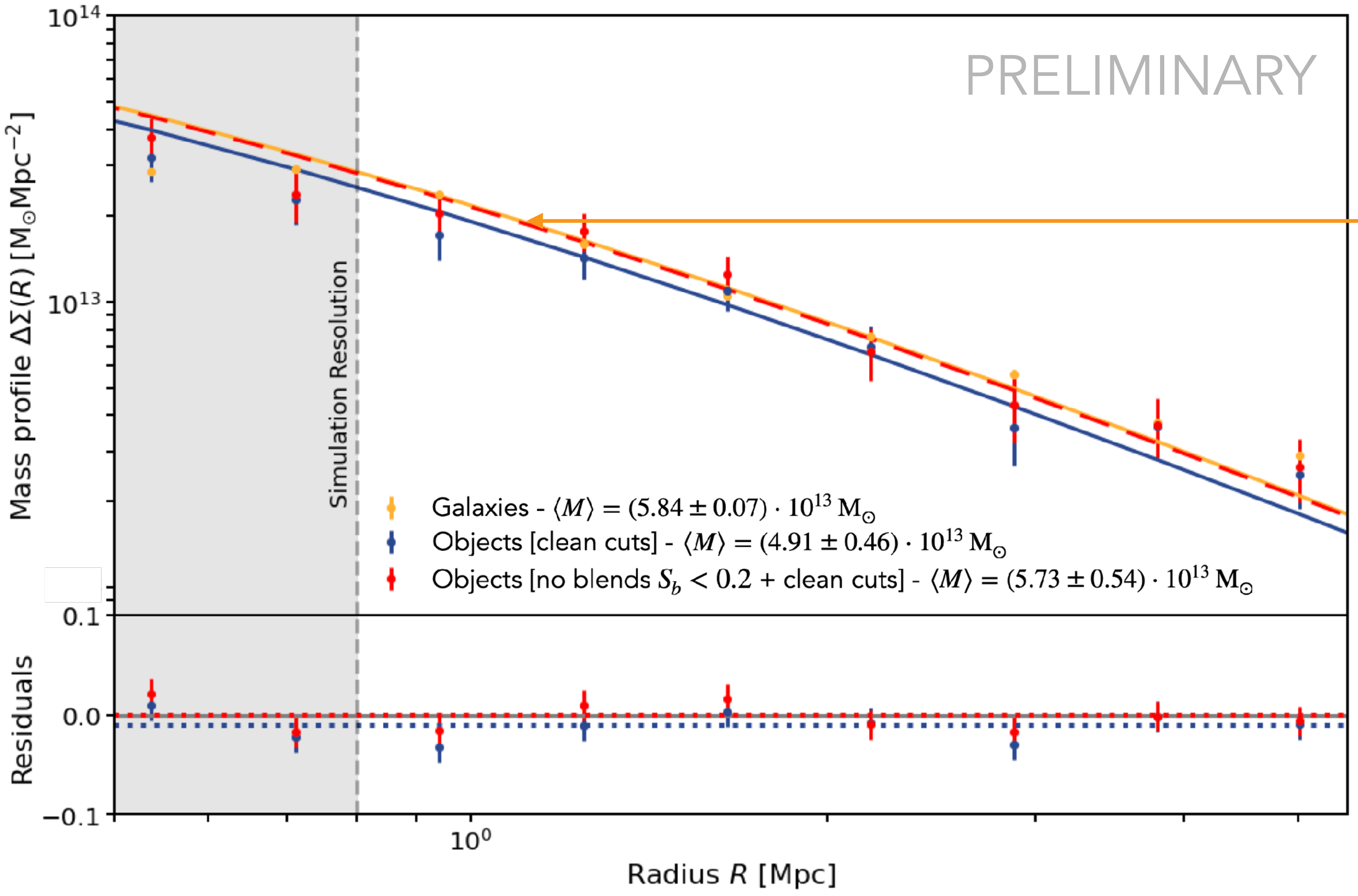
Impact of blending on lensing profiles

https://github.com/LSSTDESC/CLMM



Impact of blending on lensing profiles

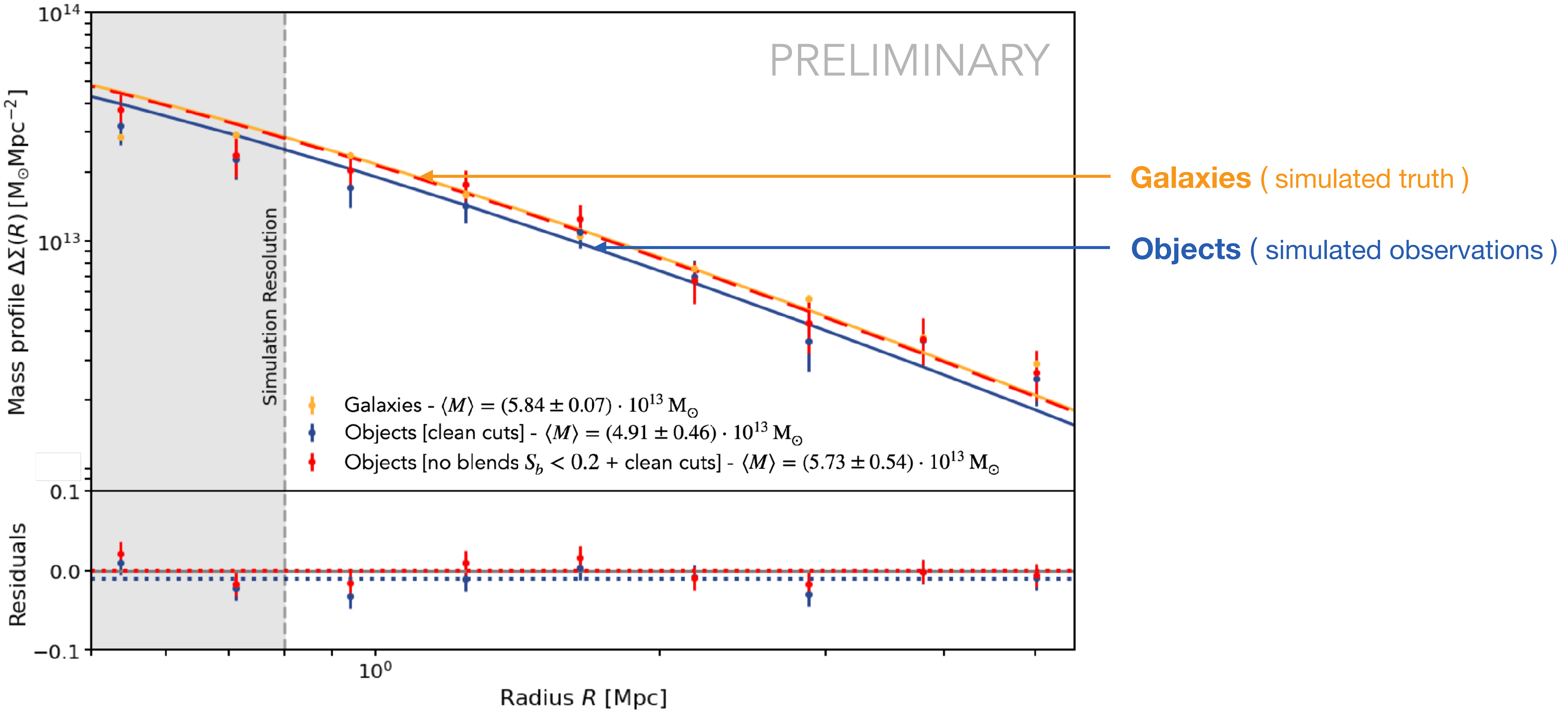
https://github.com/LSSTDESC/CLMM



Galaxies (simulated truth)

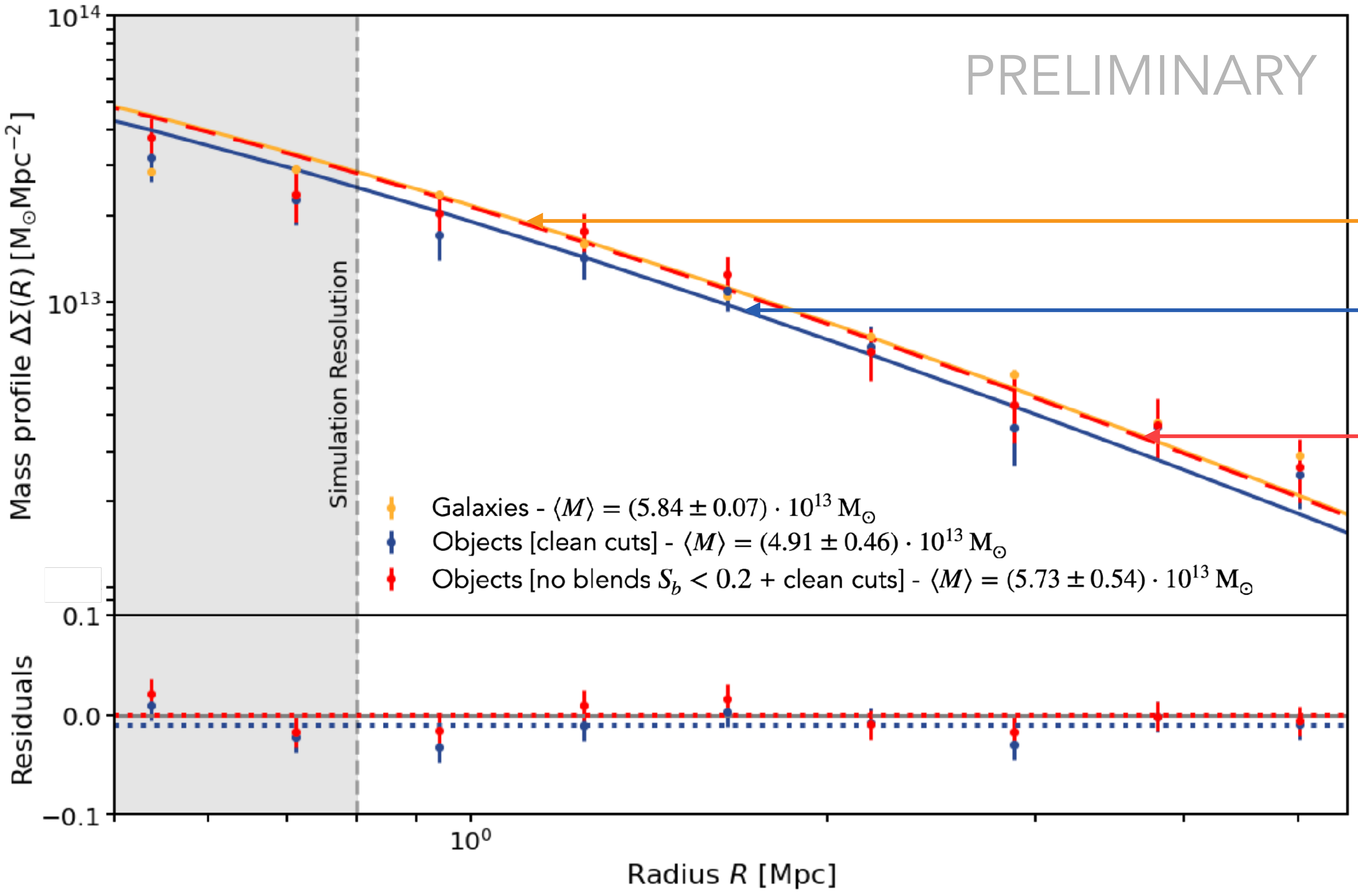
Impact of blending on lensing profiles

https://github.com/LSSTDESC/CLMM



Impact of blending on lensing profiles

https://github.com/LSSTDESC/CLMM



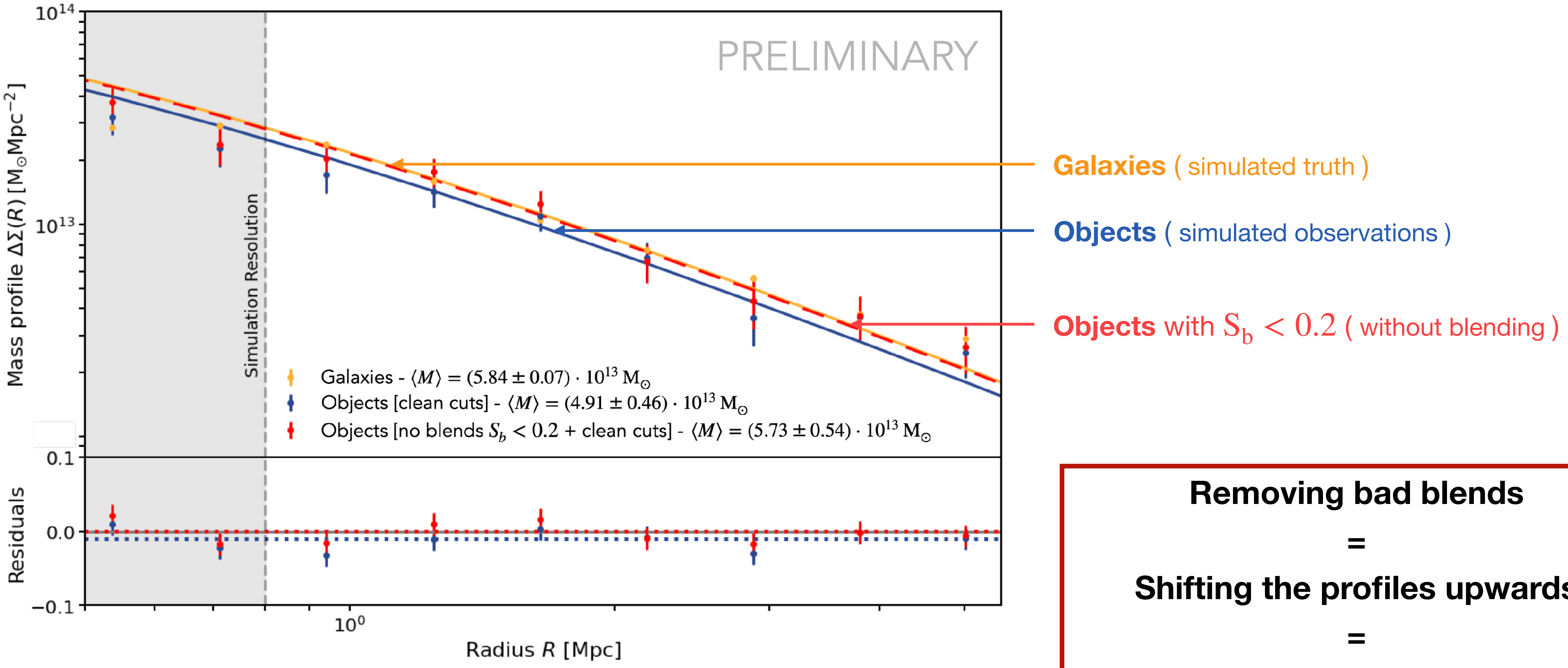
Galaxies (simulated truth)

Objects (simulated observations)

Objects with $S_b < 0.2$ (without blending)

Impact of blending on lensing profiles

https://github.com/LSSTDESC/CLMM



Removing bad blends

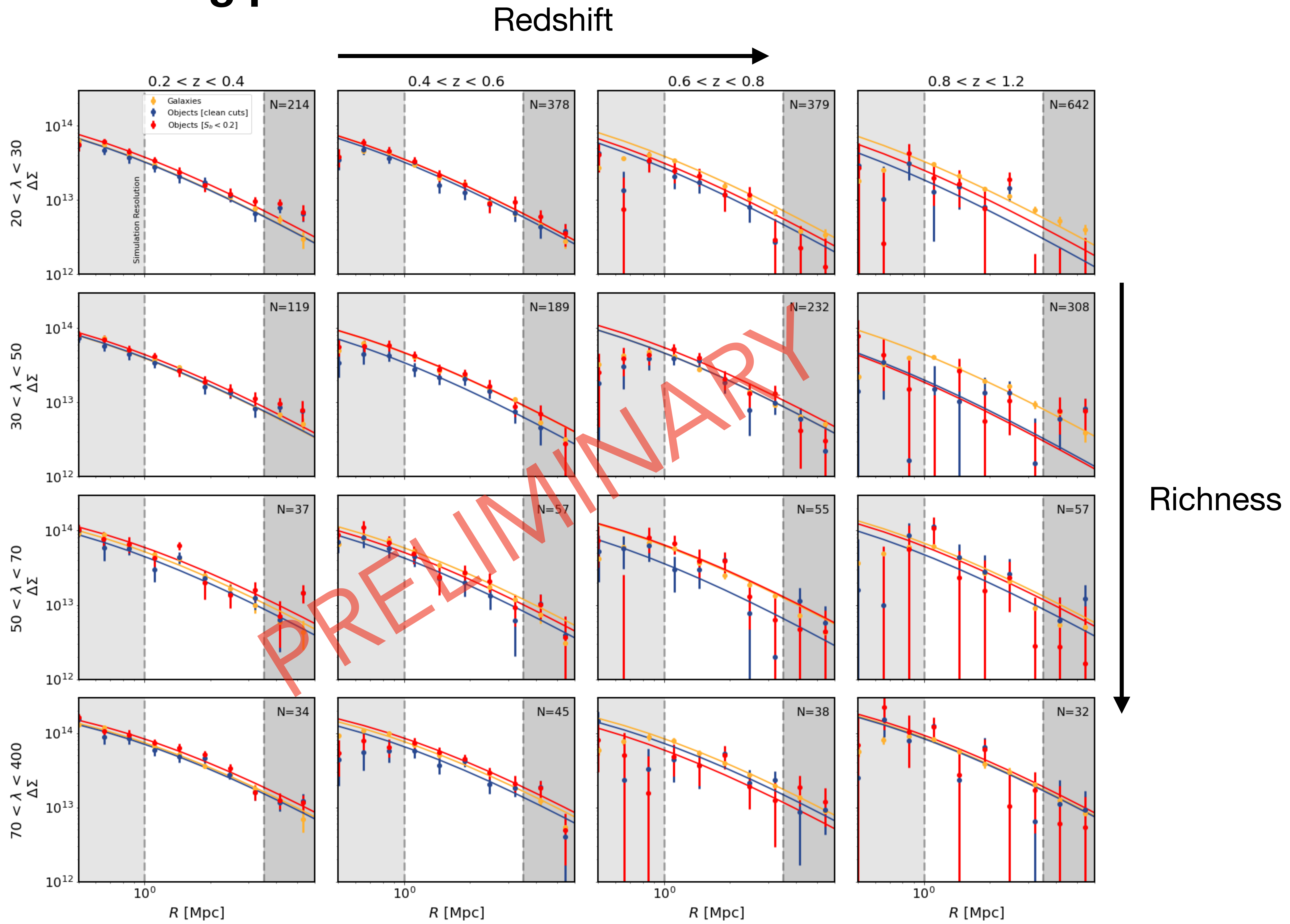
=

Shifting the profiles upwards

=

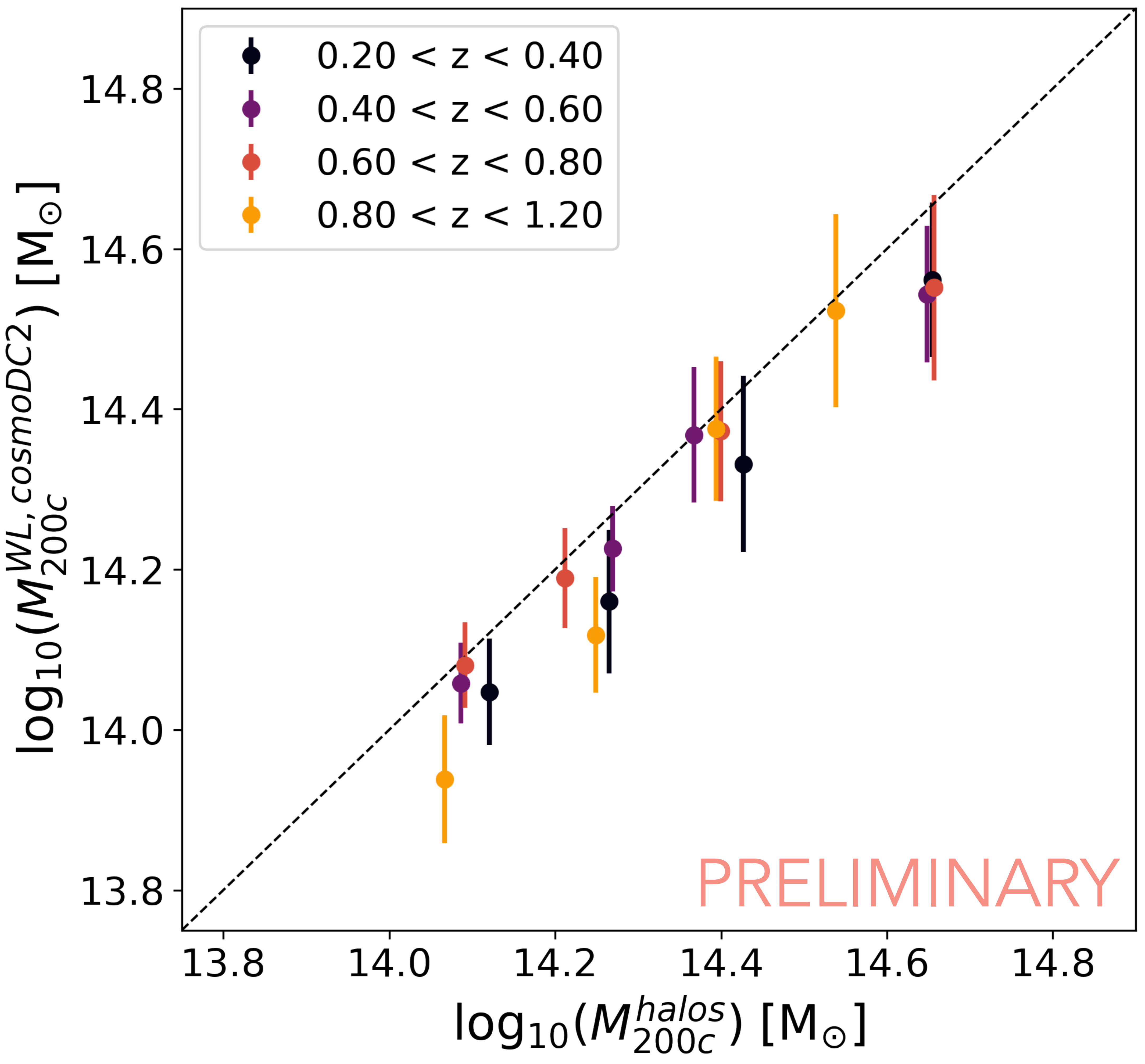
Recovering the true cluster mass

Impact of blending on lensing profiles



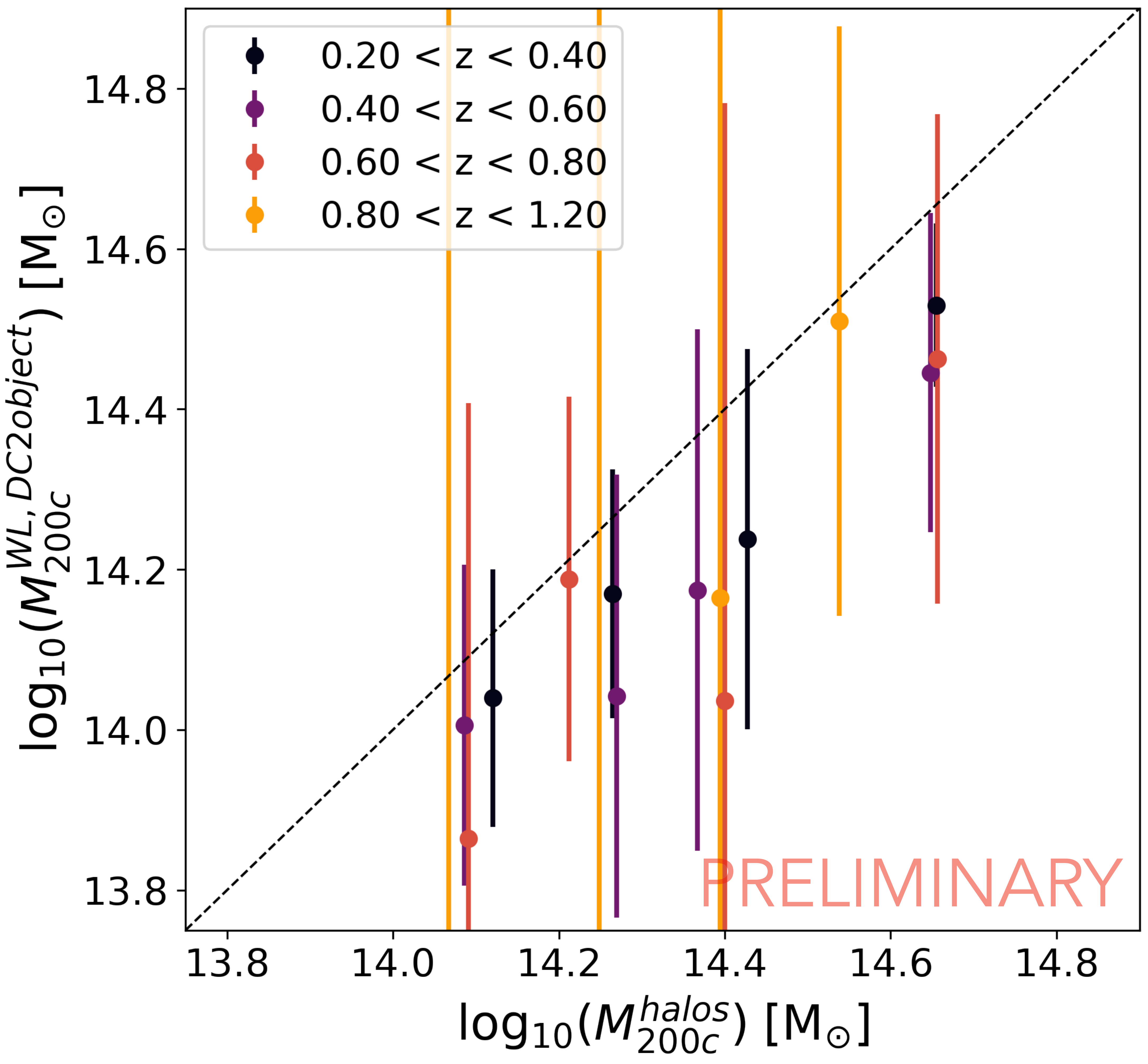
Impact of blending on lensing masses

cosmoDC2

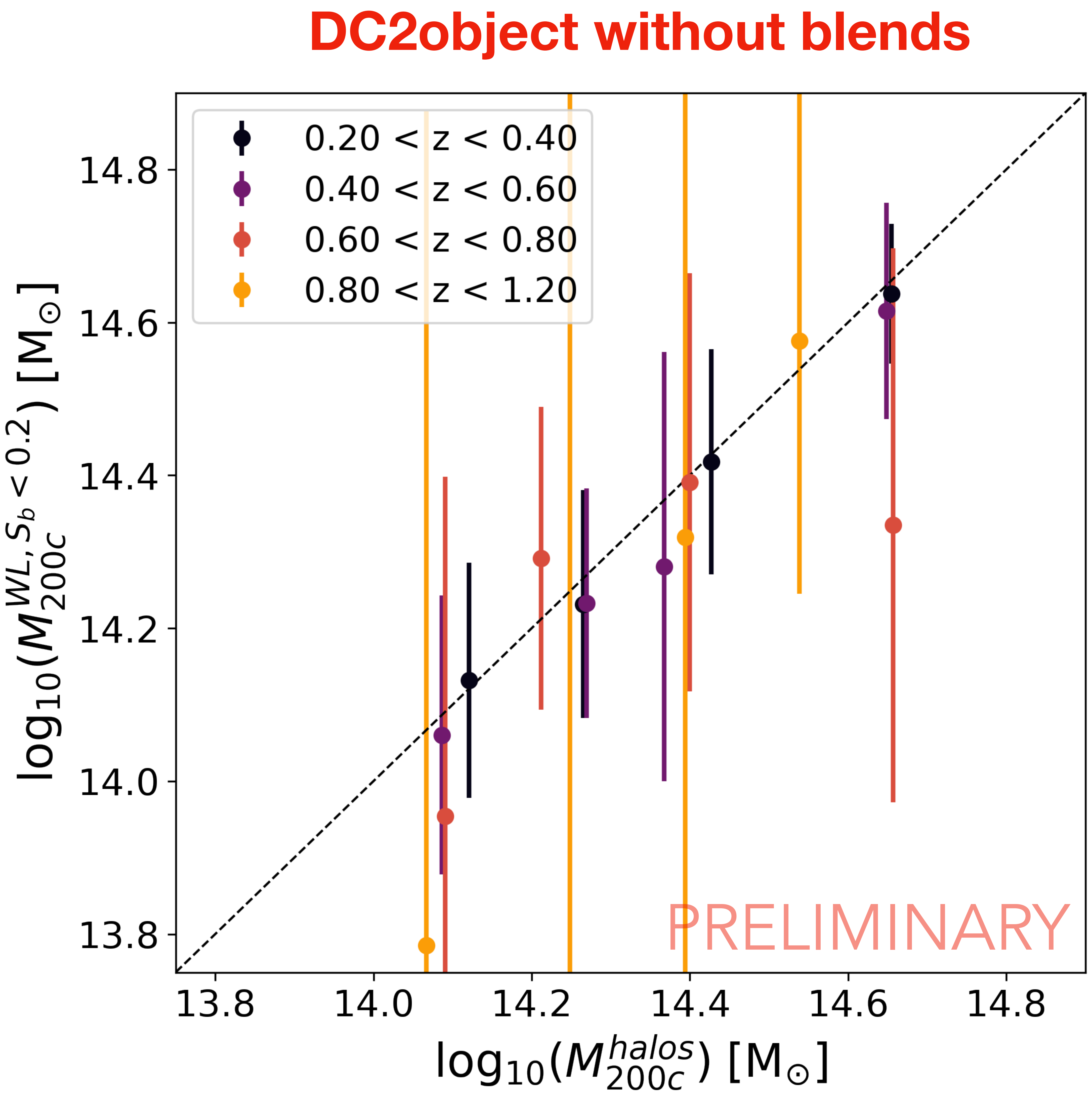


Impact of blending on lensing masses

DC2object with blends



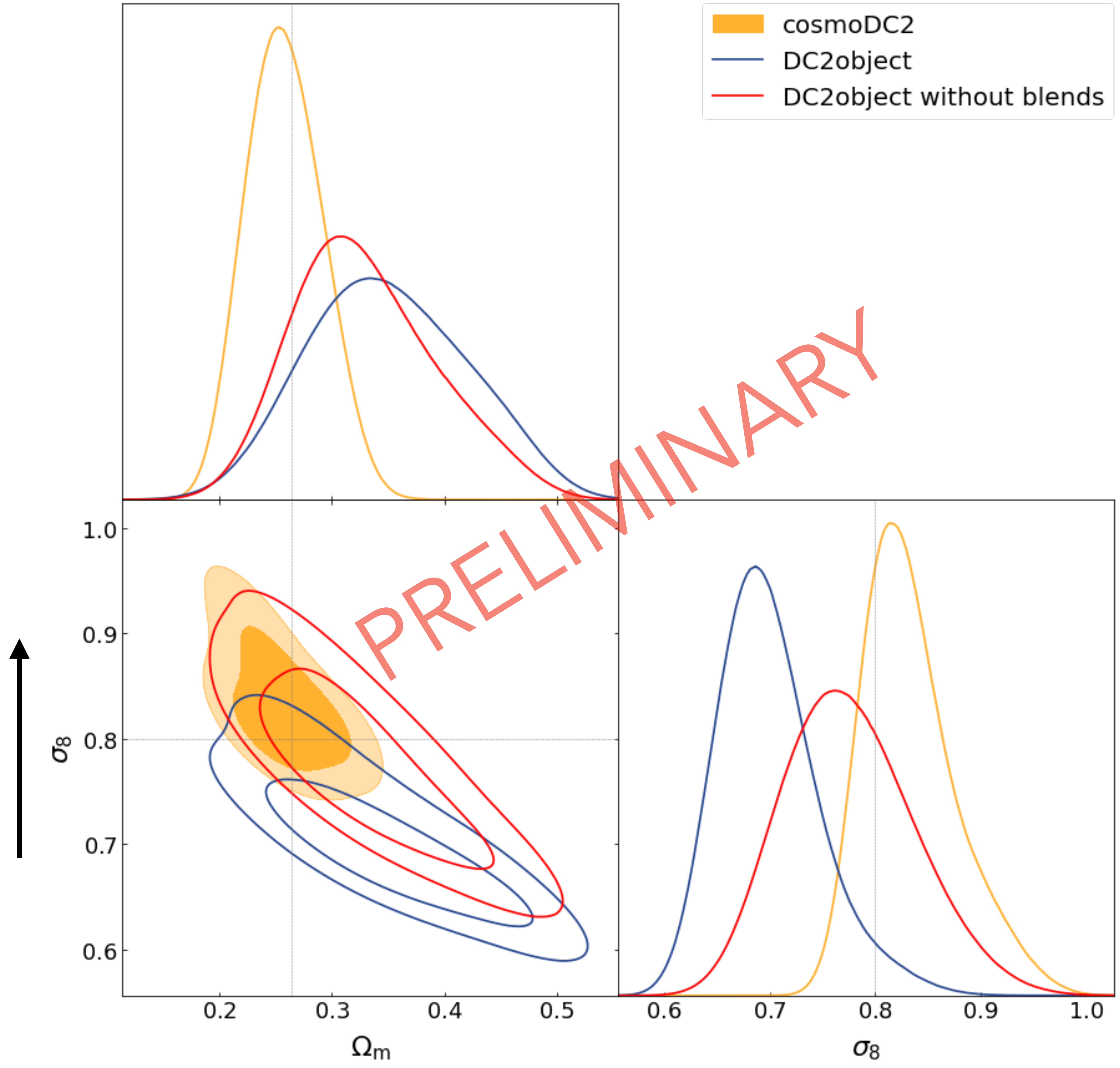
Impact of blending on lensing masses



Impact on cosmological parameters

https://github.com/LSSTDESC/CLCosmo_Sim

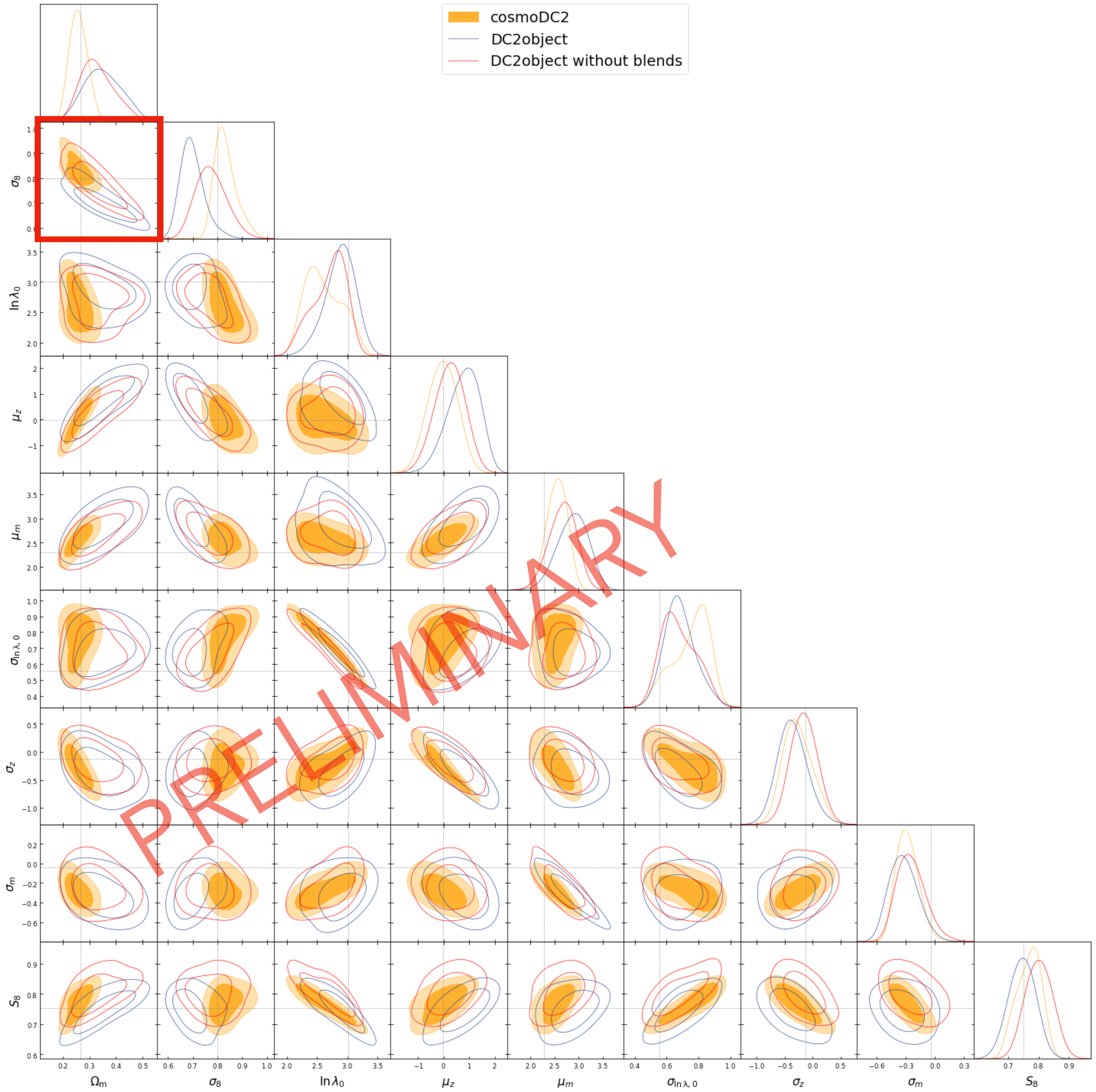
Removing blends



Impact on cosmological parameters

https://github.com/LSSTDESC/CLCosmo_Sim

- Poisson likelihood for N_{cl}, Gaussian likelihood for M_{wl}

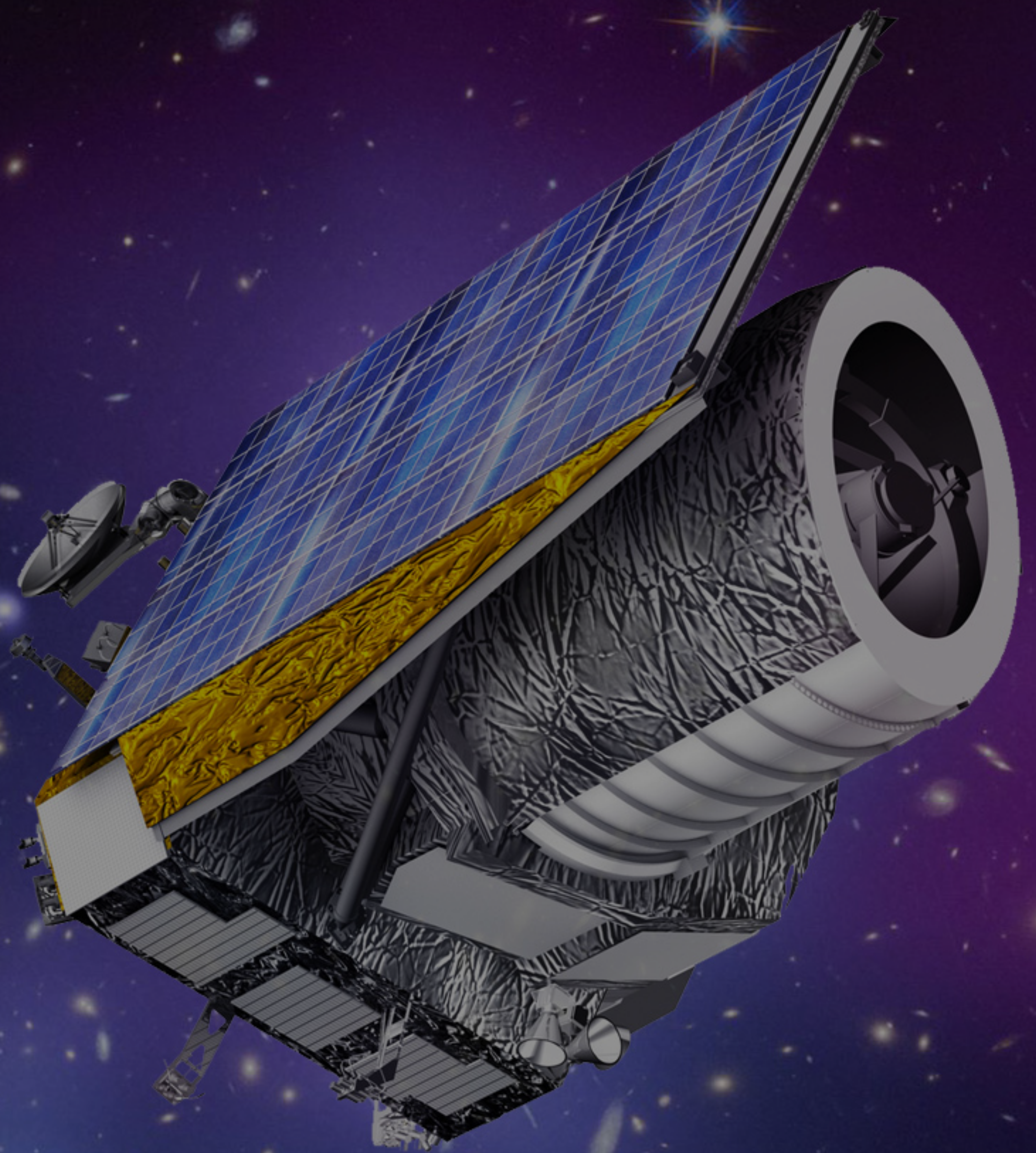


Conclusions

1. **Development of a new matching method to identify blends**
    - Relative probabilities of matching
    - Blending entropy to separate highly vs. well-matched systems

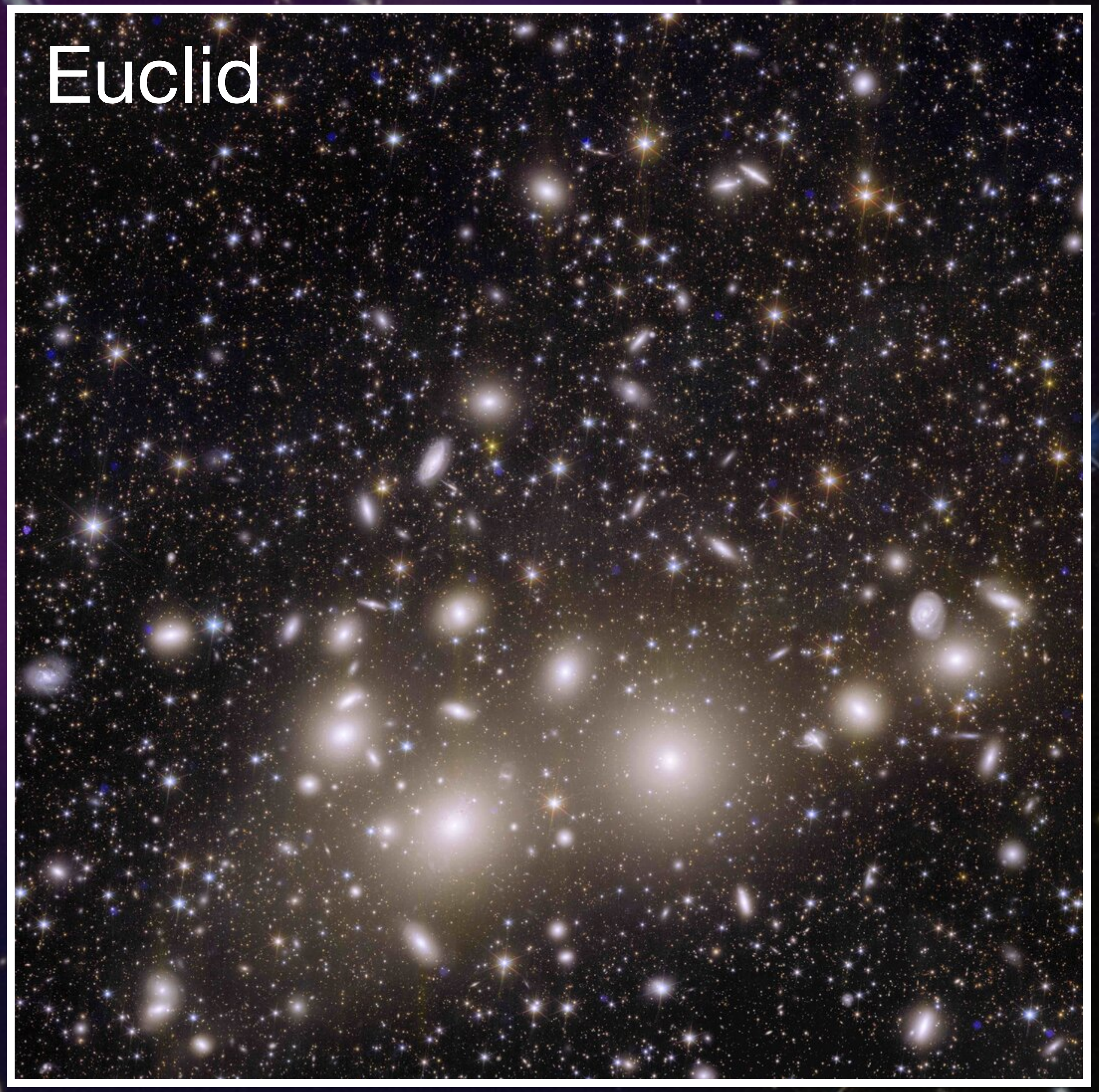
2. **Impact of blending on cluster lensing profiles**
    - Profiles biased low due to blending
    - Masses partially recovered by removing bad blends
    - Impact of blending on cosmological parameters

What about Euclid?



3. Application to real data

- Euclid won’t be impacted by blending
- Mitigation strategy, calibrated on overlapping sky areas with LSST



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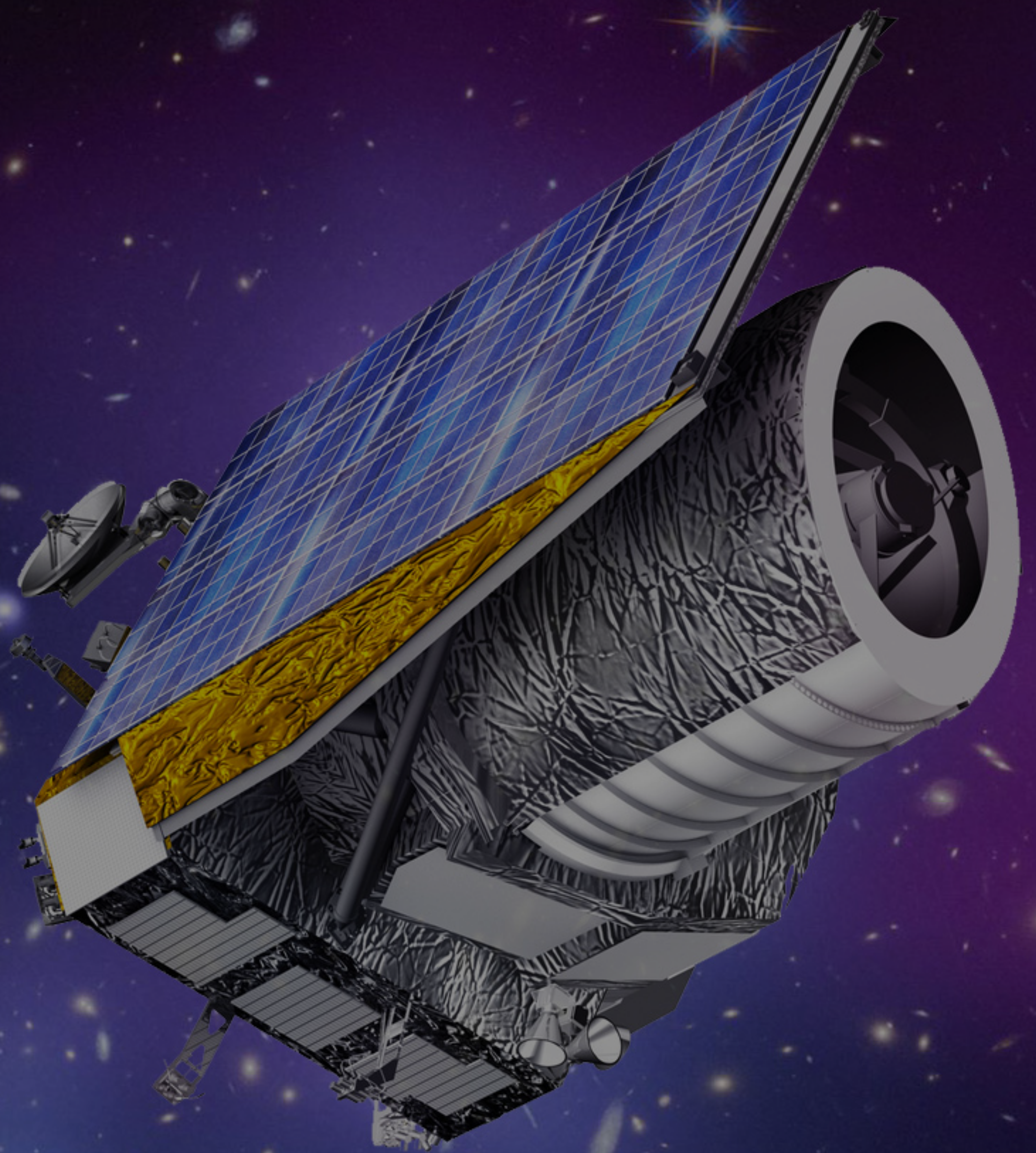

3. Application to real data

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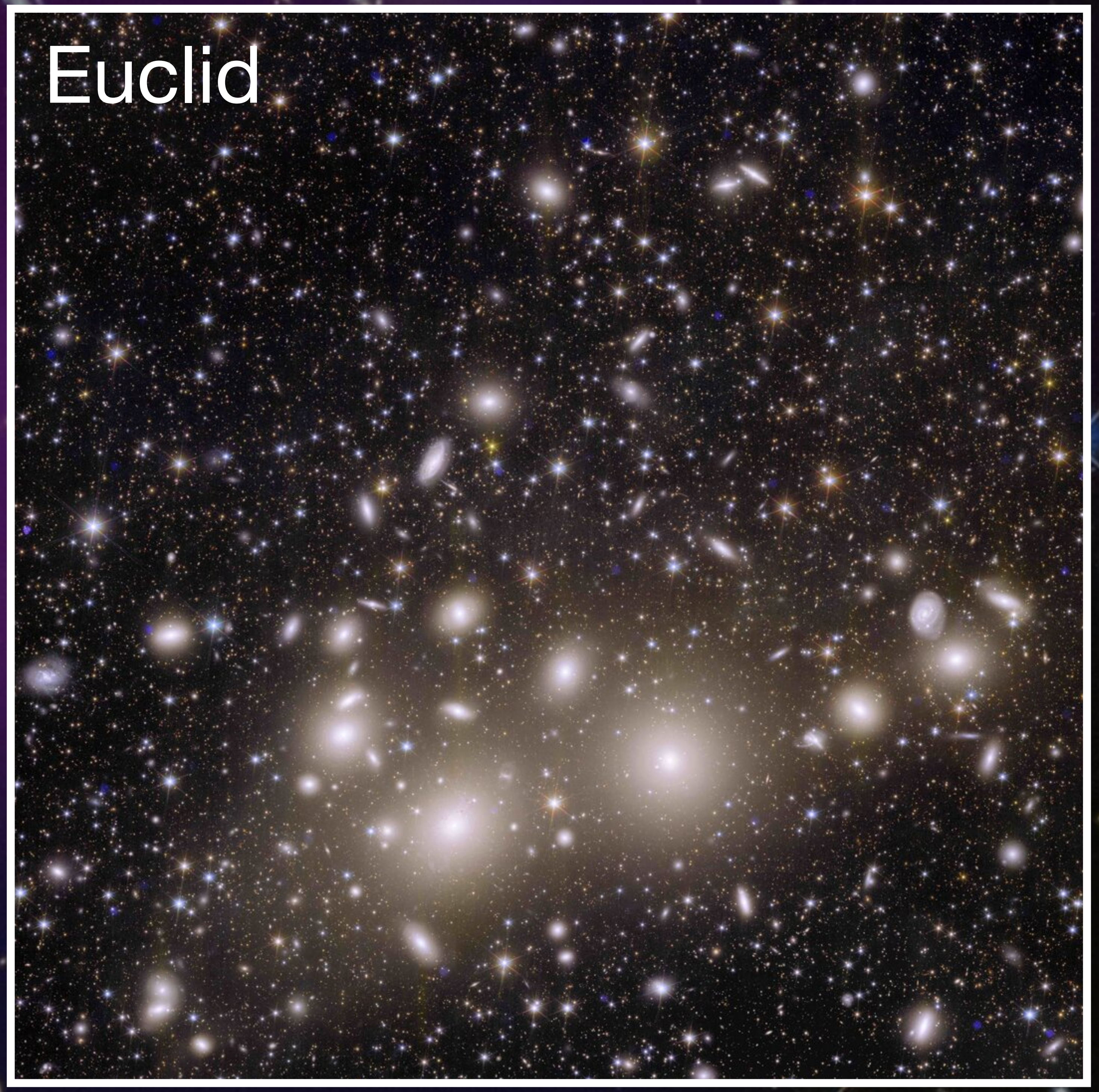
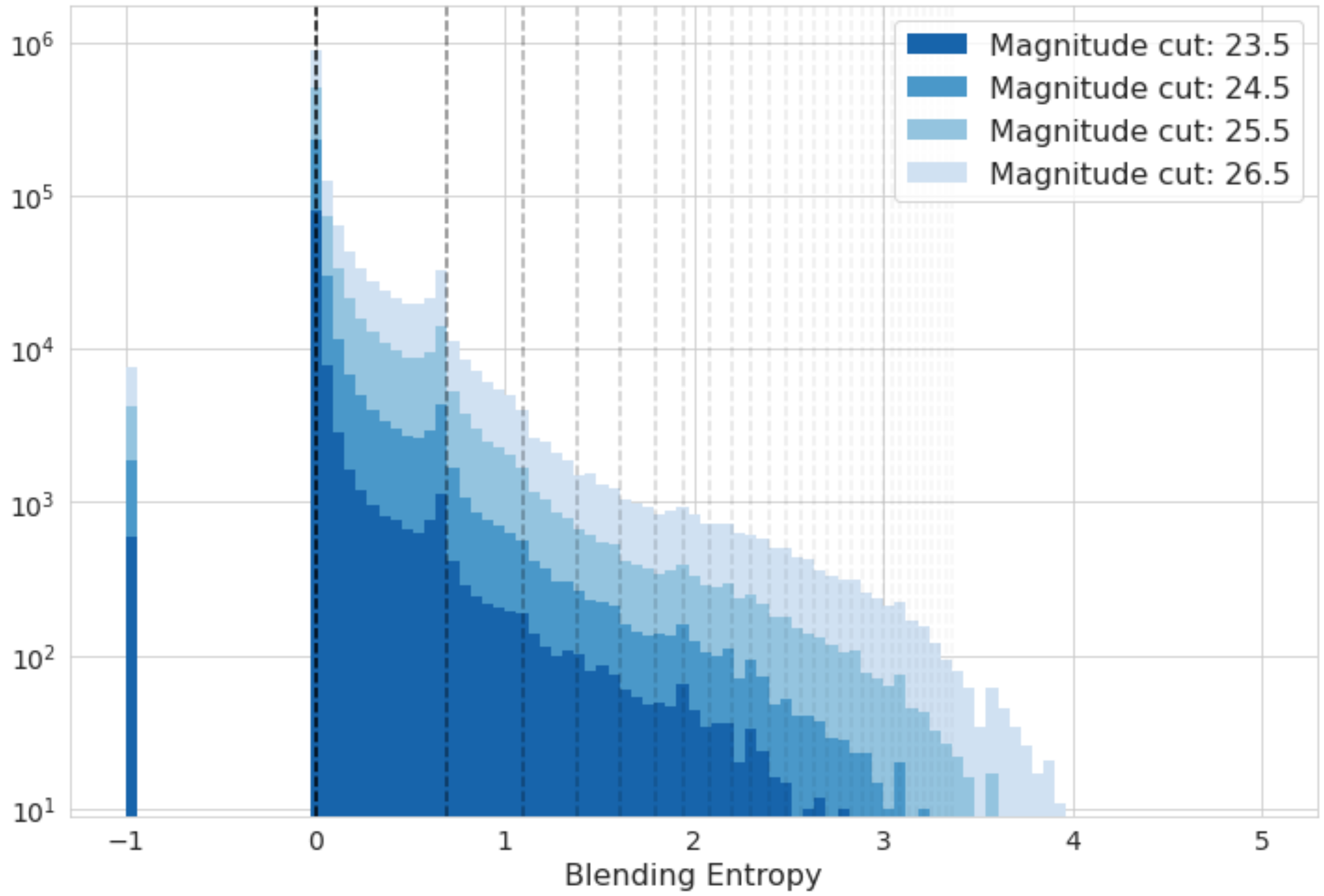
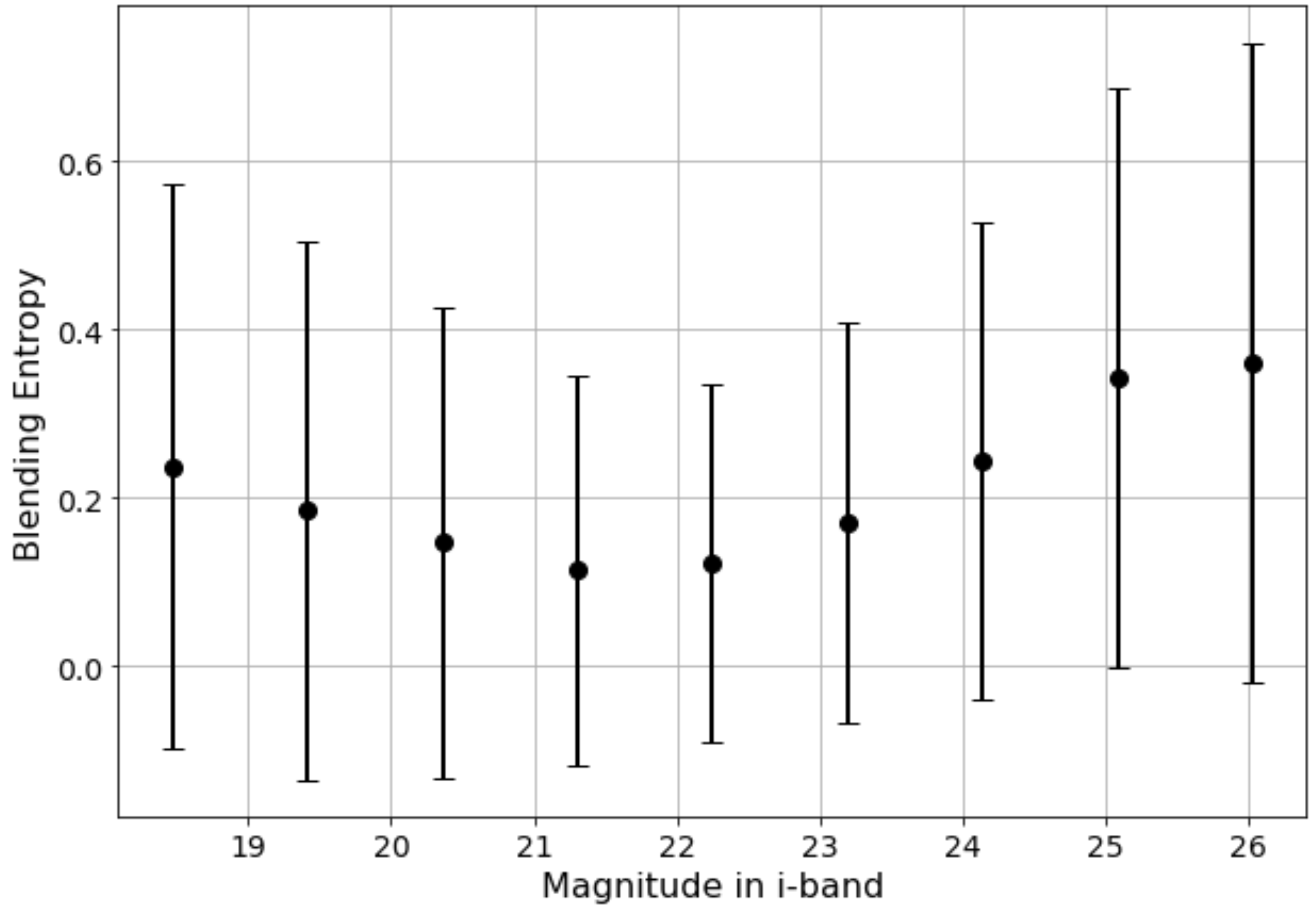


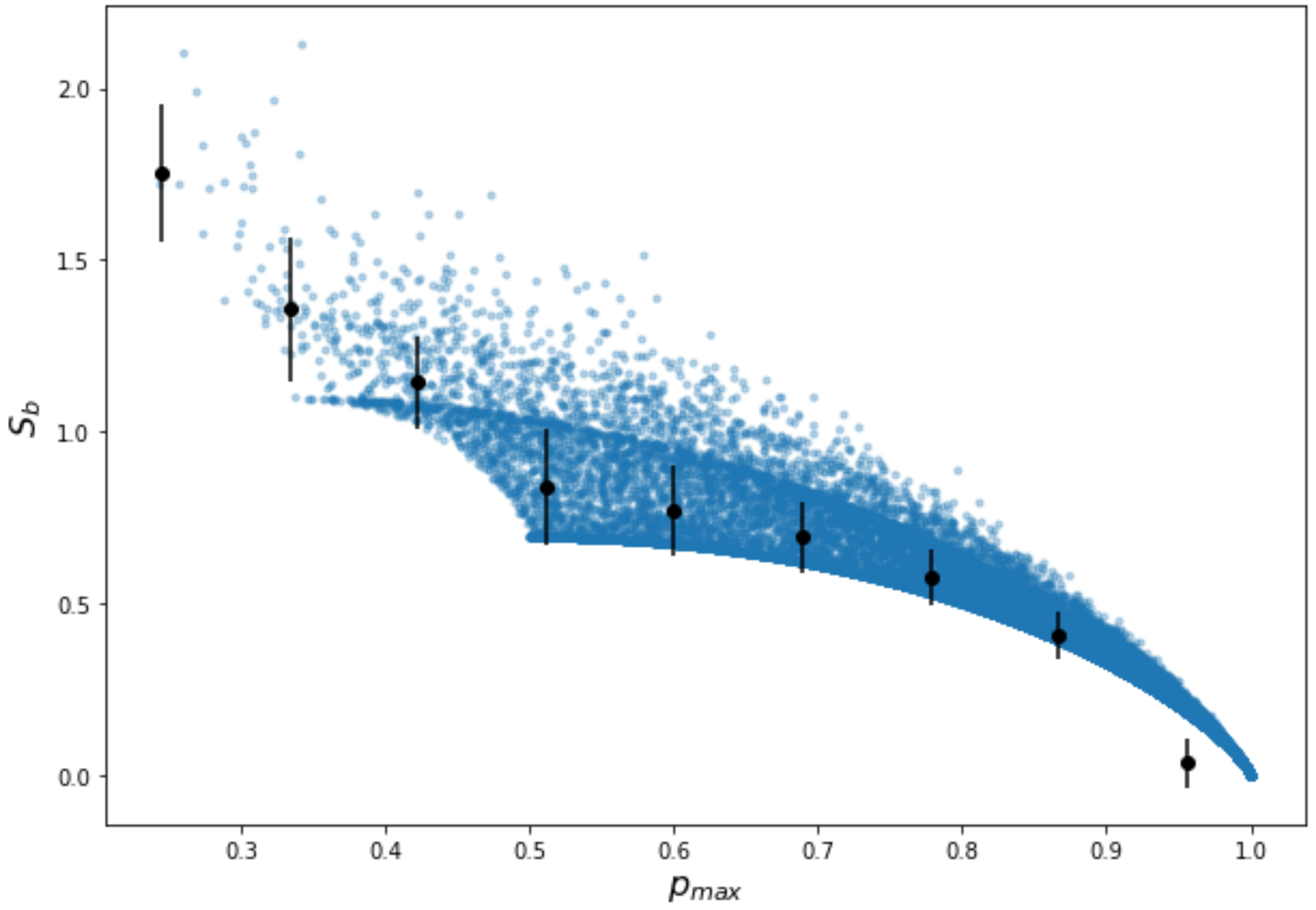
Thank you for your attention!

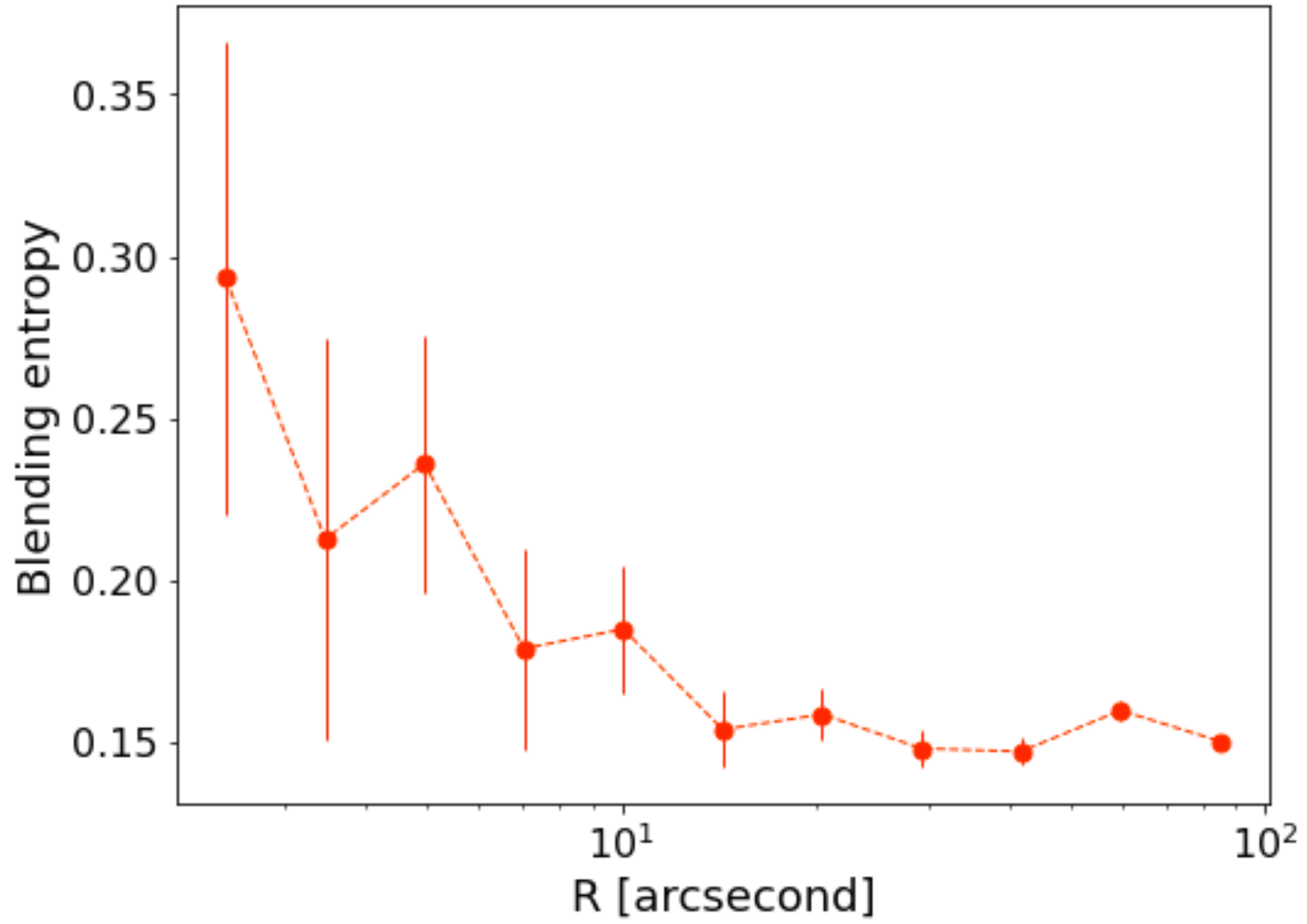
Backup

Blending entropy studies

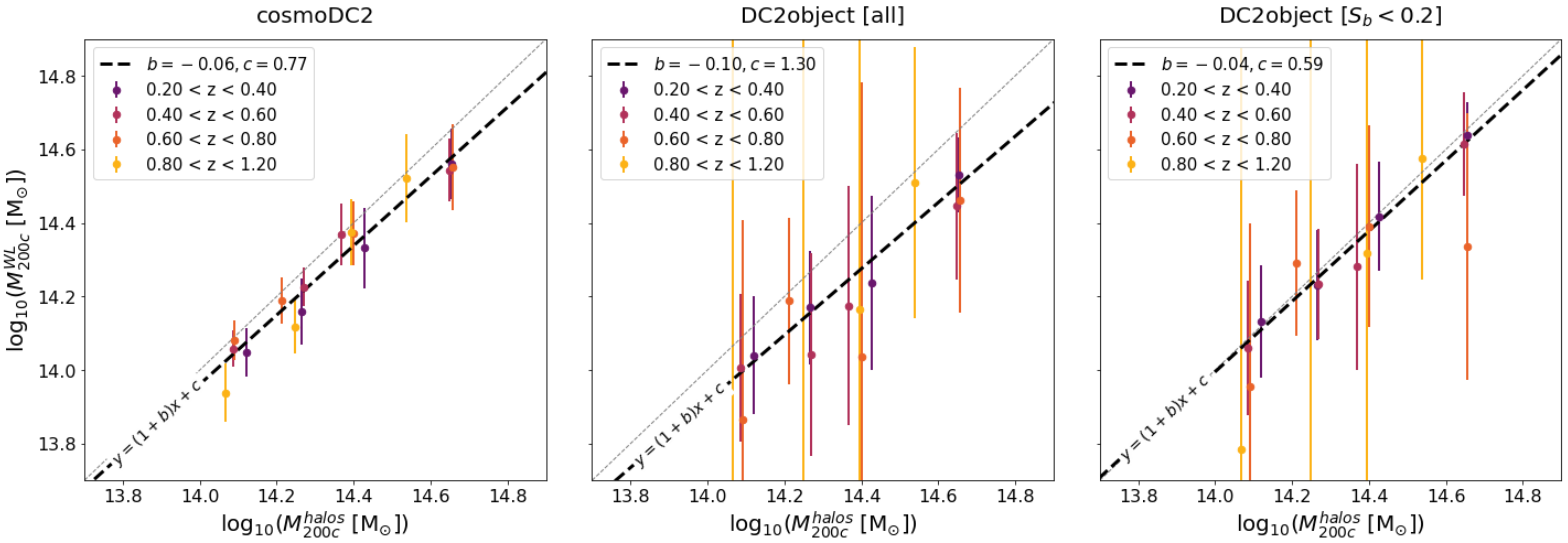




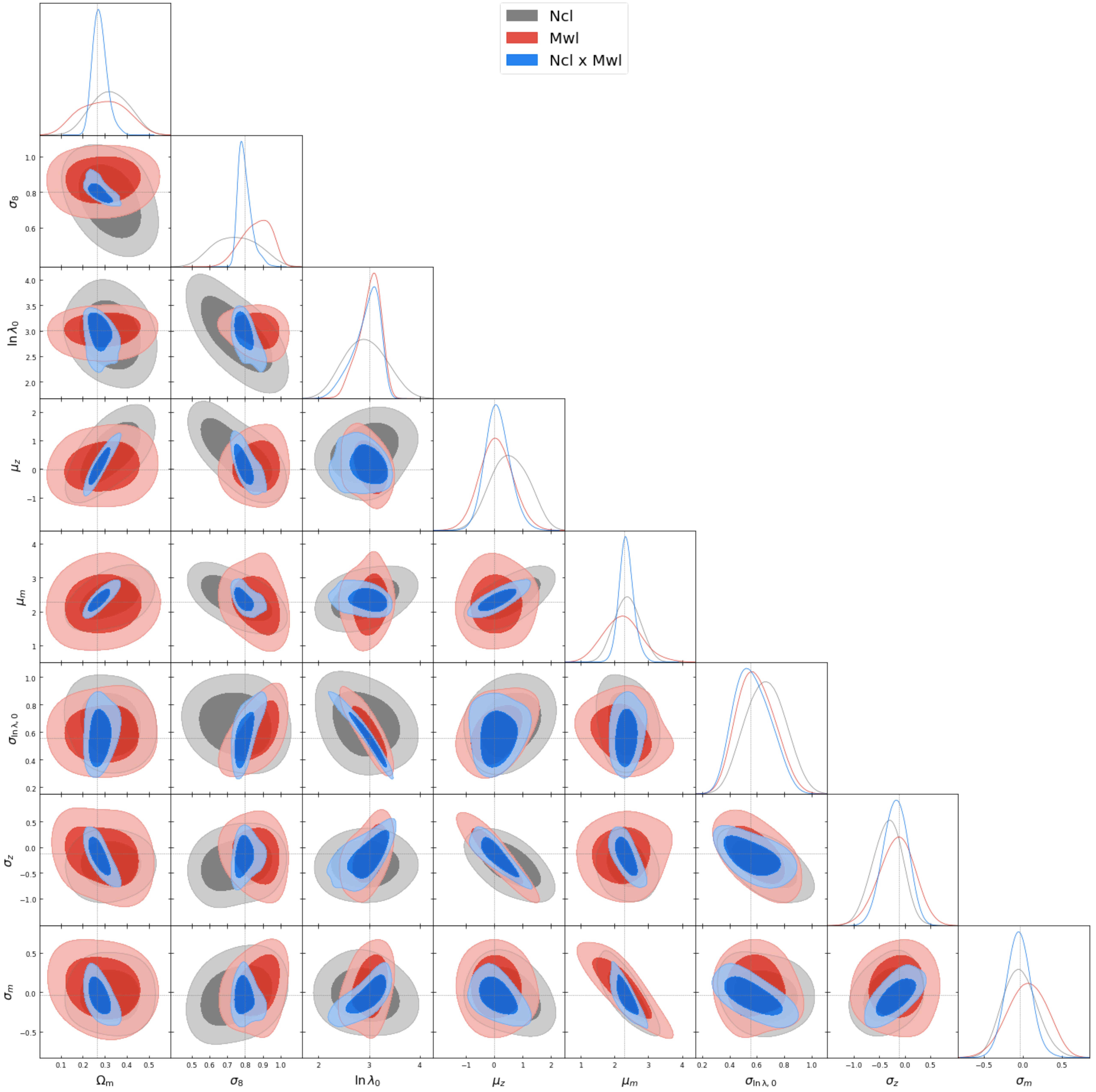




Estimated masses bias



Combinaison of probes



- Theoretical datavector
- Poisson likelihood for N_{cl}, Gaussian likelihood for M_{wl}
- Combination of probes to constrain the $M - \lambda$ relation

$M - \lambda$ relation

From C. Payerne PhD manuscript

We consider the log-normal scaling relation with 6 free parameters, that is given by

$$P(\lambda|m,z) \propto \frac{1}{\lambda}\exp\left\{-\frac{[\ln\lambda - \langle \ln\lambda|m,z\rangle]^2}{\sigma^2_{\ln\lambda|m,z}}\right\} \tag{4.34}$$

where the mean richness has both mass and redshift dependencies, such as

$$\langle \ln\lambda|m,z\rangle = \ln\lambda_0 + \mu_z \log\left(\frac{1+z}{1+z_0}\right) + \mu_m \log_{10}\left(\frac{m}{m_0}\right), \tag{4.35}$$

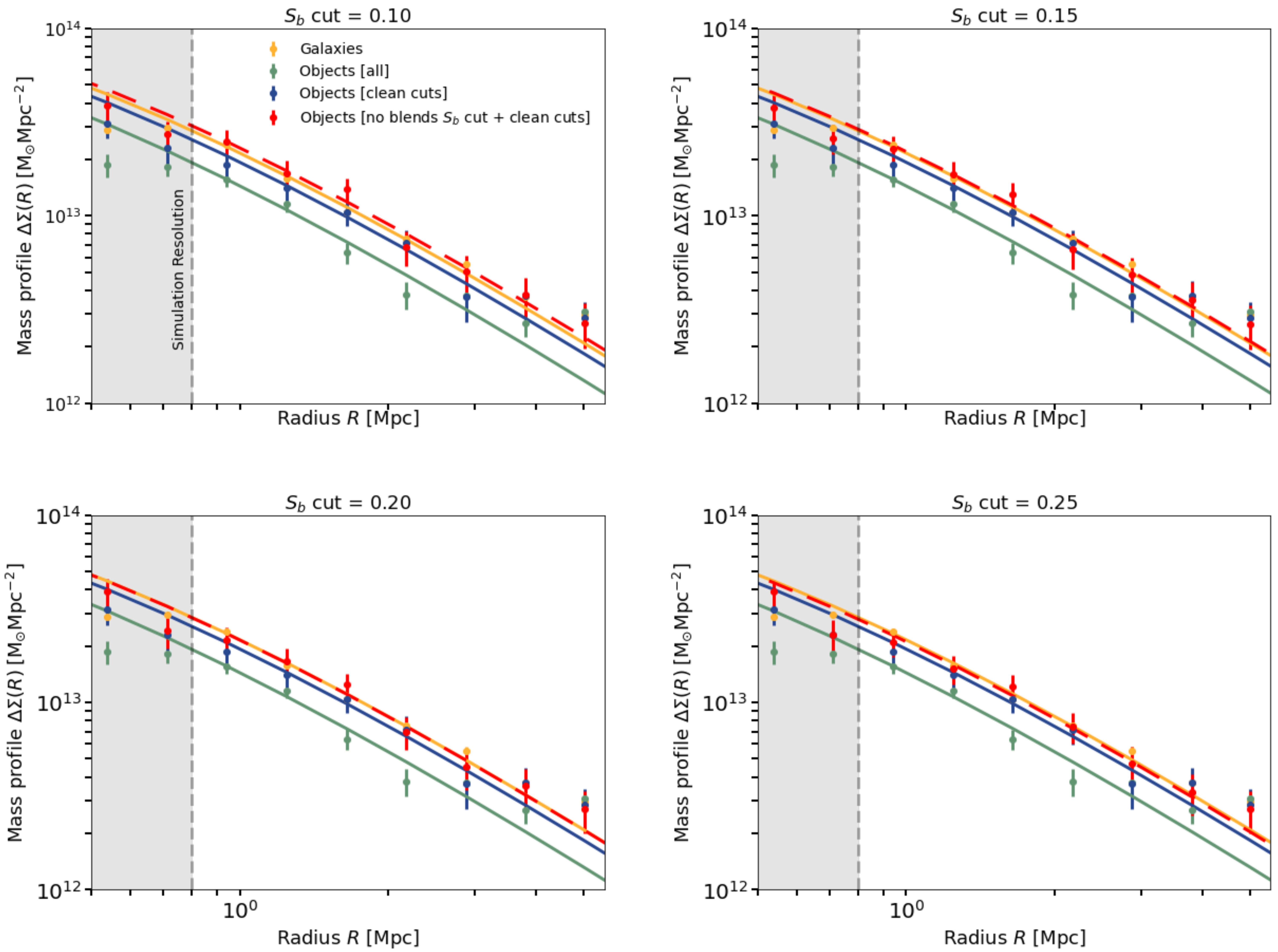
and the dispersion of the log-normal scaling relation is given by

$$\sigma_{\ln\lambda|m,z} = \sigma_{\ln\lambda_0} + \sigma_z \log\left(\frac{1+z}{1+z_0}\right) + \sigma_m \log_{10}\left(\frac{m}{m_0}\right). \tag{4.36}$$

	$p \pm \Delta p$
$\ln\lambda_0$	3.01 ± 0.01
μ_m	2.29 ± 0.02
μ_z	-0.01 ± 0.04
$\sigma_{\ln\lambda_0}$	0.556 ± 0.006
σ_m	-0.039 ± 0.006
σ_z	-0.12 ± 0.02
m_0	$10^{14.2}\ M_\odot$
z_0	0.4

Table 4.4: Best fit parameters and 1σ error bars for the mass-richness relation parameters (upper block: log-mean parameters, middle block: log-dispersion parameters, lower block: pivot values).

Impact on the S_b cut



Ellipses definition

cosmoDC2

- Positions x_0, y_0
- Minor/Major axis a and b
- Position angle θ
- Convolution with the PSF

DC2object

- Positions x_0, y_0
- Second moments I_{xx}, I_{yy}, I_{xy} converted to a, b, θ parameters

General ellipse equation: $Ax^2 + By^2 + Cxy + Dx + Ey + F = 0$

Functions of a, b, θ, x_0, y_0

Ellipse overlap test

2017, Alberich-Carramiñana et al.

https://github.com/LSSTDESC/Cluster_Blending/blob/main/match_ellipse_dc2.ipynb

General ellipse equation: $Ax^2 + By^2 + Cxy + Dx + Ey + F = 0$

Functions of a, b, θ, x_0, y_0

$$M = \begin{pmatrix} A & C & D \\ C & B & E \\ D & E & F \end{pmatrix}$$

Determinant computation

Overlap of 2 ellipses ?

- True
- False