

Probabilistic characterization of blending: application to cluster lensing cosmology

LSST France, November 2024
Manon Ramel

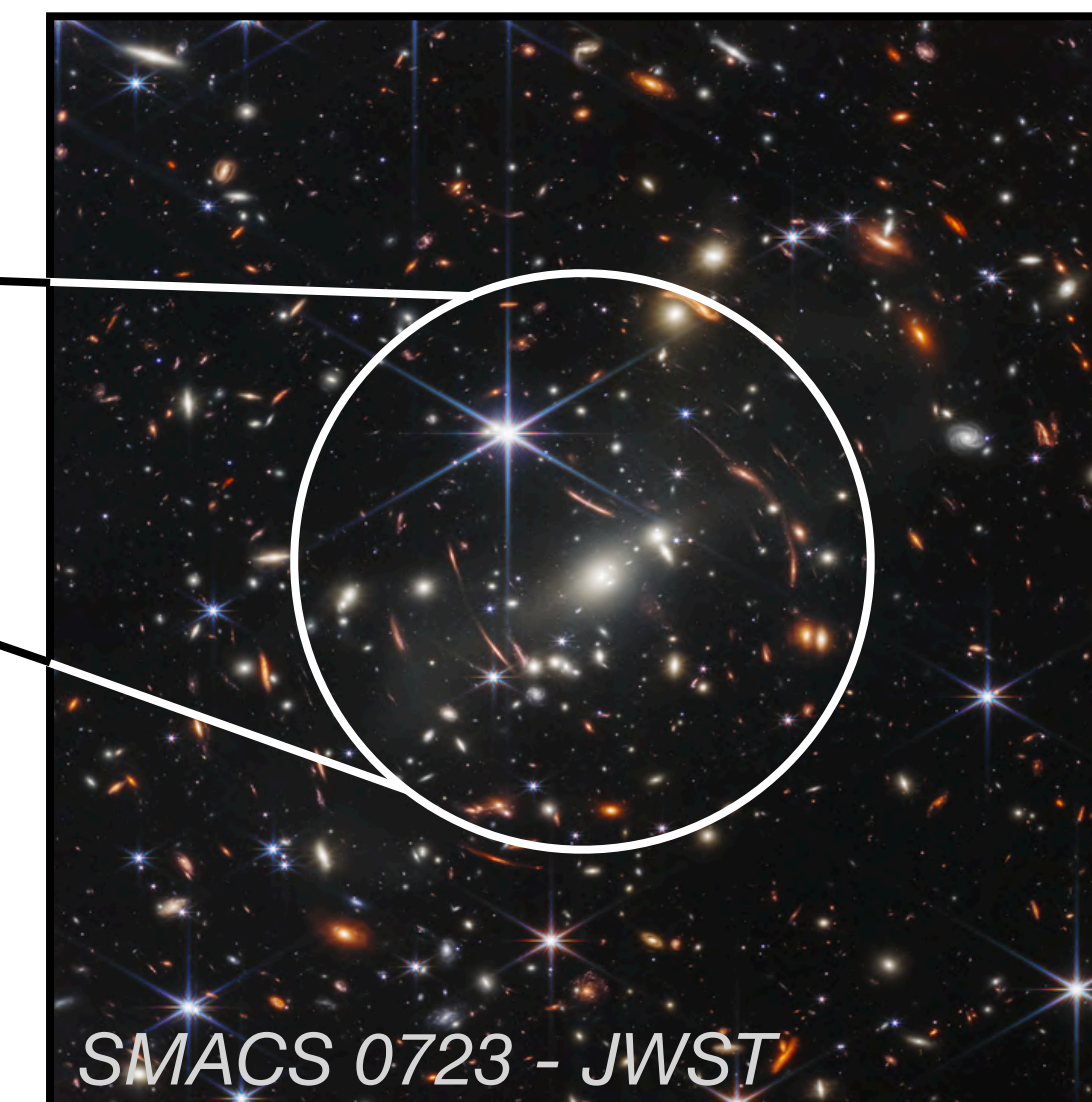
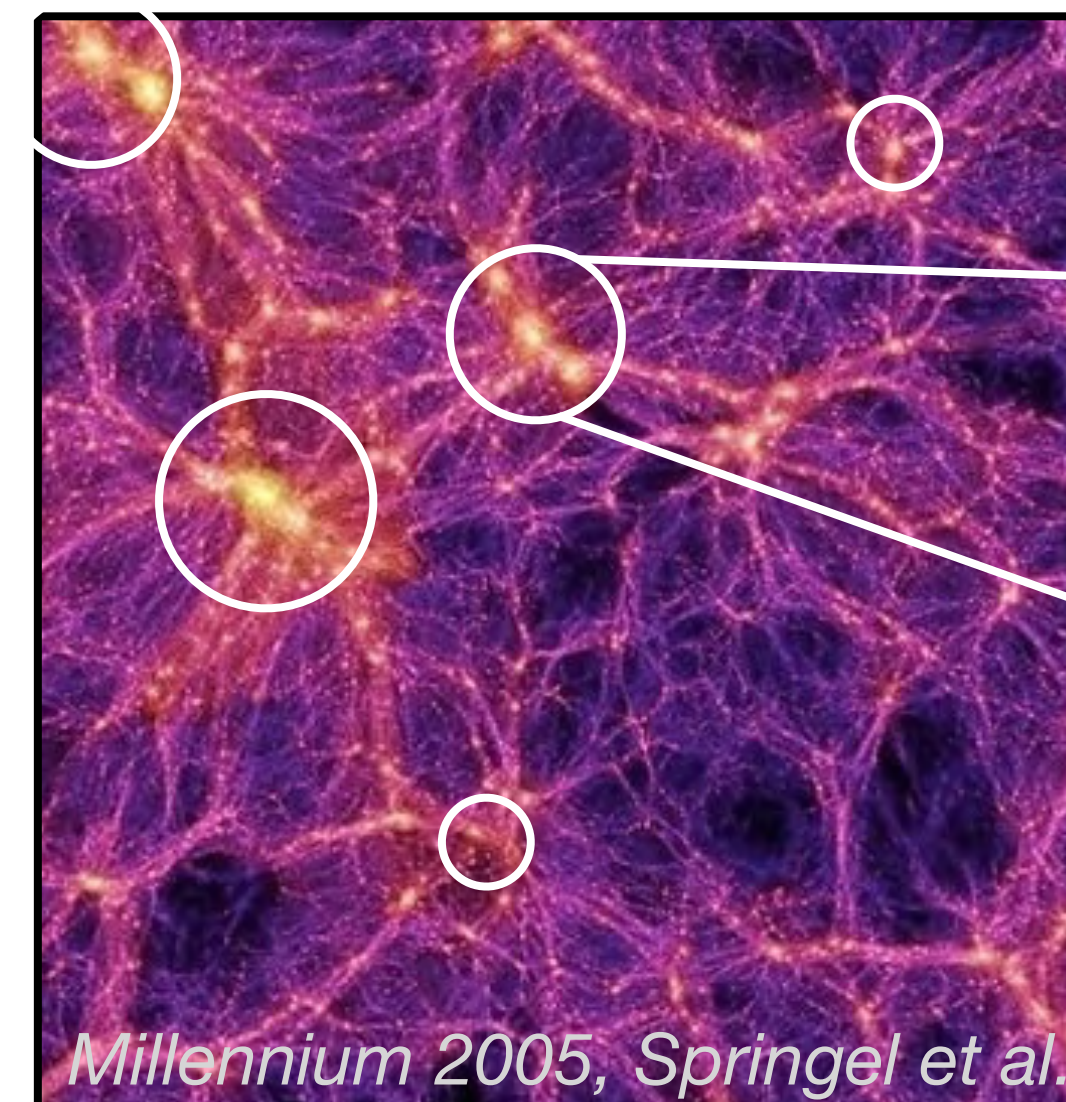
Cosmology with galaxy clusters

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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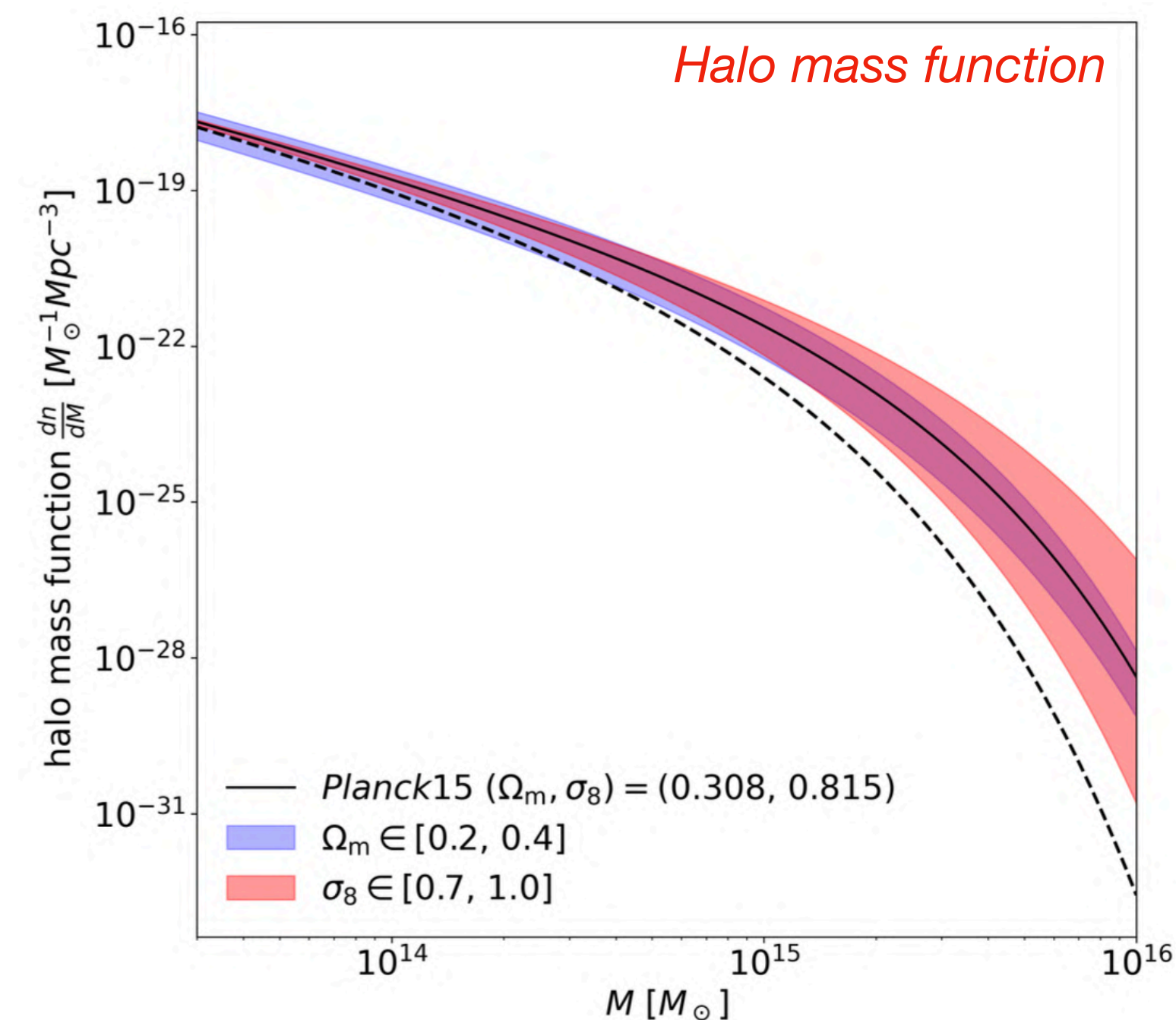
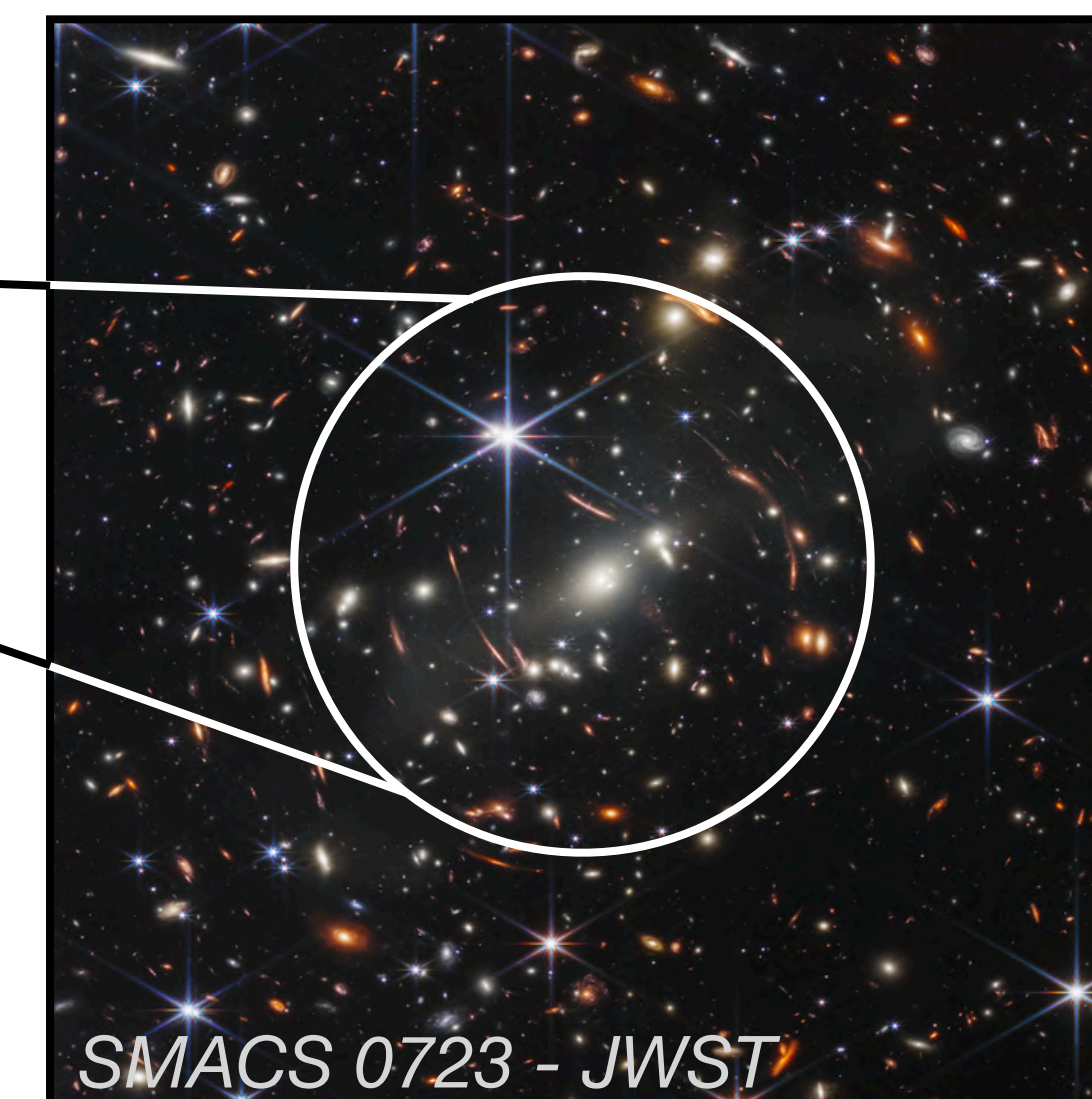
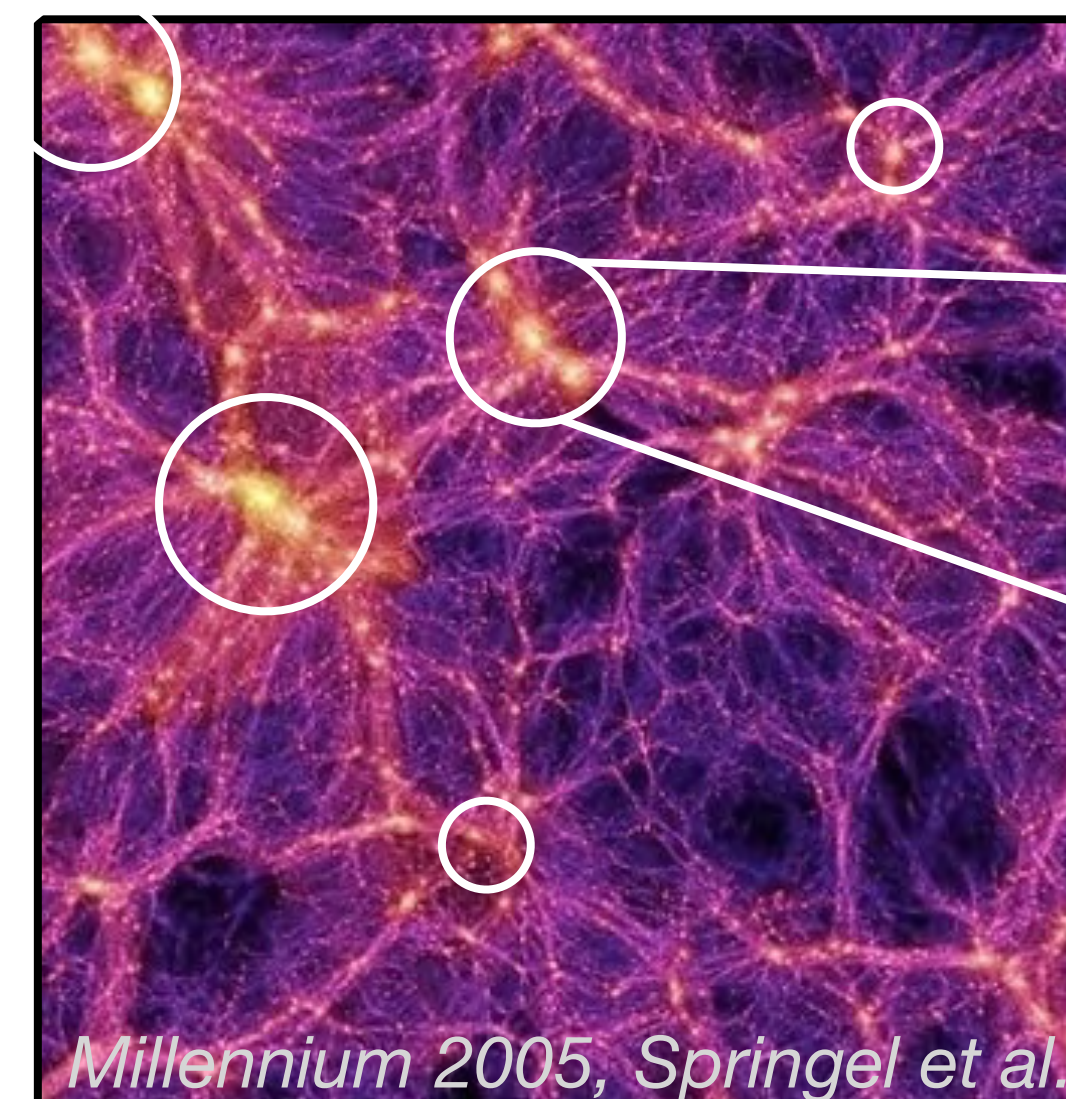
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Tracers of the matter over-densities

- Depend on cosmology

Counting per bins of mass and redshift

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



Cosmology with galaxy clusters

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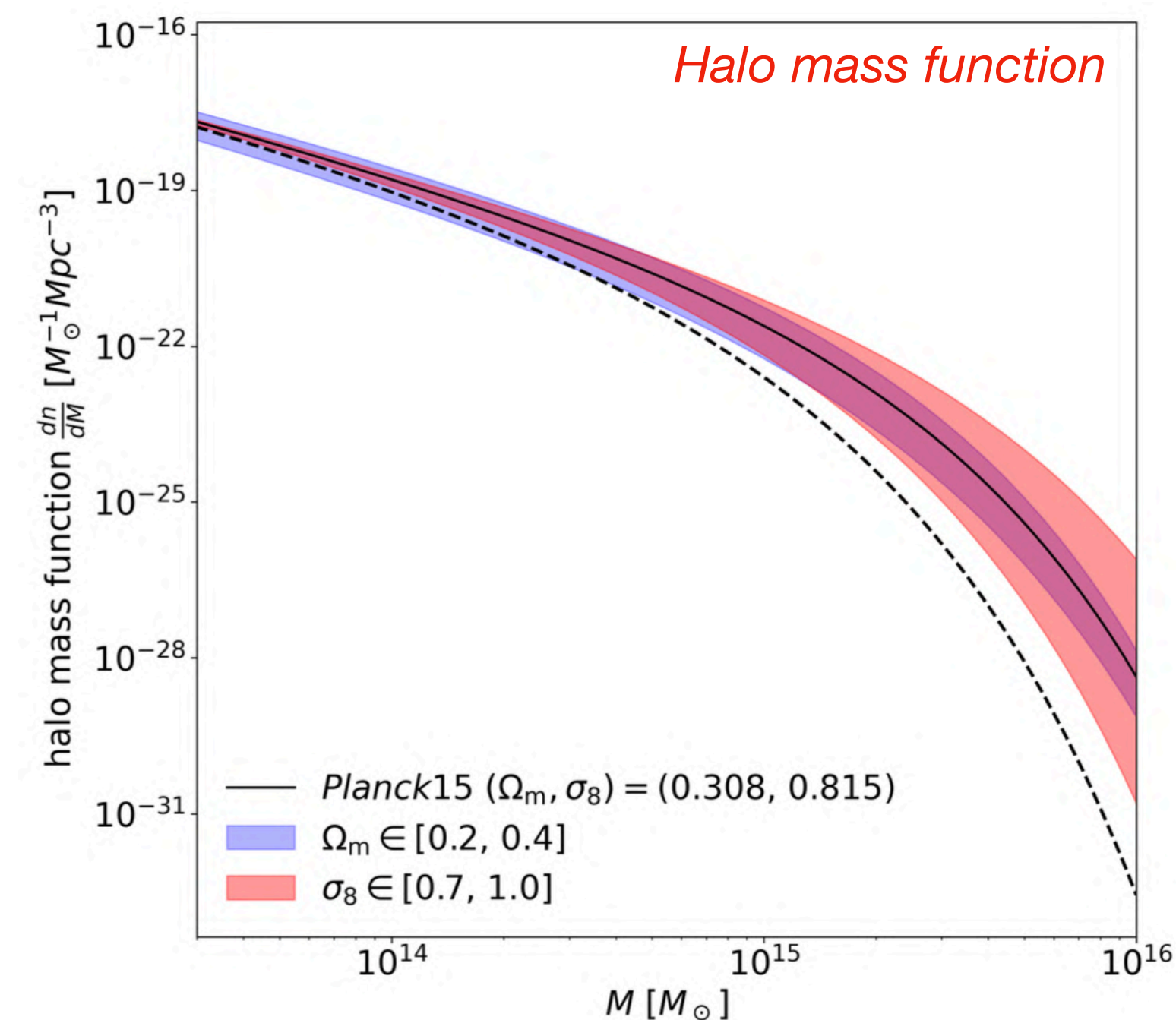
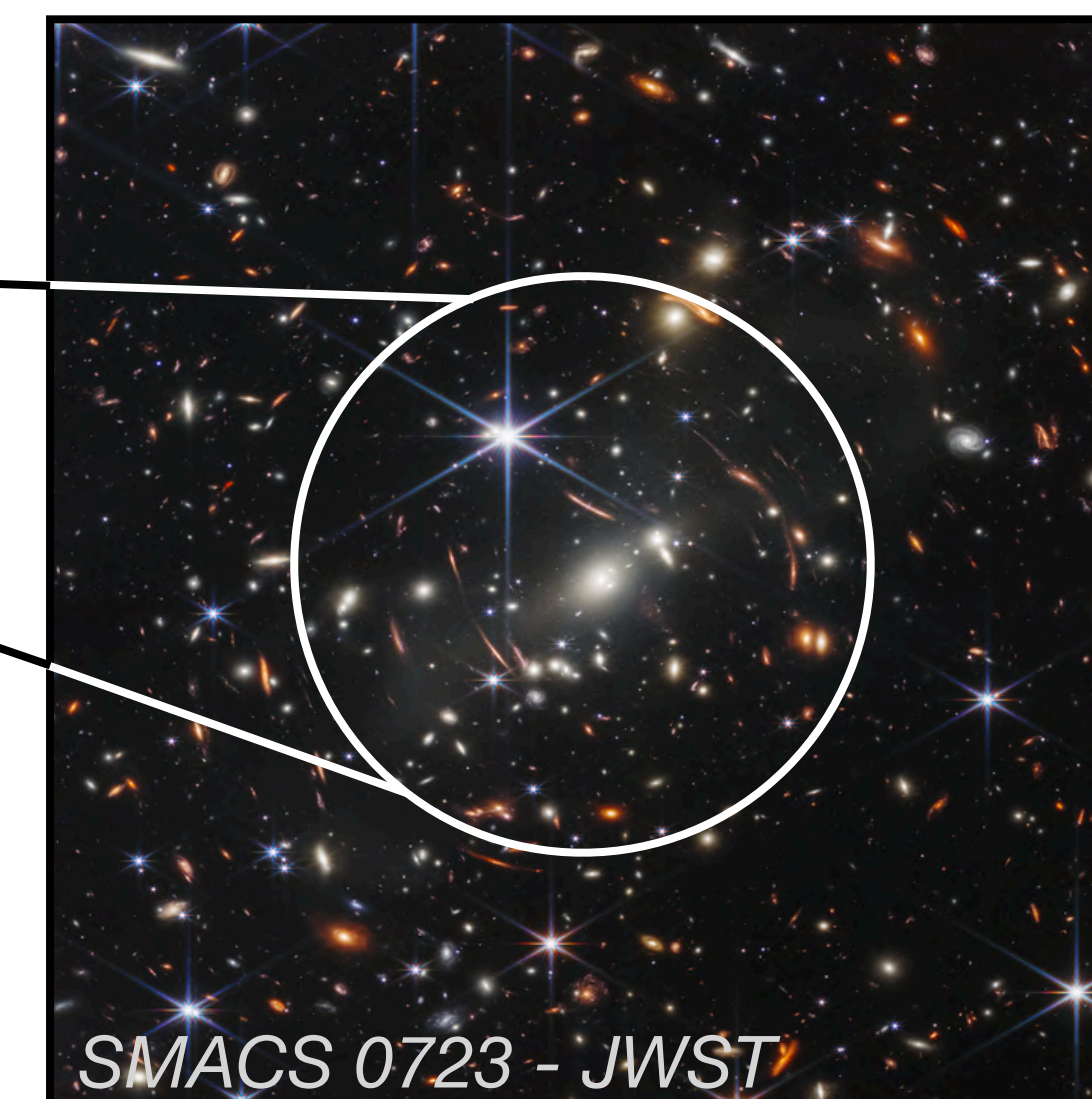
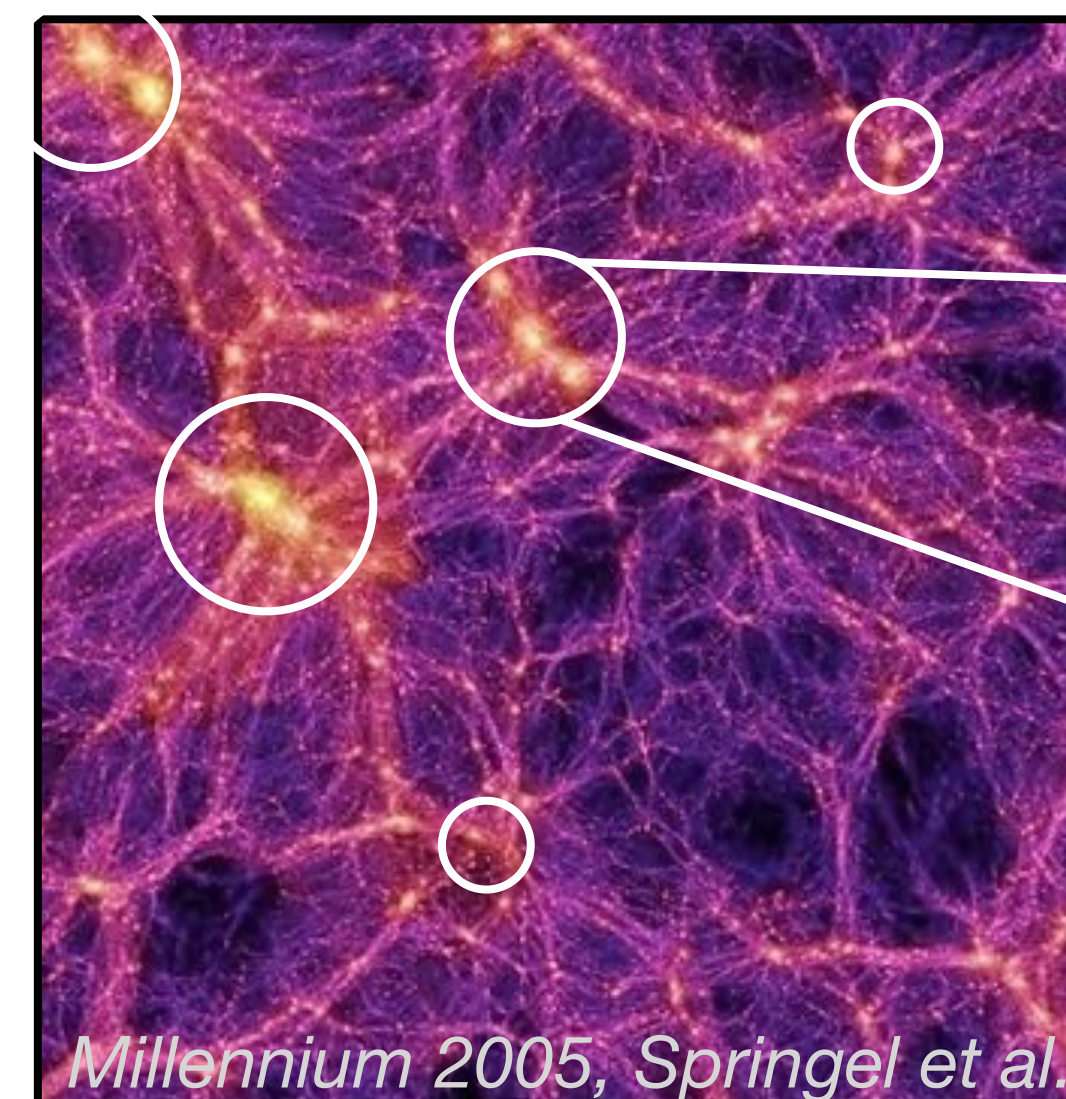
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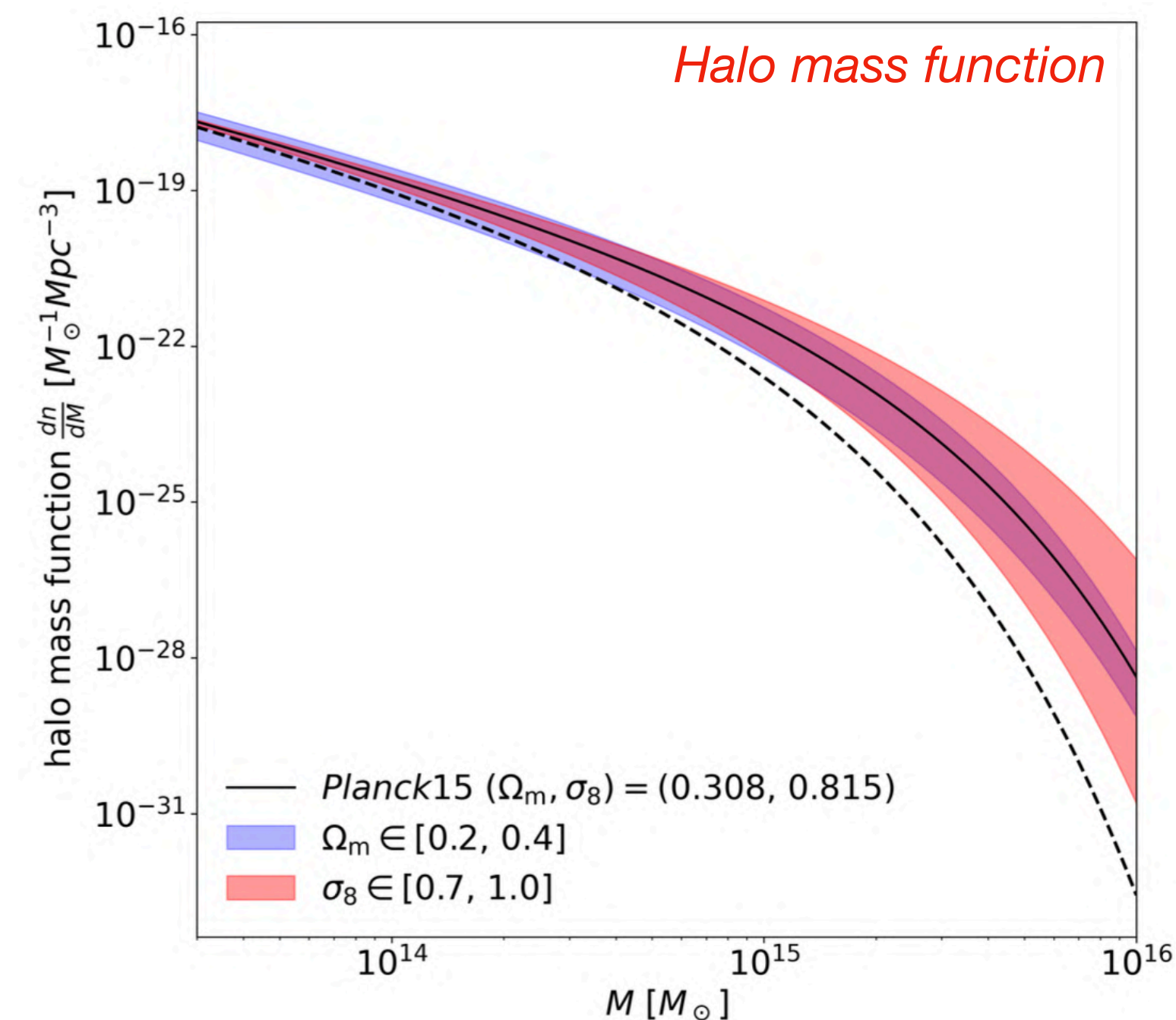
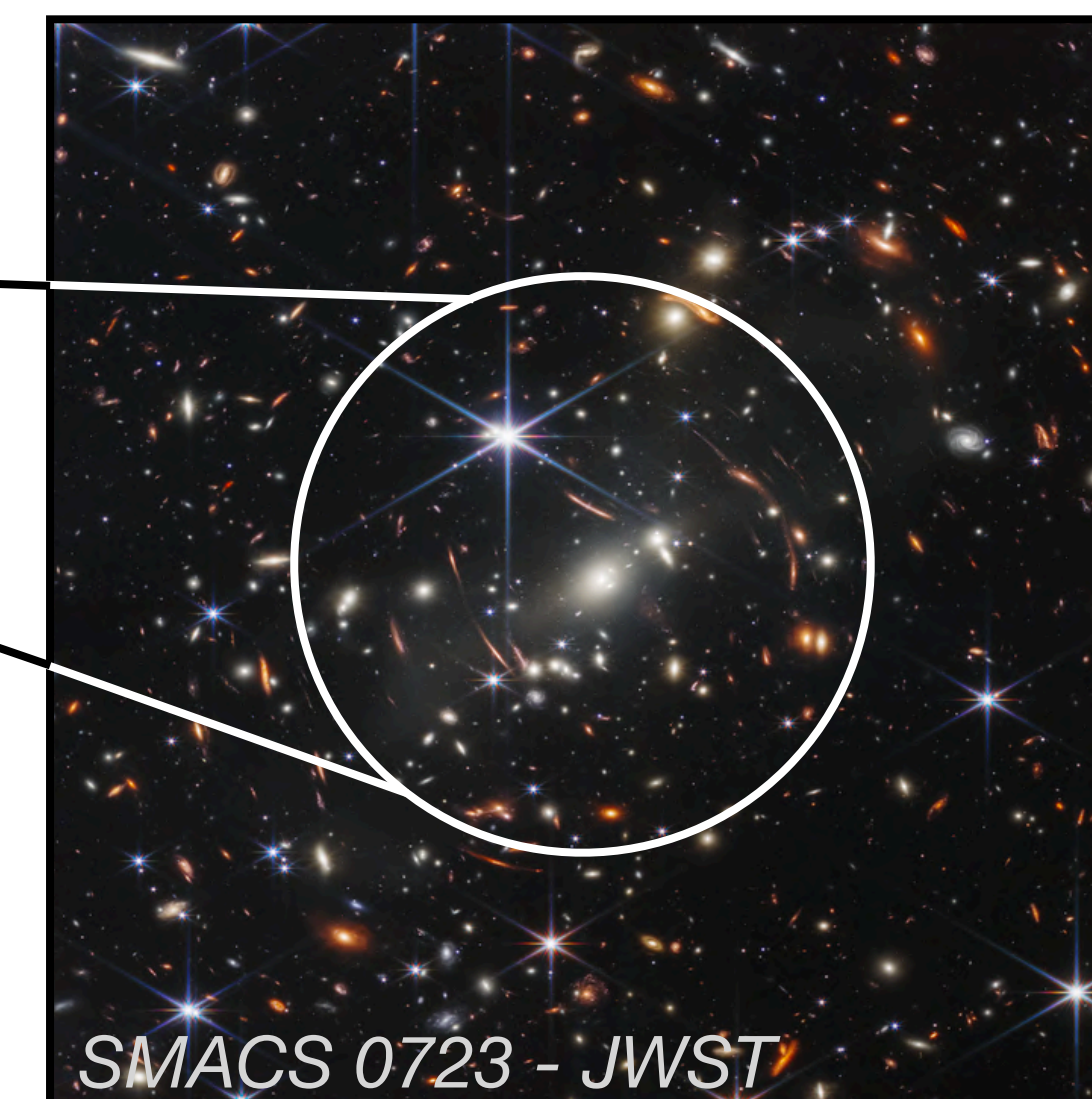
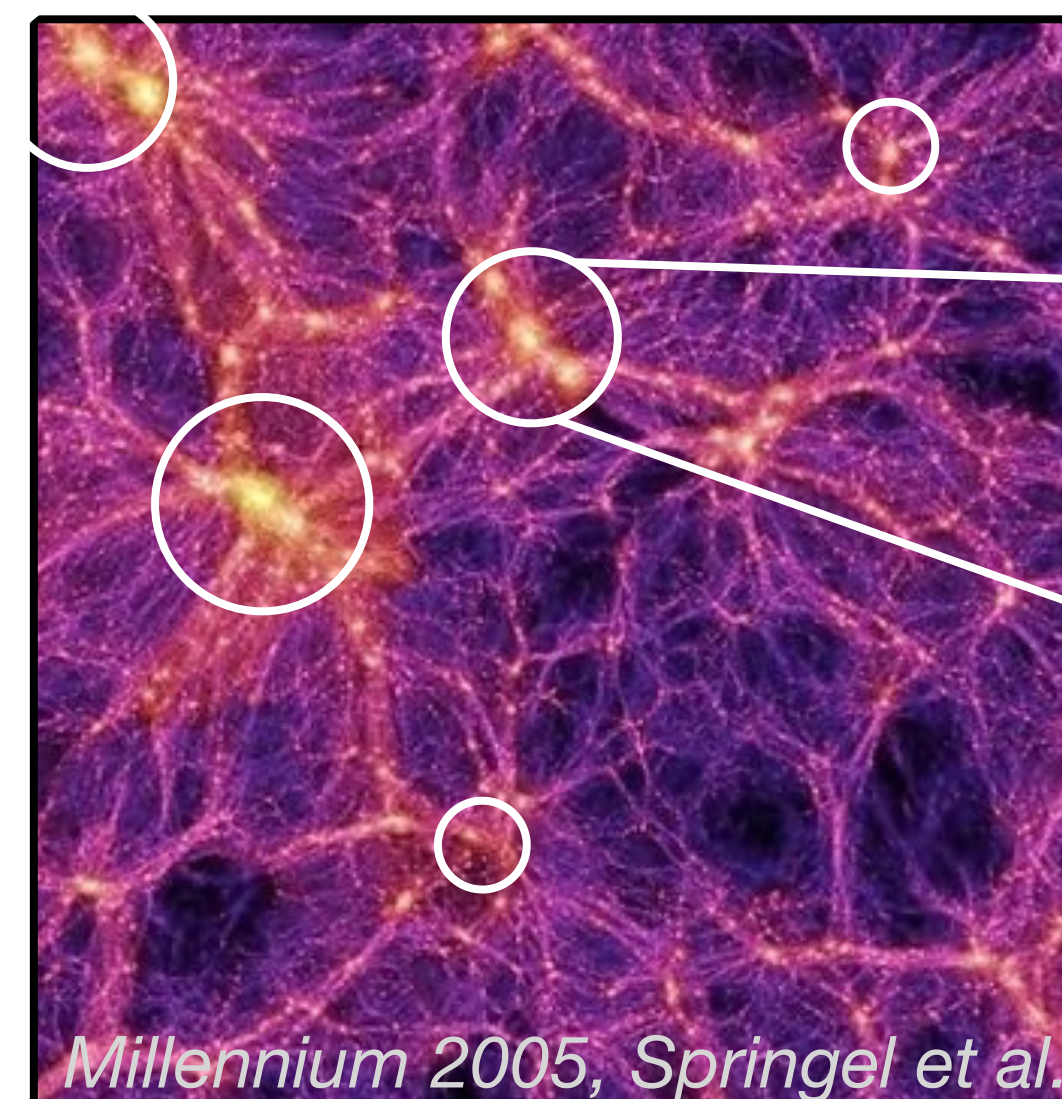
Counting per bins of mass and redshift

~~mass and redshift~~
proxys

Richness

Number of member galaxies

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



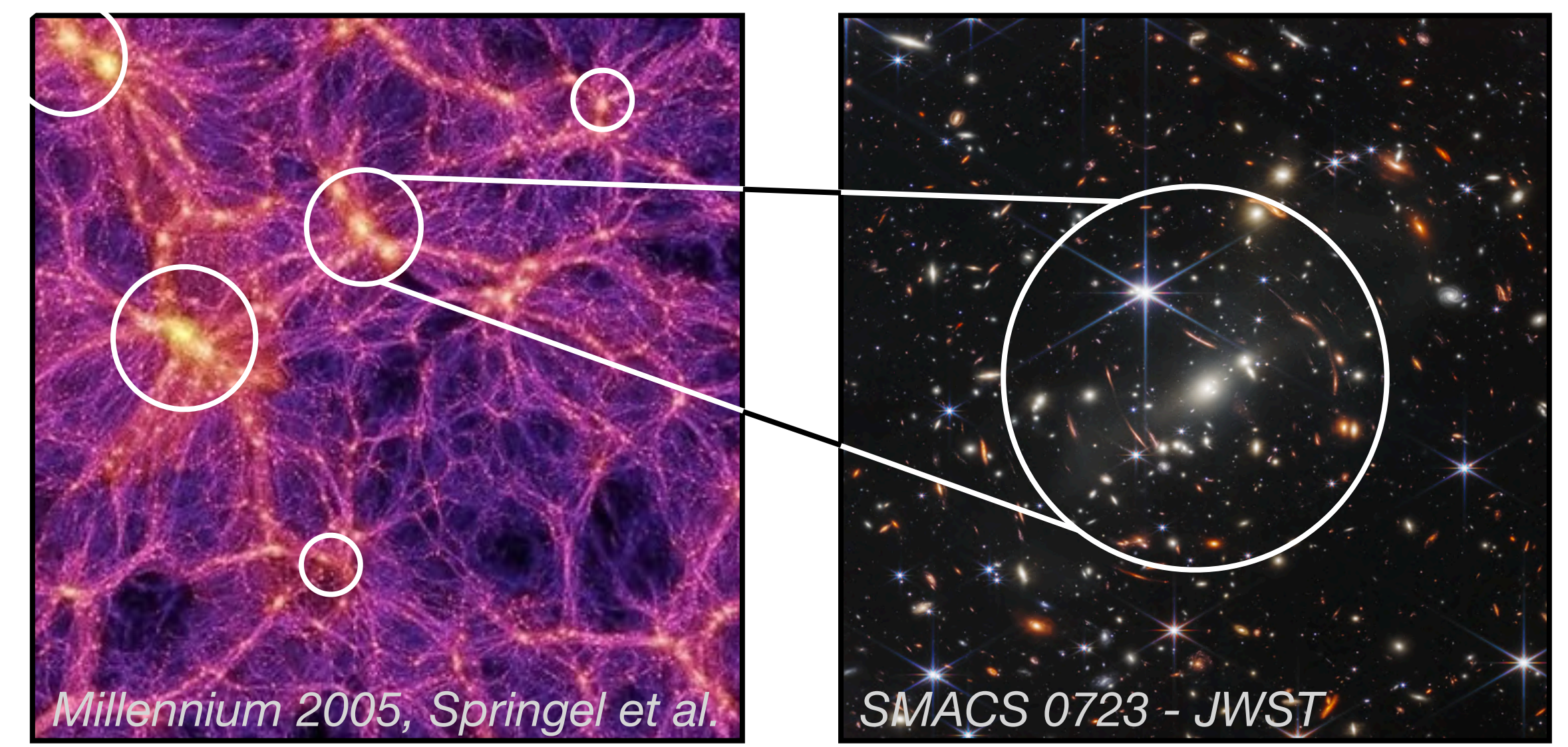
Cosmology with galaxy clusters

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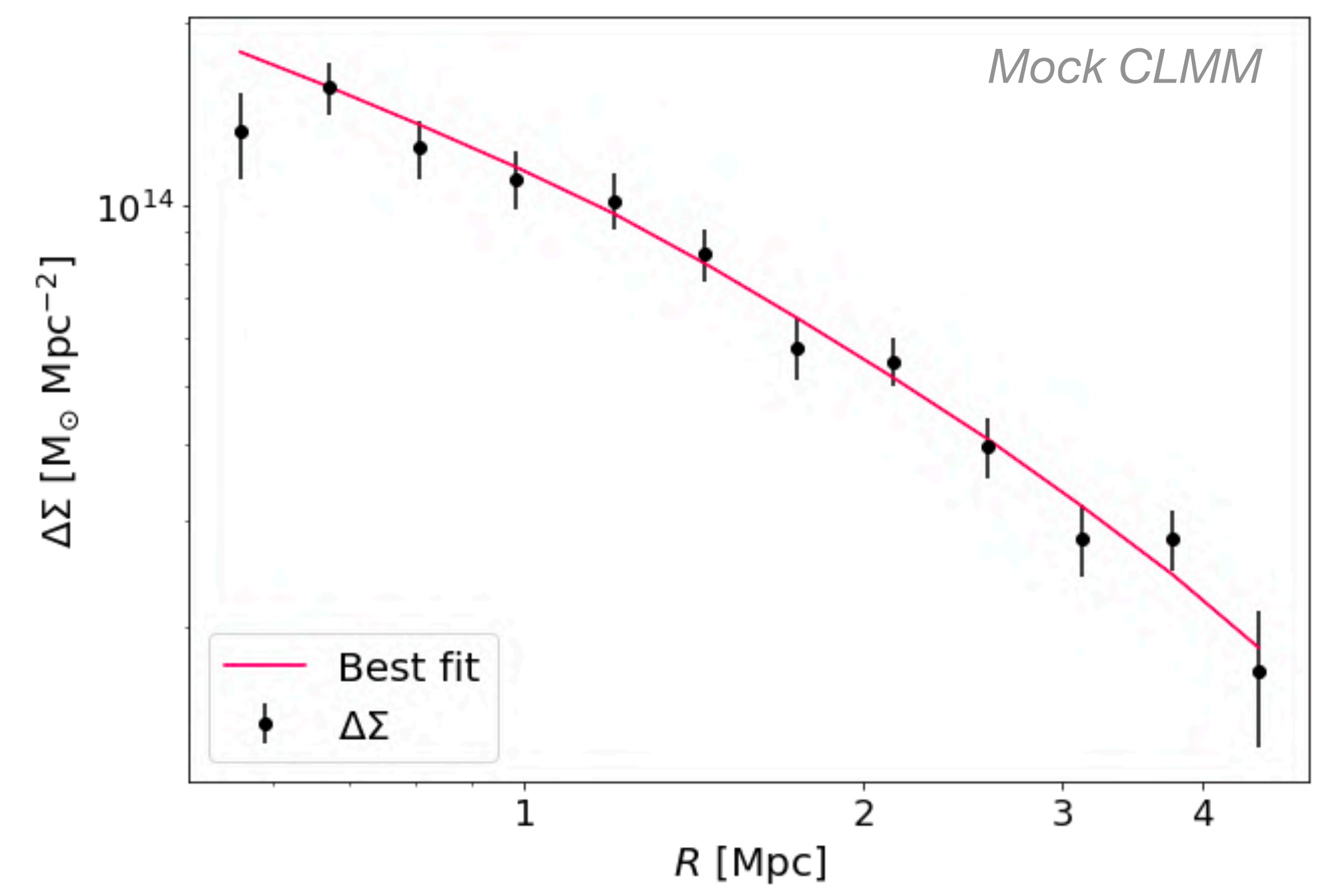
Counting per bins of mass and redshift



Richness
Number of member galaxies

Weak gravitational lensing
Cluster lensing profiles

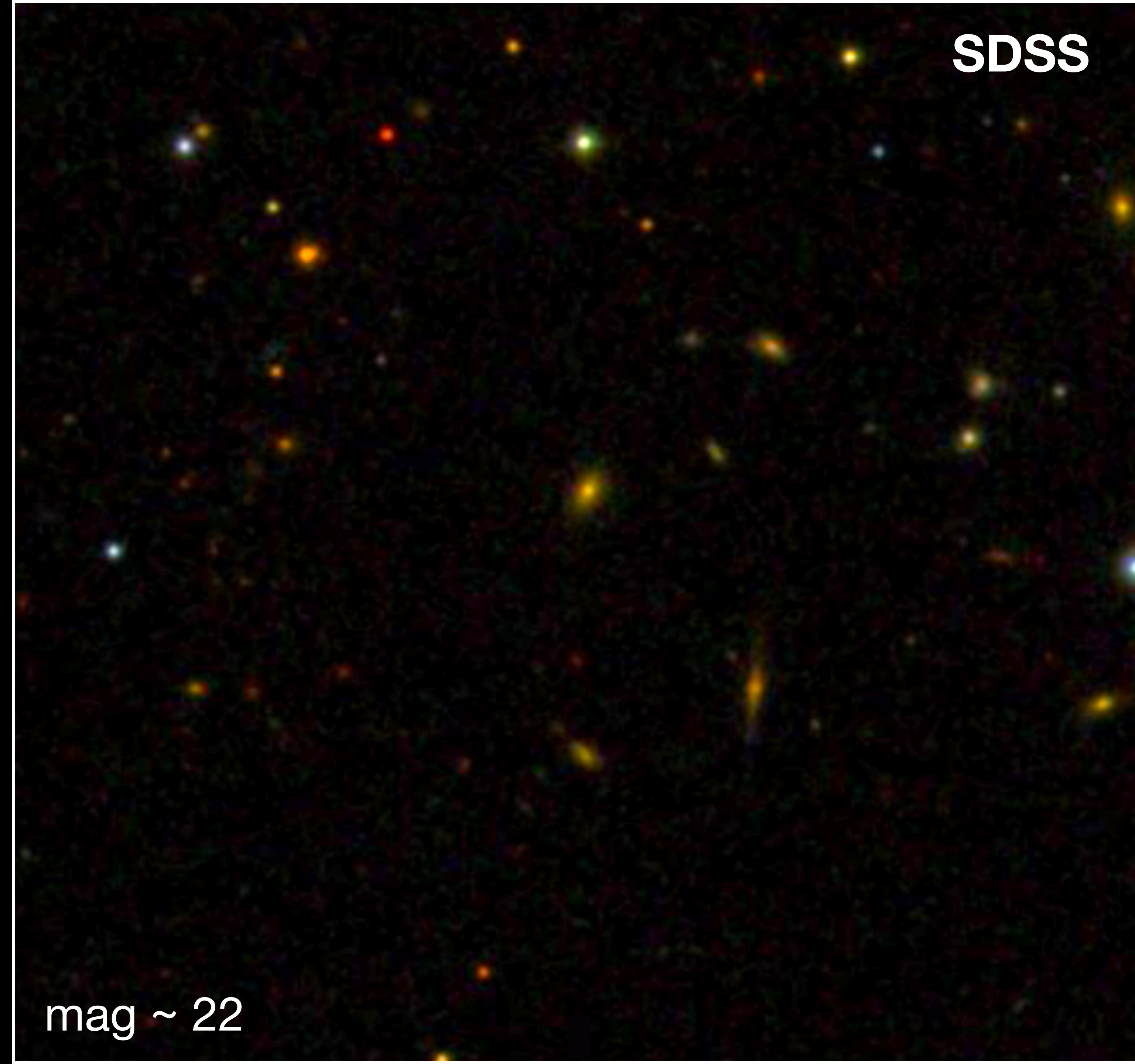
$$\frac{\partial^2 N_{th}}{dz dm} \propto \frac{dn(m, z)}{dm} \frac{d^2 V(z)}{dz d\Omega}$$



Blending

Superposition of galaxies due to:

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



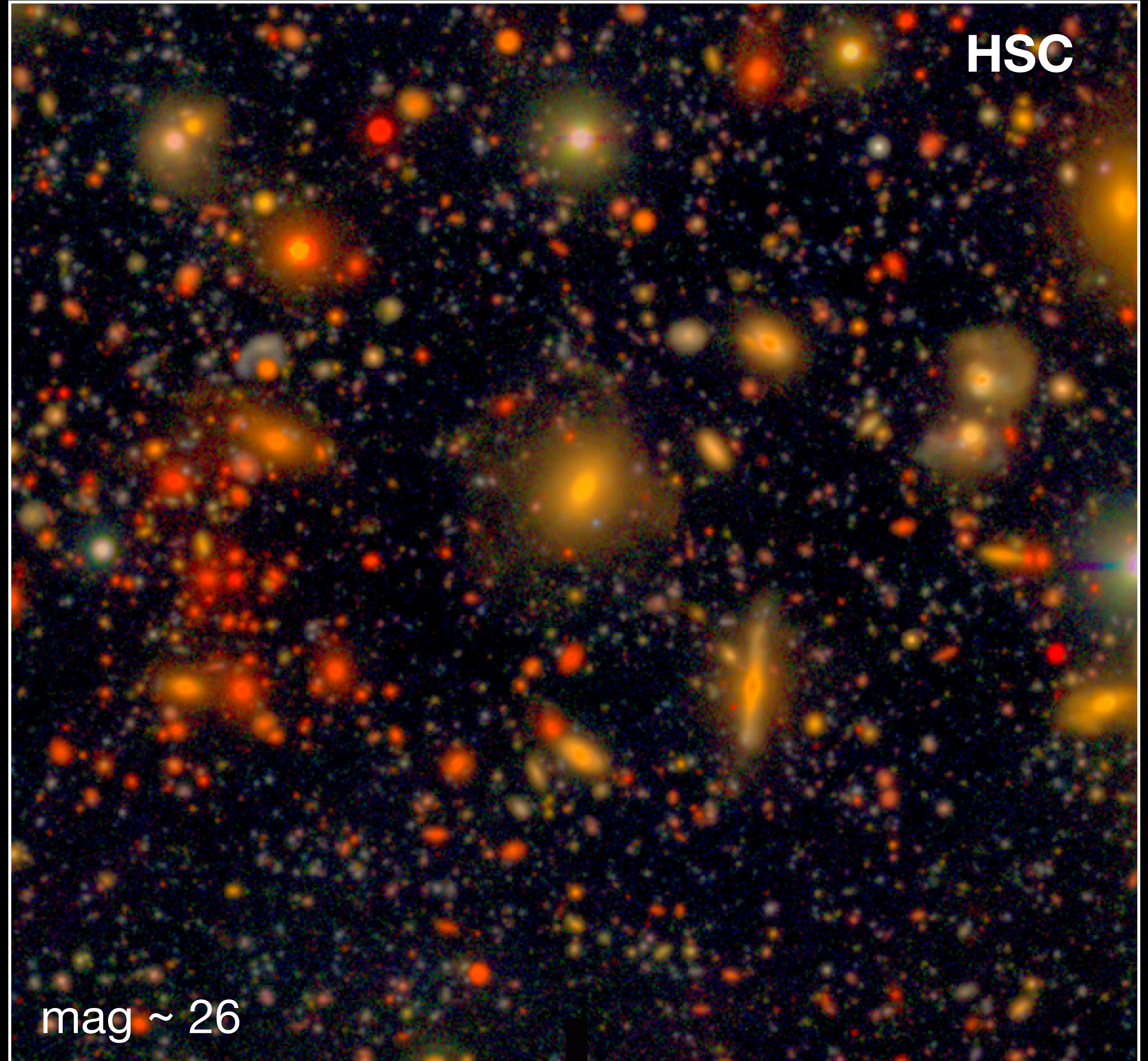
SDSS

mag ~ 22

Blending

Superposition of galaxies due to:

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Blending

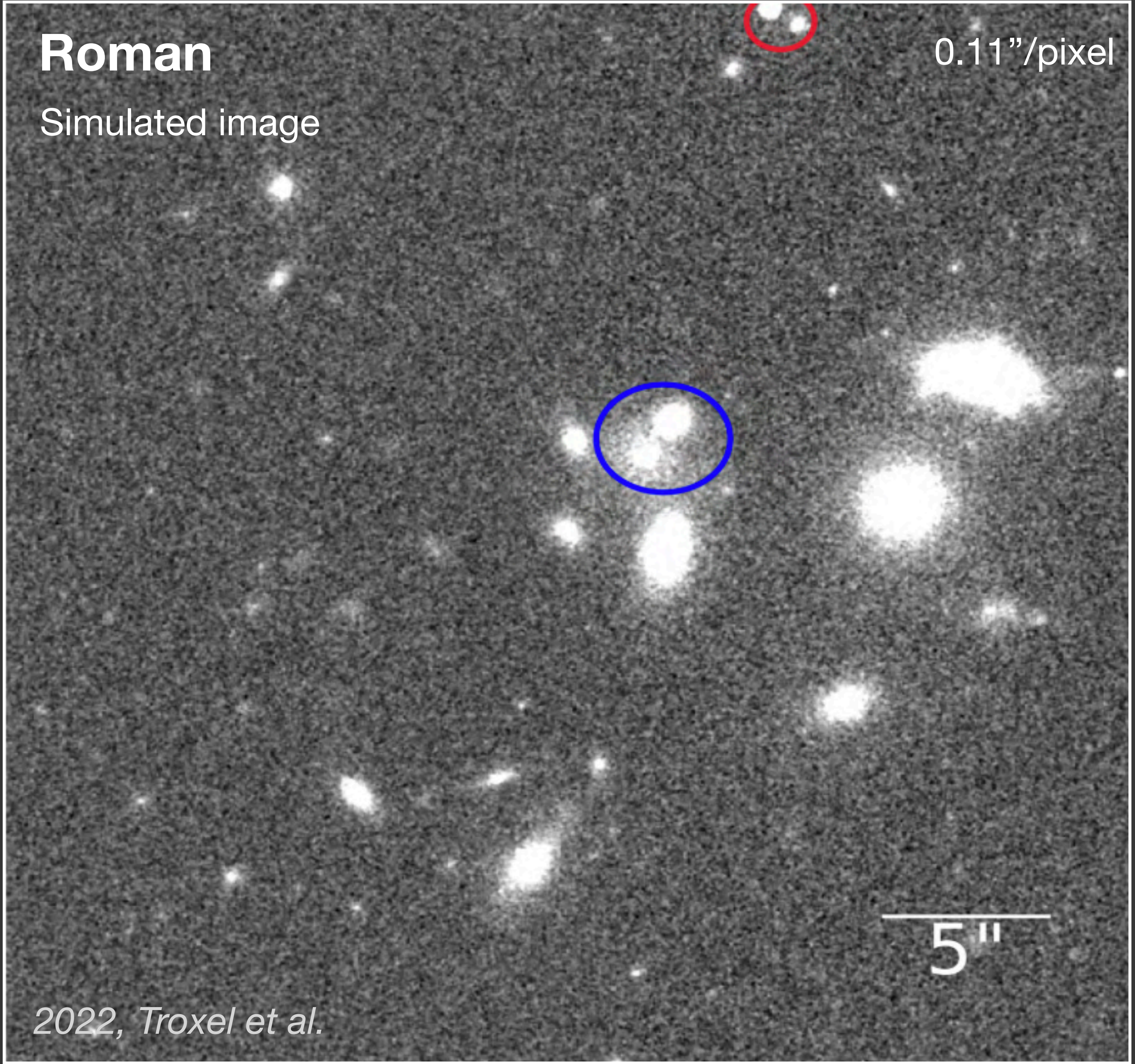
Superposition of galaxies due to:

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

Roman

Simulated image

0.11"/pixel

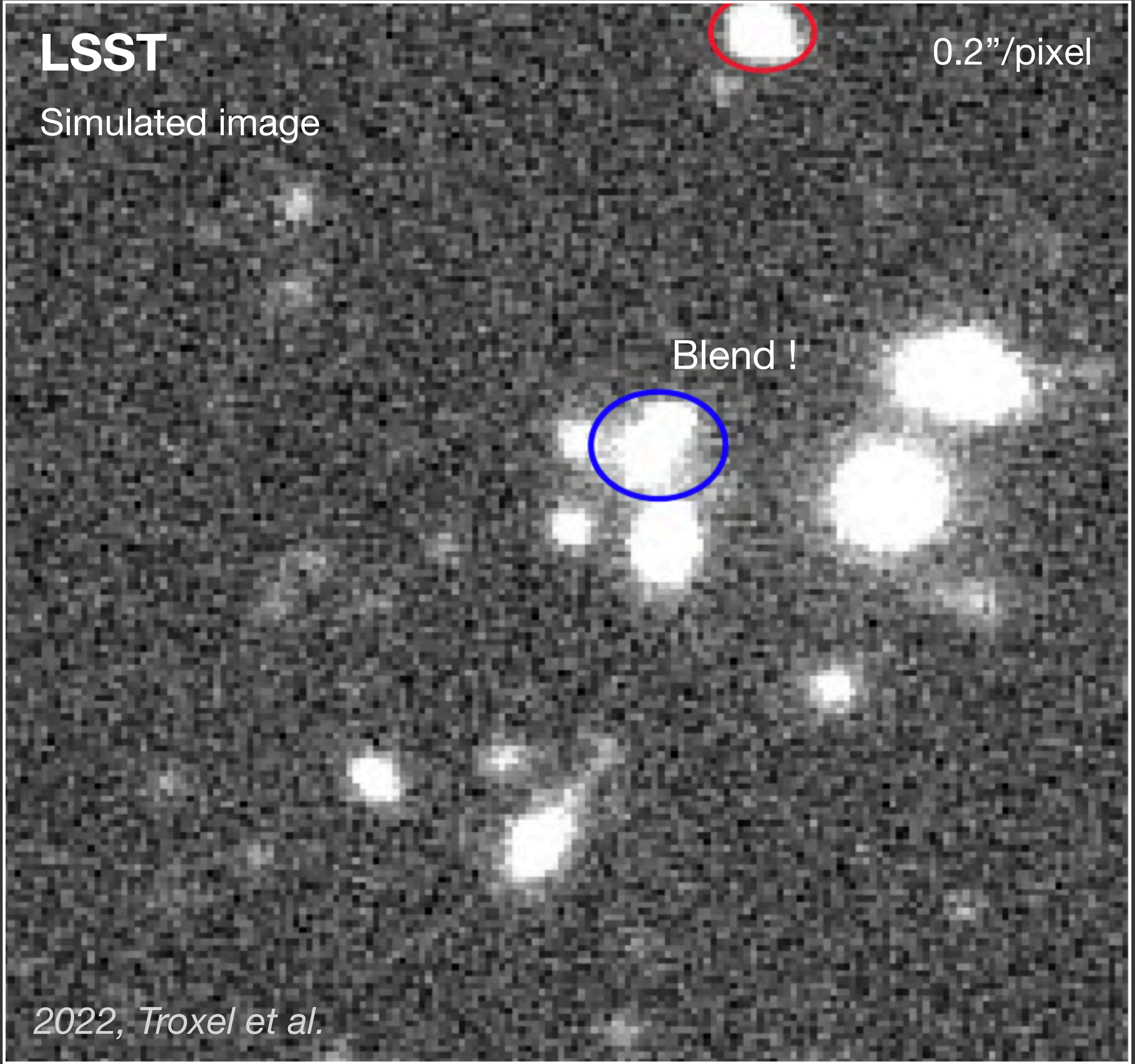


2022, Troxel et al.

Blending

Superposition of galaxies due to:

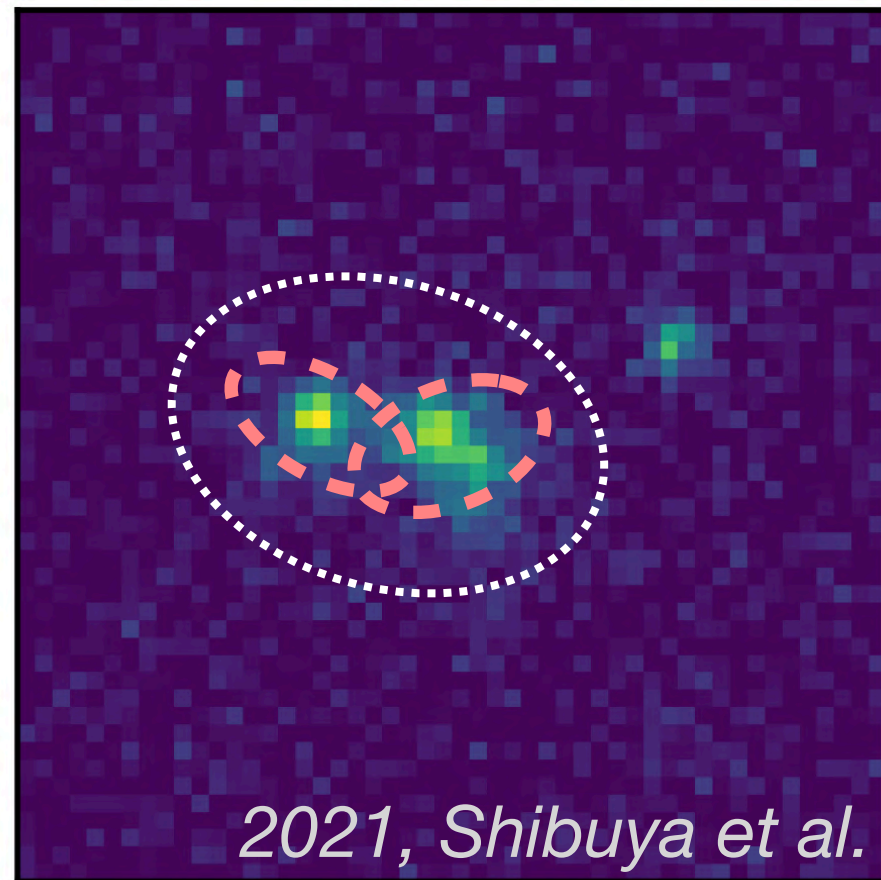
- The **depth** of observation
- The **PSF size**



Recognized/unrecognized blends

Recognized blends

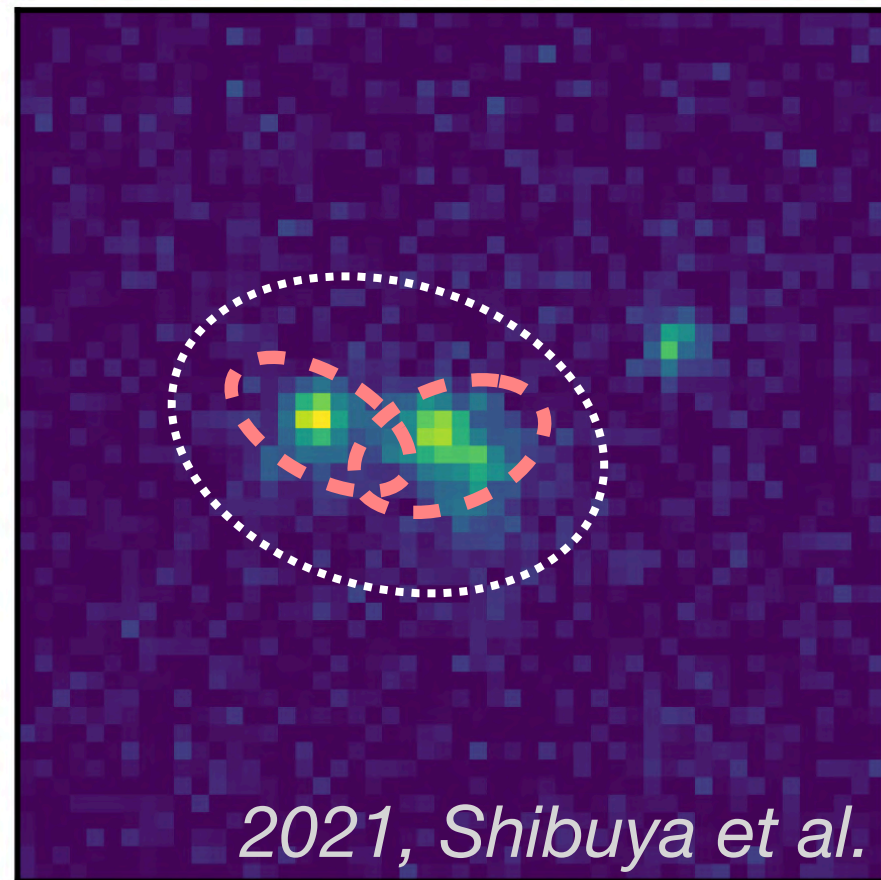
Hubble/ACS



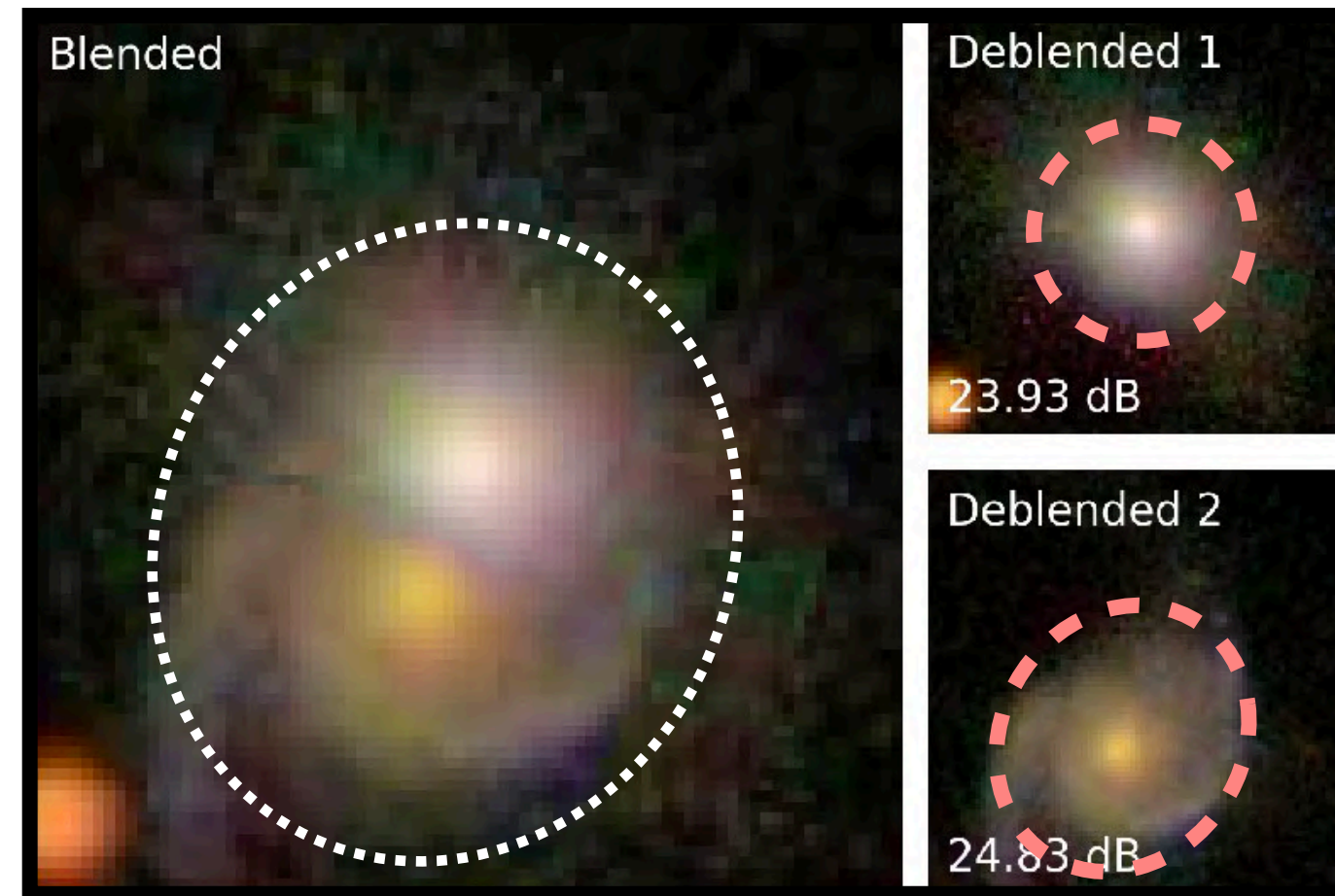
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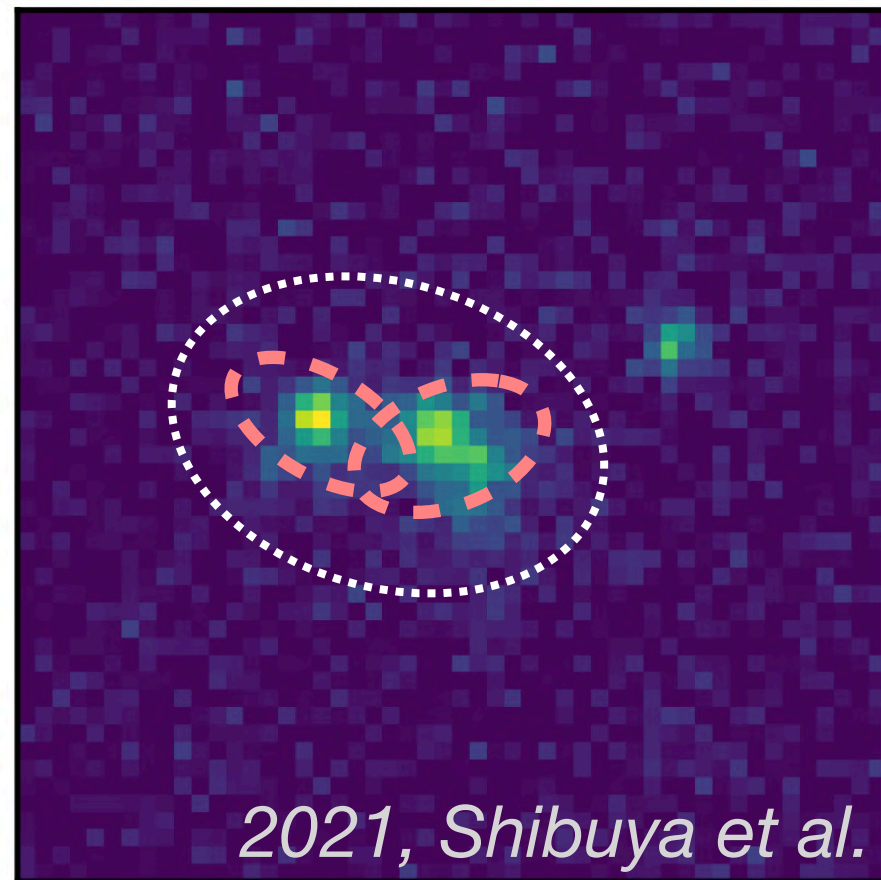
LSST deblender: **SCARLET**



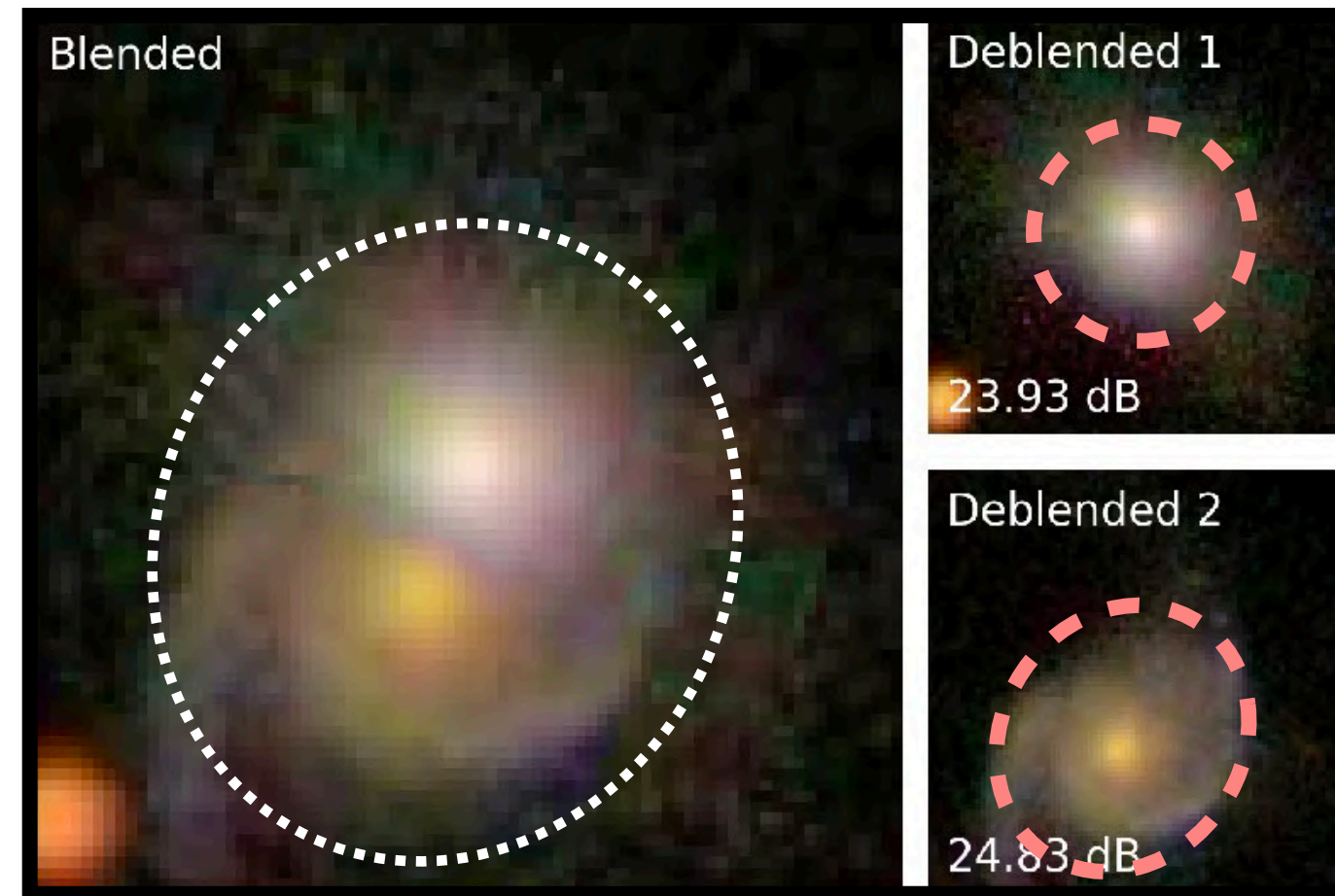
Recognized/unrecognized blends

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Hubble/ACS



LSST deblender: **SCARLET**

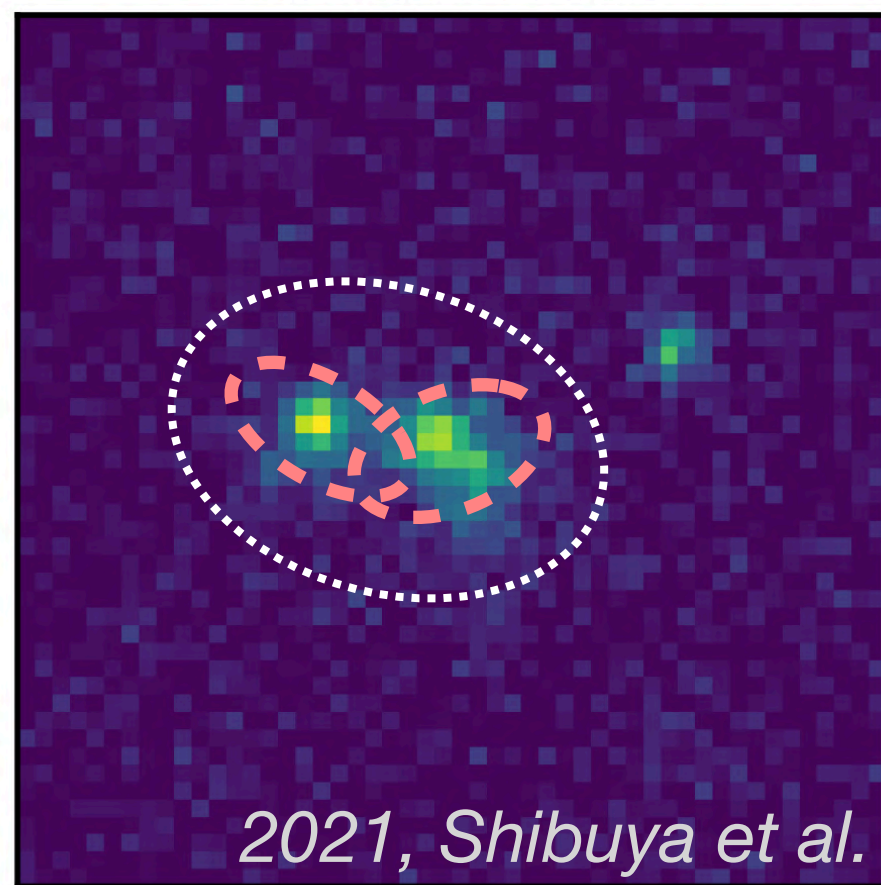


~40 %

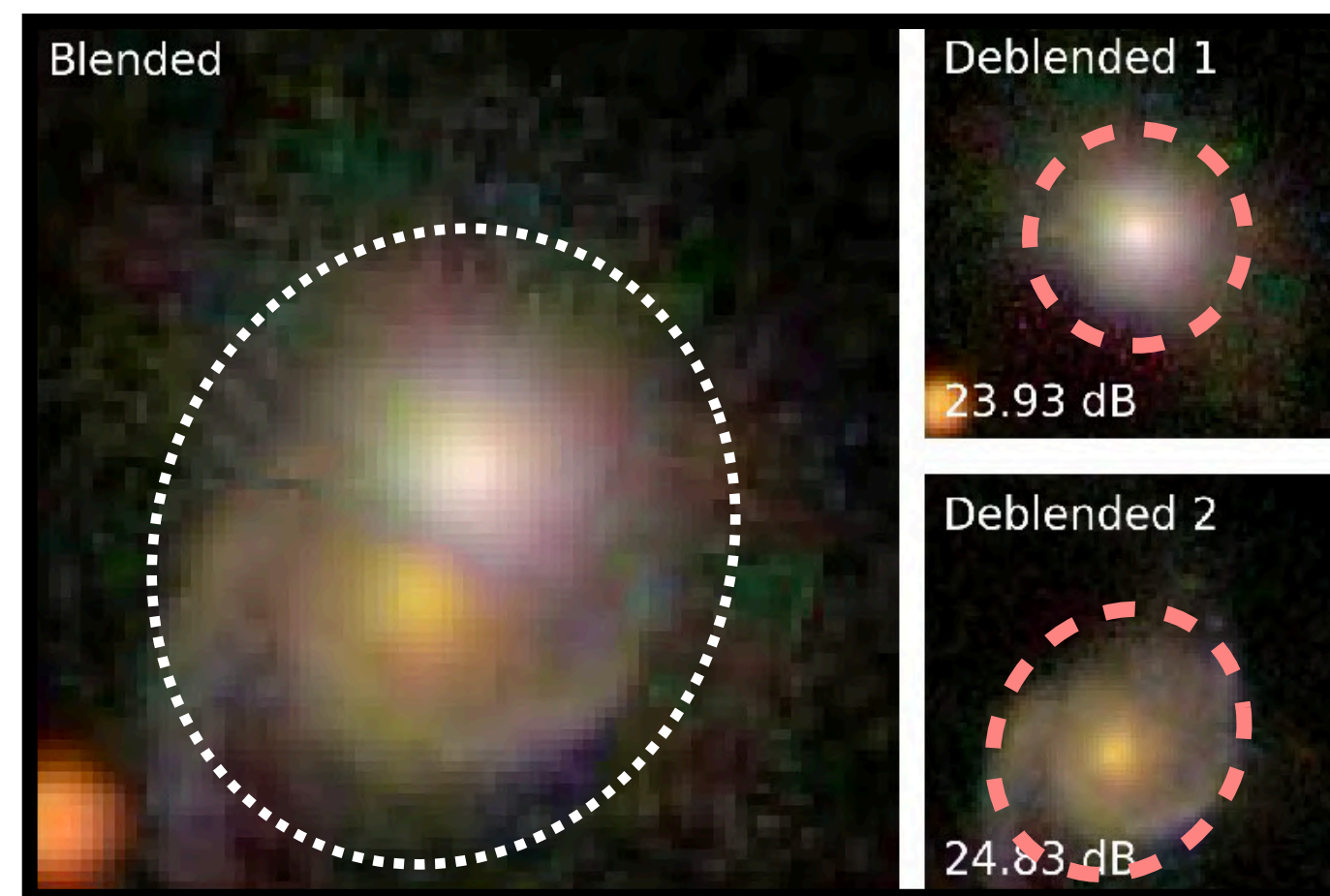
Recognized/unrecognized blends

Recognized blends

Hubble/ACS



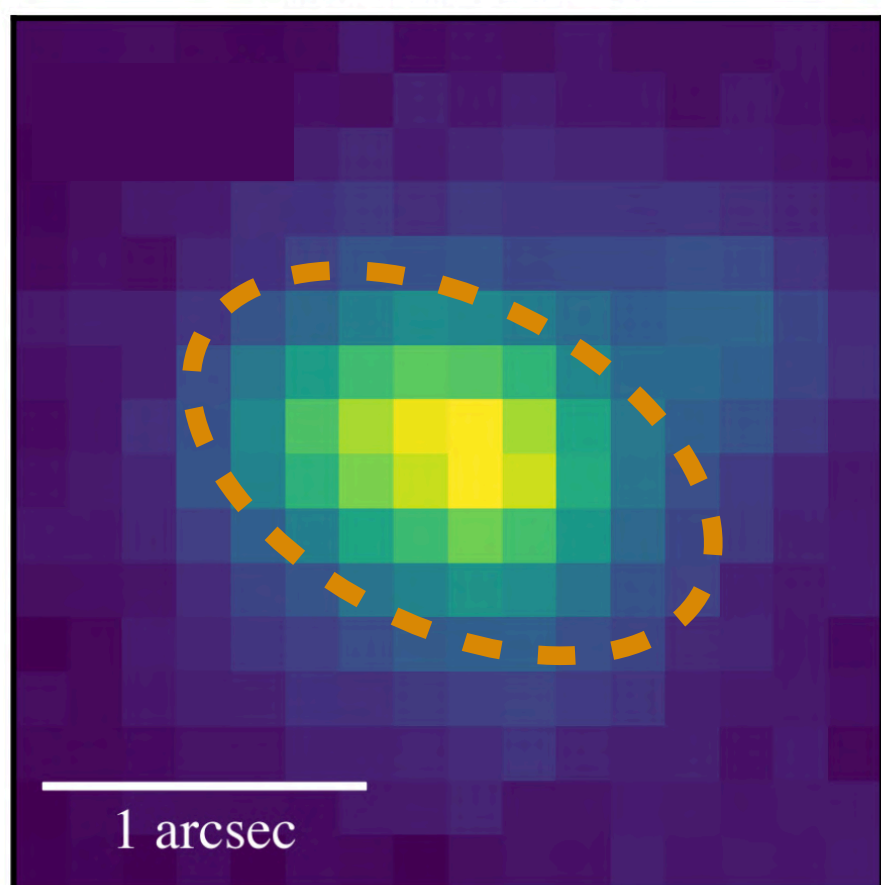
LSST deblender: **SCARLET**



~40 %

Unrecognized blends

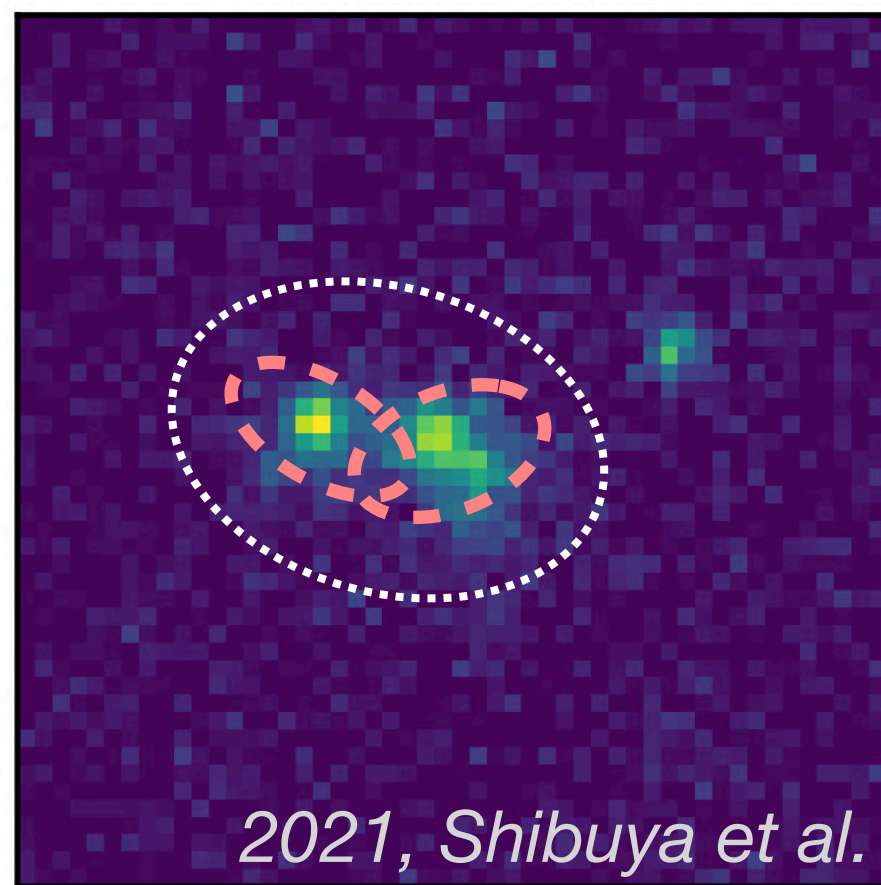
Subaru/HSC



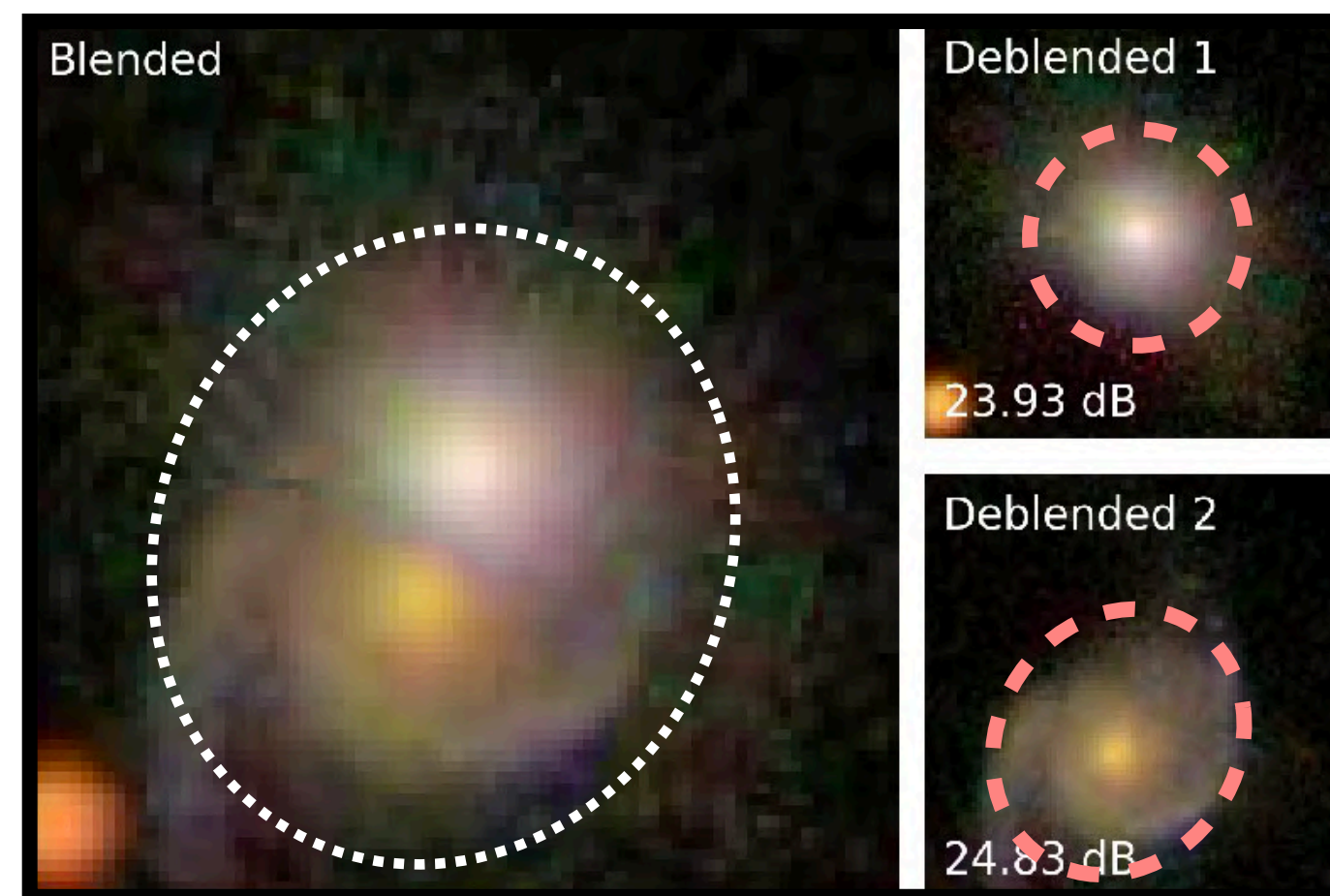
Recognized/unrecognized blends

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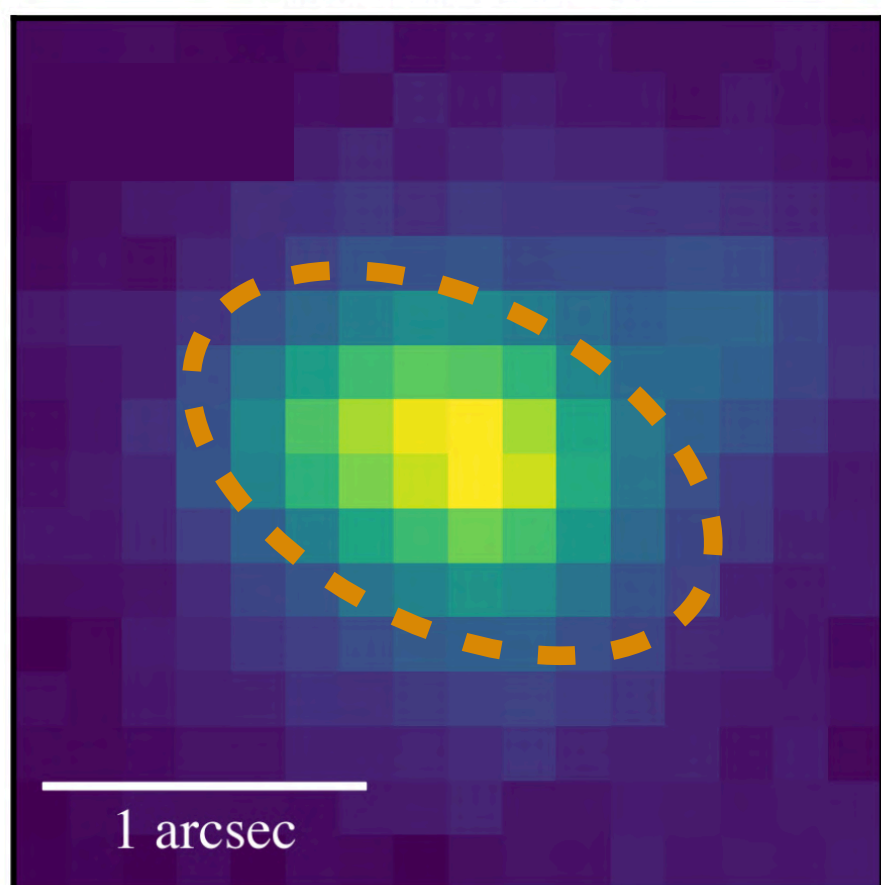
LSST deblender: **SCARLET**



~40 %

Unrecognized blends

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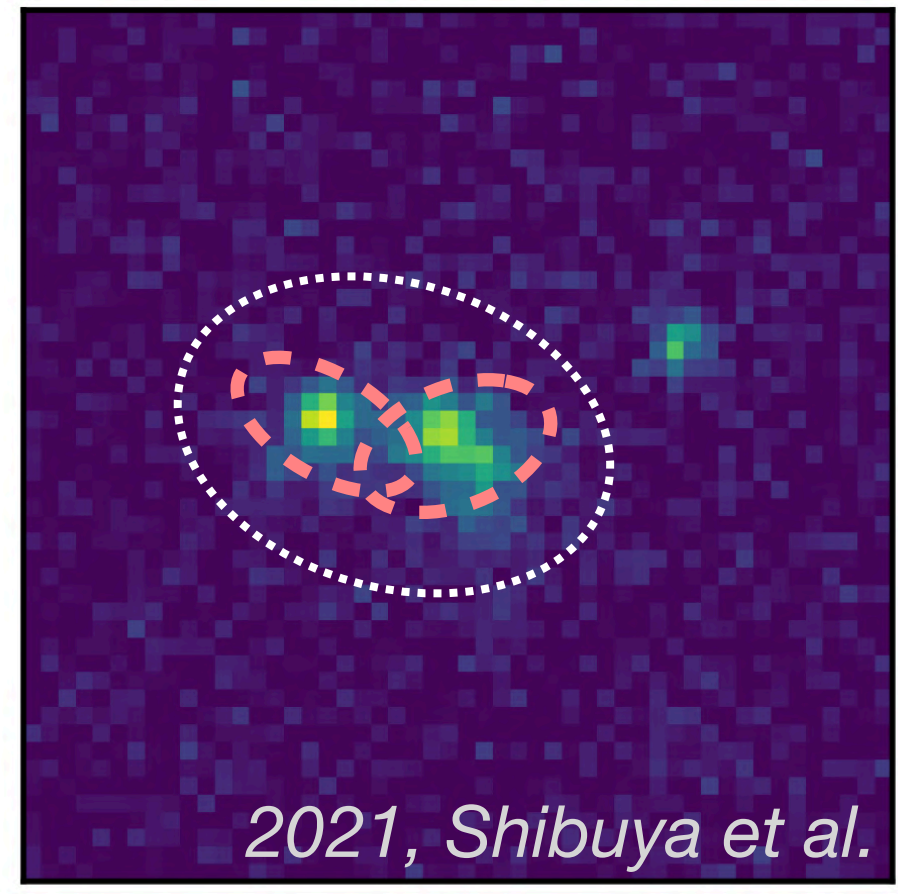


Recognized/unrecognized blends

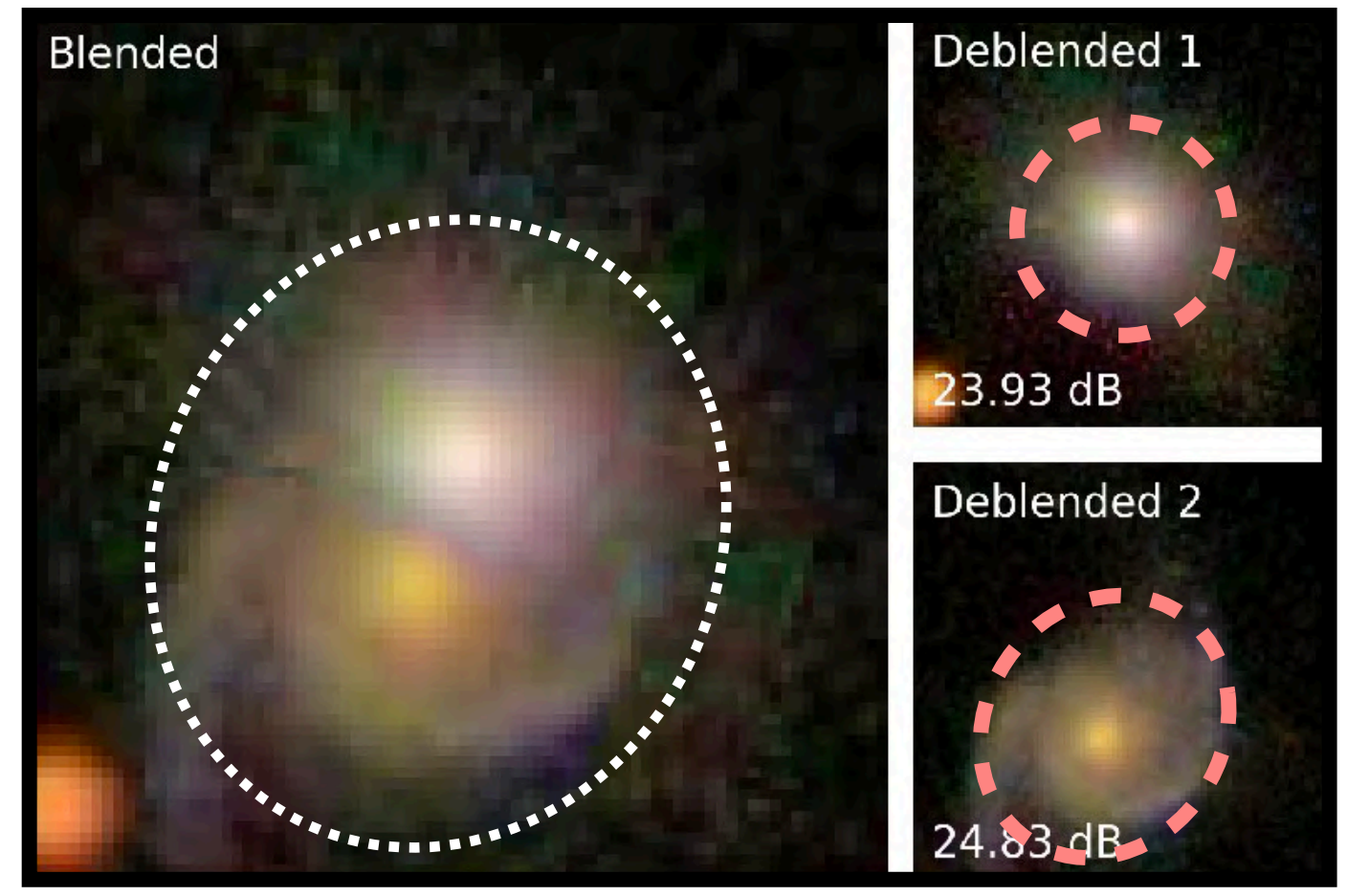
* 2016, Dawson et al.
2022, Troxel et al.

Recognized blends

Hubble/ACS



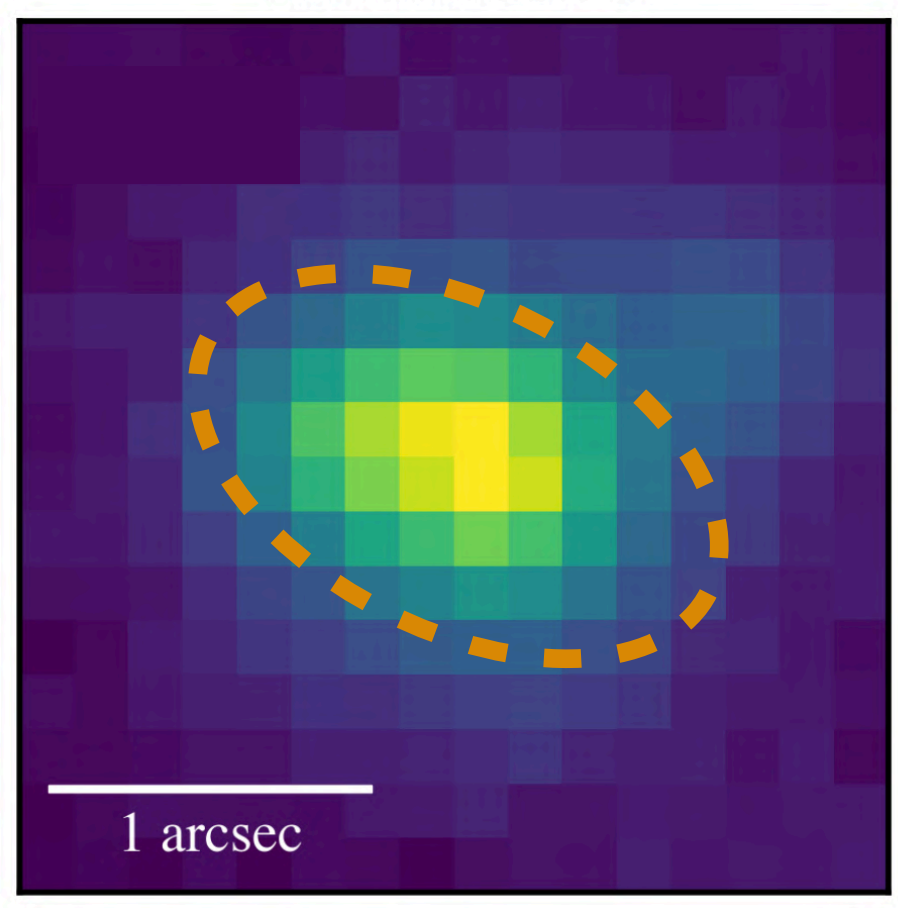
LSST deblender: **SCARLET**



~40 %

Unrecognized blends

Subaru/HSC



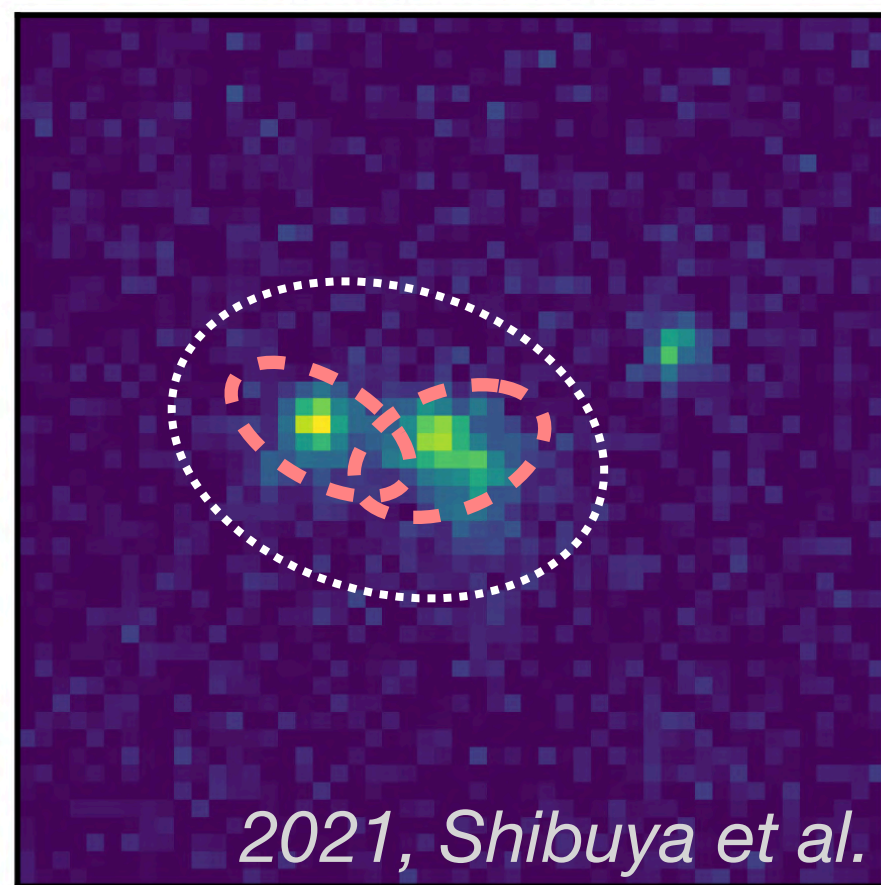
~14 - 20 %*

Recognized/unrecognized blends

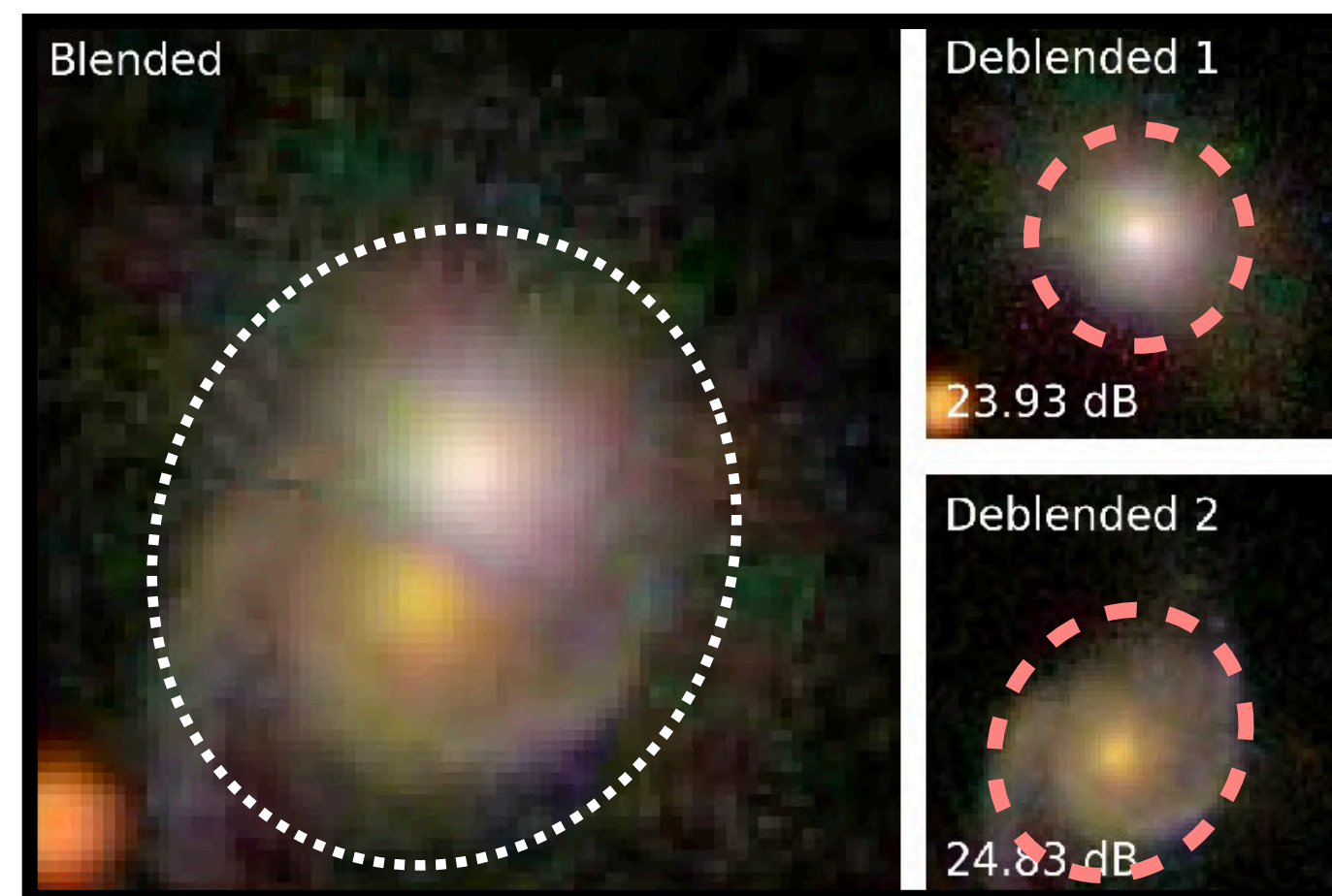
* 2016, Dawson et al.
2022, Troxel et al.

Recognized blends

Hubble/ACS



LSST deblender: **SCARLET**



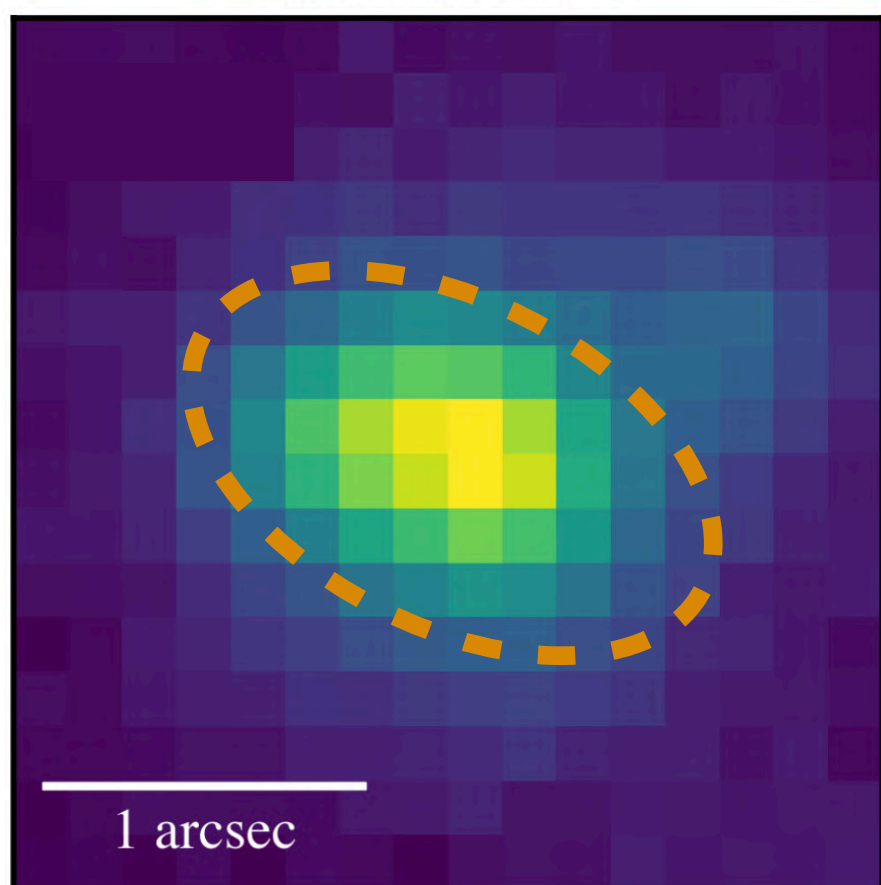
~40 %

~ 60% of blends

- Detection
- Shapes
- Redshifts

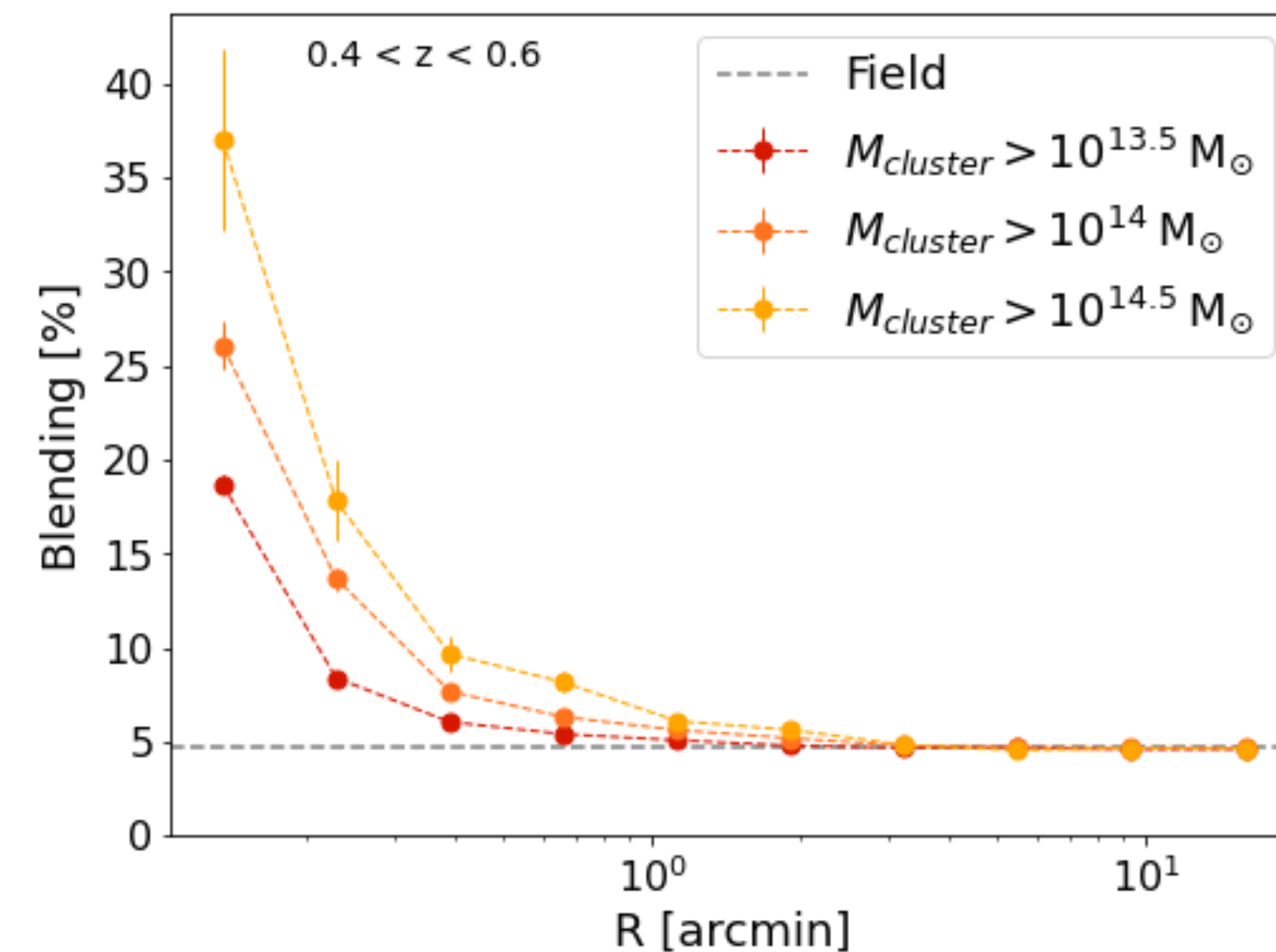
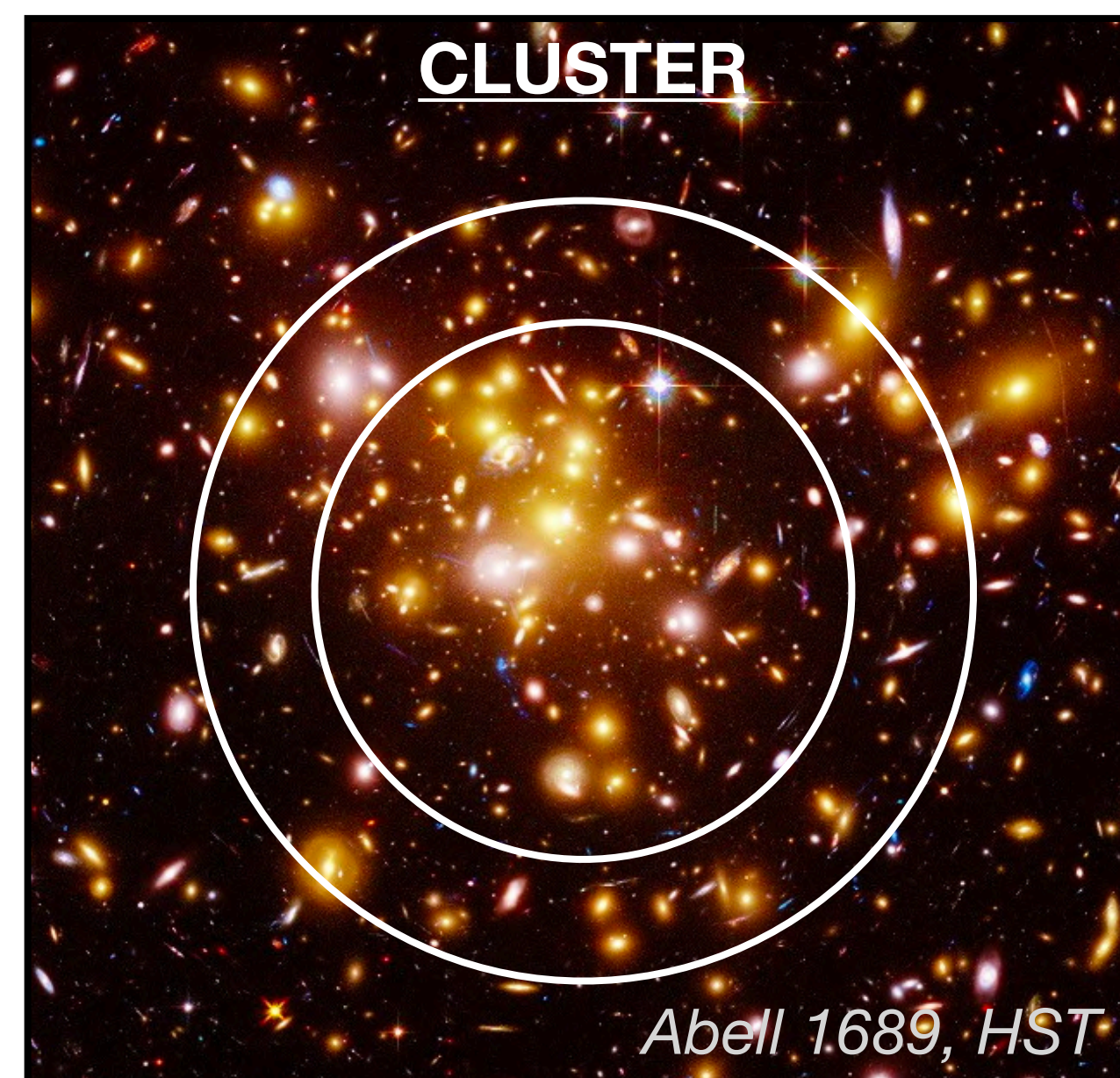
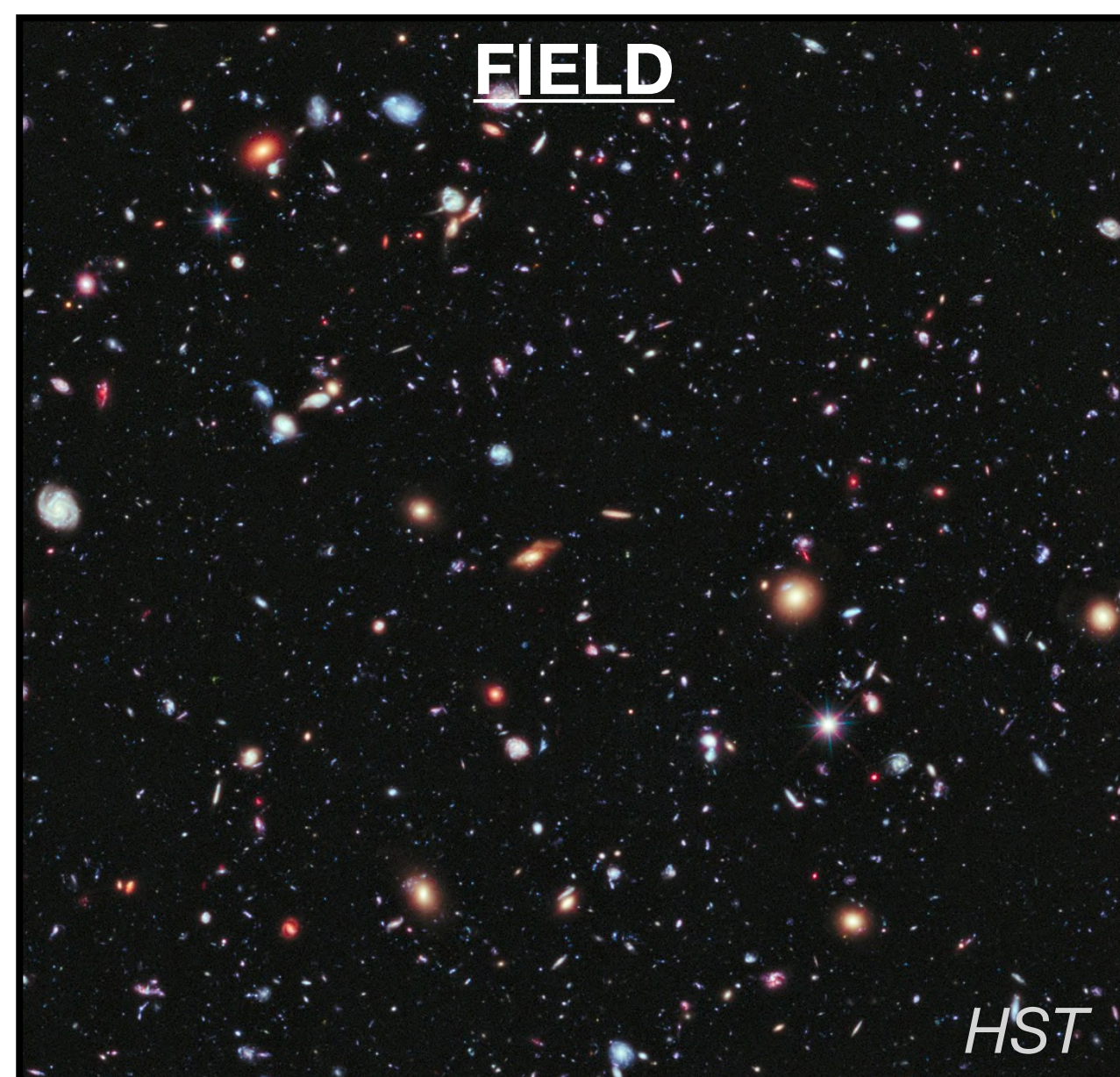
Unrecognized blends

Subaru/HSC



~14 - 20 %*

Blending around galaxy clusters

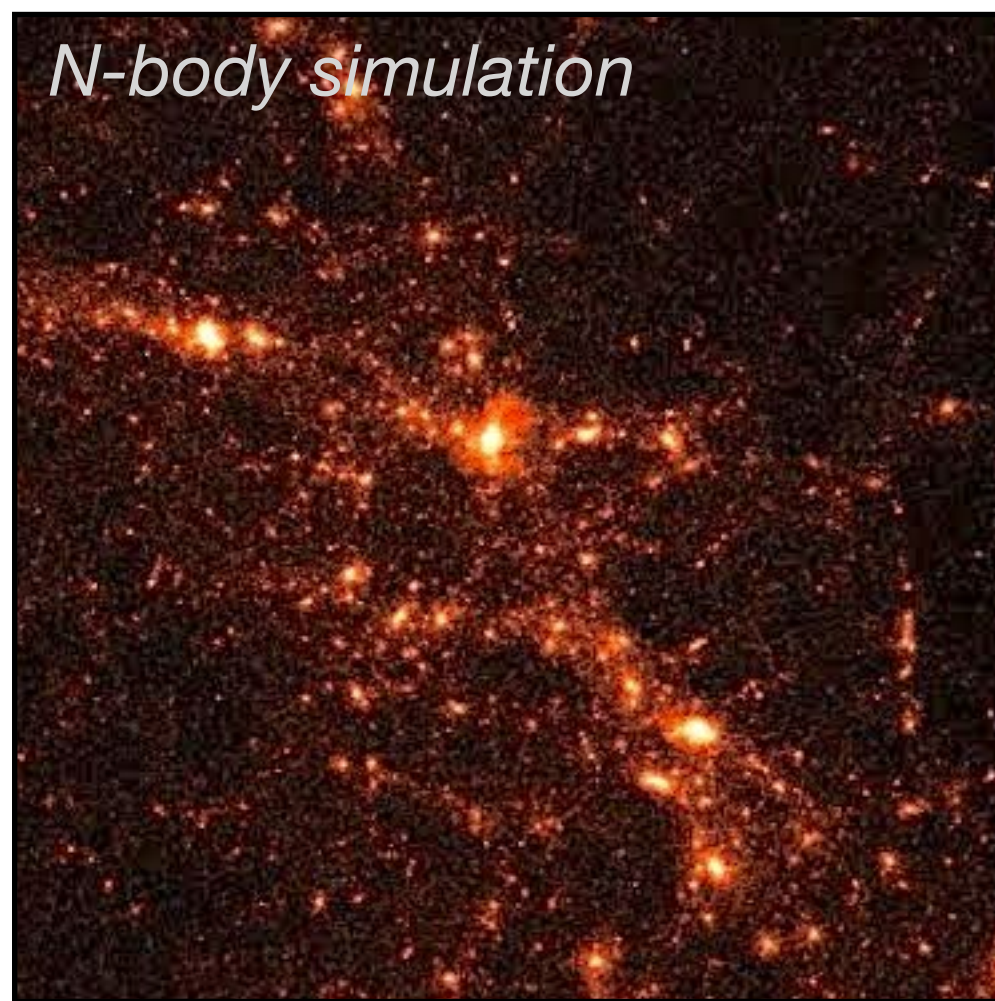


Blending in cluster fields ↔ WL profiles ↔ galaxy cluster masses ↔ cosmology

A wide-angle photograph of an astronomical observatory situated on a rugged mountain peak. The sky is a gradient of orange and blue, indicating sunset or sunrise. A bright star or planet is visible in the upper right. The observatory building is white with a dark, rectangular structure on top. The foreground shows the rocky terrain of the mountain.

Identification of blends in DC2

Simulated catalogs

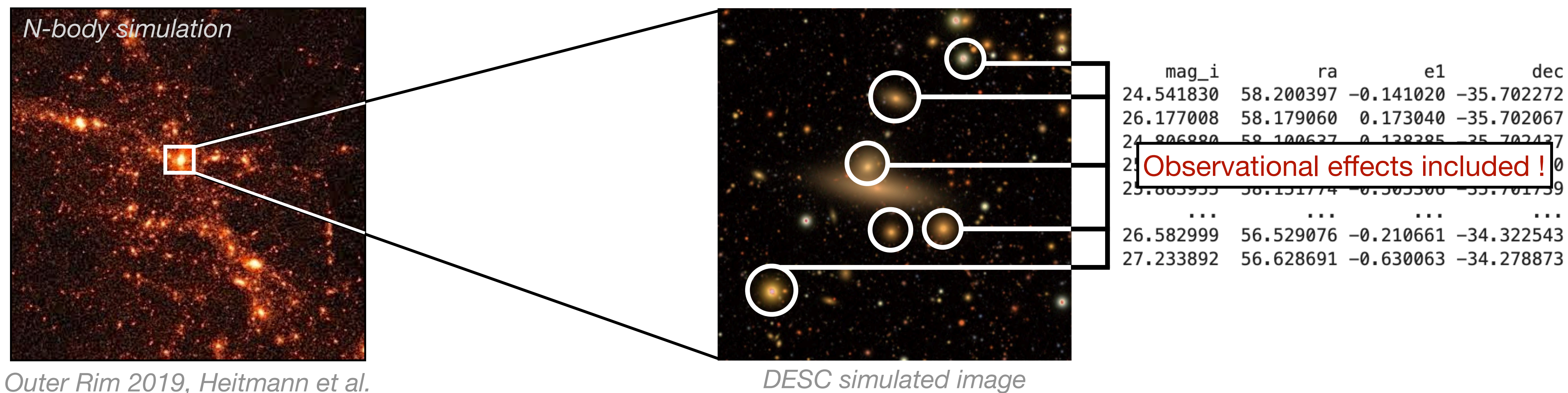


Outer Rim 2019, Heitmann et al.

cosmoDC2

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

Simulated catalogs



cosmoDC2

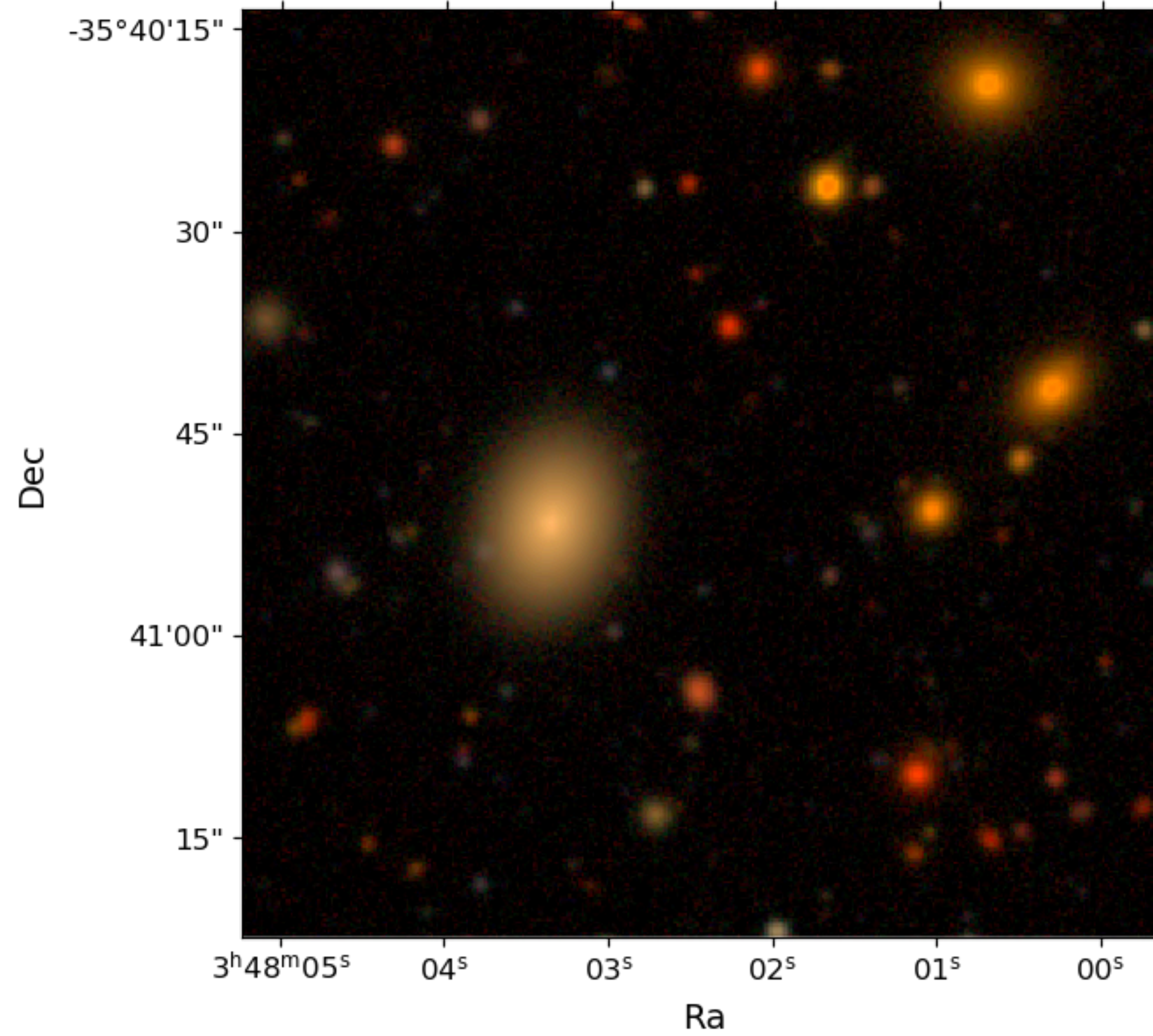
DC2object

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

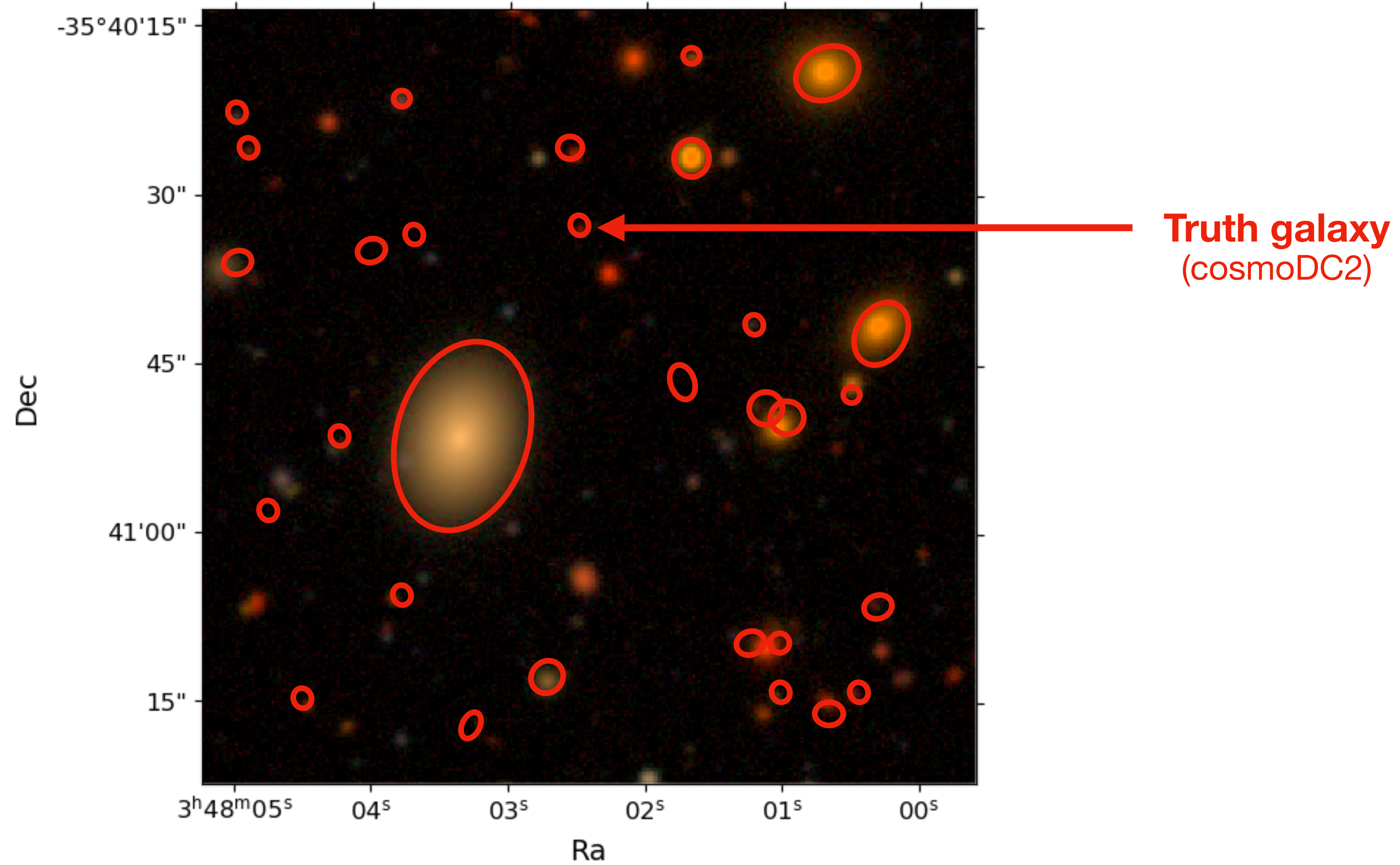
- Detected **objects** from realistic simulated images

Identification of blends through catalog matching

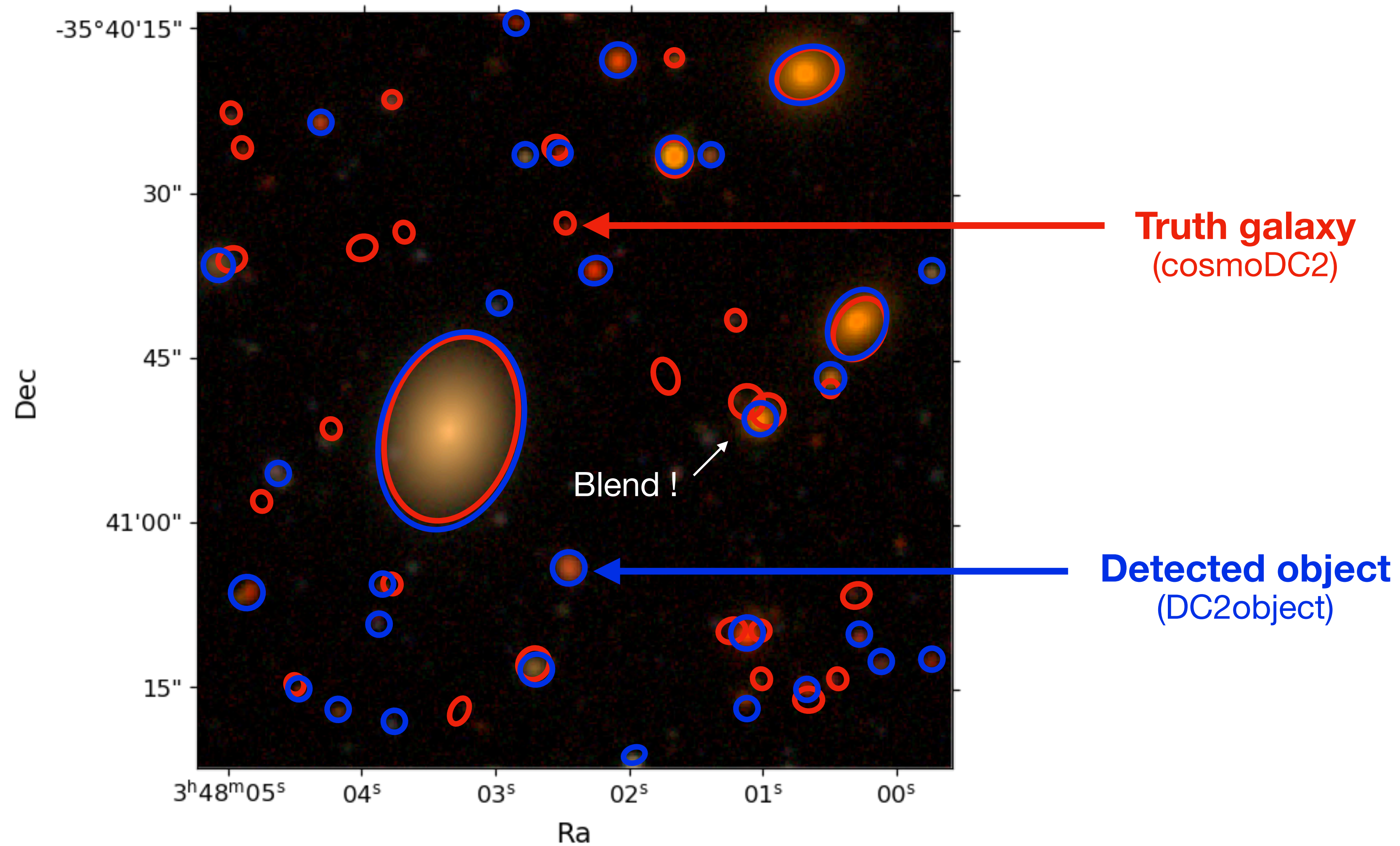
Blends in DC2 images



Blends in DC2 images



Blends in DC2 images

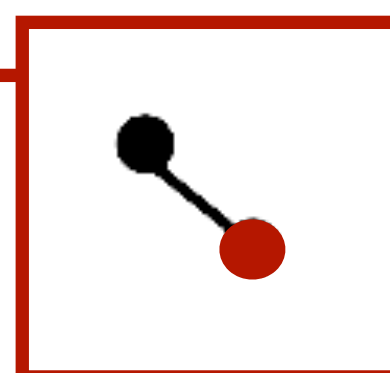


First attempt of matching

<https://github.com/yymao/FoFCatalogMatching>

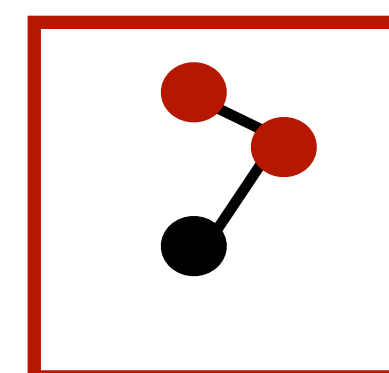
Perfect match

1-1 system



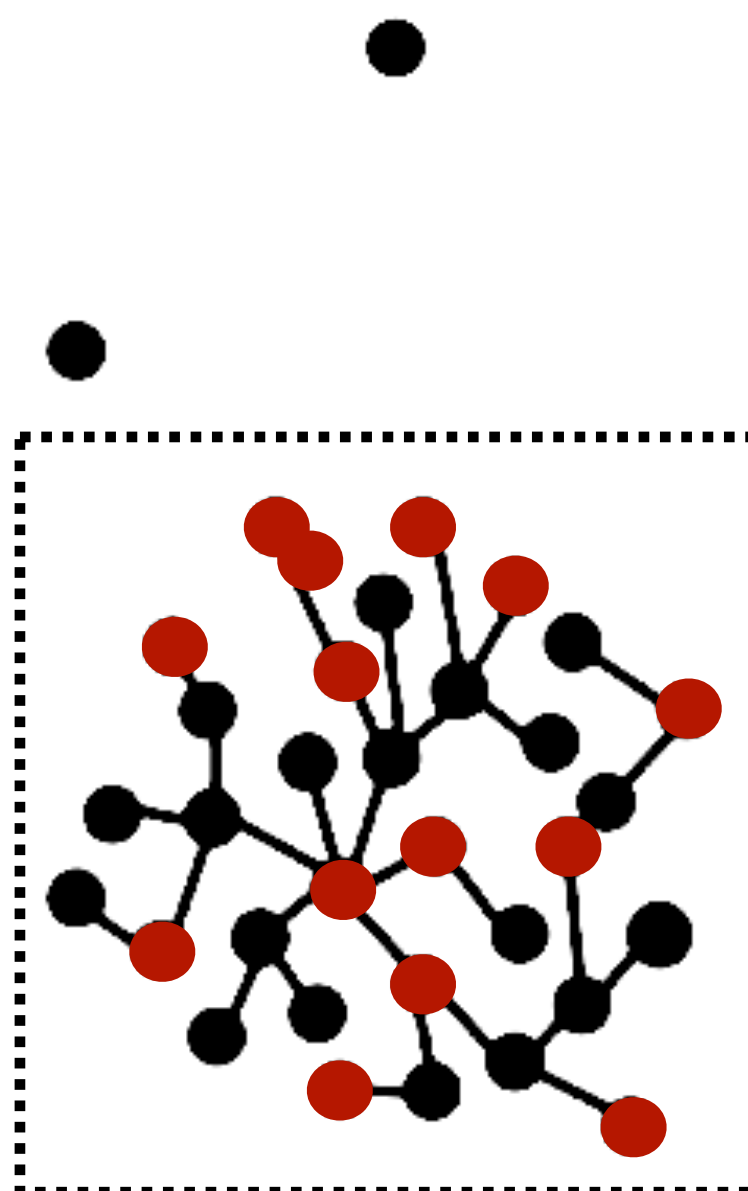
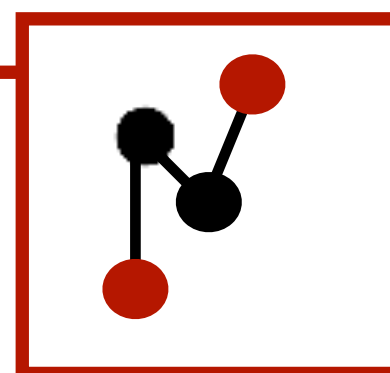
Unrecognized blend

2-1 system



Recognized blend

2-2 system



n-m system

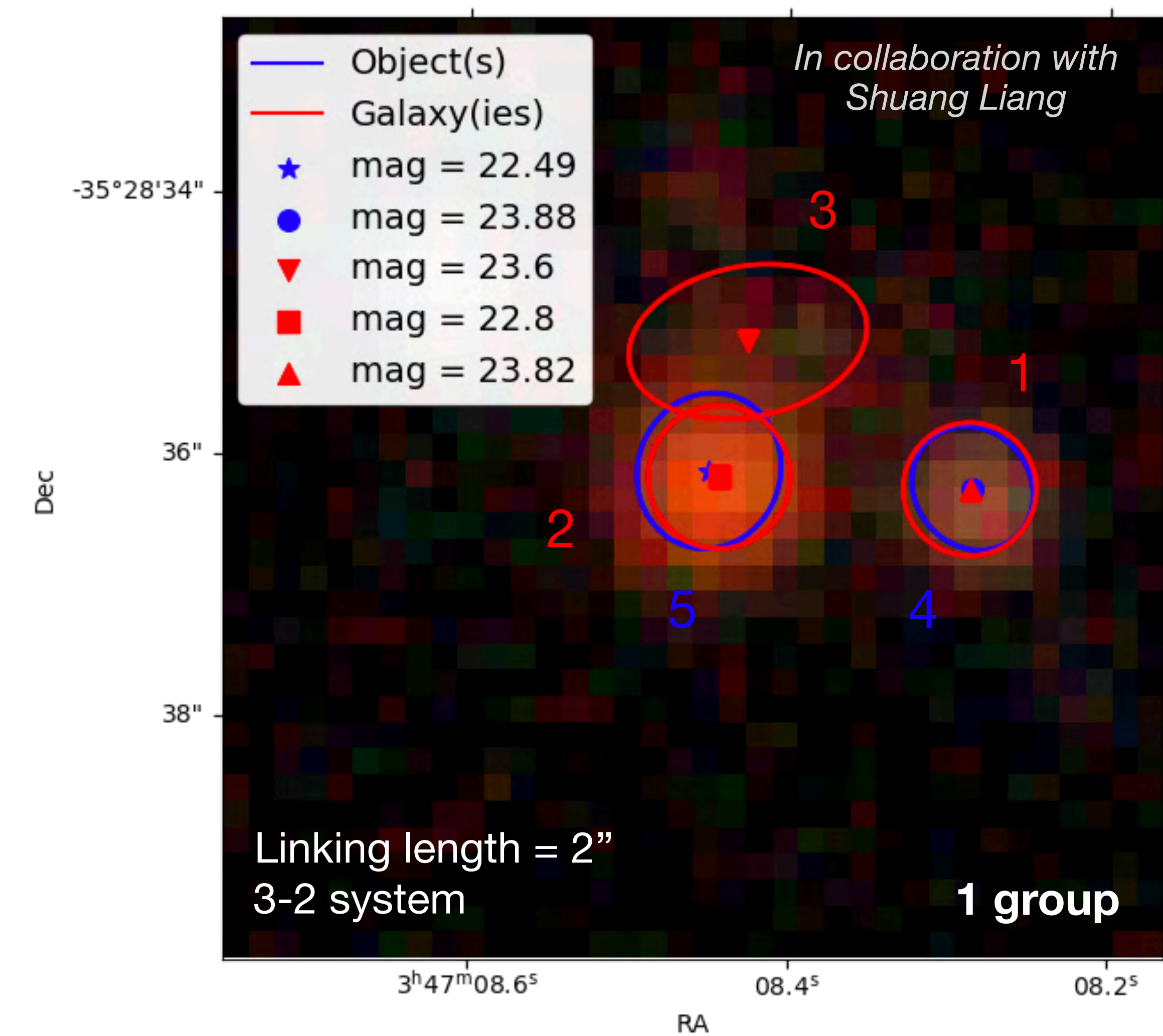
$n = \#$ of **galaxies** from **cosmoDC2**

$m = \#$ of **objects** from **DC2object**

Linking length

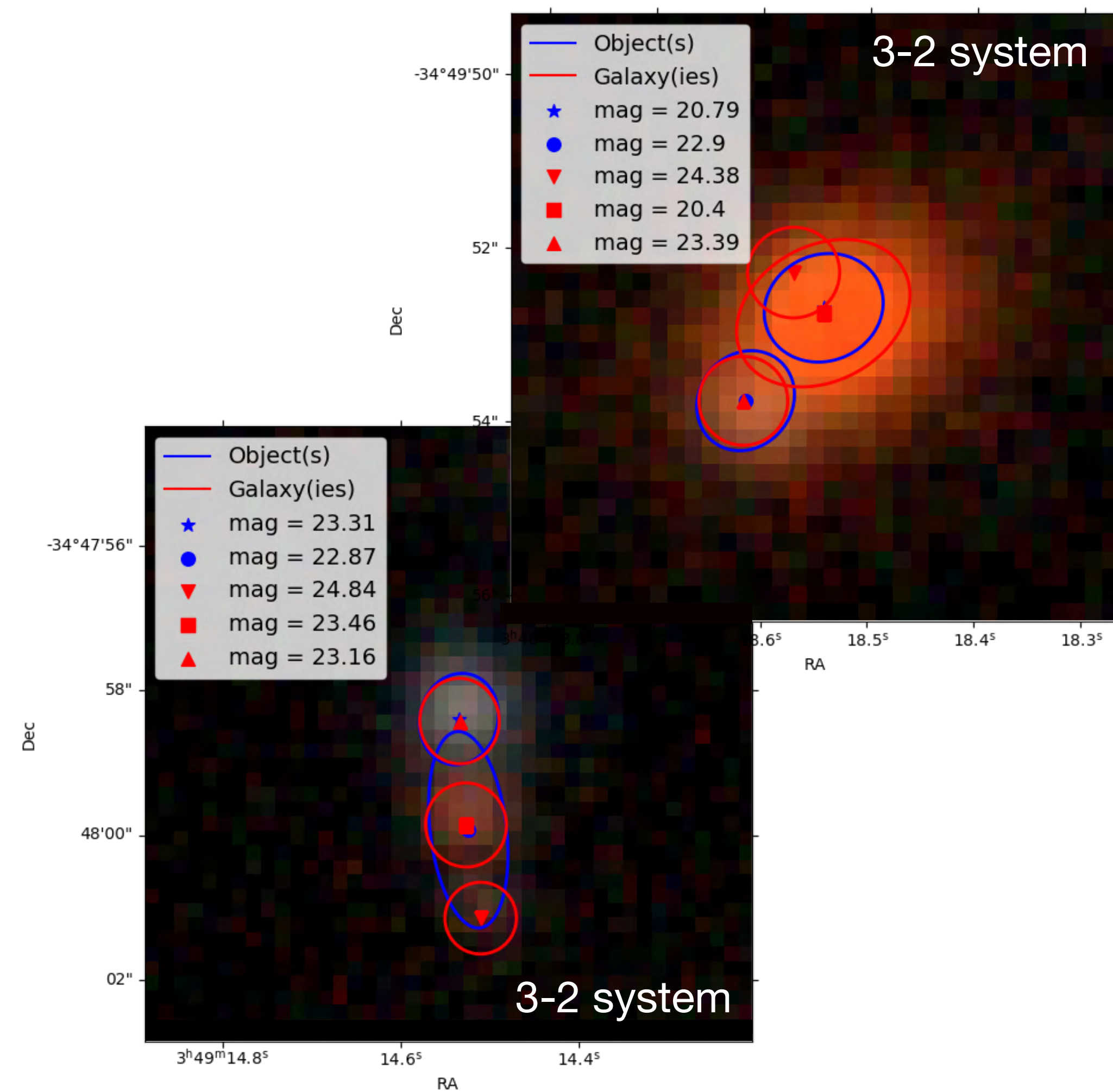
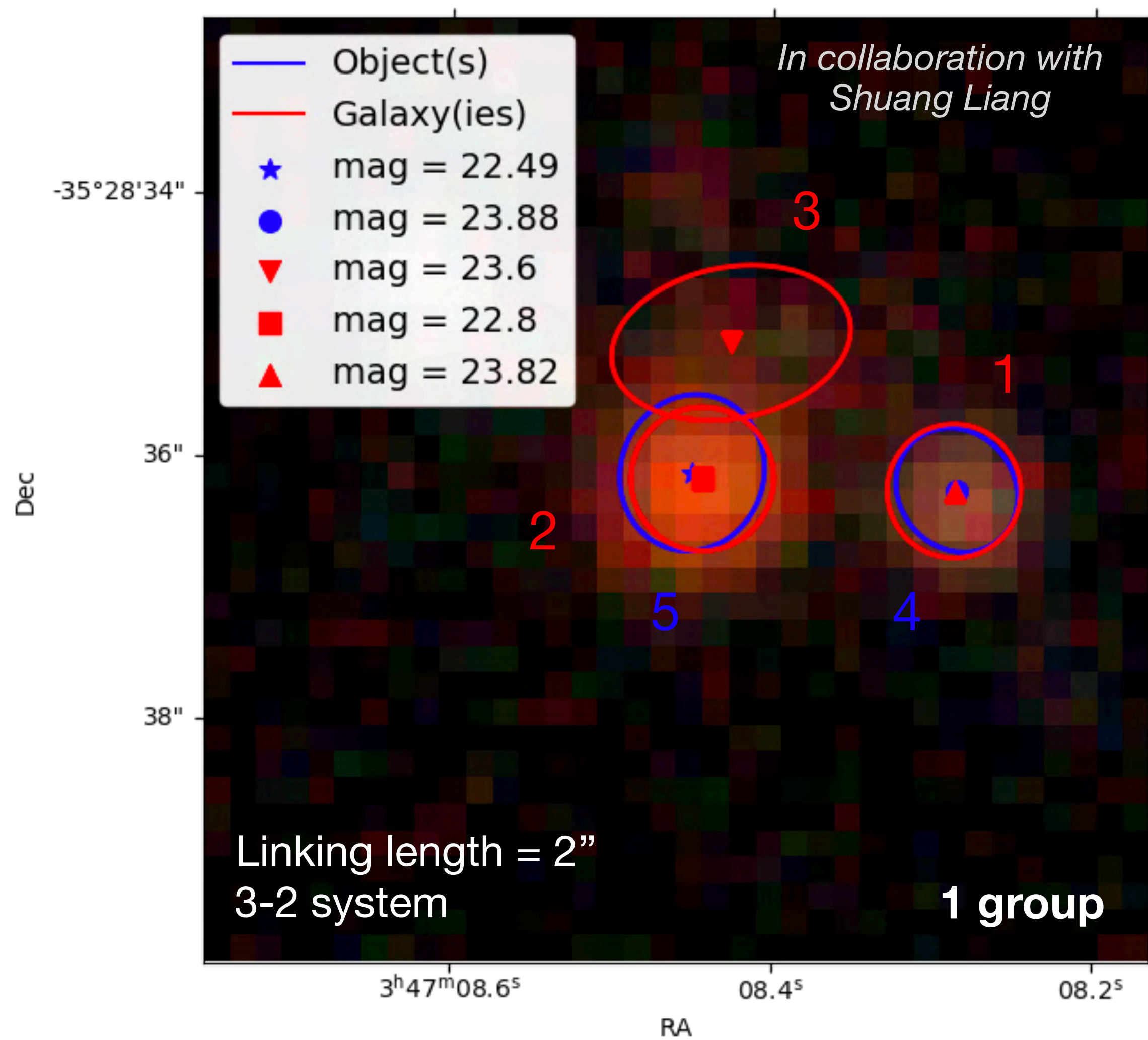
Look at FoF groups

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



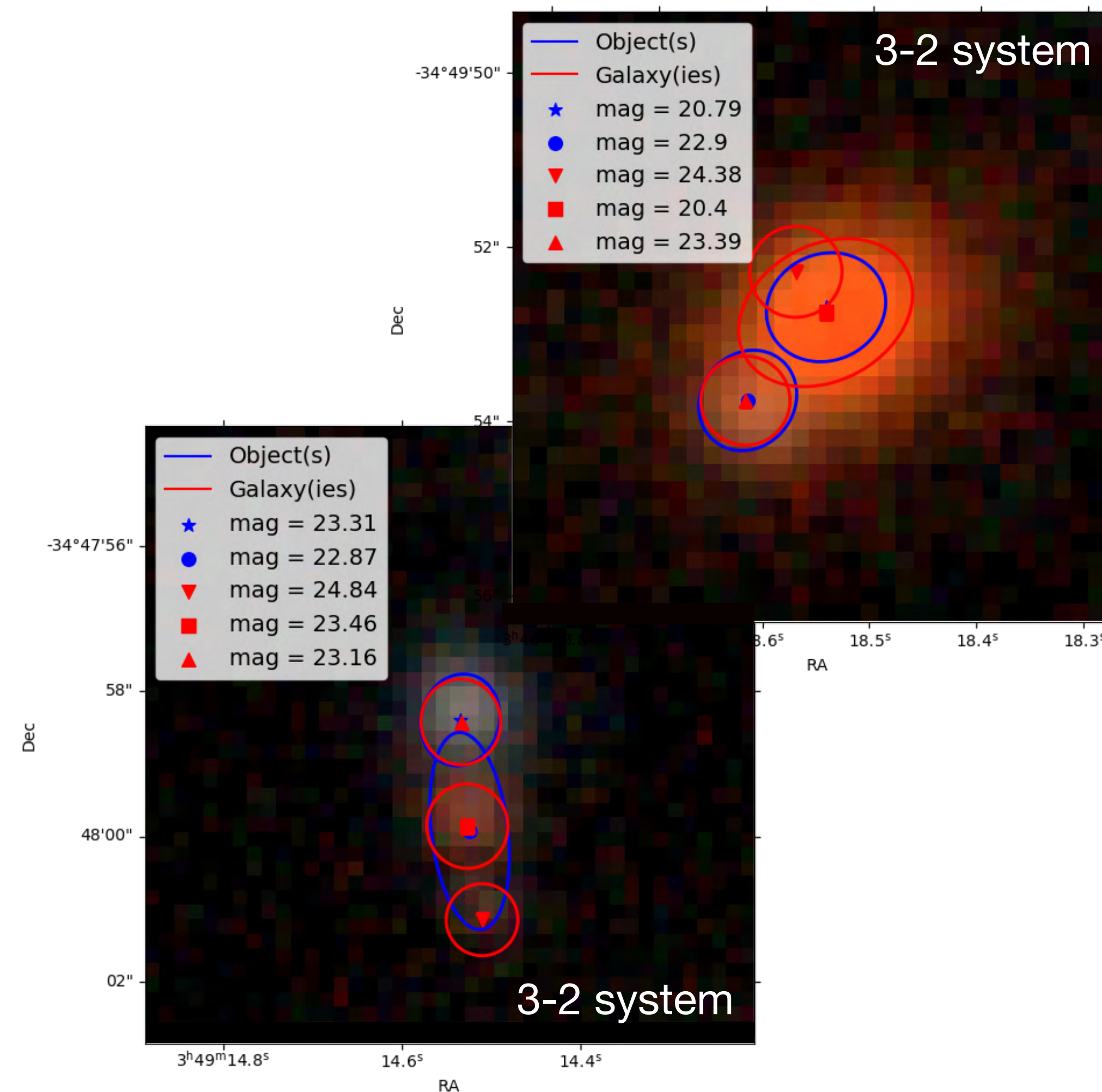
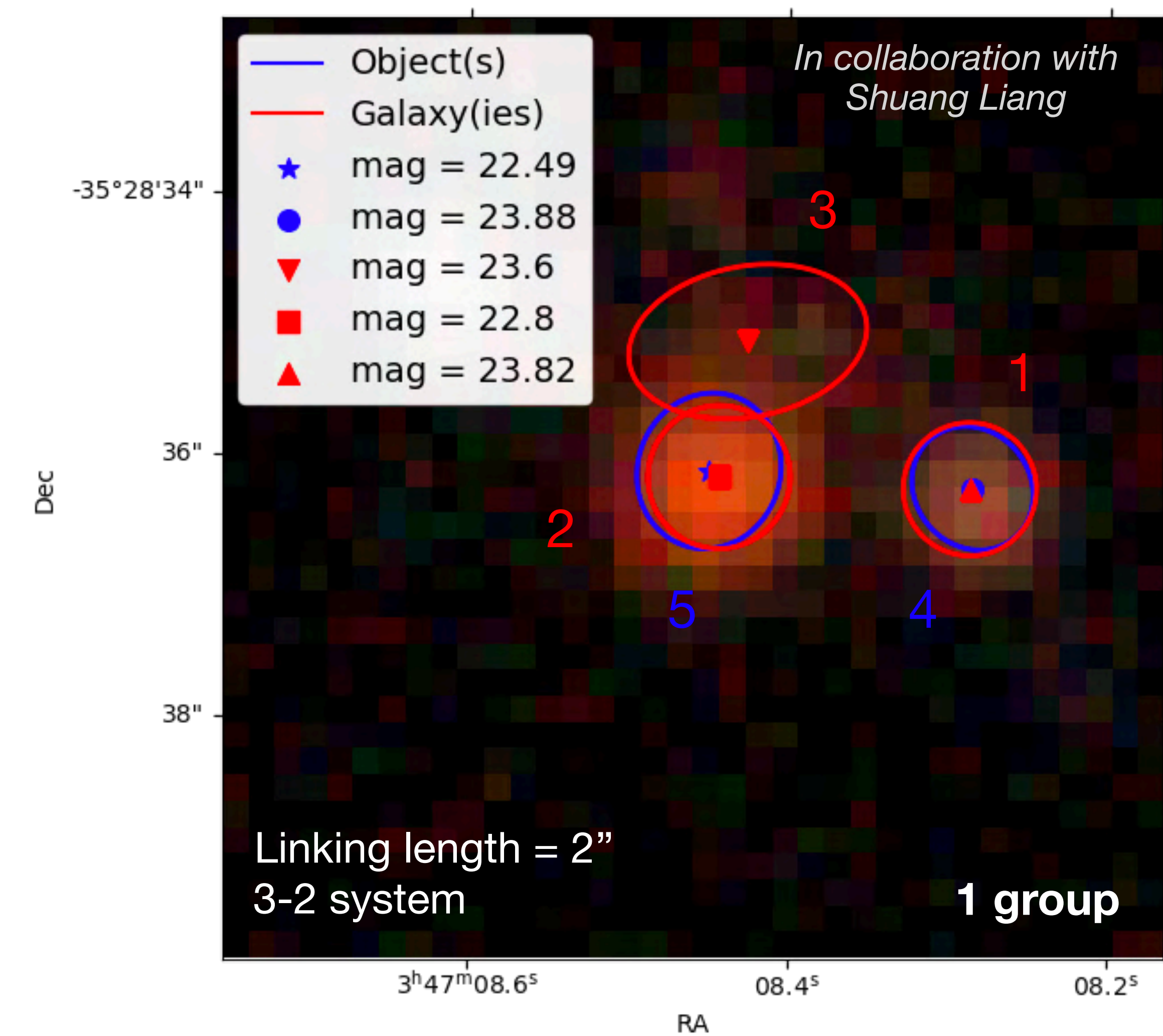
Look at FoF groups

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



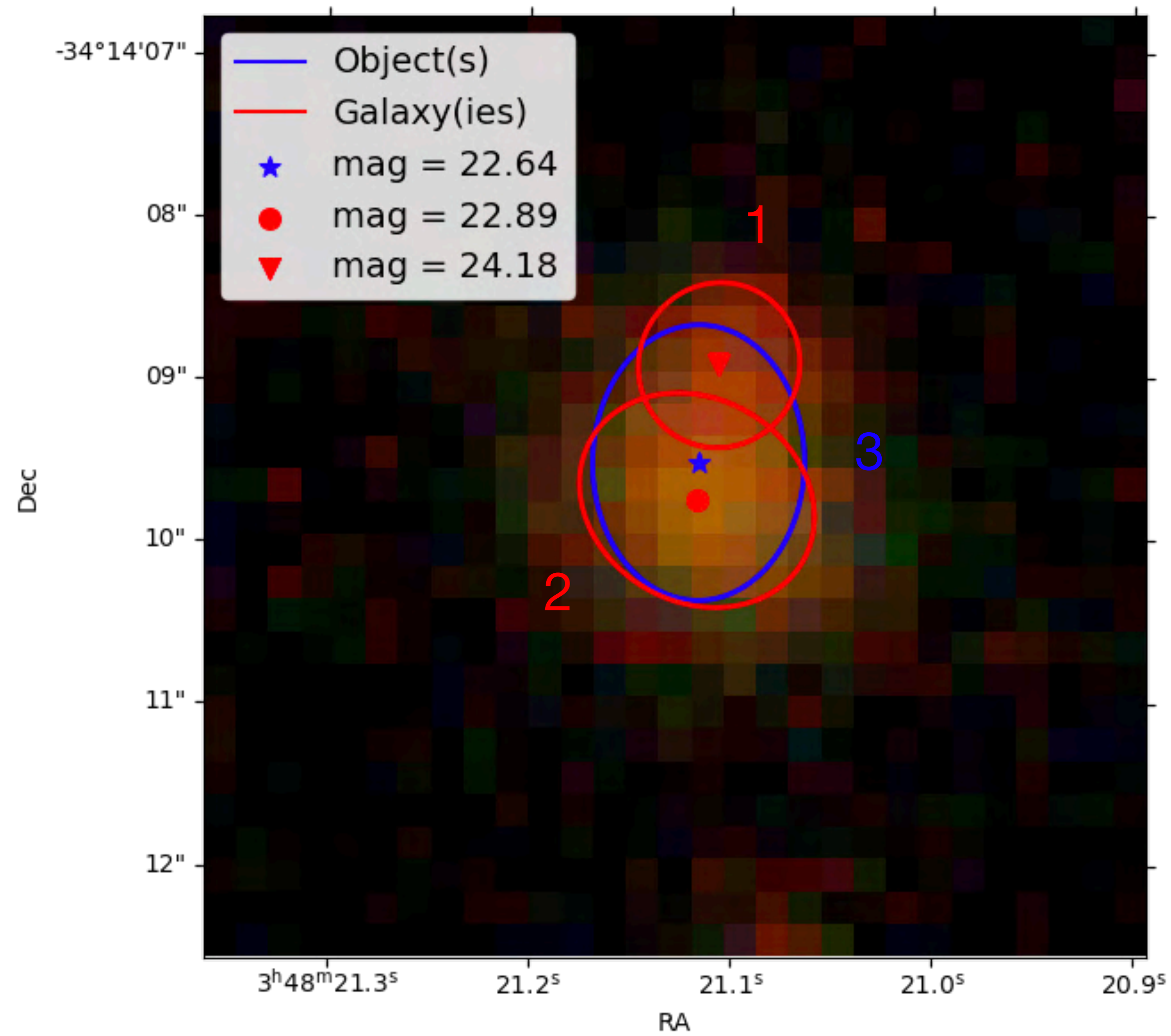
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<https://github.com/LSSTDESC/friendly>
https://github.com/LSSTDESC/Cluster_Bleeding



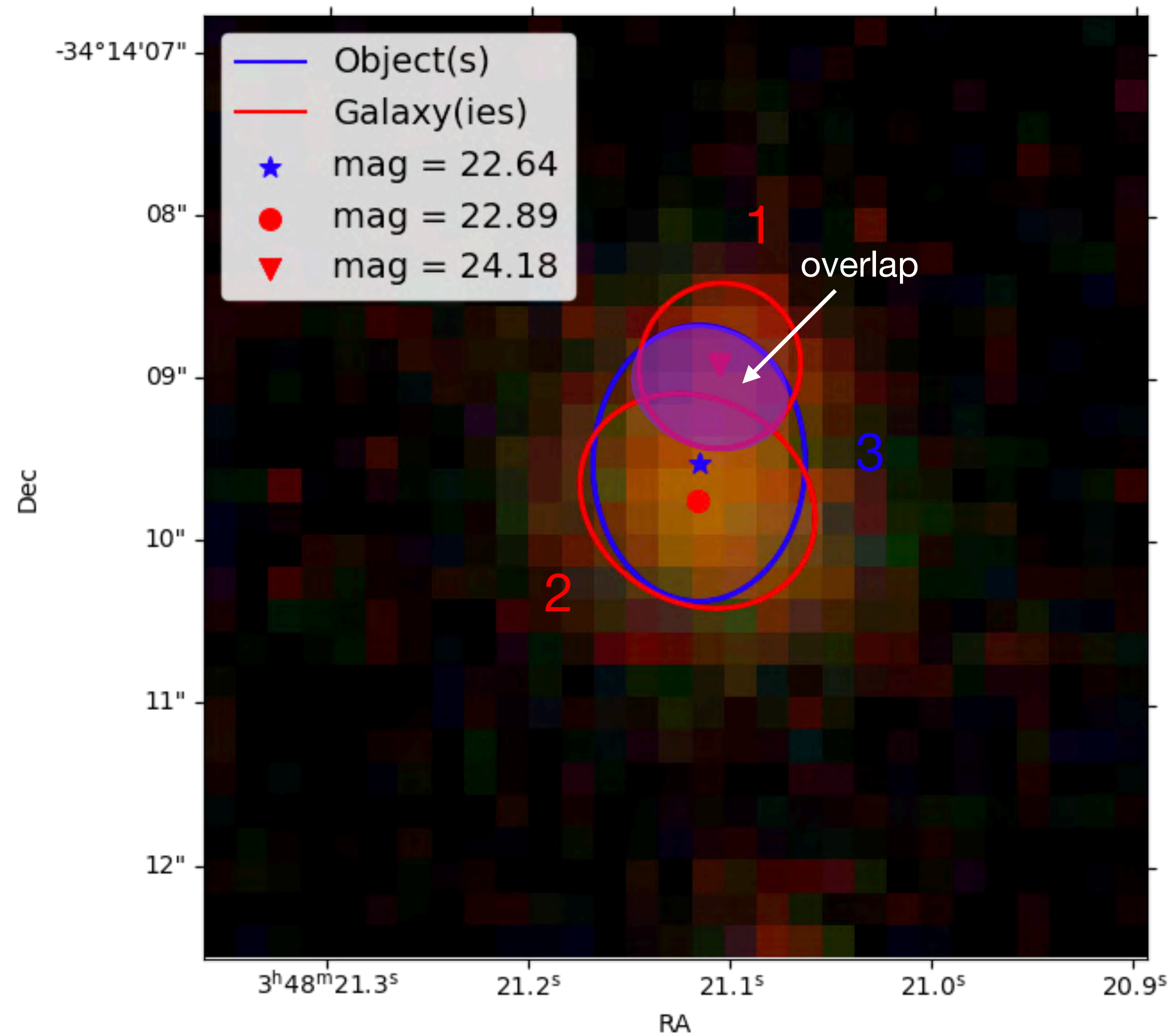
Need to account for position + shape + flux information

Blending as a matching ambiguity



Object-Galaxy matching probability

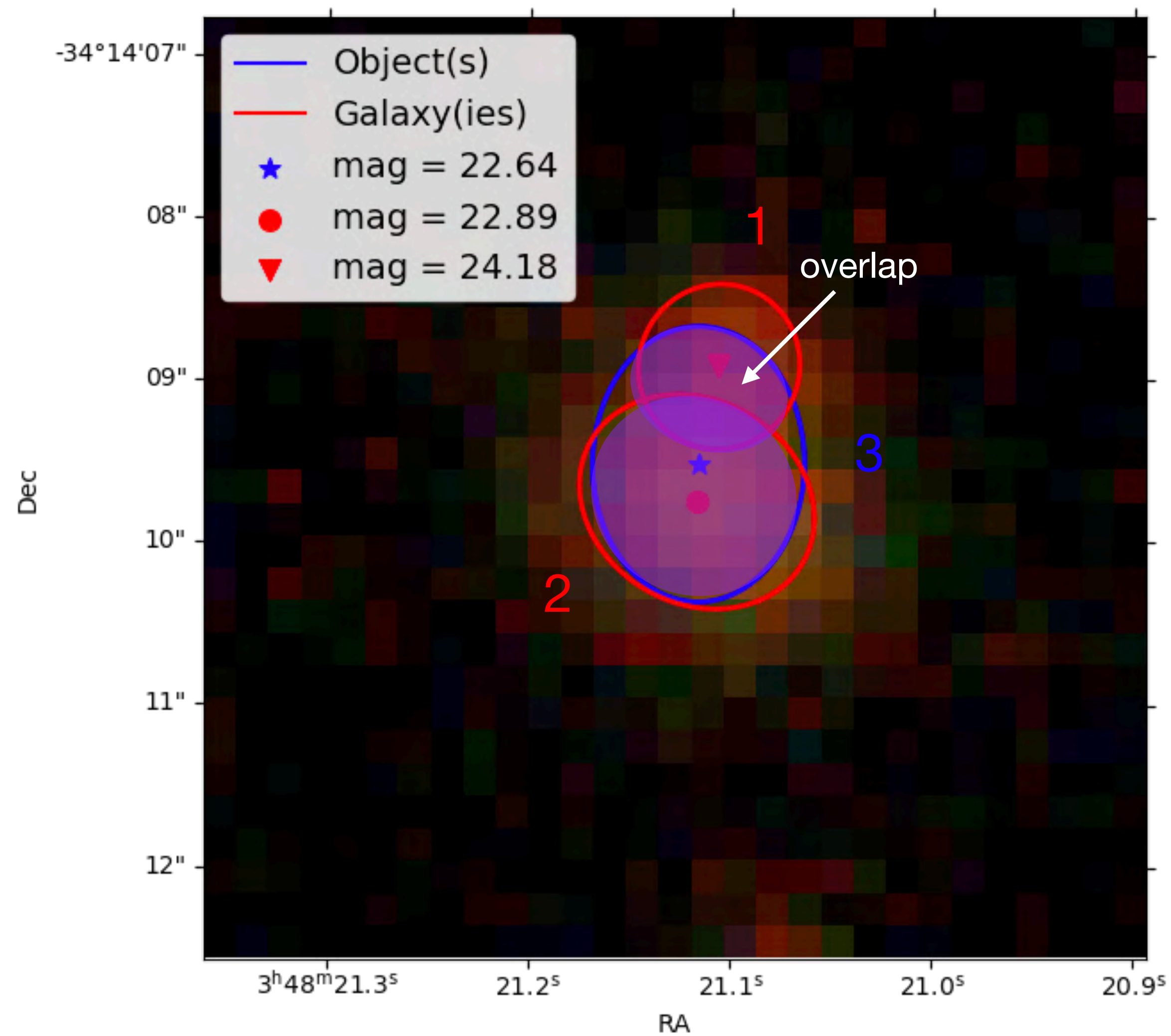
Blending as a matching ambiguity



Object-Galaxy matching probability

$p \propto \text{overlap}$ weighted by the difference in $\begin{cases} \text{magnitudes} \\ \text{colors} \end{cases}$

Blending as a matching ambiguity



Object-Galaxy matching probability

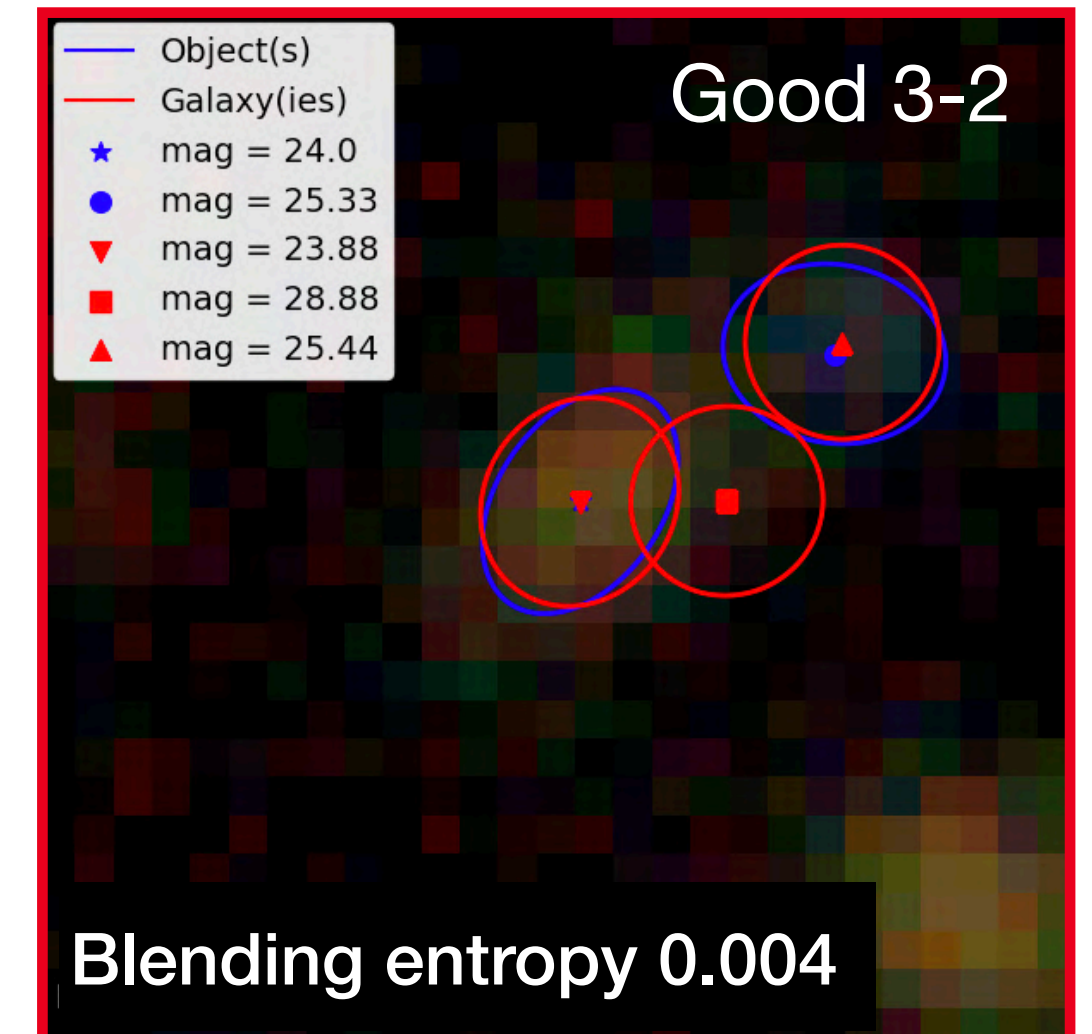
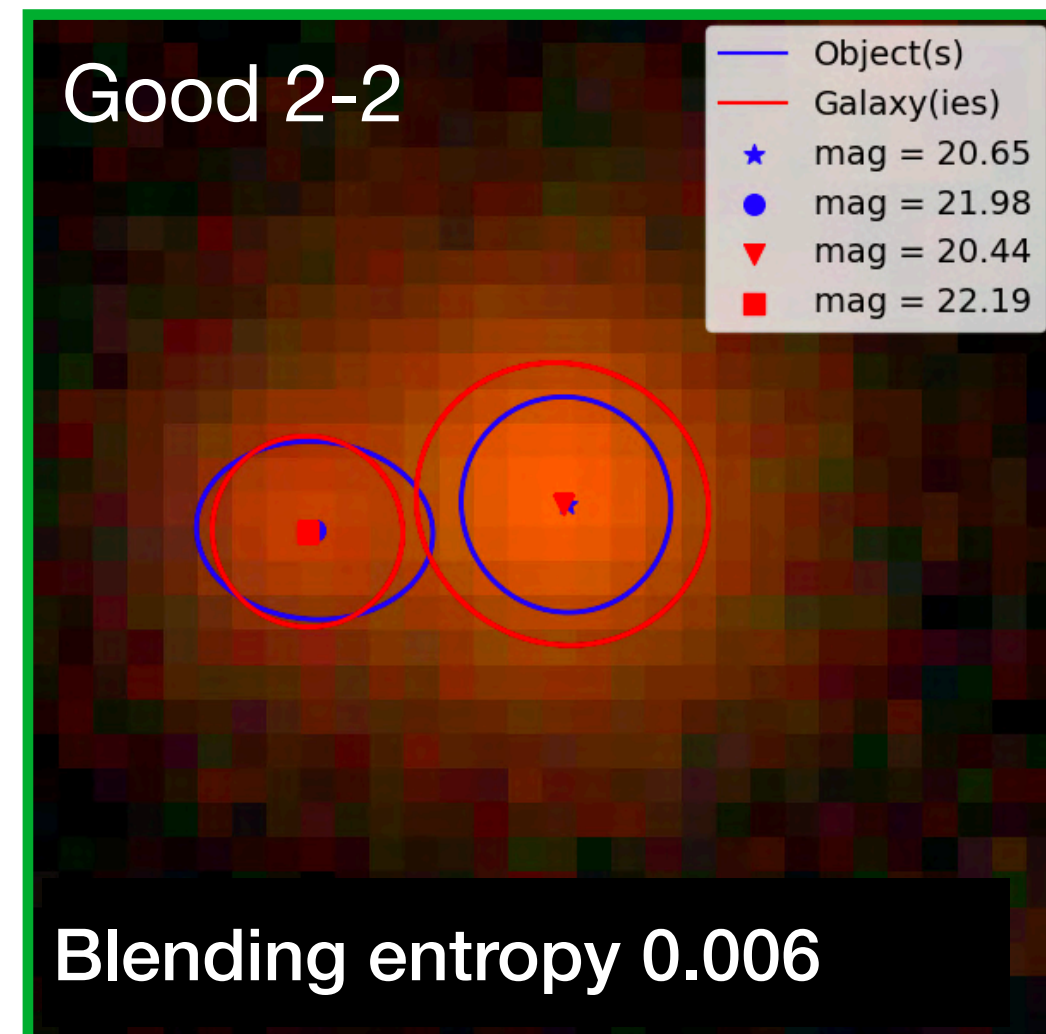
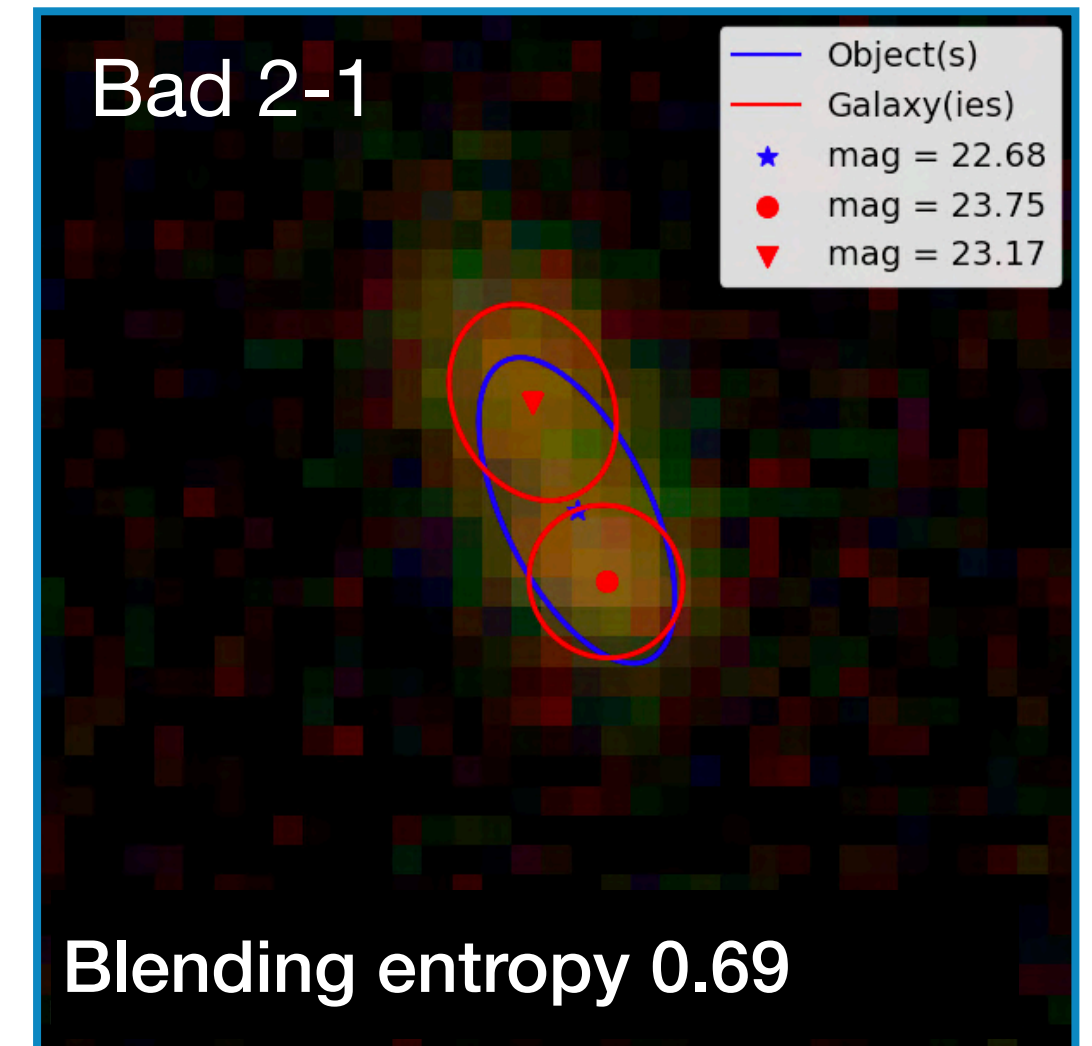
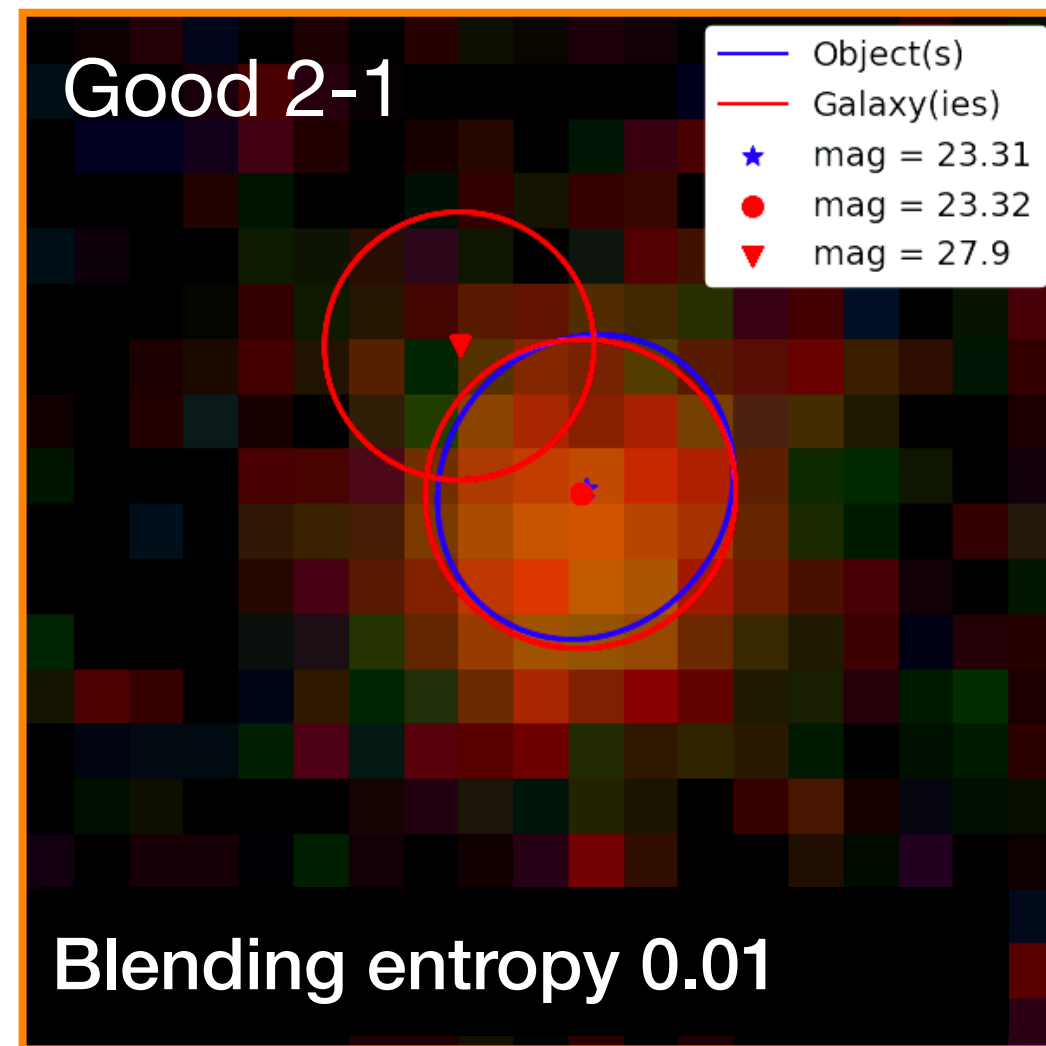
$p \propto \text{overlap}$ weighted by the difference in $\begin{cases} \text{magnitudes} \\ \text{colors} \end{cases}$

Blending entropy

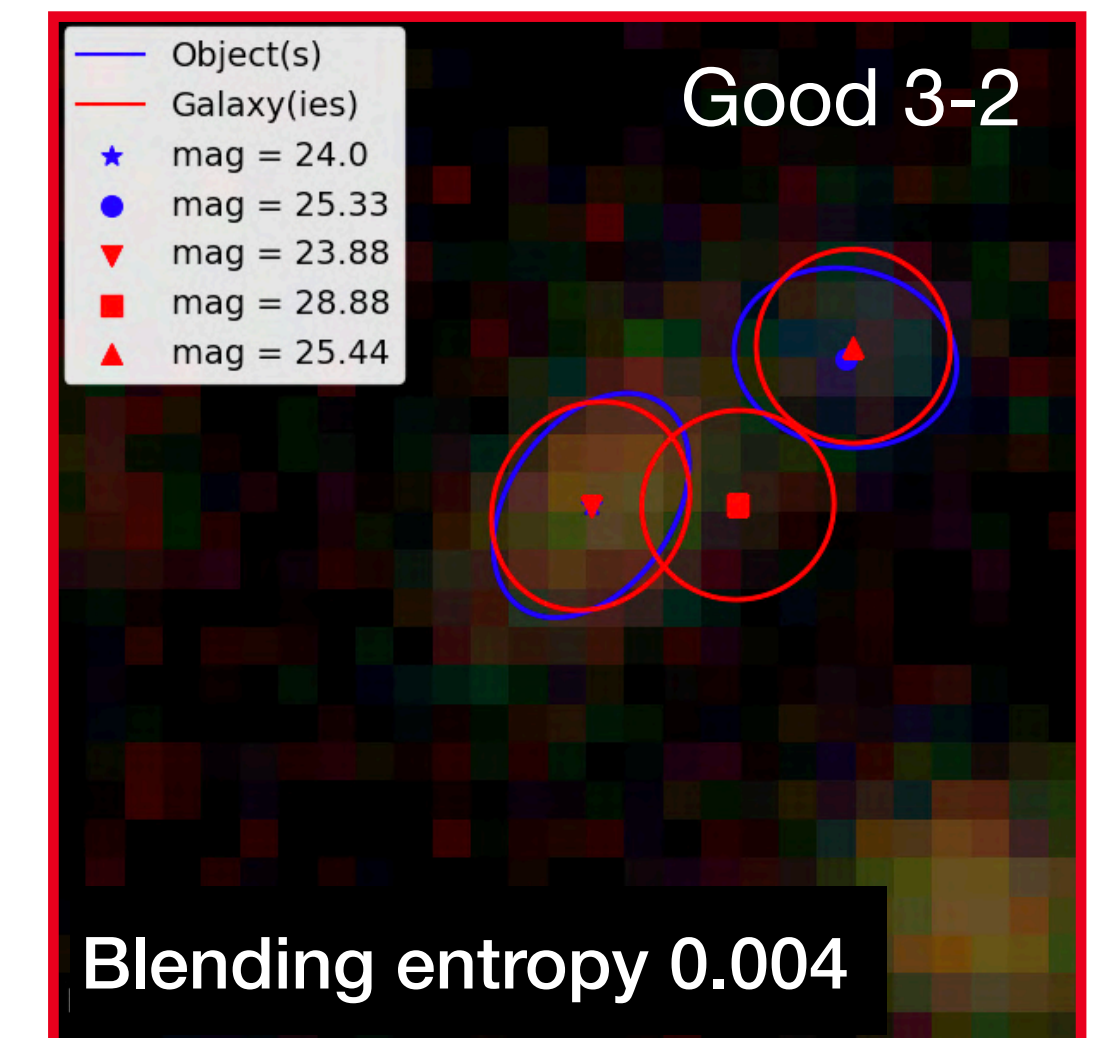
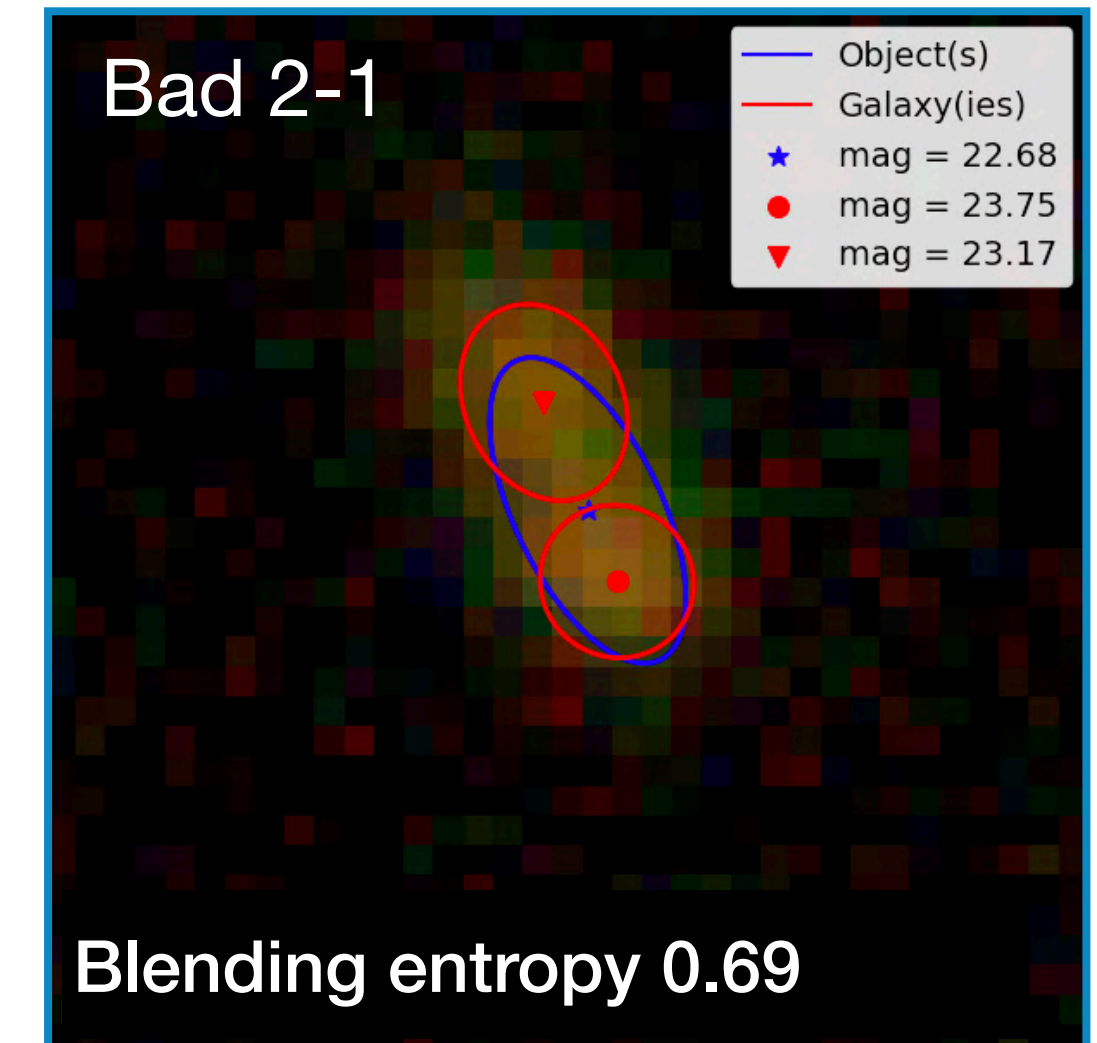
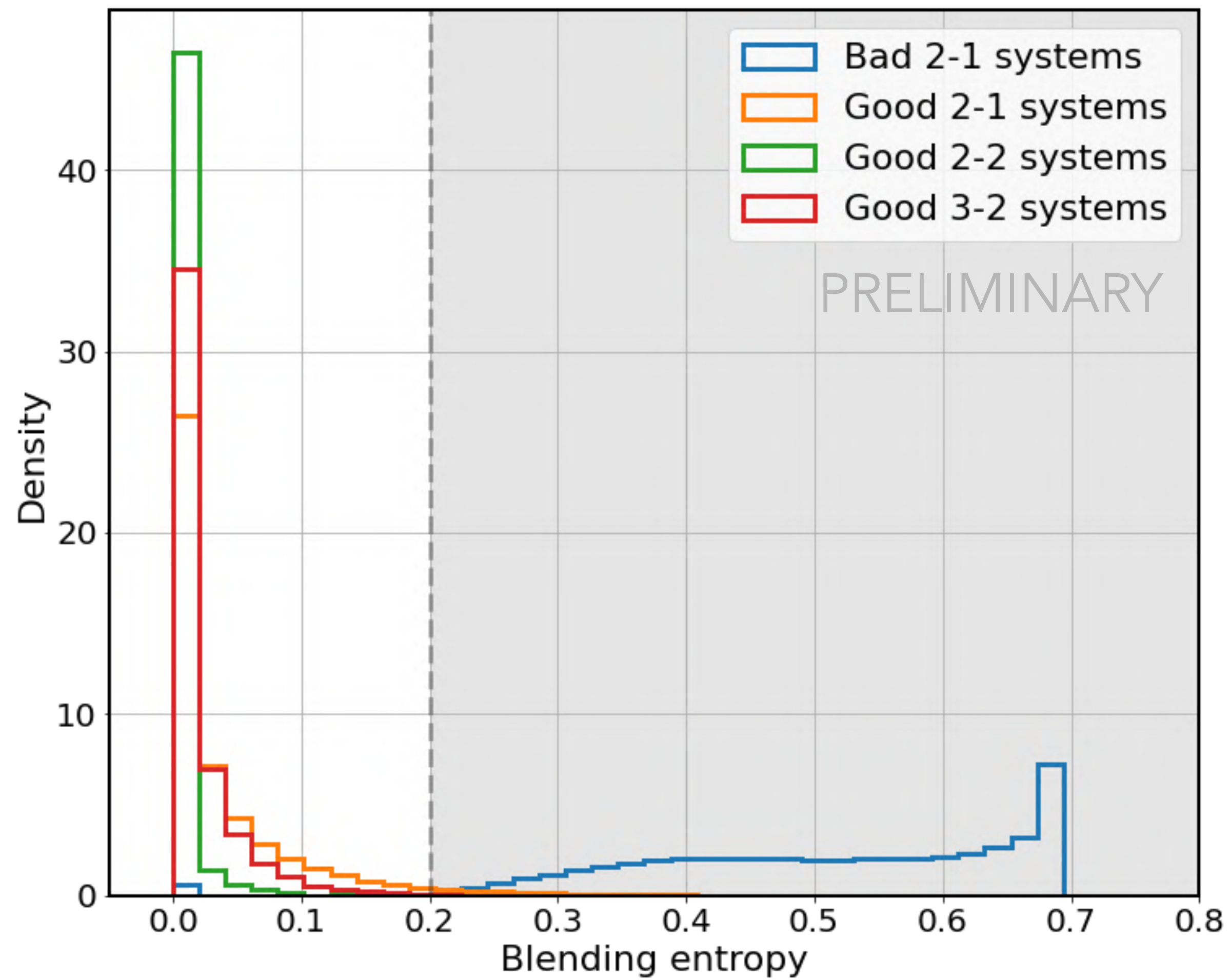
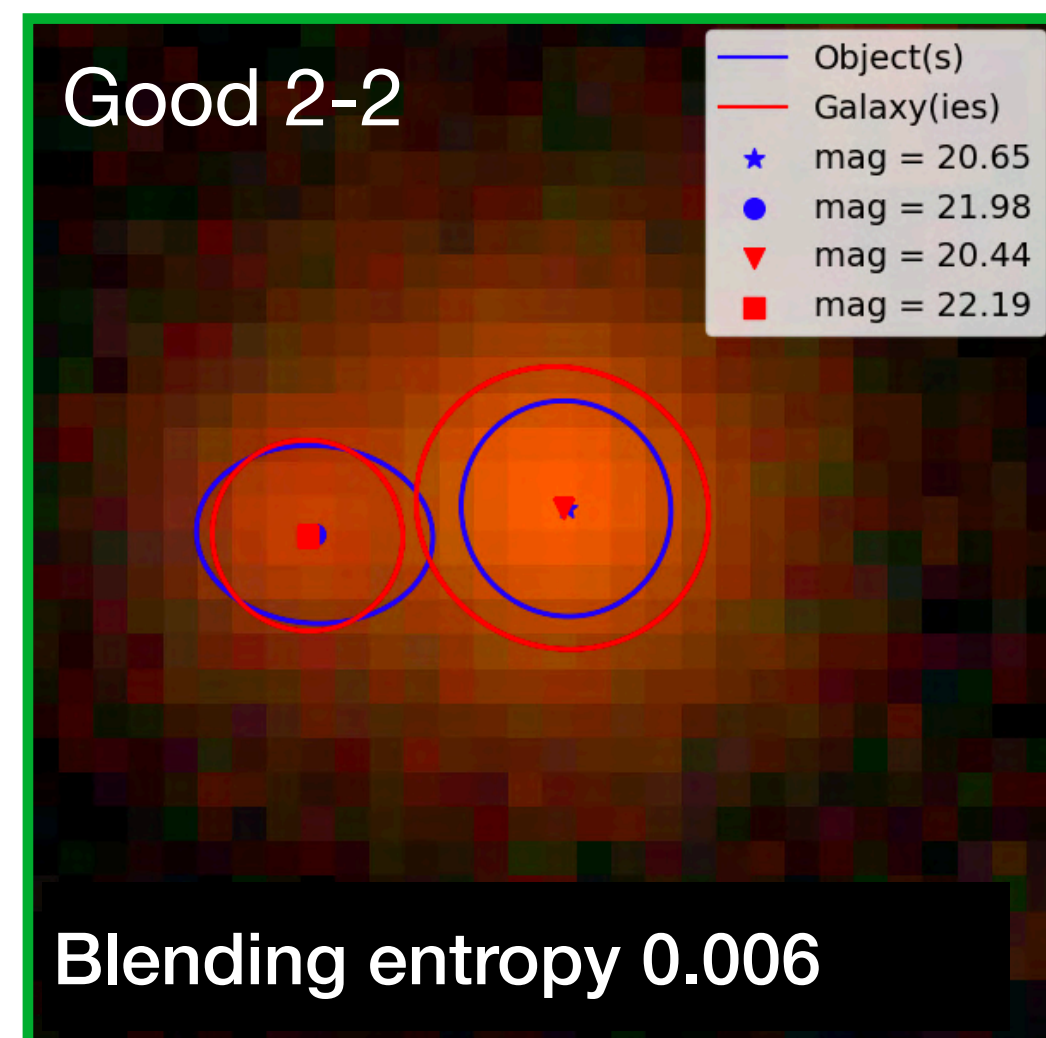
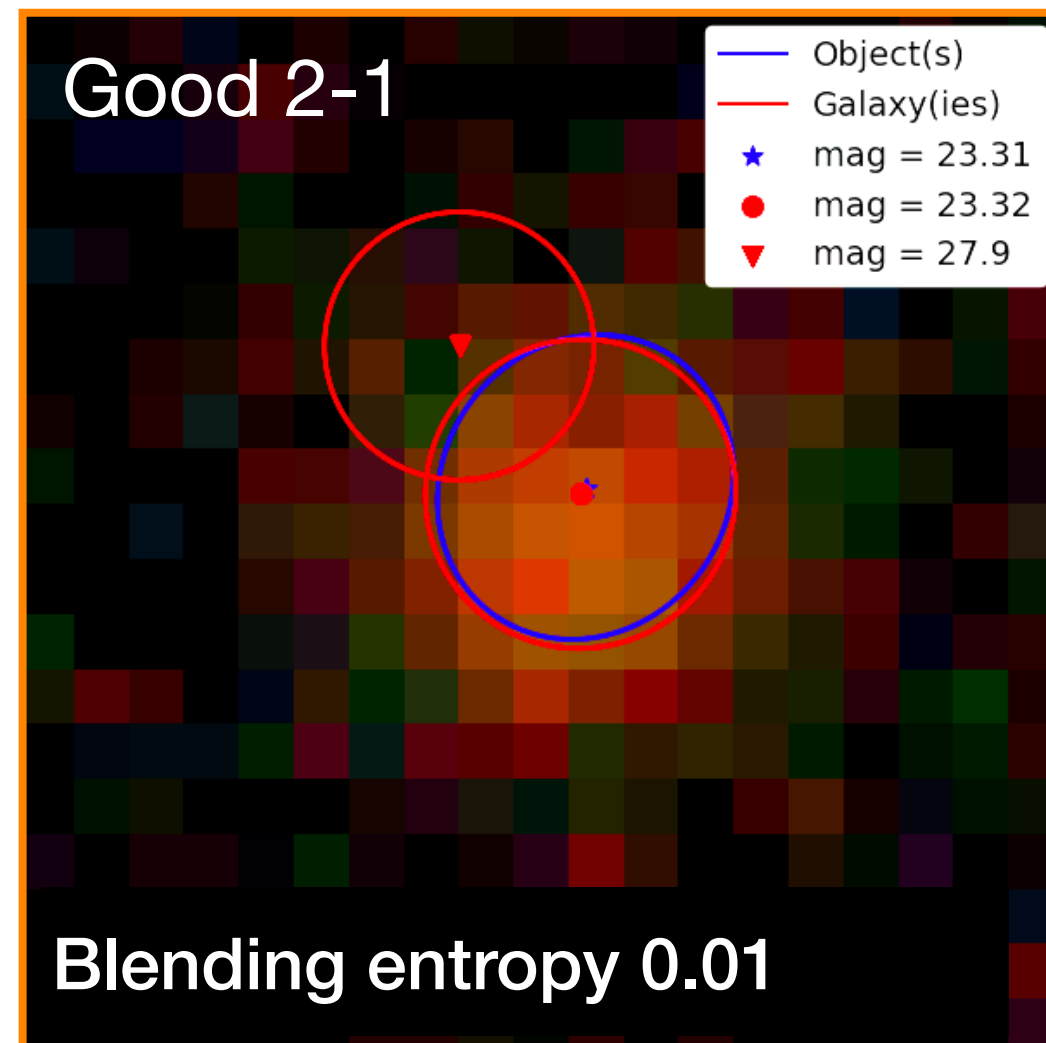
$$S_b = - \sum_{i \in \text{gal}} p_i \log p_i = \text{score for each object}$$

* $S_b = 0$ for 1-1 systems

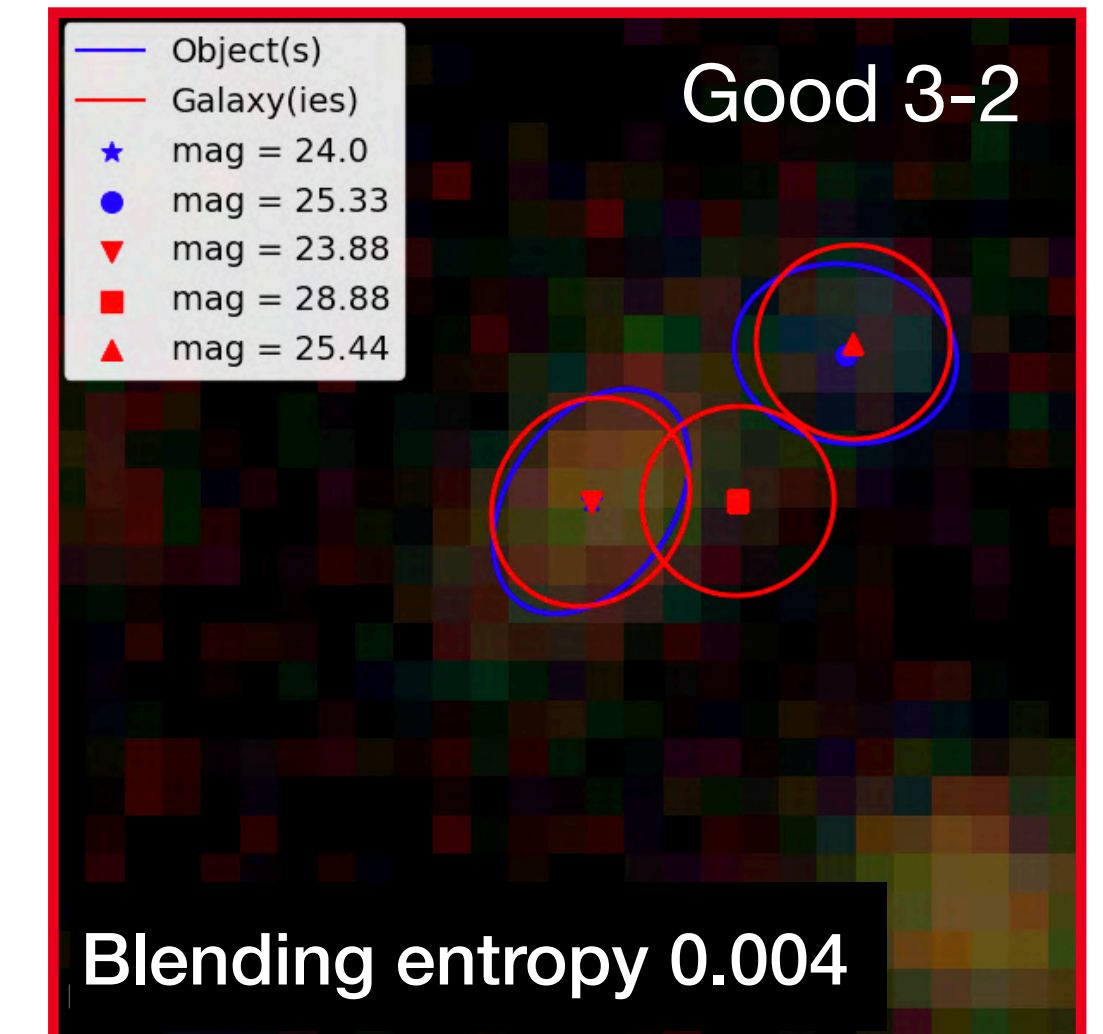
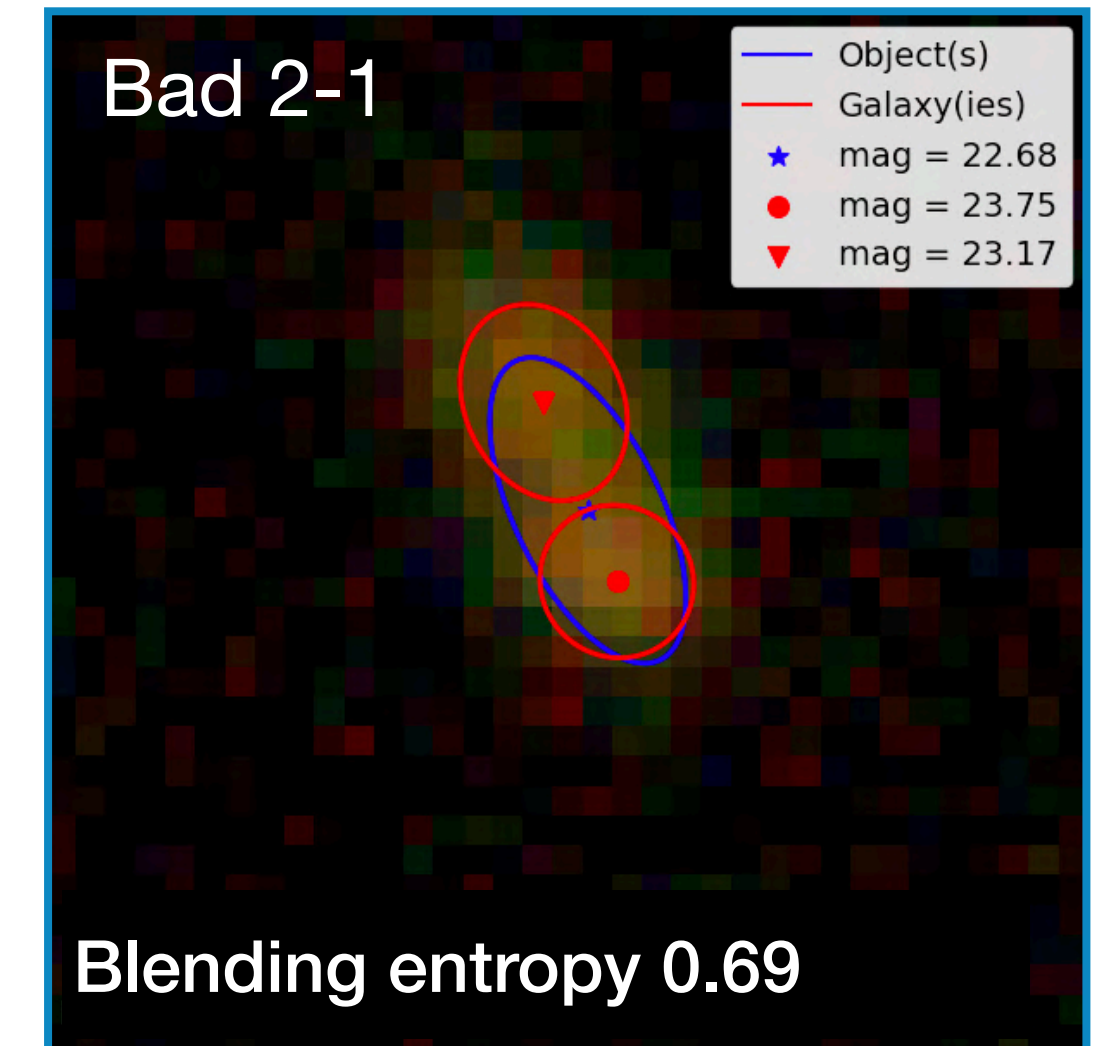
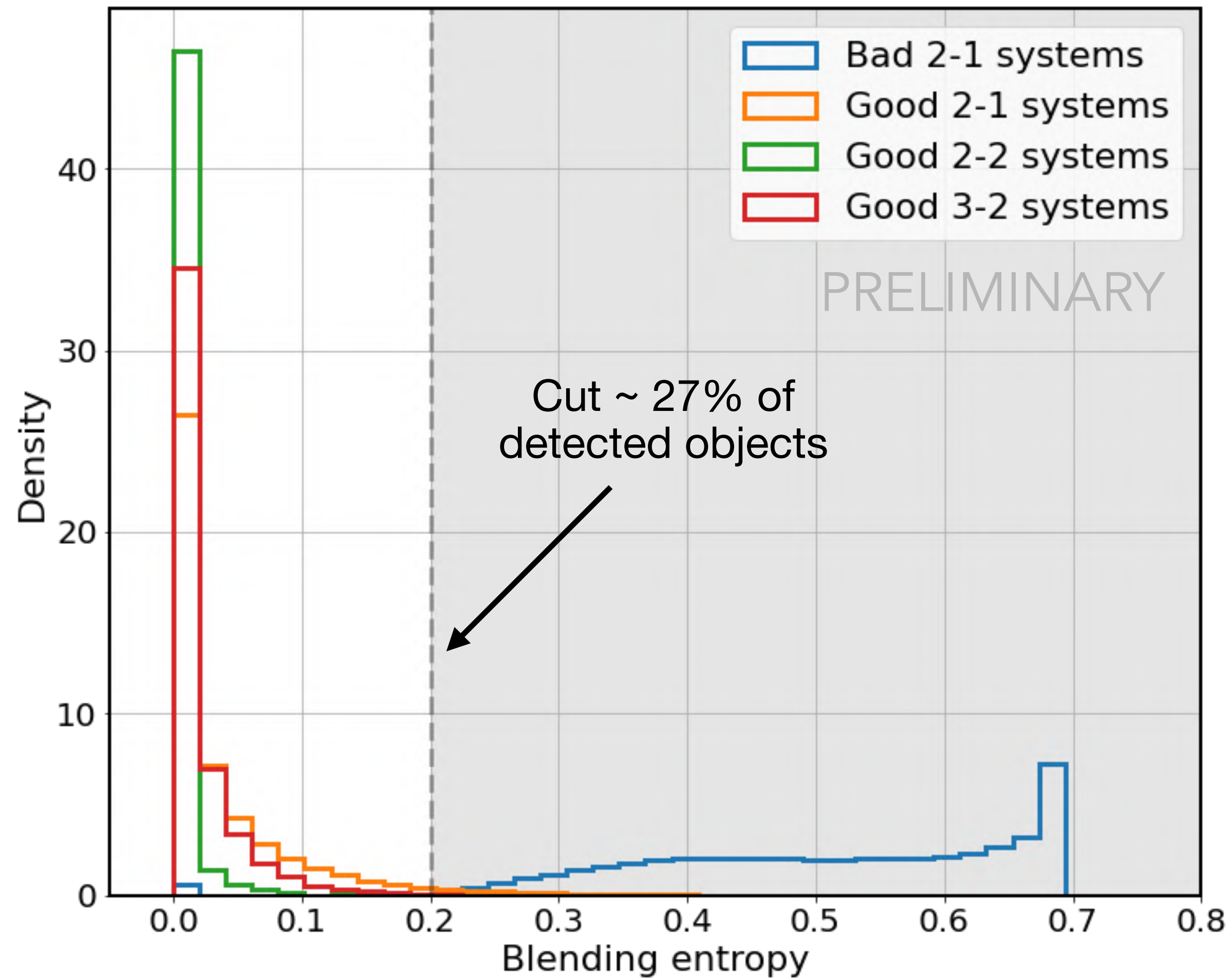
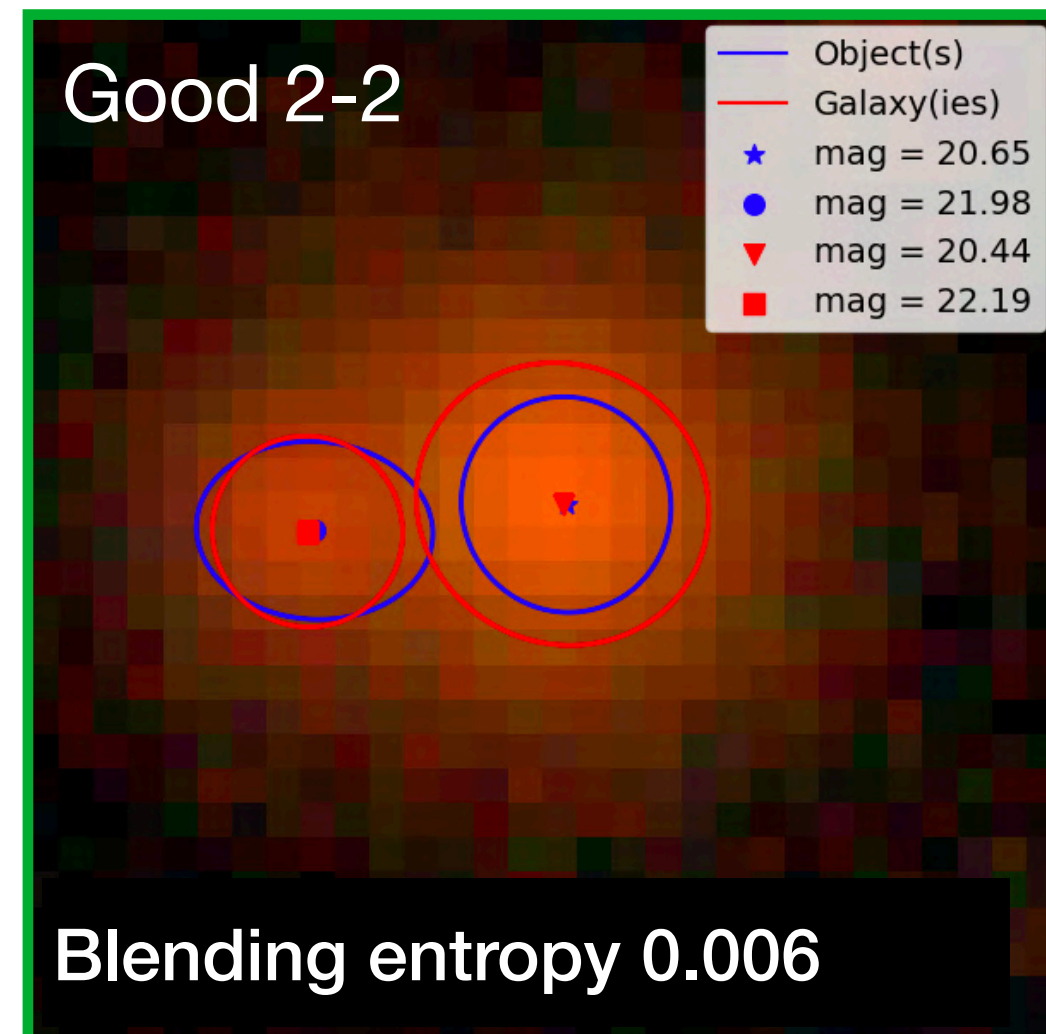
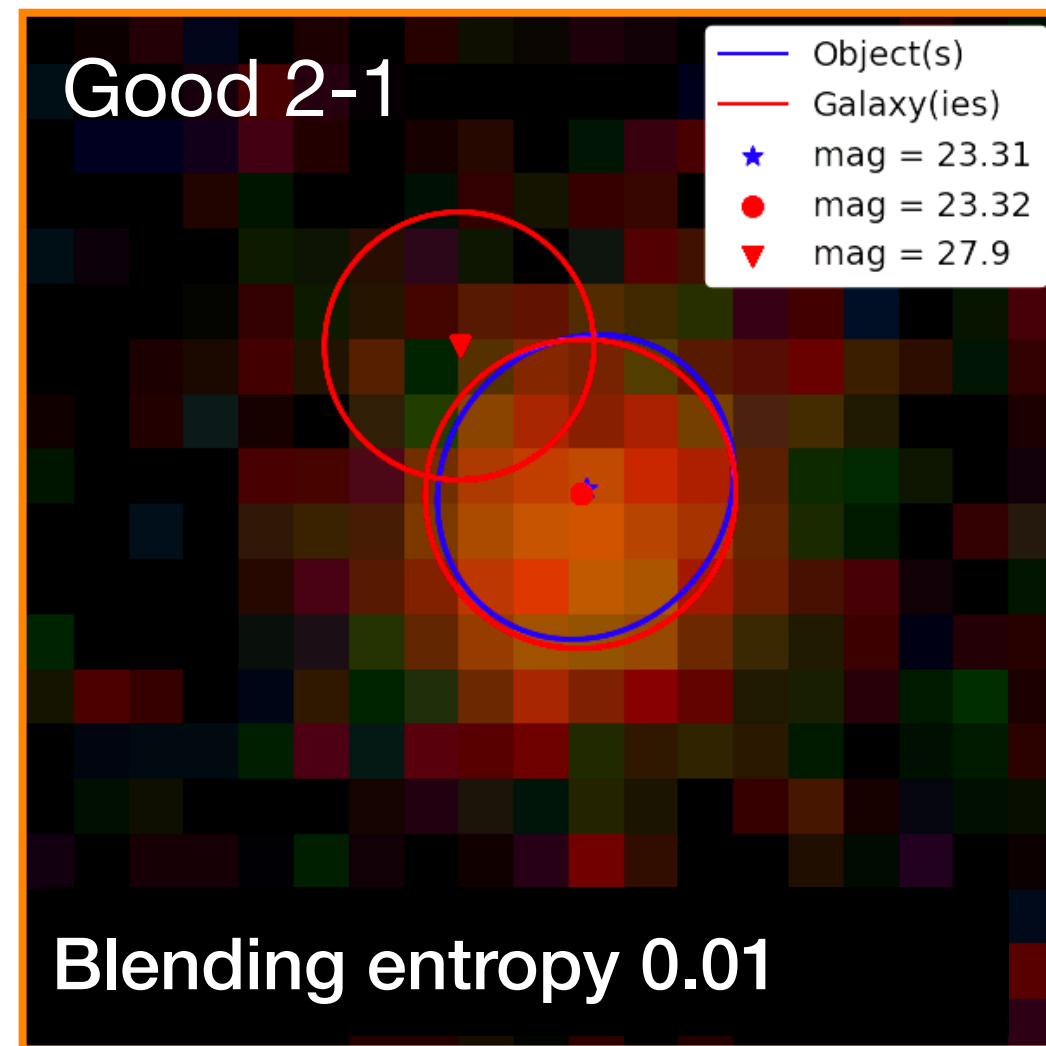
S_b as discriminant of blended systems



S_b as discriminant of blended systems

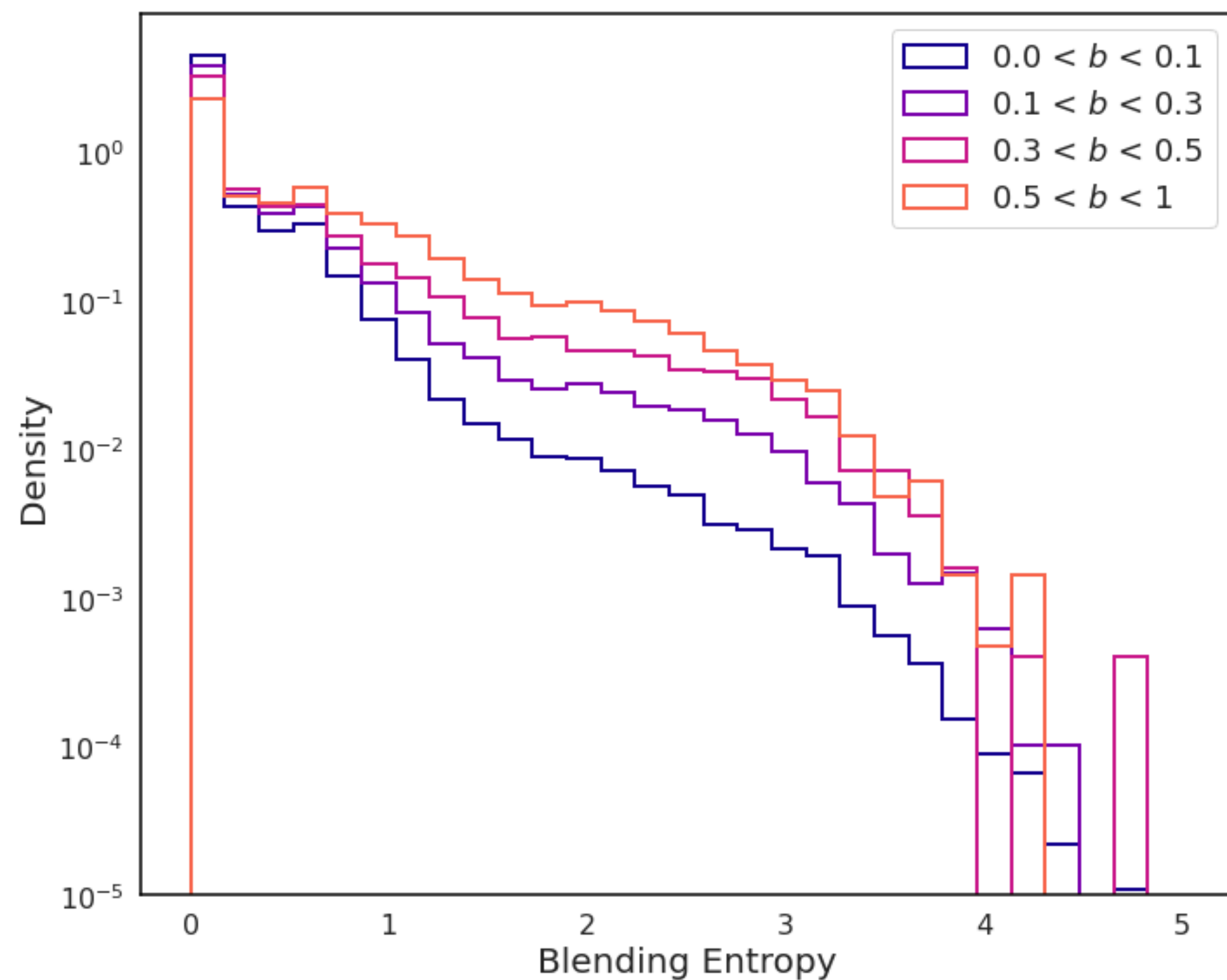


S_b as discriminant of blended systems

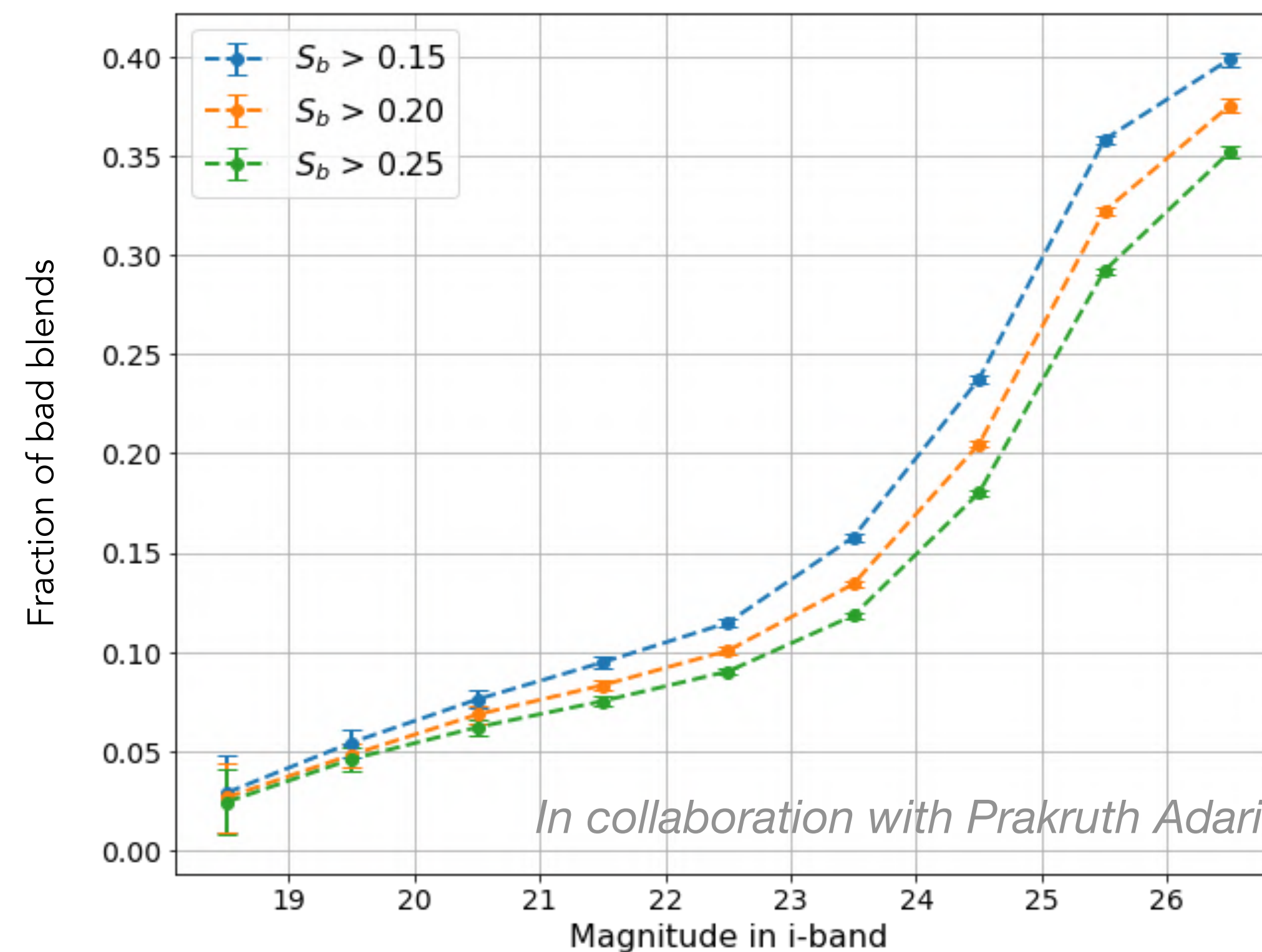


Blending entropy efficiency

Blending entropy vs. blendedness b



Fraction of *bad* blends increases with magnitude



New efficient metric to characterize blended systems

A photograph of an astronomical observatory on a mountain peak at sunset. The sky is a gradient of orange and blue, with a bright sun low on the horizon. The observatory building is white with a dark dome. The foreground shows the rocky terrain of the mountain.

Application to cluster cosmology

Framework

Set-up

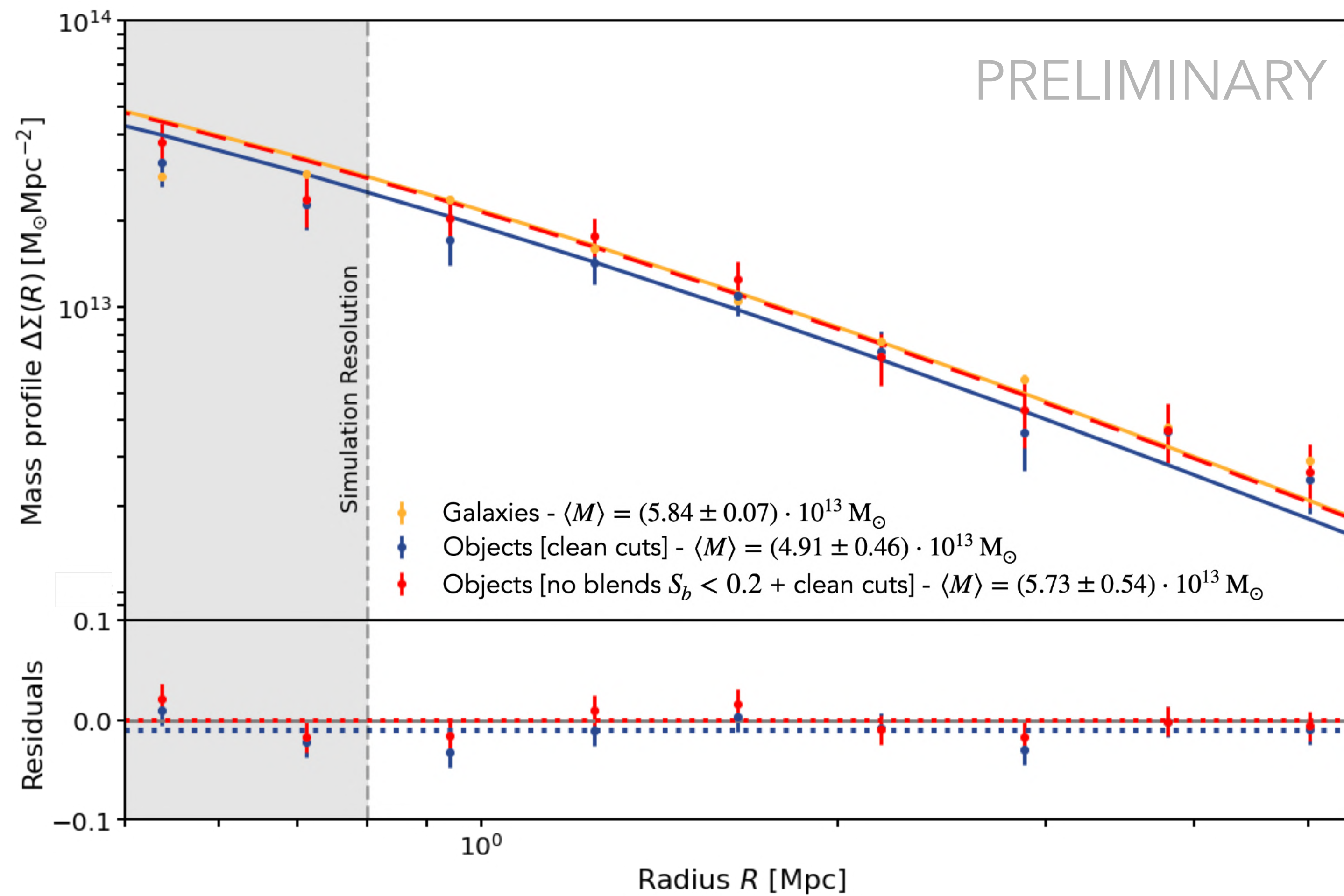
- Lensing around DC2 **dark matter haloes**
 - No detection of galaxy clusters
- Sampling fiducial $M - \lambda$ relation

Goal

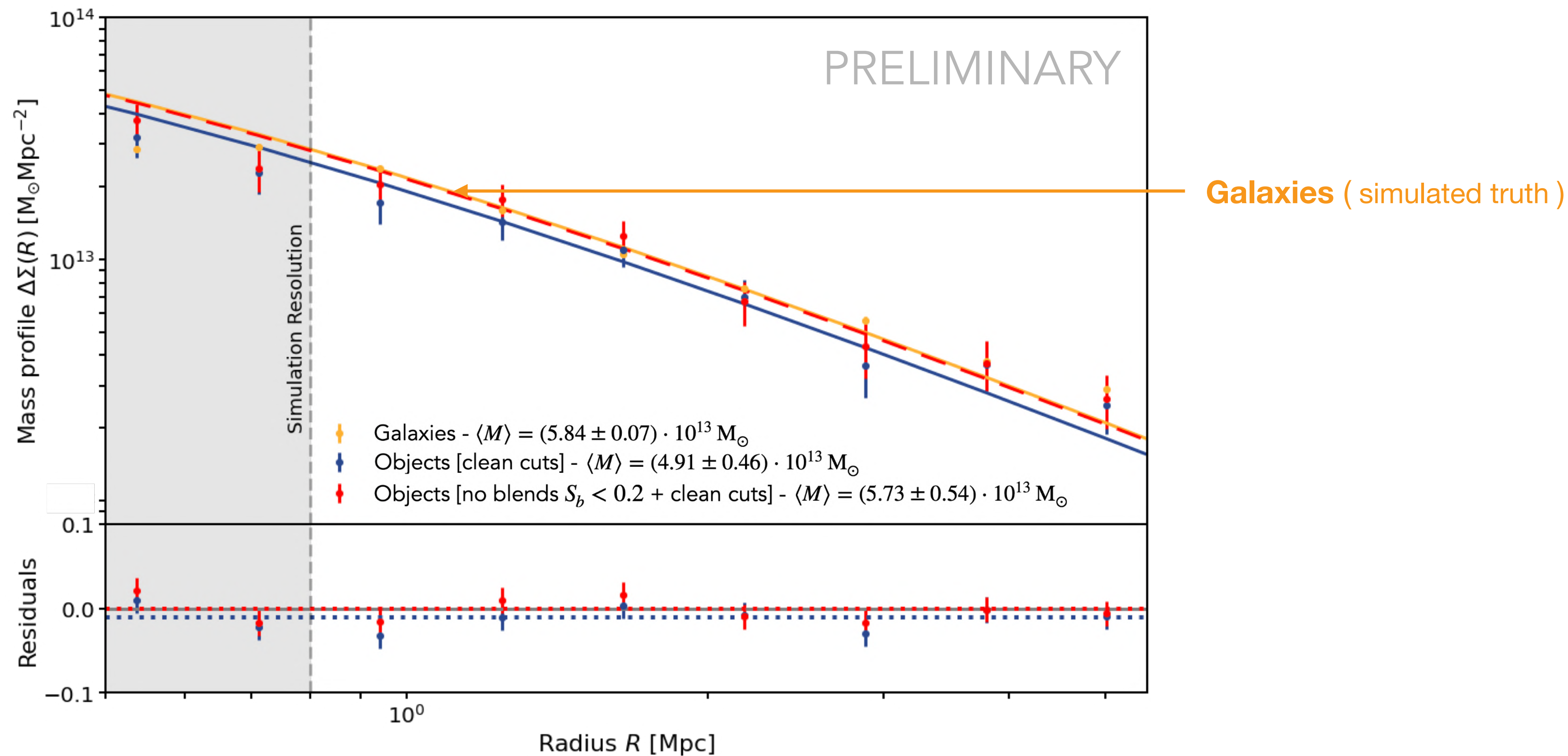
- Two observables per bins of richness and redshift
 - Haloes **number** and mean **mass**



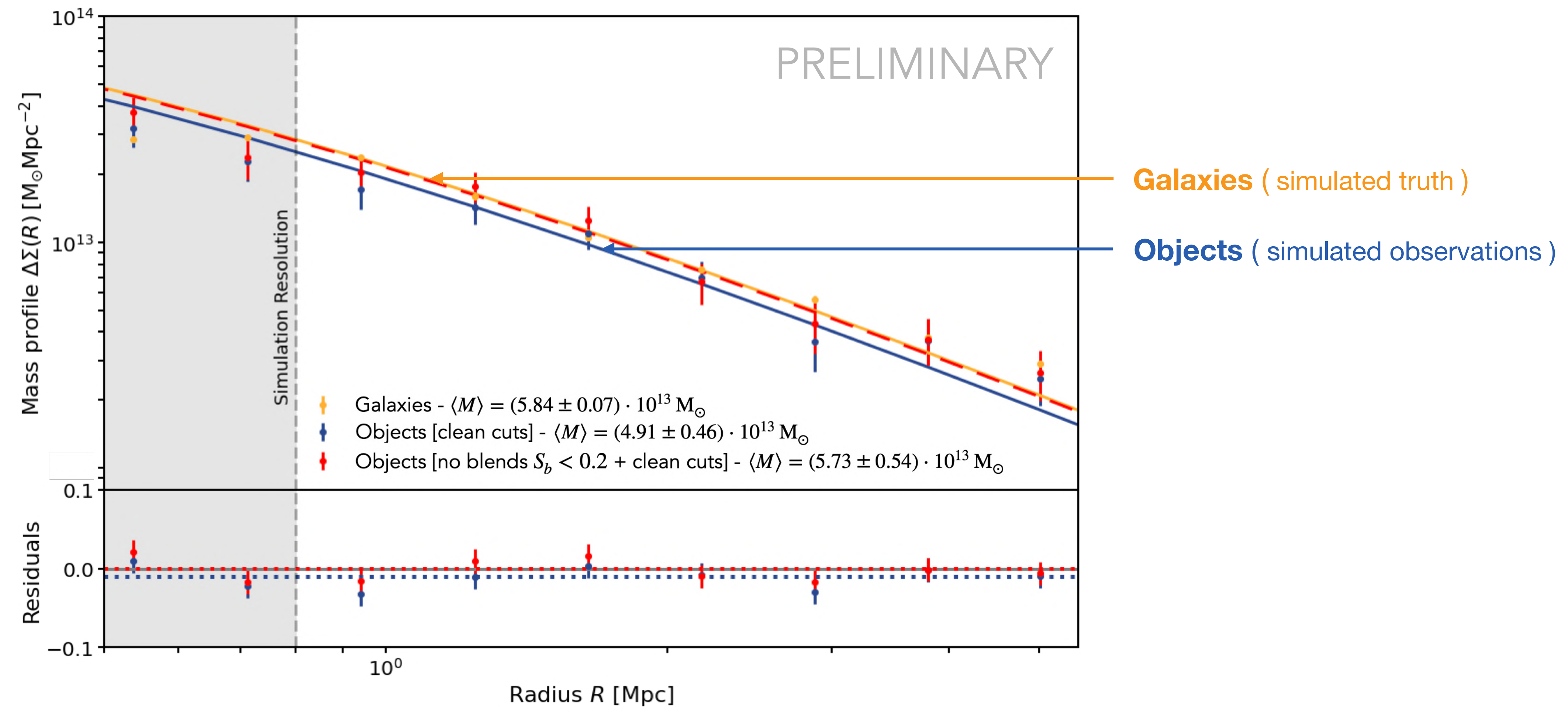
Impact of blending on lensing profiles



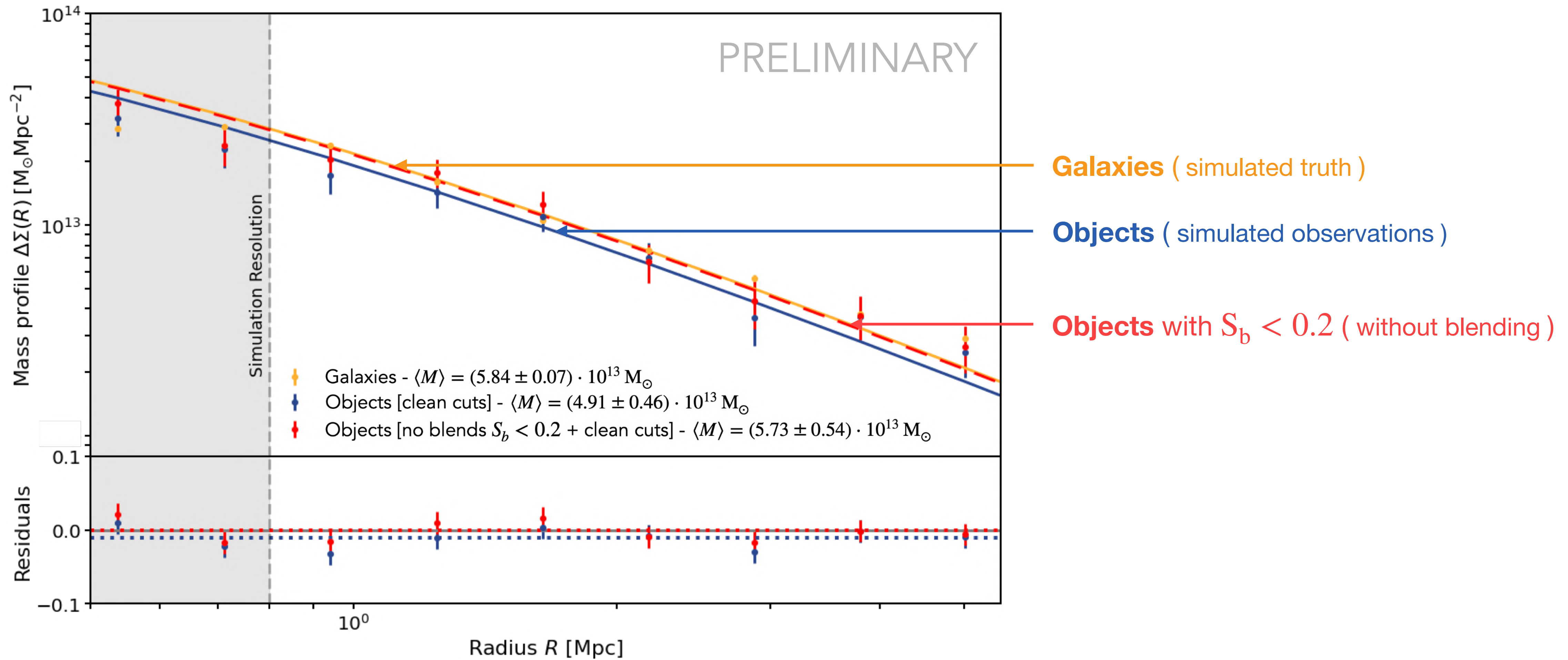
Impact of blending on lensing profiles



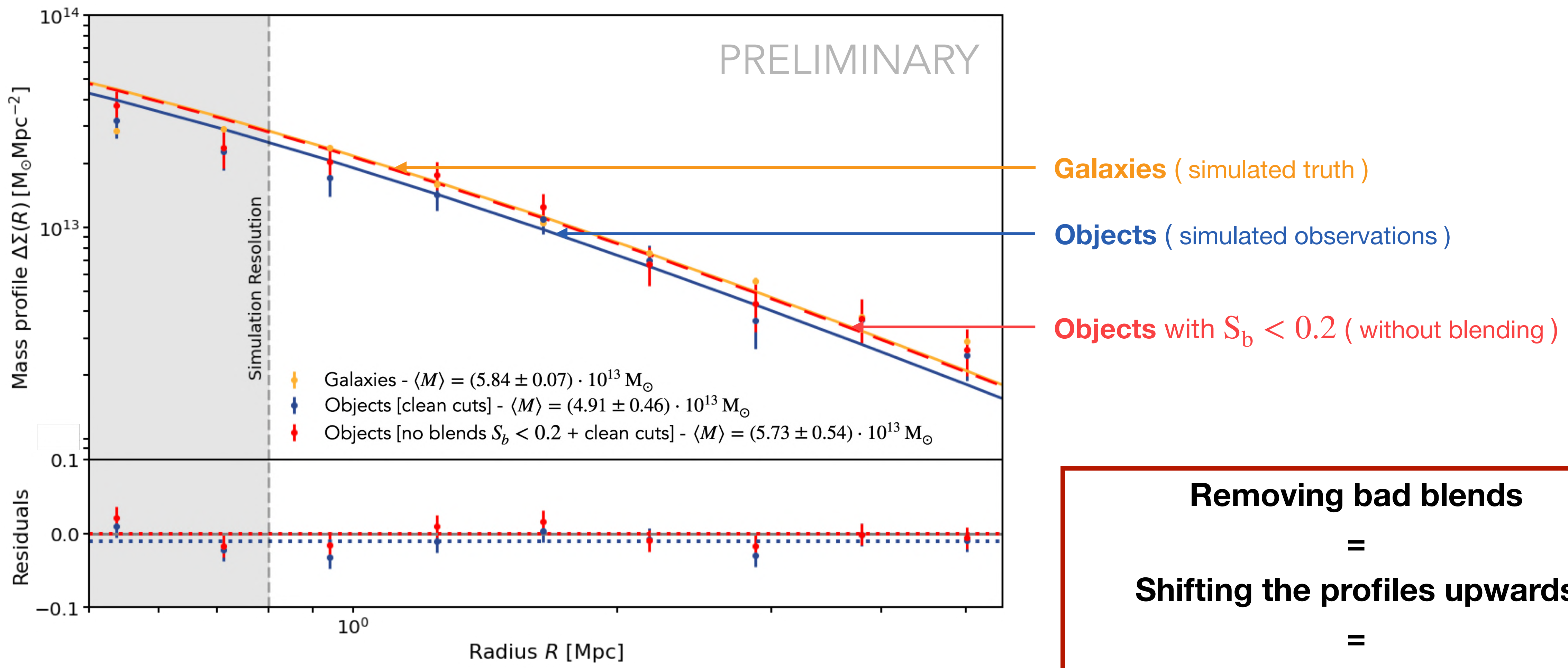
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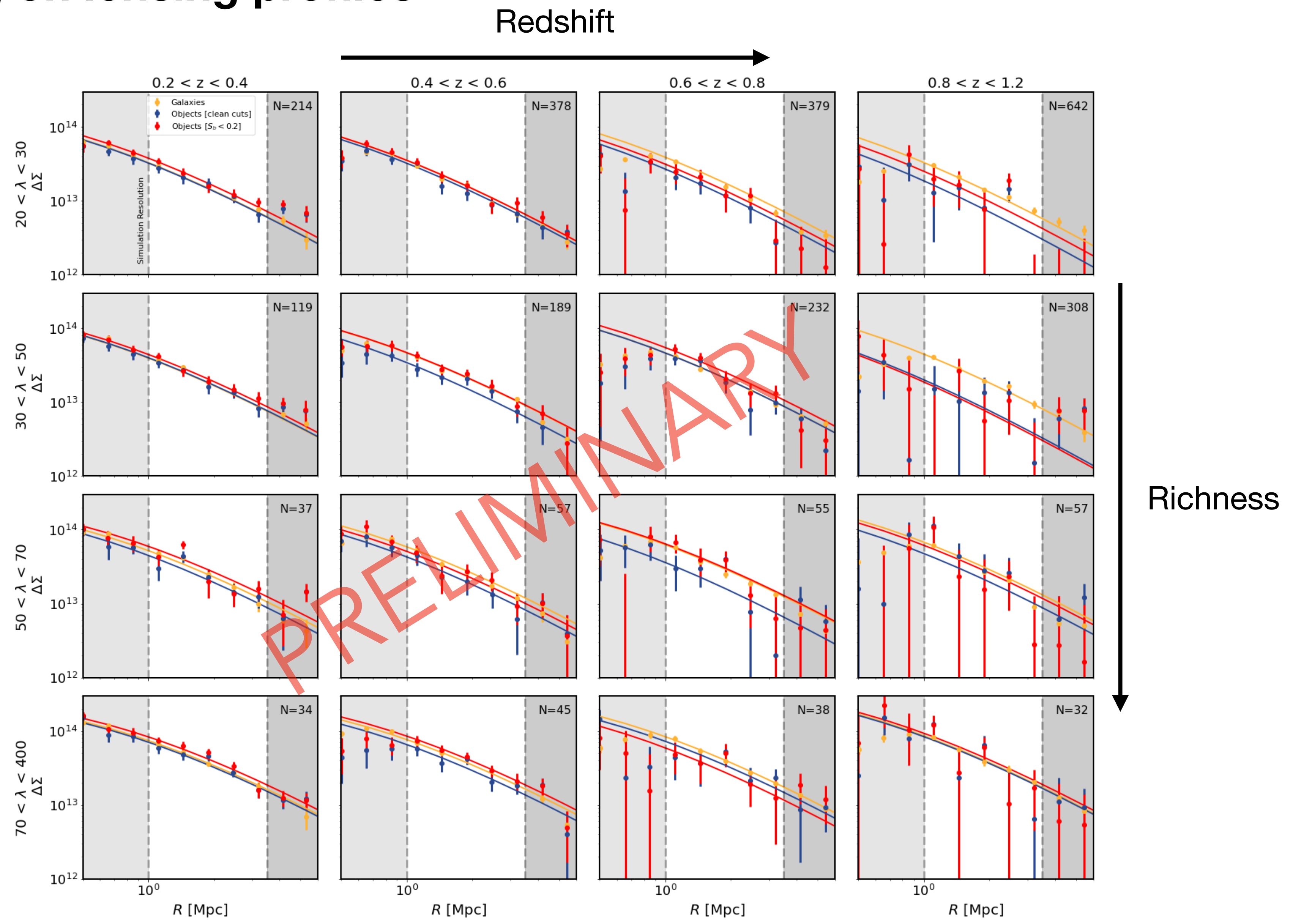


Impact of blending on lensing profiles



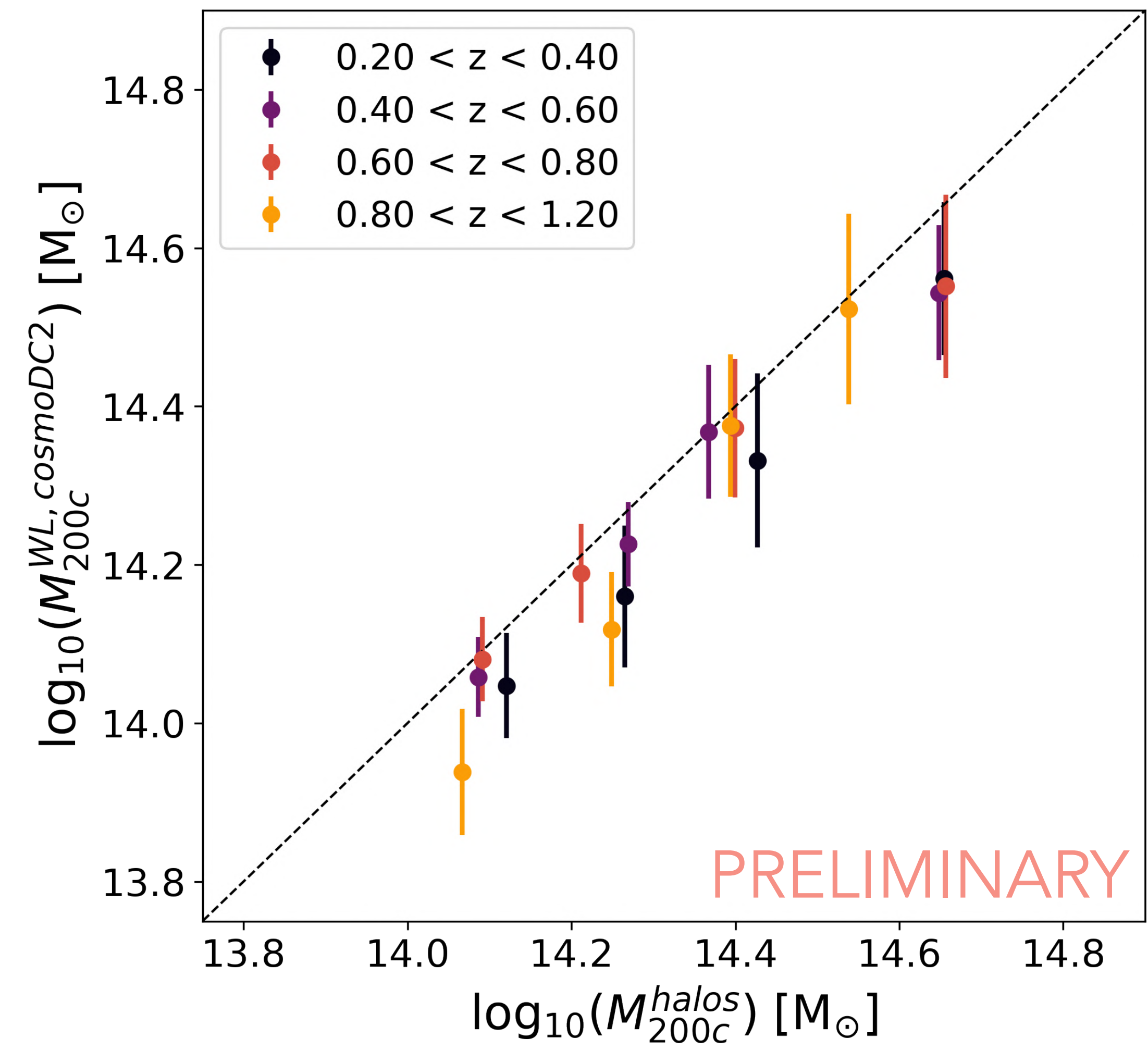
Removing bad blends
=
Shifting the profiles upwards
=
Recovering the true cluster mass

Impact of blending on lensing profiles



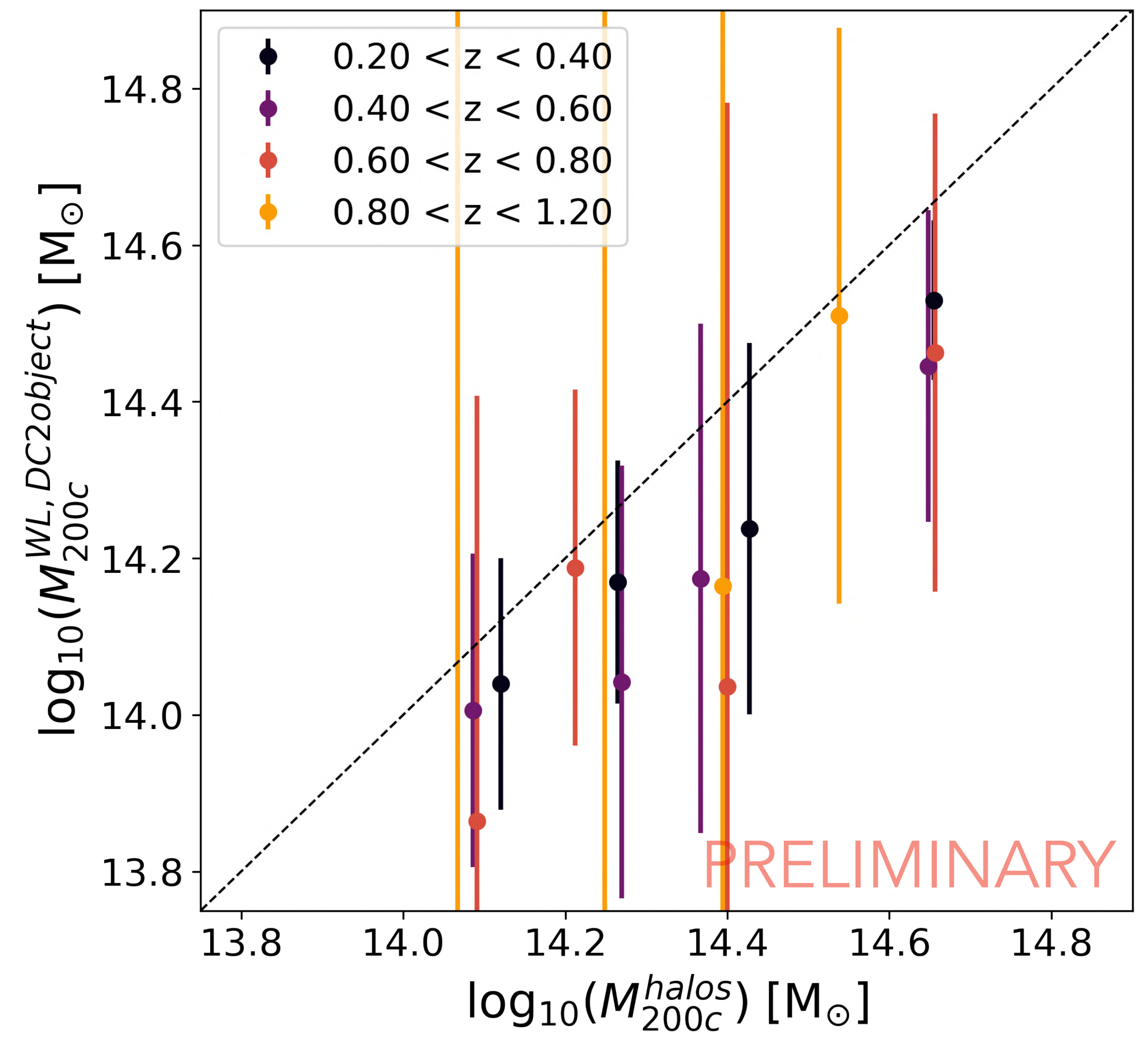
Impact of blending on lensing masses

cosmoDC2



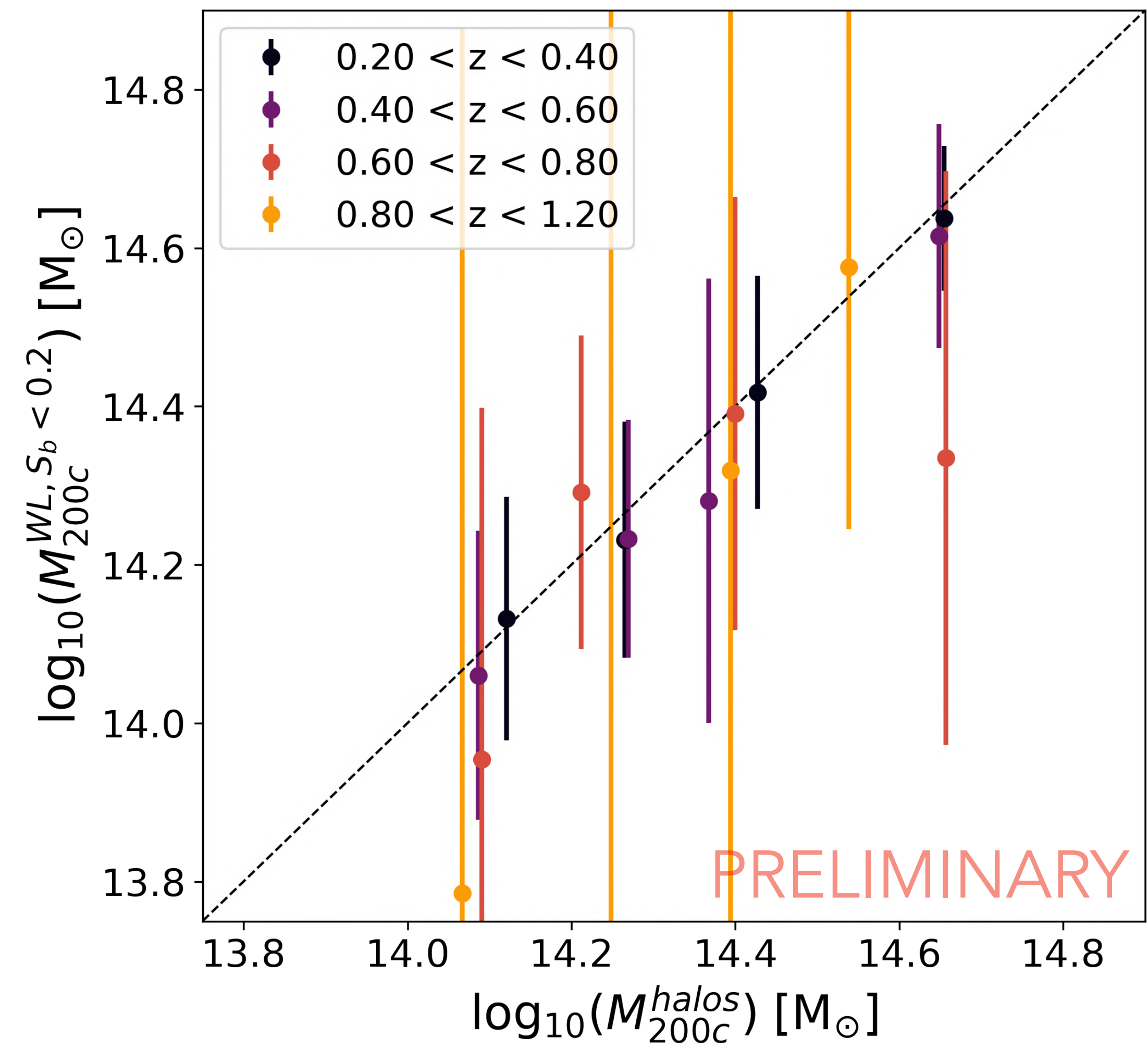
Impact of blending on lensing masses

DC2object with blends

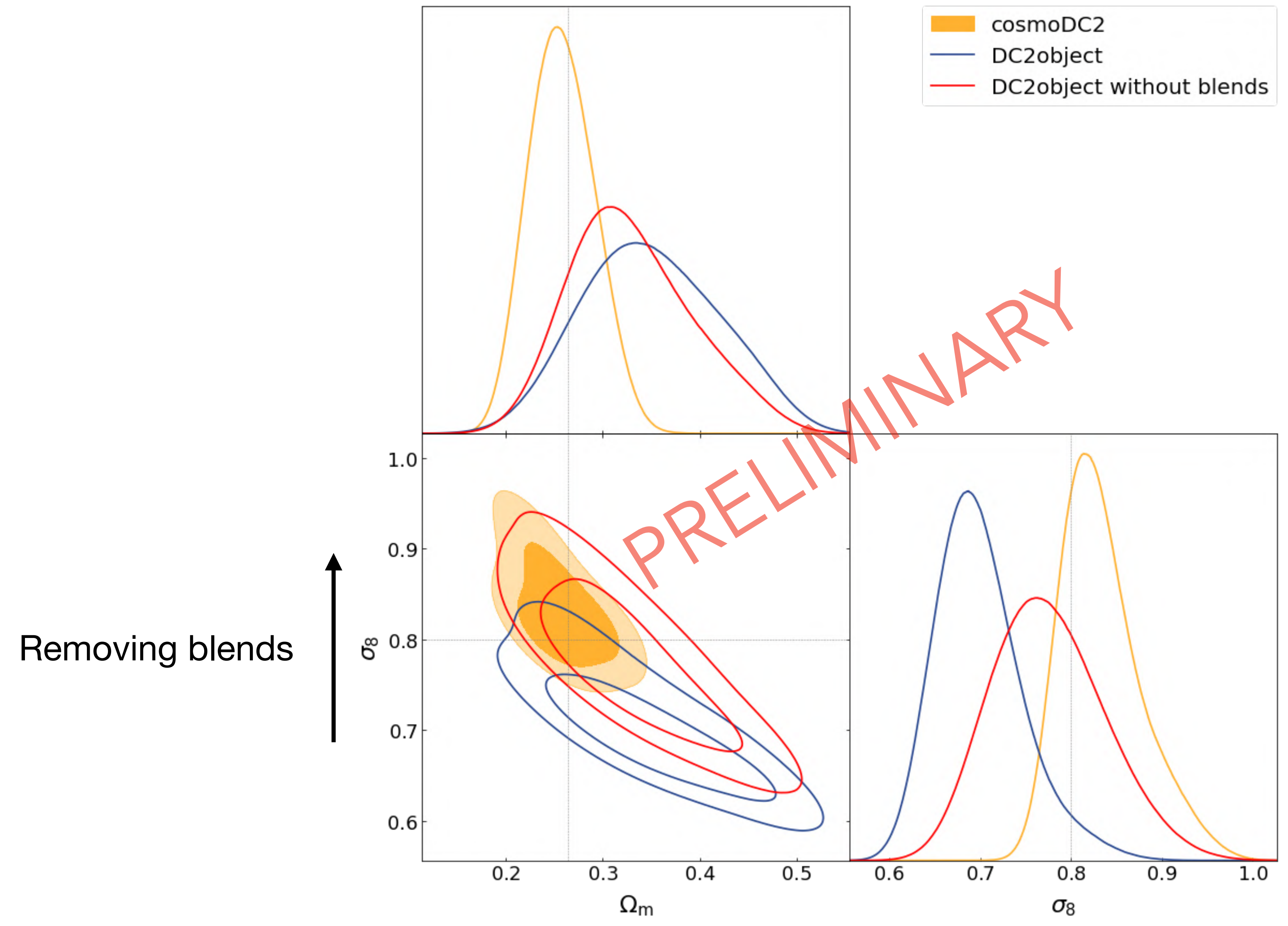


Impact of blending on lensing masses

DC2object without blends



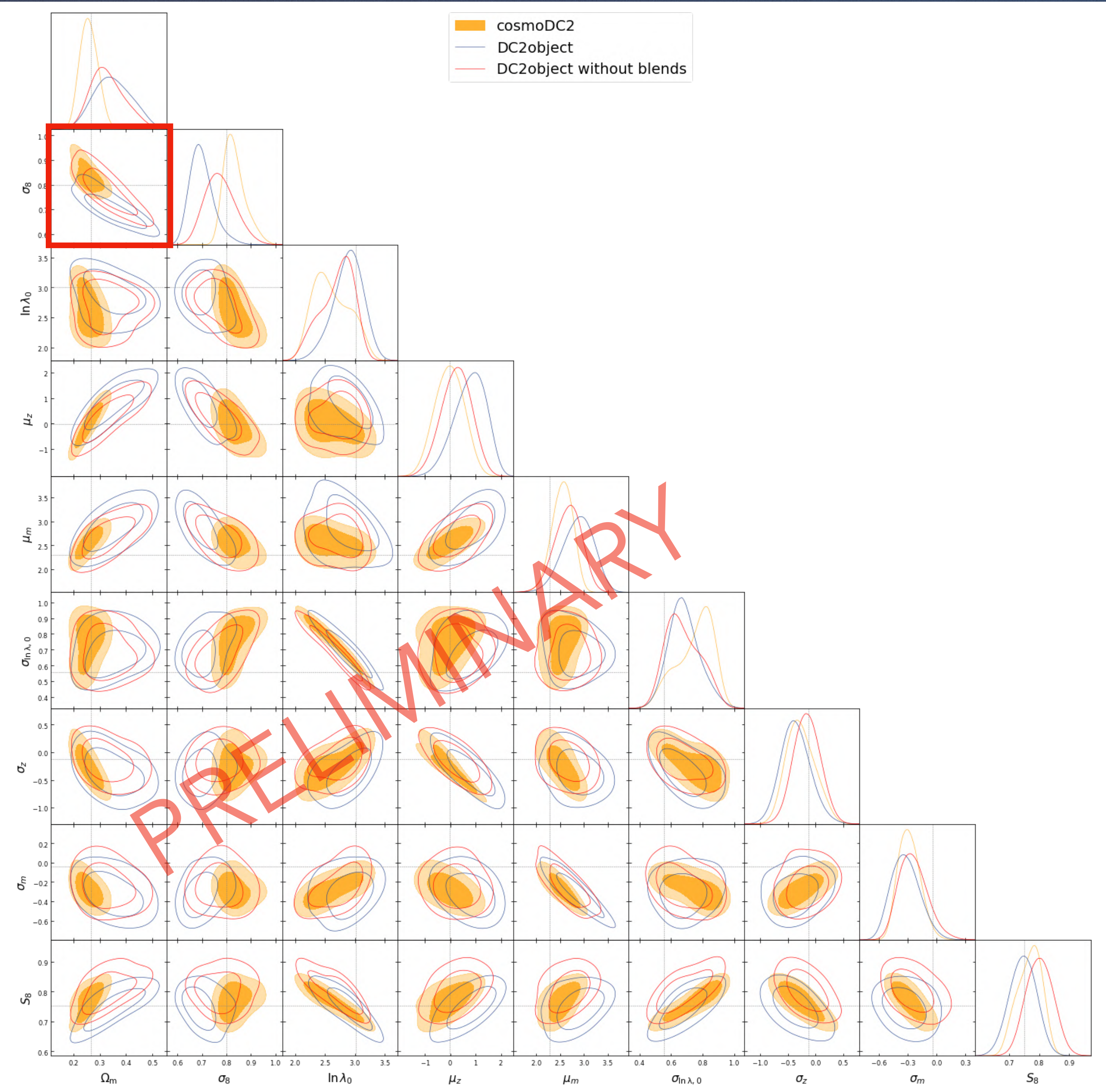
Impact on cosmological parameters



Impact on cosmological parameters

https://github.com/LSSTDESC/GLCosmo_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

3. Application to data

- Mitigation strategy in calibrated on overlapping sky areas (including deep fields/space data)
- Application to 3x2pt

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On the job market in fall 2025!

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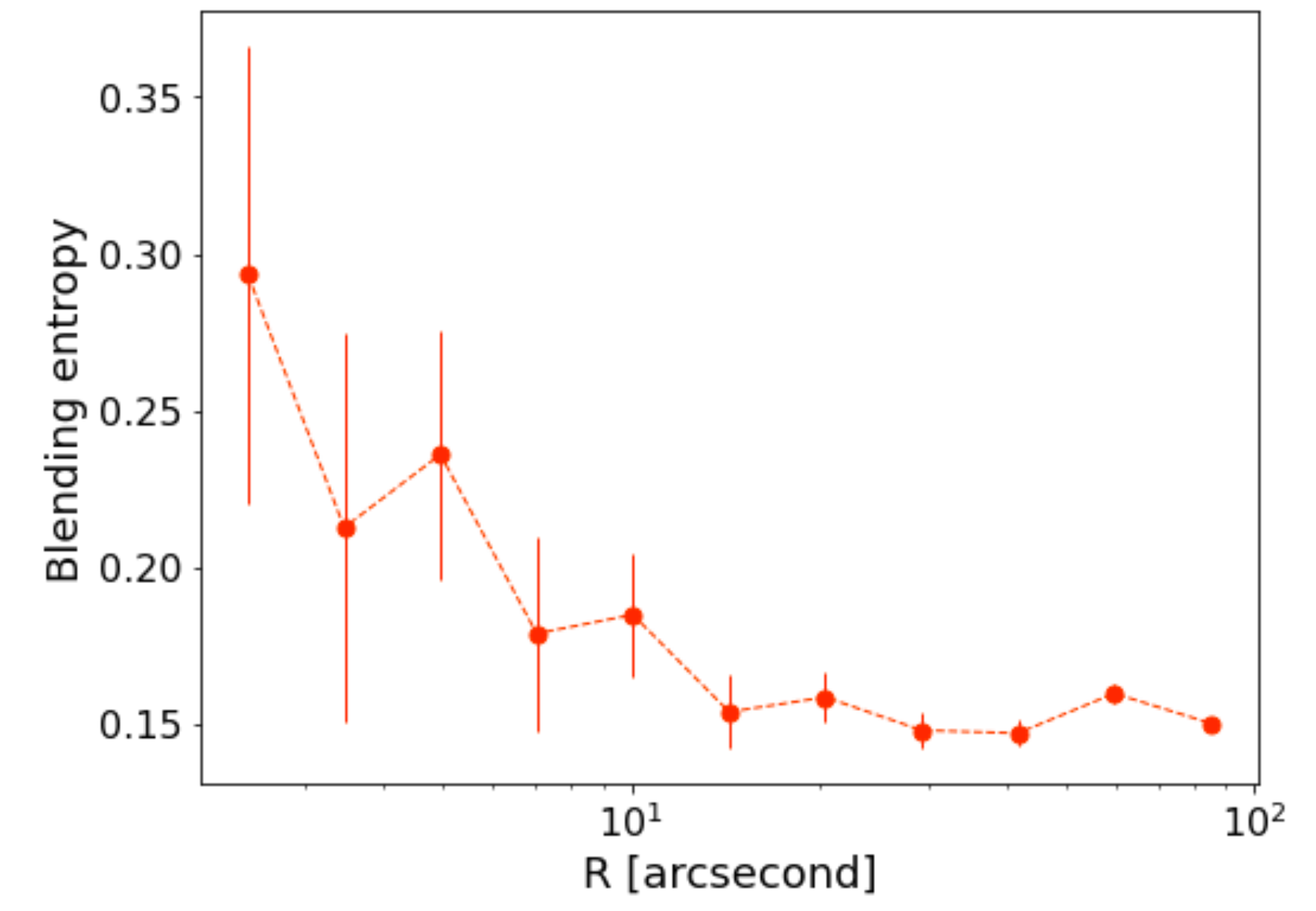
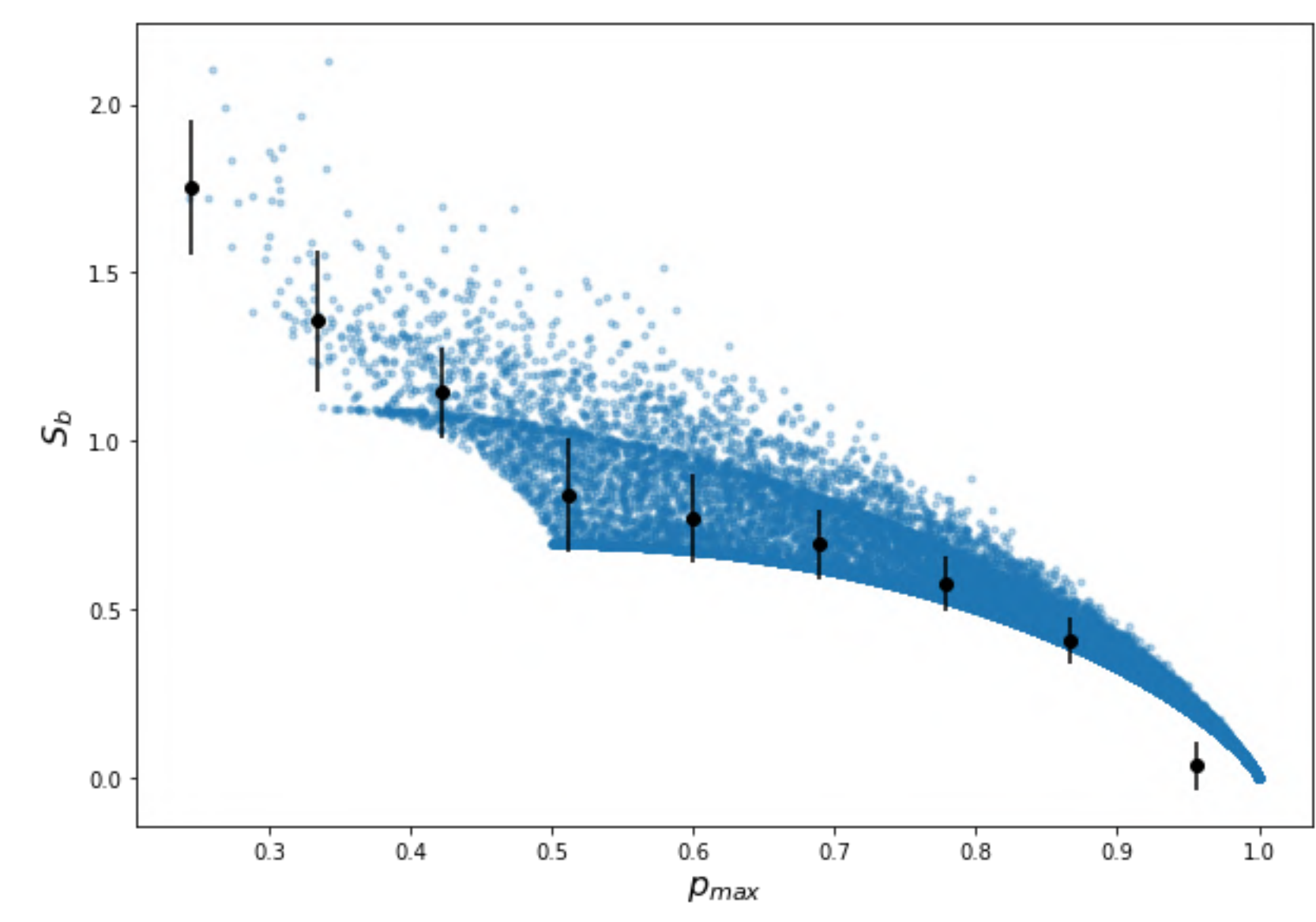
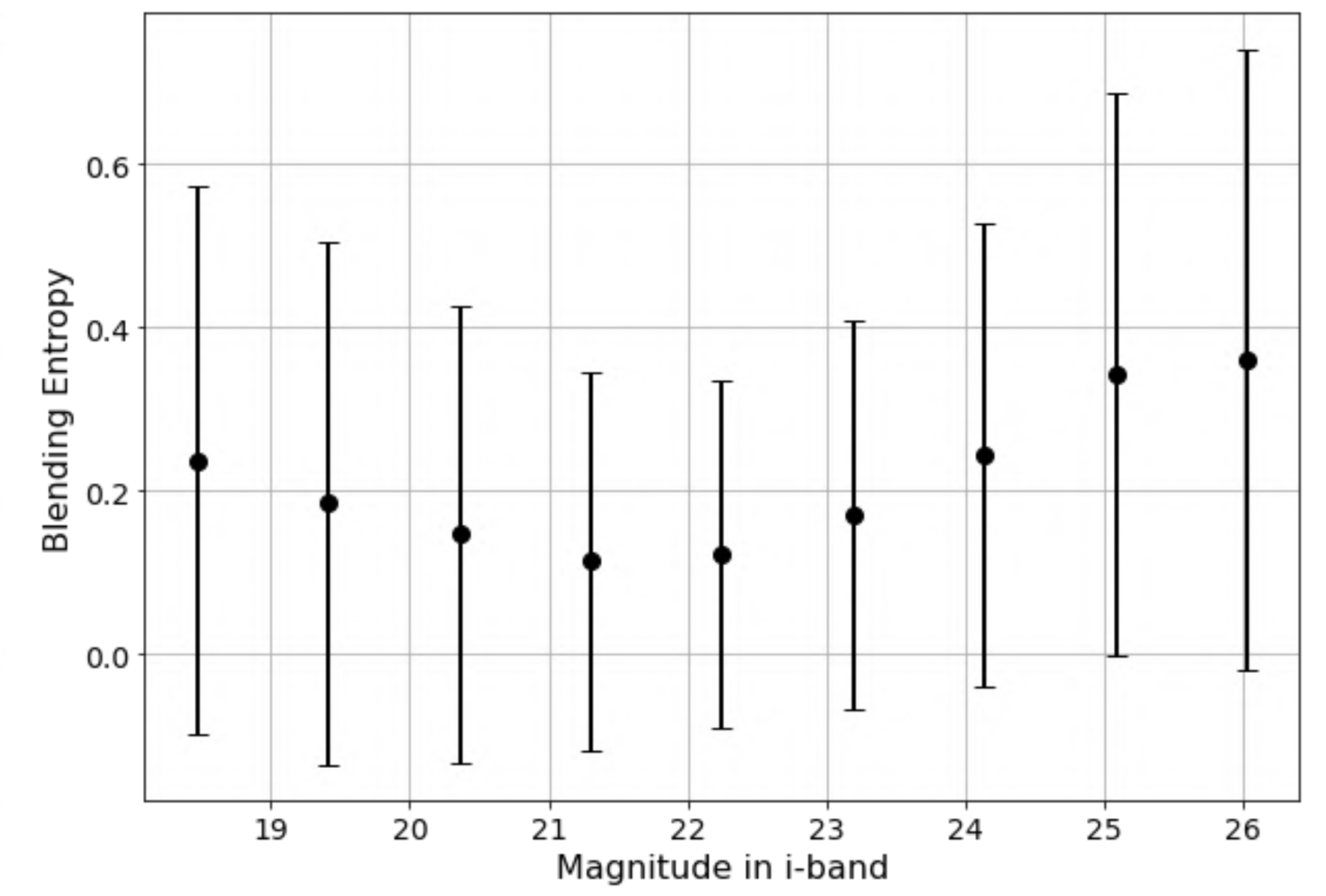
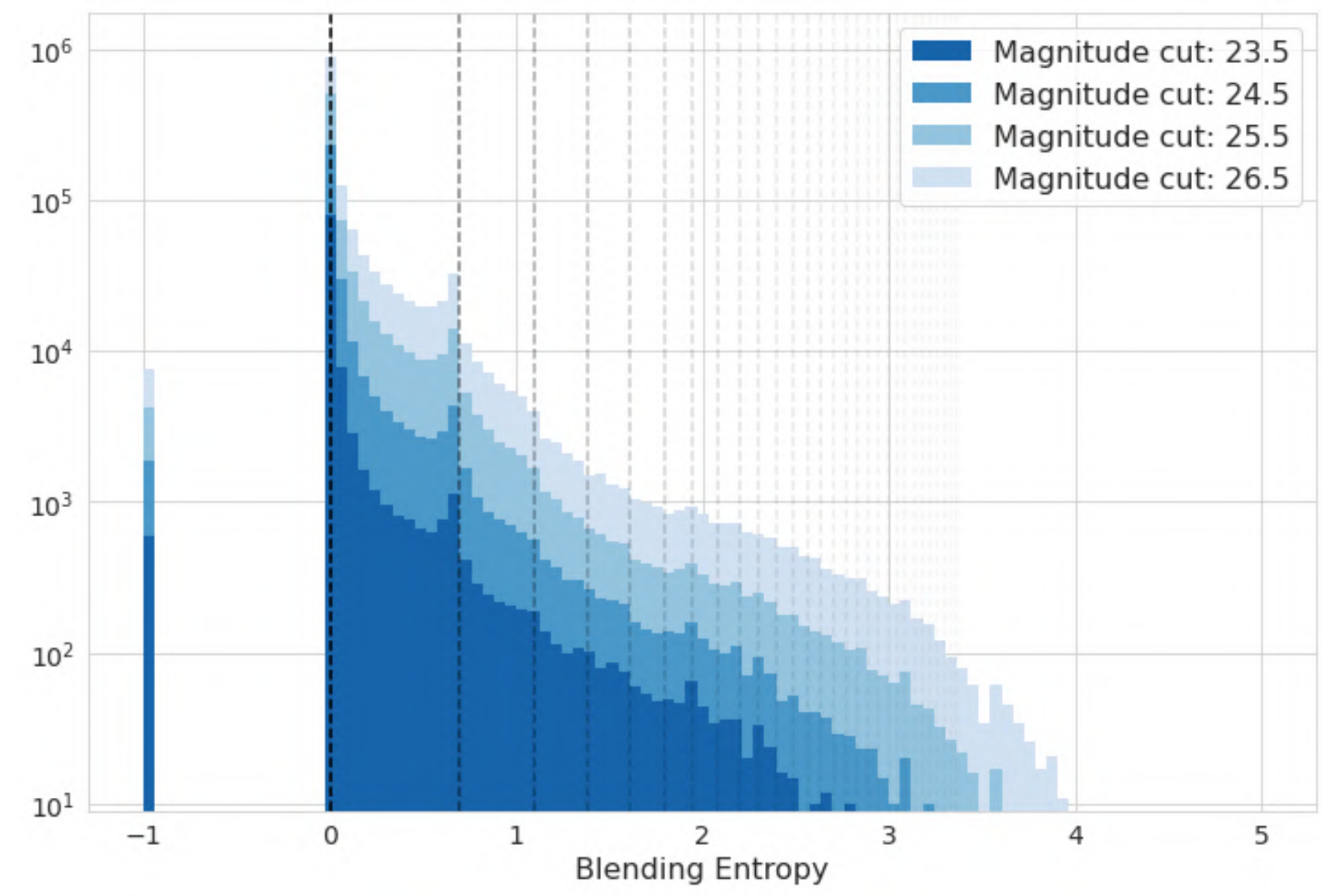
On the job market in fall 2025!

Thank you for your attention!

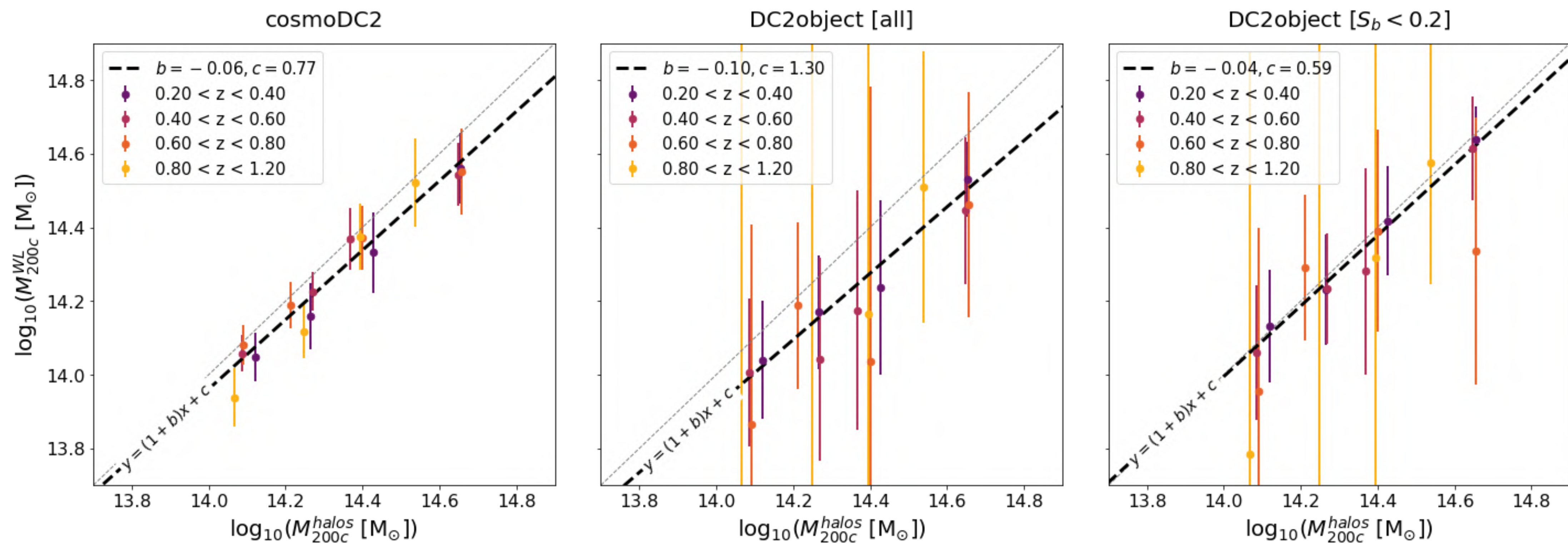
A wide-angle photograph of an astronomical observatory perched on a dark, rocky mountain peak. The sky is a gradient of colors, from a deep blue at the top to a warm orange and red near the horizon. A bright, circular object, likely the moon, is visible in the upper right portion of the sky. The observatory itself consists of several white, rectangular structures, with a prominent one having a dark, boxy top. The foreground shows the rugged, dark terrain of the mountain. The overall scene is serene and captures a moment of quiet observation in a high-altitude environment.

Backup

Blending entropy studies

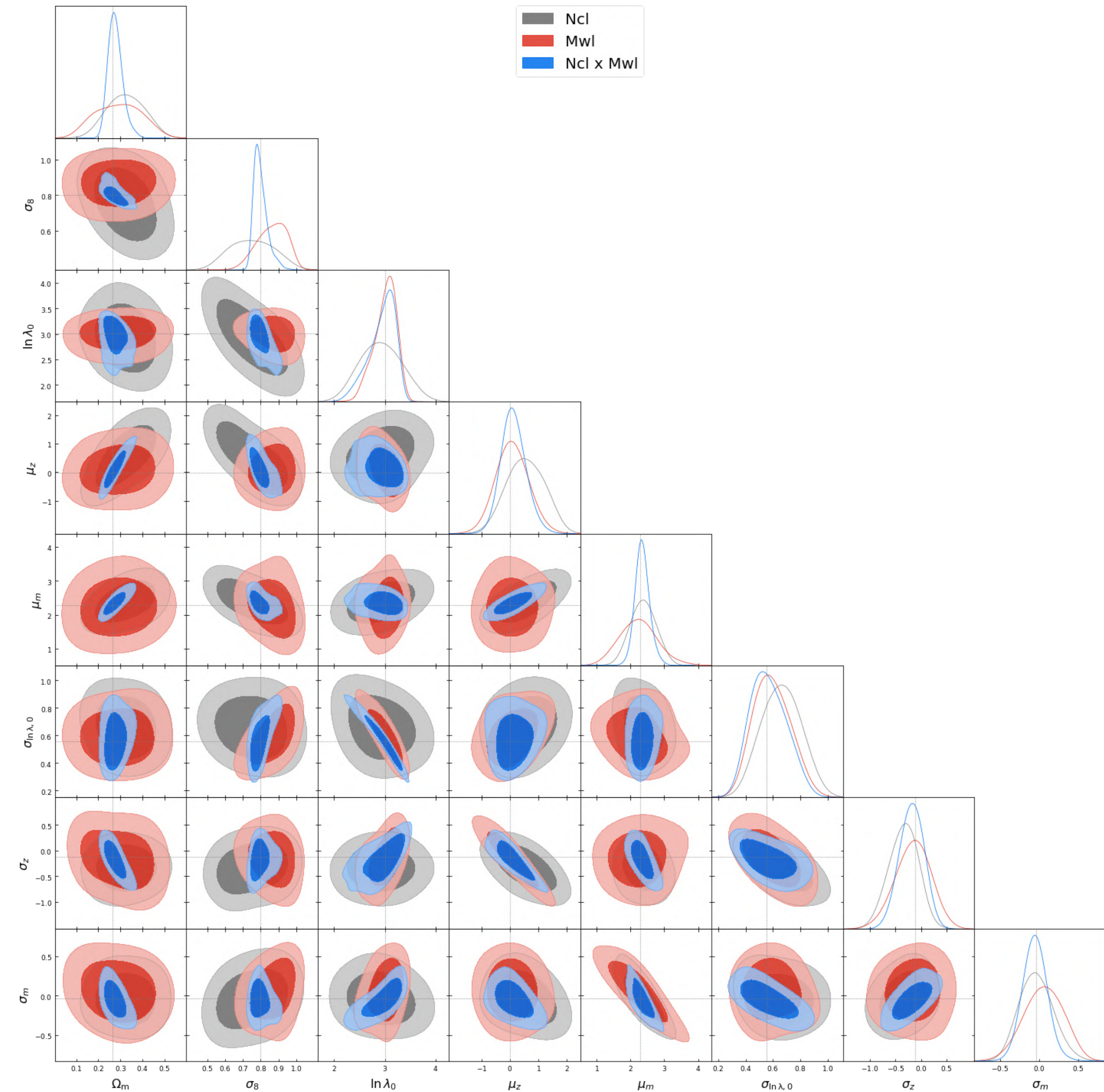


Estimated masses bias



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

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

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

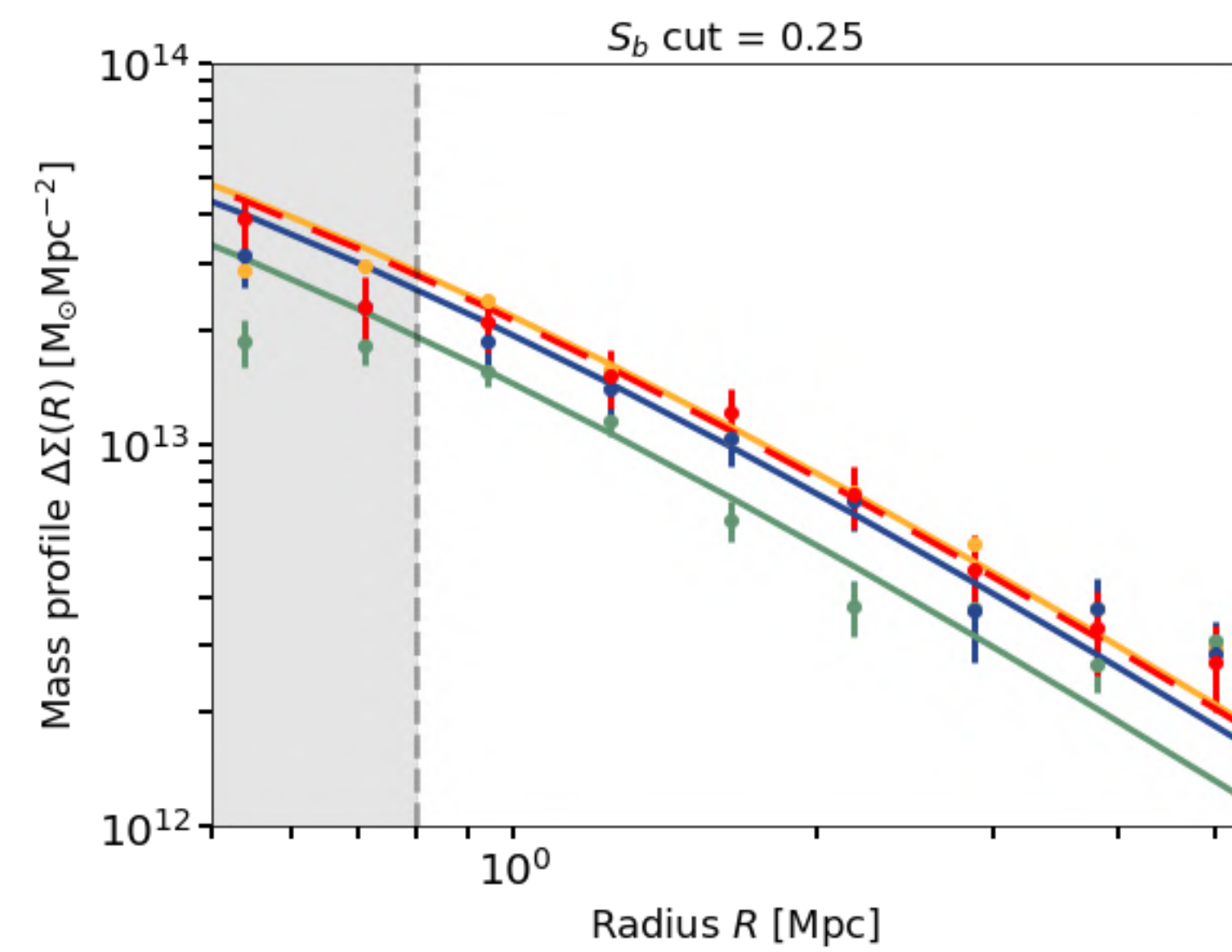
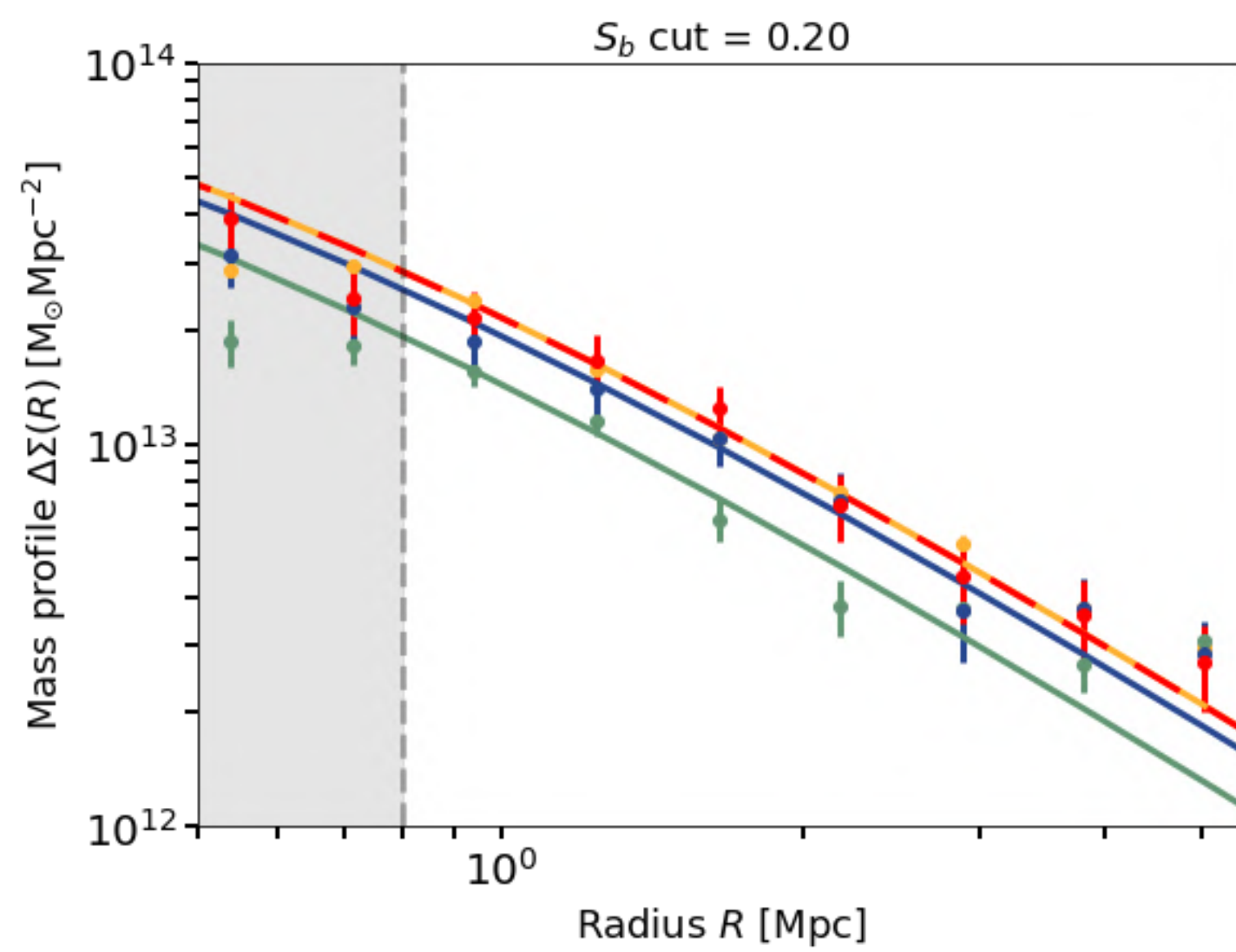
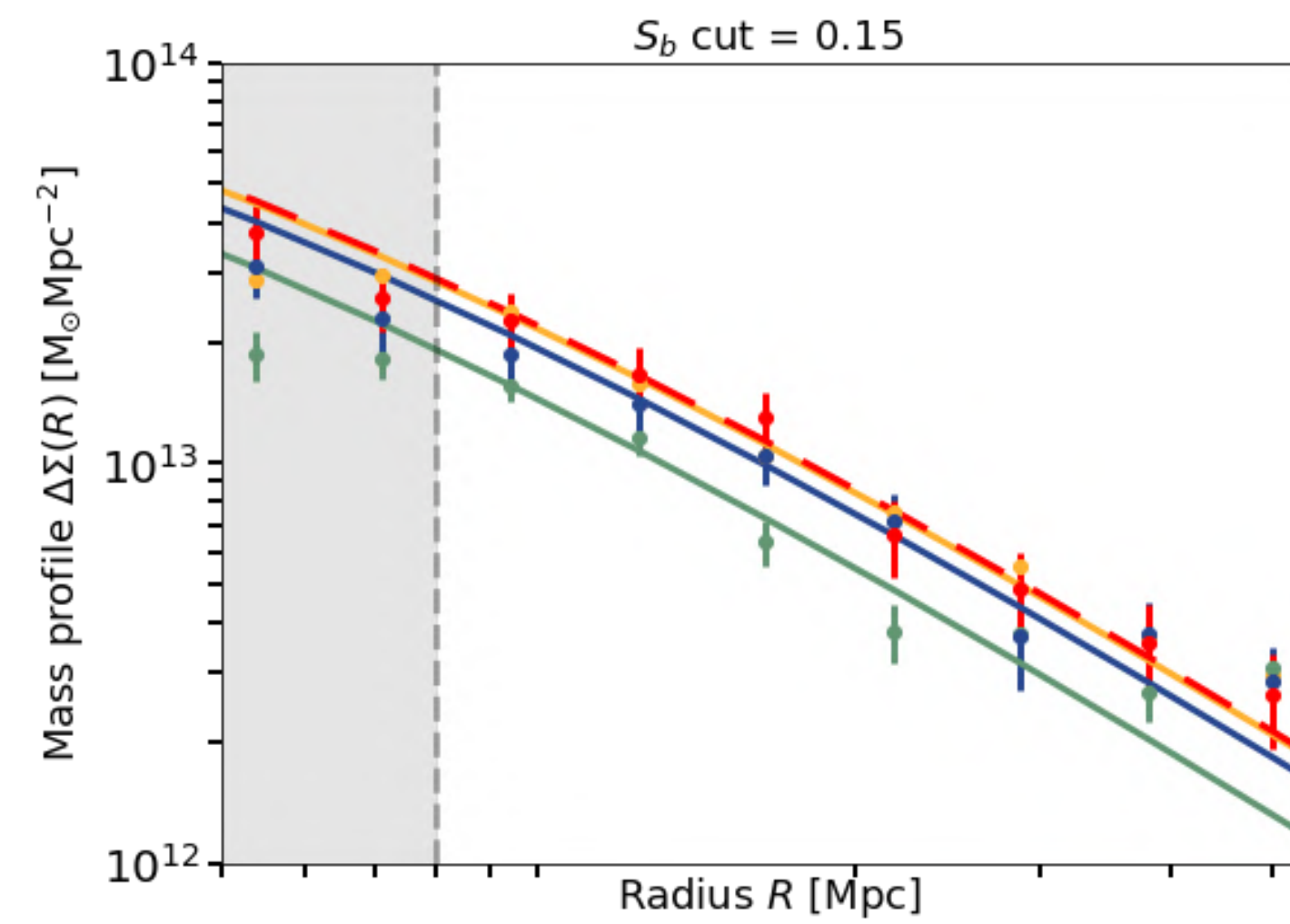
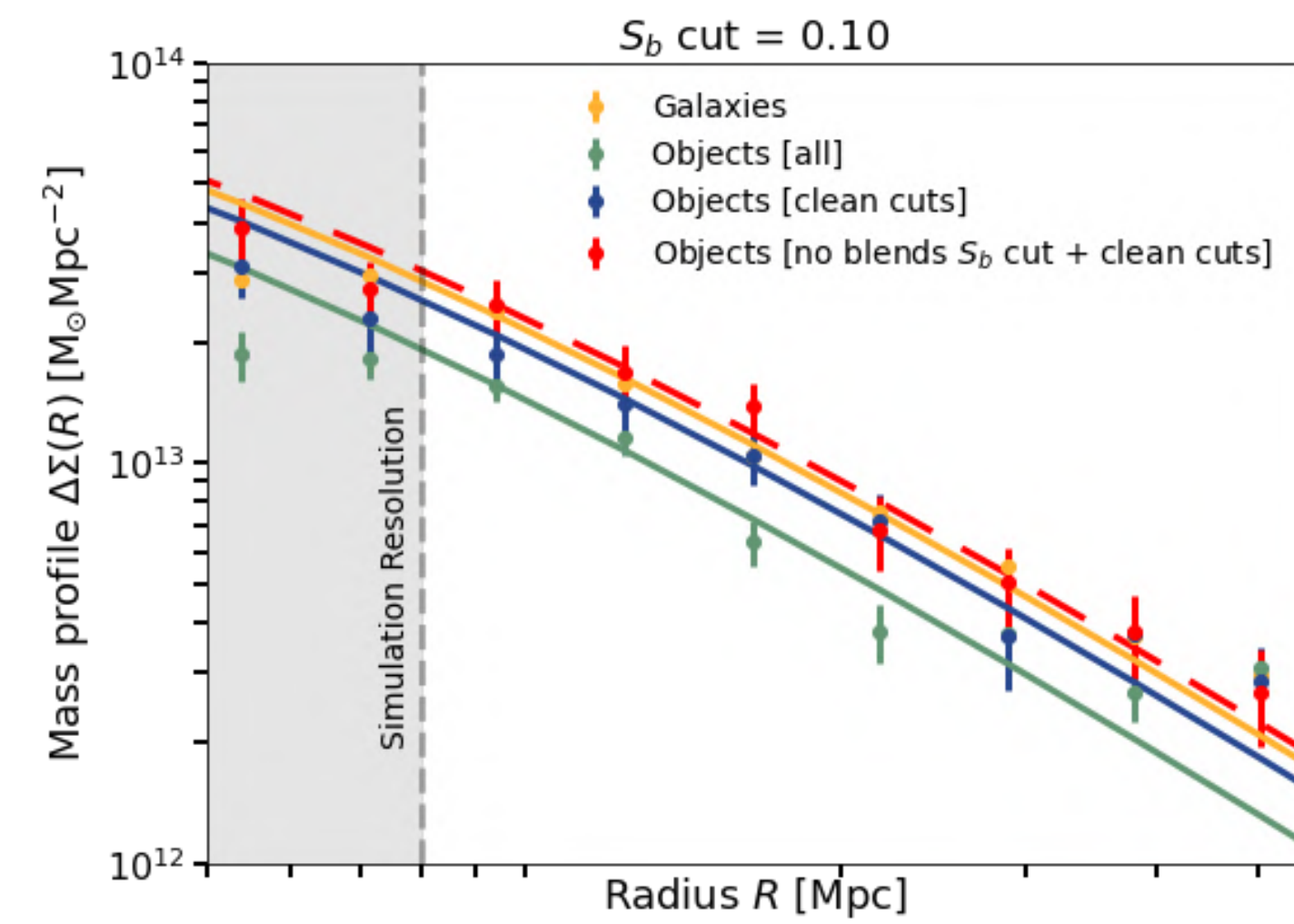
$$\langle \ln \lambda | m, z \rangle = \ln \lambda_0 + \mu_z \log \left(\frac{1+z}{1+z_0} \right) + \mu_m \log_{10} \left(\frac{m}{m_0} \right), \quad (4.35)$$

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

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

	$p \pm \Delta p$
$\ln \lambda_0$	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

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

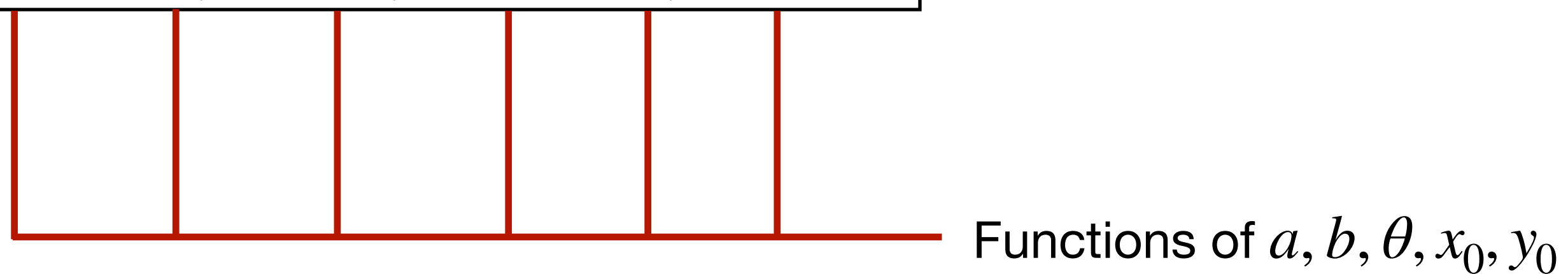
Functions of a, b, θ, x_0, y_0

Ellipse overlap test

2017, Alberich-Carramiñana et al.

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

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



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

Determinant computation



Overlap of 2 ellipses ?

- True
- False