Impact of blending on weak lensing measurements with Rubin-LSST

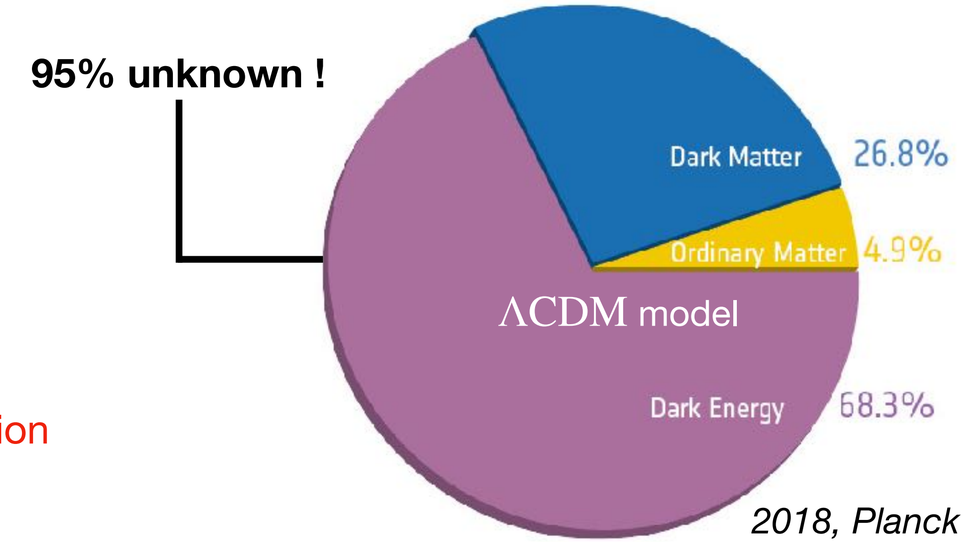
PhD Seminar, March 2024

Manon Ramel

Laboratoire de Physique Subatomique & Cosmologie - Dark team

Supervisors : Cyrille Doux, Marine Kuna

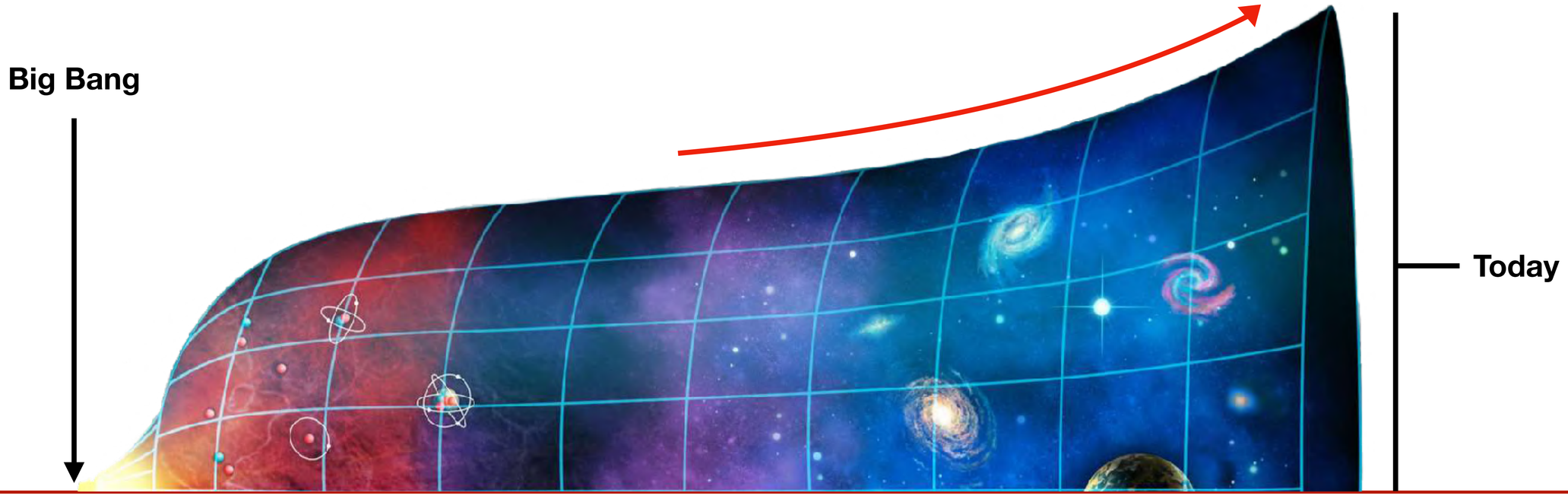
Cosmology



2018, Planck CMB

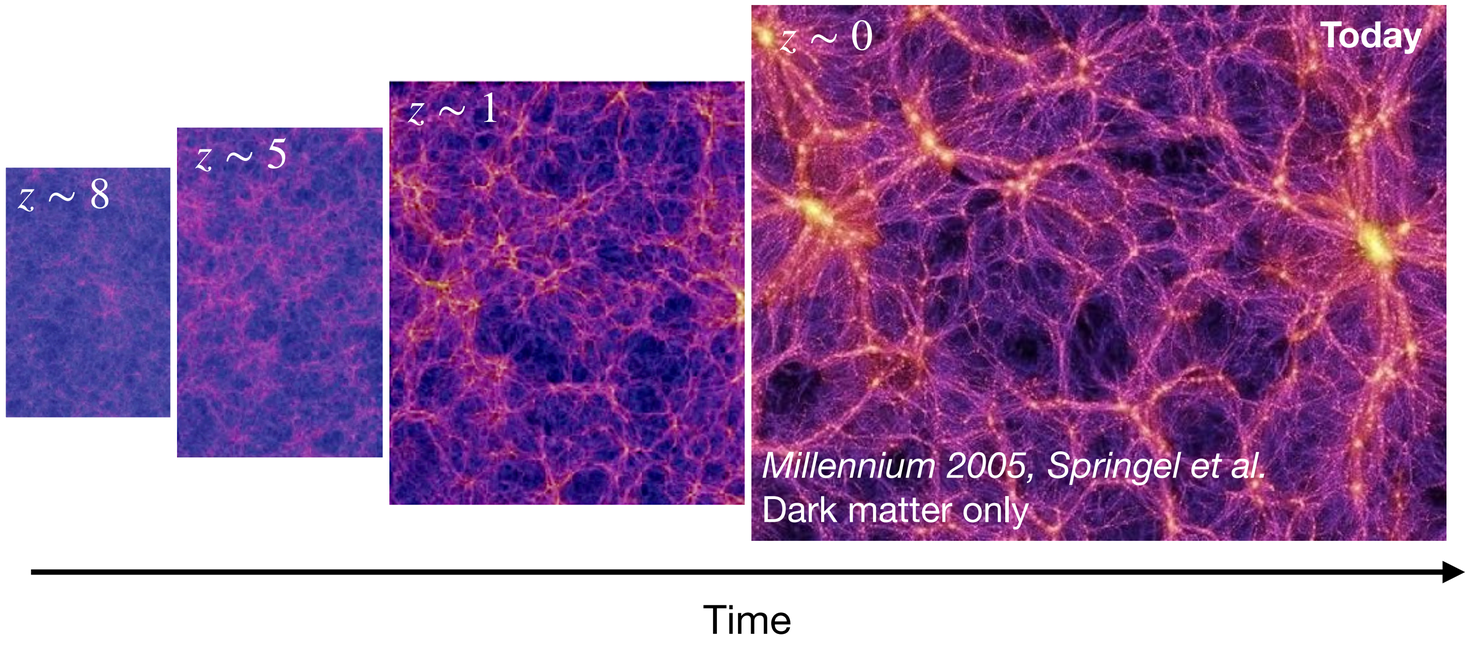
Study the nature of dark matter and dark energy

- Dark matter: invisible, detected through its gravitational effects
- Dark energy: responsible for the current acceleration of the Universe expansion



Cosmology with galaxy clusters

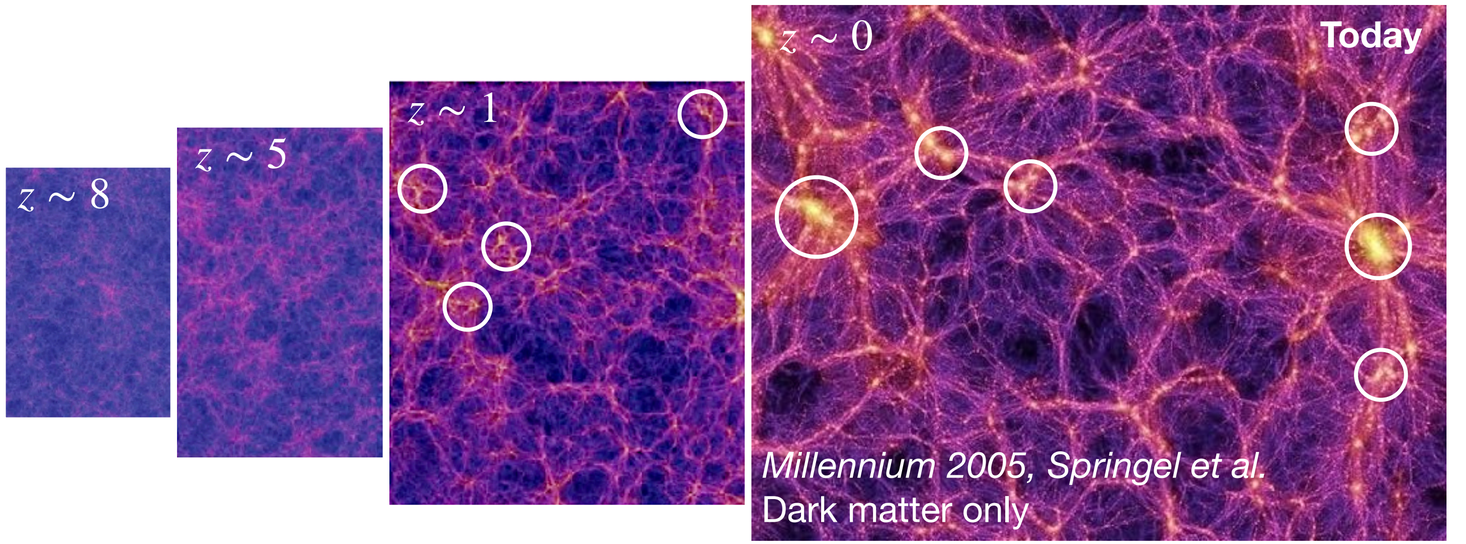
Redshift z ~ distance ~ look in the past



Time

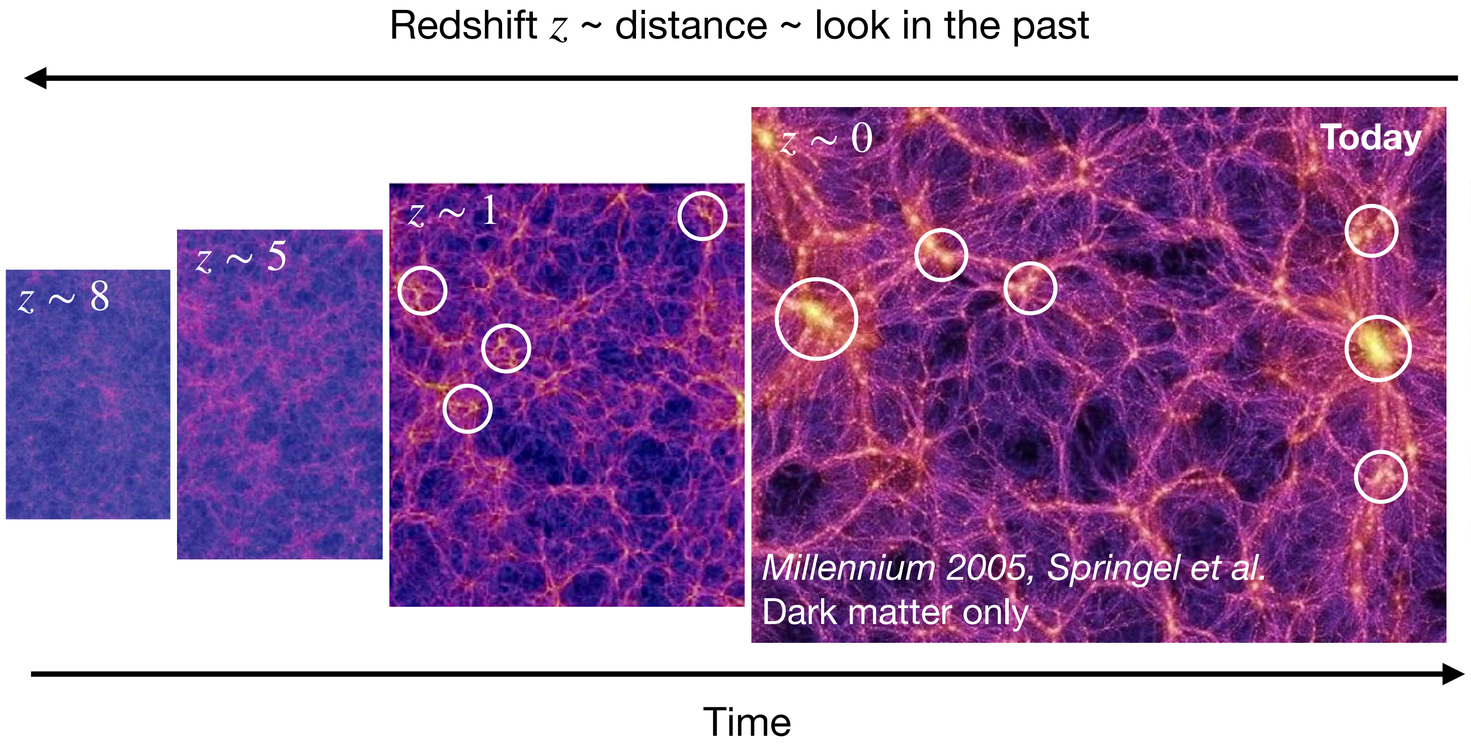
Cosmology with galaxy clusters

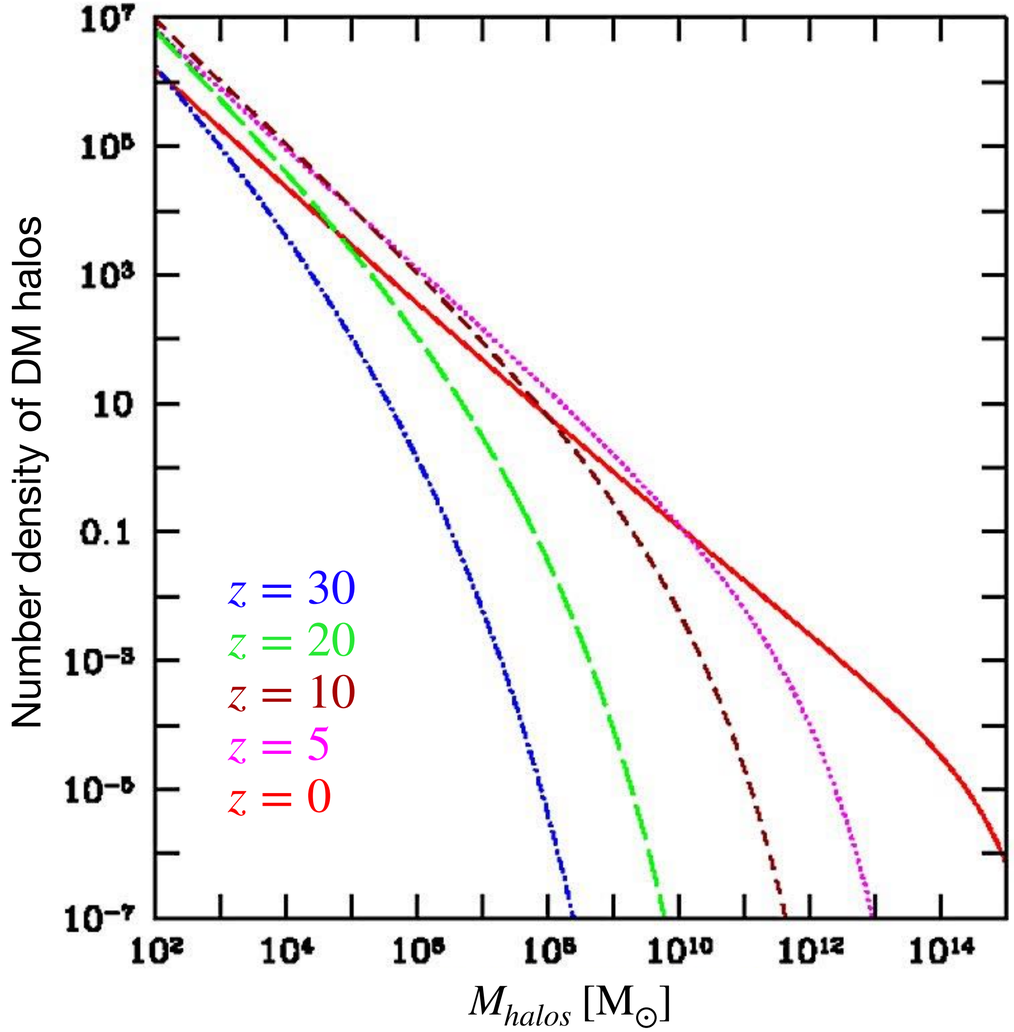
Redshift z ~ distance ~ look in the past



Time

Cosmology with galaxy clusters





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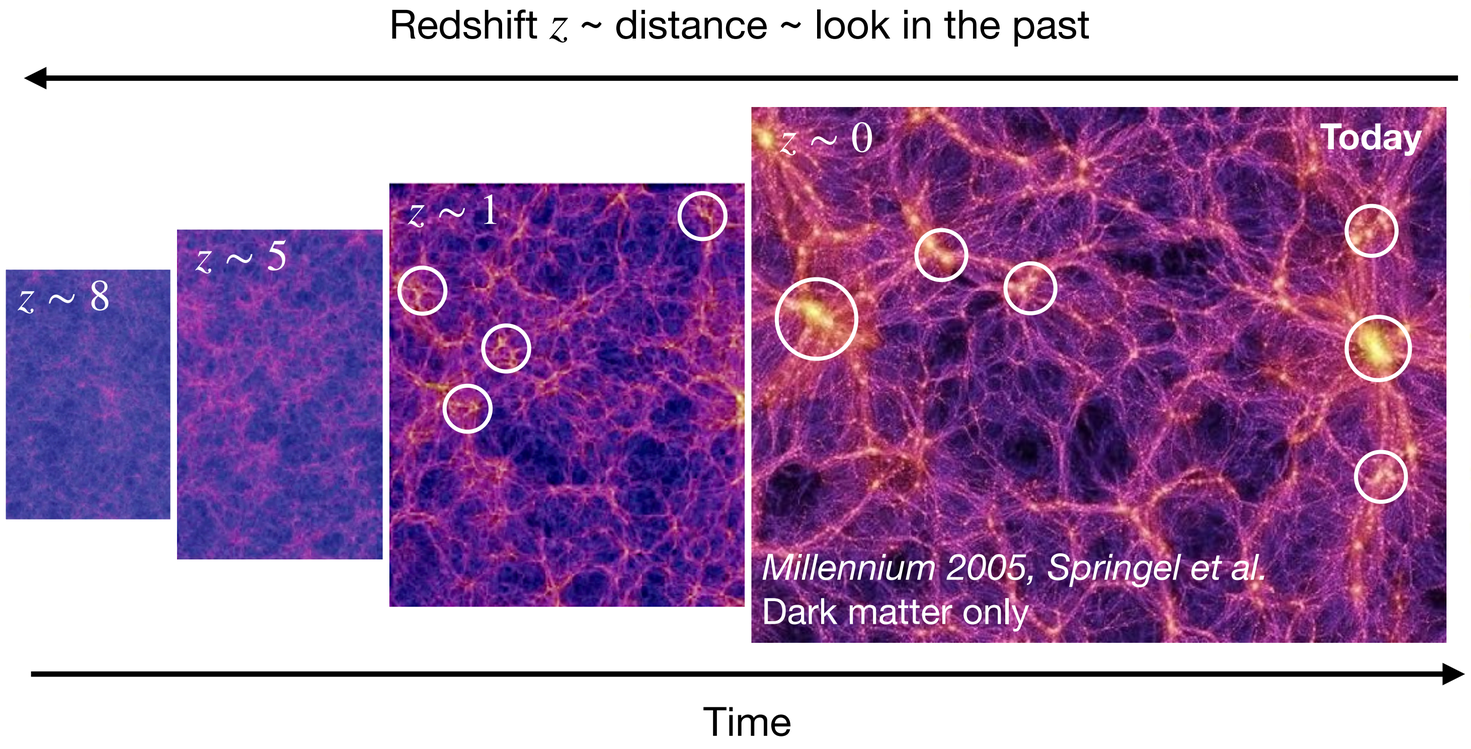

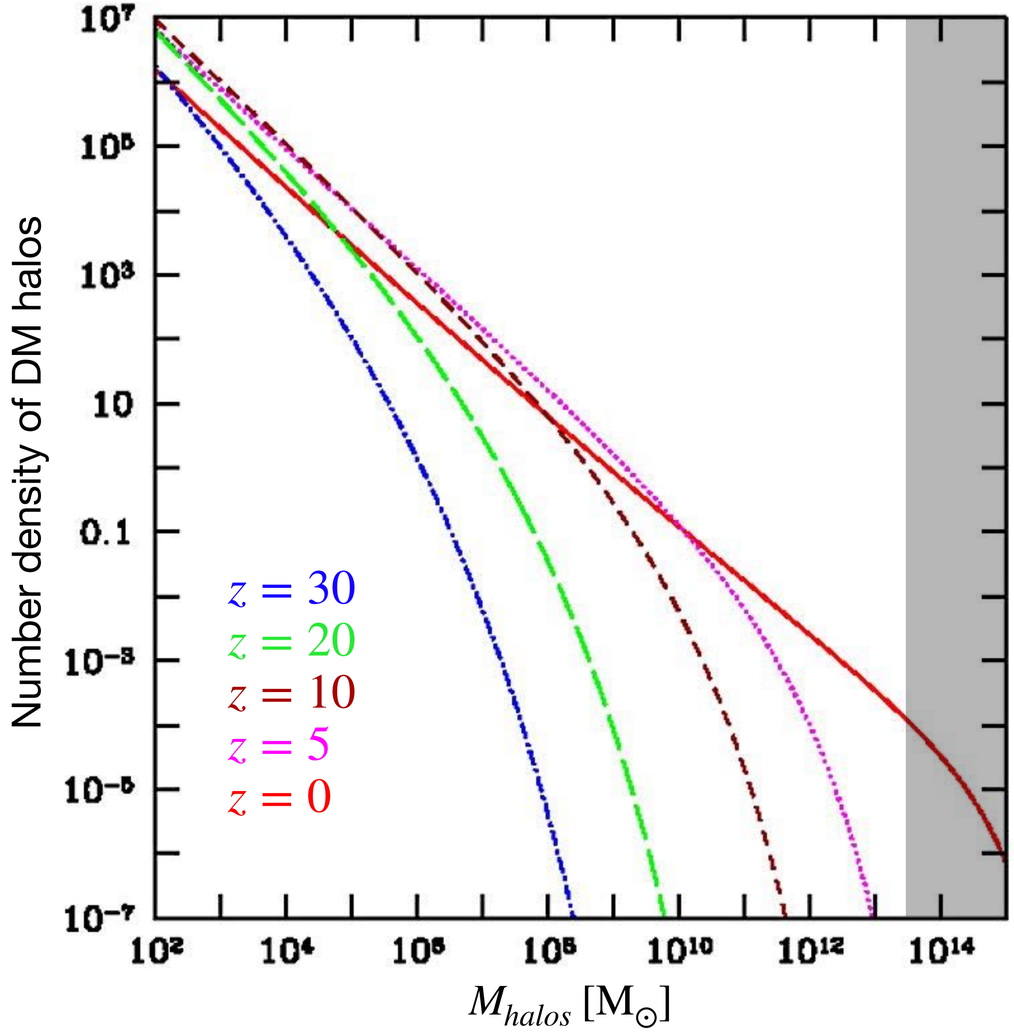

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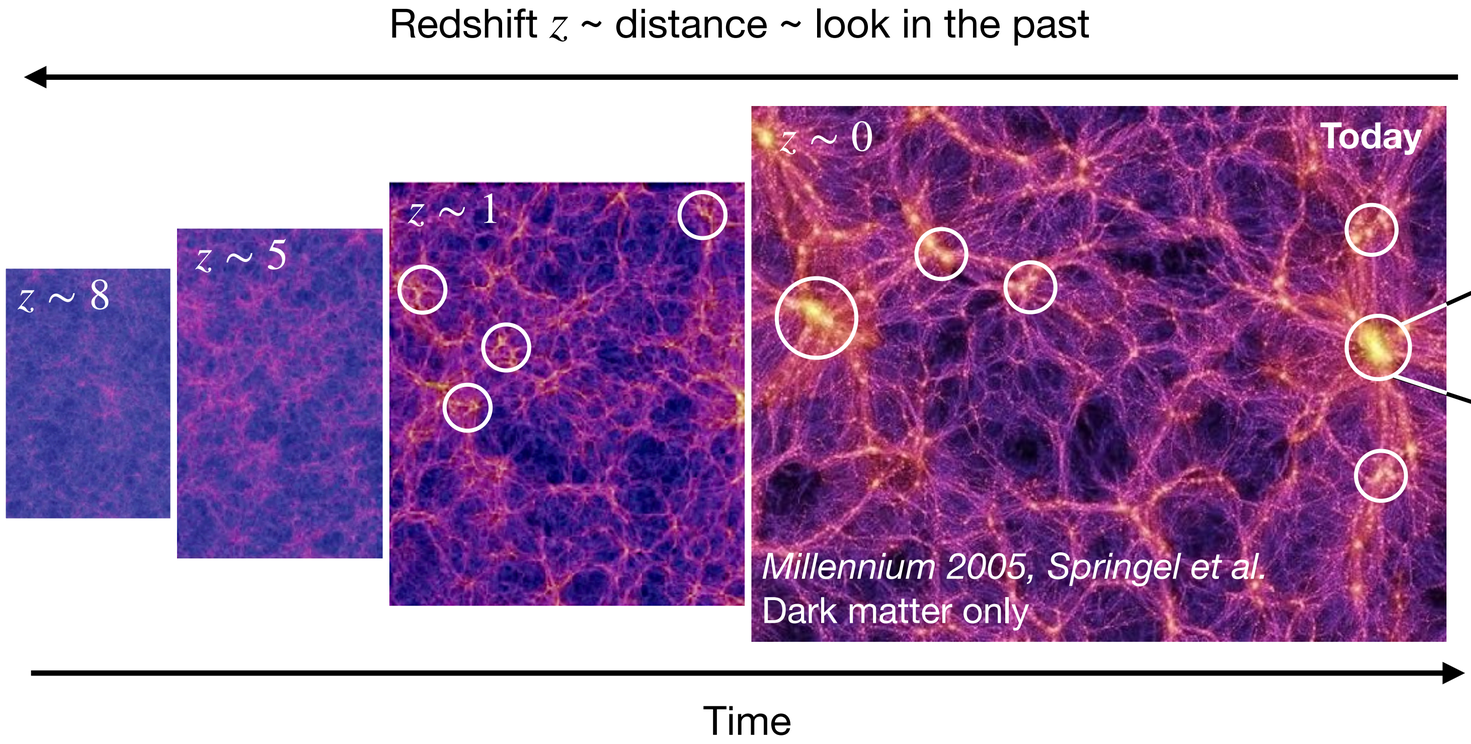
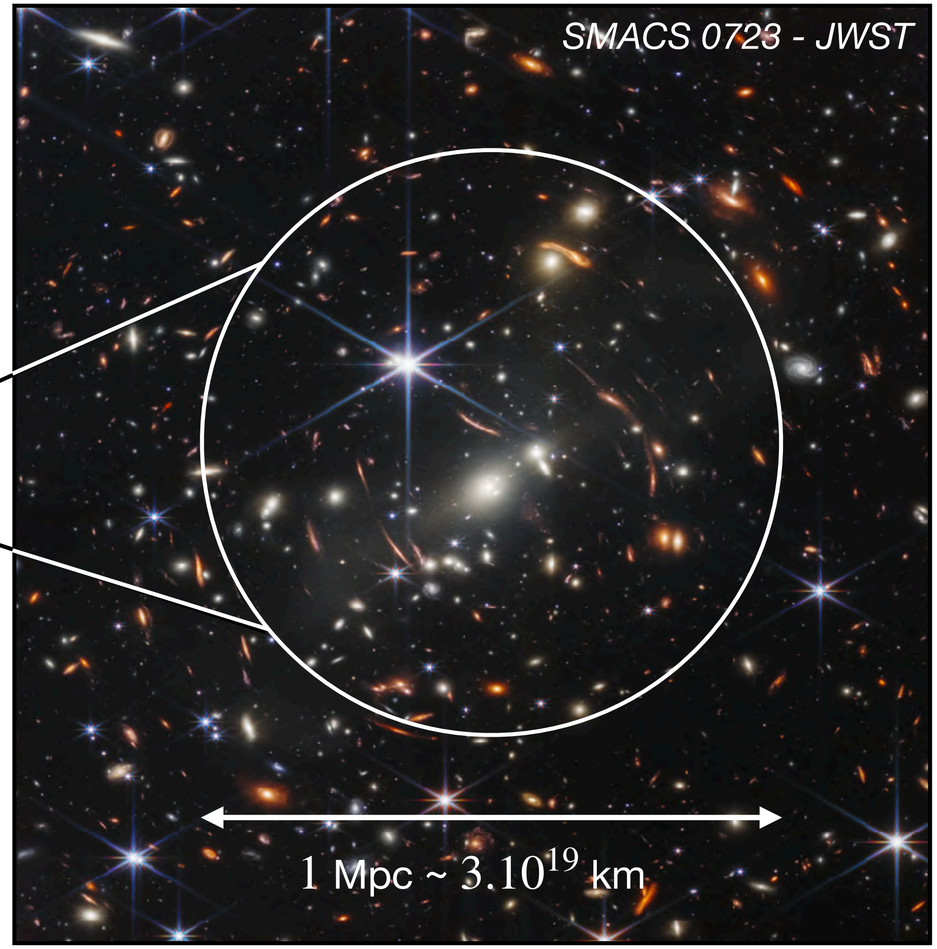


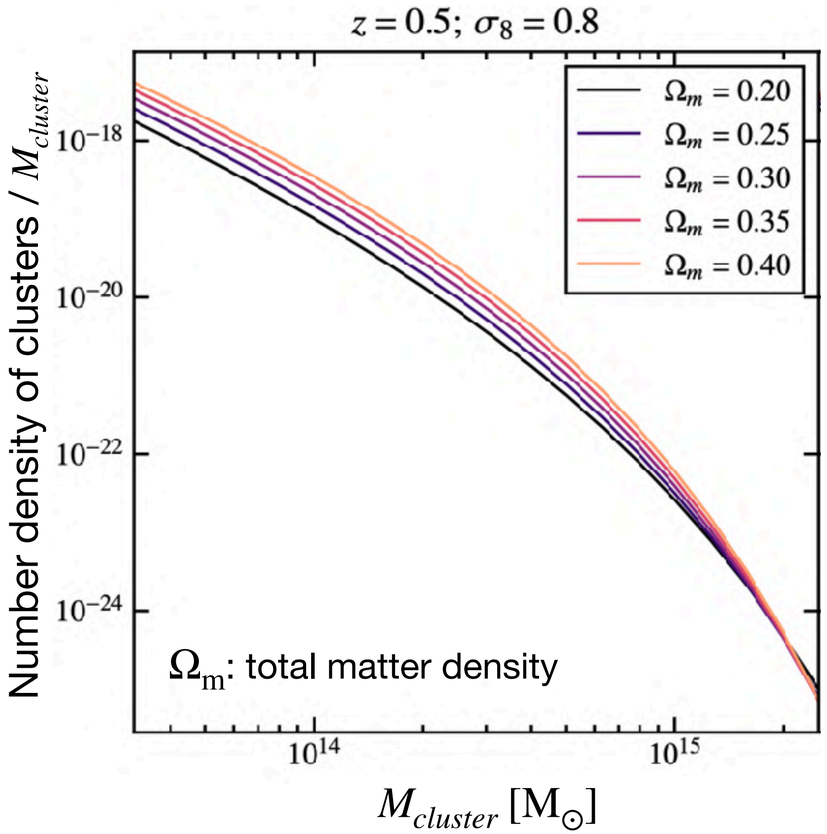


Tracers of dark matter over-densities
Composed of 80% of dark matter

Sensitive to dark energy
Accelerated expansion vs. gravity

Cosmology with galaxy clusters

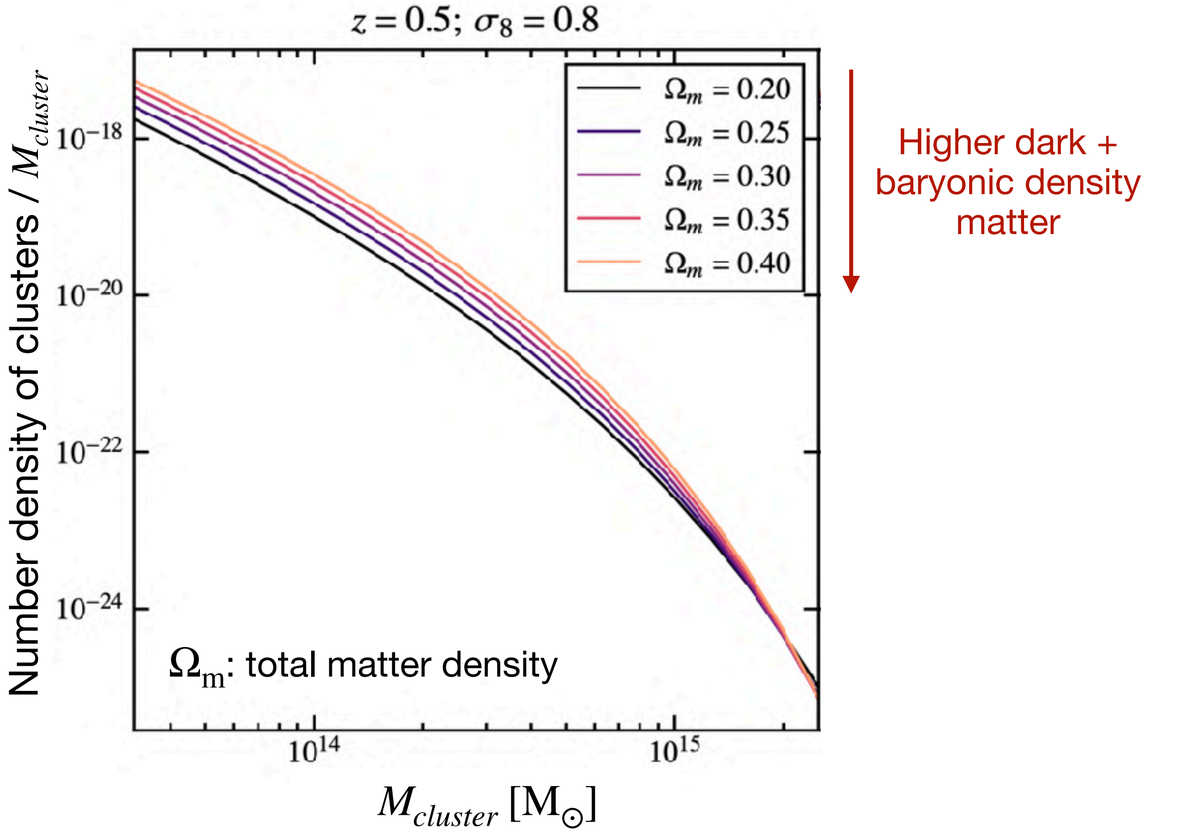
Studied through their counting per bins of mass and redshift



Higher dark + baryonic density matter

Cosmology with galaxy clusters

Studied through their counting per bins of mass and redshift



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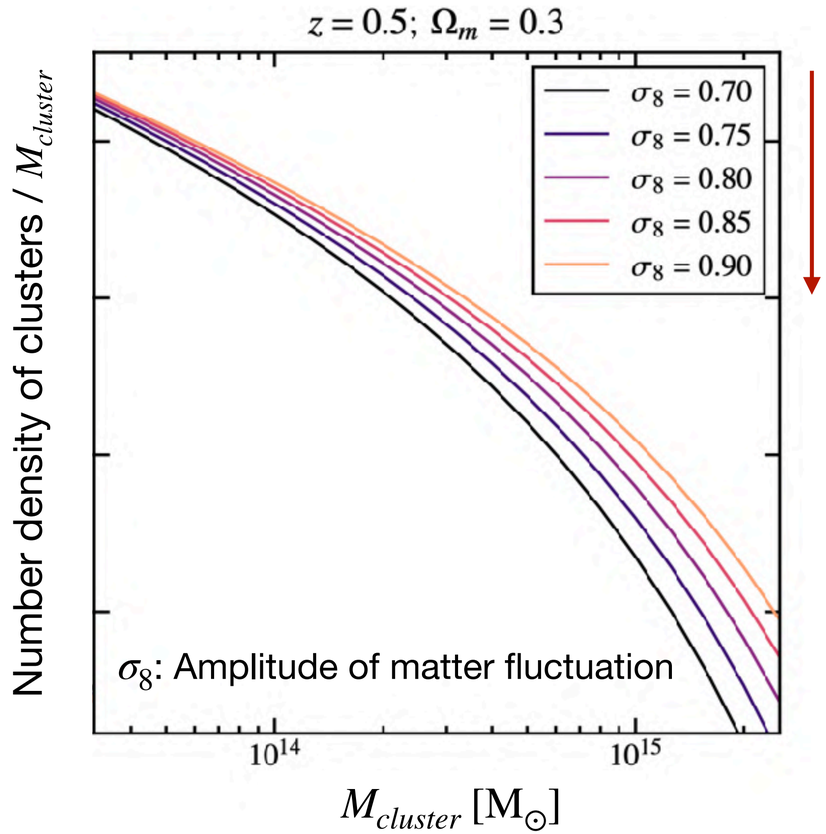
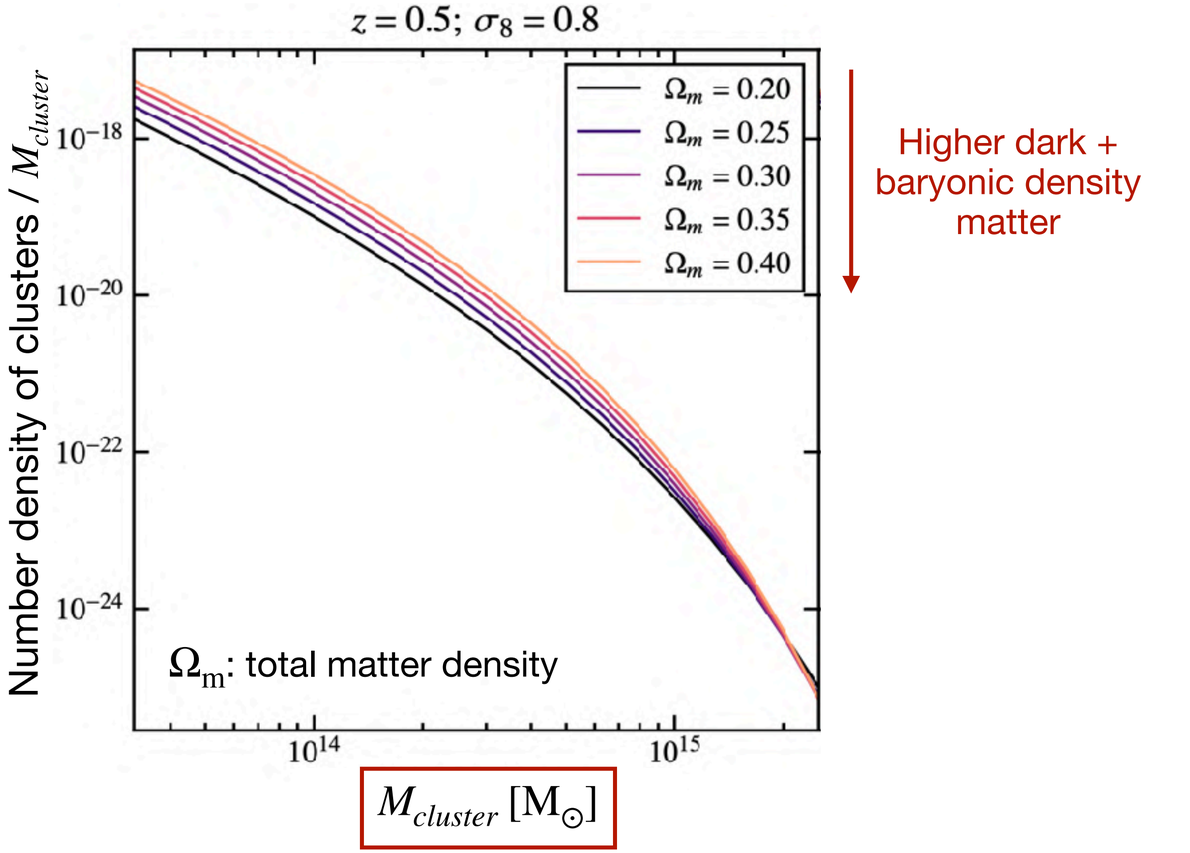


Stronger clustering of galaxies

Cosmology with galaxy clusters

Studied through their counting per bins of mass and redshift



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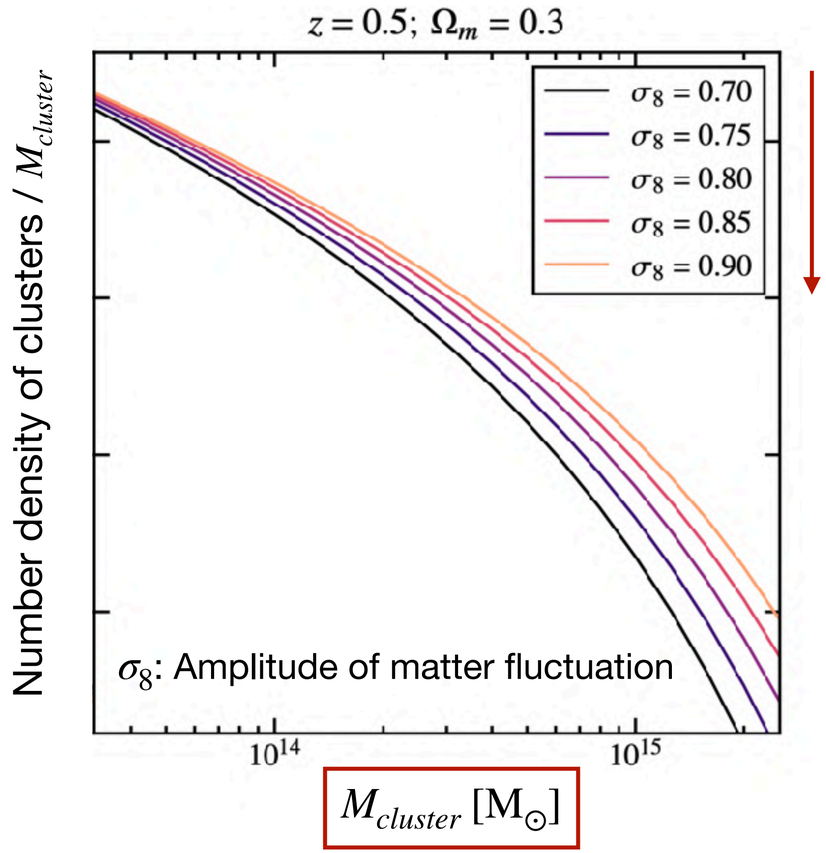
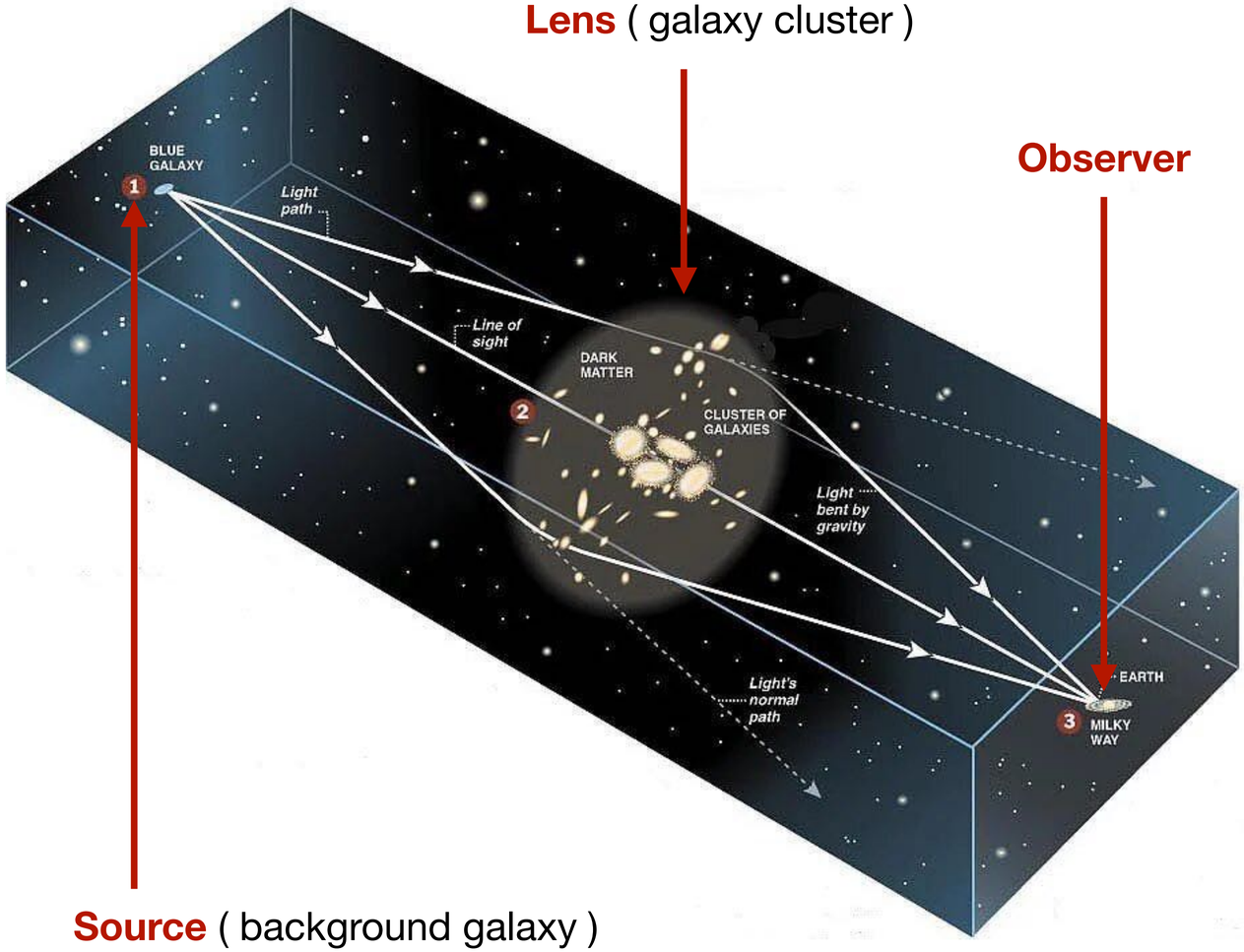


Stronger clustering of galaxies

Mass is **not an observable**: indirect measurements through weak lensing

Weak Gravitational Lensing

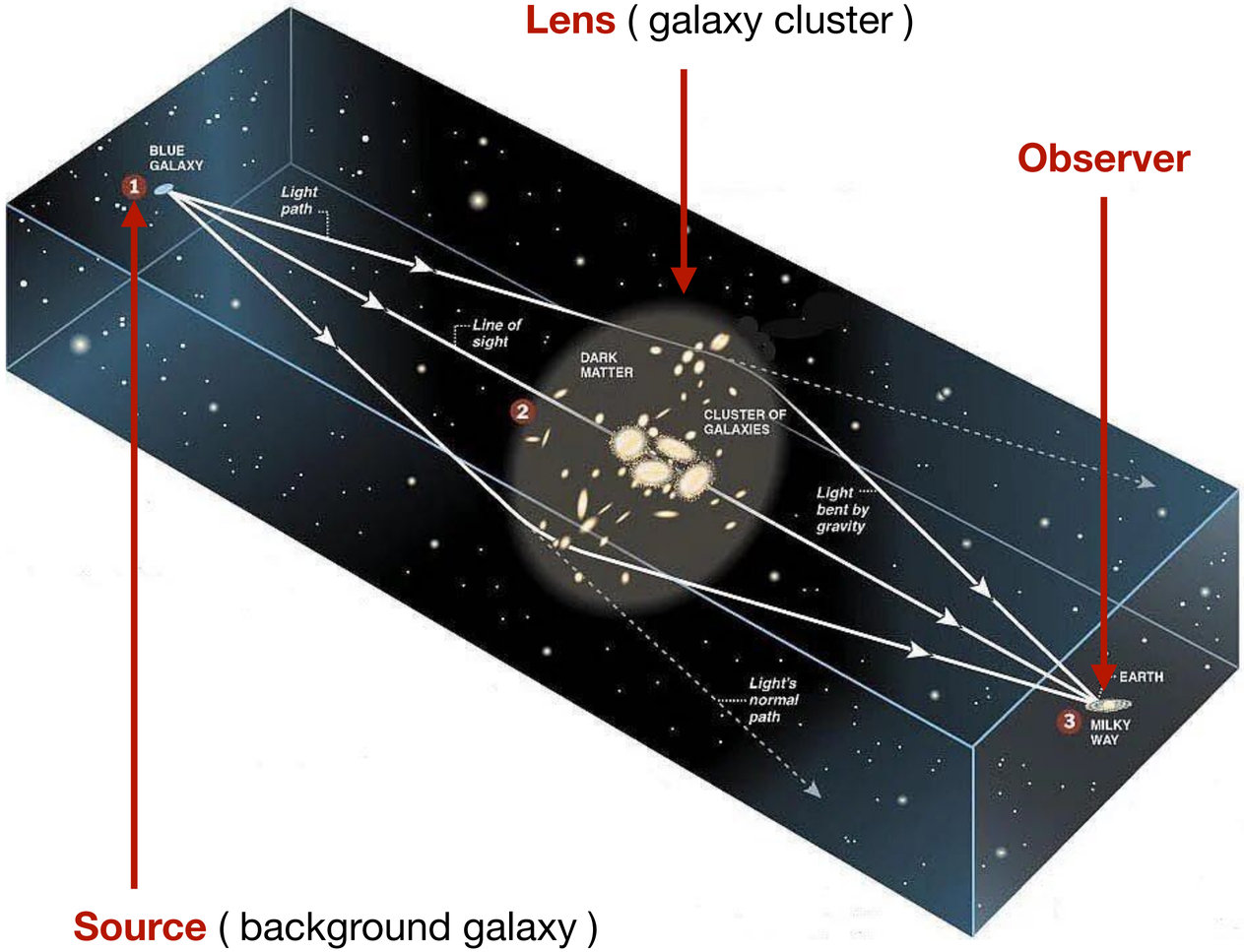


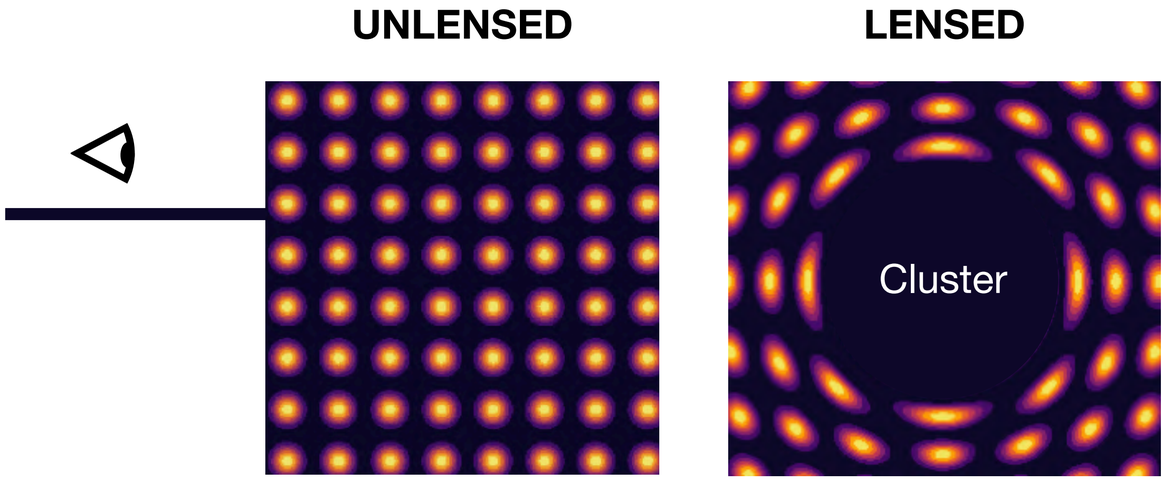
Lens (galaxy cluster)

Observer

Source (background galaxy)

Weak Gravitational Lensing





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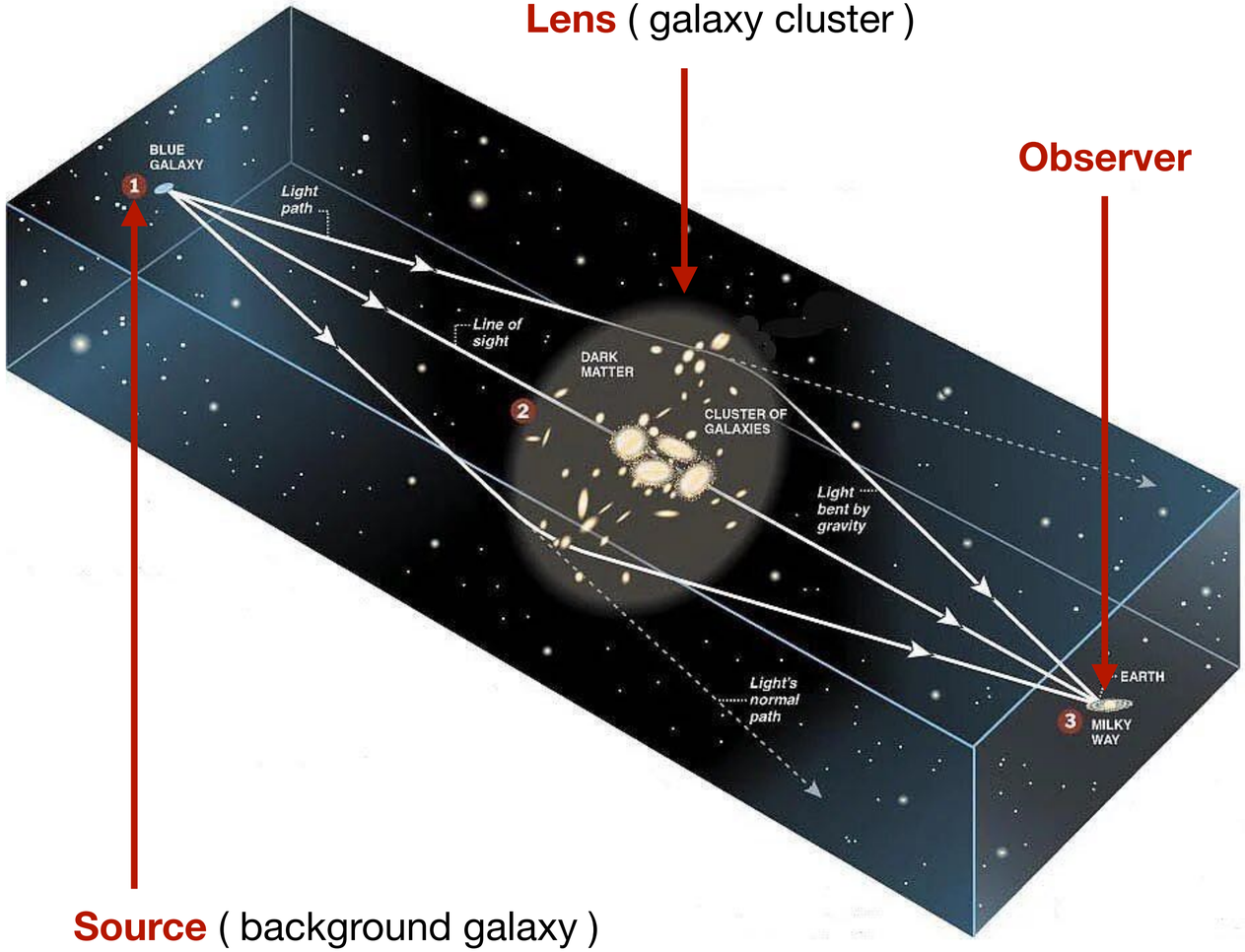

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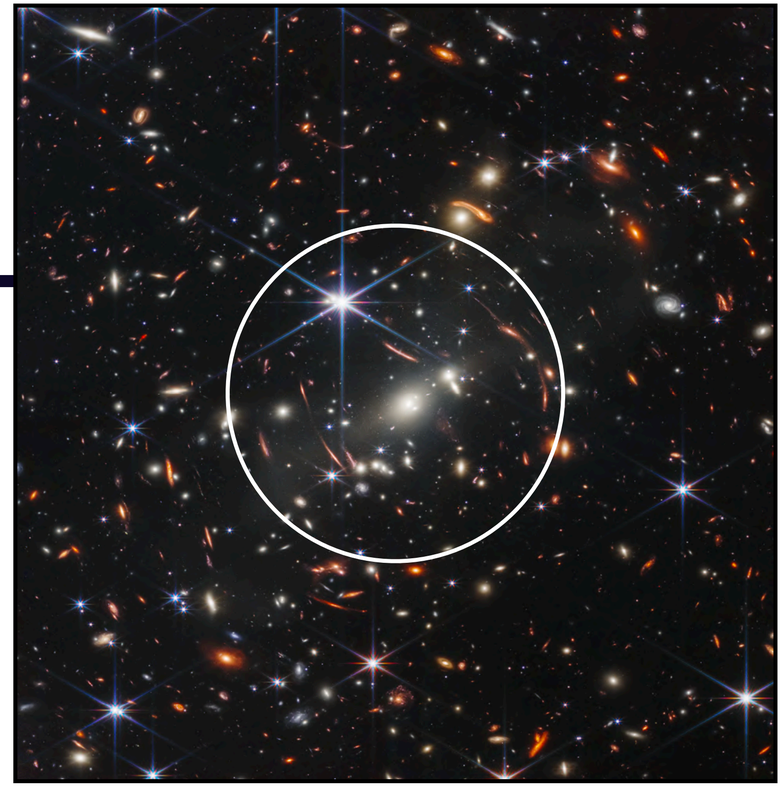

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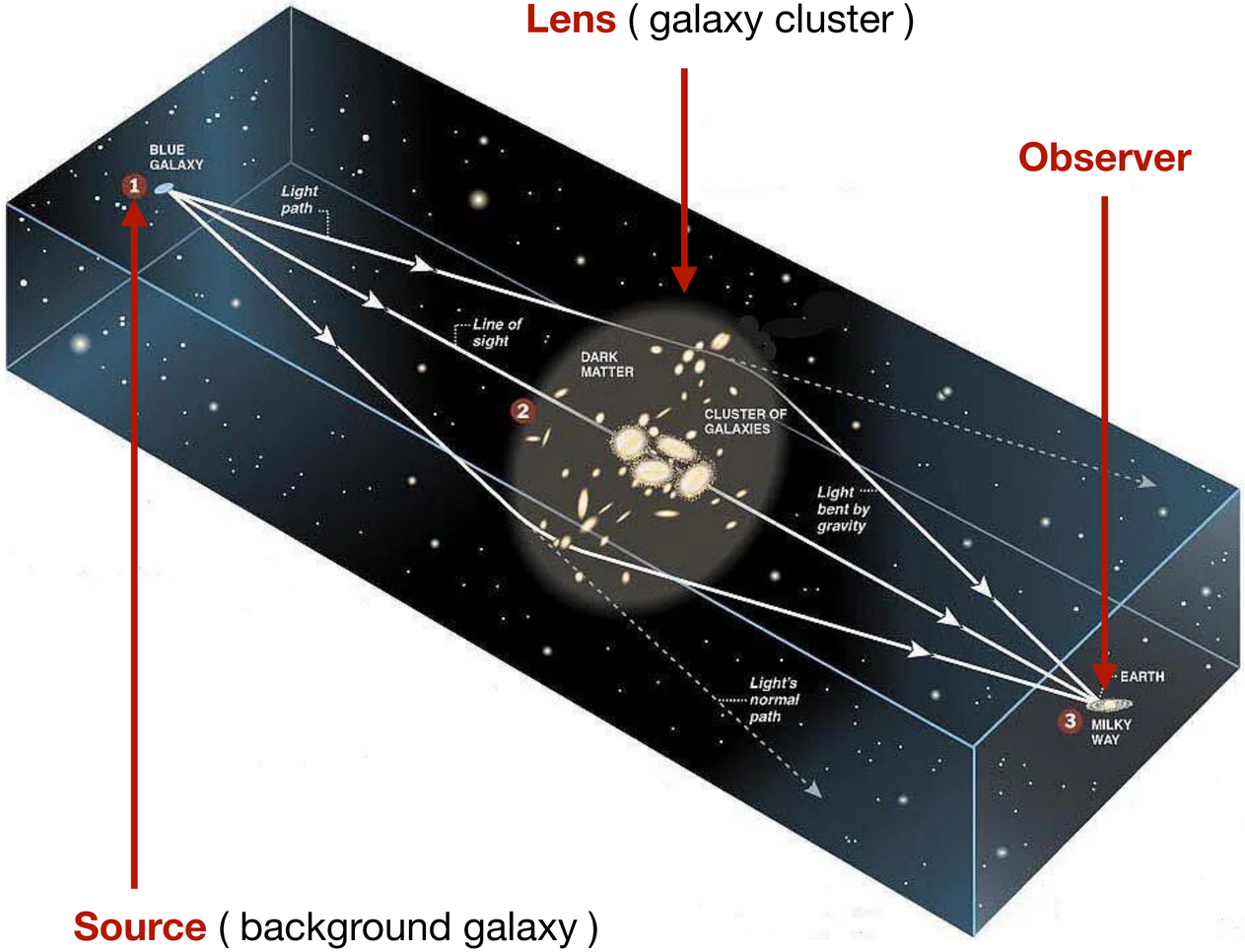

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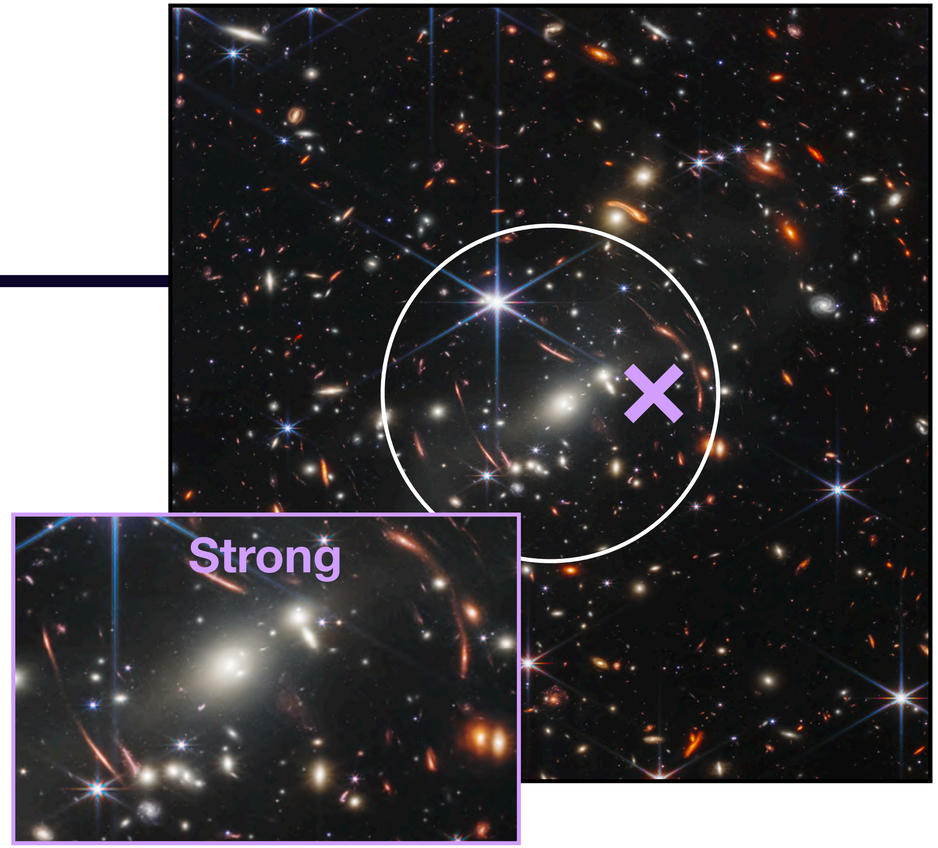

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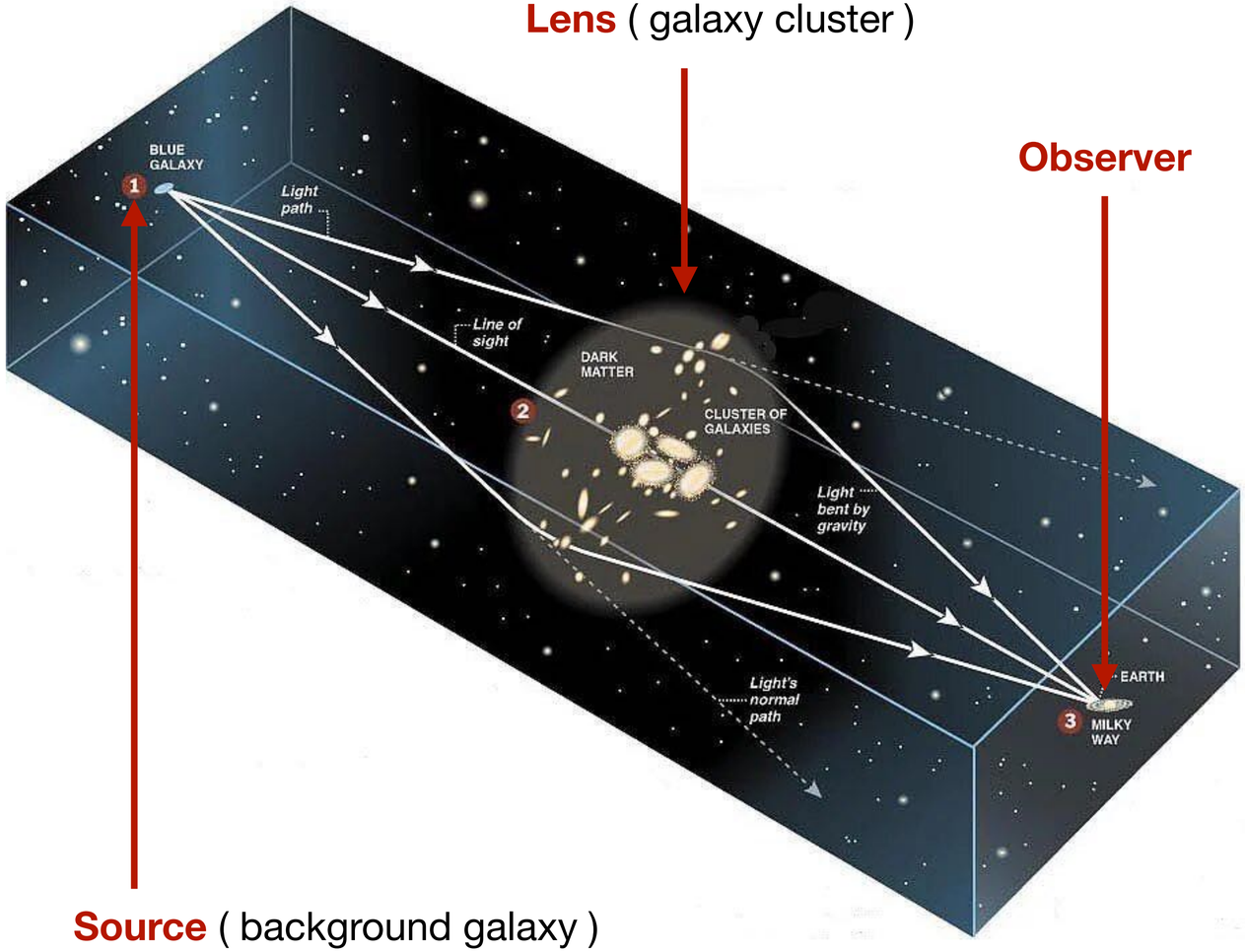

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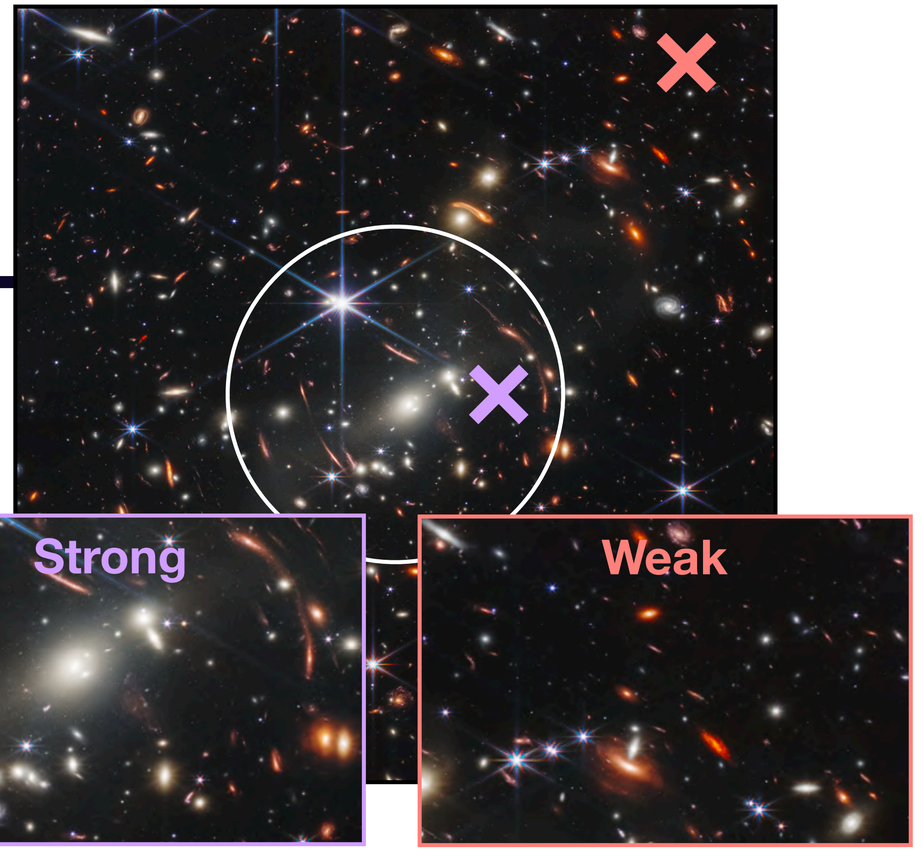

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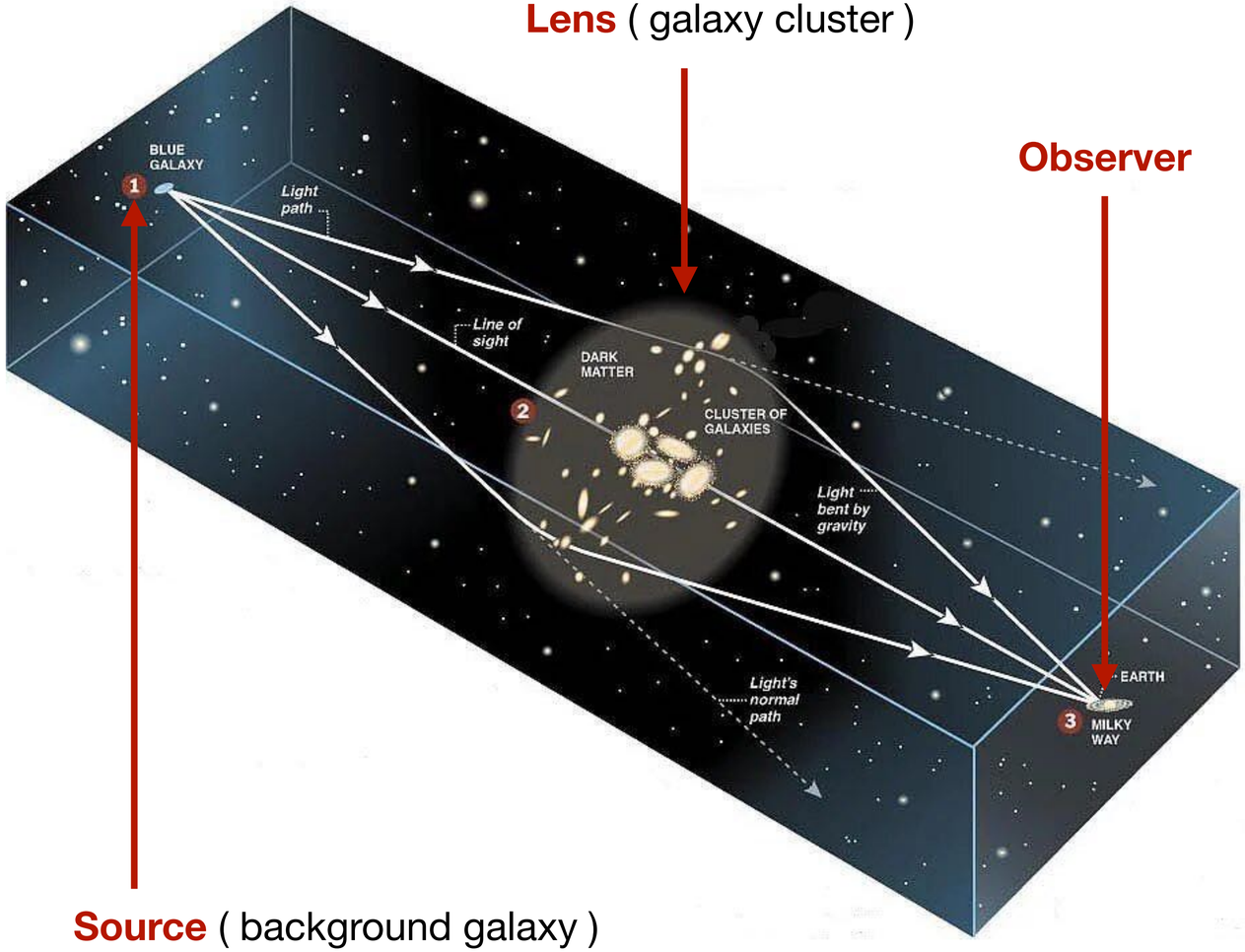
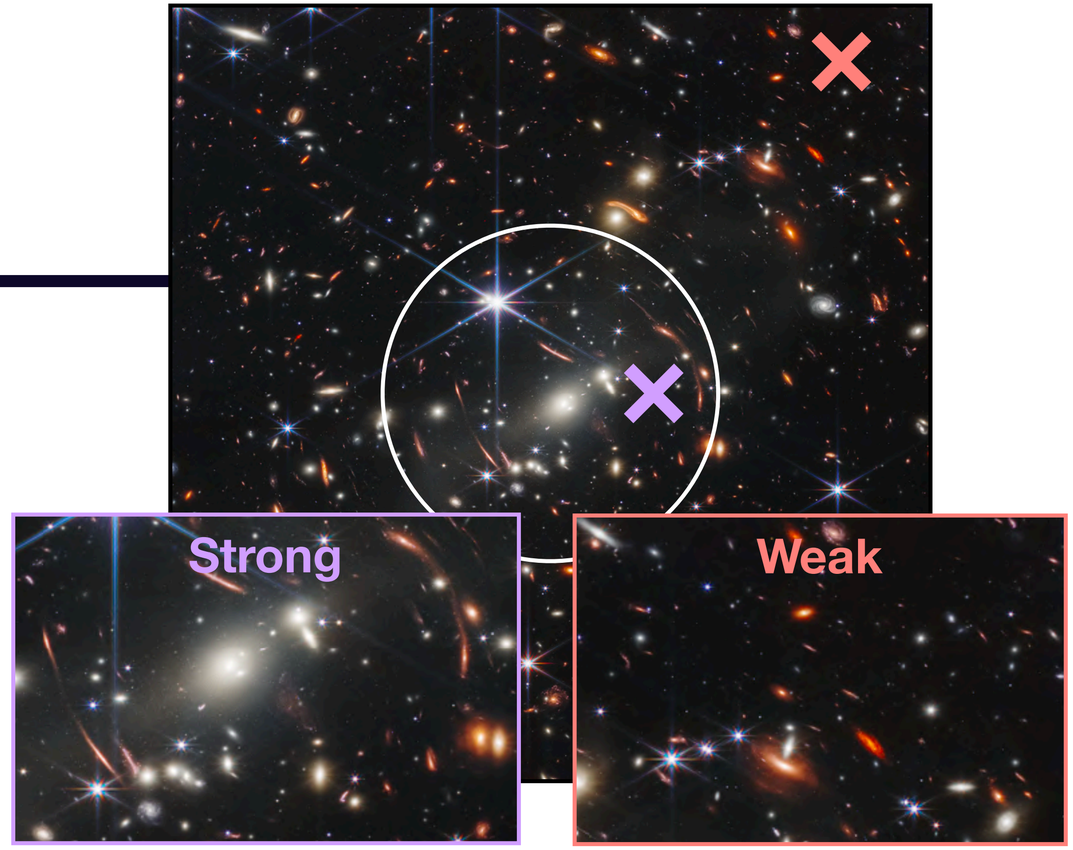


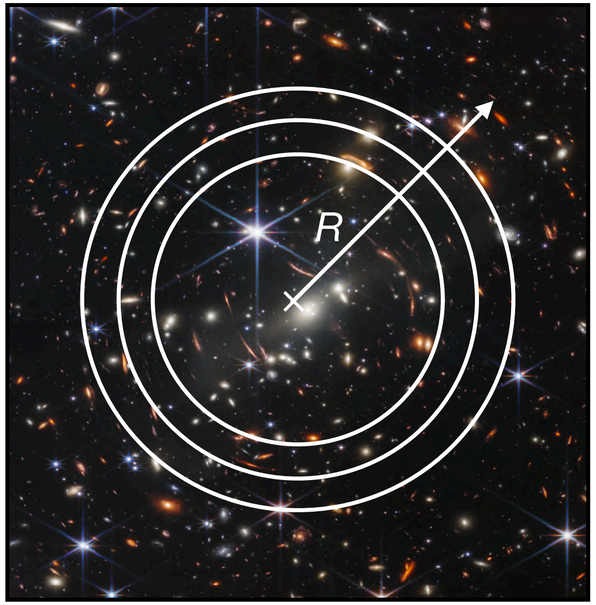


Distorted source shapes ↔ Lens mass

Cluster mass from lensing profile

Fit of the lensing profile = estimate of the galaxy cluster mass

Cluster mass from lensing profile



Fit of the lensing profile = estimate of the galaxy cluster mass

- Excess surface mass density (in $\mathrm{M}_{\odot}\,.\,\mathrm{Mpc}^{-2}$)

$$\widehat{\Delta\Sigma}(R, z_l) = \langle \Sigma_{crit}(z_{gal}, z_l)\ \epsilon_{+}^{obs} \rangle$$

Average on many galaxies

Critical surface mass density

Tangential ellipticity

Cluster mass from lensing profile

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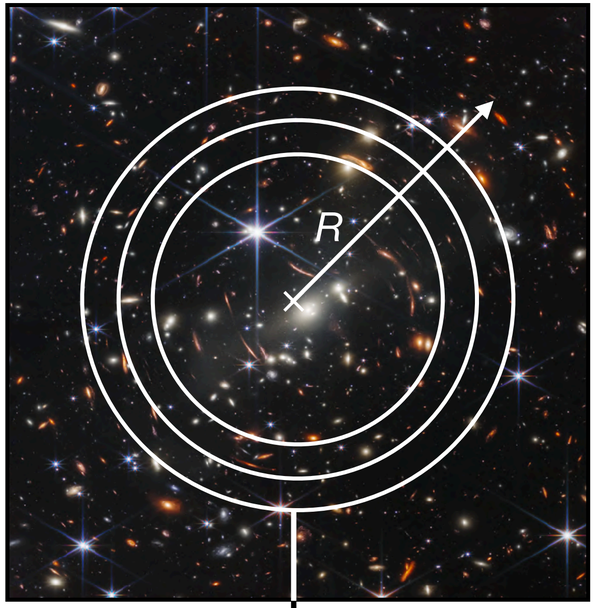

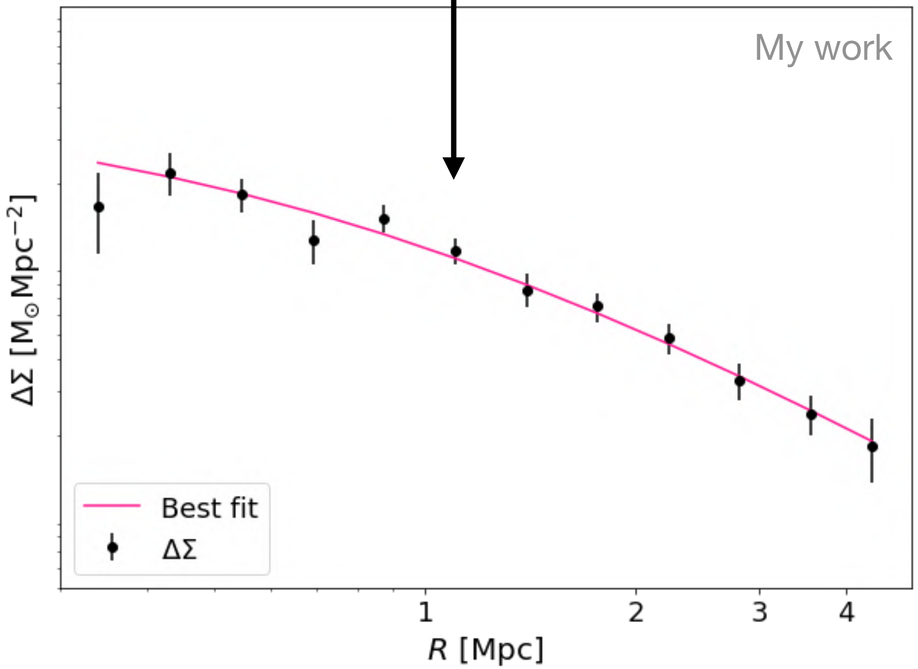

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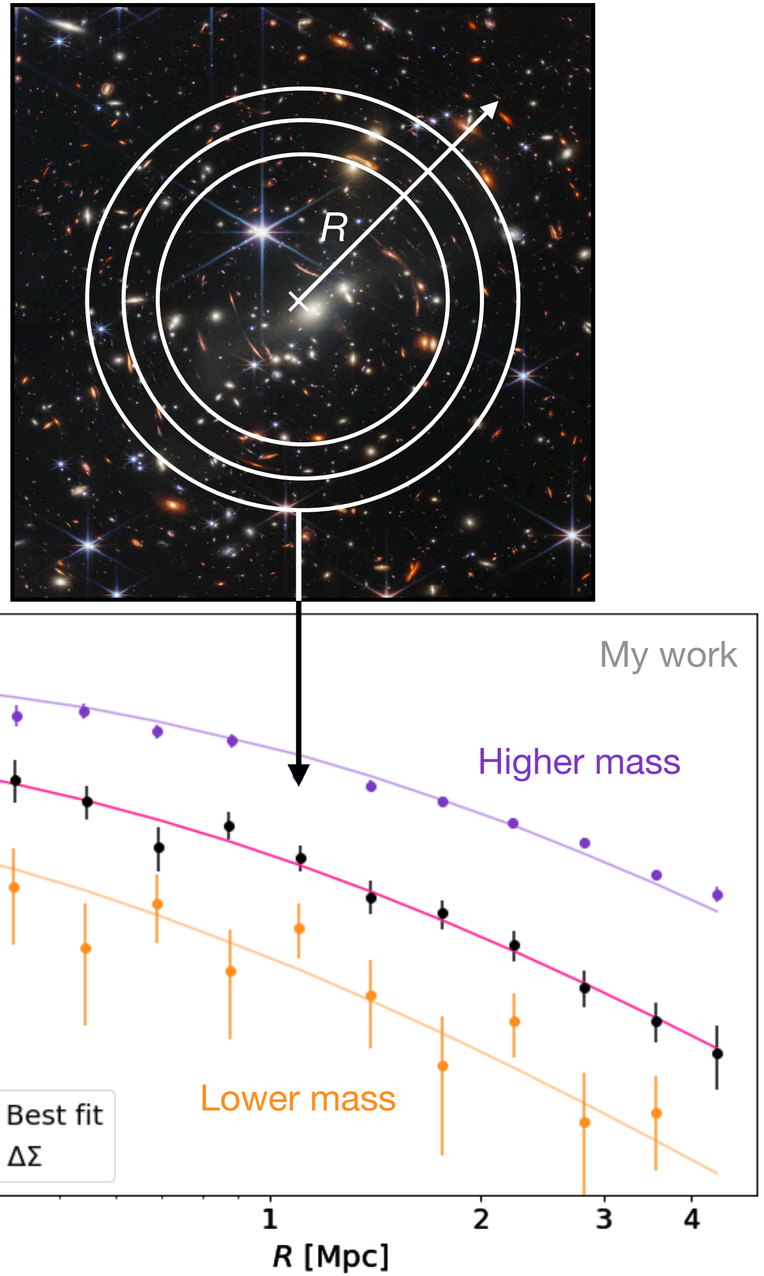

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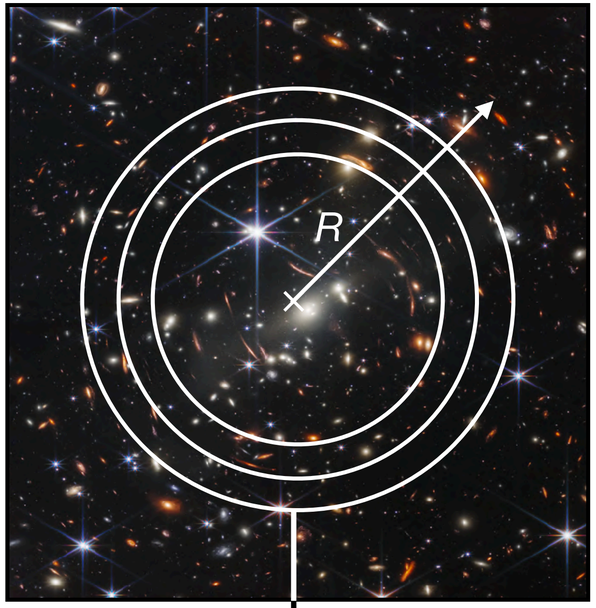
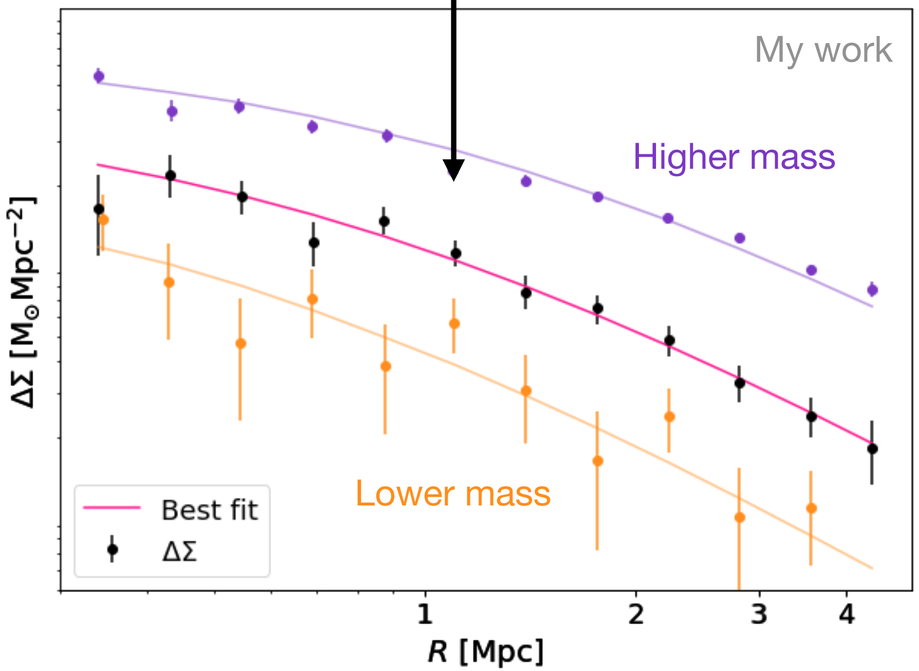
Average on many galaxies

Critical surface mass density → needs redshifts

Tangential ellipticity → needs shapes





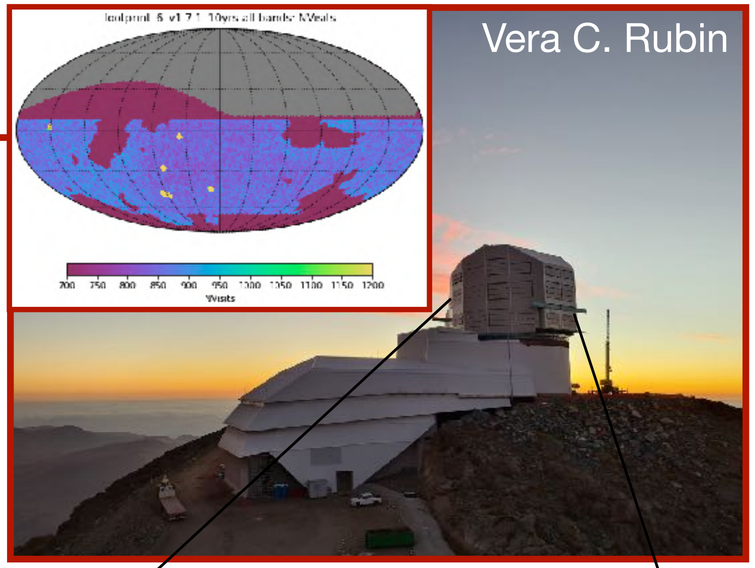
Vera C. Rubin - LSST

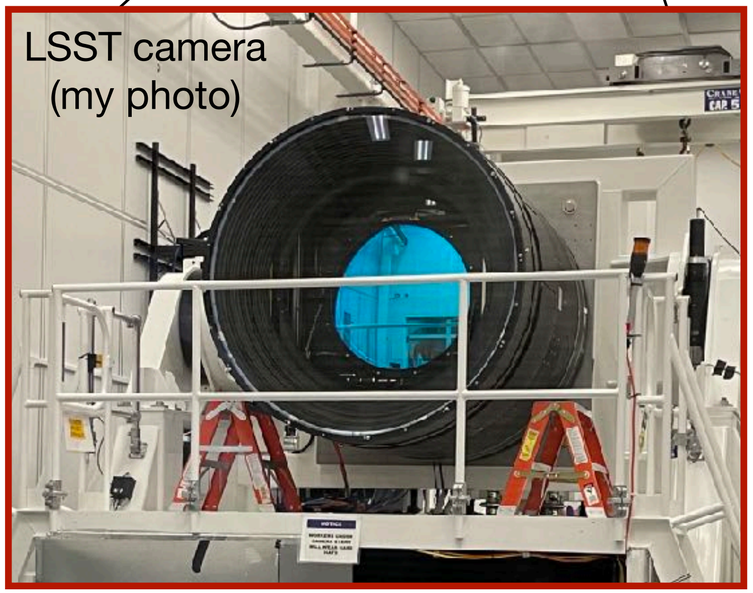
Vera C. Rubin Observatory

- World's largest camera (3 billions pixels)

Legacy Survey of Space and Time - LSST

- **Optical** and **deep** sky survey over 10 years
- First scientific data in **2025**





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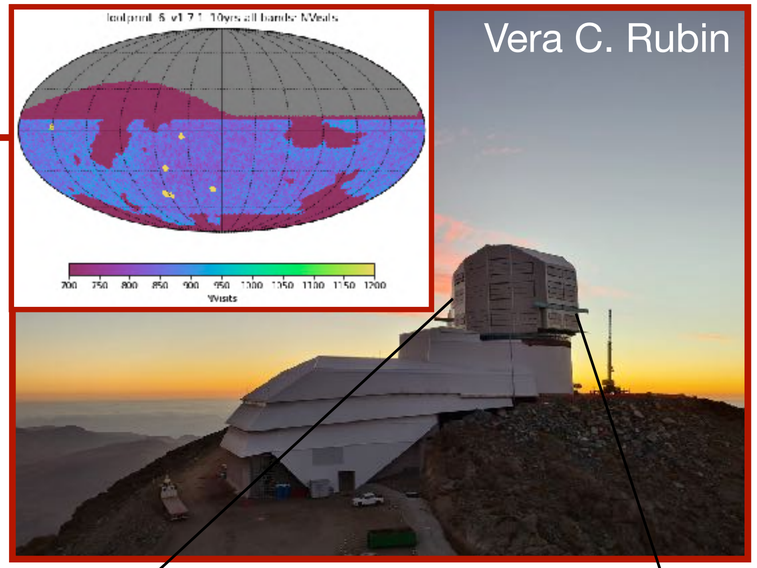

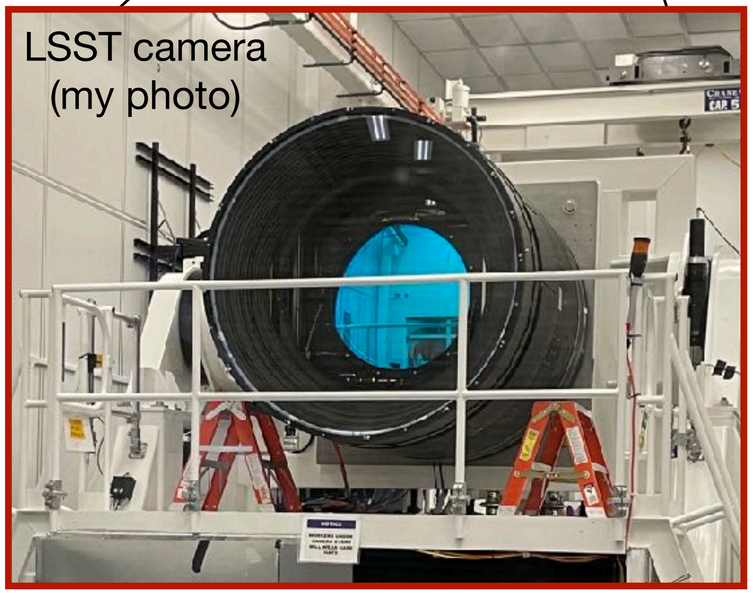

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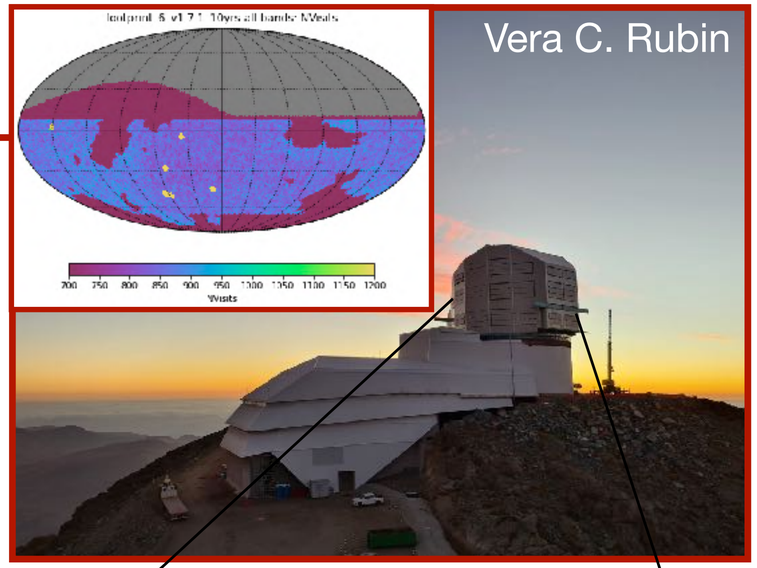

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LSST DESC
Dark Energy Science Collaboration

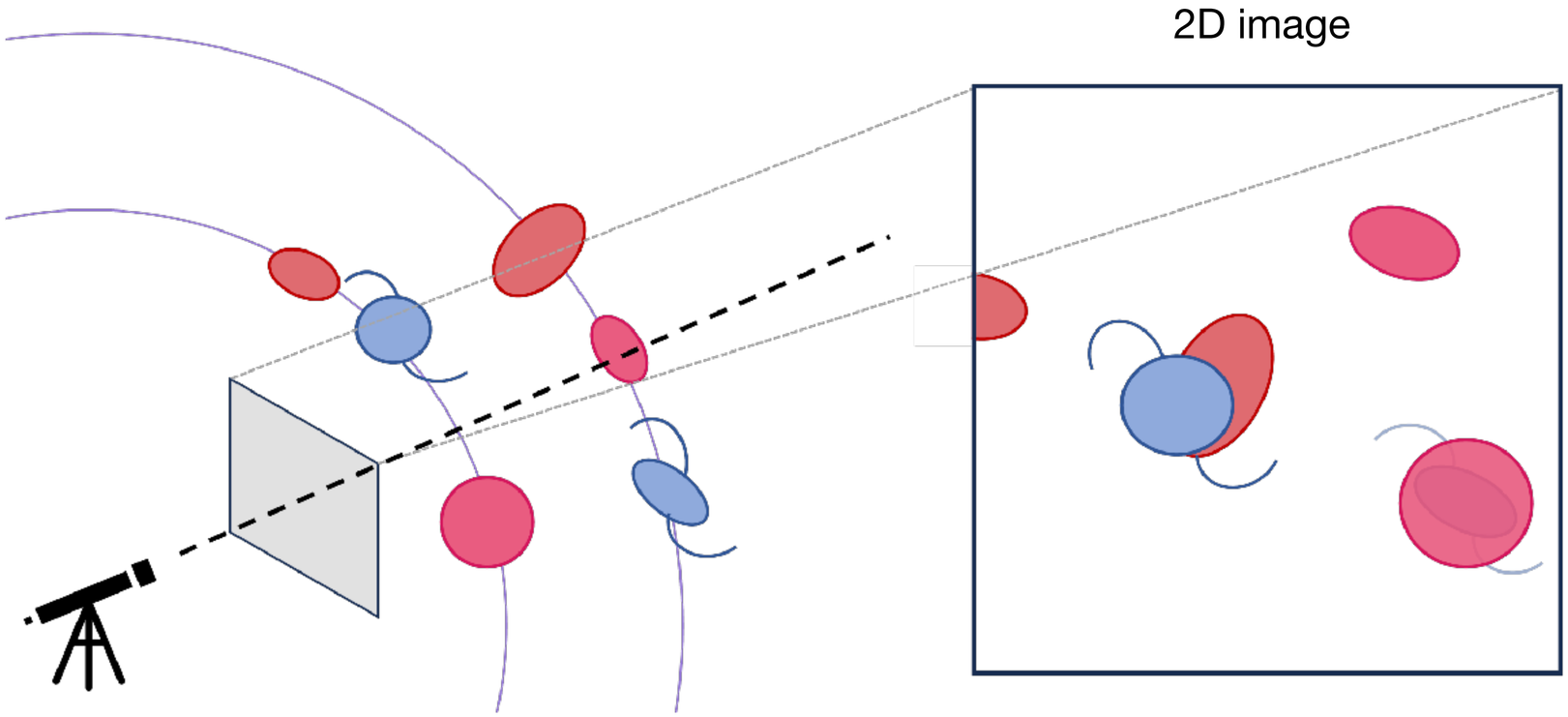
Deepest ground-based survey

Survey	Sky area (deg^2)	# of clusters	# of galaxies
LSST	18,000	100,000	10^{10}
DES	5,000	10,000	7.10^8
HSC	1,400	5,000	10^7

Blending

Superposition of galaxies due to:

- The **depth** of observation
- The survey's **resolution**



Blending

Superposition of galaxies due to:

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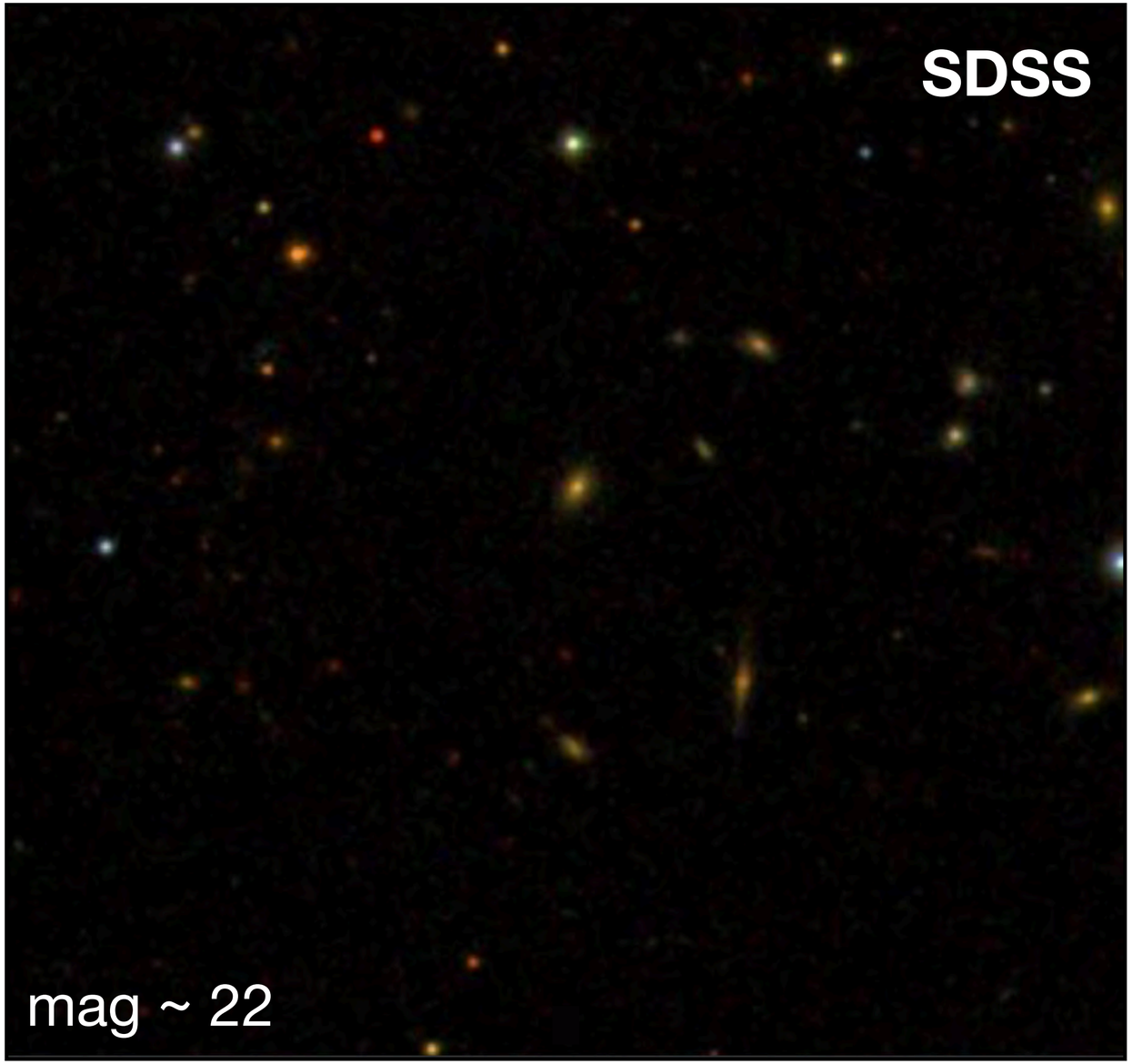
magnitude ~ $-\log_{10}(\text{flux})$

Bright ↔ low magnitude

Faint ↔ high magnitude



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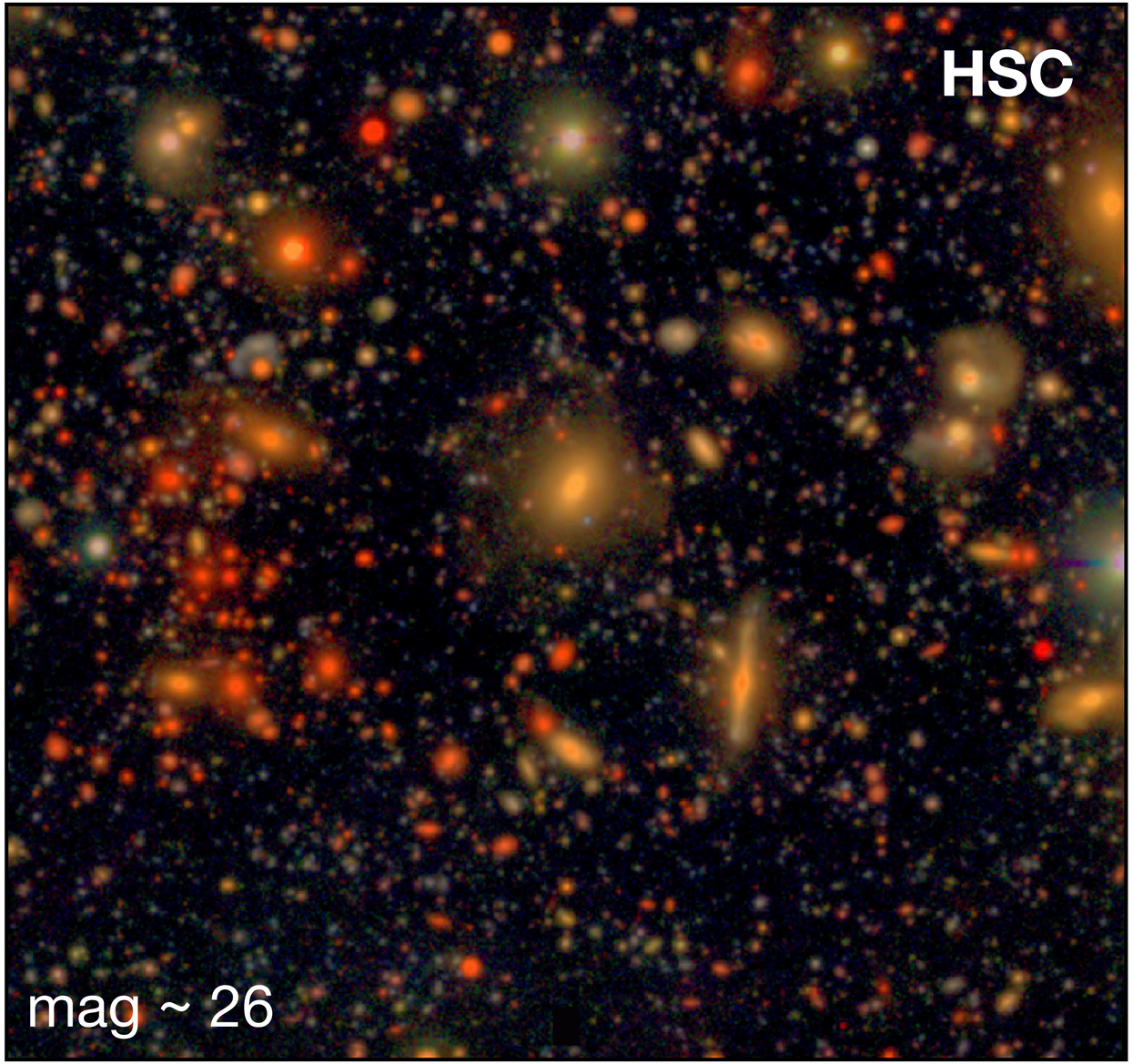

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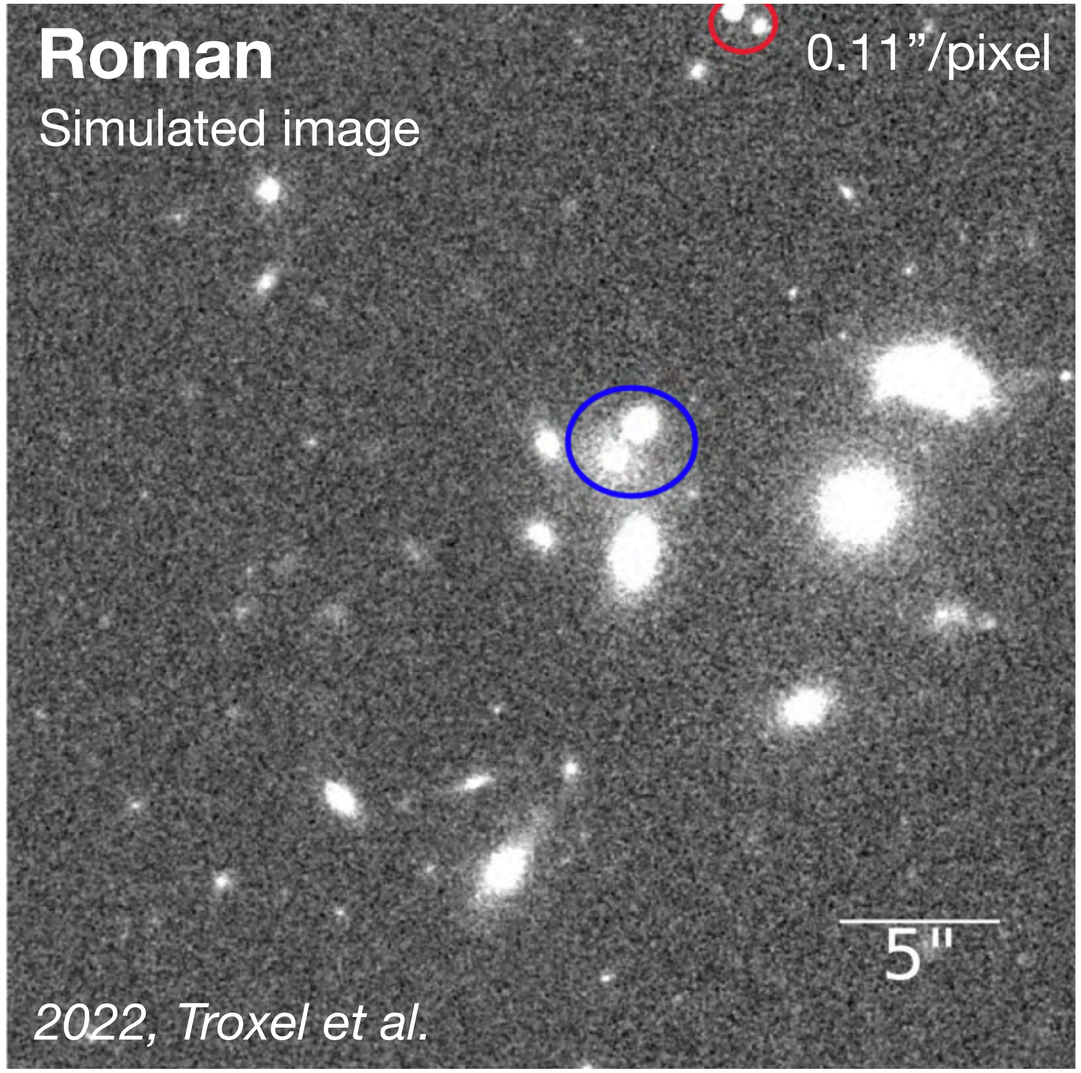

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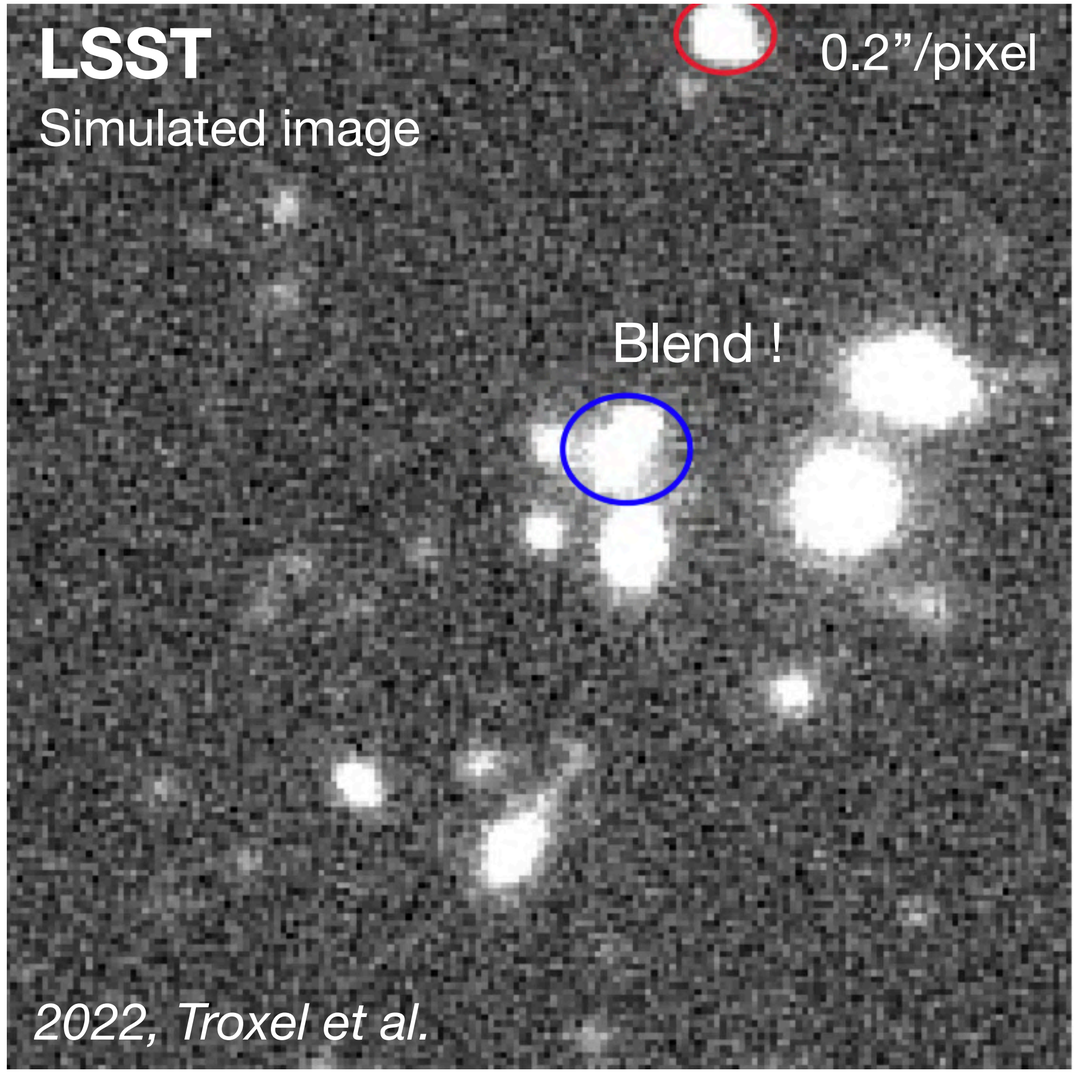
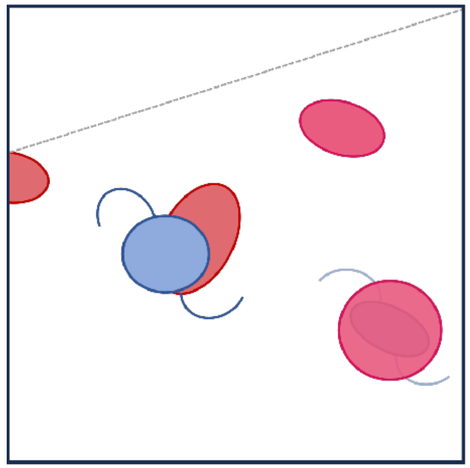


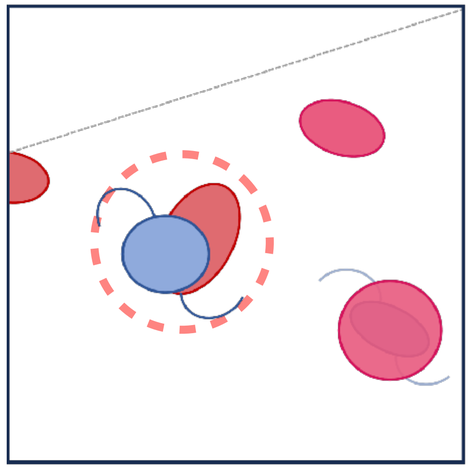
Blending

2D image

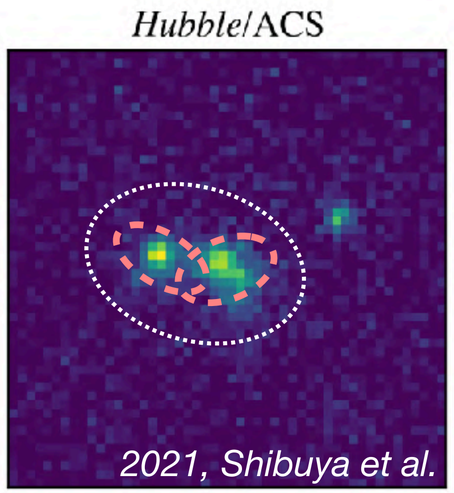


Blending

2D image

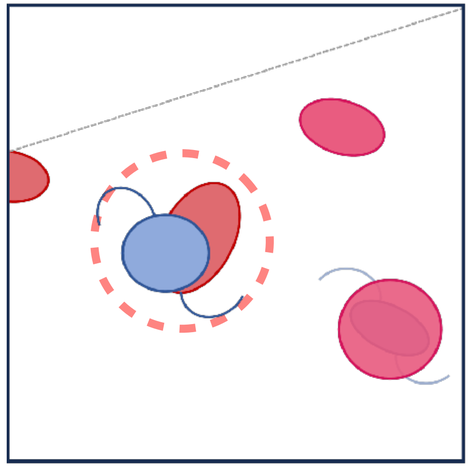


Recognized blends



Blending

2D image



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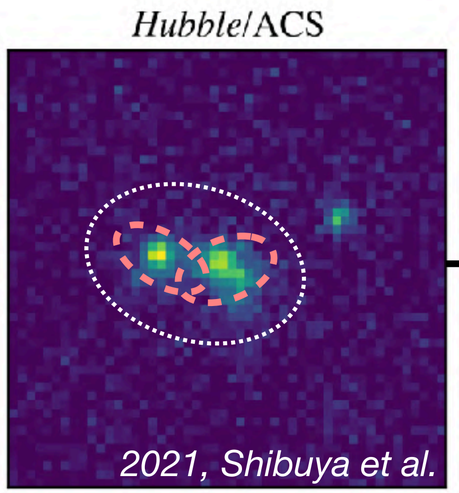
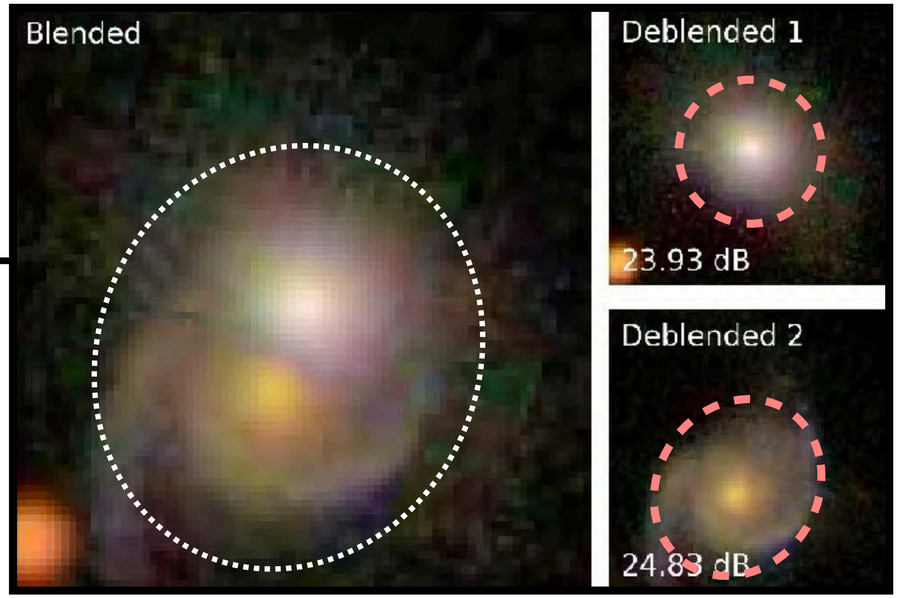


LSST deblender: **SCARLET**



Blending

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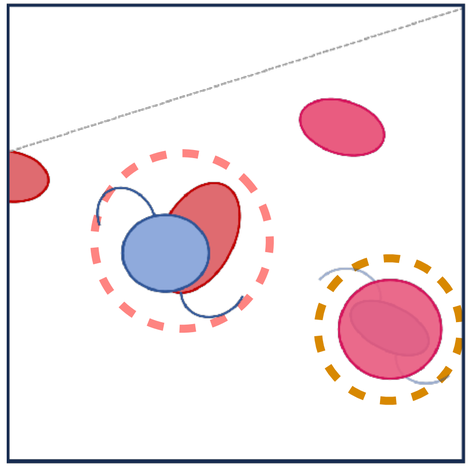
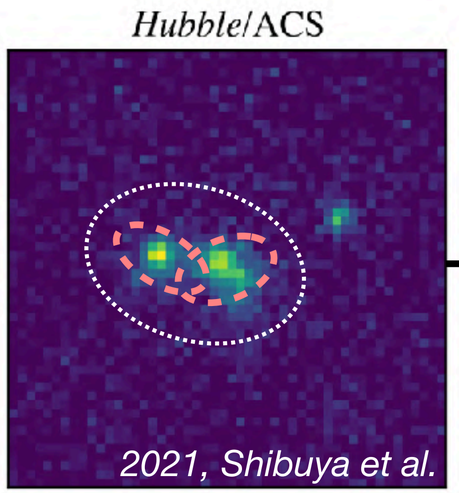
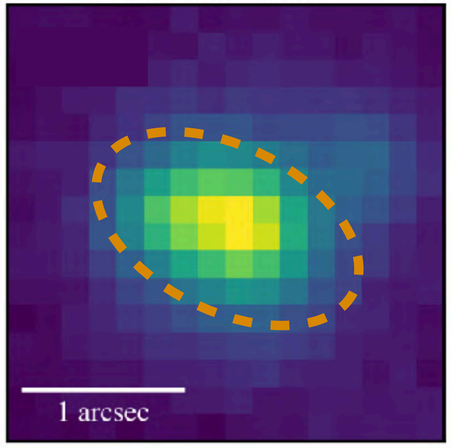


Less resolution

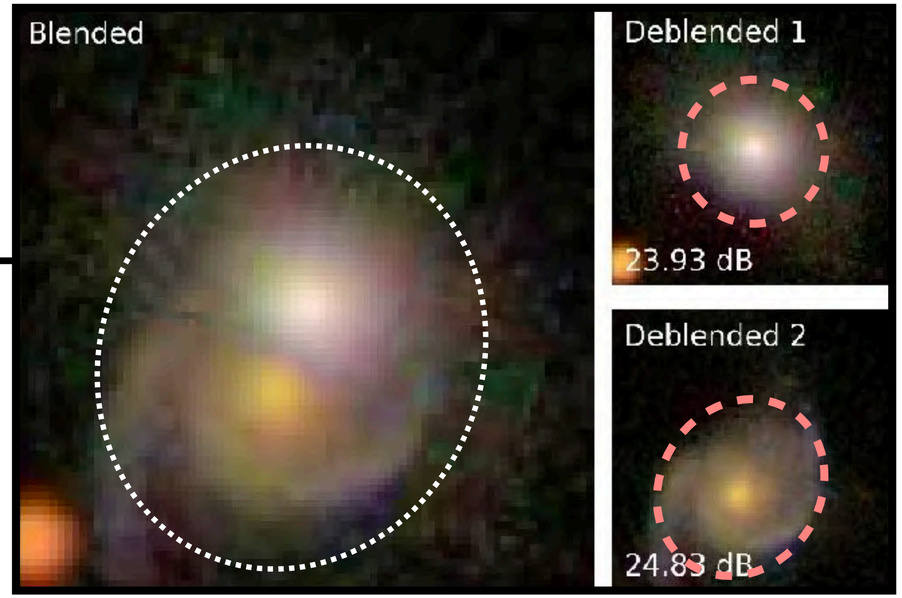
Recognized blends



Unrecognized blends

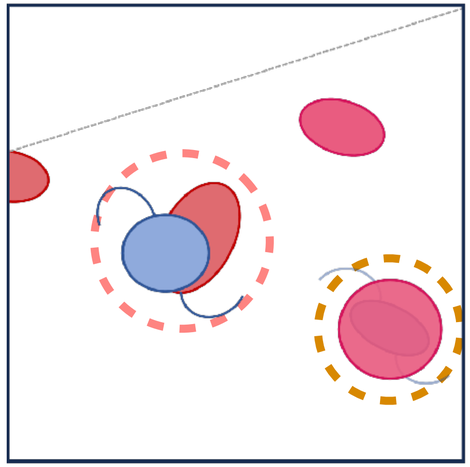


LSST deblender: **SCARLET**



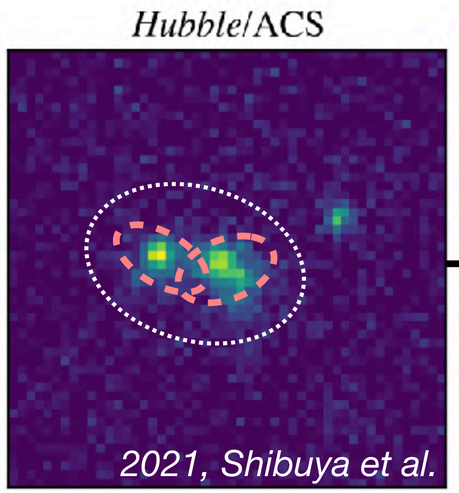
Blending

2D image

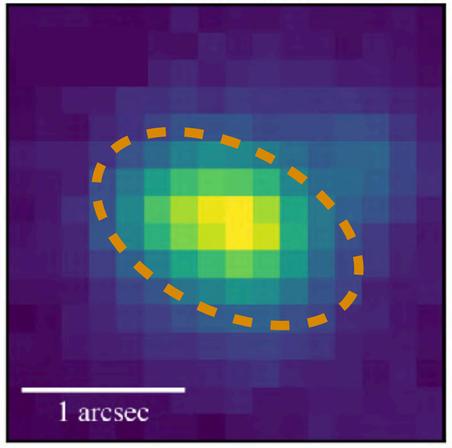


Less resolution

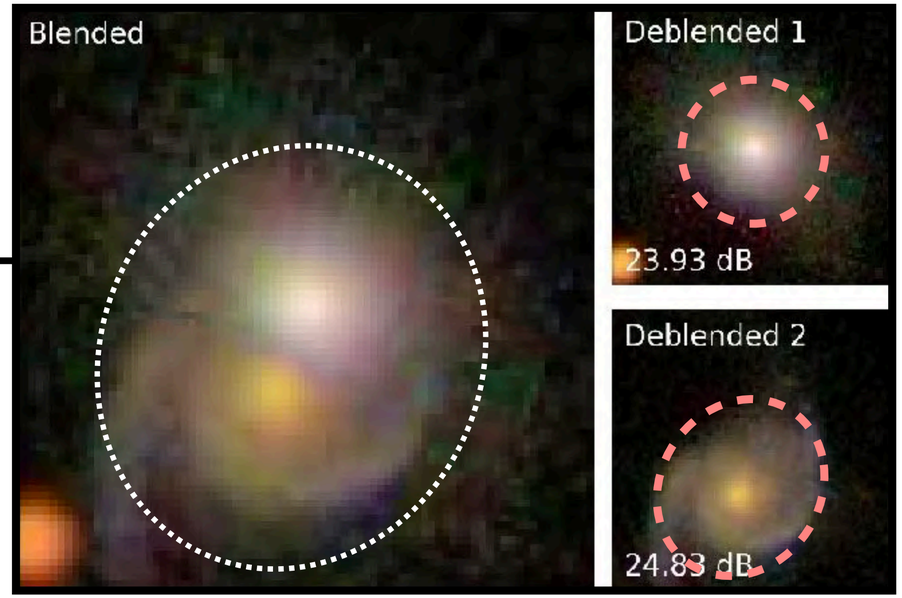
Recognized blends



Unrecognized blends



LSST deblender: **SCARLET**



LSST ~ 60% of blends

- Recognized blends: **~40 %**
- Unrecognized blends: **~14 - 20 %***

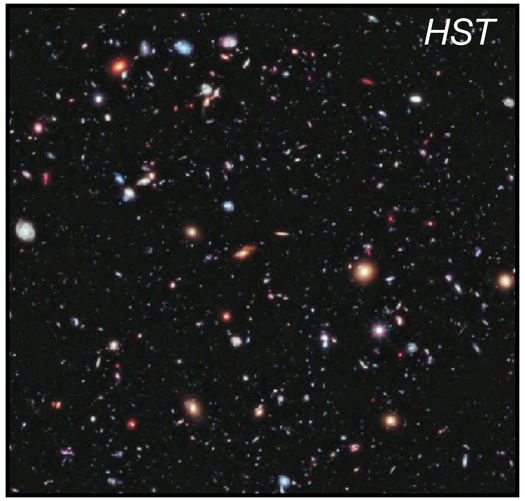
DES ~ 10% of blends

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

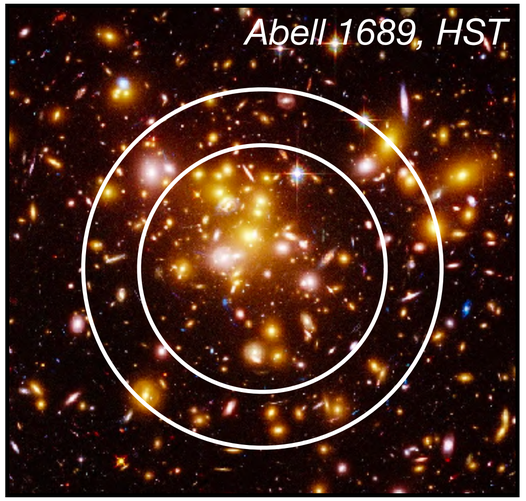
Blending around galaxy clusters

Galaxy clusters = high density regions = **blending**

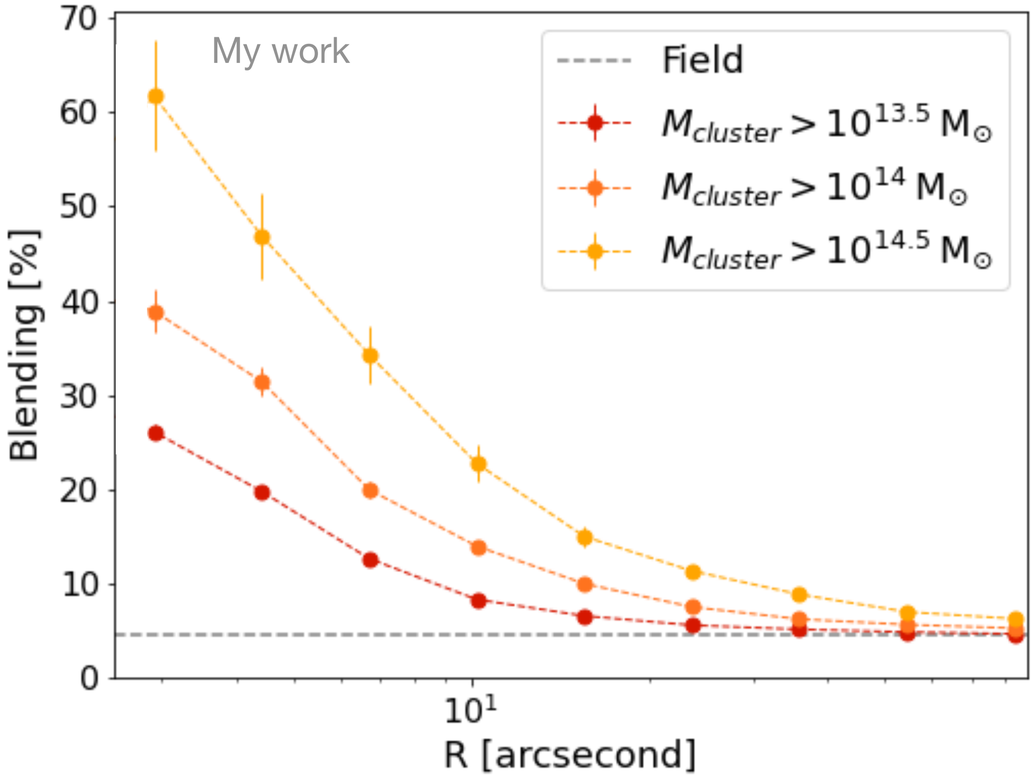
FIELD



CLUSTER



High amount of blending near clusters centres



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Galaxy clusters = high density regions = **blending**

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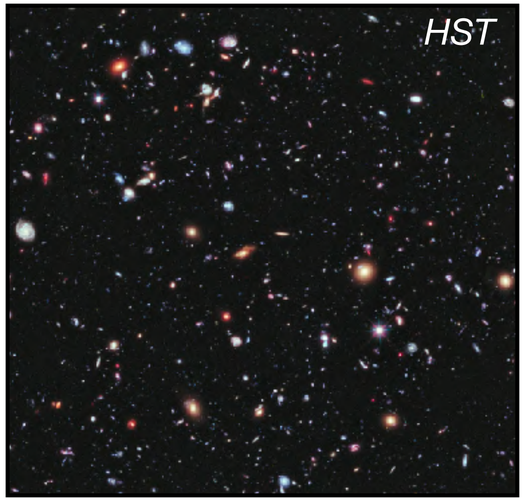
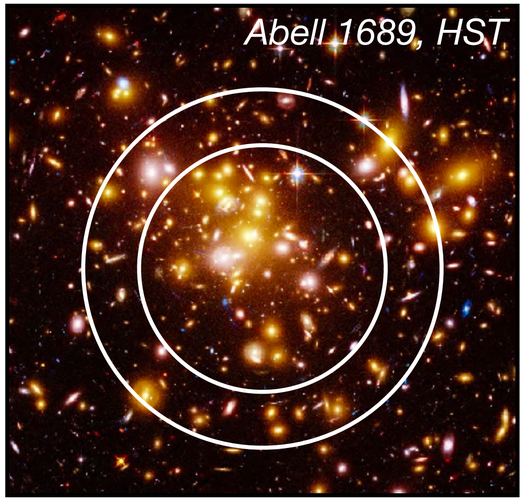


CLUSTER



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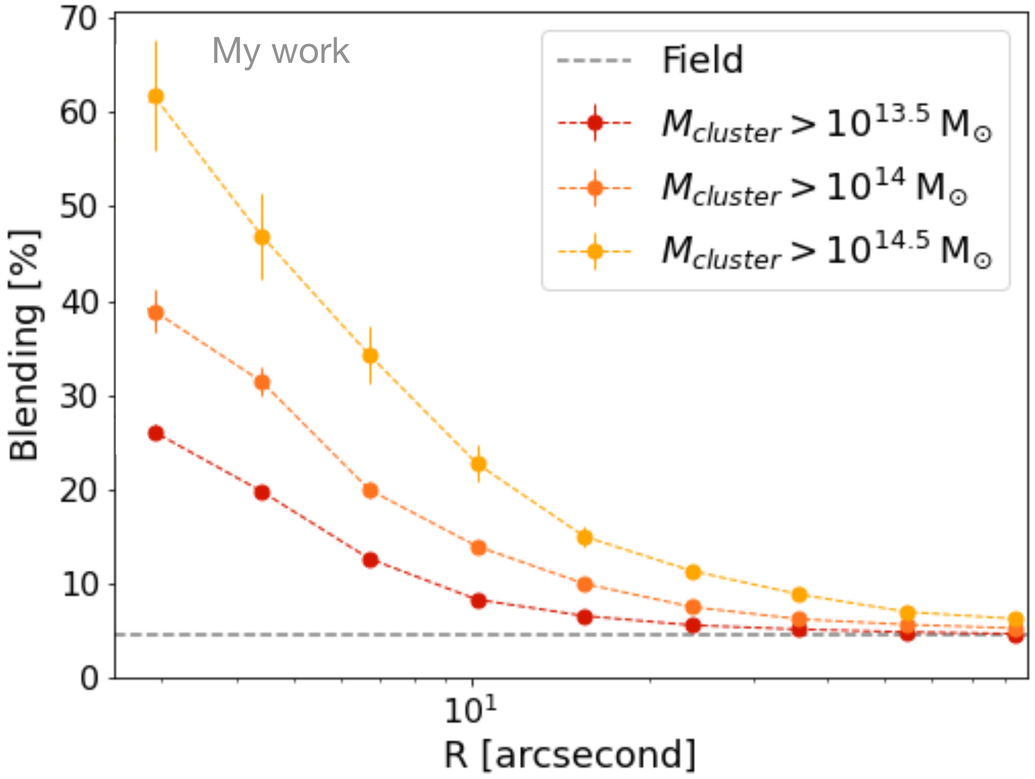

Blending impacts:

- The **detection** of galaxies
- The measurement of **shapes**
- The measurement of **redshifts**

→ WL profiles ↔ galaxy cluster masses ↔ cosmology

My PhD subject

Impact of blending on weak lensing measurements with Rubin-LSST

My PhD subject

Impact of blending on weak lensing measurements with Rubin-LSST

1) Properly **define** what is a blend
2) **Identify** the problematic blends

My PhD subject

Impact of blending on weak lensing measurements with Rubin-LSST

1) Properly **define** what is a blend
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3) **Quantify** the impact on weak lensing profiles
4) **Correct** this impact for unbiased cosmological parameters

My PhD subject

Impact of blending on weak lensing measurements with Rubin-LSST

1) Properly **define** what is a blend
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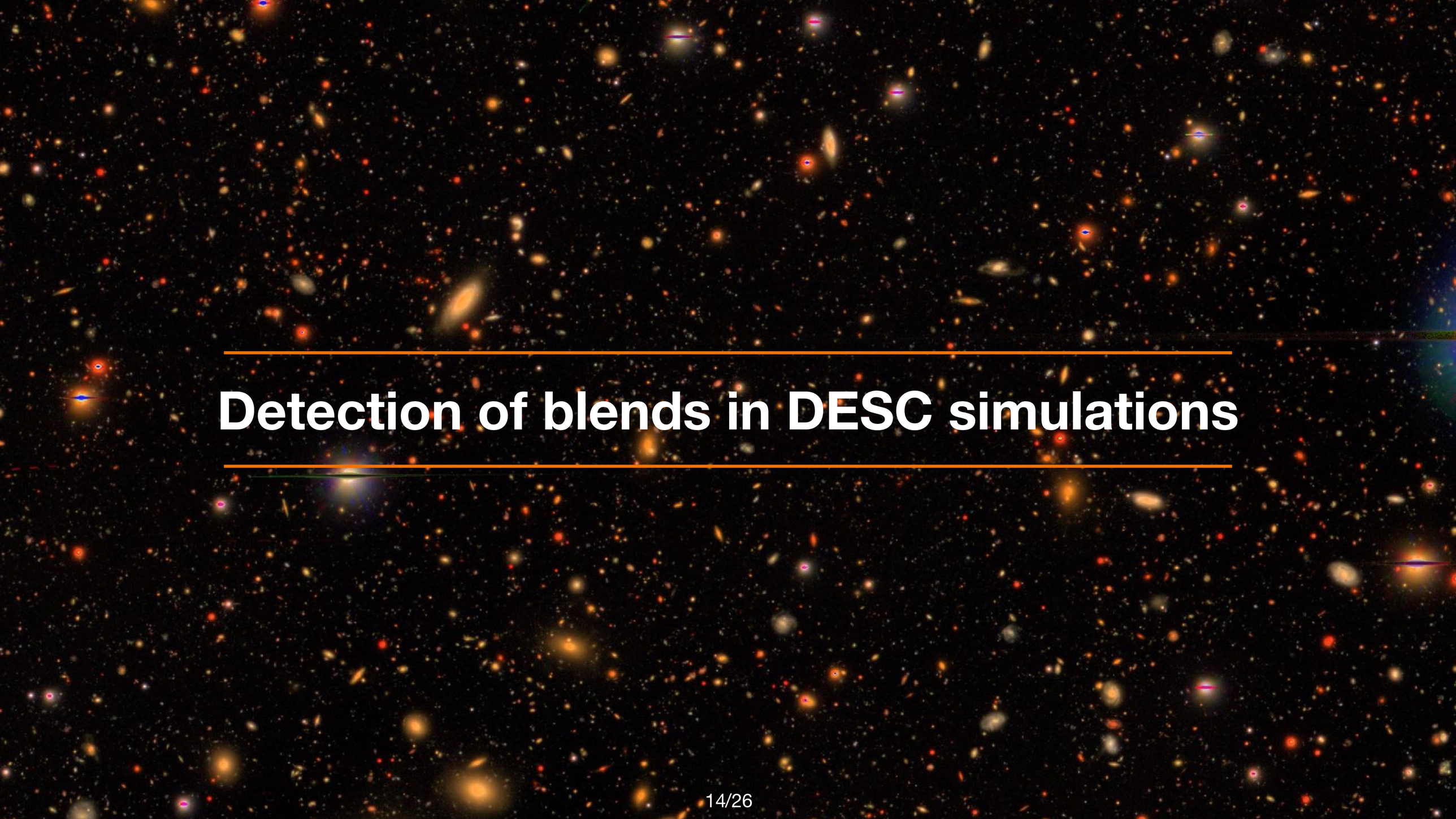
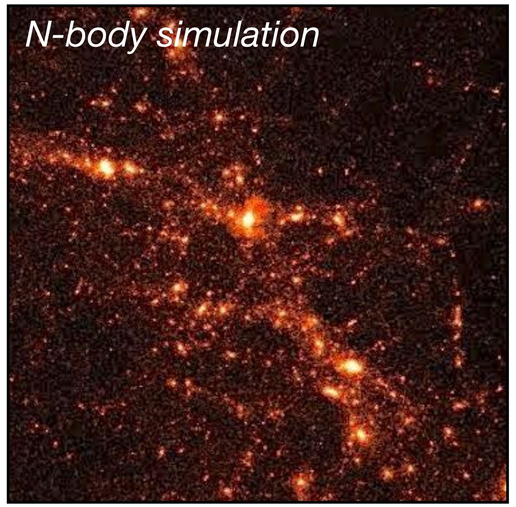
This work is part of the **DESC** collaboration of LSST



Detection of blends in DESC simulations

Simulated catalogs

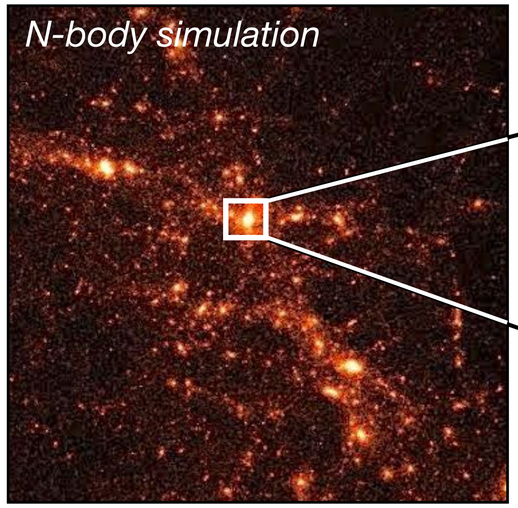


Outer Rim 2019, Heitmann et al.

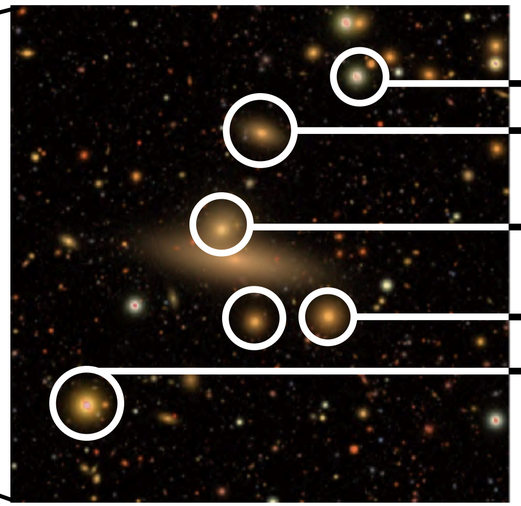
cosmoDC2 = truth catalog

- 440 deg^2 catalog from a N-body simulation
- Reference for **galaxies** and dark matter haloes
- True shapes, brightnesses, positions…

Simulated catalogs



Outer Rim 2019, Heitmann et al.



DESC simulated image

mag_i	ra	e1	dec
24.541830	58.200397	−0.141020	−35.702272
26.177008	58.179060	0.173040	−35.702067
24.806880	58.100637	0.138385	−35.702437
25.883955	58.151774	−0.505306	−35.701759
...	...	...	...
26.582999	56.529076	−0.210661	−34.322543
27.233892	56.628691	−0.630063	−34.278873

Observational effects included !

<u>cosmoDC2</u> = truth catalog

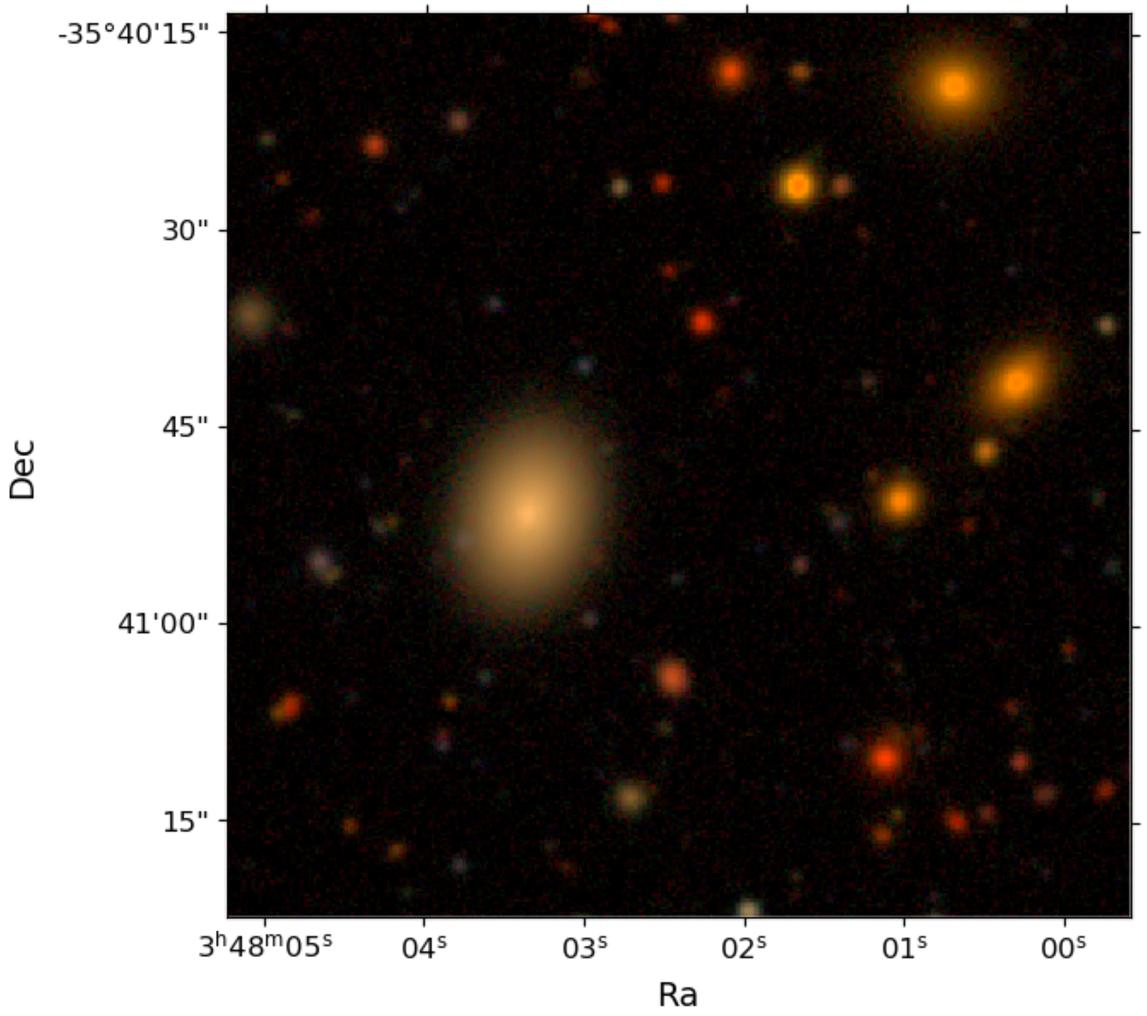
- 440 deg^2 catalog from a N-body simulation
- Reference for **galaxies** and dark matter haloes
- True shapes, brightnesses, positions…

<u>DC2object</u> = object catalog

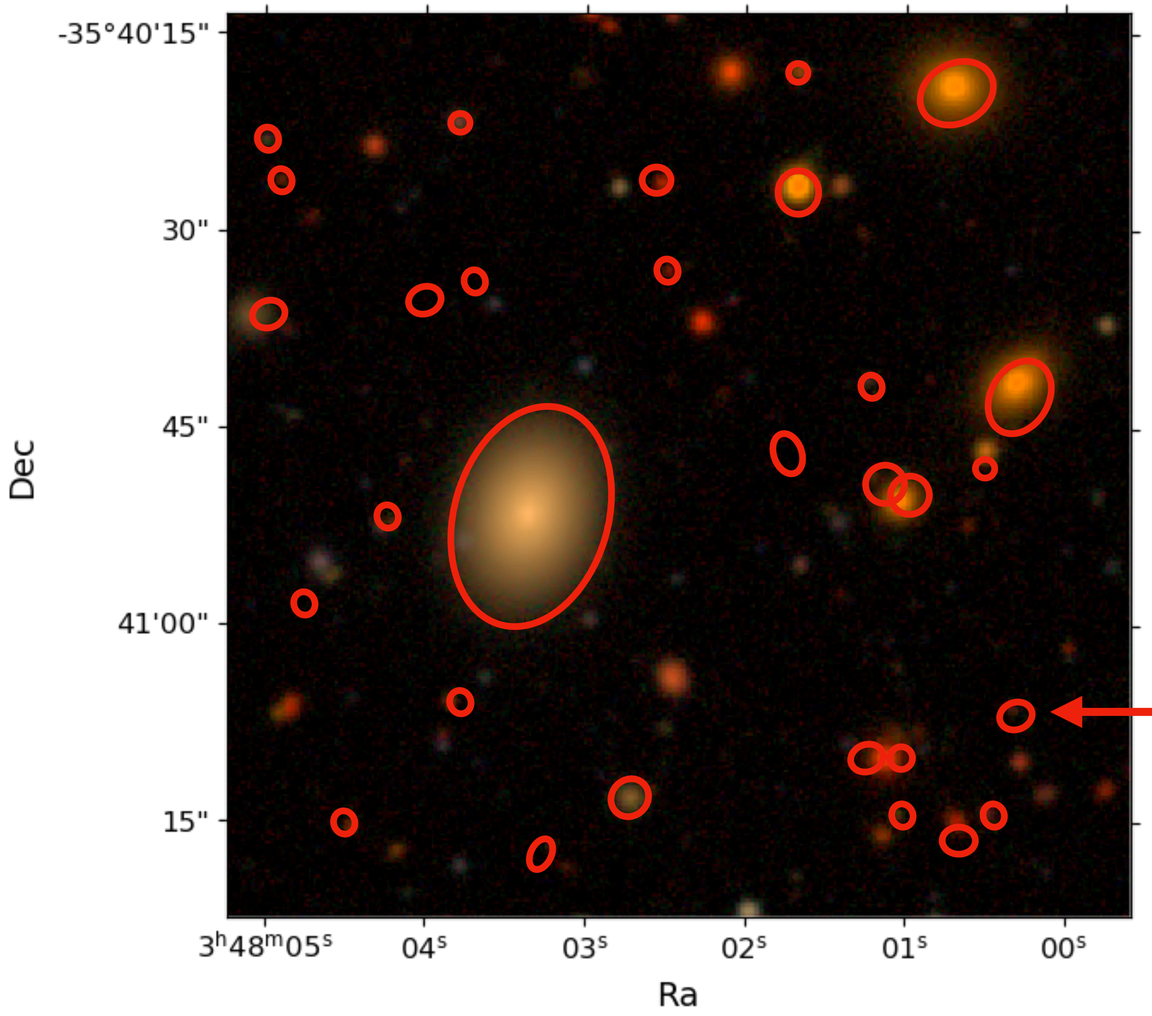
- Simulated images from cosmoDC2
- Detection of **objects**
- Measured shapes, brightnesses, positions

Identification of blends through catalog matching

Importance of catalog matching

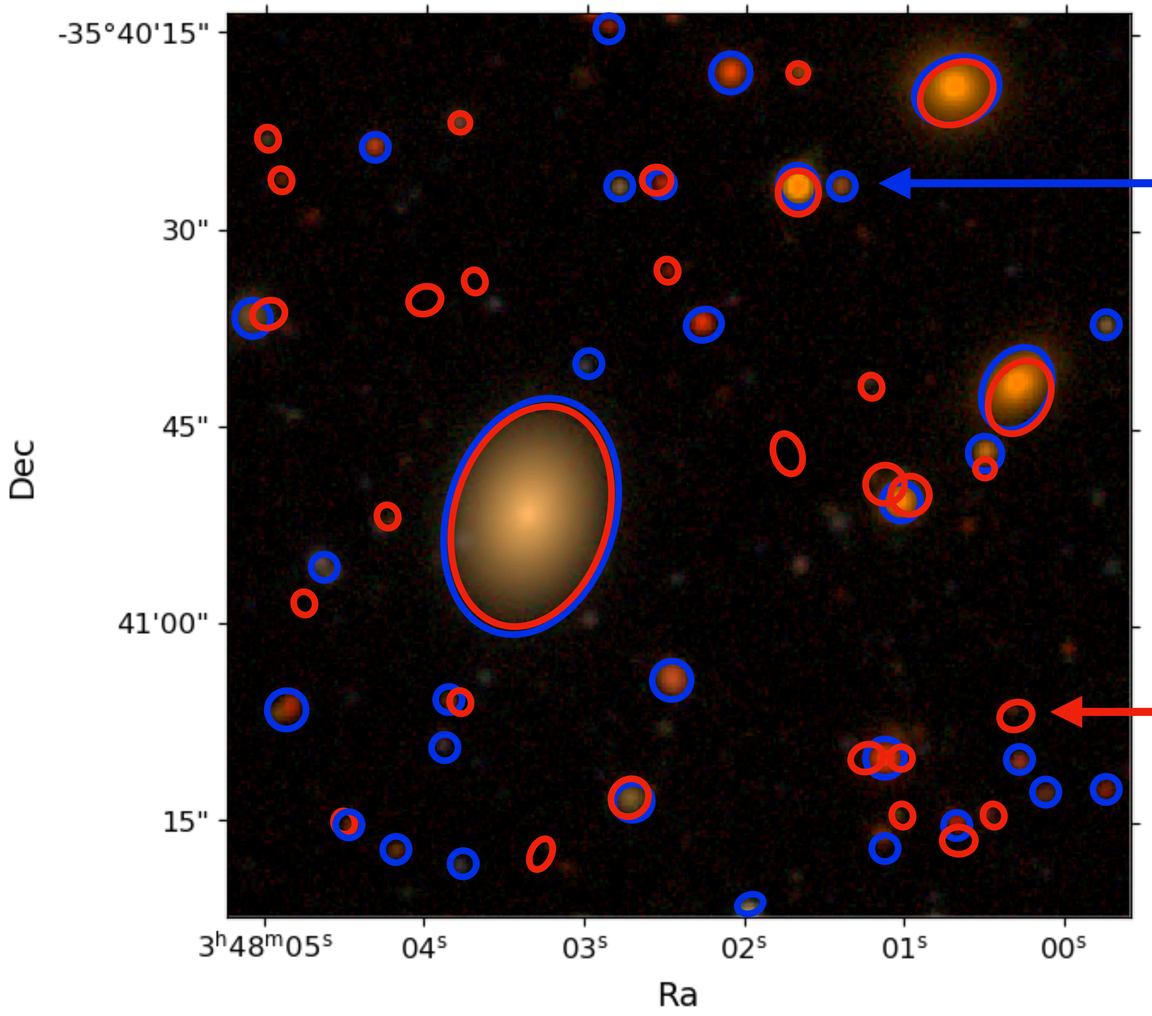


Importance of catalog matching



Truth galaxy
(cosmoDC2)

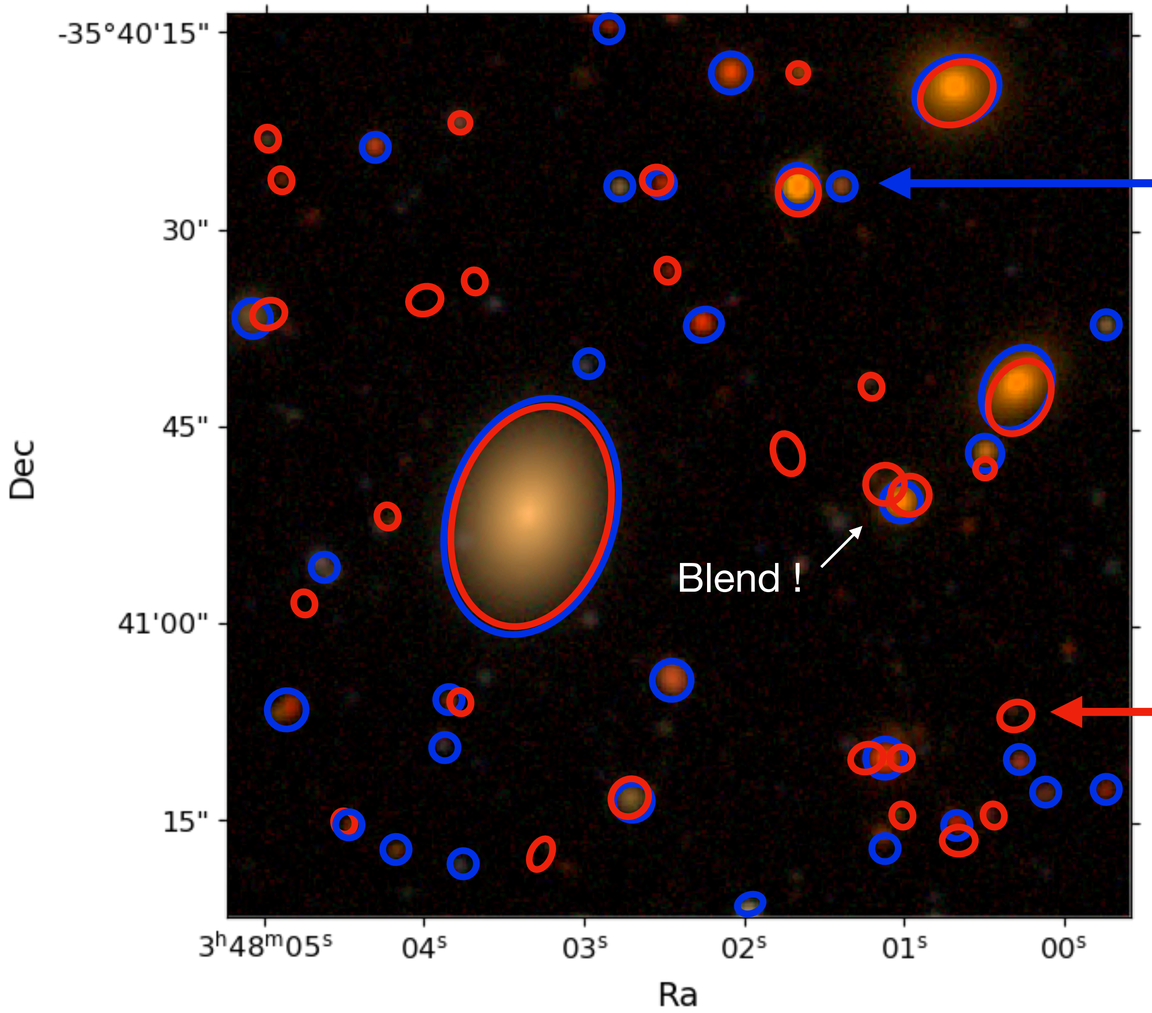
Importance of catalog matching



Detected object
(DC2object)

Truth galaxy
(cosmoDC2)

Importance of catalog matching



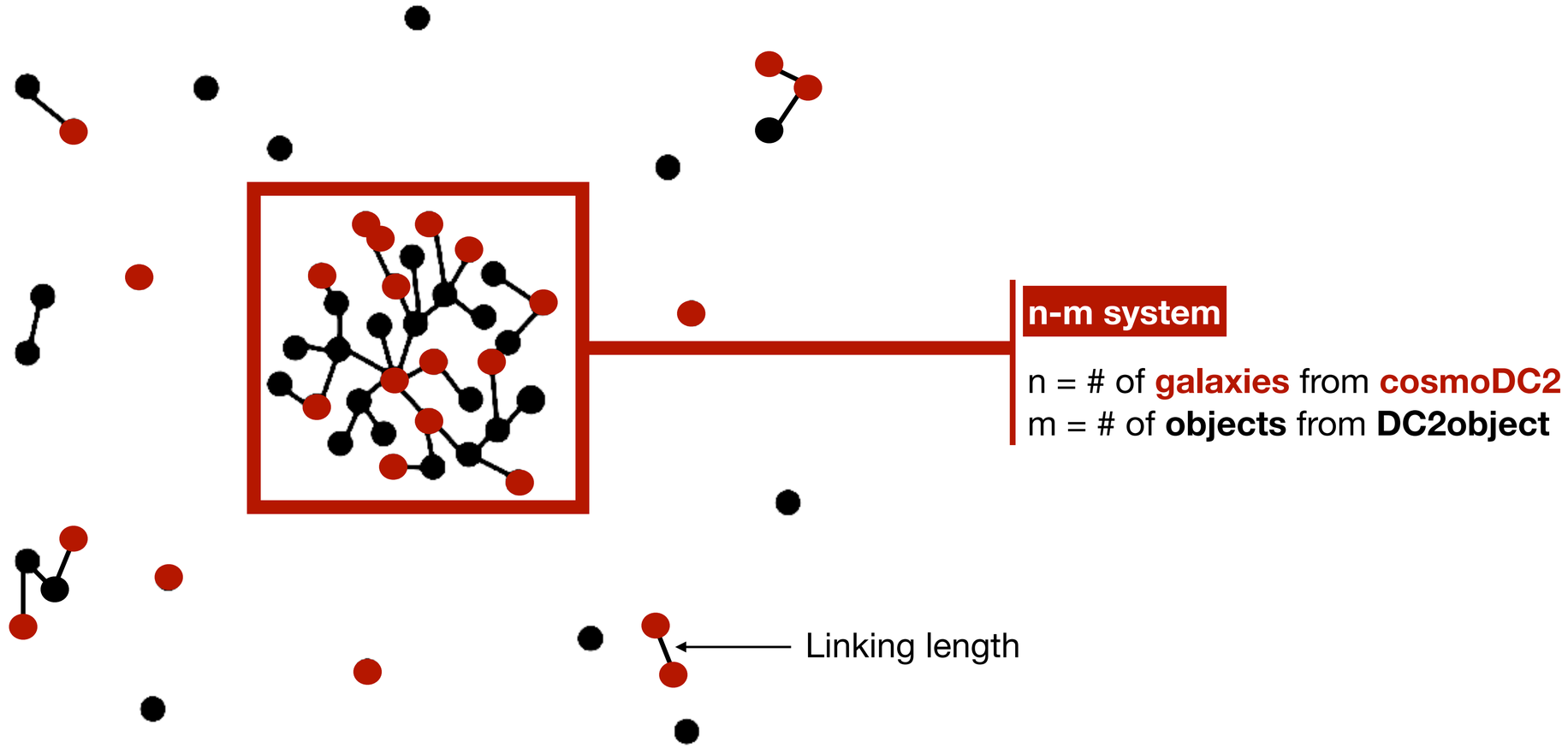
Detected object
(DC2object)

Truth galaxy
(cosmoDC2)

Catalogs matching = groups of blended systems

Matching procedure: Friends-of-Friends

https://github.com/yymao/FoFCatalogMatching



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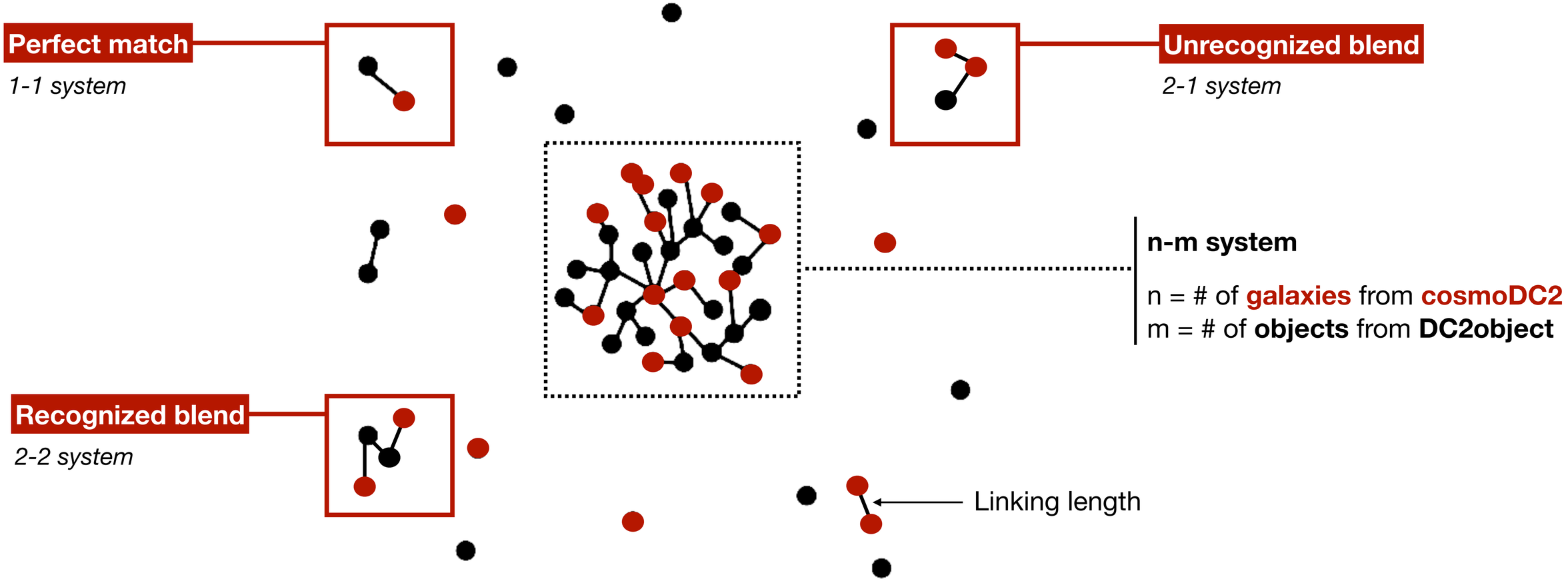
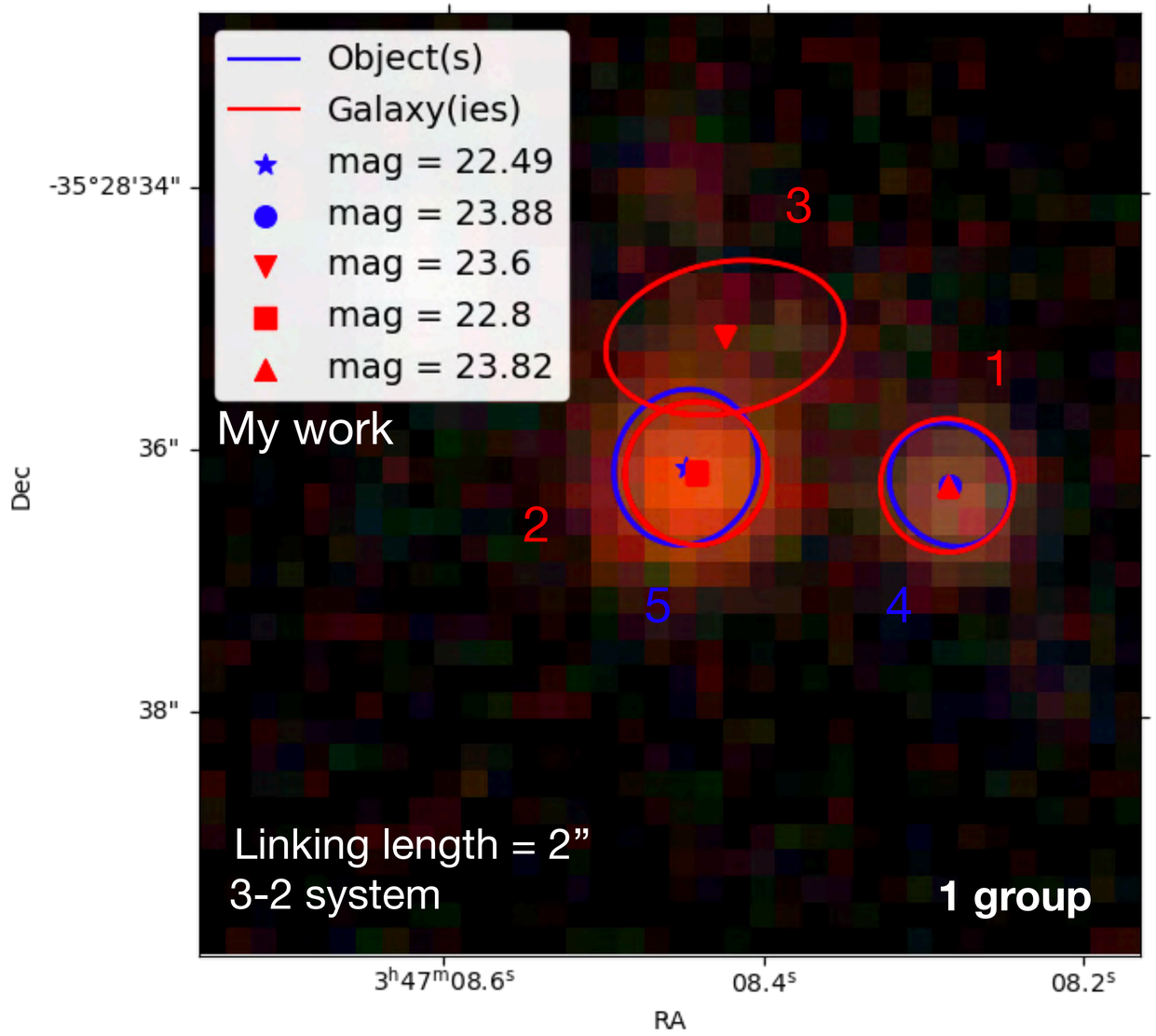


https://github.com/LSSTDESC/friendly

Matching procedure: friendly



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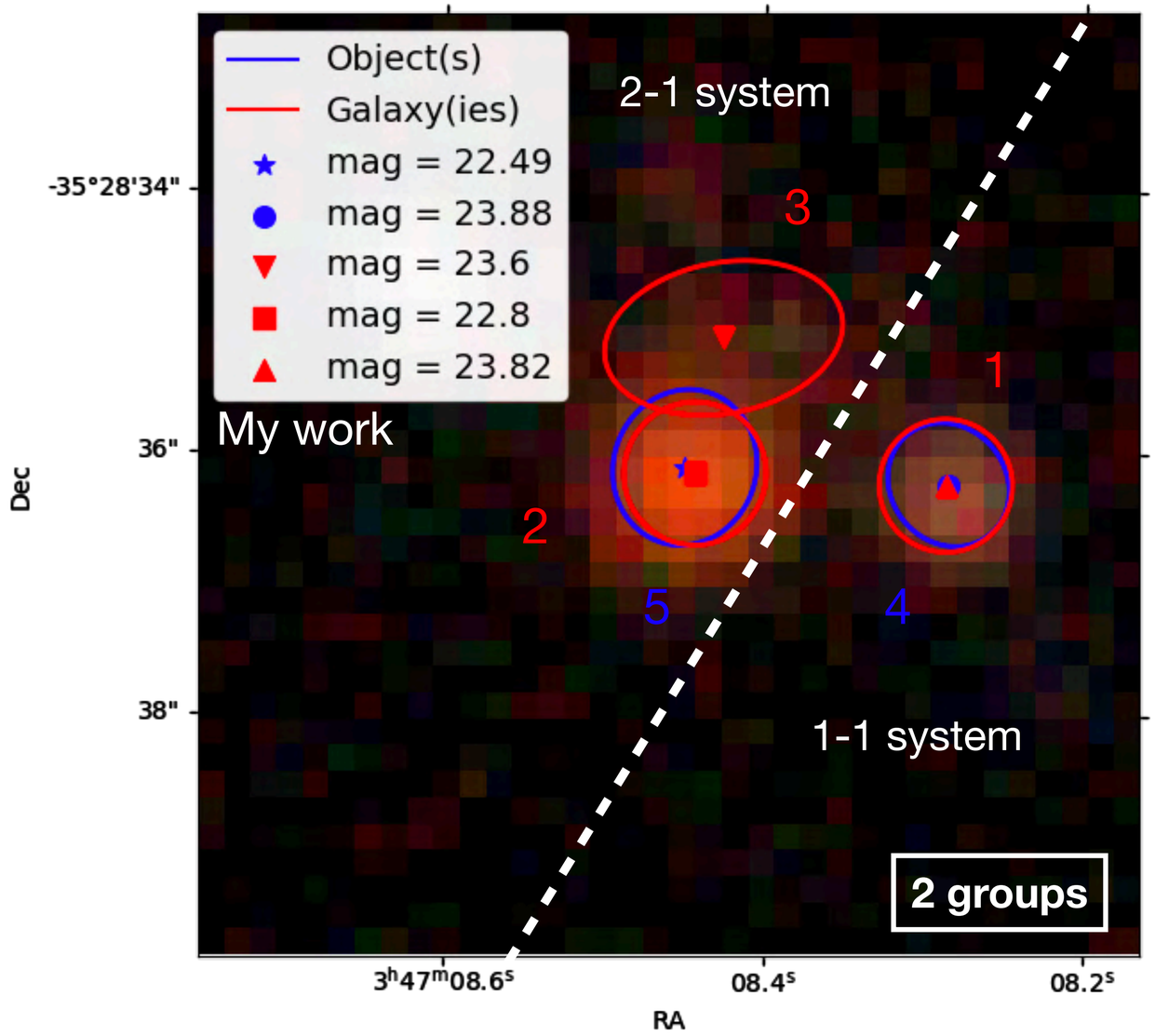
Matching procedure: friendly



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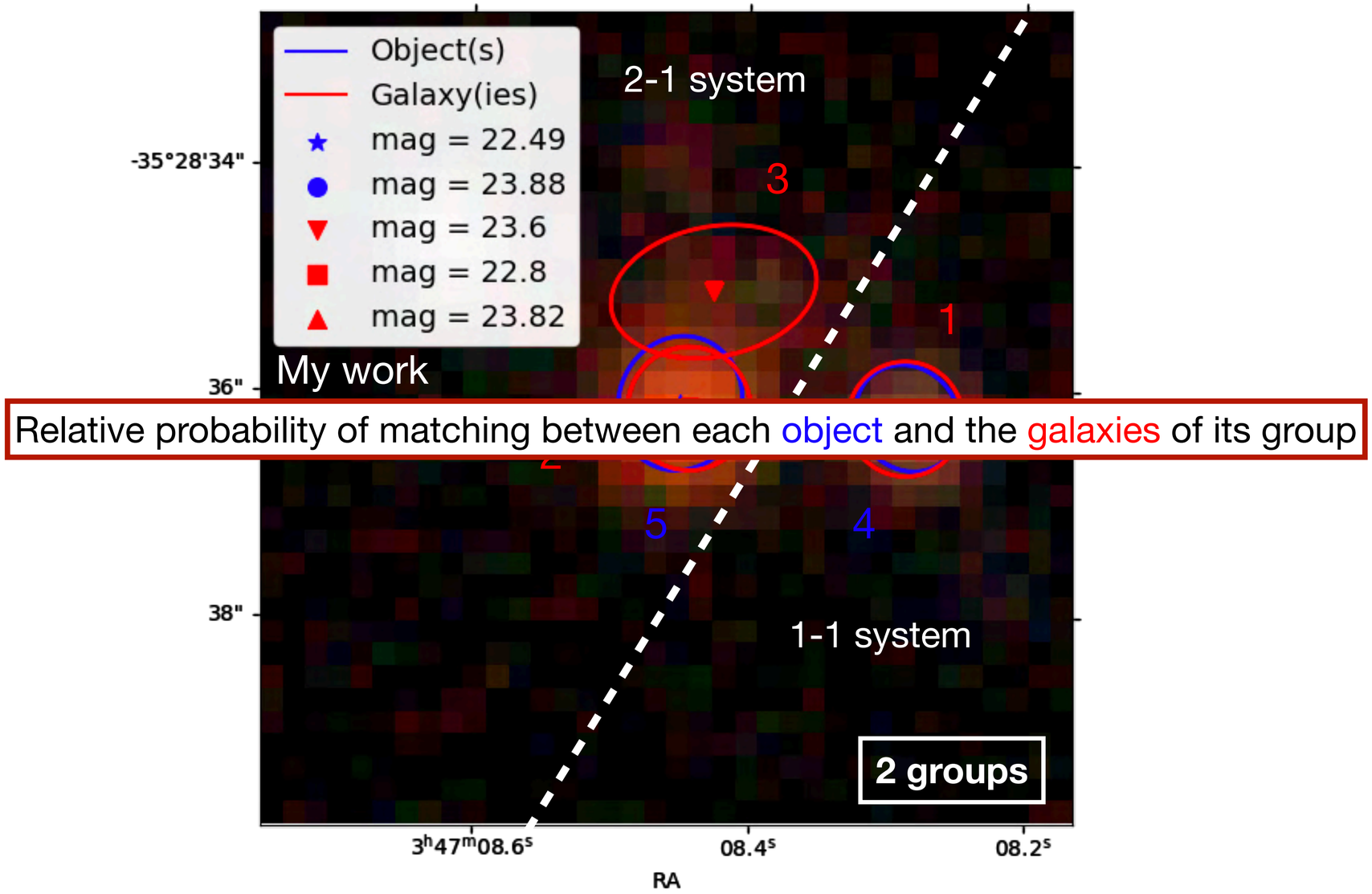
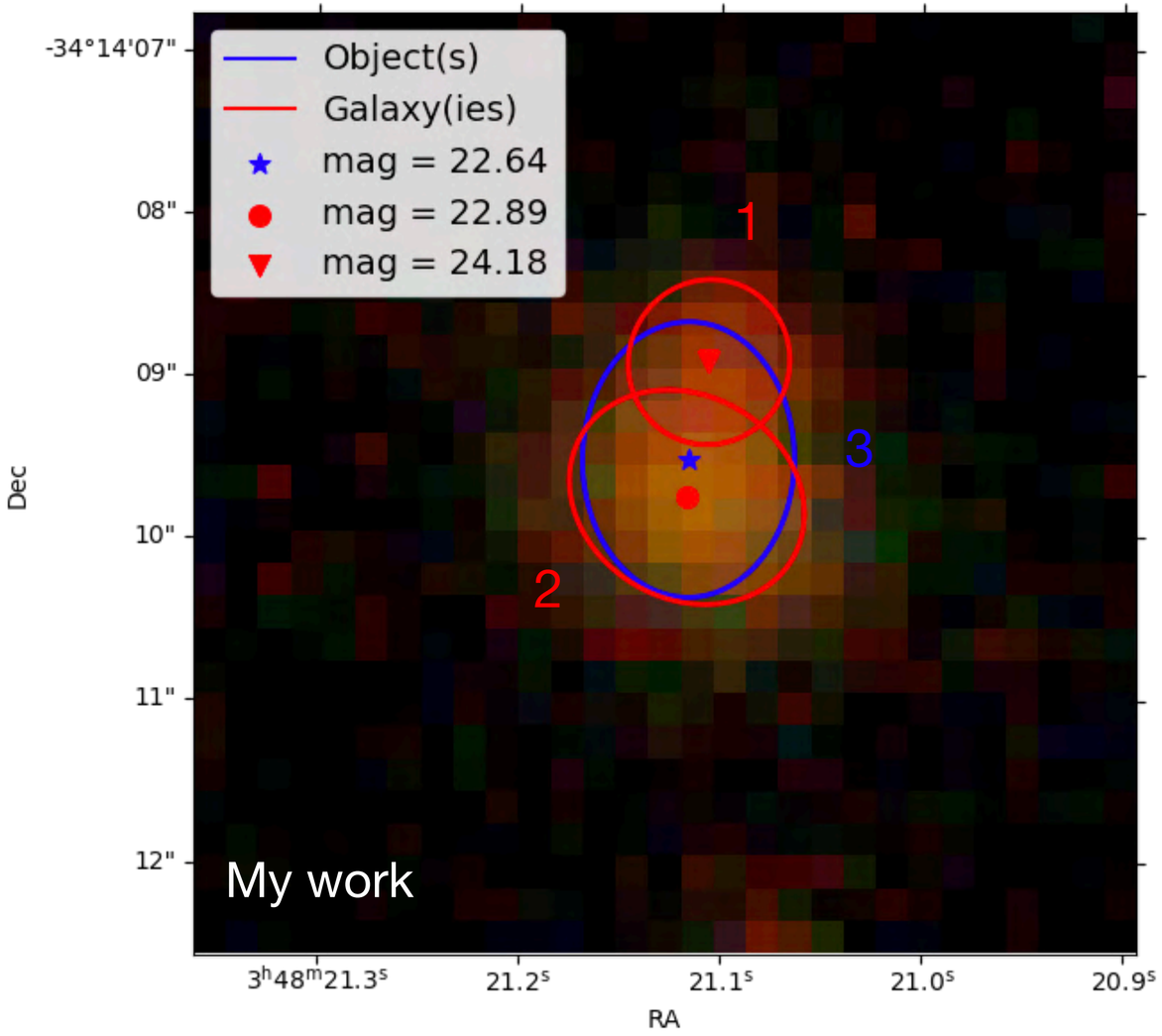
Matching procedure: friendly



Relative probability of matching between each object and the galaxies of its group

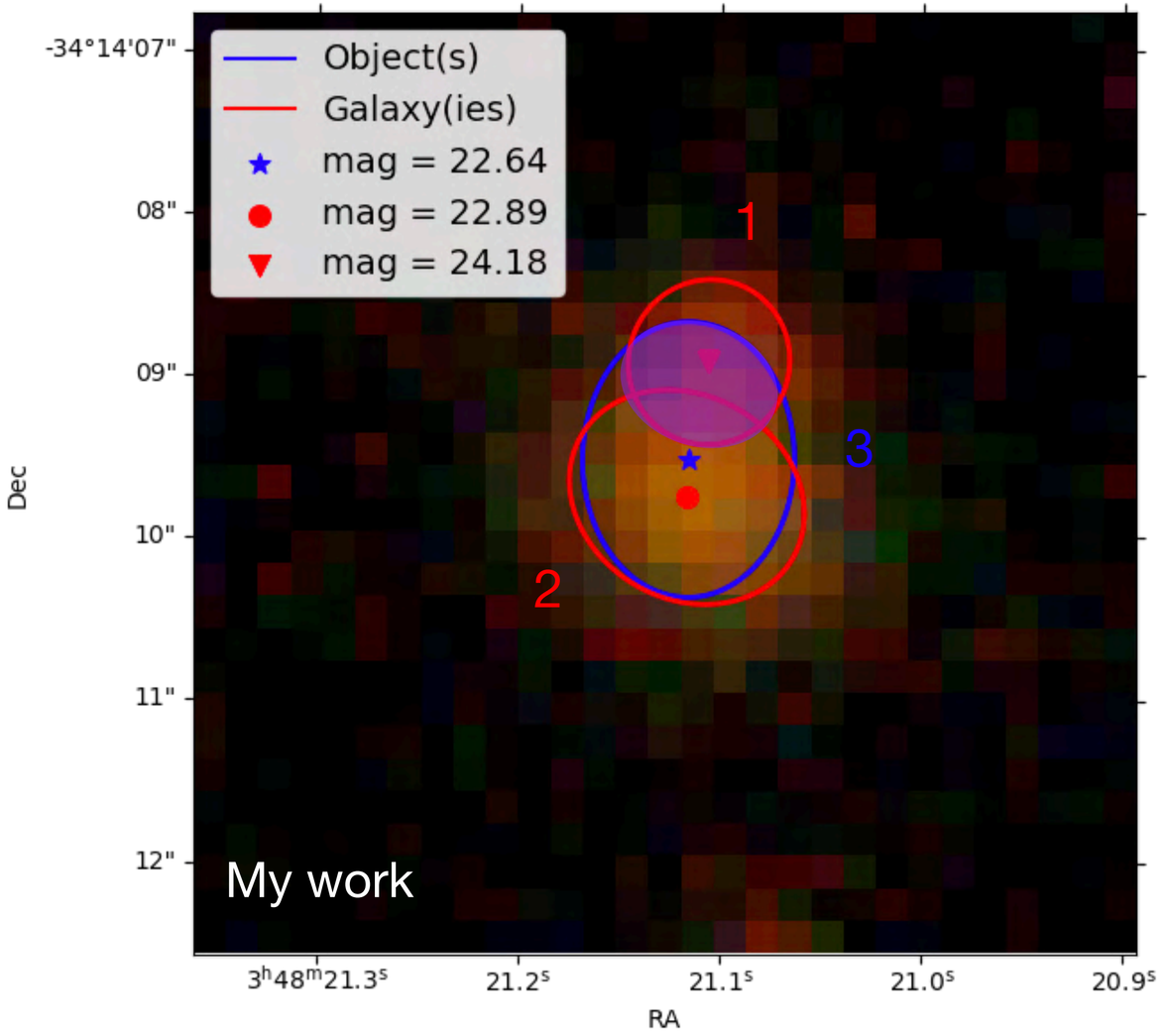
Relative probabilities of matching galaxies



1. For each object:

   Matching probability with one galaxy of the group

Relative probabilities of matching galaxies



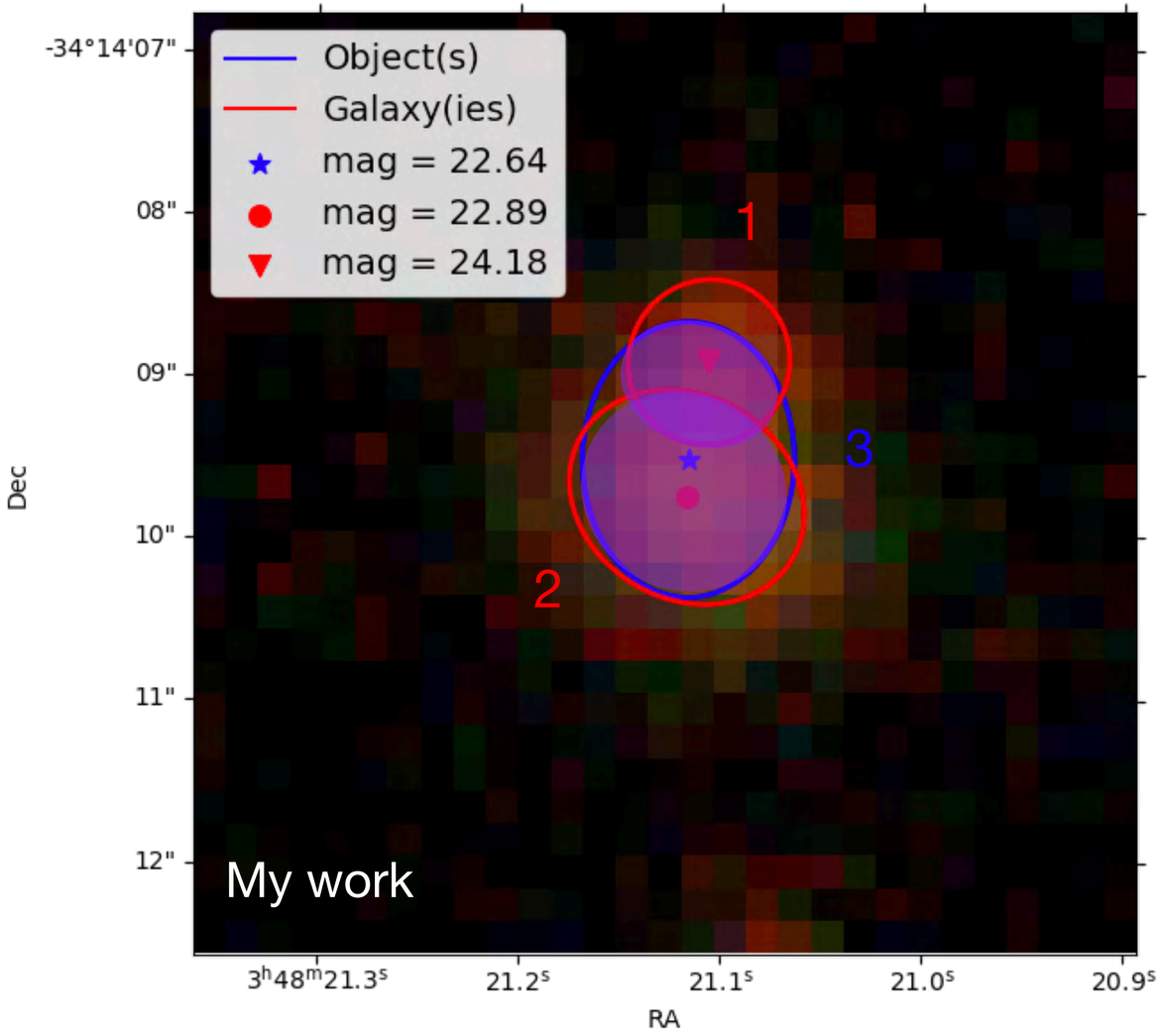
1. For each object:

   Matching probability with one galaxy of the group

   $p \propto$ overlap weighted by the difference in magnitudes

Relative probabilities of matching galaxies

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



1. For each object:

   Matching probability with one galaxy of the group

   $p \propto$ overlap weighted by the difference in magnitudes

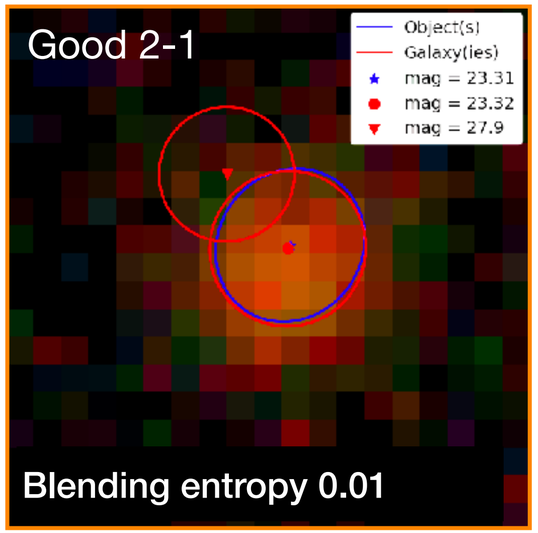
2. Vector of matching probabilities

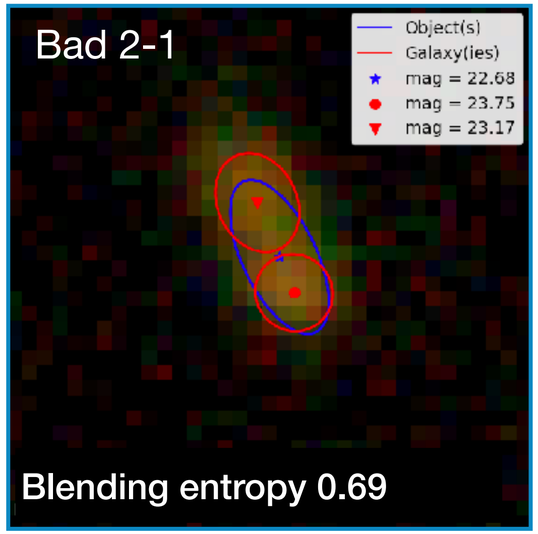
3. Blending entropy:

$$S_b = -\sum_i p_i \log p_i$$

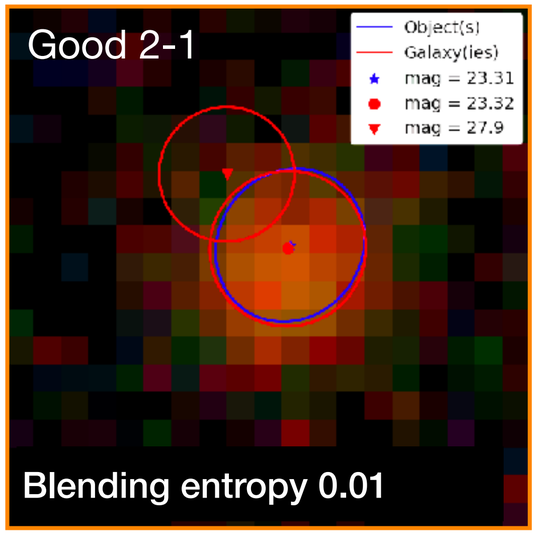
= score for each object

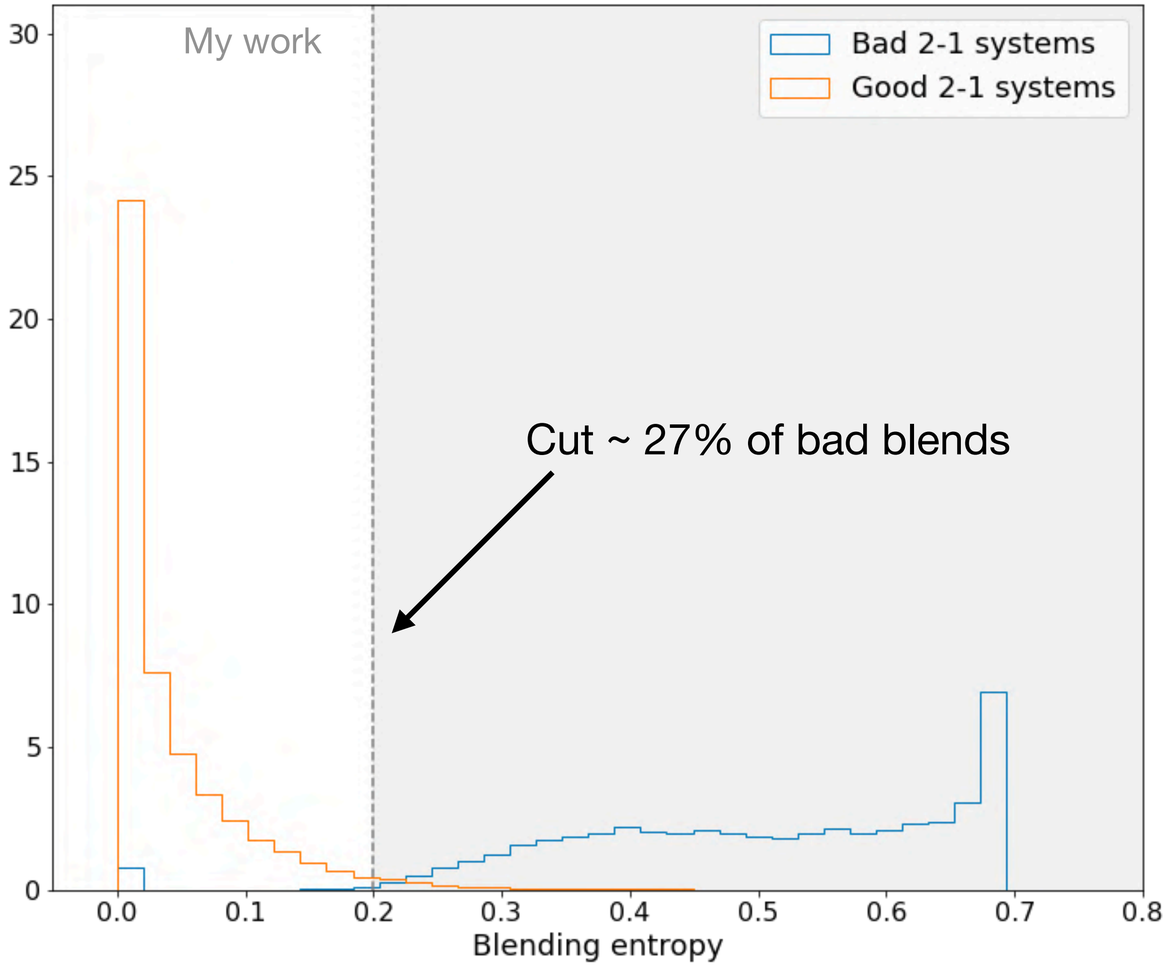
Blending entropy of blended systems

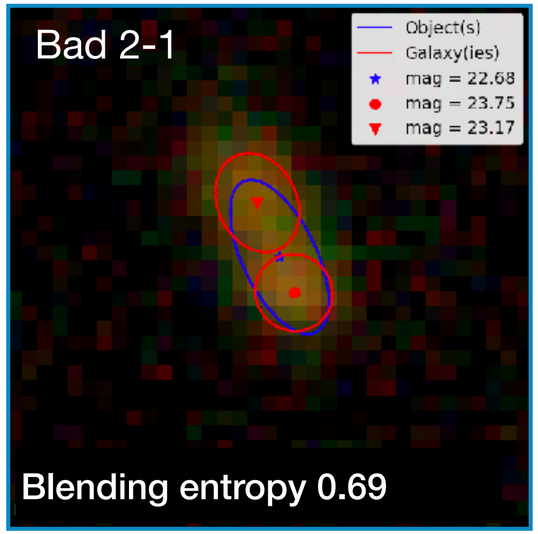




Blending entropy of blended systems







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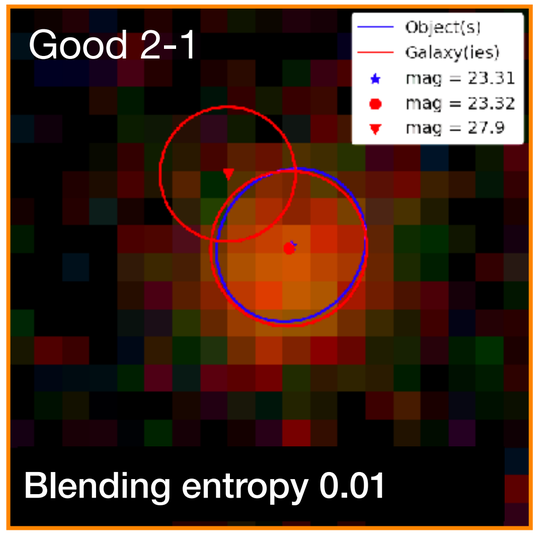
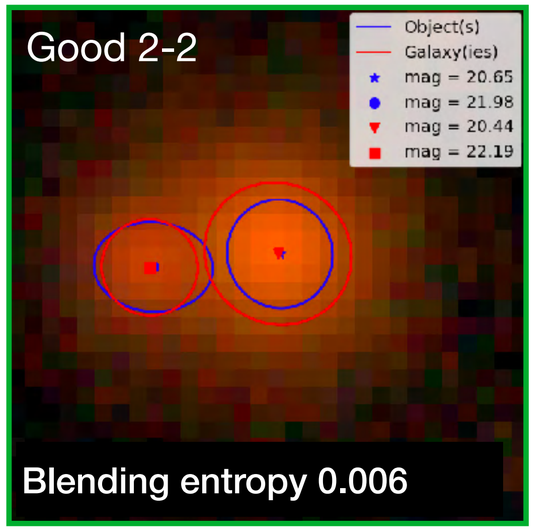
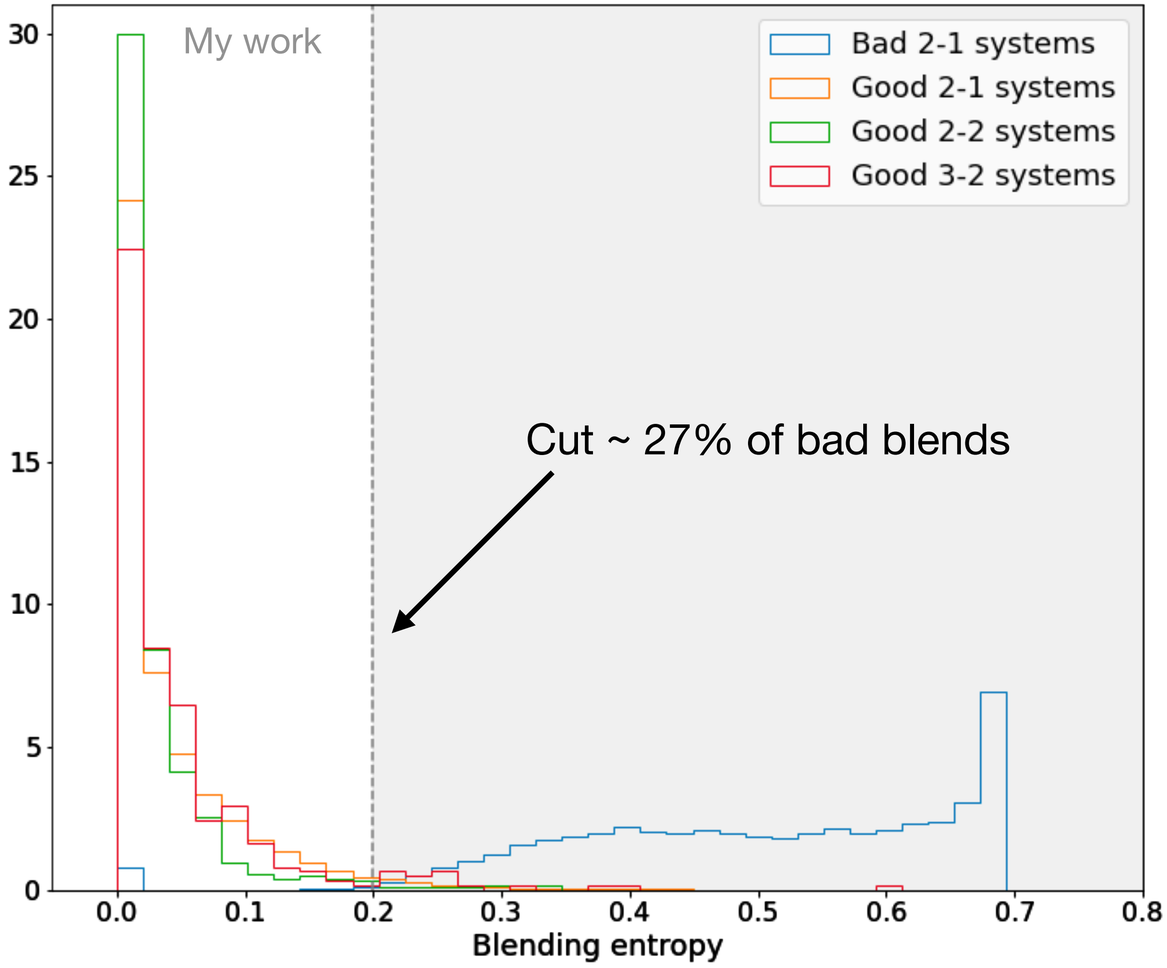
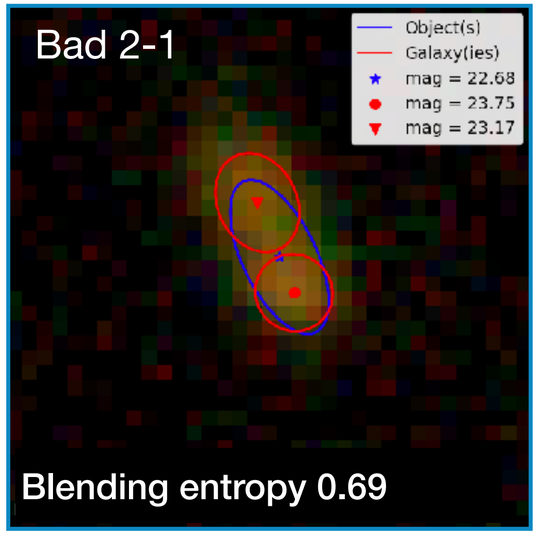
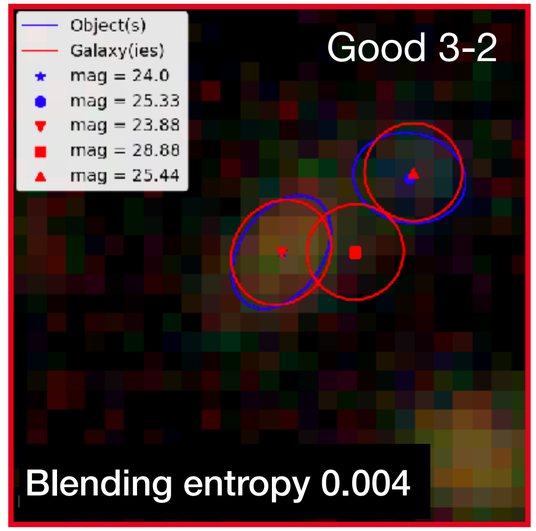




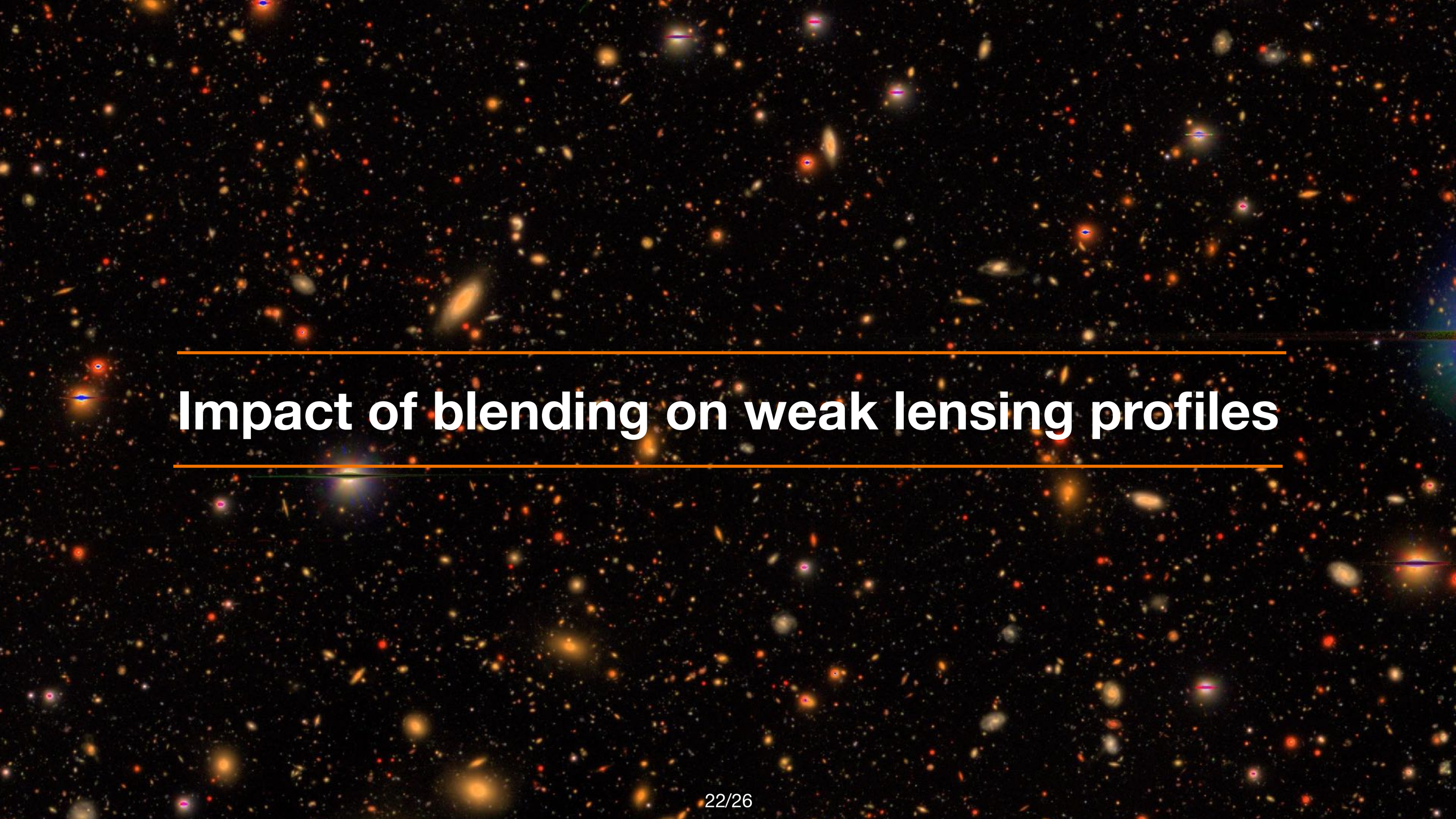






Partial conclusions

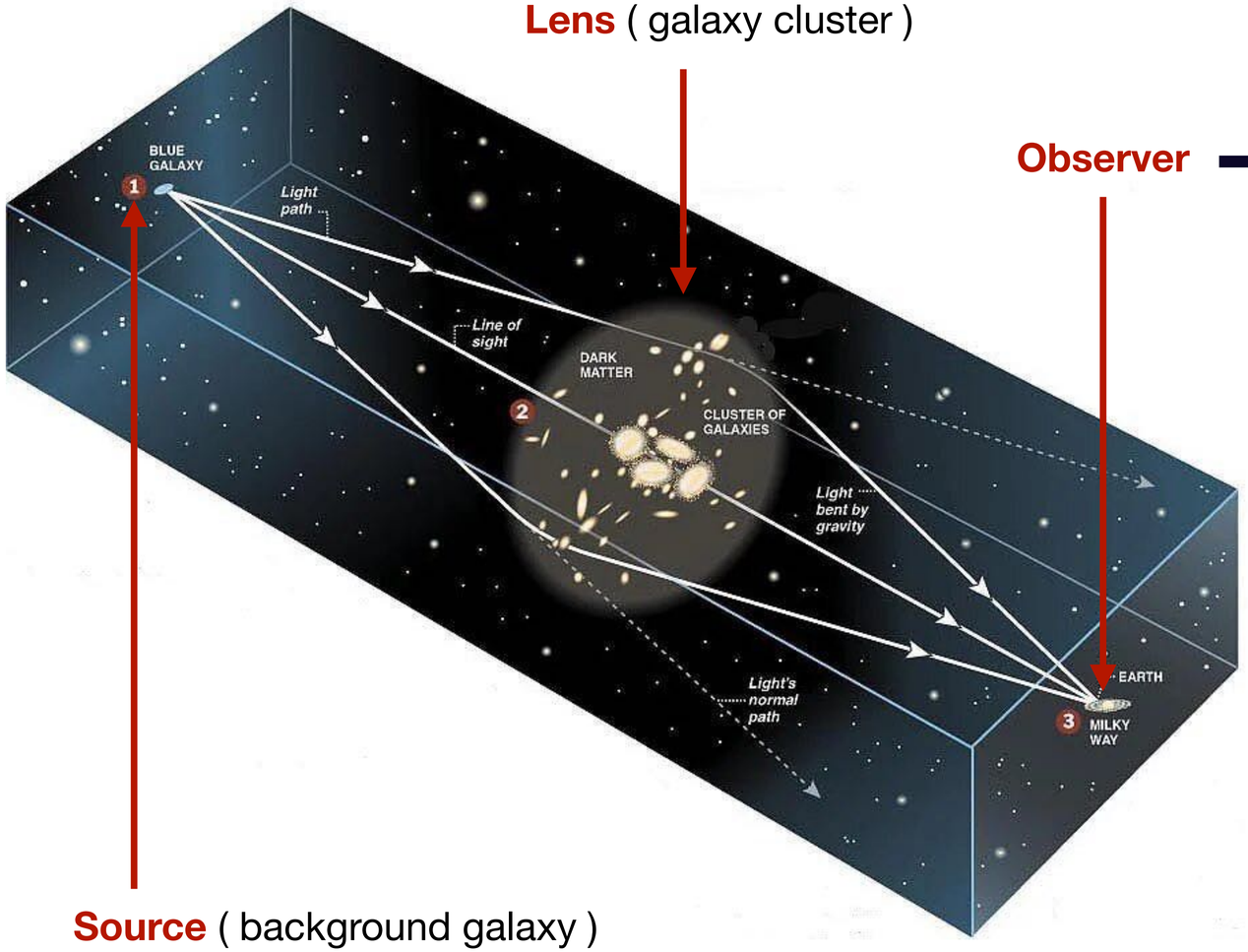
- **Friendly**: matching algorithm development for DESC
- **New approach** based on matching probabilities
- Powerful tool to **identify** problematic **blended systems**
- Integration of **blending entropy** in DC2object catalog

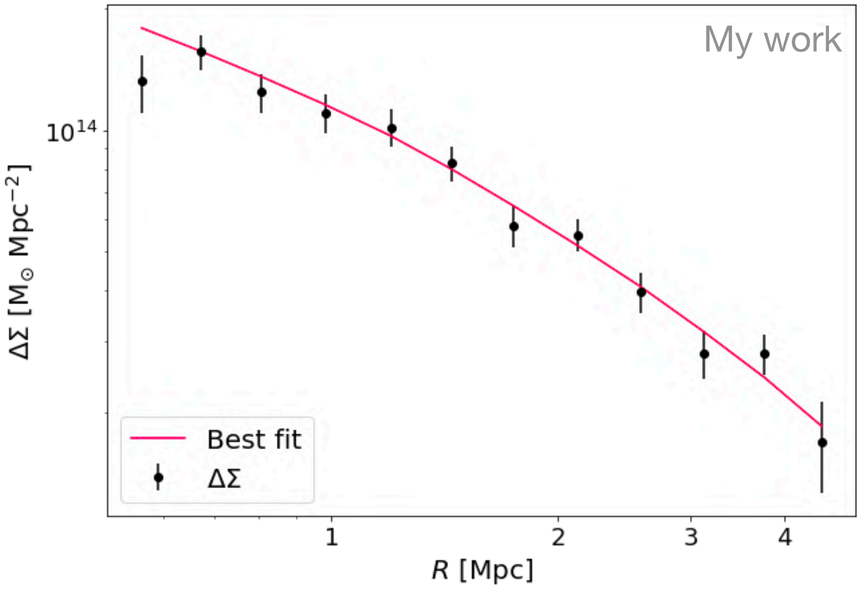


Impact of blending on weak lensing profiles

Reminder: weak gravitational lensing

$$\widehat{\Delta\Sigma}(R, z_l) = \langle \Sigma_{crit}(z_{gal}, z_l)\ \epsilon_+^{obs} \rangle$$





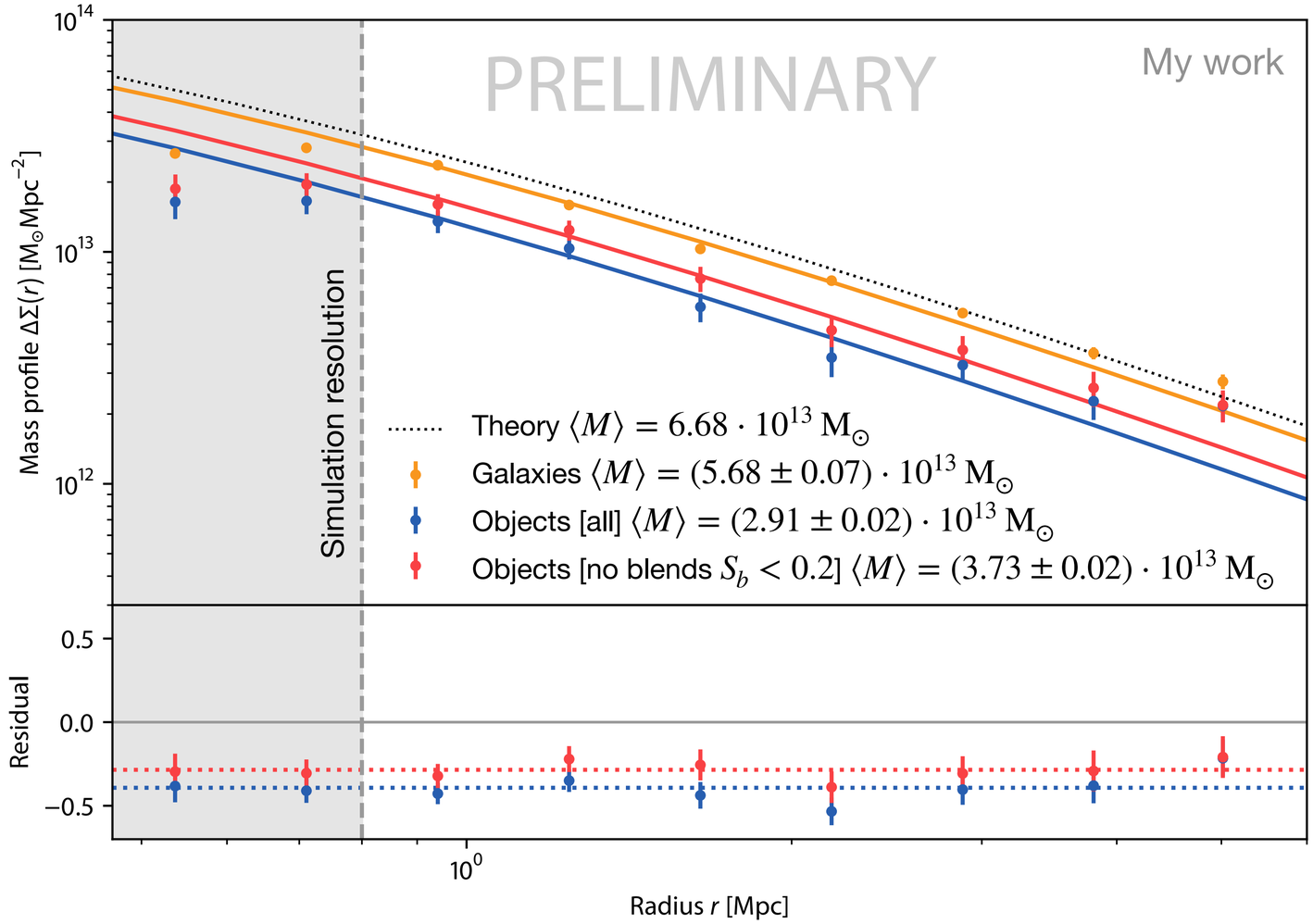
Distorted shapes + Redshifts — Lens mass

Impacted by blending

Impact of blending on $\Delta\Sigma$ profiles

DESC tool
https://github.com/LSSTDESC/CLMM

Objective: study the impact of bad blends on $\Delta\Sigma$ profiles



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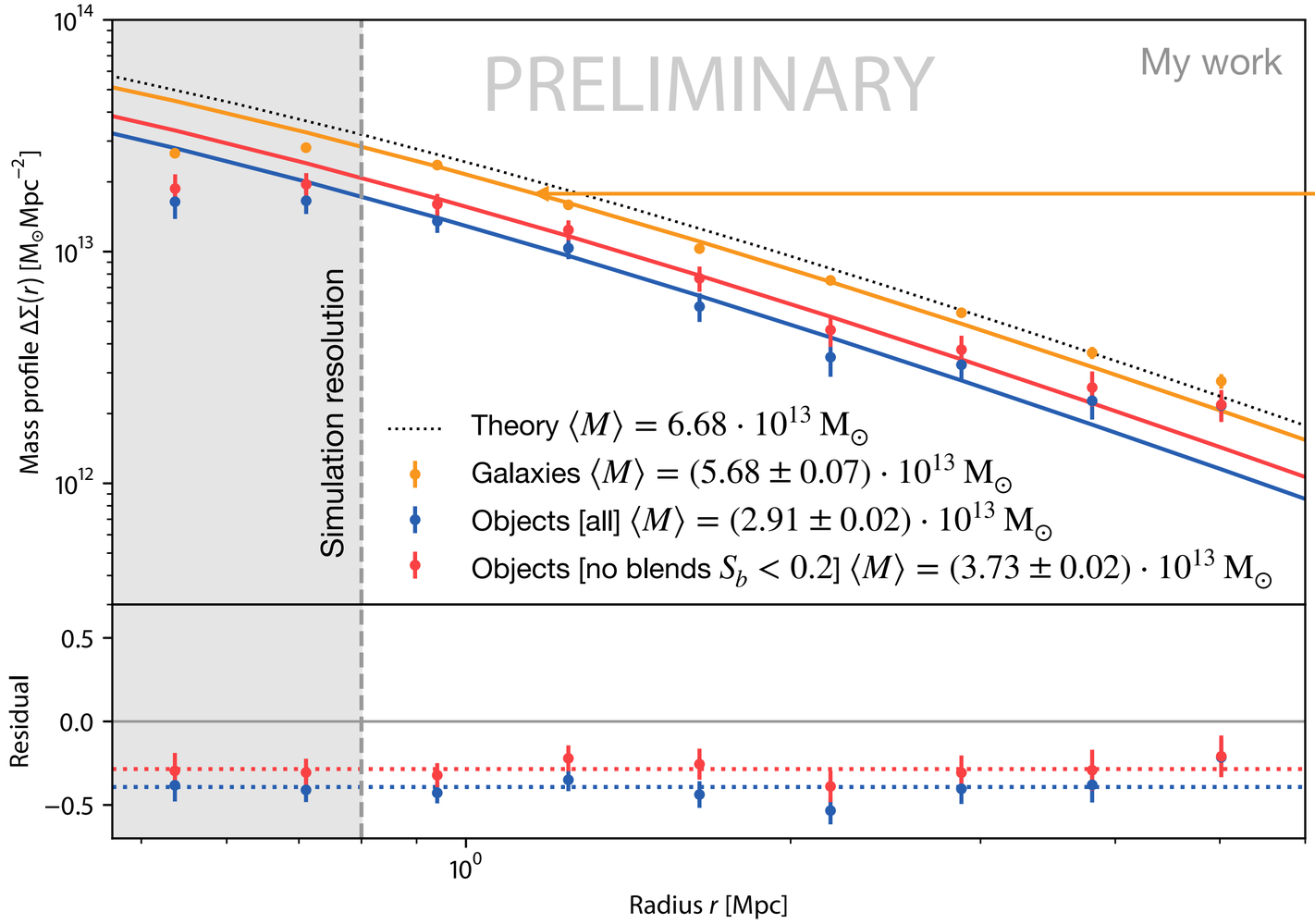

Galaxies (simulated truth)

Impact of blending on $\Delta\Sigma$ profiles

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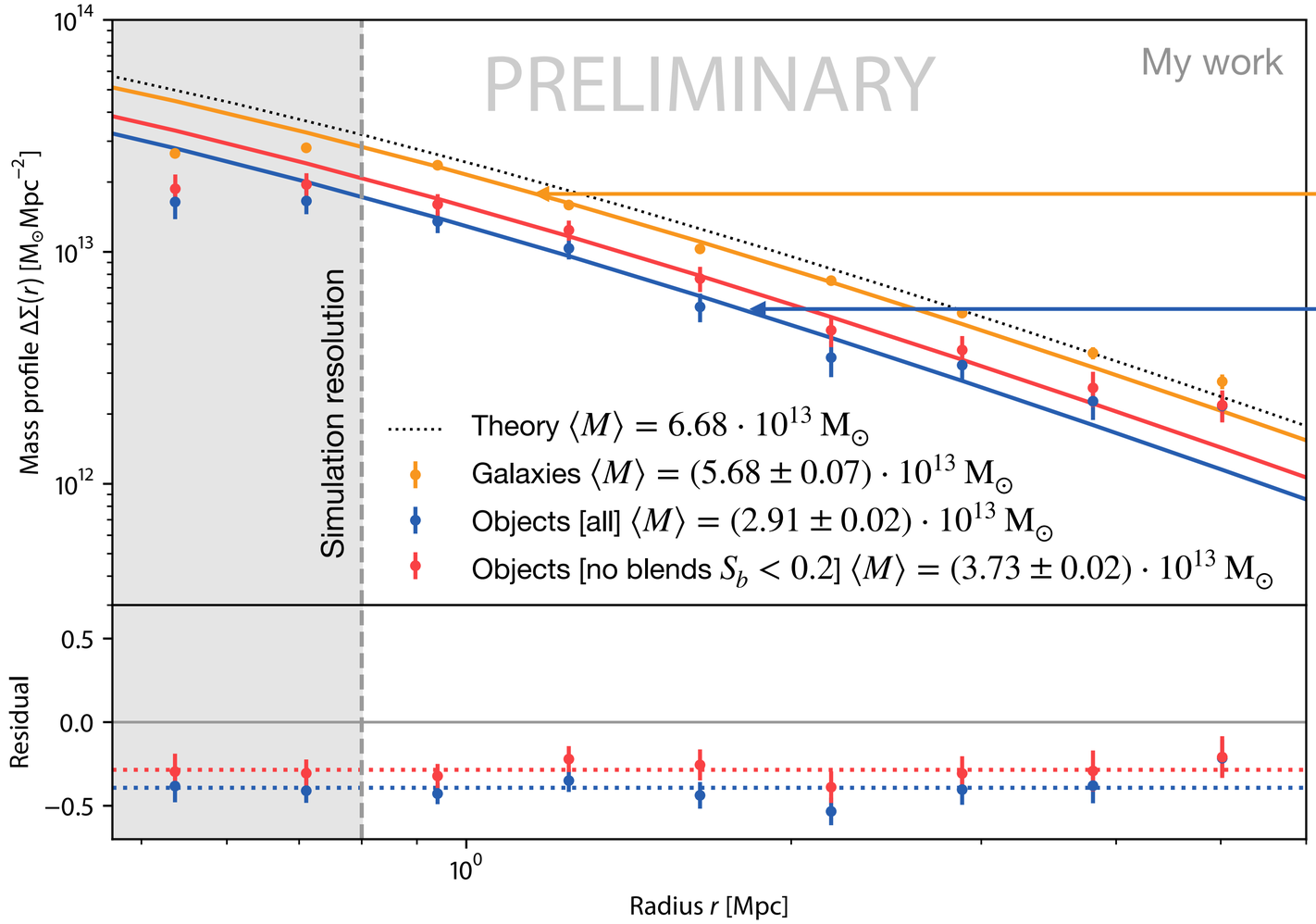

Galaxies (simulated truth)

Objects (simulated observations)

Impact of blending on $\Delta\Sigma$ profiles

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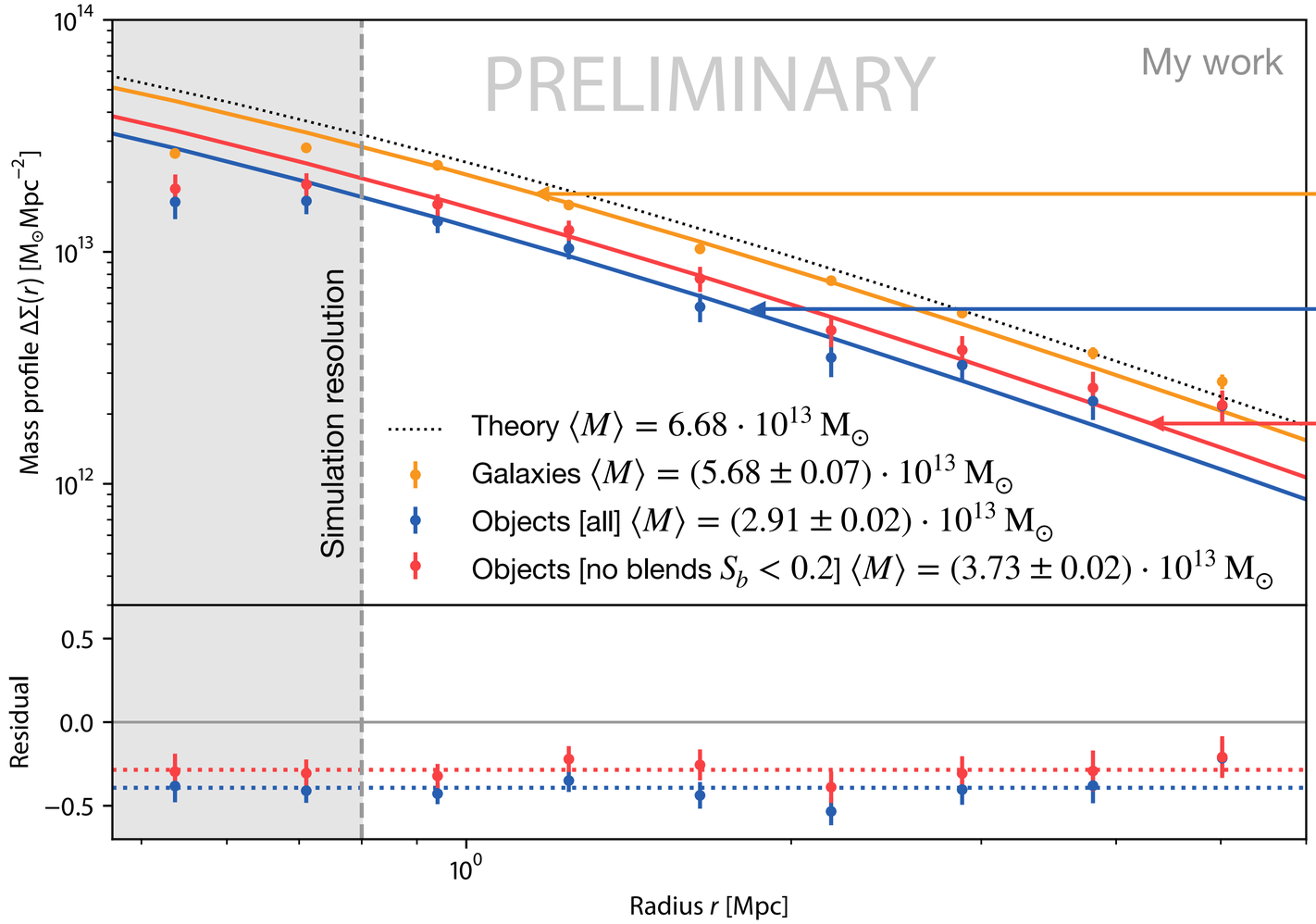

Galaxies (simulated truth)

Objects (simulated observations)

Objects with $S_b < 0.2$ (my work)

Impact of blending on $\Delta\Sigma$ profiles

DESC tool
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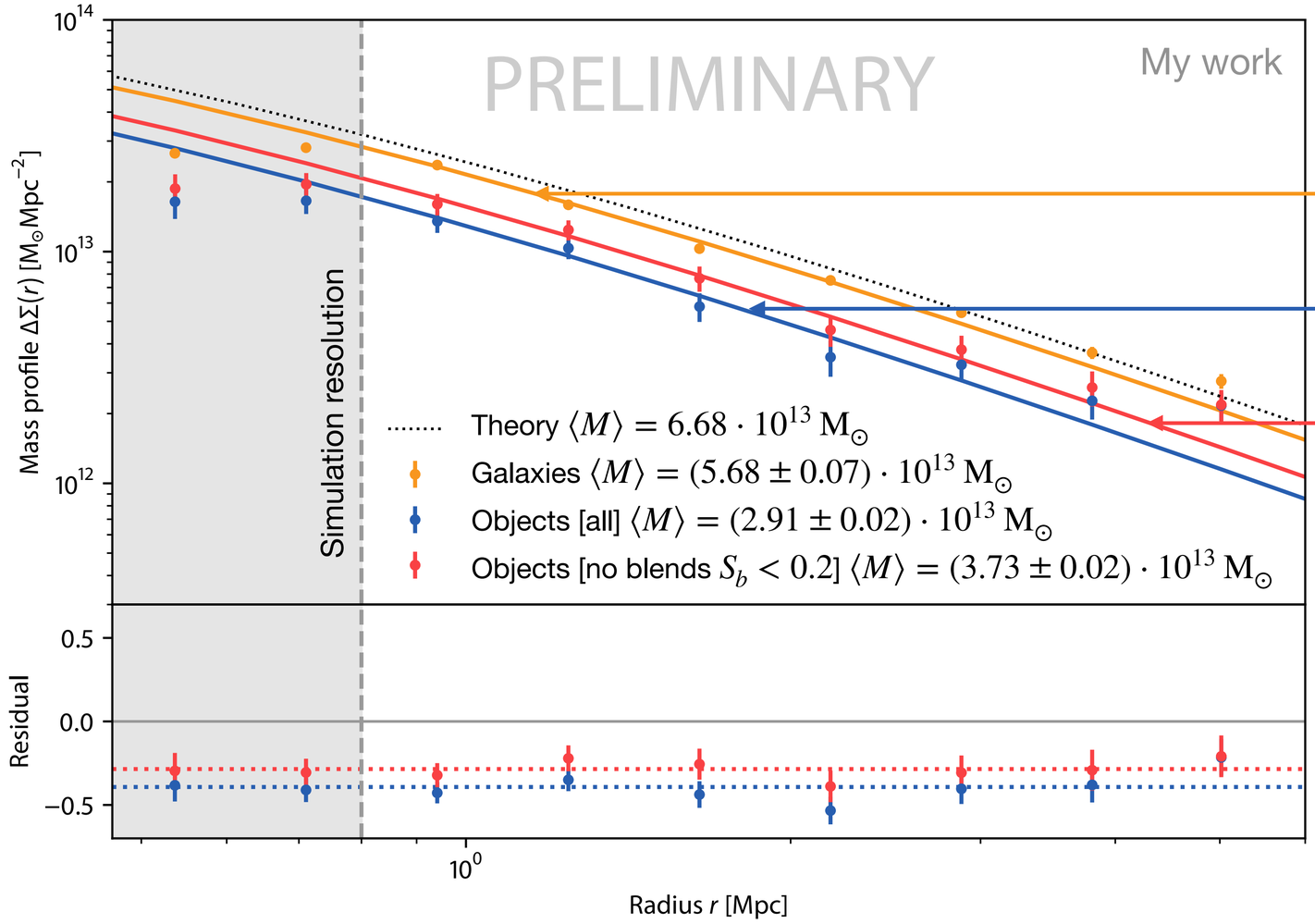
Objective: study the impact of bad blends on $\Delta\Sigma$ profiles



Galaxies (simulated truth)

Objects (simulated observations)

Objects with $S_b < 0.2$ (my work)

Removing bad blends

=

Shifting the profiles upwards

=

Getting closer to the truth galaxy cluster mass

Conclusions

1. Blending, major issue for weak lensing studies with Rubin/LSST

- Confusion of sources will impact galaxy shapes measurements
- Biased estimates of galaxy clusters masses and of cosmological parameters
- Poorly studied, difficult to separate from other systematics

2. Development of friendly, new DESC matching algorithm

- New blending entropy metric to characterize blends
- Efficiency in identifying problematic blended galaxies
- Impact of blending on weak lensing profiles and galaxy cluster mass estimates

3. Shared work with the DESC collaboration

- Friendly will be public and available for the collaboration
- Blending entropy will be added to DESC catalogs metrics
- DESC paper in preparation

Perspectives

1. PhD perspectives

- Friendly improvement: overlap of diffuse objects = gaussian overlap
- Propagation of this work to cosmological parameters
- Get involved in the commissioning: LSST data expected in 2025 !

2. Long term projects

- Machine learning classifier on detected objects to identify blends features
- Test of the existing deblenders with the blending entropy
- Application of my expertise in blending to analyze future LSST data

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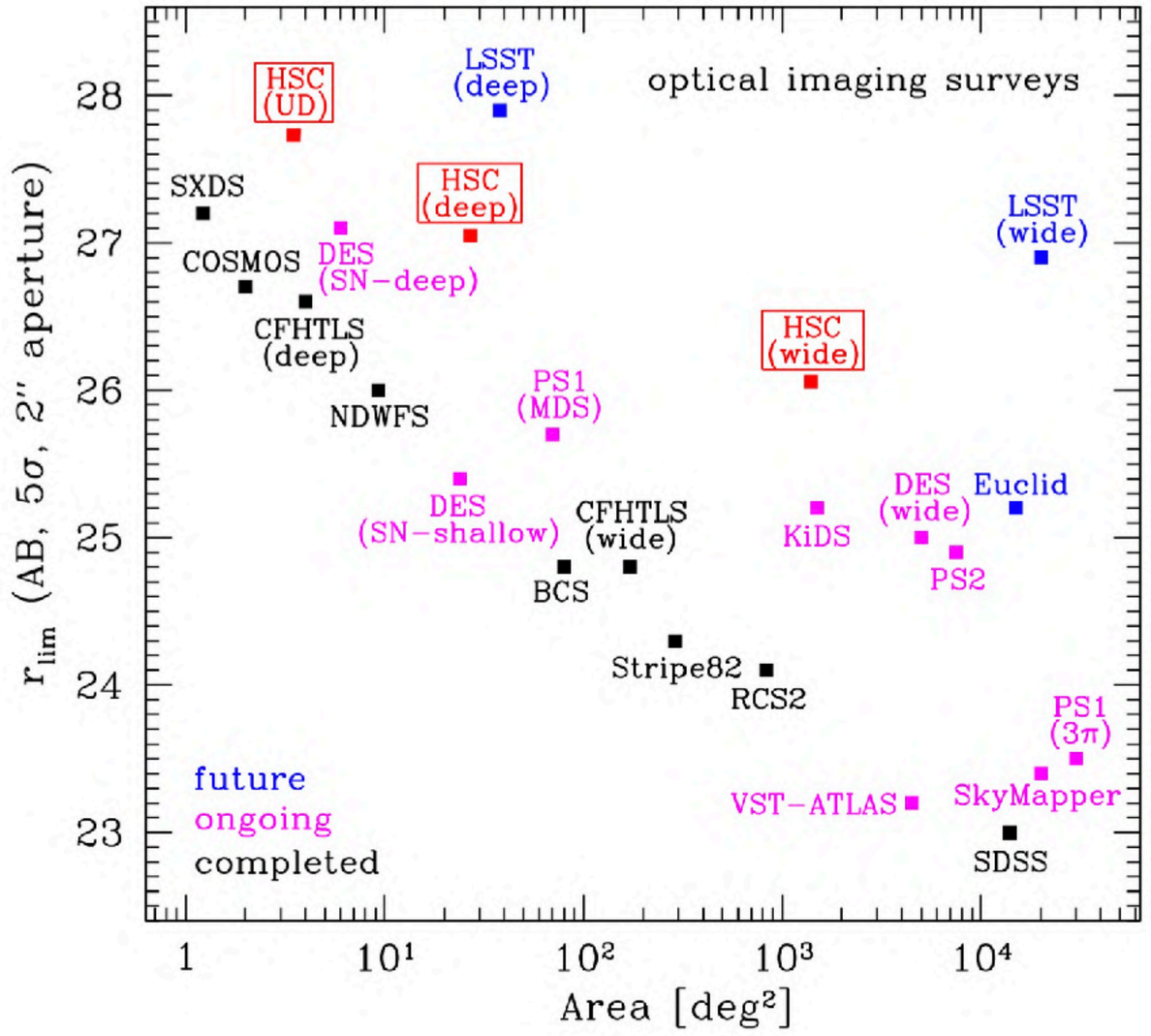
Thank you for your attention!

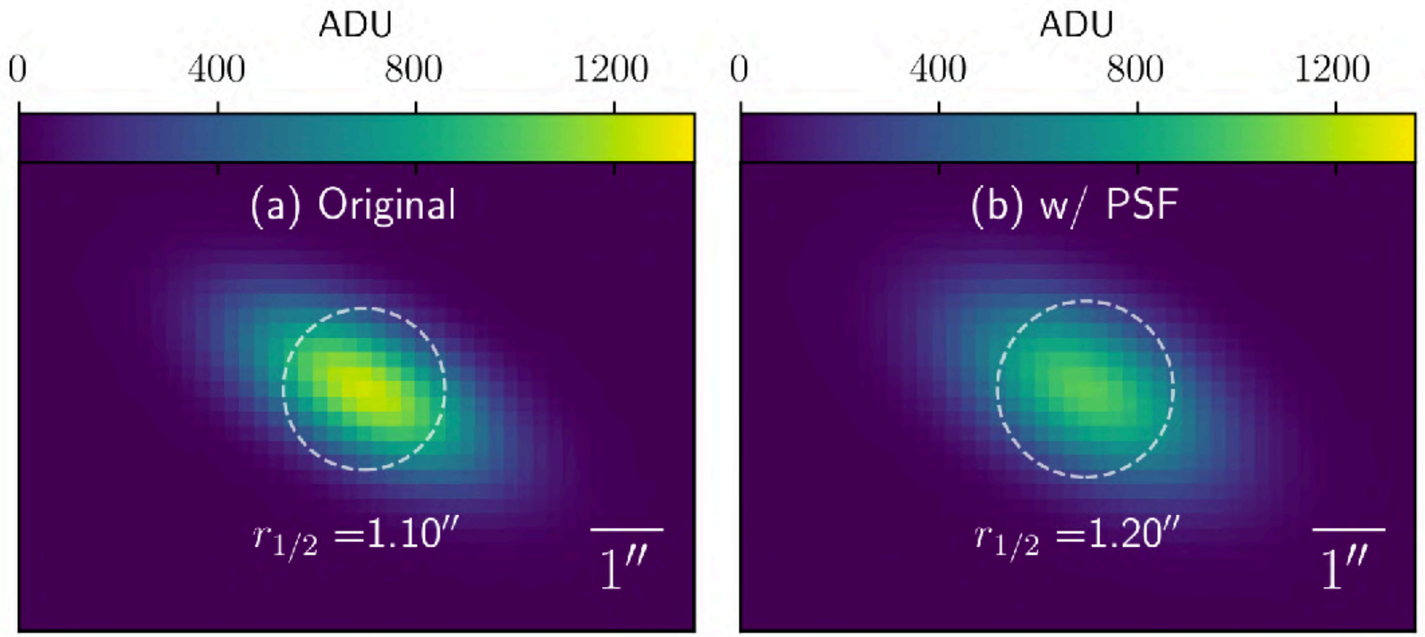
Back-up

Rubin-LSST



Back-up

Point Spread Function (PSF)



E. Nourbakhsh et. al

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

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

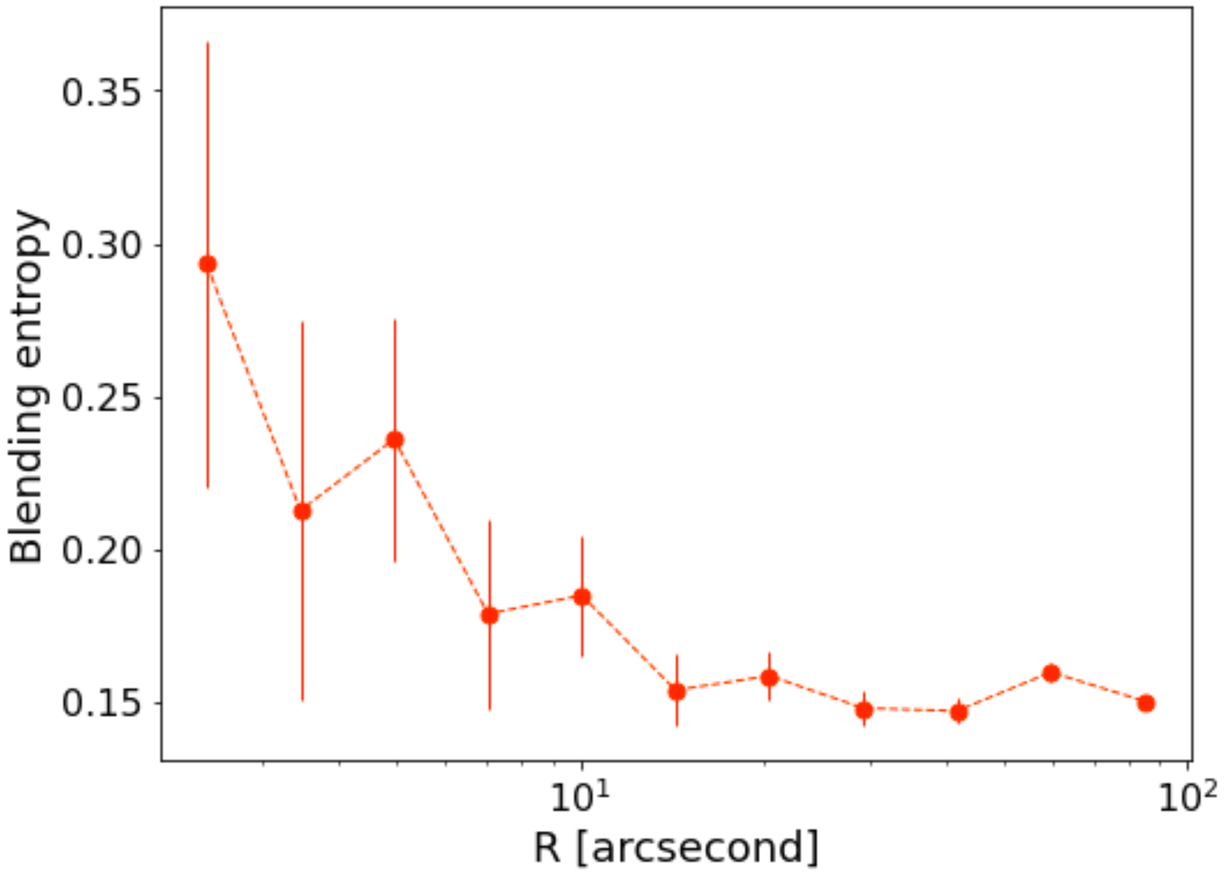
Determinant computation

Overlap of 2 ellipses ?

- True
- False

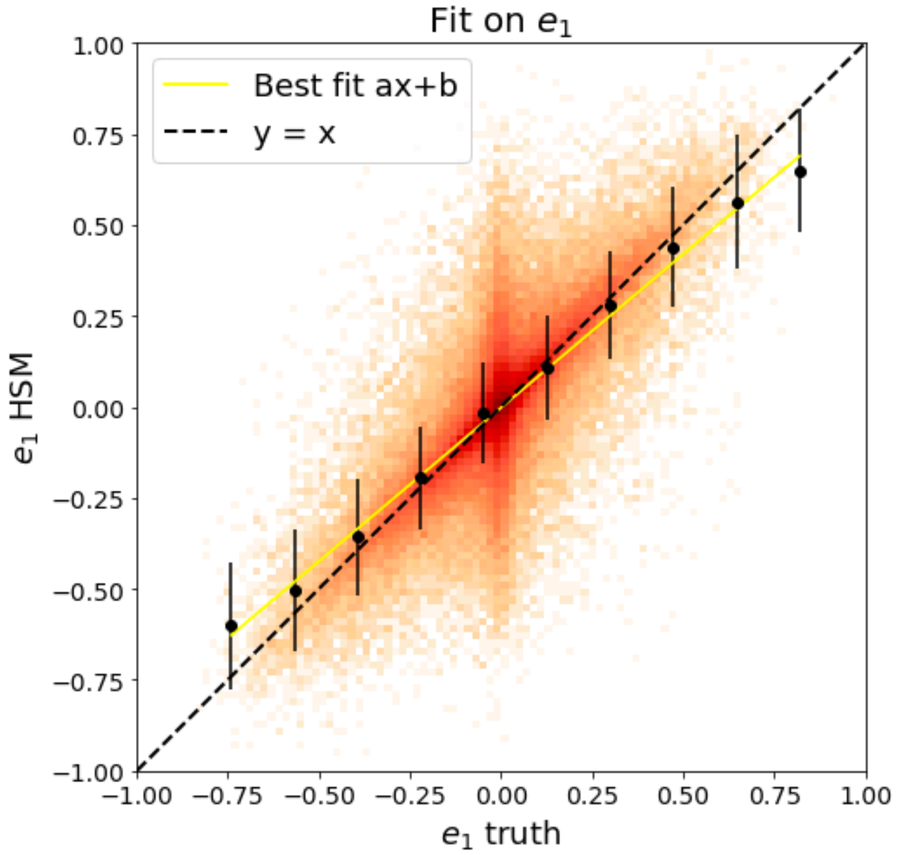
Back-up

Blending entropy vs. halo radius

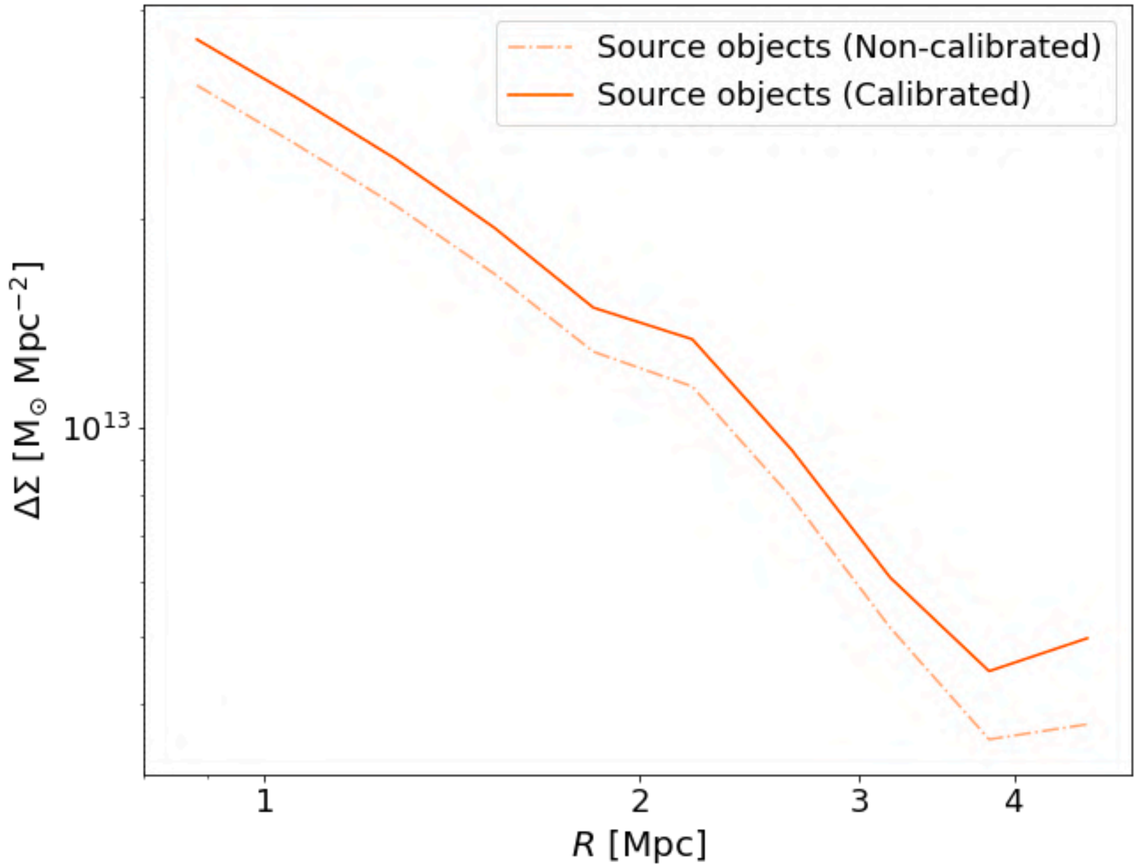


Back-up

HSM ellipticities calibration

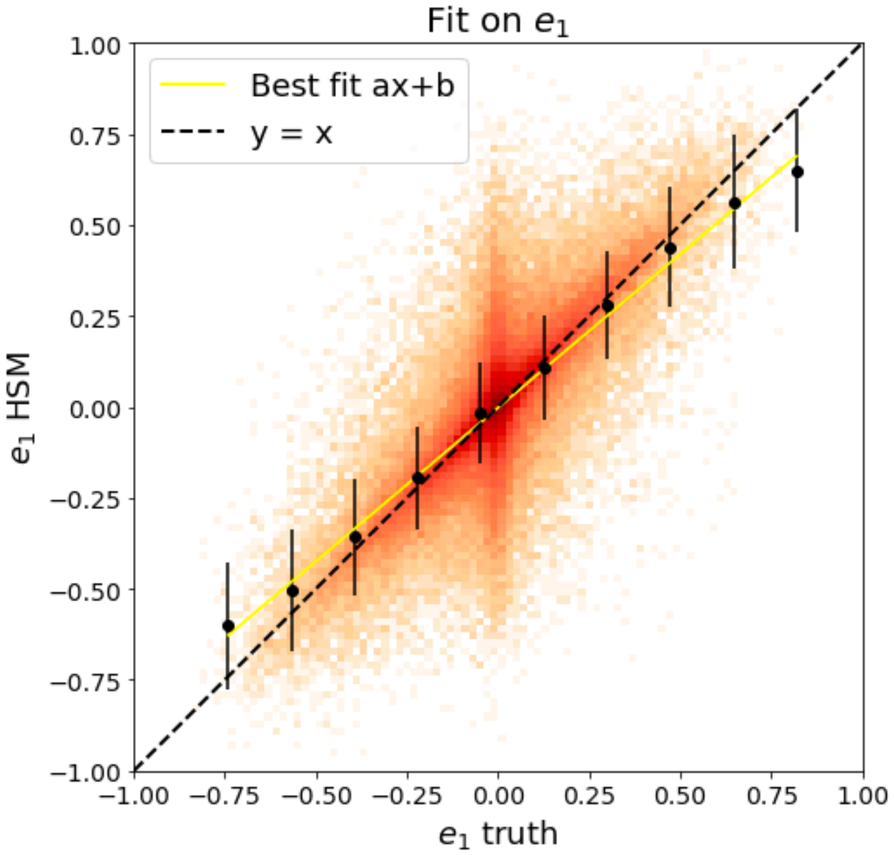


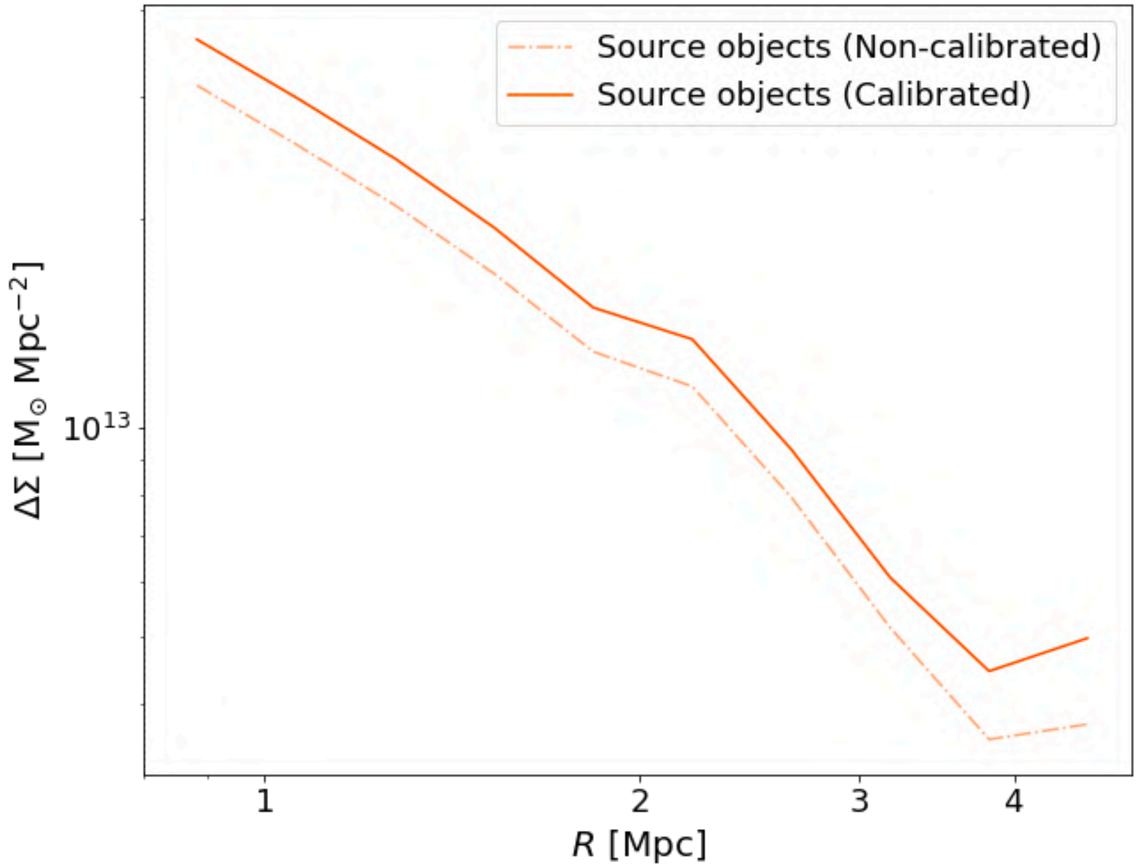
$$e_{HSM} = 0.85 \times e_{truth} - 0.003$$



Back-up

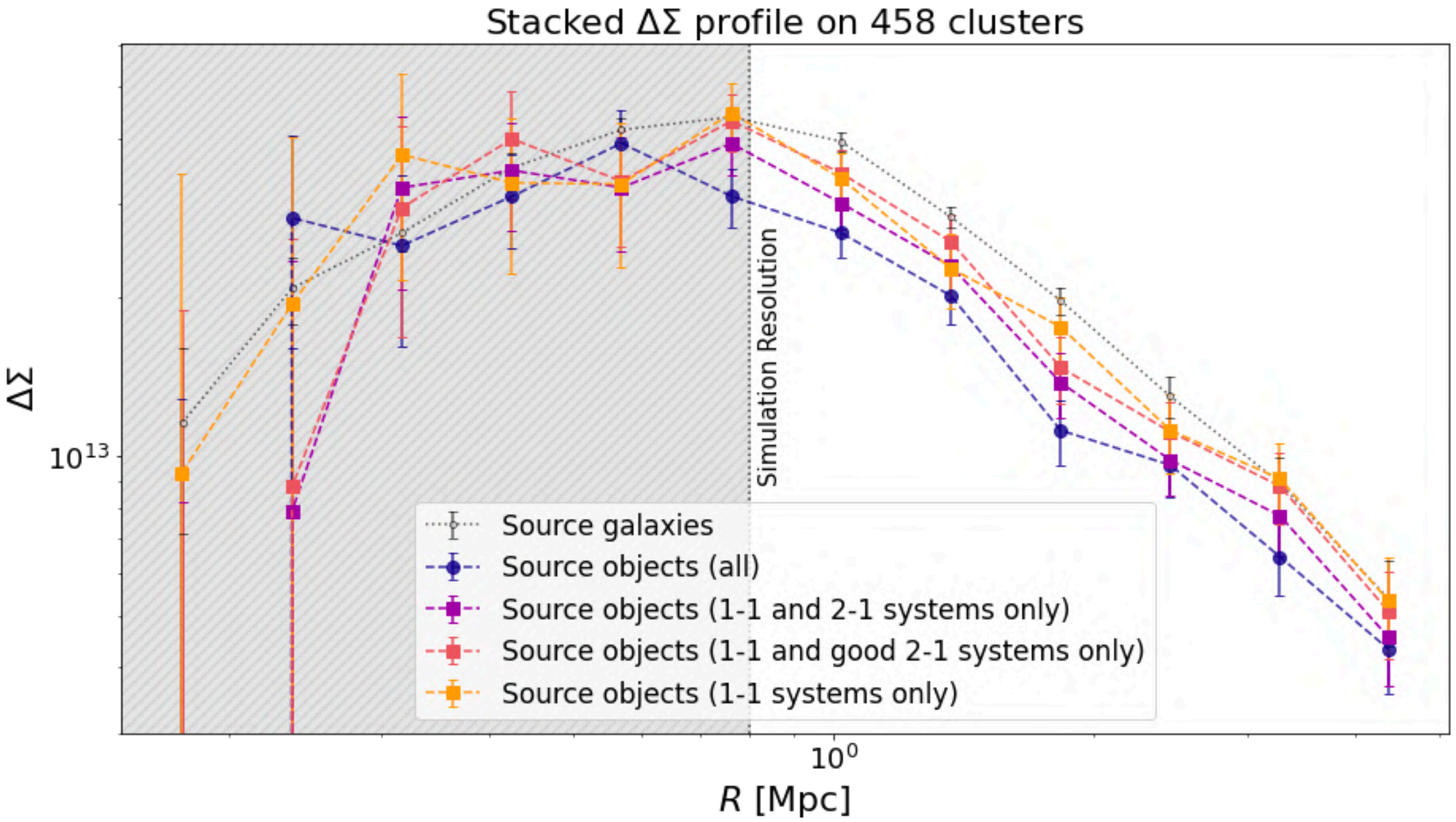
HSM ellipticities calibration





Back-up

Impact of systems on $\Delta\Sigma$ profiles



- 34 % of the objects are removed
- 42 % of the objects are removed
- 61 % of the objects are removed