Impact of blending on weak lensing measurements with Rubin/LSST

Euclid Summer School, August 2023

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Laboratoire de Physique Subatomique & Cosmologie

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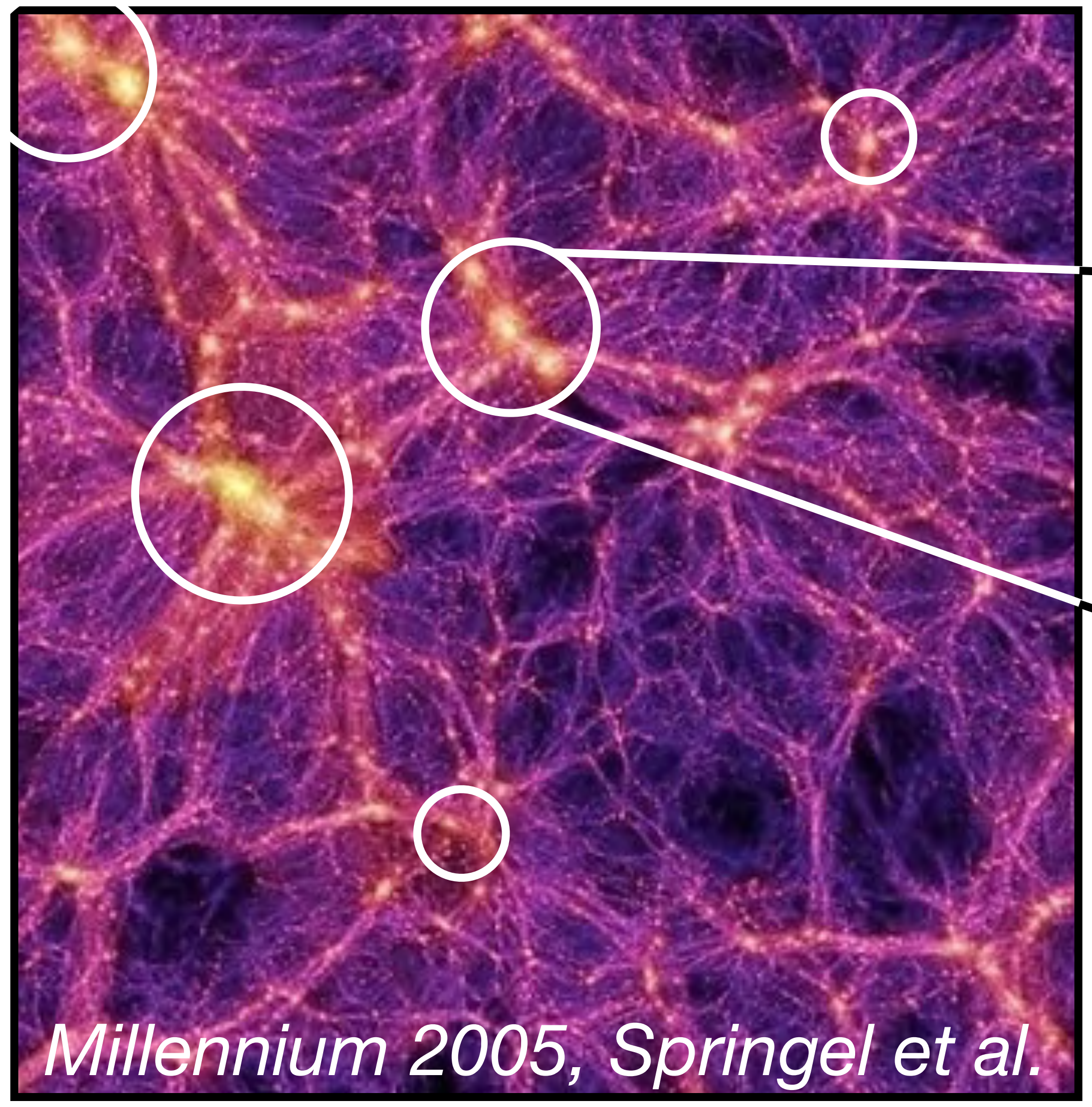
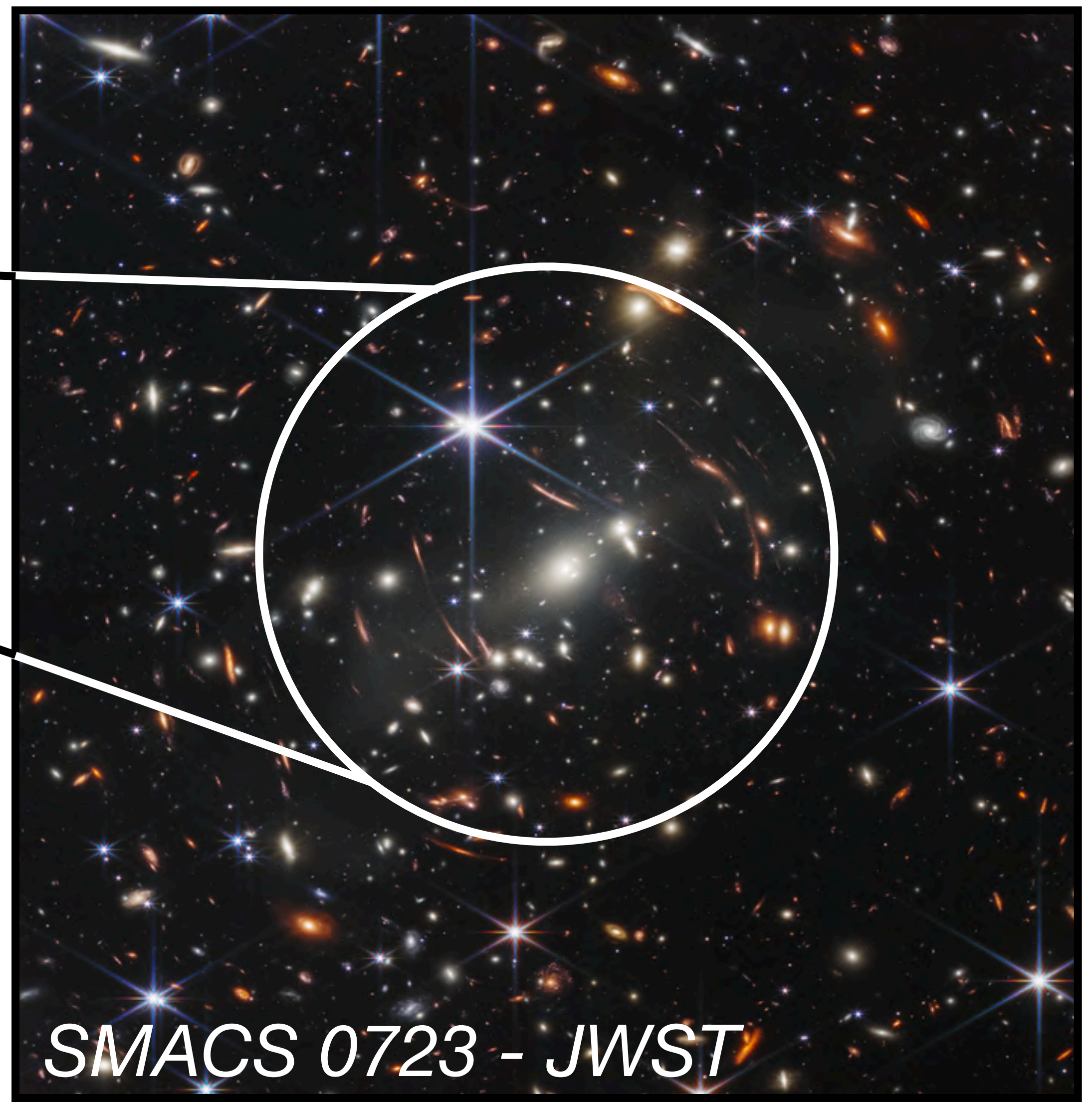
Cosmology with galaxy clusters





Largest gravitationally bound structures in the Universe

- Size of 1 Mpc
- 50 to 1000 galaxies
- $M > 10^{13.5} M_{\odot}$, $z < 3$

Tracers of the matter over-densities

- Abundance depends on cosmology

Scientific context
Cosmology with galaxy clusters

Largest gravitationally bound structures in the Universe

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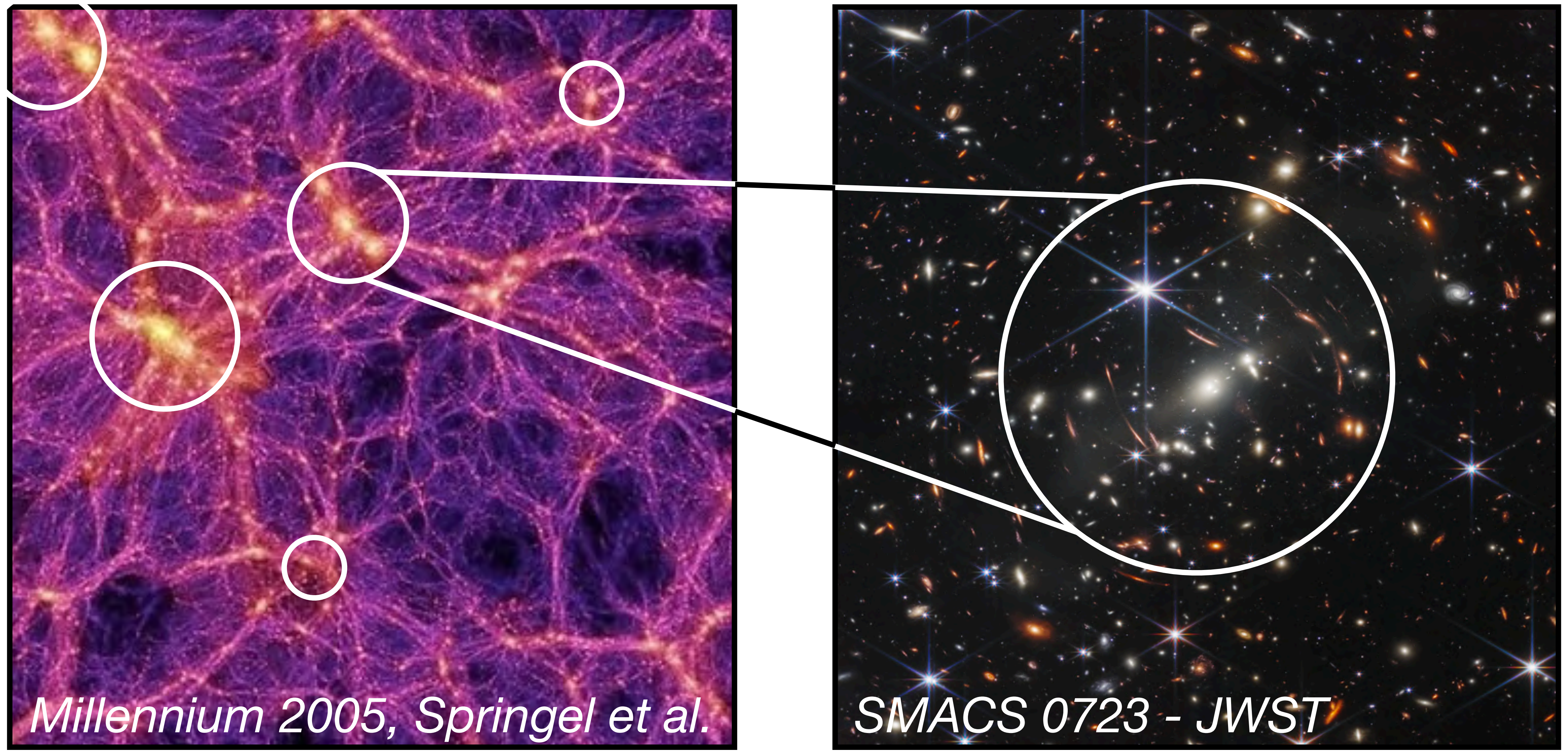
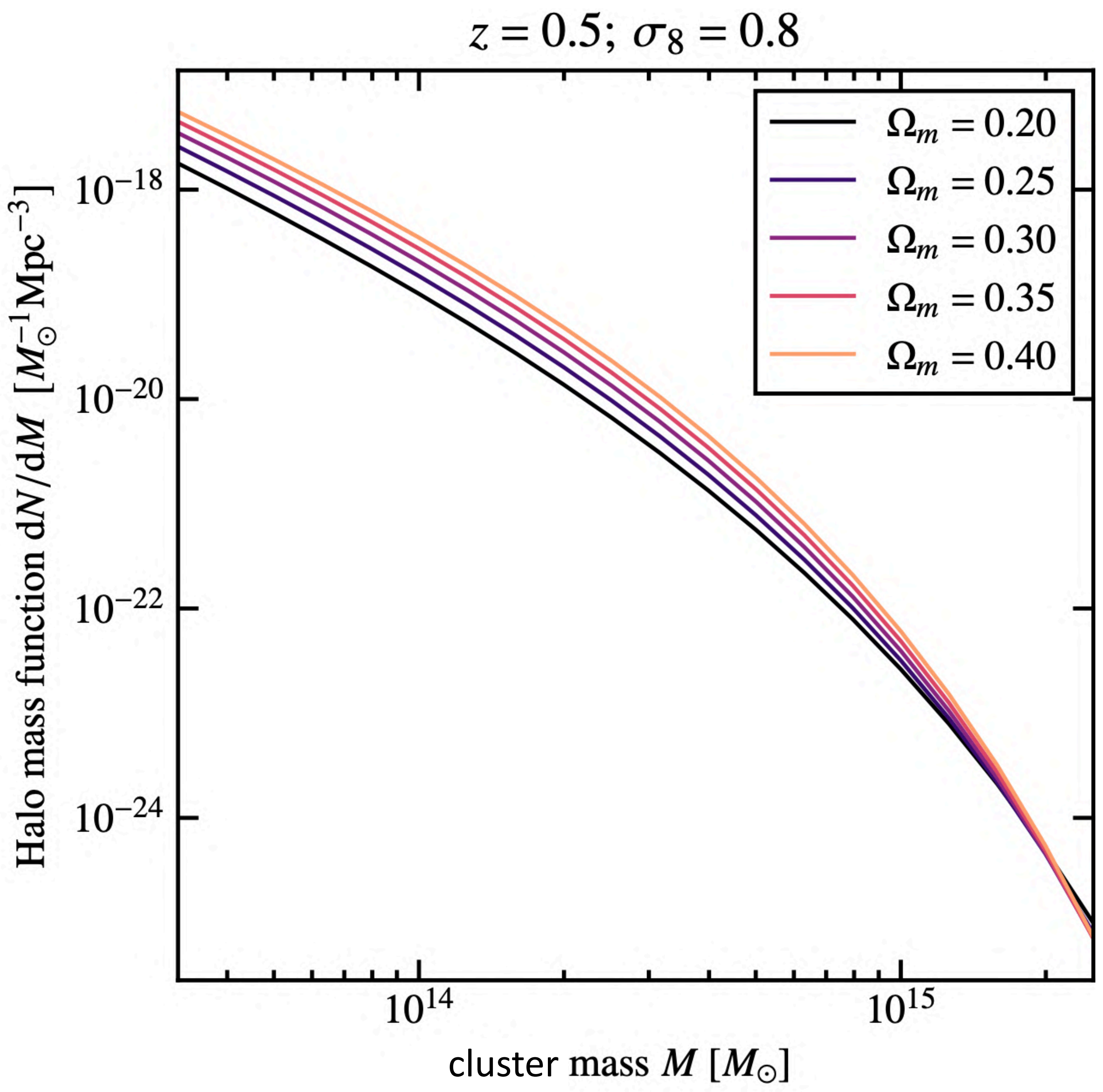
Studied through their counting per bins of mass and redshift

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

Mass is not an observable: indirect measurements through weak lensing

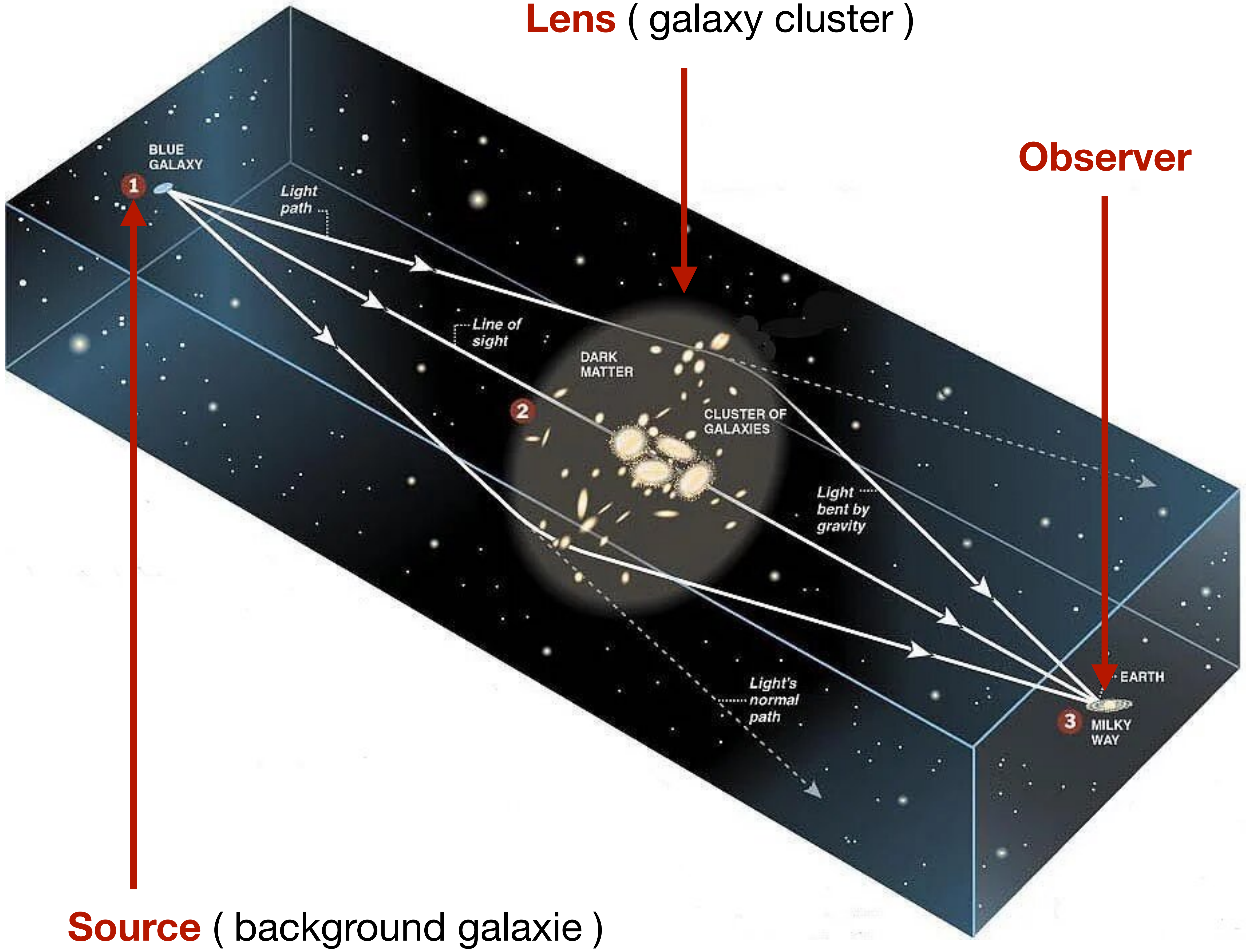




Weak gravitational lensing

Lens (galaxy cluster)

Observer

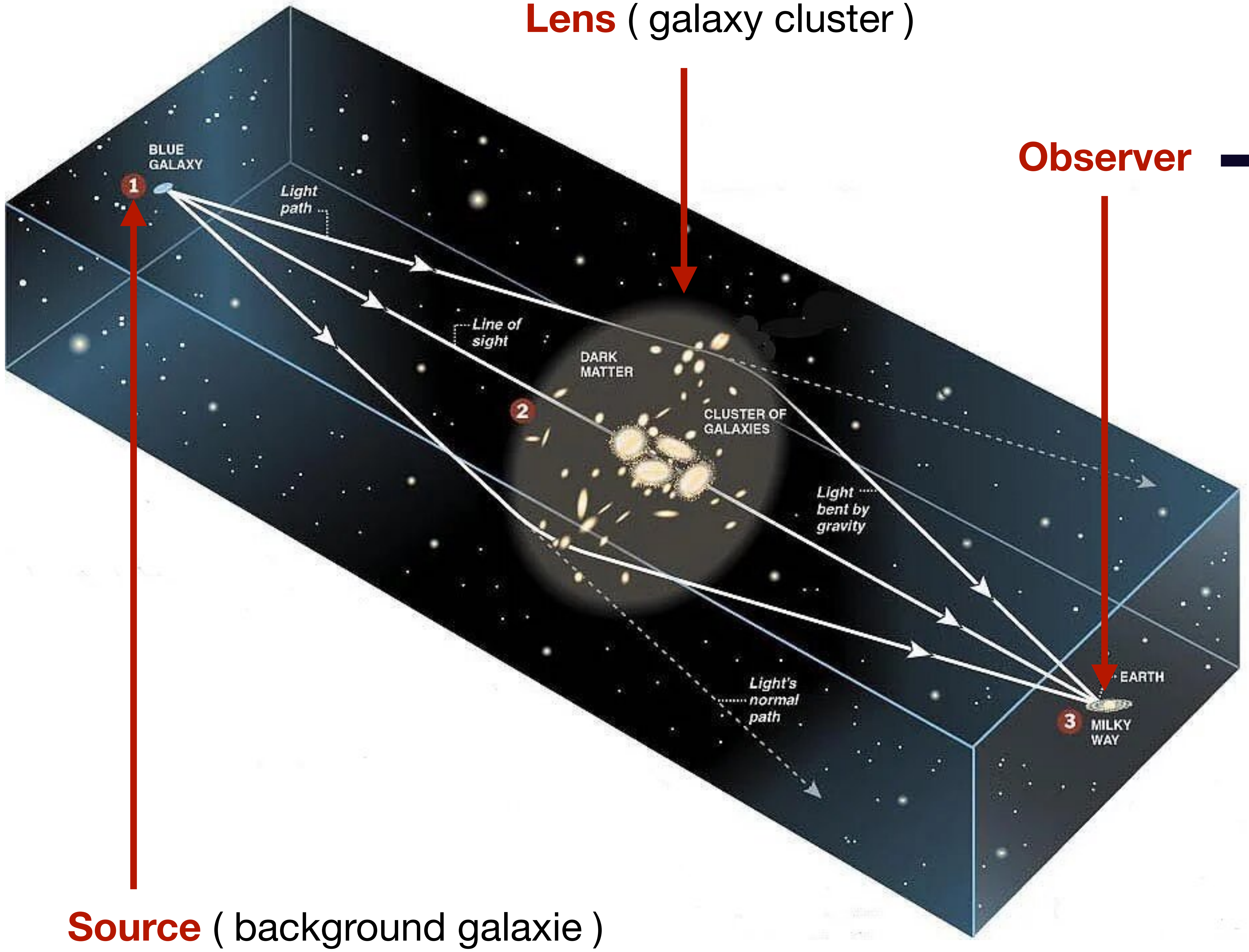


Source (background galaxie)

Weak gravitational lensing

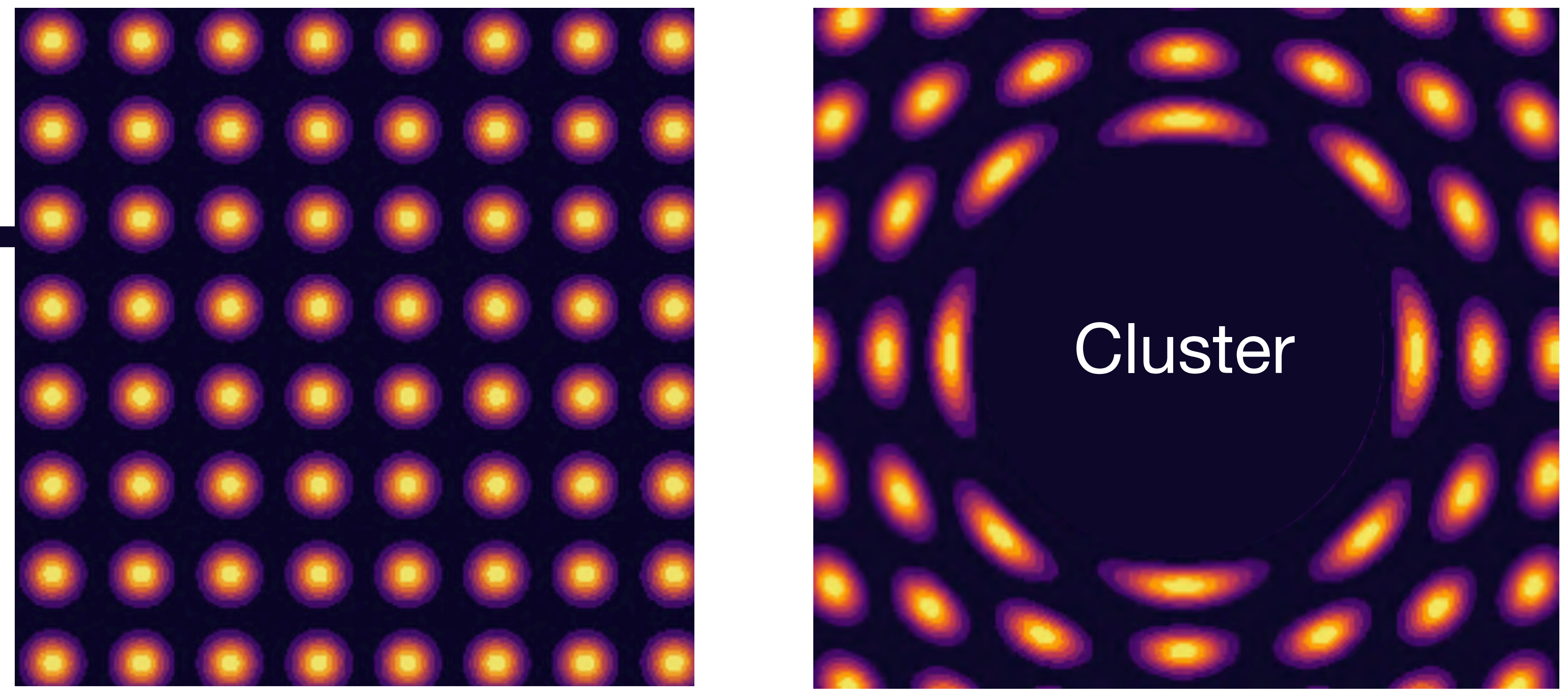
Lens (galaxy cluster)

Observer



Source (background galaxie)

UNLENSED **LENSED**



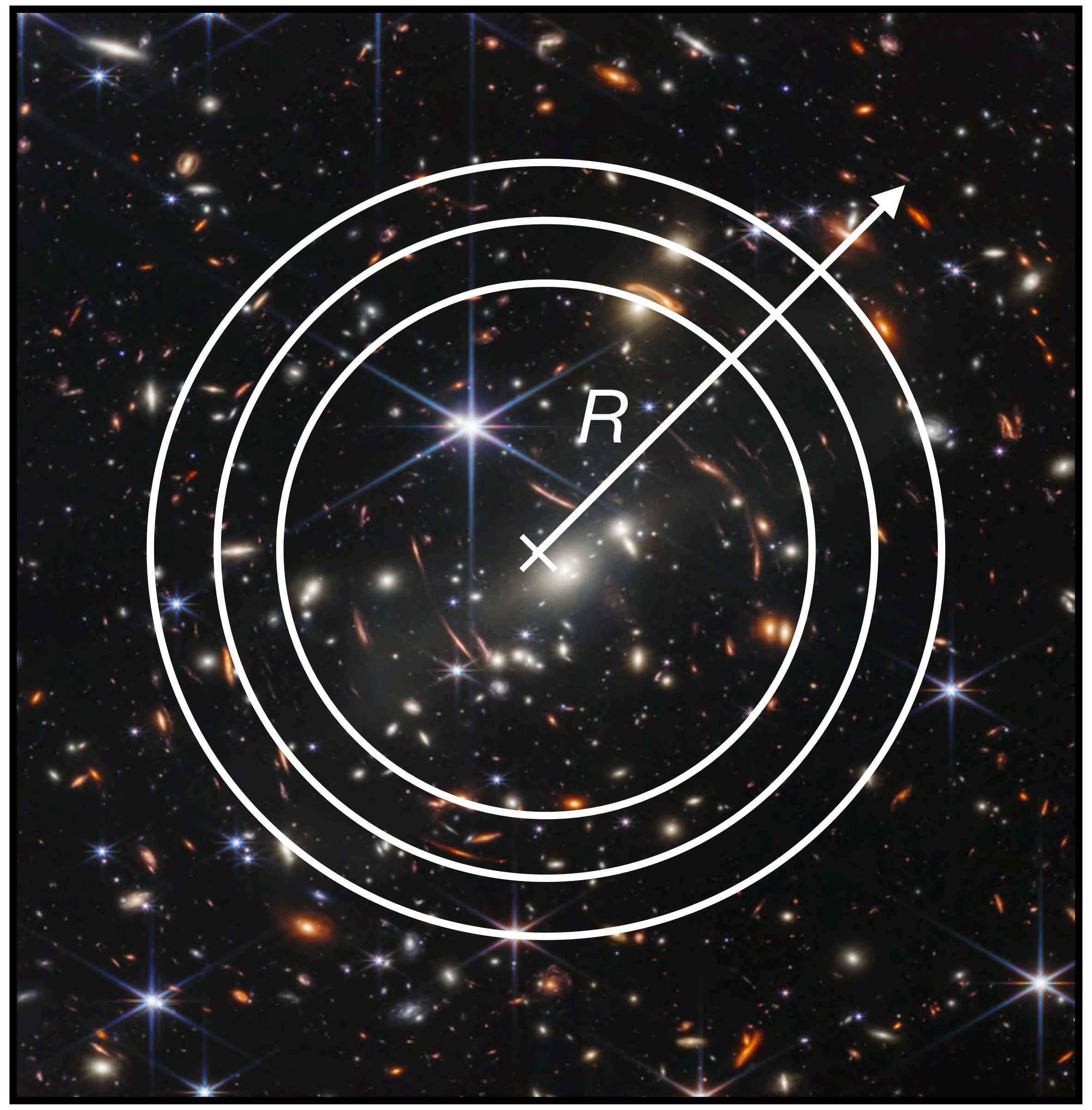
Galaxy shapes are used to measure the *lensing shear*

Weak gravitational lensing

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

$$\Delta\Sigma(R, z_l) = \langle \underbrace{\Sigma_{crit}(z_{gal}, z_l)}_{\text{Critical surface mass density}} \; \underbrace{\epsilon_{+}^{obs}}_{\text{Tangential ellipticity}} \rangle$$

Average on many galaxies



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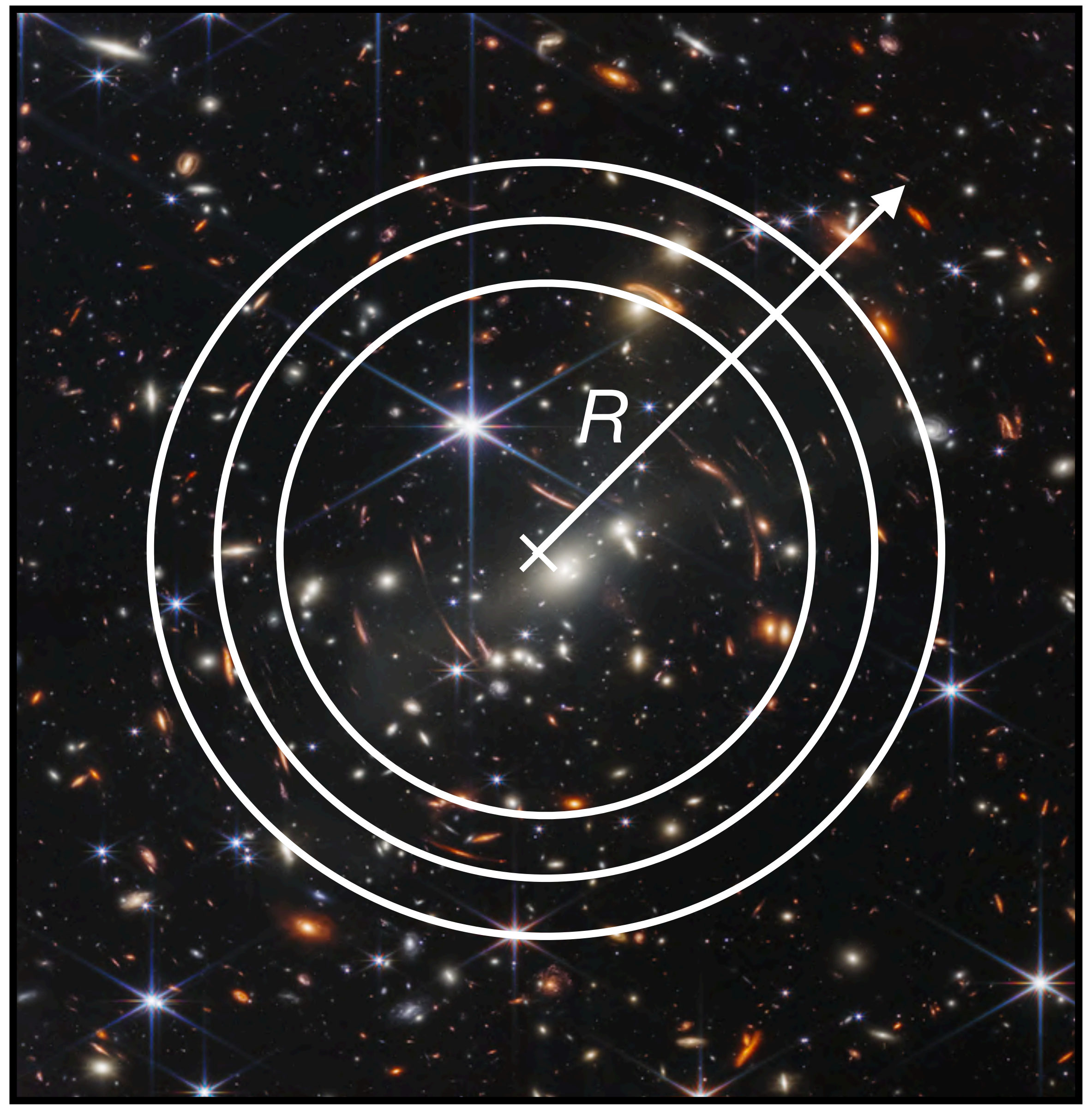
Average on many galaxies

Critical surface mass density
needs
redshifts

Tangential ellipticity
needs
shapes



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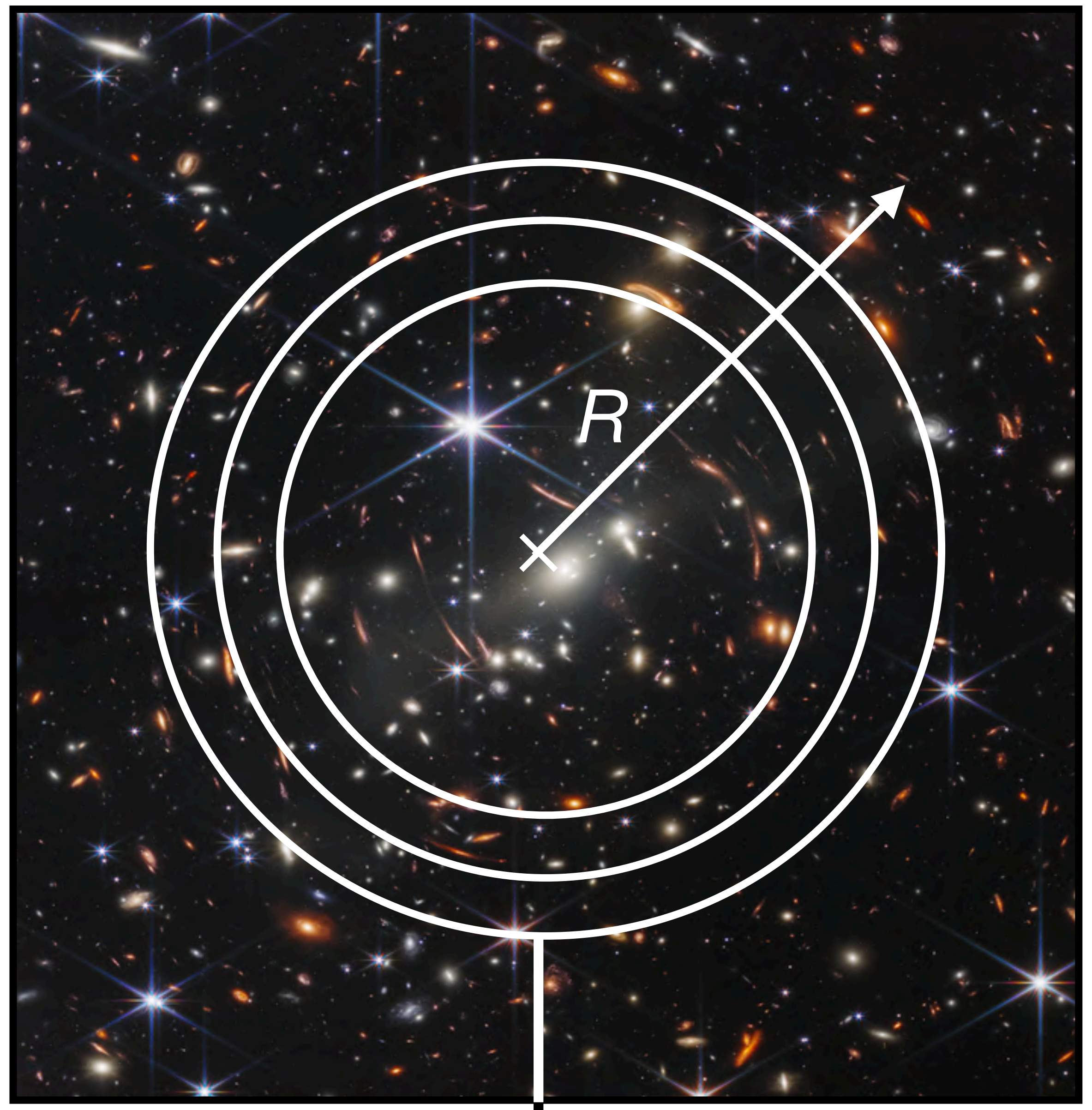
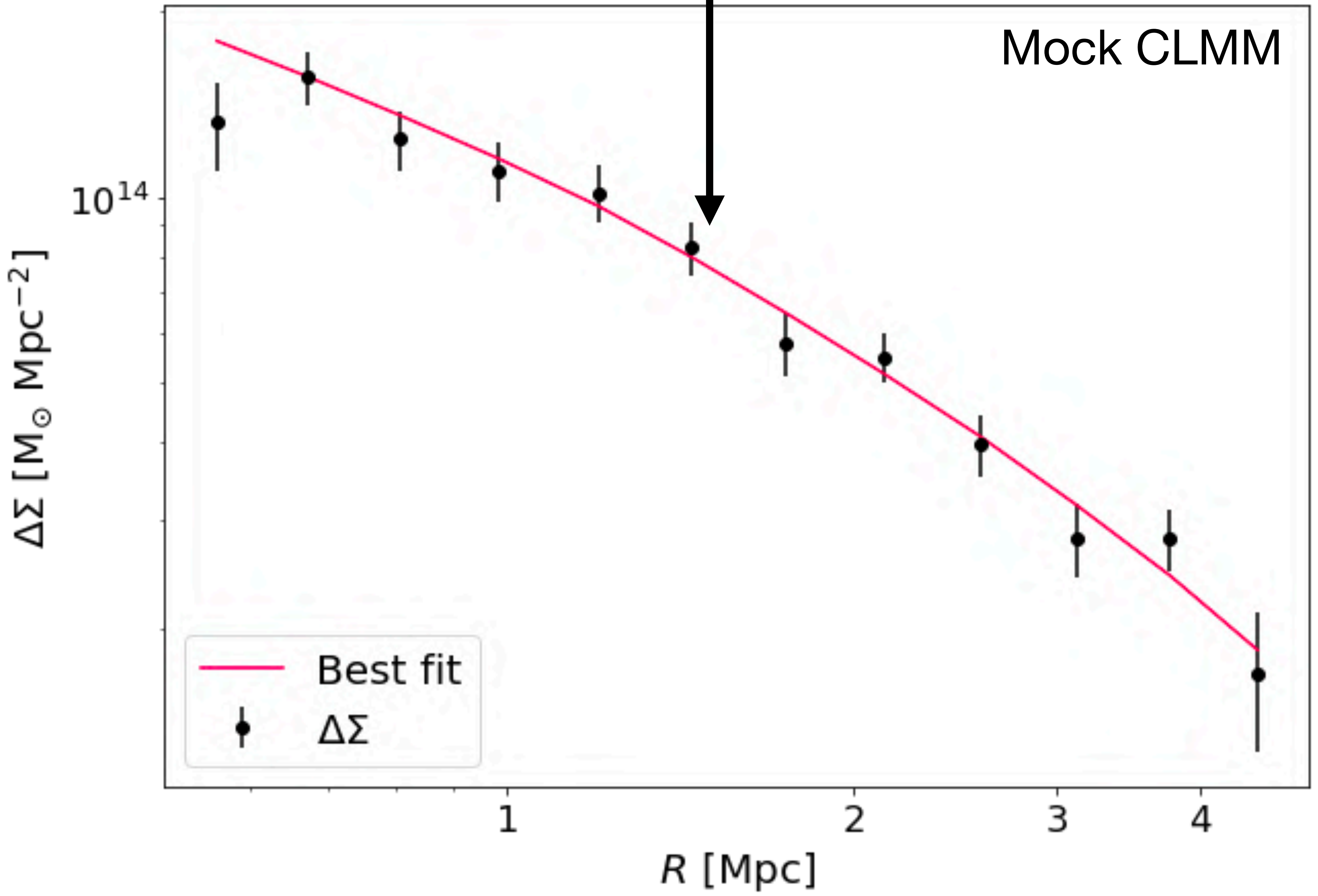
Average on many galaxies

Critical surface mass density needs redshifts

Tangential ellipticity needs shapes

Fit of $\Delta\Sigma$ = Estimate of galaxy clusters masses





Vera C. Rubin - LSST

Vera C. Rubin Observatory

- World's largest camera (3 billions pixels)
- 8-diameter primary mirror
- 0.2 arcseconds per pixel

Legacy Survey of Space and Time - LSST

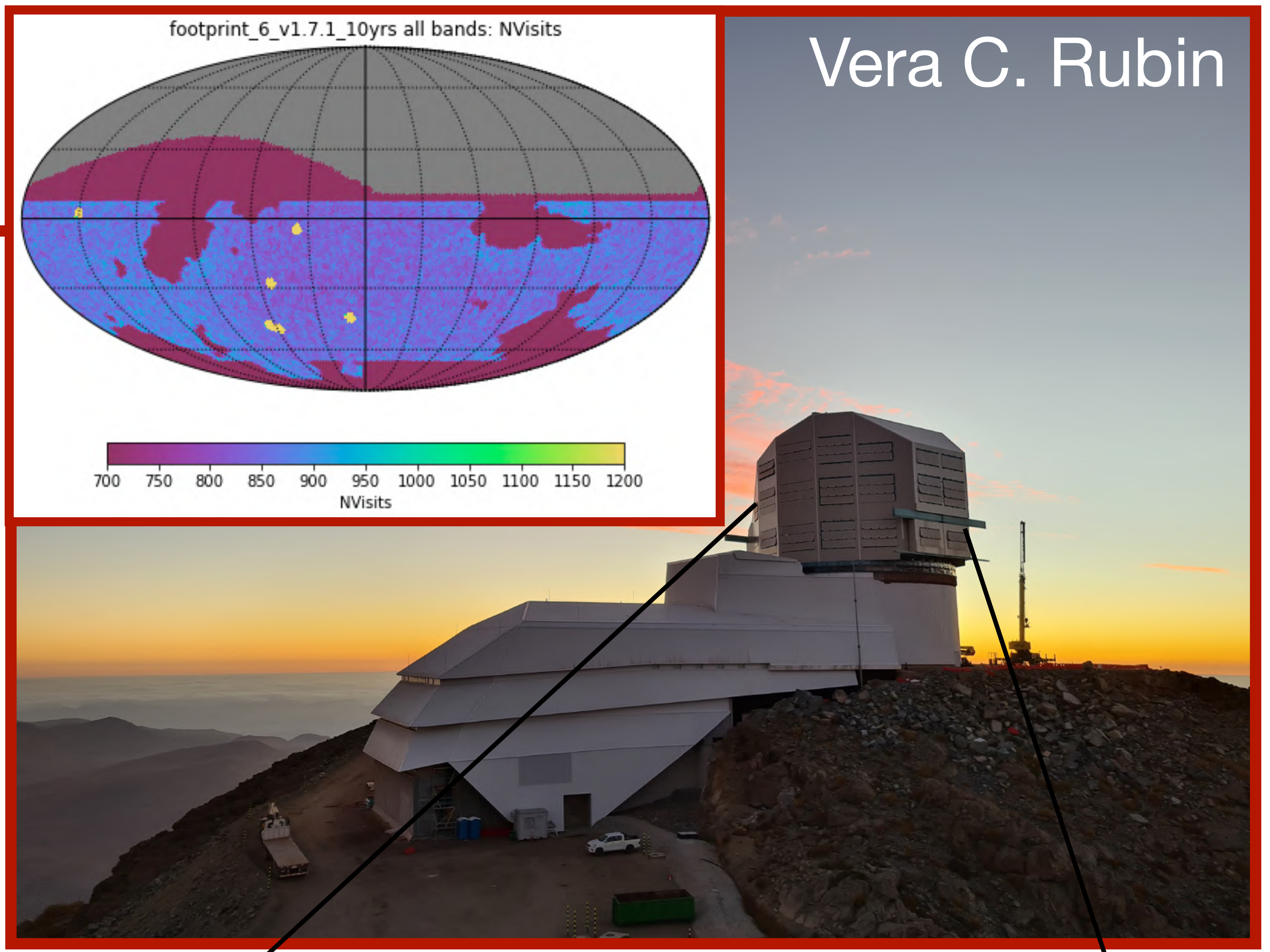
- **Optical** and **deep** sky survey over 10 years
- Footprint of 18,000 deg^2
- First scientific data in **2025**

DES	LSST
0.5 billion	10 billions of galaxies
redshift ≤ 1.5	redshift ≤ 3
magnitude ≤ 23	magnitude ≤ 27

International scientific collaboration DESC

- ~ 1000 members, 20 countries

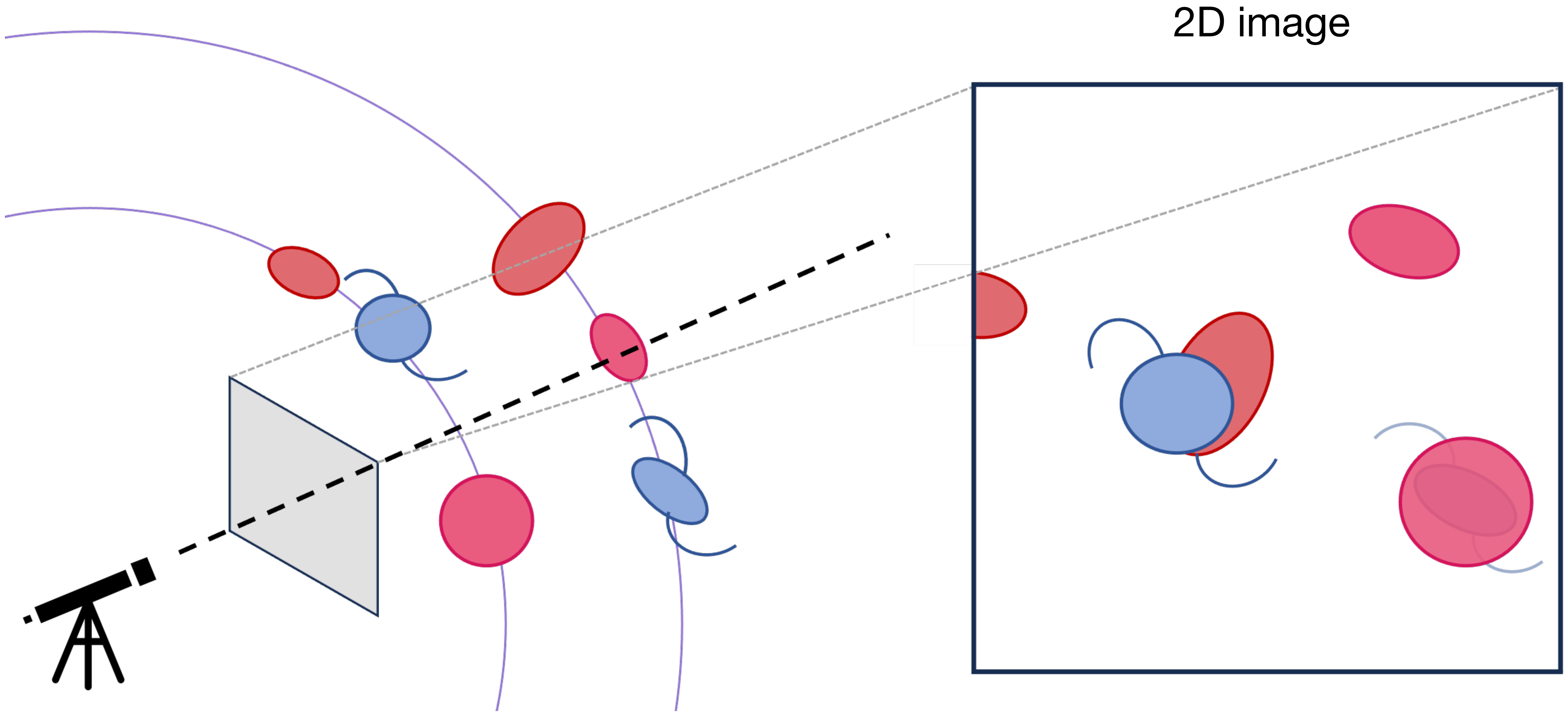
LSST DESC
Dark Energy Science Collaboration



Blending

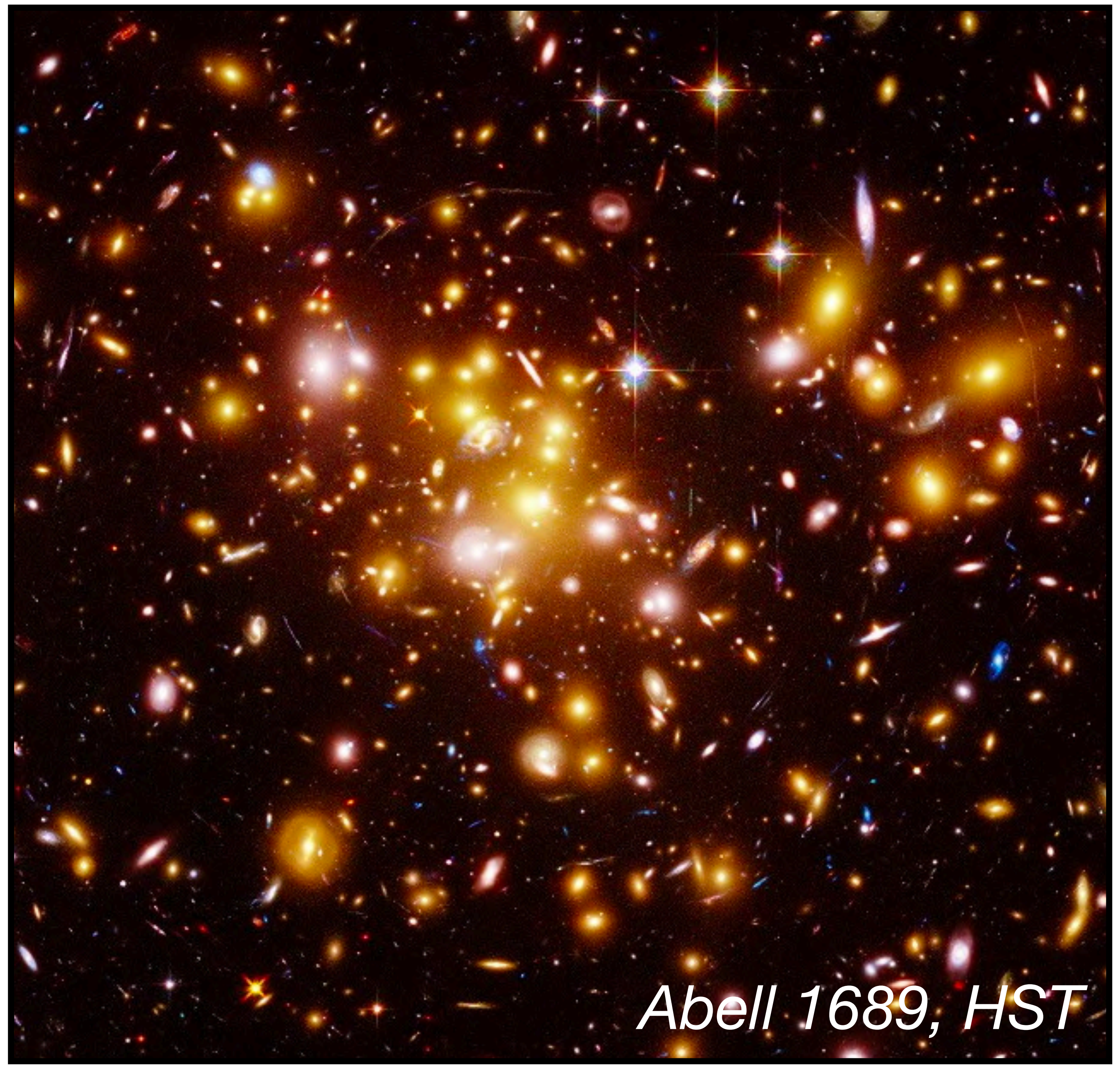
Superposition of galaxies on the images due to:

- The **number** of observed galaxies
- the **depth** of observation
- the survey's **resolution**/PSF



Blending

1. Number of galaxies



Blending

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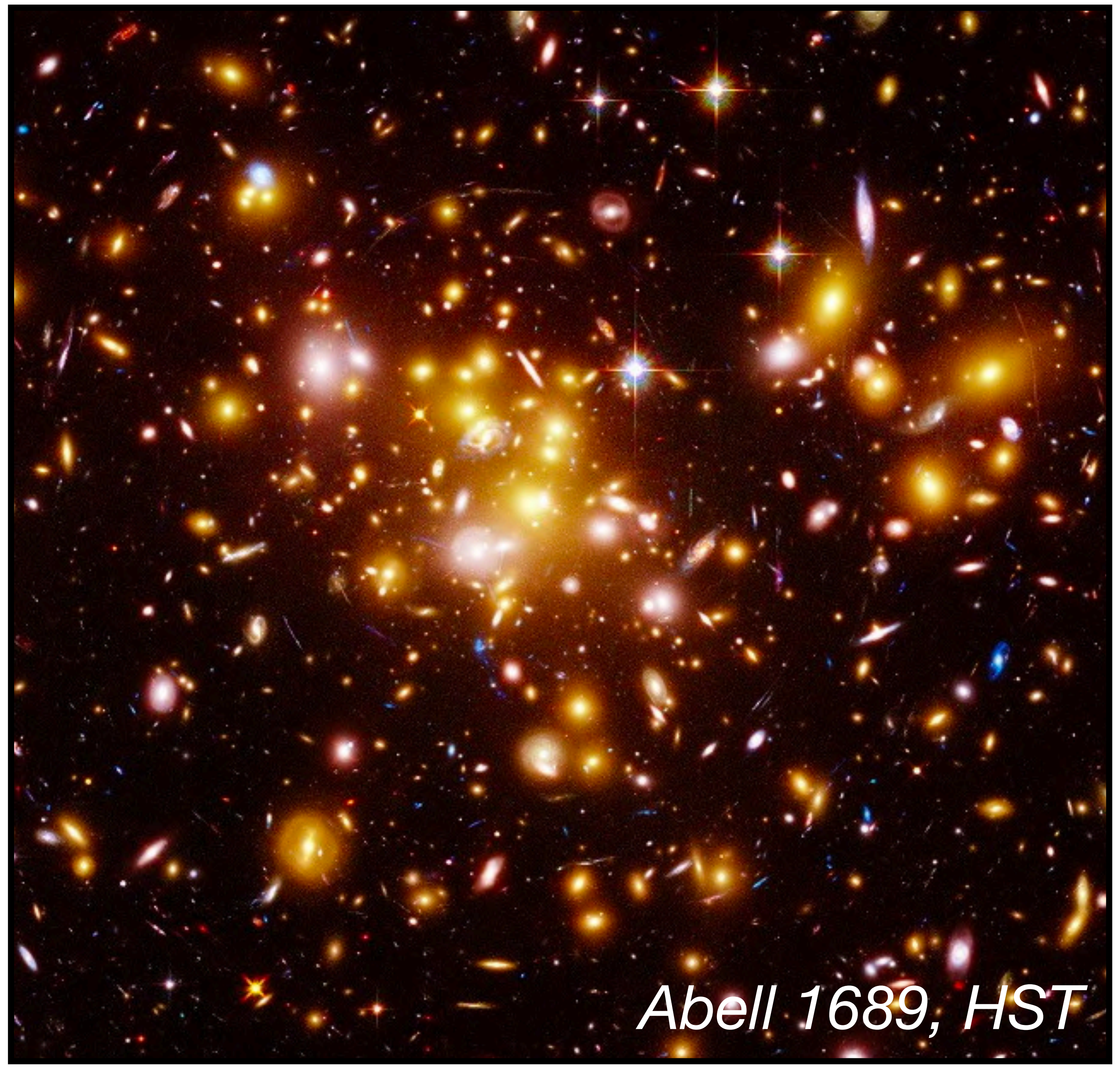
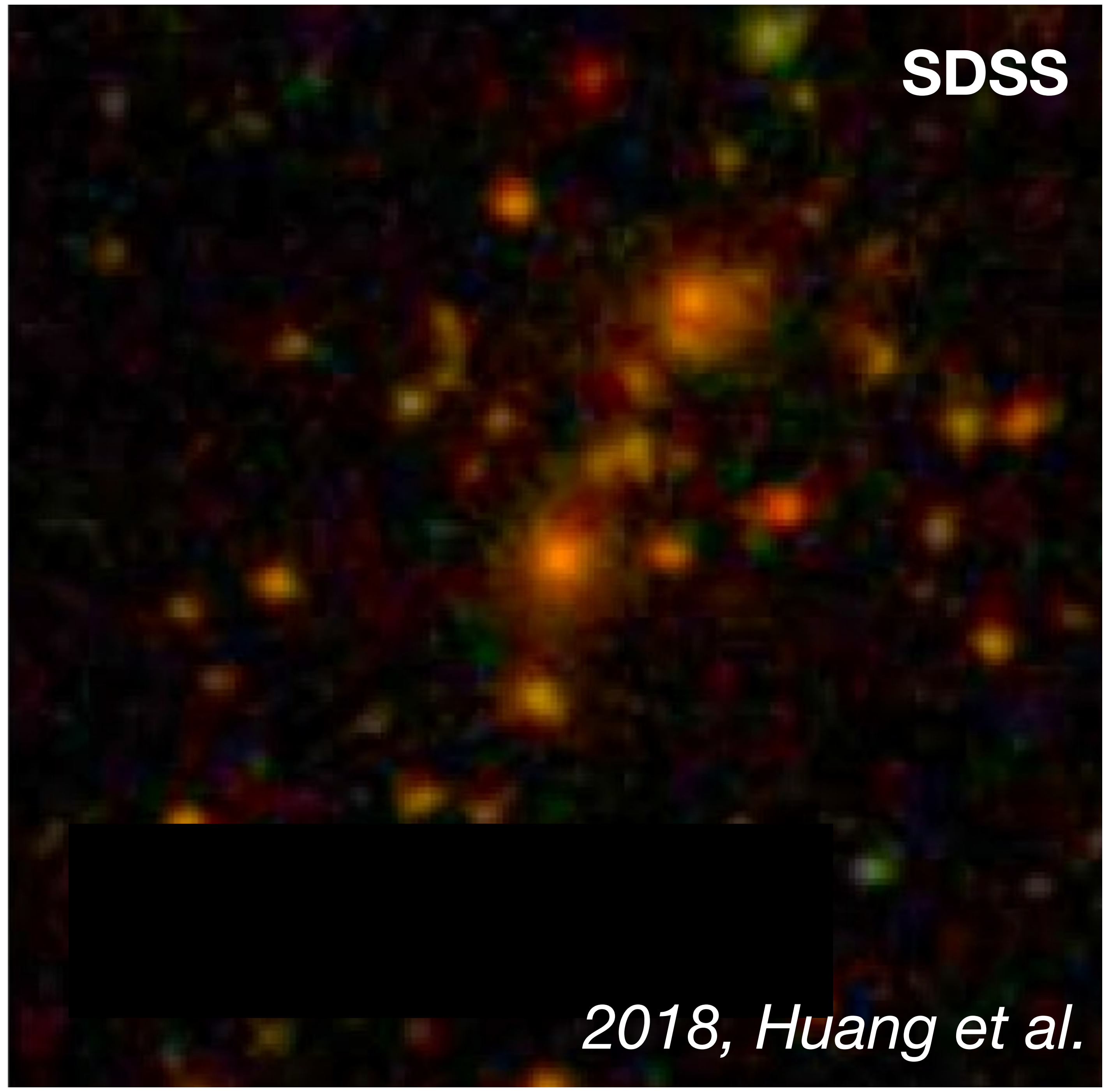


2. Depth of observation



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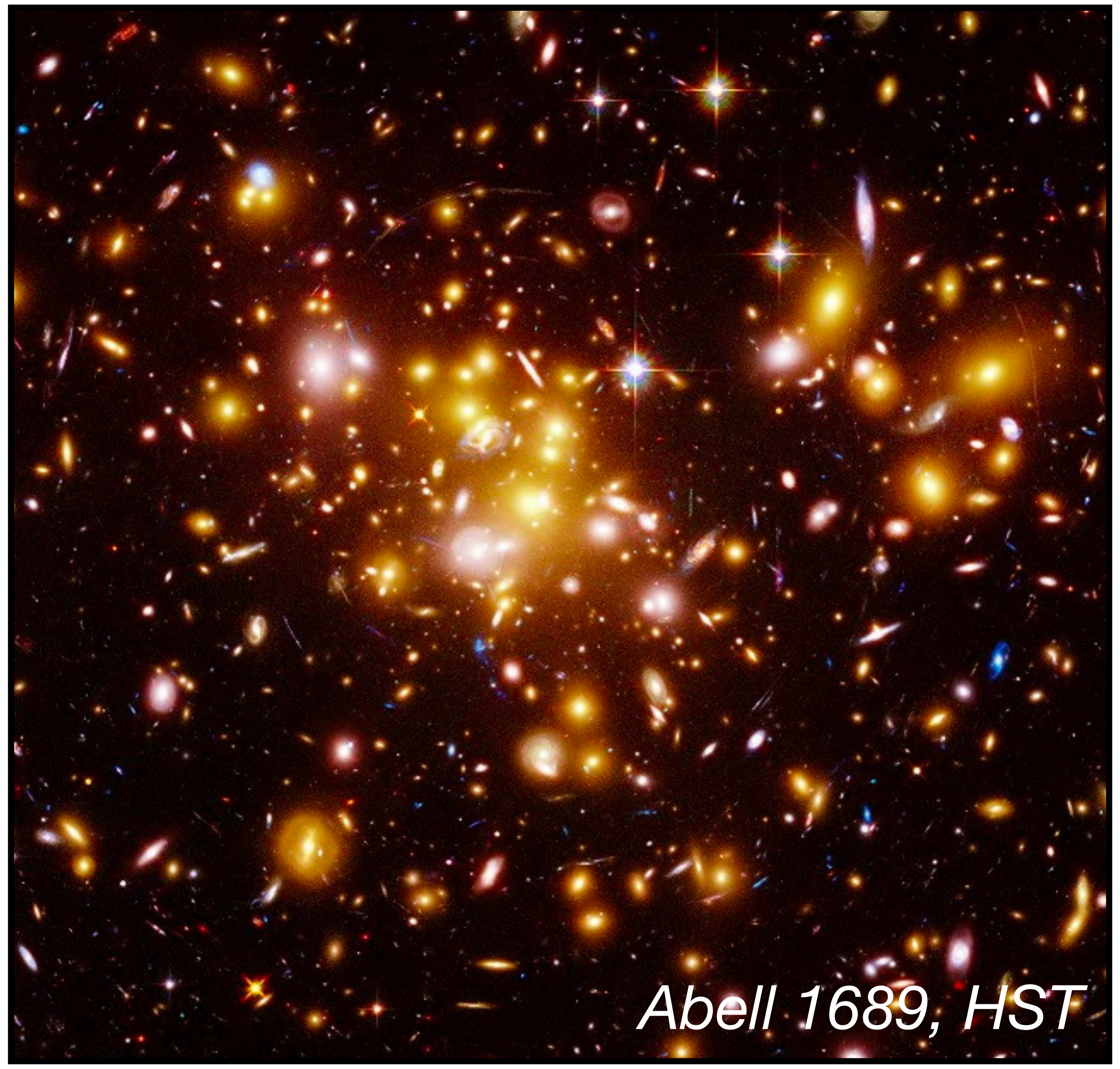

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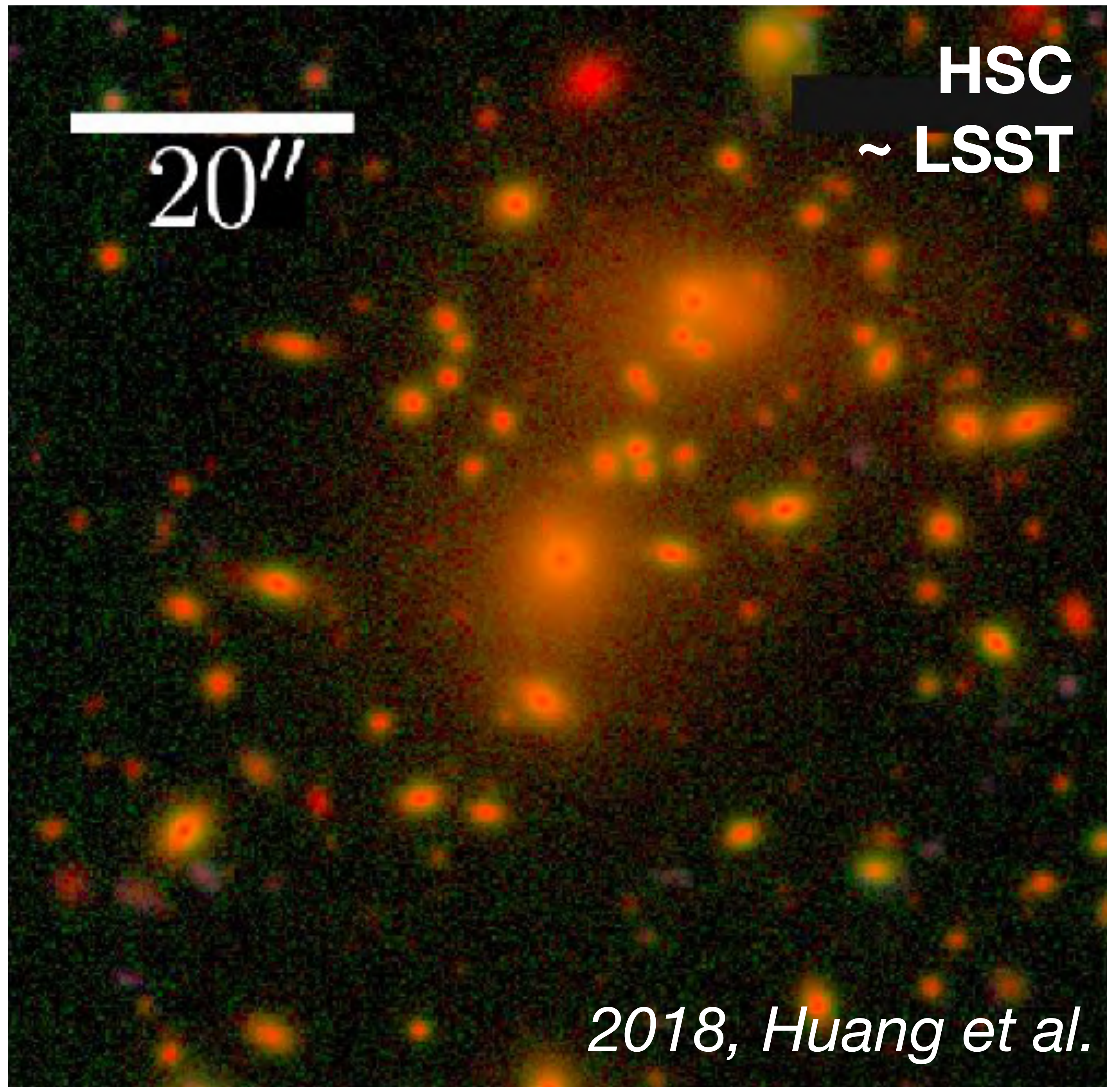

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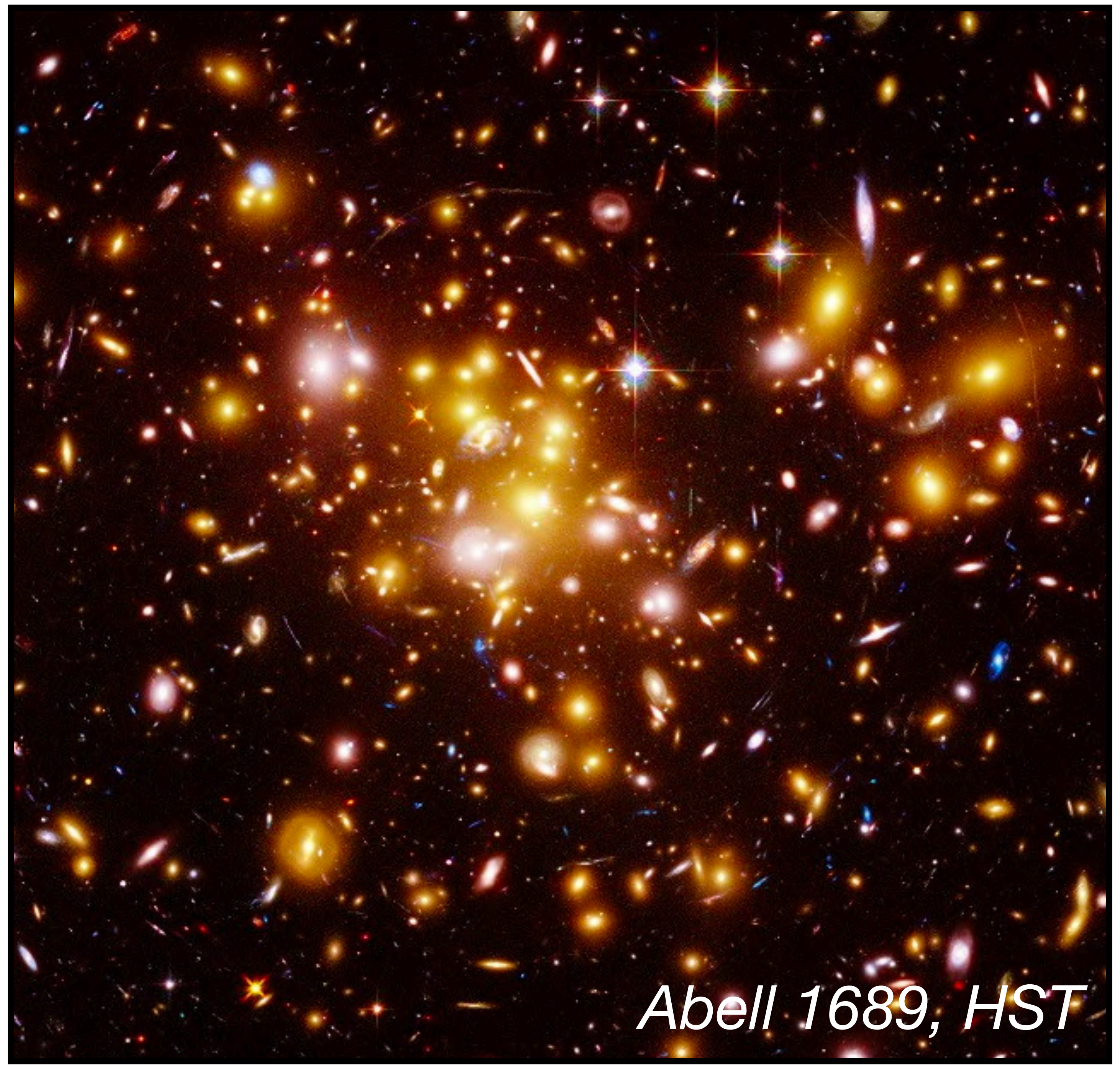

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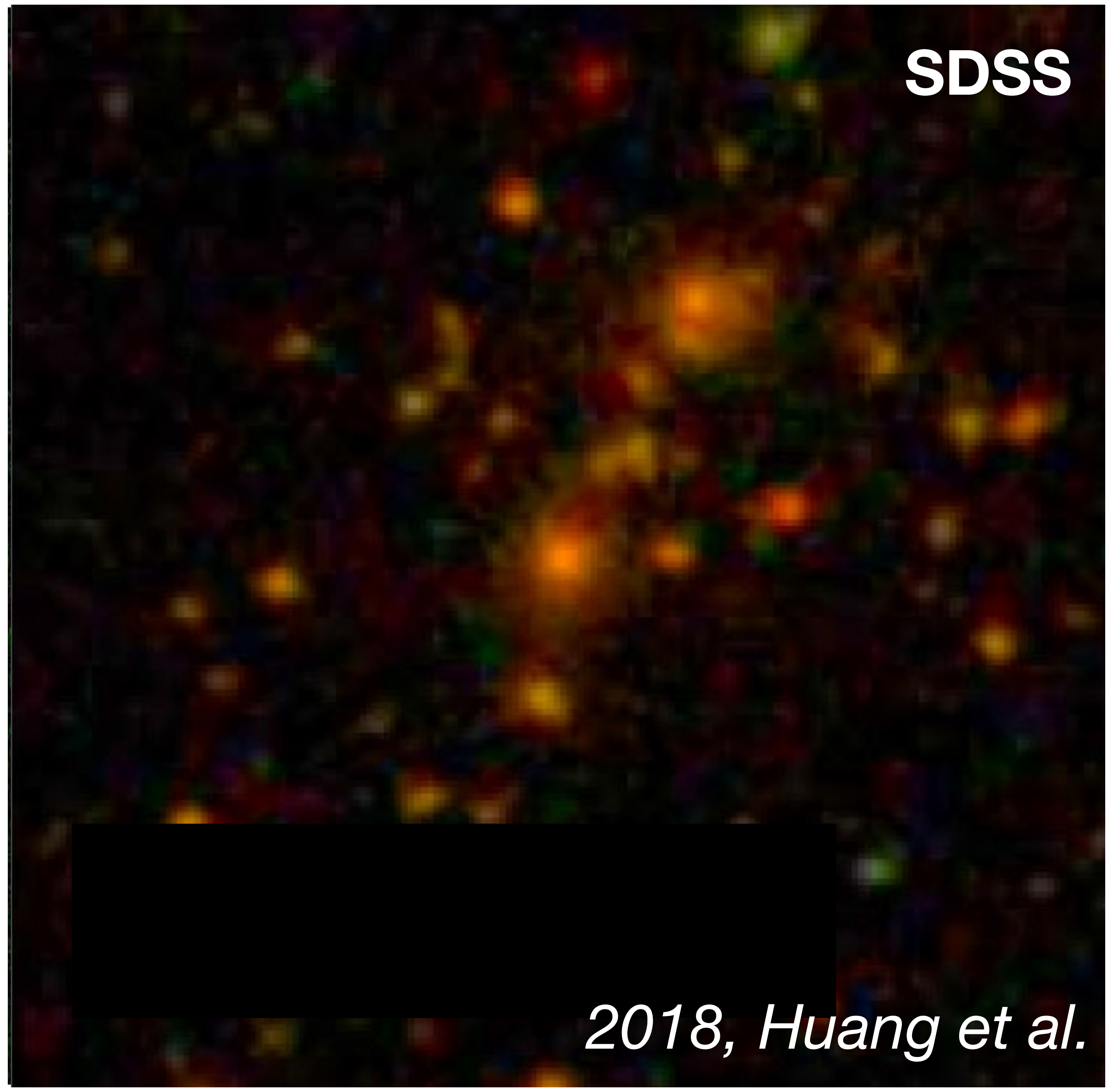

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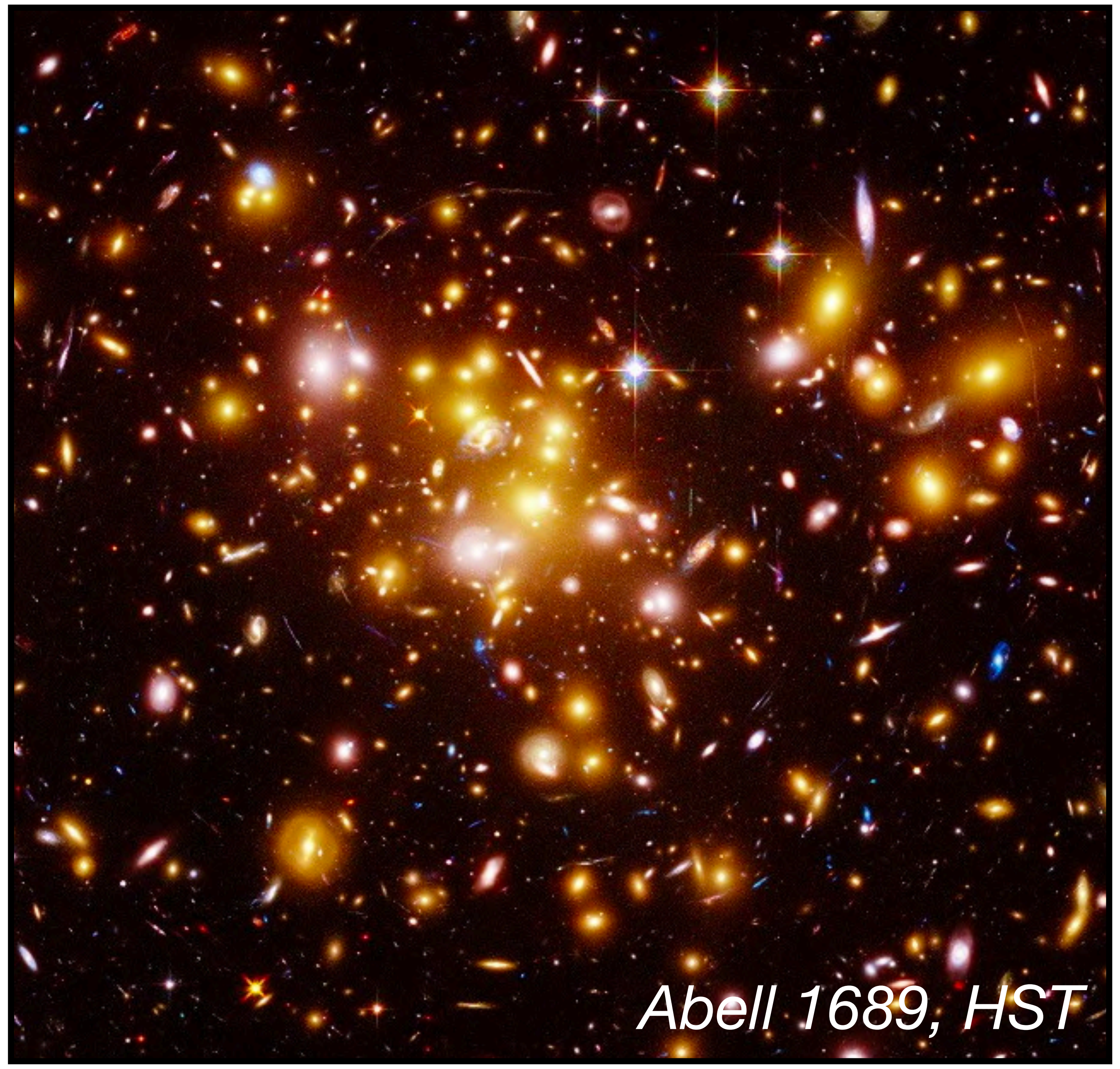

Abell 1689, HST

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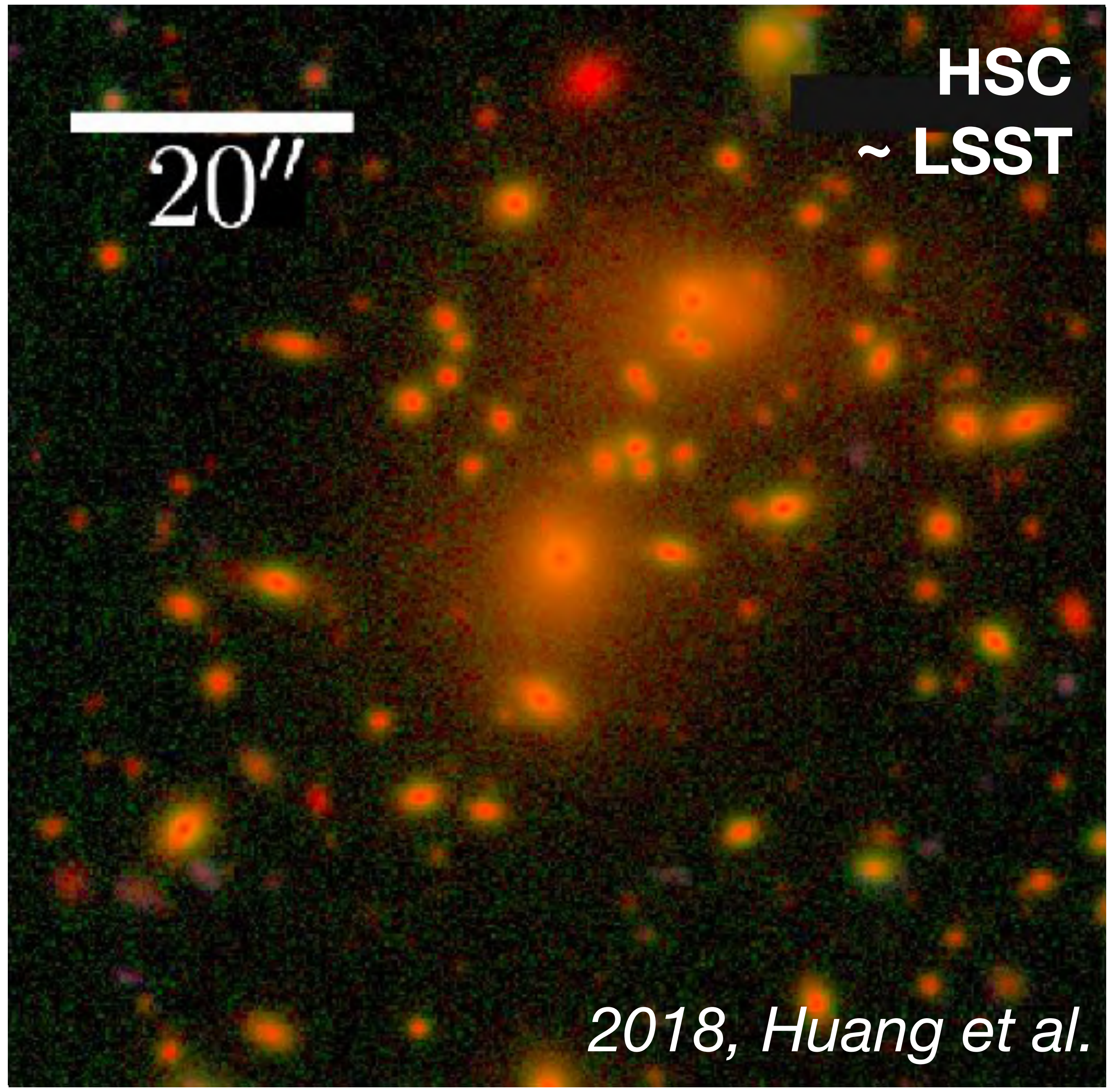

2018, Huang et al.

Blending

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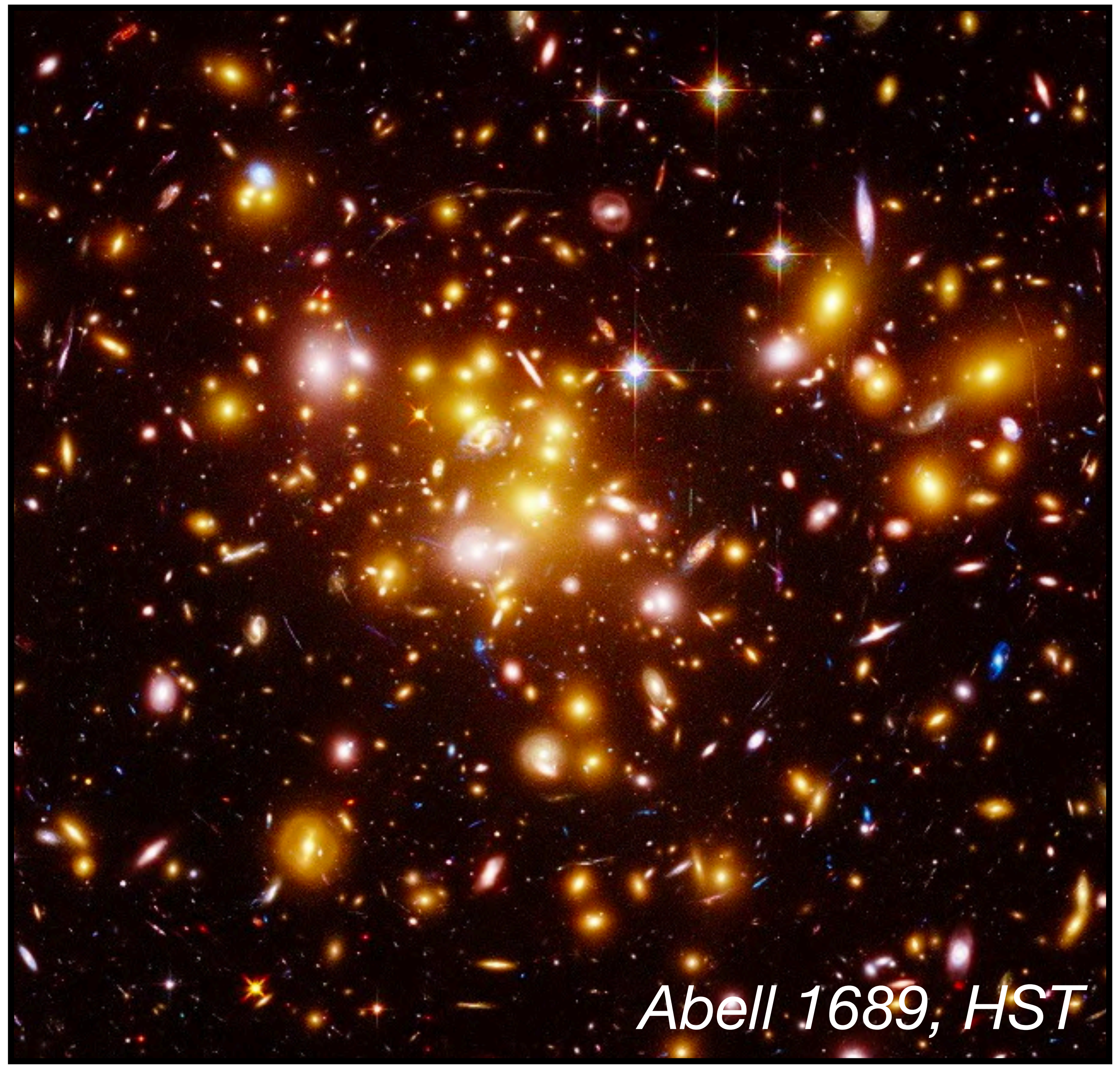

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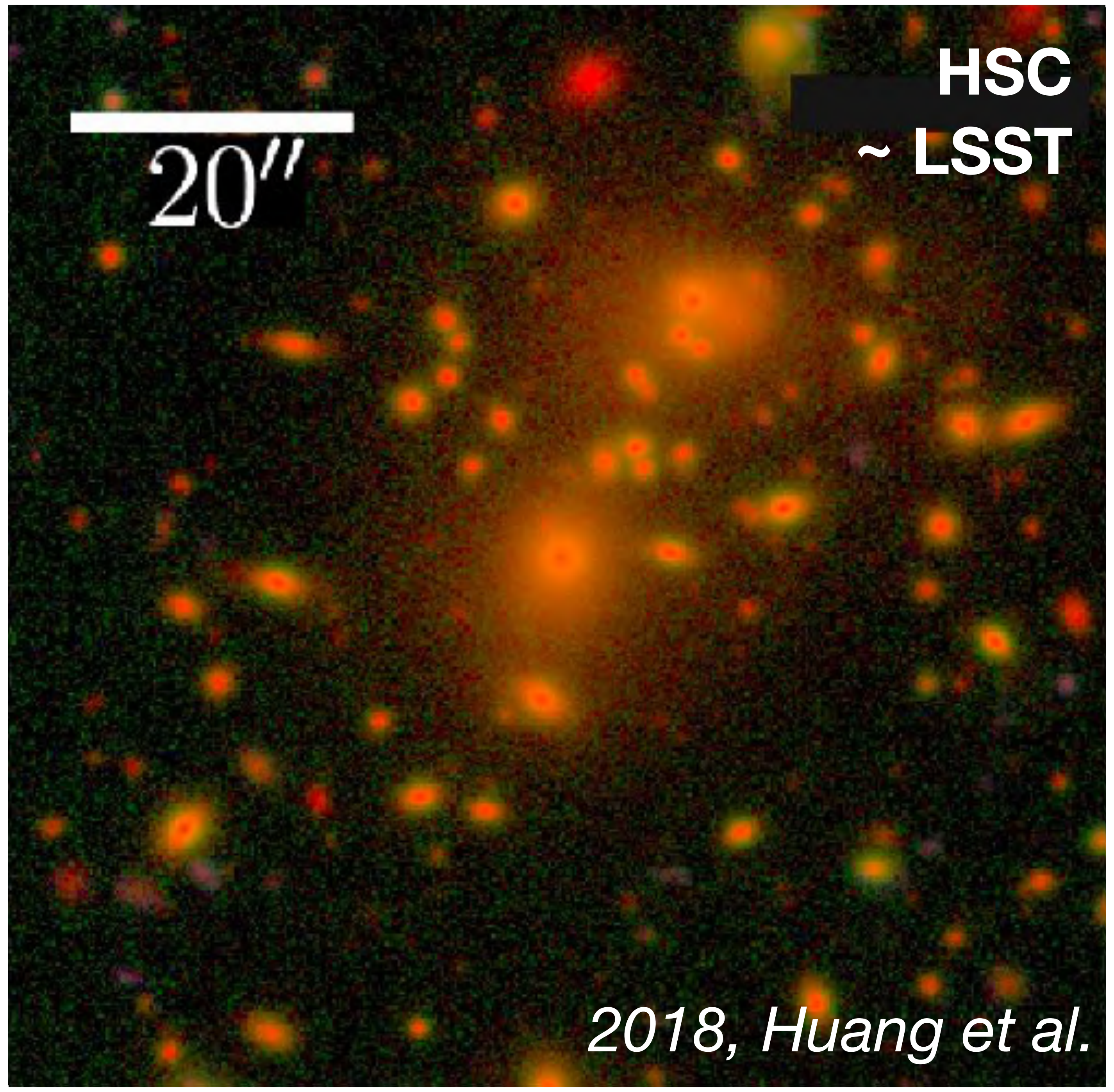
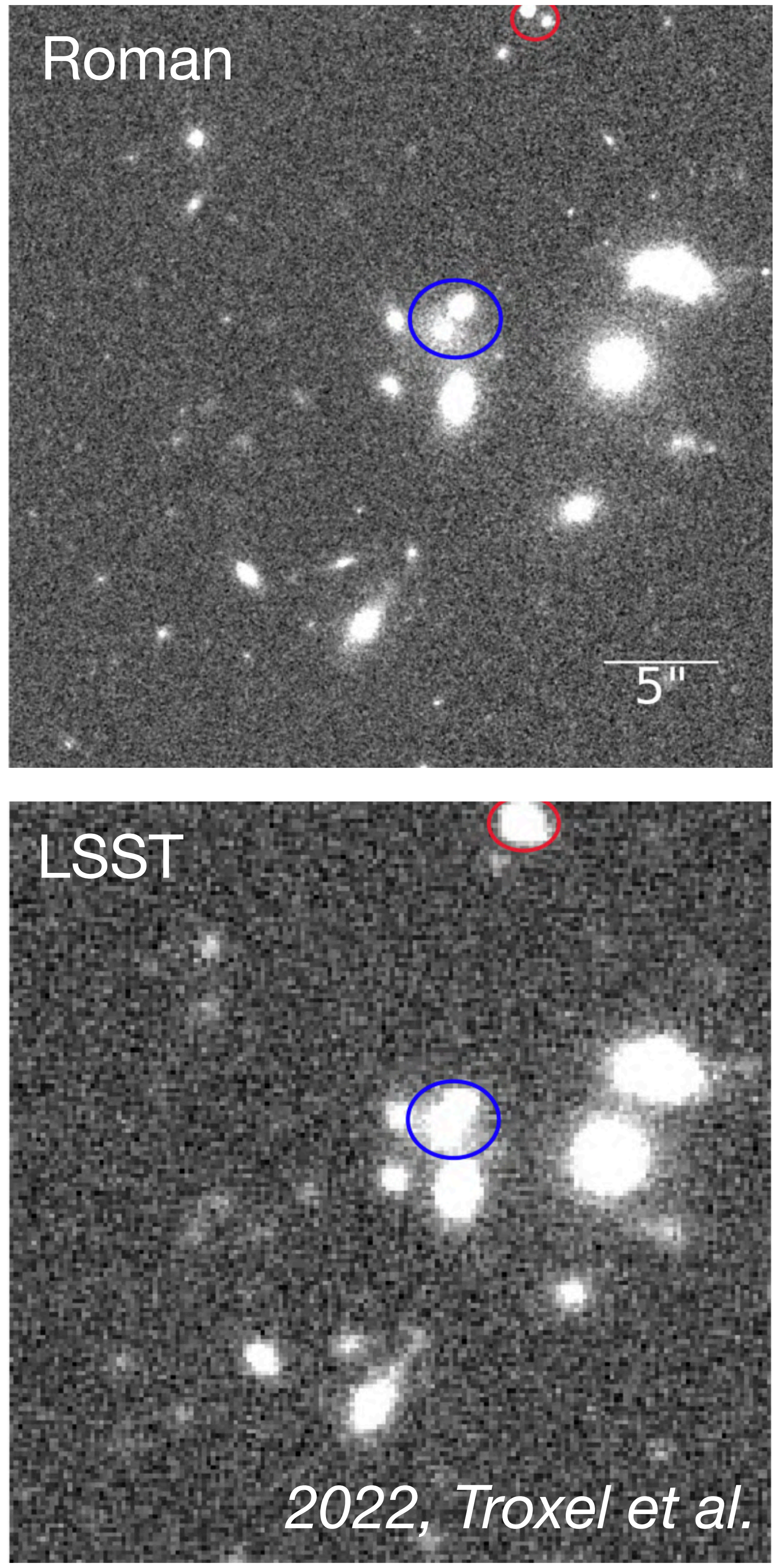


2018, Huang et al.

3. Survey's resolution

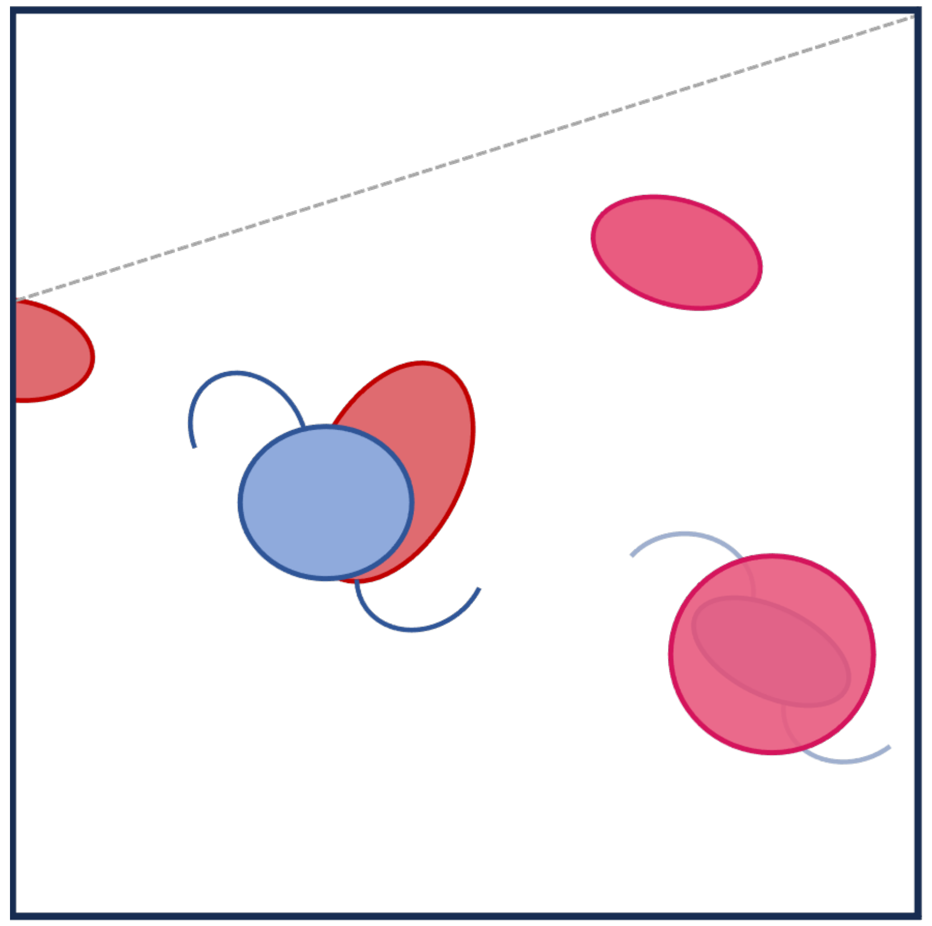


2022, Troxel et al.

Less resolution

Blending

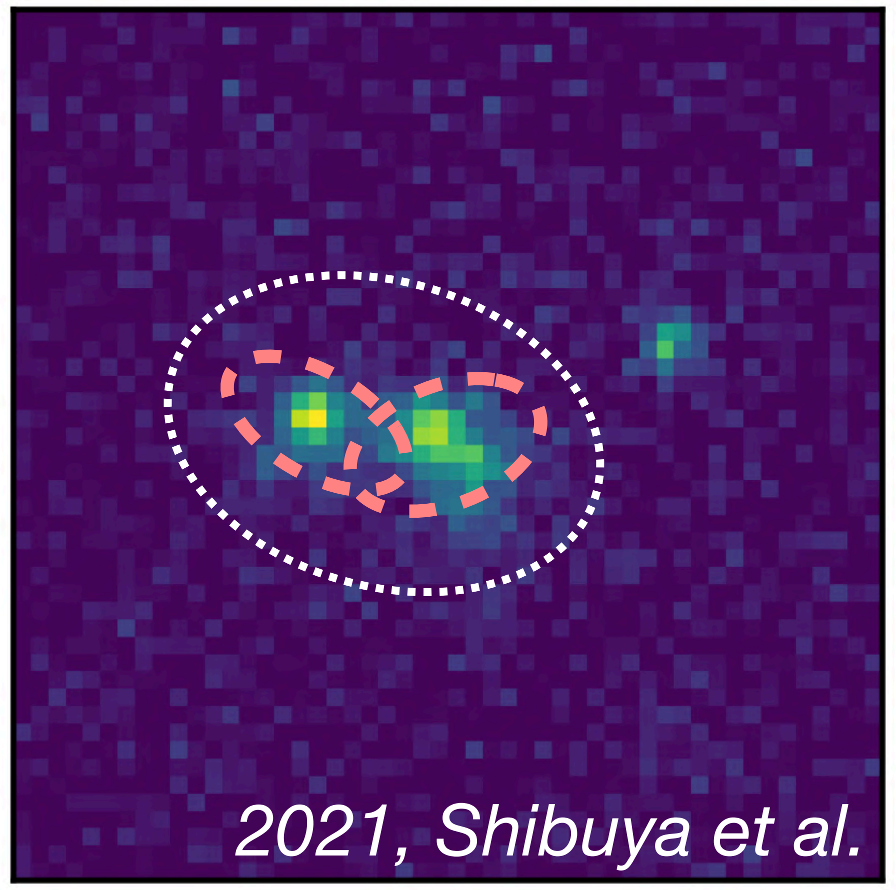
2D image



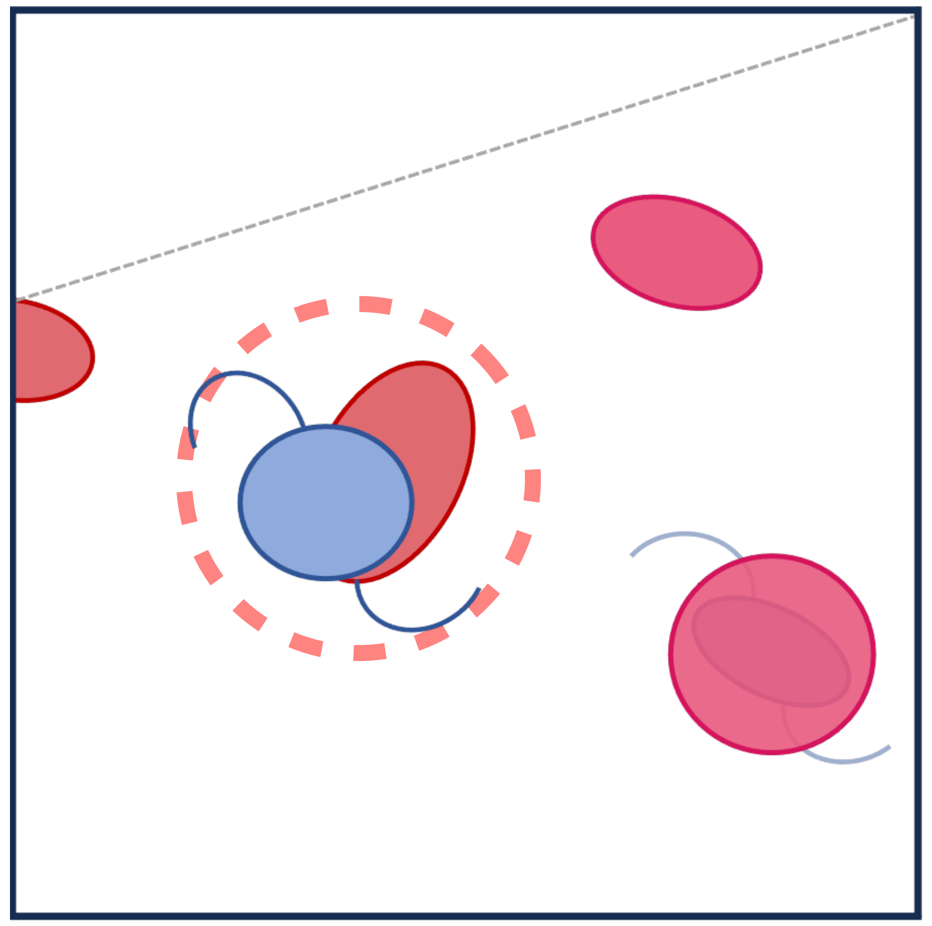
Blending

Recognized blends

Hubble/ACS

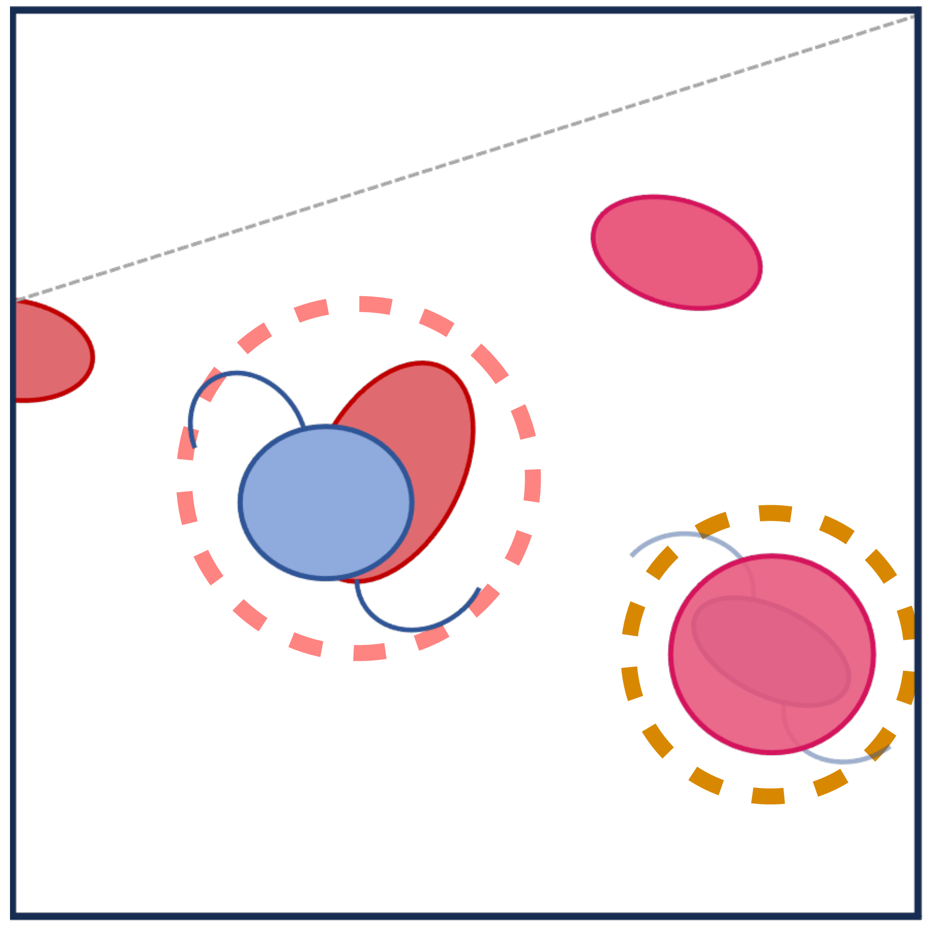


2D image



Blending

2D image



Less resolution

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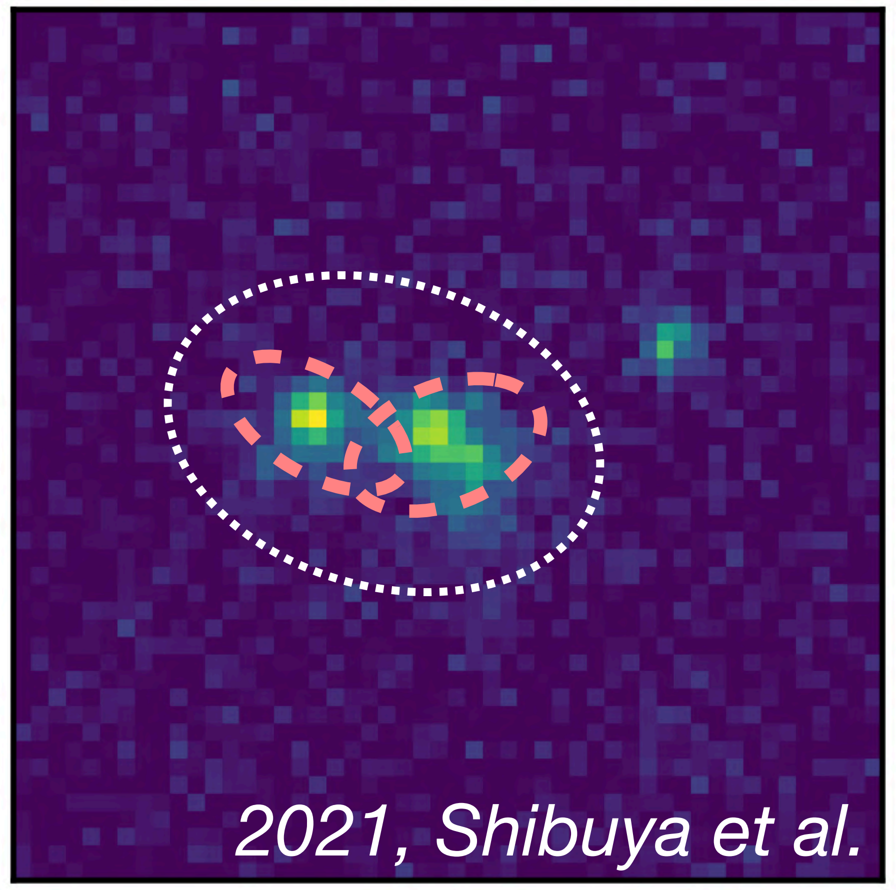
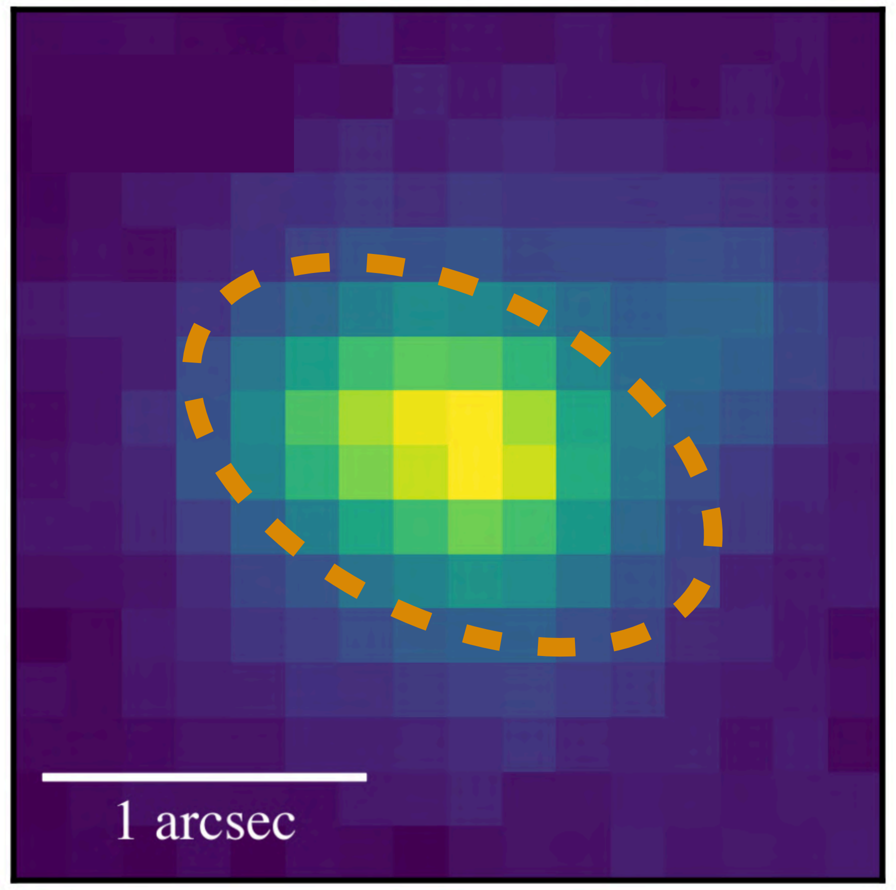


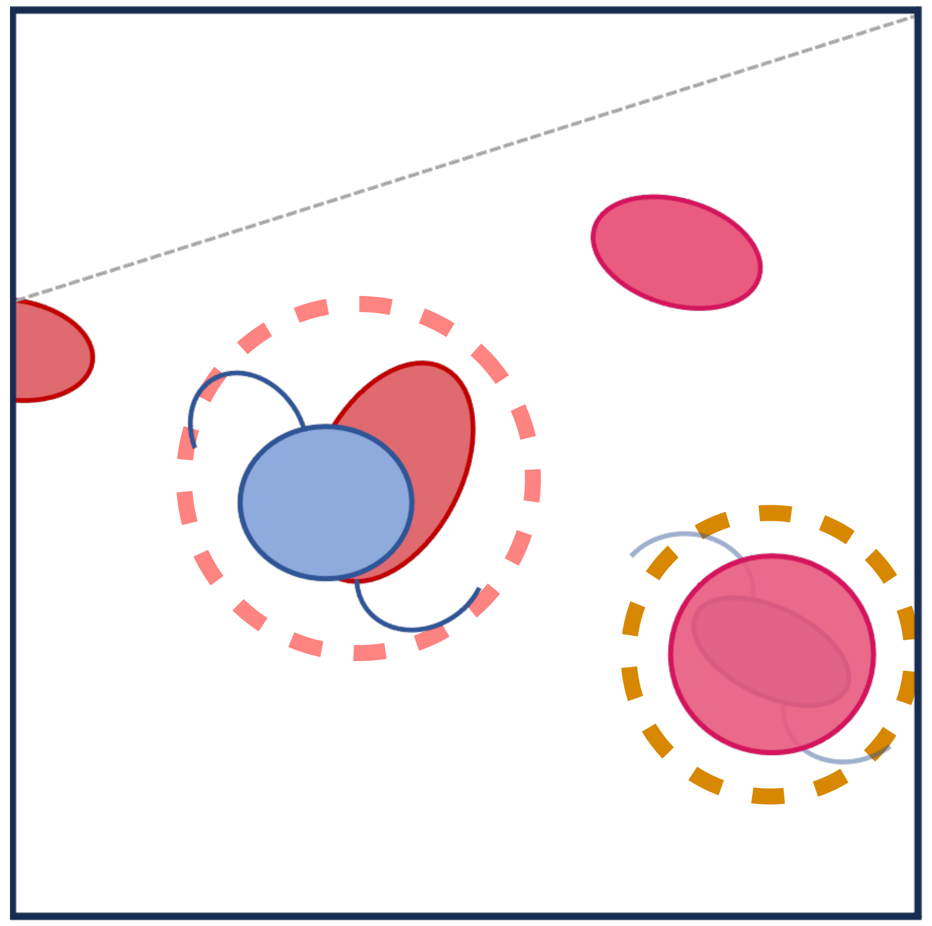
Unrecognized blends

Subaru/HSC



Blending

2D image



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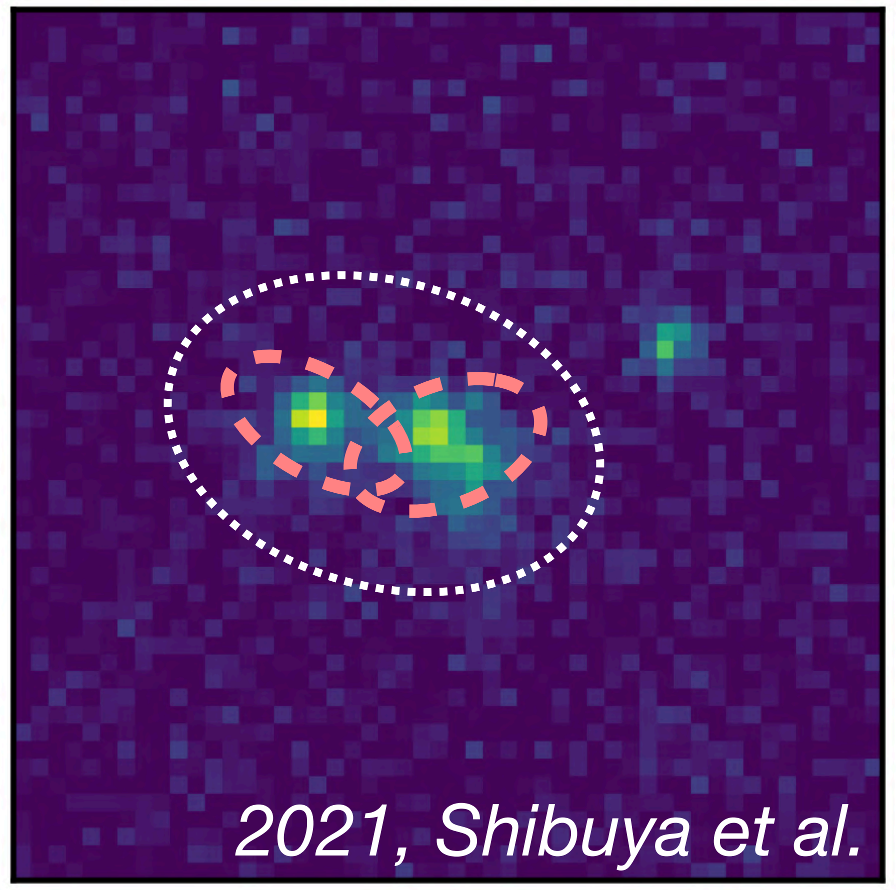

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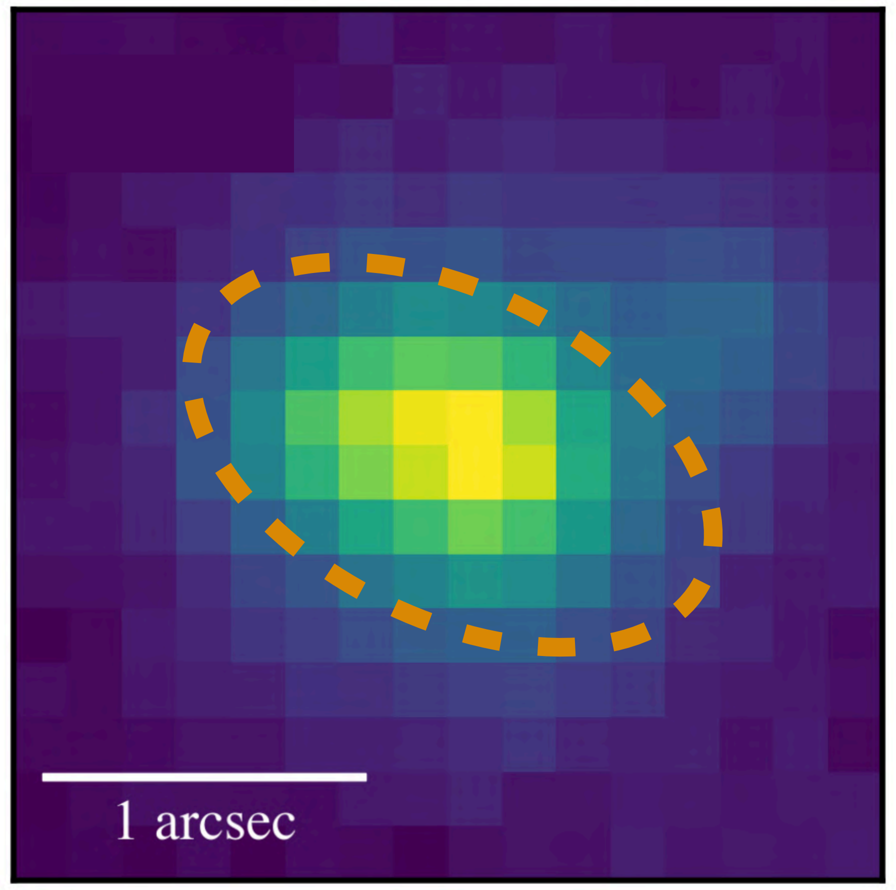
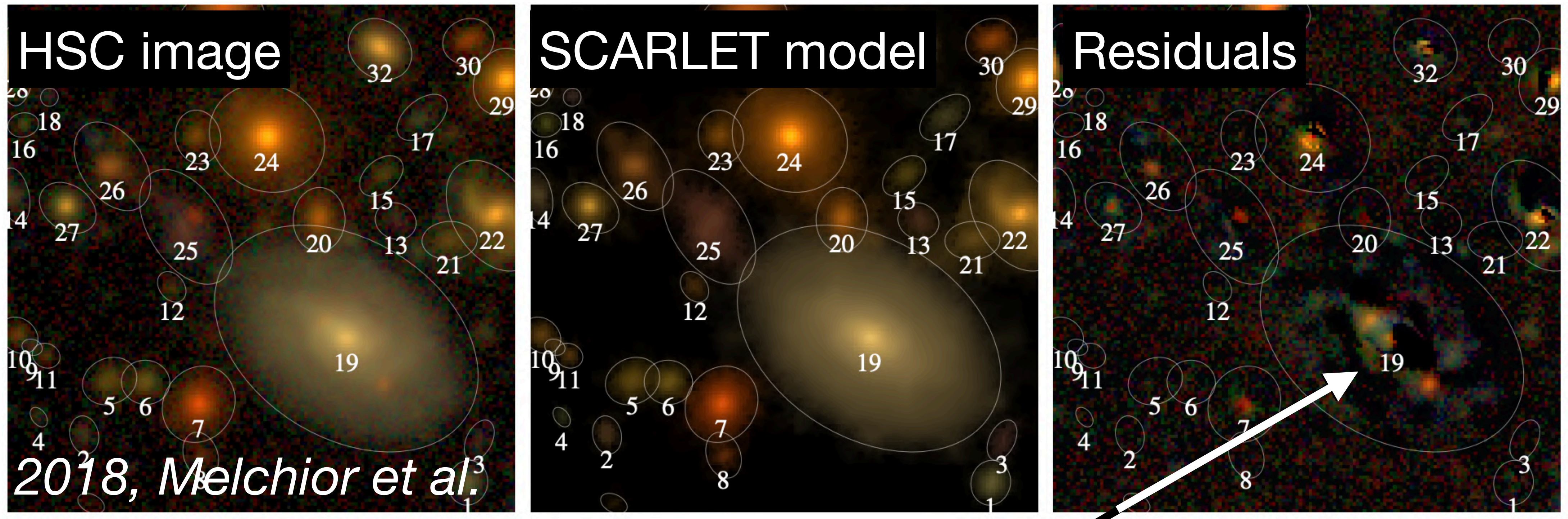


LSST deblender: **SCARLET**

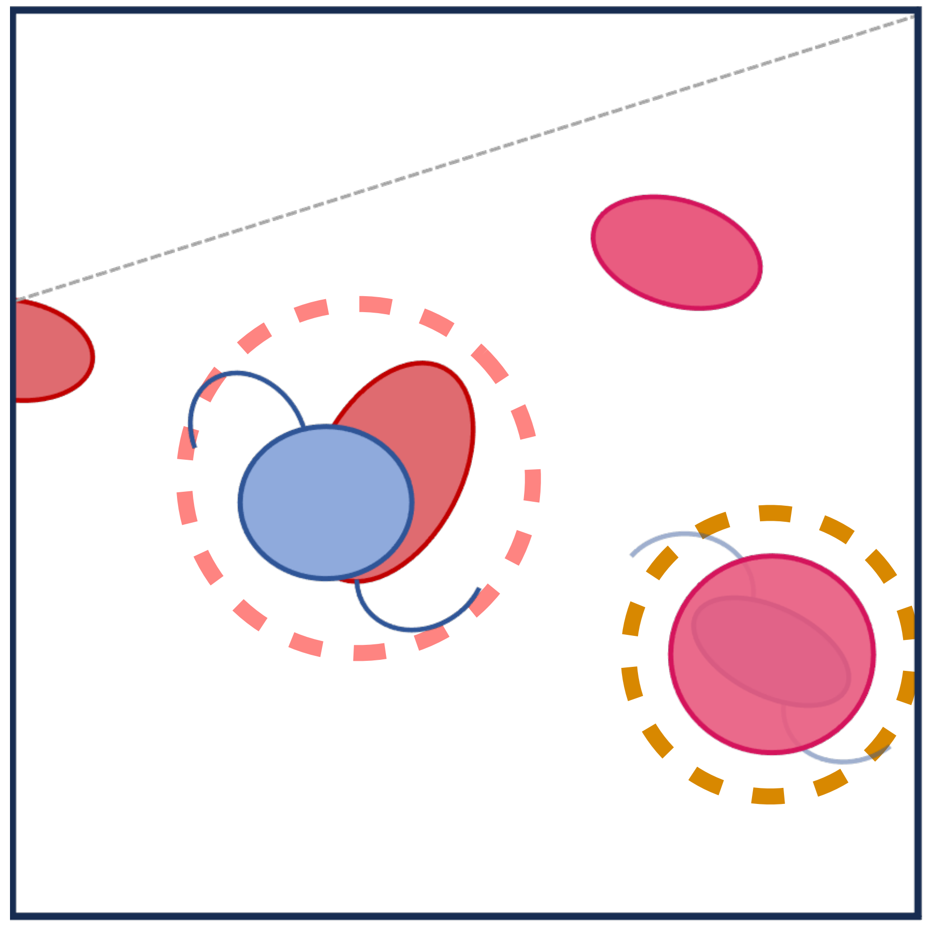
Source separation in multi-band images



Imperfect deblending

Blending

2D image



Less resolution

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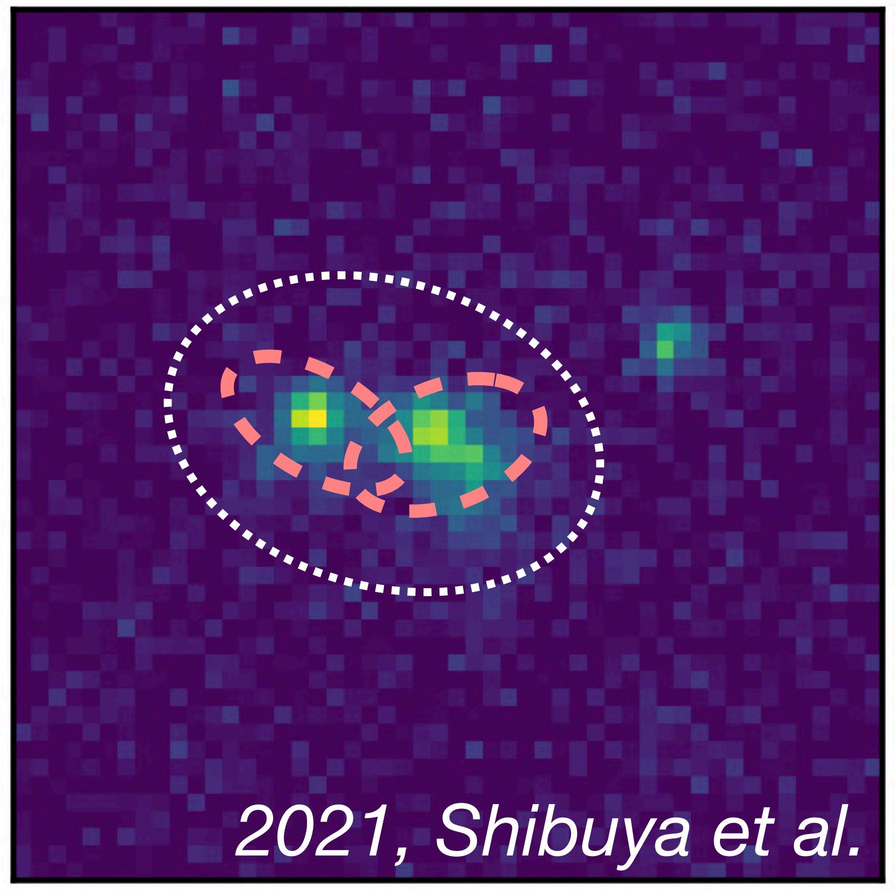

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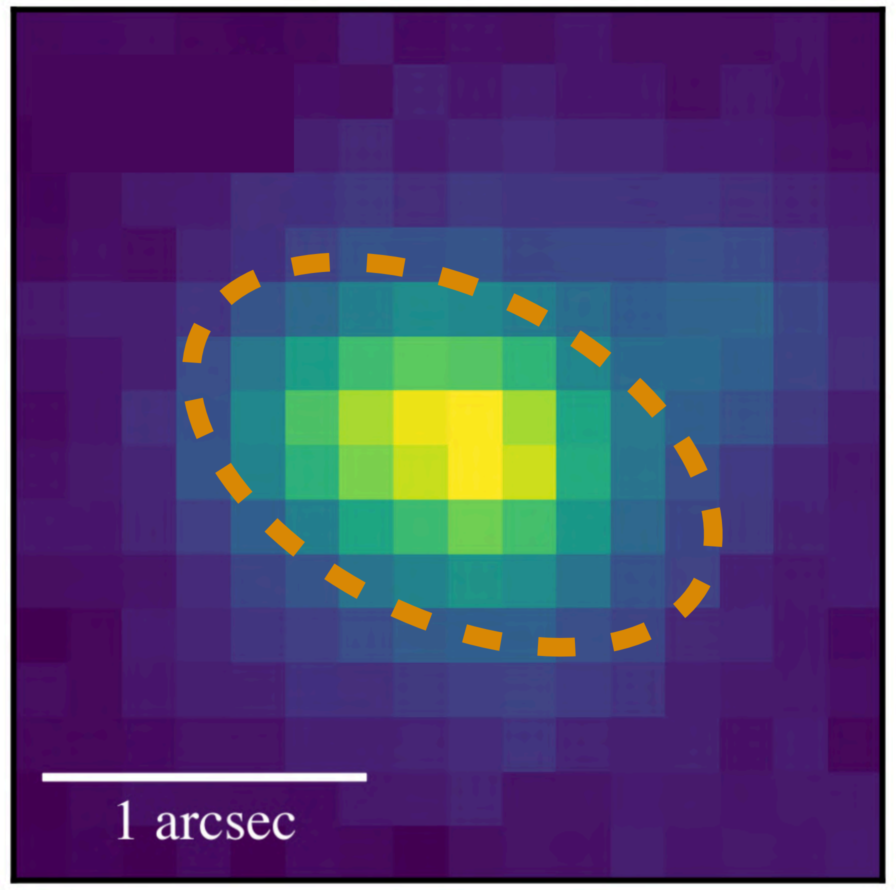

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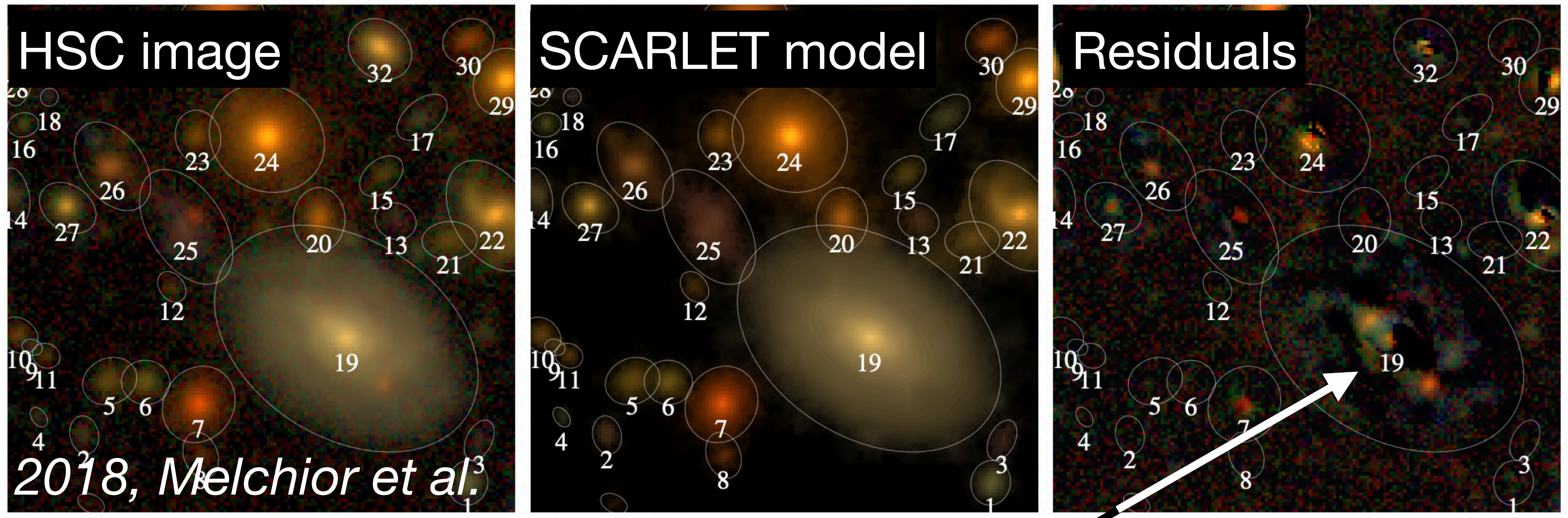


Imperfect deblending

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

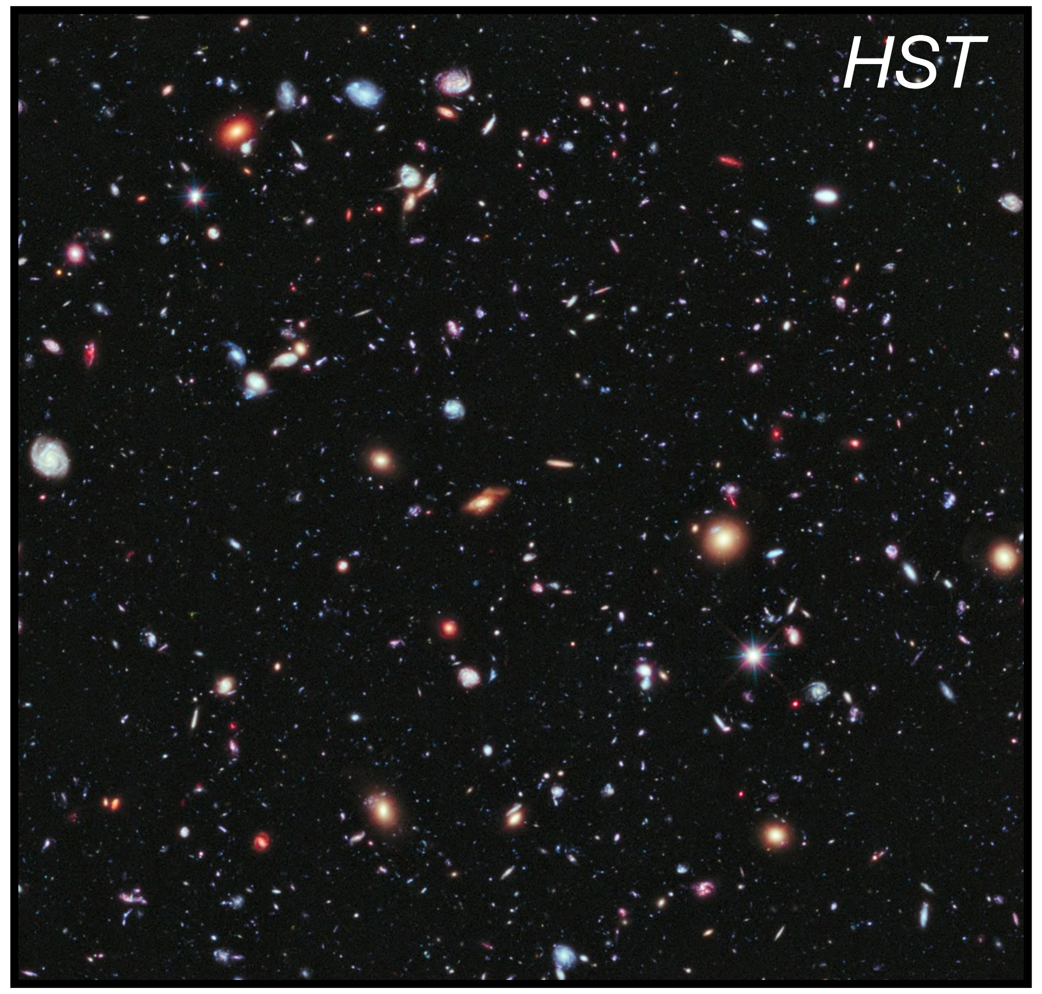
* *2016, Dawson et al.*
2022, Troxel et al.

Blending around galaxy clusters

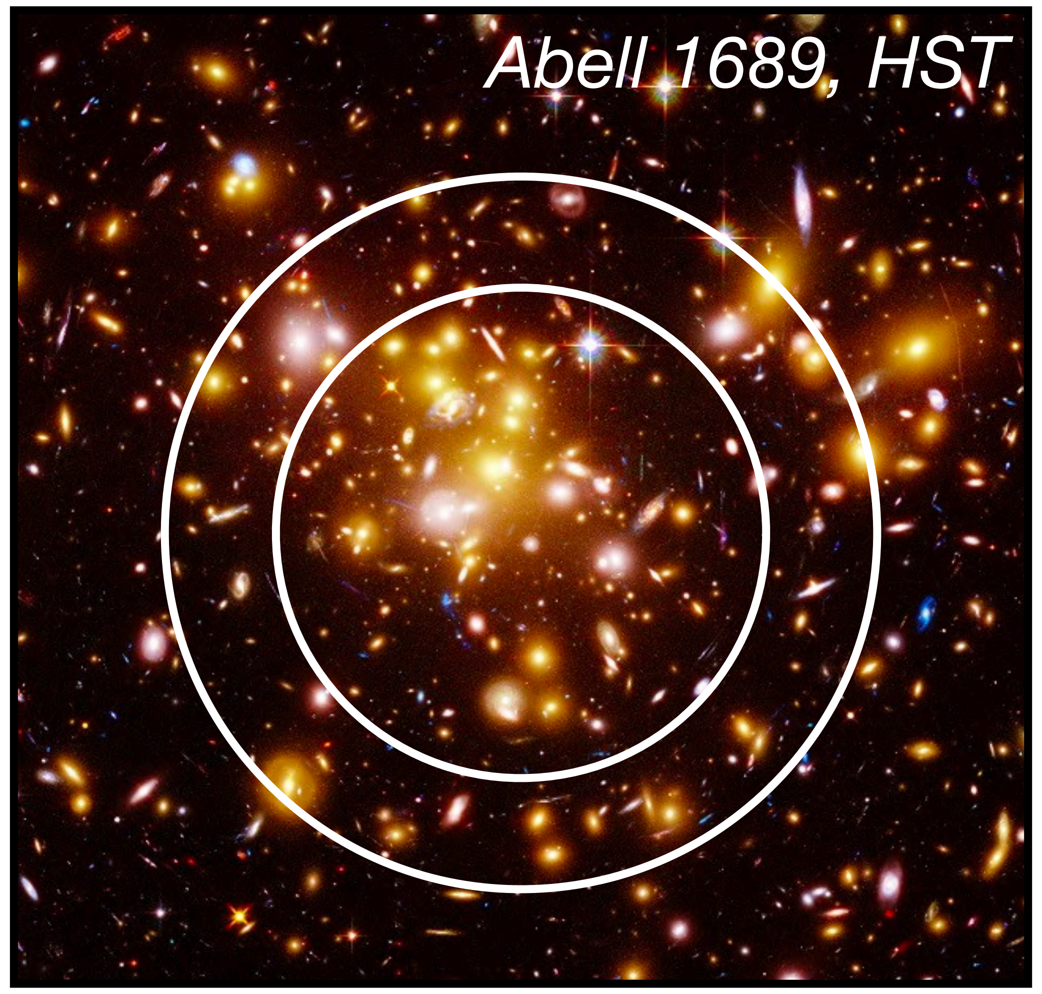
Galaxy clusters = high density regions = **blending**

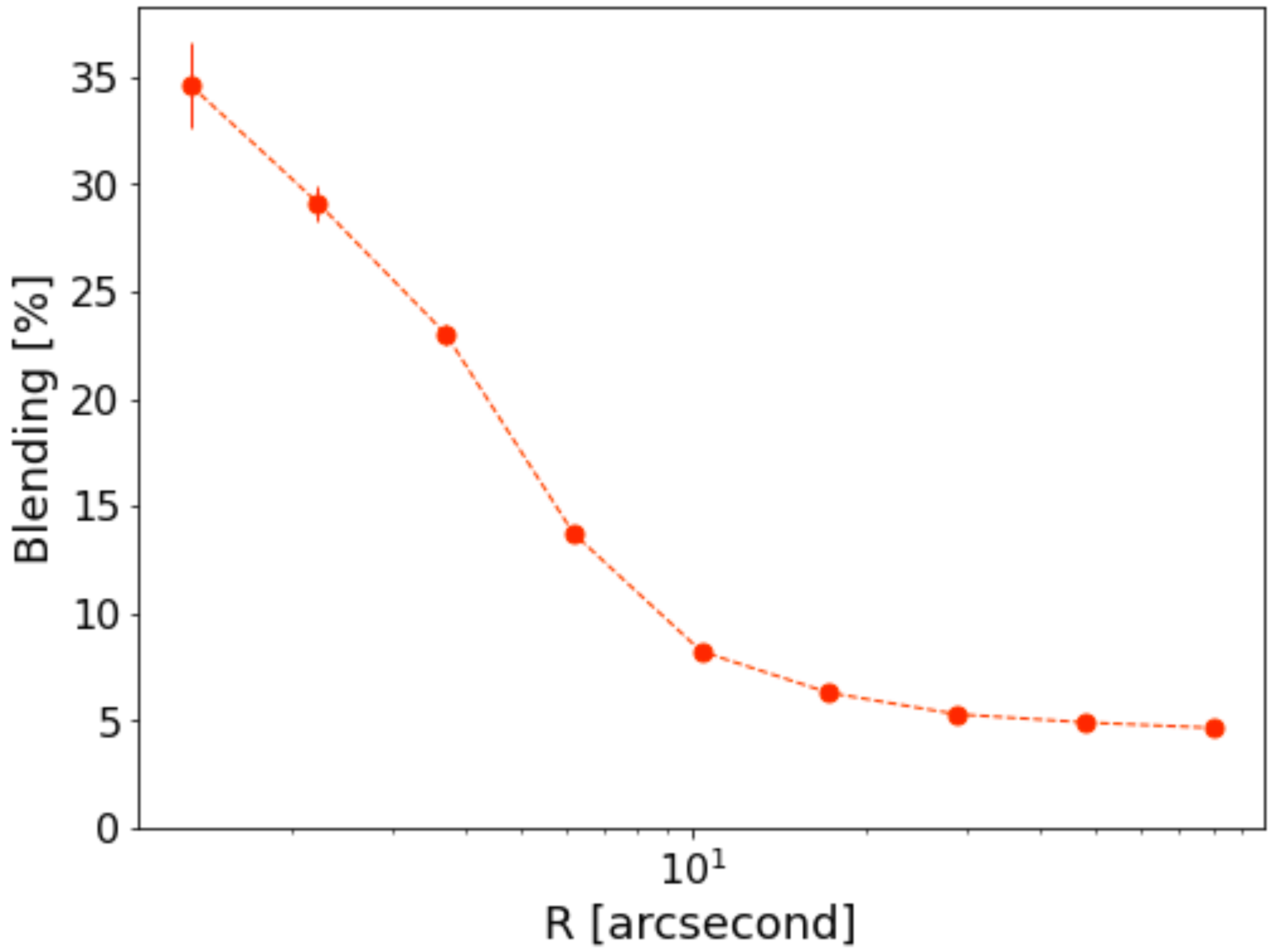
High amount of blending near clusters centres

OUTSIDE



INSIDE





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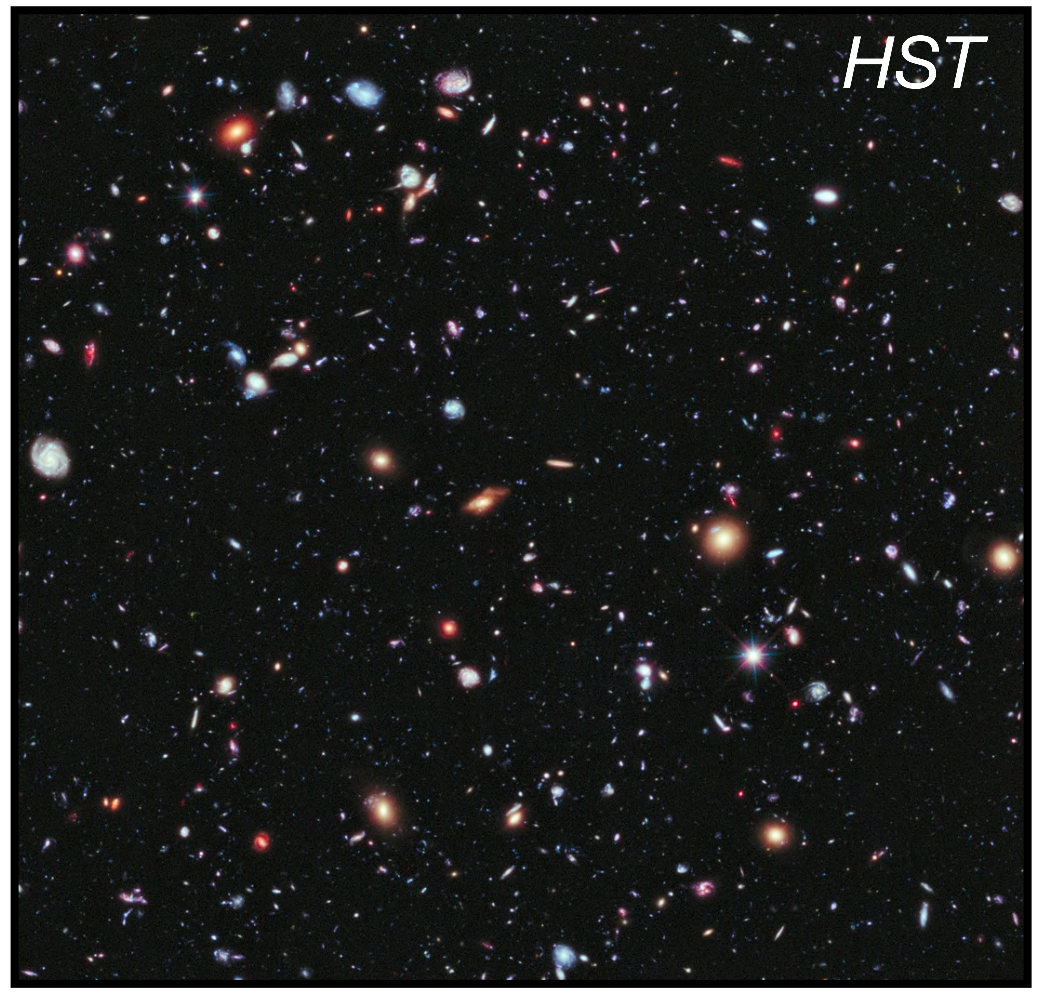

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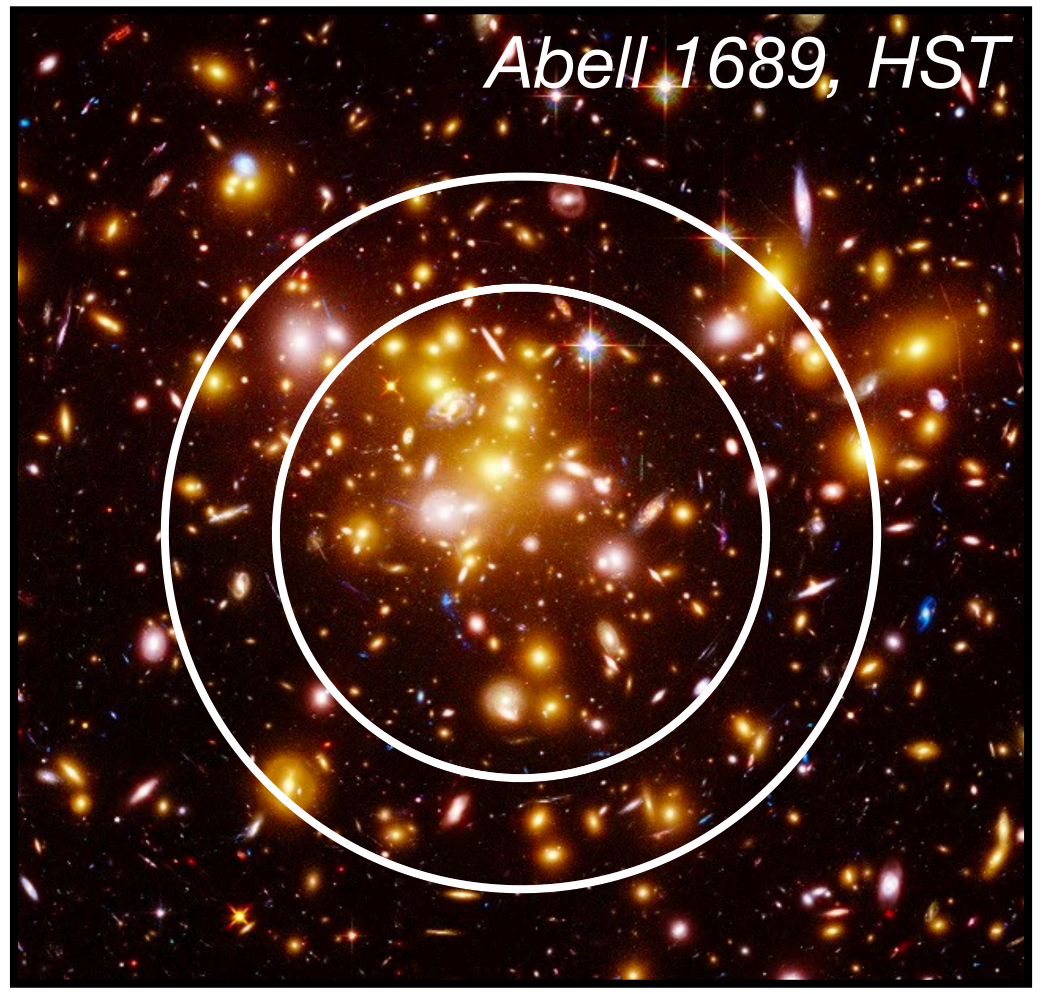
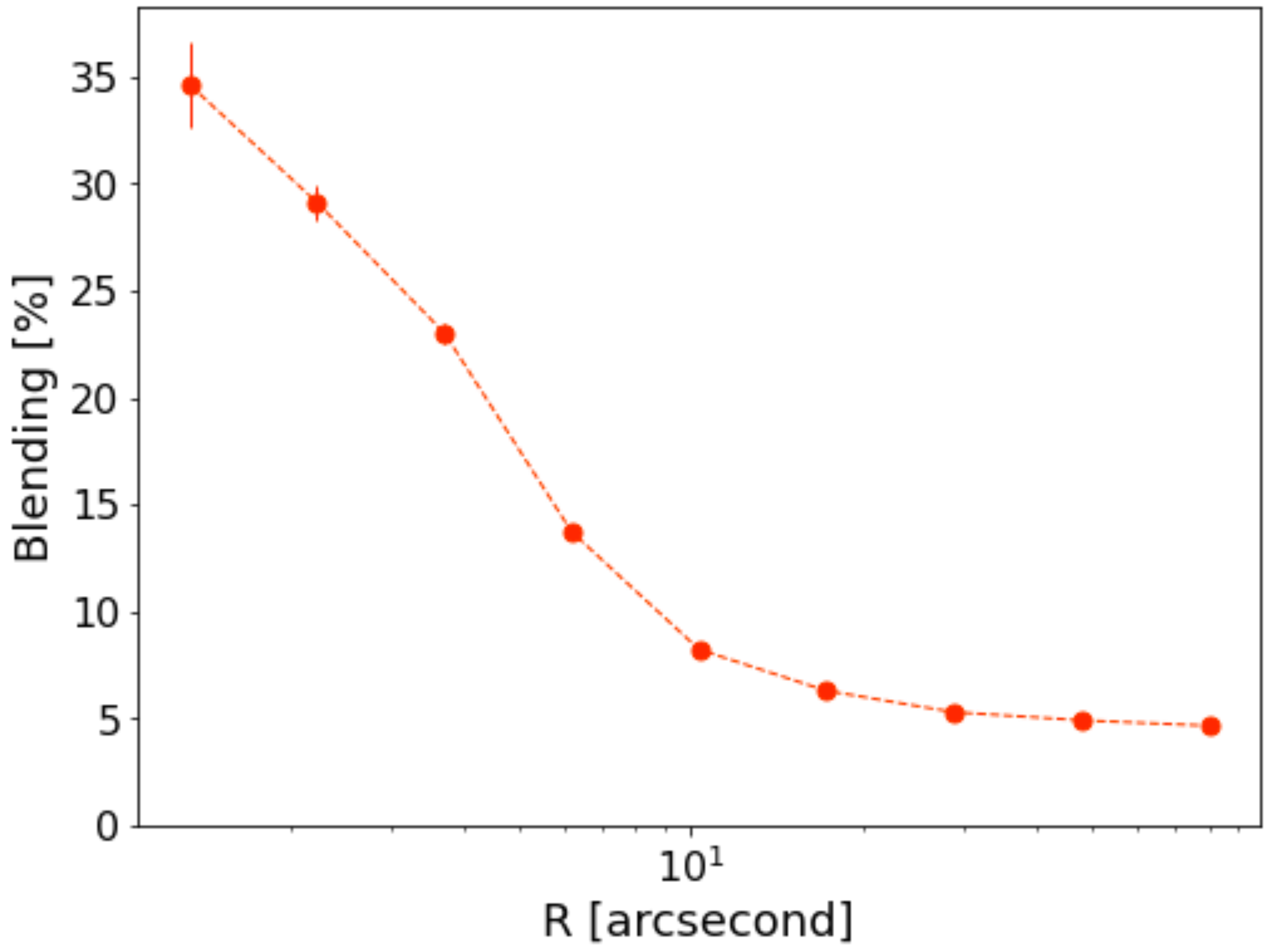


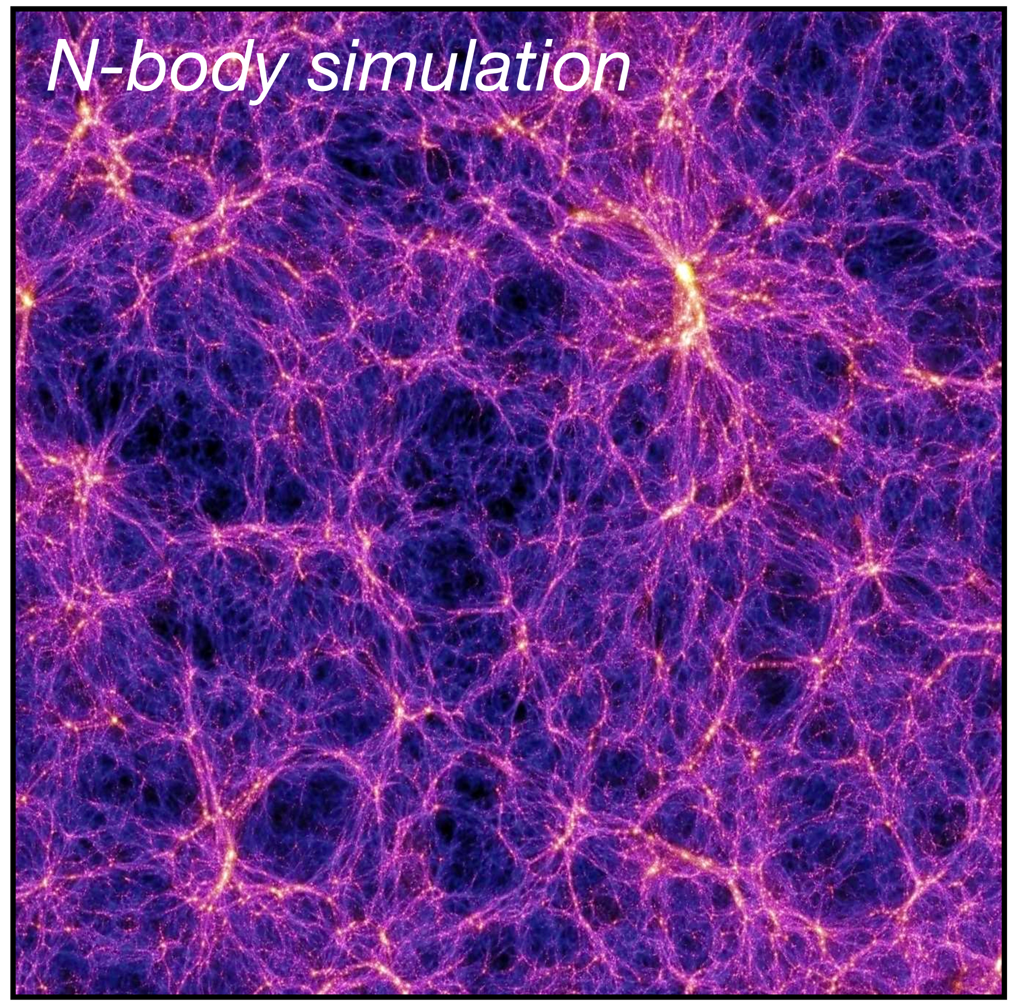


Blending impacts the **detection** of galaxies and the measurement of galaxy **shapes**

Blending will impact future Rubin/LSST weak lensing data induced by massive clusters

Tools and pre-work

Simulated catalogs

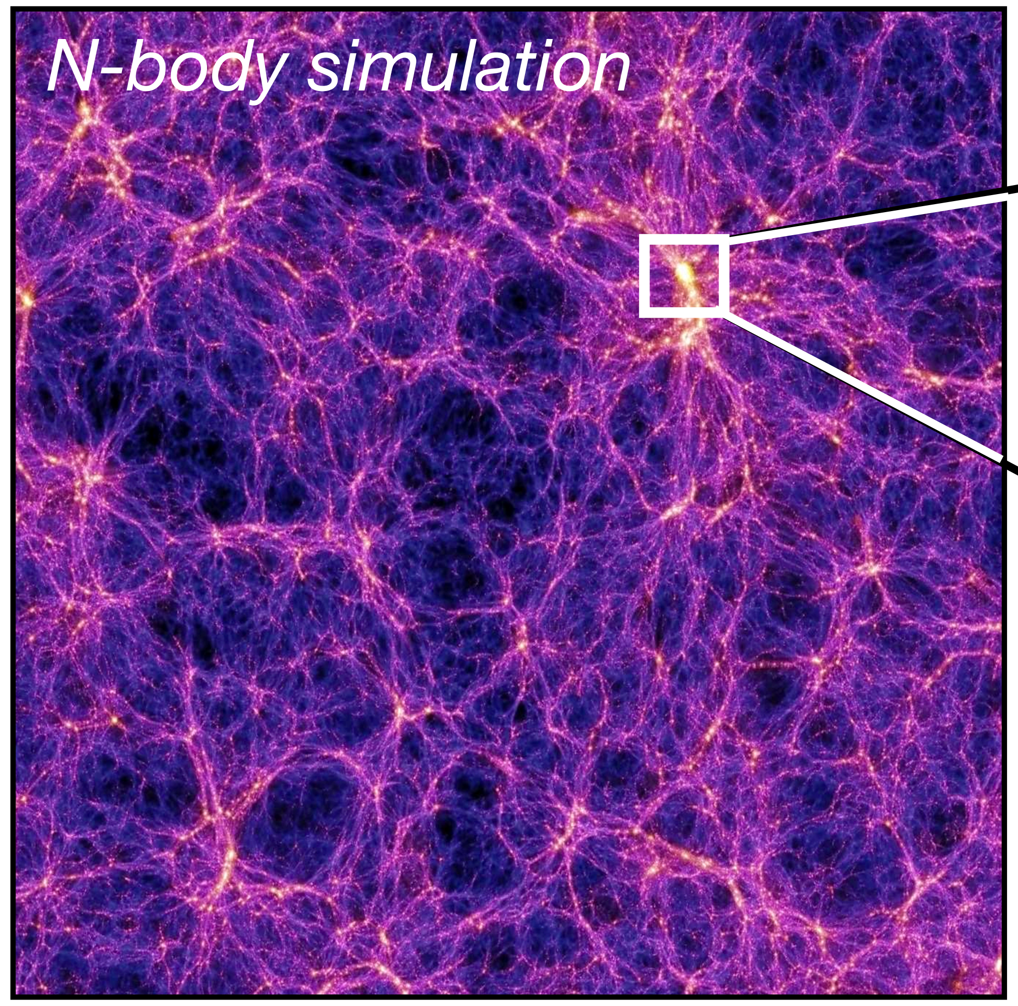


Millennium 2005, Springel et al.

<u>cosmoDC2</u> = truth catalog

- 440 deg^2 catalog from a N-body simulation
- Reference for **galaxies** and dark matter haloes
- mag < 30, z = 3

Simulated catalogs



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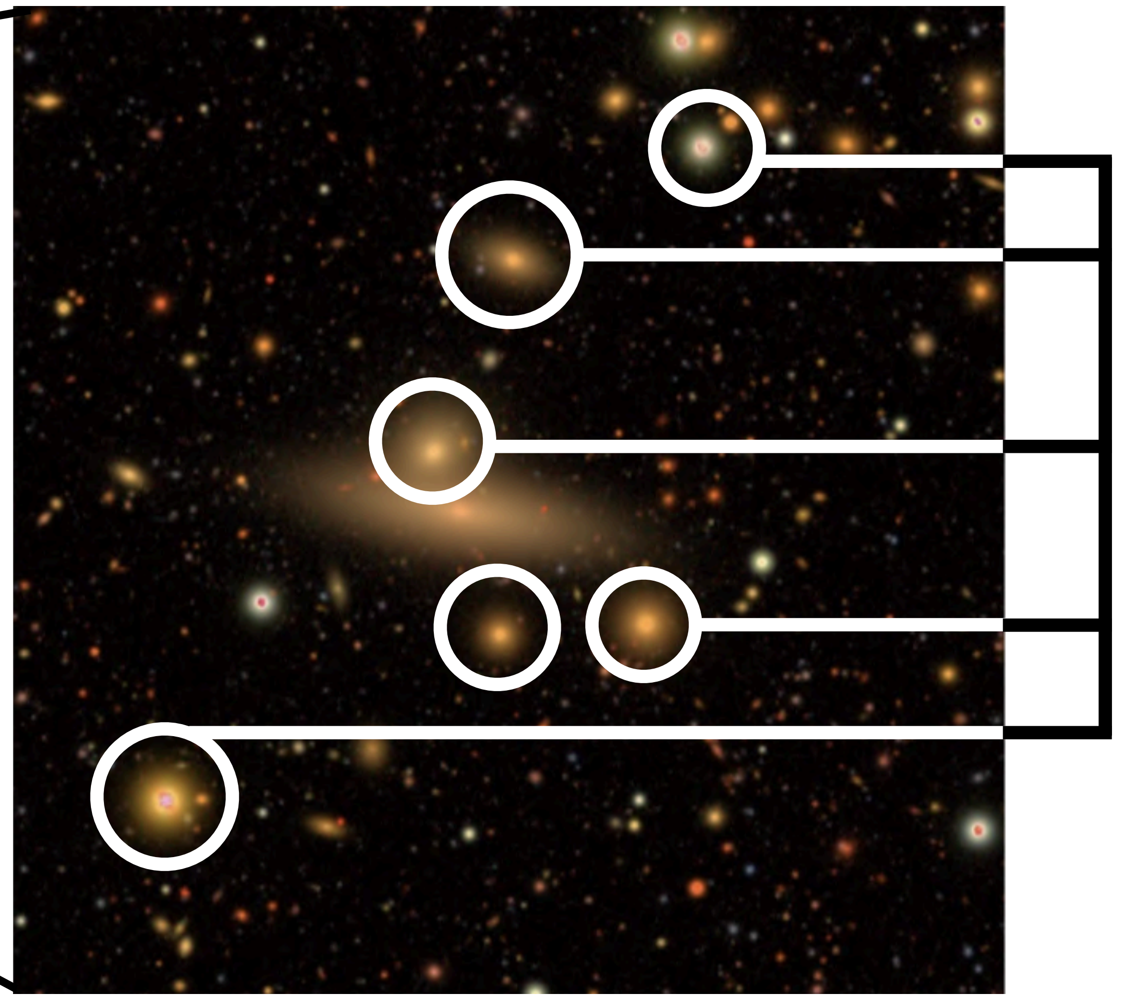


mag_i	ra	e1	dec
24.541830	58.200397	-0.141020	-35.702272
26.177008	58.179060	0.173040	-35.702067
24.806880	58.100637	0.138385	-35.702437
25.014057	58.190685	-0.148557	-35.701660
25.883955	58.151774	-0.505306	-35.701739
...	...	...	...
26.582999	56.529076	-0.210661	-34.322543
27.233892	56.628691	-0.630063	-34.278873

DESC simulated image

cosmoDC2 = truth catalog

- 440 deg^2 catalog from a N-body simulation
- Reference for **galaxies** and dark matter haloes
- mag < 30, z = 3

DC2object = object catalog

- Simulated images from cosmoDC2
- Detection of **objects**
- Measured positions, magnitudes (< 28), shapes…

Identification of blends through catalog matching

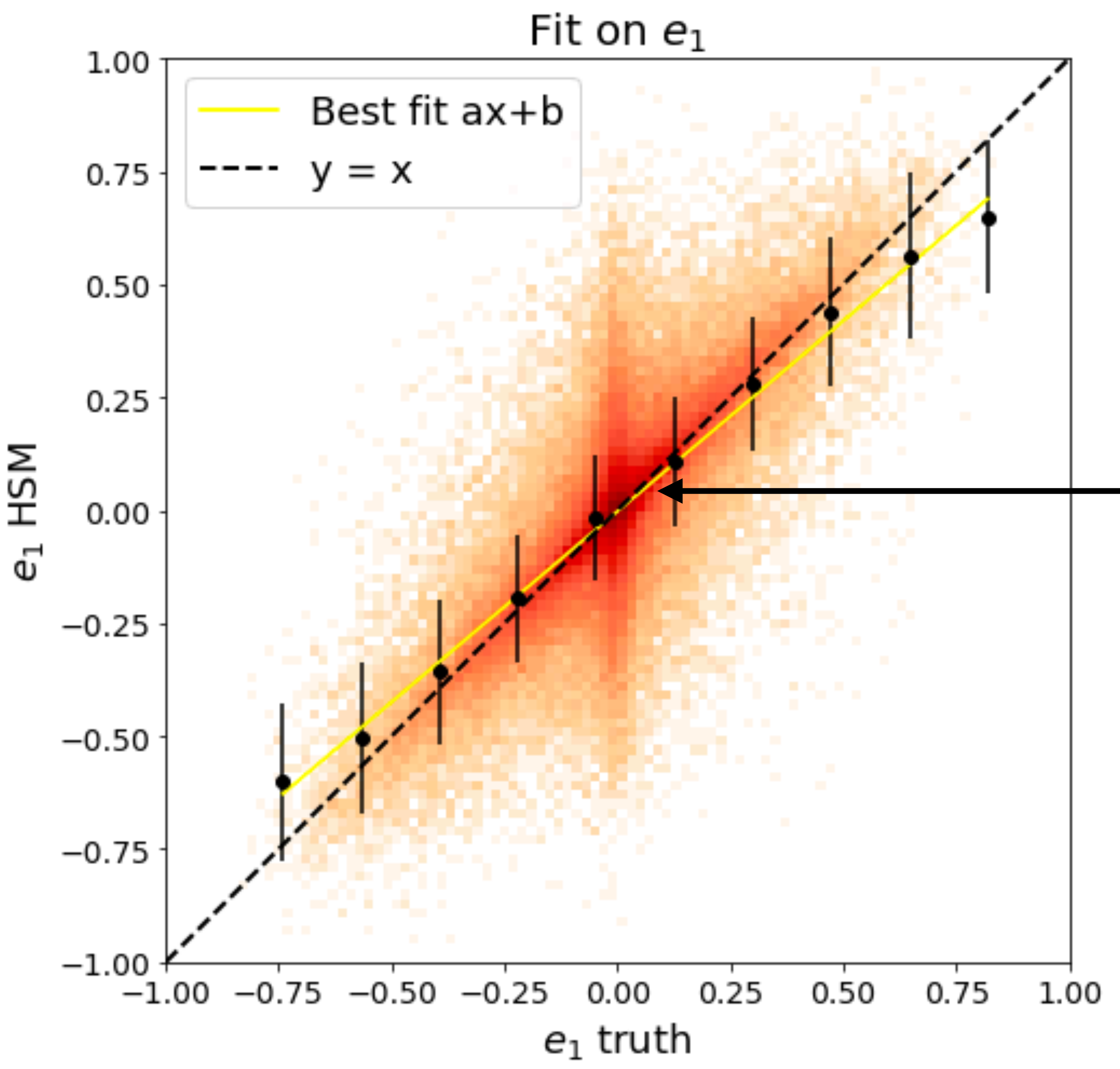
HSM calibration and DC2 photometric redshifts

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

HSM calibration and DC2 photometric redshifts

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

HSM ellipticities calibration



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

HSM calibration and DC2 photometric redshifts

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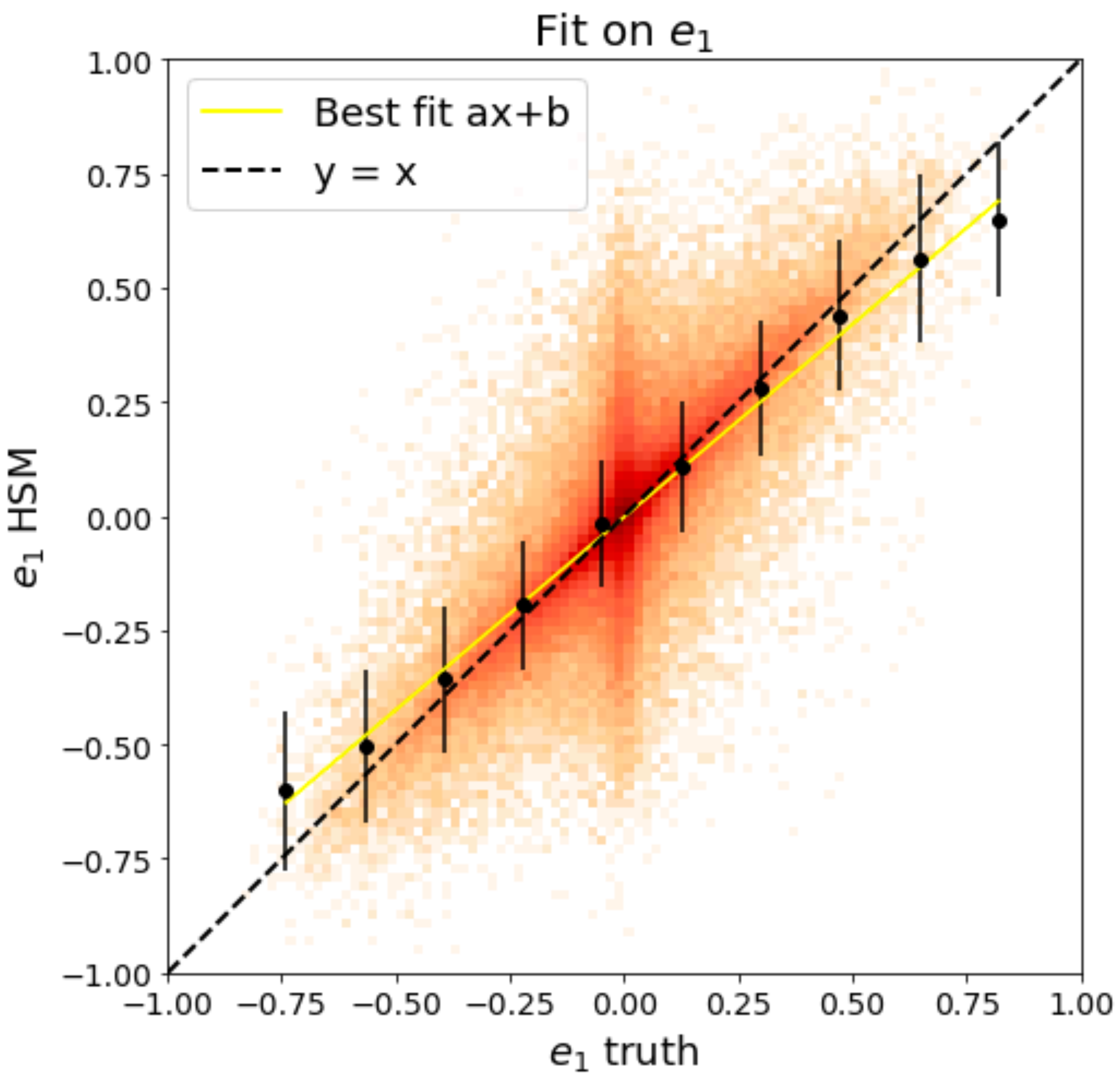
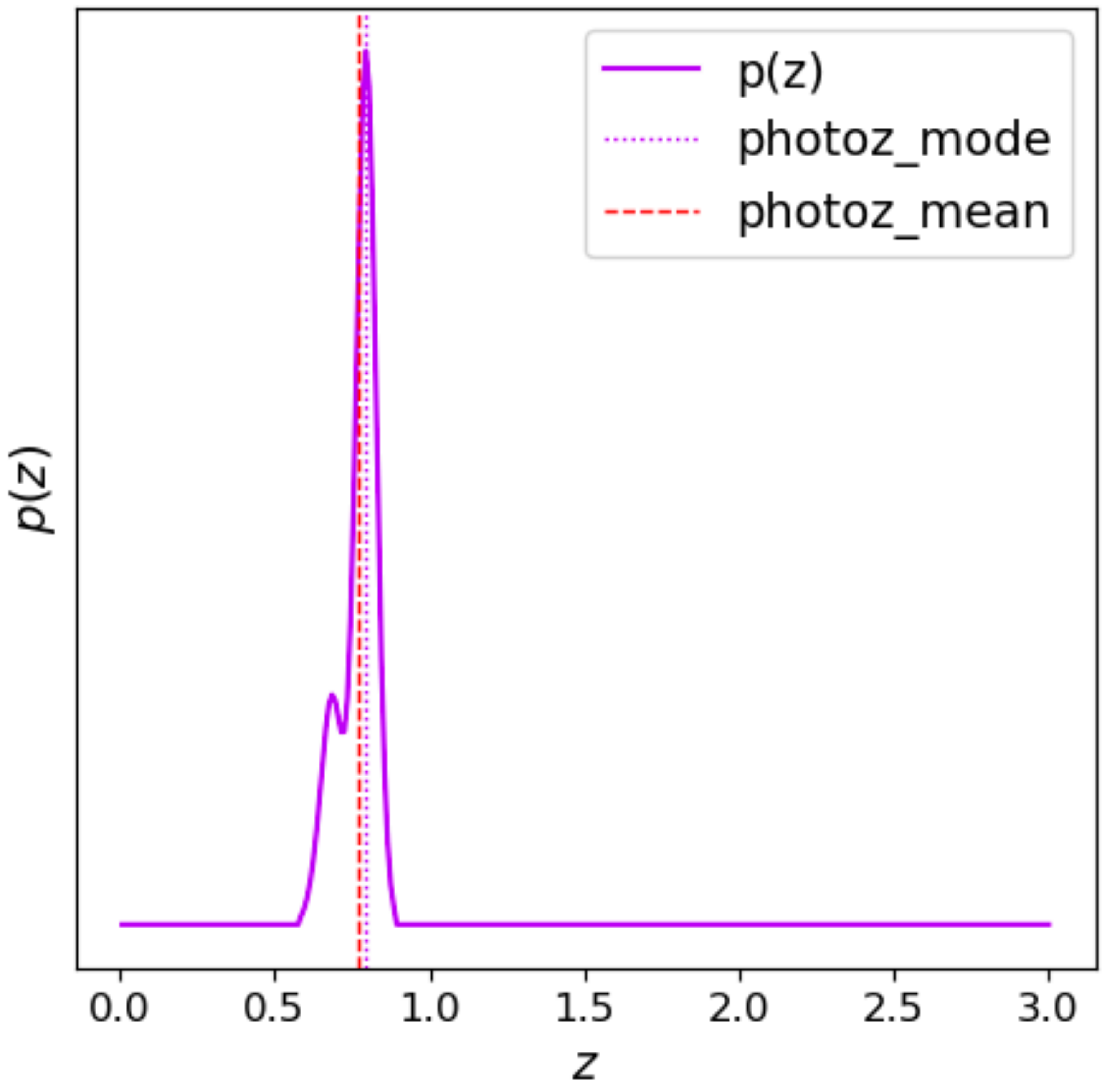
HSM ellipticities calibration



Photometric redshifts



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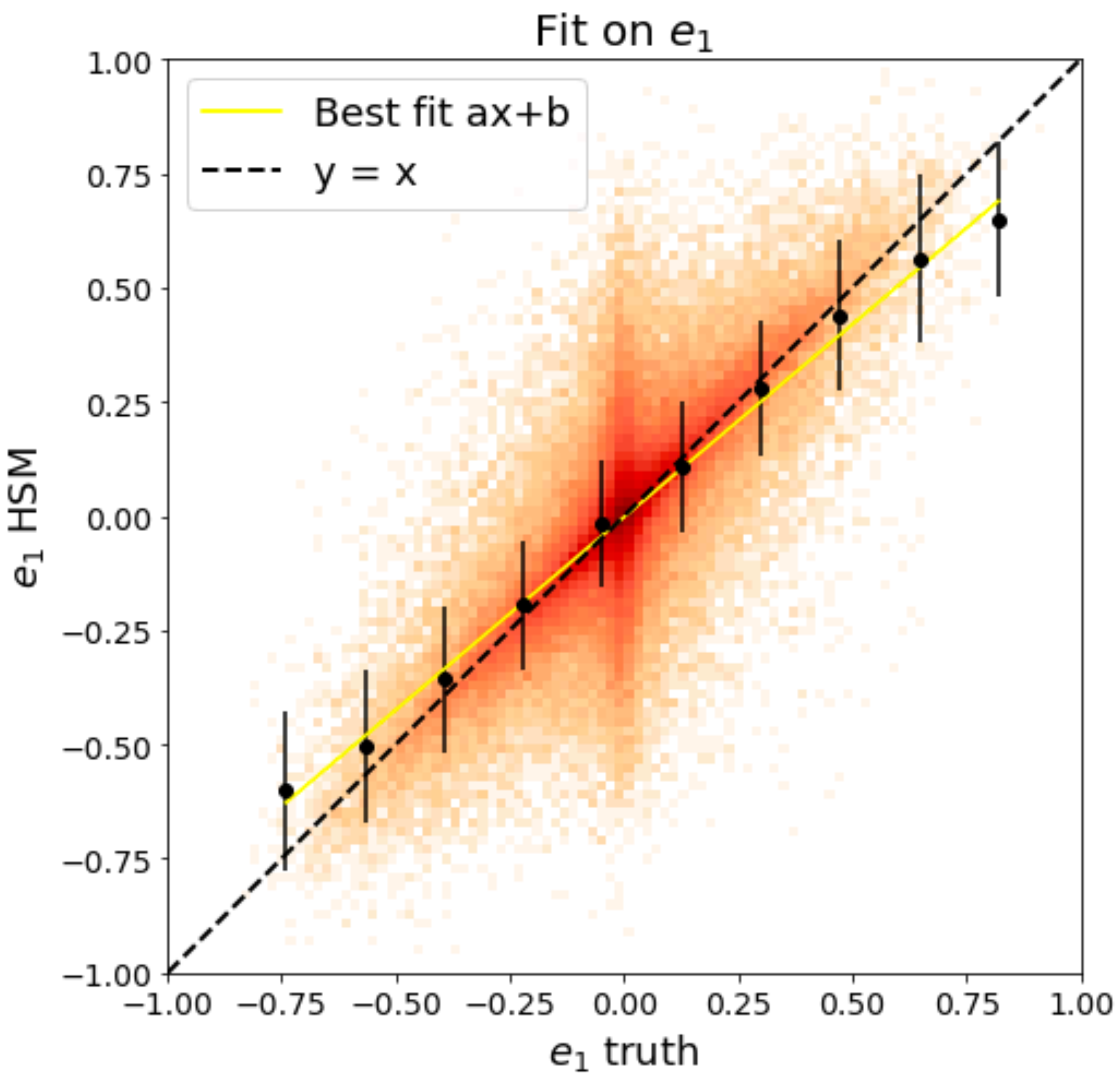

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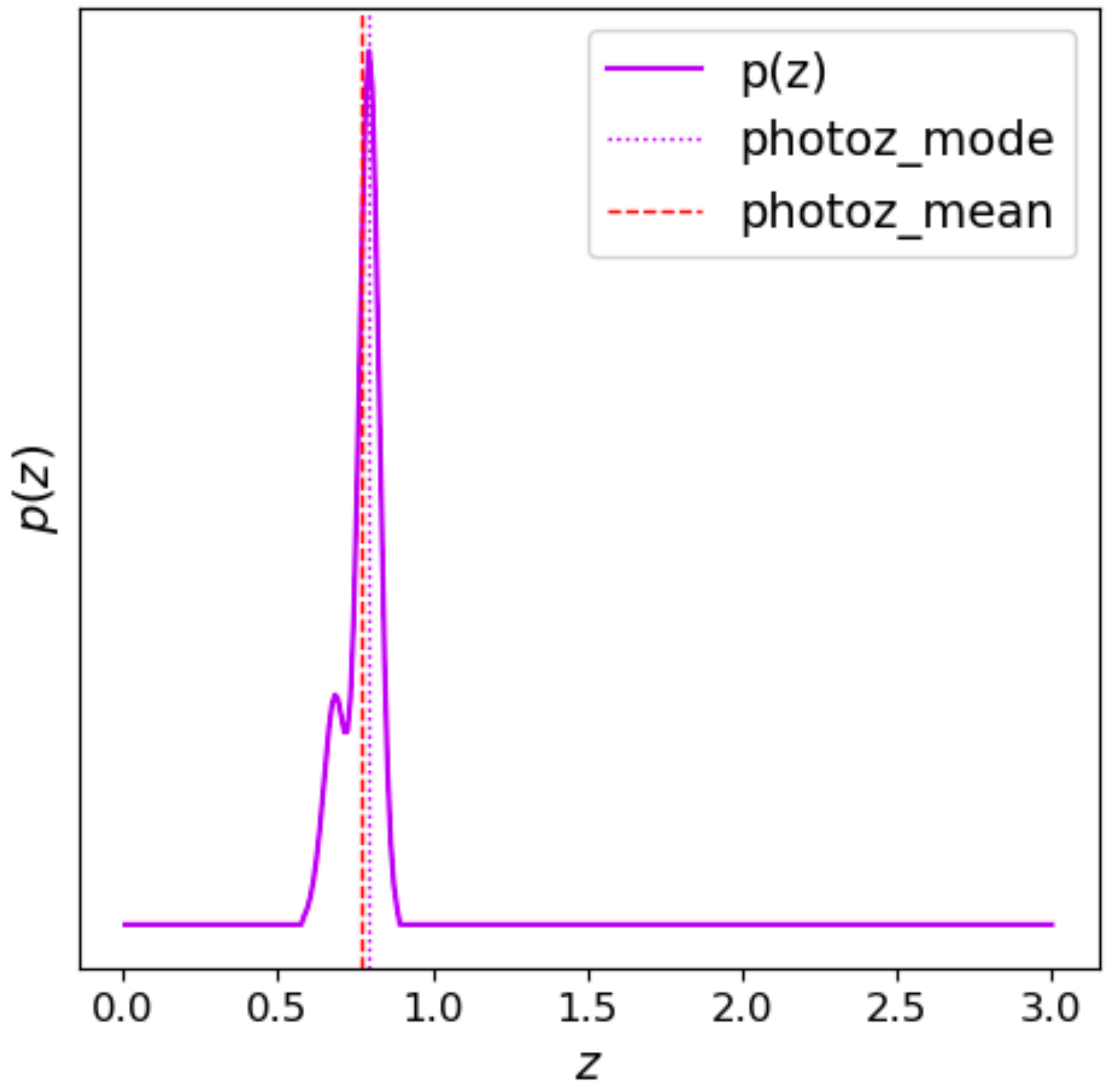
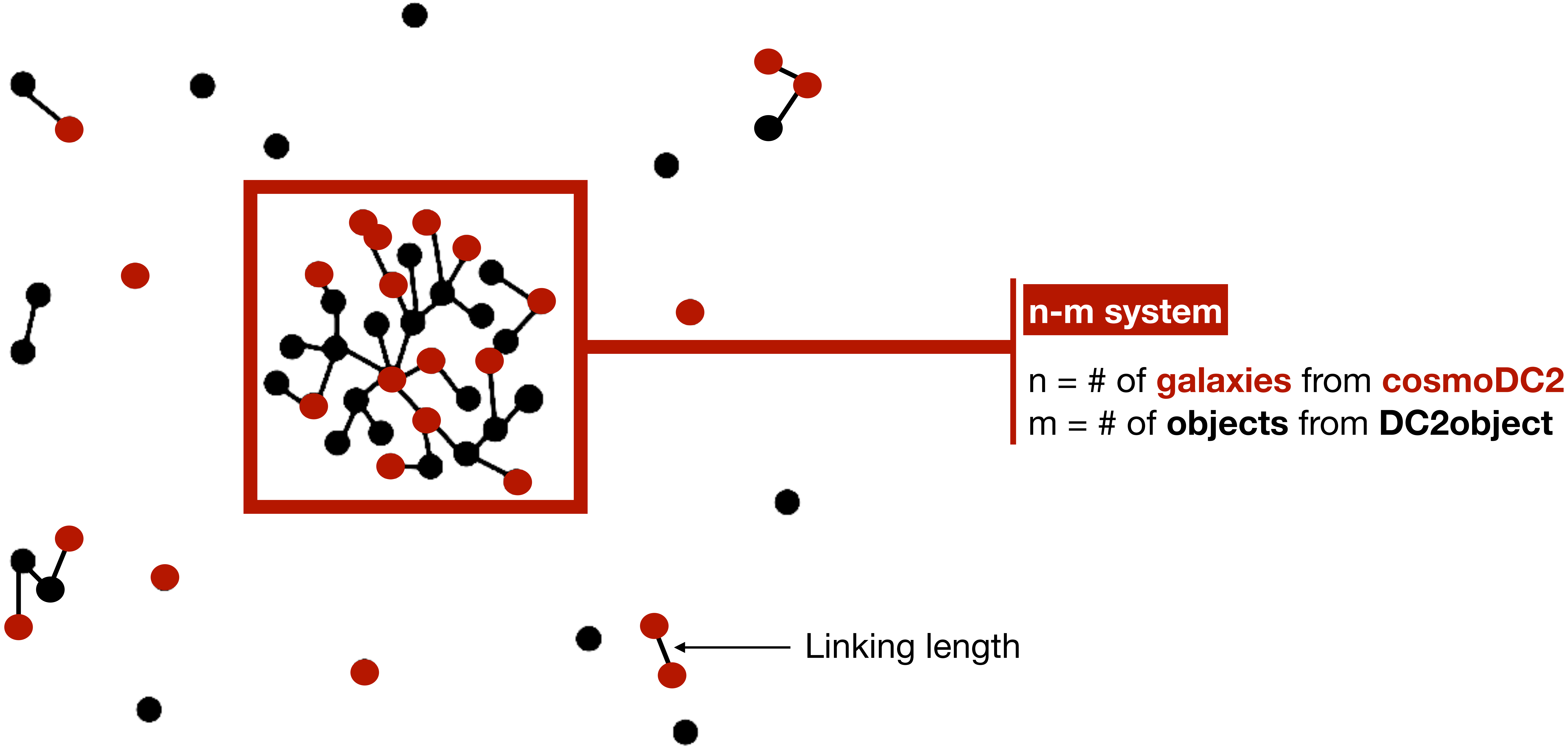


Individual errors that we can calibrate ➔ sufficient for blending?

Detection of blends in DC2

Friends-of-Friends

https://github.com/yymao/FoFCatalogMatching



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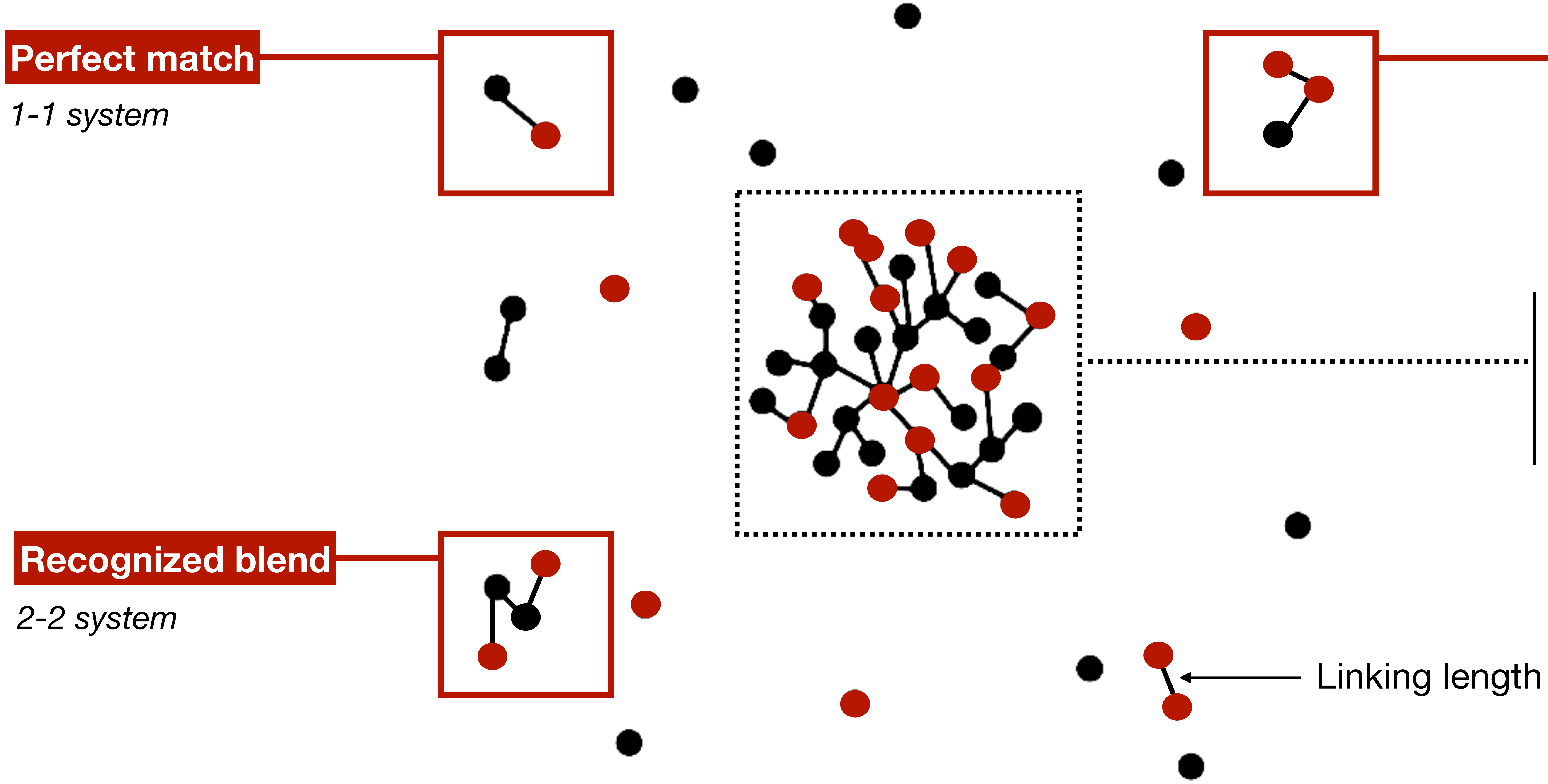


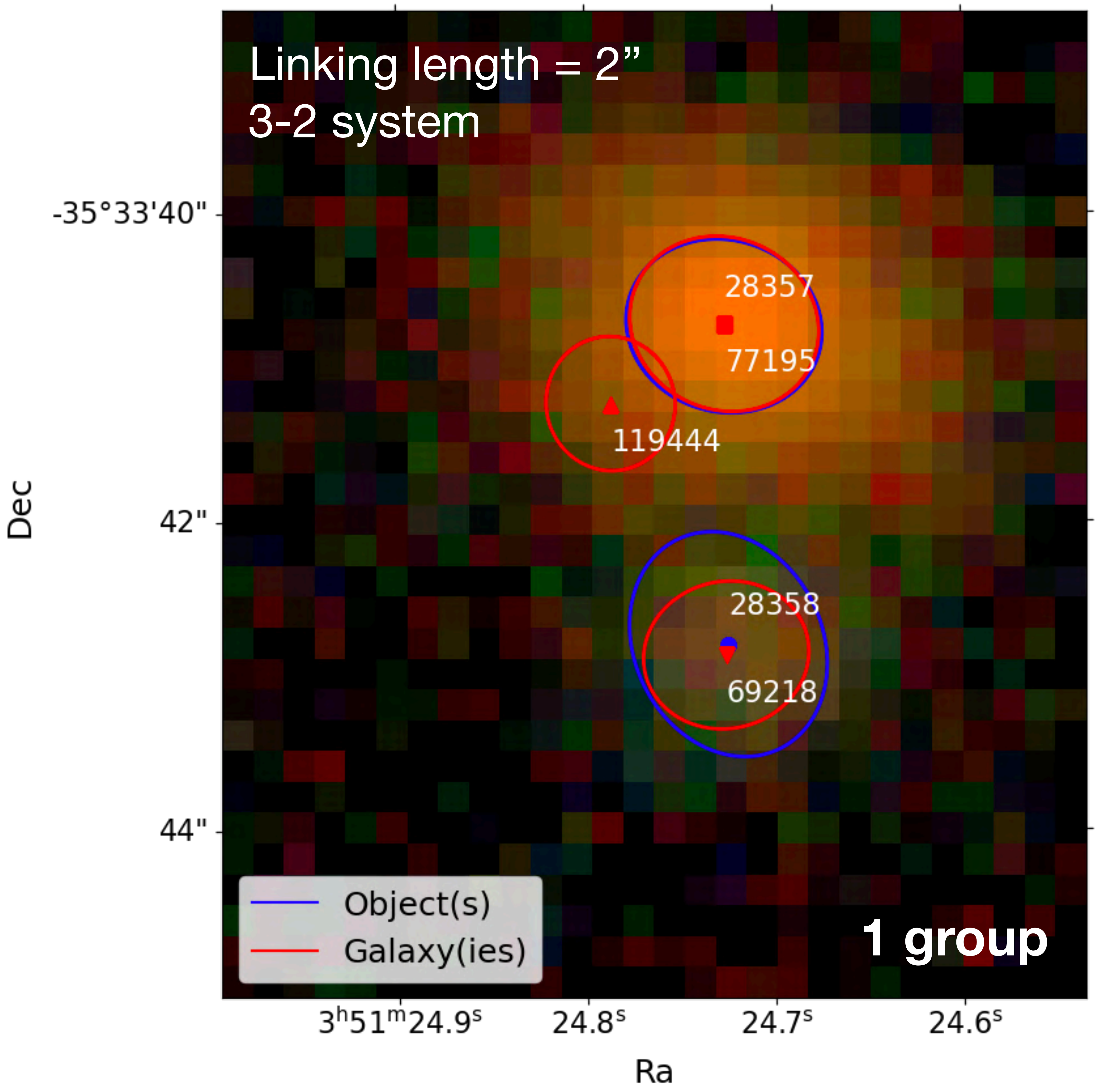
n-m system

n = # of **galaxies** from **cosmoDC2**
m = # of **objects** from **DC2object**

https://github.com/LSSTDESC/friendly

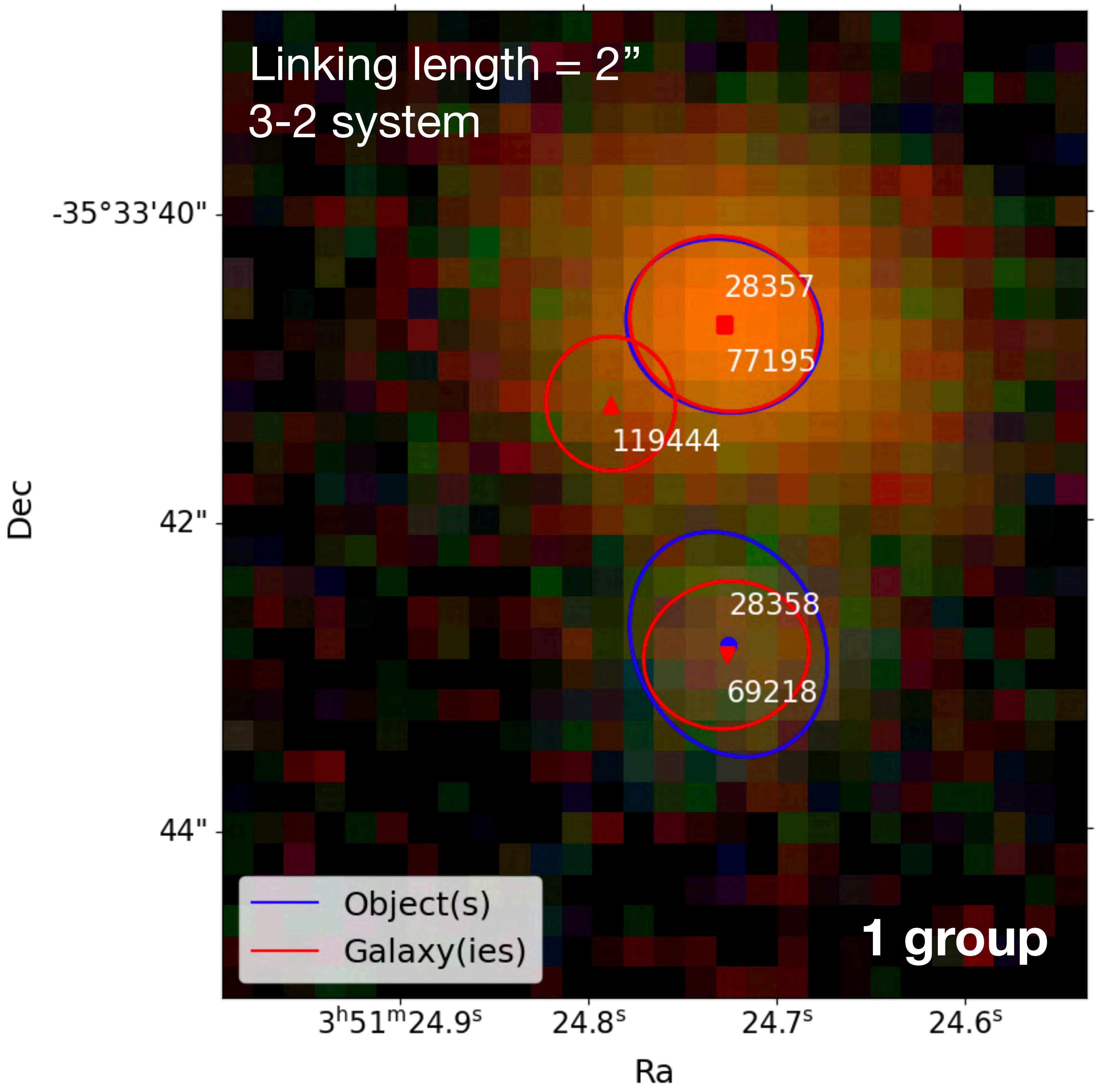
New matching algorithm: friendly

Friends-of-Friends = **distances** information

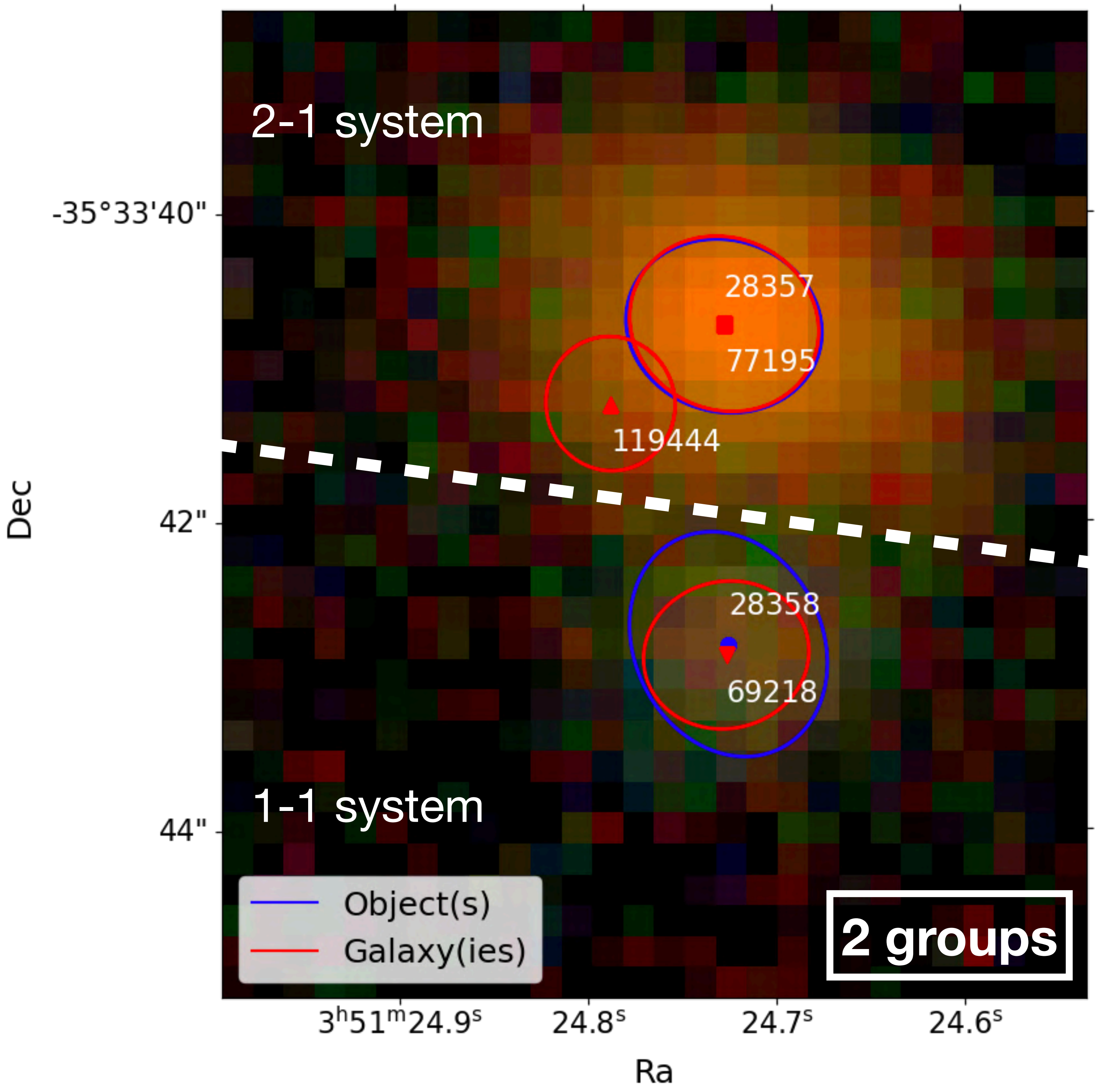


New matching algorithm: friendly

Friends-of-Friends = **distances** information



Overlap test = **shapes** information



https://github.com/LSSTDESC/friendly

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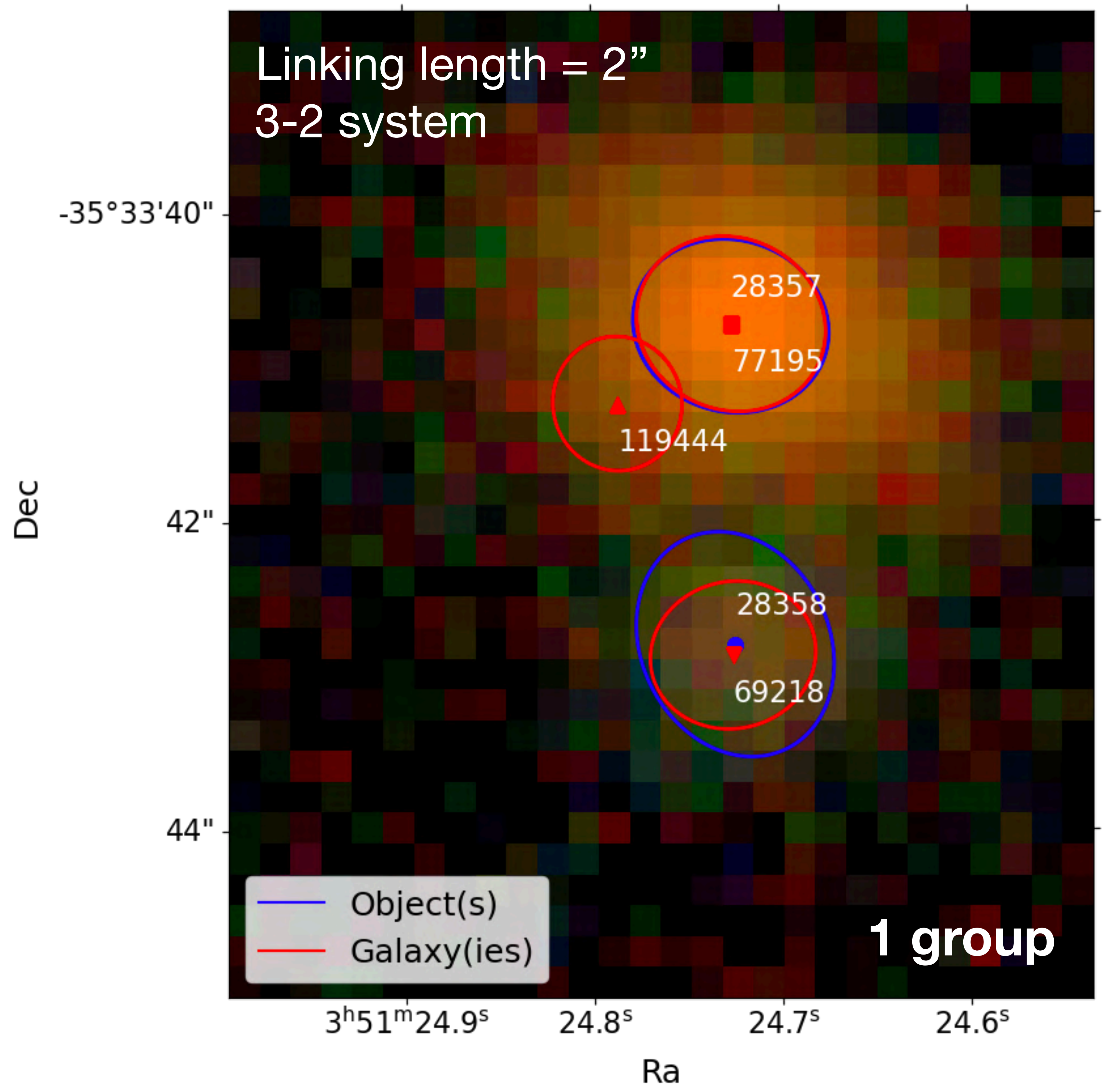

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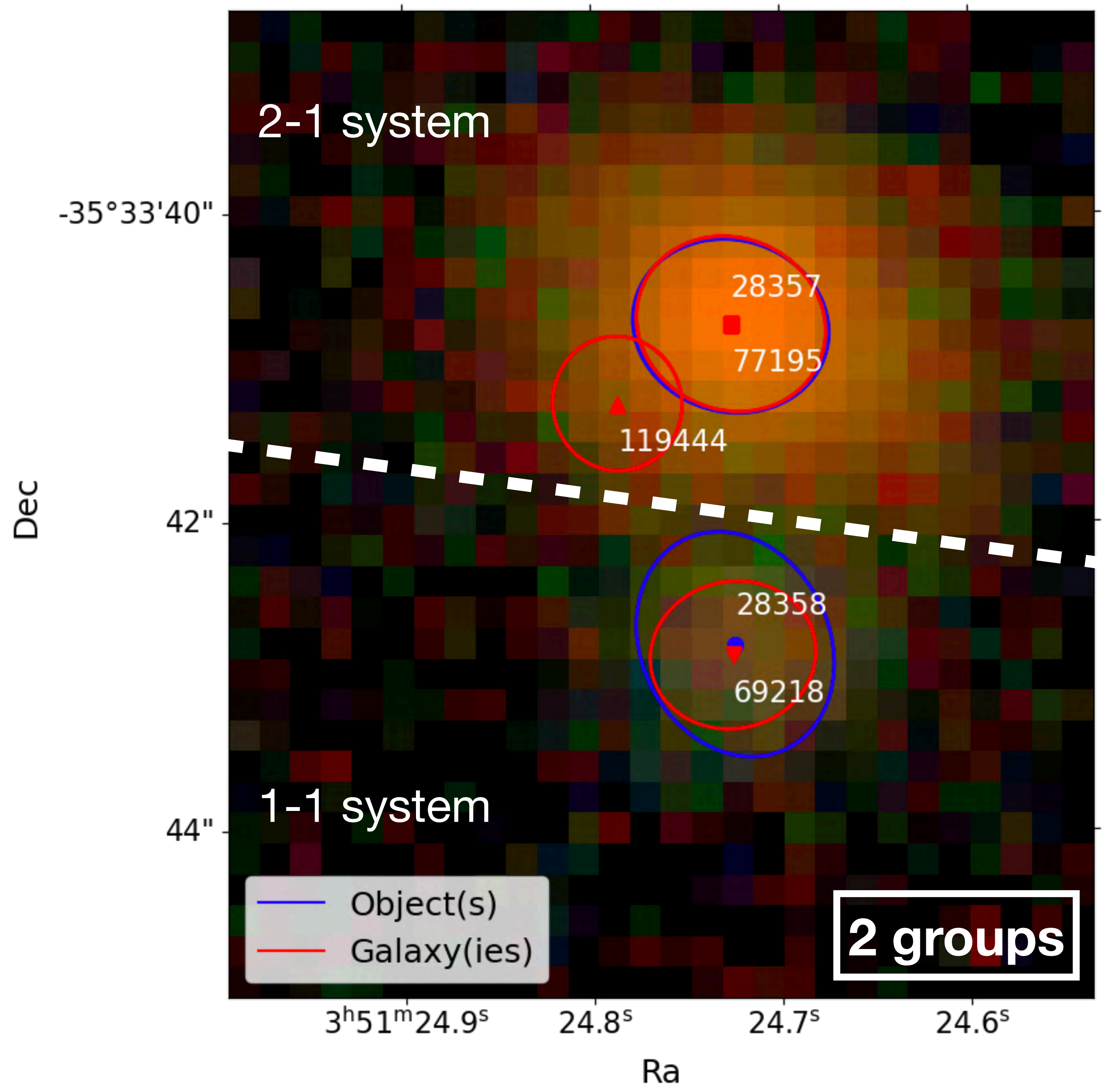
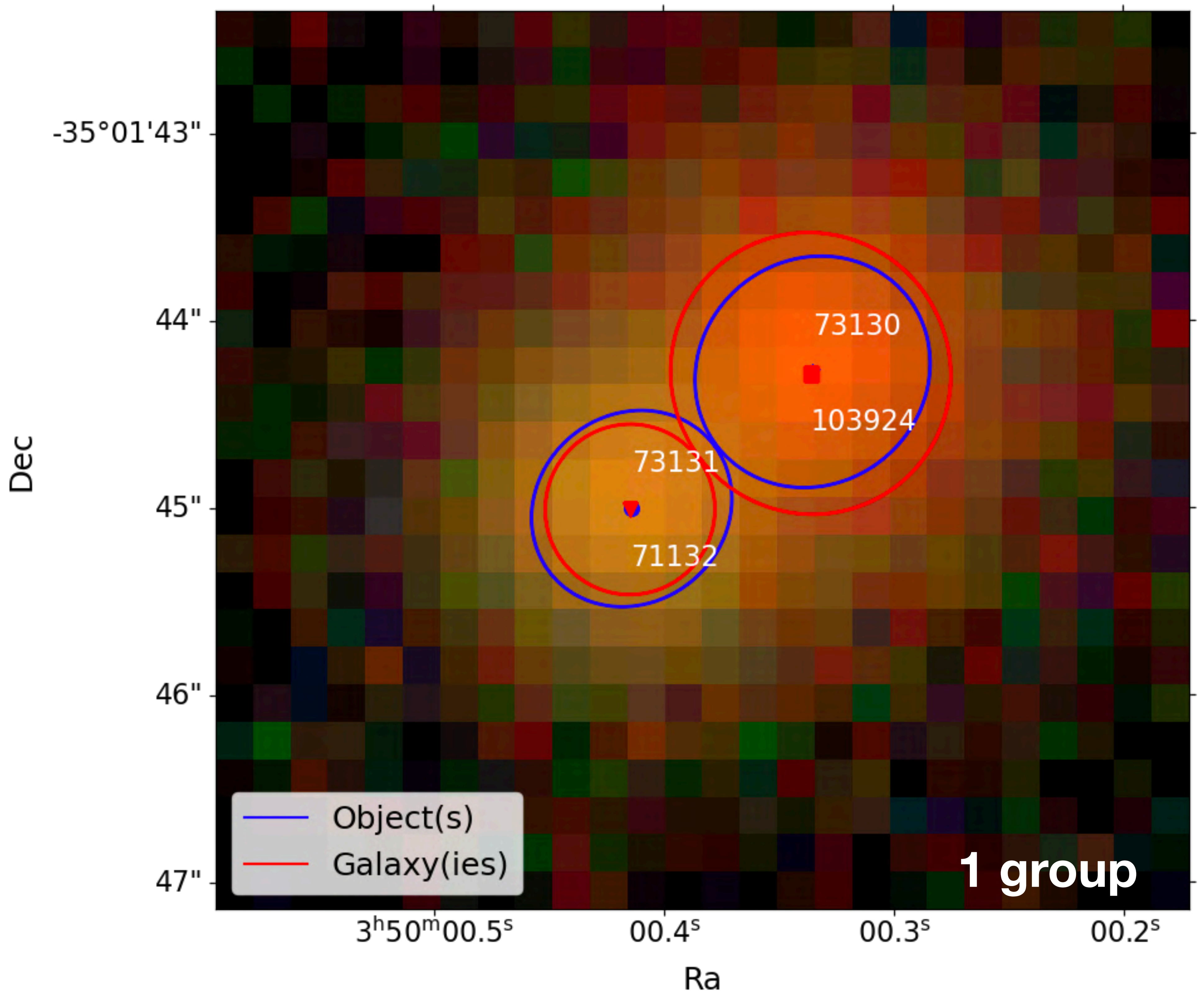


Friendly = more robust matching algorithm

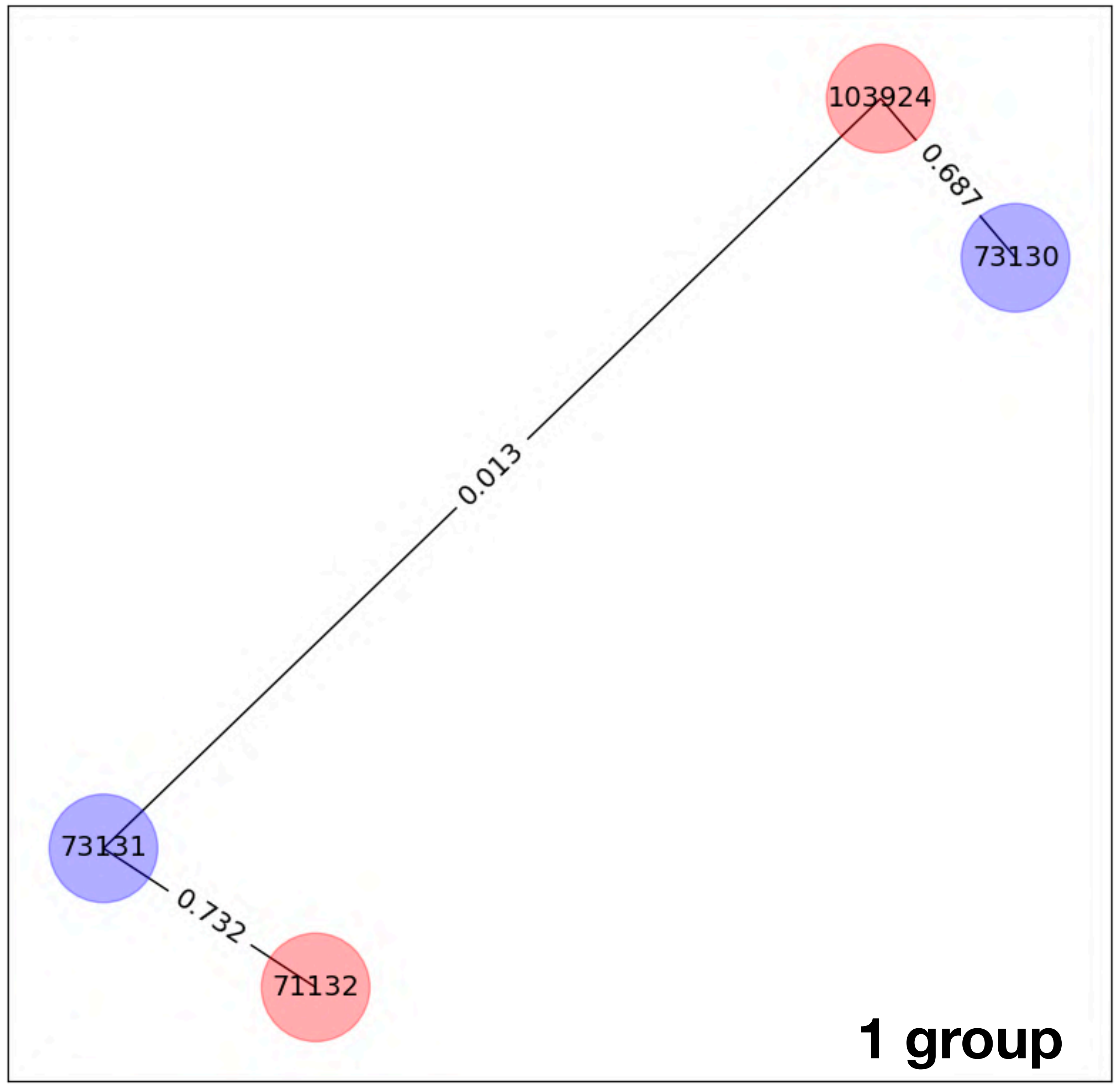
https://github.com/LSSTDESC/friendly

New matching algorithm: friendly

Friendly group



NetworkX graph



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New matching algorithm: friendly

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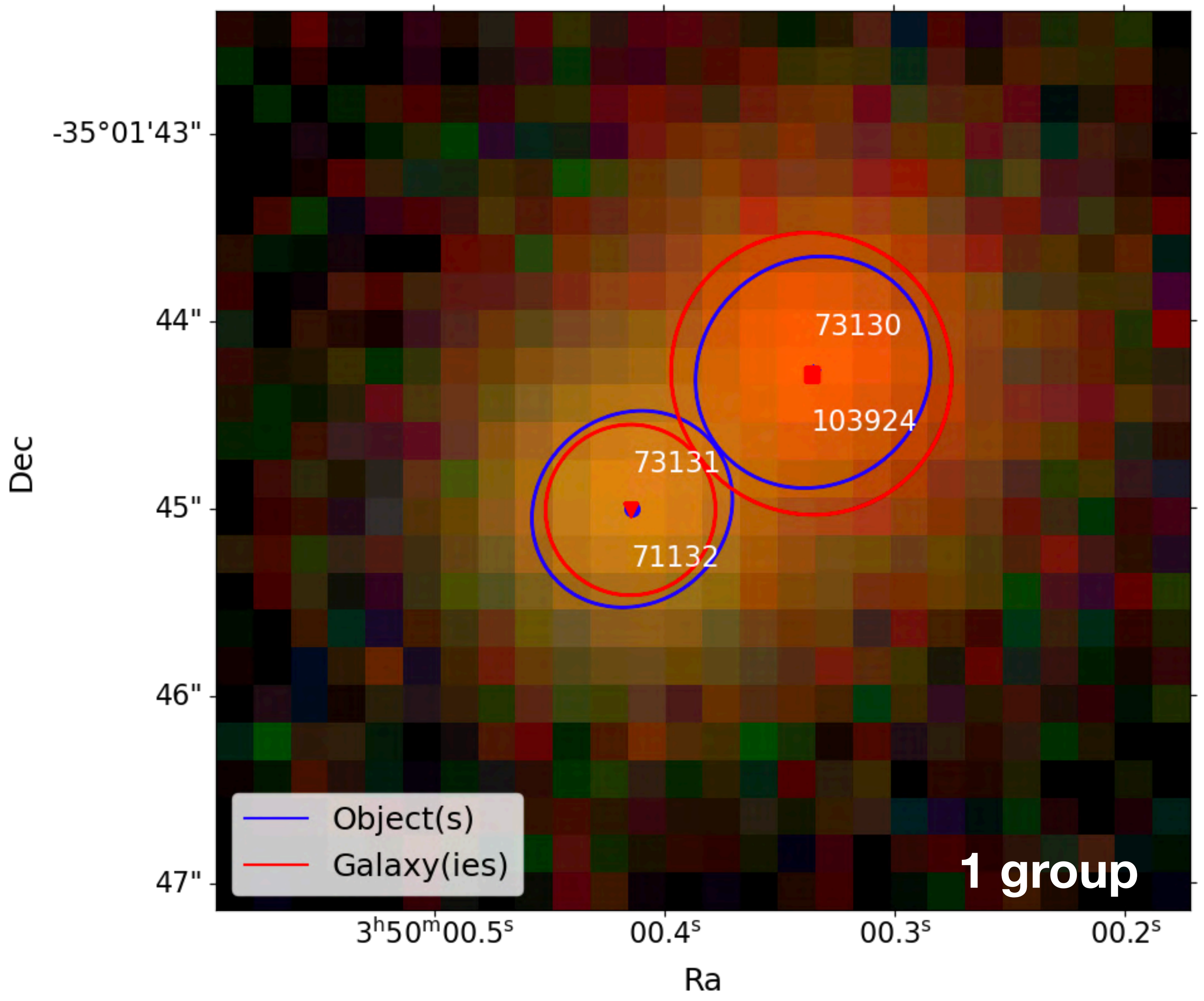
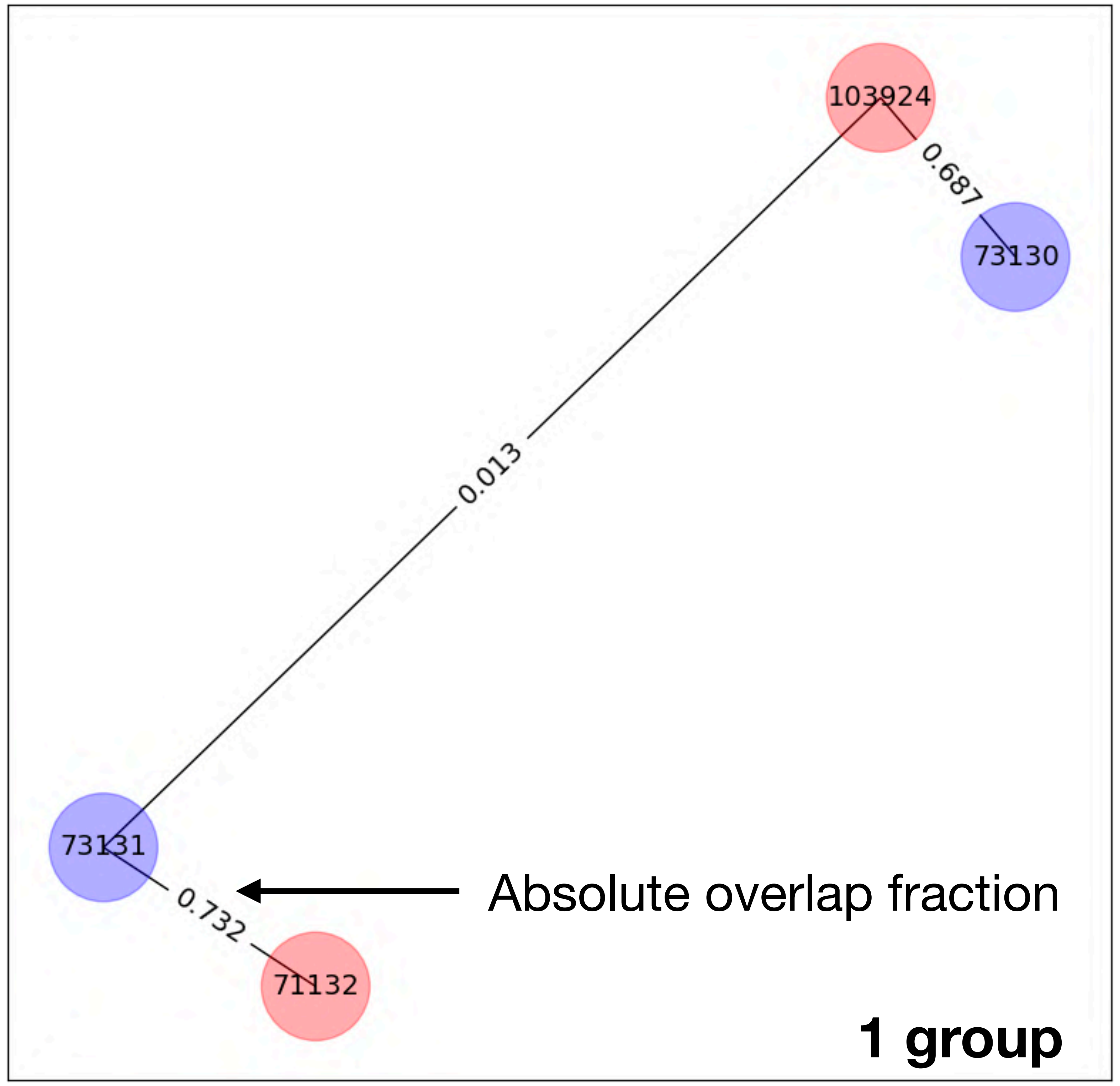


NetworkX graph



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New matching algorithm: friendly

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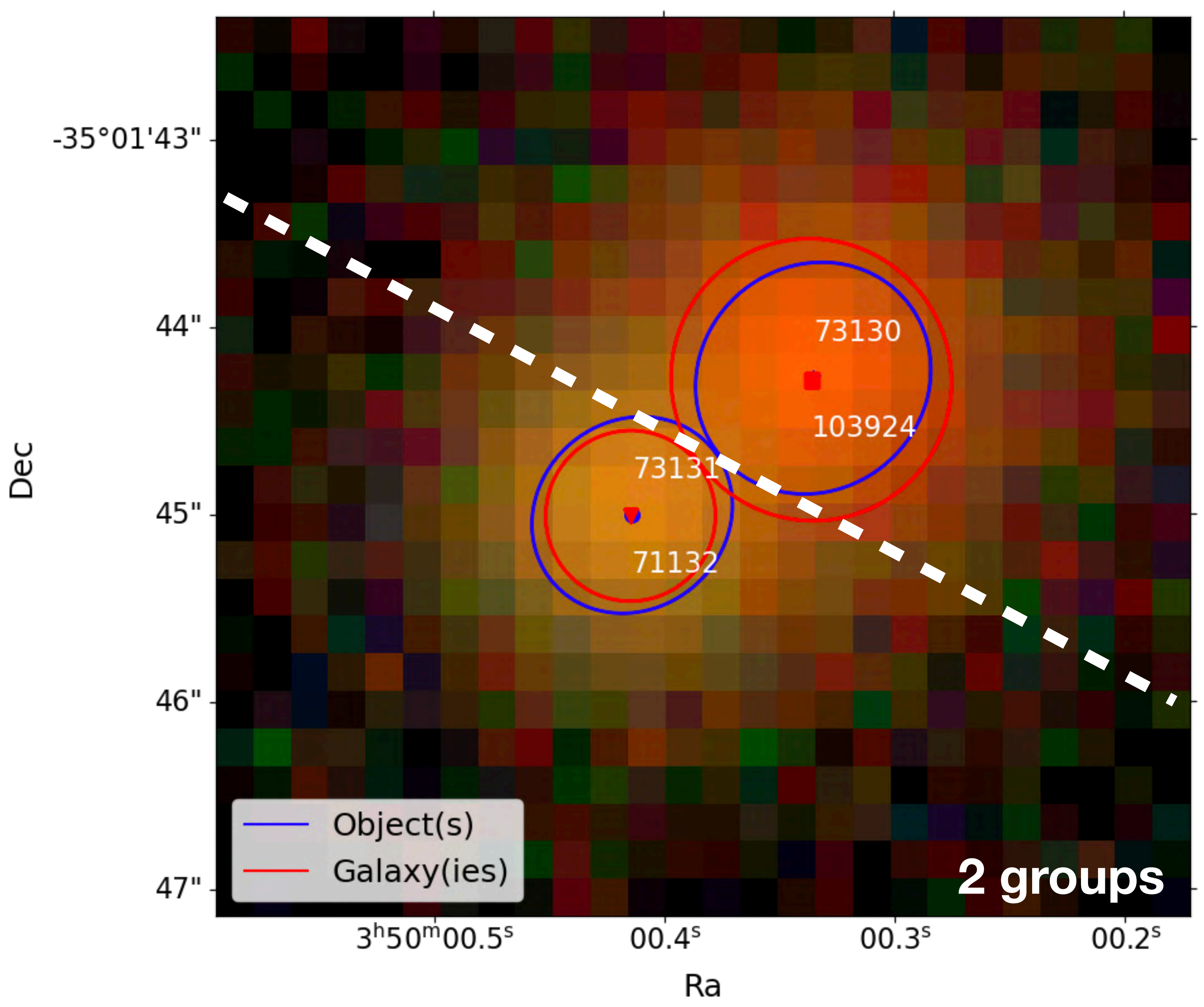
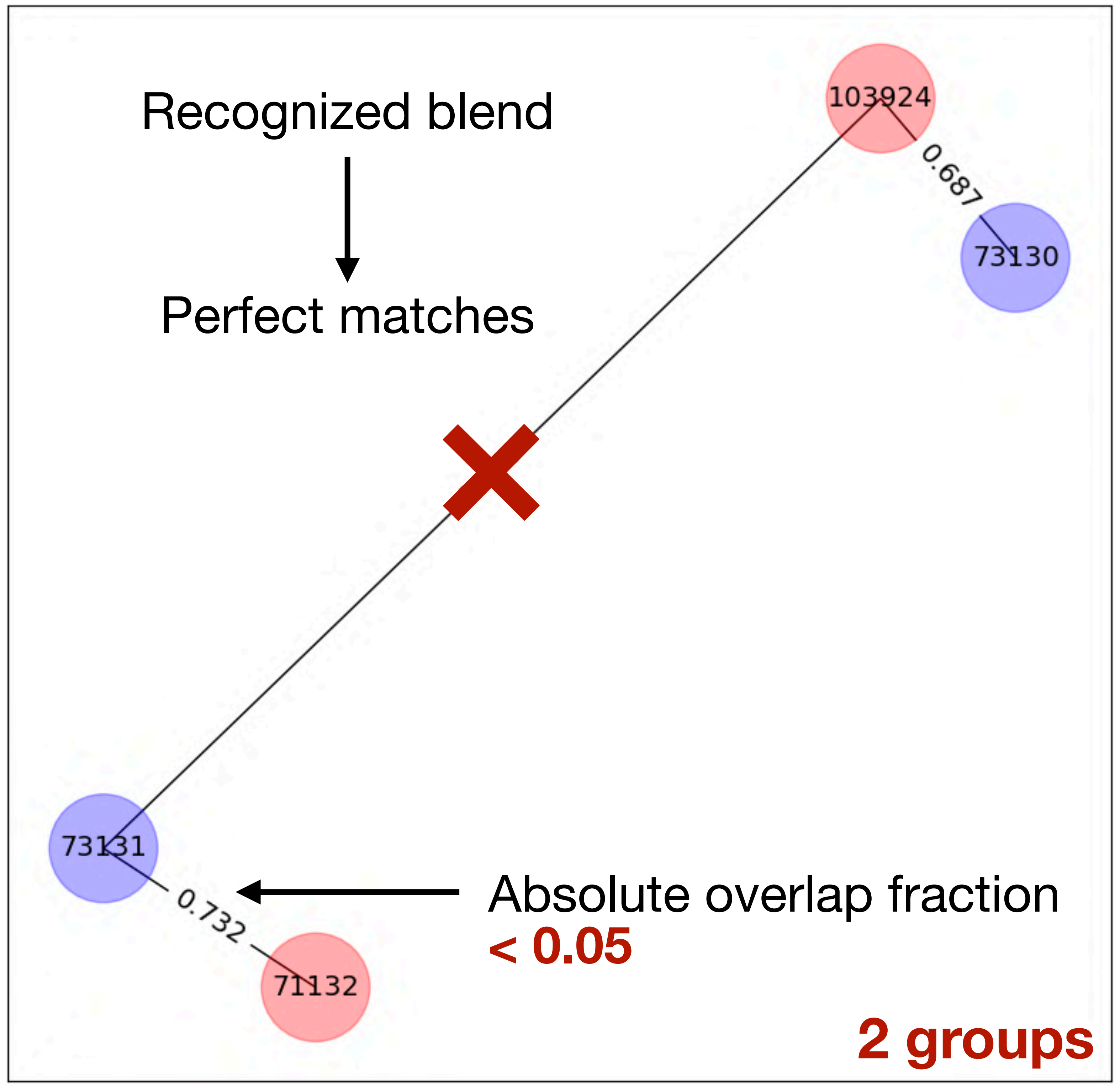


NetworkX graph

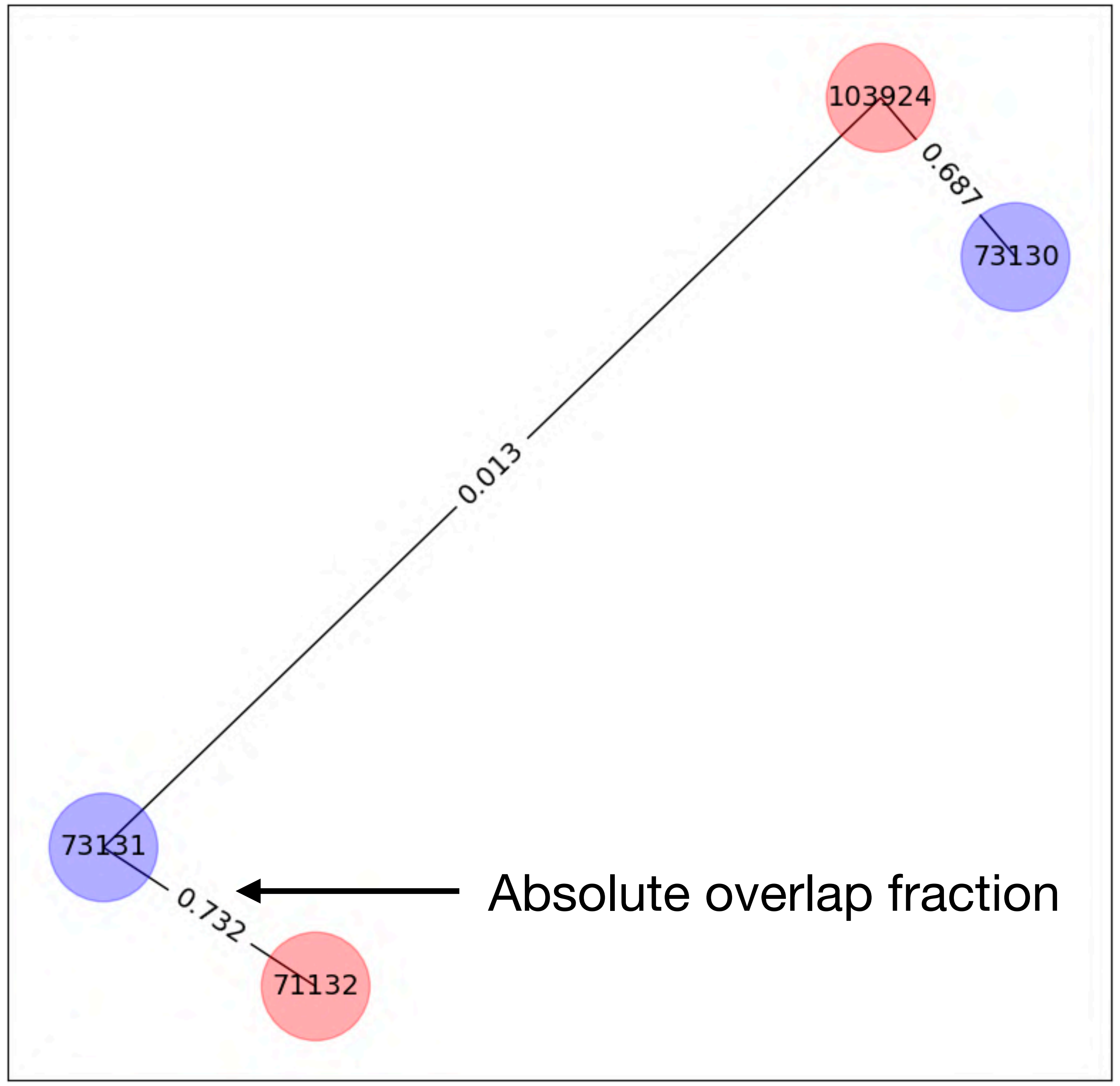


New matching algorithm: friendly

Next steps: Add metrics on the nodes/edges

- Absolute overlap fraction
- Purity
- Magnitudes/colors
- …

NetworkX graph



Friendly = useful graph structure to better define the (un)recognized blends

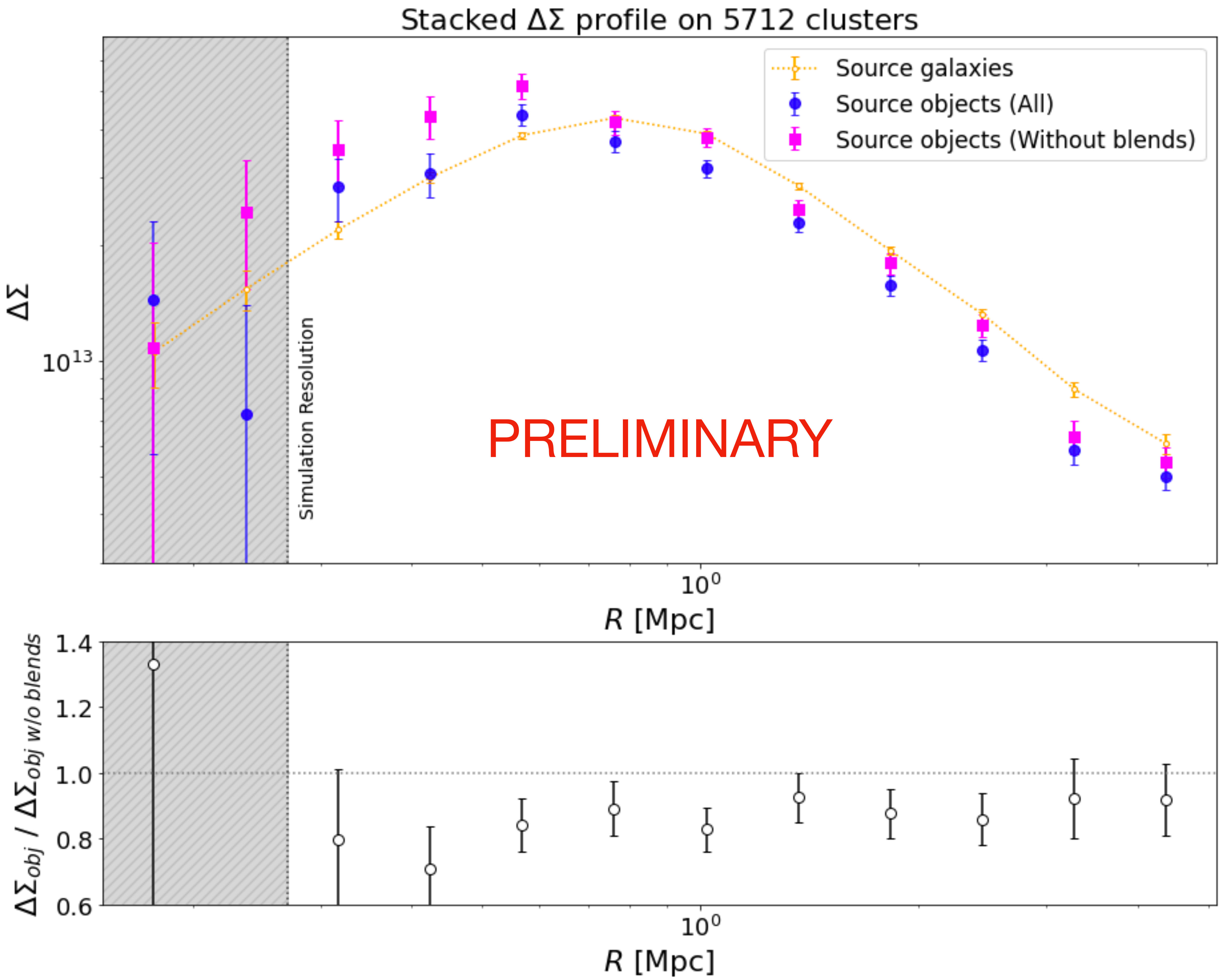
Impact of blending on $\Delta\Sigma$ profiles

Impact of blending on $\Delta\Sigma$ profiles

% of unrecognized blended sources: ~9 %
% of recognized blended sources: ~30 %

Objective: study the impact of (un)recognized blends on $\Delta\Sigma$ profiles

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



https://github.com/LSSTDESC/CLMM

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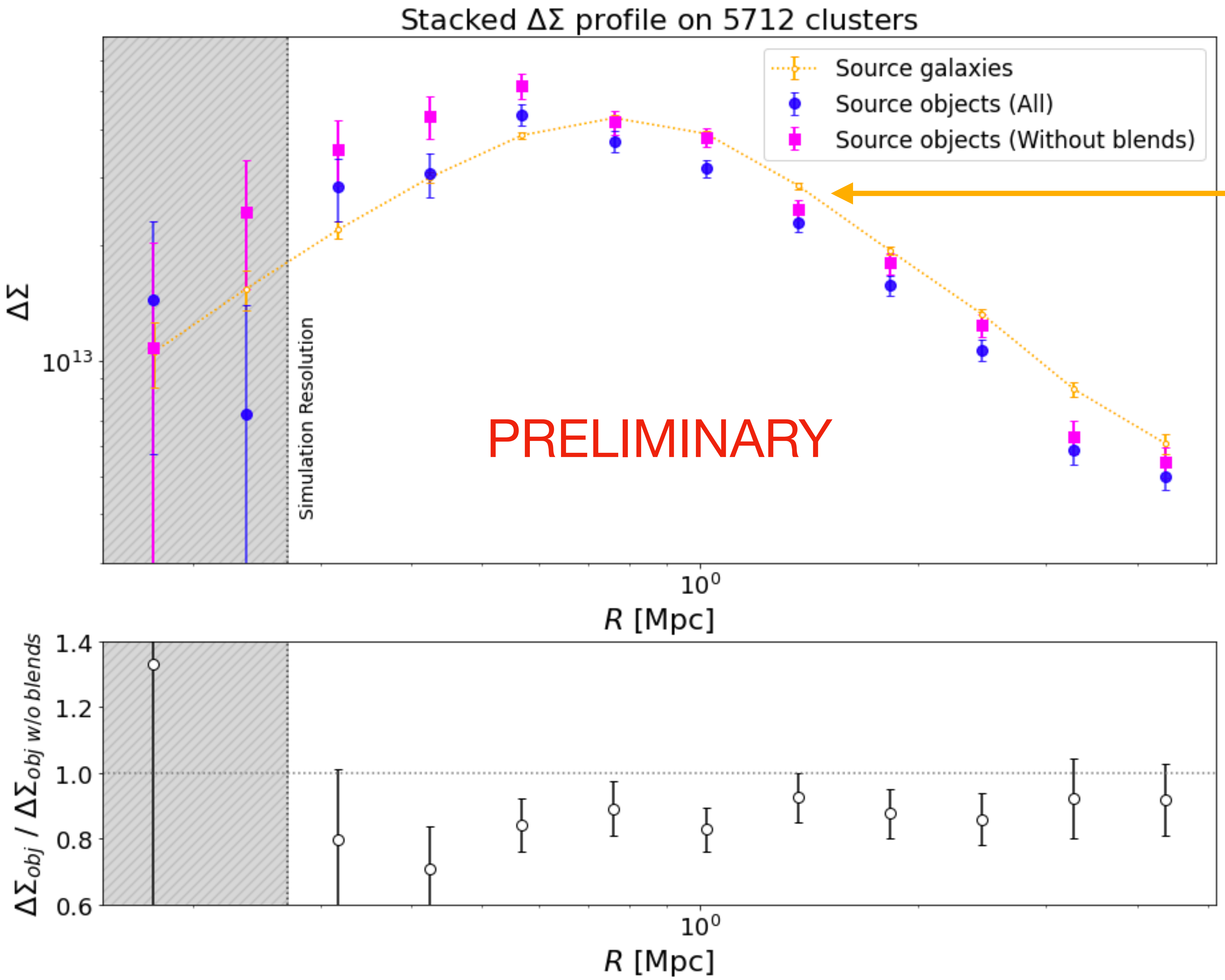

Galaxies (simulated truth)

https://github.com/LSSTDESC/CLMM

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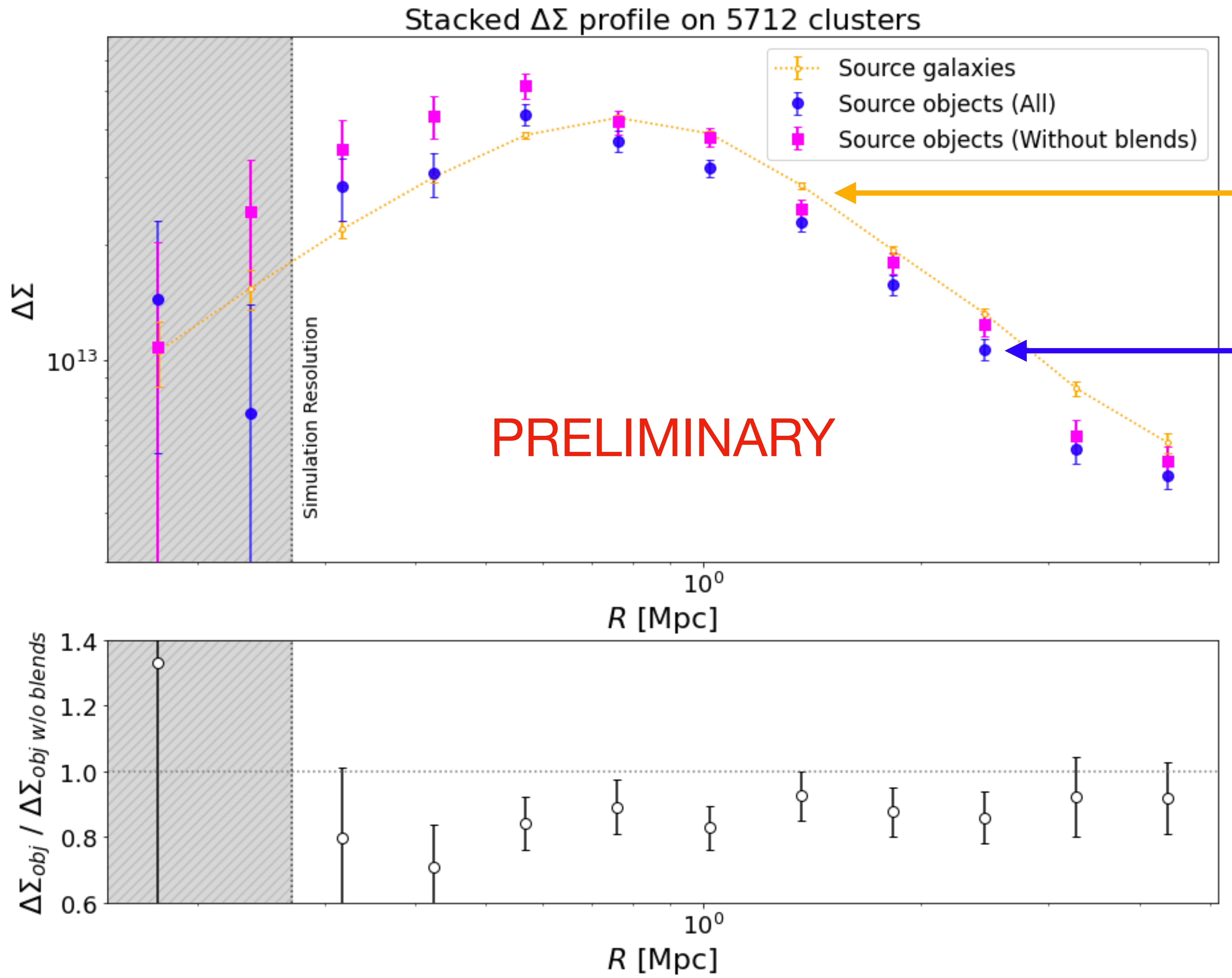

Galaxies (simulated truth)

Objects (simulated observations)

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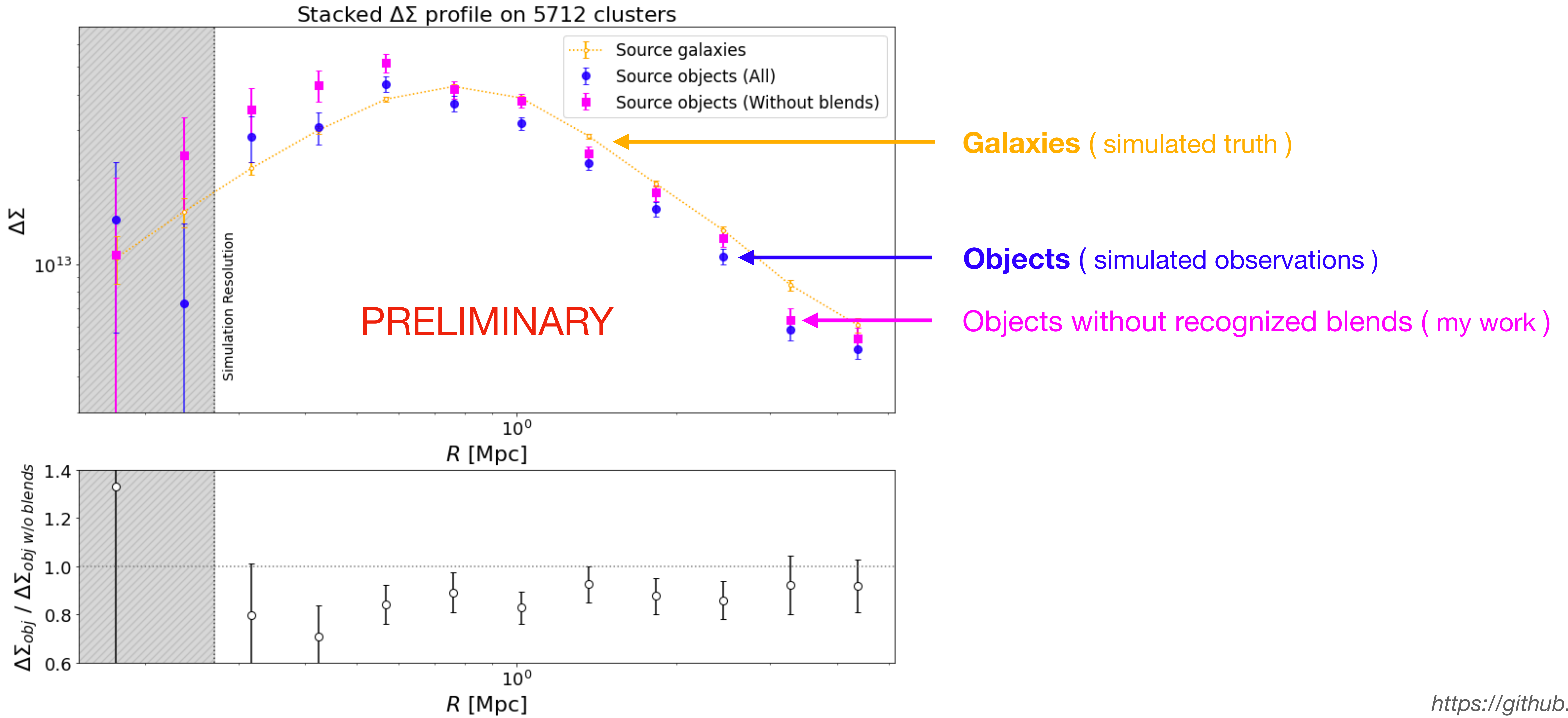

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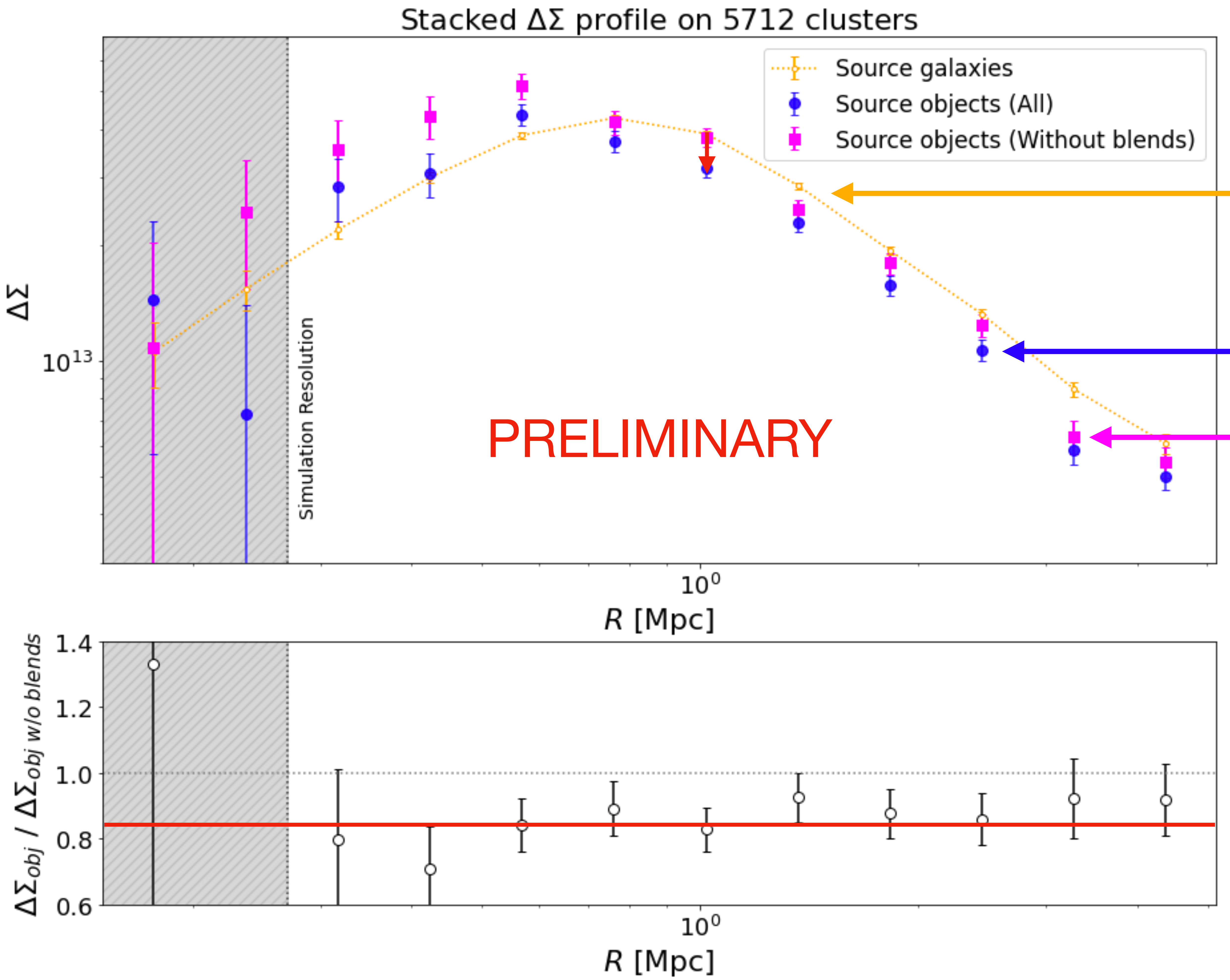


Galaxies (simulated truth)

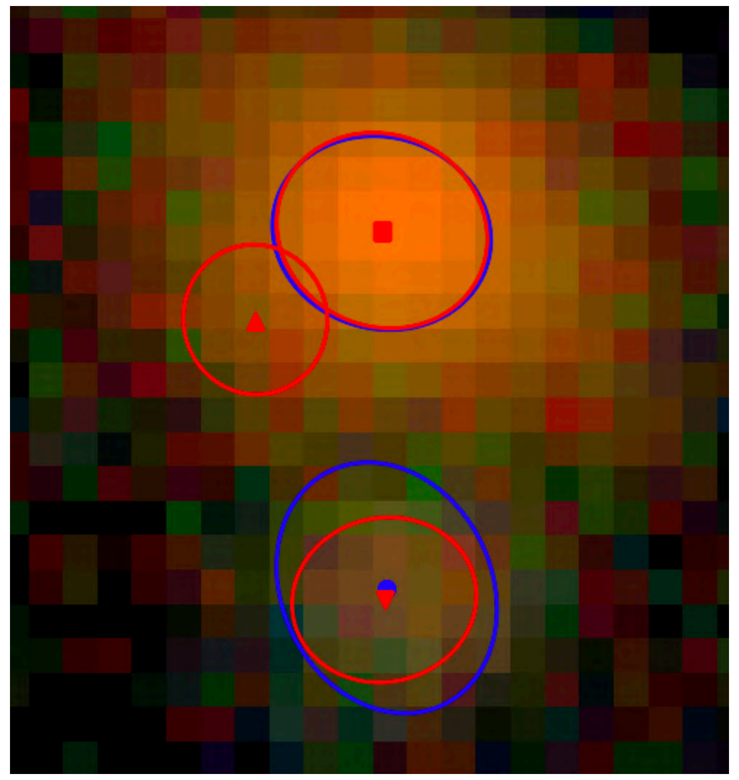
Objects (simulated observations)

Objects without recognized blends (my work)

- Remove blends **shift** the profile upwards by **20%**
- How to deal with blends instead? **Friendly**

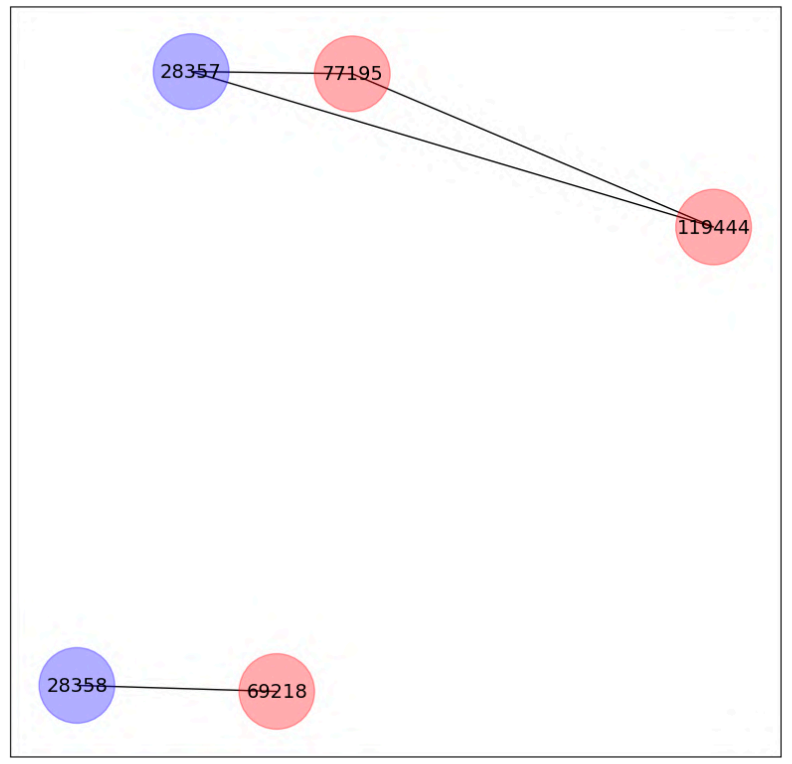
https://github.com/LSSTDESC/CLMM

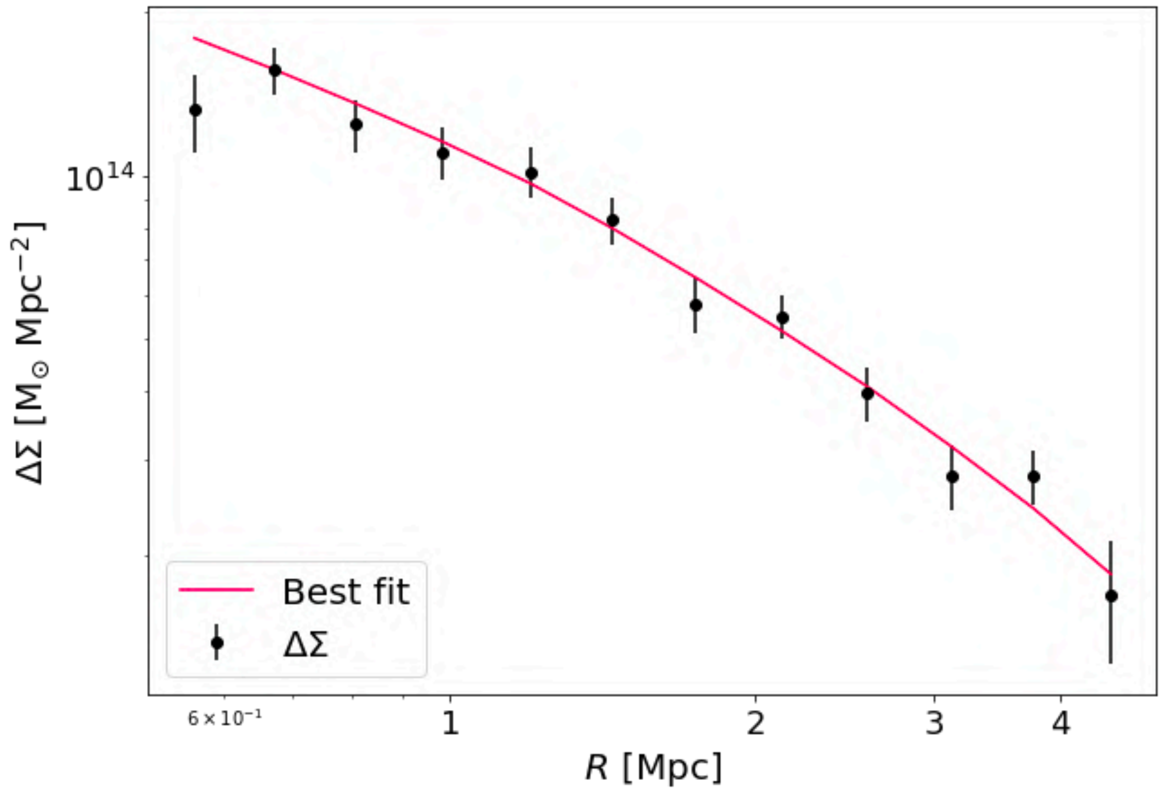
Conclusion and perspectives



Development of friendly
= new blending matching algorithm

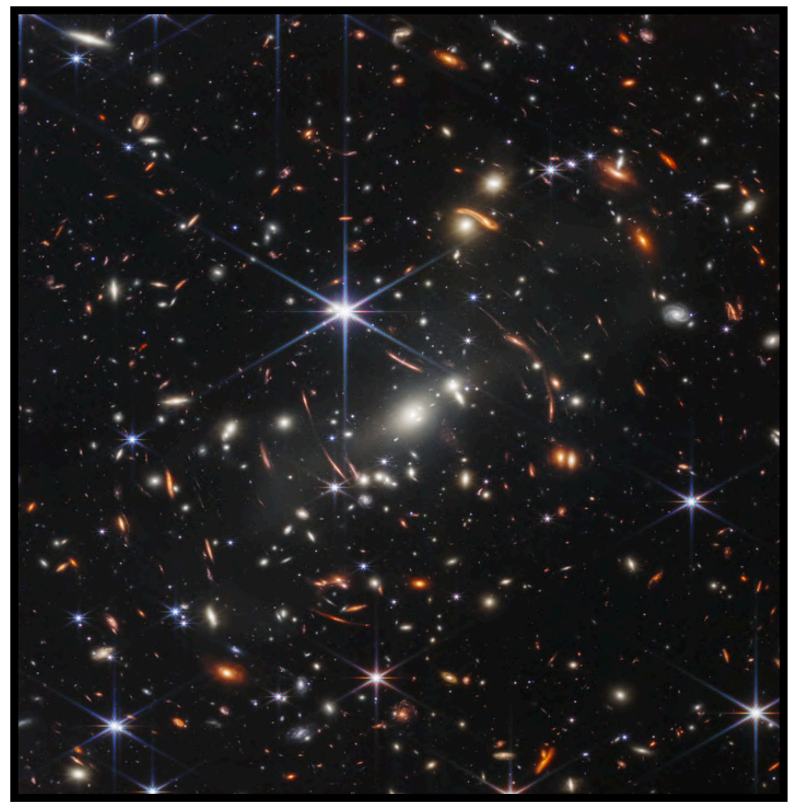
Better definition of (un)recognized blends



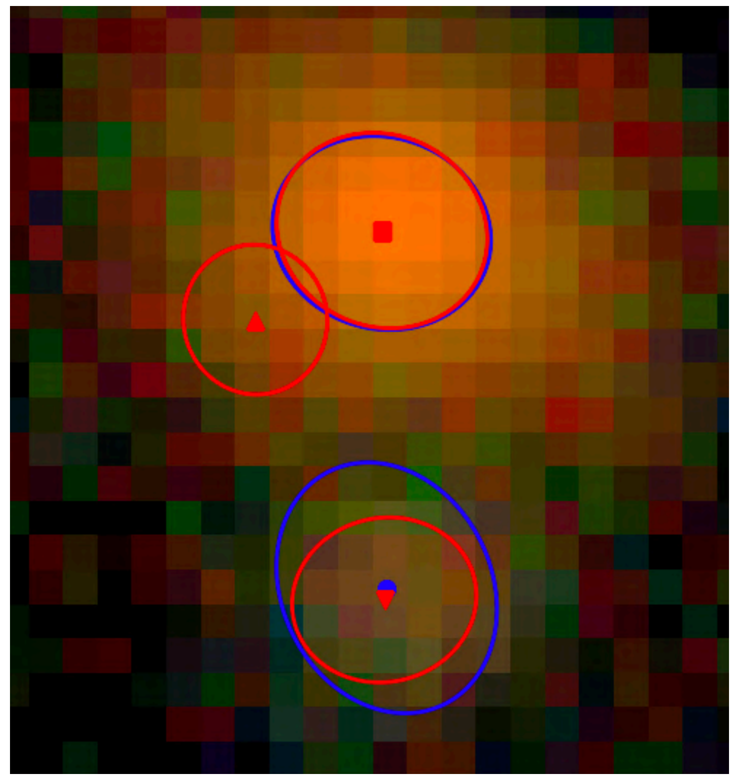


Impact of blending on $\Delta\Sigma$ profiles

Impact on galaxy clusters mass estimates and on cosmology



Conclusion and perspectives



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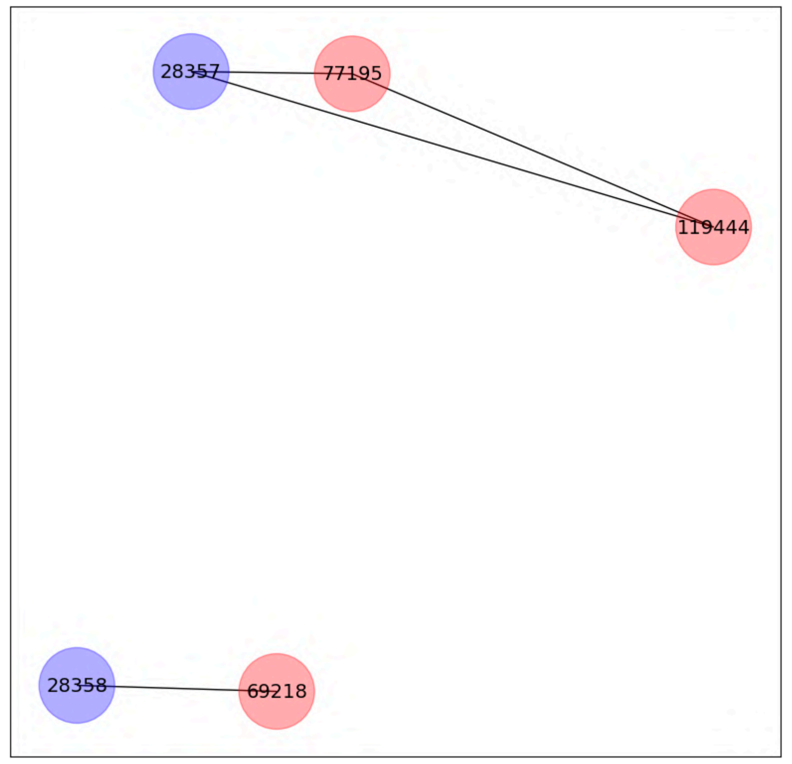

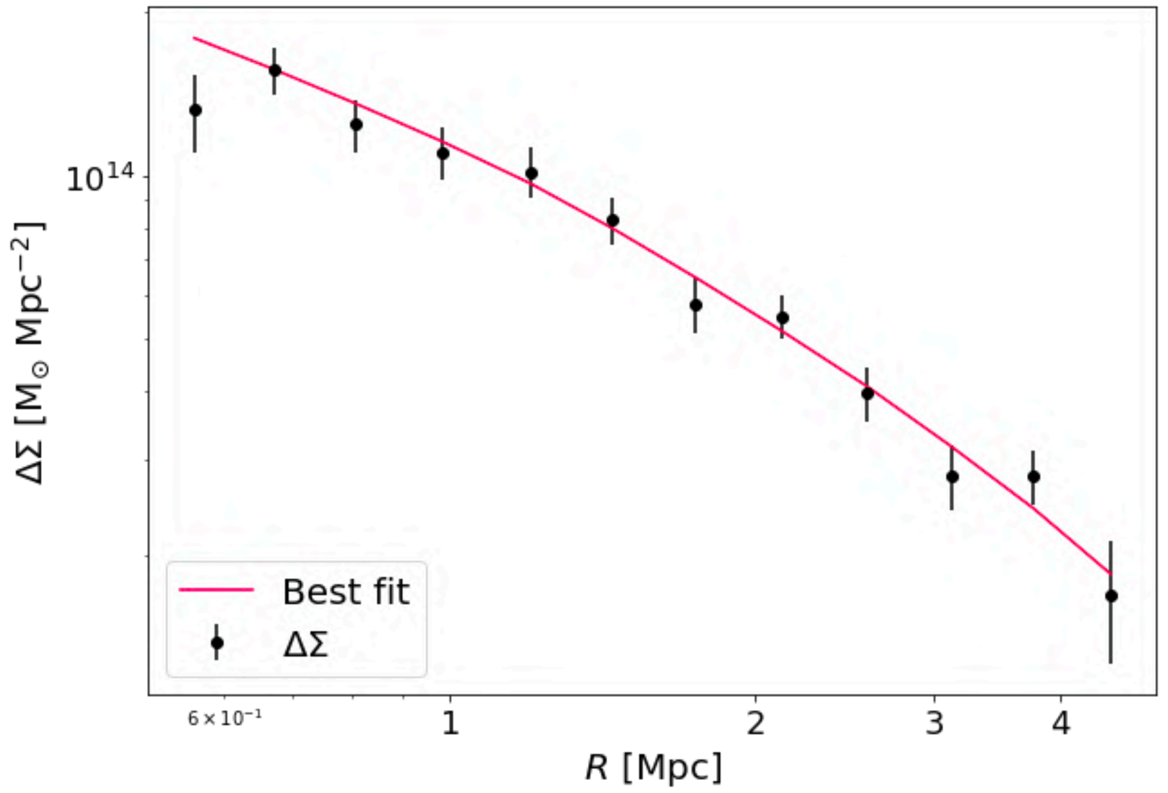

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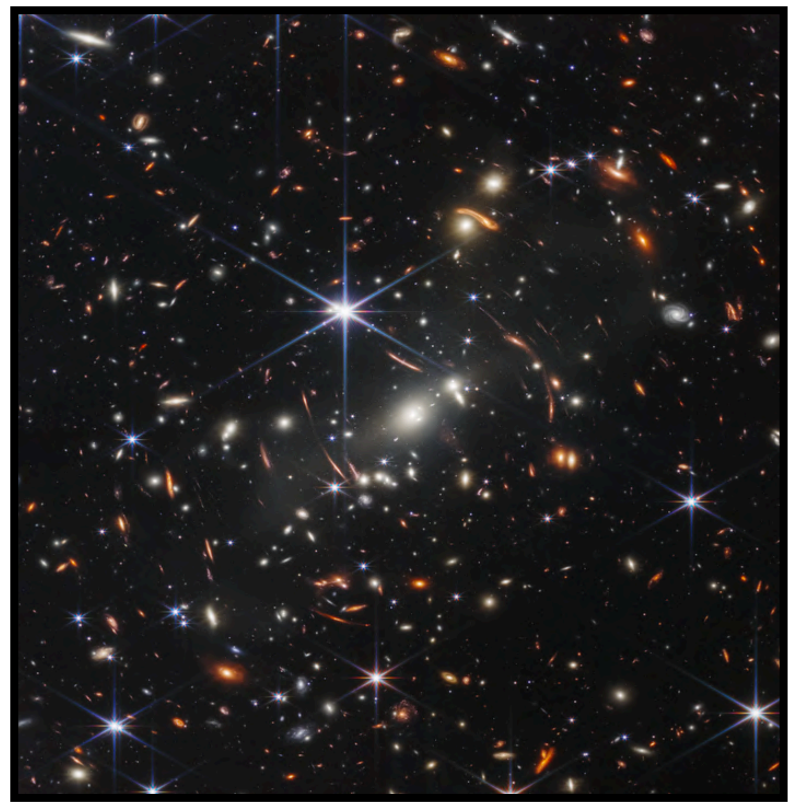
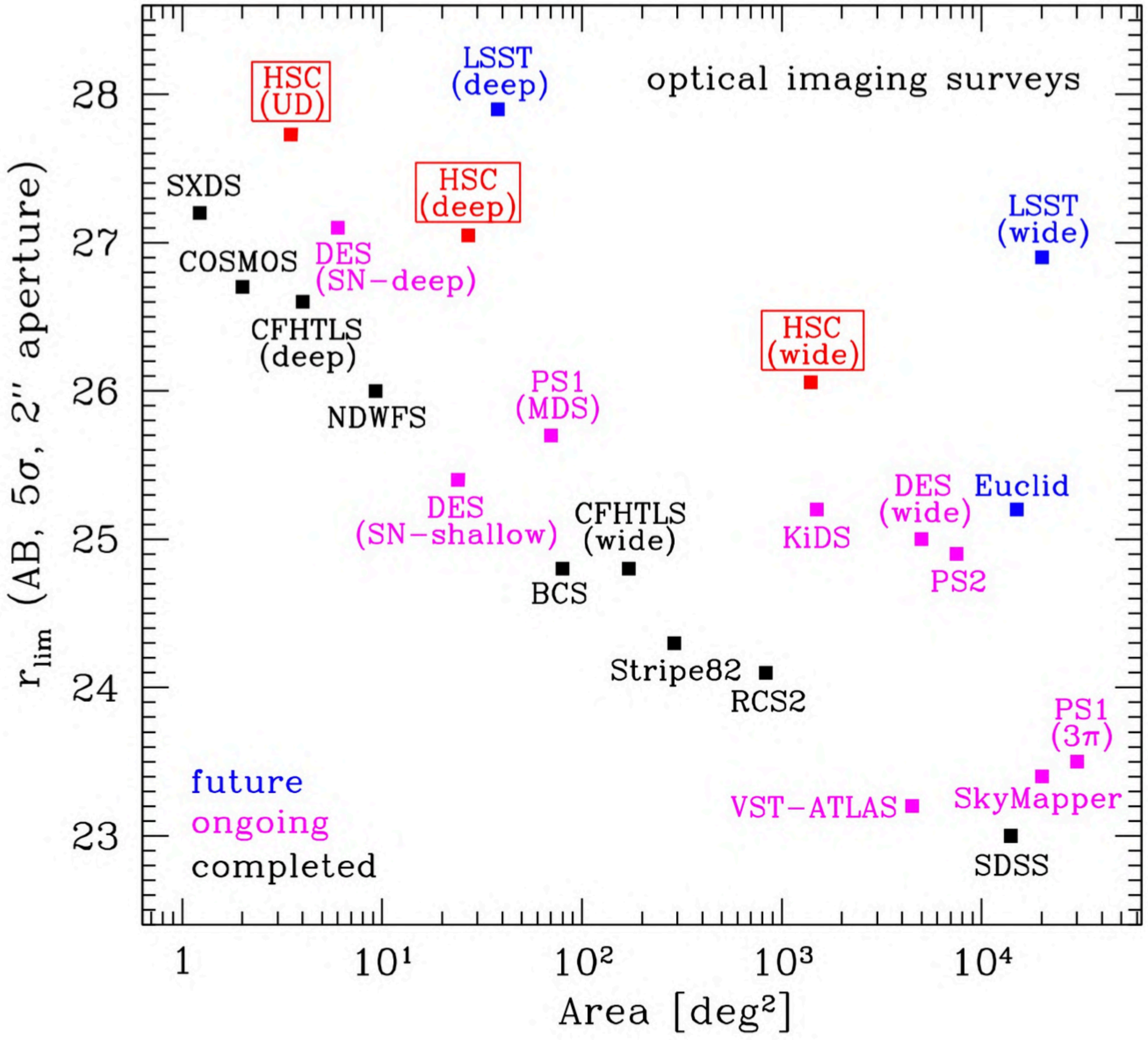


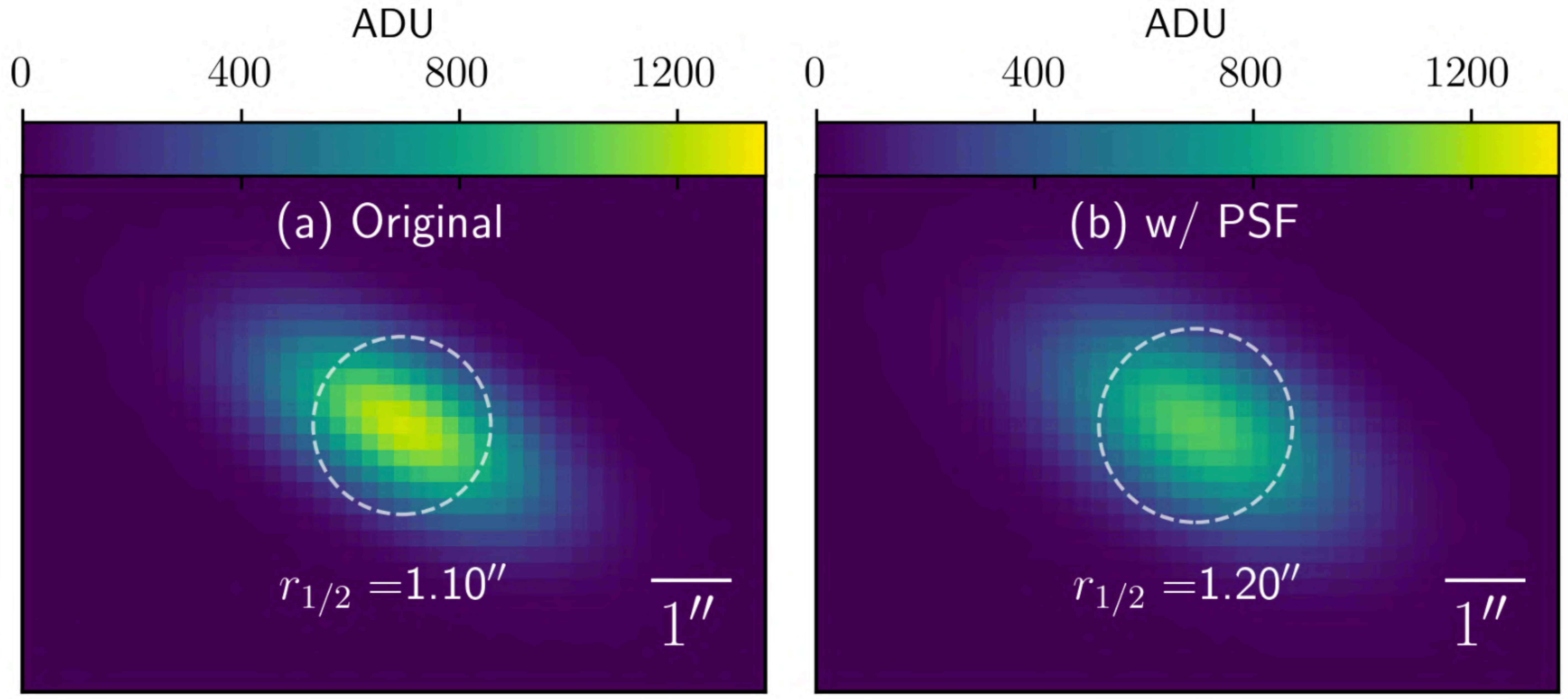
Thank you for your attention !

Back-up

Rubin-LSST


optical imaging surveys
HSC (UD)
LSST (deep)
SXDS
HSC (deep)
LSST (wide)
COSMOS
DES (SN−deep)
CFHTLS (deep)
HSC (wide)
PS1 (MDS)
NDWFS
DES (SN−shallow)
CFHTLS (wide)
KiDS
DES (wide)
Euclid
PS2
BCS
Stripe82
RCS2
PS1 (3π)
SkyMapper
VST−ATLAS
SDSS
future
ongoing
completed
r_{lim} (AB, 5σ, 2″ aperture)
28
27
26
25
24
23
1
10^1
10^2
10^3
10^4
Area [deg²]

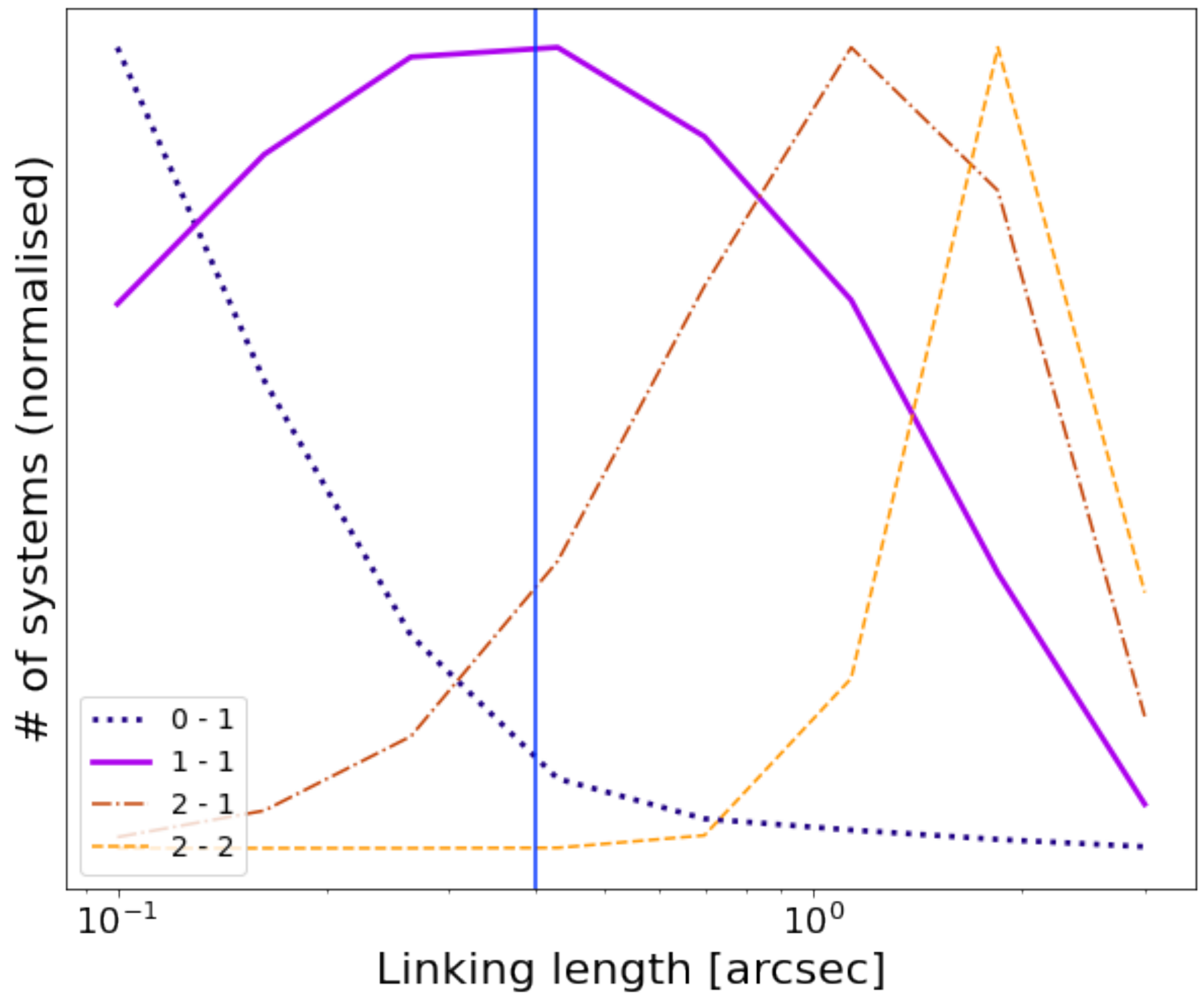
Point Spread Function (PSF)



E. Nourbakhsh et. al

Choice of the linking length

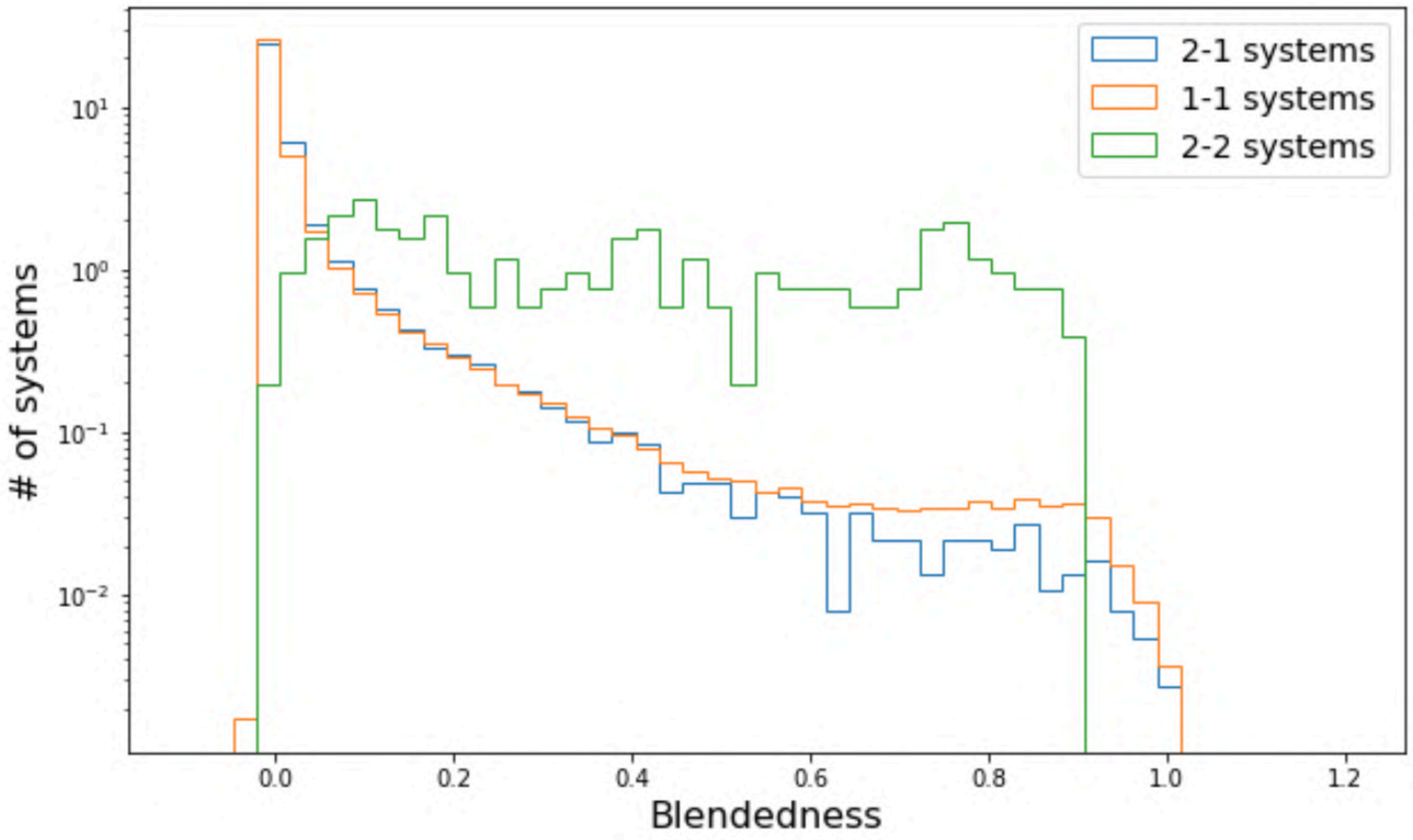
Maximize the 1-1 systems = perfect matches



$\boxed{\text{We choose: 0.4”}}$ (pixel size: 0.2”)

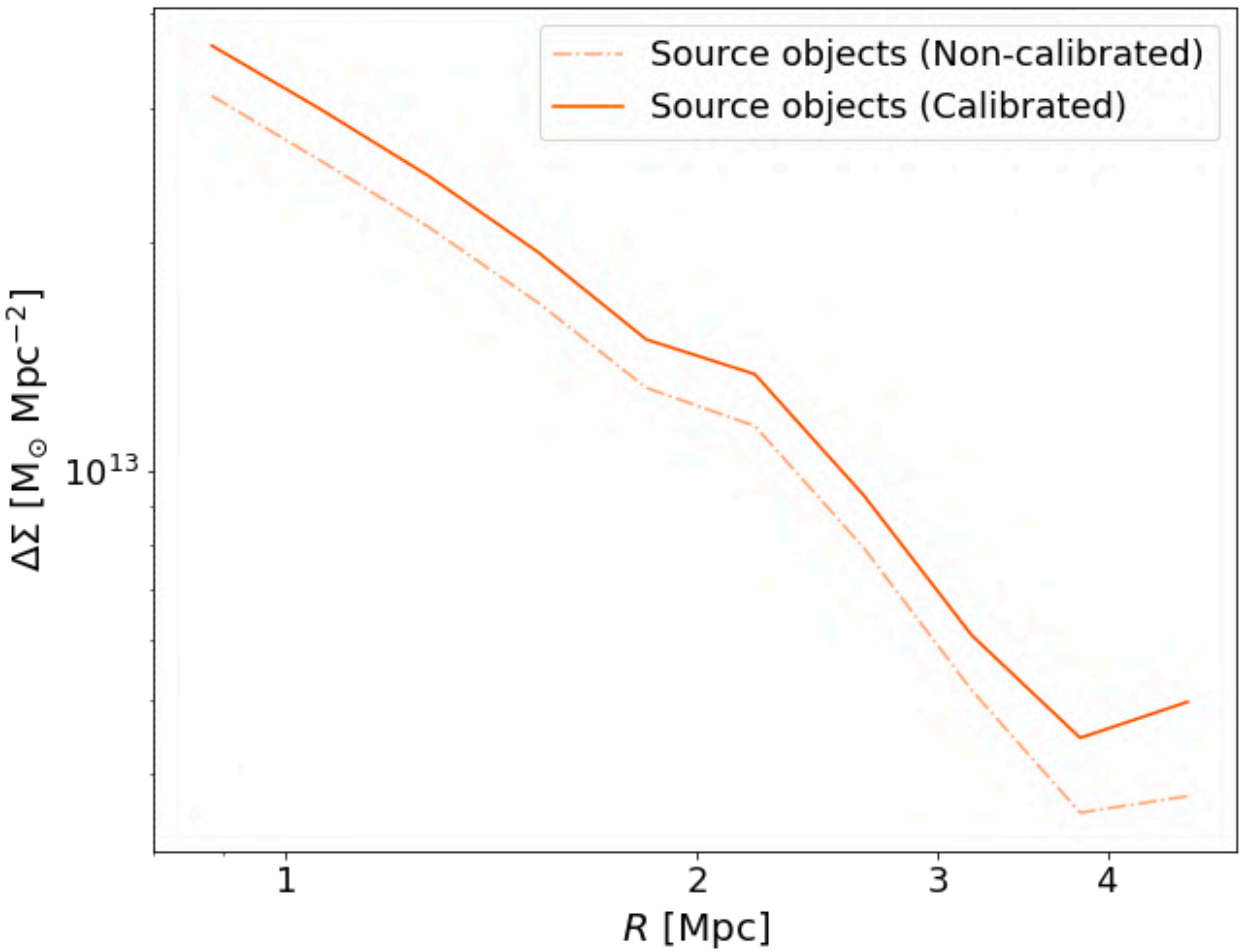
- Proportion of unrecognized blends (n-1 systems with n > 1) : $\boxed{\sim 8\%}$

Distribution of the blendedness



Back-up

HSM calibration



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

Ellipticity 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

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

$\xrightarrow{\text{Determinant computation}}$

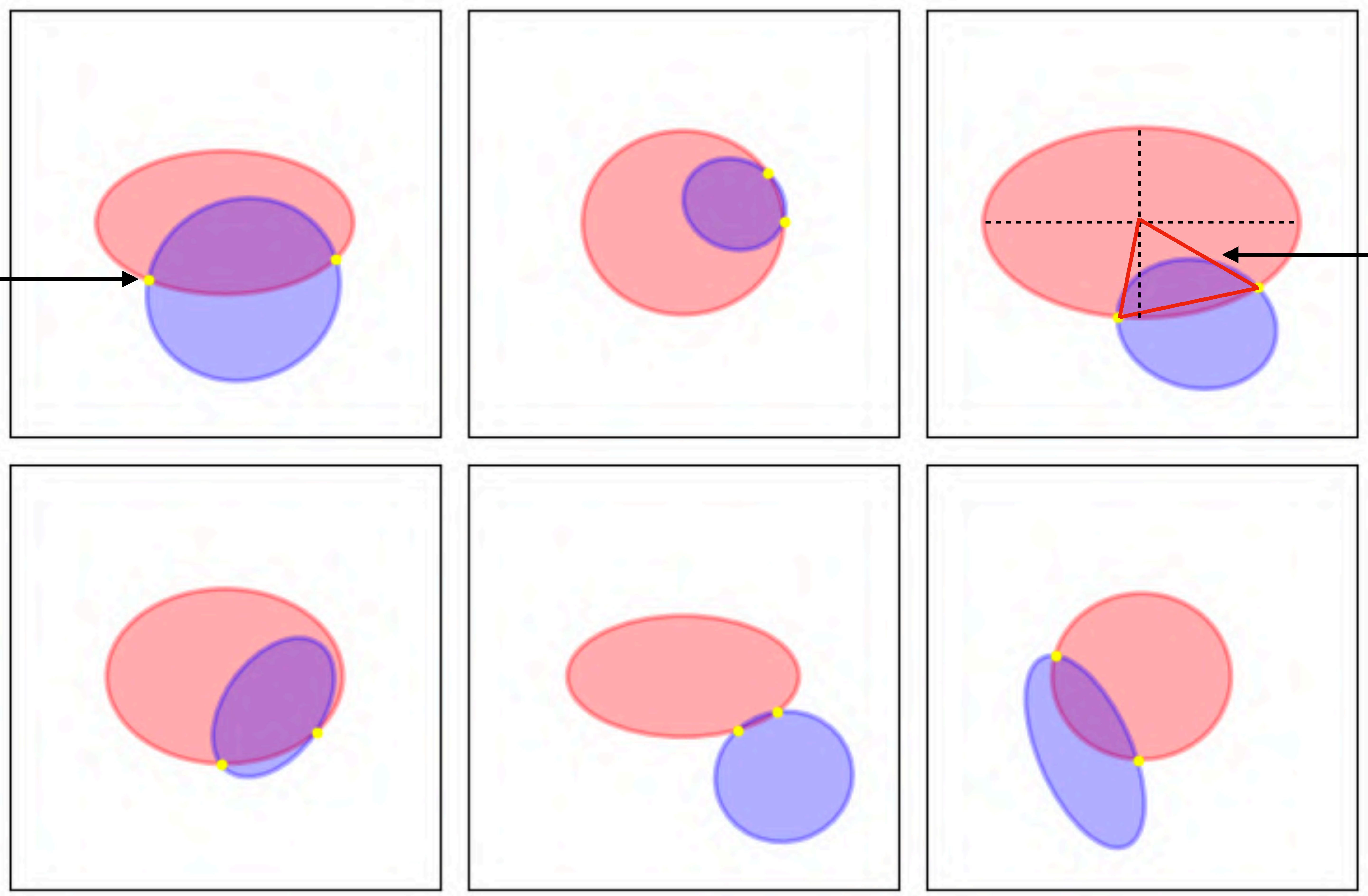
Overlap of 2 ellipses ?

- True
- False

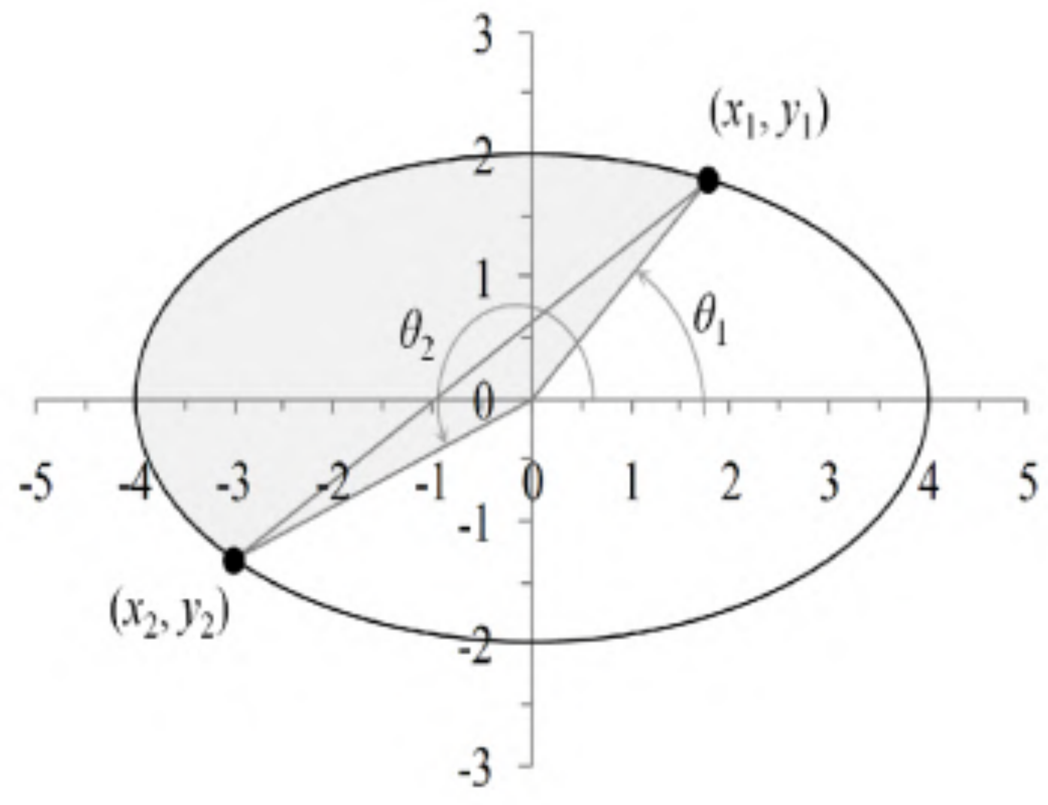
Absolute overlap fraction

2011, Hughes et al.

Interception points



Ellipse segment area



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

Purity

2021, Sanchez et al.

Purity of an object = the degree to which it overlaps with other sources

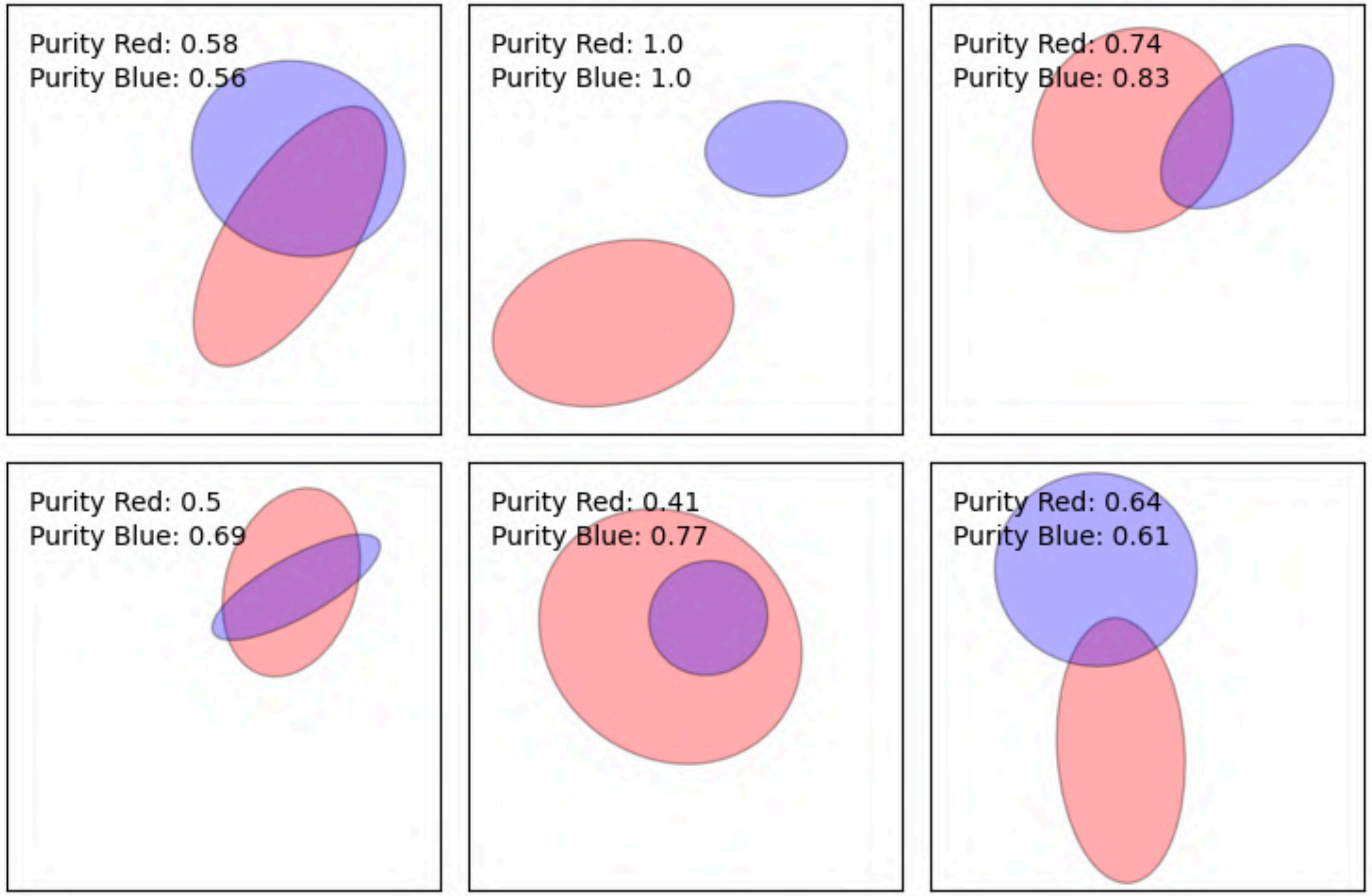
If ellipses 1 and 2 overlap, the purity of ellipse 1 is given as:

$$P_1 = \frac{\int G_1^2(\mathrm{r})dxdy}{\int \left(G_1^2(\mathrm{r}) + G_1(\mathrm{r}) \cdot G_2(\mathrm{r})\right) dxdy}$$

Gaussian profile of ellipse 1

Gaussian profile of ellipse 2

- Purity of 0: Completely blended source
- Purity of 1: Isolated source



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Back-up

Unrecognized blends and $\Delta\Sigma$ profiles