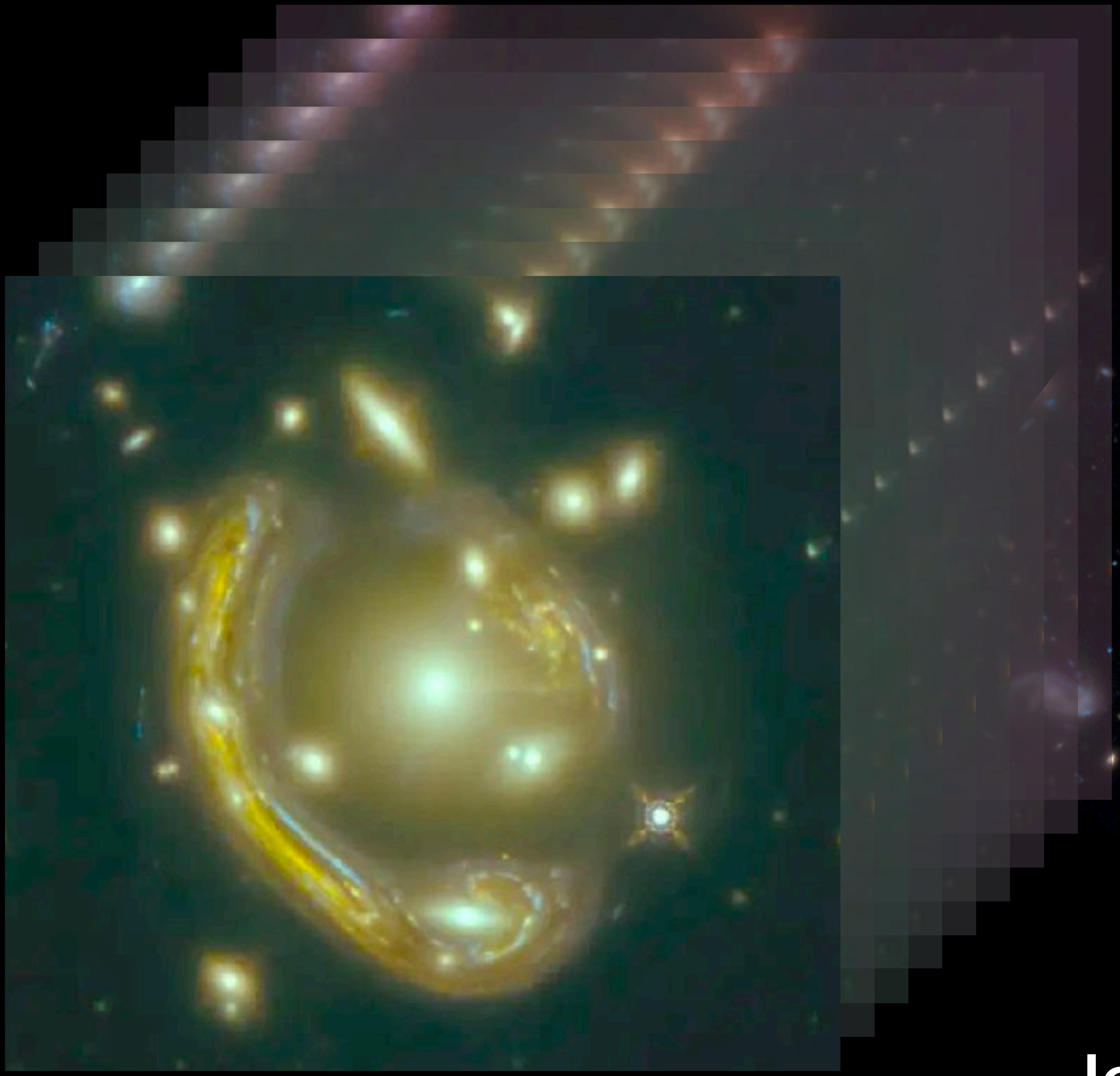
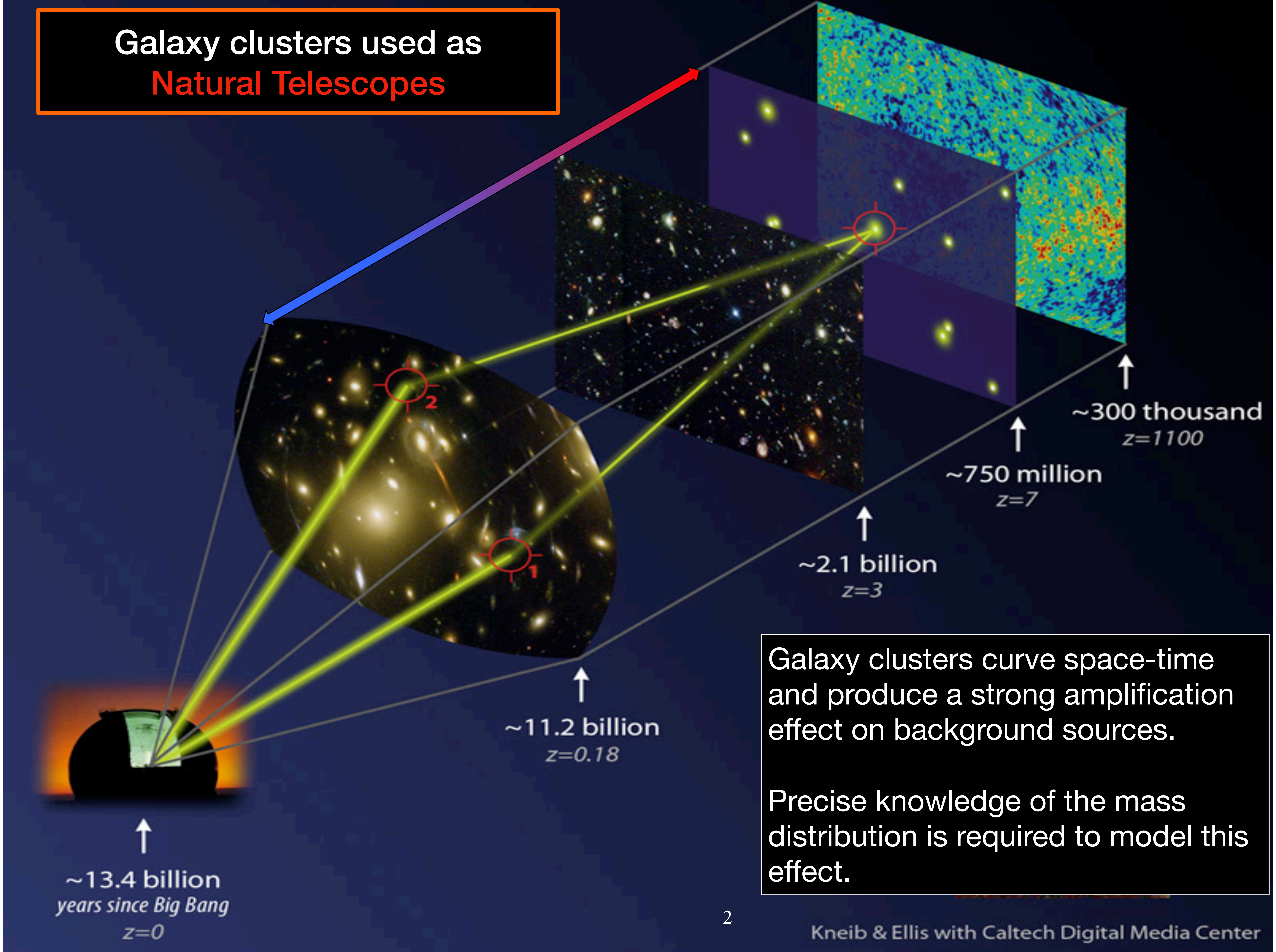
Project: Identifying strongly lensed galaxy candidates from MUSE/VLT observations



Johan Richard
(CRAL)

9th Indo-French Astronomical School

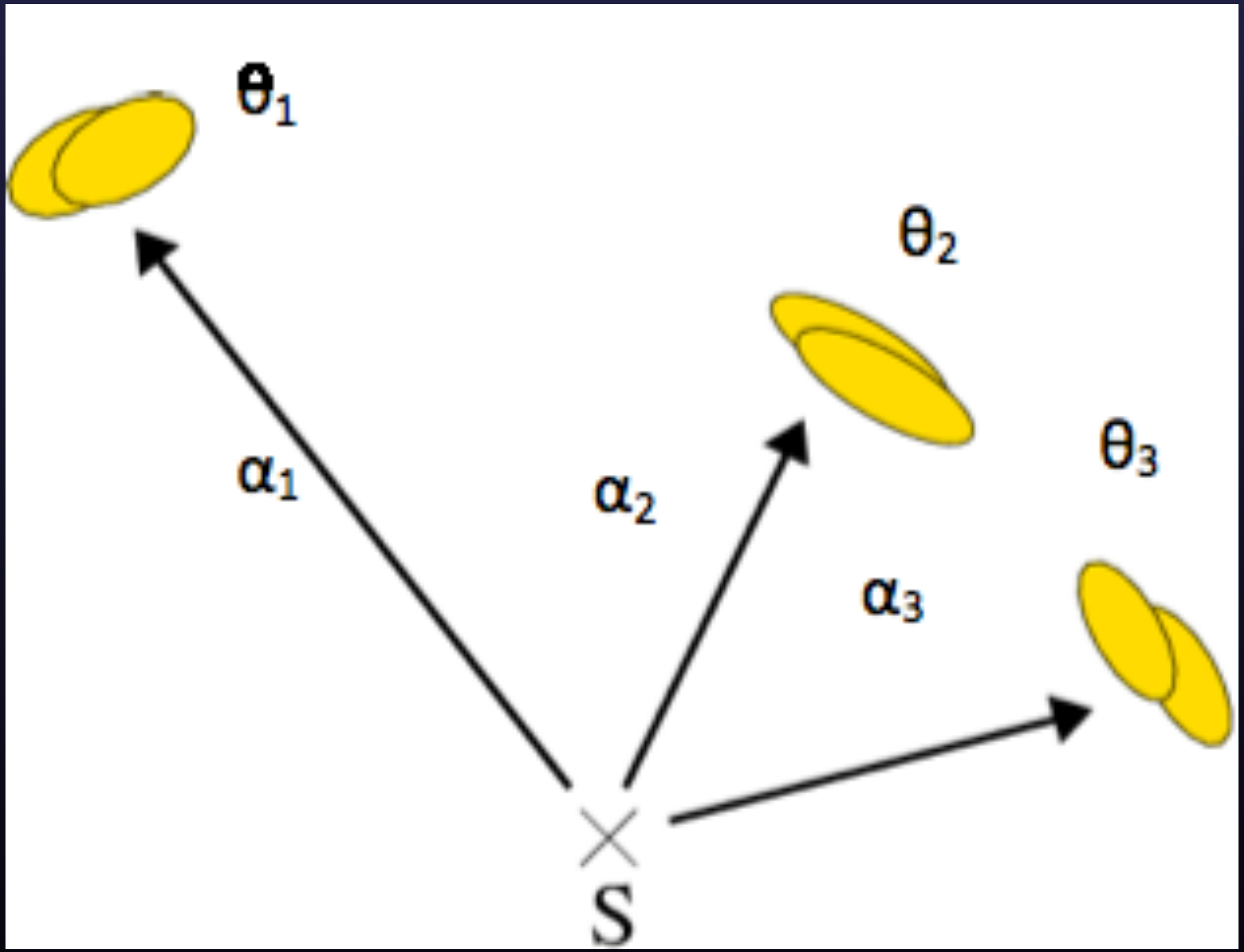
Galaxy clusters used as Natural Telescopes

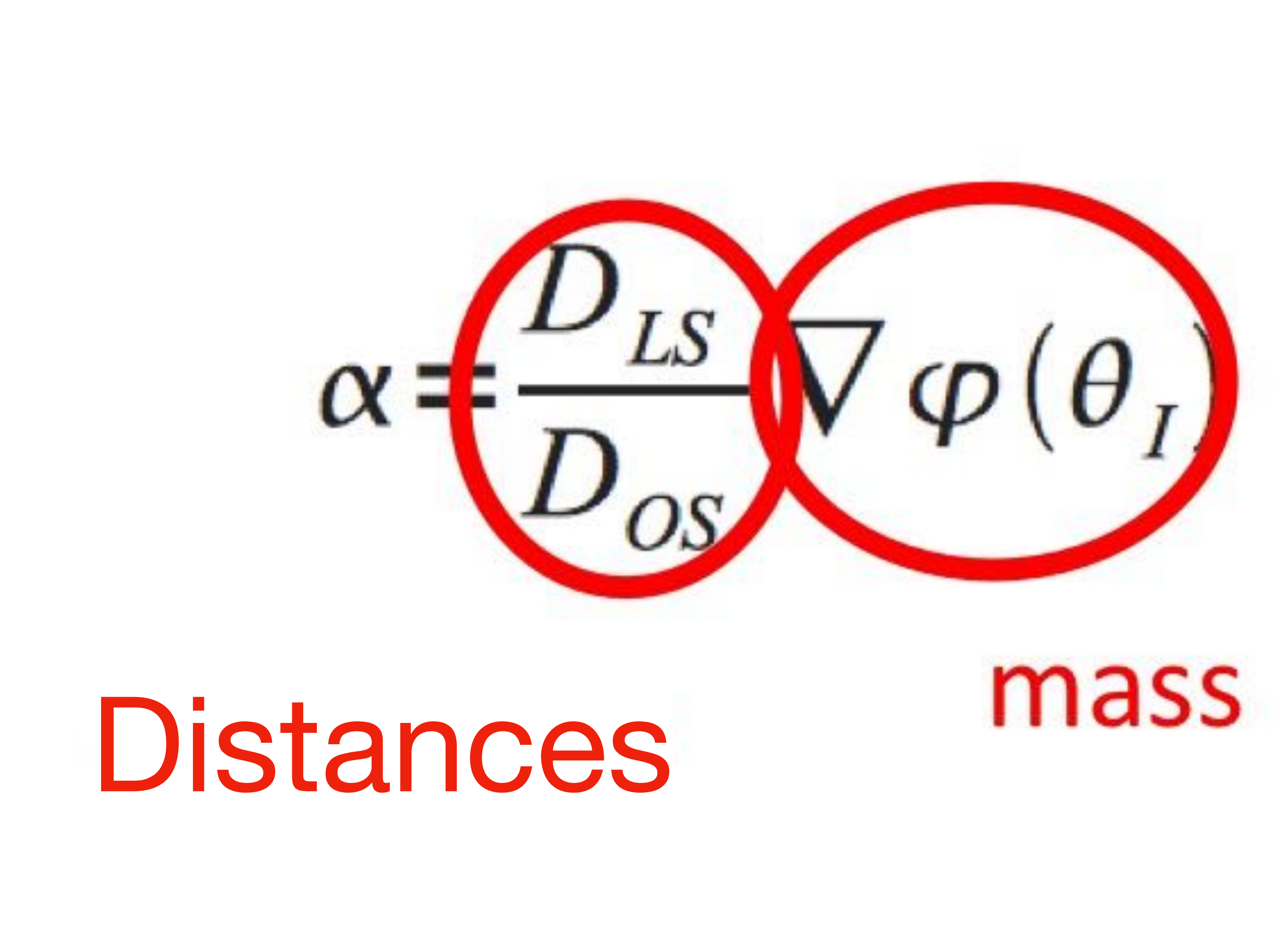


Galaxy clusters curve space-time and produce a strong amplification effect on background sources.

Precise knowledge of the mass distribution is required to model this effect.

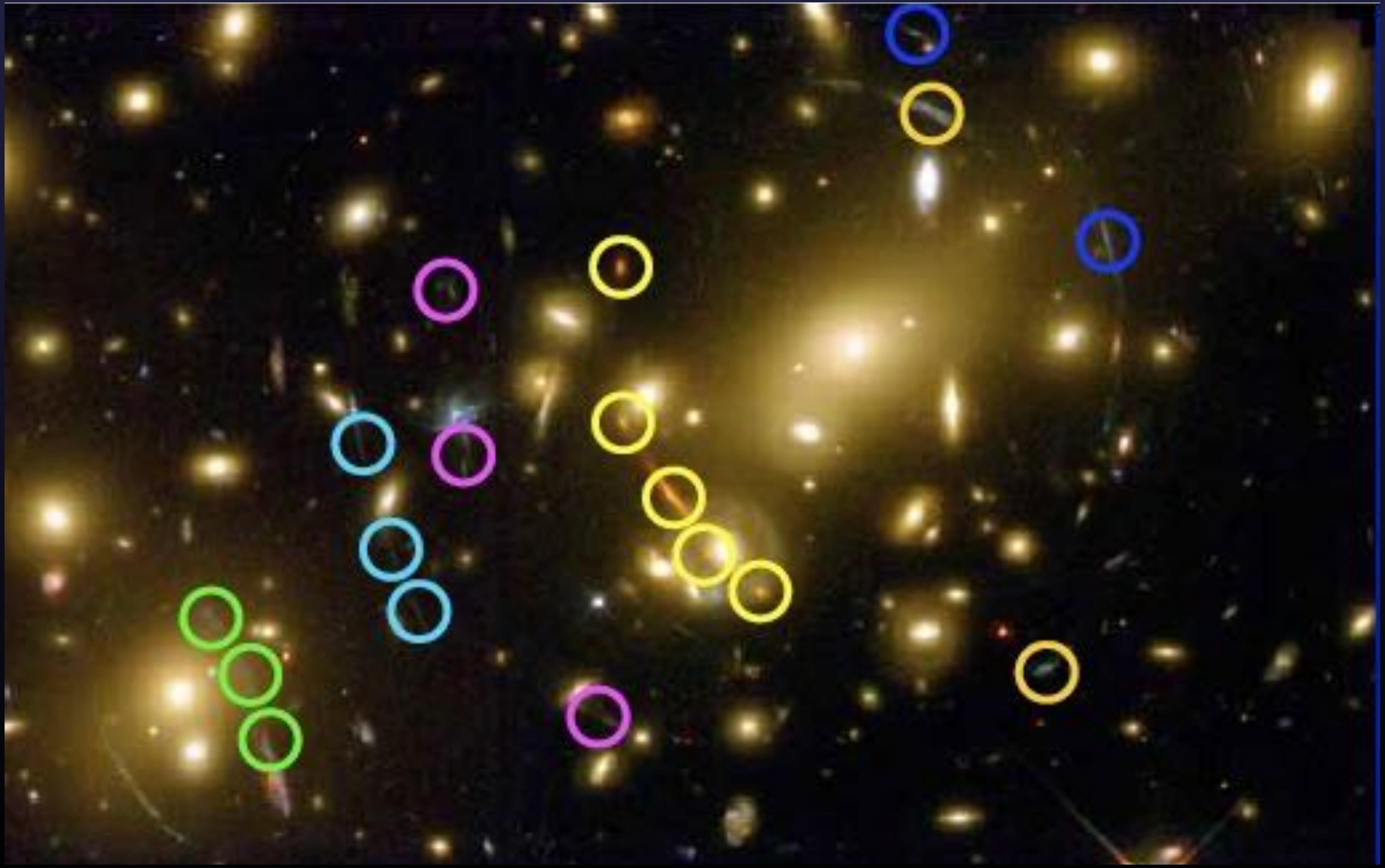
Multiple images

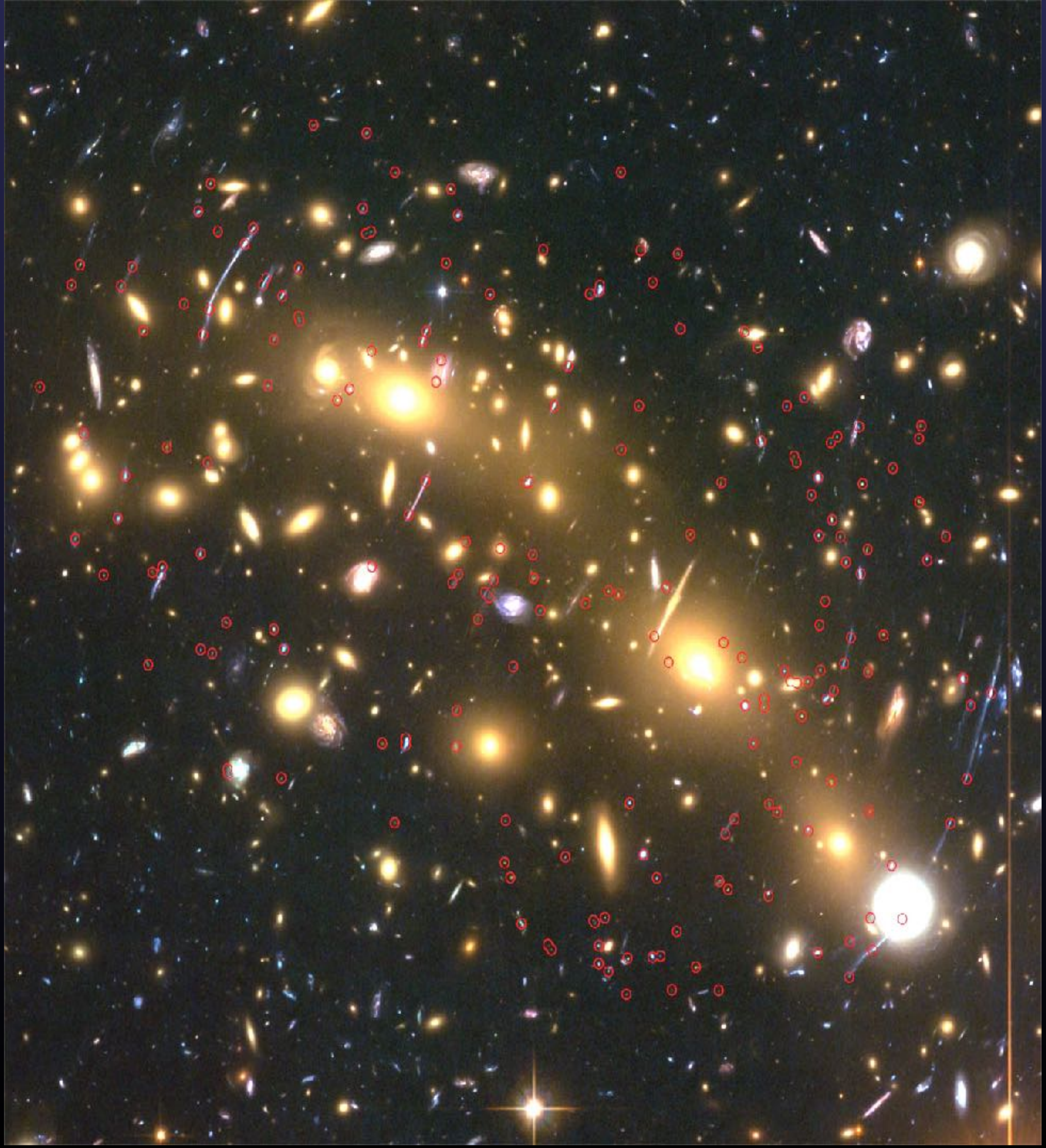




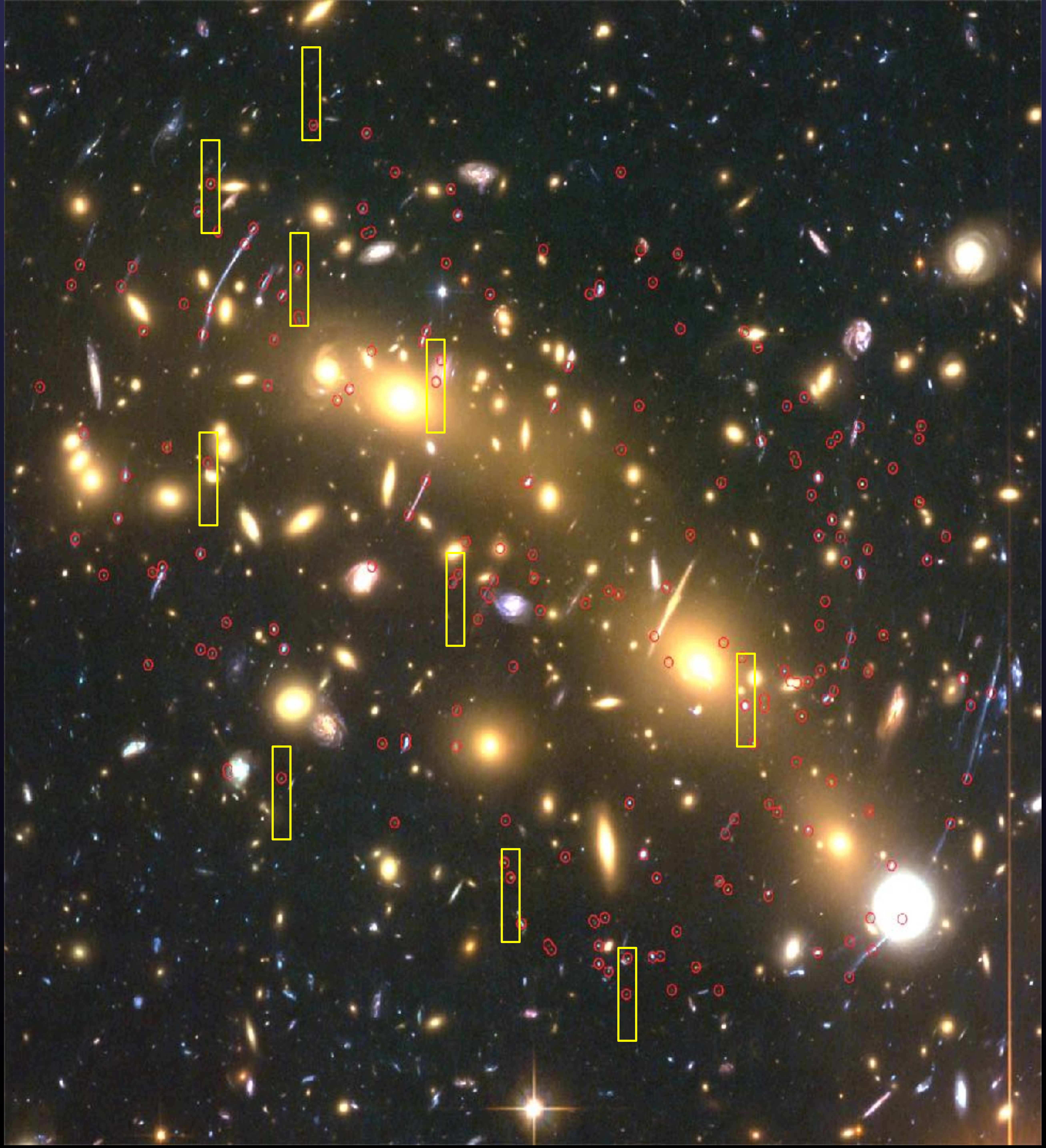
Redshifts are needed to calibrate the mass distribution.

Multiple images



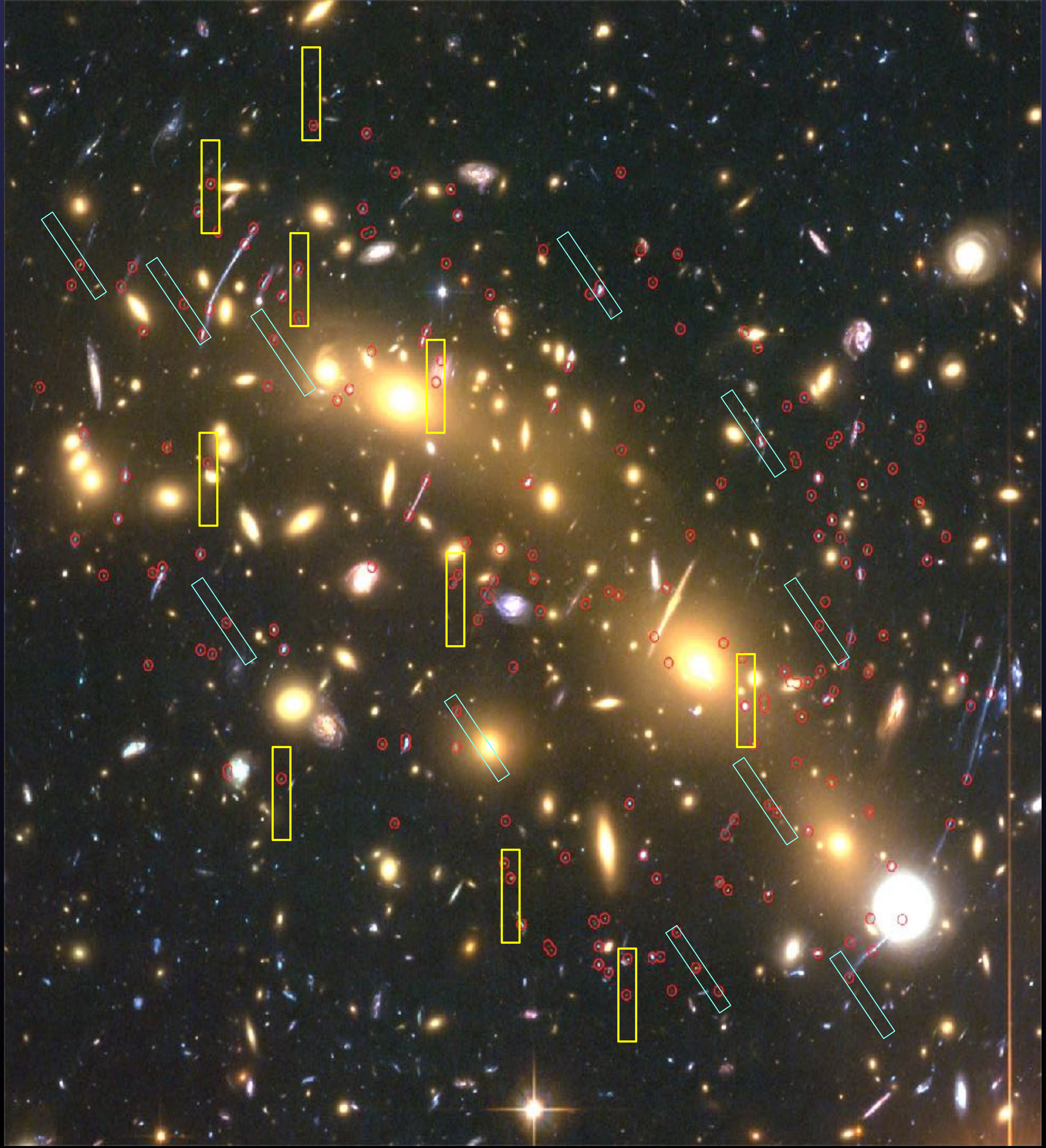


Multi-Object Spectroscopy



Multi-Object Spectroscopy

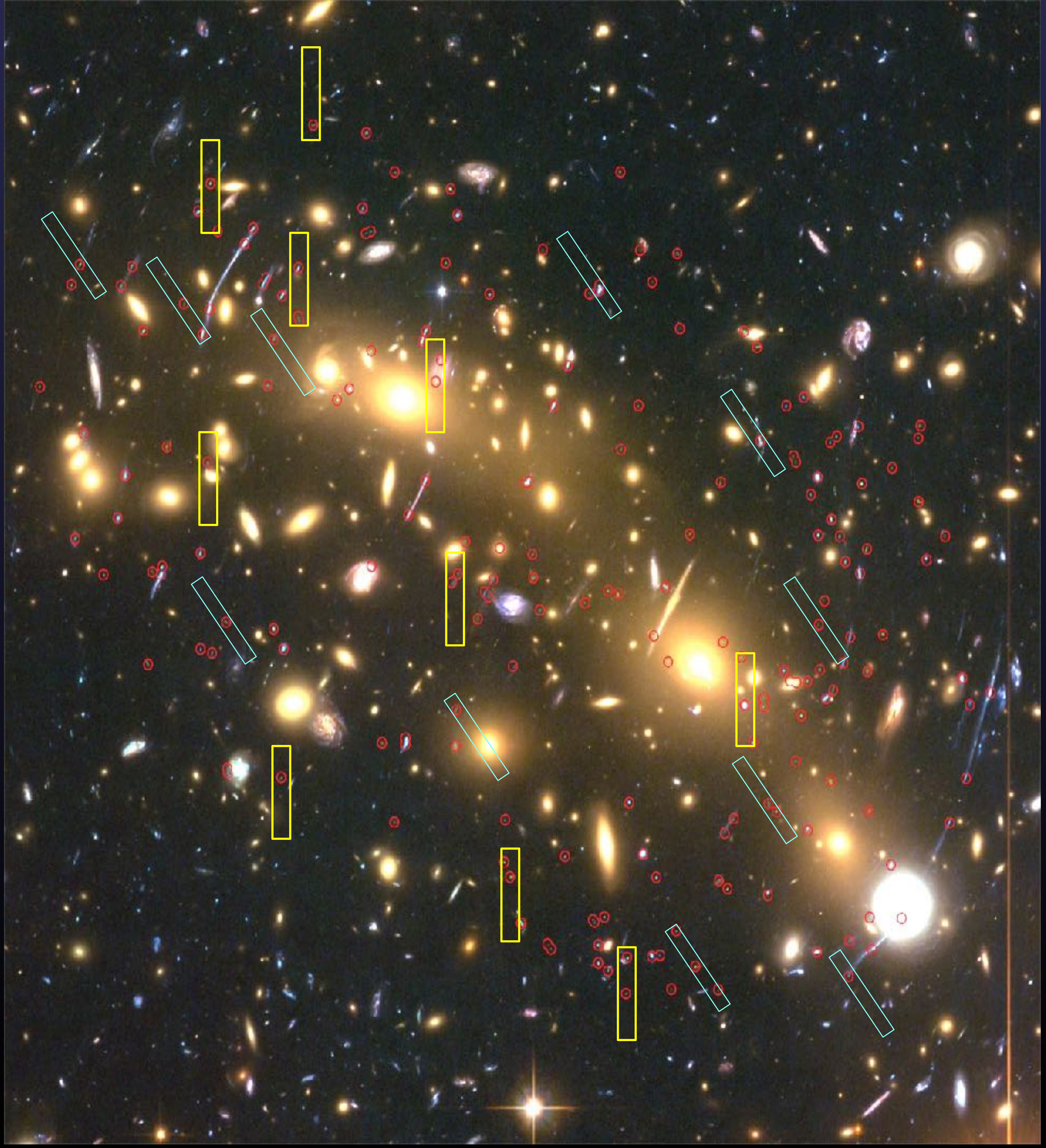
Mask 1



Multi-Object Spectroscopy

Mask 1

Mask 2

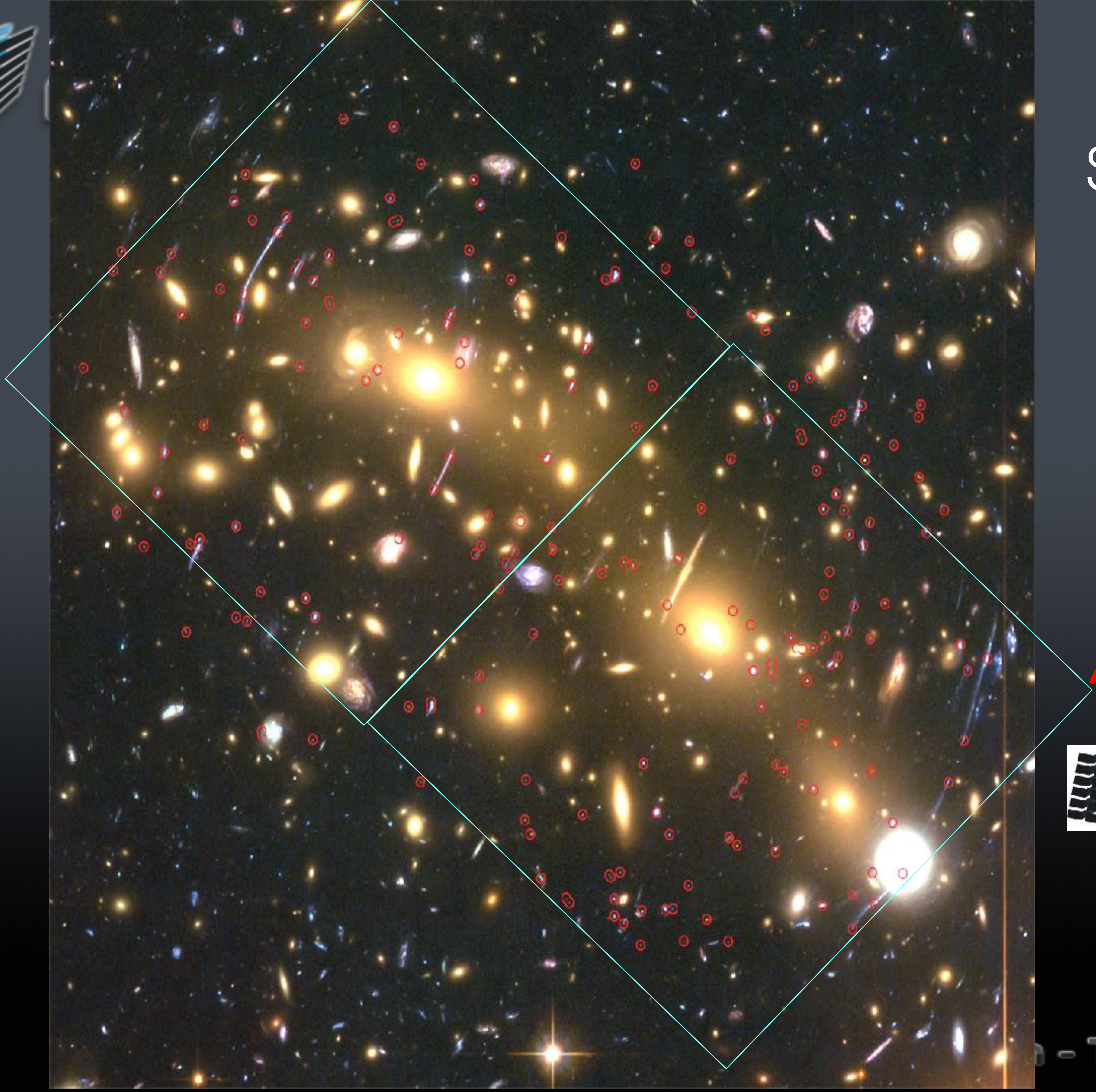


Multi-Object Spectroscopy

Mask 1

Mask 2

...

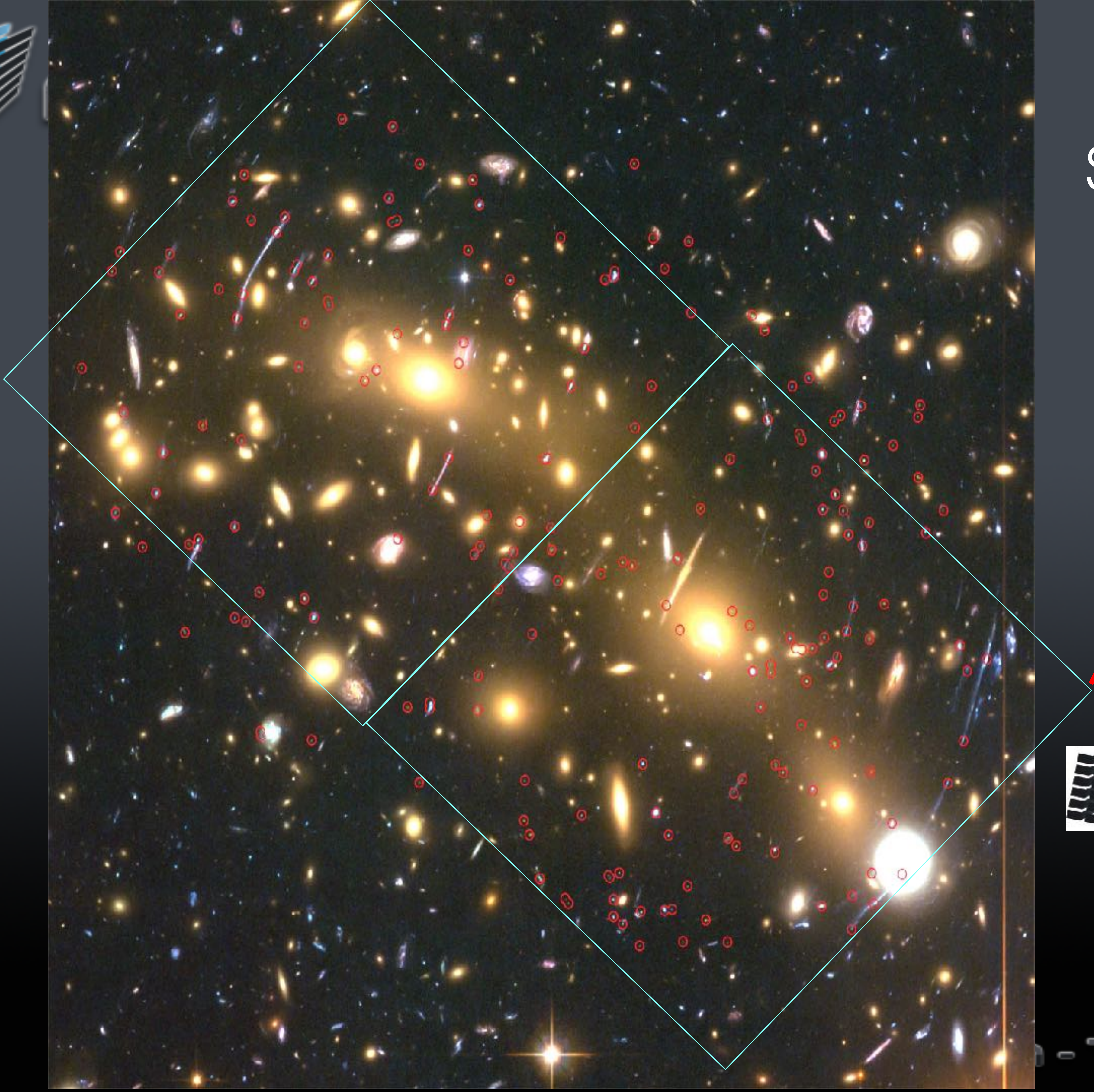


~~Multi-Object Spectroscopy~~

...

multi unit spectroscopic explorer

!!



~~Multi-Object Spectroscopy~~

~~Mask 1~~

~~Mask 2~~

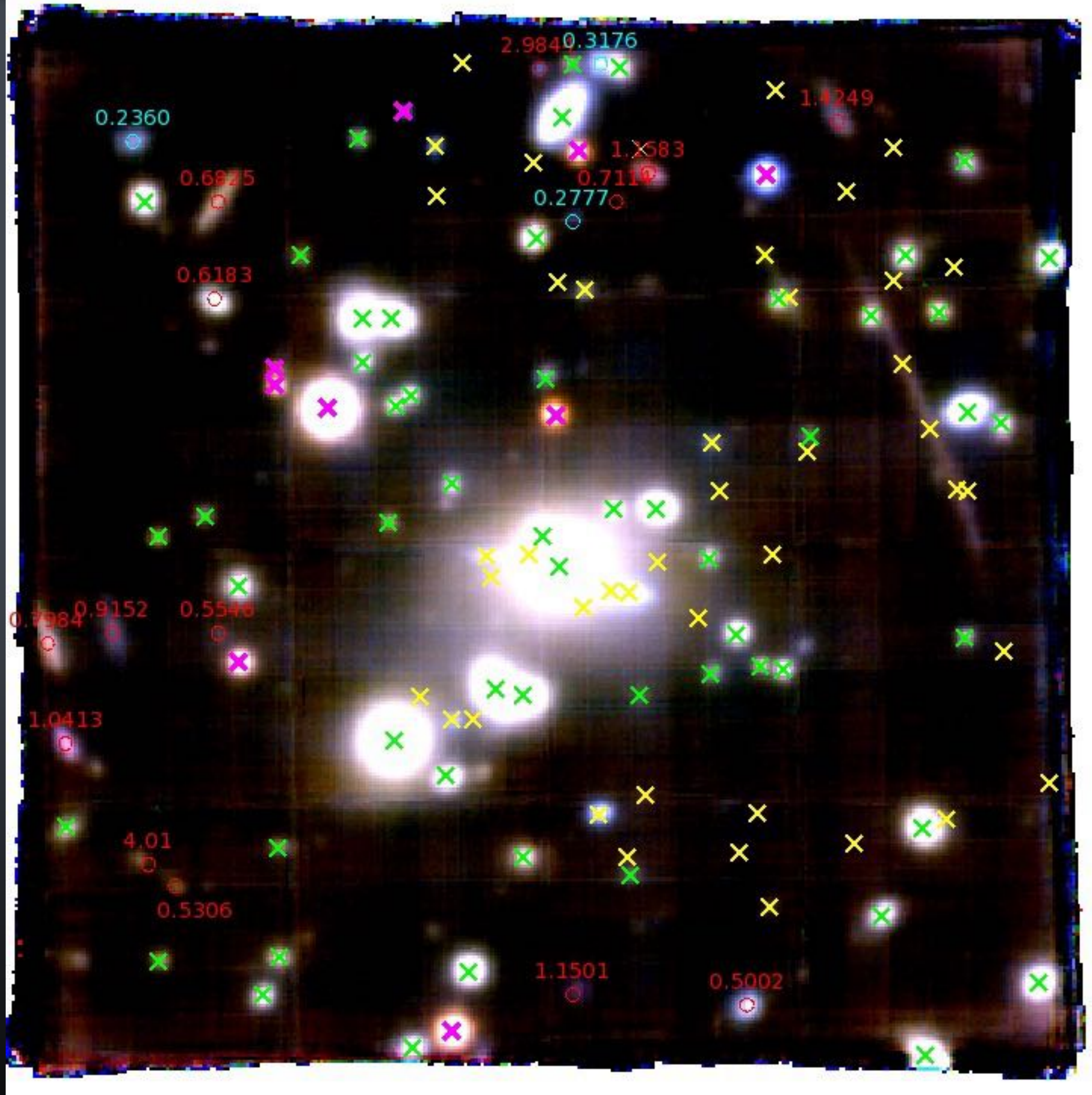
~~...~~

muse

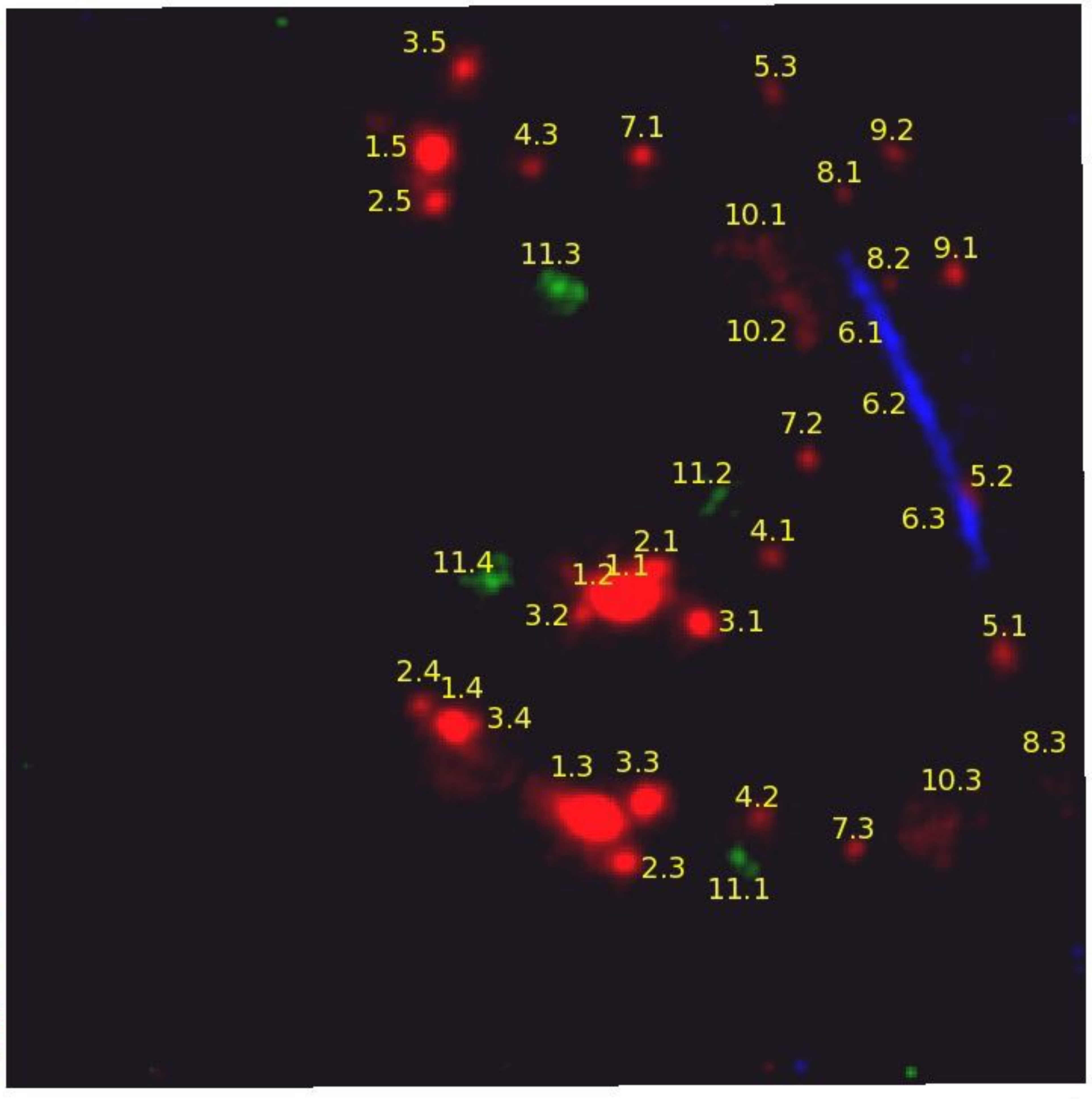
multi unit spectroscopic explorer

!!

muse



Continuum image



Emission line image for multiple systems

Lyα CIII] [OII]

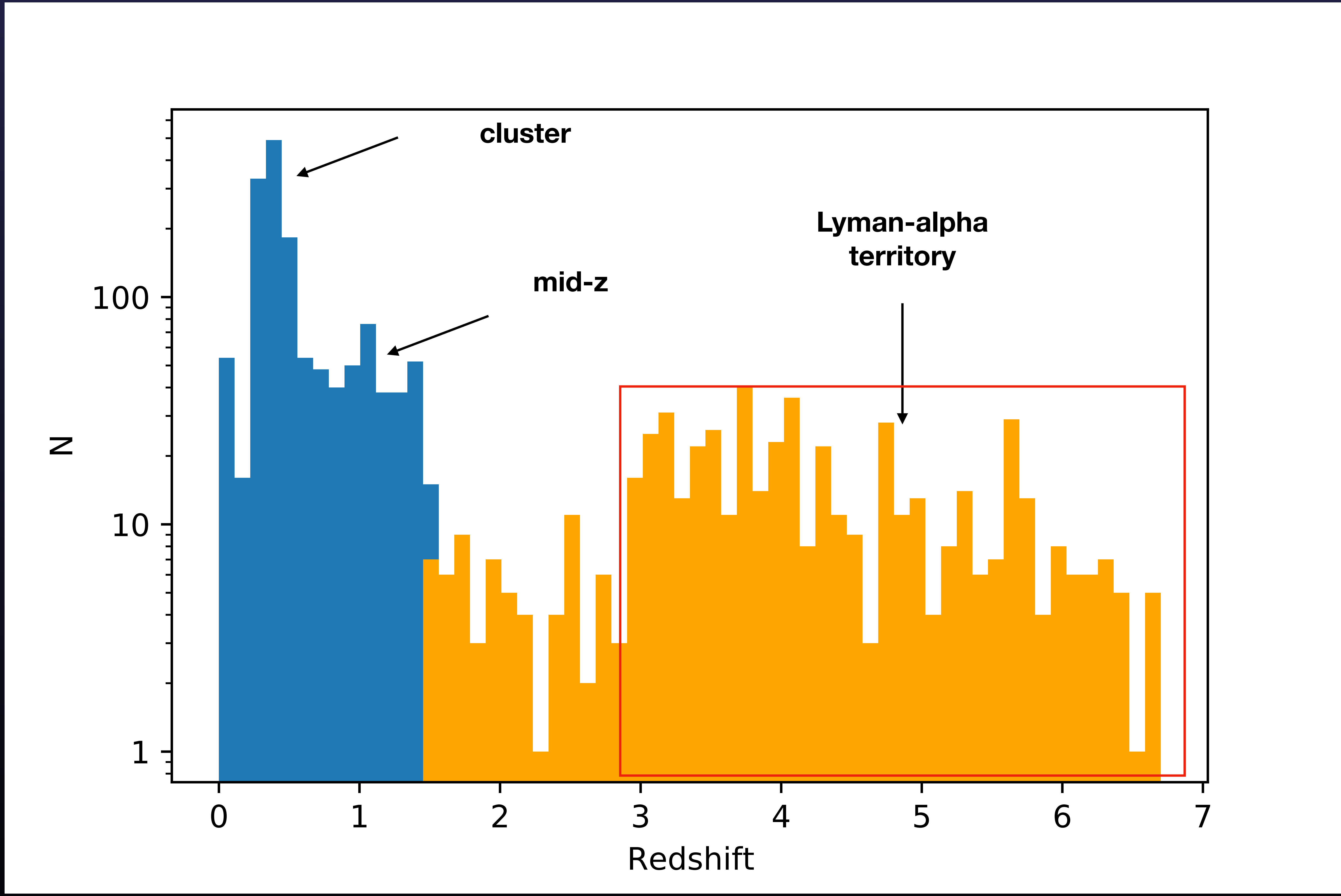
Objectives

- Detect and analyse sources in the field of a massive galaxy cluster
- Propose candidates for background sources being multiply imaged
- Build a cluster mass model based on these candidates to confirm them

Datasets:

- 1 MUSE cube
- 2 HST images for high resolution (and a bit of color)

MUSE redshift distribution behind a cluster



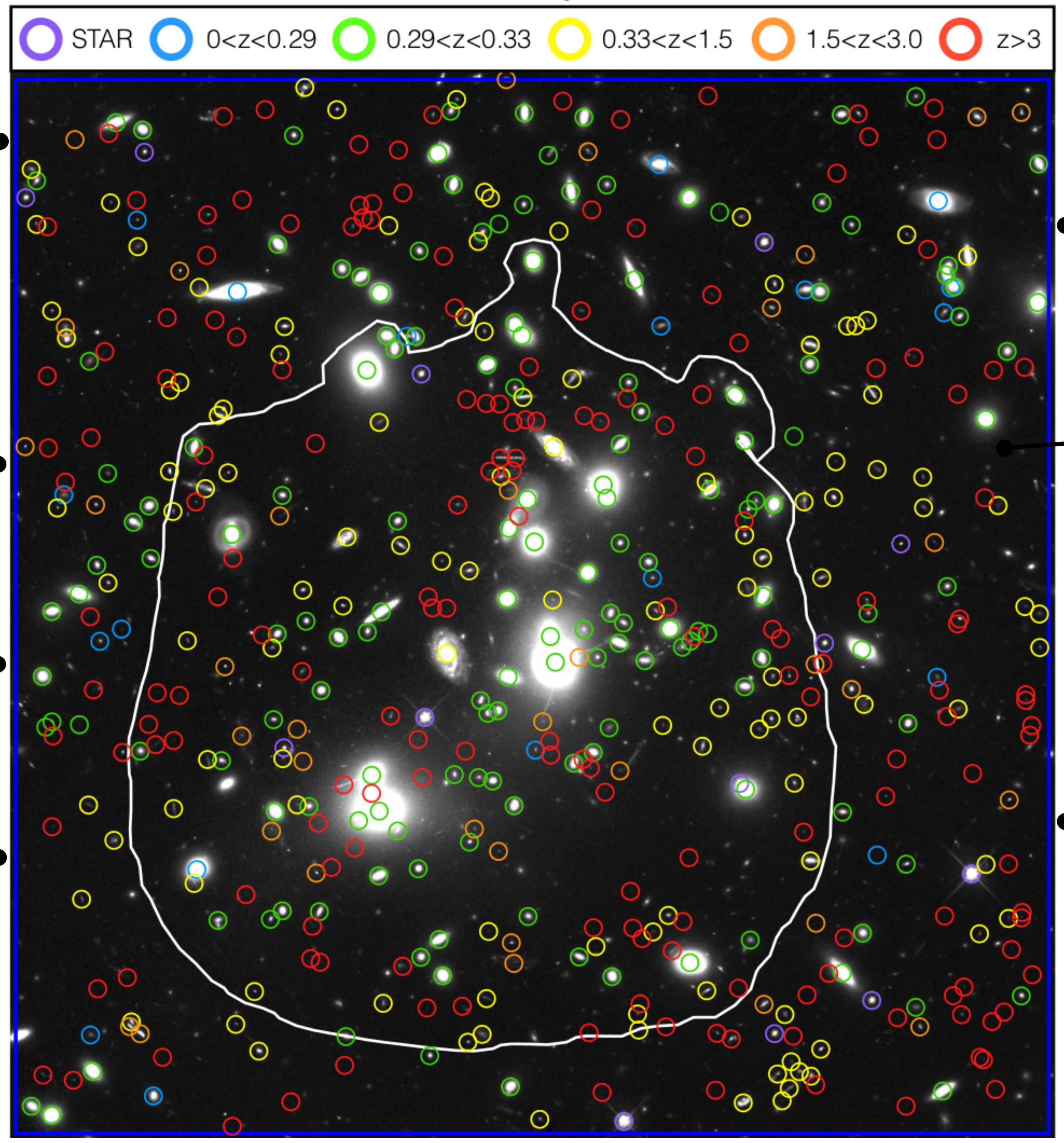
Through the lens with MUSE

Multiple images and lens model

Cluster core mass distribution

Resolved properties (arcs / arclets)

Velocity distribution of cluster members



Low mass intermediate redshift galaxies

Resolved properties of cluster members

Gas in the ICM / stripped galaxies

Low mass LAEs

Mahler et al. 2018

Through the lens with MUSE

Multiple images and lens model

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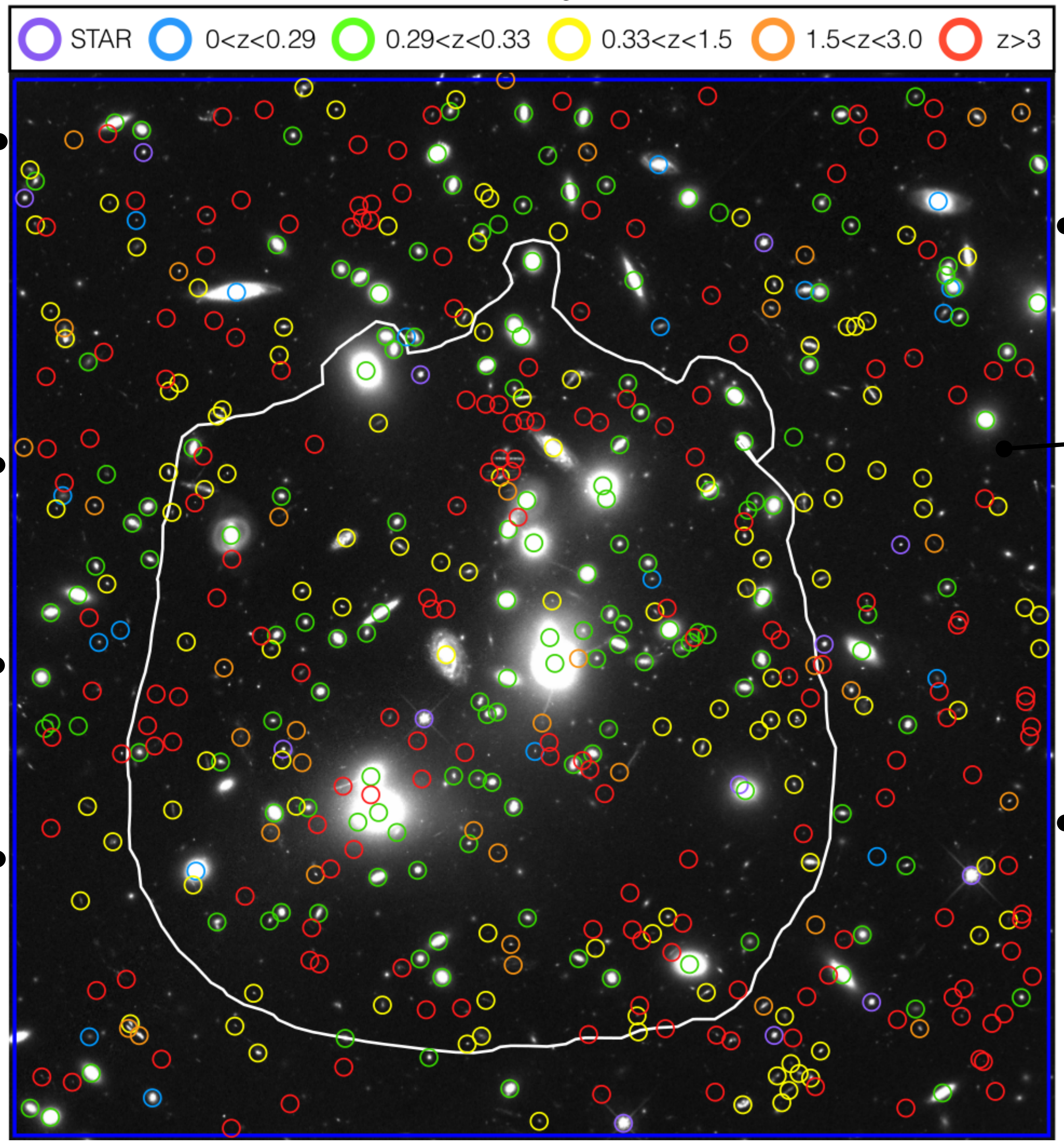
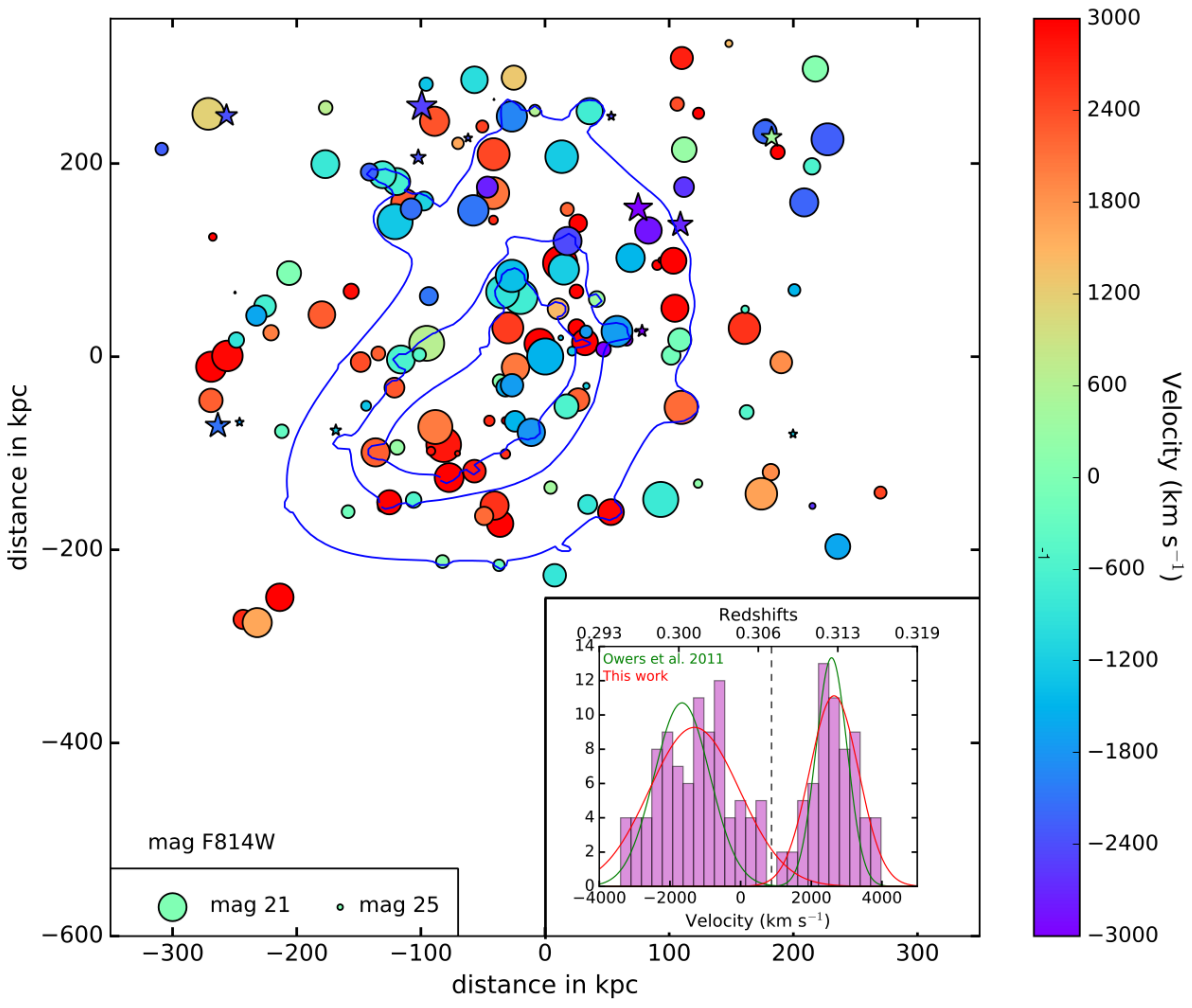
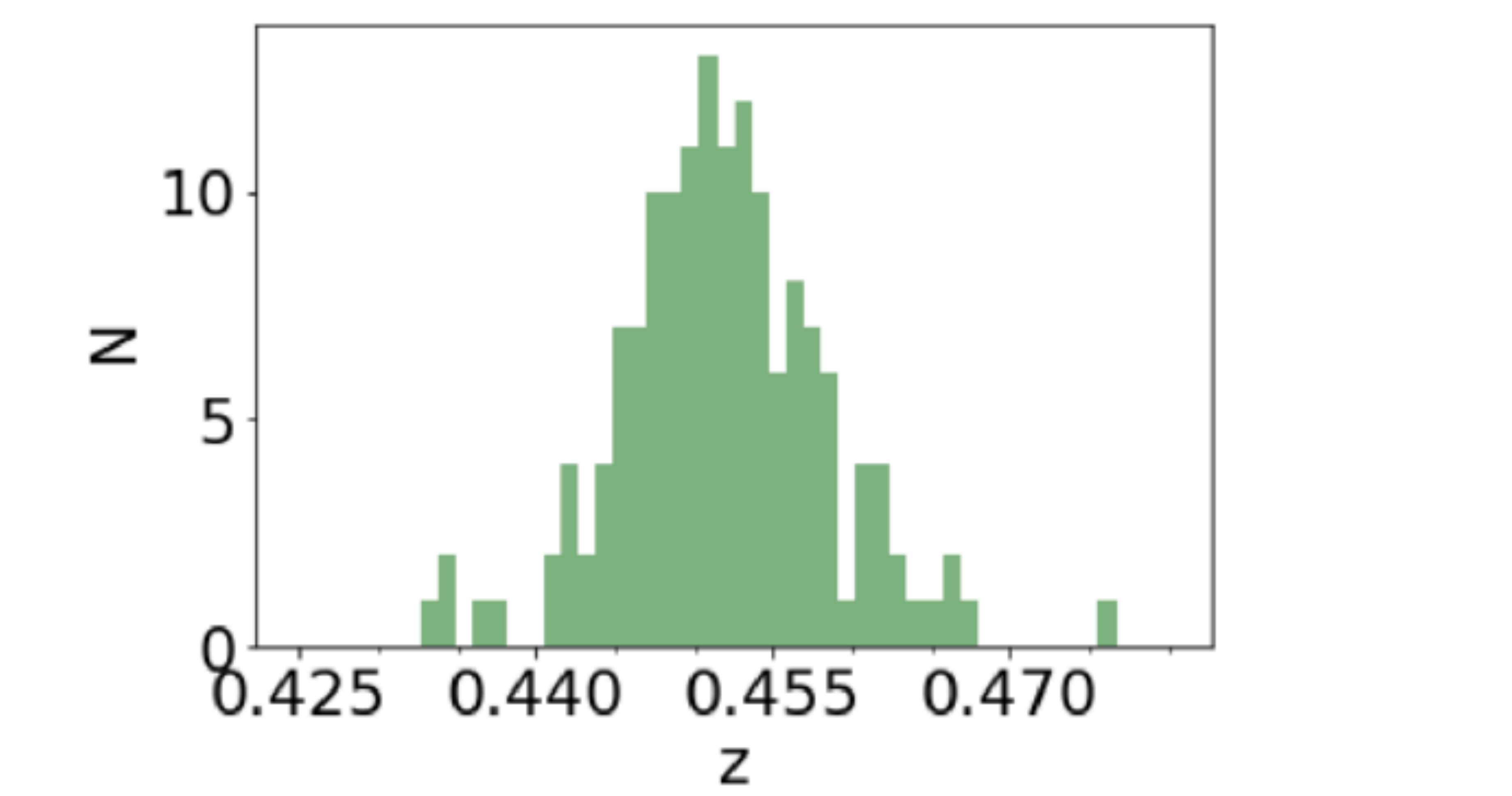


Mahler et al. 2018

Cluster spectroscopy



Mahler et al. 2018

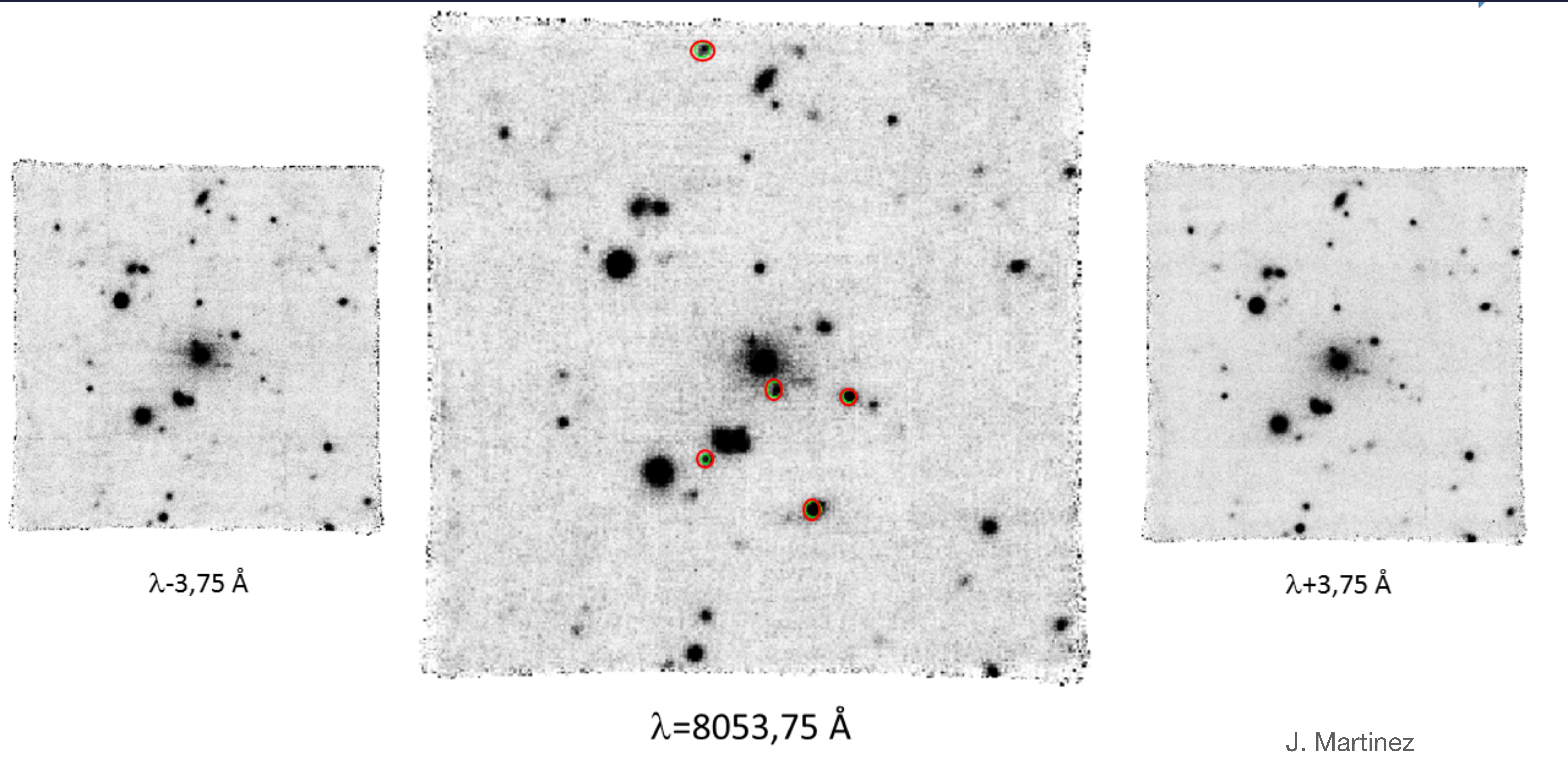


(ex. simple Gaussian)

Velocity $$v = c\,\frac{z - \bar{z}}{1 + \bar{z}}$$

Velocity Distribution $$\sigma_v = c\,\frac{\sigma_z}{1 + \bar{z}}$$

Lensed source identification: through emission lines



STEP 1: detect and classify sources in 3D dataset

> 100 spectra in a single MUSE cube

We are interested in background sources, which are typically seen thanks to emission lines.

- Line emission detector: Muselet
    - based on SExtractor: detect sources in an image
    - produces a “narrow-band” cube filtering continuum sources

Output catalog: individual line detections, grouping of lines
Redshift estimate: if multiple lines.

STEP 1: detect and classify sources in 3D dataset

- Install python mpdaf package (includes muselet)
https://mpdaf.readthedocs.io/en/latest/

muselet documentation:
https://mpdaf.readthedocs.io/en/latest/muselet.html

- Install SExtractor (for ex. in the same conda environment)
https://sextractor.readthedocs.io/en/latest/

STEP 1: detect and classify sources in 3D dataset

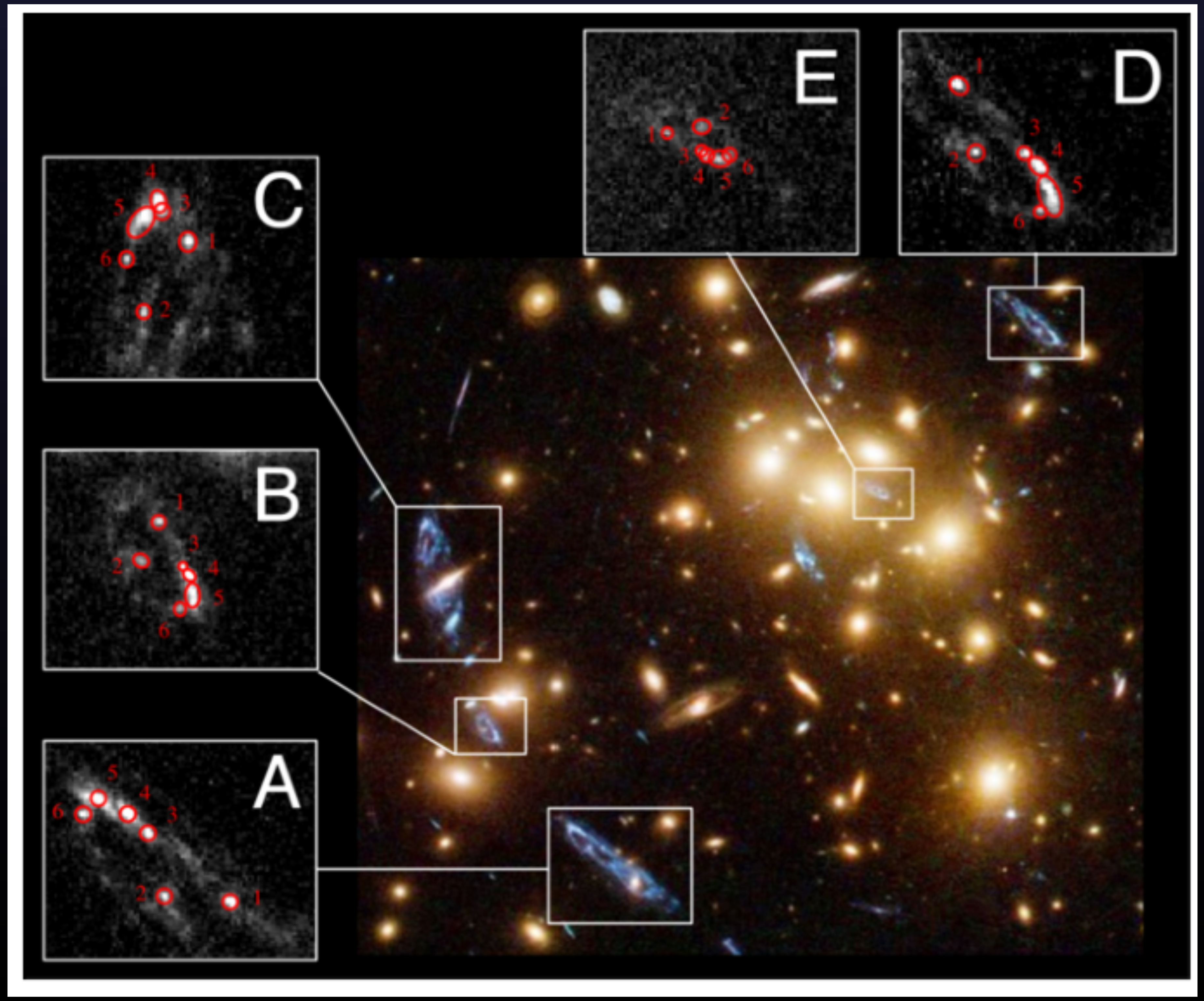
- Inpect line emitters !
  - Cube visualisation tool (ds9, Qfitsview)
  - Topcat (to review tables)
    https://www.star.bris.ac.uk/~mbt/topcat/
  - Extract and plot spectra to check lines

STEP 2: Identify multiple images

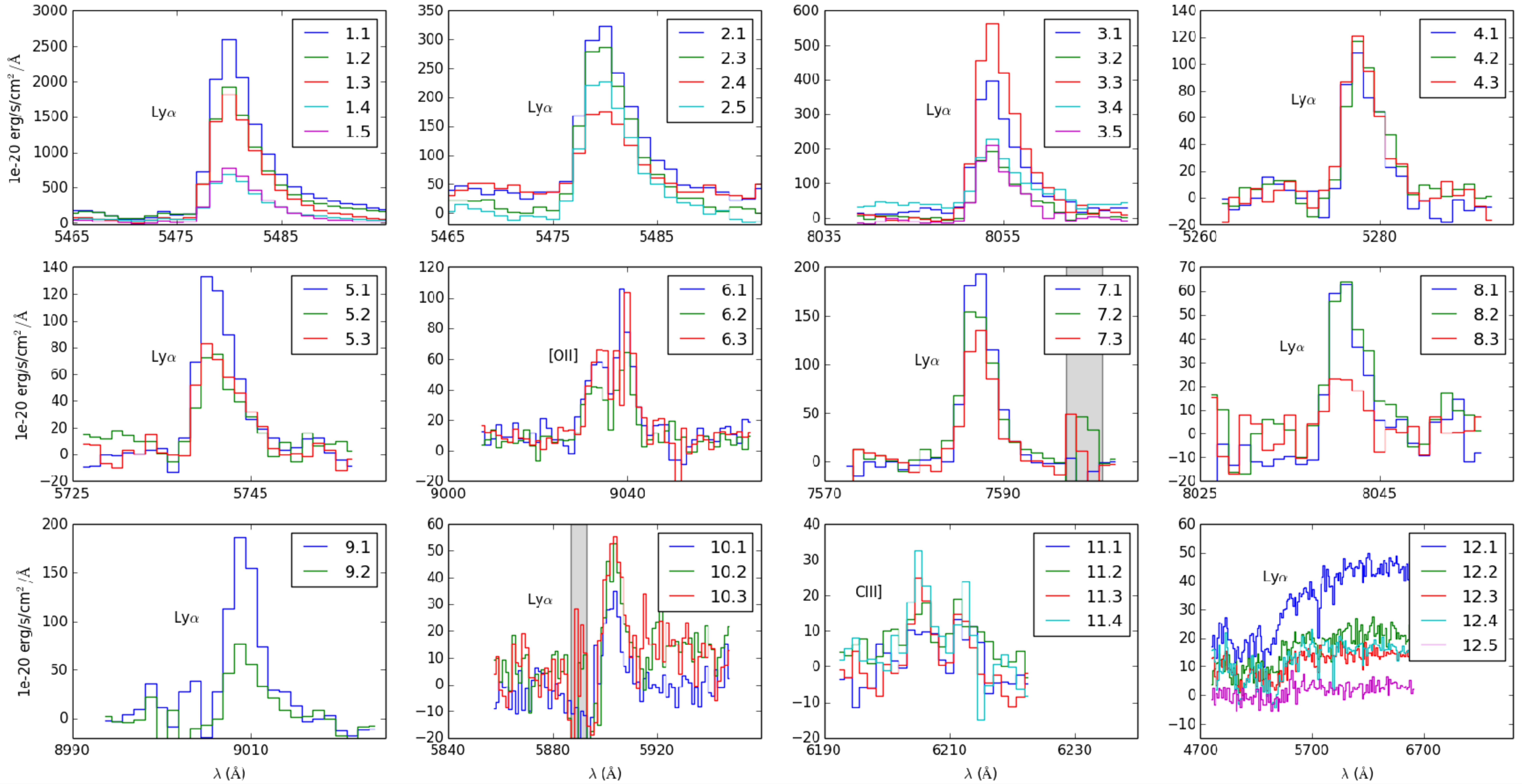
From the catalogue of background sources:

- review sources with similar redshift over the HST image

- rank candidate "systems" of multiple images according to the HST morphology (similar shape, same color)

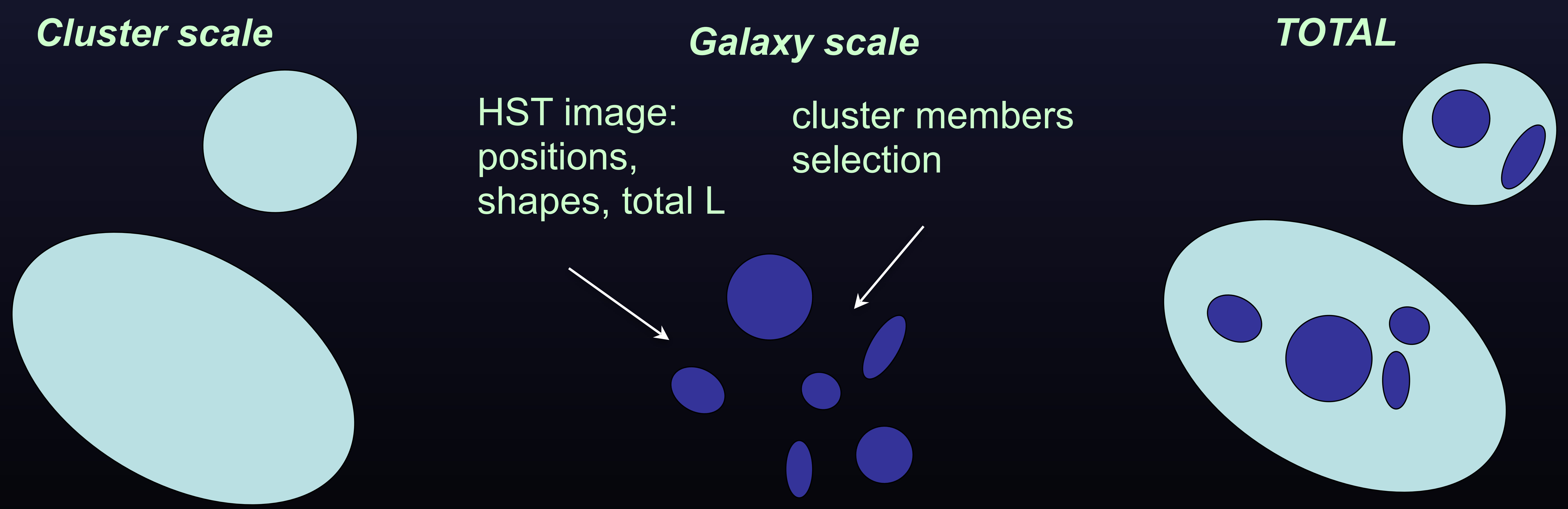


STEP 2: Identify multiple images



STEP 3: Build a mass model

- Parametric model: the mass distribution of the cluster is the superposition of N analytical models
- Use of the double pseudo-isothermal elliptical mass distribution (dPIE)



dPIE?

$$\rho(r) = \frac{\rho_0}{(1 + r^2/r_{\text{core}}^2)(1 + r^2/r_{\text{cut}}^2)}$$

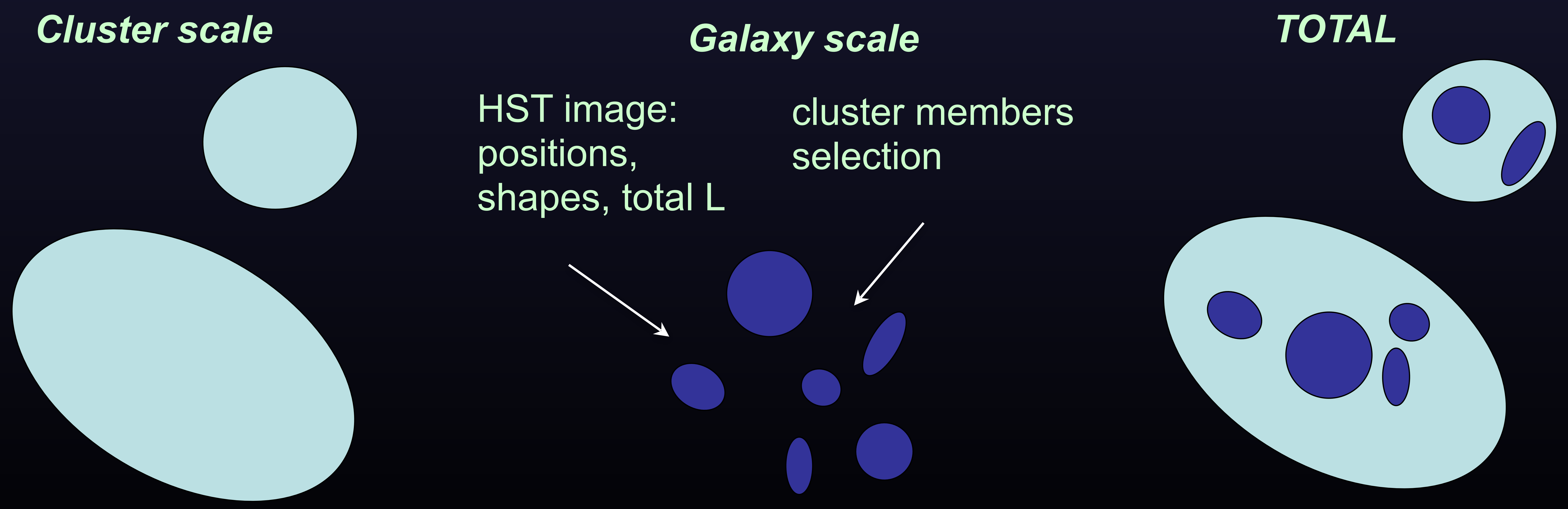
- Isothermal sphere: profile normalisation is linked with the velocity dispersion. σ_0
- double Pseudo-isothermal: two cut radii r_{core} and r_{cut}
- Central position α_0, δ_0
- Elliptical: ellipticity e, position angle θ

Total: 7 parameters per mass distribution!

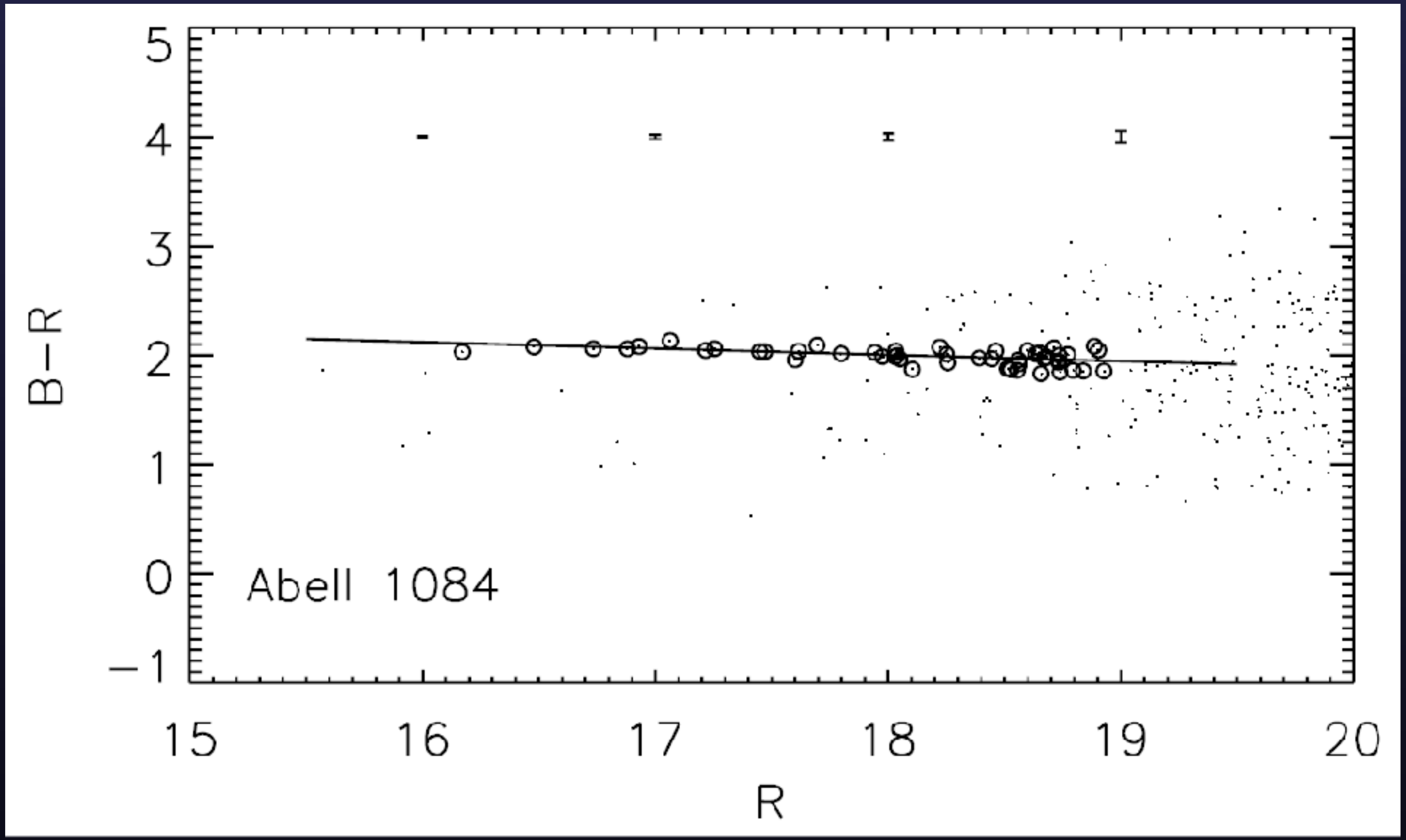
STEP 3: Build a mass model

- Assumptions (only for galaxy scale mass distribution):
- Light traces mass: we fix α_0, δ_0, e, θ from HST
- Other dPIE parameters are assumed to scale with luminosity (from HST)

$$r_{\rm core} = 0.15{\rm kpc},\ r_{\rm cut} = r^*_{\rm cut}\left(\frac{L}{L^*}\right)^{1/2},\ \sigma_0 = \sigma^*_0\left(\frac{L}{L^*}\right)^{1/4}$$



STEP 3a: Create a catalogue of cluster members



- Run SExtractor over HST images to obtain V and I band photometry
- Produce a color - magnitude diagram
- Identify the red sequence for cluster membership
- Record the shape parameters and magnitude of each galaxy.

Tip: visually inspect MUSE spectra to cross-check cluster membership !

STEP 3b: Optimise model parameters

- Use Lenstool to run an optimisation of the mass model (example parameter file provided).

https://projets.lam.fr/projects/lenstool/wiki/

$$\chi^2 = \sum_{i,j} \frac{\left\| \boldsymbol{\theta}_{obs}^{(i,j)} - \boldsymbol{\theta}_{pred}^{(i,j)} \right\|^2}{\sigma_{pos}^2}$$

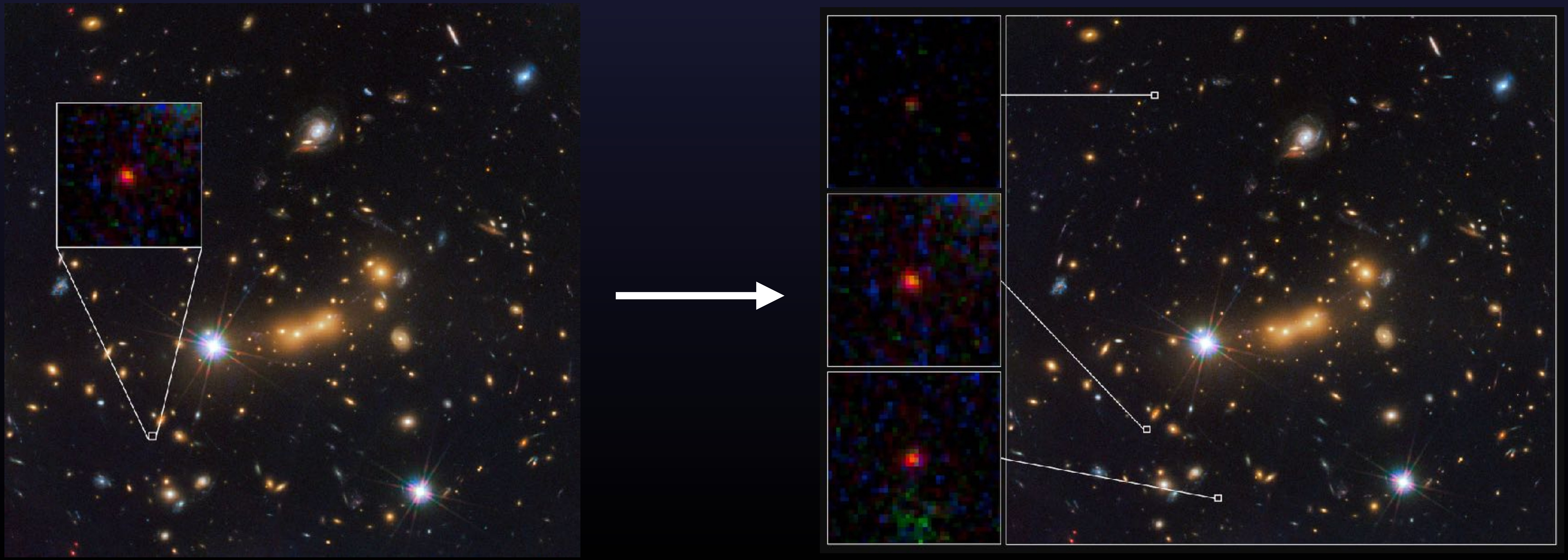
- Only use the highest priority candidates, the one you trust, at first.

- If everything goes well, obtain a small chi2

STEP 4: Rinse and repeat

- Use Lenstool to <u>predict</u> the counterimages from other candidate systems

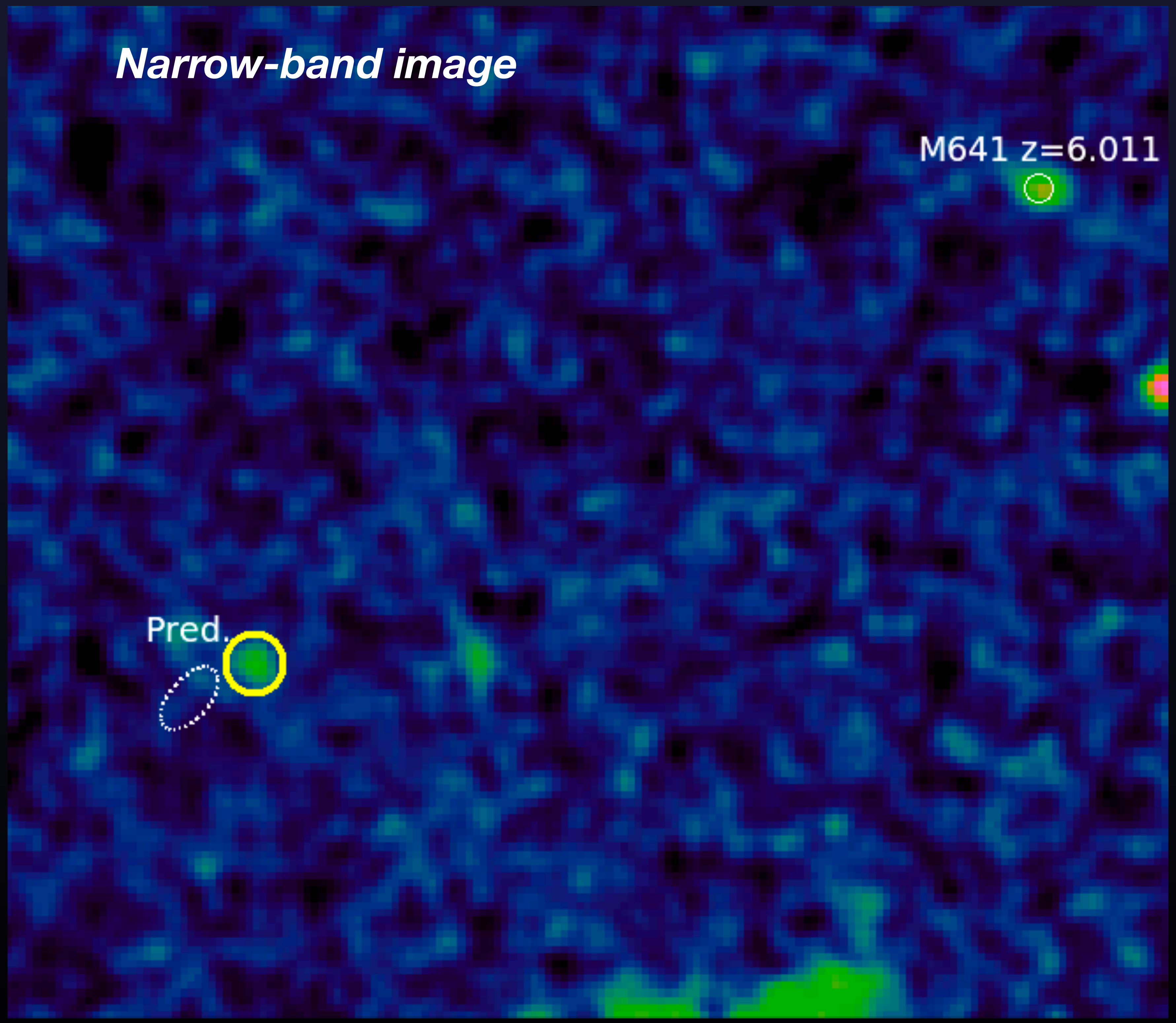
- If it roughly works, use these systems as new constraints for an improved model.



STEP 4: Rince and repeat

- Use Lenstool to predict the counterimages from other candidate systems

- If it roughly works, use these systems as new constraints for an improved model.
- If it does not work, be critical about the redshift OR the lens model.



Use the lens model for physical interpretation

- Make predictions for multiple images
- Compute local magnification
- Compare the σ from the cluster scale mass distribution with the one from the dynamics (MUSE redshifts)

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