# MAximum-entropy ReconStruction (MARS)

## : A New Strong-lensing Reconstruction Algorithm for the JWST Era

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### I. What is the MARS algorithm?

The MARS algorithm is a grid-based, free-form strong-lensing (SL) mass reconstruction method. By employing maximumentropy regularization, MARS can achieve high-fidelity mass reconstruction, converging multiple images with negligible scatters, suppressing small-scale spurious fluctuations, and providing a quasi-unique solution that is independent of the initial prior. Furthermore, MARS is capable of incorporating weak-lensing (WL) data, enabling a robust SL + WL lens modeling in the same reconstruction run. The objective function to be minimized in our approach is as follows:

$$f = m\chi_{SL}^2 + w\chi_{WL}^2 + rR$$

1)  $\chi^2$  minimization of SL

$$\chi_{SL}^2 = \Sigma \frac{\left( (\boldsymbol{\theta} - \boldsymbol{\alpha}) - \boldsymbol{\beta} \right)^2}{\sigma^2}$$

 $\theta$ : location of multiple images  $\alpha$ : deflection angle of images  $\beta$ : position of the source  $\sigma$ : scatters on the source plane

### (2) $\chi^2$ minimization of WL

$$\chi_{WL}^2 = \Sigma \frac{\left(\boldsymbol{g}_{pre} - \boldsymbol{g}_{obs}\right)^2}{\sigma_s^2 + \sigma_m^2}$$

 $g_{pre}$ : model reduced shear gobs: observed reduced shear  $\sigma_S$ : intrinsic shape dispersion  $\sigma_m$ : measurement errors

### (3) Entropy-regularized

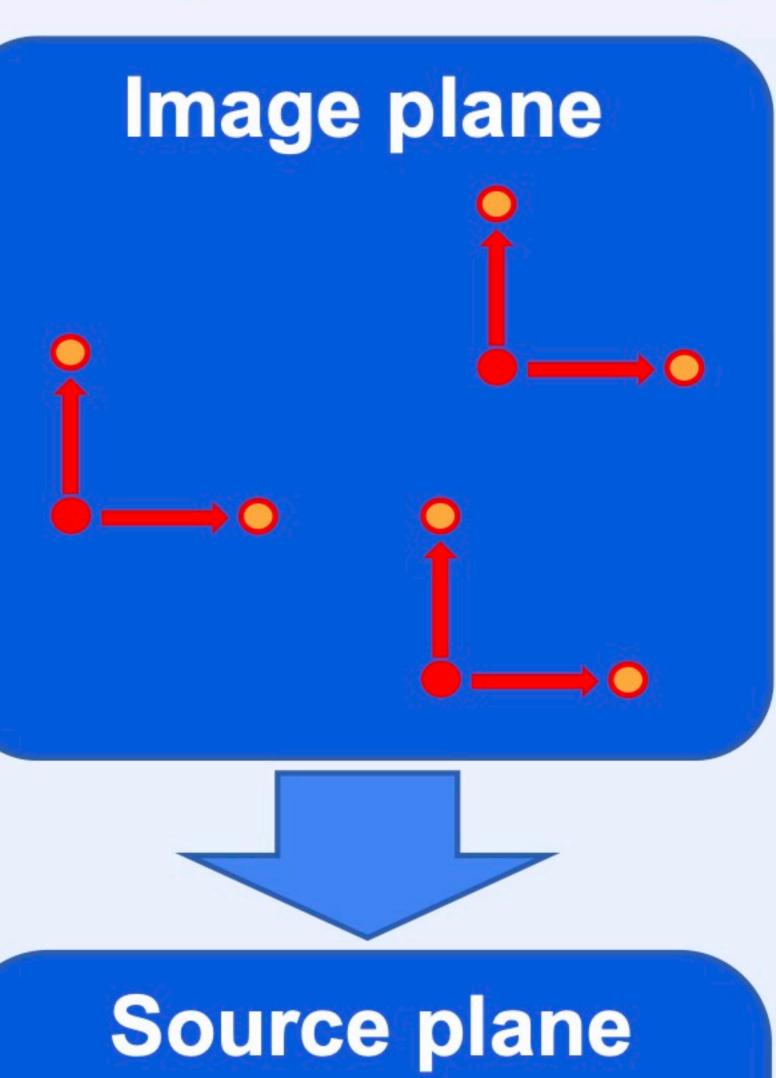
$$R = \Sigma(p - \kappa + \kappa \ln \frac{\kappa}{p})$$

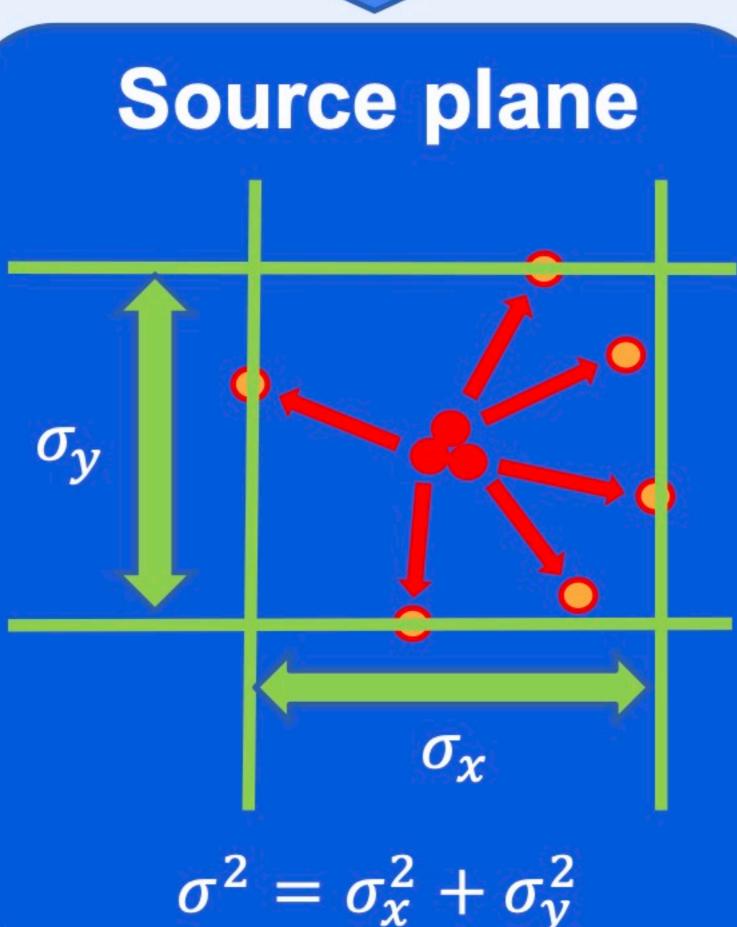
p: prior from previous iteration  $\kappa$ : convergence

# For more details,

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# Multiple images Drange: images w/ spec z Cyan: images w/o spec z

### II. Application to real galaxy clusters: HFF clusters

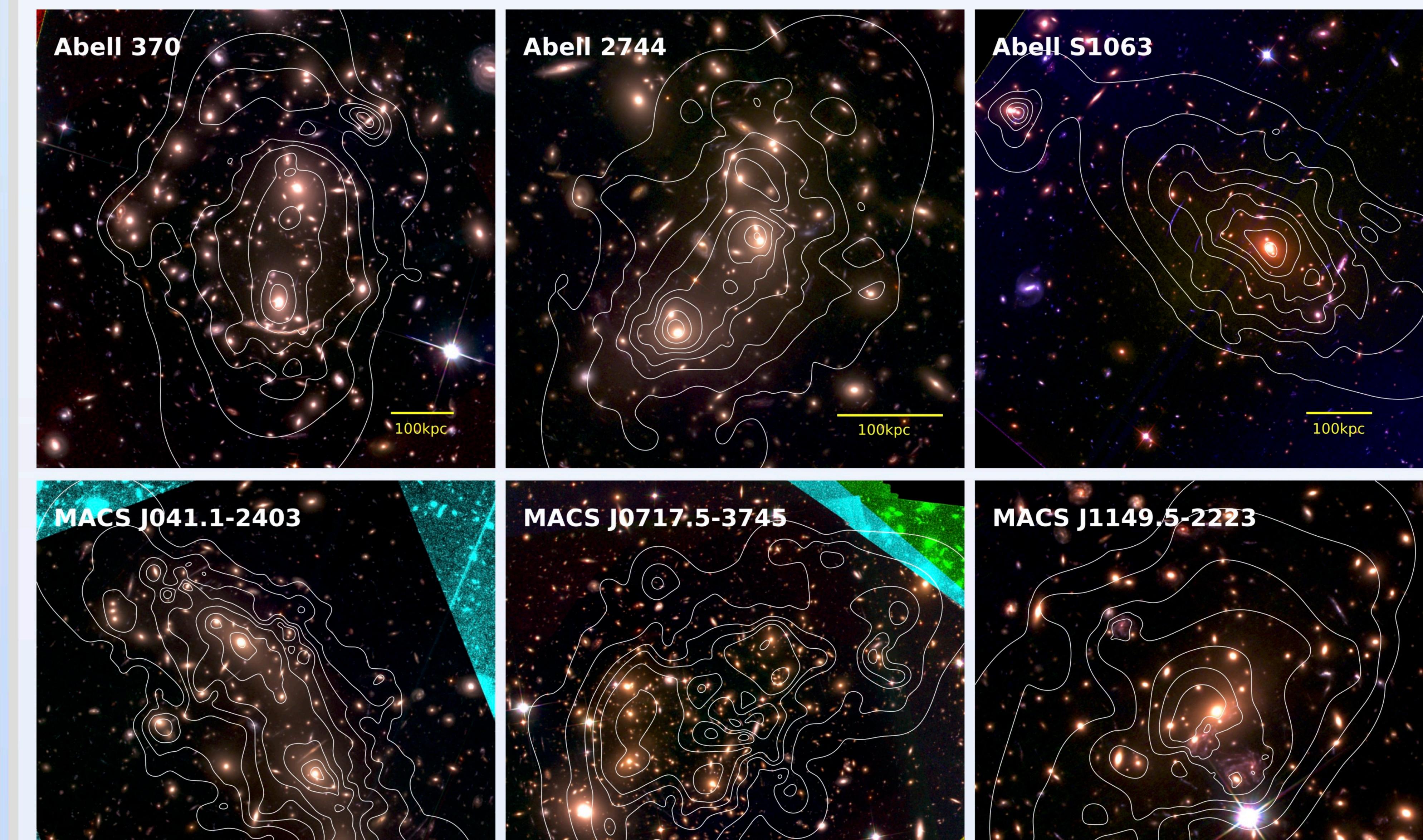
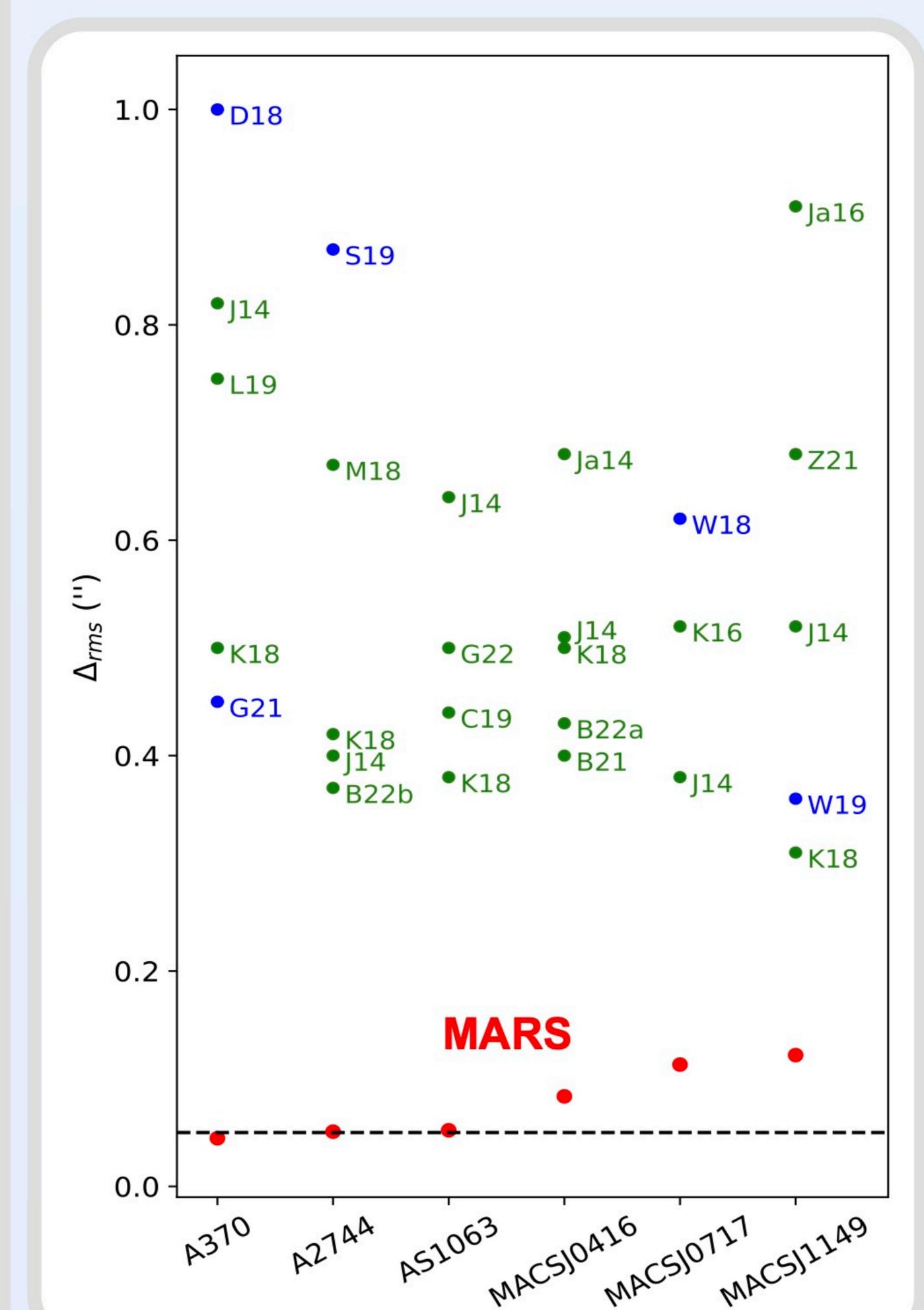


Fig1. Reconstructed mass contours of the 6 HFF clusters from the MARS algorithm.



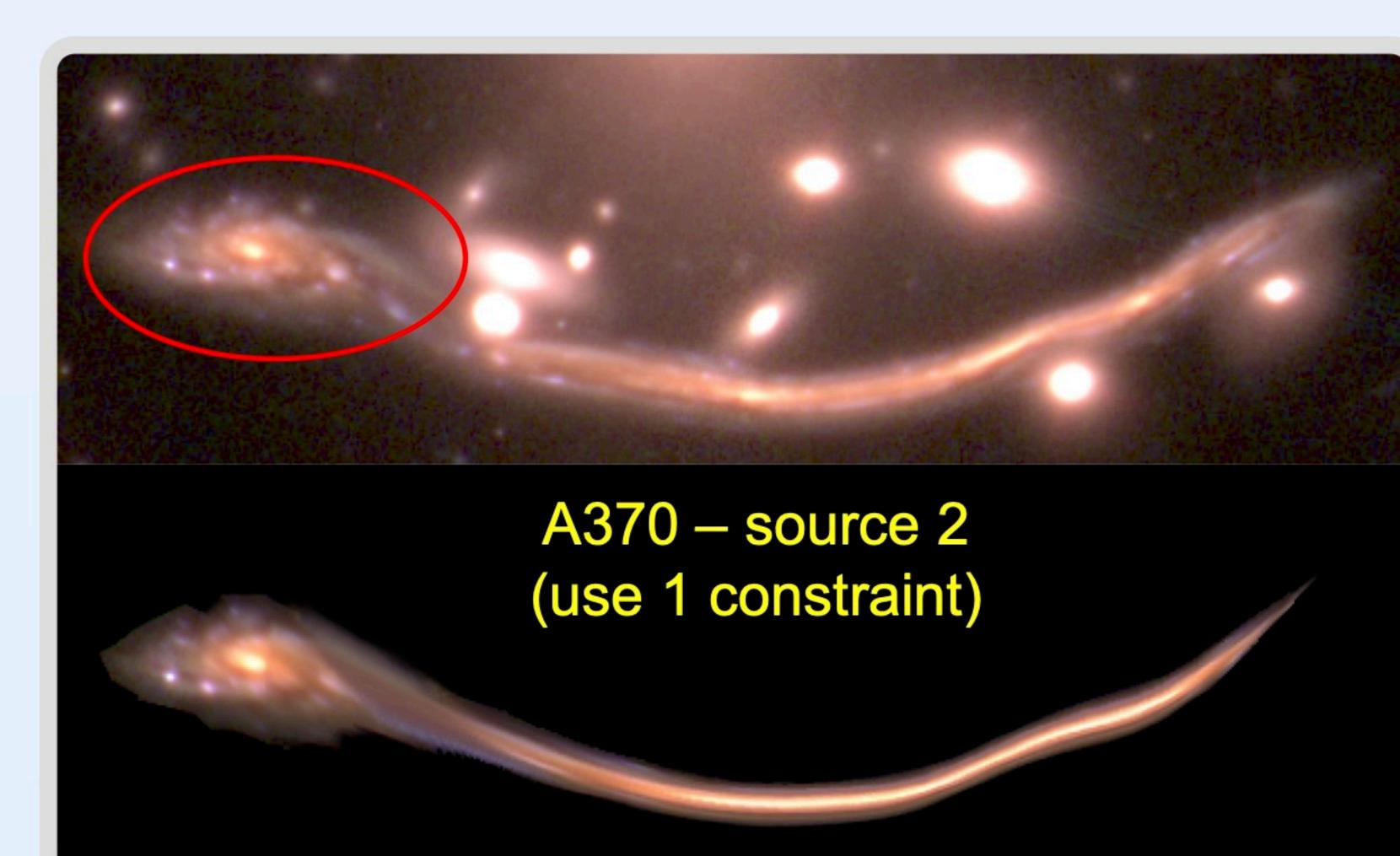
Even though we don't utilize the location information of galaxies, the mass maps from MARS show good agreement with the distributions of the cluster galaxies. The most noticeable case is the mass model of MACSJ0416, which has an RMS value of 0."084 using the 236 multiple images.

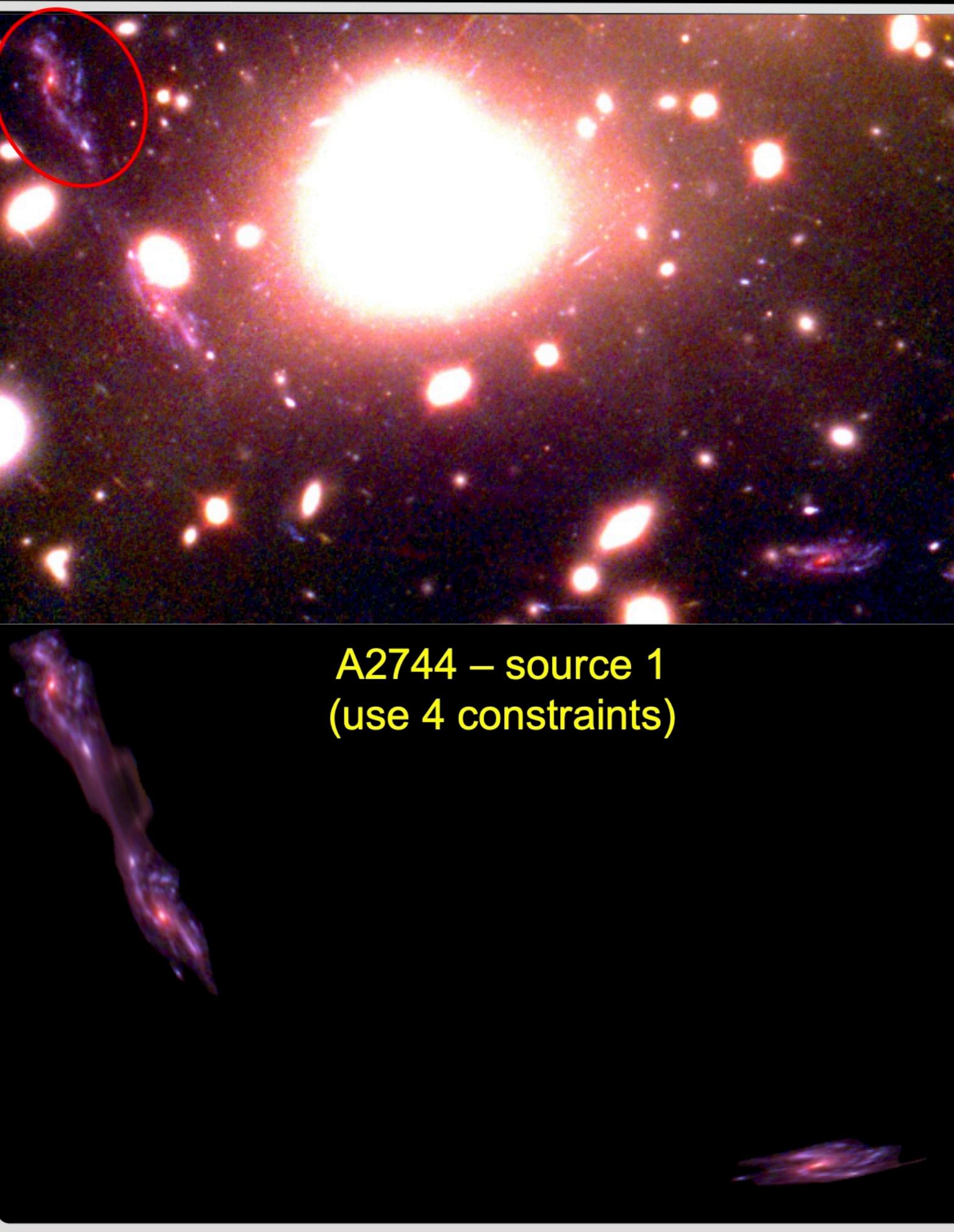
Image plane Fig2. scatter RMS comparison between MARS and the literature. The blue (green) dots present the RMS from the free-form (parametric) results. The red dots show the results from MARS. black dashed line represents an RMS value of 0."05.

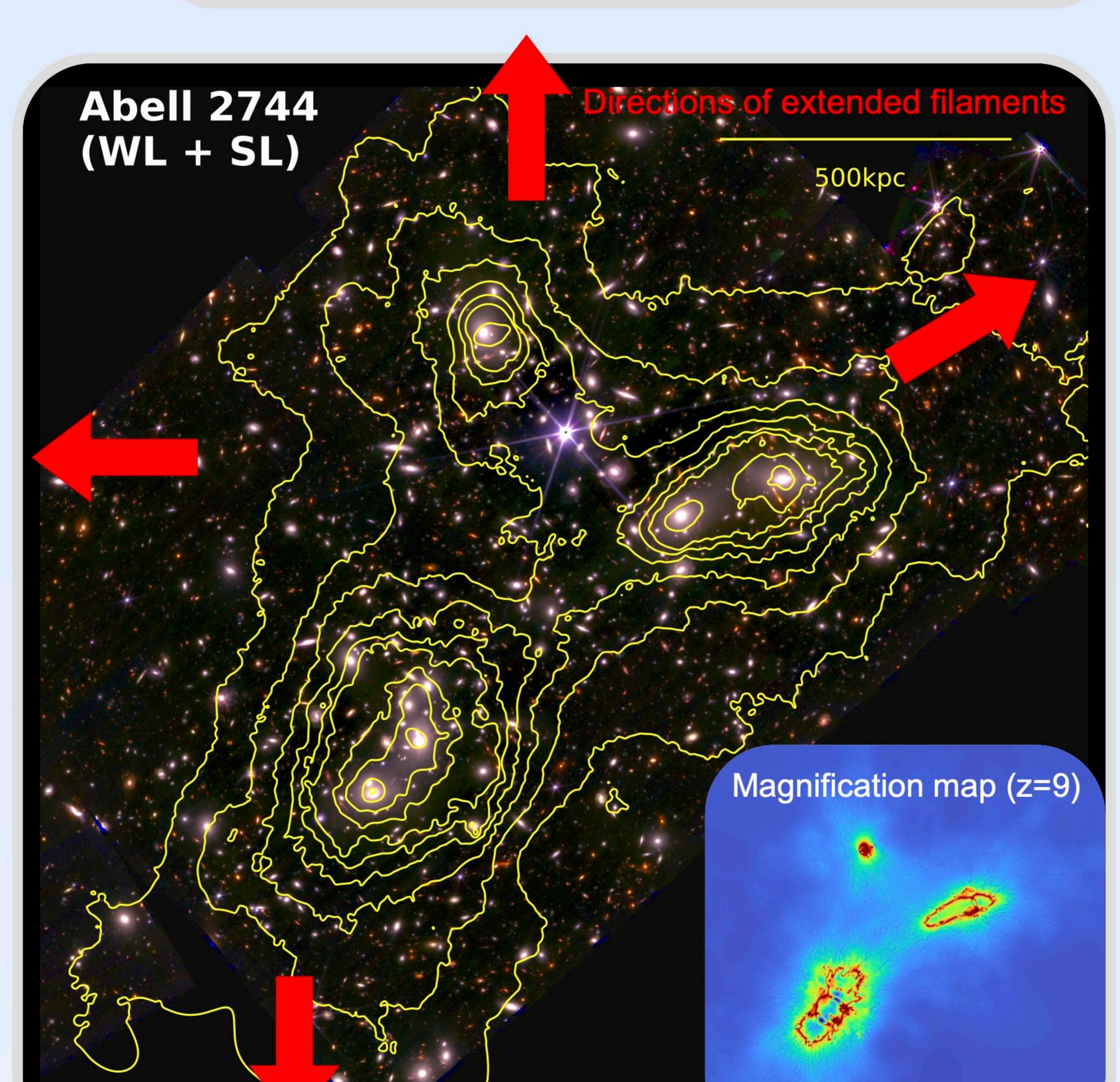
→ Fig3. Lens-plane image reconstructions. The red circles mark the images selected for reconstruction. The dimensions of panels have been matched between the observed and predicted images.

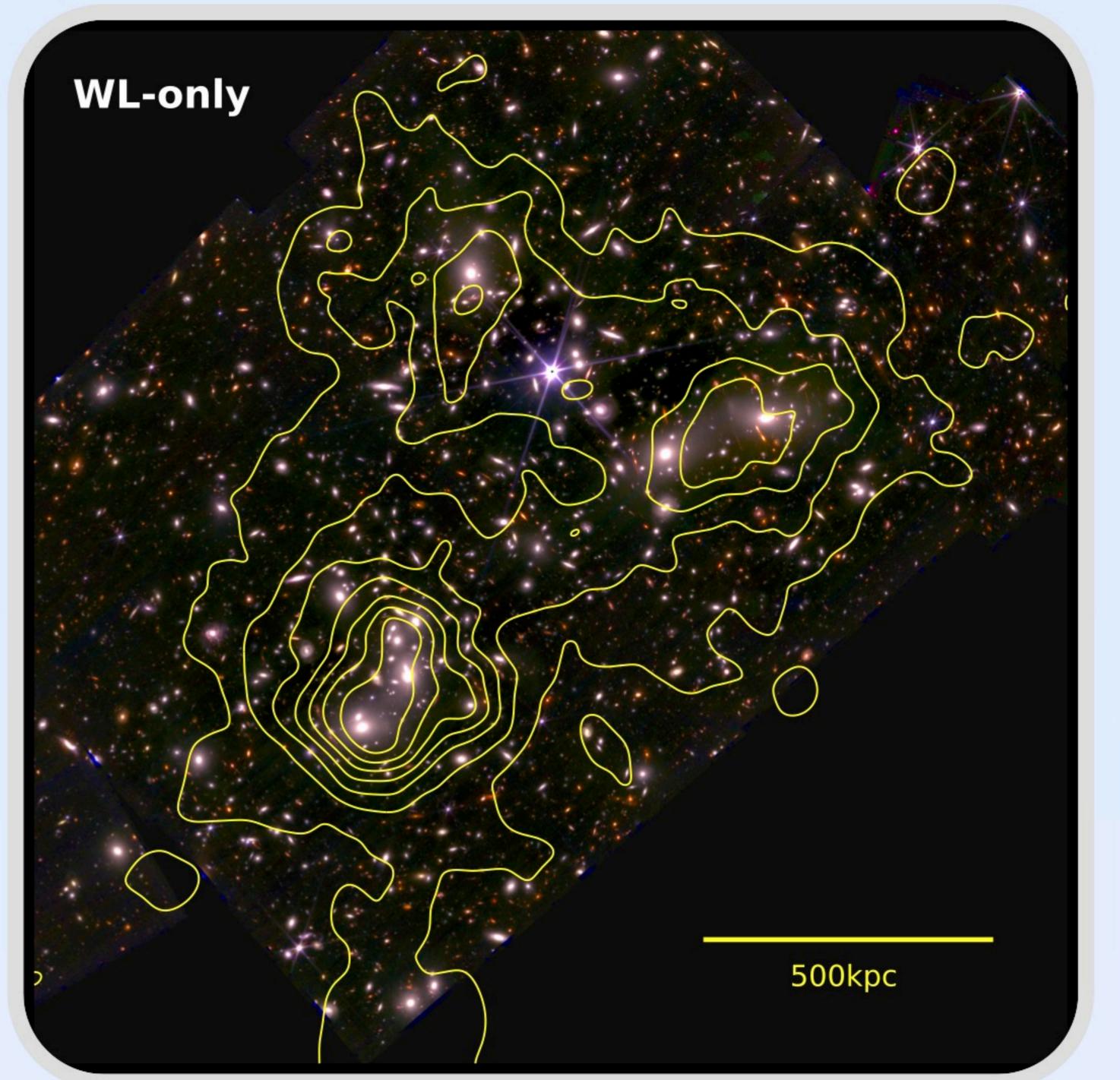


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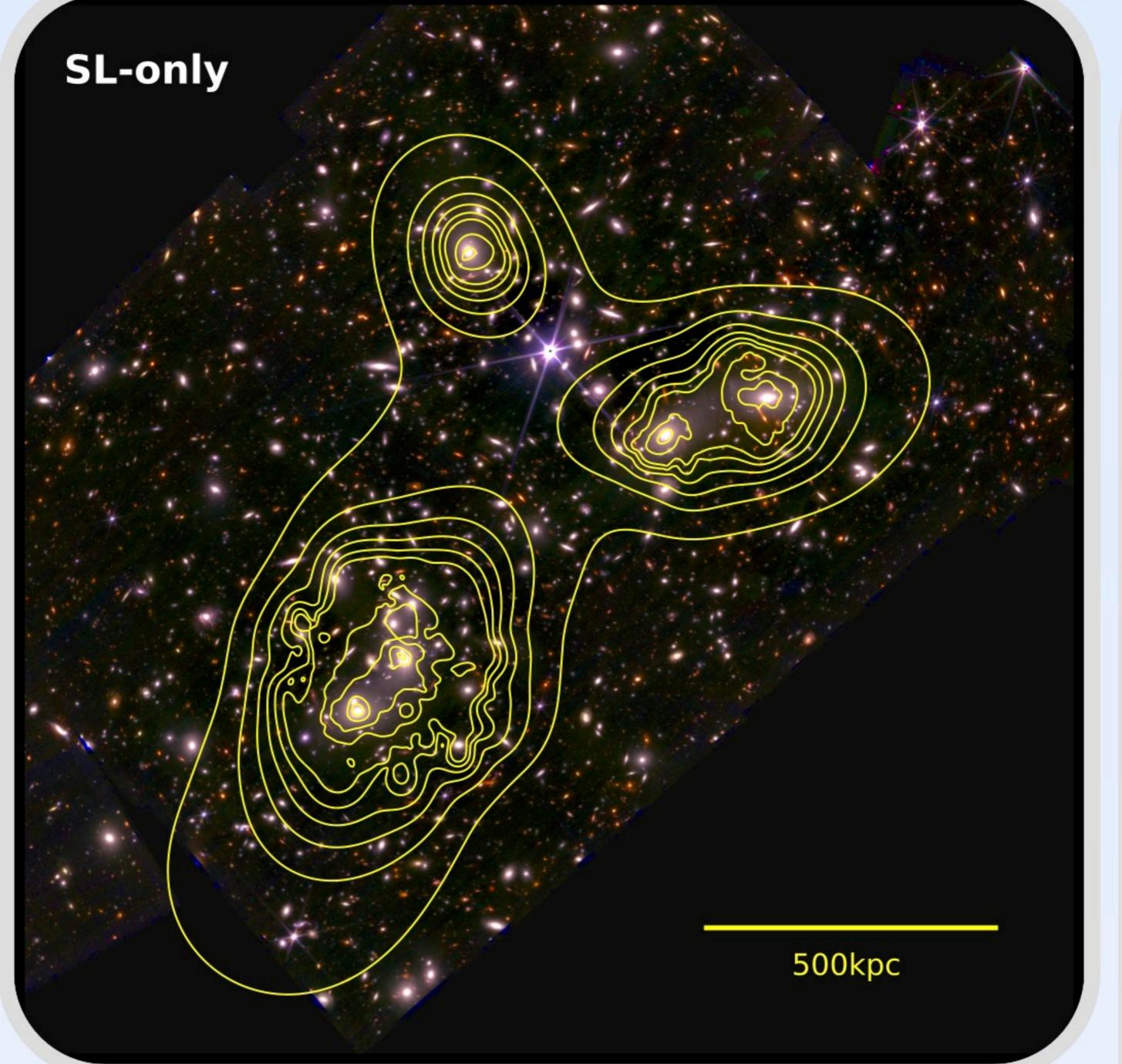


WL: constrains the outskirts

SL: constrains the central regions

Fig5. Reconstructed mass contours of A2744 using WL data-only (top), SL dataonly (right), and both WL and SL data (left). The FOV is 400"×400". The red arrows indicate the directions of extended filaments observed in the X-ray hot gas.

Thanks to the high-quality JWST images, we can utilize the largest dataset, including 286 SL multiple images and ~ 200 arcmin<sup>-2</sup> WL constraints, for lens modeling of A2744. Since MARS is the free-form algorithm, we can obtain mass distributions by solely considering the observed data without requiring any assumptions such as specific profiles or the number (or locations) of cluster member galaxies.



#### References

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