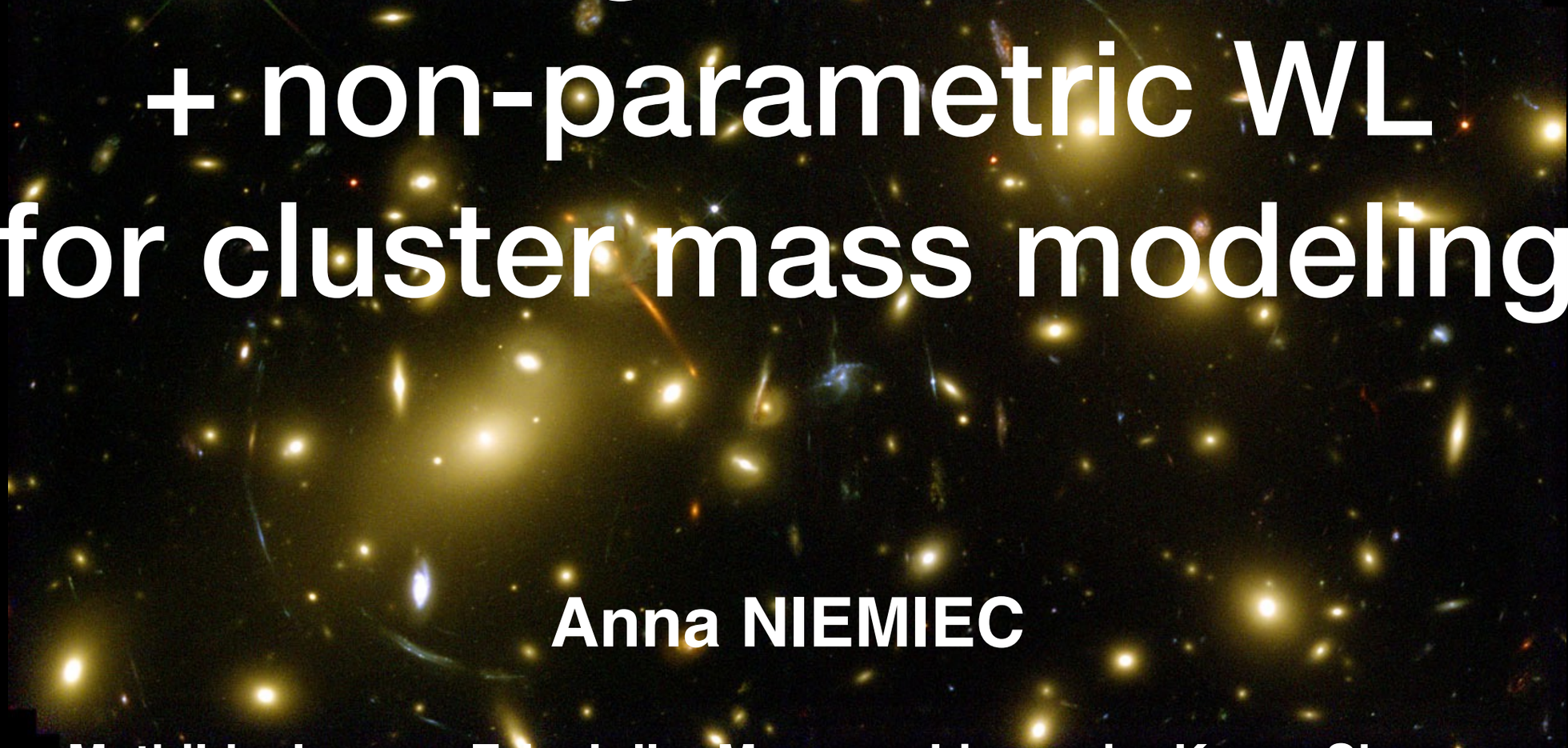
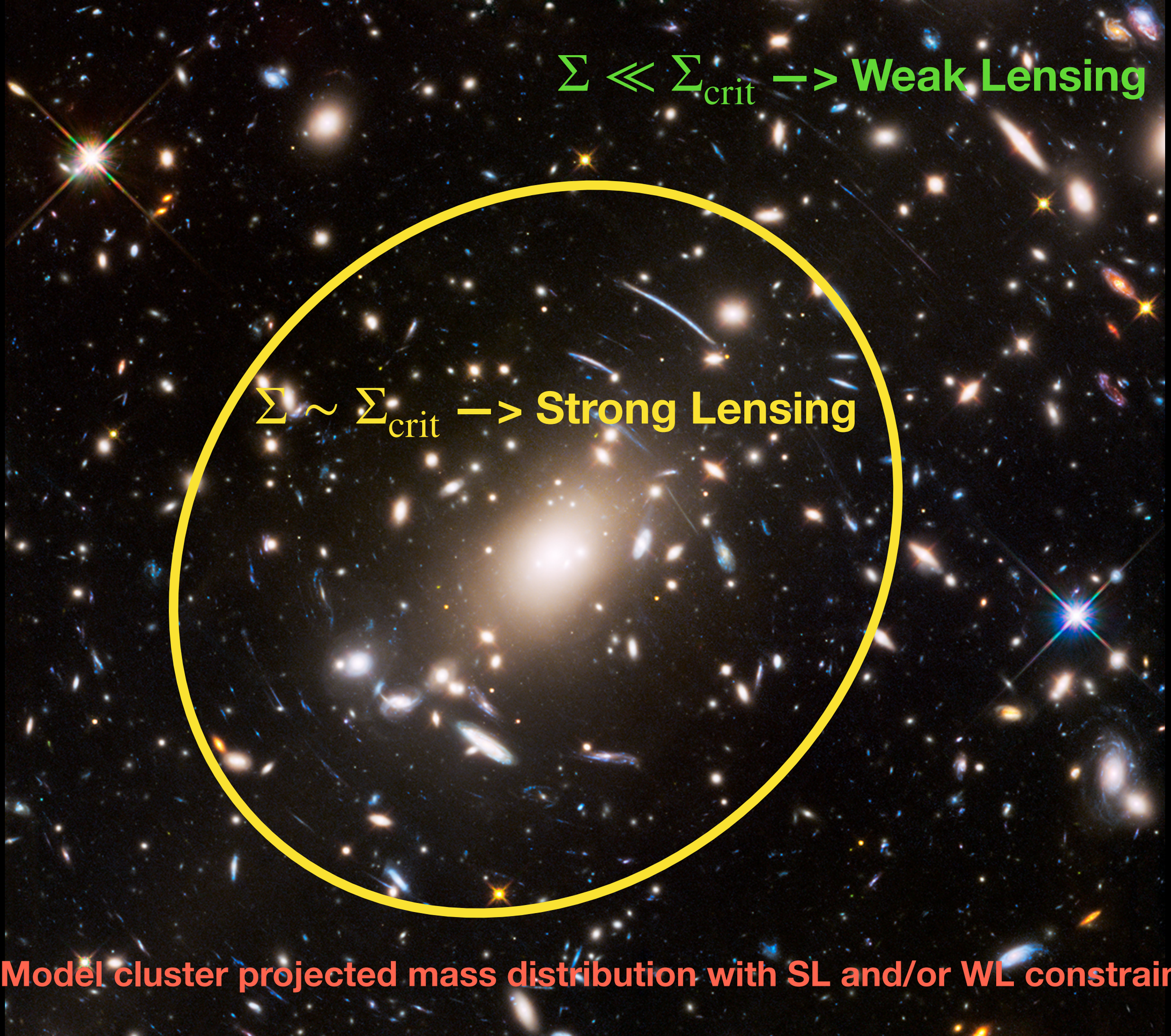
LSA ASTRONOMY
UNIVERSITY OF MICHIGAN

hybrid-Lenstool : combining parametric SL + non-parametric WL for cluster mass modeling



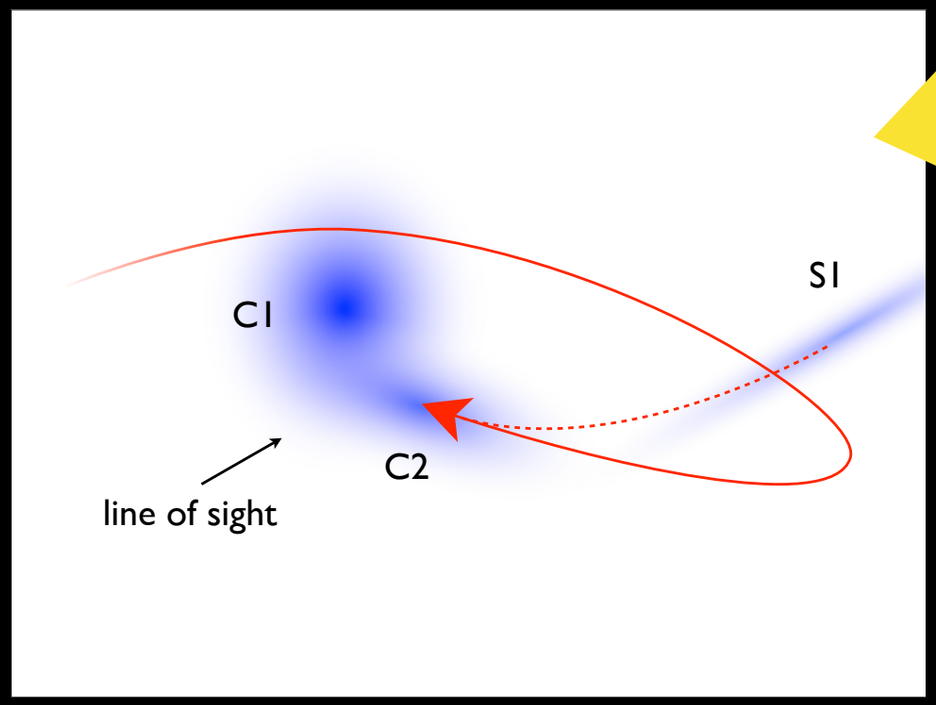
Anna NIEMIEC

Mathilde Jauzac, Eric Jullo, Marceau Limousin, Keren Sharon, Jean-Paul Kneib, Priyamvada Natarajan, Johan Richard

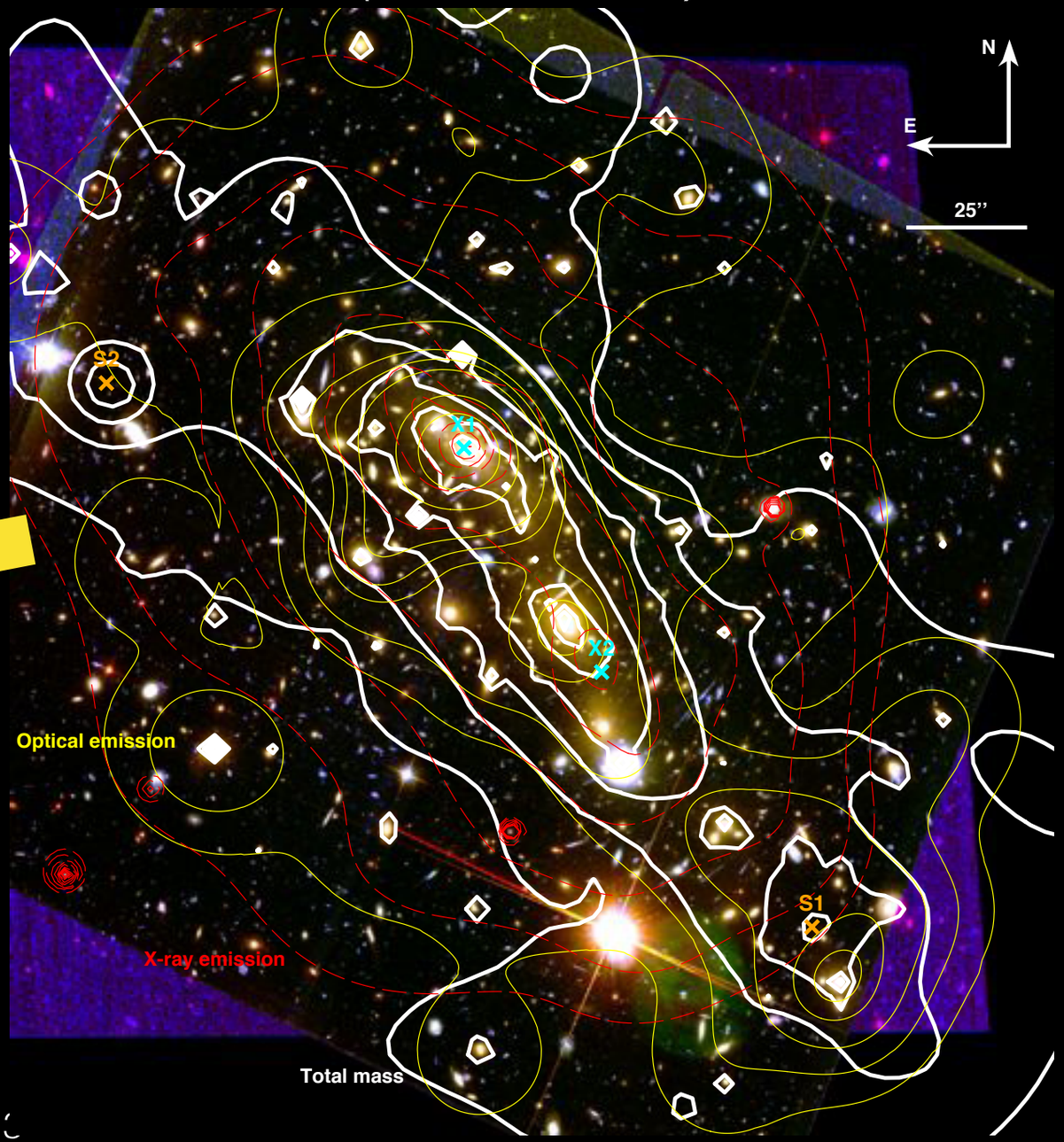

$\Sigma \ll \Sigma_{\rm crit}$ —> Weak Lensing
$\Sigma \sim \Sigma_{\rm crit}$ —> Strong Lensing
—> Model cluster projected mass distribution with SL and/or WL constraints

Cluster lensing applications

- **Cluster physics**

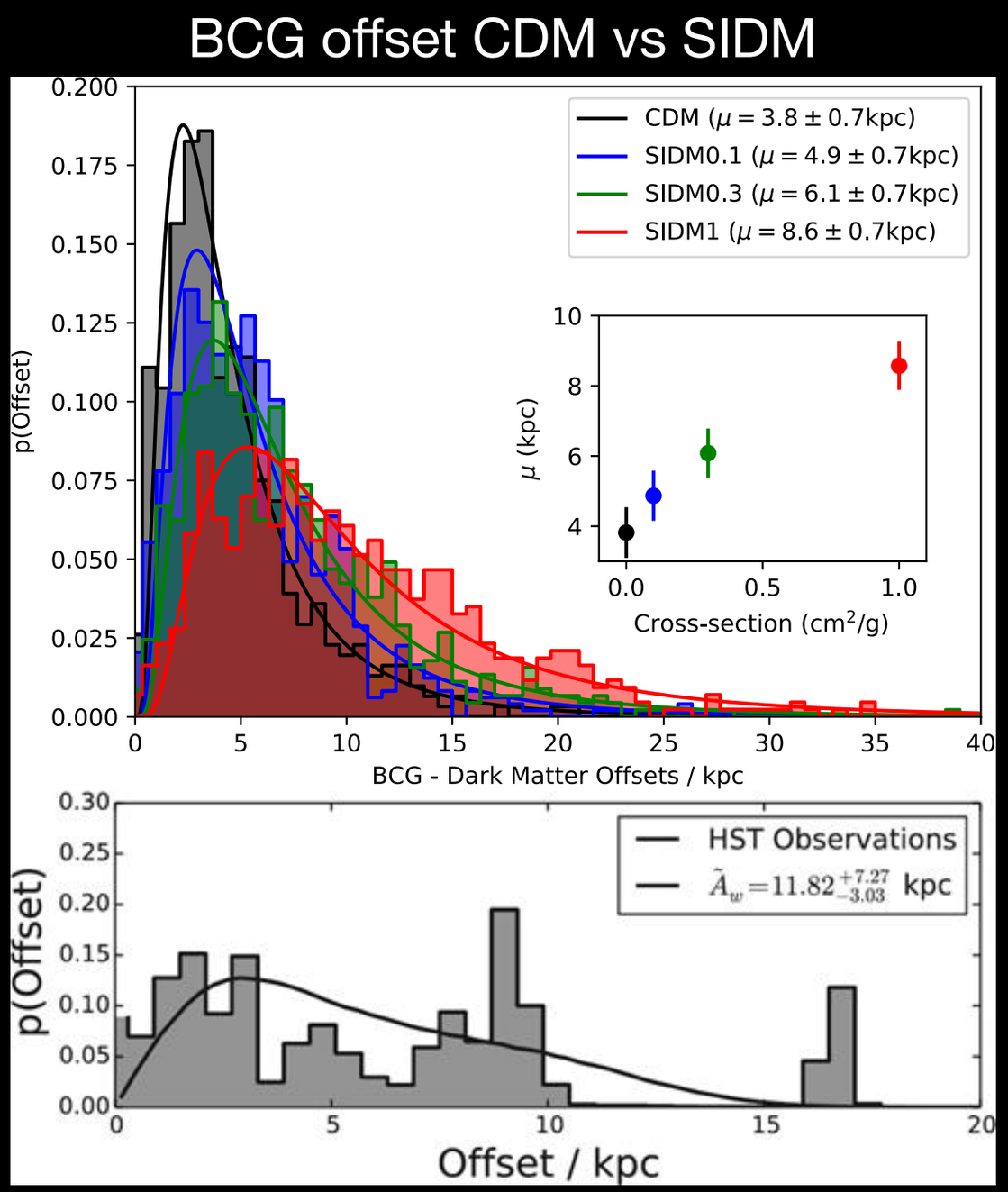


Optical + lensing + X-ray for MACS0416
(Jauzac+2015)



Cluster lensing applications

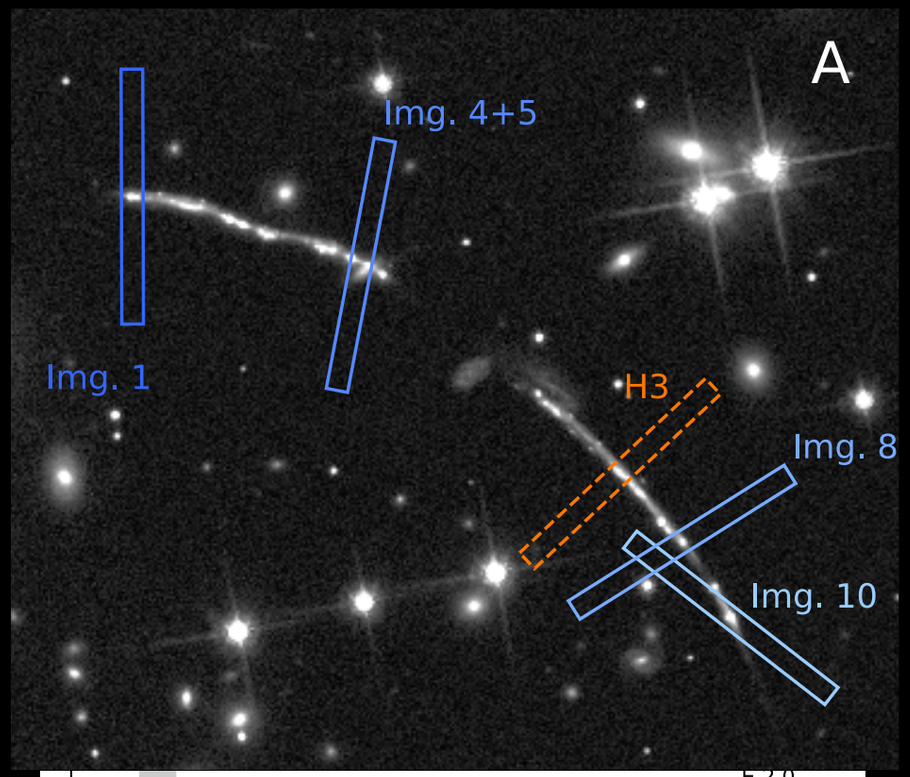
- Cluster physics
- **Dark matter properties**

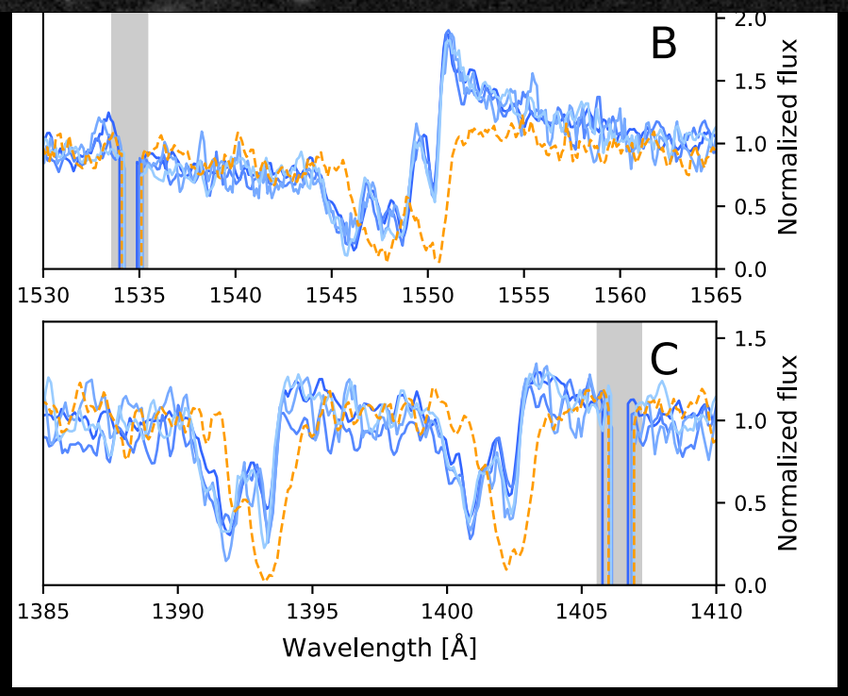


Harvey+2017,2018

Cluster lensing applications

- Cluster physics
- Dark matter properties
- **Highly magnified galaxies**



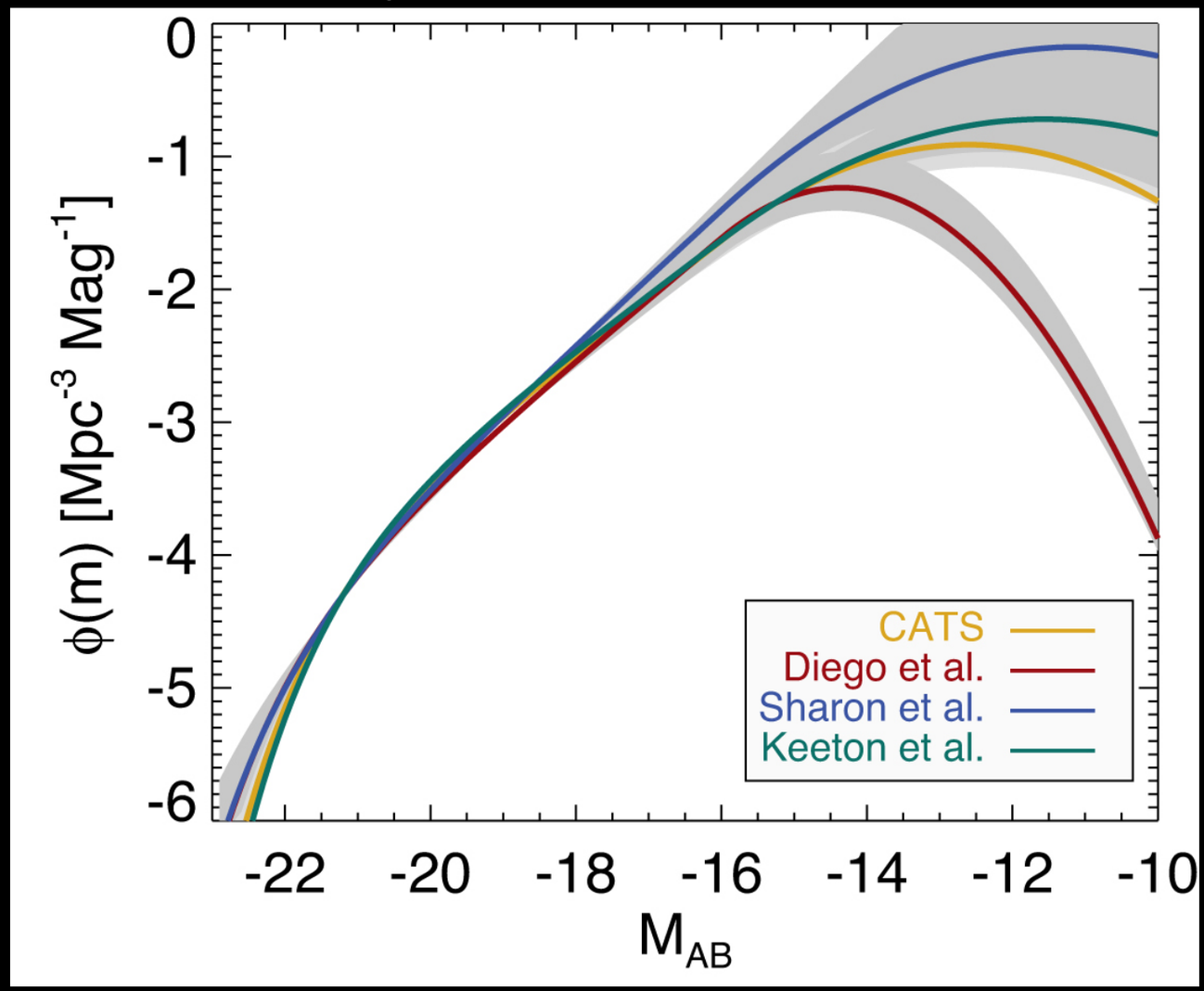


Rivera-Thorsen+2019

Cluster lensing applications

- Cluster physics
- Dark matter properties
- Highly magnified galaxies
- **High-z Universe**

UV Luminosity function at z~6 in MACS1149

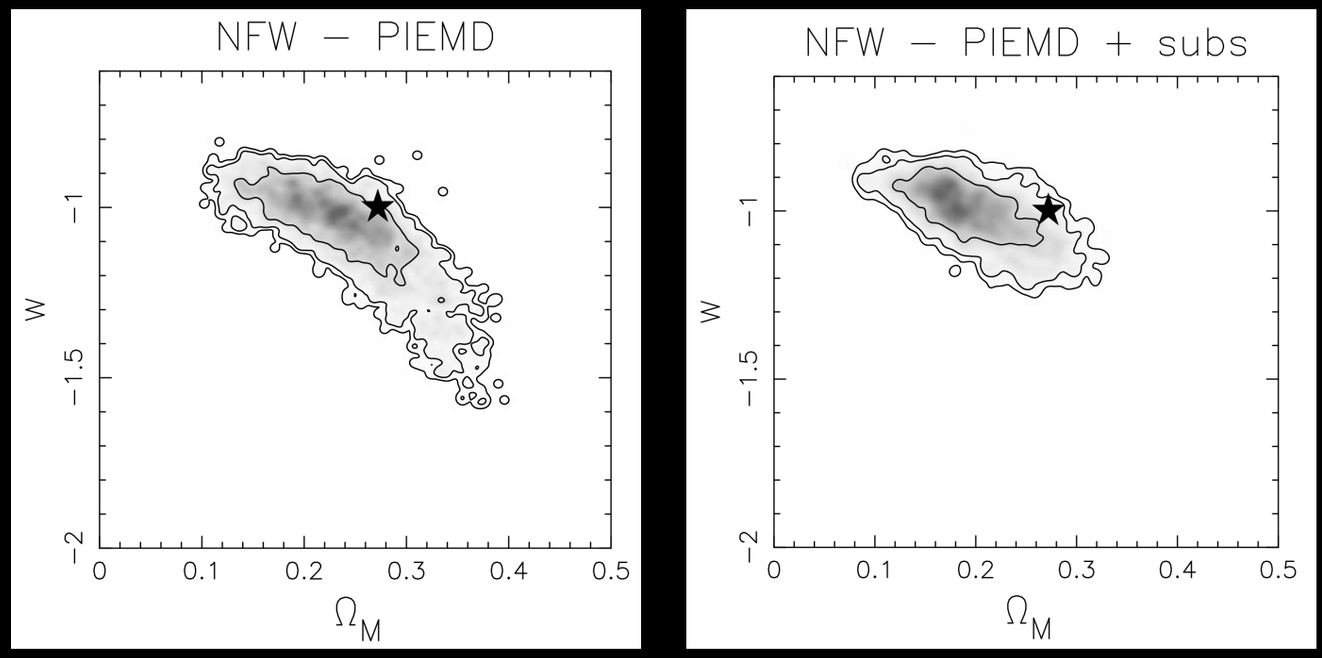


Atek+2018

Cluster lensing applications

- Cluster physics
- Dark matter properties
- Highly magnified galaxies
- Distant Universe
- **Cosmology**

Cosmography (*Ares* simulated cluster)



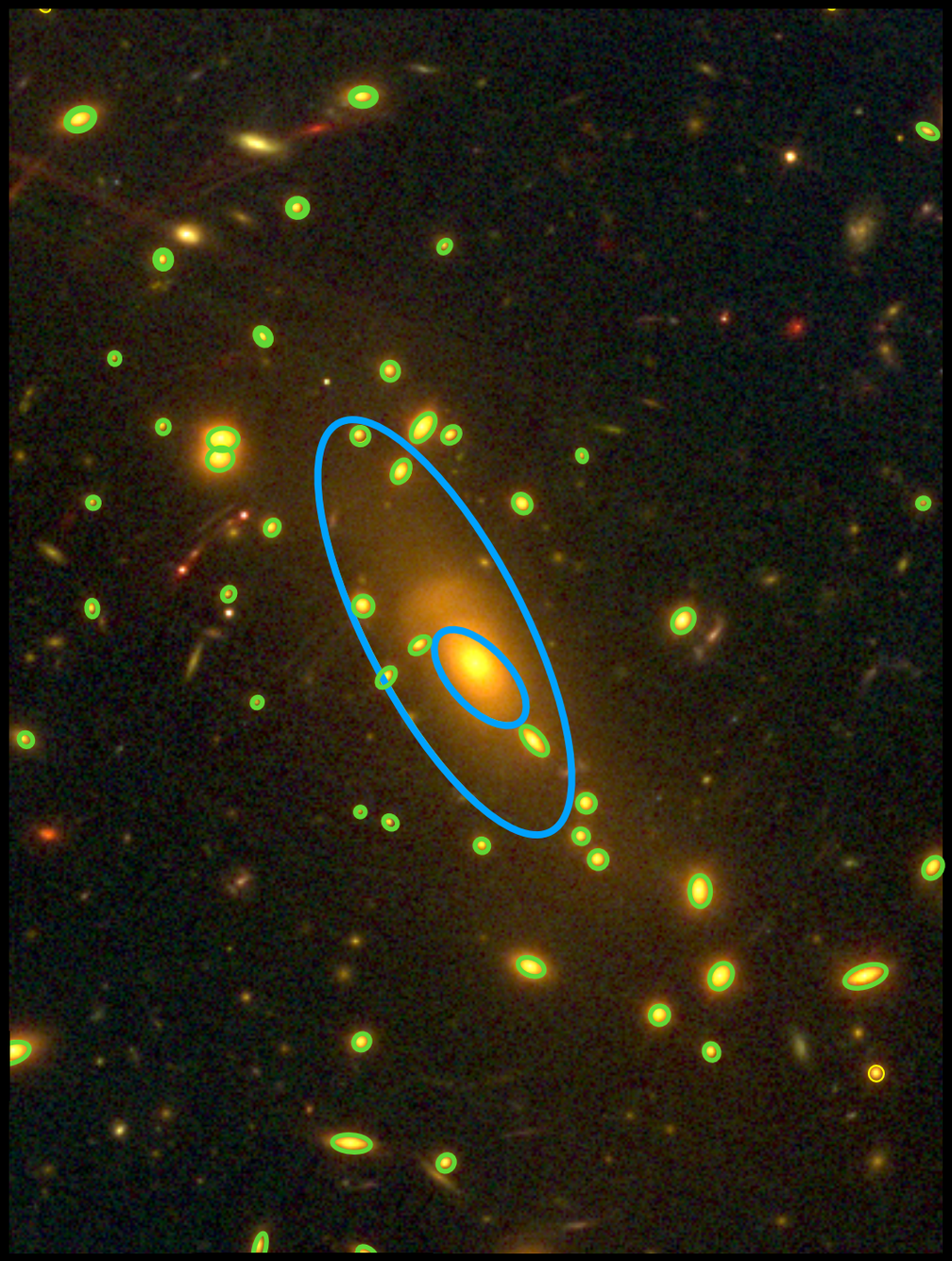
Acebron+2017

Cluster lensing applications

- Cluster physics
- Dark matter properties
- Highly magnified galaxies
- Distant Universe
- Cosmology

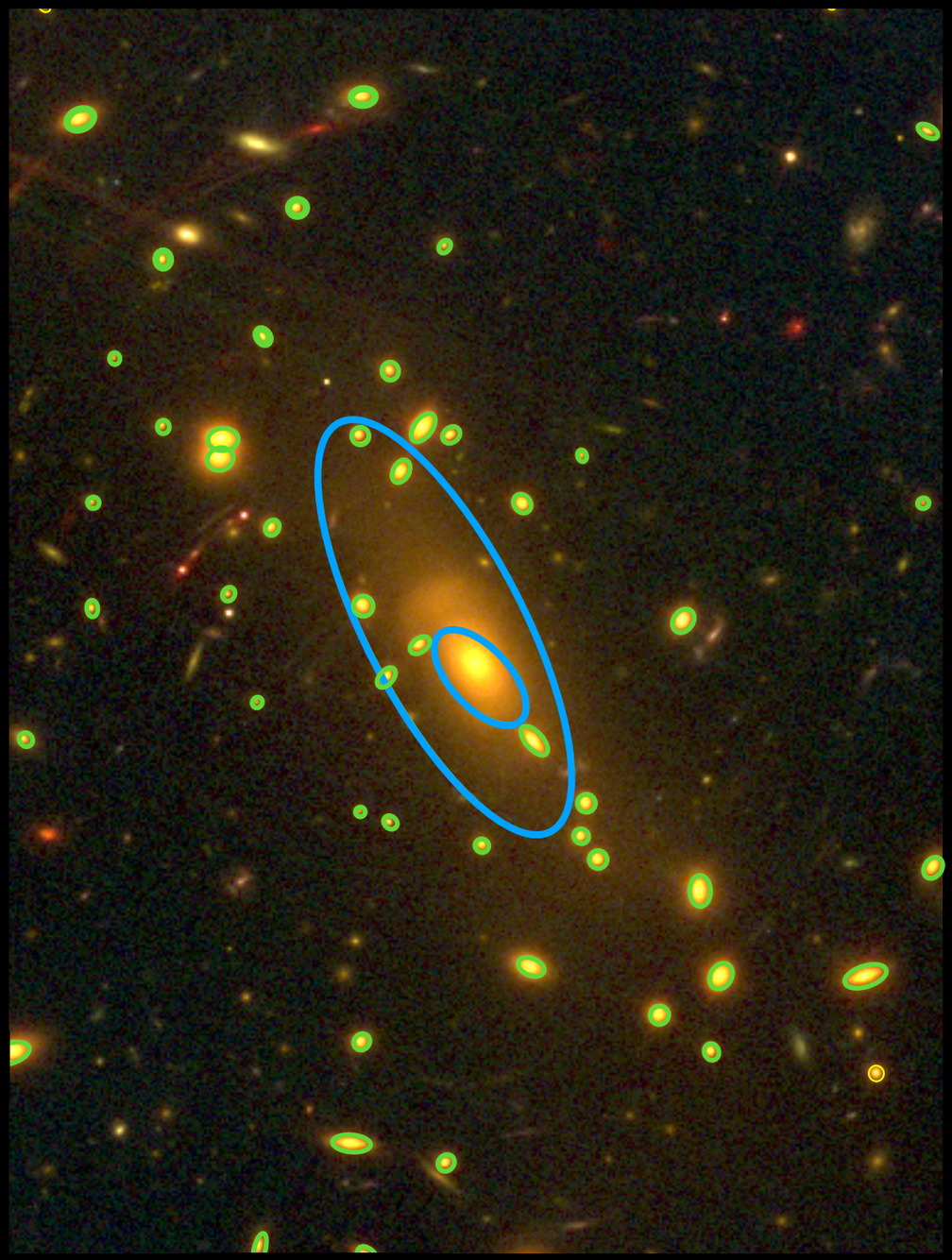
—> Need to model mass distribution with high precision and accuracy

Parametric mass modeling



- Physically motivated mass components (SL geometry + light distribution)
- Sparse distribution of SL constraints
- Ex: Glafic (*Oguri+2010*), LTM (*Zitrin+2012*), GLEE (*Suyu+2010*), …

Lenstool: parametric in SL region



- Cluster-scale potentials (x, y, e, rs, …) + galaxy scale potentials (mass-to-light relation)
- Free parameters:

$$\overrightarrow{\Theta} = [x, y, e, \dots]$$

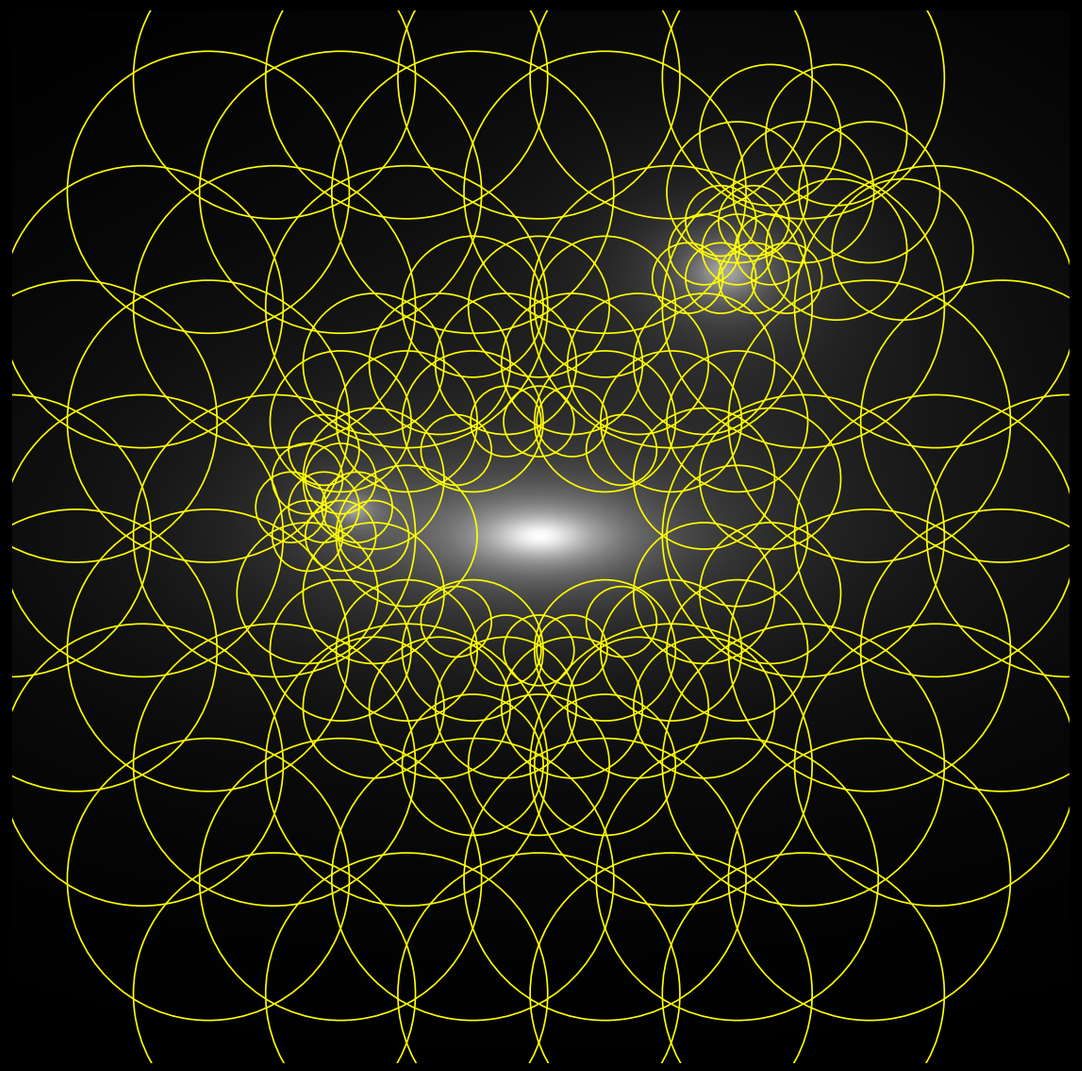
- Source-plane optimization:

$$\chi^2_{S,i} = \sum_{j=1}^{n_i} \frac{||x^j_{\rm S} - < x^j_{\rm S} > ||^2}{\mu_j^{-2}\sigma^2_{ij}}$$

Jullo+2007

Free-form mass modeling

- Grid of mass “pixels”
- More flexible for substructure detection
- Ex: SWUnited (*Bradac+2005*), WSLAP+ (*Diego+2005*), GRALE (*Liesenborgs+2006*), LensPerfect (*Cole+2008*), SaWLens (*Merten+2011*), …

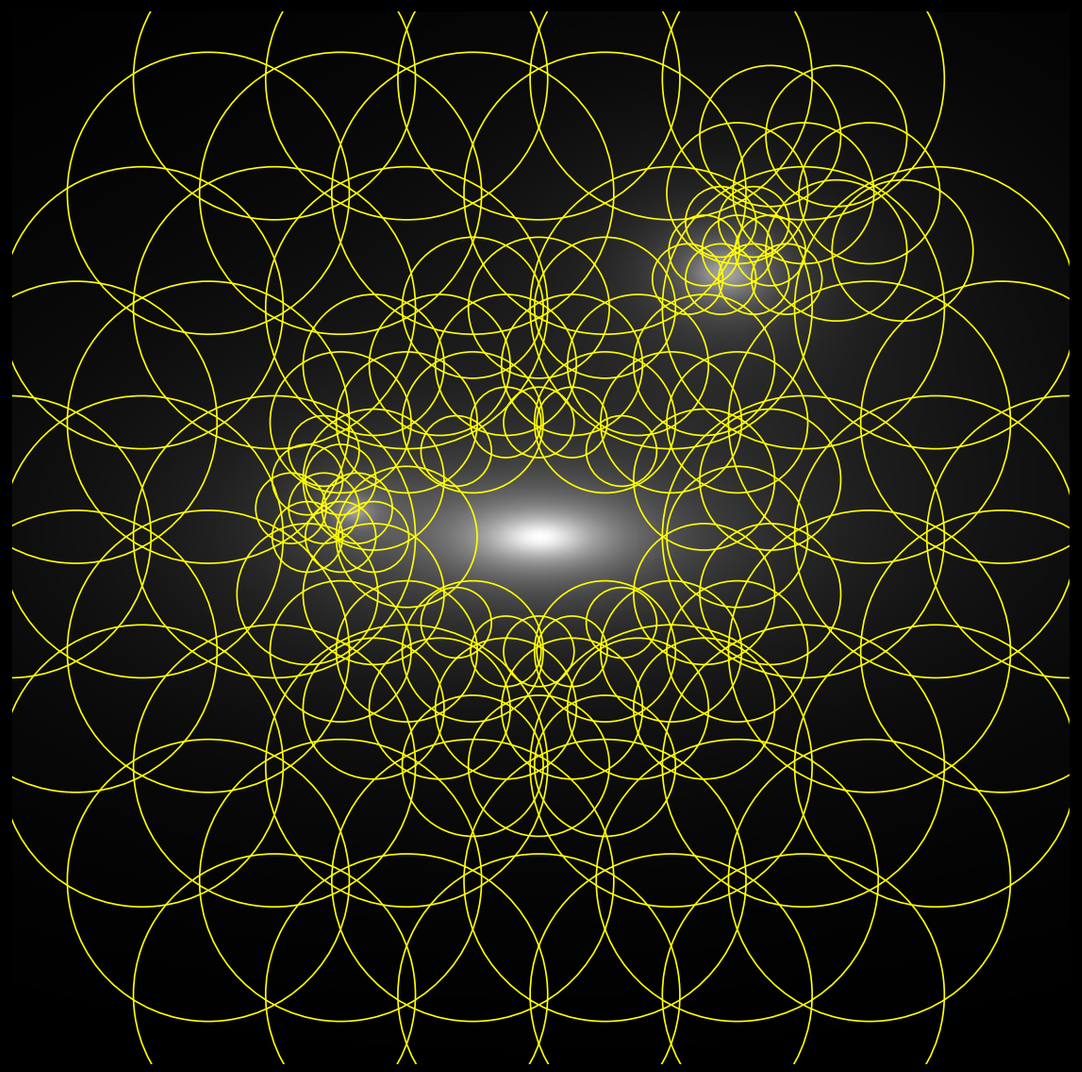


Lenstool: grid in WL region

- Position and shape fixed
- Vary amplitude and number of potential used
- Free parameters:

$$\overrightarrow{v} = [\sigma_1, \ldots, \sigma_N]$$

- Regular or multi-scale grid

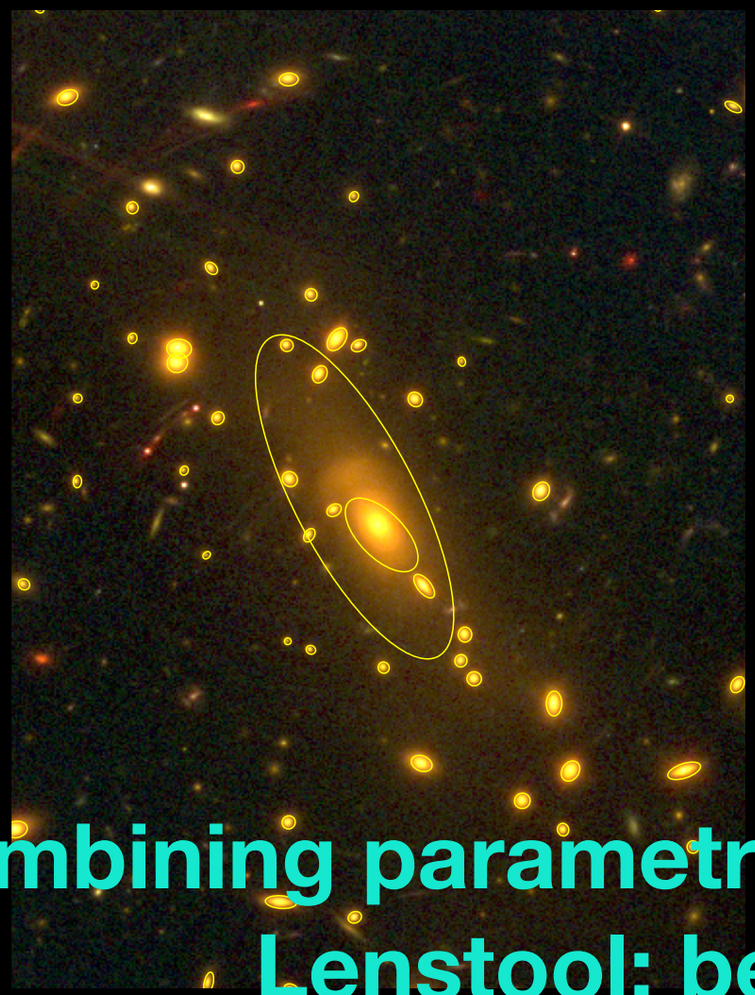


Jauzac+2012, Jullo+2014

Cluster mass modeling with Lenstool

- **Centre: parametric model, SL :**

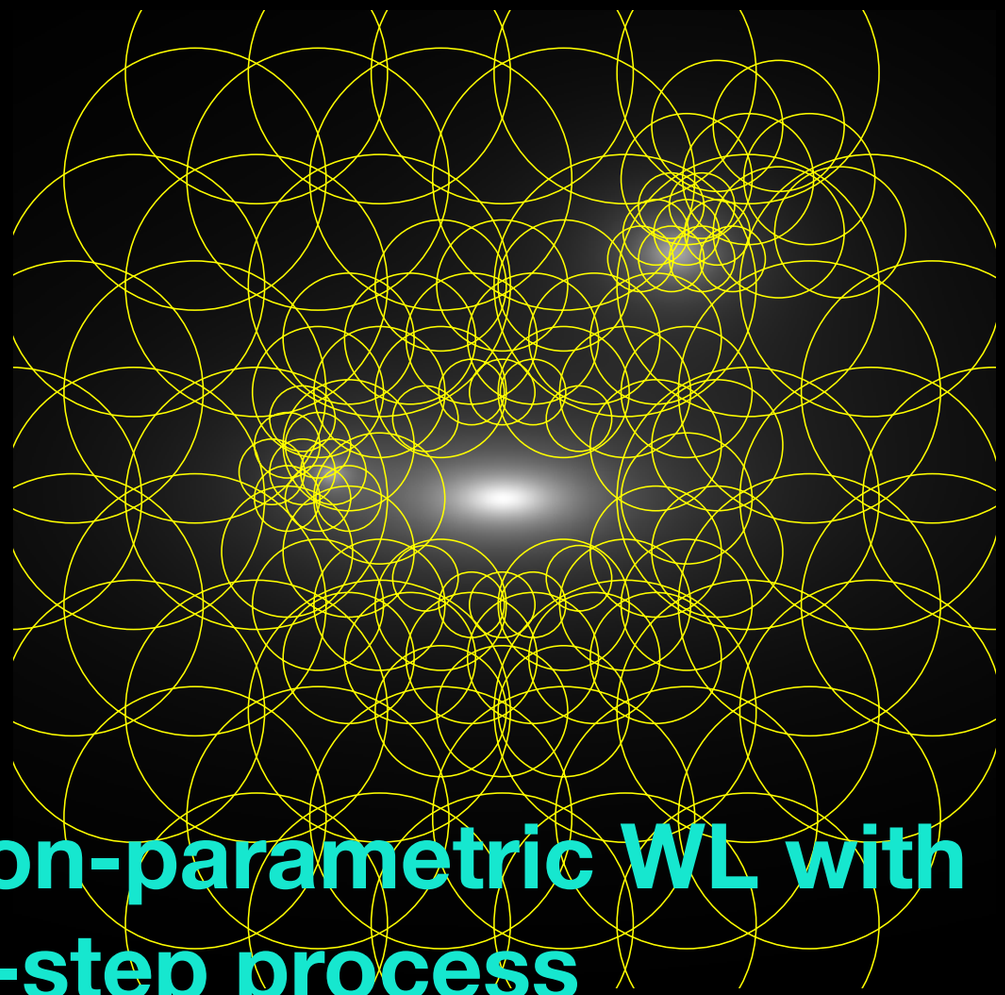
$$\overrightarrow{\Theta} = [x, y, e, \dots]$$



OR

- **Outskirts: non-parametric WL**

$$\overrightarrow{v} = [\sigma_1, \dots, \sigma_N]$$

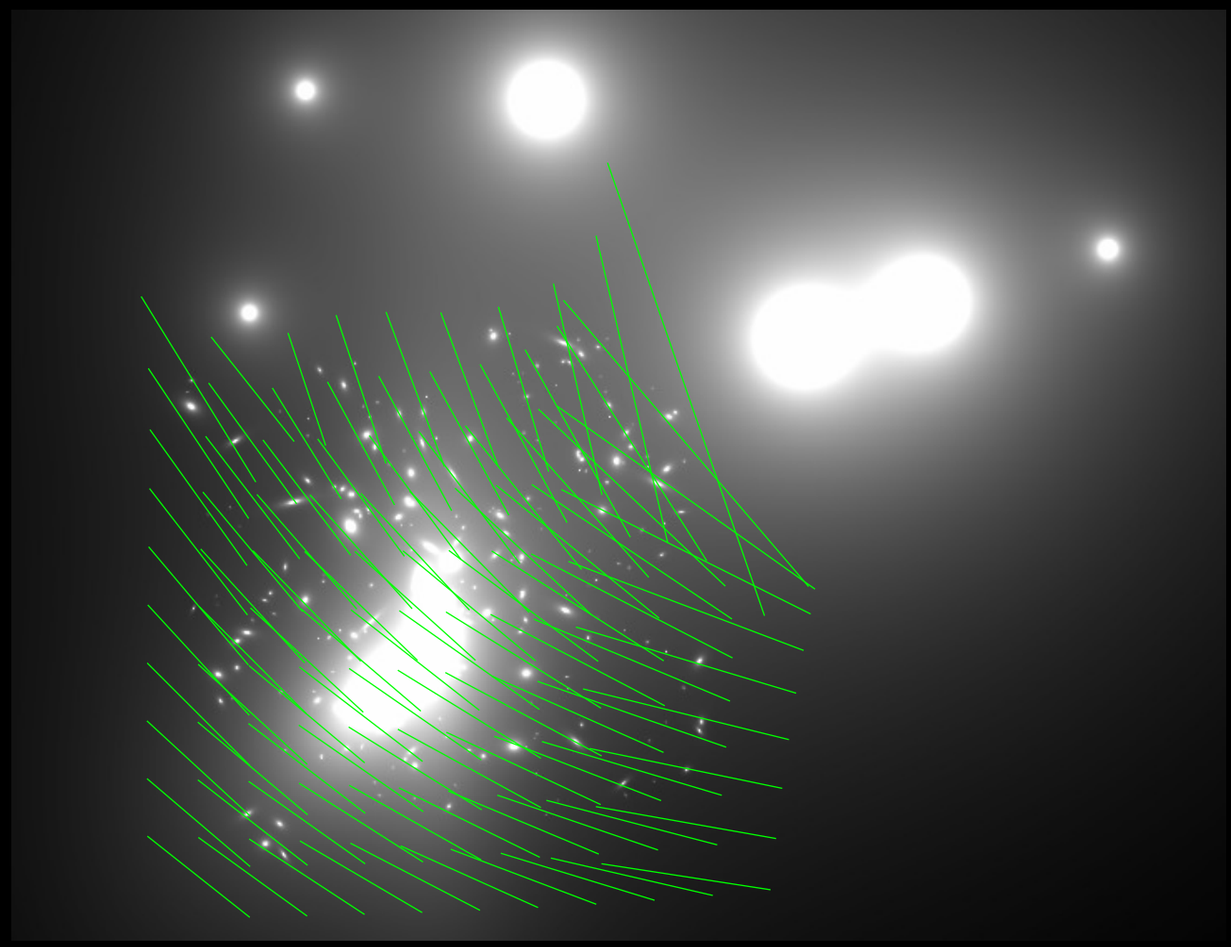


Combining parametric SL + non-parametric WL with Lenstool: before, a 2-step process

The importance of substructures

- Need to include substructures beyond the core for accurate model in the core
(e.g. Mahler+2018)

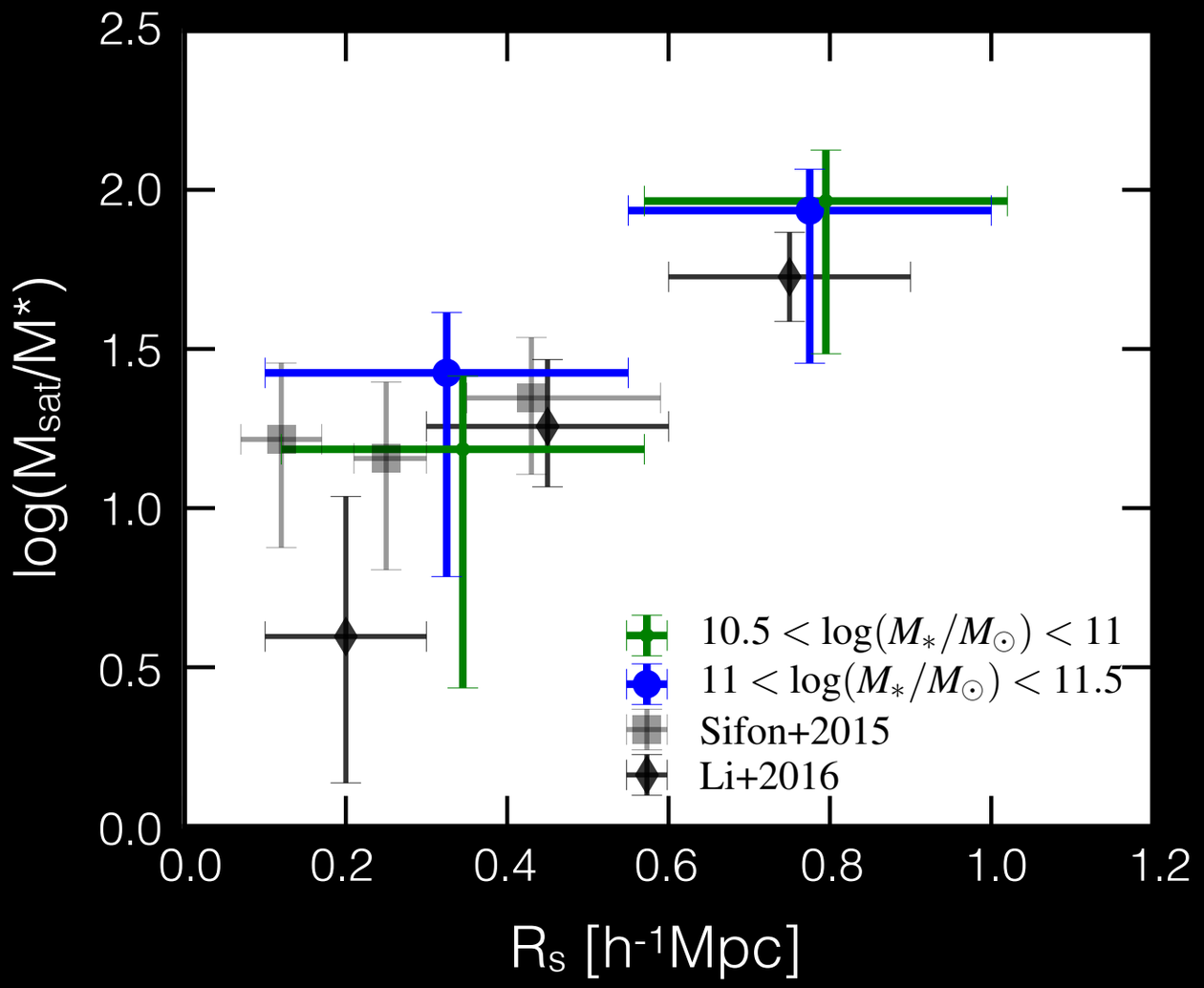
- Also for cosmology
(e.g. Acebron+2017)



Courtesy of Guillaume Mahler

M/L relation variations

- Possible M/L evolution for galaxies in clusters
- Optimize different M/L at different distances to the cluster centre



Niemiec+2017

Need to optimize parametric model + grid at the same time

MCMC sampling of the posterior PDFs, with likelihood function :

$$l_{\mathrm{tot}} = l_{\mathrm{SL}}(\overrightarrow{\Theta}, \overrightarrow{v}) + l_{\mathrm{WL}}(\overrightarrow{\Theta}, \overrightarrow{v})$$

(before : $l_{\mathrm{SL}}(\vec{\Theta})$ **then** $l_{\mathrm{WL}}(\vec{v}|\vec{\Theta}_{\mathrm{best}})$ **)**

Need to optimize parametric model + grid at the same time

2 types of models: parametric, grid

$$l_{\mathrm{tot}} = l_{\mathrm{SL}}(\vec{\Theta}, \vec{v}) + l_{\mathrm{WL}}(\vec{\Theta}, \vec{v})$$

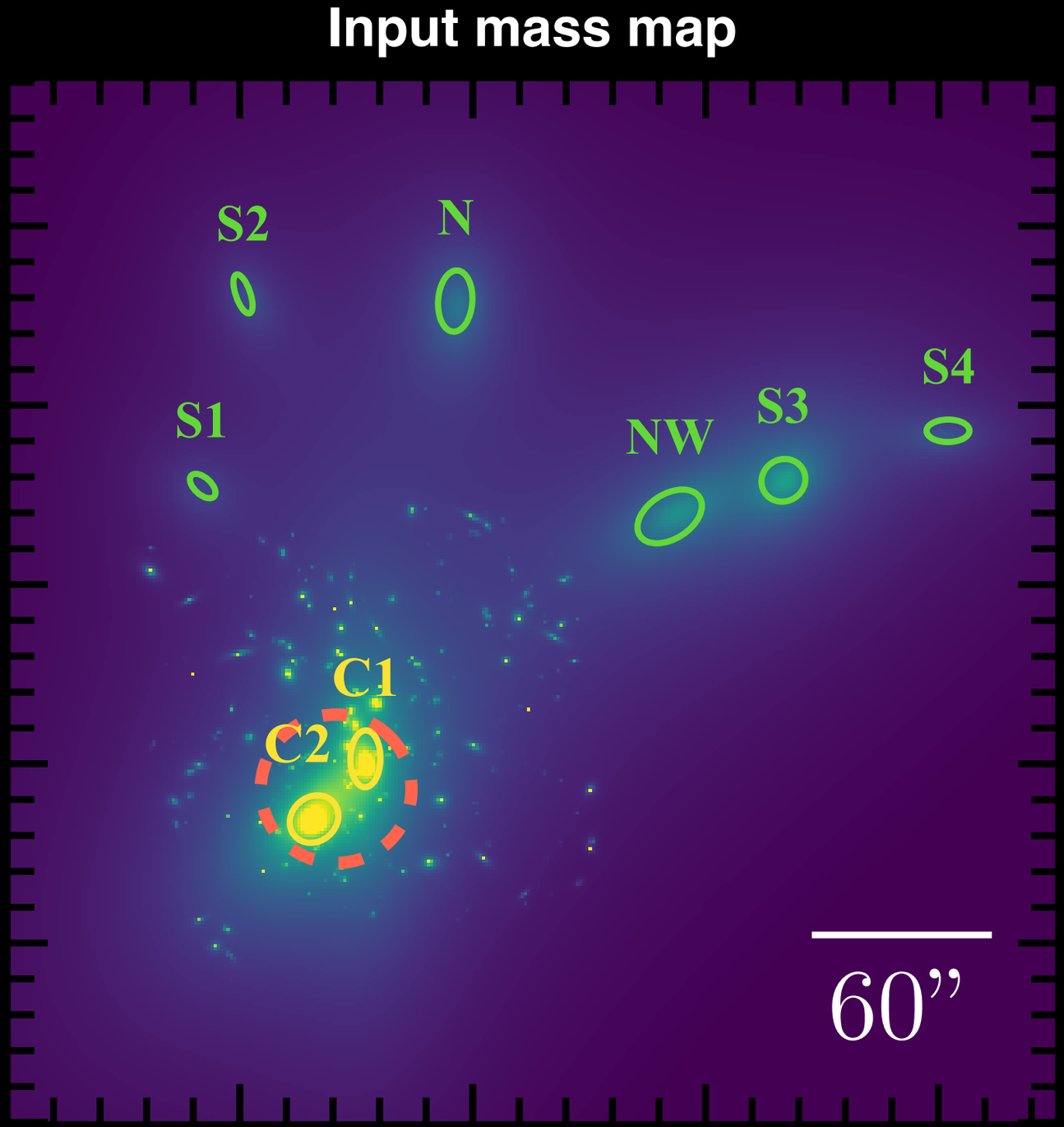
2 types of constraints: SL, WL

And 2 methods :

- **parametric : bayeSys with 1 atom** $[\vec{\Theta}]$
- **grid : massInf with N atoms** $[i][\sigma_i^2]$

—> Blockwise sampling in the MCMC = update alternately $\vec{\Theta}$ and $\vec{v}$

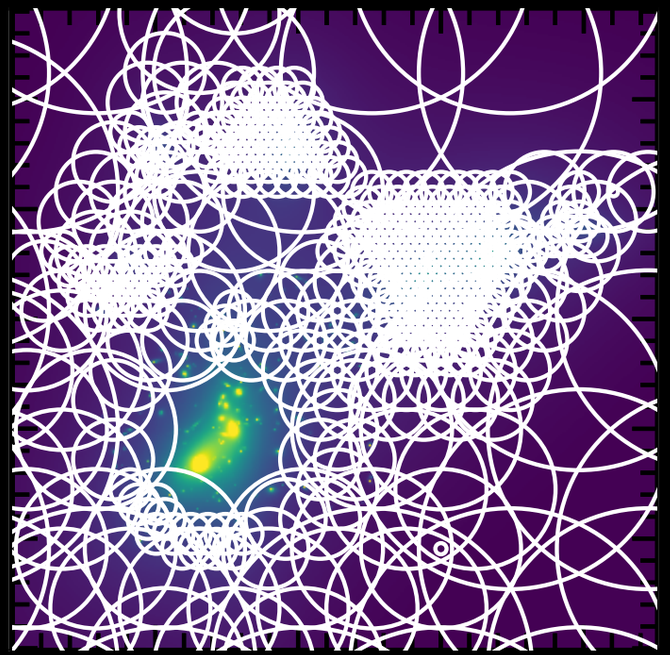
Test on simulated cluster



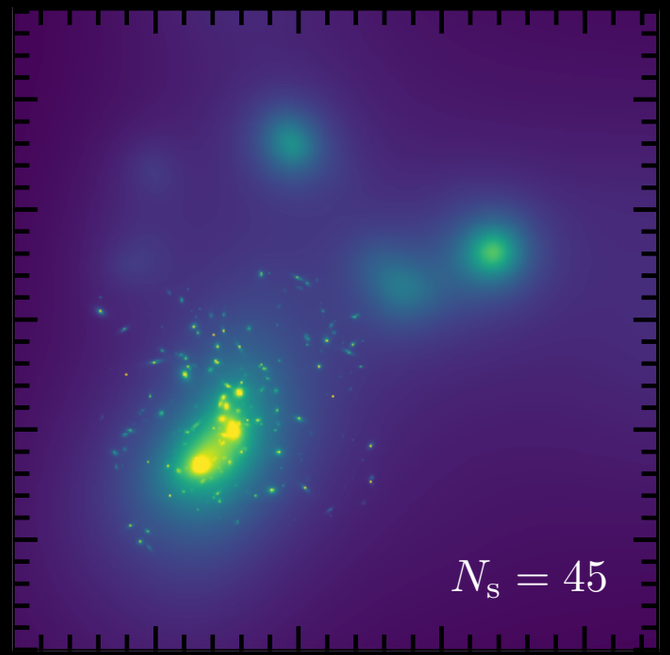
- ~ Abell 2744 : 2 large scale potentials in cluster core + 6 substructures (*Jauzac+2016b*) + 246 galaxy-scale potentials
- 15 SL multiple image systems with $1.5 < z < 5$
- Uniformly distributed WL sources, with N = 45 sources/arcmin^2 and $0.5 < z < 1.5$

Lenstool mass models

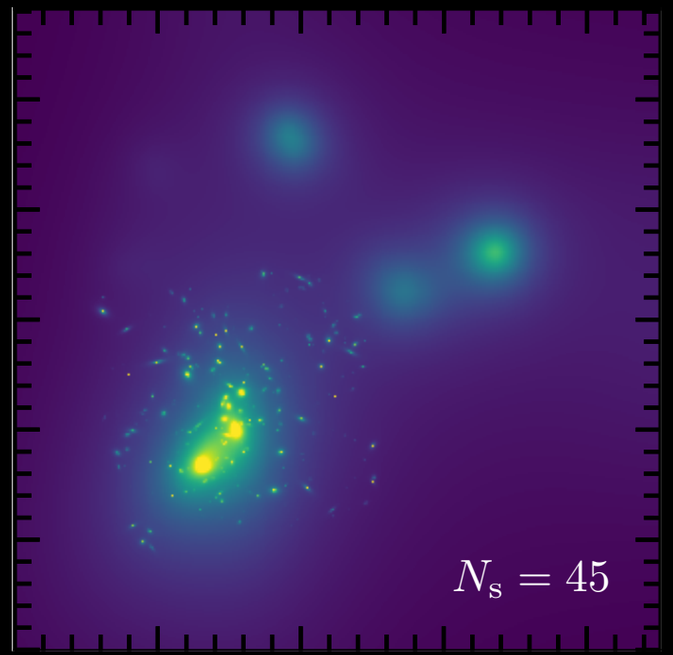
Input



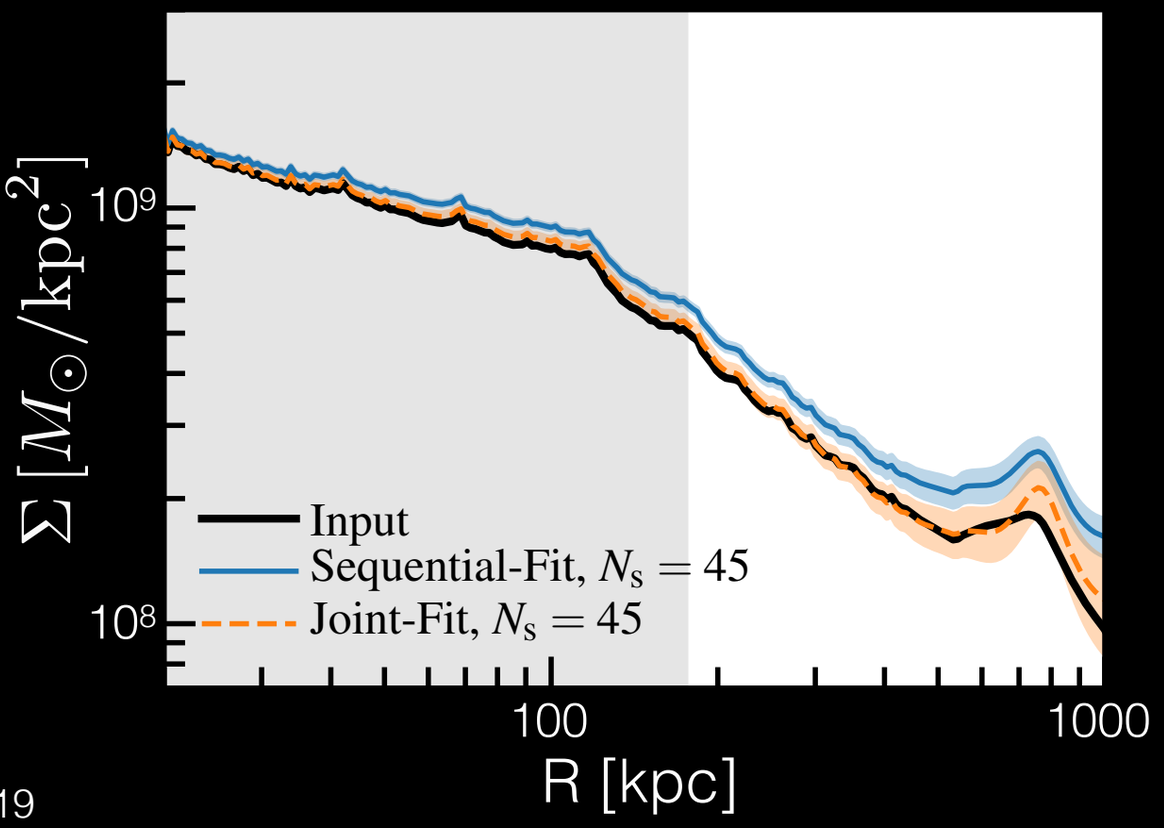
Sequential Fit



Joint Fit



- Good substructure detection with both methods
- Joint-Fit reduces bias in mass reconstruction



Future improvements

- Implement image-plane optimization —> necessary for more complex systems ?

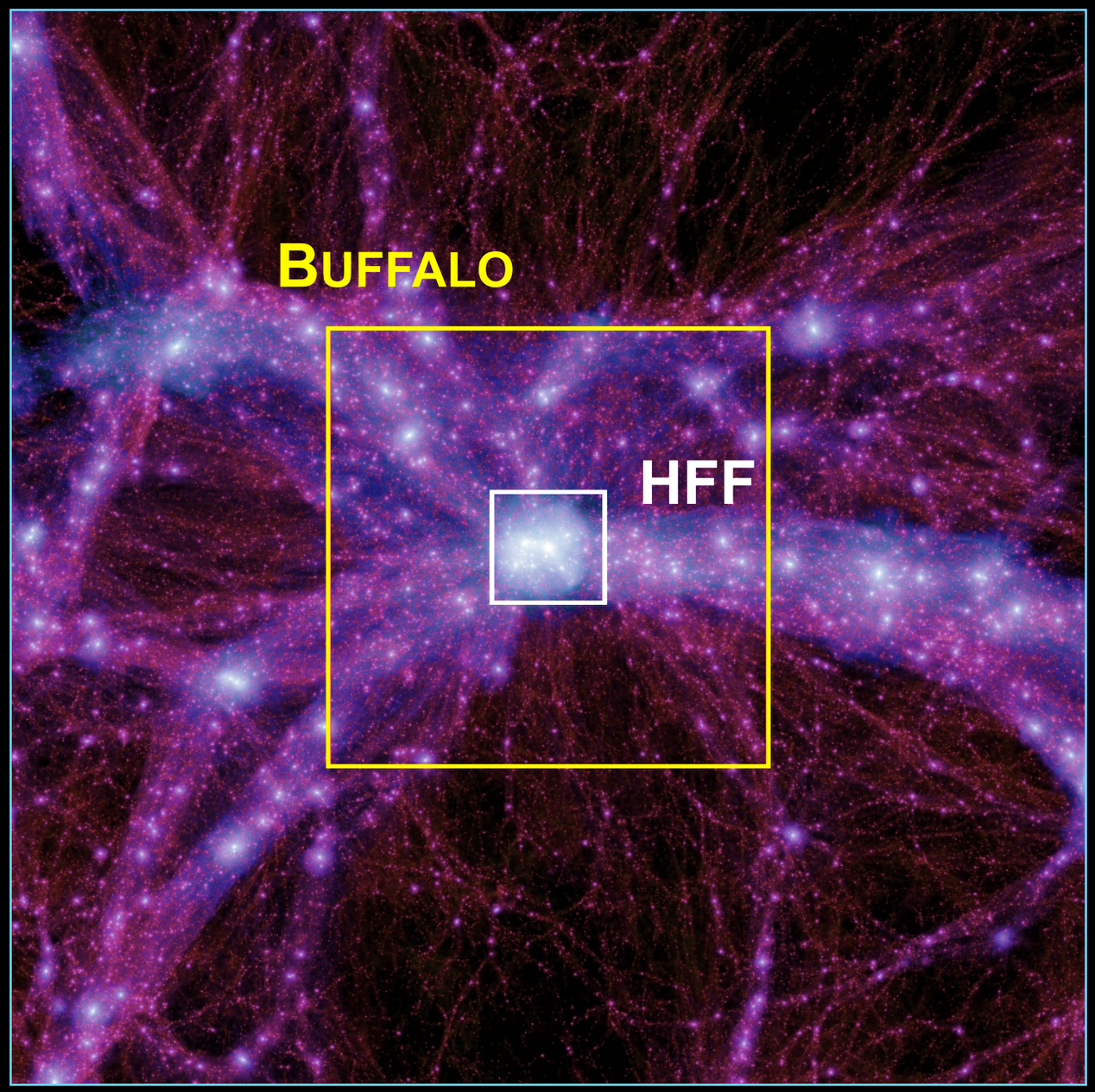
- Decrease computation time by adding more parallelization

Application :
the BUFFALO survey

BUFFALO: **B**eyond **U**ltra-Deep **F**rontier **F**ields and **L**egacy **O**bservations

GO-15117, PIs: Steinhardt & Jauzac

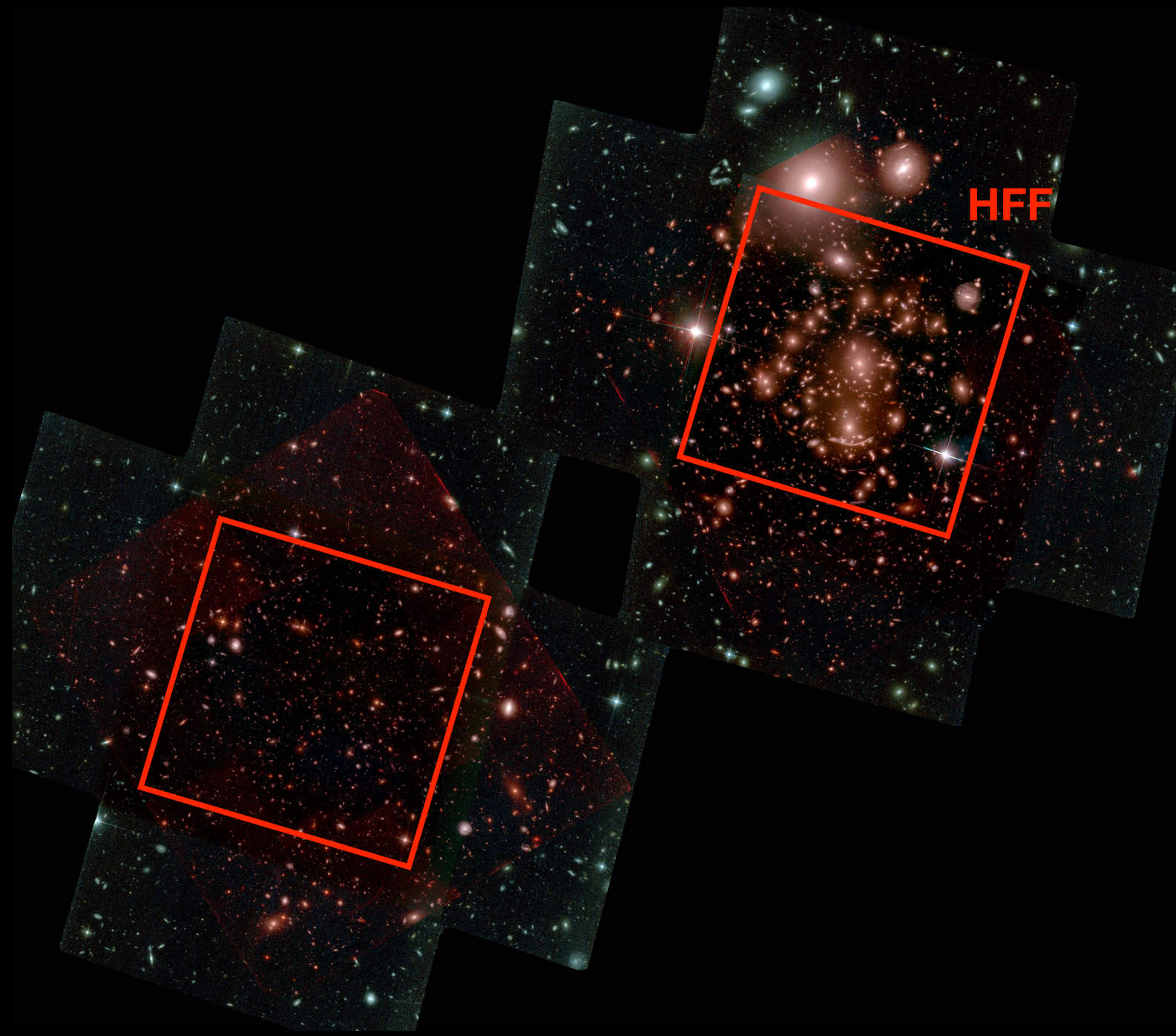
- HFF extension :
  - 101 HST orbits
  - 2 optical filter + 3 NIR
- **Cluster modeling** : add weak lensing constraints
  - Improve overall model
  - Substructure detection
- **High-z** : area previously covered by Spitzer



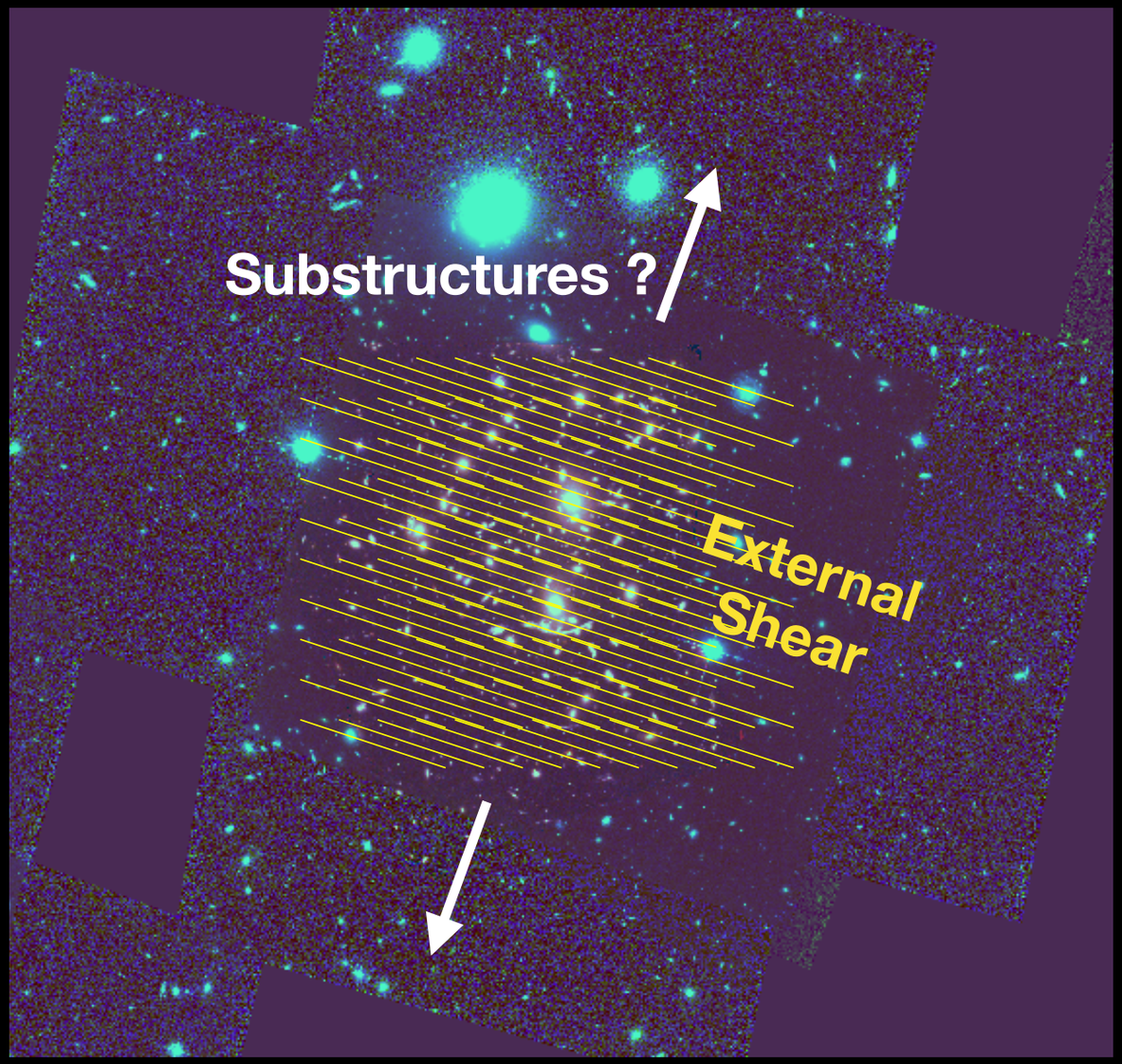
h-Lenstool model for Abell370

- Latest SL model for A370 (*Lagattuta+2019*):
  4 large-scale potentials + **external shear**

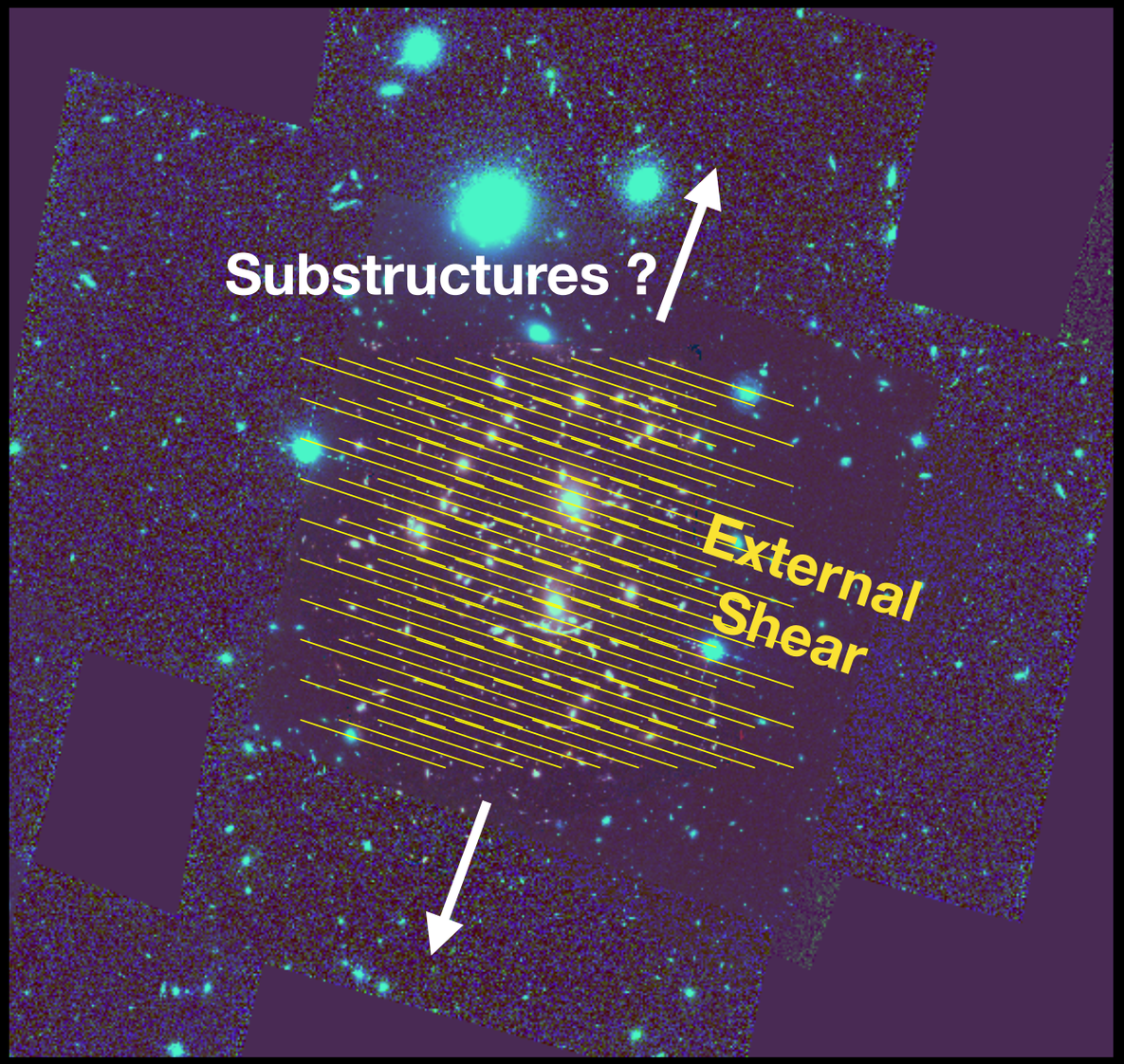
- Could including substructures replace the external shear ?



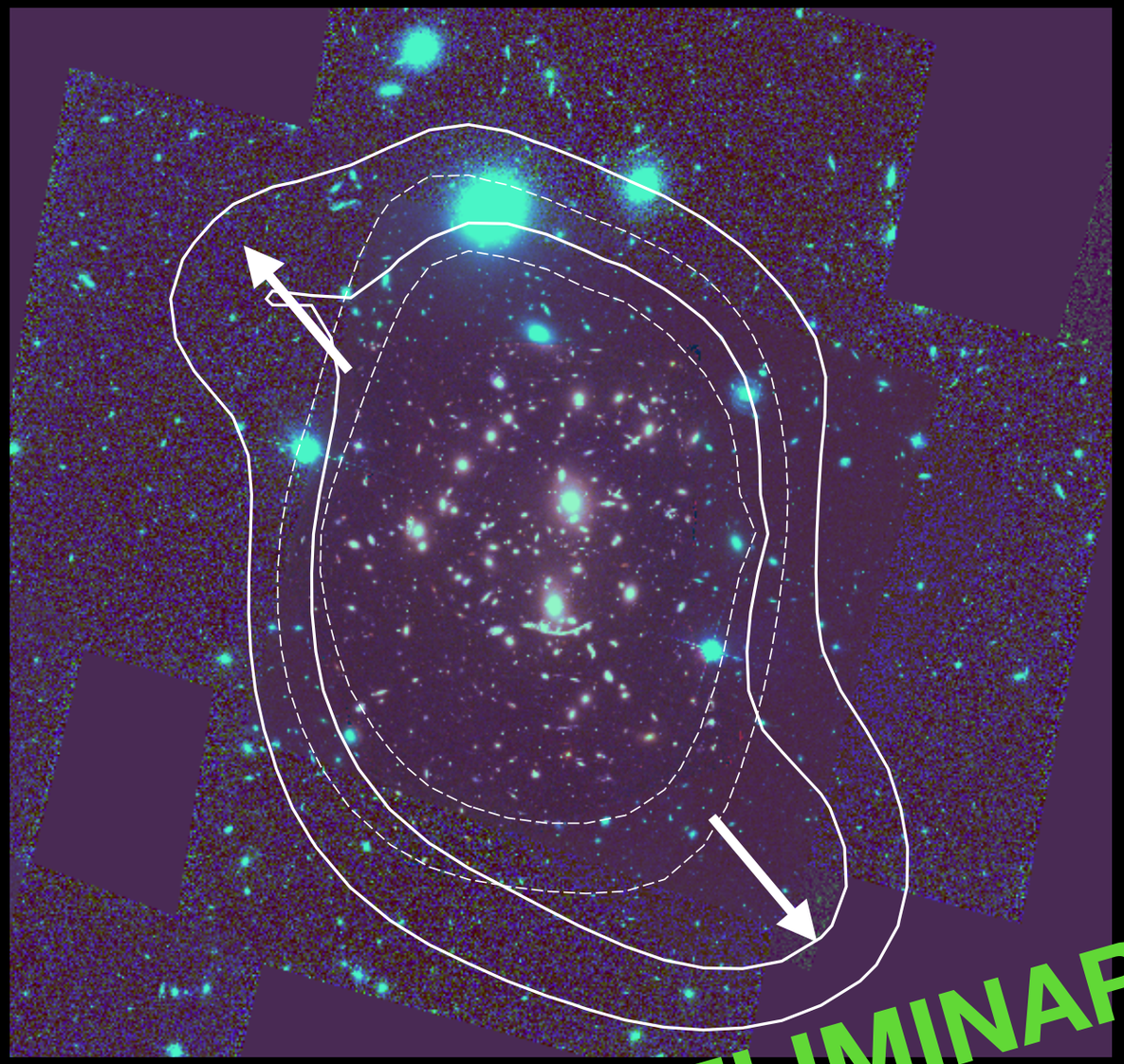
External shear in SL model from *Lagattuta+2019* :



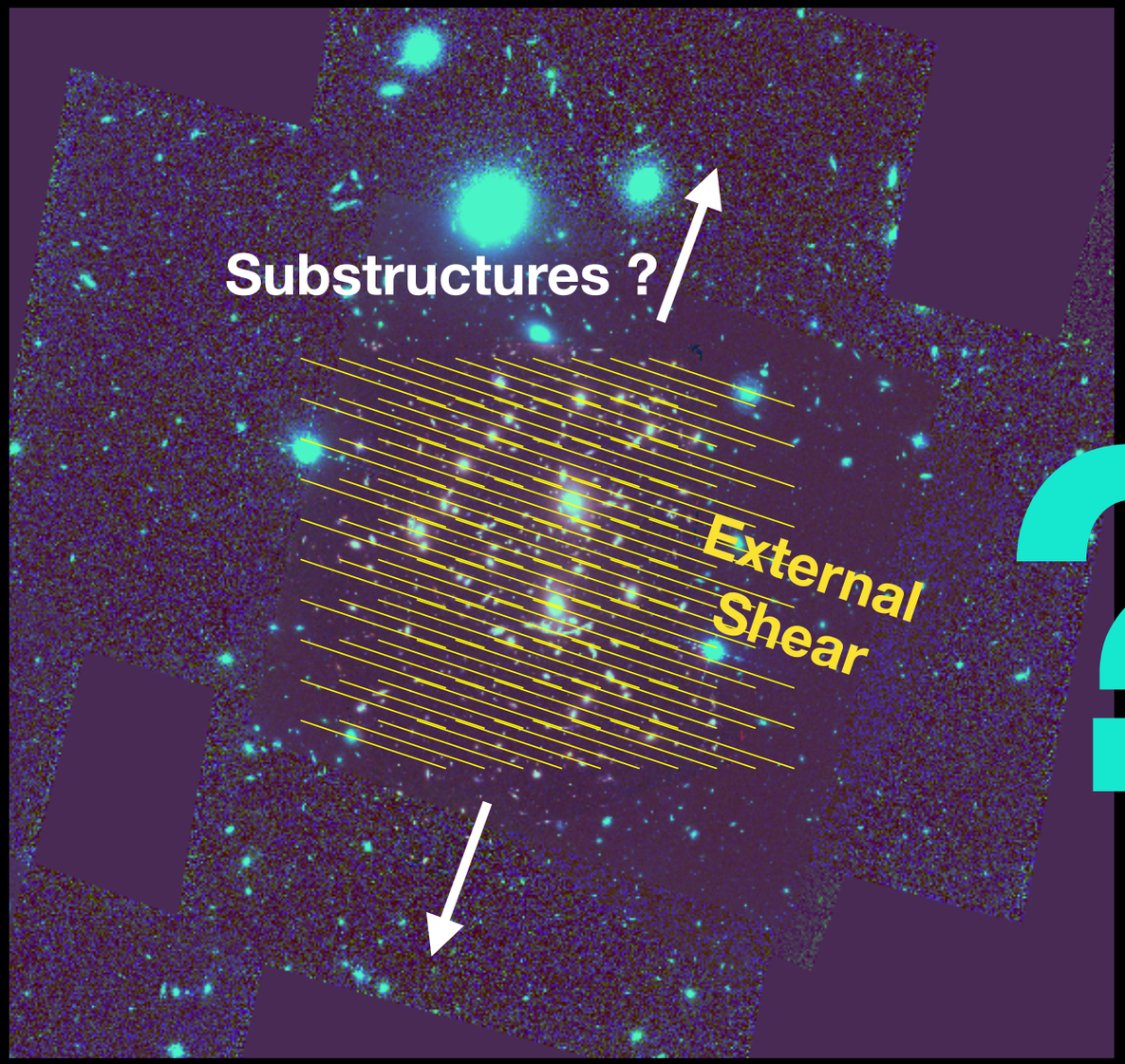
External shear in SL model from *Lagattuta+2019* :



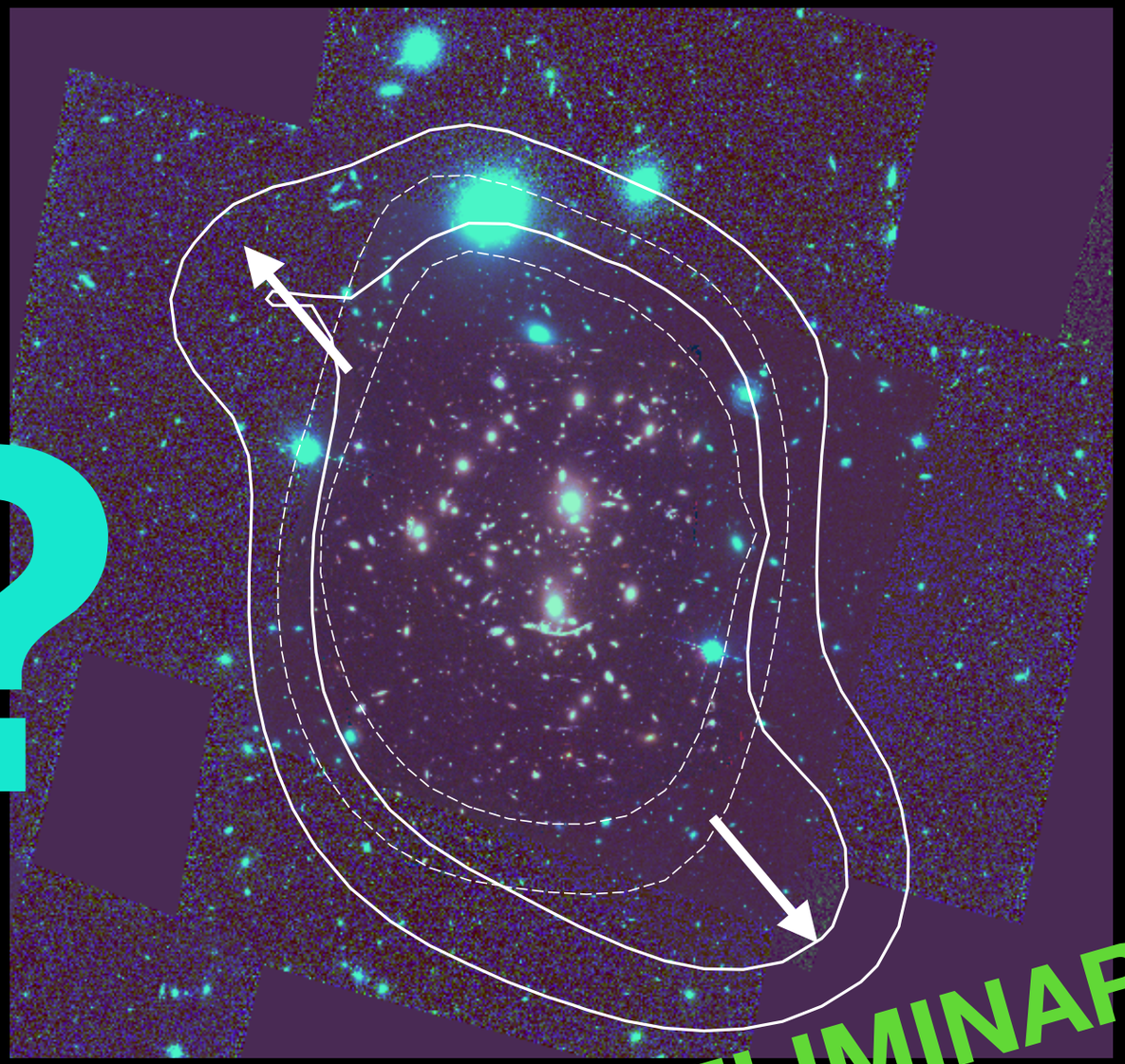
With WL :



External shear in SL model from *Lagattuta+2019* :



With WL :



- Substructures outside of field of view
- …?

BUFFALO

- 3 completed clusters: Abell370, MACS0416, MACS0717

- More info : https://buffalo.ipac.caltech.edu/

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Summary

- Combining parametric model in SL region and non-parametric grid model in WL region with Lenstool
- Model for A370 (+ other BUFFALO clusters) soon to come
- Symposium "*Panchromatic and hyper-spectral observations of cluster lenses and lensed galaxies*" @EAS2020 (https://eas.unige.ch//EAS_meeting/session.jsp?id=S4)