



BUFFALO

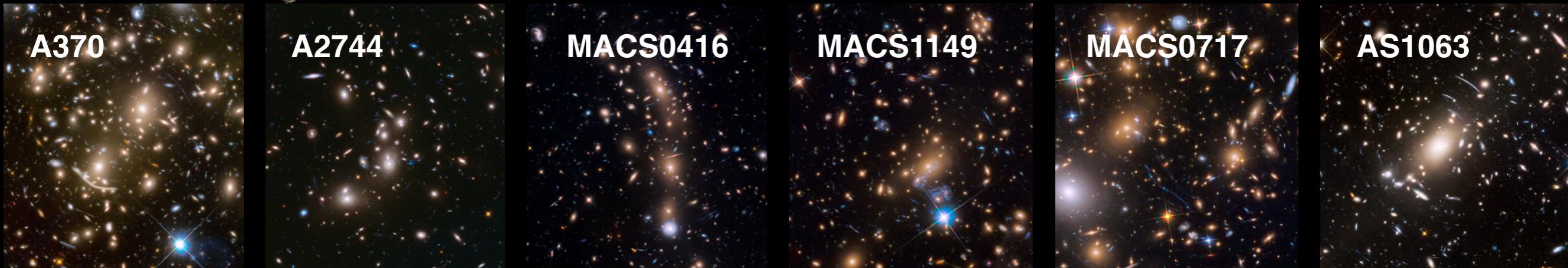
Galaxy clusters in the **BUFFALO** survey

Anna NIEMIEC



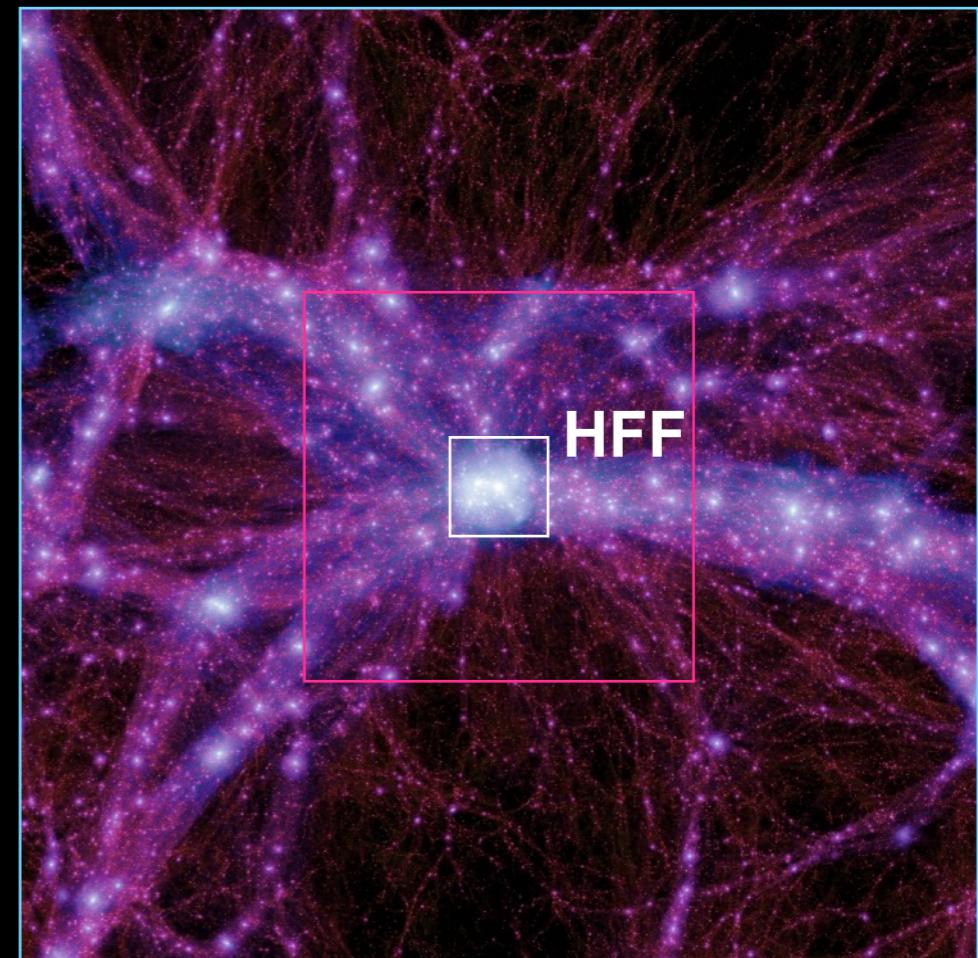
The Hubble Frontier Fields :

Lotz et al. 2017



6 strong lensing clusters (+ 6 parallel fields)

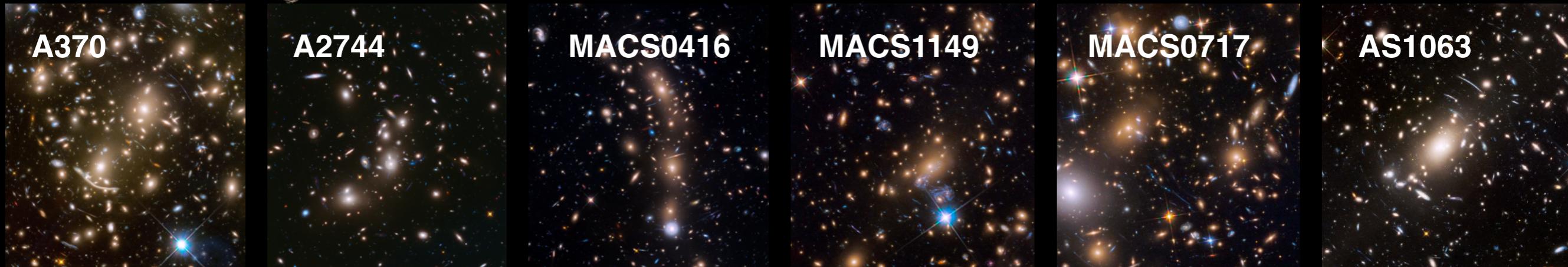
- ▶ Deepest Hubble cluster images (140 orbits, mag ~29)
- ▶ Strong lenses





The Hubble Frontier Fields :

Lotz et al. 2017



6 strong lensing clusters (+ 6 parallel fields)

- ▶ Deepest Hubble cluster images (140 orbits, mag ~ 29)
- ▶ Strong lenses

Most powerful telescopes in the Universe

= high redshift studies

Great precision on lens models

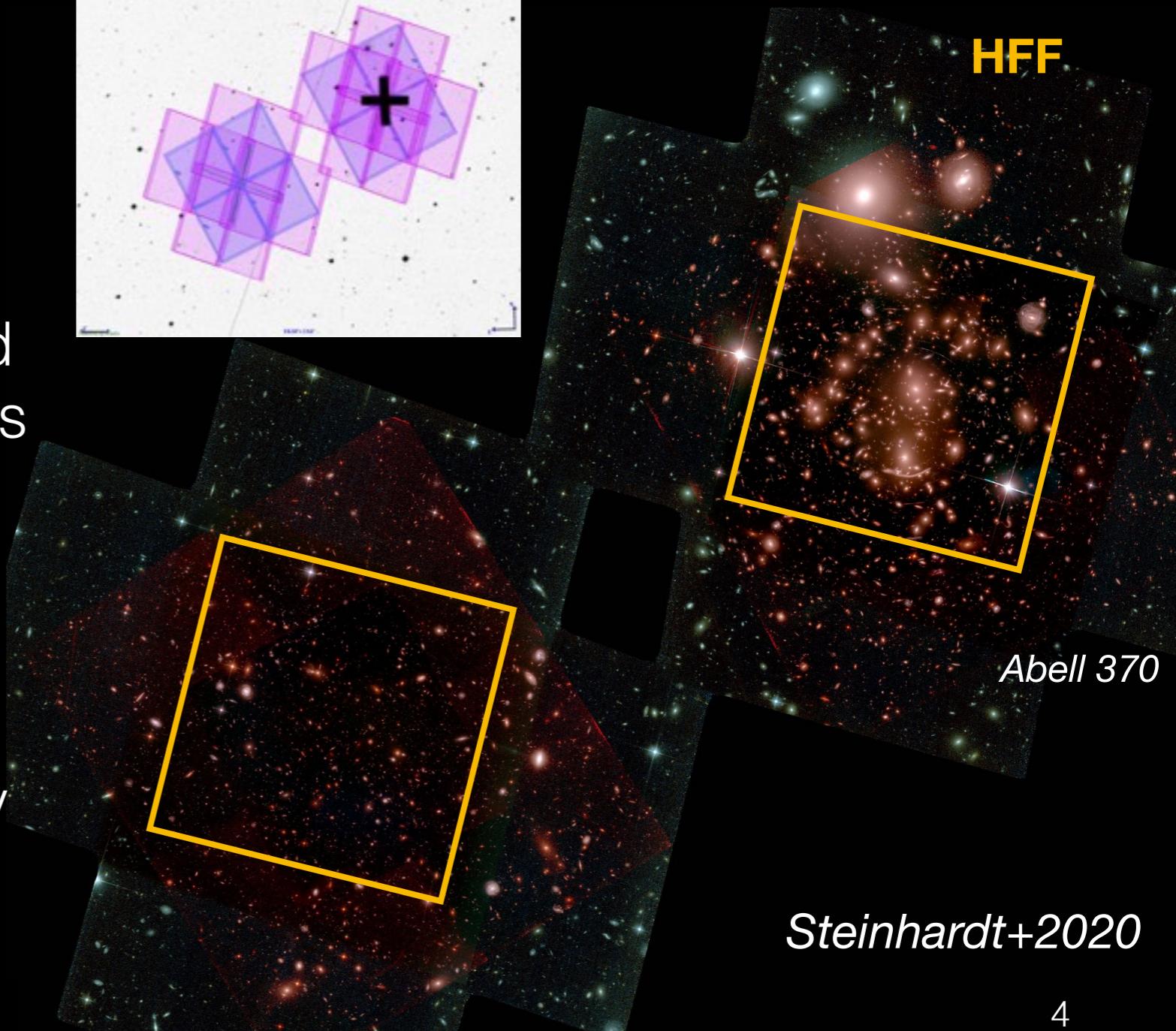
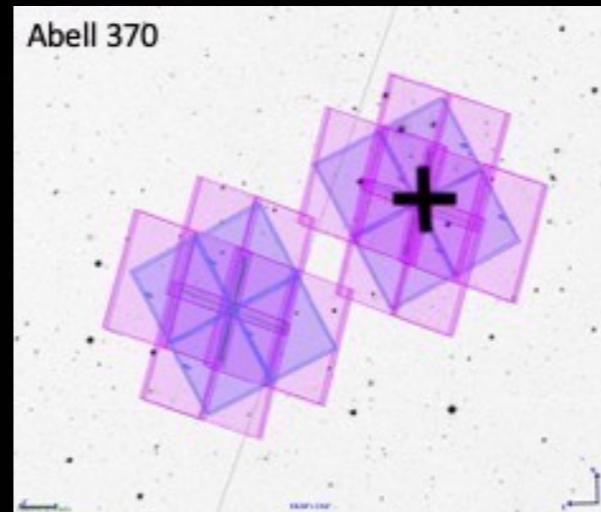
= cluster physics, galaxy evolution, dark matter, ...



BUFFalo: Beyond Ultra-Deep Frontier Fields and Legacy Observations

GO-15117, PIs: Steinhardt & Jauzac

- ▶ HFF extension :
 - ▶ 101 HST orbits
 - ▶ 2 optical filter (ACS)
+ 3 NIR (WFC3)
- ▶ **Cluster modeling** : add weak lensing constraints
 - ▶ Improve overall model (SL+WL modeling : Niemiec+2020)
 - ▶ Substructure detection
- ▶ **High-z** : area previously covered by Spitzer



Steinhardt+2020



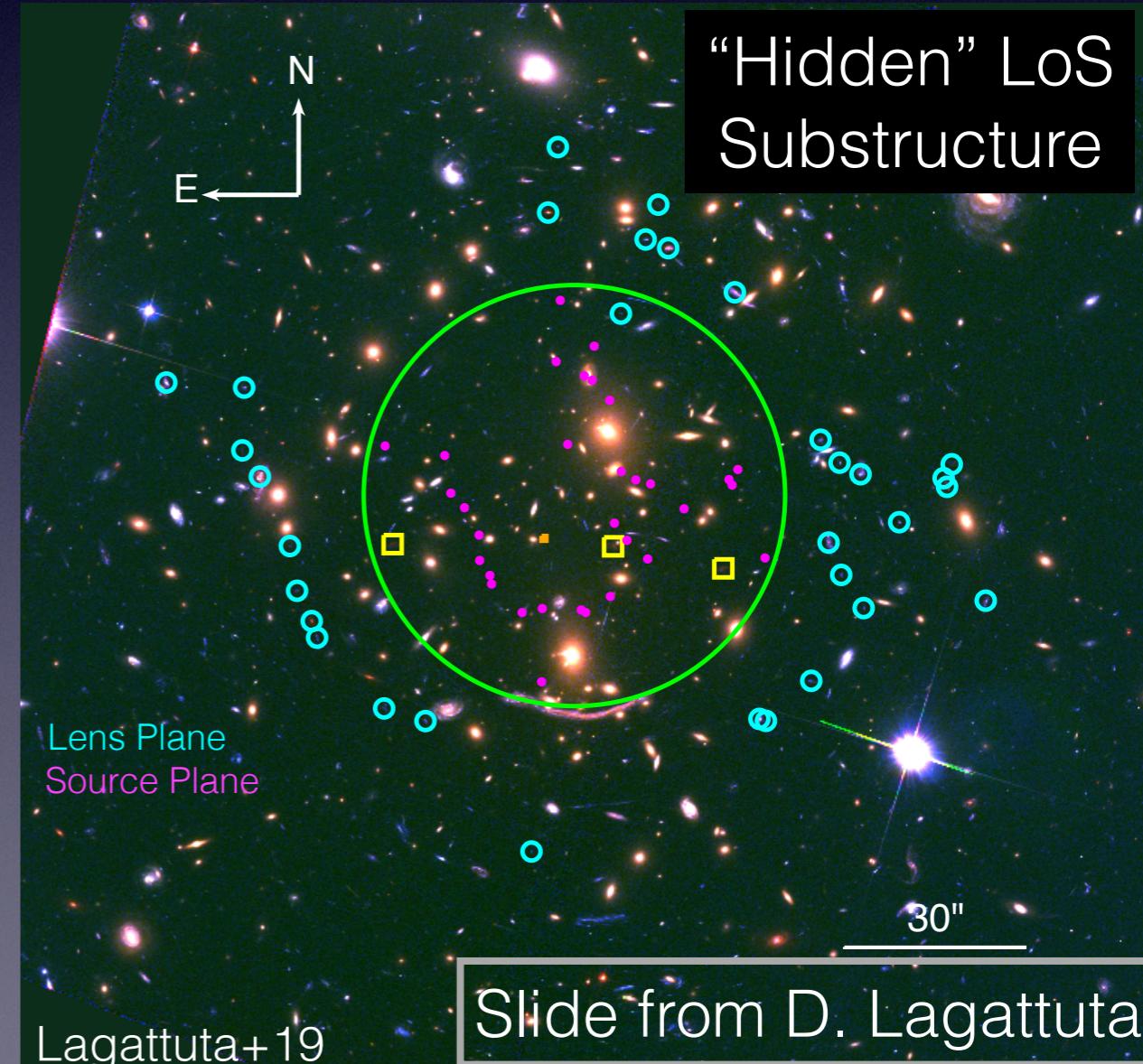
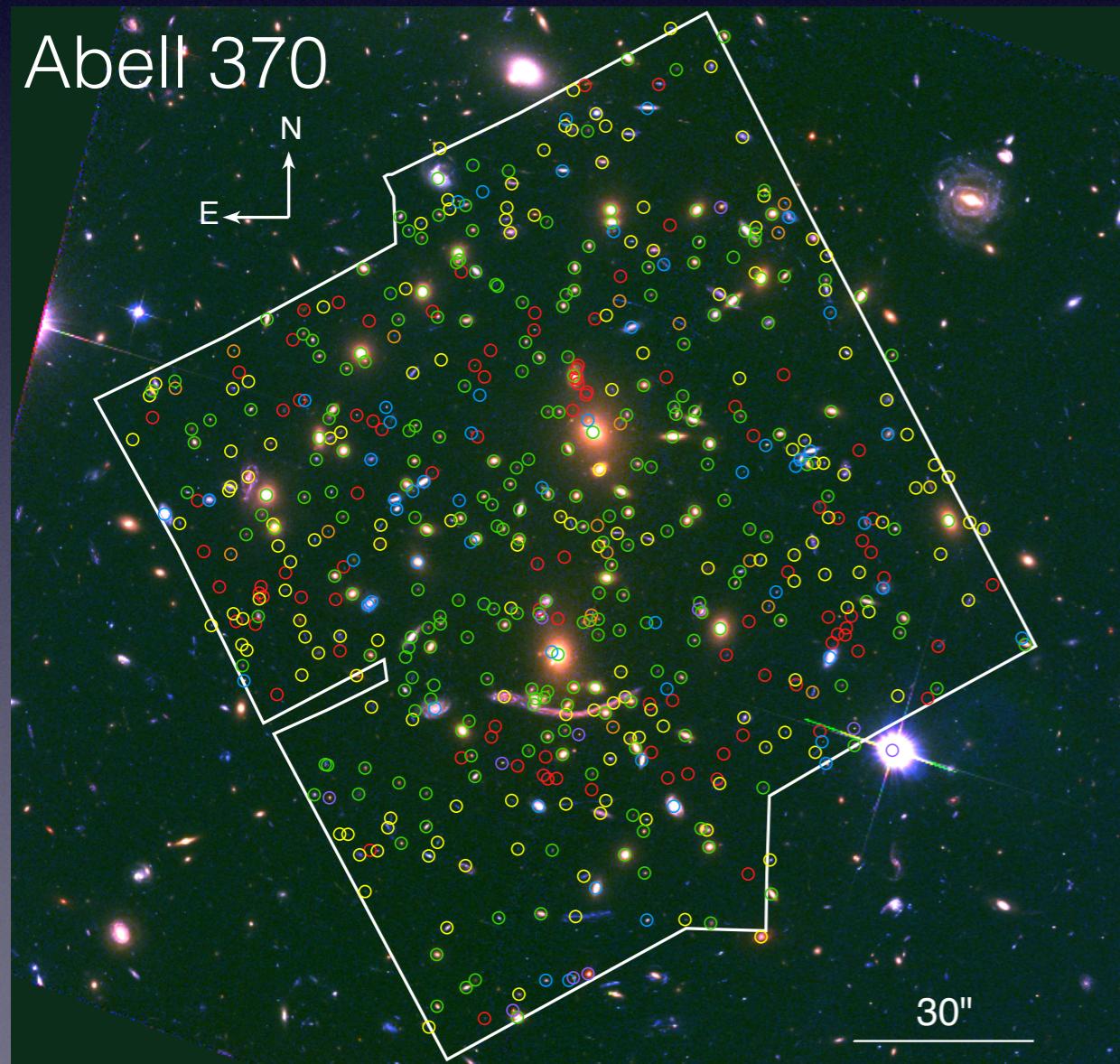
BUFFalo: Beyond Ultra-Deep Frontier Fields and Legacy Observations

- ▶ HFF extension :
 - ▶ 101 HST orbits
 - ▶ 2 optical filter (ACS)
+ 3 NIR (WFC3)
 - ▶ **Cluster modeling** : add weak lensing constraints
 - ▶ Improve overall model (SL+WL modeling : Niemiec+2020)
 - ▶ Substructure detection
 - ▶ **High-z** : area previously covered by Spitzer
-
- Physical processes in galaxy clusters
 - Dark matter halo shape
 - Substructure mapping
 - Intra-cluster light
 - Galaxy evolution in clusters,
...
- High redshift quiescent galaxies
 - UV luminosity function
 - SFR-stellar mass relation at $z \sim 7$, ...

Expanding the Spec-z footprint

David Lagattuta, Johan Richard, Franz Bauer

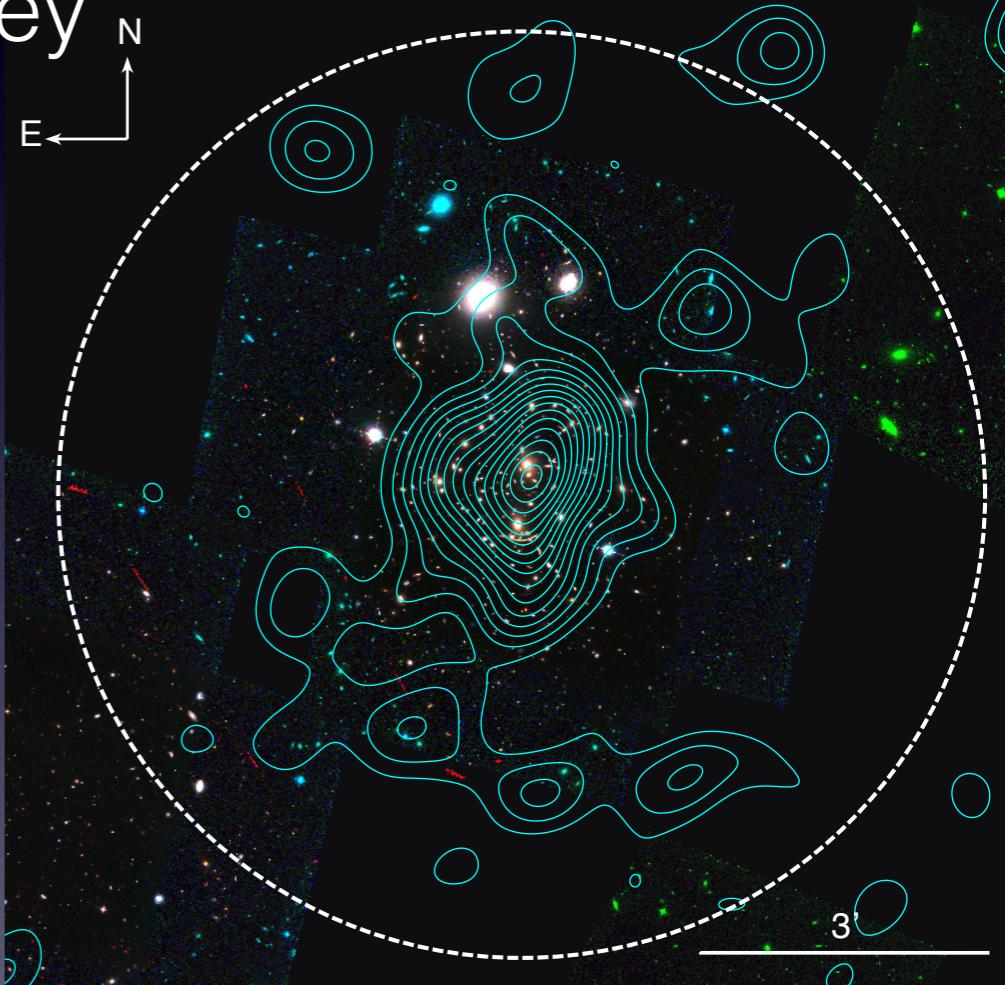
- BUFFALO is a powerful data set
 - BUT...imaging is only part of the story
- Wide-area spectroscopy reveals important cluster features
 - MUSE is leading the way



Taking flight

- Why not use the BUFFALO approach with spectroscopy?
- New idea: the BUFFALO-WINGS project
 - Wide-area INtegral-field Galaxy Survey

Ideal for confirming additional cluster mass components



+



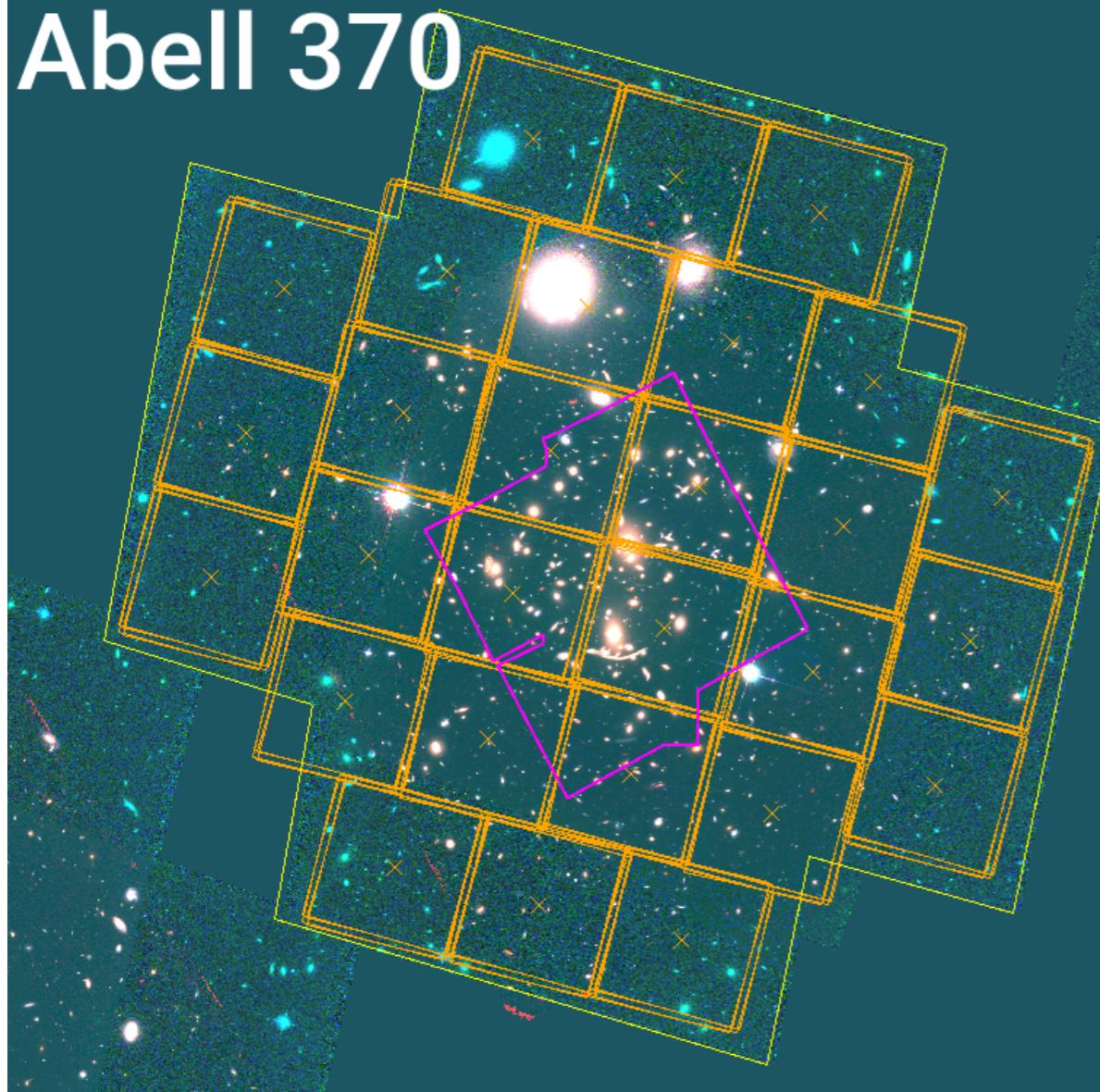
=



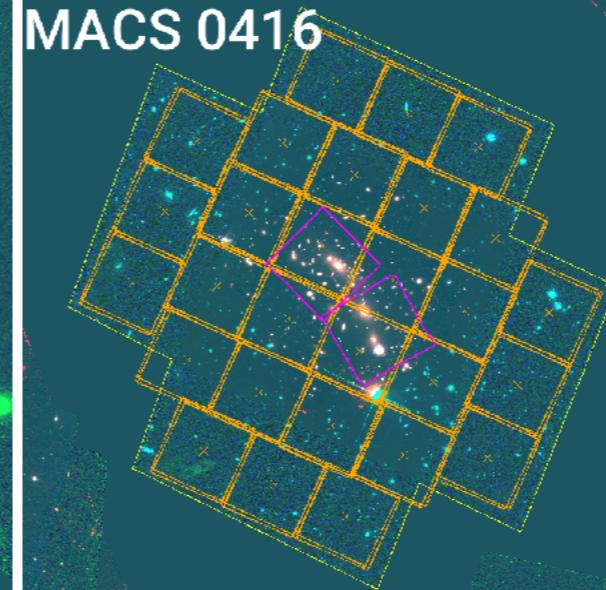
Existing data: 4-8 hr depth
BUFFALO-WINGS: 2 hr depth

Survey Design

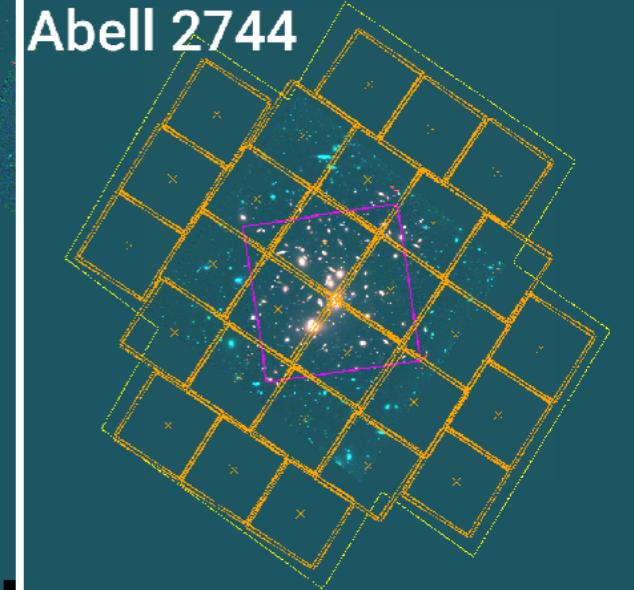
Abell 370



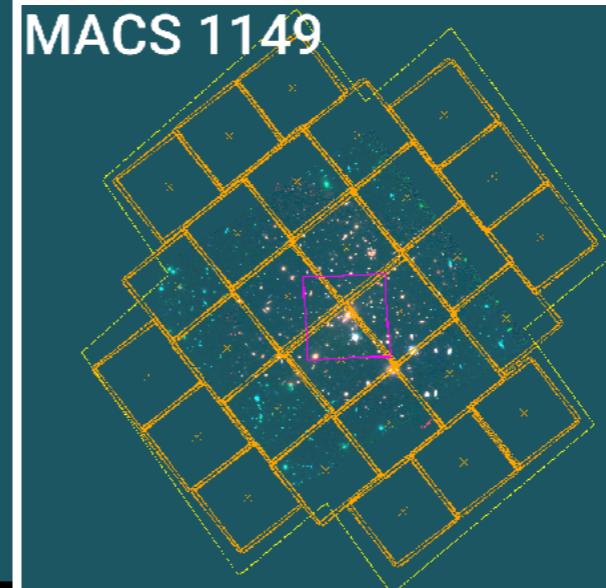
MACS 0416



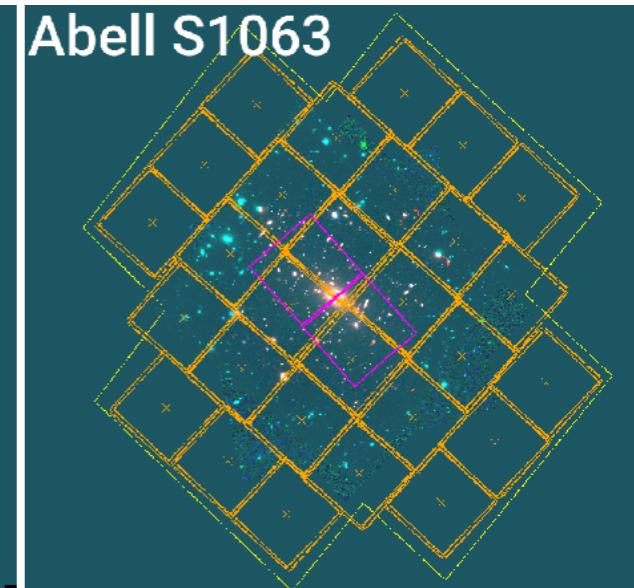
Abell 2744



MACS 1149

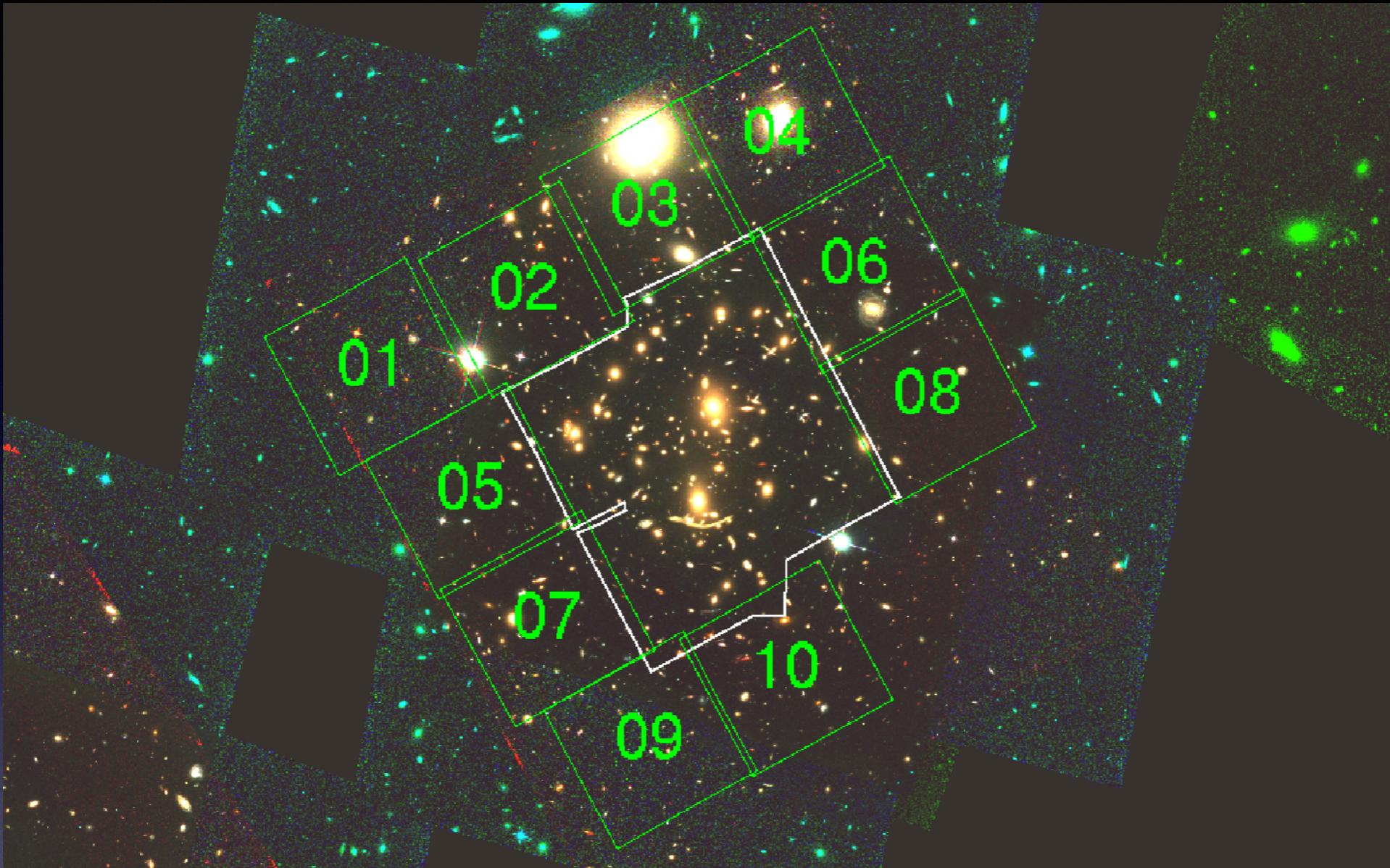


Abell S1063



- Optimally fills BUFFALO footprint
 - 5 clusters possible (MACS0717 too far North for Paranal)
- Complements existing MUSE data
 - Can provide **~6000** new redshifts between $z = 0$ and $z = 6.7$

Pilot Program



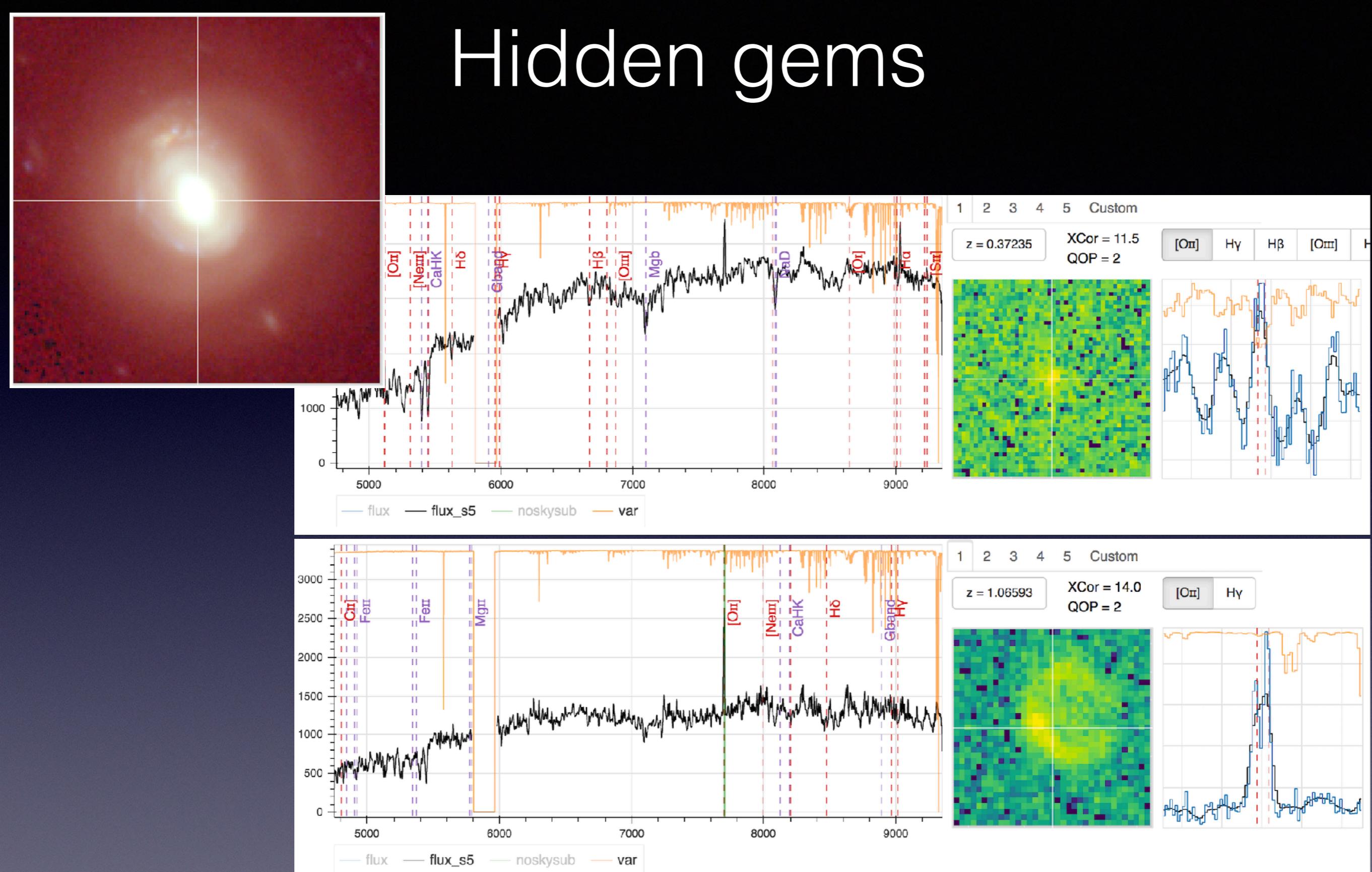
- Initial pilot survey of A370 already underway
 - Shallower pointings (1 hour), not optimally tiled
- Designed to test feasibility of full survey

Preliminary Results



- Analysis ongoing, but some interesting results already

Hidden gems



- Power of MUSE also reveals hidden galaxy-galaxy lenses not identified in HST

Slide from D. Lagattuta

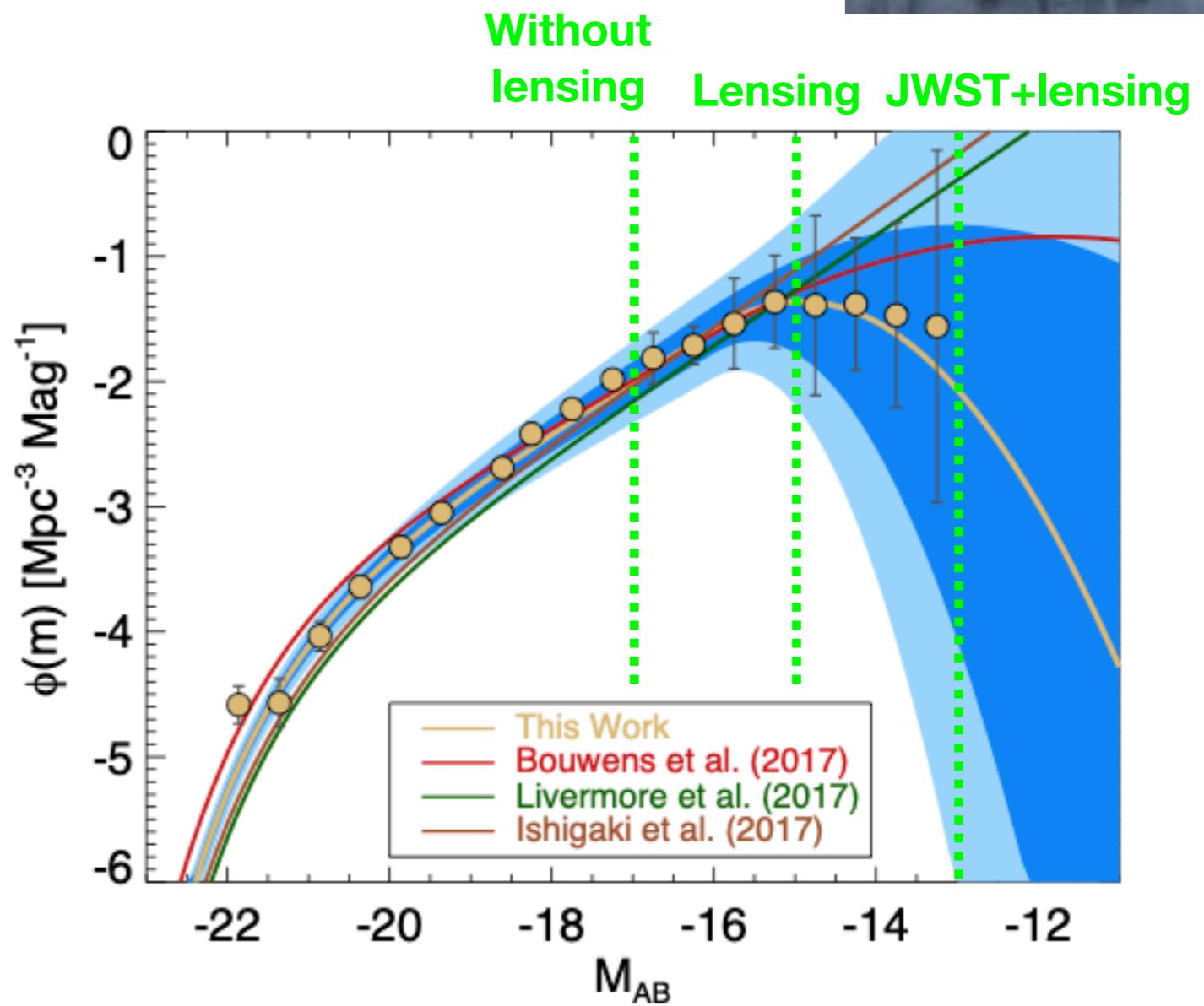
Probing the low-mass end of the $z \sim 6 - 7$ stellar mass function

Lukas J. Furtak, Hakim Atek, Matthew D. Lehnert,
Jacopo Chevallard & Stéphane Charlot



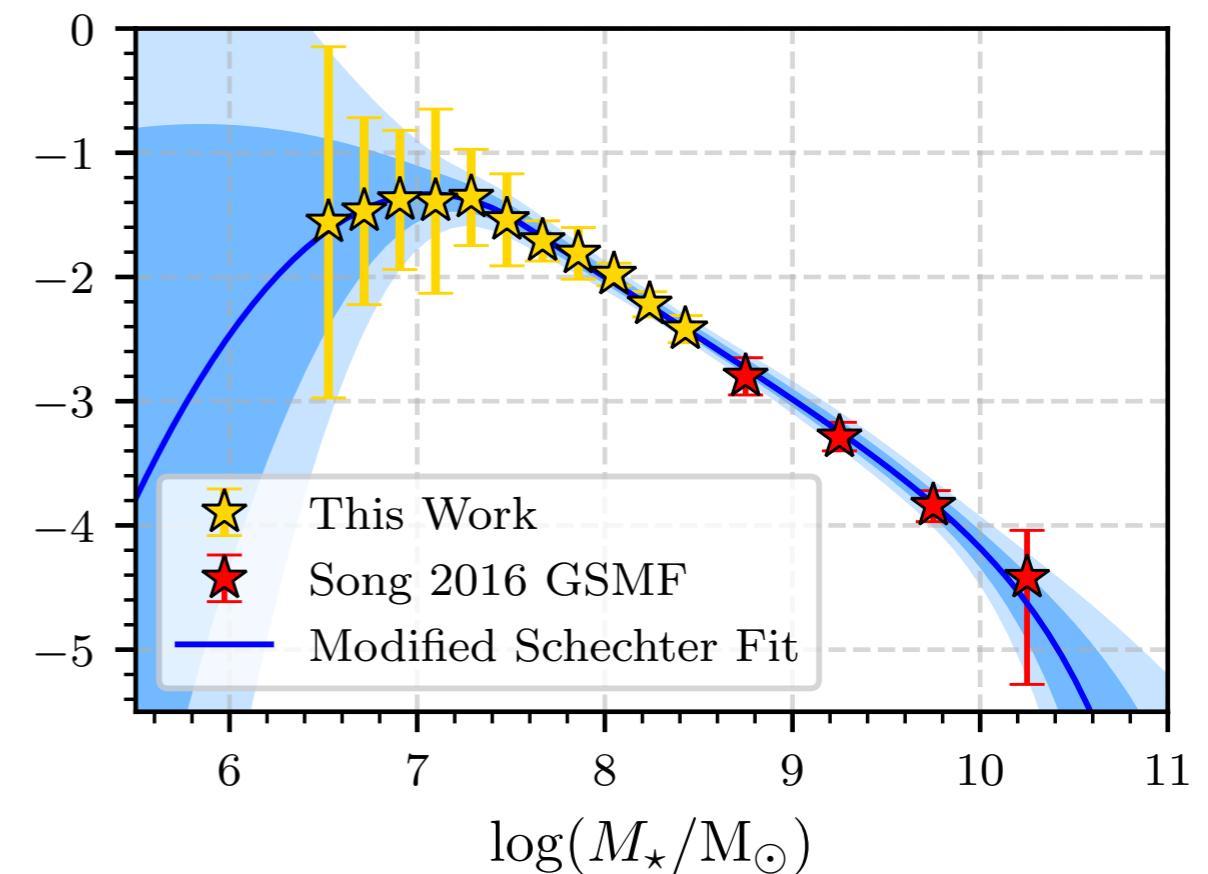
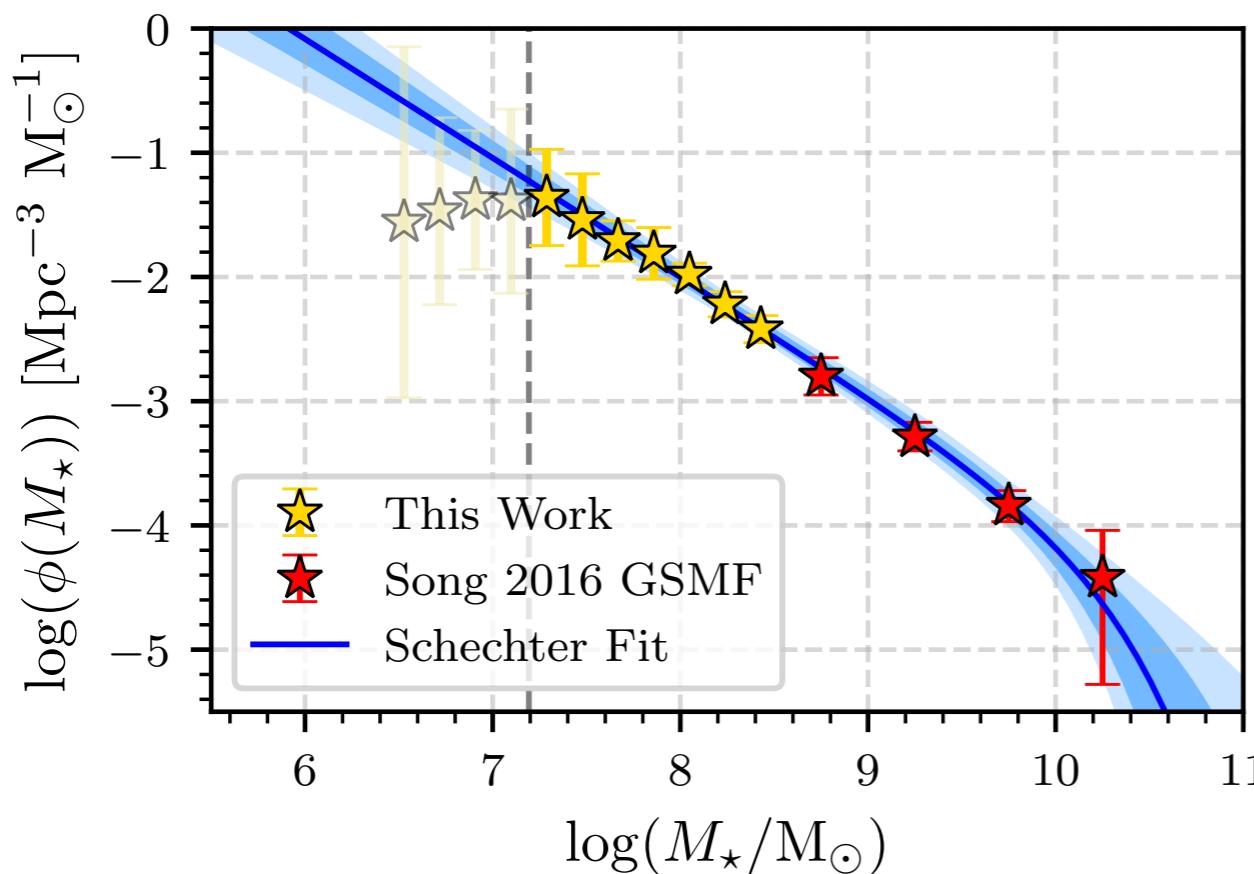
- Use **Gravitational lensing** in massive galaxy clusters to observe the very faint objects

- *Faint:* $m_{F125W} \gtrsim 26$
- Only Space-based observations with HST
- Lensing systematics introduce (very) large uncertainties on the faint low-mass end!



The $z \sim 6 - 7$ stellar mass function

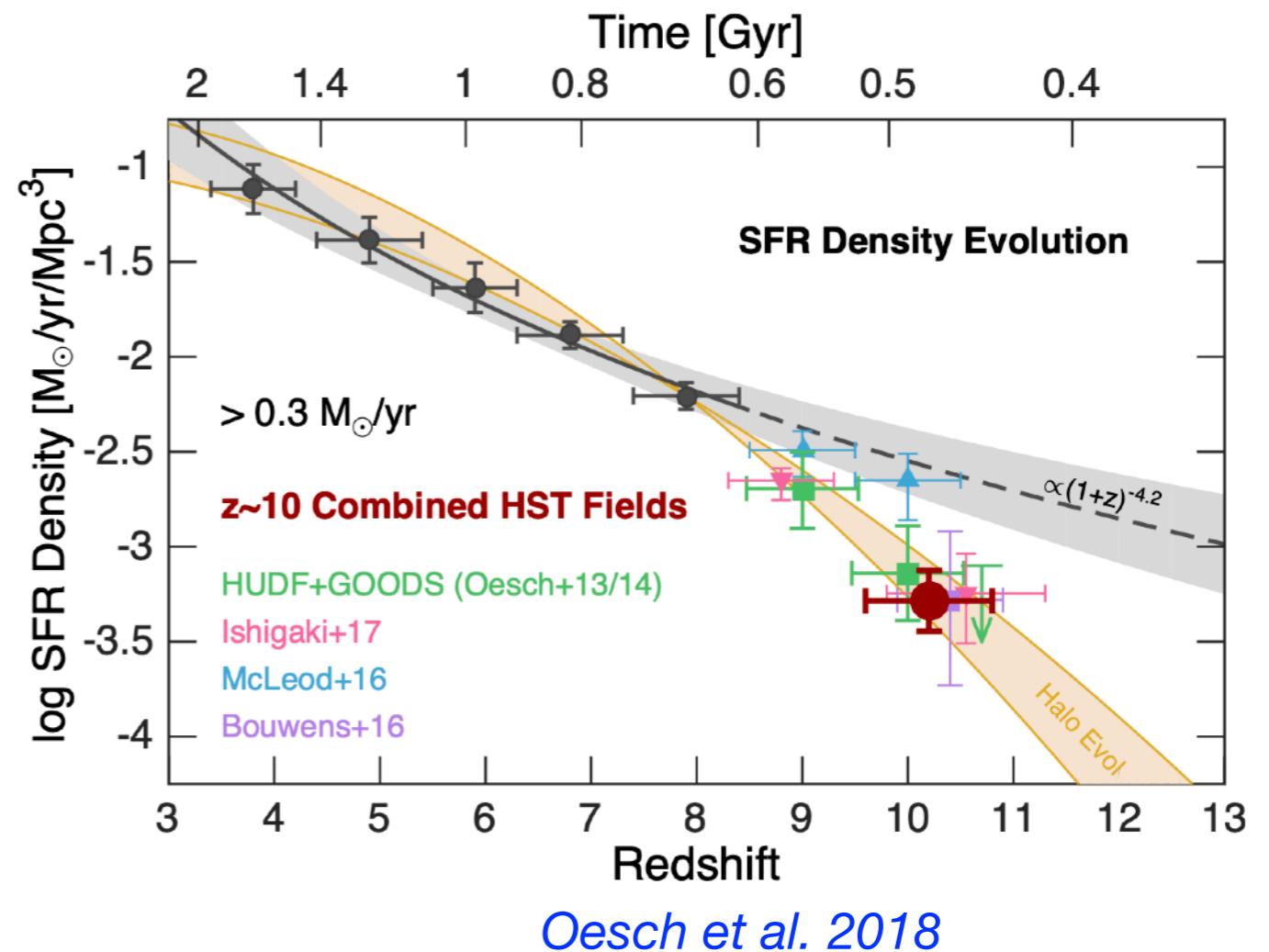
- Convert [Atek et al. 2018](#) UV LF to SMF and combine with [Song et al. 2016](#) high-mass end results
- Turnover at $M_T \sim 10^7 M_\odot \rightarrow$ Though uncertain because of lensing uncertainties on the low-mass end!



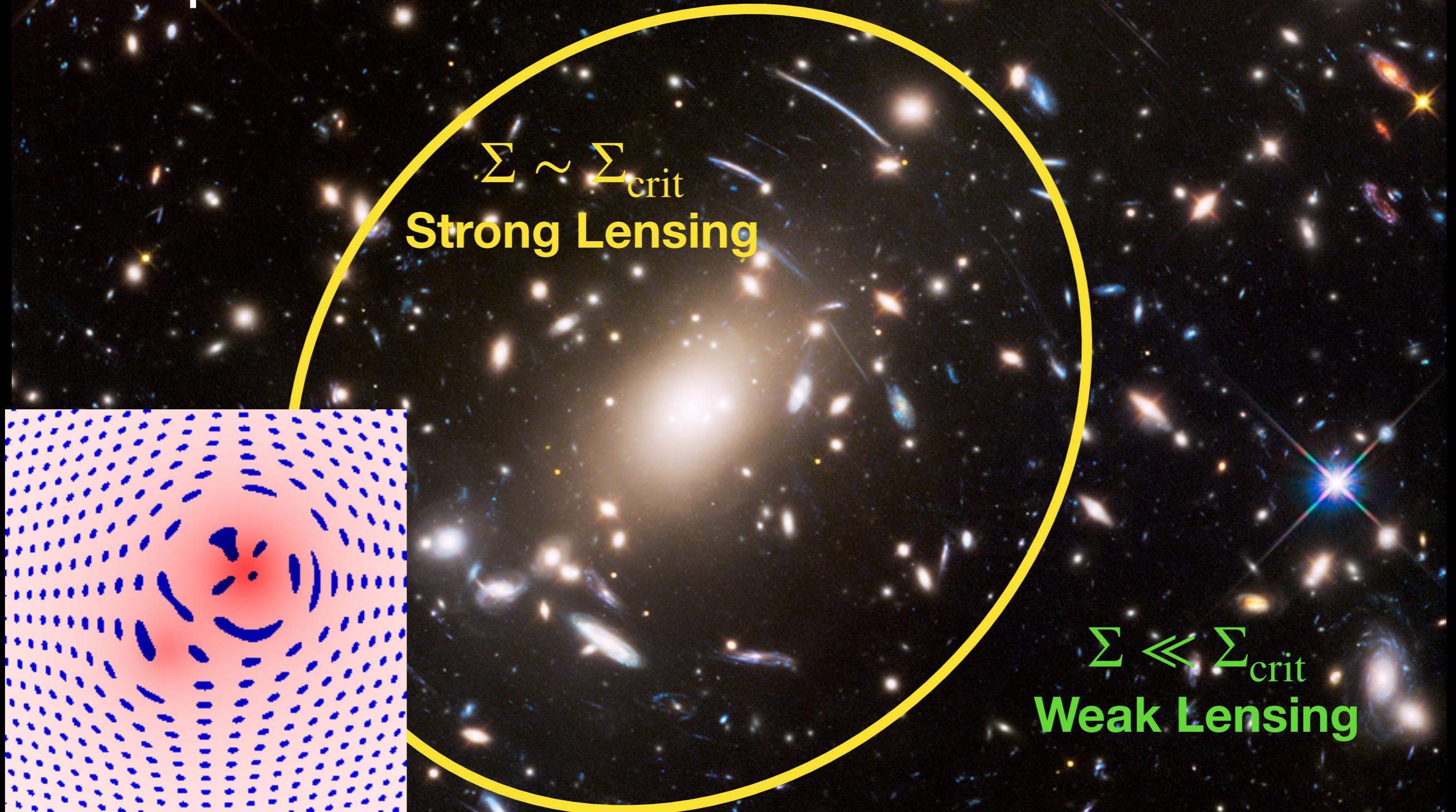
Furtak et al. 2020 (in press)

Outlook — BUFFALO High-redshift stellar mass functions

- Beyond Ultra-deep Frontier Fields And Legacy Observations (BUFFALO) survey ([Steinhardt et al. 2020](#))
 - Increase the spatial coverage around the HFF clusters by factor $\times 4$
 - Increase $z \sim 6 - 7$ sample size on the bright/massive end (by factor ~ 2)
 - Detect large $z \sim 8 - 9$ (maybe $z \sim 10$) galaxy samples
 - Develop stellar mass completeness simulations
- Goals: UV luminosity and stellar mass functions out to $z \sim 10$!



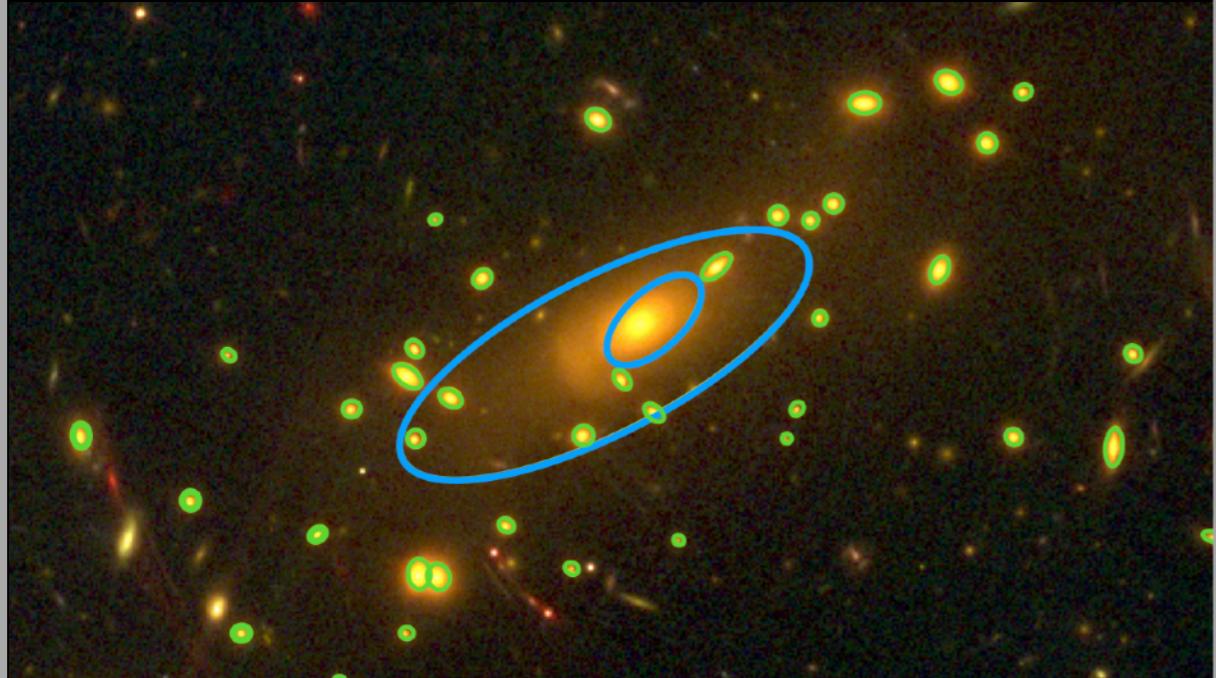
Gravitational lensing to probe matter distribution



→ Model cluster projected mass distribution with SL and/or WL constraints

Cluster mass modeling

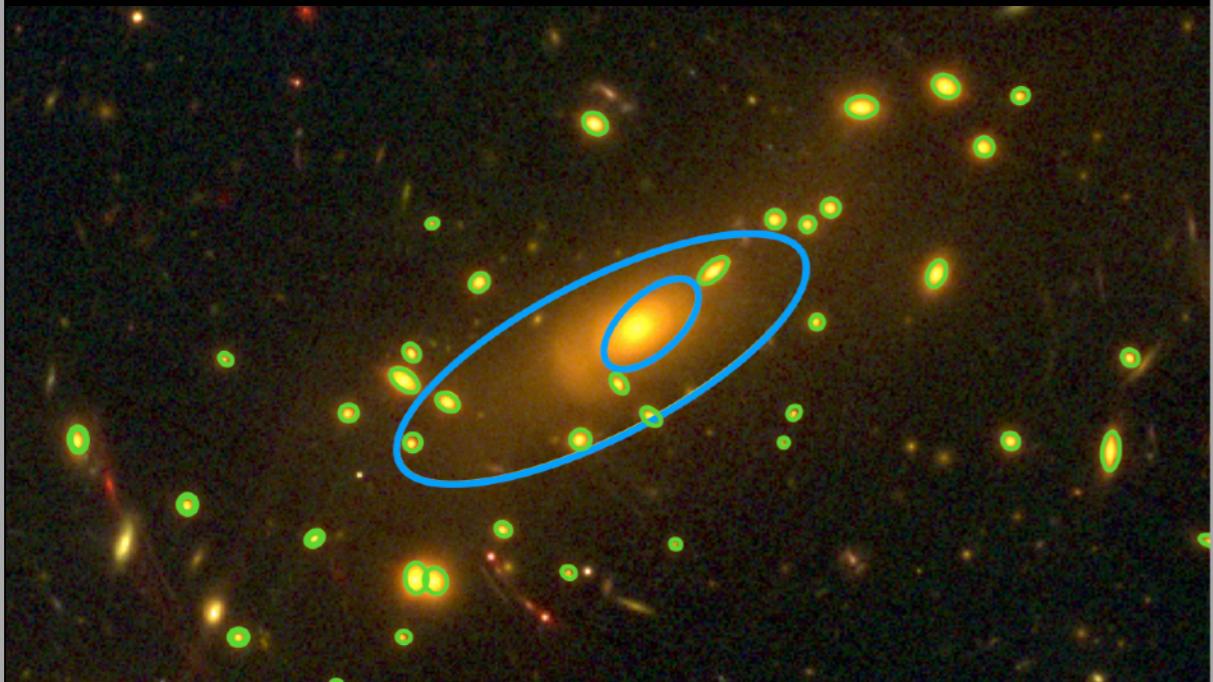
Parametric mass modeling



- Physically motivated mass components
- Sparse distribution of SL constraints
- Ex: Glafic (*Oguri+2010*), LTM (*Zitrin+2012*), GLEE (*Suyu+2010*), Lenstool (*Jullo+2007*)...

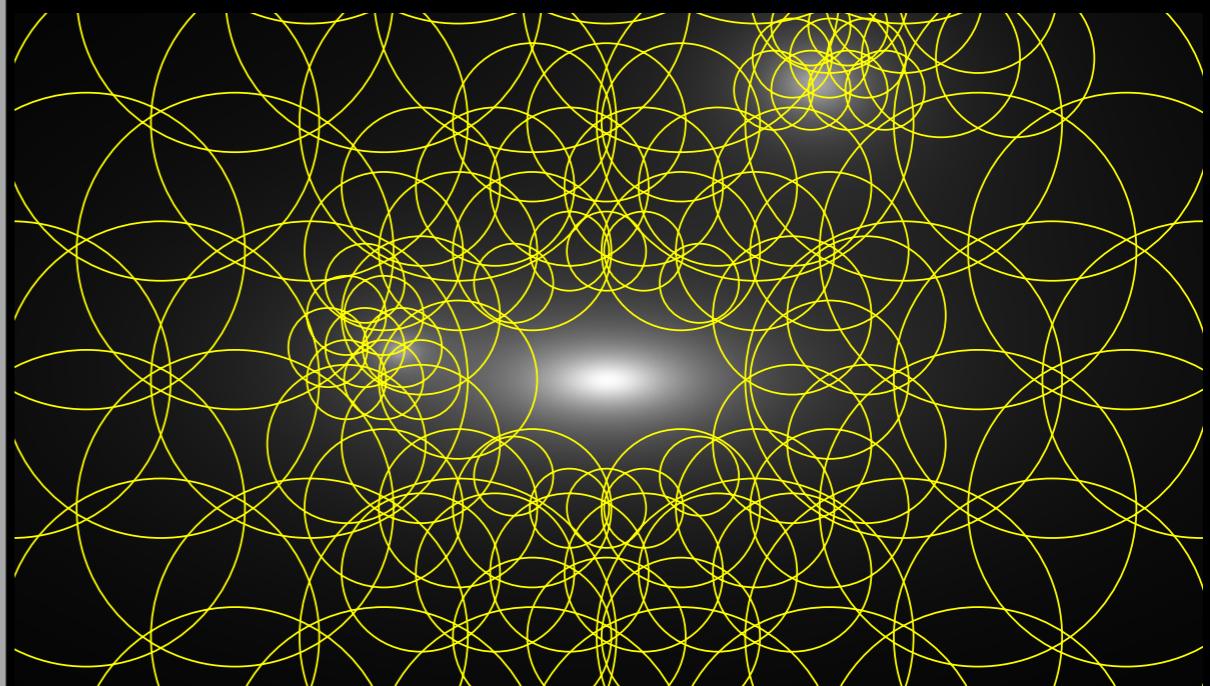
Cluster mass modeling

Parametric mass modeling



- Physically motivated mass components
- Sparse distribution of SL constraints
- Ex: Glafic (*Oguri+2010*), LTM (*Zitrin+2012*), GLEE (*Suyu+2010*), Lenstool (*Jullo+2007*) ...

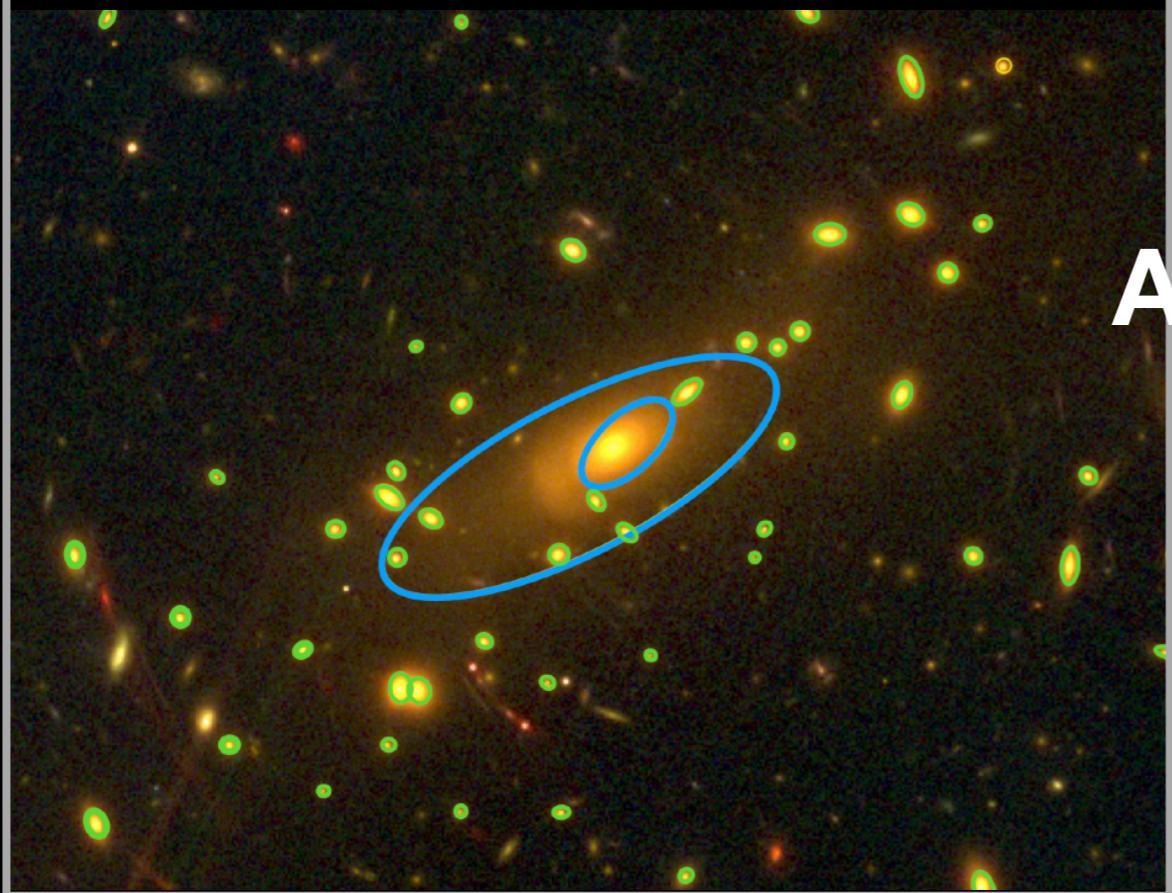
Free-form mass modeling



- 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 (*Jullo+2009*) ...

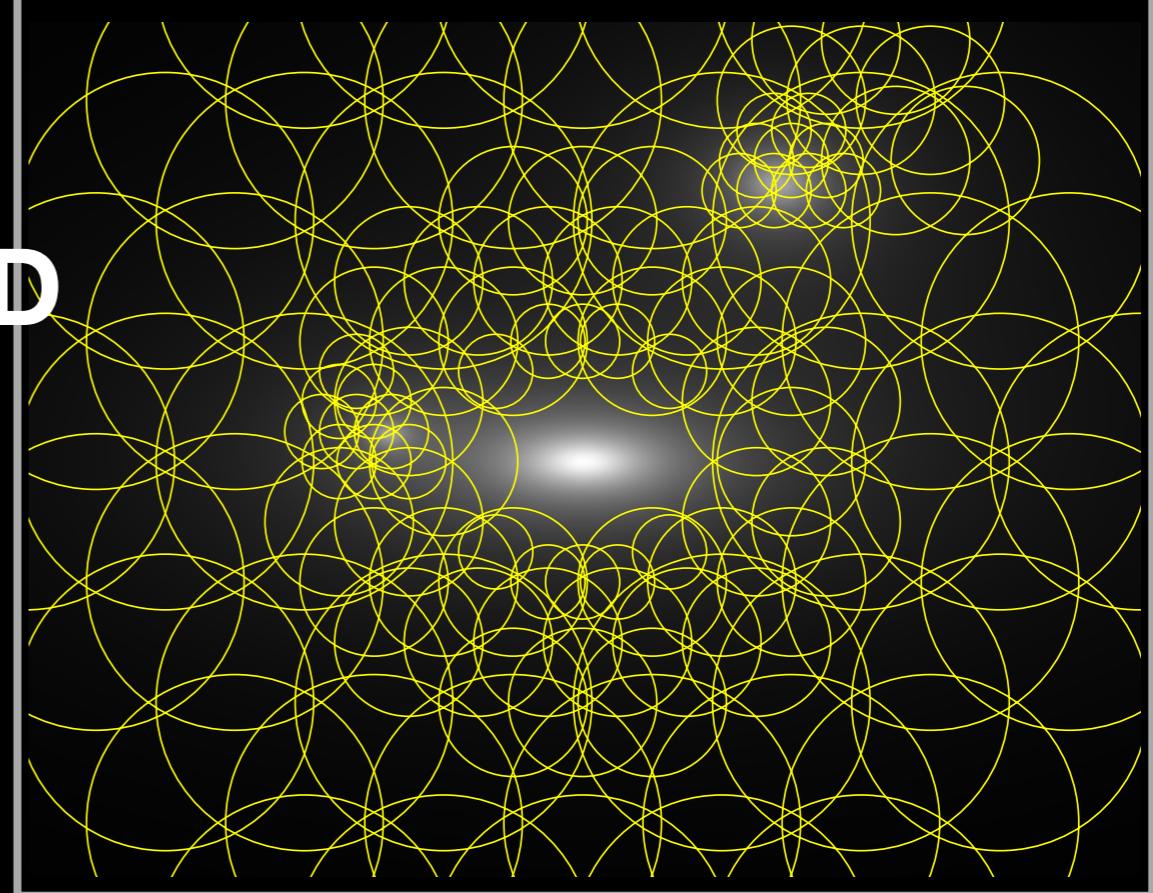
hybrid-Lenstool mass modeling

- Cluster core:
parametric model



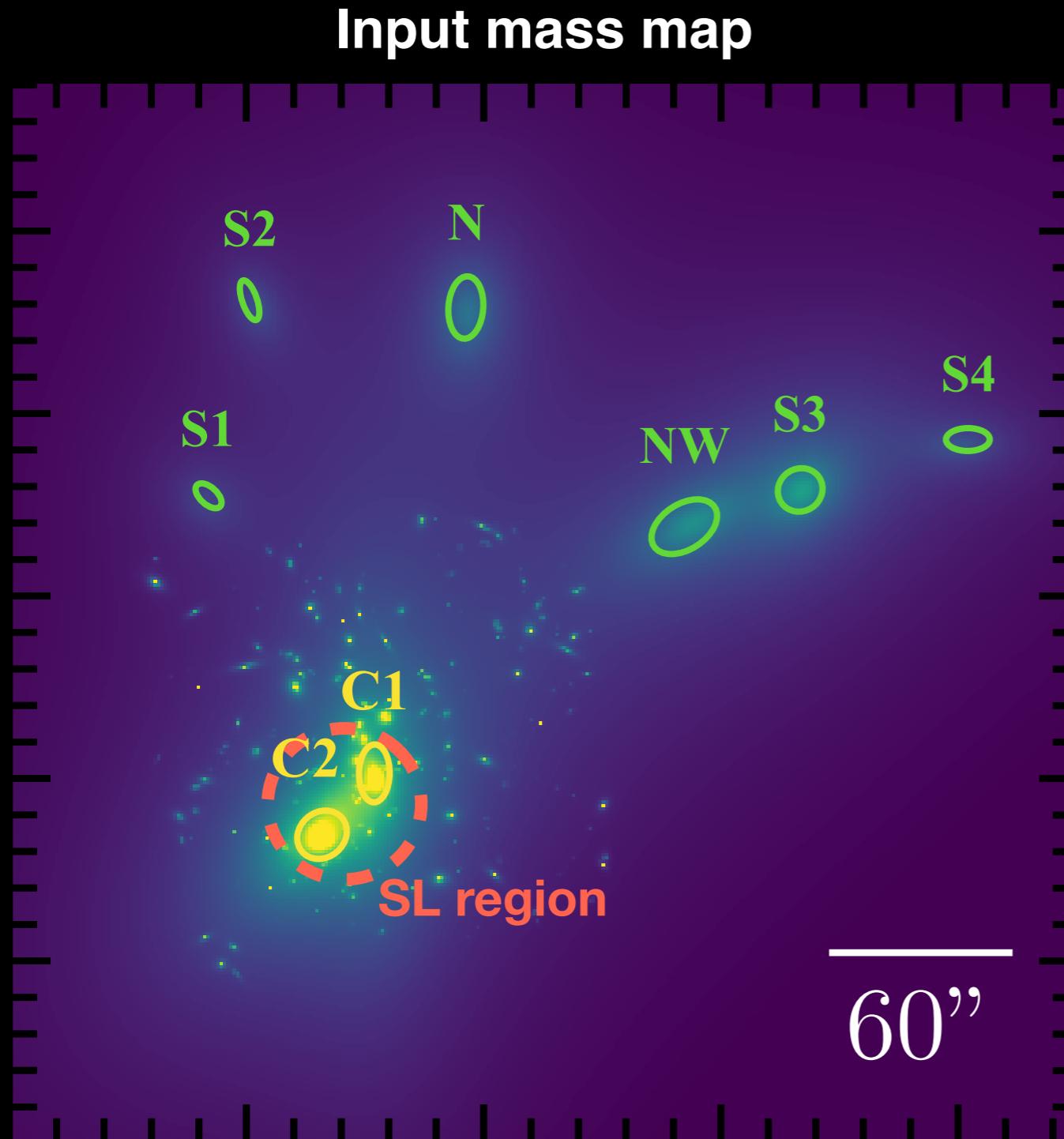
AND

- Outskirts:
non-parametric



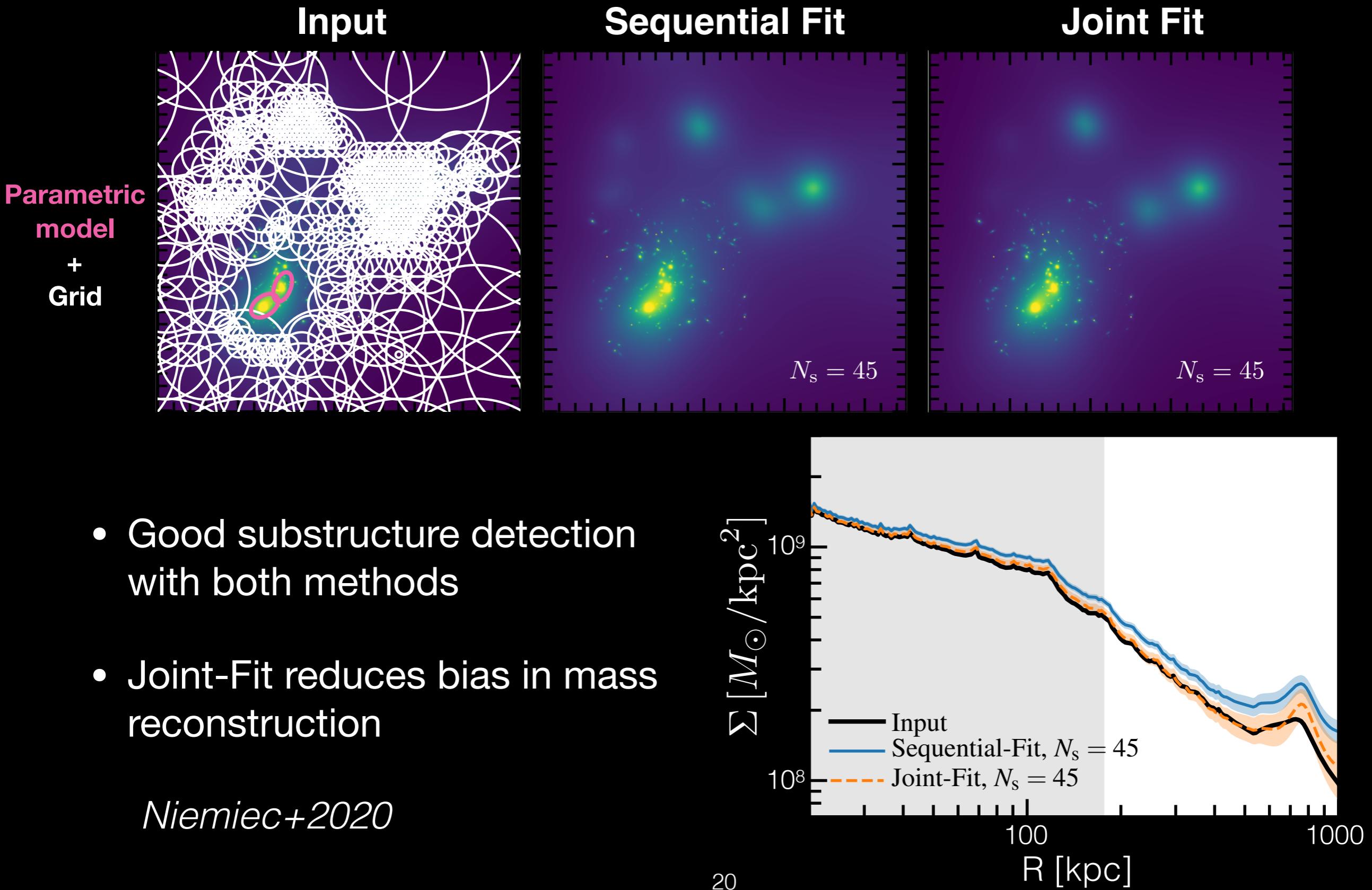
—> **Hybrid-Lenstool : combine parametric + grid and optimize both simultaneously with SL and WL constraints**

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





BUFFalo

- ▶ All clusters completed, stay tuned !

- ▶ More info :

[https://buffalo.ipac.caltech.edu/
Steinhardt+2020](https://buffalo.ipac.caltech.edu/Steinhardt+2020)

- ▶ Follow us



@buffalo_survey



@buffalosurvey

