Using gravitational telescopes to probe the faint and distant Universe

Gabriel Bartosch Caminha, et al.

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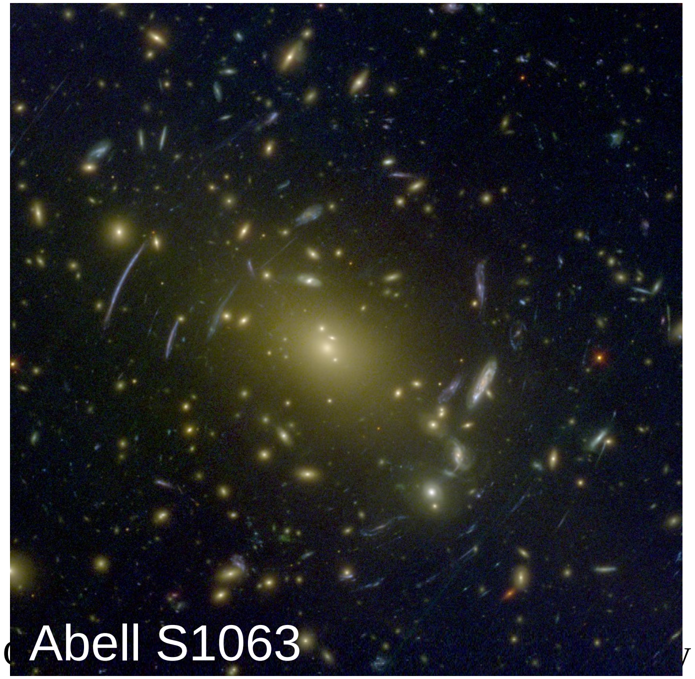
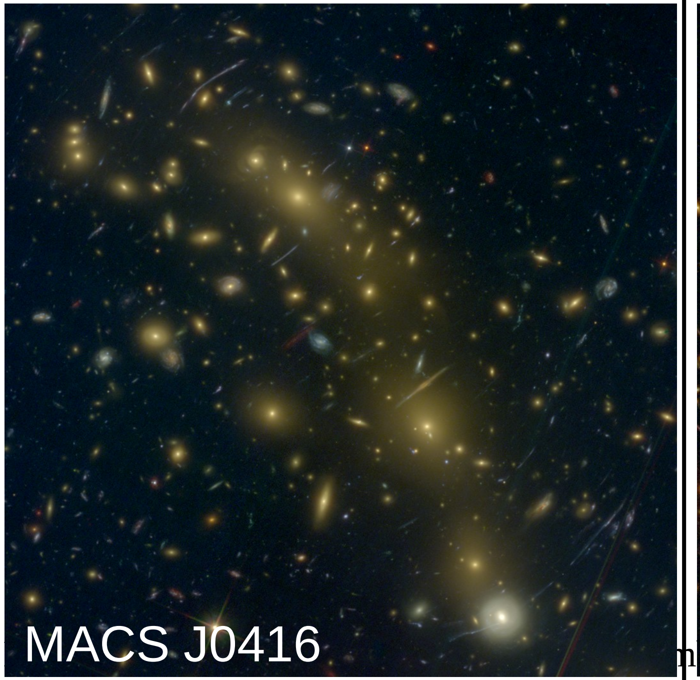
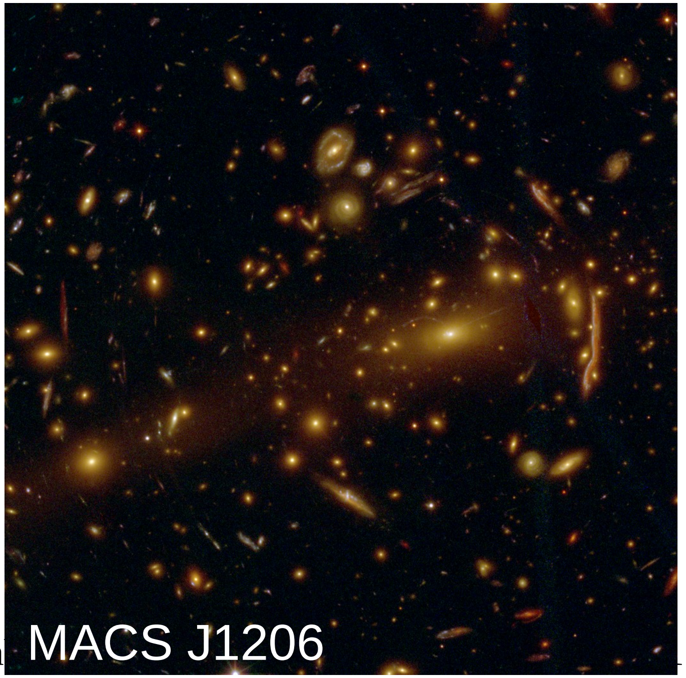
Hubble Frontier Fields

CLASH-VLT



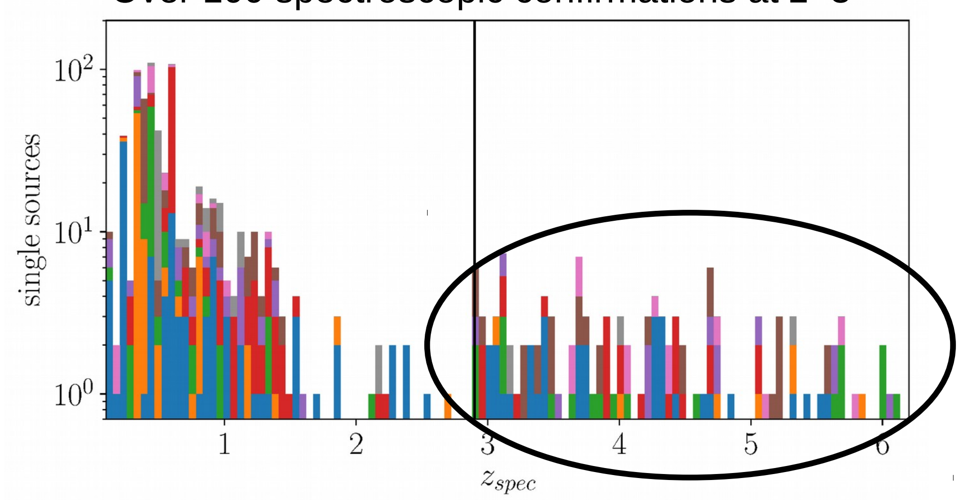




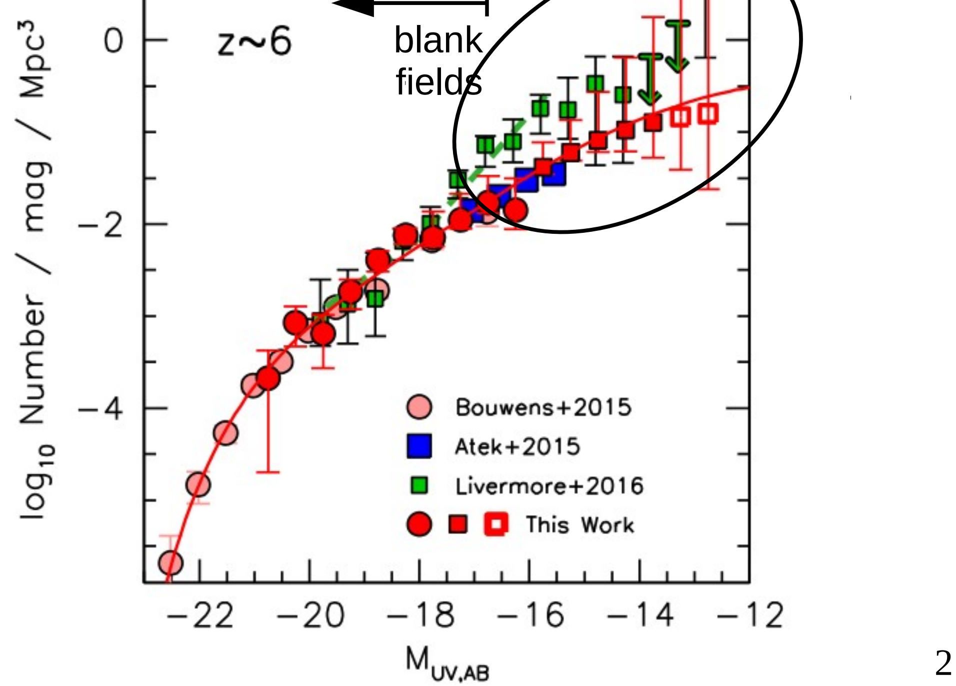
MUSE observations of lensing clusters

- Faint and high-z sources
  - Important sources for the cosmic reionization and to understand of star formation in the early and faint Universe
- Narrow area, but deep → Faint/common sources; complementary to works on non lensing fields
  - We probe around 5% of the original field of view for z=5 and μ > 10
  - log Lyα[erg/s] > 40 – 41, for regions with μ ~ 5-10
    - In regions with extreme magnifications (μ > 50) we can reach fainter detections
- Highly precise magnification maps can be achieved by combining deep MUSE spectroscopy in the core and high resolution photometric data HST.

Over 100 spectroscopic confirmations at z>3



Density of Lyman-break galaxies
Bouwens+2017 Strong lensing fields (HFF)



Galaxy cluster strong lensing (S.L.)

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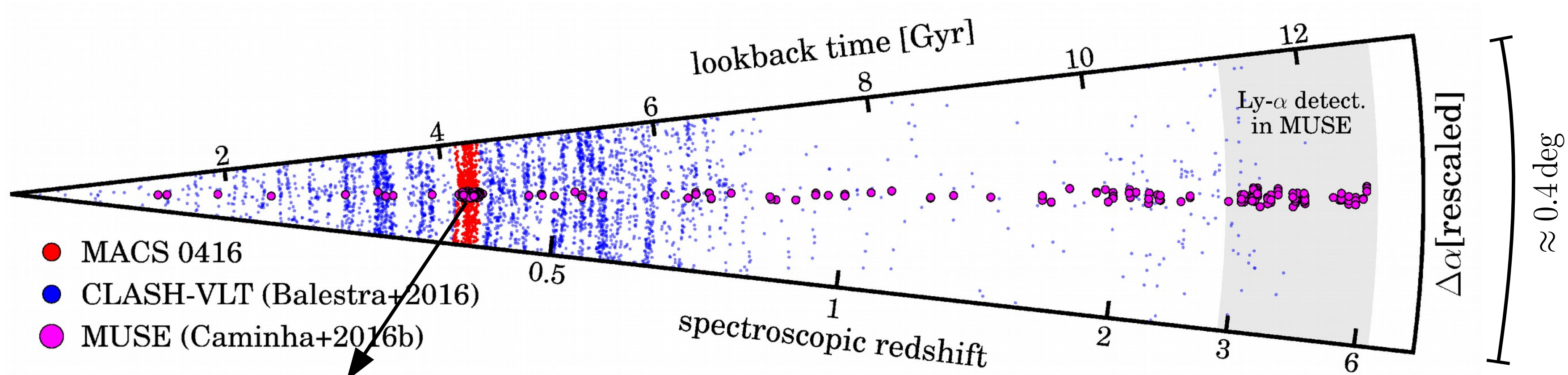
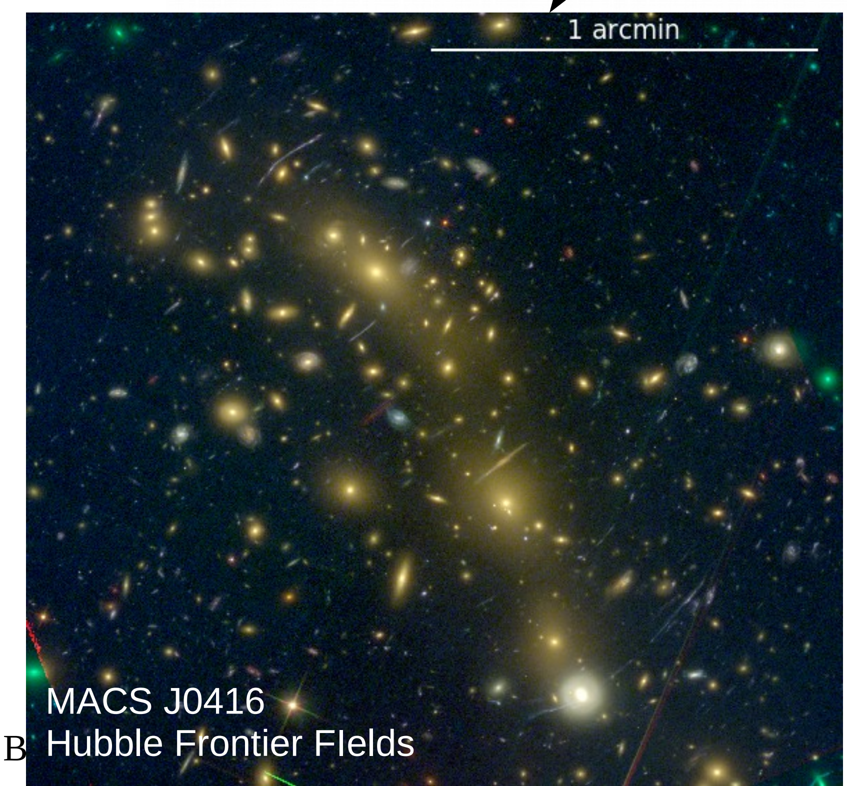
- Galaxy cluster strong lensing (SL):
  - Magnification of background sources over “large” volumes
  - Can overcome blank fields in terms of S/N (magnification μ against $\sqrt{t_{exposure}}$)
    - Accurate SL models need extensive spectroscopy → constrain the mass distribution





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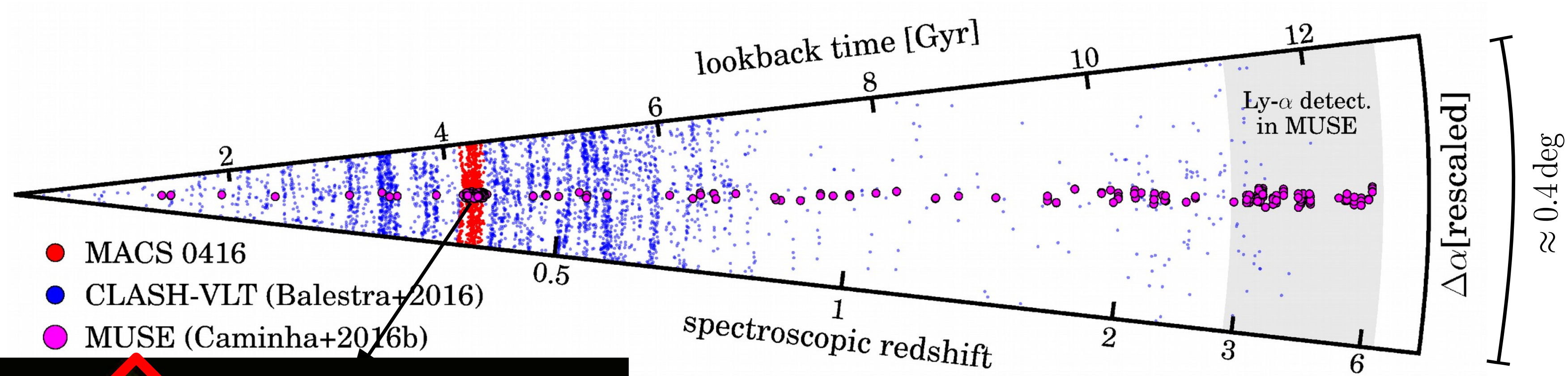

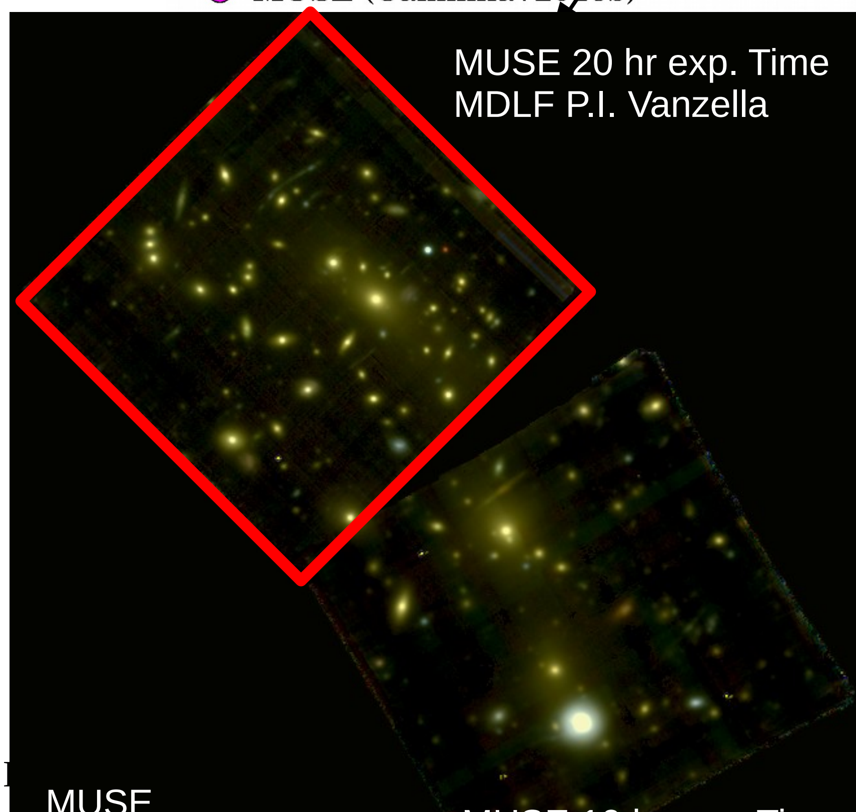

The Multi Unit Spectroscopic Explorer (MUSE)

Integral field spectroscopy over an area of 1 sq-arcmin

- No source pre-selection over this large are

Wavelength coverage of 4750Å – 9350Å

- Can confirm sources at redshifts out to z=6.7

Spatial pixel size of 0.2 arcsec, psf limited 0.6–1.0 arcsec

- Can spatially resolve emission lines

Spectral resolution of ~2.3 Å

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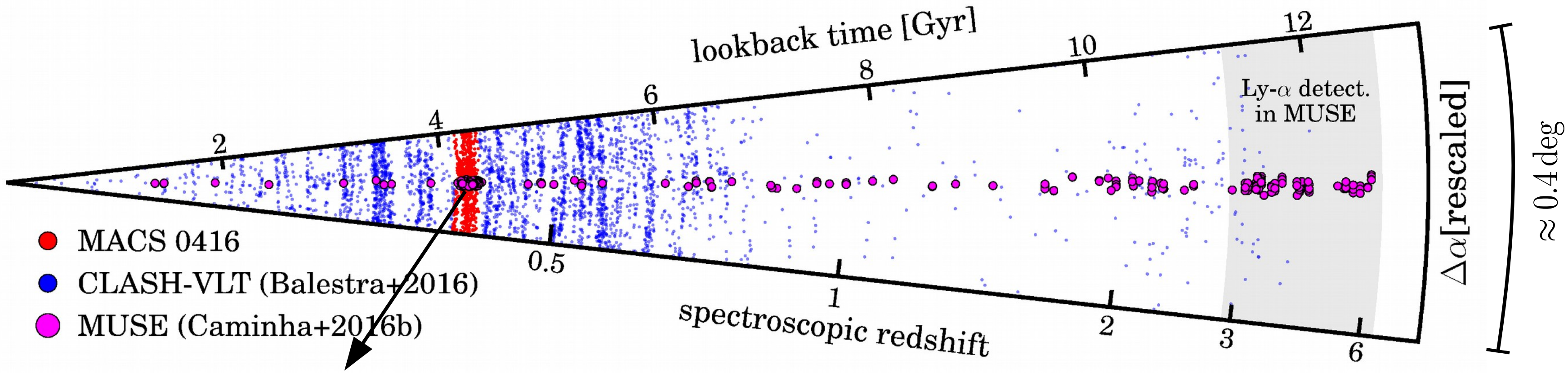

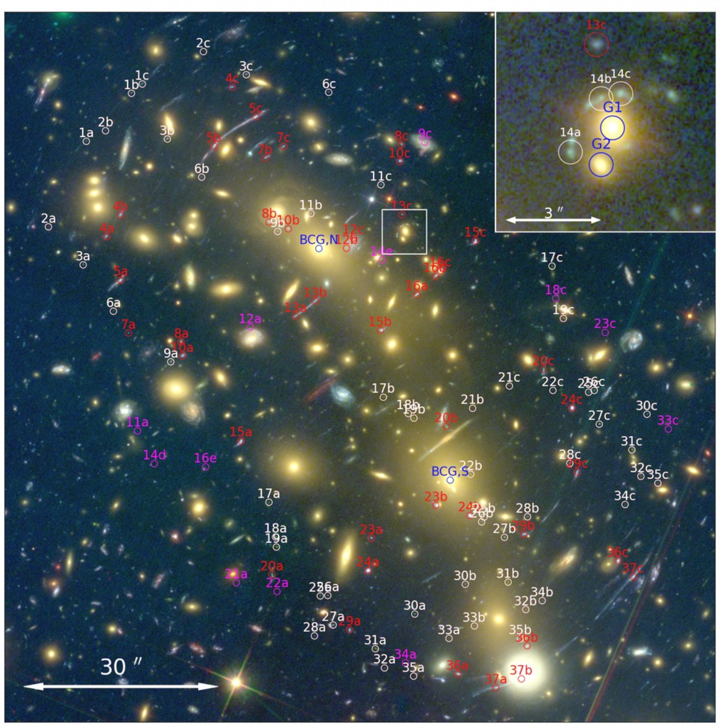

- Multiple images from the same source are the constraints of the SL model
- Members selection based on extensive spectroscopy
- Modelling using *lenstool*
  see Caminha+2017 A&A 600, A90

Increased number of strong lensing constraints

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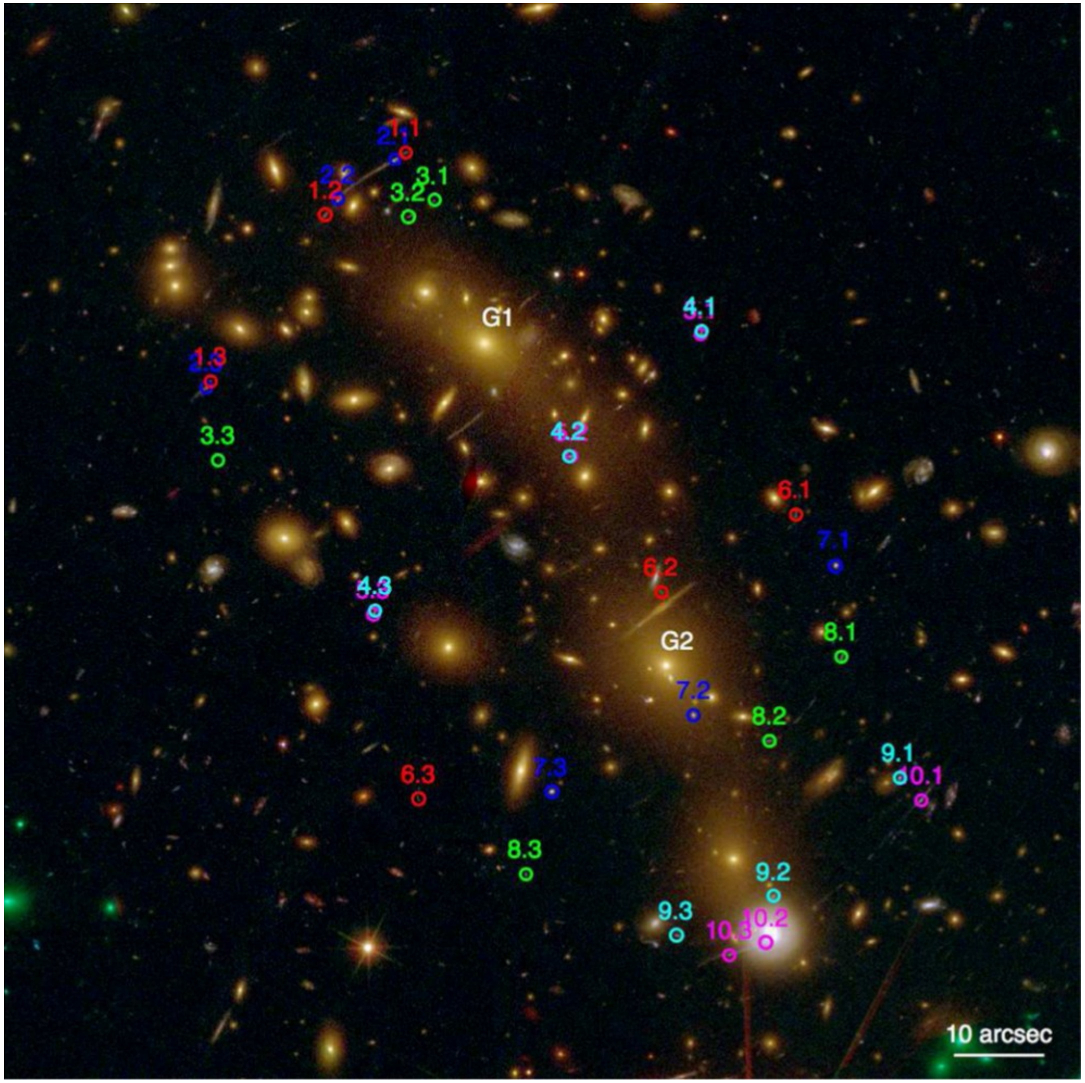

Grillo+ 2015 (ApJ, 800, 38)

- We use 10 multiple image families with spectroscopic confirmation from CLASH-VLT
- 15 families including GLASS measurements

Increased number of strong lensing constraints

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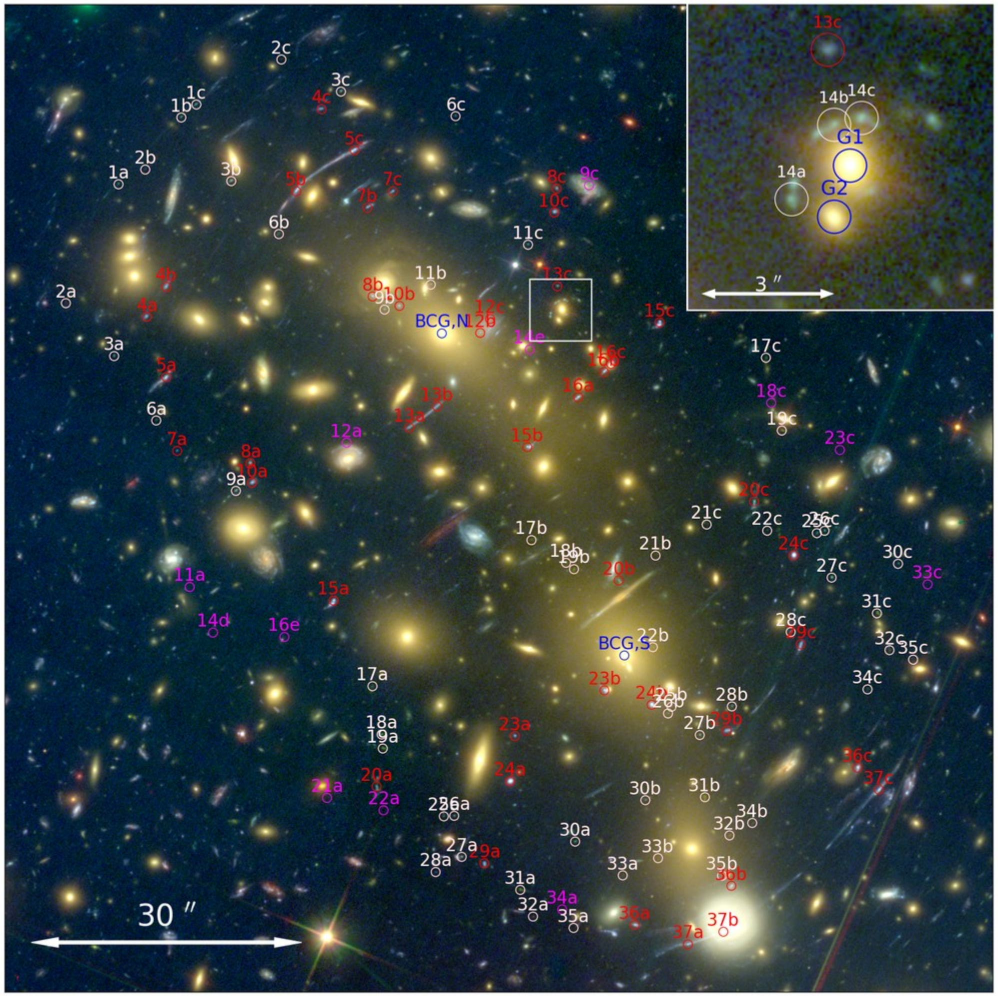

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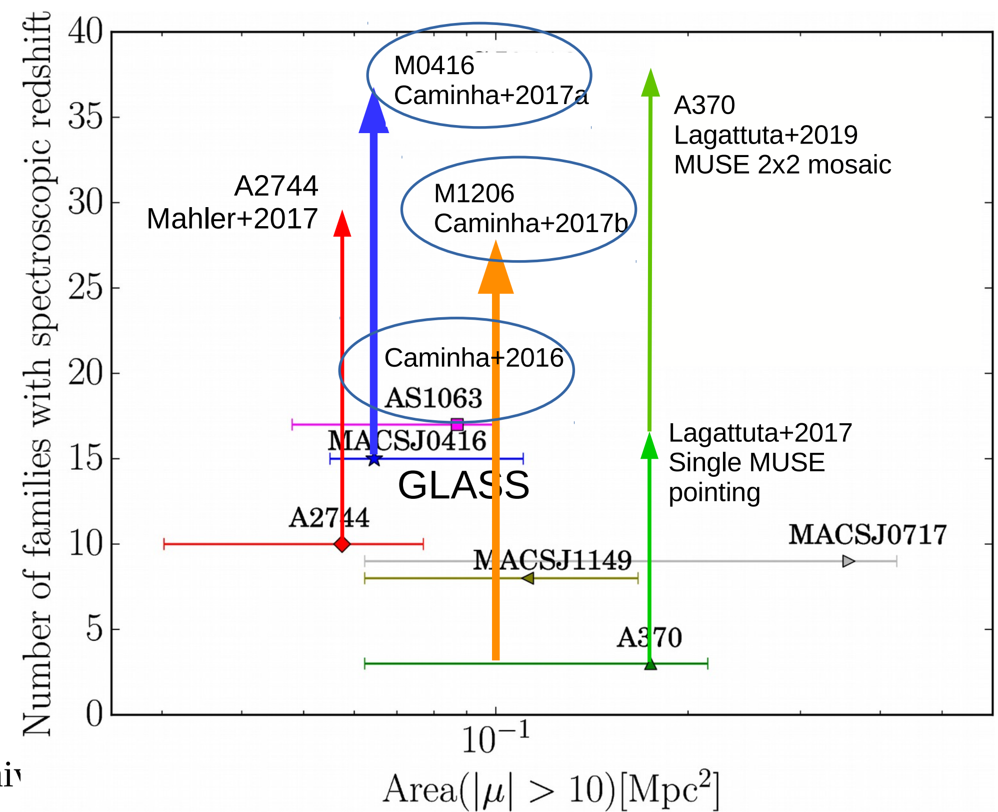
Caminha+ 2017 A&A 600, A90

- 37 multiple image families
- Free of missidentification of multiple images
- We use only spectroscopically confirmed



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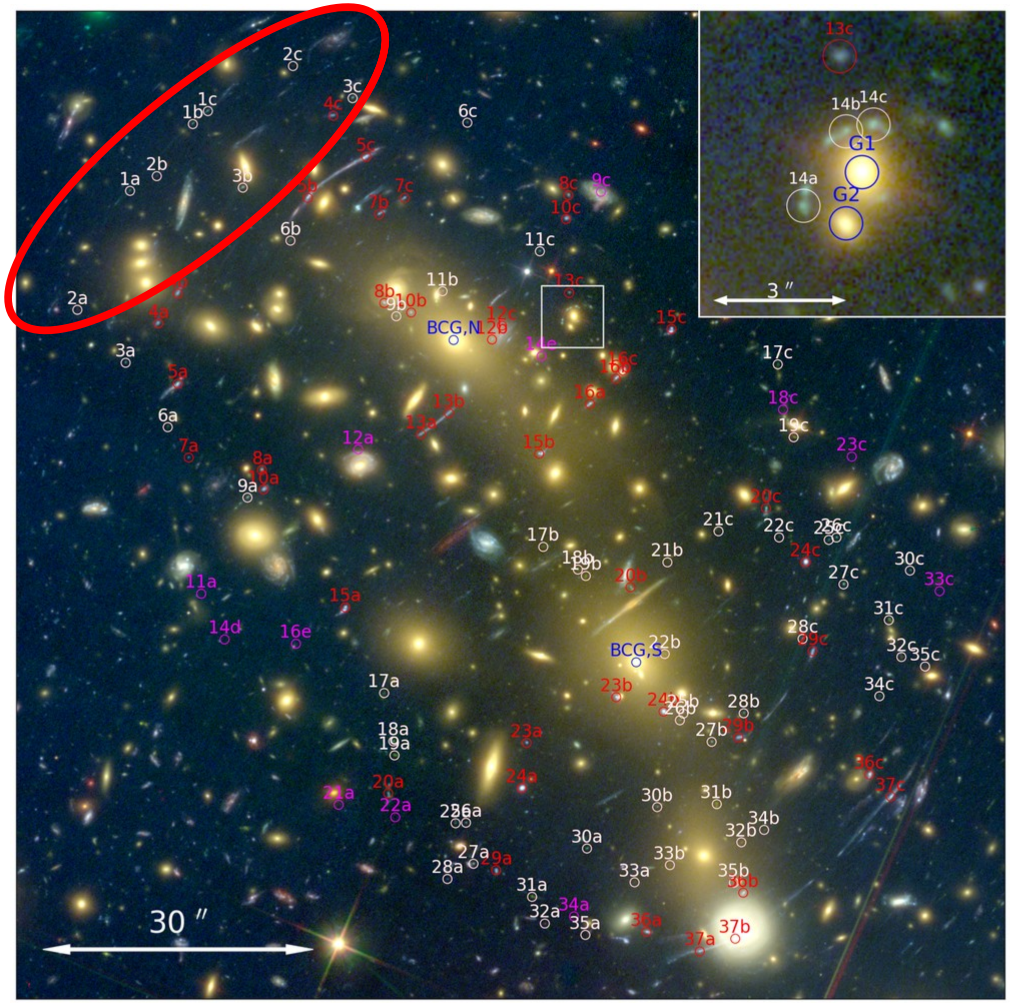

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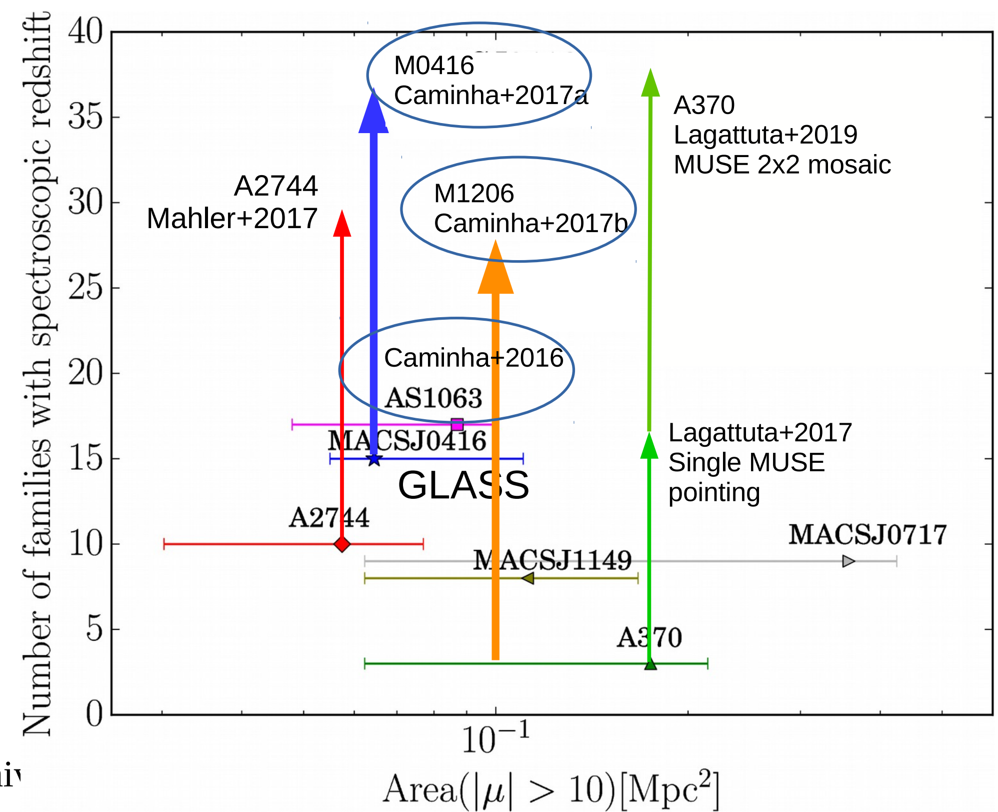

Increased number of strong lensing constraints

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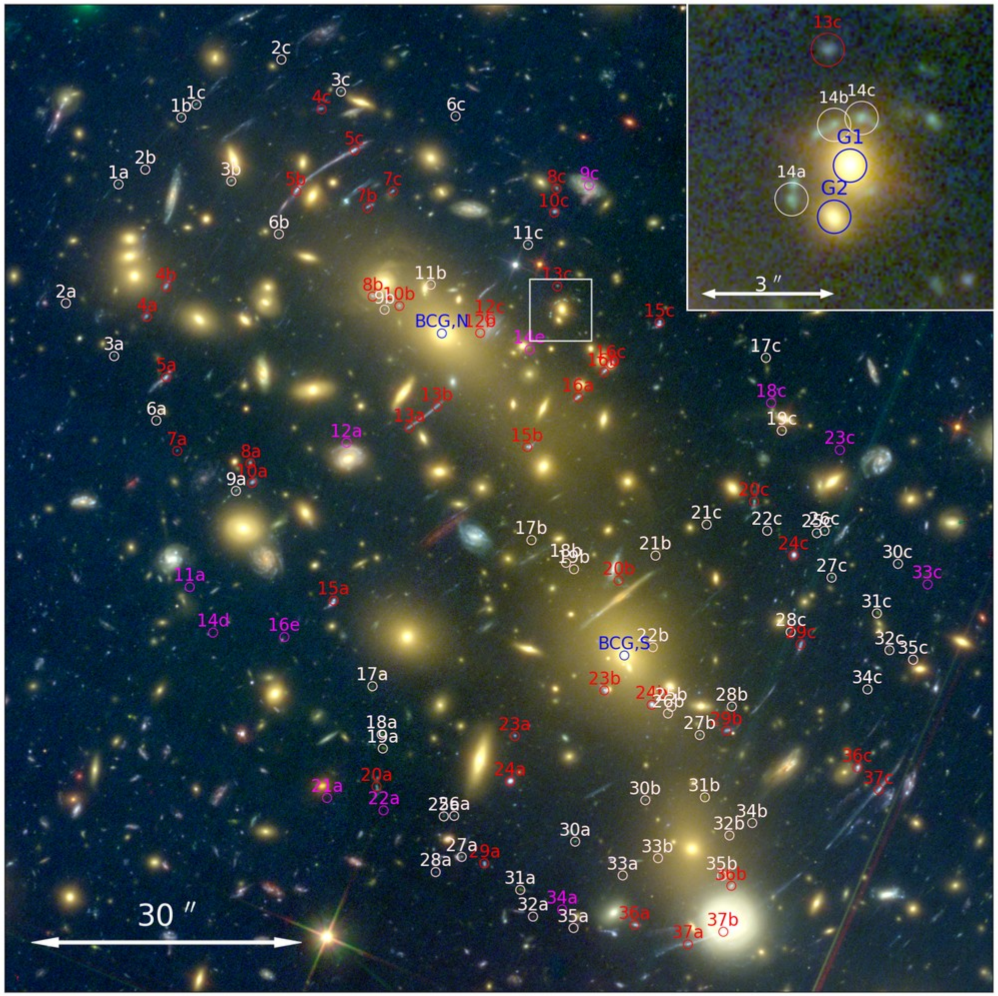

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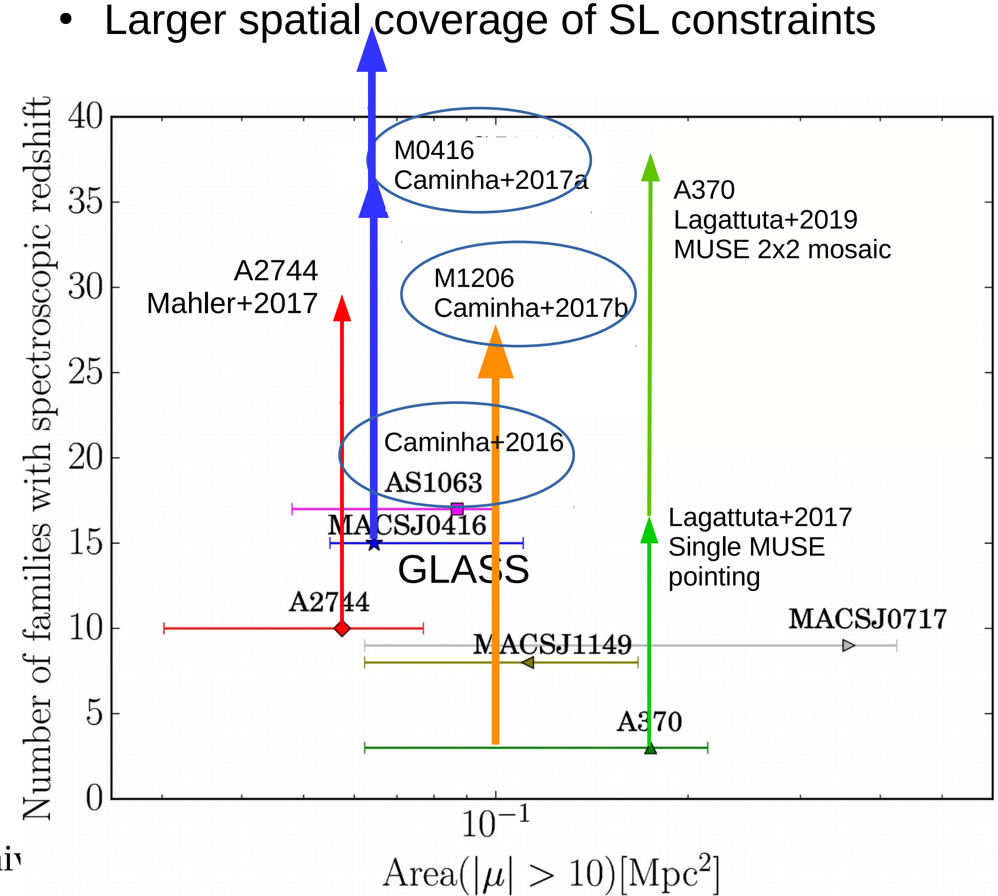
New deep MUSE observations confirmed 11 new families
Model can predict the position of all 137 multiple images with a precision of ~0.5 arcseconds



SL model improvements

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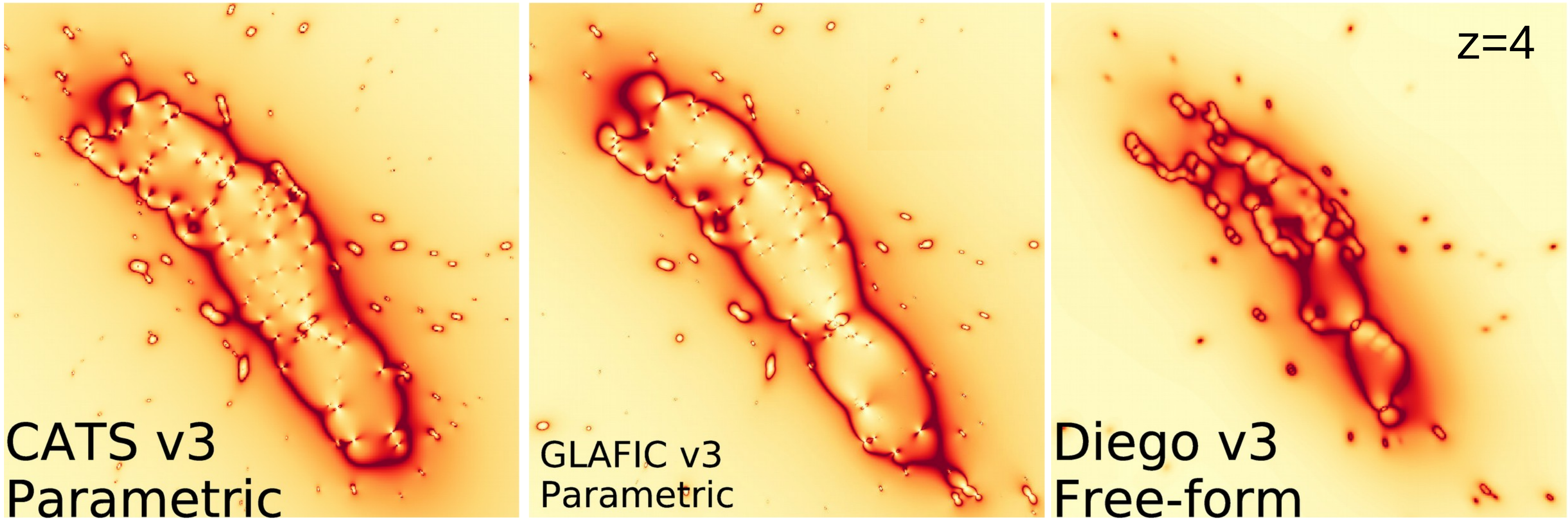
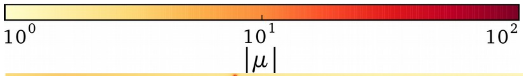
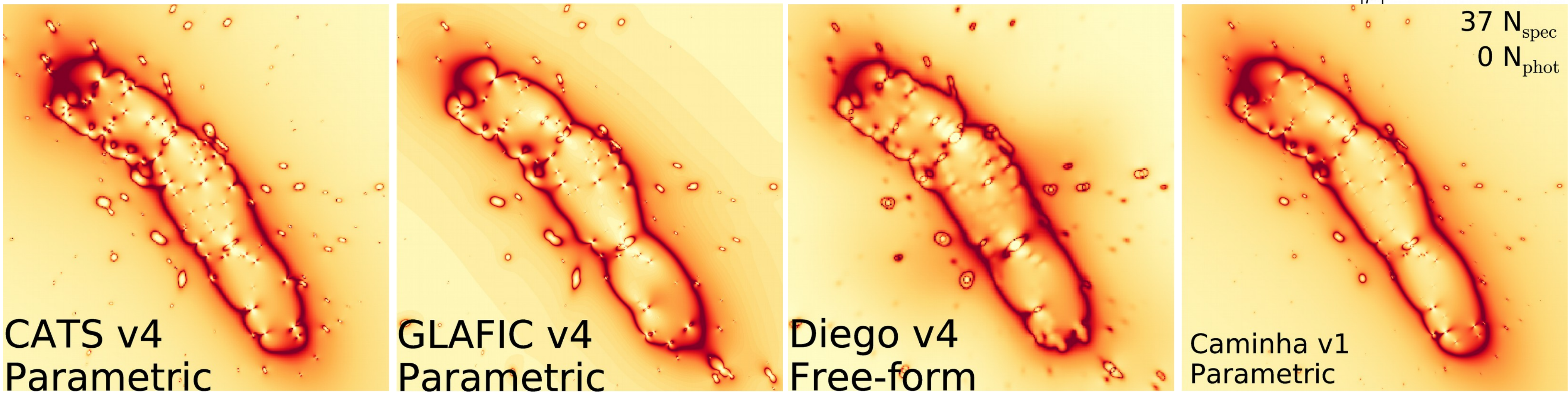
2015: 15 spectroscopically confirmed multiply lensed systems

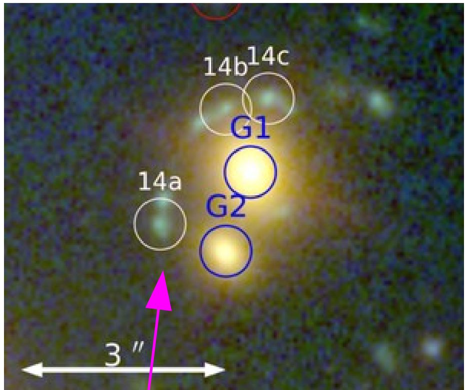


2017: 37 spectroscopically confirmed multiply lensed systems
+ improved membership selection
+ misidentification of multiple images removed





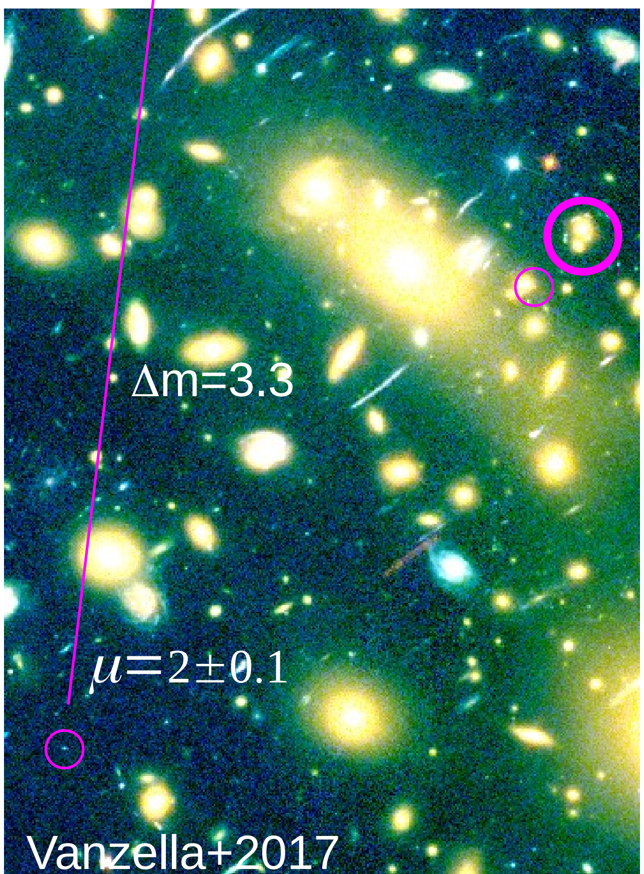
Robust measurements of magnification factors

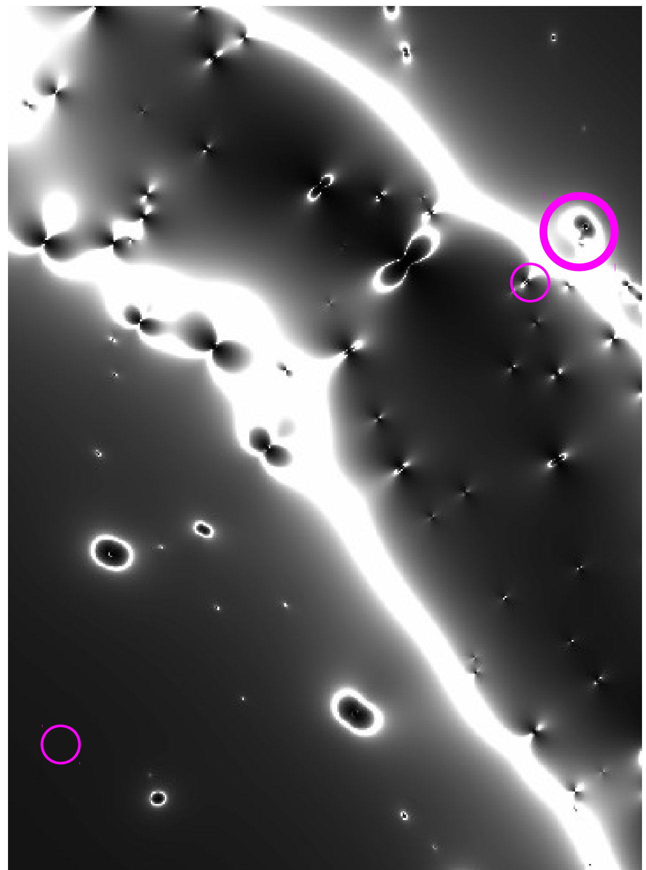


ID14 is a system at z=3.22 with 6 confirmed multiple images
- 14a,b,c are highly magnified (μ>20)

When propagating the magnification of the less magnified image we have: $\mu_{14a} = 41 \pm 7$
Directly from the SL model: $\mu_{14a} = 33^{+38}_{-12}$

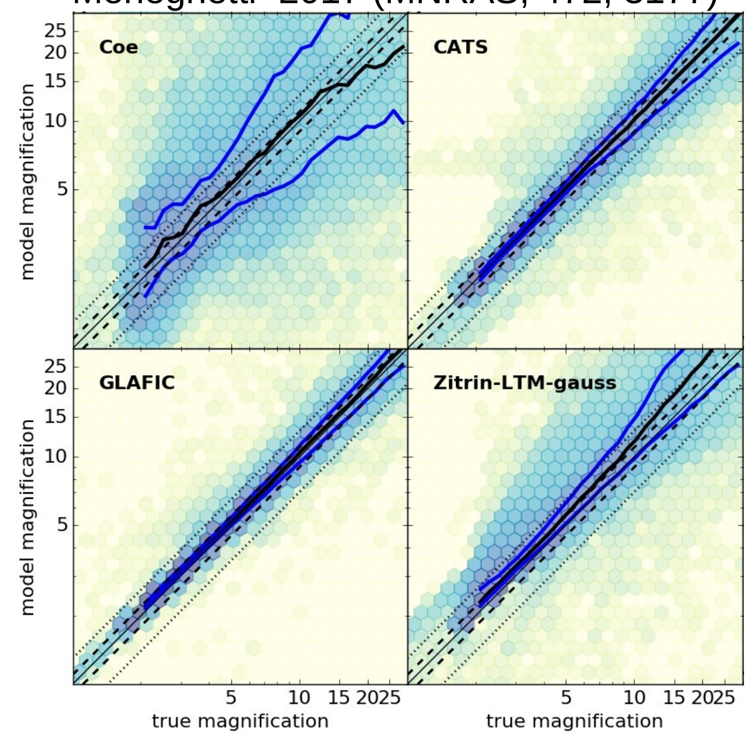
Predictions are under control when we have a large number of model constraints (multiple images)





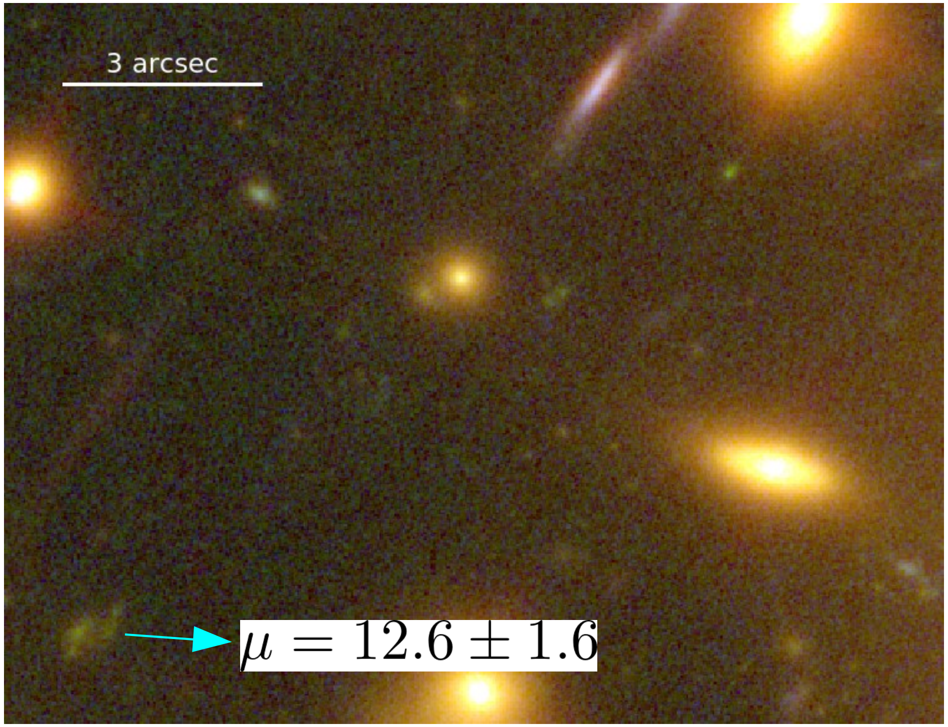
Low magnified regions are less biased and have smaller intrinsic scatter

Meneghetti+2017 (MNRAS, 472, 3177)

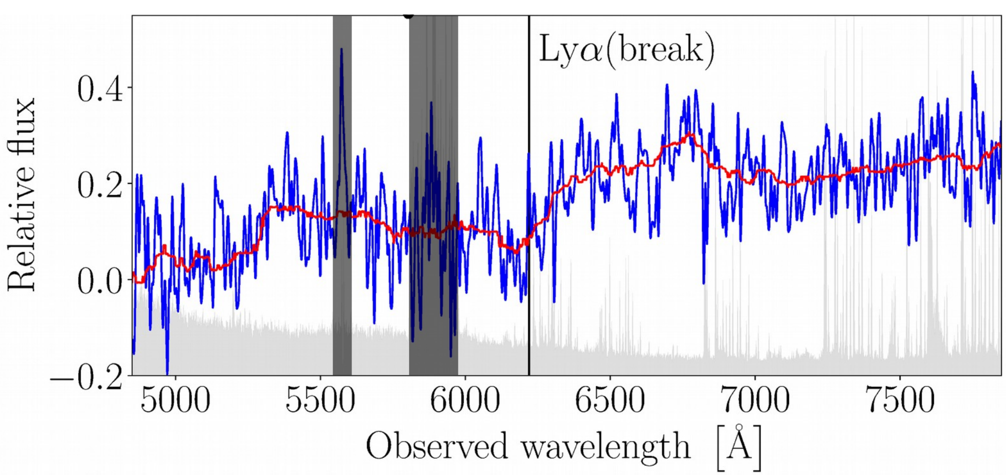


Ly-break galaxies and Ly-alpha emission

Intrinsically faint and multiply lensed Lyman-break galaxy at z=4.116

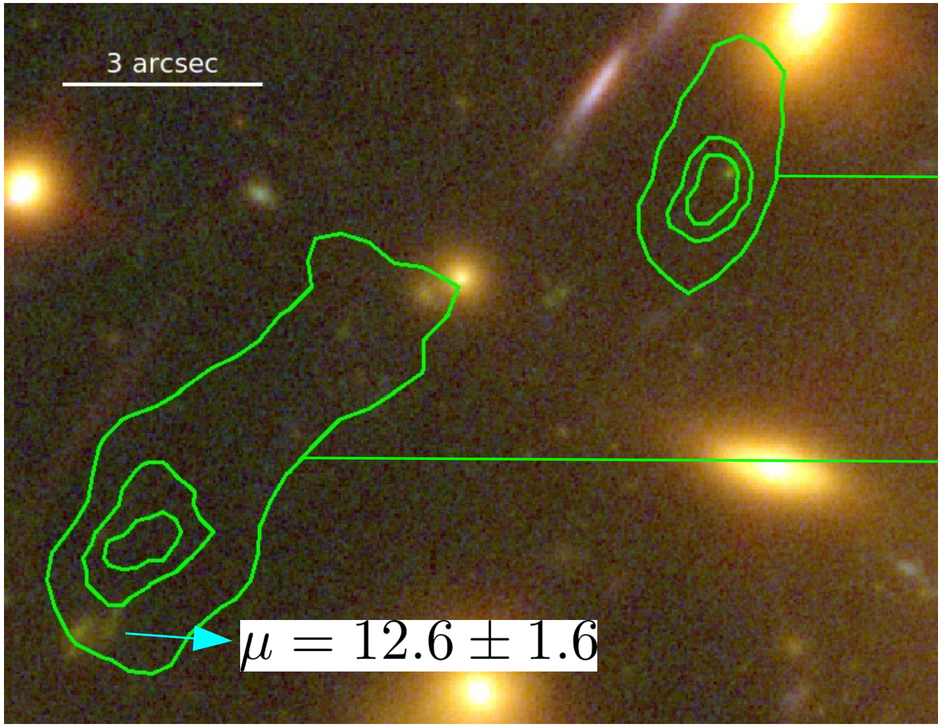


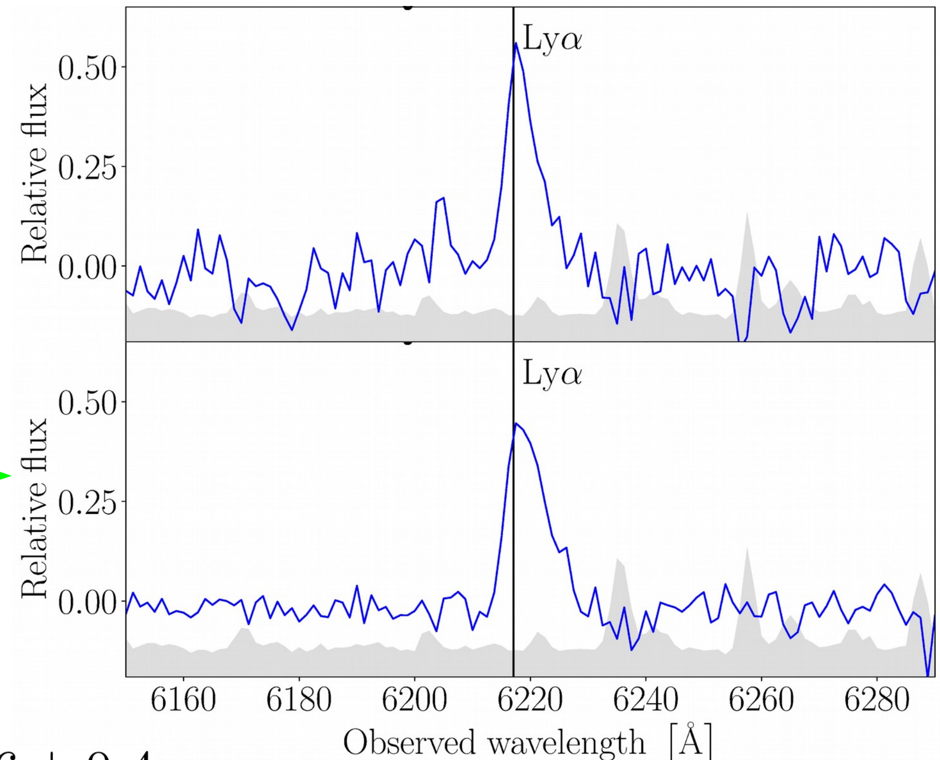
Observed $mag_{\mathrm{H}} = 25.9$, intrinsic $mag_{\mathrm{H}} = 28.6 \pm 0.4$
No ly-alpha emission from the stellar continuum (HST detection) or other emission/abs lines



Ly-break galaxies and Ly-alpha emission

Intrinsically faint and multiply lensed Lyman-break galaxy at z=4.116
Associated to extended Ly-alpha emission and another galaxy at the same redshift





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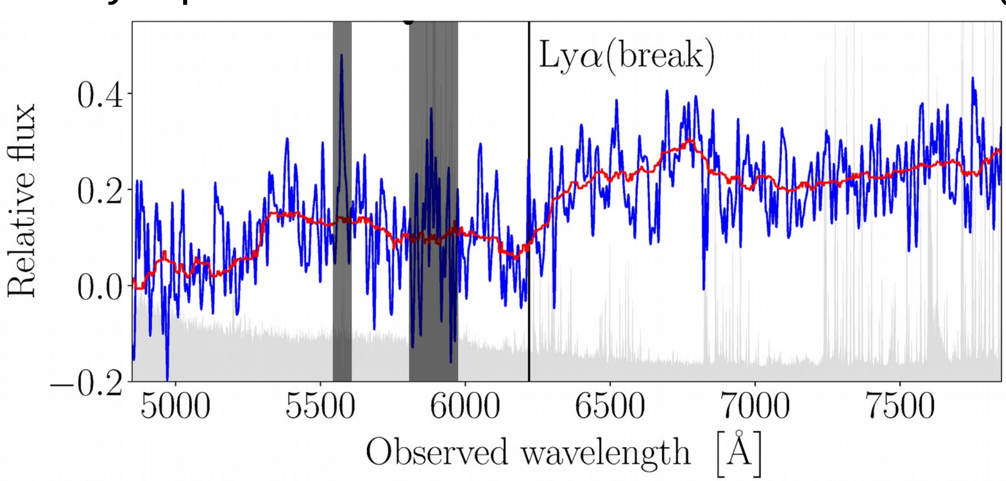

What is the mechanism responsible for the Ly-alpha emission in the nebula?

- Fluorescence by Lyman continuum escaping in the transversal direction, or
- Star formation in situ.

Lyman-α nebula around star forming galaxies

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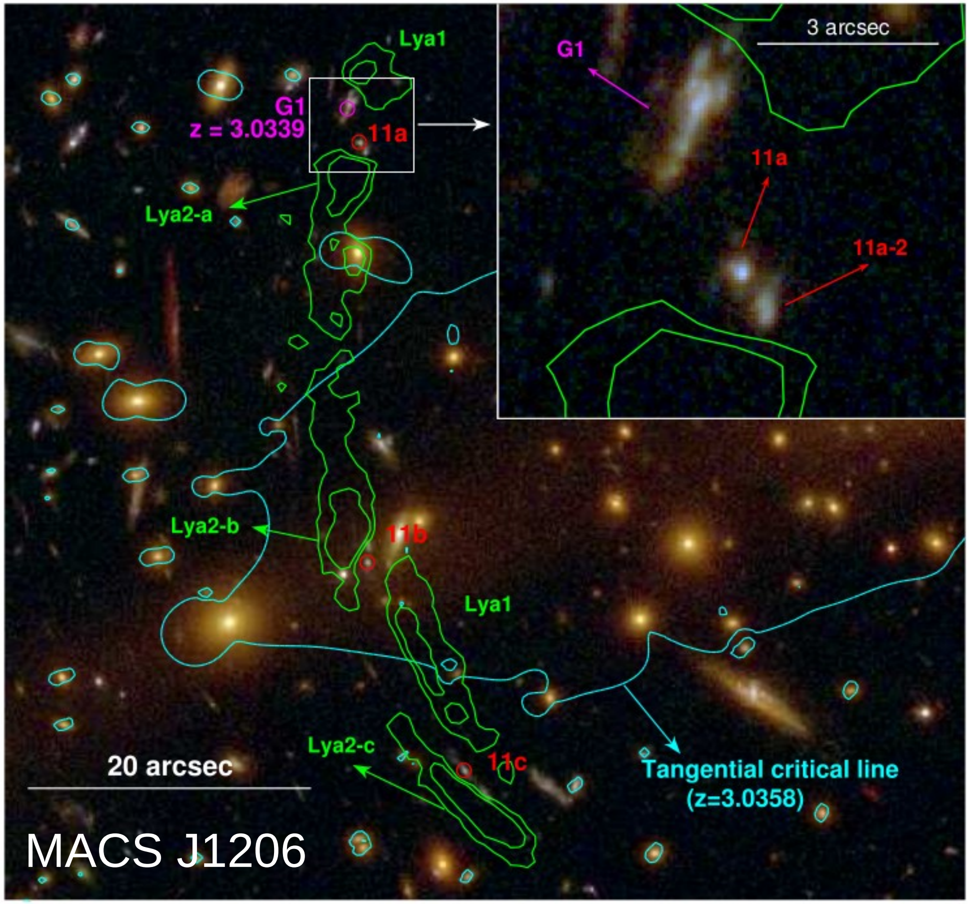
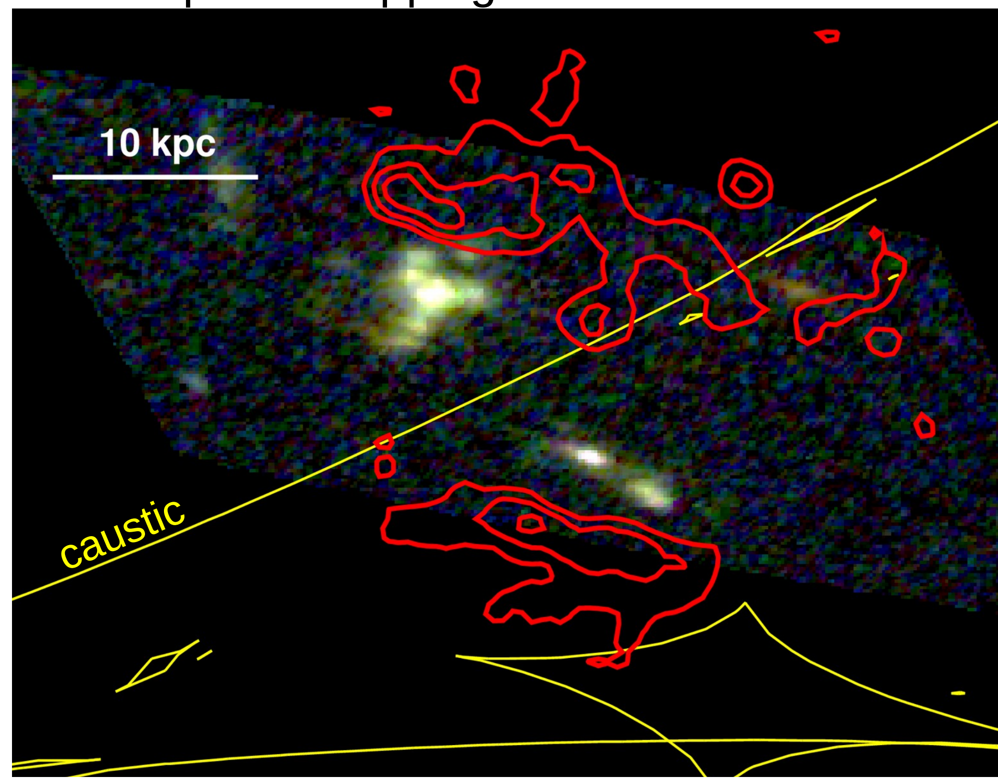
Lyman-break galaxies associated with Ly-alpha extended (off-centre) emission are relatively common

Z=3.04, Caminha+2017, A&A, 607, 93C



Source plane mapping- HST and MUSE



Observed $mag_{\rm H} = 23.5,\ 22.4$, for 11a and G1 respectively.
With HST+lensing we resolve clumps of ~2 kpc
The total stellar mass of each component (G1, 11 and 11-2) is $\approx 10^8 - 10^9\ {\rm M}_\odot$

Lyman-α nebula around star forming galaxies

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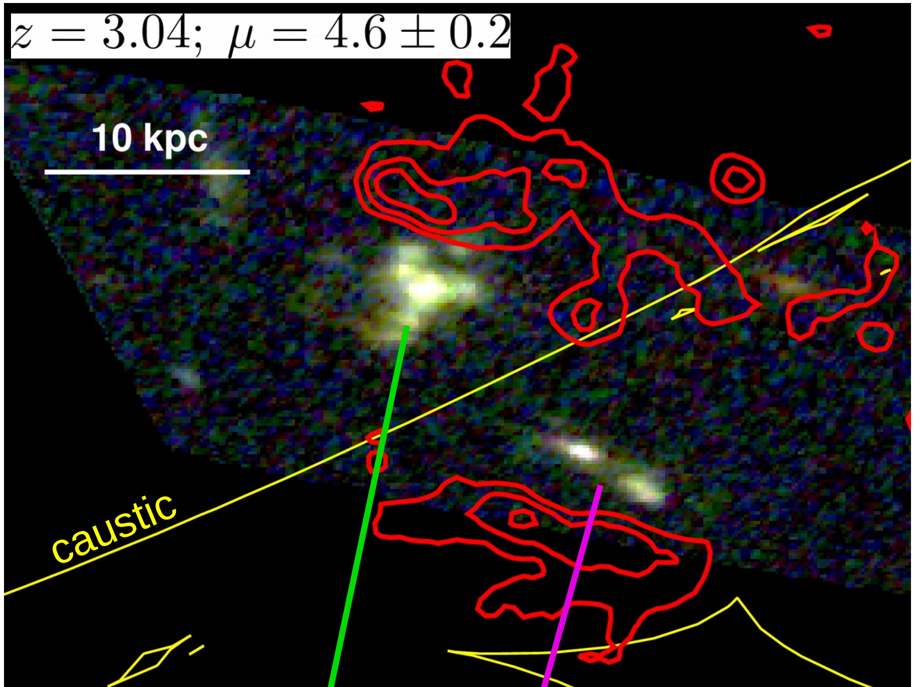


Lensing magnification increases the S/N by a factor of 5

Very high Ly-alpha EW (> 400 Å) likely to be generated by fluorescence, but scatter of Lya photos is also possible

Detection of OIII and HeII (broad?), CIV P-Cygni profile

- Stellar winds from very massive stars

Detection of strong OIII (5008 Å) emission (Christensen+2012)

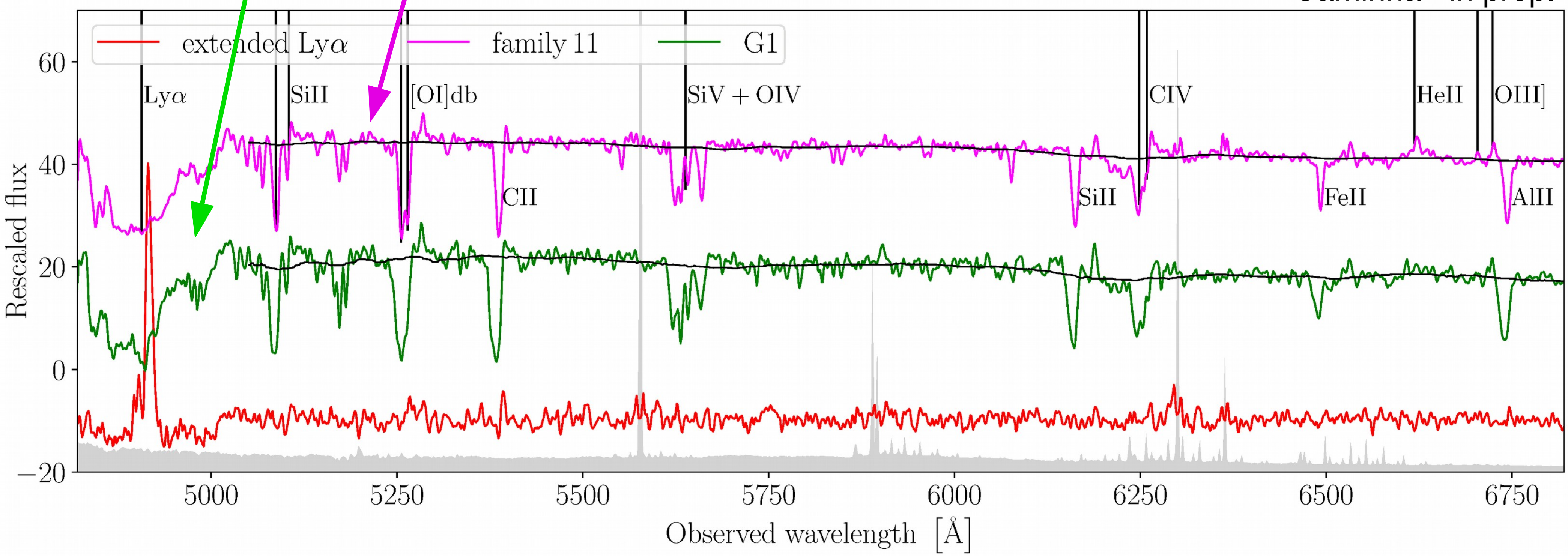
- Many similarities with known Ly-continuum emitters (< 912 Å, see Vanzella+2019) but we have no detection in the F336W HST filter

Possible LyC leakage in the transversal direction?

JWST (with NIRspec/cam and MIRI) will be able to probe the spatial distribution of H-alpha (fluorescence X scatter)

Probe the stellar population with ELT and Balmer lines with JWST

Caminha+ in prep.

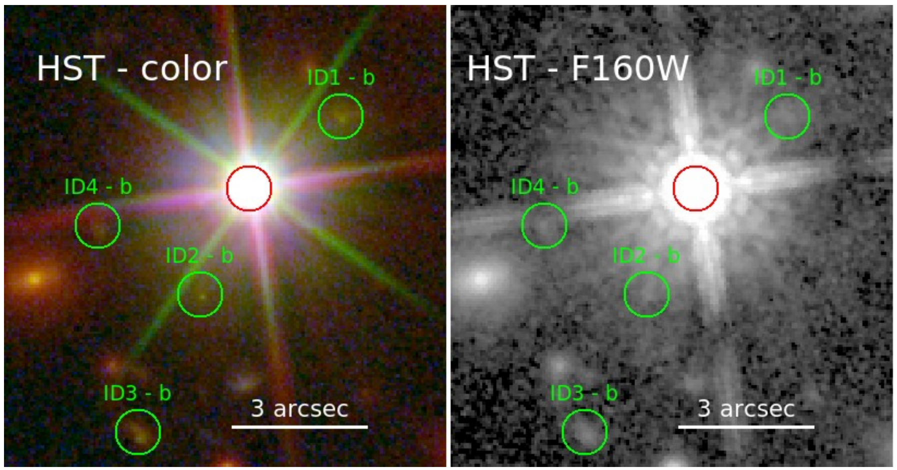


MICADO (SCAO) to detect SF clumps

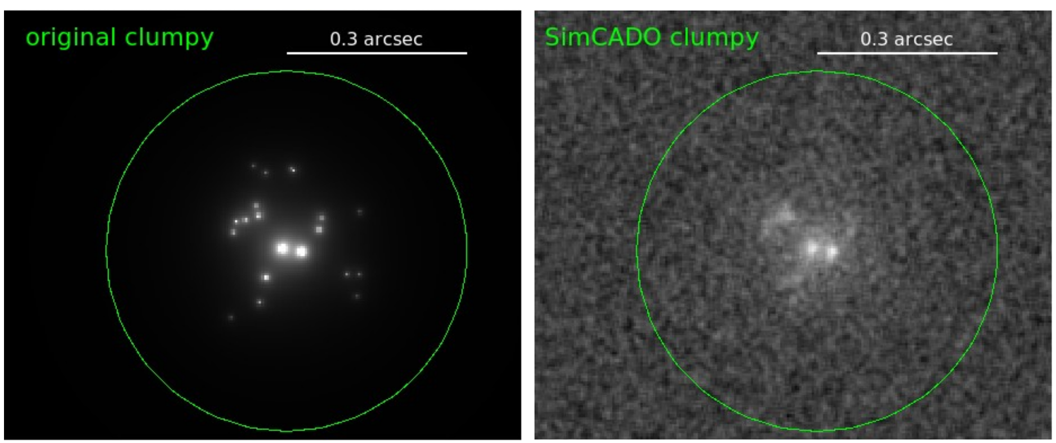
Group of galaxies at z=4.3, spectroscopically confirmed with MUSE.

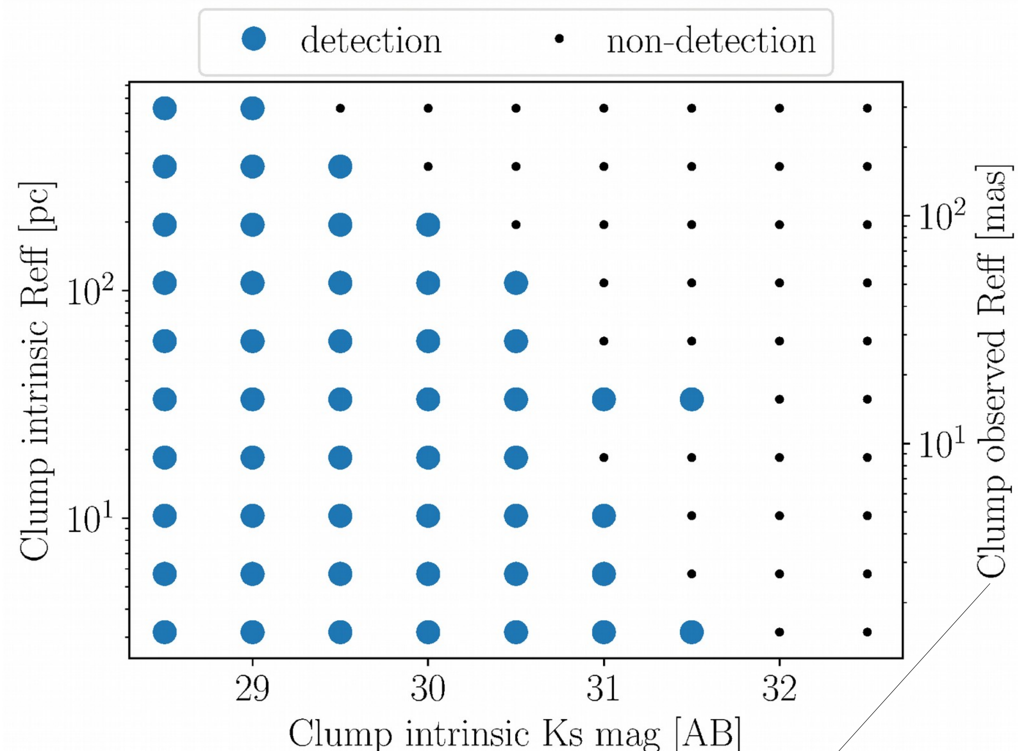
$$mag_{\mathrm{H}} = 23.61 \quad \mu_{3b} \approx 10$$

Good candidate to be targeted by MICADO (SCAO).



SimCADO simulation for 2 hr exposure time





The observed sizes are a factor of ~3.3 smaller in a non-lensing field

Discussions

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- We have control of the lensing effect to recover intrinsic properties of lensed sources
  - See e.g. Caminha+2019 arXiv:1903.05103 (A&A accepted) for the work on the SL models and MUSE data
  - We are building a large sample of lensing clusters with good models, i.e. using extensive spectroscopy, that are providing targets to the new generation of telescopes

- In lensing fields with MUSE we are characterizing the UV part of the spectrum of sources at redshifts between 2.9 – 4.5 (higher S/N) and confirming with spectroscopy sources at z=5-6.7 from Lyman-alpha emission (faint sources) or Lyman break (bright sources or deep pointings)
  - Are we observing Lyman-continuum photons escaping in preferred directions?
  - Lessons learned at low z (< 6) are extremely valuable to explore the sources in the reionization epoch (6 < z < 10)

  - With JWST we will easily access rest-frame optical lines for these system
  - With ELT we can characterize the stellar population and the morphology of these systems

- Extend works on non lensing fields towards faint objects