MNELLS:
Searching for the lowest redshift early-type strong lenses

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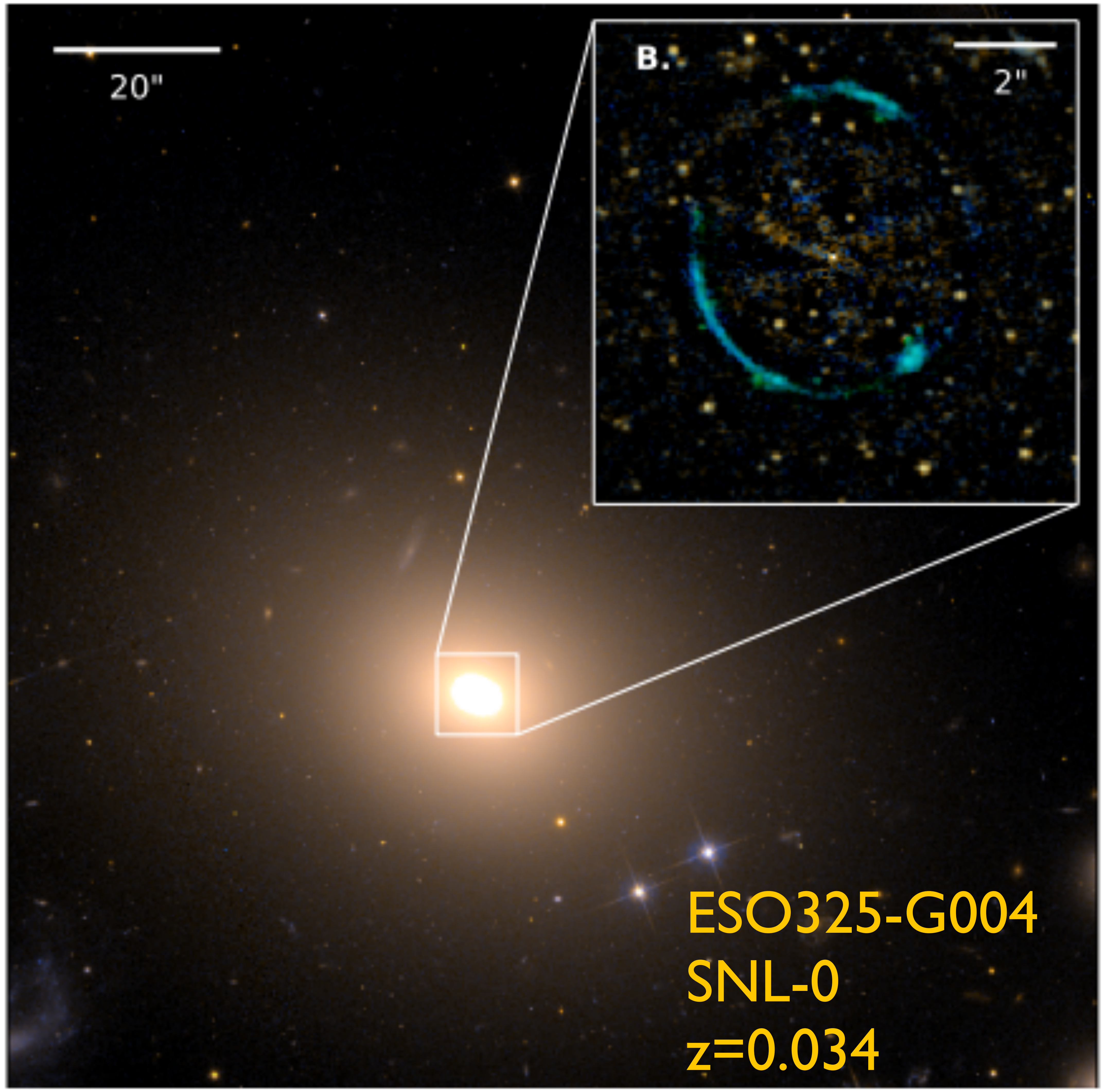
DEX 2019

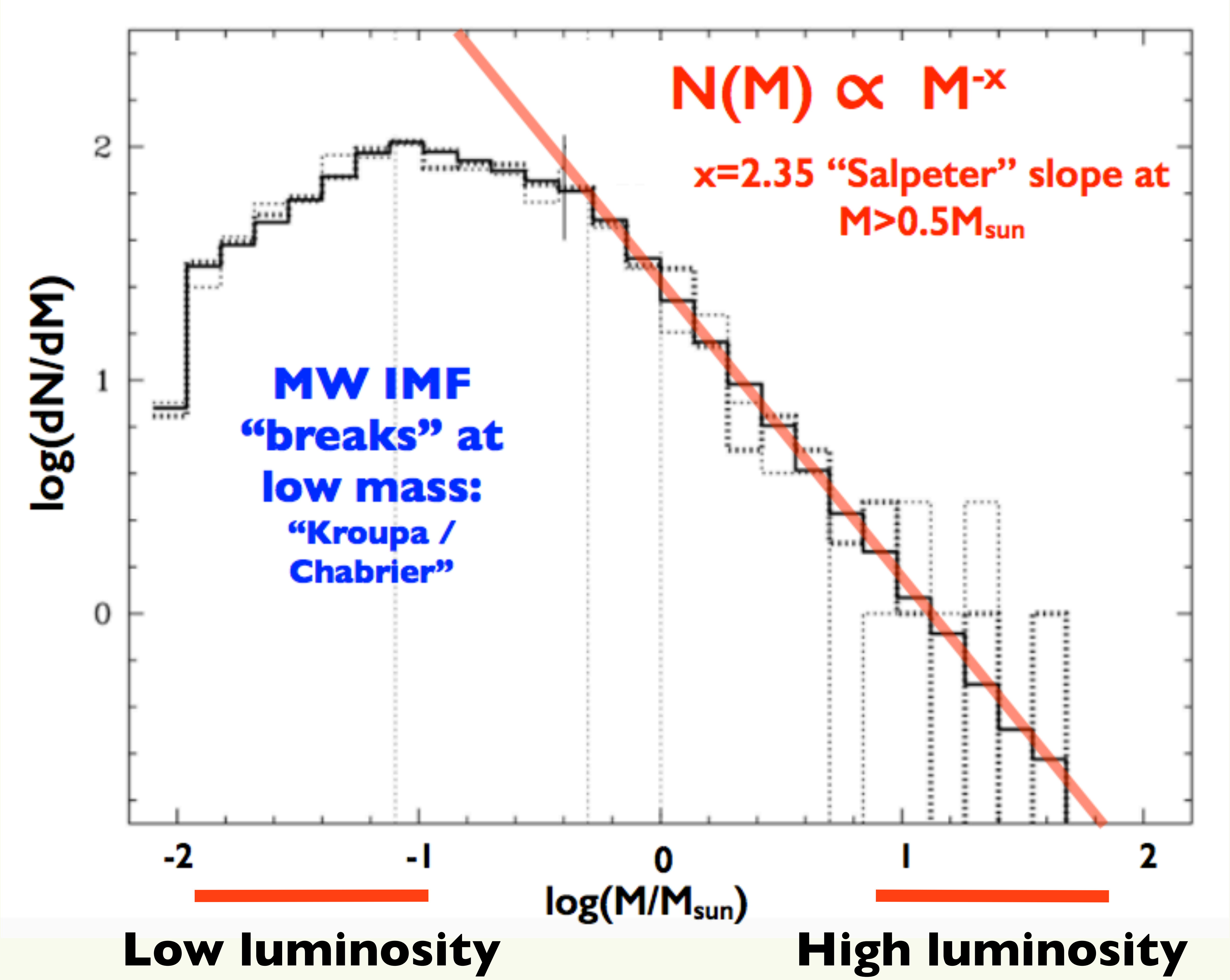
Why target low redshift lenses? (z<0.1)

- At **low** redshift the **critical density for lensing** increases, and hence is exceeded in the central, **stellar dense region**
- **Minimise** dark matter contribution by measuring mass in a region dominated by the stellar population
- $\mathbf{R_{Ein} \sim 0.25 R_e}$
- **~20%** dark matter within R_{Ein}, from projected EAGLE DM halos (Smith et al. 2013)
- Measure the stellar mass from "pure" lensing, as the dark matter correction is small



Discovery: Smith et al 2005
Image: Collett et al 2018

Investigating the IMF with ellipticals



- The **stellar initial mass function** is the **distribution** in mass of stars forming at a single epoch
- A comparison between different parametrisations of the IMF can be made via the present day ***stellar* mass-to-light ratio** compared to an evolved stelar population synthesis model
- An old stellar population formed with a **Salpeter** IMF will have an M*/L **~1.55** times that of **Kroupa**
- Gravitational lensing very accurately measures the **total projected mass** within the Einstein Radius

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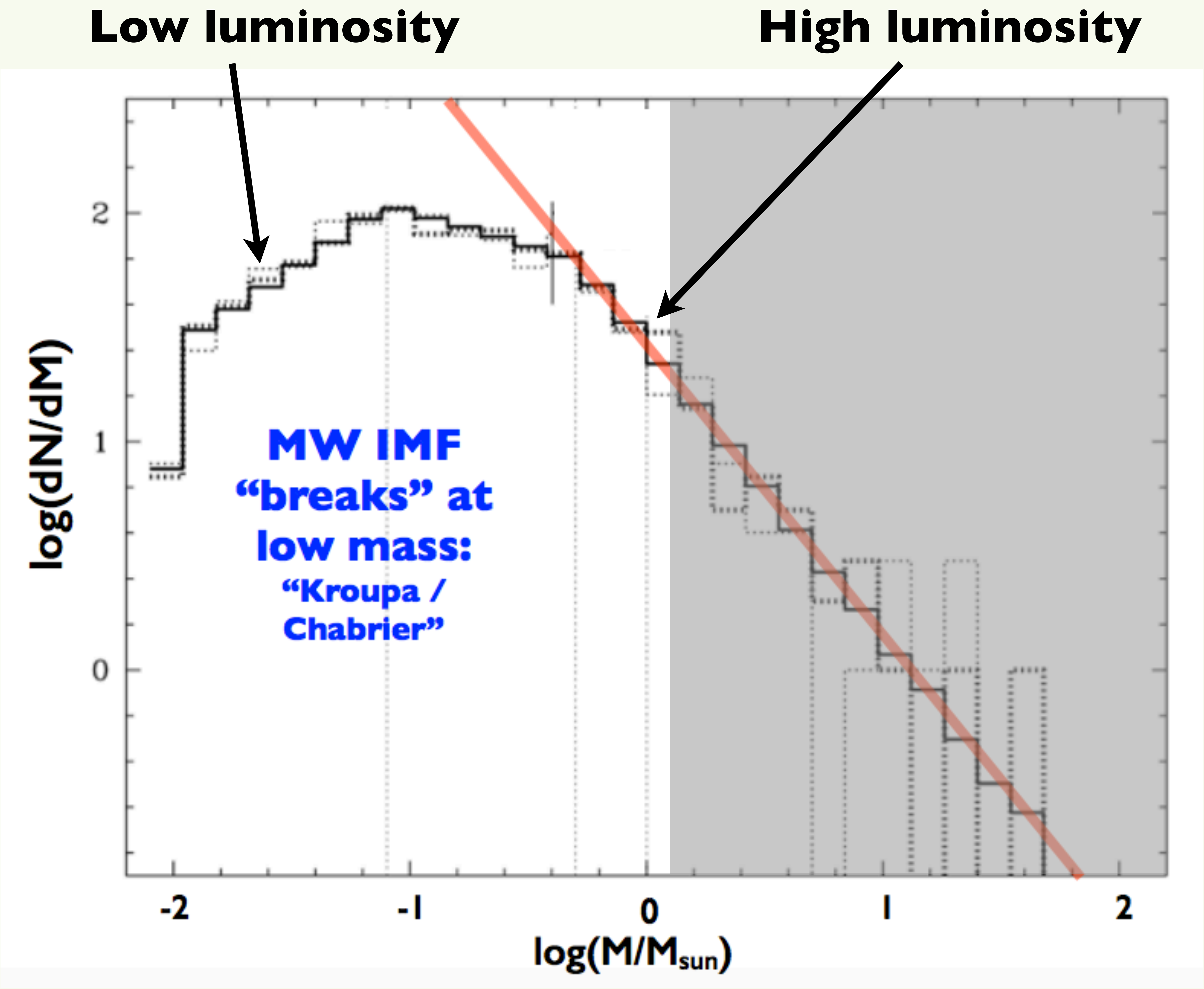

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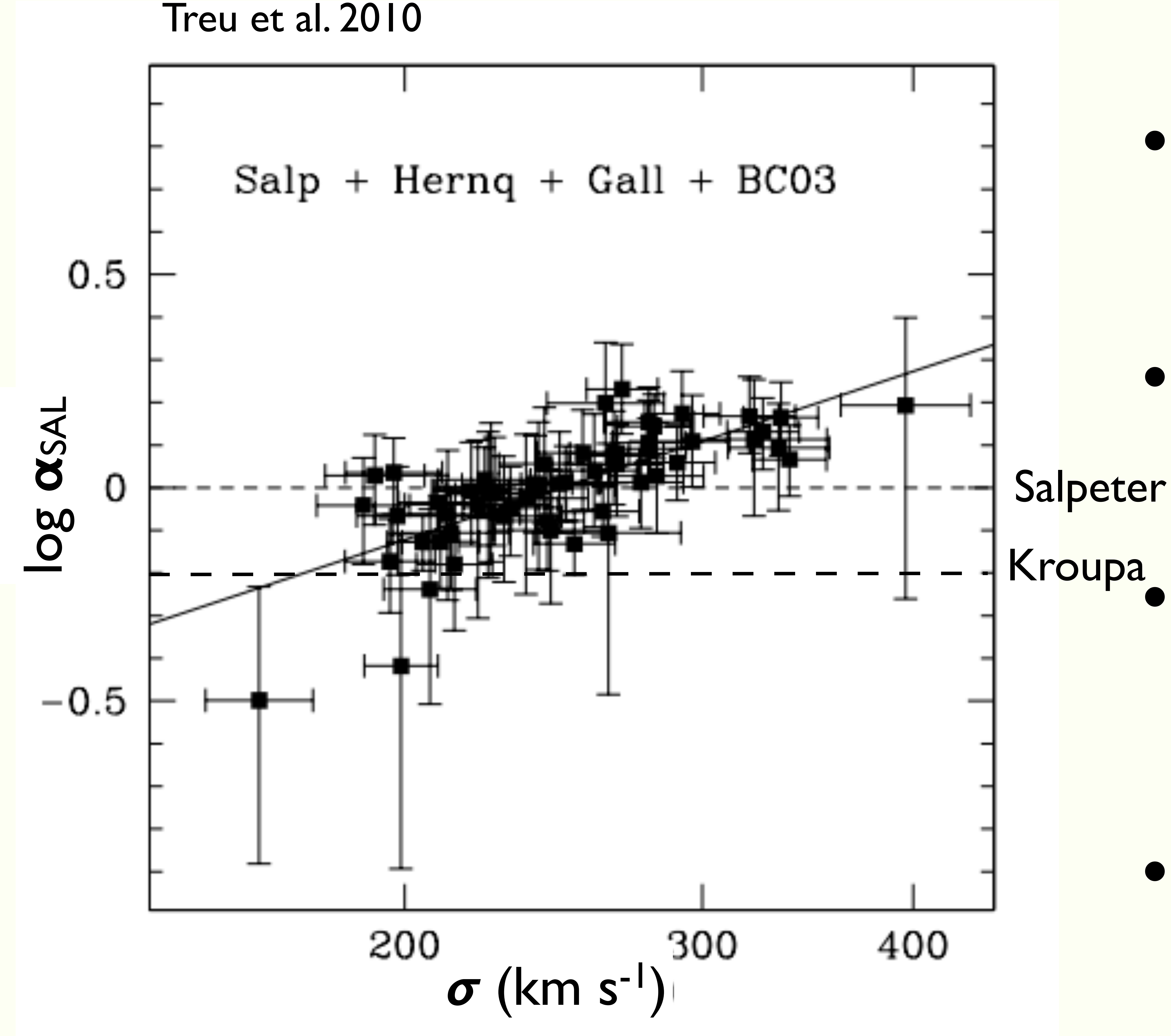
Results of the IMF from lensing



- The **Sloan Lens ACS** lensing sample - lenses discovered within SDSS single fibre surveys (<z> ~ 0.2, 160 < σ < 400 km/s)
- Requires **stellar dynamics** to **disentangle** DM halo and stars (**f_{DM} ~60%** for a Chabrier IMF, Auger et al. 2010)
- Suggests that there is **variation** in the initial mass function **with velocity dispersion** (i.e. increasingly deficit between the measured M/L ratio, and the model M/L ratio)
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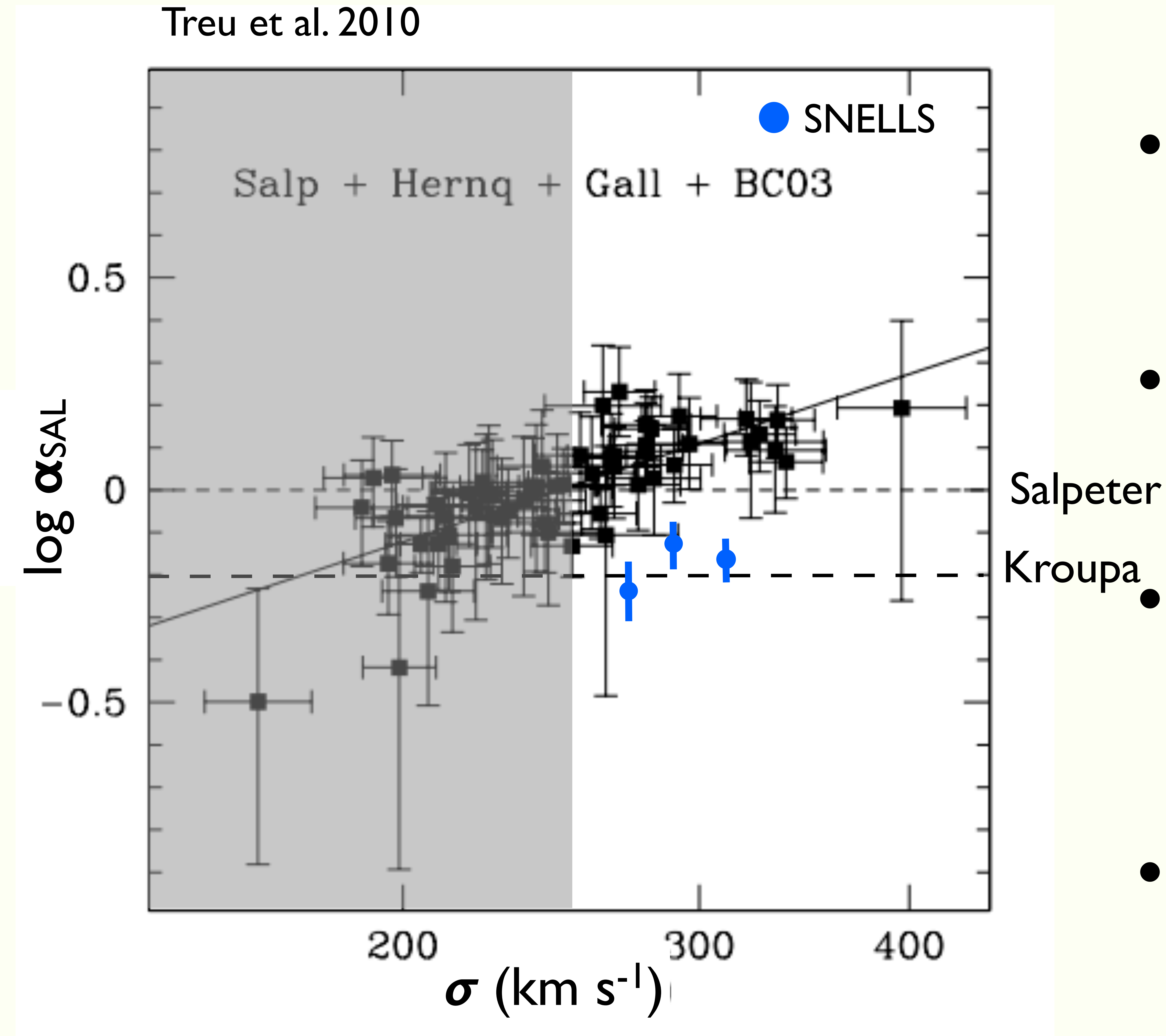

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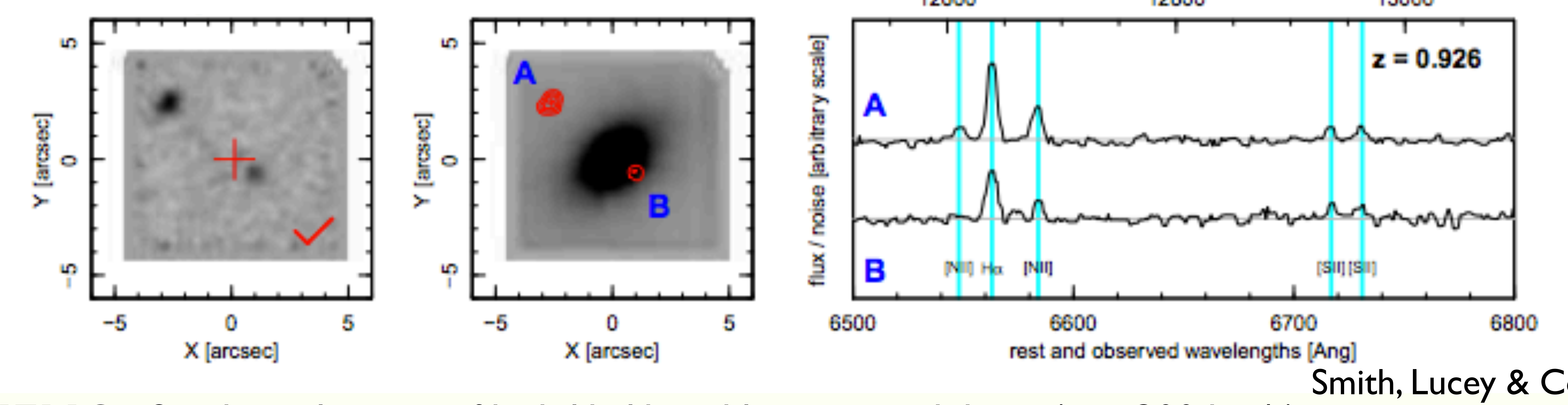
Discovering Lenses with IFUs

- **Spectral resolution** - detect and measure the redshift of lensed images via strong emission lines
- **Spatial resolution** - visually confirm the lensing configuration via narrow-band frames extracted about a lensed images emission line

SNL-1 z=0.031

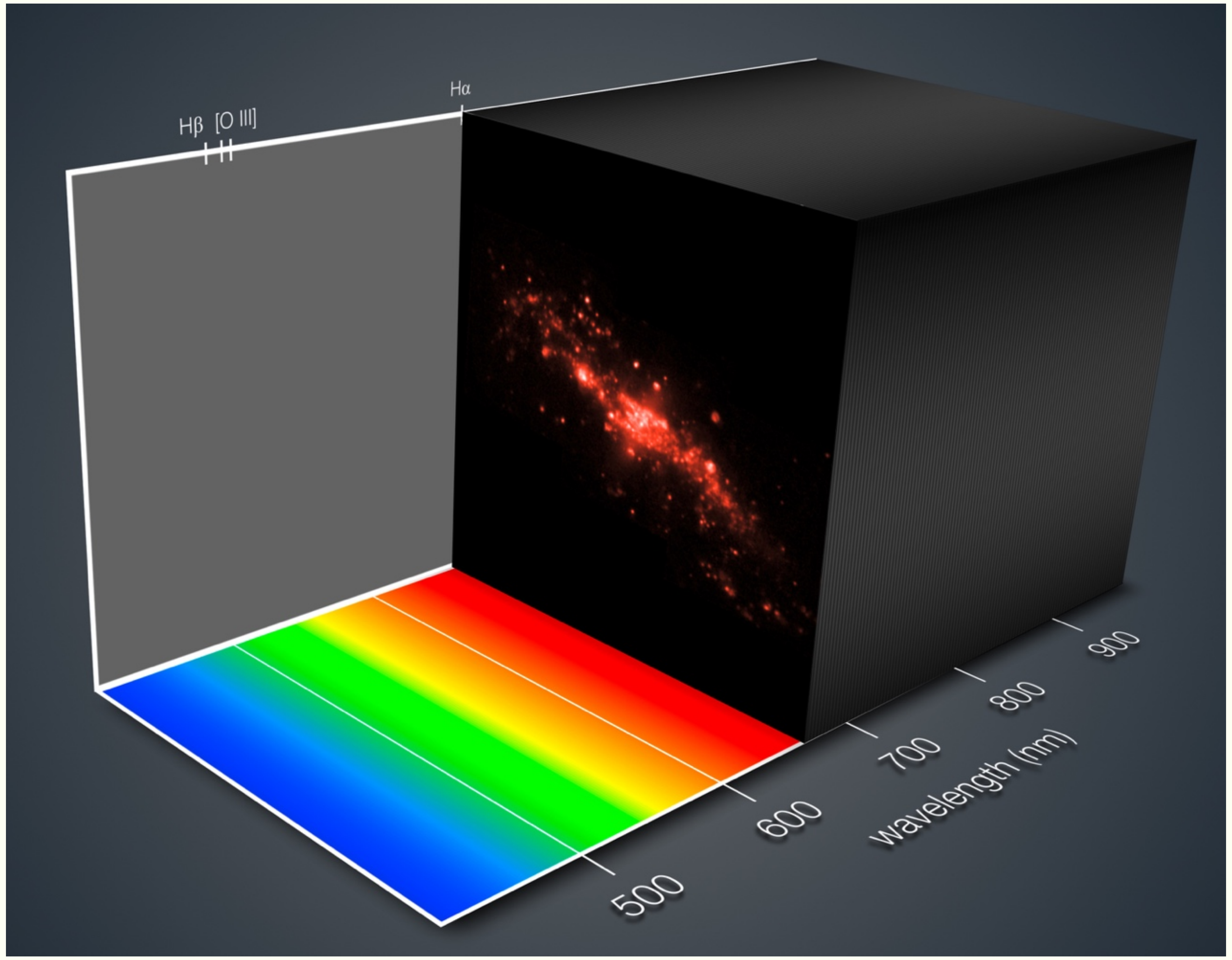


Smith, Lucey & Conroy 2015

- **SNELLS** - Smith et al. - tens of high likelihood lensing candidates (σ > 300 km/s)
- **SDSS MaNGA** - Talbot et al, and C. H. Lee - thousands of low likelihood lenses (various σ)

MUSE Nearby Elliptical Lens Locator Survey

- **MUSE** -- Multi-Unit Spectroscopic Explorer
- On the VLT -- mostly the southern sky
- Wavelength range **4750 -- 9350Å**
- Field of view **1x1 arcmin**, **0.2x0.2 arcsec/ pixel**
- Datacube ~ **3680x350x350 pixels**



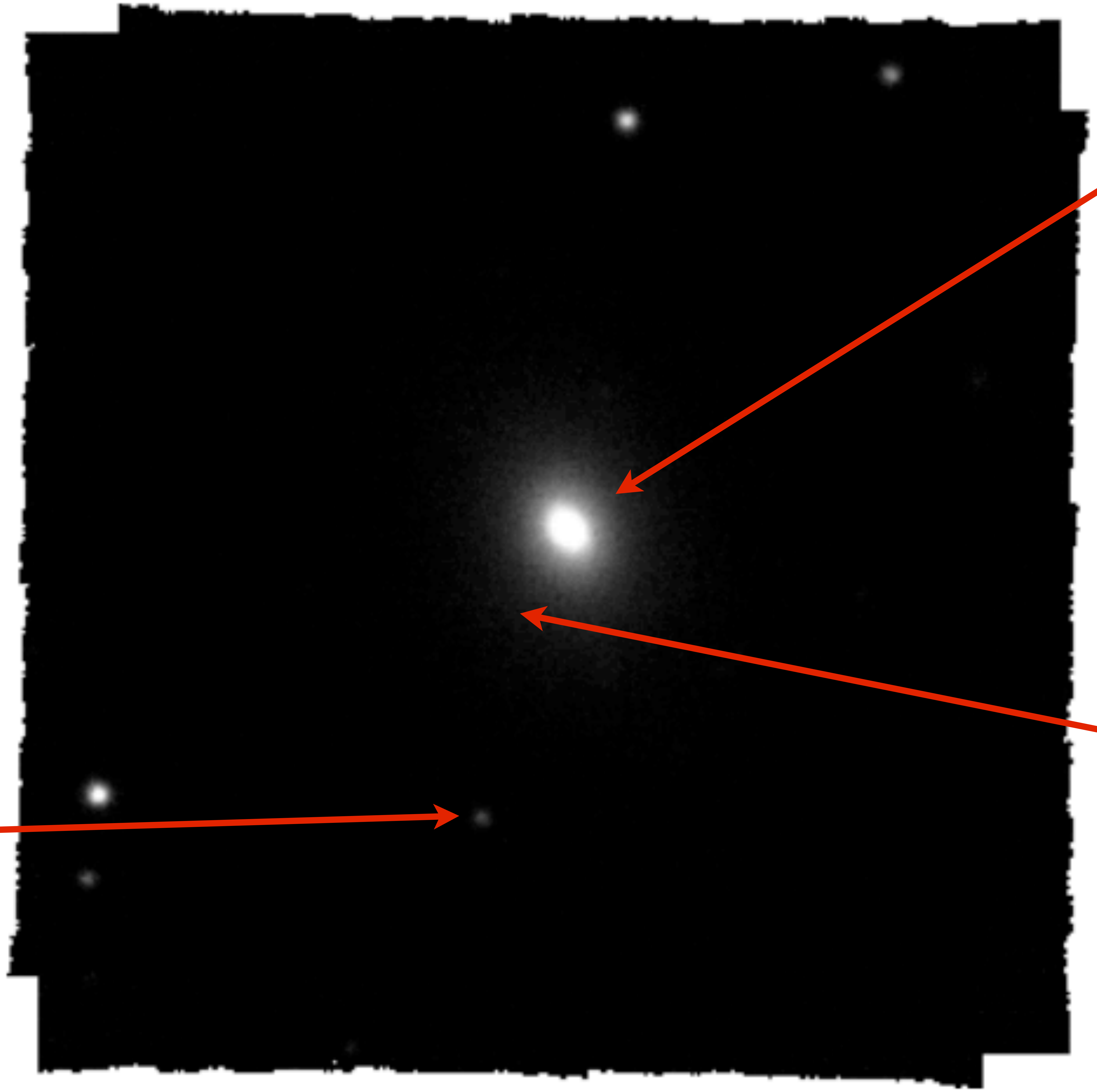
- **Targeted blind survey** -- MNELLS -- p101/103 observations ongoing -- non-cluster nearby massive early-type galaxies

- **Archival search** -- search the MUSE archive for nearby massive early-type galaxies (based on 2MASS K-band magnitude)

Galaxy subtraction

- **Filter** out the foreground galaxy with an **elliptical profile**, fit to **each spectral channel**

- The resulting cube is **smoothed spatially and spectrally**



The foreground galaxy -- to be filtered out to discover the background emission

Background emission line sources close to the target galaxy

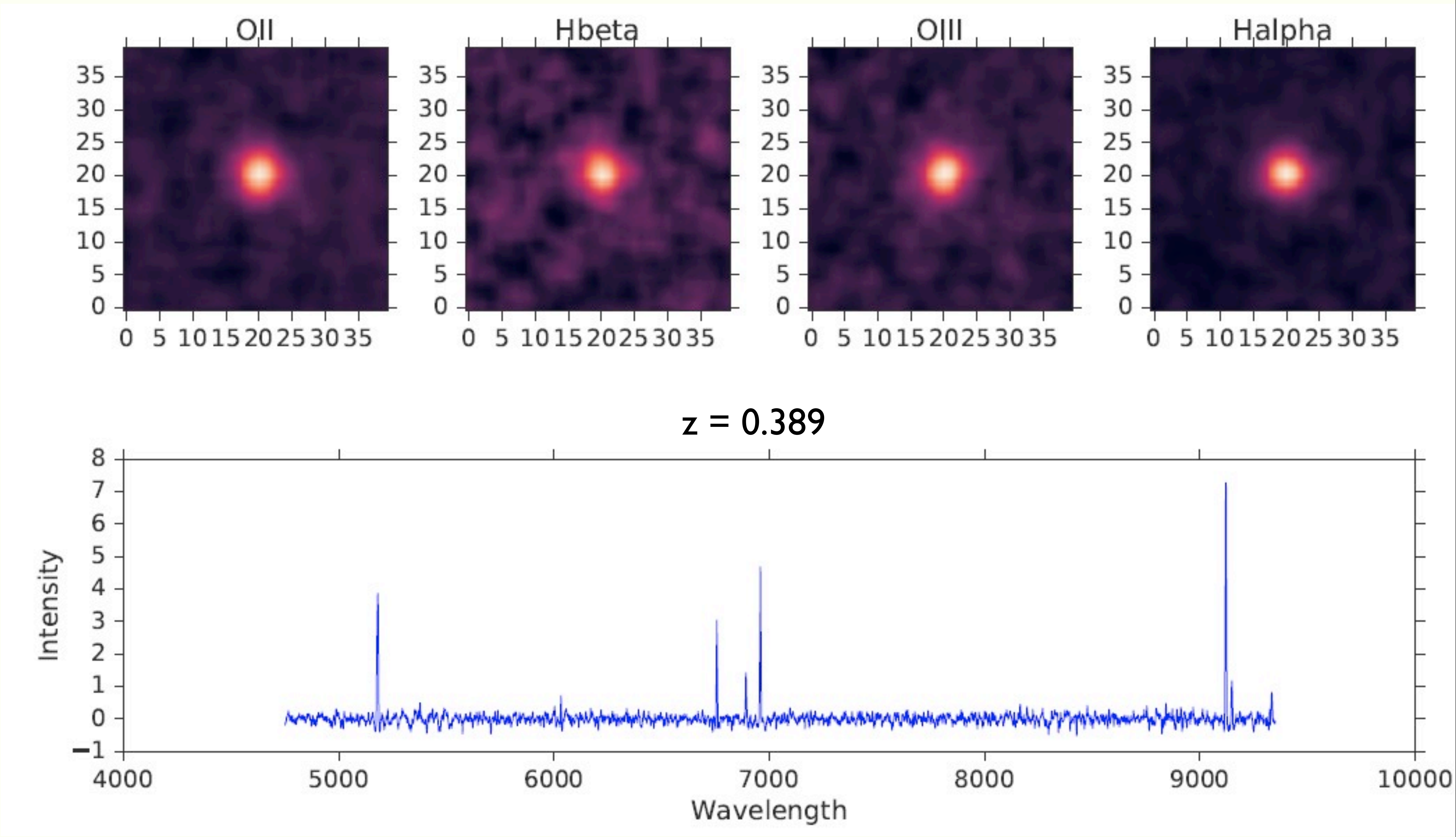
Bright background continuum source, distant from the foreground galaxy

An automated detection process

- Detect **spectrally** -- segment the cube, and label regions above the detection threshold with *scipy.ndimages* (require the region to be extended spatially and spectrally)

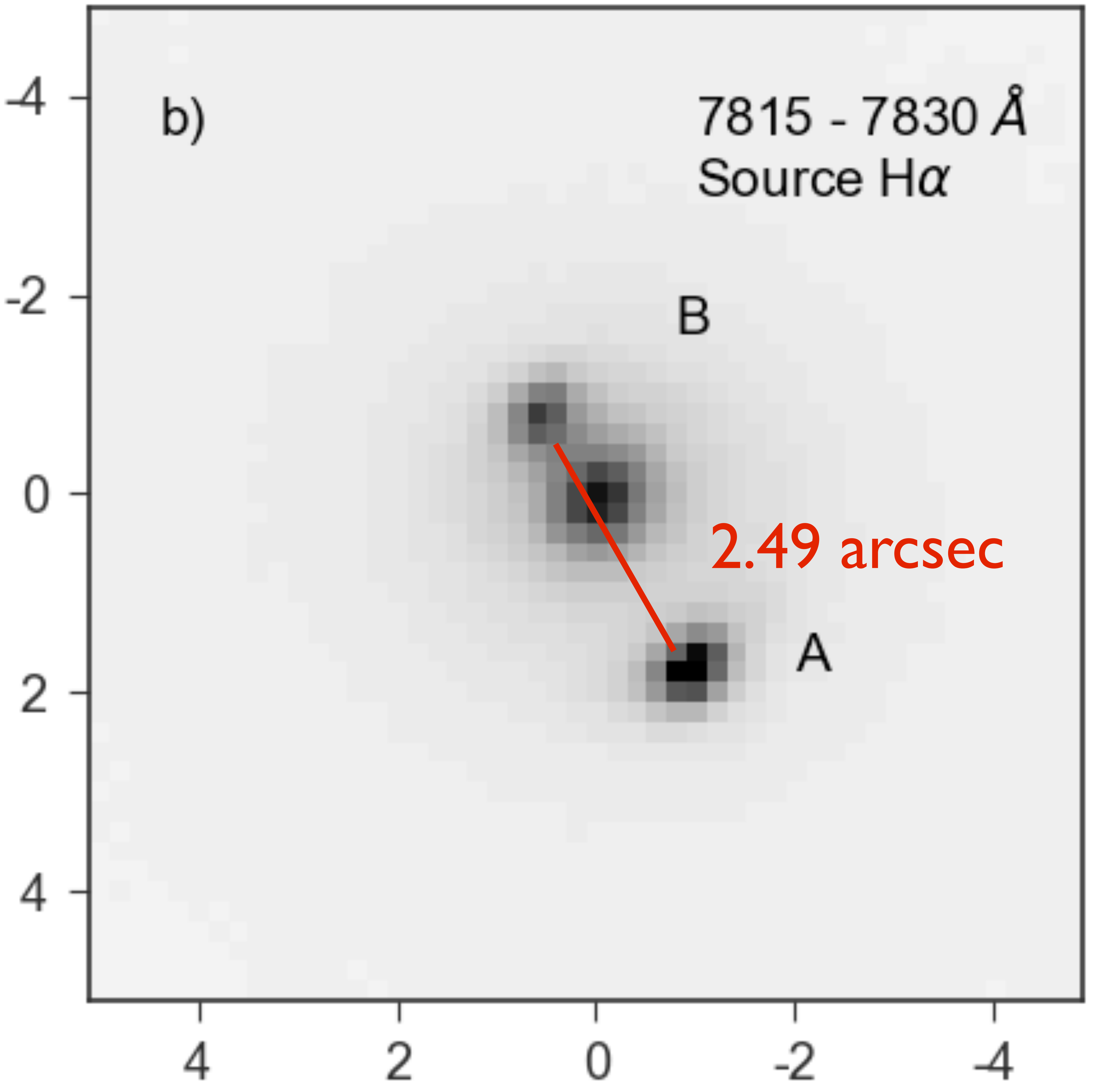
- **Redshift** -- fit a 200Å window, for single guassian, [OII], [OIII], or Hα + [NII] at each detection

- **Eyeball vetting** -- A check for validity, and removal of spurious detections



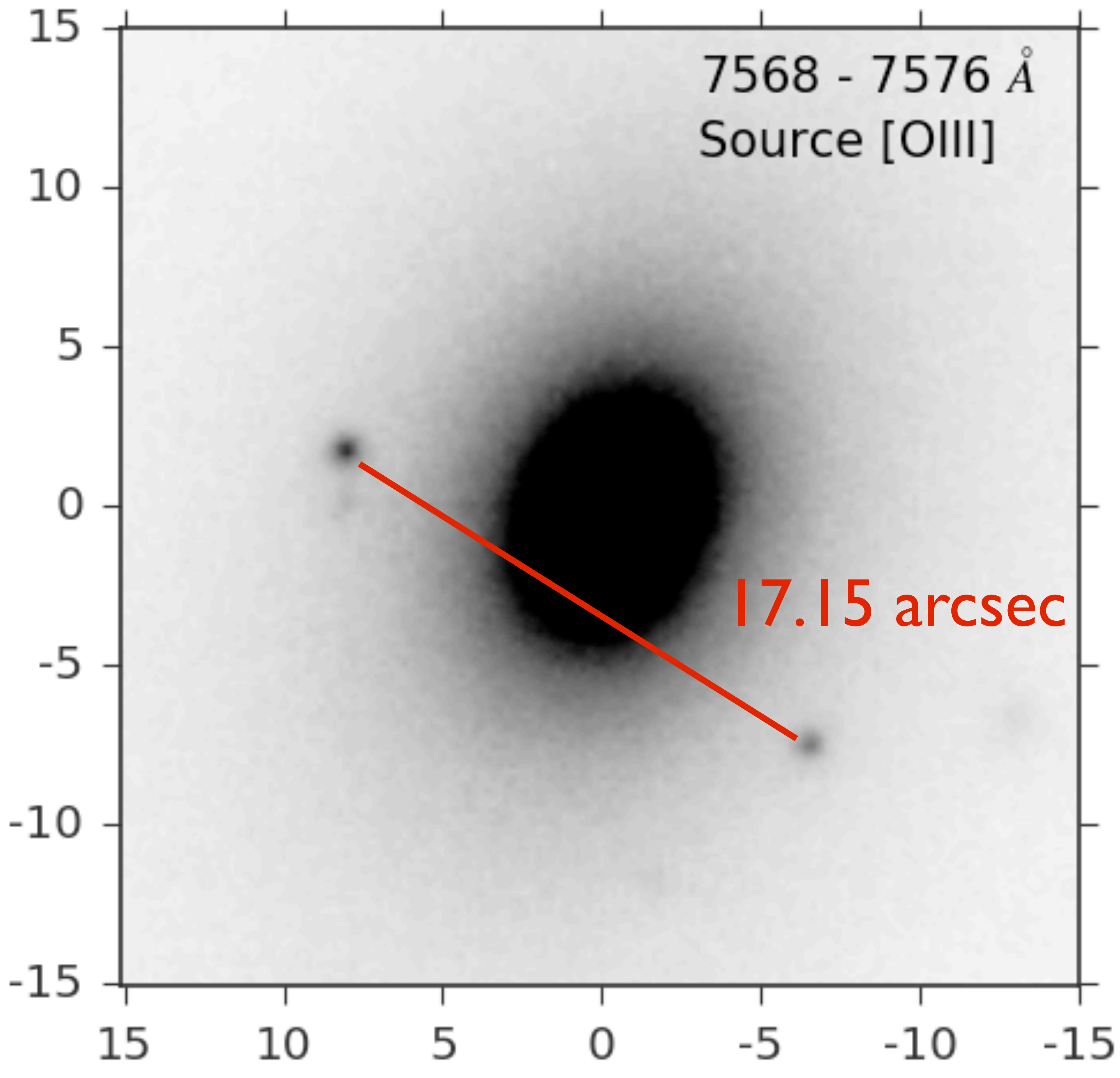
Lensing candidates

J0403 - Field galaxy



Collier, Smith & Lucey 2018b

Cluster BCGs i.e. A4059



Collier, Smith & Lucey 2019, in prep

2MASXJ0403-0239

- Massive field elliptical galaxy

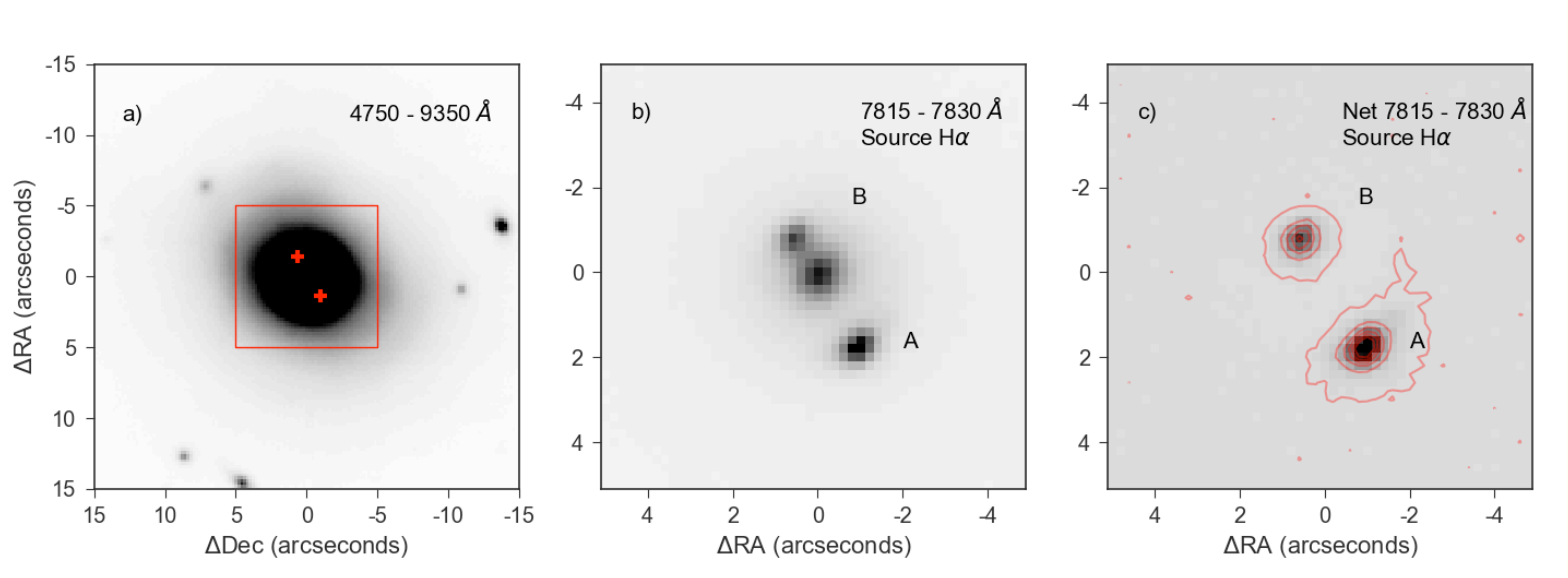
- z_{lens} = **0.066**, σ = **314** km/s
- z_{source} = **0.192**
- R_{Ein} = **1.25** arcsec

- Under the assumption of an old stellar population;

- Similarly to the three SNELLS galaxies α_{kroupa} = **1.15 ± 0.17**

- Dark matter component from the EAGLE simulation (~19%)

- The age of the stellar population is uncertain due to a lack of coverage at 4000Å



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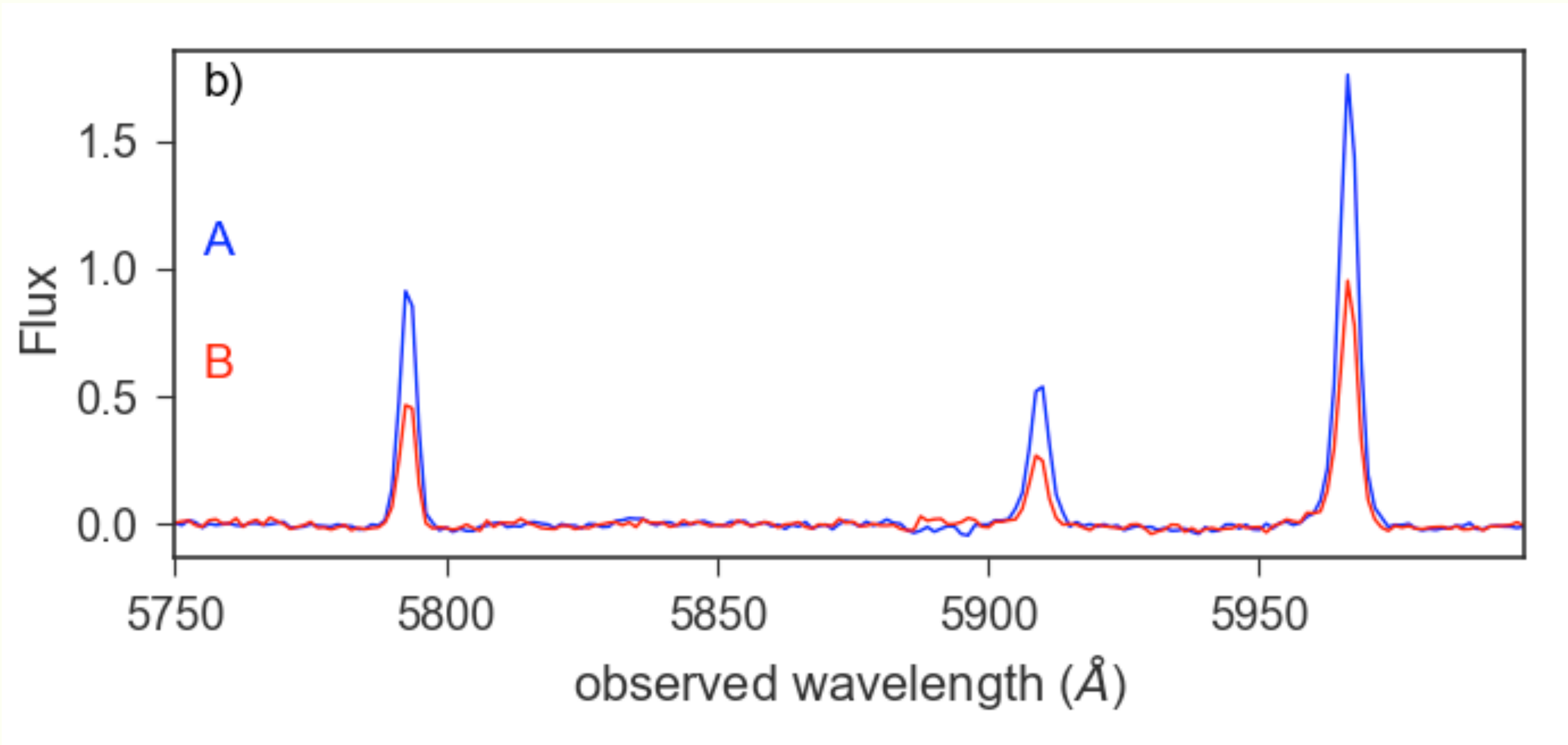

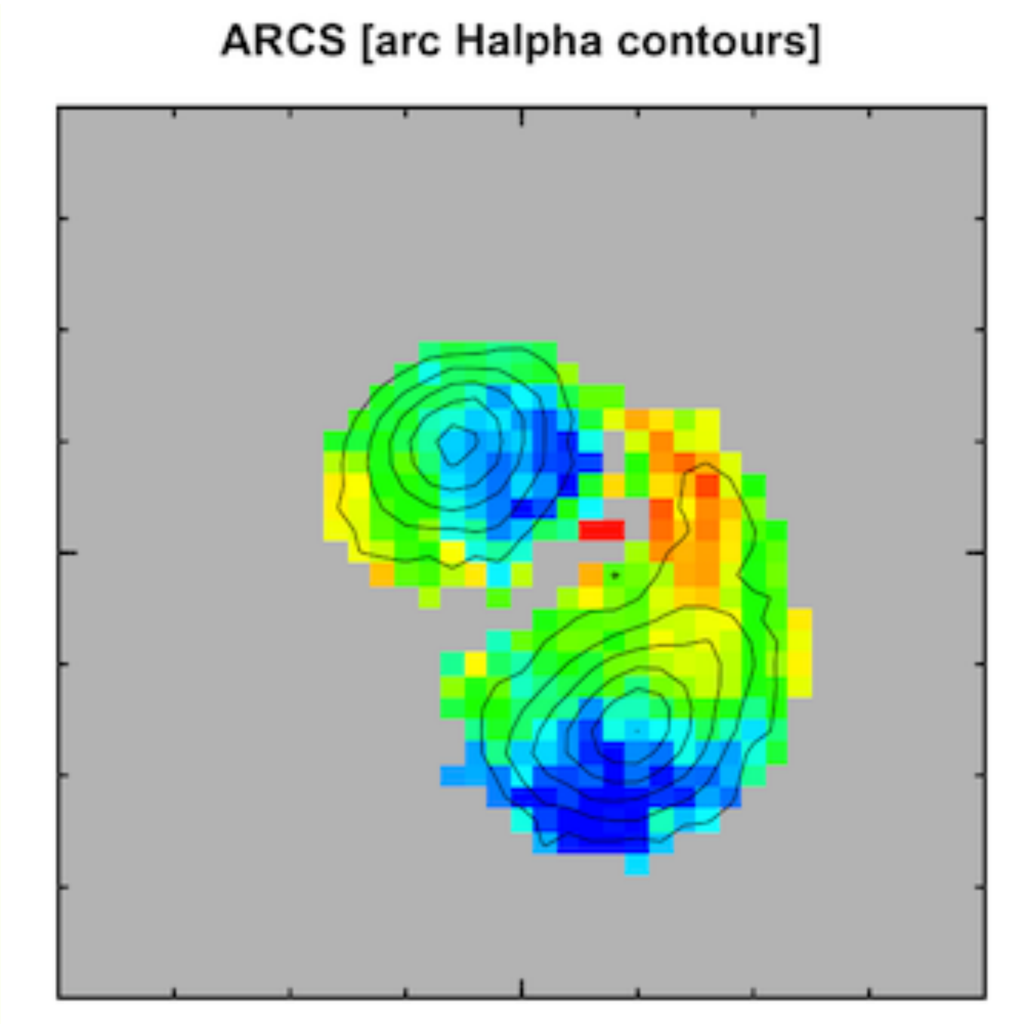

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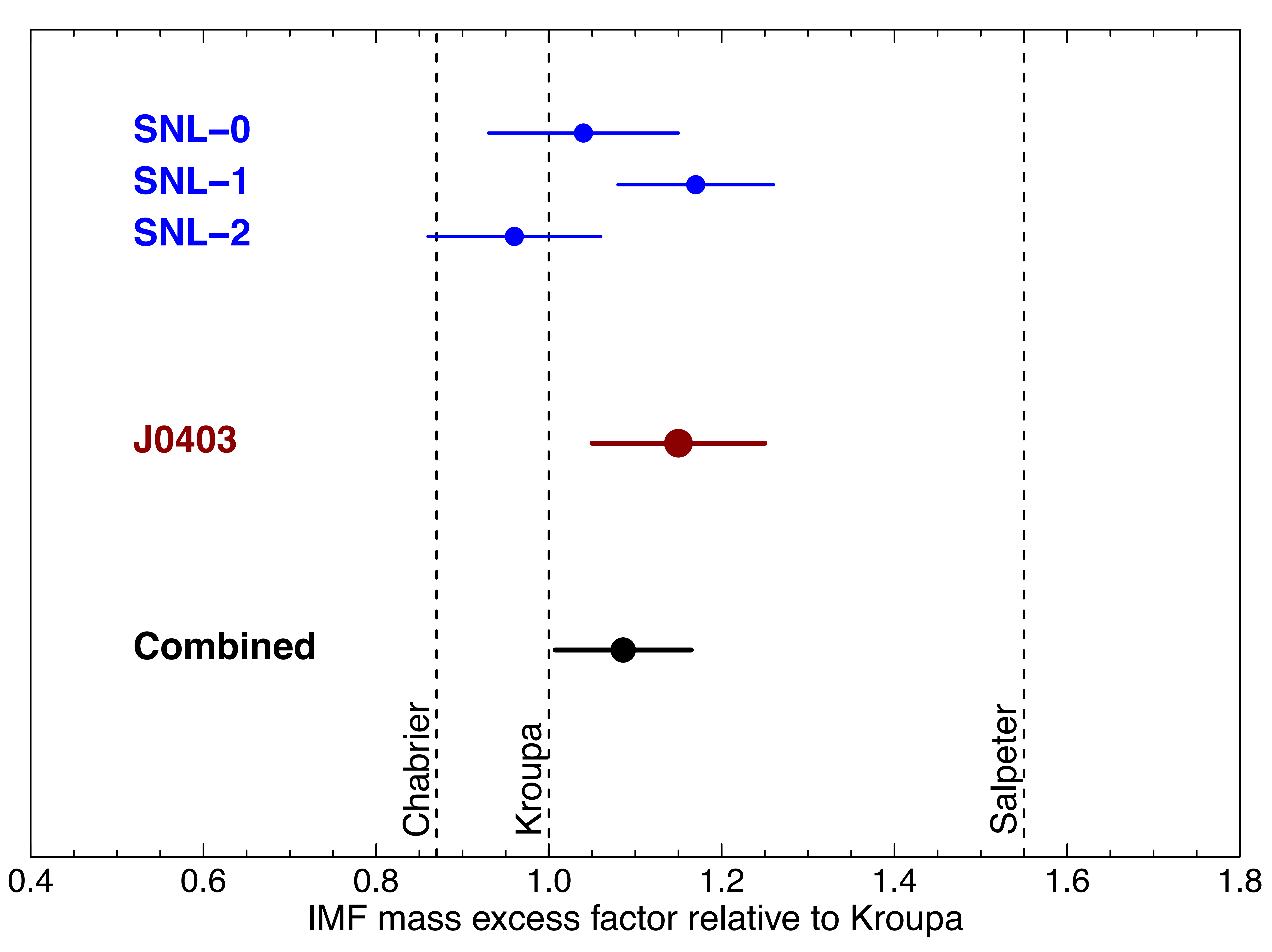


Collier, Smith & Lucey 2018b

A4059 - cluster lens

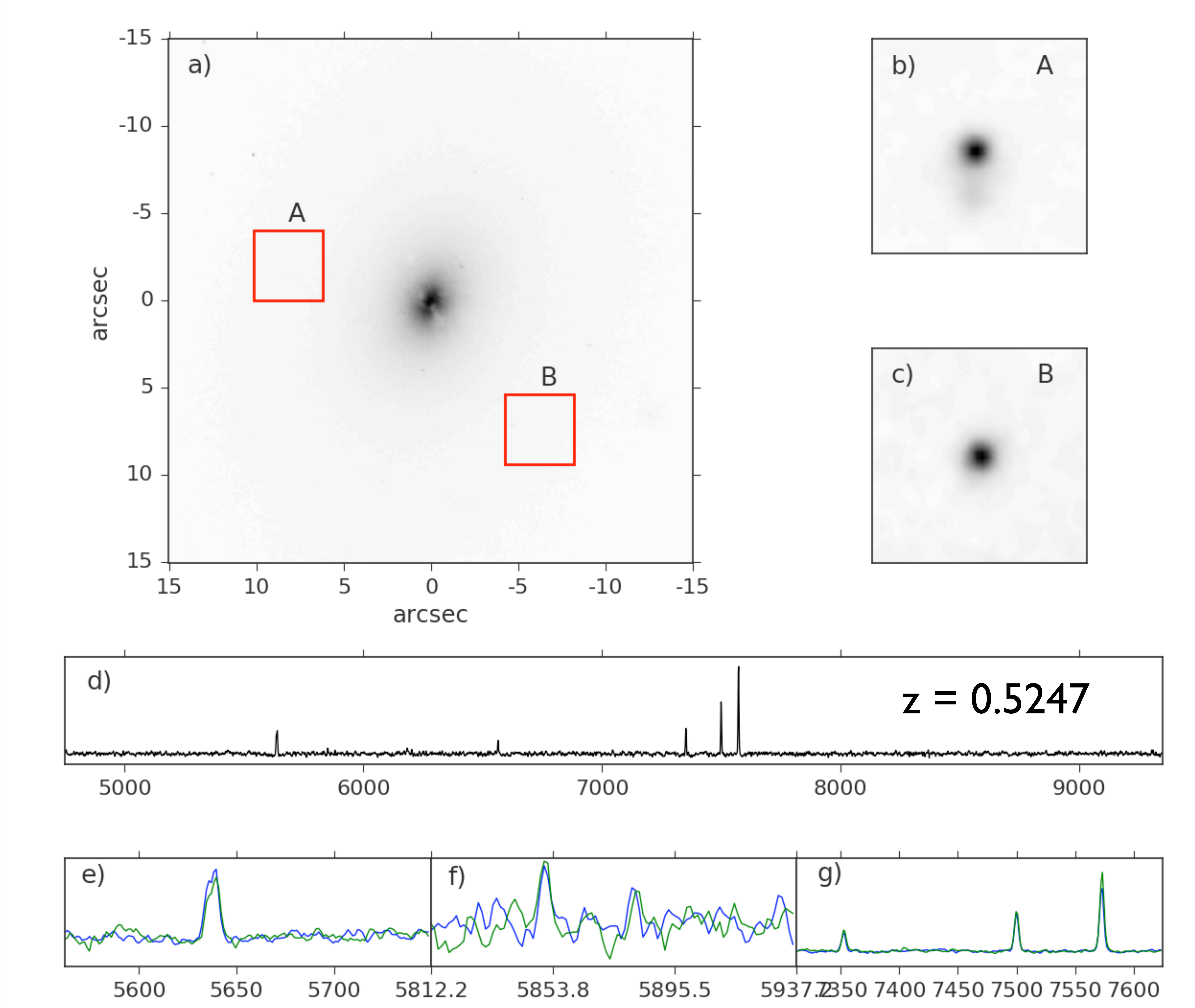
- Cluster BCG

- z_{lens} = **0.049**
- z_{source} = **0.525**
- R_{Ein} = **8.57** arcsec

- **No** counterpart to the lensed images in HST imaging

- Back of the envelope estimate:
- Total M = 2×10^{12} M_{solar}
- Total α ~ 5

- However this is **dominated** by **DM**, and complex to disentangle without additional information



A2052 - cluster lens

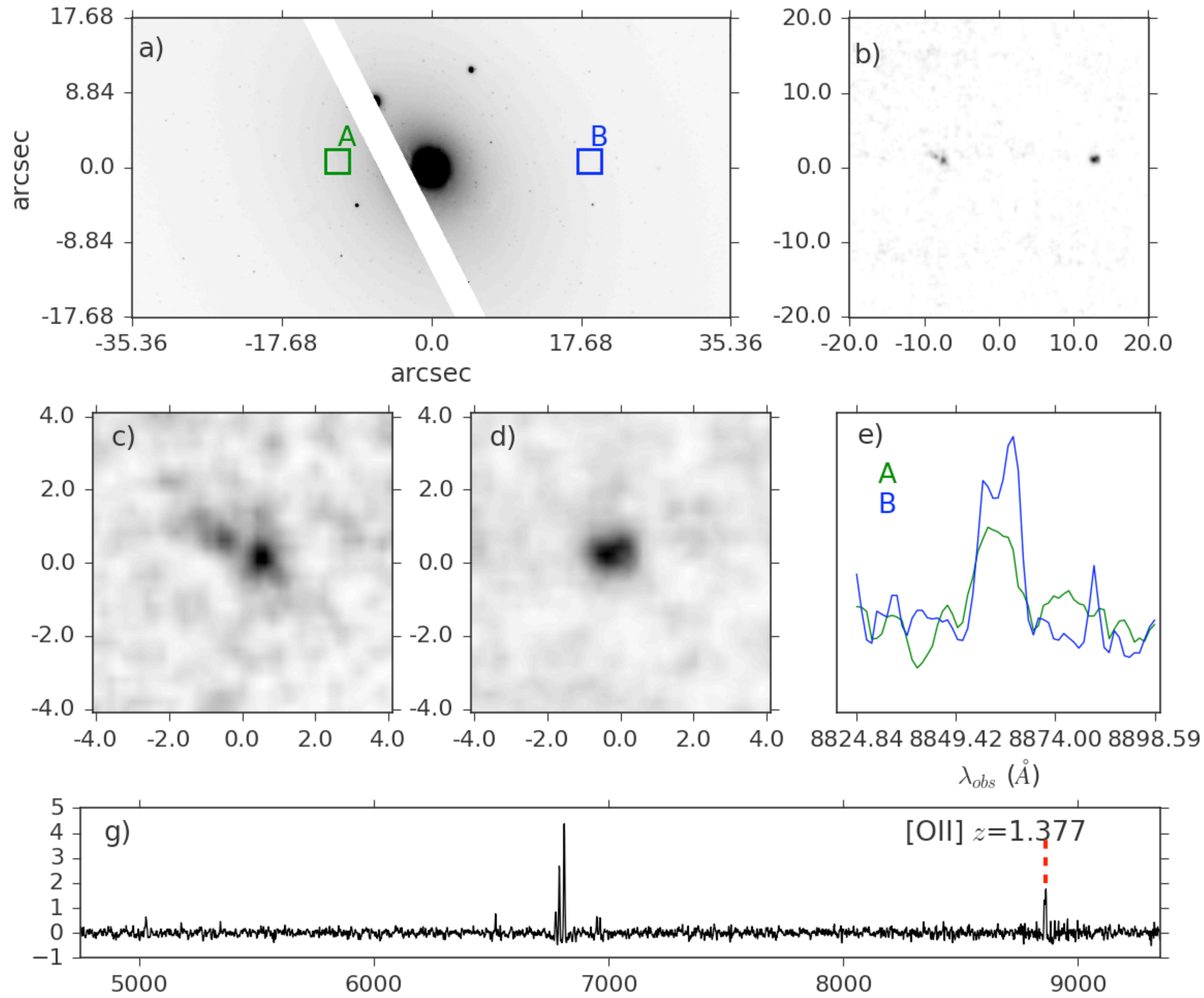
- Cluster BCG

- z_{lens} = **0.034**
- z_{source} = **1.377**
- R_{Ein} = **9.5** arcsec

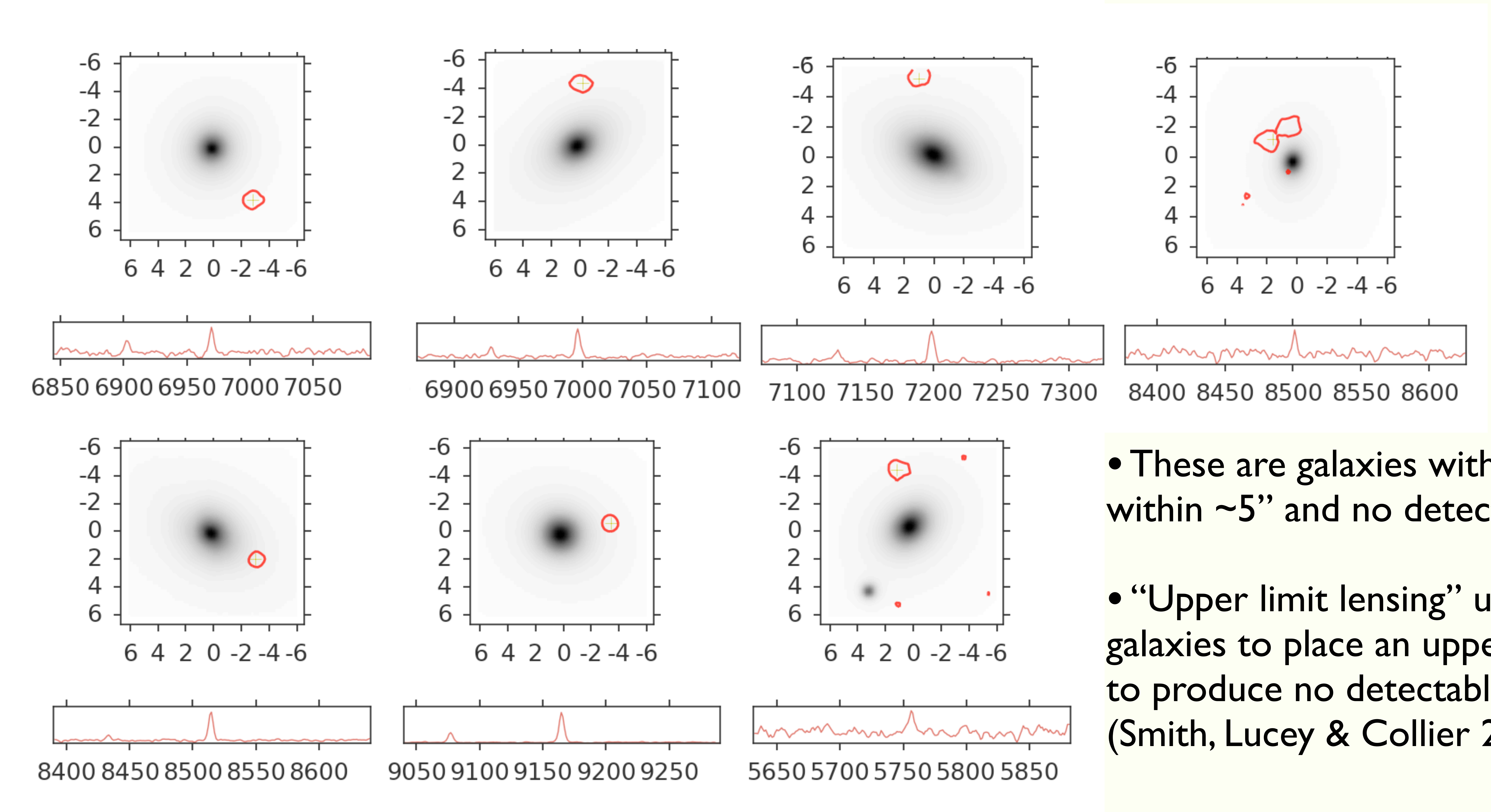
- **No** counterpart to the lensed images in HST imaging

- Back of the envelope estimate:
- Total M = 1.7×10^{12} M_{solar}
- Total $\alpha \sim 3.5$

- This is **dominated** by **DM**, and complex to disentangle without additional information



Singly-imaged, but closely projected



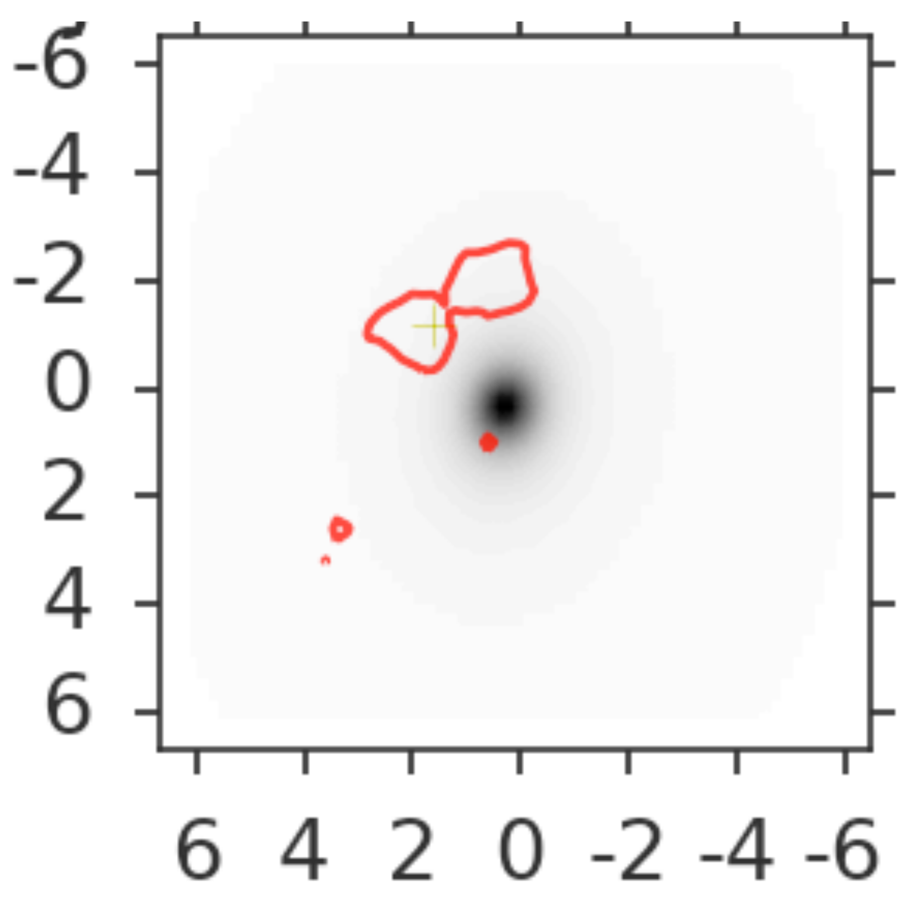
- These are galaxies with a single emitter within ~5” and no detected counter image

- “Upper limit lensing” utilises these galaxies to place an upper limit on the mass to produce no detectable counter image (Smith, Lucey & Collier 2018)

Collier, Smith & Lucey 2019, in prep

Upper-limit lensing analysis

Preliminary!



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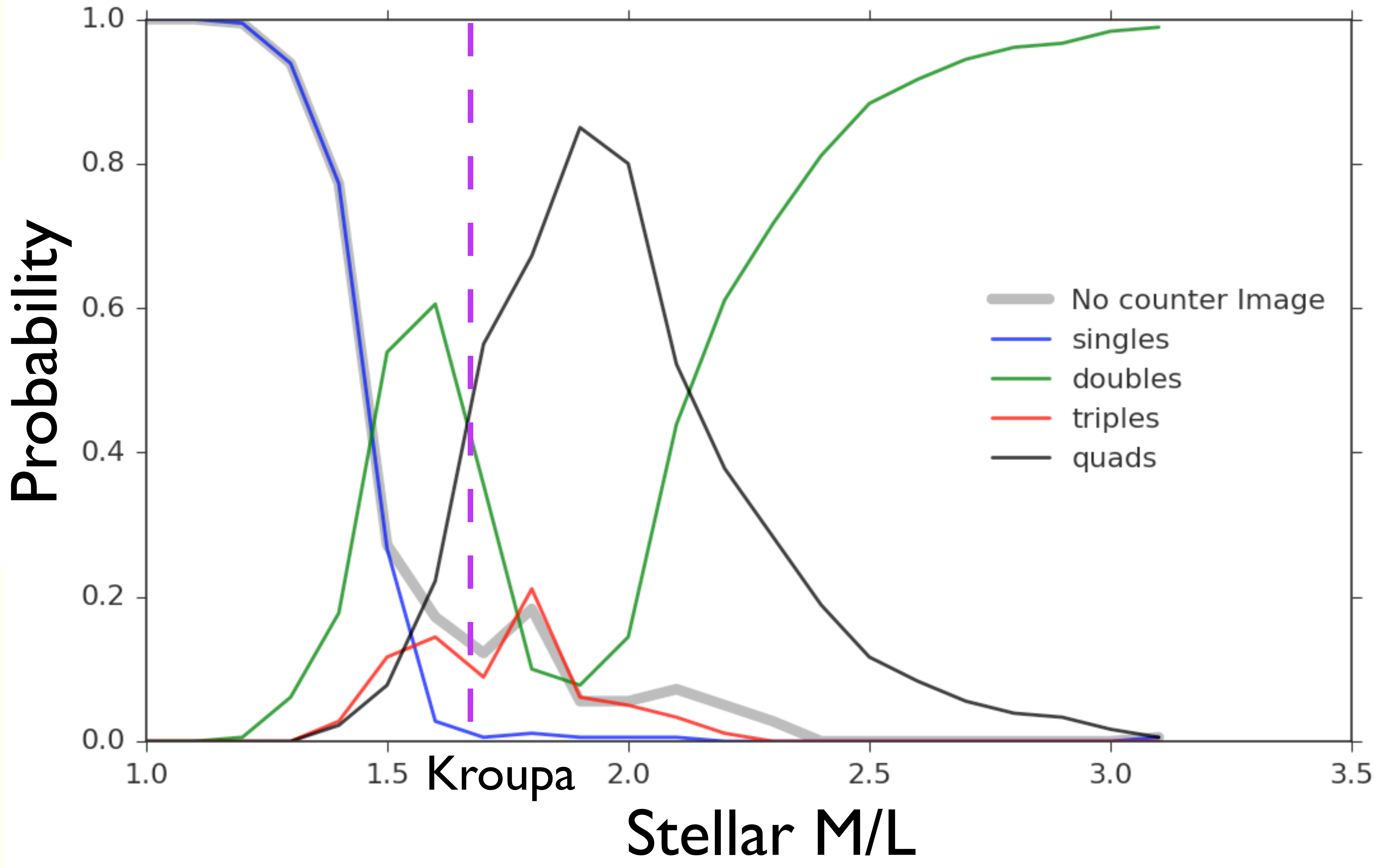

- Separated by ~**1.92”**
- Foreground 330km/s ellipitcal **z=0.021**
- Background Emitter **z=0.295**
- Can see steep turn-off in likelihood of being singly-imaged at **M/L~1.5**
- For reference a **kroupa** stellar population **M/L ~1.7**

Summary

- **MUSE** is a **proven** tool for discovering new galaxy scale strong lenses
- We have a targetted search programme in progress, from which we have already discovered **two singly-lensed candidates**
- We have uncovered **3 new strong lenses** from within the MUSE archive, and **five closely projected but singly imaged** lensing candidates
- From the archive, J0403 is found to have a M/L **consistent** with a **MW-like IMF** (for an old stellar population) like the SNELLS galaxies
- The SNELLS galaxies + J0403 have a combined $< \alpha > =$ **1.08 ± 0.09**
- The future is full of lenses! Further observations with MUSE, along with other IFU searches, will soon double the sample size of nearby galaxy-scale strong lenses