Blended Spectra

Signal from two galaxies at along the line of sight at different redshifts

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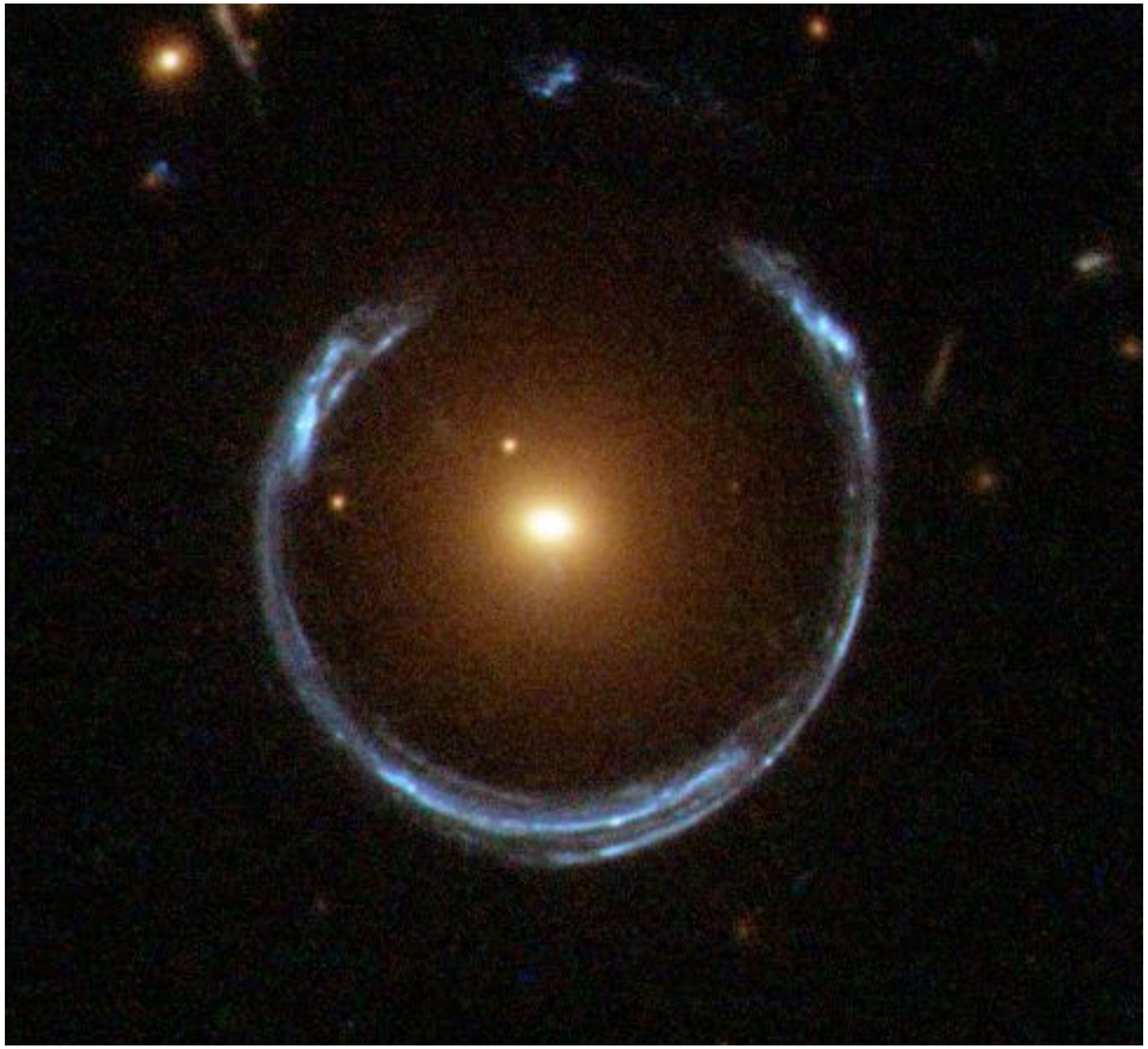
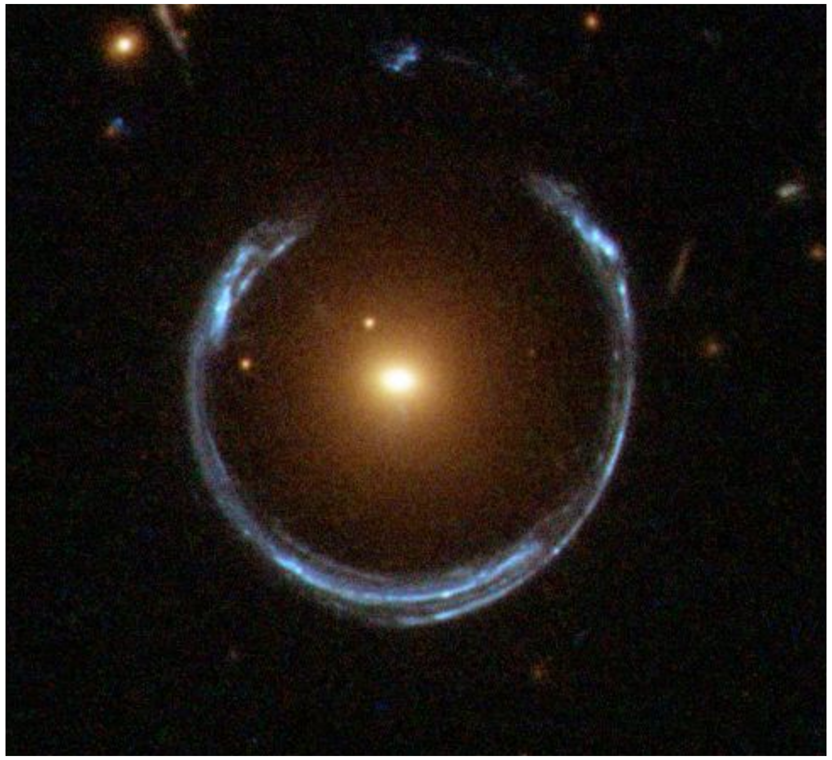
Motivation

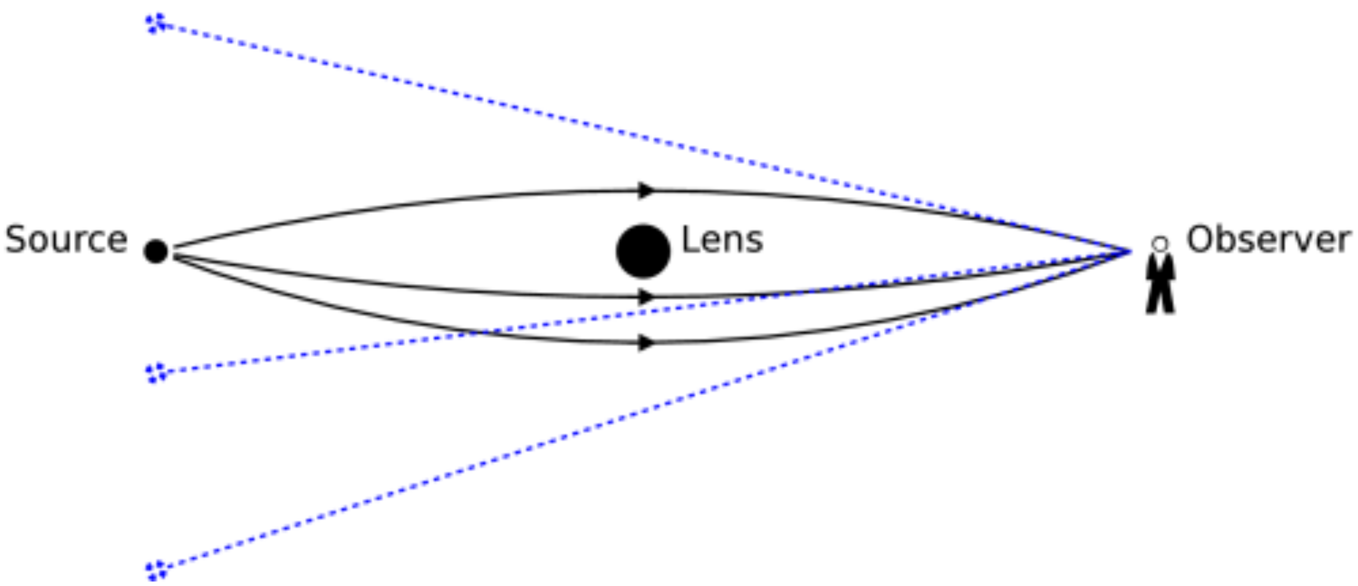
Strong gravitational lenses

- Measure mass of lensing galaxy.
- Magnify the source galaxy (e.g. HI).
- Cosmography: time-delay of transients in the source galaxy.

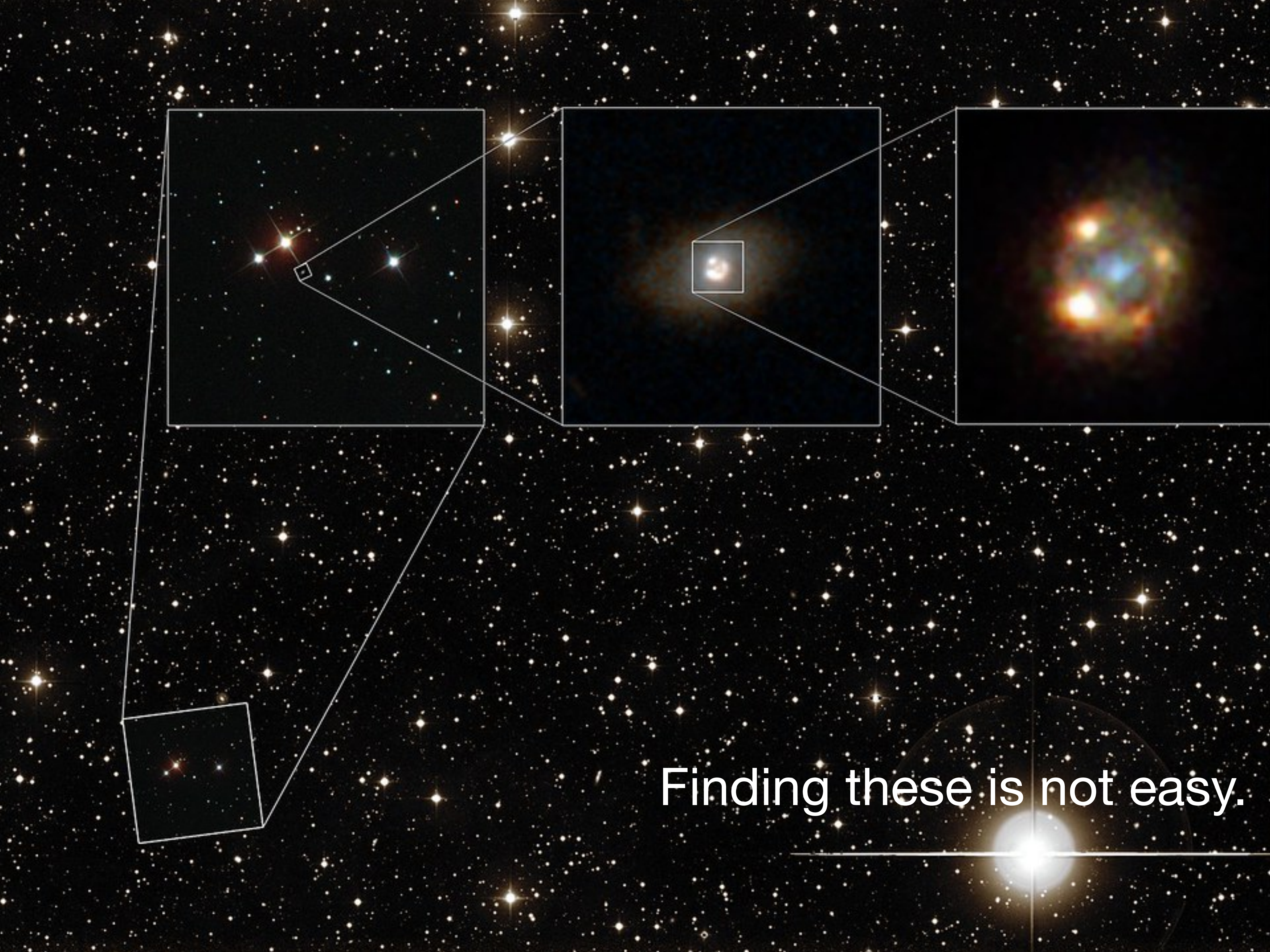


Gravitational lensing





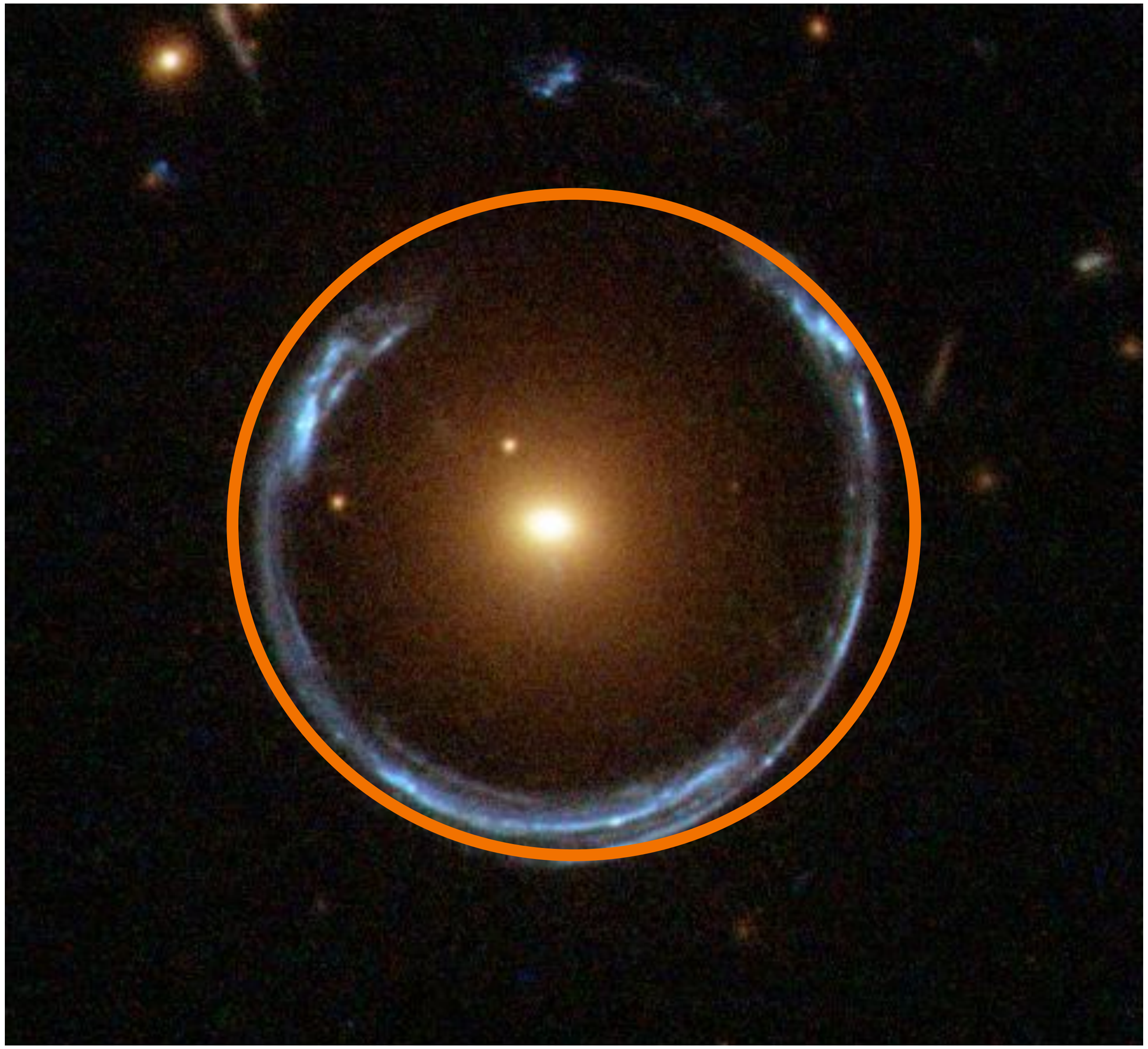
- Source galaxy is magnified.
- Ring of multiple images of the source galaxy.
- Different length light paths to the observer.


Finding these is not easy.

Gravitational Lenses

How to identify these in wide/deep surveys?

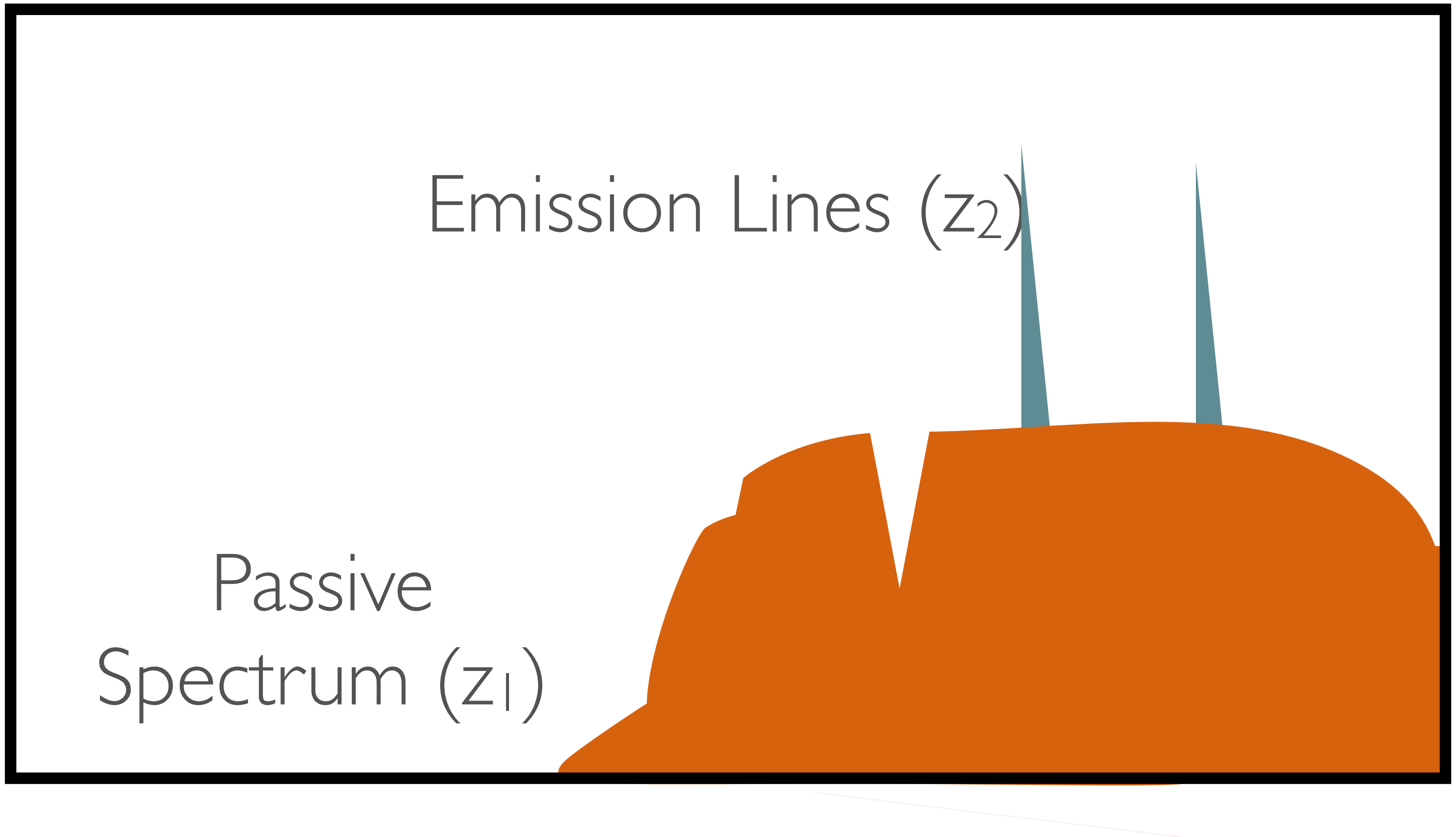
- Three main way to identify:
  - Blended spectrum
  - Citizen Science
  - Machine Learning



Blended Spectra

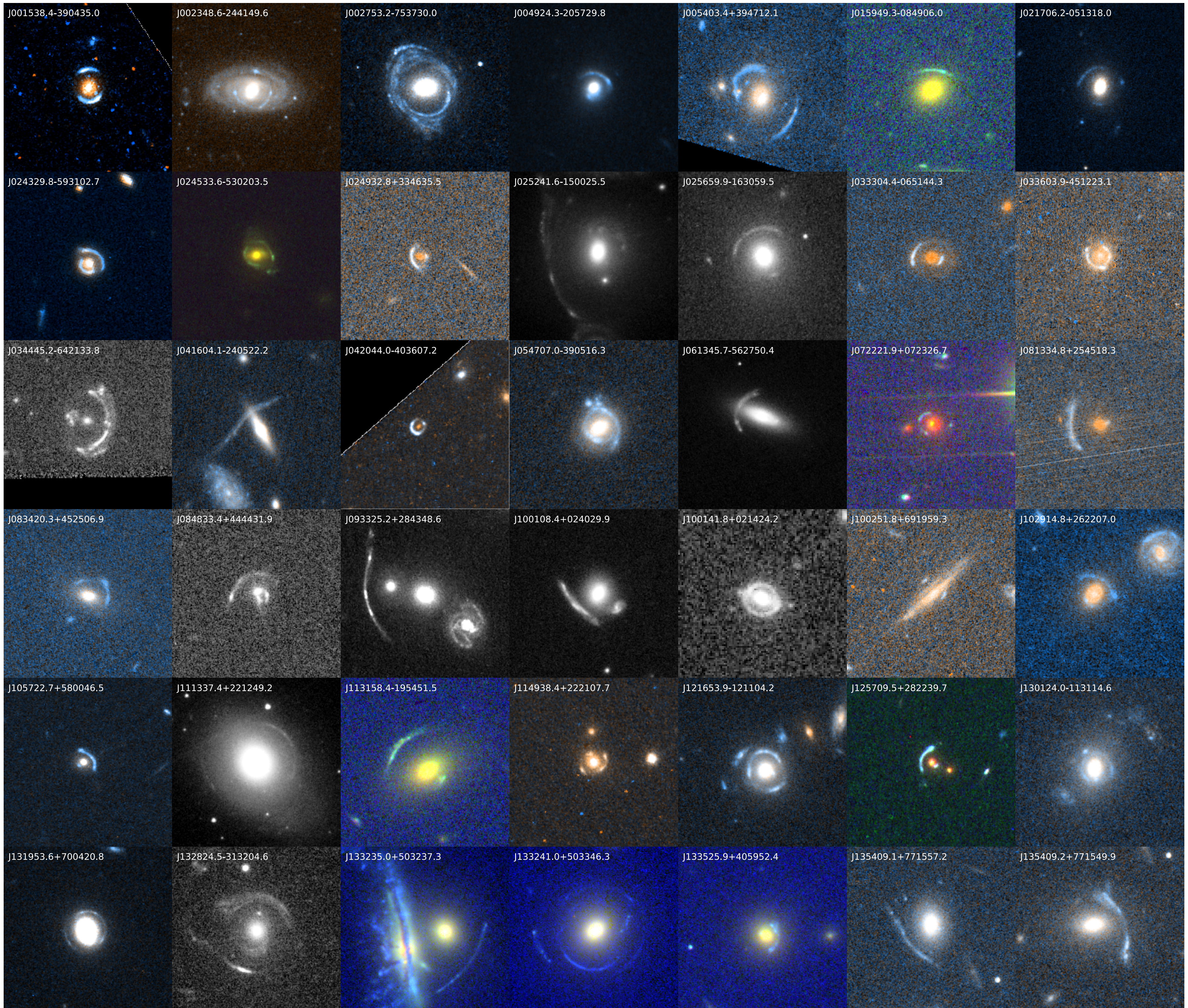
70% success rate of identifying classical lenses

- $Z_1 < Z_2$ - possible strong lens
- $Z_1 > Z_2$ - possible useful occulter.
- AUTOZ cross-correlation parameters do this automatically.



Holwerda+ (2015 & *in prep*)

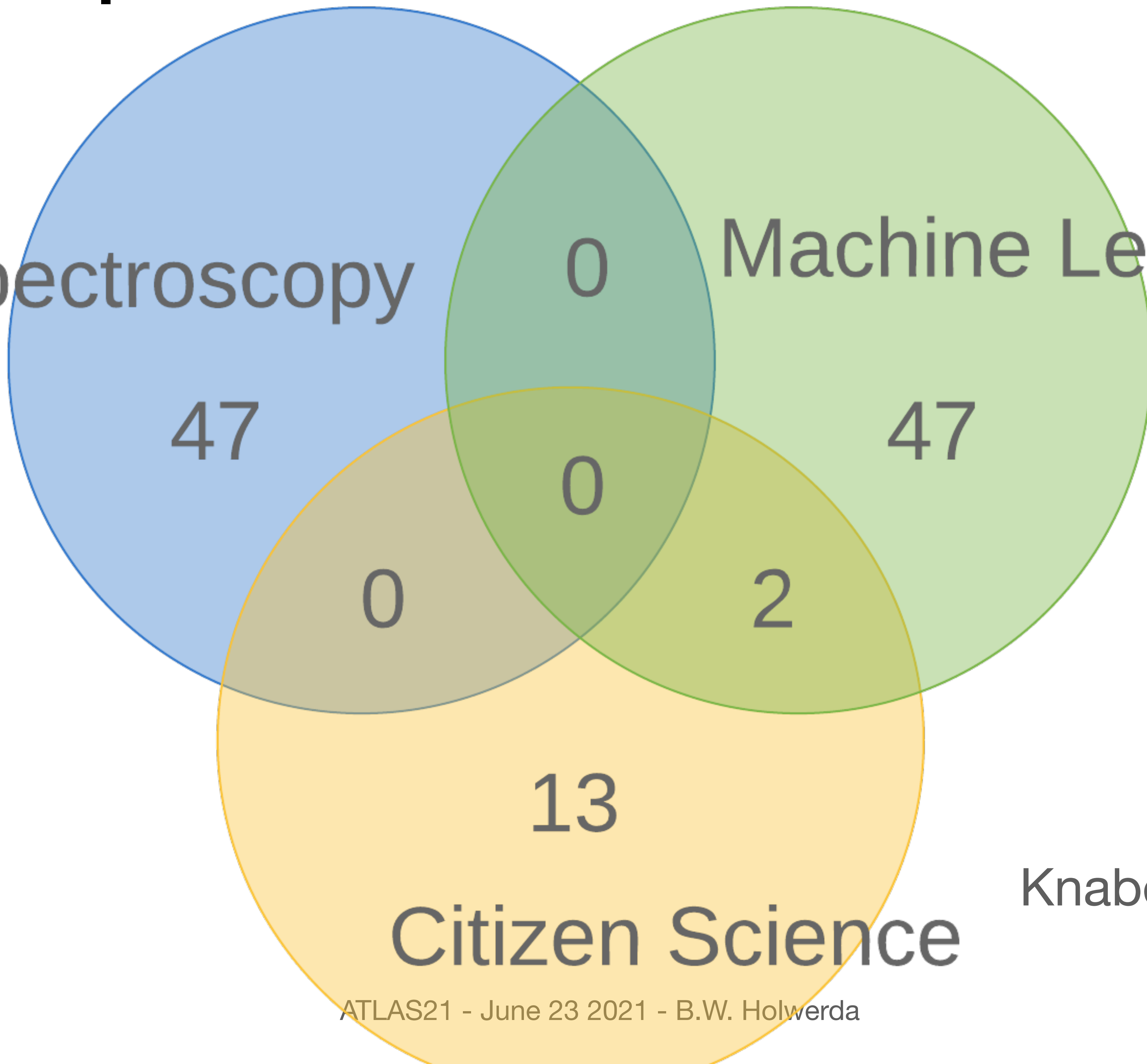
Citizen Science or crowd



Sandor Kruk

How did they do in GAMA?

GAMA Equatorial Fields

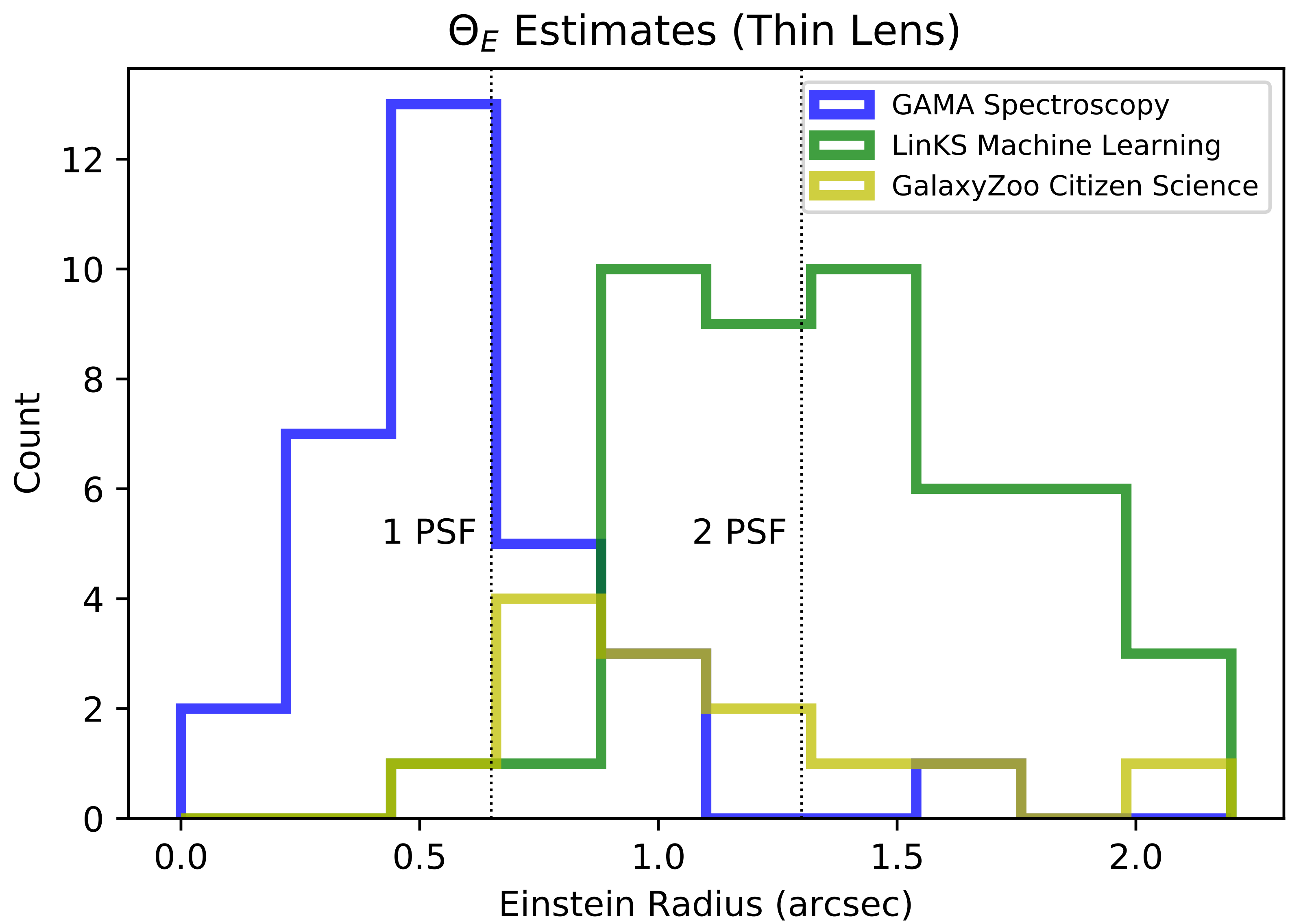


Knabel et al. 2020

Some are better resolved

Einstein radius function of redshift and mass

- Spectroscopy benefits from small Einstein radius.
- Machine Learning prefers the lensed source well-away from the lens galaxy
- GalaxyZoo somewhere in between.

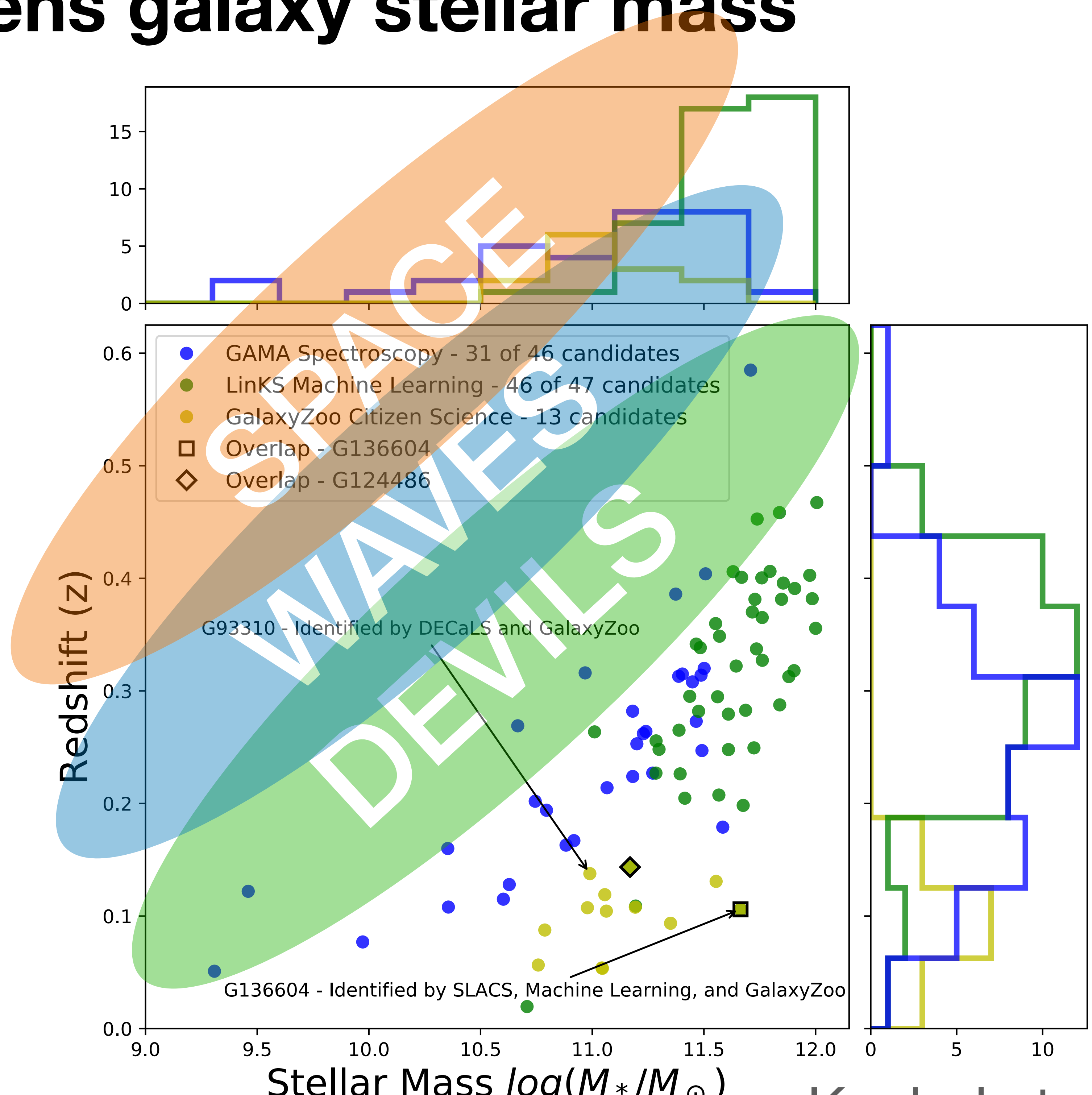


Knabel et al. 2020

Discovery Space

Redshift and lens galaxy stellar mass

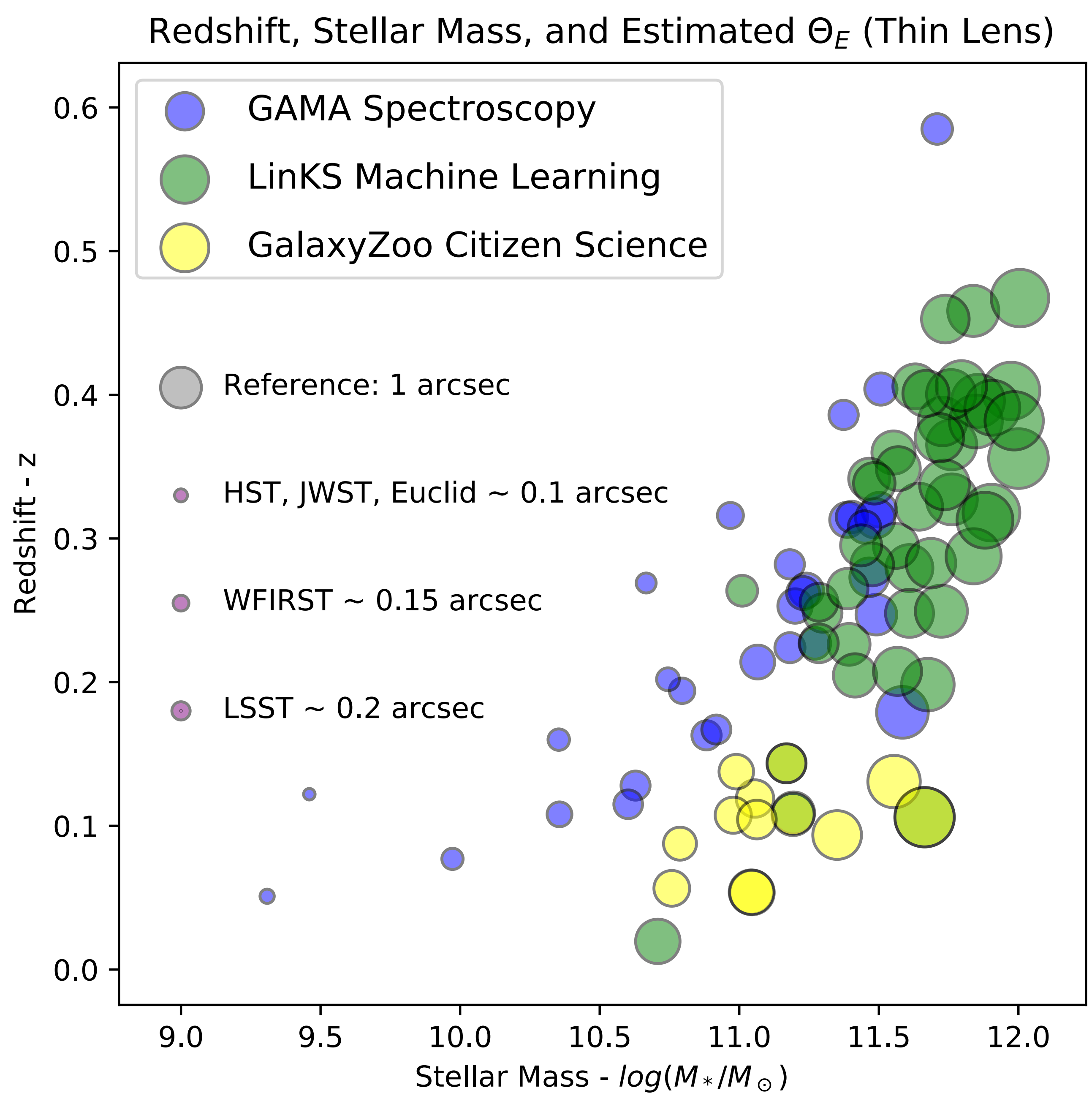
- Deeper so lenses at lower mass and/or higher redshift.
- Limit on source (lensed) galaxy because of redshift desert.
- Space-based spectroscopy takes lens detection z>0.8



Knabel et al. 2020

Follow-up?

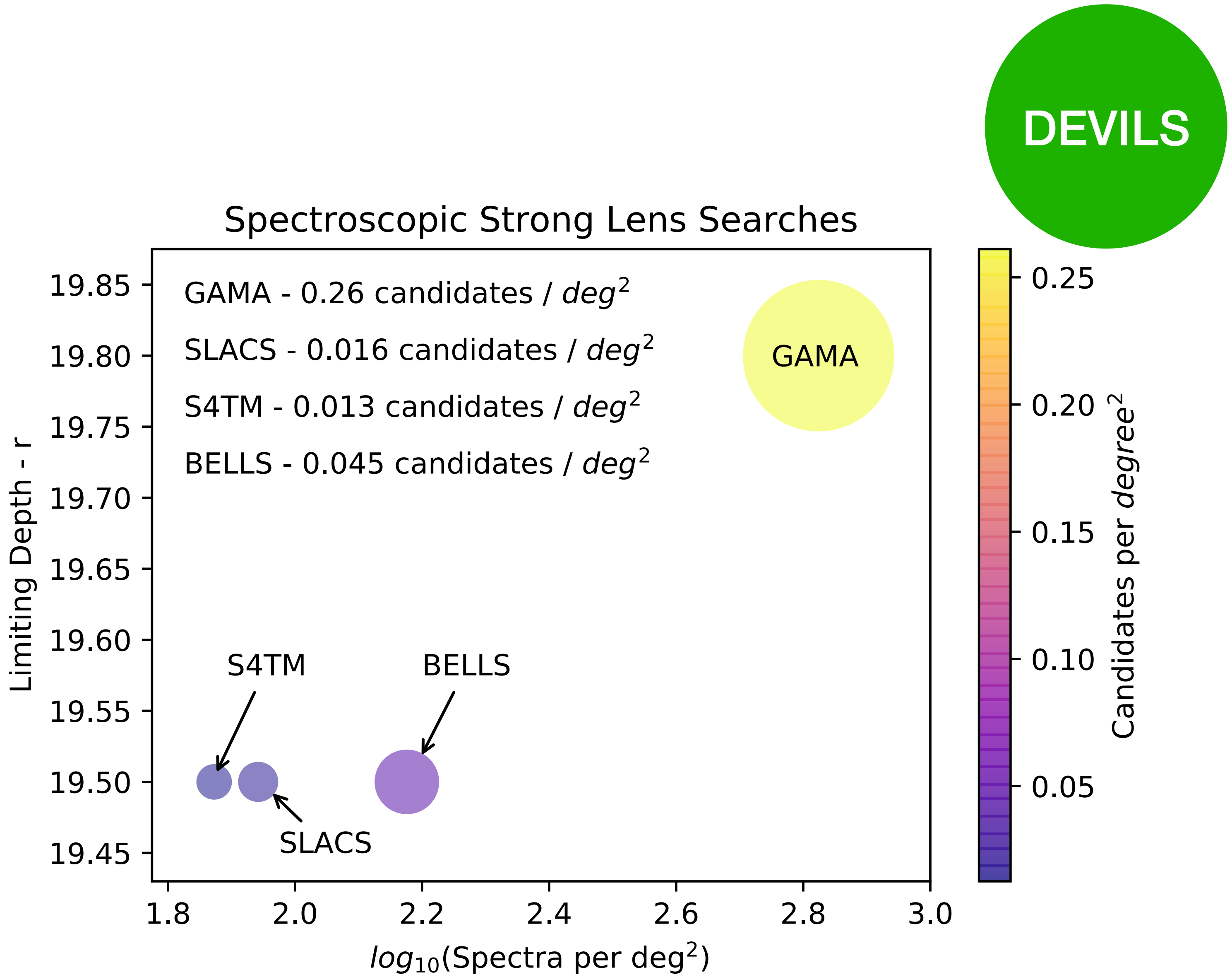
- Targeted with HST or JWST
- Euclid deep field: VIZ channel
- Roman Space Telescope



Knabel et al. 2020

Expectations

Depth and fiber density increase lens numbers

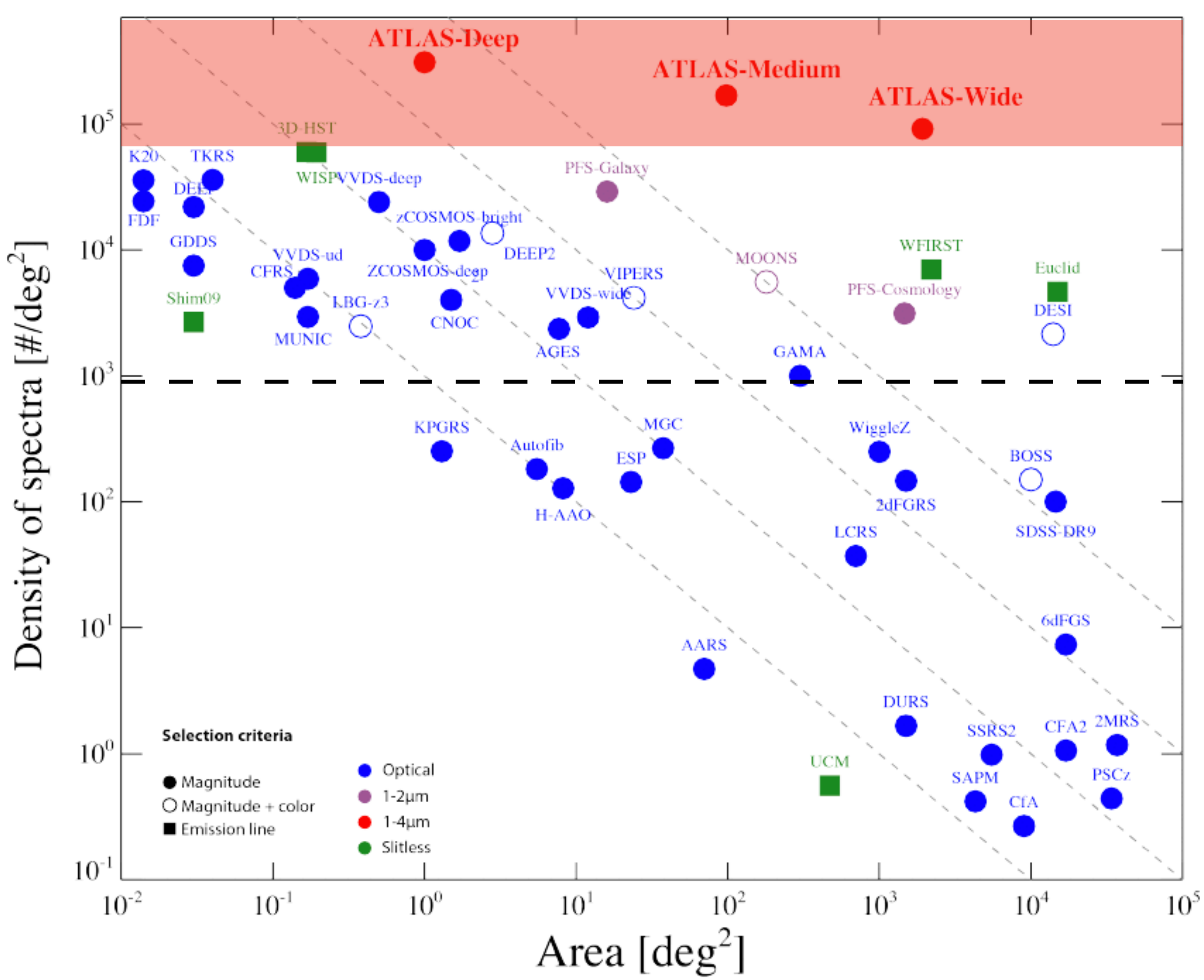


- Increasing efficiency of identification.
- Up to 1 lensing system per square degree (~0.01-0.05%).
- ATLAS increase?

Knabel et al. 2020

ATLAS lenses

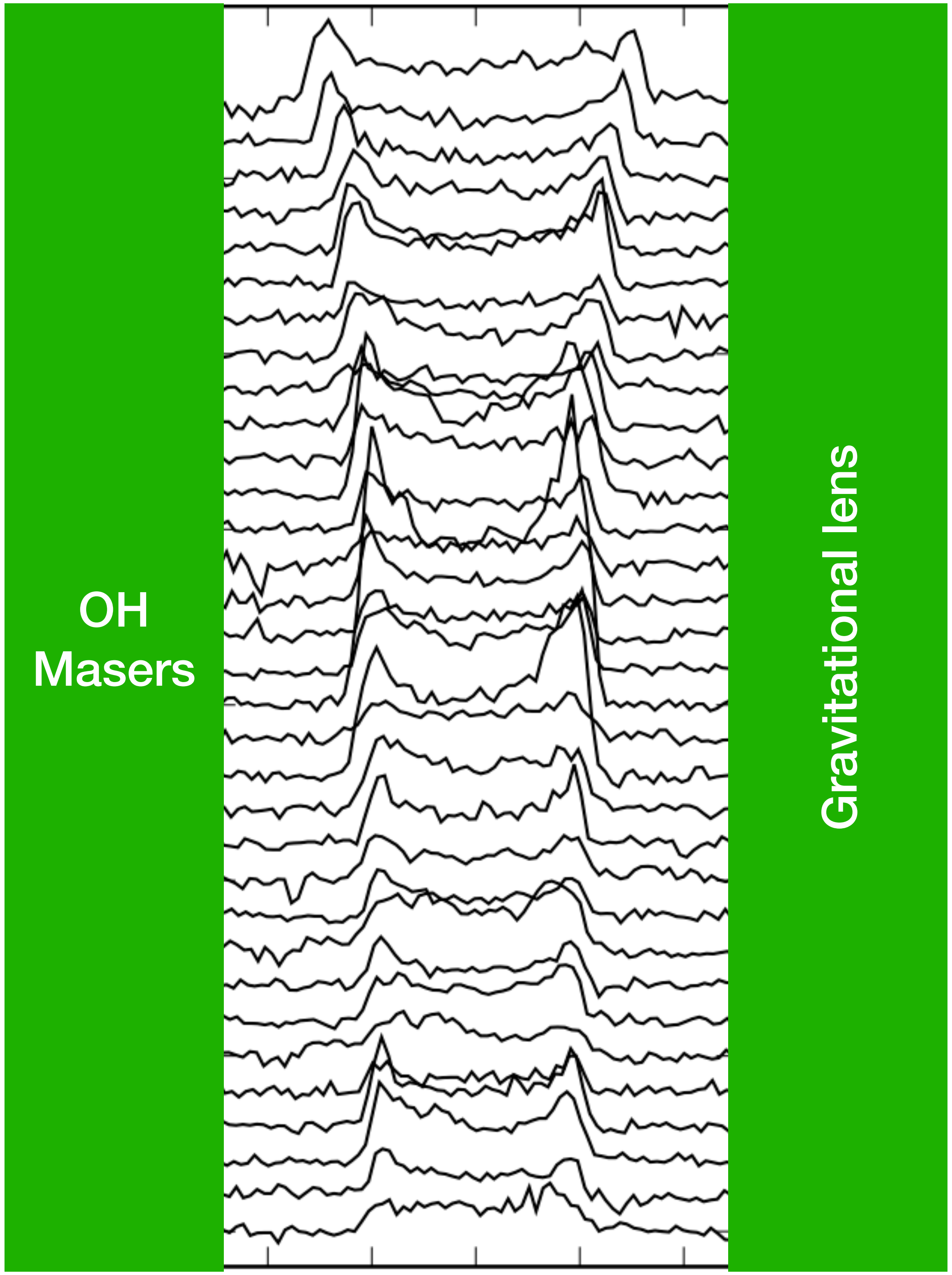
- GAMA 0.05% of spectra are blends.
- ~1 per sq degree
- ATLAS *hundreds* of blends?
- At some point the background volume density of sources peters out.



LADUMA HI

Deep L- and UHF-band observations of CDF-S

- Lensed Source Galaxy HI.
- Puts a limit on low-mass systems at higher redshift.
- No need for a “classical” lensing galaxy (elliptical).
- SKA/ATLAS synergy.

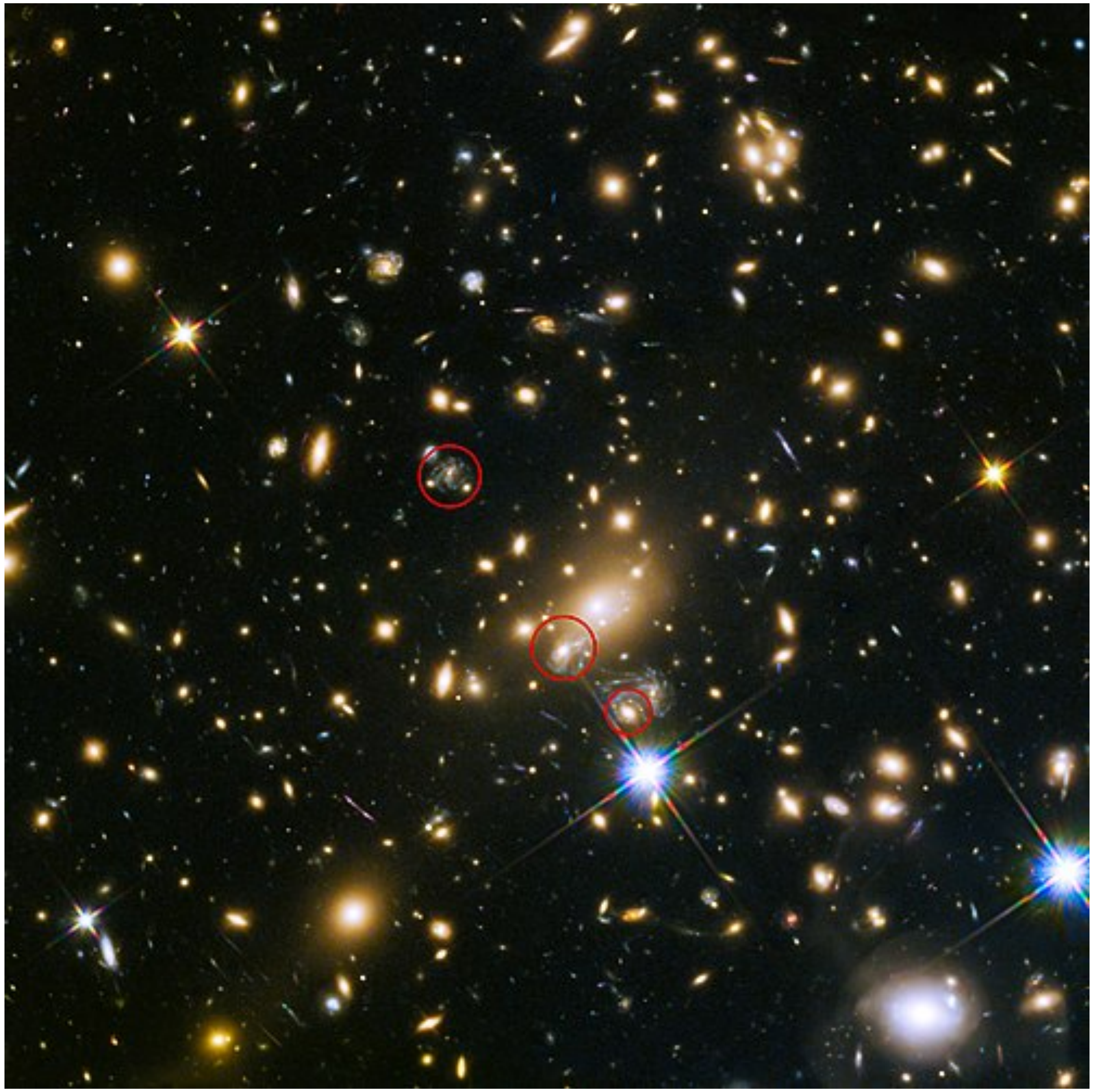


HI spectra shifted to optical redshift

Cosmography

Watch Supernovae go off multiple times

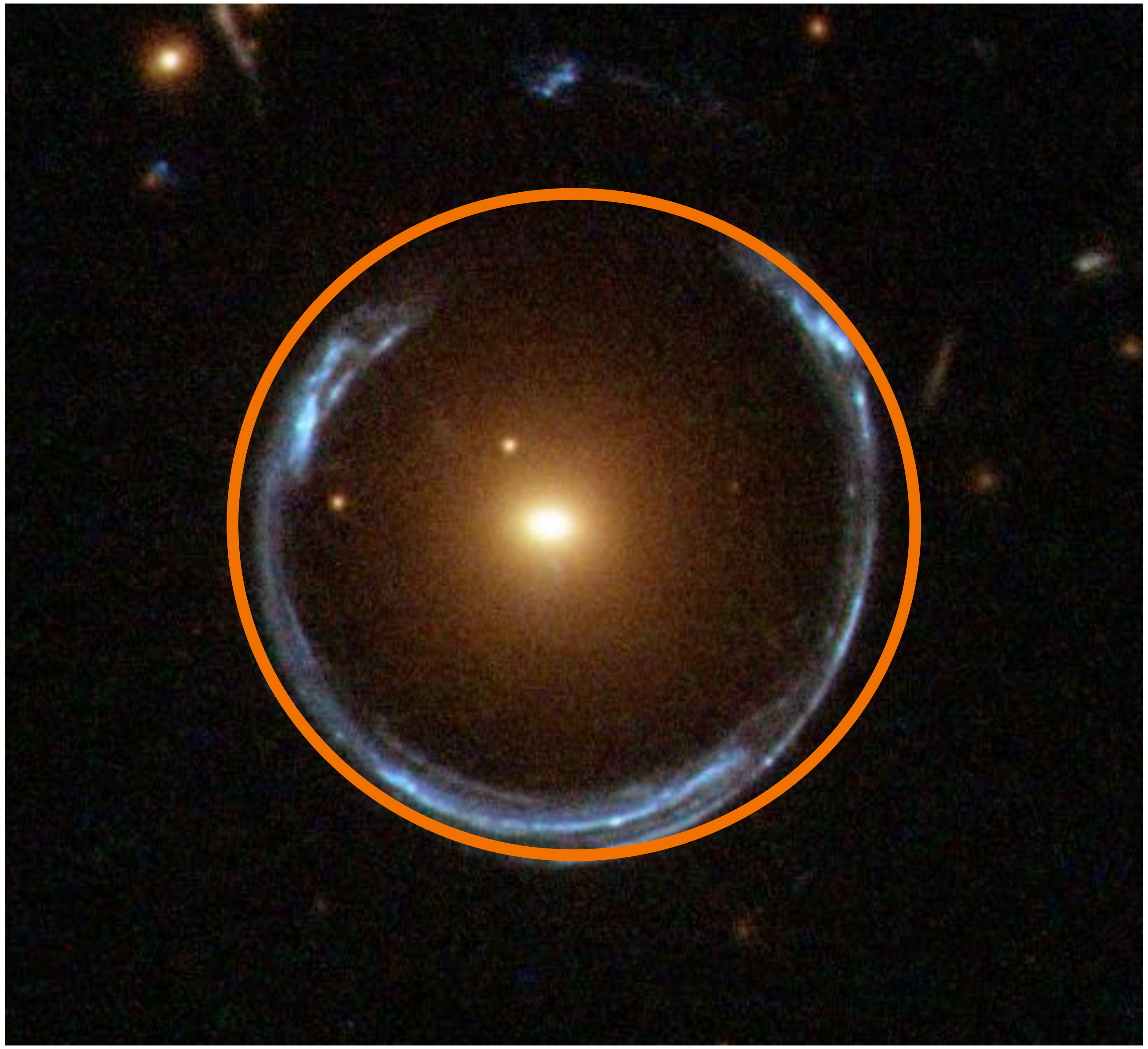
- Supernova Refsdahl
- The more distant source supernova, the longer the time delay.
- Better statistics: better H_0 measurement.



See Treu+ (2016) for review

Spectroscopic Requirements

- High completeness > 98%
- Aperture wide enough to encompass Einstein Radius.
- R~1000 to resolve emission/ absorption line redshift discrepancy.
- NIR spectra can identify lenses z>0.8



Overlapping Galaxy Pairs

- Use symmetry to estimate missing light in overlap region.
- Map dust in disk galaxies.
- Can be found from blended spectra (Holwerda+ 2007,2015,2021)

Conclusions

- Number of strong lenses per sq degree will keep going up.
- 0.01% of a spectroscopic survey is still a substantial sample.
- Going to NIR increases the numbers of lenses identified at z>0.8
- Mass (and M/L) evolution of spheroidal galaxies.
- Probe fainter HI
- Improve cosmography from supernovae.

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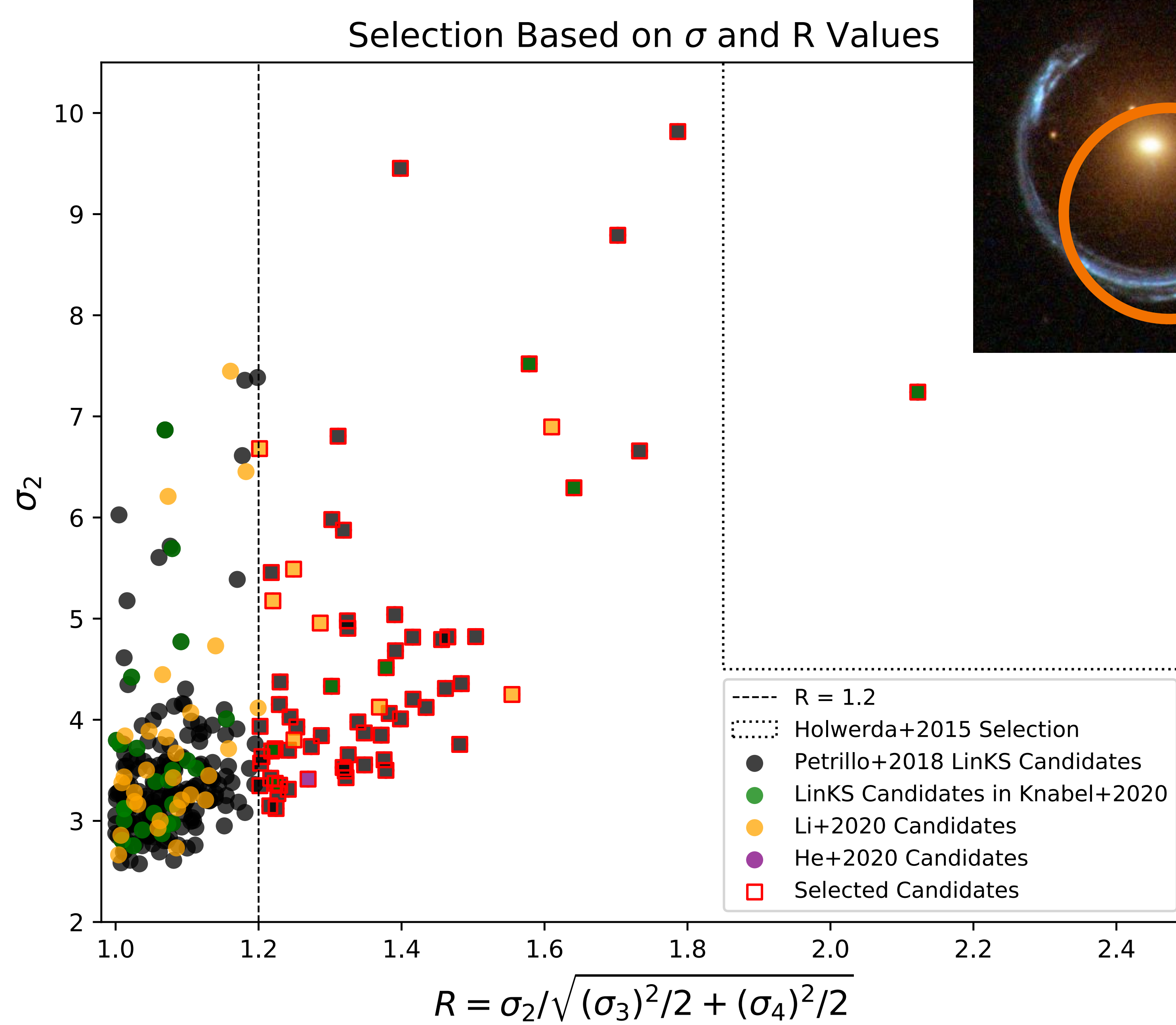
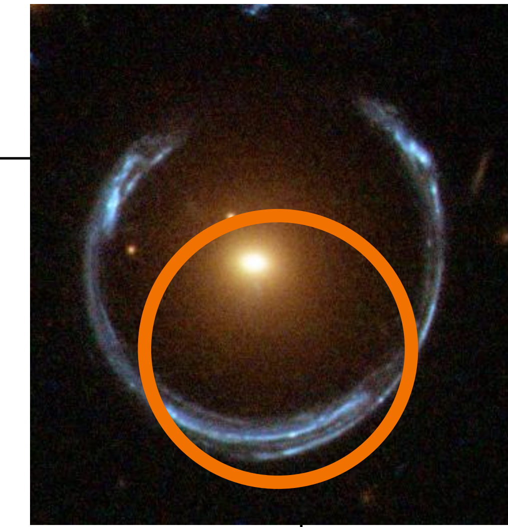
Confirmation of Machine Learning

- Weaker spectral signal.
- Aperture likely does not cover full Einstein radius.
- Enough signal to confirm independently ML identifications.

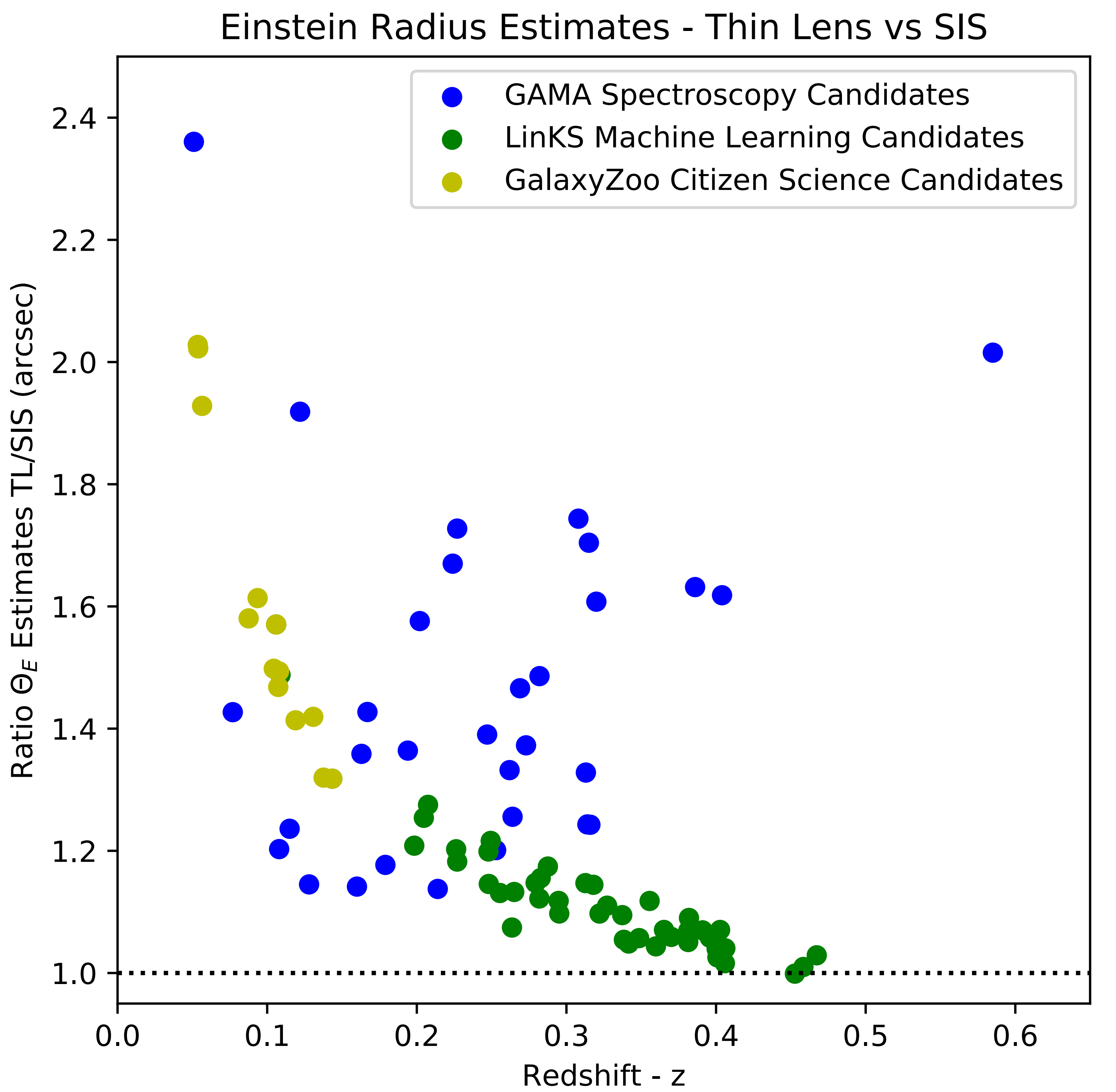




Knabel et al. *in prep.*

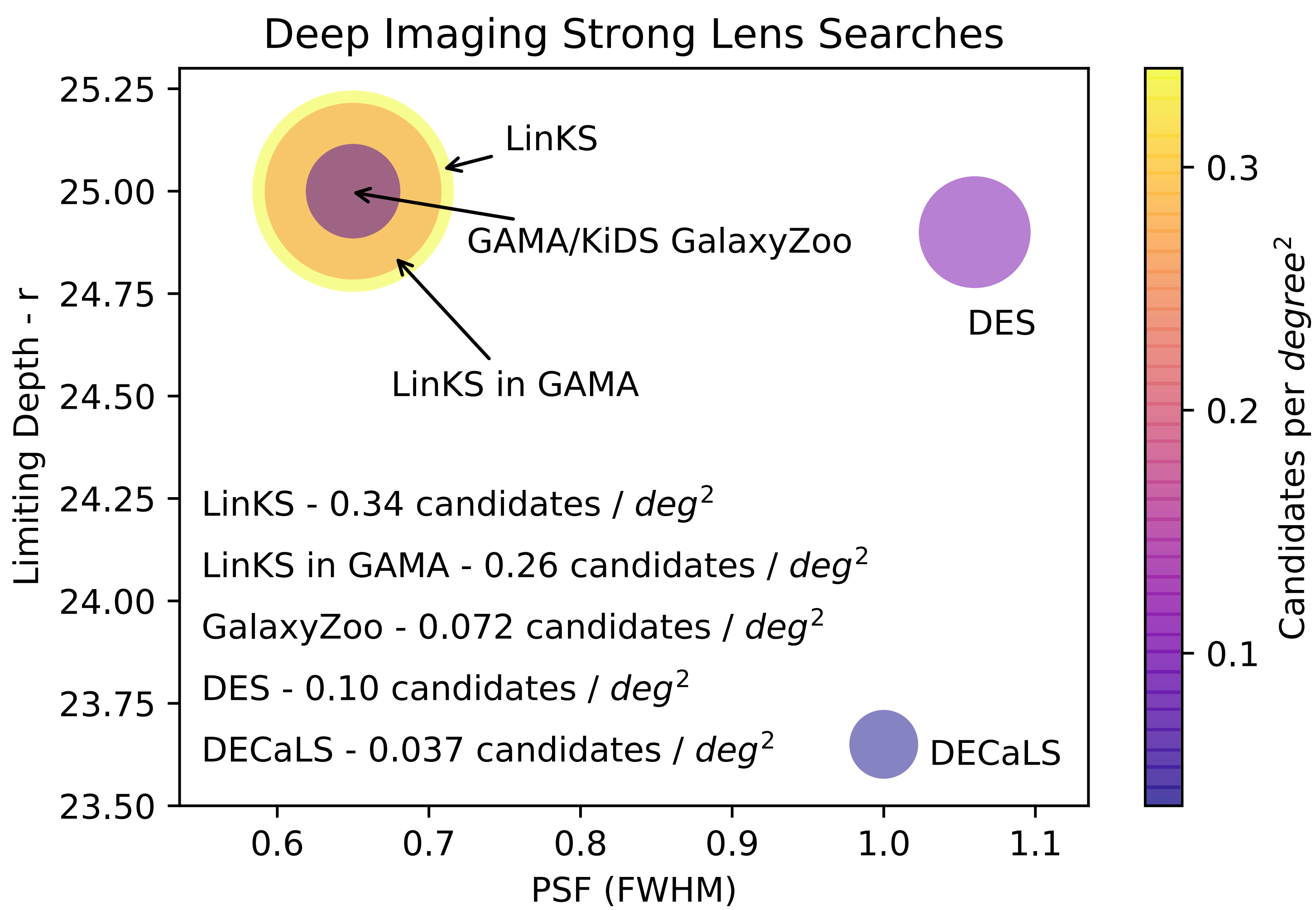
Einstein Radii predictions

- Depends on which model.
- Redshift and stellar mass dependent.



ATLA

Machine Learning Efficiency



Low-mass Lenses

- Emission line from source flips contrast in medium and narrow-band filters
- Measure the *stellar mass* dominated part of the mass profile.
- Measure stellar M/L