4MOST Strong Lensing Spectroscopic Legacy Survey

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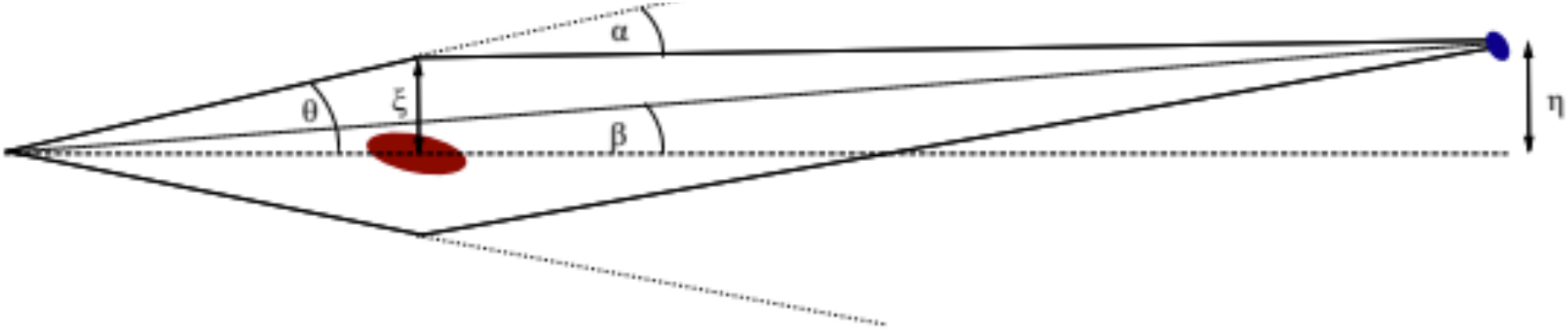
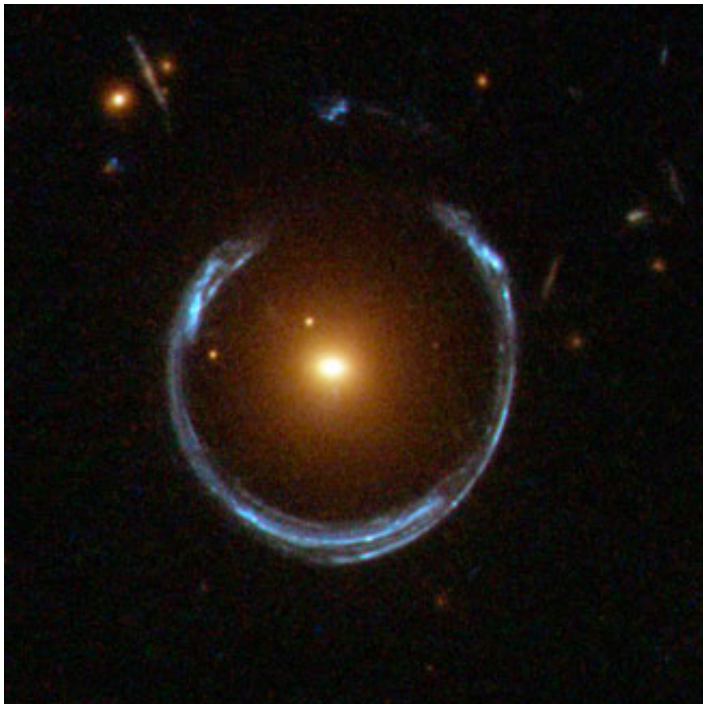
Strong lenses probe astrophysics and cosmology





What we observe depends on:

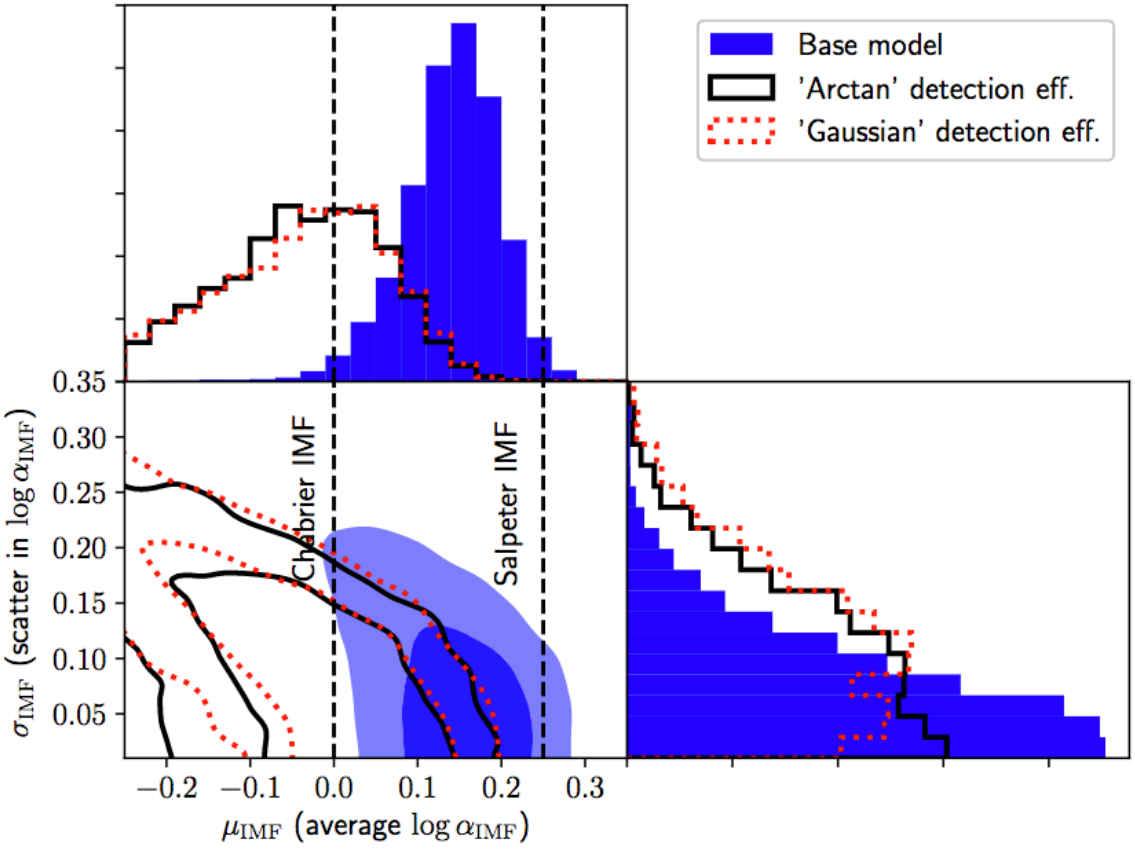
- Mass distribution of lens
- Light profile of the source
- Cosmological Distances

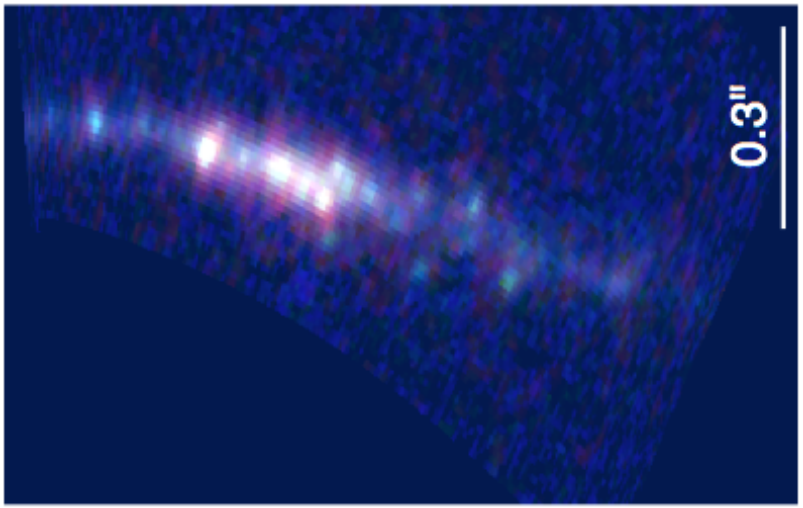
Astrophysics

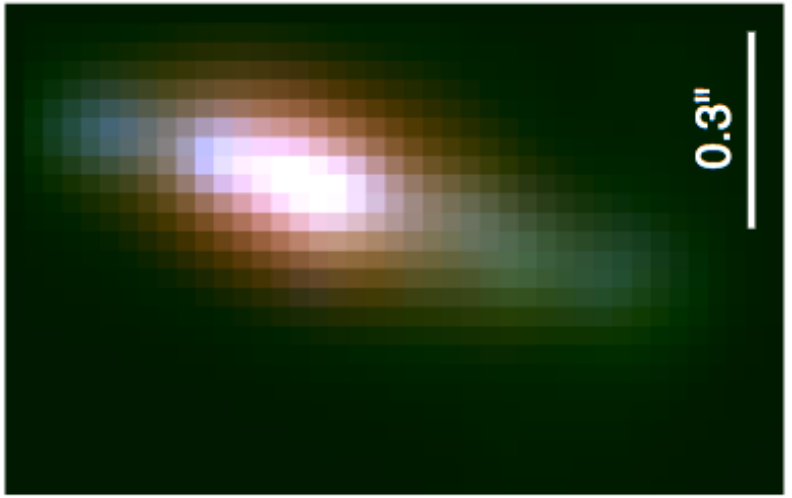
Galaxy Formation

IMF

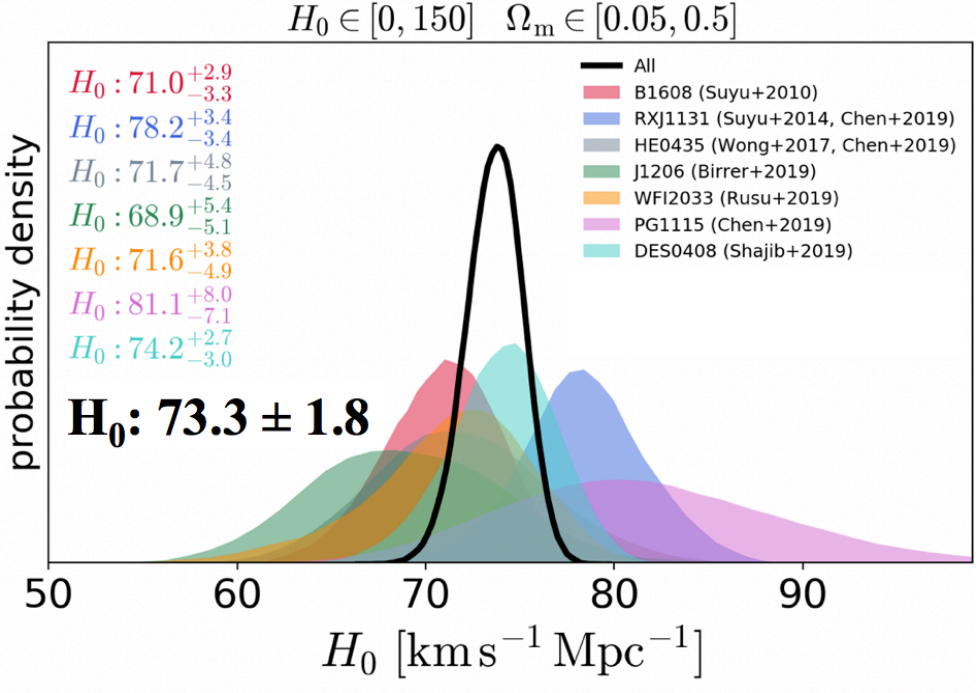
Cosmic Telescope

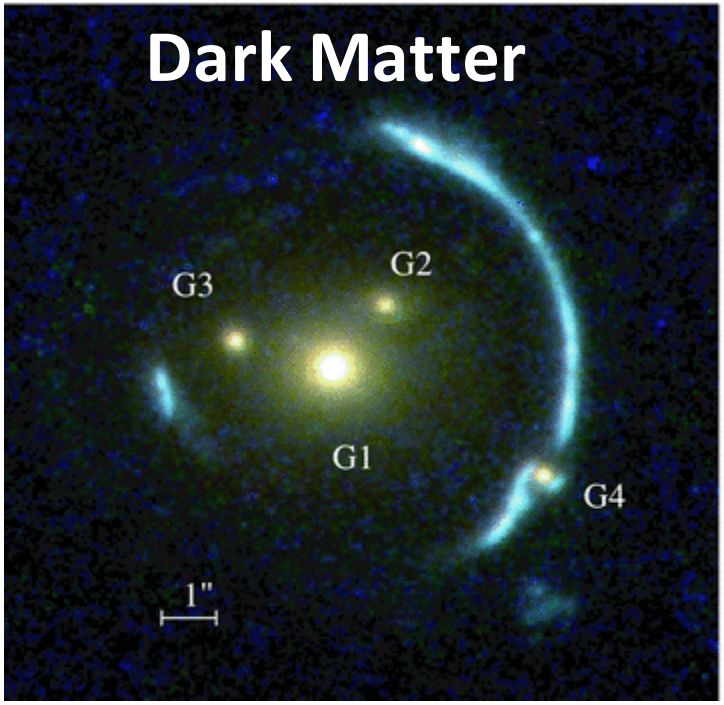


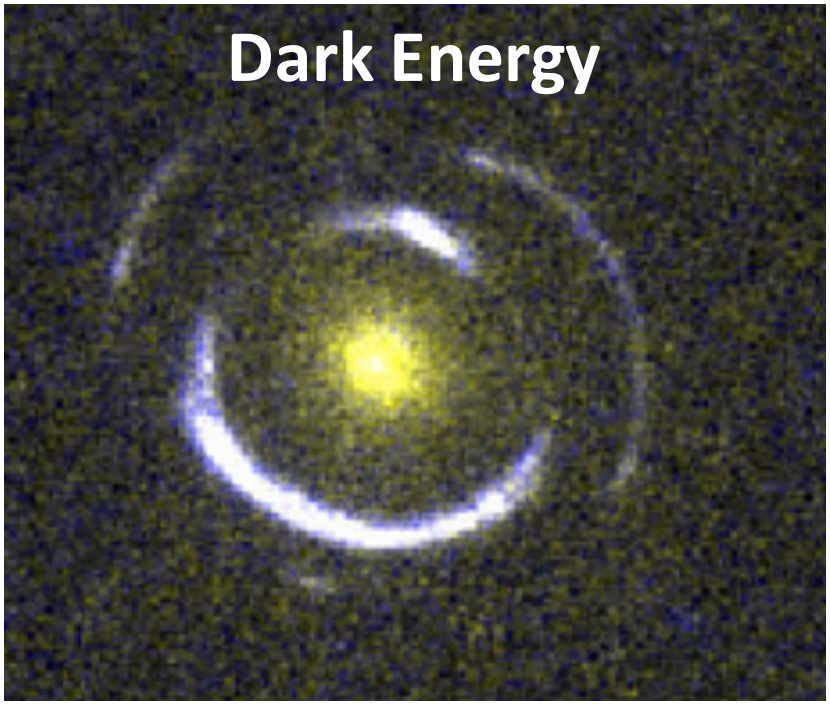




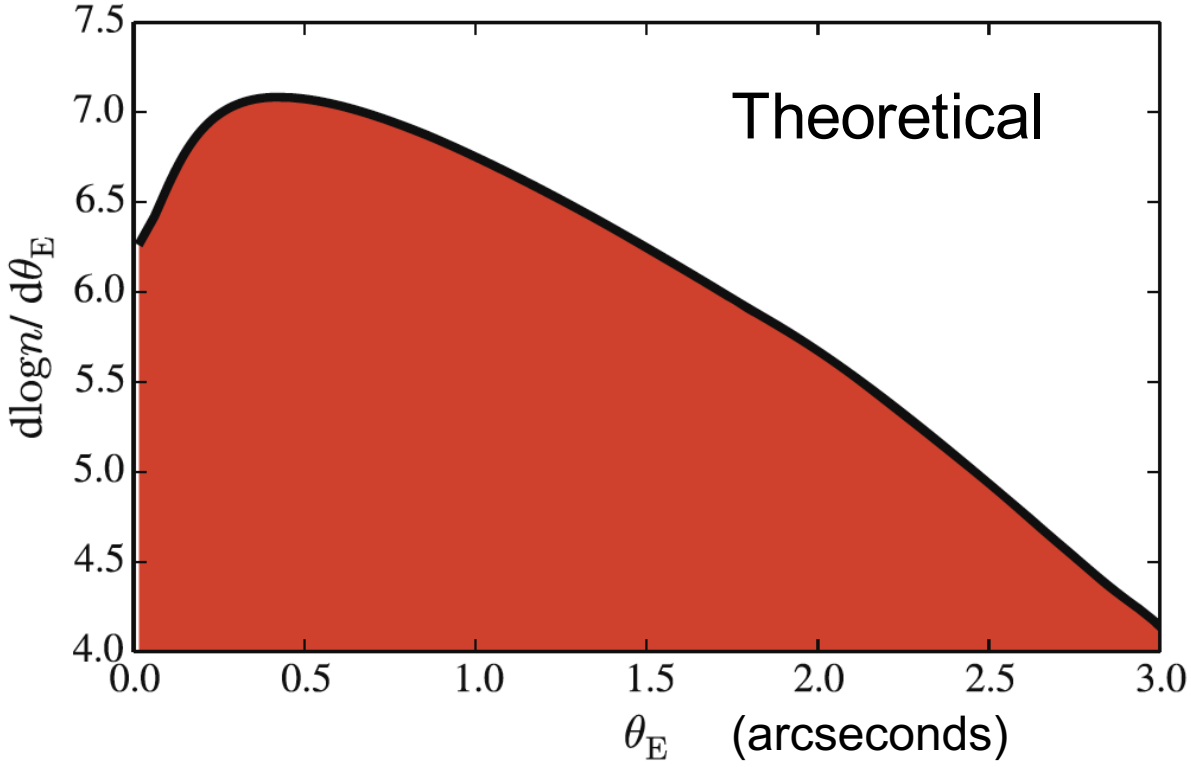
Cosmology

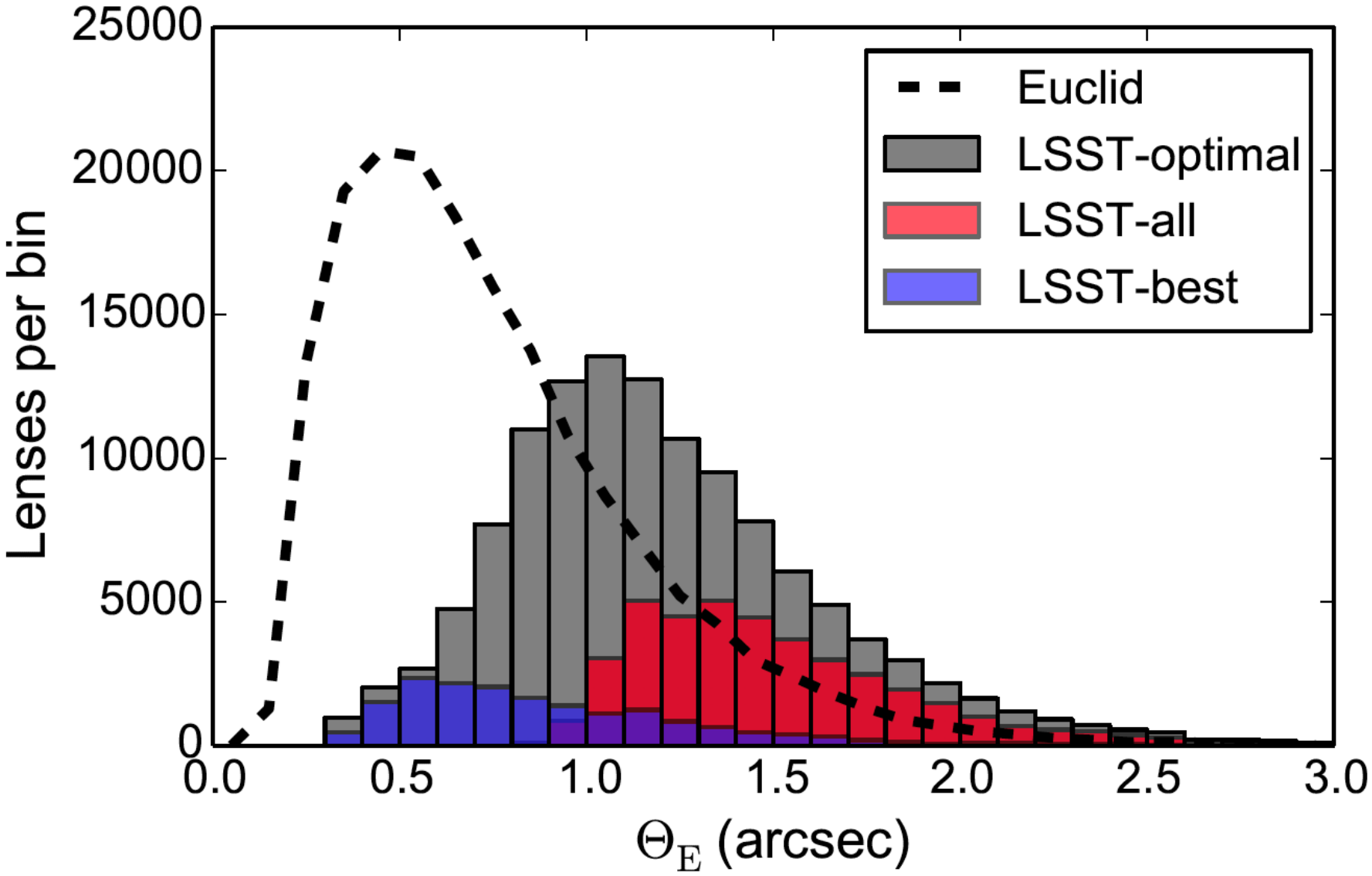

$H_0 \in [0, 150]$ $\Omega_m \in [0.05, 0.5]$
$H_0 : 71.0^{+2.9}_{-3.3}$
$H_0 : 78.2^{+3.4}_{-3.4}$
$H_0 : 71.7^{+4.8}_{-4.5}$
$H_0 : 68.9^{+5.4}_{-5.1}$
$H_0 : 71.6^{+3.8}_{-4.9}$
$H_0 : 81.1^{+8.0}_{-7.1}$
$H_0 : 74.2^{+2.7}_{-3.0}$
H_0: 73.3 ± 1.8
All
B1608 (Suyu+2010)
RXJ1131 (Suyu+2014, Chen+2019)
HE0435 (Wong+2017, Chen+2019)
J1206 (Birrer+2019)
WFI2033 (Rusu+2019)
PG1115 (Chen+2019)
DES0408 (Shajib+2019)
probability density
50
60
70
80
90
H_0 [km s^{-1} Mpc^{-1}]


Dark Matter
G3
G2
G1
G4
1"


Dark Energy

Strong lenses in the Universe





Euclid and LSST will each discover order 100,000 strong lenses!

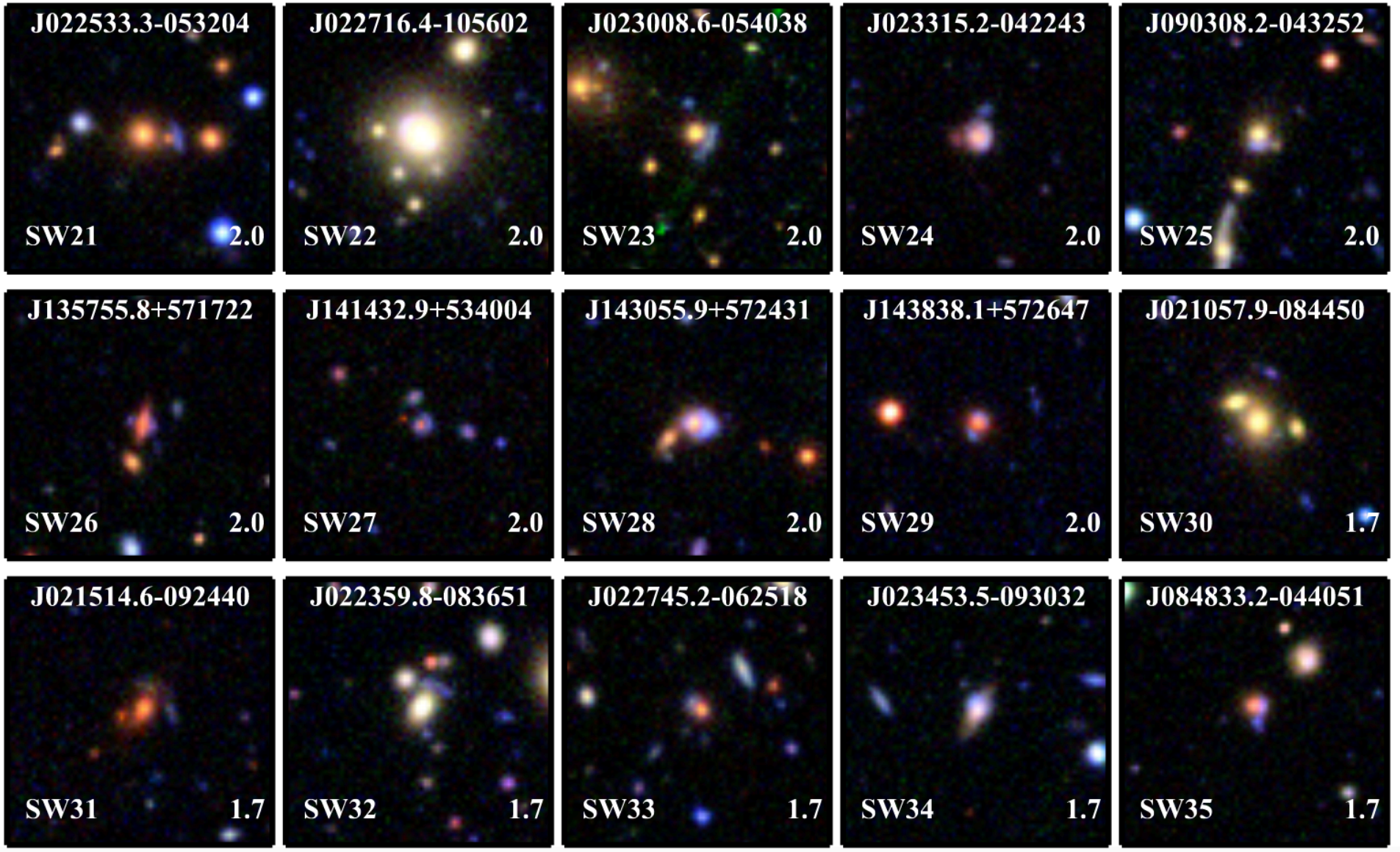
Challenges

Need to find in billion object surveys

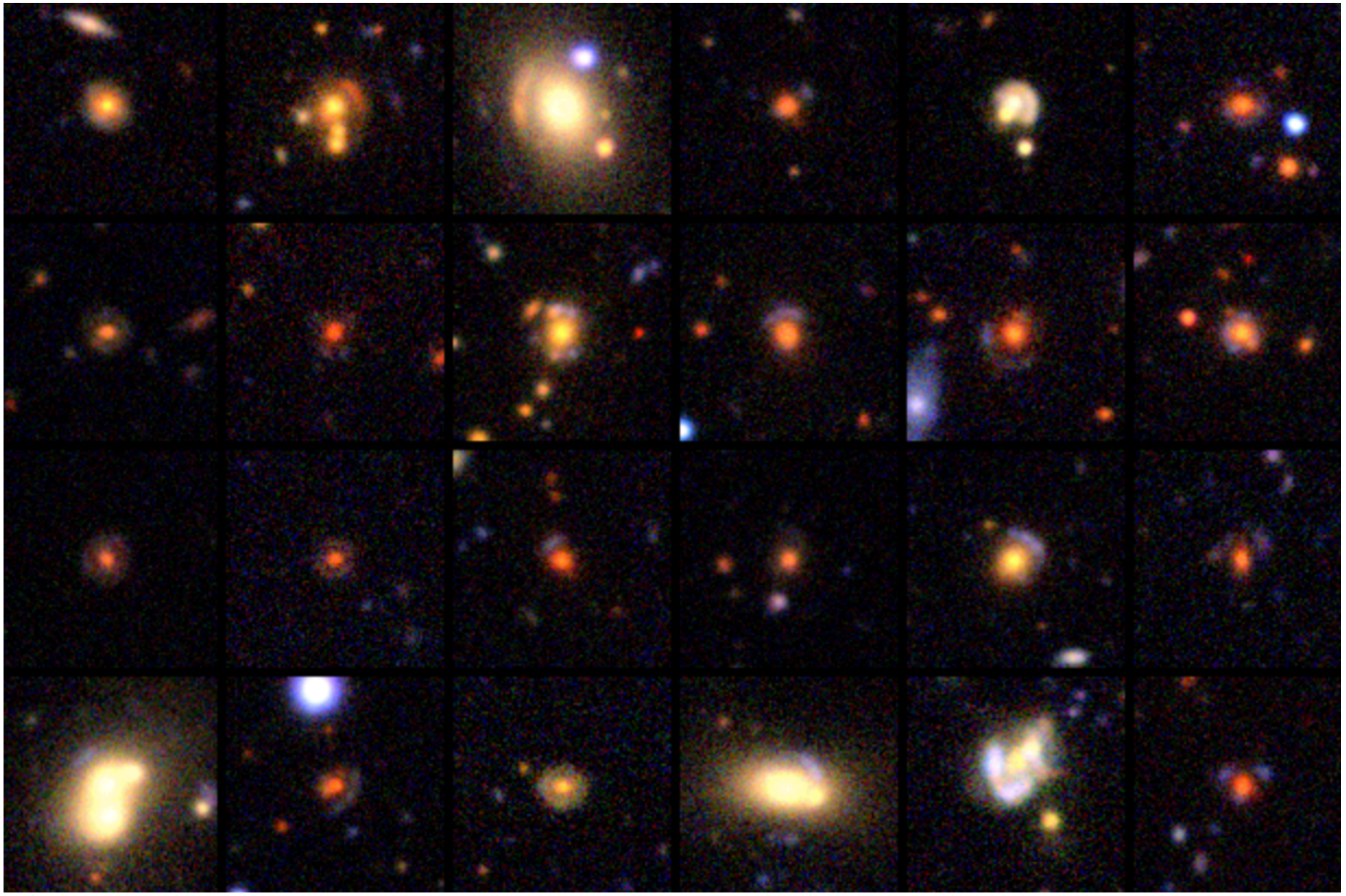
Science requires redshifts

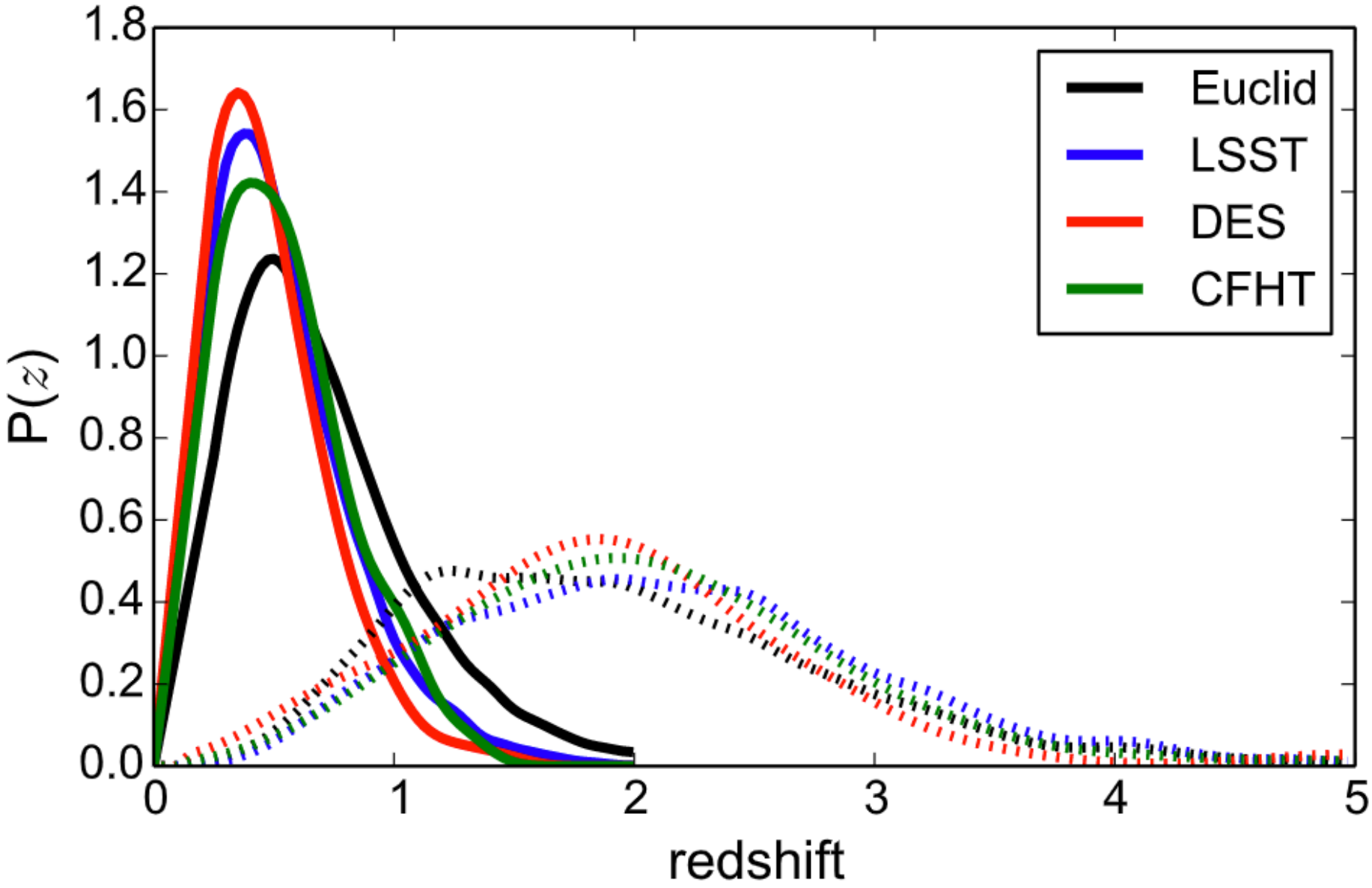
[Also need high resolution imaging, but Euclid sufficient for most]

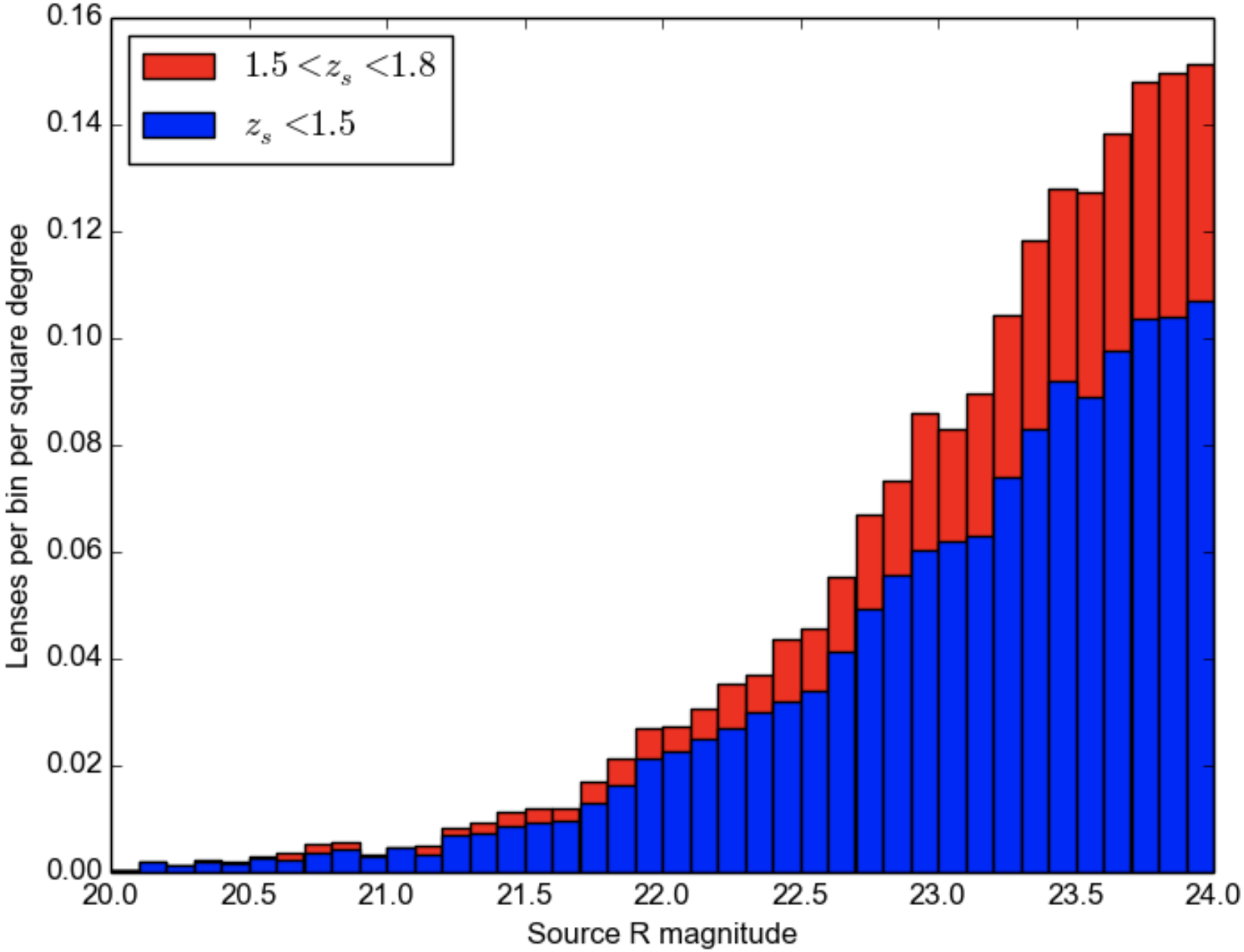
Lens finding with citizen science

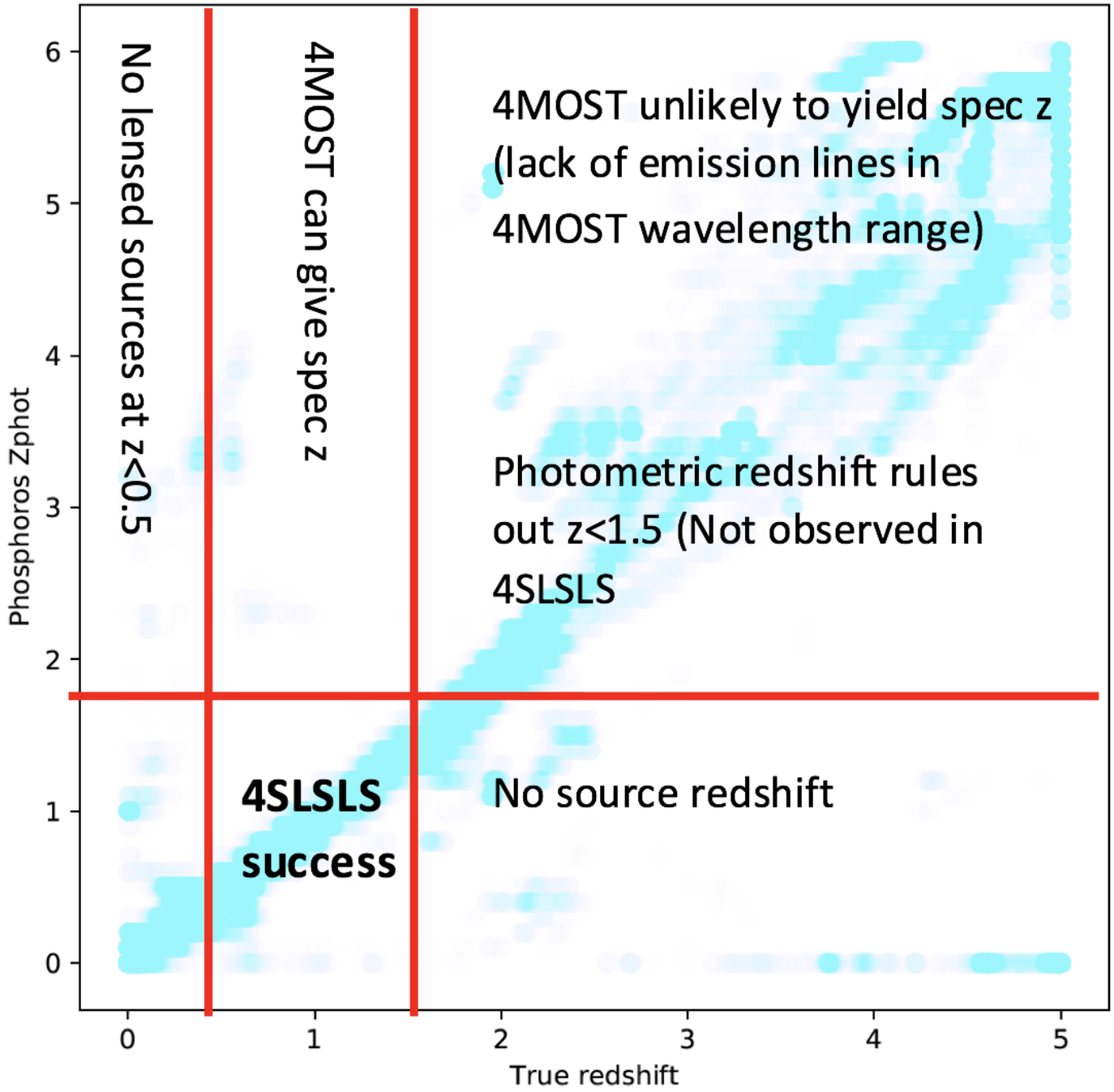


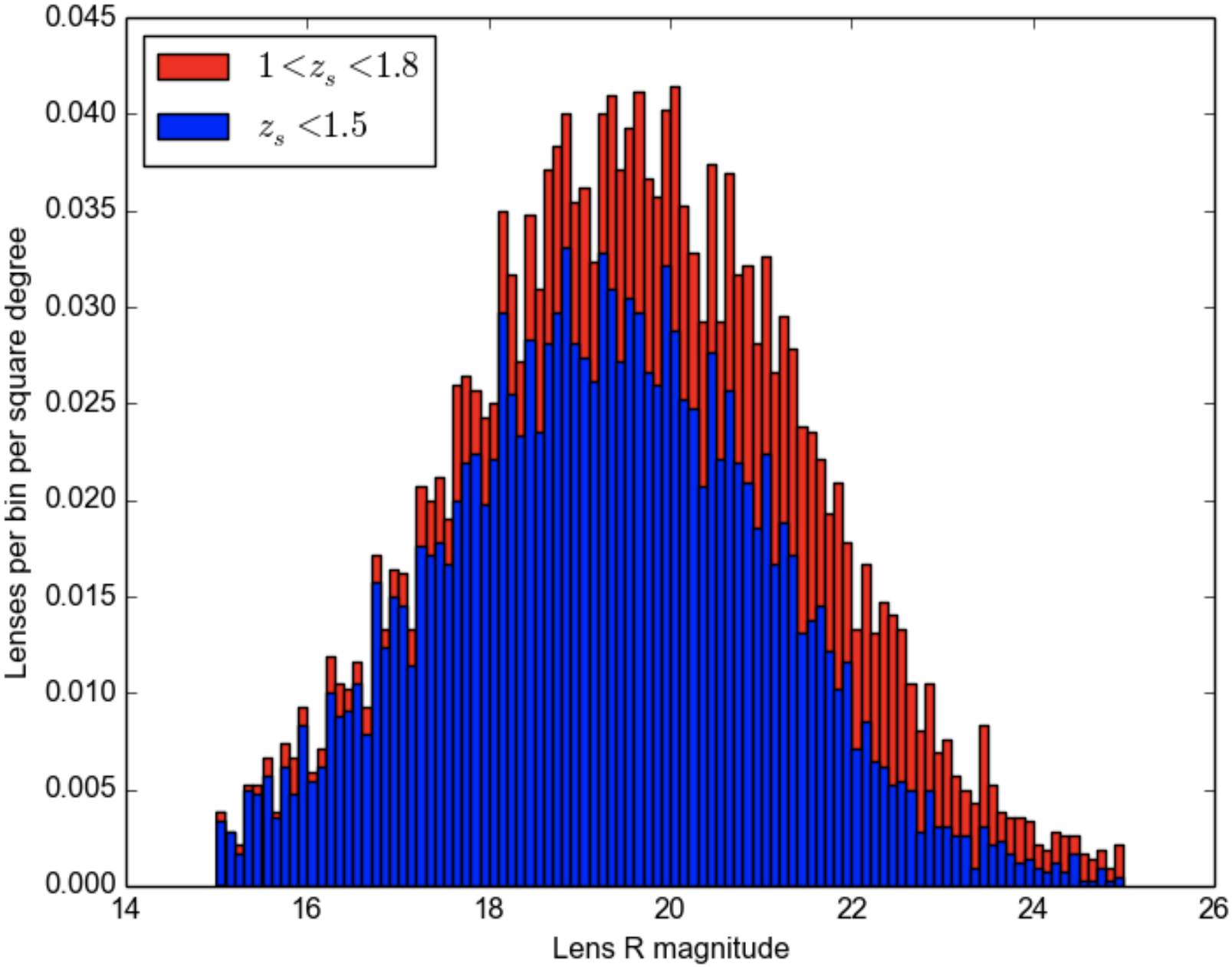
Lens finding with machine learning

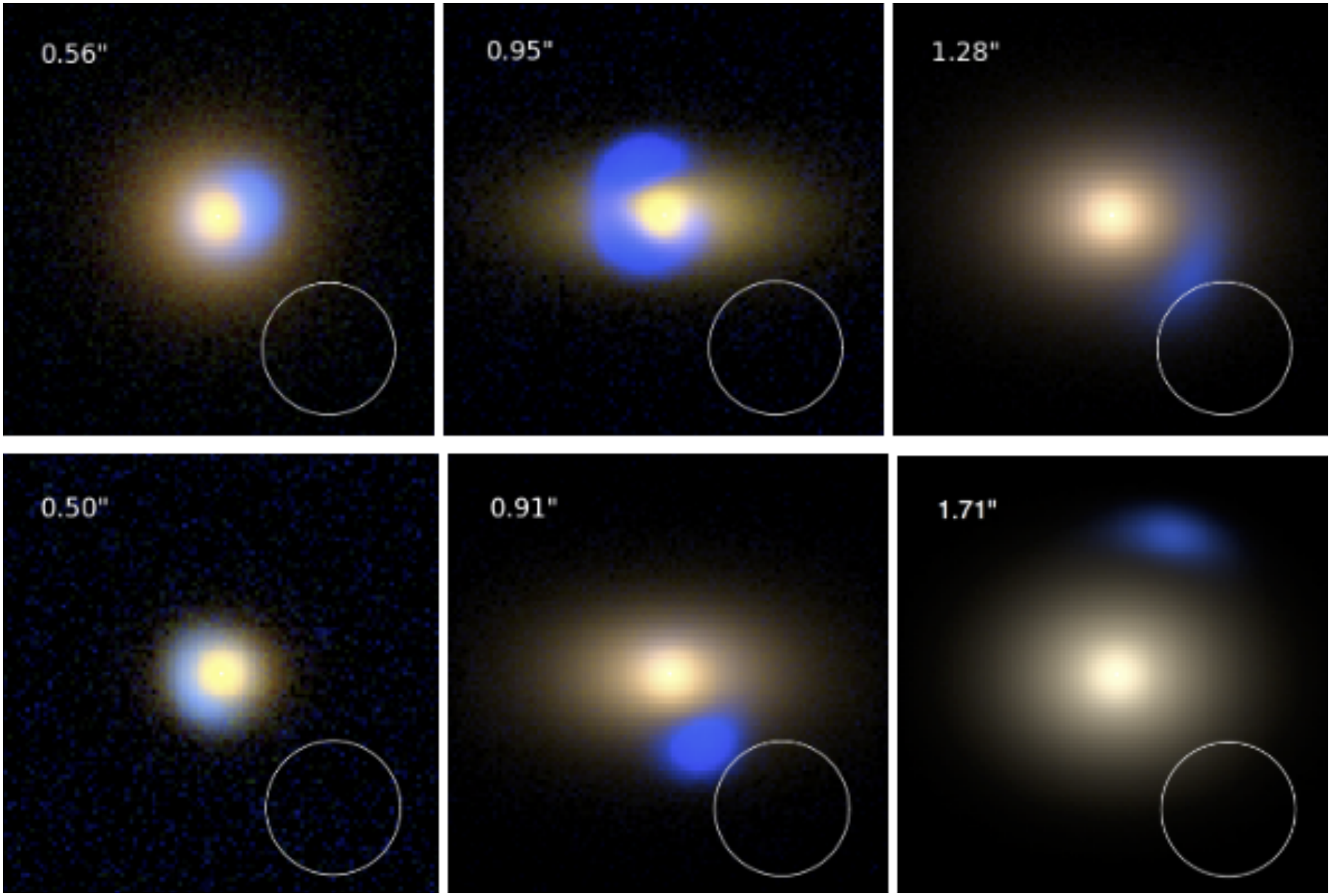



1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
P(z)
0
1
2
3
4
5
redshift
Euclid
LSST
DES
CFHT

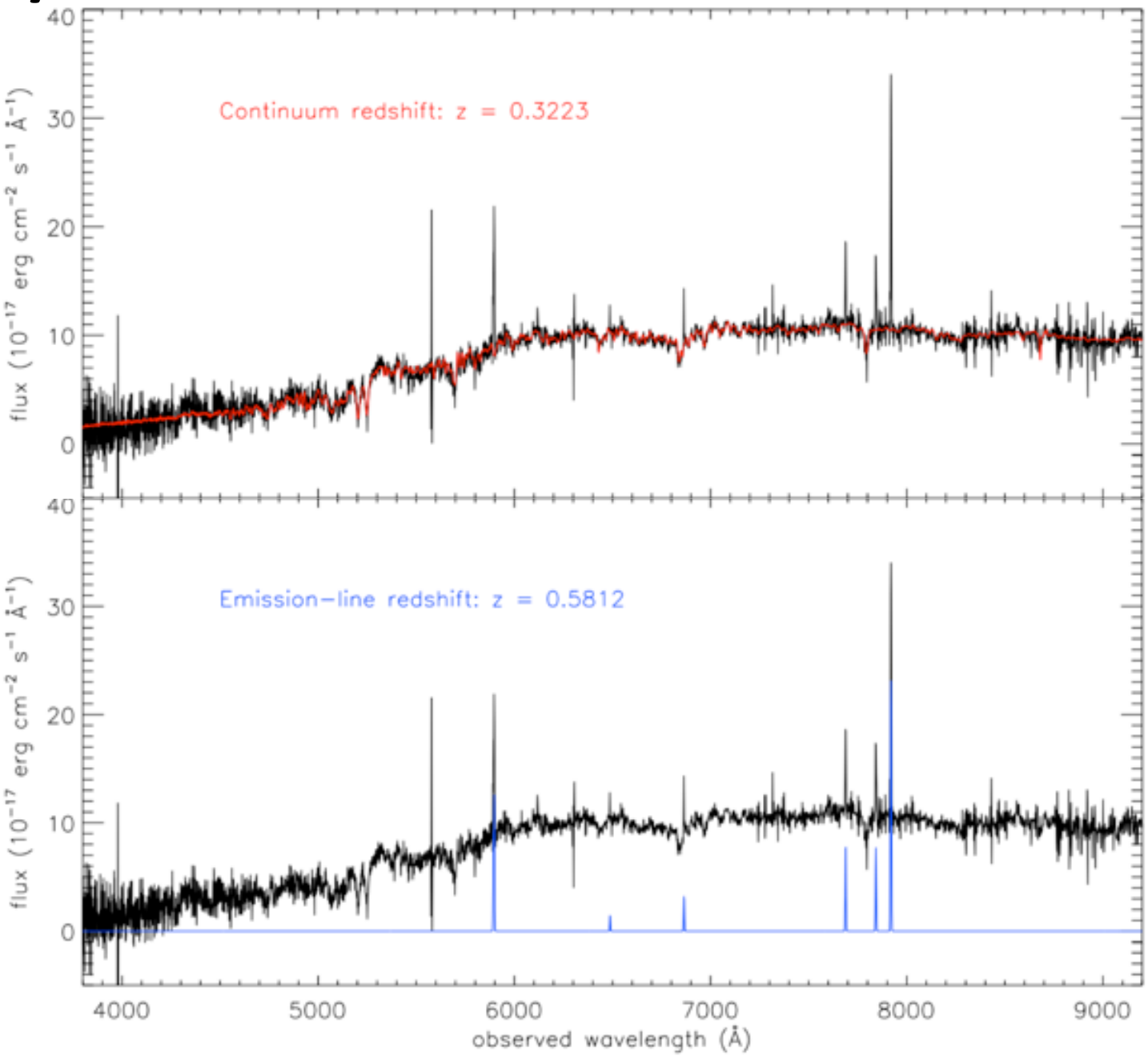

0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Lenses per bin per square degree
$1.5 < z_s < 1.8$
$z_s < 1.5$
20.0
20.5
21.0
21.5
22.0
22.5
23.0
23.5
24.0
Source R magnitude


No lensed sources at z<0.5
4MOST can give spec z
4MOST unlikely to yield spec z (lack of emission lines in 4MOST wavelength range)
Photometric redshift rules out z<1.5 (Not observed in 4SLSLS
4SLSLS success
No source redshift
Phosphoros Zphot
True redshift
0
1
2
3
4
5
6

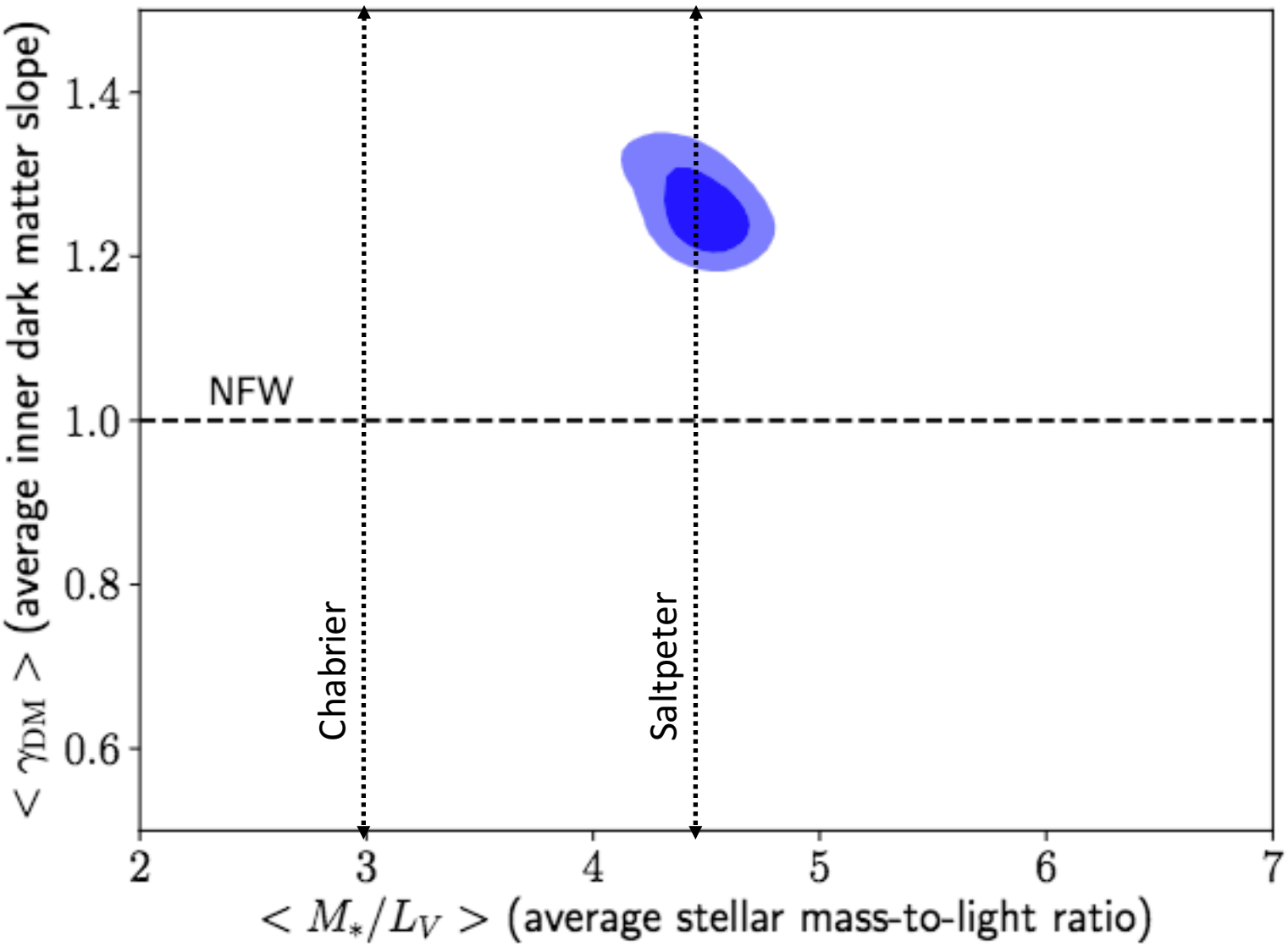

$1 < z_s < 1.8$
$z_s < 1.5$
Lenses per bin per square degree
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
14
16
18
20
22
24
26
Lens R magnitude


0.56"
0.95"
1.28"
0.50"
0.91"
1.71"

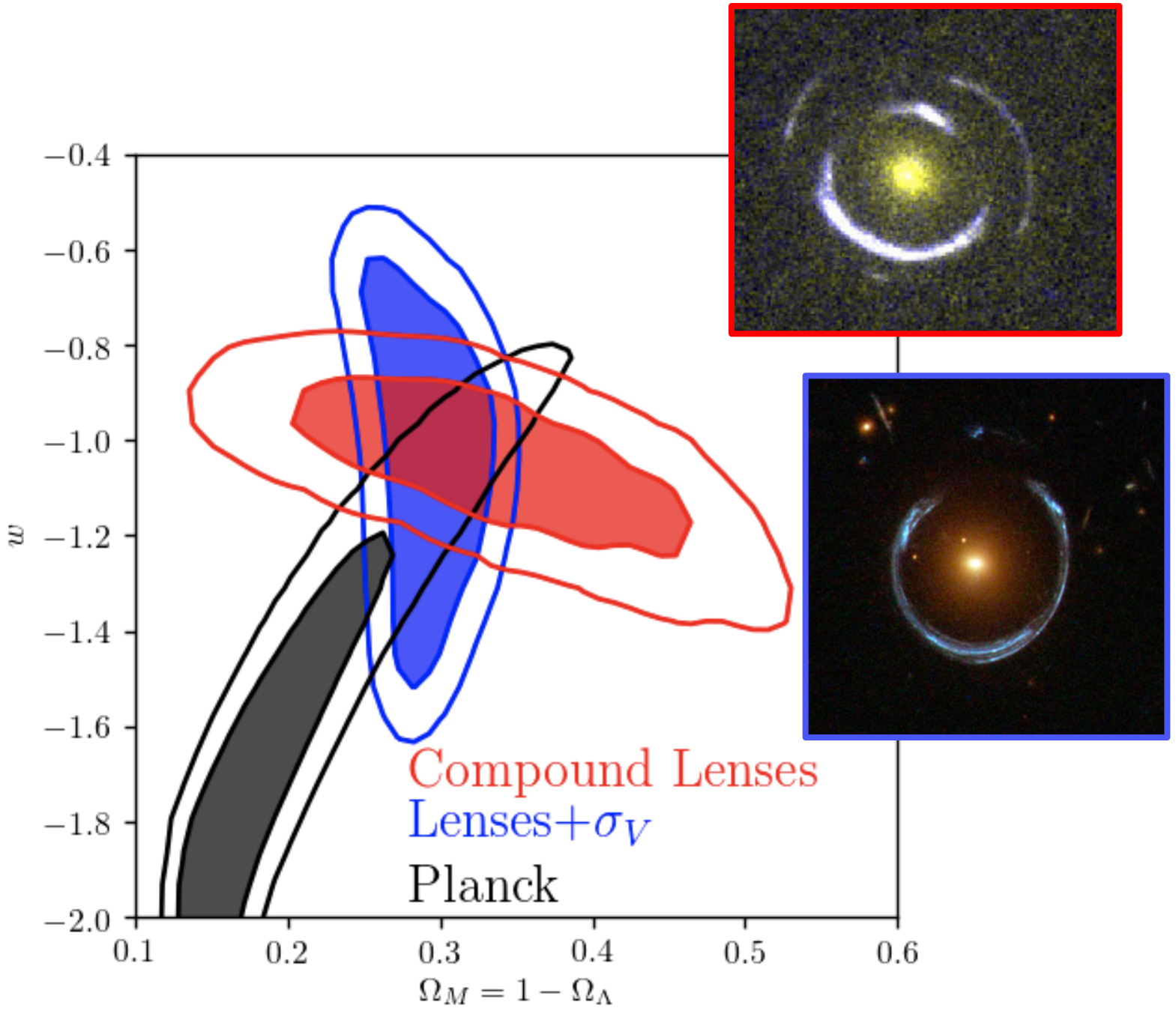
SLACS/SDSS


Continuum redshift: z = 0.3223
Emission−line redshift: z = 0.5812
flux (10^{-17} erg cm^{-2} s^{-1} Å^{-1})
observed wavelength (Å)
0
10
20
30
40
4000
5000
6000
7000
8000
9000

Survey regions	Area (deg^2)	Spectro graph (LRS/HRS)	Range of targets density (targets/deg^2)	Range and average t_{exp} (hours)	Magnitude range	Execution Priority
Euclid Wide	15000	LRS	2.5	0.6-2 hours (mostly 1.3 hr)	20<R<24 (source)	Highest
LSST Wide	20000	LRS	0.8	0.6-2 hours (mostly 1.3 hr)	20<R<24 (source)	Highest
DES footprint	5000	LRS	0.5	0.6-2 hours (mostly 1.3 hr)	20<R<24 (source)	Before LSST and Euclid fill out targets
KiDS	1000	LRS	0.5	0.6-2 hours (mostly 1.3 hr)	20<R<24 (source)	Before LSST and Euclid fill out targets



Constraints from 1000 lenses, credit Sonnenfeld


−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
−2.0
w
0.1
0.2
0.3
0.4
0.5
0.6
$\Omega_M = 1 - \Omega_\Lambda$
Compound Lenses
Lenses+σ_V
Planck

4SLSLS – Summary

Strong lenses are excellent probes of cosmology and extragalactic astrophysics

100 fold increase expected. Redshifts are critical for science

Too many for 1 at a time. Too rare for a dedicated MOS survey.

4SLSLS Goal: 10,000 lens an source redshifts. 5,000 lens velocity dispersions. **Cost:** 40,000 Fibre hours

Complication: We'll be finding them as the survey goes on.