Lensed quasars in SDSS-III and HSC Wide

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Overview

- lensed quasars are useful tool for cosmology (through their probability distribution) and galaxy evolution (as lenses)

- but rare (< 1/1000) and confused with QSO pairs, star alignments, etc.

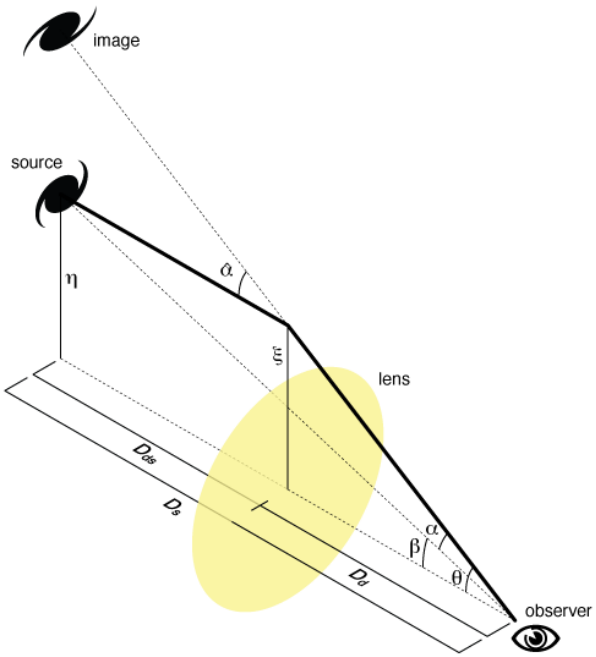
- It requires large scale surveys and careful detection methods

- detection methods currently based on morphology for small separation or colour, starting from QSO spectroscopic samples

Overview

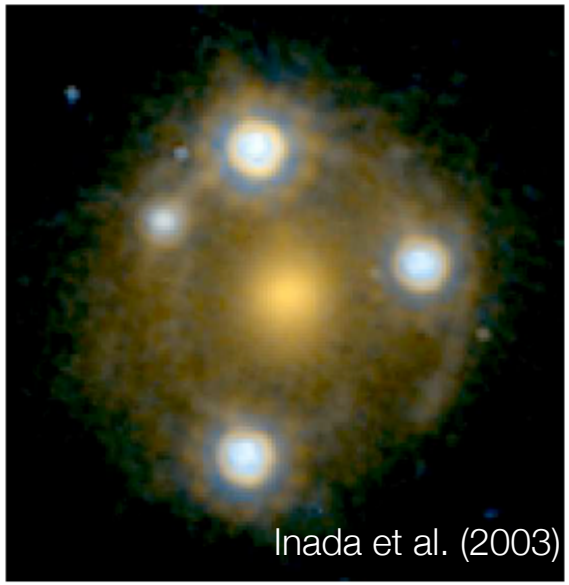
- can we detect lensed quasars starting from a photometric sample?
- Idea: using weighted colour difference
- ... and a few words on QSO magnification

Lensed quasars

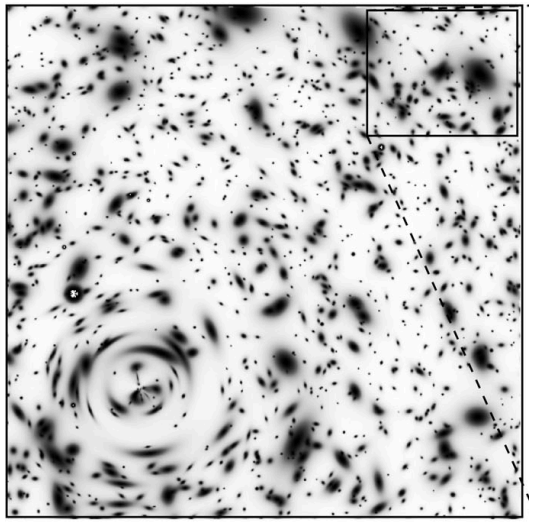


Deflection angle depends on mass and distances

if perfectly aligned, creates multiple images -> strong lensing regime



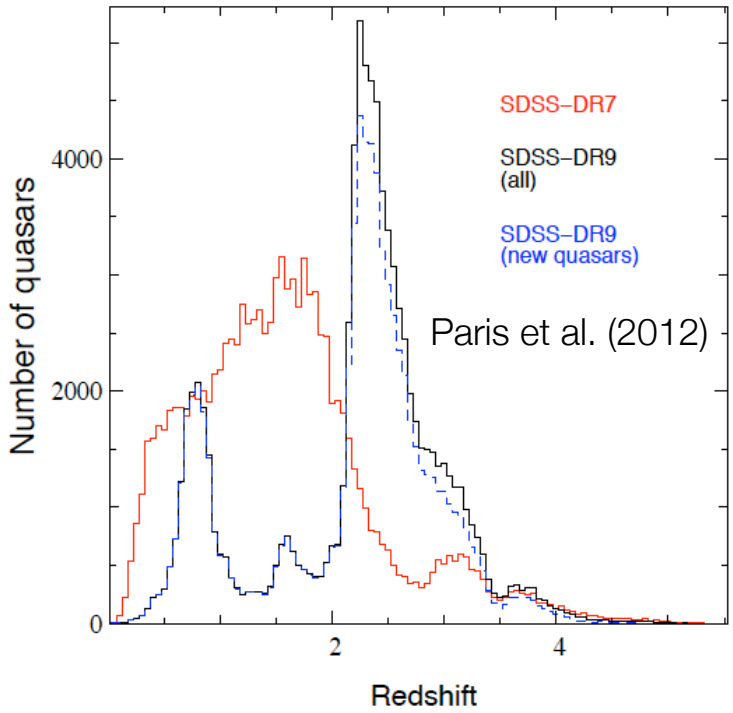
QSO are also affected by lenses at large separation -> weak lensing regime



Y. Mellier

QSOs in SDSS

- SDSS, 8000 deg2 100,000 QSOs in $1 < z < 2$
- BOSS-SDSS DR9, currently 3000 deg2, 90,000 QSOs at $z > 2$

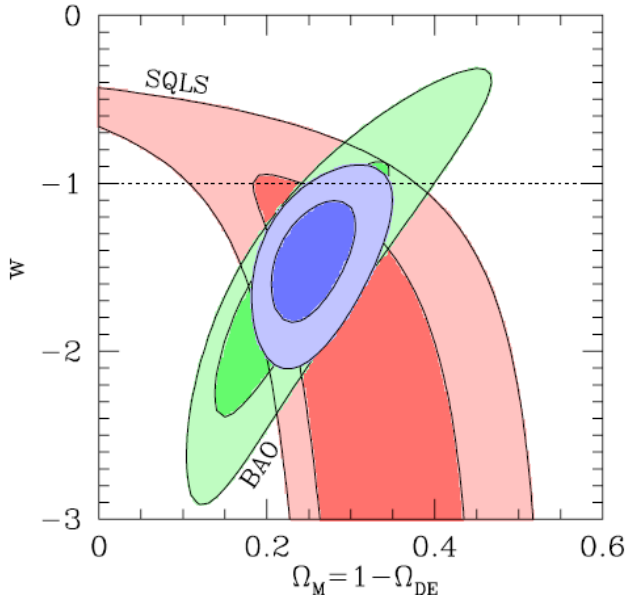


SDSS Quasar Lens Search

N	image	name	N_{im}	sep	z_s	z_l	i_{cor}	flag	references
1		SDSS J0246-0825	2	1.09	1.686	0.723	17.76	DR3stat	Inada et al. AJ 130(2005)1967
2		SDSS J0743+2457 (ULAS J0743+2457)	2	1.03	2.165	0.381	19.01	DR3	Jackson et al. MNRAS 419(2012)2014 Inada et al.
3		SDSS J0746+4403	2	1.08	1.998	0.513	18.71	DR5stat	Inada et al. AJ 133(2007)206
4		SDSS J0806+2006	2	1.49	1.538	0.573	18.89	DR5stat	Inada et al. AJ 131(2006)1934
5		SDSS J0819+5356	2	4.04	2.239	0.294	18.52	DR5	Inada et al. AJ 137(2009)4118
6		SDSS J0820+0812 (ULAS J0820+0812)	2	2.20	2.024	0.803	19.05	DR5	Jackson et al. MNRAS 398(2009)1423
7		SDSS J0832+0404	2	1.98	1.116	0.659	18.89	DR3	Oguri et al. AJ 135(2008)520
8		SDSS J0903+5028	2	2.84	3.584	0.388	19.50	DR3	Johnston et al. AJ 126(2003)2281
9		SDSS J0904+1512	2	1.13	1.826	-	17.51	DR7	Kayo et al. AJ 139(2010)1614
10		SDSS J0924+0219	4	1.81	1.523	0.394	18.12	DR3stat	Inada et al. AJ 126(2003)666

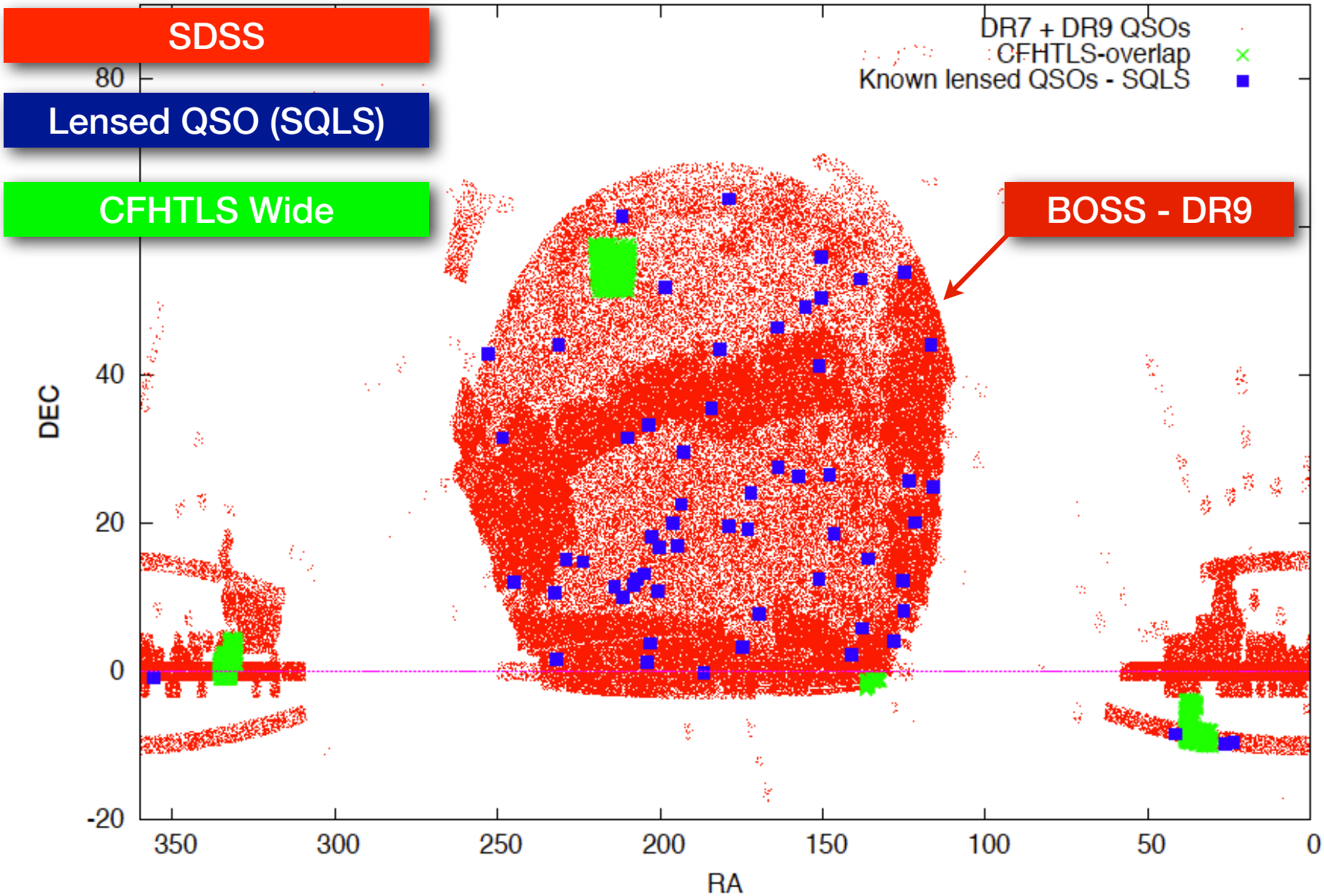
http://www-utap.phys.s.u-tokyo.ac.jp/~sdss/sqls/lens.html

Lensed QSOs in SDSS
~ **60** confirmed systems
used to constrain cosmology



Oguri et al. (2012)

SDSS QSO distribution



How to detect strongly lensed QSO?

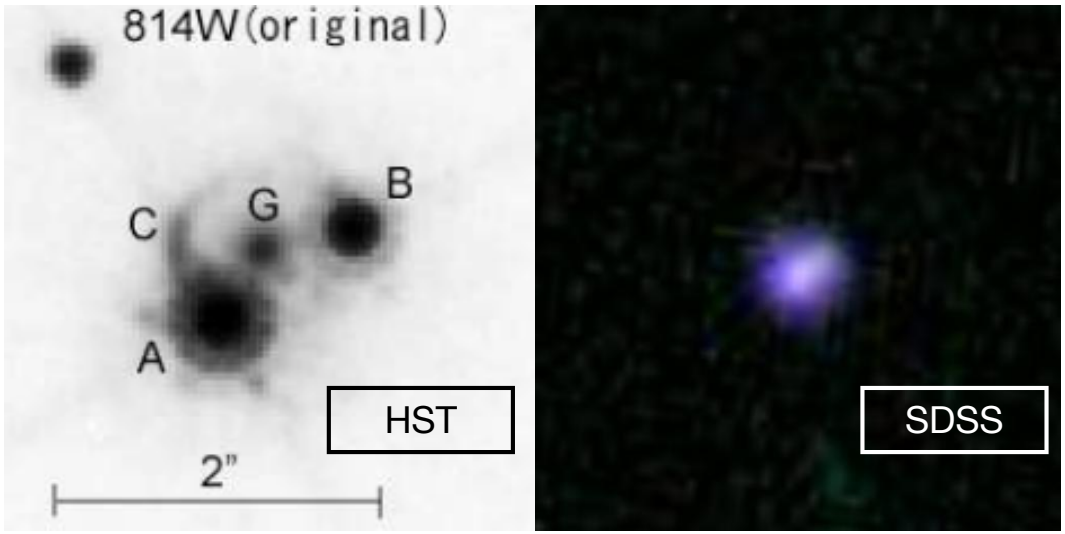
- From spectroscopic QSO sample,
- look for blended objects through morphology measurement (departure from PSF-shaped QSO)
- if not blended, look for close pairs with identical colours
- see e.g. Jackson et al. (2012), Inada et al. (2012), Oguri et al. series

QSO samples are not complete

colours suffer from magnitude errors (especially if blended)

difficult to detect systems with large separation because of higher “random” contamination

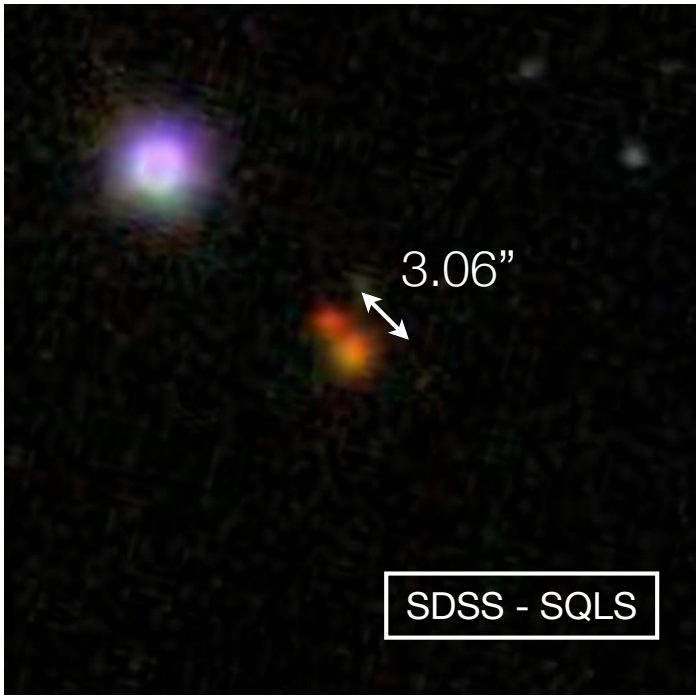
Morphology



Inada et al. (2005)

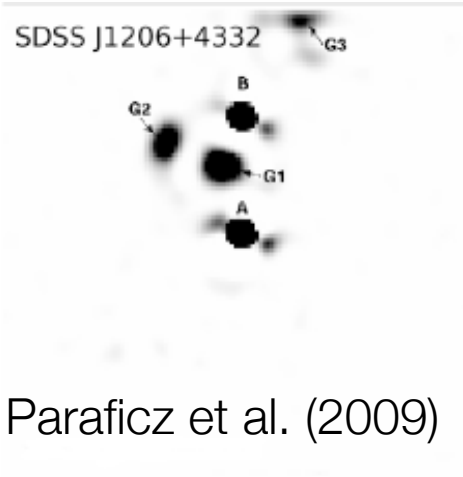
For blended pairs the detection relies on morphology (departure from PSF)

Close pairs with identical colors

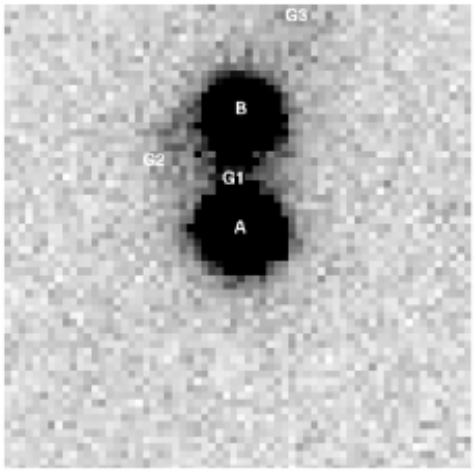


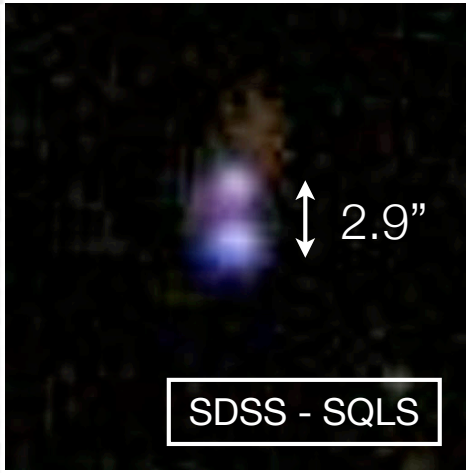
When the separation is much larger than the PSF, the detection relies on colour

Close pairs with identical colors



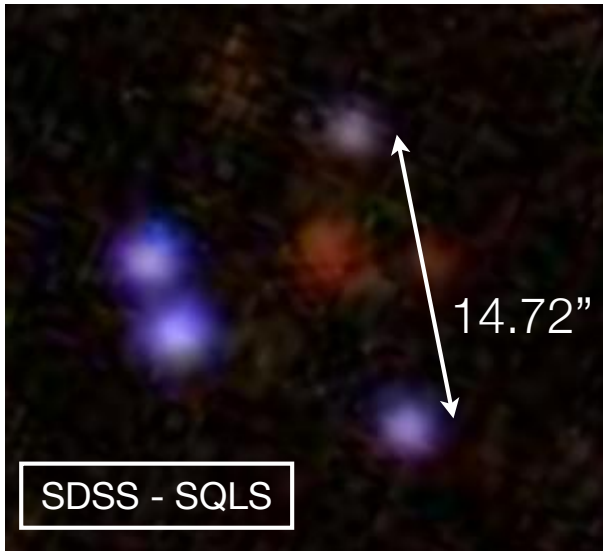
Paraficz et al. (2009)

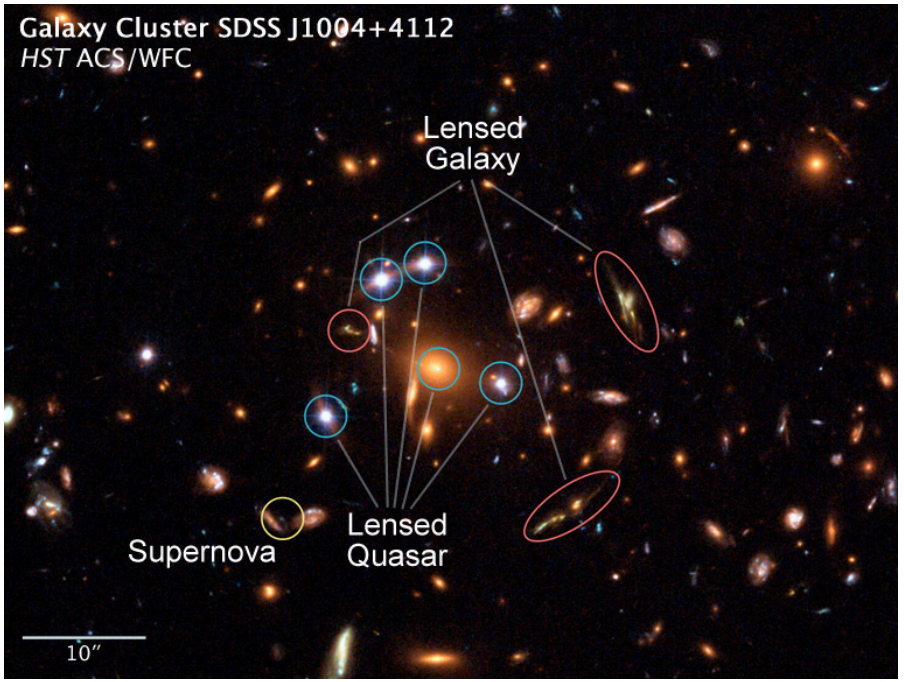




De-convolved pair

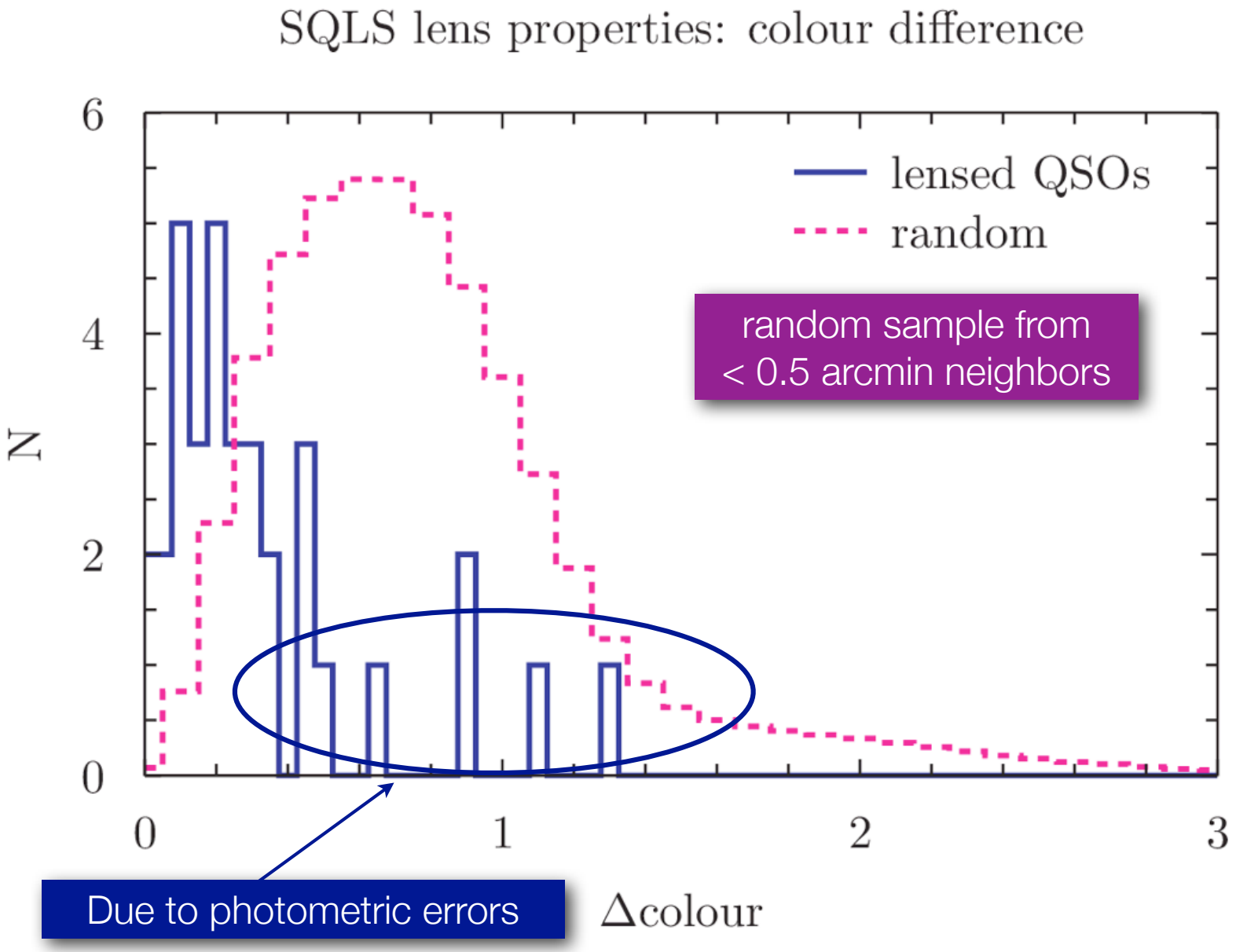
Large separation





Lensed quasars around cluster have large separation

Colour difference



Weighted colour difference

Colour difference weighted by magnitude errors

$$\Delta_c = \sqrt{\left(\frac{\sum_i w_{c_i} \Delta_{c_i}^2}{\sum_i w_{c_i}} \right)}$$

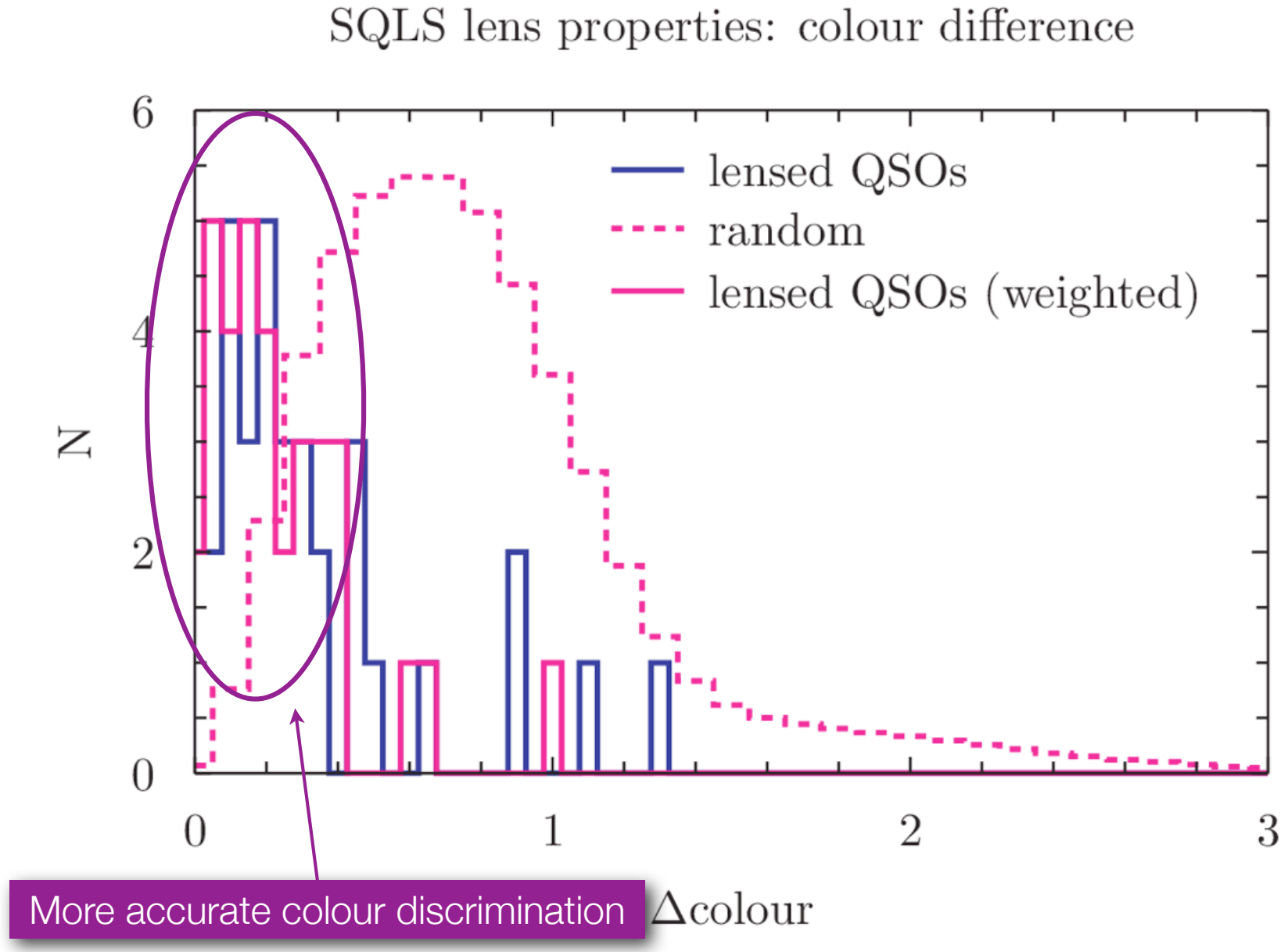
where

$c_i = (u-g) - (u-g)_{\rm neighbor}$, etc.

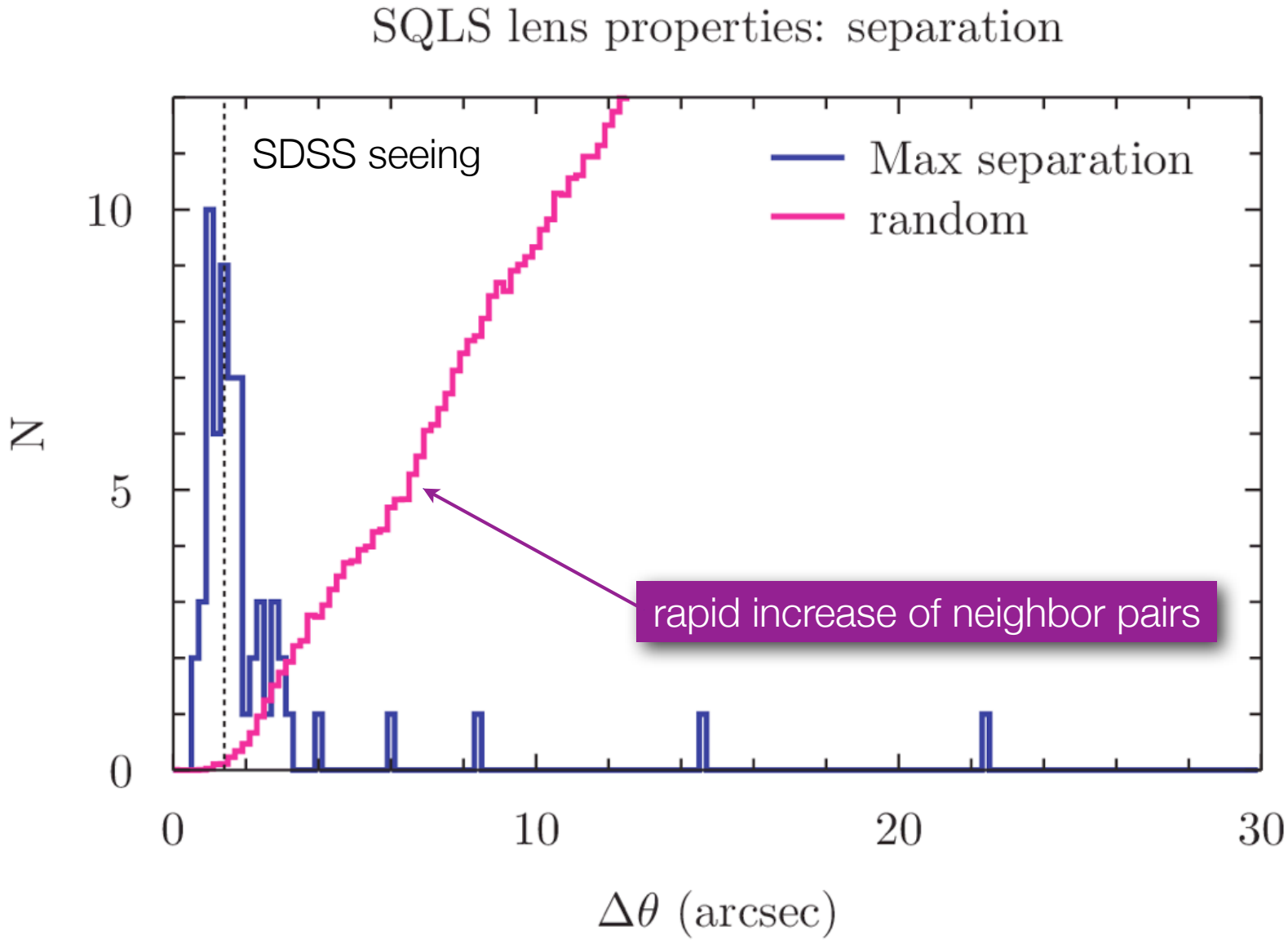
and

$w_{c_i} = 1/(\delta_u^2 + \delta_g^2 + \delta_{u,{\rm neighbor}}^2 + \delta_{g,{\rm neighbor}}^2)$, etc.

Weighted colour difference



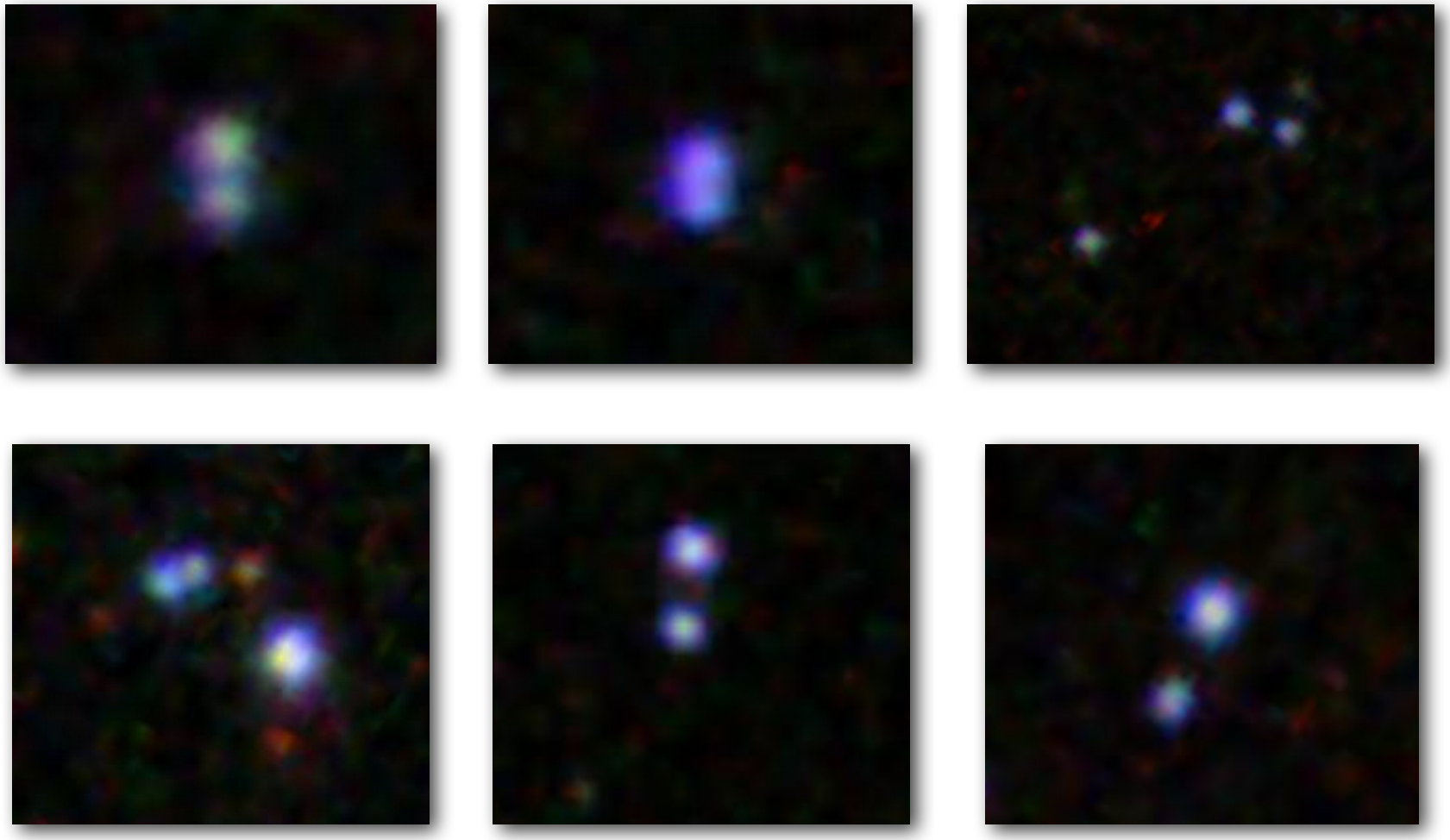
Angular separation



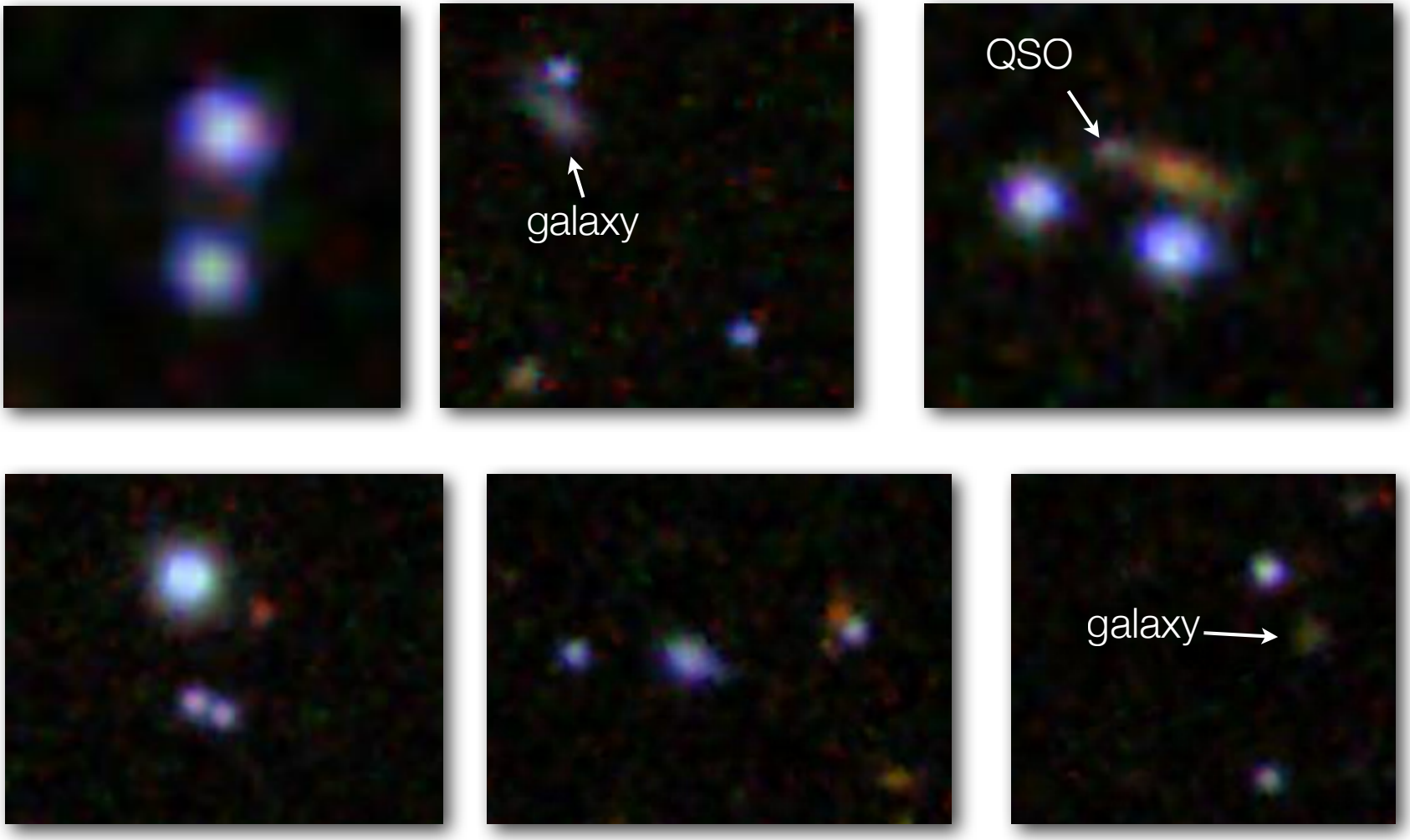
Blind selection based on colour in DR9

- **sep < 2.0** -> morphology selection ($P_{PSF} < 0.1$) and relaxed colour selection (delta colour < 1.0)
- **2.0 < sep < 5.0** colour diff < 0.2
- **sep > 3.0** colour diff < 0.2 and N > 2
- recovery rate: 22 out 28 known lenses (in neighbor's catalogue).
- total candidates: ~500/170,000 QSOs

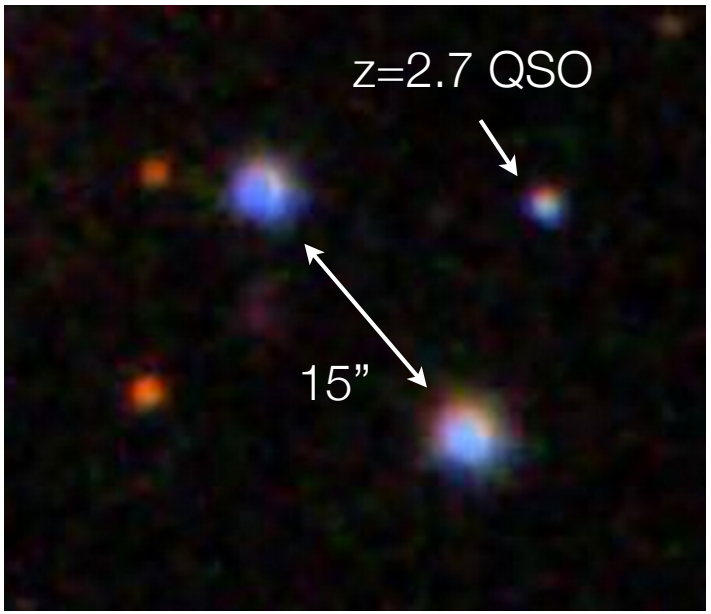
Close pair candidates (all new from DR9)

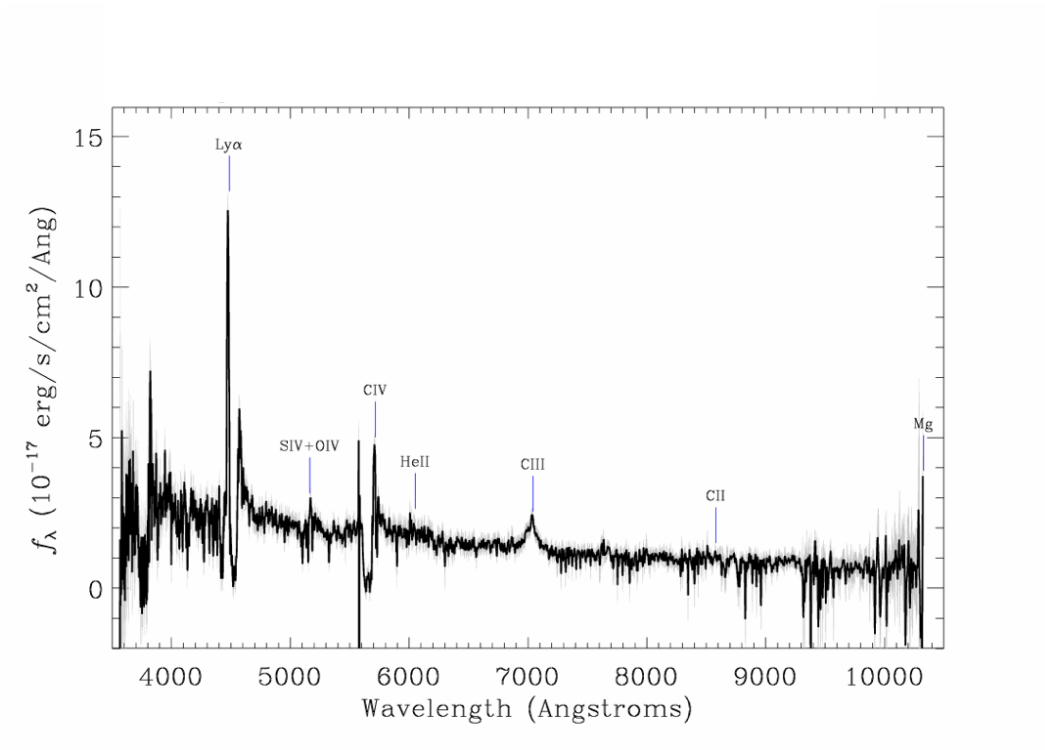


Close pair candidates (more)



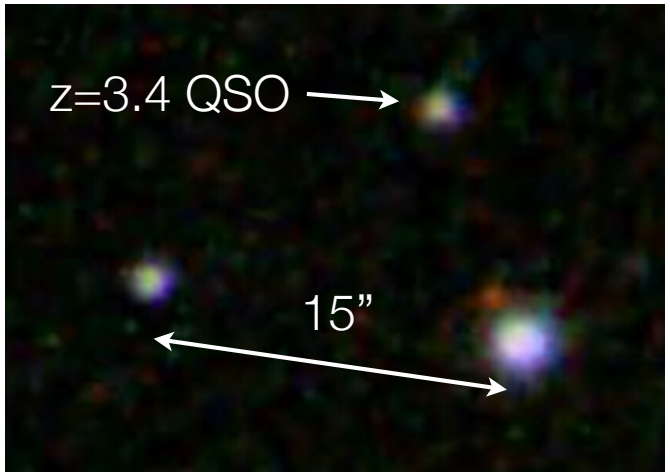
Interesting candidate close-up 1

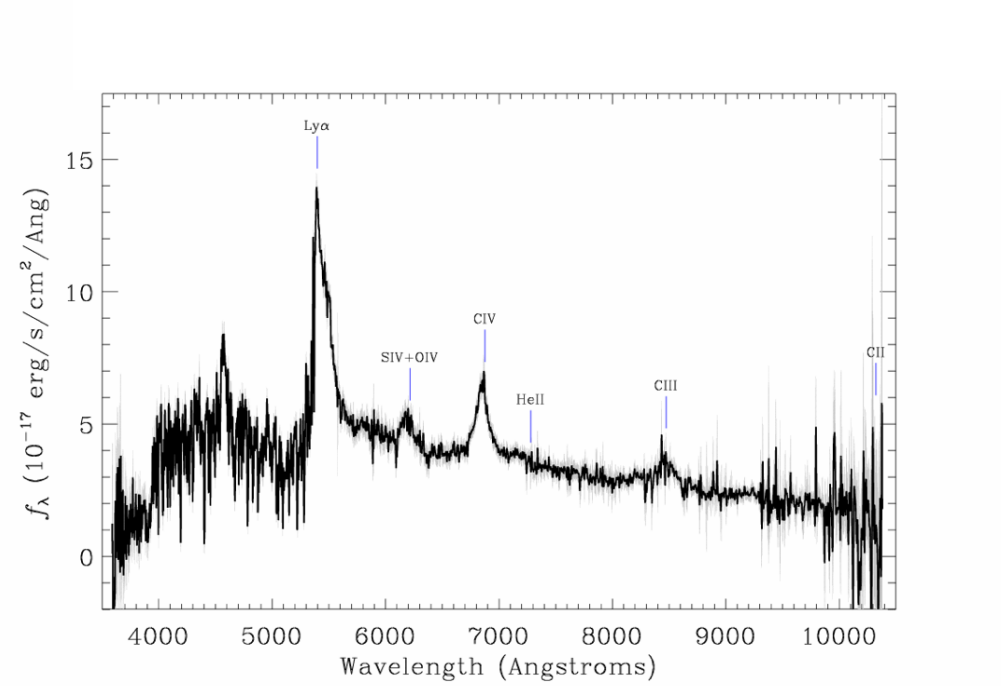




Unlikely configuration?
too large separation?

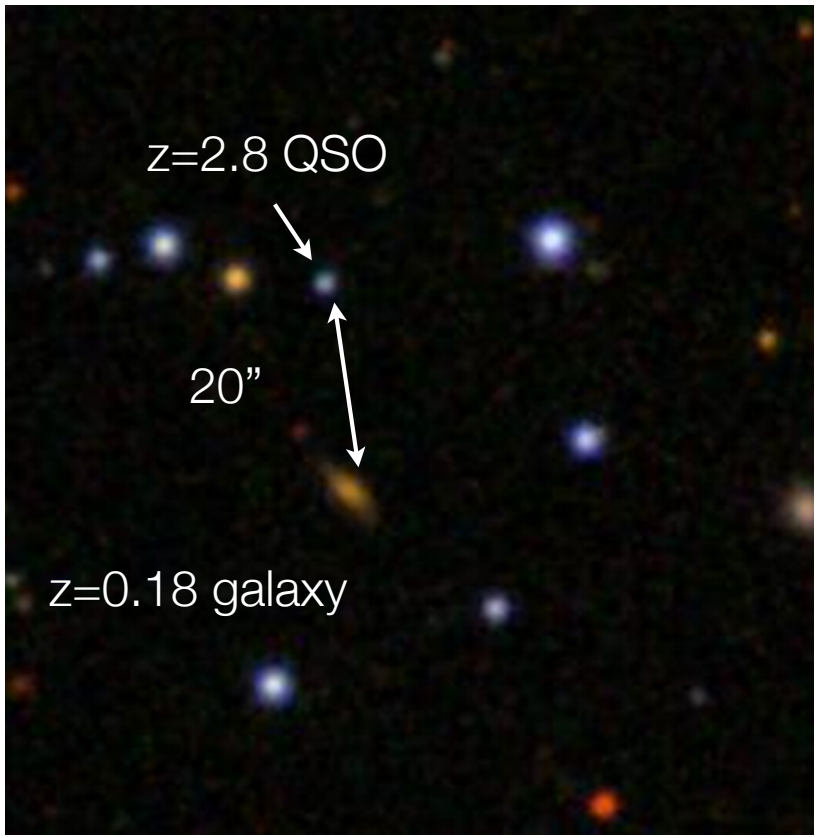
Interesting candidate close-up 2

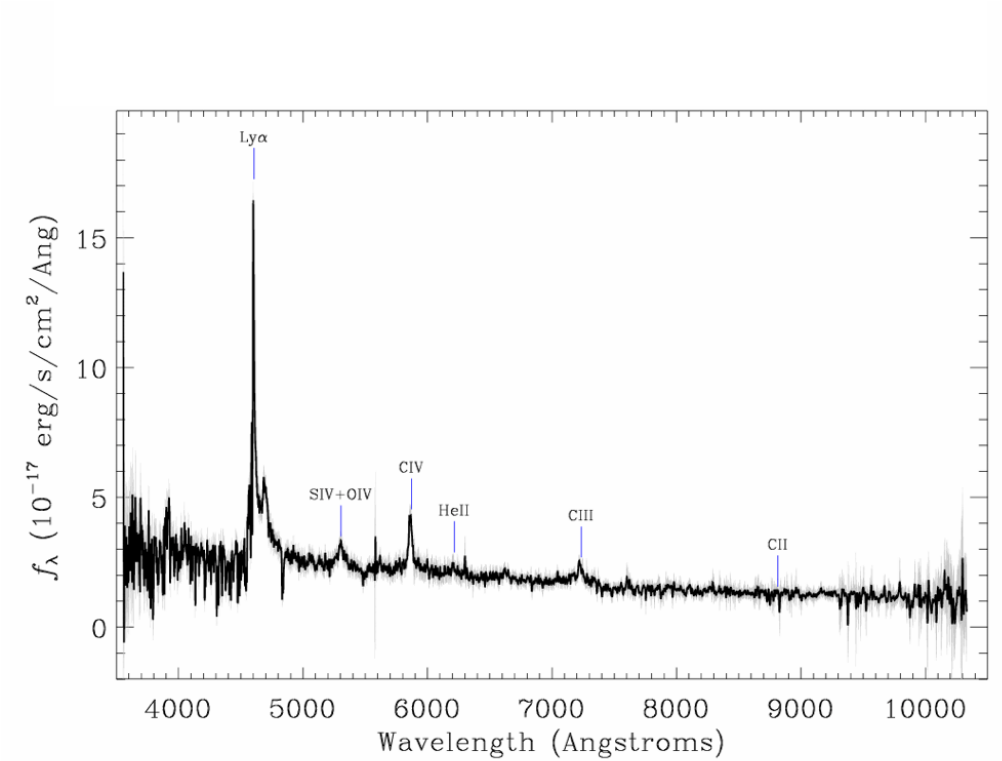




too large separation?

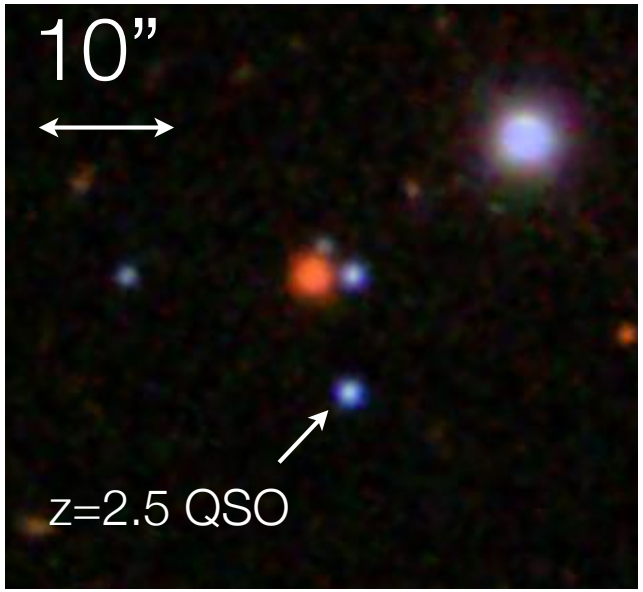
Interesting candidate close-up 3

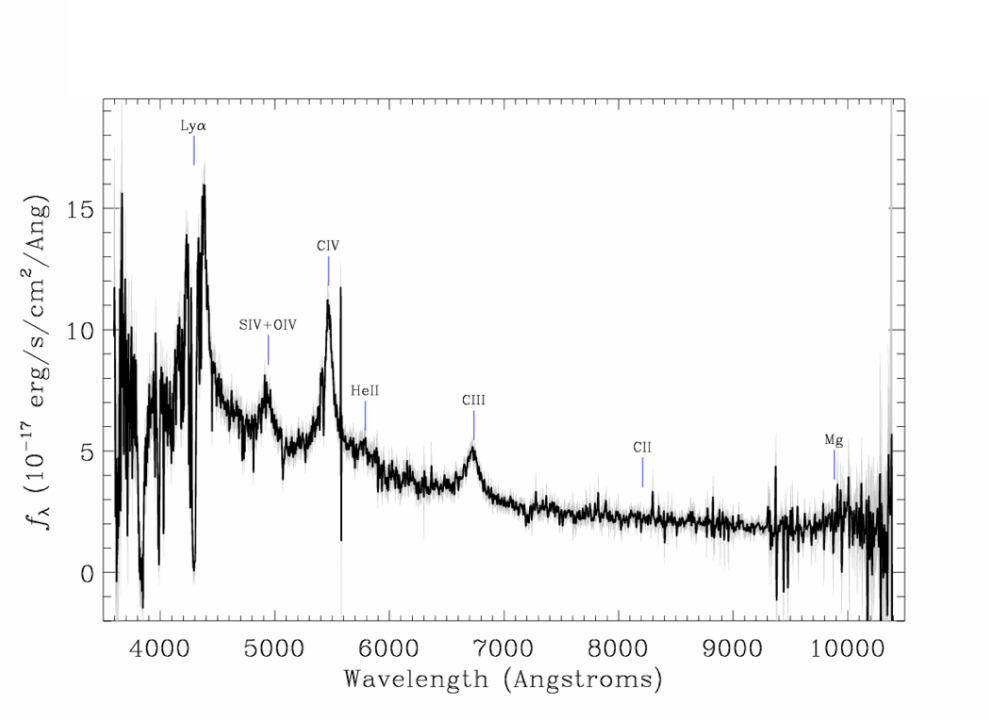




too large separation?

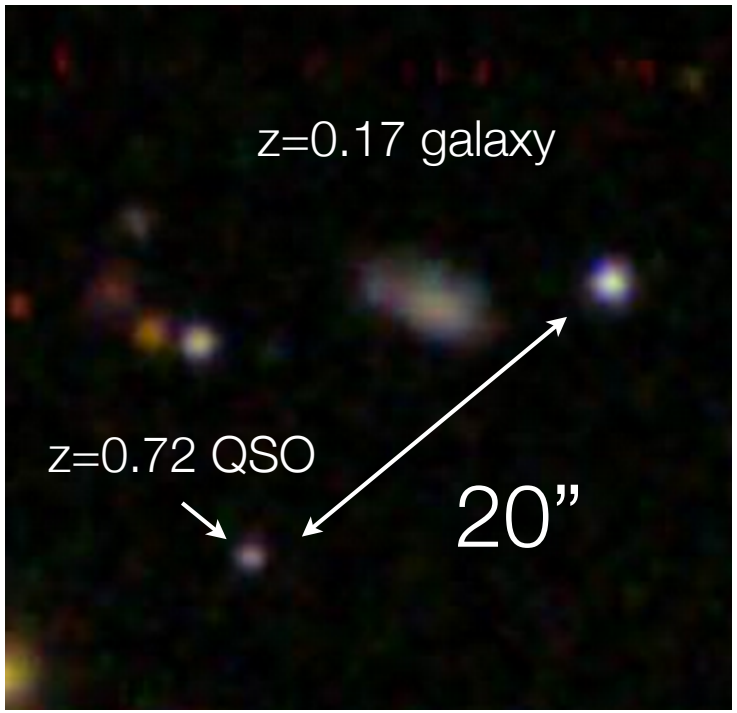
Interesting candidate close-up 4

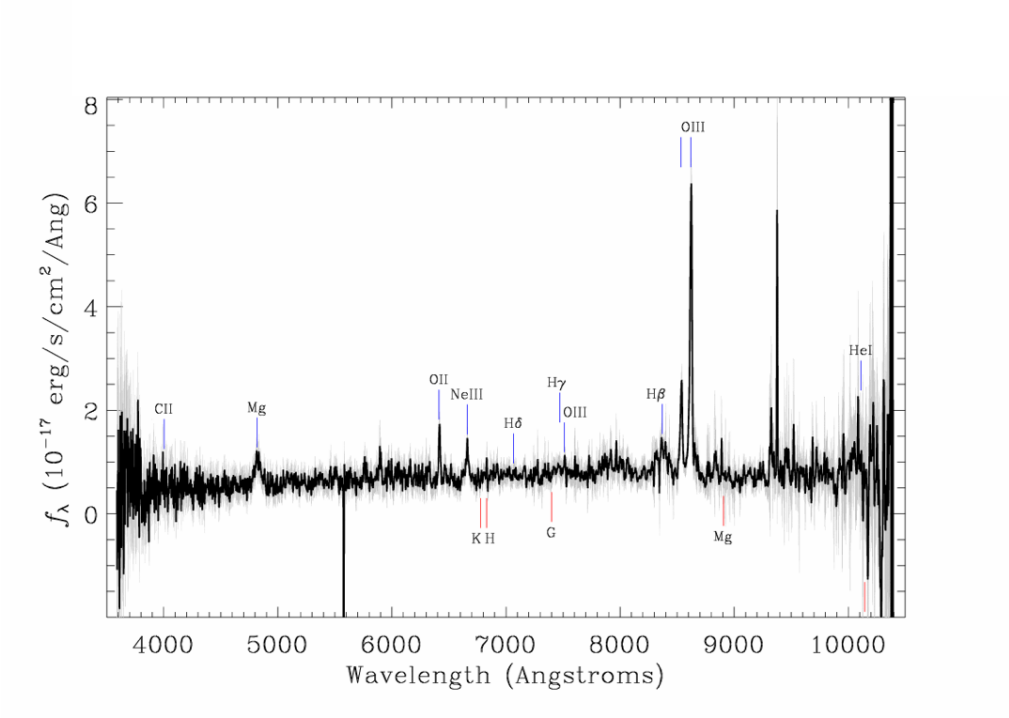




Central red object is a star

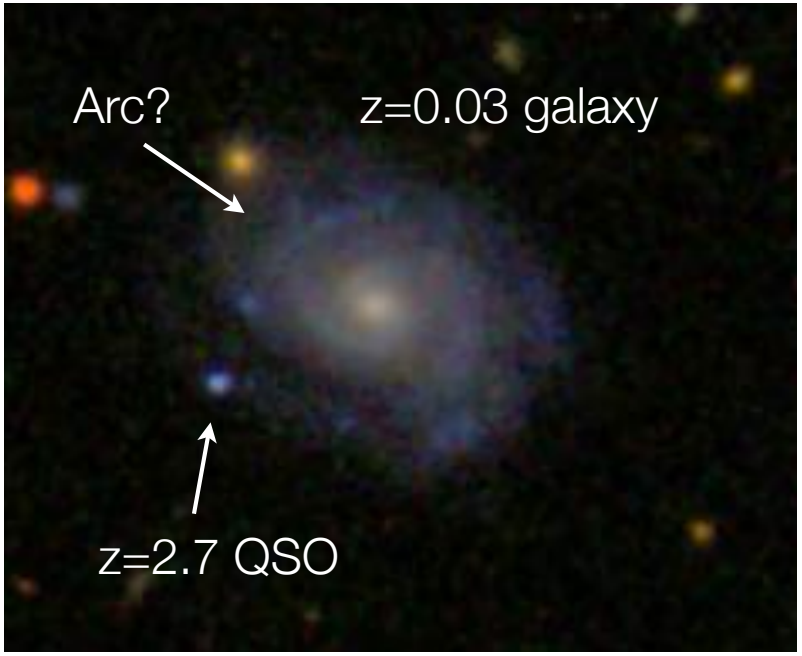
Interesting candidate close-up 5

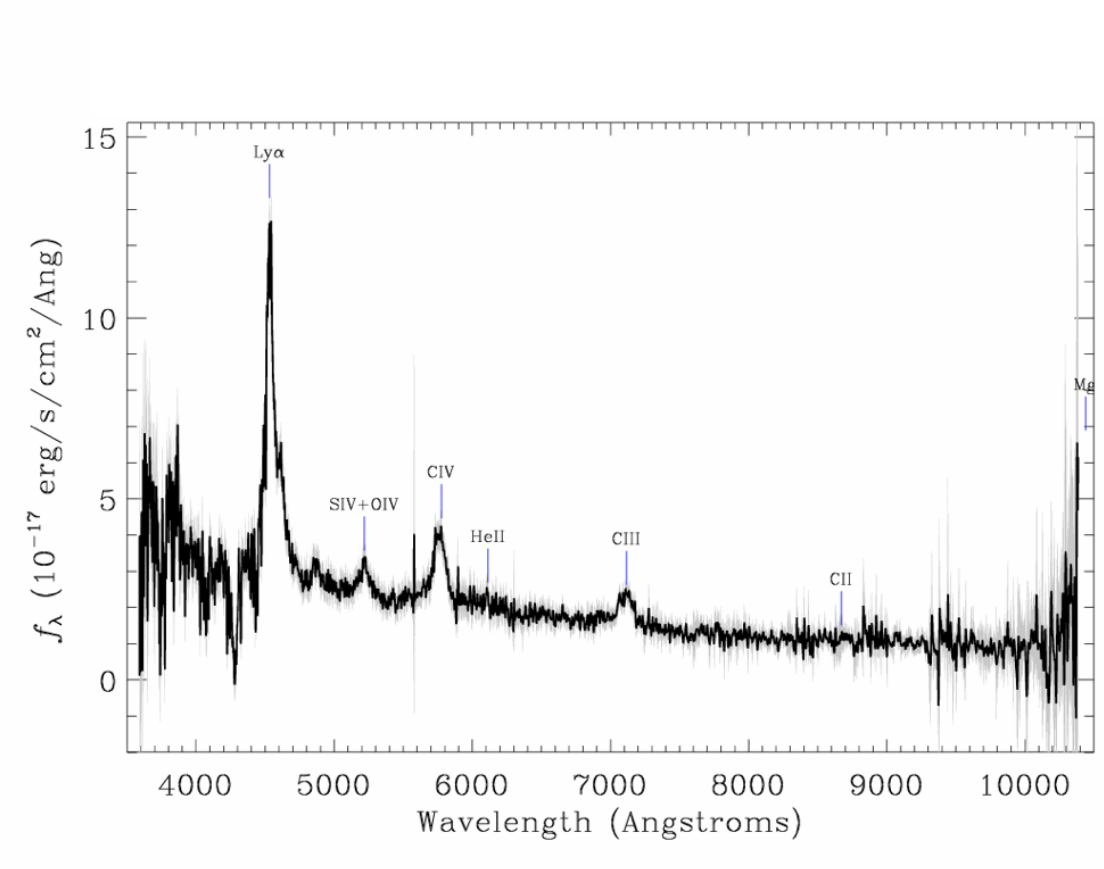




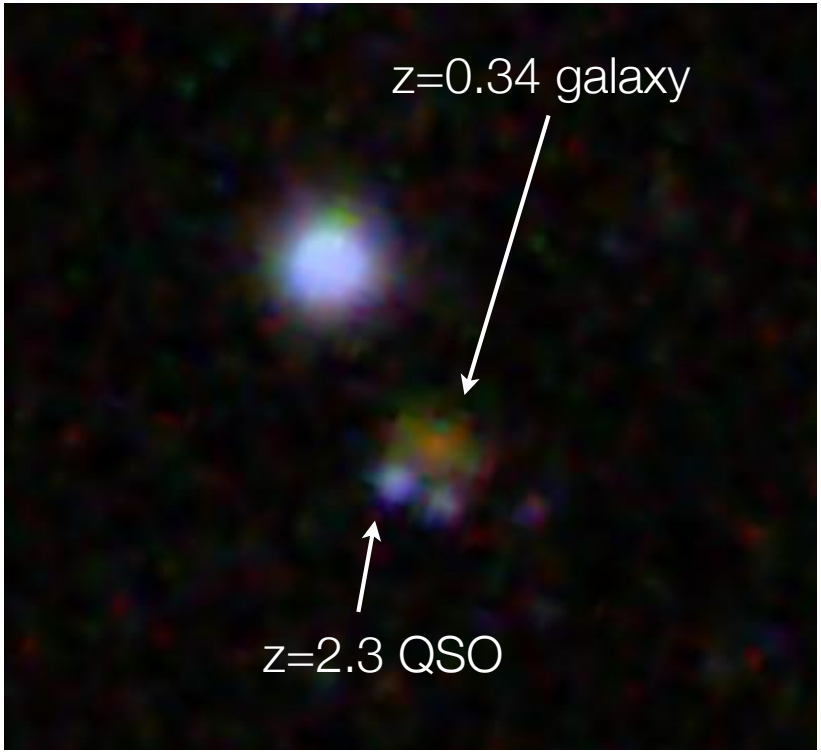
Large separation

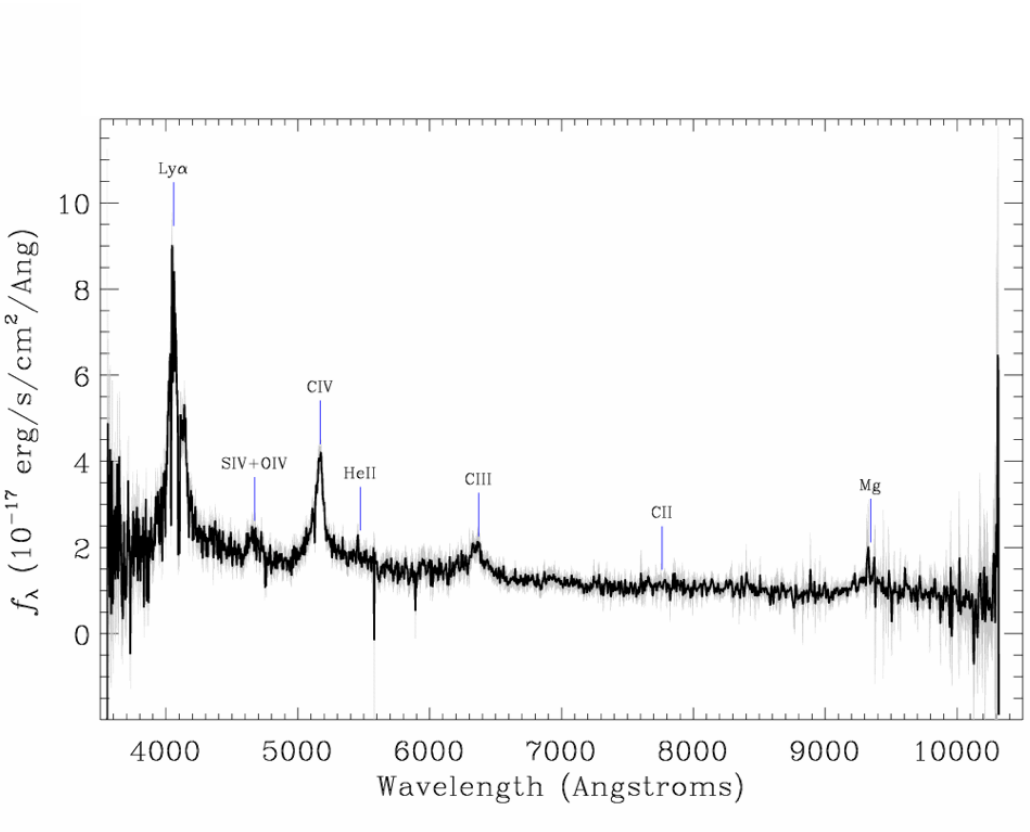
Interesting candidate close-up 6





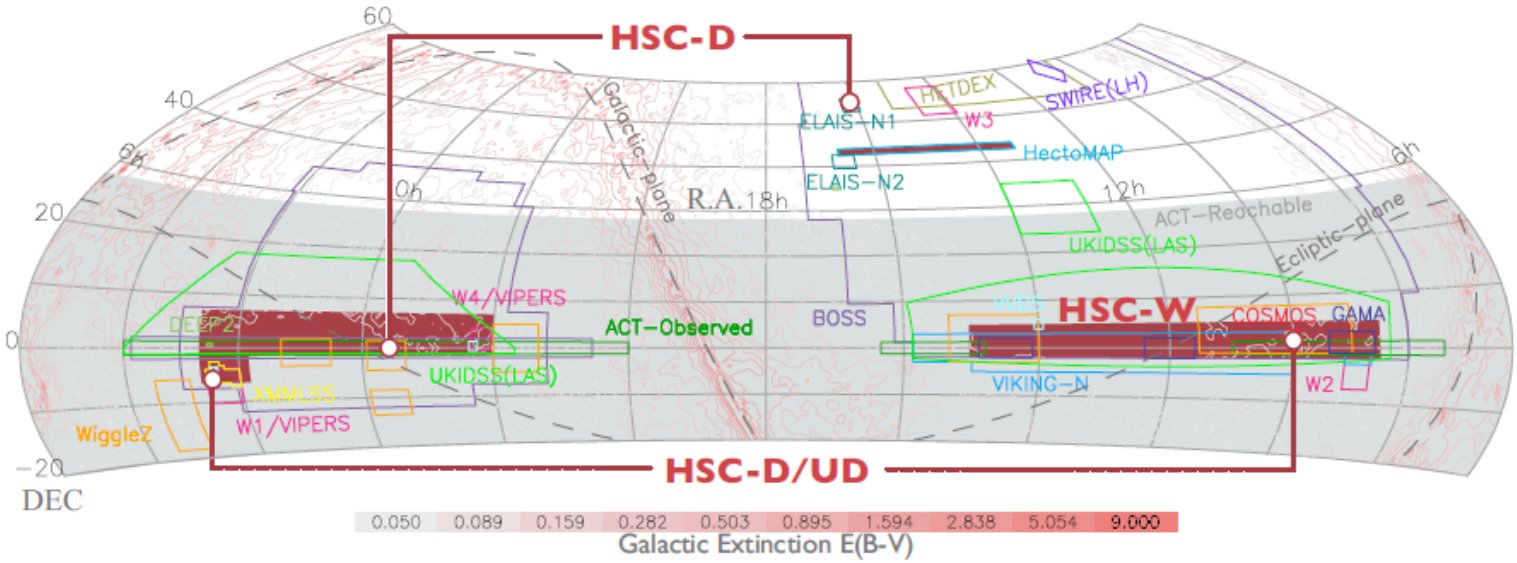
Interesting candidate close-up 5





II. lensed QSOs in HSC

QSOs in HSC



- i<19 from spectroscopic sample from BOSS

- candidate magnitude selection (see previous talks)

Lensed QSOs in HSC

HSC white paper

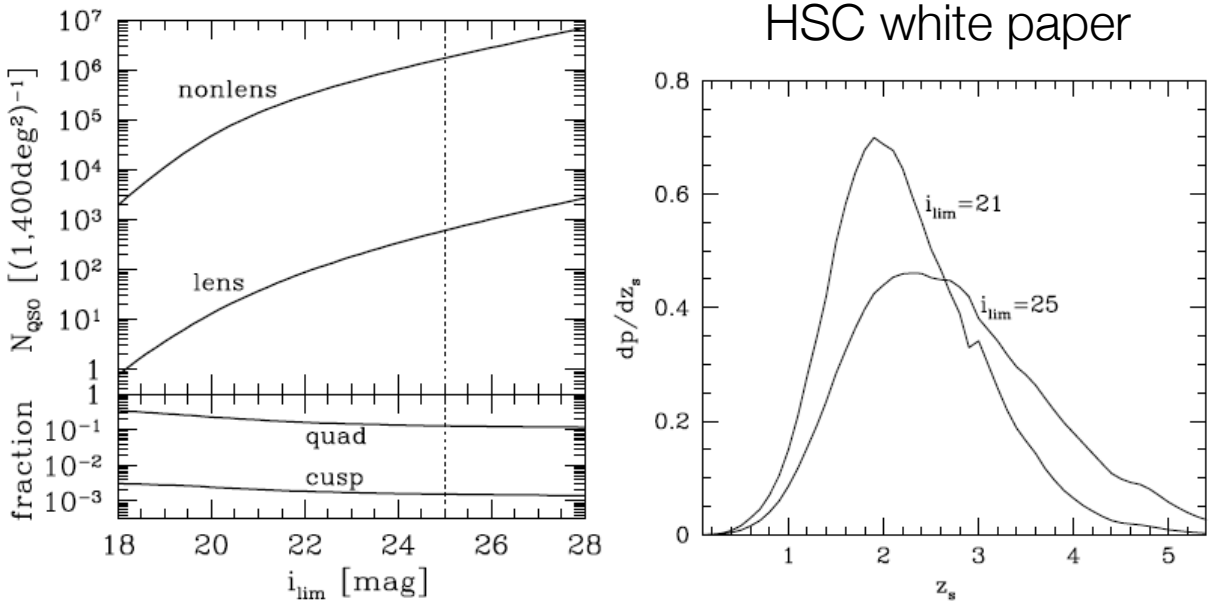
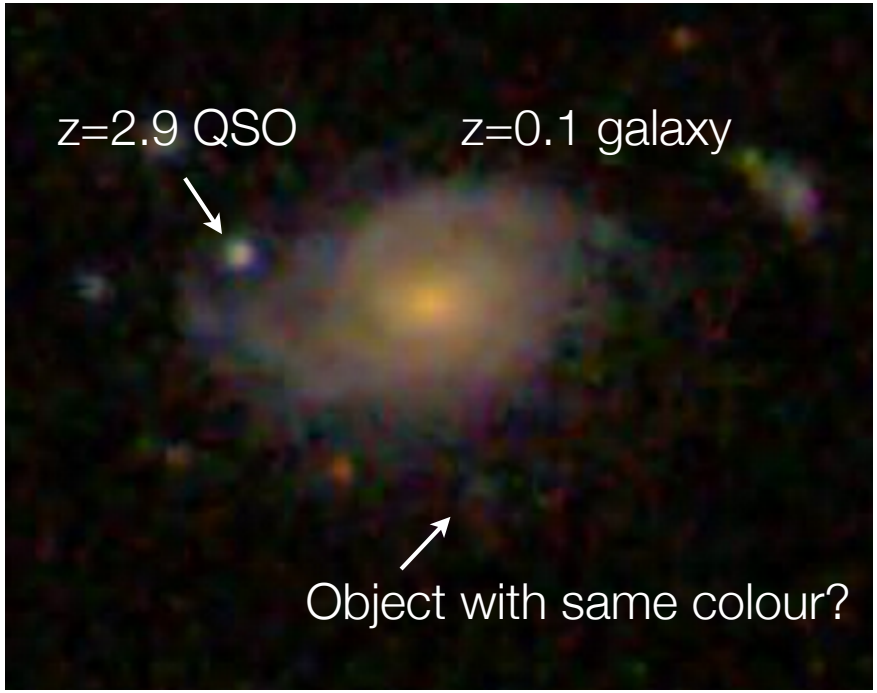
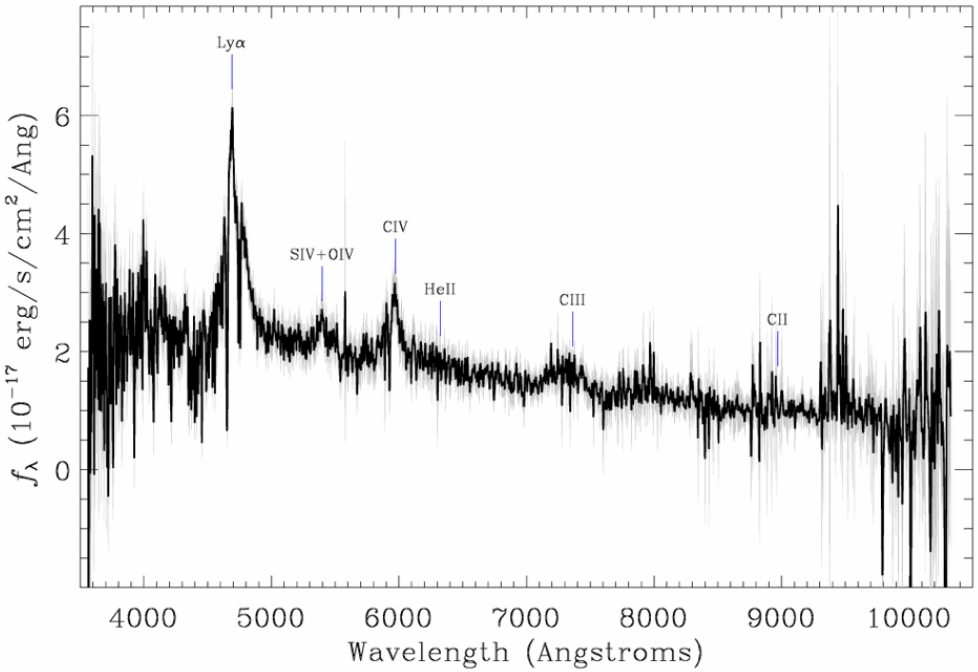


Figure 13.13.: *Left:* The expected number of quasars and lensed quasars as a function of the i-band limiting magnitude $i_{\rm lim}$ (see Oguri & Marshall 2010, for more details). A survey area of $1,400$ deg^2 is assumed. The lower panel shows the fraction of four-image lenses quad) and three-image lenses (cusp), as a function of $i_{\rm lim}$. The vertical dashed line indicates $i_{\rm lim}\sim$25.0, corresponding to 10σ magnitude limit for the HSC-Wide layer. *Right:* Redshift distributions of strongly lensed quasars for the limiting magnitudes of $i_{\rm lim}$ = 21 and 25.

Smaller area than SDSS but much deeper and with better resolution
-> total number of expected QSO is 1.6 millions and lensed quasars ~600

Gain from deeper photometry

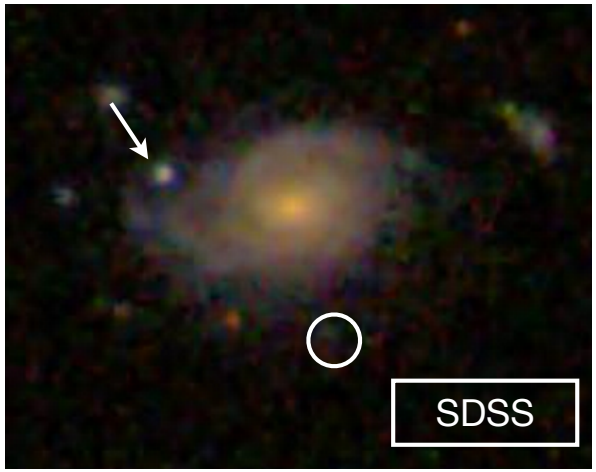




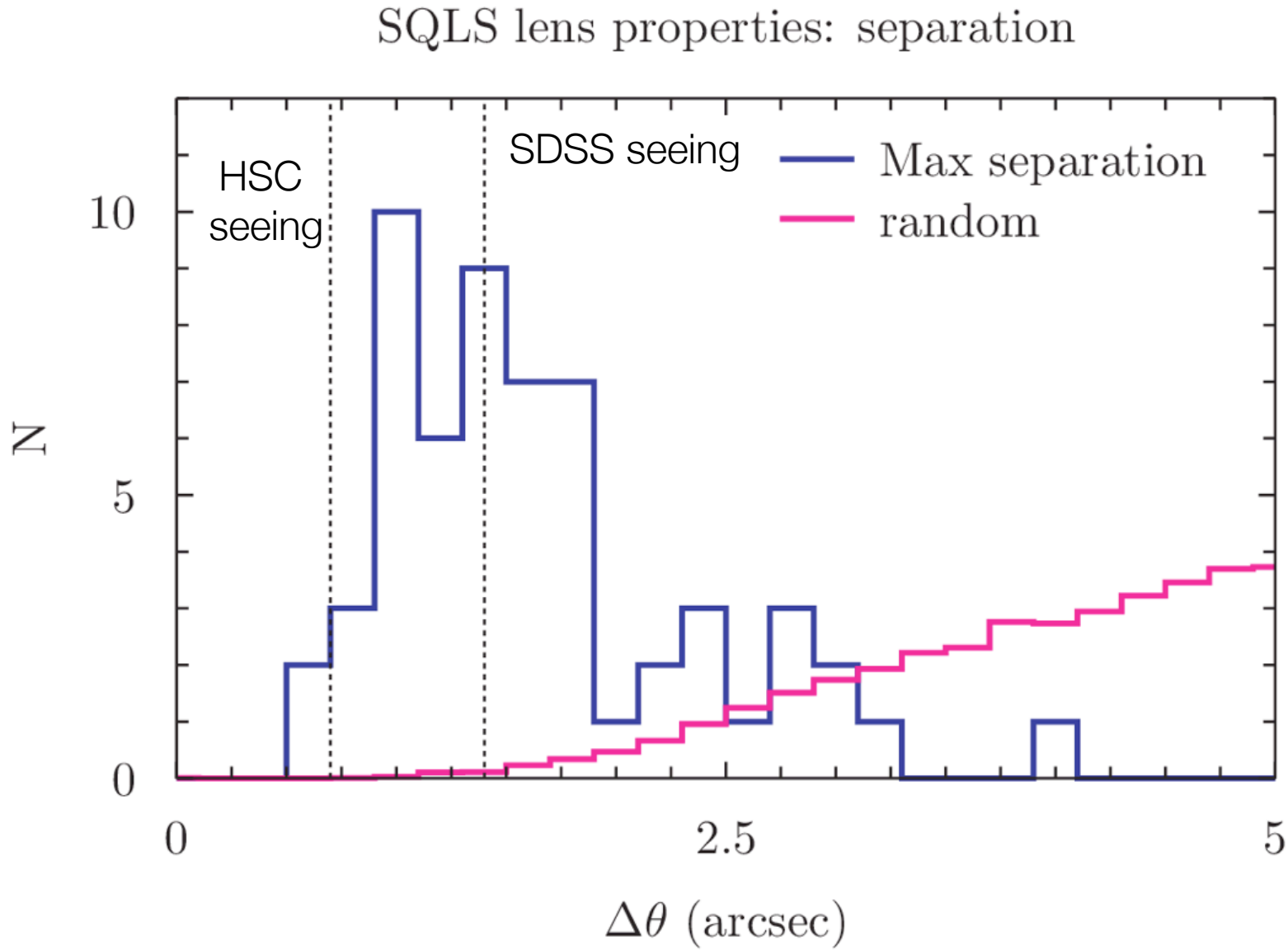
Candidate in SDSS

Gain from deeper photometry

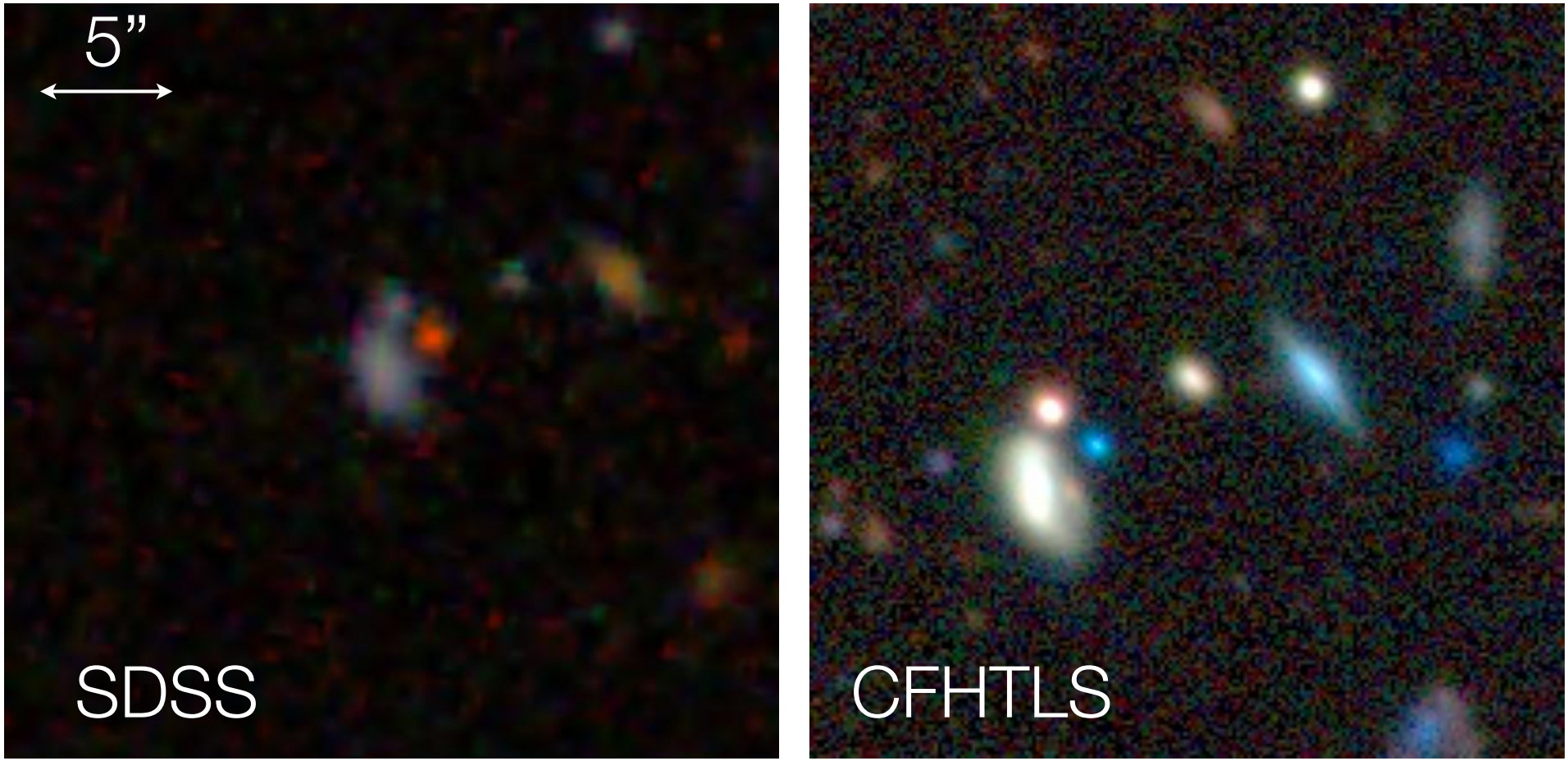
Deeper u band reveals foreground galaxy structure



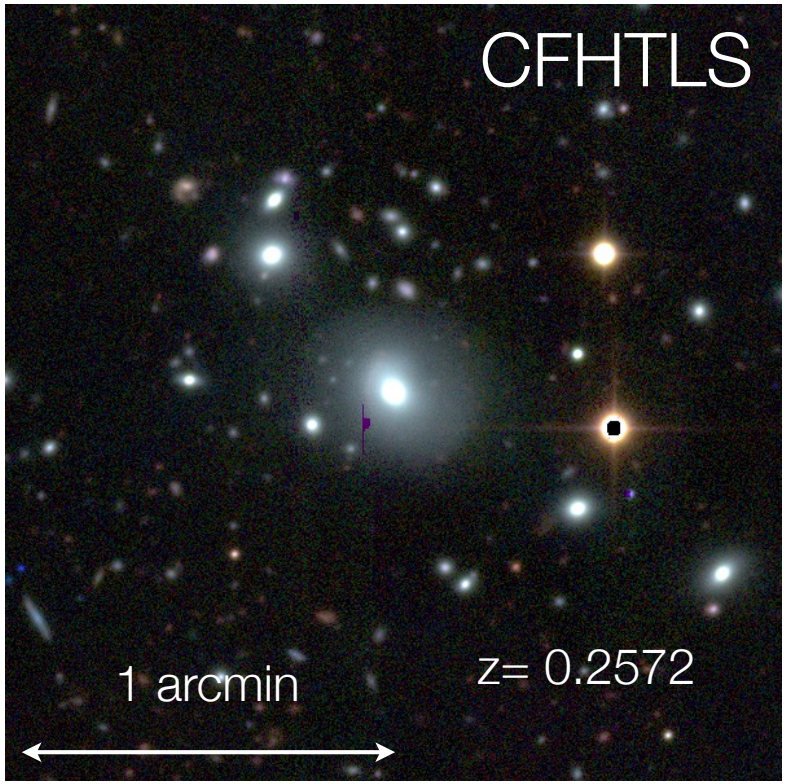
Gain from resolution

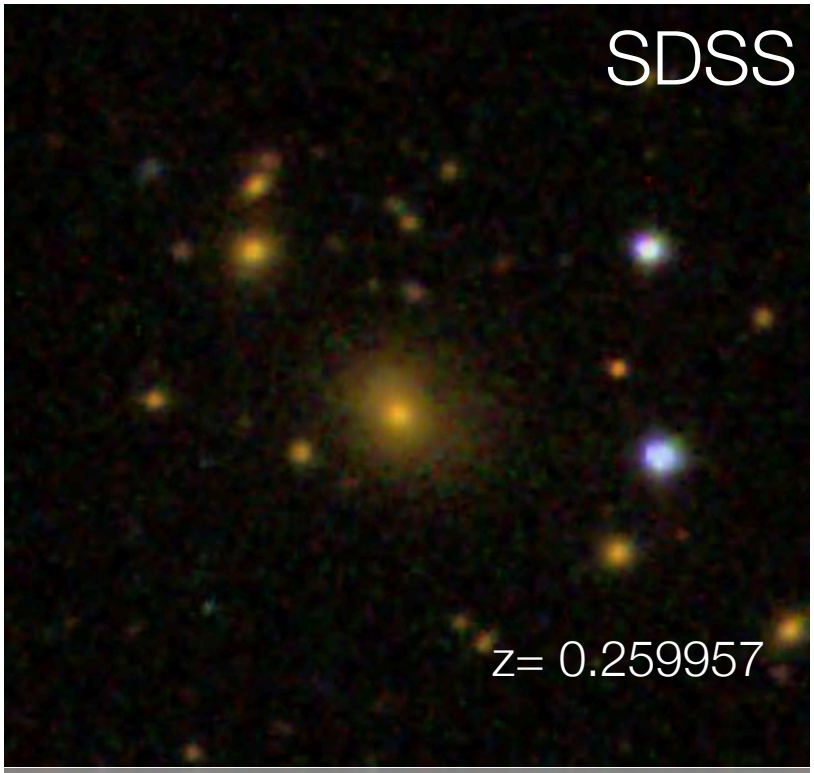


Gain from resolution

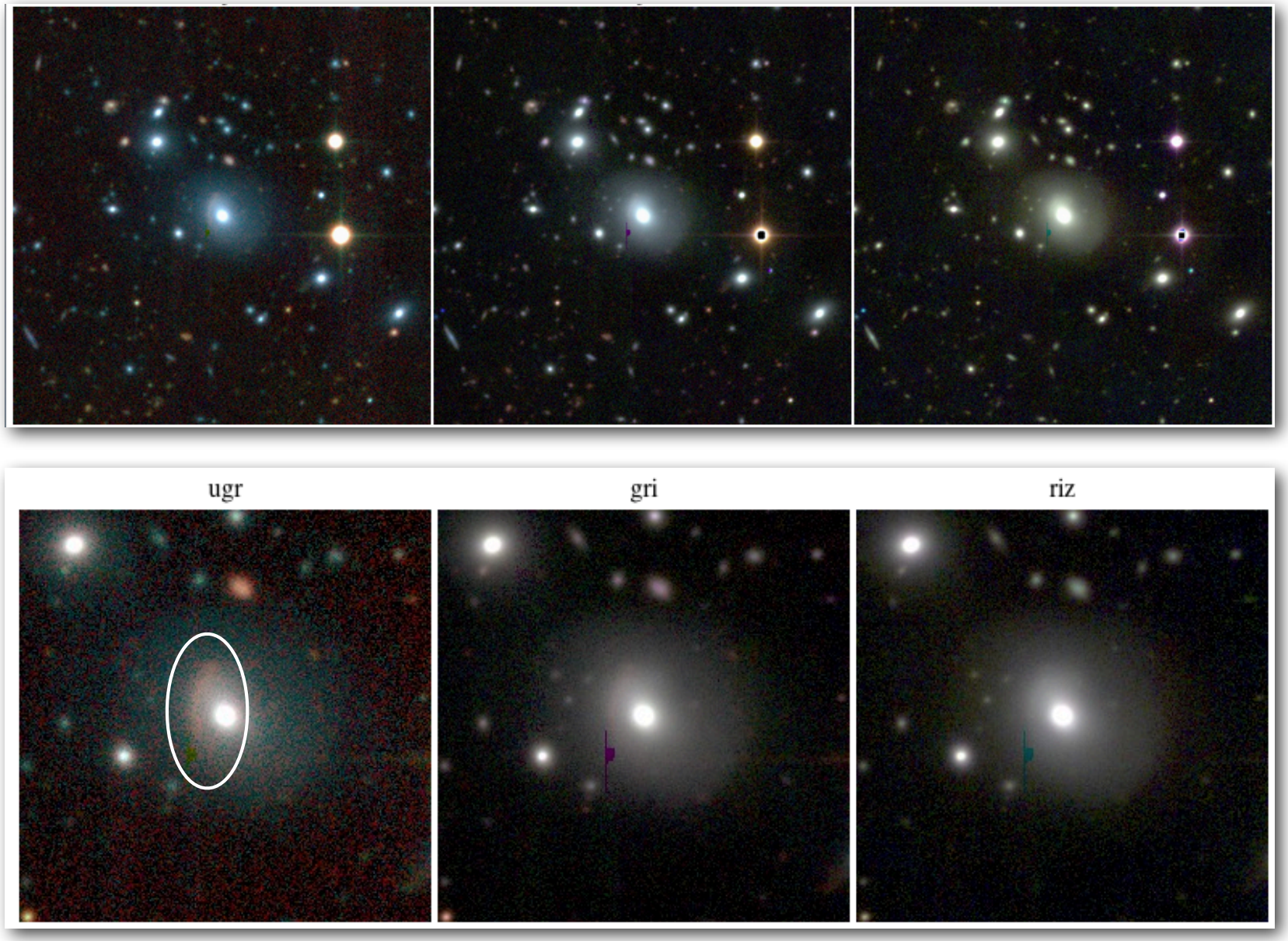


CFHTLS/SDSS





CFHTLS/SDSS



Conclusions and perspectives

- lensed QSOs are very powerful tools for cosmology and galaxy studies
- weighted colour detection can recover most know lenses with few candidates
- HSC expects 600 lensed quasars
- represents many candidates to examine but the gain in depth and resolution from SDSS will allow a more efficient selection
- Adding variability should help to refine the search for QSOs
- QSO magnification signal from clusters in SDSS. With a surface density 50 higher than SDSS, we will be able to combine several lensing method to weigh massive clusters in HSC