

Strong lensing searches with HSC

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On behalf of

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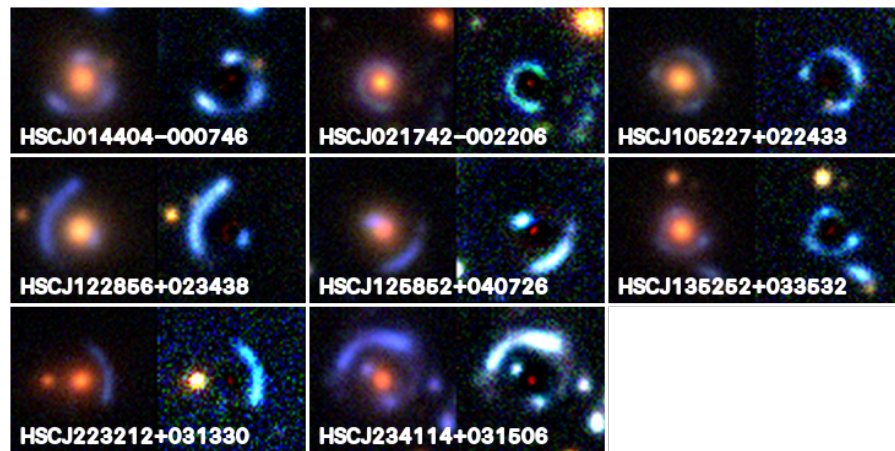
Broader science goals of the HSC - Strong lensing studies

- Studying the stellar initial mass function (IMF) and dark matter fractions in galaxies
- Dark and total mass distributions in galaxy groups and clusters
- Quadruply lensed quasars to put constraints on Cosmology
- Lensed quasars to study Black hole and host galaxy properties

New galaxy-scale lenses from HSC SSP DR4

Project Lead: Kenneth Wong

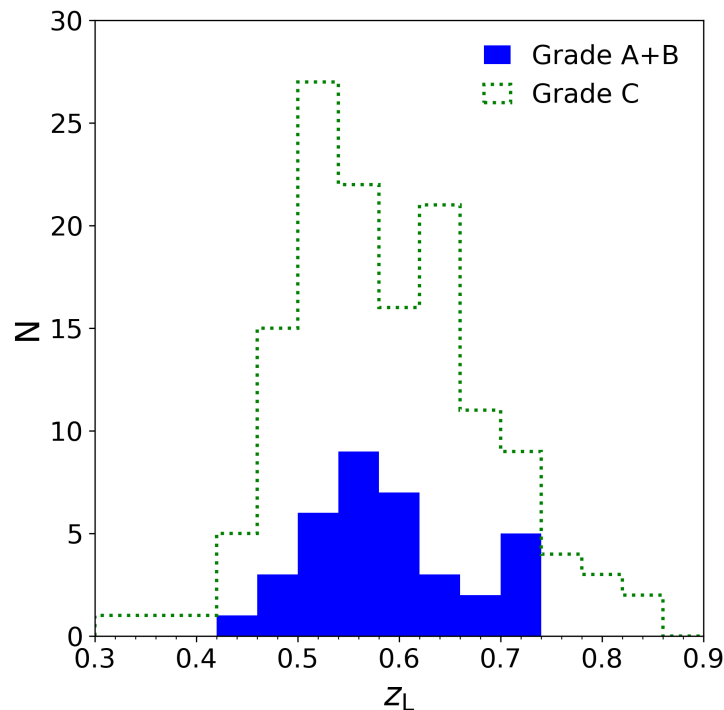
- Search for galaxy-galaxy lenses in HSC SSP DR4 using YattaLens (Sonnenfeld+2018)
- YattaLens searches for extended blue objects around central galaxy (using HSC gri-band imaging)
- Simple lens model fit to imaging, compare residual with other image models (e.g., ring galaxy, extended foreground galaxy)



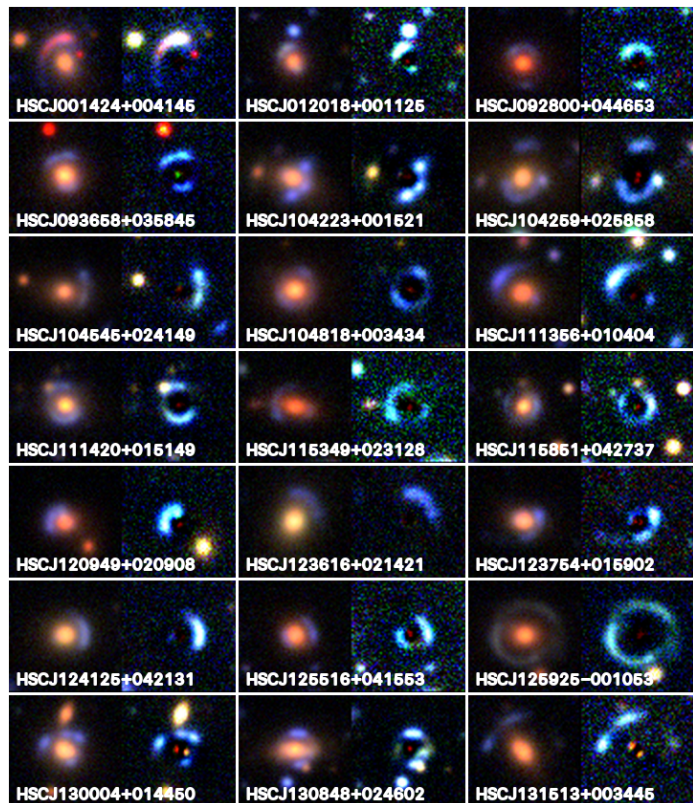
Grade A lens candidates

New galaxy-scale lenses from HSC SSP DR4

- Preselection: LRGs from BOSS DR15
- Search conducted over nearly the entire HSC-Wide area
- Candidates graded by 8 independent experts
- Discovered
 - **43 grade A+B and**
 - **138 grade C lens candidates**from $0.2 \lesssim z_L \lesssim 0.9$



New galaxy-scale lenses from HSC SSP DR4



Grade B lens candidates

- Publication of new candidates shortly (Wong et al. 2022 in prep.)
- Follow-up spectroscopy to get source redshifts will enable detailed lens modeling for studies of galaxy structure and evolution

Galaxy-scale lens search using CNN

Project Lead: Anton T. Jaelani

- Searching new galaxy-scale lenses in HSC SSP PDR2 using a Convolutional Neural Network
- Parent sample ≈ 2.3 million galaxies in HSC PDR2 Wide
 - $0.2 < z_{\text{phot}} < 1.2$
 - $r_{\text{cmodel_mag}} - a_r < 28$; $i_{\text{cmodel_mag}} - a_i < 28$; $z_{\text{cmodel_mag}} - a_z < 23$
 - Stellar mass $> 5 \times 10^{10} M_{\odot}$; SFR/Stellar mass $< 1e-10$
- Results: ≈ 21000 candidates with threshold > 0.9 (Jaelani et al. 2022 in prep.)
 - **226 grades A/B (52 are new discoveries)** after visual inspections
 - and 995 grades C candidates after visual inspections

Examples of Strong-lens Candidates



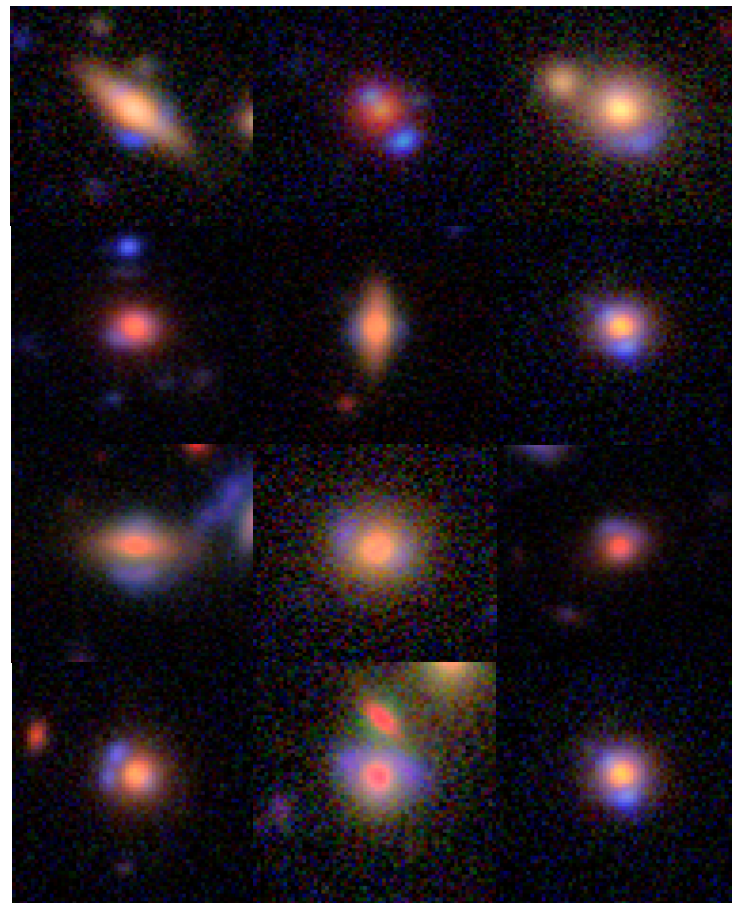
Grades A



Grades B

Status and Future plans

- About 90 candidates in our sample were assigned lower grades compared to other studies
 - E.g. lens sample on the right has grade B in Canameras et al. 2021
- Final sample is being compiled
- Lens modelling and follow-up spectroscopy to get source redshifts



(Jaelani et al. 2022 in prep.)

High-redshift Strong-lens Candidates from PDR2

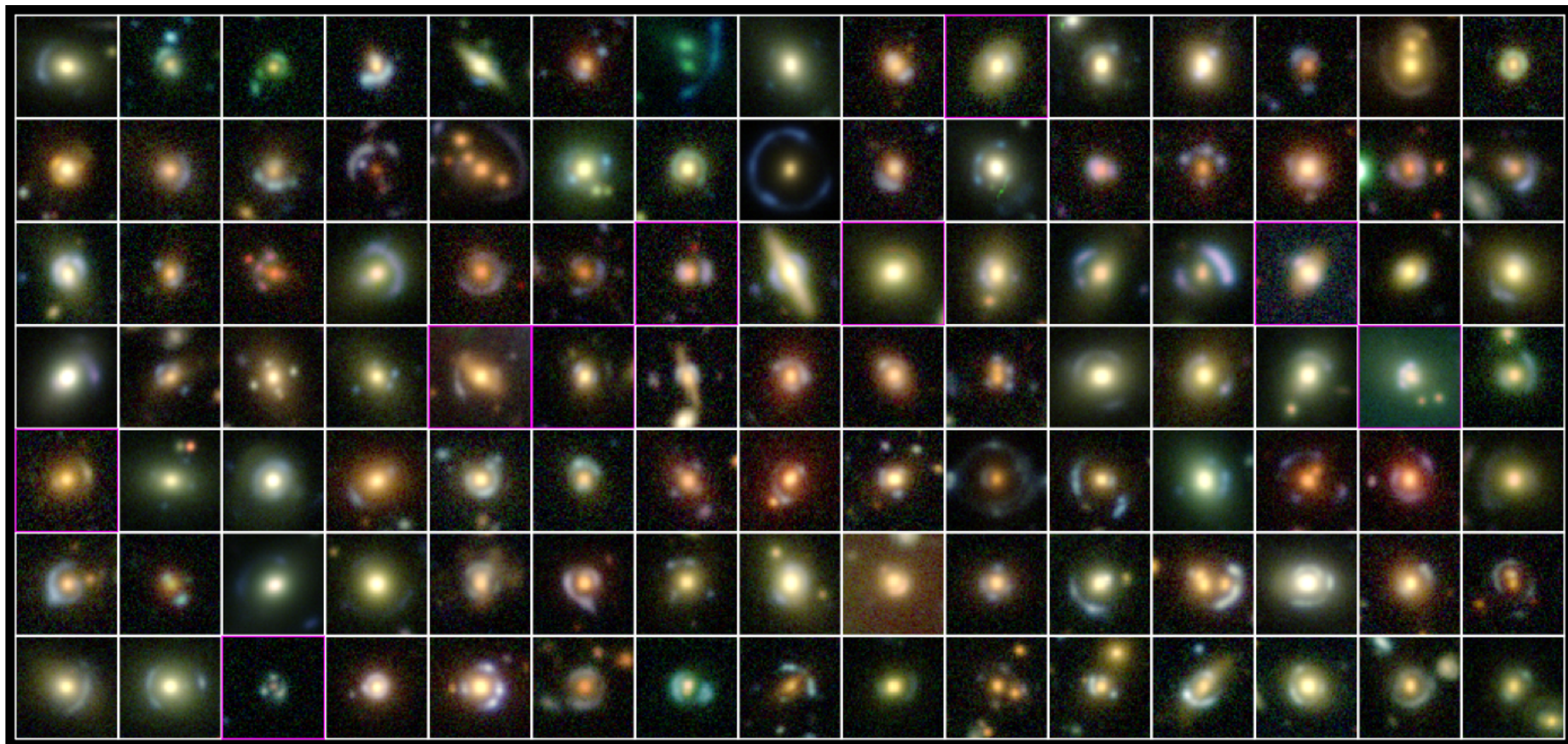
Project Lead: Yiping Shu

- ❑ Motivation: Extending strong lensing-assisted galaxy evolutionary studies (e.g. Bolton et al. 2012, Sonnenfeld et al. 2013) to earlier cosmic time
- ❑ Parent Sample: ≈ 5.4 million galaxies in HSC PDR2 Wide ($\approx 960 \text{ deg}^2$) with red colours

$$\begin{aligned} 0.6 &< g_cmodel_mag - r_cmodel_mag < 3.0 \\ 2.0 &< g_cmodel_mag - i_cmodel_mag < 5.0 \end{aligned}$$

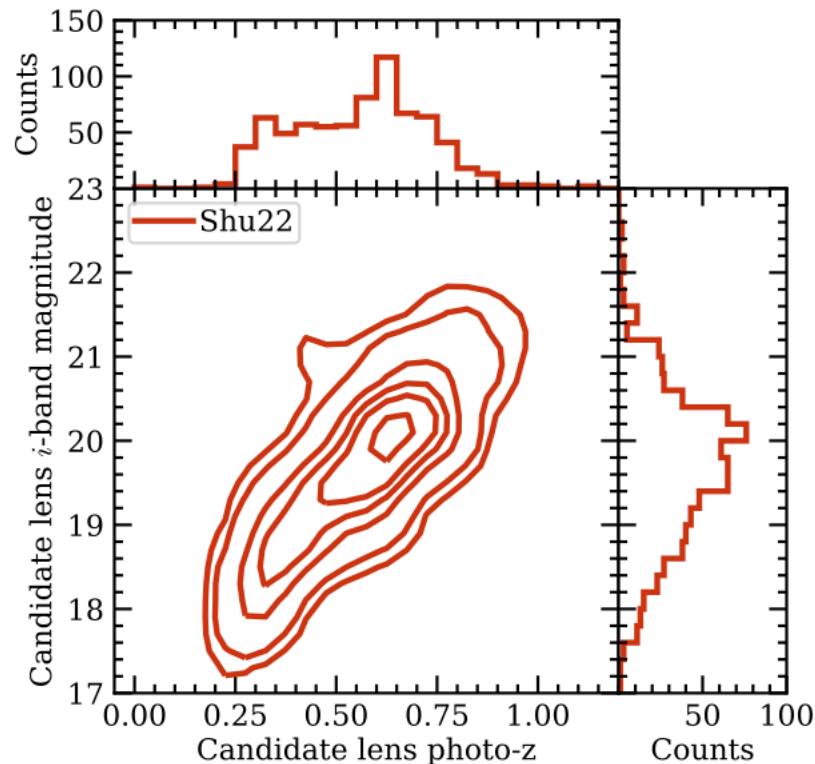
- ❑ Method: Strong-lens classifier constructed with deep residual networks
- ❑ Results:
 - ❑ $\approx 10,000$ candidates from the parent sample (~ 100 minutes)
 - ❑ 735 Grade-A/B strong-lens candidates after visual inspections, of which 277 are new discoveries (Shu et al. 2022, to be submitted)

High-redshift Strong-lens Candidates from PDR2



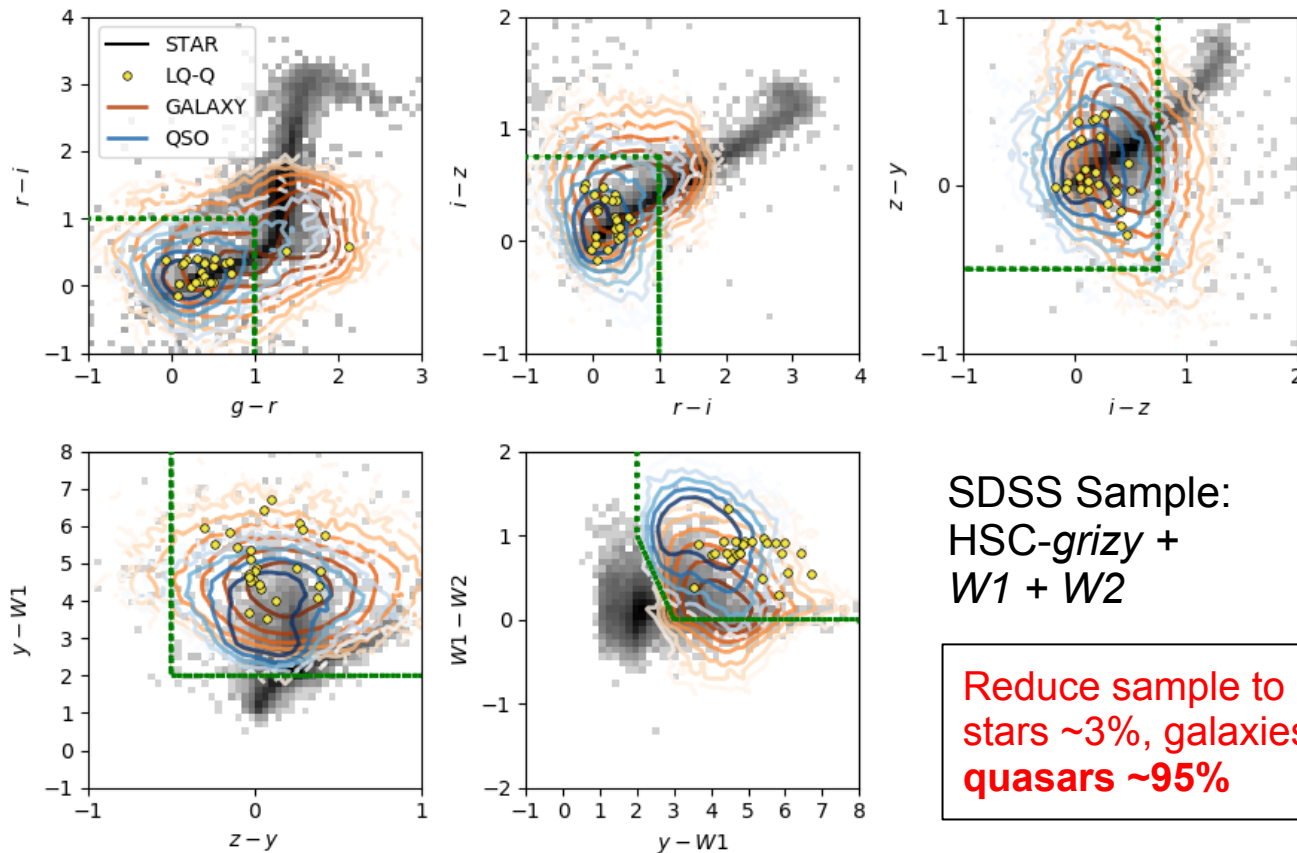
High-redshift Strong-lens Candidates from PDR2

- ❑ Single largest set of galaxy-scale strong-lens candidates in the HSC footprint to date
- ❑ > 60% objects in our parent sample had not been classified by the SuGOHI project or Canameras et al. (2021)
- ❑ Nearly half (331/735) contain lens galaxies with $z_{\text{phot}} > 0.6$
- ❑ A valuable target catalog for ongoing and scheduled spectroscopic surveys, such as PFS.



HSC Lensed Quasar Search - Preselection

Project Lead: James Chan



color cut:

$g-r < 1$
 $r-z < 1$
 $i-z < 0.75$
 $z-y > -0.5$
 $y-W1 > 2$
 $y-W2 > 3$
 $W1-W2 > 0$

SDSS Sample:
HSC-grizy +
 $W1 + W2$

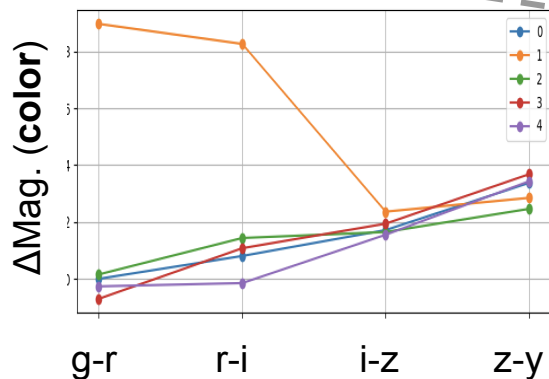
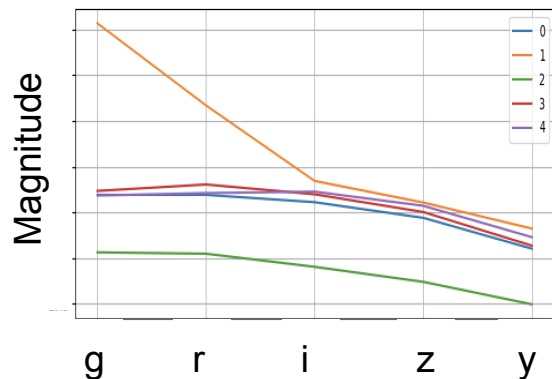
Reduce sample to
stars ~3%, galaxies ~25%
quasars ~95%

HSC Lensed Quasar Search

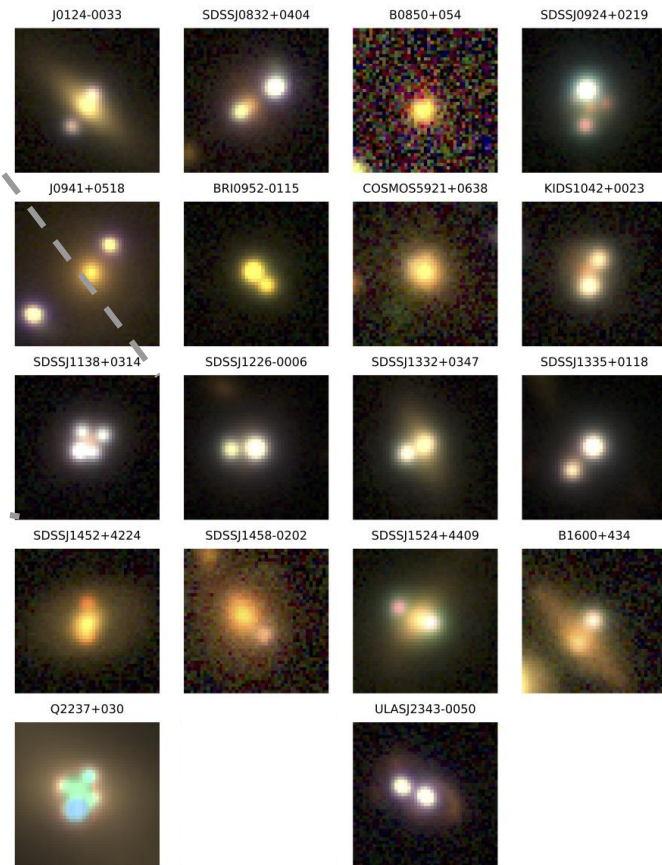
New algorithm to identify multiple blue point sources:

1. identify point sources
2. estimate the colors
3. separate into the blue/red group
4. the number blue point sources from 2 to 5 $\rightarrow$ **lens candidate**

(see details in Chan et al. 2021)



known lenses (gri) in HSC DR4 S21A



HSC Lensed Quasar Search

Current status:

1. Applying the color cut in the HSC catalog ($i < 22$)
2. Improving the algorithm to separate blue/red point sources

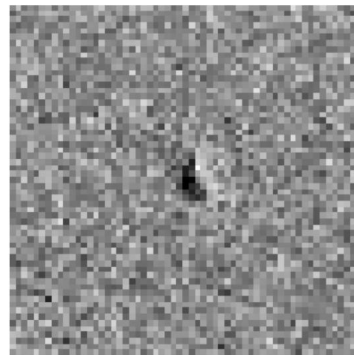
Future plan (after the classification of lens candidate):

1. Visual inspection: making use of existing data, such as SDSS spectra, GAIA information, etc.
2. Follow-up observations: spectroscopy, or high-resolution imaging.
3. Lens modeling

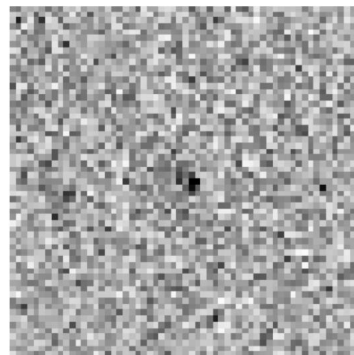
Lensed quasar search using CNN via time variability

Project Lead: Dani Chao

- Using the advantage of HSC transient survey to design/prepare a fast automatic lensed quasar search algorithm for the LSST
- Use the i-band difference images from the median-seeing epoch (2017 Feb. 25)
- Generate a training sample -
 - Mock lensed quasars (+): 2033
 - Non-lensed variables (-): 42279
- The only known quad in HSC to test: HSCJ095921+020638 (Anguita et al. 2009)



Non-lensed
variable object
(diff. Img. on Feb.
25 2017)



HSCJ095921+020638
(diff. Img on Feb. 25
2017)

Lensed quasar search using CNN via time variability

- Two kinds of samples are generated :
 - equal proportions of lensed vs non-lensed objects (2033*2)
(closer to)
 - Realistic proportions (lensed=2033, non-lensed=42279)
 - Training:Validation:Test = 60:15:25

	Overall accuracy	Precision	Recall	F1 score	The known lensed quasar
Equal	~96.9%	~95.9%	~98%	~96%	YES
Realistic	~99.6%	~94.9%	~95.6%	~95.2%	NO

Lensed quasar search using CNN via time variability

Status and Future steps

- Need to generate more mock lensed quasars in time series (difference images)
- Apply data augmentation
- Improve training of the CNN

SuGOHI Lens Database

<http://www-utap.phys.s.u-tokyo.ac.jp/~oguri/sugohi/>

• Lens Candidates Query

Show list Reset

Output format: ☒ HTML ☐ csv

Select grades:

- ☒ Grade A (definitely a lens)
- ☒ Grade B (probably a lens)
- ☒ Grade C (possibly a lens)

Lens type:

- ☒ Galaxy scale
- ☒ Group/cluster scale

Source type:

- ☒ Galaxy source
- ☒ Quasar source

Spectroscopy:

- ☒ W/ lens spec-z ☒ No lens spec-z
- ☒ W/ source spec-z ☒ No source spec-z

Combine with positional constraints:

☒ Rectangular search:

ra range: from to
dec range: from to

Cutout	Name	RA	Dec	z_{lens}	z_{source}	Lens type (GG: galaxy-galaxy; GQ: galaxy-quasar; CG: Cluster/group-galaxy; CQ: Cluster/group-quasar)	Discovery (V: visual inspection; Y: YattaLens; C: Chitah; E: emission line; K: known; S: serendipitous)	Grade (A: definite lens; B: probable lens; C: possible lens)
	HSCJ000129-000241	00:01:29.64	-00:02:41.6	0.247	-99.000	CG	V	C
	HSCJ000300+005337	00:03:00.00	+00:53:37.7	-99.000	-99.000	GG	V	C
	HSCJ000313+005425	00:03:13.08	+00:54:25.2	-99.000	-99.000	CG	V	B
	HSCJ000451-010316	00:04:51.84	-01:03:16.6	-99.000	-99.000	CG	V	A