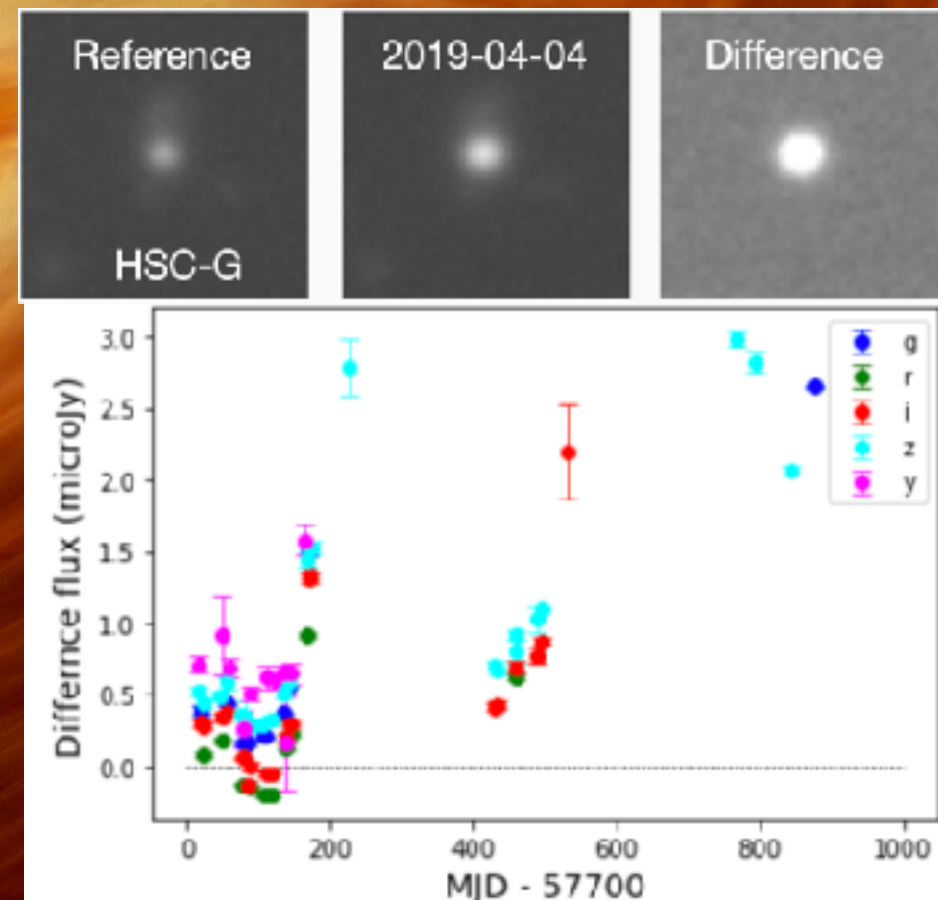
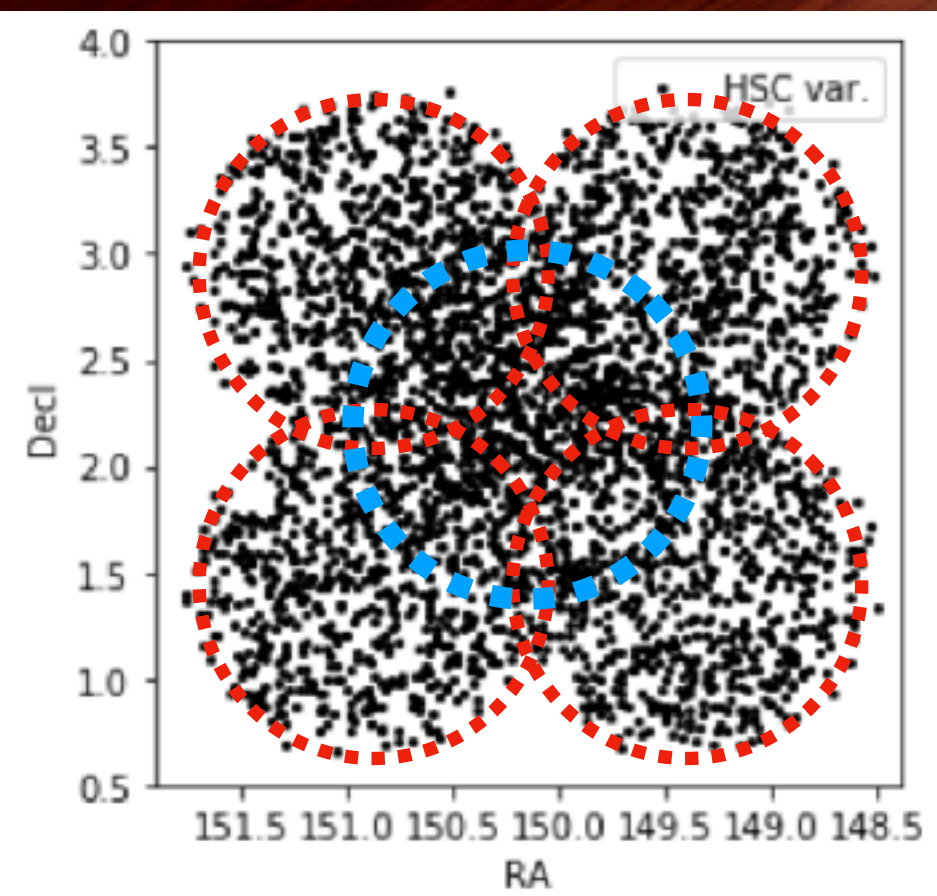


HSC project #56

Properties of variability-selected AGNs in the HSC SSP transient survey in COSMOS

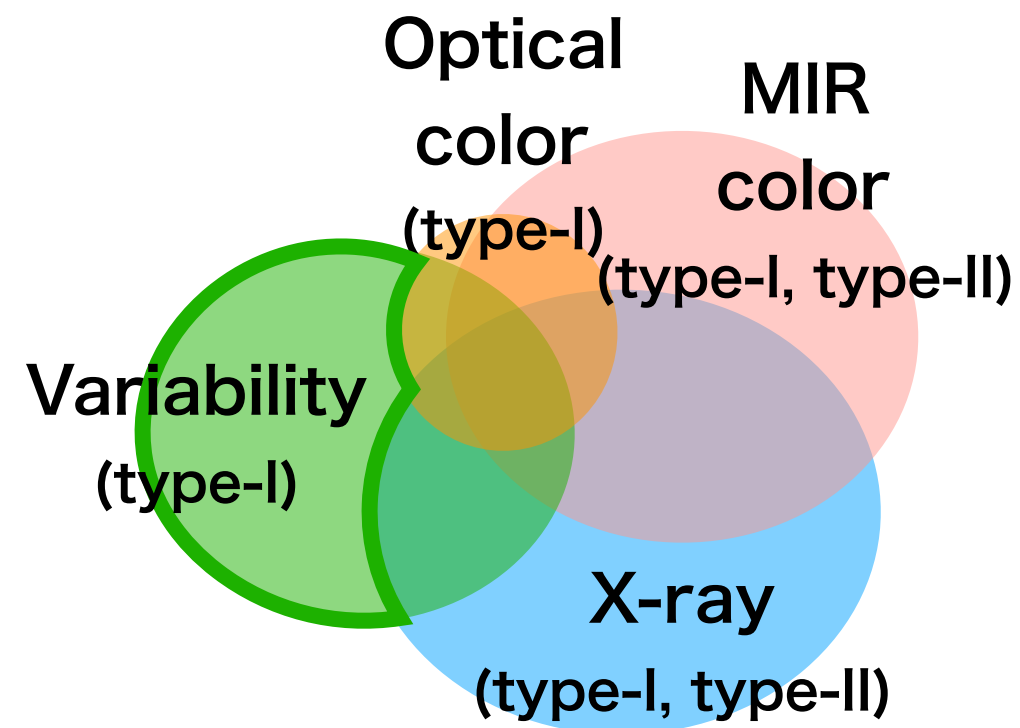
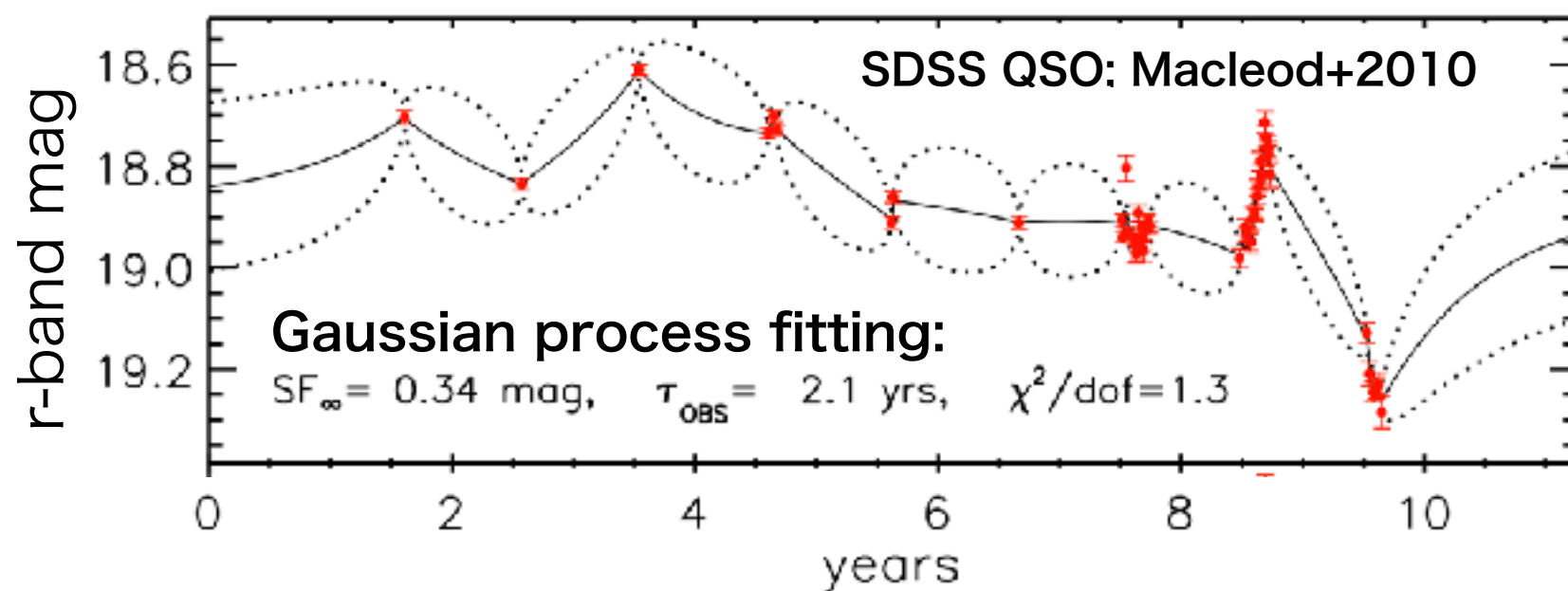
Mitsuru Kokubo (JSPS fellow, Tohoku Univ.)

M. Tanaka, Y. Kimura, M. Akiyama (Tohoku), M. Graham (Caltech),
N. Yasuda (IPMU), T. Morokuma (Univ. of Tokyo),
HSC transient working group.



Why variability-based AGN selection is important

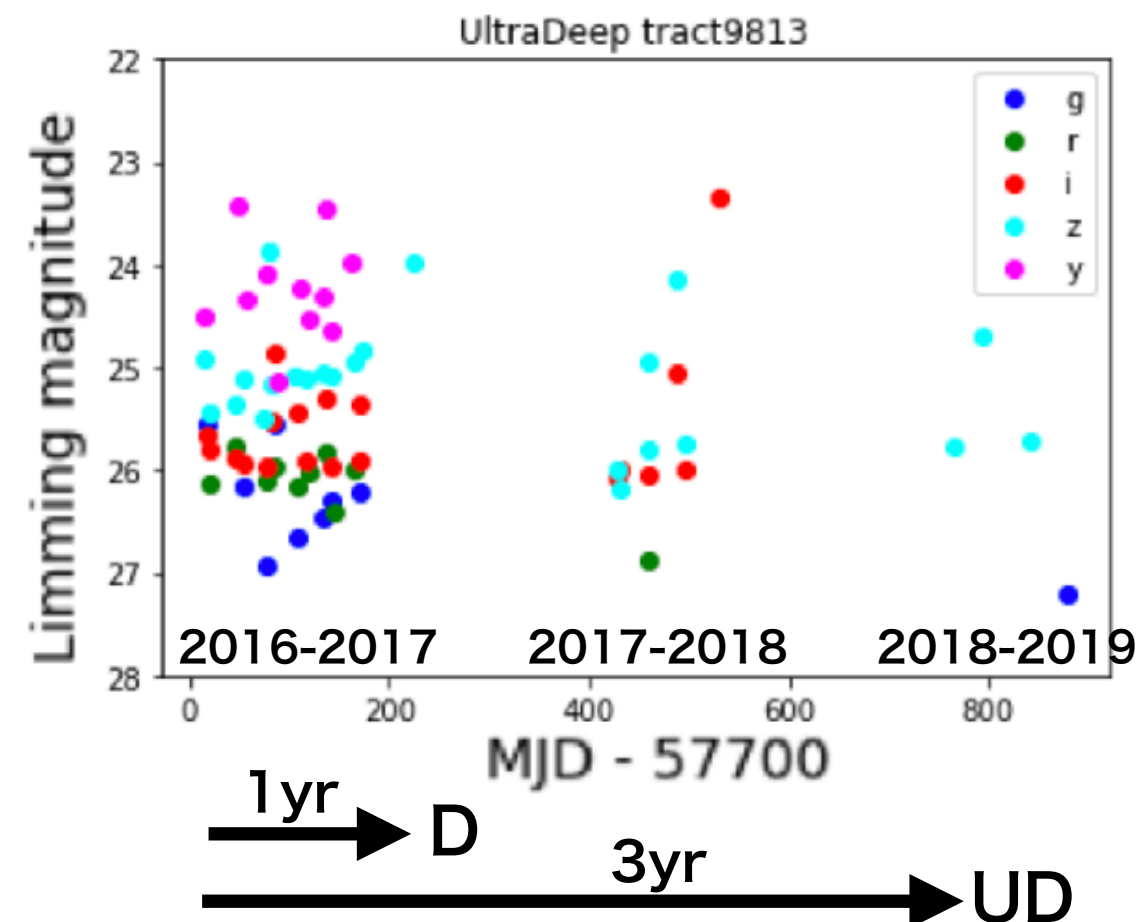
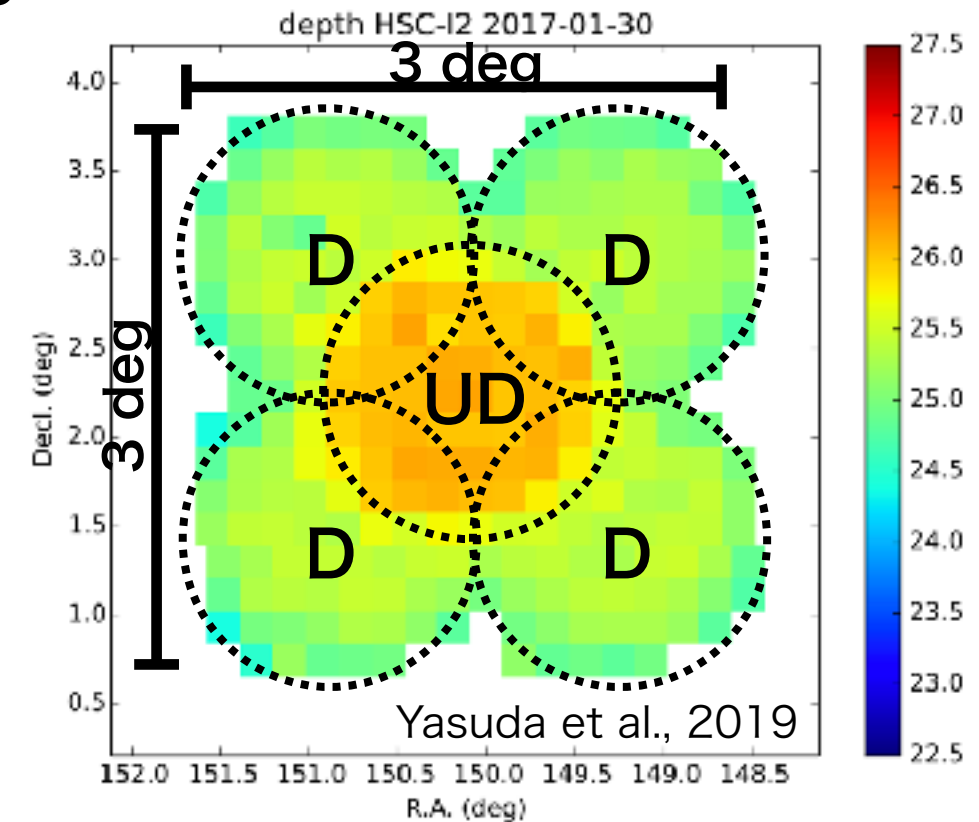
- **Almost all unobscured AGNs** show **aperiodic** optical variability
→ variability can be used to find AGNs in time-domain datasets
- not affected by **host galaxy flux contaminations**
↔ optical/MIR color selection can miss faint low-mass AGNs
- growing importance in the coming era of *LSST*



HSC-SSP transient survey in COSMOS

(ref. Yasuda et al., 2019)

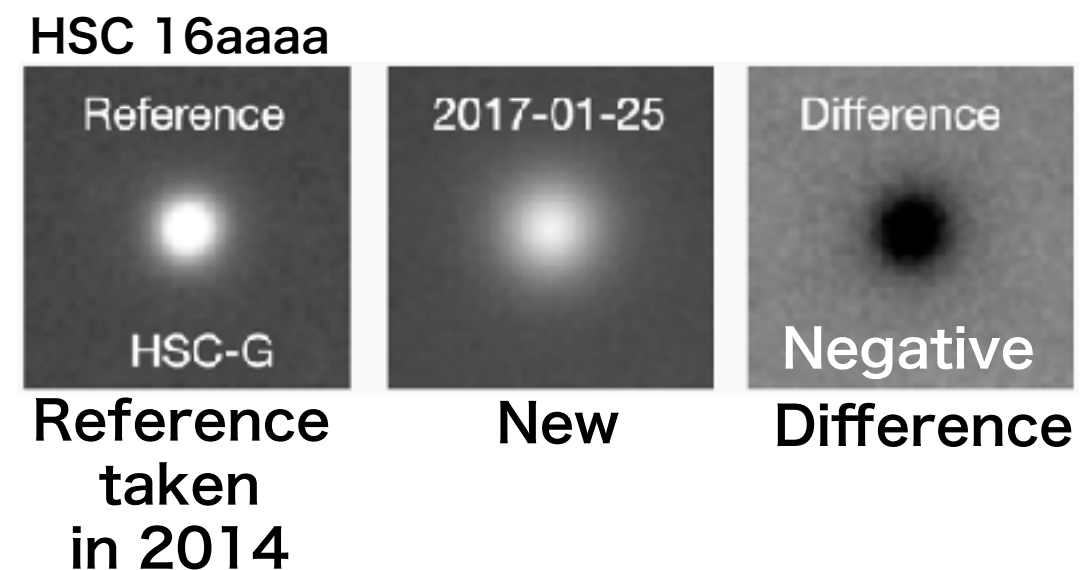
- **Wide-field deep 5-band (*grizy*) time-domain survey in the HSC COSMOS field**
- **$i \sim 26.0/25.5$ mag per epoch in UD/D**
← detected transients/variables are mostly **supernovae** and **unobscured AGNs**
with < 1 % Galactic variable star contamination
- Main survey in **UD & D**: 2016 — 2017
Additional data in **UD**: 2017 — 2019



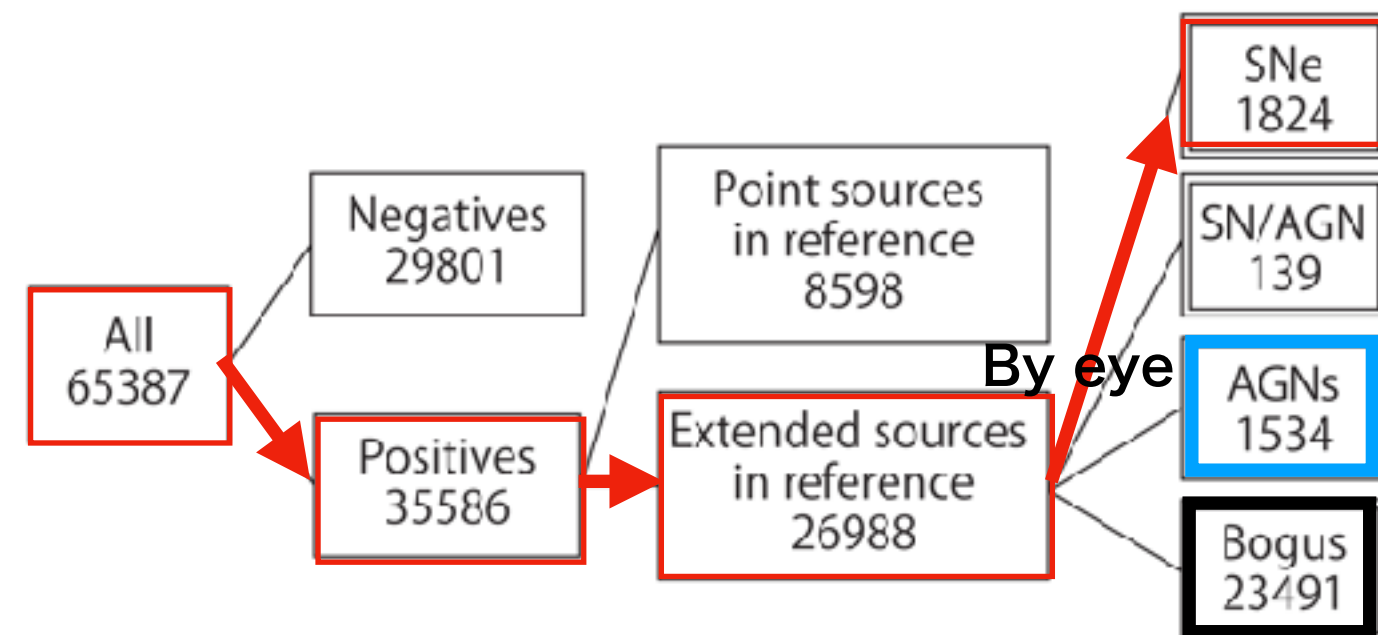
Eyeball identification of supernovae

by Yasuda et al. 2019

- Reference image subtraction
→ **65387** transient candidates
- **Visual inspection** for **26988/65387**
active SNe candidates with positive flux &
extended host galaxies
→ **1824 active SNe**, **23491 Bogus**,
and **1534 AGNs** as a by-product



AGNs in “Negative flux” and “Point sources” remain unclassified

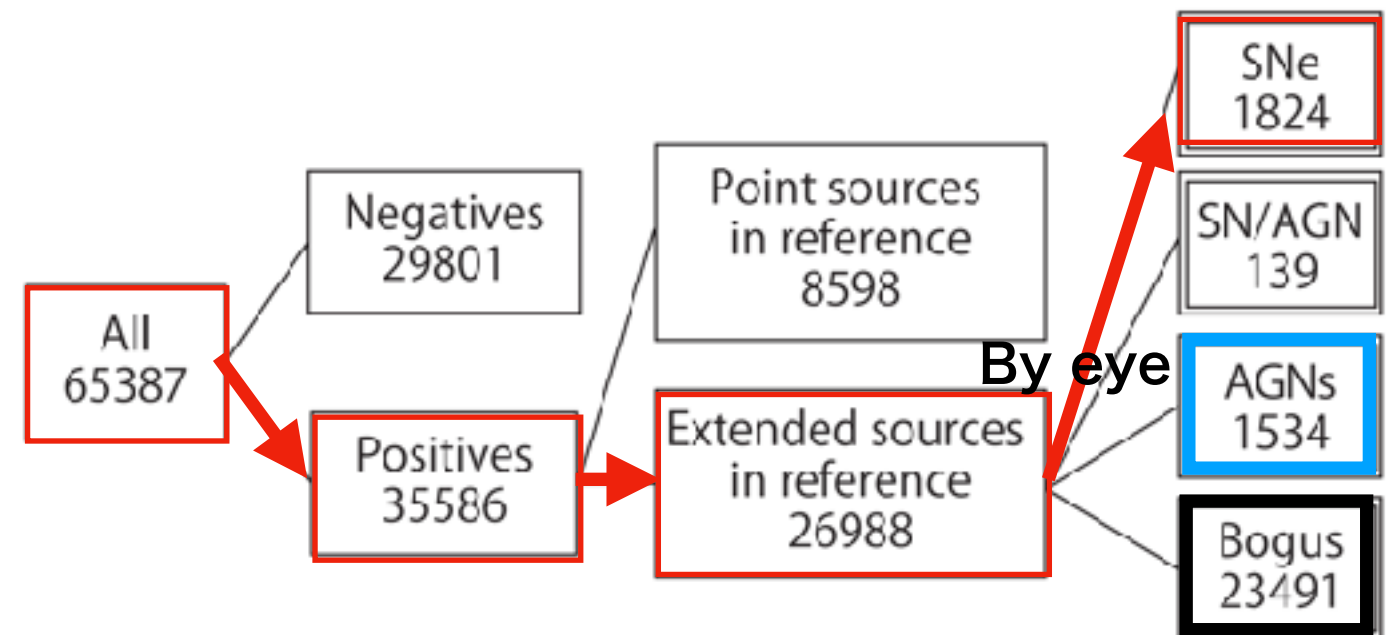
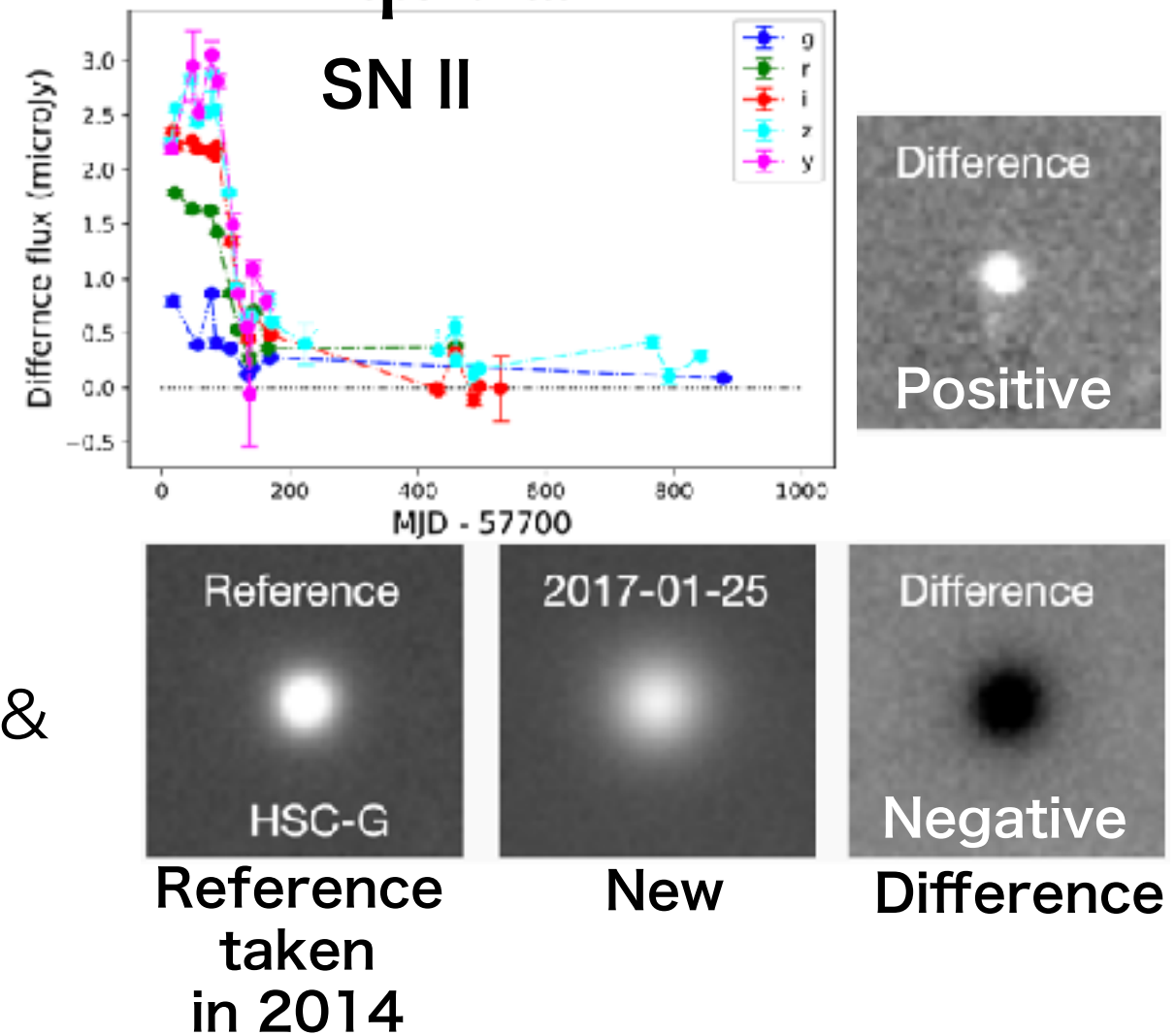


Eyeball identification of supernovae

by Yasuda et al. 2019

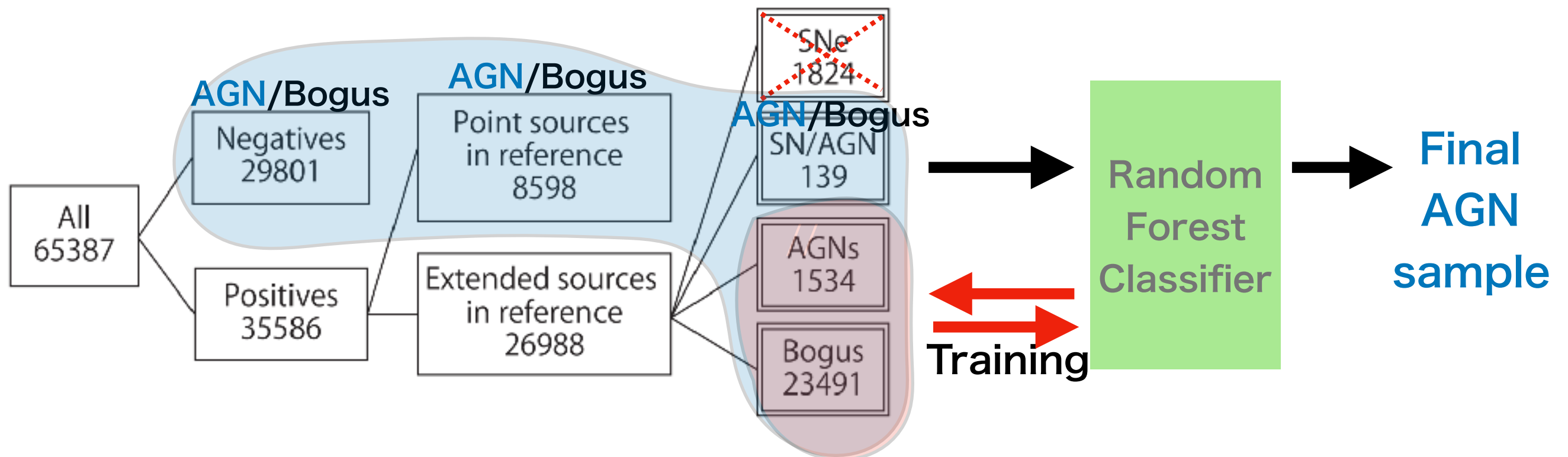
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AGNs in “Negative flux” and “Point sources” remain unclassified



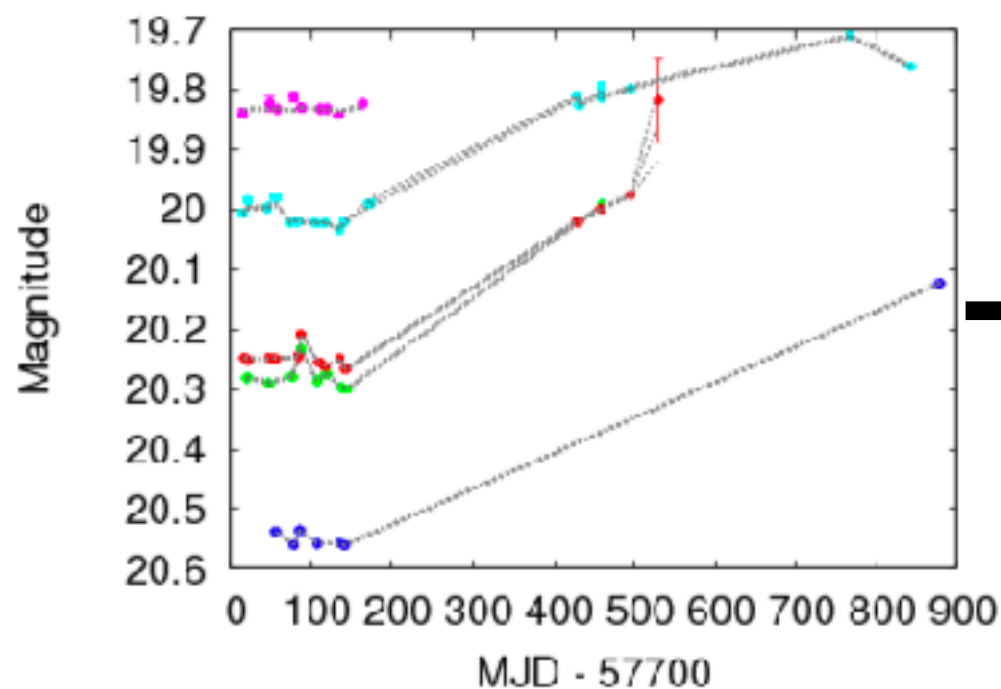
This work: systematic search for variable AGNs in the HSC COSMOS transient dataset

- A **machine learning classifier** is developed to separate **AGNs** from **Bogus**
 - **Input sample** : $65387 \text{ (All)} - 1824 \text{ (SNe)} = \mathbf{63563}$ transient candidates
 - **Training sample**: visually-classified **1534 AGNs** and **23491 Bogus**
 - **Input “features” for classification**: defined by the 5-band light curves



Feature extraction & training a random forest classifier

- **Random forest:** ensemble classifier using multiple decision trees and random subset features
- Input = **48 features:**
each feature has a weak predictive power, but the combination provides a strong classifier



48 features

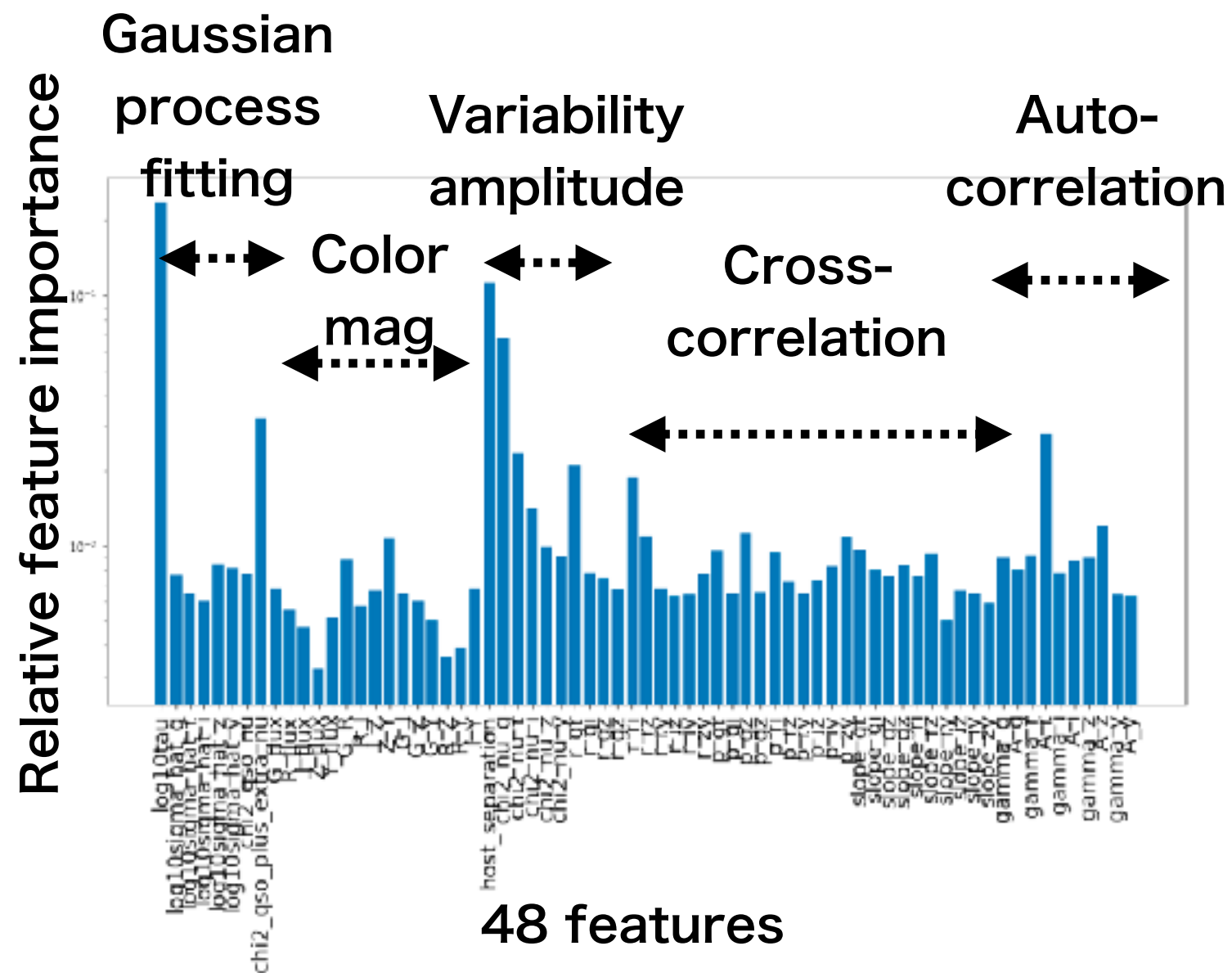
- Variability amplitudes (5-bands)
- Auto-correlation of light curves (5-bands)
- Cross-correlation (band pairs)
- “Gaussian Process” fitting (5-bands)

48 features for
1534 AGNs & 23491 Bogus

**Random Forest
Classifier**
(scikit-learn)

Result: trained Random Forest AGN/Bogus classifier

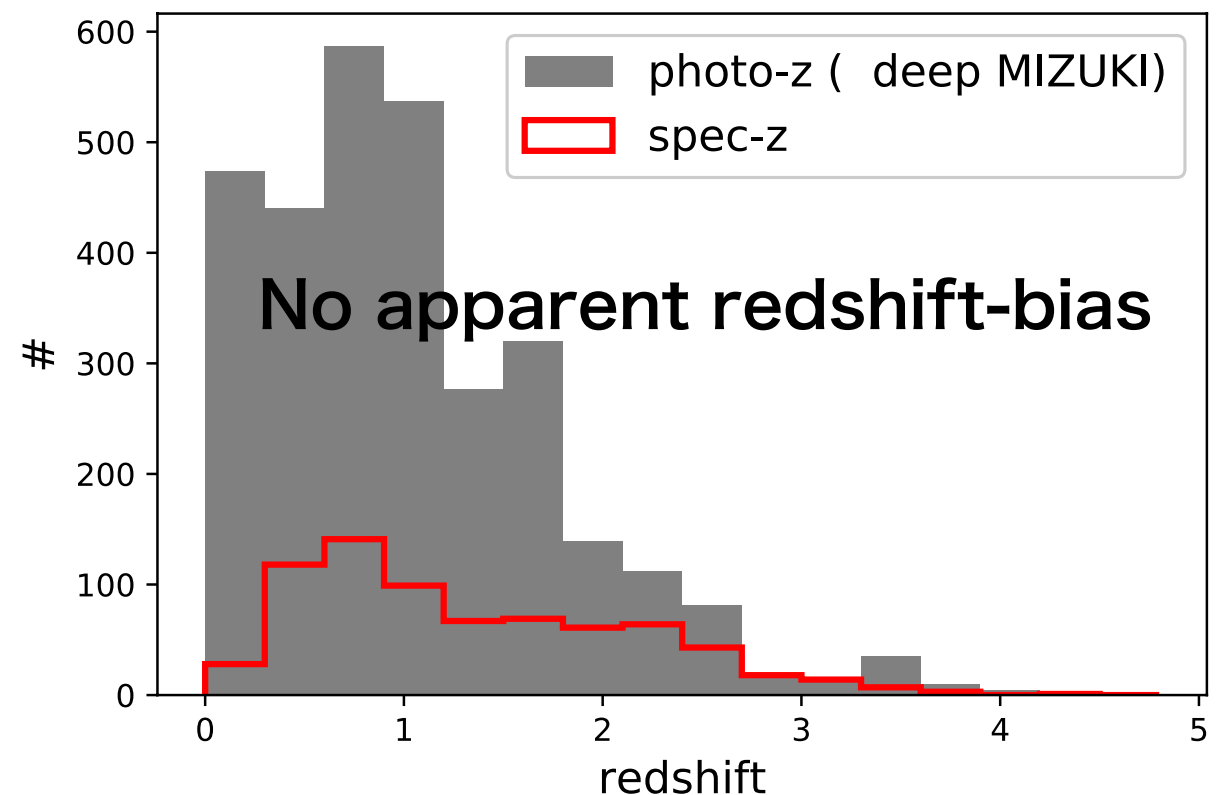
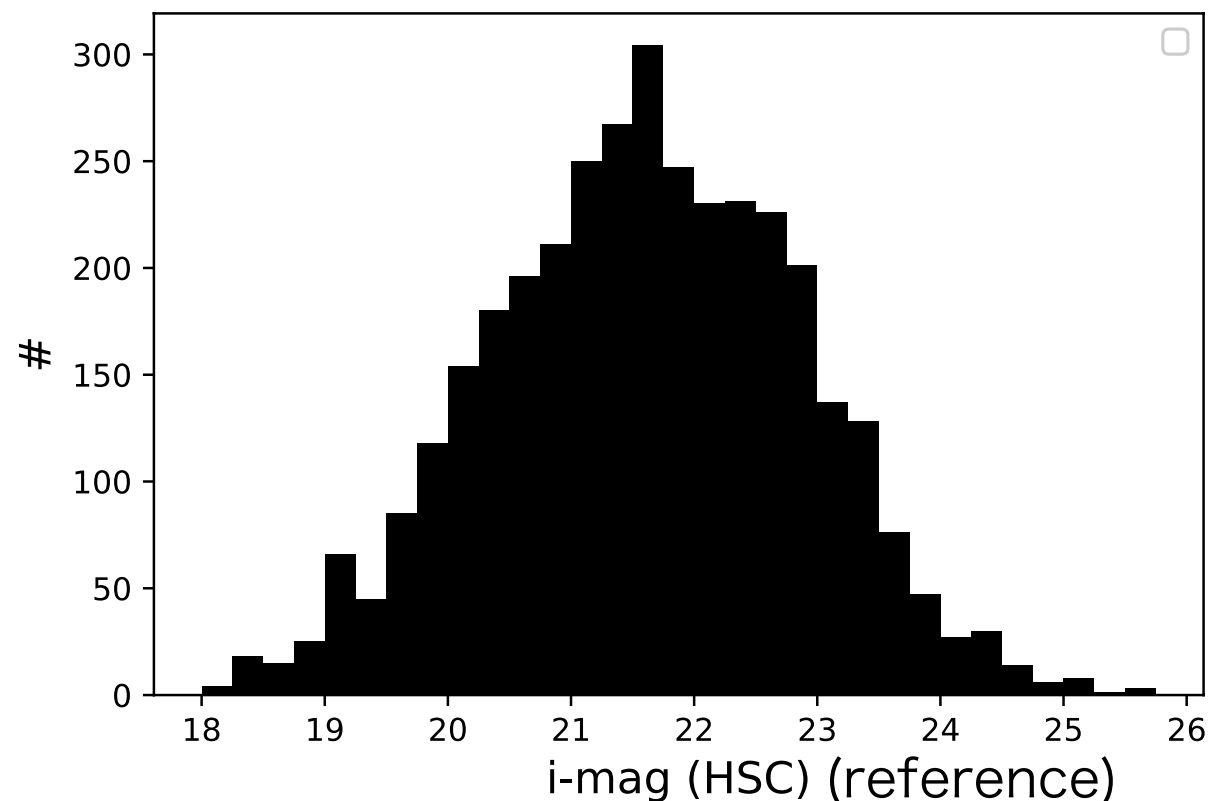
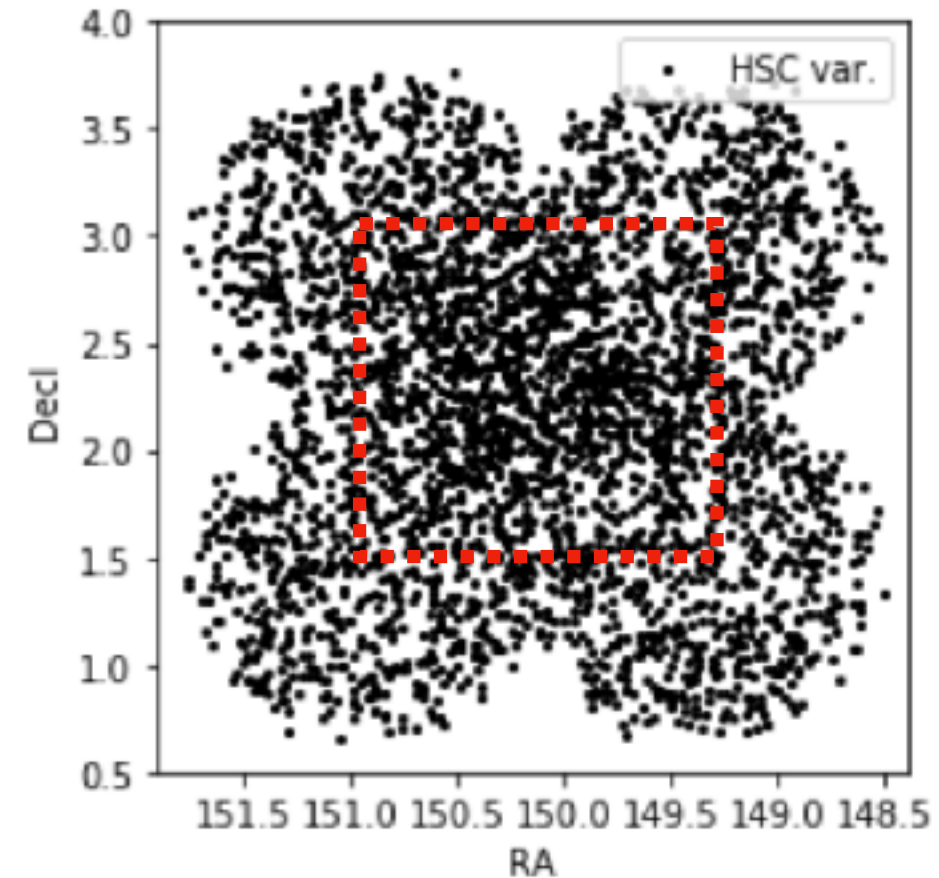
- Our classifier
 - miss 11.15% of AGNs (false negative)
 - 0.26% contamination from Bogus (false positive)



True label	Predicted label	
	AGN	Bogus
AGN	88.85% True positive	11.15% False negative
Bogus	0.26% False positive	99.74% True negative

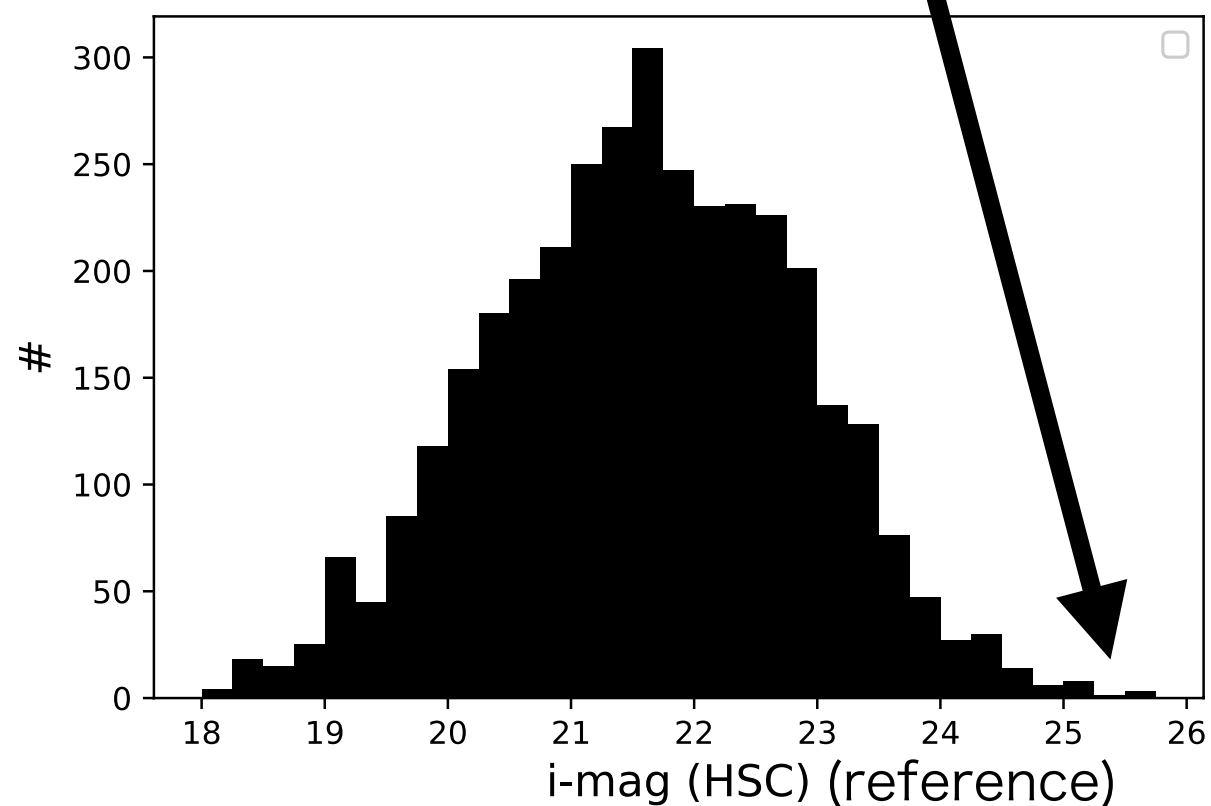
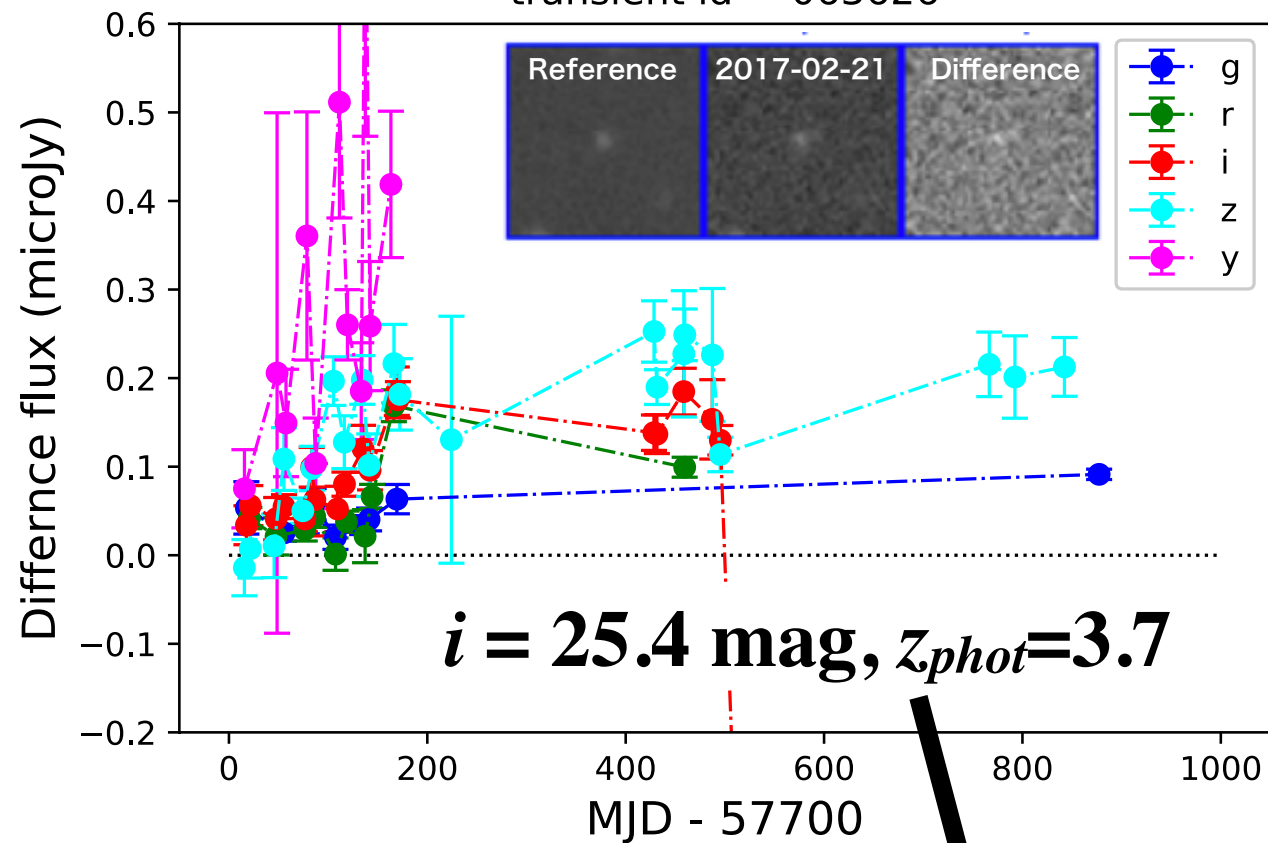
Results: 3559 variability-selected AGNs

- **63563** transient candidates → random forest classifier
→ **3559** variable AGNs
- **683/3559** (19%) have spectroscopic redshifts
(~50% in the UD)
- **1373** are in the **original COSMOS field** (Scoville+2007)
 - **6/1373 (0.4 % contamination)** are stars according to COSMOS2015 catalog (Laigle+2016)

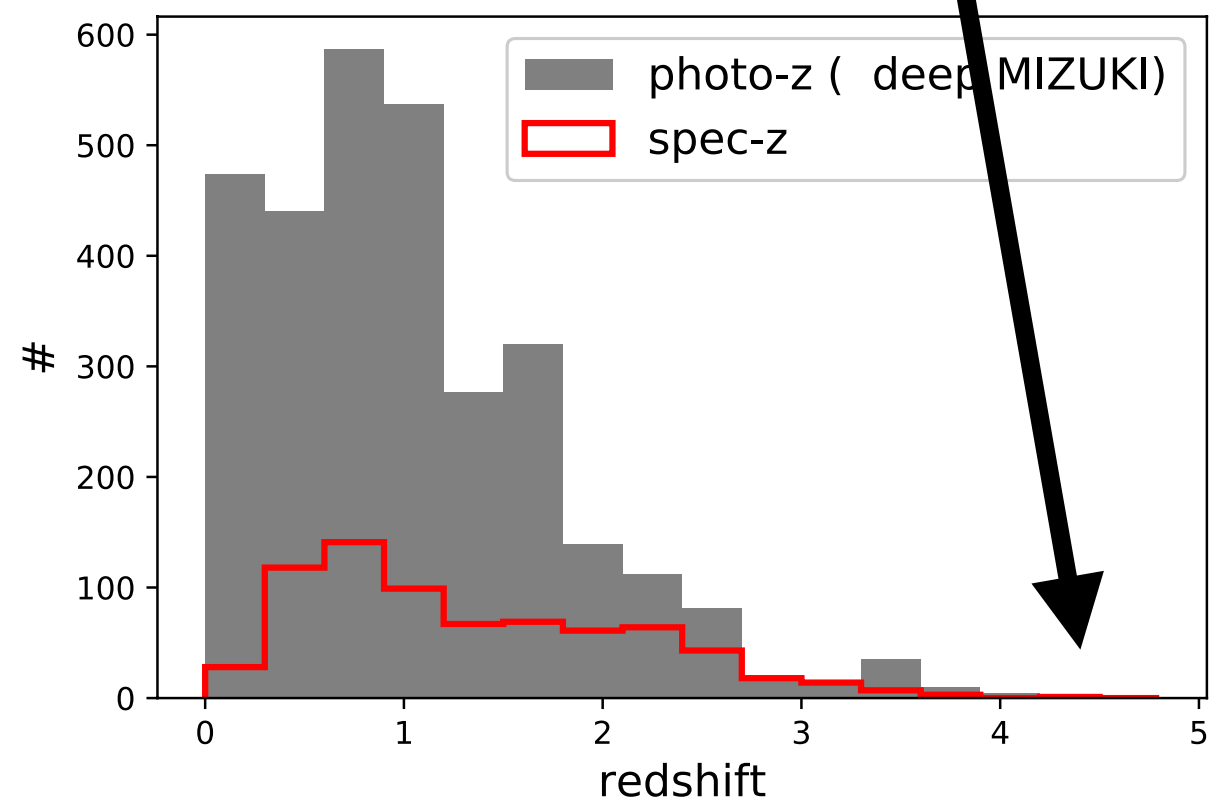
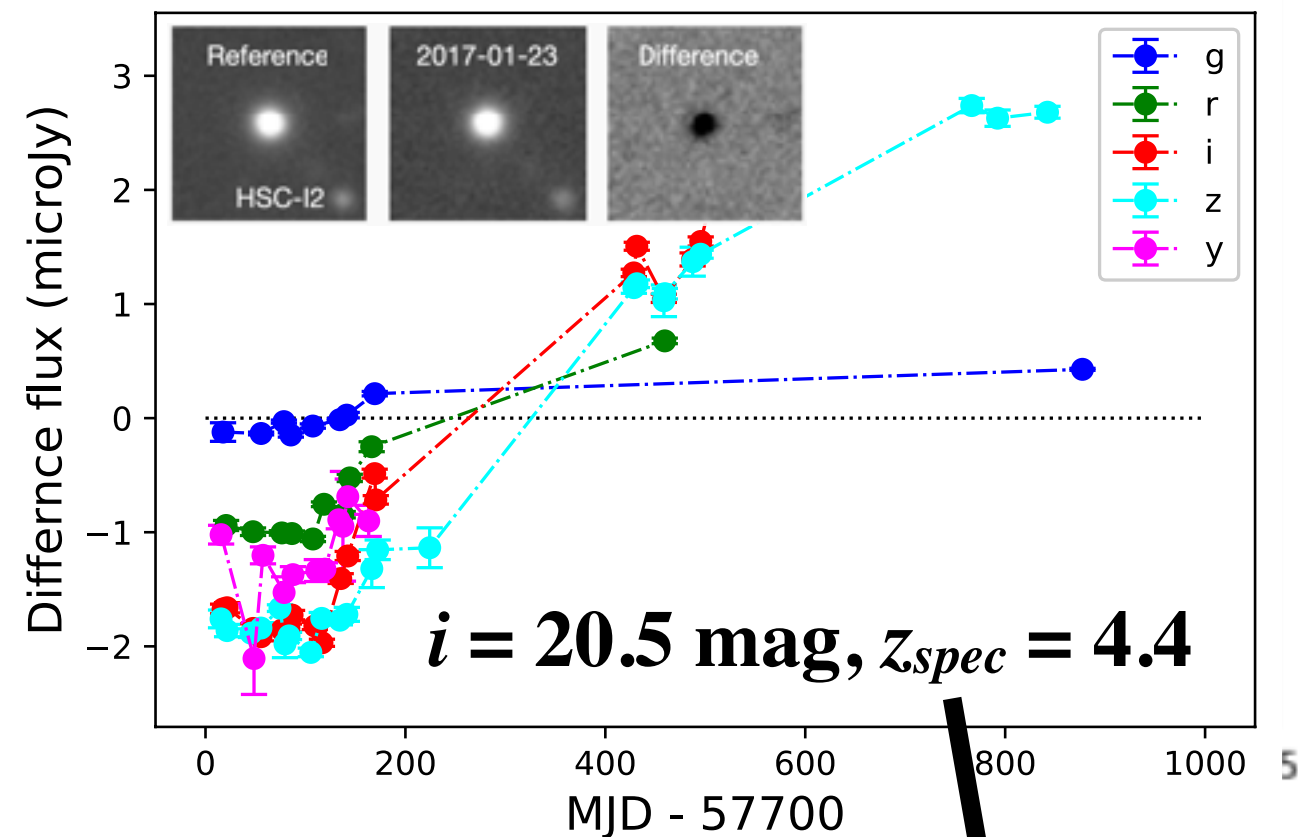


Results: 3559 variability-selected AGNs

transient id = 063626

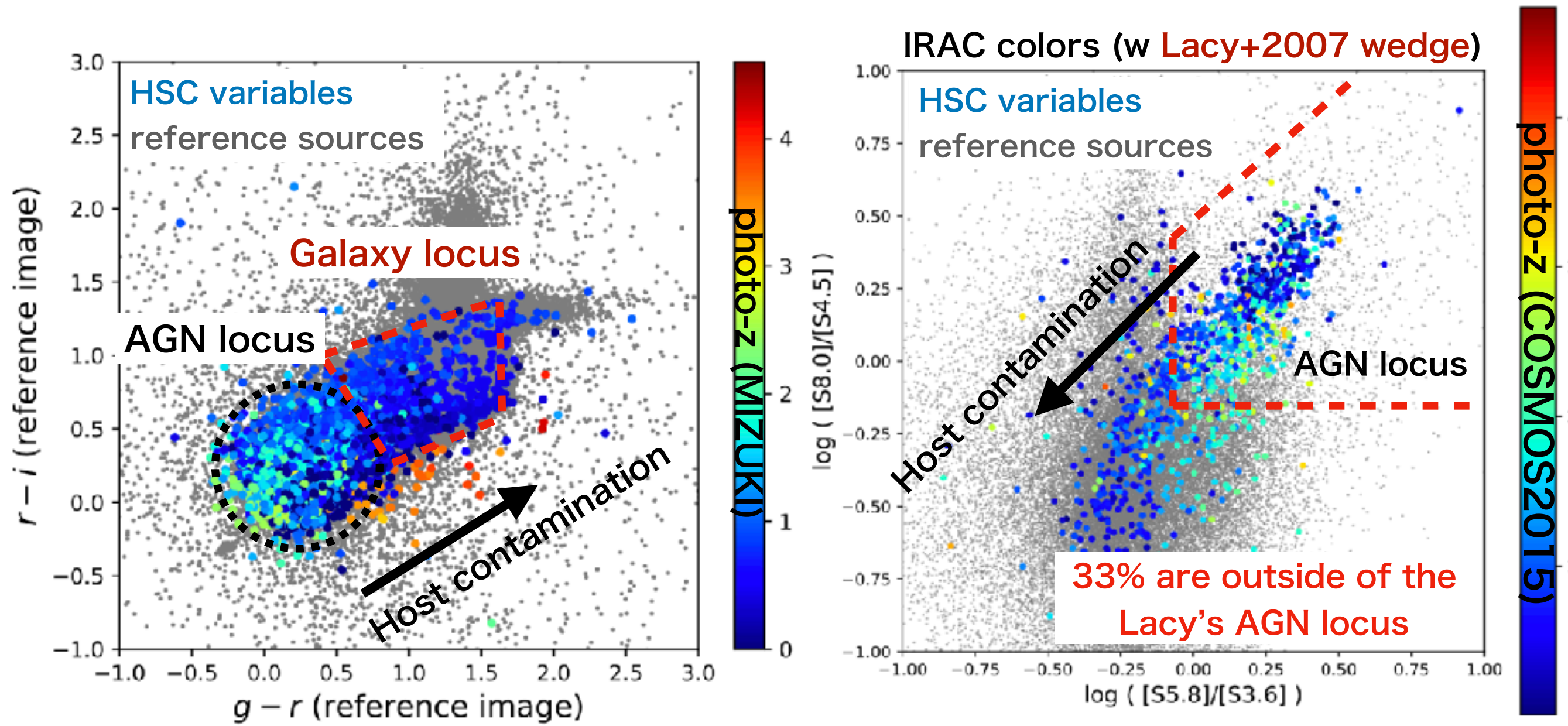


transient id = 000470



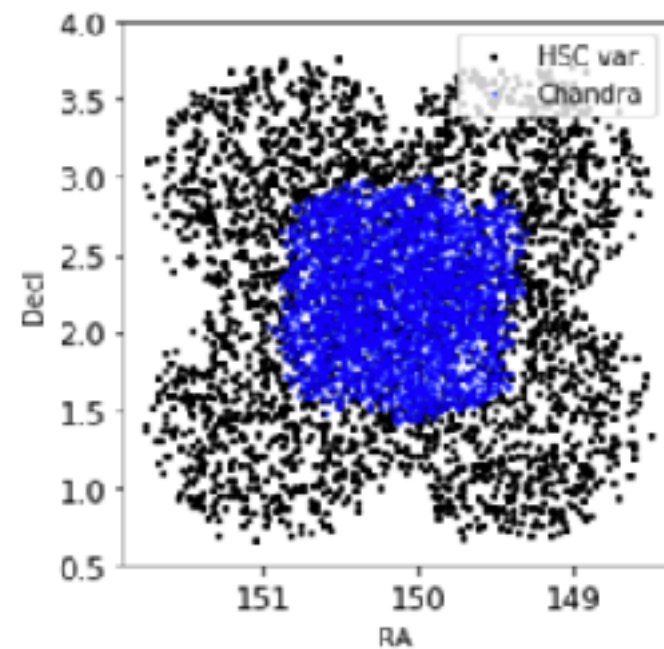
Optical and IRAC MIR color-color diagram of the HSC variable AGNs

- A fraction of the variable AGNs have multi-band colors consistent with normal galaxies
 ← **low luminosity AGNs** heavily contaminated by **host galaxy light**

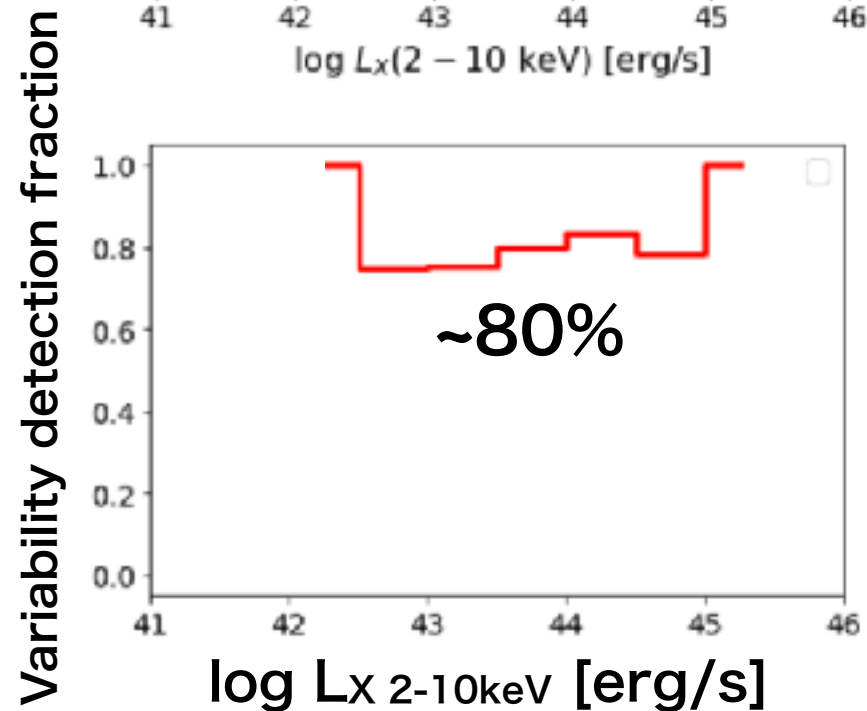
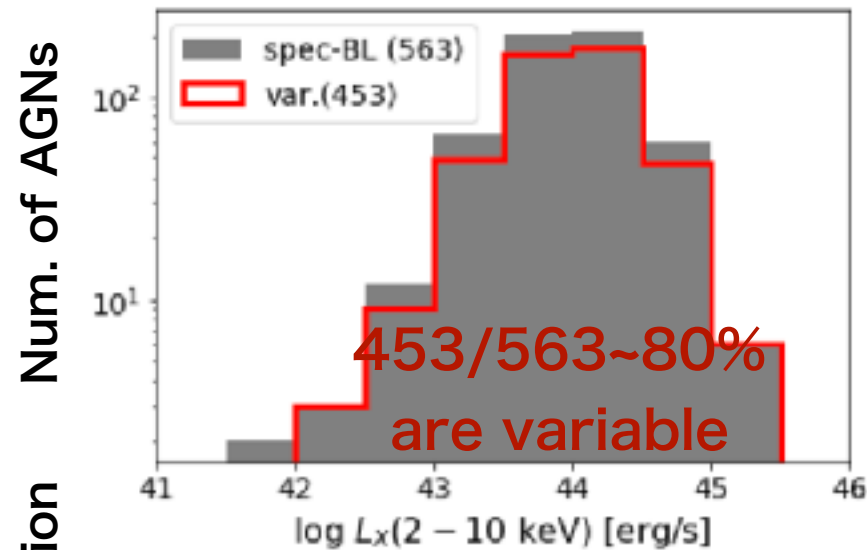


Variability detection fraction of the Chandra X-ray sources

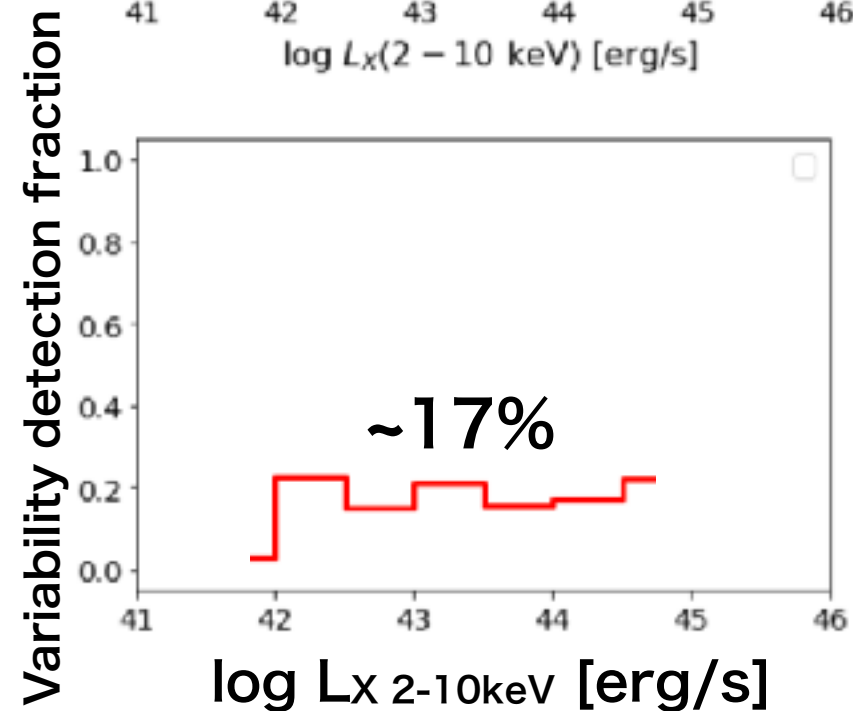
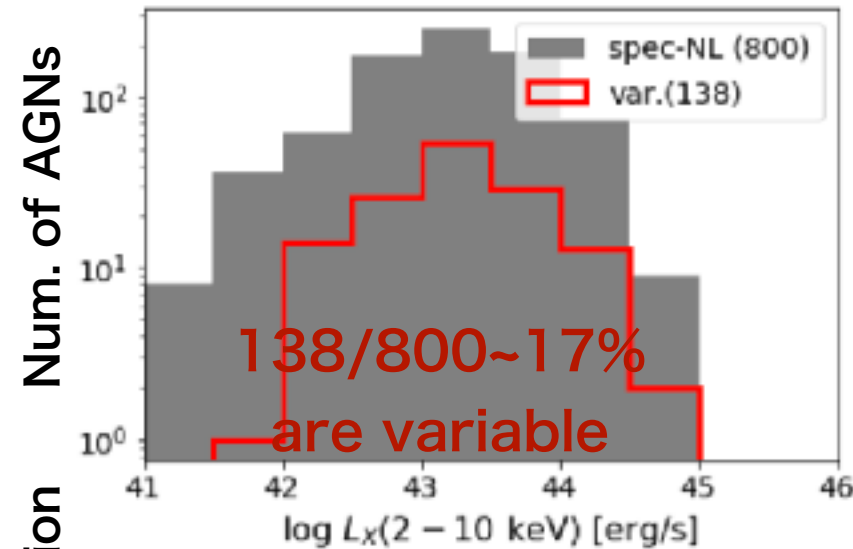
- 4.6 Ms **Chandra** COSMOS Legacy Survey (Civano+2016, Marchesi+2016)
 - 2760 X-ray source detected in hard 2-10 keV band including unobscured & obscured AGNs



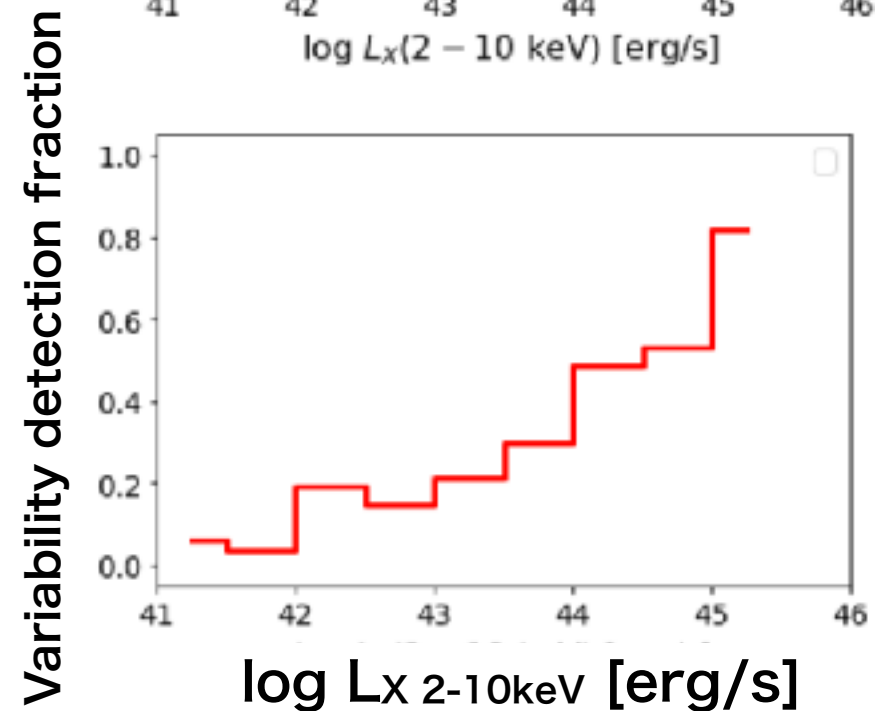
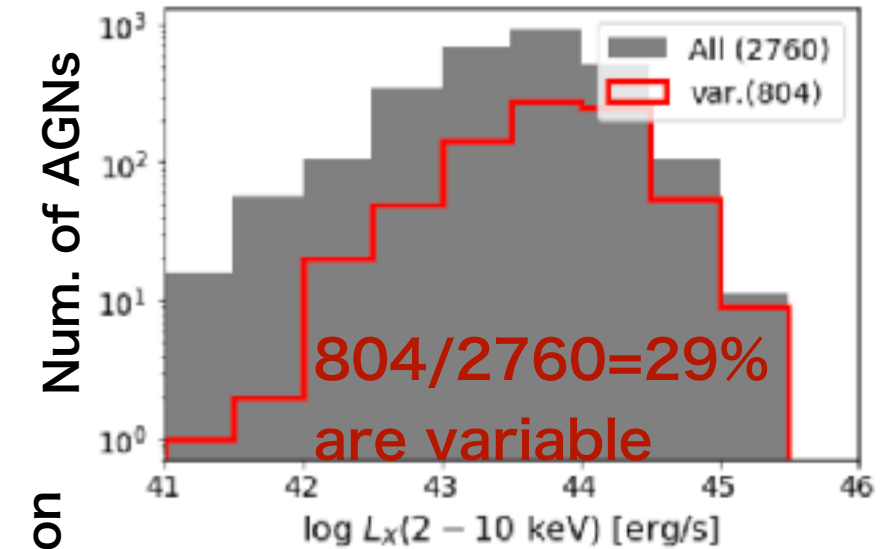
opt. spec. type-I



opt. spec. type-II

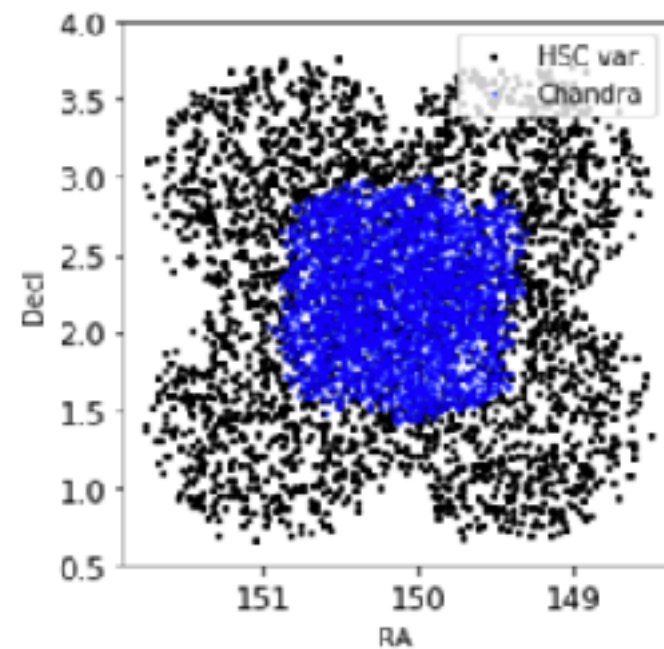


All $L_{2-10 \text{ keV}}$ sources

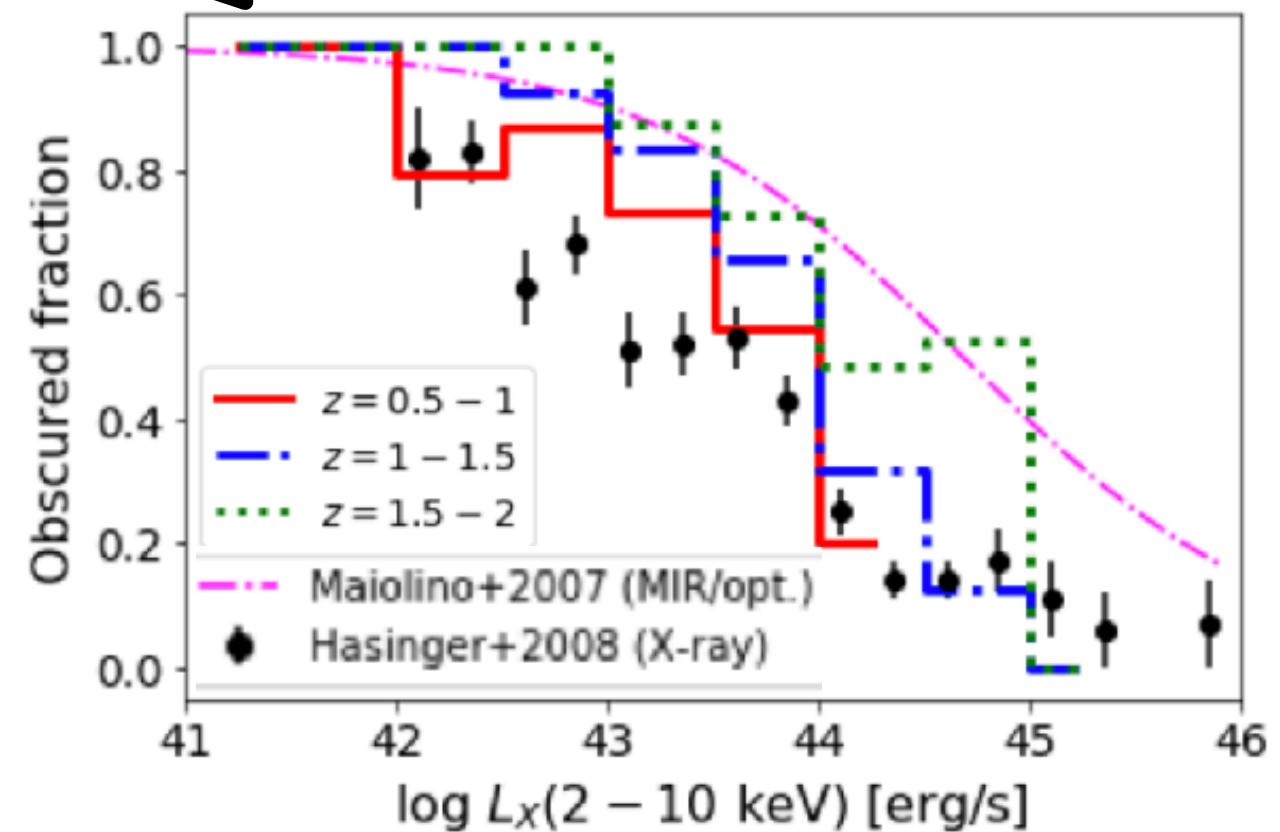
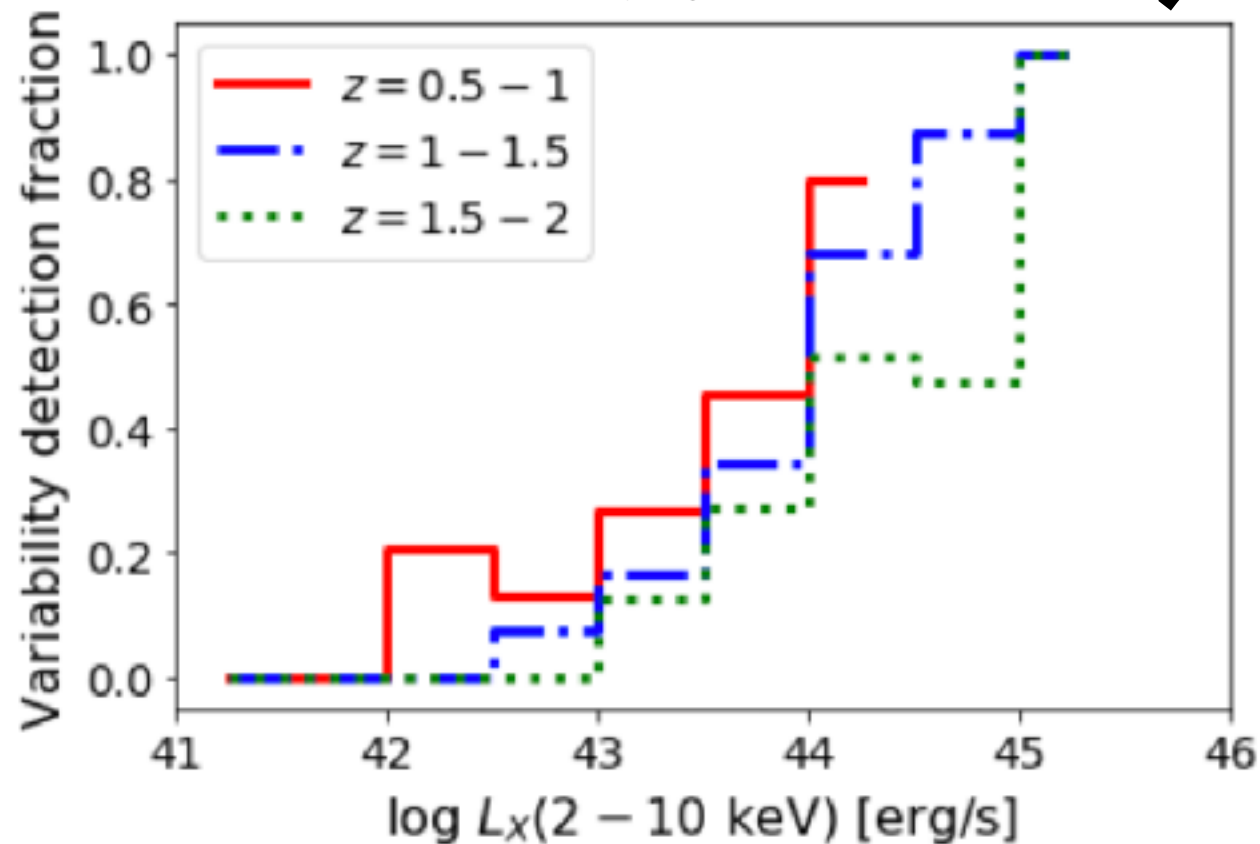


Variability detection fraction of the Chandra X-ray sources

1 — variability detection fraction



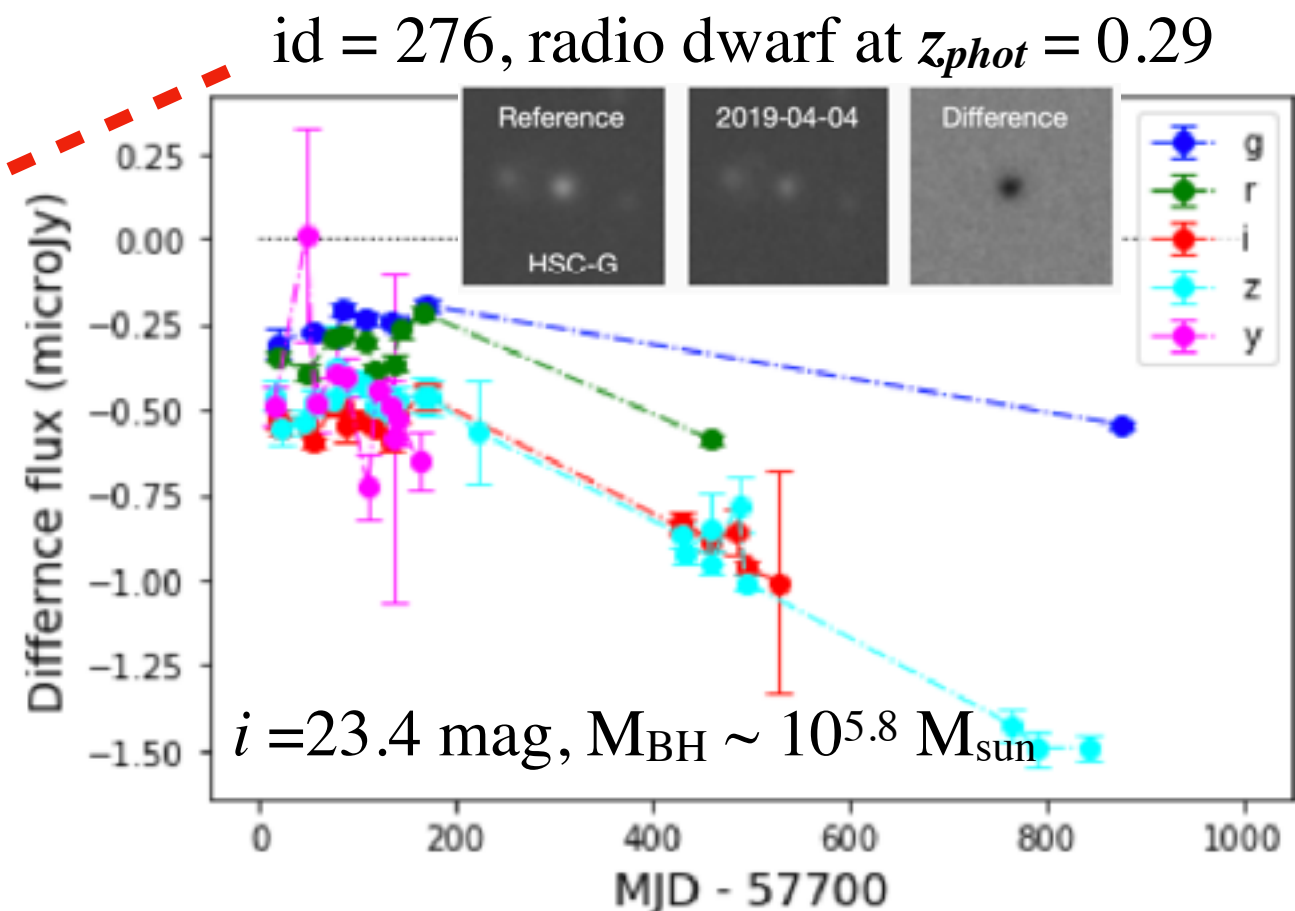
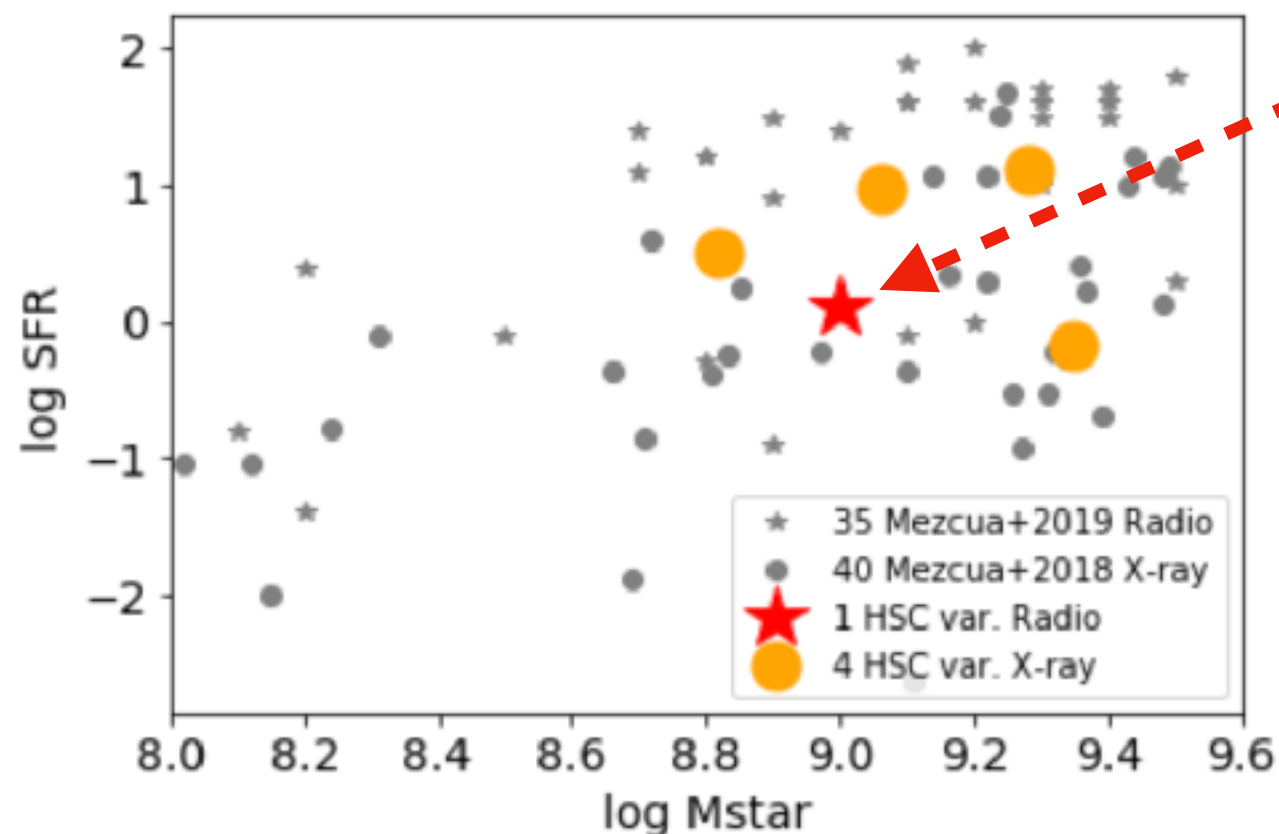
All $L_{2-10\text{ keV}}$ source



L_X dependence of the variability detection fraction among the hard X-ray sources is roughly consistent with **X-ray obscuration fraction** and **MIR covering factor** → supporting a receding torus (?)

Variable low BH mass AGN candidates in COSMOS

- Cross-match with *Chandra* X-ray (40) or *VLA* 3GHz radio (35) selected low mass AGN candidates in dwarf galaxies (Mezcua + 2018, 2019)
 - 4/40 X-ray, 1/35 radio dwarf AGN candidates are **variable AGNs**
 - Good targets for future deep spectroscopy for BH mass estimation to put constraints on BH seed formation mechanisms



Summary

- We constructed a statistical variability-selected AGN sample in COSMOS:
3559 AGNs at $z = 0 - 4$, $i = 19 - 25$ mag
 - Variability-based AGN selection is a powerful tool to pick up otherwise-undetected low-luminosity (low mass) AGNs buried under the host galaxy light
-

Future prospects

- Good targets for Subaru/PFS etc.
 - broad lines \rightarrow low BH mass AGNs
- Proposing additional HSC observations in COSMOS
- SXDF transient survey (2019 Sep. —)

(see also T. Yamada's talk for a different variability detection approach)

