HSC Optical Variability Research for AGN

Yuki Kimura (Tohoku Univ.), Toru Yamada (ISAS, JAXA), Tomoki Morokuma (Univ. of Tokyo), Naoki Yasuda (Kavli IPMU)

yuki.kimura[at]astr.tohoku.ac.jp

0. Abstract

"Variability" properties can be alternative tools to identify "fainter" AGNs (such as dwarf AGNs in the lower redshift), which are not detected in the X-ray images. To check the possibility of getting such less massive (unmatured) samples without X-ray information, we conducted variability analysis for the deep Hyper Suprime-Cam (HSC) Subaru Strategic Program (SSP) data. HSC SSP Survey is now on going and the observations with multi-band (g, r, i, z, y-band) in the COSMOS field have been conducted more than 10 times. Using these data, we investigated the flux-variation for all objects listed in the COSMOS15 catalog (Laigle et al. 2016). Consequently we found more than 400 secure flux-variable sources (more than 3σ variation compared with non-variable objects in all filters). About 80% of the samples have X-ray signal, which justifies our variability analysis. The other 20% are not detected in the deepest X-ray images obtained so far (Chandra Legacy Survey; Marchesi et al. 2016), which provides we found very low mass SMBH candidates (～10^5 $M_\odot$ @z=0.1, ～10^7 $M_\odot$ @z=1) for the first time. In my poster, I'll introduce these HSC optical variability AGN results.

1. AGN Variability Properties

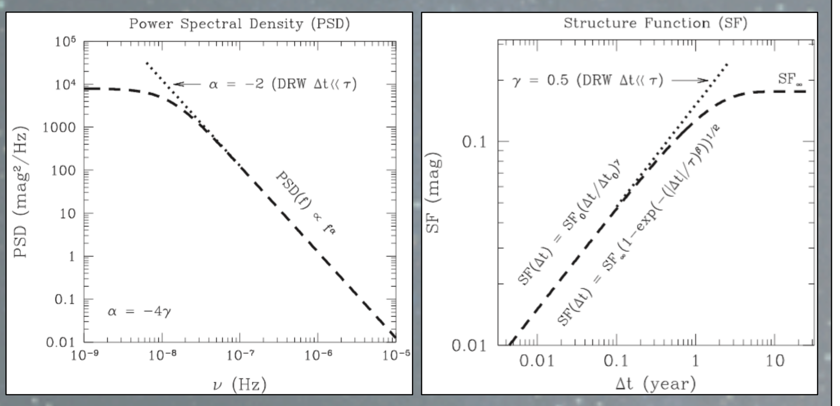


Fig 1. Standard AGN PSD (left) & Structure Function model (right) (Kozlowski+16)

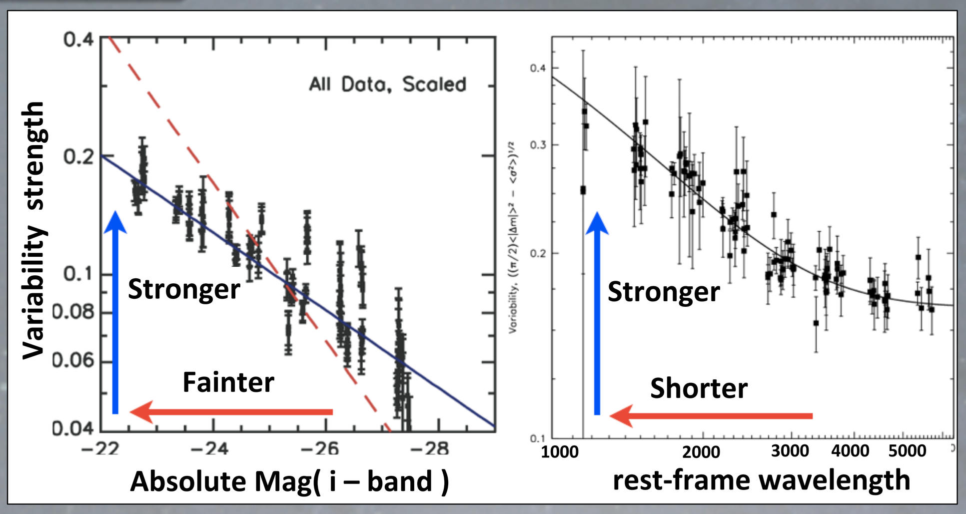


Fig 2. Variability strength vs luminosity (left), wavelength (right). (VandenBerk+10)

AGN exhibit a stochastic flux variations across X to radio wavelengths on timescales ranging from hours to years (Fig 1). There are unique properties of AGN variability that the luminosity change each time we observe. Especially fainter (= less massive) AGNs have a stronger variability (Fig 2). This means that if we find fainter and stronger variability objects, we can get low mass SMBH candidates without deeper X-ray images. For example, if we consider the Chandra Legacy Survey data (Marchesi +16), the lower limit of Lx is about 10^{43} ergs/s @ z=3 among the observed objects. From this value, we can derive the lower limit $M_{BH} = 10^{6-7} / \lambda_{Edd}$ $M_\odot$ @ z=3 (assuming the bolometric correction ～10; Lusso+12) among the X-detected AGNs. Can we find less massive SMBHs from "Variability" (not X-ray images)?

2. Previous Research

As a trial, we conducted the variability research in the SXDS / UDS field with the Subaru / Suprime-Cam z'-band 6-epoch imaging data (Furusawa+08).

(Assuming 0.1 % of galaxy stellar mass)

Less Massive ←

phot-z \ SMBH mass	~$10^6 M_\odot$	10^6~$10^7 M_\odot$	10^7~$10^8 M_\odot$	$10^8 M_\odot$~	Sum
z < 1.0	164	19	10	1	194
1.0 < z < 2.0	38	247	192	45	522
2.0 < z < 3.0	2	59	106	29	196
3.0 < z	1	4	16	5	26
Sum	205	329	324	80	938

high -z ↓

Table 3. Result of variability objects

Table 4. Spectroscopic Results

ID	z	log(MBH)	log(λLλ)	FWHM
slit	redshift	($M_\odot$)	(ergs/s)	(km/s)
4	1.667	**7.77**	44.27	2424
13	1.304	**7.99**	43.98	3709
14	0.940	8.52	44.29	5708
15	1.617	8.75	44.75	5741
61	0.896	**7.22**	43.01	2691
20	**3.325**	**7.16**	44.54	**1285**

Our variability results are summarized in the Table 3. We found many candidates that have 10^8 $M_\odot$ SMBH at z > 1. From the follow up observation (Keck/DEIMOS), we found a low mass SMBH (～10^7 $M_\odot$) in the high redshift (z ～ 3) (Table 4). This suggests that "Variability" is a useful to get less massive AGNs.

3. HSC SSP COSMOS data

We now apply this variability research to the Hyper Suprime Cam (HSC) Subaru Strategic Program (SSP) data in the COSMOS field. HSC covers 1.5 deg^2 FoV in diameter with a pix scale of 0.168''. In the SSP observation, there are multi-band data (g, r, i, z) and more than 10 epochs data set. The depths of each epoch are listed in the Table 5. These data set are much deeper (～3 mag deeper than Pan-STARS1 @ r-band ; Simm+15) and have more filter set than our previous work (and Morokuma+08), so very powerful to accurately identify low mass SMBHs (such as dwarf AGNs in the local universe).

Date: y/m	G	R	R2	I	I2	Z
2014/03		27.02		26.12	×	25.87
2014/11	27.38		×		×	
2015/01			×	26.41	×	26.51
2015/03		26.82	×		×	
2015/05	26.93		×	26.23	×	
2016/01			×		×	25.79
2016/02			×	×	25.70	
2016/03	27.31	26.55	×	×		25.88
2016/11_1		×	26.58	×	26.03	25.62
2016/11_2		×		×		25.75
2016/12		×	26.32	×	26.00	25.78
2017/01_1	27.08	×		×	26.30	25.72
2017/01_2	26.64	×	26.60	×	26.35	26.37
2017/01_3		×		×	25.98	26.04
2017/02_1	26.71	×	26.58	×	25.60	25.82
2017/02_2	26.81	×	26.58	×	25.84	
2017/03_1		×		×	26.27	25.81
2017/03_2	27.10	×	26.57	×	25.80	
2017/03_3	26.82	×	26.39	×	26.14	25.71
2017/04_1	26.66	×	26.53	×	25.92	25.37
2017/04_2		×	26.31	×	25.76	

Table 5. limiting magnitude for each epoch/filter (S/N=2)

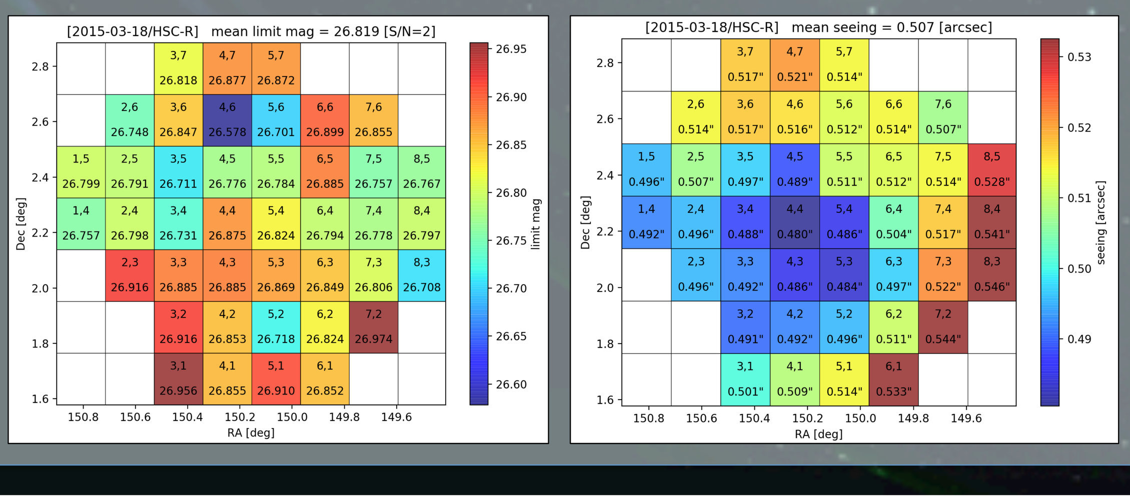


Fig 6. limit mag map (left) and PSF (FWHM) map (right) in the COSMOS field (date: 2015/03/18, filter: HSC-R)

4. Method

*1 1 patch: 4200×4200 pix^2 (11.76 $arcmin^2$) size

Here I show how to get variable AGNs in detail.

1. PSF Matching

First I measure the FWHM of objects, that are point like sources listed in the HSC DR1 catalog (extendness flag), in each epoch/patch *1 data (Fig 6). From this information, I match the PSF of all of the epoch/patch data for each interval/filter set.

2. Aperture Photometry

Next I perform aperture photometry for all of the objects listed in the HSC DR1 clean catalog. Those aperture diameters are 3 times FWHM of PSF-matched data for each filter. These sizes catch 99.91% light assuming the Gaussian point-like profile.

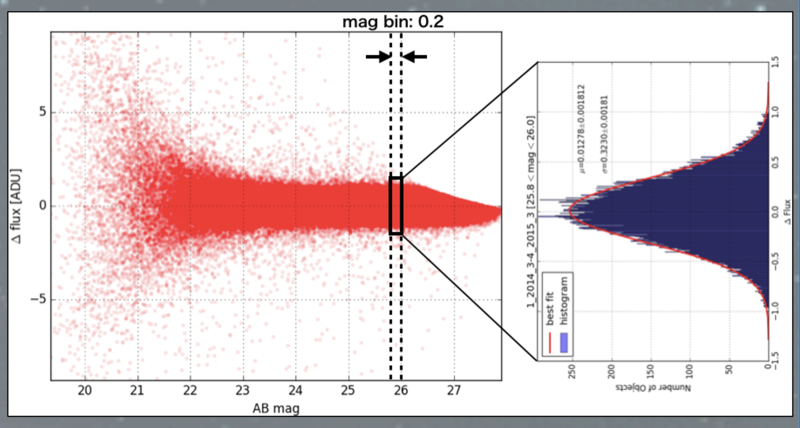


Fig 7. Photometric Error Estimation

3. Extract Variable Objects

After photometry, I construct the differential catalog of any two epoch pairs. Then I estimate the photometric error for each magnitude bin (0.2 mag) by fitting Gaussian (Fig 7). From these Gaussian sigma, I fit those Errors as a function of magnitude and extract more than 3σ variable sources in any of all two epoch data (Fig 8).

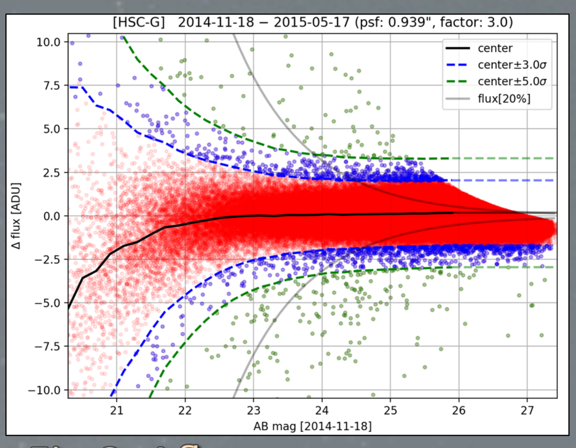


Fig 8. Δflux vs mag

4. Significant Variable Objects

To remove the contamination, I also calculate the "Correlation Efficiency" of light curves for any of two filter set. First I collect the non-variable objects and derive correlation efficiencies for all of them. Then I set the criterion at the top 10% of these value (Fig 9). Finally I choose the objects satisfied these criteria of all filter pair (contamination ～0.9%).

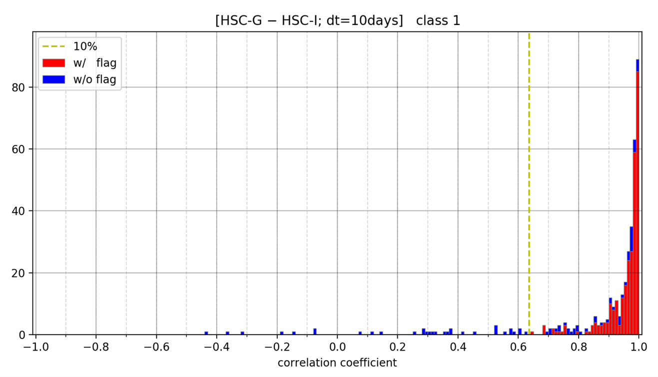
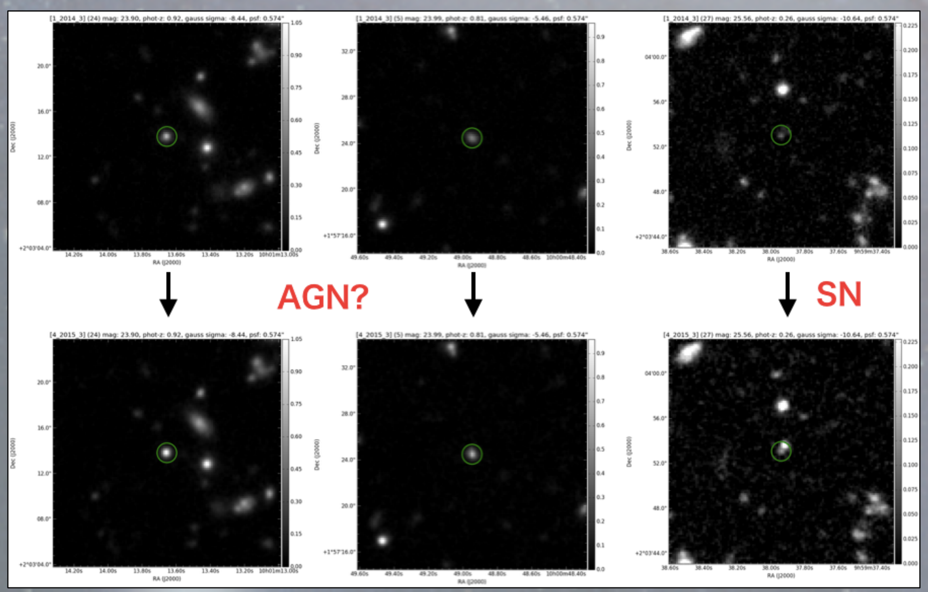


Fig 9. histogram of correlation efficiency for X-detected objects

5. Results



gif movies of variable objects

AGN SN

Fig 10. Variable objects; AGN candidates located in the galaxy center (left two) and Supernova candidates (right)

Consequently I found more than 400 secure variable objects (Fig 11); ～80 % of our samples have X-ray signal, which justifies our variability analysis. The other 20% are not detected in the deep X-ray images (Marchesi+16). Some of the latter samples have the same Structure Function trend of the standard AGN (Fig 12, ref: Fig 1), which provides we found very low mass SMBH candidates (～10^5 $M_\odot$ @z=0.1, ～10^7 $M_\odot$ @z=1) for the first time.

In the future, I will conduct the spectroscopic follow-up observation for those candidates and reveal the galaxy-SMBH co-evolution relation (M_{BH}-M_* relation) in the "lower mass side".

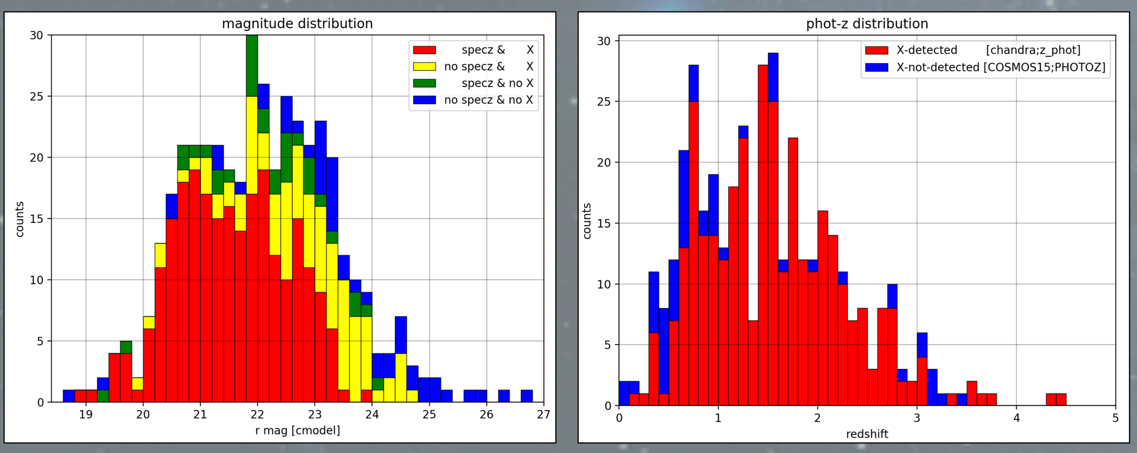


Fig 11. r-band magnitude (left) and phot-z distribution for our secure variable objects

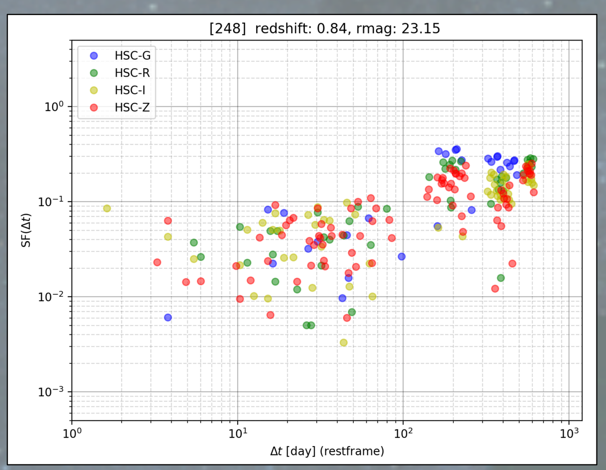


Fig 12. Structure function for X-not detected object