Probing Low-mass SMBH Population at High Redshift with Deep Multi-color Variability Observations

Toru Yamada (ISAS/JAXA), Atsushi Hoshi (Tohoku University, ISAS/JAXA)

1. Motivation for Deep variability Search for Low-Mass SMBH

It is an important astrophysical question how SMBH have been developed in the hierarchical growth of galaxies. One of the most remarkable discovery with JWST is the detection of SMBH with 10^6-10^8 M_{sun} at very high redshift (z=4-10), many of which show over-massive nature compared with the BH-stellar mass correlation observed among the local galaxies (e.g., Harikane et al. 2023). While the complete picture of SMBH and AGN population is still to be unveiled, the sample of such low-mass SMBH even at intermediate and high redshift is also still very limited.

- Comprehensive survey for Low Mass SMBH (down to ~) is essential to study evolution of BH population. Variability is one of the most efficient method to detect low-luminosity (LL-) type-1 AGN (low-mass BH with high Eddington ratio are included) .
- Unbiased detection of type-1 AGN is essential in measuring the BH mass from the broad-line velocity width (e.g., single-epoch virial method)
- Contamination of the host galaxy light makes LL-AGN selection difficult (or produce a bias to select over-massive AGN) for color/line diagnostics methods. Since host galaxies do not show variation, only photometric accuracy limits the detection of type-1 LL-AGN in variability search.
- Spectroscopic search by JWST is very powerful but expensive in time to search for AGN (although the AGN detection probability is unexpectedly high)

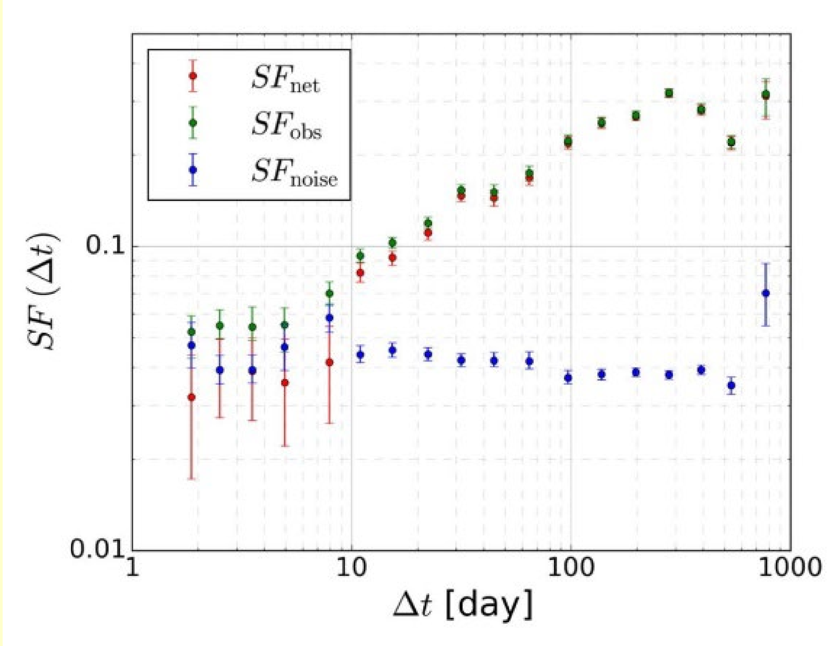


Fig.1 Structure Function of the variability-selected AGN (Kimura et al. 2020)

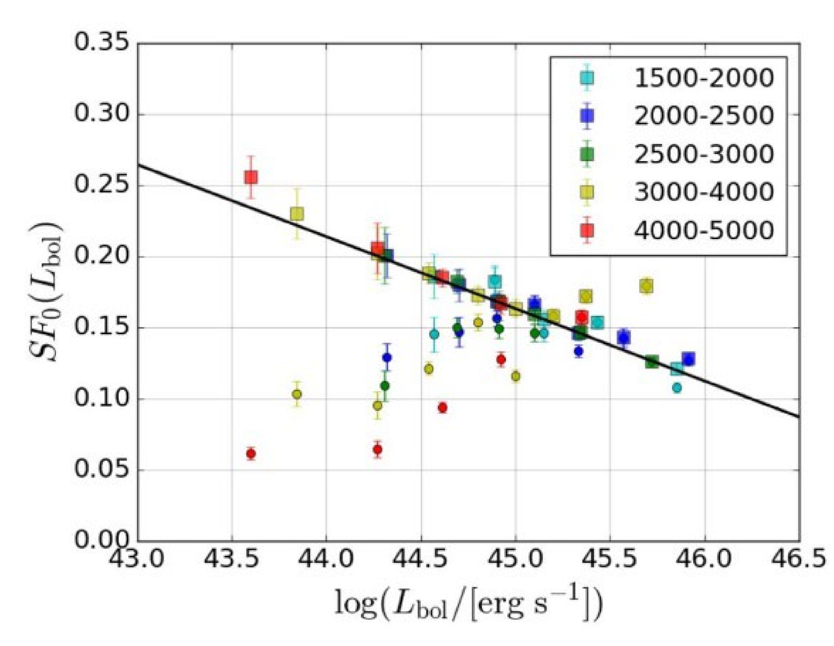


Fig.2 Apparent and host-galaxy-corrected structure function as a function of their luminosity

2. Variability Search for LL-AGN by using the HSC Ultradeep Survey (Kimura, TY, et al. (2020) ApJ, 894, 24)

- Subaru HSC-SSP Ultradeep Data in COSMOS Field taken from 2014 March to 2017April., 8, 10, 13, 15 epochs in g, r, i, and z-band, respectively
- R-band depth in each epoch 25.3-26.0
- 491 'robust' variability-selected AGN sample

> - Power-law structure function at interval of 1-300days, which is intrinsically color independent.
> - Host galaxy light affects the apparent variability strength at the faint magnitude. This compensate the intrinsic trend of large variability for the low-luminosity AGN.

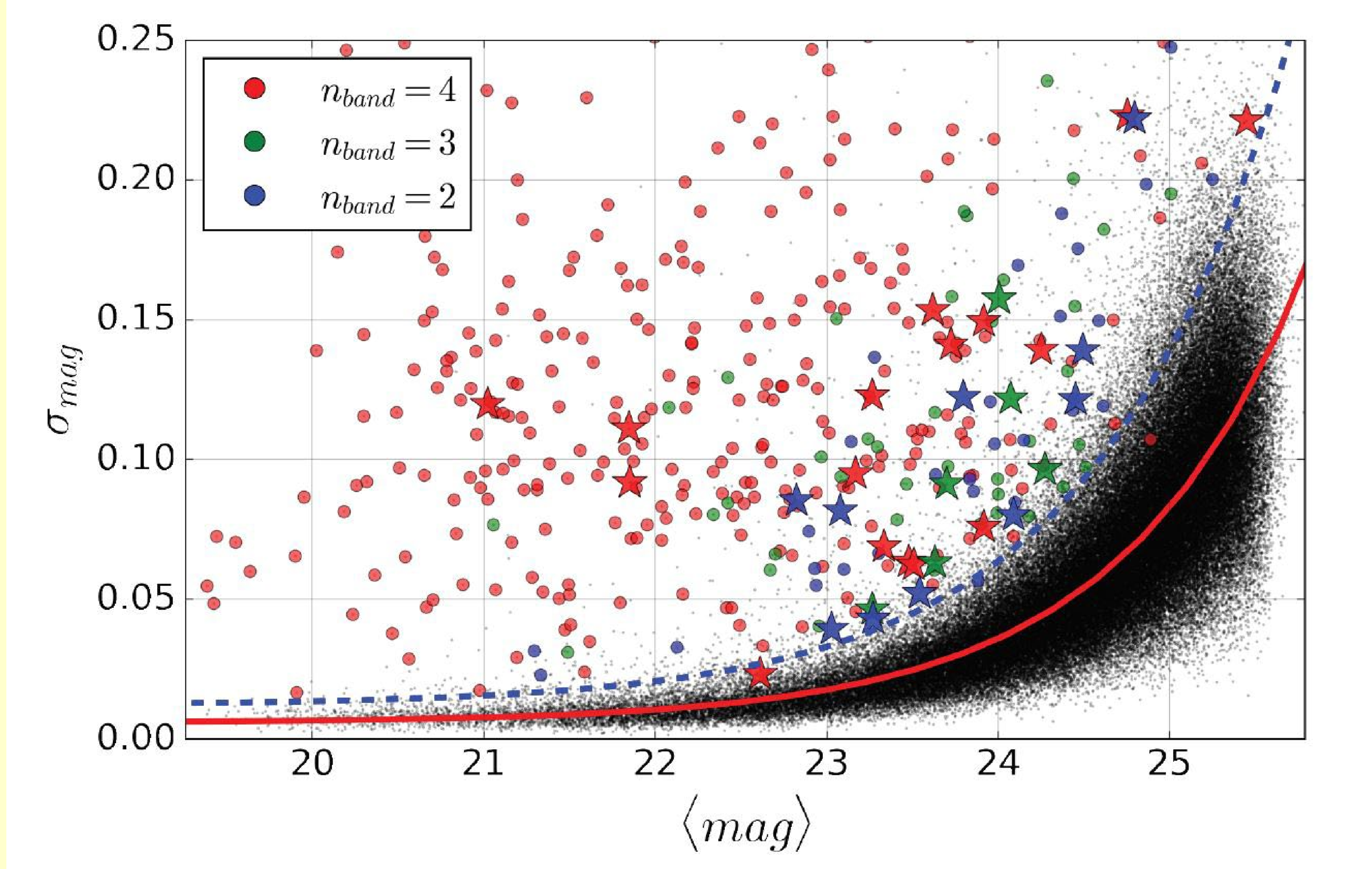


Fig.3 Variation strength of the AGN and other non-variable objects

3. BH mass and Host Stellar Mass of the AGN with 10^7-10^9 M_{sun} at z=0.5-3.5 (Hoshi, TY, et al. 2024, ApJ, 969,11)

- Measuring BH mass down to ~10^6 M_{sun} at z~0.5-2.
- AGN with $M_{BH}>10^9 M_{sun}$ tend to appear over-massive even at the intermediate redshift.
- On the other hand, BH/stellar mass ratio for AGN with $M_{BH}=10^{7\text{-}9} M_{sun}$ at z~0.5-3 shows the similar value with the local sample, or only very weakly evolve with redshift.

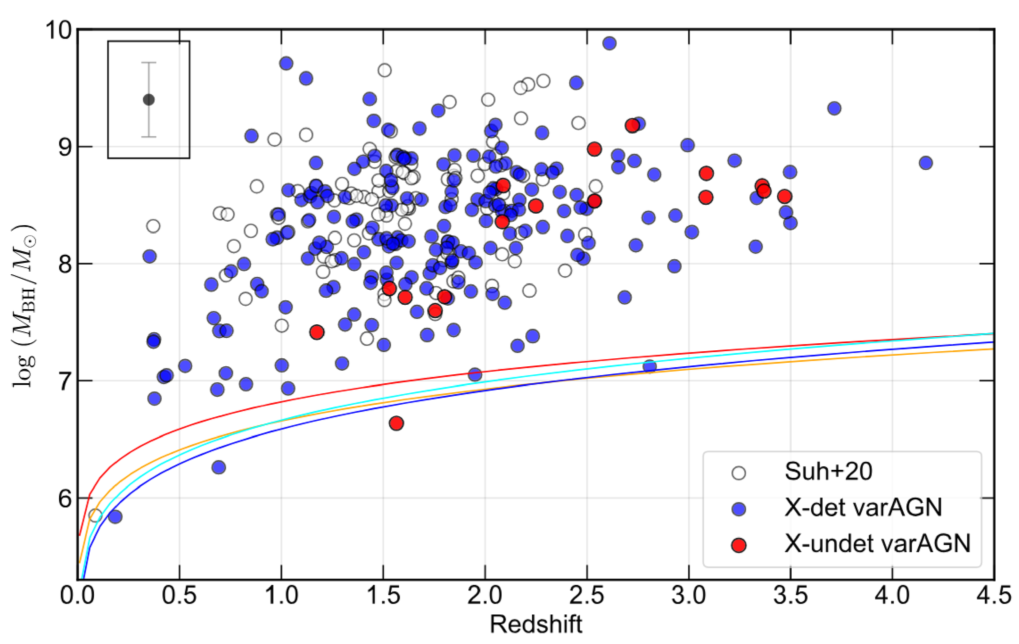


Fig.4 BH mass of the variability-selected AGN vs Redshift

$$\log(M_{\rm BH}/M_\odot) =$$
$$6.66 + 0.53\log\left(\frac{\lambda L_{\lambda(1350)}}{10^{44}\ {\rm erg\ s^{-1}}}\right) + 2\log\left(\frac{FWHM_{\rm CIV}}{10^3\ {\rm km\ s^{-1}}}\right)$$
$$6.79 + 0.5\log\left(\frac{\lambda L_{\lambda(3000)}}{10^{44}\ {\rm erg\ s^{-1}}}\right) + 2\log\left(\frac{FWHM_{\rm MgII}}{10^3\ {\rm km\ s^{-1}}}\right),$$
$$6.64 + 0.64\log\left(\frac{\lambda L_{\lambda(5100)}}{10^{44}\ {\rm erg\ s^{-1}}}\right) + 2\log\left(\frac{FWHM_{\rm H\beta}}{10^3\ {\rm km\ s^{-1}}}\right),$$
$$6.70 + 0.64\log\left(\frac{\lambda L_{\lambda(5100)}}{10^{44}\ {\rm erg\ s^{-1}}}\right) + 2.06\log\left(\frac{FWHM_{\rm H\alpha}}{10^3\ {\rm km\ s^{-1}}}\right)$$

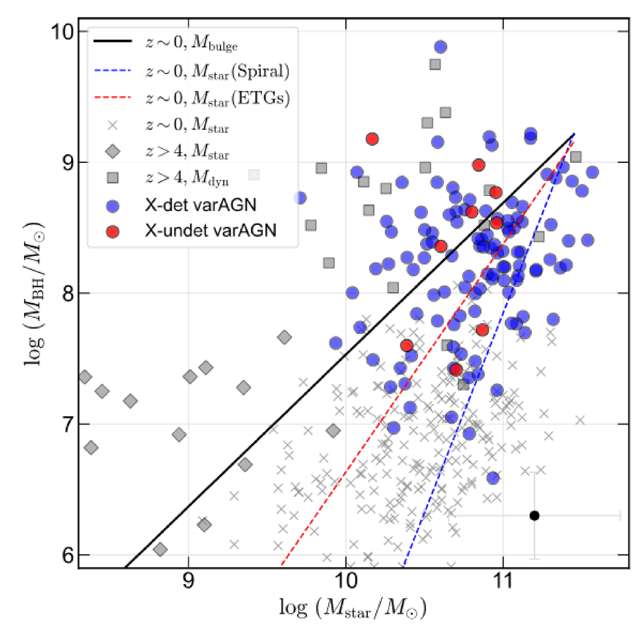


Fig.5 BH and host galaxy stellar mass of the sample

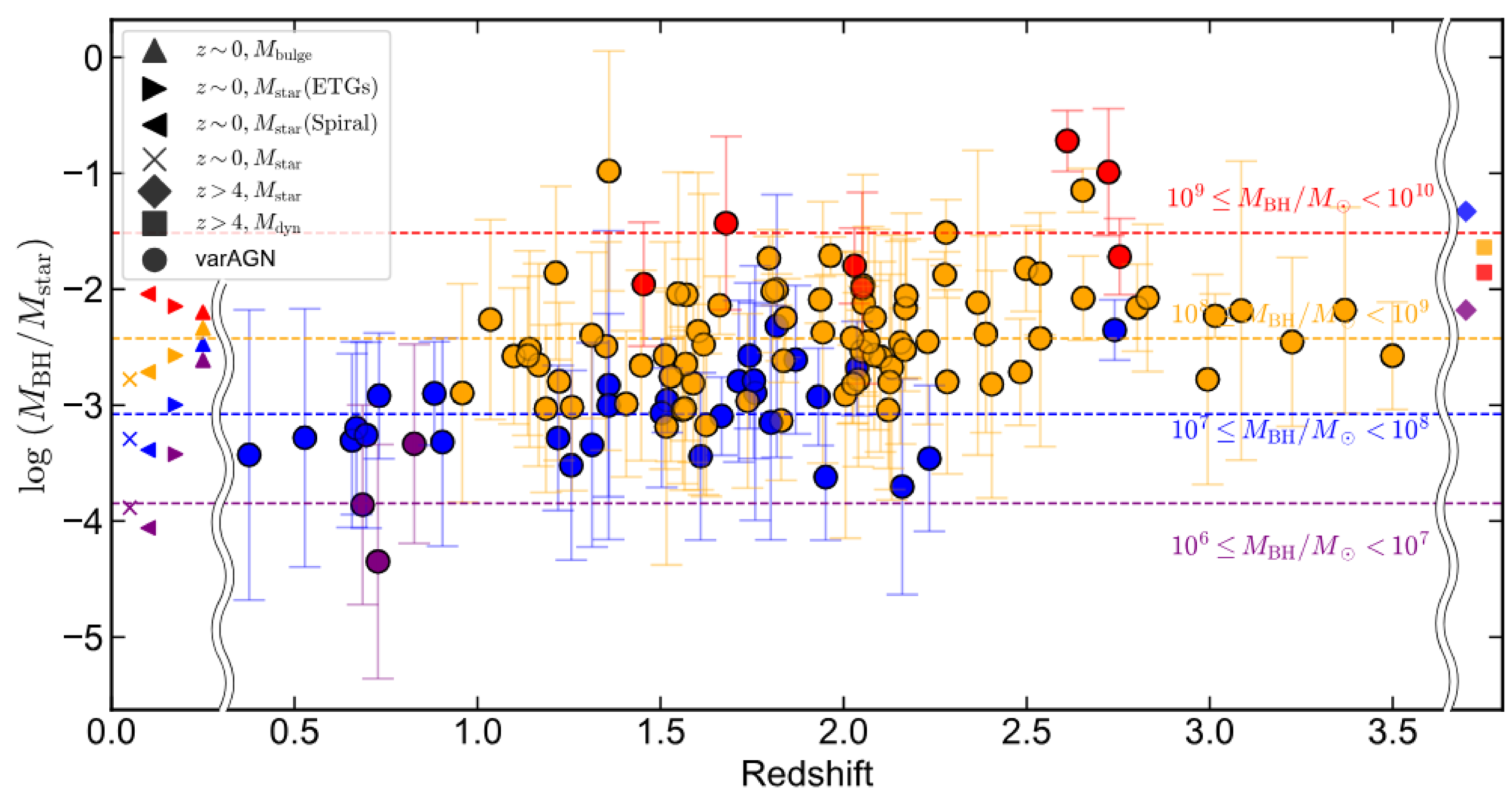
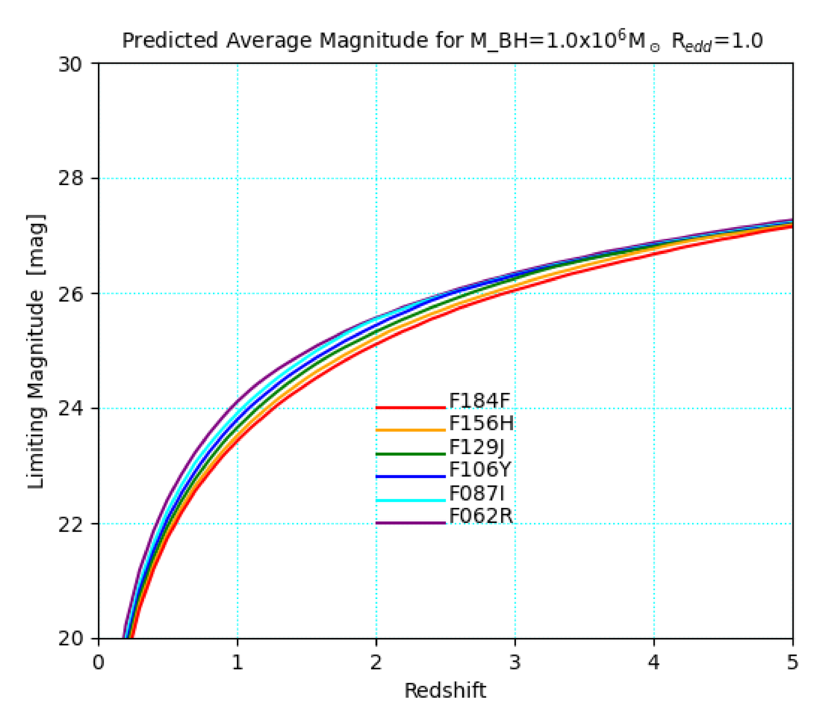
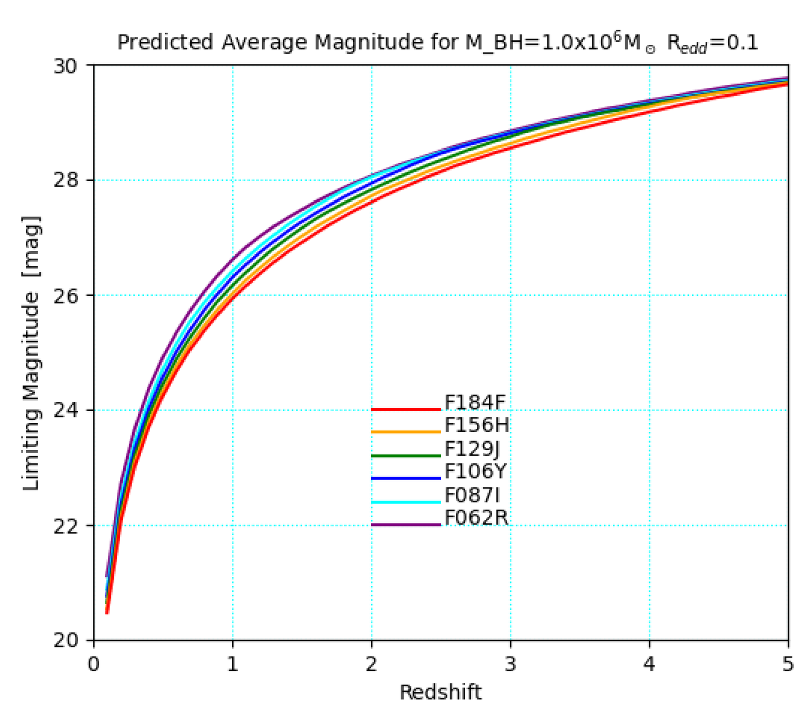


Fig.6 Redshift dependance of the BH-mass/Stellar-mass ratio. Colors show the different mass ranges of the BH.

4. Prospects for the Future Variability Search for Low-Mass SMBH with Roman Space Telescope

- Nancy Grace Roman Space Telescope (Roman) High-Latitude Time-Domain Survey provides an ideal very powerful dataset for the systematic variability search for low-luminosity AGN.
- In the reference plan the depth per visit in Wide and Deep surveys are 26.4-25.4 mag and 26.7-26.5 mag (S/N=5) respectively (Rose et al. 2022). Summing up ~10 visits can achieve 27.1-25.9 mag and 27.3-27.1 mag (S/N=10) for ONE 'EPOCH' photometric data. The depth in the Deep survey appears to deep enough to detect BH with M_{BH} ~10^6 M_{sun} at z~1.5 for the Eddington ratio λ_{edd}=0.1 and z~4 for λ_{edd}=1.0.





- Spectroscopic follow-up is needed to measure their BH mass.
- ELTs (with AO assisted) can achieve S/N~10 per spectral resolution down to ~27mag point sources with R~4000 for the continuum in 1h exposure.