HSC Variability Survey for AGN

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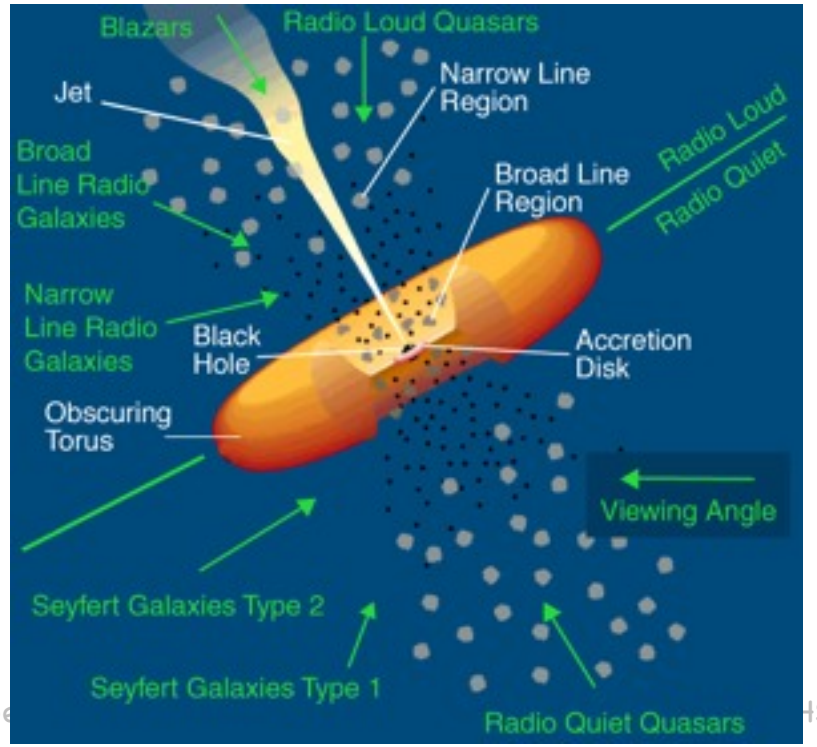
AGN UV/optical variability

- continuum & (broad) emission lines
- variation of something in an accretion disk
- recognized just after 3C273 discovery
- aperiodic
- amplitude: ~0.2-0.3 mag
- time scale: months to years
- one of AGN selection methods
- a tool to study AGN physics/properties

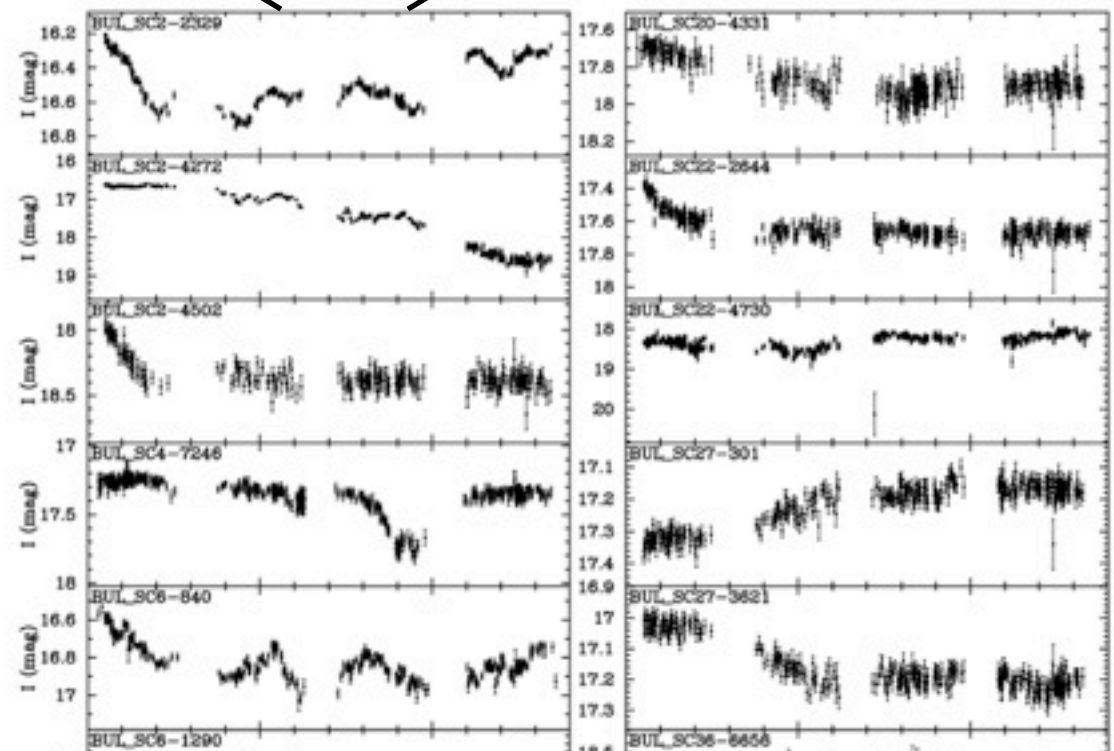
multi-epoch observations required
--> 1 (many) good & 1 bad effects

- AGN selection: deep & ultradeep
- more contamination & less efficiency due to color changes



500 days

Sumi+2005@OGLE-2



AGN variability: Bad effect @wide layer

bad effects on color selection

AGN variability: Bad effect @wide layer

Wolf+2004, COMBO-17@CDF-S

"tests ignoring the variability of quasars have **dramatically increased** their photometric redshift errors." (cf. Sasaki 2008 (PhD), Salvato+2009, Masayuki's talk yesterday)

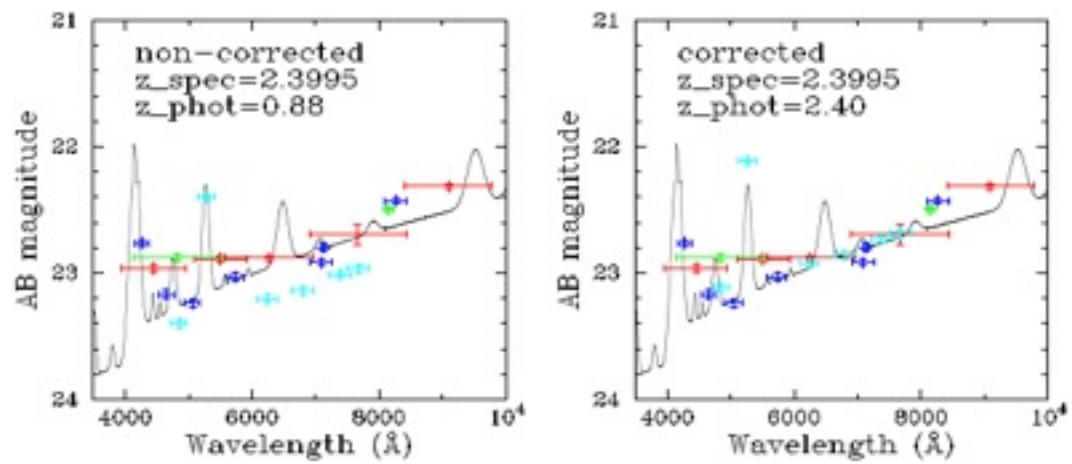
different cadence requirements from different science cases @ wide layer

- weak lensing: several-hour interval for different PSFs@i
- SN shock breakout: 4 epochs over 2 continuous days@gr
- solar system body: over several days@gri
- AGN: within 1-2 months@grizy

color-color diagram simulation

- effects on color selection
- variability selection if possible

Sasaki, 2008 (PhD thesis)



light curve model: damped random walk model@MacLeod+2011

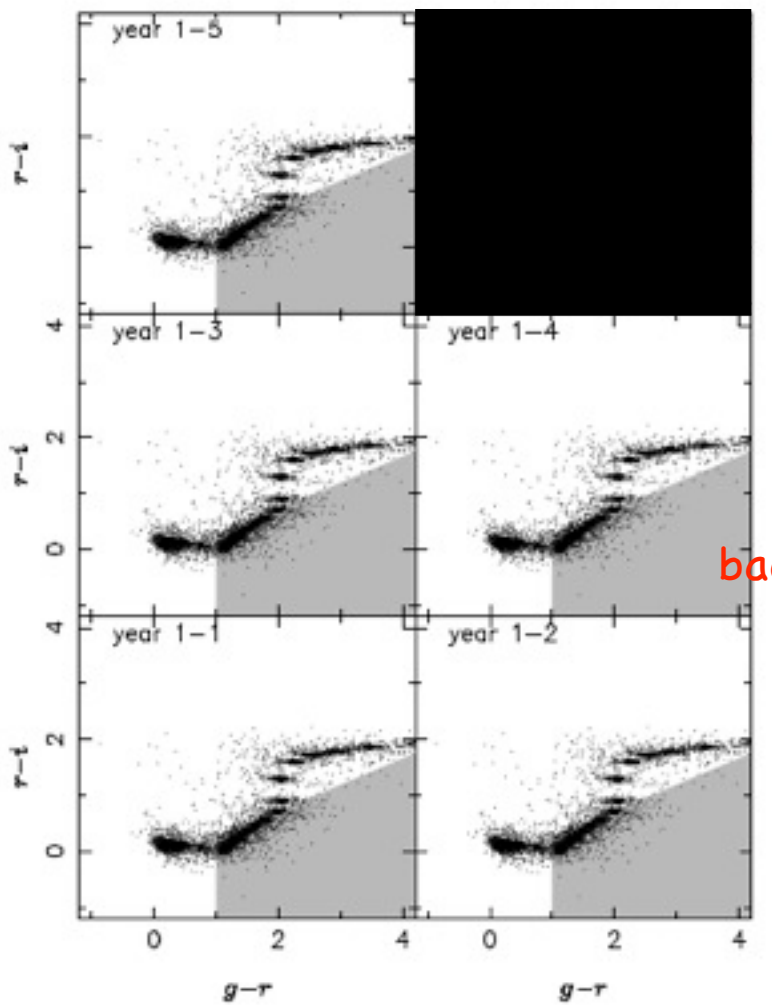
[g-r vs r-i] diagrams (for z~4)

1. grizy during one night

SED + photometric errors
+ variability

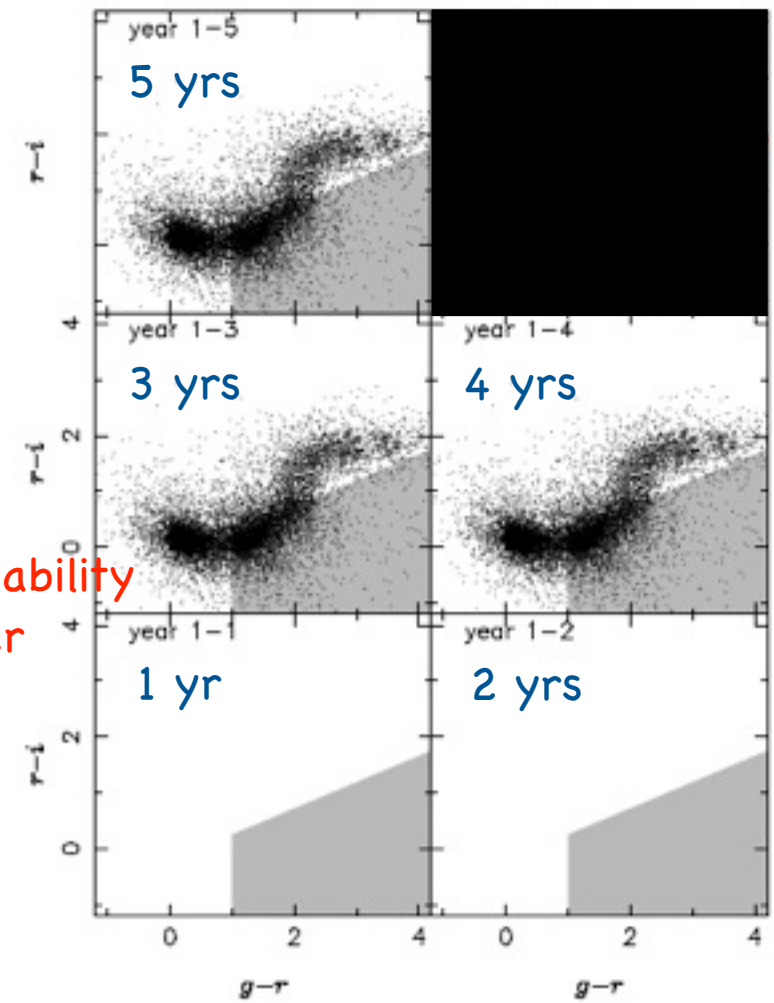
obs. pattern 1 (stacked image)

SED + photometric errors



bad effect of variability
larger scatter

obs. pattern 5 (stacked image)



5. g(1st), r(2nd), i(3rd), z(4th), y(5th) (1 band per year)

[g-r vs r-i] diagrams (for z~4)

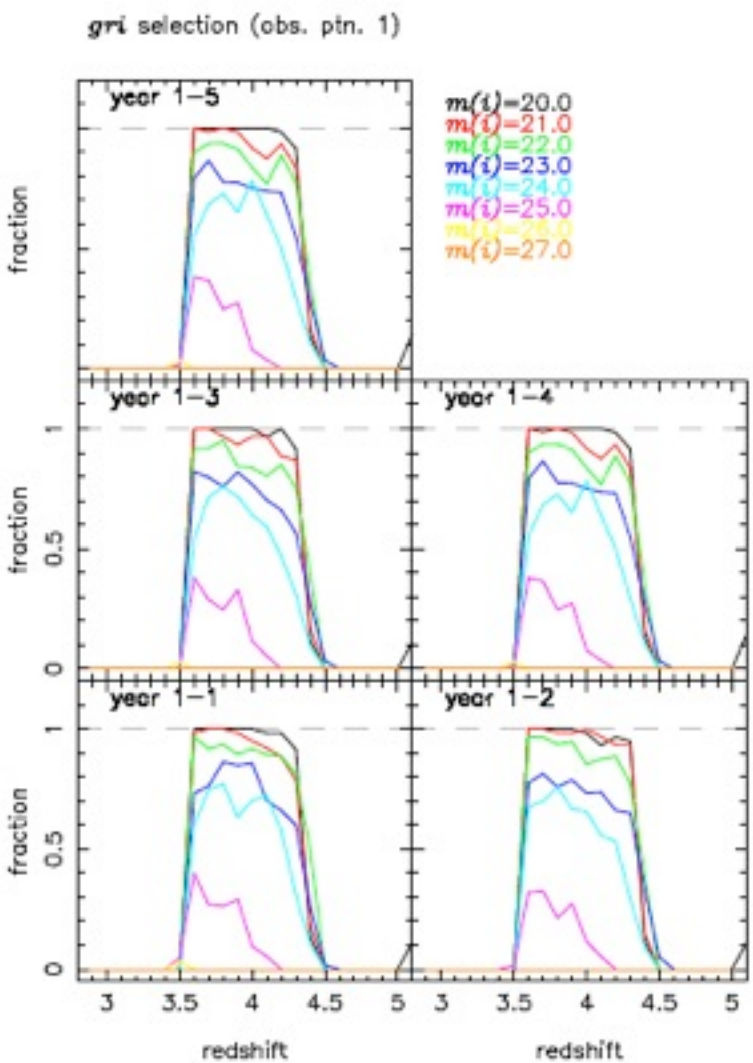
completeness reduction (~30%)

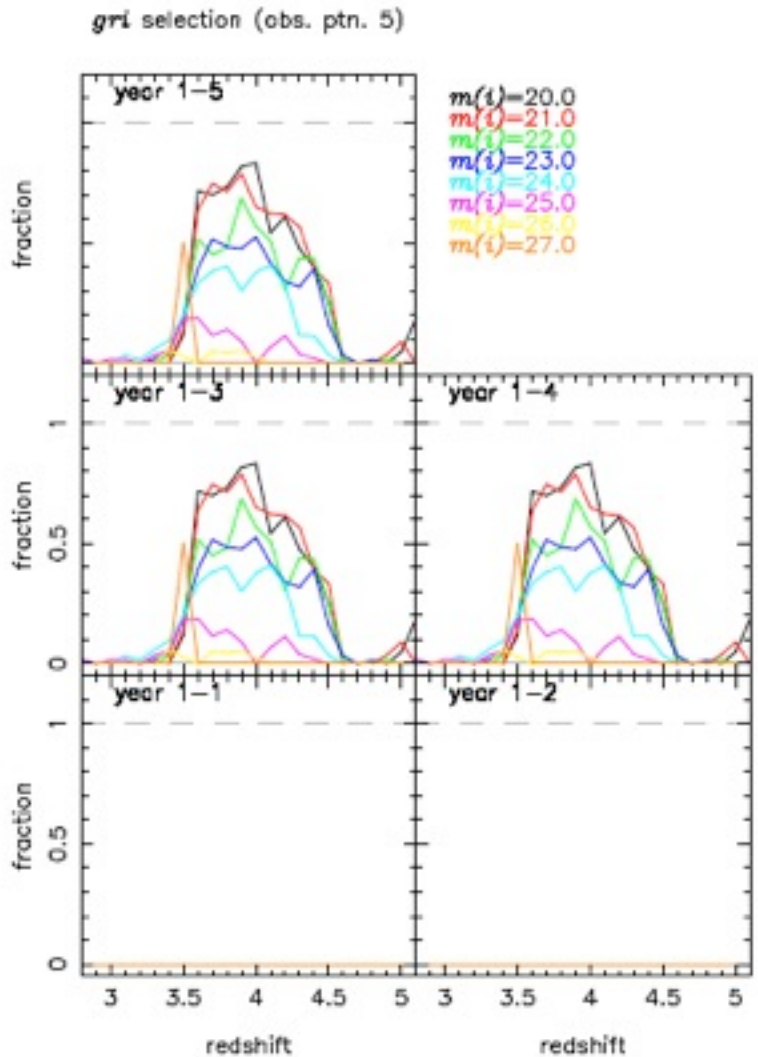
1. grizy during one night

ic

ec

ge

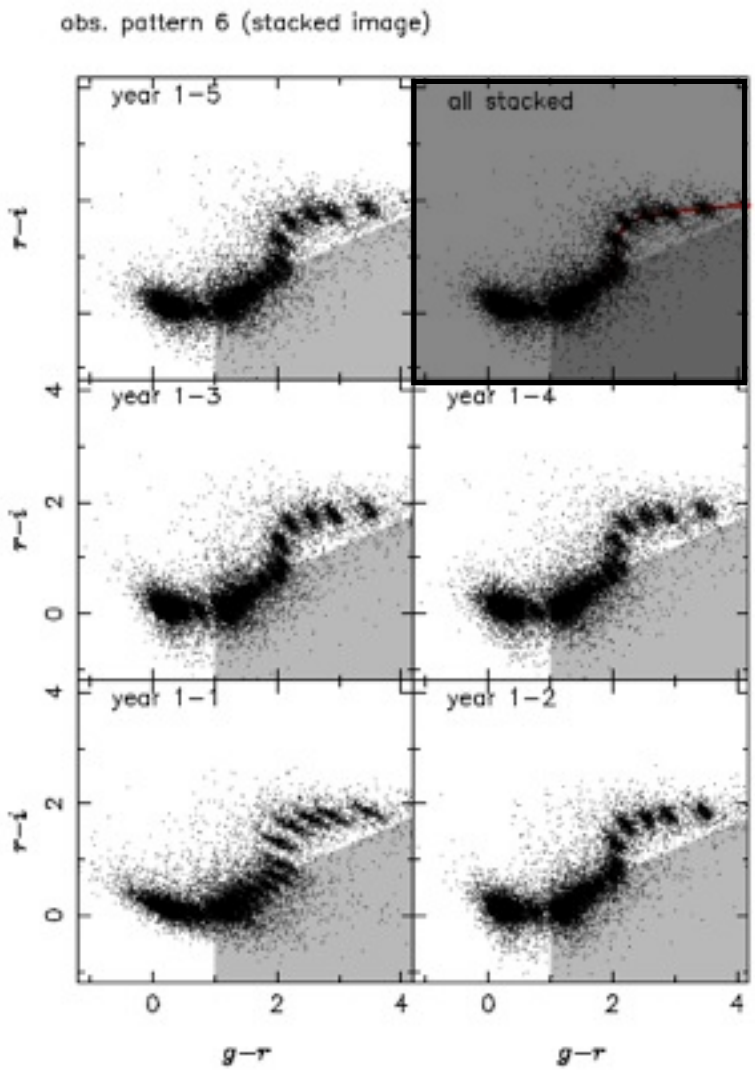


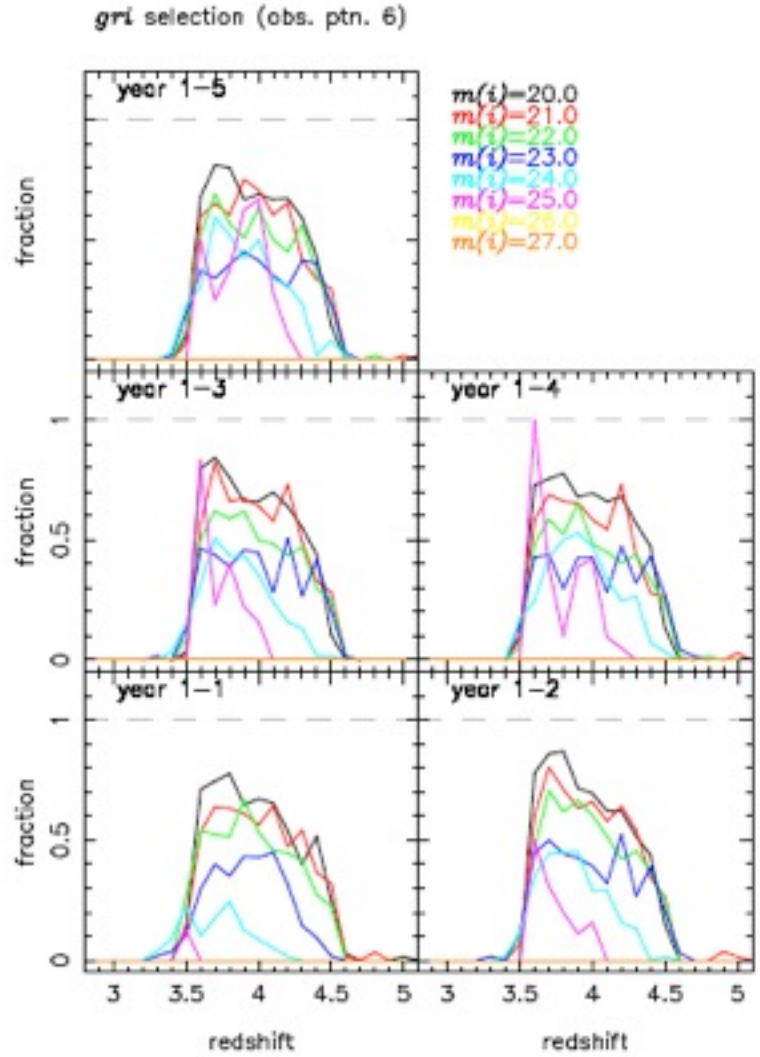


(1st), r(2nd), i(3rd), z(4th), y(5th) (1 band per year)

color-color diagrams

6. 5 epochs per band, random sampling (1)





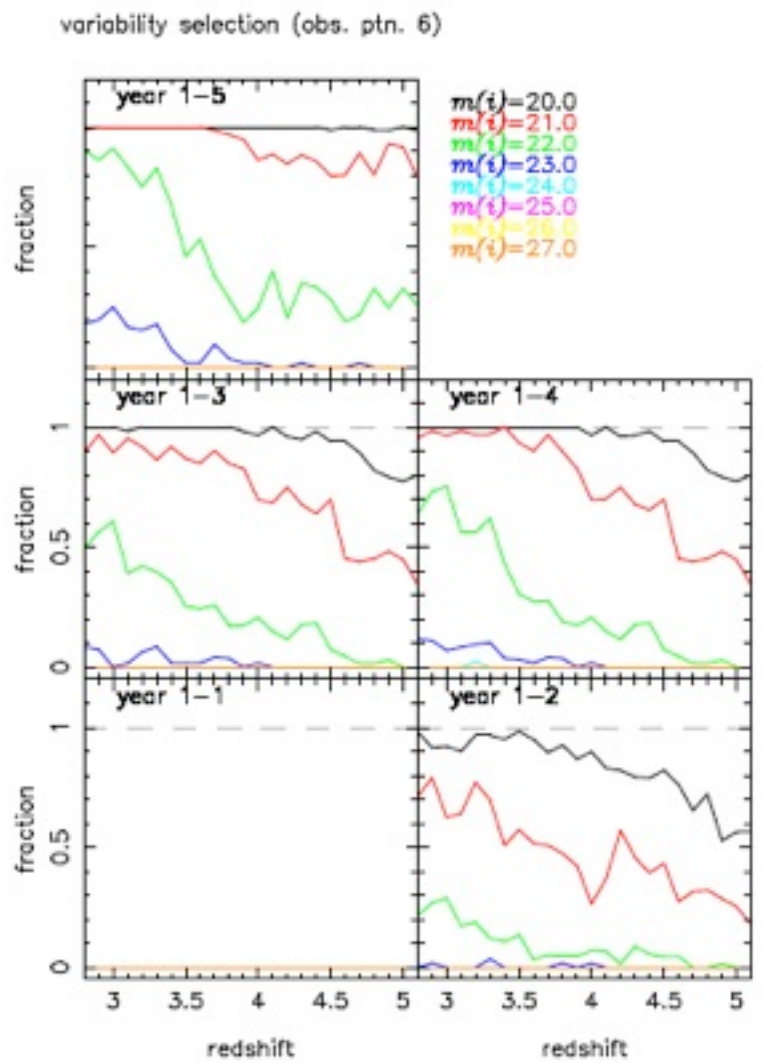
AGN variability: Bad effect @wide layer

how about variability selection???

Variability Selection

- low completeness: i~22mag
- first selection in 3rd or 4th years

6. 5 epochs per band, random sampling (1)

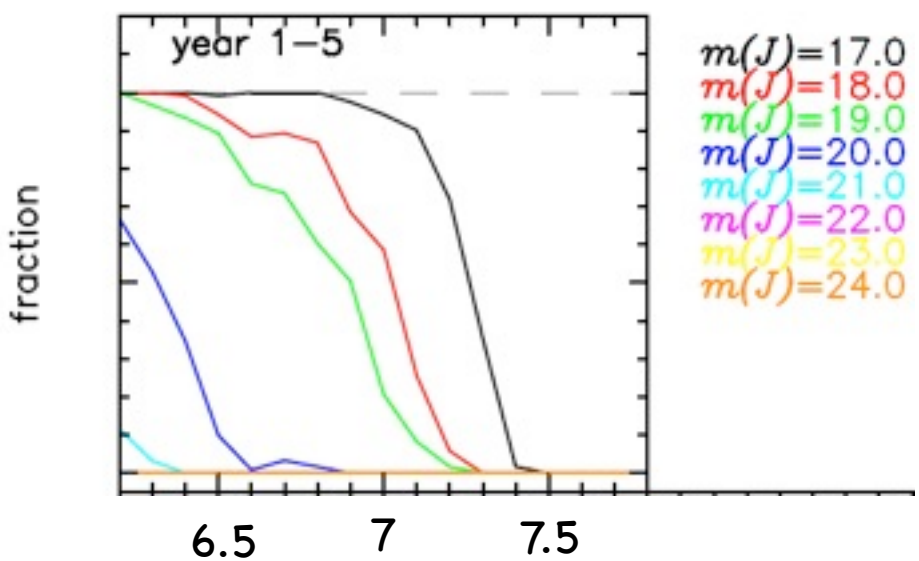


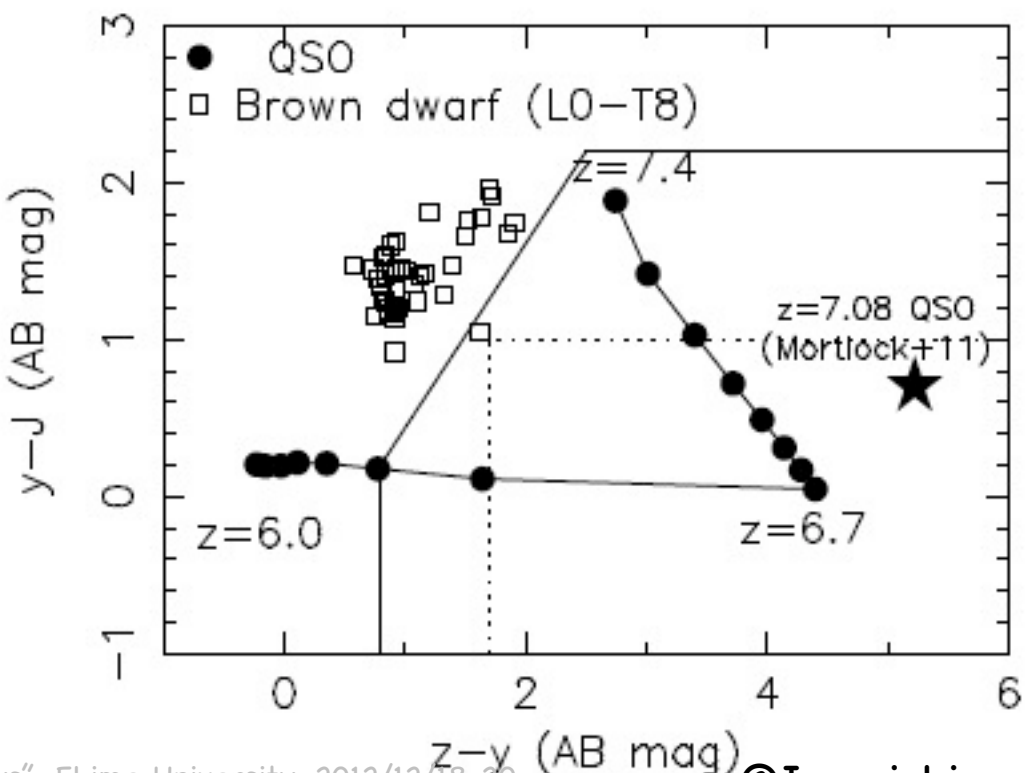
variability selections for z~7 quasars (zyJ)

y-J~0-1, z-y~2-4
--> J=22.1 (5 sigmas, VIKING) quasars@z~7: y=22.1-23.1, z=24.1-26.1
※ y(5sigma, HSC, wide) = 23.7 mag --> 22.9 mag per epoch (if 5 epochs)
※ z(5sigma, HSC, wide) = 24.9 mag --> 24.1 mag per epoch (if 5 epochs)
--> no variability detections for faint (close to J-band limit) quasars@z~7

works well only for very bright quasars @z~7(J<19mag)

- J<19mag: detectable variability@y-band
- J>19mag: only for z<6.6 (shallow y)





AGN variability: Bad effect @wide layer

color selection

- full-depth data should be taken contemporarily (within 2 months)
  - higher priority in regions with NIR data
- 1-year interval --> completeness decreases by 30%
- random time sampling --> completeness decreases by 30% and depends significantly on sampling
- separate into 5 epochs, 1-epoch data in all bands taken within 1 observing run, 5 years --> full-depth achieved after the 3rd year, science of SN shock breakout & solar system bodies can not be achieved.
- select quasars brighter than M_{1450}~-23mag --> i~23mag@z~4, z~24mag@z~5, y~25mag@z~6, J~26mag@z~7.

variability selection

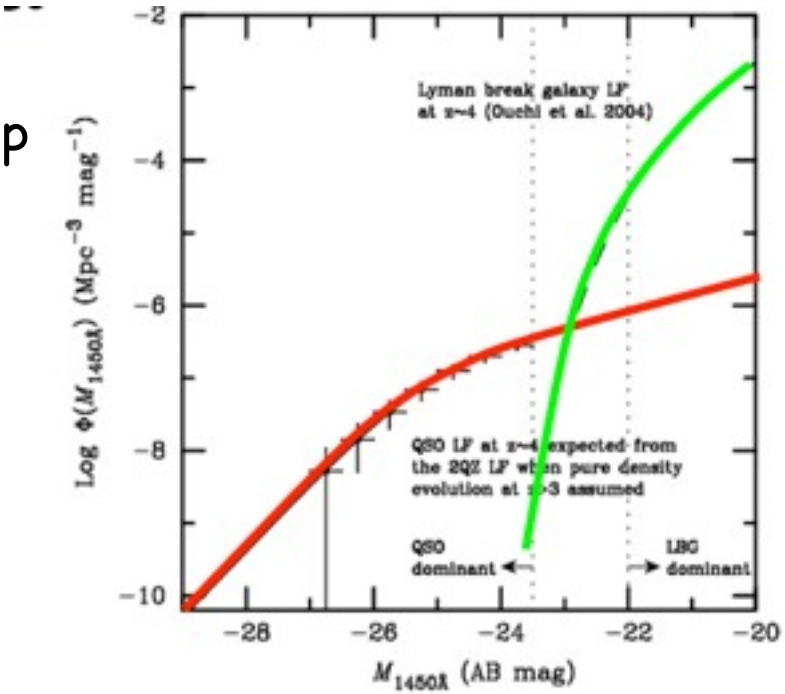
- highly (~80-90%) complete: i~<21mag@z~4, z~<21mag@z~5. small gain compared with SDSS.
- moderately (~40%) complete: 1 mag deeper. difficult completeness correction if time samplings are different from field to field. maybe good for gravitationally-lensed quasar search.
- available only after 3rd year.
- depending on (unknown) light curve behaviors
- can find gravitationally-lensed quasars effectively: extended variable sources?

AGN variability: Good effect

@deep/ultradeep layer

Brandt & Hasinger (2005) Only ultradeep optical variability studies (e.g., Sarajedini, Gilliland & Kasm 2003) may be generating comparable AGN sky densities.

+ many transient object science in deep/ultradeep
  --> variability selection also for AGN!!!
+ discrimination from low-L quasar: LBG
  - color selection for faint quasars
    LBG contamination
  - discrimination from superluminous SN?
    - z>2 SLSN (Cooke+2009)
    - 15-150@deep (Tanaka+2012)
+ interesting population: low-L AGN w/o X-ray detection (e.g., Totani+2005, Cohen+2006, Morokuma+2008)
+ AGN selection@redshift dessert: Butler+2010
+ (tidal disruption event)



AGN variability: Good effect

@deep/ultradeep layer

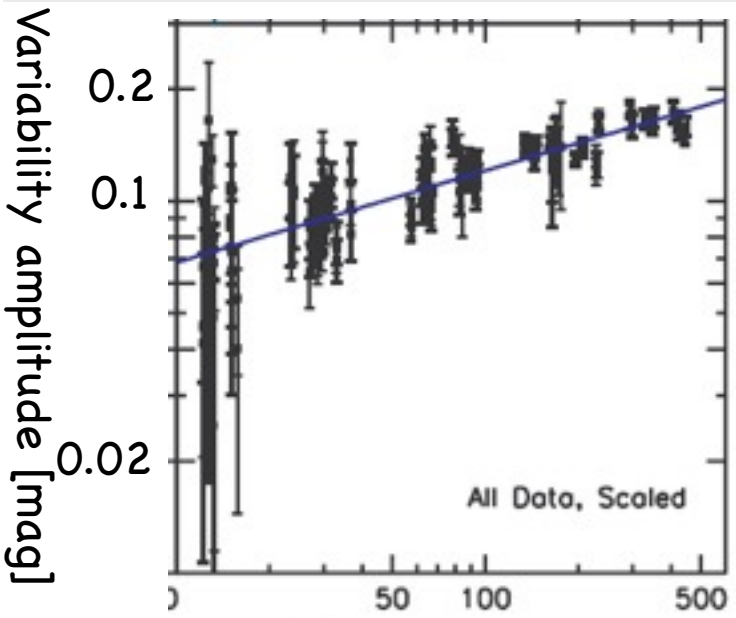
color-selected quasar: LBG contamination

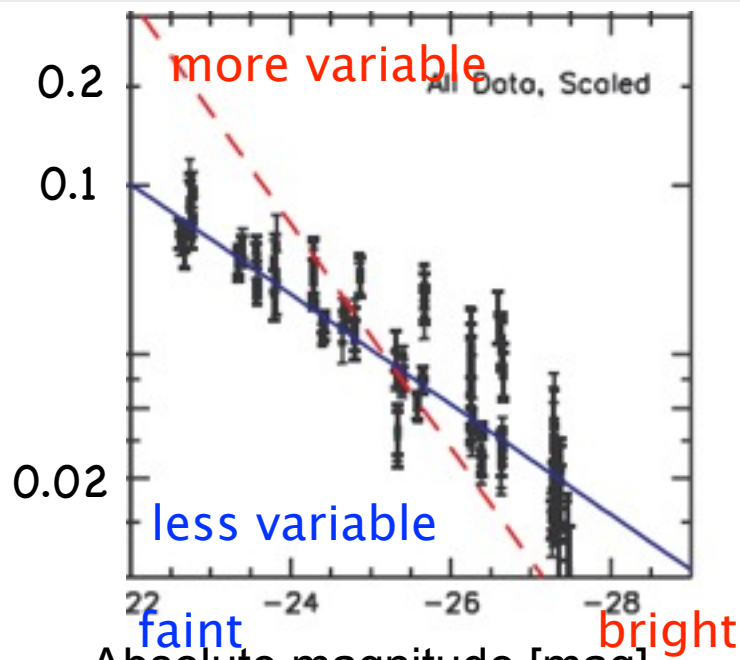
- wide@z~7: no
- wide@z~6: no
- deep@z~6: yes. but variability does not work.
- wide, deep@z~4,5: yes

z	wide	deep
4	yes	yes
5	yes	yes
6	no	yes
7	no	no

AGN variability: Good effect

- all (type-1) AGN show detectable variability in optical. (Hawkins 1993, Hook+1994, Giveon+1999, many SDSS studies ...).
- fainter AGN show larger variability amplitudes.





Vanden Berk+2004

classical optical color selection does NOT suit for low-L AGN search.

Optical variability can be a good tracer for low-luminosity AGN.

- Subaru (Suprime-Cam): Totani+2005, TM+2008a,b
- HST (WFPC2, ACS): Sarajedini+2000,2003,2006, Cohen+2006
  - (low-luminosity) type-1 AGN (up to z~5)
  - ~580 AGN / deg^2
  - significant fractions (~50%) of AGN w/o X-ray detections

Low-L Quasars: Faint-end LF

- faint quasars (LBG contamination, M_{1450}~-23mag)
  - faint-end LF
  - Ikeda+2011: morphological criteria w/ HSC/ACS image@COSMOS(1.4deg^2)
    - HST image availability is limited (deep~28deg^2)
      - How much data???

another selection criterion required
- variability
- HSC (ground-based) morphology?
- IR

variability study in Subaru/XMM-Newton Deep Survey (SXDS): TM+2008a
- 8-10 epochs over 0.918 deg2 (Suprime-Cam 5 pointings)
- 2002 to 2003/2005 (1 or 3 years)
- i-band
- 1-hour exposure per epoch
- ~1000 variable objects (AGN, SNe, variable stars)

Low-L Quasars: Faint-end LF

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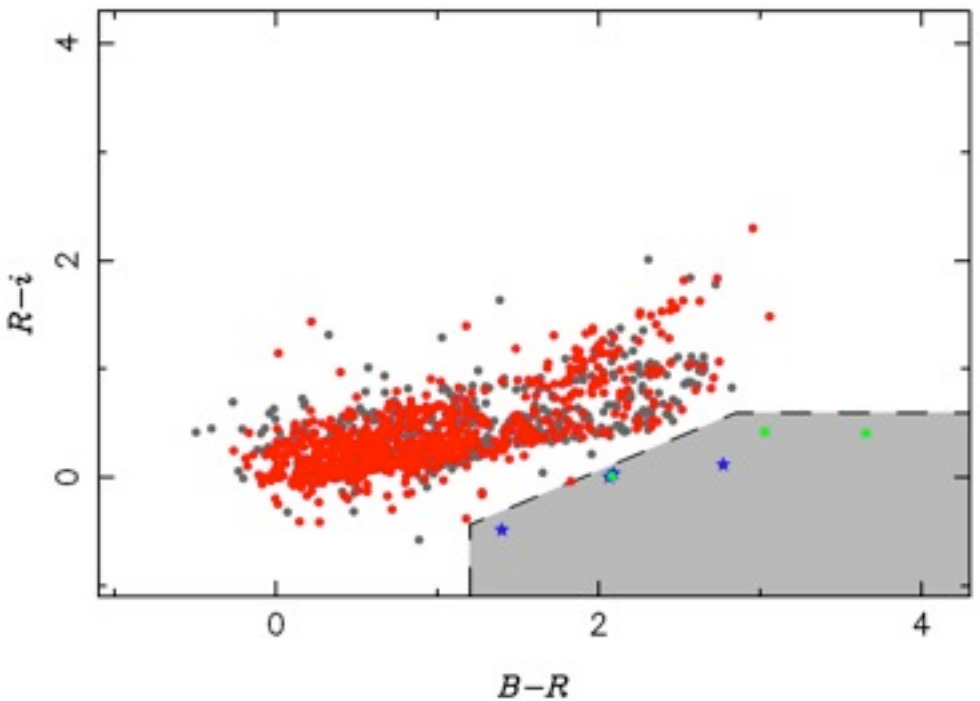
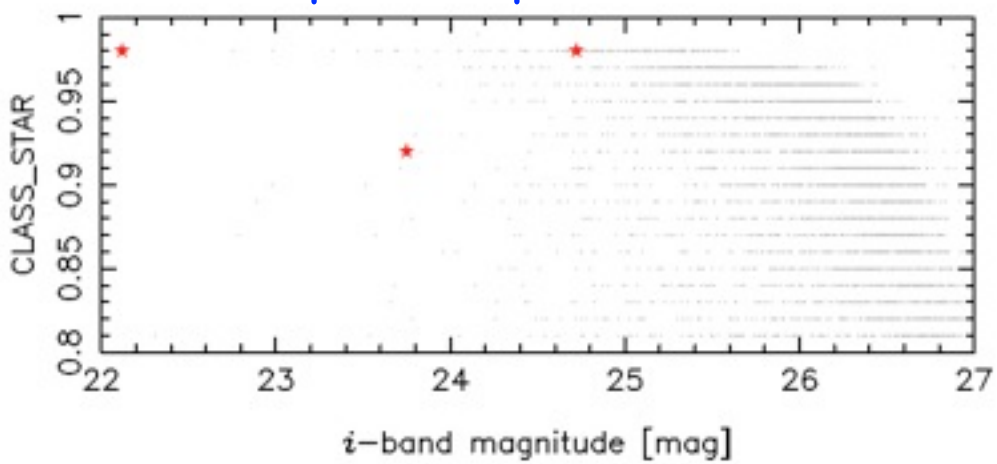
      - How much data???

- 5 plausible z~4 quasars over 0.918 deg2
  - 3 spec-IDed (z=3.974, 3.975, 4.467)



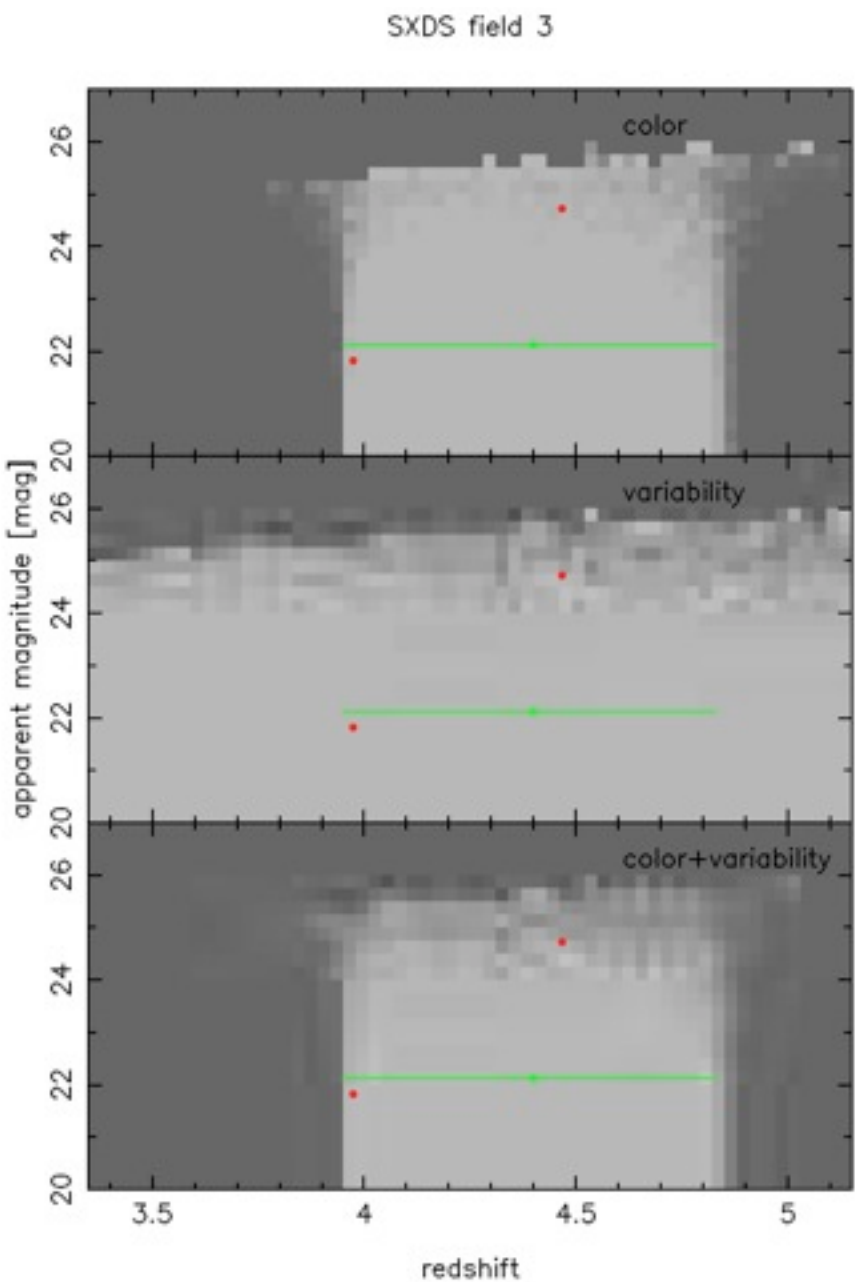
many contaminations

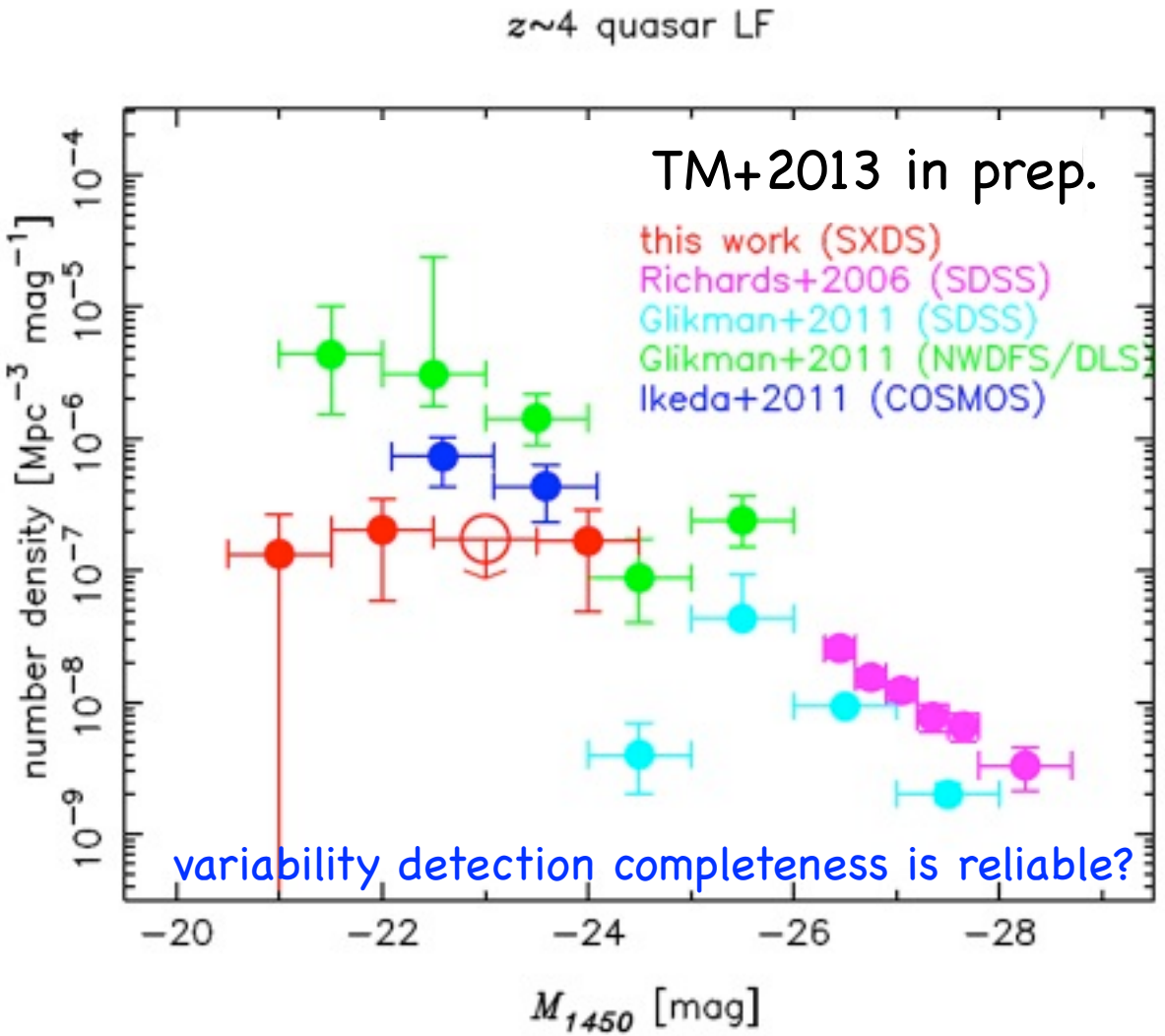
B-dropout & point source@HSC



Low-L Quasars: Faint-end LF

- 5 plausible z~4 quasars over 0.918 deg2
  - 3 spec-IDed (z=3.974, 3.975, 4.467)
  - 2 candidates





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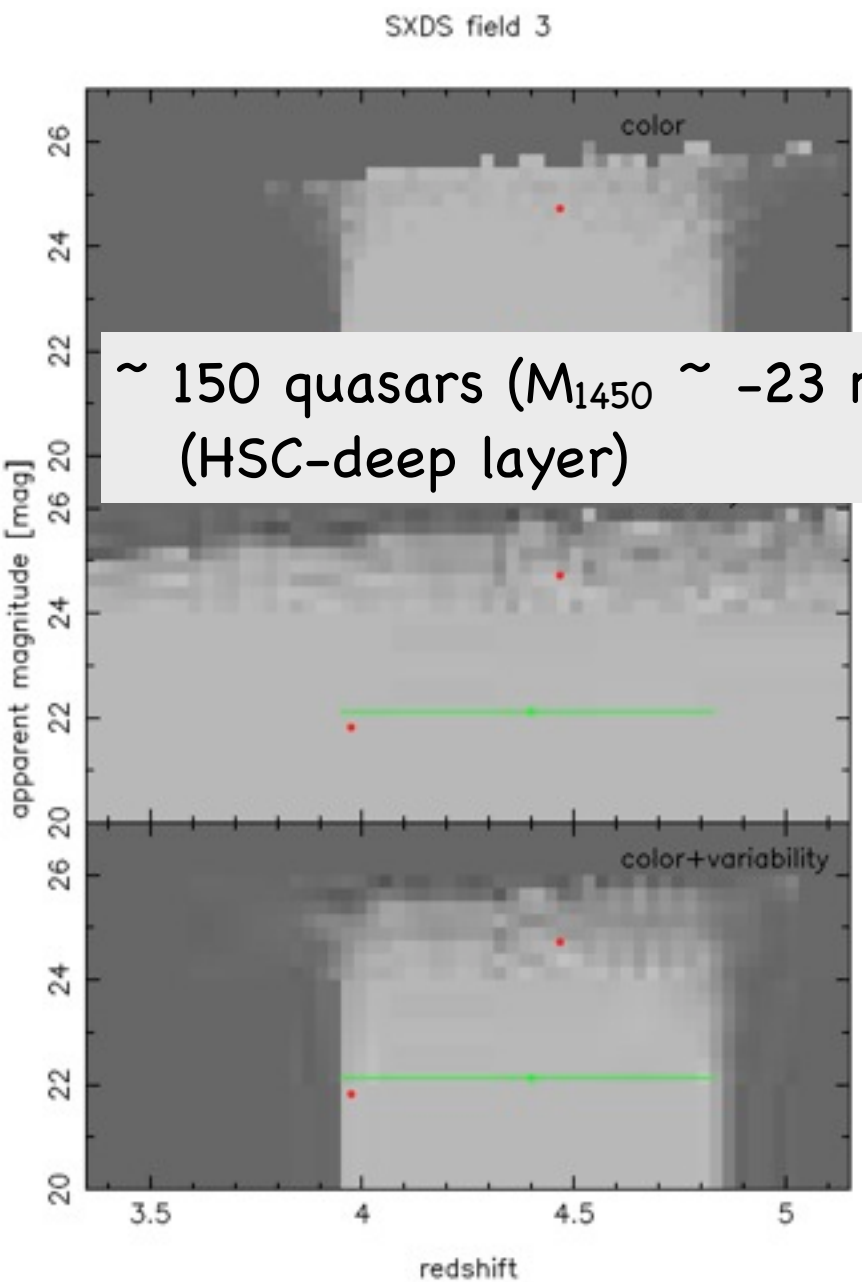
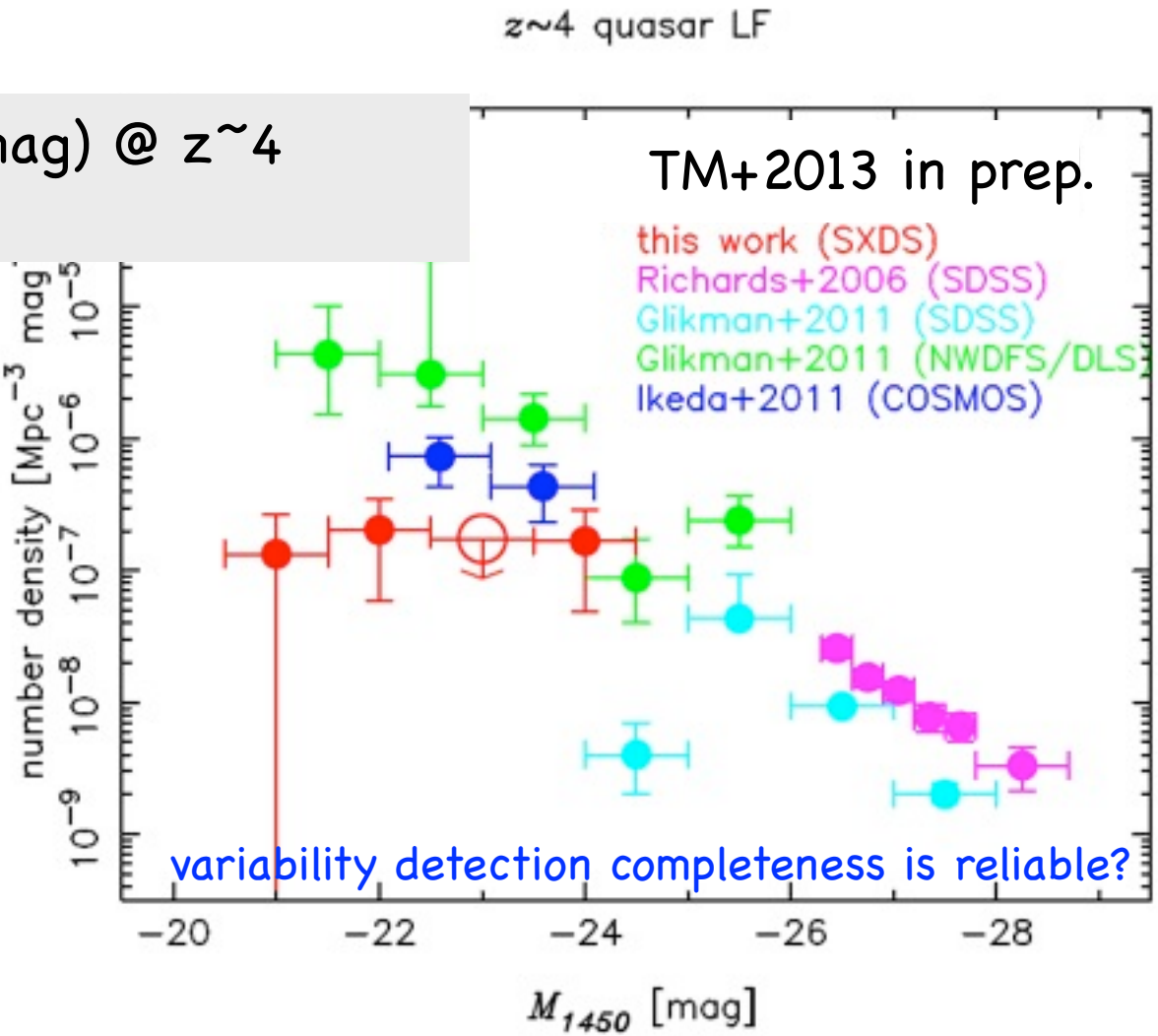


~ 150 quasars (M_{1450} ~ -23 mag) @ z~4
(HSC-deep layer)



AGN variability: Good effect

@deep/ultradeep layer

color-selected quasar: LBG contamination

- wide@z~7: no
- wide@z~6: no
- deep@z~6: yes. but variability does not work.
- w

ility info.

Action Item: selection method/completeness
color (opt, opt+IR), variability, morphology, ...

4	yes	no
5	yes	no
6	no	yes
7	no	no

Low-L AGN @ z<~1

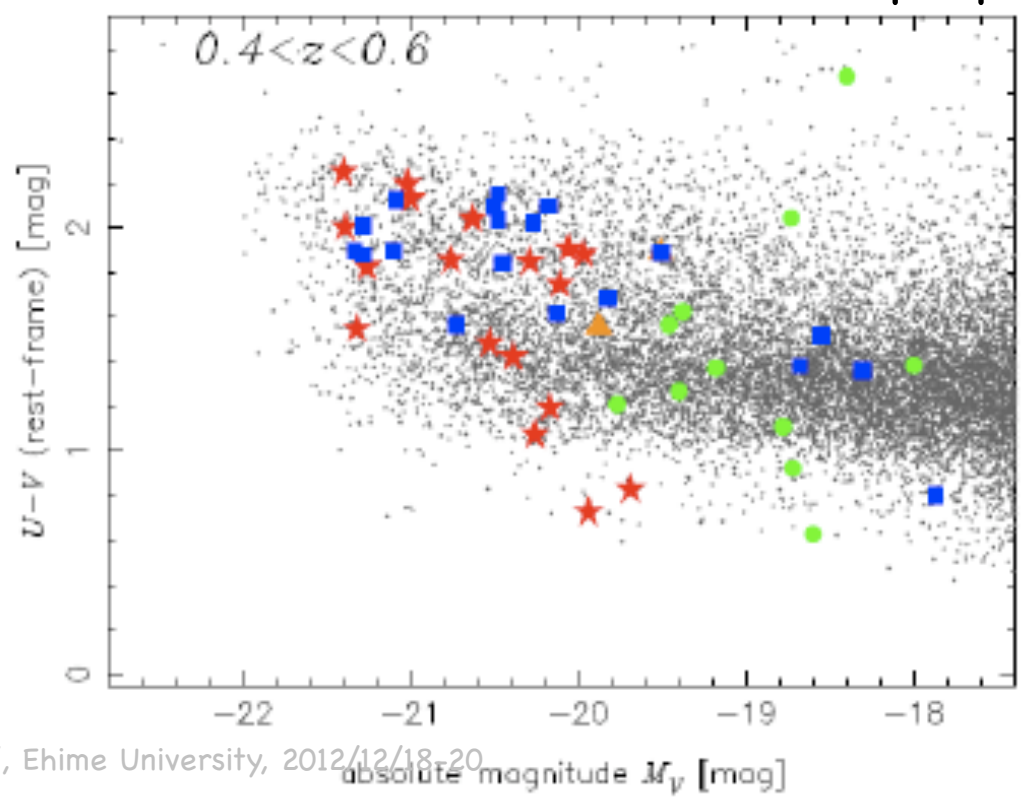
variability-selected low-L AGN@z<~1

- HST studies
  - Sarajedini+2003,2006,2008, Cohen+2006, Villforth+2010,2012
- Subaru/Suprime-Cam
  - Totani+2005, Morokuma+2008b
- others
  - Trevese+2008

properties of variability-selected AGN

- LLAGN at z~0.5 elliptical/massive galaxies
  - ~2000 @ deep layer
  - ~500 @ ultradeep layer
- environmental dependence
  - optical-variability-selected AGN is in green valley/blue cloud.
- radio-mode AGN feedback phase?
- signature of (low) AGN activity in spectra?
- X-ray/spectroscopy is useful

TM+2013 in prep



■: X-ray/~~optical-vari~~ <-- type-2

★: ~~X-ray/~~optical-vari <-- low-L

●: ~~X-ray/~~optical-vari <-- normal AGN?

▲: X-ray/optical-vari <-- normal AGN

Summary

- AGN variability affect our science results in both bad & good manners.
  - pros: photo-z/dropout selection becomes worse.
    --> take all the broad-band data within one or two months @wide layer
  - cons: select low-L quasar@high-z and low-L AGN@low-z via variability.
    (select gravitationally-lensed quasars effectively.)

"Low-L" quasars

- ~150 low-L (M_{1450}~-23 mag) quasar@z~4 @deep-layer
  - LF faint-end --> quasar lifetime
  - environment
- ~50 low-L (M_{1450}~-24 mag) quasar@z~5 @deep-layer
- need to estimate # of variability-selected quasars@ultradeep-layer

Low-L AGN

- ~2000 low-L (M1450>~-20 mag) AGN@z<~1 @deep-layer
  - environment
  - massive galaxy formation