Large-area SMI-CAM survey searching for the dusty AGN in the early universe

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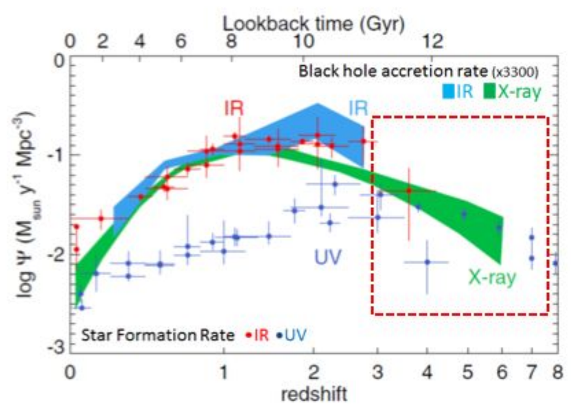
List of my talk

1. Introduction
a. SMBH evolution : Importance of high-z

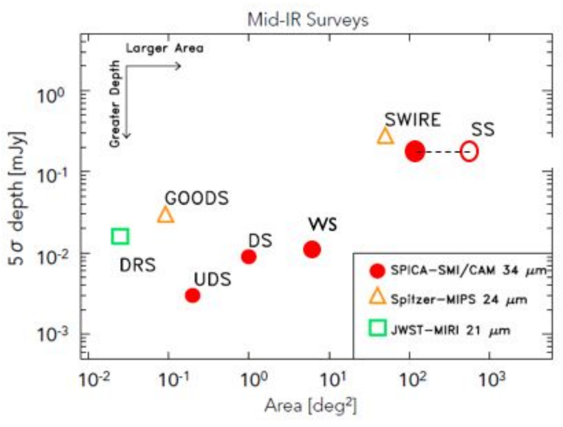
- The first billion years ($z > 5$) of the Universe
  - The first generation of stars and super massive black holes (SMBH): *how they are related each other?*
- When does dust torus emerge during the SMBH growth?
  - $z \sim 6$ dust-free quasar candidates are discovered by Spitzer (two among 21 SDSS quasars; Jiang et al. 2010) : *are they rare objects?*



How much IR AGN (dust obscured AGN) activity? How much star-formation activity ?

1. Introduction
b. Power of SPICA SMI-CAM photometric Survey

- Importance of Mid-IR
  - Rest-frame mid-IR is sensitive to the existence of dust (torus) around SMBH. → SMI-CAM mid-IR survey is essential. Detection is impossible with any opt.-NIR deep & wide surveys.



Wedding Cake Survey at 34 μm

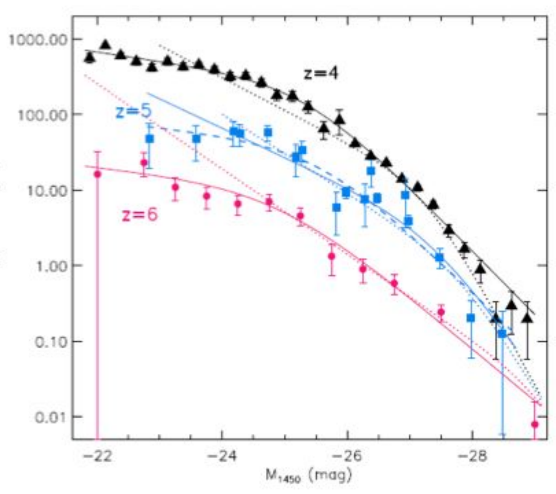
- Ultra-Deep (0.2 deg², 3 μJy)
- Deep (1 deg², 9 μJy = conf. limit) with SMI/LR survey
- Wide (10 deg², 13 μJy) with SMI/LR survey
- Shallow (≥100 deg², 200 μJy)

In this talk we focus on the shallow survey

Gruppioni et al. (2017) + *corrections by SPICA-J*

2. Dusty AGN in high-z Universe
a. Quasar's luminosity Function

- Quasar's Luminosity Function at $z = 4, 5, 6$
  - Un-obscured part of SMBH evolution is now revealed by Subaru/HSC (SHELLQs, Matsuoka et al. 2018), CFHQS, SDSS.

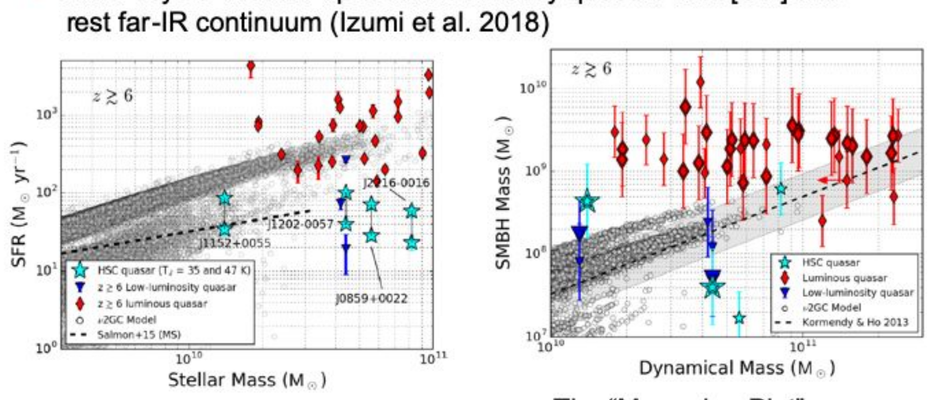


- Break magnitudes similar among $z = 4 - 6$ $M^*_{1450} \approx -25$
- Steep decline in number density toward high-z.

→ *Less active BH growth at $z = 6$ than at $z = 4$? Or, are the dust-obscured population are dominant?*

2. Dusty AGN in high-z Universe
ALMA follow-ups : properties of z~6 Quasars

- ALMA cycle 4 follow-up of low-luminosity quasars with [C II] and rest far-IR continuum (Izumi et al. 2018)



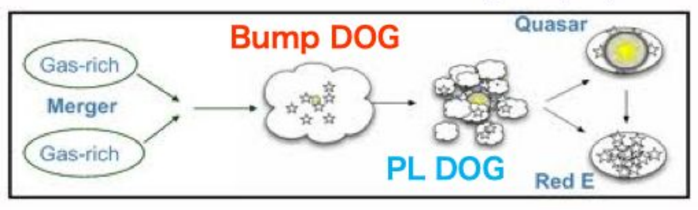
- Moderate SFR (on the z~6 Main – Sequence), $L_{C\,II}/LFIR$ consistent with local star-forming galaxies
- The "Magorrian Plot"
  - Luminous quasars are in excess
  - Low-luminosity quasars are less Black Hole mass

→ Luminous quasars are co-evolving with active star-formation (probably, obscured AGNs as well)

2. Dusty AGN in high-z Universe
b. DOGs & Dusty AGN (1)

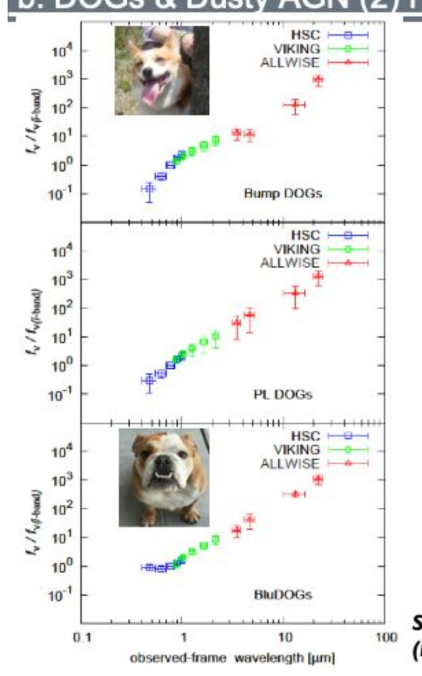
- DOGs : Dust-Obscured Galaxies at z~2 (Dey et al. 2008)
  $R - [24] \geq 7.5$ (in AB mag)
  $i - [22] \geq 7.0$ (Toba et al. 2015; HSC-VIKING-WISE)
  - Very red, no counterpart in the local Universe
  - Two types: PL (power-law) DOGs (AGN like?) & Bump DOGs (Starburst like?)
- A scenario of AGN evolution /Formation of Quasar?

Narayanan+ (2010); Bussmann+ (2012)



DOGs may be a transient population from SMG to Quasars, and massive early types?

2. Dusty AGN in high-z Universe
b. DOGs & Dusty AGN (2) Hyper/Ultra-luminous DOGs



- HSC & WISE (Toba et al. 2015, 2017)
  - HSC SSC early data (9 deg²)
    → 48 DOGs (with VISTA/VIKING),
      - all Hyper-luminous
      - 65 % is PL DOGs
  - HSC SSC 125 deg² → 1411 DOGs! which show strong clustering bias as large as SDSS quasars
    → Hyper-luminous DOGs are selectively formed in massive dark halos (proto-clusters).
- HSC & VISTA & WISE (Noboiguchi et al. 2018; 105 deg²)
  → 571 DOGs (ULIRGs)
  - Bump DOGs are redder optical color than PL DOGs
  - ~2 % of PL DOGs (AGN dominated) show `blue excess' (BluDOGs)

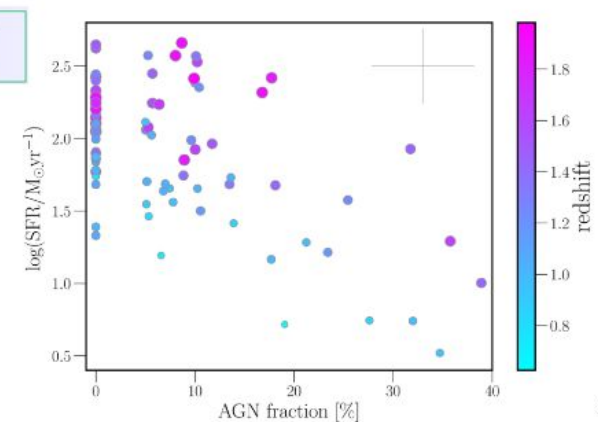
SEDs of z ~ 1 DOGs (Noboriguchi et al. 2018)

2. Dusty AGN in high-z Universe
b. DOGs & Dusty AGN (3) ULIRG & LIRG DOGs

- Based on AKARI NEP-Deep (0.5 deg²) 29 bands data (see Poster by Barrufet, L., et al.)
  - Subaru/S-cam, CFHT/megacam,CFHT/wircam, AKARI/IRC, Spitzer/IRAC, Herschel/PACS, SPIRE.
  - Physical properties of DOGs (sSFR, dust attenuation, AGN fraction, age) are estimated by using SED fitting with CIGALE (Boquien+ 2019).

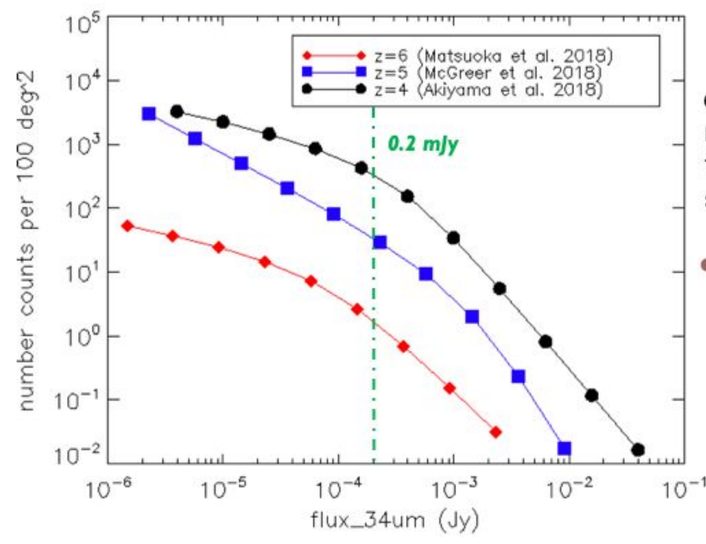
$SFR_{nonAGN} = 142 \pm 26\ M_\odot$/yr
$SFR_{AGN} = 22 \pm 9\ M_\odot$/yr

Consistent with the view that DOGs are a transient population to Quasars.



3. Hunting dusty high-z AGN
a. Expectation with CAM photometric Survey (1)

Estimation of number count of ***known z=4-6 UV-bright Quasars*** based on SHELLQs LF for the shallow 34 μm survey (100-600 deg², 0.2 mJy)



Knee magnitudes $M^*_{1450} \approx -25$ corresponds to 0.14 mJy: comparable with the shallow 34 μm survey limit.

- Expected numbers (per 100 deg²)
  - $z = 6$: ~2
  - $z = 5$: ~50
  - $z = 4$: ~500

3. Hunting dusty high-z AGN
a. Expectation with CAM photometric Survey (1)

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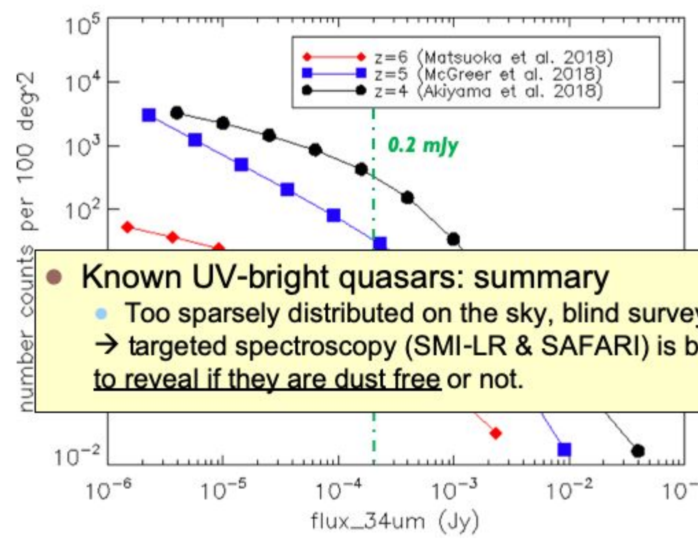


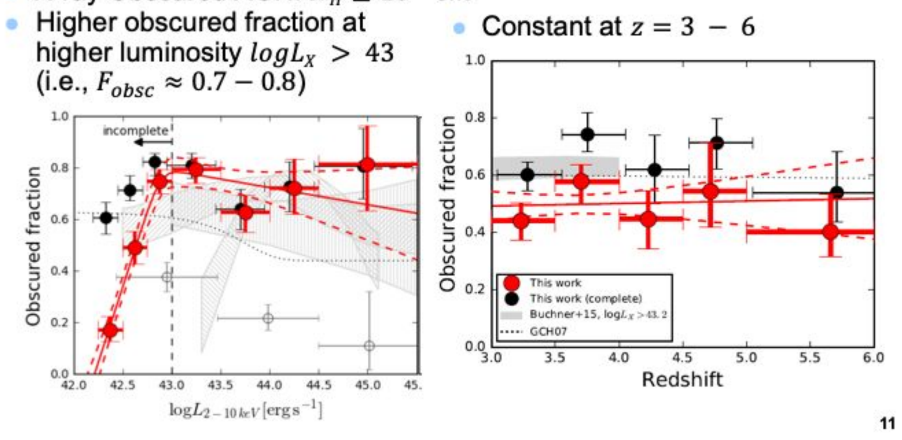
Knee magnitudes $M^*_{1450} \approx -25$ corresponds to 0.14 mJy: comparable with the shallow 34 μm survey limit.

- Known UV-bright quasars: summary
  - Too sparsely distributed on the sky, blind survey is not efficient
  - → targeted spectroscopy (SMI-LR & SAFARI) is better and promising to reveal if they are dust free or not.

3. Hunting dusty high-z AGN
a. Expectation with CAM photometric Survey (2)

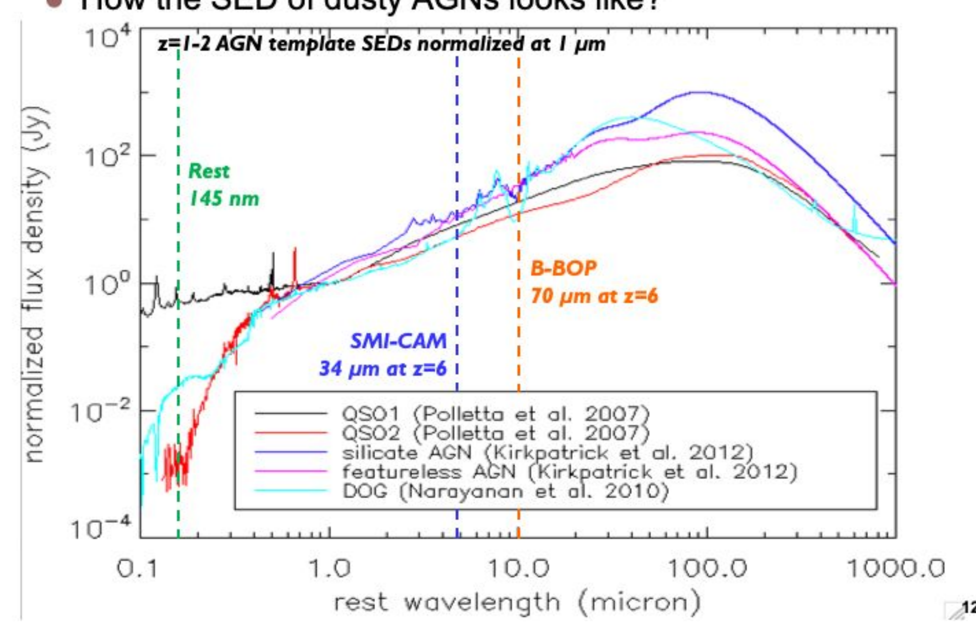
Are there much more dusty, IR bright AGNs?

- Dust torus covering factor of high-z AGNs revealed by X-ray
  - In general, less covering factor is expected for higher luminosity AGN (Hasinger 2008)
- Obscured AGN fraction (Vito et al. 2018, CDF-S)
  - X-ray Obscured AGN: $N_H \geq 10^{23}\ cm^{-2}$
  - Higher obscured fraction at higher luminosity $logL_X > 43$ (i.e., $F_{obsc} \approx 0.7 - 0.8$)
  - Constant at $z = 3 - 6$



3. Hunting dusty high-z AGN
a. Expectation with CAM photometric Survey (3)

- How the SED of dusty AGNs looks like?



3. Hunting dusty high-z AGN
a. Expectation with CAM photometric Survey (3)

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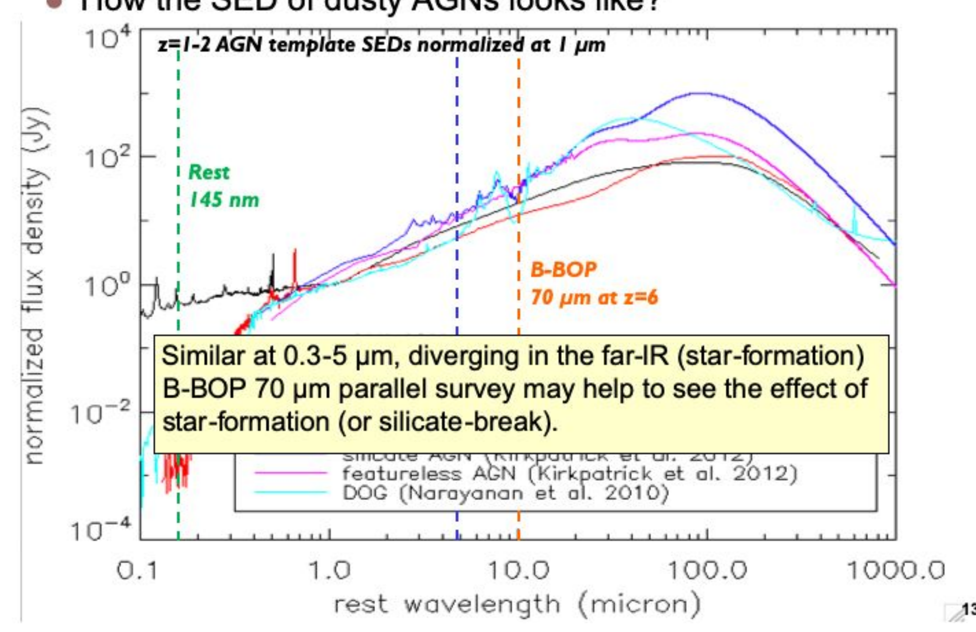
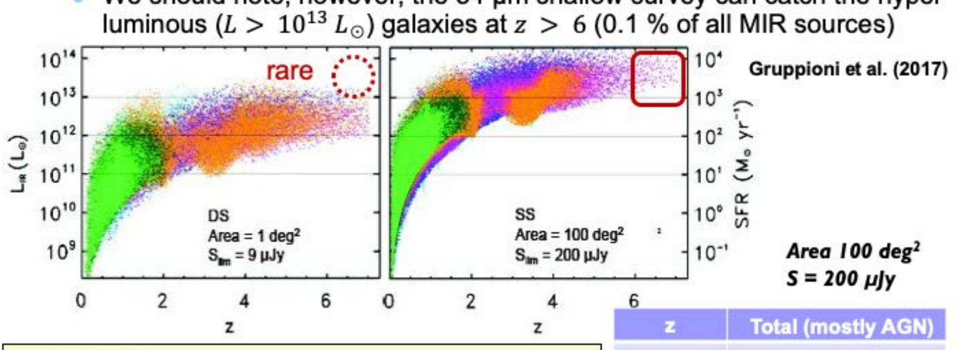


Similar at 0.3-5 μm, diverging in the far-IR (star-formation) B-BOP 70 μm parallel survey may help to see the effect of star-formation (or silicate-break).

3. Hunting dusty high-z AGN
a. Expectation with CAM photometric Survey (4)

- High-z luminous AGNs are likely co-evolving with starburst like DOGs at $z = 1 - 2$ → more chance to catch with a blind survey
- So, also considering the less covering factor, we may expect 5-10 times more AGNs than optically bright quasars?
  - We should note, however, the 34 μm shallow survey can catch the hyper luminous ($L > 10^{13}\ L_\odot$) galaxies at $z > 6$ (0.1 % of all MIR sources)



Area 100 deg²
S = 200 μJy

z	Total (mostly AGN)
3-4	1.5 x 10⁴
4-5	4.2 x 10³
5-6	6.8 x 10²
6-7	1.5 x 10²

summary
- Estimated Number of $z > 6$ luminous AGN:
  - Minimum: 5 per 100 deg²
  - Maximum: 150 per 100 deg²

3. Hunting dusty high-z AGN
b. Strategy : combination with opt. - near-IR survey (1)

- To discover dusty hyper-luminous candidates at z>6, due to their low surface density, JWST / ALMA are not appropriate due to their inefficient mapping capability.
- → so primarily, we should combine with planned opt-near-IR surveys over the same area of > 100 deg² to select candidates.
- → Then, for an order of 100 candidates, we may use JWST, ALMA, and SPICA (SMI, SAFARI), and ATHENA.

3. Hunting dusty high-z AGN
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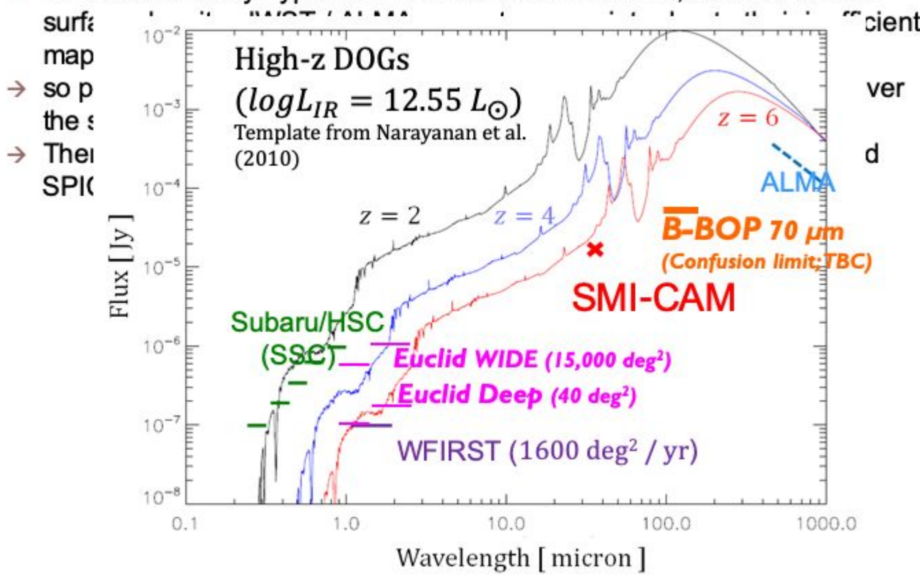

3. Hunting dusty high-z AGN
b. Strategy : combination with opt. - near-IR survey (1)

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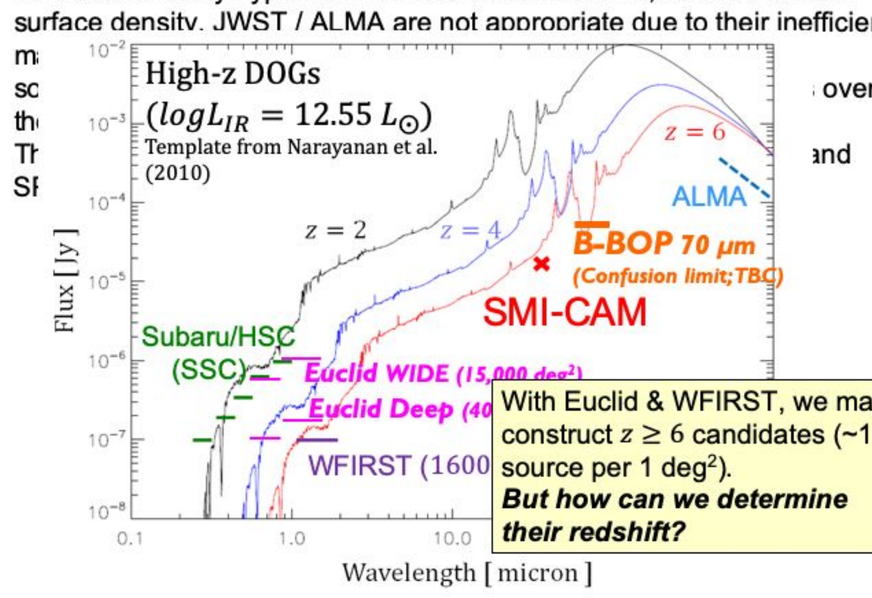
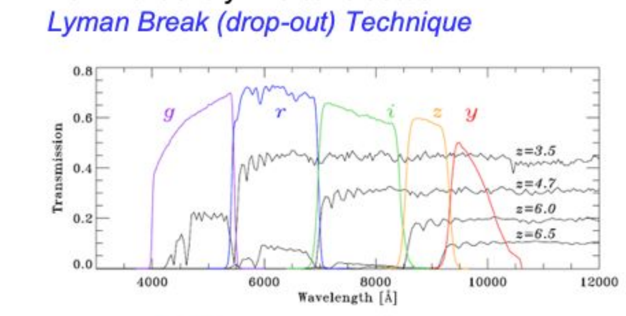


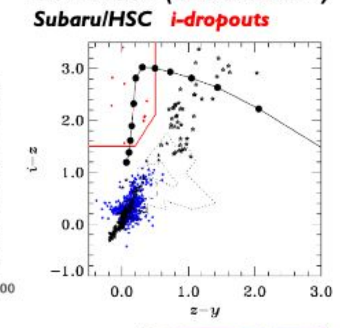
With Euclid & WFIRST, we may construct $z \geq 6$ candidates (~1 source per 1 deg²).
But how can we determine their redshift?

3. Hunting dusty high-z AGN
b. Strategy : combination with opt. - near-IR survey (2)

How we identify z>6 candidates?
Lyman Break (drop-out) Technique



GOLDRUSH (Ono et al. 2017)
Subaru/HSC *i-dropouts*




WFIRST

Four (VIS, YJH) bands of Euclid & Seven optical - near-IR (RZYJH & F184, W146) bands of WFIRST *are suitable to select z>6 LBGs.*


Euclid

Summary

- Power of SPICA SMI-CAM photometric Survey
  - SS 100-600 deg², 0.2 mJy
  - WS 10 deg², 13 μJy
  - *Parallel survey with B-BOP 70 μm??*
- UV bright high-z Quasars
  - Too small surface density for the blank field surveys
  - Targeted spectroscopy (SMI/LR, SAFARI) is promising to reveal existence of dust torus around high-z quasars.
- Hunting dusty, hyper-luminous AGN at $z > 6$
  - Minimum: 5 per 100 deg²
  - Maximum: 150 per 100 deg²
- Strategy of Identification / redshift determination
  - Combination with near-IR survey, especially WFIRST
  - Optical & near-IR bands of Euclid & WFIRST are suitable to use the Lyman Break (drop-out) technique.