

JWST

SPICA

GREX-PLUS

南極THz望遠鏡

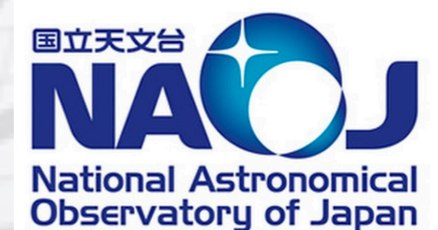
$z > 6$

SPICAで検討した high-z AGN サイエンス の紹介と南極テラヘルツ望遠鏡への展望

鳥羽 儀樹

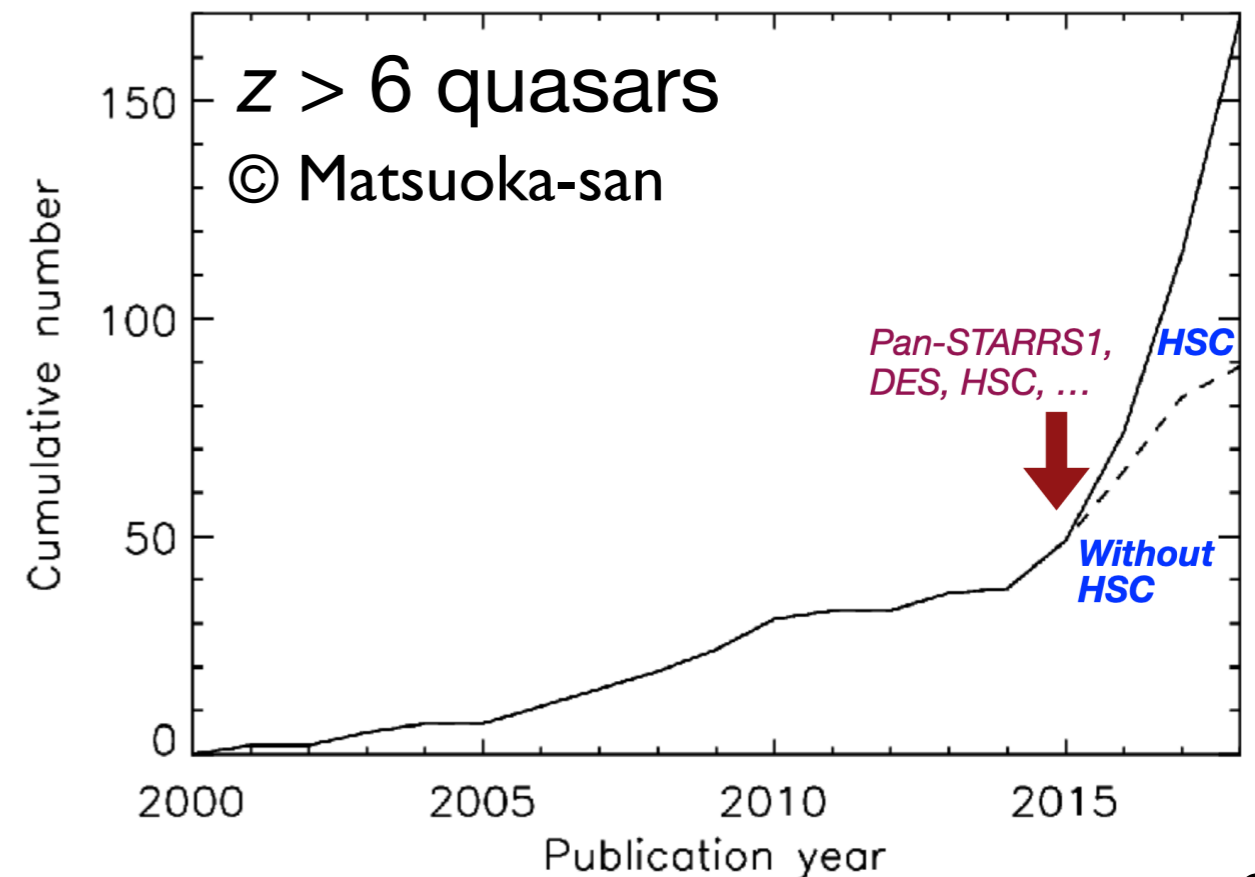
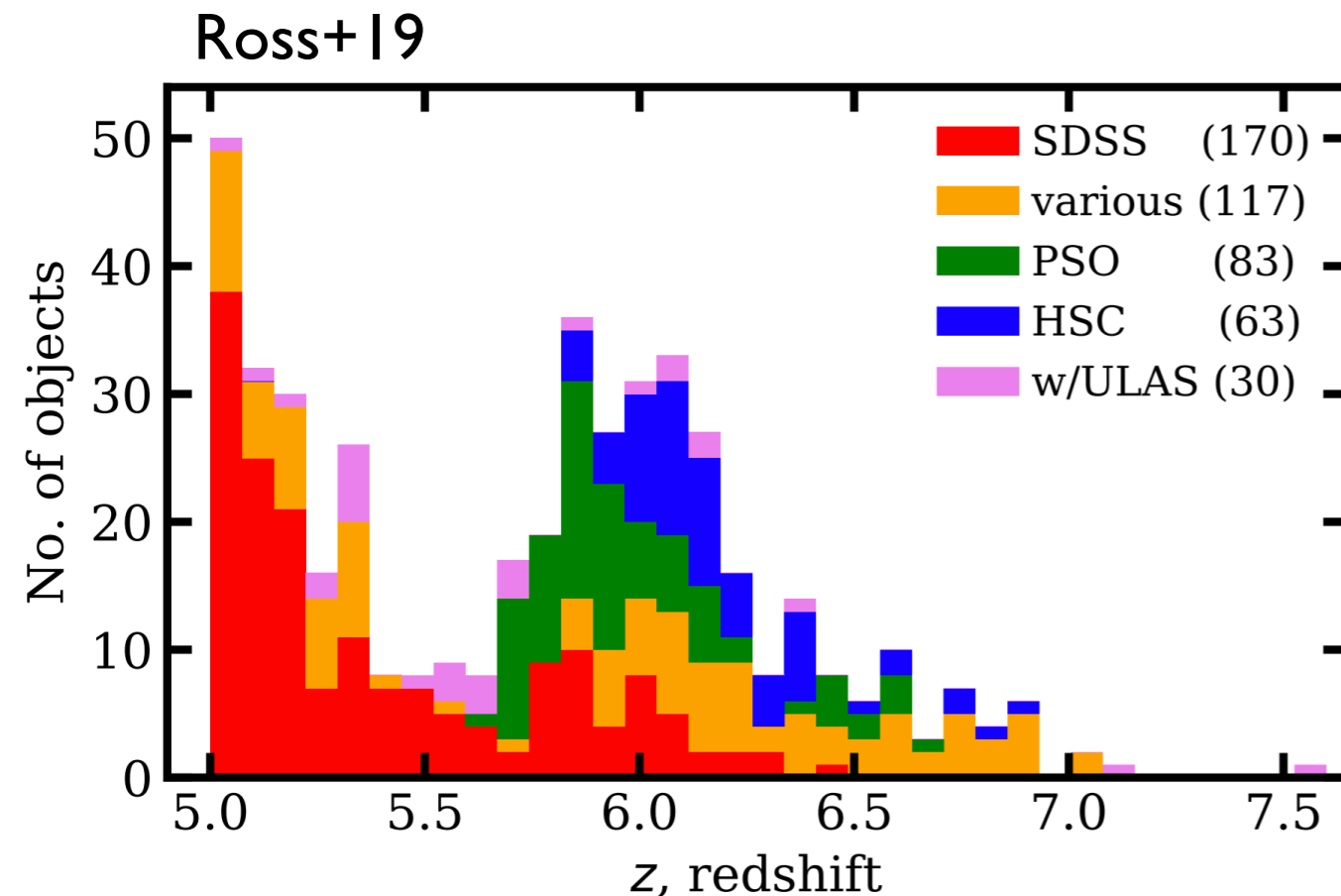


京都大学 -> 国立天文台 (4月から)



AGN in the early Universe

- ~200 quasars at $z > 6$ have been discovered so far.
- We can do **a statistical investigation** of those quasars in the early Universe (e.g., luminosity function).
- In the 2030s, can we do similar works even for $z > 7$ quasars!?



Key questions

- **When and how was the dusty torus formed?**
- **How do their NIR-FIR SEDs look like?**

SPICA Science Conference 2013

Search for dust-free quasar at $z > 6$
using SPICA MCS photometry

Yoshiki TOBA (SOKENDAI, ISAS/JAXA) and YOUR NAME here !



SPICA conference (2013) のポスター

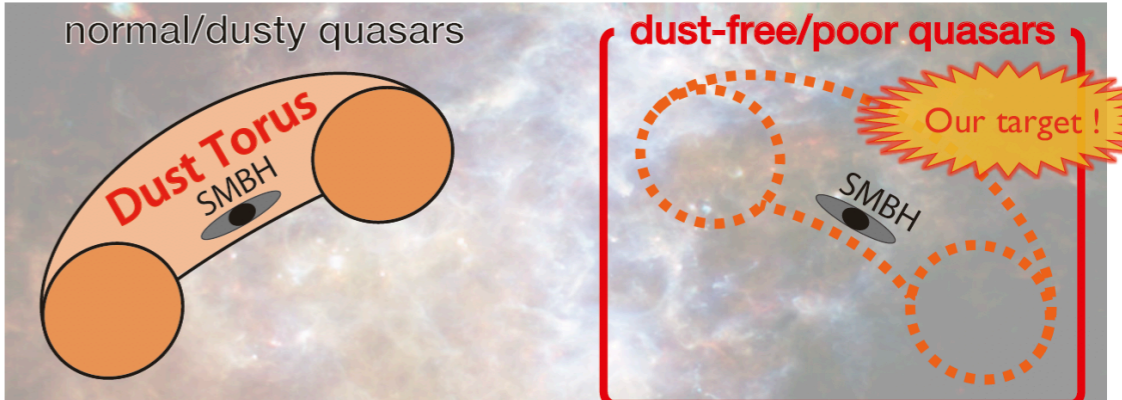
Search for Dust-free Quasars at $z > 6$ Using SPICA MCS Photometry

大学院生時代からずっと興味持ってます。

Yoshiki Toba

The Graduate University for Advanced Studies (Sokendai), Japan
Institute of Space and Astronautical Science, JAXA, Japan

Abstract. I propose to search for *dust-free quasars* without hot-dust emission at $z > 6$. I plan to perform the deep mid-infrared photometry with Mid-infrared Camera and Spectrometer (MCS). Its high sensitive and continuous-band (5–38 μm) imaging



normal/dusty quasars

dust-free/poor quasars

Our target!


SMBH

SMBH

$z > 6$

When / How dust torus was created ?

SPICA has answer !



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SPICAで検討した high-z AGN サイエンスの紹介と

南極テラヘルツ望遠鏡への展望

$z > 6$

JWST

SPICA

SPICAで検討した high-z AGN サイエンス

- **Hot dust-free quasars**
- **SED analysis**
- Dust composition



When and how was the dusty torus of quasar formed?






Altmetric: 9 Citations: 65 [More detail >>](#)

Letter

Dust-free quasars in the early Universe

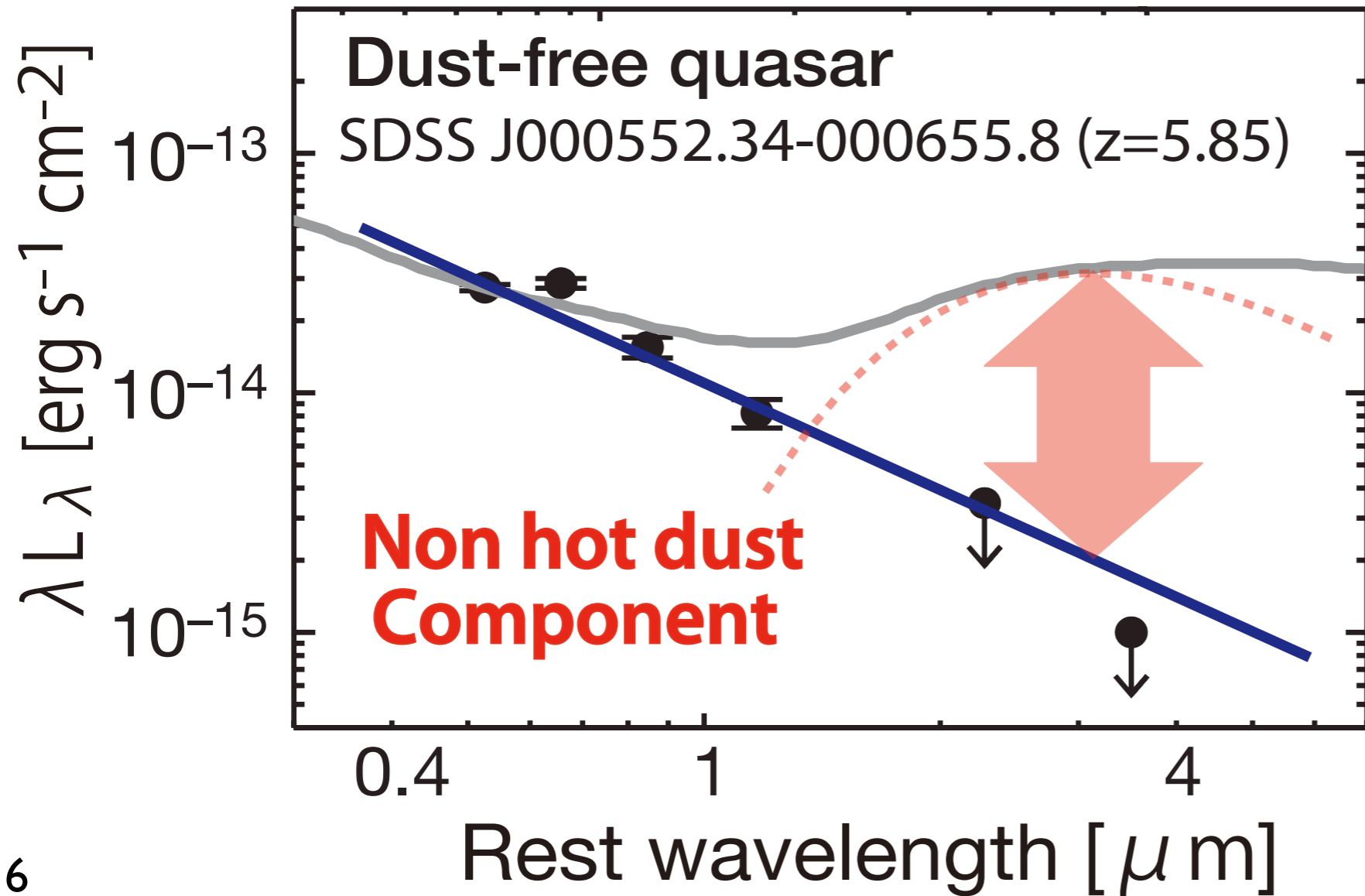
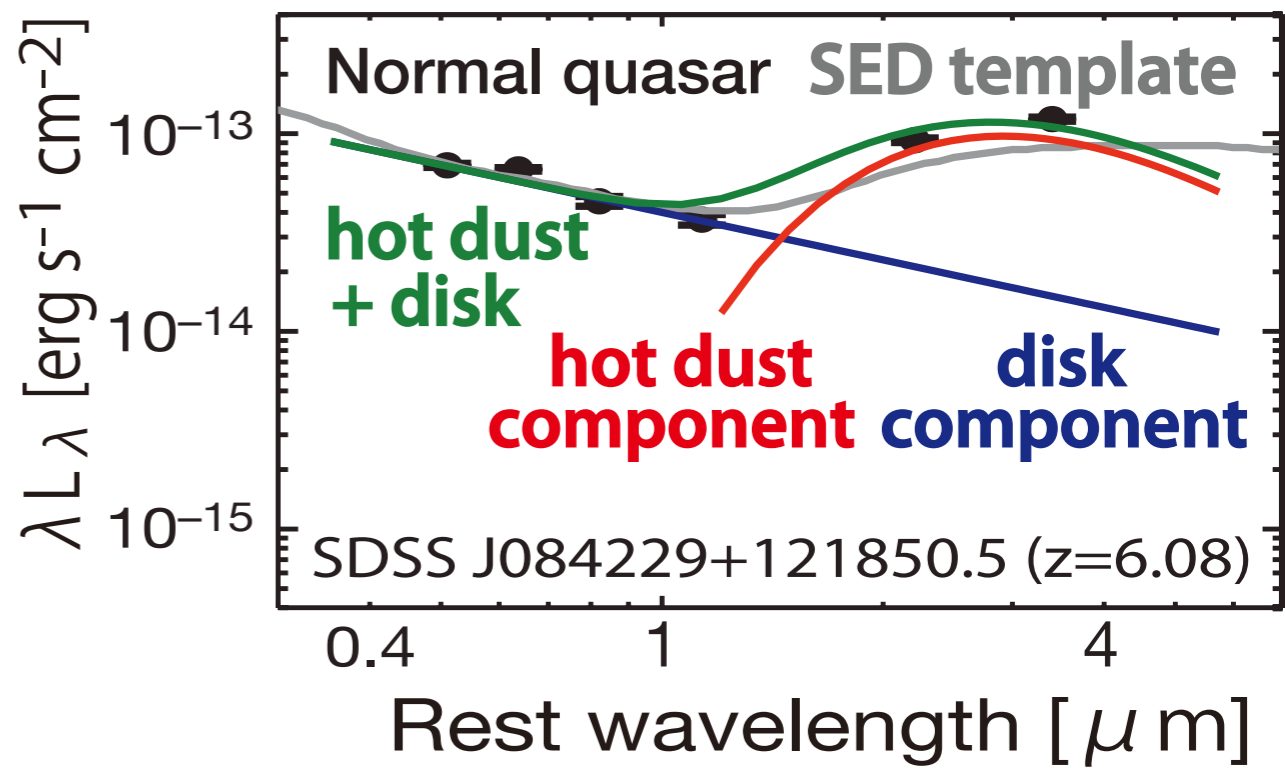
Linhua Jiang , Xiaohui Fan, W. N. Brandt, Chris L. Carilli, Eiichi Egami, Dean C. Hines, Jaron D. Kurk, Gordon T. Richards, Yue Shen, Michael A. Strauss, Marianne Vestergaard & Fabian Walter

Nature **464**, 380–383 (18 March 2010)
 doi:10.1038/nature08877
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Received: 23 November 2009
 Accepted: 26 January 2010
 Published online: 18 March 2010

Hot dust-free quasars (DFQs) at $z \sim 6$

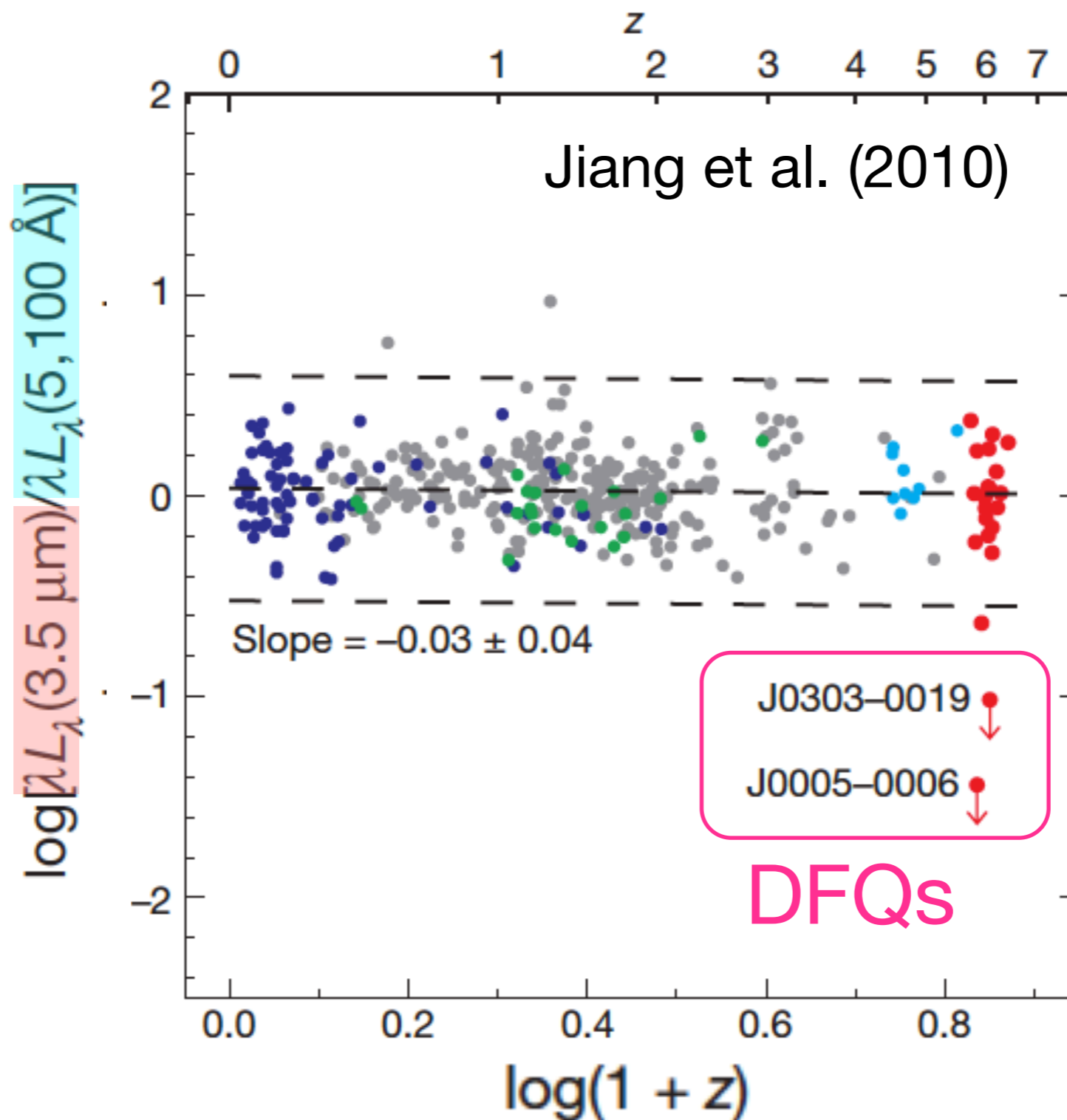


Jiang et al. (2010)

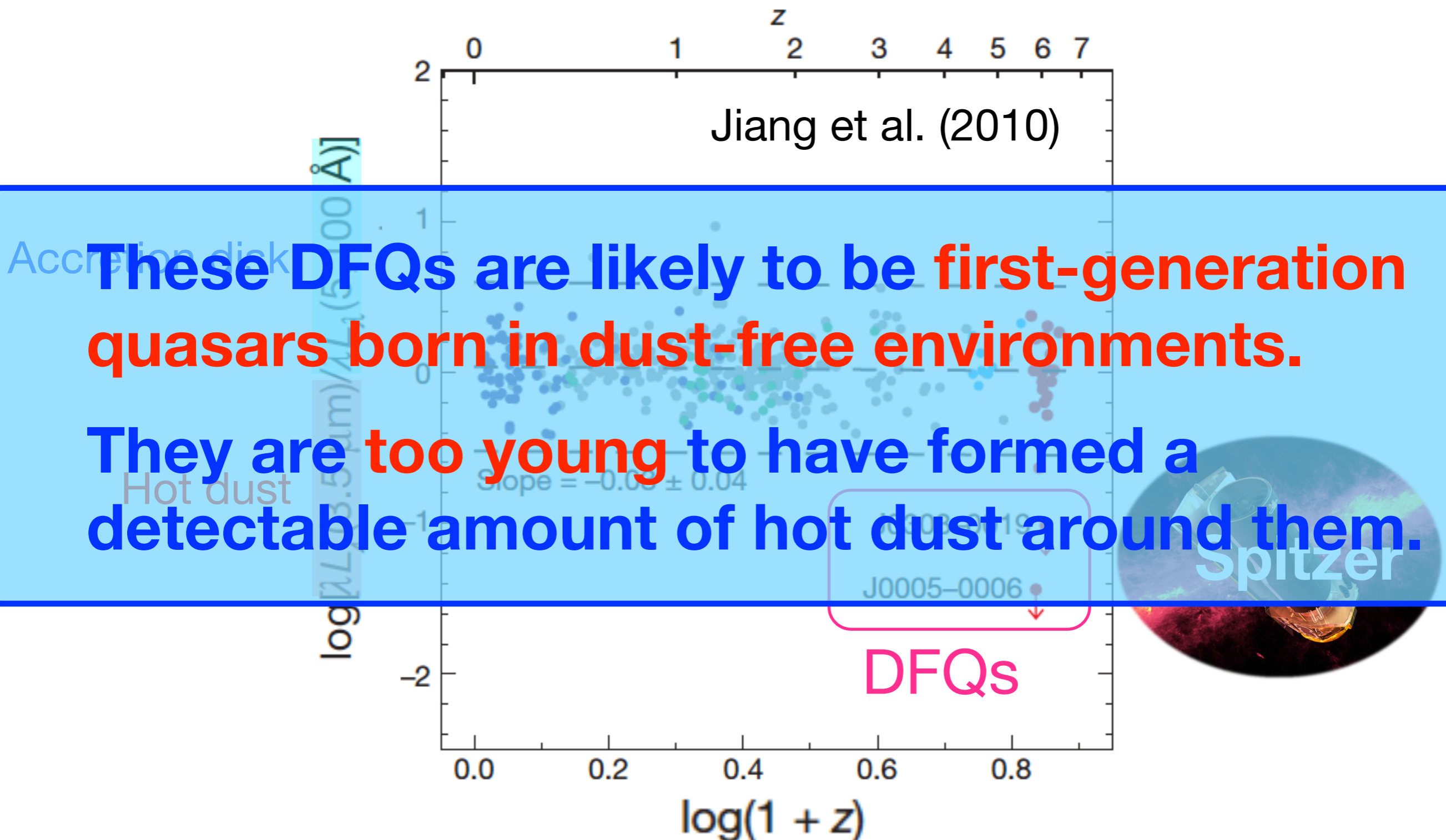
Hot dust-free quasars (DFQs)

Accretion disk

Hot dust



Hot dust-free quasars (DFQs)



These DFQs are likely to be **first-generation quasars born in dust-free environments.**

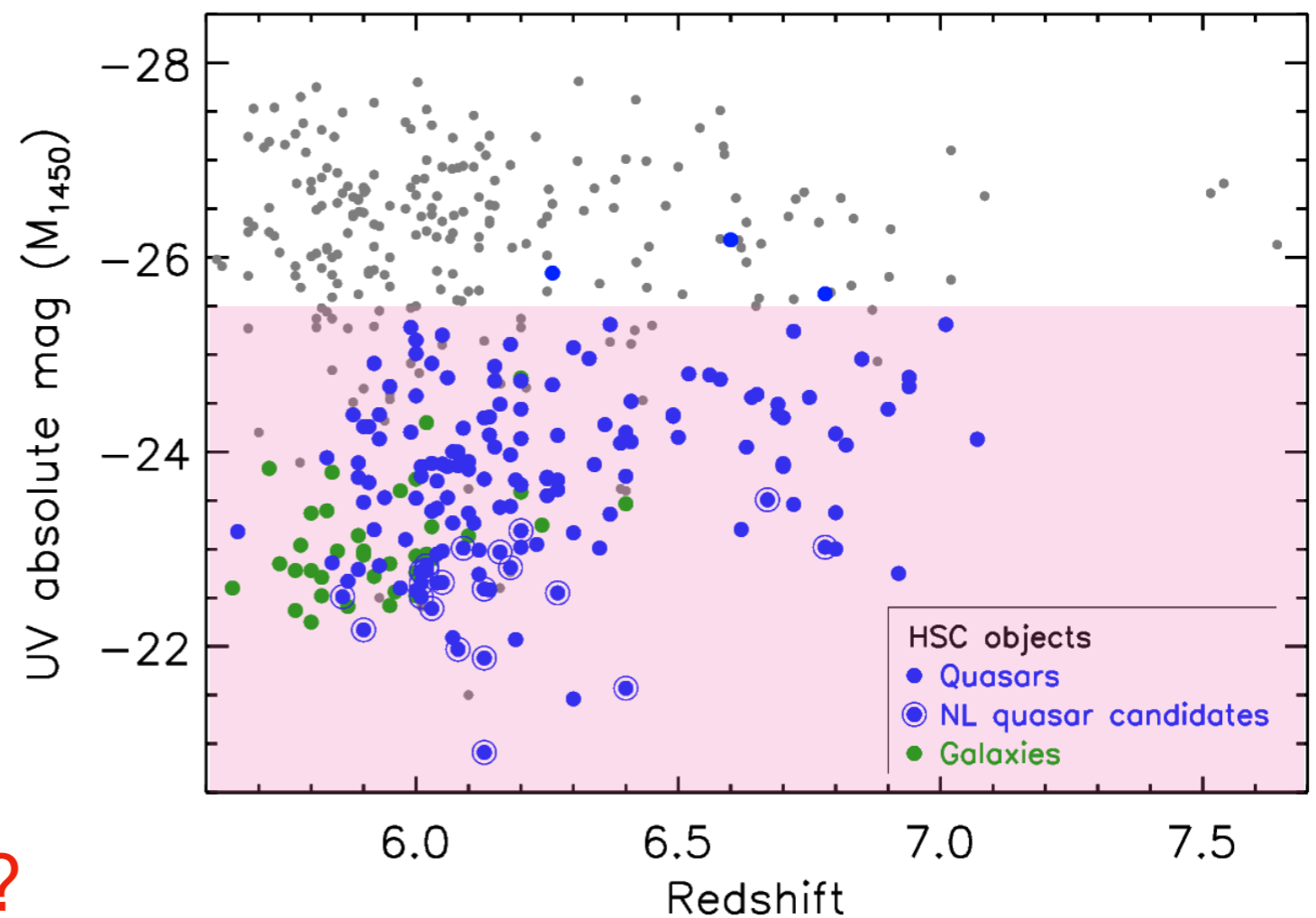
They are **too young** to have formed a detectable amount of hot dust around them.

We know only two DFQs at $z \sim 6$

name	z	M_{1450}
SDSS J0005-0006	5.84	-25.73
SDSS J0303-0019	6.07	-25.56

Eilers et al. (2017)

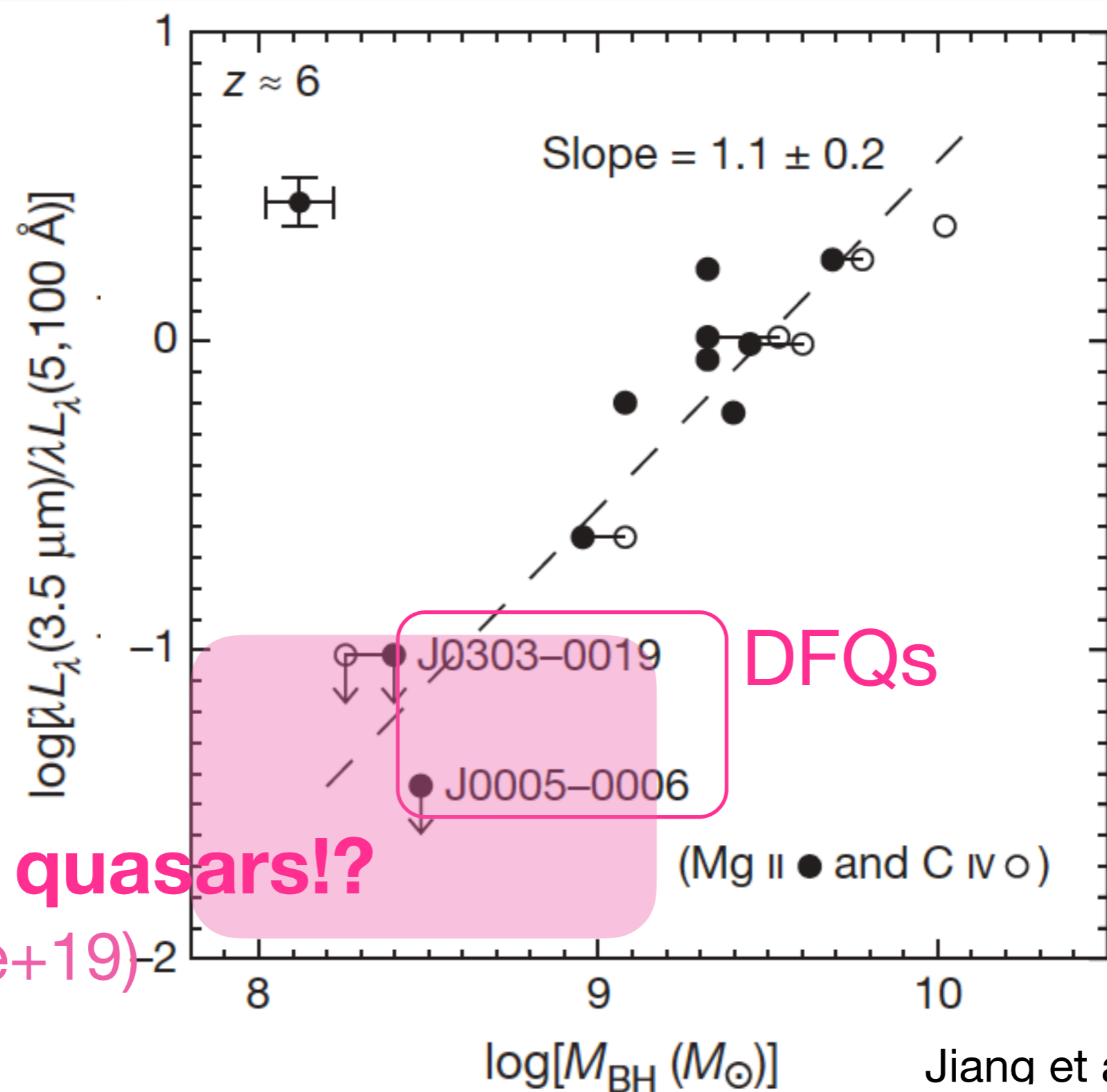
- We have investigated only luminous quasars selected with SDSS.



- How about less luminous quasars selected with HSC?

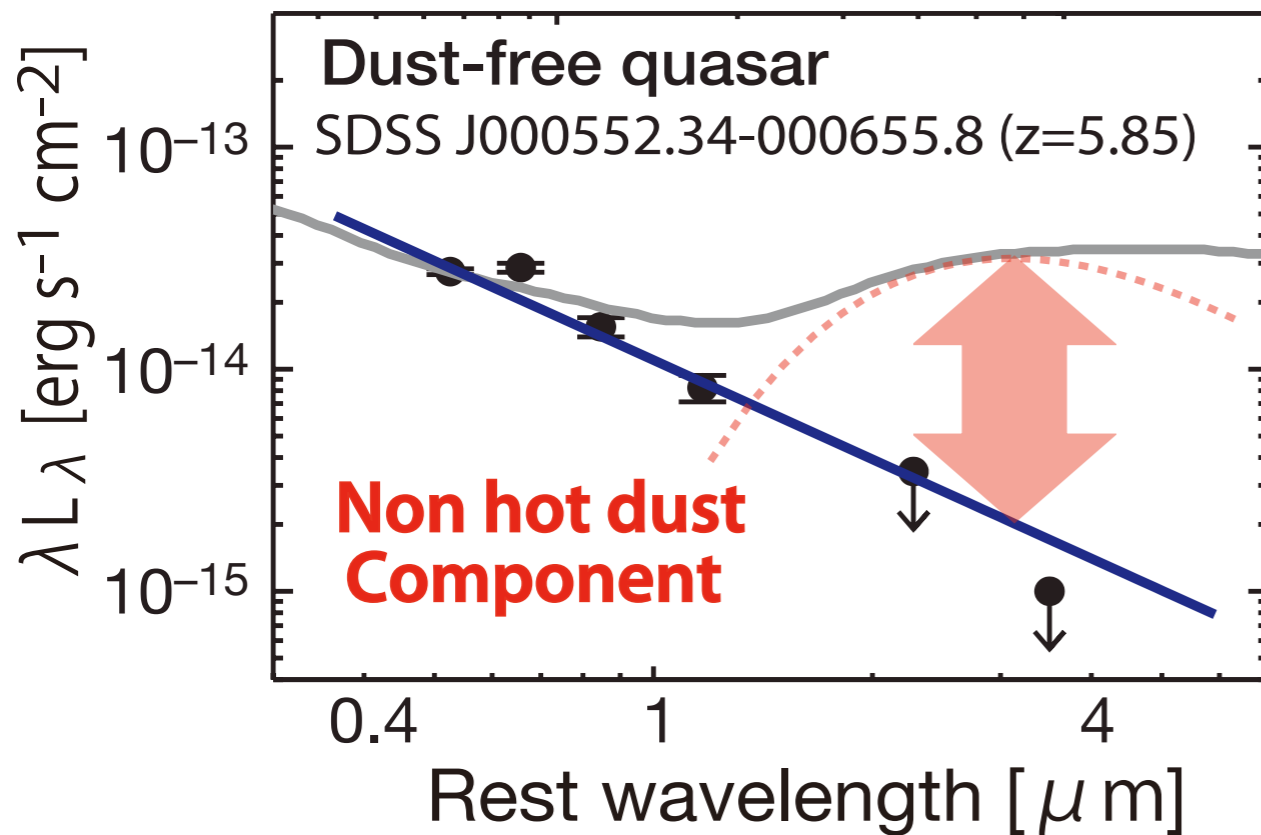
(see Matsuoka+16,18abc,19ab, 21)

M_{BH} dependence on the hot-dust abundance



SHELLQs quasars!?
(e.g., Onoue+19)

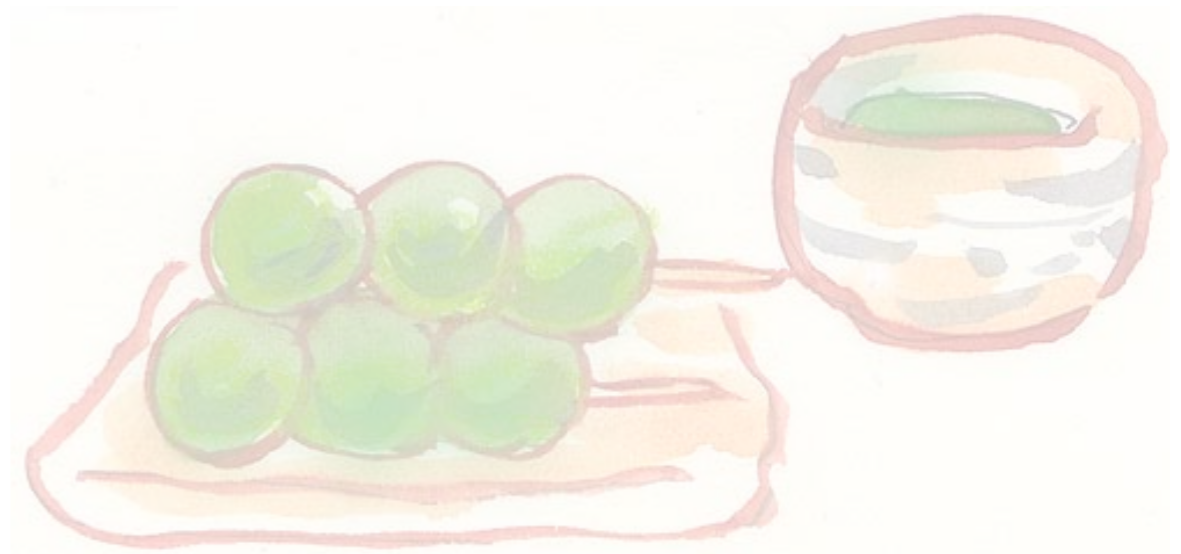
JWST/SPICA proposal



Sample selection	Follow-up obs.	Luminosity
SDSS	Spitzer	high L
HSC	JWST SPICA	low L

- Investigating **hot dust properties** of less luminous quasars.
- Search for **DFQs** in the early Universe.

How do their NIR-FIR SEDs look like?



NIR-FIR SED of luminous quasars at $z > 5$

<https://ui.adsabs.harvard.edu/abs/2014ApJ...785..154L/abstract>

SPECTRAL ENERGY DISTRIBUTIONS OF QSOs AT $z > 5$: COMMON ACTIVE GALACTIC NUCLEUS-HEATED DUST AND OCCASIONALLY STRONG STAR-FORMATION

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X. FAN⁴, M. HAAS⁵, O. KRAUSE¹, AND H.-W. RIX¹

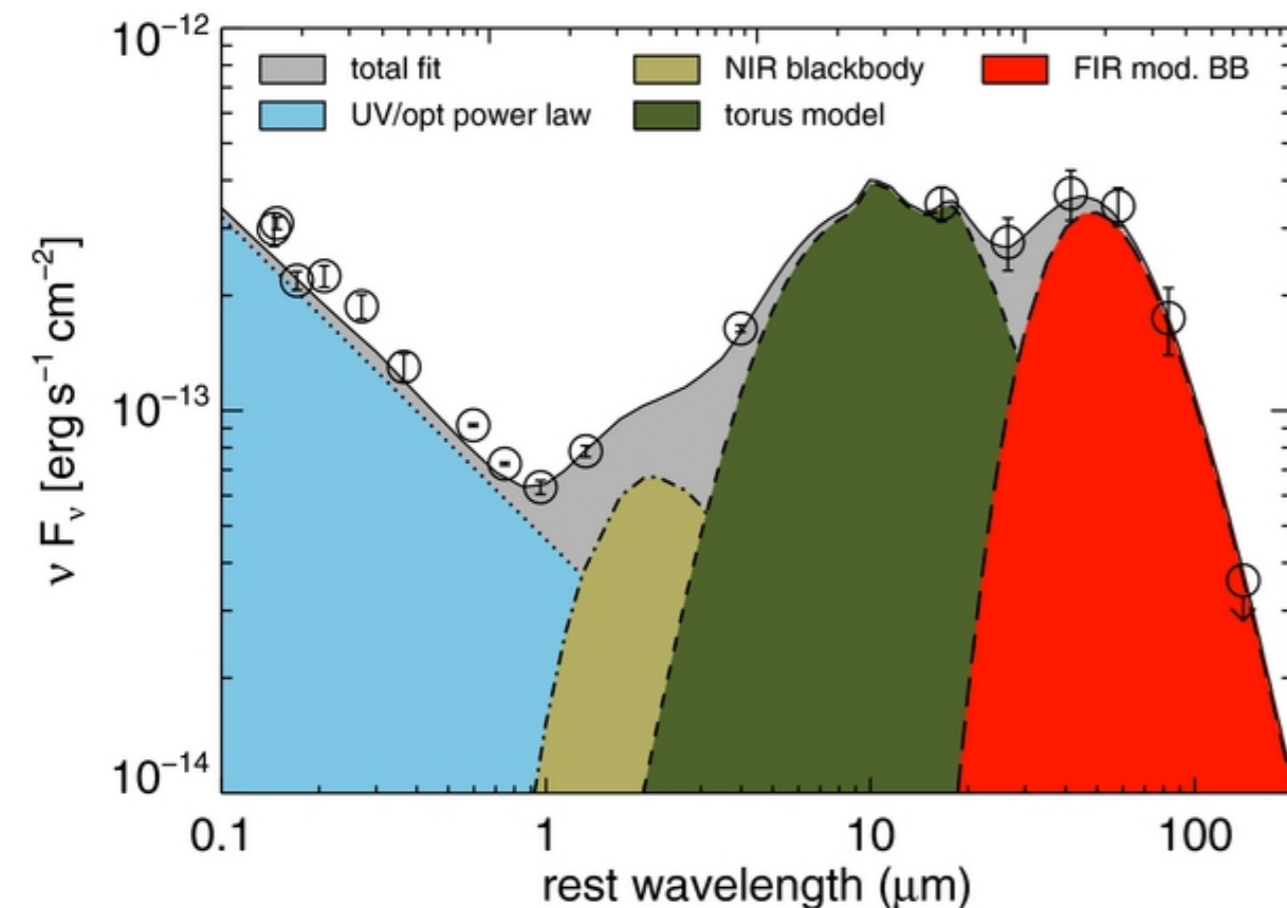
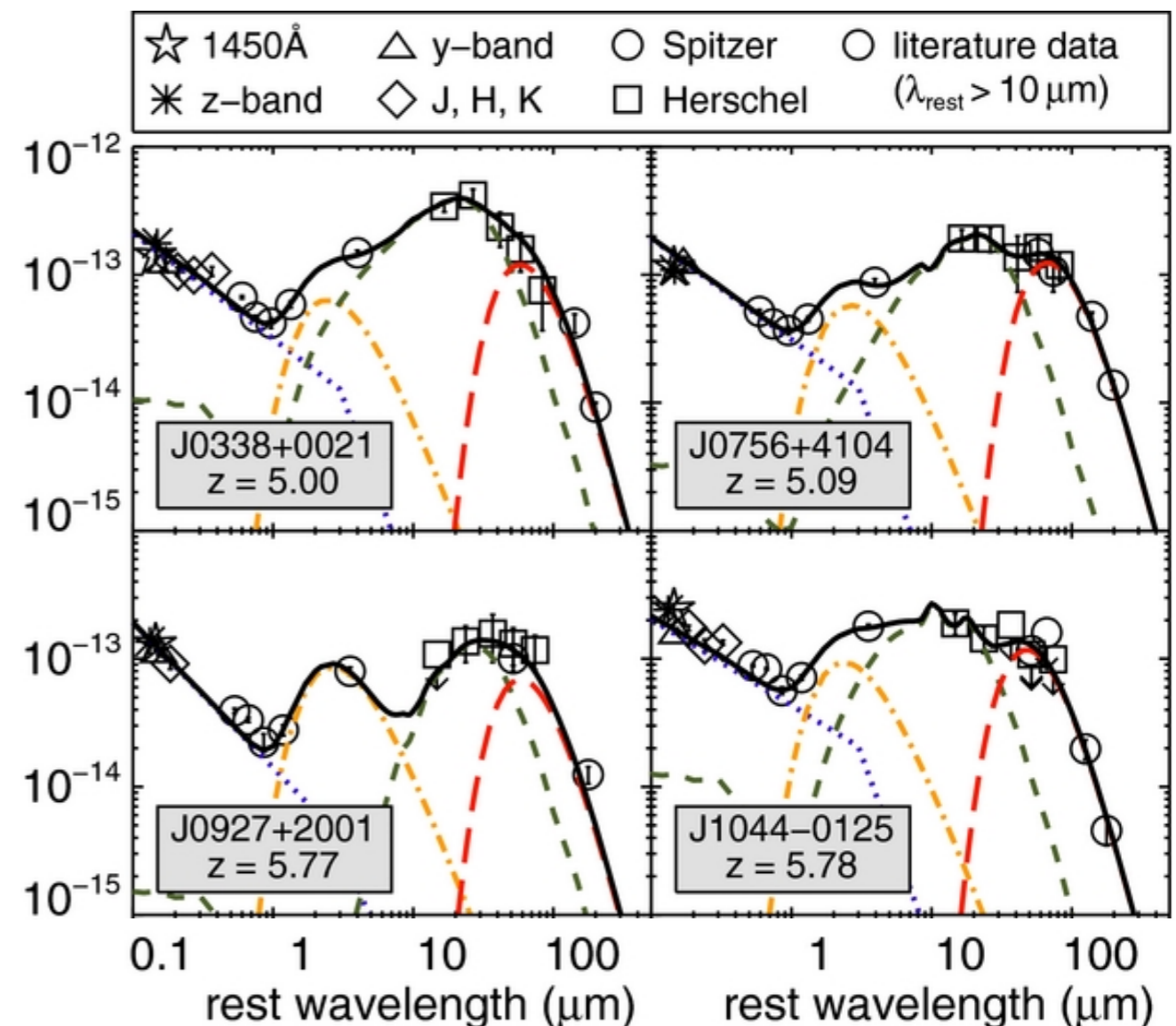


Figure 2. Schematic representation of the components used for SED fitting. As an example, we use the observed photometry of the $z = 5.03$ QSO J1204-0021.



NIR-FIR SED of luminous quasars at $z > 5$

<https://ui.adsabs.harvard.edu/abs/2014ApJ...785..154L/abstract>

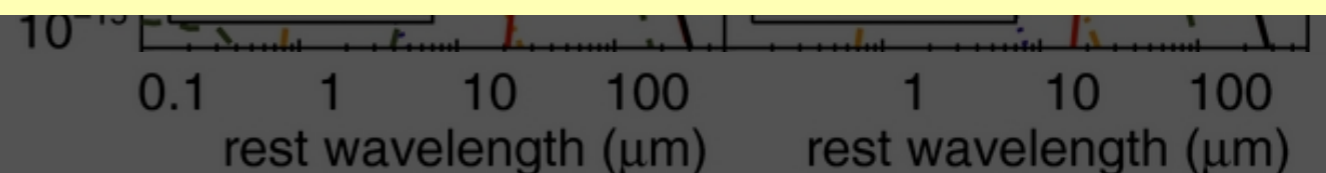
SPECTRAL ENERGY DISTRIBUTIONS OF QSOs AT $z > 5$: COMMON ACTIVE GALACTIC NUCLEUS-HEATED DUST AND OCCASIONALLY STRONG STAR-FORMATION

SPIRE で受かった天体は **12/69 (17%)**
(うち、 $z > 6$ は 3天体)

ダスト温度が決まった天体は **6/69 (8%)**
(うち、 $z > 6$ は 1天体)

(それ以外は $T_{\text{dust}} = 47 \text{ K}$ でfixして解析)

used for SED fitting. As an example, we use the observed photometry of the $z = 5.03$ QSO J1204-0021.



SPICAで検討した high-z AGN サイエンスの紹介と

南極テラヘルツ望遠鏡への展望

$z > 6$

GREX-PLUS

南極THz望遠鏡

南極テラヘルツ望遠鏡によるhigh-z AGN 研究

高感度・多周波観測が活きるサイエンス

- Unobscured AGN (quasars) の FIR SED 【追観測】

広視野が活きるサイエンス

- Obscured AGN at $z > 4$ 【探査】

南極 12m テラヘルツ望遠鏡(ATT12) の感度－連続波－

	Freq. [GHz]	HPBW [“]	η_A	B [BHz]	NEFD [mJy s ^{1/2}]	Sensitivity		Confusion 5 σ [mJy]
						5 σ_{rms} [mJy]		
						$\tau = 1\text{hr}$	10 hr	
PWV=0.14mm (冬季 50% level)								
$\epsilon = 20 \mu\text{m}$	100	61.8	0.695	30	10.75	0.896	0.283	
	230	26.9	0.674	35	10.62	0.885	0.280	1.38
	300	20.6	0.657	35	10.53	0.877	0.278	1.89
	350	17.7	0.642	35	12.20	1.017	0.322	2.055
	400	15.5	0.626	40	13.89	1.158	0.366	2.28
	460	13.4	0.603	46	17.88	1.490	0.471	2.43
	500	12.4	0.587	50	23.33	1.944	0.615	2.445
	650	9.5	0.521	65	22.67	1.889	0.598	1.965
	850	7.3	0.422	85	44.33	3.694	1.169	2.49
	1000	6.2	0.347	50	488.14	40.678	12.866	1.71
	1300	4.8	0.306	65	460.95	38.413	12.150	0
	1500	4.1	0.144	75	978.70	81.558	25.796	0
	2000	3.1	0.060	50	8594.30	716.191	226.523	0

$z > 6$

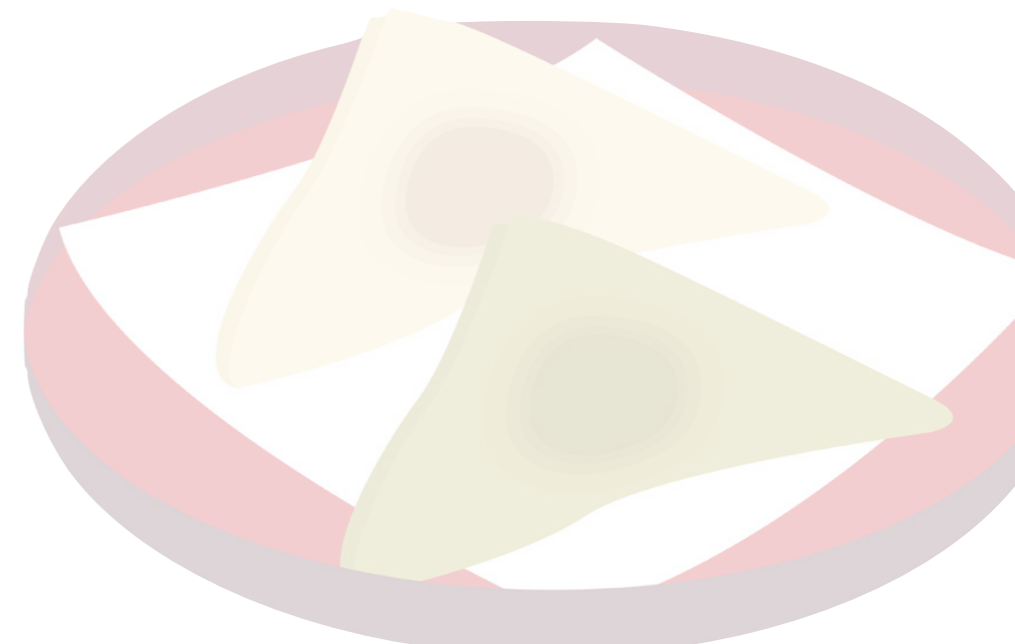
GREX-PLUS

南極THz望遠鏡

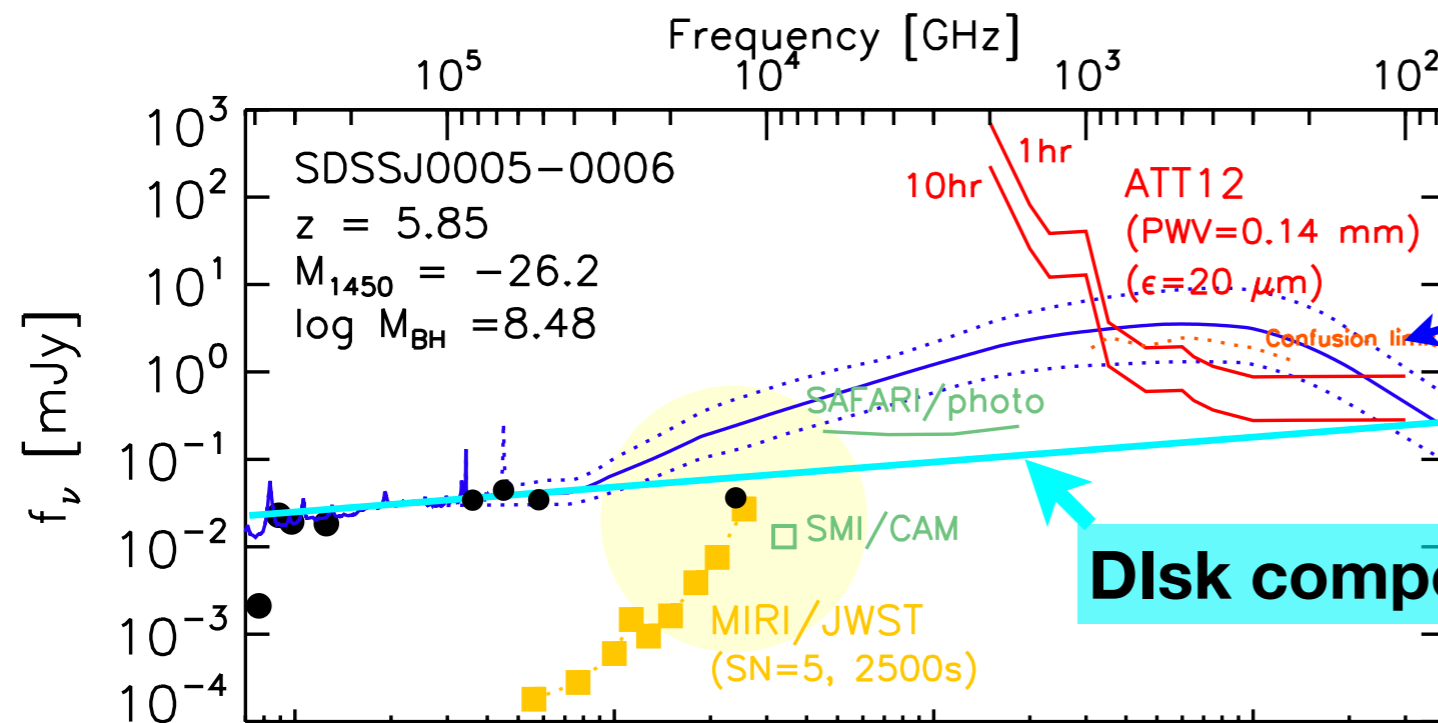
高感度・多周波観測が活きるサイエンス

Unobscured AGN (quasars) の FIR SED 【追観測】

- Hot dust-free quasars
- Low-luminosity quasars
- High-luminosity quasars

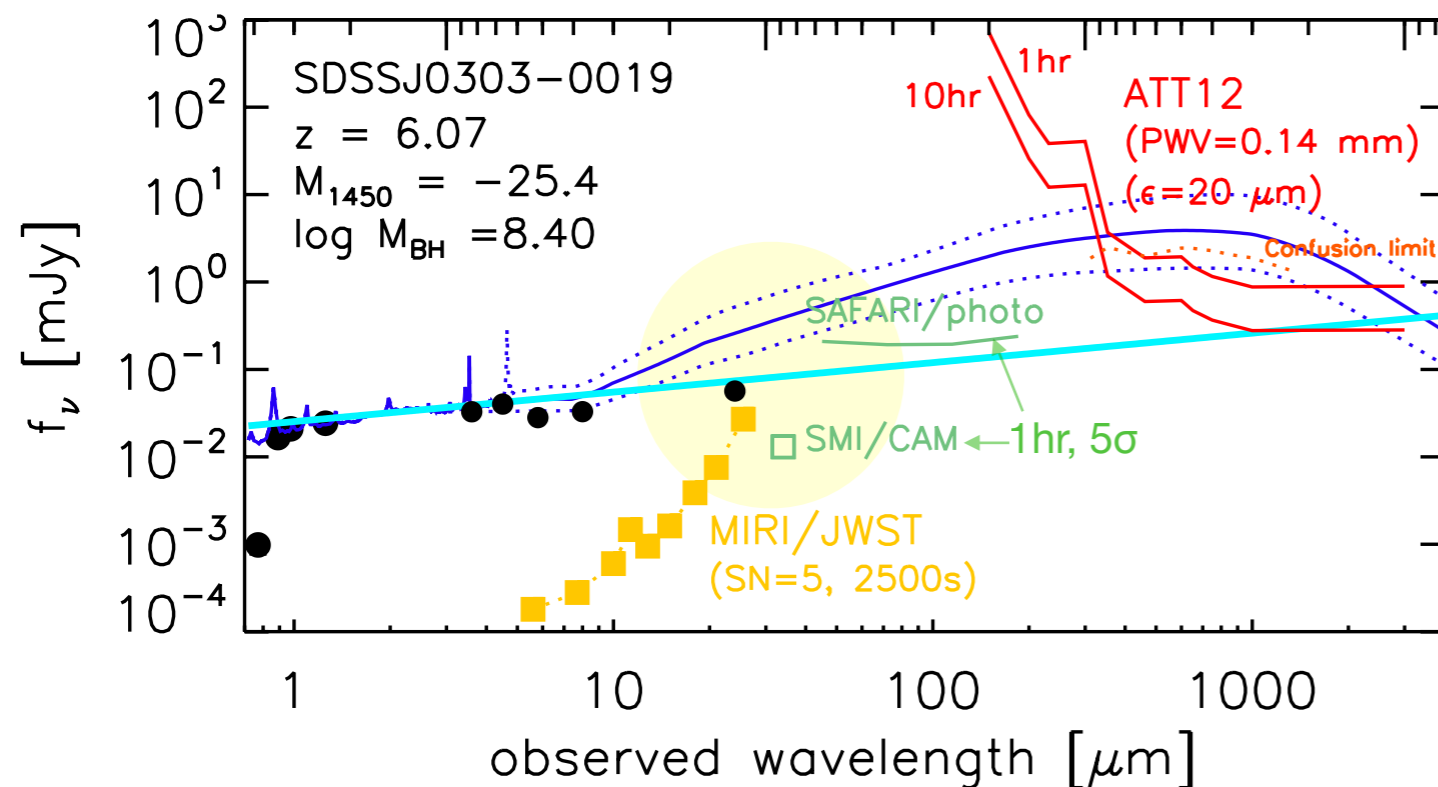


SDSS hot dust-free quasars (DFQs)



SWIRE QSO1 template (Polletta+07), scaled by y-band flux

Disk component

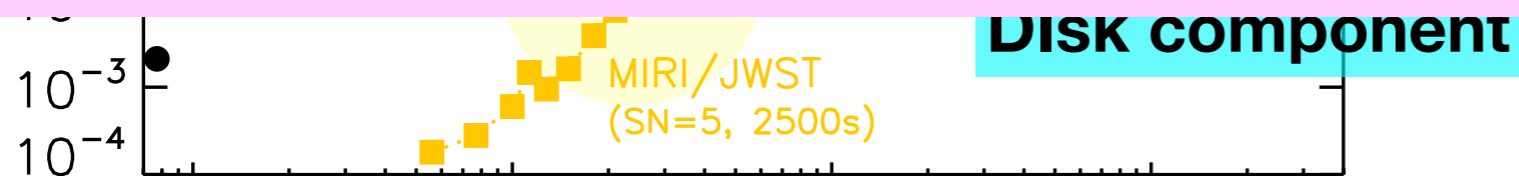


SPICAを用いることで、SDSS Hot DFQsの warm dust の有無は検証できそうだった

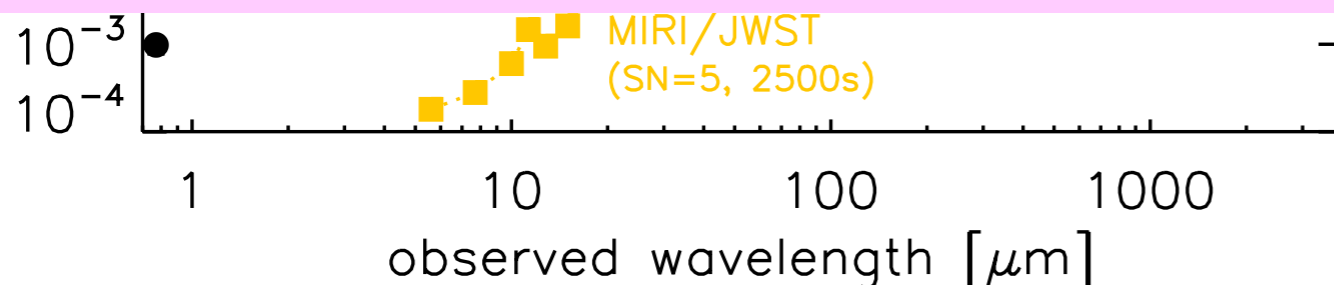
SDSS hot dust-free quasars (DFQs)

Frequency [GHz]

cold dust poor でない場合は
ATT12 で **cold dust** 放射を検出可能！

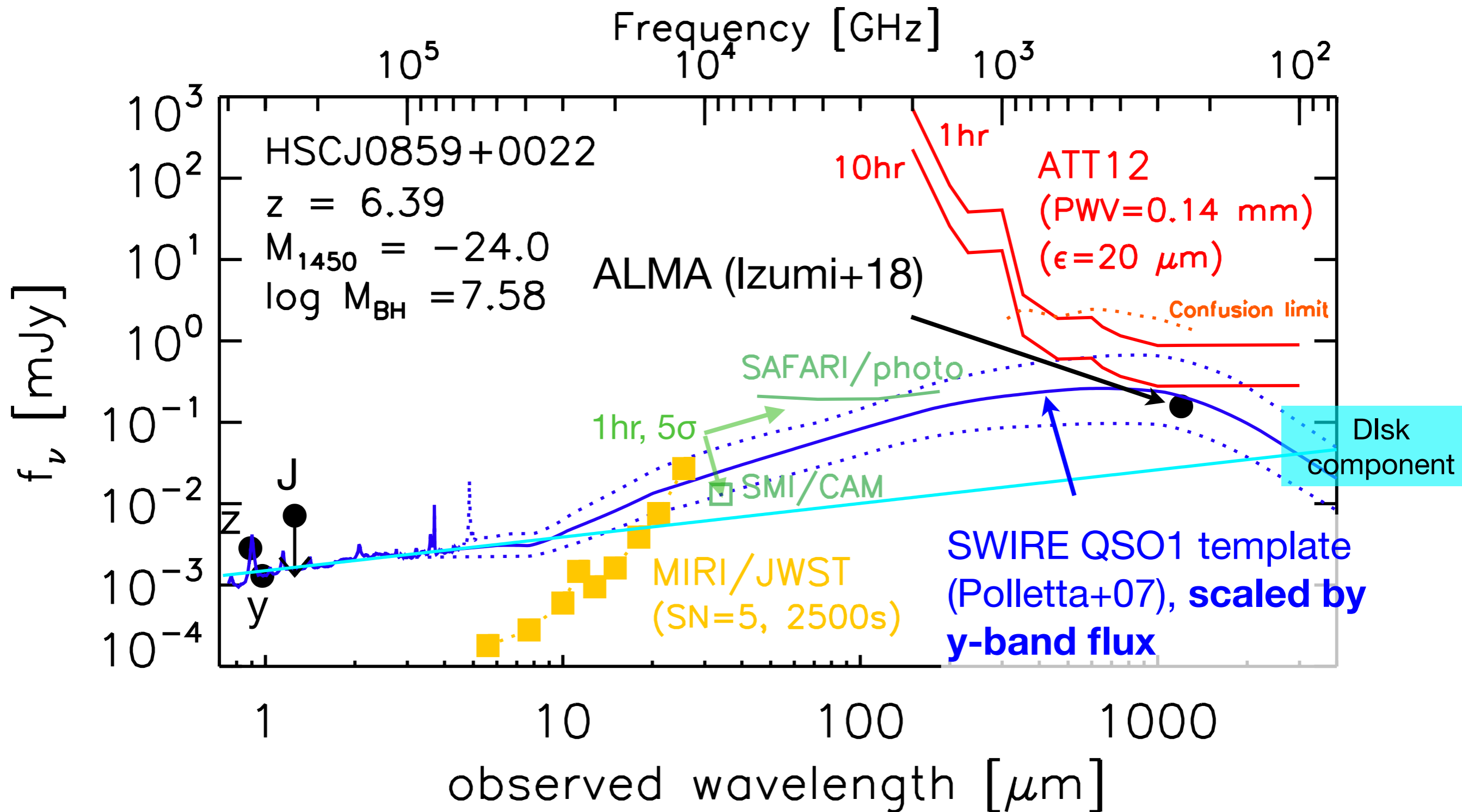


ATT30なら **cold dust free** か否かも
含めて判断可能！？

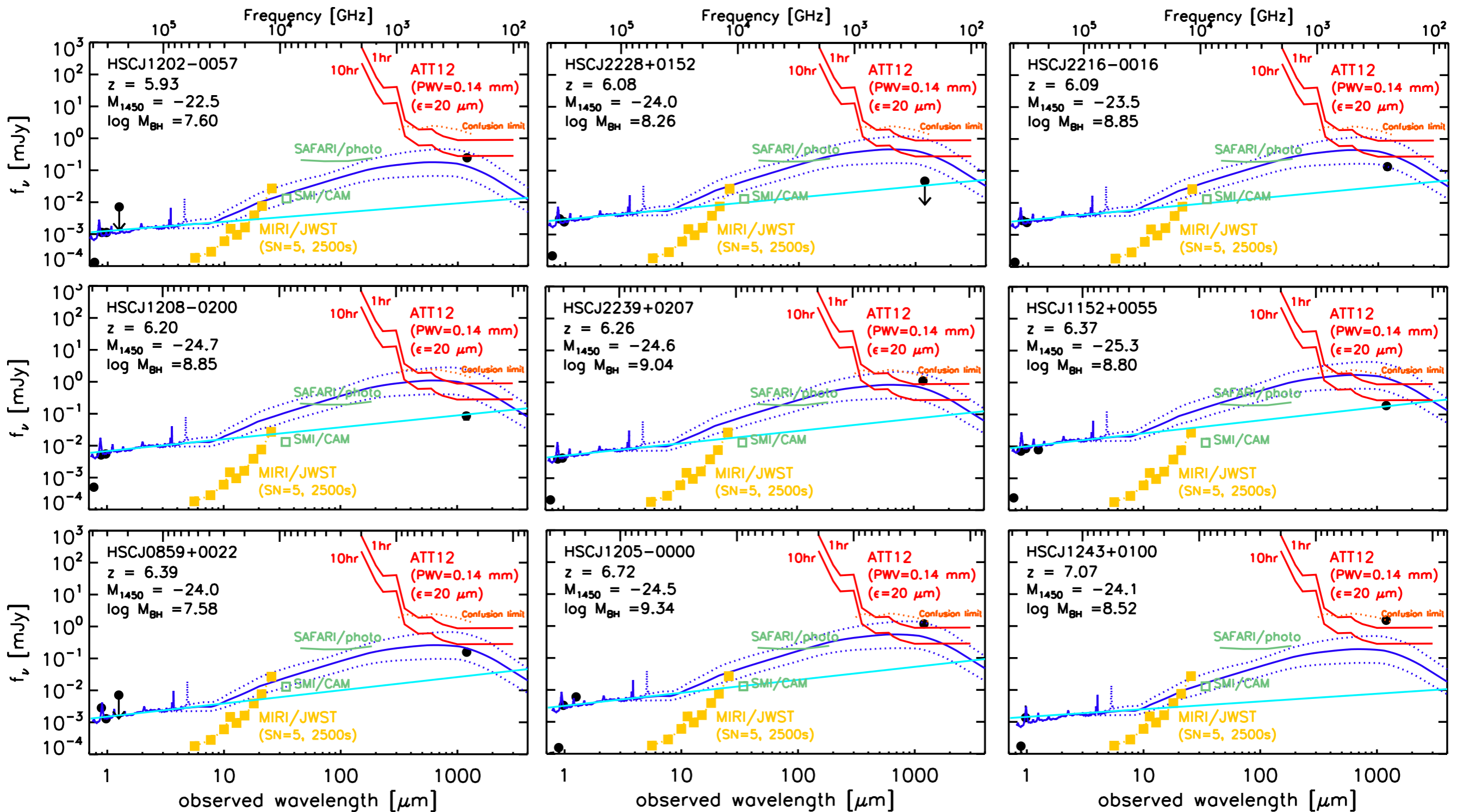


は検証できそつたつた

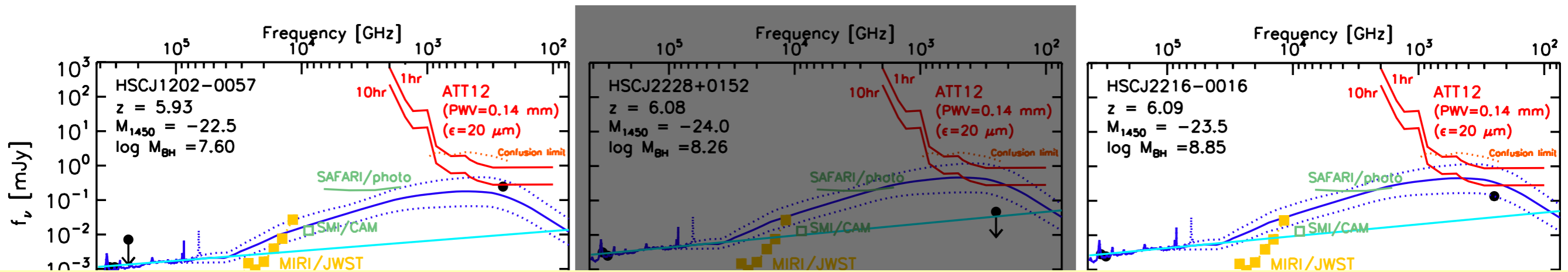
A low-L HSC quasar



SEDs of SHELLQs quasars with M_{BH}

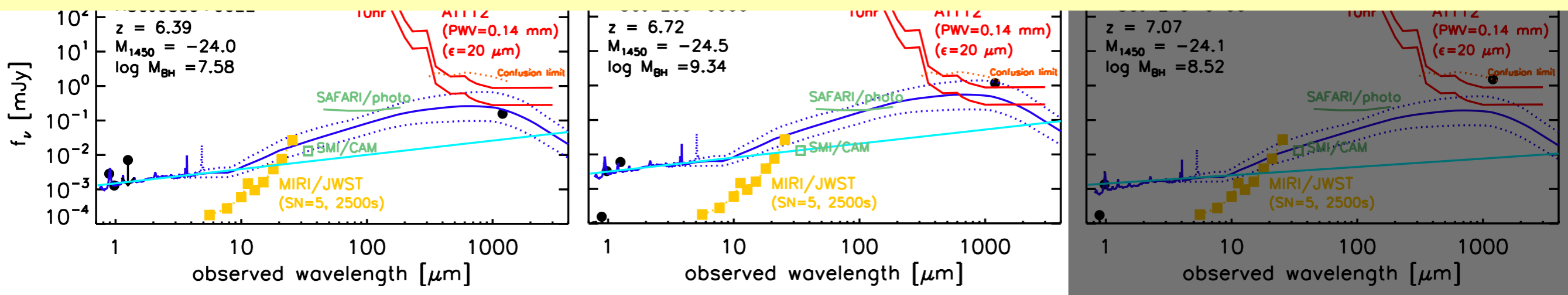


SEDs of SHELLQs quasars with M_{BH}

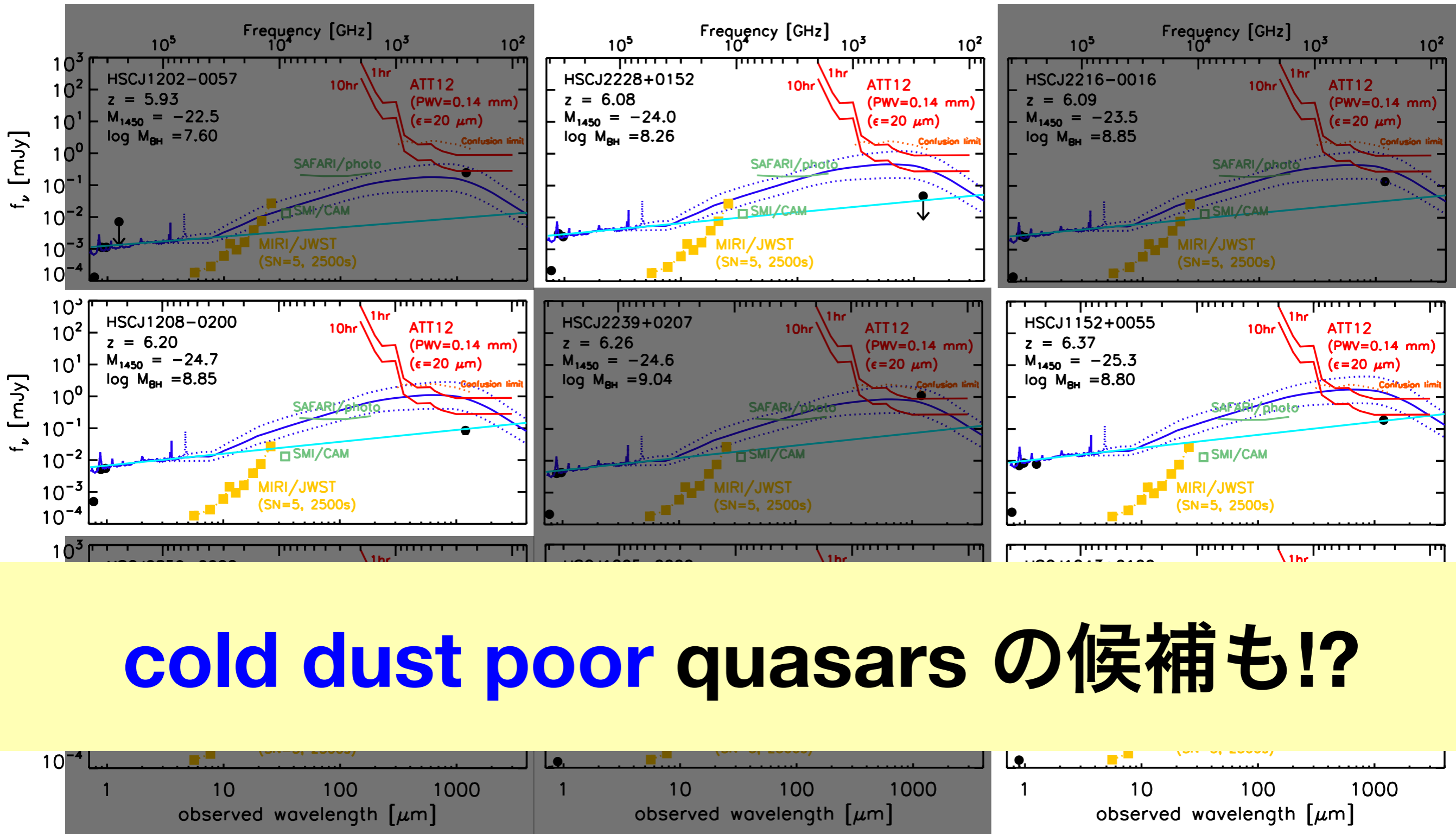


典型的な type 1 AGN template で

FIR が説明できる天体が多い!?

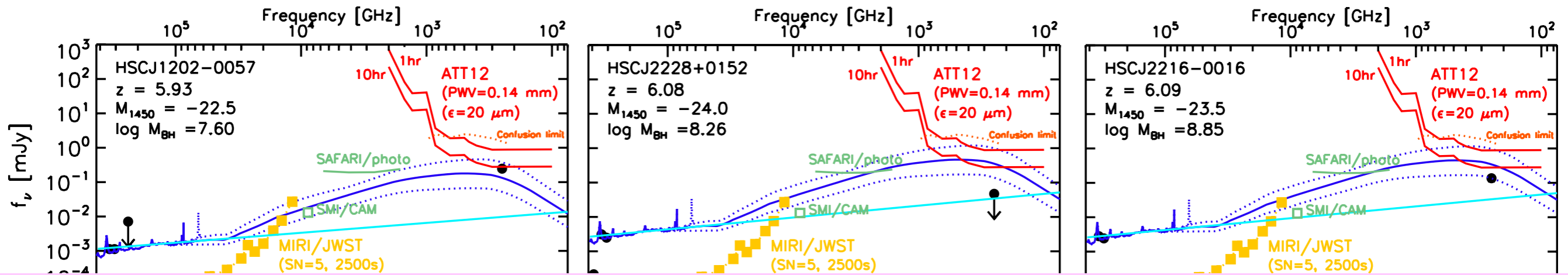


SEDs of SHELLQs quasars with M_{BH}

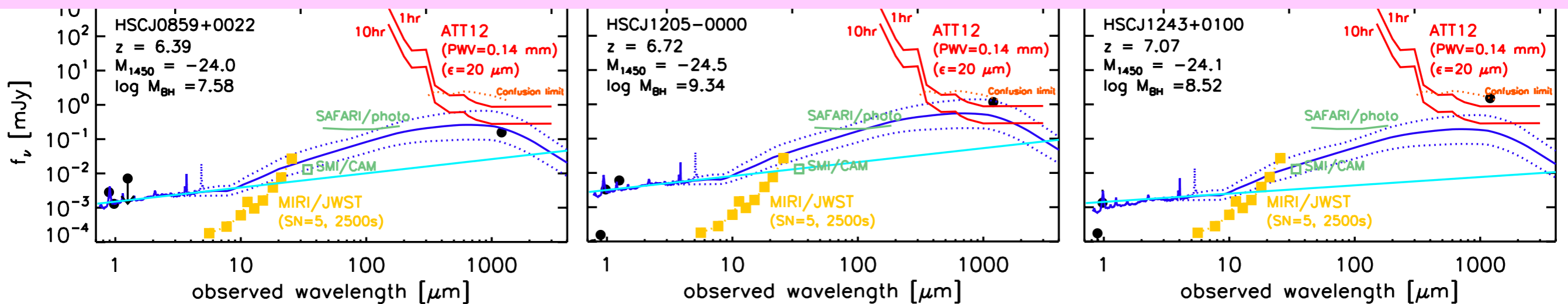


cold dust poor quasars の候補も!?

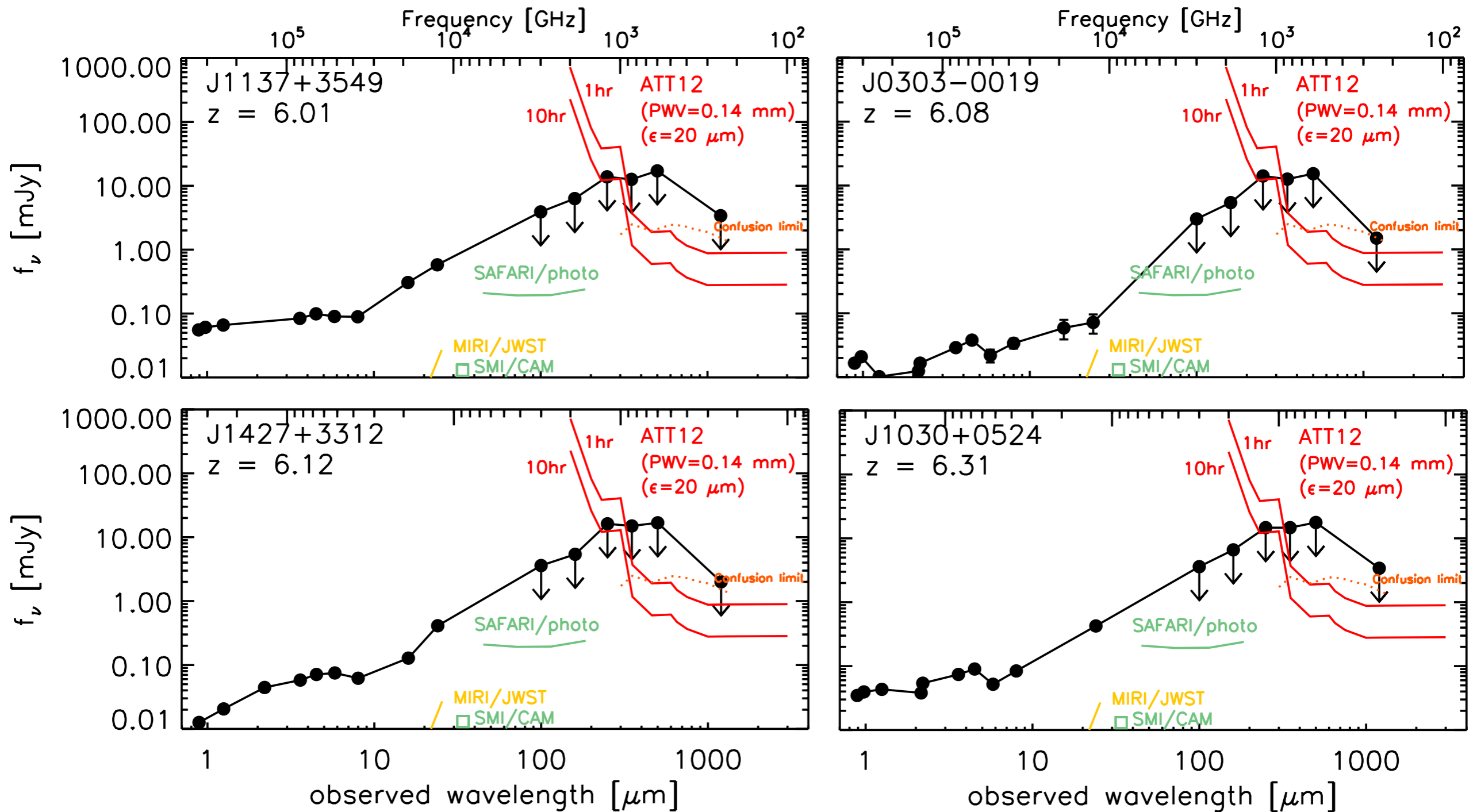
SEDs of SHELLQs quasars with M_{BH}



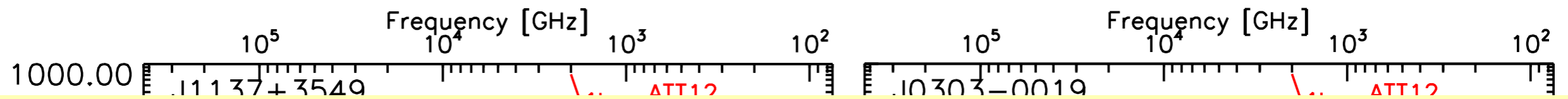
low-L quasars の FIR SED 系統的調査
は ATT30 の時代に本格化できそう



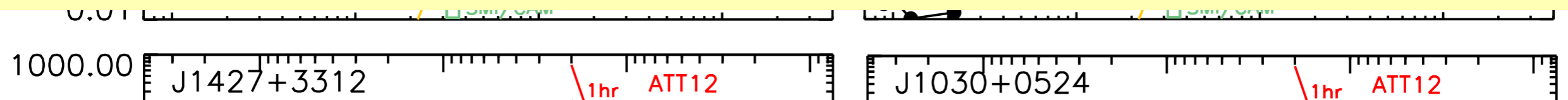
SEDs of high-L SDSS quasars at $z > 6$



SEDs of high-L SDSS quasars at $z > 6$



High- z bright quasars の **rest FIR SED**
(T_{dust} , M_{dust}) の系統的調査が可能に！



これから見つかってくるであろう

$z > 7,8$ 天体とも相性抜群

1 10 100 1000
observed wavelength [μm]

1 10 100 1000
observed wavelength [μm]

$z > 6$

GREX-PLUS

南極THz望遠鏡

広視野が生きるサイエンス

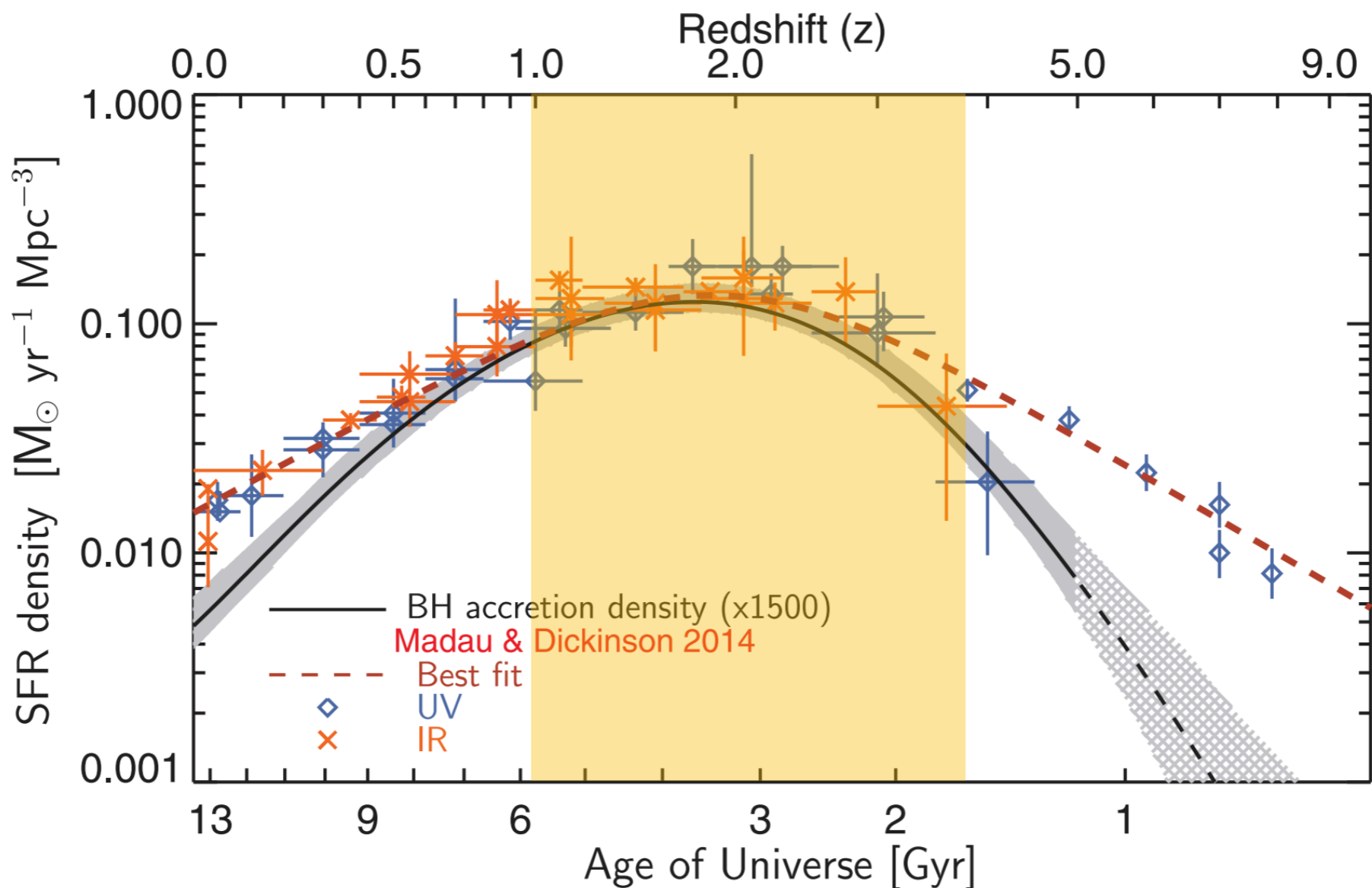
Obscured AGN at $z > 4$ 【探査】

- Optically-dark AGN
- Roman “drop-out”

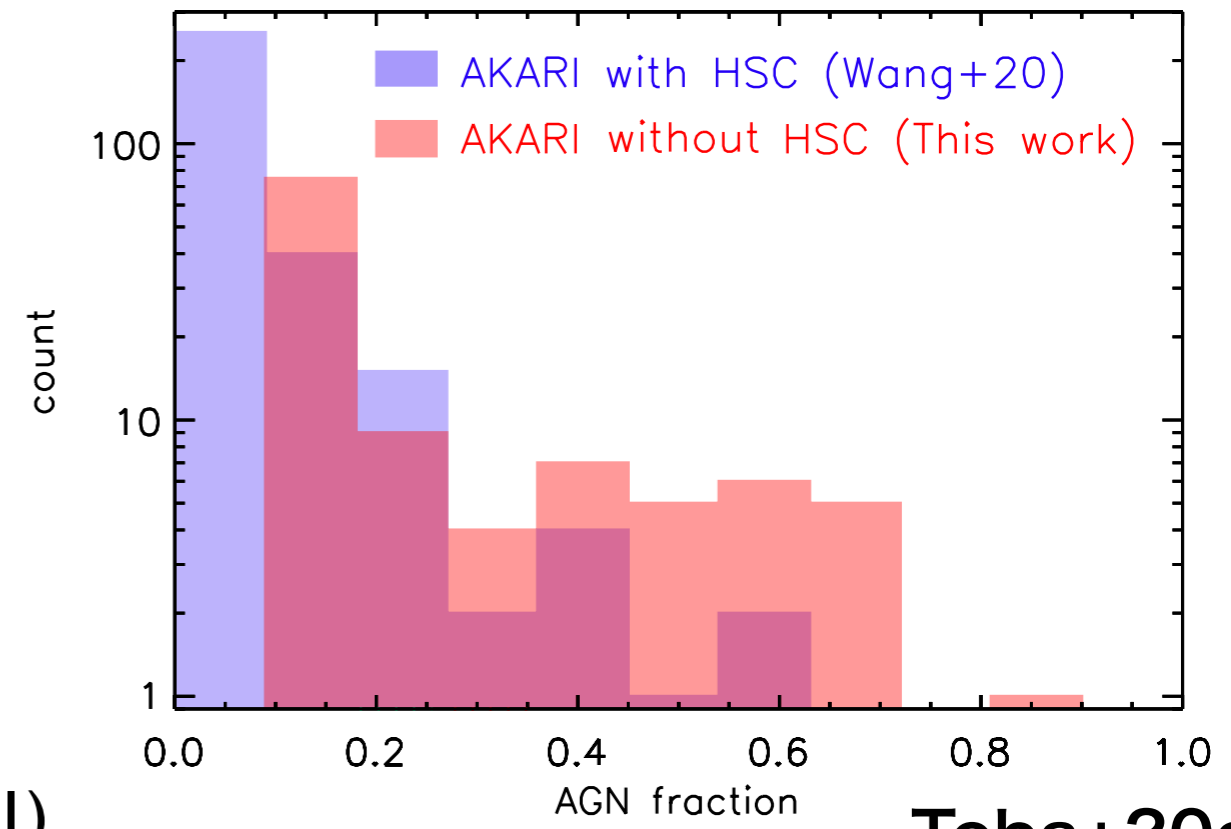
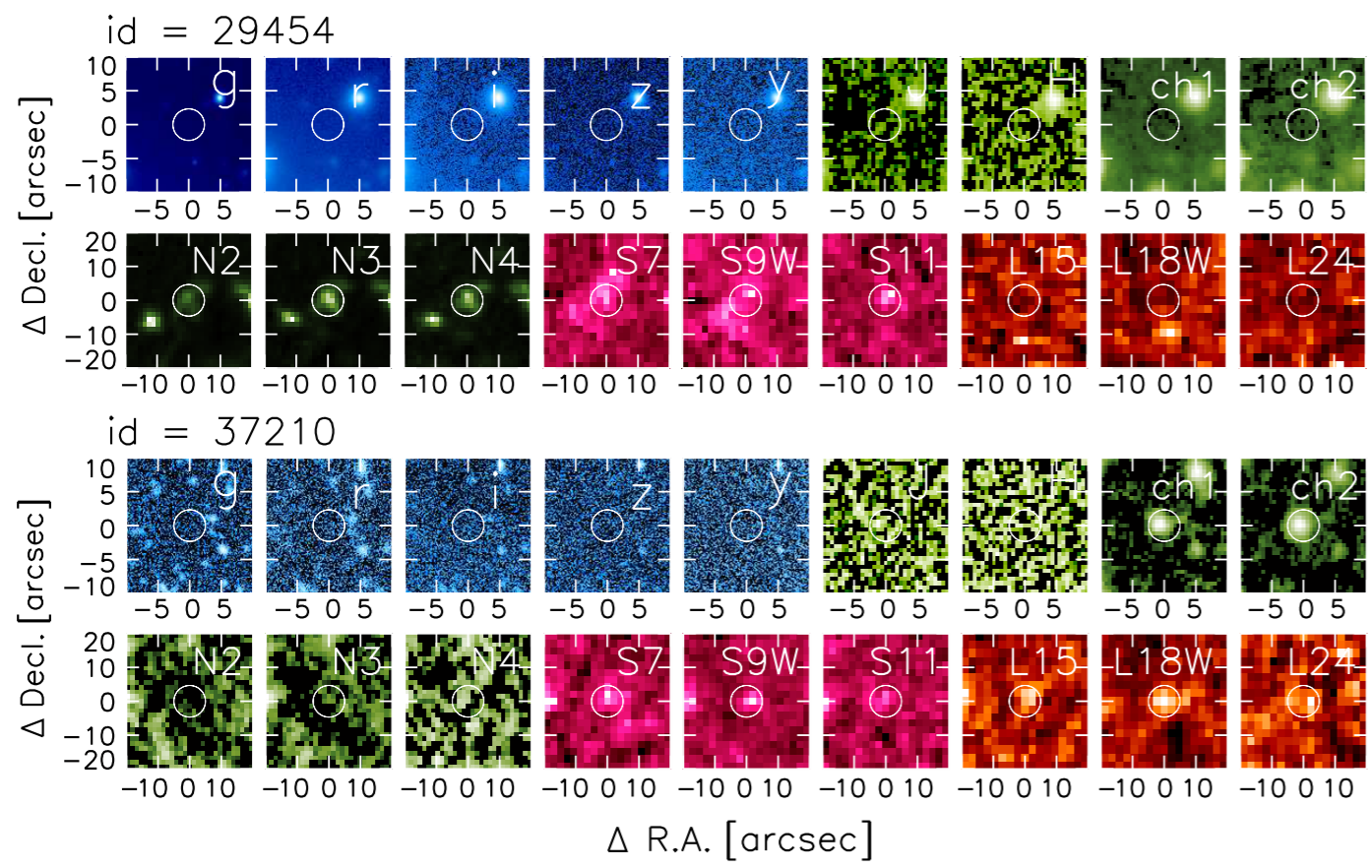
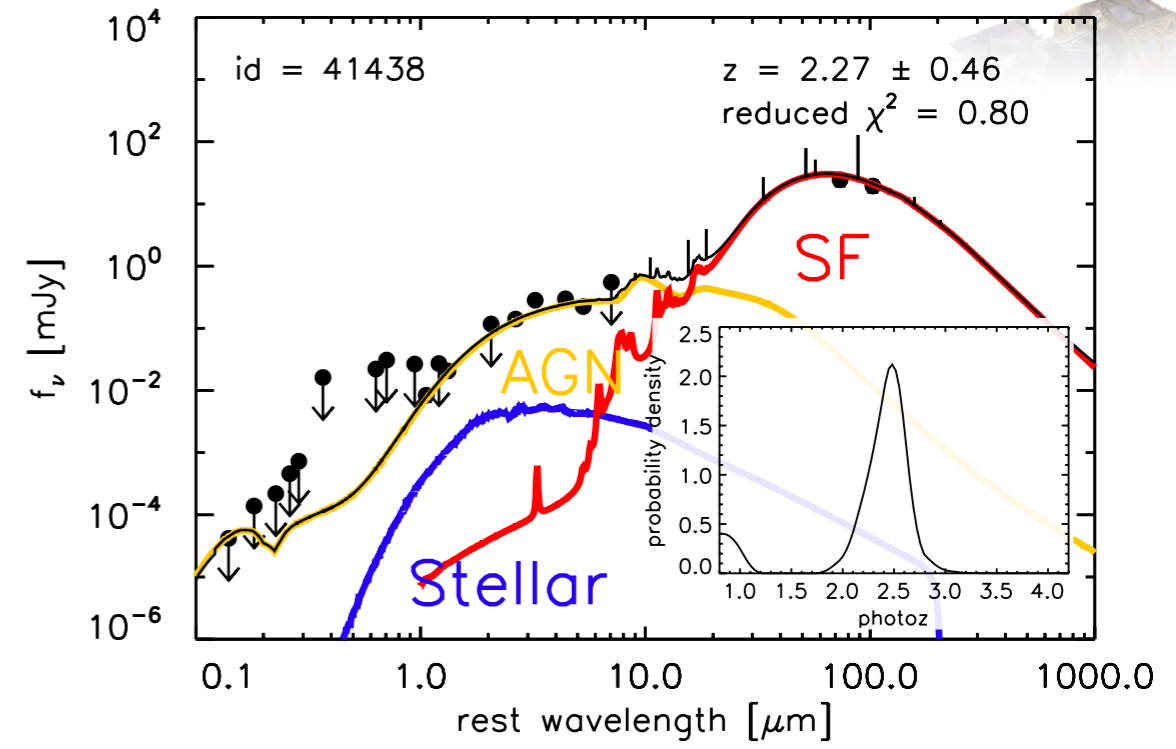
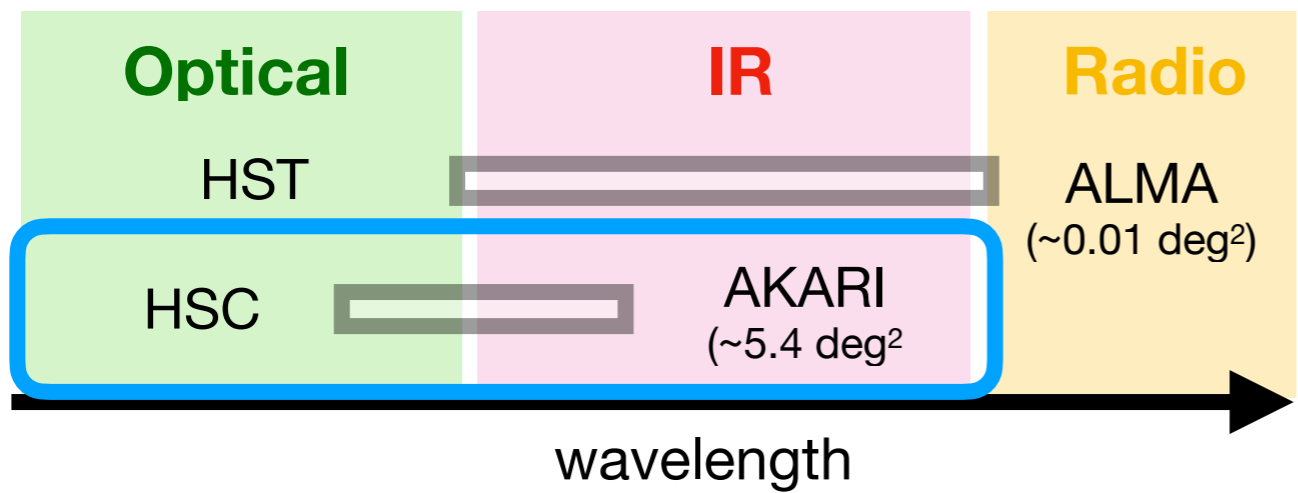
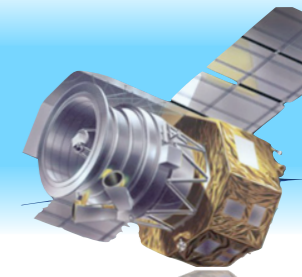


何を明らかにしたいか

Optically-dark AGN が
宇宙のSMBHの質量降着史に果たした役割

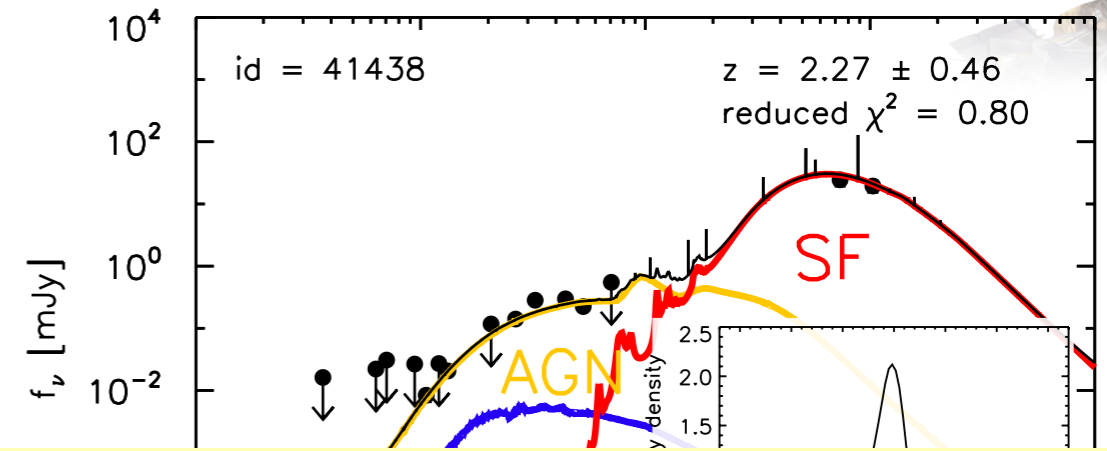
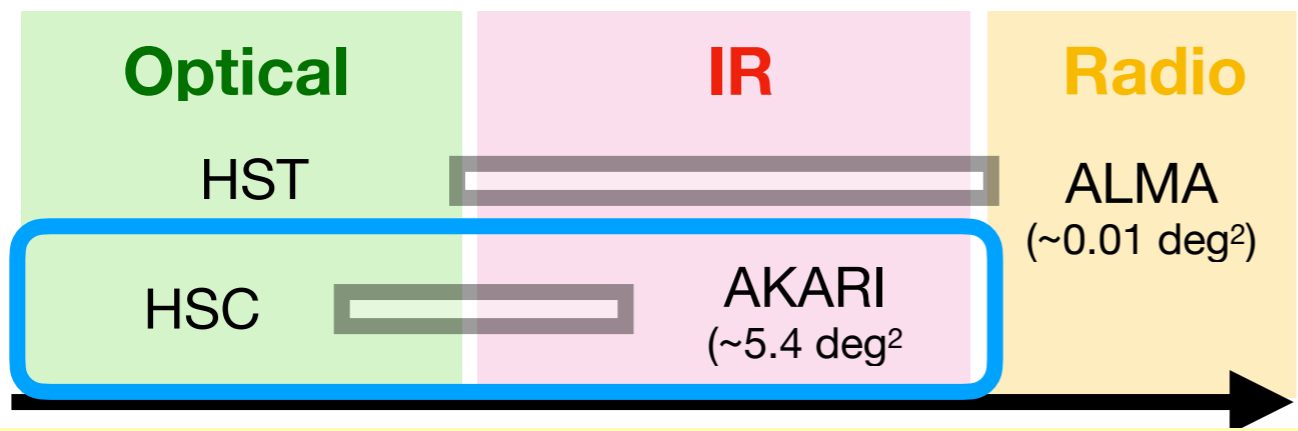
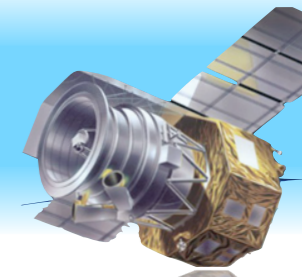


Optically dark AGN in the AKARI-NEP

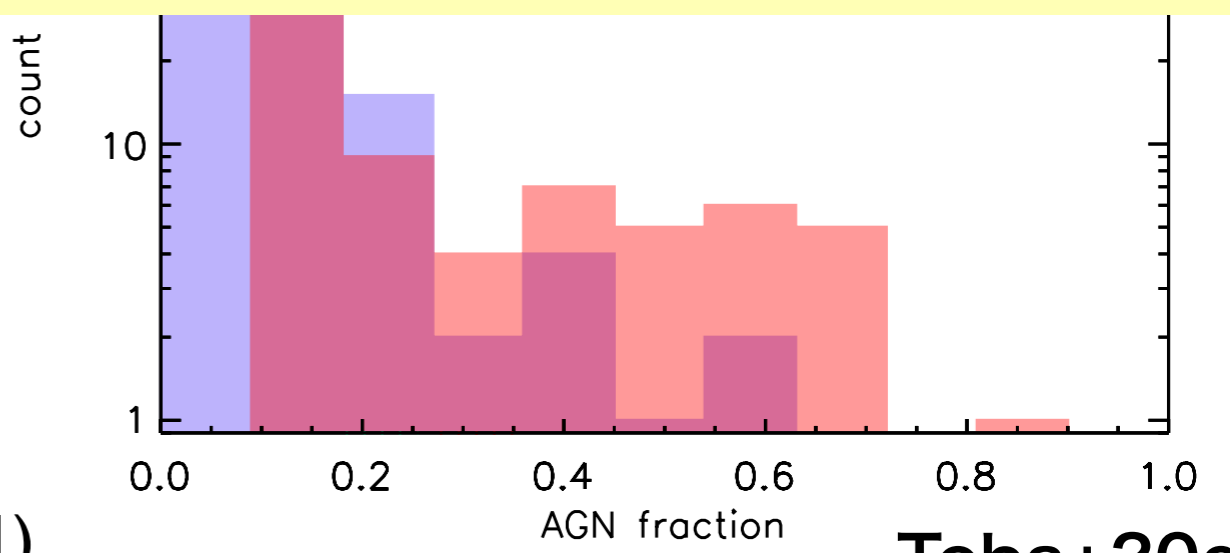
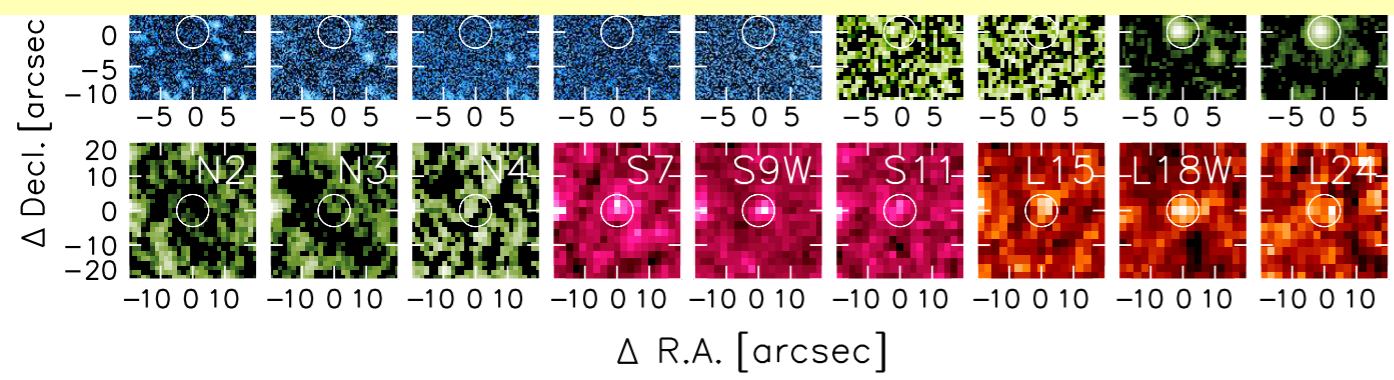


(see also, e.g., Hughes+98, Williams+19, Yamaguchi+19, Wang+19, Umehata+20, Smail+21)

Optically dark AGN in the AKARI-NEP

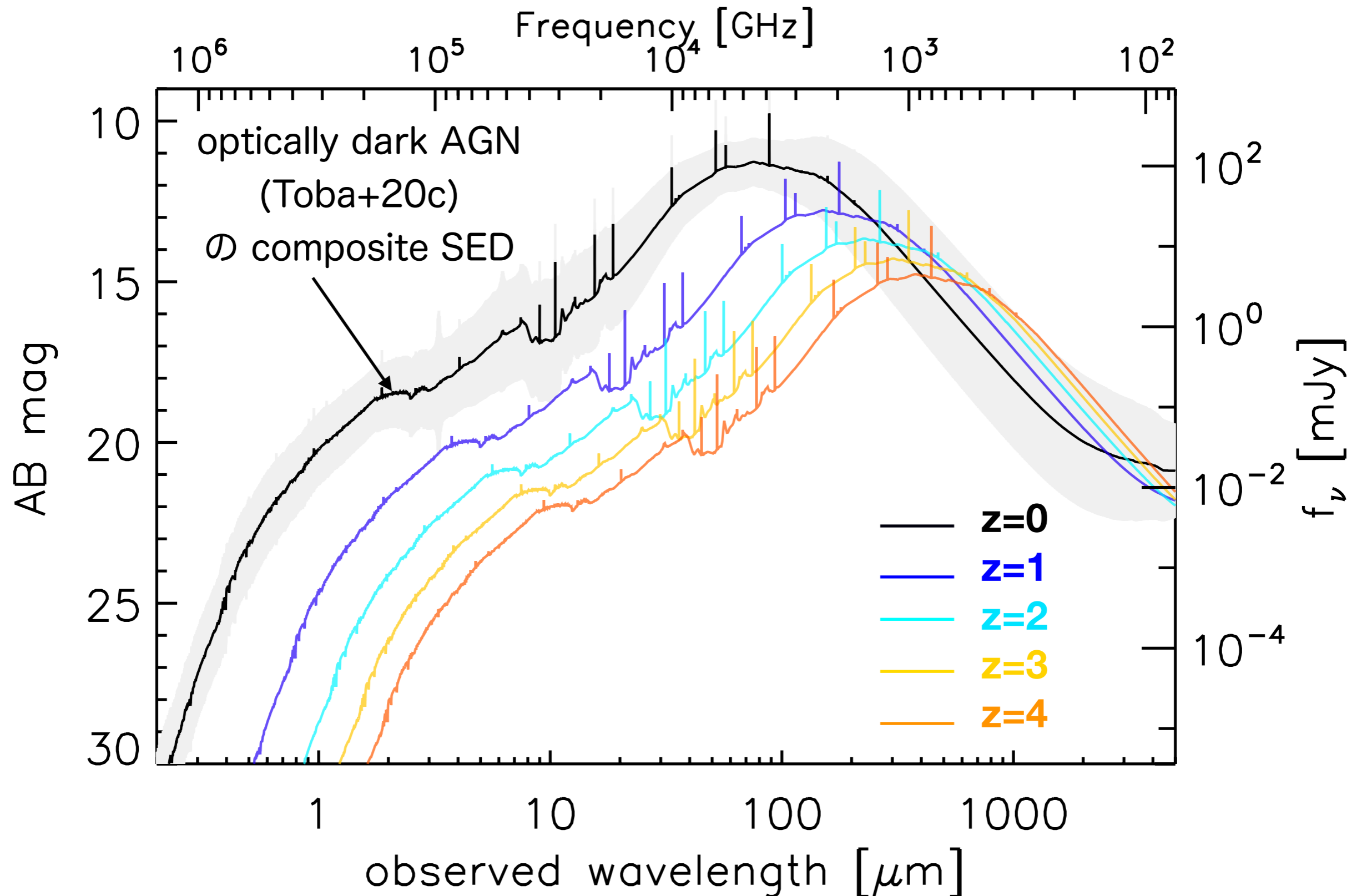


AGN-dominant と期待できる
optically dark 銀河の発見

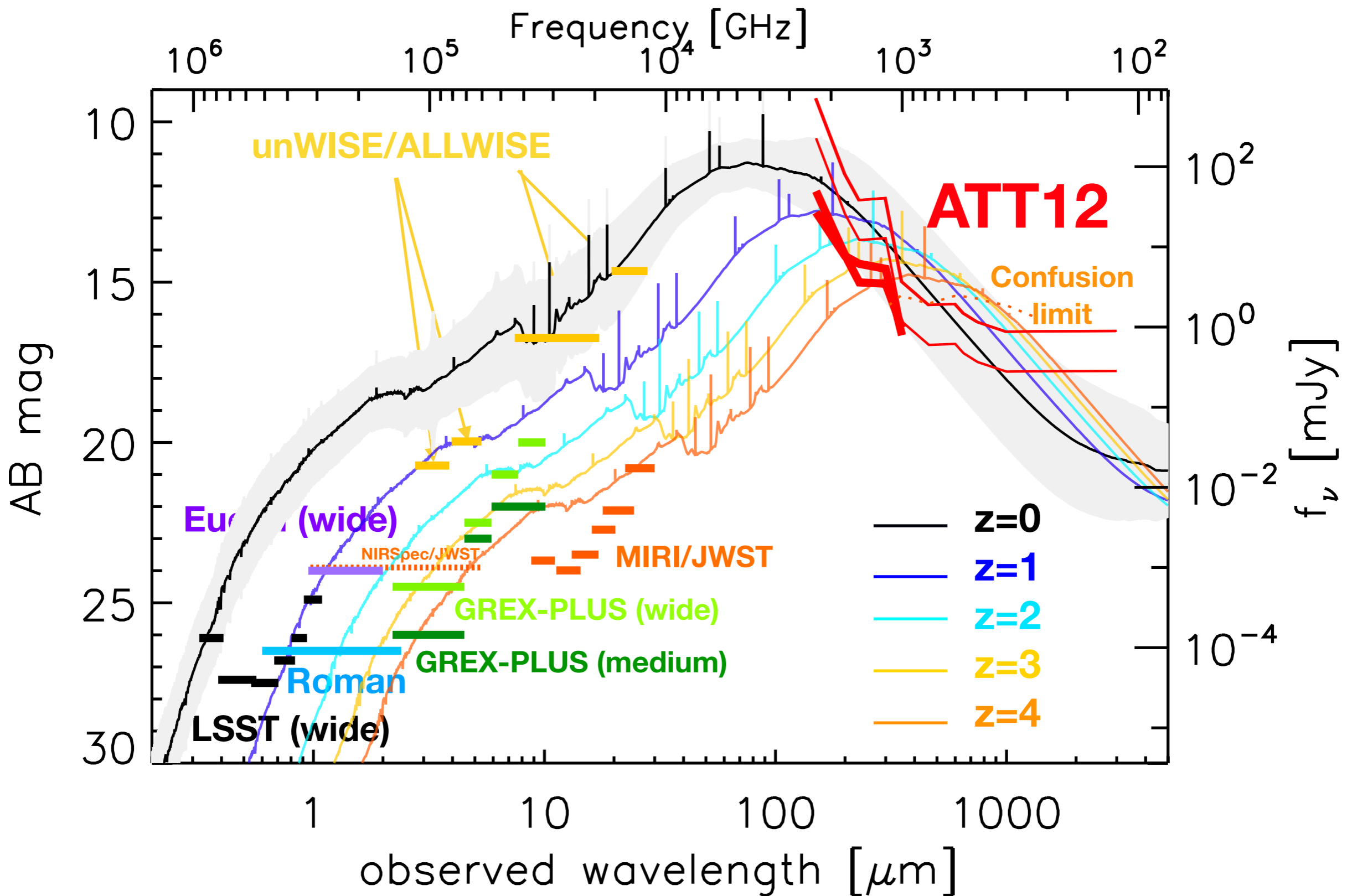


(see also, e.g., Hughes+98, Williams+19, Yamaguchi+19, Wang+19, Umehata+20, Smail+21)

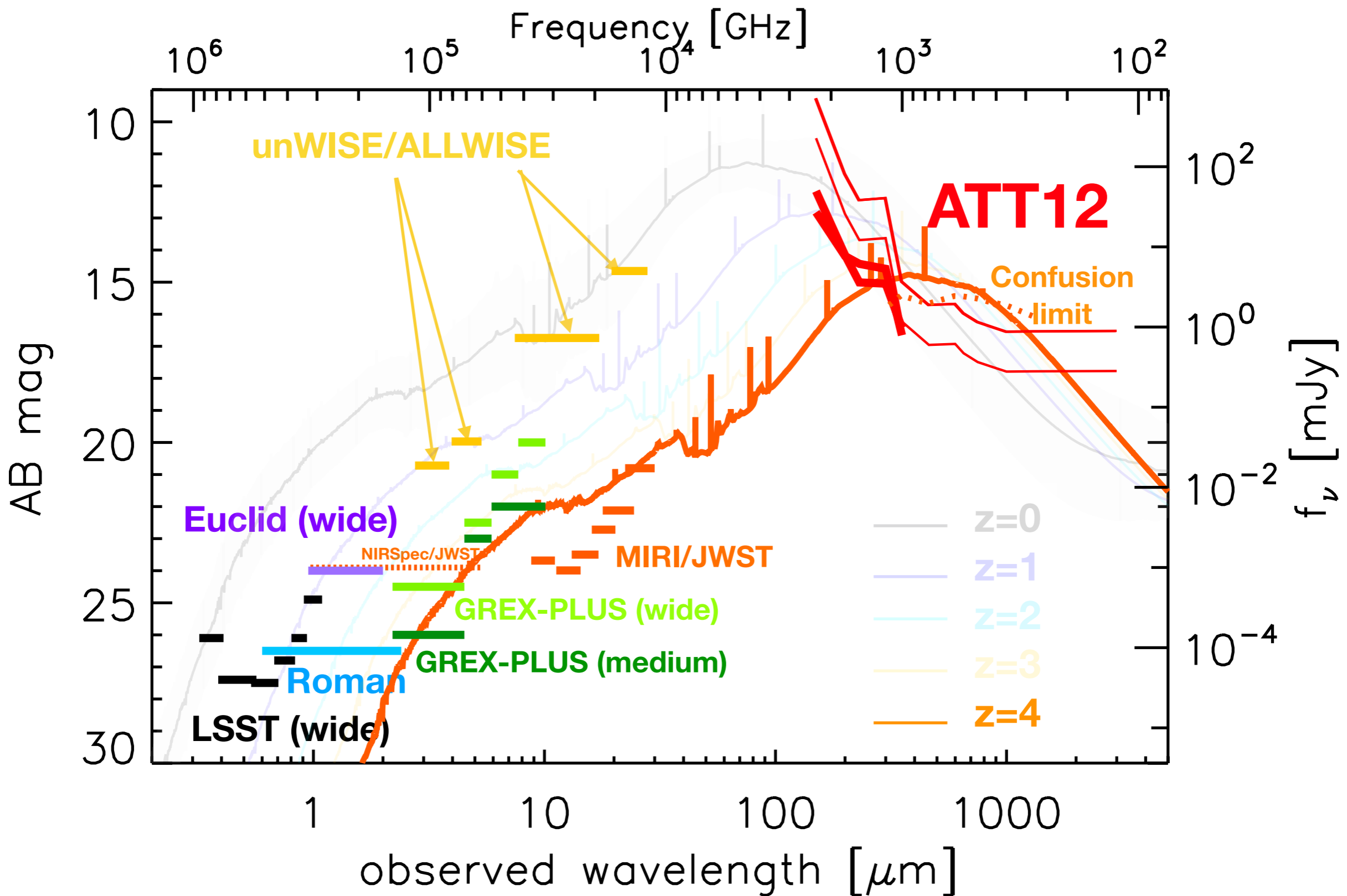
Expected SED as a function of redshift



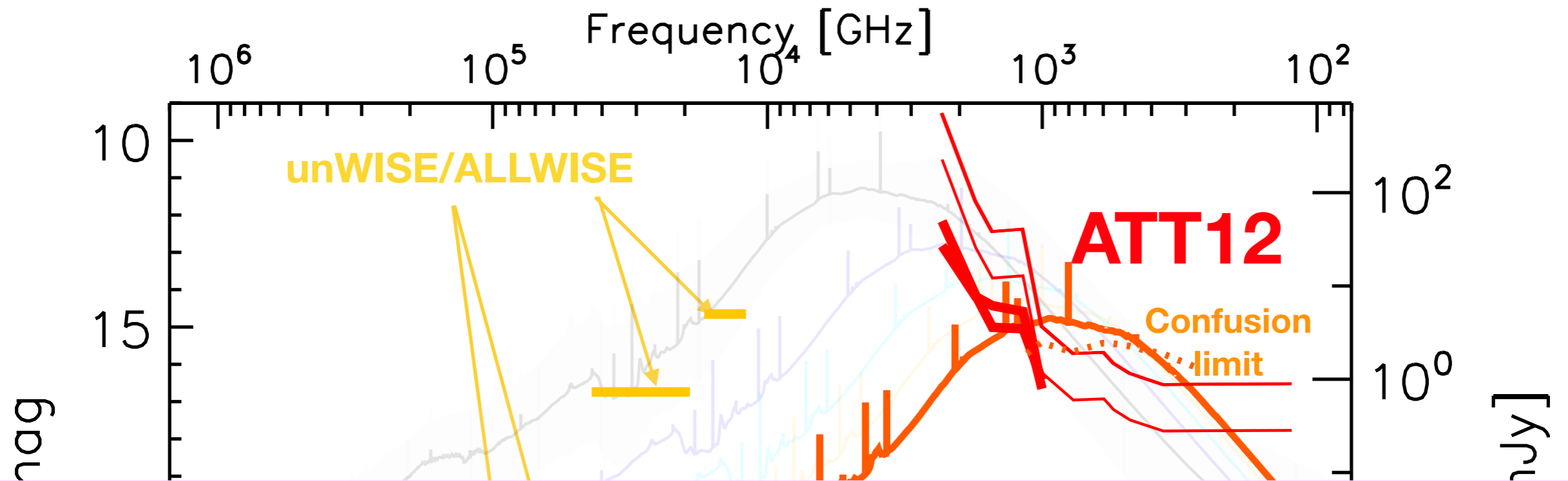
Expected SED as a function of redshift



Expected SED as a function of redshift



Expected SED as a function of redshift



**GREX-PLUS と ATT12 で
Roman “dropout” AGN at $z > 4$
の系統的探査 (e.g., 100平方度)**

observed wavelength [μm]

発見期待値 (100平方度探査した場合)

Redshift	Surface density [deg ⁻²]	Expected number
		100 deg ²
$1 < z < 2$	5.6	~550
$2 < z < 3$	1.5	~ 150
$3 < z < 4$	2.1	~ 200
$z > 4$	0.2	~ 20

※ 下限値

※ Toba+20c で発見された optically-dark 銀河のうち、photo-z が決定できた天体数からの見積もり

Summary

口径	12 m		30 m	
積分時間	1 hr	10hr	1hr	10hr
Unobscured AGN	high-L ($M_{1450} \sim -26$)	mediam-L ($M_{1450} \sim -25$)	low-L ($M_{1450} \sim -24$)	cold-dust poor AGN
Obscured AGN	Roman-dropout AGN at $z > 4$			

- SED 解析 (T_{dust} , M_{dust} の z 進化など)
- GREX-PLUSやFORCEなどとのシナジーにも期待

Summary

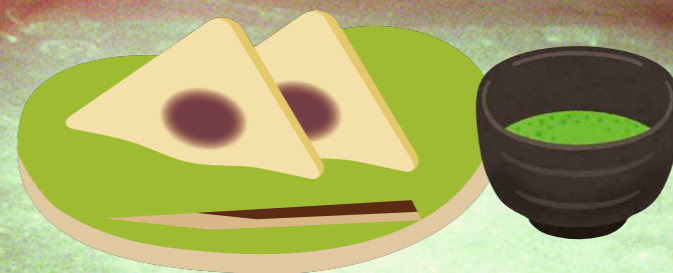
口径	12 m		30 m	
積分時間	1 hr	10hr	1hr	10hr
Unobscured AGN	高感度・多周波観測が活きるサイエンス			
Obscured AGN	広視野が活きるサイエンス			

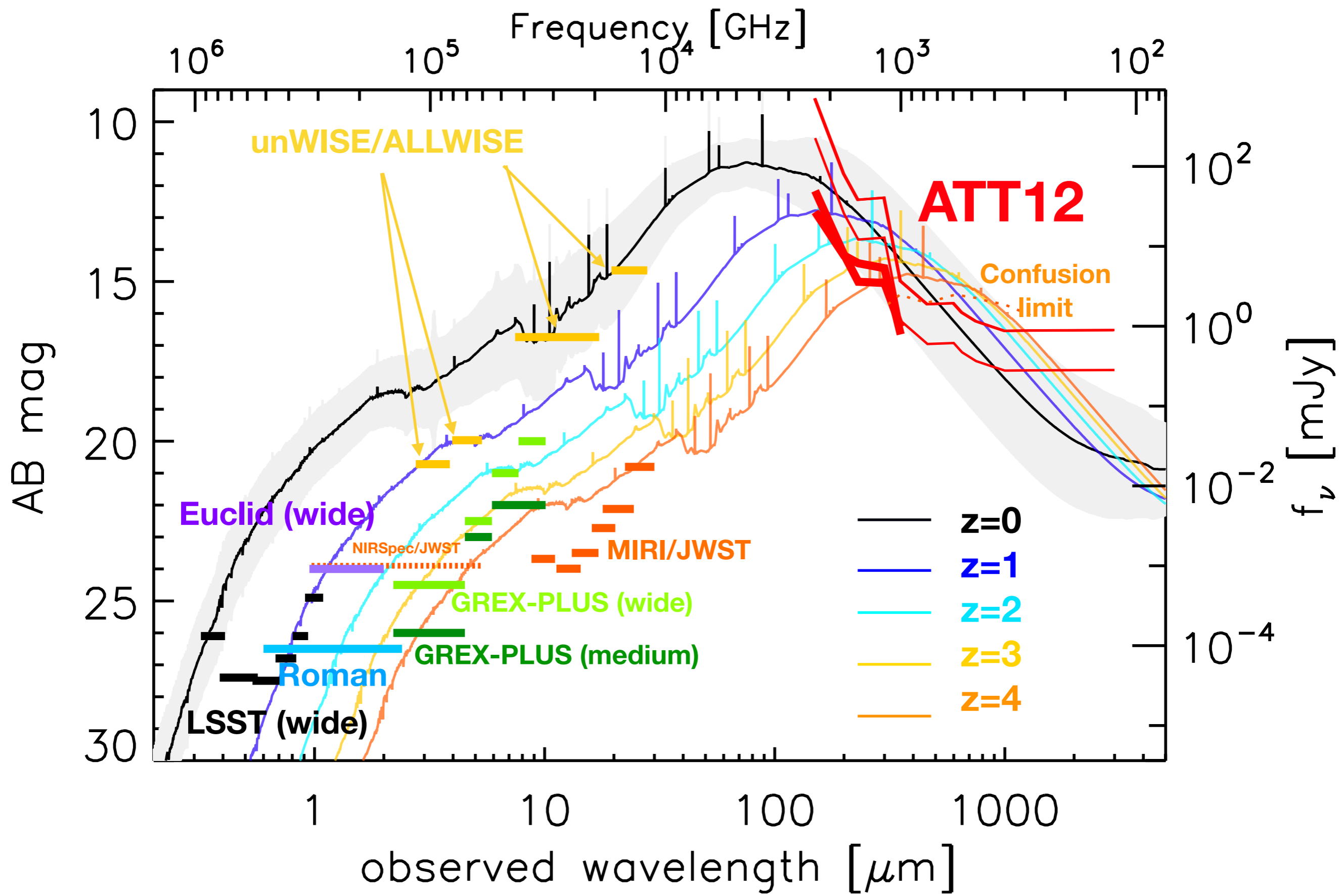
追観測

探査

- SED 解析 (T_{dust} , M_{dust} の z 進化など)
- GREX-PLUSやFORCEなどとのシナジーにも期待

END





戦略提案

rest-FIR SED の決定

-> low-z AGNのSEDと比較、ダスト質量（温度）のz進化、理論モデルとの比較など

- high-z クエーサー at $z > 6$ 【既知天体の追観測】
 - SDSSクラスの明るいクエーサーをATT12でフォローアップ。
 - HSCクラスの暗いクエーサーをATT30でフォローアップ。cold dust poor/free クエーサー探査
 - ATT稼働時に $z > 7$ や $z > 8$ のクエーサーが見つかったとしても、negative K-correction が効くので、ATT12/30で観測可能。
- high-z obscured AGN at $z > 4$ 【未知天体の探査】
 - Roman-dropout AGN は ATTやGREX-PLUSでしか見つけられない種族。FORCE とのシナジーでAGNの性質（X線光度, NHなど）も推定可能（日本主導ミッションの独壇場）
 - 銀河進化の中でこの種族を特徴付ける

時間が余れば

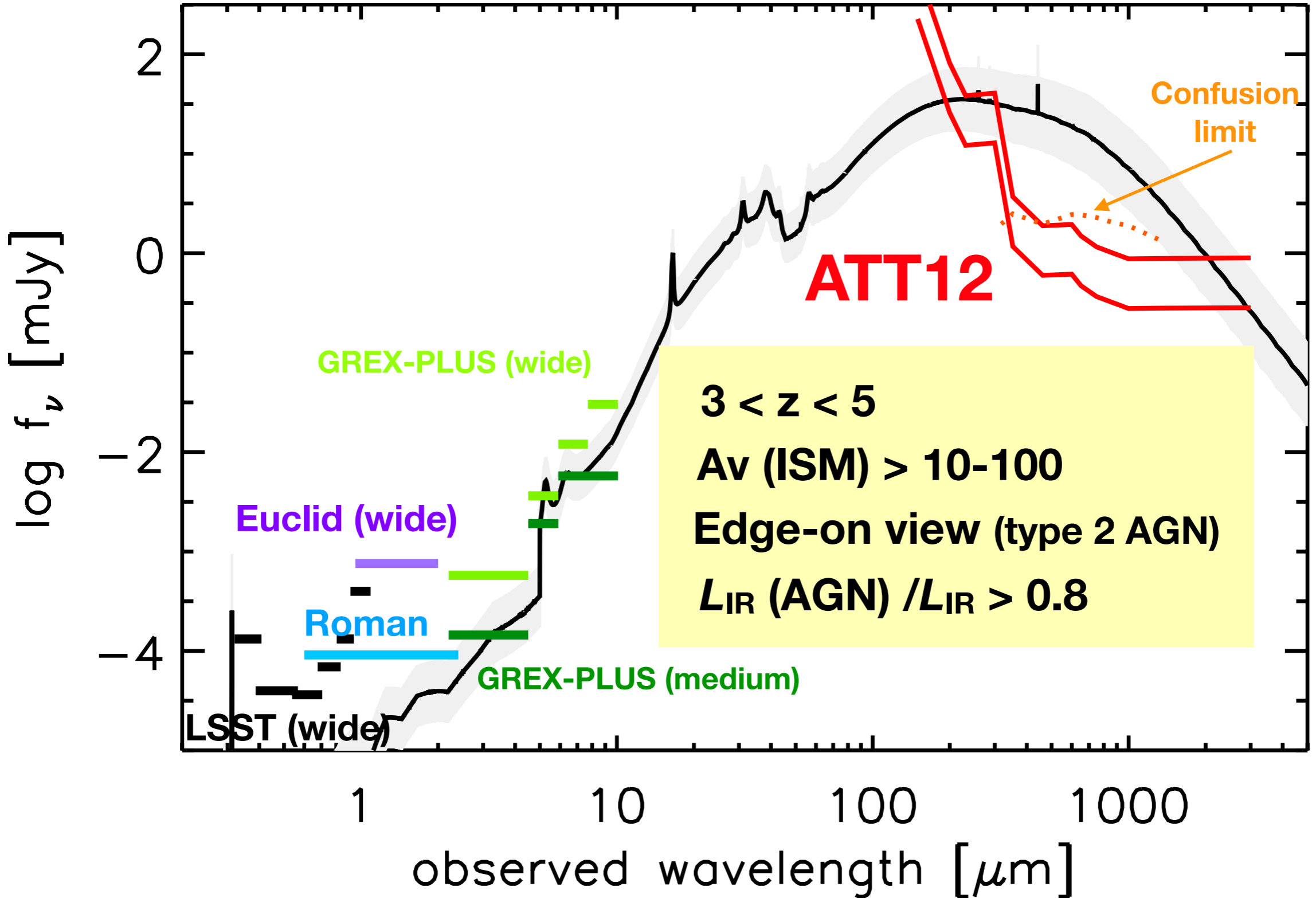
Importance of dust in high-z galaxies/AGNs

- Understanding the following dust properties as a function of redshift:
 - **Composition**
 - **Size distribution**
 - **Abundance**
- Source of dust in the early Universe:
 - type II SN?
 - AGB?
 - POPIII?

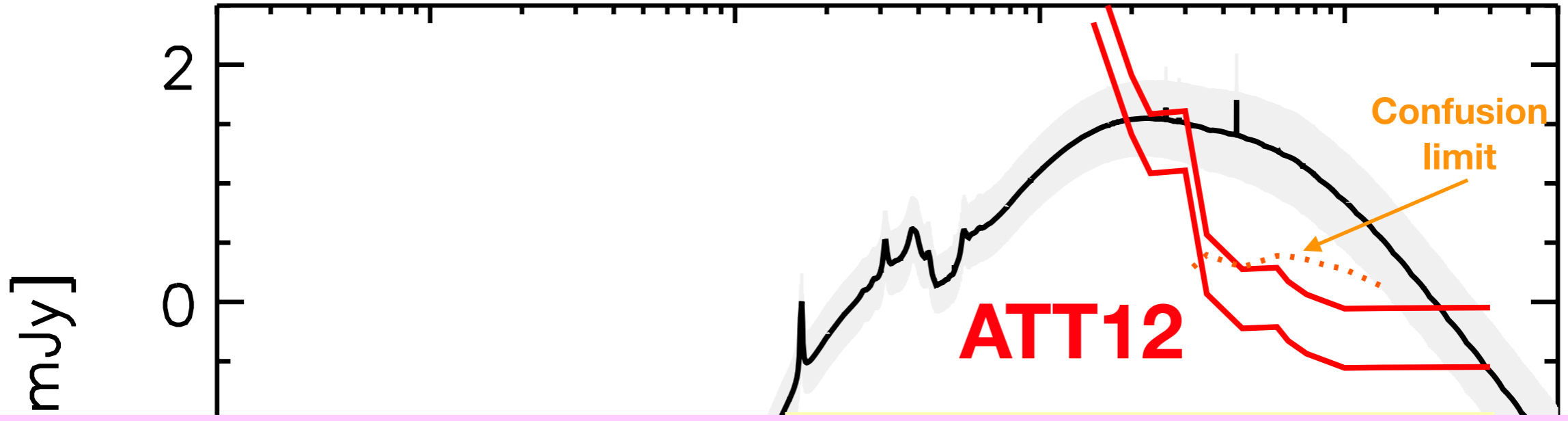
GREX-PLUSとのシナジー

- LSST や Roman でも“見えない”けど、GREX-PLUS 5-10 μm 帯だけが“見える”、そんな天体があればステキ。。 😞
- 実際にいるかは別として、そのような天体がどのような性質を持ち得るのかを調査
- SED template 生成ツールとして CIGALE を使い、パラメータサーチを実施
- redshidt, SFH, SSP, IMF, AGN トーラス モデル, ダスト モデルのパラメータを振り、約7000万個のtemplate を作成
- その中で、条件を満たしそうなものを抽出

GREX-PLUSとのシナジー



GREX-PLUSとのシナジー



Roman “dropout” AGN at $z > 4$
 の素性を知る最適な組み合わせの1つ

