Observational Studies on Super-massive Black Holes: Recent Hot Topics and the Next Steps

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"Workshop on the First Stars and First Galaxies"

What “were” our dreams for the 2010’s?

2003-04年に編集された
「2010年代の光赤外天文学」

各研究分野のチーフ

宇宙論、構造形成	杉山直 (国立天文台)
クエーサー、活動的銀河中心核	和田桂一 (国立天文台)
銀河、銀河団	児玉忠恭 (国立天文台)
銀河系、局所銀河	千葉柾司 (東北大学)
恒星物理、星形成、超新星、晩期型星	茂山俊和 (東京大学)
惑星系、太陽系	小久保英一郎 (国立天文台)

3.1 科学検討班の活動目標・経過

光赤外天文学の次期大型観測装置計画発案において、将来にわたって科学的にどのような主要課題に対して研究を進めるべきか、またそのためにどのような観測装置や観測方法が必要となるかを考察することが大変重要となる。そこで、当該目的に即した科学検討班を組織した。以下に、その活動状況と検討結果を記する。

本検討班の目標は、光赤外天文学の次期大型観測装置計画に関連して、今後 10 年から 20 年にわたって解決するべき天文学上の最重要課題を検討し、観測装置の性能や構成に対して提言を行なうことである。この科学

What the AGN WG (incl. TN) said are...

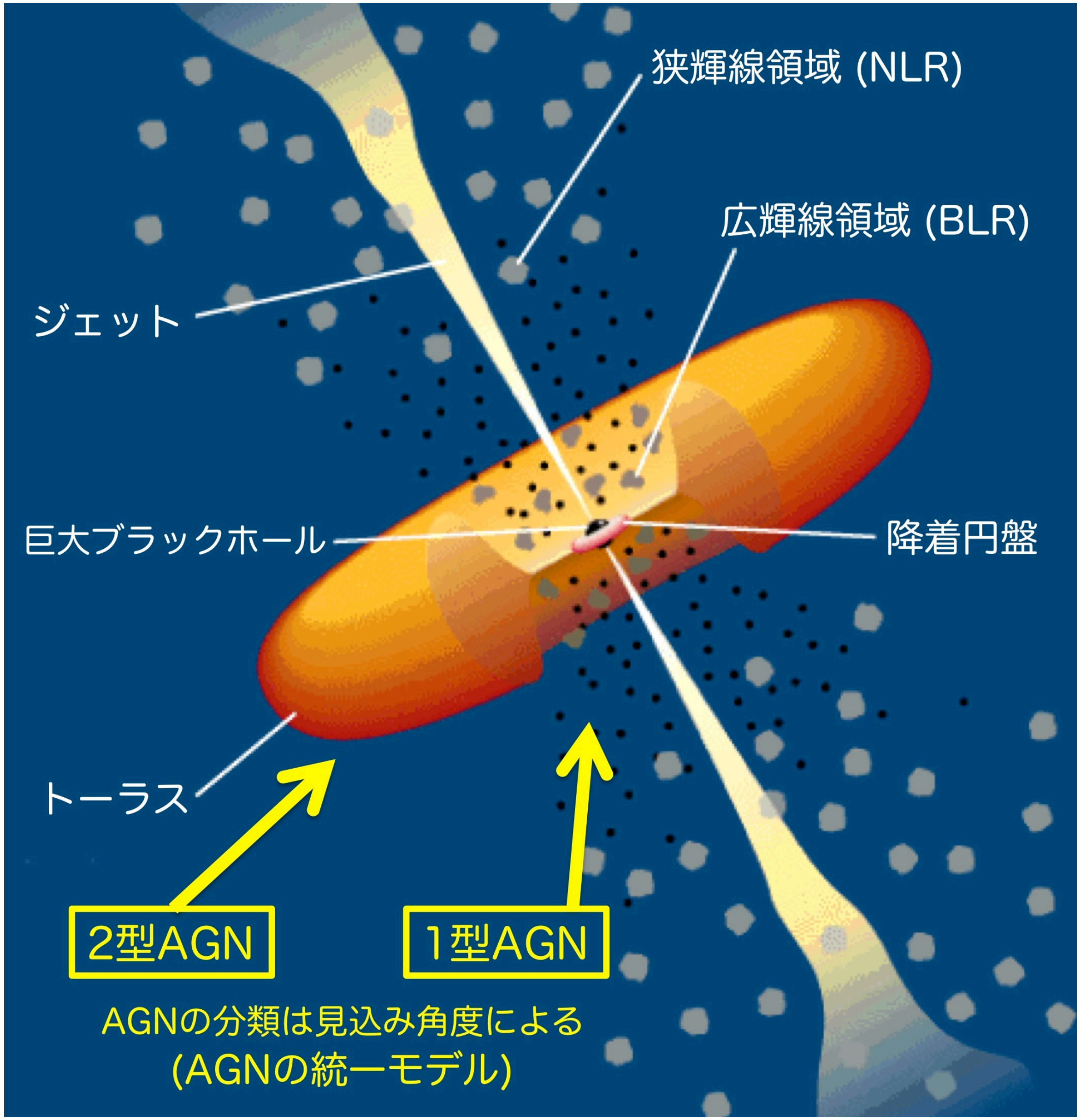
3.2.2　「クエーサー、活動的銀河中心核」分野

主題：「セントラルエンジンパラダイムの検証と巨大ブラックホール形成史の解明」

活動的銀河中心核 (AGN) の膨大なエネルギーの源は、超巨大ブラックホールへのガス降着と言われているが、近傍の AGN においても未だに中心核近傍は直接分解されていないため、その真の構造は今だに謎である。また、銀河形成過程において、巨大ブラックホールやクエーサーがどのように形成されてきたのか、それらが銀河形成や銀河間ガスに与える影響は、次世代の観測装置による遠方宇宙の観測により明らかにすべき重要な課題である。

1. (近傍) AGNの中心構造の解明
2. 近傍から遠方のAGNにおけるSMBH質量決定
3. QSO/AGNの進化： 深宇宙サンプルの確立

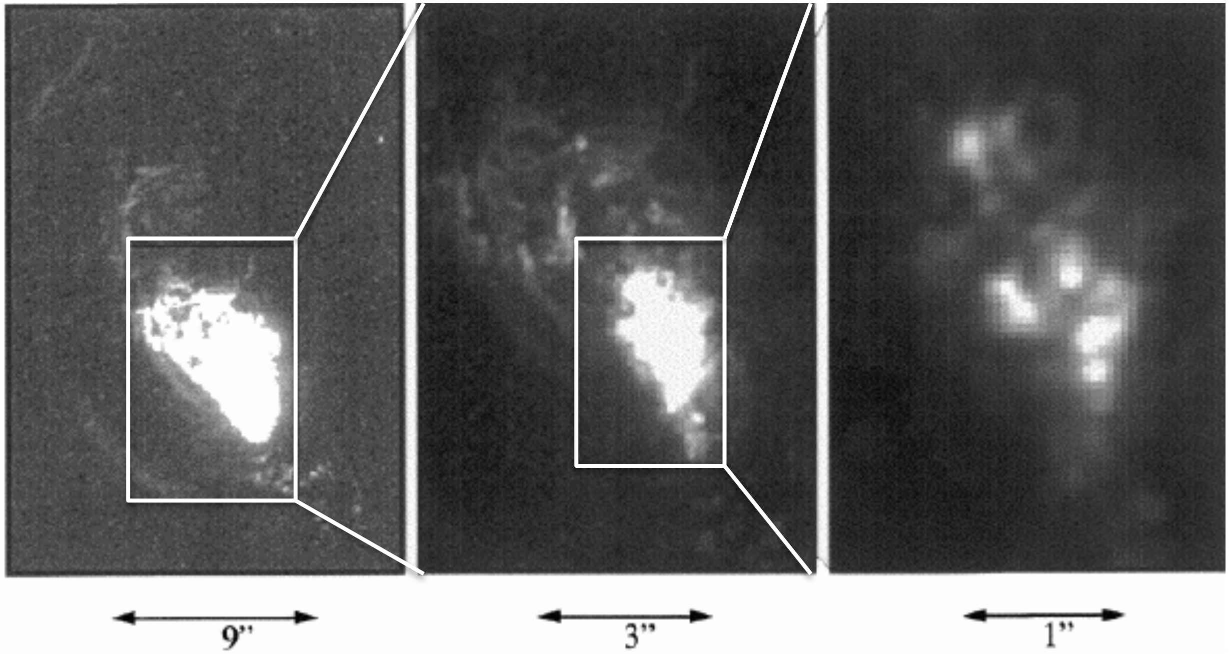
Spatial structure of the AGN ingredients

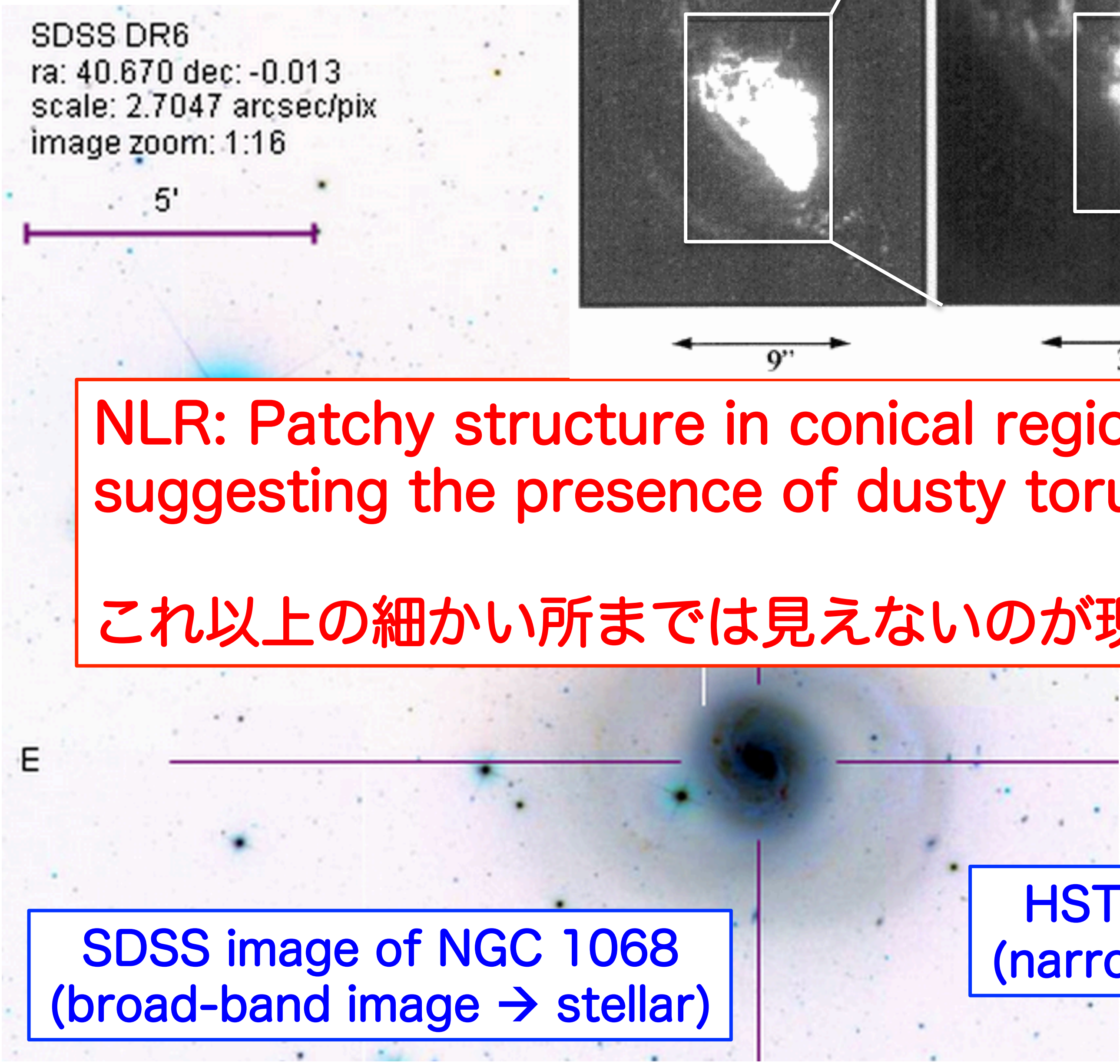


original:
Urry &
Padovani
1995

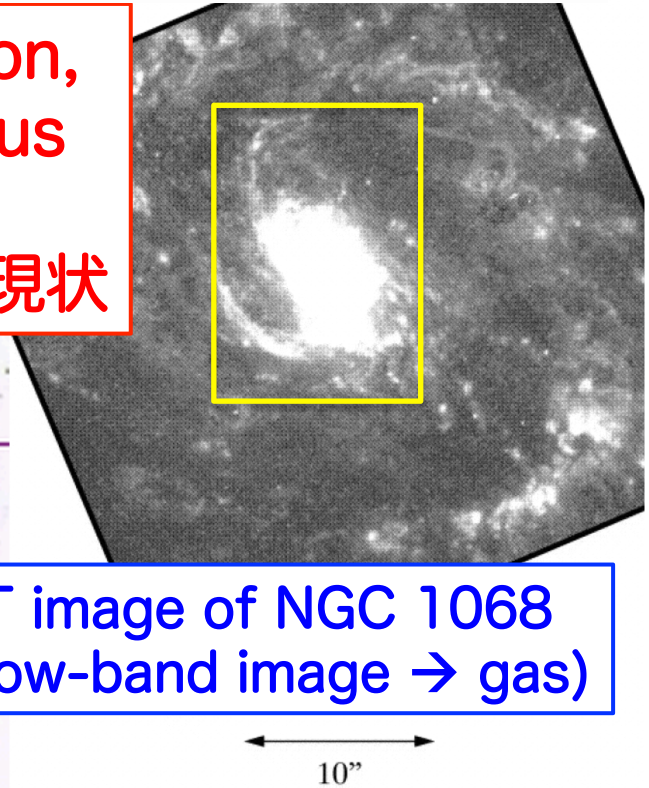
Capetti+97

In reality...





SDSS image of NGC 1068
(broad-band image → stellar)



HST image of NGC 1068
(narrow-band image → gas)

NLR: Patchy structure in conical region, suggesting the presence of dusty torus

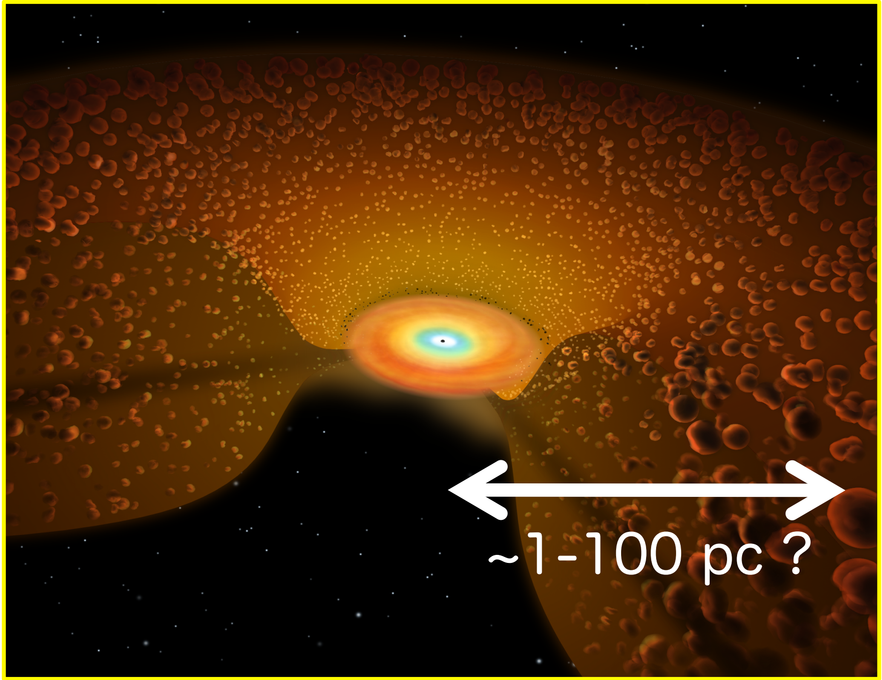
これ以上の細かい所までは見えないのが現状

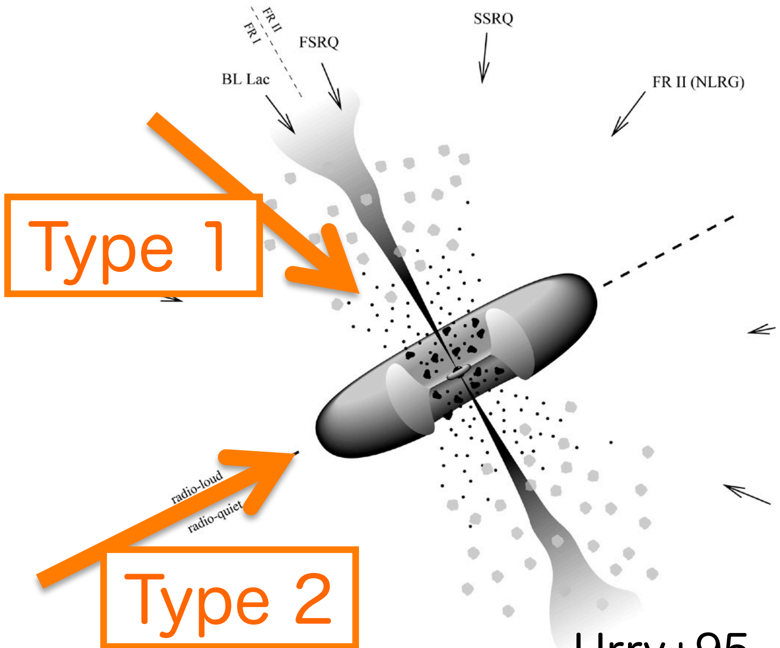
Dusty torus?

Important, because...

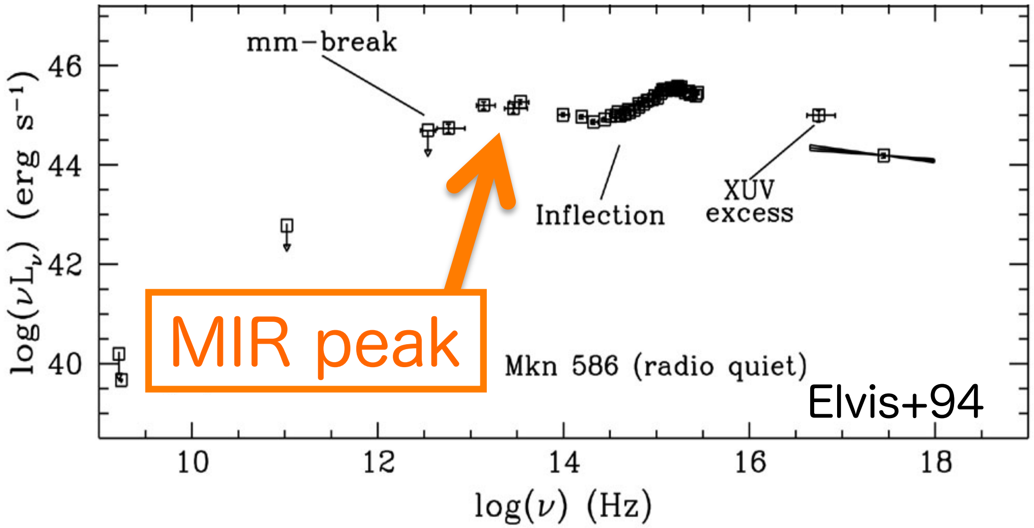
~ determining the AGN type
~ dominating the IR SED of AGNs
~ could be massive gas reservers
~ possible sites for star formation

(C) Kawaguchi-san





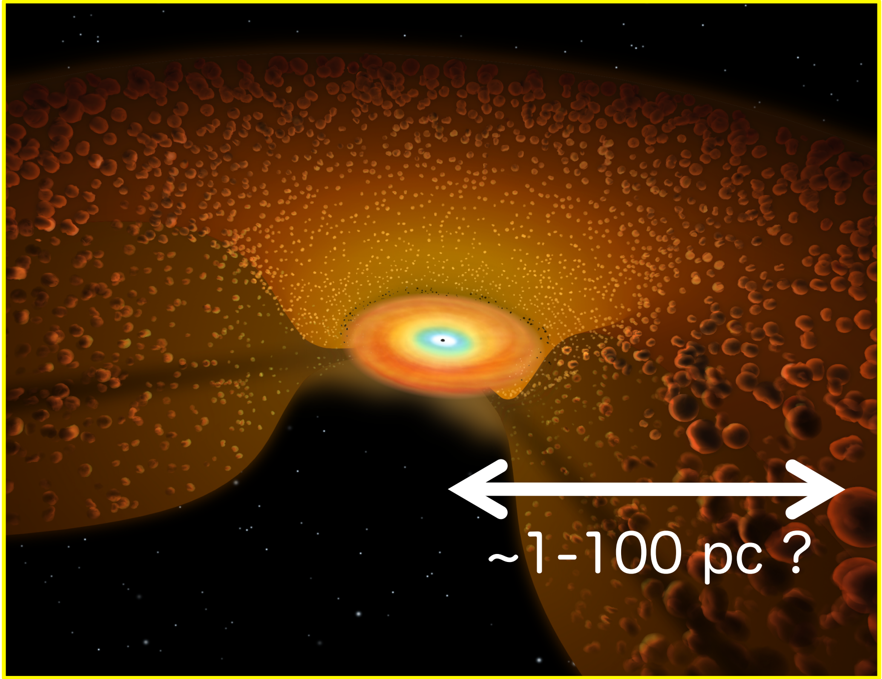
Urry+95



Elvis+94

Dusty torus?

(C) Kawaguchi-san



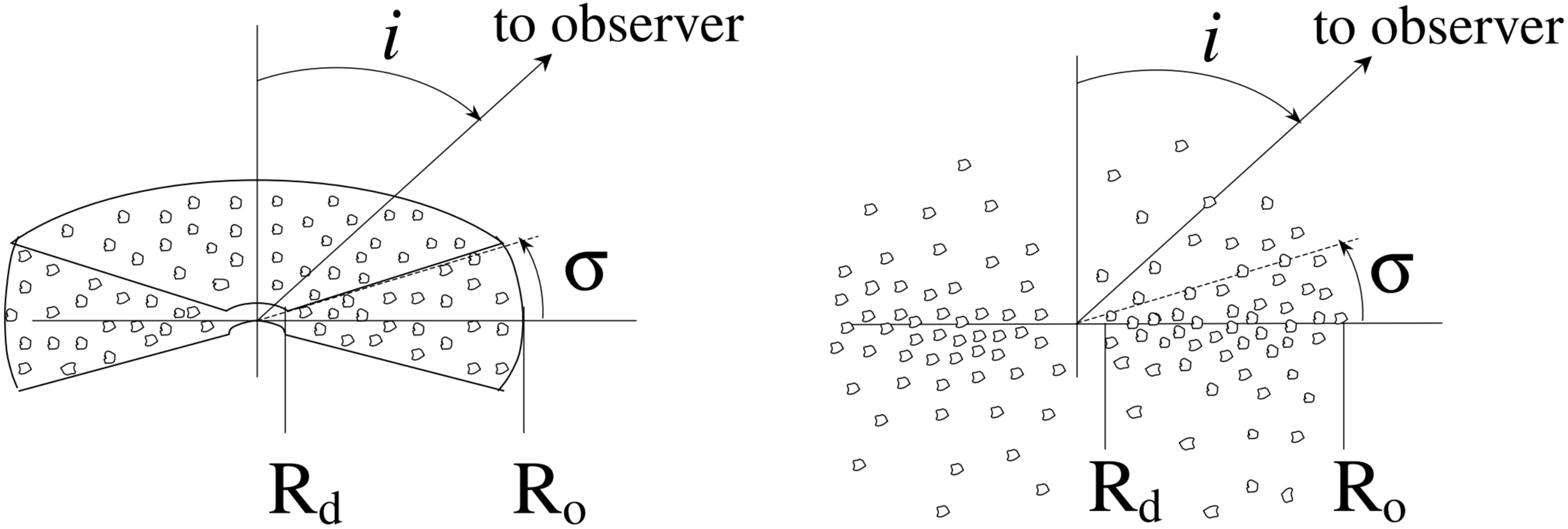
Important, because...

~ determining the AGN type
~ dominating the IR SED of AGNs
~ could be massive gas reservers
~ possible sites for star formation

However, currently...

~ various models proposed so far
~ but not yet discriminated
~ since the torus has not spatially unresolved observationally
~ thus its true spatial structure is unknown
~ relation with the star-formation activity also unknown

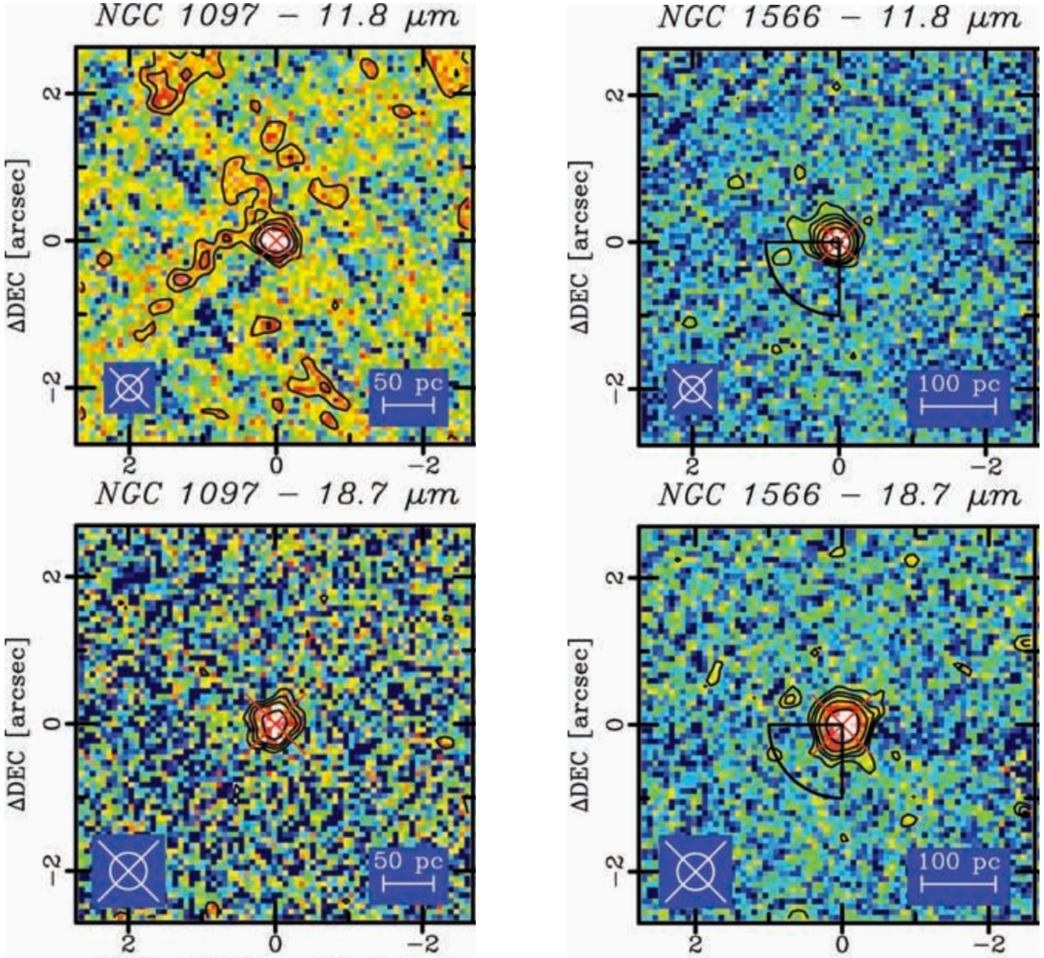
Nenkova+08



Size? Shape?

Dusty torus: MIR imaging

Reunanen+10



N-band (12um)

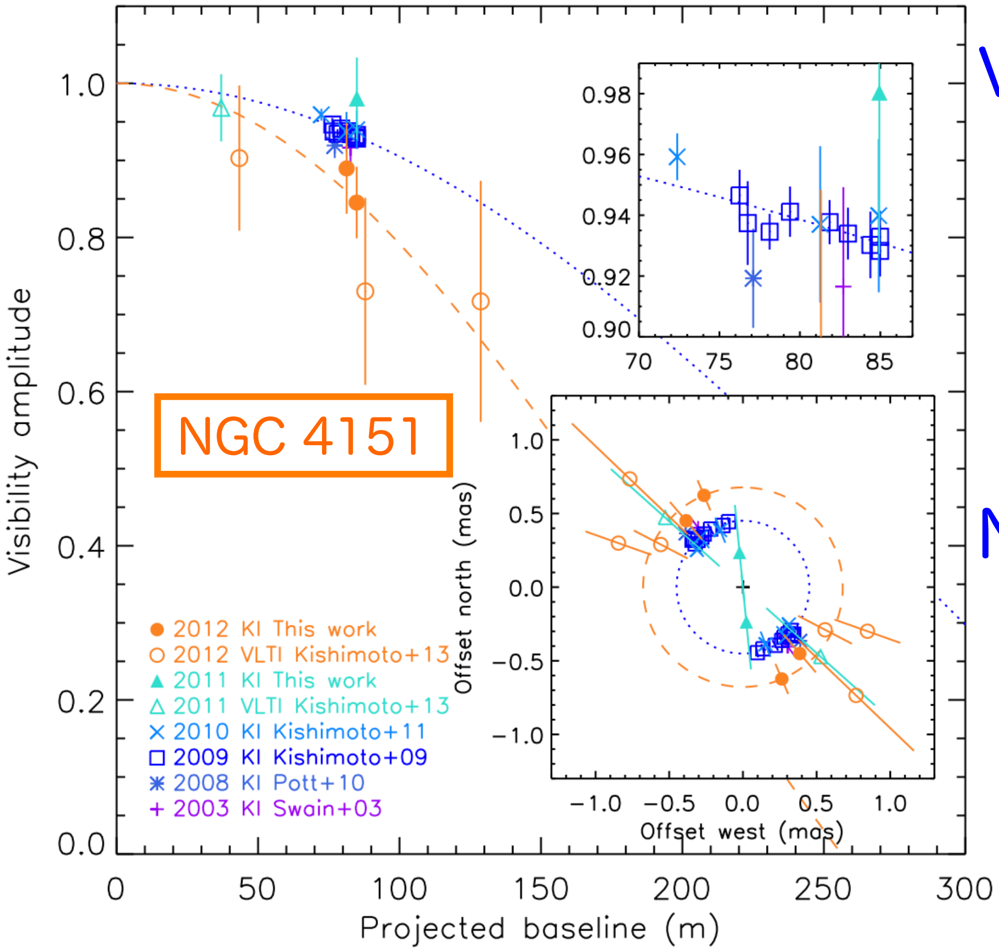
Q-band (19um)

VLT/VISIR observations

- ~ 0.3 arcsec FWHM
- ~ 13 nearby AGNs
- ~ 11.8um & 18.7um

Mostly unresolved
→ Size < a few tens pc

Dusty torus: NIR interferometry



Kishimoto+1308.6517

VLTI/AMBER observations

~ K-band imaging

~ fitted by ring models

~ best fit: R=0.65±0.09 mas

=0.056±0.008 pc

~ too small even for TMT !!

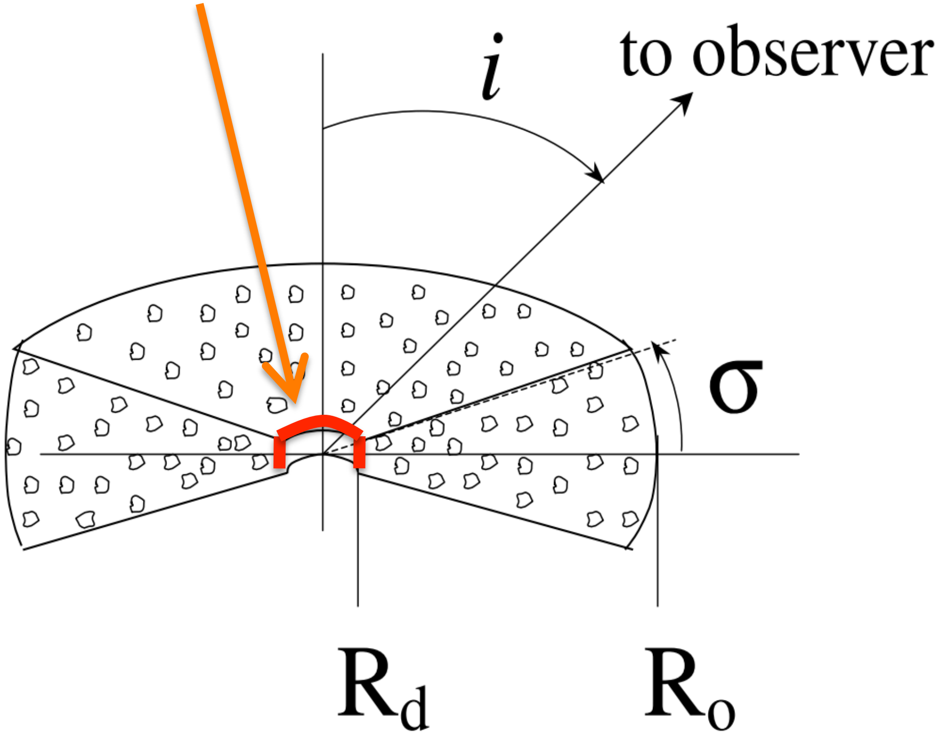
NOTE:

~ the inferred radius is consistent to the dust sublimation radius inferred by dust reverberation obs

~ only the innermost part of the torus is observed

Dusty torus: NIR interferometry

only this part is observed



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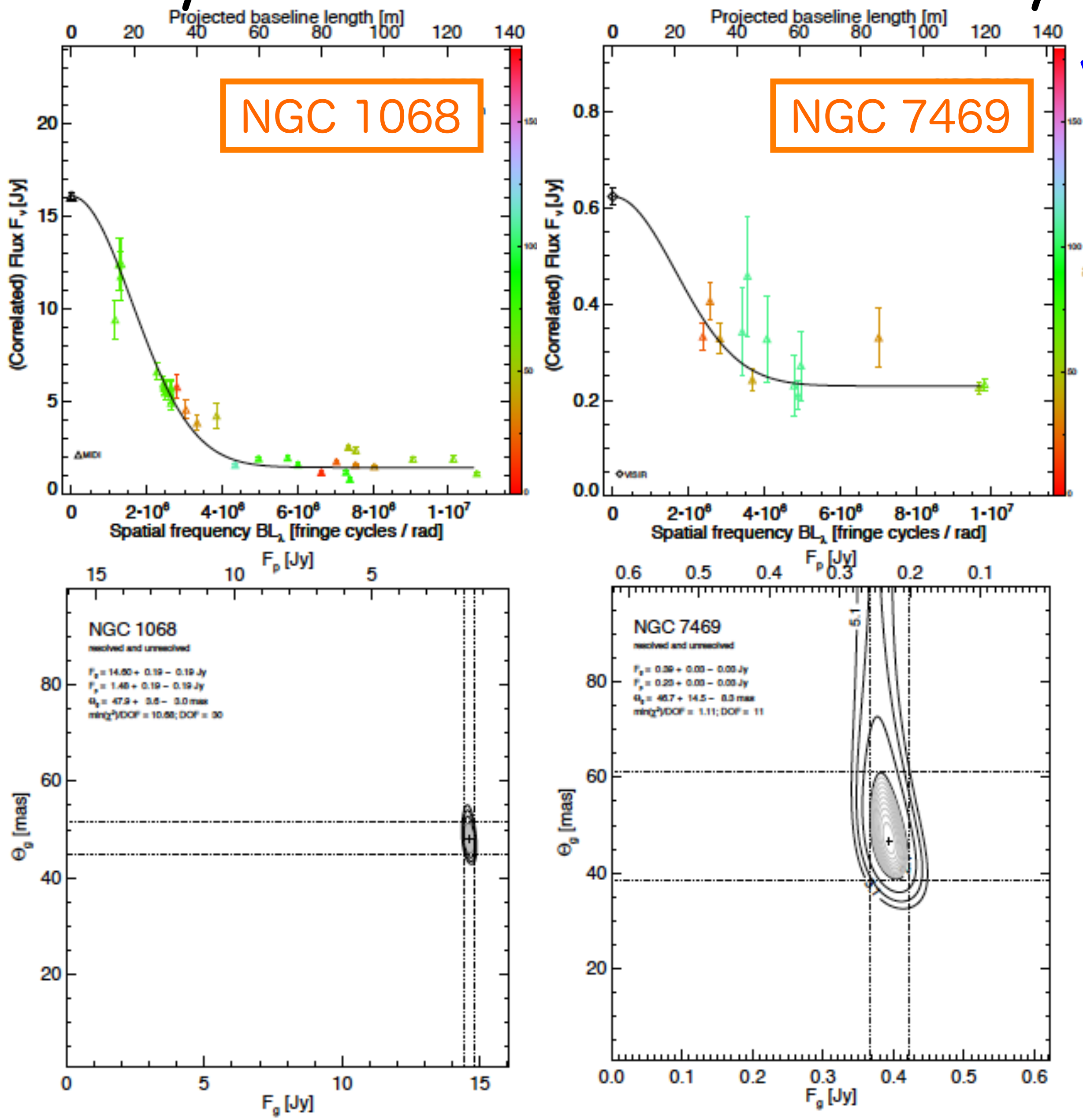
How about at longer wavelengths?

Dusty torus: MIR interferometry



VLTI/MIDI obs

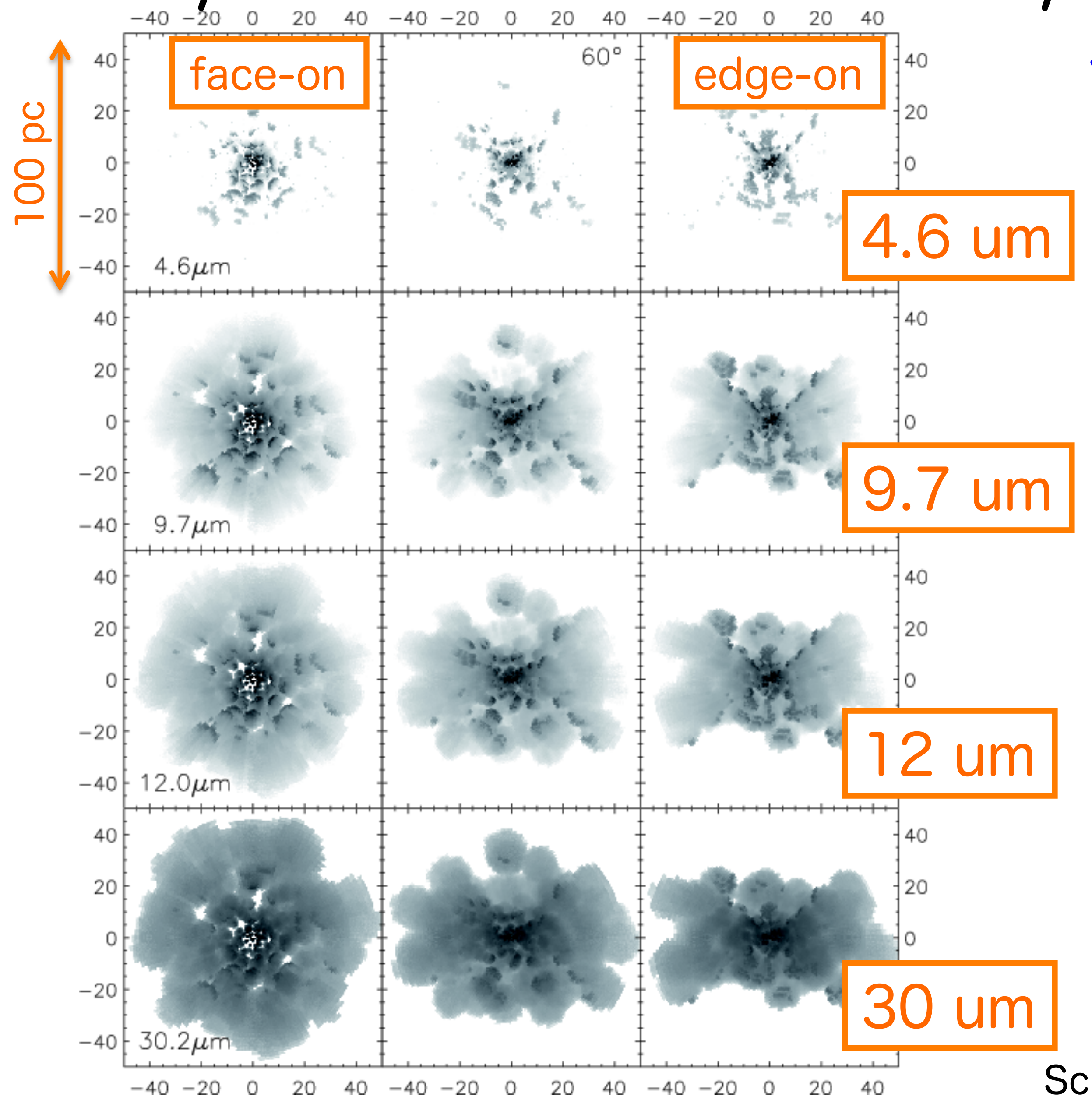
- ~ 12 micron
- ~ a few tens mas
- ~ comparable to the TMT resolution
- ~ can be resolved with TMT?

NOTE:

- ~ diffuse component could be "resolved out" by these interferometric observations
- ~ direct imaging obs needed

Burtscher+1307.2068

Dusty torus: MIR interferometry



Schartmann+08

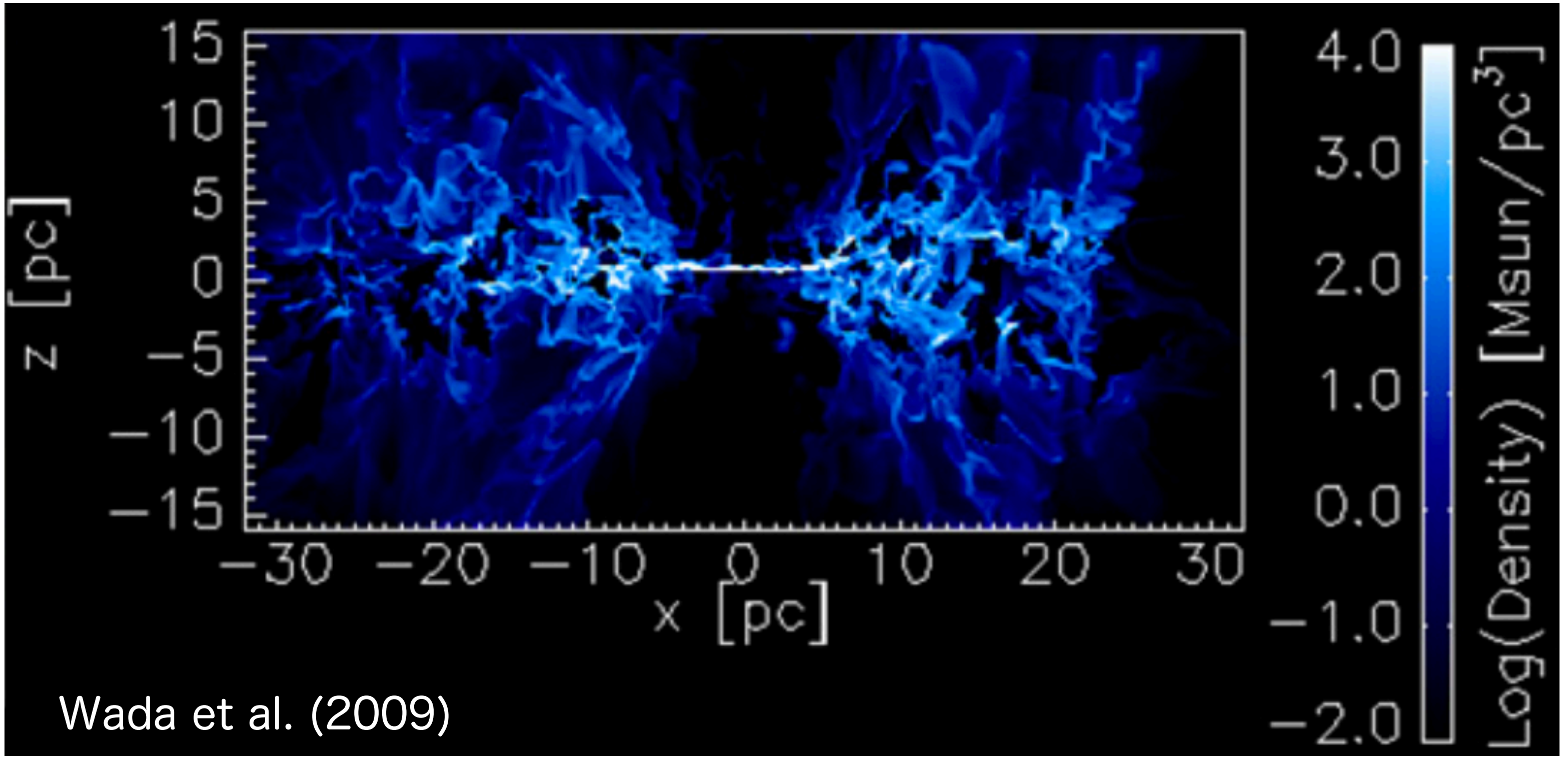
VLTI/MIDI obs

~ 12 micron
~ a few tens mas
~ comparable to the TMT resolution
~ can be resolved with TMT?

NOTE:

~ diffuse component could be “resolved out” by these interferometric observations
~ direct imaging obs needed

Dusty torus: model trials



An example of numerical simulations for dusty tori

~ (in this case) A few tens pc, distributed around 1.3×10^7 M_{sun} SMBH

~ Circumnuclear starformation (SNe) makes the vertical structure

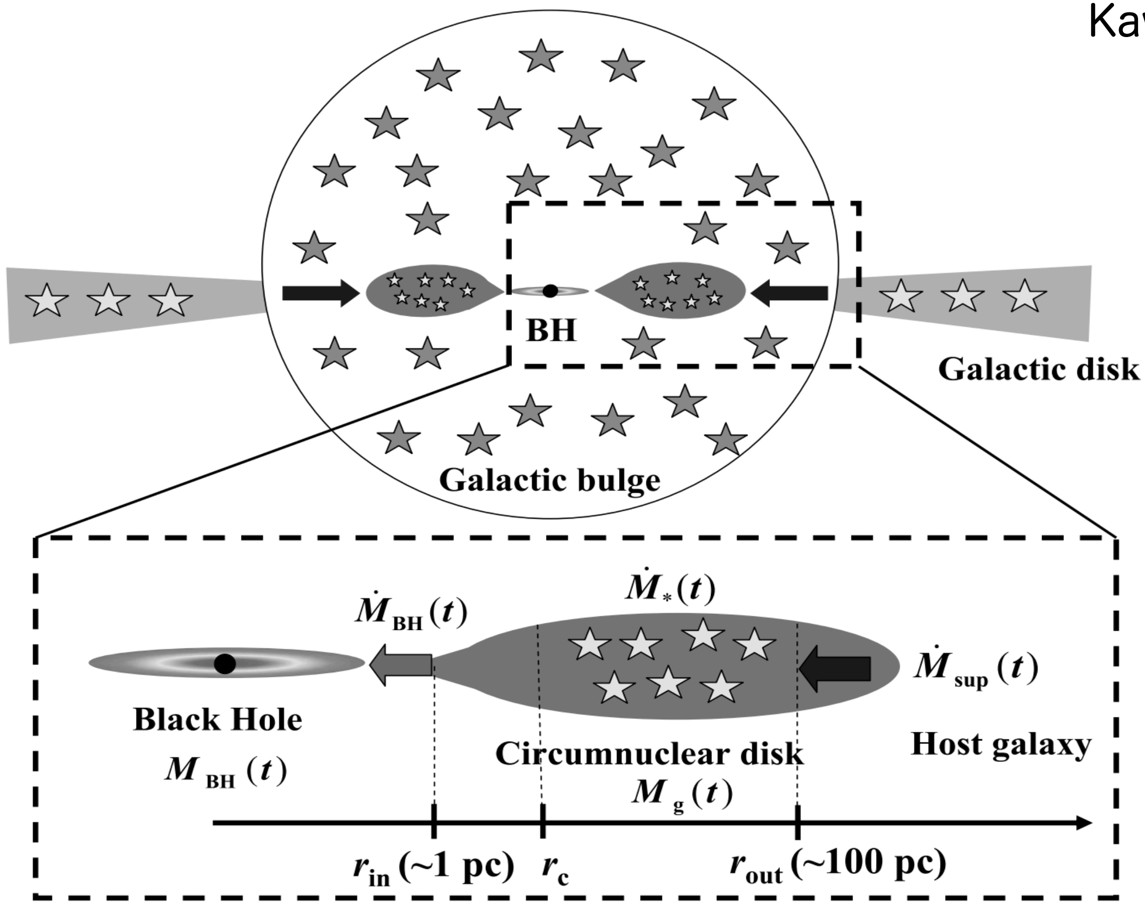
~ Is this really “dusty”? How does this look like observationally?

~ Is the circumnuclear starformation required for tori and AGNs?

~ Should be examined observationally

Nuclear starformation: model trials

Kawakatu+08



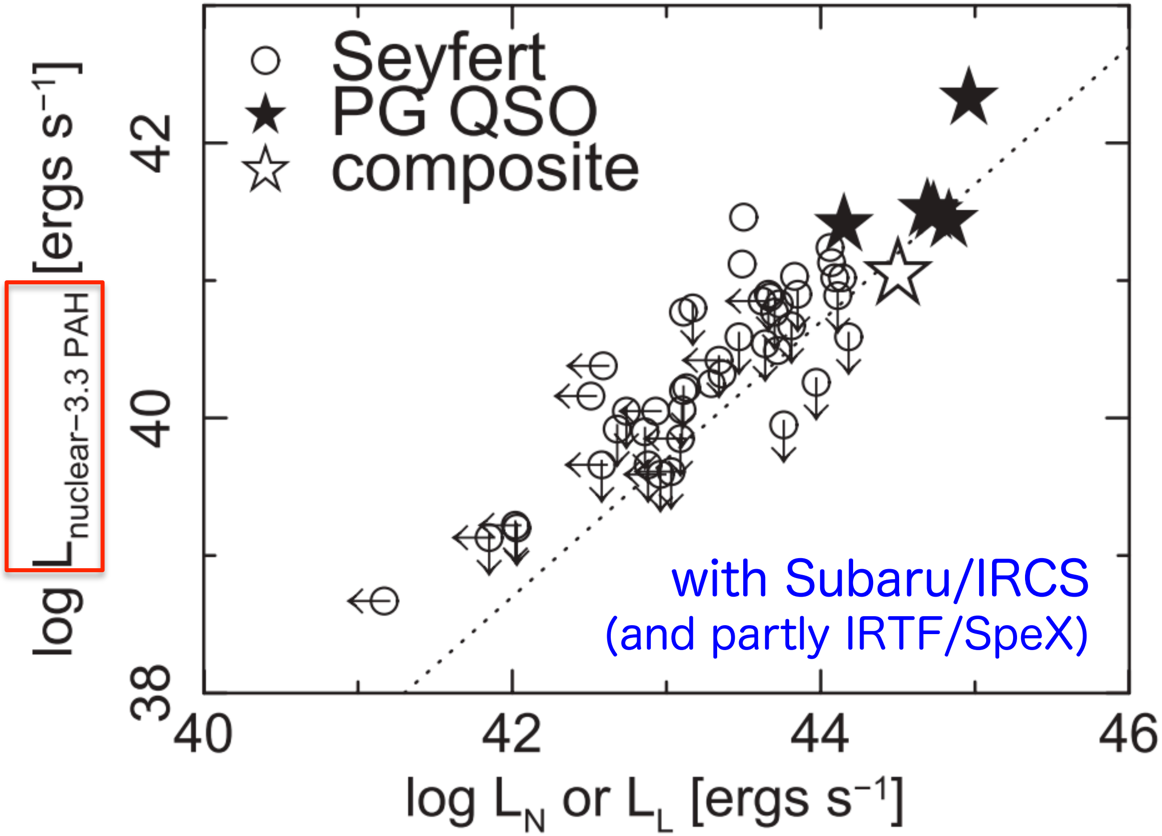
Circum-nuclear (~100 pc) star formation also expected

- ~ Is the circumnuclear starformation required for tori and AGNs?
- ~ How do they look like observationally?
- ~ Should be examined observationally

Nuclear starformation: observations

Imanishi et al. (2011,12)

PAH emission:
arising at PDRs and thus good tracer of the star formation



Active star formation is actually seen in active AGNs

~ Is this star-formation occurring at the torus region?

~ How about at somewhat larger spatial scales (circum-nuclear)?

~ Spatial info of the torus and star-forming regions necessary

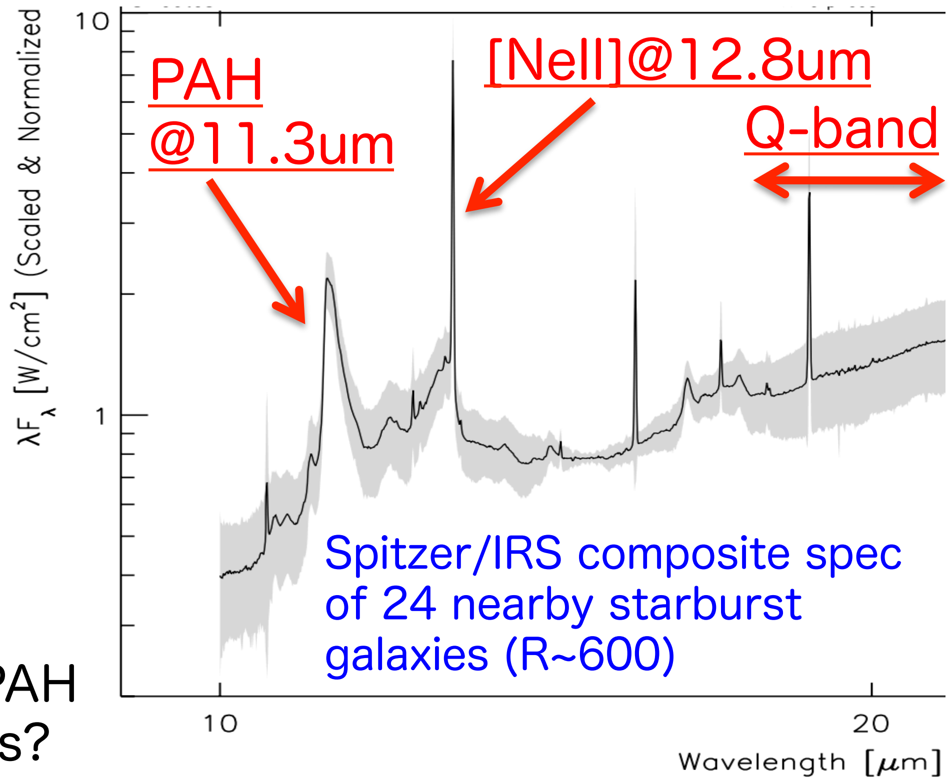
~ At MIR! (less suffering from extinction and glaring nucleus)

What TMT will do

Q-band (20um) imaging
~ 0.12” resolution with MIR-AO
~ corresponds to ~20pc @z=0.01
~ for resolving the dusty torus

N-band (10um) IFS spectroscopy
~ 0.06” resolution with MIR-AO
~ corresponds to ~10pc @z=0.01
~ for tracing the star formation w/PAH
~ is the SF associated with the torus?
~ examining the spatial coincidence
~ [NeII] 12.8um also useful to trace the star formation
~ also for kinematical structure, not only for spatial structure

Bernard-Salas+09



A candidate of TMT 2nd-generation instruments: “MICHI”

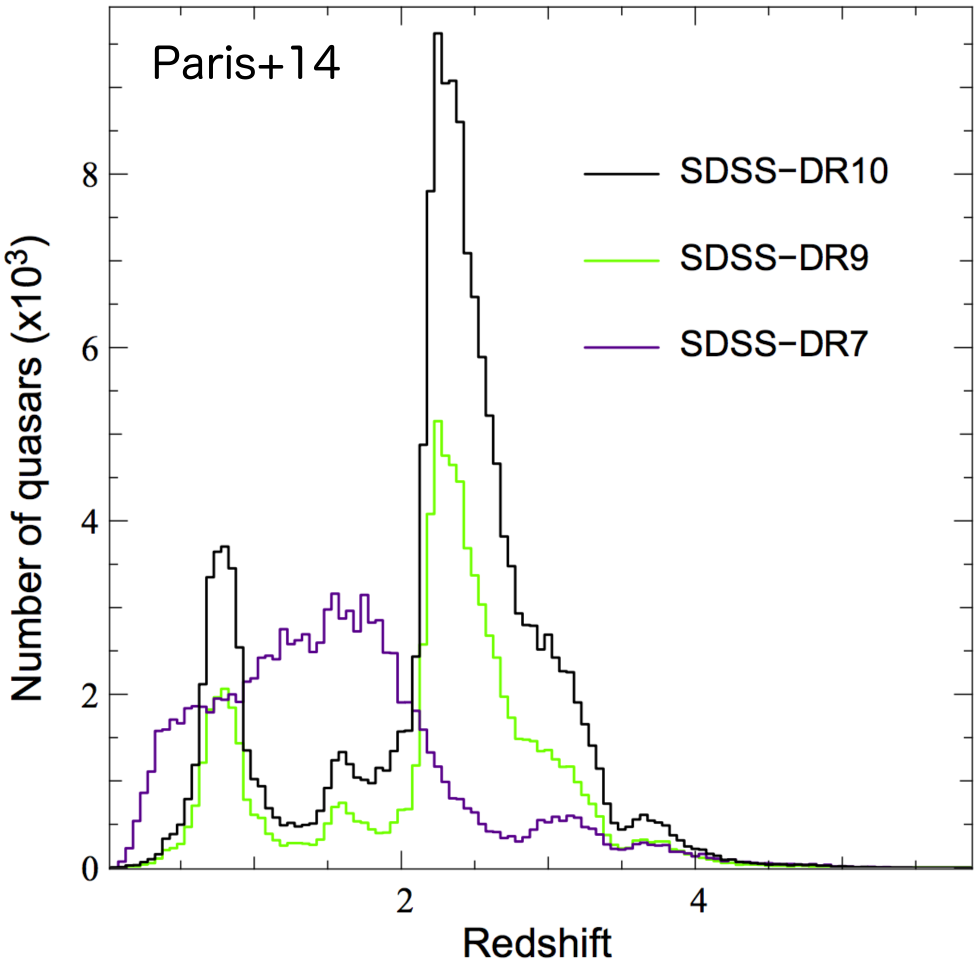
In 10 years ago, the AGN WG (incl. TN) also said…

3 QSO/AGN の進化： 深宇宙サンプルの確立

クエーサーや AGN の進化を探るためには、$z > 3$ の高赤方偏移クエーサーの質の良い統計サンプルが必要である。特に $z \sim 6$ を越えてどこまでクエーサーが存在するか、はクエーサーの起源のみならず、銀河形成や銀河間ガスの再電離との関連でも解明されるべき重要な課題である。SDSS によるクエーサーのサンプルでは、限界等級が浅いために、高赤方偏移の低光度 AGN の光度関数についての統計的な議論はできない。また、AGN 形成に関連して興味が持たれている狭輝線 1 型セイファート銀河 (NLSy1) やガスが豊富な高赤方偏移で期待される吸収を強く受けたクエーサー (2 型 QSO) の高赤方偏移での探査は、AGN 進化の描像の確立に不可欠である。さらに、クエーサーの空間分布から、クエーサーの活動期間についての情報が得られる。これらの実現のためには、広視野の可視、近赤外カメラを備えた 8m クラスの地上望遠鏡を占有的に使用し、1000 平方度程度の超広天域を深い撮像、及び分光サーベイを行い、クエーサー/AGN のサンプルを得ることが重要である。

"Wide & Deep" multi-color surveys needed.

Why new quasar survey?

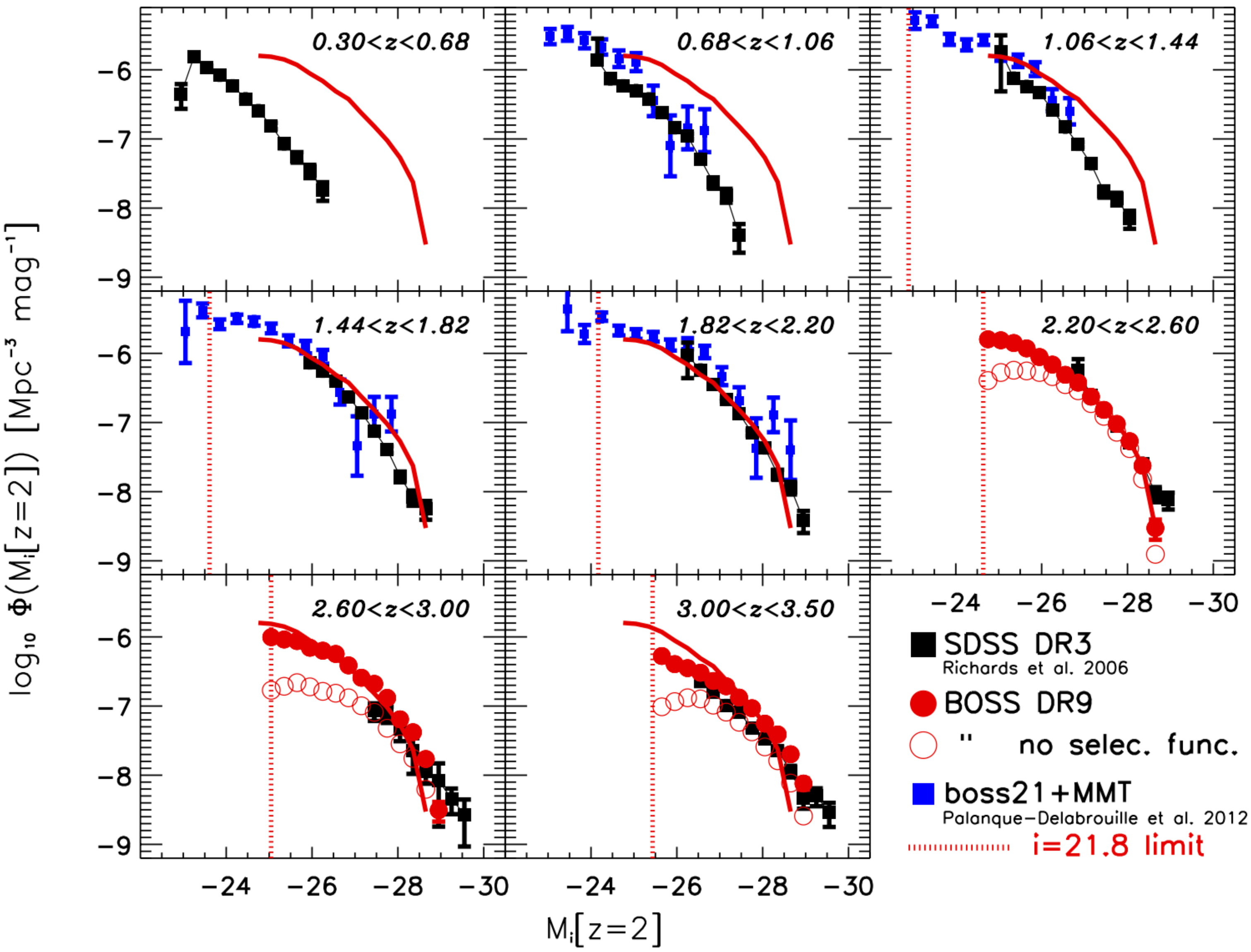


SDSS and BOSS have already discovered numerous quasars

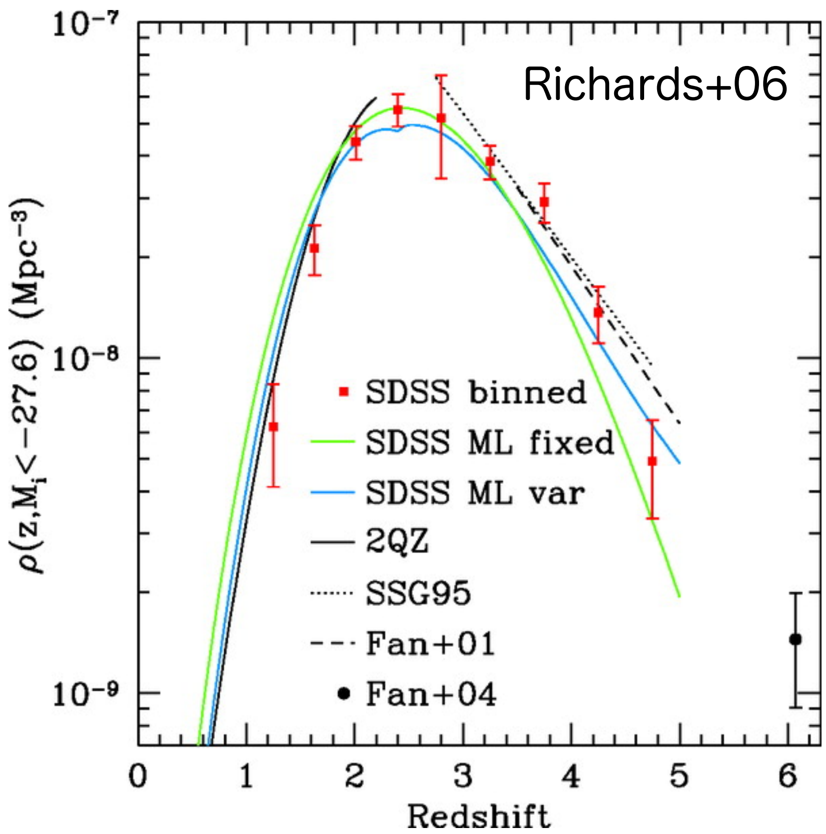
166,583 quasars in DR10

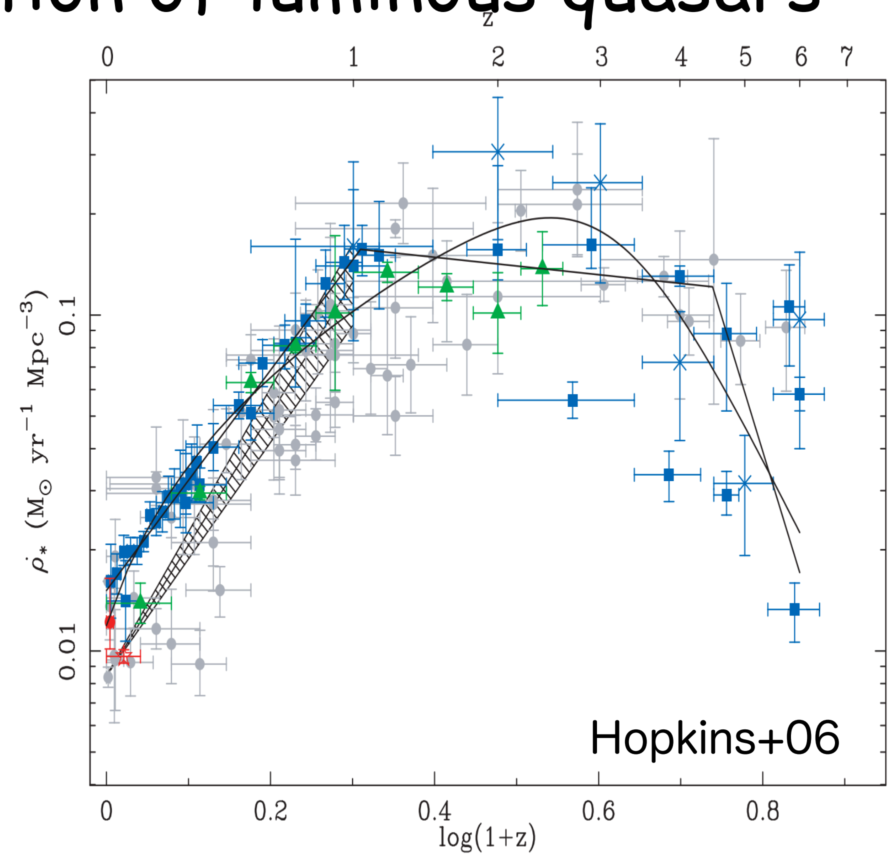
SDSS quasar luminosity function (QLF)

Ross+13



The number density evolution of luminous quasars

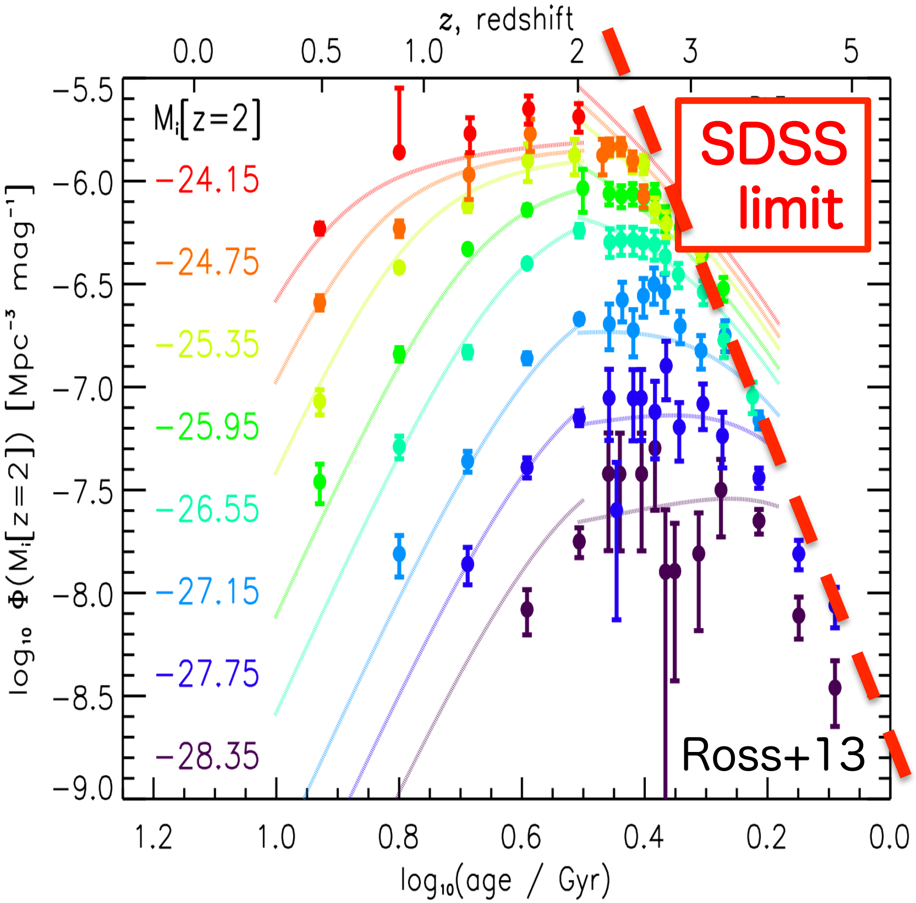




Number density of "luminous" quasars shows its peak at z~2-3. Similar to the evolution of cosmic star-formation rate density!

Indirect evidence of a close connection between the SMBH growth and the galaxy evolution

“Luminosity dependent” evolution of the QLF



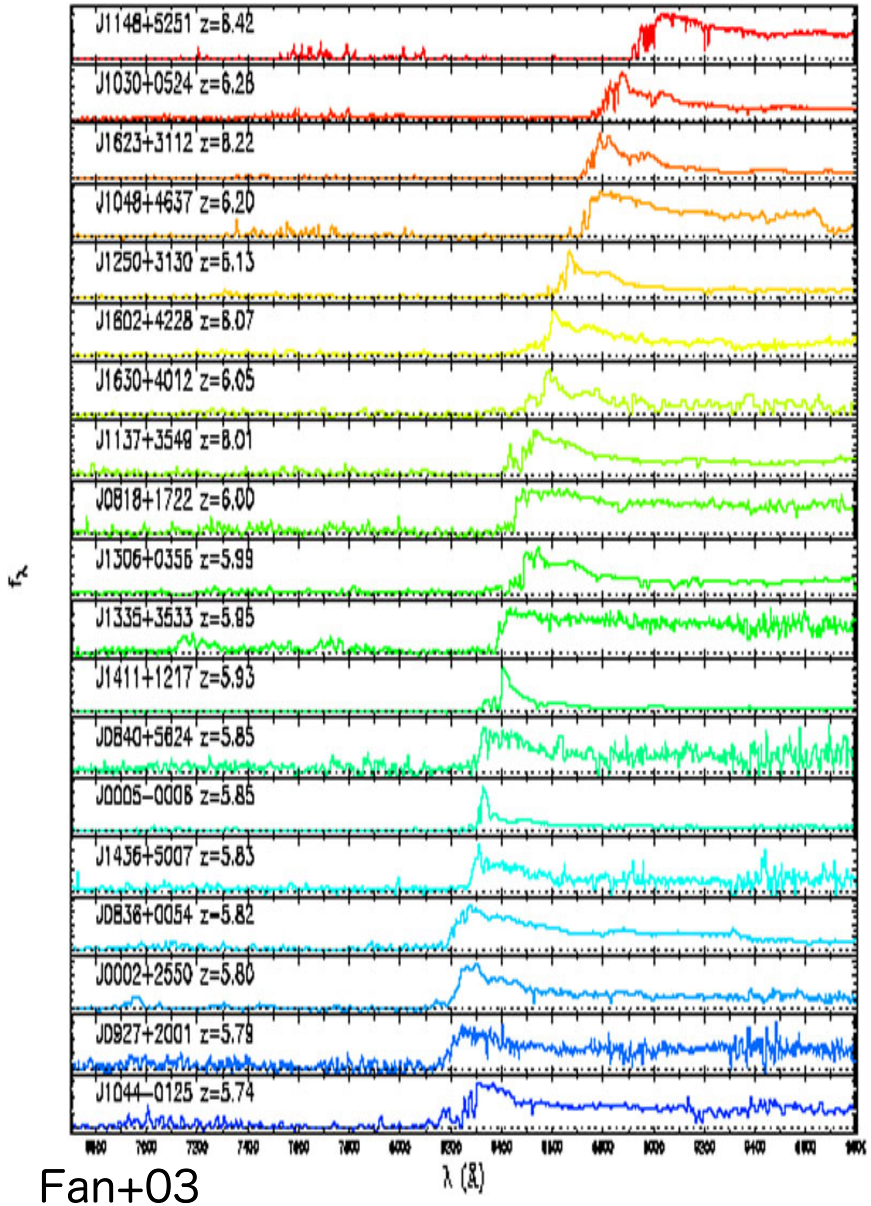
Number density evolution of SDSS III quasars. Different colors denote different luminosity ranges. See also, e.g., Croom et al. (2009); Ikeda, Nagao, et al. (2011, 2012).

More luminous SDSS quasars show the peak of their number density evolution at higher redshifts.

Luminosity-dependent density evolution of quasars, that may be consistent to the picture of the so-called “downsizing” evolution.

Caveat: the number density is not clear at higher z & lower luminosity. Downsizing really holds also at higher z?

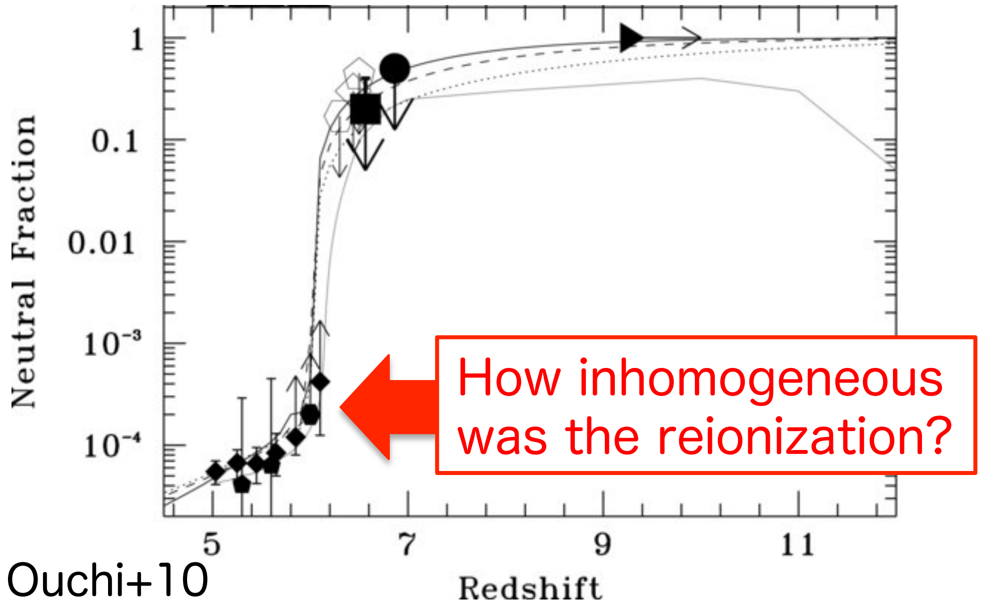
SDSS is NOT enough: at z~6



Fan+03

A few dozens of quasars at z~5.7-6.5 have been found so far

Cosmic reionization of hydrogen

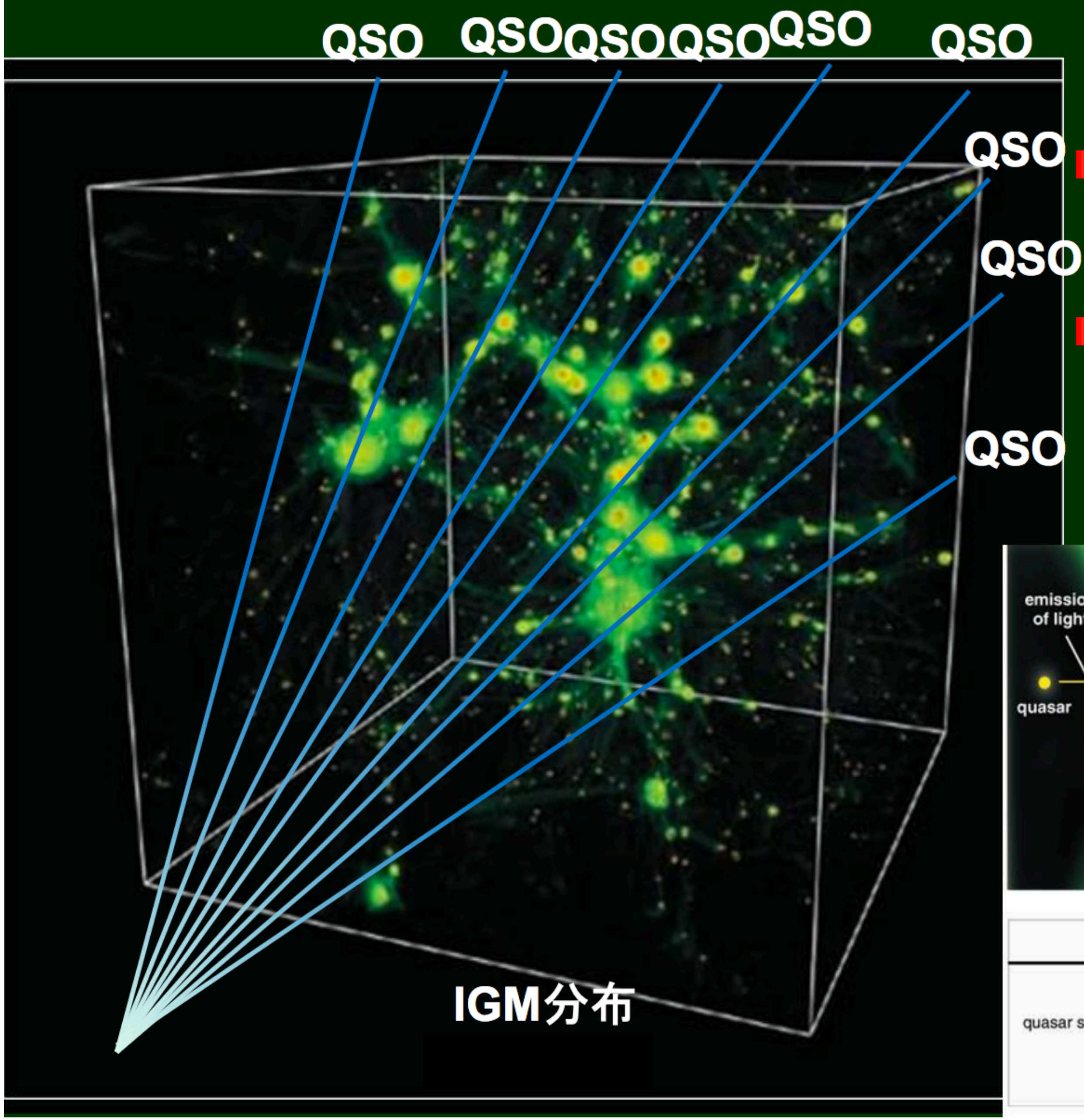


Ouchi+10

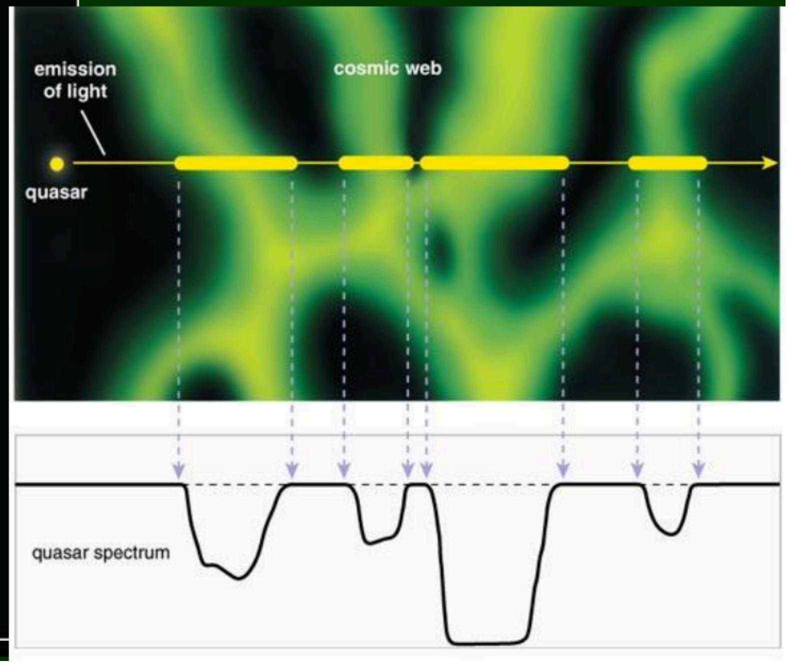
More quasars at z~6 needed!

[Courtesy of Kashikawa-san]

IGM tomography

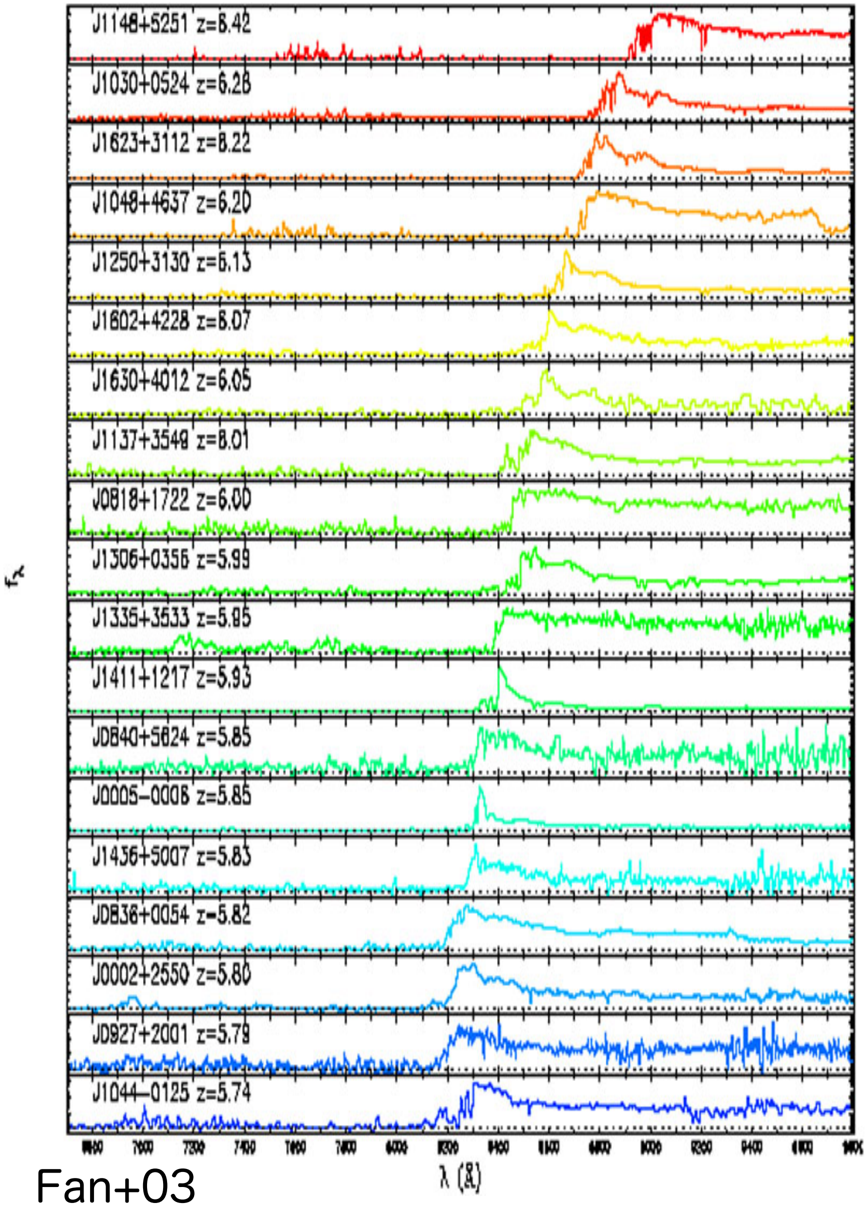


- LOS上しか分布がわからないというQAL最大の欠点を解消
- 背景光源の数密度が高くなれば、HI・metal・星・DMの3次元地図が描ける。



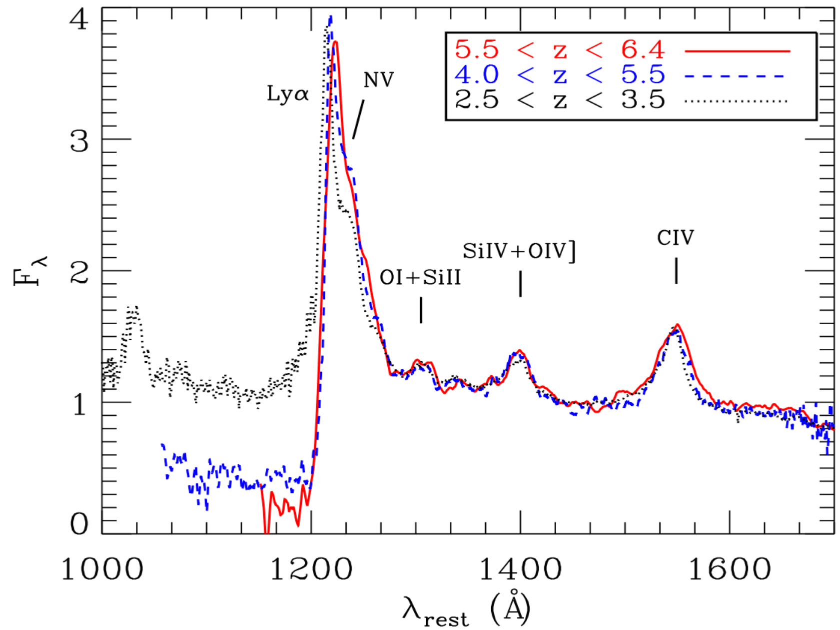
SDSS is NOT enough: at z~6

Juarez et al. (incl. TN) 2009



Fan+03

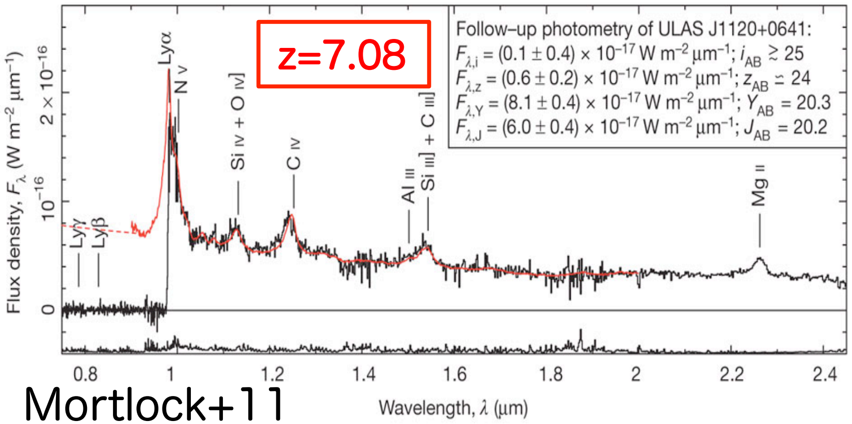
Stacked spectra of high-z quasars



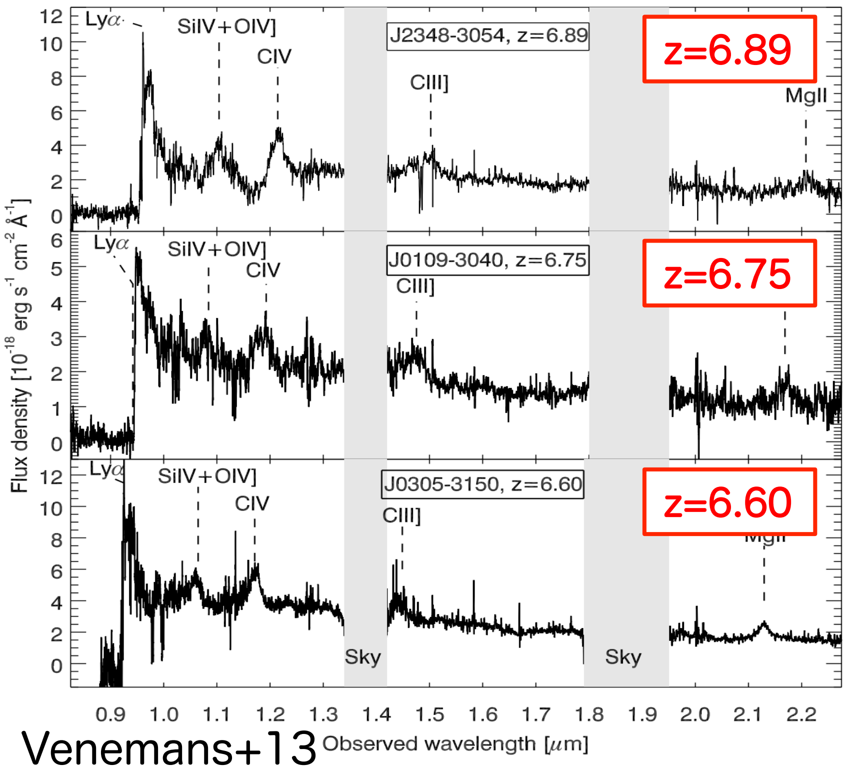
Even at z~6 (t_{age}~1 Gyr), the SMBH mass (~10^9 M_{sun}) and the metallicity are so high…

When the SMBH mass and the metals had increased??

Current NIR surveys are NOT enough: at z~7



Mortlock+11



Venemans+13

Only 4 quasars at 6.6<z<7.1, from UKIDSS & VIKING surveys

NEW Surprises:

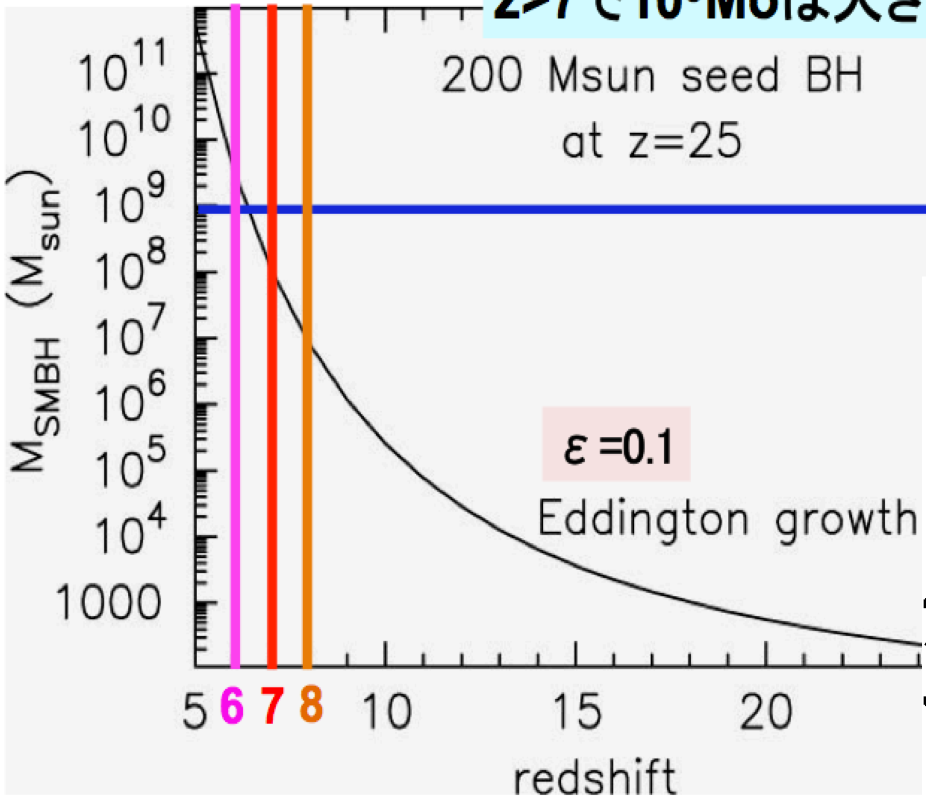
- M_{BH} ~ (1-2)x10^9 M_{sun}
- Strong metallic emission lines

but based on small statistics... and maybe we are missing "growing-up" low-M_{BH} quasars due to the limited sensitivity...

and we have NO quasars at z>7.1

宇宙初期のSMBH成長

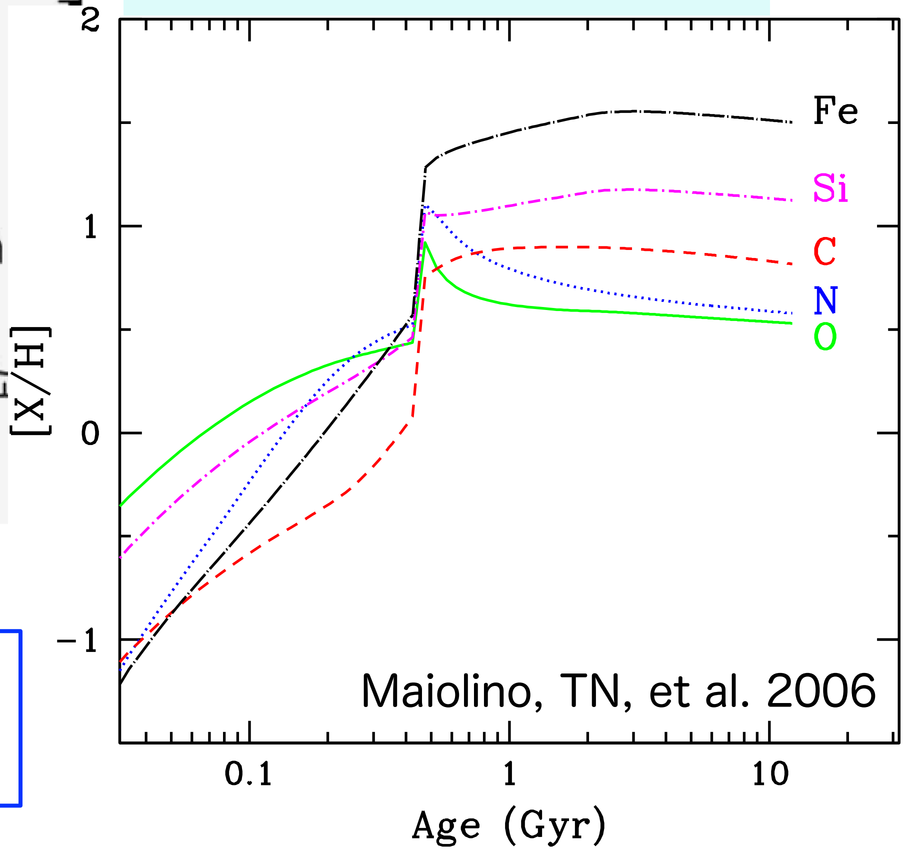
z~6.5で10^9Moは問題ない
z>7で10^9Moは大きな制限



[Courtesy of Imanishi-san]

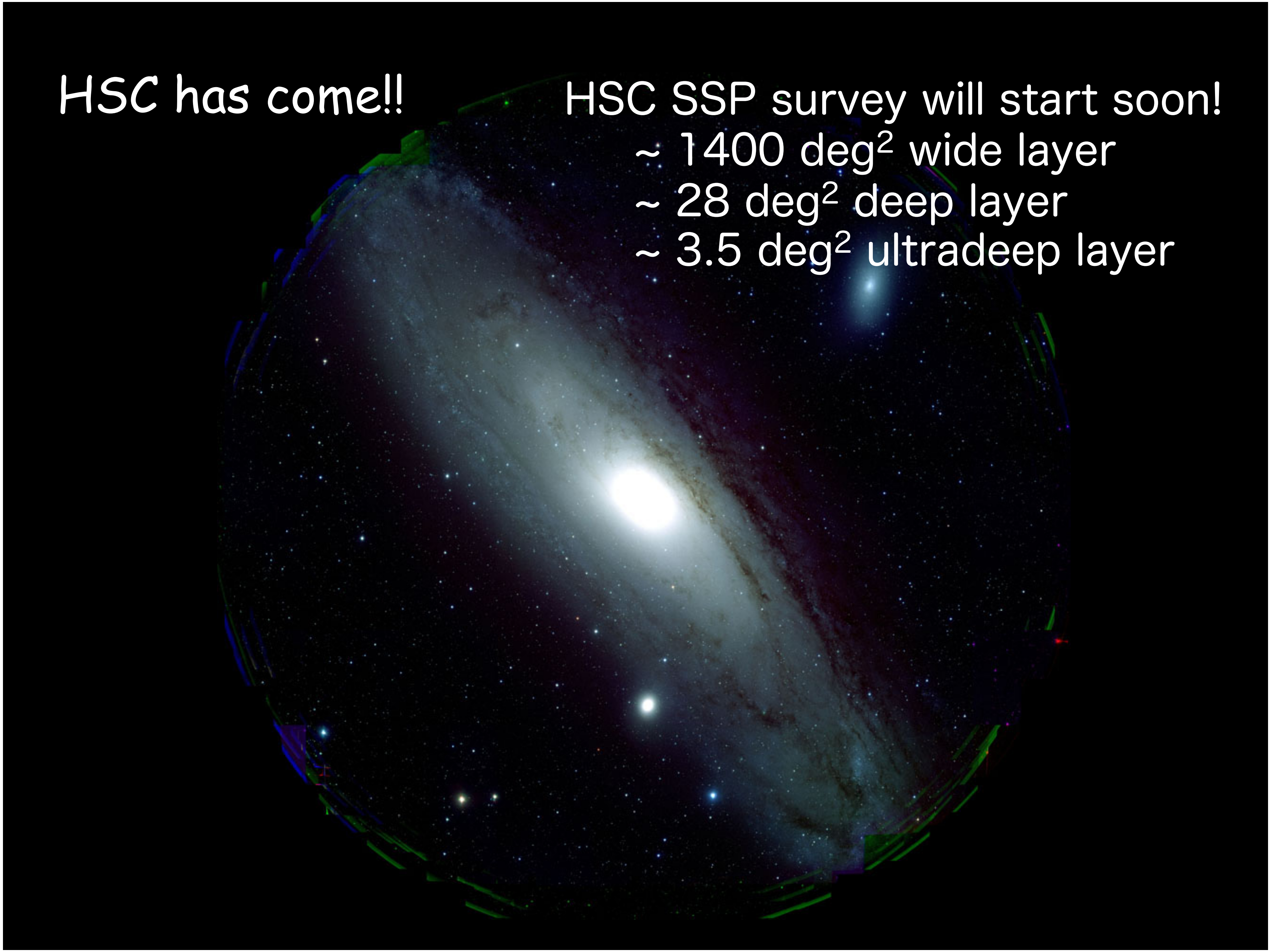
宇宙初期の化学進化

z<6 で無進化は問題ない
z>7 で無進化は大きな制限

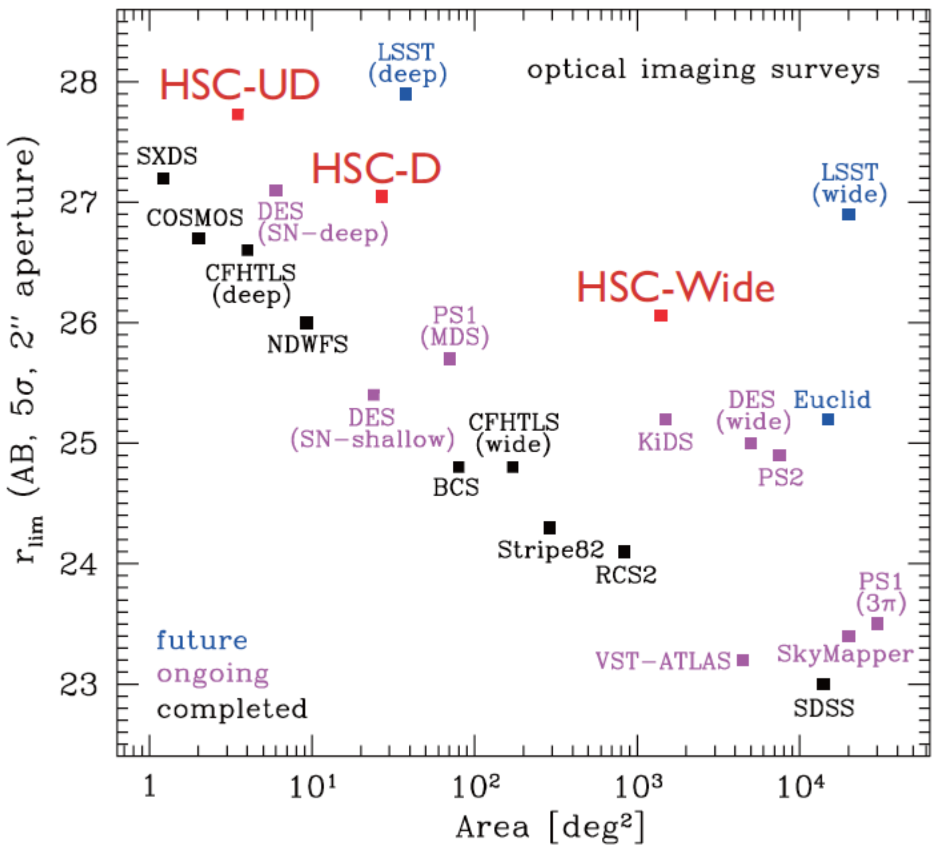


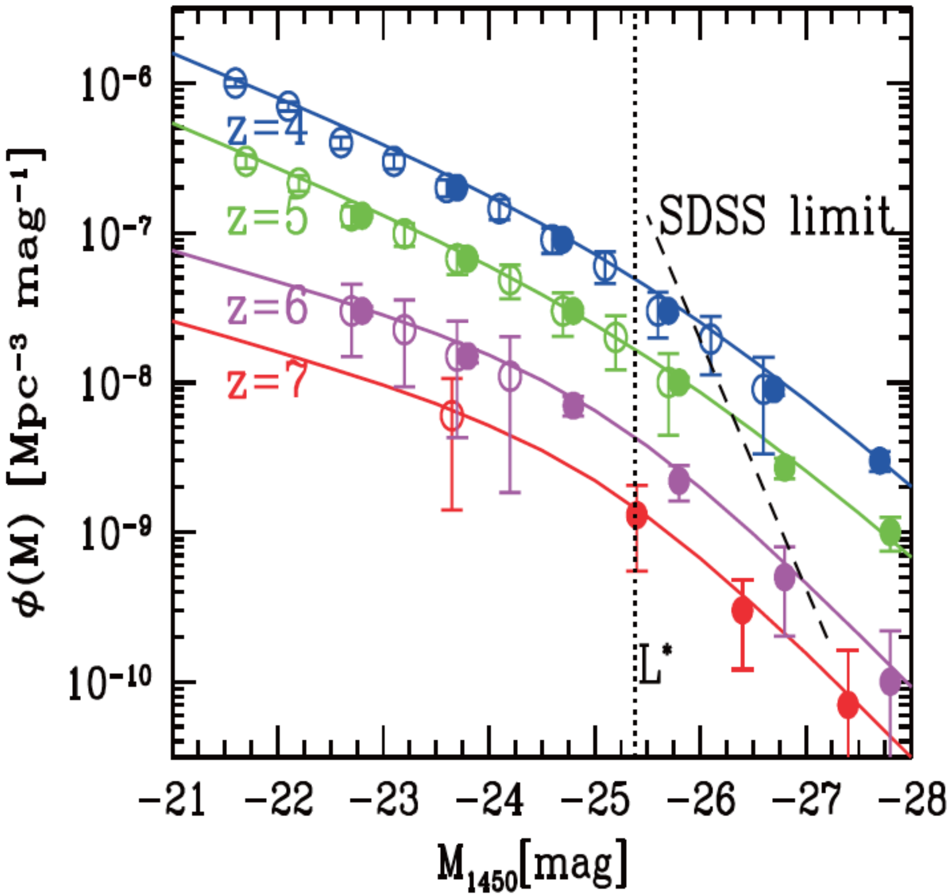
We need quasars at z > 7
for examining these issues!

逆にやたら軽い (M_{BH}~10^6 M_{sun} とか) SMBH が
z>7 でざくざく見つかってくると、それはそれで
supermassive hyper red giants (?) シナリオに制限？


HSC has come!!
HSC SSP survey will start soon!
~ 1400 deg² wide layer
~ 28 deg² deep layer
~ 3.5 deg² ultradeep layer

Our HSC legacy survey, at a glance

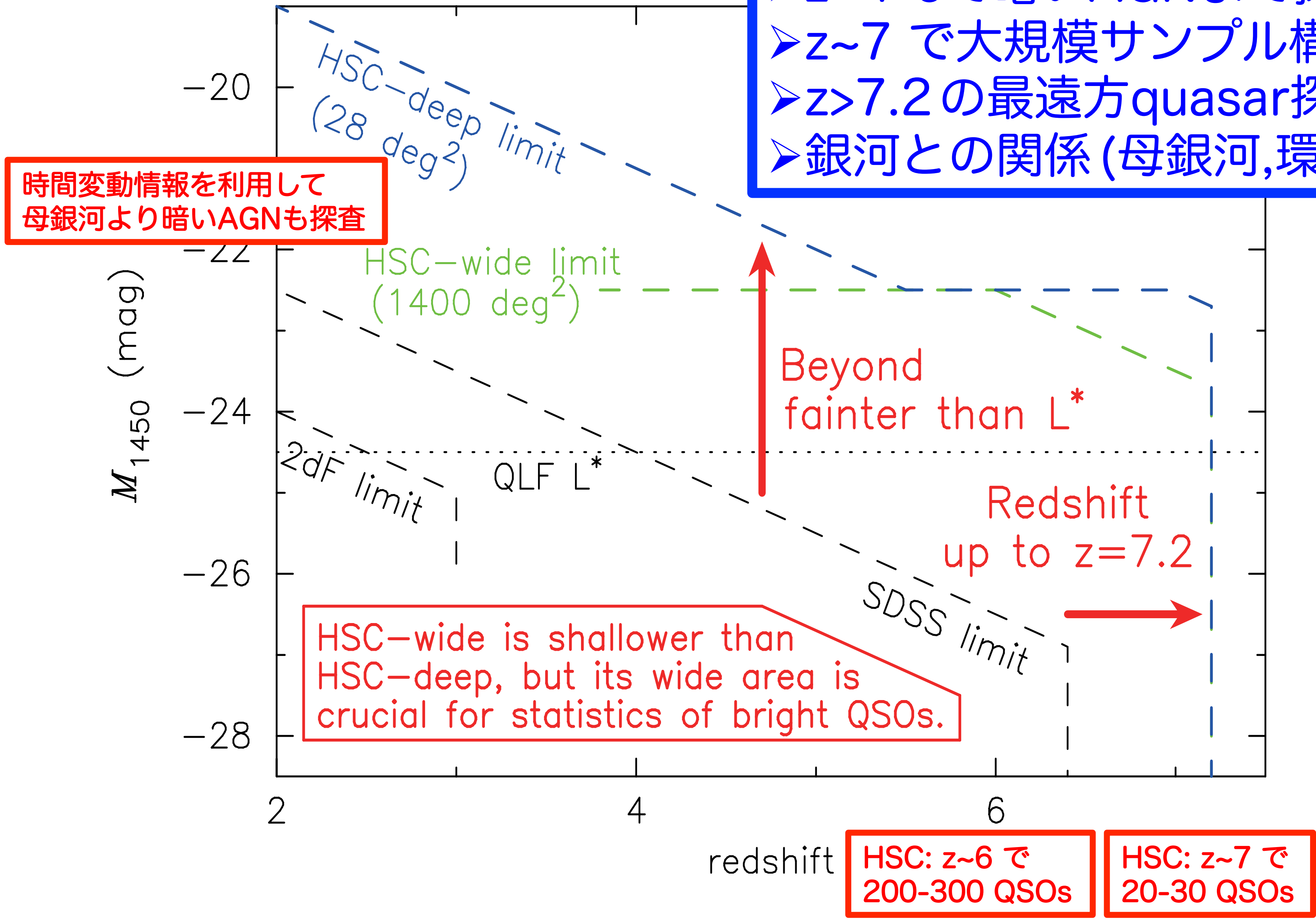


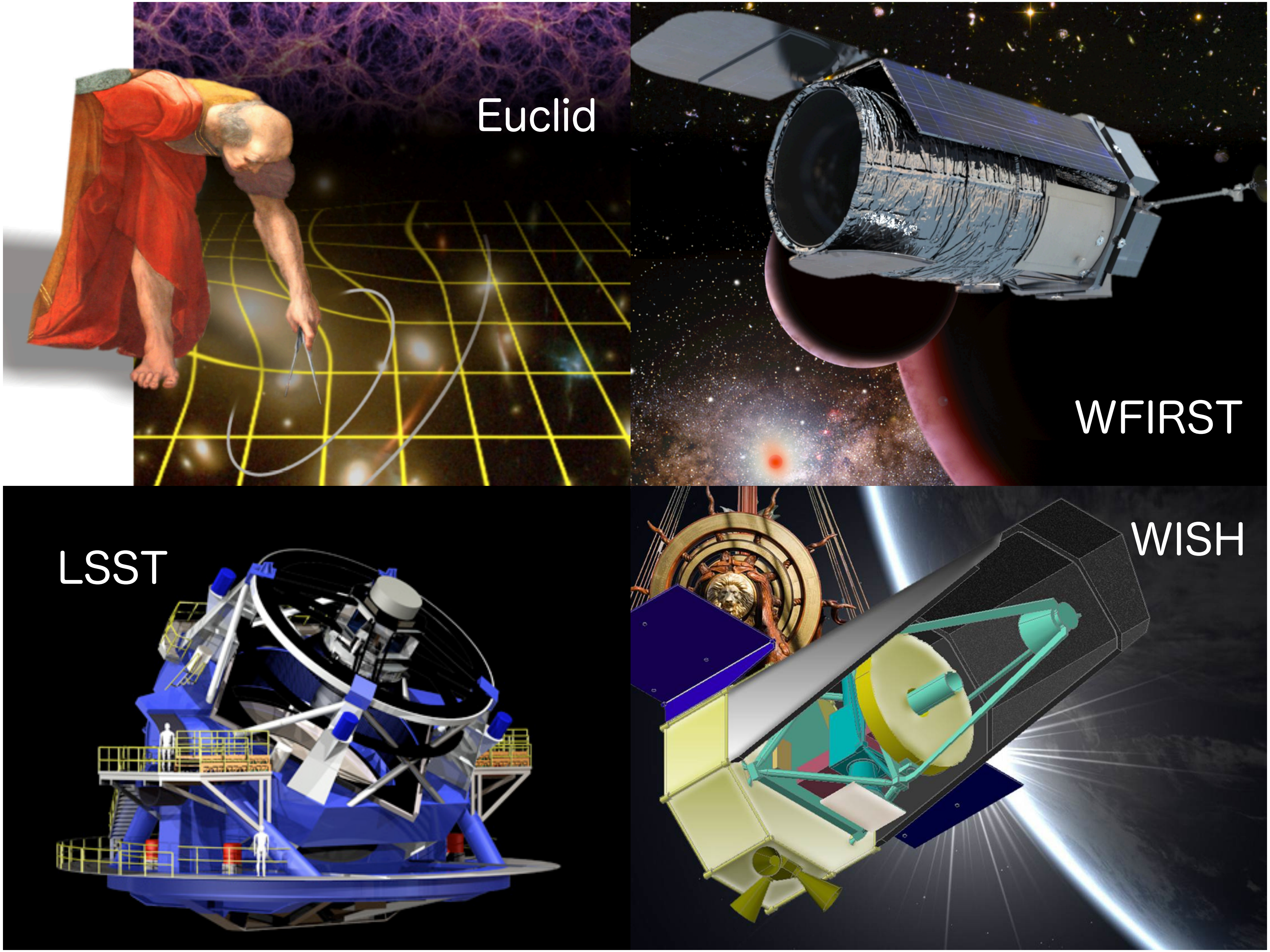


2013年3月観測開始、5年間で300夜を投入
(日本・台湾・プリンストンの国際共同研究)

Quasar surveys with HSC

HSCの「次」への期待：
- ➢z~4-6で暗いAGNまで探査
- ➢z~7 で大規模サンプル構築
- ➢z>7.2の最遠方quasar探査
- ➢銀河との関係(母銀河,環境)




Euclid
WFIRST
LSST
WISH

In the 2020's: Euclid, WFIRST, WISH, LSST

mission	start (?)	survey	band	depth (AB)	area
Euclid	2022- ?	Wide	Vis, Y, J, H	Vis=24.5, YJH=24	15,000 deg^2
		Deep	Vis, Y, J, H	Vis=26.5, YJH=26	40 deg^2
WFIRST	2025- ?	High Lat. (HLS)	Vis, Y, J, H	YJH=26	3,400 deg^2
		SN Wide	J, H	JH=28.1	6.5 deg^2
		SN Deep	J, H	JH=29.6	1.8 deg^2
WISH	2019- ?	UltraWide	JHK-ish	AB=24-25	1,000 deg^2
		UltraDeep	1-3um	AB=28	100 deg^2
		Extreme	YJH-ish??	AB=29-30	0.25 deg^2
LSST	2022- ?	Main (Wide)	u, g, r, i, z, y	gri=27-28, uzy=25-26	20,000 deg^2

mission	start	survey	band	depth (AB)	area
HSC	2014-	Wide	g, r, i, z, y	26.5,26.1,25.9,25.1,24.4	1,400 deg^2
		Deep	grizy + NBs	27.5,27.1,26.8,26.3,25.3	28 deg^2
		UltraDeep	grizy + NBs	28.1,27.7,27.4,26.8,26.3	3.5 deg^2

QSO/AGN in the 2020's surveys

Euclid:

~ quasars at z~8-9: ~30 obj. for J<22 or 55 obj. for J<22.5 in Wide

~ variability-selected low-L AGNs (1<z<4) in Deep (at NIR: new!)

WFIRST:

~ quasars at z~8-9: ~100 fainter obj. for J<24 in HLS

~ variability-selected low-L AGNs (1<z<9) in SN-Wide

WISH

~ quasars at z~8-9: ~30 obj. (similar mag as Euclid) in UW+UD

~ quasars at z~9-11: a few obj. thanks to longer wave. filters

LSST

~ variability selection! (but up to z~6.5)

i	0.5	1.5	2.5	3.5	4.5	5.5	6.5	Total
16	666	597	254	36	0	0	0	1550
17	4140	4630	1850	400	54	0	0	11100
18	19600	28600	10700	1980	321	19	0	61200
19	68200	131000	53600	8760	1230	115	0	263000
20	162000	372000	194000	35000	4290	441	1	767000
21	275000	693000	453000	113000	14000	1380	34	1550000
22	336000	1040000	756000	269000	41200	3990	157	2450000
23	193000	1440000	1060000	476000	103000	10900	527	3280000
24	0	1370000	1360000	687000	205000	27400	1520	3660000
25	0	314000	1540000	888000	331000	60800	4100	3140000
26	0	0	279000	760000	358000	86800	7460	1490000
Total	1060000	5390000	5720000	3240000	1060000	192000	13800	16700000

Table 10.2: Predicted Number of AGN in 20,000 deg^2 over $15.7 < i < 26.3$ and $0.3 < z < 6.7$ with $M_i \leq -20$. The ranges in each bin are $\Delta i = 1$ and $\Delta z_{em} = 1$, except in the first and last bins where they are 0.8 and 0.7, respectively.

taken from
LSST Science Book

Summary (+ additional comments)

AGN中心構造の解明に向けて

~ ダストトーラス分解が観測的にはホットトピック
~ 近赤外・中間赤外での干渉計観測でトーラススケールに肉薄中
~ TMTに中間赤外線装置が搭載されればブレイクスルーが期待される
~ 理論への期待は、観測と直接比較が可能なシミュレーション
~ 分子ガス・ダストがどう観測されるか、放射流体＆放射輸送計算で

高赤方偏移クェーサーの探査

~ これまでの観測だけでは低光度 and/or 高赤方偏移でサンプル不足
~ Subaru/HSC: 今後5年の観測で z~6-7 の大規模サンプルを構築
~ 2020年代: Euclid / WFIRST / WISH / LSST で z~7-9 (or 11)
~ 大規模統計の時代に観測と比較可能なモデルが必要！
~ (銀河だけでなく) AGNも合わせて取り扱う準解析的モデルが重要に
~ そういったモデルの中でSMBHの統計的進化も自然に扱われるべき
~ 観測との比較の際はダストの効果が気になる (AGNタイプとの関係)