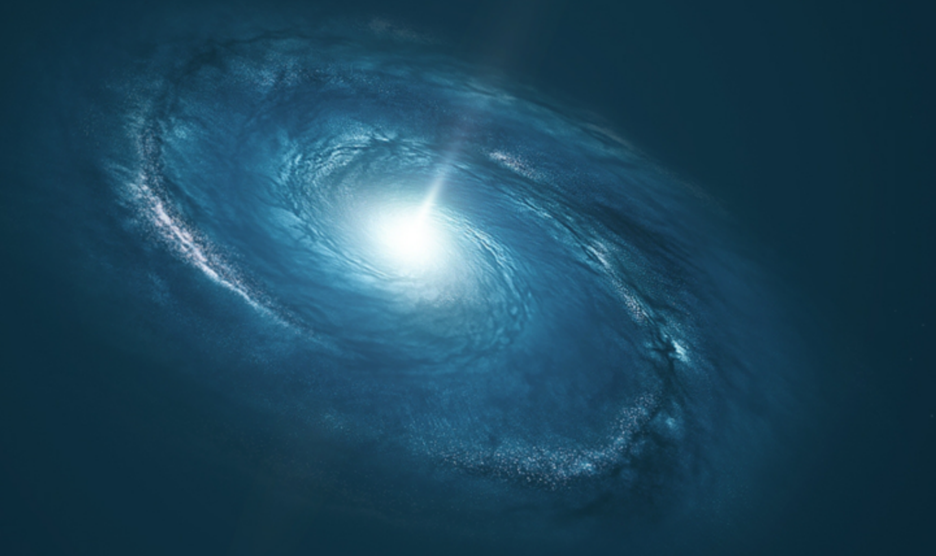
超巨大ブラックホール研究連絡会」第2回ワークショップ
2014年11月3日-4日、於・筑波大学 計算科学研究センター

SMBHの起源と進化：観測レビュー



河野孝太郎
(IoA/RESCEU, UTokyo)

Outline

- SMBHの起源と進化
  - 現在知られている最も初期のSMBH = ULAS J1120+0641から得られる示唆
  - SMBH質量の測定/Eddington比の測定とそれを決めるもの/周辺環境の調査
- SMBHと銀河の関係
  - AGN feedback

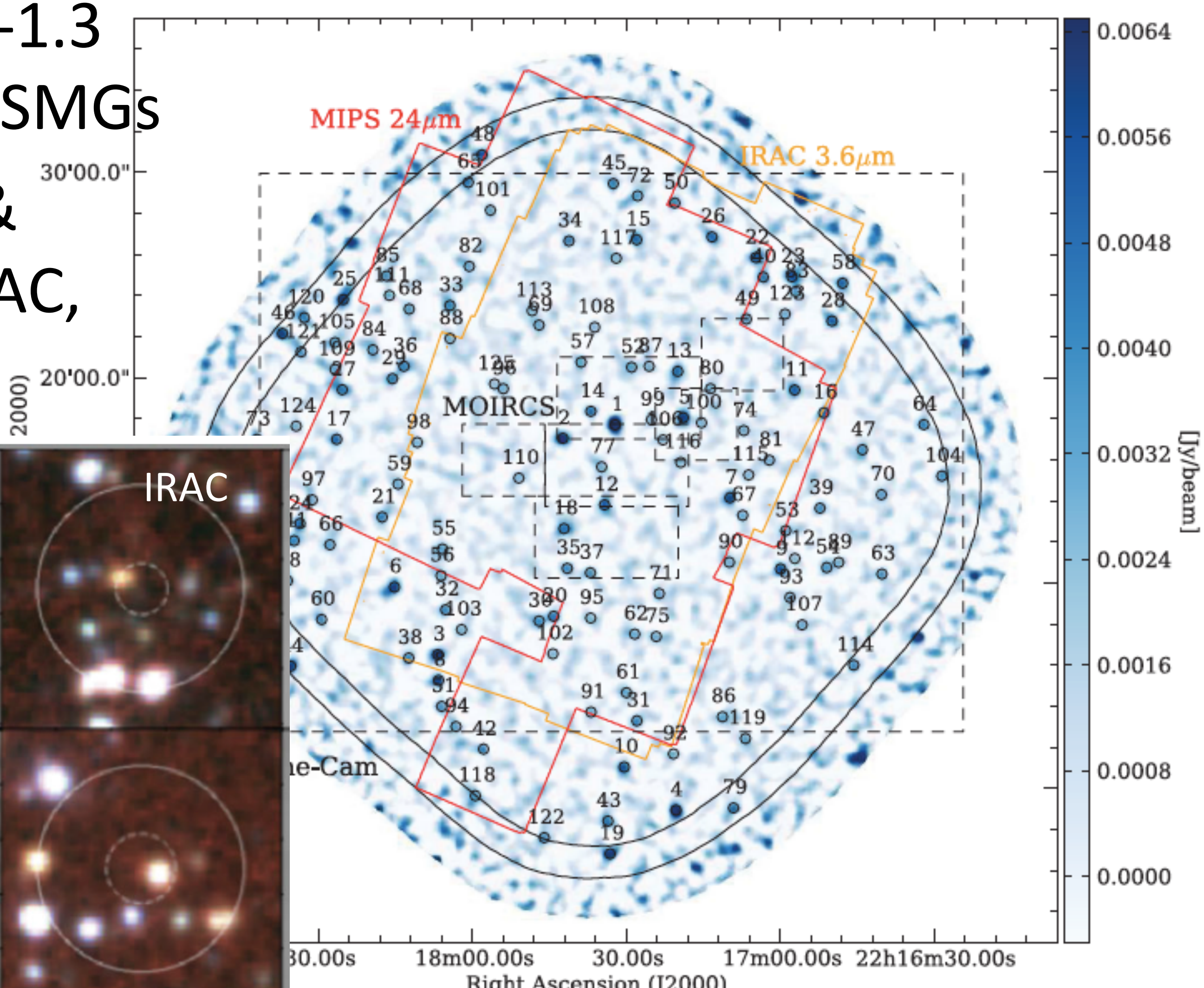
    Negative? Positive?
  - 銀河が先？SMBHが先？

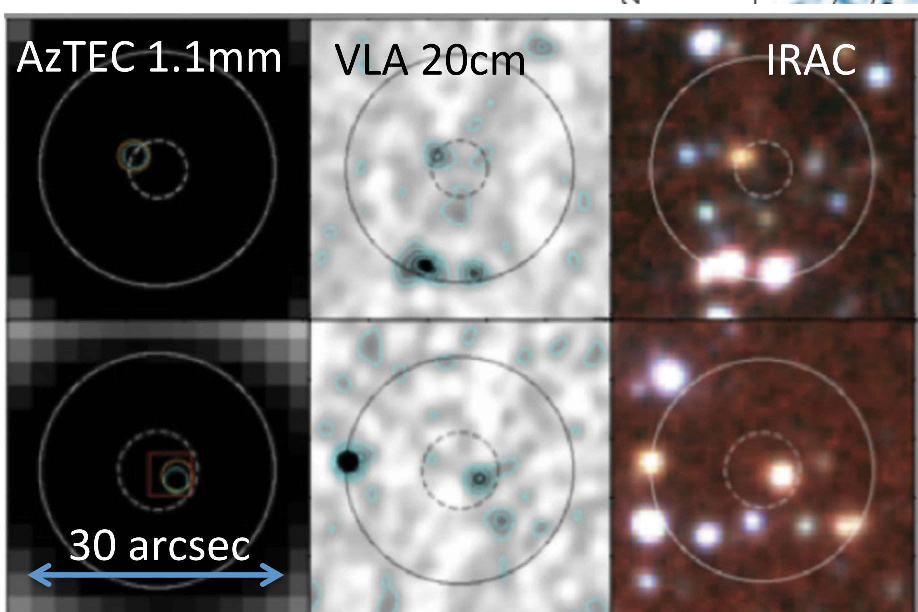
その前に、、

AzTEC/ASTE 1.1-mm survey of SSA22: Counterpart-ID and photometric redshift survey of SMGs

Umehata, Tamura, KK, et al., 2014, MNRAS, 440, 3462

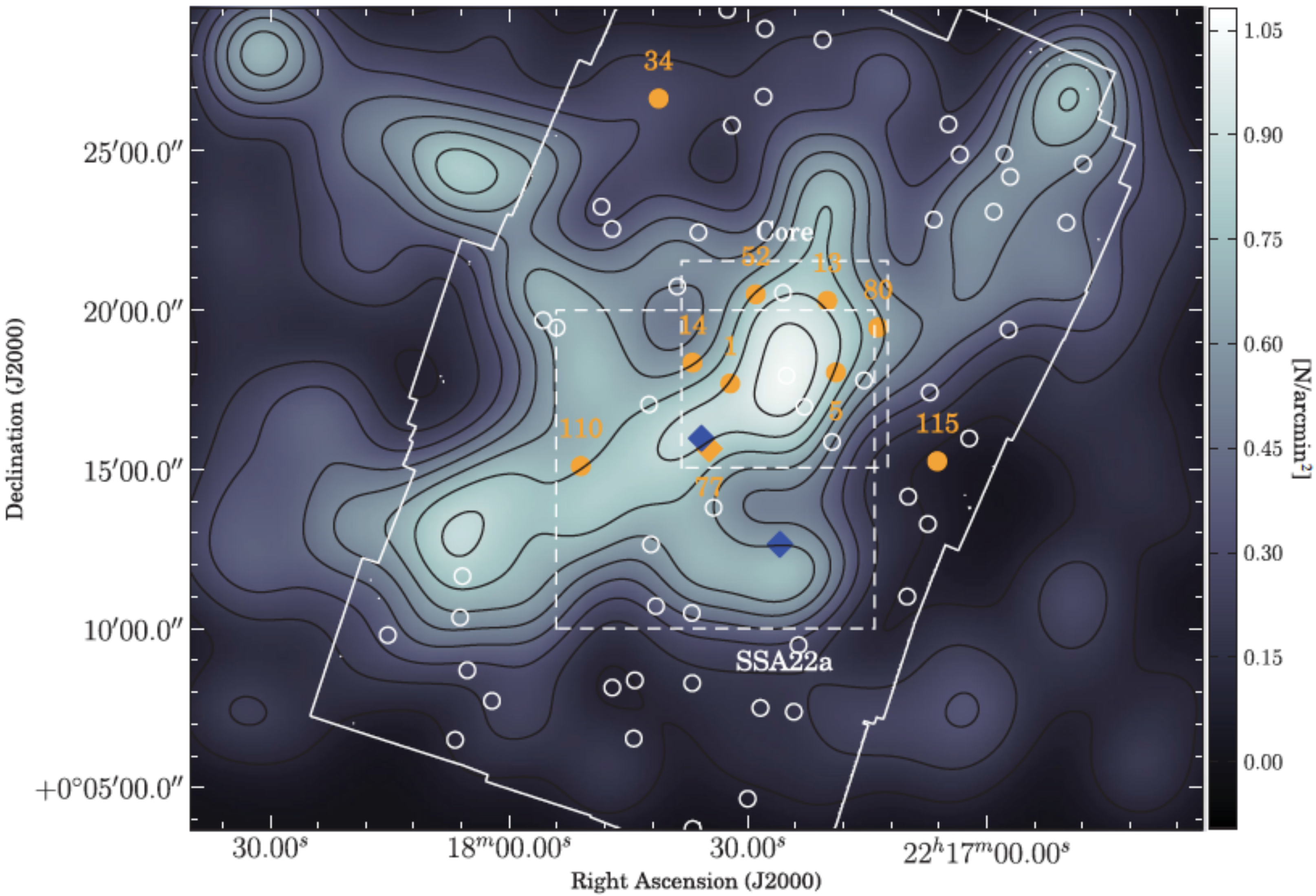
- 950 arcmin^2, 0.7-1.3 mJy (1σ) ➔ 125 SMGs
- Counterpart ID & photo-z using IRAC, MIPS, and VLA





Spatial distribution of massive dusty starbursts associated with the proto-cluster SSA22 at z~3.1

Umehata, Tamura, KK, et al., 2014, MNRAS, 440, 3462



ALMA Follow up observations of AzTEC SMGs in SSA22: 2012.1.00608.S

§ Dates

2014 May 05, 06

§ Conditions

PWV ~ 2 mm (May05), 0.7 mm (May06)

§ Configuration

N_ antenna = 32-34, C32-4 Array

§ Frequency and set up

~263 GHz (1.1 mm), TDM mode (BW=7.5 GHz)

§ Number of Field of View

45 (D=22.9 arcsec for each FoV)

§ On source time:

~1min, ~2min, and ~3.5min

§ Analysis

CASA 4.2.1

Umehata, Tamura, KK et al. in prep.

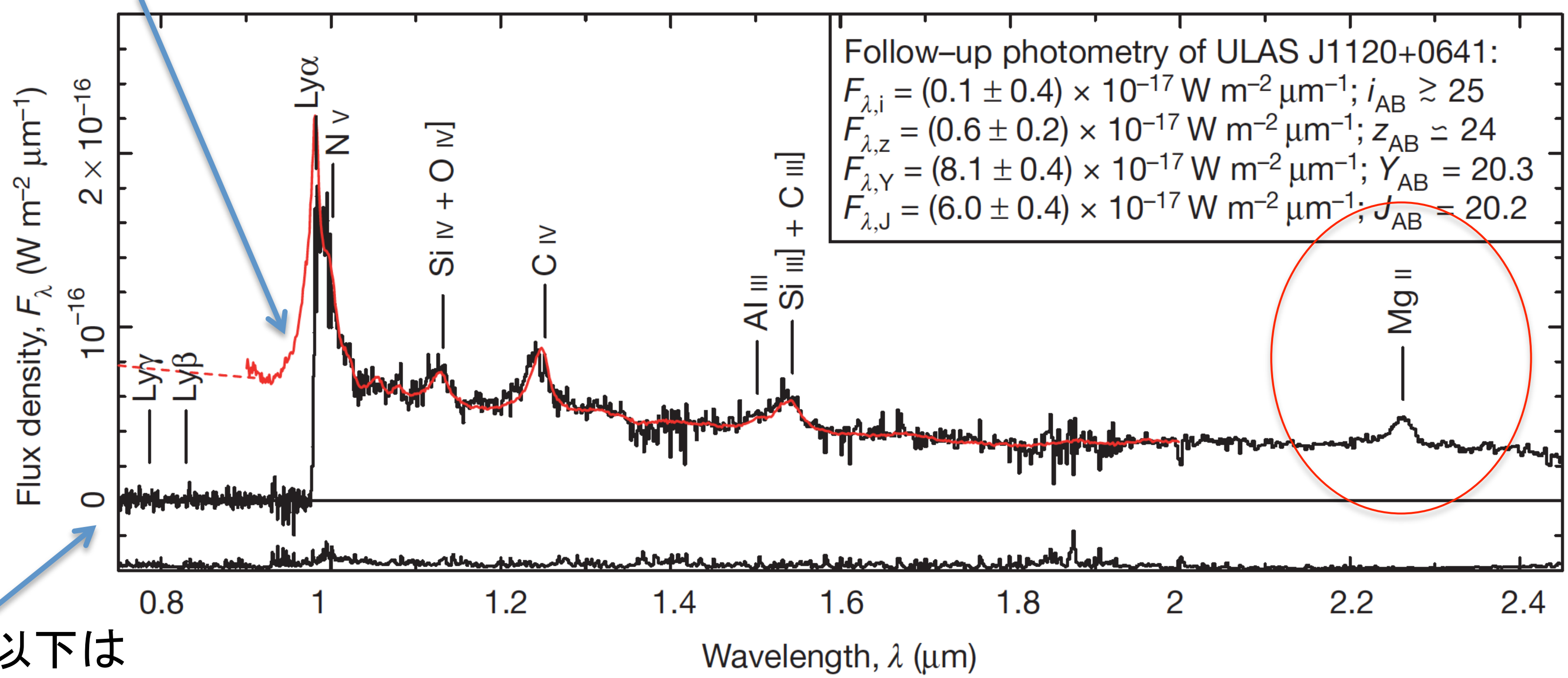
（現在知られている）最初のSMBH

ULAS J1120+0641 @z=7.084

- Combination of wide area infrared and optical imaging (UKIDSS + SDSS)
- M(BH) = $2.0^{+1.5}_{-0.7} \times 10^9\ M_\odot$ based on MgII line width
  - L(0.3μm) = $(1.3\pm0.1)\times10^{40}$ W/μm
  - MgII line width = 3800±200 km/s (FWHM)

Mortlock et al. 2011, Nature, 474, 616

Composite spectrum of 169 SDSS quasars @z = 2.3 – 2.6



1μm以下は FORS2/VLT

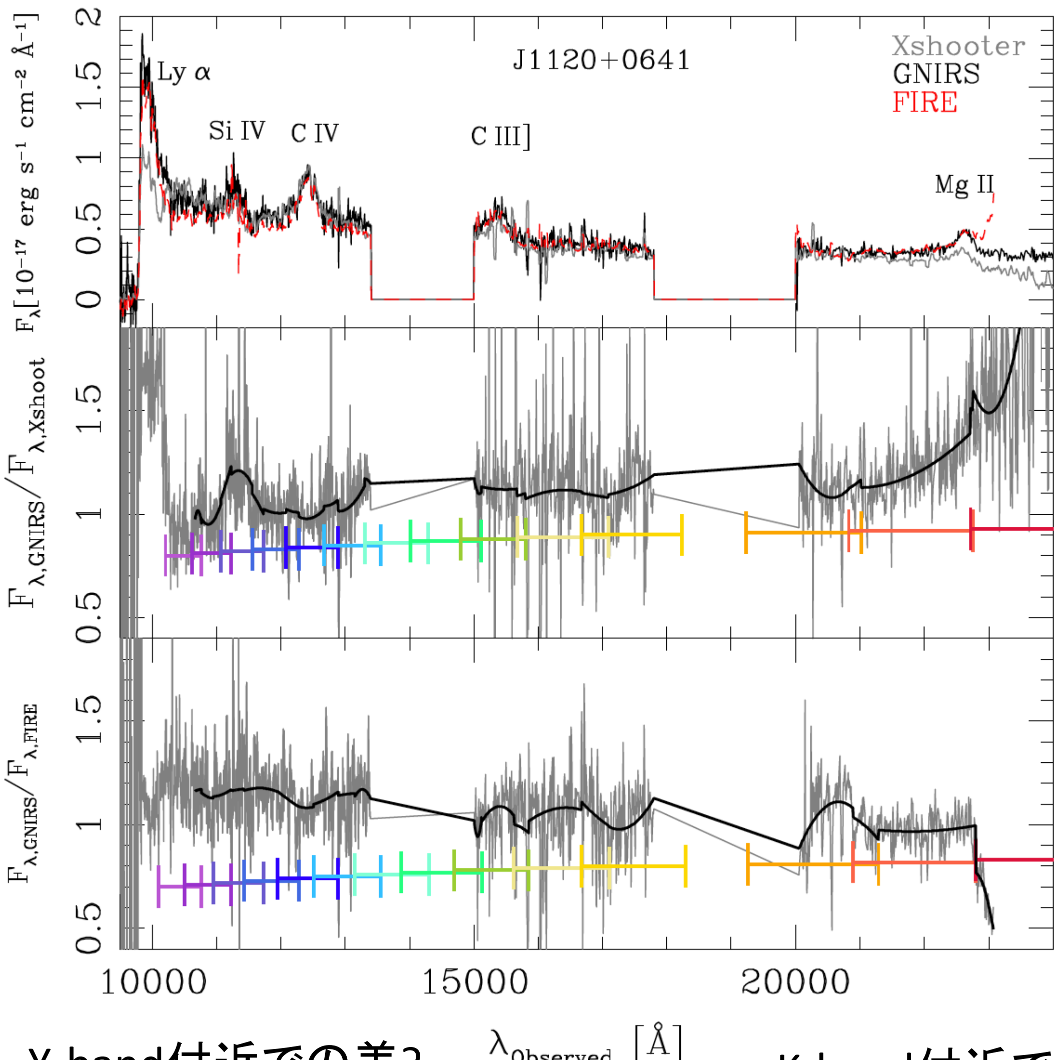
1μmから先はGNIRS/Gemini-North

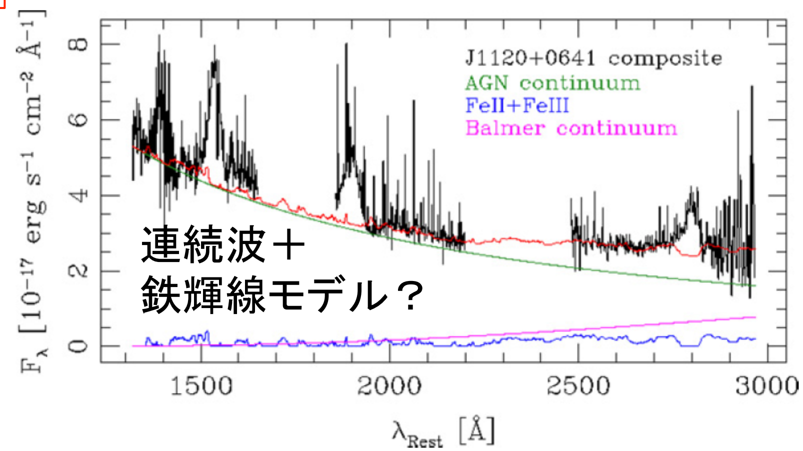
Important for SMBH mass!

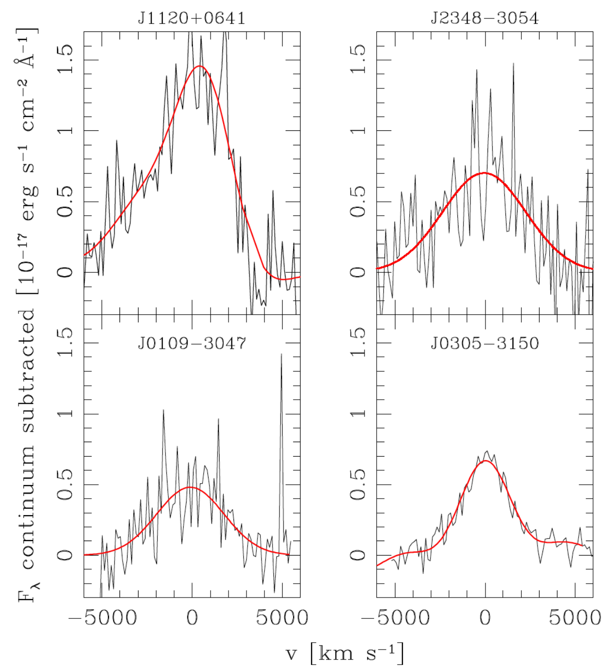
Mass of SMBH in ULAS J1120

X-Shooter/VLT vs Magellan/FIRE vs GNIRS/Gemini-N

De Rosa et al. 2014, ApJ, 790, 145







Y-band付近での差?

K-band付近での差?

Mass of SMBH & Eddington luminosity ratio in ULAS J1120

- M(BH) = $2.0^{+1.5}_{-0.7} \times 10^9\ M_\odot$ (Mortlock et al. 2011)
- M(BH) = $2.4 \pm 0.2 \times 10^9\ M_\odot$ (De Rosa et al. 2014)
  - 但し後者は系統誤差を含まず。
  - 採用しているScaling relationの分散（～0.1 dex？）が主な誤差要因。

$$M_{\rm BH} = f\ G^{-1} R_{\rm BLR}\, v_{\rm BLR}^2$$

Reverberation mappingから
AGN continuum luminosity – R_{BLR} correlation

$$M_{\rm BH}({\rm Mg\,II}) = 10^{6.86} \left(\frac{\rm FWHM_{line}}{10^3\ {\rm km\ s^{-1}}}\right)^2 \left(\frac{\lambda L_\lambda(3000\ {\rm \AA})}{10^{44}\ {\rm erg\ s^{-1}}}\right)^{0.5} M_\odot$$

Vestergaard & Osmer 2009, ApJ, 699, 800

- Eddington ratio: bolometric luminosity

$$L_{\rm Bol} = 5.15\ \lambda L_\lambda(3000\ {\rm \AA})$$

Shen et al. 2008, ApJ, 680, 169

Mass of SMBH & Eddington luminosity ratio in ULAS J1120 & z>6.5 quasars

$L/L(\mathrm{Edd}) = 1.2^{+0.6}_{-0.5}$ (Mortlock et al. 2011)

De Rosa et al. 2014, ApJ, 790, 145

Table 3

Estimated M_{BH}, Quasar Eddington Ratios, Emission Line Ratios, and C IV EW

		J1120+0641	J2348–3054	J0109–3047	J0305–3150
M_{BH} (Mg II) (10^9 $M_\odot$)		$2.4^{+0.2}_{-0.2}$	$2.1^{+0.5}_{-0.5}$	$1.5^{+0.4}_{-0.4}$	$0.95^{+0.08}_{-0.07}$
M_{BH} (C IV) (10^9 $M_\odot$)		$1.09^{+0.02}_{-0.04}$	...	$0.77^{+0.05}_{-0.1}$	$1.20^{+0.06}_{-0.05}$
$L_{\mathrm{Bol}}/L_{\mathrm{Edd}}$	Factor 2の	0.48	0.18	0.24	0.68
$L_{\mathrm{Bol}}/L_{\mathrm{Edd2011}}$	系統誤差	0.52	0.19	0.26	0.74
Si IV/C IV		0.35 ± 0.01	...	0.39 ± 0.19	0.52 ± 0.02
C III]/C IV		0.73 ± 0.01	...	...	...
Fe II/Mg II		$2.10^{+0.13}_{-0.02}$	$2.8^{+0.3}_{-1.0}$	$1.8^{+2.5}_{-1.8}$	$3.2^{+0.7}_{-0.7}$
$\mathrm{EW}_{\mathrm{C\,IV}}$ (Å)		26.3 ± 0.3	...	$20.6 \pm +4.7$	27.0 ± 0.8
		z ~ 7.1	z ~ 6.9	z ~ 6.7	z ~ 6.6

Notes. $L_{\mathrm{Bol}}/L_{\mathrm{Edd\ 2011}}$ is obtained by using Equation (4) of De Rosa et al. (2011).

Constraints (?) on formation process of SMBH in the early universe

- L/L_{Edd} = 0.4 average ratio of z > 6.5 sample — De Rosa et al. 2014, ApJ, 790, 145
- このrateでInitial mass M0からMtに要する時間tは？

$$t = 0.45\ \mathrm{Gyr} \left(\frac{\epsilon}{1-\epsilon}\right) \frac{L_{\mathrm{Edd}}}{L_{\mathrm{Bol}}} \ln\left(\frac{M_t}{M_0}\right)$$

Shapiro 2005, ApJ, 620, 59

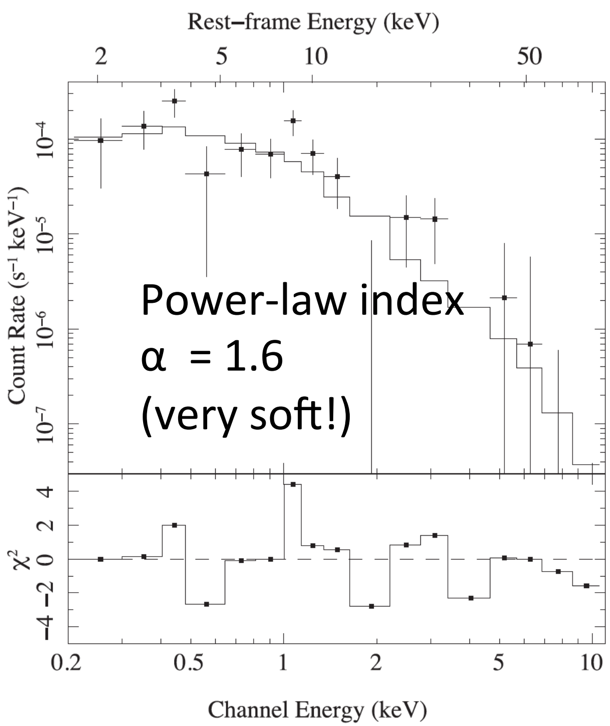
  – Characteristic time scale 0.45 Gyr
    - radiative efficiency ε = 0.07, a mean molecular weight per electron μ_e = 1
  – M_0 = 100 – 600 $M_\odot$ (e.g., Volonteri 2010)
    ➔ 10^9 $M_\odot$まで 1.2 – 1.4 Gyr必要 >> 0.8 Gyr @z=6.5-7.1
- z_0=10, 15, ∞ から出発して、Mt=10^9 $M_\odot$ を作るために必要な $M_\odot$ (seed BH mass)は？

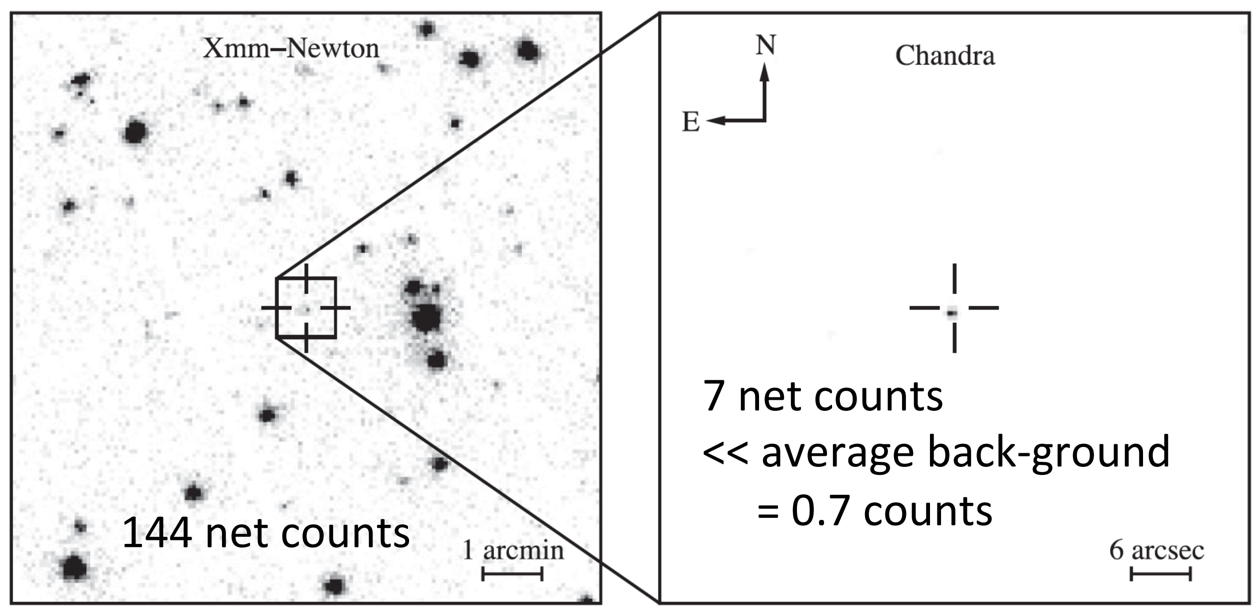
L/L(Edd)	z_0=10	z_0=15	z_0=∞
0.4	3×10^7 $M_\odot$	3×10^6 $M_\odot$	8×10^4 $M_\odot$
1	1×10^5 $M_\odot$	4×10^2 $M_\odot$	1×10^{-2} $M_\odot$

Chandra & XMM-Newton detections of X-ray emission from ULAS J1120+0641

- Chandra (16 ks)@2011 Feb
- XMM-Newton (331 ks) @2012 May-June
- Flux variation ($1.8^{+1.0}_{-0.7}$ ➔ 0.47 ± 0.09) x 10^{54} erg/s

Page et al. 2014, MNRAS, 440, L91



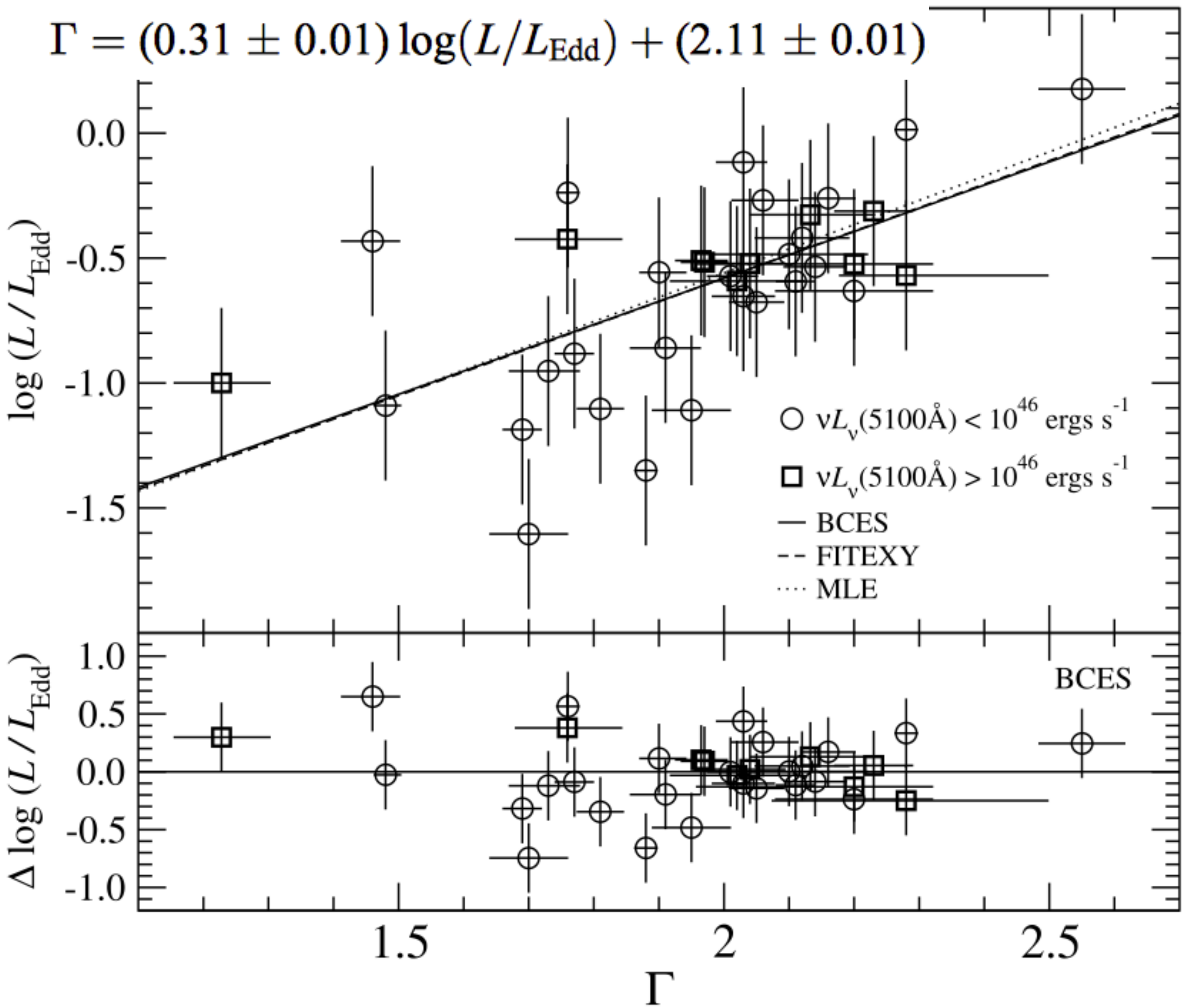


X-ray spectral index α vs L/L(Edd) ratio

Page et al. 2014, MNRAS, 440, L91

- Known correlation between α – L/L(Edd) ➔ α can be an estimator of L/L(Edd)
  - Shemmer et al. 2008, ApJ, 682, 81; Risaliti et al. 2009, ApJ, 700, L6; Jin et al. 2012, MNRAS, 425, 907; Brightman et al. 2013, MNRAS, 433, 2485
- observed X-ray slope (very soft) indicates high accreting rate (several times the Eddington rate): $L/L(Edd) = 5^{+15}_{-4} \gg L/L(Edd) = 1.2^{+0.6}_{-0.5}$ (based on rest-frame UV observations)
- This would help to reduce the discrepancy on SMBH formation … (?)

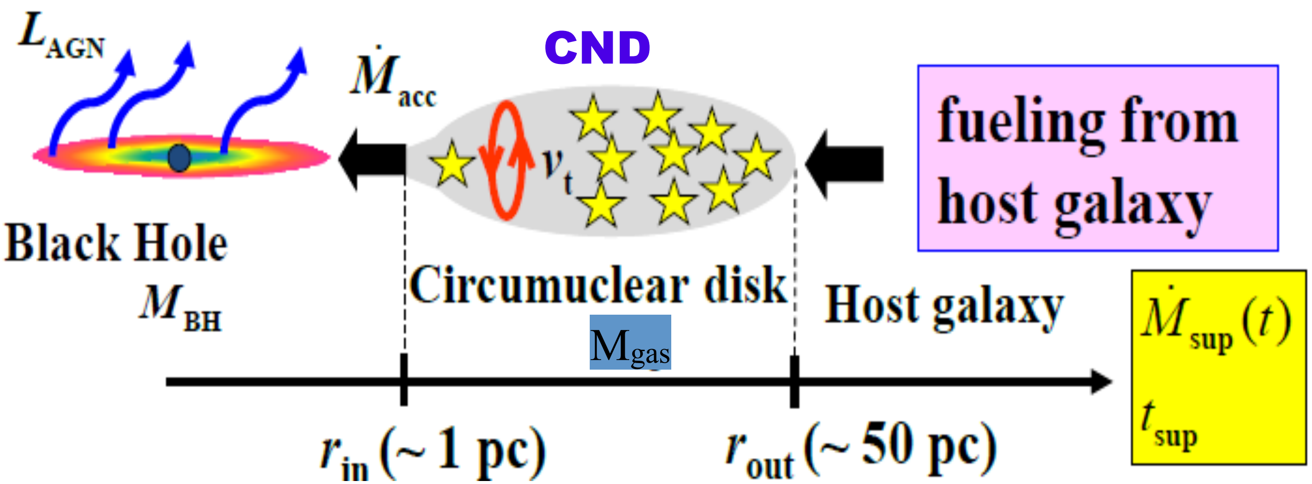
X-ray spectral index α (photon index Γ) vs L/L(Edd) ratio

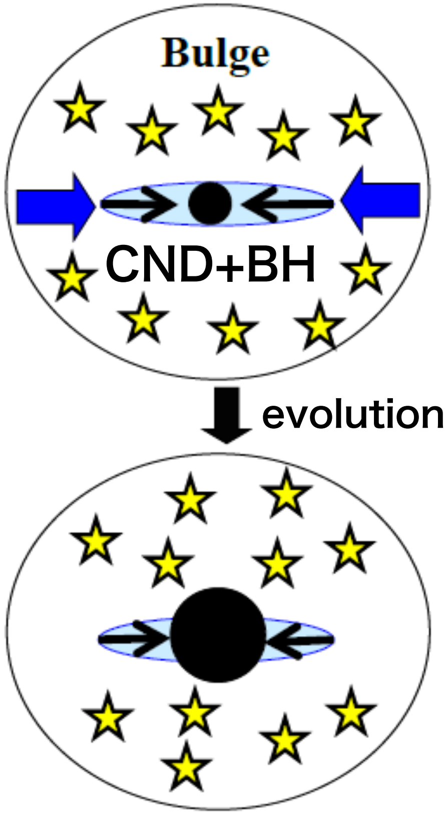


Shemmer et al. 2008, ApJ, 682, 81

L/L(Edd)比・BH成長の鍵？ Circumnuclear gas Disk (CND)

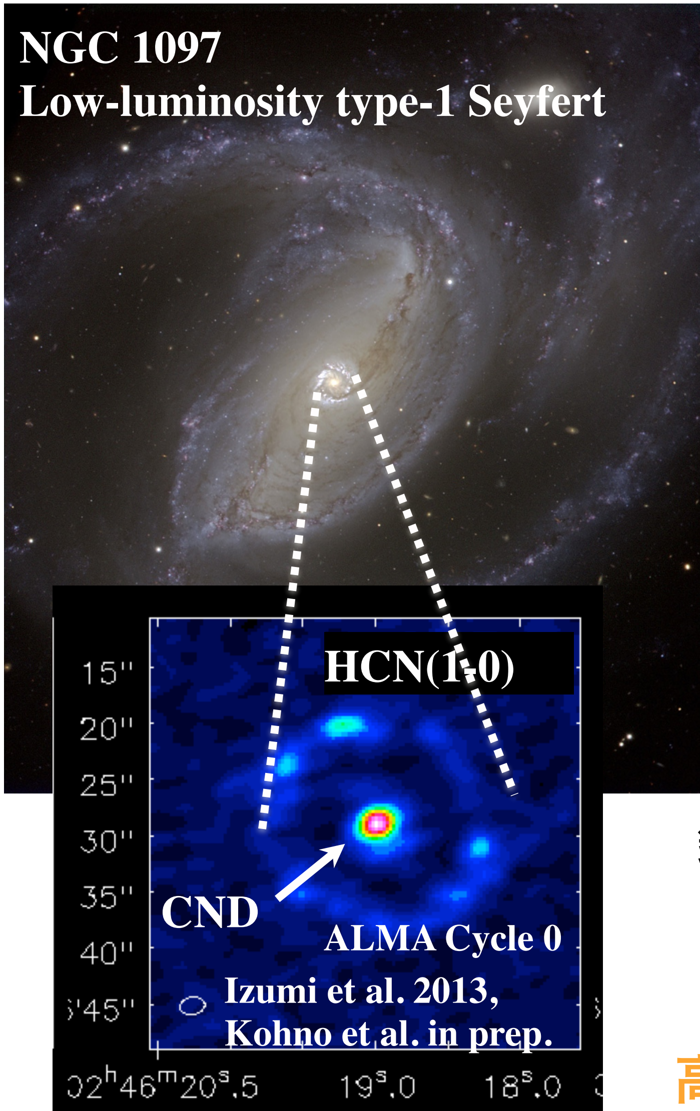
- 数十〜百pcスケールの大質量CNDがBH周辺に形成されると予測されている
  ⇒ BHへの直接的な質量供給源？
  - e.g., Kawakatu & Wada 2008, ApJ, 681, 73
- BHの活動性と、Mgas/MBHの質量比に関係あり？

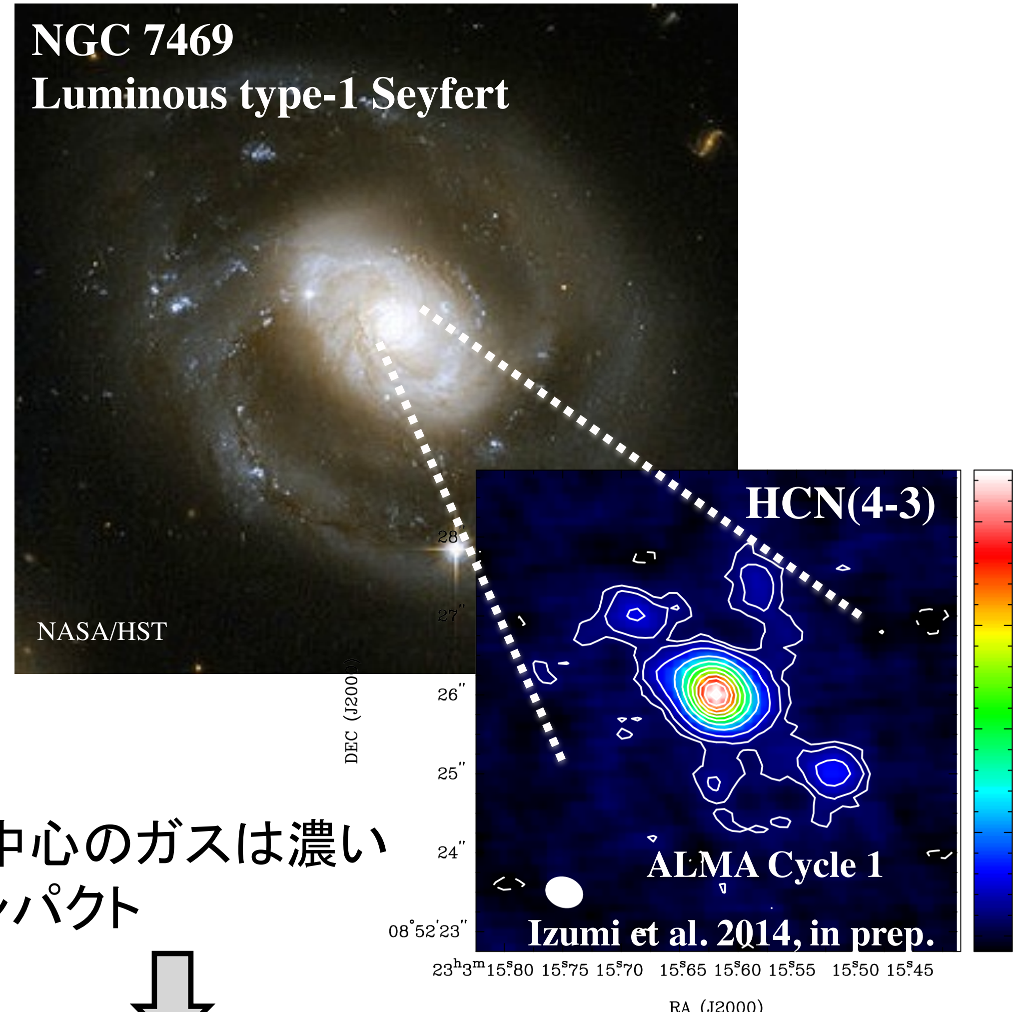




http://astrophysics.jp/ALMA-Hokudai2012/presentation/N_kawakatu.pdf

CNDs in Nearby Active Galaxies



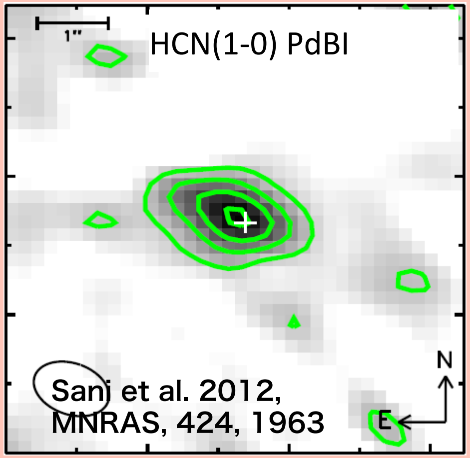


銀河中心のガスは濃い
＆コンパクト

⇩

高密度ガストレーサーの干渉計観測が重要

Kinematic structures of CNDs
NGC 4051(NLSy1) vs NGC 1097



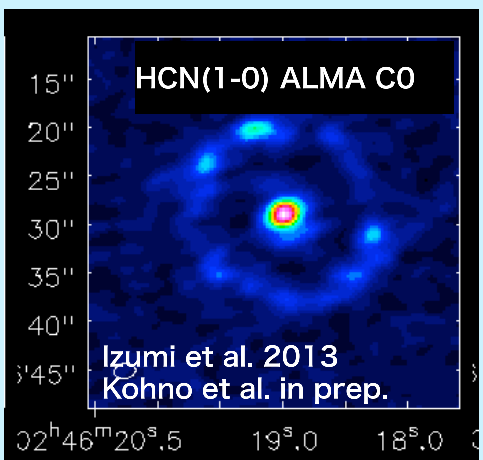
NGC 4051
$\log\lambda_{Edd}$ = -2.7
H/R = 0.25
(ただしQ > 1という結果;
Sani et al. 2012)

$$Q \equiv \frac{c_s \kappa}{\pi G \Sigma}$$

High -accretion phase

Toomre Q < 1

turbulent pressure
supported **thick** disk



NGC 1097
$\log\lambda_{Edd}$ = -4.5
H/R < 0.01
Fathi, et al. 2013

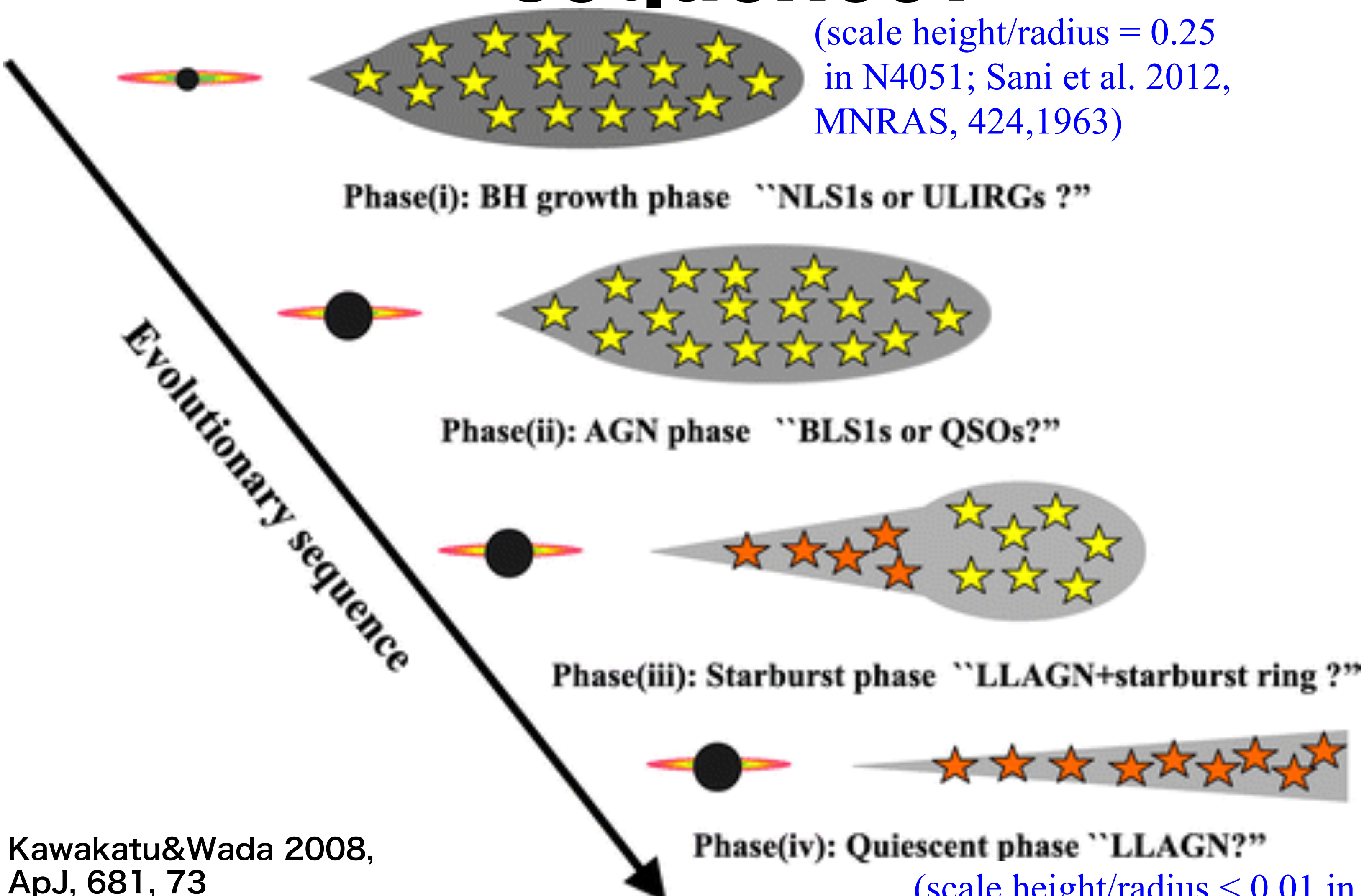
Low-accretion phase

Toomre Q > 1

gas pressure
supported **thin** disk

Black hole evolutionary sequence?

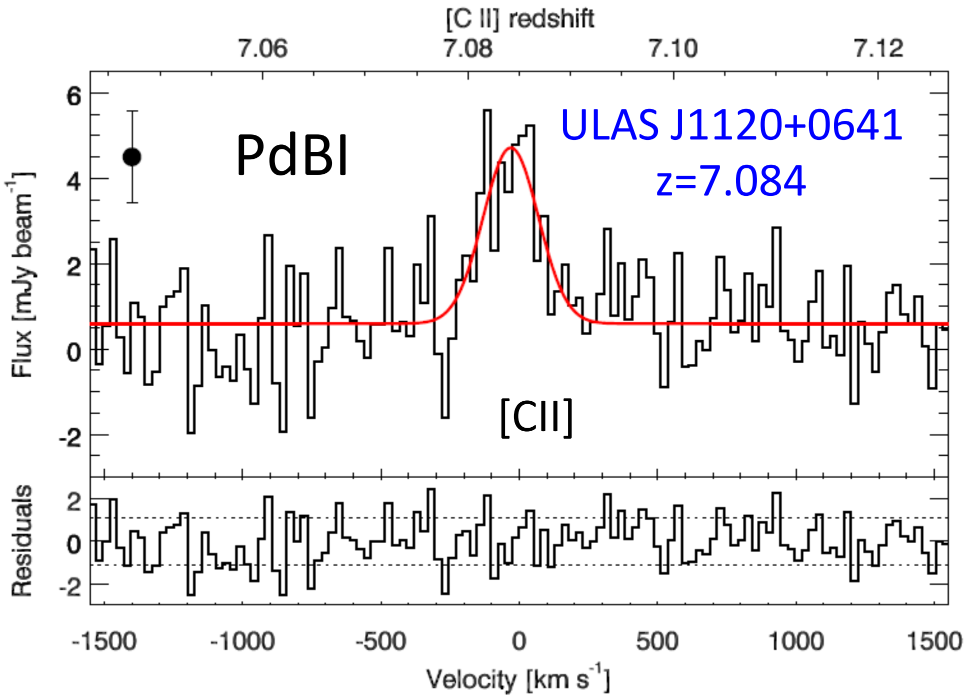
(scale height/radius = 0.25 in N4051; Sani et al. 2012, MNRAS, 424,1963)



(scale height/radius < 0.01 in N1097; Fathi et al. 2013, ApJ, 770, L27)

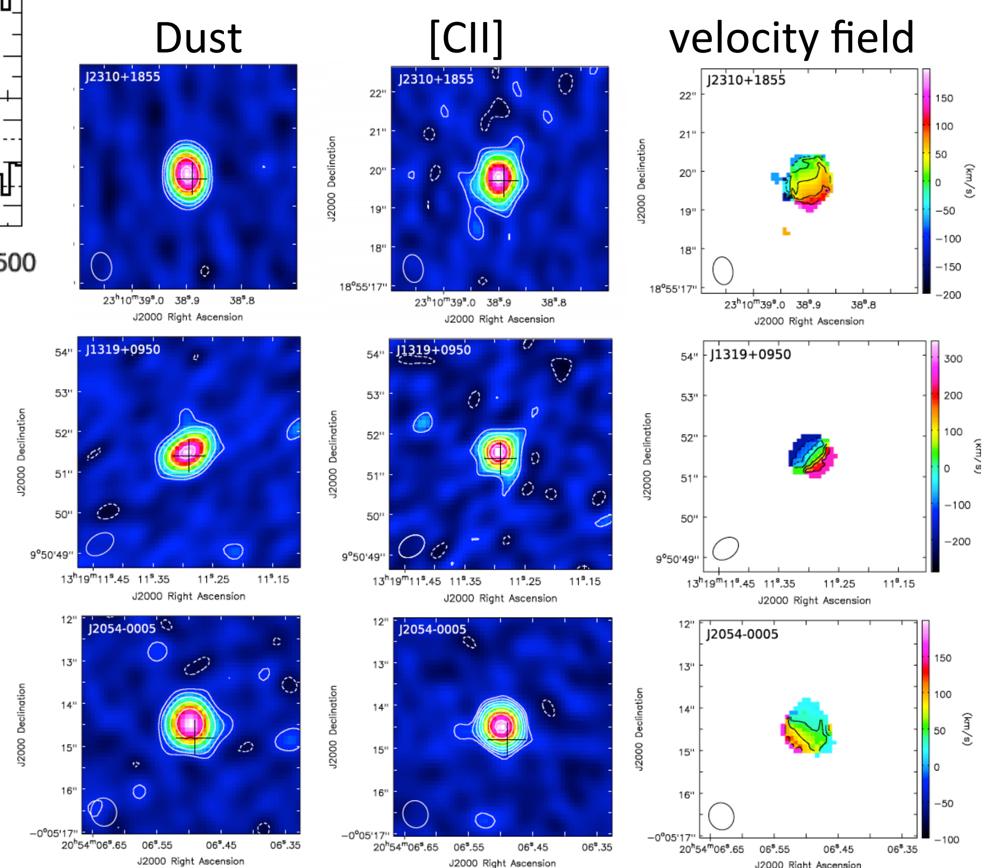
Kawakatu&Wada 2008, ApJ, 681, 73

[CII] & FIR properties of ULAS J1120



ALMA observations of [CII] in 6 quasars (z>6)

Wang et al. 2013, ApJ, 773, 44

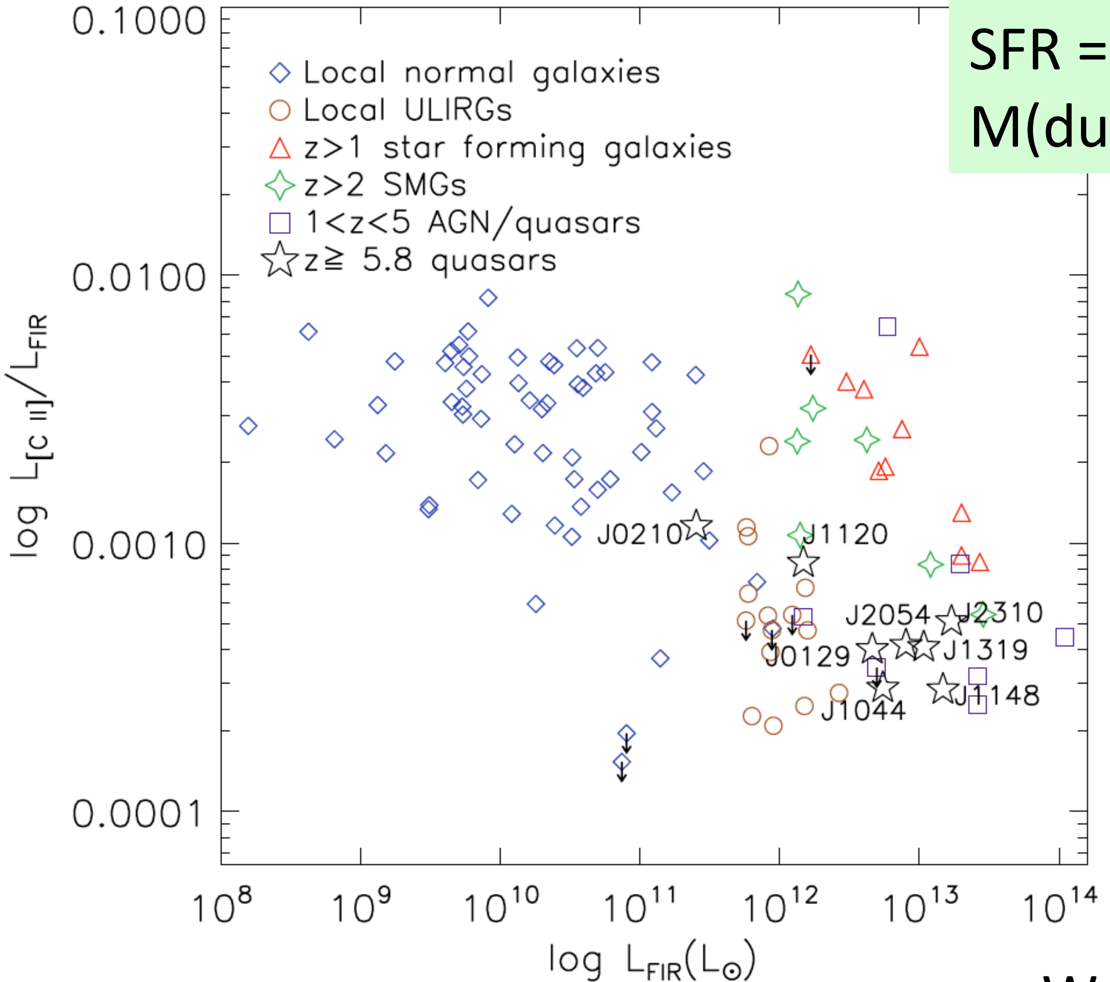


L(FIR) = $(0.6 - 2) \times 10^{12}\ L_\odot$
SFR = $160 - 440\ M_\odot$/yr
M(dust) = $(0.7 - 6) \times 10^{8}\ M_\odot$

z [CII] = 7.0842 ± 0.0004
z MgII = $7.097 +0.002 -0.001$

Venemans et al. 2012, ApJ, 751, L25

[CII] & L(FIR) properties of z > 6 quasars



FIR propertiesはサブミリ波銀河によく似ている。

SFR = a few 100 - 1000 $M_\odot$/yr

M(dust) = a few x $10^{7\text{-}8}$ $M_\odot$

かくも多量なダストの形成：
➔ いつ？どのように？

かくも多量のダストに隠された星形成： ➔ SMBH成長と母銀河成長（M_{BH}-σ*関係の発現）とのつながりは？

Wang et al. 2013, ApJ, 773, 44

Environment: do high-z quasars reside in a biased region?

- Significant excess of Lyα emitters and/or Ly break galaxies around high-z radio galaxies and quasars
  - TN J1338-1942 @z=4.11 (Venemans et al. 2002)
  - TN J0924-2201 @z=5.19 (Venemans et al. 2004; Overzier et al. 2006)
  - SDSS J0836+0054 @z=5.82 (Zheng et al. 2006)
  - SDSS J1030+0524 @z=6.28 (Stiavelli et al. 2005)
- 5 most distant quasars known (当時) w/ HST
  - 2 fields: YES (over-density of LBGs), 1 field: NO
  - 2 fields: under-dense (!) Kim et al. 2009

Search for over-density of galaxies around ULAS J1120+0641

- Using WFC3/ACS ➔ 3 LBG candidates at z~7
- Still consistent with the field luminosity function; no excess of >L* galaxies within 1 Mpc of the quasar.

Simpson et al. 2014, MNRAS, 442, 3454

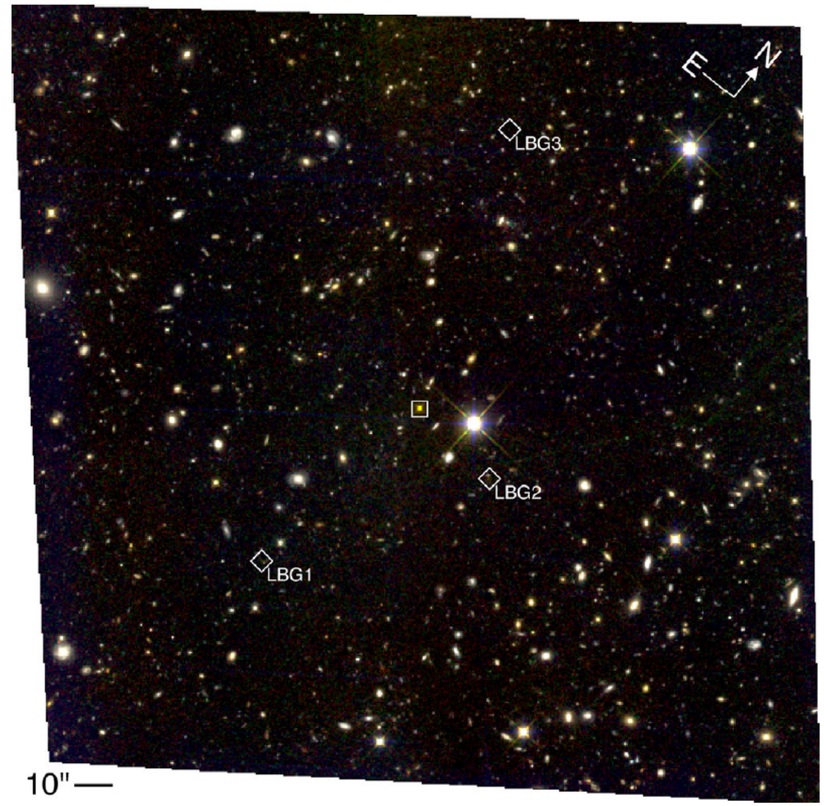
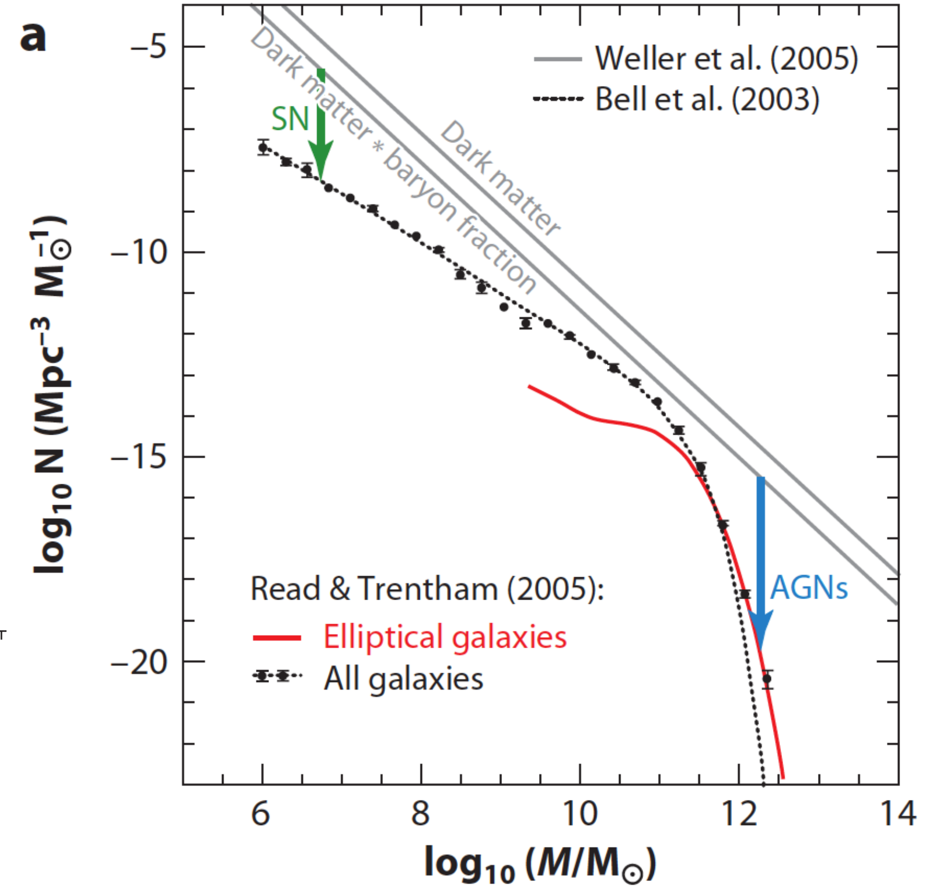


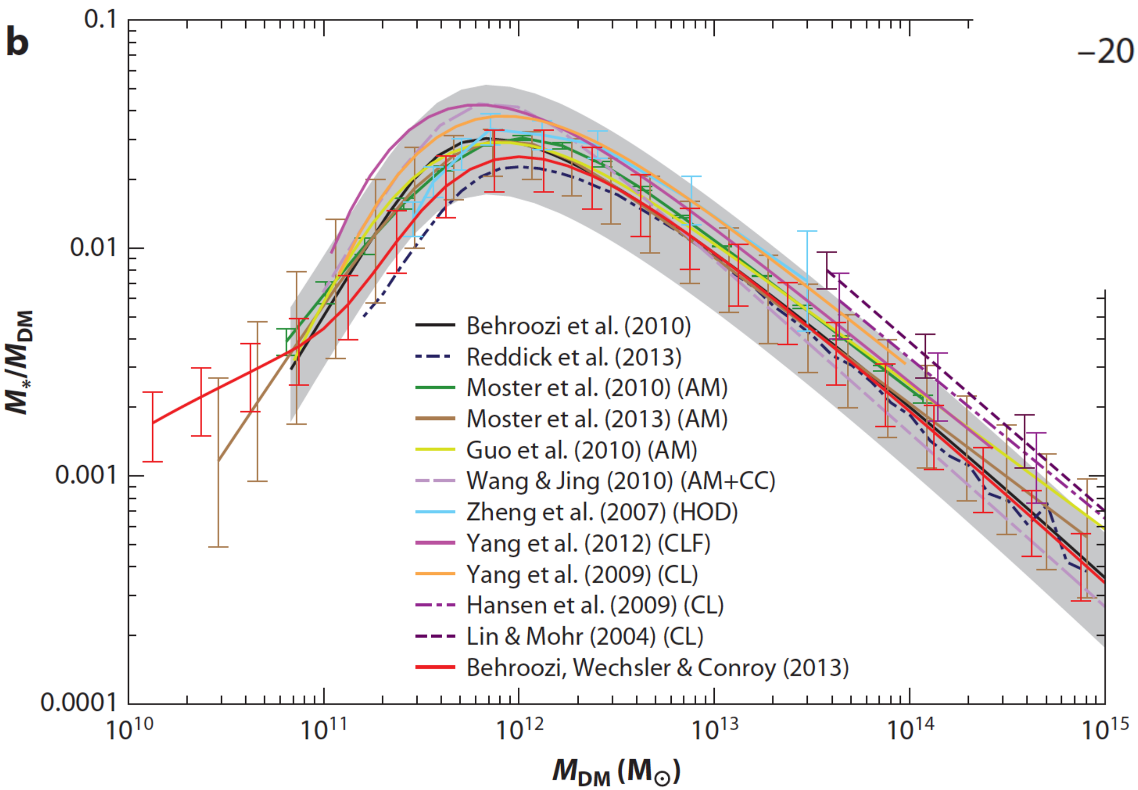
Figure 3. Combined *iYJ* image of the field around ULAS J1120+0641. The quasar is indicated with a white square, while the locations of the candidate LBGs (see Section 3.2) are marked with diamonds. The 10-arcsec scale bar represents 52 kpc (proper) at the distance of the quasar.

Impact of accreting SMBH on the host galaxies

(negative) Feedbackの必要性

Kormendy & Ho, 2013
ARAA, 51, 511



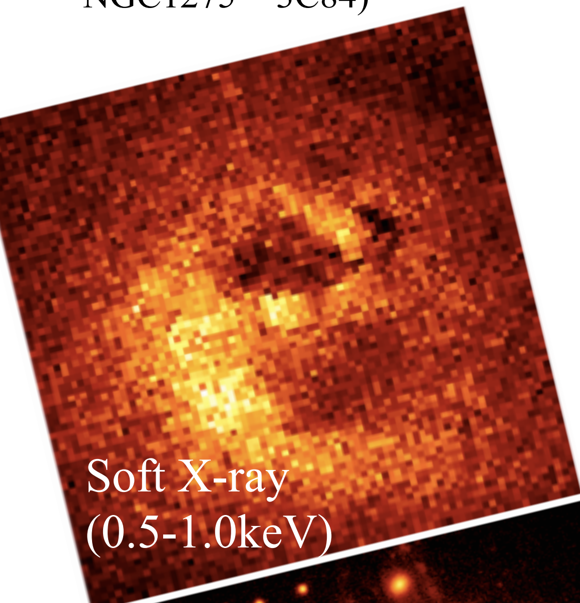


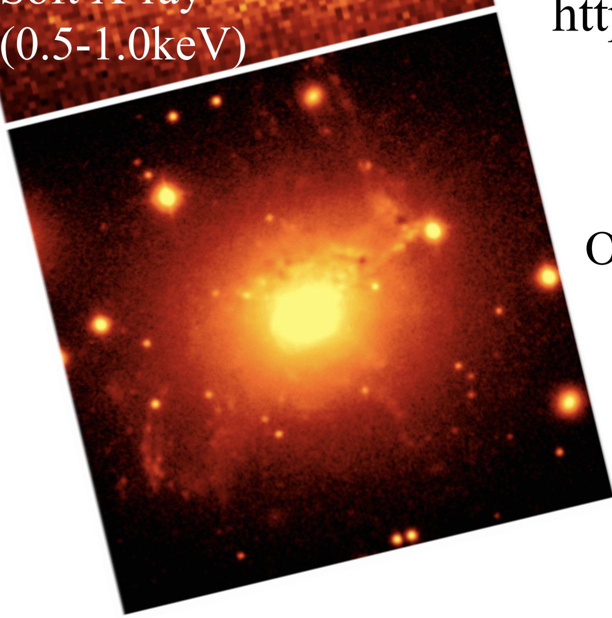
- SN feedback: low mass galaxies側でSF efficiencyを下げるために必要
- AGN feedback: high mass側

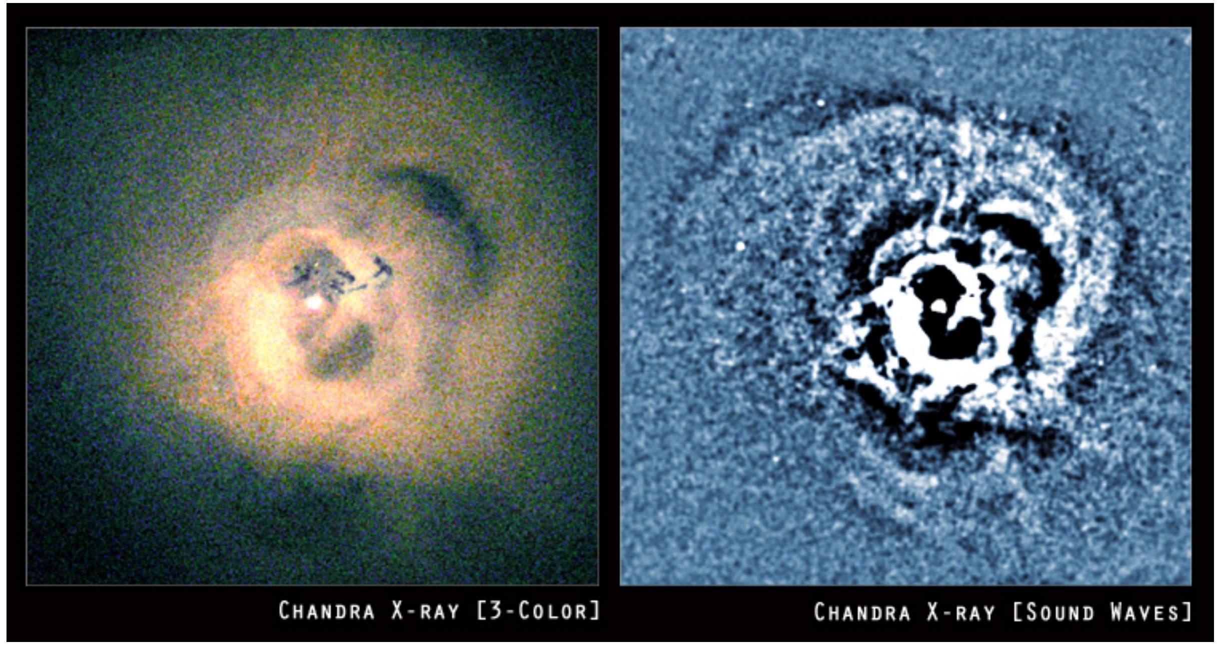
Evidence for AGN feedback in cluster scales

Perseus cluster

(the central cD galaxy
NGC1275 = 3C84)



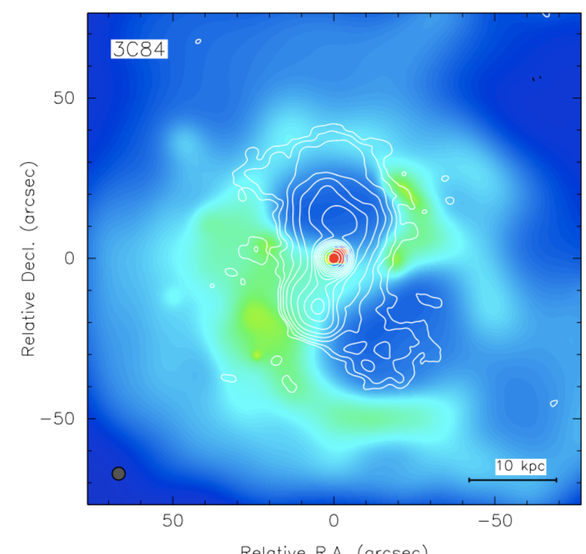




http://chandra.harvard.edu/photo/2012/phoenix/media/

Optical (B-band)

Fabian et al. 2000,
MNRAS, 331, 369



contour: 1.4GHz

Evidence for suppressed star formation in AGN host galaxies?

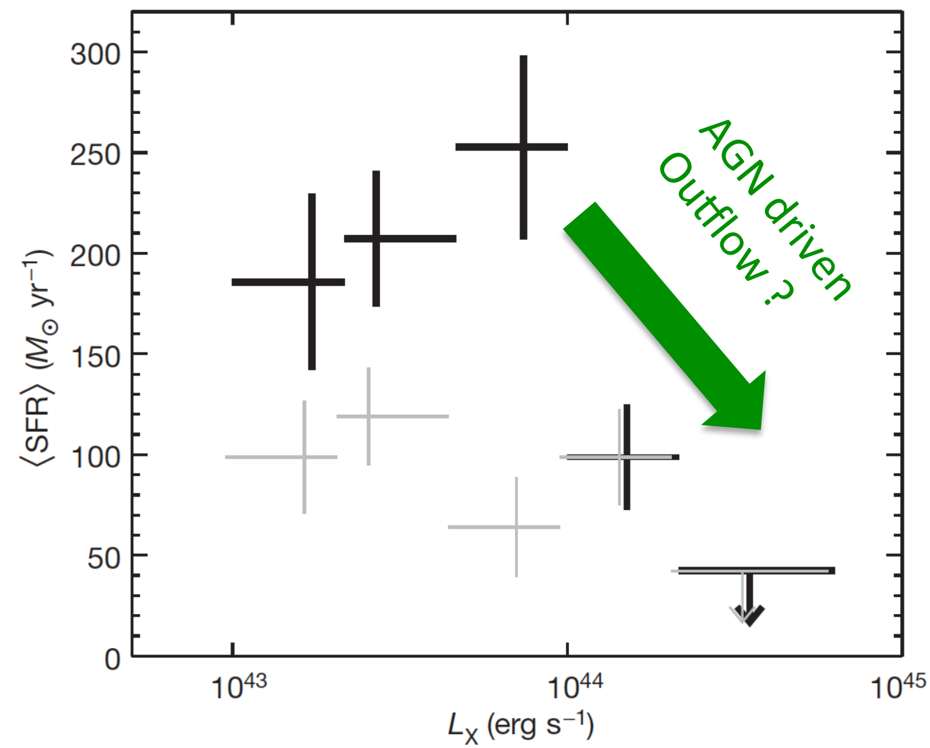


Figure 2 | Average star formation rates, ⟨SFR⟩, derived from averaged far-infrared luminosities of $1 < z < 3$ AGN, as a function of L_X. We converted the 250, 350 and 500 μm flux densities for each source into an equivalent 8–1,000 μm luminosity by fitting a grey-body curve, with a temperature of 30 K in the rest-frame of the source, an emissivity index of $\beta = 1.6$, and a power-law extension to the Wien side[29] and multiplying by $4\pi D_L^2$, where D_L is the

Chandra Deep Field North
\+ Herschel SPIRE photometry

Page et al. 2012, Nature, 485, 213

Table 1 | 250 μm detection statistics in various regions of parameter space

Region of (z,L_X) parameter space	Number of AGN	Number of AGN associated with 250 μm sources	Expected number of spurious associations	Fraction of AGN associated with 250 μm sources
All z, 10^{42} erg s^{-1} < L_X < 10^{45} erg s^{-1}	176	24	2.1	$14 \pm 3(^{+6}_{-5})$%
$1 < z < 3$, 10^{43} erg s^{-1} < L_X < 10^{44} erg s^{-1}	44	11	0.5	$25^{+8}_{-7}(^{+15}_{-12})$%
$1 < z < 3$, 10^{44} erg s^{-1} < L_X < 10^{45} erg s^{-1}	21	0	0.2	<5(<13)%

The first row corresponds to the entire sample of secure AGN in the CDF-N, while the second and third rows correspond to the regions enclosed within the blue dashed lines in Fig. 1. Confidence intervals on the fraction of AGN associated with 250 μm sources are given at 68%, with 95% intervals enclosed in brackets. It should be noted that there is one case of two AGN being associated with the same 250 μm source. The two AGN have very similar spectroscopic redshifts, and both have X-ray luminosities between 10^{43} and 10^{44} erg s^{-1}. Although the two AGN cannot be resolved at 250 μm, source extraction using X-ray and 24 μm positions as priors[25] indicates that both AGN are 5σ sources at 250 μm.

Molecular outflow in AGN

- 星形成の直接的な材料である分子ガスを散逸させる物理過程 ➔ negative feedbackの直接的な例

重要な物理量

- Mass outflow rate dM/dt ⇔ 星形成率・AGN光度と比較
- Kinetic luminosity

$$L_{\rm kin} = 1/2 \times \frac{{\rm d}M}{{\rm d}t} \times \left(\frac{V_{\rm out}}{\cos(\alpha)}\right)^2$$

⇔AGN光度との比較
(Lbolのa few x 0.1%~1%台が予想されている)

- Momentum flux

$$\frac{{\rm d}P_{\rm out}}{{\rm d}t} = \frac{{\rm d}M}{{\rm d}t} \times \frac{V_{\rm out}}{\cos(\alpha)}$$

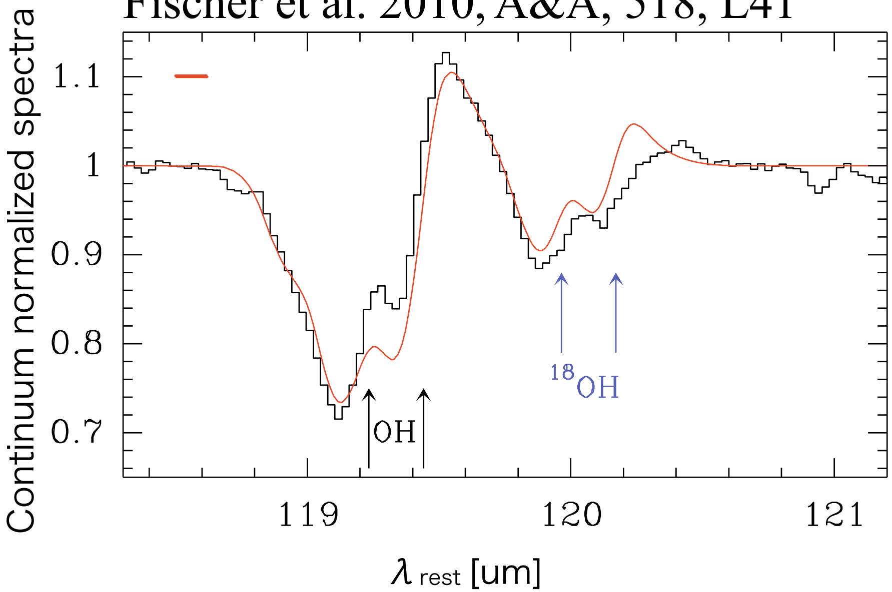
⇔AGN photonによるmomentum: Lbol/c と比較

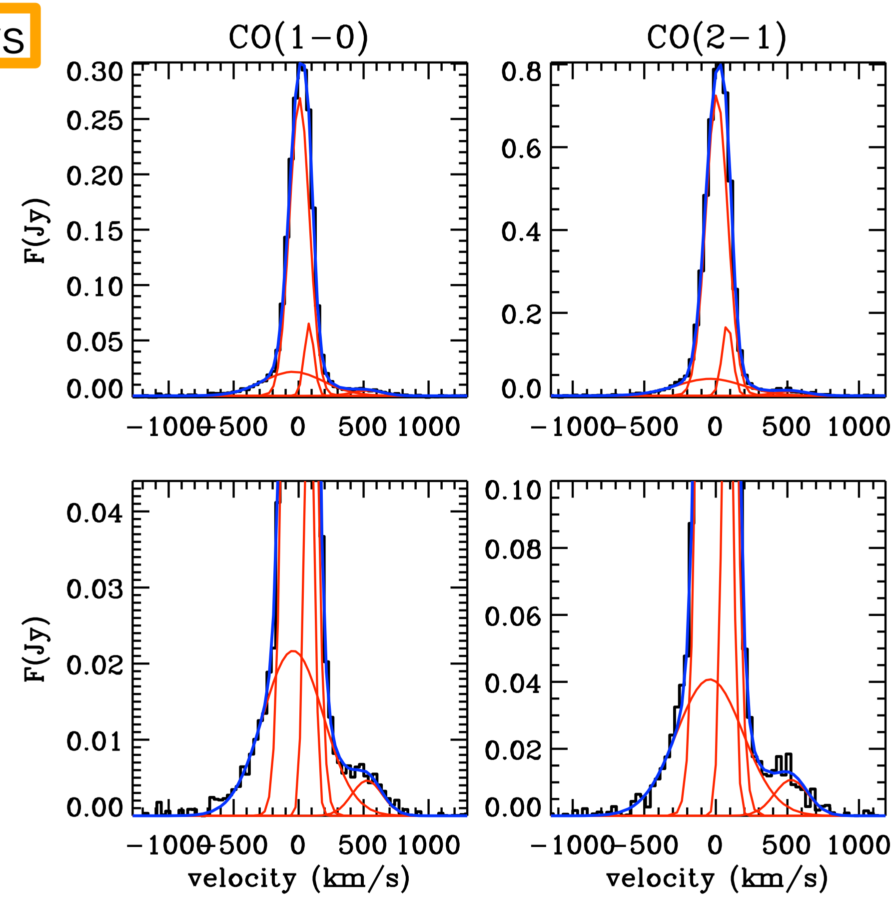
α:視線方向とoutflowの軸の角度

Detection of molecular outflows in the low-z quasar Mrk 231

The best target to study physics of outflows

Fischer et al. 2010, A&A, 518, L41



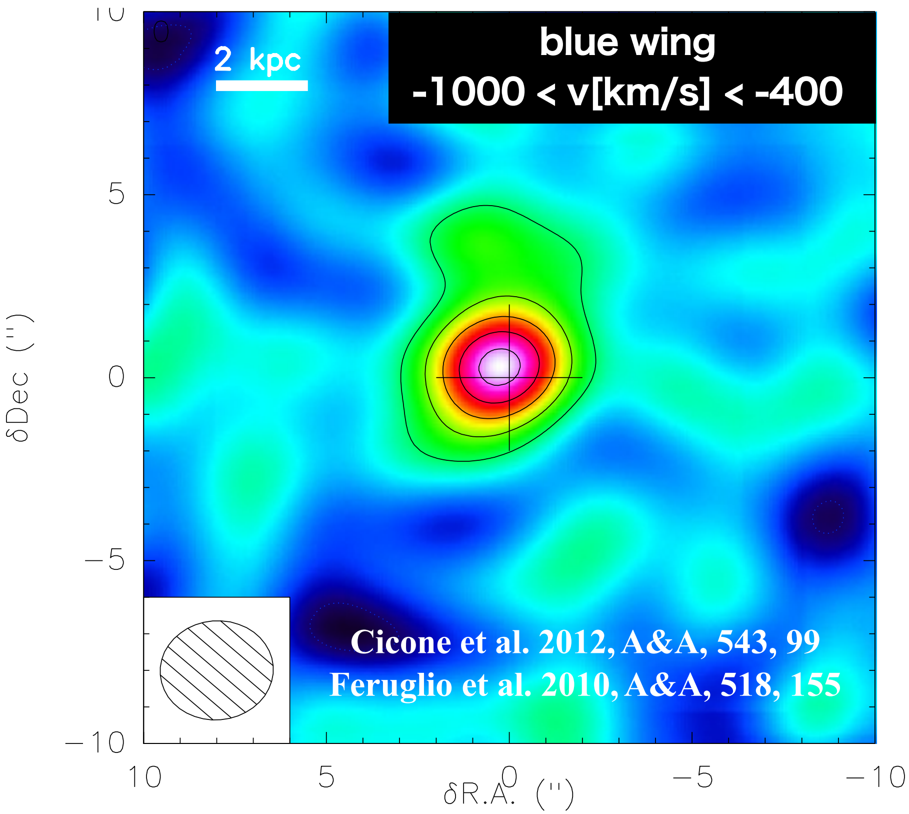


Cicone et al. 2012, A&A, 543, 99

- OH **P-Cygni** profile revealed with Herschel
- Broad wings are detected in multiple CO transitions (v_{out}~1000km/s) with IRAM PdBI

⇒ Followed by detections in other local ULIRGs and AGNs

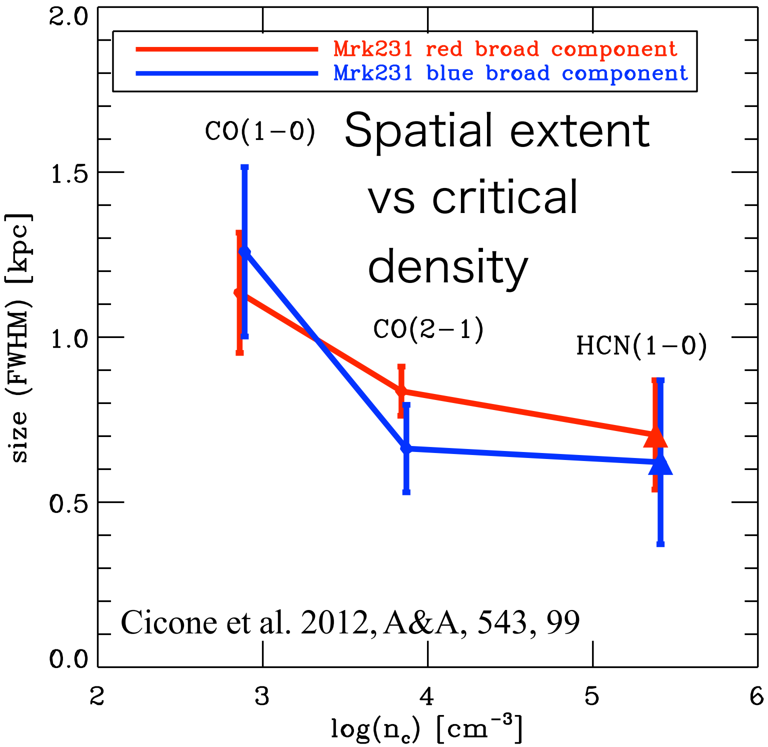
Properties of molecular outflow in Mkn 231



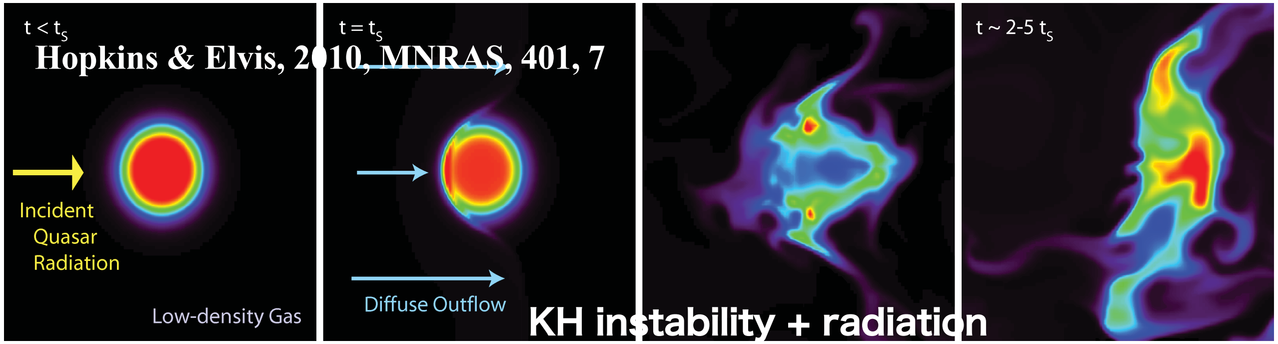
- Mass loss rate ~ 700 M_{sun}/yr >> SFR = 200 M_{sun}/yr
- Extend to ~ kpc scale ⇒ must affect the host galaxy
- Depletion time ~ 10 Myr
- L_{kin} = 2E44 erg/s << L_{AGN} = 5E45 erg/s ⇒ **AGN-driven**

(Memo) For a stellar-driven outflow, typically **mass loss rate ~ SFR**
e.g., Cicone et al. 2014, A&A, 562, 21; Murray et al. 2005, ApJ, 618, 569

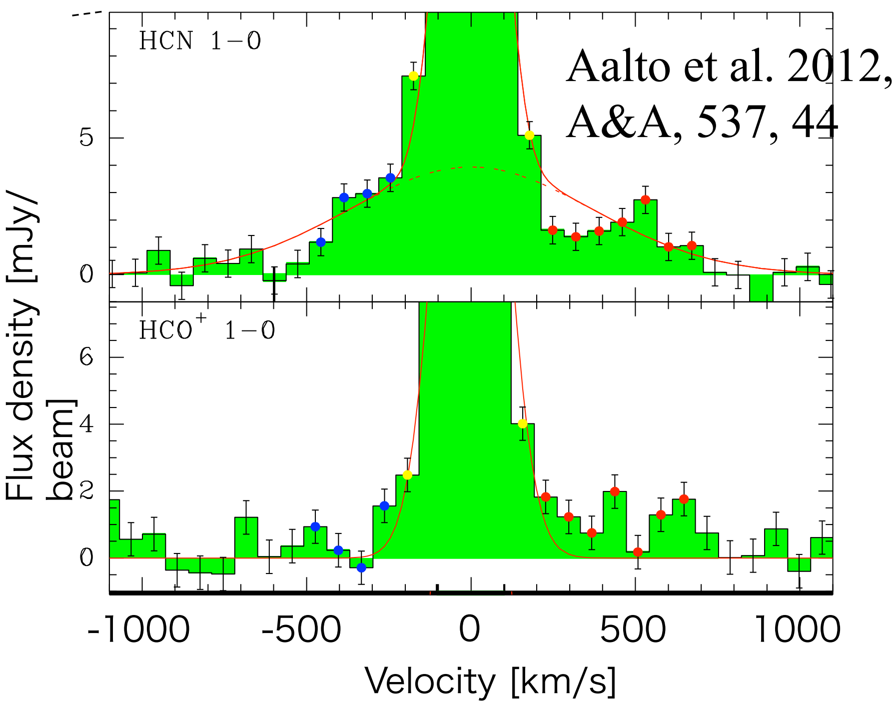
Density, spatial structure

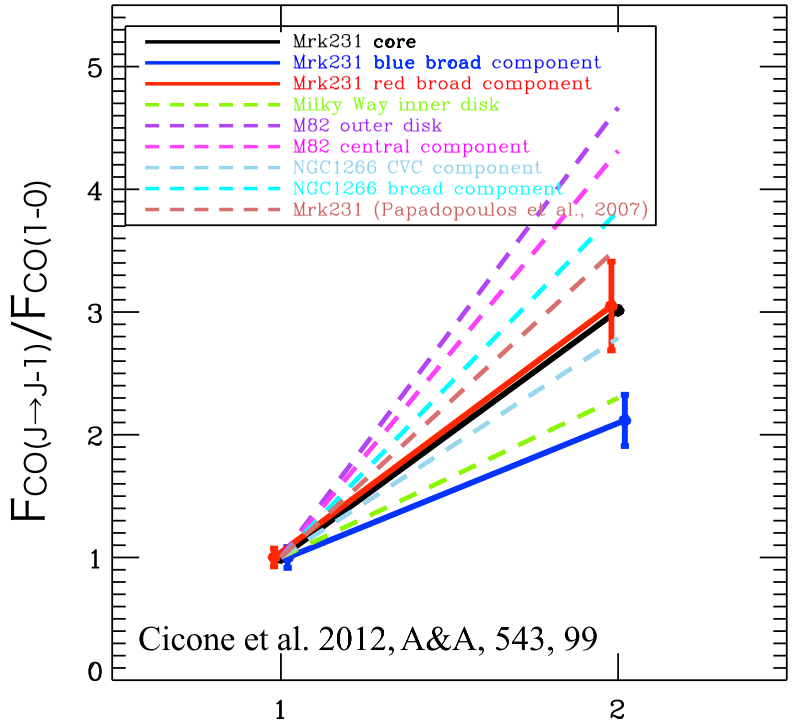


- There are various density and spatial structures in the outflow!
- Simple acceleration by radiation pressure?
  ⇔ Different F_{rad}/F_{grav} toward dense and diffuse cloud?
- Alternatively, shock + radiation pressure? Or...?



Excitation and chemistry of molecular outflows





- High density tracers (HCN, CN) are **enhanced** in the outflowing wind ⇒ shock enhancement of HCN? Or, High temperature chemistry?

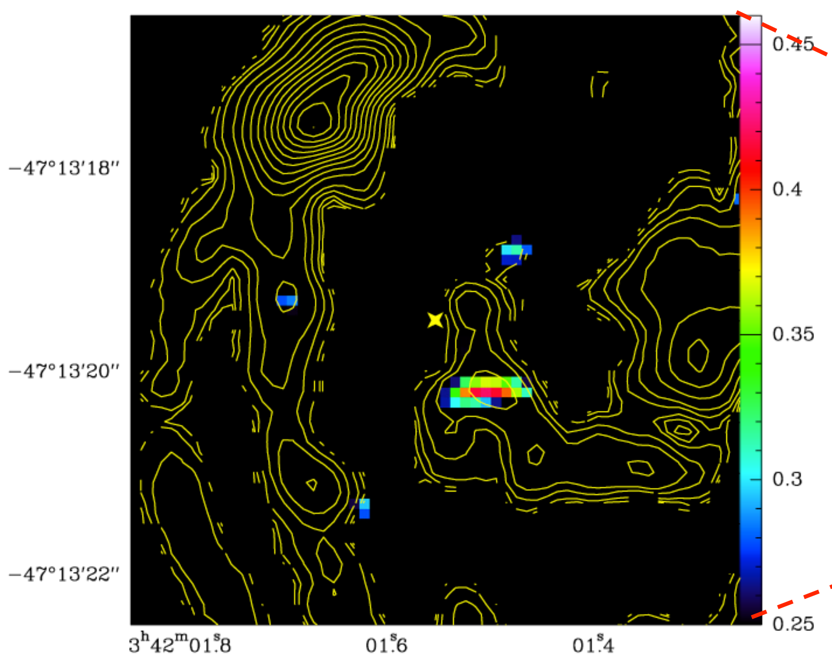
  e.g., Tafalla et al. 2010, A&A, 522, 91 ; Harada et al. 2010, ApJ, 721, 1570

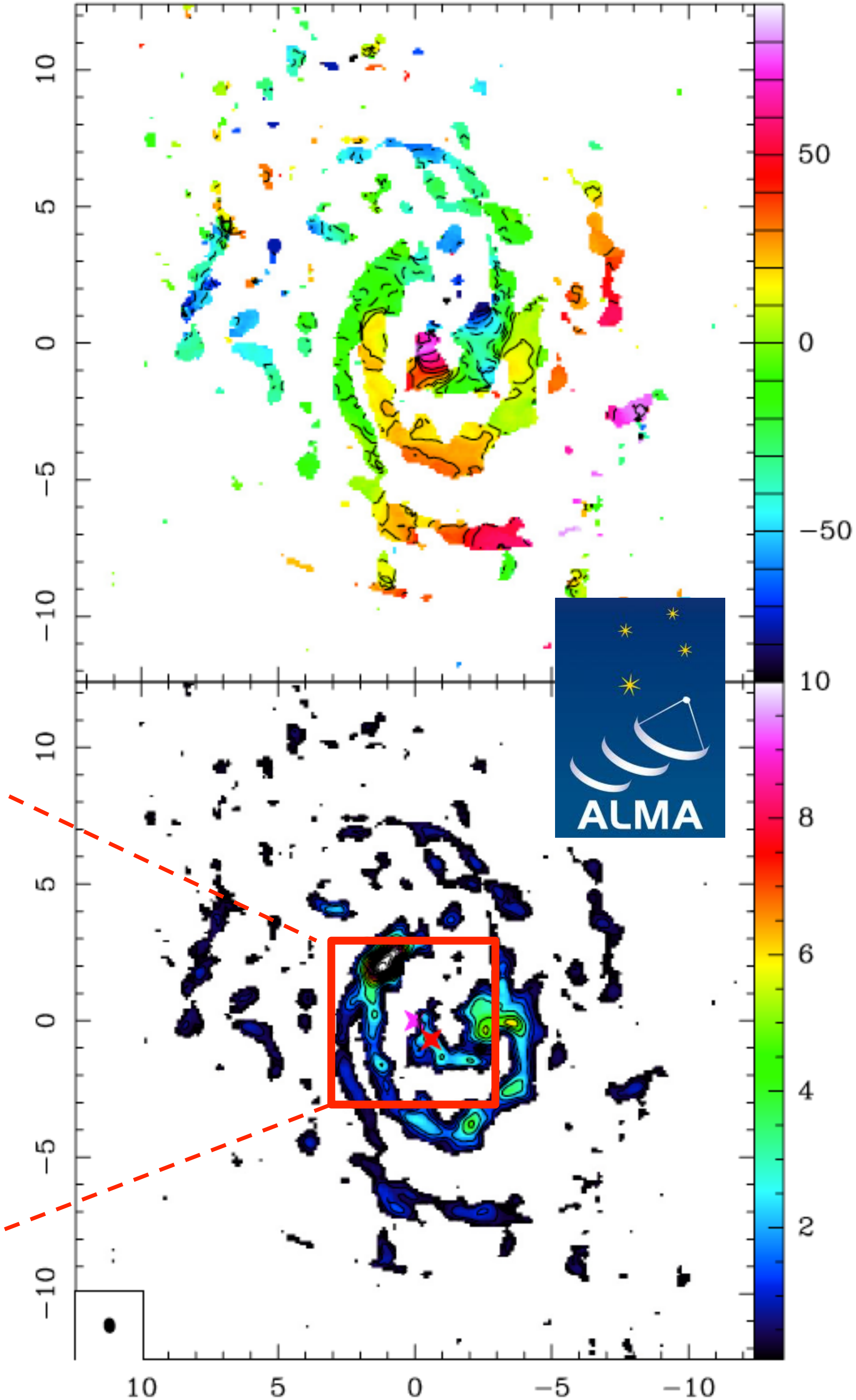
- But no significantly higher CO excitation in wings (lack of spatial resolution?)

ALMA observations of CO(3-2) in the Seyfert 2 galaxy NGC 1433

ALMA beam: 0.56” x 0.42” (27pc x 20pc)

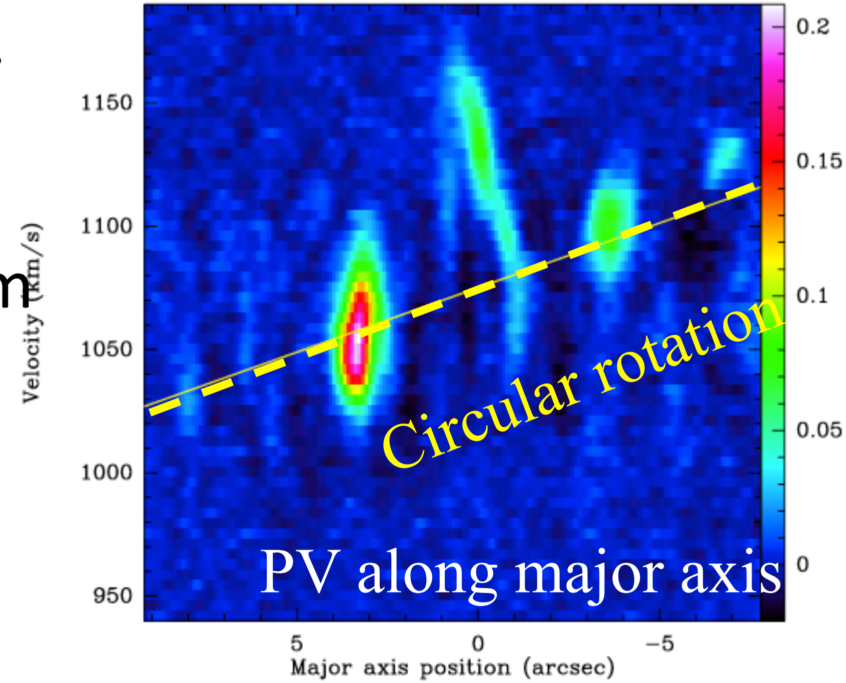
Combes et al. 2013, A&A, 558, A124

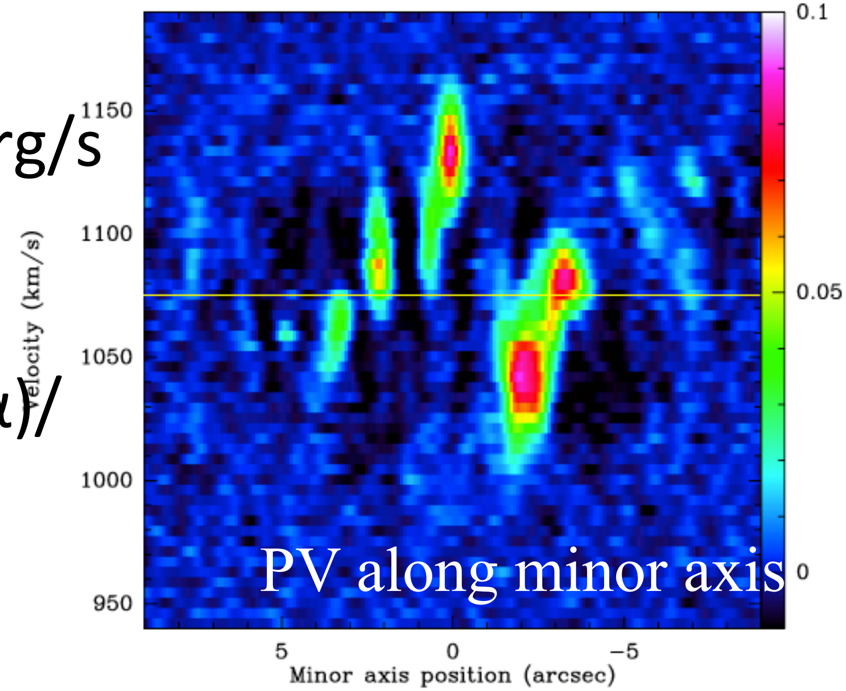




AGN-driven molecular outflow?

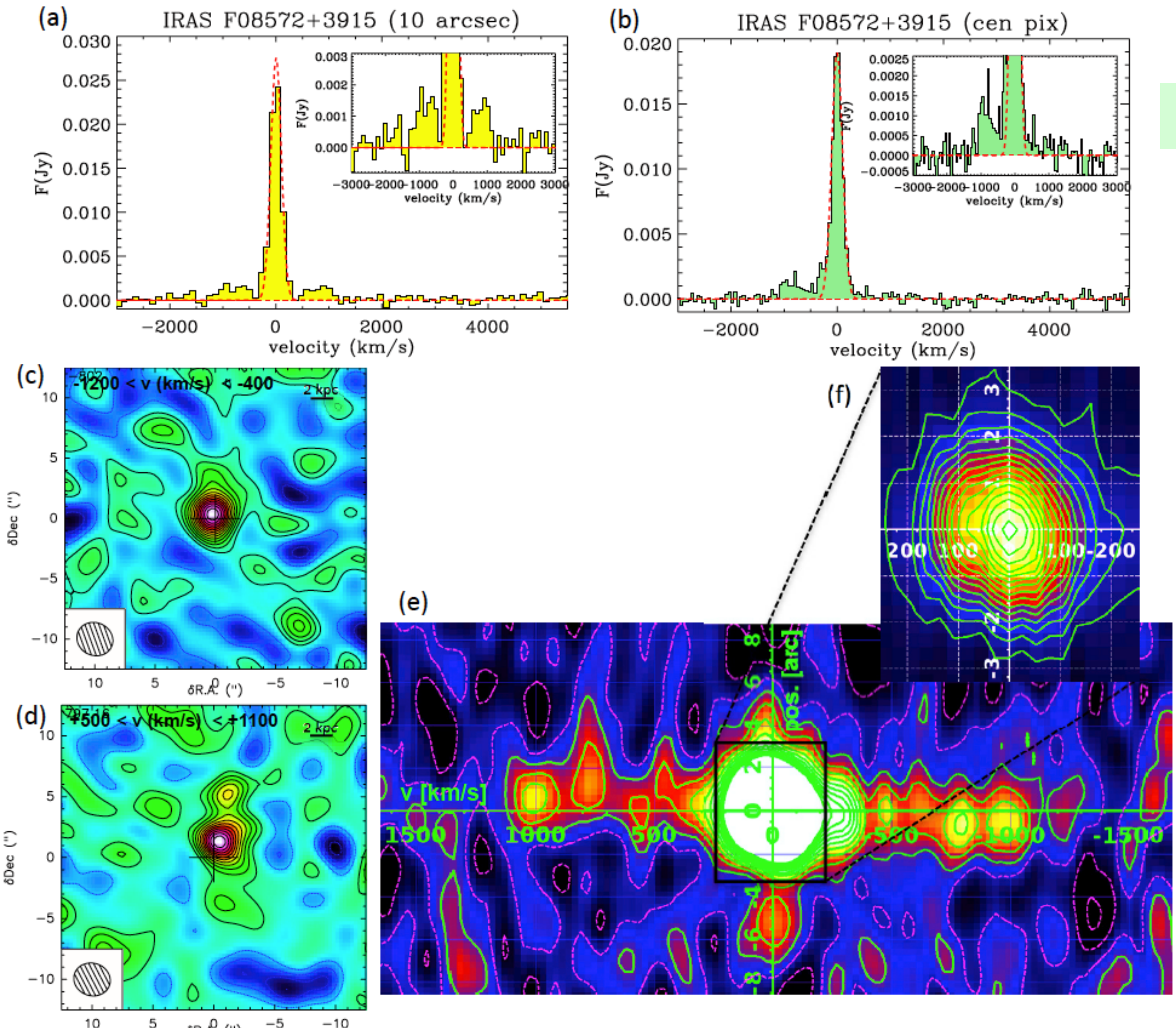
- CO with significant deviation from ordered rotation
- M(gas): 3.6 x 10^6 $M_\odot$
- gas flow rate: ~ 7 tan(α) $M_\odot$/yr
  >> SFR ~ 0.2 $M_\odot$/yr
- Kinetic luminosity of outflow
  $L_{kin} = 0.5(dM/dt)\cdot v^2$
  $\sim 2.3 \times \tan(\alpha)(1+\tan^2(\alpha)) \times 10^{40}$ erg/s
  << L_{bol} ~ 1.3 x 10^{43} erg/s
- Momentum of outflow
  (dM/dt)▪v >> Lbol/c (~2000x tan(α)/cos(α))





Combes et al. 2013, A&A, 558, A124

AGN driven massive molecular outflow



PdBI observations

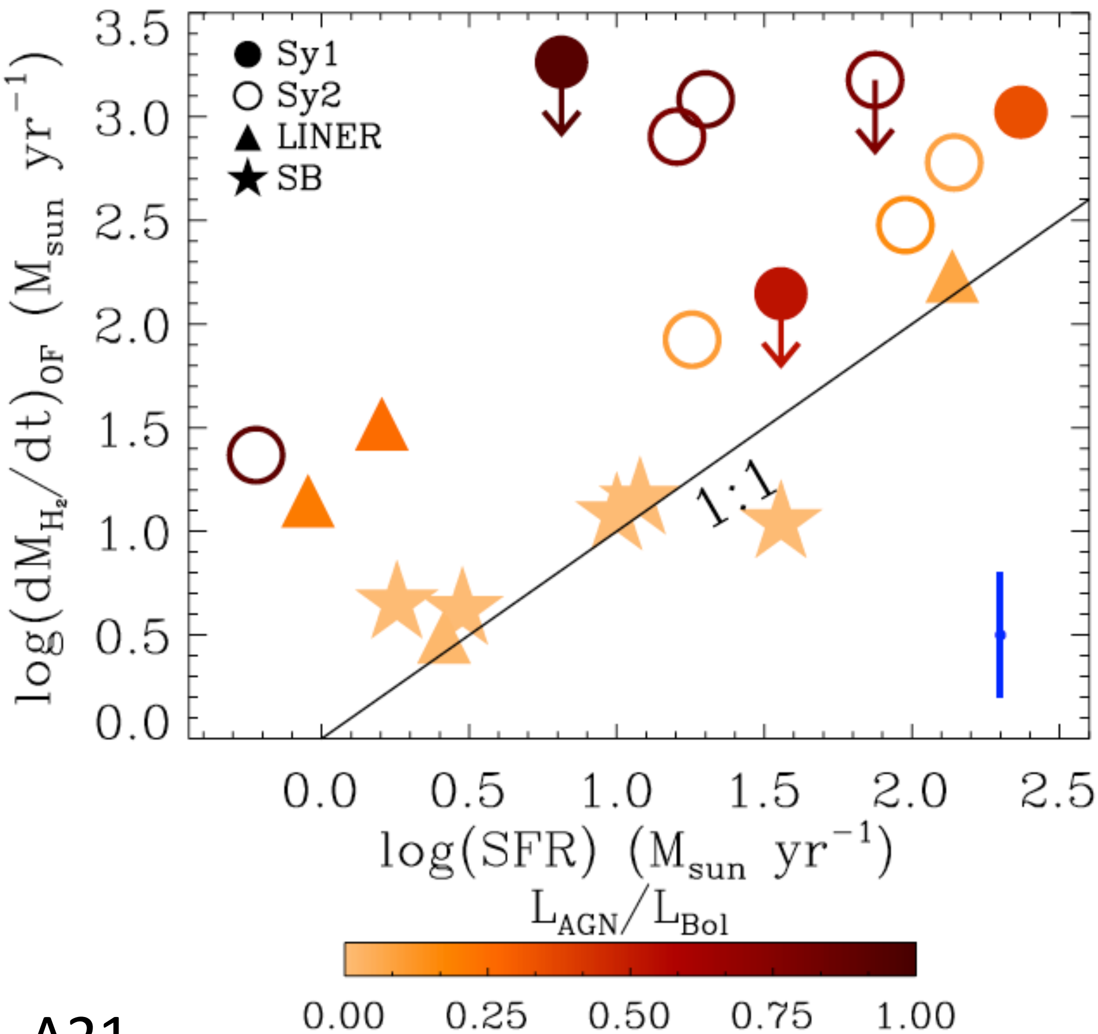
感度向上の賜物
➔ALMAで更に
大きく発展する筈

up to ~1000 km/s
up to ~kpc scale

Cicone et al.
2014, A&A,
562, A21

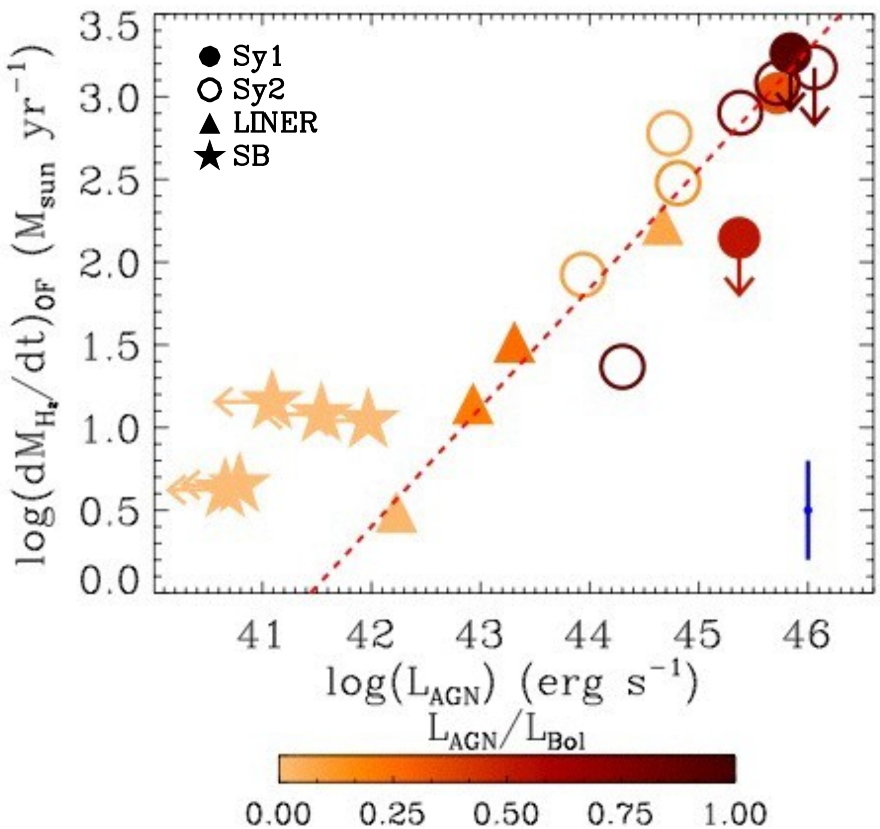
Properties of molecular outflows

- AGN-driven molecular outflow is very massive (~ several 100 $M_\odot$/yr)
- SF galaxies show dMout/dt ~ SFR
- Consistent to a model (e.g., Murray et al. 2005, ApJ, 618, 569)



Cicone et al. 2014, A&A, 562, A21

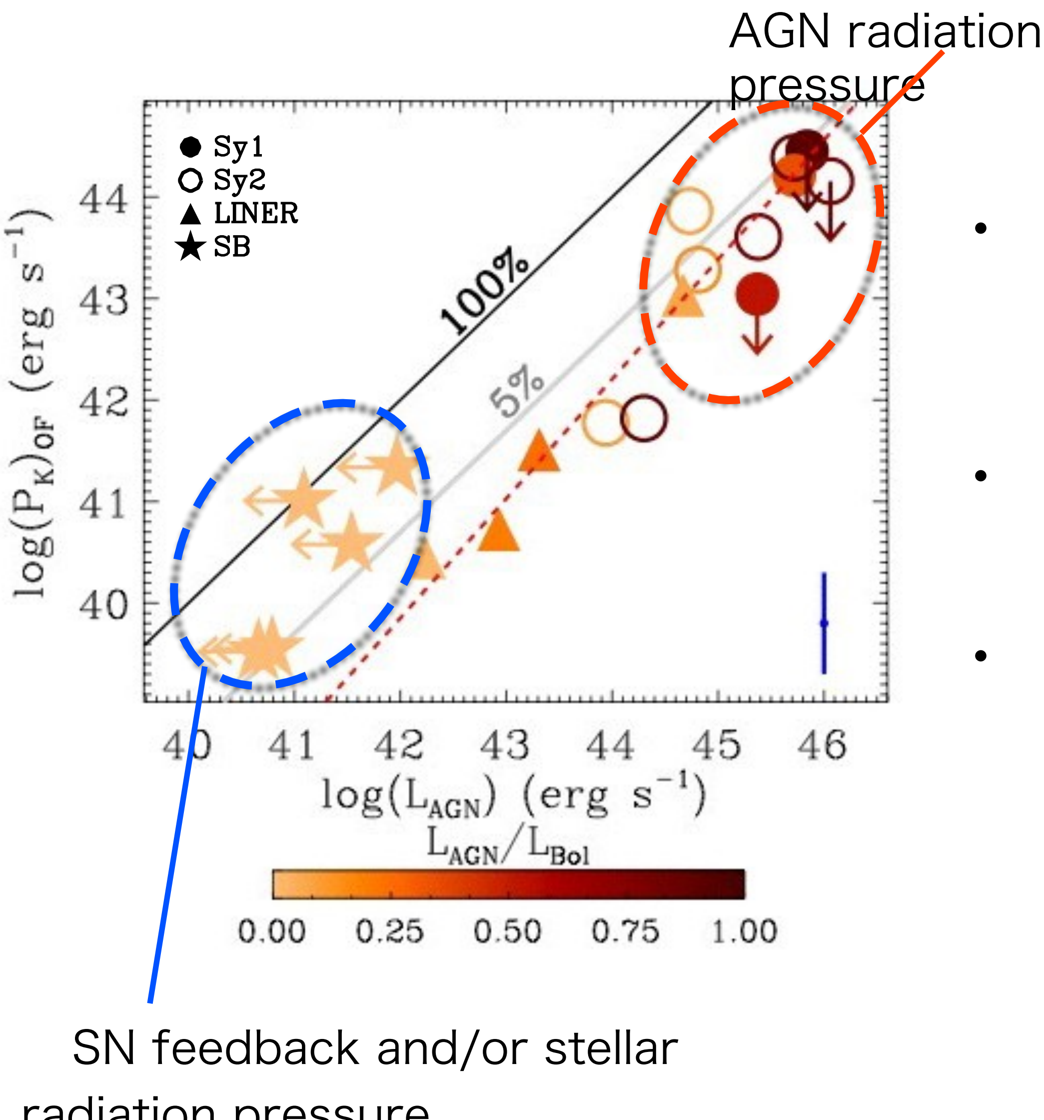
Mass loss rate vs AGN luminosity



- Clear correlation between L_{AGN} and mass-loss rate
  ⇒ **AGN-driven outflows!**
- Pure starbursts are all outliers, indicating that the feedback mechanism is substantially different
- Are we see only an upper envelope of a true, broader distribution?
  ⇒ need more and more sample!

Cicone et al. 2014, A&A, 562, A21

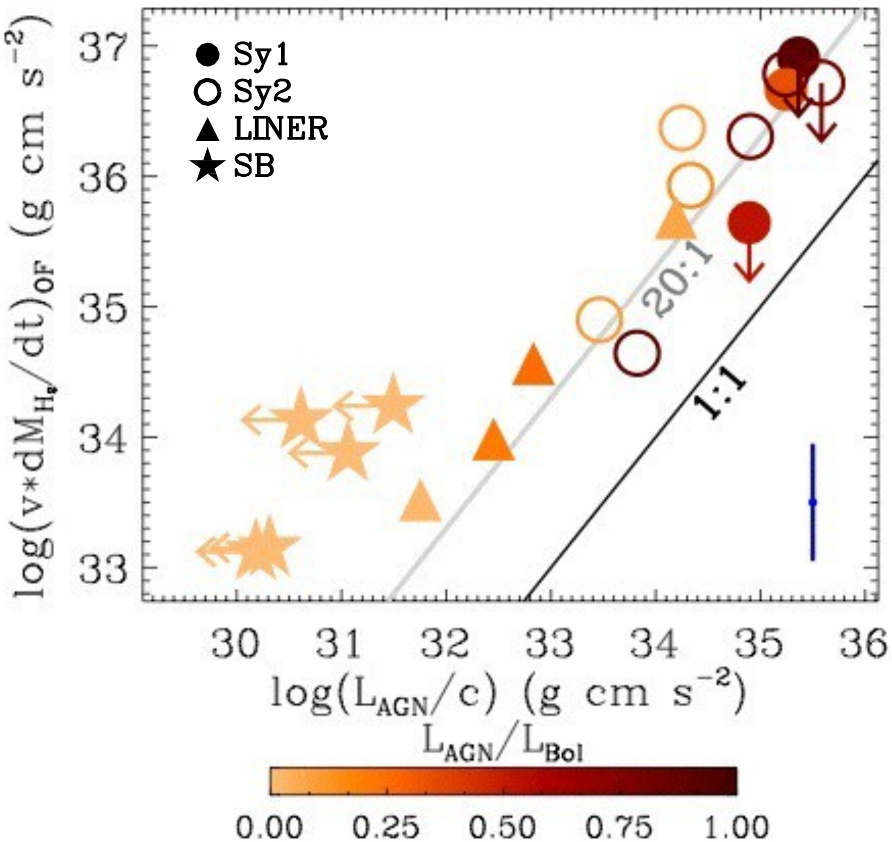
Kinetic luminosity vs AGN luminosity



- Almost confirm the model predicted value, i.e., the coupling efficiency of ~ **5%**
- Especially, powerful quasars are indeed located close to this value
- LLAGN/LINER show lower efficiency
  ⇒ (Note) some of these ones host radio-mode (= jet entrained) outflows (e.g., NGC 1266: Alatalo et al. 2011, ApJ, 735, 88)

Cicone et al. 2014, A&A, 562, A21

Momentum rate vs L_{AGN}/c



- Results of AGNs show, $v_{out}*(dM_{out}/dt) \sim 20*L_{AGN}/c$
- This value can be well explained by energy-driven outflows (e.g., Zubovas & King, 2012, ApJ, 745, L34)
- Can other mechanisms explain this correlation? If Yes, how should we distinguish those possibilities?

Cicone et al. 2014, A&A, 562, A21

Evidence for positive feedback?

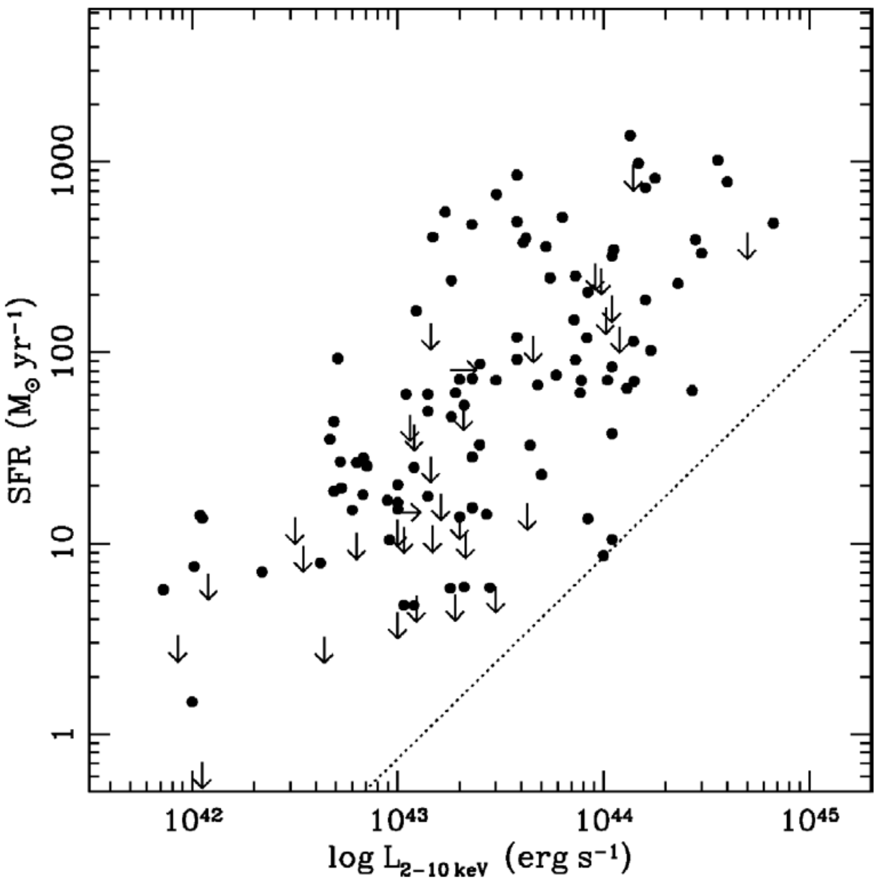


Fig. 7. Star-formation rate against hard X-ray luminosity for X-ray selected AGNs. We plot values of 99 far-infrared detected X-ray AGNs, and 32 FIR upper limits in the area covered by the deep *Herschel* survey. The dotted line is the expected FIR luminosity of a pure-AGN source, translated into SFR (see Mullaney et al. 2011). We find a strong correlation between the star-formation rate and the X-ray luminosity.

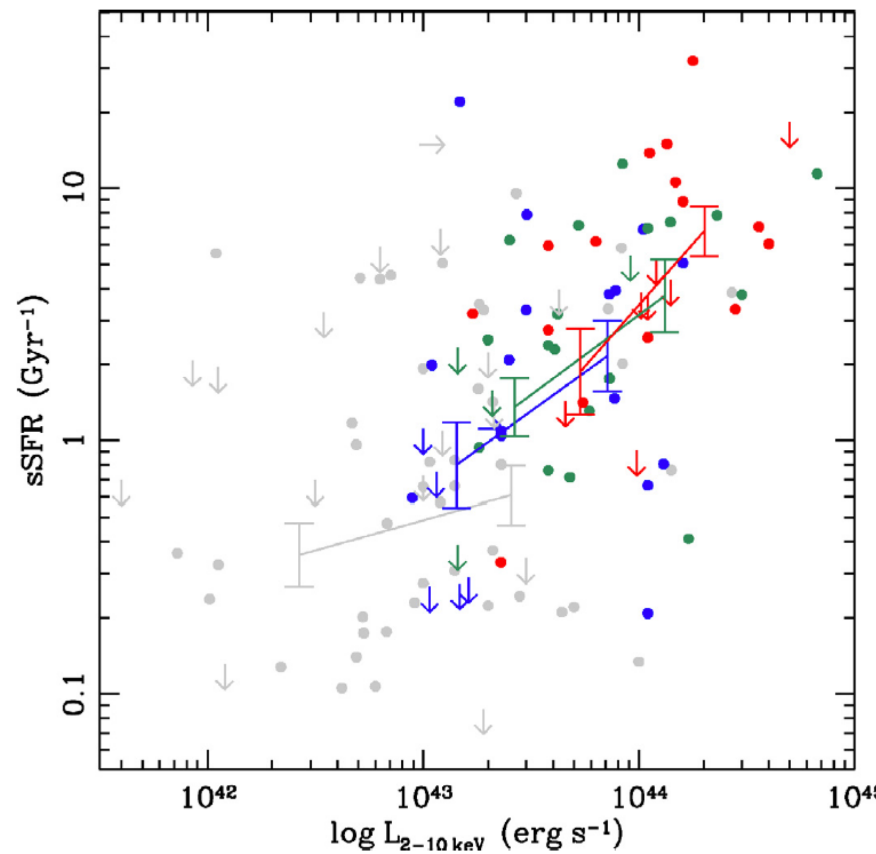
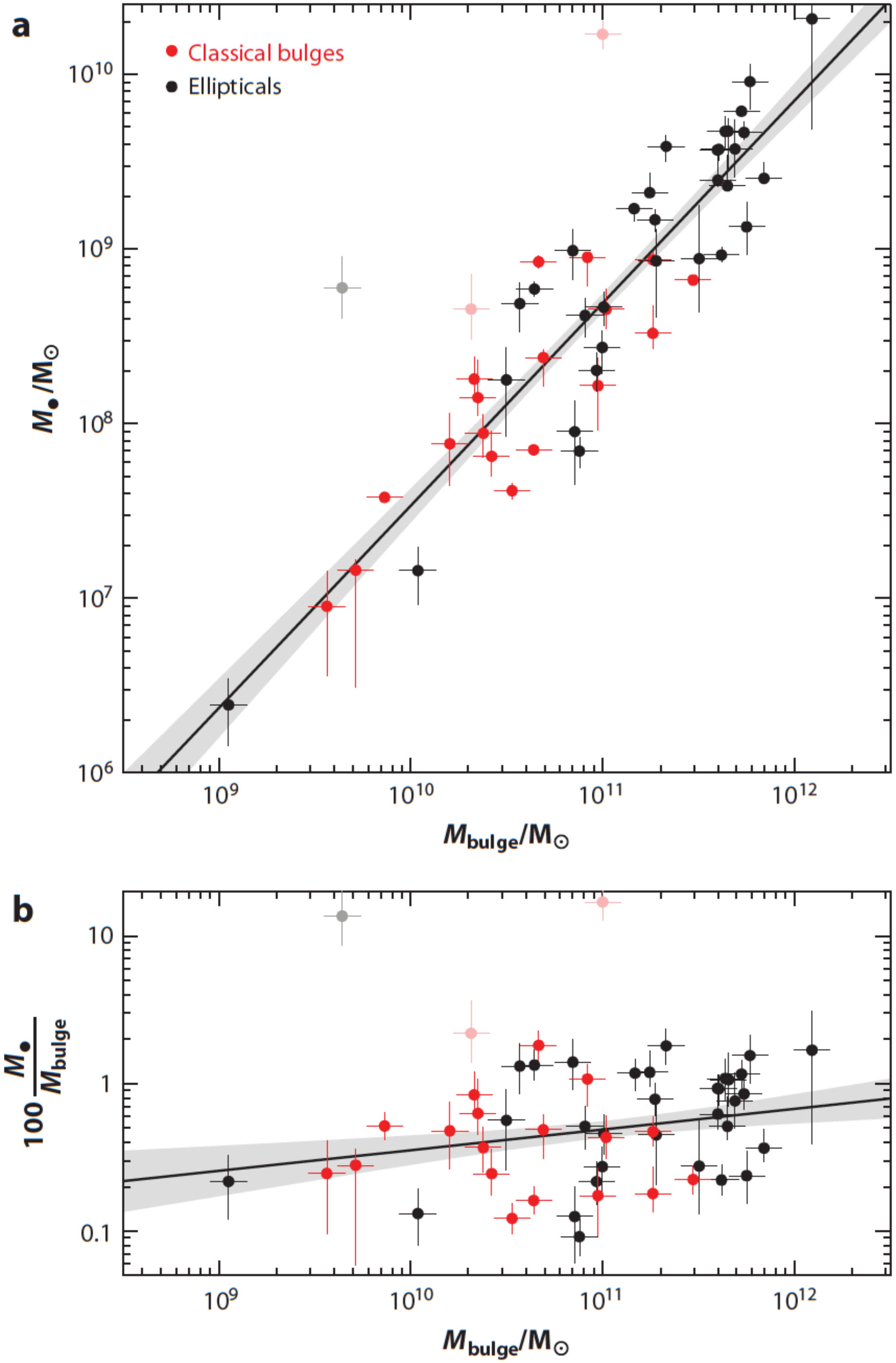


Fig. 8. Specific star-formation rate against hard X-ray luminosity for X-ray selected AGNs. The grey, blue, green and red symbols refer to $z < 1.120$, $1.120 < z < 1.615$, $1.615 < z < 2.455$ and $z > 2.455$, respectively. The error-bars and their associated lines refer to the mean luminosities and specific SFRs of the high- and low-luminosity bins within each redshift bin, using the Kaplan-Meier estimator (see Sect. 4.1). We do not detect a significant correlation between the X-ray luminosity and sSFR for the lowest redshift bin, but do detect a significant correlation for higher redshifts ($z \gtrsim 1$).

Rovilos et al. 2012, A&A, 546, A58

SMBH – galaxy mass relation



M(BH)-M(gal) relation

- より質量の大きい銀河（バルジの質量が大きい銀河）ほど、より質量の大きいブラックホールがその中心にある。
- その質量比は約0.5%
- 0.1% - 1.8%の範囲、希に10%を越えるものも

$$\frac{M_\bullet}{10^9\,M_\odot} = (0.49^{+0.06}_{-0.05})\left(\frac{M_{\rm bulge}}{10^{11}\,M_\odot}\right)^{1.17\pm0.08}$$

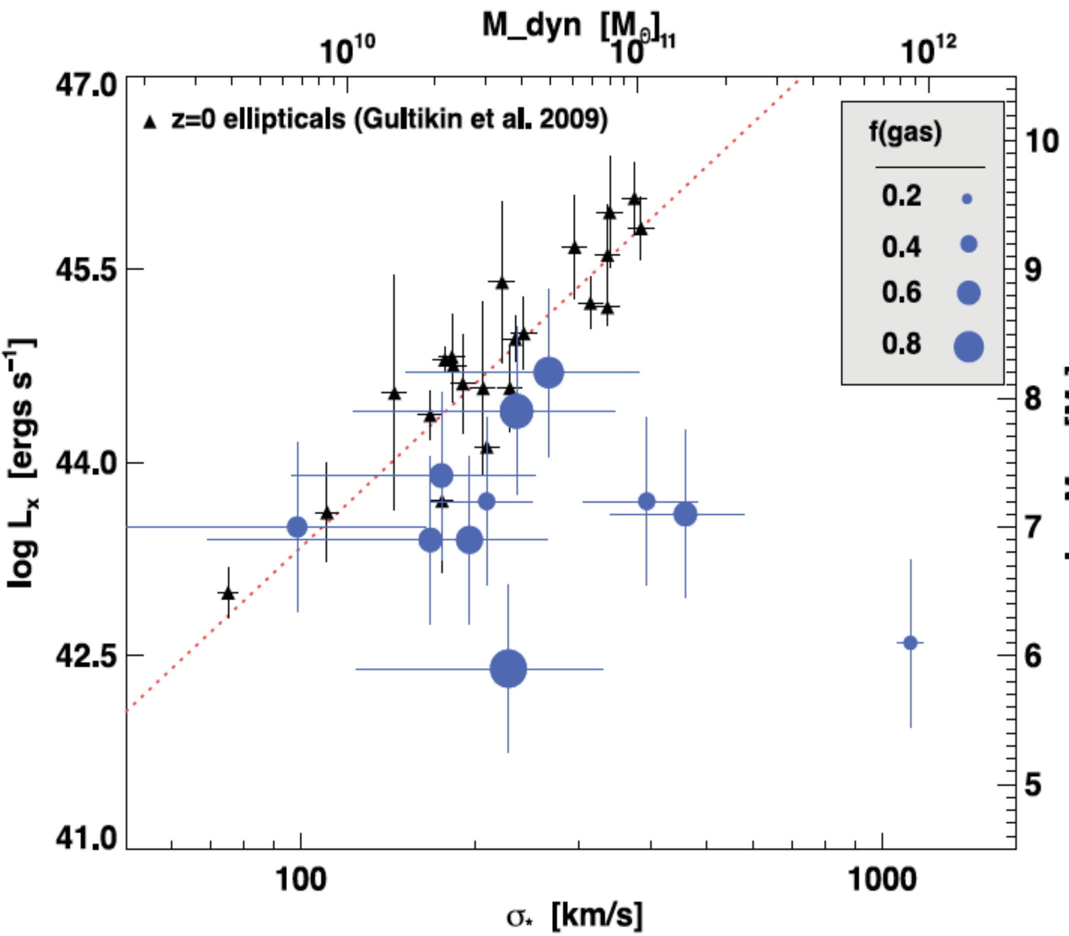
★ 何桁も大きさの異なる天体なのに、なぜかお互いのことを「知っている」？

Kormendy & Ho 2013, ARAA, 51, 511

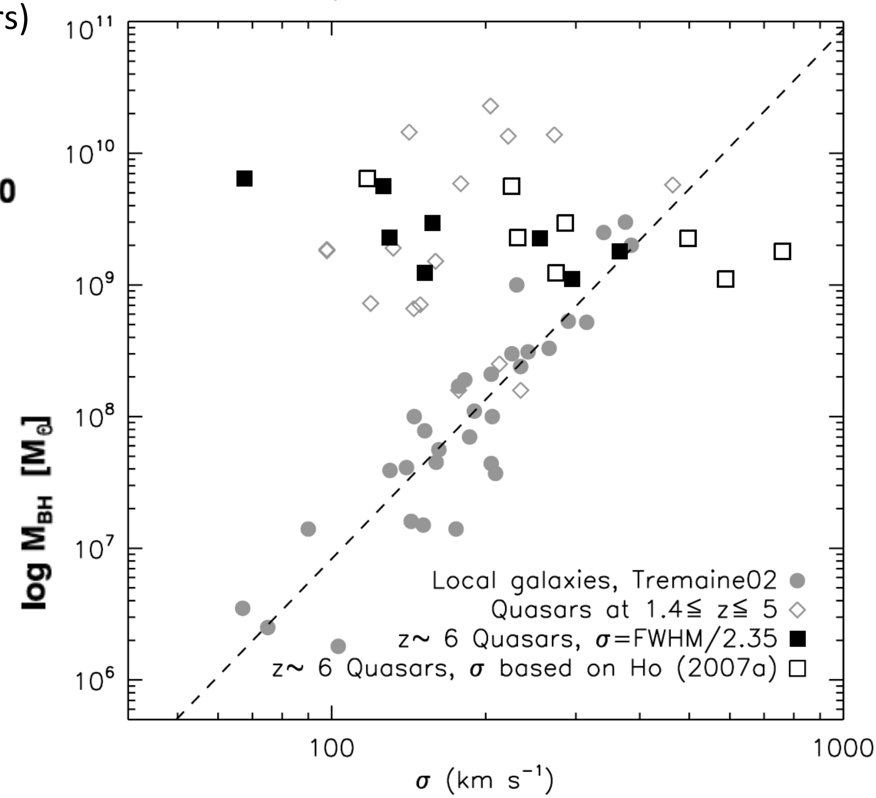
M(BH) – σ* in SMGs and quasars

Bothwell et al. 2013, MNRAS, 429, 3047

f(gas) = M(gas) / (M(gas)+M(stars))



Wang et al. 2010, ApJ, 714, 699



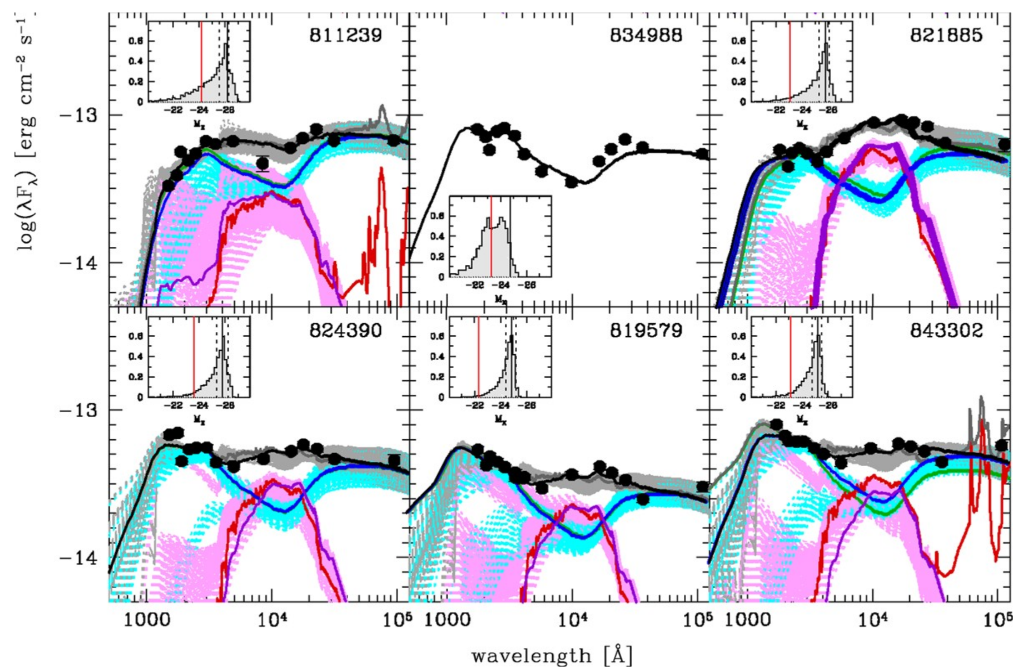
SMGのSMBHは、quasarと比較し系統的に少ない？（まだ成長途上のSMBH？）

どちらも PdBIによる（➔ 今後、ALMAで更に大きくサンプル拡大可能）

M(BH) – M(gal) relation at high-z (1<z<2.2)

- Rest-frame K-band luminosity and total stellar mass properties of 89 broad-line (type-1) AGNs in zCOSMOS
- M(BH): analysis of the broad MgII emission lines taken with VIMOS/VLT

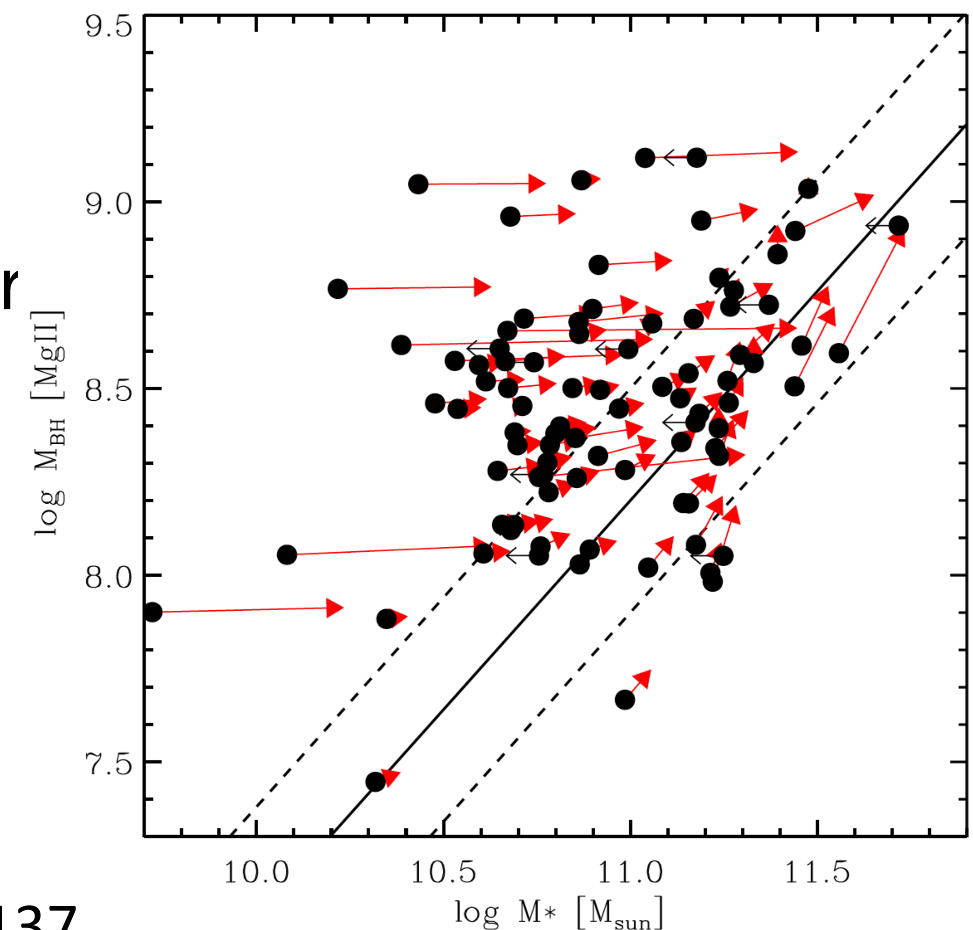
Separate AGN and galaxy via SED fitting. Large uncertainties due to assumed galaxy and AGN templates, but more accurate than the use of single band L and direct estimate of total M_{star}.



Merloni et al. 2010, ApJ, 708, 137

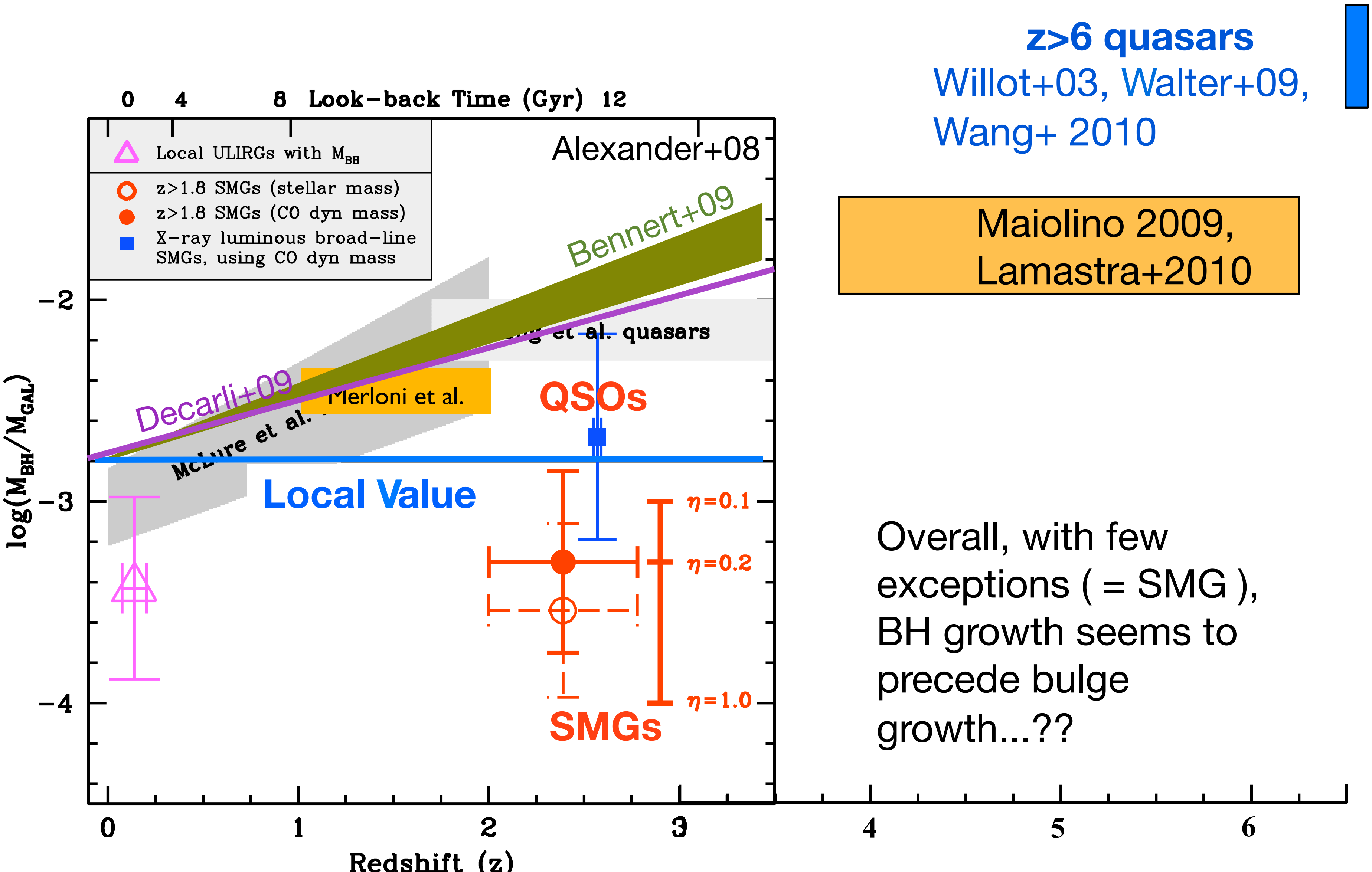
M(BH) – M(gal) relation at high-z (1<z<2.2)

- Red arrows: evolution in M_{BH}-M_{star} plane if L_{AGN} and SFR are maintained for 300 Myr considering AGN duty cycle $\delta(L,z) = \phi_{AGN}(L,z)/\phi_{gal}(L,z)$
- Convergence toward local relation!



Merloni et al. 2010, ApJ, 708, 137

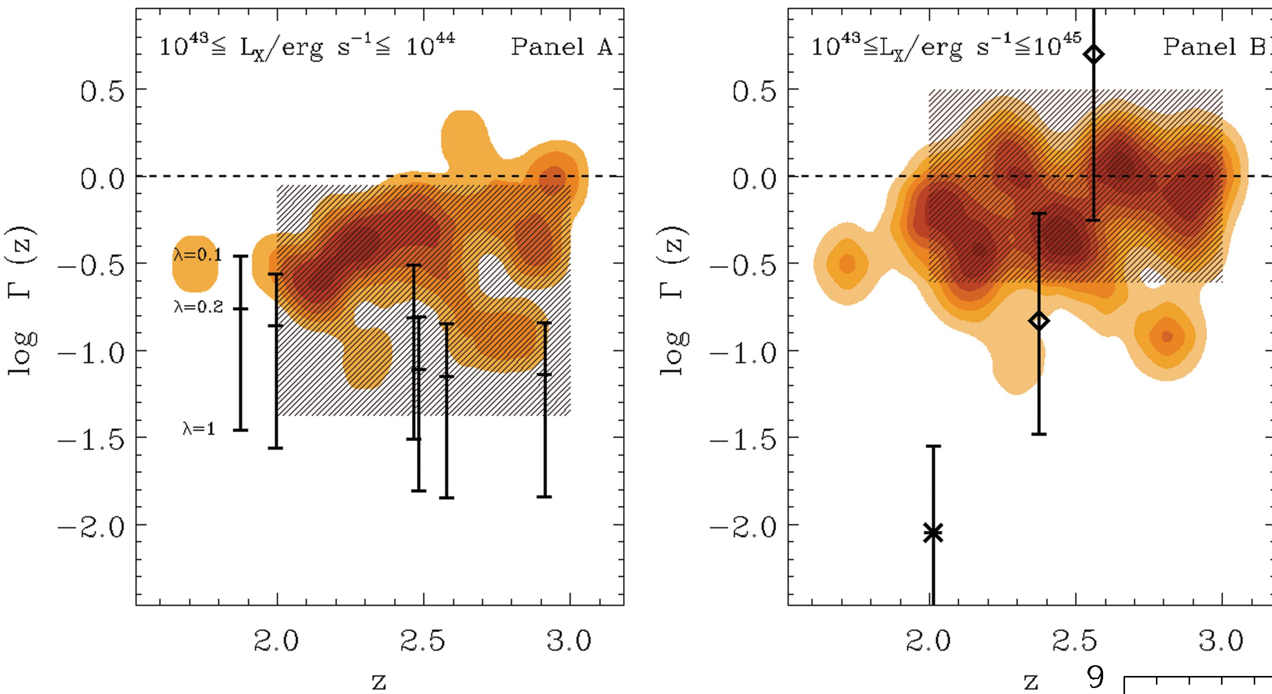
M(BH)/M(gal) ratio as a function of z



Overall, with few exceptions (= SMG), BH growth seems to precede bulge growth...??

From Marconi's viewgraph

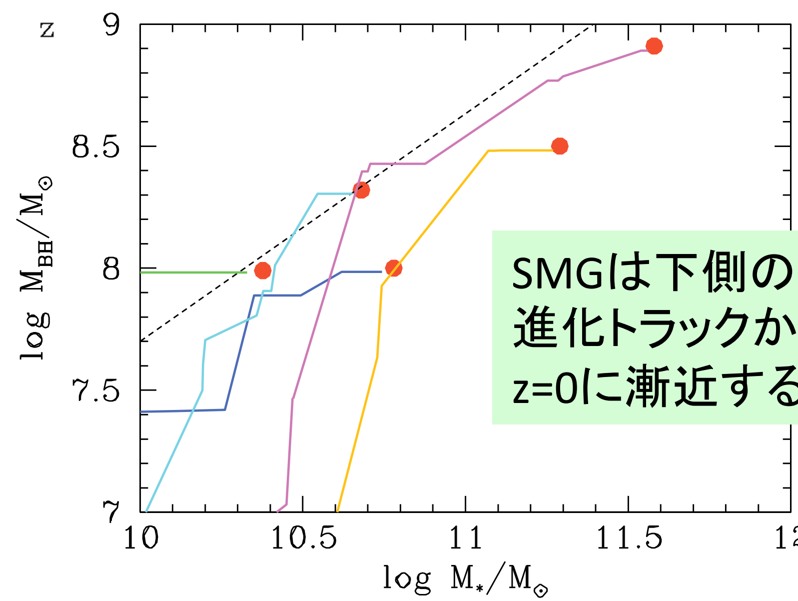
Expected growth tracks from a SA model



Lamstra et al. 2010, MNRAS, 405 29

Objects selected like SMG galaxies, i.e. extremely gas rich galaxies with large SFR @z=2-3

SMG-like galaxies represent rare evolutionary paths. They end up in $M_{BH}(final)<10^9\ M_\odot$ and approach local M_{BH}-M_{star} relation from below.



SMGは下側の
進化トラックから
z=0に漸近する？

Summary

- SMBHの起源と進化
  - 現在知られている最も初期のSMBH = ULAS J1120+0641から得られる示唆
  - SMBH質量の測定/Eddington比の測定とそれを決めるもの/周辺環境の調査
- SMBHと銀河の関係
  - AGN feedback

    Negative? Positive?
  - 銀河が先？SMBHが先？