Investigations on the optical properties and X-ray emission in young radio AGN

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Reference paper: Liao & Gu 2020a, Liao & Gu 2020b

Outline

- Introduction of young radio AGN
- Optical properties
- X-ray emission
- Summary

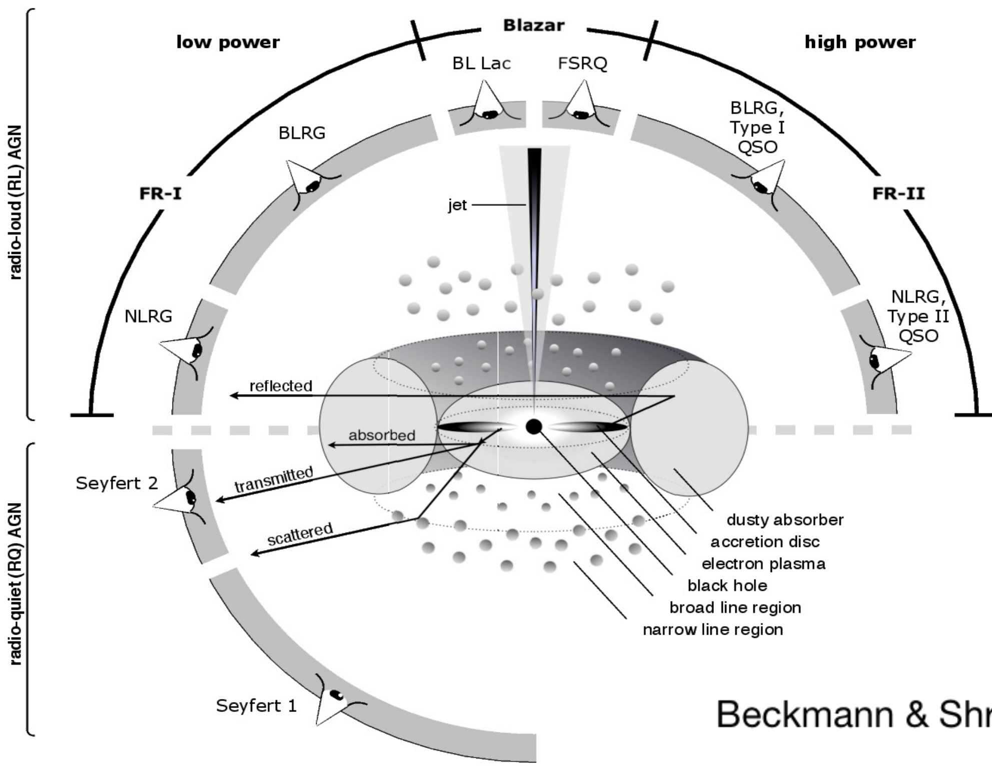
Young radio AGN

Intrinsically compact (LS ≤ 20kpc) , radio-loud, ν_t~100 MHz to tens of GHz (HFP/GPS/CSS)
(see O'dea 1998 for review)

Radio morphology: symmetric structure (galaxies); core-jet (quasars, beaming effect?)

Youth scenario: typical ages: $10^2 - 10^5$ yrs (dynamic and spectral age), scaled-down version of the extended radio sources FR II/ FR I (e.g. Giroletti & Polatidis 2009; Murgia 2003)

Importance of studying young AGN: understand the accretion/radio activity, high-energy process (X-ray/γ-ray radiation) at the early stage of AGN, evolution of AGN, accretion-jet relation, Jet-ISM interaction



Beckmann & Shrader (2012)

Young jet, also young in accretion?

1. Wu (2009), GPS/CSS sample (65 sources) for nuclear properties

Black hole mass: normal range ($10^7 - 10^{10}\ M_\odot$), Eddington ratio: similar with NLS1s (high accretion)

2. Son et al. (2012), 34 low redshift young radio galaxies (HEGs and LEGs)

Black hole mass: $10^7 - 10^{9.2}\ M_\odot$, Eddington ratio: various levels of accretion activity

- NLS1s

Low black hole mass, high Eddington ratio (may be young in accretion)

The links between CSS and NLS1s:

Share the similar radio morphology (e.g. Gu et al.2015)

Have the same [OIII] blue wing feature (outflow or jet-ISM interaction) (Holt et al. 2008, Caccianiga et al. 2014)

Have the same distributions of BH mass and accretion rate (e.g. Berton et al. 2016)

Some CSS might be the RL NLS1s counterparts observed at large angles (e.g. Berton et al. 2016)

Some of young AGN may be at the early stage of accretion activity

Both with young AGN and NLS1s properties may be at the early stage of jet and accretion activity

The origin of X-ray emission in young AGN

The X-ray emission is typically compact (e.g. Siemiginowska et al. 2008, Siemiginowska et al. 2016)

The possible origin:

- Disc-corona system: thermal Comptonization emission (Siemiginowska et al. 2008, 2016; Tengstrand et al. 2009);
- Jets or lobes: non-thermal emission (e.g. Migliori et al. 2012, Stawarz et al. 2008)
- Shocked ISM: thermal emission (e.g. 3C 303.1, 3C305, O'dea et al. 2017).

It's complex and hard to distinguish the origin of X-ray in young AGN in reality

Radio/X-ray relation and fundamental plane of black hole activity

$$L_R \propto L_X^b \quad \log L_R = \xi_{RX} \log L_X + \xi_{RM} \log M_{BH} + \text{constant}$$

- X-ray emission accretion origin (statistical studies & theoretical models: AGN & BHXBs)

ξ_{RX} and b are ~ 1.4, positive Γ-R_{edd} correlation for radiatively efficient accretion flows (e.g Merloni et al. 2003, Dong, Wu & Cao 2014)

ξ_{RX} and b are ~ (0.6-0.7), negative Γ-R_{edd} correlation for radiatively inefficient accretion flows (e.g Merloni et al. 2003)

- Fan & Bai (2016)

Showing ξ_{RX} and b ~ 0.6 for high-accreting young AGN (radio data: NVSS)

Implying accretion-related (disc-corona system) X-ray emission origin

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Motivation

- Many works have focused on radio band, but optical properties of young AGN have not been studied sufficiently
- SDSS is a large database

Goals:

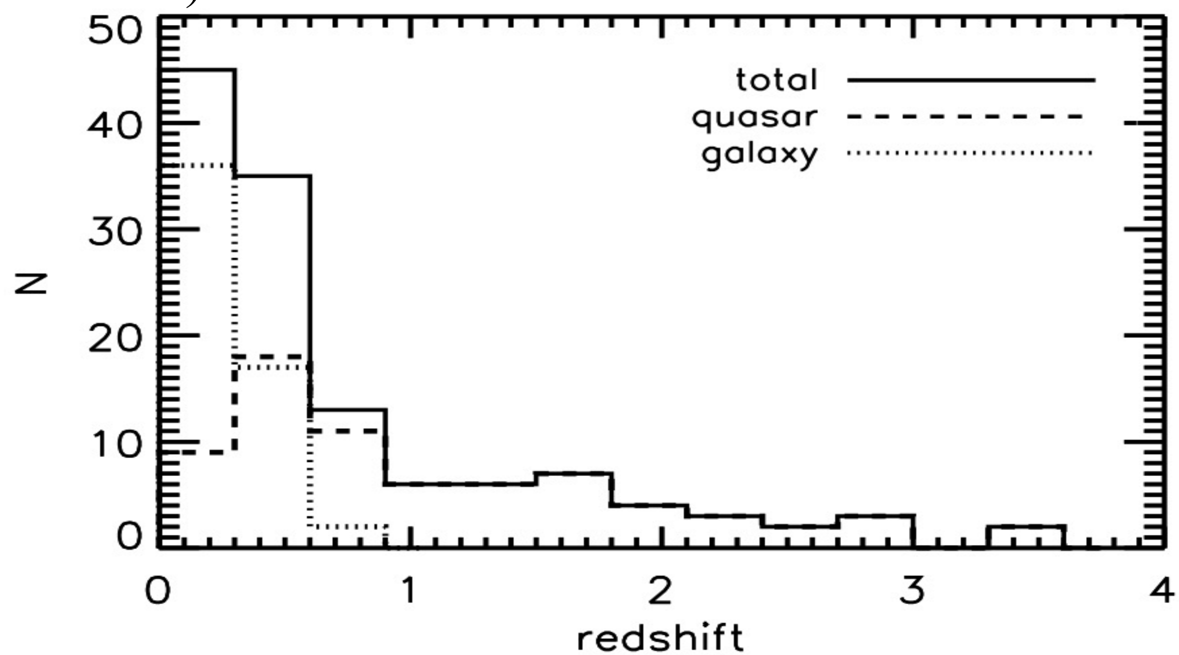
Constructing a larger optical sample from SDSS

Studying the common optical properties for young AGN (e.g. accretion, AGN evolution, jet-accretion relation)

Sample selection

- Collect the available radio-selected sample in the literature (bright sample and faint sample) (parent sample: 545 objects)
- Cross with SDSS DR12 searching optical spectra (optical sample: 147 obejcts)
- Exclude blazar-type objects, resulting 126 sources

GPS: 19, CSS: 82, HFP: 19, CSO: 6 Quasar: 71 (z: 0.077 - 3.594) , Galaxy: 55 (z: 0.025 - 0.73)



Spectroscopic analysis

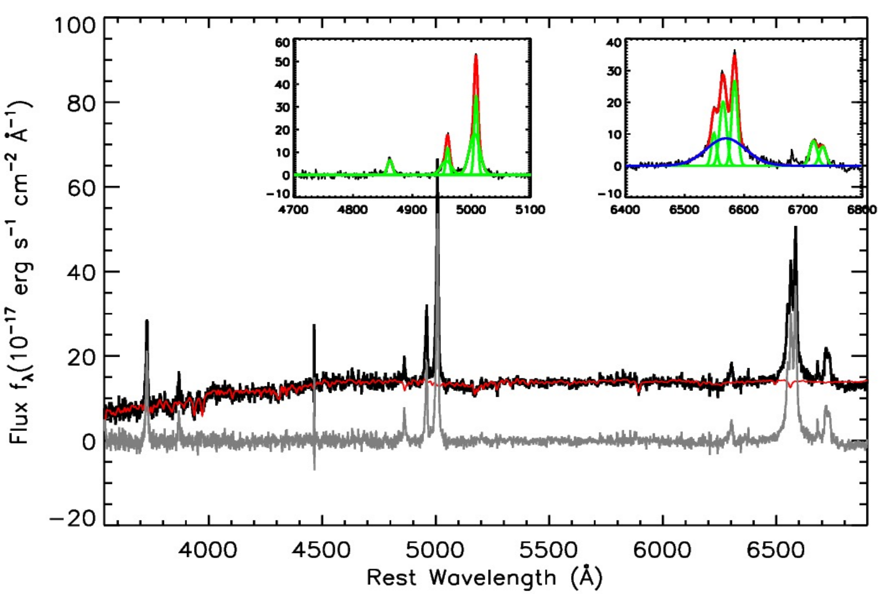
- Continuum subtraction

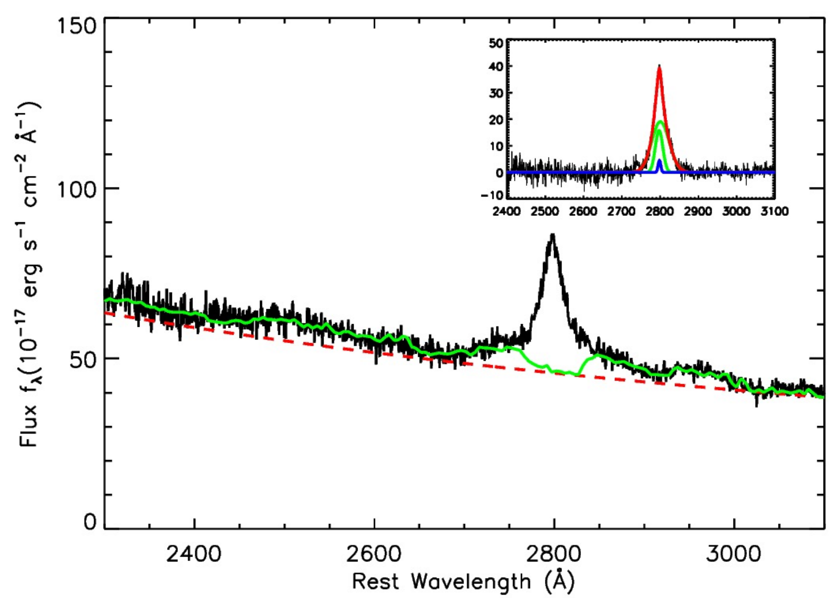
(1) power-law + Fe II (quasars: nuclear dominating; local fitting)

(2) host subtraction using PPXF (galaxies & quasars: D_{4000} >1; S/N >10; λ: 3540 - 6900 Å), and the σ_* can be measured

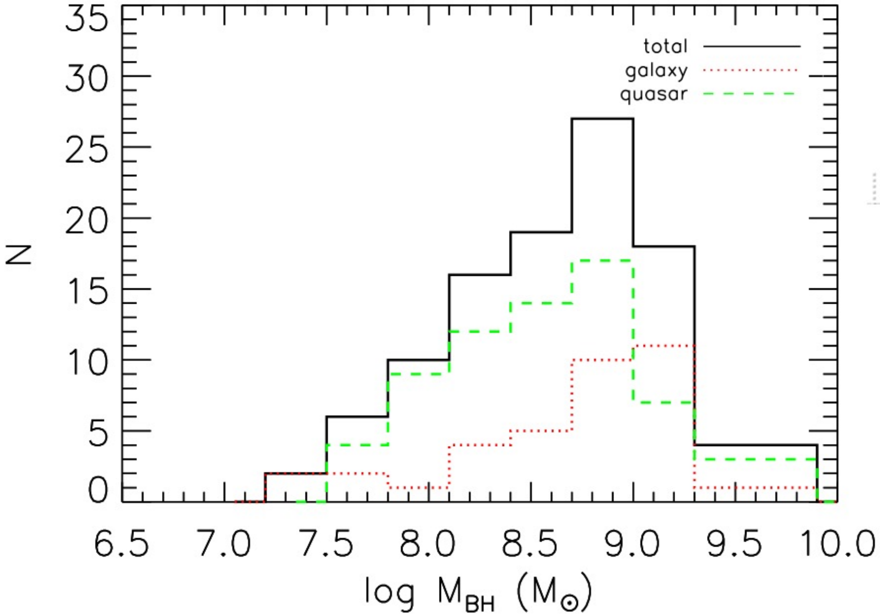
(3) single power-law (quasars: D4000>1, SN<10; local fitting)

- Emission line fitting: using Guassian function to get lines parameters (flux, FWHM)



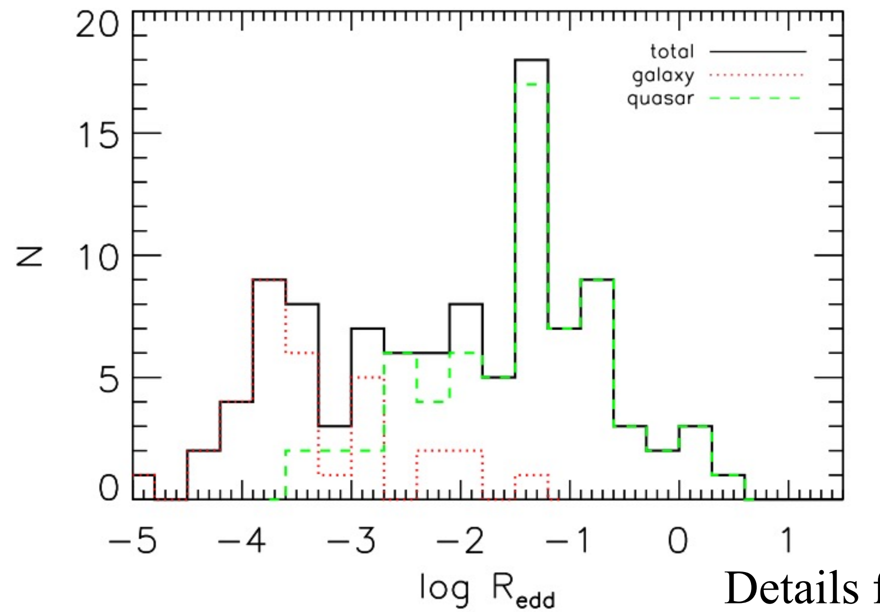


Black hole masses and Eddington ratios (L_{bol}/L_{edd})



1. $M_{BH} - \sigma_*$ relation
2. Broad line: width and luminosity
3. [O III] width

$10^{7.32} - 10^{9.84}$ $M_\odot$ (106 sources)
median: $10^{8.72}$ $M_\odot$
consistent with Wu (2009) and Son et al. (2012)



Bolometric luminosity

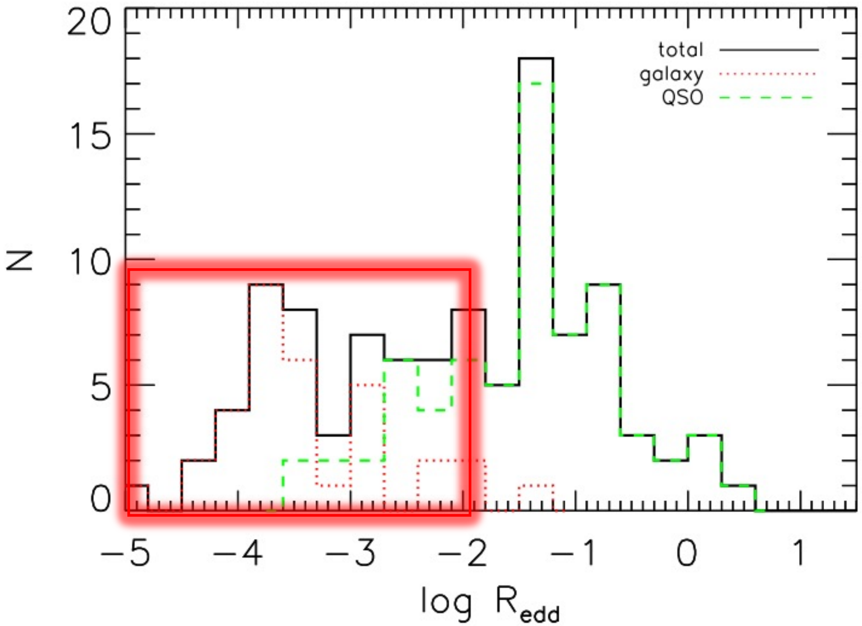
(1) L_{Line} to L_{BLR}, Assuming L_{bol}=10L_{BLR} (Liu, Jiang & Gu 2006)

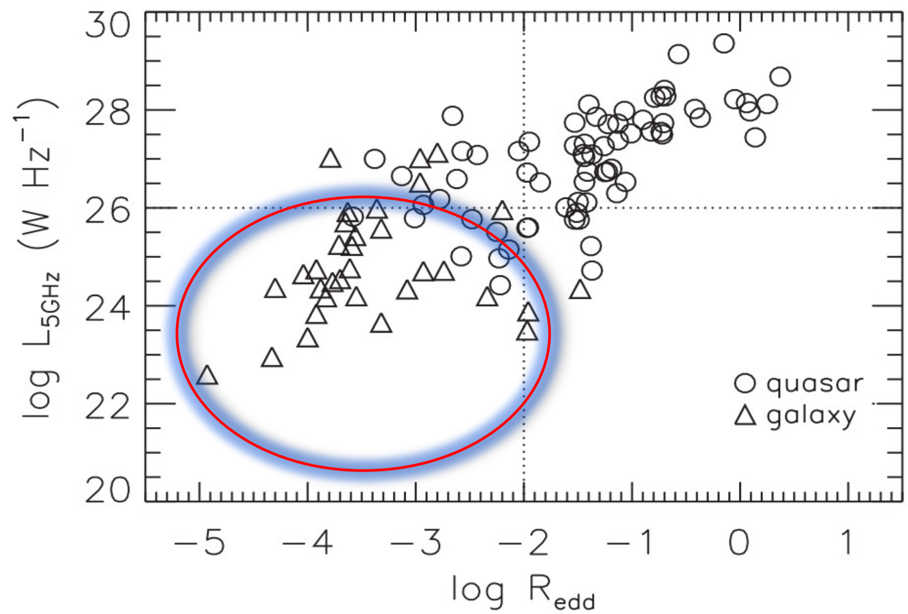
(2) $L_{[OIII]}$ (Berton et al. 2015)

$10^{-4.93} - 10^{0.37}$(102 sources)
mixed accretion mode, young jet activity could happen in various accretion systems
Consistent with Son et al. (2012)

Details for M_{BH} and R_{edd} estimations see Liao &Gu (2020)

Low R_{edd} sources





Specificity: **low radio luminosity**

Low luminosity CSS studies *in Kunert-Bajraszewska et al.,(2010a) and Kunert-Bajraszewska et al. (2010b)*:

Kunert-Bajraszewska et al., (2010a):

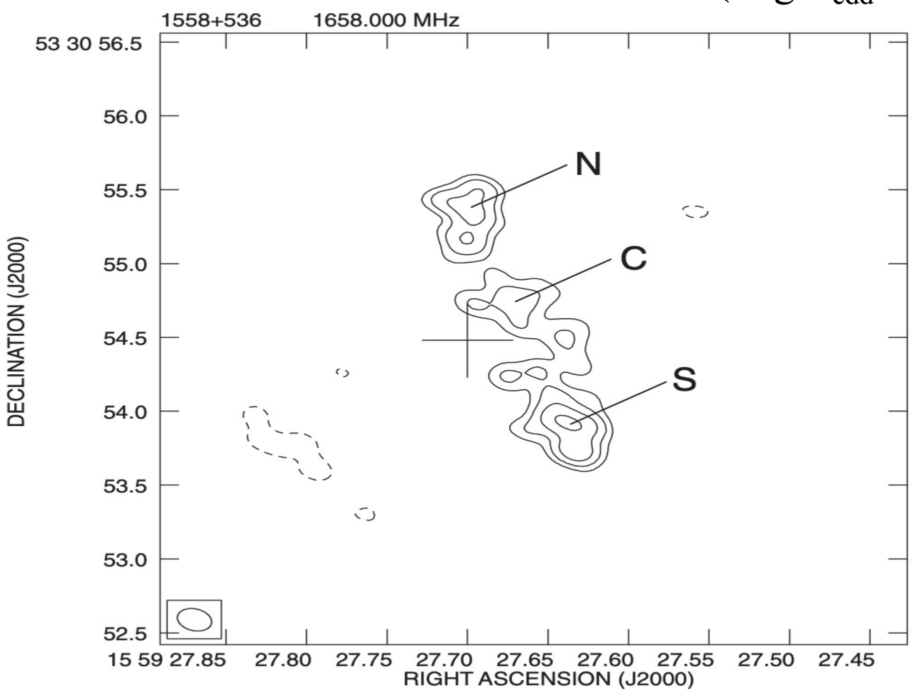
Radio: may be short-lived objects? (e.g. showing breaking-up lobes without hotspots and core morphology)

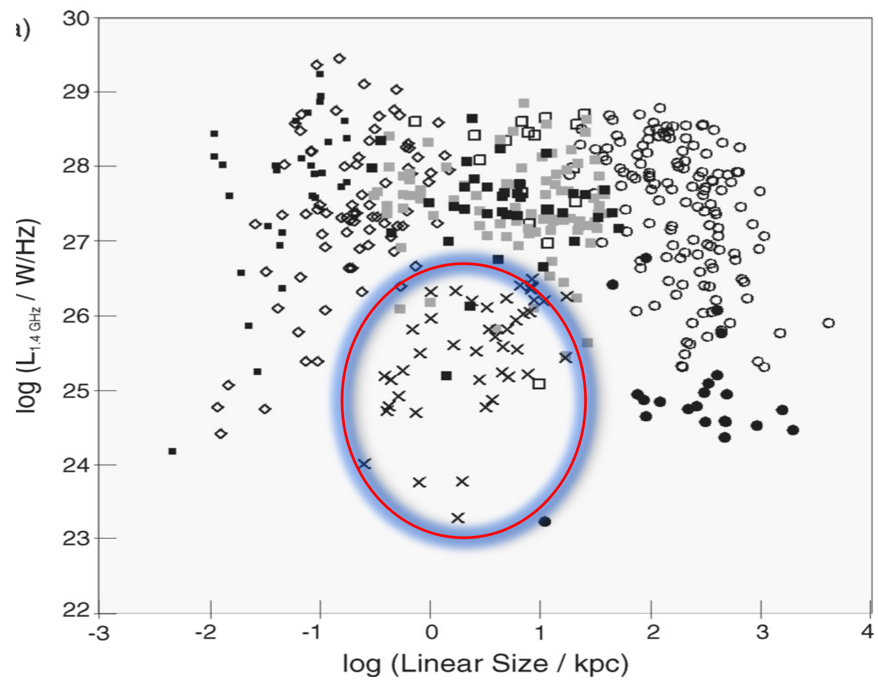
Radio luminosity-LS diagram: ocuppying the space below the main evolutionary path of powerful young AGN

Kunert-Bajraszewska et al., (2010b):

Optical: can be classified HEGs and LEGs

SDSS J155927.67+533054.4 (log R_{edd} = -2.74)





Kunert-Bajraszewska et al., (2010a)

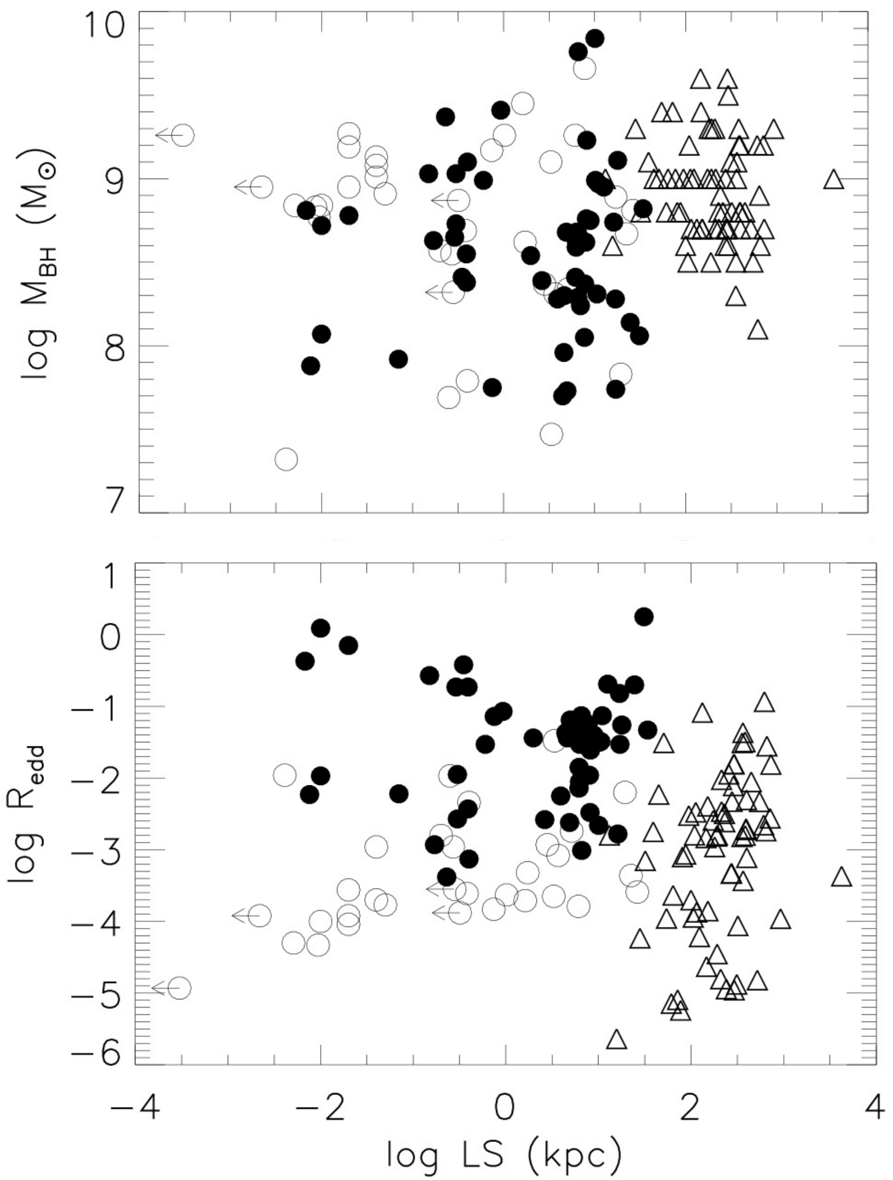
Evolution

M_{BH} and R_{edd} vs. LS:

Combine with FR II/FR I from Hu et al. (2016):
87% (total 89) of our sources have the comparable M_{BH} with FR galaxies
Mild correlation in $\log M_{BH}$-LS
Multiple accretion activity?

No correlation in $\log R_{edd}$-LS
Caused by the various levels of accretion?

Decreasing R_{edd} with LS?
Mean R_{edd}: $10^{-2.26}$ (young AGN), $10^{-3.05}$ (FR sources)
Part of young sources may be in the early stage of accretion activities



Involving the accretion rate into $L_{5\mathrm{GHz}}$ −LS plane

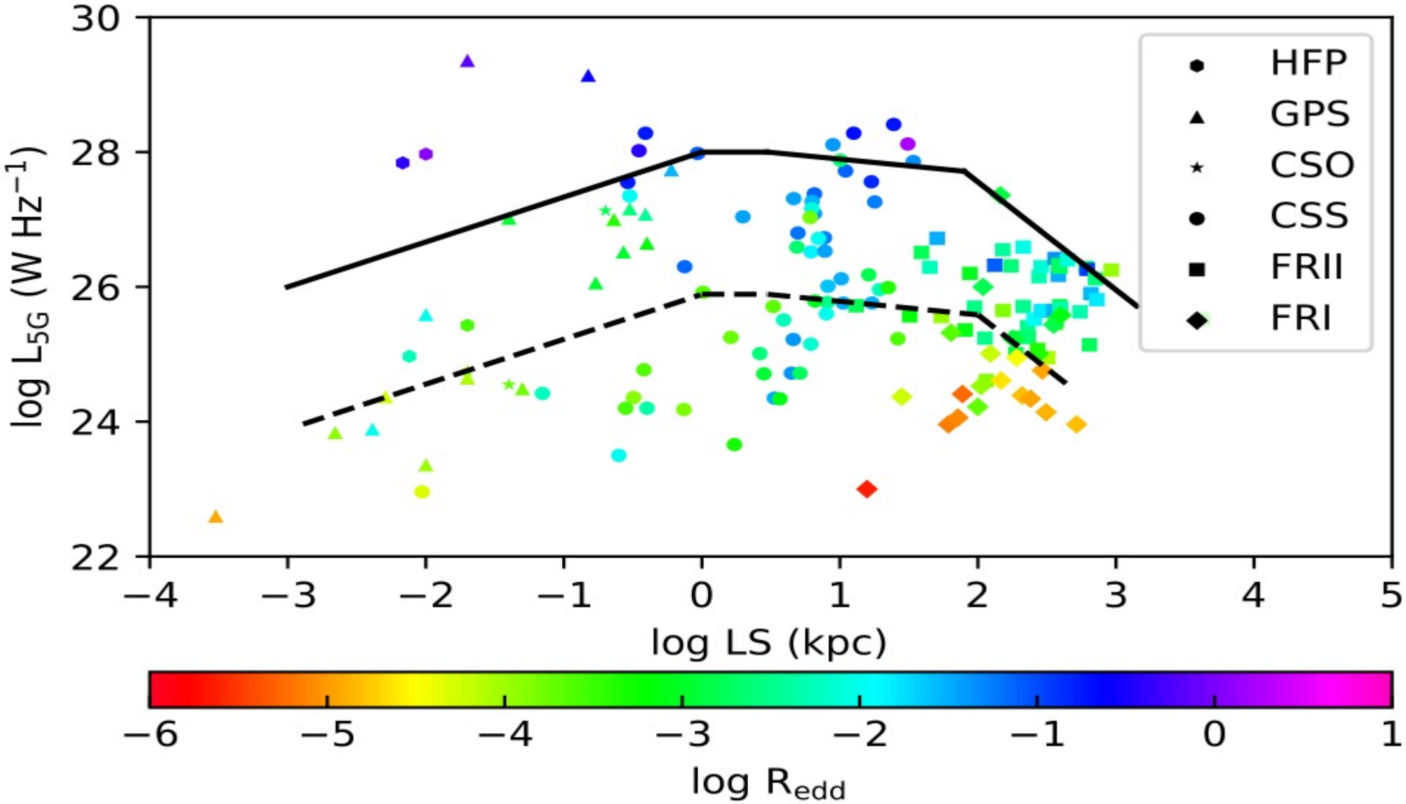
Global evolution trend: **accretion rate decrease with increasing LS for high/low luminosity AGN**

Median (log R_{edd}):

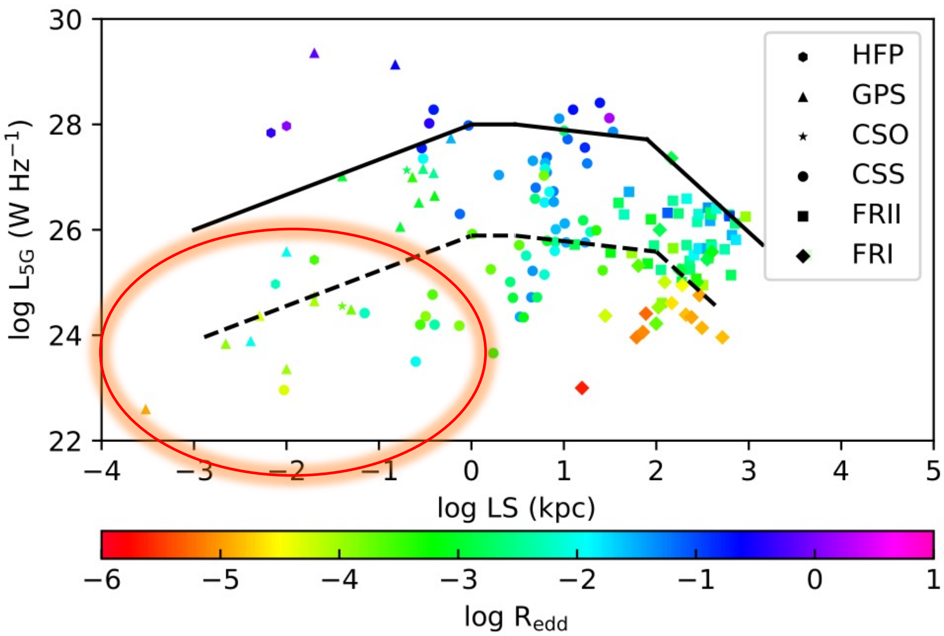
-1.44, -2.52 for high luminosity young AGN and FR II, respectively.

-3.01, -4.23 for low luminosity young AGN and FR I, respectively.

Supporting that young AGN will eventually evolve into large-scale radio AGN in general



The radio morphology of low luminosity and low accretion rate sources and implication for source evolution



Normal evolved sources?

Well-confined lobes and hotspot structure

e.g. SDSS J083139.79+460800.8 (log R_{edd} = -4.04, LS = 21 pc, log L_{5GHz}= 24.65 W/Hz), the dynamic age is 245 yr (Vries et al. 2010)

Short-lived/dying sources?

Faders: compact structure with weak radio emission; breaking-up structure in lobes with weak (no) radio core and without hotspots (e.g. Kunert-Bajraszewska et al. 2010)

e.g. SDSS J155927.67+533054.4 (log R_{edd} = -2.74, LS = 5.13 pc, log L_{5GHz}= 24.72 W/Hz)

Restarted sources?

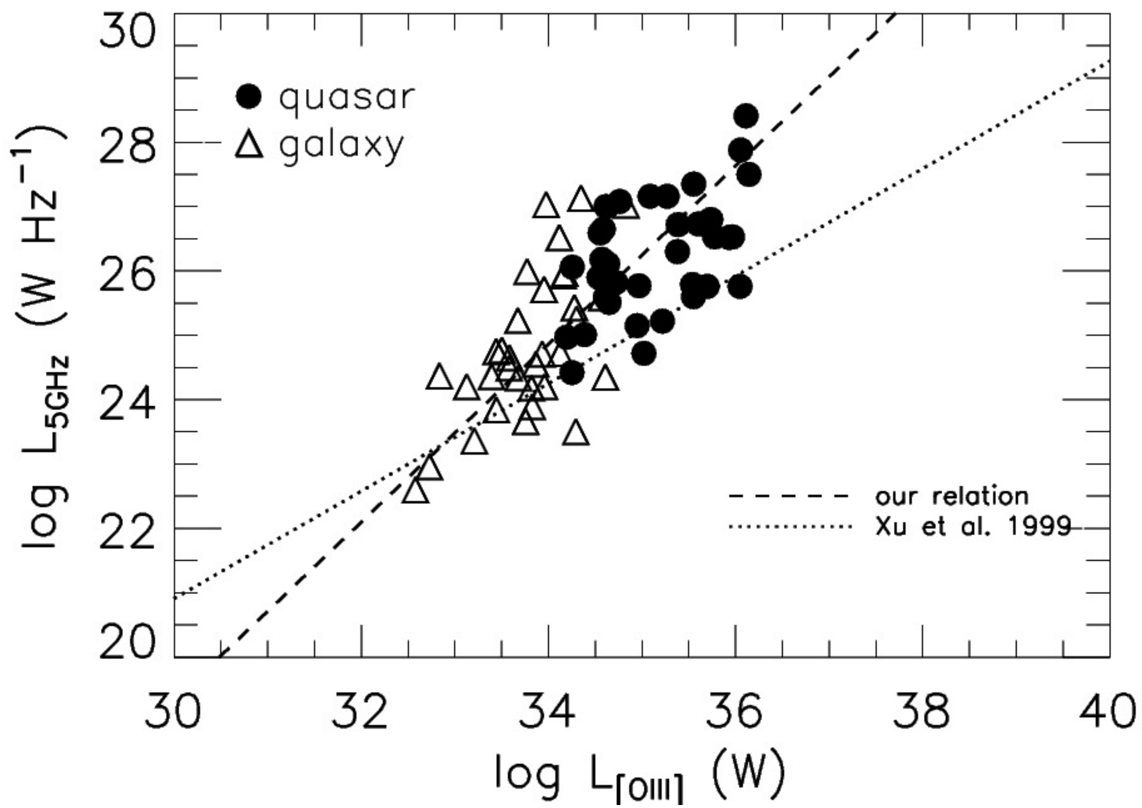
Double-double structure (e.g. Marecki et al. 2003)

SDSS J124733.31+672316.4 (log R_{edd} = -3.92, LS = 145 pc, log L_{5GHz}= 24.75 W/Hz), the dynamic age is 191 yr for inner double structure (Marecki et al. 2003)

Jet-accretion relation

$L_{[\mathrm{OIII}]}$ vs. $L_{5\mathrm{GHz}}$ (68 sources): show strong correlation (r_s=0.72, $P_{\mathrm{null}}<10^{-10}$), suggesting that accretion and radio activities are tightly linked in young AGN

$L_{5\mathrm{GHz}}$ is higher than normal radio-loud AGN in Xu et al. (1999), supporting the AGN evolution



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X-ray emission in young AGN:

Important to study the high energy radiation process at the initial stage of AGN;

compact and the origin is still unclear;

Radio/X-ray relation and fundamental plane of black hole activity are useful to constrain emission mechanism .

Our goal:

(1) Constructing a larger X-ray sample

(2) Using the higher resolution radio data compared to Fan & Bai 2016 (minimize the extended radio emission), to study the radio/X-ray relation and fundamental plane of black hole activity

(3) Collecting multi-band data to build SED and composite SED

Sample selection:

- Cross-match our parent sample (468 sources in our first work) with Chandra and XMM-newton, resulting 89 sources
- Also including 4C 13.66 and 3C 305 (Massaro et al.2009, Wilkes et al. 2013)

Final X-ray sample: 91 sources

Data:

X-ray (2-10KeV): flux and Γ (from the literature or our reduction; available for 85 sources)

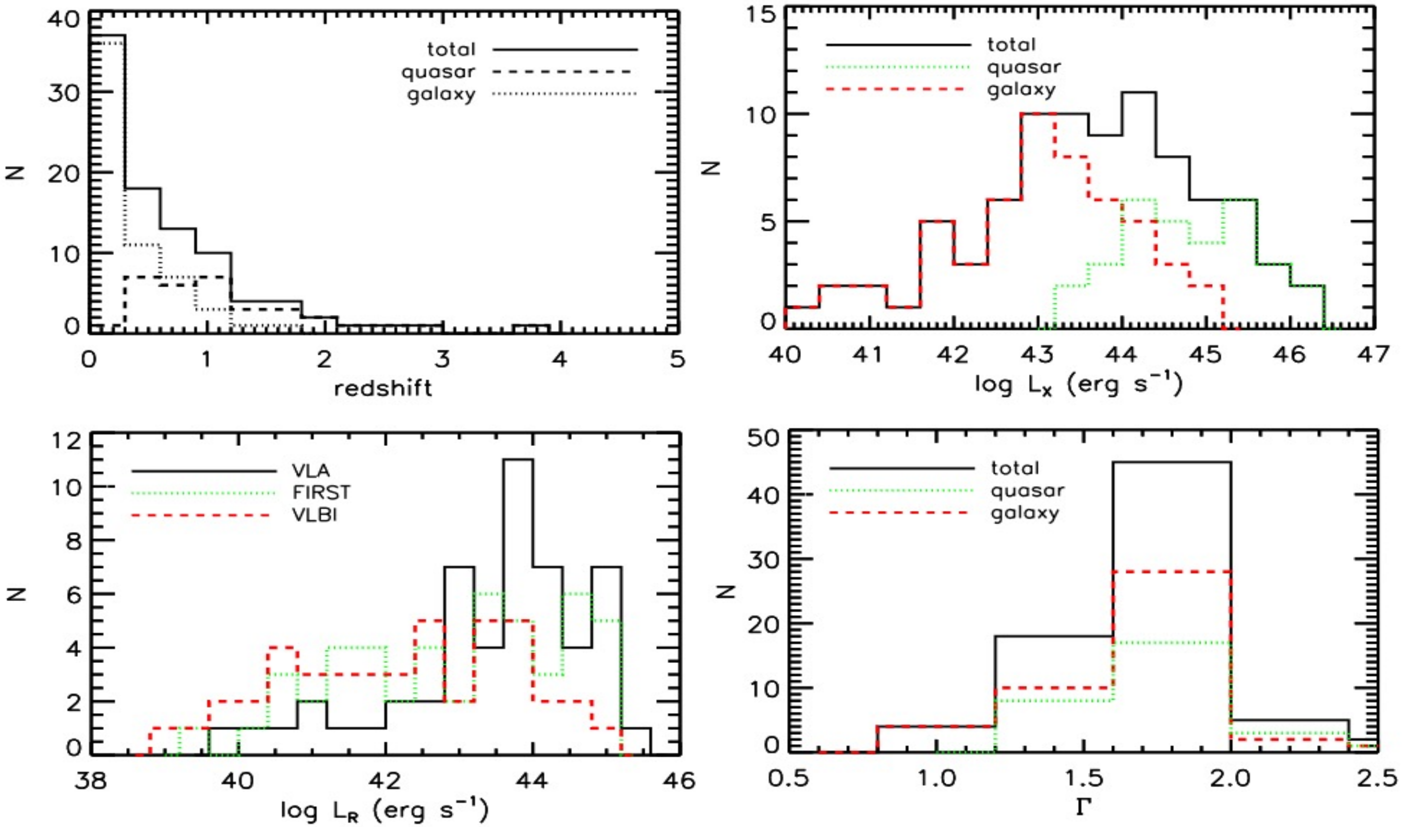
Radio: VLBI/VLA core emission (minimize the extended emission), FIRST data ($5''$), NED multifrequency data (build SED and composite SED)

Optical: $M_{\rm BH}$, $R_{\rm edd}$ from the first work (uniform estimation)

IR and UV photometric data: 2MASS & UKIDSS; WISE & IRAC; MIPS, GALEX

Sample properties

91 sources: GPS: 4, CSS: 52, HFP: 4, CSO: 9 (Quasar: 57 Galaxy: 34)
Quasars have higher L_X than galaxies
$L_{VLA/FIRST} \sim 10\, L_{VLBI}$
Γ: 0.64 – 2.62, median/mean: 1.7



Main results and discussions

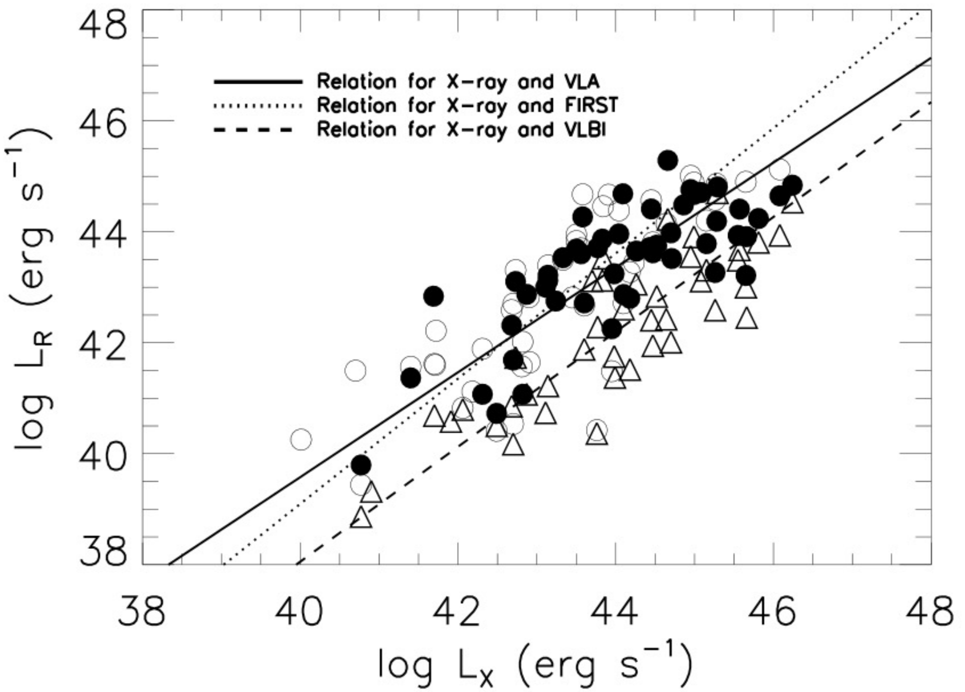
Radio/X-ray relation

For whole sample ($L_{5GHz} - L_X$)

$$\log L_{R_{VLA}} = 0.95(\pm 0.08) \times \log L_X + 1.79(\pm 3.62)$$ (50 sources)

$$\log L_{R_{FIRST}} = 1.13(\pm 0.09) \times \log L_X - 6.04(\pm 3.97)$$ (47 sources)

$$\log L_{R_{VLBI}} = 1.04(\pm 0.06) \times \log L_X - 3.37(\pm 2.83)$$ (42 sources)



All these fits: approximately linear relations between L_X and L_R

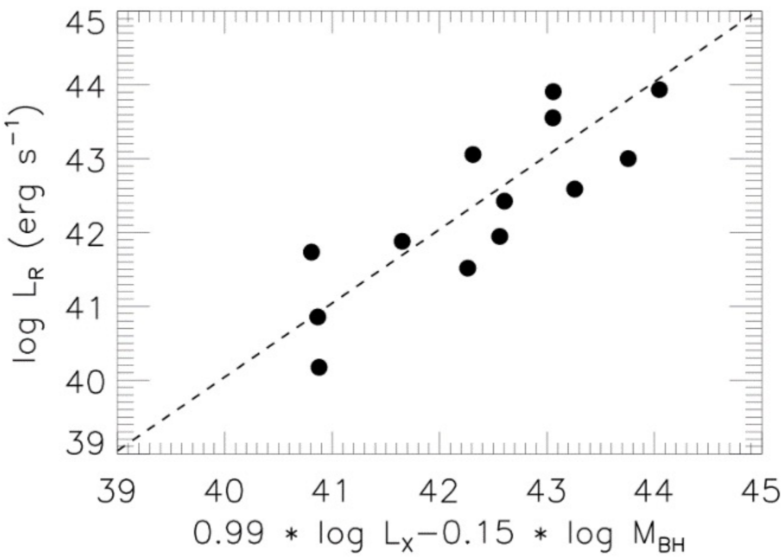
Fundamental plane

VLBI:
For our young sources with $R_{edd} > 10^{-3}$ (13 sources):

$$\log L_{R_{VLBI}} = 0.99^{+0.05}_{-0.05} \log L_X - 0.15^{+0.06}_{-0.06} \log M_{BH} + 0.04^{+1.70}_{-1.70}$$

$$\log L_{R_{VLBI}} = 1.02(\pm 0.14) \log L_X - 2.98(\pm 6.07)$$

FIRST: ξ_{RX}=1.08($\pm$0.07), b=1.15($\pm$0.23),
(12 sources with both VLBI core and FIRST detection)



The accretion-related X-ray: b and ξ_{RX} ~1.4 (statistical studies and the theoretical models)
The accretion-related X-ray in Fan & Bai (2016) : ξ_{RX} ~0.6
No significant Γ-R_{edd} correlation
Strong radio-emitters

Jet-related X-ray emission?

Synchrotron emission: no, cut-off energy below the X-ray band in strongly accreting system (Körding et al. 2006)

Inverse Compton scattering process:
SSC scenario: mean Γ is 1.64, similar to FSRQs of 1.65($\pm$0.04) (Donato et al. 2001), flatter than normal RQQs of 1.89 (Kording et al. 2006)

Possible SSC origin in Bloom & Marscher (1991): b=1.06($\pm$0.08) (using VLBI radio-core emission)

Comparing with work of Fan & Bai (2016)

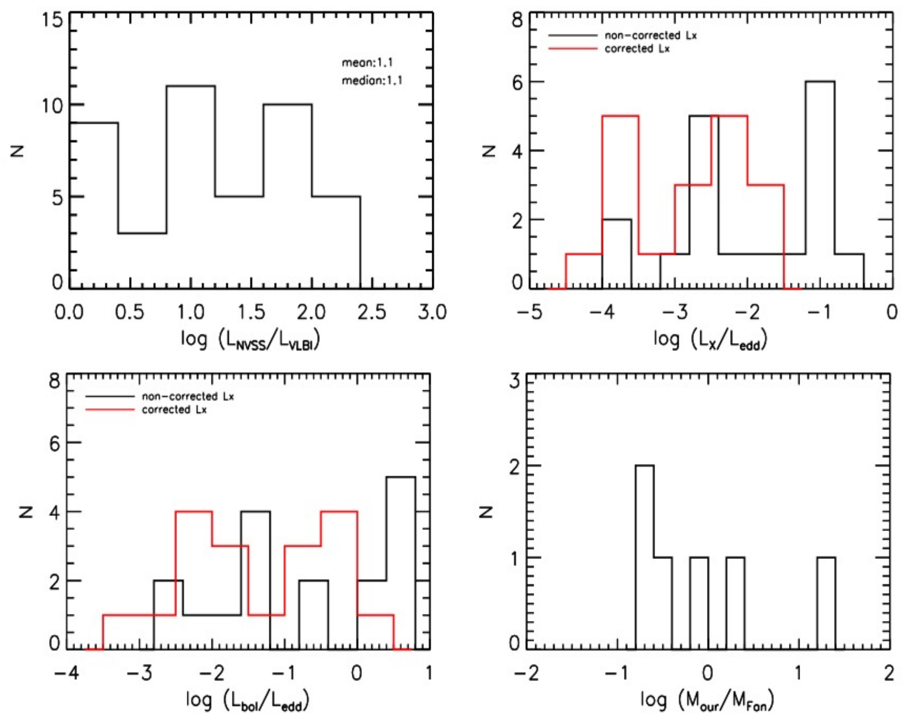


Table 2. Samples in our work and Fan & Bai (2016)

Sample	Source number
Our work	91
Fan & Bai	32
sources for FP in our work	13
sources for FP in Fan & Bai	18
common sources	31[a]
common sources for FP	6

a: one source (0500+019) in Fan & Bai is excluded in our work due to its blazar-type.

Table 3. Re-analysis of the fundamental plane for Fan & Bai (2016) with corrected L_X.

Sample	Number	b^a	ξ_{RX} *	ξ_{RM} *
All	18	0.92 ± 0.16	0.66 ± 0.08	0.46 ± 0.15
All[b]	18		0.81 ± 0.07	0.10 ± 0.10
Sources at $R_{edd} > 10^{-3}$	17[c]	1.08 ± 0.14	0.92 ± 0.05	0.32 ± 0.08
Sources at $R_{edd} > 10^{-3}$	17[b, c]		0.95 ± 0.06	0.48 ± 0.08

Notes. [a]Using the OLS bisector, as in our work.
*From the same multiple linear regression of the Bayesian approach (Kelly 2007) in our work and Fan & Bai (2016).
[b]The BH masses for the six common sources have been replaced with ours.
[c]After excluding one source, PKS 0941 – 08, with $L_{bol}/L_{edd} < 10^{-3}$.

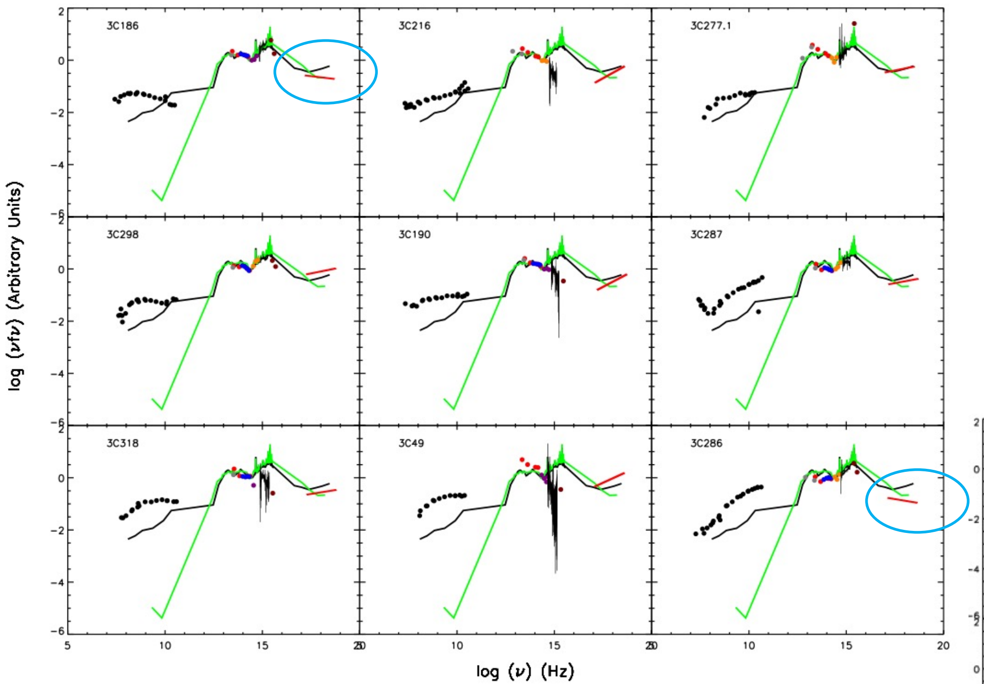
Our VLBI result of ξ_{RX} is consistent with the re-analysed result on the previous study in Fan et al. (2016) at $R_{edd} > 10^{-3}$ within errors

Liao & Gu 2020b

Spectral energy distribution (SED)

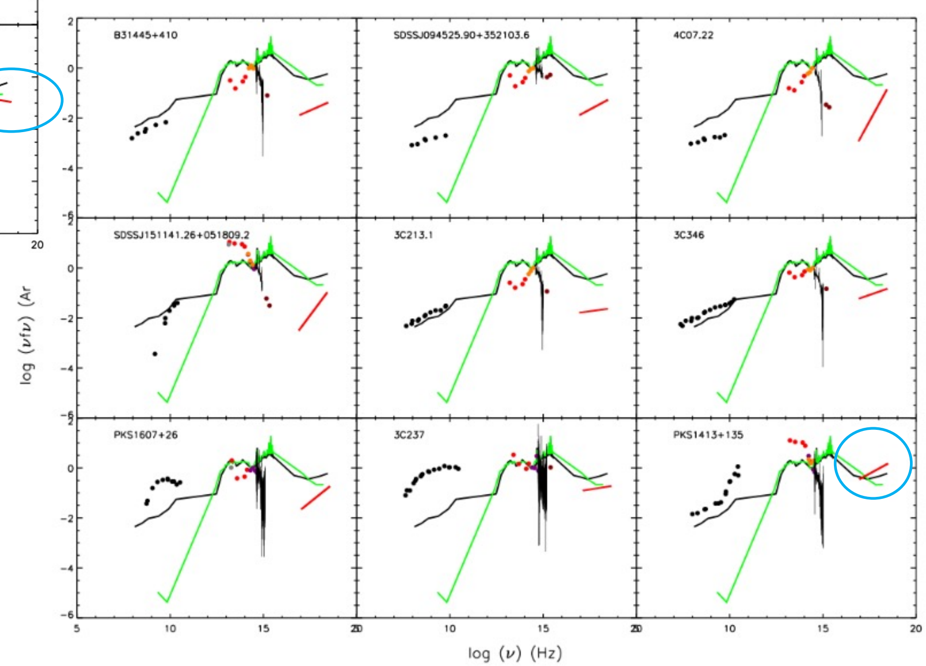
Most of them are at $R_{\mathrm{edd}} > 10^{-3}$

Higher X-ray emission in most young quasars SEDs than normal RQQs in Shang et al. 2011 (S11)



Quasars' SEDs

Large view angle in young galaxies, cause obscuration in X-ray emission and other bands



Galaxies' SEDs

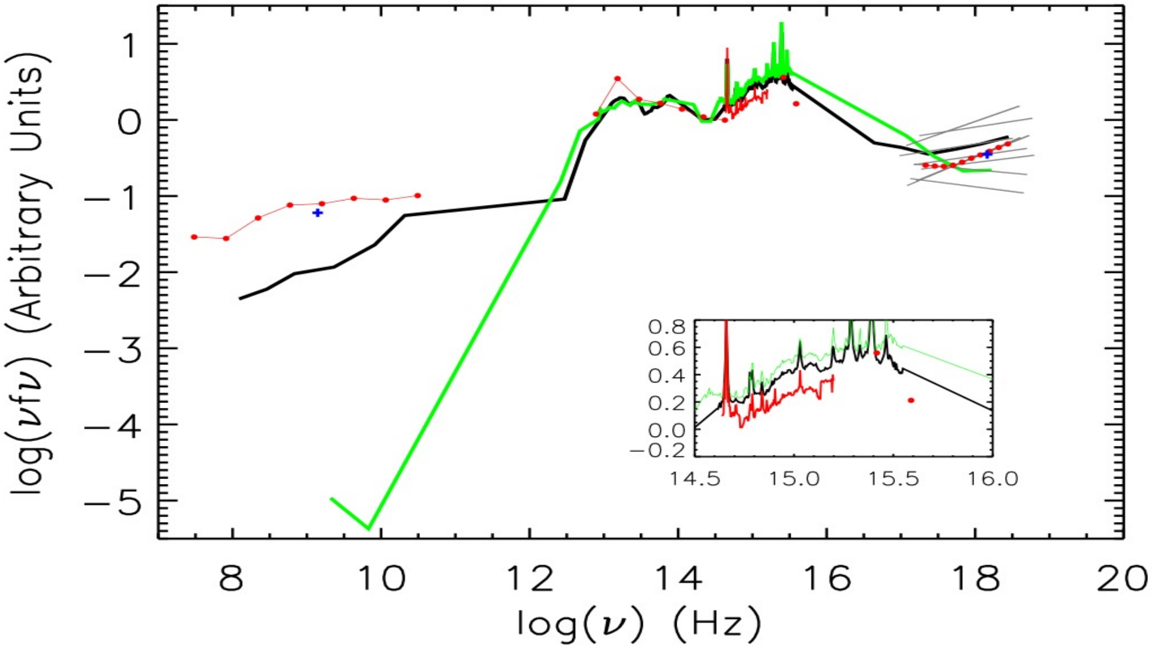
SED composite spectrum

Constructing for nine quasars: using the same method in Shang et al (2011)

Result: the hard X-ray emission is higher than that of normal RQQs in S11, implying jet-related emission at X-ray band.

K-S test show:

The nine quasars can represent all quasars in our sample and there is likely no strong bias introduced to the composite SED



Summary

We construct the largest optical and X-ray sample for young AGN, and systematically study their optical properties and the origin of X-ray emission. We find that:

- They have mixed accretion mode;
- They generally follow the evolutionary trend towards large-scale radio galaxies with increasing linear size and decreasing accretion rate in the radio power-linear size diagram;
- Accretion and radio activities are tightly linked.
- The X-ray emission of high-accreting young AGN may be from jets.

Thanks for your attention!