Galaxy Evolution Workshop 2019 on June 5, 2019 at IPMU, Japan

Infrared View of Swift/BAT AGN

Ichikawa et al. '17, ApJ, 835, 74
Ichikawa et al. '19, ApJ, 870, 31

Kohei Ichikawa (市川幸平)

FRIS fellow, Tohoku University

In collaboration with

C. Ricci, Y. Ueda, F. Bauer, **T. Kawamuro**, M. J. Koss, K. Oh, D. J. Rosario, T. T. Shimizu, M. Stalevski, L. Fuller, C. Packham, B. Trakhtenbrot, and the **BASS team**

Infr… AGN

ApJ, 835, 74

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Frontier Research Institute for Interdisciplinary Sciences
Tohoku University

About FRIS | Researcher | Feature

14 Assistant Professors from January - April, 2020

Closing Date for Application: August 1, 2019

2019.05.20

Number of position and job

14 Assistant Professors

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Please check more details from here (in Japanese) or here (in English)

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Number of position and job

14 Assistant Professors

Competitive salary:
5-6.5 million JPY/yr
Research grant:
2.5 million JPY/yr
Long term:
3+2(+2) yr

FRIS fellow, Tohoku University

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Infrared dust properties of Swift/ BAT Hard X-ray selected AGN

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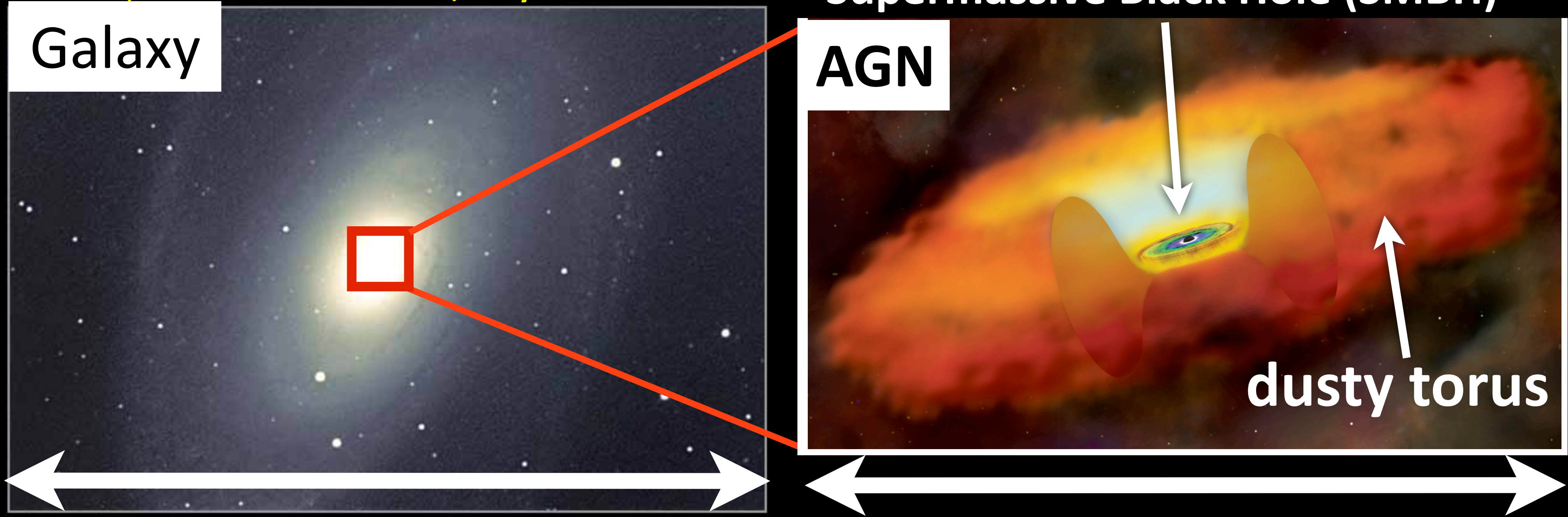
Active Galactic Nuclei (AGN)

Rees 84;Antonucci & Miller 85; Urry & Padovani95



Active Galactic Nuclei (AGN)

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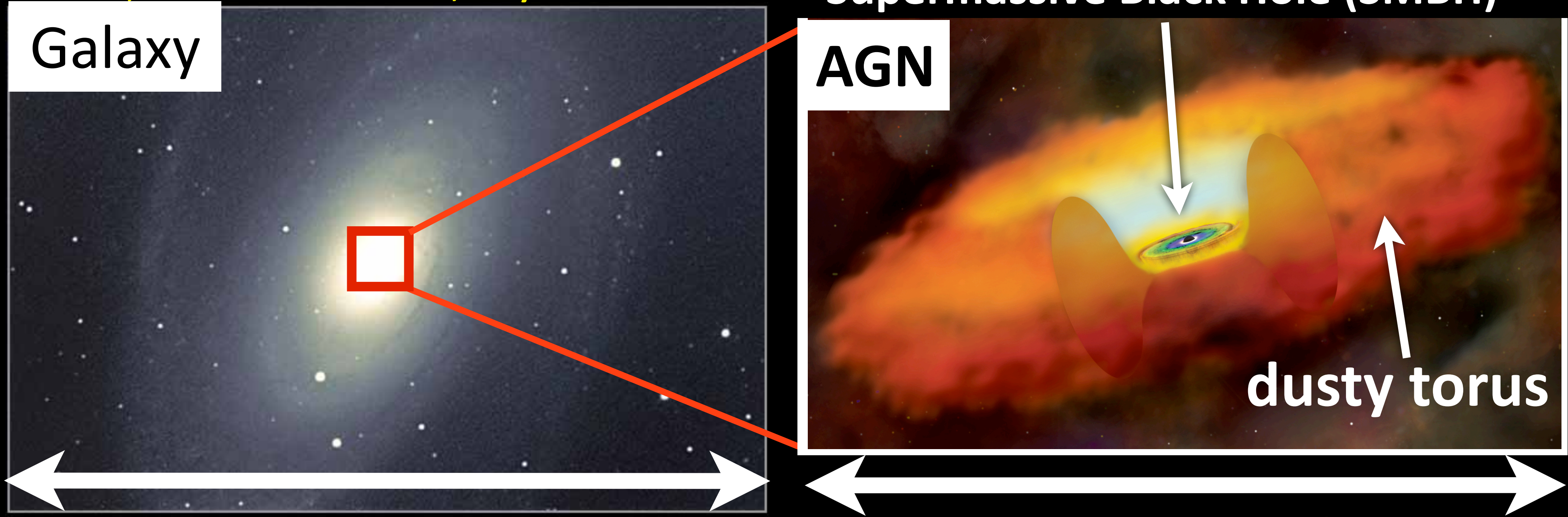
Supermassive Black Hole (SMBH)



~10 kpc

<10 pc

(see *Ichikawa+15, Burtscher+13*)

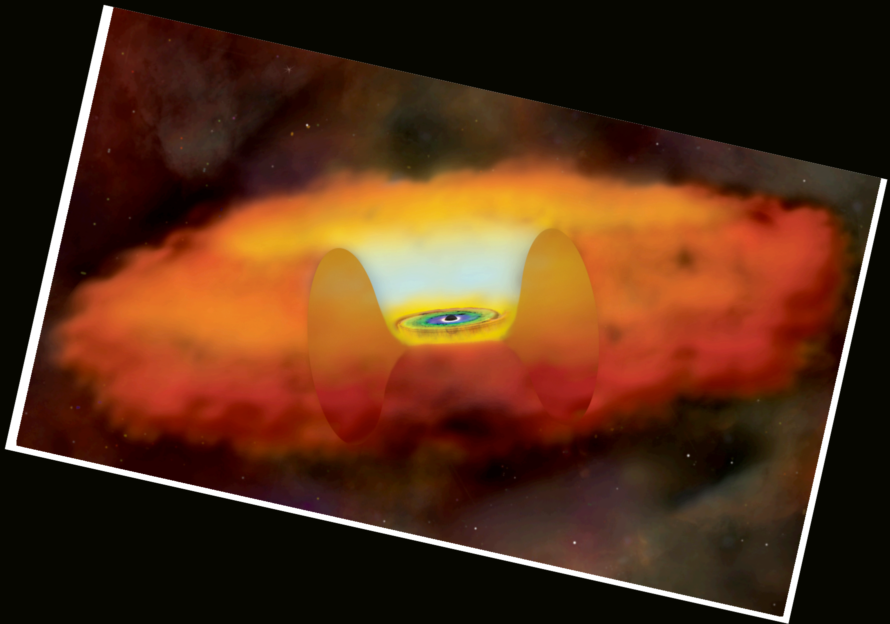
Why do we observe AGN for SMBH studies?

- ☑ AGN is a growing phase of SMBH
- ☑ easy to estimate BH mass (e.g., single-epoch method; Kaspi+00,05)
- ☑ Very, very bright in optical/UV (and also X-ray, IR!)

L_{bol} >= 10^{47} erg/s; which can be observable up to z~7!

(Mid-)IR emission of AGN= nuclear dust

Nuclear (MIR) dust emitting region is compact w/ < 10pc



Urry & Padovani '95

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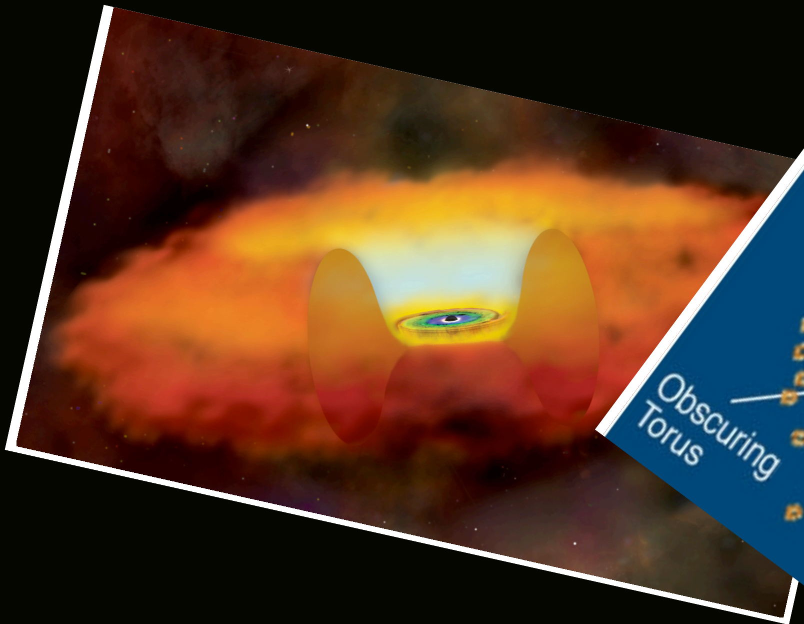

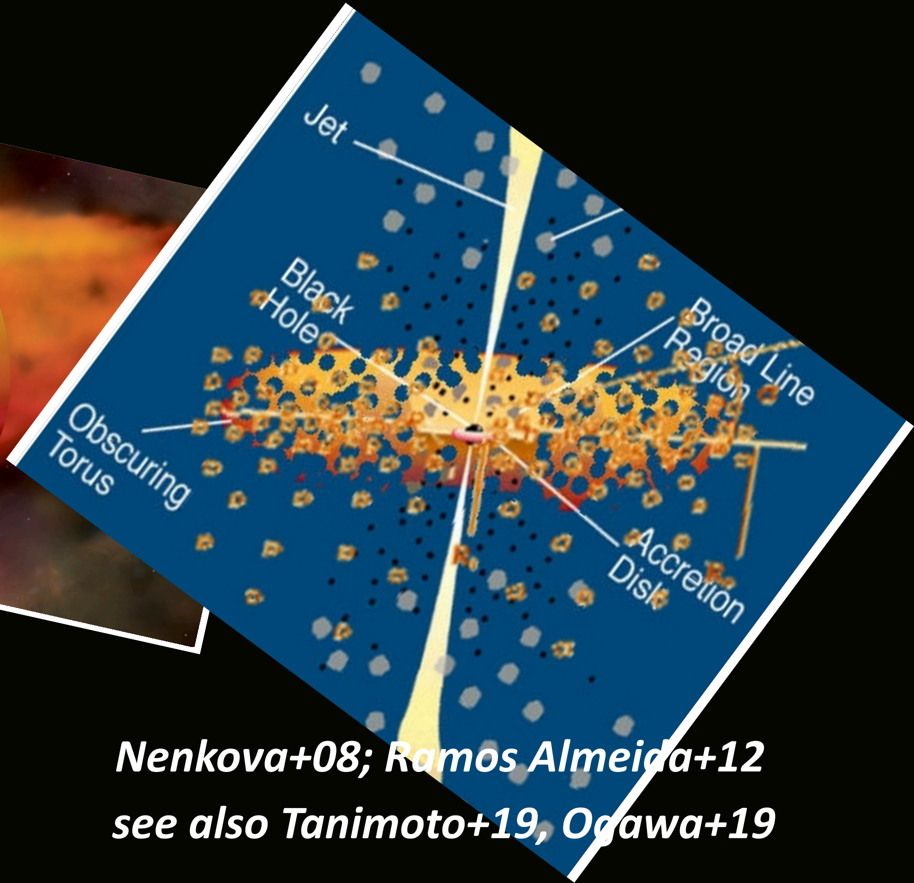

Urry & Padovani '95

Nenkova+08; Ramos Almeida+12
see also Tanimoto+19, Ogawa+19

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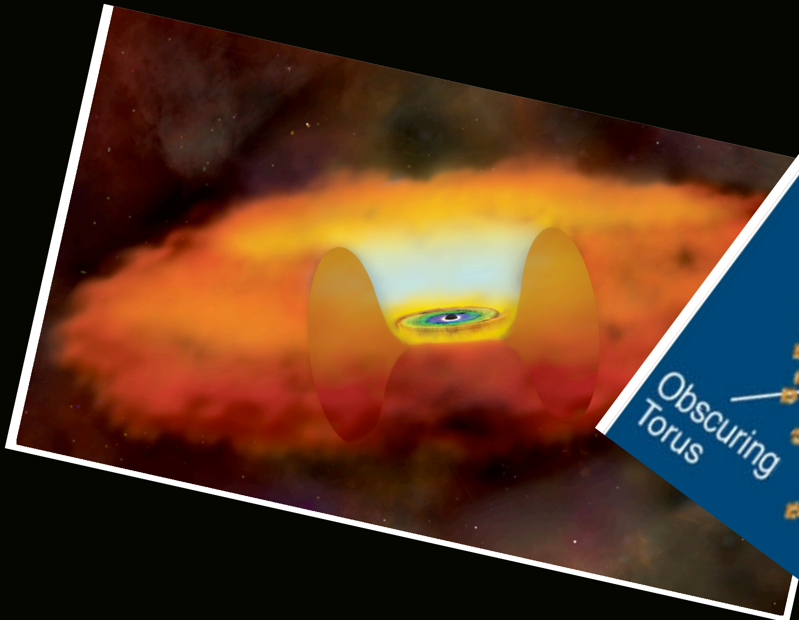
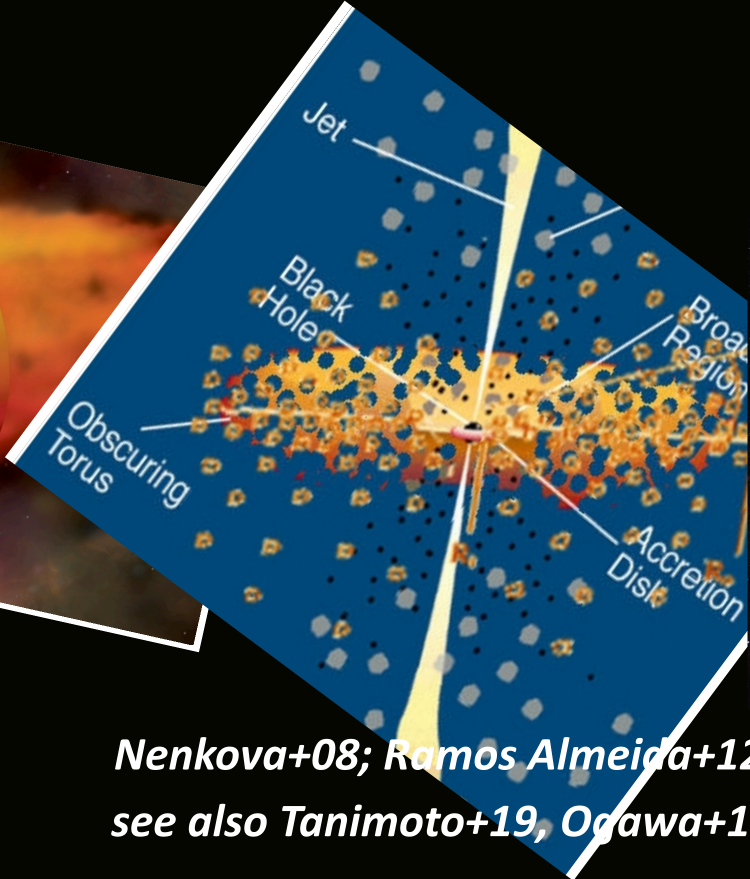


Urry & Padovani ’95



Nenkova+08; Ramos Almeida+12

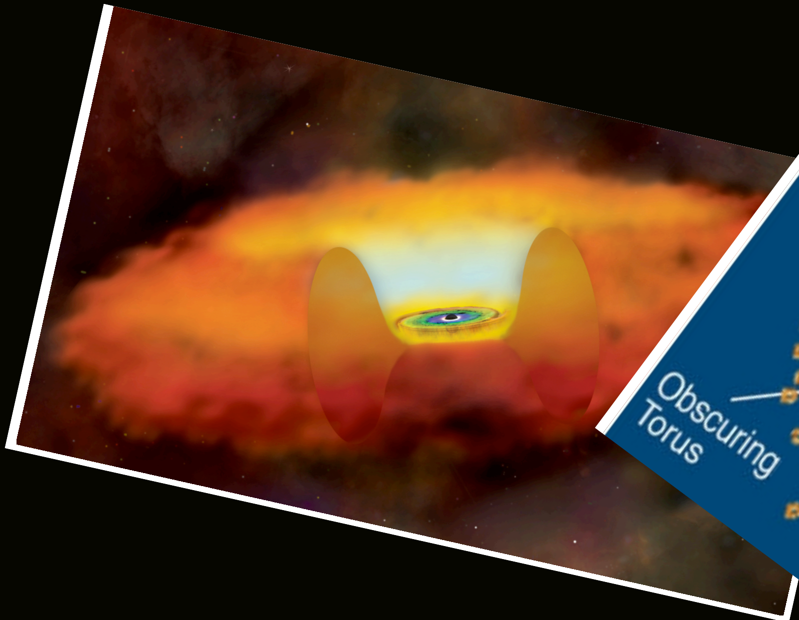
see also Tanimoto+19, Ogawa+19

e.g., Hoenig+12, Wada+15,
Tazaki & Ichikawa submitted

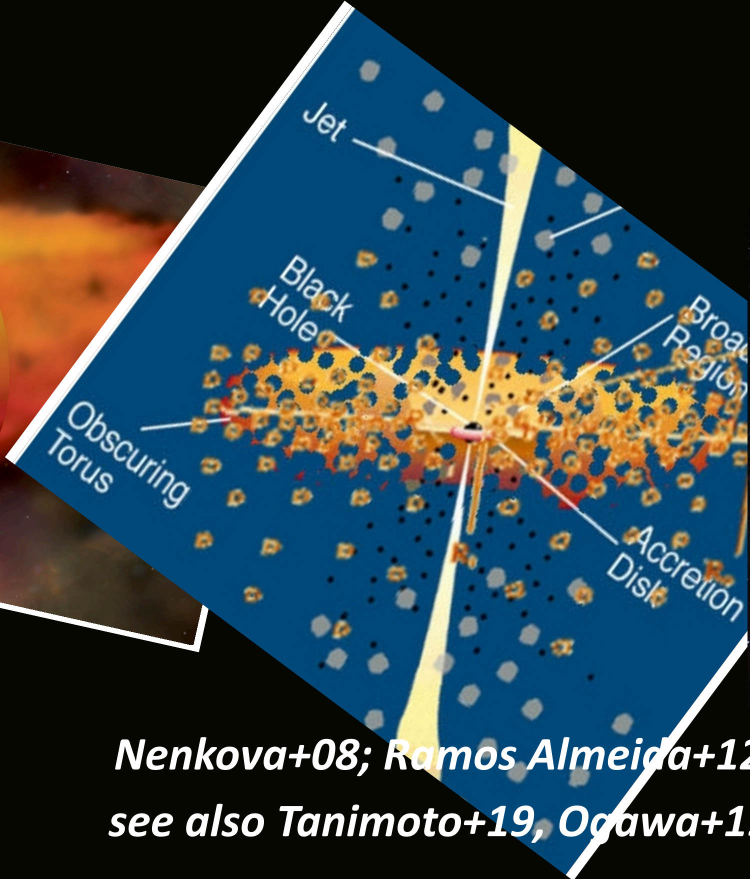
Sample size: limited to very nearby AGN (actually, mainly Circinus)

Geometry of (nuclear) dust emission

Nuclear (MIR) dust emitting region is compact w/ < 10pc



Urry & Padovani ’95



Nenkova+08; Ramos Almeida+12
see also Tanimoto+19, Ogawa+19

e.g., Hoenig+12, Wada+15,
Tazaki & Ichikawa in prep.

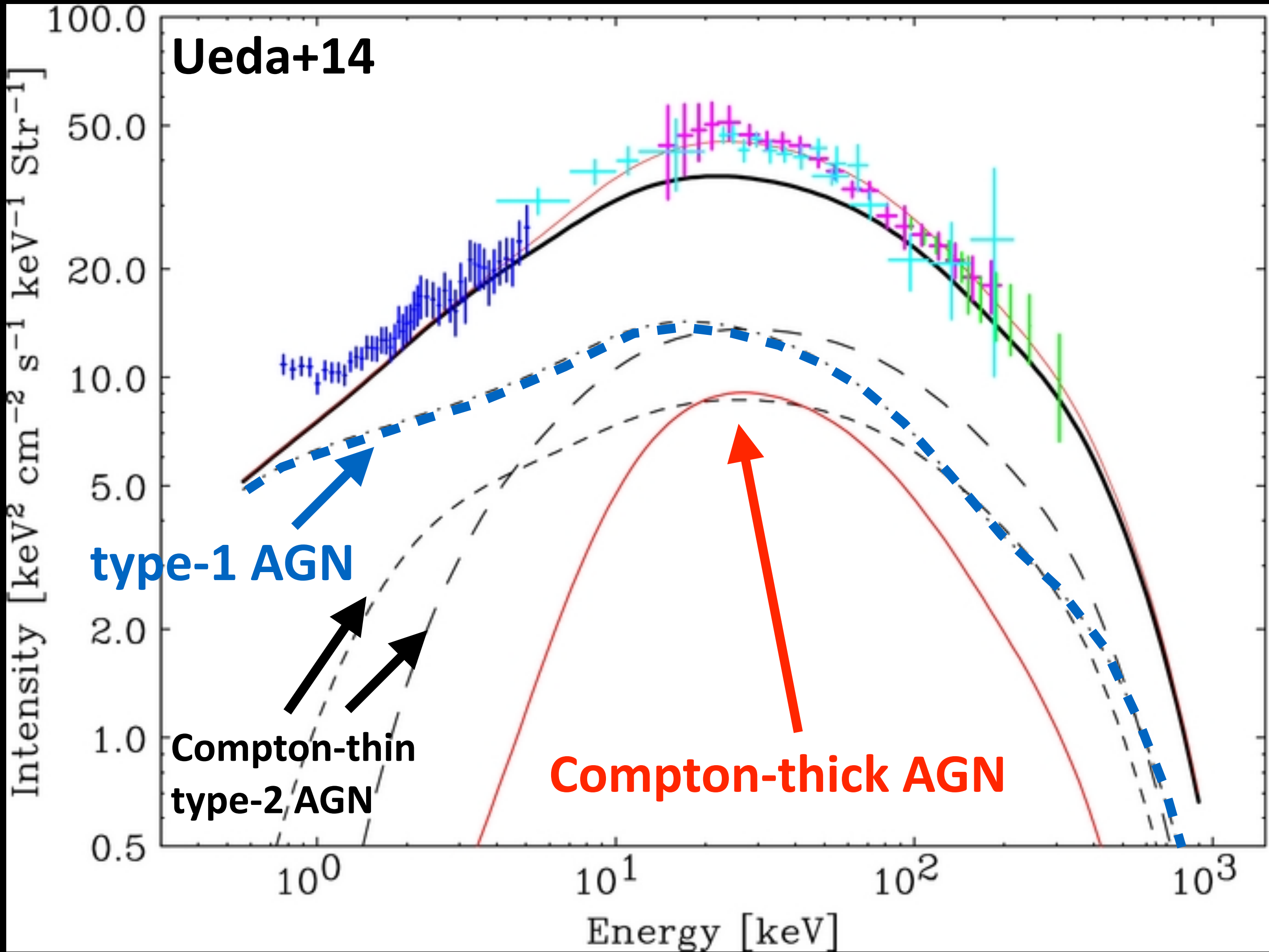
Q. How much do we know the (averaged) dust geometry?

$$C_{\mathrm{T}}(\mathrm{dust}) \propto L_{\mathrm{IR}}(\mathrm{AGN})/L_{\mathrm{bol}}(\mathrm{AGN})$$

Our Goal: Obtaining C_T(dust) using the complete AGN sample

Most of AGN are obscured

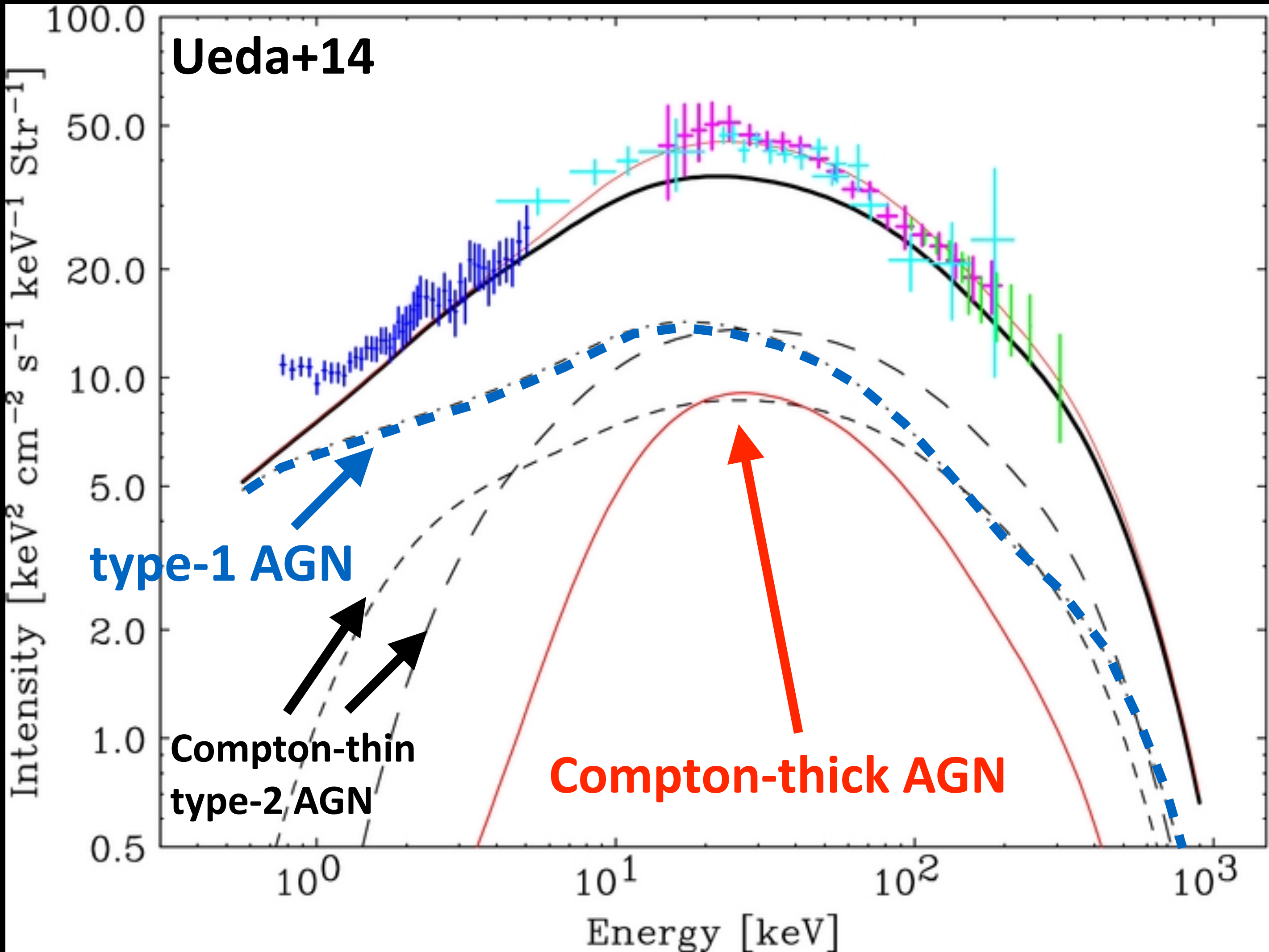
XRB indicates that most of AGN are obscured



☑ energy density peaks at **~30 keV**

Most of AGN are elusive (=obscured)

XRB indicates that most of AGN are obscured

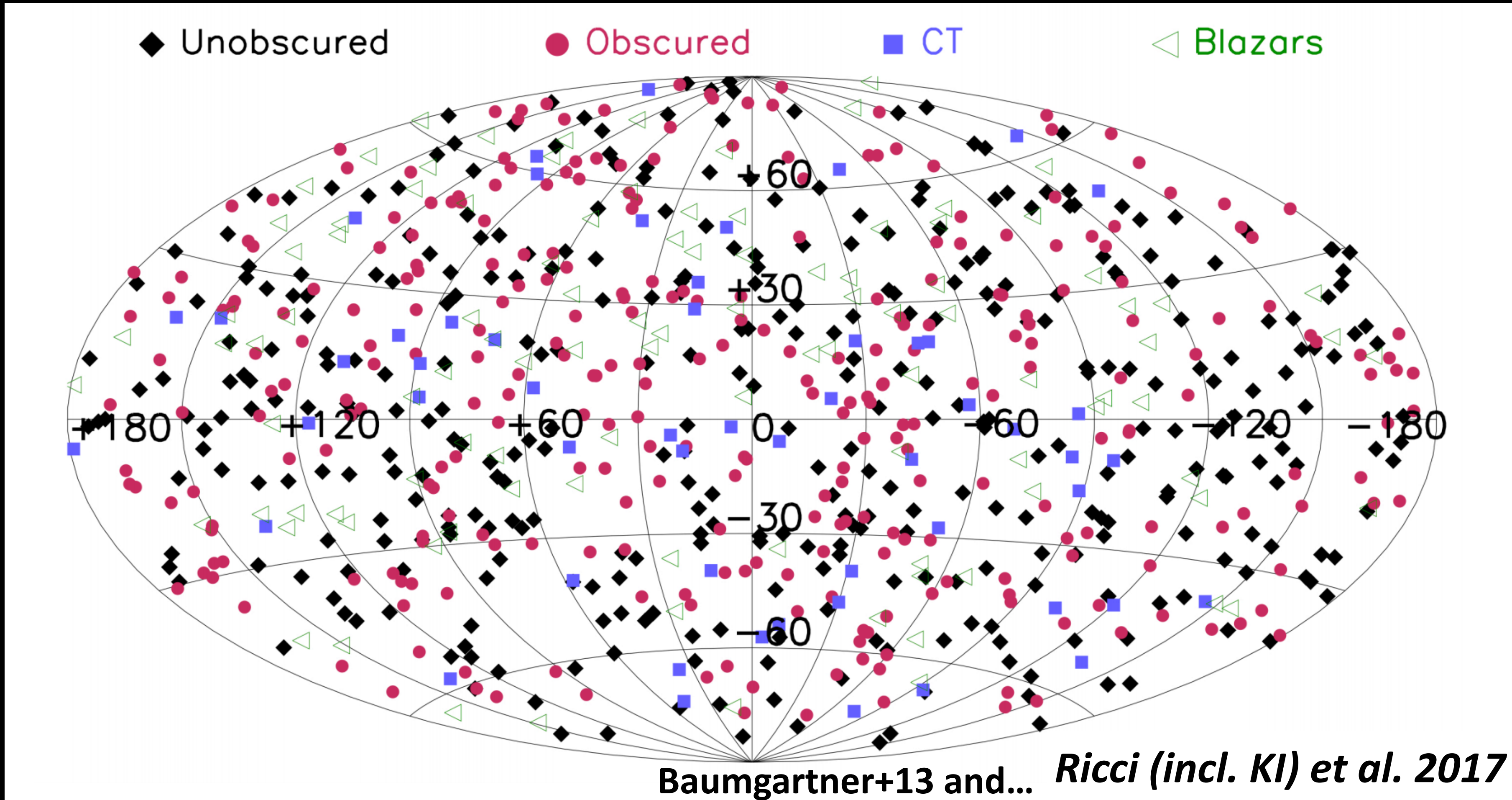


- ☑ energy density peaks at **~30 keV**
- ☑ **E>10 keV:** best energy band to detect obscured (log N_H>22) AGN

Swift/BAT AGN (14-195 keV)

70 month catalog: 836 AGN (728 non-blazars)

FYI, 105 month catalog is public ***(see Oh et al., '18) and 158 month catalog will be out in a year?***



☑ most complete up to $\log N_H$=24.0 in the local Universe

(Koss+16; Ricci+15)

☑ **606 out of 728 have z info and are located at |b|>10°**

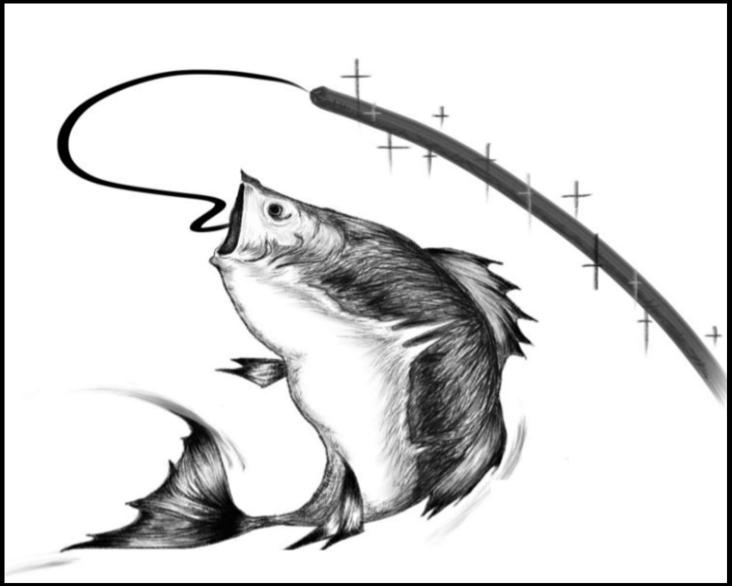
BASS

BASS=BAT AGN Spectroscopic Survey

Multi-wavelength Follow-up of BAT-AGN

co-lead by M. Koss, ***C. Ricci***, B. Trakhtenbrot, ***K. Oh***

- ☑ X-ray (L_X, N_H, Γ) Ricci et al. (2017)
- ☑ Optical Spec (M_{BH}, λ_{Edd}) Koss et al. (2017)
- ☑ NIR Spec (σ, M_{BH}) Lamperti et al. (2017)



by Courtesy of K. Oh

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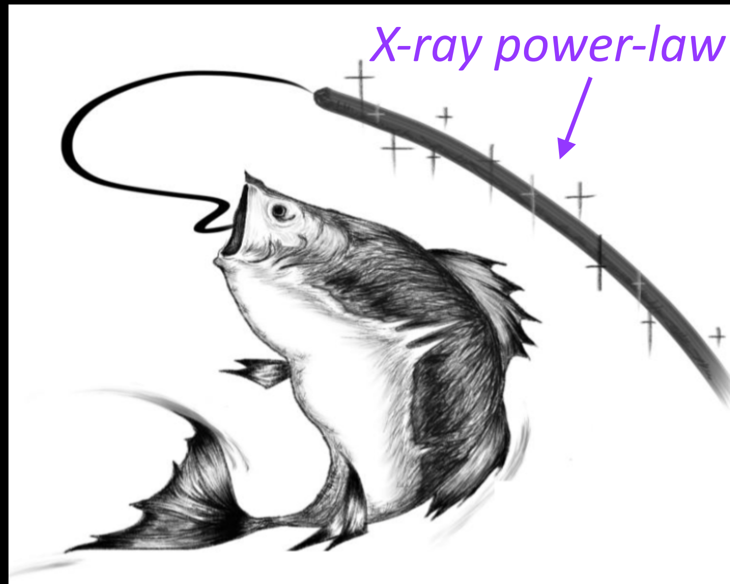

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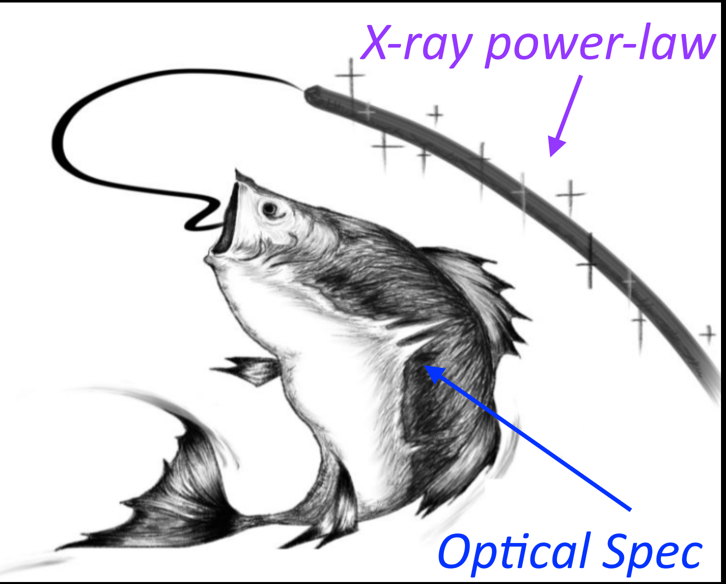


by Courtesy of K. Oh

More studies and Data, see <u>BASS website!</u>

Today's topic

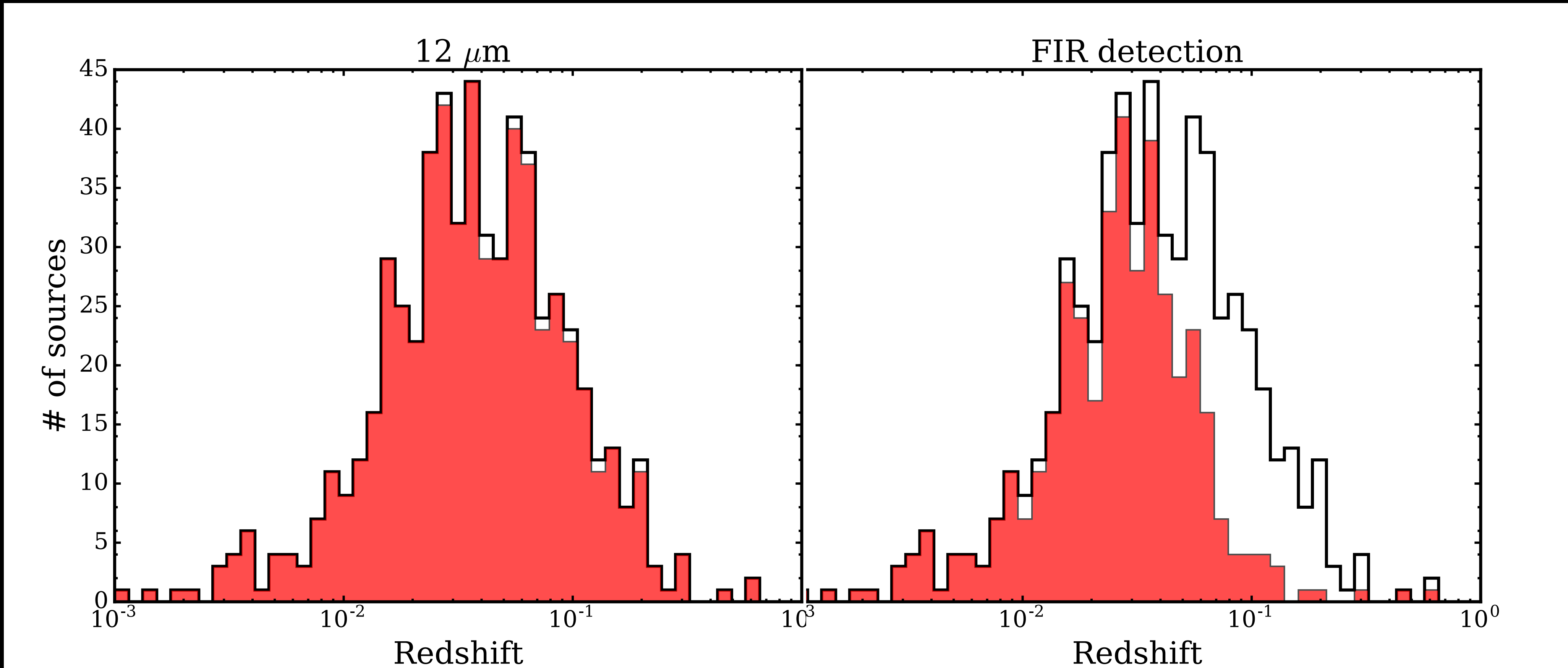
☑ IR catalog (3-500 um) ***Ichikawa et al. (2017a), ApJ, 835, 74***

☑ IR SED Decomposition; ***Ichikawa et al. (2019), ApJ, 870, 31***

IR counterparts of BAT AGN

☑ **3-500 um IR data from WISE, AKARI, IRAS, and Herschel**

(see Ichikawa+17 for more details)



☑ **601/606 MIR (, NIR) and 402/606 FIR counterparts**

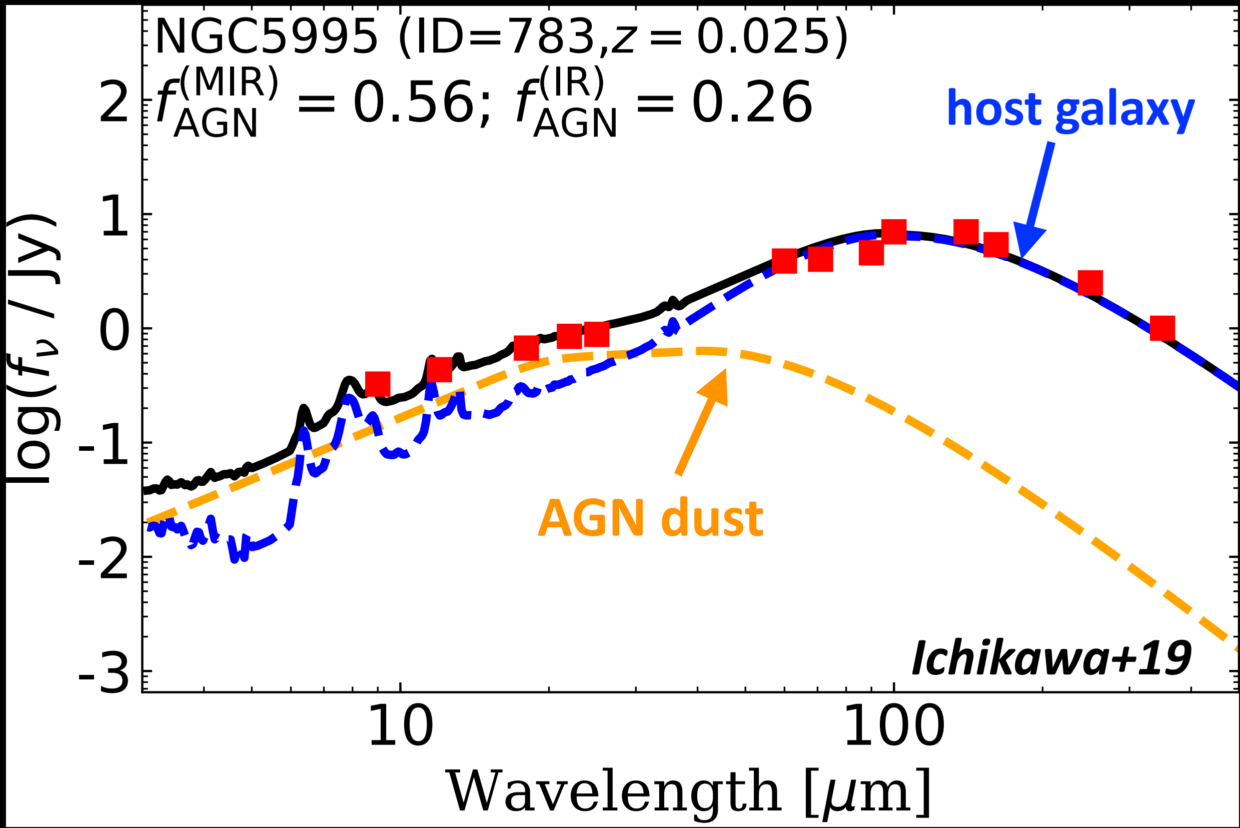
☑ **suitable for the AGN dust/host galaxy studies**

☑ **IR Data is already public.** http://iopscience.iop.org/0004-637X/835/1/74/suppdata/apjaa5154t1_mrt.txt

SED Decomposition in IR bands

☑ **SED Decomposition is done using simple AGN/(SB+stellar) templates**

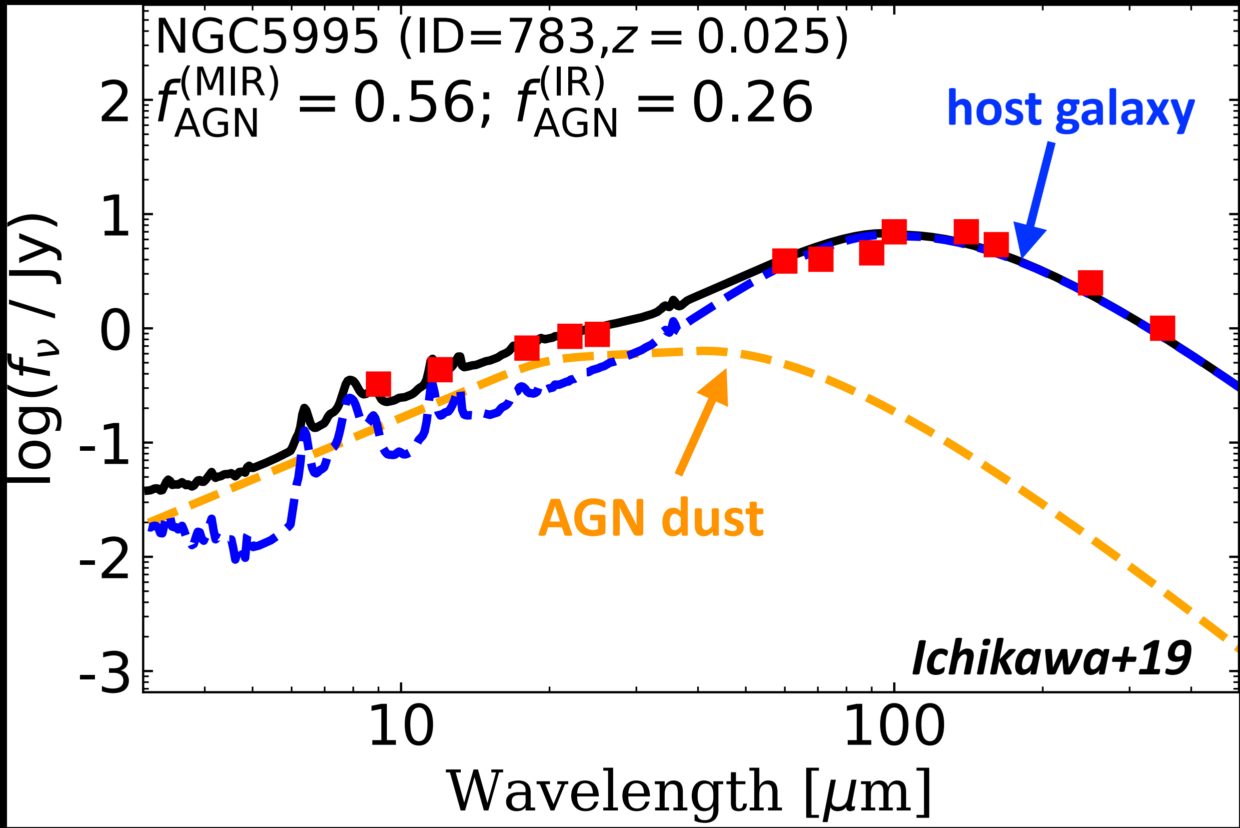
(see Mullaney+11 and Ichikawa+19 for more details)



SED Decomposition in IR bands

☑ **SED Decomposition is done using simple AGN/(SB+stellar) templates**

(see Mullaney+11 and Ichikawa+19 for more details)



☑ **SED decomposition: 587/606 sources**

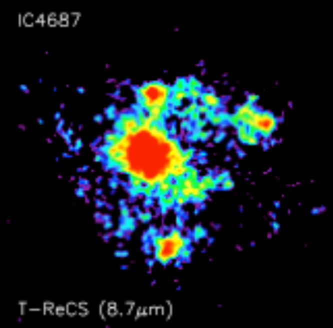
☑ **Disentangling AGN/host galaxy (SB+stellar) component**

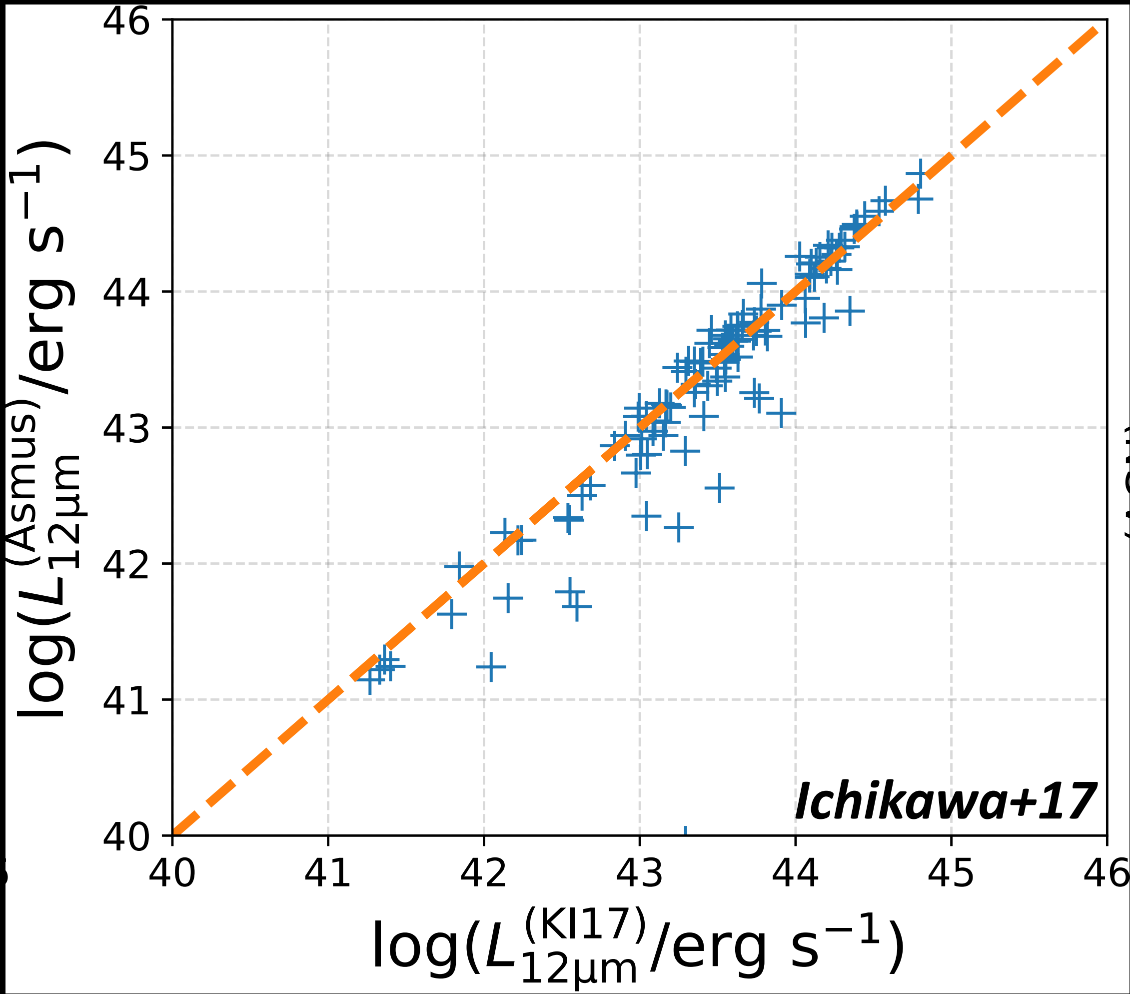
=> AGN IR emission w/o host galaxy contamination

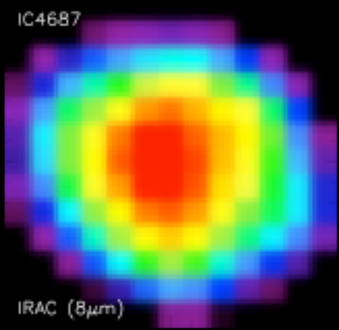
FYI, All info incl. IR SEDs, decomposed SEDs, M_{BH}, $L_{x,\ bol}$ are now public

Comparison with high-spatial resolution observations

High spatial. resol. obs.
(Asmus+14,+15)







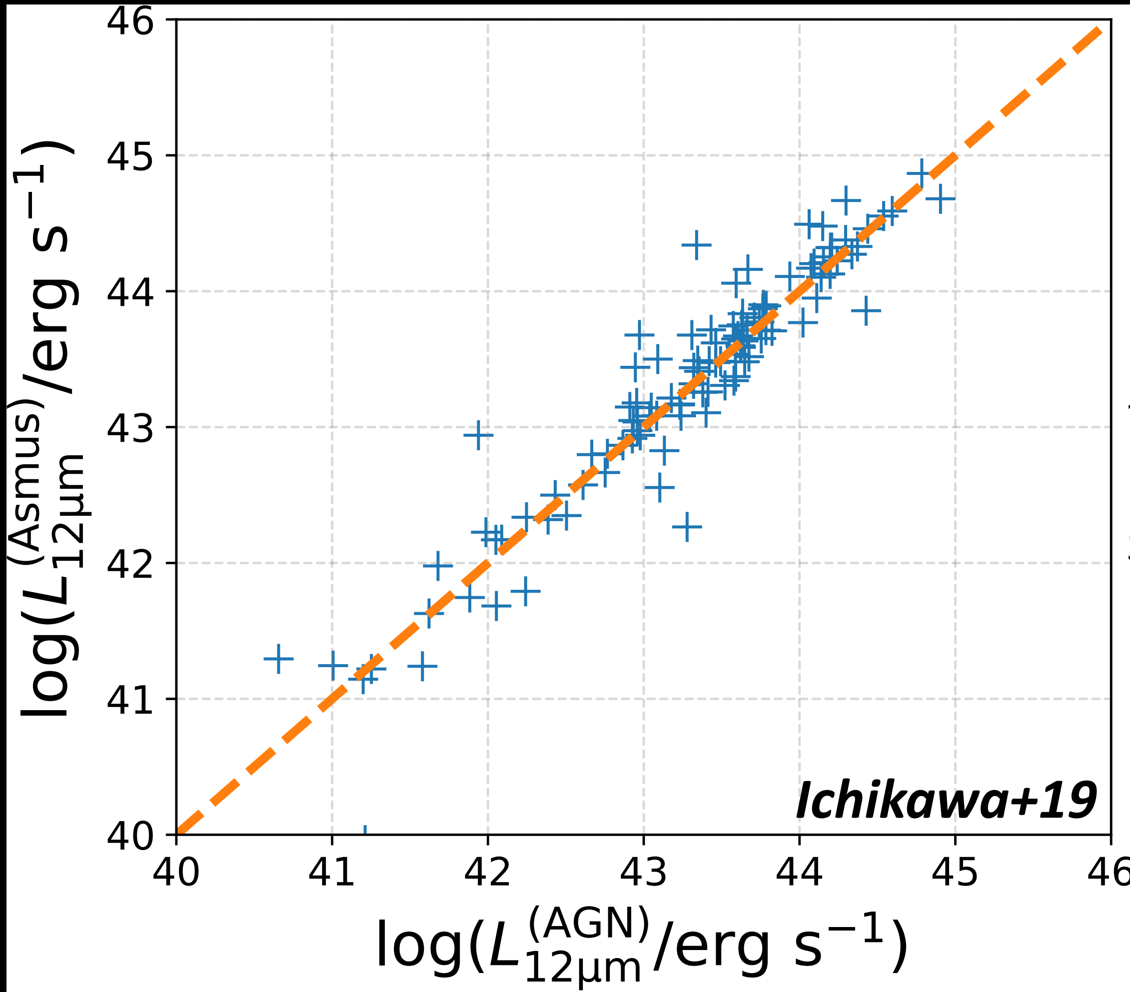
L_{12um} "Before" SED decomposition

☑ **$L_{12um}^{(KI17)}$ >= $L_{12um}^{(Asmus)}$**

Comparison with high-spatial resolution observations

☑ SED Decomposition works well!

High spatial. resol. obs.



L_{12um} "*after*" SED decomposition

☑ **SED decomposition reproduces L_{12um} of 0."3-0."7 scale high spatial resolution observations (Asmus+14;15)**

L_{IR}(AGN) vs. $L_{14\text{-}150keV}$

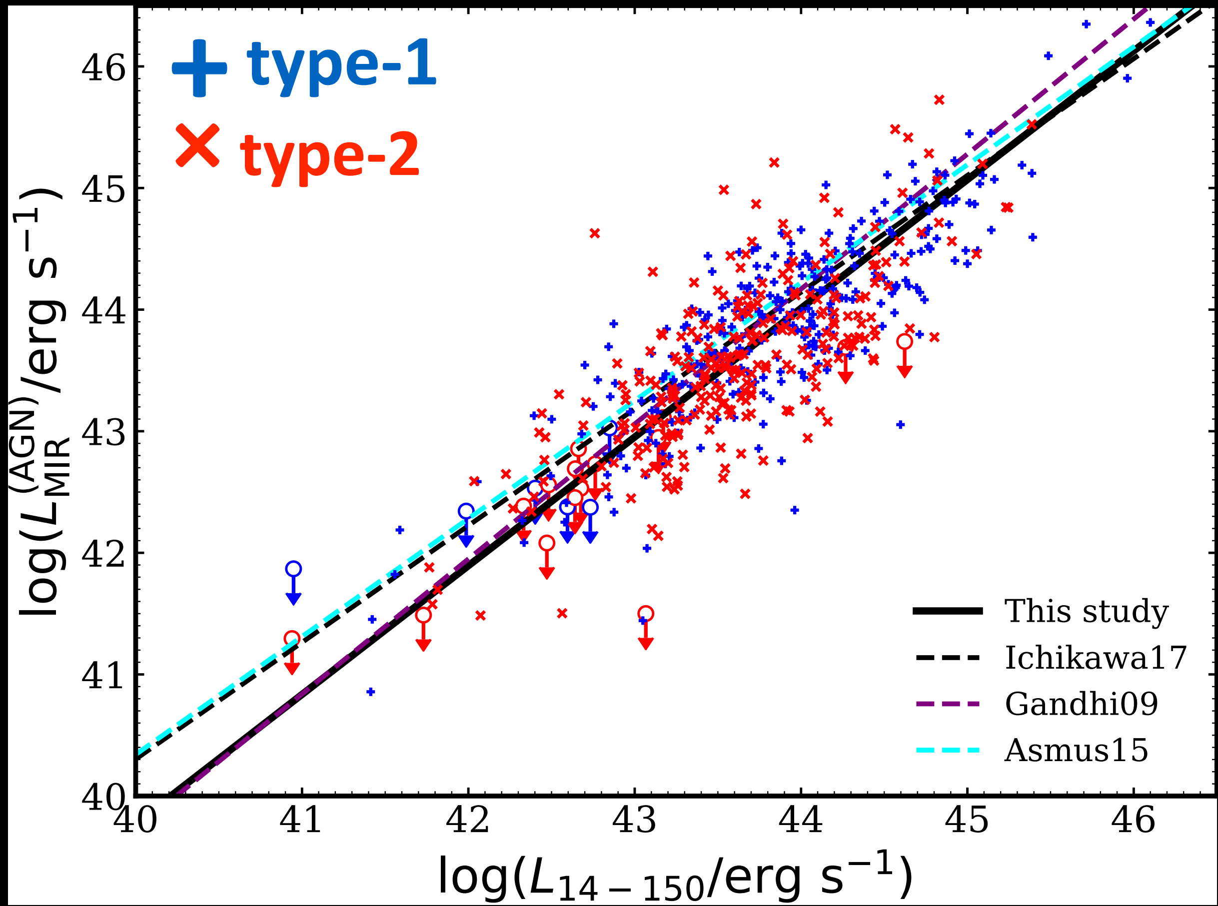
Ichikawa+19a

Our study

L_{MIR}/L_X (type-1) ~ L_{MIR}/L_X (type-2)

↓

MIR emission: isotropic

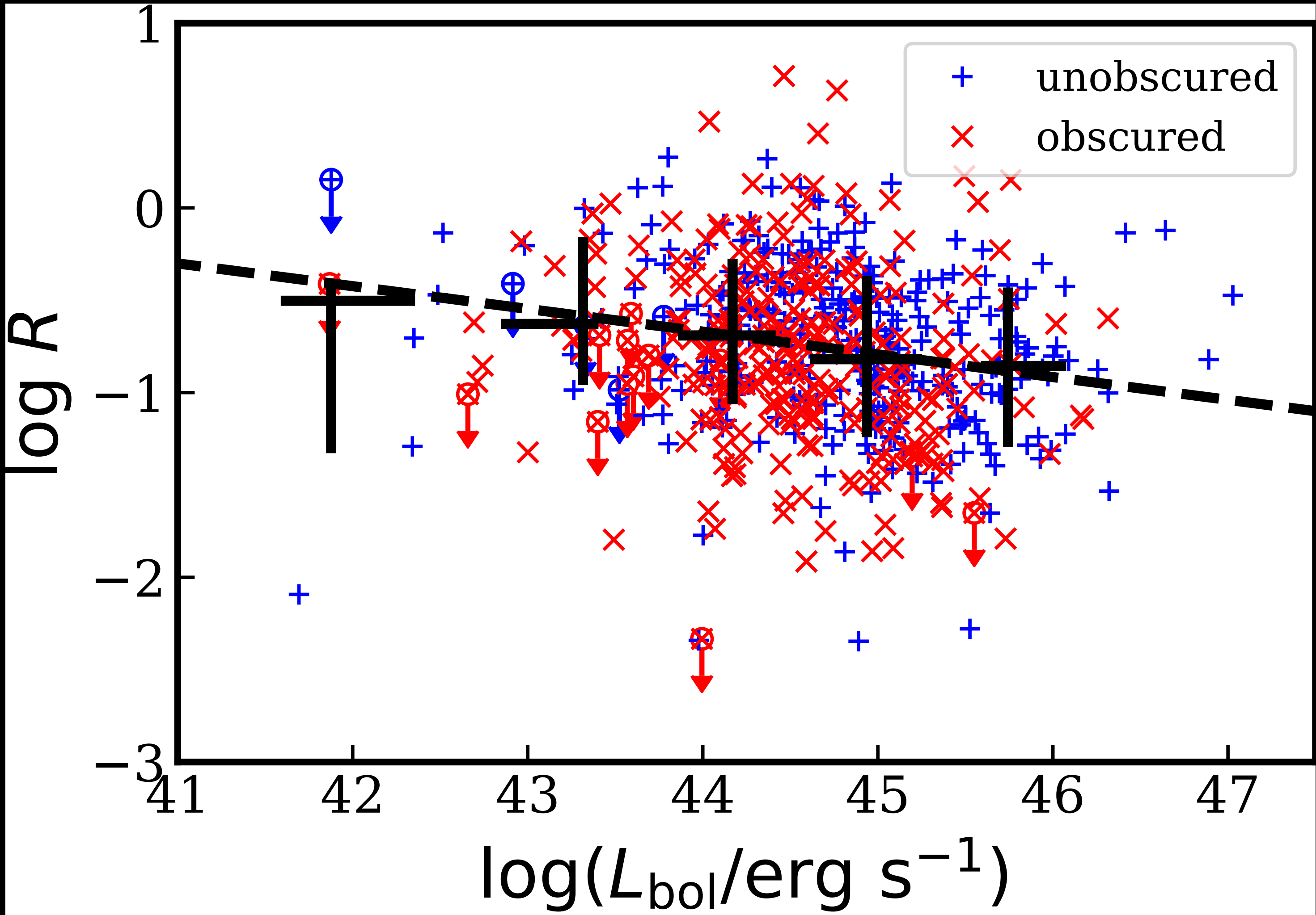


log L_{MIR} ∝ 1.06 log L_X ∴ slope b=1.06 (+/-0.03)

☑ **b=0.9-1.1** from local/X-ray selected AGN

(e.g., Gandhi+09; **Ichikawa+12,+17**; Asmus+15; Mateos+15)

L_{bol} dependence of $R = L_{IR}(AGN)/L_{bol}$



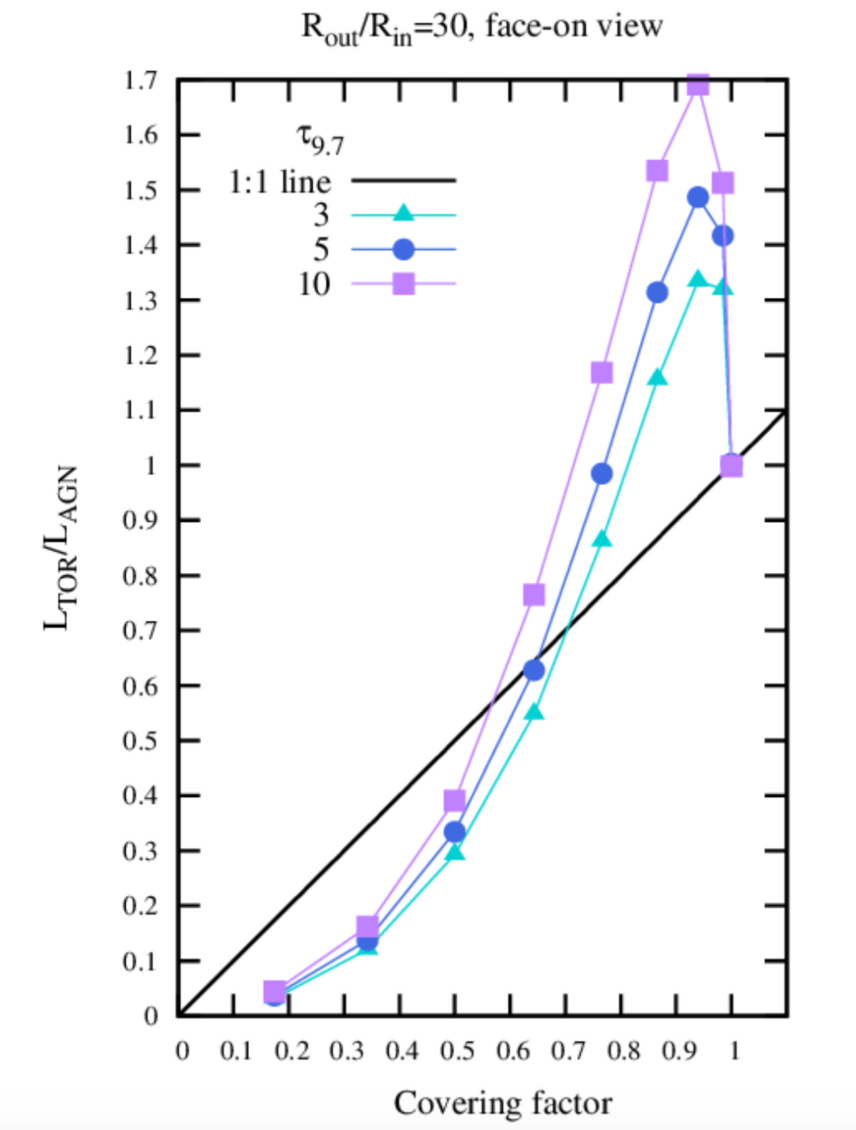
Ichikawa+19a

☑ Very shallow L_{bol} dependence w/ log R = 4.5 - 0.12 log L_{bol}

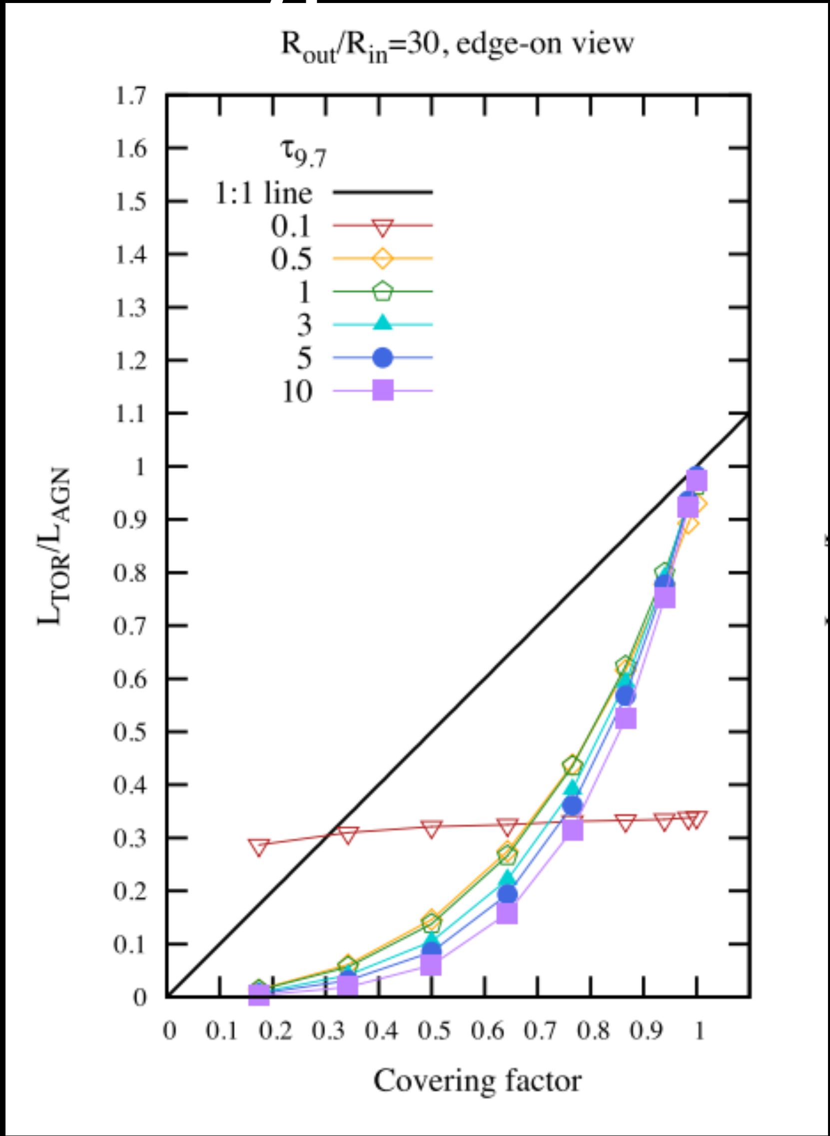
R=L_{IR}(AGN)/L_{bol} => C_T(dust)

L_{IR}(AGN) /L_{bol} vs. C_T (see Stalevski+16)

type-1 AGN



type-2 AGN



Dust Covering factor (C_T) vs. L_{bol}

L_X => L_{bol} (const) and **L_{IR}(AGN) /L_{bol} => C_T** (see Stalevski+16)

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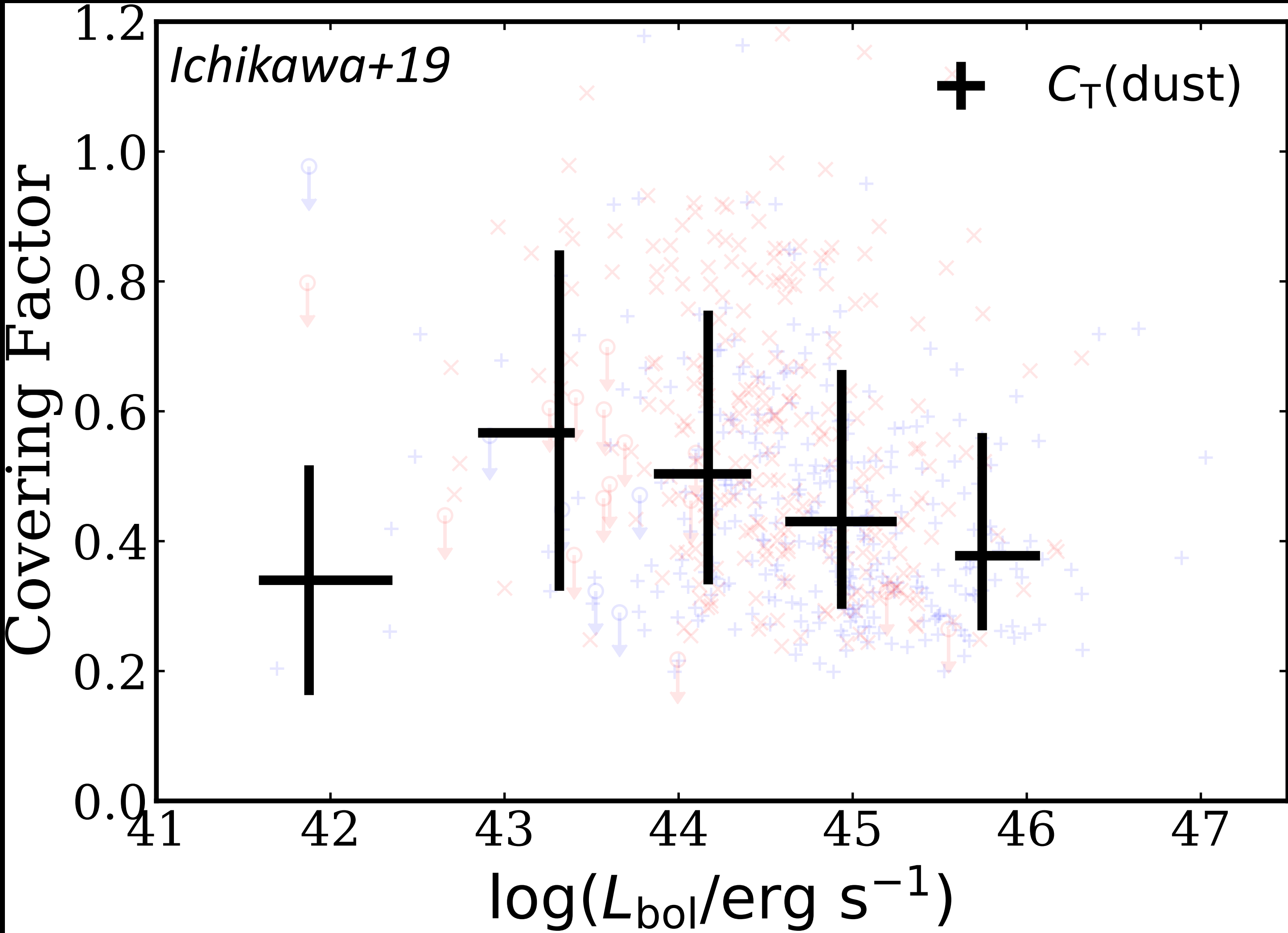
L_X => L_{bol} (const) and **L_{IR}(AGN) / L_{bol} => C_T** (see Stalevski+16)

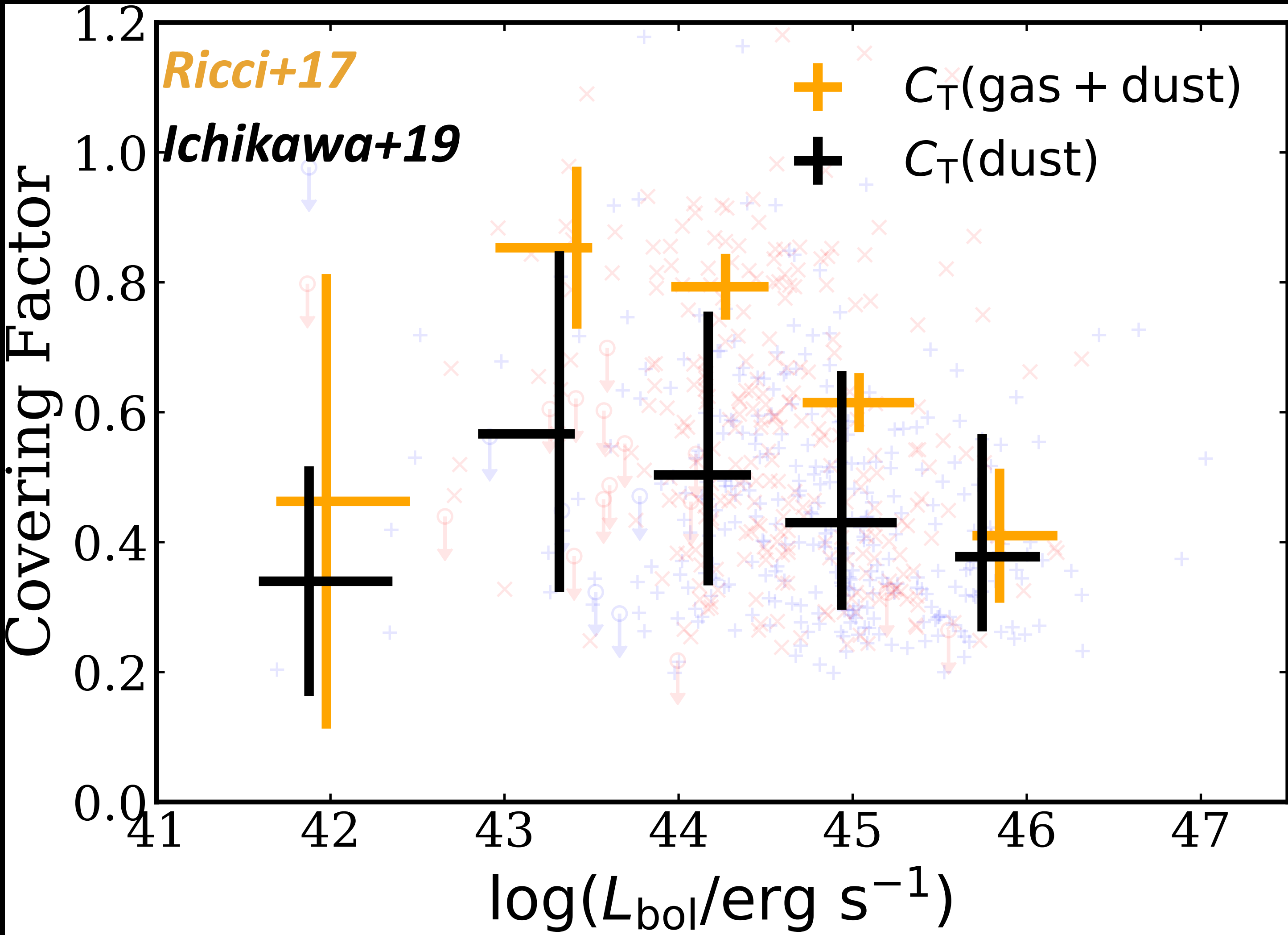


☑ **C_T (dust) : 0.4-0.6,** very weak or almost independent of L_{bol}

(see also Merloni+14, Netzer+16, Stalevski+16, Mateos+17)

Dust Covering factor (C_T) vs. L_{bol}

Lx => L_{bol} (const) and **L_{IR}(AGN) /L_{bol} => C_T** (see Stalevski+16)

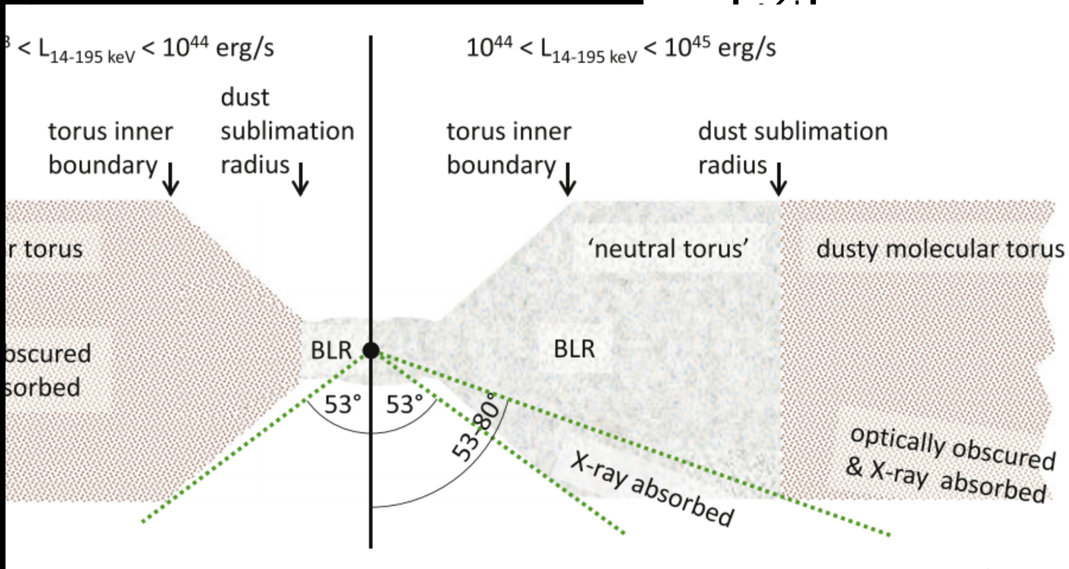


☑ **C_T(dust) < C_T (dust+gas) <= obtained from X-ray obs.**

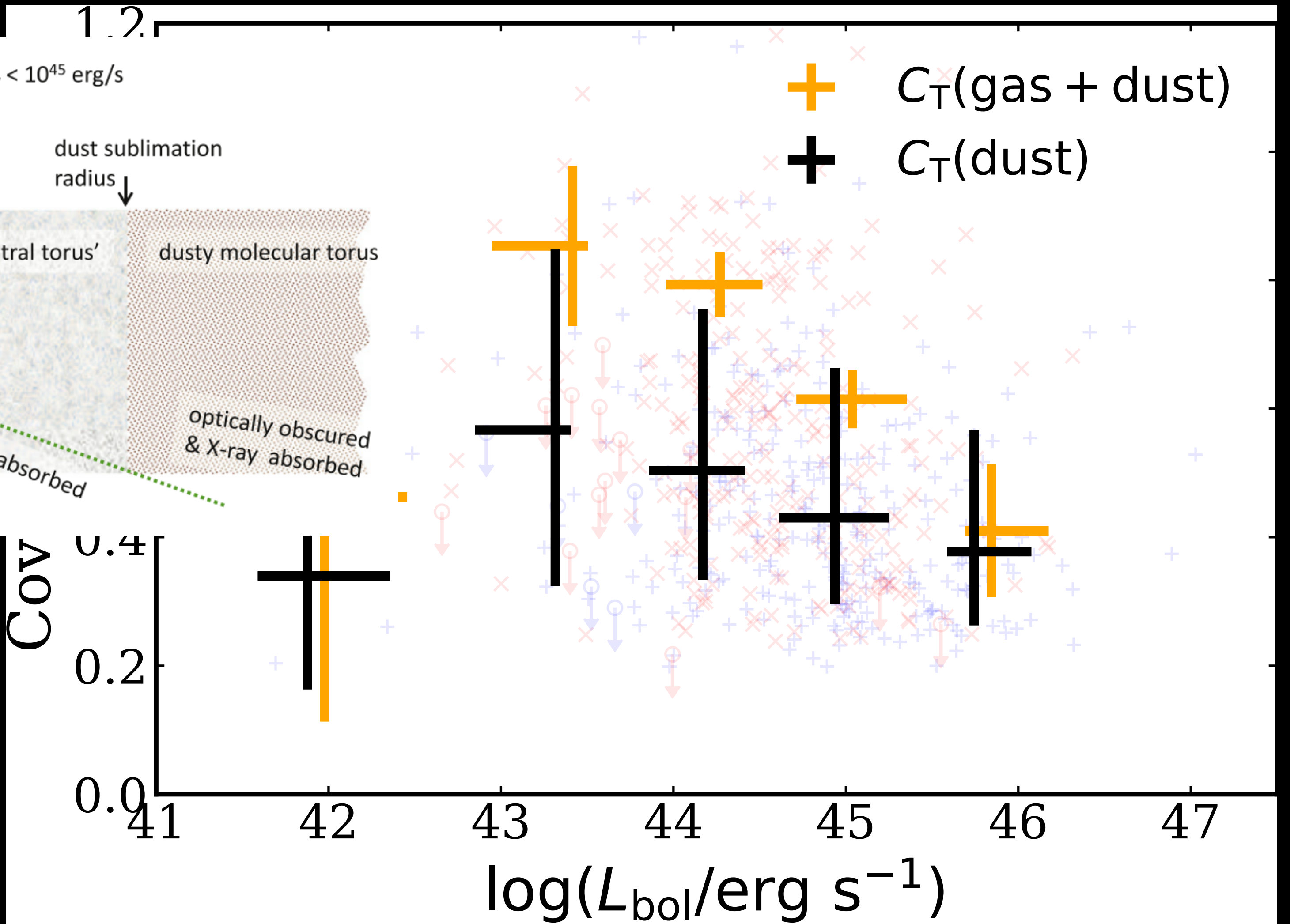
☑ **There is a dust-free (X-ray) obscuring region**

Dust Covering factor (C_T) vs. L_{bol}

L_X => L_{bol} (const) and **L_{torus}/L_{bol} => C_T (dust)** (see Stalevski+16)



Davies+15



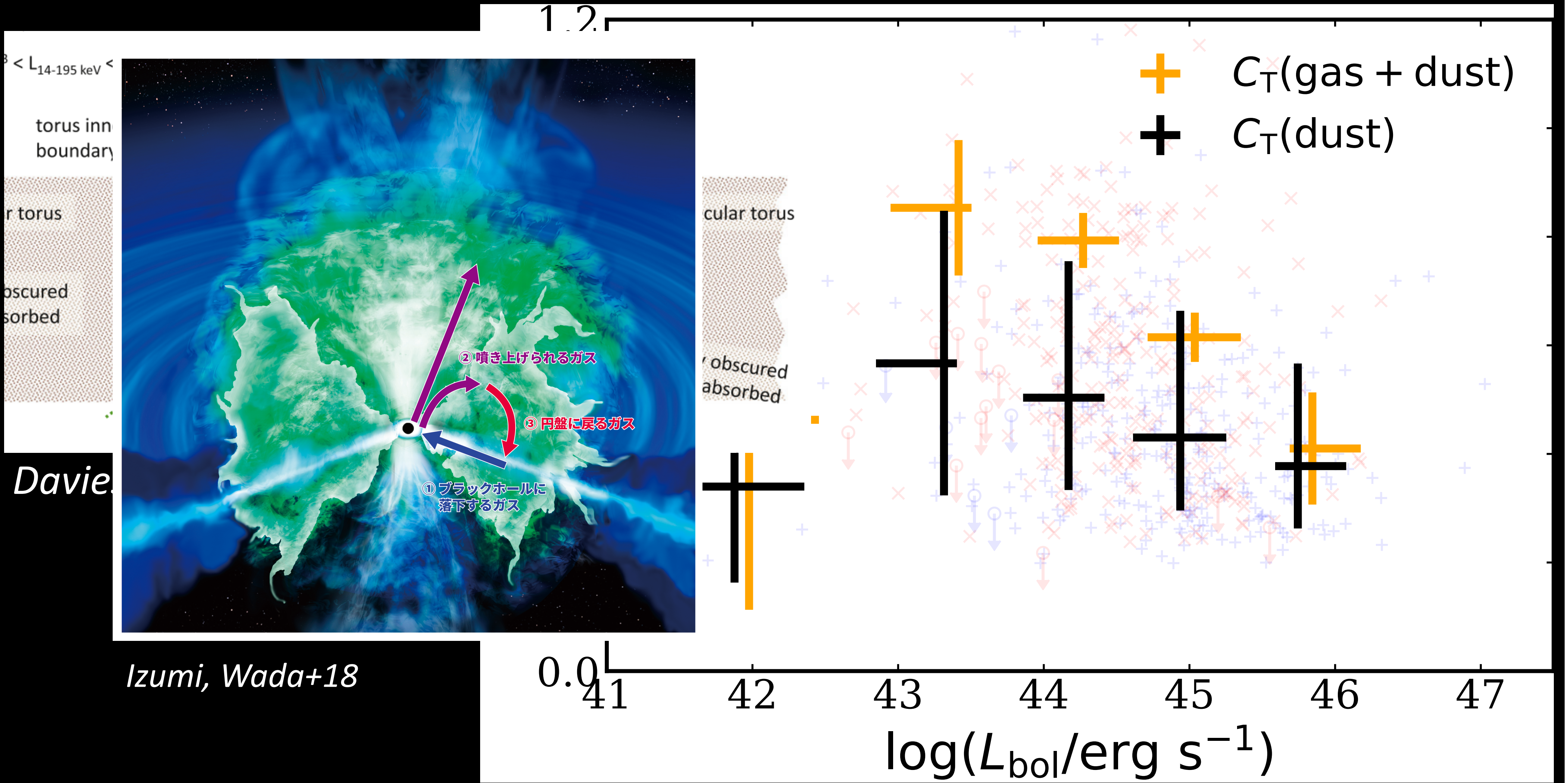
☑ **C_T(dust) < C_T (dust+gas) <= obtained from X-ray obs.**

☑ **There is a dust-free (X-ray) obscuring region (in BLR?)**

(see also Markowitz+14; Davies+15; Liu+18)

Dust Covering factor (C_T) vs. L_{bol}

Lx => L_{bol} (const) and **L_{torus}/L_{bol} => C_T (dust)** (see Stalevski+16)



Izumi, Wada+18

☑ **C_T(dust) < C_T (dust+gas) <= obtained from X-ray obs.**

☑ **There is a dust-free (X-ray) obscuring region (in BLR?)**

(see also Markowitz+14; Davies+15; Liu+18)

Summary

Swift/BAT (14-195 keV) AGN catalog

- ☑ suitable sample of an unbiased census of AGN
- ☑ **BASS provides L_X, N_H, M_{BH}, and λ_E**
- ☑ **almost complete 3-500 um IR catalog (601/606 at MIR, 402 at FIR, see Ichikawa+17)**

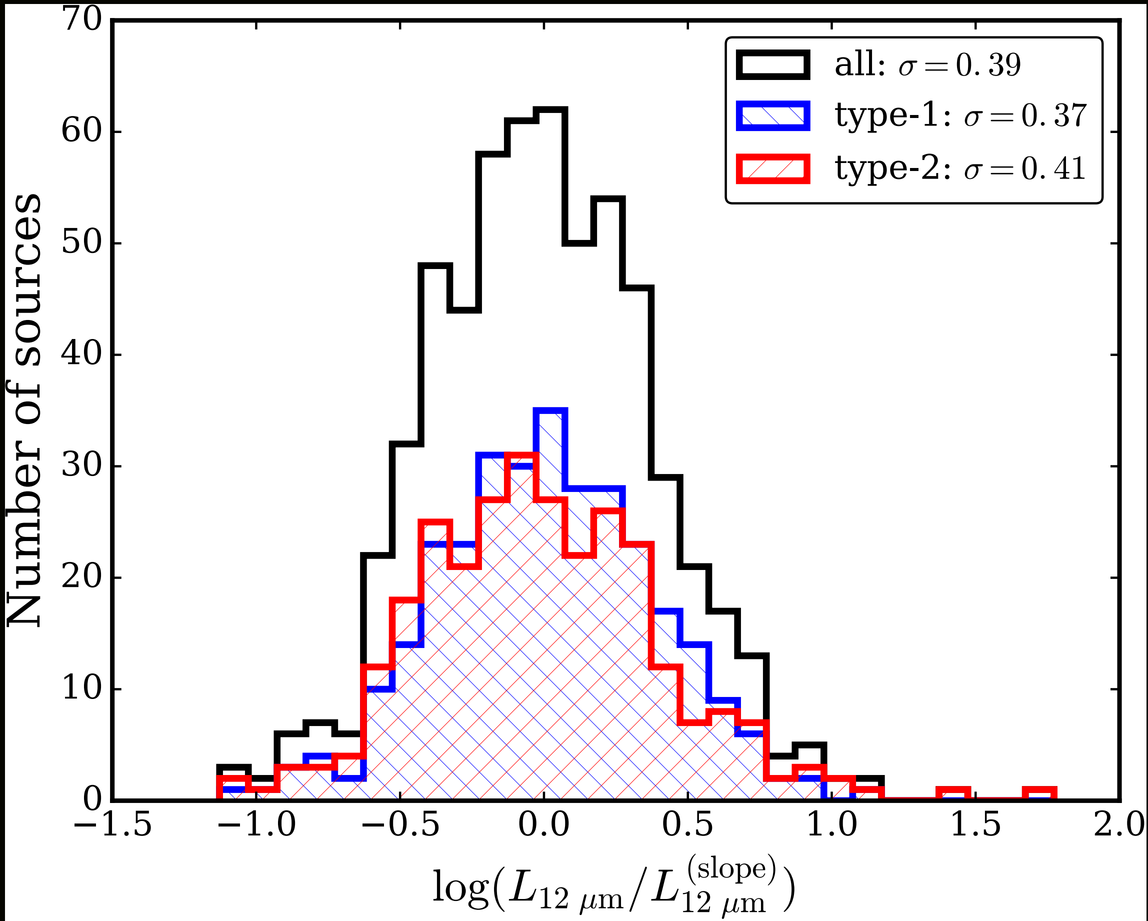
IR and X-ray properties of BAT AGN

- ☑ C_T(dust) < C_T (dust+gas) => dust-free obscuring region
- ☑ **C_T (obscured) is (on average) always larger than C_T (unobscured)**

see Ichikawa et al. (2017, 2019) for more details

Appendix

Consistency with dust polar emission



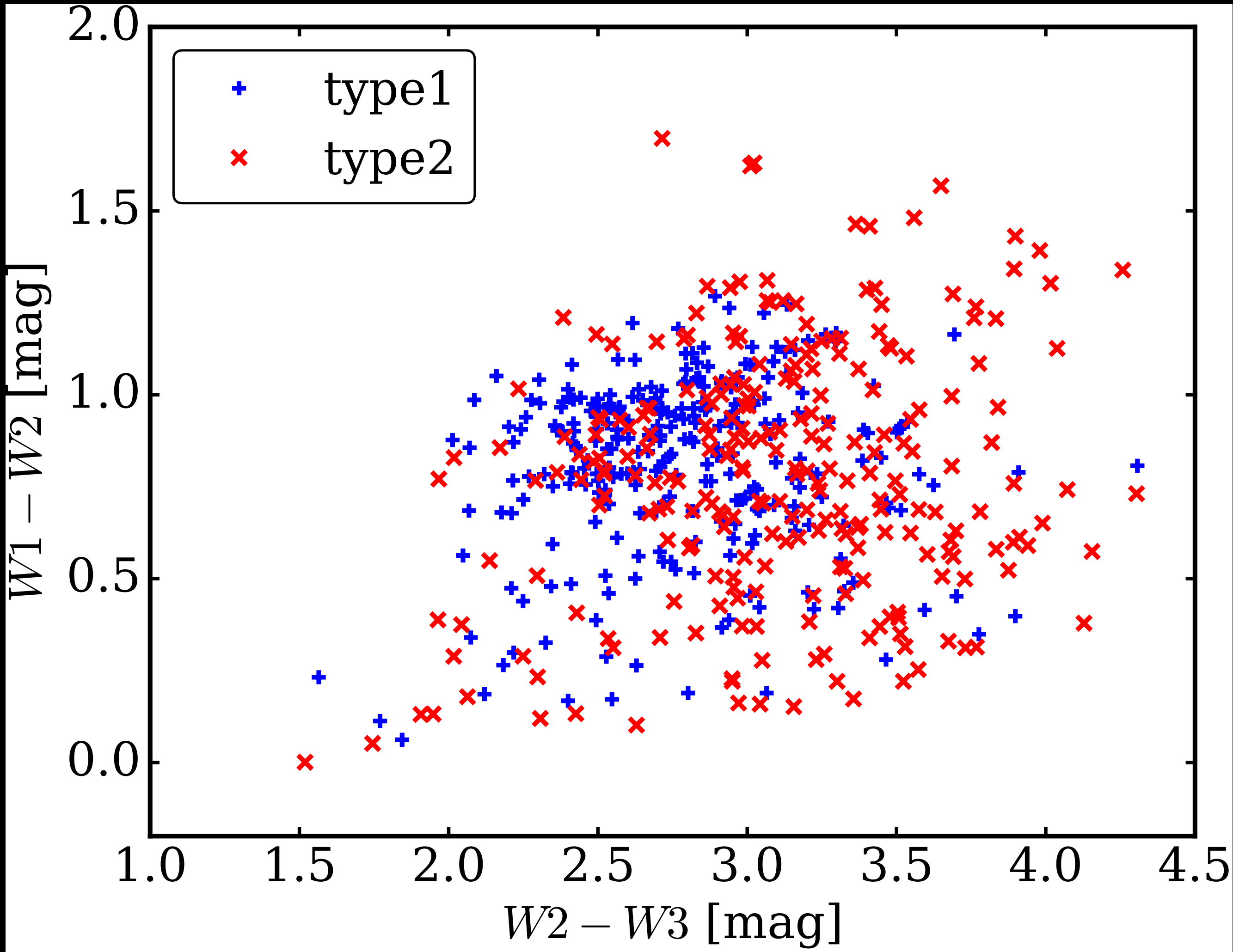
☑ **type-1/-2 has same distribution => isotropic emission**

☑ **consistent with MIR polar emission or fountain model**

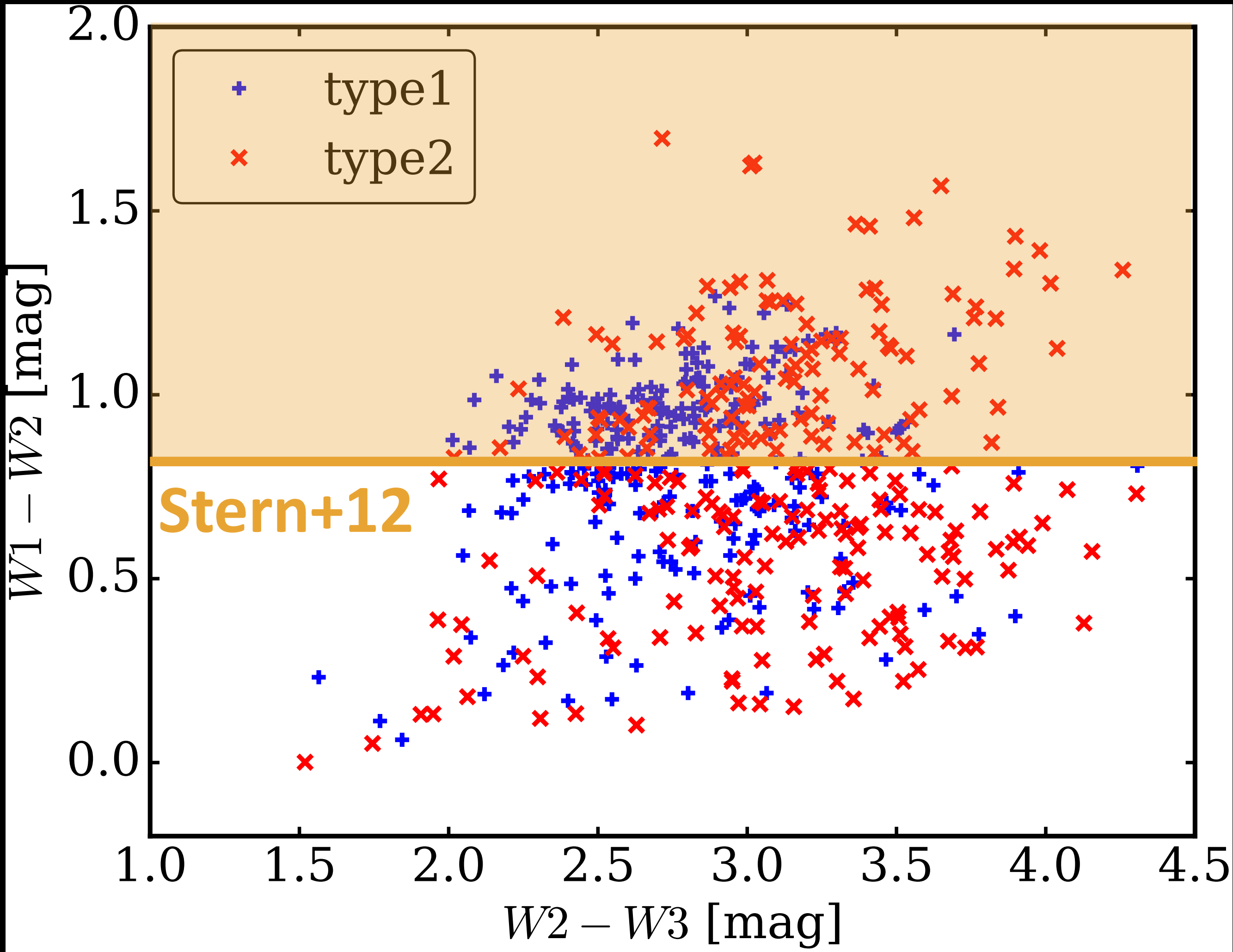
obs: Honig+13,+14, see also Asmus+16
model: Wada 12, Wada+16

WISE IR color-color selection of AGN

Ichikawa+17

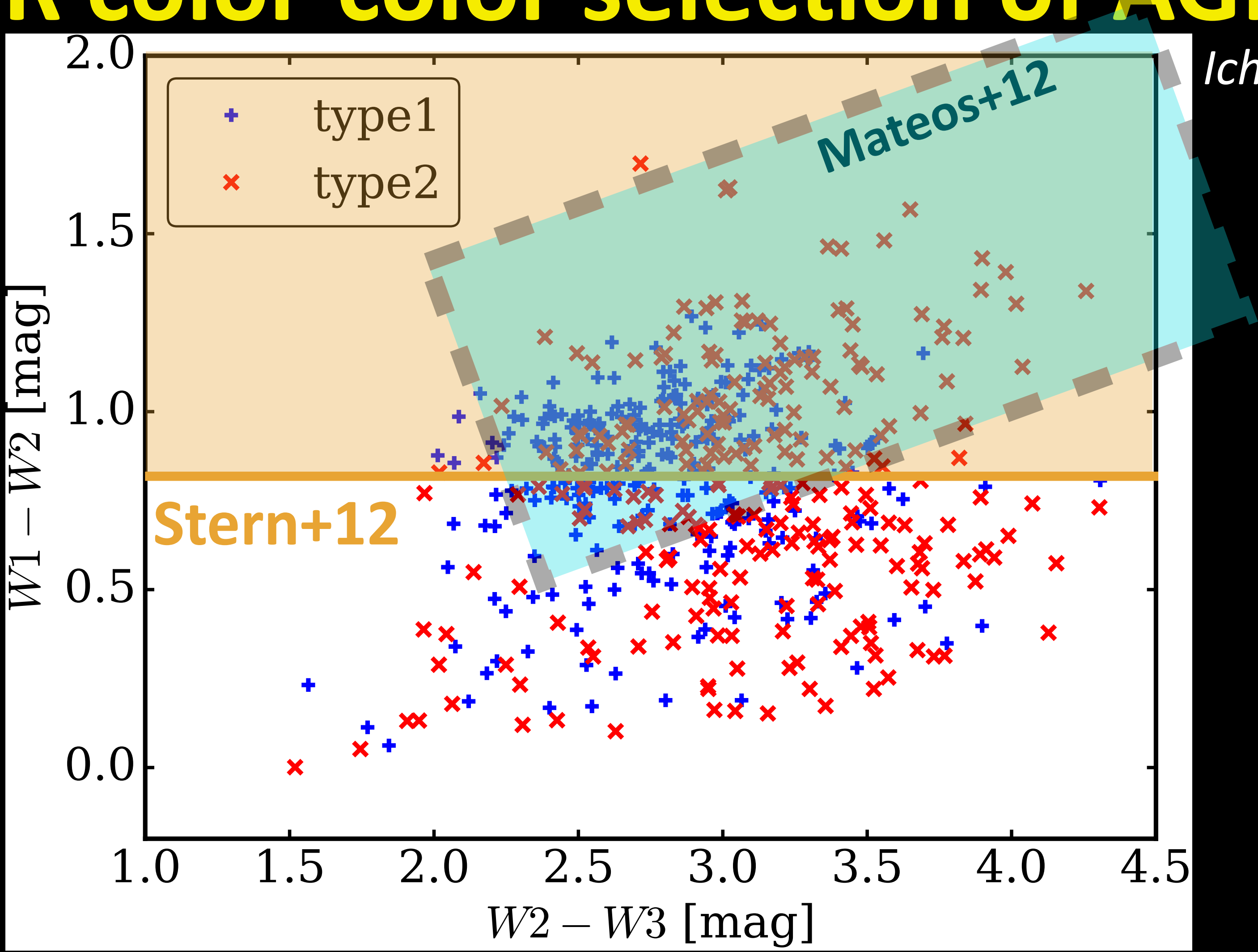


WISE IR color-color selection of AGN



Ichikawa+17

WISE IR color-color selection of AGN



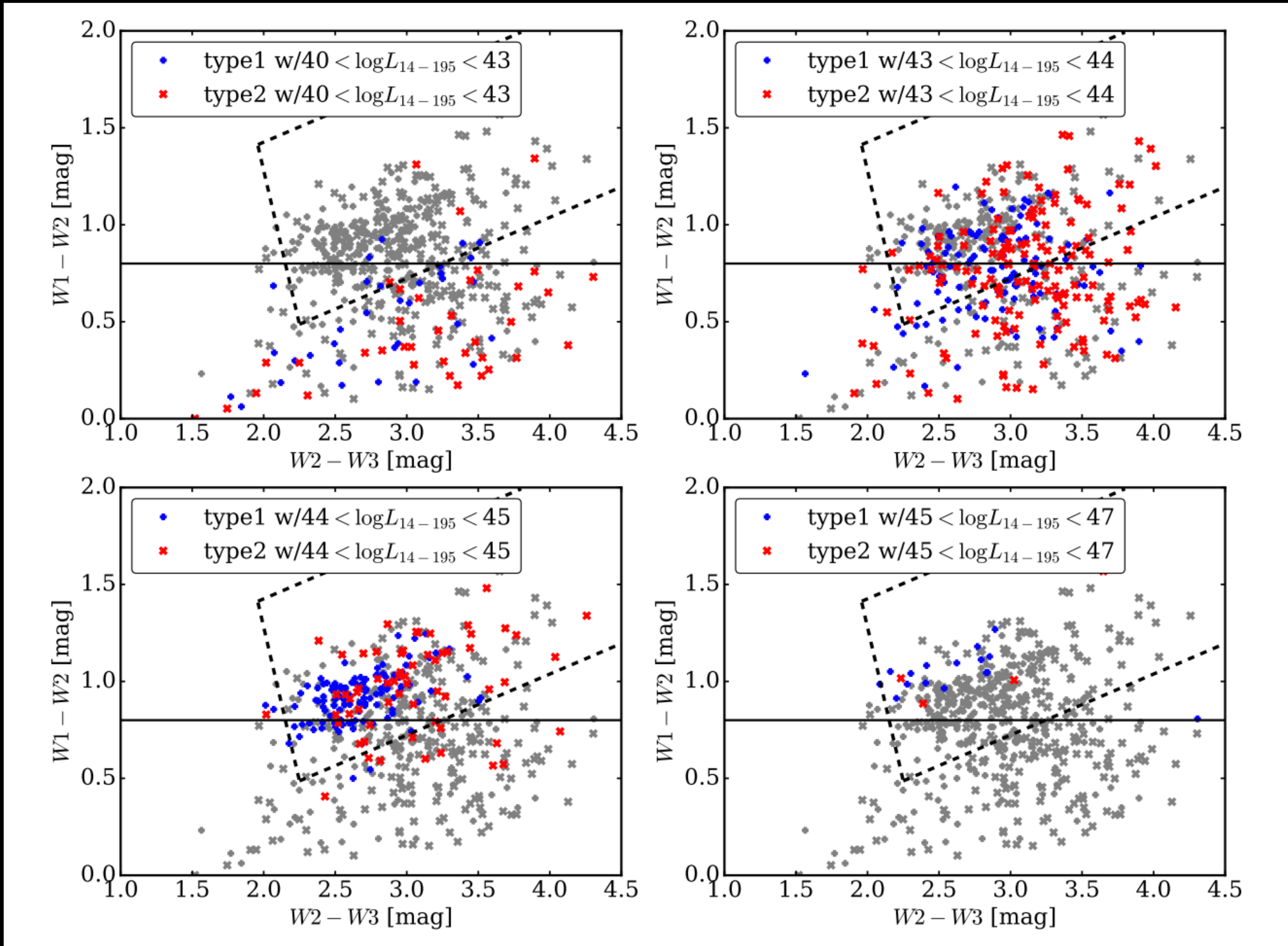
☑ **BAT**-AGN **do not always locate** at the IR selection areas of. Stern+12, Mateos+12

WISE IR color selections miss some AGN population

(see also Mateos+12, 13; Gandhi+16; Kawamuro+16; Tanimoto+16)

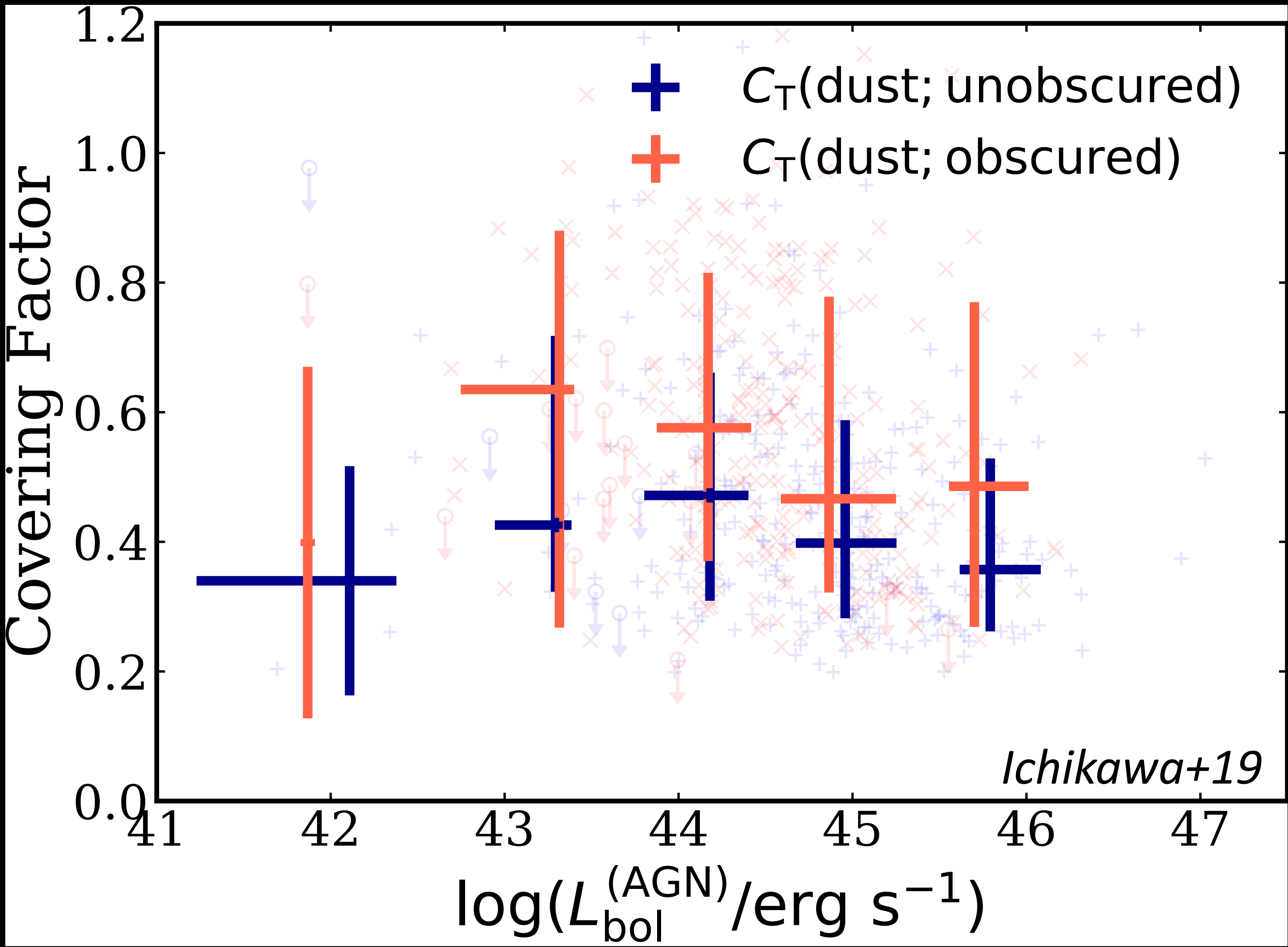
WISE IR color-color selection of AGN

Ichikawa+17



☑ **WISE IR color: insensitive to low-luminosity AGN**

Dust Covering factor (C_T) for un-/obscured AGN



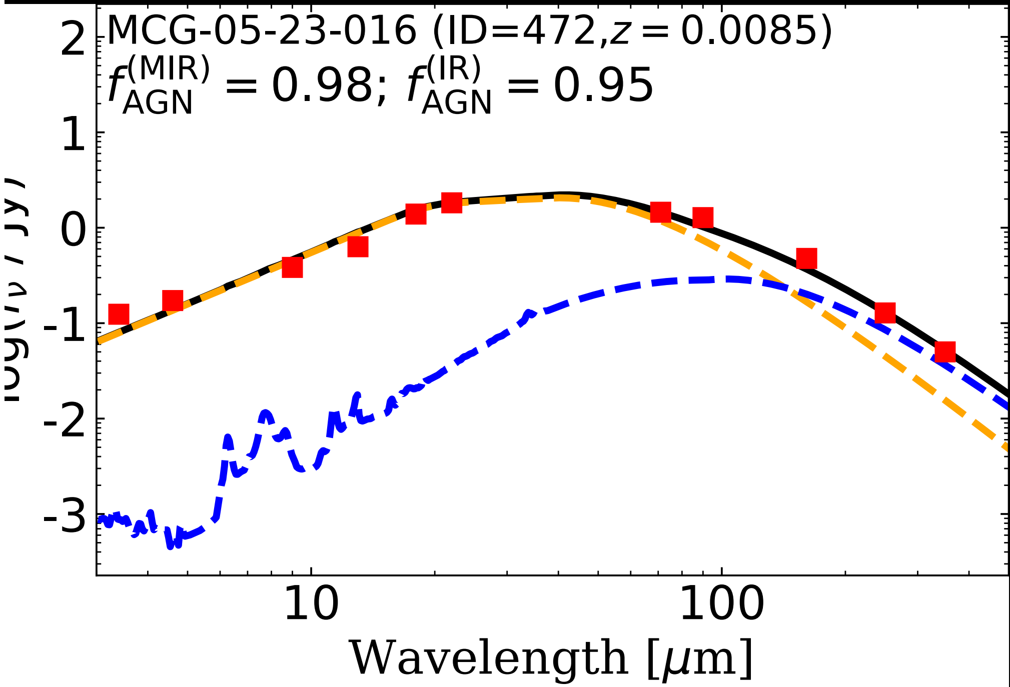
☑ **C_T (obscured) is (on average) always larger than C_T (unobscured)**

=> larger (line of sight) N_H sources tend to have larger (geometrical) C_T

(see also Ramos Almeida+09;+11, Elitzur12, Ichikawa+15, Mateos+16, and Lanz+18)

IR-Pure AGN candidates

We found 9 "IR-pure AGN" candidates



IR-Pure AGN candidates

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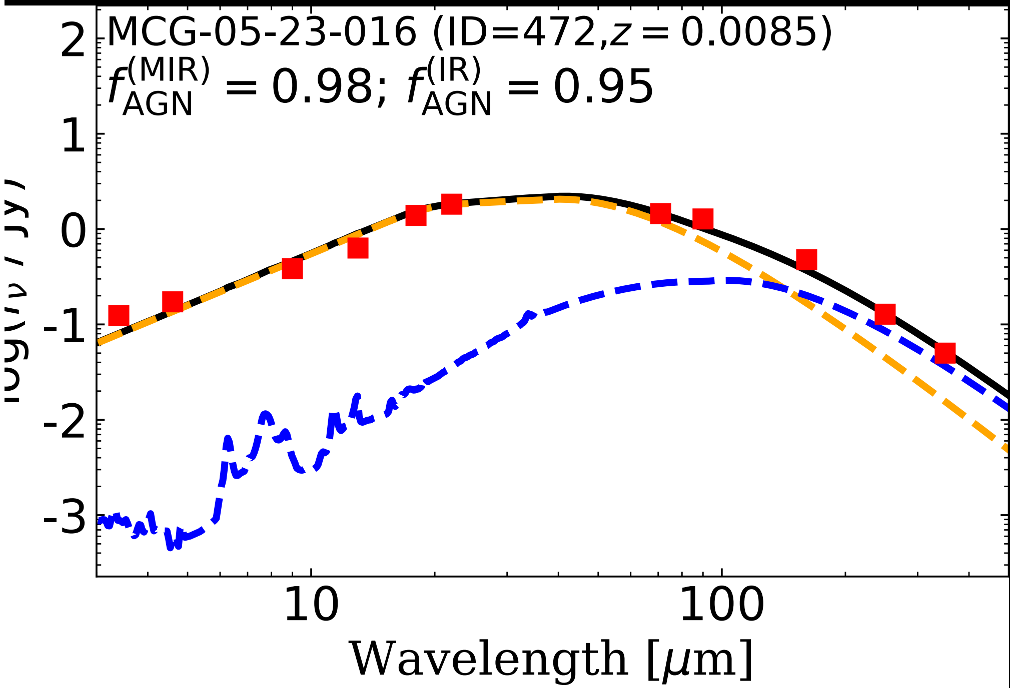
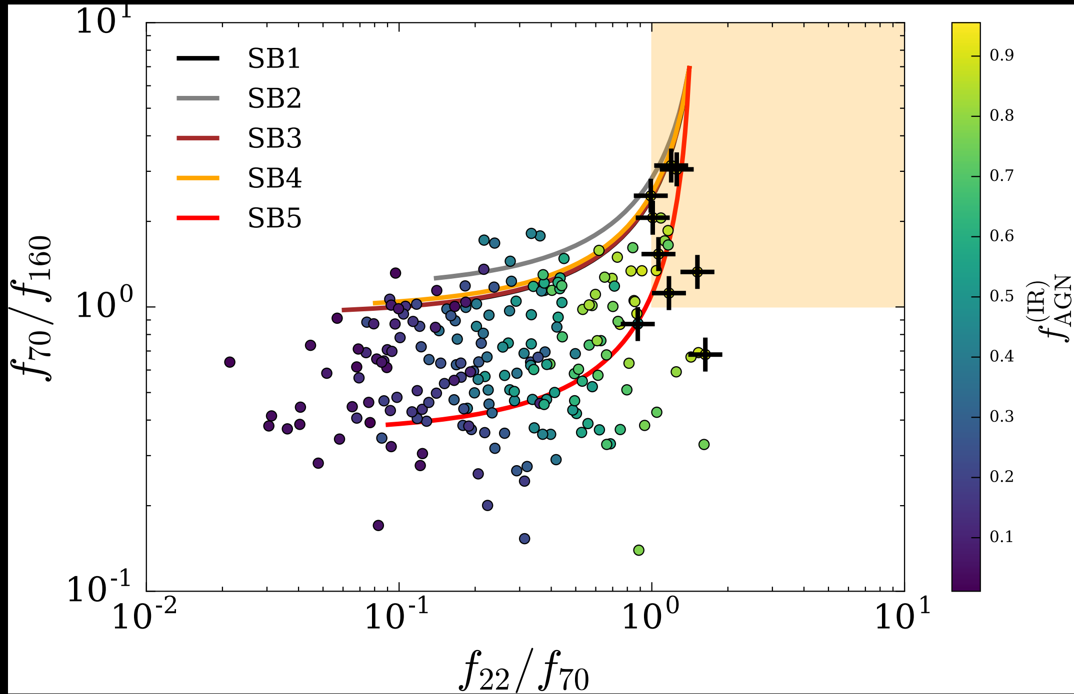
Ichikawa+19





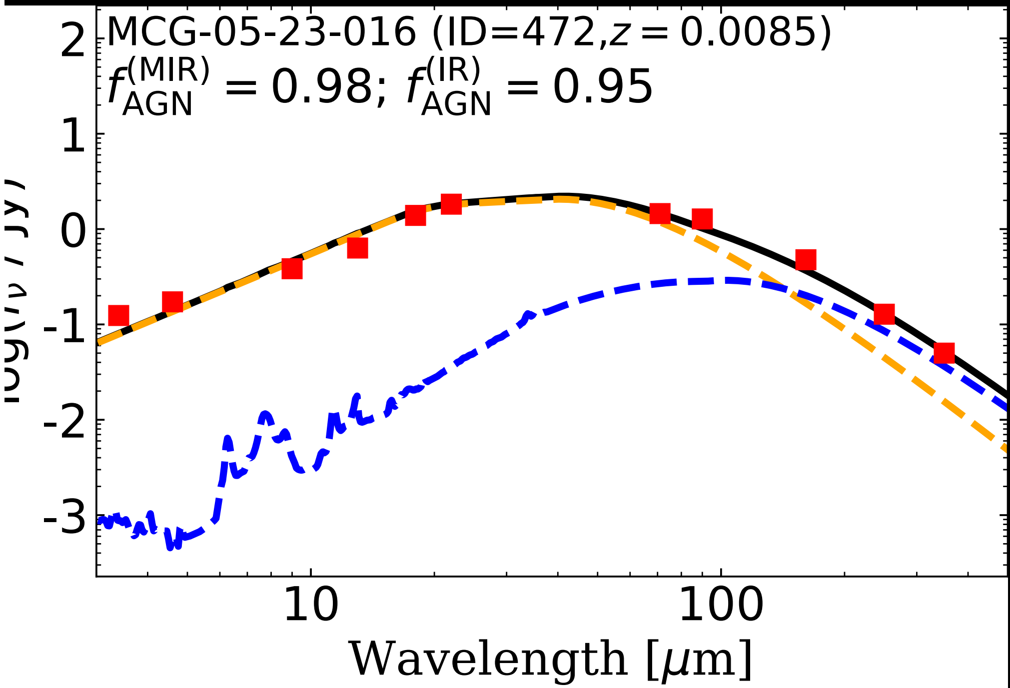
☑ **FIR (up to ~100um) is dominated by AGN torus emission**

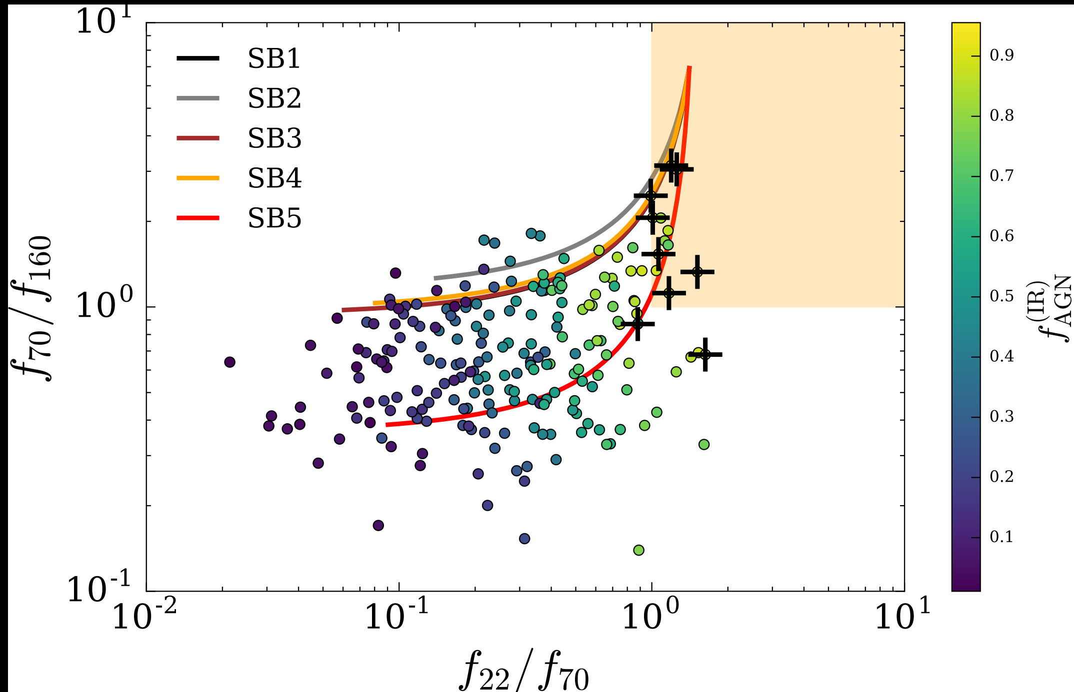
☑ **IR-pure AGN shows the SED w/ $f_{22um} > f_{70um} > f_{160um}$**

IR-Pure AGN candidates

We found 9 "IR-pure AGN" candidates

Ichikawa+19





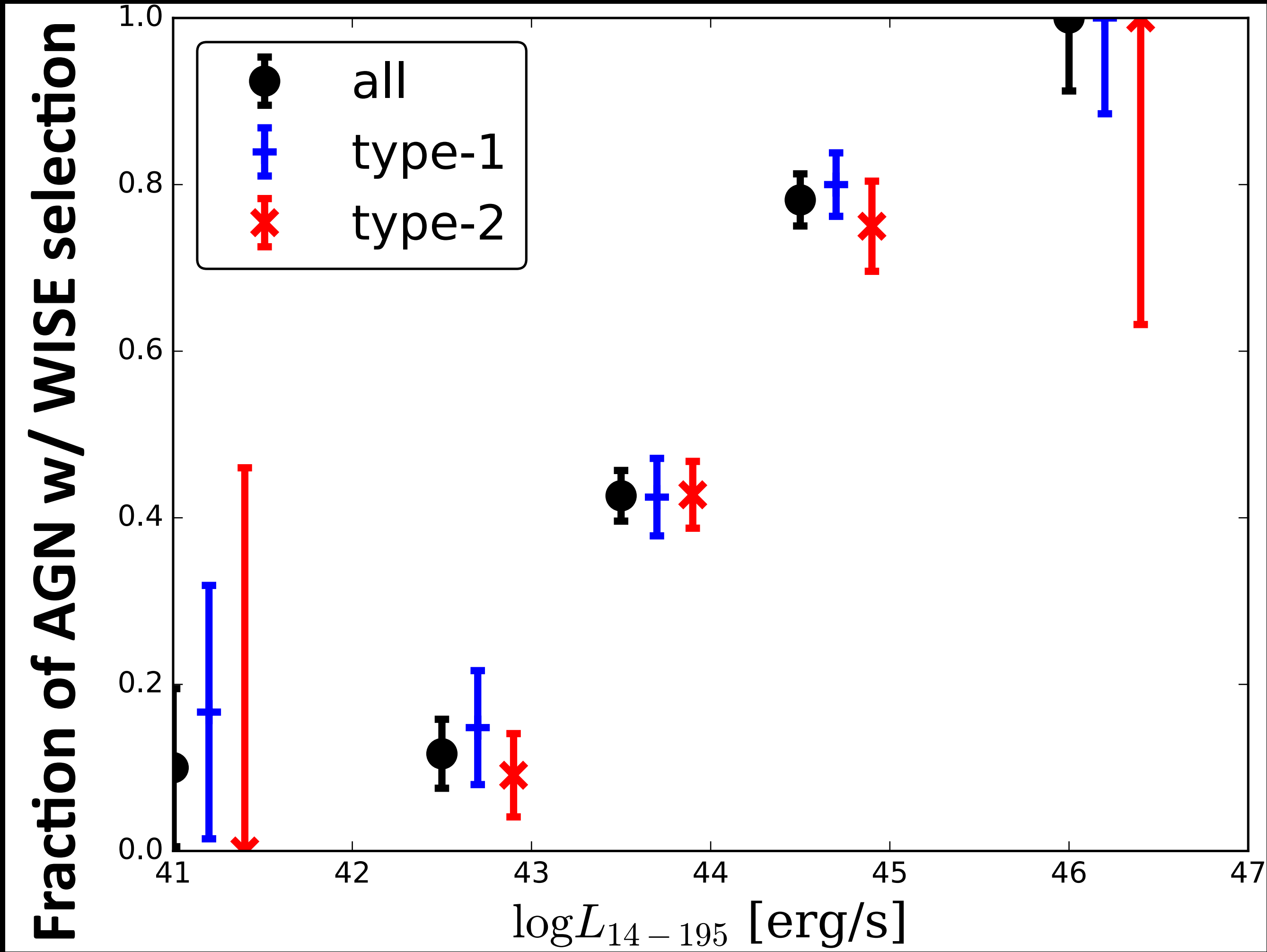
☑ **FIR (up to ~100um) is dominated by AGN torus emission**

☑ **M_{BH}, $L_{14\text{-}150keV}$ distribution is similar with the parent sample (<log M_{BH}>=7.8, <log $L_{14\text{-}150}$>=43.7)**

→ Suggesting **weaker SF activities in the host**

→ **good candidates of final stage AGN?**

Success rate of WISE color selection



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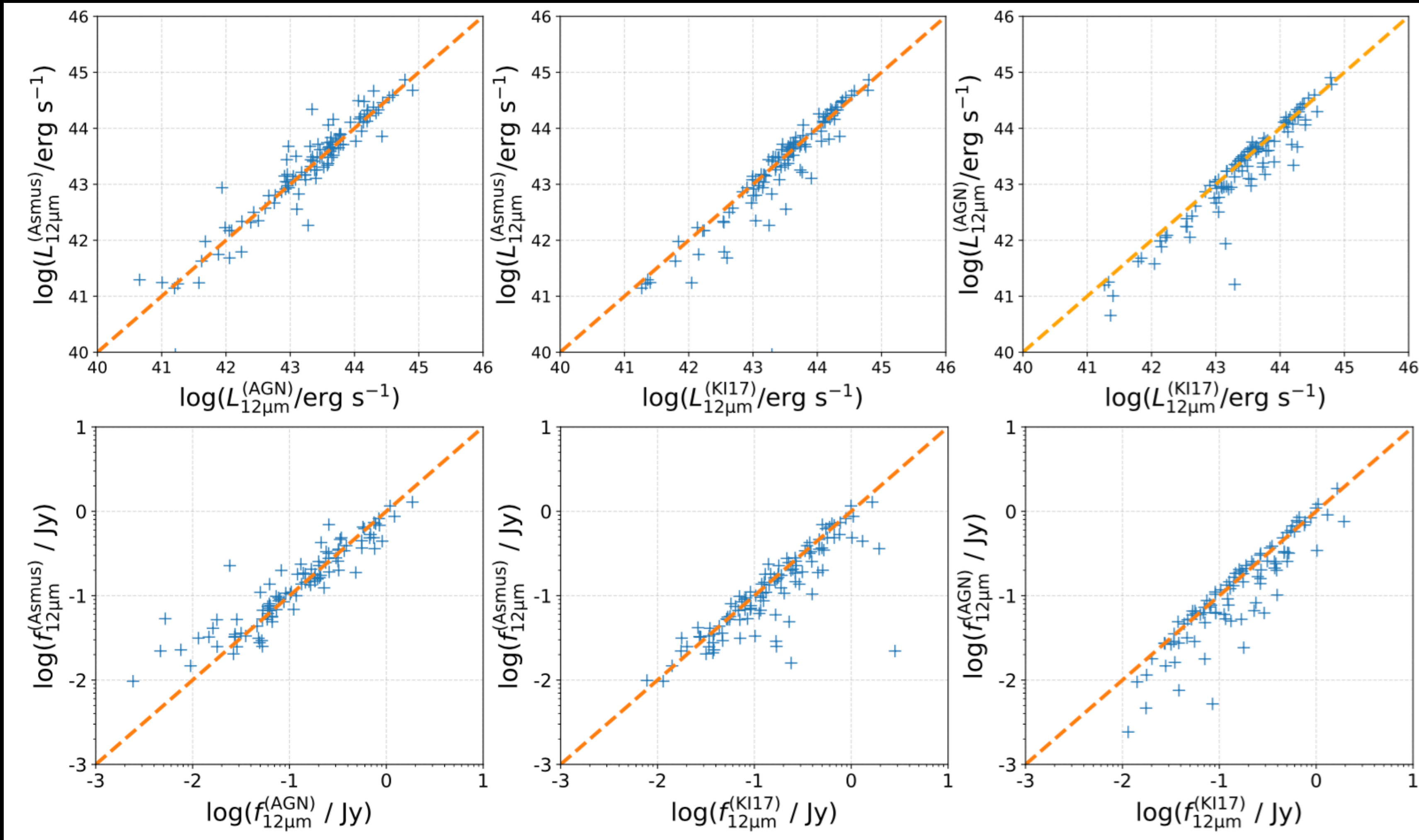
☑ **WISE IR color: insensitive to low-luminosity AGN**

☑ **<20% success rate** for low-luminosity AGN of **log Lx < 43**

Comparison with high-spatial resolution observations

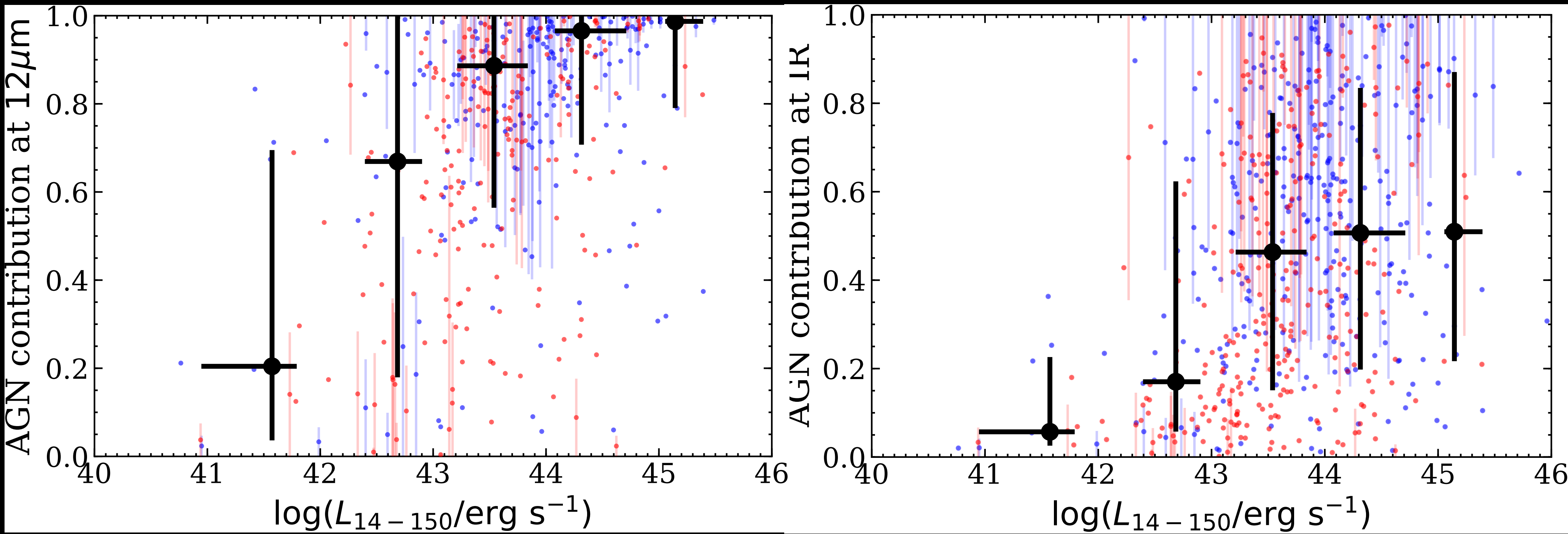
☑ **Decomposition works really well!**



☑ **Disentangling AGN/(SB+stellar) component**

☑ **suitable for the AGN torus/host galaxy studies**

AGN contribution as a function of L_{BAT}



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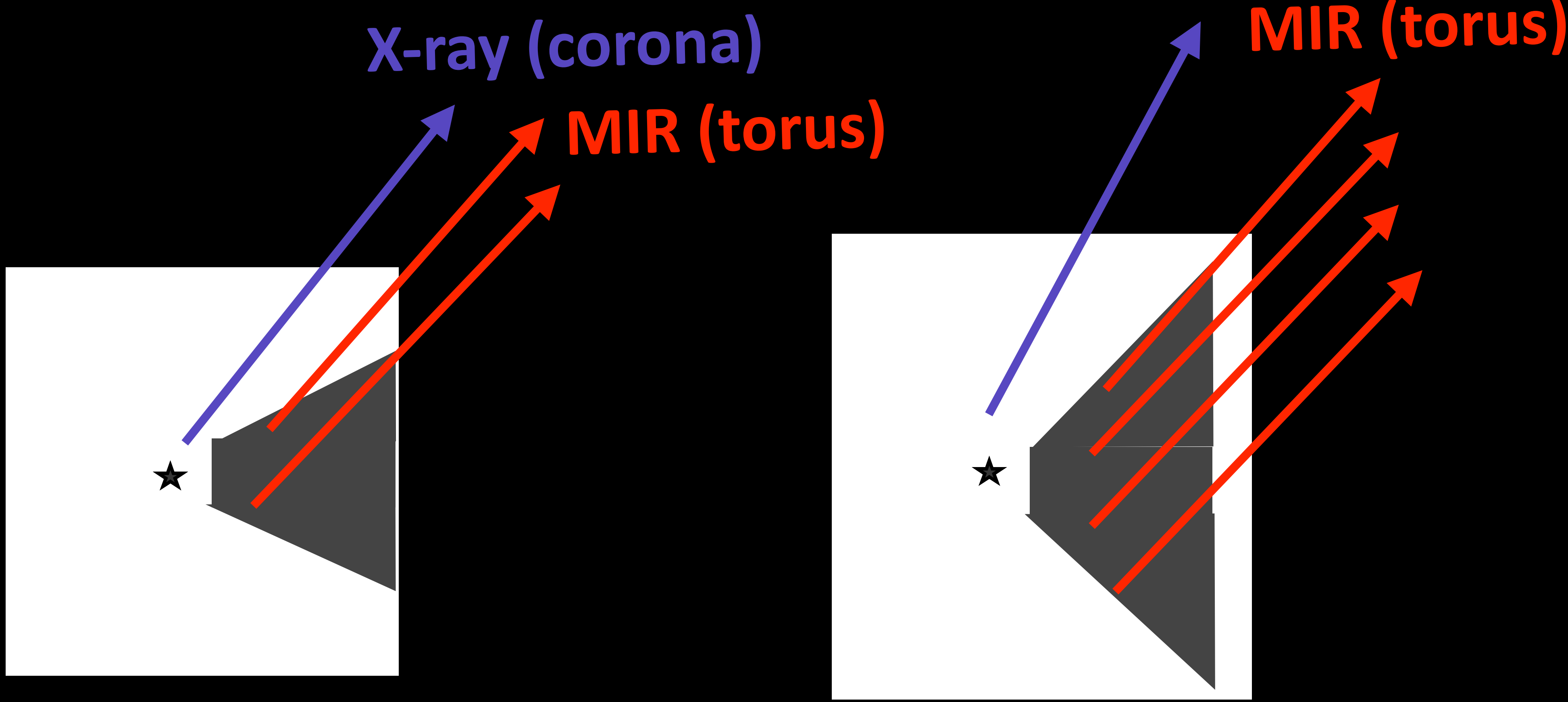
☑ **At high L_{BAT} end,** contribution reaches
~100% at 12um, 80% at MIR (5-40um), and 50% at total IR

☑ **At low L_{BAT} end,** contribution goes down to
~20% at 12um, 20% at MIR (5-40um), and <10% at total IR

→ **SED decomposition is crucial for low-luminosity AGN**

Dust Covering factor (C_T) vs. L_{bol}

$L_X \Rightarrow L_{bol}$ and $C_T \propto L_{MIR}/L_{bol}$ (see Stalevski+16)



C_T: indicator of geometrical dust obscuration

$$L_{MIR} \propto L_{bol}\, C_T \Leftrightarrow C_T \propto L_{MIR}/L_{bol}$$

Dust Covering factor (C_T) vs. L_{bol}

Lx => L_{bol} (Marconi+04) and **$C_T \propto L_{MIR}/L_{bol}$** (see Stalevski+16)

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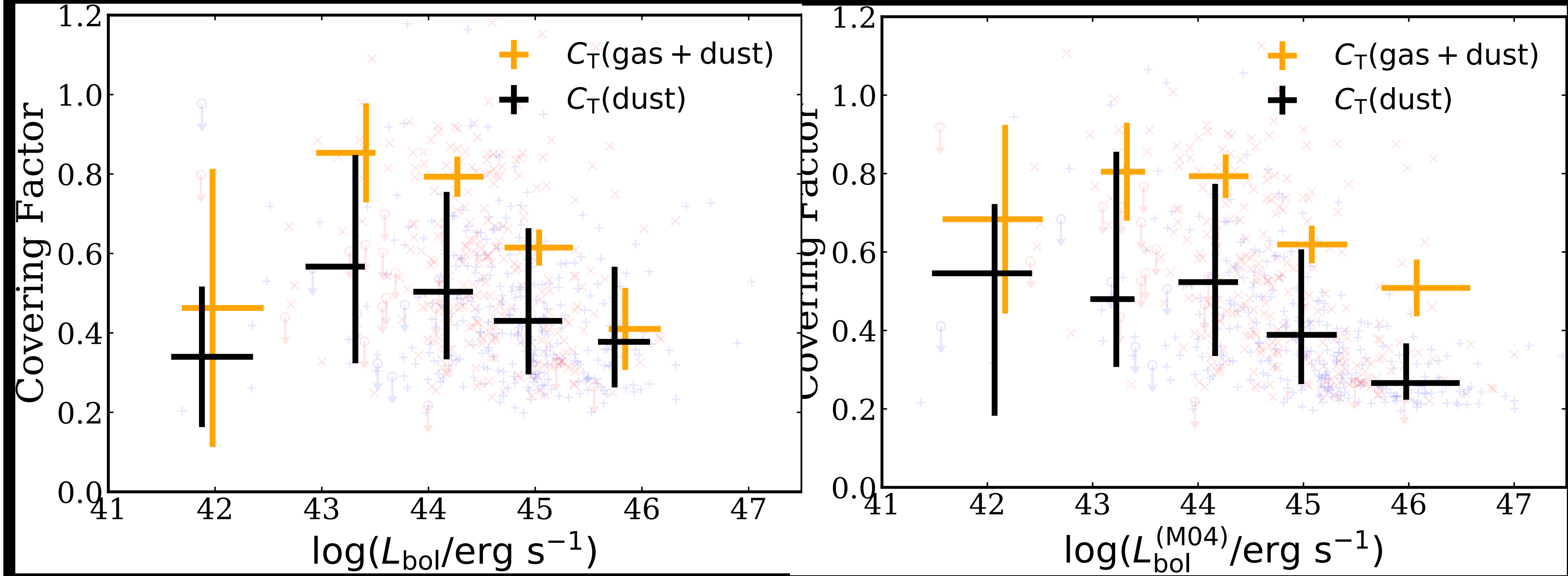
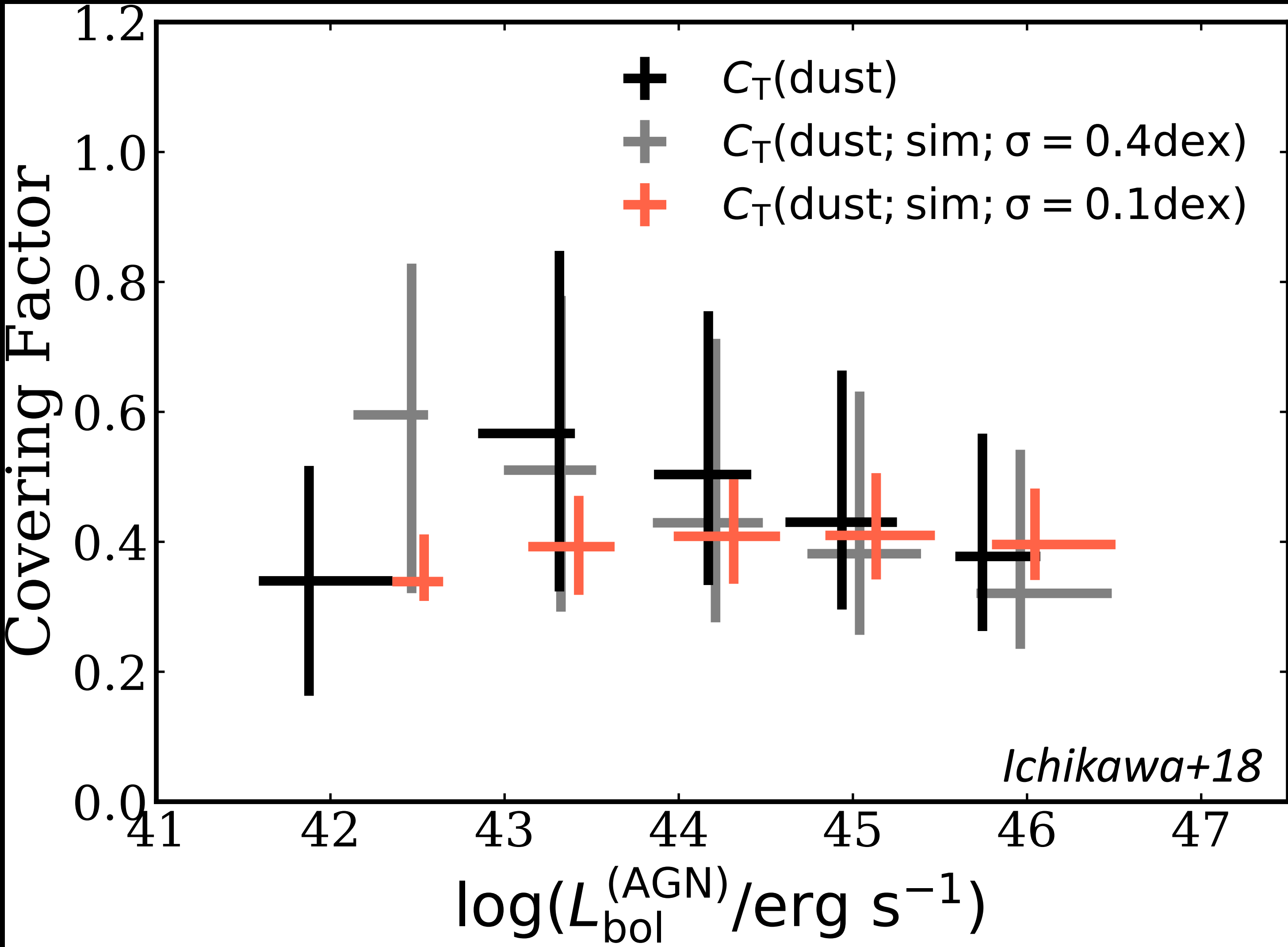


☑ **Different bol-correction does not change the main result**

L_{bol} dependence of Dust Covering factor (C_T)



☑ Small scatter of L_X-L_{IR} relation gives a flatter L_{bol} dependence of C_T(dust)

☑ This is because $\log L_{IR}(AGN) \propto 1.06 \log L_X$

∴ slope b=1.06 (+/-0.03)