SMBH: environment and evolution on June 19, 2019 in Corfu, Greece

IR View of of X-ray AGN: The Covering Factor of Gas and Dust in Swift/BAT AGN

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Kohei Ichikawa (市川幸平)
FRIS fellow, Tohoku University, Japan

In collaboration with
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Infra… AGN

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

ApJ, 835, 74

ApJ, 870, 31

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TOHOKU UNIVERSITY

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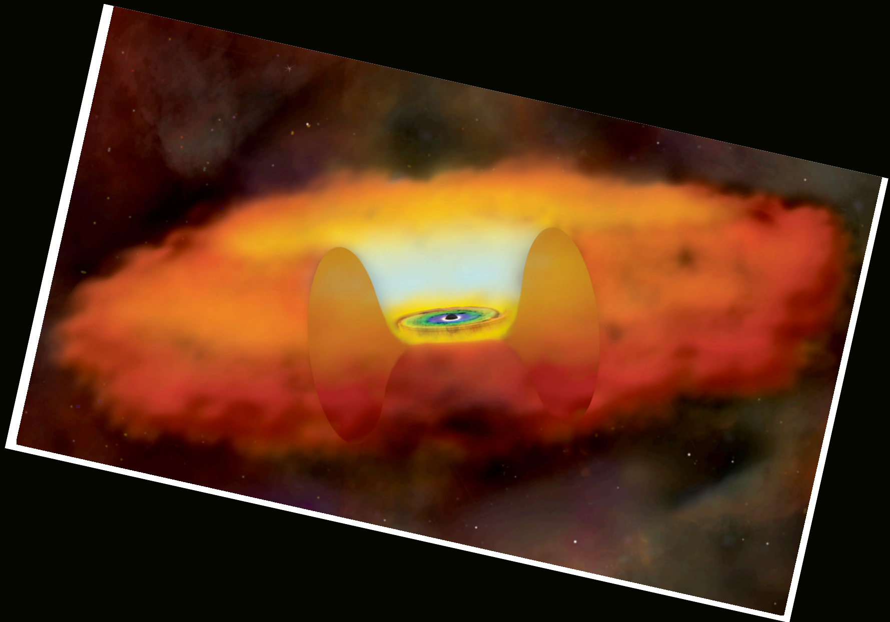
(Mid-)IR emission of AGN= nuclear dust

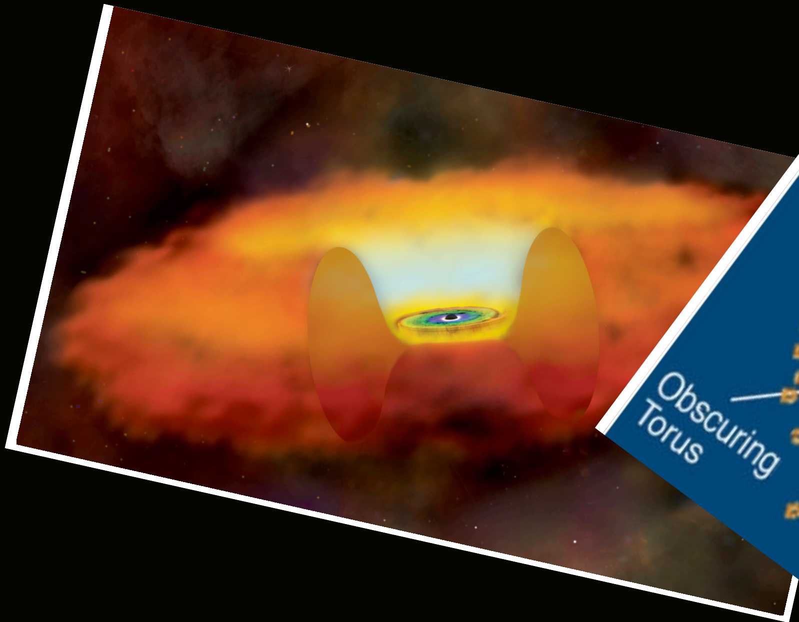
Nuclear (MIR bright) dusty region: future fuel of SMBHs



Urry & Padovani '95

(Mid-)IR emission of AGN= nuclear dust

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



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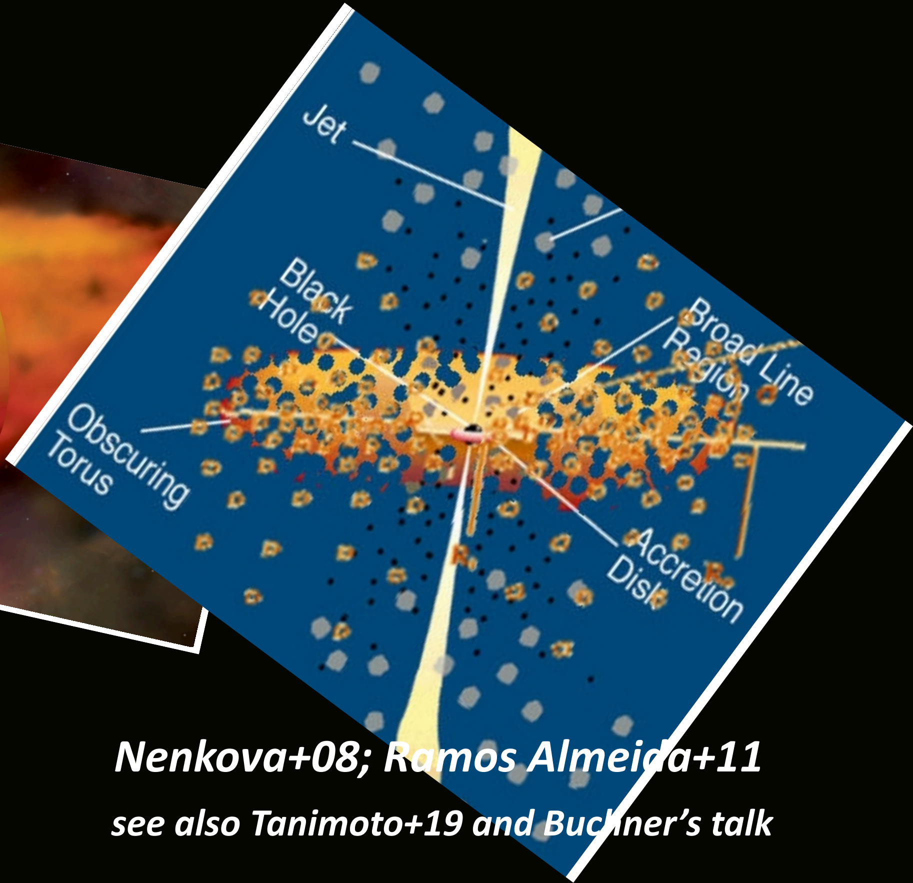

Nenkova+08; Ramos Almeida+11

see also Tanimoto+19 and Buchner's talk

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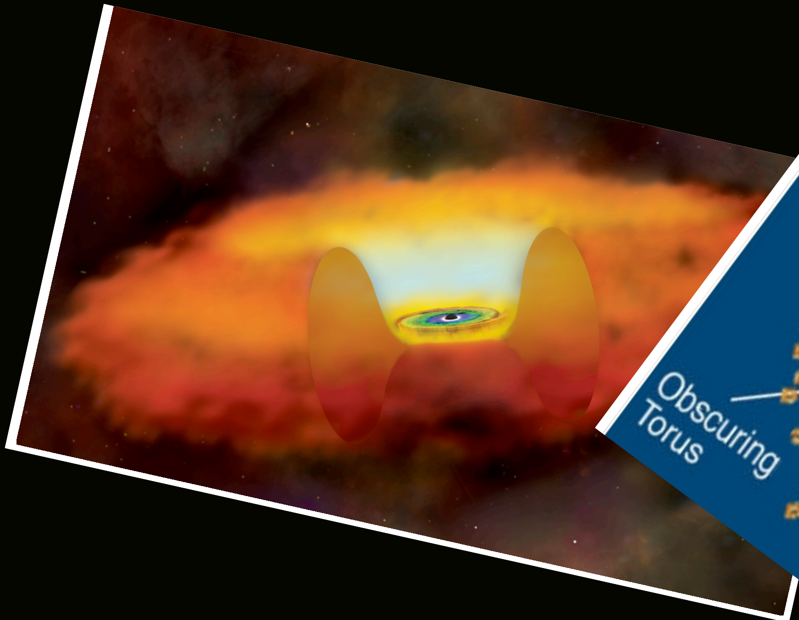

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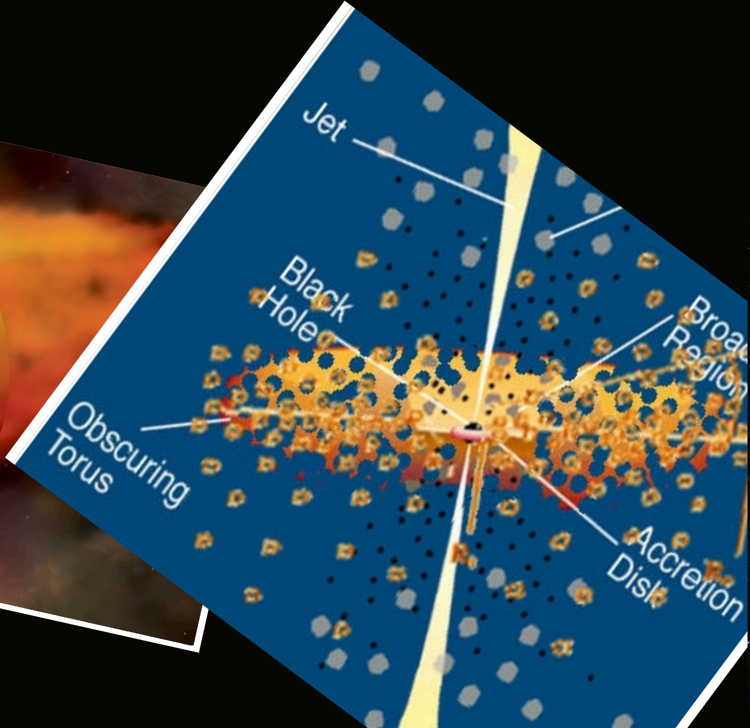


Nenkova+08; Ramos Almeida+11

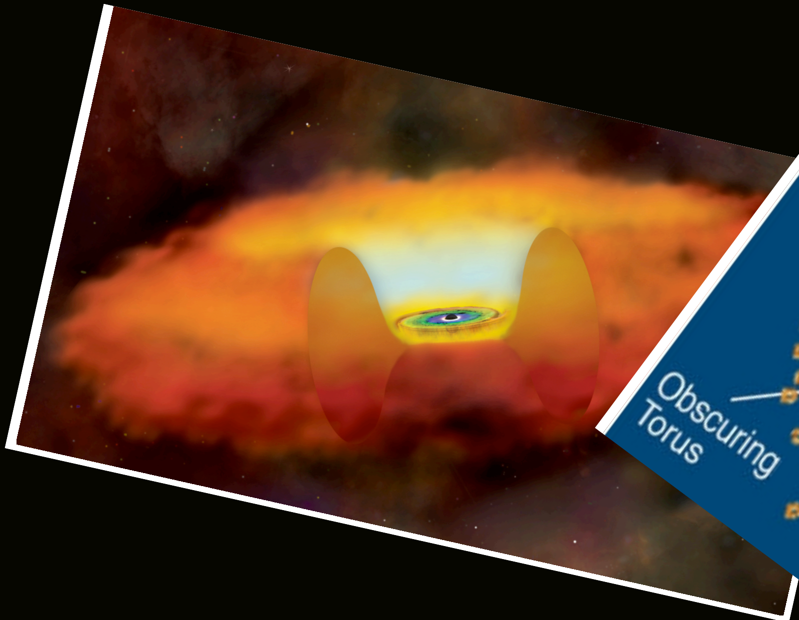
see also Tanimoto+19 and Buchner's talk

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



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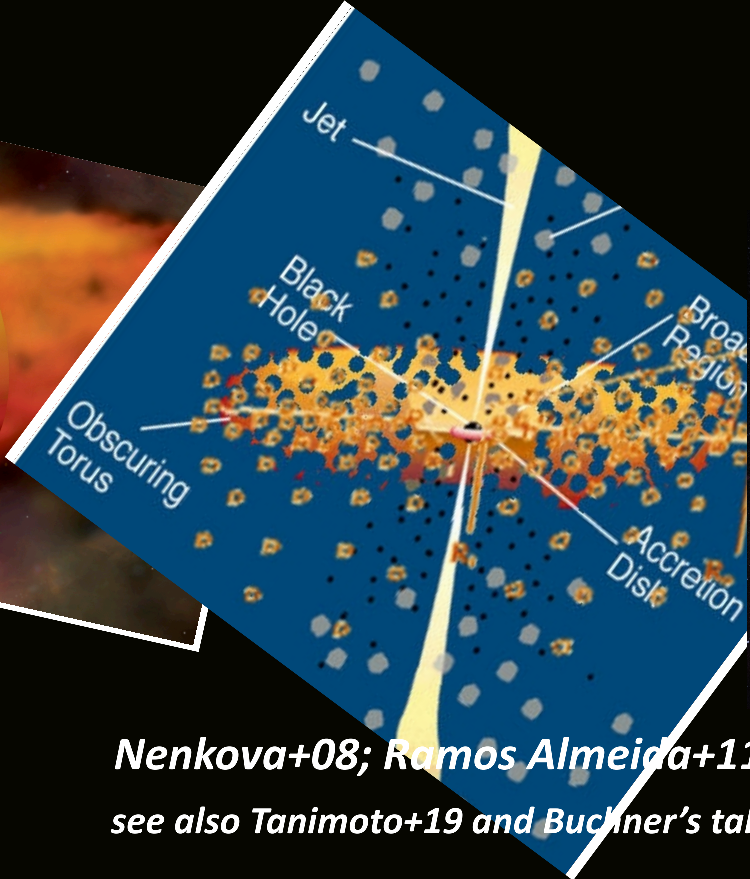

Nenkova+08; Ramos Almeida+11

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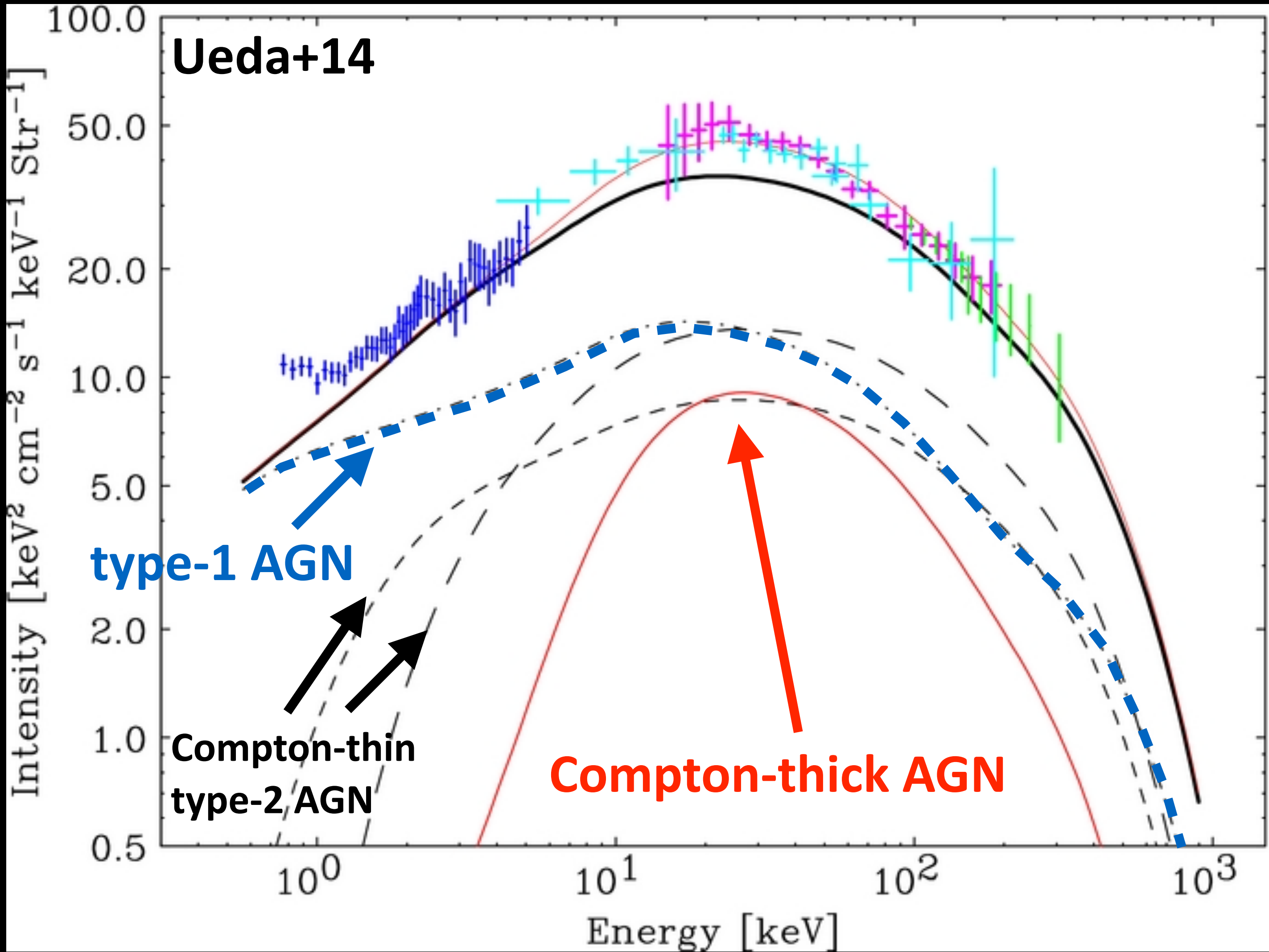
Q. How much do we know the (averaged) dust geometry?

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

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

Most of AGN are elusive (=obscured)

XRB indicates that most of AGN are obscured



☑ energy density peaks at **~30 keV**

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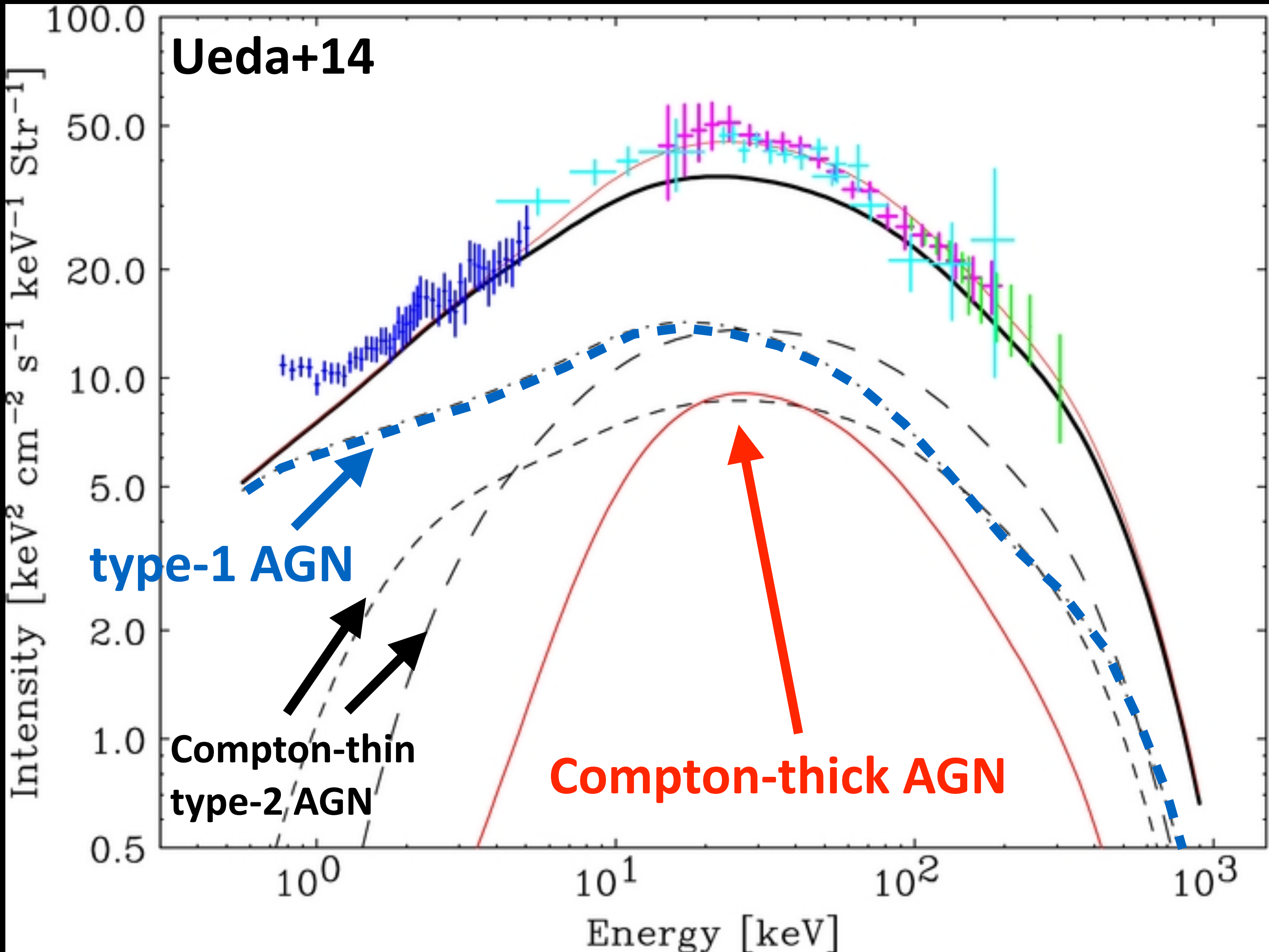


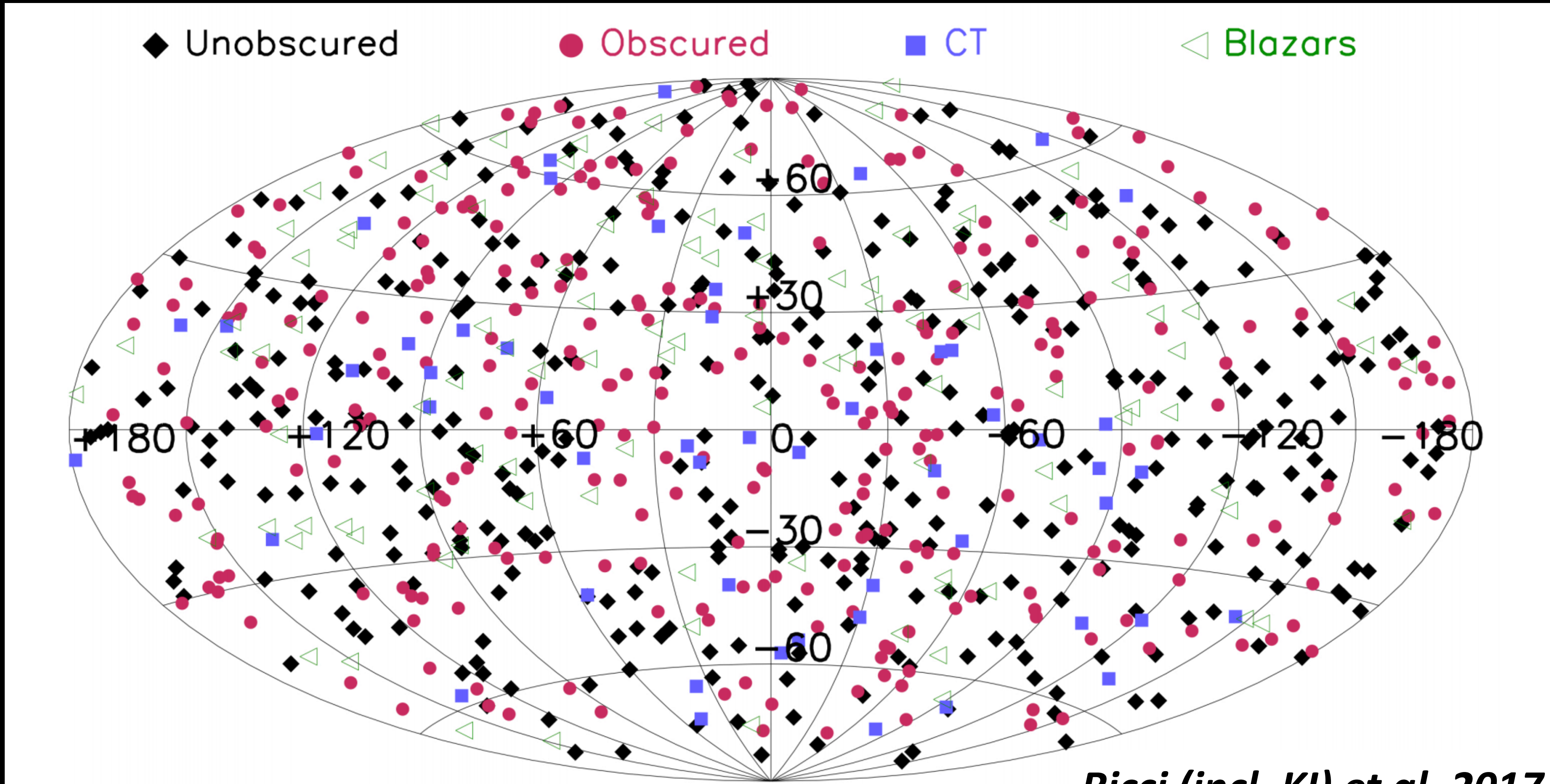
☑ energy density peaks at **~30 keV**

☑ **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)***



Baumgartner+13 and... ***Ricci (incl. KI) et al. 2017***

☑ most complete up to $\log N_H = 24.0$ in the local Universe *(Koss+16; Ricci+15)*

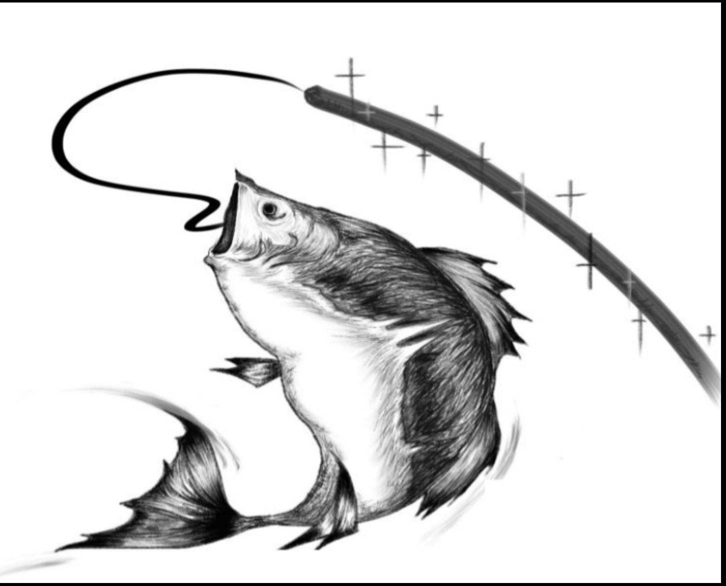
☑ **606 out of 728 have z info and are located at |b|>10°**

BASS

BASS=BAT AGN Spectroscopic Survey

Multi-wavelength Follow-up of BAT-AGN

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



by Courtesy of 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)

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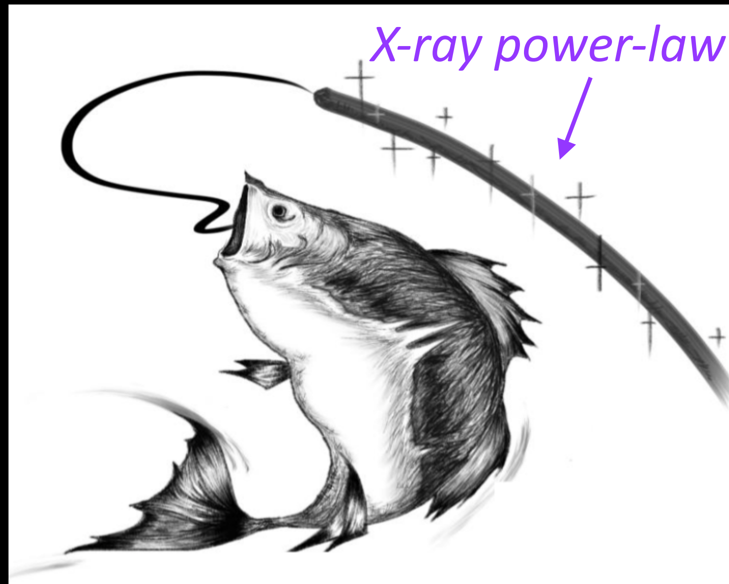

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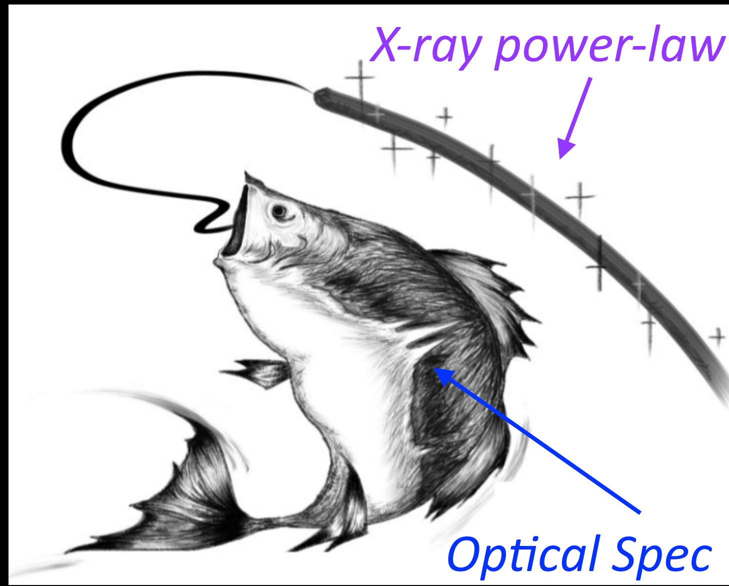

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More studies and Data, see <u>BASS website!</u>

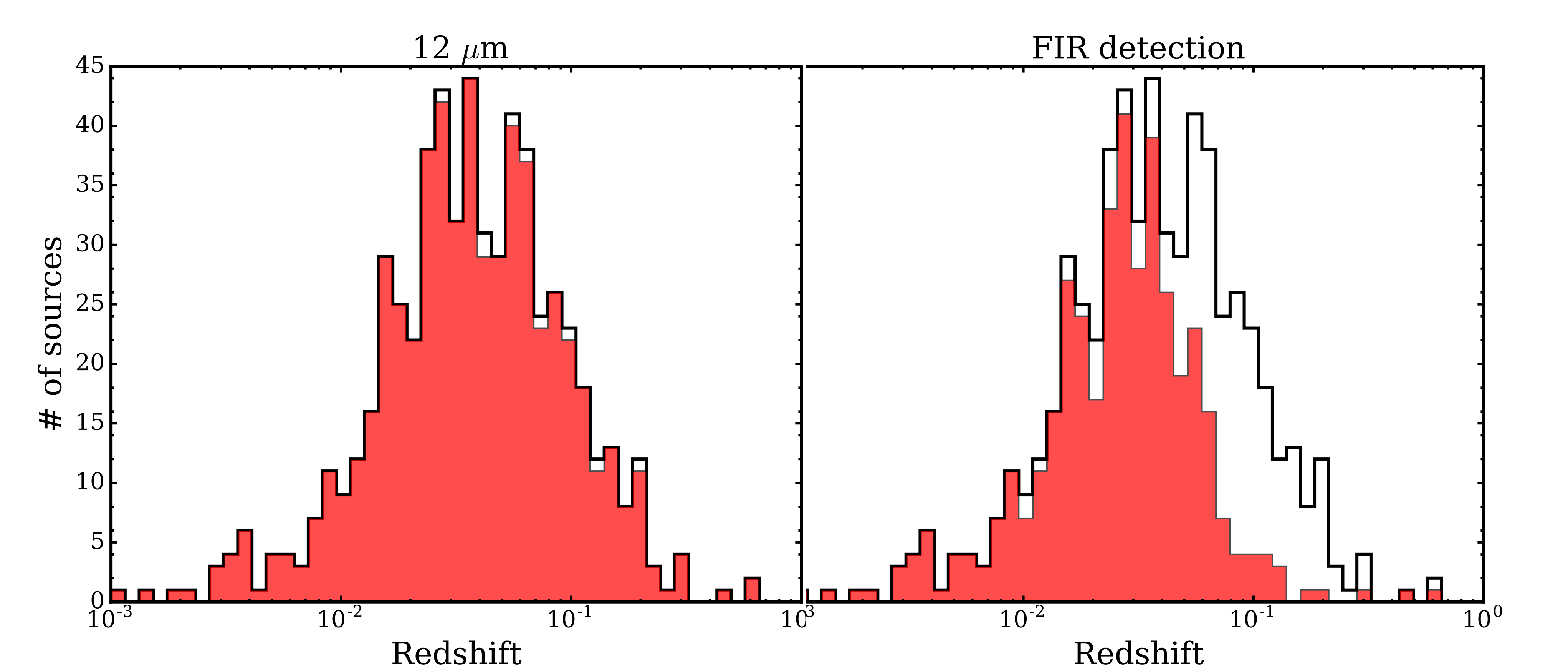
Today's topic

- ☑ 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**

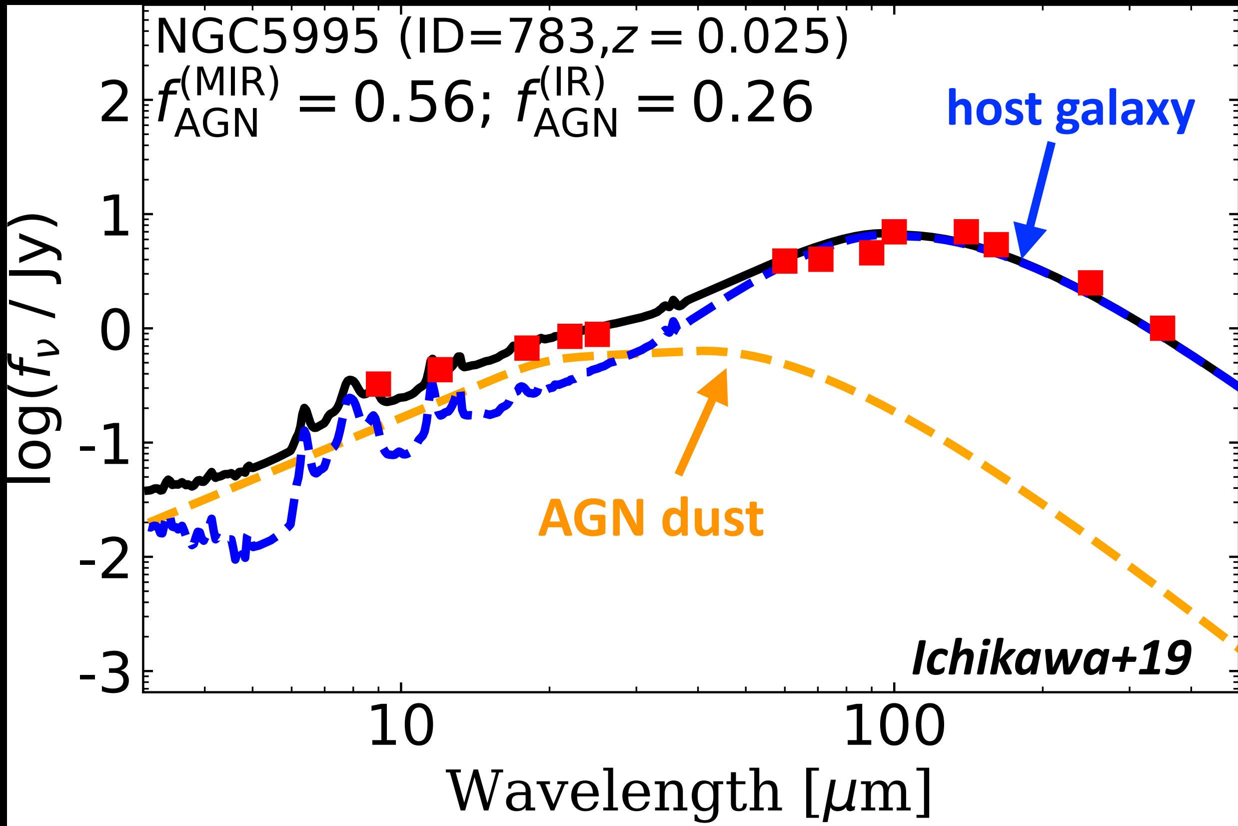
☑ **suitable for the AGN dust/host galaxy studies**

☑ **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**

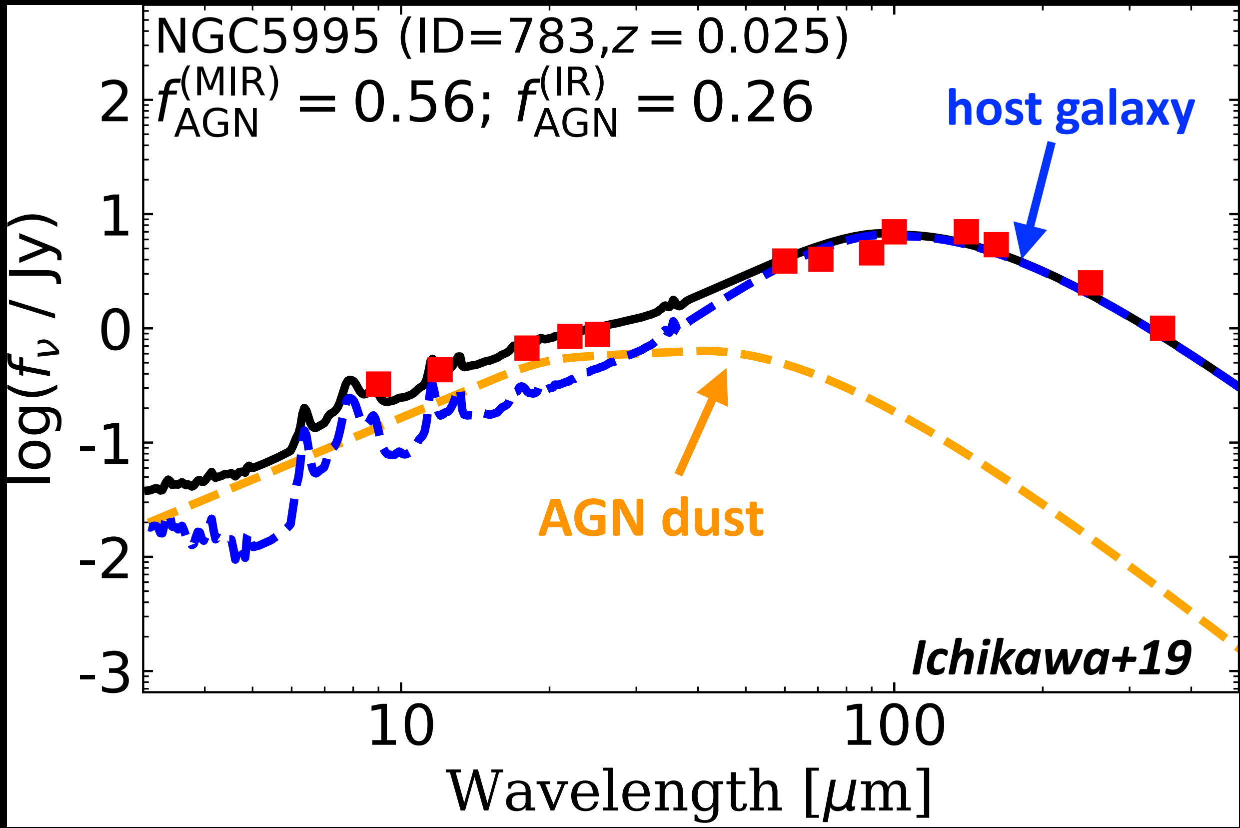
(see Mullaney+11 and Ichikawa+19 for more details)



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**

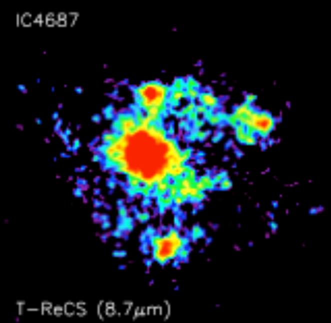
☑ **Disentangling AGN/host galaxy (SB+stellar) component**

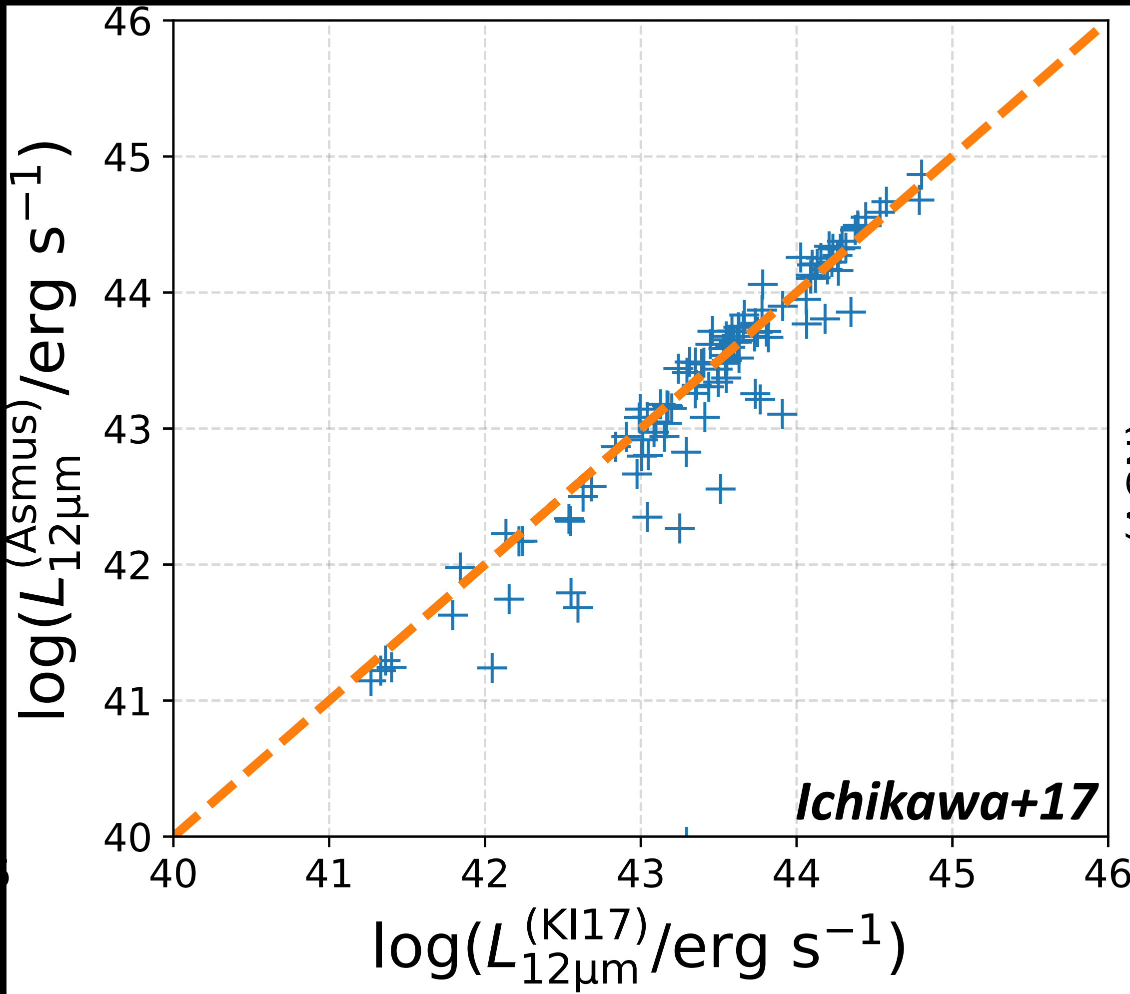
=> AGN IR emission w/o host galaxy contamination

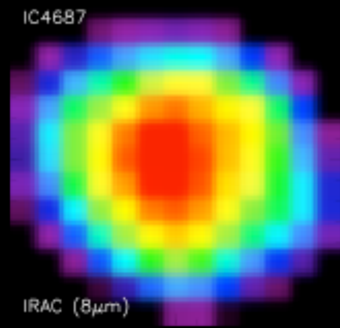
FYI, All info incl. IR SEDs, decomposed SEDs, M_{BH}, $L_{x,\,bol}$ are now public

Comparison with high-spatial resolution observations

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







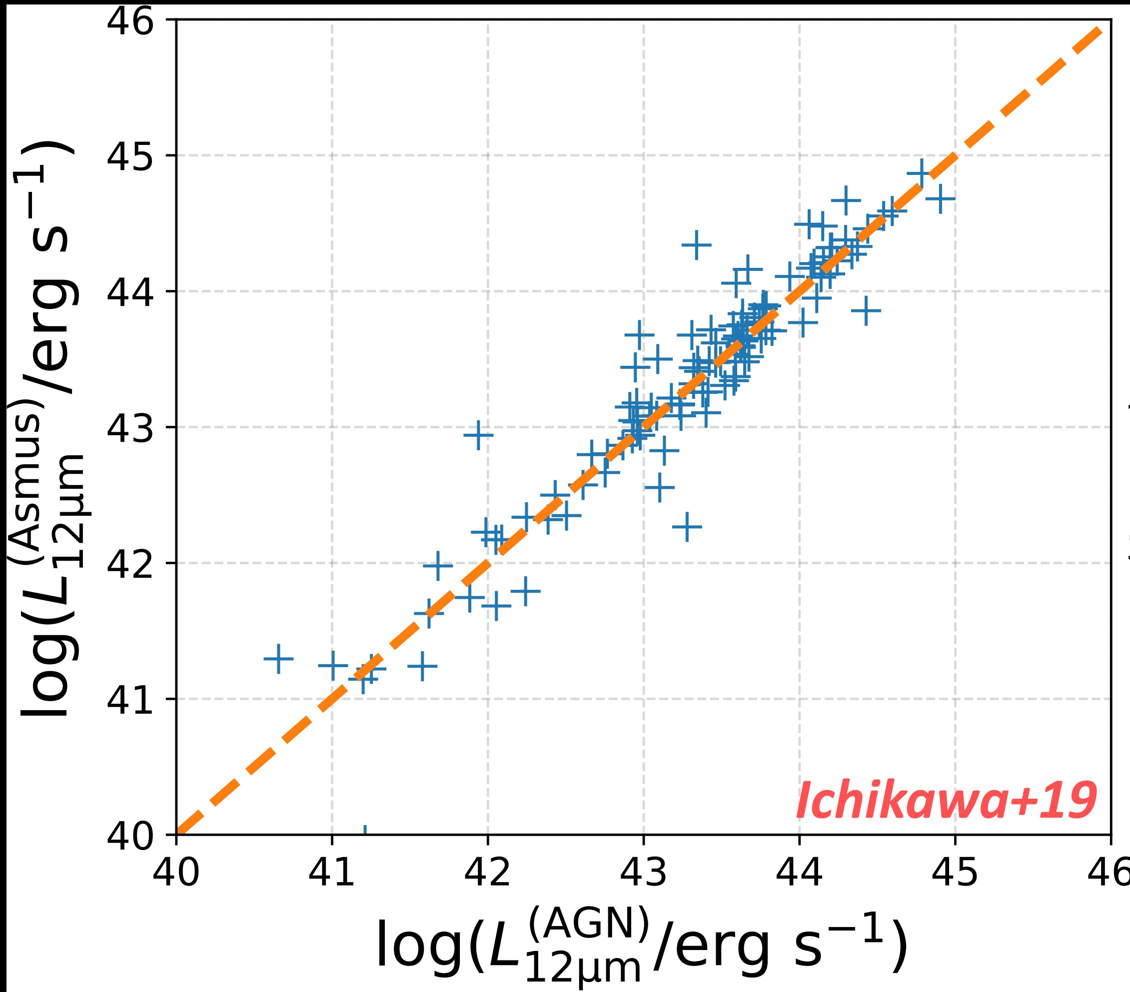
L_{12um} "Before" SED decomposition

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

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. $L_{14\text{-}150keV}$

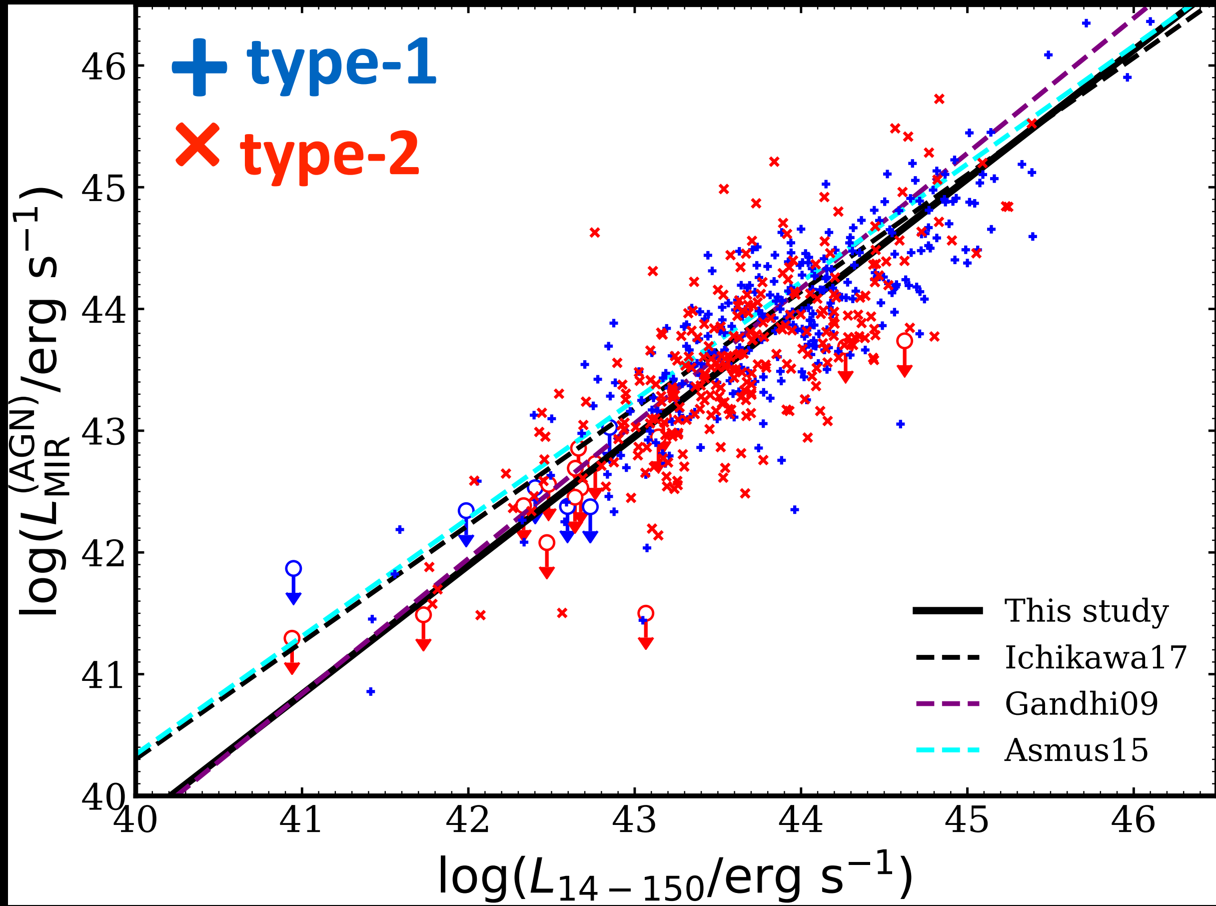
Ichikawa+19 (see also KI+12, 17)

Our study

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

↓

MIR emission: isotropic



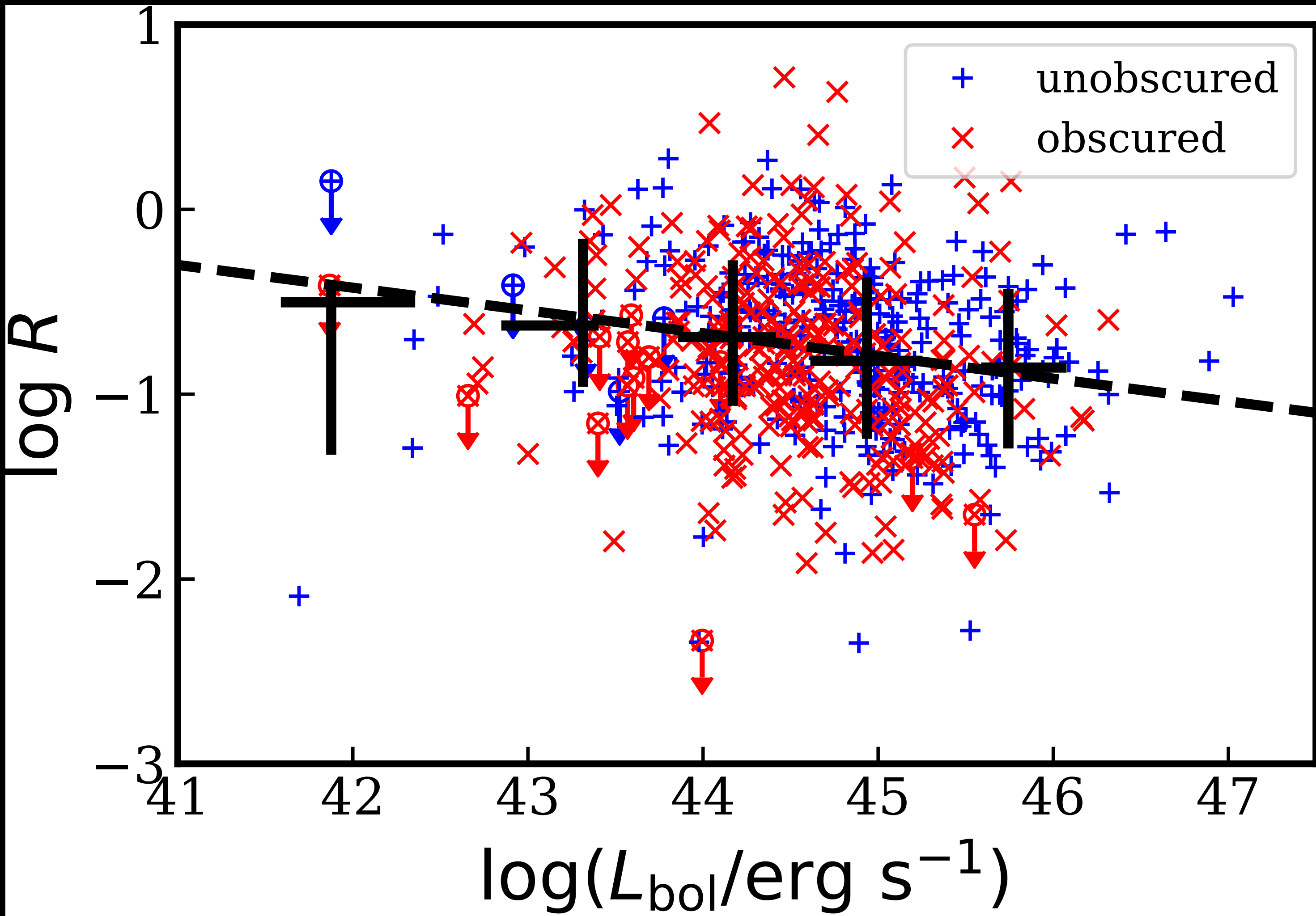
log L_{MIR} ∝ 1.06 log L_X ∴ slope b=1.06 (+/-0.03)

☑ **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 = $L_{IR}(AGN)/L_{bol}$

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



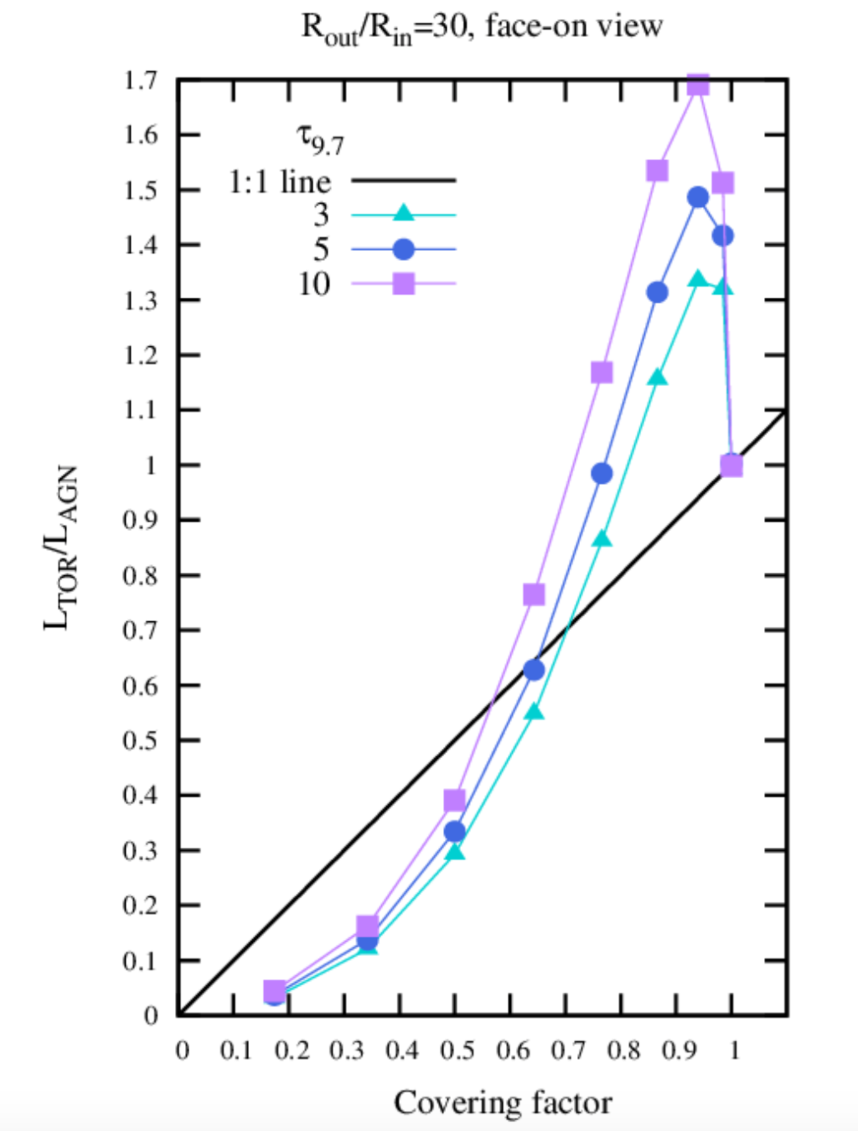
Ichikawa+19

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

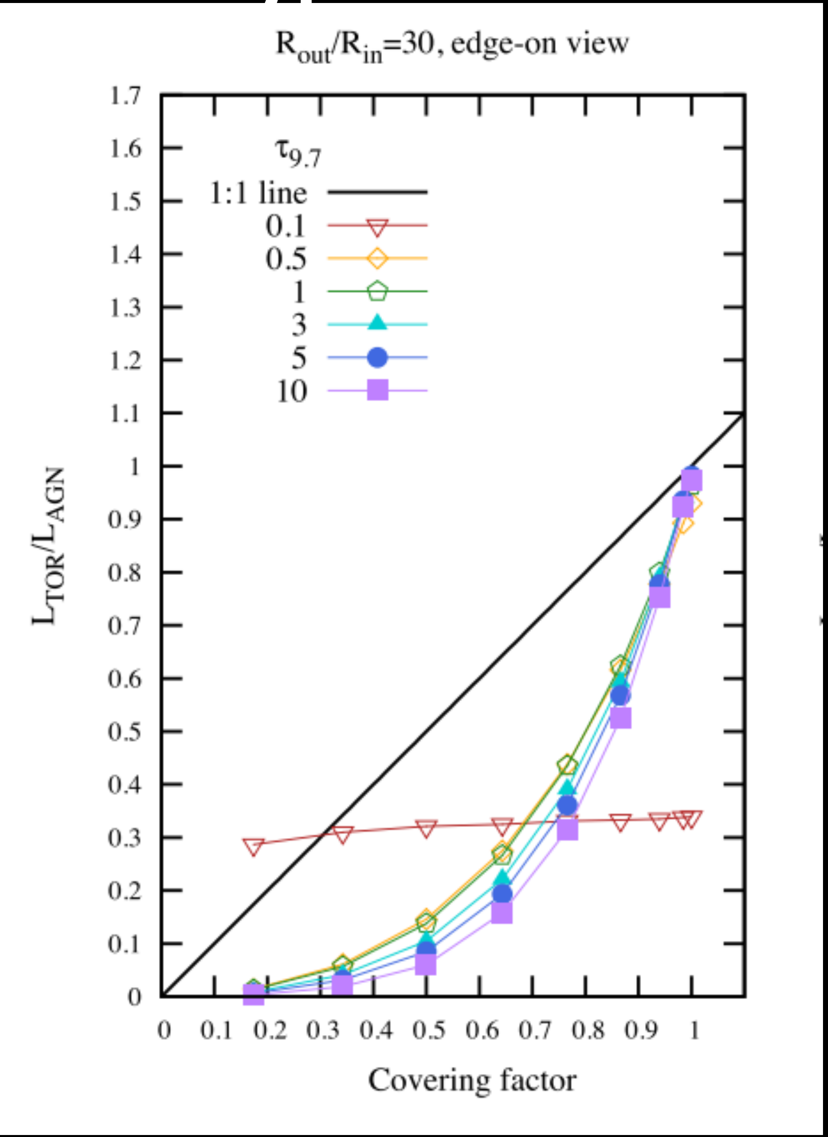
R=LIR(AGN)/Lbol => CT(dust)

LIR(AGN) /Lbol vs. CT (see Stalevski+16)

type-1 AGN



type-2 AGN

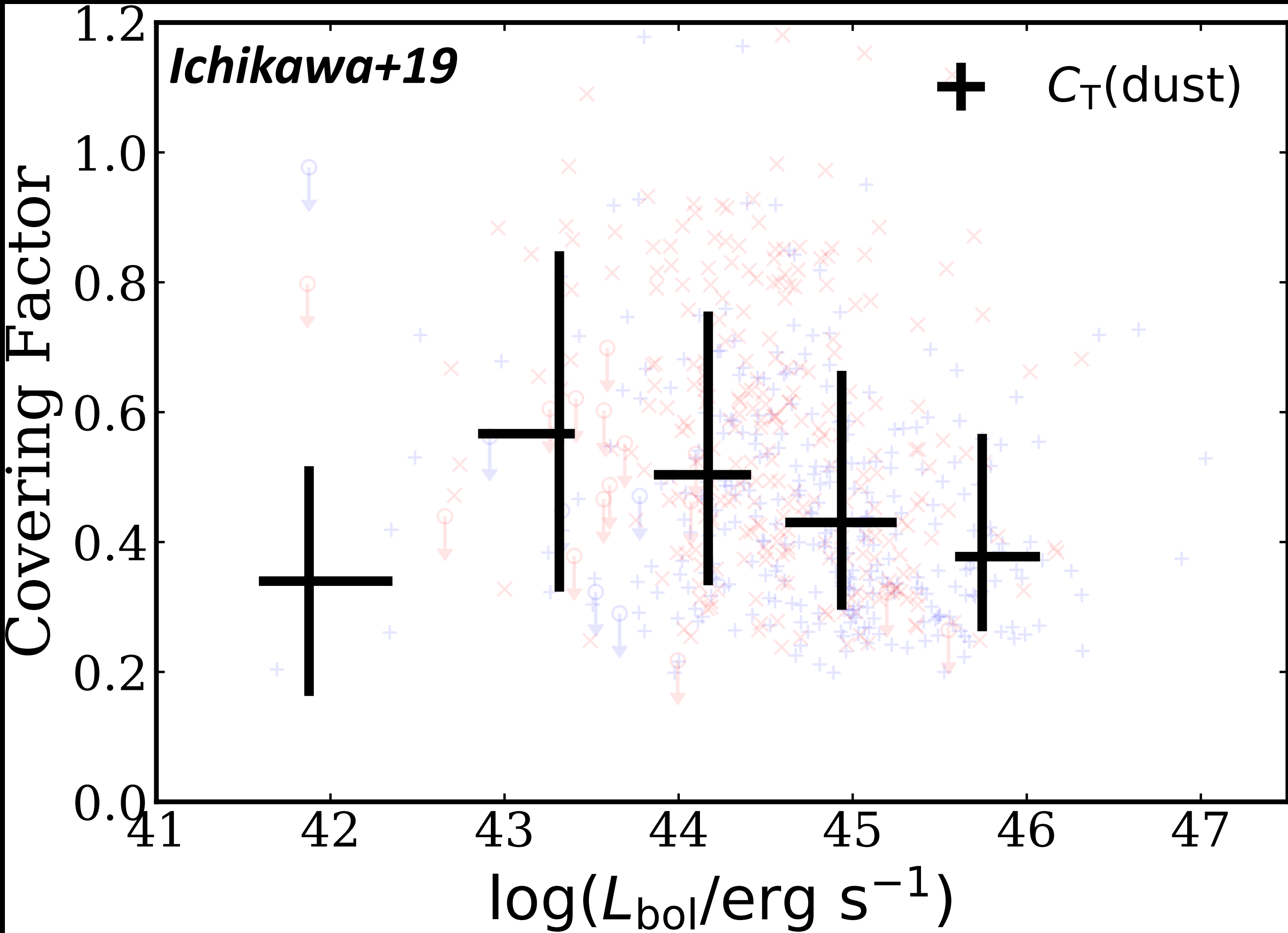


Dust Covering factor (C_T) vs. L_{bol}

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

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

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

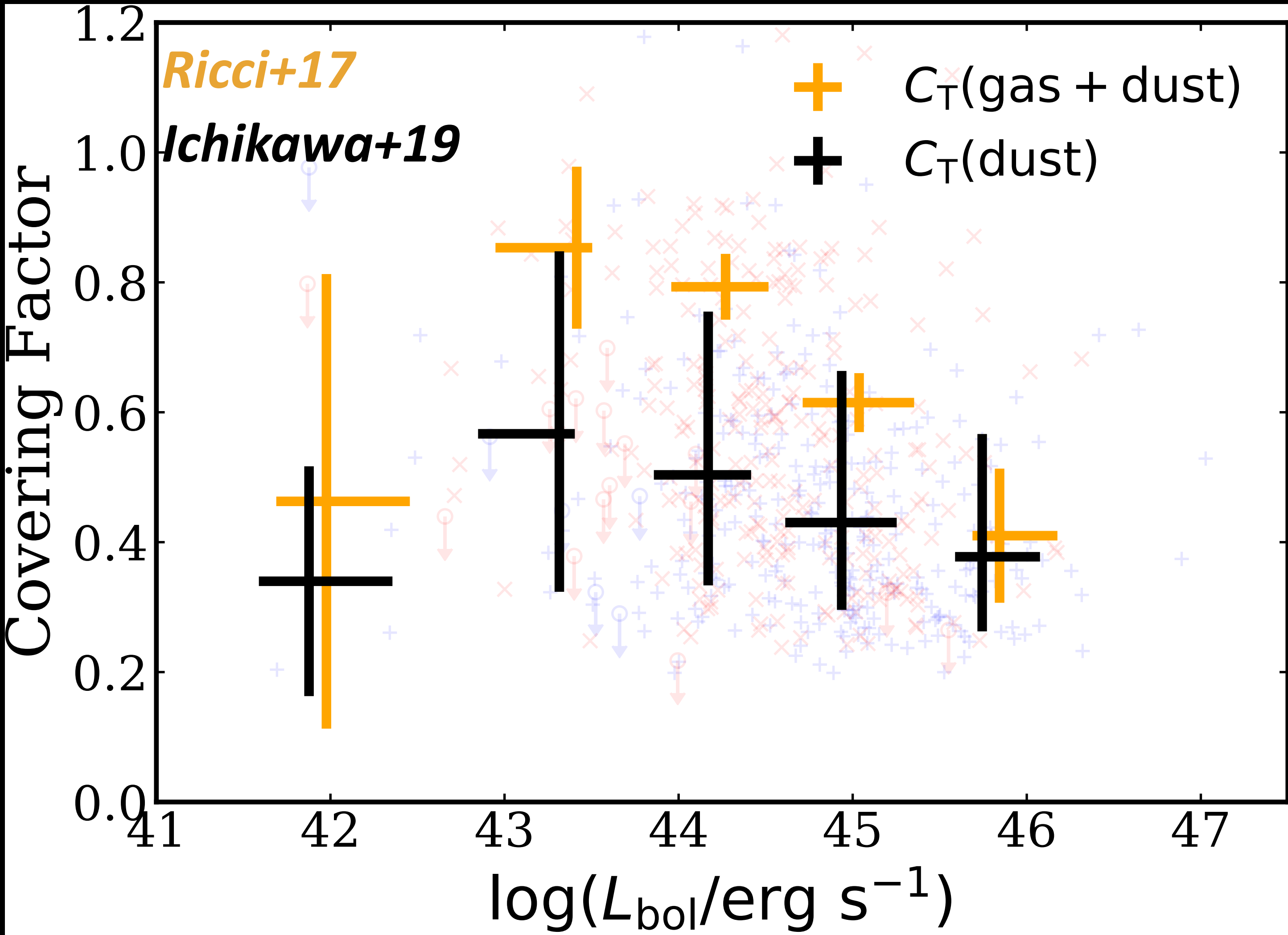


☑ **C_T (dust) : 0.4-0.6,** very weak or almost independent of L_{bol}

(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)

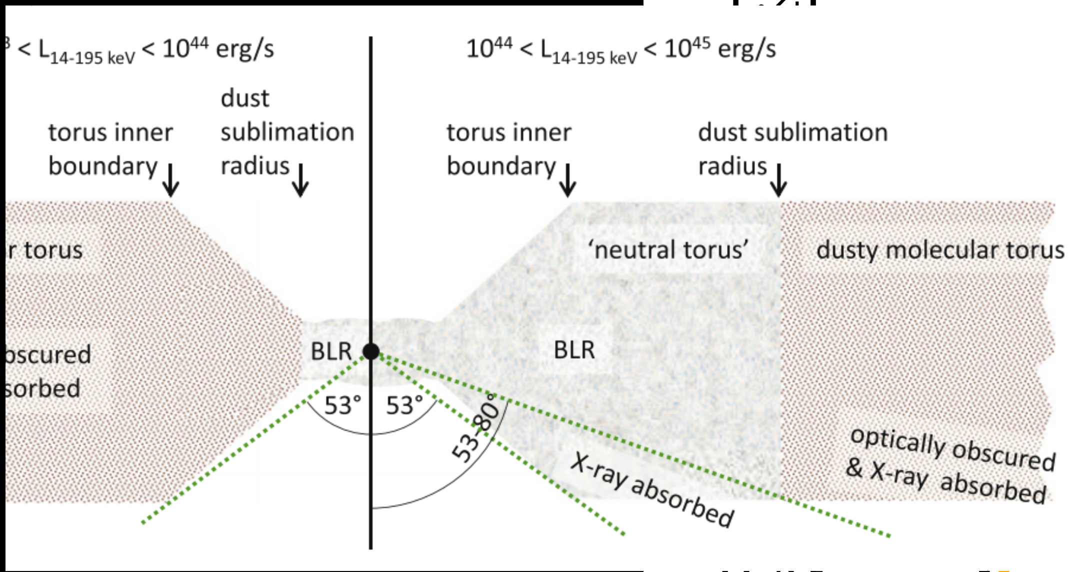


☑ C_T(dust) < C_T (dust+gas) **<= obtained from X-ray obs.**

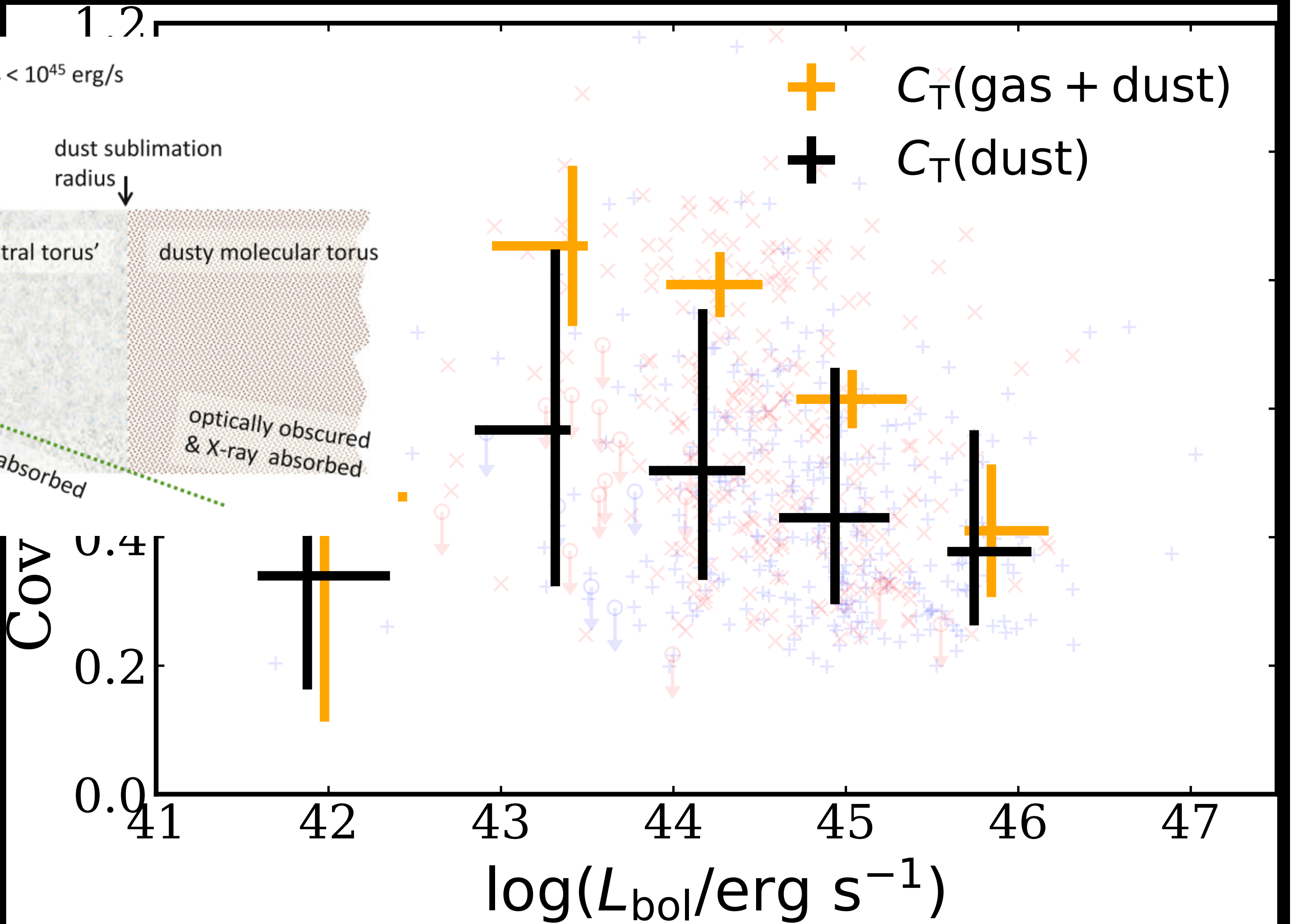
☑ **There is a dust-free (X-ray) obscuring region**

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

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



Davies+15



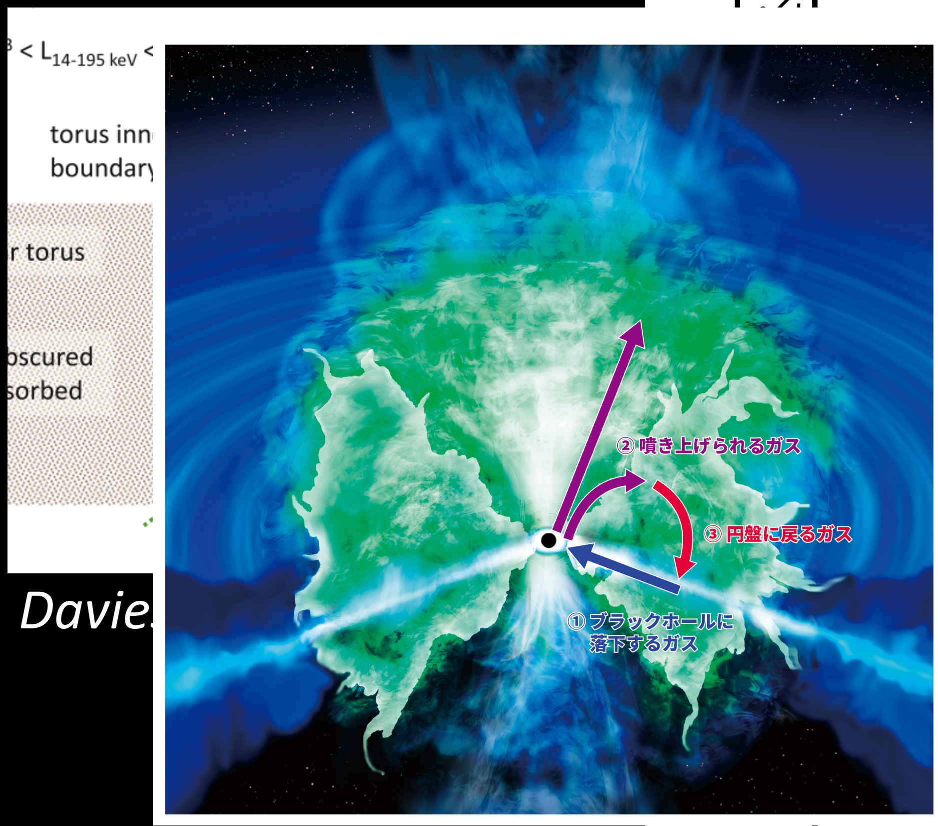
☑ **C_T(dust) < C_T (dust+gas) <= obtained from X-ray obs.**

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

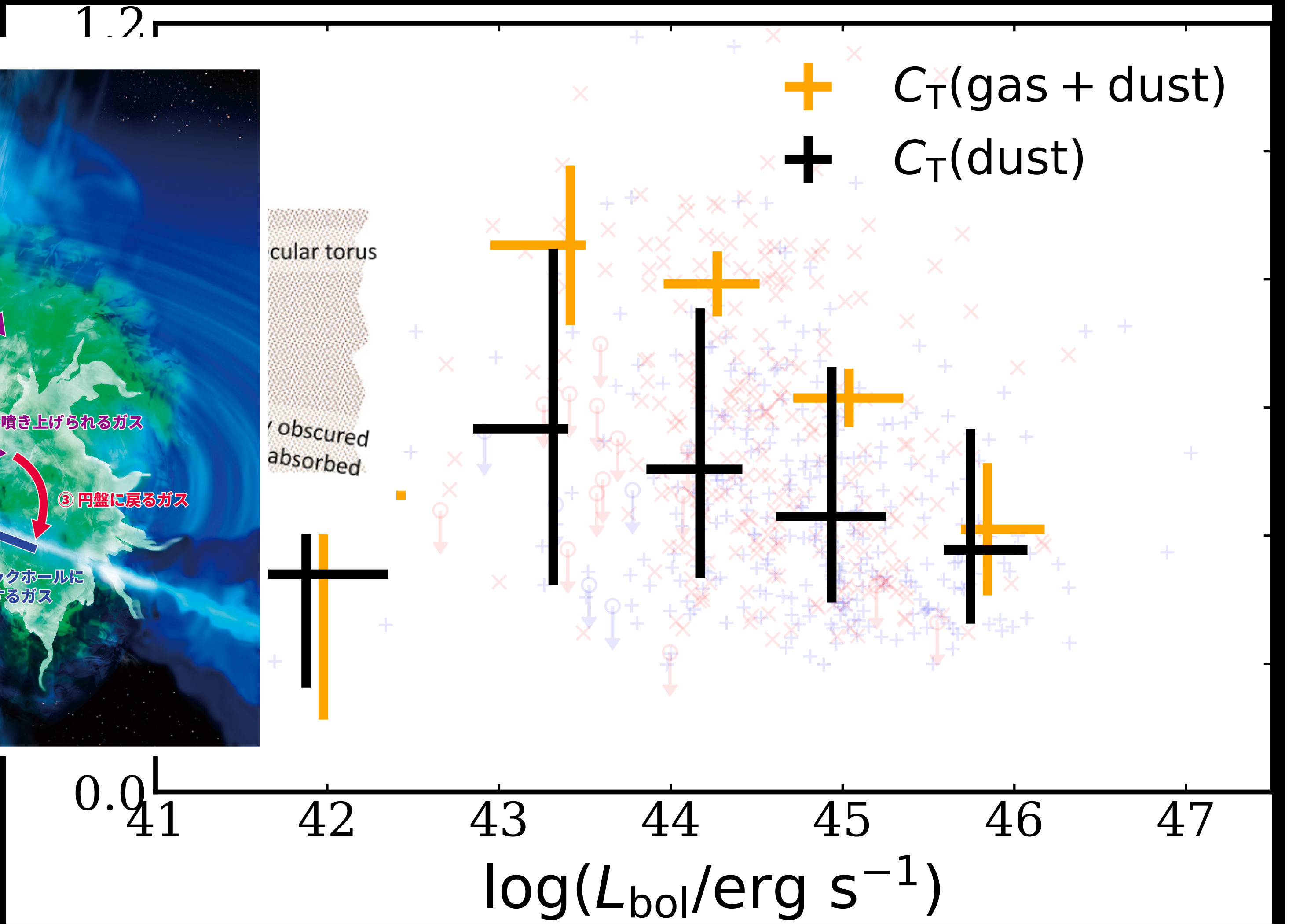
*(see also **Markowitz+14; Davies+15; Liu+18**)*

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 outflow?)**

(see also Wada '15, Izumi+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 et al. 17*****)**

IR and X-ray properties of BAT AGN

☑ C_T(dust) < C_T (dust+gas) => dust-free obscuring region

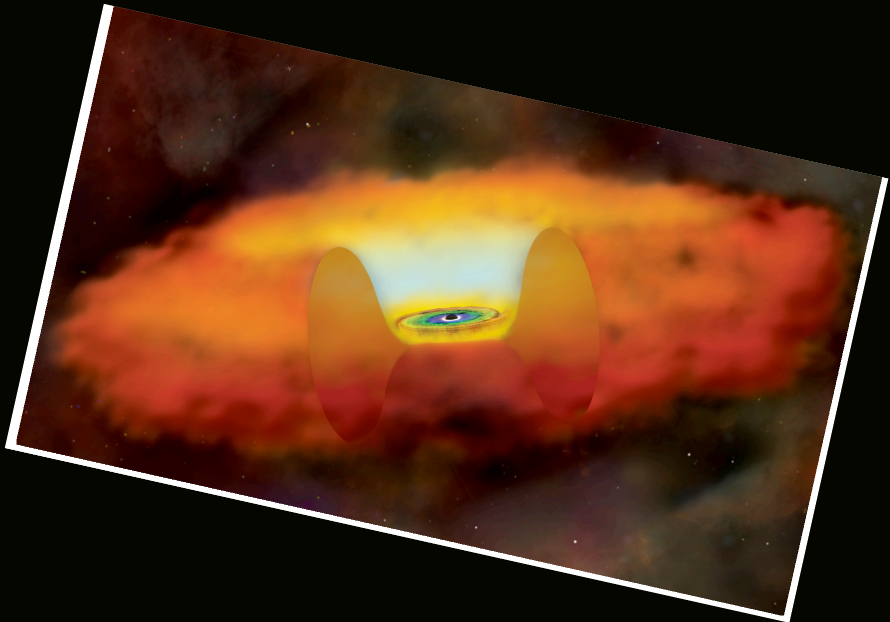
☑ **C_T (obscured) is (on average) always larger than C_T (unobscured)**

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

Appendix

(Mid-)IR emission of AGN= nuclear dust

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



Urry & Padovani '95

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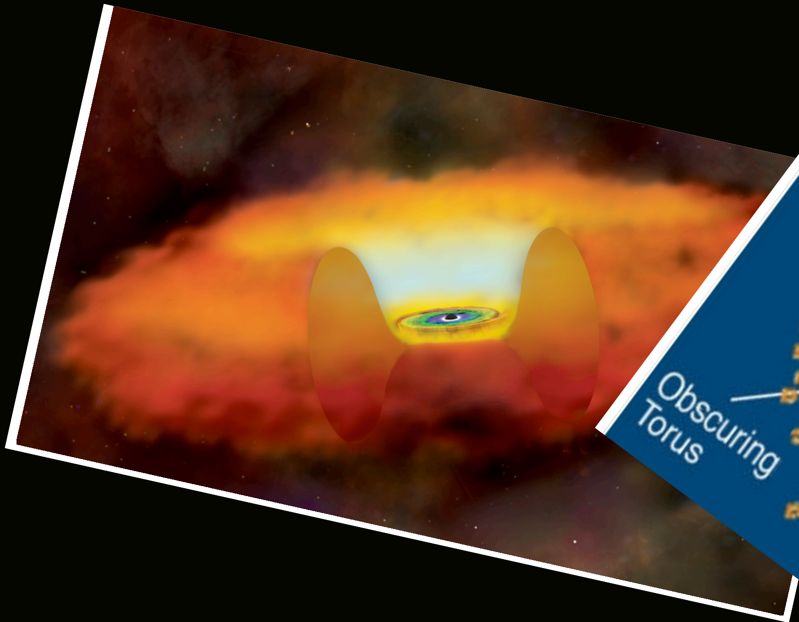
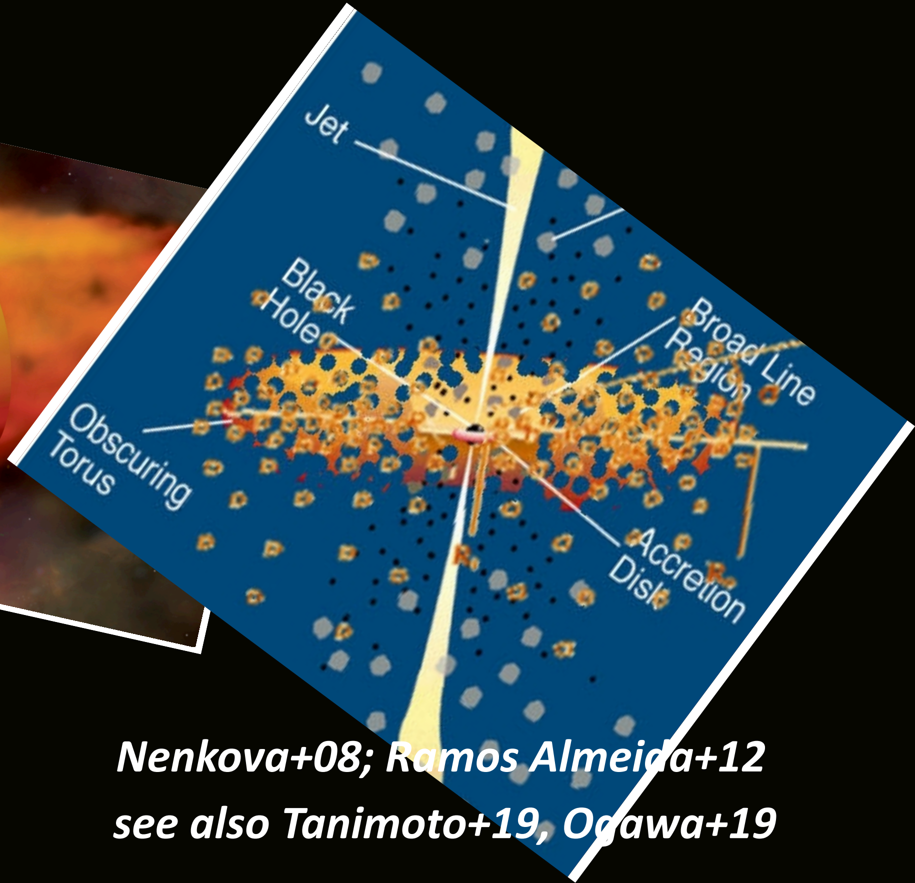


Urry & Padovani '95



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

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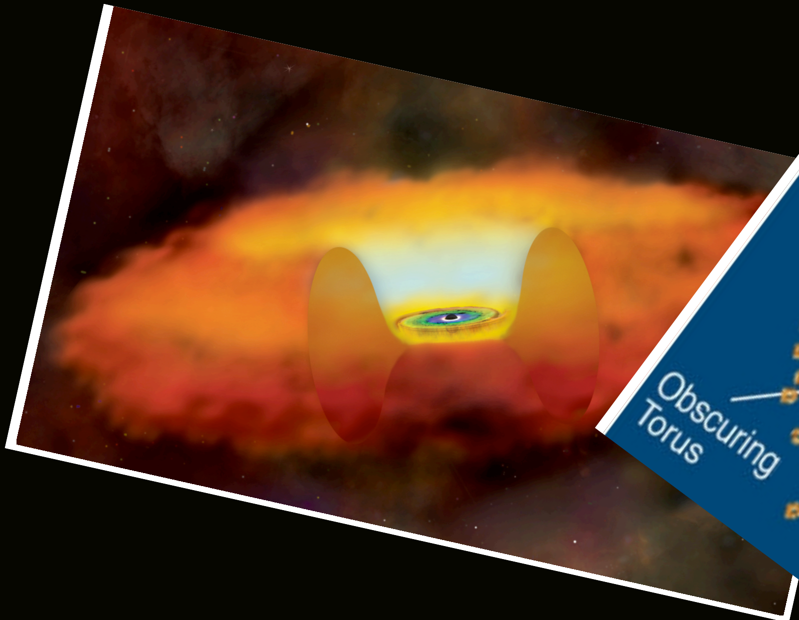
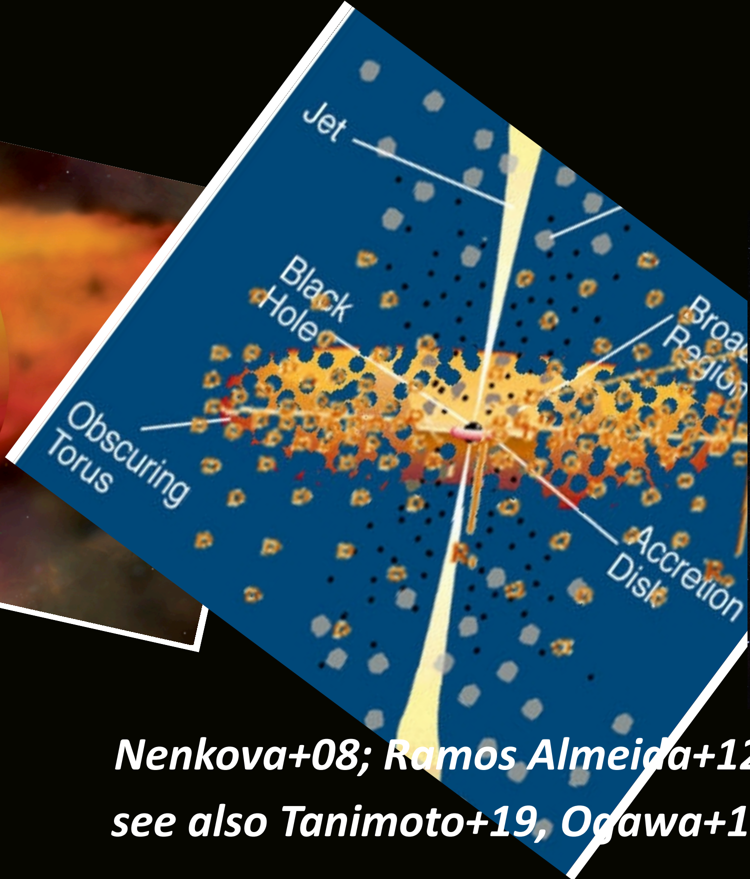


Urry & Padovani '95



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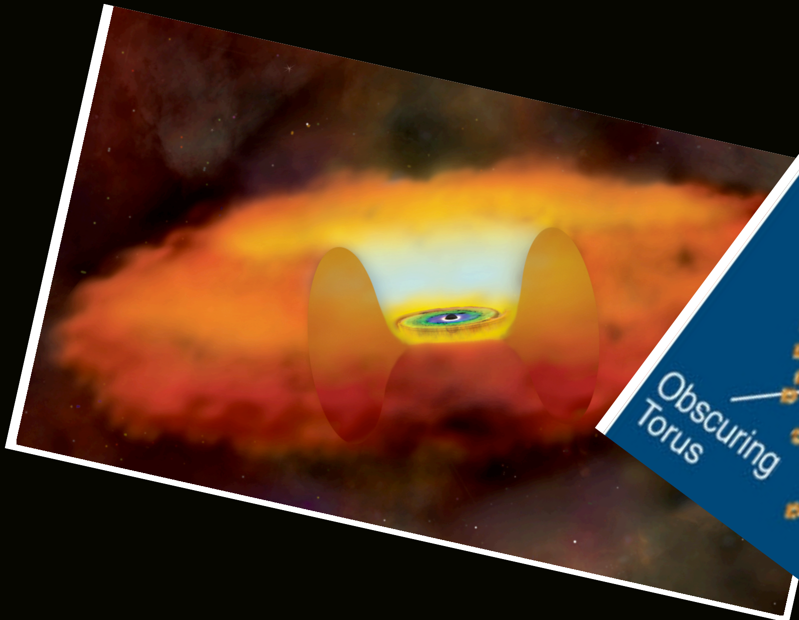
e.g., Hoenig+12, Wada+15, Tazaki & Ichikawa submitted

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

Geometry of (nuclear) dust emission

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



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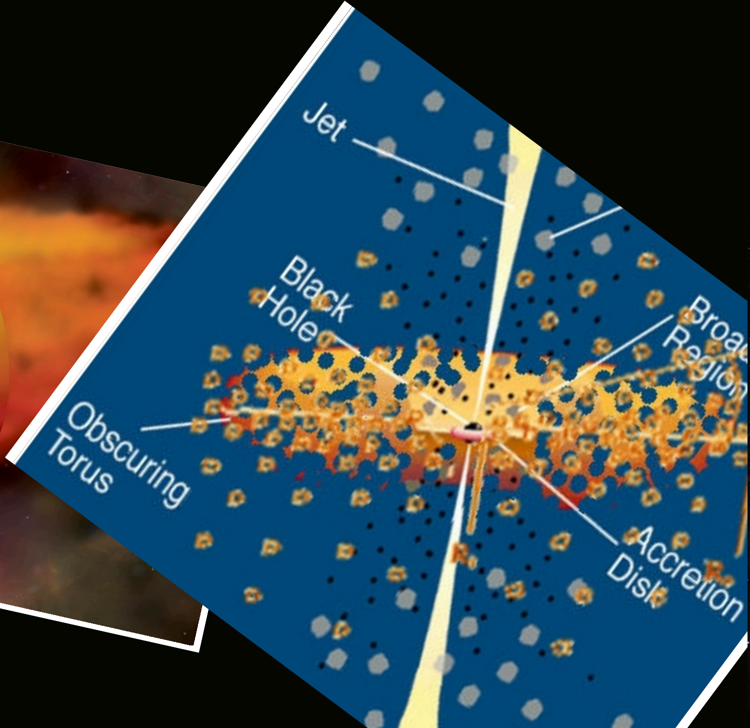


Nenkova+08; Ramos Almeida+12
see also Tanimoto+19, Ogawa+19

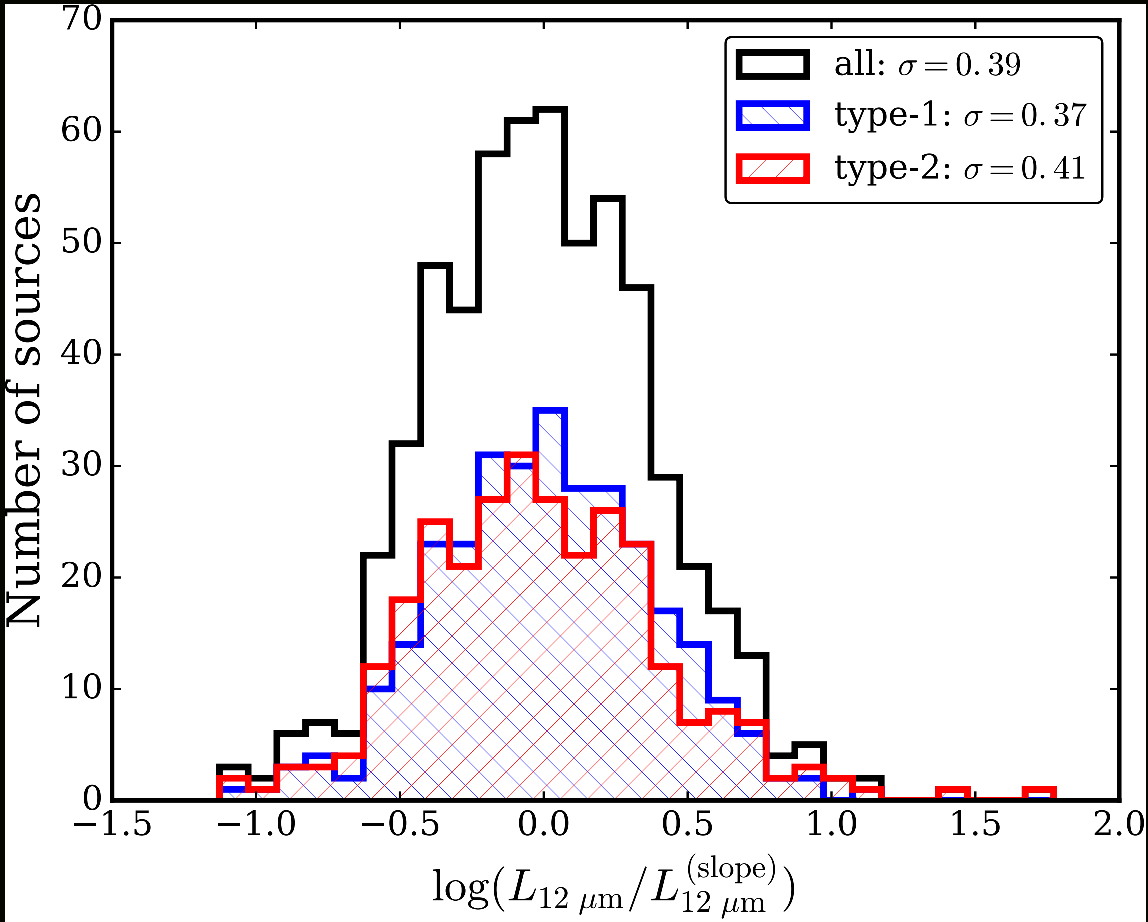
e.g., Hoenig+12, Wada+15, Tazaki & Ichikawa in prep.

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

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

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

Consistency with dust polar emission

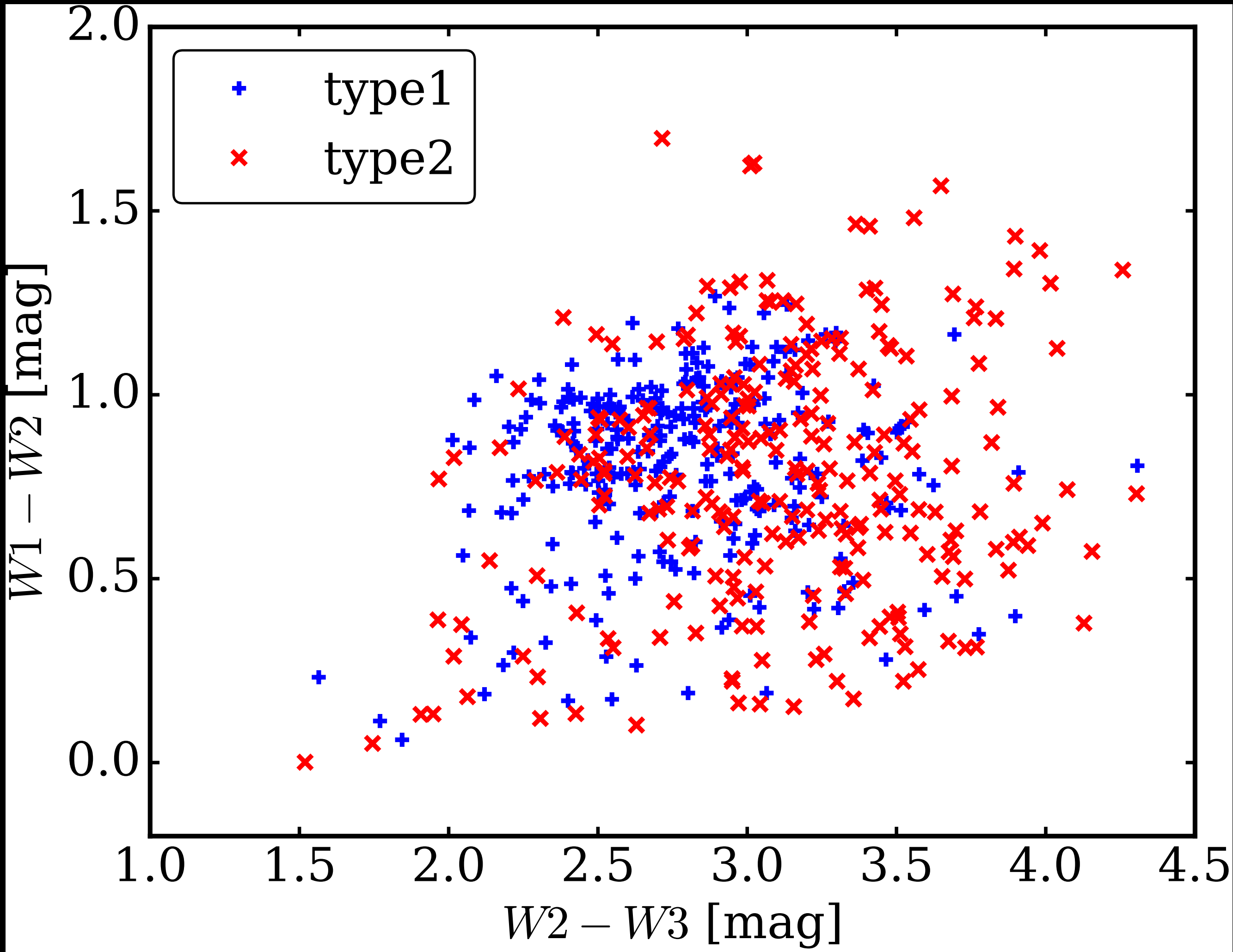


☑ **type-1/-2 has same distribution => isotropic emission**

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

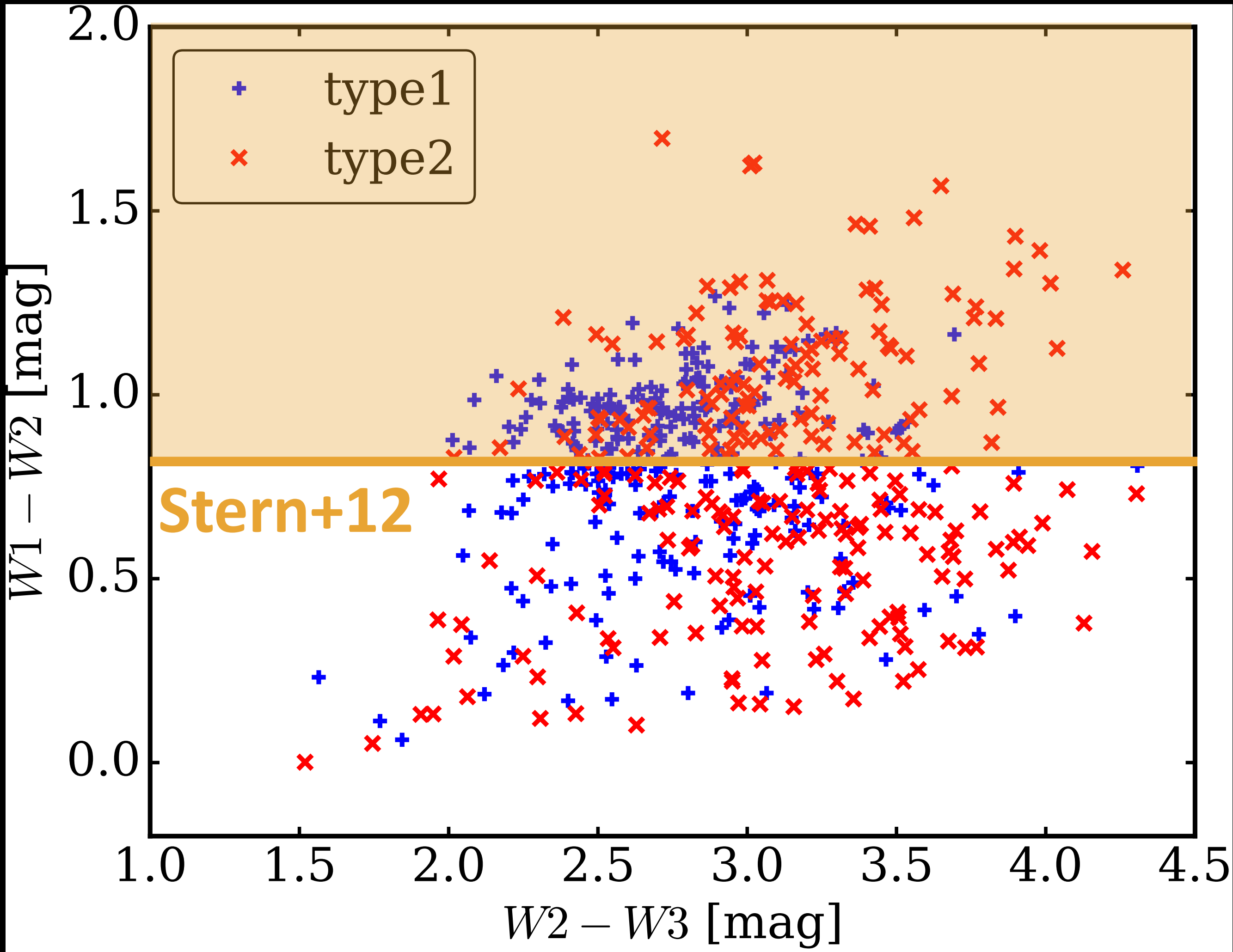
obs: Honig+13,+14, see also Asmus+16
model: Wada 12, Wada+16

WISE IR color-color selection of AGN



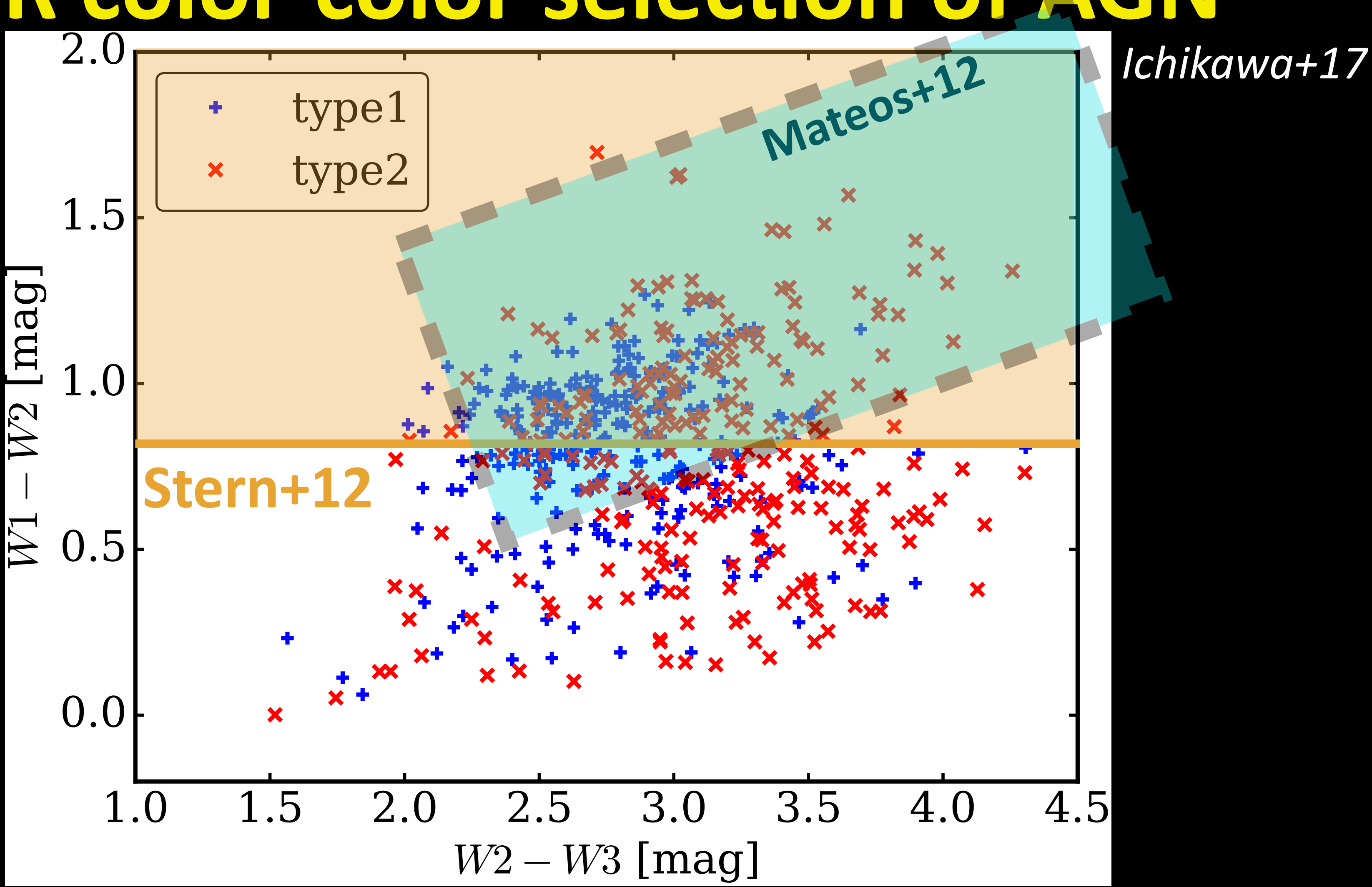
Ichikawa+17

WISE IR color-color selection of AGN



Ichikawa+17

WISE IR color-color selection of AGN



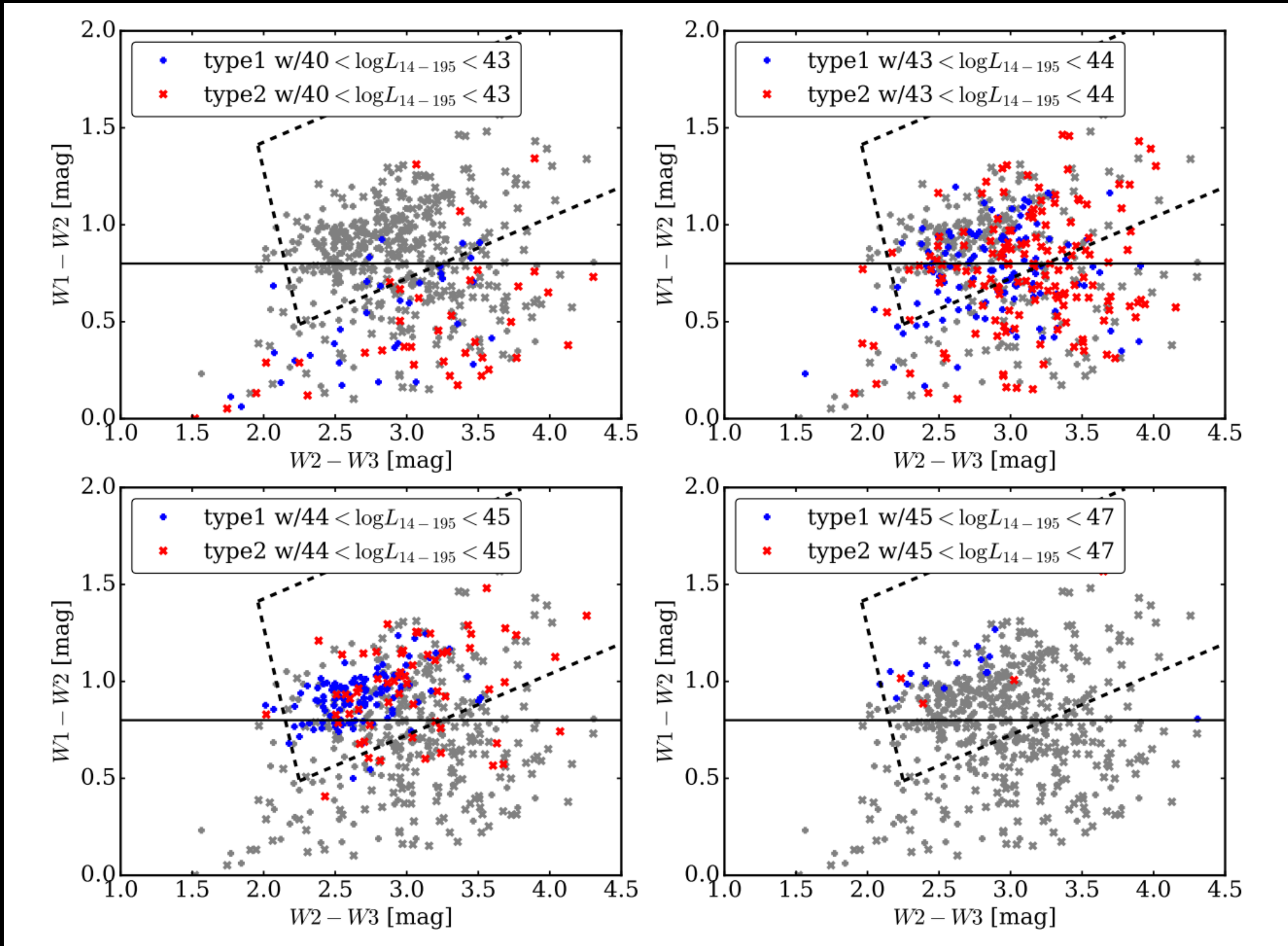
☑ **BAT**-AGN **do not always locate** at the IR selection areas of. Stern+12, Mateos+12

WISE IR color selections miss some AGN population

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

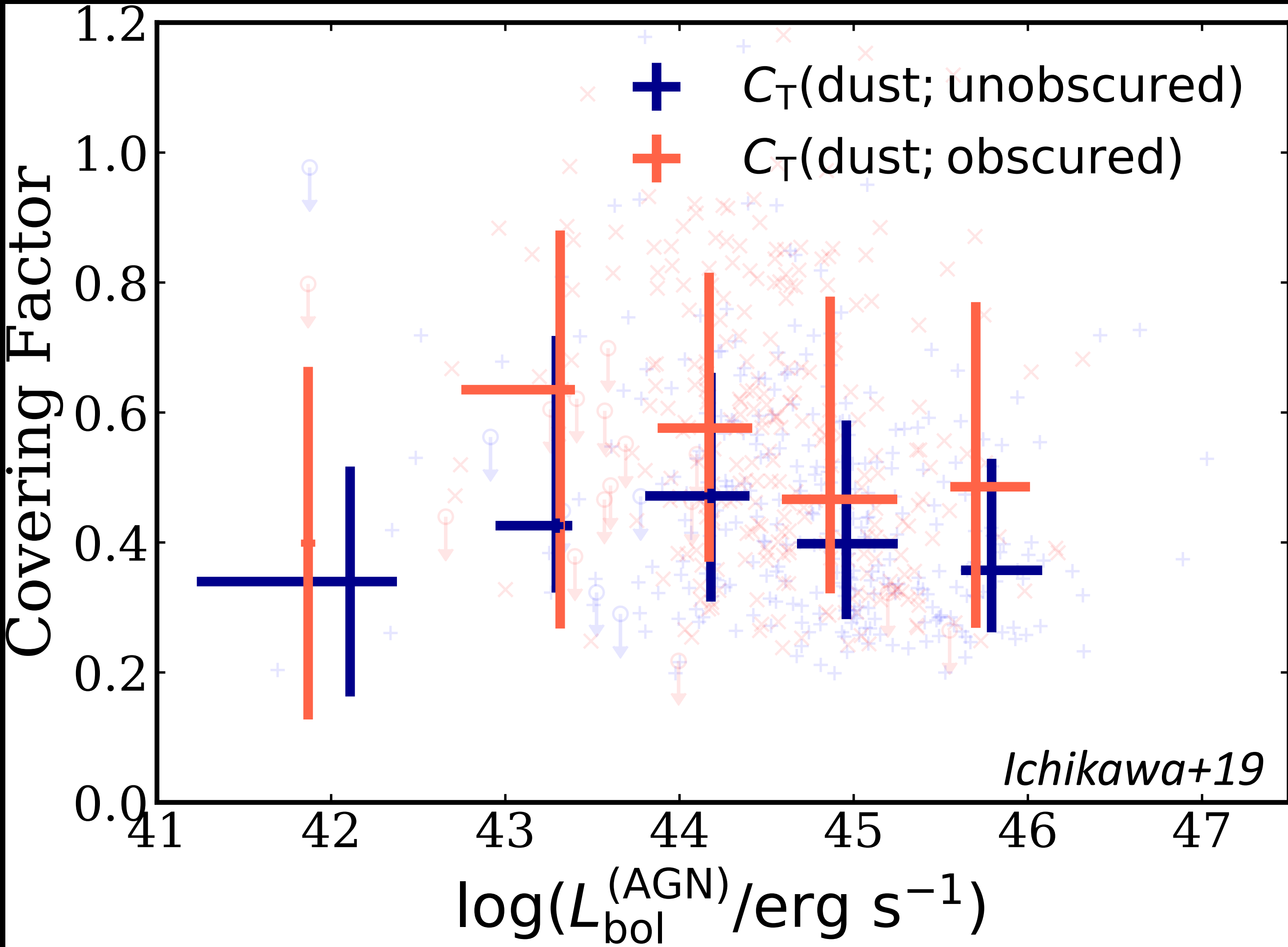
WISE IR color-color selection of AGN

Ichikawa+17



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

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



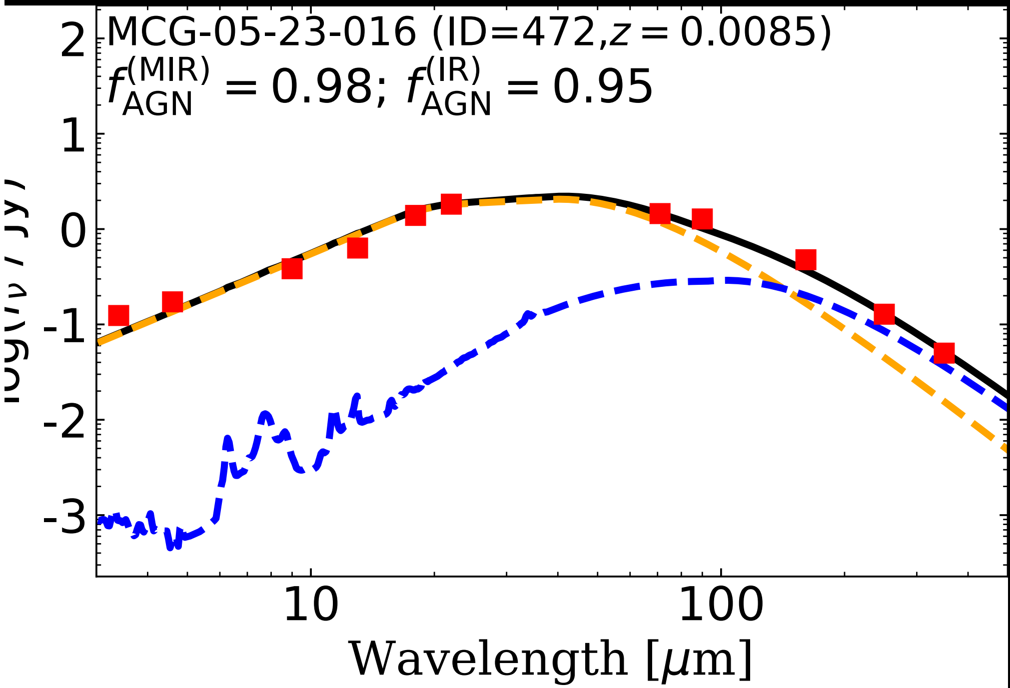
☑ **C_T (obscured) is (on average) always larger than C_T (unobscured)**

=> 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

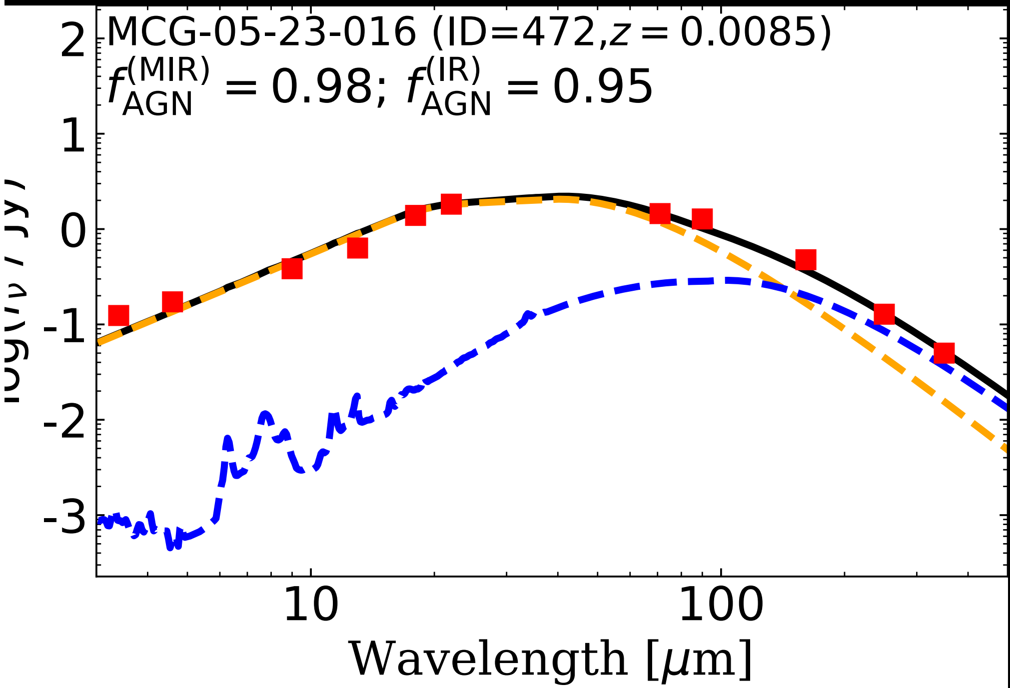
We found 9 "IR-pure AGN" candidates

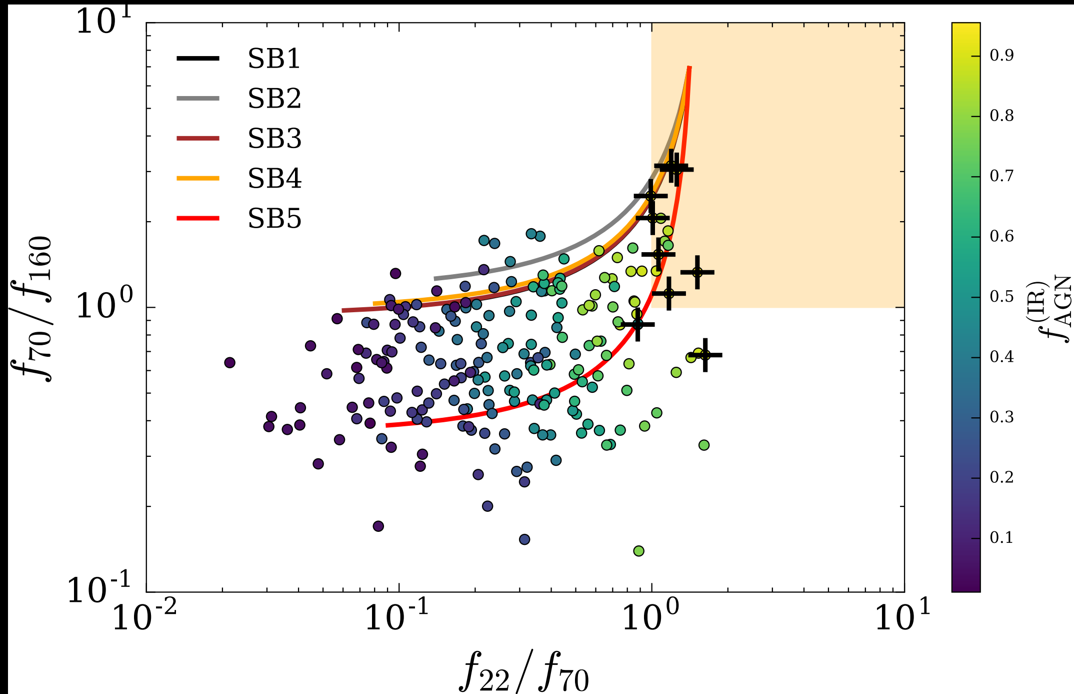


IR-Pure AGN candidates

We found 9 “IR-pure AGN” candidates

Ichikawa+19





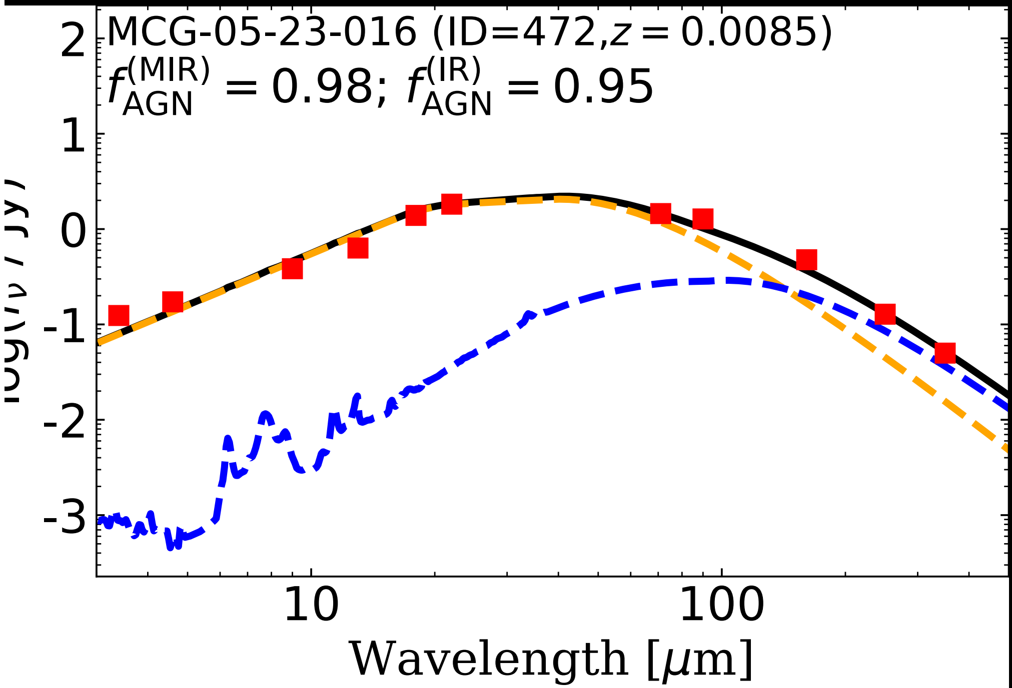
☑ **FIR (up to ~100um) is dominated by AGN torus emission**

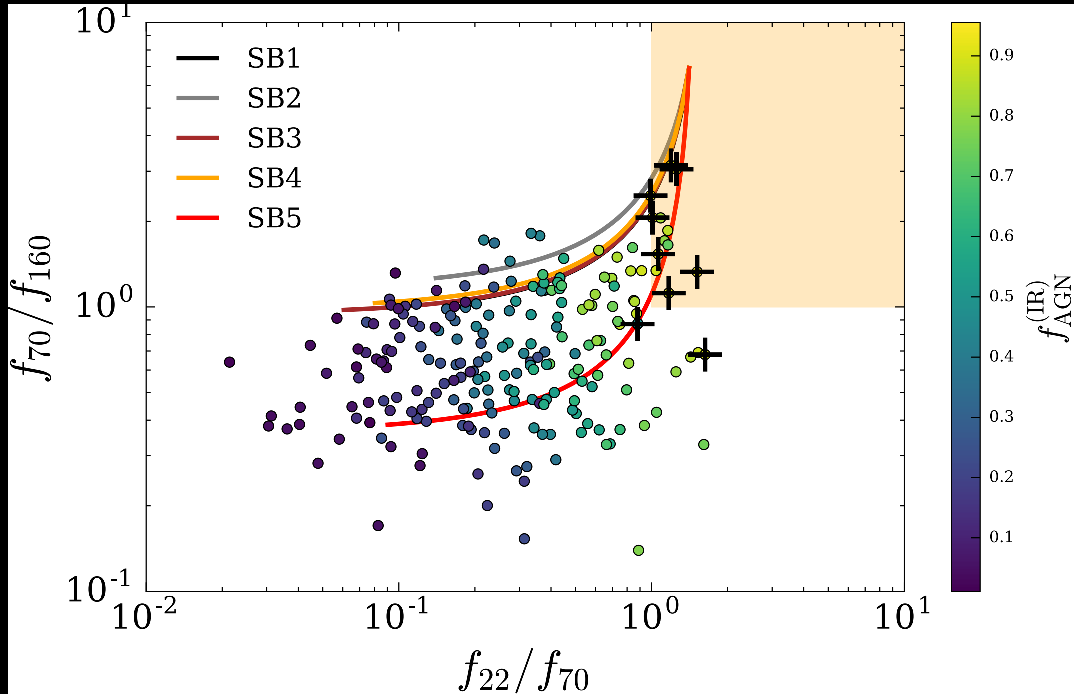
☑ **IR-pure AGN shows the SED w/ $f_{22um} > f_{70um} > f_{160um}$**

IR-Pure AGN candidates

We found 9 "IR-pure AGN" candidates

Ichikawa+19





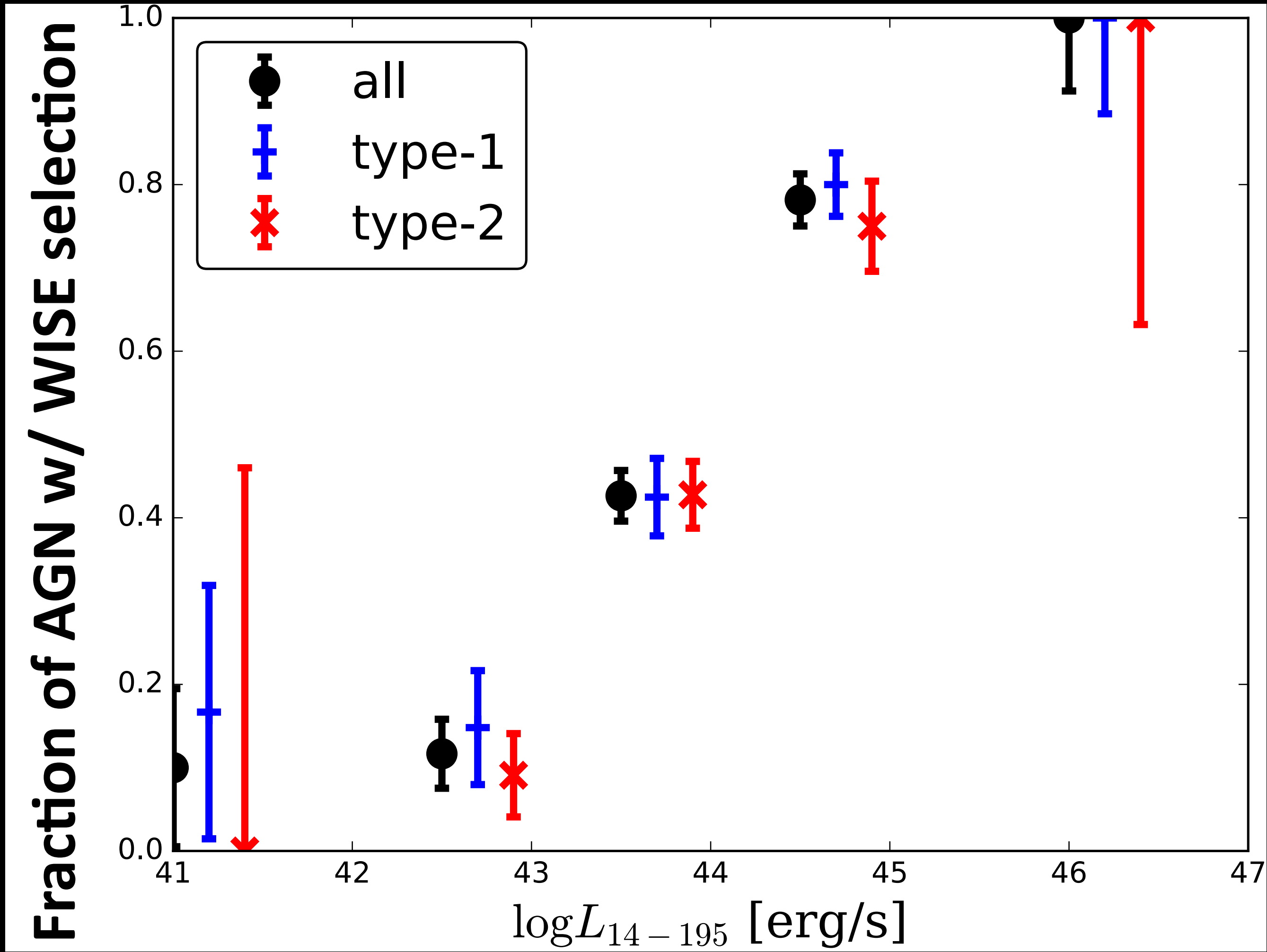
☑ **FIR (up to ~100um) is dominated by AGN torus emission**

☑ **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



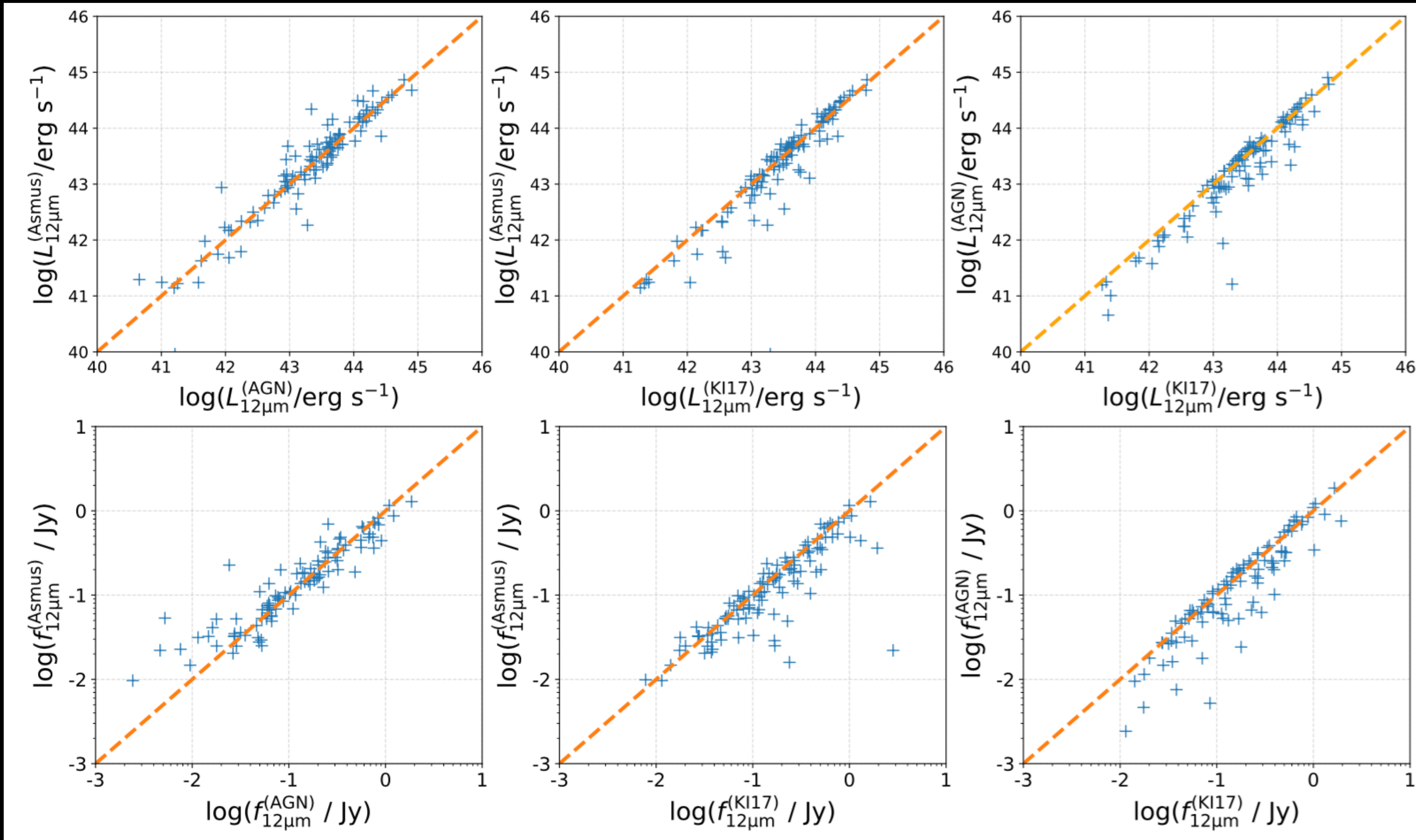
Ichikawa+17

☑ **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

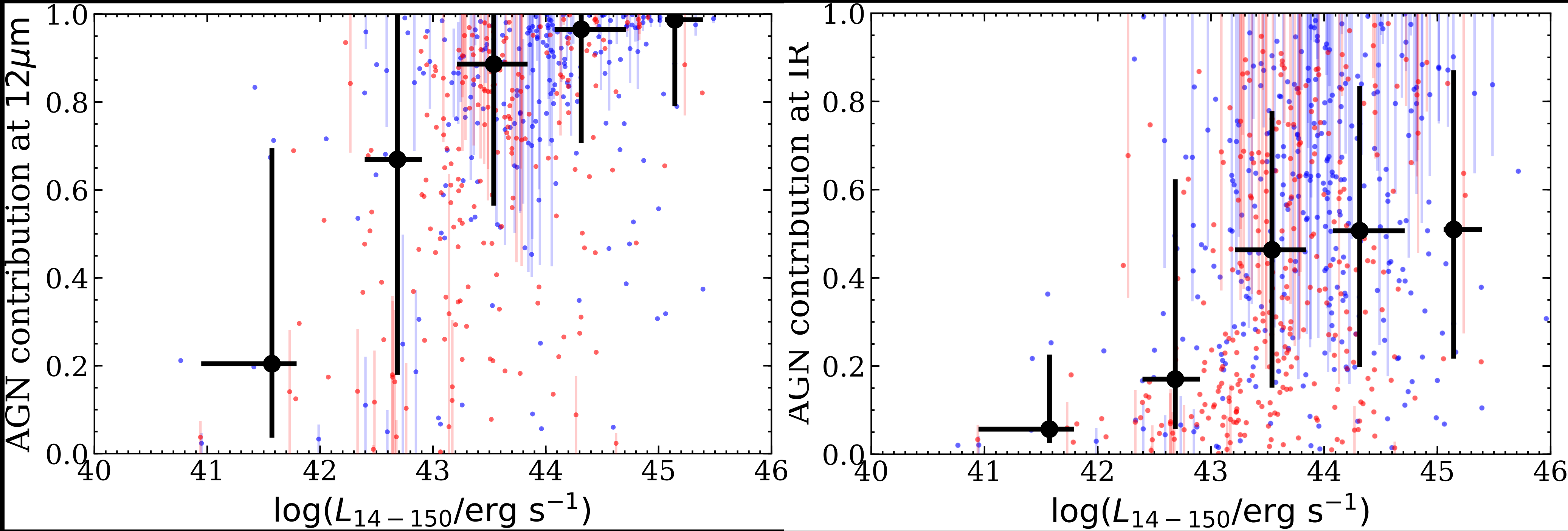
☑ **Decomposition works really well!**



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

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

AGN contribution as a function of L_{BAT}



Ichikawa+19

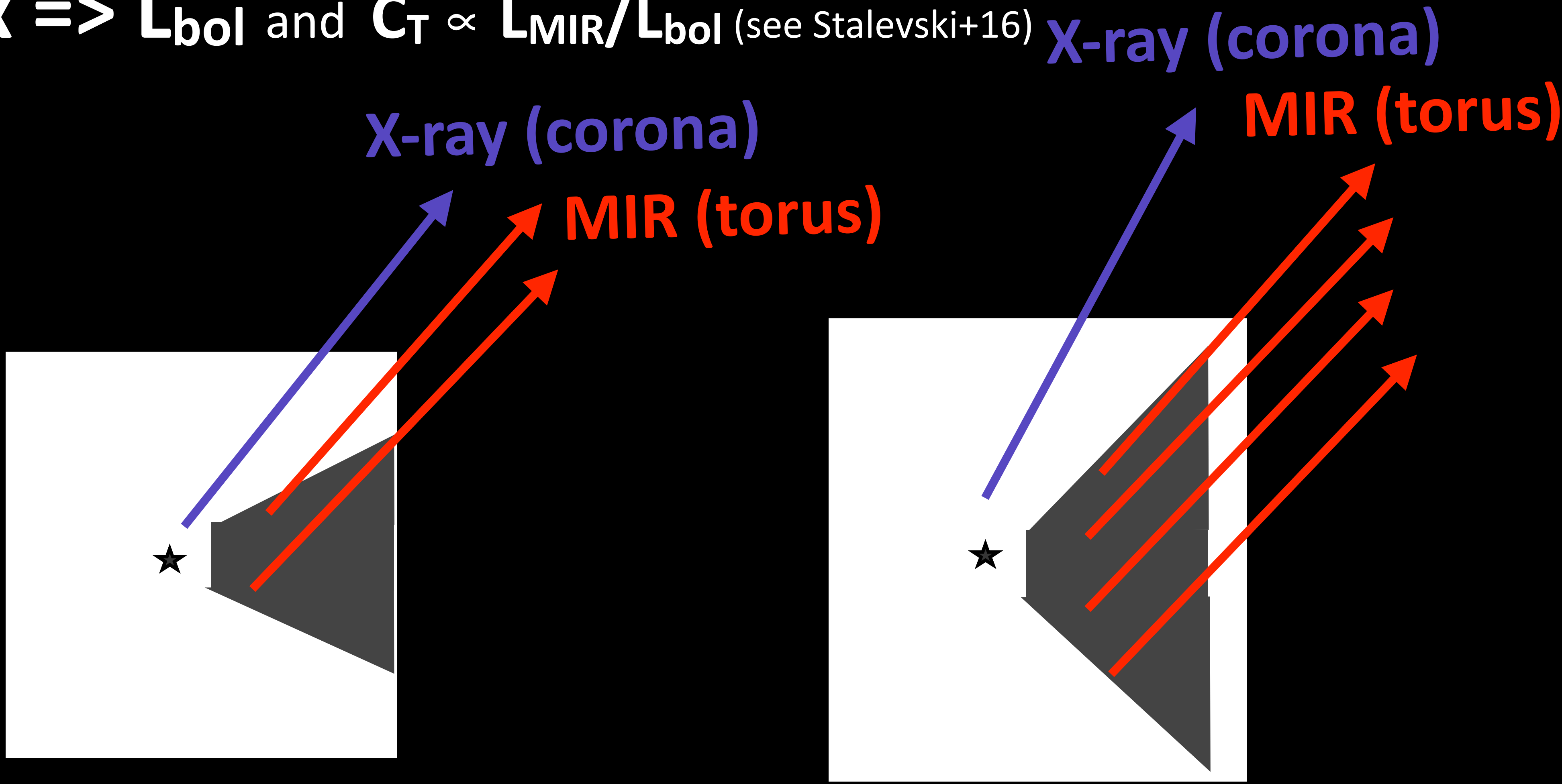
☑ **At high L_{BAT} end,** contribution reaches
~100% at 12um, 80% at MIR (5-40um), and 50% at total IR

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



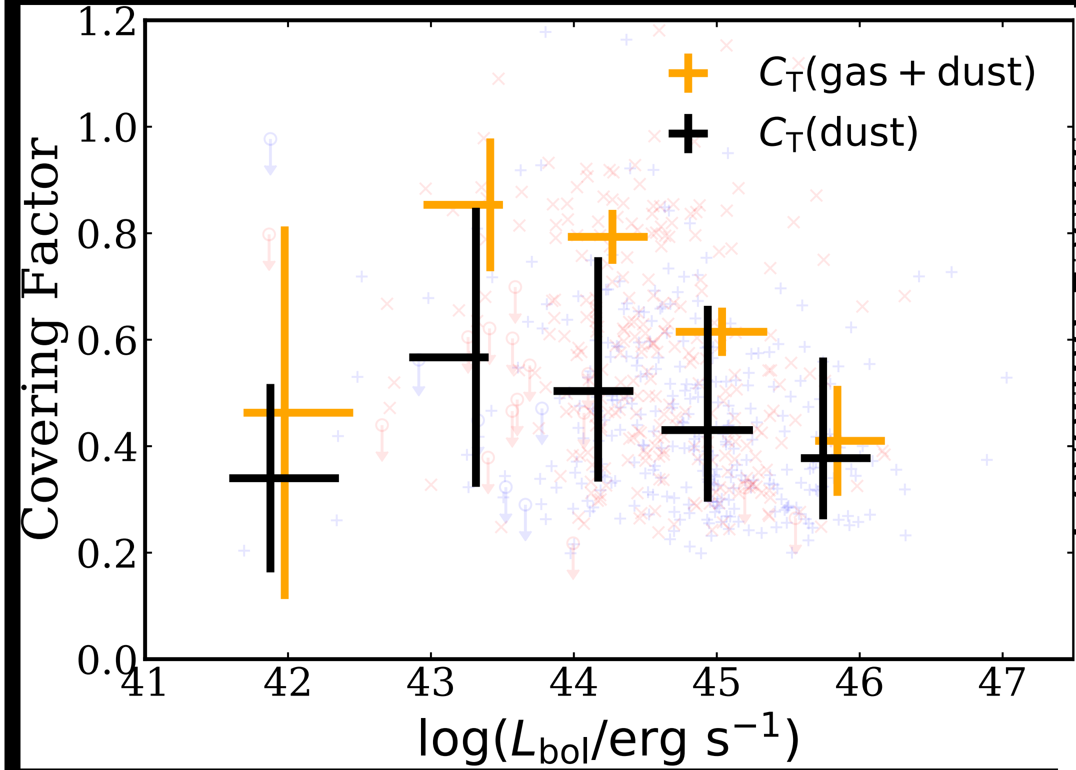
C_T: indicator of geometrical dust obscuration

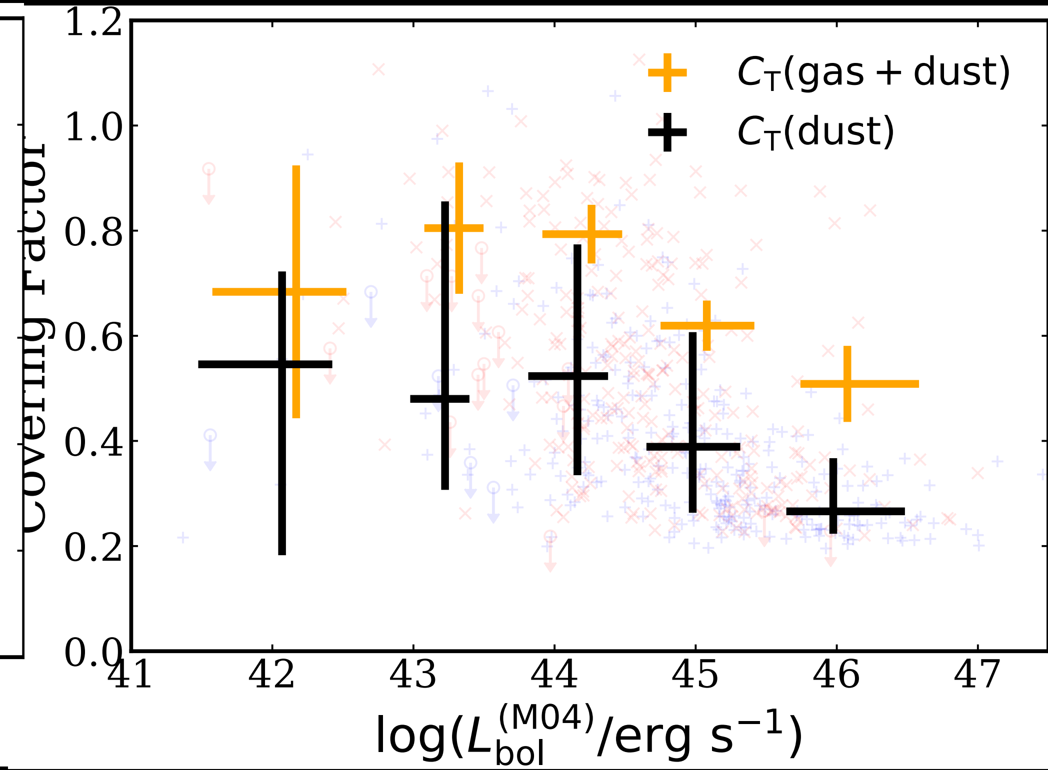
$$L_{MIR} \propto L_{bol} C_T \Leftrightarrow C_T \propto L_{MIR}/L_{bol}$$

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

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

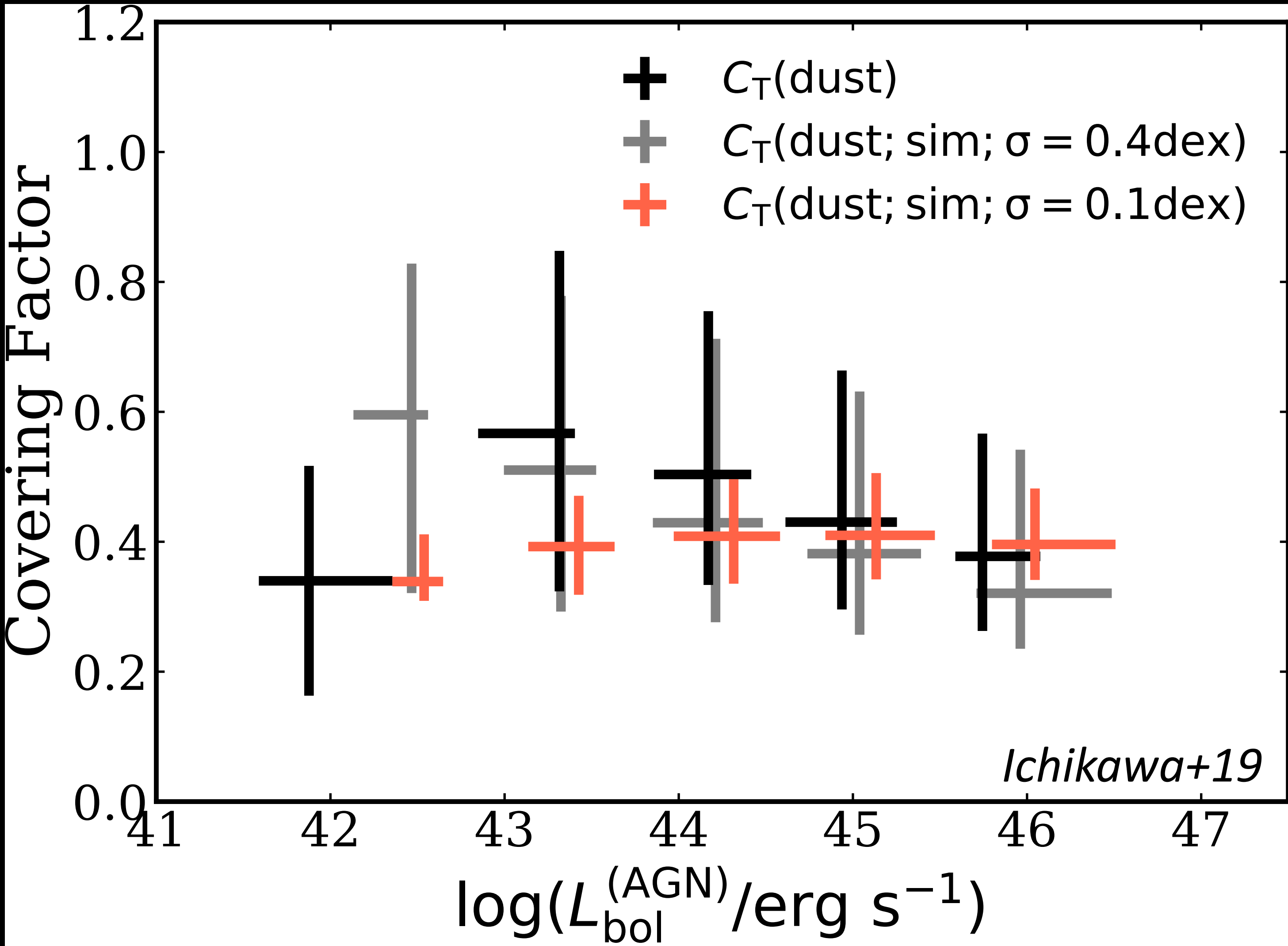
Ichikawa+19





☑ **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)