Galaxy Evolution Workshop 2018 at Ehime Univ.

Looking at drastic AGN luminosity decline in Arp 187 within 10^4 yrs

Ichikawa et al. '16
Ichikawa & Tazaki '17
Ichikawa et al. '18 in prep.

Kohei Ichikawa (市川幸平)

FRIS fellow, Tohoku/Columbia

In collaboration with

H.-J. Bae, Z. Haiman, M. Imanishi, K. Inayoshi, **T. Kawamuro**, M. Koss, N. Levenson, E. Lopez-Rodriguez, K. Matsuoka, R. Nikutta, C. Packham, C. Ricci, M. Schirmer, M. Shidatsu, R. Tazaki, B. Trakhtenbrot, **Y. Toba**, J. Ueda, Y. Ueda

Credit: ESO/M. Kornmesser

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“Dying AGN” in Arp 187

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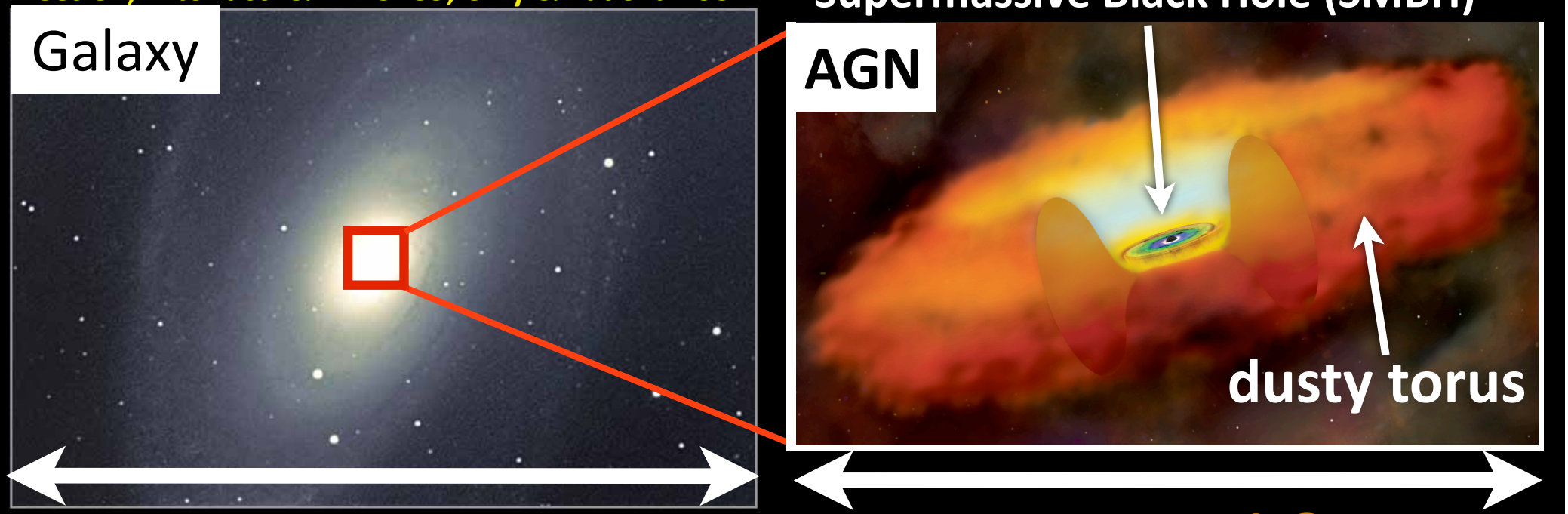
Active Galactic Nuclei (AGN)

Rees 84;Antonucci & Miller 85; Urry & Padovani95



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 even at z~7!

AGN is bright at all wavelength

from R. Hickox's talk at elusive AGN workshop

mid-infrared

optical

soft X-rays

hard X-rays

< 10 keV

> 10 keV

[OIII] line emission

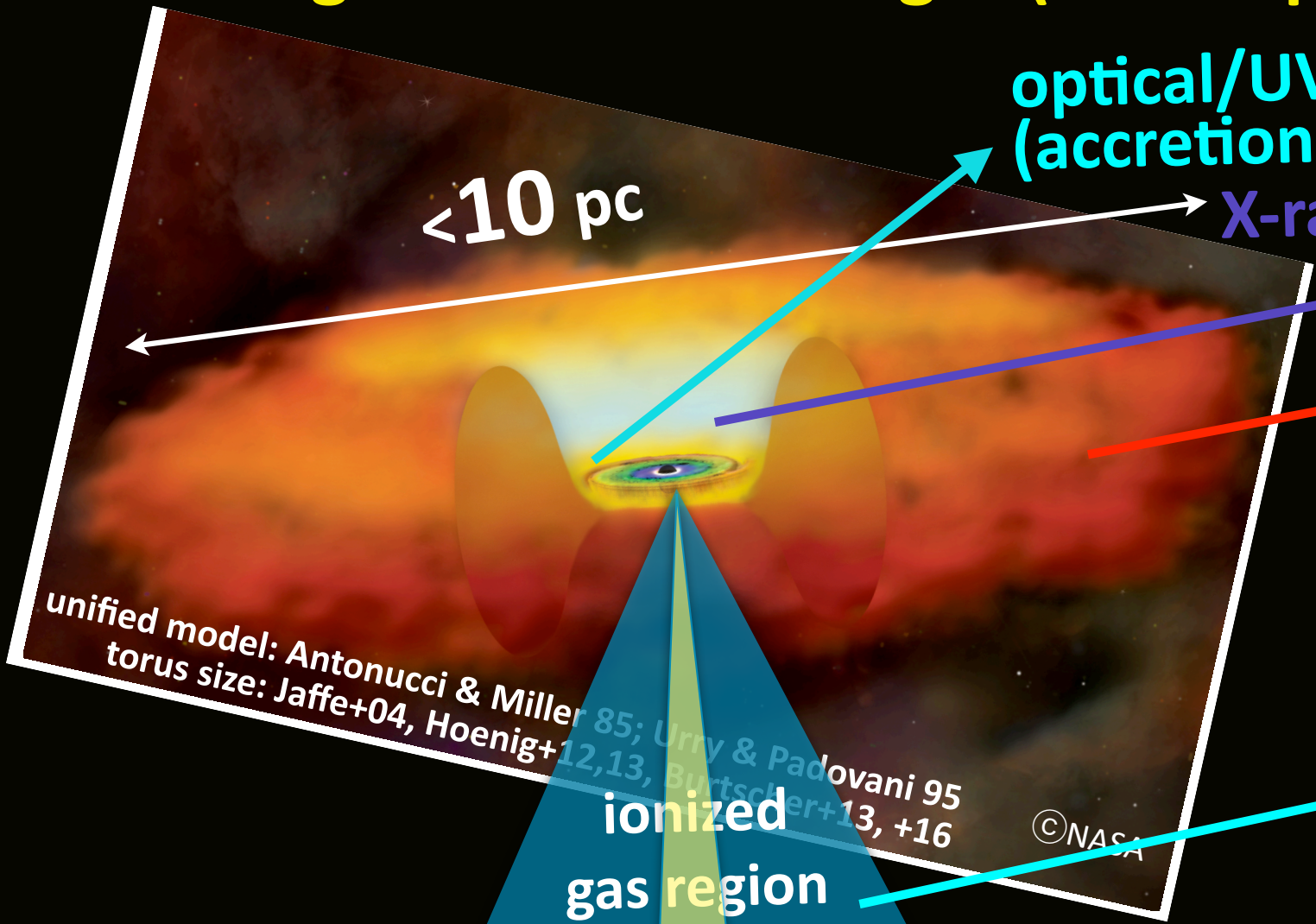
dust torus

accretion disk

narrow line regions (NLRs)

corona

AGN is bright at all wavelength (=multi physical scale)



optical/UV
(accretion disk)

X-ray (corona)

MIR (torus)

[OIII]λ5007

ionized
gas region
(NLR)

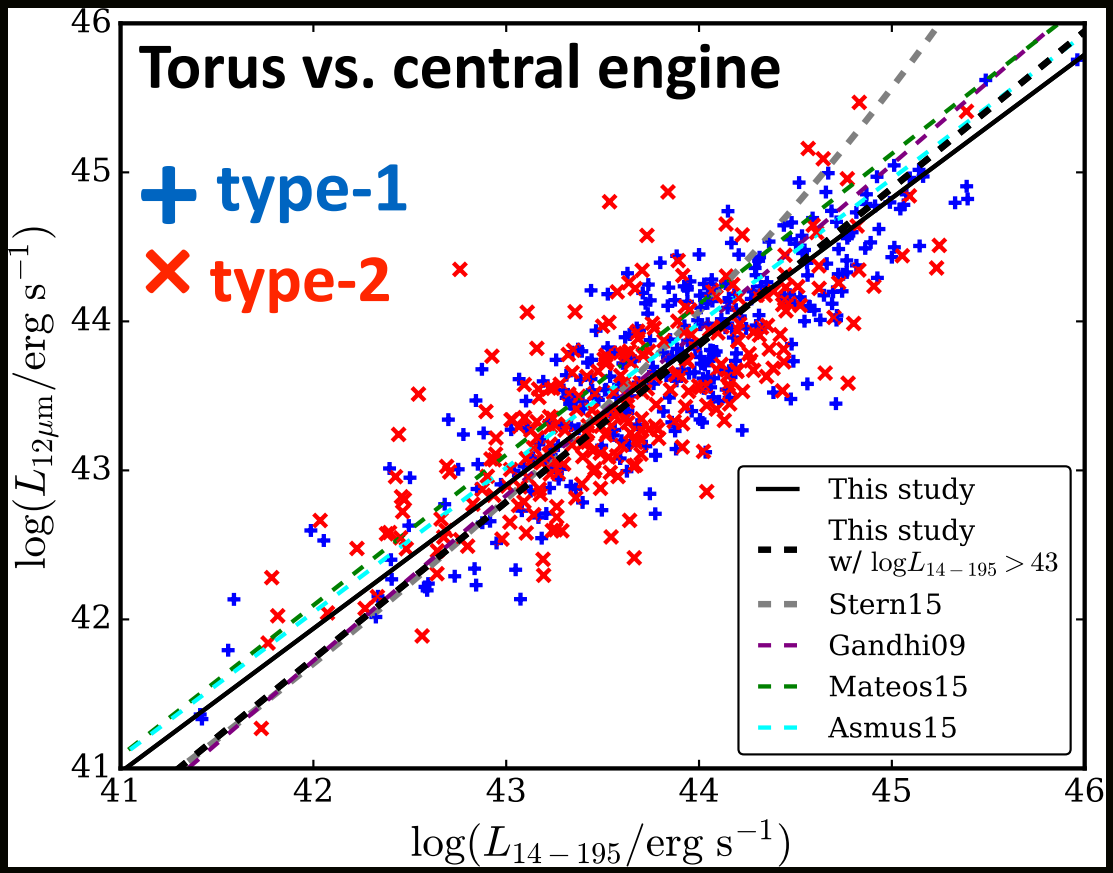
<1 kpc

1-10 GHz

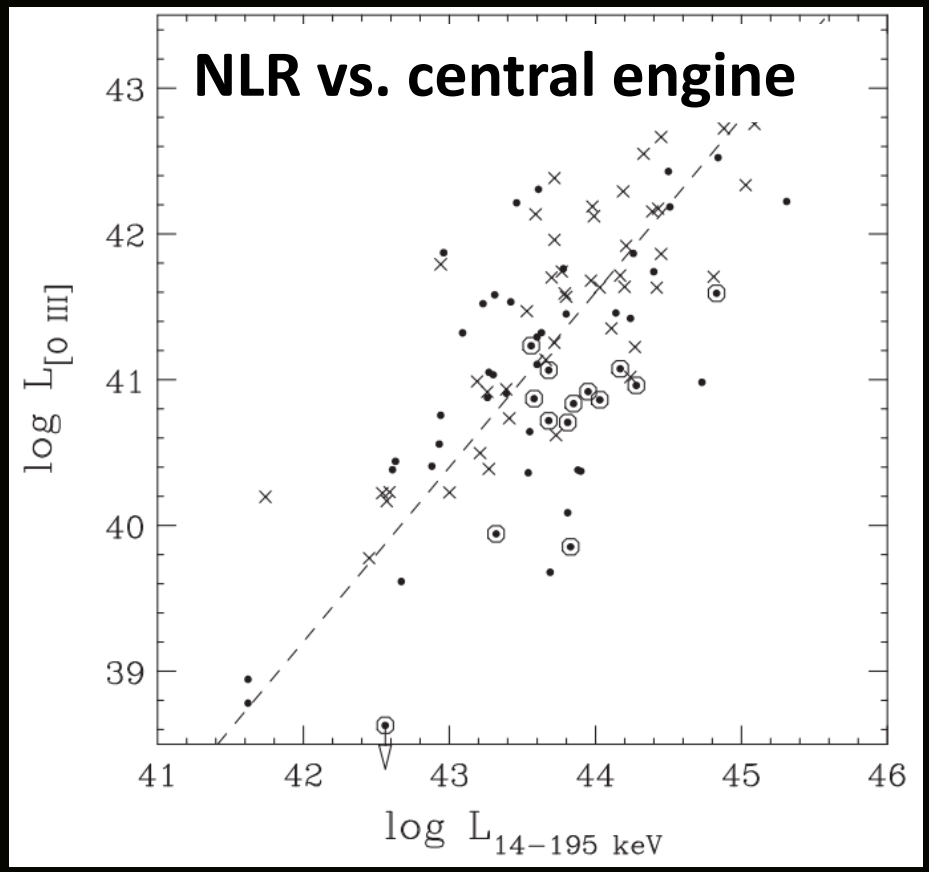
AGN jet

: 1-100 kpc

AGN is bright at all wavelength (=multi physical scale)



Ichikawa+17a (see also Ichikawa+12)



Ueda, Hashimoto, Ichikawa+15
see also Berney+15 (BASS team result)

☑ **strong L-correlation among each AGN component**

=> AGN should be stably bright for over $10^{3\text{-}4}$ yrs
(since NLR size is ~ 1 kpc~ 3000 light yrs)


There are multiple AGN indicators
and
each AGN indicator traces “different” physical scale
and this gives us the good science results!!

Key question: AGN lifetime

AGN life time: observationally poorly constrained

- ☑ **Total Accretion time scale: $10^{7\text{-}9}$ yr (e.g., Marconi+04)**
- ☑ **One AGN lifecycle: 10^5 yrs?**

(**AGN *flickering*;** Hopkins & Quataert '10; Novak+11; Schawinski+15;
see also ***Schirmer+16, Kawamuro (incl. KI)+17 on the thermal echo***)

How fast do AGN drop its luminosity?

- ☑ **1-2 orders of mag in 10^5 yr?**
  (Hanny's voorwerps e.g., Schawinski+10; Keel+12,15,16, Sartori+17**)**

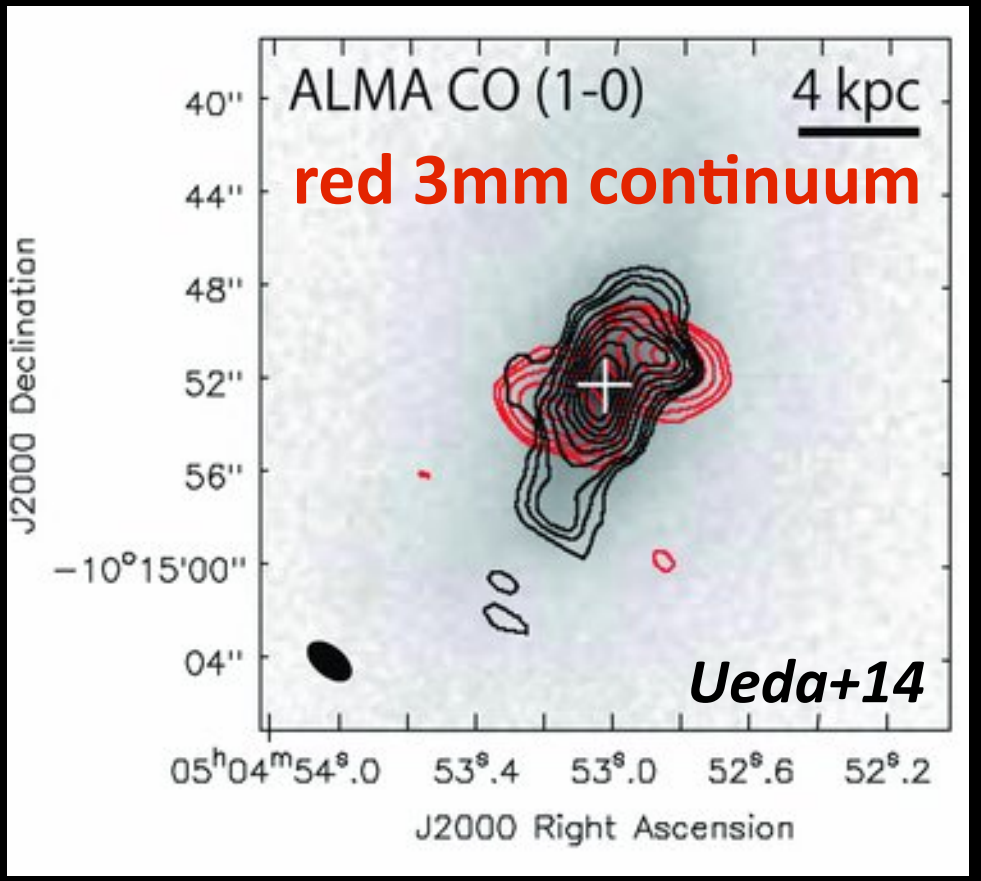
- ☑ **1 order of mag in 10 yr**
  (changing-look QSO/AGN; Tohlin & Osterbrock '76 ;LaMassa+15, MacLeod+16**)**

It might be highly related to AGN accretion disk state?

Here I report an interesting AGN

Arp 187

Arp187: Merger remnant LIRG (Rothberg & Joseph '04)



ALMA observations (Ueda+14)

- ☑ CO(1-0) associates with host galaxy K band emission
- ☑ 3mm continuum does not associate with CO(1-0) distributions
- ☑ Some dusty outflow occurs? or radio-jet?

Arp 187: VLA observations

VLA 5, 8.5 GHz show bipolar jet lobes

Ichikawa+18 in prep.

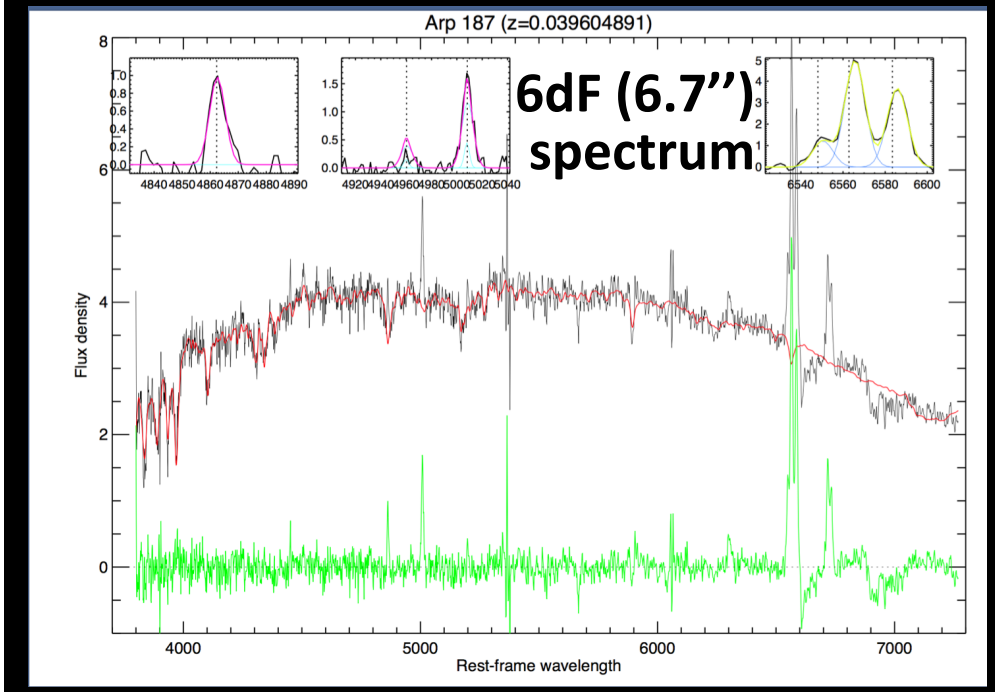
Jet properties

- ☑ Both lobes show spec index α=-1 => synchrotron jet
- ☑ jet kinetic age: 6×10^4 yr (jet angle=90° w/ v=0.1c)
- ☑ **jet core seems absent (f_{5GHz} < 210 μJy)**

=> current AGN activity might be silent?

Optical spectrum = NLR activity (~ kpc)

BPT diagram: NLR (probably) exists



Ichikawa+18 in prep.

Optical properties: suggest quasar class luminosity

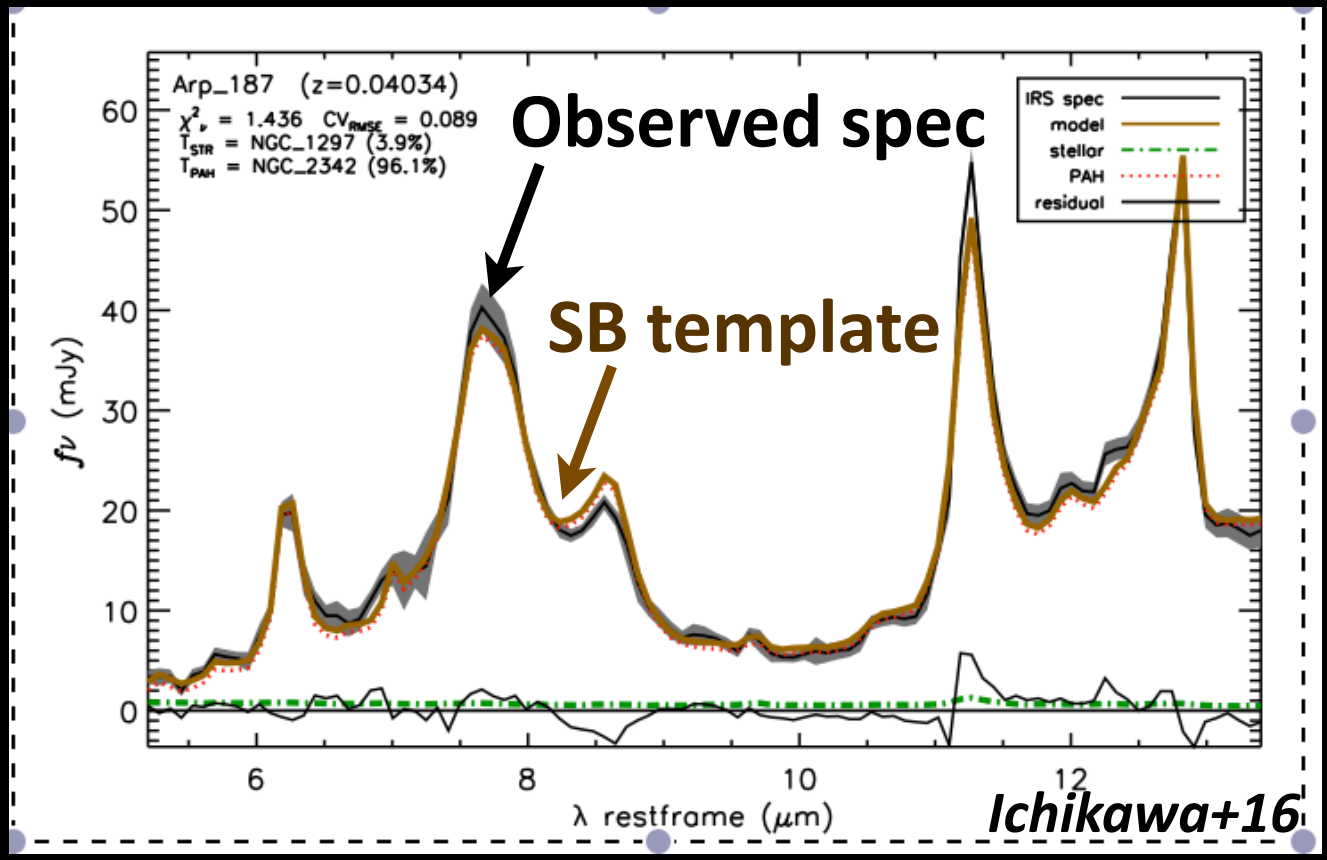
☑ detections of Ha, [NII], [SII], [OI]λ6300, [OIII]λ5007, Hb

☑ log $L_{[OIII]}^{(int)}$ =42.5, log $L_{[OI]}^{(int)}$=42.3 => **log L_{bol} = 46.2** (Netzer '09)

mid-IR = torus activity (<10 pc)

Spitzer/IRS (w/4.5''): SB dominant spectra

=> AGN torus emission (<10pc) is faint



☑ log L_{12um} < 42.2 => $L_{2\text{-}10keV}$ < 42.5 => **L_{bol} < 43.3**

(see also *Gandhi+09; Ichikawa+12;+17*)

X-ray (= electron corona << 0.1 pc)

No previous deep X-ray observations for this target

Swift/BAT all-sky survey (E=14-195 keV)

☑ Not listed in the catalog (Baumgartner+13)

=> $L_{14\text{-}195keV} < 2.8\times10^{43}$ erg s^{-1}

=> consistent w/IR upper limit: $L_{14\text{-}195keV} < 5.9\times10^{42}$ erg s^{-1}

ROSAT all-sky survey (E=0.5-2 keV)

☑ Not listed in the catalog (Voges+99)

=> $L_{0.5\text{-}2keV} < 8.8\times10^{42}$ erg s^{-1}

=> consistent w/IR upper limit: $L_{0.5\text{-}2keV} < 2.0\times10^{42}$ erg s^{-1}

(Γ=1.9; e.g., Brightman+13)

Not located in the XMM-slew survey region

=> Obs. w/ Nustar, XARM, and/or Chandra is crucial

=> NuSTAR (cycle-4) obs. is awarded! (PI: KI)

BH mass of Arp 187

Using M_{BH} - M_{bulge} relation, we estimate M_{BH}.

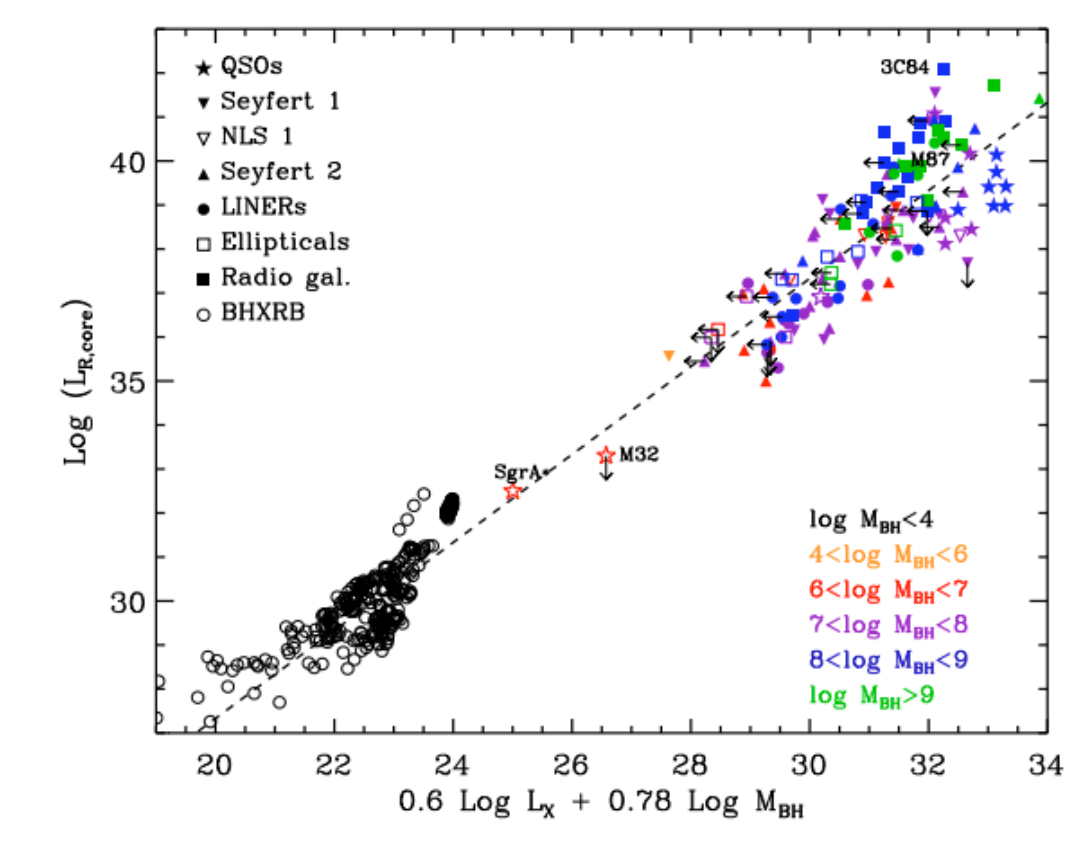
☑ L_{Kband} => $M_{stellar} = 1.3\times10^{11}\ M_{sun}$ w/$n_{sersic} \sim 4$ (Rothberg & Joseph '04)

=> $M_{stellar} \sim M_{bulge}$

=> **$M_{BH} \sim 7\times10^{8}\ M_{sun}$** (Kormendy & Ho 2013)

BH fundamental plane

If you have either two values of $L_{5GHz\ (core)}$, $L_{2\text{-}10keV}$, M_{BH}, then you can estimate the final one.



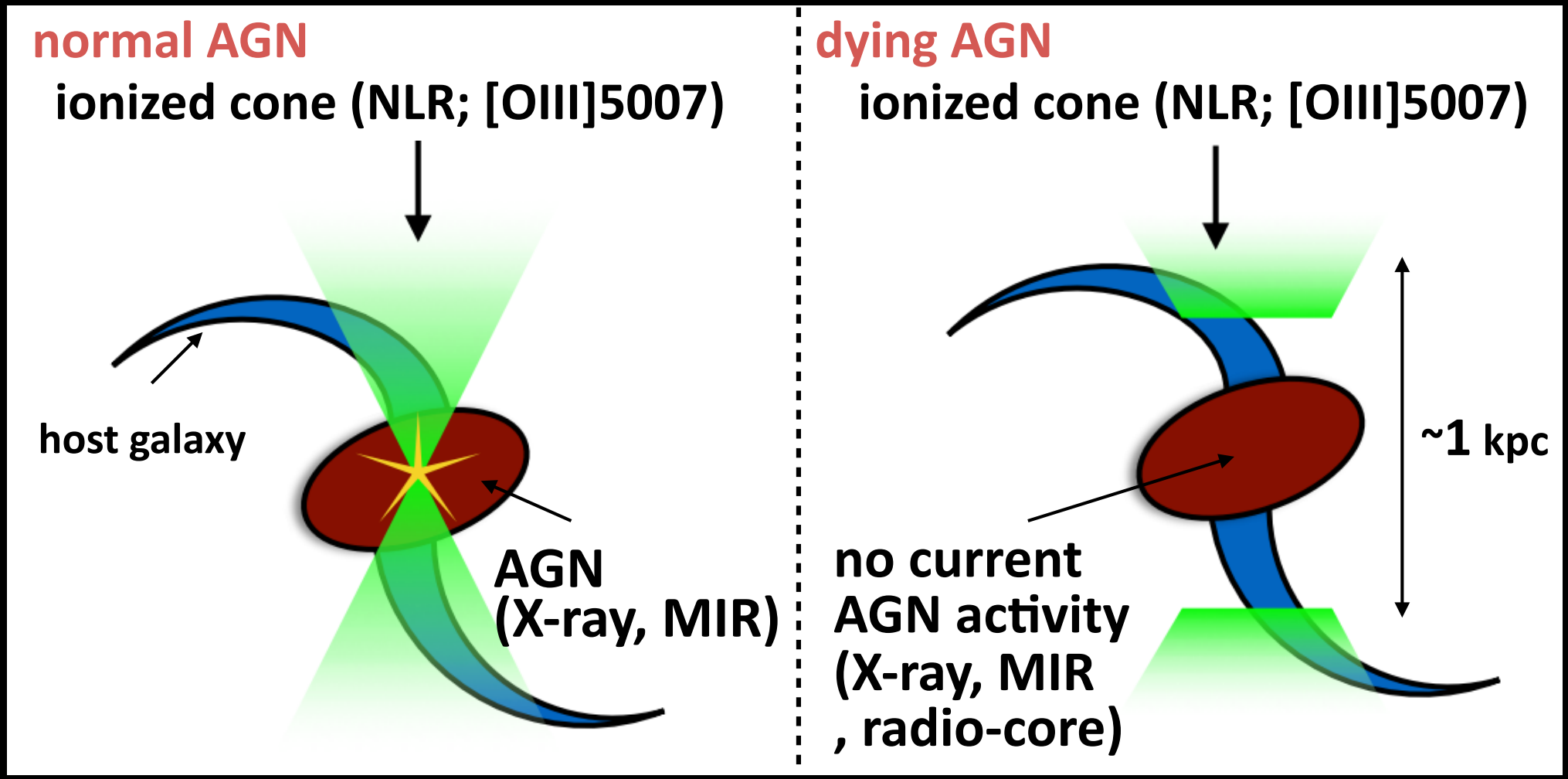
Merloni+03
Heinz+03
Yuan+14

Upper limit of L_R, and M_{BH} are given, then

☑ log $L_{2\text{-}10keV}$ < 39.6 => log L_{bol} < 40.9

What is happening in Arp 187?

- ☑ Signs of NLR, jet (> kpc)
- ☑ Absence of torus, radio core (<10 pc scale)
- ☑ AGN "was" active ~$10^{3\text{-}4}$ yrs ago, but AGN "is" dead => dying AGN



(e.g., Schawinski+15; Ichikawa+16; Ichikawa & Tazaki '17)

AGN “light curve” of Arp 187

Ichikawa et al. (2018) in prep.

L_{AGN}: $10^{3\text{-}4}$ times fainter in ~$10^{3\text{-}4}$ yr

Next questions: searching more dying AGN, but How?

L_{AGN} decreases at least $10^{3\text{-}4}$ times in ~$10^{3\text{-}4}$ yr

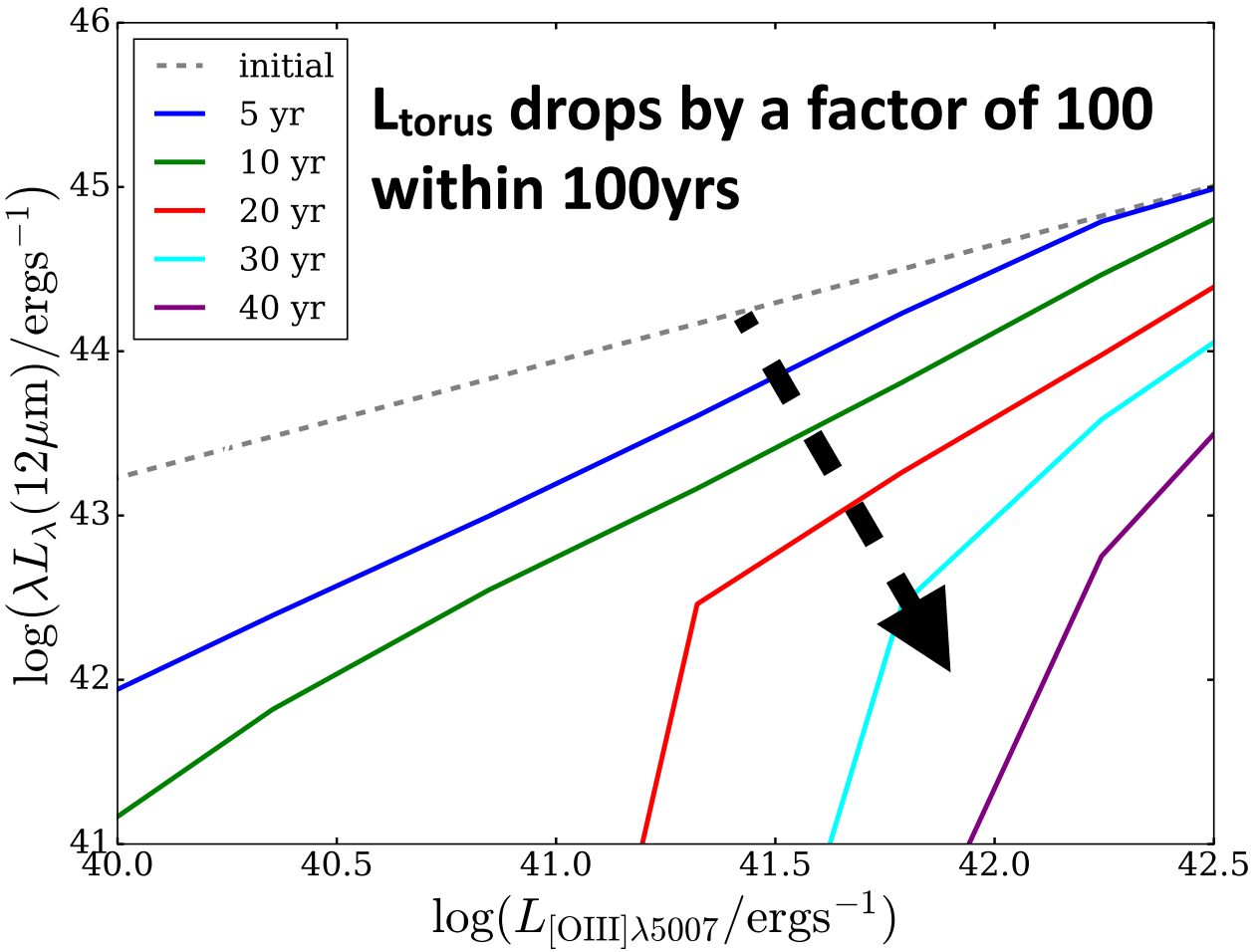
…but, only one source yet!

1. How long can we observe AGN torus after AGN quenching?
   ☑ see Ichikawa & Tazaki ’17, ApJ, 844, 21

Searching more dying AGN

☑ L(12um=torus) vs. L[OIII] (=NLR) is a good plane to search dying AGN

Ichikawa & Tazaki '17



Torus luminosity (current AGN activity)

NLR luminosity (past AGN activity)

Conclusion and Summary

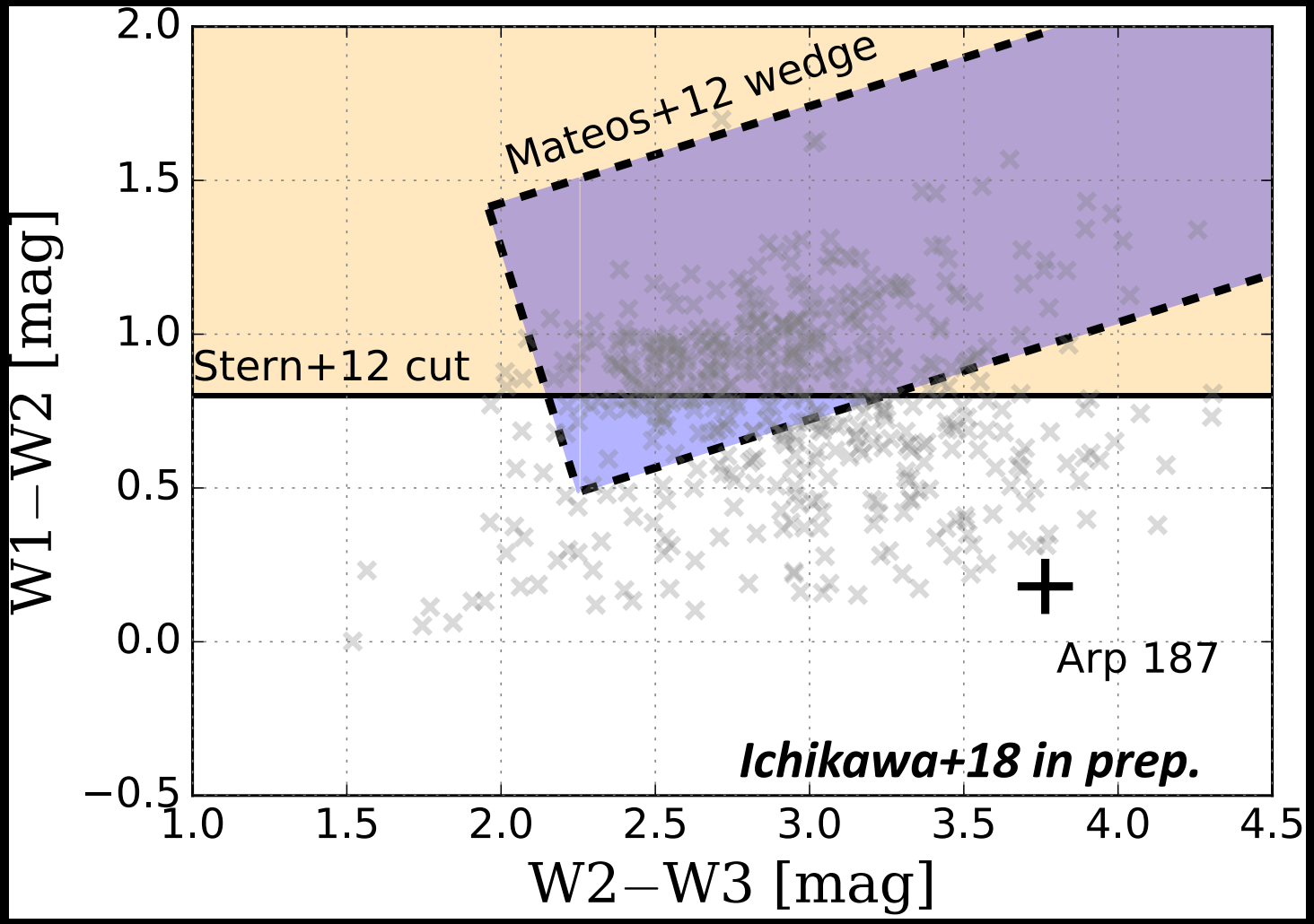
☑ AGN is bright at all-wavelength, and each band traces the different AGN component with different physical scale

☑ We found a "dying" AGN in Arp 187, whose current AGN activity is already quenched, but past AGN activity is still observable.

☑ AGN drops its luminosity by a factor of 10^{3-4} within 10^{3-4} yrs

☑ AGN torus cools down rapidly with <100 yrs. Finding outliers in the L(torus) vs. L(NLR) relation is a promising method to search dying AGN

AGN torus: WISE IR color-color diagram



- ☑ WISE IR color-color cannot pick up Arp 187 as AGN
- ☑ L_{12um}(AGN) would be already weak, and probably < 10^{43} erg/s

(see Ichikawa+17)

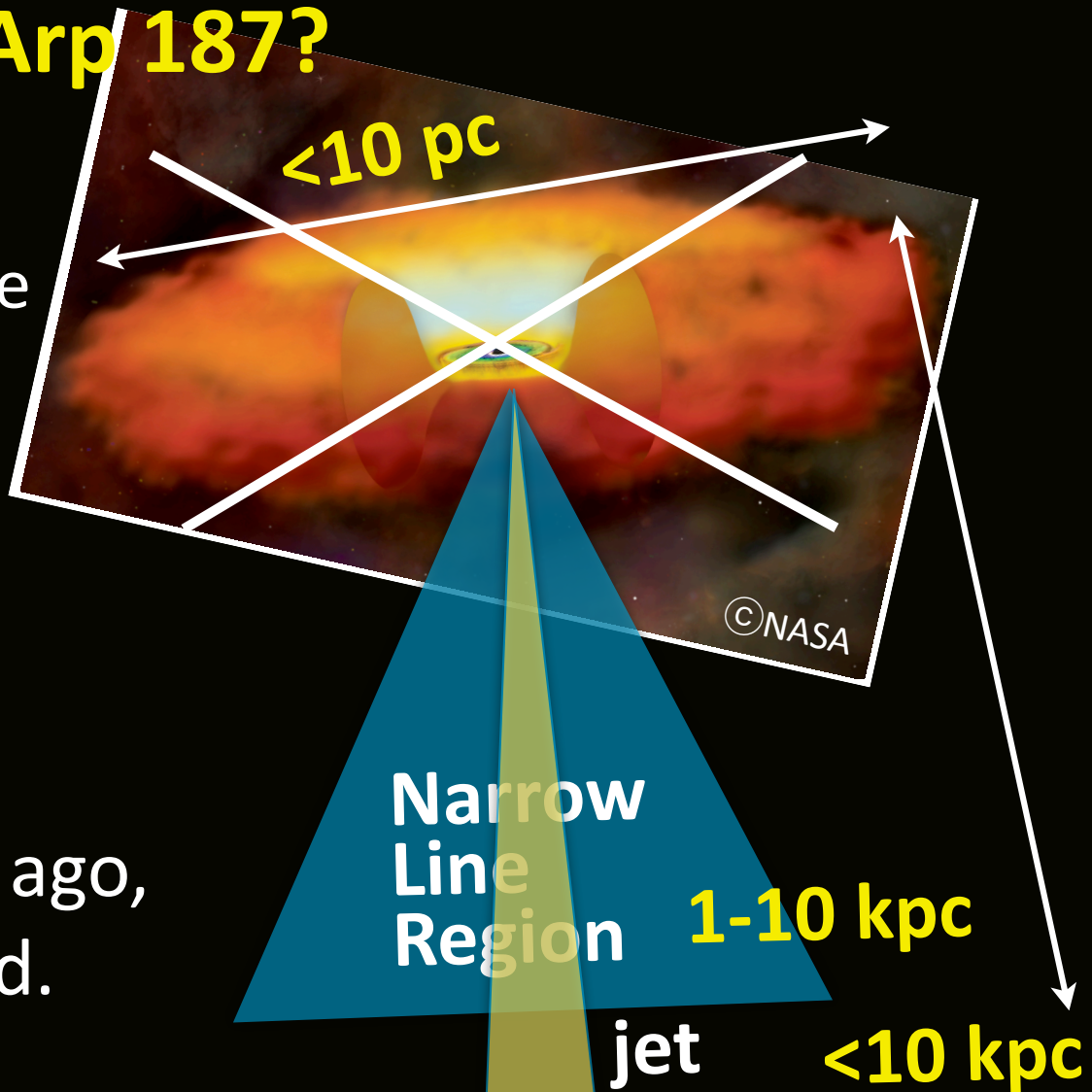
What is happening in Arp 187?

☑ Signs of NLR, jet (> kpc)

☑ Absence of torus, radio core (<10 pc scale)

FYI; torus cools down in <100 yr (Ichikawa & Tazaki '17b)

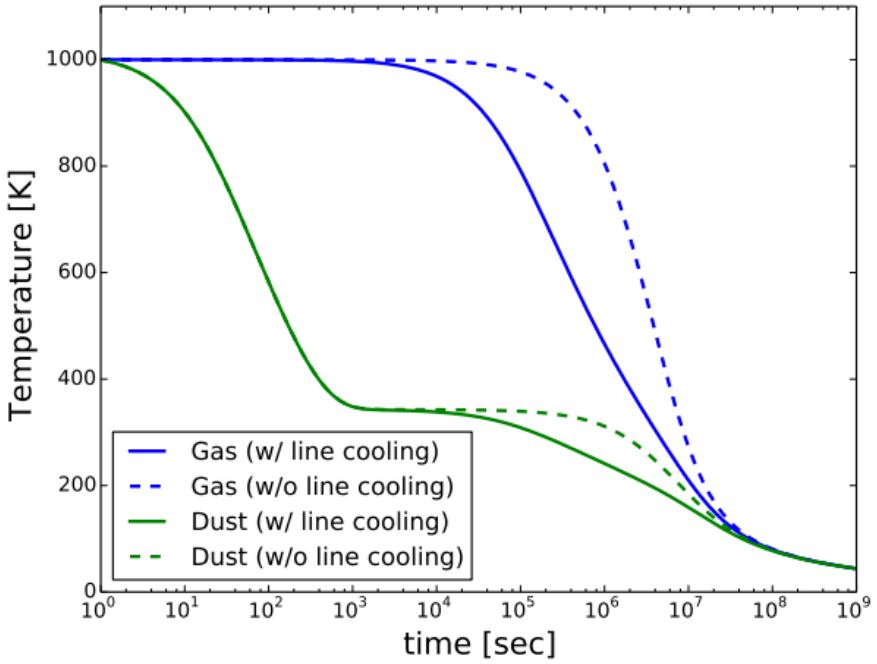
AGN "was" active ~$10^{3\text{-}4}$ yr ago, but currently AGN "is" dead.



"AGN light echo" is powerful tool to know AGN activity history

see Hanny's Voorwerp ($10^{4\text{-}5}$ yr ago; Lintott+09, Schawinski+10, 15; Keel+12)
or the galactic center (500 yr ago; Ponti+10; Capelli+12; Ryu+13; Nakashima+14)
or Fermi bubbles study (10^6 yr ago; Zubovas+11, 12; SU & Finkbeiner '12)

Torus cools down in 10-100 yrs



$$\frac{dE_{c,d}}{dt} = -4\pi R_c^2 \langle Q_c \rangle_T \sigma_{\rm SB} T^4 + \int_{V_{\rm clump}} n_g \Gamma_{\rm g-d} dV \quad (13)$$

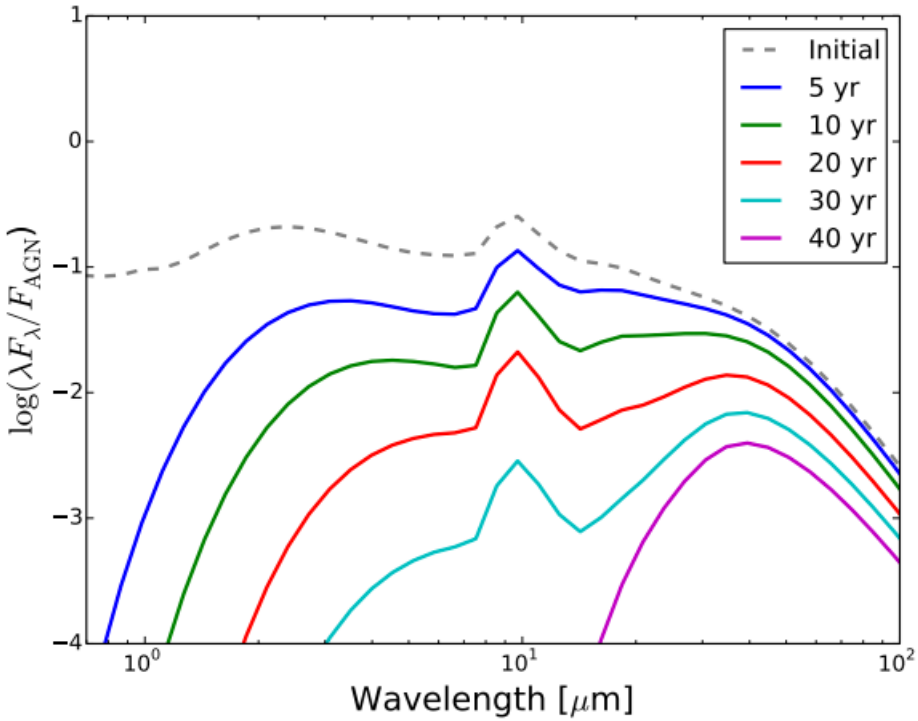


Figure 2. Time evolution of dust torus SED around dying AGN whose initial luminosity before the quenching is 10^{45} erg s^{-1}. The dashed line represents the SED under the radiative equilibrium temperature structure.

Ichikawa & Tazaki '17

One big assumption: AGN shut-down abruptly
Considering the energy exchange between the dust and gas