M. Imanishi

The AGN-starburst connections in nearby luminous infrared galaxies

We present the results of our systematic search for optically elusive, but intrinsically luminous buried AGNs in >100 nearby (z < 0.3) luminous infrared galaxies with L(IR) > 10^{11} Lsun, classified optically as non-Seyferts. To disentangle AGNs and stars, we have performed

(1) infrared 2.5-35 micron low-resolution (R ~ 100) spectroscopy using Subaru, AKARI, and Spitzer, to estimate the strengths of PAH (polycyclic aromatic hydrocarbon) emission and dust absorption features,

(2) high-spatial-resolution infrared 20 micron imaging observations using Subaru and Gemini, to constrain the emission surface brightnesses of energy sources, and

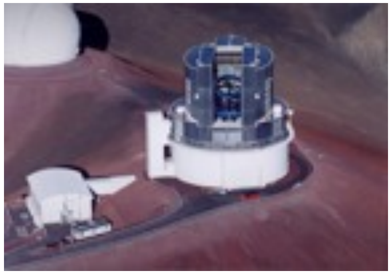
(3) millimeter interferometric measurements of molecular gas flux ratios, which reflect the physical and chemical effects from AGNs and stars. Overall, all methods provided consistent pictures. We found that the energetic importance of buried AGNs is relatively higher in galaxies with higher infrared luminosities (where more stars will be formed), suggesting that AGN-starburst connections are luminosity dependent. Our results might be related to the AGN feedback scenario as the possible origin of the galaxy down-sizing phenomenon.

Luminous buried AGNs in LIRGs

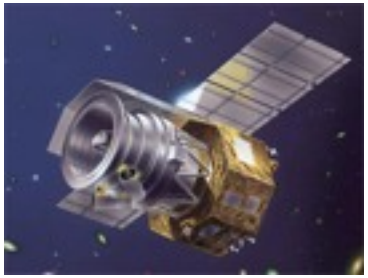
AGN-starburst connections

Masa Imanishi

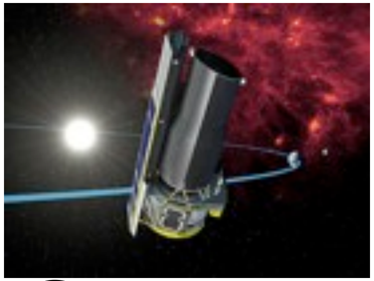
NAOJ (National Astronomical Observatory of Japan)



Subaru



AKARI



Spitzer

LIRGs : L_{IR}>10^{11}Lo

ULIRGs : >10^{12}Lo

→ **Luminous energy sources behind dust**

LIRGs : L_{IR}>10^{11}Lo

ULIRGs : >10^{12}Lo

Luminous energy sources behind dust

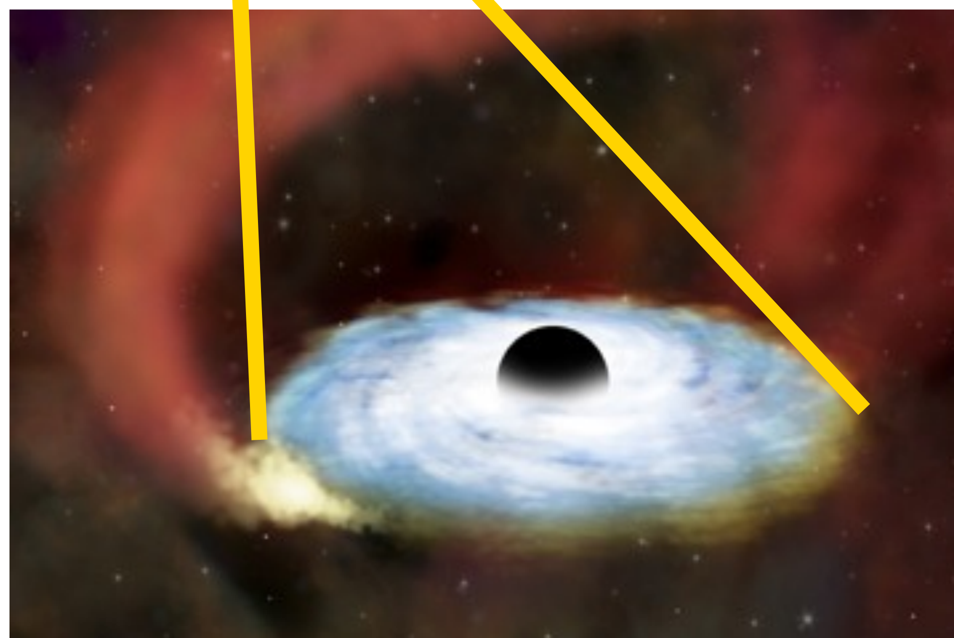
Starburst

LIRGs : $L_{IR}>10^{11}$Lo   **ULIRGs : $>10^{12}$Lo**

→ **Luminous energy sources behind dust**

Starburst

AGN

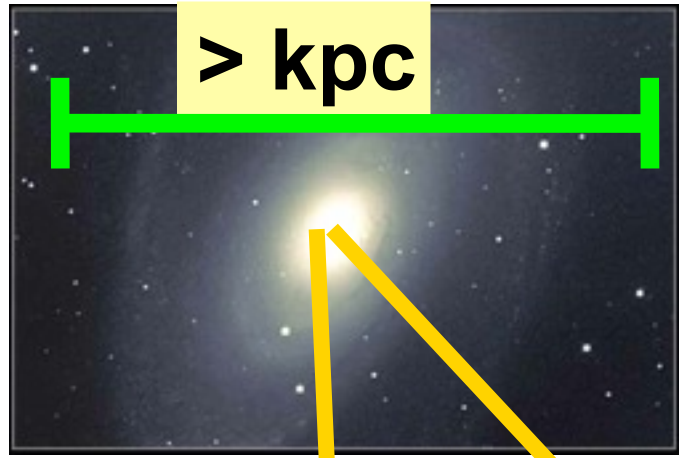


Mass accretion onto supermassive blackholes（$>10^{6}$ Mo）

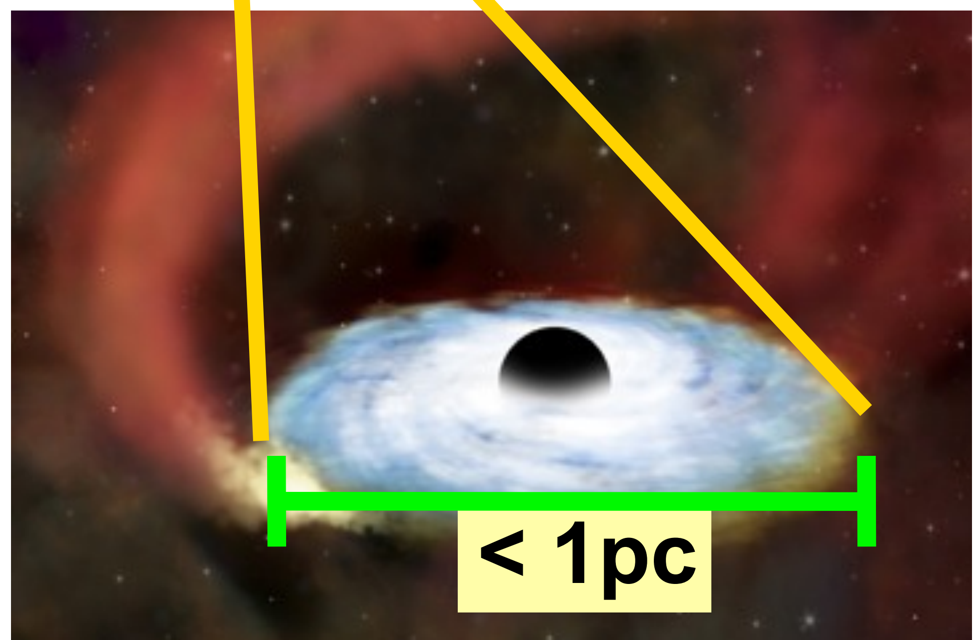
LIRGs : $L_{IR} > 10^{11} L_o$　　**ULIRGs : $> 10^{12} L_o$**

Luminous energy sources behind dust

Starburst

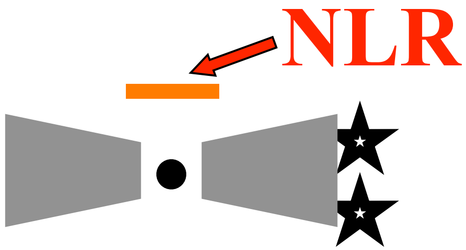


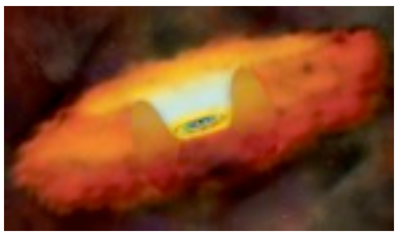
AGN



Mass accretion onto supermassive blackholes ($> 10^6$ Mo)

AGNs in (U)LIRGs are buried





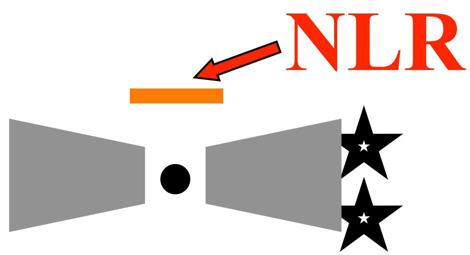
AGNs obscured by torus-shaped dust

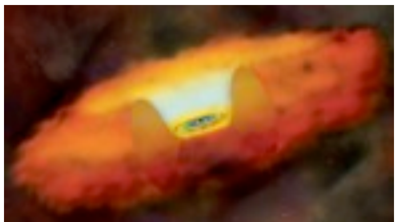
↓

Detectable via optical spectroscopy

Sy2

AGNs in (U)LIRGs are buried





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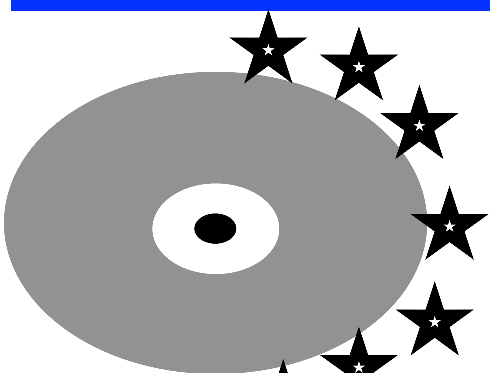
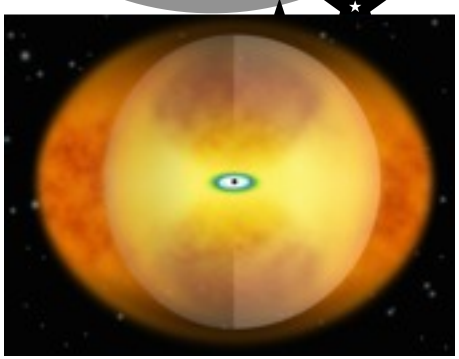
Detectable via optical spectroscopy





(U)LIRGs have a large amount of nuclear gas and dust

↓

Buried AGNs are elusive

>70% (U)LIRGs = non-Sy

Veilleux+99 (but see Yuan+10)

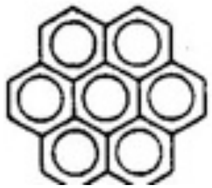
PAH

1. Infrared spectral shape

PAHs are excited in starburst PDRs but destroyed near an AGN

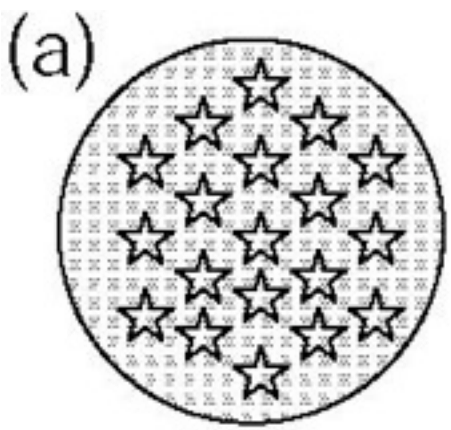
1. Infrared spectral shape

PAH

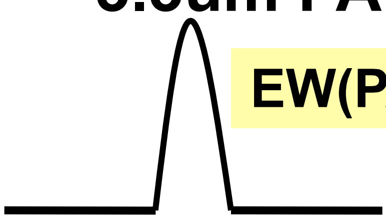


PAHs are excited in starburst PDRs but destroyed near an AGN

Starburst(SB)



3.3um PAH



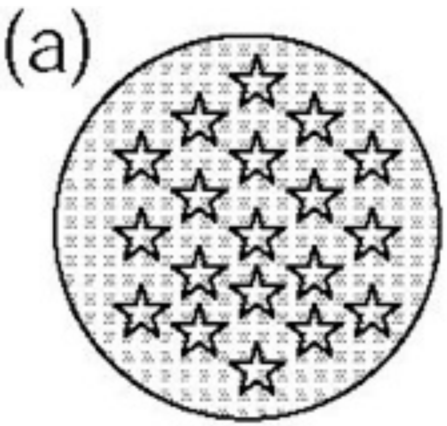
EW(PAH)~100nm

1. Infrared spectral shape

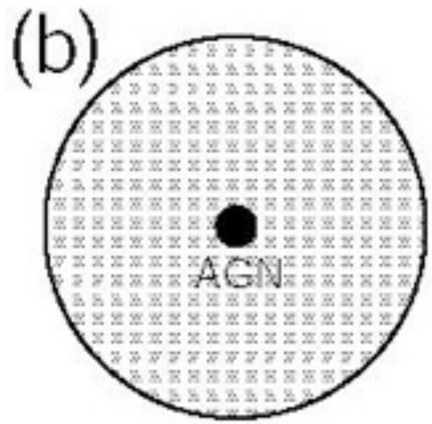
PAH

PAHs are excited in starburst PDRs but destroyed near an AGN

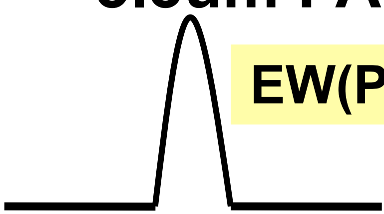
Starburst(SB)



Buried AGN

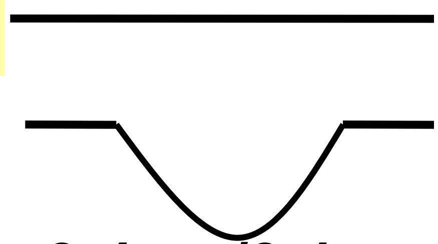


3.3um PAH



EW(PAH)~100nm

featureless



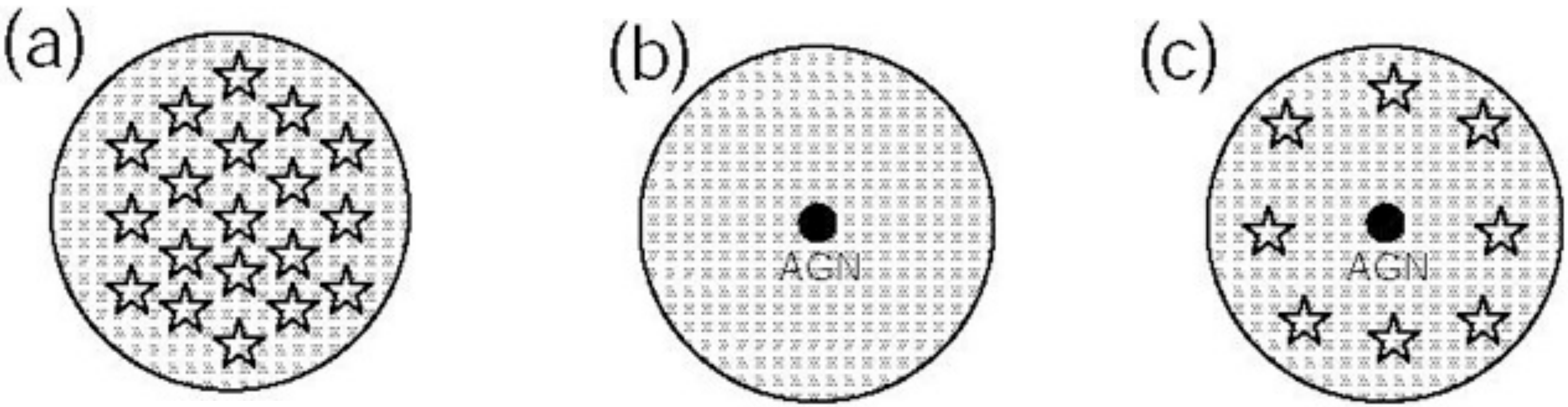
3.4um/3.1um

1. Infrared spectral shape

PAH

PAHs are excited in starburst PDRs but destroyed near an AGN

Starburst(SB) | Buried AGN | AGN+SB

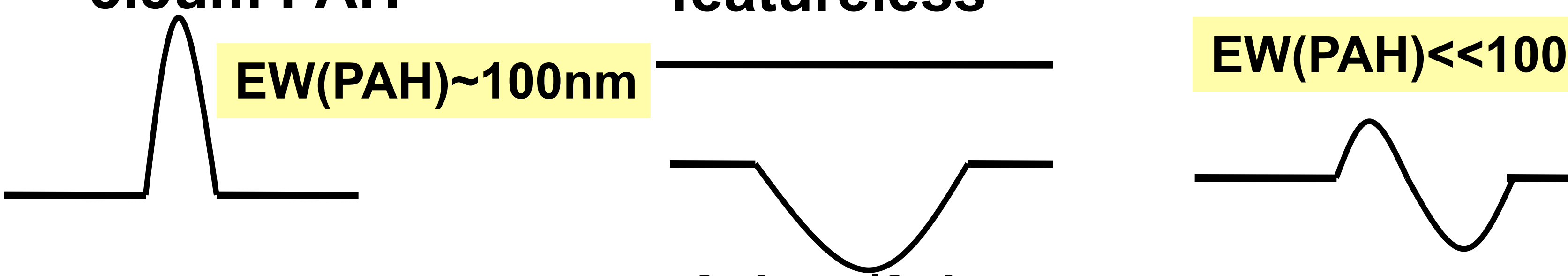


3.3um PAH

featureless

EW(PAH)~100nm

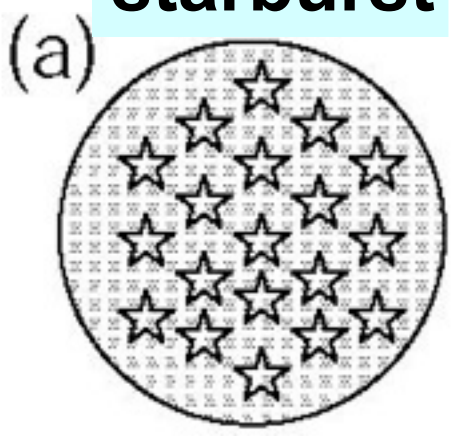
EW(PAH)<<100nm



3.4um/3.1um

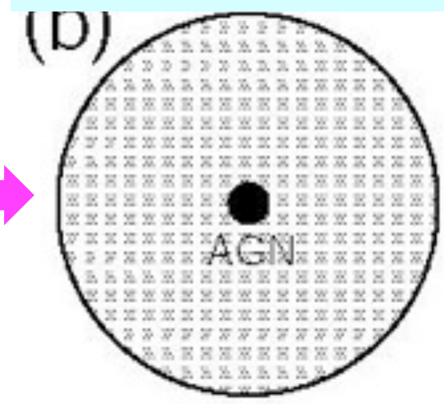
2. Dust absorption feature strength

starburst



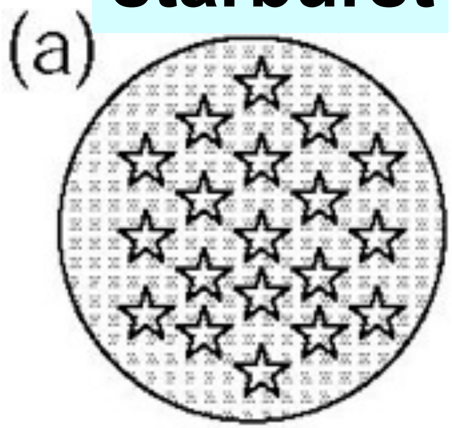
(U)LIRG core
<500pc

Buried AGN

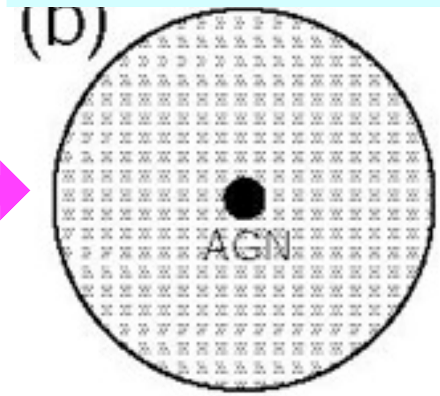


2. Dust absorption feature strength

starburst



Buried AGN

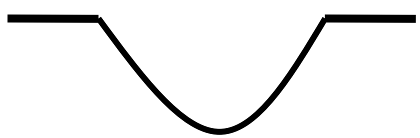


(U)LIRG core
<500pc

Mixed dust model

$$\frac{1-\exp(-Tau)}{Tau}$$

Dust absorption feature: <u>weak</u>



Foreground screen dust model

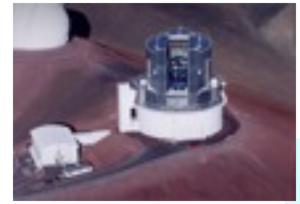
$$\exp(-Tau)$$

<u>strong</u>

(Imanishi+06,07)

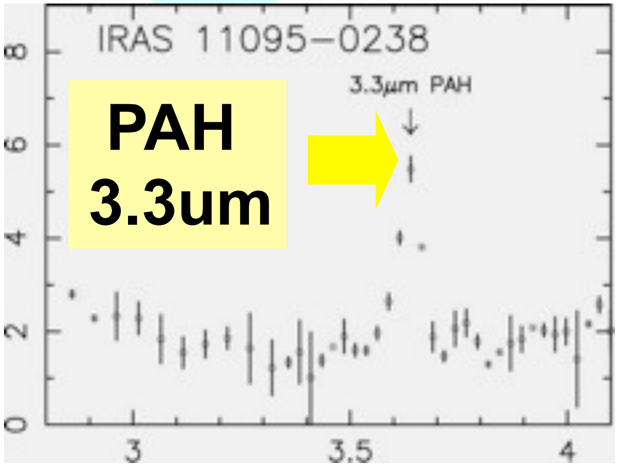
3-4 um

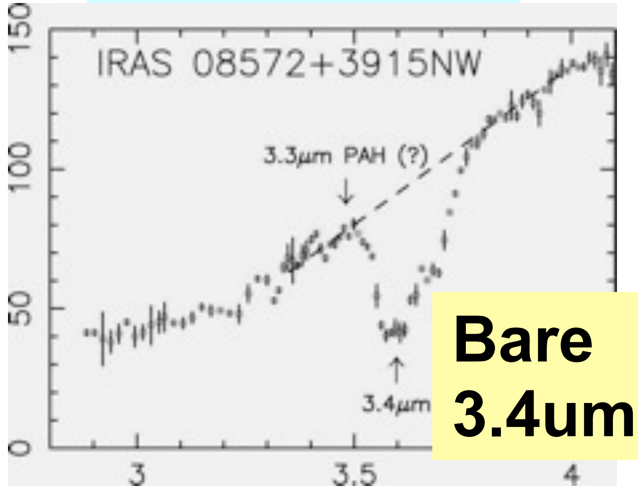
z<0.15 ULIRG

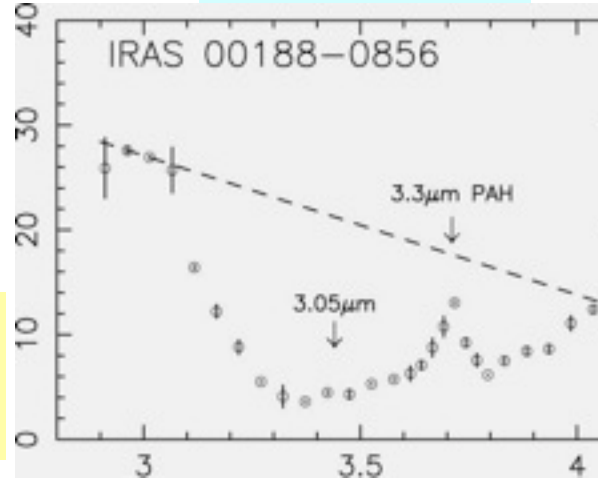


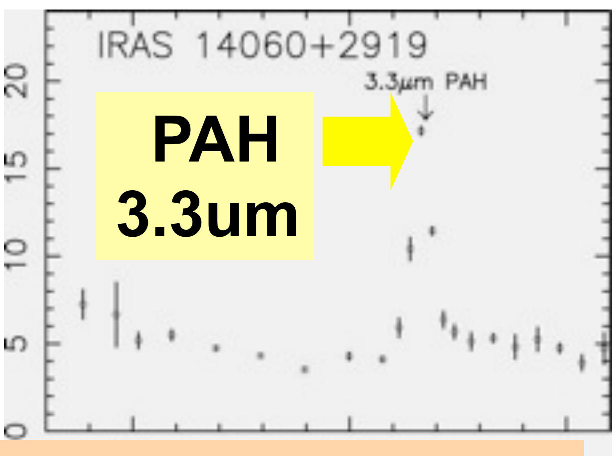
Subaru

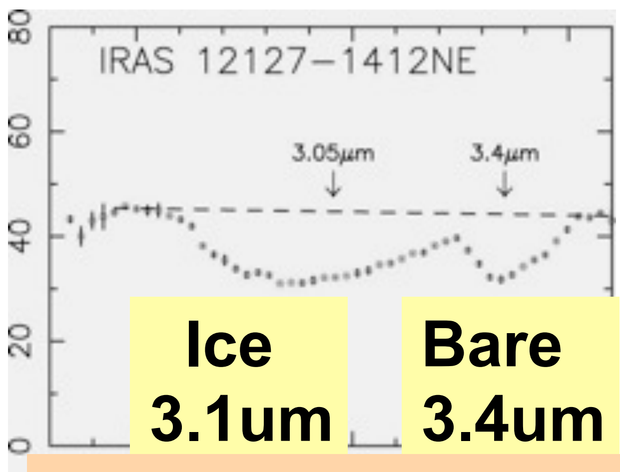
SB | Buried AGN | AGN+SB

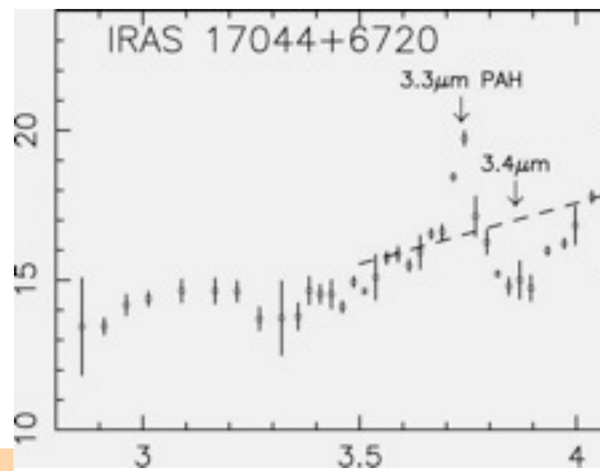












wavelength

PAH strong (SB):
Dust abs. weak

PAH weak (AGN):
Dust abs. strong

Imanishi+06

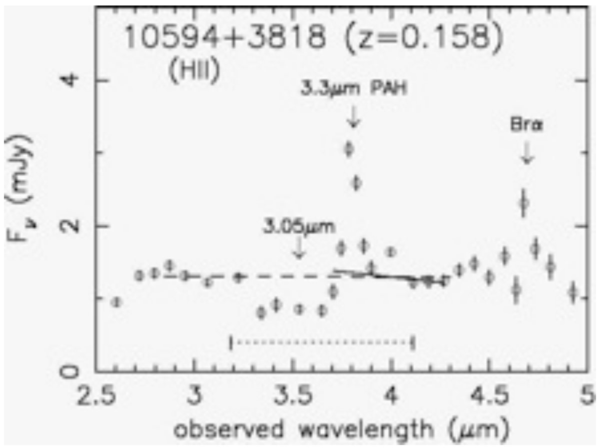
2.5-5 um

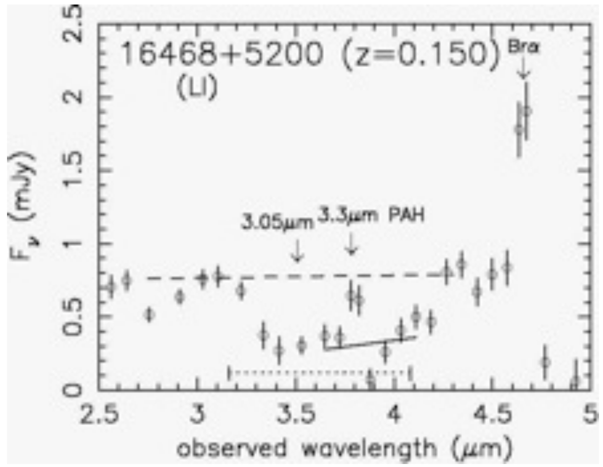
z>0.15 ULIRG

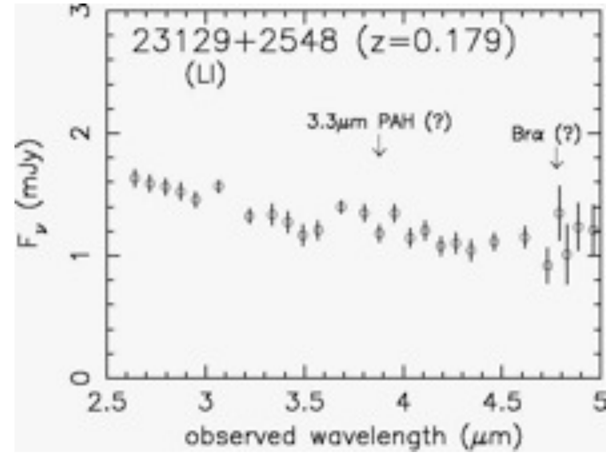
AKARI

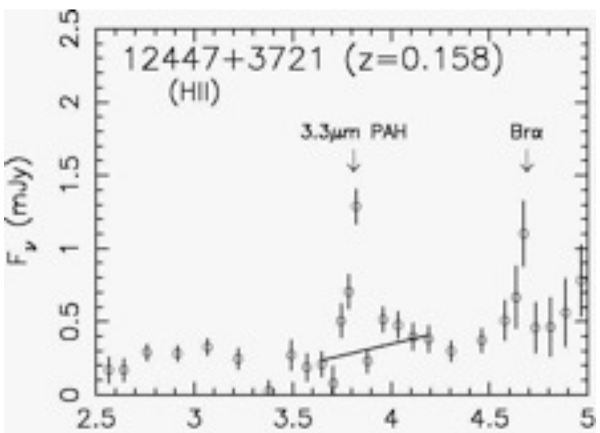
SB

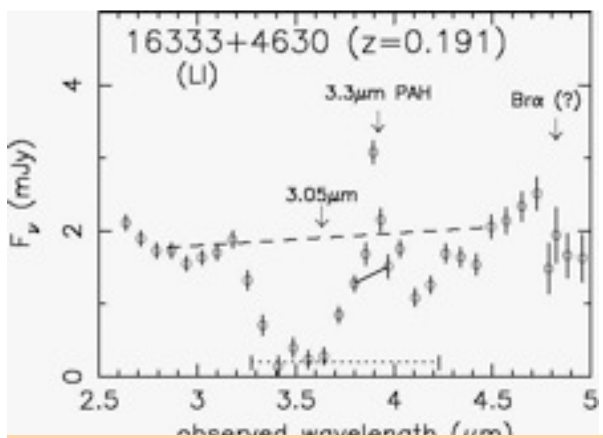
AGN+SB

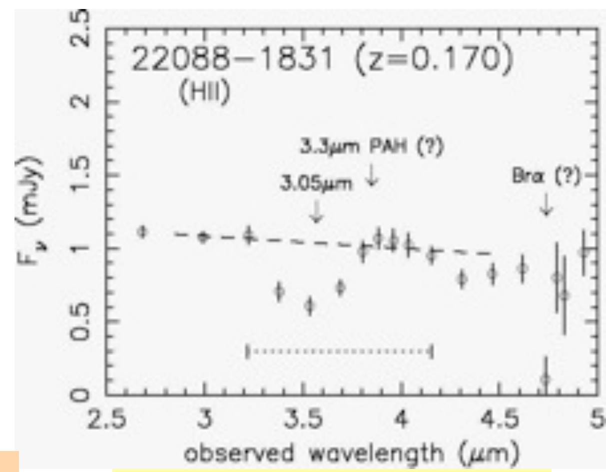












PAH strong (SB):
Dust abs. weak

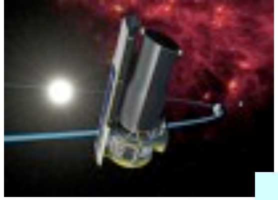
PAH weak (AGN):
Dust abs. strong

wavelength

Imanishi+08

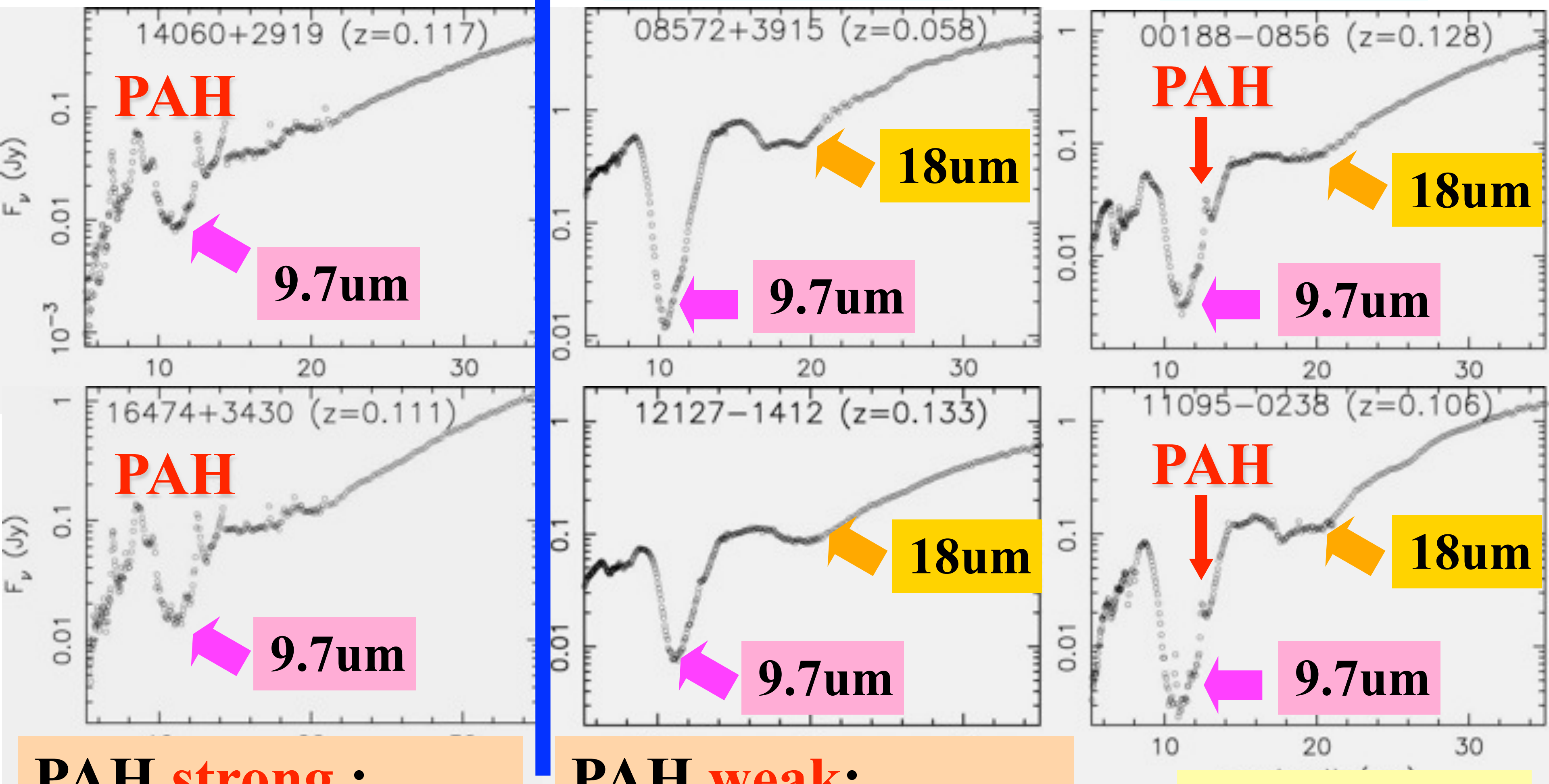
5-35 um

z<0.3 ULIRG



Spitzer

SB | Buried AGN | AGN+SB



PAH strong : Silicate Abs. weak

PAH weak: Silicate Abs. strong

wavelength

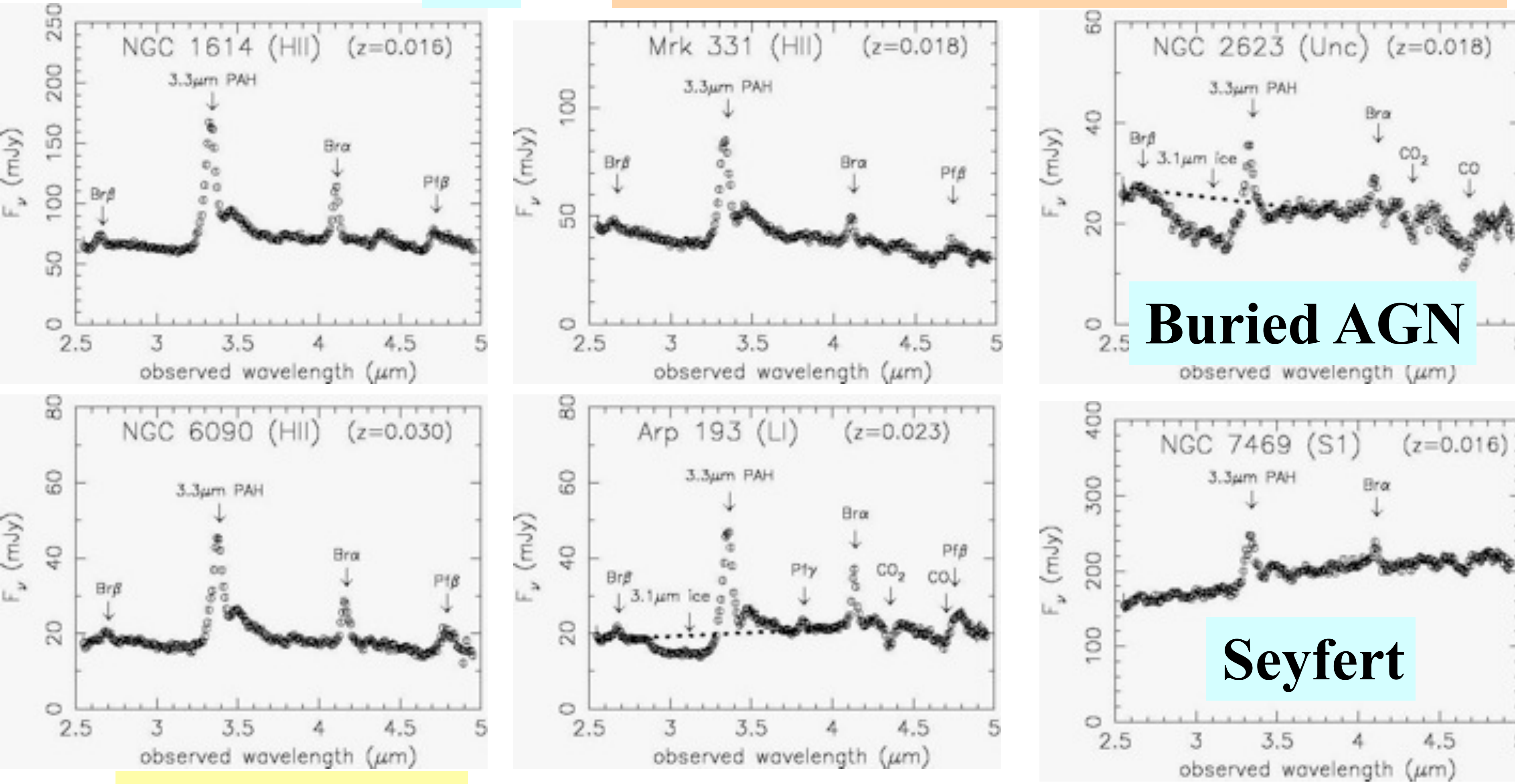
Imanishi+07,09,10a

LIRG (<10^{12} Lo) (spatially extended)

AKARI

SB

2.5-5 um slitless spectroscopy



Buried AGN

Seyfert

wavelength

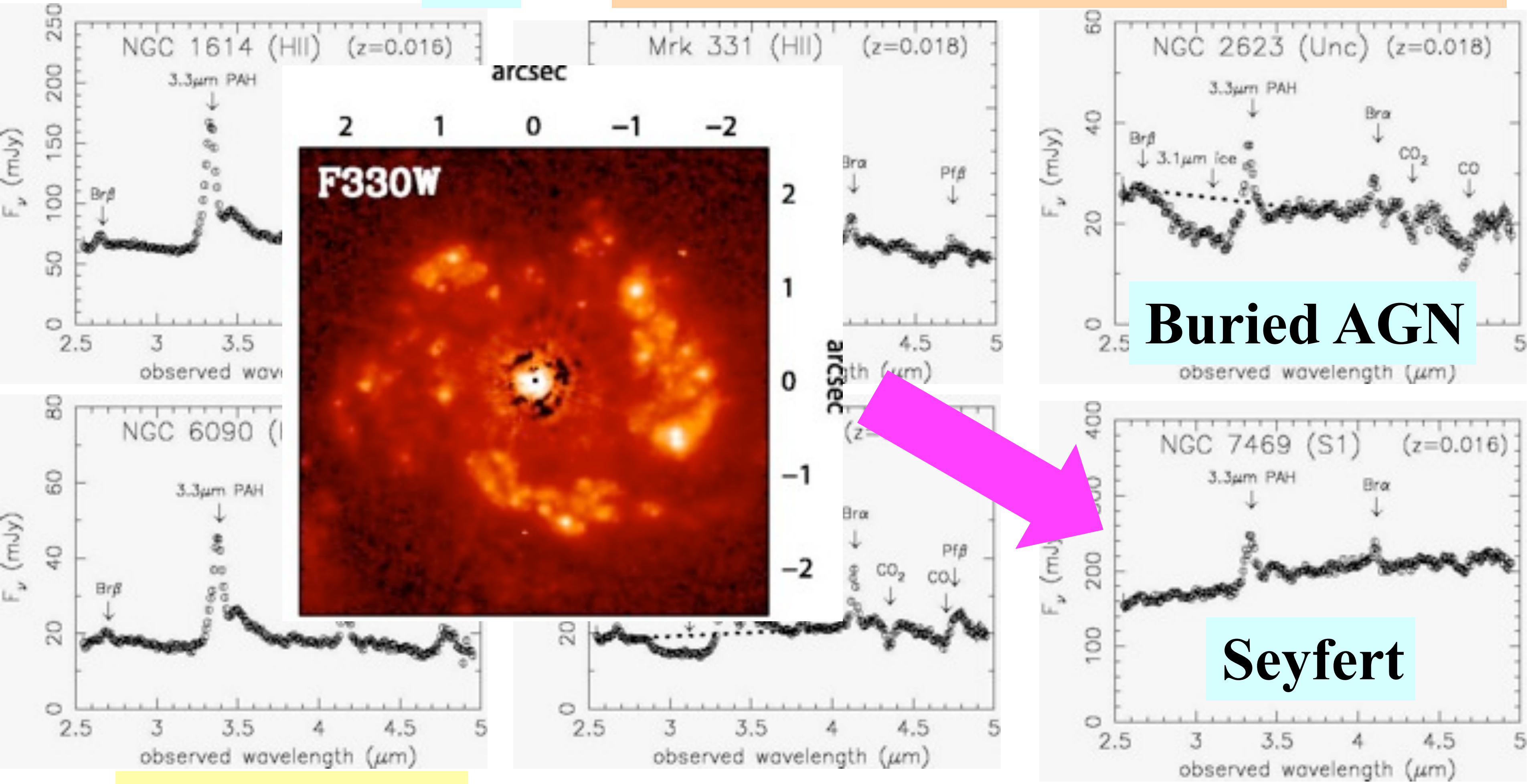
Imanishi+10b submitted

LIRG（<10^{12} Lo）（spatially extended）

AKARI

SB

2.5-5 um slitless spectroscopy



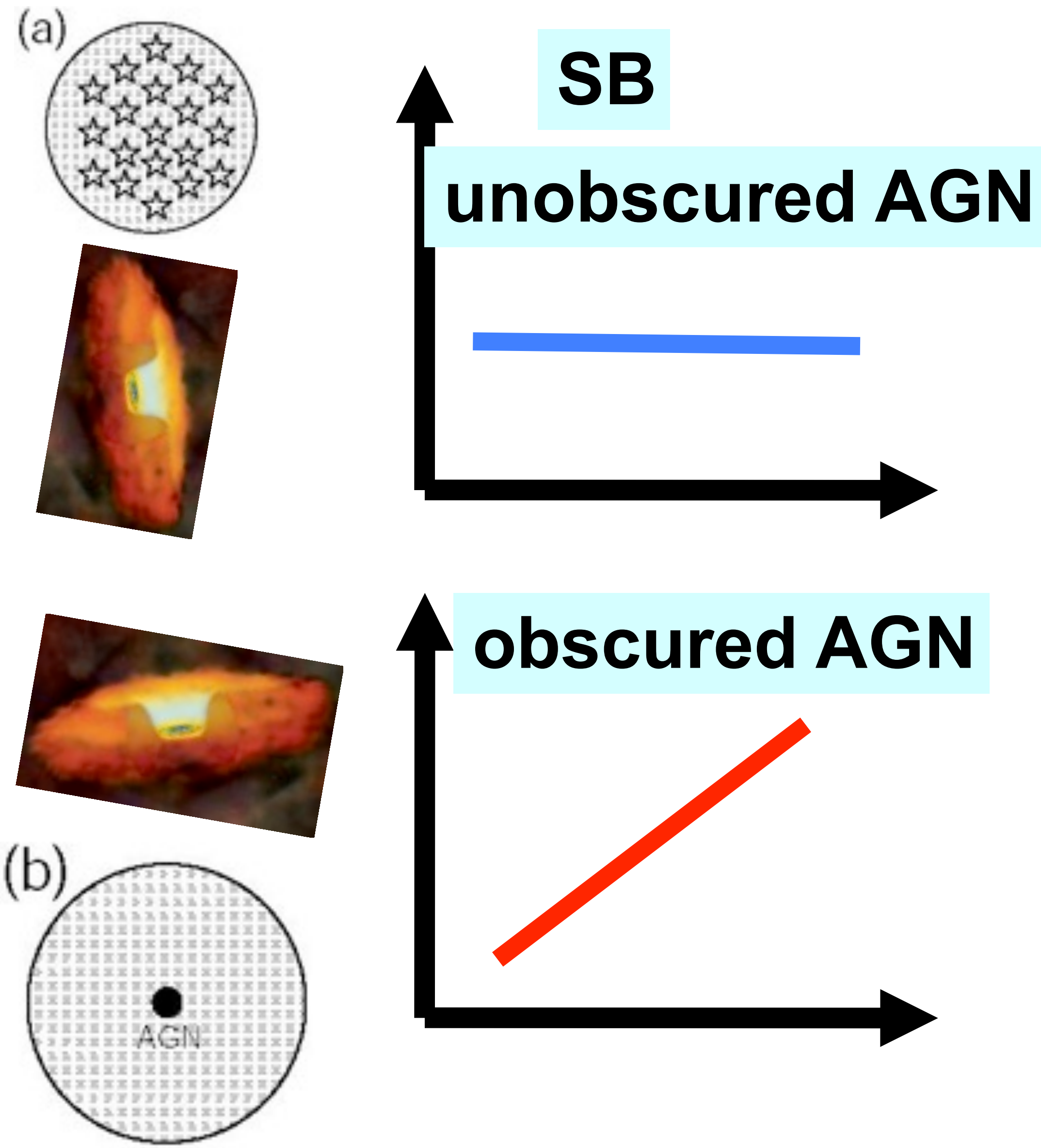
Buried AGN

Seyfert

wavelength

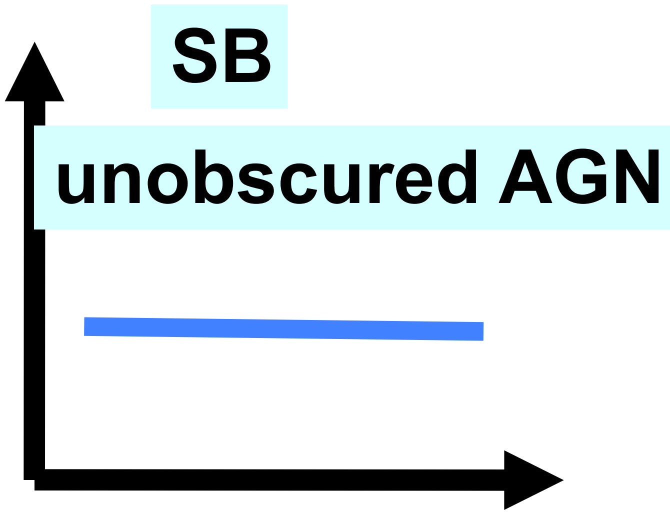
Imanishi+10b submitted

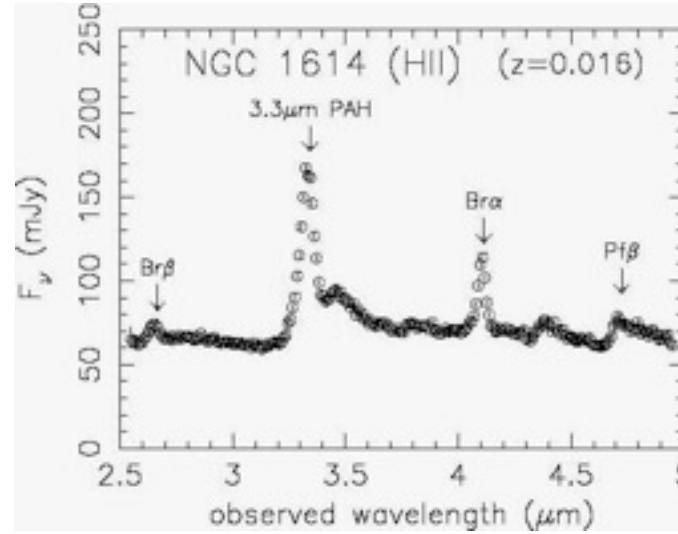
3. Continuum slope

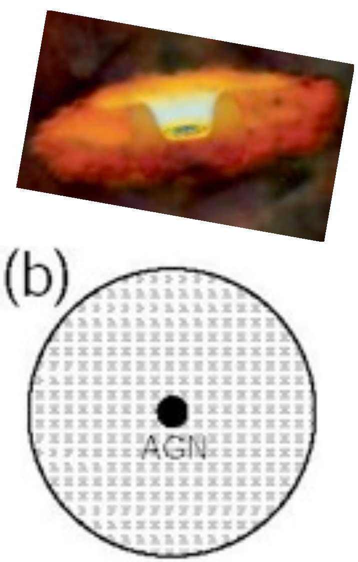


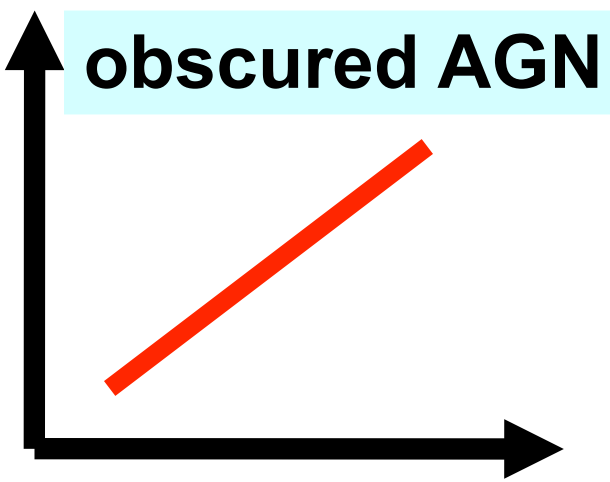
3. Continuum slope

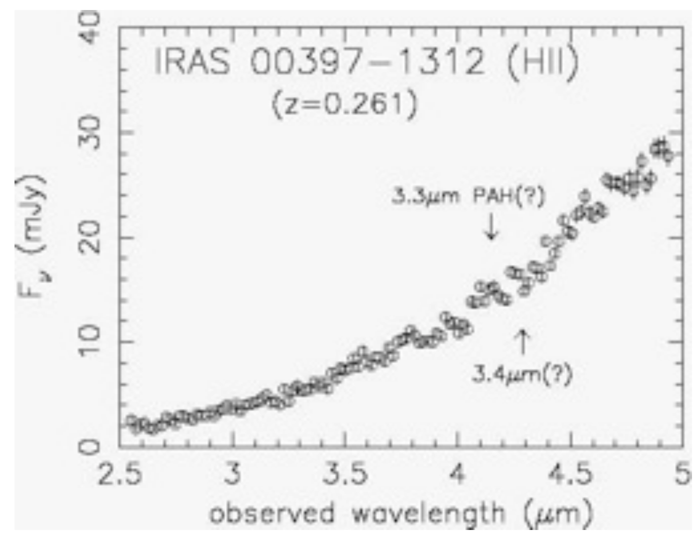
AKARI 2.5-5um



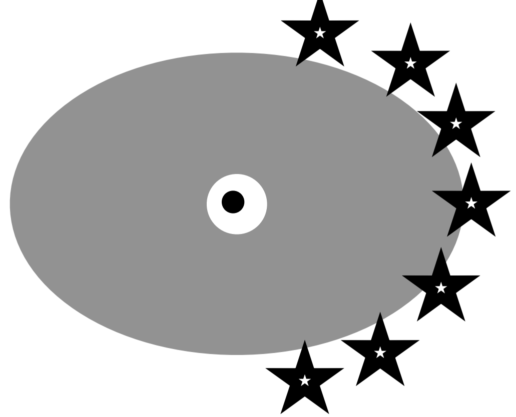








Results

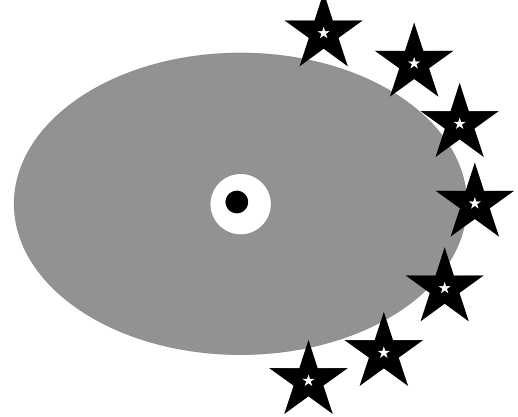


nearby(z<0.3) >130 sources

Opical non-Seyfert (U)LIRGs

→ **Luminous buried AGNs ~ 50%**

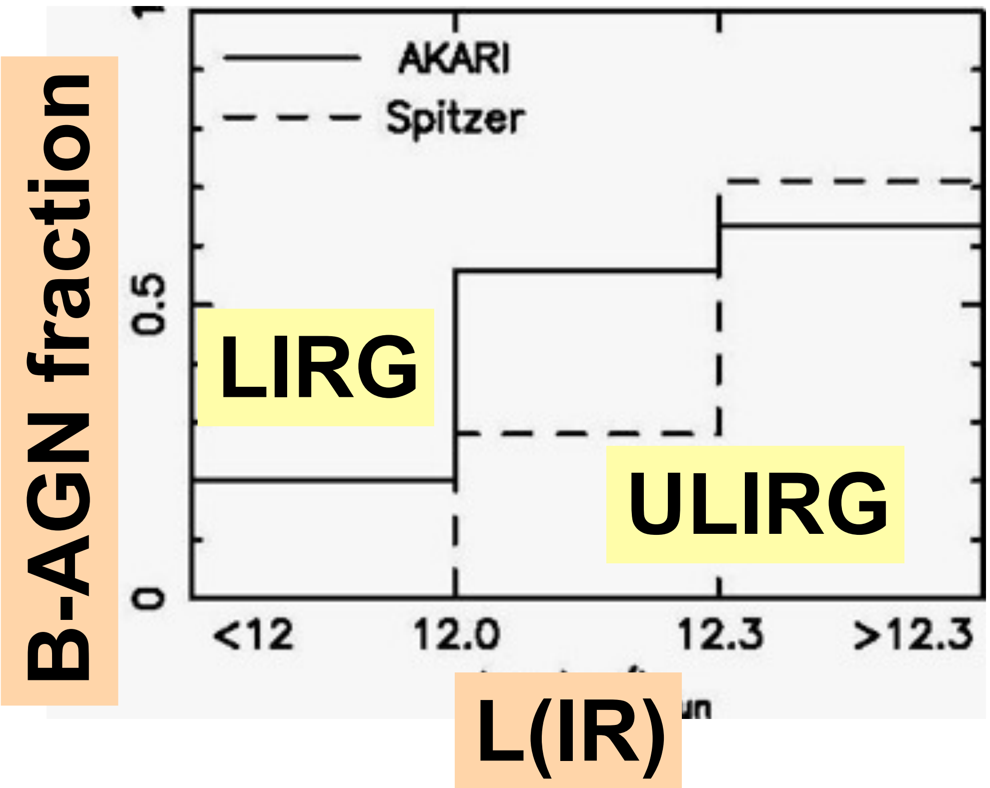
Results



nearby(z<0.3)   >130 sources

Opical non-Seyfert (U)LIRGs

<u>Luminous</u> buried AGNs ~ 50%

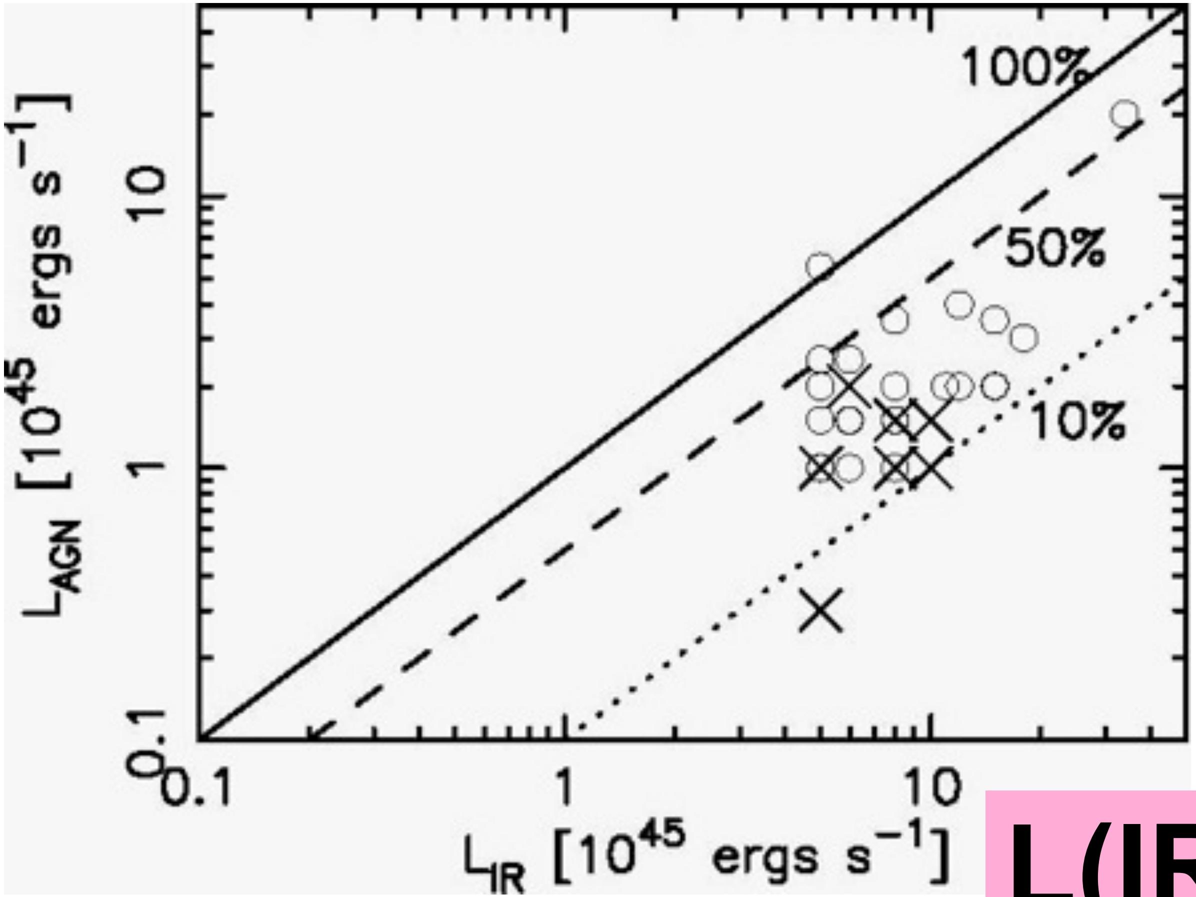


Buried AGNs (B-AGN) increase with L_{IR}

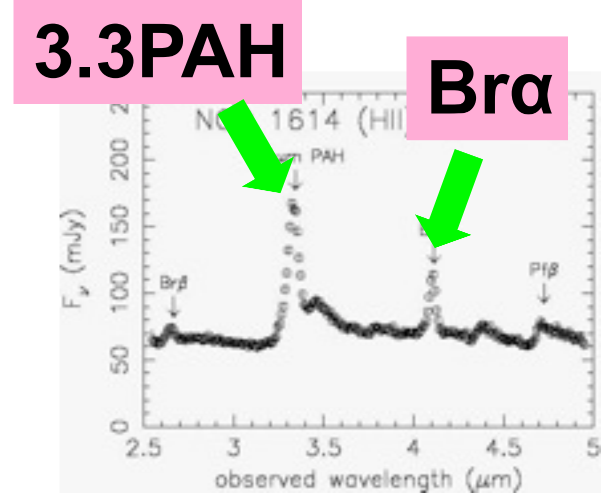
B-AGN luminosity (extinction-corrected)

~10-50% of L(IR)

L(B-AGN)



L(IR)



$A_{3.3PAH}$ = Av/30

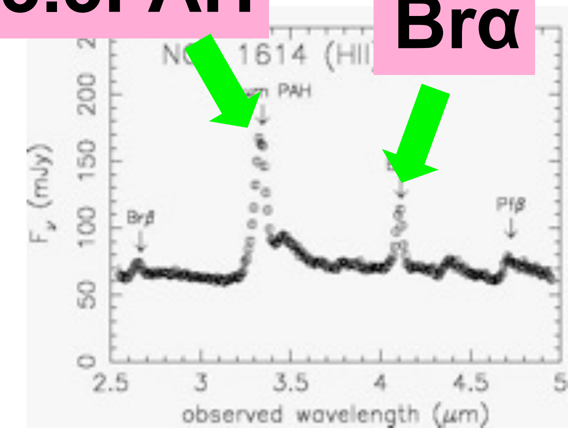
Nishiyama+09

$A_{3.3PAH}$ < 1 mag for Av < 30 mag

PAH = good SB indicator

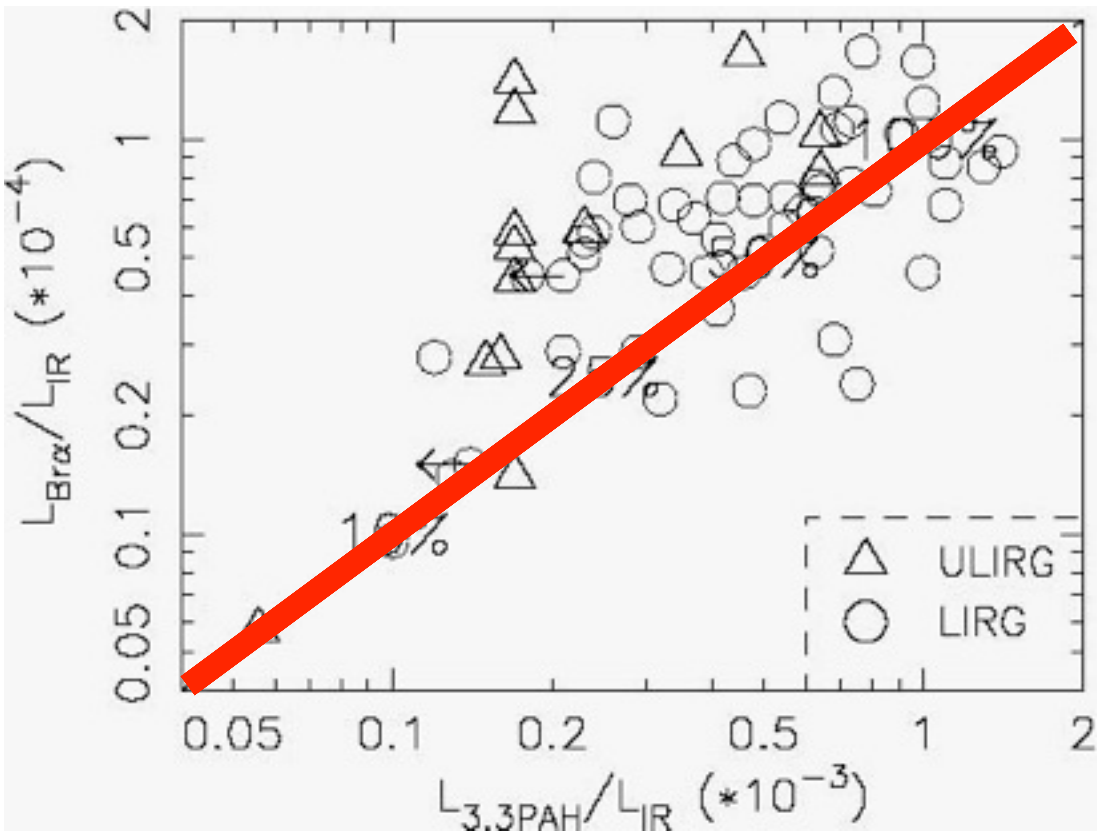
3.3PAH

Brα



SFR(Brα) ~ SFR(3.3PAH)

SFR(Brα)



SFR(3.3PAH)

Imanishi+10b

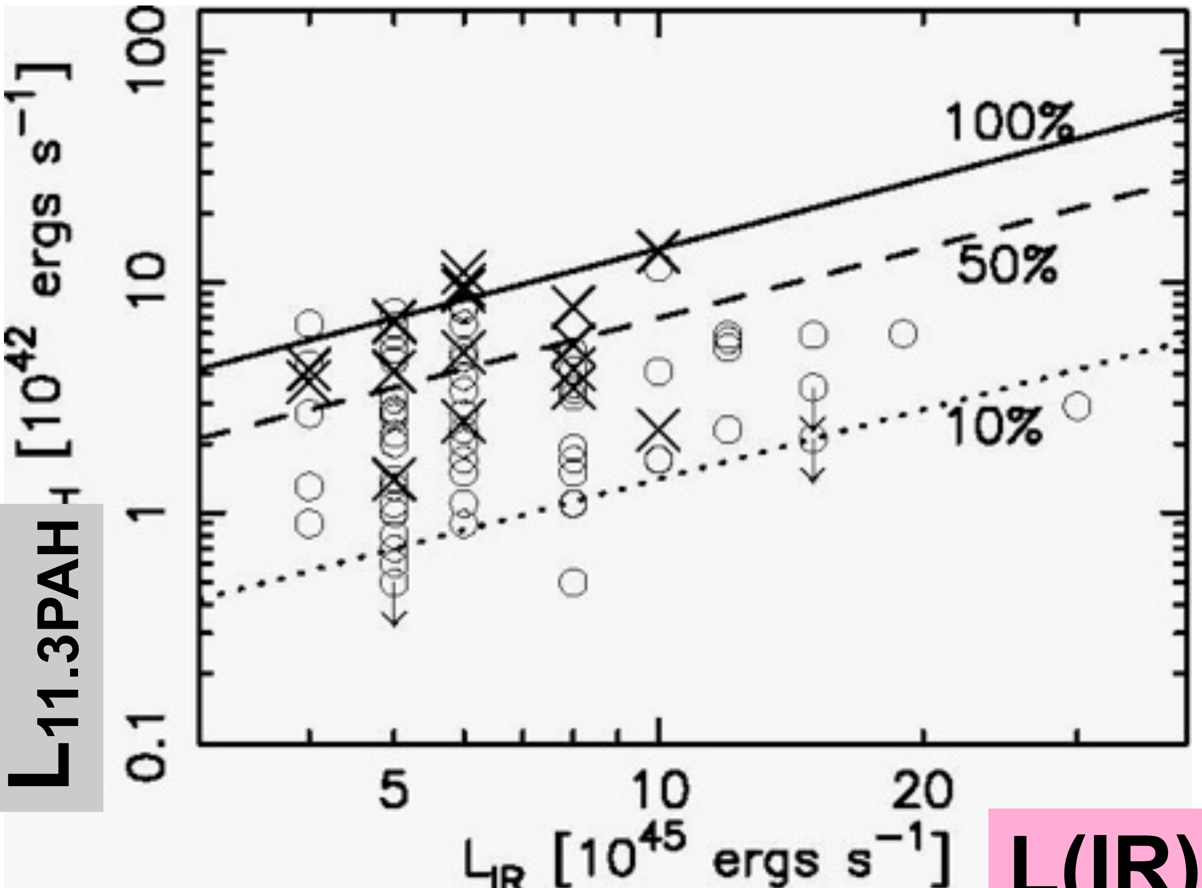
$A_{3.3PAH}$ = Av/30

Nishiyama+09

$A_{3.3PAH}$ < 1 mag for Av < 30 mag

L(PAH-derived SB)

~10-100% of L(IR)

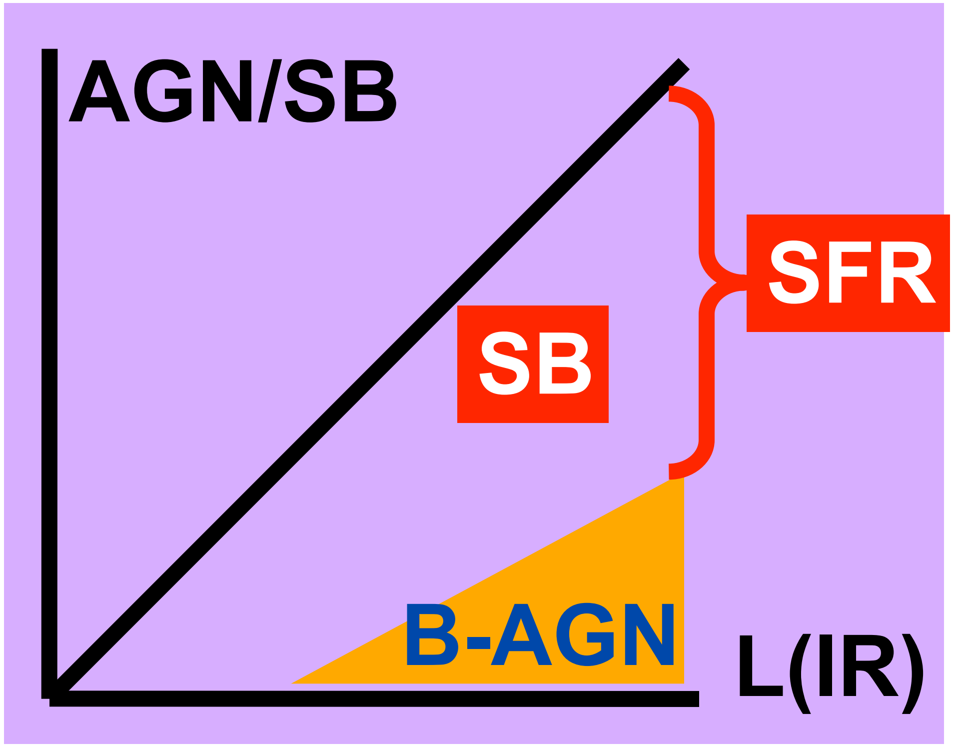


L(SB) from PAH

$L_{11.3PAH}$

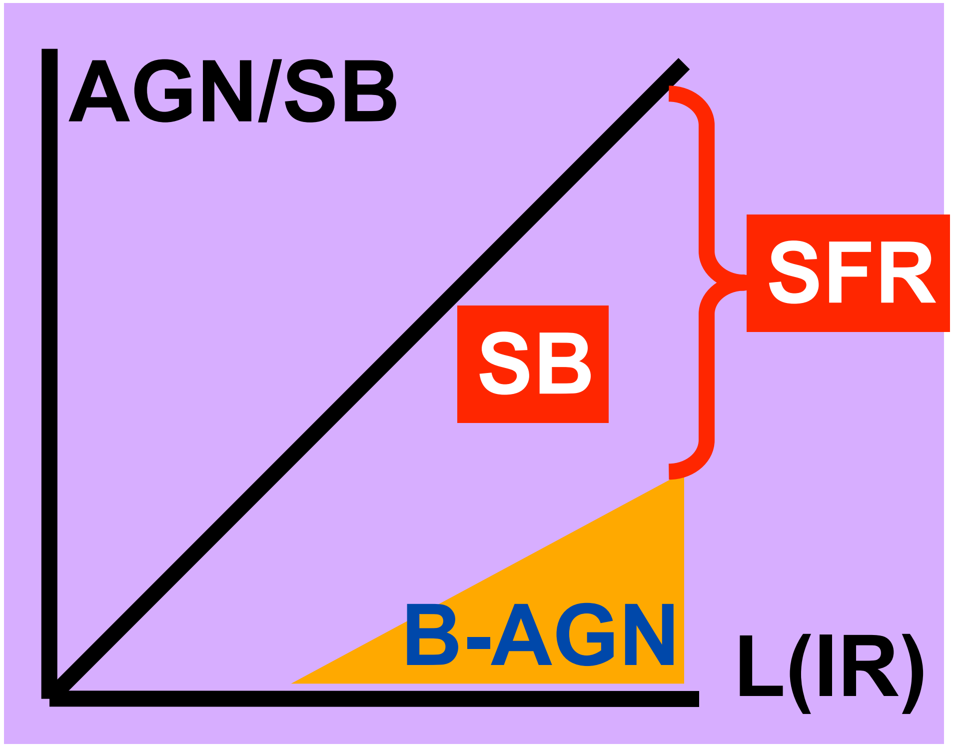
L(IR)

B-AGN vs SB connections are luminosity dependent



see also Nardini+10

B-AGN vs SB connections are luminosity dependent



see also Nardini+10

low M(star)

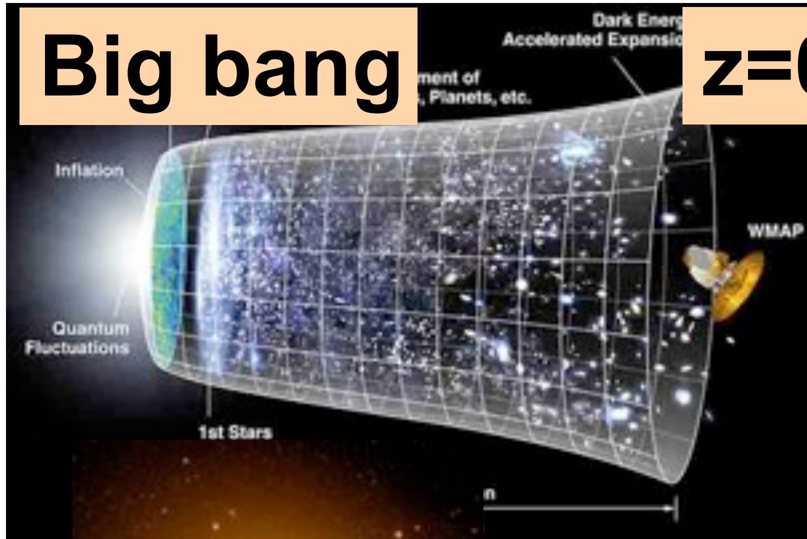
high M(star)

Galaxy down-sizing

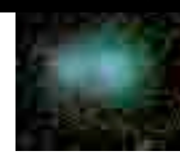
More massive galaxies have finished major SF at higher-z

Big bang

z=0



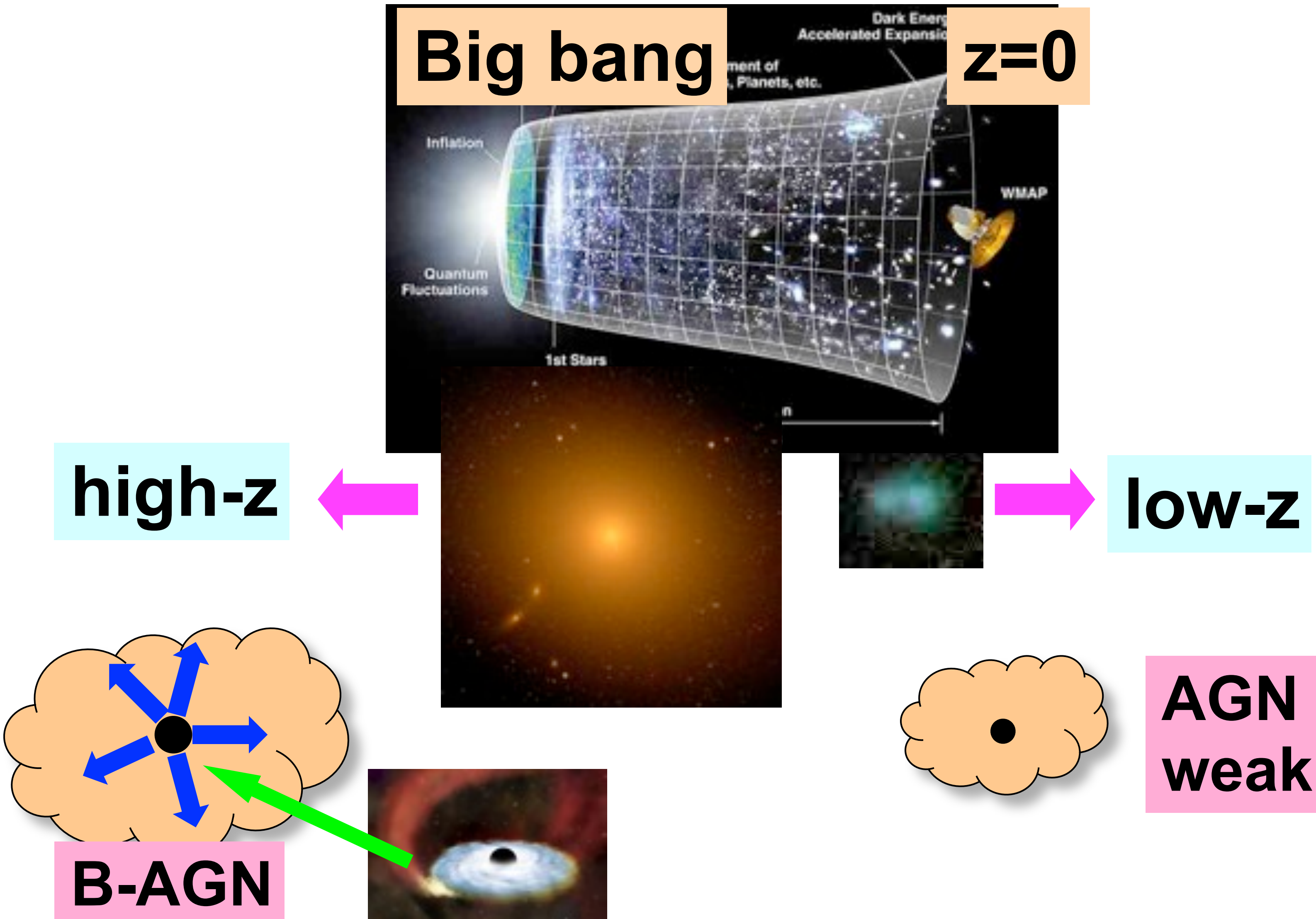
high-z



low-z

Galaxy down-sizing

More massive galaxies have finished major SF at higher-z



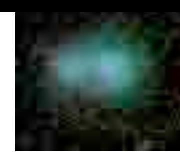
Galaxy down-sizing

More massive galaxies have finished major SF at higher-z

Big bang

z=0

Link (?)



low-z

Luminosity-dependent B-AGN - SB connections

Summary

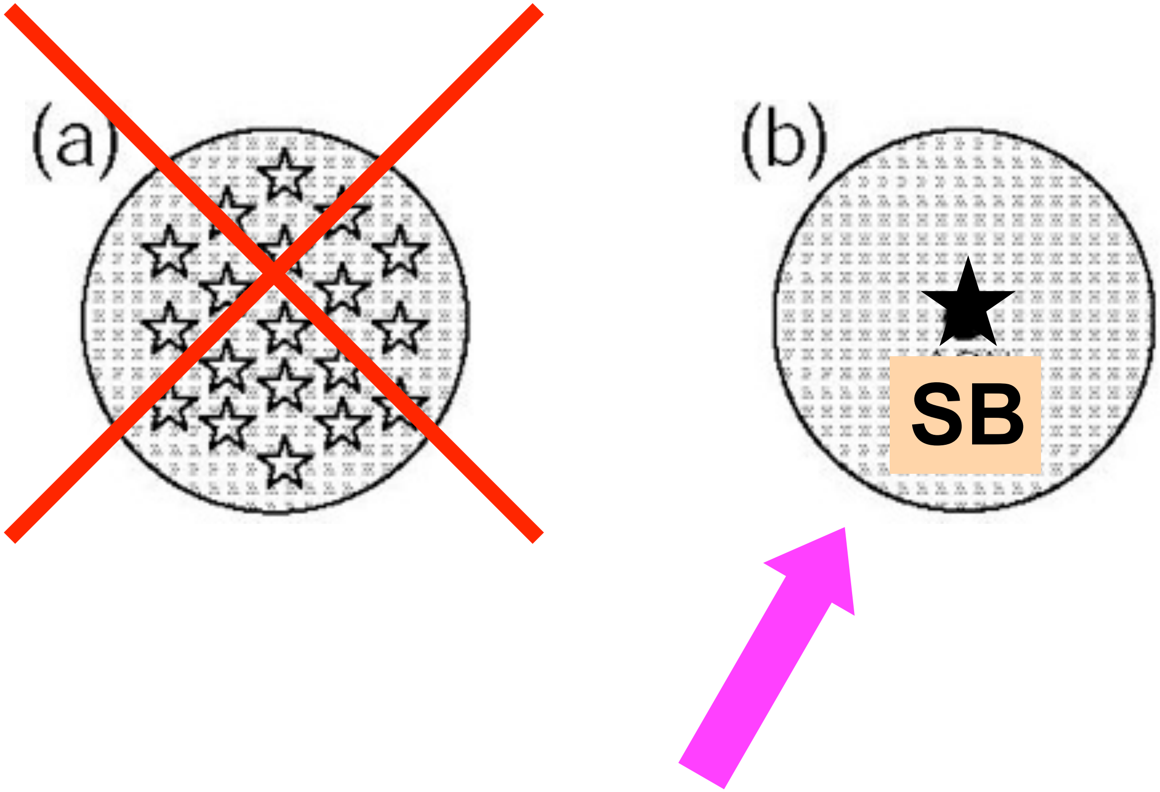
Buried AGNs are common in non-Sy LIRGs

B-AGN vs SB connections are L-dependent

Imanishi+06 ApJ 637 114 (Subaru)
Imanishi+07 ApJS 171 72 (Spitzer)
Imanishi+08 PASJ 60 S489 (AKARI)
Imanishi+10a ApJ 709 801 (Spitzer2)
Imanishi+10b submitted (AKARI2)

End

Possibility of extreme SB ?

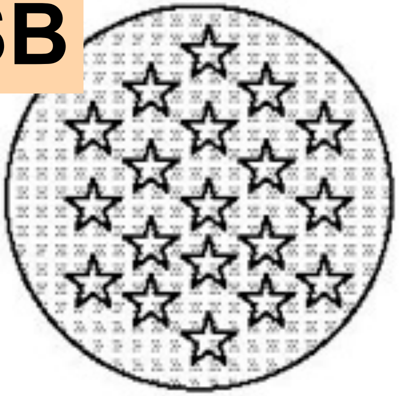


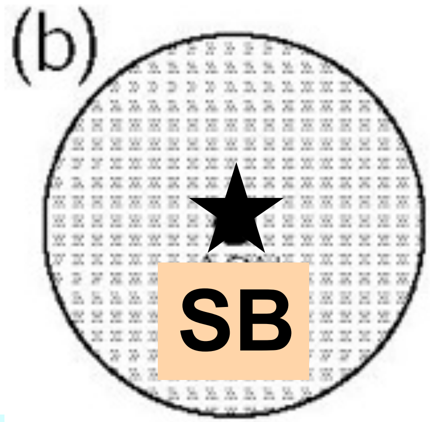
Exceptionally centrally-concentrated SB

HII-region only (no PDRs, no molecular gas)

Emission surface brightness

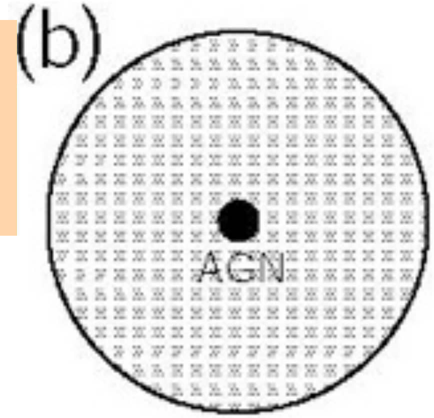
SB





SB

Buried AGN



E = 0.5% Mc^2

E = 6-40% Mc^2

>>10^13 Lo/kpc^2

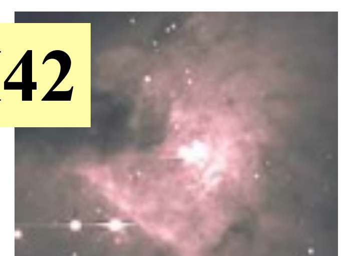
10^11 Lo/kpc^2

<10^13 Lo/kpc^2

M82

SB

M42

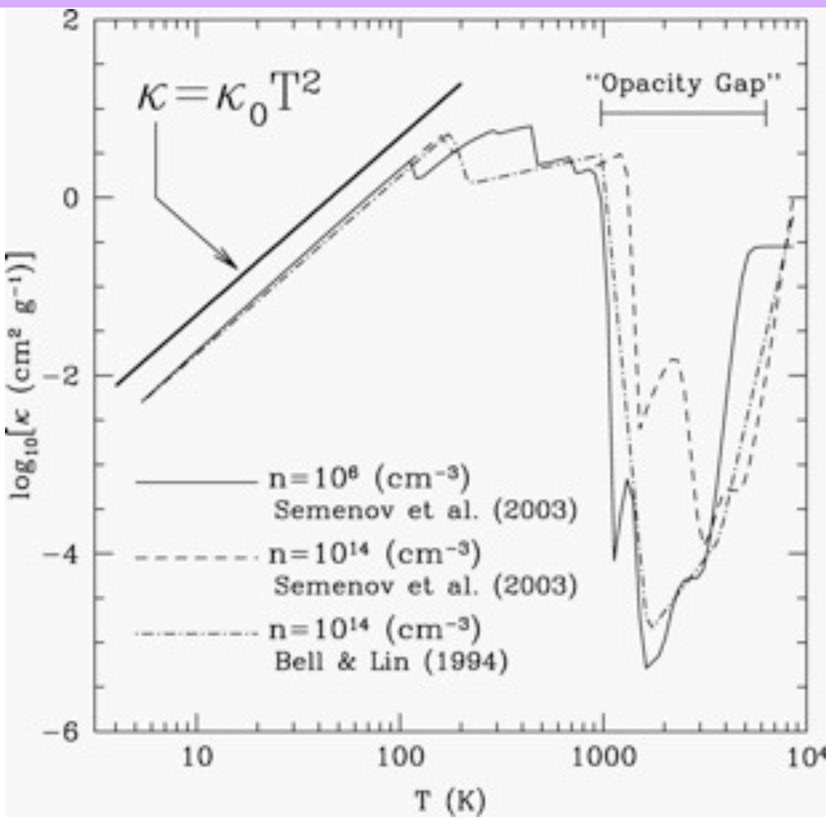


HII-region core

SB : < 10^13 Lo/kpc^2

Supported by theory

Eddington-limited SB



Thompson et al. 2005

At T<150K,
<10^13Lo/kpc^2

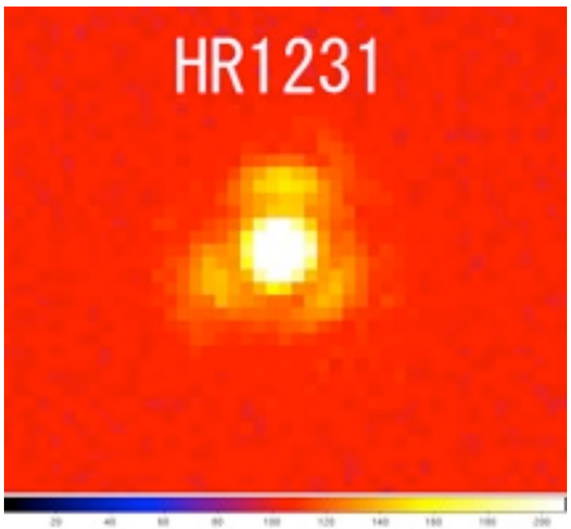
Tcolor of ULIRGs
= 60-80K

Subaru COMICS

20um

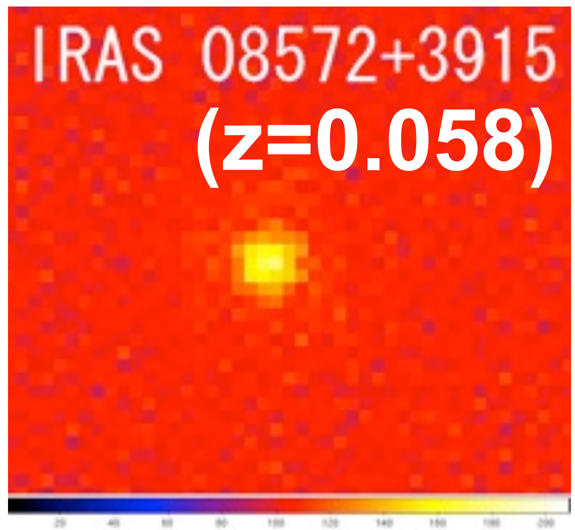
Diffraction-limited images are usually achieved

Standard star



Mitsubishi-patten

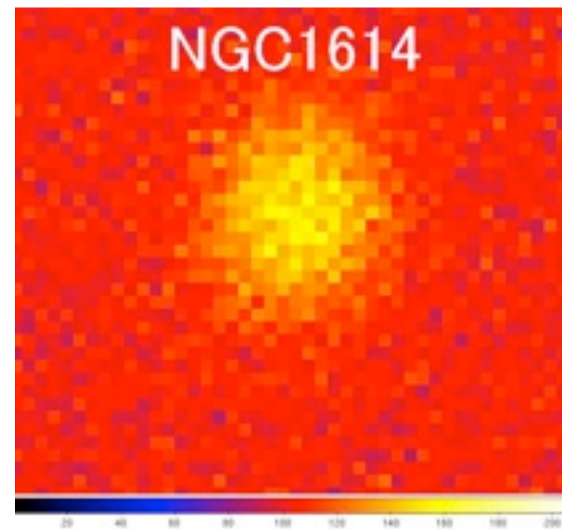
ULIRG (compact)



size<0.2”

>10^14Lo/kpc^2

starburst (extended)



10^12Lo/kpc^2