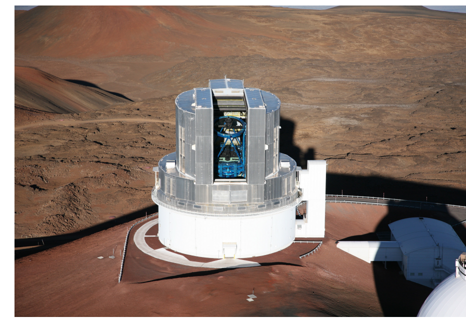
Nuclear starbursts and AGN fueling
- IR view -

Masa Imanishi
(Subaru Telescope/NAOJ)



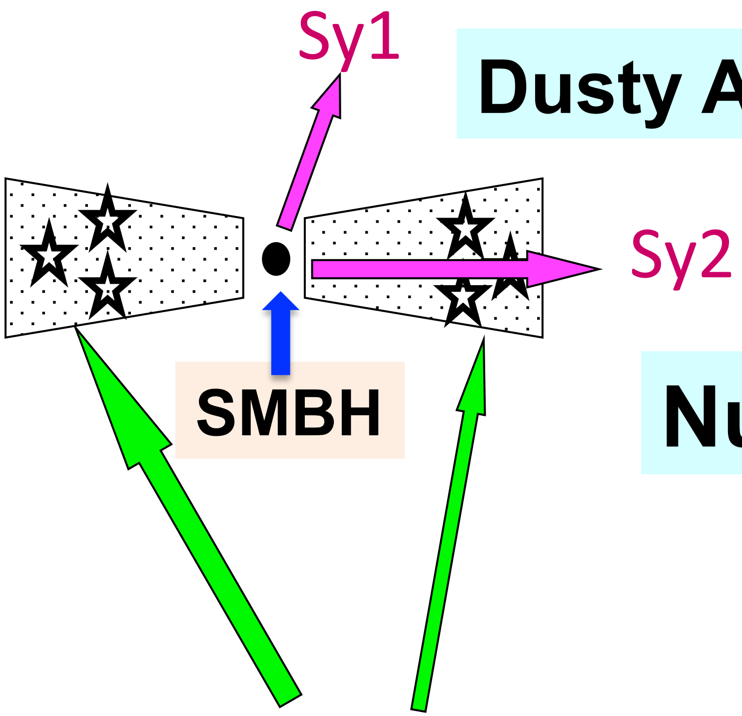
ALMA AGN workshop

2015 Dec 21

Outline

1. Our IR study
2. Related IR study
3. Implication
4. Unknowns and future work

Nuclear starbursts in the AGN torus



Dusty AGN torus is molecular gas rich

⬇

Nuclear starbursts may occur

(Fabian+98, Wada+02, +09)

⬇

Outer part of the torus

Gravitationally more unstable

$Q = \sigma \kappa / \pi G \Sigma_{gas}$

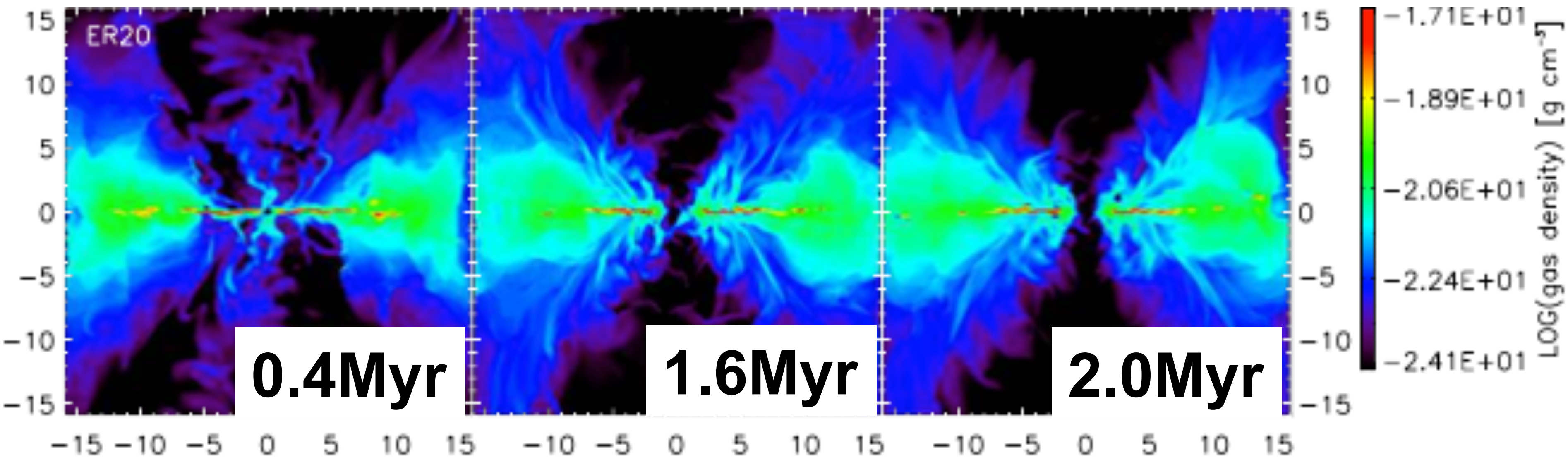
Keplerian : $\kappa \propto r^{-1.5}$

Flat : $\kappa \propto r^{-1}$

Kishimoto+11,+09; Fritz+06: $\Sigma(\mathrm{dust}) \propto r^{0} \sim r^{-1}$

Inflated dusty/molecular torus by nuclear SB

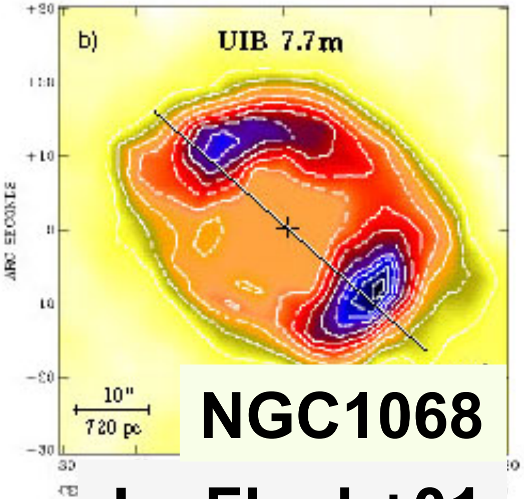
0.2 L_{Edd}



0 15pc

Time evolution

Schartmann+14 MN 445 3878
(see also Wada12 ApJ 758 66)



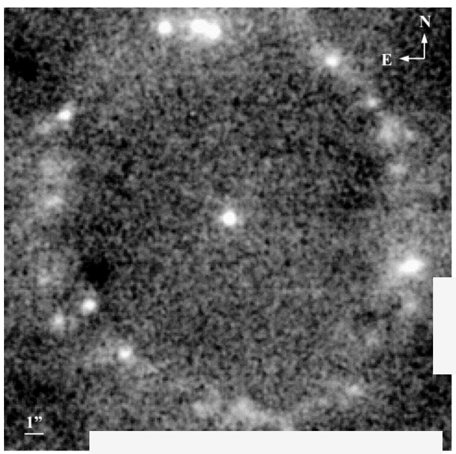
NGC1068

Le Floch+01

Nuclear starbursts in the torus

≠

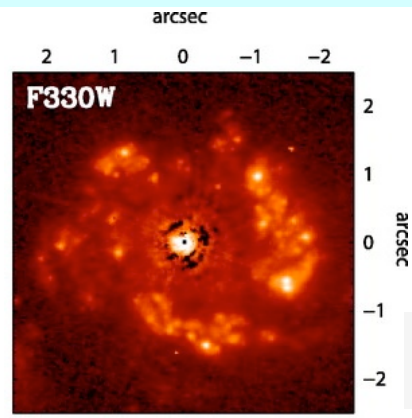
>100pc - kpc scale ring-shaped circumnuclear starbursts



NGC1097

1” = 80 pc

Mason+07



NGC7469

1” = 300 pc

Diaz-Santos+07

Nuclear starbursts : <several 10 pc (< 1” at z > 0.01)

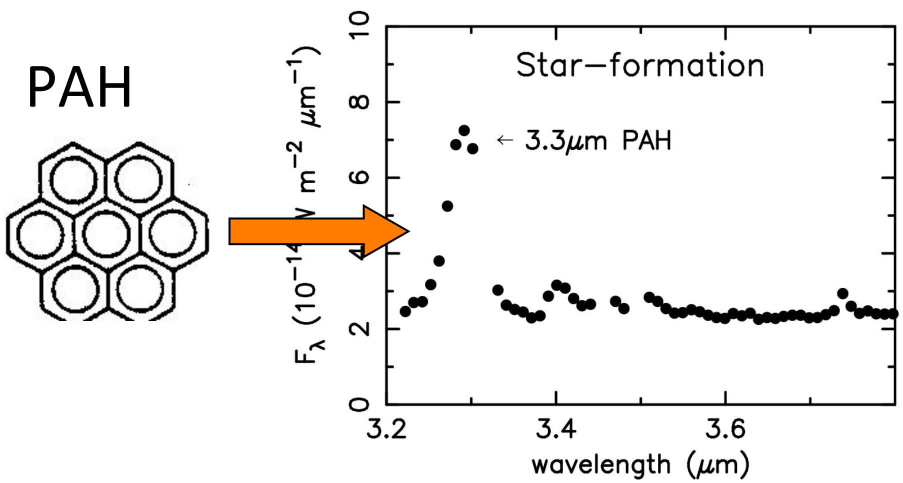
→ **Slit spectroscopy**

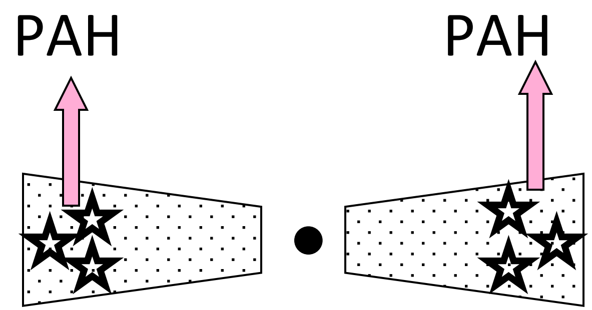
Infrared 3-4 um (L-band)spectroscopy

1: 3.3um PAH from starburst (not AGN)

→ **Excellent probe for starburst**

PAH





2: PAH is intrinsically strong (EW~0.1um)

→ **Weak starburst detectable**

Infrared 3-4 um (L-band) spectroscopy

3: Low dust extinction (0.03-0.04Av)

Nishiyama+08,09

L(SB) from OBSERVED PAH

||

L(SB) from Av-corrected UV

For 3 Sy2s (Imanishi 2002 ApJ 569 44)

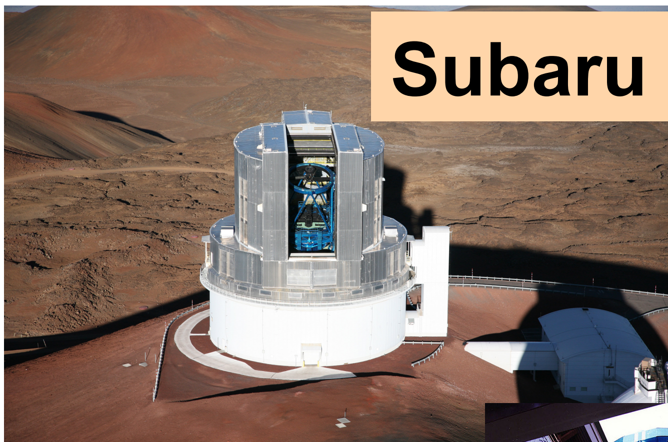
Starbust luminosity is quantifiable

4: More sensitive than N-band (8-13um)

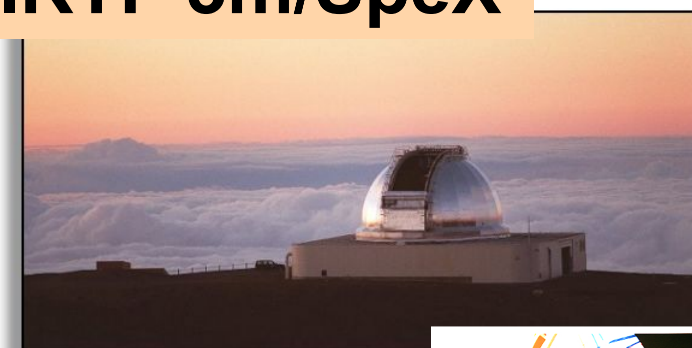
Observations

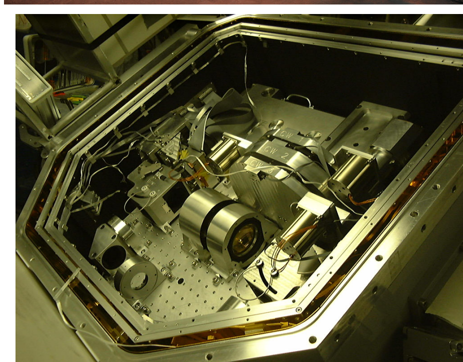
Infrared 3-4um (L-band) slit spectroscopy of

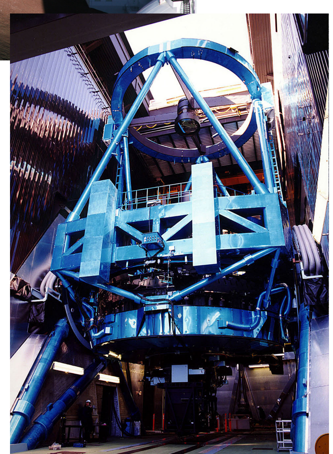
- **32 <u>Sy2s</u> and 23 <u>Sy1s</u> (<u>moderate-luminosity AGN</u>)**
- **30 <u>PG QSOs</u> (<u>high-luminosity type-1 AGN</u>)**

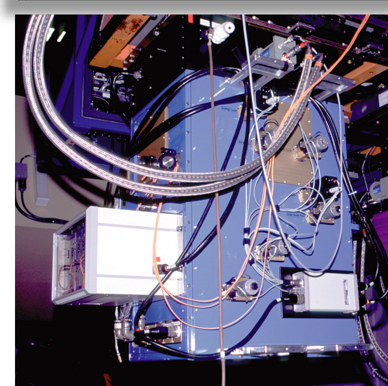


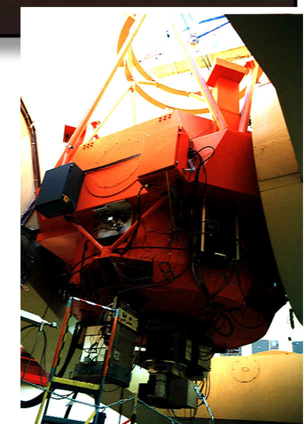
Subaru 8.2m/IRCS, IRTF 3m/SpeX



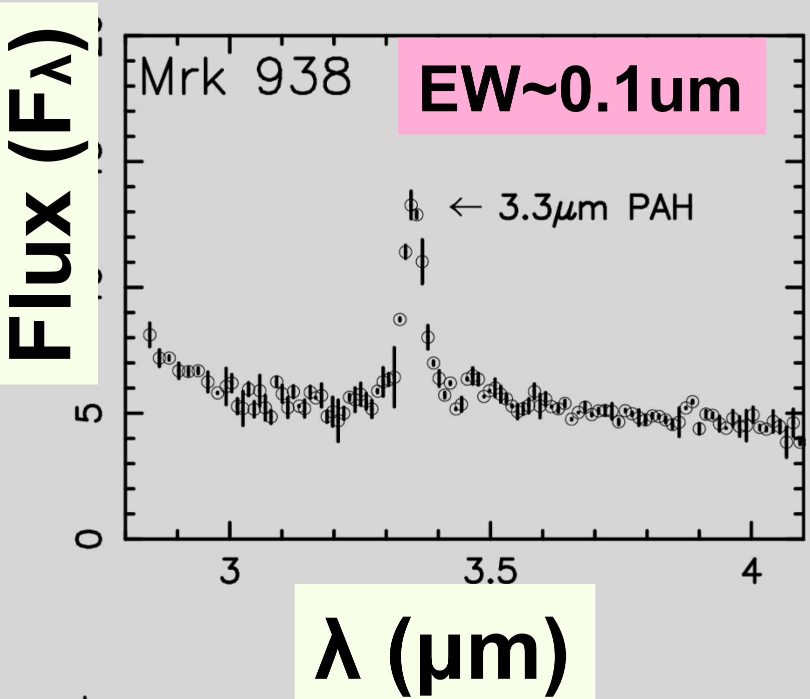


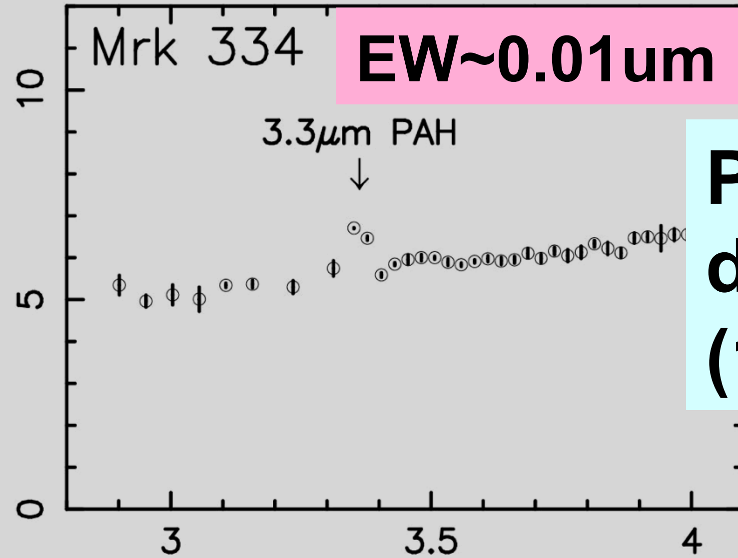




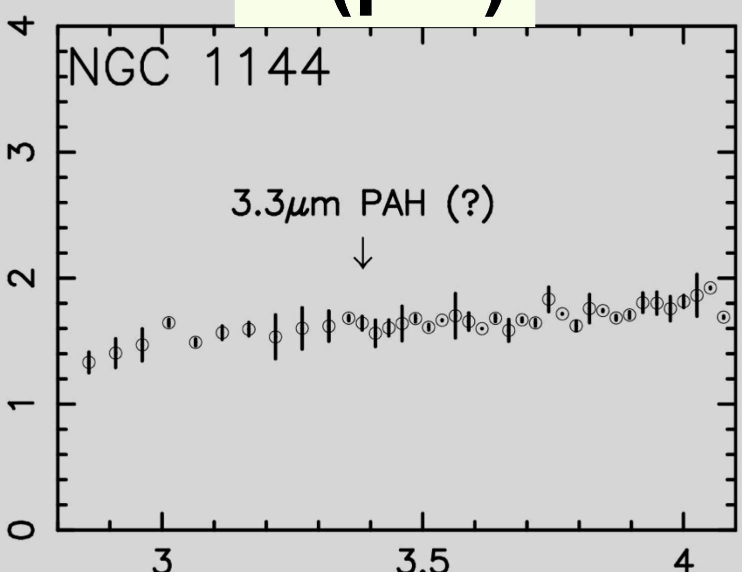


Sy2s





PAH detected (11/32)

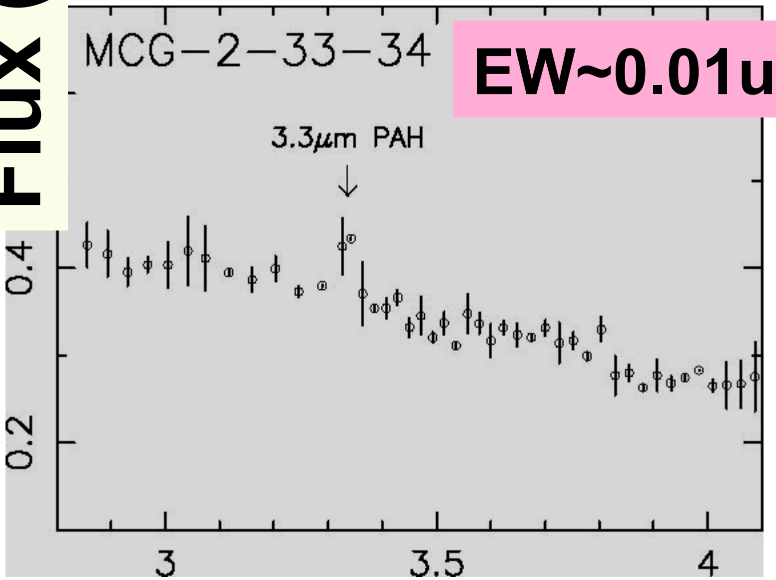


PAH non-detected (21/32)

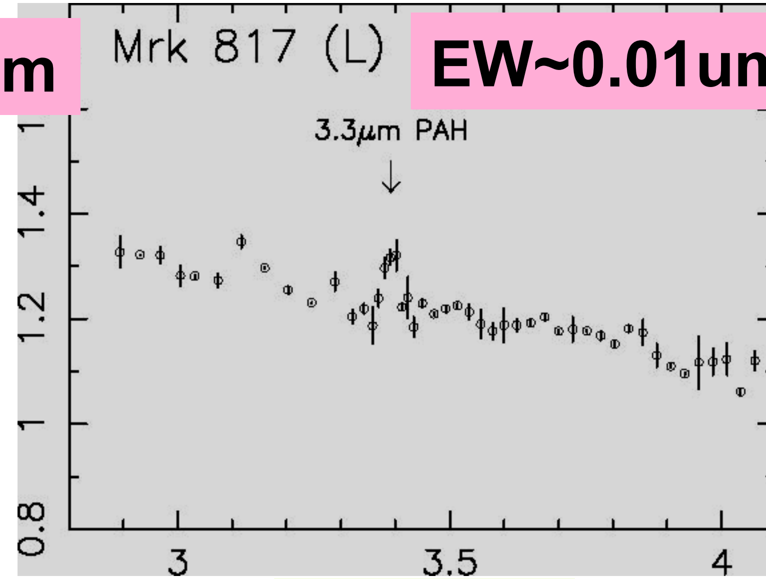
Imanishi 2003 ApJ 599 918

Sy1s

Flux (F_λ)



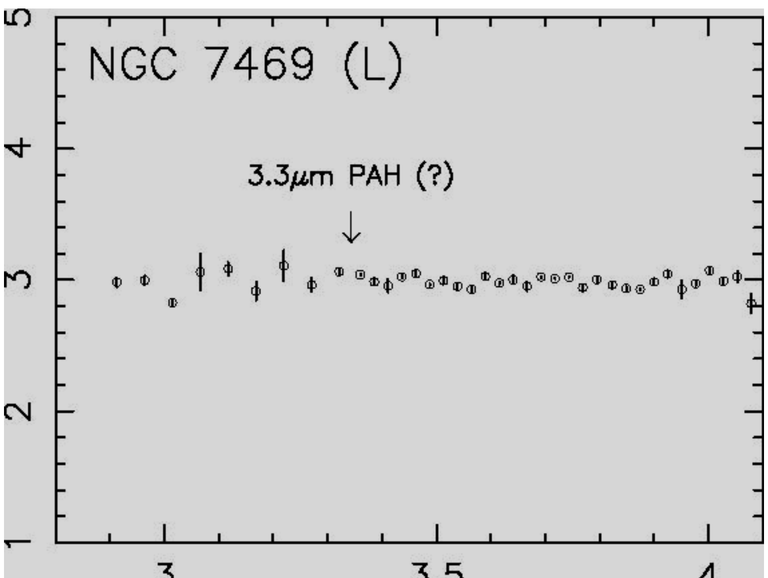
EW~0.01um



EW~0.01um

PAH detected (10/23)

λ (μm)



PAH non-detected (13/23)

Imanishi & Wada 2004
ApJ 617 214

Origin of nuclear PAH emission

- **AGN / Old bulge stars (central regions)**

→ **no PAH**

- **Disk star-formation / Nuclear starbursts**

Surface brightness:
PAH > $20*10^{39}$ [ergs s^{-1} kpc^{-2}]
IR > $20*10^{42}$

→ Starbursts

PAH emission is of <u>nuclear starbursts</u> origin

Results

- rest EW(3.3 PAH) << 0.1 um

Observed nuclear 3-4 um fluxes are dominated by AGN (not starbursts)

- L(3.3 PAH)/L(IR) << 10^{-3}

Nuclear starbursts contribute little to L(IR) of Seyferts

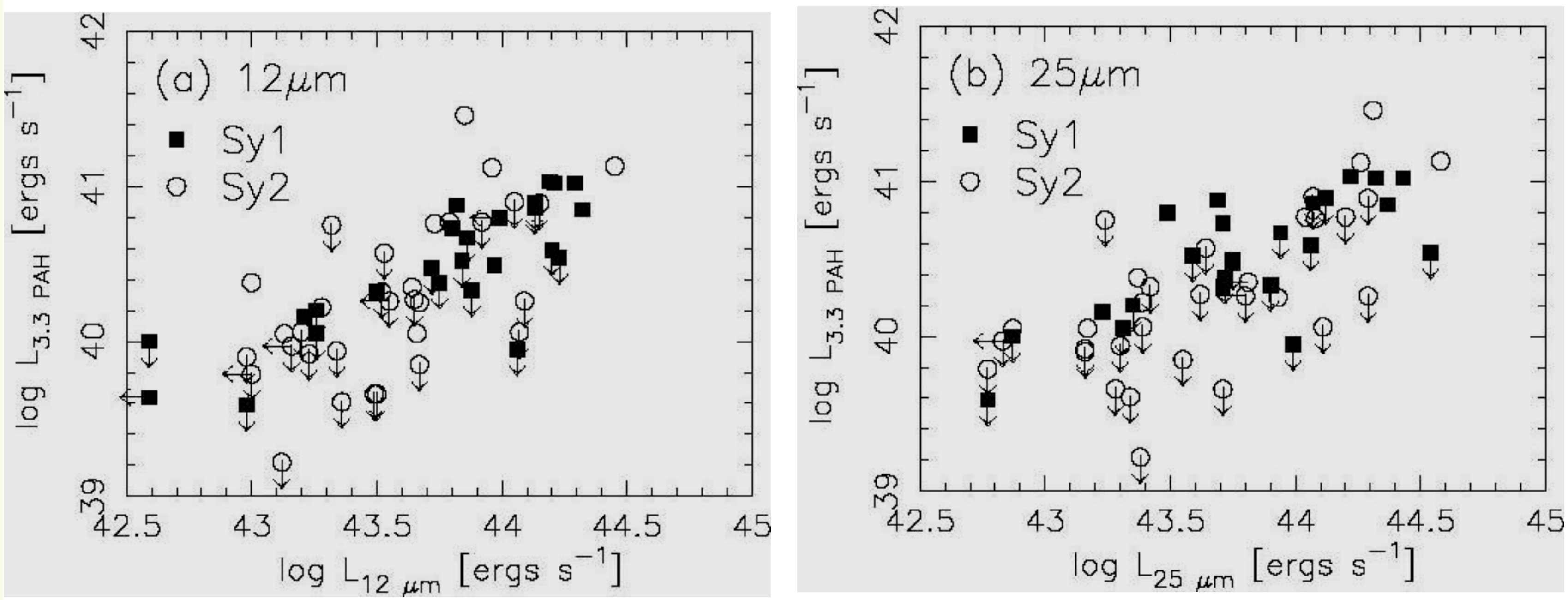
Nuclear starburst luminosity

Sy2 = Sy1 or Sy2 > Sy1 (?)

Starburst ➡ inflate torus ➡ Sy2

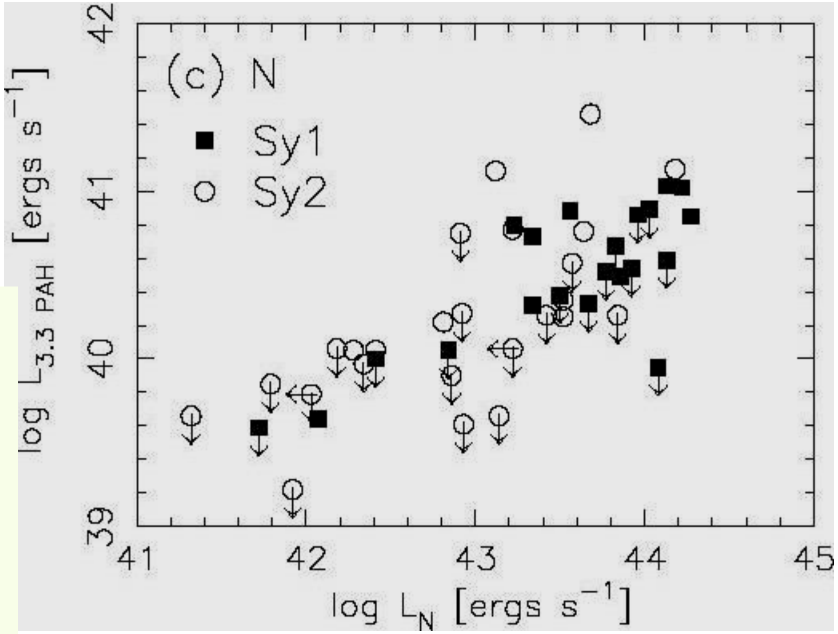
(Wada+02, Levenson+02)

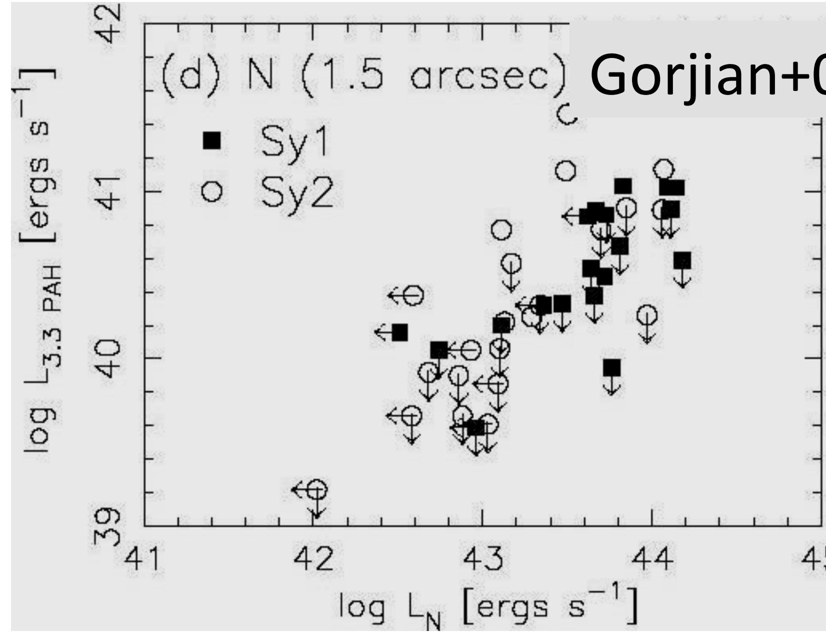
L(3.3 PAH) = nuclear starburst



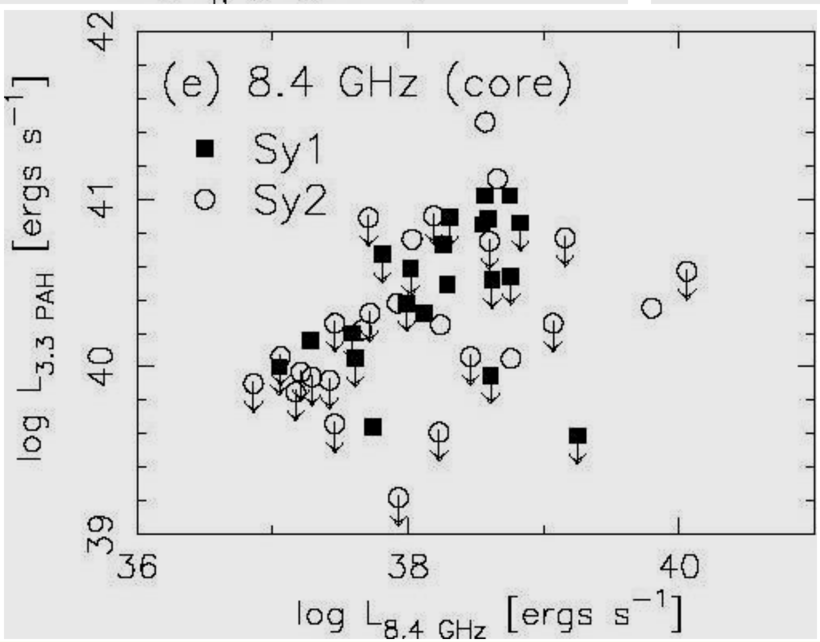
IRAS 12um, 25um = AGN power

L(3.3 PAH)
= nuclear starburst





Gorjian+04



Imanishi & Wada 2004
ApJ 617 214

Nuclear N-band, radio core = AGN power

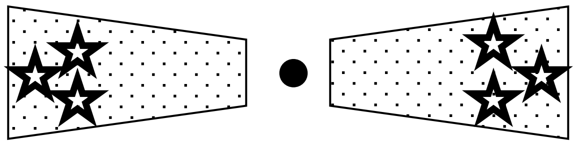
Main results (Moderate luminosity AGNs)

L(nuclear SB) : Sy1 ~ Sy2

Scenario of L(nuclear SB) : Sy2 > Sy1

Not supported

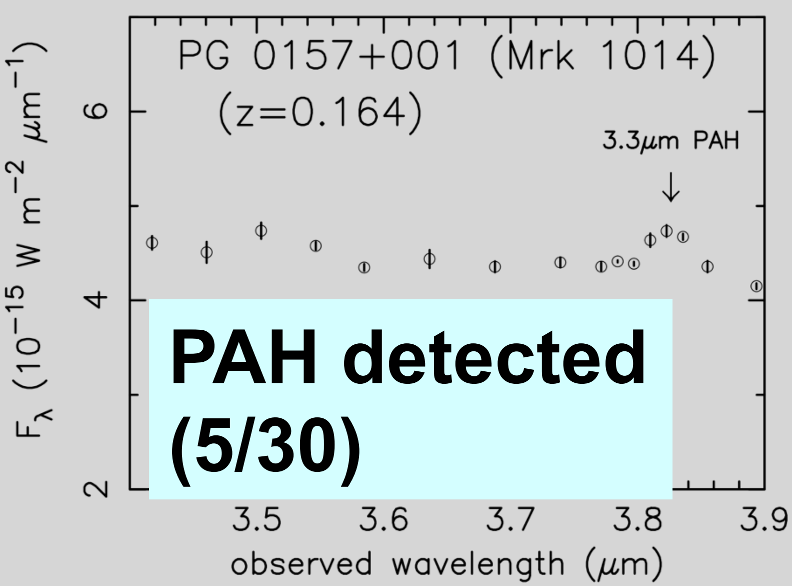
L(nuclear SB) and L(AGN) : correlated



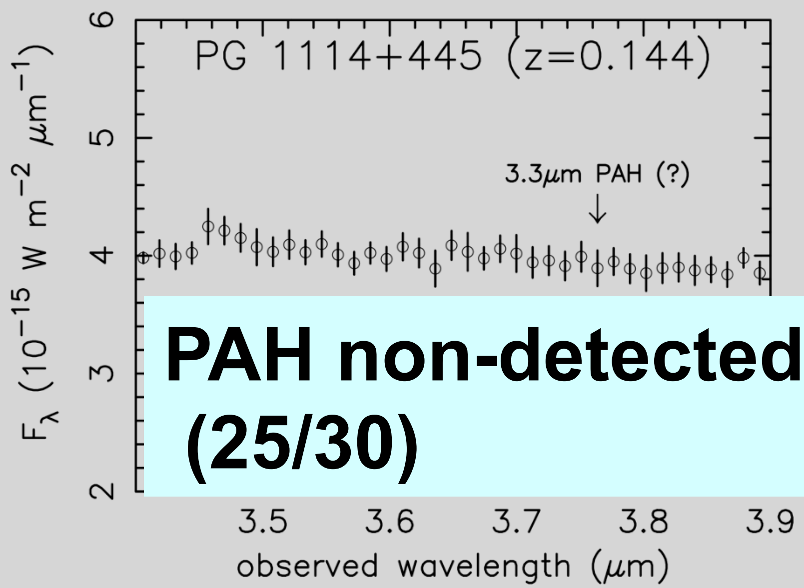
Physical connection ?

Nuclear SB is energetically not dominant,
but <u>physically close to AGN</u>

PG QSOs (high-luminosity type-1 AGN)

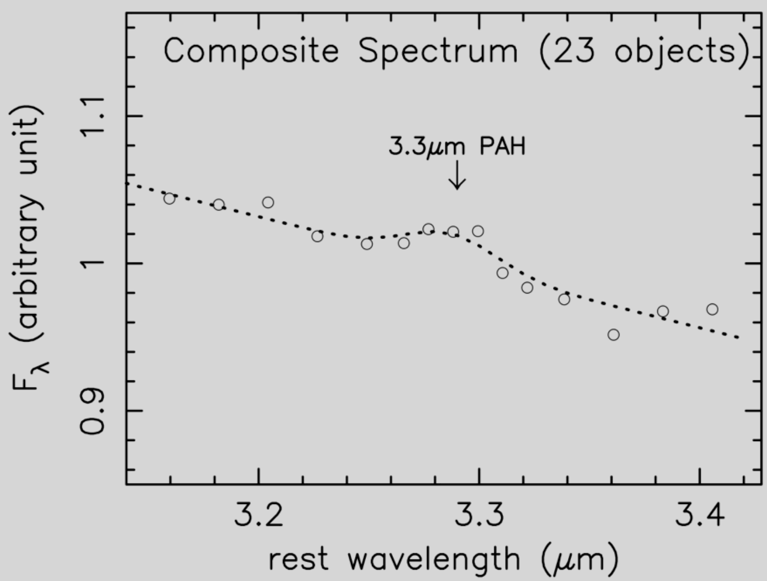


PAH detected (5/30)



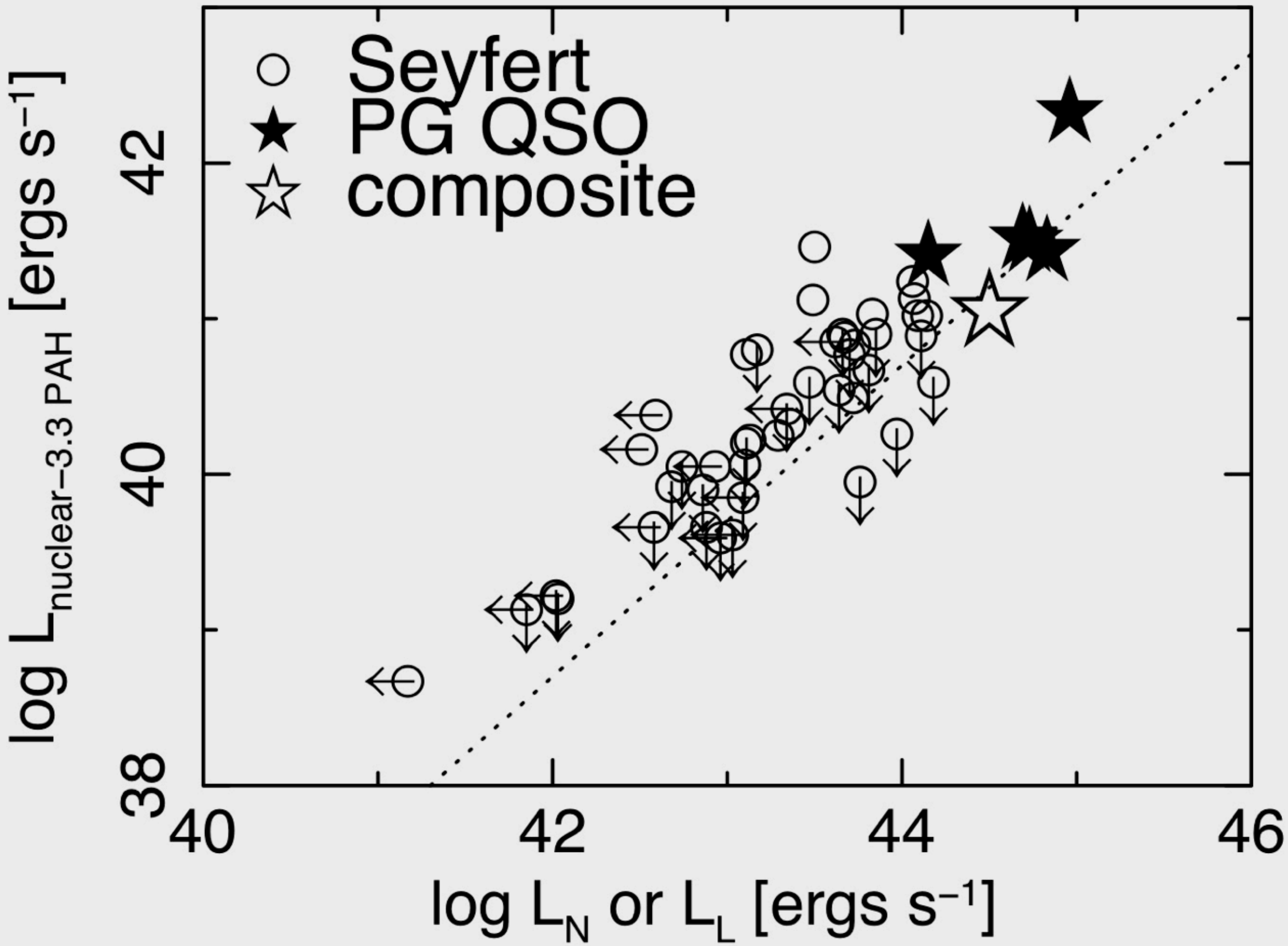
PAH non-detected (25/30)

Composite of no-PAH sources (Subaru/IRCS)



Imanishi+11 PASJ 63 S447

AGN – nuclear SB connections in a wide AGN luminosity range



L(3.3 PAH) = nuclear starburst

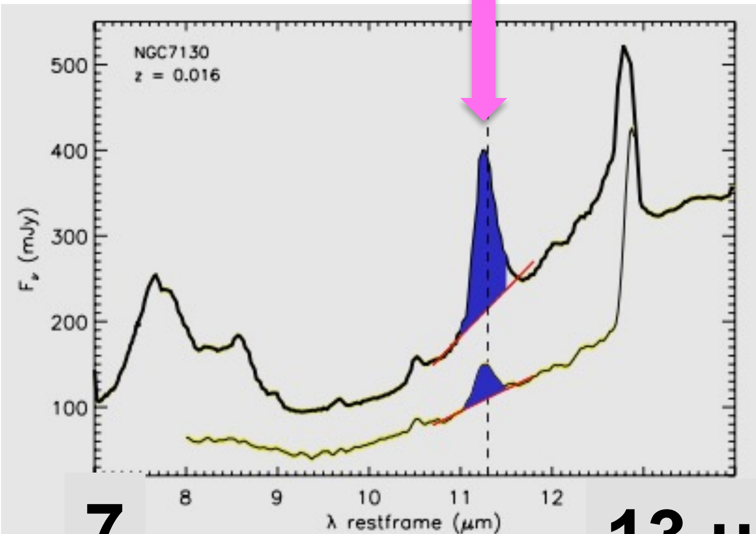
Nuclear L- or N-band = AGN power

Imanishi+11 PASJ 63 S447

MIR 8-13um (N-band) spectroscopy

Esquej+14 ApJ 780 86

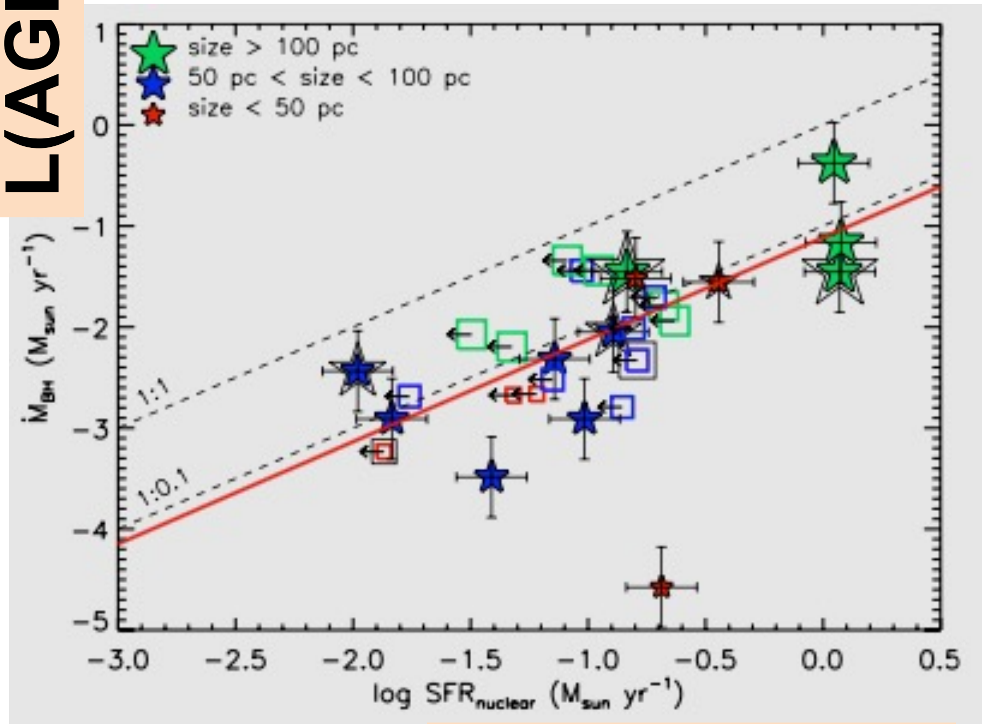
11.3um PAH



7

13 um

L(AGN)

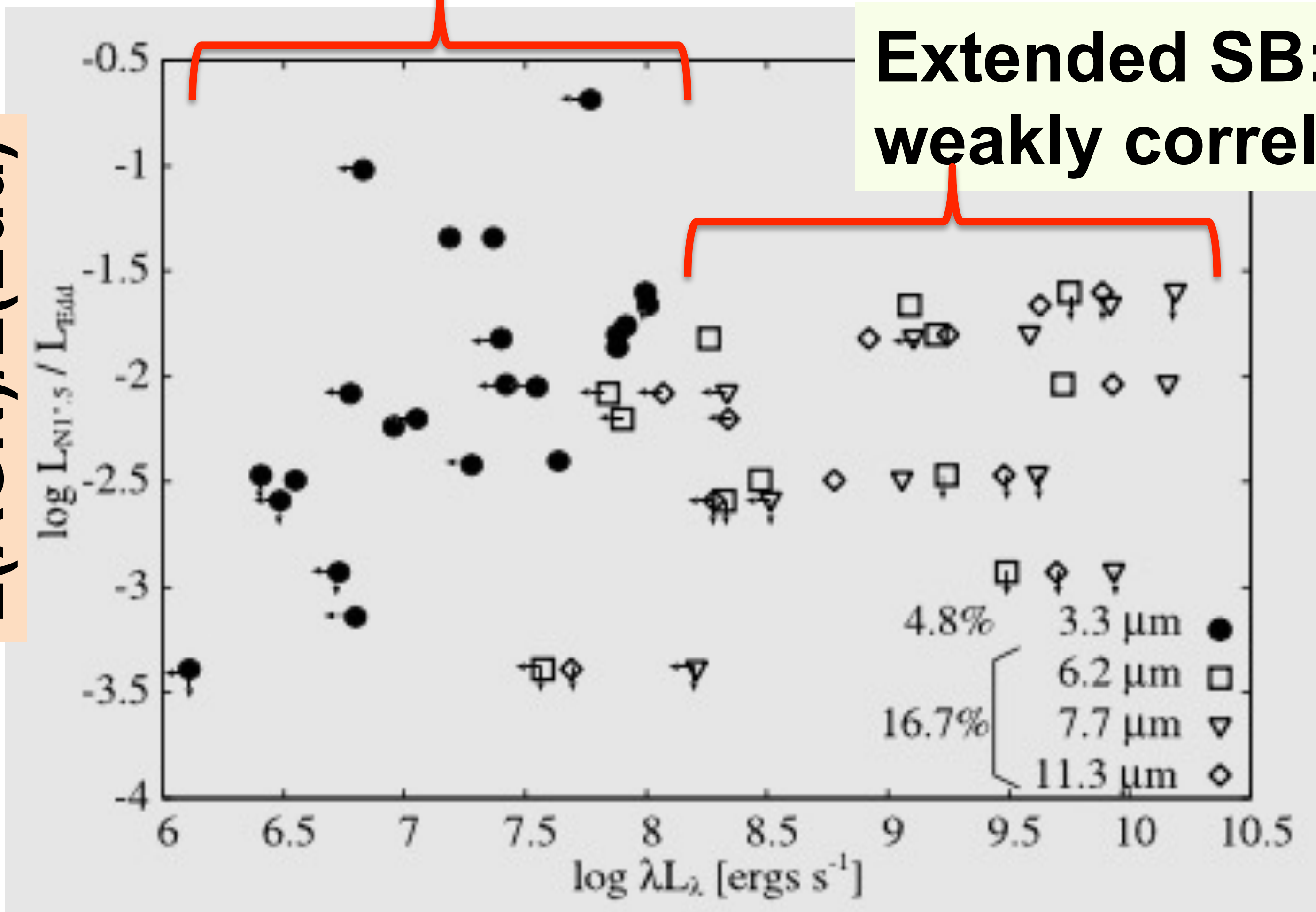


L(nuclear SB)

Nuclear SB vs extended SB

Nuclear SB : strongly correlated with L(AGN)

Extended SB: weakly correlated



L(AGN)/L(Edd)

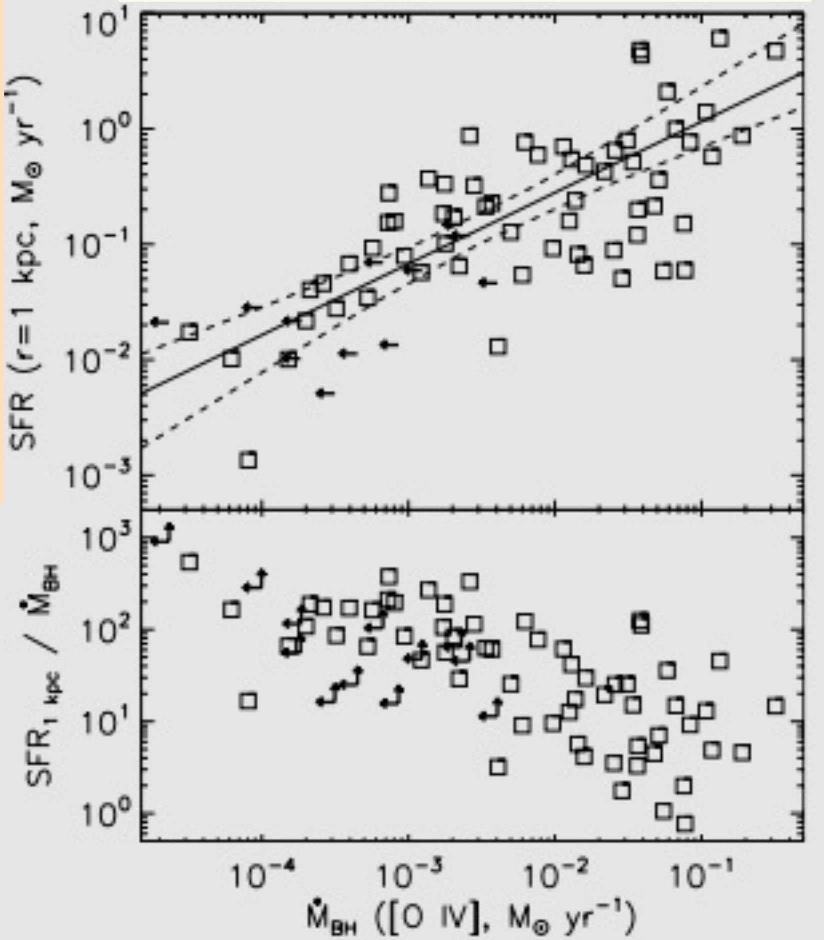
L(SB)

Watabe+08 ApJ 677 895

Nuclear SB vs extended SB

Strong correlation

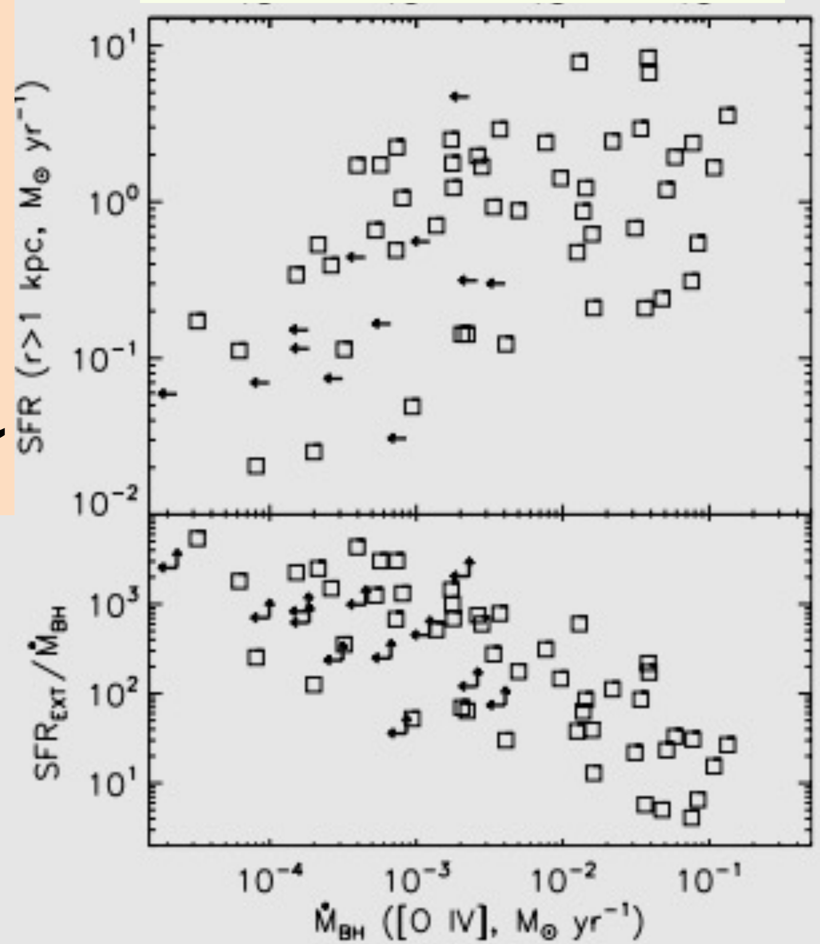
L(compact SB)



L(AGN)

Weak correlation

L(extended SB)



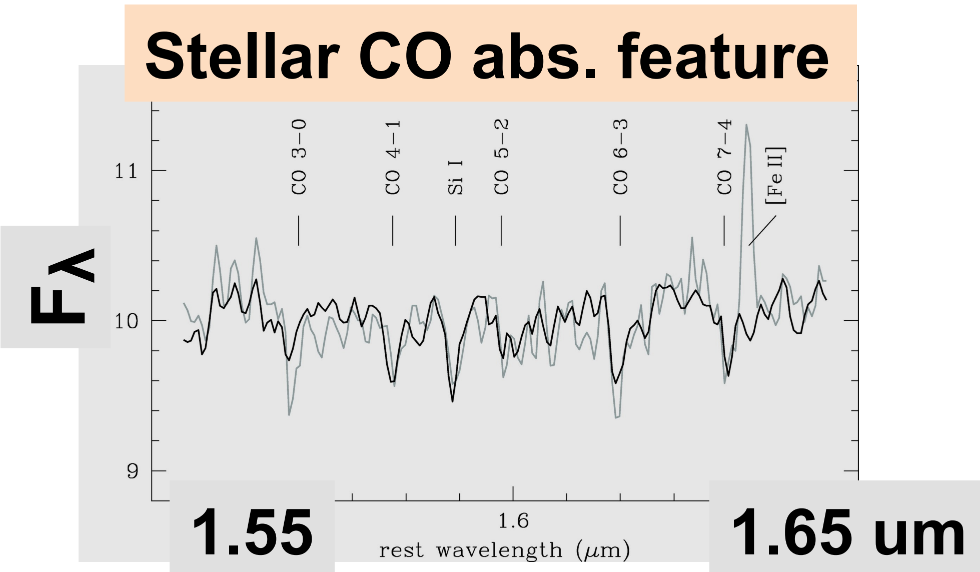
L(AGN)

Diamond Stanic+12 ApJ 746 168

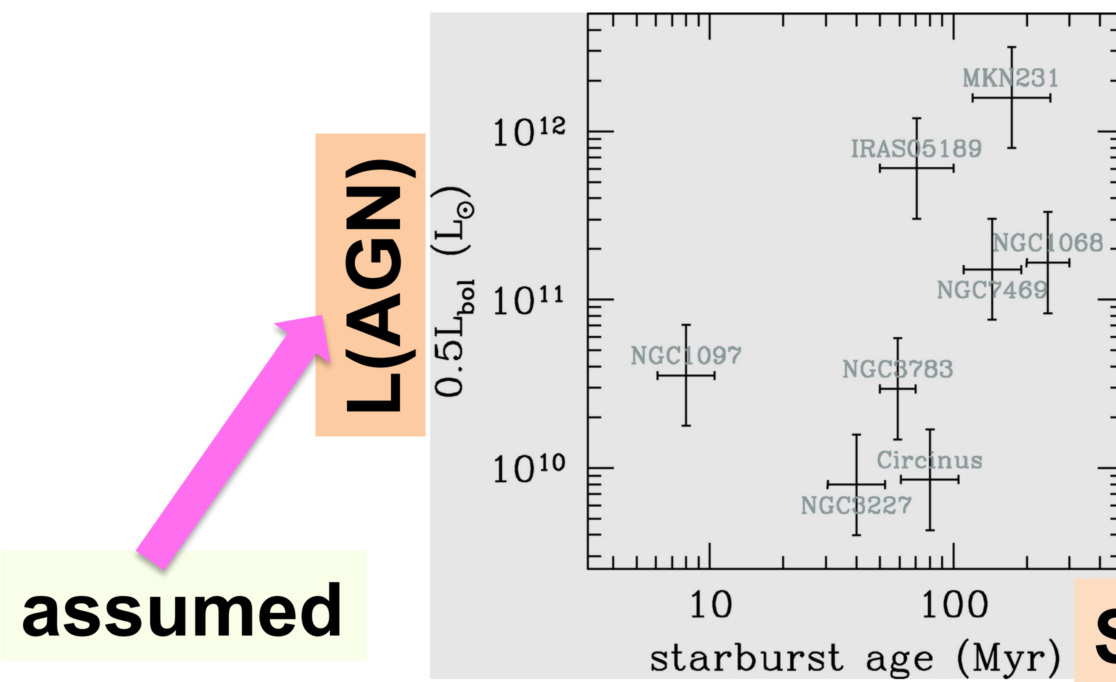
NIR H- (1.65um) and K-(2.2um) spectroscopy

Davies+07 ApJ 671 1388

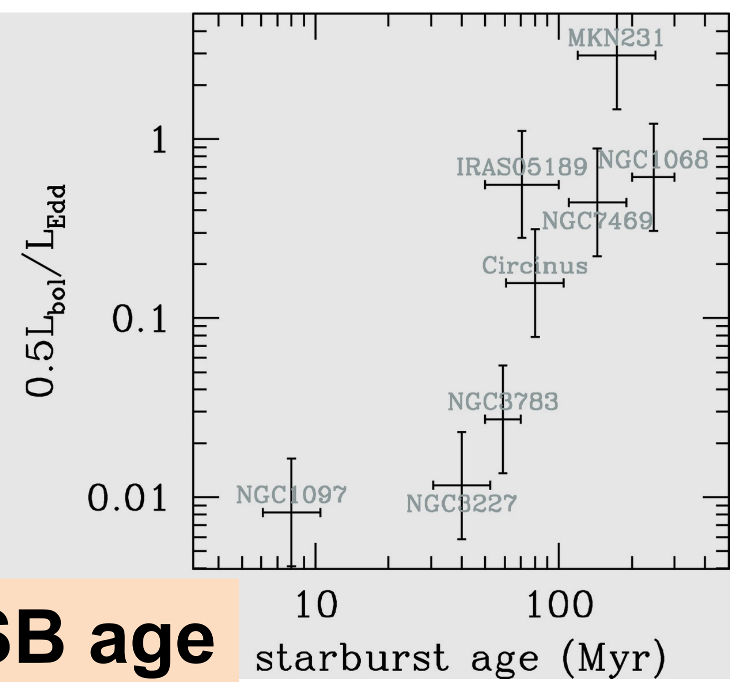
Stellar CO abs. feature



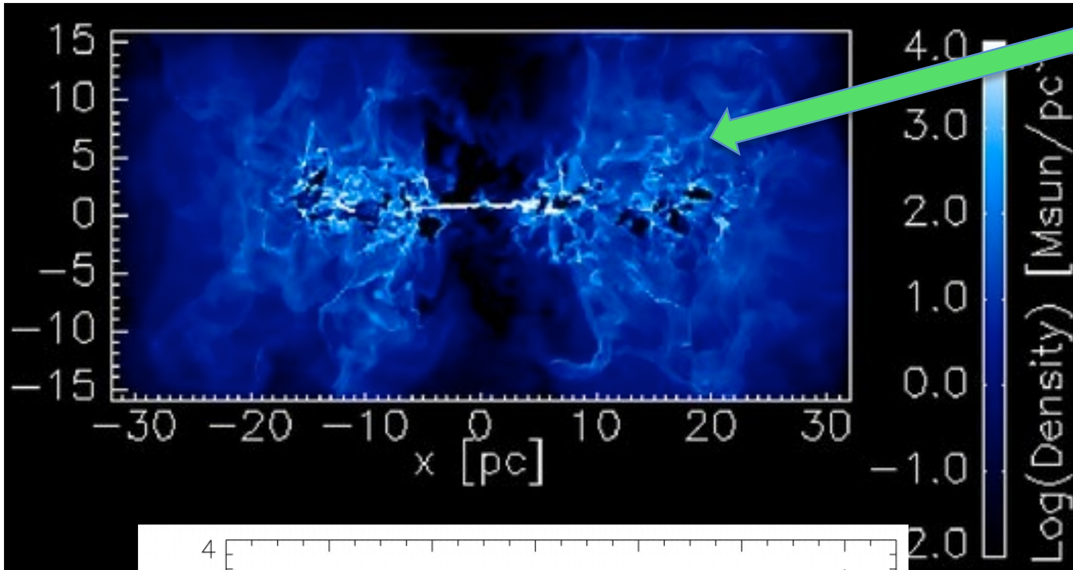
Time delay between nuclear SB and AGN ?
(SB regulate AGN)



SB age

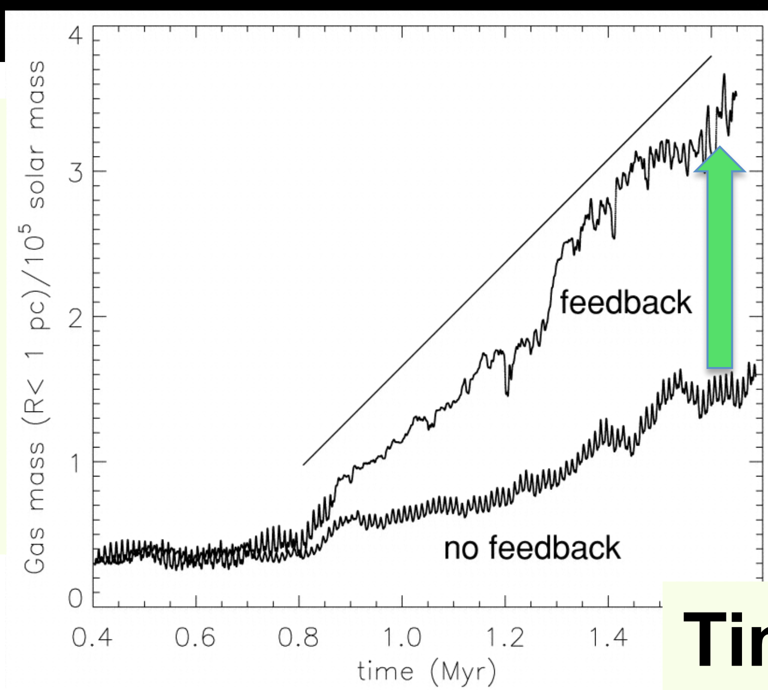


Nuclear SB regulates L(AGN) ?



Nuclear SB inflates outer dusty tori (due to energy input)

Wada+02 ApJ 566 L21
Wada+09 ApJ 702 63



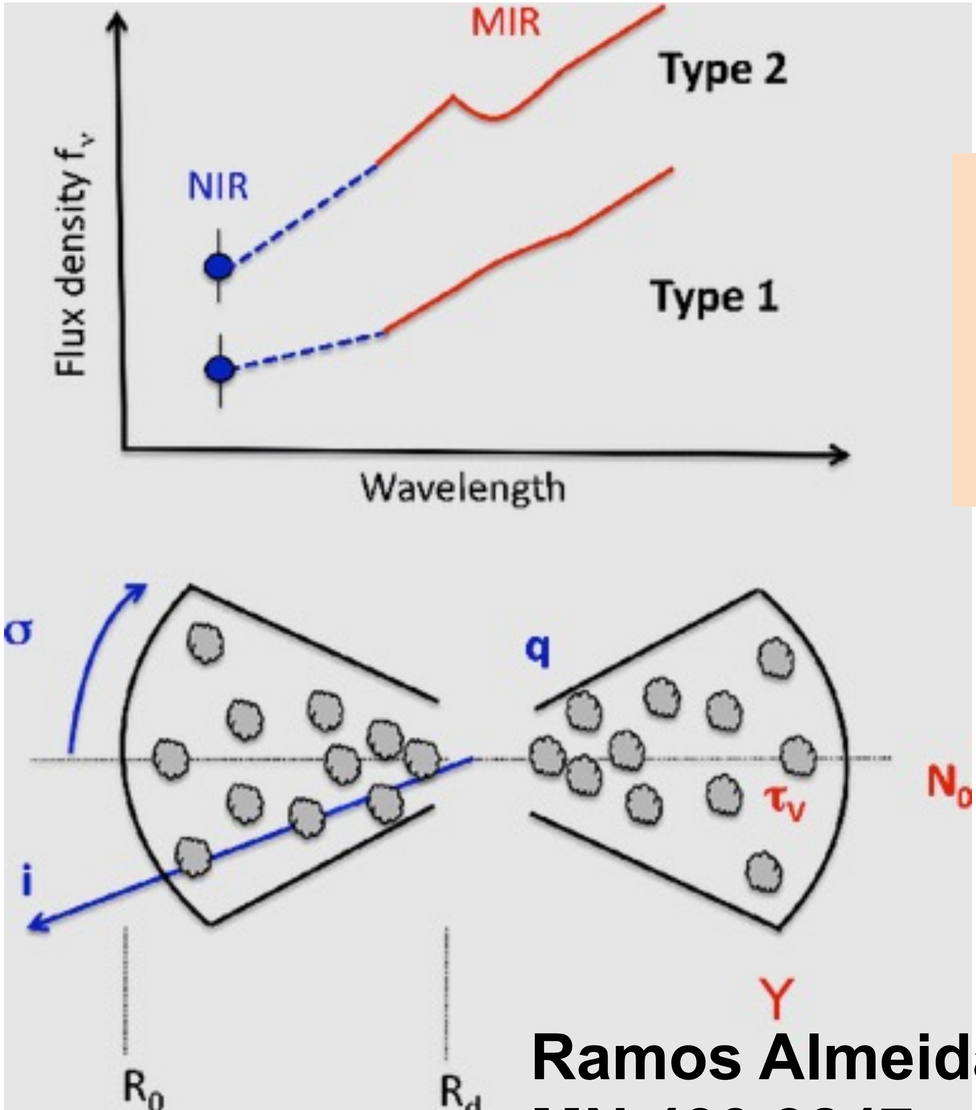
Mgas(<1pc)

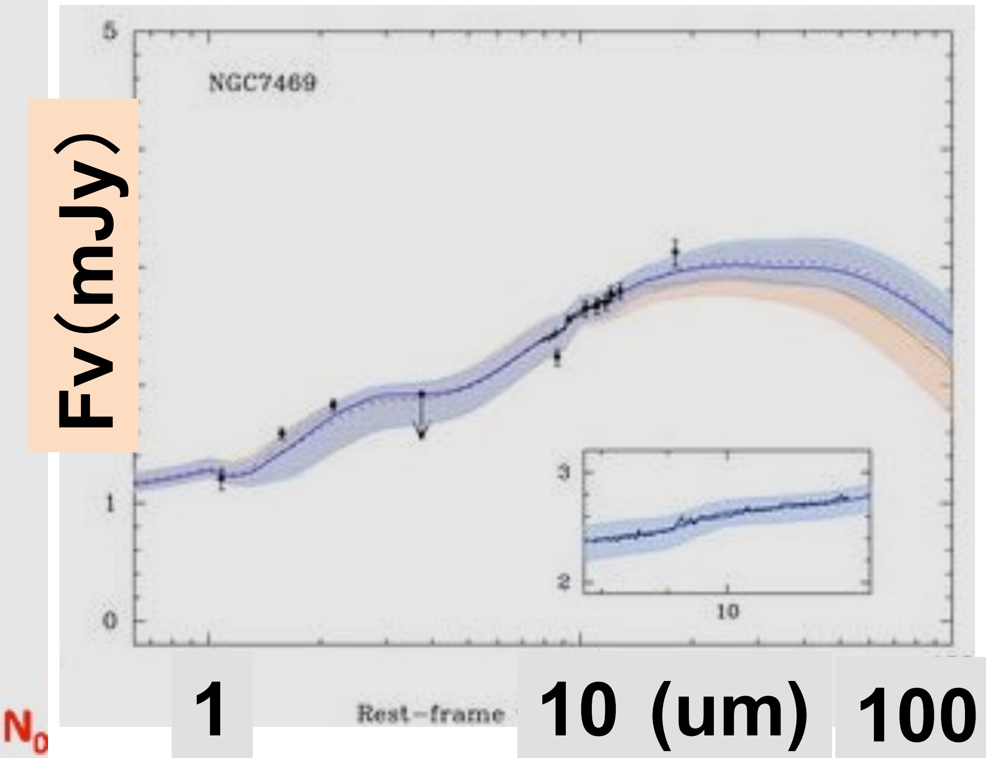
Time (Myr)

Gas accretion onto SMBH increases by nuclear SB at outer dusty tori

Q: Do we indeed understand torus?

Fit nuclear MIR emission with clumpy torus model





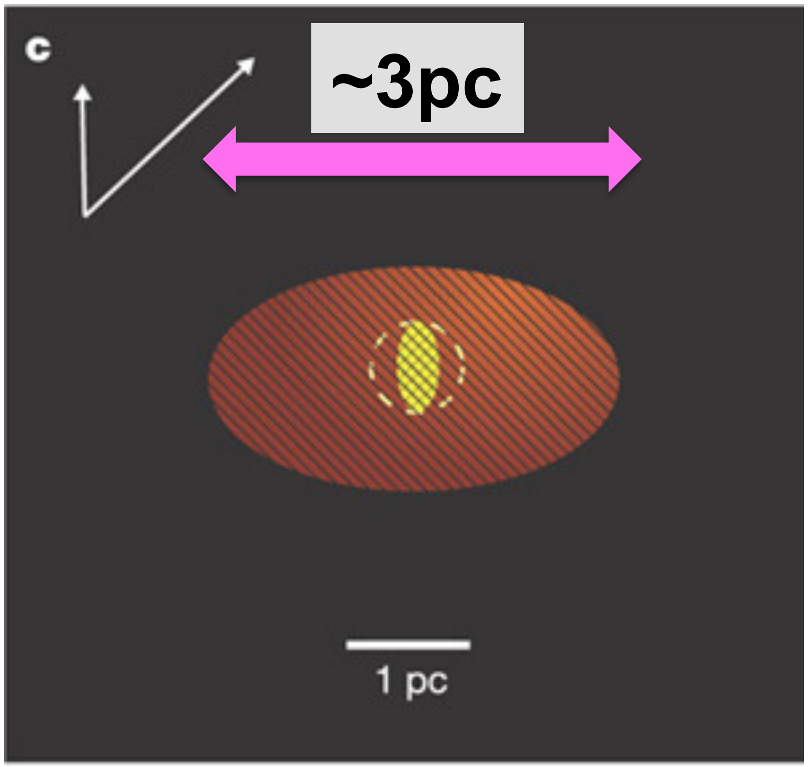
Ramos Almeida+14
MN 439 3847

Torus size = 1-6pc

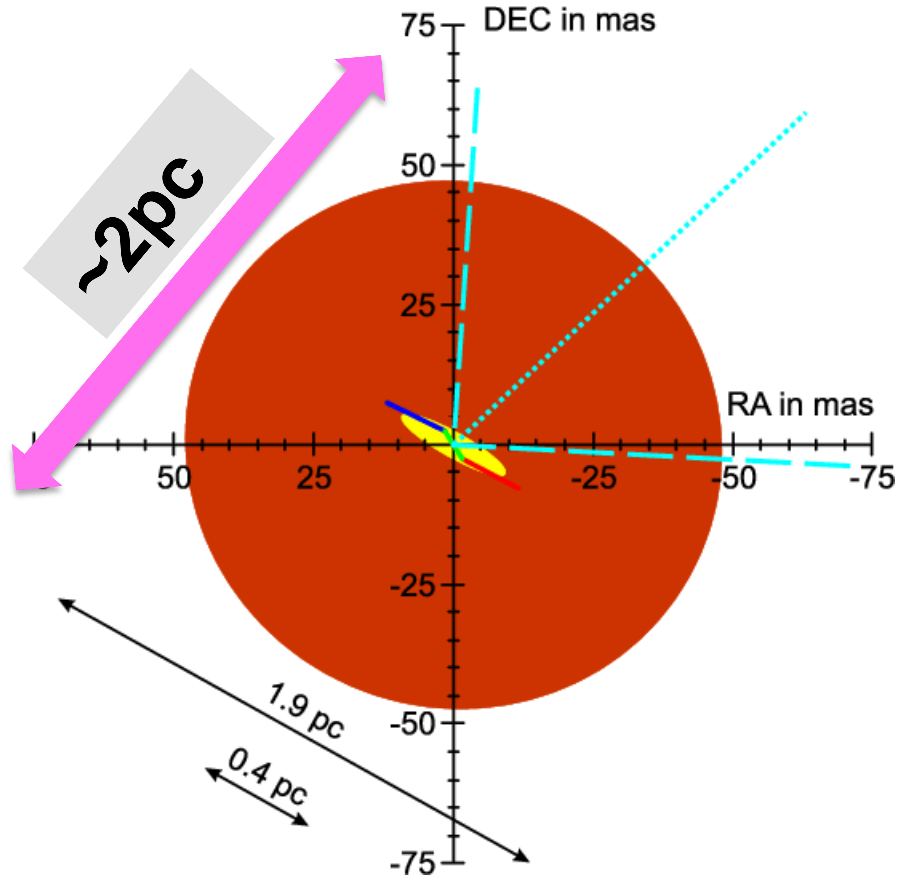
Alonso-Hererro+11
ApJ 736 82

VLTI: MIR 10um emission is compact

NGC 1068



Circinus

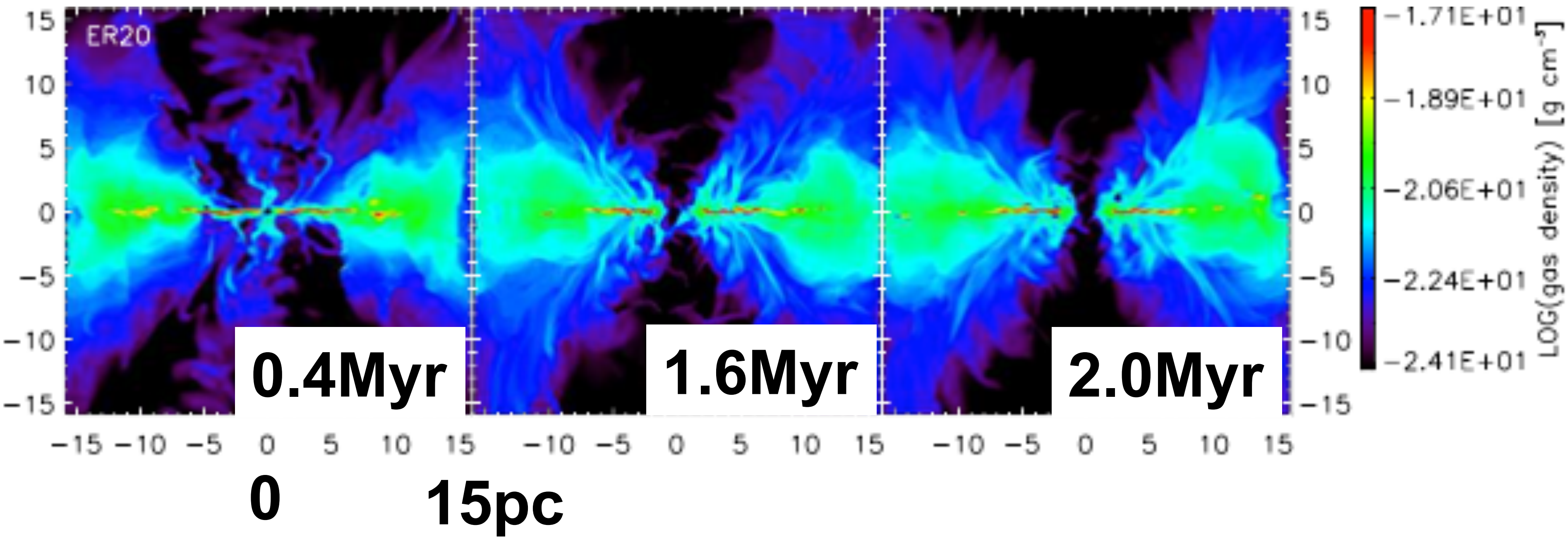


Jaffe+04 Nature 429 47

Tristram+07 AA 474 837

Inflated dusty/molecular torus by nuclear SB

0.2 L_{Edd}



Time evolution

Torus size = 10-20 pc

Schartmann+14
(see also Wada12)

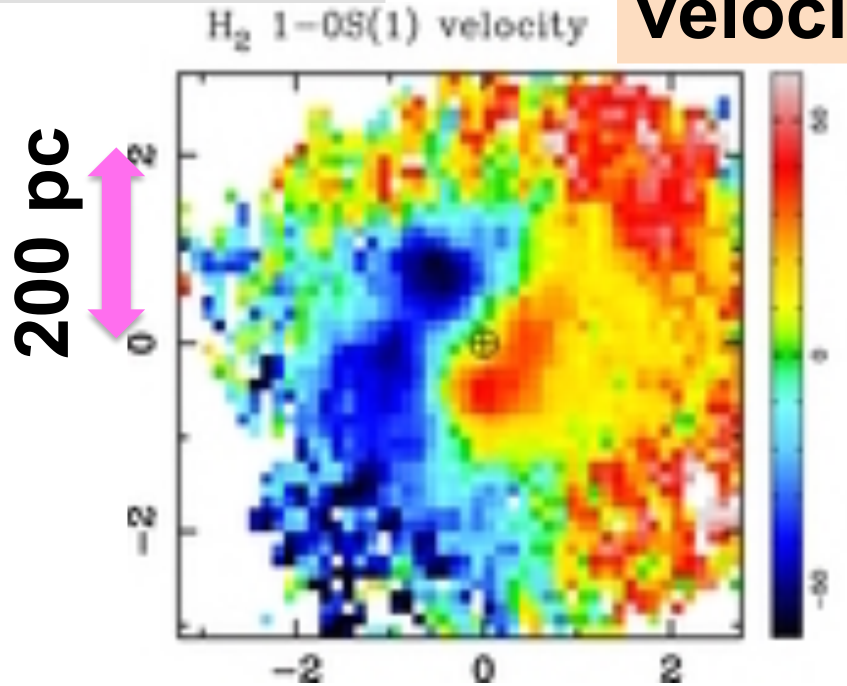
50-100 pc scale thick molecular gas

NIR 2um IFU (H_2 line)

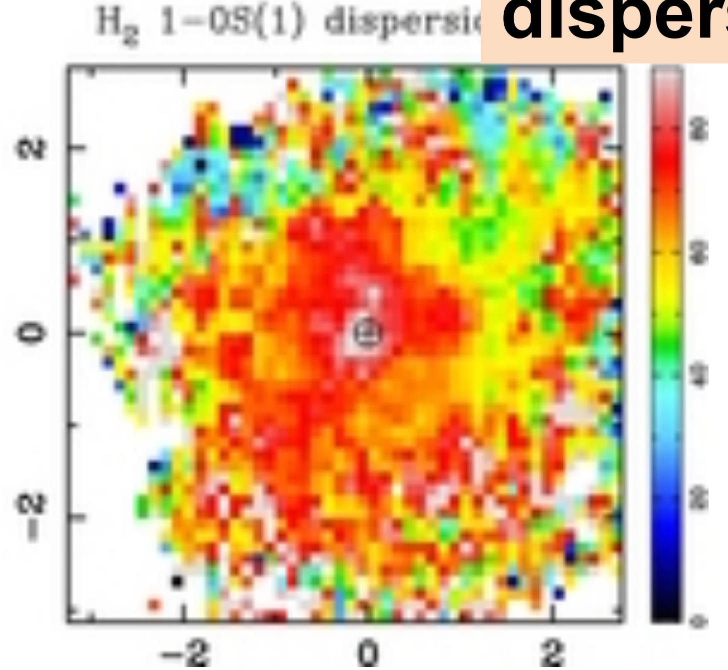
High σ/v at 50-100 pc

NGC 7743

velocity



dispersion



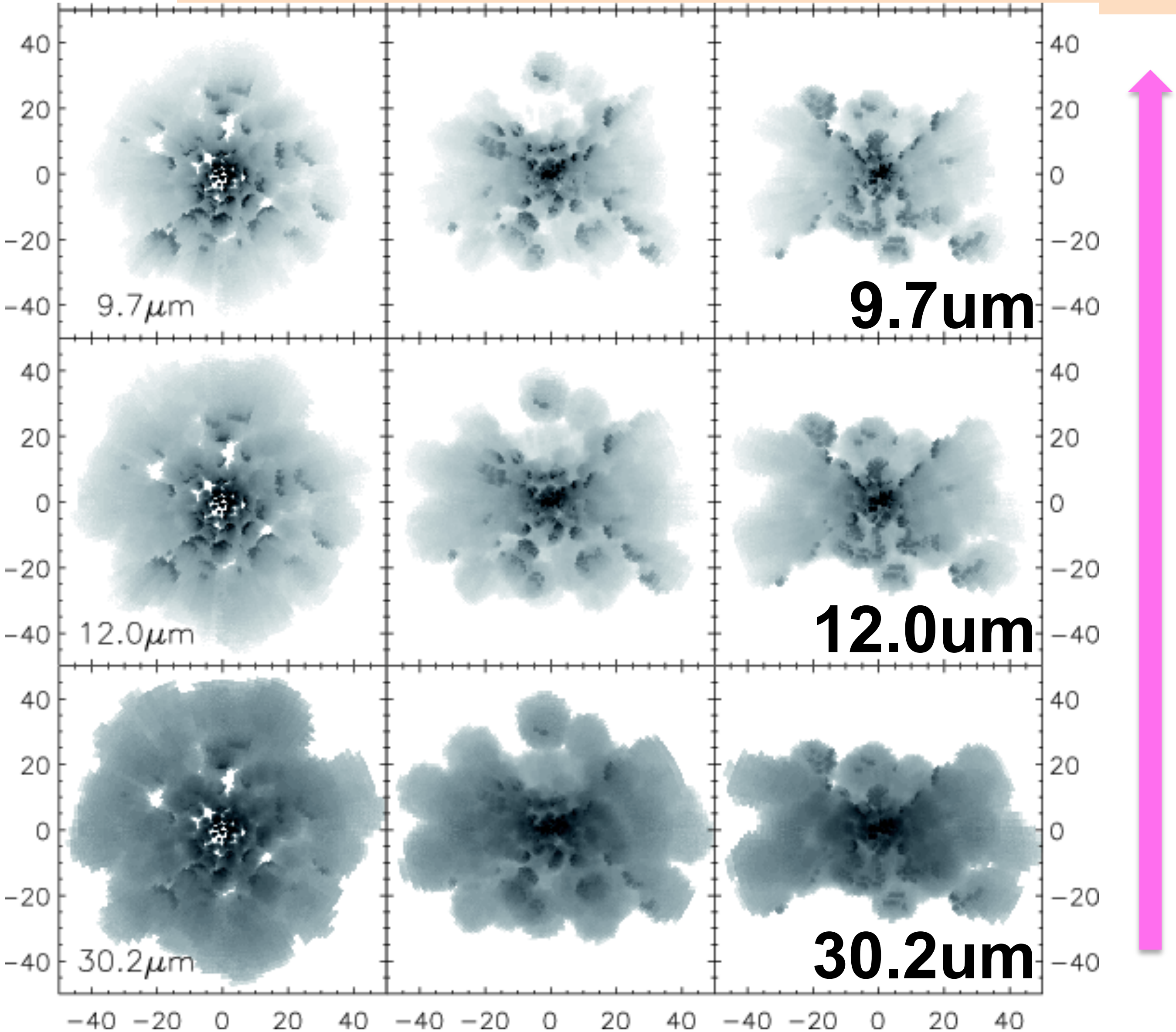
Davies+14 ApJ 792 101

Dust and molecular gas usually coexist

Inflated dust at 50-100 pc ?

10um emission probes hot (~300K) dust

Smaller than the actual torus outer radius?



Shorter λ

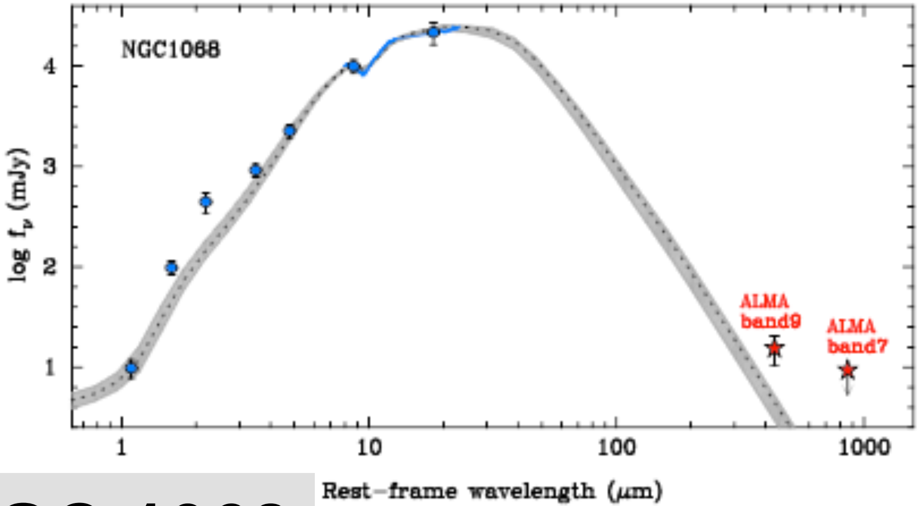
compact

Schartmann+08
AA 482 67

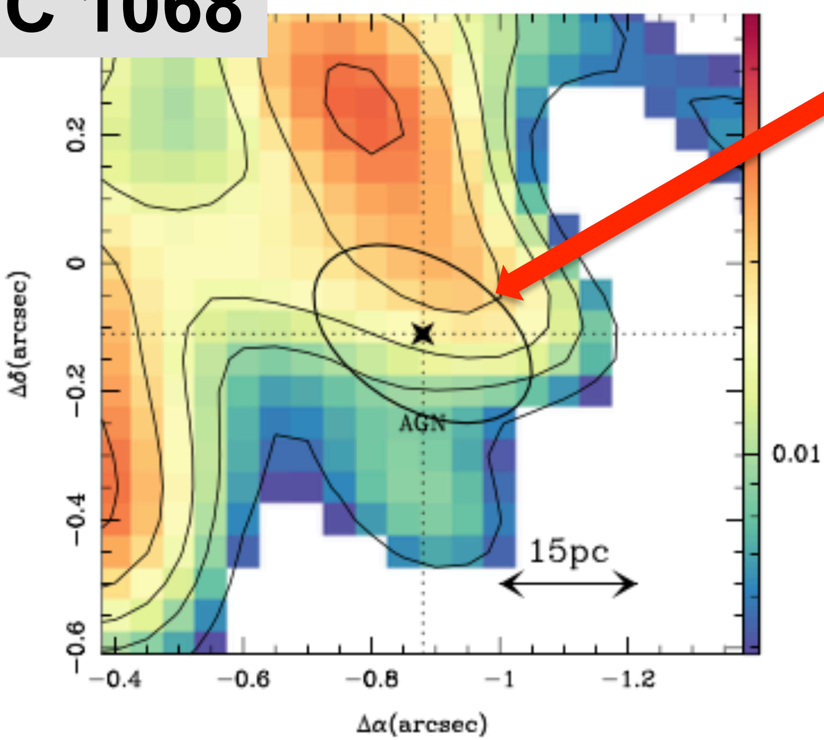
ALMA high-spatial-resolution 350um image

Garcia-Burillo+14
AA 567 A125

0.3-0.5”



NGC 1068



No discrete torus emission at 350um

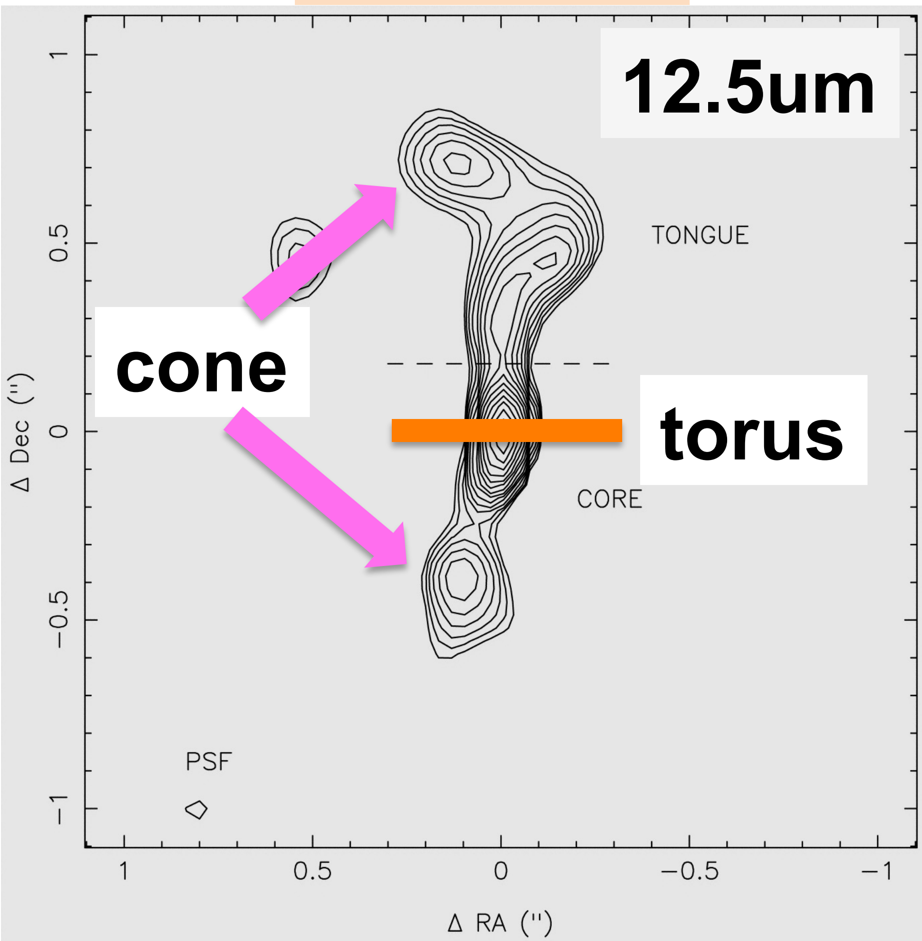
Even higher resolution help?

Veiled by extended cool dust emission?

Need 20-30um?

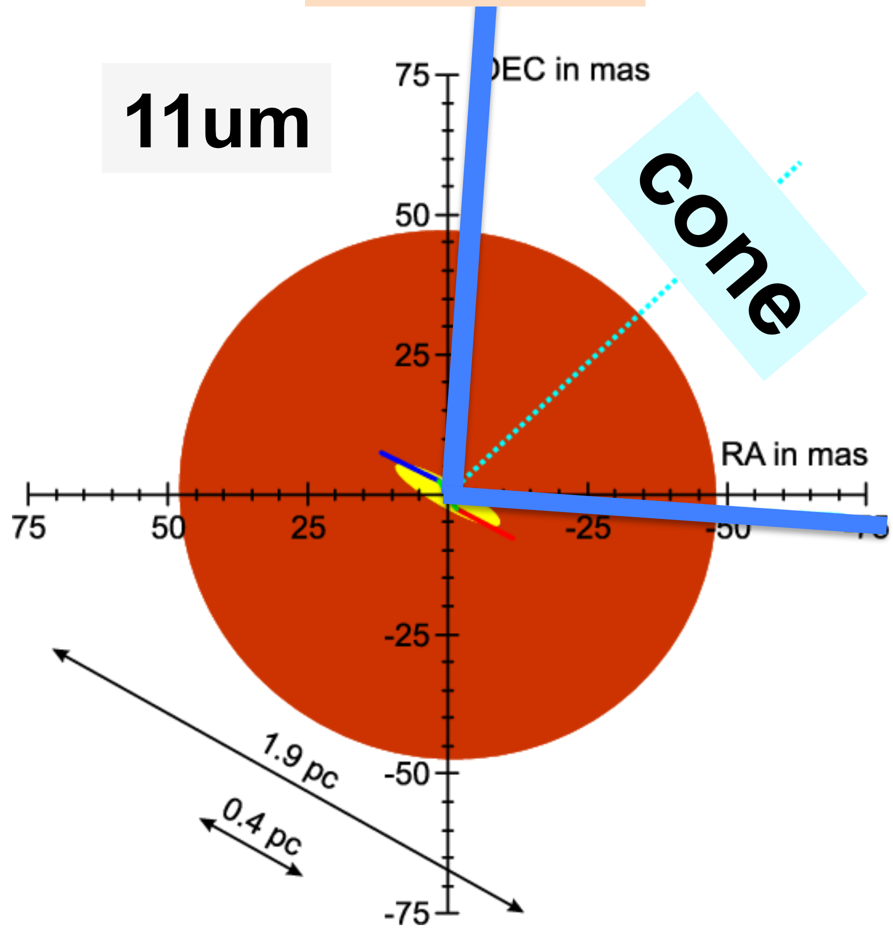
Nuclear MIR emission = torus origin ?

NGC 1068



Jaffe+04 Nature 429 47

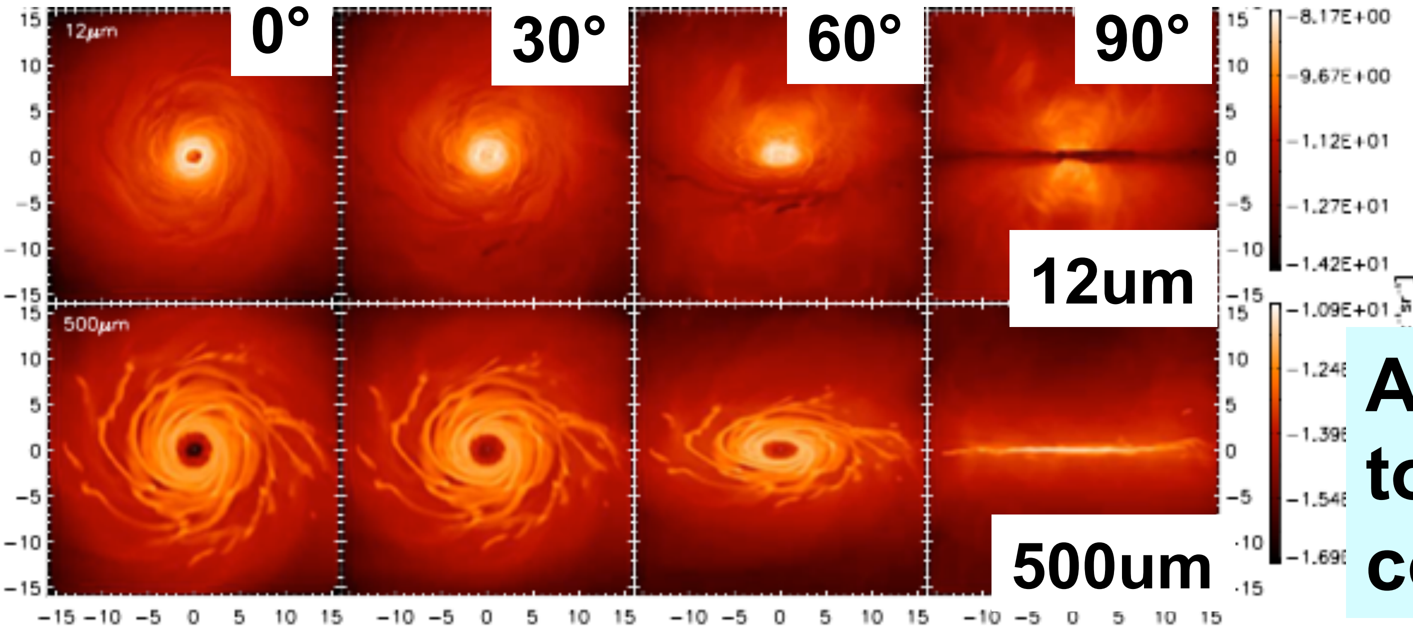
Circinus



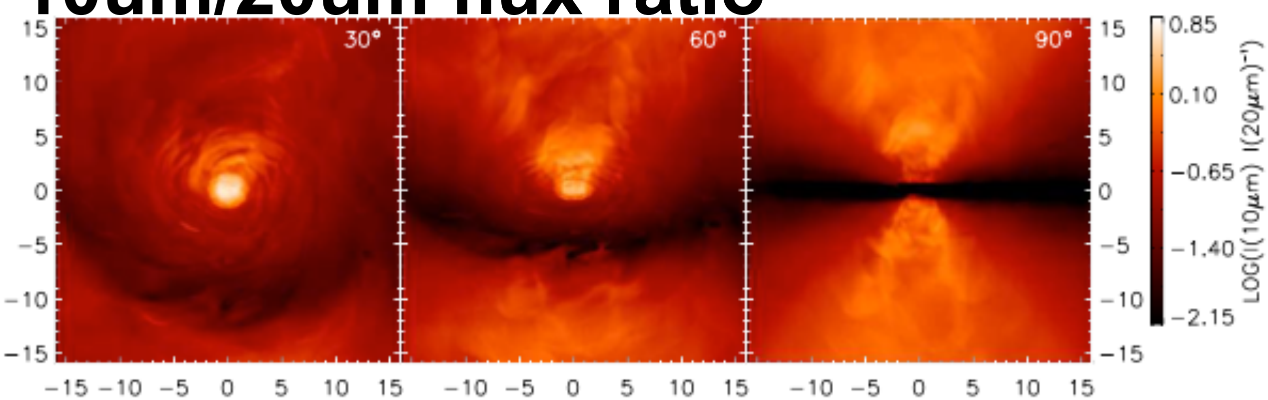
Tristram+07 AA 474 837

Origin of nuclear MIR emission

Schartmann+14



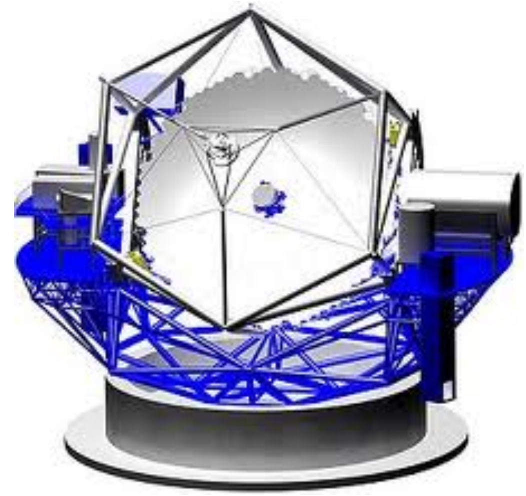
10um/20um flux ratio

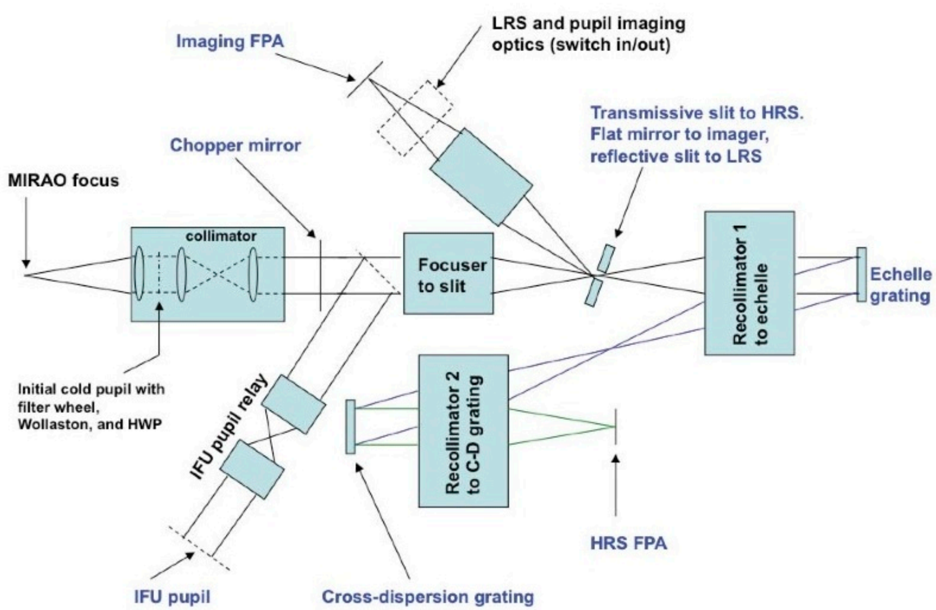


At 12um,
torus is dark
cone is bright

20um obs
TMT/MICHI ?

TMT 30m + MICHI 10,20um





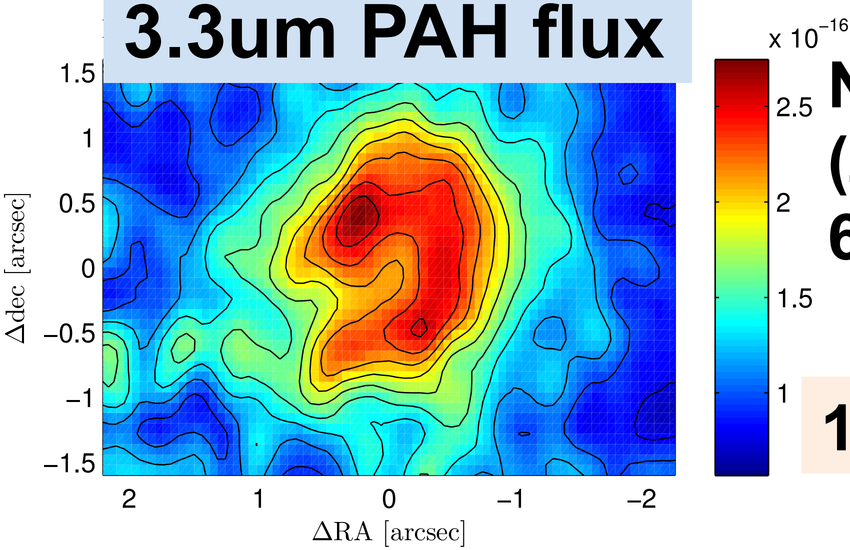
PI:Packham

UKIRT/UIST : 3-4um (L-band) IFU

Seeing-limited 3.3um PAH map of >100 pc-scale circumnuclear SB

Vaisanen+12
MN 420 2209

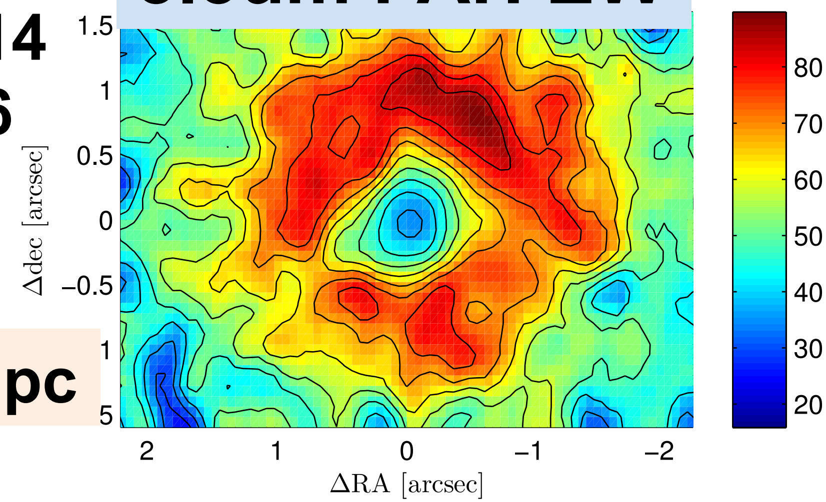
3.3um PAH flux



NGC1614
(z=0.016
64Mpc)

1” ~ 300pc

3.3um PAH EW



High-spatial-resolution, AO-assisted, 3-4um IFU is ideal

No such instrument in the world

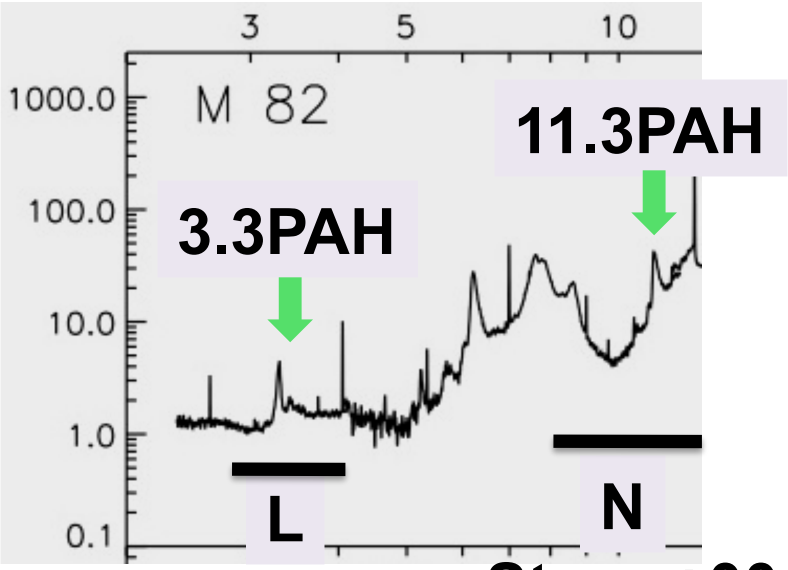
UKIRT/UIST decommissioned

TMT 30m has no 3-4um (L-band) instrument

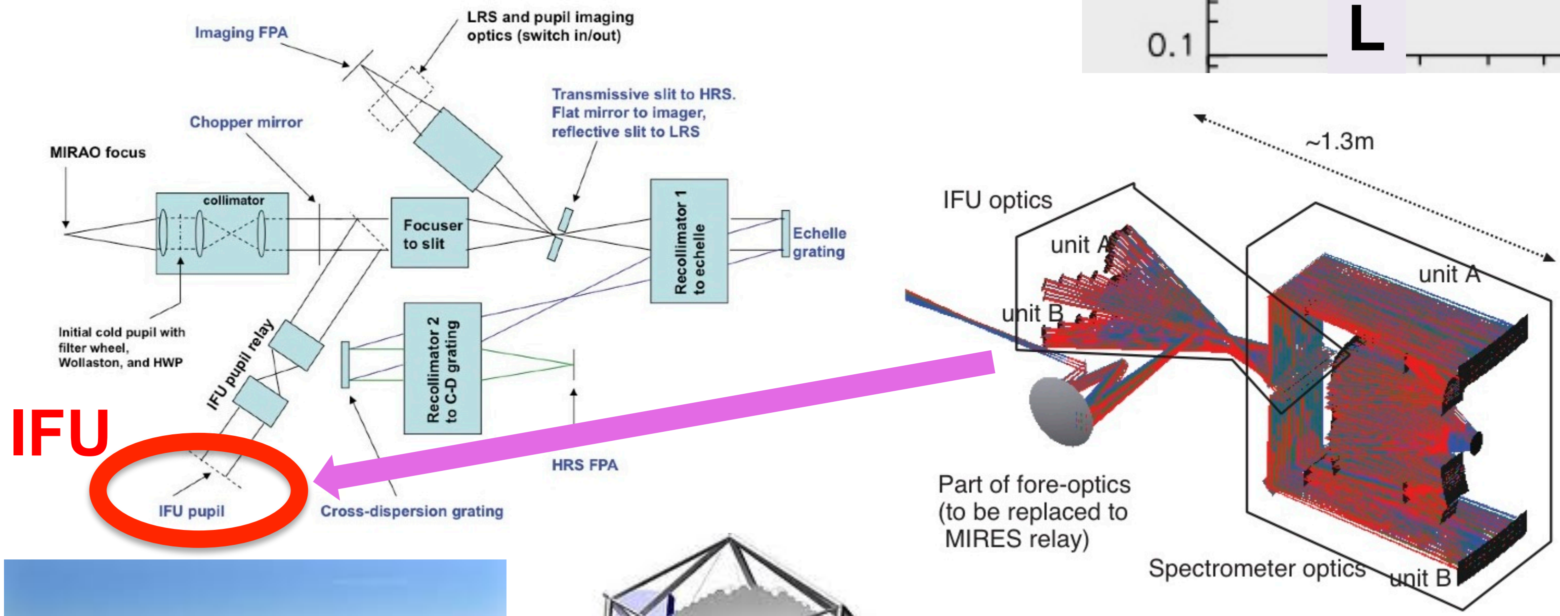
TMT MICHI

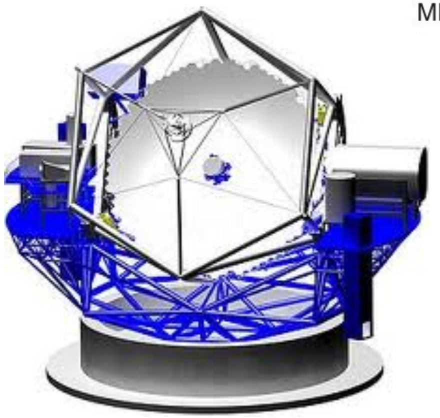
IFU at 10um (N-band) to study 11.3um PAH

0.08” resolution

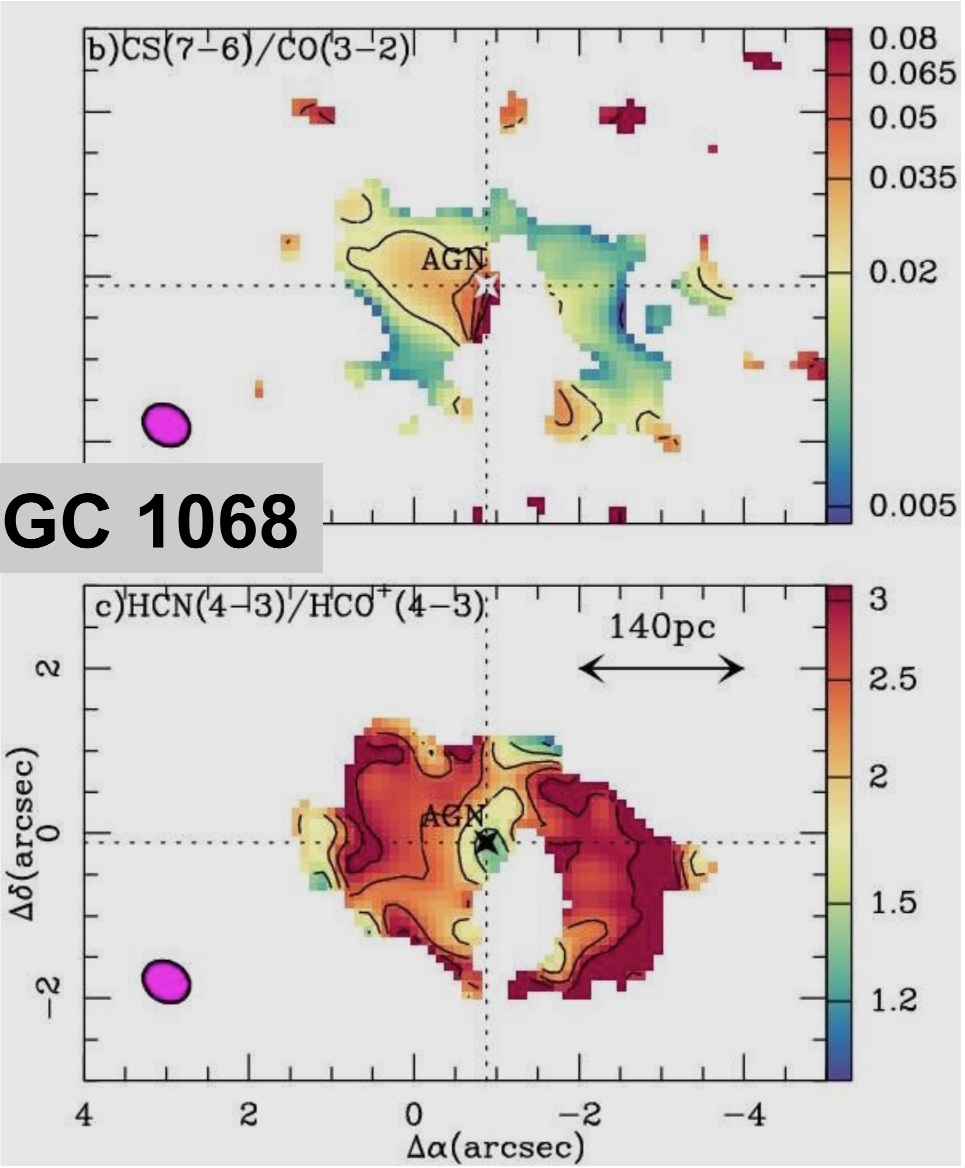


Sturm+00





ALMA spatially-resolved molecular line flux ratios in very nearby AGN



NGC 1068

Viti+14 AA 570 A28

0.6" x 0.5"

Higher-spatial-resolution?

A reliable unique model needed

Summary

AGN fueling could be explained by
AGN – nuclear starburst connection

↓ but

Essential parts are still far from complete understanding

TMT/MICHI + ALMA may be powerful

AGN regulate nuclear SB ?

Nuclear SB regulate AGN?

End