

SPICA高分散分光観測で明らかにする、 ULIRGs中心領域のガスの物理状態

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ULIRGs (Ultra-Luminous Infrared Galaxies)

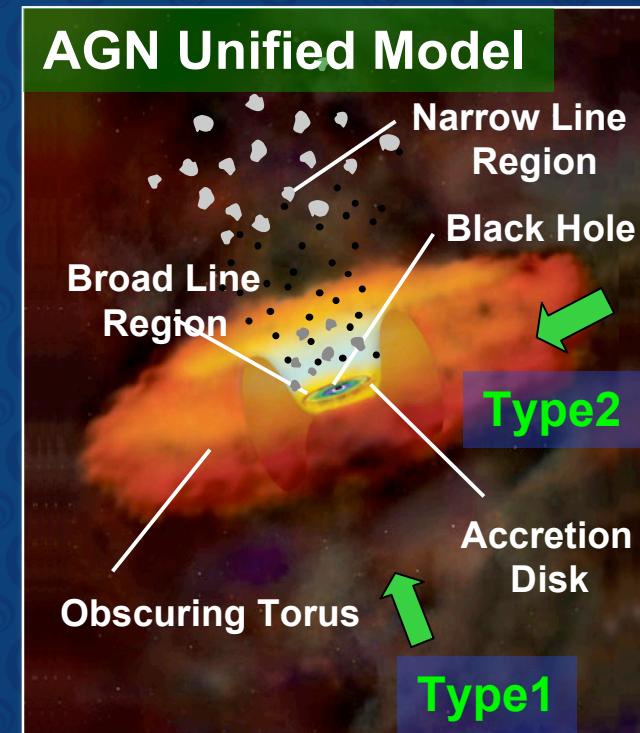
- Discovered by IRAS (Sanders, et al. 1988)
- Radiate most of their extremely large, quasar-like luminosities as infrared dust emission.

$$L_{\text{FIR}} \geq 10^{12} L_{\odot}, \quad L_{\text{FIR}} / L_{\text{Bol}} \geq 90\%$$

- Interacting / merging systems
- Rich in molecular gas and dust

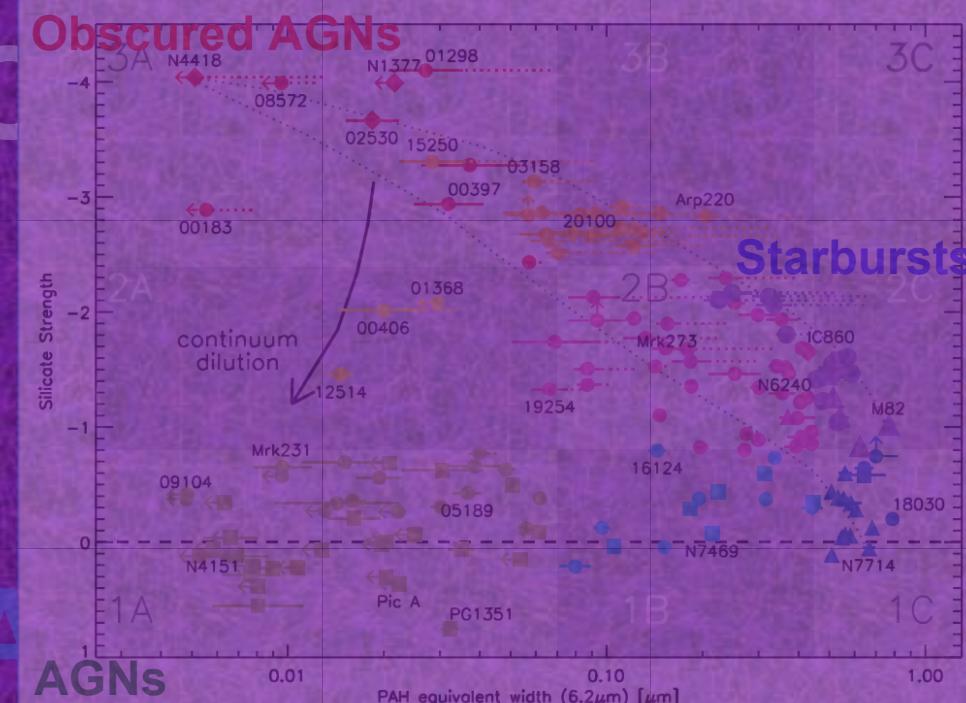
● Energy sources ?
 AGN vs Starburst
 * hidden behind gas/dust

- Dominate the CIB
 A fundamental constitution of the high-z galaxy population



Urry & Padovani (1995)

Gas & Dust in ULIRGs

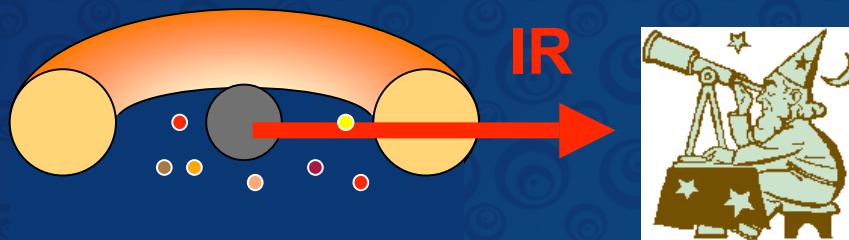


Spoon et al. (2007)

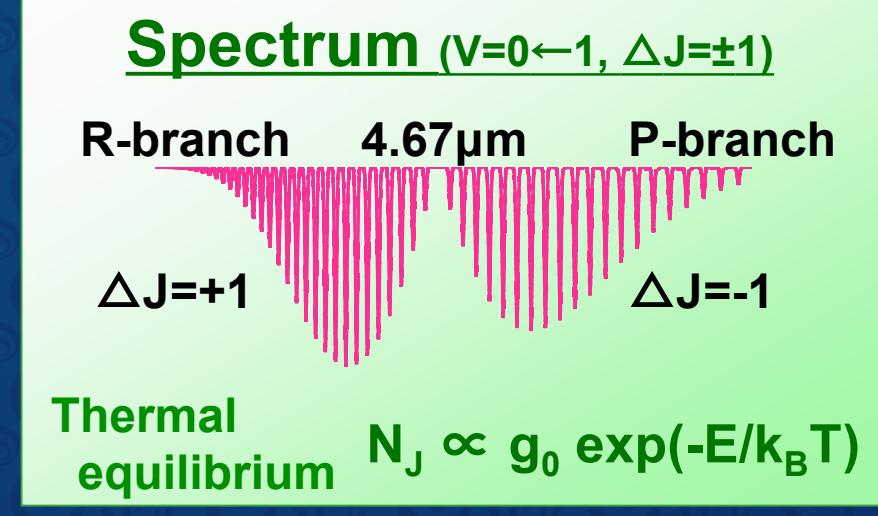
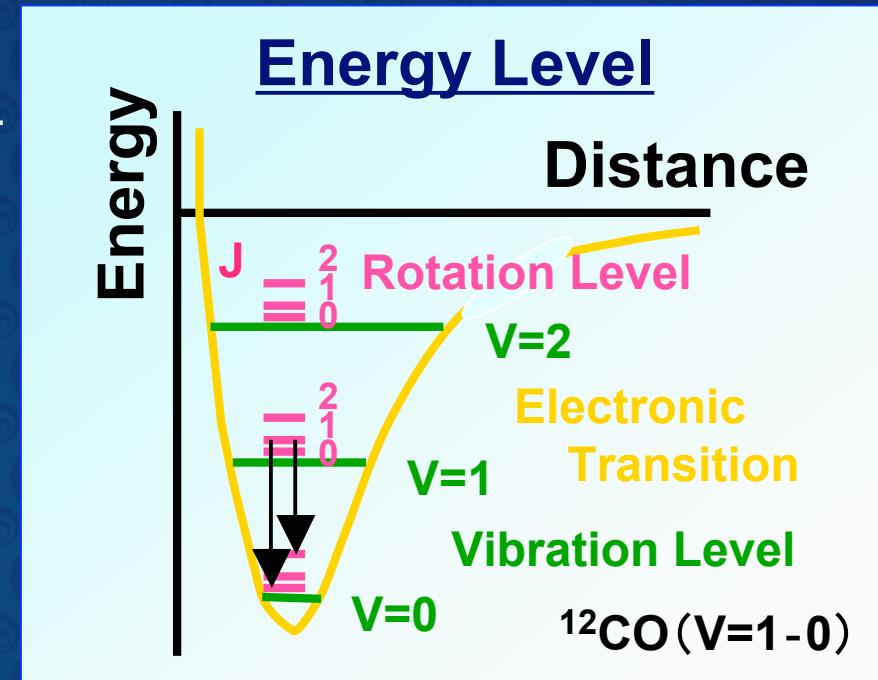
the physical condition of
the obscuring **gas & dust**
(Temperature, Density, Total amount)

CO Ro-vibrational Absorption Lines

CO is much contained in molecular gas.
Observe CO ro-vibrational lines in absorption.



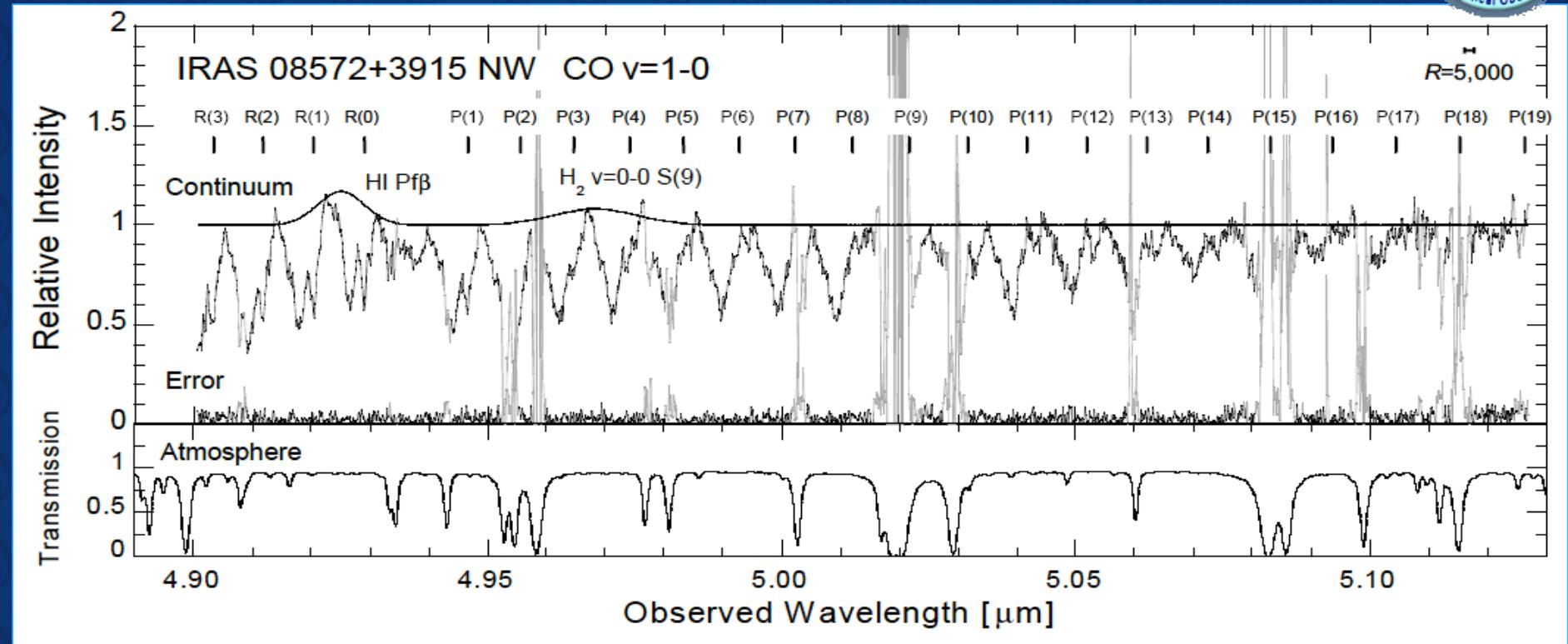
- ① Many lines at different excitation energy levels can be observed simultaneously.
⇒ Temperature, Column density
 - ② Use the bright, compact AGN as a background continuum source.
⇒ High spatial resolution
 - ③ High spectral resolution
⇒ Velocity structure in the molecular gas
- ★ Need background source
⇒ Seyfert 2 galaxies, obscured AGNs



IRAS 08572+3915



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Shirahata et al. submitted

- High excitation ($J \leq 17$)
- Line width : extremely broad ($\text{FWZI} > 400 \text{ km/s}$)
- Red- & Blue- shifted components were revealed.
- Line depth : Deep (60% of the continuum level)

Physical Conditions

Temperature

- At least two components: 273K(warm) & 24K(cold)
- High temperature (c.f.) typical molecular clouds $\ll 100$ K
- heated by AGN ?

Column density

- $N_{\text{CO}} = (1.98 \pm 0.01) \times 10^{18} \text{ cm}^{-2}$ (cold)
- $N_{\text{CO}} = (4.48 \pm 0.04) \times 10^{18} \text{ cm}^{-2}$ (warm)
- $N_{\text{H}_2} = 1.1 \times 10^{22} \text{ cm}^{-2}$ (cold)
- $N_{\text{H}_2} = 2.5 \times 10^{22} \text{ cm}^{-2}$ (warm)

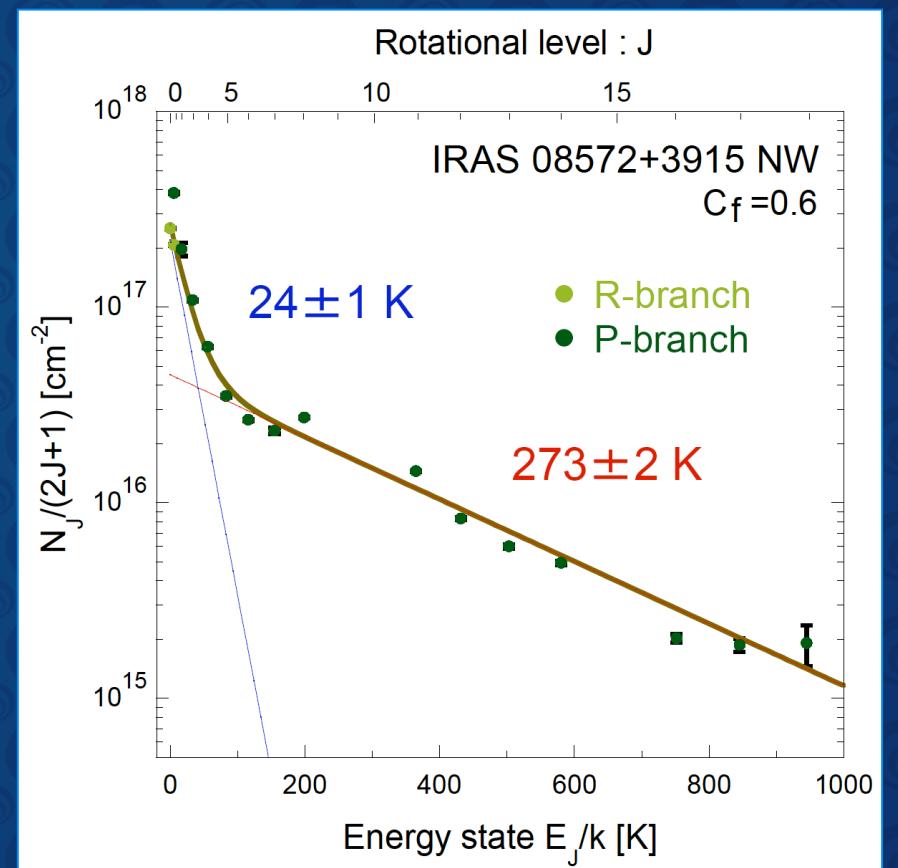
Density

- well thermalized at least $J=17$
- Critical density (collision with H_2)
 $n_c = 2 \times 10^7 \text{ cm}^{-3}$ (dense)

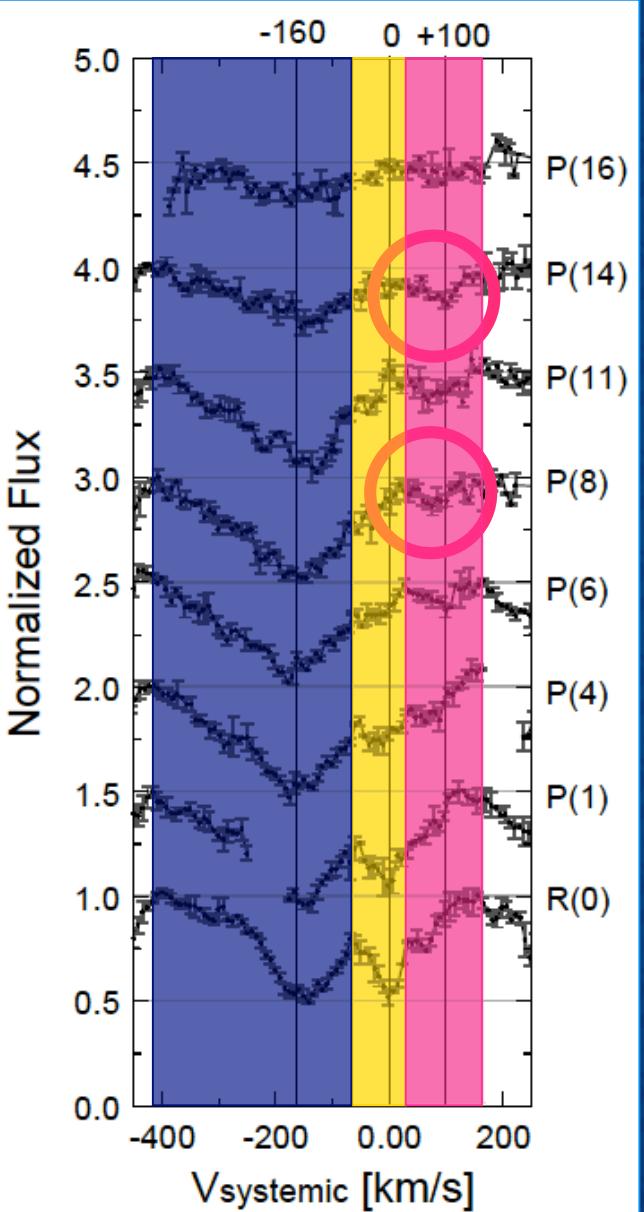
Geometrical thickness

$$N_{\text{H}_2}/n_c < 4 \times 10^{-4} \text{ pc} \sim 80 \text{ AU}$$

- Even if highly Clumpy... $(1-100) \times 10^{-4} \text{ pc} \Rightarrow$ still extremely thin



Line Profile



Many components were revealed obviously.

0km/s component

detected in only low-J ($J \leq 5$)

\Rightarrow low temperature (24K@ $C_f=0.6$)

Systemic velocity \Rightarrow Host galaxy

-160km/s component

detected in all transitions ($J=0 \sim 17$)

\Rightarrow high temperature (272K@ $C_f=0.6$)

Blue Shift \Rightarrow Outflow ? Mass ejection?

+100km/s component

detected only in high-J ($J \geq 4$)

\Rightarrow more high temperature (700K)

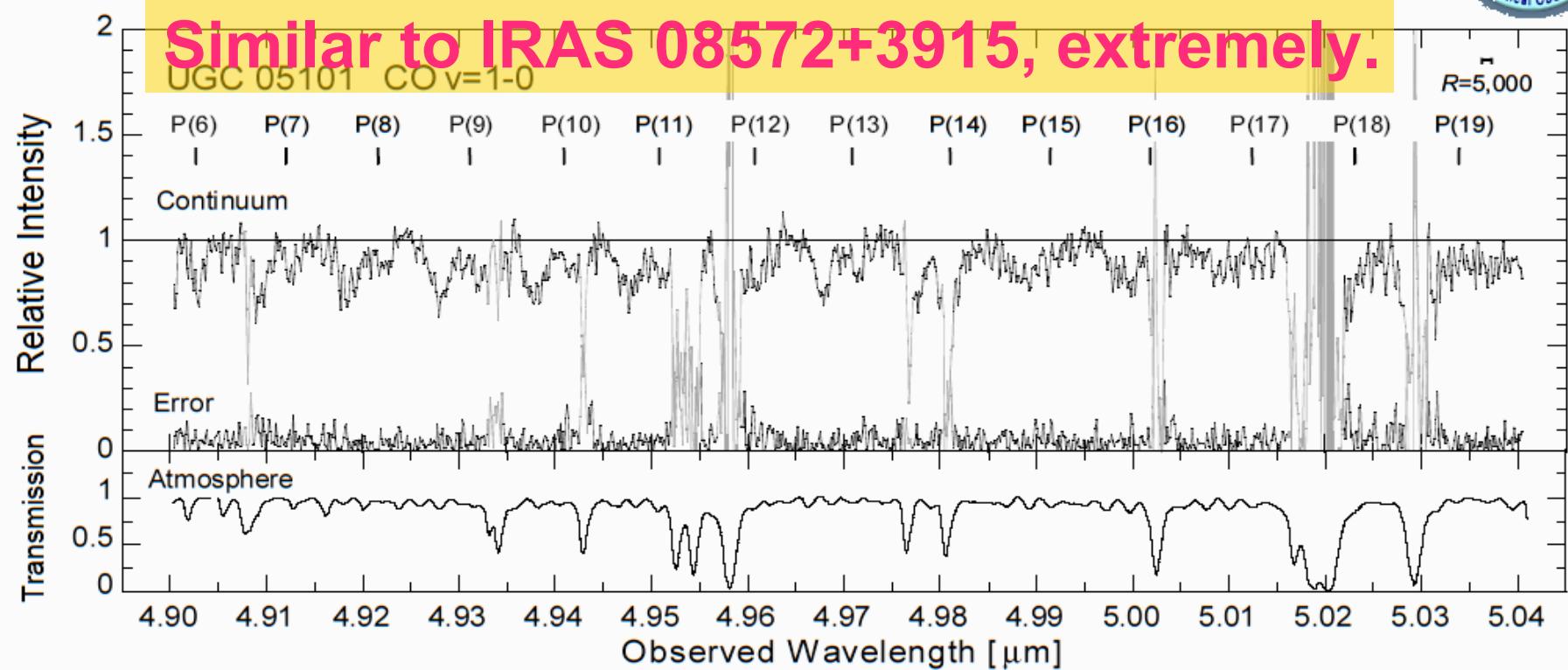
Red Shift \Rightarrow Inflow? Mass injection?

UGC 05101



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Similar to IRAS 08572+3915, extremely.



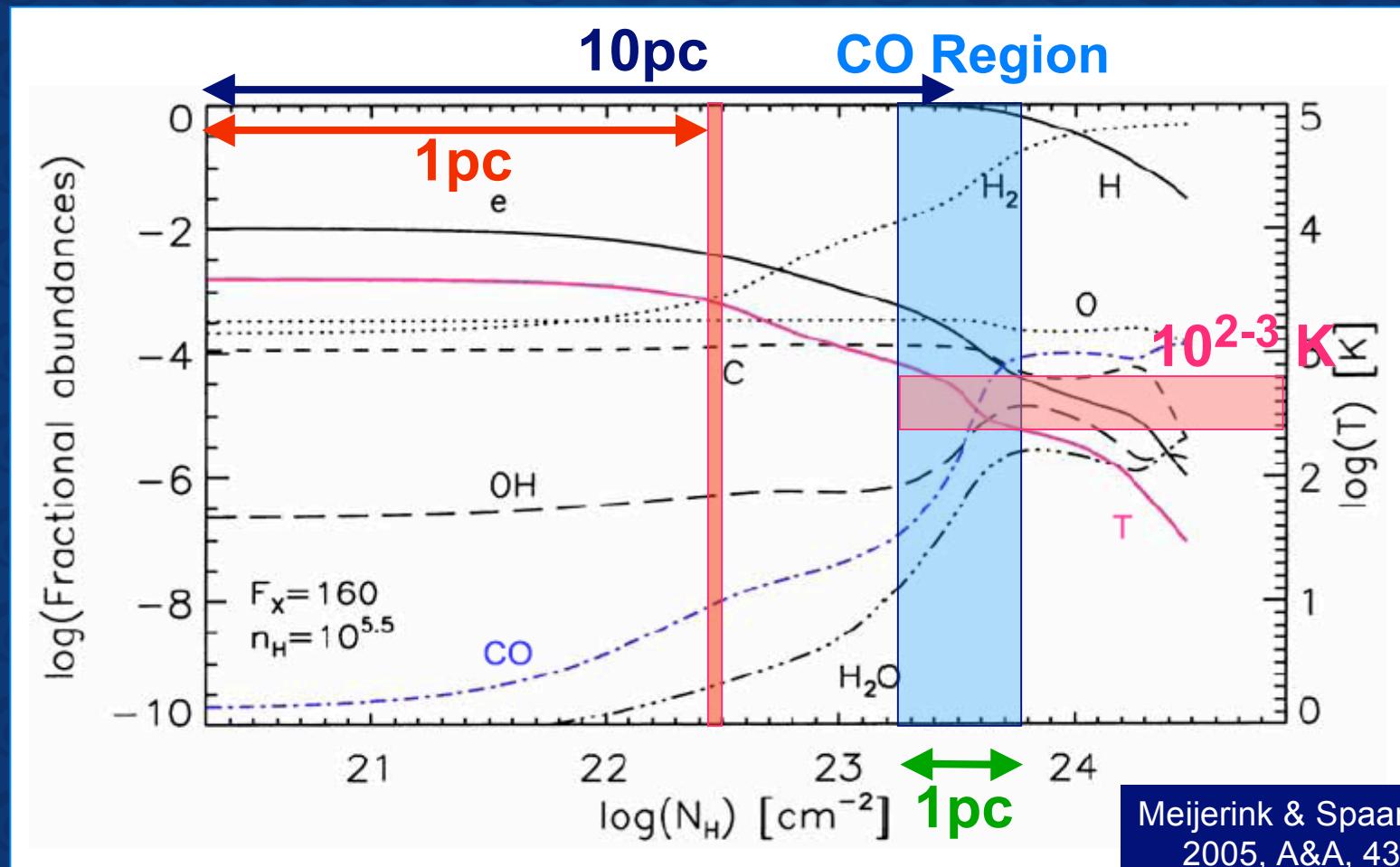
- **High excitation ($J \leq 19$)**
- **Line width : extremely broad (FWZI >400 km/s)**
- **Red- & Blue- shifted components (-200km/s,+30km/s)**
- **Temperature 759 ± 56 K**

Column density $N_{\text{CO}} = (1.82 \pm 0.09) \times 10^{18} \text{ cm}^{-2}$, $N_{\text{H}_2} = 1.0 \times 10^{22} \text{ cm}^{-2}$

Critical density $n_c = 3 \times 10^7 \text{ cm}^{-3}$, Thickness $1 \times 10^{-4} \text{ pc} \sim 20 \text{ AU}$

Absorbers

- XDR Theory Model

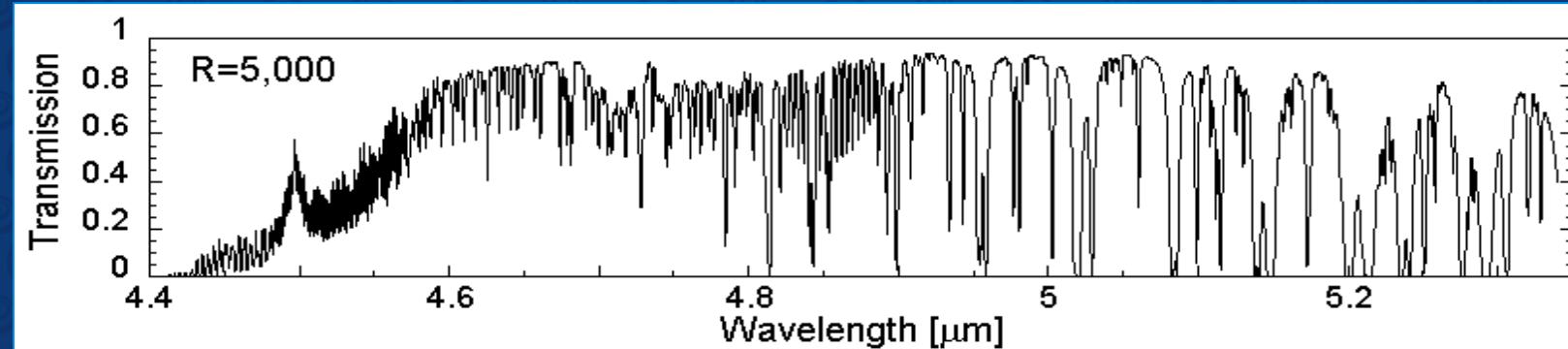


- CO molecules can be exists at here ($N_{\text{H}} > 10^{23.5} \text{ cm}^{-2}$)
- Temperature : 10^{2-3} K
- Thickness : $\sim 1\text{pc}$

From Subaru to AKARI

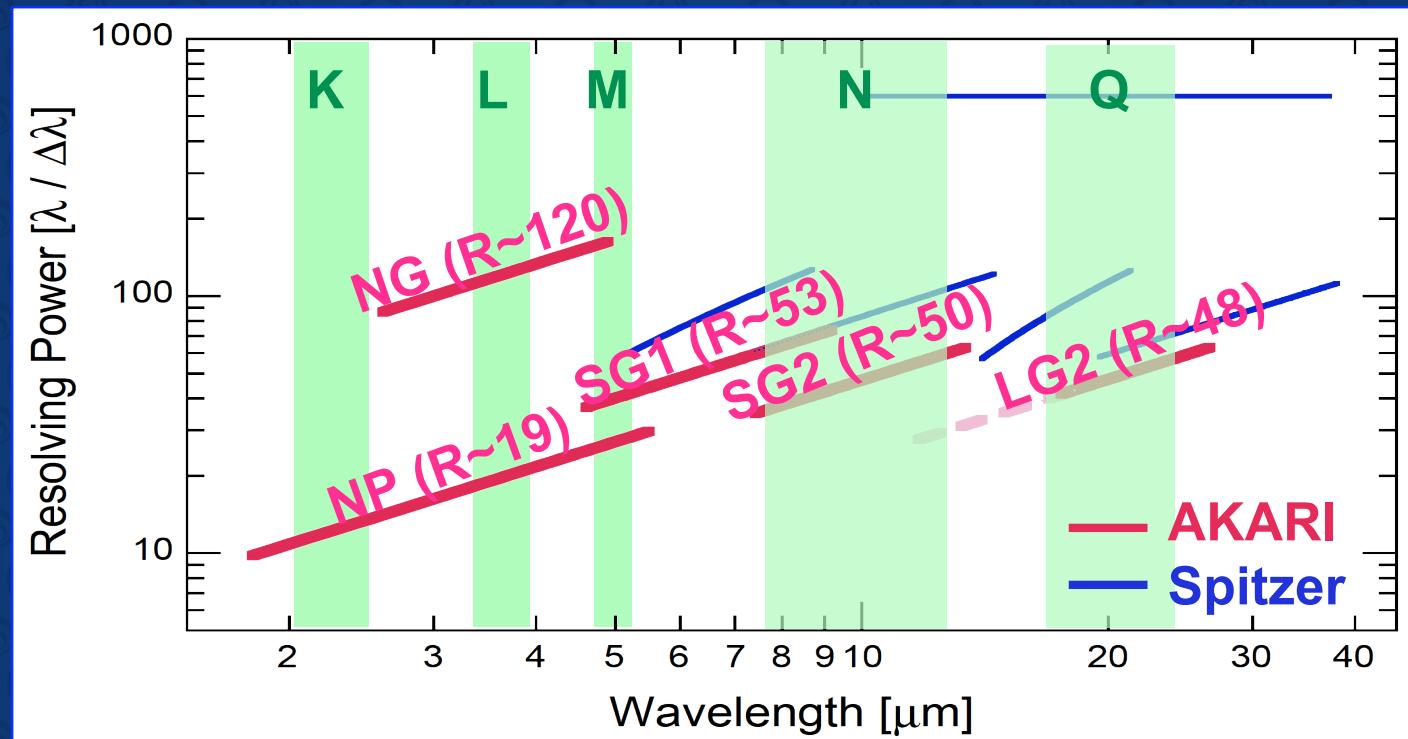


- CO absorption lines were detected from **3 obscured AGNs**. (Arp220 is too weak.)
- Target selection criteria
→ bright at **5um**($\sim 100\text{mJy}$), Redshift < **0.13**



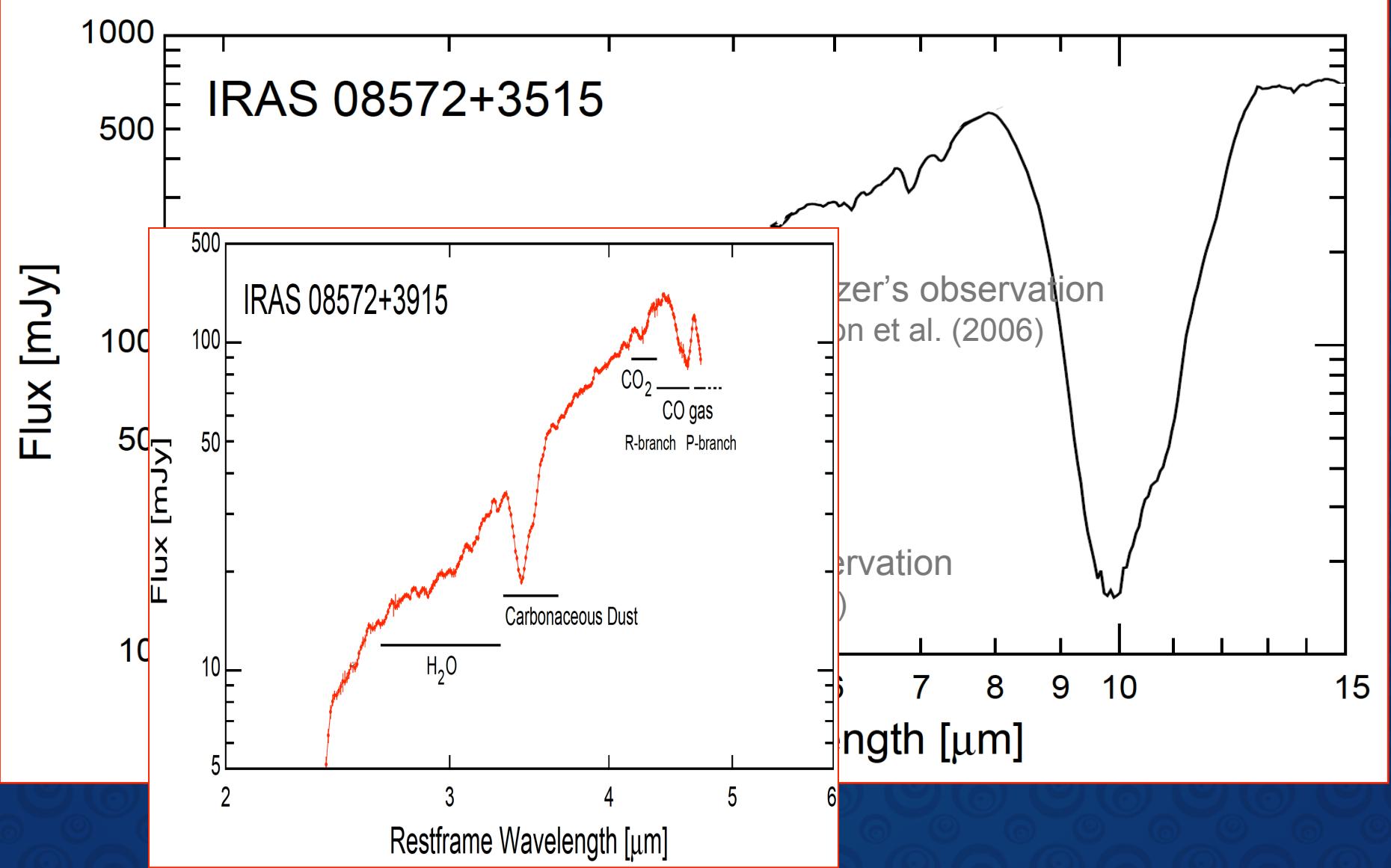
- Increase the number of targets
→ need the high sensitivity observation
- Increase the range of observing wavelength
→ need to free from the earth's atmosphere

Unique capability of AKARI/IRC

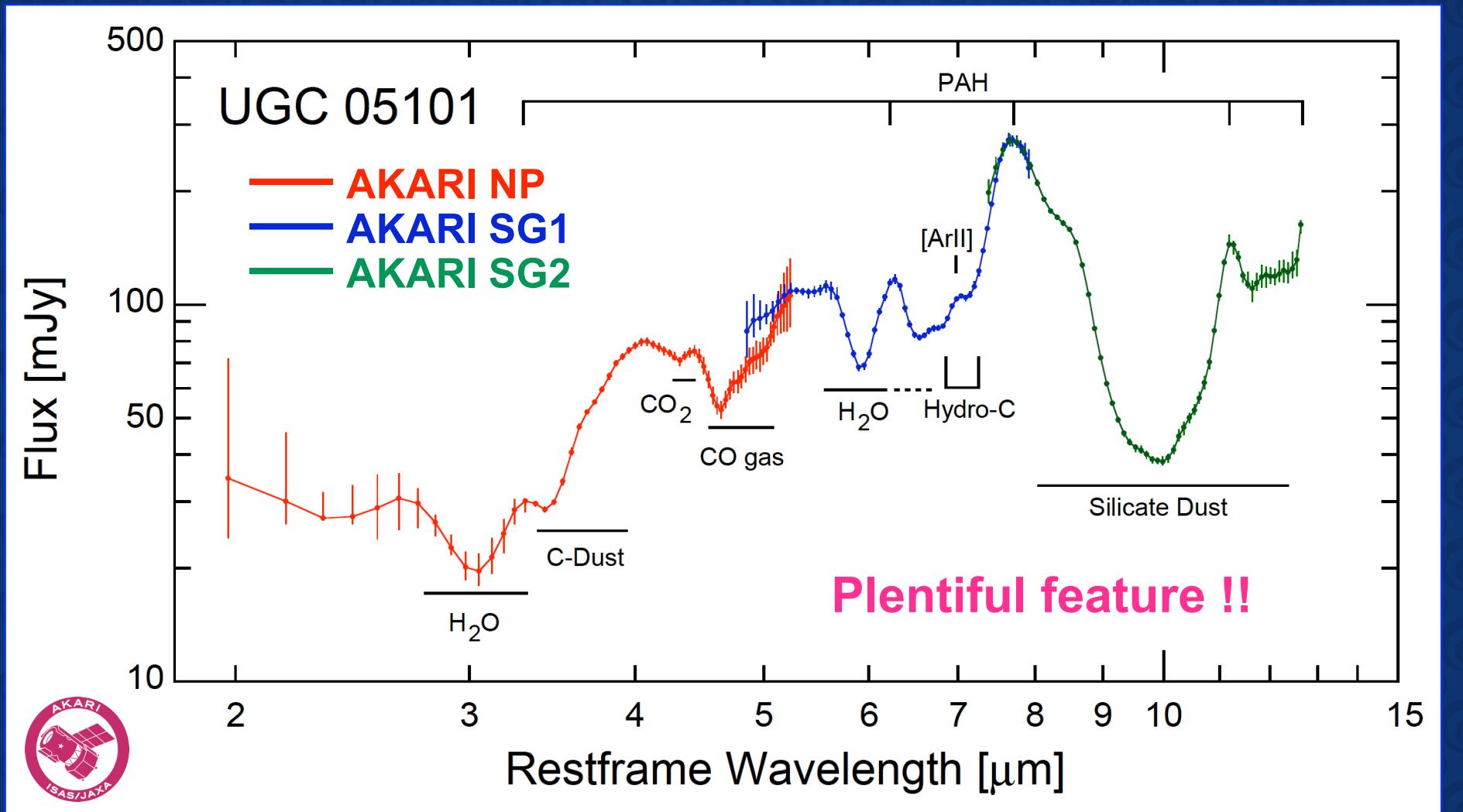


- Continuous coverage from NIR to MIR
important plentiful molecular absorption & PAH emission
- High quality spectra
free from the atmospheric influence
- The only equipment to take 2-5 μm spectra.
Spitzer does not have.

IRAS 08572+3915



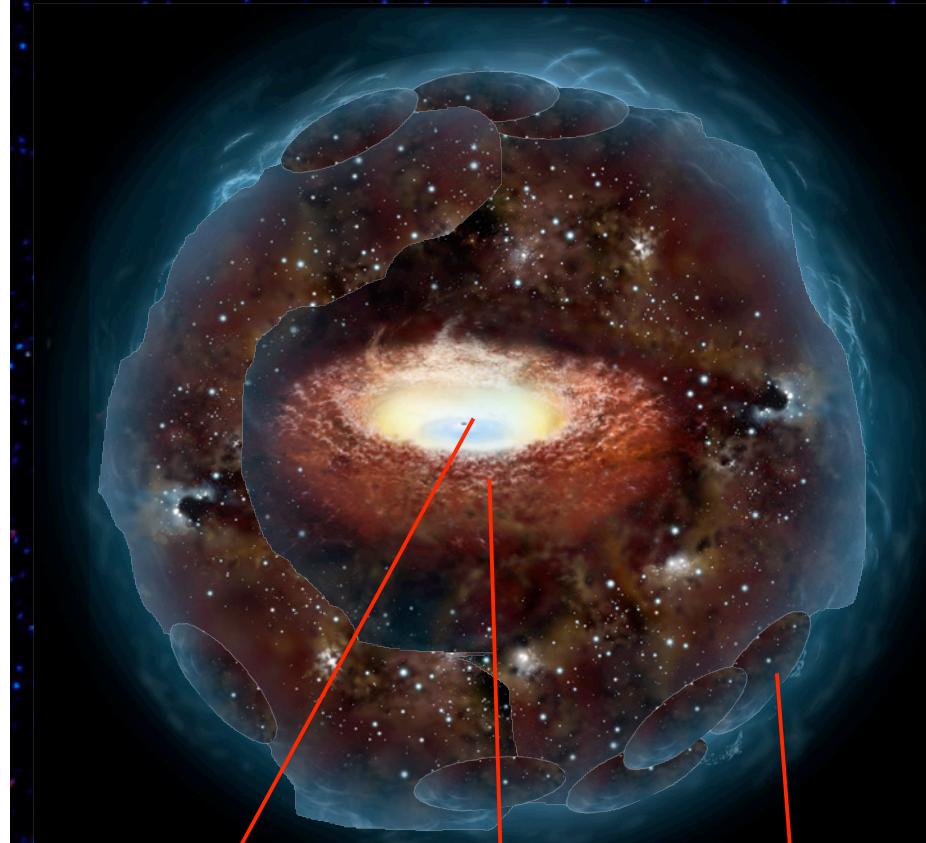
UGC05101



Nakagawa et al., in prep.

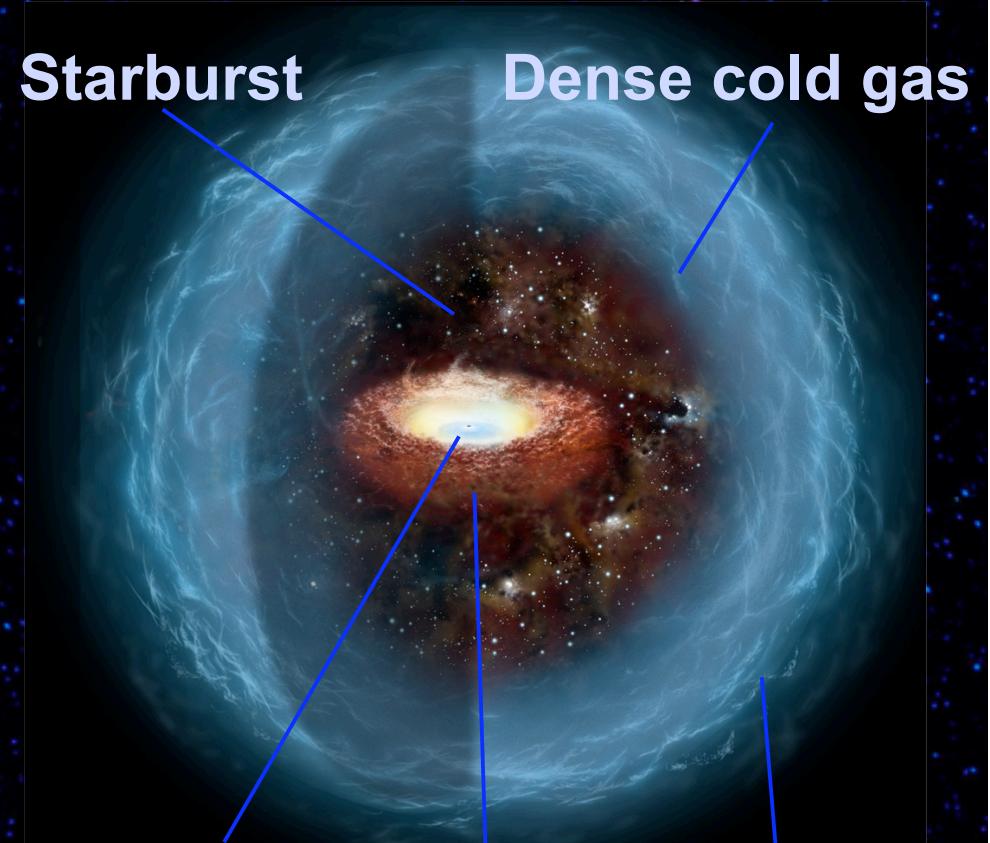
Structure of ULIRGs

IRAS 08572+3915



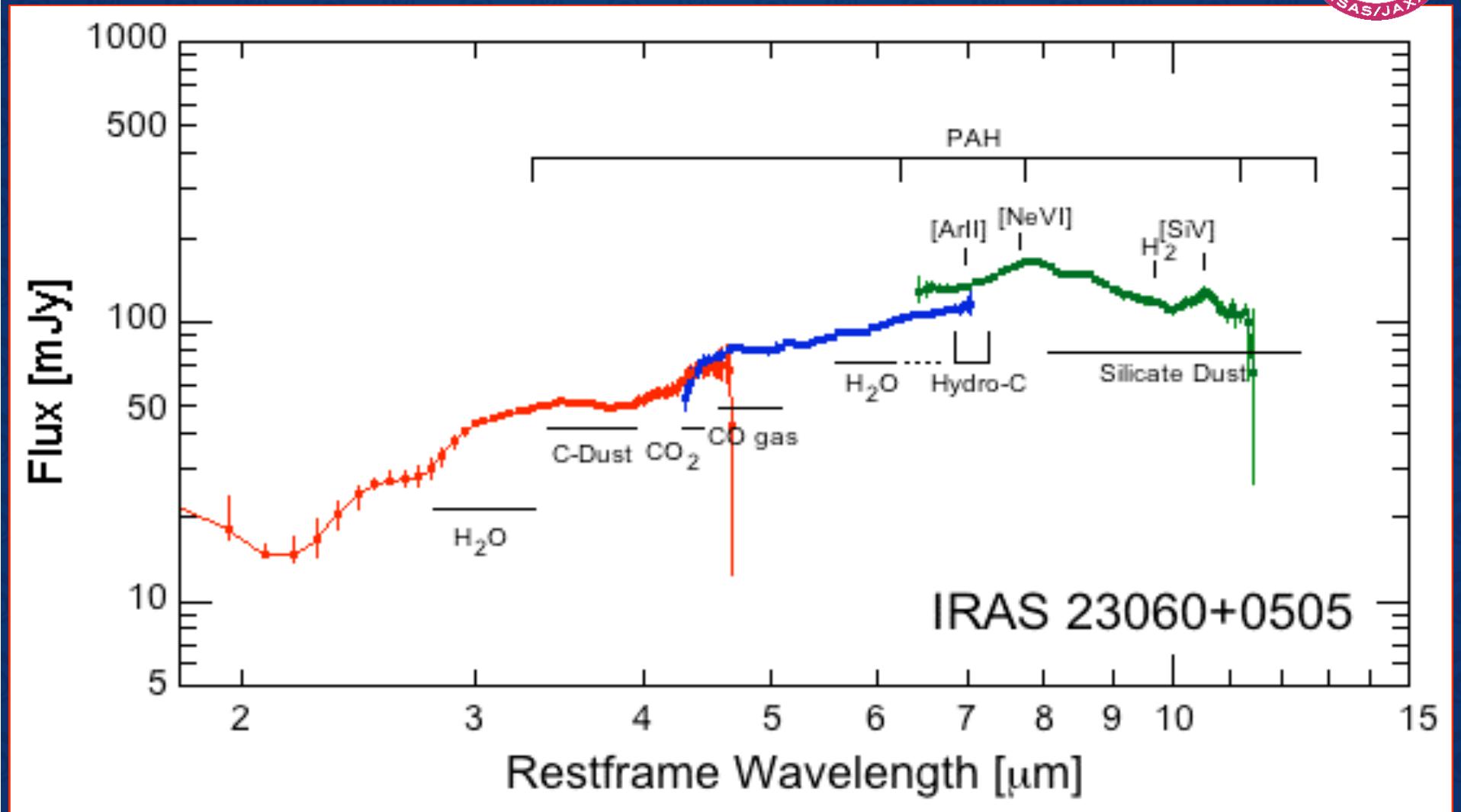
AGN
Dense warm gas
Diffuse cold gas

UGC 05101



Starburst
Dense cold gas
AGN
Dense warm gas
Diffuse cold gas

AKARI's variety spectra



Shirahata et al., in prep.

From AKARI to SPICA



- CO absorption lines were detected from **30 obscured AGNs !!**
- Brightness at 5um : **>1mJy**, Redshift : **< 0.3**

We need high-spectral resolution spectra !!

- High spectral resolution : **R~10000**
- Wide wavelength coverage : **4 - 7um**

[SPICA]

MCS / HRS-S

4-8 um, R=30,000

[TMT]

IRIS

0.6-5 um, R > 3500

MIRES

4.5-28 um, R = 5000-10000

[JWST]

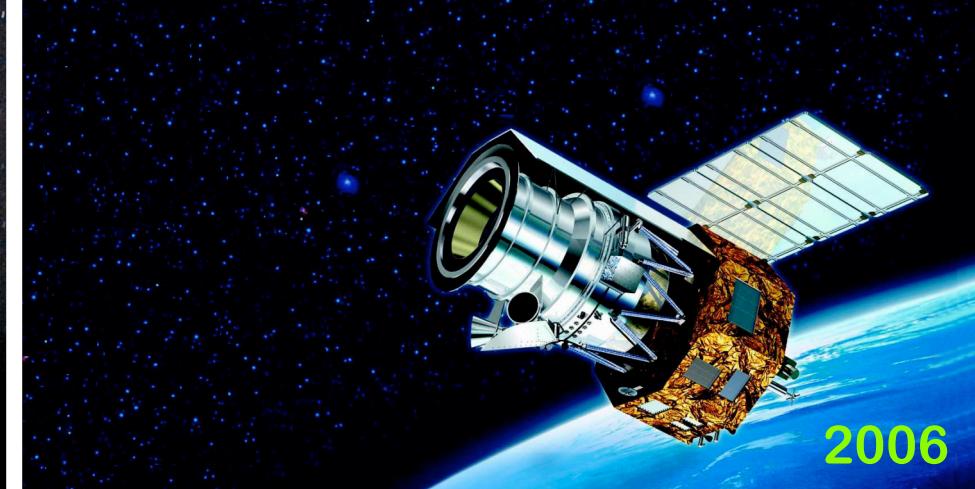
MIRI

5-28 um, R=2070-3730

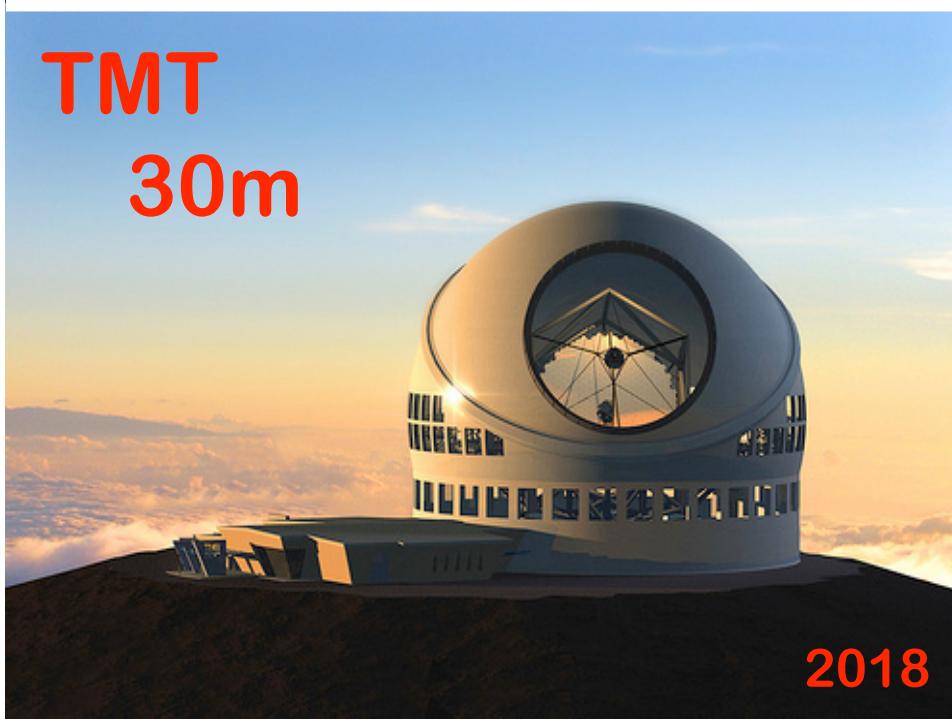
Subaru
8.2m



AKARI
68cm



TMT
30m



SPICA
3m



Subaru
8.2m

3 ULIRGs

~100mJy
0.15"(w/AO)
 $R \sim 10000$

AKARI
68cm

30 ULIRGs

~1mJy
3"
 $R \sim 100$

TMT
30m

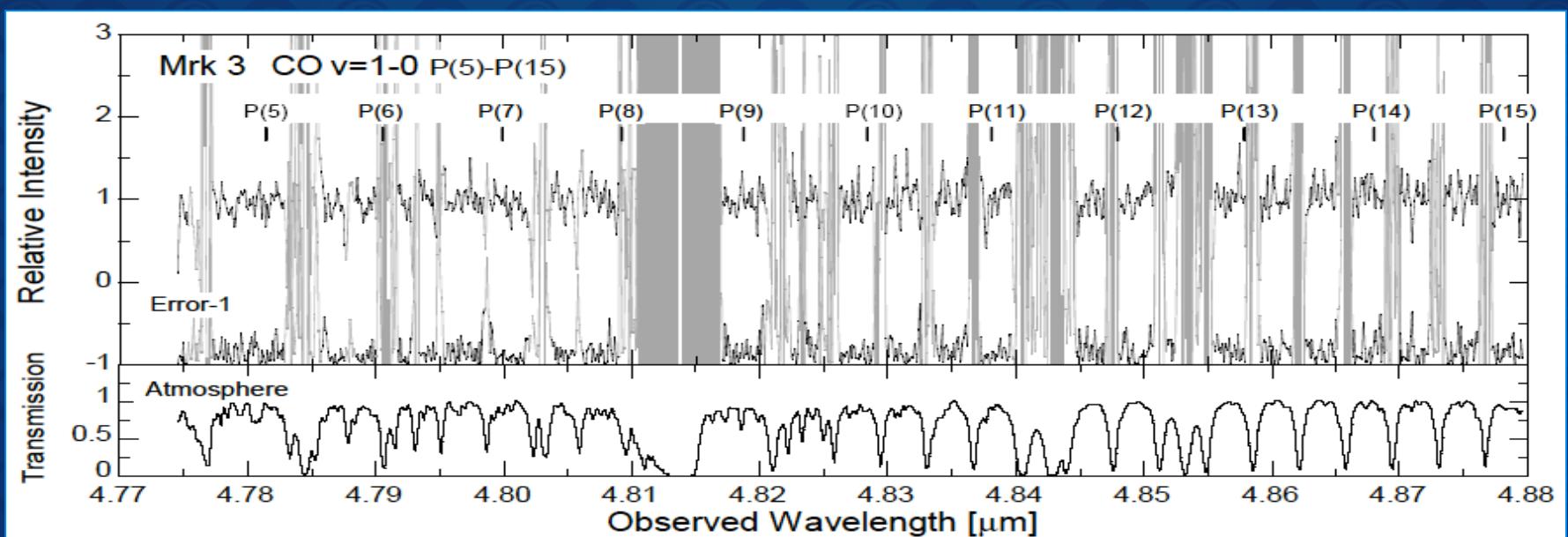
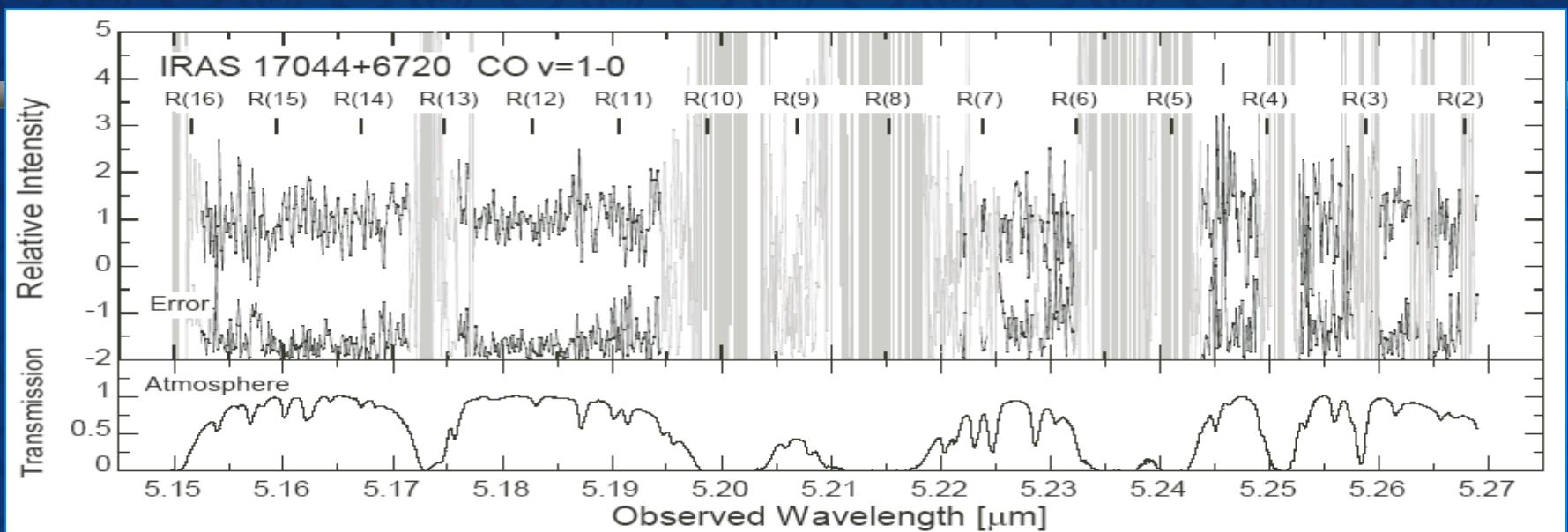
15 ULIRGs

~7mJy
0.04"(w/AO)
 $R \sim 5000$

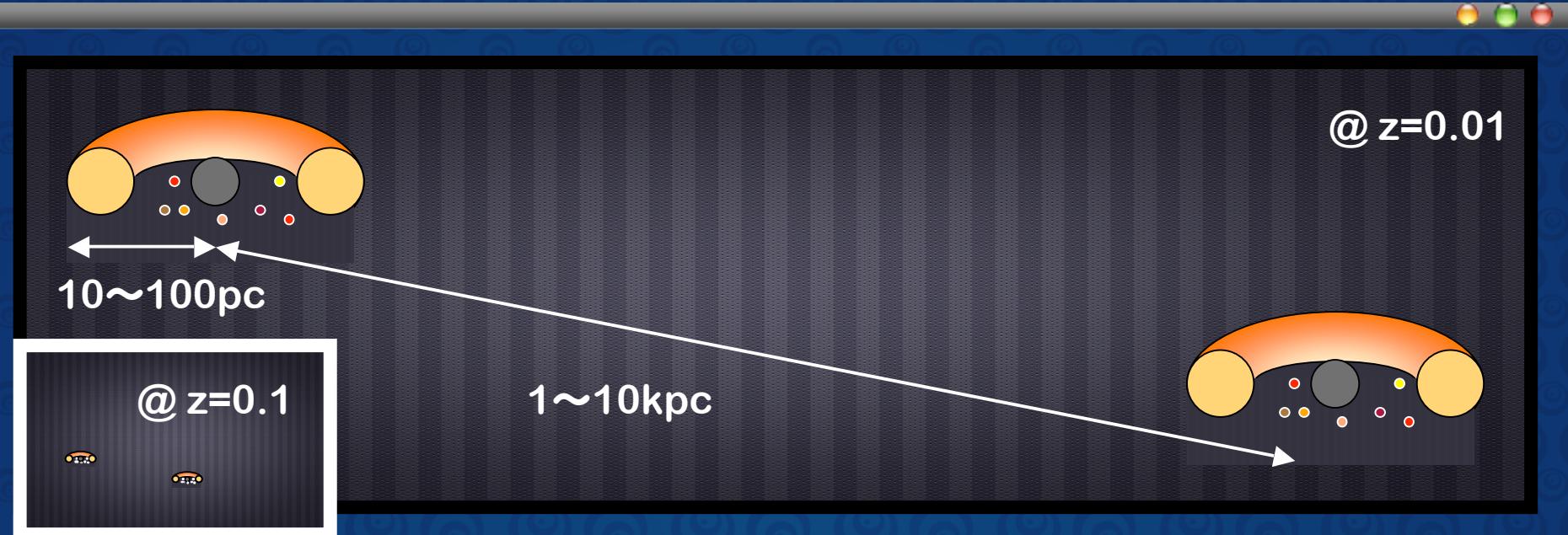
SPICA
3m

30 ULIRGs

~5mJy
0.4"
 $R \sim 30000$



Future : SPICA & TMT



TMT

■ 0.04"

Low-z, spatial resolution

Subaru

■ 0.15"

SPICA

■ 0.4"

High-z, wide wavelength coverage

AKARI

■ 3"