一酸化炭素吸収バンドから探る AGN中心核付近の温かいガスの状態と分布

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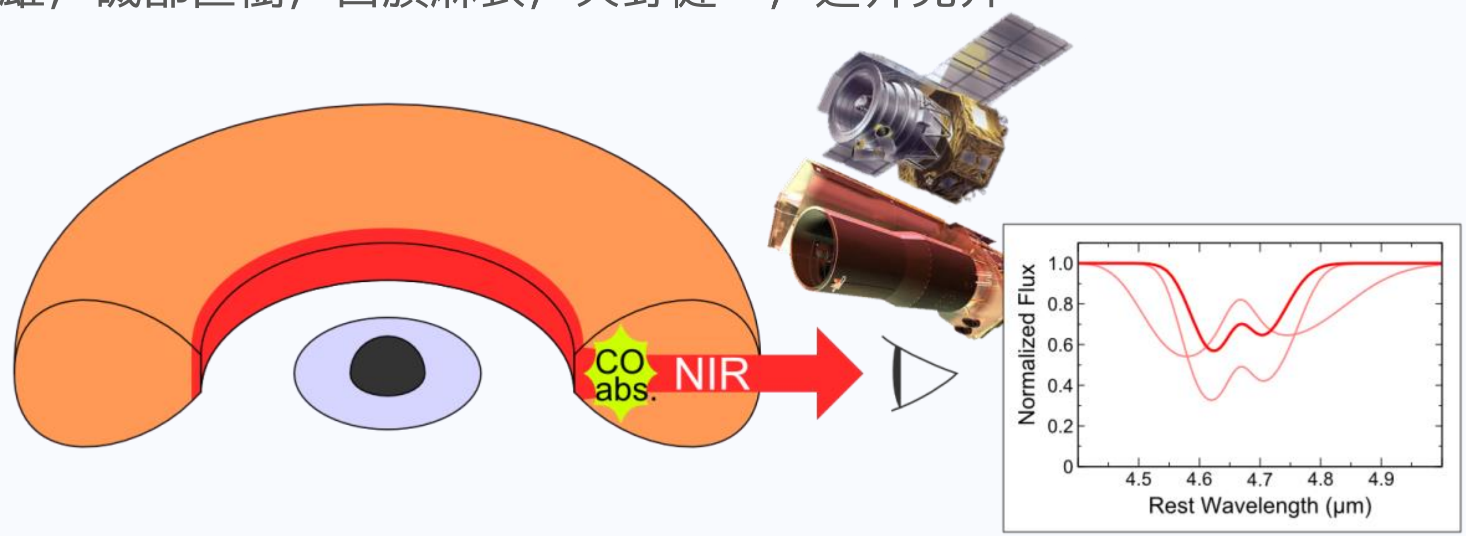


Outline

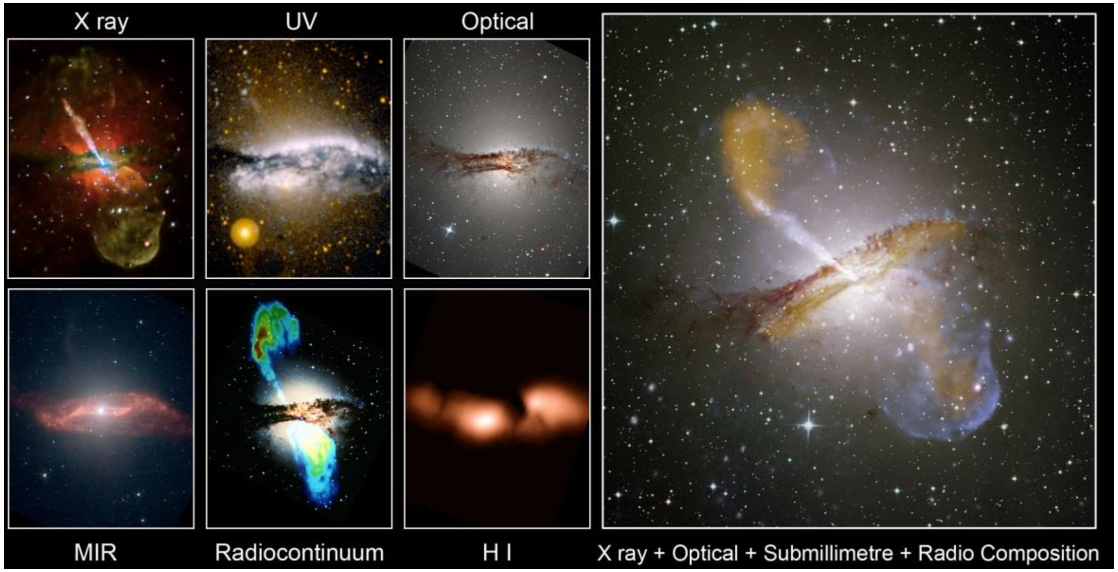
- Introduction
- Method
- Targets
- Results
- Discussion
- Summary

Introduction

- Active Galactic Nuclei (AGNs)
- AGN Unified Model
- Observing AGN Tori
- CO Ro-Vibrational Transition
- Earlier Studies

Active Galactic Nuclei (AGNs)

e.g., Centaurus A

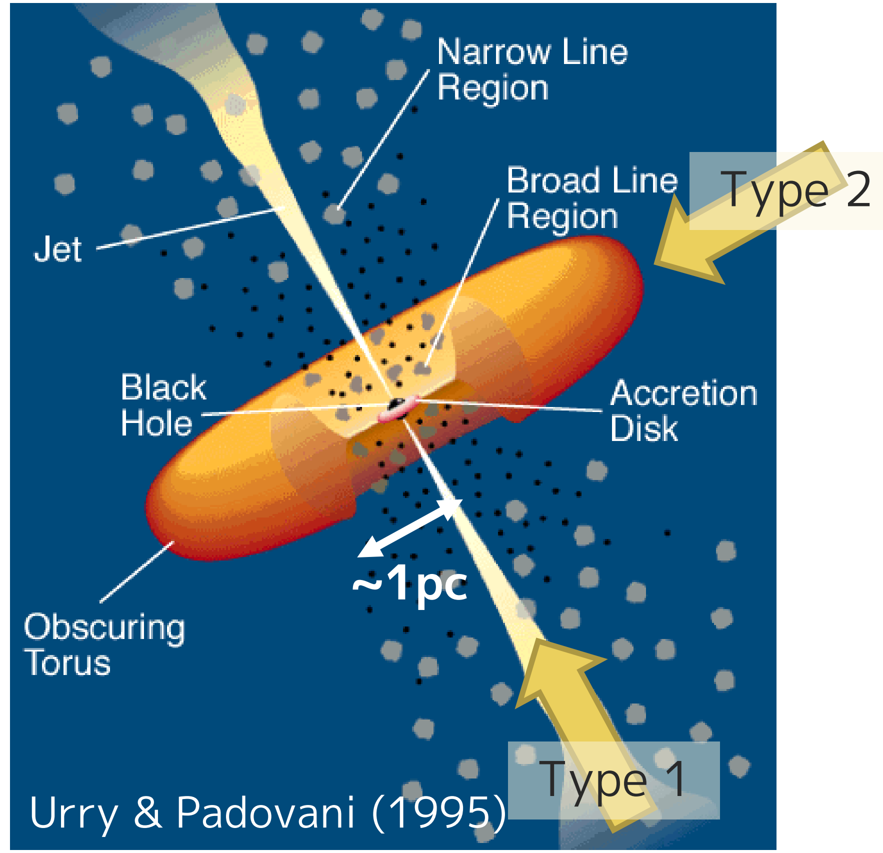


- strong activity
- coevolution with their host galaxies
- mass accretion onto a supermassive black hole (10^6—10^9 M_{sun})

- classification
  - type 1: broad permitted emission lines and narrow permitted and forbidden emission lines
  - type 2: no broad permitted emission lines

AGN Unified Model

- AGN unified model
  - central SMBH, accretion disk
  - Broad Line Region near the nucleus
  - **optically and geometrically thick dusty molecular torus (~ 1 pc size)**
  - Narrow Line Region above the torus
  - face-on → type 1
  - edge-on → type 2



Urry & Padovani (1995)

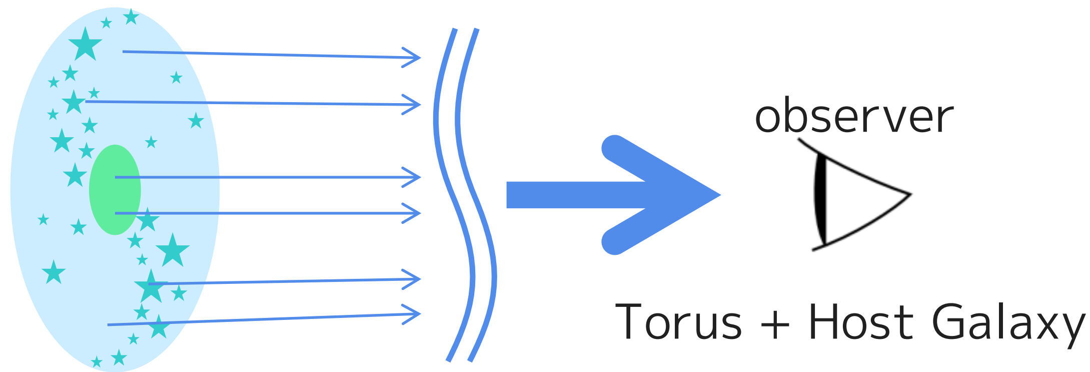
key component!

Observing AGN Tori

- face-on
- sub-millimeter CO rotational emission

→ small scale

hard to resolve spatially



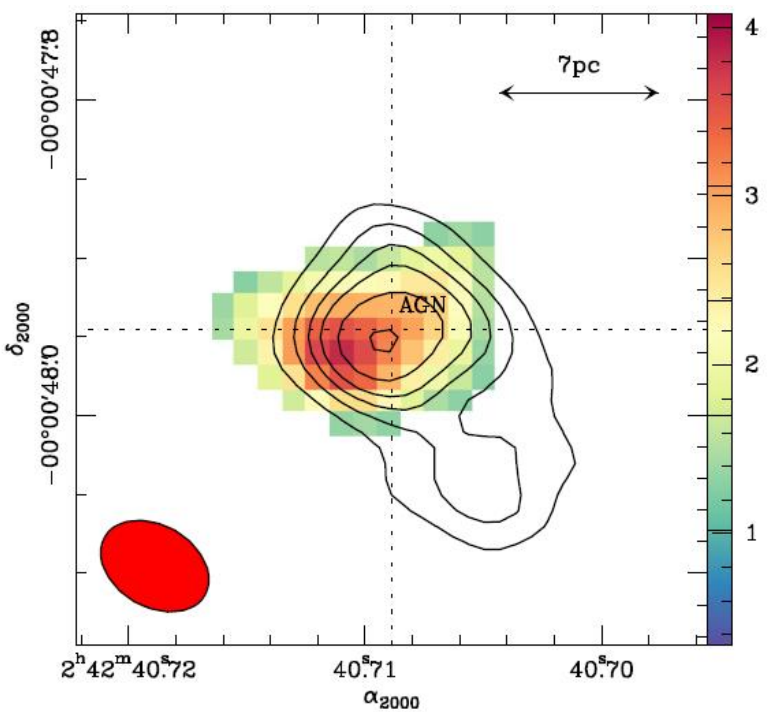


Figure 3. Overlay of the continuum emission contours of Figure 1 on the CO(6–5) emission (color scale) from the AGN torus. Units are in Jy km s^{-1} $beam^{-1}$.

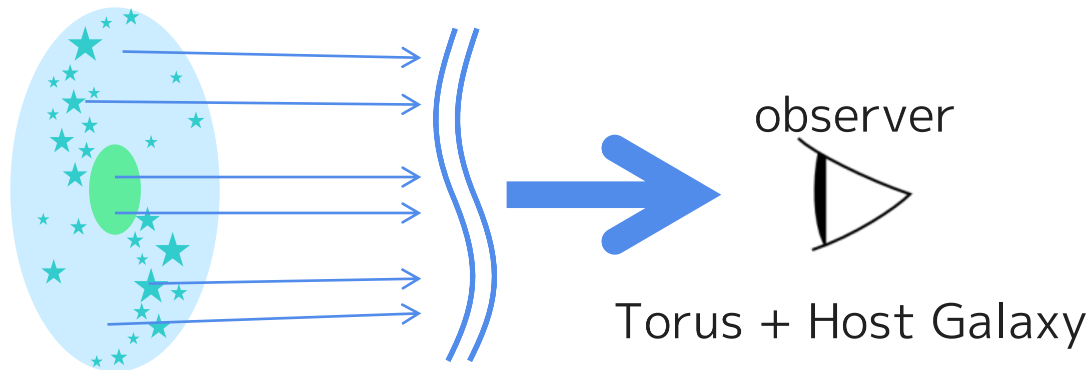
e.g.,
ALMA observation of CO(6-5) emission from the nucleus of NGC1068
(García-Burillo et al. 2016)

The geometry is not resolved.

- face-on
- sub-millimeter CO rotational emission from AGN tori

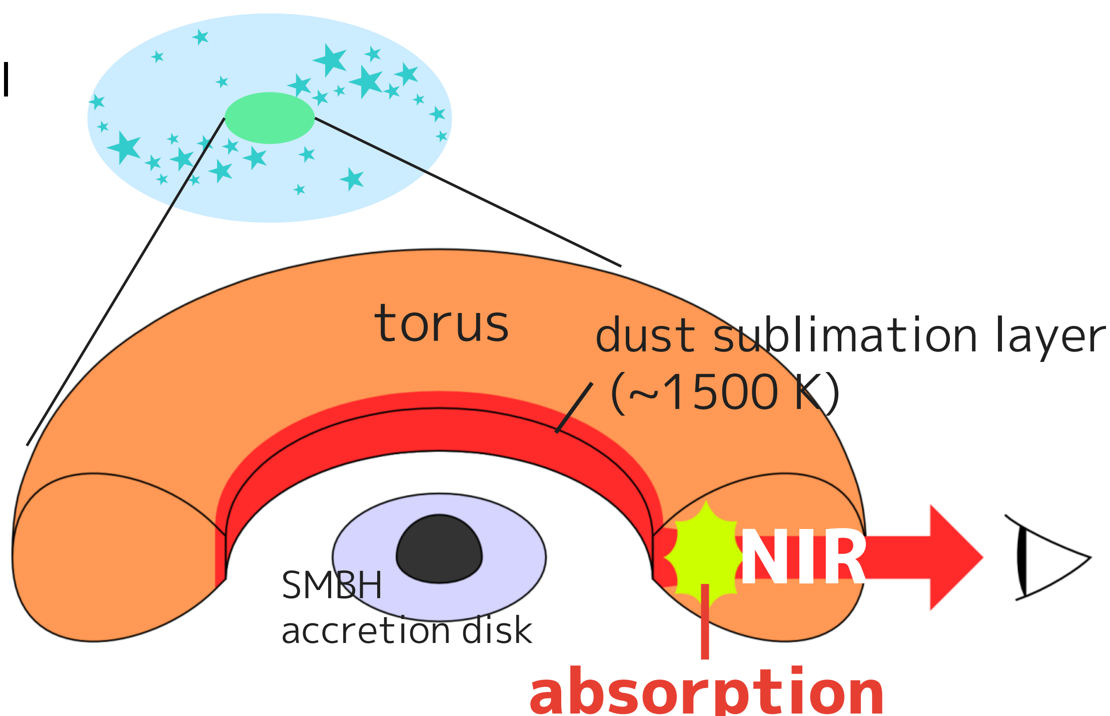
→ small scale

hard to resolve spatially

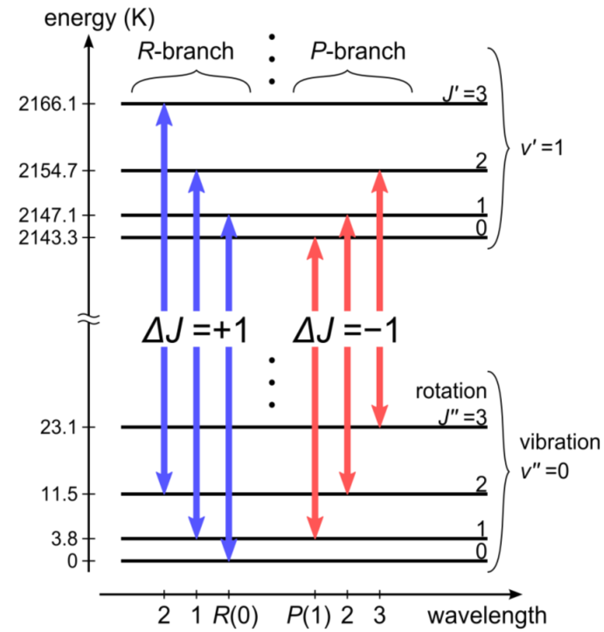


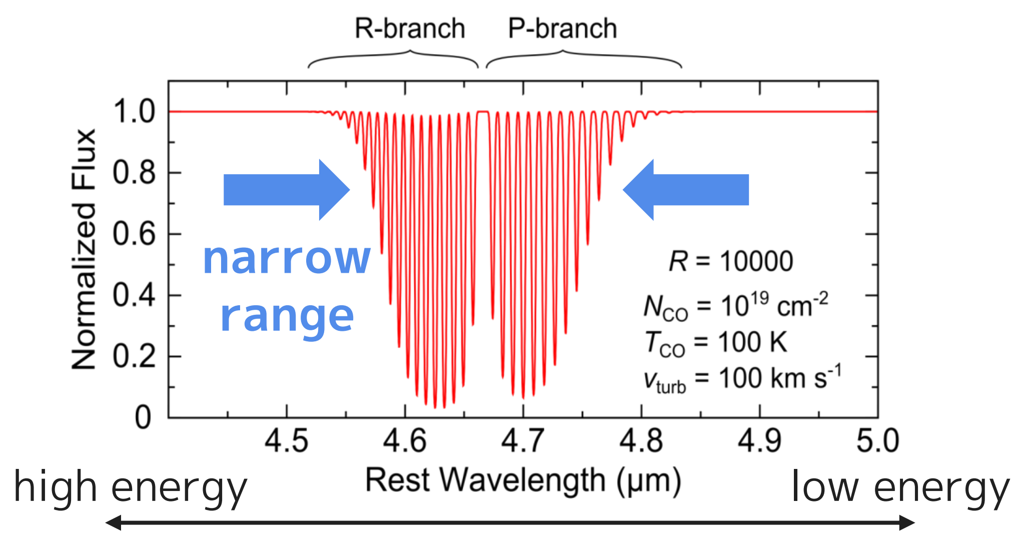
- edge-on
- near-infrared CO ro-vibrational **absorption** in AGN tori
- inner edges of AGN tori as the NIR continuum sources
  - dust sublimation layer (~1500 K)
- negligible contamination from host galaxies

effectively high spatial resolution



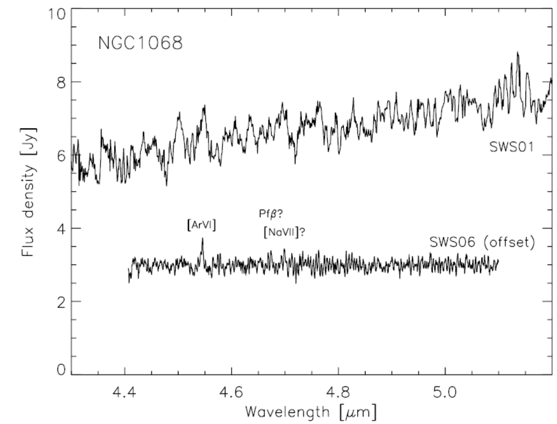
- band center 4.7 μm
- vibration: $v = 1 \leftarrow 0$
- rotation: $\Delta J = \pm 1$
- 2 branches
  - *R*-branch: $\Delta J = +1$
  - *P*-branch: $\Delta J = -1$
- simultaneous observation of many rotational levels
- good probe for physical properties



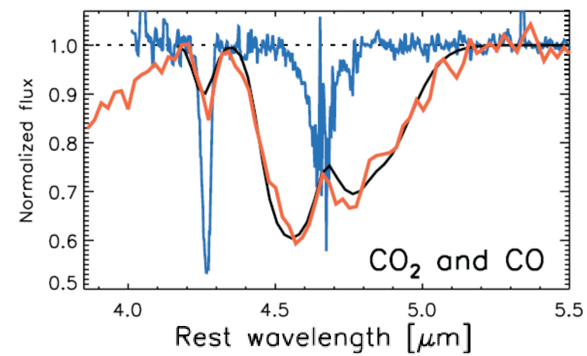


Earlier Studies

- Lutz et al. 2004, A&A, 426, 5
  - nearby 31 Seyfert galaxies
    - 19 type 1 and 12 type 2
  - ISO observations
  - no detection of the CO absorption



- Spoon et al. 2004, ApJS, 154, 184
  - IRAS F00183-0711
    - z =0.3282
    - obscured AGN?
  - Spitzer observation
  - strong CO absorption



What determines the presence or absence? Geometrical effect?

➡ systematic analysis with a larger sample

Method

- AKARI & Spitzer
- Model Fitting
- Parameter Dependences

AKARI & Spitzer

AKARI

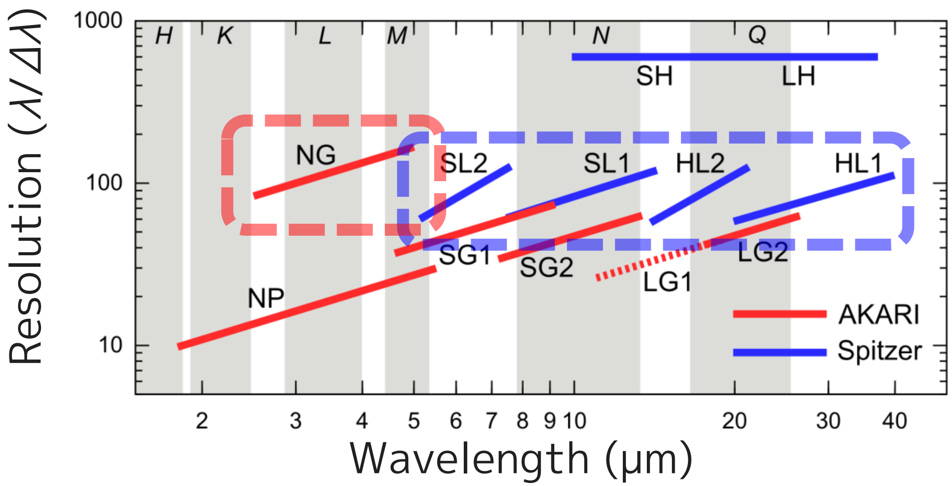
JAXA's project with ESA

- Launch: 2006
- Telescope: 68.5-cm diameter
- Wavelength: 2.5—5.0 μm → z<0.07
- Resolution: $\lambda/\Delta\lambda$ =120 @ 3.6 μm

Spitzer

NASA's Great Observatory

- Launch: 2003
- Telescope: 85-cm diameter
- Wavelength: 5.2—40 μm → z>0.11
- Resolution: $\lambda/\Delta\lambda$ = 86 @ 5.2 μm



AKARI + Spitzer

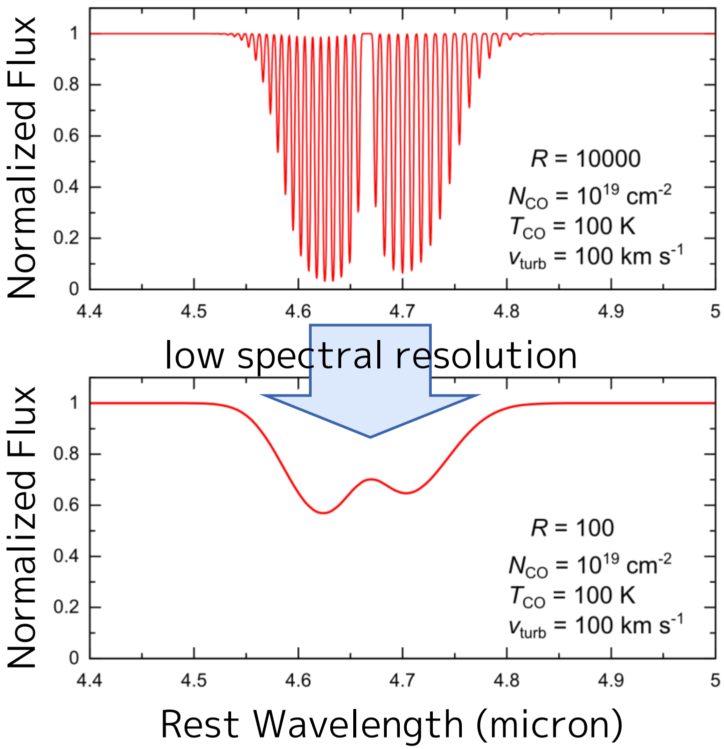
↓

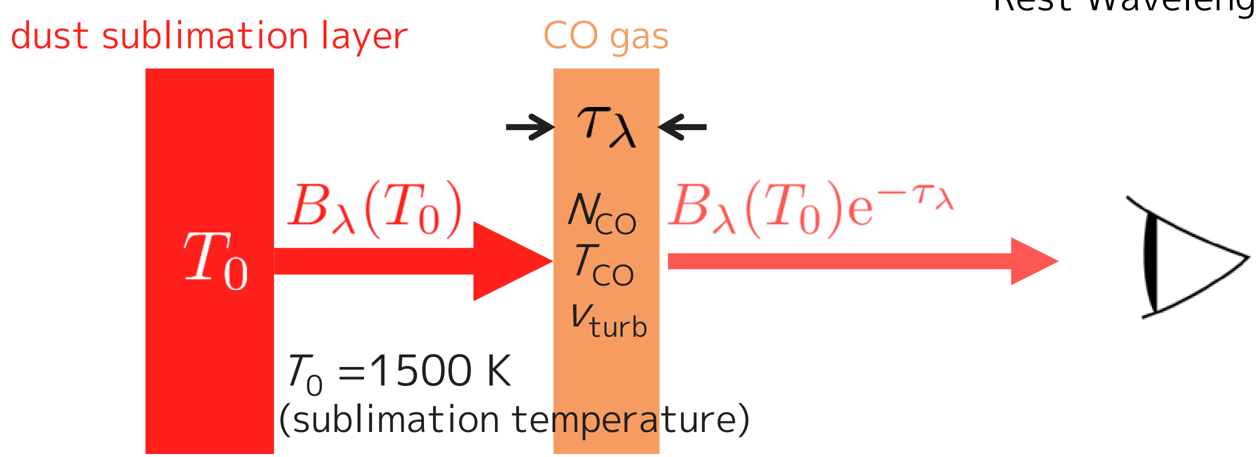
wide redshift coverage

○	Redshift	Space: Not limited by the atmosphere Ground: z < 0.13 for M-band
○	Detection Limit	Space: > 1 mJy for ten-minute observations with AKARI Ground: > 100 mJy for one-night observations with Subaru
✕	Spectral Resolution	Space: $\lambda/\Delta\lambda$ ~ 100 Ground: $\lambda/\Delta\lambda$ ~ 10000

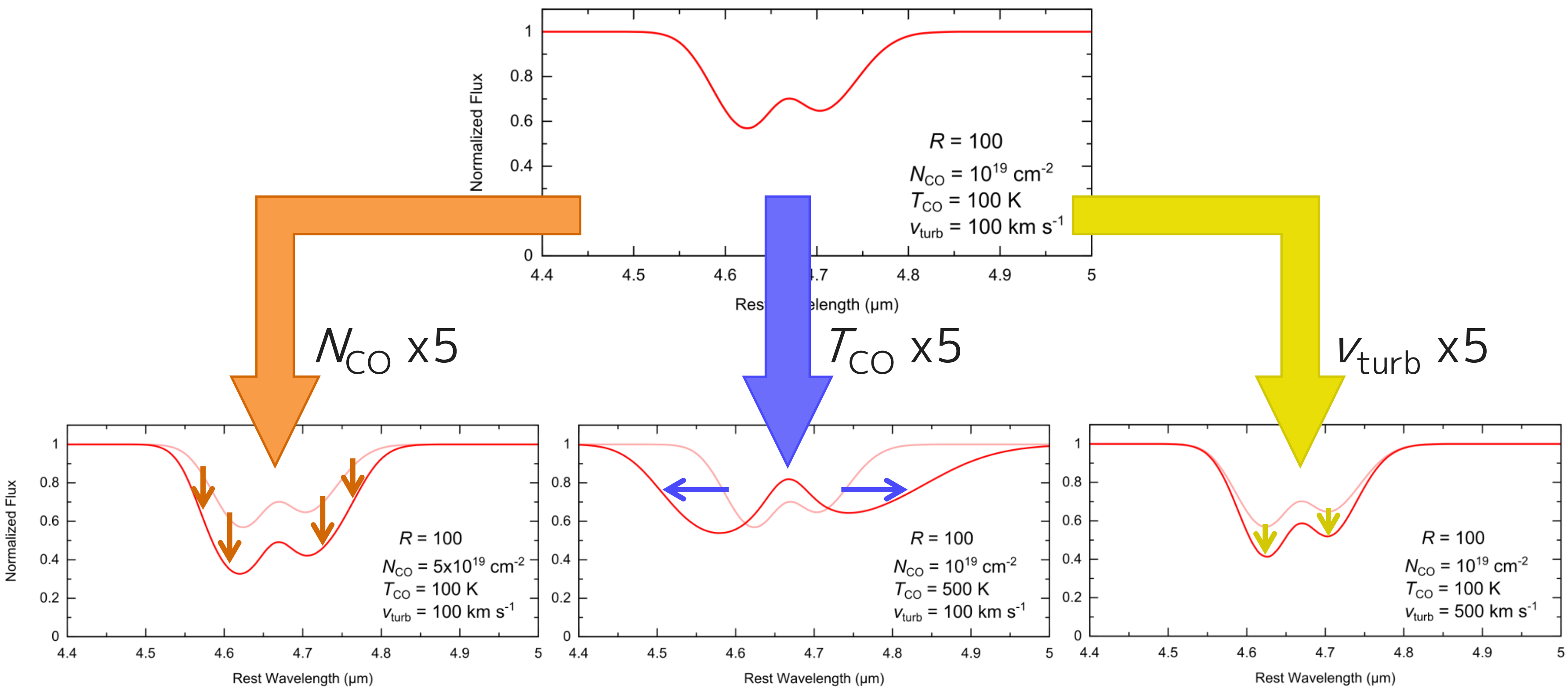
Model Fitting

- AKARI and Spitzer observations cannot resolve rotational levels.
- model fitting assuming local thermal equilibrium and slab geometry (Cami 2002)
  - single component
  - three free parameters:
    - column density N_{CO}
    - temperature T_{CO}
    - turbulent velocity v_{turb}





Parameter Dependence



deeper — large N_{CO} → large optical depth

wider — high T_{CO} → higher J

narrow and deeper — v_{turb} broaden equivalent widths only when the absorption is saturated. (restricted to 10—300 km s^{-1})

Targets

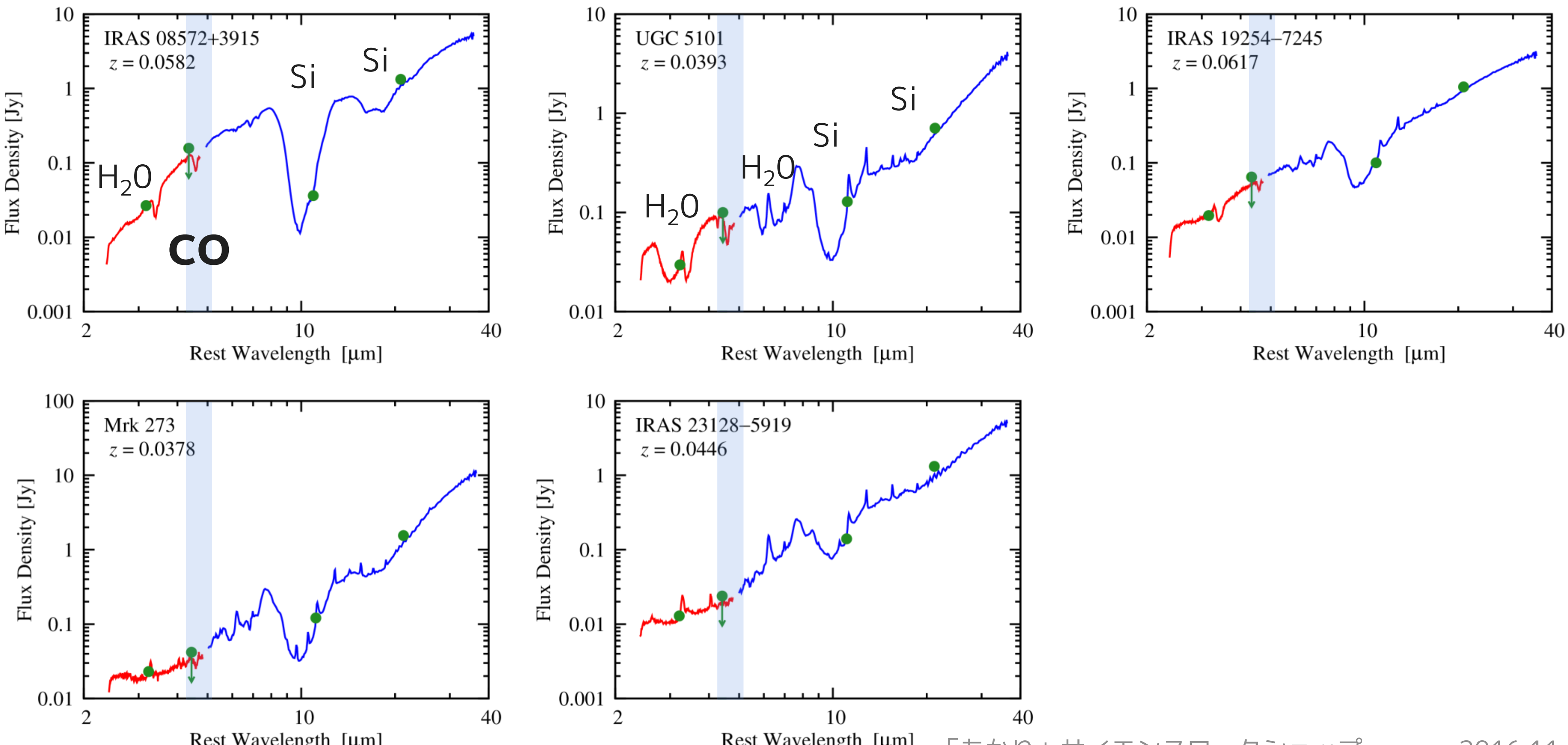
- Targets
- Spectra (AKARI)
- Spectra (Spitzer)

Targets

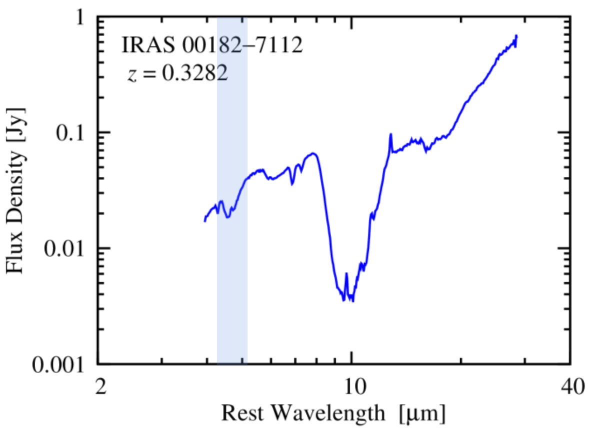
- AKARI
  - mission program “AGNUL” (AGNs and Ultra-Luminous infrared galaxies)
  - **5 out of 8** ULIRGs show the CO absorption (2 out of 3 type 2 AGNs)
    - Sy 2 galaxy IRAS 05189-2524 does not show the CO absorption
    - Not all of type 2 AGNs show the CO absorption. Consistent with Lutz et al. (2004).
- Spitzer
  - 4 targets reported by Spoon et al. (2005)

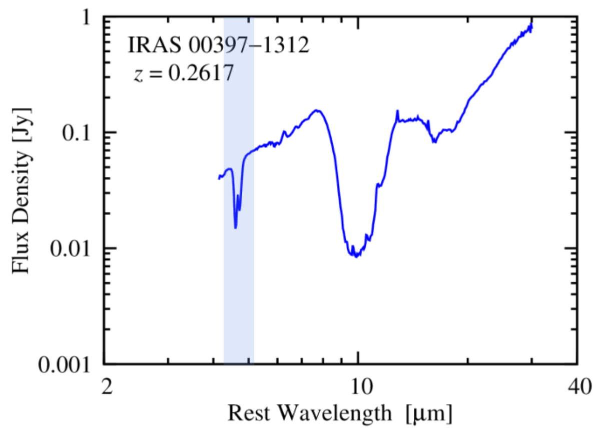
Telescope	Object	redshift	Optical Class
AKARI	IRAS 08572+3915	0.0582	LINER
	UGC 5101	0.0393	LINER
	IRAS 19254-7245	0.0617	Seyfert 2
	Mrk 273	0.0378	Seyfert 2
	IRAS 23128-5919	0.0446	Seyfert 2
Spitzer	IRAS F00183-7111	0.3270	LINER
	IRAS 00397-1312	0.2617	H II
	IRAS 00406-3127	0.3424	Seyfert 2
	IRAS 13352+6402	0.2370	?

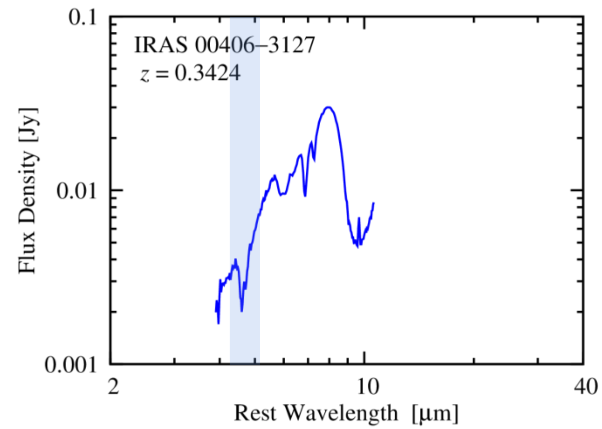
- missing longward continuum (due to redshift)
- combined with Spitzer spectra
    - normalized to WISE fluxes

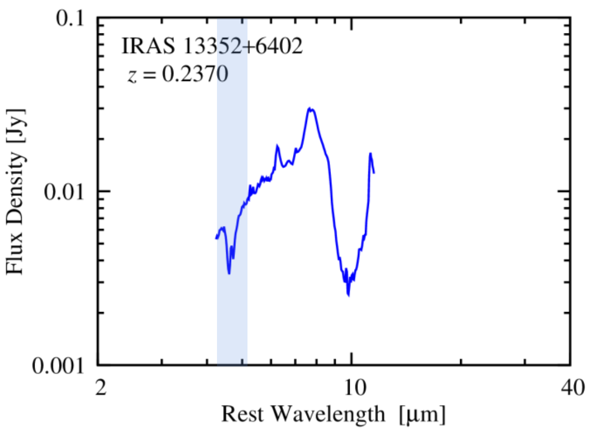


- the IRS Enhanced Products on the Spitzer Heritage Archive







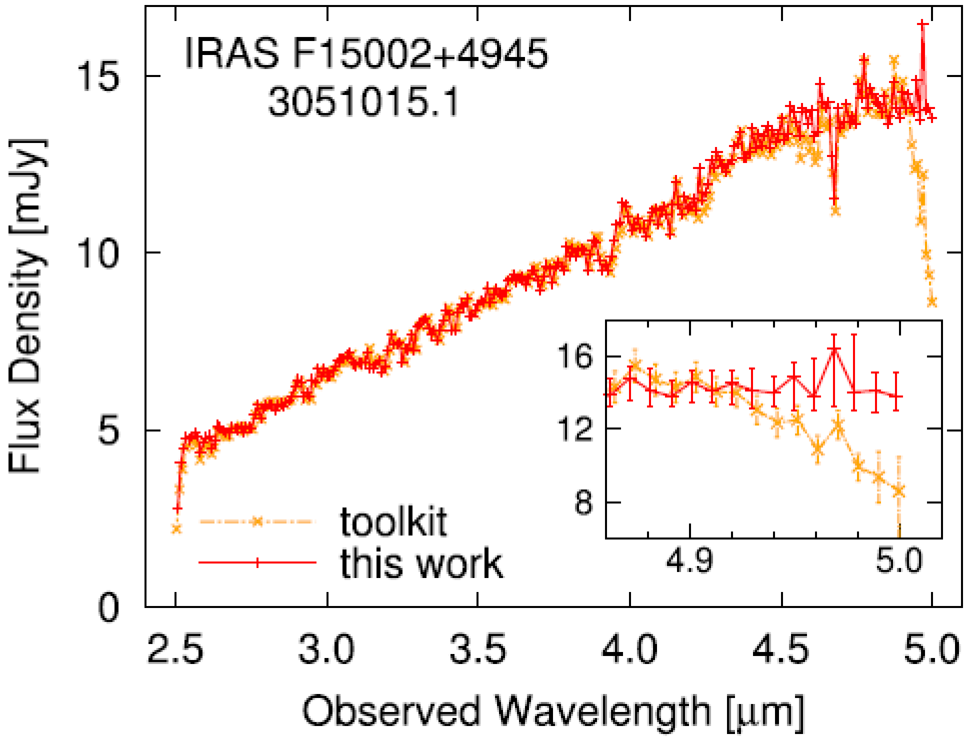


Results

- Case of IRAS 08572+3915
- Best-Fit Models

4.9 μm artifact の補正

4.9 μm artifact ＝ 混入二次光の較正残し

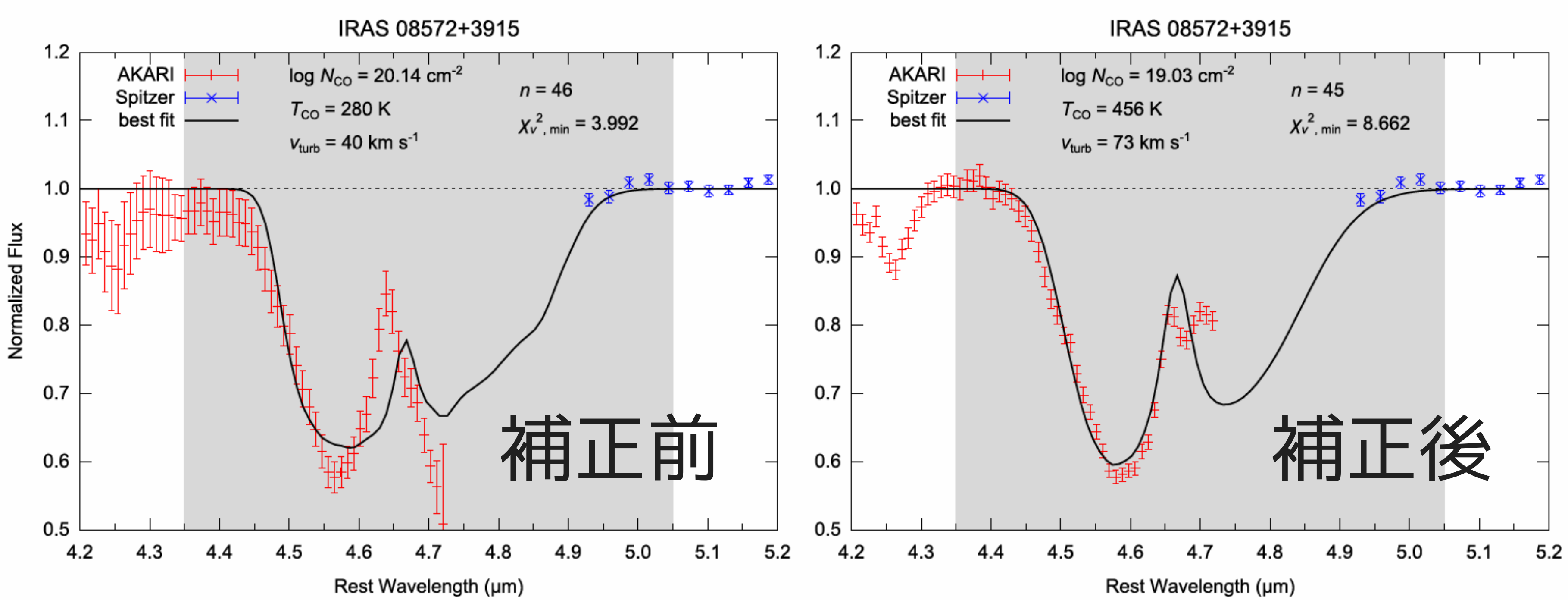


橙：補正前
赤：補正後

Baba et al. 2016, PASJ, 68, 27

4.9 μm artifact の補正

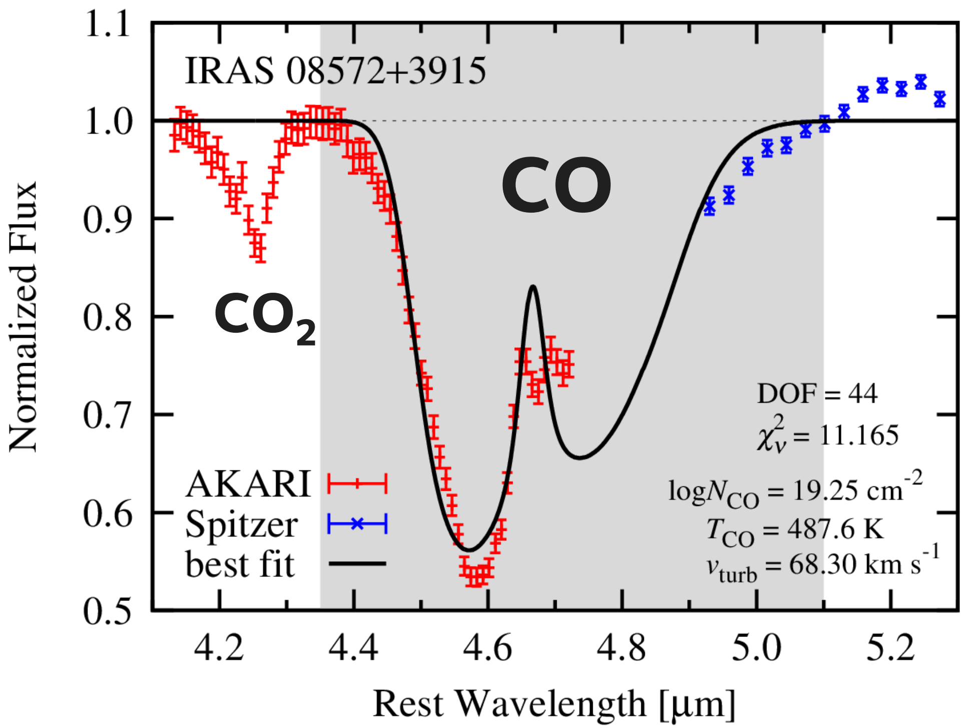
4.9 μm artifact ＝ 混入二次光の較正残し



Baba et al. 2016, PASJ, 68, 27

Case of IRAS 08572+3915

IRAS 08572+3915 (z =0.0582)



$\log N_{\rm CO} = 19.2^{+0.11}_{-0.09}$

→ $\log N_{\rm H} \sim 23$ (in cm^{-2})

$T_{\rm CO} = 488^{+37}_{-37}$ K

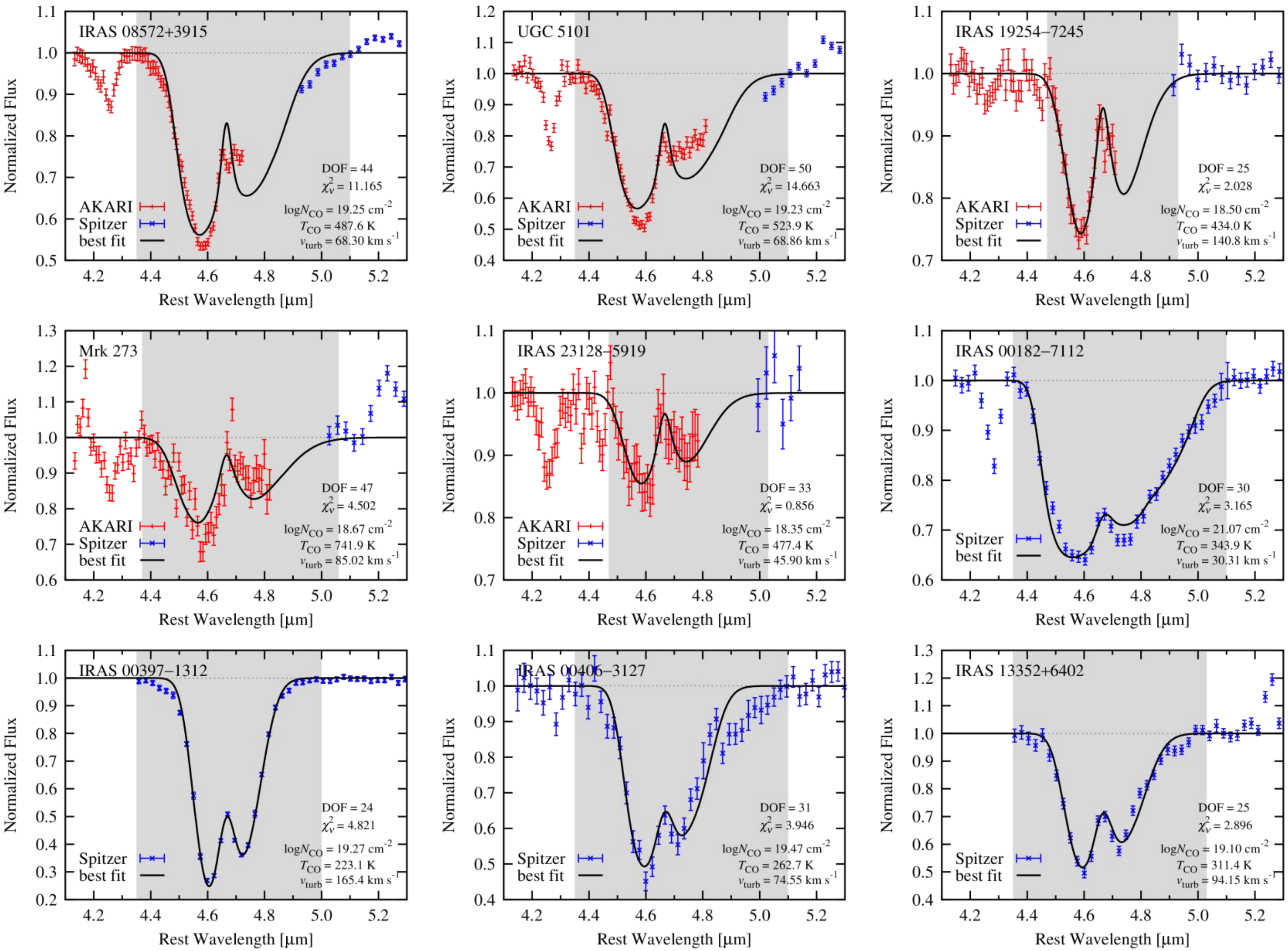
$v_{\rm turb} = 68^{+8}_{-6}$ km s^{-1}

Warm and **large** $\boldsymbol{N_{\rm CO}}$

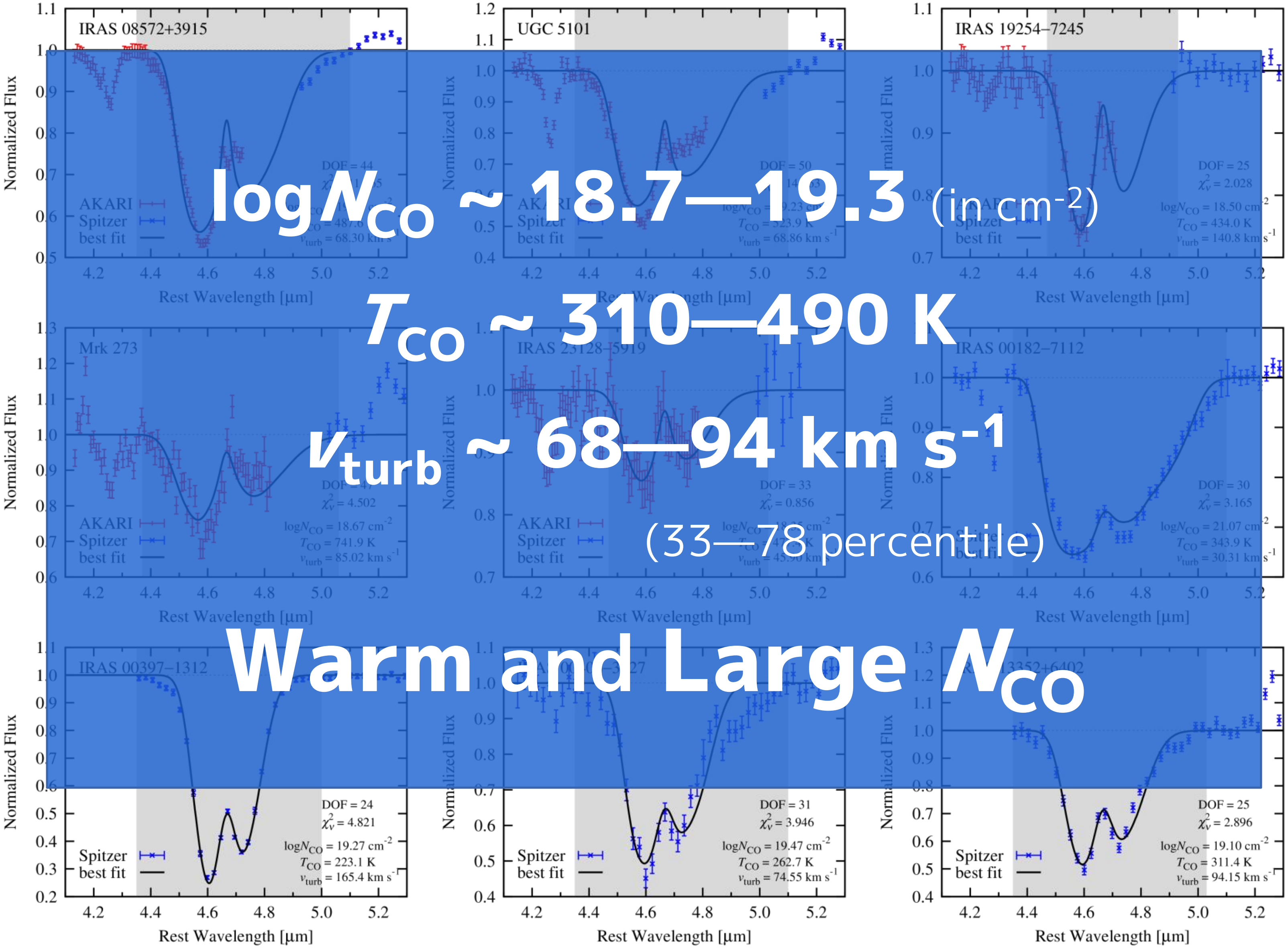
super/subscripts indicate the 99% confidence range

cf: typical molecular clouds in star-forming regions, $T < 50$ K

Best-Fit Models



Best-Fit Models



logN_{CO} ~ 18.7—19.3 (in cm^{-2})

T_{CO} ~ 310—490 K

v_{turb} ~ 68—94 km s^{-1}

(33—78 percentile)

Warm and Large N_{CO}

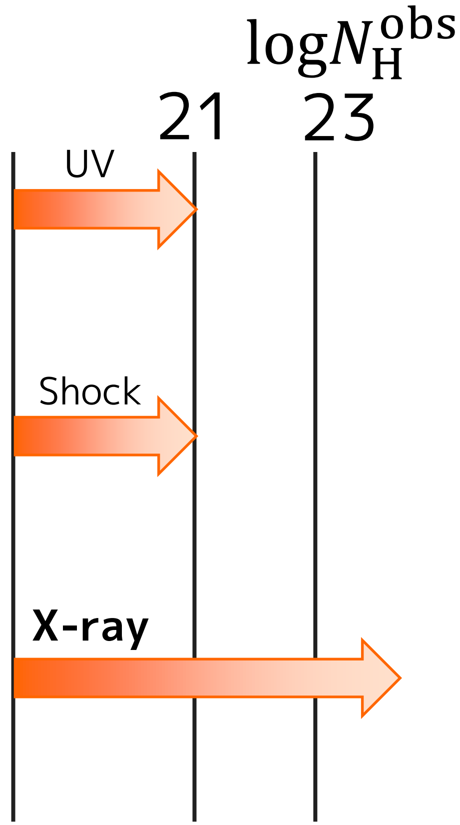
Discussion

- Heating Mechanism
- Absorber
- Innermost Geometry

Scale of heating

The observed gas has high temperature ($T_{\rm CO}^{\rm obs} \sim 400$ K) and large column density ($\log N_{\rm H}^{\rm obs} \sim 23$).

1. UV heating
   - The accretion disk emits UV light and heats surrounding gas up to 10^4 K (Tielens & Hollenbach 1985).
   - UV flux is attenuated by dust and penetrates column density of only $\log N_{\rm H} = 21 \ll \log N_{\rm H}^{\rm obs}$ (Diplas & Savage 1994).
2. Shock Heating
   - Shock layers caused by such as outflows can be heated up to ~1000 K.
   - But the scale of shock layers is only $\log N_{\rm H} = 21 \ll \log N_{\rm H}^{\rm obs}$ (McKee et al. 1984)
3. X-ray heating
   - The gas heated by X-ray photons (2—10 keV) from AGN nuclei reaches ~10^4 K.
   - Hard X-ray can penetrate $\log N_H = 24 \sim \log N_{\rm H}^{\rm obs}$ before photo-electrically absorbed (Meijerink & Spaans 2005).

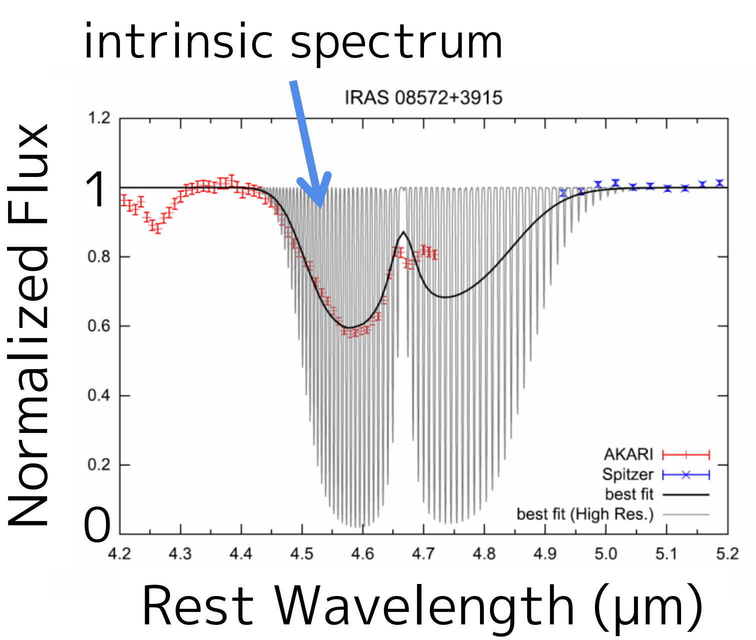


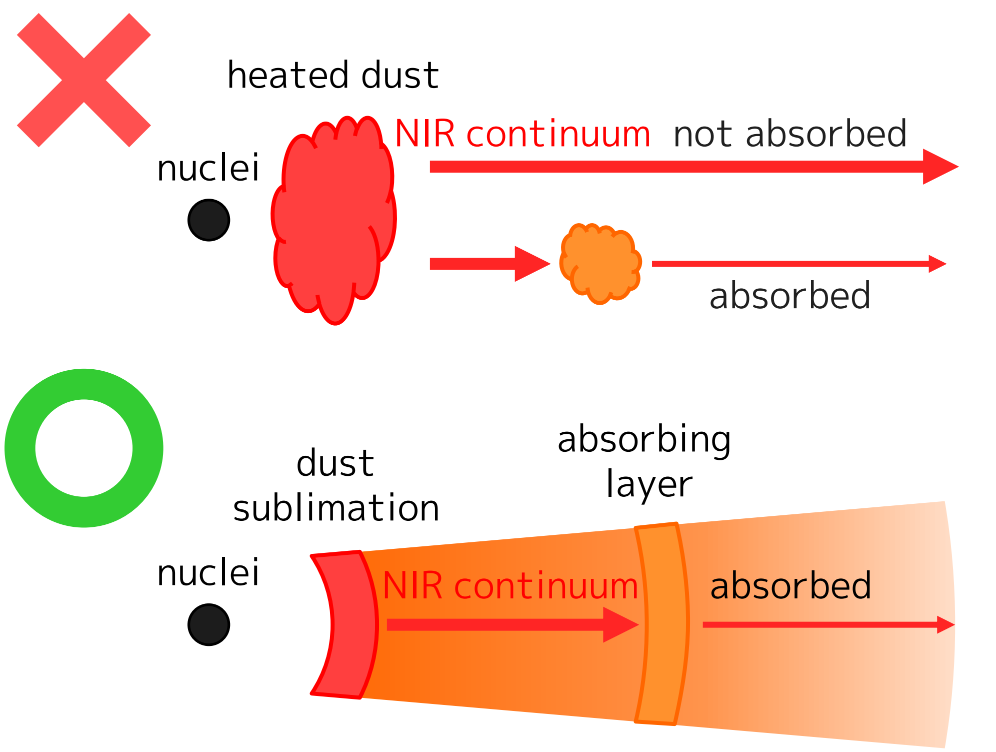
X-ray heating is a good candidate of the heating mechanism.

→ The observed gas exists near the X-ray sources (=AGNs).

Absorber

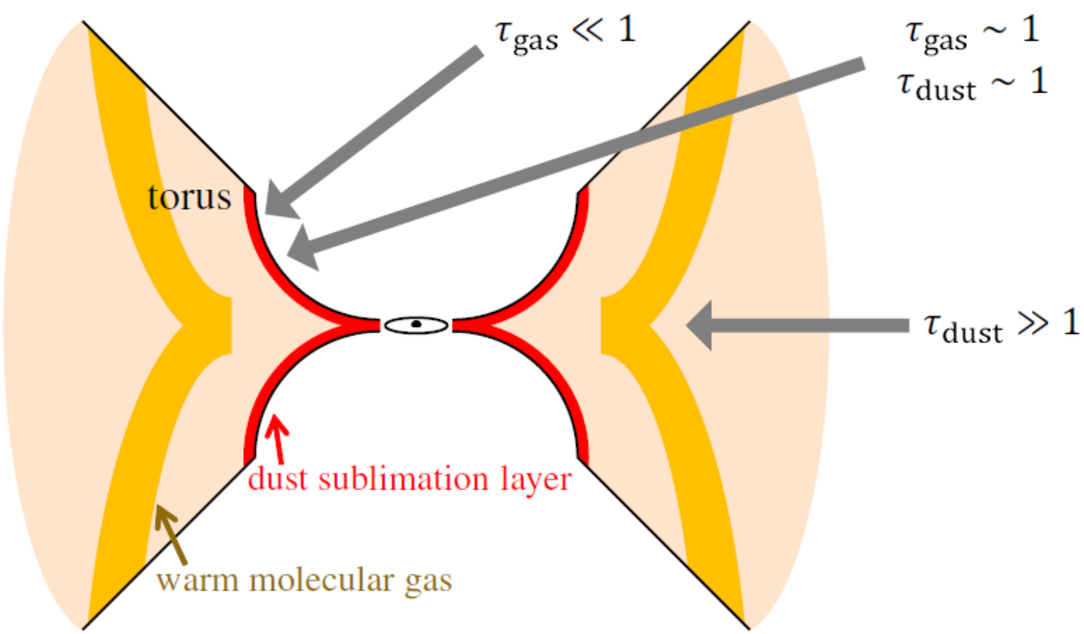
- Absorption line of each *J* is almost saturated.
- Molecular clouds in star-forming regions distribute randomly and cannot cover the continuum source entirely.
- Molecular cloud of systematic geometry surrounding the nucleus





Type 2 AGNs do not necessarily show the CO absorption.
In the AKARI program "AGNUL", the CO absorption is present in 5 out of 8 ULIRGs (**2 out of 3 type 2 AGNs**).

The presence or absence reflects the innermost geometry of the torus?



concave dust sublimation layer (Kawaguchi & Mori 2010, 2011)

The CO absorption can be detected only when both τ_{gas} and τ_{dust} are close to unity.

→ A specific inclination angle is required.

Summary

Summary

- We analyzed CO ro-vibrational absorption (4.7 μm) in ULIRGs to study the gas properties around AGNs with effectively high spatial resolution.
- We analyzed low-resolution spectra obtained with AKARI and Spitzer by fitting the isothermal gas model.
- The results indicate the presence of the warm gas of large column density.
  - Typically, $\log N_{CO} \sim 19$, $T_{CO} \sim 400$ K, $v_{turb} \sim 80$ km s^{-1}.
- X-ray heating is a good candidate of the heating mechanism.

  →The observed gas possibly exists near the X-ray source=AGN.
- The absorption is almost saturated.

  →The absorption cannot be attributed to molecular clouds in star-forming regions.
- We confirmed the results of Lutz+04 and Spoon+04: Some but not all type 2 AGNs show the CO absorption.

  →The presence or absence perhaps reflects the innermost geometry of the torus.