Near-Infrared High-Resolution Spectroscopy of the Obscured AGN IRAS 01250+2832

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ABSTRACT

We provide a new physical insight on the hot molecular clouds near the nucleus of the heavily obscured AGN IRAS 01250+2832, based on the results of near-infrared high-resolution spectroscopy of gaseous CO ro-vibrational absorption lines with Subaru/IRCS+AO188. The detected CO absorption lines up to highly excited rotational levels reveal that hot dense molecular clouds exist around the AGN under the extreme physical conditions.

1. INTRODUCTION

Recent observations at many wavelengths, for example the X-ray background observations, infrared deep cosmological surveys, and (sub)millimeter deep galaxy surveys, surely show the importance of heavily obscured active galactic nuclei (AGNs) in the galaxy evolution history. However, the physical conditions of obscuring molecular clouds near the nuclei have never been measured directly, and the exact nature of the obscured AGNs is still controversial.

IRAS 01250+2832 is a new notable object which is identified as an obscured AGN using the catalogue of *AKARI* Mid-infrared All-Sky Survey (Oyabu et al. 2011). *AKARI* detected the excess of mid-infrared emission that implied the existence of hot dust associated with an AGN. Though the optical spectrum of this galaxy is that of a typical elliptical galaxy, the *AKARI* near-infrared spectrum shows a steep red continuum with deep CO absorption feature (see Figure 1). *AKARI*/IRC has superb sensitivity with no influence of atmosphere. However, its spectral resolution is moderate (R∼100) and is not enough to resolve the CO absorption into each CO ro-vibrational absorption line.

2. OBSERVATION

First, we performed near-infrared imaging observations using the IRCS+AO188 on the Subaru Telescope, to check the compactness of the emission region. Figure 2 shows the reduced multi-band (J, H, K, L', M') images with the pixel scale of 20 mas. Thanks to the high spatial resolution (∼0.″1) of IRCS+AO188, which corresponds to the physical scale of ∼90 pc on IRAS 01250+2832 at $z = 0.0428$, we can resolve the extended stellar emission in the host galaxy at JHK-bands.

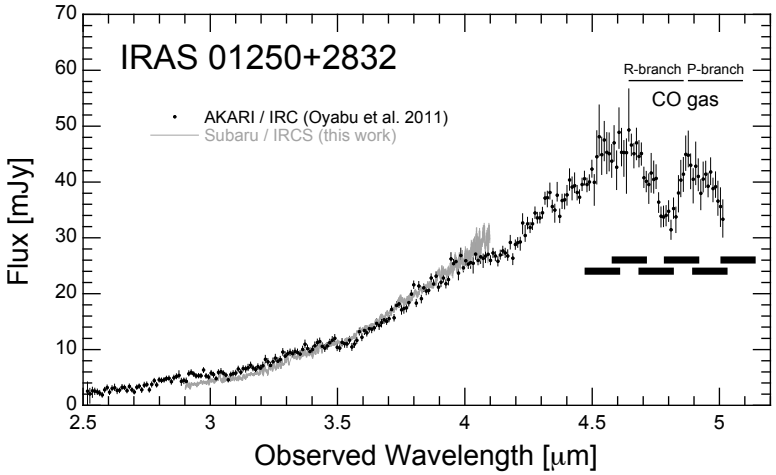

Figure 1. *AKARI*/IRC NIR grism spectrum of IRAS 01250+2832 (black circles; Oyabu et al. 2011), which shows a steep red continuum with strong CO absorption feature. Gray lines are the Subaru/IRCS L-grism spectrum taken with the 0.″23-wide slit (this work). The good agreement of these spectra indicates that the infrared dust emission of IRAS 01250+2832 is dominated by a compact (≪ kpc) nuclear source with a very small contribution from extended starburst activity in the host galaxy. The black thick lines show the wavelength coverage of the Subaru/IRCS M-echelle spectrum shown in Figure 3.

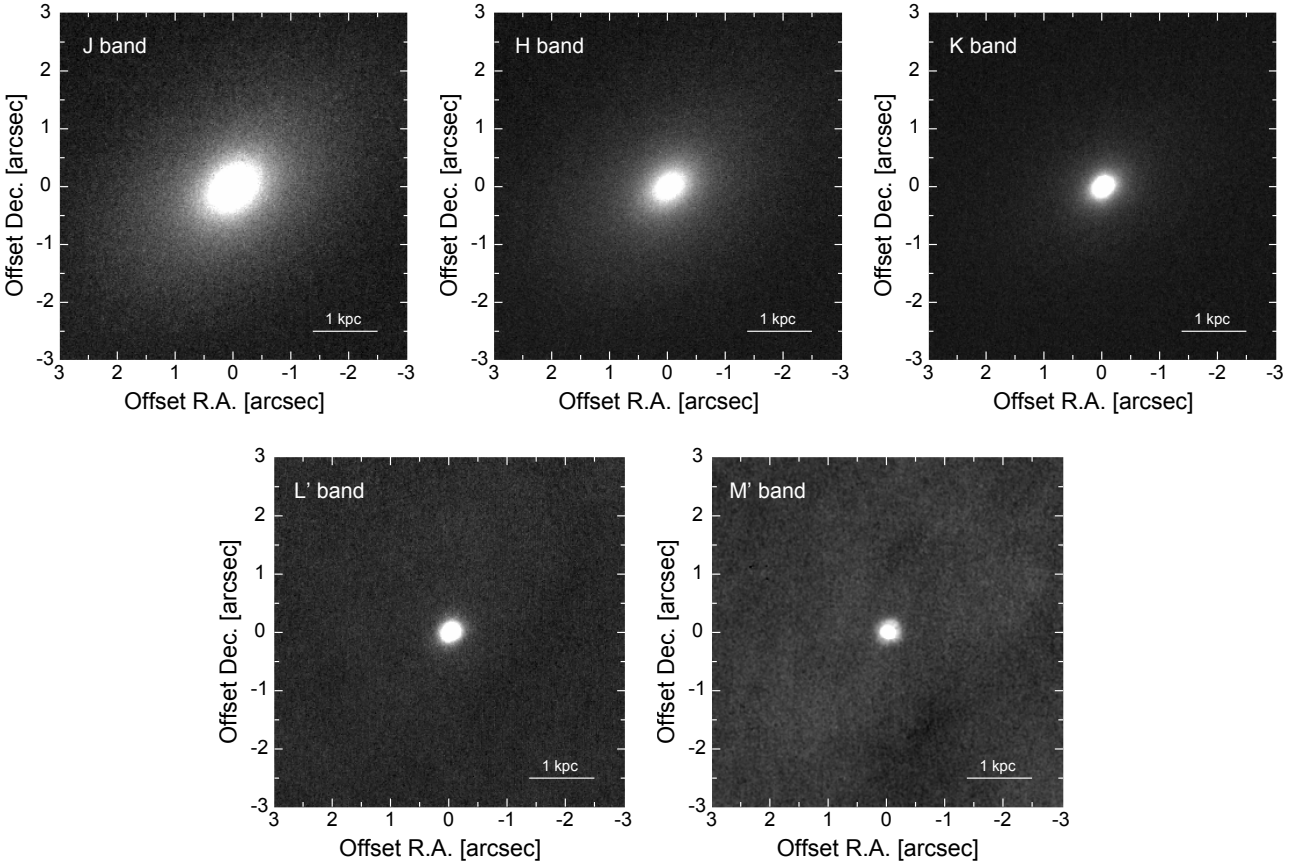

Figure 2. Subaru/IRCS+AO188 images of IRAS 01250+2832 obtained at J-band (1.25 μm; *top left panel*), H-band (1.63 μm; *top center panel*), K-band (2.20 μm; *top right panel*), L'-band (3.77 μm; *bottom left panel*), and M'-band (4.68 μm; *bottom right panel*). North is up and East is left. The color scale in each panel is linear.

While, $L'M'$-band images suggest that the infrared dust emission of this galaxy is quite compact ($\ll$ kpc) to be composed of the hot dust associated with an AGN.

In order to investigate the physical conditions of molecular clouds near the AGN directly, we have made high-resolution (R~10,000) spectroscopic observations at M-band toward this heavily obscured AGN IRAS 01250+2832 with the IRCS+AO188 on the Subaru Telescope. We observed fundamental ($v = 1 \leftarrow 0$) ro-vibrational absorption lines of gaseous CO centered around 4.7 μm. Continuum emission associated with the bright, compact central engine of the AGN is used as a background continuum source, and the foreground molecular clouds are to be observed in absorption. This technique is unique and very powerful, because the detection of many lines at different excitation levels enables us to make the direct estimates of temperatures and column densities of the molecular clouds very accurately (Shirahata et al. 2013).

3. RESULTS

Figure 3 shows the observed spectrum toward IRAS 01250+2832, which clearly shows many absorption lines up to highly excited levels ($J > 30$). These lines are very deep ($\tau_{\rm max} \sim 4$) and extremely broad (FWHM $\sim 200\,{\rm km\,s^{-1}}$), and also have the complicated line profile consisting of some velocity components. The characteristics of the detected CO lines are very similar to that of the CO absorption in other obscured AGNs, IRAS 08572+3915 and UGC 05101 (Shirahata 2006). This result is remarkable in the sense that IRAS 01250+2832 shows very strong CO absorption but no dust absorption features, though the other obscured AGNs having CO absorption always show the strong dust absorption features.

4. DISCUSSION

On the assumption of local thermodynamic equilibrium, the detected CO absorption lines of IRAS 01250+2832 reveal two distinct components; a hot gas with a temperature of 700 K, and a warm gas with a temperature of 150 K. The CO column density of the hot molecular gas is estimated to be $N_{\rm CO} \sim 1.3 \times 10^{19}\,{\rm cm^{-2}}$, which corresponds to a H_2 column density of $N_{\rm H_2} \sim 7.2 \times 10^{22}\,{\rm cm^{-2}}$, for a covering factor of 0.5. The CO column density of the warm molecular gas is estimated to be $N_{\rm CO} \sim 8.0 \times 10^{18}$ cm^{-2}, which corresponds to a H_2 column density of $N_{\rm H_2} \sim 4.4 \times 10^{22}\,{\rm cm^{-2}}$, for a covering factor of unity. The high temperatures combined with the large column density of both components imply that the CO absorption originates in molecular clouds near the nucleus of the AGN. The thermal excitation of CO up to the

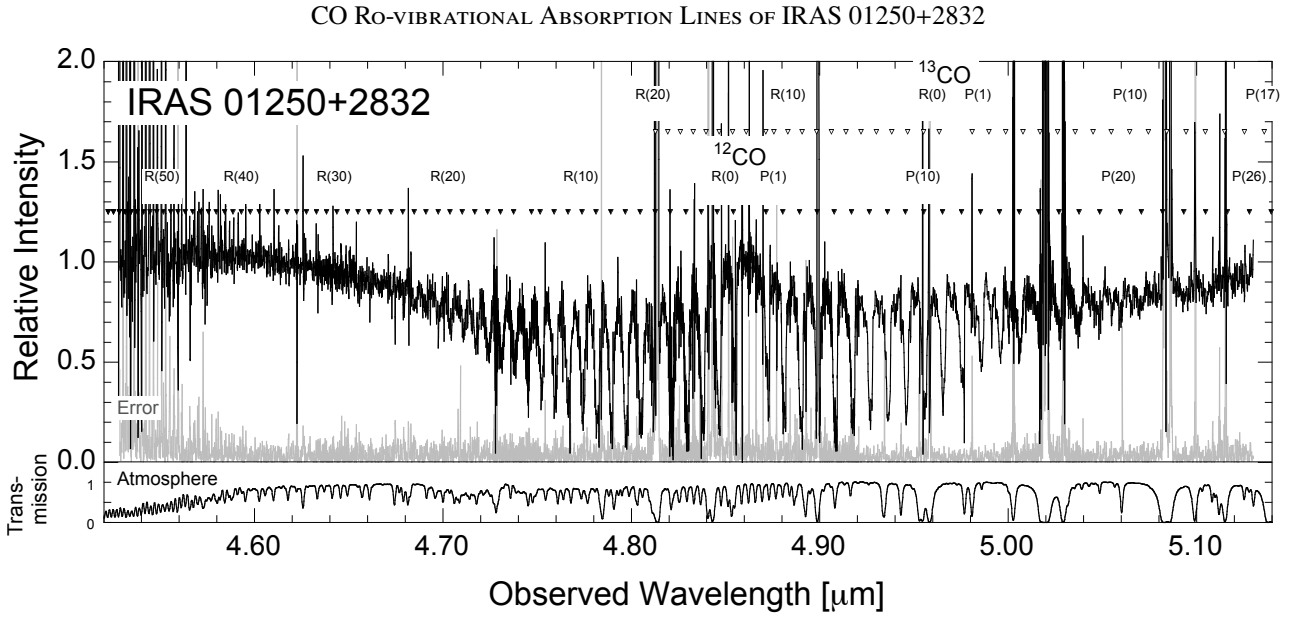

Figure 3. Subaru/IRCS spectrum of IRAS 01250+2832, taken with 6 echelle grating settings. Many absorption lines of CO in the fundamental band ($v = 1 \leftarrow 0$) up to highly excited rotational levels ($J > 30$) were detected, in 4.53–5.13 μm. The wavelengths of the R- and P-branch lines of $^{12}C^{16}O$ and $^{13}C^{16}O$ corresponding to the redshift of the host galaxy are indicated on the top by triangles. The error and the atmospheric transmission curve are shown on the bottom panel.

observed high rotational levels requires a density greater than $n_c(H_2) > 1 \times 10^8\,cm^{-3}$, implying that the thickness of the absorbing layer is extremely small ($\Delta d < 10^{-2}$ pc) even if it is highly clumped. This means that both absorption clouds must themselves be composed of numerous well-separated thin sheets of dense gas that are detached from the continuum source. One more interesting point of this spectrum is that these clouds exhibit very low CO isotopic ratio ($^{12}CO/^{13}CO$ = 13.3) based on the spectral shape at 4.9–5.1 μm. Such a low CO isotopic ratio cannot be explained with the normal well-mixed dust model.

5. SUMMARY

We have observed and analyzed a high-resolution M-band spectrum of the obscured AGN, IRAS 01250+2832, which contains strong absorption lines of the fundamental ($v = 1 \leftarrow 0$) band of CO. The detected CO ro-vibrational absorption lines reveal that hot dense molecular clouds exist around the AGN. The derived extreme physical conditions of molecular clouds with insinuated complex geometry indicate that the environment around the AGN is not as simple as that proposed in the unified scheme of AGNs.

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