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Dust and Gas in the Nucleus of NGC 1068: Comparison to the Galactic Center's Central Molecular Zone

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Abstract.
We report new 3–5-μm spectroscopy of the nucleus of NGC 1068, obtained at $0\farcs3$ resolution (corresponding to 20 pc at the distance of NGC 1068), sufficient to partially resolve the continuum peak. The data yield a strong upper limit on the column density of CO, as well as evidence that the 3.4-μm hydrocarbon absorption feature has a similar distribution across the nuclear infrared continuum emission as the previously studied 9.7-μm silicate absorption. Together these imply that at 3–10 μm the bulk of the gas in front of the continuum peak has the properties of Galactic diffuse molecular clouds rather than dense clouds. This nuclear environment in NGC 1068 resembles the central molecular zone of the Galaxy.

1. Introduction

A comparison between the interstellar medium (ISM) in the nucleus of NGC 1068 and the ISM in the Galactic center (GC) is somewhat outside of the mainstream of this conference, as the luminosity of the central engine of NGC 1068 is 10^{45} ergs s^{-1}, exceeding that of the Sgr A* by a factor of $\sim 10^8$. Nevertheless there is an interesting parallel between the ISMs in the central regions of the two galaxies.

2. NGC 1068, the unified model of AGNs, and the obscuring medium

NGC 1068 is the prototypical Seyfert II galaxy and the poster-child for the unified model of active galactic nuclei (AGNs). That model postulates that the different appearances of the nuclei of Seyfert I and Seyfert II galaxies, and of AGNs in general is more a matter of how the nuclear regions are oriented with respect to our line of sight than any intrinsic differences in them. In a Seyfert II nucleus the view to the very center is believed to be obscured by dusty gaseous material. In a Seyfert I nucleus that material is present, but is not in the direct line of sight to the central engine, and thus the innermost region of the nucleus can be observed, in particular the broad permitted line emission that arises in high-density, rapidly moving gas close to the supermassive black hole.

The geometry, chemistry and evolution of the obscuring matter are subjects of much current investigation. It has generally been assumed that the gas associated with the obscuring dust is largely molecular. If so, then one might expect to detect molecular species in the line of sight to a Seyfert II nucleus. Surprisingly however, probably the easiest interstellar molecular band to observe, the fundamental vibration-rotation band of CO, whose center lies near 4.7 μm, has not been detected toward NGC 1068 by several groups of investigators using a variety of spectral resolutions (Lutz et al. 2004; Mason et al. 2006; Geballe et al. 2009). The most recent spectrum, which provides the most stringent upper limit, is shown in Fig. 1. As the continuum emitting region at the nucleus of NGC 1068 has a FWHM of ~20 pc at 3–5 μm, the upper limit on CO applies to the gas beyond a distance of ~10 pc from the central engine.

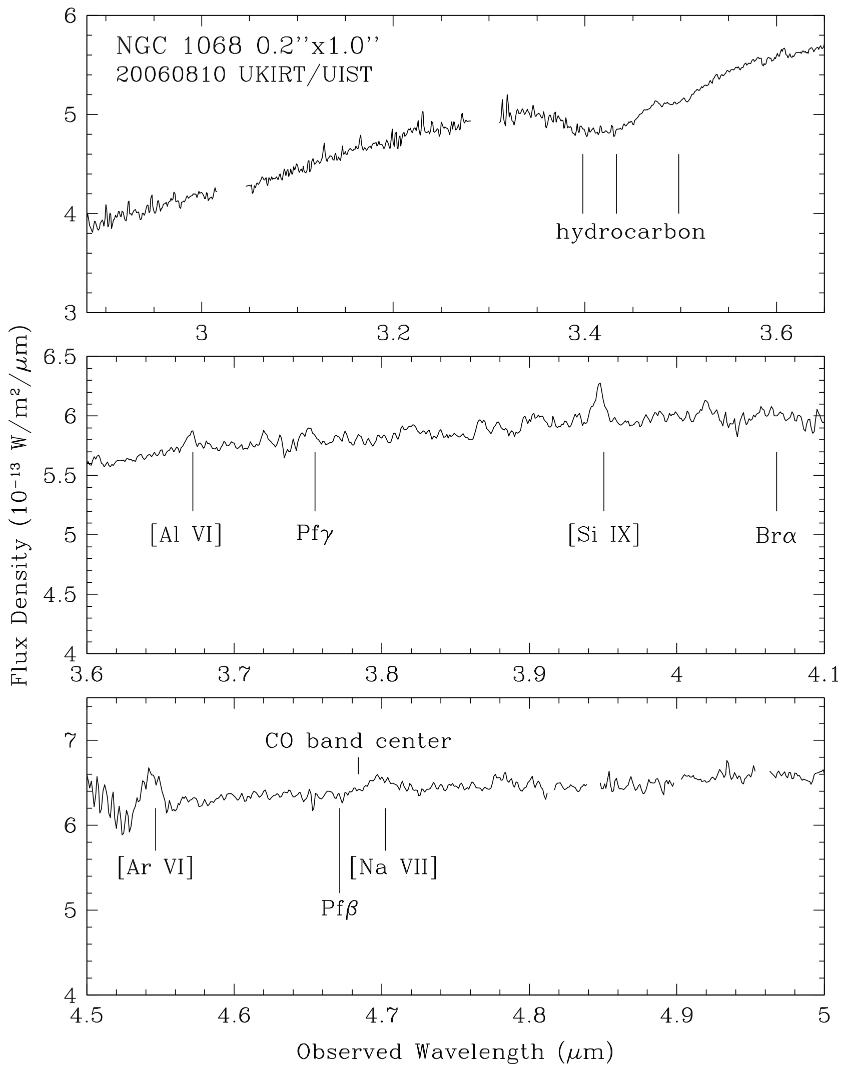

Figure 1. 3–5-μm spectrum of the central $0.2'' \times 1.0''$ (EW x NS) region of NGC 1068 (Geballe et al. 2009). Wavelengths of atomic lines of interest are shown, as are the components of the 3.4-μm hydrocarbon feature and the band center of CO, all at the systemic redshift of 0.003793.

3. The nature of the ISM in the nucleus of NGC 1068

How is it possible that there is no detectable infrared CO absorption, and what is the nature of the foreground gas beyond r$\sim$10 pc? The spectrum in Fig. 1 shows a prominent 3.4-μm absorption feature, produced by interstellar aliphatic hydrocarbons, and known from studies of clouds in the Galaxy to be present in diffuse clouds but not in dense clouds. NGC 1068 is also known to possess a prominent silicate absorption at 9.7 μm (e.g, Mason et al. 2006). In the Galaxy the silicate feature is found both in diffuse and dense clouds. In dense clouds gaseous CO is abundant, and accounts for most of the carbon except in the coldest portions of the clouds. There is little CO in Galactic diffuse clouds, as the carbon in them is almost entirely in atomic form. Thus in its 3.4-μm and 9.7-μm absorption features and its lack of absorption by interstellar CO the mid-infrared spectrum of NGC 1068 mimics that produced by a diffuse ISM.

Does this mean that the ISM in front of the IR nucleus of NGC 1068 is entirely diffuse? Is it possible that the silicate and hydrocarbon absorptions are not co-located along the line of sight? If so the mid-infrared spectrum could be a coincidence of unrelated absorption features, possibly with a significant fraction of the absorbing silicates located in dense cloud material that is spatially separated from the diffuse cloud material that provides the 3.4-μm absorption. This scenario has two serious difficulties. First, Geballe et al. (2009) report similar spatial variations of the strengths of both the hydrocarbon and silicate features across the nuclear IR source (Fig. 2). That implies that both absorption features occur in gas close to the continuum source and are largely co-located. Second, any substantial contribution to the silicate absorption by dense cloud material on the line of sight would imply a detectable column density of CO in the same dense cloud; yet no absorption by CO is detected. In conclusion, the present data point to the interstellar environment in the line of sight to the nuclear infrared source of NGC 1068 being largely that of a diffuse ISM, i.e., low density (10^{2-3} cm^{-3}) with carbon largely atomic.

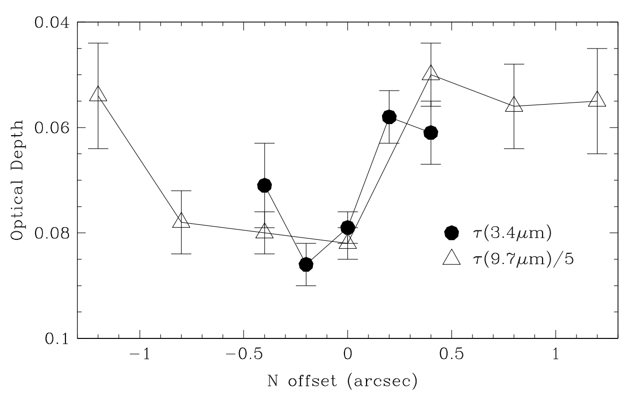

Figure 2. Optical depth of the 3.4-μm hydrocarbon absorption feature (Geballe et al. 2009) and the 9.7-μm silicate absorption feature (Mason et al. 2006) across the nucleus of NGC 1068. Error bars are $\pm 1\sigma$.

4. Comparison with the GC

Like NGC 1068, the mid-infrared spectrum of the GC contains absorptions due to hydrocarbons at 3.4 μm and silicates at 9.7 μm (e.g., Lutz et al. 1996, 2000). Unlike NGC 1068 it has strong absorption by gaseous CO (e.g., Geballe et al. 1989; Moultaka et al. 2009). However, the sightline to the Galactic center passes through several spiral arms, which contribute the bulk of the CO absorption (Geballe et al. 1989; Oka et al. 2005); this is not the case for NGC 1068. The spiral arms also must be significant contributors to the silicate absorption. As described in this conference (Oka et al. 2009) and elsewhere (Oka et al. 2005; Goto et al. 2008) high-resolution spectroscopy of infrared sources in the Central and Quintuplet clusters strongly suggest that warm diffuse gas containing little CO pervades much of the Central Molecular Zone, the region within $\sim$180 pc of Sgr A*. Apart from its temperature, this newly discovered environment appears similar to that of diffuse clouds elsewhere in the Galaxy. It is the likely source of much of the 3.4-μm hydrocarbon absorption and some of the silicate absorption.

5. Concluding comments

Despite the enormously different luminosities of the nuclei of NGC 1068 and the Galaxy, the ISM producing the absorption features seen in the mid-infrared spectrum of NGC 1068 and the extensive warm diffuse gaseous component within the Central Molecular Zone of the Galaxy appear to be quite similar. Clearly, there also are gaseous regions in the nuclei of these two objects that are vastly different. NGC 1068 contains an extremely hard UV source responsible for its coronal line emission and it has a broad line region; the GC has neither. The central parsec of the Galaxy contains low excitation ionized gas; such gas exists in NGC 1068 only at distances of many tens of parsecs from its central engine. It is not known how common the diffuse cloud environment is toward type II AGN. Non-detections of CO at 4.7 μm have been reported in other AGNs, but the limits on CO are much less strict than the limit in NGC 1068. Better understanding of the complex environments of type II AGNs likely will come with future observation including those by the next generation of space-based and large ground-based telescopes.

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