The obscured mid-infrared continuum of NGC 4418: A dust- and ice-enshrouded AGN*

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Abstract. We report the detection of absorption features in the 6–8 μm region superimposed on a featureless mid-infrared continuum in NGC 4418. For several of these features this is the first detection in an external galaxy. We compare the absorption spectrum of NGC 4418 to that of embedded massive protostars and the Galactic centre, and attribute the absorption features to ice grains and to hydrogenated amorphous carbon grains. From the depth of the ice features, we infer that the powerful central source responsible for the mid-infrared emission must be deeply enshrouded. Since this emission is warm and originates in a compact region, an AGN must be hiding in the nucleus of NGC 4418.

Key words. galaxies: individual: NGC 4418 – galaxies: ISM – galaxies: Seyfert – infrared: ISM: lines and bands

1. Introduction

The ISO mission has considerably enhanced our knowledge of the mid-IR properties of normal, starburst, Seyfert and Ultra-luminous Infrared Galaxies (ULIRGs). The spectra of most sources are dominated by ISM emission features, the most prominent of which are the well-known PAH emission bands at 6.2, 7.7, 8.6, 11.3 and 12.7 μm. The PAH features and the emission lines have been used qualitatively and quantitatively as diagnostics for the ultimate physical processes powering the galactic nuclei (Genzel et al. 1998; Lutz et al. 1998; Rigopoulou et al. 1999; Tran et al. 2000). A broad absorption band due to the Si-O stretching mode in amorphous silicates, centered at 9.7 μm, is also commonly detected in galaxies. Since the center of the silicate absorption coincides with a gap between the 6.2–8.6 μm and 11.3–12.8 μm PAH complexes, it is not readily apparent whether a 9.7 μm flux minimum should be interpreted as the “trough” between PAH emission features or as strong silicate absorption, or as a combination of the two. In spectra observed towards heavily extincted Galactic lines of sight, a strong silicate feature is often accompanied by ice absorption features.

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Fig. 1. The 1–3000 µm spectral energy distribution of NGC 4418, including the new ISO-PHT-S, ISO-CAM and smoothed ISO-LWS data. The data shown in grey is the spectrophotometry of Roche et al. (1986). Other data shown has been taken from Dudley (1997), Lisenfeld et al. (2000), Roche & Chandler (1993), Soifer et al. (1989) and Wynn-Williams & Becklin (1993). The dotted and dashed curves show two choices for the local mid-IR continuum. The dotted line interpolates the peaks of the observed data, whereas the dashed line assumes a stronger 18 µm silicate absorption.

Fig. 2. A comparison of the ISO spectra of NGC 4418, M82, the embedded massive protostar W33A and the Galactic centre (Sgr A*). Except for NGC 4418, the spectra have been scaled and offset. We removed the strong 7 µm [Ar II] line from the Sgr A* spectrum. The vertical dashed lines facilitate comparison between the four spectra with well known Galactic absorption features. The arrows mark the rest wavelengths of the 6.2, 7.7, 8.6 and 11.3 µm PAH features. The zero flux levels for M82, NGC 4418 and W33A are indicated with horizontal dotted lines.

3. The mid-IR spectrum of NGC 4418

3.1. Spectral features

The mid-IR spectrum of NGC 4418 (Fig. 2) bears little resemblance to the spectrum of (almost) any other galaxy obtained by ISO. The spectra of normal and starburst galaxies (Rigopoulou et al. 1999; Helou et al. 2000) are dominated by strong PAH emission features. Seyfert galaxies with a clear line of sight to AGN-heated hot dust, on the other hand, are dominated by a strong mid-IR continuum with PAHs barely recognizable (Clavel et al. 2000). The mid-IR spectrum of NGC 4418 is rich in features but does not resemble PAH spectra. Rather it is similar to spectra observed towards heavily extincted Galactic lines of sight, such as deeply embedded massive protostars or the Galactic centre (Fig. 2). These show no evidence for PAH emission features but do show strong absorption features. A simple criterion for the role of PAH emission and absorption features is based on the location of maxima in the 6–7 µm region: PAH spectra show the 6.2 µm emission feature, whereas absorption spectra show a peak at 6.5–6.7 µm, which is not an emission feature but a window of reduced absorption between two features.

A detailed comparison of the absorption features with Galactic templates may be able to shed further light on the origin of the extinction in NGC 4418. The absorption features were determined by fitting a local polynomial to the peaks of the 5.8–8 µm spectrum of NGC 4418. The absence of the 6.2 µm PAH feature indicates that emission features are very weak in the spectrum, and justifies this simple procedure to derive the shape and depth of the absorption feature.

Table 1. Observed parameters for the NGC 4418 features

<table>
<thead>
<tr>
<th>λ [μm]</th>
<th>τ</th>
<th>τ_int [cm⁻¹]</th>
<th>carrier</th>
<th>N [10¹⁷ cm⁻²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>0.8</td>
<td>87</td>
<td>H₂O</td>
<td>73</td>
</tr>
<tr>
<td>6.85</td>
<td>1.1</td>
<td>27</td>
<td>HAC?</td>
<td>~200</td>
</tr>
<tr>
<td>7.3</td>
<td>0.6</td>
<td>12</td>
<td>HAC?</td>
<td>~200</td>
</tr>
<tr>
<td>7.67</td>
<td>0.12</td>
<td>1.2</td>
<td>CH₄</td>
<td>1.6</td>
</tr>
<tr>
<td>9.7</td>
<td>7</td>
<td>—</td>
<td>silicates</td>
<td>—</td>
</tr>
<tr>
<td>18</td>
<td>~1.5</td>
<td>—</td>
<td>silicates</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>atomic H</td>
<td>~2 10⁶*</td>
</tr>
</tbody>
</table>

* Column to the mid-IR dust source calculated assuming Galactic gas to dust ratios. Note that the X-ray absorbing column to the central engine may be even higher.

of the absorption features. Figure 3 shows the resulting NGC 4418 optical depth spectrum along with the optical depth spectrum of ices towards the massive protostar W 33A (Gibb et al. 2000) and the spectrum of the Galactic centre (Sgr A*), which displays absorptions due to ices as well as features due to dust in the diffuse ISM (Chiar et al. 2000). The spectrum of NGC 4418 shows absorption features at 6.0, 6.8, 7.3, 7.6, 10 and 18 μm (Table 1). The 6.0 μm feature in NGC 4418 is similar to that in the Galactic sources but with a perhaps more pronounced long wavelength wing. The 6.85 μm feature is considerably narrower than the molecular cloud feature but is similar in width to the diffuse ISM feature. The band at 7.3 μm is substantially broader than the molecular cloud and diffuse ISM features. The absorption band near 7.6 μm is similar to that observed locally.

The presence of ice along the line of sight toward NGC 4418 is suggested by the identification of the 7.6 μm band with CH₄ (Boogert et al. 1996, 1997) and by the presence of the 6.0 μm band due to H₂O ice (Keane et al. 2000; Chiar et al. 2000). The origins of the 6.85 μm and 7.3 μm bands in NGC 4418 are unclear. Interstellar ices also show features at these wavelengths, however, their relative strengths as well as widths are markedly different in NGC 4418. The 6.85 μm and 7.3 μm band ratios are consistent with those derived for embedded massive protostellar objects in molecular clouds (Boogert et al. 1996; Keane et al. 2000). Also shown in Table 1 are the calculated HAC column densities for the 6.85 and 7.3 μm bands, assuming the intrinsic integrated band intensities for saturated aliphatic hydrocarbons from values by Wexler (1967). These integrated intensities are stronger than other current literature values (Sandford et al. 1991; Furton et al. 1999). For NGC 4418 a substantial fraction of the carbon is locked up in HAC (~20%) as compared to the Galactic centre (a few % in Sgr A*; Pendleton et al. 1994).

As mentioned previously (Sect. 2), two continua, differing only longward of 8 μm were considered for NGC 4418 (Fig. 1). The effect of the different continua on the silicate feature is noticeable when fitting the silicate profile by the Galactic Centre Source GCS 3, a pure absorption feature, i.e. no intrinsic emission (Figer et al. 1999). However, the exact optical depth is still difficult to determine due to saturation of the silicate feature in NGC 4418. Adopting the dotted line in Fig. 1 results in a NGC 4418 silicate profile in which the blue wing is well matched but the red wavelength wing is poorly fitted by the GCS 3 profile. If however the dashed line is adopted, then the fit to the red wing improves while still maintaining a reasonable match to the blue wing of the 10 μm silicate band. The 9.7 μm and 18 μm optical depths for the second case are τ₉₋₇ ~ 7 (corresponding to Aᵥ ~ 130) and τ₁₈ ~ 1.5. These numbers, along with the derived hydrogen column density, are shown in Table 1. The apparent optical depth ratio of the 9.7/18 μm silicate bands, regardless of adopted continuum, is significantly larger than the ratio determined by Deinnyk et al. (1999) for two Galactic protostars. This might suggest that complex radiative transfer effects are important, which are however beyond the scope of this Letter.

3.2. Dust and ice column densities

The column densities of the ice species can be derived by dividing the integrated optical depth (τ_int) by the molec-
4. Discussion and conclusions

We have compared the ISO-PHT-S spectrum of NGC 4418 with spectra of our template sources and found no sign of PAH emission, neither from the nucleus, nor from that part of the disk contained within the 24” x 24” ISO-PHT-S aperture. Instead we found deep absorption features imposed upon a featureless mid-IR continuum. We identify the 6–8 μm absorption features with foreground ices and HAC-like grains.

The nature of the central source in NGC 4418 cannot be inferred from the observed mid- to far-IR spectrum alone, given the absence of any “signposts”, like the 6.2 μm PAH emission feature (F_{PAH} < 6 \times 10^{-20} \text{ W/cm}^2), and of fine structure lines ([O i], [C ii] and [O iii]). Malhotra et al. (1999); \( F_{[N ii]} < 2.3 \times 10^{-20} \text{ W/cm}^2 \), from archival ISO-SWS data. Both a heavily enshrouded AGN or a similarly extincted nuclear starburst could be responsible for the observed continuum. Even if a starburst could be accomodated within the compact central source (<70 pc in the mid-IR, Scoville et al. 2000, and 25–70 pc at 6 and 20 cm, Eales et al. 1990; Kawara et al. 1990), it would be highly unlikely to block the escape of any mid-IR starburst indicator from a region of that size. The most likely origin is therefore a heavily enshrouded AGN as suggested previously by Roche et al. (1986), Kawara et al. (1990) and Dudley & Wynn-Williams (1997). The 0.1'' point source (5 mJy) detected with the Parkes Tidbinbilla Interferometer (PTI) at 13 cm (Kewley et al. 2000; L. Kewley, priv. comm.) may actually pinpoint the AGN itself. Fur-IR to millimetre sizes are less well constrained but the warm IRAS colours suggest that the emission in this range also arises in the nuclear region.

Our finding of strong absorptions due to cold silicates and ices in NGC 4418 leads us to believe that the same absorptions may be present in the mid-IR spectra of other galaxies. Indeed, we have found similar absorptions in about a dozen of 225 galaxies observed spectroscopically by ISO. Spectral identifications have to be done with great care since simultaneous presence of PAH emission may make other spectra more complex than the one of NGC 4418.

Since the overall shape of the NGC 4418 6–11 μm spectrum with its maximum around 5 μm mimicks at first glance a PAH spectrum, we point out the need for high S/N spectra to clearly identify the indicators for bona fide PAH spectra or absorption dominated spectra. The most obvious discriminator is the 6.2 μm PAH peak to be contrasted with the 6.5–6.7 μm pseudo-maximum in absorption spectra, which is due to a window between two absorption features. In a forthcoming paper we will address this issue for our large ISO galaxy sample.

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