# ISOCAM Mid-Infrared Spectral Imaging of the Sab Galaxy NGC 4736 (M94)

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**Abstract.**
ISOCAM mid-infrared spectral images of the nearby Sab galaxy NGC 4736 reveal a prominent mid-infrared bulge, encircled by a ring of radius $\sim$ 1.3 kpc. The 'unidentified' mid-infrared dust features are present in both the post-starburst bulge and the ring of H II regions, indicating that there is no large scale destruction (on $\sim$200 pc scales) of the 'macromolecules' that produce these features in the ring, and starlight from the older, redder stars in the bulge is able to excite these grains.

## 1. Motivation and Background

In the 1970's, a mysterious set of interstellar spectral features at 3.3, 6.2, 7.7, 8.6, and 11.3 $\mu$m were discovered (Gillett et al. 1973; Russell et al. 1977). These are the so-called *'Unidentified Infrared Bands' (UIBs).* Theoretical and laboratory studies (e.g., Léger & Puget 1989; Allamandola et al. 1989; Papoular et al. 1991) have demonstrated that the UIBs originate from large organic 'macromolecules', however, the exact identity of the carriers of these bands is still uncertain. The excitation mechanism of these grains is also not well-known, nor is the required photon energy range for excitation and destruction of these grains.

Ground-based and IRAS spectroscopy revealed the presence of UIBs in luminous starburst galaxies (e.g., Roche et al. 1991; Cohen & Volk 1989). IRAS broadband studies showed that $F_{12}/F_{60}$ increases with decreasing $L_{FIR}$ (Smith et al. 1987), hinting that the UIB features may be strong in lower luminosity galaxies. However, before the Infrared Space Observatory (ISO), the strength of these features in these galaxies could not be measured directly, because of the low S/N of the available spectra. The higher sensitivity of ISO has now made it possible to directly measure these dust features in lower luminosity galaxies, and to investigate environmental differences in grain properties.

Our goals in this project are: 1) to use ISO to determine the mid-infrared structure of a 'normal' spiral galaxy, 2) to measure the UIB strengths in a non-starburst galaxy, 3) to compare with luminous starburst galaxies and other 'normal' spirals, and 4) to search for environmental effects on the grain properties in galaxies, by investigating spatial variations in the UIBs across the galaxy.

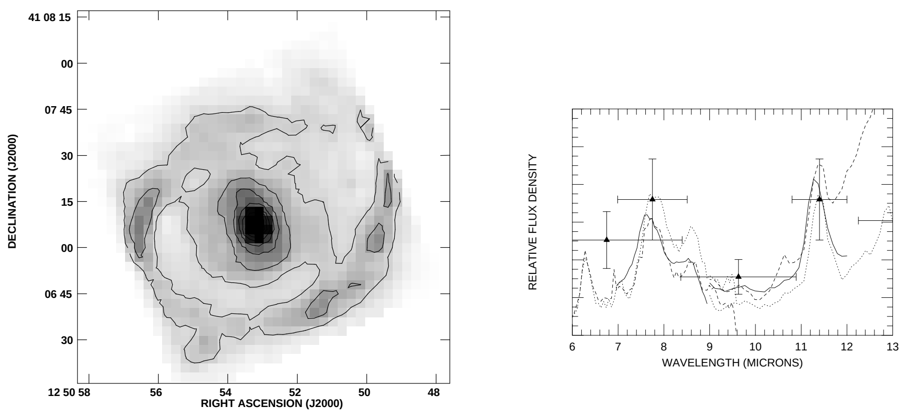


Figure 1. a) The ISOCAM 7.7 $\mu$m image of NGC 4736. b) The total sky-subtracted $7 - 12$ $\mu$m spectrum of NGC 4736 (solid curve), compared with NGC 7331 (filled triangles; Smith 1998) and two regions in the Antennae (hot spot, dashed curve; NGC 4038 nucleus, dotted curve; Vigroux et al. 1996).

Our target galaxy NGC 4736 (Table 2) is a nearby 'normal' Sab galaxy with a moderate far-infrared luminosity. It has a circumnuclear ring of H II regions (Pogge 1989) surrounding an optically-bright bulge with a 'post-starburst' stellar population (Walker et al. 1988) and a 'LINER' nucleus (Heckman 1980).

The details of our ISO observations are given in Table 1.

## 2. The Mid-Infrared Morphology of NGC 4736

Our ISOCAM images of NGC 4736 (Figure 1a) show *a prominent central bulge* with FWHM $\sim 7''$ (230 kpc), smaller than the optical and far-infrared sizes (Smith et al. 1991, 1994). This bulge contains 30% of the mid-infrared flux of NGC 4736, similar to the far-infrared percentage (Smith et al. 1994). Figure 1a also shows *a circumnuclear ring* of radius $\sim 45''$ (1.3 kpc) coincident with the far-infrared (Smith et al. 1991, 1994) and H$\alpha$ (Pogge 1989) rings. This structure may mark the Inner Lindblad Resonance (ILR) (Schommer & Sullivan 1976).

The 'ring+bulge' mid-infrared morphology of NGC 4736 is similar to that seen in other 'normal' galaxies: M 31, the Milky Way, and NGC 7331. However, there are some important differences (Tables 2 and 3). *NGC 4736's ring is smaller than the other three.* The bigger bulge of NGC 4736 may affect the ILR's location. The NGC 4736 bulge has a larger fraction of total L(MIR) and L(FIR), perhaps because of the more prominent bulge and a younger stellar population. Note that the bulge of the Milky Way is not very mid-infrared luminous compared to these other bulges. Thus, if viewed from outside, the Milky Way would probably also be classified as a LINER/quiescent galaxy.

Table 1. Details of the ISO Observations

| | |
|---|---|
| **Dates:** | 1996 June 24 and 25 |
| **Telescope:** | 0.6m Infrared Space Observatory (ISO) Telescope |
| **Instrument:** | 32 × 32 element Mid-Infrared Camera (ISOCAM) |
| **Mode:** | Circular Variable Filter (CVF) |
| **Pixel Size:** | $3''$ |
| **Field of View:** | $96''$ |
| **Wavelength Range:** | 7 − 12 $\mu$m |
| **Step Size:** | 0.056 − 0.10 $\mu$m |
| **Resolution:** | 0.18 − 0.30 $\mu$m |
| **Exposures/Step:** | ten (7 − 9.2 $\mu$m); two × seven (9 − 12 $\mu$m) |
| **Time/Exposure:** | 10 seconds |
| **Positions Observed:** | Center; $8'$ South (Sky Position) |

Table 2. 'Normal' Spiral Galaxies with Mid-Infrared Rings

| **GALAXY** | **DISTANCE** | **L(FIR)** | **TYPE** | **Ring Radius** |
|---|---|---|---|---|
| *NGC 4736* | 6.3 Mpc | $5 \times 10^9$ L⊙ | Sab | 1.3 kpc |
| *NGC 7331* | 15 Mpc | $1.8 \times 10^{10}$ L⊙ | Sb | 3.3 kpc |
| *M31* | 0.69 Mpc | $1.7 \times 10^8$ L⊙ | Sb | 9 kpc |
| *Milky Way* | – | $1.1 \times 10^{10}$ L⊙ | Sbc | 5 kpc |

Table 3. Properties of the Bulges of Selected Galaxies

| **GALAXY** | $\mathbf{L}_{FIR}$[a] (L⊙) | $\mathbf{L}_{12}$ (W/Hz) | **Bulge/Total** (12 $\mu$m) | $\mathbf{L}_{12}/\mathbf{L}_K$ | $\mathbf{M}_{H_2}$[b] (M⊙) |
|---|---|---|---|---|---|
| *NGC 4736* | $1.4 \times 10^9$ [c] | $7.8 \times 10^{21}$ [d] | 30%[d] | 0.9 [d] | $10^8$ [e] |
| *NGC 7331* | –[f] | $1.6 \times 10^{21}$ [g] | 2% [g] | 0.2 [g] | $\leq 10^8$ [g] |
| *M31* | $2 \times 10^7$ [h] | $2.9 \times 10^{20}$ [h] | 2%[h] | 0.09[h] | $\leq 3 \times 10^7$ [i] |
| *Milky Way* | $3.3 \times 10^9$ [j] | $4.5 \times 10^{20}$ [j] | 8% | – | $2 \times 10^8$ [k] |

[a]$L_{FIR} = 3.65 \times 10^5 (2.58\ F_{60} + F_{100}) D^2$, where $F_{60}$ and $F_{100}$ are in Jy and D is in Mpc. [b]Assuming the Galactic $I_{CO}/N_{H_2}$ ratio (Bloemen et al. 1986). This is controversial in the bulges of galaxies, so these values are for comparison only. [c]Smith et al. 1994. [d]This work. [e]Gerin et al. 1991. [f]The bulge is unresolved from the ring in the far-infrared with the KAO (Smith & Harvey 1996). [g]Smith 1998. [h]Soifer et al. 1986. [i]Dame et al. 1993. [j]corrected for extinction, from Sodroski et al. 1997. [k]Scoville & Sanders 1987.

## 3. The Mid-Infrared Spectral Energy Distribution of NGC 4736

The 7 − 12 $\mu$m spectrum of NGC 4736 (Figure 1b) shows that *the UIBs are prominent in NGC 4736.* In contrast, the spectrum of the nearby sky is featureless, consistent with zodiacal light. *The 7 − 12 $\mu$m spectrum of NGC 4736 is similar to that of the Antennae and NGC 7331*, except at 12 $\mu$m, where the Antennae 'hot spot' has enhanced emission. *The UIBs are detected throughout the galaxy*, therefore there is no large-scale destruction (i.e., 200 pc scale) of the UIB carriers in the ring of H II regions, and the older stars in the bulge are sufficient to excite these grains. *No short-wavelength excess is seen in the bulge*, thus photospheric light is not a major contributor there. This is in contrast to the M31 and NGC 7331 bulges, where starlight is important in the mid-infrared (Soifer et al. 1986; Smith 1998). This may be due to more ISM and younger stars in the NGC 4736 bulge (note the larger 12 $\mu$m/K ratio).

## 4. Summary

Our ISOCAM mid-infrared images of NGC 4736 show a prominent bulge surrounded by a circumnuclear ring. The 'unidentified' mid-infrared dust features are present in both the 'post-starburst' bulge and in the star-forming ring. The older stars in the bulge are therefore sufficient to excite the 'macromolecules' producing these bands, and furthermore, the ultraviolet radiation field in the ring is not energetic enough for large-scale destruction of these particles. These results provide limits on the composition and excitation of these particles.

**Acknowledgments.** We thank the ISO team for making these observations possible. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by JPL under contract with NASA. This work was supported by ISO data analysis funding from NASA.

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