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SPATIALLY-RESOLVED MID-IR SPECTROSCOPY OF NGC 1068

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RESUMEN

Presentamos espectros espacialmente resueltos, cercanos al límite de difracción, de 10 μm, del núcleo de la galaxia Seyfert 2 NGC 1068. Estos revelan variaciones notables en la pendiente del contínuo, el perfil y la profundidad del rasgo de silicato, y flujos de líneas de estructura fina en escalas de subsegundos de arco, que ilustran en detalles sin precedente la complejidad de las regiones circunnucleares de esta galaxia en longitudes de onda del IR medio. Las imágenes de adquisición muestran dos componentes distintos: una fuente brillante compacta (radio < 15 pc) dentro de los 0.4 segarc centrales, identificada con el toro obscurecedor de AGN, y una emisión extendida, de brillo más bajo proveniente del polvo de los conos de ionización. El espectro observado de la fuente compacta se compara con modelos de toro grumoso, siendo ésta la primera comparación detallada de estos modelos con observaciones. Los modelos requieren que la mayor parte de las nubes se localice dentro de unos cuantos parsecs de la máquina central, lo cual concuerda muy bien con observaciones interferométricas recientes del IR medio. Sin embargo, el flujo del IR medio medido con aperturas mayores de alrededor de 1 segarc está dominado por la emisión de polvo procedente de los conos de ionización. Muchos de los intentos previos para determinar la distribución de la energía espectral del toro estarán probablemente afectados por la contaminación procedente de la emisión extendida, lo cual pone de relieve la importancia que la resolución espacial tiene para estudios IR de AGN cercanos.

ABSTRACT

We present spatially-resolved, near-diffraction-limited 10 μm spectra of the nucleus of the Seyfert 2 galaxy NGC 1068. The spectra reveal striking variations in continuum slope, silicate feature profile and depth, and fine structure line fluxes on subarcsecond scales, illustrating in unprecedented detail the complexity of the circumnuclear regions of this galaxy at mid-IR wavelengths. The acquisition images show two distinct components: a compact (radius < 15 pc), bright source within the central $0.4'' \times 0.4''$ ($\approx 30 \times 30$ pc), identified with the AGN obscuring torus, and extended, lower brightness emission from dust in the ionization cones. The observed spectrum of the compact source is compared with clumpy torus models, the first detailed comparison of such models with observational data. The models require most of the clouds to be located within a few parsecs of the central engine, in good agreement with recent mid-IR interferometric observations. However, the mid-IR flux measured with apertures larger than about $1''$ is dominated by the dust emission from the ionization cones. Many previous attempts to determine the torus spectral energy distribution are thus likely to be significantly affected by contamination from the extended emission, highlighting the importance of spatial resolution in IR studies of nearby AGN.

Key Words: **GALAXIES: ACTIVE**

1. INTRODUCTION

The unified model of AGN, with its torus of dusty material, brought much-needed order to the AGN zoo, and the detection of broad emission lines in polarised light in several Seyfert 2 galaxies demonstrates the basic validity of the model. However, questions remain as to the nature of the torus (its origin, composition, size, geometry...) and to the extent to which it can really account for the differences between AGN of types 1 and 2. Here we summarise results from spectroscopy at approx. $0.4{\times}0.4''$ resolution of the nucleus of NGC 1068, taken with Michelle, the mid-IR imager and spectrometer on Gemini North, which allow us to address some of these issues and which demonstrate the utility of high-spatial-resolution mid-IR observations of nearby galaxies. The full data set, together with

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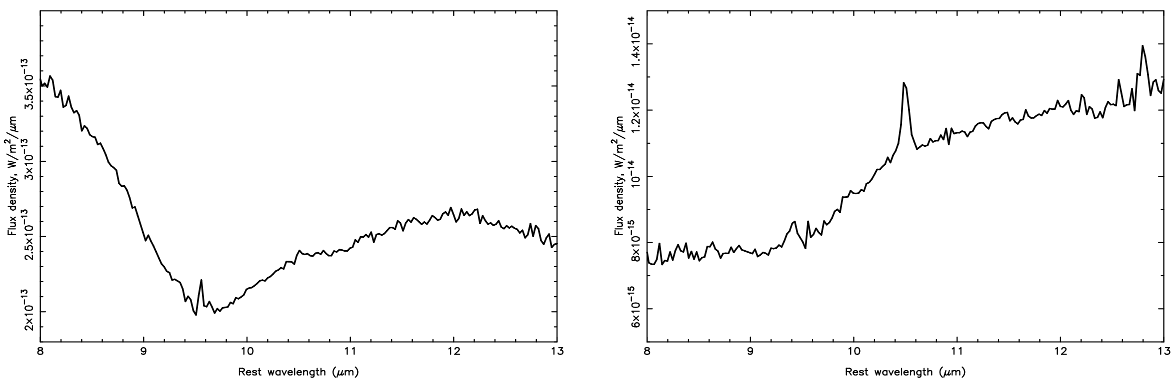

Fig. 1. Spectra of two 0.4 x 0.4″ regions in the nucleus of NGC 1068, centered 1.2″apart. The full data set is presented in Mason et al. (2006).

mid-IR imaging, model fits and UKIRT/CGS4 5 μm spectroscopy, is presented in Mason et al. (2006).

2. SPECTRA AND MODEL FITS

While we find a moderately deep silicate absorption feature at the position of the nucleus, in agreement with previous larger-aperture spectra and the predictions of the unified model, the shape of the spectra vary considerably on subarcsecond scales (Figure 1). This variation is seen in the silicate feature profile and depth, continuum spectral slope and emission line strength and shows that the nucleus of this galaxy is every bit as complex in the mid-IR as at shorter wavelengths.

A comparison of photometry in various apertures on the 11.6 μm acquisition image shows that the central point source, which we identify with the torus, contributes <30% of the flux measured in a 1.2″ aperture, with the rest of the mid-IR emission arising in structures coincident with the ionisation cones. This implies that determinations of AGN torus properties based on large-aperture data are likely to suffer serious contamination from dust heated by the AGN but not associated with the torus itself. However, the surface brightness of the central unresolved source is much higher than that of the surrounding regions, suggesting that 10 μm observations of NGC 1068 on ∼0.4″ scales are dominated by the torus.

We compare the nuclear spectrum and SED of NGC 1068 with the clumpy torus models of Nenkova et al. (2002; Figure 2), and are able to achieve good fits to subarcsecond-aperture thermal-IR data from the literature. The models predict that most of the torus clouds are within a few pc of the central engine, in good agreement with 10 μm interferometric observations of NGC 1068 (Jaffe et al. 2004) and

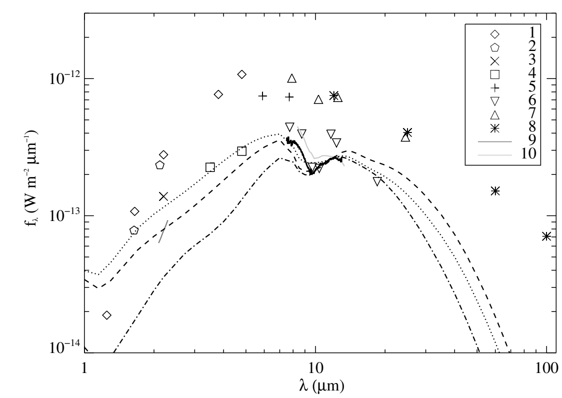

Fig. 2. Fit of the Nenkova et al. (2002) clumpy torus models to the SED and nuclear 10 μm spectrum of NGC 1068. The fit to the small-aperture data is good, but the <1″-aperture data are comtaminated by non-torus emission.

single dish images of an increasing number of nearby AGN (e.g. Packham et al. 2005; Prieto et al. 2005; Radomski et al. 2003).

The wealth of detail revealed by these observations emphasizes how ground-based mid-IR observations form an essential complement to sensitive but large-aperture Spitzer measurements of extragalactic objects.

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