Galaxies in the infrared

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Abstract

The mid infrared spectra of the starbursts show the 9.7µm silicate absorption feature and strong mid infrared emission bands centered at 6.2, 7.7, and 11.3 µm. Illustrative models of the active galaxies are presented: As the starbursts are most likely confined to the central region of the galaxy the radiative transfer in the nucleus is solved under the assumption of spherical symmetry. The distribution of stars and dust are adjusted until the complete infrared spectrum of the galaxies are modeled. The dust is described as a mixture of large grains, very small grains and PAH, which are undergoing temperature fluctuations. Although the galactic nuclei are deeply hidden in the dust its global structure can be estimated by the simple calculations presented.

ISOPHOT samples of eleven active galaxies and seven inactive spirals are presented. The far infrared and submillimeter spectrum of the active galaxies can be described by a single modified black-body at a color temperature of 31.5±2.8 K. This leads to a ratio of infrared luminosity to gas mass, $L_{\text{IR}}/M_{\text{gas}}$, of $\sim 90 \text{L}_{\odot}/\text{M}_{\odot}$. In contrast, the spectral energy distributions of inactive spirals require, apart from warm dust of 31.8±2.8 K, an additional very cold component of at most 12.9±1.7 K. This implies a $L_{\text{IR}}/M_{\text{gas}}$ ratio of $\sim 3 \text{L}_{\odot}/\text{M}_{\odot}$ for the inactive spirals, a factor $\sim 30$ lower than for the active galaxies. The detection of such cold dust can be predicted by radiative transfer models.

Key words: Dust, radiative transfer, active galaxies, spirals

1 Introduction

Star formation in external galaxies are intimately linked to questions concerning galaxy formation and evolution. Of particular interest are galaxies with star bursts. Because formation is taken place in interstellar clouds, the UV and optical stellar light is re-processed into infrared photons and it is necessary to observe at infrared/millimeter wavelengths and interpret the observations by dust and radiative transfer models.
2 Dust model

A two component model of the dust in the interstellar medium (Siebenmorgen & Krügel, 1992) has found some success in the last years. This model computes the emission per unit mass of dust heated by radiation of known intensity and spectral distribution. The dust consists of a mixture of large grains, very small grains and organic molecules. We assume here that the molecules are polycyclic aromatic hydrocarbons (PAH), though other band carriers have been suggested (e.g. Sakata et al. 1984, Duley 1988, Papoular et al. 1989). To consider somehow the shape of the bands a Lorentzian profile with some damping constant was suggested by Siebenmorgen et al. (1998). Such a simple oscillator model can account for observations taken at moderate spectral resolution. One typical example demonstrating the importance of PAH in the mid infrared as well as of large grains but in the far IR is shown in Fig.1.
Fig. 1. Observations vs. radiative transfer models for the starburst galaxies Mkn 496, Mkn 1116 and NGC 6000. Left: Our P=40 data and the 12µm IRAS point (big square). Right: ISO photometry (circles), IRAS fluxes (squares). At 1.3 mm, the points for both Markarians refer to an 11' beam (Chini & Krügel, priv. communication); for NGC 6000 at 1.3 mm to a 24' beam and at the two submm wavelengths to ~18' beams (Chini et al. 1995). The models refer to a 24' diaphragm.
3 Radiative transfer model

The galactic nuclei are deeply hidden by dust so that it necessary to carry out radiative transfer calculations in some form of approximation. We applied the numerical code by Krügel & Siebenmorgen (1994) which considers in a consistent computation also a distribution of stars in the galactic nuclei. Because some of the massive stars are so luminous each immediate environment of an OB star presents a hot spot where the dust temperature has a local peak. At those hot spots the heating of the dust is dominated by the stars while outside the hot spots the dust is heated by the interstellar radiation field (ISRF). In Fig.2 we present some of our ISO data together with submillimeter observations. The data are fit quite well with the dust and radiative transfer model described above. In particular note the strong silicate absorption best seen in the log-log diagrams. The silicate absorption feature is quite difficult to be recognized from the PHT-S data alone.

For all galaxies the model parameters give some tentative description of the nucleus and its structure (Siebenmorgen et al. 1999a). However, one should also not forget about its limitations: Computations are done in a broken three dimensional but still spherical grid. The real configuration of the nucleus is evidently not spherical so that the structure of the model becomes oversimplified on scales smaller than 400 pc.

4 FIR/mm continuum emission of galaxies

The far IR emission of the starburst galaxies presented in Fig.2 are well fit by a single modified black body at about 32K. Siebenmorgen et al. (1999b) have studied the far IR/mm emission of another sample of 8 galaxies extracted from the Markarian Catalog (Gardner 1995). All of them show a similar FIR/mm spectral energy distribution. The spectral energy distribution of the inactive galaxy UGC2936 is shown Fig.3. Our best fit which is constrained by ISO, IRAS and IRAM data reveals the presence of second component. We need to employ a 29.9K cold and a 12.8K very cold dust component.

Our multi-filter far IR photometric study of 7 spirals shows that at least two dust components are needed to account for the spectra. Beside a cold dust component of about 32K an additional component of very cold dust of about 12K is present. A simple average over all Markarian and another average over all inactive galaxies of our ISO sample give us generic spectra for both types of galaxies. They are shown in Fig.4. Siebenmorgen et al. (1999b) therefore confirm the original claim by Krügel et al. (1998) of the existence of such an additional component of very cold dust in spiral galaxies. Determining the
gas mass from 1.3mm dust continuum maps that cover the optical extent of the inactive spirals we find a ratio of total infrared luminosity to gas mass $L_{\text{IR}}/M_{\text{gas}} \sim 3 \, L_\odot/ M_\odot$, which is a factor 30 lower than found for the Markarian galaxies. This demonstrates that the $L_{\text{IR}}/M_{\text{gas}}$ ratio can be used as a discriminator of the activity type of a galaxy.

**Question:** P. Barthel
Could it be that cold dust is present in the MKN galaxies but warm dust is just swamping it?

**Answer:**
Both galaxy samples are at about similar distance scale and have been observed with the same instrument sensitivities. The (very) cold dust can be best studied in the submillimeter. There is no or only marginal evidence for source extension at 1.3mm for the Mkn sample whereas the spirals have similar extension as the optical diameter. Therefore the observations do not give evidence of a very cold dust component for the active sample but for the spirals.
Fig. 4. Generic spectra calculated as a simple average over our ISO sample of Markarian (top) and spirals (bottom). The FIR/mm emission of the Markarian galaxies can be fit by a single modified black body. However, for all spirals an additional very cold dust component is needed to fit the observations. The derived $L_{\text{IR}}/M_{\text{gas}}$ ratio can be used as a good discriminator of the activity type of a galaxy.

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