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On dust, beaming and orientation

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Abstract. In this paper we present results from ISOPHOT and IRAM observations of two small samples of radio-loud active galaxies. The ISOPHOT data were obtained to study the far-infrared output of radio galaxies and quasars of comparable radio loudness. The IRAM data provide information about the amount of relativistic beaming at infrared and millimeter wavelengths. We find that the infrared emission is dominated by thermal dust emission, whereas the millimeter emission is mostly synchrotron radiation. Also, the quasars are brighter in both spectral ranges. For the millimeter range relativistic beaming is the obvious explanation, but for the infrared excess in quasars there are several possibilities. Due to the small sample, we cannot distinguish between them.

1. Introduction

Unification theories predict that double lobed radio quasars and radio galaxies are similar objects, observed at different lines of sight. An obscuring dust torus causes them to have similar radio structures, but different optical appearances (Barthel 1989). The torus aborbs the soft X-rays and UV radiation of the central core and re-emits this in the infrared. Models for this process predict that the dust becomes optically thin in the wavelength range of 60 to 100 μm (Pier & Krolik 1992). Combining this result with the unification model, it predicts that quasars and radio-galaxies of comparable radio power should emit comparable far-infrared power. Previous studies with IRAS have shown that quasars are intrinsically brighter than radio galaxies (Heckman et al. 1992). However, in that sample the emitted wavelenghts are all below 40 μm, due to the large redshift (average of 0.9). In this mid-infrared range the dust is still optically thick, and thus the observed flux depends on the orientation of the object. As a consequence, quasars can be a factor of two up to orders of magnitude brighter than radio galaxies in the mid-infrared.

We obtained ISOPHOT observations of four matched pairs of one quasar and radio-galaxy each, in order to make a direct comparison. The pairs are matched in radio power at 178 MHz and redshift. Since these objects are radio loud, there could be a significant contribution to the far-infrared from relativistically beamed non-thermal emission, especially in the quasars. In order to estimate this contribution, we have obtained short wavelength VLA radio data for the quasars and MAMBO 1.2 mm data with the IRAM 30 m telescope for a mixed sample of objects. Extrapolation of the radio-millimeter spectrum to the infrared enables us to estimate the contribution of non-thermal emission to the infrared.

2. Results from ISOPHOT observations

ISOPHOT data were obtained at 60, 90 and 160 μm and reduced with the software package PIA8.0. In combination with the VLA centimeter observations, we find that in all cases the infrared emission is dominated by thermal emission from dust. In all of the eight objects in this sample we find that a single black-body or grey-body fit does not match all three datapoints, which indicates that there might be more than one component of dust present in these objects. In Seyfert galaxies this was shown to be the case (Rodriguez-Espinosa et al. 1996), as well as in many other local active galaxies (Haas et al. 1998).

The results from ISOPHOT are displayed in Fig. 1. It can be clearly seen that in two of the pairs (3C 334 & 3C 19, and 3C 351 & 3C 42) the quasar is significantly brighter in the infrared than the matched radio galaxy. In the pair 3C 323.1 and 3C 460 the radio galaxy has an anomalously high 160 μm flux, which might be due to the presence of a nearby compation, but the quasar is still brighter at shorter infrared wavelengths. In the last pair 3C 277.1 and 3C 67 there is no difference.

3. Results from IRAM observations

IRAM 30 m telescope observations were obtained with the MAMBO instrument, which has a peak sensitivity at 1.2 mm. The sample consisted of a mix of narrow-line radio galaxies, broad-line radio galaxies, quasars and one unidentified object which we will refer to as 3C 59. Reduction was done with the MOPSI package in Bonn. The 1.2 mm flux is always the lowest in the radio–infrared range, it even lies below an extrapolation of the radio

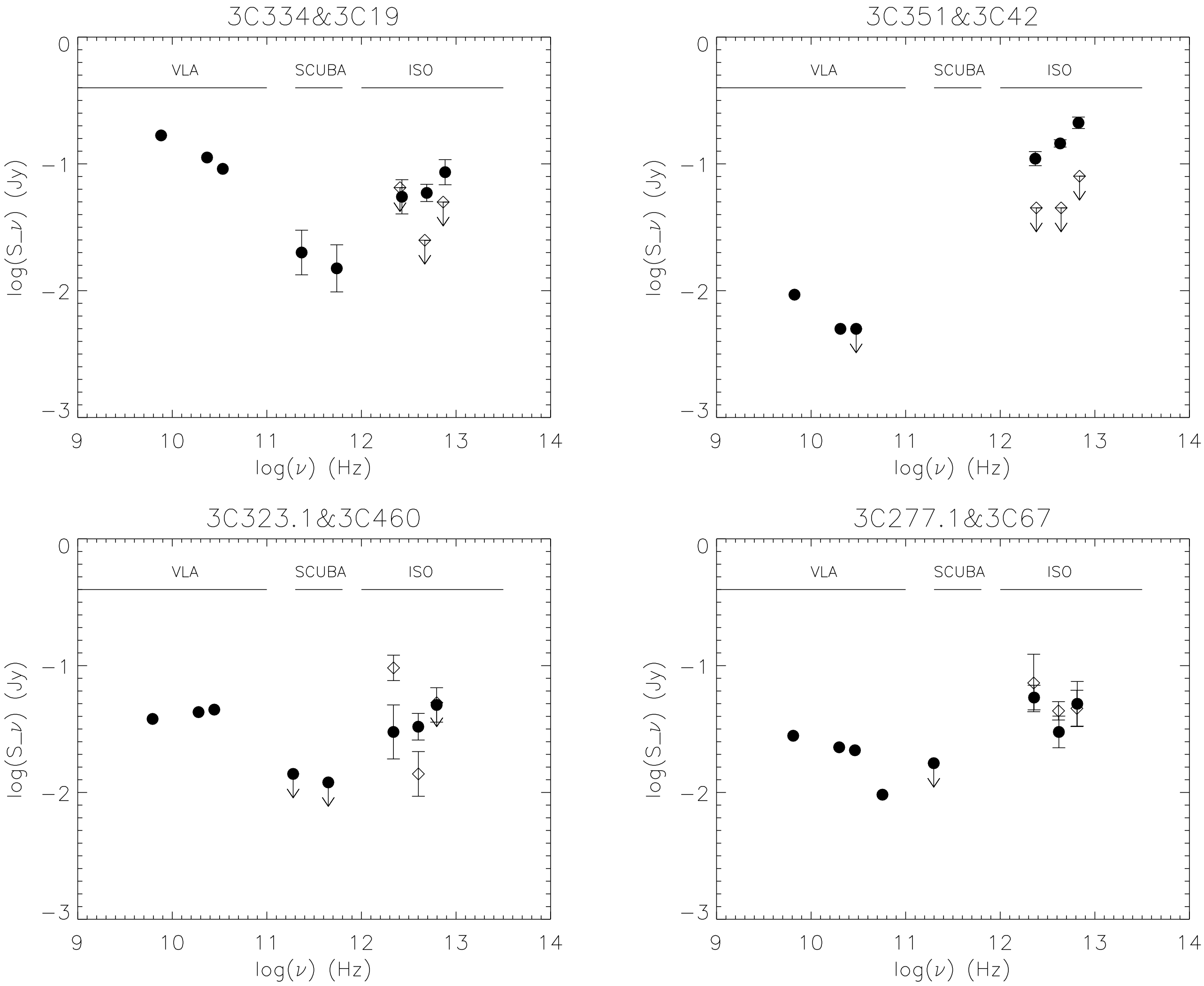

Fig. 1. Spectral energy distributions in restframe for the four matched pairs. The quasar is always the first mentioned in the title. Filled circles are quasar data, open diamonds are radio galaxy data. For some quasars we have additional SCUBA observations at 2 mm and/or 850 μm.

data to millimeter wavelengths. However, if the radio spectrum declines faster than indicated by the radio data, the 1.2 mm point could be the beginning of a rising slope to the far-infrared and thus be due to thermal emission from very cold dust. The 160 μm point has been fitted with a 20 K grey-body to show that the 1.2 mm flux is not due to cold dust, the IRAM point lies well above the extrapolation. Only in RBS 0281 and 3C 460 a contribution from cold dust is present, but not more than 30% of the observed 1.2 mm flux. Therefore, in this sample the 1.2 mm emission is dominated by synchrotron emission and not by cold dust, as observed in radio-quiet active galaxies and starbursts.

In Fig. 2 we show the spectral energy distributions of this sample. The quasars (3C 277.1, 3C 323.1 and 3C 334) stand out, since they seem to have less steep mm–infrared slopes than the radio galaxies. When we compare the luminosities, the quasars are a factor of 3 brighter than the radio galaxies. The infrared luminosities are comparable, and the radio luminosities at 178 MHz are a factor of 1.5 higher for the quasars. This last factor should remain constant in the case of non-beamed synchrotron emission. The fact that it increases with wavelength indicates a contribution of beamed emission, which reaches ~50% at 1.2 mm in the quasars.

When we extrapolate the non-thermal spectrum to the infrared points (dashed line in the plot), the result is that the contribution of beamed synchrotron emission to the far-infrared is negligible in all objects, with a maximum of 10% beamed infrared emission in 3C 277.1. This is not enough to explain the far-infrared excess in quasars as observed with ISOPHOT. For more details, see van Bemmel & Bertoldi (2001).

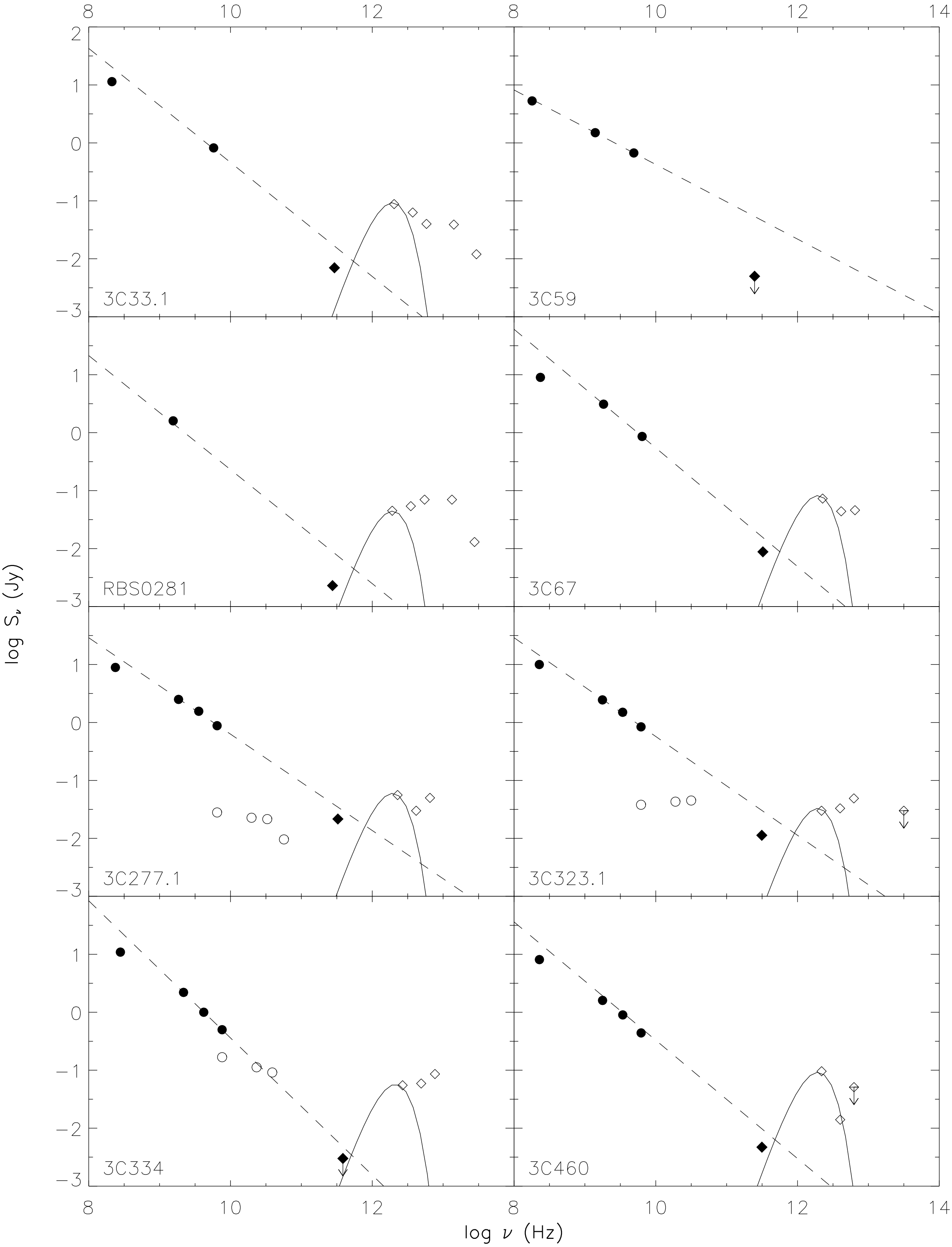

Fig. 2. Spectral energy distributions in restframe of the IRAM sample. The filled diamond is the IRAM point. Narrow-line radio galaxies are 3C 33.1 and 3C 460, broad-line radio galaxies are RBS 0281 and 3C 67, quasars are 3C 277.1, 3C 323.1 and 3C 334. 3C 59 is an unidentified extragalactic radio source. The dashed line is a least squares fit to the highest frequency VLA points, assuming an average slope for the objects with not enough points. The solid line is a grey-body fit of 20 K to the 160 μm point. Open circles are radio core fluxes, which are discussed in detail by van Bemmel & Bertoldi (2001).

4. Discussion

4.1. Infrared excess in quasars

There are several explanations for the observed far-infrared flux difference in three of four pairs. Three quasars in these pairs have significantly larger radio structures than their matched radio galaxies, which implies a more powerful central source by a factor of 2, even if the pairs are matched in radio power (Kaiser et al. 1997). This would be consistent with the observed flux differences with ISOPHOT. In addition there might be environmental factors that play a role in the size of the objects; smaller radio sources could be hosted in a denser environment. Also evolution can play a role, the pair 3C 277.1 and 3C 67 consists of compact steep spectrum sources (CSS), which are believed to be younger than their larger counterparts (Murgia et al. 1999). Remarkably, this is the only pair where the quasar and radio galaxy are indistinguishable, which could point to an evolution in dust geometry from a more spherical distribution in young sources to a flat disk in older ones. Also, the optical thickness of the dust could still be important at these far-infrared wavelengths. For more details see van Bemmel et al. (2000).

In theory, there is still the possibility that the far-infrared emission is affected by non-thermal radiation. However, if there is synchrotron radiation at $160\,\mu$m this should come from an extremely young electron population. This plasma has to be very close to the center, and is therefore strongly beamed. In both samples the quasars should then be very much brighter in the far-infrared, which is contradicted by the observations.

4.2. Millimeter excess in quasars

There are two possibilities to explain the excess of millimeter emission in quasars. First there could be an additional dust component in the quasars, which is not observed in the radio galaxies. This possibility is hard to justify in the light of unification schemes. Dust is always optically thin at millimeter wavelenghts, so it should be visible in both radio galaxies and quasars. The second possibility is that there is an additional component of non-thermal emission. The quasars are slightly more luminous than the radio galaxies at longer wavelenghts, but not enough to explain the difference at 1.2 mm. Relativistic beaming is the only way to create an orientation dependend excess at this wavelength.

4.3. Determining the orientation of a source

If the relativistic beaming in quasars is confirmed in larger samples, this can provide a unique test of the orientation of a source. Since the strength of the observed beamed compenent depends strongly on orientation of the beam, millimeter observations in combination with radio observations will allow us to determine the amount of beaming, and thus the viewing angle. There are no optical depth effects at these wavelenghts, so there can be no hidden components that contribute to the millimeter flux.

5. Summary

We have shown that quasars are brighter than radio galaxies, both in the millimeter and in the far-infrared. However, the emission at these wavelengths is due to different processes. The millimeter emission is dominated by non-thermal synchrotron radiation, and the excess in quasars is most likely due to an additional beamed component. This component provides a possibility to measure the orientation of the source direct, since the observed amount of beamed emission depends on the orientation of the source on the sky.

The infrared emission on the other hand, is due to the thermal emission from dust. The dust absorbs and re-emits the soft X-rays and UV radiation from the central source. The excess in quasars could be due to the radio size difference in our sample, but might also be related to internal differences in the dust geometry. Also optical thickness effects could still play a role, if the dust is optically thick up to $100\,\mu$m.

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