

The broad-line radio galaxy story

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Abstract

In this paper I discuss the issue of the so-called $25\mu\text{m}$ -peakers, which were discovered with IRAS, and consist almost solely of broad-line radio galaxies. I find that this peak is caused by the absence of colder dust that emits at $60\mu\text{m}$ and not by an excess of hot dust, as suggested by the name. On optical images, the $25\mu\text{m}$ peakers show a lack of extended dust. The peakers are consistent with being in a later evolutionary stage, in which all the extended dust has been formed into stars and the dust torus is smaller. If the $60\mu\text{m}$ dust is heated by stars, there might be a correlation between the star-formation rate and the power of the AGN.

Key words: galaxies: active, galaxies: infrared, quasars: infrared, galaxies: ISM

1 A prelude

The first galaxies with nuclear activity were studied in detail by Seyfert in the 1940's (Seyfert 1943). Now, over 50 years later, their numbers have increased by several orders of magnitude, revealing a rich diversity. In their attempt to reach a physical understanding of active galaxies, people have proposed unified schemes (e.g. Barthel 1989), which combine several apparently different classes into one, depending on the orientation of a central symmetry axis. A dusty torus causes anisotropy at wavelengths where the dust is optically thick, but is transparent to hard X-rays and radio emission. This easily explains many differences between Seyfert 1 and Seyfert 2 galaxies, and also between radio galaxies and radio quasars. However, there are many open questions, e.g. the presence and nature of type 2 radio-quiet quasars, the absence of broad emission lines in some objects (e.g. Hill et al. 1996). In this paper I will study one specific problem, that of the $25\mu\text{m}$ peakers. These are broad-line radio galaxies (BLRGs) which have a clear peak in their spectral energy distribution around $25\mu\text{m}$, whereas all other radio-loud AGN have this peak at longer wavelengths ($60\text{--}100\mu\text{m}$).

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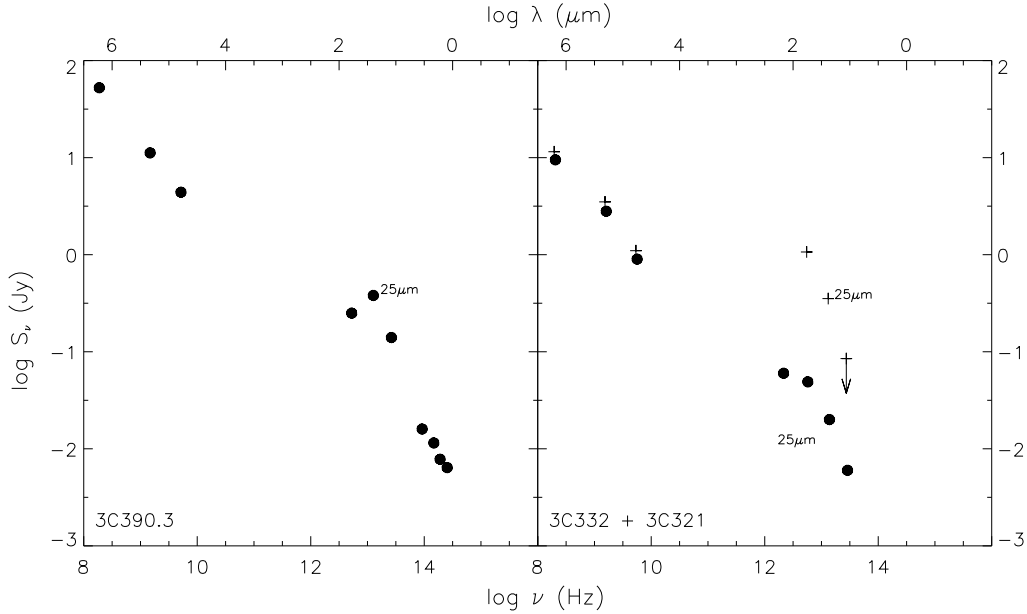


Fig. 1. The SED in restframe for the BLRG 3C 390.3 (peaker), and the SEDs of BLRG 3C 332 (filled circles) and NLRG 3C 321 (plusses), both non-peakers. The $25\mu\text{m}$ points are marked in the plot.

2 The problem starts

The properties of the obscuring torus have been modeled by Pier & Krolik (1992) and Granato & Danese (1994). Both groups conclude that the dust should be optically thin in the far-infrared, at wavelengths larger than $\sim 80\mu\text{m}$. Combining this result with the unified models, one can predict that narrow-line radio galaxies (NLRGs) and radio quasars (QSRs) of comparable radio power should emit comparable far-infrared power. No conclusive result was reached when comparing NLRGs and QSRs in the far-infrared, either with IRAS (Heckman et al. 1994), or with ISO (van Bemmelen et al. 2000). However, one would expect the general shape of the far-infrared SEDs to be the same for all objects that belong to one class, which is true for NLRGs and QSRs.

Broad line radio galaxies were discovered and classified first in the 1960's, when the first radio surveys were done. They are typically galaxies with a bright nucleus and extended radio structures (like NLRGs), but a quasar spectrum in the optical. In the light of unified models, there seems to be an easy way to fit them in; BLRGs can simply be intermediate angle quasars. The dust torus is seen at an angle that just obscures the central source (and therefore enables us to see the host galaxy), but part of the broad-line region is un-obscured.

As discussed above, one would expect that the infrared SEDs are the same for NLRGs, BLRGs and QSRs. However, there is a group of BLRGs which have a peak in their SED at $25\mu\text{m}$, instead of $60\text{--}100\mu\text{m}$ as in NLRGs and QSRs (see Fig. 1). This seems to be in contradiction with expectations of the unification schemes, unless these $25\mu\text{m}$ peakers are somehow different. So far no NLRGs or QSRs are known with a clear peak in their SED at $25\mu\text{m}$.

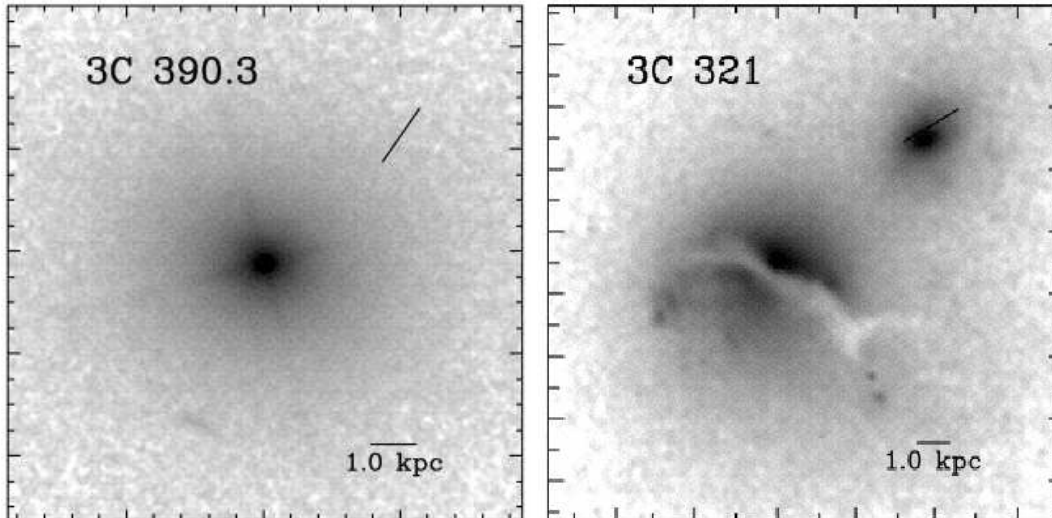


Fig. 2. Optical HST images of 3C 390.3 and 3C 321. The black lines indicate the radio axis and the image scale (de Koff et al. 1996).

3 Searching for clues

Data were obtained for a limited sample of BLRGs with ISOPHOT on board ISO (Lemke et al. 1996, Kessler et al. 1996), in the bands 12, 25, 60, 90 and $160\,\mu\text{m}$, using the P1, P2, C1 and C2 detectors. The observations were made in raster mode, to avoid the known problems with chopping, which are especially serious for these faint sources. The reduction of the C1 and C2 data is described in van Bemmelen et al. (2000), and the reduction of the P1 and P2 data will be described in a future paper (van Bemmelen et al. 2001). From additional ISOPHOT and literature data, two samples were selected, one of $25\,\mu\text{m}$ peakers and one of normal NLRGs and BLRGs. Due to the limited amount of infrared data, the comparison sample consists largely of NLRGs.

Data in other spectral regimes were extracted from the NASA/IPAC Extragalactic Database (NED) and the literature. The exact references for all data will also be given in the future paper (van Bemmelen et al. 2001). The two samples are listed in Table 1, which gives their classification, infrared powers at 25 and $60\,\mu\text{m}$ and radio power at 178 MHz.

4 Lining up the facts

From here I will refer to the BLRGs with a peak at $25\,\mu\text{m}$ as the peaker sample, and the comparison sample as the non-peaker sample. For both samples literature data were studied from X-ray, optical, infrared and radio observations, with different observational techniques (imaging, photometry, spectroscopy and/or polarimetry). There are always objects lacking data, but in general there were no immediate differences to be found when comparing the average luminosities over this spectral range and the spectral shape. However, a closer

Name	ID	P_{25}	P_{60}	P_{178}	Name	ID	P_{25}	P_{60}	P_{178}
3C 33.1	B	24.41	24.36	–	3C 61.1	N	23.97	24.59	27.39
3C 98	B	23.19	<23.15	25.92	3C 79	N	24.95	25.40	27.52
3C 109	B	25.78	25.36	27.60	3C 111	B	24.01	24.16	26.20
3C 234	B	25.29	25.14	27.38	3C 321	N	24.84	25.30	26.31
3C 382	B	23.78	23.82	–	3C 327	N	24.80	25.16	26.96
3C 390.3	B	24.36	24.15	26.50	3C 332	B	23.99	24.36	26.63
3C 445	B	24.32	24.21	26.16	3C 381	B?	24.31	24.48	26.92
					3C 403	N	24.17	24.47	26.27
					3C 405	N	24.70	25.25	28.75
Average		24.45	<24.31	26.71	Average		24.42	24.80	26.99

Table 1

Luminosity densities in W Hz^{-1} for the peakers sample (left) and the non-peakers sample (right). Averages for each sample are given for comparison. The second column gives the nature of the object, B for BLRG and N for NLRG.

comparison reveals that there is no evidence at all for a peak at $25\mu\text{m}$, as suggested by the name, it rather seems that these objects display a lack of $60\mu\text{m}$ emission. This means there is less cold dust in $25\mu\text{m}$ peakers than in non-peakers.

The $60\mu\text{m}$ dust can either be heated directly by the AGN (Hes et al. 1995) or by stars; many star-burst galaxies have a peak in their SED at $60\mu\text{m}$ (Calzetti et al. 2000). This leaves two options: either the peakers have weaker AGN, so the dust is not hot enough to radiate at $60\mu\text{m}$, or there is not enough dust in the host galaxy to detect it. The first option can be tested by comparing the 178 MHz power of the two samples. Since the 178 MHz emission is isotropic, thus independent on the amount of dust in the host galaxy and the orientation of the object, the 178 MHz power should be significantly weaker for peakers. This is not confirmed in this sample.

The second option can be tested by comparing optical images. Data from the HST snapshot survey of the 3CR sample (de Koff et al. 1996) were used to compare the optical appearance of the two samples (see also Fig. 2). A blind test was done with three people to classify the galaxies as non-interacting/dust-free, interacting/dust-rich or unclear. It turned out that there is a good relation between the distortion of the host (including dust lanes) and the shape of the infrared SED. The peakers are predominantly normal, dust-free elliptical galaxies, and often reside in sparse environments. The non-peakers, however, display dust lanes (as seen in Centaurus A) and other typical signs of interaction. The dust is usually extended and often perpendicular to the radio axis, which excludes the AGN as being the dominant heating source.

5 How to solve the problem

5.1 *Unification*

With two groups of BLRGs it might seem that the unification schemes no longer apply. However, there is an historical pitfall. In the past, an active galaxy was classified as a radio galaxy when the optical galaxy was visible. When it was only a point-like source, it would be called a quasi-stellar object. The names stuck, but with present day instruments, there are many QSRs with visible host galaxies. Also, nearby quasars would have been classified as BLRG. A radio study reveals that there are indeed two groups of BLRGs, one consisting of low-luminosity quasar counterparts and another of mis-oriented quasars. Only the last group are BLRGs which fit into unified models (Dennett-Thorpe et al. 2000). In the sample with $25\mu\text{m}$ peakers, there might be more of the first group, while the comparison sample consists mostly of objects from the second group. This does not contradict unified models, but it shows that there is more to it than just orientation.

5.2 *Nuclear and extended dust*

In the HST images the peakers lack extended dust related to star-formation, but there is no clear evidence that a central torus is absent as well. The fact that the broad-line region is visible indicates that the torus could be smaller in these objects. In the classical unification schemes there might be confusion between obscuration of the central parts by a nuclear torus, or by extended dust in the host galaxy. There is no easy way to tell the difference between these two geometries, but it implies that NLRG without extended dust could appear as BLRG, irrespective of the presence of a nuclear dust torus.

5.3 *Evolution*

There might be an evolutionary link between $25\mu\text{m}$ peakers and normal BLRGs. Dust is the main fuel for both star-formation and the AGN, but there is a limited supply. Especially when the galaxy is isolated, there are no ways to re-fuel the host galaxy and star-formation will cease. When the fuel for the AGN runs out as well, one expects to see weaker emission lines and lower radio power. In addition, without extended dust, these galaxies should have little reddening and low polarization. Studies of the polarization, colors, stellar populations and X-ray absorption columns will provide more clues on the nature of the peakers.

Hes et al. (1995) show that there is a correlation between 178 MHz power and $60\mu\text{m}$ power, which would imply that the AGN heats the cold dust. However, this work indicates that in many objects the $60\mu\text{m}$ dust is related to star-formation processes, as in star-burst galaxies. Combining both results, there could be a relation between the star-formation rate in the host galaxy and the

power of the AGN. If one can confirm this relation in larger samples, it will provide important insights in the formation and evolution of both the host galaxy and the central black hole.

6 Live long and happy

From observations with IRAS and ISOPHOT I find that there is a number of BLRGs with a peak in their SED at $25\mu\text{m}$. Not all BLRGs show this behaviour, which deviates from the typical SED for NLRGs and QSRs. The peaker sample is compared with a sample of NLRGs and BLRGs which have a peak at $60\text{--}100\mu\text{m}$. I find no excess of hot dust in the $25\mu\text{m}$ peakers, but a lack of cold dust, which is the dust heated by (hot) stars. This might be related to the evolutionary state of the object, being an older NLRG in which the extended dust has been depleted by star-formation and the nuclear dust torus is smaller. The fact that two classes of BLRG seem to exist is not contradicting the unification schemes, however, it adds an important new dimension.

Finally, the name $25\mu\text{m}$ peaker should be abandoned as soon as possible, as it is misleading, but so far I have not found a good alternative.

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