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2.2 and 1300 μm observations of a complete sample of southern quasars

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Abstract. We present 2.2 and 1300 μm data of a complete sample of optically selected southern quasars. All objects have 1300 μm flux densities below $\approx$ 20 mJy (3σ), except QSO 0448 − 392 which shows a faint signal of $\approx$ 40 mJy. These results clearly indicate that previously claimed detections at Jy level must have been erroneous. The 2.2 μm data allow the determination of the spectral turnover at short wavelengths and define the spectral slope between IR and radio wavelengths. The sample can be divided into two categories of 7 radio–loud and 10 radio–quiet quasars. The radio–loud quasars have redshifts between z = 1.3 and 3.2 and their energy distributions do not differ significantly from nearby quasars; the emission from cm to mm wavelengths is due to synchrotron radiation. The analysis of the radio–quiet quasars does not show any conclusive evidence for thermal components apart from QSO 0530 − 379 where the FIR emission is probably dominated by thermal radiation from dust.

Key words: galaxies: ISM – quasars: general – infrared: galaxies – radio continuum: galaxies – radiation mechanisms: non thermal

1. Introduction

The submm regime has turned into an important spectral region for the interpretation of quasar spectra and plays a key role in distinguishing thermal and non–thermal components. One of the early experiments in submm astronomy was the attempt to detect 1 mm emission from quasars (Sherwood et al. 1981, 1982). These authors observed a complete sample of 17 optically selected southern quasars brighter than 17.6 mag and reported the detection of all objects with 1 mm flux densities above 1 Jy. From the steep, inverted spectral index between the radio range and the 1 mm data it was suggested (Sherwood, 1983) that the FIR/submm emission may be dominated by thermal radiation from dust. However, the re–observation of quasar 0420 − 388, with a claimed 1 mm flux density of 2.7 Jy, did not corroborate this result: Robson et al. 1985 obtained only a 3σ upper limit of 1.4 Jy at UKIRT. Furthermore, similar quasar samples on the northern hemisphere did not show any detectable 1 mm flux density when observed at UKIRT (Robson et al. 1985). Therefore, the results of Sherwood et al. were criticised and it was suspected that the data might have been affected by instrumental effects.

Meanwhile, *IRAS* data got available for a number of quasars (Neugebauer et al. 1986; Sanders et al. 1989a) and the controversial discussion about the origin of FIR emission ignited again. An observational breakthrough in this field has been achieved by Chini et al. (1989a), who presented 1300 μm data of all northern radio–quiet quasars in the Neugebauer et al. sample. The steep spectral turnover between *IRAS* and mm data demonstrated that thermal dust emission on kpc scale may explain most readily the observations in a satisfactory way, whereas non–thermal models have to adopt exotic electron energy distributions to explain the observed spectra (de Kool & Begelman 1989; Schlickeiser et al. 1991). The thermal interpretation was subsequently corroborated by additional submm observations (Hughes et al. 1993). It was found that in a thermal model the bulk of dust attains temperatures of about 35 K, similar to that in starburst galaxies (Chini et al. 1992). Assuming a galactic gas–to–dust ratio of $\approx$ 150 one obtains gas masses of 10^8 to 10^{10} $M_\odot$, which are also typical for gas–rich spirals. Independent HI and CO observations (e.g. Barvainis et al. 1989; Krügel et al. 1989; Sanders et al. 1989b) confirm the results with respect to the amount of gas mass in radio–quiet quasars and Seyfert galaxies and thus corroborate a thermal interpretation of the FIR/submm spectra.

When SEST got operational, we re–observed the complete sample of southern quasars from Sherwood et al. with a considerably improved sensitivity at 1300 μm. Since little NIR data exist for this prominent sample of the 17 optically brightest quasars in the southern sky, we also observed them at 2.2 μm. Nevertheless, a physical interpretation of the observations is rather difficult because the spectral information at other wavelengths is poor; in particular, apart from one object, no *IRAS* data are available for these QSOs. The major aim of this investigation

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is to improve the mm data of this quasar sample obtained almost 15 years ago and to understand the origin of the emission.

2. Observations

2.1. 1300 μm data

The MPIfR bolometer system (Kreysa, 1990) was used at the SEST during three periods from 1988 to 1990 for observations at 1300 μm; the bandpass of the system is about 50 GHz, completely within the atmospheric window. The beamwidth was 30″ (FWHM) (1988, 1989) and 24″ (FWHM) (1990). We used the standard observing procedure, i.e. offsetting the telescope from a nearby radio/mm bright quasar and performing ON–ON measurements at the position of the program quasars. Chopping in azimuth was provided by a focal plane chopper at 8.5 Hz giving two beams of 105″ (1988, 1989) and 70″ (1990) separation. Beam–switching was done in the ON–ON mode, alternating the source between the two beams after 10 s of integration time. The weighted average of 10 ON–ON pairs was recorded as one observation. The pointing was checked after each observation and turned out to be stable to within 3″. We determined the atmospheric transmission frequently by skydips. Uranus was used as calibration standard, adopting a brightness temperature of 97 K. The overall system sensitivity was often limited by skynoise; on average we obtained 450m Jy/s in 1988 and 1989. Due to an improved surface of SEST and a better coupling of our receiver to the telescope, we eventually reached a sensitivity of 200 mJy/s in 1990. The final flux densities were obtained by averaging all observations for each object, weighted by their statistical errors. Table 1 contains object designations, observed positions and averaged 1300 μm flux densities as well as redshift, visual magnitude, luminosity and spectral indices.

2.2. NIR data

The 2.2 μm data have been obtained at the 1.9 m telescope of the South African Astronomical Observatory in Sutherland during June 1990, using the MkIII facility photometer with an aperture of 9″ and a beam separation of 30″. For identification purposes we used the original charts given by Osmer and Smith (1980) and references therein. During excellent photometric conditions all objects were clearly visible on the TV–system; neighboring bright stars were used to guide the telescope during the integration time of typically 300 s, resulting in a 10% accuracy at K = 13.8 mag. We used standard reduction methods; calibration stars were taken from the list of Glass (1974). From our repeated observations we achieved a final accuracy between 0.1 and 0.2 mag, depending on the brightness of the QSOs. The 2.2 μm flux densities are also listed in Table 1.

3. Results

As shown in Table 1 only quasar 0448 − 392 has a significant 1300 μm detection of 38 (97) mJy while the remaining objects have 3σ upper limits of about 20 mJy and below. These observations exceed former attempts by at least a factor of 70 in sensitivity and thus are the most stringent mm data for this sample of quasars. They clearly rule out the former detections by Sherwood et al. (1981, 1982) which must have been due to spurious signals in the ON–OFF observations performed at the ESO 3.6 m telescope. This telescope has a large central obscuration of 0.42 (linear), which is likely to result in high side lobes. Tests at the 3.6 m telescope (Kreysa, priv. com.) showed that under unfavourable circumstances such a contribution could have significantly influenced the early quasar observations.

As mentioned in the previous section, our 1300 μm observations of the sample were performed repeatedly between 1988 and 1990. Until JD 2448135 quasar 0448 − 392 showed a 1300 μm flux density of about 38 mJy. During JD 2448143 and JD 2448144, the two final nights of our observing run in 1990, the 1300 μm flux density had increased by a factor of 2.6 to a level of 97 mJy and remained constant for 2 consecutive days. This rise in brightness must have occurred between JD 2448135 and JD 2448143. Quasar 0448 − 392 is the only object in the sample whose variability has been detected earlier by Peterson and Bolton (1972), who list this object as optically variable. We therefore can also exclude variability as a possible explanation for the detections by Sherwood et al. (1981, 1982).

Only three quasars (0122 − 380, 0420 − 388, 2204 − 408) in the sample have been previously observed at NIR wavelengths by Wright and Kleinmann (1978), Glass (1981) and Hyland and Allen (1982). These authors give for QSO 0420 − 388 2.2 μm values of 13.5 ± 0.2, 14.07 ± 0.09 and 14.40 ± 0.15 mag, respectively; our value of 14.05 mag agrees well with the result of Glass. It is unclear whether the other deviations are due to variability and/or a beam size effect or simply due to observational uncertainties. There are 2.2 μm measurements for QSO 0122 − 380 by Glass (14.47 ± 0.19 mag) and Hyland & Allen (14.67 ± 0.12 mag), which agree within the observational errors; due to time limitations we could not include QSO 0122 − 380 in our observations. Finally, QSO 2204 − 408 has been observed by Glass only, giving a 2.2 μm brightness of 14.52 ± 0.22 mag. This is comparable to our value of 15.06 ± 0.26 mag. This difference, which is still within the errors, might be due to observational uncertainties caused by the faintness of the source.

4. Discussion

According to their radio properties, we divide this optically selected sample into two distinct categories: 7 quasars are "radio–loud", i.e. their radio emission is between 20 and 800 mJy while their optical flux density is of order 0.5 mJy. Having the same optical brightness, the remaining 10 quasars are "radio–quiet" in the sense that there was no cm radio emission detected down to a level of 10m Jy. This implies that the ratio of radio–to–optical luminosity is below 10^{-3} - a sufficient condition for classification as radio–quiet. Integrating the energy emitted between 0.3 μm to 6 cm, one finds that quasars in the radio–loud group emit about ten times more energy than do objects in the radio–quiet group ($q_0 = 0.5$, $H_0 = 75\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$). Neglecting those three QSOs with redshifts below $z = 1$ (their total luminosity is $< 2 \cdot 10^{12}\ \mathrm{L}_\odot$ and thus a factor of ten below the rest of

Table 1. 2.2 and 1300 μm observations of a complete sample of southern quasars. The upper limits at 1300 μm are 3σ values. For QSO 0448 − 392 there are two 1300 μm flux densities, the latter one obtained during an outburst on JD 2448143 and JD 2448144; the errors- are 1σ statistical uncertainties; the absolute accuracy is estimated to be about 20%. C denotes the classification into radio–loud (L) and radio–quiet (Q), the spectral indices are described in the text.

QSO	RA [1950]	Dec [1950]	z	V [mag]	C	$S_{2.2}$ [mJy]	S_{1300} [mJy]	spectral indices $R-IR$	spectral indices $IR-X$	L [10^{12} $L_\odot$]
0002 − 422	00 02 15.9	−42 14 07.0	2.758	17.21	L	0.60	< 12.6	−0.38		149.0
0122 − 380	01 22 02.2	−38 00 04.0	2.181	16.5	Q		< 14.4	> −0.19	−1.12	20.0
0125 − 400	01 25 39.1	−40 01 03.0	1.39	17.1	Q	0.51	< 18.0	> −0.24		4.4
0130 − 403	01 30 50.5	−40 21 54.0	3.015	17.02	Q	0.84	< 15.9	> −0.23		33.1
0205 − 379	02 05 20.6	−37 56 12.4	2.42	17.4	L	2.35	< 15.9	−0.24	−1.32	84.9
0207 − 398	02 07 24.3	−39 53 50.0	2.805	17.15	Q	0.55	< 17.7	> −0.27	−1.14	24.8
0254 − 404	02 54 39.1	−40 24 59.0	2.29	17.4	Q	0.95	< 13.5	−0.25		15.2
0329 − 385	03 29 14.8	−38 34 16.2	2.423	16.92	L	0.75	< 13.5	−0.45		198.0
0347 − 383	03 47 53.7	−38 19 30.0	3.23	17.3	Q	0.59	< 18.9	> −0.23		27.6
0353 − 383	03 53 01.0	−38 18 39.7	1.953	17.5	L	1.15	< 18.9	−0.40		90.8
0420 − 388	04 20 29.9	−38 51 49.3	3.12	16.92	L	1.60	< 9.9	−0.44	−1.16	385.0
0448 − 392	04 48 00.4	−39 16 13.7	1.288	16.46	L	1.20	37.9 ± 6.6	−0.63		292.0
							97.3 ± 5.8			
0453 − 423	04 53 48.0	−42 21 00.0	2.661	17.06	Q	1.11	< 15.9	> −0.17		27.8
0530 − 379	05 30 48.6	−37 55 26.0	0.29	16.7	Q	1.88	< 21.0	> −0.15		1.0
0540 − 389	05 40 12.1	−38 57 43.0	0.83	17.2	Q	0.75	< 22.5	> −0.24		1.6
2204 − 408	22 04 33.2	−40 51 36.9	3.170	17.57	L	0.63	< 9.6	−0.38	−1.20	159.0
2319 − 383	23 19 33.4	−38 19 33.4	0.37	17.3	Q	1.09	< 14.7	> −0.23		0.3

the sample), the average luminosity of the radio–loud objects is (194 ± 41) · 10^{12} $L_\odot$, whereas the corresponding value for the radio–quiet objects is ≈ (21.9 ± 3.6) · 10^{12} $L_\odot$. It should be noted that a similar amount of energy is emitted in the range from optical to X–ray wavelengths.

In order to investigate physical properties within the two groups of radio–loud and radio–quiet objects it is convenient to compare the spectral energy distributions (SEDs) in their rest frames. Due to the poor spectral coverage, however, we discuss certain spectral indices α defined as $S_\nu \propto \nu^\alpha$ rather than displaying the incomplete spectra.

4.1. Radio–loud quasars

The similarity of the intrinsic SEDs from X–rays to 1300 μm is striking: The spectral index between X–rays and IR (2.2 μm) for the three objects with X–ray data is $\alpha_{IR-X} = -1.23 \pm 0.05$ - a value which is typical for both, radio–quiet quasars ($\alpha_{IR-X} = -1.25 \pm 0.14$, Chini et al. 1989a) and radio–loud quasars with steep and flat radio spectra ($\alpha_{IR-X} = -1.20 \pm 0.06$, Chini et al. 1989b). The average spectral index between the radio range (5 GHz) and IR (2.2 μm) is $\alpha_{R-IR} = -0.42 \pm 0.05$, well within the range of values found for other radio quasars.

Apart from these global properties one may speculate about the presence of physically distinct components: synchrotron emission in the radio range and thermal emission in the FIR/submm range. As mentioned above only one of the radio–loud quasars (0448 − 392) could be positively detected at 1300 μm. The observed flux density of about 38 mJy can be extrapolated from the radio range, using a spectral index of -0.79 ± 0.01. Due to the variability of this quasar at optical and mm wavelengths, it is likely that the entire range from optical to radio wavelengths is dominated by non–thermal emission. The radio spectrum and the 1300 μm upper limit for QSO 2204 − 408 is consistent with a single flat spectrum synchrotron component as well, extending into the mm and FIR range and to shorter wavelengths; the spectral turnover occurs around 1 μm.

The synchrotron emission of the remaining objects seems to turn over at radio or mm wavelengths. Chini et al. (1989b) found this behaviour to be a common property of many core dominant quasars. In those cases, the emission from FIR to NIR wavelengths was found to originate from an additional thermal component. As in active galaxies, such a component attains its maximum around 100 μm corresponding to a dust temperature of 35 K. In the present cases there is no observational evidence for thermal emission.

4.2. Radio–quiet quasars

The two quasars with X–ray data have an average $\alpha_{IR-X} = -1.13 \pm 0.05$, consistent with the value derived above. The upper limits in the radio regime do not completely rule out the existence of a flat spectrum, however, taking them at their face value, one obtains on average a spectral index $\alpha_{R-IR} > -0.22 \pm 0.01$. This is at least a factor of two above the α_{R-IR} result for the radio–loud sample and suggests inverted spectra. Because our 1300 μm data cannot solve this problem, the final answer has to await radio data of much higher sensitivity and FIR observations with *ISO*. Nevertheless, a possible dust emission at 1300 μm would be more than one order of magnitude below the present limit.

Next we investigate the possibility of a thermal hump at FIR/submm wavelengths as seen in many radio–quiet quasars. Chini et al. (1989a) have presented spectra of radio–quiet quasars from X–ray to 1300 μm. The SEDs of these objects keep rising until FIR wavelengths with a common spectral index $\alpha_{IR-X} = -1.25 \pm 0.14$, apart from a hump around visible wavelengths. The SEDs of the present sample have an identical slope until at least 2.2 μm and a similar appearance around 0.5 μm. Therefore, we can extrapolate the flux densities at longer *IRAS* wavelengths and obtain values of a few hundred mJy at maximum. This is slightly below the detection limits of *IRAS* in the normal survey mode so that the missing FIR fluxes cannot serve as an argument against a thermal hump.

The only object in the sample that could be detected by *IRAS* in the pointed mode is quasar $0530-379$ (Neugebauer et al. 1986) with the lowest redshift of 0.29. Its spectral index from 2.2 to 25 μm is -1.29 ± 0.04 and thus perfectly consistent with the general value of α_{IR-X} as discussed above. The observed 12 and 25 μm flux densities and the radio limits, however, yield a positive spectral slope. This is in contrast to all synchrotron components known in that wavelength range. Therefore, it is likely that the FIR emission originates from a separate thermal component similar to those observed by Chini et al. (1989a).

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