ISO Observations of Quasars and Quasar Hosts

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Abstract. The Infrared Space Observatory (ISO), launched in November 1995, allows us to measure the far-infrared (far-IR) emission of quasars in greater detail and over a wider energy range than previously possible. In this paper, preliminary results in a study of the 5–200 μm continuum of quasars and active galaxies are presented. Comparison of the spectral energy distributions show that, if the far-IR emission from quasars is thermal emission from galaxian dust, the host galaxies of quasars must contain dust in quantities comparable to IR luminous galaxies rather than normal spiral galaxies. In the near-IR, the ISO data confirm an excess due to a warm 'AGN-related' dust component, possibly from the putative molecular torus. We report detection of the high-redshift quasar, 1202-0727, in the near-IR indicating that it is unusually IR-bright compared with low-redshift quasars.

1 Introduction

Quasars are multi-wavelength emitters, emitting roughly equal amounts of radiation throughout the whole electromagnetic spectrum from far-IR through to γ-ray energies. 10% are also strong radio emitters. To understand the energy generation mechanisms at work, it is first essential to obtain multi-λ data covering the full spectral range of the emission. We now have a good understanding of the spectral energy distributions (SEDs) of low-redshift quasars and active galaxies. However, in the far-IR this has been limited by the short lifetime and wide beam of the ground-breaking IRAS satellite. Now, more than 10 years later, ISO is providing us with the chance for a second, more detailed look at the far-IR sky, allowing us to extend our knowledge to IR-fainter and higher redshift sources and to longer and shorter wavelengths (5–200μm).

To this end we are observing a sample of quasars and active galaxies with the photometer on ISO (ISOPHOT). The sample was originally designed to include ~ 130 quasars and active galaxies covering the full range of redshift and of known SED properties. With the reduced in-flight sensitivities of ISOPHOT, our program has been reduced significantly and will likely include ~ 50 objects, not all with full wavelength coverage. The sample will include full wavelength coverage for a well-defined subset of optically-selected, PG quasars (Laor *et al.* 1996), along with a few high-redshift quasars, X-ray selected Seyfert 1 galaxies, and red quasars.

One question that the ISO data will address is particularly relevant to this conference, namely the contribution of the host galaxy in the far-IR. Figure 1 shows SEDs of spiral and elliptical galaxies superposed on the SED of a median low-redshift quasar (from Elvis *et al.* 1994). The plot clearly shows the near-IR

($\sim 1-2\mu m$ "window" on the host galaxy which has been used to great advantage (McLeod & Rieke 1994, Dunlop *et al.* 1993). Although the strength of the far-IR peak, due to cool dust, is as yet unknown, Figure 1 demonstrates that this is the most likely wavelength range for a second "window" on the host galaxy.

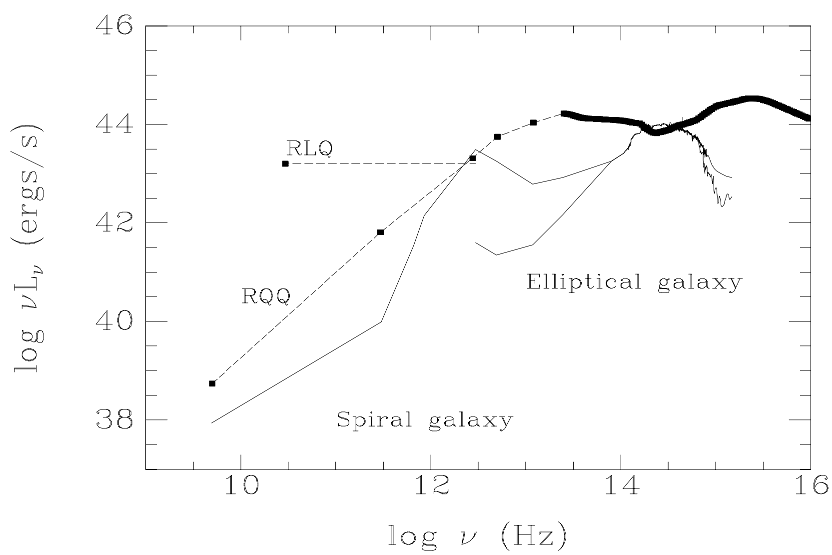

Fig. 1. The Median SED of a low-redshift quasar superposed on the SED of a spiral galaxy showing the well-explored, near-IR "window" ($\sim 1\mu m$) and the potential far-IR "window" on a quasar's host galaxy (courtesy Kim McLeod).

2 ISO Observing Program

ISOPHOT observations are being made in eight broad bands covering the full energy range of the instrument, 5–200 μm. The detector/filter combinations are: P1:5,7,12 μm; P2: 25 μm; C100: 60,100 μm and C200: 135,200 μm. Until October 1996, AOTs P03 and P22 were used in rectangular chopping mode with a chopper throw of 180" in all cases. The apertures, chosen to match the instrument field of view or the point spread function as applicable, are 52" for $\lambda \leq 12\mu m$, 120" for $\lambda = 25\mu m$ and the array size for the long wavelength points. For the largest and/or brightest sources, we use staring mode with a separate sky observation. Following the recommendations of the ISOPHOT team, we have re-specified our remaining time to observe a smaller subset of objects, re-observing where necessary, using small rasters whose dimensions depend on the detector in use. These observations are scheduled to begin in early 1997 and should provide the reliable long-wavelength data which is currently lacking.

3 Analysis of ISOPHOT data.

ISOPHOT suffers from several well-known problems which complicate the data analysis and limit (currently) the accuracy with which fluxes can be determined (for details see ISOPHOT Observers Manual and associated updates):

- The responsivity of all detectors drifts significantly following a change in the incident signal, for example when pointing to a new source or changing filters. This drift is difficult to calibrate and the analysis software does not yet support fitting for chopped observations such as ours. We have thus concentrated our efforts on analysing objects with observations sufficiently long that the detector reaches a stable portion of the drift curve, generally $\gtrsim 128$ secs total time.
- The internal (FCS) calibrators needed to be re-calibrated in-orbit following a change of state of FCS1 in February 1996. The combination of the shortness of the FCS observations (16/32 secs) taken during an individual observation and the lack of a definitive re-calibration led us to use the default responses for all detectors in this analysis. There is a drift $\sim$ 30% in the detector responsivity as a function of time during an orbit so our flux normalisation errors are expected to be of this order.
- At long wavelengths (C200 detector in particular) the two adjacent beams are large enough that part of the detector lies within a part of the telescope beam which is significantly vignetted. This leads to an asymmetry in the derived fluxes across the detector and a $\sim$ 20% flux correction. The correction for this affect has not yet been released and has not been applied to our data.

Our analysis was performed using the PHOT Interactive Analysis Package (PIA), an IDL-based system provided by the PHOT team. We carried out the following steps: non-linearity correction, read-out de-glitching, 1st order fit to ramps, dark current subtraction, de-glitching to delete highly discrepant points, deletion of data during strong detector drifts and of remaining highly-discrepant points, background subtraction, and calibration using the default responsivities. Background subtraction is done using the average of the background in the chopper plateaux before and after each source plateau. On a non-linear drifting curve, this is not accurate and adds noise to the signal which could be reduced by fitting the background and source curves separately and then subtracting them. Currently points on the drift curve are deleted, reducing the potential S/N of the observations once more sophisticated analysis is carried out.

From the subset of our sources with relatively long exposure times, we chose four objects covering a range of luminosity and redshift: PG1244+026, a radio-quiet Seyfert 1 galaxy; PG1543+489, a radio-quiet quasar; 3C249.1 (PG1100+772), a radio-loud quasar; and 1202-0727, a high-redshift, radio-quiet quasar. The observational details are provided in Table 1. For these sources we found reliable detections in most/all the short wavelength bands (5-25 μm). In the long wavelength bands, however, only two of the sources are detected, the other two have negative "detections" in all four long wavelength bands.

Subsequent analysis of additional sources not reported here has shown a large number of negative signals at long wavelengths, particularly 135,200 μm. We are currently investigating the cause and, since the negative signals are often at levels similar to the positive ones, are treating all our long wavelength data with scepticism. The most likely cause is cirrus confusion and would imply significant structure on the scale of $\sim 3'$ (our chop distance). However further investigation is required to confirm this.

Table 1. Details of the ISOPHOT observations.

Name	z	ISO date	AOT[1]	Filter μm	Time sec[2]	Filter μm	Time sec[2]	Filter μm	Time sec[2]	Filter μm	Time sec[2]
PG1244+026	0.048	14/07/96	PHT03	4.85	16	7.3	256	12	256	25	256
			PHT22	60	64	100	64	135	64	200	64
PG1543+099	0.400	30/05/96	PHT03	4.85	256	7.3	128	12	128	25	256
			PHT22	60	64	100	64	135	64	200	128
3C249.1	0.313	17/06/96	PHT03	4.85	256	7.3	256	12	256	25	256
(PG1100+772)			PHT22	60	128	100	128	135	256	200	256
1202−0727	4.69	19/07/96	PHT03	4.85	512	7.3	512	12	512	25	512
			PHT33	60	512	100	128	135	512	200	512

1: AOT: Astronomical Observation Templates
2: on-source time

4 Spectral Energy Distributions

We have combined our ISO results with data from other wavelengths collected by ourselves and from the literature to generate SEDs of the four objects (Figure 2). To investigate possible contributions from the quasar host galaxy, particularly in the far-IR, SEDs for several kinds of galaxies were generated using data from the literature (McLeod, private communication). The IRG and ULIRG templates correspond roughly to $L_{IR} \sim 10^{10-11}$ $L_\odot$and $10^{11.5}$ $L_\odot$respectively. Superposed on each quasar SED, we have shown various galaxy SEDs as labelled and a median SED for low-redshift quasars (Elvis *et al.* 1994) for direct comparison (Figure 2).

PG1244+026 is a low luminosity active galaxy (L$\sim 10^{44}$ erg s^{-1}), officially classified as a Seyfert 1 galaxy and with low redshift (z=0.048). Figure 2 shows an L* spiral galaxy which is consistent with the AGN SED $\sim 1\mu m$ and with the cool dust contribution in the far-IR. Between 5 and 100 μm the quasar SED is dominated by an "AGN" component believed to originate in warm dust within the putative molecular torus. This component peaks $\sim 25-60\mu m$ in PG1244+026.

PG1543+489, also an optically selected PG quasar, has a luminosity$\sim 10^{45.5}$ erg s^{-1} (a bona fide quasar) and a redshift of 0.400. In this case an L* galaxy

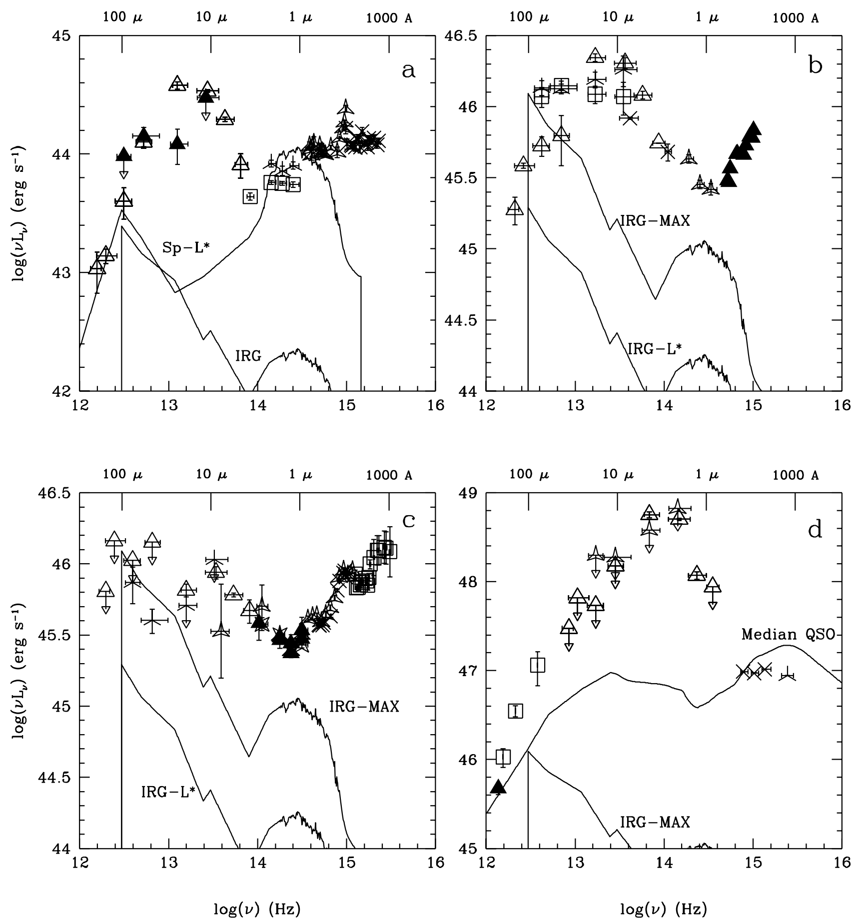

Fig. 2. The far-IR – ultra-violet SEDs of a: PG1244+026, b: PG1543+489, c: 3C249.1, d: 1202-0727, with various galaxy and quasar SEDs (as labelled) superposed. Each different dataset uses a different symbol, the ISO points are always indicated by open triangles.

would make no significant constribution in the near-IR. A galaxy with the maximum host galaxy luminosity seen to date (McLeod & Rieke 1994) is a factor ~ 4 too low at $1\mu m$. An amount of dust comparable to an IR-bright galaxy is necessary to explain the far-IR emission ($L_{IR} \sim 10^{10-11}$ $L_{\odot}$). Once again a mid-IR bump due to warm dust is apparent, peaking $\sim 100\mu m$.

3C249.1 is a lobe-dominated, radio-loud quasar at a reshift 0.389. The ISO short wavelength detections once again show a typical mid-IR bump with a peak

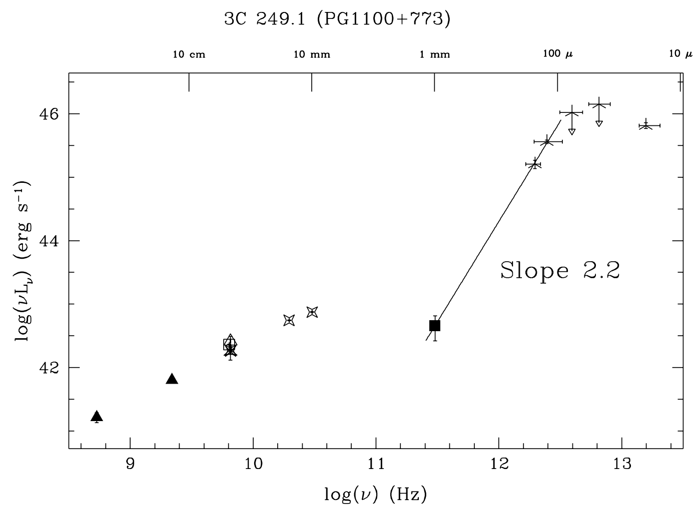

Fig. 3. The radio–far-IR SED of 3C249.1 showing the current limits on the slope of the far-IR turnover.

$< 100\mu m$. The IRAS upper limits (Elvis *et al.* 1994) are very low ($\sim$ 20 mJy at 100 μm) and inconsistent with the ISO detections. Re-analysis of the IRAS survey data using the current software (XSCANPI) yields upper limits which are largely consistent, as shown in Figure 2c. Unfortunately we currently have only weak upper limits on the far-IR emission of this source from ISO indicating that the data could be consistent with an L*, IR-bright galaxy but not one with maximal luminosity in the near-IR. However since we have no estimates of the host galaxy from the near-IR, this provides a very weak constraint on the amount of dust. Figure 3 shows the far-IR SED with a marginal detection at 1mm (Antonucci *et al.* 1990). Assuming that the 1mm flux represents the long wavelength tail of the far-IR emission, our current data give an upper limit to the slope of the far-IR turnover of $\alpha < 2.2$ ($f_\nu \propto \nu^\alpha$). The discontinuity between the far-IR and radio emission in the SEDs of lobe-dominated, radio-loud quasars is generally interpreted as evidence for differing emission mechanisms and thus thermal IR emission (Antonucci *et al.* 1990). However, the flat lower limit to the far-IR turnover in this source prevents us from ruling out non-thermal synchrotron emission.

1202-0727 is one of the highest redshift quasars known (z=4.690). It is an extremely interesting source, mentioned a number of times in these proceedings (Barvainis, Yamada). It is a double source with 4" separation at mm wavelengths, has strong CO emission (Ohta *et al.* 1996, Omont *et al.* 1996), a sub-mm spectrum which suggests emission from 50–100 K dust (Isaak *et al.* 1994) and a Lyα emission companion 2" away with the same redshift (Hu *et al.* 1996). The source has a very high luminosity, $\sim 10^{47}$ erg s^{-1}, such that the contribution from its host galaxy in the rest-frame optical and near-IR is several orders of magnitude below that seen by ISO (12, 25 μm observed frame, Figure 2d). The mid-IR bump, with a broad peak from 4–80 μm in the rest frame, is two orders of magnitude stronger than that of the low-redshift median (Fig. 2d). The rest-frame far-IR emission determined by the sub-mm observed frame data (Isaak *et al.* 1994) would require a host galaxy similar to an ultra-luminous IR galaxy (ULIRG) in a pure dust scenario. The crude far-IR upper limits from ISO suggest that our planned re-observation could strongly constrain the mid-IR SED.

5 Conclusions

Although the current status of the ISO far-IR data limits the usefulness of ISO to study the host galaxy dust contribution, we can already demonstrate that, if the far-IR emission of bona fide quasars (L$>10^{44}$ ergs^{-1}) is from the host galaxy, these galaxies are unusually far-IR bright, comparable to IR-bright galaxies or ULIRGs ($L_{IR} \sim 10^{10-11.5}$ $L_{\odot}$). The ISO data also allow us to investigate the mid-IR "AGN" bump in quasars covering a range of redshift and luminosity. We plan to use these data to test and constrain current models of emission from a molecular torus (Pier & Krolik 1992, Efstathiou & Rowan-Robinson 1995).

We have detected the z=4.69 quasar, 1202-0727, in the rest-frame near-IR at a level far above that seen in typical low-redshift quasars. Observations of more high-redshift quasars are necessary to determine whether the near-IR emission is unusual, as are many other aspects of this source. For pure host galaxy far-IR emission, the host must be comparable to an ULIRG to explain the mm data (Isaak *et al.* 1994).

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XSCANPI, Interactive software for the analysis of IRAS data provided by IPAC via "telnet xscanpi.ipac.caltech.edu"