*Astrophysics with Infrared Surveys: A Prelude to SIRTF*
*ASP Conference Series, Vol. 177, 1999*
*M. D. Bicay, C. A. Beichman, R. M. Cutri, and B. F. Madore, eds.*

# The U.S. ISO[1] Key Project on Quasars

Eric Hooper[2], Belinda Wilkes[2], Kim McLeod[3], Jonathan McDowell[2],
Martin Elvis[2], Matthew Malkan[4], Carol Lonsdale[5], Chris Impey[6]

## 1. Introduction

A substantial fraction of the bolometric luminosity of many quasars emerges in the infrared (Elvis et al. 1994), from synchrotron radiation and dust. Which of these emission mechanisms is dominant depends on quasar type and is an open question in many cases. The non-thermal component is likely connected with radio and higher frequency synchrotron radiation, providing information about the relativistic plasma and magnetic fields associated with quasars. Much of the dust emission is due to heating by higher energy photons from the active nucleus, and is therefore important for understanding the overall energy balance. Moreover, this thermal component provides an orientation-independent parameter for examining unification hypotheses. Fundamental phenomenological questions about quasar infrared spectral energy distributions (SEDs) include: the range of SEDs within each quasar type; differences between one type and another; the evolution of the SEDs; and correlations with fluxes at other wavebands, host galaxy properties, and orientation indicators.

The IRAS satellite provided an enormous boon for infrared studies of quasars, detecting a large number of sources for the first time in the mid-infrared. Its major limitations were a lack of coverage of the far infrared, $\lambda > 100\mu$m; shallow limiting flux, especially in the sky survey from which most quasar data were obtained; and relatively low spatial resolution. The recently completed ISO mission (Kessler et al. 1996) was an important step in the evolution of infrared astronomy, providing extensive spectroscopic capabilities, a large number of photometric passbands from 3 to 200 $\mu$m, higher spatial resolution, and the opportunity to achieve deeper flux limits. Two major ISO observing programs have obtained broad-band photometry for large samples of quasars: a European Core program which focused on low-redshift, predominantly radio-loud quasars; and a US Key Project to examine quasars spanning a wide range of redshifts and SEDs, e.g., X-ray and IR-loud, plus those with unusual continuum shapes.

---

[1] ISO is an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands, and the United Kingdom) and with the participation of ISAS and NASA.

[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138

[3] Department of Astronomy, Wellesley College, 106 Central St., Wellesley, MA 02181

[4] Astronomy Department, UCLA, Los Angeles, CA 90095

[5] IPAC, Caltech MS 100-22, 770 S. Wilson Ave., Pasadena, CA

[6] Steward Observatory, University of Arizona, Tucson, AZ 85721

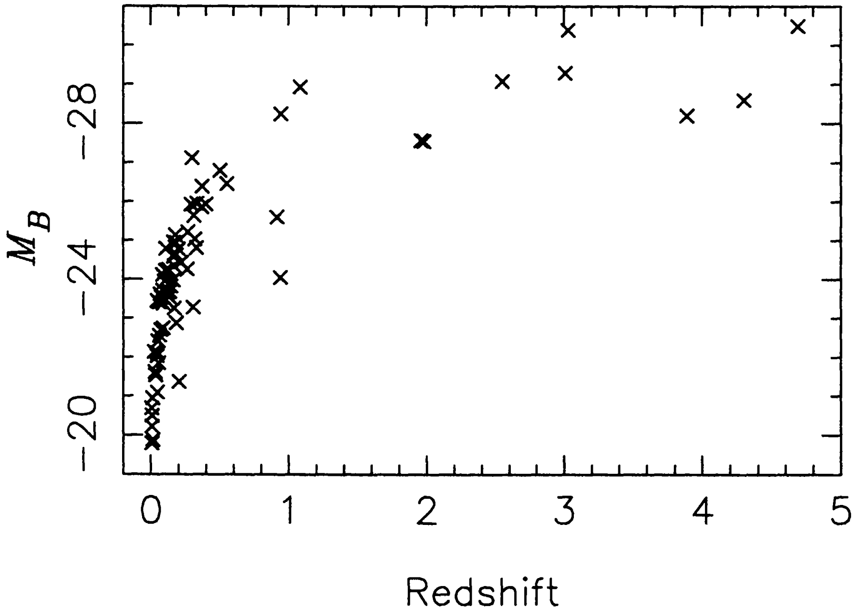

Figure 1. Absolute blue magnitude ($H_0 = 50$ km $s^{-1}$ $Mpc^{-1}$ and $q_0 = 0.5$) against redshift for the 72 quasars in the sample.

## 2. Observations with ISO

The final sample for the US Key Project consists of 72 quasars observed with the ISOPHOT instrument (Lemke et al. 1996) in most or all of the following bands: 5, 7, 12, 25, 60, 100, 135, and 200 $\mu$m. Ninety percent of the quasars in the sample have redshifts $< 1$, while the remaining 10% lie in the range $2 < z < 4.7$ (Figure 1). More than half of the sample consists of luminous X-ray sources, 25% are strong UV emitters, and smaller subgroups contain strong infrared sources, X-ray-quiet objects, red quasars, and BALQSOs. Data collection was completed with the end of the longer-than-expected mission in April, 1998, and analysis is ongoing. The infrared data points will be combined with all available fluxes at other wavebands to generate a comprehensive atlas of broadband SEDs (see Wilkes 1997 for some examples).

The ISO mission, particularly the ISOPHOT instrument, has suffered from some unanticipated difficulties. The most egregious of these is that the instrument sensitivity in some bands is lower than preflight expectations by a large factor. This was ameliorated somewhat by the extended mission lifetime. The originally preferred technique for observing faint sources, chopping between the source and the sky, was abandoned due to concerns about uncertainties in interpreting and calibrating chopped measurements, particularly at long wavelengths. Our program was switched mid-stream from chopping to small raster scans. Chopped data were obtained for 53 targets, 18 were reobserved in raster mode, plus 19 new sources were observed only with raster scans. The change in observing strategy, combined with the lost sensitivity, has resulted in a halving of the originally planned sample. However, we now have the added benefits of data from both observing modes for a subset of the targets and better information about background variations from the raster maps.

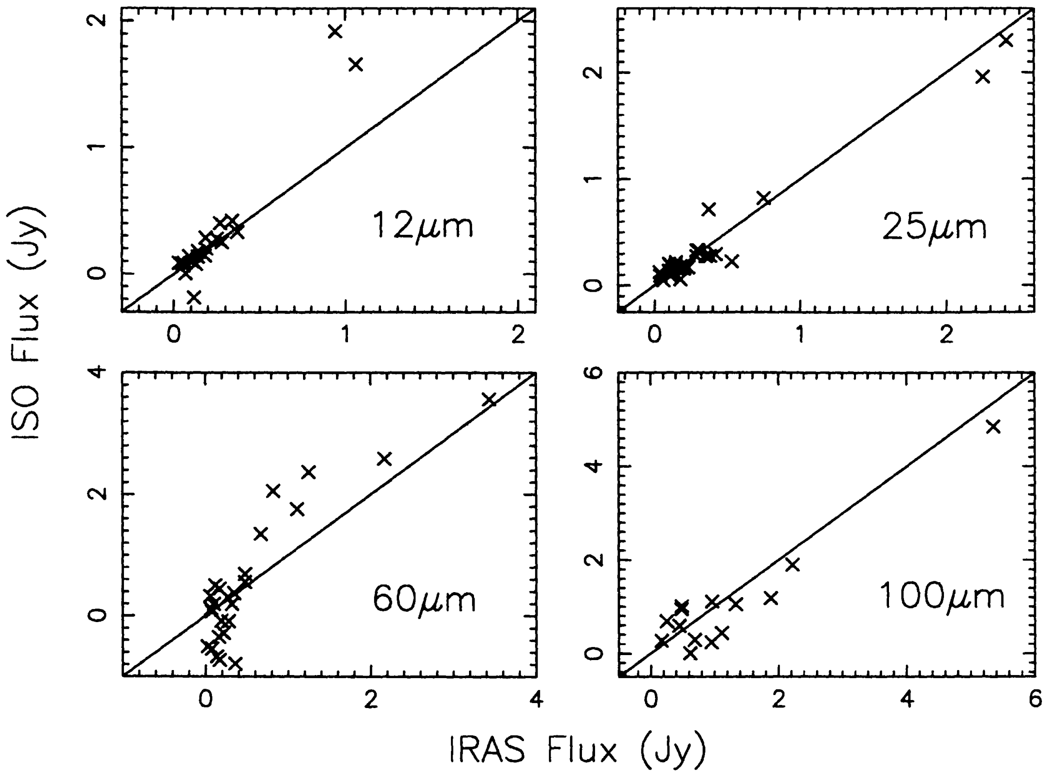

Figure 2. Comparison of ISO and IRAS fluxes for chopped measurements. Lines corresponding to equal flux observed with both telescopes are provided to guide the eye.

## 3. The Data

Reduction of faint object data taken with the ISOPHOT instrument has been complex and somewhat uncertain, due to factors including the difficulties mentioned above, the effects of cosmic rays, a very large parameter space which needs to be calibrated, and the familiarization time required for any new instrument. However, the ISOPHOT instrument team, the ISOPHOT Data Center, and the PHOT Interactive Analysis (PIA) software team have worked diligently to bring the reduction process to the point where reliable fluxes for some quasars are being produced (Haas et al. 1998). While our results at this stage are still preliminary, current progress in reduction technique and calibrations is rapid.

The bulk of the data reduction, including most instrumental calibrations and corrections, is done with PIA, the standard software for PHOT reductions (Gabriel, Acosta-Pulido, & Heinrichsen 1998). Multiple techniques are being explored for the final step, extracting the source flux. Consequently we use scripts written by members of the ISOPHOT Data Center (IDC) which have not yet been incorporated into PIA. Two methods for processing chopped data are currently utilized: subtracting the average of adjacent sky measurements from each on-source value in the observing sequence; and Fourier analysis to look for a significant signal at the chopping frequency. Small maps can be generated from the raster scans using PIA, but the simpler technique of subtracting the flux at the source position from average adjacent sky values for each pixel has proven to be easier to interpret and possibly more sensitive.

Figure 2 shows a comparison of ISO fluxes from chopped observations reduced in PIA batch mode with the corresponding IRAS values. There is general agreement between the two sets of measurements, particularly at the shorter wavelengths. However, the 60$\mu$m plot has some disturbing features, notably a large dispersion about zero for the ISO values and a systematic discrepancy with the IRAS results at higher flux levels. The C100 array, which was used for the 60$\mu$m and 100$\mu$m observations, is known to have had abnormally high dark current in some pixels. Cosmic ray strikes can have residual effects on the data stream which are not fully corrected or flagged with standard batch reduction. These and other instrumental effects are probably responsible for the behavior at 60$\mu$m. The highest quality final results will require detailed individual data reduction beyond the batch processing in some cases.

Several issues are being investigated in the pursuit of an optimal data reduction strategy and set of calibration information. Measurements of the on-board flux calibration sensors were occasionally affected by glitches and detector responsivity drift. Alternative default calibrations are being further refined at the IDC. In collaboration with workers at the IDC and elsewhere, we are testing new sets of vignetting corrections, which can have a substantial effect on the detection of faint sources. Different techniques for estimating source flux, taking into account the long-term drift over the whole observation, are being explored. More accurate uncertainty estimates, utilizing all of the available data, will soon be incorporated into the scripts.

**Acknowledgments.** Martin Haas, Sven Müller, Mari Poletta, Ann Wehrle provided invaluable help with the data reduction. We benefitted greatly from discussions with Thierry Courvoisier, Péter Ábrahám, Ilse van Bemmel, Rolf Chini, and Bill Reach. The IDC, IPAC, and the INTEGRAL Science Data Center were very hospitable during visits to work on this project. The financial support of NASA grant NAGW-3134 is gratefully acknowledged.

## References

Elvis et al. 1994, ApJS, 95, 1

Gabriel, C., Acosta-Pulido, J., & Heinrichsen, I., Proc. of the ADASS VII conference, ASP Conf. Ser. 145, ed. R. Albrecht, R.N. Hook, & H.A. Bushouse (San Francisco: ASP), 165

Haas, M., Chini, R., Meisenheimer, K., Stickel, M., Lemke, D., Klaas, U., & Kreysa, E. 1998, ApJ, 503, L109

Kessler, M. E. et al. 1996, A&A, 315, L27

Lemke, D. et al. 1996, A&A, 315, L64

Wilkes, B. J. 1997, in Quasar Hosts, ed. D. L. Clements & I. Pérez-Fournon (Heidelberg: Springer-Verlag), 136