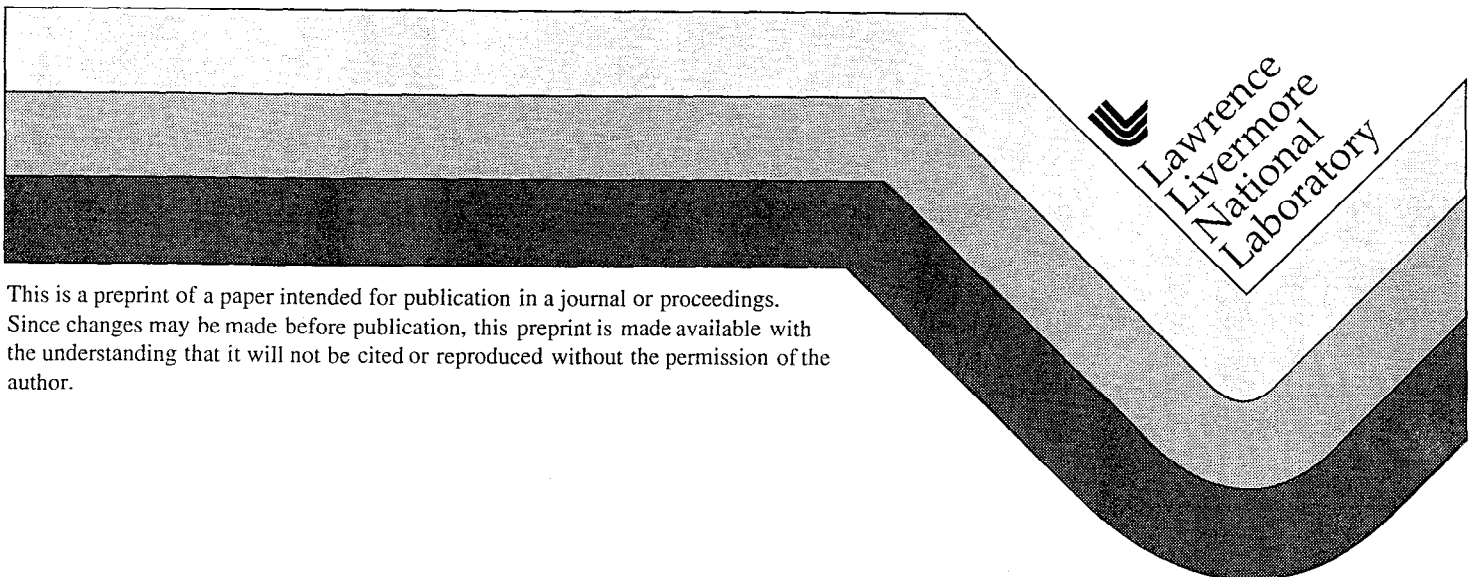


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MONSTERS AND BABIES FROM THE FIRST / IRAS SURVEY

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1. Abstract

Radio continuum emission at cm wavelengths is relatively little affected by extinction. When combined with far-infrared (FIR) surveys this provides for a convenient and unbiased method to select (radio-loud) AGN and starbursts deeply embedded in gas and dust-rich galaxies. Such radio-selected FIR samples are useful for detailed investigations of the complex relationships between (radio) galaxy and starburst activity, and to determine whether ULIRGs are powered by hidden quasars (monsters) or young stars (babies).

We present the results of a large program to obtain identifications and spectra of radio-selected, optically faint IRAS/FSC objects using the FIRST/VLA 20 cm survey (Becker, White and Helfand 1995). These objects are all radio-*'quiet'* in the sense that their radio power / FIR luminosities follow the well-known radio/FIR relationship for star forming galaxies.

We compare these results to a previous study by our group of a sample of radio-*'loud'* IRAS/FSC ULIRGs selected from the Texas 365 MHz survey (Douglas *et al.* 1996). Many of these objects also show evidence for dominant, A-type stellar populations, as well as high ionization lines usually associated with AGN. These radio-loud ULIRGs have properties intermediate between those of starbursts and quasars, suggesting a possible evolutionary connection.

Deep Keck spectroscopic observations of three ULIRGs from these samples are presented, including high signal-to-noise spectropolarimetry. The polarimetry observations failed to show evidence of a hidden quasar in polarized (scattered) light in the two systems in which the stellar light was dominated by A-type stars. Although observations of a larger sample would be needed to allow a general conclusion, our current data suggest that a

large fraction of ULIRGs may be powered by luminous starbursts, not by hidden, luminous AGN (quasars).

While we used radio-selected FIR sources to search for evidence of a causal AGN/starburst connection, we conclude our presentation with a dramatic example of an AGN/starburst object from an entirely unrelated quasar survey selected at the opposite, blue end of the spectrum.

2. The FIRST/IRAS Survey: radio-quiet selected ULIRGs

In order to investigate the AGN-starburst connection, particularly at higher redshifts, we have constructed a new sample of potential ultraluminous infrared galaxies (ULIRG) by making use of FIRST ("Faint Image of the Radio Sky at Twenty cm"; Becker, White, and Helfand 1995) survey which is currently underway at the VLA. This 1.4 GHz survey, with unprecedented sensitivity (~ 1 mJy; 5σ) and resolution ($4''$), will eventually cover π steradians centered at the North Galactic Cap.

We position matched the FIRST catalog with the IRAS FSC catalog, and selected the sources which follow the well known radio-FIR flux correlation for starburst galaxies and which showed faint or no optical counterparts on the POSS. We then used the Lick 3m telescope to obtain optical identifications and spectroscopy of the unknown sources. This resulted in a very high rate of finding ULIRG at moderate redshifts. All except two of the approximately 70 sources observed so far showed optical objects in our CCD imaging at the radio position. Spectra with the KAST spectrograph yielded redshifts in the range $0.1 \leq z \leq 0.9$ and most of these are ULIRG at $z > 0.3$.

The new ULIRG in our FIRST/FSC (FF) sample are shown in Figure 1, along with other representative classes of IR-luminous objects. Their radio-FIR properties place our FF sample mostly in the same region as the original ULIRG sample of Sanders *et al.* (1988). The highest redshift FF objects ($z = 0.710, 0.727, 0.904$) fall near the area in the radio-FIR luminosity plane as other well-known ULIRGs. The FF optical spectra contain typical starburst emission lines, including [O II], [O III], and H α in the lower- z objects, as well as absorption lines characteristic of young stars. An example is plotted in Figure 2a where a Keck spectrum of FF J1614+3234 $z = 0.710$ shows [O II], the 4000 Å break, Ca H+K, and several of the Balmer lines in absorption.

3. The Texas/IRAS Survey: radio-loud selected ULIRGs

A preliminary report about the Texas/IRAS results was given by Dey and van Breugel (1993). The original sample was constructed by correlating the Texas catalog with an early, pre-release version of the IRAS catalog which

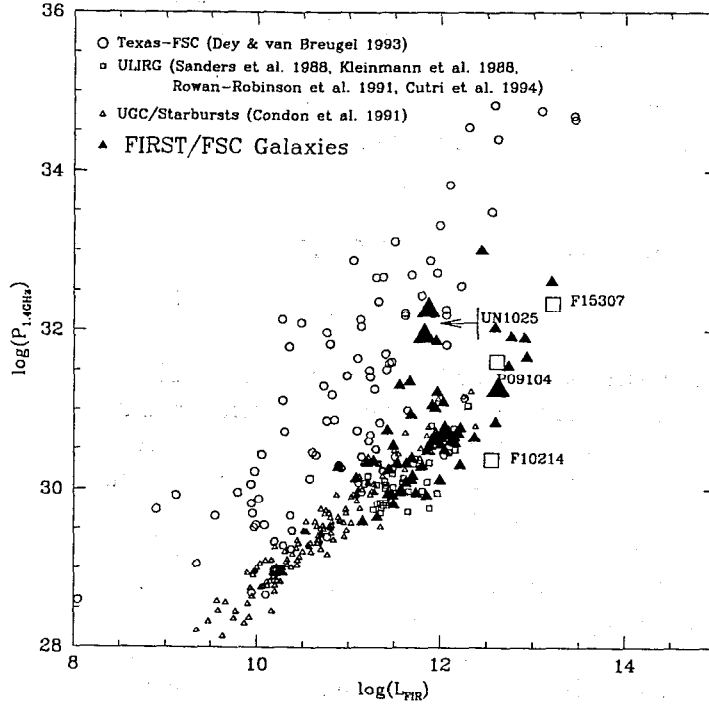


Figure 1. Radio vs. FIR luminosity plot for various radio selected IRAS/FSC samples. The radio-quiet 'starburst' track forms the bottom envelope, while radio-loud galaxies and quasars form the upper envelope. The region in between consists of intermediate-type objects, many of which have stellar populations dominated by A-type stars. The large triangles refer to the three ULIRGs observed at Keck, as described in the text.

included the Faint Source Catalog, as well as possible spurious sources. One of the results from this original sample was the possible identification of faint 60μ sources ($3\sigma - 4\sigma$) with a number of high redshift far-infrared quasars. However, the far-infrared nature of these objects could not be confirmed by deep mm-continuum or CO molecular line observations at the JCMT and IRAM 30m. The radio/FIR/optical identification in these objects therefore remains doubtful, or the faint IRAS detections are spurious. A sanitized version of this sample, which excludes these objects, and includes only Texas/FSC (TF) sources, is shown in Figure 1. This sample remains of much interest as it shows the existence of a significant class of objects which are intermediate between starburst galaxies and quasars.

A large fraction of these intermediate luminosity systems show deep

Balmer absorption lines associated with relatively young, A-type stellar populations similar to FF J1614+3234 (Fig 2a), as well as high ionization emission lines suggestive of the presence of AGN (but not necessarily of quasar luminosities; see for example FF J1020+6436 in Tran *et al.* 1999). They may form an important evolutionary link between starburst and quasar activity.

4. Keck spectropolarimetry of radio-selected ULIRGs

FF J1614+3234, with $L_{FIR} \sim 10^{12.6} L_{\odot}$, is one of the most luminous ULIRG in our sample (we use the definition for L_{FIR} as given by Sanders and Mirabel 1996). To determine the power source in this and other ULIRGs we began a program to obtain high signal-to-noise spectropolarimetry data of a number of galaxies with the Keck telescope. The presence of a monster, possibly hidden in a dusty lair, might then expected to be visible via indirect, reflected and hence polarized light.

We observed three ULIRGs in detail (Tran *et al.* 1999). Two ULIRGs with dominant *young* (A-star type) stellar populations and weak high ionization lines failed to show evidence for hidden quasars in polarized (scattered) light. On the other hand, similar observations of a ULIRG with only a modest young stellar population but with strong high ionization lines did show polarized broad lines. Other well-known examples in this high ionization class which show evidence for polarized broad lines and hidden quasars are the ‘hyper’ luminous FIR galaxies P09104+4109 ($z = 0.44$), F15307+3252 ($z = 0.926$), and F10214+4724 ($z = 2.286$).

The detection of hidden quasars, using spectropolarimetry, in this high ionization group but not in the low-ionization, starburst-dominated ULIRGs (classified as LINERs or H II galaxies) may indicate an evolutionary connection, with the latter being found in younger systems. Since approximately 75% of the FF objects in our sample do not show any signs of high excitation emission lines the majority of the ULIRGs may not contain monsters and even some of the most energetic ULIRGs may be powered by massive starbursts (monstrous baby nurseries).

5. A Spectacular, UV-selected Starburst-Quasar

While our radio/far-infrared ULIRG project is specifically aimed to search for a possible causal relationship between starburst and quasar activity, our most spectacular ‘proto-type’ object may have been found accidentally during an entirely unrelated program aimed to study radio-loud UV-excess quasars.

Using the NVSS survey (Condon *et al.* 1998) we selected radio loud quasars from the 2dF quasar survey (Smith *et al.* 1998). We then observed

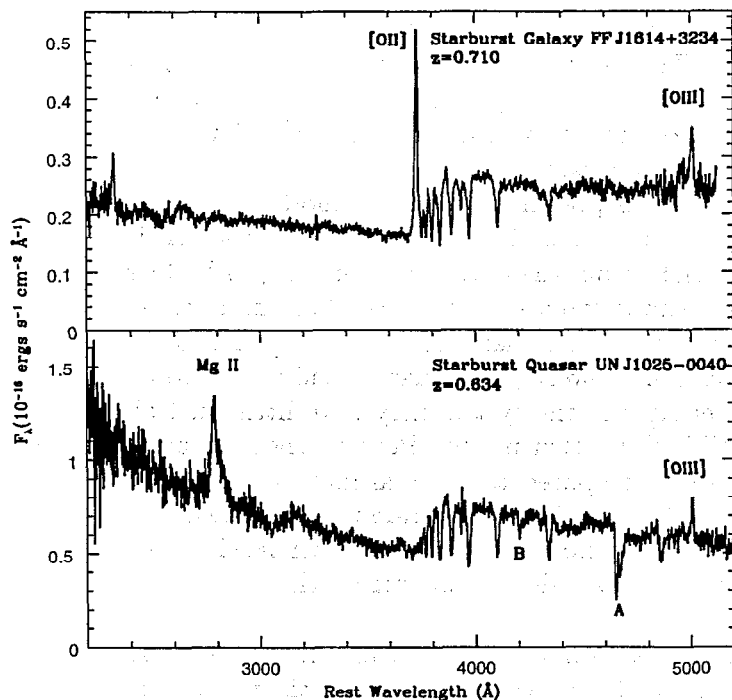


Figure 2. Keck spectra of the $L_{FIR} \sim 10^{12.6} L_{\odot}$ starburst ULIRG FF J1614+3234 (top), and the UV-excess starburst quasar UN J1025-0040.

a subset of these using Keck ‘snapshot’ spectroscopic observations and discovered a spectacular ‘post-starburst quasar’, UN J1025-00400 ($B = 19$ and $z = 0.634$; Brotherton *et al.* 1999). The optical spectrum is extraordinary, dominated by a quasar in the blue, and by a young, A-type stellar population with a large Balmer jump and deep Balmer absorption lines in the red (Fig 2b). There is no [OII] seen in emission, and only a hint of broad $H\beta$. Deep Keck spectropolarimetry showed weak polarized continuum, but no strong polarized emission lines.

A Keck K-band image ($0.5''$ FWHM) fails to resolve the quasar from the starburst, but does reveal surrounding asymmetric fuzz and a nearby companion, suggestive of a galactic interaction. Stellar synthesis population models can reproduce the starlight component with a 400-Myr-old instantaneous burst of $2 \times 10^{10} M_{\odot}$. While starbursts and interactions have been previously associated with quasars, no quasar ever before has been seen with such a luminous young stellar population.

We searched the IRAS data base using ADDSCAN to determine whether

UN J1025–00400 is also a far-infrared source. No emission was found at 60μ at a level of 0.15 Jy (3σ). The location of the source in the radio/far-infrared luminosity diagram is indicated in Fig 1 and does not rule out that UN J1025–00400 may be a ULIRG and a member of the intermediate class of objects between starbursts and quasars.

So, although we know a quasar is present, as well as a moderately aged starburst, the low percentage polarization (1% - 1.6%) suggests that their geometry might be such that light from the quasar nucleus and BLR does not intercept a large number of suitably placed ‘reflectors’. This might arise, for example, if the starburst is located in a plane (ring ?) orthogonal to the spin axis of the putative black hole powering the quasar (and we are looking down this direction). Alternatively the system may have little dust all together, and may not be a ULIRG for that matter. Perhaps the starburst-quasar is a more evolved system compared to the real intermediate class objects shown in Fig 1. It’s true location in this diagram might fall near the upper envelope of the radio/FIR luminosity diagram. Further far-infrared observations of this system would be needed to investigate this.

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