Faint Far-Infrared Sources: Galaxies, Clusters, or Cluster Galaxies

Petri Väisänen  
South African Astronomical Observatory, Cape Town, South Africa

Mika Juvela, Kalevi Mattila  
Observatory, University of Helsinki, Helsinki, Finland

Jari Kotilainen  
Tuorla Observatory, University of Turku, Piikkiö, Finland

Abstract. We present results from an ongoing follow-up campaign of far-infrared sources detected as part of our ISOPHOT Cosmic IR Background project. Fields have been imaged in the optical and near-infrared, and we find at least a third of the FIR targets are to contain a bright and nearby star-forming galaxy. We also explore the largely neglected possibility that instead of individual galaxies some of the fainter FIR sources are confused sums of several sources – or even whole cores of galaxy clusters at redshifts of \( z \sim 0.4 \) – 0.8. We look for correlations in the FIR positions with extremely red objects (ERs) and significant peaks in the galaxy surface density and peaks in cluster red sequence signal. Several matches are found and we have set out to study cluster candidates spectroscopically. The campaign is producing an interesting base to study IR-luminous, strongly star-forming galaxies in potential cluster environments.

1 Introduction

The Cosmic IR background (CIRB) consists of the integrated light of all galaxies along the line-of-sight plus any intergalactic contributions, and includes up to 2/3 of all energy generated since recombination (\cite{1, 2}). Starlight lost to dust obscuration reappears in the far-IR CIRB after reprocessing in galaxies, especially during their dusty formation era, making the CIRB an important window into the enigmatic era of galaxy formation.

Much effort has been put into resolving the CIRB and studying the galaxies responsible for it (e.g. \cite{3}). Because of the large beam (\( \approx 1 \) arcmin) of the ISO and Spitzer at FIR, the unambiguous ground-based identification and follow-up of such faint FIR galaxies has been extremely difficult. In the ISOPHOT EBL project (\cite{3}) we detected 55 FIR objects at multiple wavelengths from 90 to 180 \( \mu \)m down to \( \sim 100 \)mJy. All detections are in at least two FIR bands allowing the separation of galactic cirrus knots and helping to fit galaxy templates of varying temperatures and redshifts.

Optical and near-infrared follow-up of the sources has been recently performed with the Nordic Optical Telescope and the VLT and the areas are all covered with R, I, and K imaging to R \( \approx 24 \) and K \( \approx 20 \). We have also started multi-object spectroscopic follow-up of selected fields. Here we present results from the North Galactic Pole hole (\( l \approx 88, b \approx 73 \)) that has practically as low hydrogen column density as the Lockman hole.

2 Star-forming galaxies and confused sources

Of the 22 individual ISOPHOT detections in the NGP field, we observed 21. Of these 21 targets, 7 are found to be unambiguous, relatively nearby disk galaxies. We fit a range of SED templates to the photometry from the optical to FIR and find these galaxies to be well fit by evolved Sc or NGC 6090 starburst templates at redshifts of \( z = 0.05 – 0.25 \) (see left panel of Fig.1).

We can not find unambiguous identifications for the remaining 14 NGP FIR sources, even though 7 of them do have relatively bright (R \( \sim 20 \) mag) galaxies in the field. In a typical case there are two or more such bright galaxies, but none of them alone can easily explain the FIR source, while a combination could. In addition, a total of 8 of these fields have one or more faint red sources whose optical-to-FIR SEDs are well fit with an ultra-luminous IR-galaxy SED template, such as Arp 220, at \( z \sim 1 \).

If the FIR flux of half of these confused sources are split into two separate FIR sources, the FIR source counts in the range 100-200 mJy reduce by 50%. If the remaining sources were split into 3 separate sources, source counts in this range decrease by a factor of 2. Since model fits assume single galaxies to populate FIR source count bins, this confusion has potentially serious effects on the interpretation of FIR galaxy counts.
Figure 1: **Left panel:** Observed and fitted SEDs of 7 bright disk galaxies (shifted for clarity); redshifts and types are indicated. The lowest SED is an example of our fainter red sources, with a ULIRG template, found in many target fields. **Right panel:** Large circles are FIR targets. The map and contours show the surface overdensities of galaxies with respect to field galaxies, in colour bins of $R - I = 1.3 - 1.5, 1.1 - 1.3,$ and $1.5 - 1.7$, from top to bottom. Small red crosses are EROs ($R-K > 5$).

### 3 Clusters of galaxies

Instead of attempting to force individual optical and NIR counterparts for each FIR source, we also searched for correlations in their positions with extremely red objects (EROs) and significant peaks in the galaxy surface density, and peaks in cluster red sequence signal. The motivation is that some faint ISOPHOT sources could in principle be caused by the integrated emission of whole galaxy clusters. Our simulations show that combined radiation of normal galaxies in the central areas of rich clusters at redshifts $z = 0.4 - 0.8$ result in point-sources of 50-200 mJy in the FIR when seen through the ISOPHOT PSF.

Indeed, 4 of the 14 NGP FIR fields without an unambiguous bright galaxy counterpart can be associated with $> 3\sigma$ ERO overdensities. Moreover, 6 of the 14 fields are associated with overdensities of $> 6\sigma$ in galaxy surface density calculated in R-I colour slices (right panel of Fig.1). One of the identified cluster candidates is a previously detected X-ray cluster at $z = 0.70$. We are currently studying the FIR fields spectroscopically for cluster confirmations.

### 4 Conclusions

Classification of 21 NGP hole FIR sources from ISOPHOT CIRB project yields 7 unambiguous nearby star-forming galaxies and/or starbursts. The rest are confused targets, with likely contribution from 2-3 bright nearby star-forming galaxies in half the cases and possible contribution from $z \sim 1$ ULIRGs in 5-7 cases. The confusion of FIR sources has significant consequences on the interpretation of FIR source counts.

We also find significant spatial correlation of FIR positions of the confused target class with ERO overdensities and red colour sequences.

### References

[1] Dole et al., 2001, A&A 372, 364
[2] Elbaz & Cesarsky, 2003, Science 300, 270
[3] Juvela et al., 2000, A&A 360, 813
[4] Puget et al., 1996, A&A 308, L5