MORPHOLOGY OF LUMINOUS IRAS GALAXIES: SUMMARY TALK

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As my part of the summary I will discuss the morphology of luminous IRAS galaxies and make a few comments about where we go from here in our understanding.

MORPHOLOGY OF LUMINOUS IRAS GALAXIES

I will define a luminous IRAS galaxy as one with a luminosity of $>3 \times 10^{10}$ $L_\odot$, corresponding to the break in the galaxy luminosity function (Soifer et al. 1986). I will discuss the morphological properties of three subgroups, each separated in luminosity by about a factor of ten.

For galaxies just above the break at $L \sim 3 \times 10^{10}$ to 10^{11} $L_\odot$, there appear to be two dominant types. First, there are luminous Sc galaxies in which most of the emission is coming from the disk of the galaxy. Significant infrared emission is seen both from interstellar grains and grains in giant molecular clouds (Persson and Helou 1986; Mezger et al. 1986). For these galaxies the infrared to blue luminosity ratio is similar to galaxies of a lower luminosity. Second, there appears to be a class of optically barred galaxies (~10% of all barred galaxies) that show significant infrared emission in this luminosity range (Hawarden et al. 1986). The galaxies have been discovered by their strong 25-μm emission, but also show a blue (hot) 60- to 100-μm color. Devereux (1986) has shown that these "hot" barred galaxies appear predominantly in earlier types. Observations by Devereux (1986) and Hawarden et al. (1986) indicate that the emission is nuclear in origin and probably from a burst of star formation. The galaxies NGC 253 and M82 may be nearby examples. Very interesting results on M82 indicate a ring structure and an outflow (Sofue 1986; Lo et al.1986).

For galaxies with luminosities at $L \sim 10^{11}$ L_O to 5×10^{11} $L_\odot$, we find that galaxy interactions and mergers become much more important (Joseph and Wright 1986; Cutri 1986; Lonsdale et al. 1984). It appears from previous work and papers presented here by Keel (1986); Rodriguez-Espinosa et al. (1986); Wilson (1986); as well as the review by Rieke (1986), that we see both nuclear star formation and an active nucleus in the form of Seyfert-type activity. Surprisingly, the amount of luminosity seen in star formation and a Seyfert-type nucleus appear almost equal. This occurs collectively in a sample of galaxies and also in many individual galaxies such as NGC 1068. At this point we do not know which phenomenon is more fundamental. Put simply, we do not know the relationship between star formation and an active compact nucleus. The results presented certainly indicate that there must in fact be an important connection. Is it as simple as the fact that both are fed by interstellar material?

At a luminosity at or greater than 10^{12} $L_{\odot}$ we find the following properties.

1) Infrared selected galaxies have as high or a higher space density, at a given luminosity than objects selected from optical, x-ray, or radio surveys (Soifer et al. 1986, and references therein).

2) Most or all of the galaxies have a high $L_{IR}/L_{B}(>10)$. These are true infrared galaxies.

3) Most or all are interacting or merging.

4) There is evidence for great amounts of interstellar material from the interstellar reddening, CO line observations (Young 1986; Sanders et al. 1986) and submillimeter continuum measurements (Emerson et al. 1984; Chini et al. 1986). Most interesting, the region of strong CO emission is, in some galaxies, very compact (Sargent et al. 1986).

5) I would speculate based on a few nearby galaxies (Becklin and Wynn-Williams 1986) that most of the infrared radiation from this class of galaxy comes from an active compact nucleus.

Finally, at a luminosity of > 10^{13} $L_{\odot}$, we do not presently know the space density of infrared objects, although a few appear to have been found (Kleinmann and Keel 1986).

COMMENTS ON FUTURE OBSERVATIONS OF LUMINOUS IRAS GALAXIES

I would like to make some points about observations of high-luminosity infrared galaxies like Arp 220.

1) Understanding of these objects will probably be critical in solving QSO-Seyfert-energy source problem. The explanation of these phenomena may require an understanding of new physical processes (for example Harwit et al. 1986).

2) We will be better off if we study a moderate number of galaxies in great detail rather than gathering large quantities of statistics.

3) The objects will be difficult to study at optical, near infrared, and x-ray wavelengths because the optical depth in dust is too large. This was nicely pointed out by Rieke in his review.

4) We need infrared diagnostics and tools to make these studies. The primary diagnostic will be infrared spectroscopy with high angular resolution. The spectroscopy is important to understand the physical environment and to get velocity information. High quality observations will be necessary in conjunction with theoretical and laboratory studies of molecular and atomic lines.

FACILITIES FOR FUTURE OBSERVATIONS

As regards tools for these studies, ground-based, suborbital, and space-based platforms will all be important. From the ground, infrared use of the new large telescopes like the Keck 10-meter will be extremely important. This is especially true with the use of multi-element detectors at infrared wavelengths, both for imaging and spectroscopy. Also the new submillimeter telescopes, presently under construction, will be of extreme importance in studying these galaxies in the continuum and in spectral lines. Another important tool will be the proposed 3-meter airplane telescope, SOFIA. This instrument will provide a large collecting area for spectroscopy above the earth's atmosphere and will allow high angular resolution for imaging in the far-infrared.

In space, the second generation of instruments on HST will include an instrument that extends the wavelength coverage to 2.5 μm. Because of the extreme high angular resolution possible with HST this instrument will be very important. This is particularly true for the P_α line that cannot be seen from the ground.

The reduced background of a cryogenic telescope in space increases the sensitivity of an infrared telescope many orders of magnitude. Therefore, ISO and SIRTF will be critical in studies of these galaxies. I have a political concern about where these projects are headed. ISO is approved, but is now making many critical compromises because of funding. These compromises will seriously jeopardize the science return. SIRTF does not appear to be able to get in the long NASA queue of approved projects. As an outsider, I have the following question: Is it not scientifically reasonable to bring the two projects together and create the best of both projects? It seems especially relevant to discuss this today at the scientific meeting discussing the results of the extremely successful European-USA project IRAS.

SUMMARY

A year ago Malcolm Longair reviewed the first IRAS conference and concluded that the most important new result discussed at the conference was the existence of small grains or large molecules--a discovery that, in fact, was not made by IRAS. This year I am happy to report that IRAS has brought infrared astronomy into the "big league" with respect to luminous phenomena in galaxies. It now seems clear that in the luminosity range from 10^{12} to 10^{13} $L_\odot$ there is a large density of luminous infrared galaxies. In this luminosity range, the space density of galaxies selected by their infrared emission appears larger than the corresponding objects selected on the bases of their optical, radio, or x-ray emission. More important, I personally believe that it will be the detailed studies of these infrared galaxies that will give us the answer to the energy source in all luminous objects such as Seyfert galaxies and QSOs.

REFERENCES

Beckiin, E. E., and Wynn-Williams, C. G. 1986, this conference.
Cutri, R. M. 1986, this conference.
Devereux, N. 1986, this conference.
Emerson, J. P., Clegg, P. E., Gee, G., Cunningham, C. T., Griffin, M. J., Brown, L. M. J., Robson, E. I., and Longmore, A. J. 1984, Nature, 311, 237.
Harwit, M. O., Houck, J. R., Soifer, B. T., and Palumbo, G. G. C. 1986, this conference.

Hawarden, T. G., Mountain, C. M., Leggett, S. K., and Puxley, P. J. 1986, this conference.

Joseph, R. D., and Wright, G. S. 1986, *M.N.R.A.S.*, 214, 87.

Keel, W. C. 1986, this conference.

Kleinmann, S., and Keel, W. C. 1986, late paper this conference.

Krugel, E., Chini, R., Kreysa, E., and Mezger, P. G. 1986, this conference.

Lo, K. Y., Masson, C. R., Phillips, T. G., and Scoville, N. Z. 1986, this conference.

Lonsdale, C. J., Persson, S. E., and Matthews, K. 1984, *Ap. J.*, 287, 95.

Mezger, P. G., Cox, P., and Krugel, E. 1986, this conference.

Persson, C. G., and Helou, G. 1986, this conference.

Rieke, G. 1986, this conference.

Rodriguez-Espinosa, J. M., Rudy, R. J., and Jones, B. 1986, this conference.

Sanders, D. B., Scoville, N. Z., Soifer, B. T., Young, J. S., Schloerb, F. P., Rice, W. L., Danielson, G. E. 1986, this conference.

Sargent, A. I., Scoville, N. Z., Sanders, D. B. and Soifer, B. T. 1986, late paper this conference.

Sofue, Y. 1986, this conference.

Soifer, B. T., Sanders, D. B., Neugebauer, G., Danielson, G. E., Persson, C. J., Madore, B. F., Persson, S. E. 1986, this conference.

Wilson, A. S. 1986, this conference.

Young, J. S. 1986, this conference.