Longslit Optical Spectroscopy of Powerful Far-Infrared Galaxies

Lee Armus[1]
Timothy M. Heckman[1]
George K. Miley[2]

[1]Astronomy Program, University of Maryland
[2]Space Telescope Science Institute, on leave from Leiden University

It has been known since the IRAS mission that there exist galaxies with far-infrared luminosities of 10^{11}-$10^{12}L_o$, and $L_{FIR}/L_B \approx$10-100. Through extensive modelling and observations of HII-region/molecular cloud complexes in the Galaxy, this infrared radiation is believed to be thermal emission from heated dust grains (c.f. review by Stein and Soifer 1983). While starburst models are consistent with the data over a large range in wavelength, direct evidence for sizeable populations of young stars is scarce, and in many cases the presence of an active nucleus either cannot be ruled out, or is required on the basis of energy considerations. In order to better understand the energy source responsible for heating the dust, we have undertaken a spectroscopic survey of galaxies chosen to have far-infrared spectral energy distributions similar to the prototypical class members Arp 220, NGC 6240, NGC 3690, and Mrk 231. It was required that between 25μ and 60μ, $\alpha \leq -1.5$, and that between 60μ and 100μ, $\alpha \geq -0.5$, where $S_v \propto v^{\alpha}$.

1. Emission-line ratios

When placed on two-dimensional line ratio diagrams, such as those studied by Baldwin, Phillips, and Terlevich (1981), our far-infrared galaxies cannot be comfortably assigned to either the AGN, or HII-region class. As can be seen in Fig.1, the galaxies straddle the boundary between the loci of objects photoionized by hot stars, and those thought to be shock heated, or ionized by a non-thermal continuum. There are very few galaxies in our sample (≤ 5%) with line ratios typical of those found in Seyferts. Shock model D of Shull and McKee (1979), with a shock speed of 90 km s^{-1} and a preshock density of 10 cm^{-3}, produces relative line intensities similar to those found for the members of our sample that fall in the LINER region. Also, the power law photoionization models of Ferland and Netzer (1983) with $-3.5 \leq \log U \leq -3.0$, and one tenth solar metal abundance seem coincident with the location of our far-infrared galaxies in two of the three line ratio diagrams studied. The [OI] λ6300Å / Hα ratio in M82 has a pronounced minimum in the vicinity of the nucleus. As one samples the emission-line gas at increasing radii along the minor axis, the [OI]/Hα ratio becomes more characteristic of gas that is shock heated. Seven galaxies display composite emission-line profiles, consisting of relatively narrow line cores, plus broad, often asymmetrical bases. This asymmetry usually takes the form of a blueward excess.

2. Stellar populations

The average value of the equivalent width of the MgI λ5174Å absorption band in our infrared color selected galaxies is much lower than that found in a complete comparison sample of optically bright galaxies (Heckman, Balick, and Crane 1980). This can be seen in Fig. 2. In at least some cases, this weak MgI absorption is extended well off the nucleus. The continuum colors of the program galaxies span a range that is equivalent to that found for the galaxies in the optically bright sample. A linear correlation is seen between the continuum color, and the balmer decrement, with most of the galaxies falling between the reddening lines of a population of ZAMS stars, and a cluster of stars 10^9yrs old (Jacoby, Hunter, and Christian 1984). A strong correlation is also found between the continuum colors, and the equivalent width of the blended interstellar Na D lines at 5890Å, and 5896Å. Four galaxies in our sample exhibit strong balmer absorption lines in their integrated spectra, similar to that found in A stars. In another four of our galaxies, a broad feature identified with HeII λ4686Å is observed. This feature is typically very weak, (EQW ≤ 2Å), except in the galaxy 01003-2238, and is believed to arise in the winds of Wolf-Rayet stars.

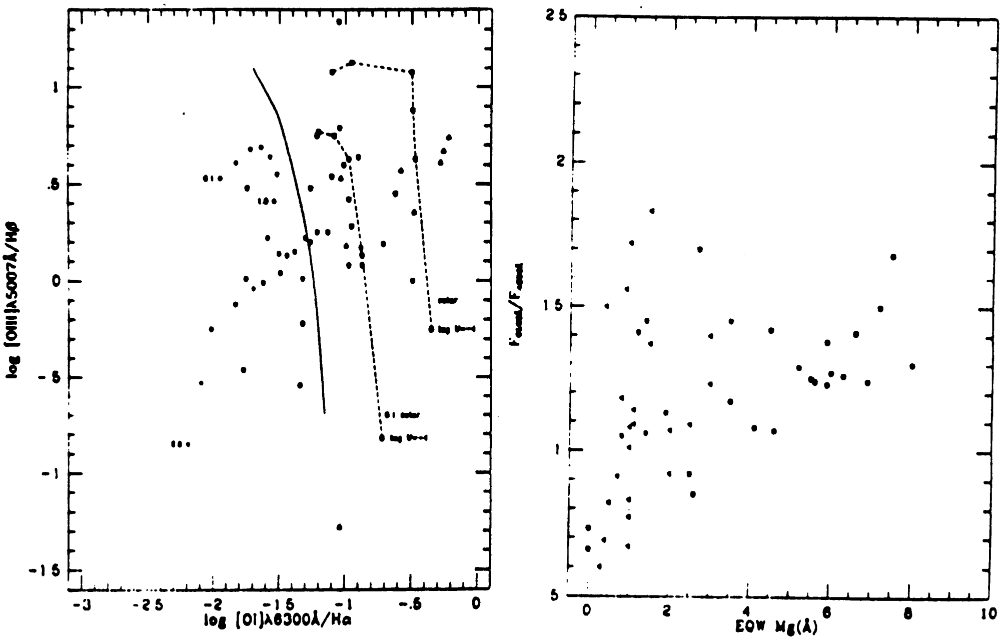
D. E. Osterbrock and J. S. Miller (eds.), Active Galactic Nuclei, 414–415.

Conclusions

The relative emission-line fluxes measured for our far-infrared galaxies most probably represent the fact that we have chosen a mixture of different types of galaxies, all of whom show infrared emission characteristic of dust at temperatures hotter than normal galaxies, but cooler than typically found in Seyfert galaxies. There do seem to be at least some members of our sample that can have their relative emission-line fluxes reproduced by shock models with reasonable parameters, or low metal abundance power-law photoionization models. These might be objects that harbor a relatively weak active nucleus. In fact, the variation in relative emission-line flux in M82 as a function of nuclear distance suggests that a number of these galaxies might exhibit strong contributions to the ionizing radiation from OB stars, as well as from shocks.

The asymmetrical line profiles seen in some of the galaxies could very well be the result of either infall of optically thick clouds, or outflow of the ionized gas due to the kinetic energy input of the many supernovae which would follow a starburst phase. Outflow such as this is believed to be occuring in M82 (Heckman, Armus, and Miley 1987).

The weak, extended MgI absorption, and the spectroscopic signatures of Wolf-Rayet stars, suggest that in many of the galaxies a significant young stellar population is present, and is instrumental in ionizing much of the emission-line gas. The range in continuum colors is apparently the result of varying, and in some cases considerable amounts of interstellar extinction acting upon this young stellar population.



Baldwin, J.A., Phillips, M.M., and Terlevich, R. 1981, *P.A.S.P.*, *93*, 5.

Ferland, G.J., and Netzer, H. 1983, *ApJ.*, *264*, 105.

Heckman, T.M., Armus, L., and Miley, G.K. 1987, *Astron. J.*, *93*, 276.

Heckman, T.M., Balick, B., and Crane, P.C. 1980, *Astron. and Astrophys. Suppl.*, *40*, 295.

Jacoby, G.H., Hunter, D.A., and Christian, C.A. 1984, *ApJ. Suppl.*, *56*, 257.

Shull, J.M., and McKee, C.F. 1979, *ApJ.*, *227*, 131.

Stein, W.A., and Soifer, B.T. 1983, *Ann. Rev. Astron. and Astrophys.*, *21*, 177.