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STAR FORMATION IN SEYFERT GALAXIES

J.M. Rodriguez Espinosa
European Southern Observatory,
Garching bei München, F.R.G.

Richard J. Rudy
Space Science Laboratory,
The Aerospace Corporation, Los Angeles

and

Barbara Jones
Center for Astrophysics and Space Science,
University of California, San Diego

An analysis of the IRAS data for a sample of classical (optically selected) Seyfert galaxies is presented. The IRAS fluxes at 25 μm, 60 μm, and 100 μm are found to be uncorrelated or only very weakly correlated with the UV/Optical continuum flux and the near and mid IR flux at 3.5 and 10 μm. To investigate the possibility that star formation accounts for the far IR flux, the IRAS measurements for the Seyfert galaxies are compared to IRAS observations of a sample of normal spiral galaxies, and a sample of Starburst galaxies. It is shown that the far IR luminosities and far IR colors of Seyfert galaxies are indistinguishable from those of the Starburst galaxies. Besides, normal galaxies are an order of magnitude less luminous than both the Seyfert and the Starburst galaxies. This indicates that star formation produces the bulk of the far-infrared emission in Seyfert galaxies.

1. INTRODUCTION

For quite a few years now, it has been known that Seyfert galaxies are strong near and far-IR sources (Rieke 1978). In this classical paper, Rieke also inferred that Seyfert galaxies might also be strong far-IR sources, and moreover, that a large fraction of their total luminosities is emitted in the infrared at wavelengths longer than ~30 μm. However direct ground-based observations of the far-IR output of these sources was not feasible due to the opacity of the atmosphere. In some instances balloon and aircraft observations of a few bright objects were carried out. That is the case for NGC 1068 (Telesco, Harper and Loewenstein 1976; Telesco and Harper 1980), NGC 4151 (Rieke and Lebofsky 1979) and NGC 4051 (Smith et al. 1983). It is interesting that in all these cases the far-IR output was interpreted as arising from emission by warm dust heated in regions of star formation. However it is only in the post-IRAS era that the far-IR emission from larger samples of objects can be studied.

Concerning Seyfert galaxies the first question to be asked is: what is the role of the active nucleus in the far-IR? It is well known that the nucleus is responsible for most of the properties of Seyfert galaxies. However, very recently we (Rodriguez Espinosa et al. 1986; Paper I) have concluded that the far-IR emission from the active nucleus does not account for the bulk of the emission from Seyfert galaxies observed by IRAS. Our claim was based on two main points:

i) the far-IR emission originates in an extended region.

ii) in most Seyfert galaxies the non-thermal UV-optical continuum luminosity is not large enough to account for the far-IR emission via dust-reradiation of the UV-optical continuum.

Here we would like to explore further the relationship between the nucleus and the far-IR properties of Seyfert galaxies.

2. THE DATA

For our study we have considered a sample of optically selected Seyferts consisting primarily of those galaxies in Rieke (1978) and Yee (1980), most of which are overlapping. The 3.5 μm and 10 μm data are from Rieke while the UV data are from Yee. We have increased the sample with objects measured in the IR by Rudy et al. (1982) and Rudy and Rodriguez Espinosa (1985). In total there are 96 objects in the sample. Of these, 58 were detected by IRAS, and 2 objects (Mrk 304 and NGC 4151) were not observed. As for the objects not detected most of them are at redshifts such that more likely their IR emission is below the IRAS sensitivity limits.

3. RESULTS

Correlation analysis has been used to explore possible relationships of the far-IR emission of Seyfert galaxies with the active nucleus. The active nucleus is considered responsible for the UV-optical continuum emission (Weedman 1977) and for the near (3.5 μm) and mid-infrared (10 μm) emission (Rieke 1978; McAlary, McLaren and Crabtree 1979). These have been correlated with the IRAS data at 25, 60 and 100 μm with the following results:

i) Only the 25 μm emission correlates to a high degree of confidence with the 3.5 μm and 10 μm emission, indicating that whatever mechanism powers the near and mid-IR emission is also responsible for a large part of the emission from these objects at 25 μm.

ii) The UV-optical continuum emission from Seyfert galaxies does not correlate with the far-IR emission detected by IRAS.

iii) The 60 and 100 μm IRAS emission from Seyfert galaxies is uncorrelated or only weakly correlated with the 3.5 μm and 10 μm infrared emission from these sources, suggesting a weak or, at most, indirect relation between the mechanism producing the near and mid-IR emission and that responsible for the far-IR fluxes detected by IRAS.

These results underscore the idea proposed in Paper I that a large fraction of the far-IR emission from Seyfert galaxies originates in a source other than the active nucleus (see also Neugebauer, Soifer and Miley 1985).

4. STARBURSTS IN SEYFERT GALAXIES

To investigate the possibility that star formation accounts for a large fraction of the far-IR output from Seyfert galaxies, we have compared the IRAS

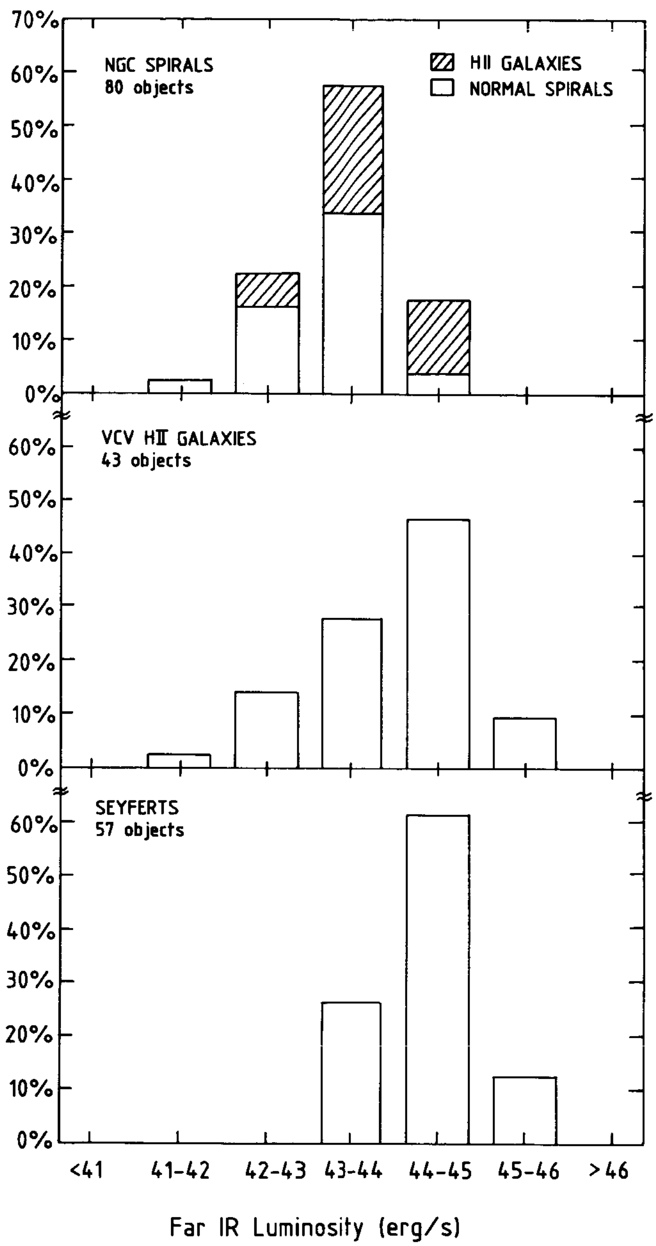

Fig. 1. The far-IR luminosity distribution of NGC spiral galaxies (top), Starburst galaxies (Véron-Cetty and Véron HII galaxies; middle), and Seyfert galaxies (bottom). In the top histogram those NGC spirals undergoing starbursts are represented by the shaded area. Note that the Seyfert galaxies are, on the average, an order of magnitude brighter than normal NGC spirals, and comparable in far-IR luminosity to the starburst galaxies.

measurements of these objects to the IRAS observations of both a sample of normal spiral galaxies and a sample of HII region galaxies. The samples of spiral galaxies and HII galaxies are those of Keel (1983) and Véron-Cetty and Véron (1984). An examination of the far-IR (IRAS) luminosity distribution of the spiral galaxies shows that on average, in the far-IR, spiral galaxies are an order of magnitude less luminous than Seyfert galaxies (Fig. 1). Moreover, the majority of the spiral galaxies whose far-IR luminosity is comparable to the far-IR luminosity of the Seyfert galaxies are what Keel (1983) described as galaxies having HII region-like spectra.

The central diagram of Figure 1 shows the luminosity distribution of the Véron-Cetty and Véron (1984) HII region galaxies. Note the striking similarity with the far-IR luminosity distribution of the Seyfert galaxies (Fig. 1, bottom).

The far-IR spectral indices for the Seyfert and the Starburst (HII) galaxies have also been examined. Figures 2 and 3 show the 60 through 100 μm,

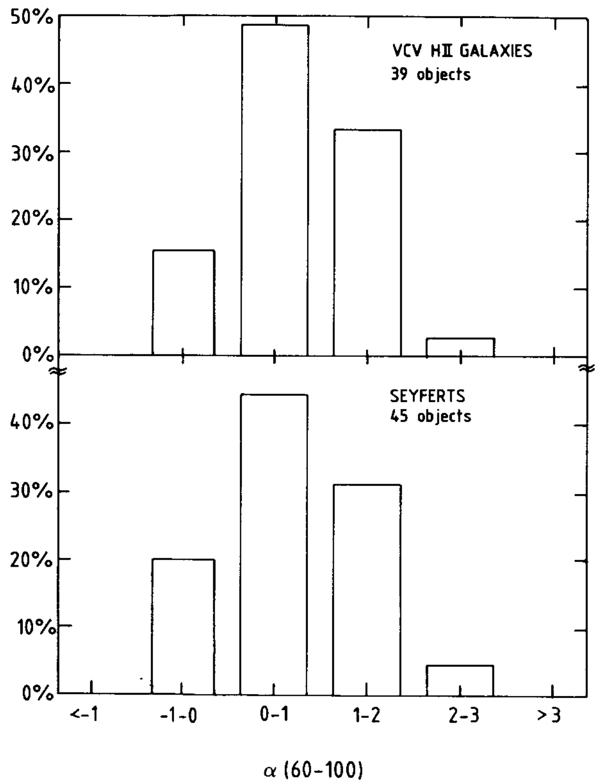

Fig. 2. The 60 through 100 μm spectral index distribution for the starburst objects (top) and the Seyfert galaxies (bottom). Note again the very clear similarity of these two distributions.

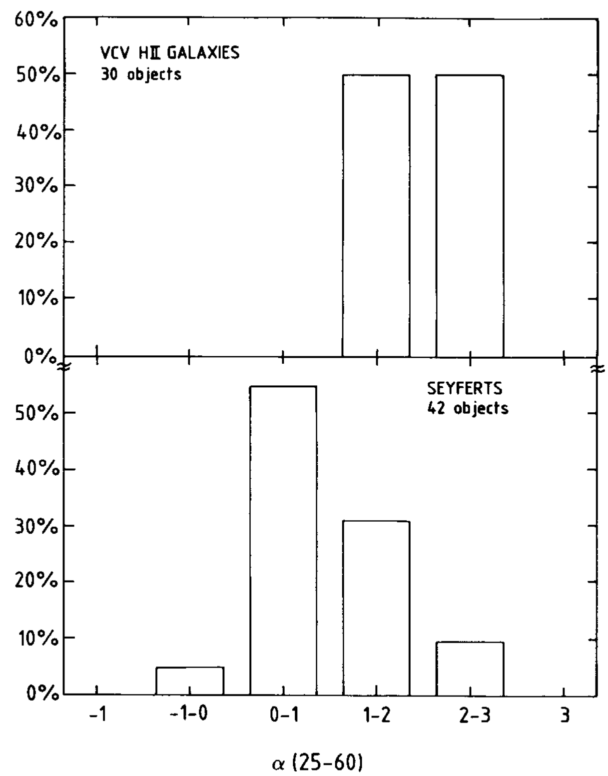

Fig. 3. The 25 through 60 μm spectral index distribution for the starburst objects (top) and the Seyfert galaxies (bottom). The Seyfert galaxies show much bluer spectral indices due to the emission from the active nucleus at the shorter wavelength.

α(60-100), and the 25 through 60 μm, α(25-60), spectral index distributions for the two types of galaxies. Note the great similarity between the α(60-100) spectral indices (Fig. 2) of both the Seyfert and the Starburst galaxies. Note at the same time the large dispersion in the values of α(60-100) for both the Seyfert and the Starburst galaxies. This dispersion can be explained by assuming that most of the 60 and 100 μm emission is due to radiation by warm dust at temperatures ranging from about 35 to 75°K (λ^{-1} emissivity). Furthermore, these temperatures are typical of dust heated by young stars in regions of star formation (e.g. Harper 1974).

Coming now to the 25 through 60 μm spectral indices we find much bluer indices in the Seyfert galaxies than in the Starburst galaxies. But this is not surprising since we would expect the strong emission from the active nucleus to reveal its presence at the shorter (25 μm) wavelength. The Starburst galaxies on the contrary show a very steep rise at the short wavelength (Fig. 3). The large dispersion seen in the α(25-60) spectral indices of the Seyfert galaxies is probably related to variations in the relative contributions of the active nucleus and the Starburst component at these two IRAS bands.

5. CONCLUSION

From the high similarity between the far-IR properties (luminosity and spectral index) of Seyfert and Starburst galaxies we conclude that a large fraction of the emission at far-IR wavelengths of Seyfert galaxies is produced by star formation episodes in regions around the active nucleus. Besides, the high incidence of large far-IR output among the Seyfert population suggests the existence of a causal link between the active nucleus and the presence of bursts of star formation.

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DISCUSSION

EDELSON:

Your sample is both optically and infrared selected (only approx. 60% IRAS detections), so dusty objects will be over-represented compared to a true optically selected sample. Also, you study generally nearby low nuclear luminosity AGNs because of your stringent IRAS limit. You find larger values of $S_{12\mu m}/S_{10\mu m}$ than other AGN samples because the ratio of nuclear/galaxy luminosity is unusually low. The relatively steep 60-100μm IRAS spectra seen are caused by a mixture of the steep spectrum emission from the underlying galaxy mixing with the flat nuclear component. These is no evidence for starbursts in most high luminosity AGNs.

RODRIGUEZ ESPINOSA:

I think that the sample is really optically selected. It consists mainly of Markarian Seyferts, which by definition are not dusty objects, and a few classical NGC Seyferts. Your question is nevertheless very relevant. I agree that in very high luminosity objects it is difficult to find evidence of starbursts, but is it because they are not there or because we do not see them? It may well be that you can see starbursts only in a certain luminosity range, in the same way that it is difficult to observe the galaxy envelope in high redshift QSOs.

DEVEREUX:

What evidence do you have that the star formation is near the nucleus? Be wary when using IRAS colors because they reflect the nucleus/disk contrast and so you need spatial resolution to separate the nucleus and disk emission.

RODRIGUEZ ESPINOSA:

Presently, no high spatial resolution far-infrared data are available and hence the only information we have is from optical, near and mid-infrared photometry and radio work for a small set of well known sources (NGC 1068, NGC 7469...)

Concerning the far-infrared contribution of the galaxy disk we have shown that 'normal' galaxy disks are on the average one order of magnitude less luminous than either Seyfert or starburst galaxies.

BEGELMAN:

Based on the spectropolarimetry of Antonucci and Miller, one can make a strong case that NGC 1068 contains a normal type 1 Seyfert nucleus, which is obscured by a ring of gas which is so optically thick that it may well be molecular. If Seyfert 2's differ from Seyfert 1's in the presence of absence of a thick molecular disk, one might expect starbursts to be associated preferentially with Seyfert 2's.

RODRIGUEZ ESPINOSA:

That is an interesting point, although I do not think that the difference between type 1 and type 2 Seyferts is as simple as that.

DENNEFELD:

One should be careful in using the 'HII region galaxies' from the VCV catalogue as a comparison sample because it contains only the few objects which have at some time been considered as AGN and disregarded later. They might well have some peculiarity (faint or hidden active nucleus, hotter gas, ...). The luminosity or $\alpha(60,100)$ histograms of 'normal' galaxies are much broader: the fact that your histograms for HII region type or active galaxies from the VCV catalog coincide might just be a selection effect.

RODRIGUEZ ESPINOSA:

An important consideration that went into choosing the VCV HII region galaxy sample is that their redshifts are comparable to the redshifts of the optically selected Seyferts and therefore one avoids the problems associated with beam size effects. You are right, however, in that one should be cautious when using the VCV sample of HII regions. I shall look into that....