EXTENDED FAR-INFRARED EMISSION AND STAR FORMATION IN SEYFERT GALAXIES

A. P. MARSTON
Dept. of Physics & Astronomy, Drake University, Des Moines, IA 50311

ABSTRACT An investigation into the extended distribution of far-infrared (FIR) emission associated with nearby Seyfert galaxies is made using a set of MEM reconstructions of IRAS Chopped Photometric Channel (CPC) data (Marston 1993). The data is compared to a set of H II/starburst galaxy images similarly processed in order to compare distributions and FIR color properties. It is shown that the central 1 kpc or so of Seyfert galaxies show extended FIR emission. FIR colors suggest that the bulk of this emission is not directly associated with an active nucleus. They further suggest that the origins of the majority of the emission is from heated dust associated with star formation surrounding the nucleus rather than dust heated by the active nucleus. Nearby Seyfert galaxies are shown to have a higher concentration of far-infrared emission from their centers than the H II/starburst galaxies and a number appear to reside in disk galaxies with relatively low ongoing star formation in their disks. An example of this is NGC 7582 which has a smooth disk but an active nucleus/starburst center.

INTRODUCTION

IRAS point source results showed Seyfert galaxies to be strong FIR emitters. There are three main candidates for this emission:

i) direct association with an active nucleus
ii) circumnuclear dust heated by the active nucleus
iii) circumnuclear dust heated by hot stars.

Although direct emission from a central nucleus is unlikely in all but the brightest of blazers, there is some debate as to the which of the other two possibilities are the main cause for the FIR emission (see, e.g., Miley et al. 1985; Rodriguez Espinosa et al. 1986). There is also the possibility that unresolved disk emission from the Seyfert galaxies may contribute to the IRAS point source fluxes used in these studies.

A link between star formation and the presence of an active nucleus has been presented by Rodriguez Espinosa et al. 1987 and Edelson et al. 1987. They suggest that Seyfert host galaxies are substantially more luminous than galaxies in the field which might be explained by a link between global star formation and the activity observed in the nuclei.

S. Terebey and J. Mazzarella (eds.), *Science with High-Spatial Resolution Far Infrared Data*, 107–113, 1994, Jet Propulsion Laboratory, Pasadena, CA.

PROGRAM OF INVESTIGATION

In order to investigate the distribution of FIR emission in Seyfert galaxies and its possible connection to the active nucleus and star formation, a study of MEM processed IRAS CPC images of 13 nearby Seyferts, 4 LINERs and 12 H II/SB galaxies has been made. The procedure for this is detailed in Marston (1992) and Marston (1993). Basically, several raster scans of a given object, made at 50 and 100 μm by the IRAS CPC, were background subtracted and then coadded. This image was then reconstructed using MEM, with a noise estimate based on the image repeatability being used to constrain the MEM image reconstructions.

The specific intent of this investigation was to:

i) to search for extended FIR emission in Seyfert galaxies

ii) to compare their FIR properties with those of H II/SB galaxies

iii) To consider their star formation properties based on their FIR emission, in particular their disk emission properties compared to that of more normal galaxies.

EXTENDED FAR-INFRARED EMISSION IN SEYFERT GALAXIES

In 11 out of 13 Seyfert galaxies investigated, extended FIR emission was observed. Extended emission included elongated contours up to a full, distinct disk component in the images. Some examples of images obtained are shown in Figure 1. Extended emission was noted in 9 out of the 12 H II galaxies and all 4 LINERs (examples shown in Figure 2). Taking the full width at half maximum of the processed image of a point source to be 24″, estimates of the size of the FIR emitting regions were made. Estimates for emitting region sizes ranged from unresolved to 8 kpc (NGC 1566, a Seyfert 1). A synopsis of these results are given in Table 1.

The extended x-ray emission in NGC 2992 and NGC 1566 have the same positional angle along the extension as compared to the extended FIR emission (Elvis et al. 1990).

The existence of significant extended emission rules out direct FIR emission from the nucleus as a possible source in Seyfert galaxies.

COLORS IN RESOLVED GALAXIES

Estimates of the optical depth for the nuclear regions of these galaxies did not exceed 0.1 at 100 μm. So FIR colors should be relatively unaffected by optical depth effects.

It is worth noting that of the 6 Seyfert 1 galaxies observed, those with the smallest optical depth were NGC 1566 and NGC 2992, both of which were shown to have extended x-ray emission in the study of Elvis et al. (1990).

For Seyfert and H II region galaxies where the disk and nuclear emission regions were resolved, their FIR colors were obtained and compared. In the case where an active nucleus is heating dust we might expect a significant portion of the FIR emission to be from higher temperature dust at the center. This would show as a high 50/100 μm FIR ratio. Comparison of nuclear to disk

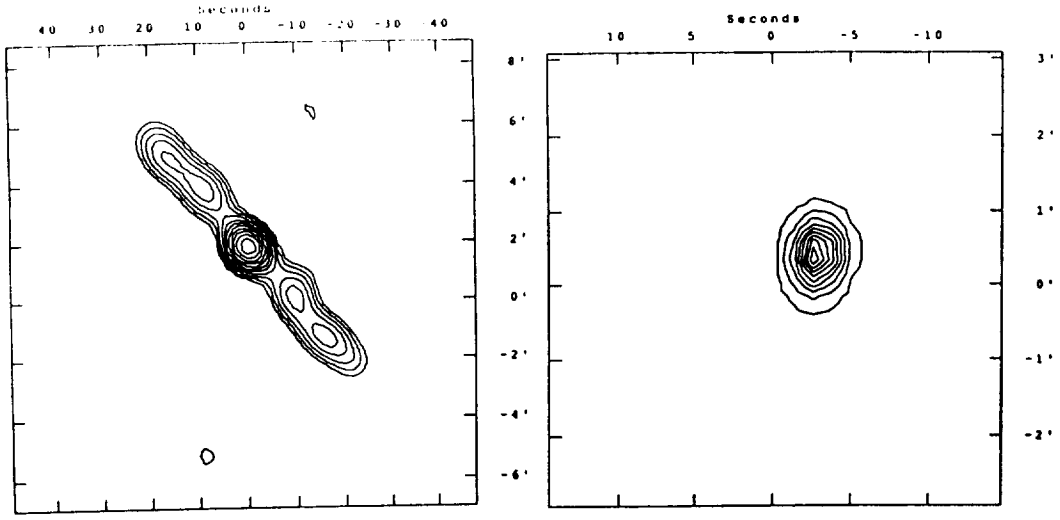

FIGURE 1 MEM reconstructions of the galaxy NGC 4945 (a Seyfert 1 galaxy) at 50 μm (left) showing a FIR disk, and NGC 3281 (a Seyfert 2 galaxy) at 100 μm (right) showing extended FIR emission but no obvious disk.

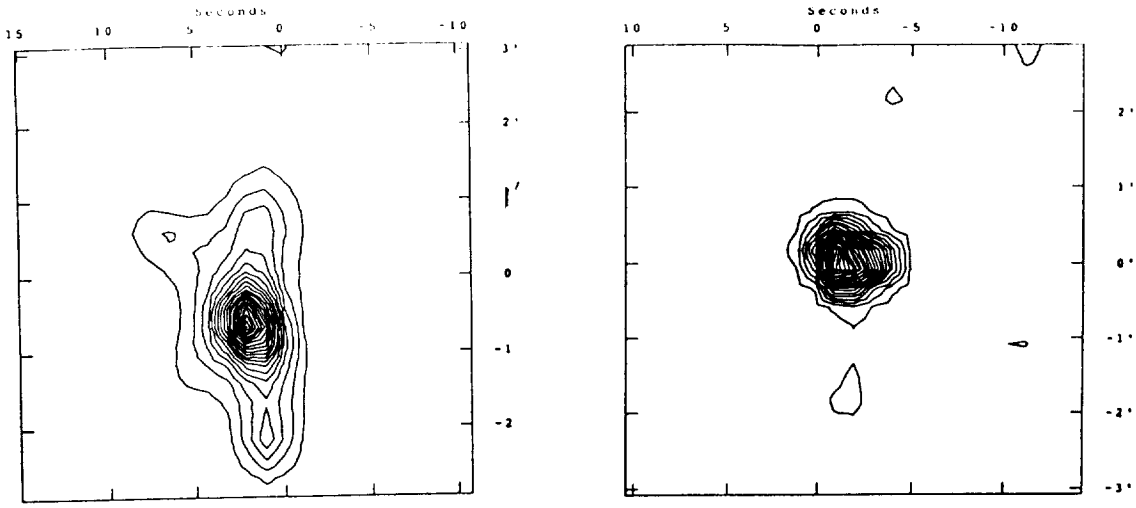

FIGURE 2 MEM reconstructions of the H II galaxies NGC 2903 at 50 μm (left) and NGC 660 at 50 μm (right) showing disk and extension.

Table 1 – Sample Listing and Far-Infrared Source Sizes.

Name (NGC)	Type	Disk	Nuclear size (kpc)	Name (NGC)	Type	Disk	Nuclear size (kpc)
660	H II	No	2.1	1275	Sy1	No	-
1365	Sy1	Yes	4.0	1566	Sy1	No	7.8
1569	H II	Yes	0.5	1808	H II	Yes	1.9
2377	H II	No	-	2903	H II	Yes	1.2
2992	Sy1	No	2.9	2993	H II	No	2.9
3079	LINER	Yes	3.8	3281	Sy2	No	2.6
3310	H II	No	-	4438	LINER	No	1.9
4631	H II	Yes	3.0	4945	Sy1	Yes	1.2
5033	Sy1	Yes	1.0	5055	LINER	Yes	1.0
5194	Sy2	Yes	2.2	5195	H II	No	-
5236	SB	Yes	0.9	5866	H II	No	0.8
6221	Sy2	Yes	2.6	6300	Sy2	Yes	-
7331	LINER	Yes	1.9	7469	Sy1	No	-
7552	H II	No	4.5	7582	Sy2	Yes	1.2
7590	Sy2	No	2.5				

Sy1 = Seyfert 1, Sy2 = Seyfert 2, SB = Starburst, H II = H II region galaxy, LINER = Low Ionization Narrow Emission-line Region (from Marston 1992).

colors shows no significant difference between Seyfert and non-Seyfert nuclear and disk color ratios (see Figure 3, taken from Marston 1992). Further, if the nuclear emission dominated the rest of the emission in the Seyfert galaxies we might expect the nuclear FIR ratio be particularly high for these galaxies. In Figure 4 (from Marston 1992) this is again shown not to be the case. However, the Seyferts observed do have a greater tendency for nuclear rather than disk FIR emission.

STAR FORMATION IN THE DISKS OF SEYFERT GALAXIES

In order to investigate whether the active nucleus has any effect on star formation in the disk of the host galaxies we can compare the FIR disk luminosity of the Seyfert galaxies with that of the non-Seyfert galaxies. The FIR luminosity was calculated from the FIR flux obtained from the following equation

$$F(FIR) = 1.26[3.1S(50) + S(100)] \times 10^{-14} W\ m^{-2} \qquad (1)$$

where $F(FIR)$ is the FIR flux, $S(50)$ is the flux at 50 μm in Janskys and $S(100)$ is the flux at 100 μm measured in Janskys (from Marston 1991). For resolved galaxies, non-Seyferts have an average disk luminosity of $1.7 \pm 0.7 \times 10^{10} L_{\odot}$, while the Seyferts have an average disk luminosity of $1.4 \pm 0.6 \times 10^{10} L_{\odot}$. But 3 out of 6 disk resolved Seyferts have $< 5 \times 10^{9} L_{\odot}$ in their disks.

These findings are consistent with the longslit findings of Carone (1992), where no differences could be discerned between the properties of H II emission line complexes in RnormalS and Seyfert galaxies.

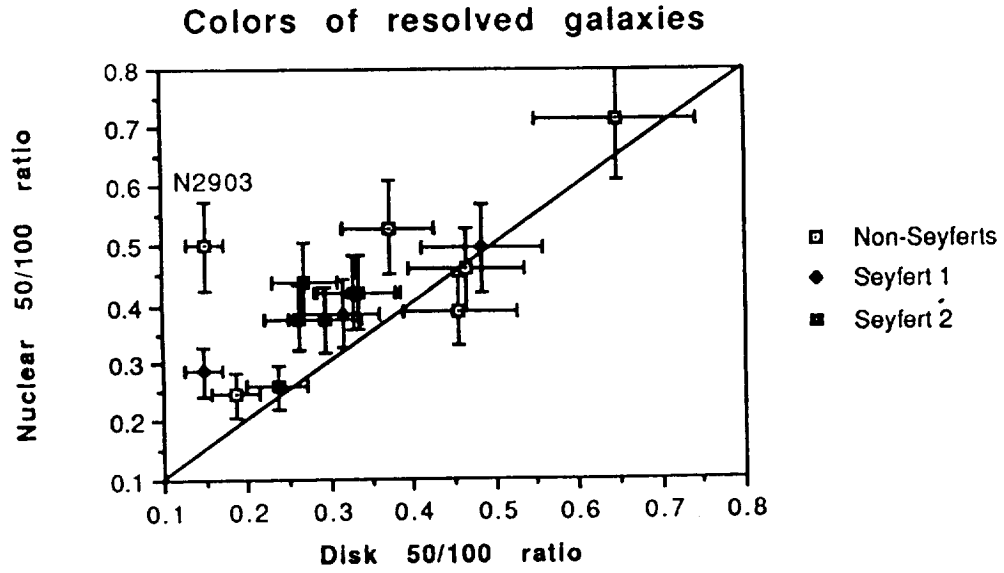

FIGURE 3 FIR disk and nuclear colors compared for the Seyfert and H II region galaxy samples. The distribution suggests no extra heating components are obvious from the emission of the central regions of Seyfert galaxies (from Marston 1992).

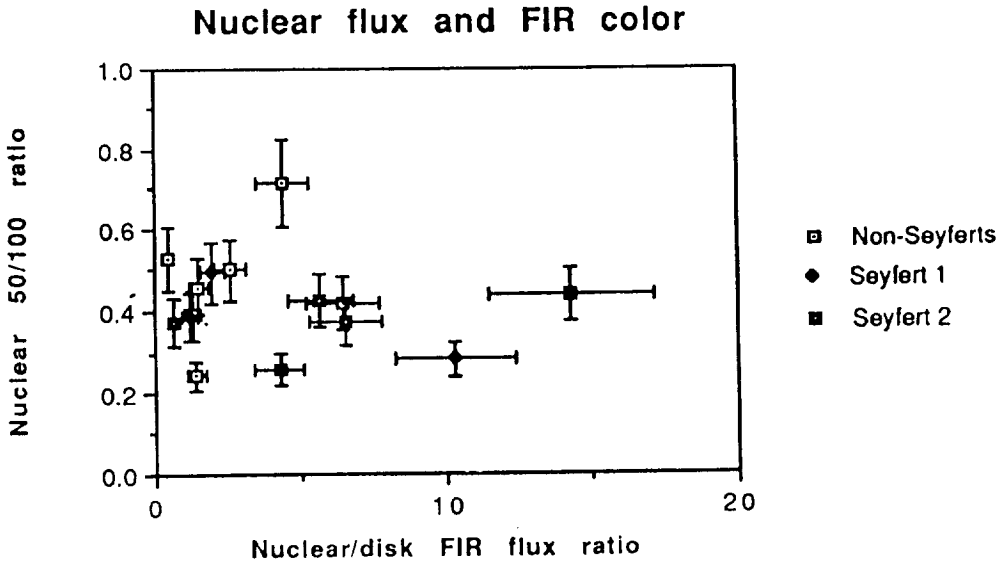

FIGURE 4 Nuclear color compared to the nuclear/disk FIR luminosity ratio. The presence of a dominant nuclear region in the FIR does not affect the nuclear colors (from Marston 1992).

CONCLUSIONS

The extended nature of the FIR emission in nearby Seyfert galaxies indicates that little if any FIR emission comes directly from their nuclei.

Few observable differences exist between the FIR properties of the disks and nuclei of the Seyfert and H II galaxies investigated. Their disk and nuclear colors suggest similar heating mechanisms, which would indicate that the FIR emission associated with the heating of dust by an active nucleus is minimal. A more likely source of dust heating is hot, new stars in both the disks and nuclei of Seyfert galaxies.

The FIR colors seen in the disks of Seyfert galaxies and the FIR luminosity from these disks suggest that the host galaxies of Seyferts have similar star formation properties to more "normal" galaxies. Typically, Seyfert galaxies have higher FIR luminosity nuclei compared to their disks than the other galaxies investigated, which suggests that star formation is often proceeding at an enhanced rate in the central few kiloparsecs of Seyferts.

The low FIR emission observed in the disks of Seyfert galaxies suggests that there is a lack of star formation in these regions, and suggest that the active nucleus has little or no effect on star formation this far out. However, the excess FIR emission seen in the central regions suggests there may be a causal link here, the star formation possibly being induced by the output from an active nucleus and its interaction with the interstellar medium in the central few kiloparsecs of Seyfert galaxies. A good example of this combination is NGC 7582 which has an H II region surrounding the active nucleus but also has a smooth, quiescent disk (Morris et al. 1985). This agrees with the suggestions of Rodriguez Espinosa et al. (1987) and Edelson et al. (1987) of a connection between the active nucleus and star formation in Seyfert galaxies.

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