IRAS OBSERVATIONS OF SEYFERT GALAXIES

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ABSTRACT

IRAS measurements at 25, 60 and 100 μm have been used to analyze the infrared properties of Seyfert galaxies from the Markarian and NGC Catalogs. One hundred and sixteen of 186 Seyfert galaxies were detected. About 50% of all Seyfert galaxies in the sample have 60-μm luminosities in excess of $\sim 10^{10}$ $L_\odot$, and the mean 60 μm luminosity increases with the optical B absolute magnitude. The luminosity functions of the Seyfert 1 and Seyfert 2 galaxies appear quite similar. It is possible, however, to statistically separate the two types of galaxies in color-color plots. The 100- to 60-μm energy distributions flatten systematically with increasing 60-μm luminosity. The infrared measurements provide a measure of the bolometric luminosity of the Seyfert galaxies, but do not discriminate between the physical processes involved.

I. INTRODUCTION

The mid- and far-infrared properties of Seyfert galaxies are intriguing for several reasons, but have been measured for only a few galaxies. The IRAS survey of the sky at 12, 25, 60 and 100 μm (Neugebauer *et al.* 1984) has for the first time provided a means of making a statistical survey of a significant number of Seyfert galaxies at these infrared wavelengths.

In this paper we present highlights of an initial statistical survey of the infrared properties of Seyfert galaxies and contrast these properties on the basis of IRAS-produced luminosity and spectral information.

II. THE SAMPLE

All Markarian and NGC galaxies classified as either Seyfert 1 or Seyfert 2 in the compendium of Veron-Cetty and Veron (1984; henceforth VCV) were selected as the prime sample of Seyfert galaxies. Since one of the main goals was to compare the properties of different classes of Seyfert galaxies, the few objects from the sample whose type designation by Huchra (1984) differed from that of VCV were excluded. The sample chosen in this way, which consisted of 104 Seyfert 1 and 84 Seyfert 2 galaxies, had similar selection criteria to the sample used by Meurs (1982) to compute the radio luminosity function of Seyfert galaxies but is enlarged to include later installments of the Markarian Catalog. Galaxies from the 3% of sky not covered by the IRAS survey (see The Explanatory Supplement to the IRAS Catalog, 1985; henceforth the Supplement) were excluded from consideration. In order to provide a comparison, the Markarian and NGC galaxies detected by IRAS and designated by VCV as having nuclear emission-line spectra characteristic of H II regions were also selected as a separate sub-set of emission line galaxies.

Associations with IRAS sources were defined purely on the basis of position, and included all IRAS sources in the IRAS Point Source Catalog (1985) within a radius of 90" of each Seyfert galaxy in VCV (see the Supplement). When no source was detected in the Point Source Catalog, limiting flux densities were obtained from the IRAS Working Survey Data Base described in the Supplement. The chance of a spurious association is about 1 part in 800 at $|b| > 45°$, and increases towards the galactic plane. IRAS sources were associated with 50 of the 104 Seyfert 1 galaxies in VCV and 66 of the 84 Seyfert 2 galaxies.

A discussion of the IRAS observations and uncertainties is given in the Supplement. For the purpose of the statistical study, flux densities of good and medium quality in the IRAS Point Source Catalog(1985), as defined in the Supplement, are included in the sample of detected sources. Objects with good quality flux densities comprise more than 90% of the sample. No color correction was applied to the quoted catalog flux densities since such a correction is less than 3% at 60 and 100 μm and less than 10% at 25 μm for the observed colors of the Seyfert galaxies.

III. RESULTS

Figure 1 is a plot of $\alpha(100,60)$, the 100 to 60 μm spectral index, plotted against $\alpha(60,25)$, the 60 to 25 μm spectral index The spectral index α is defined by $f_\nu \propto \nu^{\alpha}$ where f_ν is the flux density and ν is the frequency. In those cases where only a limit has been measured for one of the flux densities involved in defining the spectral index, no index has been plotted. From the figure it can be seen that there is a segregation of points in the color-color plot. Although the lower right of the diagram appears to be populated by all three classes of galaxies, the upper portion is predominantly filled with Seyfert 1 galaxies. The median spectral indexes for the sources detected at at least one of 25, 60 or 100 μm and divided according to galaxy type are given in Table 1.

The fraction of Seyfert galaxies observed as a function of the 60 μm luminosity was calculated taking into account not only the detected sources but also the detectability of all sources in the sample. The 60 μm luminosity of each source was estimated as the product νL_ν where L_ν is the luminosity density of the source[1]. The luminosity fraction was found by dividing the number of sources of measured luminosity νL_ν, and with flux density f_ν above an adopted completeness limit in each luminosity bin by the number of sources in the VCV sample that could have been detected above the completeness limit if they had the luminosity of that bin (see e.g., Meurs, 1982). Although the IRAS survey is complete to f_ν = 0.5 Jy at 60 μm, 0.7 Jy was chosen as a conservative limit. The resultant distribution in Figure 2 shows that there is no significant difference between the 60 μm fractional luminosity function of Seyfert 1 and Seyfert 2 galaxies. The higher detection rate of Seyfert 2 galaxies is due simply to the fact that the mean distance of the Seyfert 2 galaxies is half that of the Seyfert 1 galaxies in the sample. About half the sample of Seyfert galaxies have luminosities at 60 μm in excess of $\sim 10^{10.1}$ $L_\odot$ or $\sim 10^{36.7}$ Watt. A comparison of the 60 μm fractional luminosity function with that at the optical B waveband shows that the two curves have a displacement consistent with a simple proportionality between the infrared and optical luminosities.

Figure 3 shows that when the 100 to 60 μm spectral index is plotted against the 60 μm luminosity, higher luminosity objects tend to have flatter energy distributions. The different effective diaphragm sizes at 60 μm (~1.5' × 4.8') and at 100 μm (~ 3' × 5') could create an obvious selection effect. For extended sources this would result in an underestimate of the 60 μm flux density relative to that at 100 μm up to a factor of 2 or ~ 1.4 in $\alpha(100,60)$. This would only affect energy distributions of sources close enough to be significantly resolved. If the

[1] Throughout this Letter the Hubble constant will be taken as $H = 75$ km s^{-1} Mpc^{-1}.

typical size of a galactic disk is 20 kpc, a 3′ diaphragm corresponds to recessional velocities $\lesssim$1700 km s^{-1}. Since the correlation is still present after removal of the dozen points due to the Seyfert galaxies closer than this, this effect is probably not important.

IV. DISCUSSION

The infrared observations of Seyfert galaxies have given a measure of the bolometric luminosities of these galaxies. Large numbers of these galaxies (more than 60% of Seyfert 2 galaxies) have their maximum energy output in the mid- and far-infrared implying that this emission must play a crucial role in the overall energetics.

In a simplified picture based on previous observations, the infrared emission from Seyfert galaxies is conjectured to be a mixture of three components:

(1) a cold (~ 30 K) disk component having spectral indexes similar to those in spiral galaxies with non-active nuclei.

(2) a nonthermal nuclear component which extrapolates into the optical and X-rays with an approximate power law index.

(3) a mid-infrared nuclear component which peaks between 20 and 50 μm (see e.g. Jones *et al.* (1977)).

The observations in Figure 1 and Table 1 show that between 60 and 100 μm, Seyfert galaxies have energy distributions which are flatter than those characteristic of non-active galaxies (e.g. de Jong *et al.* 1984) or infrared selected galaxies (e.g. Soifer *et al.* 1984a). For both these latter groups typical spectral indices are α ~-1.7, while more recent samples of infrared selected galaxies have α ~ -1.5. The flat energy distributions of Seyferts would be a natural consequence of a relatively larger contribution to the infrared emission from the nuclear components of these active galaxies. The observed colors of this optically defined sample are also consistent with recent spectroscopic observations of objects identified with flat-spectrum IRAS sources. Using a color selection criterion of $-1.5 < \alpha(60,25) < -0.25$, de Grijp *et al.* (1985) achieved a 70% success rate in detecting hitherto unknown Seyfert galaxies.

The fact that almost all Markarian Seyfert nuclei are located in spiral galaxies might well explain the correlation between luminosity and spectral index in Figure 3. At the larger distances at which the more luminous objects tend to be located the disk component would be relatively fainter and the composite spectrum would be flatter.

The statistical difference between the spectral indexes in Seyfert 1 and Seyfert 2 galaxies can also be explained by different relative contributions of nonthermal and thermal nuclear components. Malkan (1984) has shown that Seyfert 1 galaxies have a very narrow spread in near infrared to X-ray luminosity ratios corresponding to a continuum following a power law between 3.3 μm and 2 keV with an index of -1.18 ± 0.07. The agreement between this slope and that observed in the mid- and far-infrared can be taken to imply that either the power law extends into the mid- to far-infrared or that a cut-off in the presumed nonthermal power law component is balanced by increased emission from other components of infrared emission.

The mean colors of the Seyfert 1 galaxies also agree with those of the handful of objects (not in the above samples) with strong flat-spectrum radio cores and known mid- and far-infrared colors. Examples of such sources are NGC1275, 3C120 (The IRAS Point Source Catalog, 1985) and 3C273, 3C345 and 0537-441 (Neugebauer *et al.* 1984b).

The separation between the Seyfert 1 and Seyfert 2 galaxies in Figure 1 can be accentuated by displaying the spectral curvature at 60 μm rather than the indexes themselves. In Figure 4 histograms of the curvature, defined as $\alpha(60,25)$

- α (100,60) are shown for the three classes of emission line galaxies in the samples. It is seen that the Seyfert 2 galaxies show greater curvatures than do Seyfert 1 galaxies, approaching those of the HII galaxies. The curvature is in the sense that there is excess emission at 60 μm relative to a continuum with a fixed power law between 25 and 100 μm.

A clue in understanding the implications of the preferred 60 μm curvature comes from the measurement of the archetypical Seyfert 2 galaxy, NGC 1068. The location of this galaxy in Figure 1 is given by $\alpha(100,60)$ = -0.49 and $\alpha(60,25)$ = -0.87, an undistinguished position. For this object, Jones *et al.* (1977) have concluded that the mid- and far-infrared emission is almost certainly thermal in origin. Indeed, for this galaxy much of the far infrared flux comes from star forming regions outside the nucleus. Given the quite ordinary location of NGC1068 in Figure 1, it seems reasonable to postulate the widespread existence of similar components in many Seyfert 2 galaxies.

It should be noted, however, that if the infrared emission from Seyfert 1 and Seyfert 2 emission do have fundamentally different origins it seems strange that they just happen to produce similar luminosities and spectral distributions in the IRAS bands. The relatively flat 60 to 100 μm energy distribution and pronounced 60 μm curvature in the HII galaxies indicate that these starburst galaxies contain thermal components similar to those in the Seyfert 2 galaxies but that the temperature of the dust is slightly lower.

The purpose of this letter has been to summarize the main general characteristics of Seyfert galaxies in the mid- and far-infrared. Although by themselves the IRAS observations place no unambiguous constraints on the radiation mechanisms involved, the observations are consistent with current prejudices. A more detailed analysis will consider the overall spectrum of individual galaxies from the radio through the infrared to the optical and X-ray as well as the relationship of the infrared emission to the detailed properties of the nuclear emission lines. Also, analysis of pointed observations made with IRAS of several hundred active galaxies with various well-defined types should in the future allow the infrared properties of radio galaxies and quasars to be compared with those of the Seyfert galaxies.

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Table 1

Spectral Indices for Selected Galaxies of Various Types

	α(100,60)		α(60,25)	
	median	spread*	median	spread*
Seyfert 1	-1.1	1.7	-1.0	1.6
Seyfert 2	-0.8	0.7	-1.2	1.1
HII	-0.6	0.8	-1.8	0.5

*Spread calculated from 2 × | median - 33.3 percentile |.

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FIGURE CAPTIONS

Figure 1. A mid- to far-infrared color-color plot for galaxies with strong nuclear emission lines. The spectral indexes are defined in the text. In all figures, Seyfert 1 galaxies are denoted by open triangles, Seyfert 2 galaxies are denoted by filled triangles and galaxies with HII region nuclear regions by circles.

Figure 2. The fraction of Seyfert galaxies as a function of their 60 μm luminosity. This was derived by dividing the number of detected galaxies in a given luminosity bin by the number of objects in the sample that could have been detected in that luminosity bin. Although for ease of plotting each pair of points is plotted side by side the relevant luminosity for both points in the pair is the mean indicated by the arrows.

Figure 3. A plot of the 100-60 μm spectral indices versus the 60 μm luminosities for Seyfert galaxies.

Figure 4. Histograms of the 60 μm curvature are shown for the three classes of emission line galaxies studied.

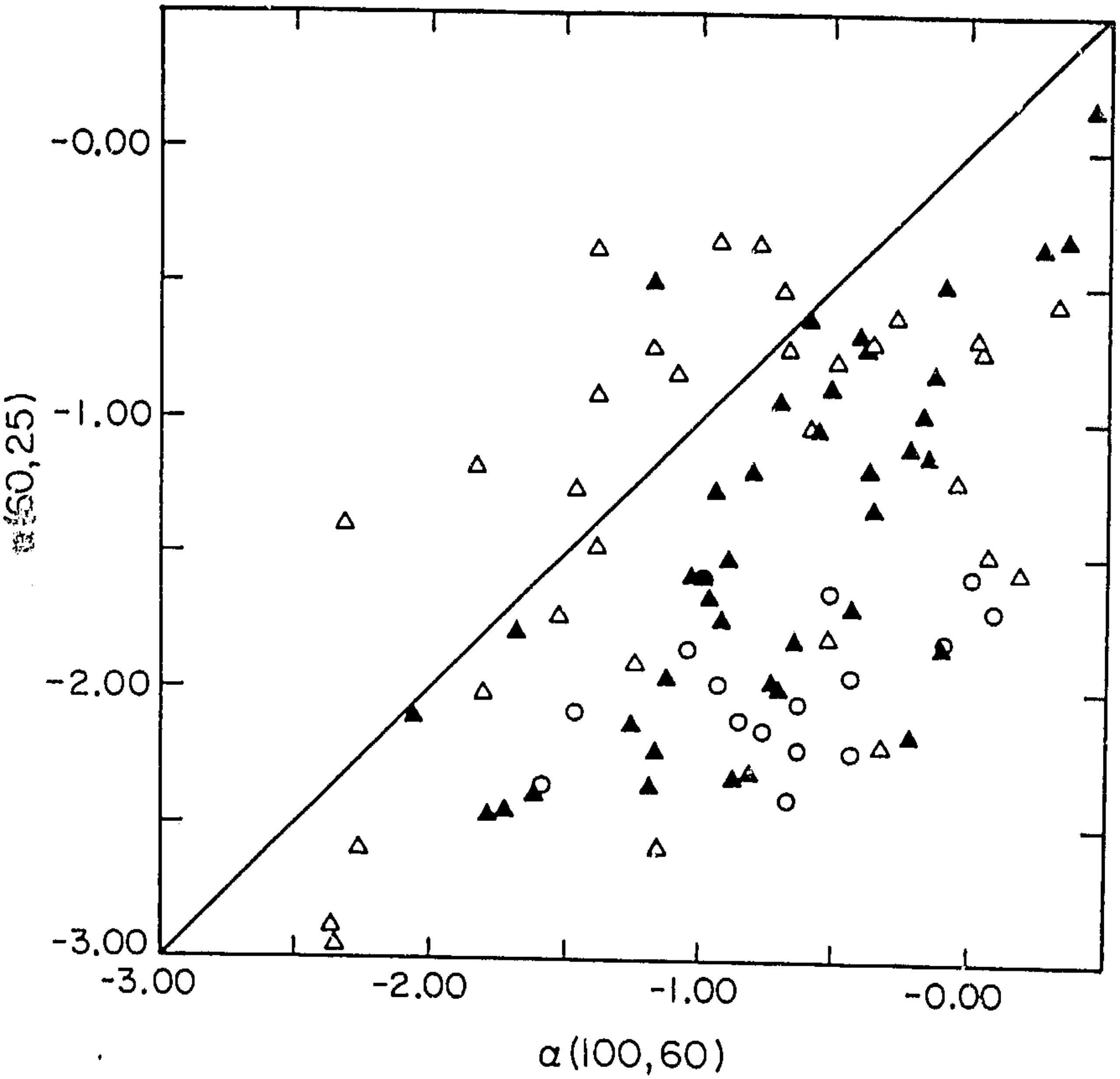


Figure 1

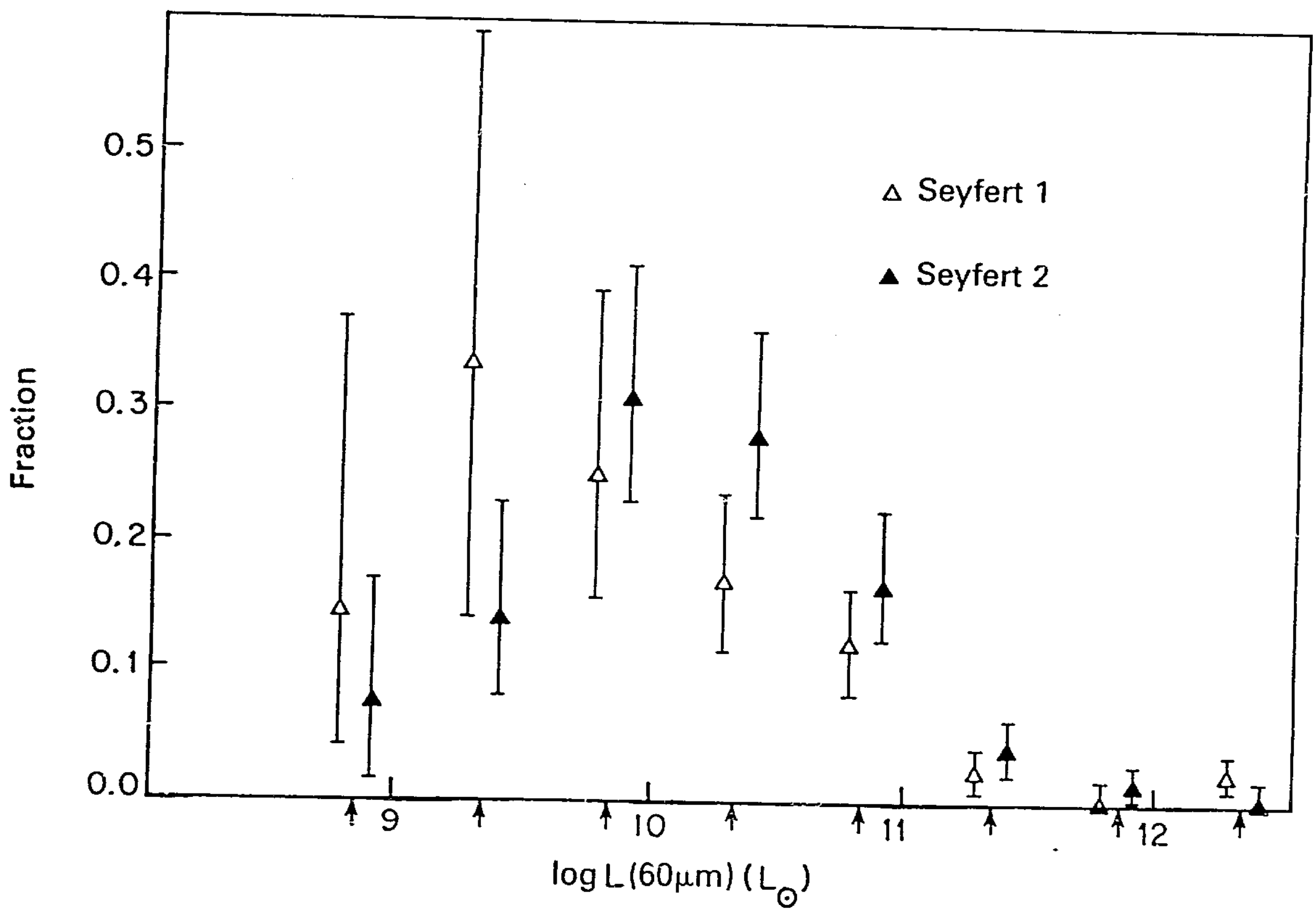

Fraction
0.5
0.4
0.3
0.2
0.1
0.0
Seyfert 1
Seyfert 2
9
10
11
12
log L(60μm) (L⊙)

Figure 2

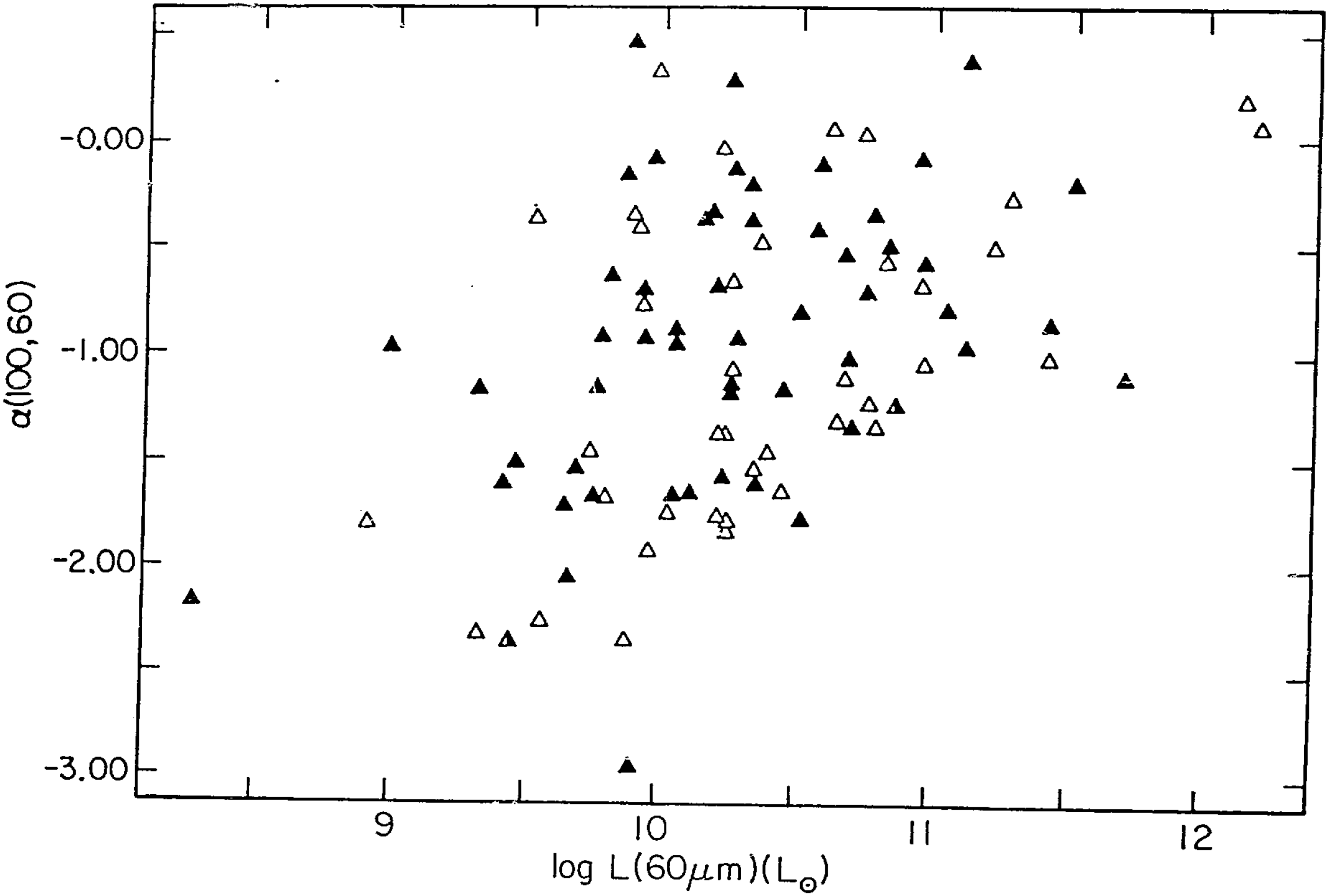
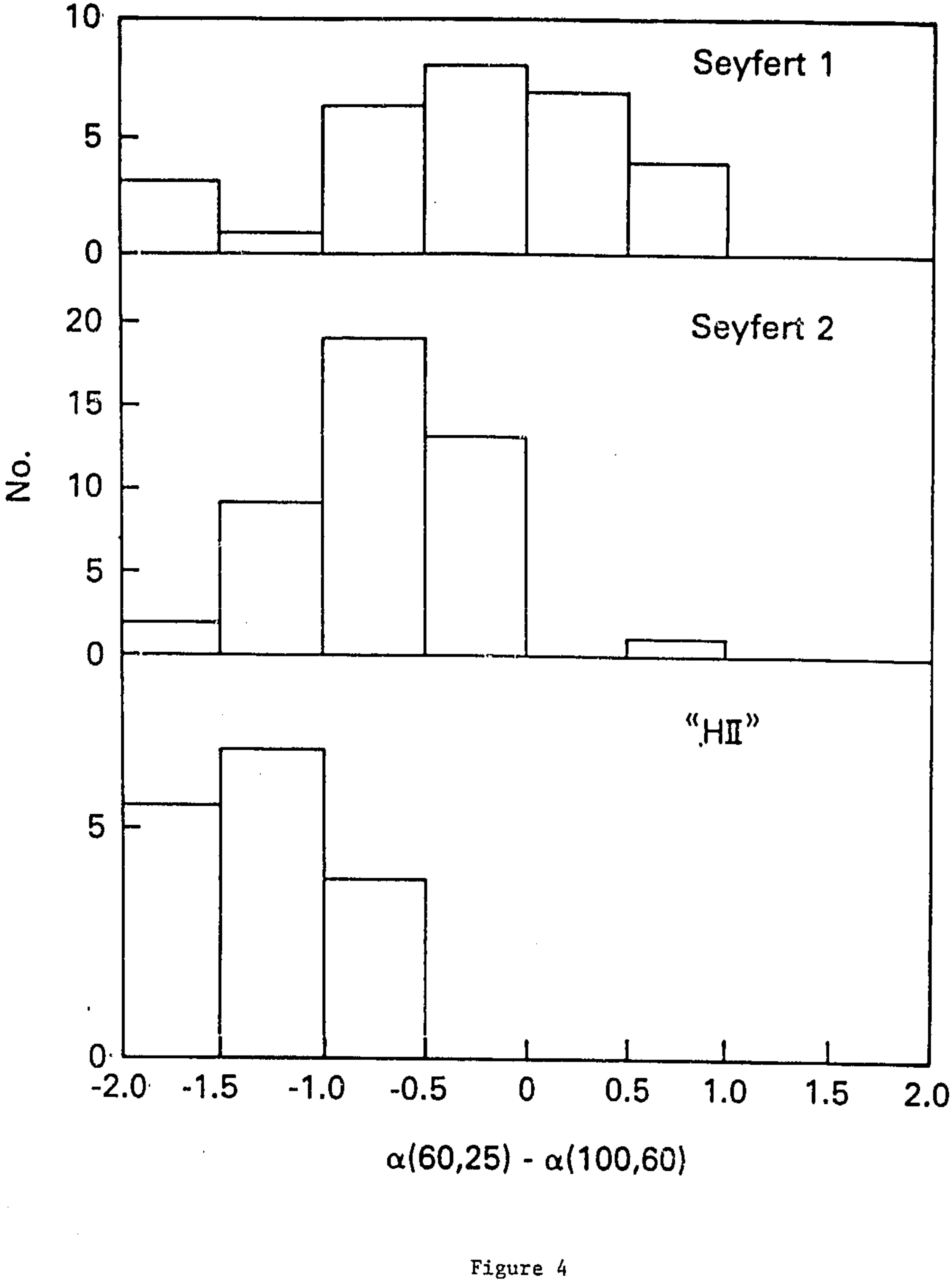


Figure 3



10
Seyfert 1
5
0
20
Seyfert 2
15
No.
10
5
0
"HII"
5
0
-2.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
α(60,25) - α(100,60)

Figure 4