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IRAS OBSERVATIONS OF ACTIVE GALAXIES

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ABSTRACT: The IRAS survey gives an unbiased view of the infrared properties of the active galaxies. Seyfert galaxies occupy much the same area in color-color plots as do normal infrared bright galaxies, but extend the range towards flatter 60-25 μm slopes. Statistically the Seyfert 1 galaxies can be distinguished from the Seyfert 2 galaxies, lying predominantly closer to the area with constant slopes between 25 and 100 μm. The infrared measurements of the Seyfert galaxies cannot distinguish between the emission mechanisms in these objects although they agree with the currently popular ideas; they do provide a measure of the total luminosity of the Seyferts. The quasar's position in the color-color diagrams continue the trend of the Seyferts. The quasar 3C48 is shown to be exceptional among the radio loud quasars in that it has a high infrared luminosity which dominates the power output of the quasar and is most likely associated with the underlying host galaxy.

The survey by the *Infrared Astronomical Satellite* (IRAS) provides an unbiased way in which to understand the infrared properties of active nuclei . In this review, we present a preliminary summary of the gross infrared properties of the active galaxies as seen by IRAS (Neugebauer *et al.* 1984; *The Explanatory Supplement to the IRAS Catalogs and Atlases* 1985).

In order to set the context for the active galaxies seen by IRAS, the spectral indexes of a sample of infrared "bright" galaxies seen in the survey proper are shown in Figure 1. The spectral indexes α are defined such that the flux density f_ν is proportional to ν^α where ν is the frequency. By "bright" is meant a flux density limit of 5 Jy at 60 μm with detections at 25 and 100 μm as well. The sample represents about 3% of the ~ 20,000 galaxies detected by IRAS with Galactic latitude $|b| > 30°$. No attempt was made to isolate sources that were, in fact, Galactic, nor was there any attempt to take account that some of the galaxies were extended. Both of these effects probably do not change the

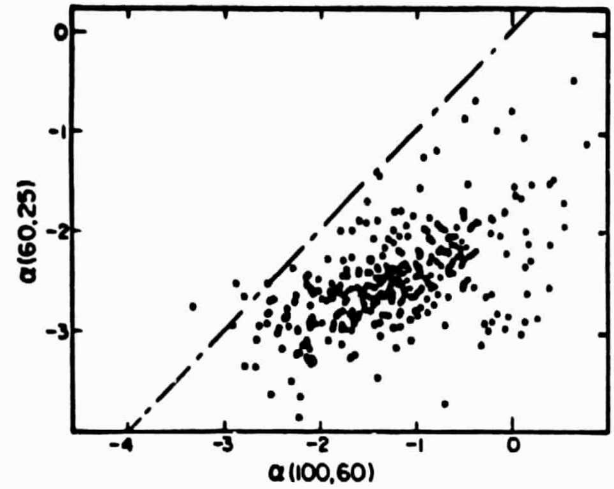

Figure 1: A plot is given of the spectral indexes between 25 and 60 μm ($\alpha(60,25)$) and those between 60 and 100 μm ($\alpha(100,60)$) for the bright infrared galaxies, i.e., sources with $f_\nu(60\ \mu m) > 5$ Jy, found in the IRAS survey. The spectral indexes and sample are defined in the text. The dashed line represents equal spectral indexes. The uncertainty in each coordinate is about 0.3.

statistical conclusions of the study. The 60 to 100 μm color temperatures lie between 30 and 60 K. The sample, which will be discussed in detail by Soifer *et al*. (1985), probably is representative of the population of galaxies seen by IRAS, although significant selection effects, primarily having to do with the requirement that the galaxy be observed at 25 and 100 μm, are present. The sample includes examples of nearby normal galaxies, such as M33, and more distant infrared active galaxies such as Arp 220, as well as several active galactic nuclei as exemplified by MKN 231.

Figure 2 shows the location in the same plot and scale as Figure 1 of the Seyfert galaxies listed by Veron-Cetty and Veron (1983) and detected in the survey. Although the distribution of Seyfert galaxies covers the same area as do the bright galaxies, the distribution extends towards flatter 25 to 60 μm slopes.

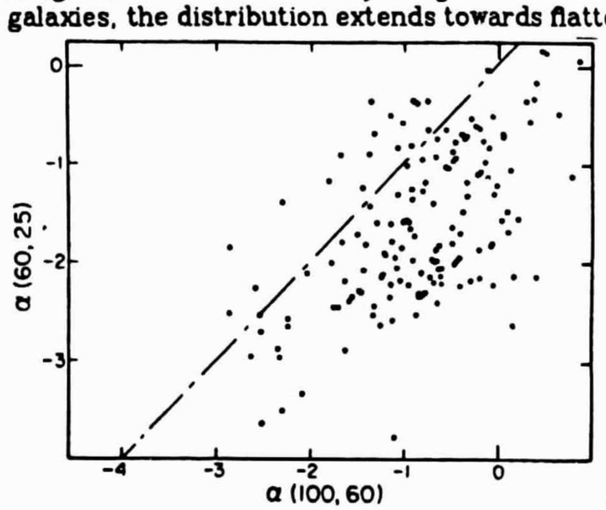

Figure 2: The same plot and on the same scale as Figure 1 is shown, but for the Seyfert galaxies in the Veron-Cetty and Veron Catalog (1983).

The IRAS properties of the Seyfert galaxies, as derived from a preliminary look at the IRAS catalog, are discussed by Miley, Neugebauer and Soifer (1985) who studied the properties of all Seyfert galaxies in the Markarian and NGC catalogs. One hundred and sixteen out of a possible 186 Seyfert galaxies are included in the study by Miley *et al.*,(1985). About 50 % of all Seyfert galaxies have 60 μm luminosities in excess of 10^{10} $L_{\odot}$, and the mean 60 μm luminosity increases with optical B luminosity. The luminosity functions of Seyfert 1 and Seyfert 2 galaxies are quite similar. It is possible, however, to statistically separate the two types of galaxies in color-color plots as shown in Figure 3.

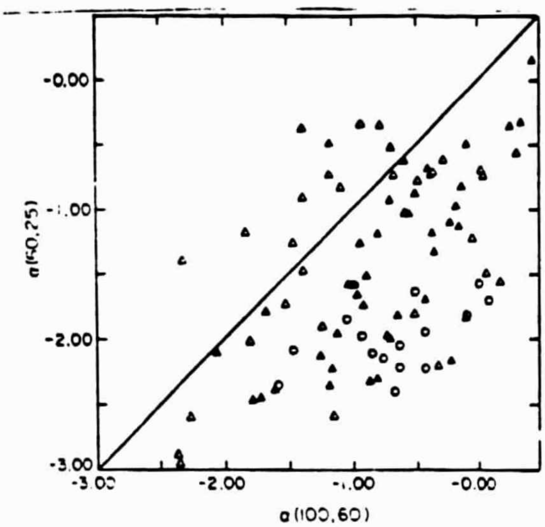

Figure 3: The same plot as in Figure 2 is shown, but for Seyfert galaxies listed in the Markarian and NGC catalogs; from Miley *et al.* (1985). The Seyfert galaxies are separated according to type. Seyfert 1 galaxies are denoted by open triangles, Seyfert 2 galaxies by filled triangles and galaxies with HII region nuclear regions by circles.

Figure 3, from Miley *et al.* (1985), is similar to Figure 2, but the Seyfert 1 and Seyfert 2 galaxies are given different designations. It is seen that the area above the line of constant spectral index is preferentially, but not exclusively, filled with Seyfert 1 galaxies. As a further base of comparison, galaxies listed in Veron-Cetty and Veron (1983) as having nuclear emission-line spectra characteristic of HII regions are also included in this plot. It is seen these lie preferentially in the same area as the "bright" galaxies. Although the infrared measurements provide a measure of the total bolometric luminosity of the Seyfert galaxies, they do not discriminate between the physical processes involved. They are, however, consistent with the current prejudices that the infrared emission of Seyfert 2 galaxies is dominated by starburst activity, while the infrared emission of Seyfert 1 galaxies is dominated by non-thermal emission.

Figure 4 shows the distribution of all sources with $|b| > 45°$ and detections at 25, 60 and 100 μm, on the same plot and scale as Figures 1 and 2. Although this plot is subject to many selection effects, it includes many sources which

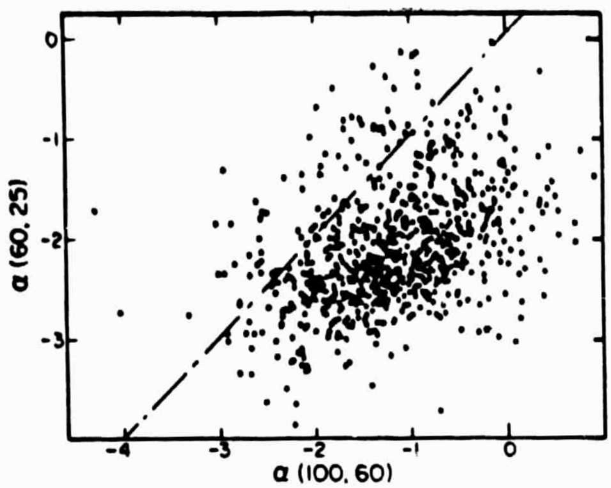

Figure 4: The same plot and scale as Figures 1 and 2 are shown, but for all sources with |b| > 45 ° and detections at 25, 60 and 100 μm.

have a larger ratio of 25 to 60 μm flux than does Figure 1, i.e., more positive spectral indexes α(60,25). It is seen that there are many sources in the upper left hand corner, i.e., in the area where the slopes are steeper from 60 to 25 μm than from 100 to 60 μm. To the extent that this area is the primary location of Seyfert 1 galaxies, see Figure 3, it is clear that the IRAS survey is an ideal searching ground for Seyfert 1 galaxies; see also de Grijp, *et al.* (1985).

Figure 5 shows the distribution of those sources defined by Veron-Cetty and

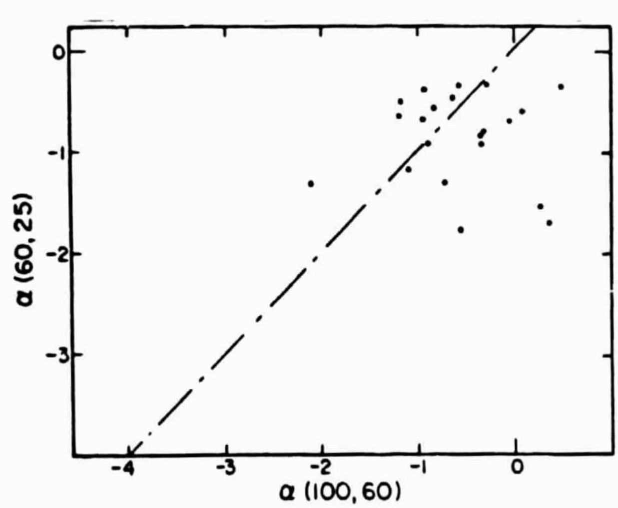

Figure 5: The same plot and scale as Figures 1, 2 and 4 but for those sources identified as quasars by Veron-Cetty and Veron(1983). The three quasars with the lowest values of α(60,25) are 3C48, MKN 231 and MKN 1014.

Veron (1983) to be quasars which were detected in the IRAS survey with good quality fluxes in at least one band. For all but six of these, pointed observations were used to provide sufficient signal to noise ratios in the different wavelength bands to provide reasonable measures of the slopes. For those six with no pointed measurements, the survey observations were coadded in order to increase the signal to noise ratios. The parent sample included all quasars from the catalog of Veron-Cetty and Veron who "arbitrarily defined a quasar as a starlike object, or object with a starlike nucleus, brighter than absolute (visual) magnitude -23." In addition to the detections whose spectral indexes are shown in Figure 5, there was an approximately equal number of IRAS sources with positional coincidences with quasars, but which were either poor quality IRAS detections or which were masked or confused by the presence of a nearby galaxy. The luminosities in the infrared range from 3×10^{10} to 10^{14} $L_{\odot}$.

Although the IRAS survey lasted only nine and one half months, the survey scanned approximately 70 % of the sky at times separated by about 6 months. Thus there are some data available on potential variability of the sources. In addition, several of the well known active galaxy nuclei were monitored as part of the pointed observation program. A study of the variability of these sources has not been finished at this time, but the effects on Figure 5 should be small compared to the uncertainties.

It is seen that the quasars cluster around the line of equal spectral indexes more closely than do either the galaxies as a whole or the Seyfert galaxies. Three quasars by the luminosity definition of Veron-Cetty and Veron (1983) -- 3C48, MKN 231 and MKN 1014 -- lie well below the line of constant spectral index. Of these three, two -- MKN 231 and MKN 1014 -- have also been classified as Seyfert 1 galaxies. The three lie in the area which is steeper in $\alpha(60,25)$ and flatter in $\alpha(100,60)$ than the constant spectral index line; i.e., they have a bump at 60 μm. The energy distribution of 3C48, shown in Figure 6, shows that the

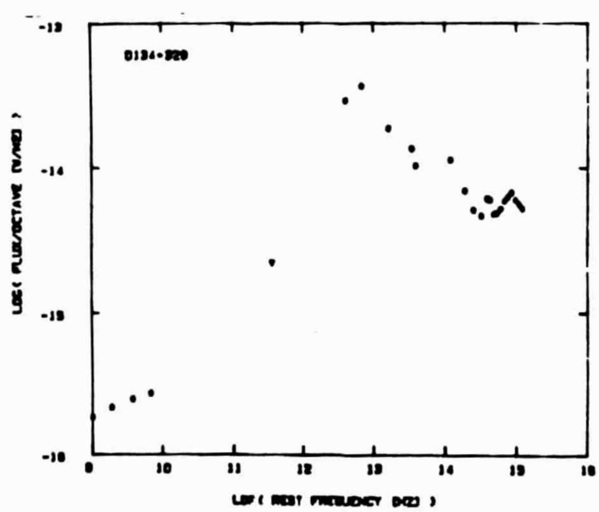

Figure 6: The continuum energy distribution of 3C48 is given. The bump near 60 μm (frequency $\sim 5 \times 10^{12}$ Hz), which is ascribed to thermal reradiation of heated dust grains, is clearly seen. The near-infrared points were obtained at the Palomar Observatory. The radio points are from Kellermann, Pauliny-Toth and Williams (1969) while the millimeter limit is from Ennis, Neugebauer, and Werner (1982) and the visual observations are from Neugebauer *et al.* (1979).

infrared emission does dominate the power output of this quasar. The luminosity in the infrared is ~ $5 \times 10^{12} L_{\odot}$, about six times that in the visible. Its observed color temperature between 60 and 100 μm is 55 K.

Figure 7 shows the continuum energy distributions of 3C273 and 3C345, two radio loud, variable quasars. The energy distribution of 3C345 is a result of a

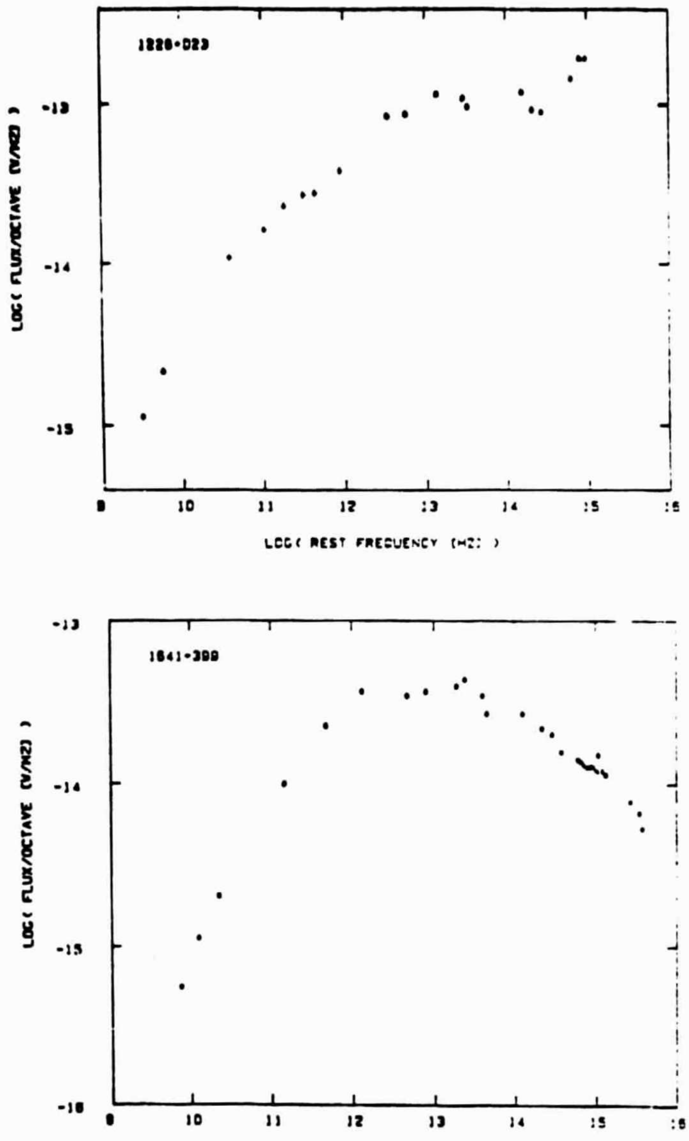

Figure 7: The continuum energy distributions for 3C273 and 3C345 are shown on the same scales. The points marked with (+) in 3C273 are from Clegg *et al.* (1983), and were obtained in 1982, April; the difference from a smooth curve probably reflects variability in the source. The measurements of 3C345, including the IRAS and near infrared points, were obtained in the 1983 April-May time period (Bregman *et al.*, 1985).

study by Bregman *et al.* (1985) and represents observations taken within two months during 1983 April and May. The observations of 3C273 were taken over a period of several years and the discontinuities are probably the result of variability. The continuum distribution of 3C48 is obviously different from those of the other radio loud quasars. Furthermore, there is no evidence in the radio structure of 3C48 for the presence of a milli arc-second source characteristic of flat spectrum radio sources, and there is no sign of strong variability in either the radio or near infrared continuua. Unlike 3C273, 3C345 and other radio loud quasars found in the survey, the infrared emission in 3C48 therefore most likely does not come from an extension of the radio emission.

It should be emphasized that the radio loud quasars generally show much more radio emission relative to their infrared than do normal galaxies. Figure 8 shows the ratio of the radio luminosity to that the infrared luminosity for the quasars and for a sample of normal galaxies studied by Helou (1985). The samples include only those objects with measured emission both in the radio and infrared, so that the sample does not contain the bulk of the radio quiet quasars. The figure is intended only to show that the "radio loud" quasars are, indeed, very radio loud relative to normal galaxies. No statistical inferences should be drawn from the figure.

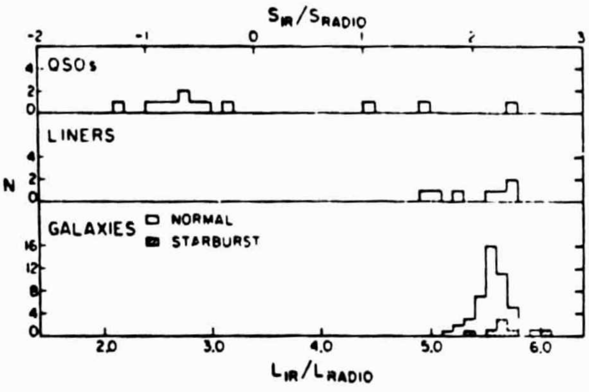

Figure 8: Histograms of the ratio of the radio luminosity to that in the infrared is given for the different types of objects listed. The ratios for the galaxies are from Helou, 1985. Only those quasars with measurements in both the radio and infrared have been counted, so, e.g., radio quiet quasars are under represented.

Before discussing the infrared emission of 3C48 further, it is of interest to ask how common an infrared peak is in the quasars. Of the 22 quasars from the sample of Veron-Cetty and Veron (1983), eight in this preliminary study show definite maxima between 25 and 100 μm. Examples of the energy distributions of two are shown in Figure 9. Most, but not all of the objects with an infrared peak are also defined to be Seyfert galaxies. Thus while infrared emission is not uncommon, it does certainly not universally dominate the emission from quasars.

The origin of the infrared emission of 3C48 is discussed by Neugebauer and Soifer (1985). They conclude that the most likely source of the emission is thermal reradiation from heated dust. In the rest system of the quasar, the

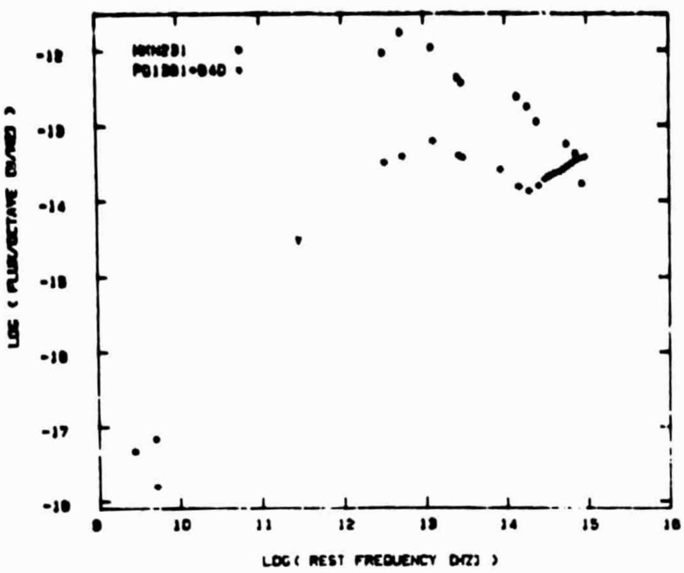

Figure 9: The continuum energy distributions for PG 1351+640 and MKN231 are shown. For 1351+640, the millimeter limit is from Ennis *et al.* (1982), the radio point is from Condon *et al.* (1981) and the visual observations are from Neugebauer *et al.* (1979). For MKN231 the visual and radio points are from references given in Veron-Cetty and Veron (1983); the near infrared points are from Palomar Observatory.

representative temperature of the grains, assuming a (wavelength)$^{-1}$ emissivity dependence, is ~ 57 K. The mass in dust inferred from the observations is 6×10^7 $M_\odot$. If the grains were heated by a single luminosity source, the grains must be ~ 2 kpc from the source. All of these numbers place the origin of the radiation well outside the classical broad and narrow emission line regions of the quasar. It must be acknowledged, however, that 3C48 is well known to have a narrow line emission region which extends asymmetrically out some 40 kpc from the nucleus (Sandage and Miller 1966, Wampler *et al.*, 1975). The direct association of the infrared emission with this region is excluded because the mass derived from the infrared measurements again far exceeds that obtained from the line measurements.

We conclude that the heated dust is most probably located in an extremely luminous host galaxy surrounding 3C48. The 3C48 system is well known to contain a highly luminous galaxy (Gehren *et al.*, 1984; Boroson and Oke (1982); Fried (1985). If this host galaxy is the location of the infrared emission, the relative infrared and visual properties would be similar to those of Arp 220 (Soifer *et al.*, 1984). If the dust is heated by a single central luminosity source, a special geometry must be invoked since there is no evidence of extinction within the broad line region. If the dust is heated by a set of luminosity sources spread throughout the galaxy, the most likely explanation is that an enormous amount of star formation is occurring in the galaxy. In either case, the infrared observations of 3C48 might thus represent the harbingers of a new type of phenomena associated with quasars.

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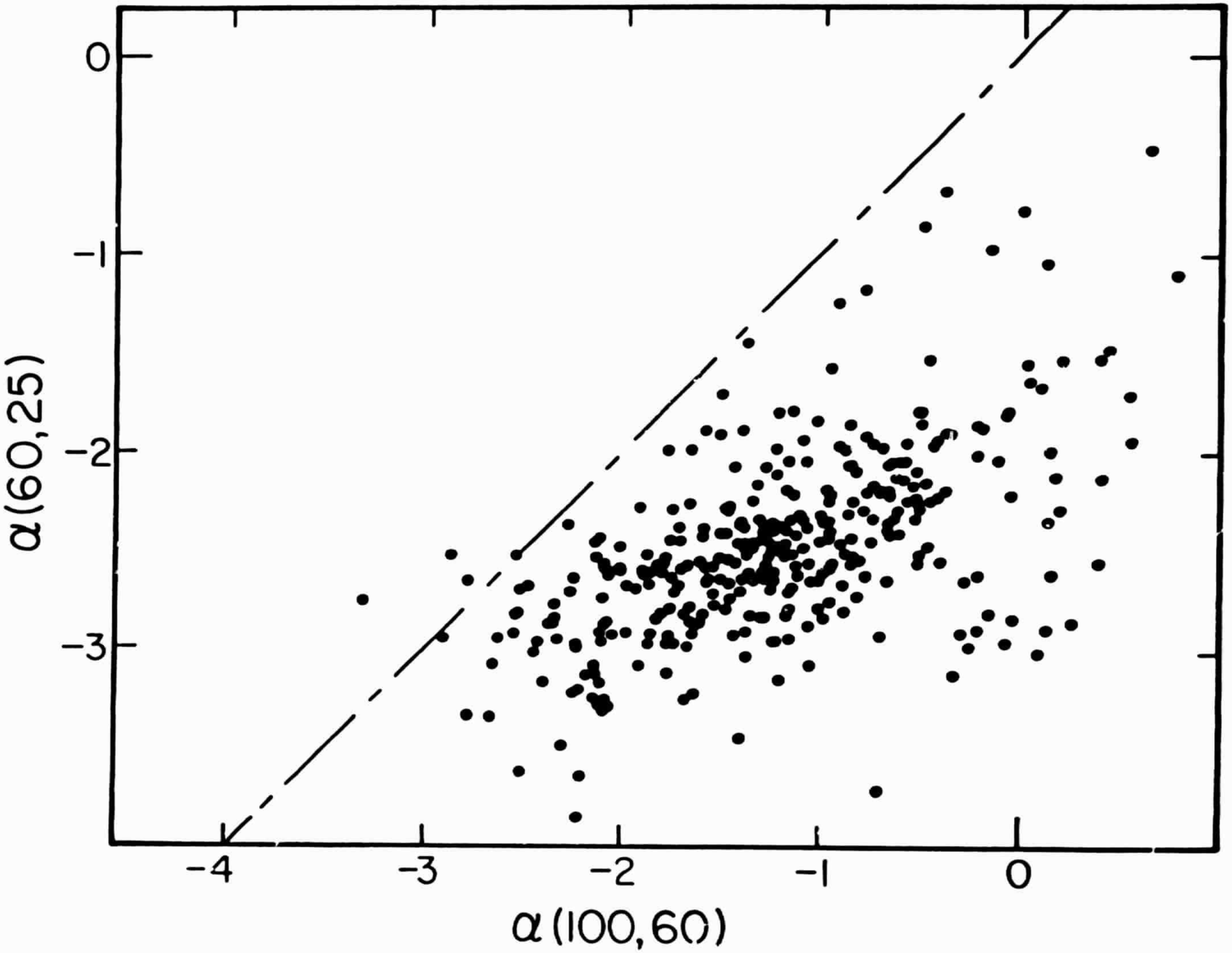
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α(100,60)
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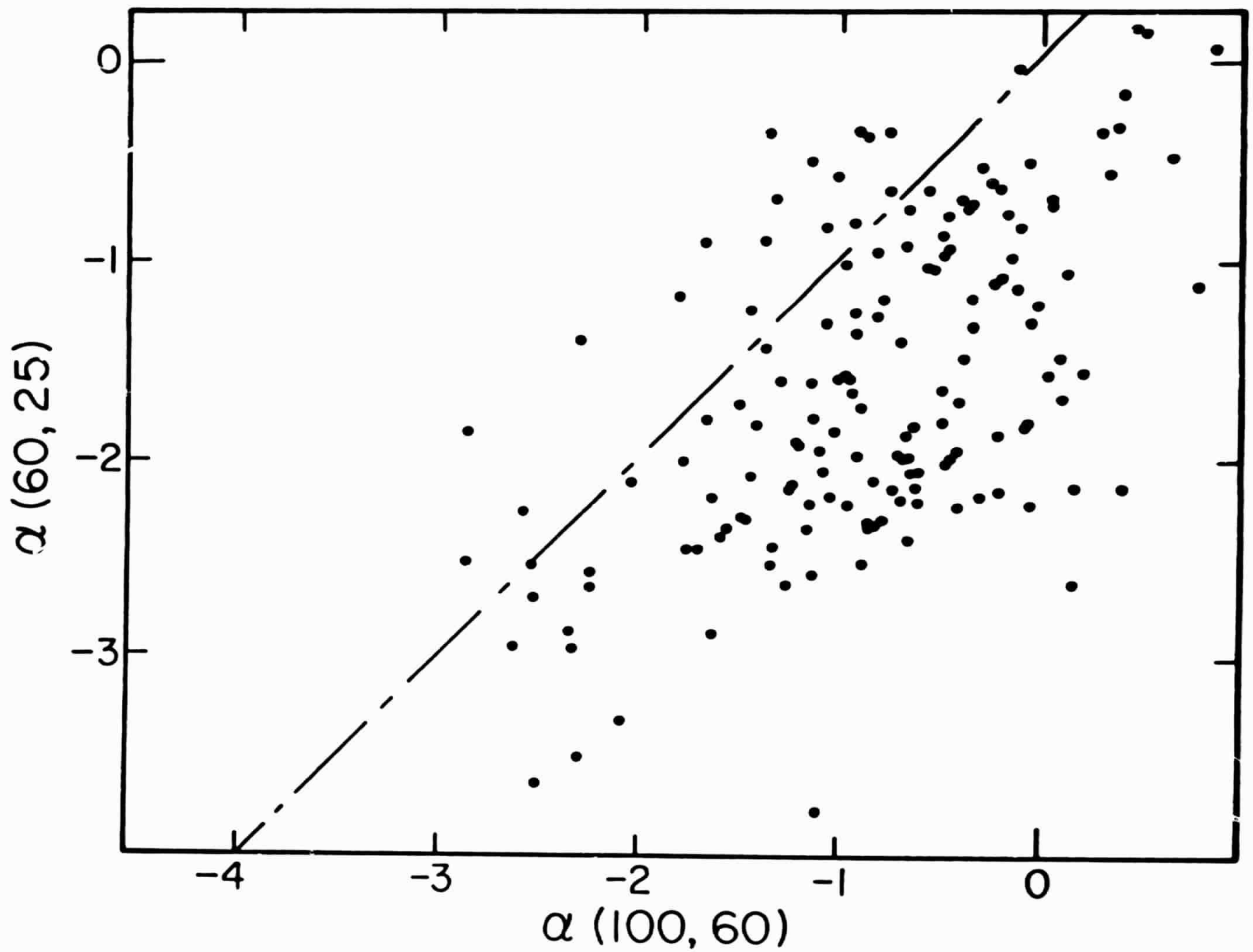
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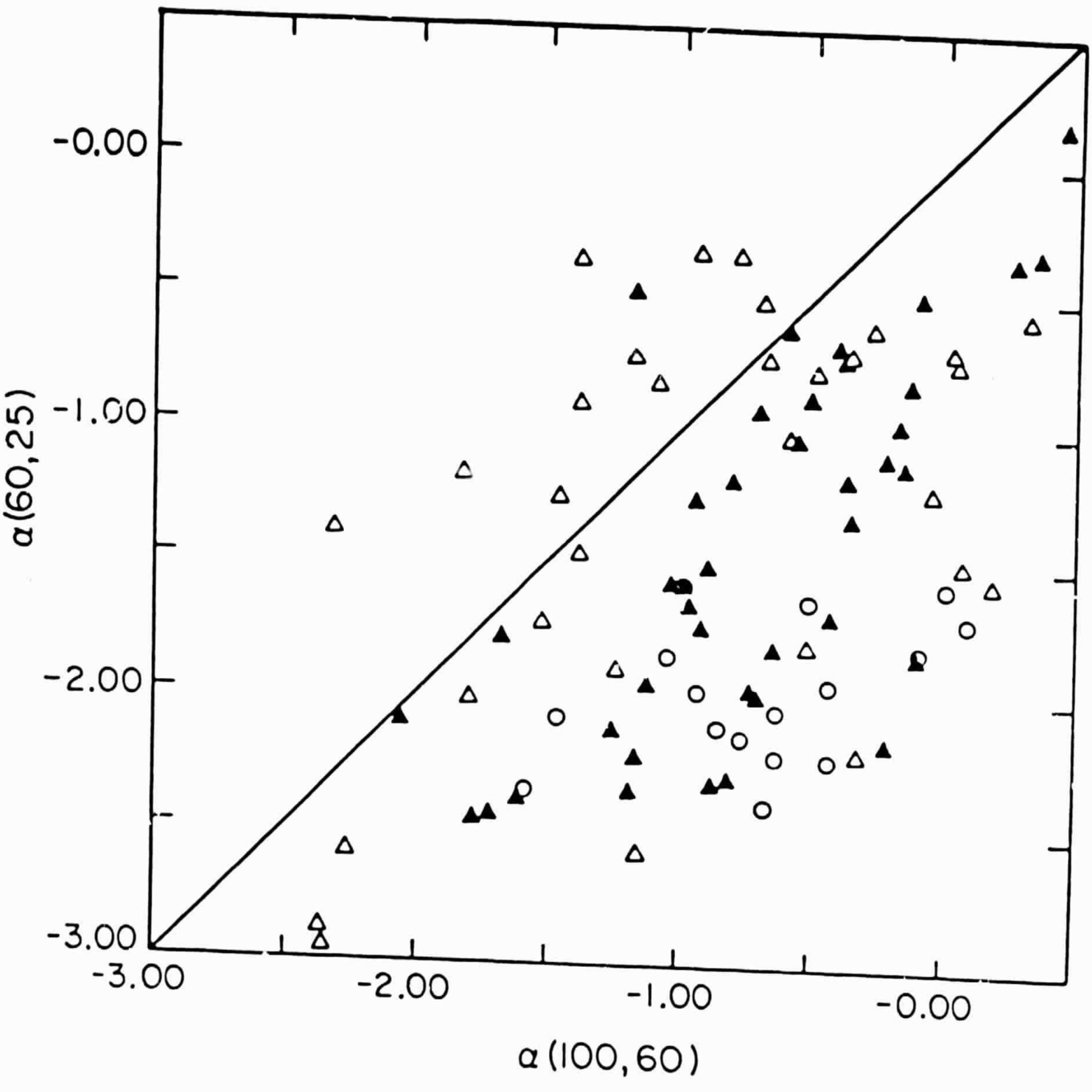

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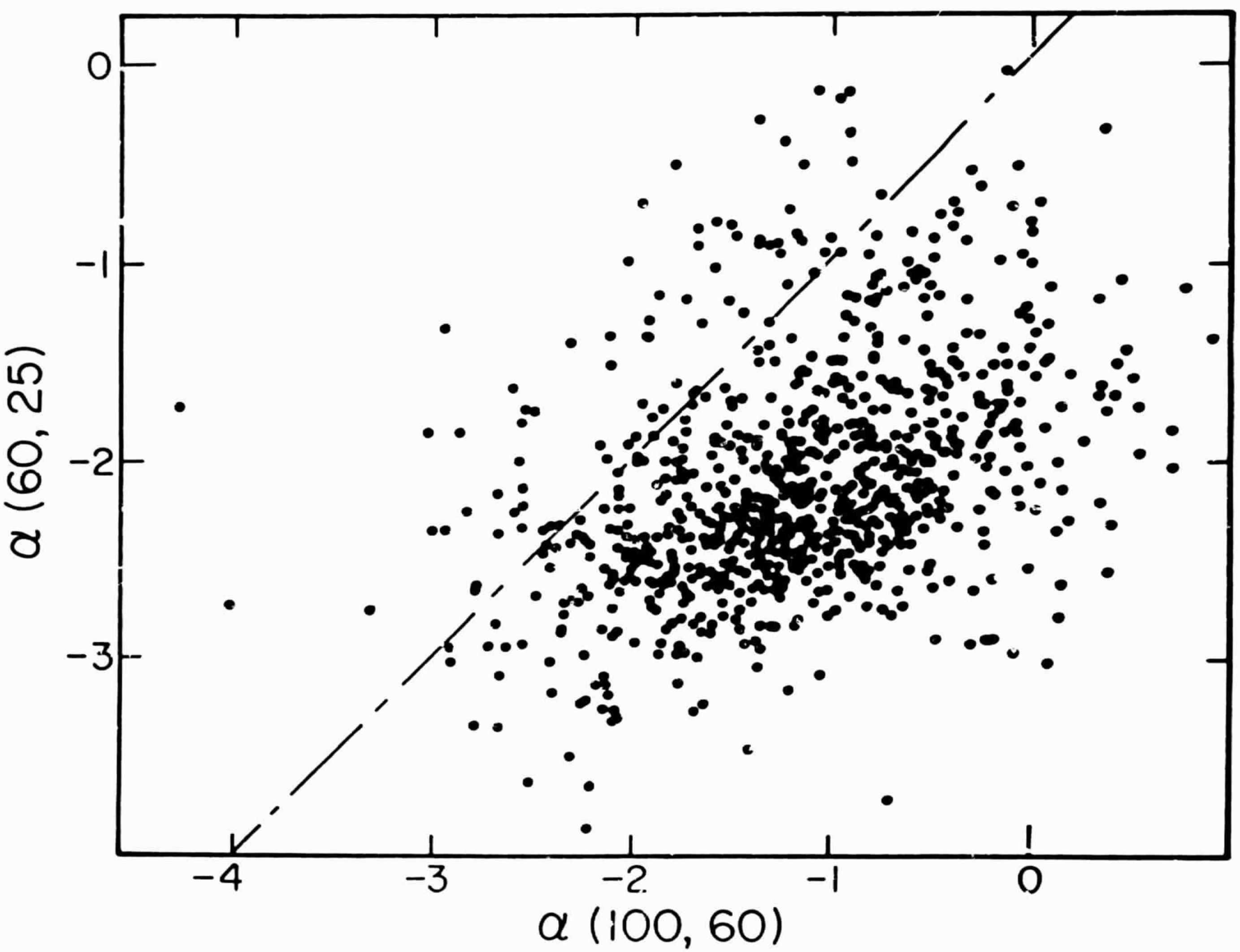

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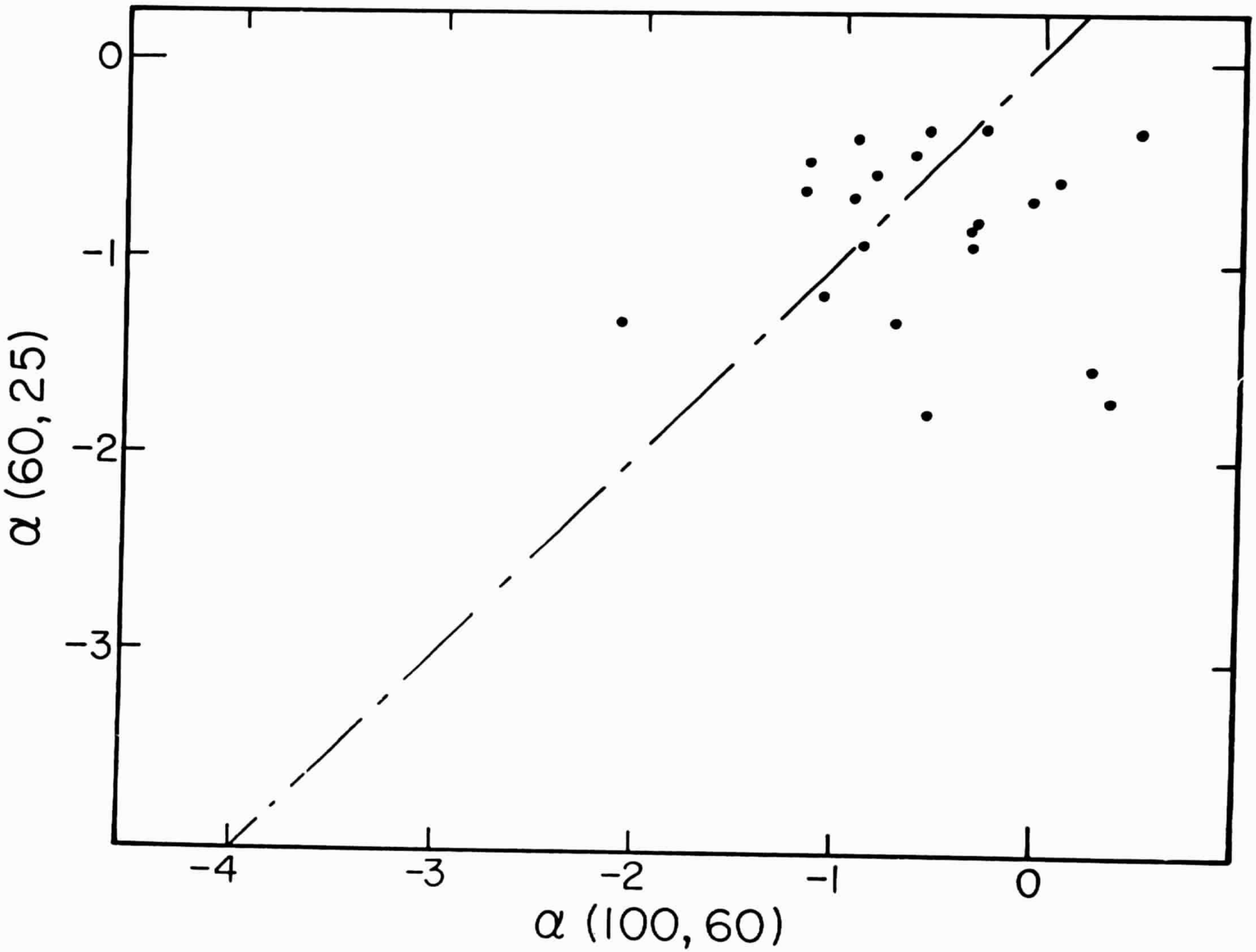
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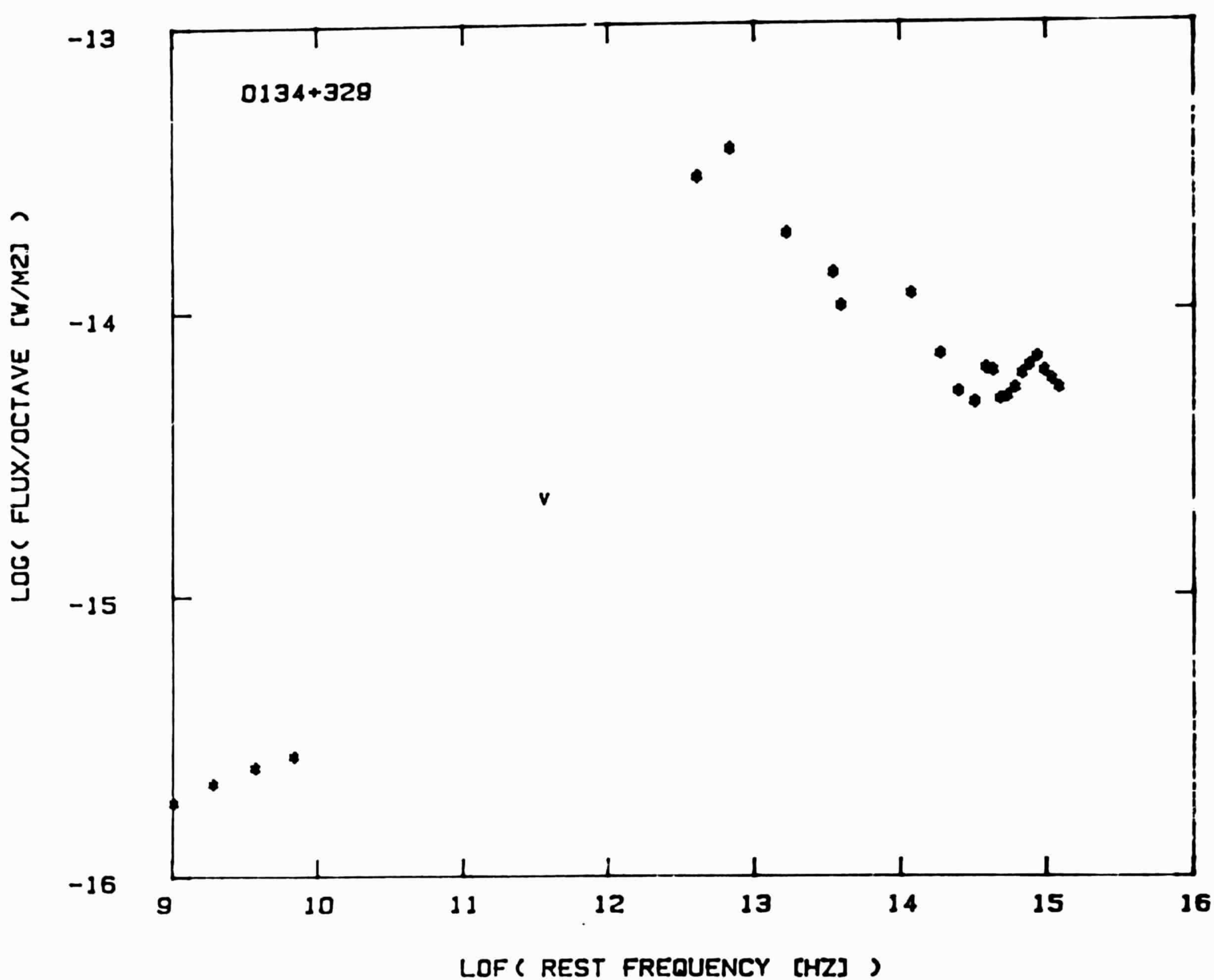
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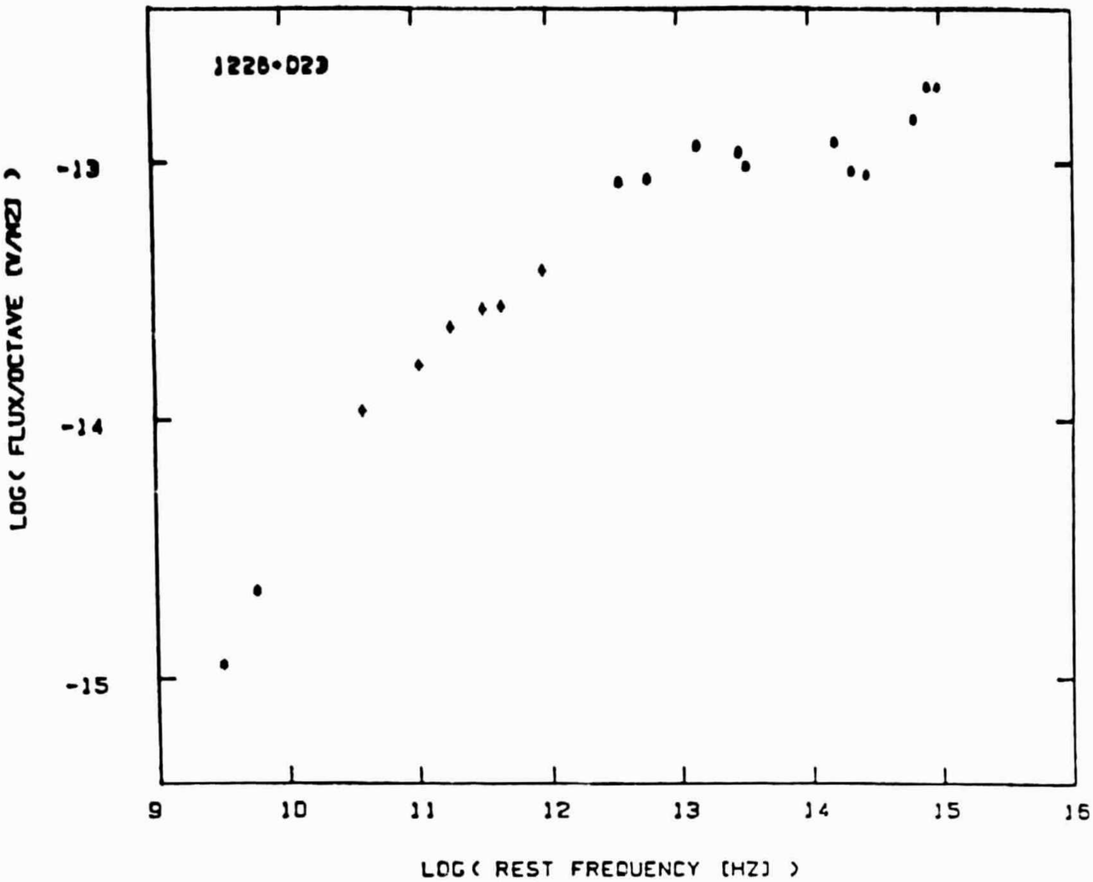

1226+023
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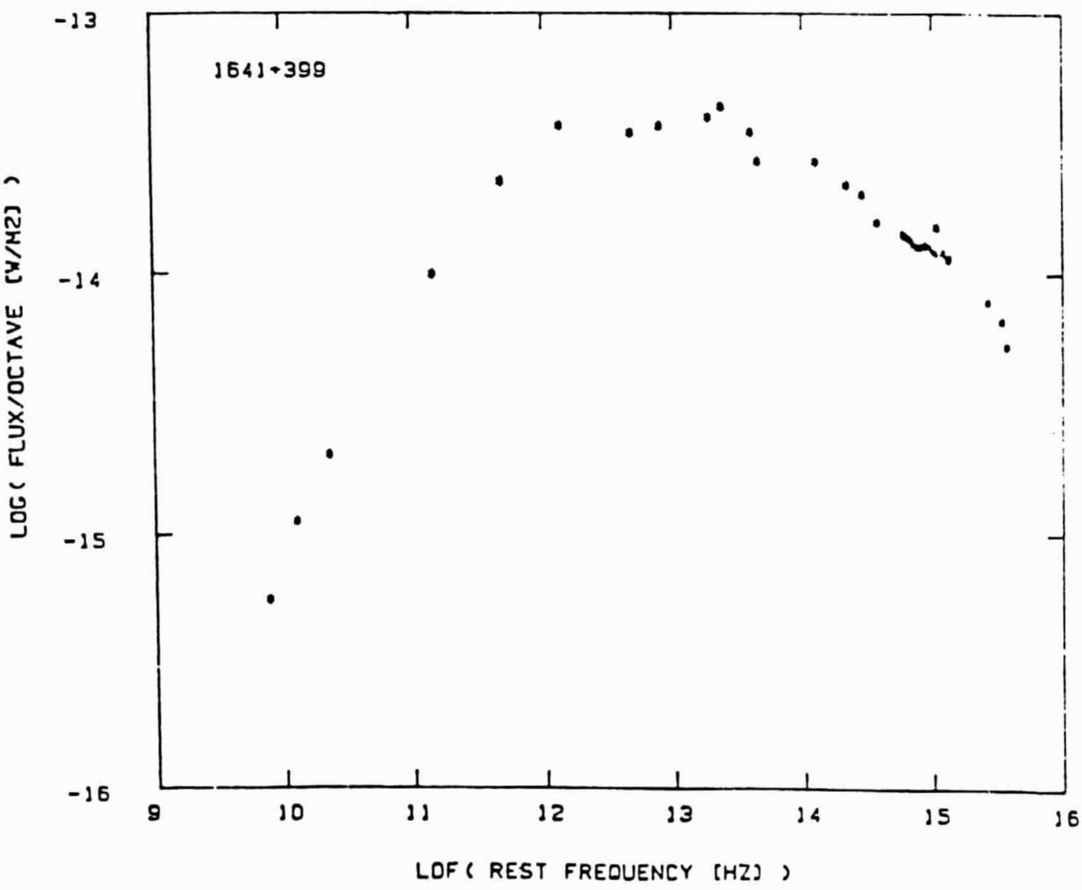

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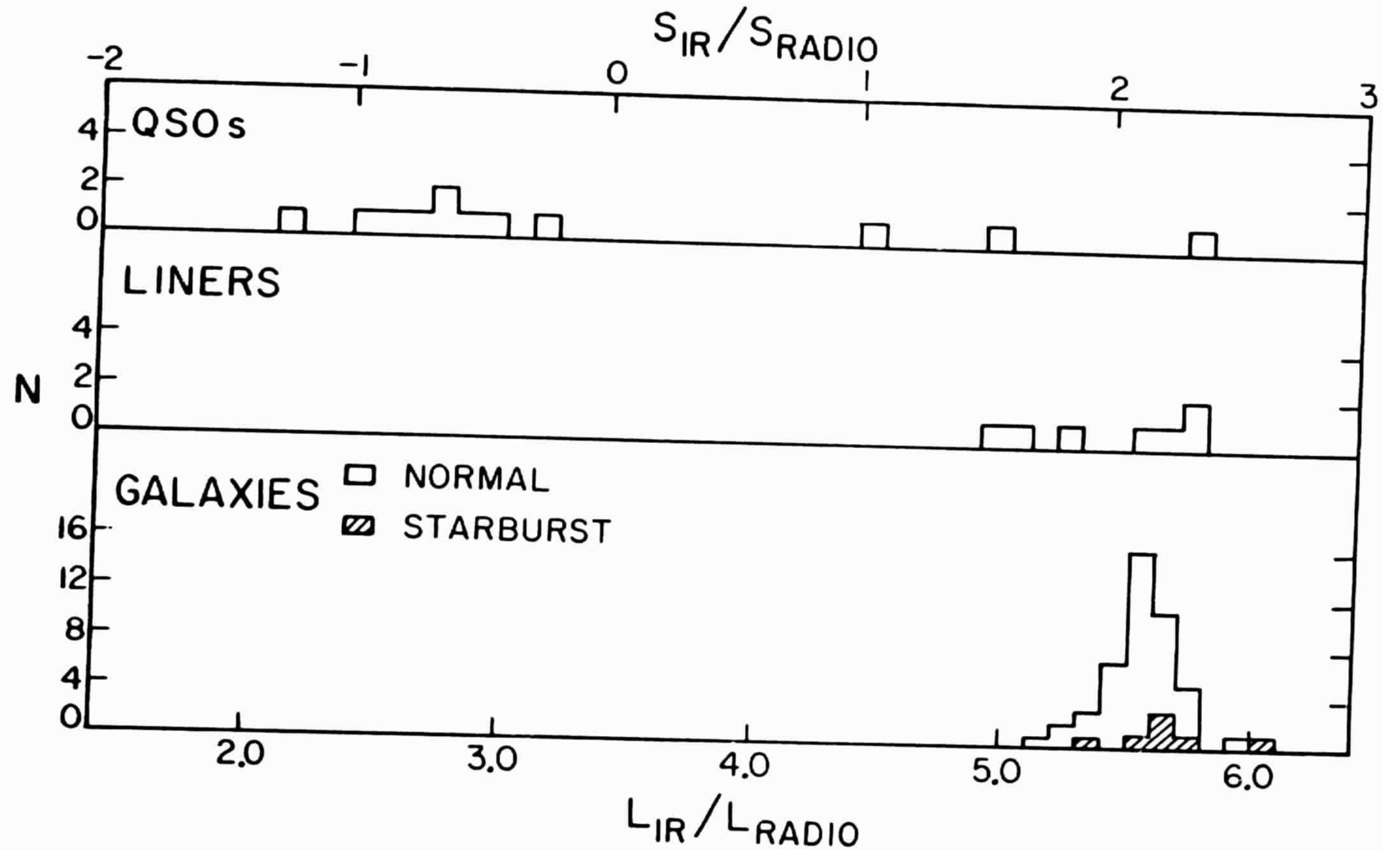

S_{IR}/S_{RADIO}
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QSOs
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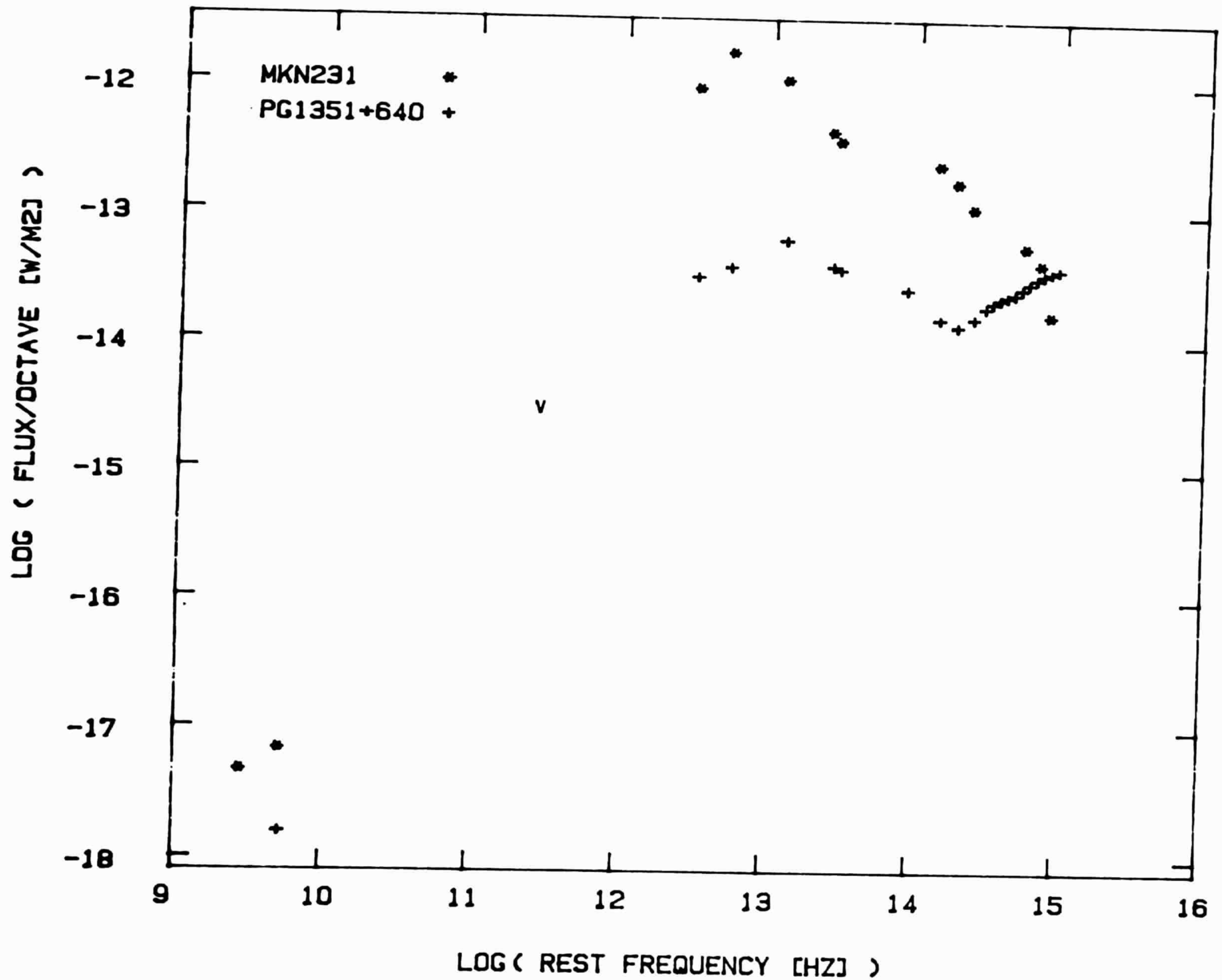
MKN231
PG1351+640
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