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The Correlation Between Far-IR and Radio Continuum Emission from Spiral Galaxies

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ABSTRACT

We have observed a sample of 30 galaxies selected for their intense IRAS flux at 60 and 100 μm using the Arecibo telescope at 21 cm to measure the continuum and HI line luminosities. The centimeter-wave continuum correlates very well with the far-infrared flux, with a correlation coefficient as high as that found for other samples, and the same ratio between FIR and radio luminosities. Weaker correlations are seen between the FIR and optical luminosity and between the FIR and radio continuum. There is very little correlation between the FIR and the HI mass deduced from the integral of the 21 cm line. The strength of the radio continuum correlation suggests that there is little contribution to either the radio or FIR from physical processes not affecting both. If they each reflect time integrals of the star formation rate then the time constants must be similar, or the star formation rate must change slowly in these galaxies.

BACKGROUND

In spiral galaxies the 60μm and 100μm luminosity is closely tied to star formation processes, as indicated by its tight correlation with star formation tracers such as Hα emission, CO emission, and radio continuum emission. In this study we concentrate on the correlation with radio continuum among galaxies selected for their intense FIR (far-infrared) emission.

Correlations between FIR and centimeter-wave continuum have been found in many samples of galaxies chosen by many criteria and in diverse environments. Examples are spirals in clusters of galaxies (Helou et al. 1985, Dickey and Salpeter 1984), FIR flux limited samples such as the point source catalog (Gavazzi et al. 1986, Sanders and Mirabel 1985), and radio flux limited catalogs (Condon and Broderick 1986).

The question we address here is whether this correlation extends to the brightest FIR galaxies, and if so whether the radio continuum stays in the same proportion to FIR luminosity. We use the list of galaxies in IRAS circular #6 (1984) supplemented by galaxies from the point source catalog with extremely high FIR luminosity. This sample is essentially FIR flux-limited at 5 Jy, and relatively complete for the Arecibo declination range. We have used the Arecibo telescope to measure the 21cm line and continuum emission from these galaxies, as well as the 18cm OH line emission and absorption. Measured fluxes are tabulated and the spectra are shown and discussed in detail for each galaxy by Garwood et al. (1986); in this presentation we give a brief description of the major results. The most important result is that the same ratio of FIR to radio luminosity holds for these galaxies as for more normal spirals, and that the correlation is as good or better as for other samples.

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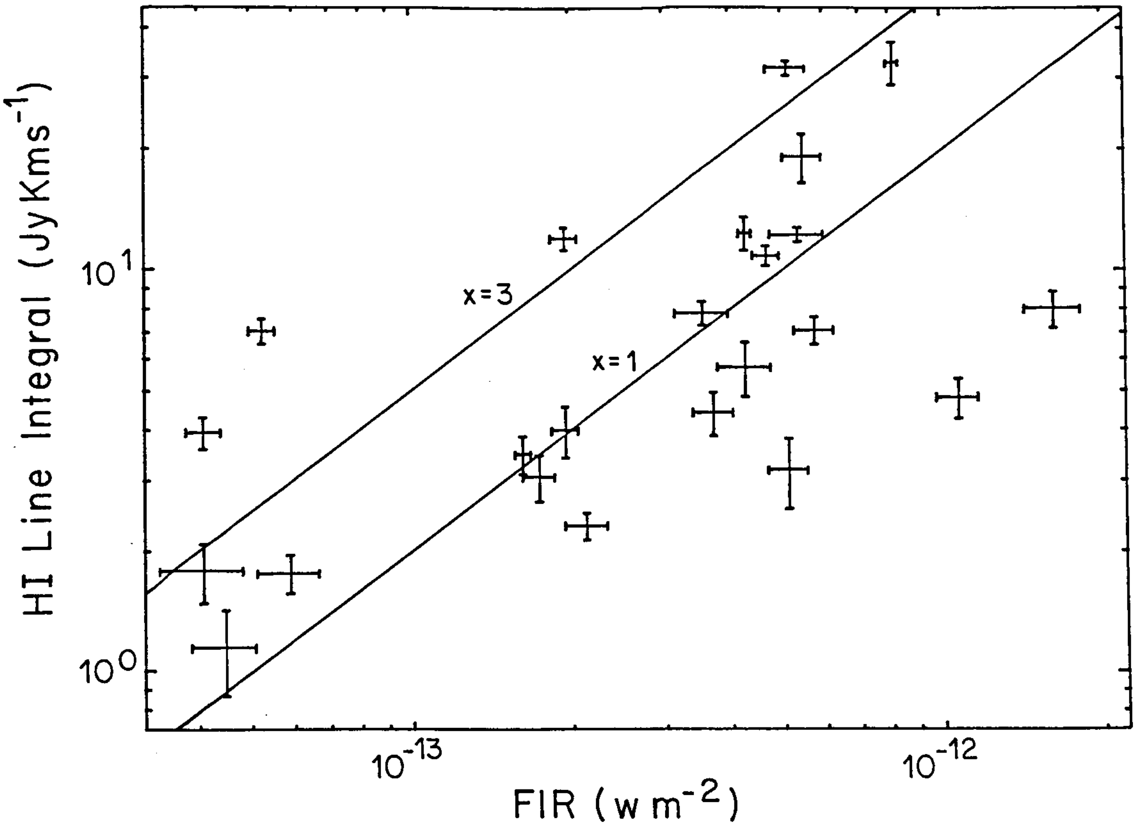

Fig. 2 - The relationship between the HI line integral and the FIR flux.

The main result of this project is to show that active spirals with FIR emission as high as 10^{38} watts may be described as having a higher level of activity of processes similar to those operating in more ordinary spirals with FIR of 10^{36} watts or less. The results imply that the same physical processes link the radio and FIR emission in these most luminous IRAS galaxies as in others. On the other hand, the intensity of the FIR is not simply a result of a larger and brighter system overall. The HI masses of these galaxies are not particularly large compared to ordinary spirals, indicating that these galaxies do not simply have scaled-up disks. As shown in figure 2, there is little correlation between HI mass and FIR luminosity, in contrast to CO emission (Young et al. 1986) which traces the molecular component. As figure 3 shows, the overall blue luminosity of these galaxies is somewhat correlated with their FIR and 21cm continuum emission, but not as well as the latter two are correlated with each other. This is partially due to high and variable extinction, but must also be in part the effect of the longer time scale (several times 10^8 years) associated with the population contributing to the blue luminosity (Bothun 1982).

The high correlation coefficient and the consistency of q in many samples has severe astrophysical implications. The total contribution to the FIR emission from sources unrelated to radio synchrotron emission must be small. Similarly, cosmic ray acceleration mechanisms which are unrelated to the massive star formation rate must be negligible in spiral galaxies. Since the characteristic energy loss lifetime for the cosmic ray particles emitting the radio continuum is 1.5 to 2×10^8 years, this may indicate that variations in the star formation rate do not occur much faster than this (Hummel 1986).

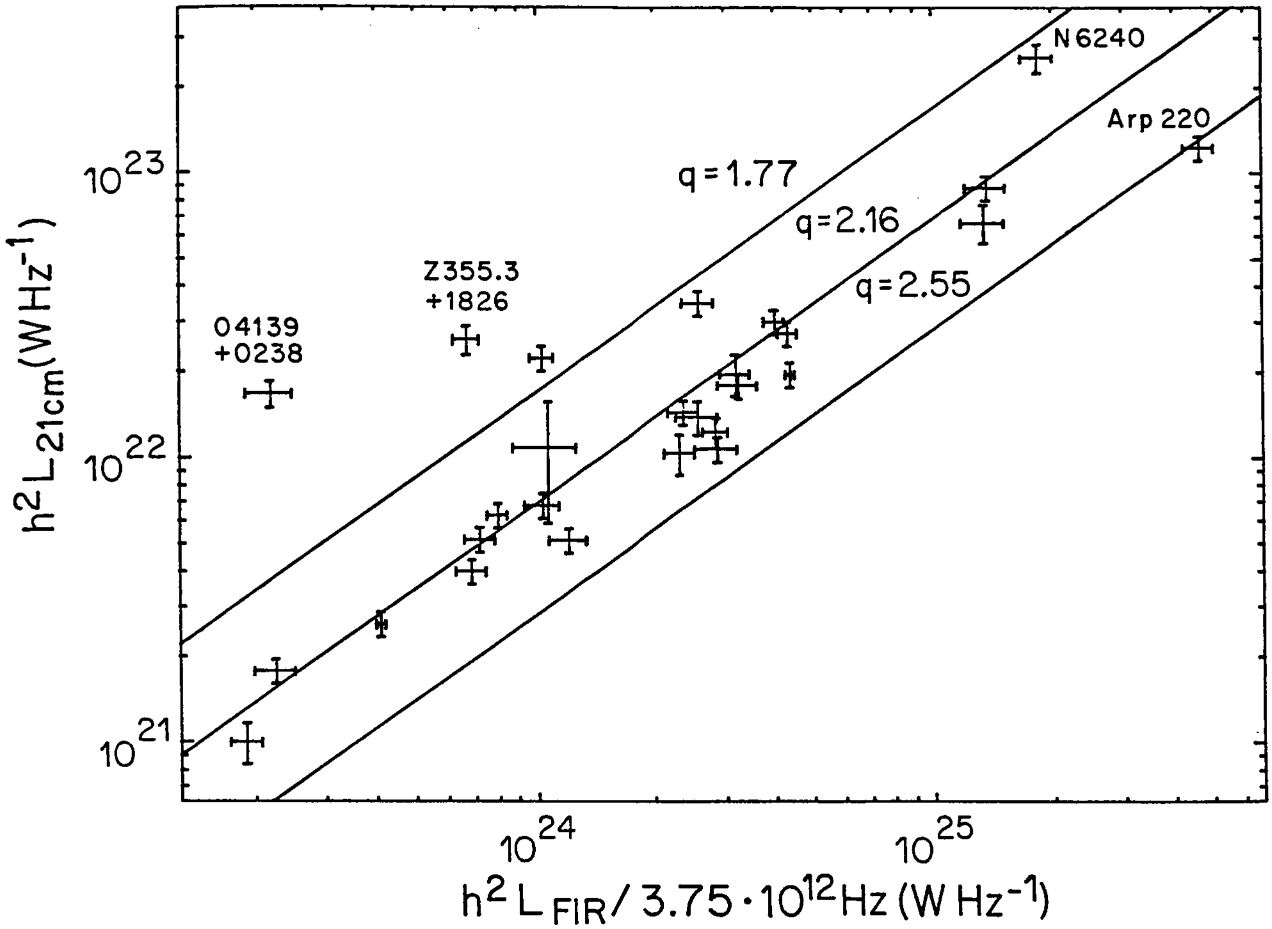

Fig. 1 - The relationship between radio continuum luminosity and FIR luminosity. Three values of q are indicated.

RESULTS

Figure 1 shows the relationship between luminosity at 21cm (watts/Hz) and FIR (watts) defined as an average of the 60μ and 100μ emission weighted by the two bandwidths. The best fit slope is indicated by the line, which corresponds to q = 2.16 where q is the average ratio of FIR to radio flux. The correlation coefficient is 85%, deleting the two galaxies with lowest q's (labelled 04139+0238 and Z355.3+1826) the correlation coefficient increases to 94%. This is as good a correlation as shown by most samples of normal spiral galaxies selected by other criteria.

The q value of 2.16 is similar to that found for many other samples, notably the Virgo cluster galaxies considered by Helou et al. (1985). As discussed by those authors this value is consistent with radio synchrotron emission by high energy electrons generated (indirectly) by the supernovae associated with a high rate of formation of massive stars. The FIR emission in this case is from dust in and around their HII regions. The supernova remnants are not the direct source of the radio continuum (assuming that they obey a normal Σ-d relation, Ulvestad 1982) but only a small fraction of the remnant energy is needed to power the radio emission through a secondary acceleration process such as interstellar shocks.

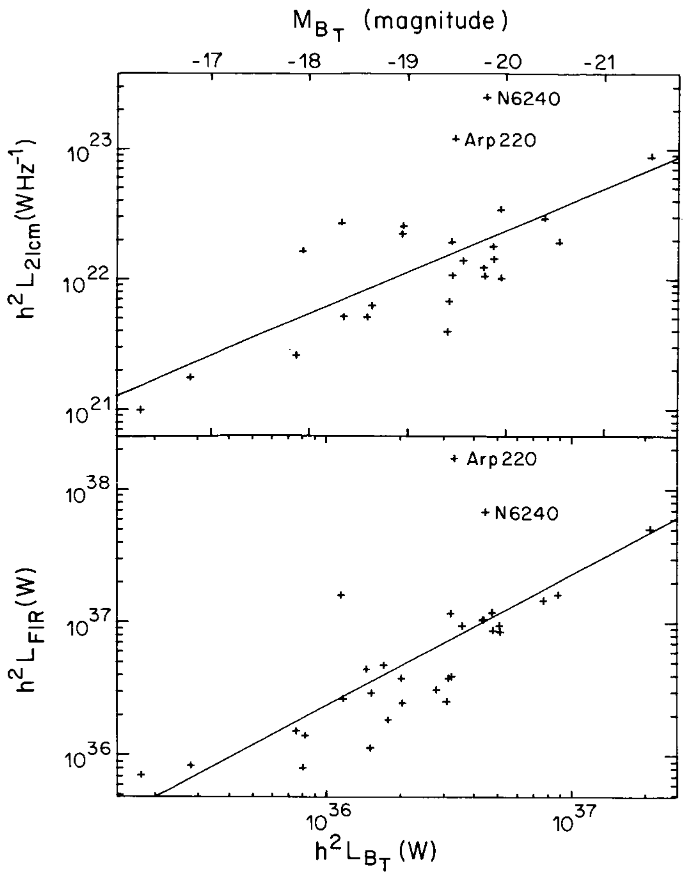

Fig. 3 - The relationships between blue luminosity (lower ordinate scale in watts, upper scale in B magnitudes) and radio continuum and FIR luminosities for galaxies in this sample.

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