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HI And FIR Emission From S0 Galaxies

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A large body of work has accumulated in recent years which throws into disarray the traditional assumption that S0 systems are inert, non-starforming galaxies with uniform, old stellar populations. The copious 21cm data have been recently reviewed and assessed by Wardle and Knapp (1986). This work showed that roughly a third of the several hundred observed S0's contain detectable amounts of HI. More recently, Pogge and Eskridge (1987) have shown that a significant fraction of HI-rich systems also exhibit Hα emission. Thronson *et al.* (1989) report detection of CO line emission from two thirds of the S0's in their sample. Both of these last papers, however, report on fairly small data sets ($\sim$ 20 objects each). From co-added IRAS data, Knapp *et al.* (1989) report that roughly two thirds of a sample of several hundred S0's are detected at 60μ and 100μ. Work by Bally and Thronson (1989) and Walsh *et al.* (1989) has shown that, while a large number of S0's follow a relation between radio continuum and FIR emission similar to that found for spirals, significant numbers of both radio-bright, and FIR-bright S0's exist. Clearly, a large number of factors are involved in determining the state of the ISM in S0 galaxies. The class is probably heterogeneous, suggesting that large data samples are required to sort out various sorts of objects. The 21cm and FIR samples are the two largest currently available. It is therefore of interest to compare the two and see where this leads.

The 21cm data were drawn largely from Wardle and Knapp (1986), with some additional sources. The most significant of these being Chamaraux *et al.* (1986). The FIR data were determined from 60μ and 100μ flux densities in Knapp *et al.* (1989), using the relationship given in Lonsdale *et al.* (1985). The intersection of these samples is a set of 254 objects. Rather than making a series of assumptions as to the distances of these objects, we decided to simply scale all the quoted observational data by the true apparent blue flux of each object. Thus, what we examine is the relative brightness of the 21cm line emission or FIR emission to the blue optical emission for each galaxy. Obviously, an optical band which is less seriously effected by internal absorption, such as the *H*-band, would have been preferable. Such data are, however, not generally available.

An examination of the full data set indicates that a limit analysis of the sort discussed by, e.g., Walsh *et al.* (1989) would be most appropriate. However, we have initially limited ourselves to an analysis of the detections only. The double detections appear to be roughly fit by a power-law, with significant populations of both 21cm-excess and FIR-excess galaxies. An iterative least-squares power-law fit was made to the double detections. Galaxies which deviated from this fit by more than $3\sigma_i$ were removed from the sample, and the fit was repeated. The fit was essentially unaltered by this second pass. Figure 1 shows those double detections which survive the 3σ rejection, along with the power-law fit.

As mentioned above, the 3σ rejection yields sets of galaxies which are either significantly HI- or FIR-bright, relative to the fit. In addition, examining the two single-limit data sets provides a number of systems which are also clearly inconsistent with the fit. Figure 2 shows all these points, again with the fit line drawn in.

In a Universe in which there were a smooth, consistent relationship between the amounts of gas in the neutral atomic and molecular phases, the rate and efficiency of star-formation, the IMF, and the gas-to-dust ratio, and in which there were no other significant processes contributing to the FIR emission (ambient heating of grains, nuclear emission ...), one would expect a tight correlation between the total HI content and the total FIR emission in a given galaxy. The obvious interpretation is that the power-law galaxies basically fit this picture: they are normal star-forming systems, which are able to process their neutral gas into stars in a fairly typical manner for disk galaxies. (Note that this does NOT mean they are "typical S0's", whatever that means).

Those galaxies which are HI-bright, relative to their FIR emission (or limit) are clear candidates for systems which have accreted their gas. In fact, the extreme systems in this category for which HI maps have been published (van Driel 1987 and references therein, Schweizer *et al.* 1989) all appear, on the basis of those maps, to have accreted their gas. It is also likely that a number of these systems have not accreted their gas, but the total amount and concentration of what gas they do have is simply insufficient to trigger star-formation at this time. This pertains mainly to those systems which have small ratios of HI to blue flux, but essentially no sign of FIR emission to quite low levels.

Those galaxies which are FIR-bright for their HI emission (or limit) do not have so simple an explanation. Three physical processes appear to be at work: enhanced star-formation (as in NGC 694, Balzano 1983); ram-pressure stripping, especially for the Virgo S0's, which may lead to both reduced HI and enhanced FIR, due to compressionally induced star-formation; FIR emission from grains heated by the ambient radiation field of a basically gas-poor galaxy. In general, those systems with both FIR and HI detections are more FIR-bright than those with FIR detections but HI limits. This suggests the first and second processes are important in the double detected galaxies in this sample. More observational work, specifically CO and Hα studies are needed to sort out these various possible effects.

While further consideration of these data are clearly warranted, including a statistical assessment of the limit points, the following results are already clear: HI and FIR flux data can be used to isolate strong candidates for systems which have gained their HI gas via accretion; a rough power-law relationship exists for galaxies which are undergoing relatively normal star-forming activity; a heterogeneous class of galaxies with strong FIR emission compared to their HI emission exists. Further work is required to determine the various physical processes responsible for this last class.

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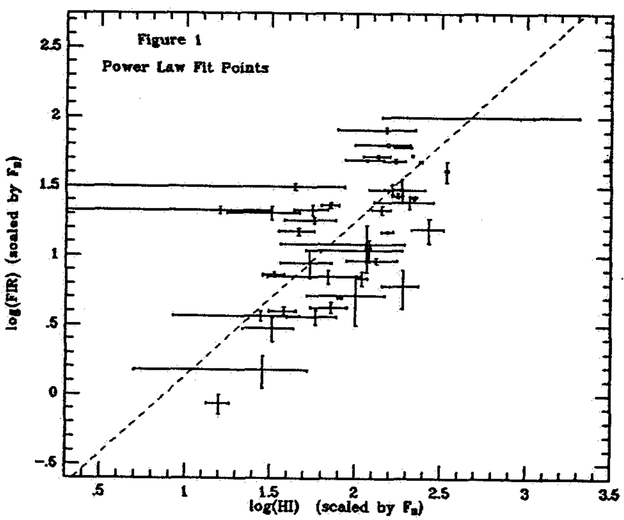

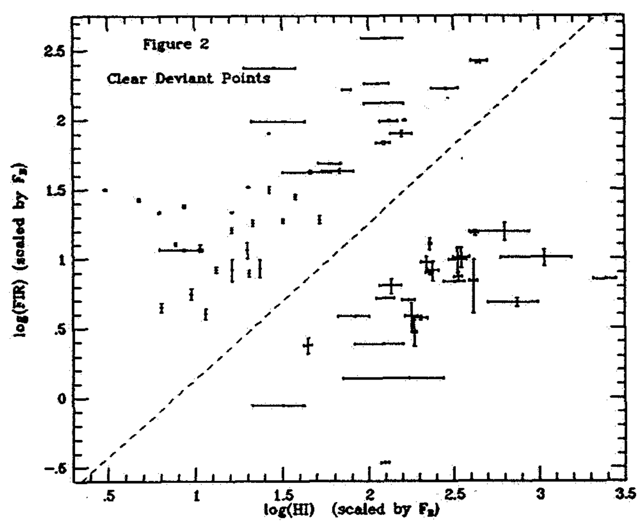

Distribution, Kinematics, and Origin of HI Gas in SO and SO/a Galaxies

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A minority of SO and SO/a galaxies are known to be enriched in HI gas. Their HI content does not appear to correlate with optical properties of the galaxies.

We have mapped the HI distribution and motion in about 20 gas-rich SO and SO/a galaxies using Westerbork and the VLA. Most gas-rich SO galaxies show outer rings of HI, often with radii of about $2R_{25}$. Several show inner rings and some have both inner and outer rings. The outer rings are often strongly inclined. Almost all objects have large contral holes in their HI distribution. Non-barred SO/a galaxies show filled HI disks, like the early-type spirals. Barred SO/a galaxies show large central HI holes.

In most cases, the HI appears to be in well-ordered rotation. A few objects with large outer HI rings show very high M/L ratios, suggesting massive dark halos. The Tully-Fisher relation for gas-rich lenticulars is similar to that of the spirals.

We discuss possible evolutionary scenarios for these objects.