EQUIPARTITION: FACT OR FICTION?

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The use of equipartition calculations in estimating magnetic field strengths and energetics of extragalactic radio sources is widespread and well known. Since it is one of the few ways in which to calculate radio source parameters, it is important to determine how reasonable the approach generally is. Since this assumption is approximately a minimum energy criterion one expects that deviations from equipartition are limited at some level by independently determined constraints on the total energy. In this regard we have analyzed radio images of nearby spiral galaxies in order to determine equipartition magnetic fields and relativistic gas energies and to explore their possible nonequipartition configurations.

Maps of equipartition fields and relativistic gas energies have been constructed through a program we have written and incorporated in to the Astronomical Image Processing System (AIPS). The program EQPRT applies the equipartition calculations to each pixel of a pair of images separated in frequency. In this way, spatial variations of the synchrotron spectral index can be taken into account in order to do the calculations properly. We have combined pairs of VLA maps at 1.4 GHz and 4.8 GHz at a resolution of $\approx 4''$ for NGC 3504, NGC 5005, NGC 5033 and NGC 5055. Except for NGC 3504 which is a starburst galaxy, these are normal, quiescent galaxies whose disk properties are not expected to differ much from those in our galaxy. Sample maps of the synchrotron emission at 1.4 GHz, the equipartition magnetic fields and equipartition relativistic gas energies for NGC 5033 are shown in figure 1. Table 1 summarizes the typical equipartition values found and the range of these values in the observed portions of the galaxy disks. Generally, we find that, except for the starburst galaxy NGC 3504, there is a gradient in the disks such that the fields and energies have their greatest values at the galactic centres. Typical observed values in the inner disks are $10\,\mu G$ for the magnetic field and $10\,eV\,cm^{-3}$ for the energy density of the relativistic particles (which are assumed to have proton to electron energy ratios of ≈ 30 as observed at the Earth). Table 2 illustrates the consequences of varying the magnetic field from its equipartition value.

We have constructed table 2 in order to determine a 'range of plausibility' for nonequipartition values of the magnetic field, B and the relativistic particle energy density, ϵ_r. If B is too low relative to B_{eq} then ϵ_r is unrealistically high. For example, an order of magnitude decrease in B results in $\epsilon_r = 300\ eV\,cm^{-3}$. Anything higher than this represents a disproportionate source of pressure and there is no

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evidence that the thermal pressures in these galaxies are sufficient to contain the relativistic particles under those conditions. In fact, observations of galaxies like NGC 3079 (and possibly NGC 3504) suggest that such values of ϵ_r lead to large scale outflow from the disk. In our galaxy, equipartition of relativistic particles, magnetic fields and thermal gas motions exists at the $1 eV\, cm^{-3}$ level. The huge ϵ_r implied by low B in these galaxies would represent a strong deviation from our galaxy. The propagation scale length l_p (defined as $V_A t_{\frac{1}{2}}$ where V_A is the Alfvén velocity and $t_{\frac{1}{2}}$ the synchrotron lifetime) of the electrons adds another constraint to possible values of B. With $l_p > 30 kpc$ the relativistic electrons should have no trouble populating halos of spiral galaxies. Although such halos may exist they have been seen in very few galaxies. Finally, large values of ϵ_r are implausible if no evidence exists for unusual activity in the disks of these galaxies.

If one considers values of B larger than B_{eq} one encounters a different set of difficulties. An order of magnitude increase in B results in uncomfortably short lifetimes of the synchrotron emitting electrons. This results in very short propagation scale lengths of $\approx$ 300 pc. Such scale lengths are just enough to produce synchrotron disks of similar thicknesses to the optical disks of spiral galaxies. Further increases in B also prevent the spreading of relativistic electrons in the planes of the disks so that these particles should remain tied to their sources. The rapid increase of the magnetic pressure and energy density with B quickly leads to unreasonable values for $B > 10B_{eq}$.

Within the bounds of our assumptions, it appears that the range of plausibility for B and ϵ_r is limited to, at most, an order of magnitude above and below the equipartition values.

Figure 1

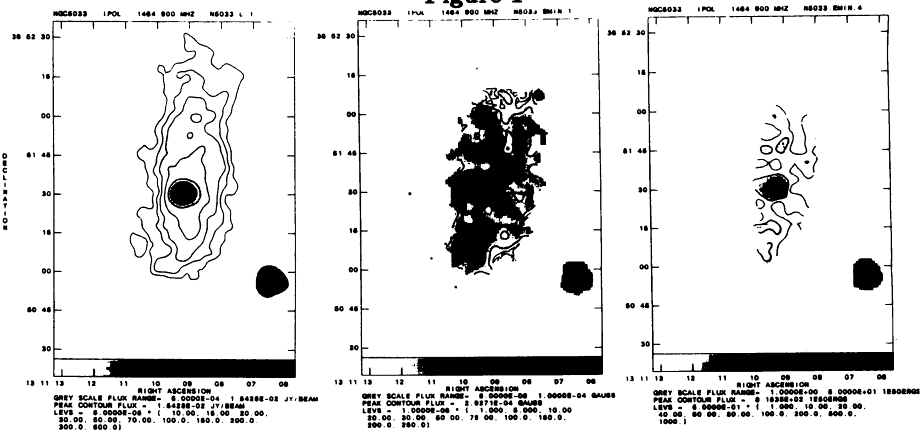

Table 1: Observed ranges of $B_{eq}(\mu G)$ and $\epsilon_r(eV\, cm^{-3})$

Galaxy	$< B_{eq} >$	$< \epsilon_r >$	ΔB_{eq}	$\Delta\epsilon_r$
NGC 3504	10	20	0.5 – 100	2 – 600
NGC 5005	15	40	1 – 70	2 – 160
NGC 5033	10	25	5 – 30	3 – 150
NGC 5055	20	20	2 – 50	2 – 120

Table 2: Departures from equiparition
$B_{eq} = 10^{-5}\, G$, $(\epsilon_r)_{eq} = 10\, eV\, cm^{-3}$

B/B_{eq}	$\epsilon_r(eV\, cm^{-3})$	$t_{\frac{1}{2}}$ (yrs)	l_p (pc)
10^3	3×10^{-4}	10^2	3
10^2	10^{-2}	3×10^4	30
10	0.3	10^6	3×10^2
1	10	3×10^7	3×10^3
10^{-1}	3×10^2	10^9	3×10^4
10^{-2}	10^4	3×10^{10}	3×10^5
10^{-3}	3×10^5	10^{12}	3×10^6