CONSTRAINTS ON THE MAGNETIC FIELDS IN GALAXIES IMPLIED BY THE INFRARED-TO-RADIO CORRELATION

GEORGE HELOU and M. D. BICAY
Infrared Processing and Analysis Center
California Institute of Technology
Pasadena, CA 91125, USA

ABSTRACT. We propose a physical model for understanding the tight correlation between far-infrared and non-thermal radio luminosities in star-forming galaxies. This approach suggests that the only constraint implied by the correlation is a universal relation whereby magnetic field strength scales with gas density to a power $1/3 \leq \beta \leq 2/3$.

1. Model

The constant ratio between thermal far-infrared and non-thermal radio luminosities of star-forming galaxies (de Jong *et al.* 1985; Helou *et al.* 1985) has been a puzzle for several years, because this ratio involves several parameters (including the magnetic field strength, cosmic ray confinement efficiency, and optical depth in the dust) which would not be expected a priori to be constant among galaxies. Furthermore, the results by Bicay *et al.* (1989) and Bicay and Helou (this Symposium) point out that cosmic rays escape from the disks of galaxies before they have decayed radiatively, thus forcing any treatment of the problem to take into account all at once their diffusion, decay, and escape. This apparent complication turns into an advantage, for it allows us to write the radio luminosity from the system as $L_{rad} = L_{CR} t_x (1 + t_x)^{-1}$, where L_{CR} is the cosmic ray luminosity, and t_x is the ratio of escape time-scale to radiative decay time-scale. On the other hand, the infrared luminosity may be written as $L_{IR} = L_{UV}(1 - e^{-\tau_{UV}})$, where L_{UV} is the heating luminosity, and τ_{UV} is the effective optical depth presented to this luminosity by the disk of the galaxy. Observations indicate that L_{rad}/L_{IR} is practically constant in the most general case.

This constancy implies first that $L_{CR}/L_{UV} \simeq$constant, which is strongly suggested by the global correlation, and is interpreted to mean that massive stars dominate as the common source of both the heating photons and the cosmic ray electrons accelerated during the supernova phase. The second implied condition is $\tau_{UV} = t_x$ at least between 0 and 5, beyond which it is enough to have both τ_{UV} and $t_x >> 1$. Assuming that magnetic field and density are related by $B = B_0(n/n_0)^{\beta}$, with $1/3 < \beta < 2/3$, the condition can be rewritten in terms of quantities averaged over the system, namely, $< \ell_{esc}/1\mathrm{kpc} > \simeq (h/100\mathrm{pc})^{1/2} < n/1\mathrm{cm}^{-3} >^{\epsilon}$, where ℓ_{esc} is the distance from source to cosmic ray at the time of escape, and h is the thickness of the galaxy disk. For the indicated range in β, we have $-1/6 < \epsilon < 1/12$, so we neglect the dependence on n in what follows. Since the geometry and sizes of star-forming galaxies are roughly constant, the condition would be met if $< \ell_{esc} >$ was roughly constant among galaxies.

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2. Implications

Based on the formalism above, the constancy of the global infrared-to-radio ratio among galaxies requires the following three conditions:

(a) That the dust-heating photons and the cosmic ray electrons be produced at the same sites and in constant proportion to each other. This is a plausible scenario since massive stars are the best candidates for emitting the photons during their life-time, and then accelerating the electrons as part of the supernova explosion and subsequent shock wave.

(b) That the magnetic field (strength B) and the gas (density n) in the interstellar medium of galaxies be well mixed, following a relation of the form $B = B_0(n/n_0)^\beta$ over most of the interstellar medium, with β near 1/2, and the same B_0 and n_0 applying universally. Such a relation may be assumed to hold in the Milky Way, given present observational evidence (Fiebig and Güsten 1989). It is also a priori compatible with either a primordial origin or a dynamo-effect origin for the magnetic field. The most severe aspect of this requirement is that the relation must maintain the same normalization (B_0 and n_0) for all galaxies. Its advantage is that it obviates the need for a servomechanism coupling directly magnetic fields and star formation activity, or regulating the infrared-to-radio ratio locally within the disk (Beck and Golla 1988).

(c) That the geometry of star-forming systems be roughly constant, which is certainly true of disk galaxies, and that the escape scale-length for cosmic ray electrons also be roughly constant, which is reasonable in light of the constant geometry. The model result that ℓ_{esc} should be on the order of a kpc or more agrees very well with the observed "cosmic ray spreading" scale lengths reported by Bicay and Helou (this Symposium). The implications for cosmic ray confinement models need further exploration.

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