THE INFLUENCE OF EXTENDED SOURCE DISTRIBUTIONS ON COSMIC RAY SPECTRAL INDEX VARIATIONS IN THE GALACTIC WIND MODEL

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ABSTRACT. The solution of the steady-state transport equation describing the propagation of relativistic electrons perpendicular to the galactic plane in a galactic wind is discussed for extended source distributions. The wind velocity is assumed to be zero in the plane and to increase with galactic height. The electrons undergo simultaneously diffusion, convection, adiabatic deceleration, radiative losses and injection. We contrast the resulting spectra with those derived for an infinitely thin source distribution and discuss the dependence of the variation of the spectral index inside the source distribution on the form of this distribution in any transport model. Apart from a new region at very small energies the asymptotic spectra agree with those of the line-source model (LS). Inside the source distribution the spectral index break is doubled from $\Delta\gamma_{lin}$=0.5 to $\Delta\gamma_{ext}$=1.0.

1. INTRODUCTION AND BASIC EQUATIONS

The interpretation of observations of nonthermal radio emission depends strongly on our understanding of the dynamics of relativistic electrons in their environment. This led to the introduction of electron transport models for static halos, in which the electrons undergo radiative losses and diffusion (Webster, 1970; Bulanov and Dogiel, 1974). In the early Eighties the picture of the ISM changed radically (Savage and DeBoer, 1981; York, 1982; McCammon et al, 1983). It exists a hot (10^5 K), tenuous (10^{-3}cm^{-3}) coronal phase, which occupies a large fraction of the ISM. This coronal phase is maintained by high-velocity shocks ($V > 20 km/sec$) from supernova explosions or from powerful winds of early-type stars. Thus, transport models have to include the effects of convection and adiabatic deceleration.

Following Lerche and Schlickeiser (1982,LS) we consider the 1-dim. stationary continuity equation for the differential number density N(E,z) of relativistic electrons including terms for diffusion, convection, adiabatic deceleration and radiative losses

$$\frac{\partial}{\partial z}\left(D(E,z)\frac{\partial N}{\partial z} - V(z)N\right) + \frac{\partial}{\partial E}\left(\left[\frac{1}{3}\frac{\partial V}{\partial z}E - \dot{E}(E,z)\right] N\right) + q(r,\phi,z,E) = 0$$

H. Bloemen (ed.), The Interstellar Disk-Halo Connection in Galaxies, 369–372.

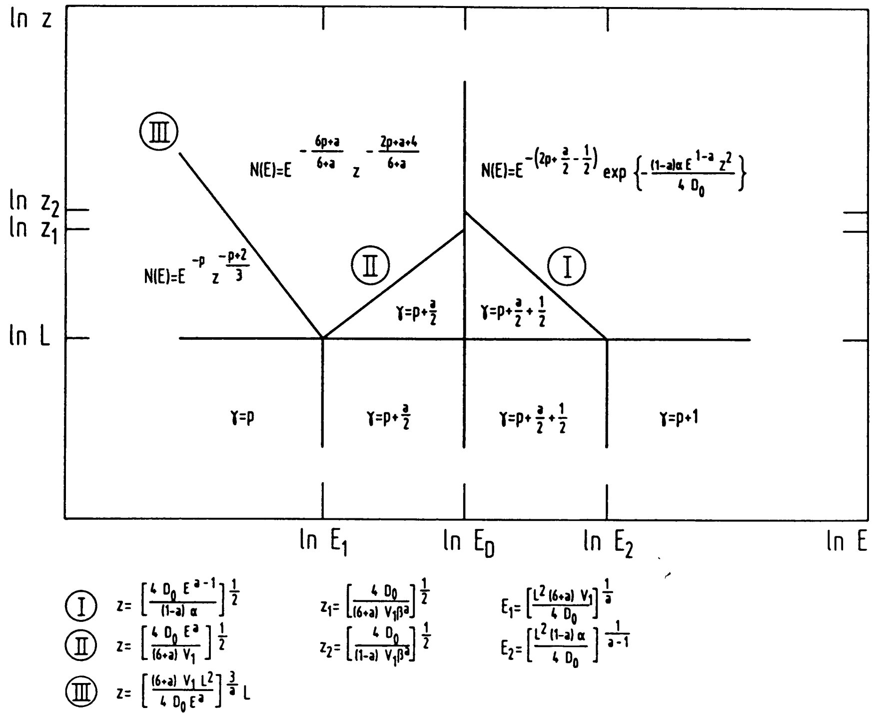

Figure 1. Schematic illustration of the nine regions in z-E-space considered for the assumption of a uniform diffusion d(z)=1, and thus μ =z, for which asymptotic spectra have been derived. One may also replace z by μ yielding the original μ-E-diagram. The asymptotic number density and the spectral index, respectively, are given.

which is analytically solvable under the assumptions discussed in LS.

Relaxing on their line-source assumption we present asymptotic solutions for extended source distributions, e.g. the step function

$$q(r,\phi,\mu,E) = q_0(r,\phi)S(\mu)E^{-p} \qquad \text{with} \quad S(\mu) = \begin{cases} 1 & \text{for } |\mu| < L \\ 0 & \text{otherwise} \end{cases}$$

2. RESULTS AND CONCLUSIONS

The solution of the continuity equation yields (for details see Pohl and Schlickeiser 1990,PS)

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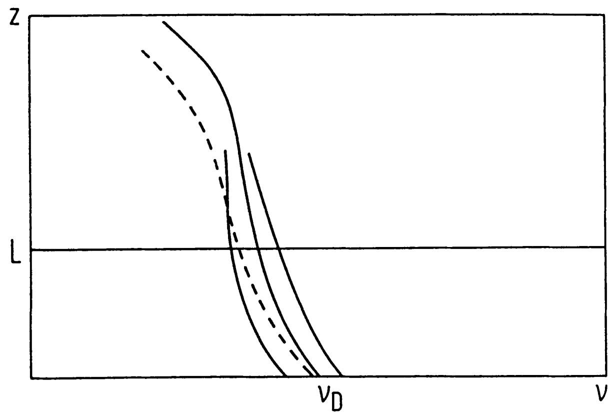

Figure 2. Variation of the break frequency ν_D in the case of a scale height of the magnetic field much smaller than L. The dashed line is valid for very small scale heights, whereas the solid line marks the case that ν_D does not vary with galactic height over a wide range of z resulting in a step in the z-variation of the spectral index. The accompanying solid lines mark the breaks around E_1 and E_2.

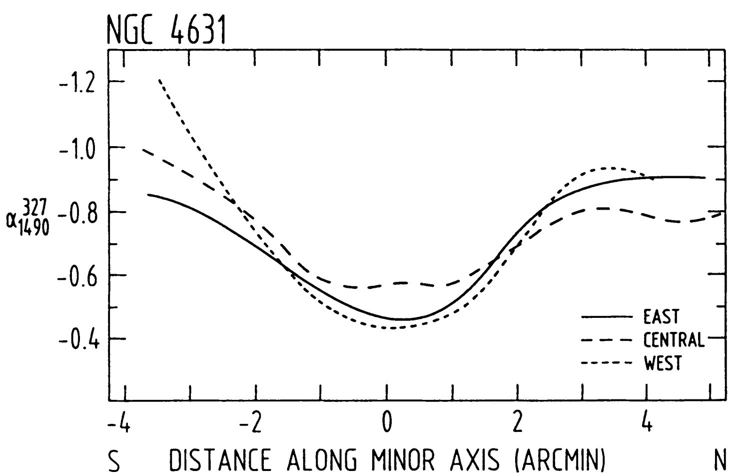

Figure 3. Variation of the spectral index between 327 and 1490 MHz for NGC 4631 as obtained by Hummel and Dettmar (1990). On the northern side a stepwise steepening is visible.

$$N(\mu,E) = \frac{q_0\ E^{-(p+a/2)}}{2(1+\beta E)^4\sqrt{\pi}\ V_1\ D_0} \int_{-\infty}^{\infty} d\mu'\ S(\mu') \int_1^{\infty} \frac{d\rho\ \rho^{-p}}{\left(\int_1^\rho \frac{dx\ x^{5+a}}{(1+\beta E x)^7}\right)^{1/2}}$$

$$\times\ exp\left[-\frac{V_1\left(\mu'\left(\frac{1+\beta E}{1+\beta E\rho}\right)^3\ \rho^3\ - \mu\right)^2}{4D_0\ E^a(1+\beta E)^6\ \int_1^\rho \frac{dx\ x^{5+a}}{(1+\beta E)^7}}\right]$$

$$\text{with } \beta^{-1} = E_D\ = V_1/\alpha$$

We derive asymptotic solutions for regions in which one of the following timescales is smallest (see figure 1)

$$\tau_r\ = (\alpha E)^{-1} \qquad \text{radiative losses}$$

$$\tau_D\ = \frac{\mu_0{}^2}{D_0\ E^a} \qquad \text{diffusion}$$

$$\tau_A\ = V_1{}^{-1} \quad \text{adiabatic deceleration}$$

Inside the source distribution the spectra can be determined with the concept of the catchment sphere introduced by Webster (1970).

For a comparison of our results with the observations one needs a translation of the μ-E-diagram into a z-ν-diagram. The best way to do this is a hydrodynamical calculation of realistic galactic wind patterns and therefore the spatial variations of parameters like the magnetic field strength and the wind speed gradient. For large values of L (e.g. secondary electrons, reacceleration) and an exponentially decreasing magnetic field strength the synchrotron break frequency ν_D related to the break energy E_D does not vary with the galactic height over a wide range of z (see figure 2). Then in a specific frequency range around ν_D one observes a more or less stepwise steepening of the spectra with z. This behaviour is observed on the northern side of NGC 4631 (figure 3).

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