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SRL Internal Memo
Fraction of Ionized Hydrogen in the ISM
J. George, February 17, 1999

Propagation calculations that describe the transport of cosmic rays through the Galaxy include energy loss due to ionization. Since the rate of energy loss is different for an ionized medium, it is important to know the fraction of hydrogen in the ISM which is ionized. Relatively recent surveys of the Milky Way at various wavelengths have provided new data which can be used to estimate the average density of ionized hydrogen.

A number of different values for the ionized fraction of hydrogen have been used in propagation calculations. The choice of value seems to have as much dependence on the person choosing it as on the sources and quality of the data available at the time. I will try here to summarize where some well-known values came from and provide the data they are based on in order to make a more informed choice for future propagation code.

A value which is possibly familiar to SRL people comes from Rick Leske [6]. He uses a value of 16% for the ionized hydrogen fraction, citing Soutoul, Ferrando, and Webber [10]. The Soutoul paper does not actually give a number explicitly, but rather states that the energy loss in an ionized medium is 3.6 times as large as in neutral hydrogen, resulting in an overall increase in energy loss of 1.4 for the combined material. This is enough to work out the ionized hydrogen fraction they were using.

$$1.4 = 1.0(1-\eta) + 3.6\eta \tag{1}$$

where $\eta = n_{H+}/n_H$ is the fraction of ionized hydrogen, about 0.15. The reference cites several sources [5, 2, 4] which give a column density of $3.7 \times 10^{20}\mathrm{cm}^{-2}$ for neutral atomic hydrogen and $0.7 - 0.9 \times 10^{20}\mathrm{cm}^{-2}$ for the free electron disk. The electrons presumably come from photo-ionization of the neutral hydrogen so are a good measure of the ionized hydrogen component. These sources give a ratio that is closer to 21%.

A previous paper by Soutoul and Ferrando used a two-component ISM [9]. The neutral component had a density of 1 cm^{-3} and a scale height of about 100pc. The ionized component had a density of 0.031 cm^{-3} and a scale height of 750-1500pc. This gives a ratio of column densities of about 31%. The references that these values were based on are studies of pulsars whose distances have been measured [1, 8, 12]. These older surveys contain fewer pulsars than the more recent ones above.

Thayer included an ionized fraction of 28% in his propagation model [11]. His sources include several quite recent references [7, 3, 2]. These give an electron density based on 61 pulsar measurements of 0.033 cm^{-3} with a scale height of 0.53-0.84 kpc [7]. The neutral hydrogen density is roughly 0.366 cm^{-3} with a scale height of 195 pc away from large clouds [3]. This gives a ratio of column densities of 31%. Thayer cites Soutoul, Ferrando, and Webber [10] for his method and states that his 28% is "consistent with the 30% used" by them.

My conclusion is that the early value of 16% for the ionized hydrogen fraction was based on early measurements with a much smaller sample of pulsar data. Newer measurements seem more consistent with a value around 30%, though it is not completely clear to me how each author calculated the exact value they chose. Given the large range available in the scale heights for neutral hydrogen and the galactic free electron disk, it is probably just fine to take 30% as a working value for current propagation calculations.

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