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ON THE DISCREPANCY OF CORONAL MAGNETIC FIELDS IN SOLAR OPTICS AND RADIO

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ABSTRACT

It is analysed the discrepancy about the coronal magnetic field between solar optic and solar radio using magnetic fibril concept with filling factor and fractal structure model. The magnetic field of $\sim$ 100 G considered in solar optics is mean value in a large scale, and that of $\sim$ 1000 G in solar should be the value of fine structures inside "macro" loop.

I. INTRODUTION

The magnetic field in the solar corona is poorly known because there are few kinds of observations that can measure it unambiguously (Gary et al.1993). It is contentious about the coronal magnetic fields in solar optics and radio. In solar optics, the magnetic field is usually considered as $\sim$ 100 G, many measurements indicate that few or no prominences have field strengths above 150 G, and typical strengths are 26 G (Harvey 1969); in solar radio, it is always takens as $\sim$ 1000 G to fit the observed emission flux, Peterson and Winckler (1959) took the field strength of 1000 G in calculating the number of fast electrons in the solar flare, Holt and Cline (1968) and Holt and Ramaty (1969) used numerical calculations of gyrosynchrotron emissivity to estimate the number of electrons for the flare of gyrosynchrotron emissivity to estimate the number of electrons for the flare of 1966 July 7, and deduced the field strength is $\sim$ 1000 G, De Feite (1975) made a rough estimate and obtained a typical source field strength of 1200 G for solar flare. By observation, Gary et al. (1993) deduced that the magnetic field strength at the base of the corona above the leading spots was $\sim$ 1200 G, and $\sim$ 1100 G above the folling spots. Now it is known that there are observed small-scale magnetic fields on the solar surface, perhaps the sunspots contain complex internal fine structure that are far from being fully resolved. It is believed that these magnetic structures are composed of many thinner fluxtubes (De Jager et al. 1993), for convenience called magnetic fibrils. The corona is highly inhomogeneous, many observations suggest such a structure in the solar corona. Several authors (De Jager 1986) have found that magnetic loops on the sun are not homogeneously filled with magnetic fields but that there is a filling factor being $\ll 1$; De Jager (1986) had summarized data available at that time and concluded to averge values of 0.01. It is proposed that the gas is limited to a number of very thin magnetic fibrils inside each "macro" structure (Dere et al. 1987; Golub et al. 1990). The inhomogeneous magnetic structures have the property of fractal dimension idea.

Our work is to study the coronal magnetic field using magnetic fibril concept with filling factor and fractal structure model, to analyse the difference of coronal magnetic fields in solar optics and radio.

II. FIBRILLARY STRUCTURE AND FILLING FACTOR

The magnetic loops are inhomogeneously filled with magnetic fibrils with filling factor, the mean field should be (De Jager et al. 1993)

$$\langle B \rangle = \phi b_f + (1-\phi) b_i$$

here, b_f and b_i are the magnetic fields of the fibrils and interfibrillary volumes, respectively, and ϕ is the filling factor. Taking $b_f = 1000G$, $\langle B \rangle = 100G$; if $\phi = 0.01$, then $b_i = 90.91G$; if $\phi = 0.005$, then $b_i = 95.48G$. Due to the filling factor is small, the magnetic fields of the interfibrillary volumes are sligtly smaller than the mean magnetic field. In solar optics, a corona-flare loop has "macro" structure, its mean value of magnetic field is $\sim$ 100 G ; in solar radio, the gyrosynchrotron emission corresponding to that of fibrils is $\sim$ 1000 G.

III. FRACTAL STRUCTURES

The idea of fibrillary structures with filling factor describe a system as discrete scalling distribution ; the fractal structures correspond to a continuum limit for the discrete scalling of the system, which is a porous self-similar distribution. For this distribution, within a certain radius $r_\circ$, there are $N(r_\circ)$ objects, within r, there are $N(r)$ objects, the relation between $N(r)$ and r is (Coleman and Pietronero 1992)

$$N(r) = N(r_\circ)(\frac{r}{r_\circ})^D (r \geq r_\circ) \tag{1}$$

here $D \approx 1.2$ is a fractal dimension.

For a sphere of radius r the average density $n(r)$ is

$$\bar{n}(r) = \frac{N(r)}{\frac{4\pi}{3}r^3} \tag{2}$$

Substituting Eq.(1) into Eq.(2), it gives

$$n(r) = n(r_\circ)(\frac{r_\circ}{r})^{3-D}, \tag{3}$$

where $n(r_\circ) = \frac{N(r_\circ)}{\frac{4\pi}{3}{r_\circ}^3}$ is the average density for the small sphere of radius $r_\circ$.

Similarly, for a sphere of radius r, the average magnetic energy density $W(r)$ should be

$$W(r) = W(r_\circ)(\frac{r_\circ}{r})^{3-D}, \quad (4)$$

with

$$W(r) = \frac{B^2(r)}{8\pi}, \quad (5)$$

where $B(r)$ is magnetic field strength. From Eqs.(4) and (5), we get

$$B(r) = B(r_\circ)(\frac{r_\circ}{r})^{\frac{3-D}{2}}. \quad (6)$$

For optically thin radio emission, the flux F measured from a radio source is

$$F = \int \frac{\eta_\nu}{R^2} dV, \quad (7)$$

where η_ν is the emissivity, dV is the element of volume for the source, R is the distance between the source and our instrument, here $R = 1.5 \times 10^13cm$. Since the gyrosynchotron emissivity $\eta_\nu \propto n'(r)B(r)$ (Gary 1985), then

$$F = \frac{K}{R^2} \int \bar{n'}(r)\bar{B}(r)dV, \quad (8)$$

here the ratio coefficient $k = \eta_\nu/\bar{n}'\bar{B}$, $\bar{n}'$ is the number density of non-thermal electrons, B is the magnetic field strength.

And a semiempirical expression for the emissivity from a power-law distribution of electrons is by Dulk and Marsh (1982), derived from numercial evaluation of formulae by Takakura and Scalise (1970),

$$\begin{aligned} k &= \frac{\eta_n u}{\bar{n}'\bar{B}} \\ &= 3.3 \times 10^{-24} 10^{-0.52\delta} (\sin\theta)^{-0.43+0.65\delta} s^{1.22-0.90\delta} \quad (9) \end{aligned}$$

where δ is the electron spectral index, θ the angle of the field direction to the line of sight, s the hamonic number.

We take $\delta = 3$, $\theta = \pi/4$, then $k = 5.36 \times 10^-26 s^-1.48$. Gyrosynchrotron emission during solar flares generally occurs at $s = 10$ to 100 (Gary 1985), and the harmonic numbers of samples given in Gary's paper (1985) are 10 to 42, now we select $s = 25$, then the ratio coefficient $k = 4.57 \times 10^-28$.

For a loop of radius r and lengh L, from Eqs.(3), (6) and (8), we have

$$\begin{aligned} F &= \frac{k}{R^2}\{\int_{r_\circ}^{r} \bar{n}'(r)\bar{B}(r)L2\pi r dr + n'(r_\circ)B(r_\circ)\pi {r_\circ}^2 L\} \\ &= \frac{k}{R^2} n'(r_\circ)B(r_\circ)(\pi r^2{}_\circ L)\frac{1}{0.7}[2.7 - 2(\frac{r_\circ}{r})^{0.7}. \quad (10) \end{aligned}$$

From Eq.(10), we can deduce the magnetic field strength of the fibrils $B(r_\circ)$ for a certain measured flux.

Table 1. Magnetic fields of fibrils for several condition

$r_\circ$(km)	$B(r_\circ)$	
	$n' = 10^5 \mathrm{cm}^{-3}$	$n' = 2 \times 10^5 \mathrm{cm}^{-3}$
200	2.3kG	1.16kG
100	2.6kG	1.3kG
1	6.4kG	3.2kG

A general coronal loop, its radius $r \sim 10^9 cm$, $L \sim 10^10 cm$, the number density of thermal electrons and non-thermal electrons are $n \sim 10^8 - 10^9 cm^-3$ and $n' \sim 10^5 cm^-3$, respectively. Define $\beta = n'/n = 10^-3 - 10^-4$. Assume $r_\circ = 2 \times 10^7 cm$, $n' = 2 \times 10^5 cm^-3$, from Eq.(3), $n'(r_\circ) = 2.29 \times 10^8 cm^-3$. The hottest and densest plasma region in cocona is related to X-ray fibrils or emitting cores, which temperature can be as high as 10^7K, electron density is about $10^11 - 10^14 cm^-3$, the fibrils is possibly as thin a $1.6 \times 10^6 cm$ (Zhang 1992), then $n'(r_\circ)/(10^11 - 10^14) = 10^-3 - 10^-6 \leq \beta$, this shows that the derived non-thermal electron density of the fibrils is reasonable.

Substituting all known values into Eq.(10), we get

$$F_s fu = 2.15 \times 10^{-1} B(r_\circ) \quad (11)$$

For the samples given in Gary's paper (1985), the average radio flux is a about $250(sfu)$ except No.11 flare, according to Eq.(11), the magnetic field strength of the fibrils is

$$B(r_\circ) \approx 1.16kG.$$

IV. DISCUSSION

Using magnetic fibril concept with filling factor and fractal stucture model, we have been able to explain the discrepancy about the coronal magnetic fields in solar optics and radio. In solar optics, the usual magnetic field is mean value in a large scale; in solar radio, the field should be the strong field of fine structures inside each "macro" loop. The actual field strength are 1-2kG, and the characteristic sizes are in the range around $100km$ (Stenflo 1989), perhaps there are still thin fibrils on the sun, but their sizes are not smaller than $1km$ due to turbulence and viscosity. Table 1 is the magnetic fields of fibrils for three characteristic sizes and two values of $\overline{n}'$. From Table 1, we can see the maximum of the magnetic field is not over 6.4kG.

The magnetic fibril concept is very important, it is the key to a unified understanding of the physics of solar activity (Stenflo 1989, De Jager et al. 1993).

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