ISSN: 2527-533X

Low Solar Coronal Thermal Structure Derived from Magnetohydrostatic Model

Bambang Setiahadi
Instansi Indonesian National Institute of Aeronautics and Space (LAPAN)
Email: bambangsetiahadi@rocketmail.com

Abstract: By assuming the Sun in quiet condition we derived coronal thermal structure for low solar coronal magneto-plasma atmosphere. Ideal gas law in a static equilibrium configuration in coronal magnetic plasma state is derived and the solution may be directed to figure-out the thermal structure in mixed plasma and magnetic fields within the low corona. The results show that corona may have hot and 'cool' solution in low corona under the condition when the Sun in quiet condition.

Key Words: Coronal equilibrium, magnetohydrostatic, thermal structure

1. INTRODUCTION

The solar corona until present days exposes a character of very high temperature, ranging from 10,000^{o}K for lower corona to as high as 2.0×10^6 ^{o}K for high corona. With such high temperature only material in plasma state inhibit the solar corona. Together with magnetic fields which co-exist with electron plasma, solar corona has opened a research to understand of how the solar corona may persist its high temperature in equilibrium [2].

In initial phase of this research, let us concentrate for thermal structure in low solar corona. It is good to guide our selves in innovating mathematical approach for the low corona physical circumstance without entering sophisticated and complex mathematical assignments. Other component to simplify our approach is deleting gravitational acceleration and it is parallel with low and homogen solar corona.

Within the low solar coronal magnetic pressure (~½ ***B.B***) and electron plasma pressure (~***P***) are decisive to final conclusions of solar thermal for low coronal structure. We may consider the famous Grad-Shafranov equation with modifications needed to fulfill our objectives to figure out the coronal thermal structure. More over we assume ideal gas law, since we assumed the solar corona is not in degenerate state and fulfills the low corona such that plasma pressure is interchangeable with temperature (***T***).

The solar corona in some extent permits ideal magneto-hydrostatic approximation since the relatively high temperature plasma electron characteristic environment makes no artificial displacement static current in coronal plasma which interacts with magnetic fields. This situation makes us to easily construct thermal structure imbedded in magnetic fields structure under ideal circumference of plasma in solar corona [1].

2. MAGNETOHYDROSTATIC THEORY

The Sun is actually very active and far from statically image. From the very center of the Sun into well define photospheric granular, chromospheric activities, and low to high corona have active images. Even though one may consider a static image in the low corona as immediate state corona in a certain condition [6]. This is in conjunction with solar activity phase which has around 11.3 year's periodicity.

After previous activity phase and before next activity phase, the Sun exposes no sunspot at all and it is may persist within 1.0 year to 1.5 years. The solar corona is quiet within this time spans and exhibit the basic coronal quiet structure. Under these circumstances we try to derive the low solar coronal thermal structure.

As the first step we try to direct and to focus on the dynamical state that within a relatively short time scale the situation may be considered as static low corona. It is meant that an equation of state in dynamical situation is needed to modify as static, which is the momentum equation of state below

$$\frac{\partial}{\partial t}{}^\circ V+\nabla.V{}^\circ V=\neg\nabla^2{}^\circ V-\nabla P+(\nabla\times B)\times B+¢({}^\circ\Omega\times V)+{}^\circ G, \quad (1)$$

under the absence of global solar differential rotation, low corona with uniform gravitational fields, and static circumference, the equation is permitted to express as,

$$-\nabla P + (\nabla \times B) \times B = 0 \quad (2)$$

The equation (2) is the expression of magneto-hydrostatic equilibrium for low solar corona as our basic equation to derive the coronal thermal structure. Other expression is the ideal gas law taking in standard form as,

$$\boldsymbol{P} = \circ\, \boldsymbol{T} \quad (3)$$

The equation (2) can be re-written as interchangeable with temperature as thermal main parameter as below and it is represented the simplest modification of Grad-Shafranov equation,

$$-\circ\, \nabla T + (\nabla \times B) \times B = 0\,, \quad (4)$$

and since we consider low corona the plasma density ° is only a scalar constant along our discussions. The situation can be simplify optimally as

$$-\nabla T + (\nabla \times B) \times B = 0 \quad (5)$$

Equation (5) pointed-out that derivation of thermal structure may be directly resulted by choosing and then manipulating the magnetic fields and derives an associated thermal structure or sometimes mentioned as temperature solution.

2.1. MAGNETIC ARCADE

H It has long been known that low solar coronal magnetic fields have two dimensional magnetic cylindrical structures. At least in two dimensional views, the above assumption is valid. Other view from the STEREO solar mission and subsidiary data from SOHO and TRACE solar mission [5], the magnetic cylindrical structure may have extension in third dimension; this is called as magnetic arcade type geometry. Instead of as long as solar circumference, the third dimension of the arcade is limited with how large area of polarity regions on the solar photosphere below the arcade structure. The area is more or less proportional with the length of dark filament.

If the variation along the third dimension is fixed, a two-dimensional simple coronal magnetic arcade will easily be constructed. That is a magnetic arcade with the third slot along neutral region is set to be constant. In other words, various two-dimensional cylindrical geometry may represent the solar coronal structure. One of these is semi-circle closed structure on the photosphere. Let the semi-circle has initially only radial dependent variable *r* in that way the equation (5) may be represented as a differential equation with single variable *r*, in which the temperature is decided after the magnetic field ***B*** is choosen. The situation of coronal arcade under consideration is illustrated in figure (1). The magnetic field is best chosen for this purposes may be written as

$$B(r) = B_0\, r \quad (6)$$

The corresponding differential equation is expressed in equation (7) below,

$$\frac{d}{dr}\left[T + \frac{1}{2}B^2\right] + \frac{1}{r}B^2 = 0 \quad (7)$$

consequently the corresponding integral equation may be expressed as equation (8) below,

$$B^2 r^2 = -2\int r^2 \frac{dT}{dr} \quad (8)$$

and one permissible solution of the equation (8) is the temperature profile under the assumption for semi-circle two-dimensional solar coronal magnetic arcade, in figure (1), and as pointed out in equation (9) below,

$$T(r) = \left[T_o - T_e\right] e^{\left(-r^2/a^2\right)} + T_e \quad (9)$$

where T_o is the magnetic arcade base temperature represented base solar coronal temperature at 10,000^{o}K, as mentioned in introduction. While T_e is external temperature outside arcade temperature that follows exponential properties with the initial temperature at the base is T_o. The graphical representation of the solution of temperature profile as a function of radial distance *r* may

ISSN: 2527-533X

be inspected in figure (2).

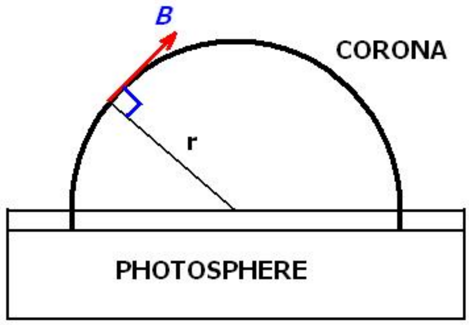

Figure 1: A coronal arcades may be represented as a simple cylindrically-symmetric unsheared arcade with the axis on the photosphere. A magnetic arcade may consists of many field lines and so an arcade can be thought of as a continuum of such loops and the thermal structure of an arcade can be found by solving for the thermal structure.

4. TEMPERATURE SOLUTION

Temperature solution is immediately found to be as expresses in equation (9) as a direct consequences from magnetohydrostatics equlibrium within cylindrical magnetic model. More explicite profile of magnetic fields may be formulated by solving the differential equation in equation (8).

In circumstances of the magnetic fields model in equation (8) and equation (9) the solar corona may preferable explicitely magnetic stucture that depends on the thermal structure as presented in equation below,

$$B^2(r) = \frac{c}{r^2} - 2(T_0 - T_e)\left(1 + \left(\frac{a}{r}\right)^2\right)\exp\left(-\left(\frac{r}{a}\right)^2\right) \quad (10)$$

avoiding singularities at the center of cylindrical magnetic structure, we have chosen the constant c in equation (10), such that the expression of explicite magnetic fields is as follow,

$$B^2(r) = 2(T_0 - T_e)\left(\frac{a}{r}\right)^2 - 2(T_0 - T_e)\left(1 + \left(\frac{a}{r}\right)^2\right)\exp\left(-\left(\frac{r}{a}\right)^2\right) \quad (11)$$

One may consider a temperature solution as having parametrical representation that depends on radius as represented below,

$$T(r) = 1 + (T_0^* / T_e^* - 1)\exp(-(r/a)^2) \quad (12)$$

The value of *T(r)* increases with radius r when lower temperature is chosen on the base and tends towards the constant value of unity large distance. While the value of *T(r)* is decreasing when higher temperature is chosen on the base. The situation may be inspected in figure (2) and figure (3). It is in accordance with solar coronal temperature observation at relatively far from solar surface or photosphere that temperature of solar corona will eventually drops as distance inceases.

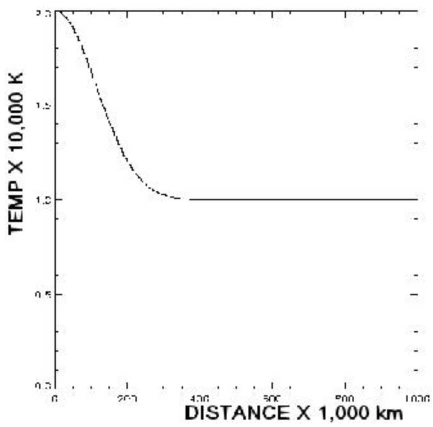

Figure 2: Temperature profile of solar coronal magnetic arcade with hot solution [4]. Below 300x10^3 km from above photosphere the temperature is 2.0x10^3 K. As radius increases from 300x10^3 km to 1,000x10^3 km, temperature tends to attain constant temperature of 1.0x10^3 K.

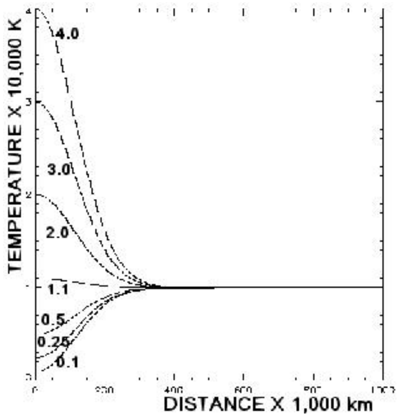

Figure 3: Temperature profile for several temperatures at the center of cylindrical arcade model when the physics is based on magnetohydrostatics theory. The situation is derived by parameterization of temperature solution.

5. DISCUSSIONS

Observations show that the differential emission measure which representing the amount of coronal plasma at a particular temperature, has a temperature of $0.1x10^4$K. Below the value, the solution is considered has no physical meanings. Several explanations have to be put forward to explain the cooler plasma. It is might be the structure of spicules. Spicules that have high emission at low temperature are due to electric currents.

While the hot solution [3] might correspond to subsequent evolution of the solar coronal loop that have nearly fulfilled by plasma electron from the photosphere, send through electric currents. The process might gains plasma pressure inside the loop and brings more temperature into the loop. The hot loop might attain $4.0x10^4$K.

References

[1]. Aschwanden, M.J., Poland, A.I., Rabin, D.M. (2001), The New Solar Corona, Annu. Rev. Astron. Astrophys., Vol. 39, pp. 175-210.

[2]. Miller, D., De Groof, A., Hansteen, V.H., Peter, H. (2004), Thermal Non-Equilibrium in Coronal Loops: A Road to Complex Evolution, , Multi-Wavelength Investigation of Solar Activity, Proceedings IAU Symp. No. 223, eds. A.V. Stepanov, E.E. Benevolenskaya, A.G. Kosovichev., pp. 289-294.

[3]. Ofman, L., Wang, T. (2002), Hot Coronal Loop Oscillations Observed by SUMER: Slow Magnetosonoc Wave Damping by Thermal Conduction, The Astrophysical Journal, Vol. 580, pp. L85-l88.

[4]. Schmieder, B., Rust, D.M., Georgoulis, M.K., Demoulin, P., Bernasconi, P.N. (2004), Emerging Flux and the Heating of Coronal Loops, The Astrophysical Journal, vol 601, pp. 530-545.

[5]. Singh, J., Mineer, S., Sakurai, T., Ichimoto, K. (2007), Magnetic Nature of Coronal Loops, Bull. Astr. Soc. India, Vol. 35, pp. 437-445.

[6]. Wiegelmann, T., Solanski, S.K. (2004), Similarities and Differnces Between Coronal Holes and the Quiet Sun: Are Loop Statistics the Key?, Solar Physics, Vol. 225, pp. 227-247.