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On The Solar Coronal Heat Problem

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Abstract: The solar corona is the outer atmosphere of the sun and the temperature reaches above 10 MK. It is 200 times higher than its underlying layer, which obviously challenges the second law of thermodynamic. Although the source of the extra heating is originated in the magnetic field of the sun, the mechanism of the extra heating has been remained as a mystery for several decades. AC and DC heating are the two main mechanisms of energy dissipation in the corona. Advanced studies found that Alfven waves (related to AC heating) infiltrated through the solar prominences could in fact solve the coronal heating problems, but in active region. Nonetheless, more works are required to confirm this issue. New recent studies have covered most part of this kind of heating, and thus we will make a review on their latest articles to give adequate information to future researches.

Keywords: Solar corona, Coronal heat, Nano-flare, Alfven wave

1. INTRODUCTION

The solar corona is an aura of plasma that surrounds the sun. Studying the solar corona enable us to understand the outer atmosphere of the sun, which may affect our daily life on earth. The solar corona extends millions of kilometers out to space and can be observed optically during a total solar eclipse. It is also observable with a coronagraph which blocks out direct rays from the sun. The temperature of the corona reaches above one million degrees of Kelvin. However, the mechanism of this heating remains unclear, but it is thought to be due to the large magnetic field creating high-ionized radiations. The reason for the extra heating has yet remained unsolved.

The two main approaches to solve the heating problems are the simulation and observation. Though, both the approaches are complementary to each other with their own advantages and disadvantages, we focus only on the latter (i.e. observables). In this review we do not address the former (simulations). Both X-ray and UV observation can be used to understand the small scales coronal structure in 3D (Peter 2012 and Bingert; and Peter et al 2013).

In this study, we will make a review of some recent articles explaining the most important issues related to heating problem within the last ten years; and we will especially focus on the main components attending in the heating of the solar corona, the energy source, the solar magnetic fields with ionizing radiations and the probable mechanisms of the heating.

What we see with visually from our sun or other stars in our galaxy is the optical radiation that is emitted from the star. The optical emission produced by Thomson scattering from the much more tenuous atmosphere is many orders of magnitude less intense and thus can only be seen when the solar surface is occulted (e.g., by the moon during a total solar eclipse). The oldest observations of the solar corona backs to ancient eclipse observations, which have been reported from Indian, Babylonian, or Chinese sources. A detailed study of historical eclipses can be found in Guillermier & Koutchmy (1999), includes for example, Chinese solar eclipse early in 2800 BC, the failure of a prediction done by the two luckless Chinese royal astrologers Hsi and Ho around 2000 BC, the successful prediction of the solar eclipse of 28 May 585 BC done by the Greek mathematician and philosopher Thales, or the eclipse of 1919 May 29 in Sobral (Brazil) and Principe (West Africa), which has been observed by two expeditions of the British astronomer Arthur Stanley Eddington to prove Einstein's theory of relativity. Regular observations of both the solar eclipses and prominences started with the eclipse of 1842, which was done by experienced astronomers like Airy, Arago, Baily, Littrow, and Struve. Photographic records started since the 1851st eclipse in Norway and Sweden, when the professional photographer Berkowski succeeded to produce a daguerrotype of prominences and

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the inner corona. Visual and spectroscopic observations of prominence loops were carried out by Pietro Angelo Secchi in Italy and by Charles Augustus Young of Princeton University during the 19th century. The element helium was dis- covered in the solar corona by Jules Janssen in 1868. George Ellery Hale constructed a spectro-heliograph in 1892 and observed coronal lines during eclipses. Bernard Lyot made his own research with solar coronal heating problems. It is in extreme ultraviolet and we know that the Earth is atmosphere avoids it and then we cannot find data on the Earth from solar explorers had to send to out of the atmosphere. In the following we make a brief review of recent missions (TRACE, STEREO, SDO) launched to observe many aspects of the sun. The Transition Region and Coronal Explorer (TRACE) satellite were aimed to explore the three-dimensional magnetic structures, which emerge through the visible surface of the sun, the photosphere, and define both the geometry and dynamics of the upper solar atmosphere- the Transition Region and Corona. The magnetic field geometry can be seen in the images of solar plasma taken in wavelengths emitted or absorbed by atoms and ions formed in a different temperature range.

2. SOLAR CORONA

The solar corona is the outer layer of the sun that can be seen only during solar eclipse due to blocking both photosphere and chromosphere. Corona is much hotter than the underlying layers. It could have a heat source, possibly electromagnetic interactions. Coronal mass ejection occurs when a large bubble detaches from the Sun and escapes out to the interstellar space. In a sub-structural level, the corona is composed of magnetic flux tubes with curvature geometry. The so-called coronal loops are considered to be monolithic (Peter et al 2013) or composed of a bundle of unresolved strands. However, the exact composition of these loops remained controversial. Nonetheless, two hypotheses have been proposed including nanoflares caused by magnetic reconnection under microscopic scales and evaporation process of the chromosphere in macroscopic levels. X-ray observation (Aschwanden and Boerner 2011) has been applied to find conflicting aspects between the microscopic and macroscopic plasma heating process of the solar corona.

Some areas on photosphere seem to have appeared dark relative to their surroundings. It is because of the fact that they are slightly cooler than their neighbor areas. Sunspots appear and disappear, typically in a period of a few days. They are connected by magnetic field lines. Sunspots arise when magnetic field lines are distorted by Sun's differential rotation.

Those regions appear dark during X-ray or EUV observations are Coronal holes. They are less dense compare to their surroundings. The plasma erupts out during a solar flare causes the magnetic field to disrupt. Open magnetic fields are the characteristic of these regions.

2.1 Magnetic reconnection:

There are two main mechanisms suggested to interpret how the magnetic field energy is converted into thermal energy (i.e., AC dissipation and DC dissipation; see Klimchuk 2006). The secondary instability is a mechanism explains the dissipation of energy via magnetic reconnection. Parker 1968 used the idea to extend the concept of nanoflares, small impulsive bursts of energy release, which form while the magnetic field lines twist, and wrap. The dissipation of energy occurs in the current sheets appear in tangential discontinuities arisen from mechanical work done by random photospheric motion on magnetic field lines.

2.2 Nano-flares in the solar corona:

Nano-flares are the scale down version of flares (a type of explosion), less energetic than solar flares, that appears as brightness while detecting by X-rays and UV telescopes. Nanoflares are good candidates to explain solar coronal heating (Benz 2004).

2.3 Solar coronal loop oscillations:

Coronal loops are magnetic field lines emerging out from the solar surface that are the building blocks of the X-ray corona. These filament arcs owe their brightness to the very hot plasma that is confined in the magnetic field lines. Peter and Bingert (2012) have performed a three-dimensional magneto-hydrodynamics (3D MHD) model of the corona solving the detail observation of the cross sections of the loops. From these details, they interpreted the mechanism of energy transferred into the corona.

2.4 Alfvenic waves:

The other corona-heating scenario is the dissipation from waves. Alfven waves are supposed to be among those, which can penetrate the corona without damping efficiently. They are produced by the interaction of electric currents and magnetic fields of the solar plasma that lead to oscillation of ions (Alfven 1942). A recent research has found the propagation of these waves in the corona is crucially created by counter propagations (Morton et al 2015).

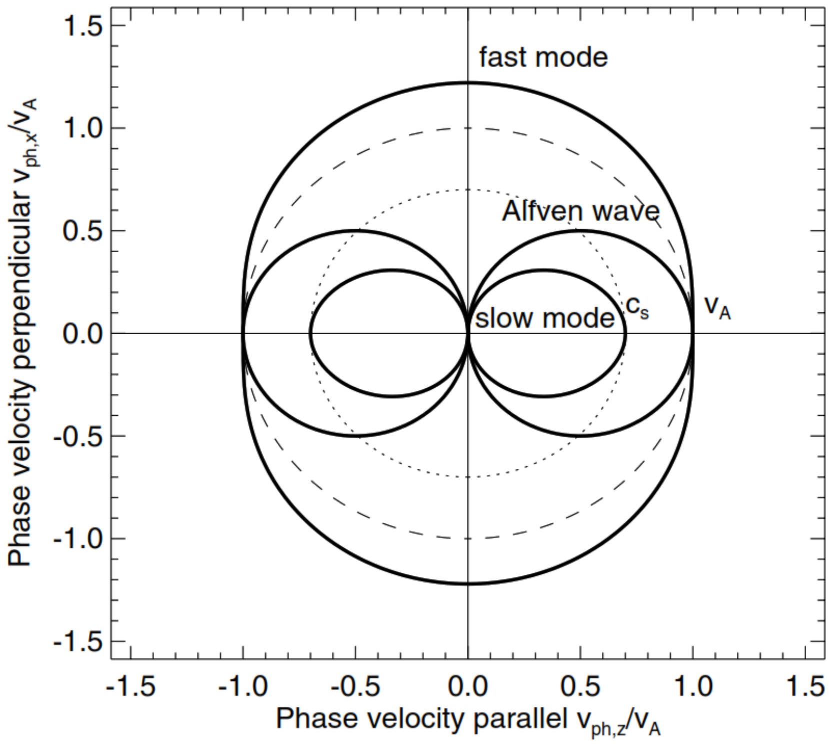

Figure 1: Polar diagram of phase speeds $\boldsymbol{V_{ph}}$ of magneto-acoustic waves, shown for a ration of $\boldsymbol{C_s/V_A = 0.7}$. The sound speed $\boldsymbol{C_s}$ is marked with a dotted circle, and the Afve'n waves are shown with thick curves. [1]

2.5 Kink waves and sausage waves:

These waves are considered as a magneto-hydrodynamic (MHD) wave with a magneto-acoustic mode, which is present in the solar corona. This kink wave is different from the Alfvenic wave as the former's mode is magneto-acoustic while the latter has a torsional Alfven mode. Also, both waves have different behaviors such as speeds and distributions (Doorsselaere et al 2008). In fact, these modes impact on the coronal heating phenomena occurred on the surface of the sun, possibly due to changing the mode of energy influx and propagation. One other type of Alfven waves named sausage waves. They instead of external of Alfven wave's speed and tend to kink waves.

2.5 Magnetic fields of corona:

Solar magnetic field is created by dynamic action that has not been fully understood. However, magnetic fields and energies, which are produced in the solar surfaces, are thought to be mechanisms of the heating in both sun and its corona (Cirtain et al 2013).

On the other hand, the structure of the coronal loops can be studied associated with the coronal emission to the magnetic field. In other words, the magnetic fields and its thermal structure are important for the visibility of the coronal loops (Peter et al 2013).

3. MECHANISM OF CORONAL HEATING

Research indicates that studying the internal structures of the coronal loops are important for understanding the mechanism of the coronal heating (Peter et al 2013). Recent research has found that magnetic braids in the active regions of the corona can inject enough energy to heat the coronal structures for 4 million Kelven (Cirtain et al 2013). It has been hypothesized that the coronal heating might be due to heating by nano-flares, which are considered as a power of energy coming out from the solar core. These nanoflares include two types of loops detected by X-ray 2D model: Hot loops are more abundant in the cores of active regions, whereas warm loops are more distributed outside the core (Fuentes and Klimchuk 2016). Although Aschwanden and Boerner 2011 has concluded inconsistent results with nanoflares hypothesis as heating mechanism of solar corona, but rather it is a flare-like heating mechanism that forced the evaporation of the chromosphere and hence heats the plasma over the loops. Collectively, Cranmer et al 2015 has argued that no single physical hypothesis can solve the coronal heating problems. Since the nanoflares has not yet been detected to convert such high amounts of electromagnetic energy to thermal energy so as to heat the corona 200 times than the photosphere. Recent advanced study from Japanese "Hinode" mission that was launched in 2006, found that the solar atmosphere is pervaded with "Alfvénic" waves.

Considerable amounts of energy along the magnetic field lines can be carried by these magnetically driven waves (Antoin et al 2015 and Okamoto et al 2015). This seems to drive enough energy to heat and maintain the corona.

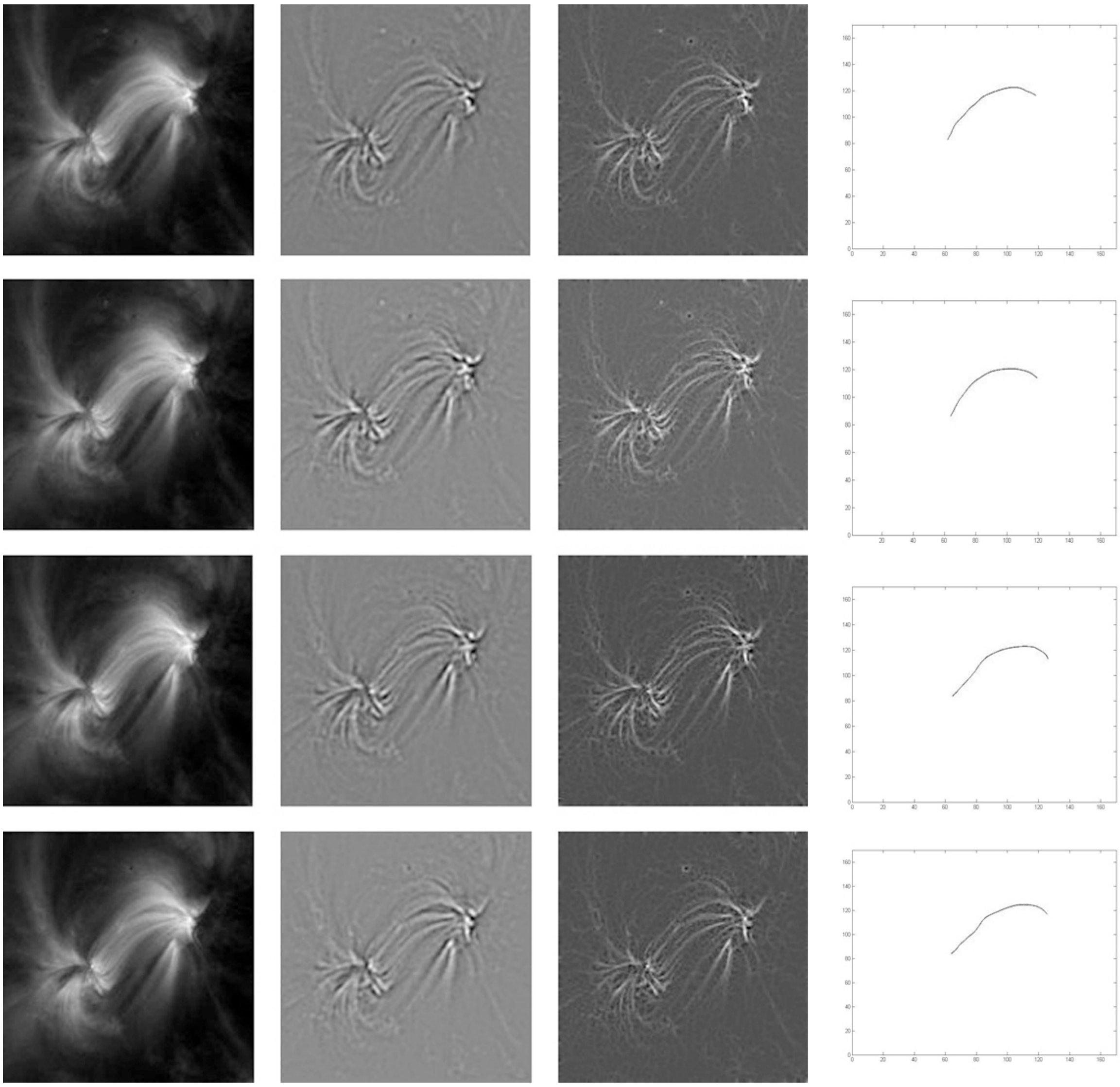

Figure 2: Solar coronal loops segmented from solar Magnetic field.

4. CONCLUSION AND RECOMMENDATIONS

Research indicates that studying the internal structures of the coronal loops are important for understanding the mechanism of the coronal heating (Peter et al 2013). Recent research has found that magnetic braids in the active regions of the corona can inject enough energy to heat the coronal structures for 4 million Kelvin (Cirtain et al 2013).

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