1996Ap&SS.243...43V

OBSERVABILITY OF CORONAL HEATING PROCESSES

P. VENKATAKRISHNAN
Indian Institute of Astrophysics, Bangalore 560034, India

September 23, 1996

Abstract. The mechanisms that could possibly heat the corona are briefly reviewed with emphasis on their observability. Observing enhanced wave flux at footpoints of active regions would confirm wave heating. Observation of nonthermal electrons in tiny coronal events (nanoflares) would confirm dissipation of current sheets. Presence of large scale flows in coronal arcades would underline the importance of turbulent resistivity for coronal heating. A comparison of HeI absorption in quiet and active regions demonstrates the difficulty of interpreting data that connect chromospheric dynamics with coronal heating. Finally, the implications of the search for observations of coronal heating processes are mentioned.

Key words: SUN – CORONA – Heating

1. Introduction

The theme of this conference is solar and interplanetary transients. Earlier speakers have described coronal transients, especially coronal mass ejections. We have learnt that solar flares might not be the causative agents of these mass ejections. Further, we were also told in another talk that the interplanetary transients might have nothing to do with the coronal mass ejections. This might make us wonder whether a discussion of coronal heating processes could have anything to do with the theme of this conference! However some thought on this will tell us that most of the physical processes that produce the transients require the existence of a million degree plasma in the first place. Thus it is very much in order to review the coronal heating processes, especially in the light of the new results expected from SOHO (Domingo, Fleck and Poland, 1994).

That the corona indeed has a temperature of a million degrees became evident after Edlen identified certain coronal lines observed in total solar eclipses to be emitted from multiply ionized atoms. Later, xray images of the sun obtained from Skylab clearly established the high temperatures and the location of this hot plasma that produced the xrays. The existence of a hot plasma above a cooler plasma (the solar photospheric plasma) raised questions about the processes that can possibly maintain this hot plasma against the radiative and conductive heat losses. In modern language, one would say that we require a process that transports "non random" energy generated at a remote site to the corona and deposits this energy in the form of heat which is a "random" kind of energy. Several processes have been

Astrophysics and Space Science **243:** 43-47, 1996.

proposed in the literature, and several excellent reviews exist (see Zirker, 1993 for a review of reviews). In this talk I will focus on the observability of such processes. In other words, I shall focus on the possibility of seeking correlations between the remote drivers and enhanced coronal emission.

2. Mechanisms of Coronal Heating and Their Observability

There are basically three ways of heating the corona, viz. wave heating, current heating, and turbulent heating.

Wave heating processes require a means of generating waves, a way to transport these waves without attenuation through the photosphere and chromosphere and ultimately a way to dissipate the energy in the form of heat. The constant churning of plasma in the convection zone provides a ready mechanism to generate waves. An important question here is the reason for active regions to be preferentially hotter than quiet regions. If this implies more flux of waves emanating from the footpoints of the active regions, then observing the convective origins directly is out of the question. The enhanced flux at the photosphere could be observed, but there is no systematic study done so far to look for enhanced wave flux at the feet of active regions. The observation of enhanced line width of the 530.3 nm coronal line within closed structures during the 1980 eclipse (Singh, Bappu, and Saxena, 1982) could be one example of this process.

Current heating proceeds by the dissipation of current sheets. Current sheets could be produced in a variety of ways (Parker, 1979; Priest and Forbes, 1989). The electron resistivity of coronal plasma being very small, the dimensions of the current sheets would be very small. Thus, the direct observation of a current sheet is out of the question. There are indirect ways of inferring the presence of current sheets, chief amongst these is to look for non thermal electrons. Non thermal electrons are evident in radio bursts and xray flares. However, these are not frequent enough to account for the general heating of the corona. The xray observations of Lin *et al.* (1984) and the radio observations of Gopalaswamy *et al.* (1994), show promise of going towards nonthermal events of very small power output. These tiny events could indeed be evidence for coronal heating by currents. Theoretically, Cargill (1994) has simulated the effects of tiny non thermal events (nanoflares), to show observable signatures. The chief among these is the emission measure, which can throw light on the fill factor of these events, thereby providing some measure of the sizes of these events. One might argue that the dissipation of waves could also proceed via current heating. One difference is that wave fluxes at lower atmospheric layers must be correlated with the number of tiny current dissipation events, if waves are the agents that transport mhd energy. On the other hand, Parker's theory for nanoflares allows the current sheet formation even for static conditions in the footpoints of the loops (Parker, 1979). The presence of incompatible boundary conditions at the two ends of a field line is sufficient for the spontaneous production of current sheets. The observational implication is that one might see enhanced number of tiny nonthermal events in the corona without evidence of enhanced wave flux at the footpoints. Furthermore, the electrodynamic signature of the coronal events expected at the photosphere on the basis of the virial theorem (Low, 1984), can be seen only if the magnetic field is force free at the observed photospheric layer.

Turbulent heating proceeds by the cascading of energy from the scales of say granulation into the tiny scales at which resistive dissipation becomes effective. Heyvaerts and Priest (1992) describe a self consistent way to relate the velocity flow at the footpoints of an arcade to the amount of coronal heating. One consequence of their model is the possibilty of large scale flows within coronal arcades (Venkatakrishnan,1994) . Careful observations of velocity fields in coronal structures might well provide evidence for the contribution of turbulent resistivity to coronal heating.

3. HeI Absorption and Coronal Heating

The observed darkening of active regions in the HeI 1083 nm line and the comparatively low level of its absorption seen in coronal holes seemed to indicate a link between coronal emission and HeI absorption. The photoionization of He atoms by EUV photons followed by recombination to the lower energy level of the 1083 nm transition appears to provide the link (Zirin, 1989). Thus, this line would be a good candidate line to look for evidence linking wave fluxes at lower atmospheric layers to enhanced coronal emission. The observations of Venkatakrishnan *et al.* (1992) provide a data base to look for this evidence.

The data base consists of a time sequence of spectra obtained with the 512 channel magnetograph at Kitt Peak operating in the intensity mode. Each spectrum had 512 samples along the slit, and each observing run had one sample per minute (2 samples on a different day). Spatial binning of two samples to match the seeing and correcting for solar rotation allowed 250 samples each 2 arcsec × 1.4 nm in size. These spectra were analysed to extract line parameters like equivalent width, central line depth, doppler shift and doppler width. These parameters were temporally averaged and scatter plots of pairs of these average quantities against each other were obtained. A plot of equivalent width against the line width revealed a trend of increasing equivalent width for increasing line width. This fact, taken along with the fact of very tight correlation of the central line depth with equivalent width, as well as the fact that the line is effectively optically thin, seems to indicate that the deeper line has a larger width. This was interpreted as an observational correlation between chromospheric dynamics and coronal heating (Venkatakrishnan, 1993).

The story does not end here, however. Recent analysis of HeI spectra of active regions obtained from Norikura (Suematsu, Ichimoto, and Sakurai, 1995) show a similar correlation between doppler width and equivalent width. What is intriguing is that the range of line width is the same as was for quiet regions, with a much larger range in equivalent width. This can be interpreted in two ways. If the efficiency in converting the mechanical energy seen at chromospheric levels into heat is large for active region configurations, then the same input of mechanical energy would result in a greater heat conduction back into the transition region of active regions as compared to quiet regions. Alternately, the line width has nothing whatsoever to do with coronal heating. The latter interpretation would lean towards current heating mechanisms, while the former would decrease the importance of searching for enhanced wave flux at the footpoints of active regions. This example of HeI 1083 nm line serves to illustrate the difficulties in interpreting the observed results, inspite of having a means of observationally connecting chromospheric processes with coronal emission.

4. Discussion and Conclusions

A pertinent question that can arise after all these discussions is the need for such a detailed search for the exact mechanism of coronal heating. One chief reason is that the sun provides the maximum opportunity for understanding this process. Only after fully understanding this process for the sun can we venture to quantitatively predict the amount of mass loss from stars at various stages of their evolution. It is now well recognized that the major cause of uncertainty in predicting the advanced stages of stellar evolution is the uncertainty about the amount of mass lost by a star in its earlier evolutionary phases. Thus study of coronal heating and consequent mass loss by solar wind has a larger implication for understanding the final stages of stellar evolution.

Stellar winds carry away momentum, and coronal transients carry away magnetic flux. In the very early stages of stellar birth, these two phenomena help the star to contract. Thus coronal heating studies have applications even in the study of star formation.

Finally, if all the currently known mechanisms of coronal heating fail to show up in observations, then we might have to resort to drastic measures. One such recipe in terms of non-equilibrium thermodynamics is provided by Scudder (1992a,b). Here, the free streaming of particles from a non maxwellian boundary distribution can result in a distribution that has a

FWHM which increases with height. In Scudder's corona, the large width of particle distribution does not imply a large energy. Thus heat will not flow from such a corona back into the transition region. Observationally, transition region emission must then not relate to the conventional heat content of the corona. This can be perhaps verified.

In summary, we must search for correlations between wave flux at the foot points of coronal loops and the brightness of the loops if we were looking for observational evidence for wave heating. The nature of heat dissipation in the corona could be revealed by very sensitive instruments, both in the radio and in the xray region, that can detect nanoflares. If turbulent resistivity were to be important for coronal heating, then large scale flows must result in the corona, which must be observed.

References

Cargill, P.:1994 in J.L. Burch and J.H. Waite, Jr. (eds) *Solar System Plasma Physics: Resolution of Processes in Space and Time*, AGU Monograph.

Domingo,V., Fleck, B., and Poland, A.I.:1994, *Space Sci. Rev.* **70**, 7.

Gopalaswamy, N., Payne, T.E.W., Schmahl, E.J., Kundu, M.R., Lemen, J.R., Strong, K.T., Canfield, R.C. and de la Beujardiere, J.:1994, *Astrophys. J.*, **437**, 522.

Heyvaerts, J. and Priest, E.R.:1992, *Astrophys. J.* **390**, 297.

Low, B.C.:1985 in M.J. Hagyard (ed) *Measurement of Solar Vector Magnetic Fields* NASA-CP 2374, NASA, p.49.

Lin, R.P., Schwarz, R.A., Kane, S.R., Pelling, R.M., and Hurley, K.C.:1984, *Astrophys. J.* **283**, 421.

Parker, E.N.:1989, *Cosmical Magnetic Fields* Oxford Univ. Press.

Priest,E.R. and Forbes, T.S.:1989, *Solar Phys.* **43**, 177.

Scudder, J.D.:1992a, *Astrophys. J.* **398**, 299.

Scudder, J.D.:1992b, *Astrophys. J.* **398**, 319.

Singh,J., Bappu, M.K.V.B., and Saxena, A.K.:1982, *J. Astrophys. Astron.* **3**, 248.

Suematsu, Y., Ichimoto, K., and Sakurai, T.:1995 in J.Kuhn (ed) *Infrared Tools for Solar Astrophysics: What's Next?*, Proc. XV NSO Summer Workshop.

Venkatakrishnan, P.:1993, *Solar Phys.* **148**, 233.

Venkatakrishnan, P.:1994, in G. Simon and K.S. Balasubramaniam (eds)

Venkatakrishnan, P., Jain, S.K., Singh, J., Recely, F., and Livingston, W.C.:1992, *Solar Phys.* **138**, 107. *Evolution of Active Regions*, Proc. XXIV NSO Summer Workshop.

Zirin, H.:1989 *Solar Astrophysics*

Zirker,J. B.:1993, *Solar Phys.* **148**, 43.