“Coronal Heating”?

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Outline

I. “Velocity filtration” and exospheric models
II. Differential magnetization and vorticity coupling
III. Nanoflares (see also Iain Hannah’s NuSTAR poster)

Introduction

Kinetic physics brings important tools to the analysis of “coronal heating.” These new tools could also have applications in the chromosphere. If “heating” involves significant particle acceleration, as in flares, it is not a point function of position, for example. *Caveat: I recklessly comment on these theoretical ideas even though I’m an observer!*

I. Velocity filtration and exospheric models

The entire volume of the solar corona likely has magnetic connections to the chromosphere. Particles in non-thermal tail distributions can readily move between the chromosphere and corona, and it greatly restricts the physics to ignore this basic fact. In flare physics, the well-known “Neupert effect” (Neupert, 1968) prominently illustrates the need to describe this coupling for the bulk plasma, as well as the tail populations.

Scudder (1992a, 1992b) has described the plasma physics involved in this coupling using the term “velocity filtration,” and this underlies the broad development of the exospheric models of coronal physics (e.g. Marsch, 2006). This term reflects the inverse velocity dependence of the Coulomb cross-section, which implies that a tail, once generated, no longer remains local to the plasma where it forms.

Literature:

Neupert, W.M., “Comparison of Solar X-Ray Line Emission with Microwave Emission during Flares,” ApJ 153, L59
Marsch, E.A., "Kinetic Physics of the Solar Corona and Solar Wind” LRSP (2006)
Scudder, J.A., “On the causes of temperature change in inhomogeneous low-density astrophysical plasmas,” ApJ 398, 299 (1992a)
Scudder, J.A., “Why all stars should possess circumstellar temperature inversions,” ApJ 398, 319 (1992b)

III. Nanoflares

What is a nanoflare? If it resembles a flare, its “heating” involves non-thermal effects such as the strong generation of electrons to energies above 100 kT, if from the corona. Since we have no direct observations of nanoflares, and perhaps the theory forbids this (e.g., Klimchuk 2014), it may be possible for more tepid energy extraction from the magnetic field simply to warm the plasma in place. But ordinary flares show no tendency for the nonthermal signatures to diminish disproportionately as event energies decrease, so this must remain speculative.

The Hannah poster (Hannah et al., 2014) describe highly sensitive searches for very faint flares, or perhaps nanoflares, using the NuSTAR hard X-ray observatory.

Literature:

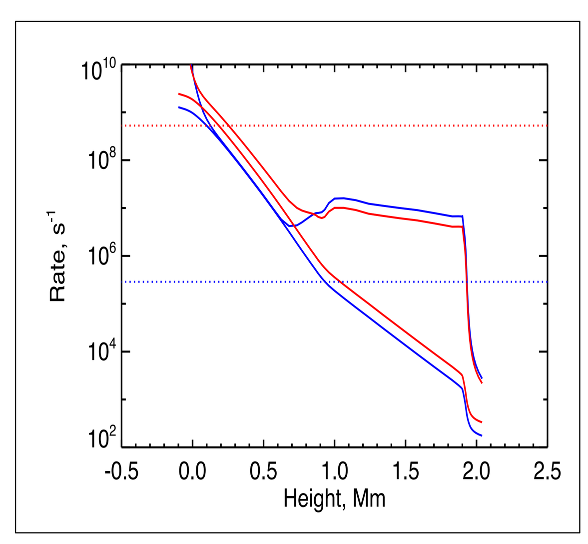
Klimchuk, J. A., “The coronal heating problem: current understanding and future directions,” (lead presentation here, 2014)
Hannah, I.G. et al., “NuSTAR’s solar observing campaign: Towards detecting the faintest HXRs from flare-accelerated electrons,” (poster here, 2014)

II. Differential magnetization and vorticity coupling

If one accepts the semi-empirical models of the VAL-C type to represent the chromosphere, one can estimate the magnetization of the different particle species based on the tabulated parameters. This requires a comparison of the collision frequencies with the corresponding Larmor frequences for each species, as illustrated in Figure 1 (from Krasnoselskikh et al., 2010). Figure 2 shows the “dynamo layers” resulting from the different heights at which the species magnetize. Throughout most of the chromosphere the two species separate from one another.

With the assumption of vortical turbulence (e.g., from baroclinic flows) in the (neutral) lower chromosphere, this differential magnetization implies the generation of parallel currents on the vortex scales in the “dynamo layer.” The (nonlinear) development of the basic Krasnoselskikh mechanism may remain speculative, but its existence seems inescapable.

Fontenla, J.M., et al., “Semiempirical Models of the Solar Atmosphere. III. Set of Non-LTE Models for Far-Ultraviolet/Extreme-Ultraviolet Irradiance Computation,” ApJ 707, 482 (2009)
Krasnoselskikh, V. et al., “Generation of Electric Currents in the Chromosphere via Neutral-Ion Drag,” ApJ 724, 1542 (2010)



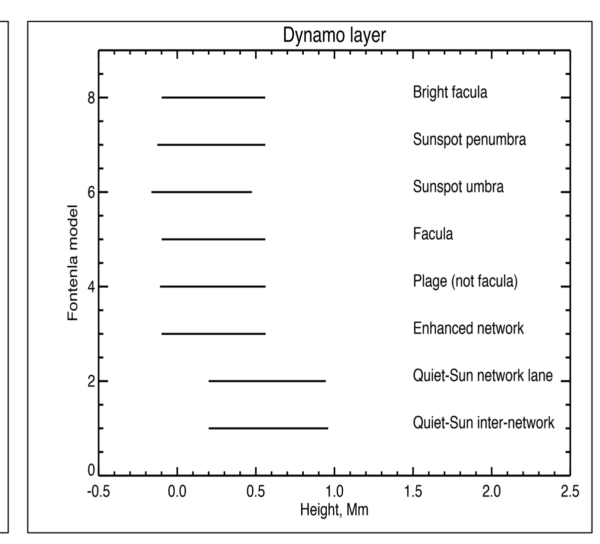


Figure 1 (left above): *Collision frequencies for electron (red) and proton (blue) species, with the lower branch showing the neutral rates from De Pontieu et al. (2001). The dotted lines give Larmor frequencies for an assumed 30 G (quiet Sun model).*

Figure 2 (right above): *Chromospheric “dynamo layer” domains for the Fontenla models, assuming 30 G for the quiet Sun (lower two models) and 1500 G for the rest. In these domains electrons are magnetized while protons are collisional.*

Conclusions

Exospheric and kinetic ideas regarding coronal physics should not be disregarded, especially if one requires new directions for the “coronal heating” problem.