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FORMATION AND SUPPORT OF PROMINENCES

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INTRODUCTION

This article is a short introduction to the concepts discussed by the group on the formation and support of prominences, and it is hoped that the reader will consult the individual contributions to obtain a more complete understanding. Only quiescent and long-lived active region prominences were considered, since transient prominence phenomena, such as sprays, surges, Hα flare-loops, and coronal rain, are dynamically distinct from long-lived, prominences.

Stable prominences (which are often referred to as filaments when seen against the disk) can be subdivided into three categories, namely active region prominences, quiescent prominences and polar crown prominences. The third category is closely related to the second since a quiescent prominence will eventually evolve into a polar crown prominence if it lasts long enough. The distinction between the first and second categories is not sharp either since intermediates exist here as well (Martin, 1973).

SOME OBSERVATIONAL CONSTRAINTS

The mass contained in a typical quiescent prominence has been estimated to be $\gtrsim 5 \times 10^{16}$ gm - a value which is about 20% of the total mass of the corona (Tandberg-Hanssen, 1974). Although the density of the corona is often depleted in the vicinity of a quiescent prominence, the pre-existing mass of the depleted region (i.e. the coronal cavity) does not appear to be large enough to account for the mass of the prominence. Therefore, it has been inferred that for these prominences most of the mass is supplied by transport from the chromospheric level of the solar atmosphere.

The growth of a large prominence is thought to begin with the formation of a section on a time-scale of a few hours(see Figure 1a), and in the case of a quiescent prominence, several such sections may develop in a half a day or more. These sections are composed of fine-scale strands whose formation time is on the order of a few minutes, and whose behavior is chaotic.

Why sections exist is difficult to account for theoretically. One of the more physically attractive explanations that has been proposed is that they are due to the convection associated with the supergranulation cells. Plocieniak and Rompolt (1972) found evidence that the "legs" of the sections tend to occur at the interstices of 3 or 4 cells where the circulation of the cells gathers the magnetic flux into a small region (cf. Figure 1b). In general it is very difficult to locate accurately the position of the section legs with respect to the supergranulation network, and so the correlation between the location of the legs and the network remains somewhat controversial. However, Plocieniak and Rompolt have suggested that some of this controversy may be due to the fact that

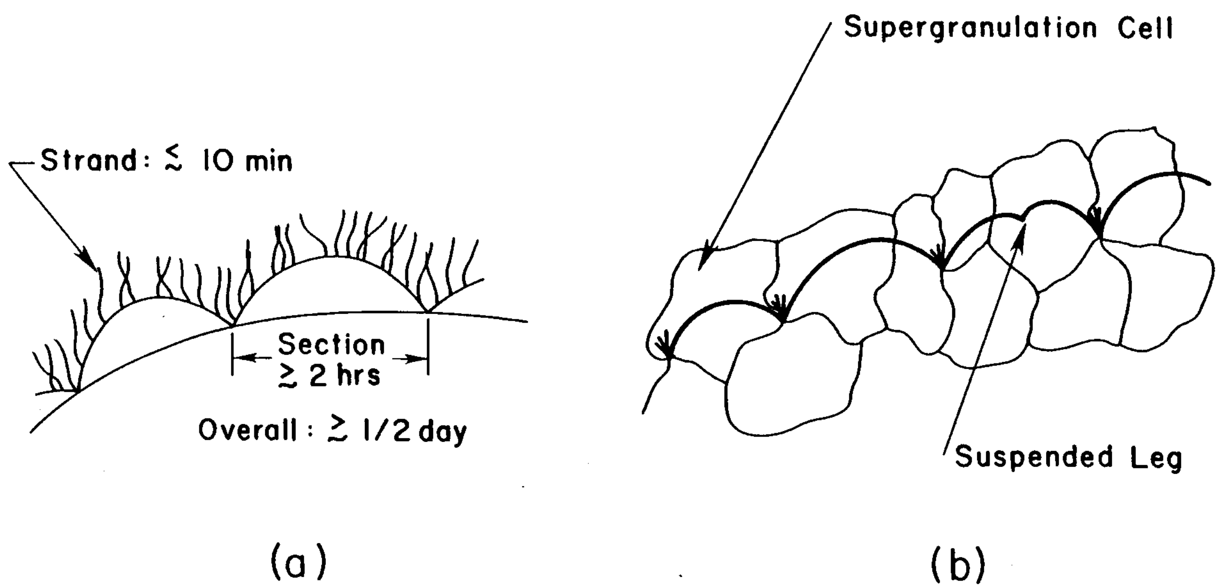

Figure 1. (a) Formation times of various prominence features. (b) Proposed location of prominence legs with respect to supergranulation cells.

sometimes legs occur at the center of a cell but do not extend all the way down into the chromosphere. They refer to these features as "suspended legs". In a separate study of the correlation between the photospheric magnetic field and the legs, Martin (1986) has found that the legs terminate at the chromosphere where underlying photospheric fields of opposite polarity move together and cancel. It has not yet been established whether these cancellation sites correspond to the interstices of the supergranulation cells, and so as yet there is no independent confirmation of the Plocieniak and Rompolt picture.

It is now fairly well accepted that shear in the chromospheric magnetic field is a prerequisite for prominence formation in active regions, and it seems likely that it may also be necessary for prominences in quiet regions (Martin 1973, 1986, Wu and Xiao 1986). About 10-30 minutes prior to the formation of a prominence, an alignment of fibrils is observed in the chromosphere. Such an alignment is referred to as a channel, and if it continues to exist after the disappearance of the prominence, the prominence will often reform in the same location (Martin 1973, 1986, Hagyard, 1986).

THEORETICAL MECHANISMS - MODELS

Our theoretical understanding of prominences is still in a relatively primitive state, and this is somewhat surprising when one considers that they have been observed for over 250 years. Perhaps, part of the explanation for this lies in the inherent difficulty of trying to create deductive models of plasmas. For example, in the MHD approximation, the number of degrees of freedom in a magnetized plasma is proportional to the cube of the magnetic Reynolds number, R_m (Parker, 1984). Typically, for a prominence in the corona $R_m \gtrsim 10^{12}$, and therefore, in the absence of any constraints, there are $\gtrsim 10^{36}$ possible states! This profusion of states underlies the basic difficulty that one has in trying to construct a quantitatively rigorous model upon the basis of a few observational constraints.

The theory of prominence formation involves several physical processes each of which alone are quite difficult to consider. The most important are thermal and gravitational stability, coronal wave-heating, anisotropic thermal conduction, radiation dynamics, and magnetic reconnection. The situation is complicated by the fact that all of these are highly nonlinear and interacting phenomena which must be considered within the context of a relatively unknown magnetic field geometry. To date theoretical efforts have been limited to exploring various aspects of one or more of the above processes within the context of highly idealized field geometries (such as a simple magnetic loop).

Possible mechanisms of prominence formation can roughly be divided into two categories, namely, condensation and injection. The first focuses on the formation of a cool dense plasma from a hot, ambient plasma, whereas the second is concerned with the transport of plasma from the chromosphere to the corona. Neither mechanism alone is likely to be sufficient, since the coronal plasma is not sufficient to supply the mass, and the direct injection of cold chromospheric plasma has never been observed.

Condensation Mechanisms

The classic study on condensation is the one by Field (1965), and much recent interest has focused on extending this work to include magnetic interaction aspects. Van Hoven (1986) has considered the thermal and condensation instabilities in the presence of an inhomogeneous, sheared magnetic field, and Malherbe and Forbes (1986) have numerically studied condensation in current sheets which are tearing unstable.

Injection Mechanisms

One can subdivide injection mechanisms into surge-like and evaporation-like models. In the first category material is launched ballistically from the chromosphere into the corona (cf. Figure 2b), whereas in the second a sustained heat release gives rise to a solar-wind-like evaporation (cf. Figure 2c).

For a surge-like injection one might reasonably assume an input injection velocity of 20 km/sec since this is a value characteristic of spicules.

However, with such a velocity one would only be able to ballistically lift material to a height of 4×10^3 km which is sufficient for some active region filaments but is too low for large quiescent prominences (An 1986, An et al. 1986). An interesting aspect of the surge-like models is that the input injection velocity must have a fairly precise value in order for material to be captured at the top of the loop. If the velocity is too small, or too large, then the injected material simply returns to the chromosphere. This might explain why prominences form on some loops but not on others.

An alternative to direct ballistic injection is a solar wind-like evaporation of chromospheric material (Poland et al., 1986). In this model an evaporative upflow of chromospheric material is produced by suppressing the coronal heating mechanism everywhere in the loop except at the foot points. This induces a condensation at the top of the loop, but the heating rate in the loop must be restored once the prominence has begun to form, otherwise realistic prominence densities can not be achieved in a reasonable time.

Support

Early models such as those of Kippenhahn and Schluter (1957) concentrated on the static support of the plasma by the magnetic field. Yet, Hα films and

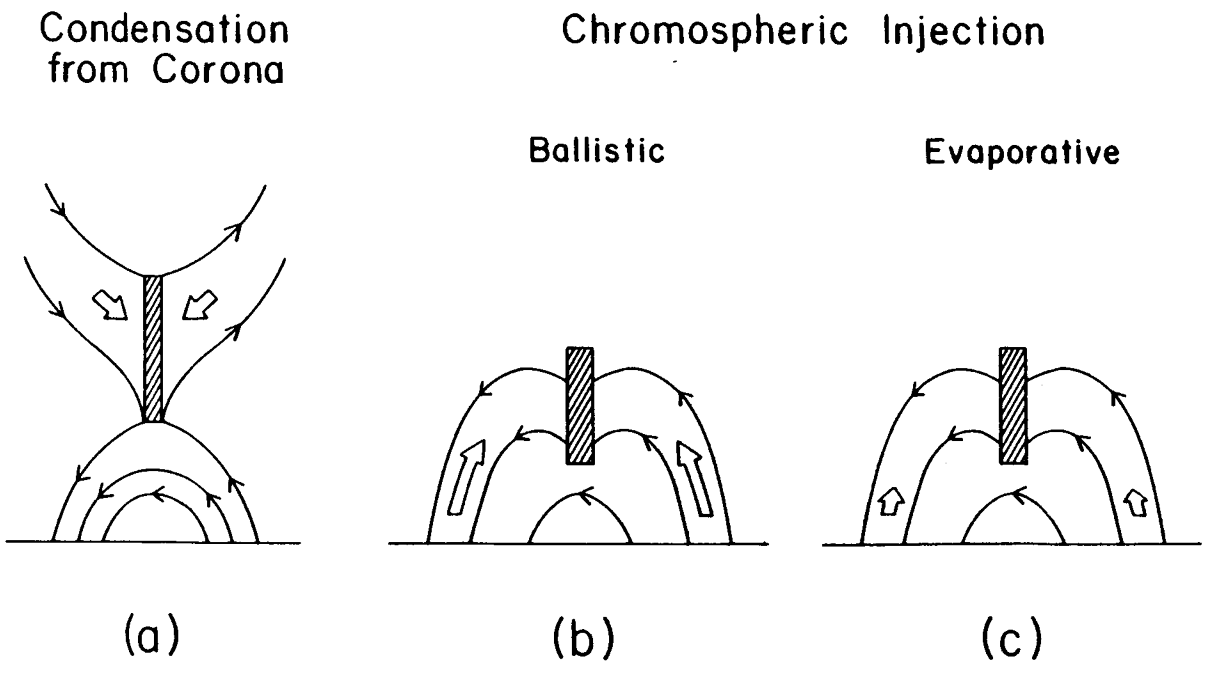

Figure 2. Schematic of three mechanisms involved in prominence formation: (a) condensation, (b) ballistic injection, and (c) evaporation.

direct measurements of Doppler shifts often indicate that even in quiescent prominences the plasma is not static, but is instead in continuous motion (Engvold et al, 1976; Schmieder et al., 1985). However, this motion is not simply due to free fall, and it is still necessary to invoke a force which opposes gravity. This has led to ideas for dynamic, non-static support. An early example of such a dynamic support mechanism is the one due to Kuperus and Raadu (1974) which incorporates reconnection (cf. Figure 2a). An alternate idea for dynamic support using Alfvén Waves has been proposed by Jensen (1986). The outward momentum flux of such waves is already thought to be important for the solar wind, and so he has suggested that it could also play a role in prominence support. This is an interesting idea, but it is not certain at the moment whether it can really account for the appearance of a quasi-steady-state structure like a prominence.

Interest in static support models continues since it is still possible that to first approximation one may be able to neglect flows and waves. Recent work for static support models has concentrated on trying to construct realistic three dimensional configurations (e.g. Wu and Low 1986, Wu and Xiao 1986).

SOME UNANSWERED QUESTIONS

Here are some questions concerning the problem of prominence formation and support, which, for the most part, have been around for 40 years or more. They are repeated here to emphasize that the prominence phenomenon is still very much an enigma.

1. Where does the prominence material originate - in the corona, the chromosphere, or both? If in the chromosphere, where exactly?

2. What is the three-dimensional magnetic field structure in and around the prominence before and after its appearance?

3. How is the prominence material supported against gravity? Is the support only partial or is it total as in a static situation?

4. To what extent does the physics of the coronal heating mechanism affect the appearance and dynamics of prominences?

5. What is the key photospheric factor that determines the location of a prominence? Is it the magnetic field, the velocity field, or both?

6. What physically distinguishes active region prominences from quiescent prominences? If it is simply the magnetic field strength, then exactly how does the variation in this quantity give rise to the quite different morphological properties of these two classes?

7. What is the role of sheared magnetic fields?

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