PROMINENCE CONDENSATION AND MAGNETIC LEVITATION IN A CORONAL LOOP

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Abstract. We describe the results of a model dynamic simulation of the formation and support of a narrow prominence at the apex of a coronal magnetic loop or arcade. The condensation process proceeds via an initial radiative cooling and pressure drop, and a secondary siphon flow from the dense chromospheric ends. The anti-buoyancy effect as the prominence forms causes a bending of the confining magnetic field, which propagates toward the semi-rigid ends of the magnetic loop. Thus, a wide magnetic 'hammock' or well (of the normal-polarity Kippenhahn-Sehlater-type) is formed, which supports the prominence at or near the field apex. The simplicity of this 1.5-dimensional model, with its accompanying diagnostics, allows one to comprehend the various contributions to the nonlinear dynamics of prominence condensation and levitation.

1. Introduction

Filaments and prominences are cool and dense structures which form and levitate in the hot and diffuse, magnetized, solar atmosphere (cf. Priest, 1989, for a review of their physical properties). It is believed that these condensations are initiated by a radiative instability (Parker, 1953; Field, 1965; Hildner, 1974; Sparks and Van Hoven, 1988) but their thermal and dynamical evolution is dominated by the anisotropic influence of the solar magnetic field (Chiuderi and Van Hoven, 1979; Van Hoven, Sparks, and Tachi, 1986; Sparks, Van Hoven, and Schnack, 1990). The ambient field suppresses thermal conduction (Orrall and Zirker, 1961), channels siphon flows (Pikel'ner, 1971), and ultimately supports (Kippenhahn and Schlüter, 1957) the prominence mass above the solar surface.

Earlier workers have attempted to examine specific aspects of the thermal condensation and magnetic support of solar prominences. In particular, the complex, anisotropic, nonuniform, nonlinear dynamics and energetics of this problem have led to computational approaches. Following Hildner (1971, 1974), a number of 2-D simulations have explored the effects of an ambient magnetic field in the absence of realistic chromospheric boundaries. Van Hoven, Sparks, and Schnack (1987) and Sparks, Van Hoven, and Schnack (1990) have concentrated on a complete treatment of the anisotropic energy transport in a sheared field, and have emphasized the nonlinear space-time evolution arising from the thermal instability. Wu et al. (1990) and Choe and Lee (1992) have considered arcade-like fields and the influence of gravity, and have initiated
condensations in *isothermal* atmospheres by mass injection and shear increase, respectively.

The other crucial aspect of the prominence-condensation problem involves the intrinsic *nonuniformities* of the solar atmosphere, and the energy and mass flows to and from the chromospheric *boundaries*. These fluxes, which are substantially along the field, suppress thermal instability in the corona and provide the condensation mass, respectively. Simulations of these phenomena, originating with those of Oran, Mariska, and Boris (1982), argue that the dynamic and energetic problem is made quasi-one-dimensional by a strong magnetic field. This *non-isothermal* 'coronal loop' model has been extended to include deep chromospheres (Mariska *et al.*, 1982) and siphon flows (Boris and Mariska, 1982), and then to establish global stability (Klimchuk, Antiochos, and Mariska, 1987; Mok, Schnack, and Van Hoven, 1991).

The next challenge is to form a prominence at the apex of such a non-isothermal loop. This requires a disturbance of the local energy balance, by modification (or 'loss') of the equilibrium or by instability, which eventually lowers the apex pressure by rapidly cooling the plasma. A subsequent siphon flow from the chromosphere provides the necessary prominence mass. The maintenance of the elevated position of the condensation also requires some deformation of the confining magnetic field. Poland and Mariska (1986) accomplished the first (parallel dynamics) aspect of this problem by a complex three-phase modification of the axial variation of the loop heating function, in a symmetric application of the heat-driven siphon-flow mechanism of Boris and Mariska (1982). The condensation process was abetted, to an unspecified extent, by the existence of a preset, rigid, magnetic-field depression.

More recently, Mok *et al.* (1990) showed that a depression of the loop-heating function with altitude, assumed to be caused by a change of heat input from sub-surface sources, spontaneously produced an apex prominence with observable values of temperature and density. The heating function was taken to decrease with length along the loop, and the departure from energy balance at the apex led to an accelerating local isobaric cooling. When the radiative rate eventually exceeded the pressure-equilibration rate, a significant pressure drop caused a large siphon inflow to the top of the loop. Prominence formation occurred, effectively, in the absence of a magnetic depression which was only added (for support) after the condensation process had begun.

In the present paper, we attack the next step in a *self-consistent* treatment of the full dynamics of this problem in the coronal-loop (quasi-one-dimensional) model. Starting from the 1-D parallel-dynamics heat-interruption model of Mok *et al.* (1990), we now allow the growing condensation to distort (by negative buoyancy) the loop magnetic field. To do so, we add another half dimension (0.5-D) to the problem (via \( v_\perp \) and \( B_\perp \), but with \( \partial v_\perp / \partial r_\perp = 0 \)), and allow the dynamic development of the gravitationally driven distortion of the initial field. The field bending grows and spreads (as an Alfvén wave) until a magnetic sling is formed which prevents the prominence from sliding off of the apex of the loop.

Section 2 describes the dynamic model, including the magnetic-field structure, the heating modification, and the equations describing the perpendicular motion and the