IV. Prominences and Filaments
(J.M. Malherbe)

This report is a summary of the work done on the physics of prominences and filaments . An overview of modern observations has been written by Hirayama (1985). The behaviour of solar Coronal and Prominence Plasmas (CPP) has been the topic of two SMM meetings, organized by A. Poland in 1985 and 1986, in Goddard Space Flight Center. An extensive review of the subject (formation, spectroscopic diagnostics and instabilities, with a large amount of contributed papers) can be found in the proceedings (Poland, 1986 (I)). Also, the physics and the structure of prominences will be discussed, from a more theoretical point of view, during a next workshop, in Palma de Mallorca, organized by E. Priest and J.L. Ballester in November 1987.

Recent progresses in the understanding of the formation, the structure, the equilibrium and support, and the instabilities ("Disparitions Brusques") of solar prominences will be summarized in this paper, and results of spectroscopic diagnostics (measurements of magnetic fields, velocities, temperatures and densities) will be stressed, from both a theoretical and observational point of view.

Prominences are structures of the solar corona ; but it is commonly thought that they are 100 times denser and cooler (chromospheric like conditions). They are anchored in the photosphere by feet ; the MHD mechanisms which operate in the formation, equilibrium and instabilities of these objects are complex and involve non linear effects due to interactions between heating, conduction, radiation, magnetic field reconnection and gravity, which make fascinating these beautiful features of the Sun.

A. FORMATION

It is well known that the mass of a quiescent prominence is an appreciable part of the mass of the entire corona (roughly one tenth or more), which makes difficult to form these structures only by coronal condensation. Hence, possible mechanisms of formation are now divided in two categories, namely condensation (of the coronal plasma) and injection (of the chromospheric material into the corona). Martin (1986), from recent observations, shows that filament formation is characterized by a continuous accumulation of dense threads along the channel between large scale opposite magnetic polarities, and by small scale magnetic field cancellation.

1. Condensation.

Sparks and Van Hoven (1985) considered thermal instabilities of the coronal plasma in sheared magnetic fields, without conduction; Van Hoven et al (1984) studied the interaction between radiation and tearing, while Tachi et al (1985) investigated the effects of viscosity in radiative and reconnection instabilities of sheared fields; Van Hoven and Mok (1984), and Van Hoven et al (1986), incorporated the effect of anisotropic thermal conduction and found unstable modes due to the perpendicular component. Malherbe (1987) and Forbes and Malherbe (1986) have numerically solved the 2D resistive-radiative MHD equations in line-tied current sheets and discovered a shock condensation mechanism. An (1984, 1985) looked at the condensation modes in cylindrical plasmas (loops) and examined the effect of the shear (An, 1986) (see also section V A).

2. Injection.

Injection processes can be subdivided into surge-like and evaporation-like models. An et al (1986) suggested that material is ballistically launched from the chromosphere to the corona at the speed of spicules, while Poland and Mariska (1986) showed that a sustained heat release in a loop may give rise to a solar evaporation and thermal instability at the top of the loop.

B. SPECTROSCOPIC DIAGNOSTICS

1. Velocity field.

It is now clear that the equilibrium of filaments is not static, but dynamic. Upward motions were found by Schmieder et al (1984a) in chromospheric lines, by Athay

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et al (1985) and Engvold et al (1985) in UV lines. A correlation between these flows and large convective motions in the photosphere (giant cells) is suspected by Schmieder et al (1984b). Ioshpa et al (1986) have compared Hα and photospheric velocities around a filament. Small scale motions were studied by Landman (1985a). Oscillations in prominences were searched by Bashkirtsev and Mashnich (1984) (long periods), while short periods were found by Tsubaki and Takeuchi (1986) and Tsubaki et al (1987). On the contrary, no chromospheric oscillations were observed by Malherbe et al (1987) in filaments.

Large scale motions in loop prominences have also been reported by Loughead and Bray (1984), Cui et al (1985), while oscillations in loops have been studied by Solovev (1985).

2. Magnetic fields.

Prominences are composed of a set of dense and cold threads of electric currents supported against gravity (and partly isolated from heating by conduction and wave dissipation) by magnetic fields. Longitudinal fields were recorded in filaments by Maksimov and Ermakova (1985), and in prominences by Nikolsky et al (1984, 1985) using Zeeman effect. Kim et al (1986) have studied correlations between line of sight magnetic and velocity fields.

Landolfi and Landi (1985) investigated line polarization as a function of the vector magnetic field. Also Hanle effect was theoretically studied by Bommier (1987) and used for magnetic vector measurements in quiescent prominences by Gornyj et al (1984), Leroy et al (1984) and Querfeld et al (1985). It is now well established that the angle between the field and the filament axis is small (25 degrees), and that the topology is more often of the Raadu-Kuperus type (1973) than the Kippenhahn-Schluter one (1957). At last, Ballester and Kleczek (1984) and Ballester (1984) give a model derived from observations of magnetic and electric fields in prominences.

3. Pressure, temperature, and densities.

Radio emission was investigated above filaments by Stewart (1984), Apushkinskij (1985) and Hiei et al (1986). Zirker (1985) observed infra-red prominence H lines. Smartt and Zhang (1984) analysed soft X-ray data of a quiescent prominence. Loughead et al (1985) give a complete description of MHD physical quantities in an active loop.

Radiative transfer in prominences has also been extensively studied by several authors : Fontenla and Rovira (1985), Landman (1984, 1985b), Cram (1986), Zarkhova (1984) present new calculations. Semi-empirical models are proposed by Zhang and Fang (1987), including transfer and hydrostatic equilibrium. The gas pressure in prominences has been determined by Hellwig et al (1984). Stellmacher et al (1986) have measured electron densities in faint prominences. Some discrepancies exist in the density measurements : Bommier et al (1984) found densities of 10^{10} cm^{-3} and less, while Landman (1984) obtains values bigger than 10^{11} cm^{-3} ; this last result makes questionable condensation mechanisms of the coronal plasma to account for the huge mass contained in prominences.

The thermal structure of filaments is still unclear: Kundu (1986) and Gary (1986) suggested hot threads around a cold core, while Schmahl and Orrall (1986) suggested non isothermal loops at various temperatures.

C. OVERALL STRUCTURE, EQUILIBRIUM AND SUPPORT

1. Large scale structure.

The overall structure of solar filaments was studied by Soru-Escaut et al (1985) and singularities in the solar rotation were found. The behaviour of filaments as a function of the solar cycle was investigated by Gnevyshev and Makarov (1985), Makarov (1985) and Fujimori (1984). Liggett and Zirin (1984) have studied proper motions of prominences and gave evidence of rotational motions. It becomes now urgent for a better understanding of prominence structure and formation to collect data on feet, which connect filaments to the solar convective zone.

2. Equilibrium and support.

New equilibrium (magnetostatic) models for the support of prominences (which are often considered as thin current sheets) against gravity have been proposed: Anzer and Priest (1985) considered the equilibrium of Kuperus-Raadu type prominences imbedded in potential coronal magnetic fields; Amari and Aly (1986) investigated the equilibrium of massive lines of current in sheared force-free coronal fields. Also, the externally driven quasi-static evolution of magnetostatic equilibria (especially current sheets) has been reviewed by Aly (1986), while Wu et al (1986) suggested that induced mass and wave motions could be driven by converging or diverging photospheric flows.

Low (1984) put forward three-dimensional magnetostatic models relevant to prominence support ; and Osherovich (1985) obtained different magnetic supports based on eigenvalue solutions and examined the behaviour of filaments in horizontal external magnetic fields. Galindo-Trejo and Shindler (1984) investigated the MHD stability of sheet equilibria, relevant to the Kippenhahn- Schluter model. Jensen (1986) suggested that Alfvén wave dissipation could provide a support mechanism for prominences. At last, a thermal model for the fine structure of prominences has been proposed by Démoulin et al (1987).

D. INSTABILITIES AND DISAPPEARANCES

It is now well established that disappearances of filaments can be subdivided in two classes: thermal disappearances (corresponding to plasma heating) and dynamic ones (characterized by ejecta). Eruptive filaments may reform later after instabilities, and a lot of events are assiociated to flares (and two ribbon flares). What causes filament instability is a difficult problem : the emergence of new flux (followed by magnetic reconnection), the variation of the shear, thermal non-equilibrium, bifurcations between multiple equilibria under changes of boundary conditions are possible candidates. The association between flares and filament eruptions was investigated by Tang (1986). Interaction between filaments and flares was also analysed by Rust (1984). Apushkinskij and Topchilo (1984) have suggested that deformations due to differential rotation may trigger prominence instabilities.

Particle acceleration during filament disappearances was studied by Kahler et al (1986). Fast material ejecta during instabilities have been modelled by Raadu et al (1987). Schmieder et al (1985), Wang (1985) and Kurokawa et al (1987) reported twisting and untwisting motions in activated filaments and prominences. Pneuman (1984) has presented a model for rising helical prominences during activation. The dynamics of active prominences was also analysed by Klepikov and Platov (1985).

Coronal mass ejection, in relation with eruptive prominences, is also studied by Illing and Athay (1986), Athay and Illing (1986) and Illing and Hundhausen (1986). Heating processes have been examined by Mouradian and Martres (1986) and by Simon et al (1984) ; in this last case, the observed event is suggested to be the consequence of a new emerging flux and magnetic reconnection which ensues.

The fine structure of an active prominence was studied by Nikiforova (1985). At last, the density of post flare loops, dense and cold features which are observed to form during the gradual phase of two ribbon flares, is studied by Hanakoa and Kurokawa (1986); the results are consistent with reconnection models proposed by Kopp and Pneuman in 1976.

References

I : Proceedings of Coronal and Prominence Plasmas (CCP) Workshops, NASA Conference Publication 2442, Poland, K.V. (ed), 1986.

Aly, J.J.: 1986, Proceedings of the Workshop on "Interstellar Magnetic Fields", Schloss Ringberg, Germany, in press.

Amari, T., Aly, J.J.: 1986, proceedings of the workshop on "Interstellar Magnetic Fields", Schloss Ringberg, Germany, in press.

An, C.H.: 1984, Astrophys. J., 276, 755.

An, C.H.: 1985, Astrophys. J., 298, 409.

An, C.H.: 1986, Astrophys. J., 304, 532.

An, C.H., Bao J.J., Wu S.T.: 1986, CPP proceedings, A. Poland Ed., 51.

Anzer, U., Priest, E.R.: 1985, Solar Phys., 95, 263.

Apushkinskij, G.P.: 1985, Astron. Z., 62, 992.

Apushkinskij, G.P., Topchilo, N.A.: 1984, Astron. Z., 61, 1150.
Athay, G., Jones, H., Zirin, H.: 1985, Astrophys. J., 288, 363.
Athay, G., Illing, R.M.E.: 1986, J. G. R., 91, 10961.
Ballester, J.L.: 1984, Solar phys., 94, 151.
Ballester, J.L., Kleckzek, J.: 1984, Solar Phys., 90, 37.
Bashkirtsev, V.S., Mashnich, G.P.: 1984, Solar Phys., 91, 93.
Bommier, V.: 1987, thèse de Doctorat d'Etat, Université de Paris VII.
Cui, L.S., Hu, J., Ji, G.P., Ni, X.B., Huang, Y.R., Fang, C.: 1985, Chin. Astron. Astrophys., 9, 49.
Cram, L.E.: 1986, Astrophys. J., 300, 830.
Démoulin, P., Raadu, M.A., Malherbe, J.M., Schmieder, B.: 1987, Astron. Astrophys., in press.
Engvold, O., Tandberg-Hanssen, E., Reichmann, E.: 1985, Solar Phys., 96, 35.
Fontenla, J.M., Rovira, M.: 1985, Solar Phys., 96, 53.
Forbes, T.G., Malherbe, J.M.: 1986, Astrophys. J. letters, 302, L67.
Fujimori, K.I.: 1984, Publ. Astron. Soc. Japan, 36, 189.
Galindo-Trejo, J., Schindler, K.: 1984, Astrophys. J., 277, 422.
Gary, D.: 1986, in CPP proceedings, A. Poland Ed., 121.
Gornyj, M.B., Kupriyanov, D.V., Matisov, B.G.: 1984, Astron. Z., 61, 1158.
Gnevyshev, M.N., Makarov, V.I.: 1985, Solar Phys., 95, 189.
Hanaoka, Y. and Kurokawa, H.: 1986, Solar Phys., 105, 133.
Hellwig, J., Stellmacher, G., Wiehr, E.: 1984, Astron. Astrophys., 140, 449.
Hiei, E., Ishiguro, M., Kosugi, T., Shibasaki, K.: 1986, in proceedings of CPP meeting, A. Poland Ed., 109.
Hirayama, T.: 1885, Solar Phys., 100, 415.
Illing, R.M.E., Athay, G.: 1986, Solar Phys., 105, 173.
Illing, R.M.E., Hundhausen, A.J.: 1986, J. G. R., 91, 10951.
Ioshpa, B.A., Kozhevatov, I.E., Kulikova, E.K., Mogilevskij, E.I.: 1986, Soln. Dannye, 5, 68.
Jensen, E.: 1986, CPP proceedings, A. Poland Ed., 63.
Kahler, S.W., Cliver, E.W., Cane, H.V., Mc Guire, R.E., Stone, R.G., Sheeley, N.R.:1986, Astrophys. J., 302, 504.
Kim, I., Koutchmy, S., Stellmacher, G., Stepanov, A.I.: 1986, in proceedings of "the role of fine-scale magnetic fields on the structure of the Solar atmosphere" meeting, Tenerife, Canary Islands, in press.
Kippenhahn, R., Schluter, A.: 1957, Astrophys. J., 43, 36.
Klepikov, V., Platov, V.: 1985, Astron. Z., 62, 983.
Kundu, M.R.: 1986, in CPP proceedings, A. Poland Ed., 117.
Kurokawa, H., Hanaoka, Y., Shibata, K., Uchida Y.: 1987, Solar Phys., in press.
Landolfi, M., Landi, E.: 1985, Solar Phys., 98, 53.
Landman, D.A.: 1984, Astrophys. J., 279, 438.
Landman, D.A.: 1985a, Astrophys. J., 295, 220.
Landman, D.A.: 1985b, Astrophys. J., 290, 369.
Leroy, J.L., Bommier, V., Sahal-Brechot, S.: 1984, Astron. Astrophys., 131, 33.
Liggett, M., Zirin, H.: 1984, Solar Phys., 91, 259.
Loughead, R.E., Bray, R.J., Jia-Long Wang: 1985, Astrophys. J., 294, 697.
Loughead, R.E., Bray, R.J.: 1984, Astrophys. J., 283, 392.
Low, B.C.: 1984, Astrophys. J., 277, 415.
Malherbe, J.M.: 1987, thèse de Doctorat d'Etat, Université de Paris VII.
Malherbe, J.M., Schmieder, B., Mein, P., Tandberg-Hanssen, E.: 1987, Astron. Astrophys., 172, 316.
Makarov, V.I.: 1984, Solar Phys., 93, 393.
Maksimov, V.P., Ermakova, L.V.: 1985, Astron. Z., 62, 558.
Martin, S.F.: 1986, in CPP proceedings, A. Poland Ed., 73.
Mouradian, Z., Martres, M.J.: 1986, in proceedings of the CPP meeting, A. Poland Ed., 221.
Nikiforova, T.P.: 1985, Soln. Dannye, 8, 79.
Nikolsky, G.M., Kim, I.S., Koutchmy, S., Stellmacher, G.: 1984, Astron. Astrophys., 140, 112.

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Nikolsky, G.M., Kim, I.S., Koutchmy, S., Stepanov, A.I., Stellmacher, G.: 1985,Astron. Z., 62, 1147.
Osherovich, V.A.: 1985, Astrophys. J., 297, 314.
Pneuman, G.W.: 1984, Solar Phys., 94, 299.
Poland, A.I., Mariska, J.T.: 1986, Solar Phys., 104, 303.
Querfeld, C.W., Smartt, R.N., Bommier, V., Landi, E., House, L.L.: 1985, Solar Phys., 96, 277.
Raadu, M.A., Kuperus, M.: 1973, Solar Phys., 28, 77.
Raadu, M., Malherbe, J.M., Schmieder, B., Mein, P.: 1987, Solar Phys., in press.
Rust, D.M.: 1984, Solar Phys., 93, 73.
Schmahl, E., Orrall, F.: 1986, in CPP proceedings, A. Poland Ed., 127.
Schmieder, B., Malherbe, J.M., Mein, P., Tandberg-Hanssen, E.: 1984a, Astron. Astrophys., 136, 81.
Schmieder, B., Ribes, E., Mein, P., Malherbe, J.M.: 1984b, Mem. S.A. It., 55, 319.
Schmieder, B., Raadu, M.A., Malherbe, J.M.: 1985, Astron. Astrophys., 142, 249.
Simon, G., Mein, N., Mein, P., Gesztelyi, L.: 1984, Solar Phys., 93, 325.
Smartt, R.N., Zhang, Z.: 1985, Solar phys., 90, 315.
Solovev, A.A.: 1985, Soln. Dannye, 9, 65.
Soru-Escaut, I., Martres, M.J., Mouradian, Z.: 1985, Astron. Astrophys., 145, 19.
Sparks, L., Van Hoven, G.: 1985, Solar Phys., 97, 283.
Stellmacher, G., Koutchmy, S., Lebecq, C.: 1986, Astron. Astrophys., 162, 307.
Stewart, R.T.: 1984, Solar Phys., 94, 379.
Tachi, T., Steinolfson R.S., Van Hoven G.: 1985, Solar Phys., 95, 119.
Tang, F.: 1986, Solar Phys., 105, 2.
Tsubaki, T., Ohnishi, Y., Suematsu, Y.: 1987, Publ. Astron. Soc. Japan, 39, 179.
Tsubaki, T., Takeuchi, A.: 1986, Solar Phys., 104, 2.
Van Hoven, G., Mok, Y.: 1984, Astrophys. J., 282, 267.
Van Hoven, G., Sparks ,L., Tachi, T.: 1986, Astrophys. J., 300, 249.
Van Hoven, G., Tachi, T., Steinolfson, R.S.: 1984, Astrophys. J., 280, 391.
Wang, J.L.: 1985, Scientia Sinica, 28, 1308.
Wu, S.T., Hu, Y.Q., Nakagawa, Y., Tandberg-Hanssen, E.: 1986, Astrophys. J., in press.
Zarkhova, V.V.: 1984, Astron. Astrophys., 51, 45.
Zhang, Q.Z., Fang, C.: 1987, Astron. Astrophys., 175, 277.
Zirker, J.B.: 1985, Solar Phys., 102, 33.

V. Solar Maximun Analysis
(Z. Svestka)

The basic results of the SMA were presented and summarized in two SMA Symposia Proceedings, edited by Simon (1984 (I) we will refer to this publication using abbreviation SIM) and by De Jager and Svestka (1986, DJS (II)). Other papers discussing SMA results can be found in Proceedings of SMM Workshops (Kundu and Woodgate, 1986 - KAW (III) ; Poland, 1986 - POL (IV) ; Dennis et al., 1987 (DOK (V)) and three other meetings held at Kunming (De Jager and Chen Biao, 1985, JCB (VI)) Irkutsk (Stepanov and Obridko, 1986 (SAO (VII)) and Sacramento Peak (Neidig, 1986, NEI (VIII)). A summary of Soviet contributions to the SMA (until 1985) was prepared by Stepanov (in SAO, p. 5). Kindly note that this Section does not mention most of the SMA results that belong to the topics of the subsequent sections of this report : thus the SMA results of space observations should be found in Section VI, radio observations in Section VII, etc. The present report will be mostly limited to those results of the SMA which use or interpret optical ground-based data.

A. FLARE BUILD -UP

A useful discussion of preflare activity can be found in Priest et al. (in KAW, Chapter 1). Kuin and Martens (Martens, 1986 and ref. there) extended the scenario for preflare energy build-up in a filament circuit to a 3D-model. Energy storage in sheared magnetic field structures has been discussed by Zwingmann et al. (1985) and Hofman et al. (1987). Peres-Enriquez (1985) revived and reexamined the old Elliot's idea of a build-up in the form of energetic particles stored in magnetic loops. Lin Xinping and Chang Guohua (in JCB, p. 436) suggest a transformation of kinetic energy