Salucci, G., Bertello, L., Cavallini, F., Cepatelli, G., Righini, A. 1994, A&A, 285, 322.
Sánchez Almeida, J., Landi Degl'Innocenti, E. 1996, Sol. Phys., 164, 203.
Sánchez Almeida, J., Landi Degl'Innocenti, E., Martínez Pillet, V., Lites, B.W. 1996, ApJ, 466, in press.
Sánchez Almeida, J., Ruiz Cobo, B., del Toro Iniesta, J.C. 1996, A&A, in press.
Schmidt, W., Balthasar, H. 1994, A&A, 283, 241.
Severino, G., Gomez, M.T., Caccin, B. 1994, II, p. 169.
Solanki, S.K., Bruls, J.H.M.J. 1994, A&A, 286, 269.
Solanki, S.K., Montavon, C.A.P. 1993, A&A, 275, 283.
Solanki, S.K., Finsterle, W., Rüedi, I. 1996, Sol. Phys. 164, 253.
Solanki, S.K., Montavon, C.A.P., Livingston, W. 1994, A&A, 283, 221.
Solanki, S.K., Bruls, J.H.M.J., Steiner, O., Ayres, T., Livingston, W., Uitenbroek, H. 1994, II, p. 91.
Staude, J. 1996, Sol. Phys., 164, 183.
Steiner, O., Grossmann-Doerth, U., Schüssler, M., Knölker, M. 1996, Sol. Phys., 164, 223.
Thomas, J.H. 1994, II, p. 219. &C.J. Schrijver (eds.), KAP, p. 219.
del Toro Iniesta, J.C., Ruiz Cobo, B. 1995, in La polarimétrie, outil pour l'étude de l'activité magnétique solaire et stellaire, N. Mein & S. Sahal-Bréchot (eds.), p. 127.
del Toro Iniesta, J.C., Ruiz Cobo, B. 1996, Sol. Phys., 164, 169.
del Toro Iniesta, J.C., Tarbell, T.D., Ruiz Cobo, B. 1994, ApJ, 436, 400.
del Toro Iniesta, J.C., Ruiz Cobo, B., Bellot Rubio, L.R., Collados, M. 1995, A&A, 294, 855.
Volmöller, P., Komm, R., Mattig, W. 1996, A&A, 306, 294.
Wiehr, E. 1996, A&A, 309, L4.
Wiehr, E., Degenhardt, D. 1993, A&A, 278, 584.
Zhang, H. 1994, Sol. Phys., 154, 207.

17. SOLAR ATMOSPHERIC DYNAMICS

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In the last years, studies of the structure of the solar atmosphere have demonstrated — yet more than before — that the solar atmosphere is so intrinsically dynamic in nature that it is a fallacy to speak of "the quiet solar atmosphere". The term denotes areas where magnetism is not obviously dominating; but even there the atmosphere is far from the classic paradigm of stably stratified plane-parallel layers in hydrostatic equilibrium. In fact, even the existence of a ubiquitous "temperature minimum" between photosphere and chromosphere has now been put into doubt (Carlsson & Stein 1995).

The major current improvement in this regard is the advent of realistic numerical simulations. Time-dependent hydrodynamics modeling including detailed radiative transfer, currently cast in 1D, 2D and 3D versions with different capabilities, now enable solar astrophysics to finally leave the one-dimensional standard modeling that was so long required for tractability. In addition, new groundbased techniques (see report by Keller) provide the high spatial and temporal resolution needed to properly appreciate the dynamic nature of the photosphere. The spate of instruments onboard the SOHO mission furnishes unprecedented long-duration views of chromospheric dynamics from space.

This section covers the so highly unquiet behavior of the "quiet" photosphere and chromosphere. For subsurface dynamics see Brown's report; dynamics of magnetic structures is covered by Solanki; coronal dynamics is treated by Hammer.

17.1. PHOTOSPHERIC GRANULATION

In essence, the hydrodynamics of the solar granulation has been understood in the past decade (see reviews in Rutten & Severino 1989 and by Spruit et al. 1990) and translated to stellar granulation as well (Nordlund & Dravins 1990). Currently, simulations are used to detail the turbulent convective processes. An issue is the occurrence of supersonic flows, both in the fast downflow plumes ("fingers", Stein & Nordlund 1989) where partial hydrogen ionization contributes appreciably to the dynamical topology (Rast et al. 1993) and which act as the major scale-setting agent (Rast 1995), and in the horizontal flows at the edges of large granules near downdraft sites (Malagoli et al. 1990). Rimmele et al. (1995) found that exceptionally dark intergranular lanes accompany the acoustic events that are thought to mark p-mode excitation sites. Nesis et al. (1992) have claimed that supersonic flows are actually observable as post-shock intergranular line broadening, but Solanki et al. (1996) disagree and suggest instead that the predicted supersonic horizontal flows themselves may be diagnosed from excessive line broadening along slanted lines of sight.

17.2. PHOTOSPHERIC FLOWS

The emphasis in studying photospheric dynamics has moved to the effects of turbulent convection on the structures and patterns of magnetic activity. At the smallest scale, current efforts concentrate on the Muller bright points seen in the G–band (CH lines around 430.5 nm), which for a not-understood reason brighten considerably in the smallest flux concentrations. They appear to furnish direct diagnostics of the basic components of solar magnetism, so far observed only indirectly through Stokes polarimetry — but nevertheless modeled in great detail as flux "tubes" (*e.g.*, Spruit et al. 1991, Buente et al. 1993) or "sheets" (*e.g.*, Steiner et al. 1994, Grossmann-Doerth et al. 1994). The G–band points are tiny (0.1–0.2 arcsec) and stand out only when the seeing is excellent (Title & Berger 1996), but they then provide direct views of the highly dynamical nature and topology of the photosphere as experienced by flux concentrations (Berger et al. 1995). The current frontier is to enhance their visibility through sophisticated image restoration (speckle plus phase diversity, Paxman et al. 1996).

The phenomenon of mesogranulation (*e.g.*, Muller et al. 1992) is still being debated. It is seen clearest in the vorticity and divergence patterning of granular flow motions (Wang et al. 1995). November (1994) has proposed that it drives the supergranulation, while Straus & Bonaccini (1996, cf. Straus et al. 1992) doubt its existence, and Rast (1995) attributes it to granular downflow topology.

The larger-scale topology of the supergranulation and the roughly (but not exactly) corresponding magnetic and chromospheric network is actively studied using various diffusion formalisms (percolation, Voronoi tessellation; Balke et al. 1993, Lawrence & Schrijver 1993, Lawrence et al. 1993, Tao et al. 1995, Lawrence et al. 1996, Schrijver et al. 1996). Currently, space observation with SOHO's MDI supplies long-term distortion-free measurements that enable quantitative analyses of this type. A major goal is to ascertain the field topology at emergence in order to derive subsurface dynamo patterning.

17.3. CHROMOSPHERIC OSCILLATIONS

A recent breakthrough in chromospheric dynamics is the identification of the oscillatory phenomena that constitute the so-called Ca II H_{2V} and K_{2V} internetwork grains. A review of the extensive literature on this subject led Rutten & Uitenbroek (1991) to propose that these portray three-minute shock formation with *p*-mode excitation and interference, of purely acoustic nature rather than marking fluxtubes as claimed by Sivaraman & Livingston (1982), Kalkofen (1989) and Kariyappa et al. (1994). Extensive observational studies (Kulaczewski 1992, Von Uexkuell & Kneer 1995, Steffens et al. 1996, Hofmann et al. 1996) have confirmed that internetwork K_{2V} grains are tip-of-the-iceberg extrema of oscillation interference patterns. At the same time, numerical simulations by different groups (Carlsson & Stein 1992, Kalkofen et al. 1994, Schmitz & Fleck 1995, Ulmschneider & Sutmann 1995a, 1995b) have culminated in the qualitative reproduction of observed H_{2V} behavior by Carlsson & Stein (1994). Using a broad-band subphotospheric piston derived from the actual Doppler excursions of a photospheric line observed by Lites et al. (1993) they established that the K_{2V} grains indeed betray shock interference between upward propagating acoustic disturbances and backfalling matter from previous shock passages. Issues now under study are the signatures of reflection from higher layers (Kumar et al. 1994, Steffens et al. 1995, Deubner et al. 1996) and the signatures of the shocks within higher layers (Cook et al. 1996, Hoekzema et al. 1996). An open question is yet how much these acoustic phenomena contribute to the "basal" heating of the solar chromosphere (cf. Schrijver 1995).

The dynamics of the chromospheric network, mapped by bright elements in Ca II K, differs strongly from the non-magnetic internetwork domains (or at least less magnetic, see Keller et al. 1994 and Lites et al. 1996). Lites et al. (1993) confirmed the dichotomy between three-minute internetwork oscillations and the long-period modulations displayed by network elements (cf. Bocchialini et al. 1994). However, Volkmer et al. (1995) have found evidence for 100 s oscillation within a small-scale magnetic element.

17.4. CHROMOSPHERIC FLOWS

A topic where much is to be expected now that SOHO provides extended coverage with short-wavelength diagnostics (SUMER, CDS and EIT) is the dynamical behavior of the magnetically structured middle and upper chromosphere. Current ground-based studies of mottle flows lead the way (*e.g.*, Heinzel & Schmieder 1994, Tsiropoula et al. 1994). Elaborate radiative transfer modeling is required (Mein et al. 1996) — if not detailed hydrodynamical simulation, for example to establish the importance of siphon flows (*e.g.*, Degenhardt et al. 1993, Montesinos & Thomas 1993).

Finally, two topics of chromospheric dynamics should be pointed out that merit focus in the coming years. The first consists of spicules, a subject largely been neglected since the sixties (Beckers 1968, cf. Gaizauskas 1994) but bound to resurface while chromospheric dynamics is detailed SOHO-wise. The second is the FIP-flip observed in the closed-field corona and the slow solar wind (and even in energetic cosmic rays). This fractionation between low and high first ionization energy species must occur where hydrogen is yet mainly neutral, so that transport across field lines is easy for C, N and O but not for the charged ions of Mg, Fe, Si etc. (Marsch et al. 1995).

References

Balke, A. C., Schrijver, C. J., Zwaan, C., Tarbell, T. D. 1993, Solar Phys., 143, 215
Beckers, J. M. 1968, Solar Phys., 3, 367
Berger, T. E., Schrijver, C. J., Shine, R. A., Tarbell, T. D., Title, A. M., Scharmer, G. 1995, ApJ, 454, 531
Bocchialini, K., Vial, J.-C., Koutchmy, S. 1994, ApJ, 423, L67
Buente, M., Solanki, S. K., Steiner, O. 1993, A&A, 268, 736
Carlsson, M., Stein, R. F. 1992, ApJ, 397, L59
Carlsson, M., Stein, R. F. 1994, in M. Carlsson (ed.), Chromospheric Dynamics, Proc. Miniworkshop, Inst. Theor. Astrophys., Oslo, p. 47
Carlsson, M., Stein, R. F. 1995, ApJ, 440, L29
Cook, J. W., Rutten, R. J., Hoekzema, N. M. 1996, ApJ, in press
Degenhardt, D., Solanki, S. K., Montesinos, B., Thomas, J. H. 1993, A&A, 279, L29
Deubner, F. L., Waldschik, T., Steffens, S. 1996, A&A, 307, 936
Gaizauskas, V. 1994, in R. J. Rutten, C. J. Schrijver (eds.), Solar Surface Magnetism, NATO ASI Series C433, Kluwer, Dordrecht, p. 133
Grossmann-Doerth, U., Knoelker, M., Schuessler, M., Solanki, S. K. 1994, A&A, 285, 648
Heinzel, P., Schmieder, B. 1994, A&A, 282, 939
Hoekzema, N. M., Rutten, R. J., Cook, J. W. 1996, ApJ, in press
Hofmann, J., Steffens, S., Deubner, F. L. 1996, A&A, 308, 192
Kalkofen, W. 1989, ApJ, 346, L37
Kalkofen, W., Rossi, P., Bodo, G., Massaglia, S. 1994, A&A, 284, 976
Kariyappa, R., Sivaraman, K. R., Anadaram, M. N. 1994, Solar Phys., 151, 243
Keller, C. U., Deubner, F. L., Egger, U., Fleck, B., Povel, H. P. 1994, A&A, 286, 626
Kulaczewski, J. 1992, A&A, 261, 602
Kumar, P., Fardal, M. A., Jefferies, S. M., Duvall, T. L., J., Harvey, J. W., Pomerantz, M. A. 1994, ApJ, 422, L29
Lawrence, J. K., Cadavid, A. C., Ruzmaikin, A. A. 1996, ApJ, 465, 425
Lawrence, J. K., Ruzmaikin, A. A., Cadavid, A. C. 1993, ApJ, 417, 805
Lawrence, J. K., Schrijver, C. J. 1993, ApJ , 411, 402
Lites, B. W., Leka, K. D., Skumanich, A., Martinez Pillet, V., Shimizu, T. 1996, ApJ, 460, 1019
Lites, B. W., Rutten, R. J., Kalkofen, W. 1993, ApJ, 414, 345
Malagoli, A., Cattaneo, F., Brummell, N. H. 1990, ApJ, 361, L33
Marsch, E., Von Steiger, R., Bochsler, P. 1995, A&A, 301, 261
Mein, N., Mein, P., Heinzel, P., Vial, J. C., Malherbe, J. M., Staiger, J. 1996, A&A, 309, 275
Montesinos, B., Thomas, J. H. 1993, ApJ, 402, 314
Muller, R., Auffret, H., Roudier, T., Vigneau, J., Simon, G. W., Frank, Z., Shine, R. A., Title, A. M. 1992, Nat, 356, 322
Nesis, A., Bogdan, T. J., Cattaneo, F., Hanslmeier, A., Knoelker, M., Malagoli, A. 1992, ApJ, 399, L99
Nordlund, Å., Dravins, D. 1990, A&A, 228, 155
November, L. J. 1994, Solar Phys., 154, 1
Paxman, R. G., Seldin, J. H., Loefdahl, M. G., Scharmer, G. B., Keller, C. U. 1996, ApJ, 466, 1087
Rast, M. P. 1995, ApJ, 443, 863
Rast, M. P., Nordlund, A., Stein, R. F., Toomre, J. 1993, ApJ, 408, L53
Rimmele, T. R., Goode, P. R., Harold, E.,
Stebbins, R. T. 1995, ApJ, 444, L119
Rutten, R. J., Severino, G. (eds.) 1989, Solar and Stellar Granulation, NATO ASI Series C263, Kluwer, Dordrecht
Rutten, R. J., Uitenbroek, H. 1991, Solar Phys., 134, 15
Schmitz, F., Fleck, B. 1995, A&A, 301, 483
Schrijver, C. J. 1995, A&AR, 6, 181
Schrijver, C. J., Hagenaar, H. J., Title, A. M. 1996, ApJ, in press
Sivaraman, K. R., Livingston, W. C. 1982, Solar Phys., 80, 227
Solanki, S. K., Rueedi, I., Bianda, M., Steffen, M. 1996, A&A, 308, 623
Spruit, H. C., Nordlund, A., Title, A. M. 1990, ARA&A, 28, 263
Spruit, H. C., Schuessler, M., Solanki, S. K. 1991, in Solar interior and atmosphere. Tucson, AZ, University of Arizona Press, 1991, p. 890-910., p. 890
Steffens, S., Deubner, F. L., Hofmann, J., Fleck, B. 1995, A&A, 302, 277
Steffens, S., Hofmann, J., Deubner, F. L. 1996, A&A, 307, 288

Stein, R. F., Nordlund, A. 1989, ApJ, 342, L95
Steiner, O., Knölker, M., Schüssler, M. 1994, in R. J. Rutten, C. J. Schrijver (eds.), Solar Surface Magnetism, NATO ASI Series C433, Kluwer, Dordrecht, p. 441
Straus, T., Bonaccini, D. 1996, A&A, submitted
Straus, T., Deubner, F. L., Fleck, B. 1992, A&A, 256, 652
Sutmann, G., Ulmschneider, P. 1995a, A&A, 294, 232
Sutmann, G., Ulmschneider, P. 1995b, A&A, 294, 241
Tao, L., Du, Y., Rosner, R., Cattaneo, F. 1995, ApJ, 443, 434
Title, A. M., Berger, T. E. 1996, ApJ, 463, 797
Tsiropoula, G., Alissandrakis, C. E., Schmieder, B. 1994, A&A, 290, 285
Volkmer, R., Kneer, F., Bendlin, C. 1995, A&A, 304, L1
Von Uexkuell, M., Kneer, F. 1995, A&A, 294, 252
Wang, Y., Noyes, R. W., Tarbell, T. D., Title, A. M. 1995, ApJ, 447, 419

18. FLOWS AND OSCILLATIONS IN SMALL-SCALE MAGNETIC STRUCTURES

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Small-scale magnetic features (or magnetic elements) contain most of the magnetic energy and flux on the solar surface, and play, through their dynamics, a dominant role in channelling energy into the upper atmospheric layers. First a brief review is given of the work done in the last 3 years on stationary flows.

On average, magnetic elements are well known to be free of substantial steady flows. Recently Montagne et al. (1996) confirmed these results, although their line shifts were derived from Stokes I profiles alone. The redshift of roughly 200 m s^{-1} they observe in and around magnetic features relative to the quiet sun corresponds to no flow when corrected for the granular blueshift. Amer & Kneer (1993) and Kneer & Stolpe (1996) also find little net shift of the Stokes V zero-crossing when averaged over a few arc sec on the solar surface. Individual high-spatial-resolution profiles can be shifted by up to 1 km s^{-1}, however (both blue- and redshifts being common).

Even stronger flows within magnetic elements have been detected on both sides of a magnetic neutral line and have been interpreted as the footpoints of a siphon flow. Degenhardt et al. (1993) showed from the comparison of model calculations with infrared (1.56 μm) observations that this siphon flow is supersonic near the top of the loop connecting the footpoints and shocks above the downstream footpoint. The models they used were developed by Montesinos & Thomas (1993) and include the effects of partial ionization and lateral radiative exchange (via Newton's law of cooling).

Magnetic elements are surrounded by fast, quasi-stationary flows concentrated in narrow lanes, which are fed by horizontal inflows. This picture is substantiated by both empirical modelling of the Stokes V and I profile asymmetry (Bünte et al. 1993, Márquez et al. 1996) and in still greater detail by theoretical simulations (Steiner et al. 1995, 1996). A radically different view of how the Stokes V asymmetry is produced is proposed by Sánchez Almeida & Landi Degl'Innocenti (1996), who argue that the magnetic features are composed of many strands of field, each thinner than the photon mean-free-path. These strands are interleaved with flows.

In the following, recent advances in the theory and observation of oscillations and waves related to magnetic elements are reviewed.

Lundberg (1994) derived the non-linear dispersion relation of a weakly non-linear slow sausage surface wave travelling along a magnetized slab (considered as a simple model of a flux tube, which is thought to be the basic physical structure underlying magnetic elements), and Goossens et al. (1995) obtained dissipative MHD solutions for resonant Alfvén waves in a cylindrical model of a flux tube, while Nakariakov & Roberts (1995) have worked out the theory of magnetosonic waves in magnetic slabs, including the influence of steady flows. On applying their results to photospheric conditions they find that downflows of 1–3 km s^{-1} around flux tubes (i.e. downflows of the observed magnitude) lead to the disappearance of certain wave modes in the flux tube. All these investigations do not take the effects of gravity into account, however. The theory of magneto-atmospheric waves subject to Newtonian cooling (including