Chromosphere: network

The chromospheric network was discovered by Hale in 1892 with his newly-invented spectroheliograph. It is a patchy pattern (Hale called it a “reticuled structure”) covering the solar disk outside active regions that appears when the sun is imaged in spectral diagnostics formed in the chromosphere (Figure 1; Schmieder xxx).

The network pattern has a honeycomb appearance at characteristic cell sizes of 10–40 arcsec and consists of small magnetic patches which outline, although incompletely, the borders of the supergranulation cells (Simon xxx) in the underlying photosphere. Each magnetic patch measures a few arcsec and consists probably of a cluster of flux tubes (Solanki xxx, Roberts xxx) that are either already physically merged at chromospheric heights (1000 – 5000 km above the photosphere) or appear merged due to radiation scattering.

The chromospheric network is to high precision cospatial with the magnetic network observed with magnetographs in the photosphere. The reason for the cospatiality is the kilo-Gauss field strength of the photospheric flux tubes. Such high field strength goes together with near-evacuation, therefore large buoyancy, and therefore radial (upright) orientation (Spruit xxx, Roberts xxx).

The network patches appear bright in chromospheric lines (the Ca II H & K resonance lines at $\lambda = 396$ nm and 393 nm, the inner wings of the hydrogen Balmer-series Hα line at 656.3 nm, and many emission lines in the mid-ultraviolet). The observed brightness increases with the apparent magnetic flux density in the underlying photosphere, effectively measuring the spatial flux tube density. The intensity enhancement is presumably due to magnetism-related heating, but the precise mechanism has not been identified (Ulmschneider xxx).

The network pattern is dynamic on timescales of hours. Its evolution is governed by the continuous appearance of new magnetic field within supergranulation cells, the subsequent field migration to the cell boundaries imposed by the supergranular flows, further migration along the supergranular boundaries, and eventual field disappearance through dispersion, reconnection, subduction or rise into the upper atmosphere.

Composition

The magnetic flux tubes that make up the magnetic network are individually seen in the highest-resolution pictures of the photosphere. In particular, they are most sharply imaged in the Fraunhofer G-band around $\lambda = 430.5$ nm. This band is made up of molecular CH lines that brighten considerably, in not-understood fashion, at locations where strong-field flux tubes in intergranular lanes are dynamically interacting with the surrounding convective flows. The fluxtubes show up

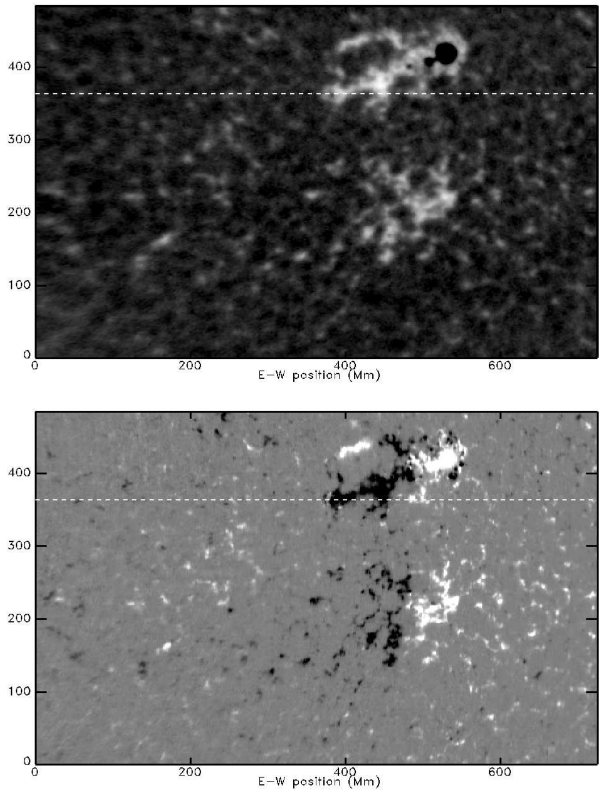

Figure 1: Chromospheric network. Upper panel: solar image in the Ca II K line taken December 21, 1994 at the South Pole. Dashed: solar equator. Upper bright patch: small active region with sunspot (blanked out). Lower bright patch: active network. Remainder of the field: quiet network. Lower panel: corresponding photospheric magnetogram taken at the same time at Kitt Peak. Black and white: longitudinal magnetic field strength in both polarities.

on G-band filtergrams as tiny bright points with 0.1–0.2 arcsec diameter — just at the diffraction limit of the best telescopes (Muller xxx).

The patches in the overlying chromosphere appear more diffuse, with grainy structure at 1–2 arcsec scale. In ground-based observations they are best seen when imaging the solar chromosphere in the cores of the Ca II H & K. These are the strongest spectral lines of the optically accessible part of the spectrum because calcium is an abundant element and most calcium particles reside in the singly-ionized ground state throughout the photosphere and low chromosphere. In addition, the network patches are well visible in the ultraviolet lines from the lower ionization stages of abundant elements such as C I and C II in the mid-ultraviolet. It remains visible in ultraviolet lines from higher ionization stages up to formation temperature $\approx 10^5$ K. It is also evident in Lyman α at $\lambda = 121.5$ nm (the strongest line in the solar spectrum).

More complex morphology is seen in Hα than in Ca II K because Hα has additional contributions from much higher layers, due to its high excitation energy. Only at high temperature and relatively high density does it become sufficiently opaque. When observed at Hα line center the network has dark extensions called mottles or, when they are longer than a few arcsec, fibrils. These extend into spicules when seen at the limb (Beckers xxx). Such filamentary structures undoubtedly portray magnetic field topology and they may represent the lower parts of coronal loops (Durrant, xxx), but their behavior is very dynamical and clearly more complex than static loop models would predict. In fact, static models of flux tube expansion with height (Roberts, xxx) predict that at much lower levels the magnetic field should already funnel out to nearly homogeneous space filling (canopies, Steiner xxx). The existence of Hα mottles and fibrils higher up indicates a more dynamic structuring. Thus, the network undoubtedly consists of strong-field vertical flux tubes at the photospheric level, but portrays dynamical field structuring higher up of which the topology and nature are not yet clear.

The spatial coincidence with the magnetic network in the photosphere can be used to deternine the magnetic polarity of the chromospheric network. It tends to be mixed-polarity over large areas in the quiet sun and to become unipolar near active regions. Large unipolar areas also occur near the solar poles.

Topology and pattern evolution

The cellular appearance of the chromospheric network is incomplete, in contrast to the supergranulation cell boundaries observed on photospheric Dopplergrams. On low-resolution Ca II K spectroheliograms the cells are easier outlined than on high-resolution Ca II K filtergrams, illustrating that the supergranulation flows do not produce field-filling of the cell boundaries everywhere. In addition, there are mobile, small patches of field concentration within the supergranulation cells that haven't yet made it to a cell boundary and so upset the apparent cell patterning. It is likely that many of these mobile patches have recently emerged from below the surface.

The cell sizes of the chromospheric network are larger (32 Mm diameter) when determined with classical autocorrelation methods than when topological methods are used that identify cells from gradient diagnostics (13–18 Mm diameter). There seems to be no direct relation between cell size and magnetic content, although in non-quiet plage areas the field-free cells seem to be much smaller. The spatial cell characteristics are dominated by the spatial density of the upflow centers, as is also the case for the smaller-scale granulation (Brandt, xxx). Indeed, both granulation and supergranulation appear to form as bubbles starting from a “seed” location, i.e., a center of outflow, and that both are surface filling.

Magnetic patches originally emerge in bipolar ephemeral regions inside supergranular cells, and are subsequently transported to the supergranulation cell boundaries, where they stay confined. The motion of the magnetic concentrations can be described by a random walk in response to the continually evolving convective motions. On the granulation scale the granular buffeting makes magnetic concentrations move in a random walk with typical step lengths equal to a granular radius ($R \simeq 0.5$ Mm) and time steps equal to a granular lifetime ($T \simeq 10$ min). The flow patterns across supergranulation cells survive longer than the individual small-scale granular flows so that the patches are eventually collected in the supergranular boundaries by the supergranular outflows. They subsequently move along these boundaries and so outline the supergranular boundaries. This can be observed both for the chromospheric network on Ca II K filtergrams and high-resolution ultraviolet images, and on photospheric magnetograms.

Along the supergranular boundaries, the magnetic field appears concentrated in patches with an average magnetic flux content of 2.5×10^{18} Mx, varying from well below 10^{18} Mx to more than 15×10^{18} Mx per patch and with an exponential dropoff in frequency of occurrence. The observed Ca II K excess brightness $I_{\rm K}$ above the non-magnetic background (“basal flux”) increases with the apparent magnetic flux density ϕ in the underlying photosphere according to the power law $I_{\rm K} \propto |\phi|^{0.65}$. Note that the apparent flux density if often confused with intrinsic solar magnetic field strength; it is primarily a measure of the spatial density of unresolved fluxtubes with intrinsic field strength $|\vec{B}| \approx 1400$ Gauss over the angular resolution element of the telescope.

On the supergranulation scale the cell pattern evolution causes another random walk with typical step lengths equal to a supergranular cell radius ($R \simeq 6 - 9$ Mm) and typical time steps equal to the characteristic supergranular lifetime ($T \simeq 24$ hrs).

While diffusing along supergranular boundaries, the flux patches may interact with one another. When field concentrations of opposite polarity meet, they may cancel against each other, i.e., vanish from sight. This may be due to actual field reconnection, but may also indicate that magnetic fields move upwards or downwards through the observed layer, in the form of small vertical loops with their apex pointed downward or upward, respectively. When patches of the same polarity meet flux merging may be observed. The reverse process, fragmentation, is also seen.

The overall exponential flux distribution function can be described by a "magnetochemistry" model that describes the emergence of new concentrations (a source function), fragmentation into pieces and disapperance through cancellation or merging. Taking the frequencies of these processes into account, the maximum lifetime of an individual field concentration is estimated to be no more than about 40 hrs. Thus, the fine structure of the quiet network cannot be recognized after a longer time span.

Dynamical properties

The precise co-spatiality between the chromospheric network and the photospheric magnetic field and the power-law relation between network brightness and apparent flux density (primarily measuring spatial flux tube density) strongly suggest that a magnetically domimated heating mechanism operates in or along the kiloGauss flux tubes that make up the network (Ulmschneider xxx). However, many attempts have failed to find wave modes that would betray kinetic energy transfer from the photosphere where the flux tubes are buffeted by the granular flows up to the chromospheric heights where wave dissipation might contribute the heating that is required to explain the observed brightness. So far, all network oscillation studies have only identified rather slow periodicities, 5 min or longer. This result is in stark contrast with the roughly 4 to 2 min acoustic waves that are ubiquitously present in the internetwork regions (Carlsson, xxx). It is not even clear wether the observed slow modulations describe wave modes (such as breaking internal gravity waves) or just random motions enforced by the foot-point swaying. Thus, the actual mechanism through which the network patches are bright, while undoubtedly due to dynamical flux tube physics, is yet to be identified.

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