EPSC Abstracts
Vol. 6, EPSC-DPS2011-14, 2011
EPSC-DPS Joint Meeting 2011

Manifestations of deep convection in the solar mm radio emission

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Abstract

The structure and size of super-giant complexes activity are studied in solar radio images of 1996-2011 from the archive of the Observatory Metsahovi. It is argued that large-scale (20° to 25°) bright spots surrounded by the dark halo (40° to 50°) can be manifestations of giant convection cells.

1. Introduction

It is known that deep (up to ~10^4 km) supergranulation of the Sun is observable in the form of the chromospheric network. In this connection the question arises: could signs of more deep (~10^5 km) structures of the solar convective zone (CZ) be detected in the chromosphere? It was found from the analysis of Fe I line intensity that the longitudinal dimensions and the time scale of variability of supergiant complexes of solar surface activity are related with the Kolmogorov's index of turbulence [1]. This is a 'fingerprint' of deep convection, because there are no such large-scale (from 2×10^5 to 4×10^6 km) turbulent eddies in the solar photosphere. The goal of this work is the search for manifestations of giant convection cells in the chromosphere activity pattern.

2. The expected phenomenology

Numerical modeling shows that downflows and upflows of the solar substance control the rising velocity of particular regions of the magnetic flux tube and could in principle favor the emergence of flux through Ω-loop structures [3]. Horizontal transport of magnetic elements on the solar surface is not the dominant factor in the formation of large-scale (>2×10^5 km) activity pattern [1]. Therefore, the region of enhanced magnetic field is formed in the center of a convection cell, but no on its boundary as in the case of supergranulation. As the locally enhanced magnetic field in the photoshere correlates with the chromosphere brightening, we expect the formation of the bright region in the chromosphere above the upward flow of matter in the center of the giant convection cell. This bright core can be surrounded by a dark halo which is formed above the downward flows of the solar substance (Fig. 1). The giant convection cell efficiently modulates the emersion of magnetic tubes if the convection cell covers the most part of the CZ depth. We use the typical diameter (D) of the laminar convection cell as the minimal size of a trans-CZ cell: D/R_{sun}~$2^{3/2}$ $H/R_{sun} = 0.79$ rad = 45°, where H=0.3R_{sun} is the CZ depth, and R_{sun} is the Sun radius (derived in [2]). Although the size of such convective cells could be decreased in the turbulent CZ, the equatorial 45°-cells survived in the numerical model of the turbulent solar convection [3]. Since the number of cells in the solar disk is $[1—\cos(0.5D/R_{sun})]^{-1}\approx4R_{sun}^2/D^2$, the minimal size ($D/R_{sun}$ ~ 45°) of chromospheric disturbance from a trans-CZ cell is most probable for detection. Since the non-radiative heating is most effective at the upper chromosphere, the radio emission at a wavelength of ~1 cm seems to be most interesting.

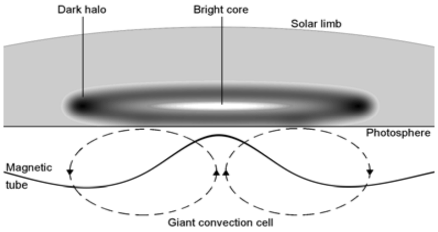

Figure 1: Scheme of the interaction of a giant convection cell and the chromosphere.

3. The chromosphere pattern

We use the 244 images of the solar disk obtained at the Metsähovi Observatory at 37 GHz (8 mm) since May 1996 to March 2011. To visualize the average pattern around an activity complex, we calculated the correlation coefficient (r) between the brightness of the solar disc at 37 GHz in the reference point, where the brightness is more than 105% of quiet Sun, and

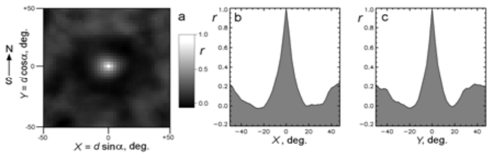

Figure 2: The correlation pattern around bright spots in 244 solar images 1996-2011 at 37 GHz (a) and its cross sections (b,c) show the typical dark halo.

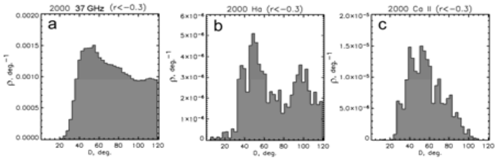

Figure 3: The autocorrelation histograms reveal the most probable halo diameters (D) about predicted 45^{o} (ρ is the density of probability of the D estimates).

the probe point displaced at distance d along solar surface with position angle α. As a result, Figure 2 shows the clear dark halo around the central maximum of correlation. The halo diameter (41±3 heliocentric degrees) agrees with the prediction.

Another method is the calculation of autocorrelation function of the longitudinal brightness variations at the fixed latitudes in the solar disc. The lag of the autocorrelation minimum ($\Delta\lambda_{\mathrm{min}}$) could be used to estimate the longitudinal dimension of the halo: $D=2\,\Delta\lambda_{\mathrm{min}}$. We estimate D only with such minima, where the minimal correlation coefficient is below the accepted threshold (typically $r<-0.3$). Figure 3 shows the cumulative histograms of D estimates calculated with the 37 GHz (a), H_{α} (b) and Ca II (c) images of the Sun obtained in 2000 at the Metsähovi Observatory and the Big Bear Solar Observatory. The dominating peaks at D=40^{o} to 55^{o} confirm the prediction as well as Fig. 2. The core diameter can be estimated using the position of the left (minimal D) border of autocorrelation minima in Fig. 3. From the total data histograms (1996-2011) we find that the core has a typical diameter about 20^{o}.

The independent estimate of the diameter of a typical bright core is obtained using the USAF/NOAA Sunspot Data on 39,392 newborn sunspot groups (SGs) which appeared in the solar disk during 130 years since 1874 to 2004. Figure 4 shows the distribution of the coordinate differences in longitude (δλ) and latitude (δφ) between the positions any two SGs. The half-dimension of the central cluster (25^{o}) corresponds to the diameter of a typical core. The half-dimension of the central hole (≈3 deg. or 37000 km) corresponds to the typical supergranular size.

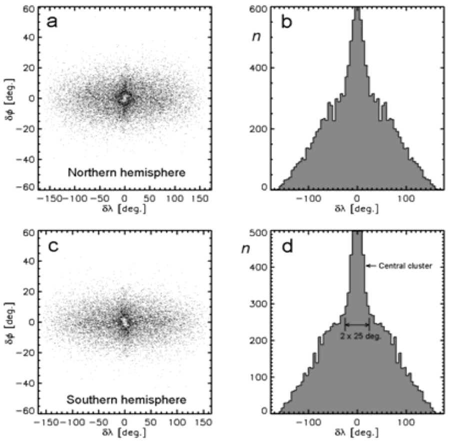

Figure 4: The relative positions of newborn 39392 active regions on the Sun during 1874-2004: the 2D-patterns (a,c) and corresponding longitudinal histograms for the northern (b) and southern (d) solar hemispheres. The symbol n is a number of SG pairs in one bin of the histograms.

6. Summary and Conclusions

We find the predicted diameter of the core-halo pattern in the solar chromosphere (H_{α}, Ca II) and the transition region (37 GHz). This result and the supergranula effect are the new arguments for the important role of the deep convection in the surface solar activity.

References

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