HIGH RESOLUTION SPECTROSCOPY OF THE DISK CHROMOSPHERE

III: *Evidence for the Propagation and Dissipation of Mechanical Energy in the Chromosphere*

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Abstract. We describe time-series observations of small-scale Ca II emission features located outside the network in the quiet chromosphere. Simultaneous spectra in K and λ8542 show unambiguously that the evolutionary behaviour of the K-line profile is due to an outwardly propagating velocity pulse. Assuming that this pulse is a progressive acoustic wave, as suggested by the inferred flow parameters, we show that the wave loses mechanical energy in traversing the chromosphere. This implies that the bright Ca II features (K grains) are the manifestation of local heating in the chromosphere, possibly by shock waves.

DISCUSSION

At first the discussion was concerned with clarification of the details of the evolution of these features and whether they occur in the interior of supergranule cells or in the network or both.

Grossmann-Doerth: I would like to know how many examples of this kind of evolving feature you have found.

Cram: This one was selected because it is a very clear example. Liu (1972) observed the evolution of many K_{2v} 'points' which were not followed by K_{2r} emission, and there are features on these spectra which do the same. I think this implies the wave motion in many of these points stops before the wave reaches the K_3 layers, and this is also a possible explanation of why the spatially-averaged K-line profile exhibits stronger K_{2v} emission than K_{2r}.

Wilson: I would just like to add that, although this is by far the best example I have seen, I have seen several different sequences of this sort of evolution in observations at Kitt Peak and with both the Big Dome and Tower Telescope at Sac Peak.

Athay: I would like to comment that there are many different examples. Liu has observed the K line out to about 7 Å in the wings, and he has followed the brightening from the wings right into the K_2 regions, progressively in time. So, that's a good indication that they're moving upwards.

Zwaan: I am interested in whether these features usually occur in the interior of a supergranular cell. Have the other observations been made together with filtergrams and slit-jaw pictures?

Wilson: In one case we had slit-jaw pictures and it was clear that the features were interior to the supergranule cell. In the others we didn't have pictures, but we had the impression by studying the spectra and noting where the really bright emission features occurred that the evolving features were indeed interior to the supergranule cells. You don't really see the same sort of evolution occurring in the emission in the network.

Beckers: These are the features which I called 'grains' about 10 yr ago, and which were also pointed out by Dr Rosch this morning on the drawing made by Dr Michard. The features were called 'dots' and on the drawing they were shown in the supergranule cells – in quiet regions. How do these features show in Hα?

Wilson: I don't know but that might be very interesting to find out.

Tanaka: I will show on Thursday that the grains in Hα show a very clear oscillation with 180-s period. Sou-Yang Liu has found similar oscillations in the K_{2v} cell points.

R. Grant Athay (ed.), Chromospheric Fine Structure, 51–53. *All Rights Reserved.*

Cram: Liu did not claim that every point was oscillating. He exhibited one grain that had something like 9 oscillations but other grains did not oscillate at all.

Tanaka: I think Liu claims most of them – 90% – oscillate.

Cram: That's not the impression I got from his thesis.

Schmidt: Do your results imply that the same physical processes are absent in the network, or can't they be seen?

Cram: I would say that the evolutionary behaviour of the network component is quite different from the K grains inside the cells. I think the K grains are shock waves which heat the chromosphere, but I don't think that the same interpretation applies in the network.

Schmidt: The spicules of course are something different, but would you be able to see the same processes in the network if they are there by this method, or are there other features which might prevent detection there?

Cram: One sees time-dependent behaviour in the network region, but I have certainly never seen singly-peaked features in these regions on the disk.

Wilson: I think the point is that, although there are time variations in the network structures, the predominant features in the network appear to be doubly peaked when they are resolved. There are so many extraordinary things going on that it's hard to be absolutely sure. The results of statistical counts which I think some people are doing should be very interesting.

Meyer: What is the spatial extent of these features?

Cram: They are about 1000–2000 km in diameter and they are separated by something like 6000 km.

The discussion then turned to the types of models required to interpret these observations and in particular to the role of velocity fields in these models.

Pasachoff: I'm very interested by your calculations. How large are the velocities you need for the evolution you've been discussing?

Cram: In the case where there is upward motion only in the K_3 layer, so that the K_{2v} peak is removed, the velocity field is about 6 or 8 km s^{-1}. That's smaller than the wavelength displacement from line center to K_2, but the absorption is still enough to obscure the violet peak.

Athay: When you extract the velocity from the asymmetric profile you have to know the thickness of the layer that's moving. What is it in this case?

Cram: The upwardly moving K_3 slab is about 300 km thick.

Athay: Isn't that ambiguous? If you increase the slab thickness you can get the same effects with a smaller velocity.

Cram: Not when the slab is so thick that the K_2 layer moves as well, because then the whole line core shifts.

At this point Thomas raised the important question of time-dependence in the radiative transfer theory used in the model calculations.

Thomas: This is a question to both Cram and Cannon. You have both made calculations of time-dependent behaviour, but have you correctly included time-dependent distributions of atmospheric thermodynamic parameters?

Cram: In order to understand the rather complex effects of velocity fields on the K line, I have performed model calculations which postulate ad hoc source functions and velocity fields. I am now combining my non-LTE Ca II models with Leibacher's solution of the time-dependent continuum hydrodynamic equations in order to obtain self-consistent solutions.

Cannon: My main concern has been the development of a method of solution to the aerodynamic equation of radiative transfer, i.e. the macroscopic equations specifying conservation of mass, energy and linear momentum coupled to the non-LTE equation of radiative transfer. One of the problems studied, however, involved the propagation of some initial periodic disturbances through a medium of finite optical thickness with the subsequent development of this disturbance into a shock. It was found that once every period of the disturbance, the red emission peak quickly doubled in intensity and then equally quickly disappeared over a time of order 1/20th of the cycle. This was *not* a result of mechanical energy dissipation. Although the atmosphere chosen was somewhat pathological in structure and not meant to relate to any specific problem, the results strongly suggest that the time development of the Ca II K peaks mentioned by Cram may possibly be explained solely by radiative transfer effects.

Thomas: I made this point because if you look at a lot of the earlier work on cepheid spectra, each phase mimics a supergiant with a different effective gravity, so that you apparently get instantaneous adjustment all the way through. I think it's very interesting to do the self-consistent time-dependent calculations. Do you include the correct time-dependence in the transfer equation?

Cram: Cannon and I have shown that it is important to take into account the fact that a moving atom can excite and de-excite in different physical conditions. The expression for the line source function includes the Lagrangian derivative of population ratios, in the form $S_L = (1-\varepsilon)\,\bar{J} + \varepsilon B + \alpha(\mathrm{d}S/\mathrm{d}t)$.

Delache: To be more specific on this point, you have not taken into account the $(1/c)\,(\partial I/\partial t)$ term in the radiation transfer equation, and I think that that can be important in some cases where a photon scatters many times before destruction.

Cram: Do you really believe that the relative difference between the velocity of light and of the material could be important?

Delache: I think that the time-dependent term has to be retained but this I cannot explain briefly (see paper by Delache and Fróeschle (*Astron. Astrophys.* **16** (1972), 356).

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