THREE-DIMENSIONAL DOPPLER IMAGING OF THE ACTIVE ATMOSPHERE OF HU VIRGO

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ABSTRACT Rotational modulation of several photospheric absorption lines, chromospheric emission lines (Ca II K and Hα), and the continuum brightness of the RS CVn binary HU Virgo ($P_{\text{orb}} = 10.4$ days) is used to obtain the spatial structure at different heights of its active atmosphere.

THE NEED FOR SPATIAL INFORMATION

In the recent years, increasing attention has been given to the question of spatial relation of photospheric, chromospheric, and coronal activity tracers on late-type stars. But only few results from simultaneous and multi-wavelength studies exist in the literature yet, even for disk-integrated measurements. Moreover, the emerging picture is still rather confusing and demonstrates the rich variety of magnetic surface phenomena and physical processes in these stars. A coherent picture of the relations between spatial structure in stellar chromospheres, transition regions, and coronae and, e.g., starspots still remains to be determined.

One of the current goals in Doppler imaging is thus to produce a “3-D picture” of an inhomogeneous stellar atmosphere from a combination of several Doppler images taken at different heights (or excitation temperatures) throughout a stellar atmosphere. This requires simultaneous ground-based and space-based observations at various wavelengths and the use of adequate spectral activity indicators. As a first step toward this goal I am currently applying the Doppler-imaging technique to several photospheric absorption lines of different strength and excitation potential as well as (optical) chromospheric emission lines like Ca II H and K and Hα.

A FIRST 3-D DOPPLER MAP OF HU VIRGO = HD 106225

From Doppler imaging of four photospheric lines we obtained the surface temperature distribution at two observing epochs in April 1991 (Strassmeier 1993). Spot temperatures were determined from three different proxy indicators and yield values between 1000-1500 K. Simultaneous Ca II H and K and Hα line-profile variations provide some clues on the spatial relation between the temperature distribution of the photosphere and the location of active regions in the chromosphere and I present, for the first time, a crude three-dimensional picture
FIGURE I  Pseudo three-dimensional temperature and intensity distribution in the lower atmosphere of HU Virgo. The photospheric map is shown at the bottom. The chromosphere from Ca II K and Hα on top of it. The arrows indicate local velocity fields associated with the plages. Data were obtained with the KPNO coudé feed telescope at a resolution of 40,000 and S/N of ≈150.
of a stellar atmosphere (Fig. I). We see a big, cool polar spot on HD 106225 and two hot plages $180^\circ$ apart from H$\alpha$ and Ca II line-profile analysis (a stronger one at medium latitudes and a weaker one presumably at lower latitudes). The chromospheric plages seem to be spatially related to two large appendages of the polar spot. A transient absorption feature in the residual Ca II H and K profiles likely arises from absorbing gas located directly above the stronger plage and shows an outward-pointed velocity of $12 \text{ km s}^{-1}$. Excess broadening of the blue H$\alpha$-emission wing when the strong plage is at the central meridian and similar broadening of the red H$\alpha$ wing when the weaker plage is at the central meridian suggests an outflow correlated with the stronger plage and an inflow correlated with the weaker plage of approximately equal velocities of $250 \text{ km s}^{-1}$. We tentatively suggest a flow in a coronal (magnetic) loop connecting the two plages possibly across the visible rotation pole with an extent of order one stellar radius. Additionally, we found a steady, inward-pointed, and global velocity field ("antiwind") of $\approx 100 \text{ km s}^{-1}$ at some H$\alpha$ absorbing layer and suggest it arises from a cool corona.

Simultaneous and contemporaneous $UBV$ photometry is used to trace the evolution of spotted regions in 1991. We applied a time-series spot modeling code and found a fairly stable spot configuration with two major spots. Only small and sporadic spot-area changes were present in 1991, which likely are unrelated to a long-term cycle. The total spotted area varied from 9.5% to 11.3% within six months. The spot migration rates are consistent with differential surface rotation 10 times less extreme than on the Sun and of opposite sign, i.e. on HD 106225 the polar regions rotate faster than the equatorial regions.

THE NEXT STEP: ADDING THE X-RAY CORONA
Models of the quiescent solar corona are based on magnetic loops (Rosner et al. 1978). Solar observations confirm this picture and also detect systematic plasma flows. As we have seen from ground-based observations it is very likely that the coronal emission from HU Virgo is also confined to localized regions with high plasma flow velocities (dubbed coronal loops in analogy to solar phenomena). Thus, an X-ray signal will be modulated when these loops rotate in and out of sight. This will be searched for in an upcoming ROSAT observing run. The goal of the ground-based observations is to provide spatial maps of the photosphere and the lower chromosphere of HU Virgo and to combine them with the X-ray observations such that an approximate 3-D picture of the entire stellar atmosphere, from the photosphere to the corona, can be constructed. This might lead to a better understanding of the physics in these regions of the stellar atmosphere, especially in view of the still much debated coronal heating mechanism.

ACKNOWLEDGMENTS
This work was supported by the Austrian FWF grant P8942 and by the Austrian Academy of Sciences with grant OWF-40.

REFERENCES