THE DICHOTOMY BETWEEN CO ABSORPTIONS AND CA II EMISSIONS IN THE SUN AND STARS: AN INDIRECT DIAGNOSTIC FOR GAS DISTURBED BY MAGNETIC FIELDS?[1]

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ABSTRACT. Spectra of the 4.7 μm bands of carbon monoxide in absorption, and spectra of the cores of the 0.4 μm resonance lines of ionized calcium in emission, might be used to diagnose the presence of atmospheric inhomogeneities, caused by the action of surface magnetic fields, on stars as diverse as the Sun and the red giant Arcturus.

1. EVIDENCE FOR INHOMOGENEITIES IN THE SOLAR CHROMOSPHERE

Several years ago, L. Testerman and I used the newly commissioned fourier transform spectrometer (FTS) on the McMath telescope at Kitt Peak to acquire a series of high-quality recordings of the 4.7 μm fundamental ($\Delta V = 1$) vibration-rotation bands of carbon monoxide at the center of the quiet solar disk, and at a number of positions near the extreme limb. The CO fundamental bands become opaque in the layers of the solar atmosphere immediately above the location of the temperature minimum region of the best-available single-component models (e.g., Avrett 1985). Further, the statistical equilibrium of molecular bands is thought to be quite close to LTE: Thus, they should be a reliable diagnostic of physical conditions in the layers in which they become optically thick. Much to our surprise, we found that the cores of the strongest of the CO transitions did not exhibit limb-brightening, but in fact continued to darken towards the limb (Ayres and Testerman 1981). The corresponding brightness temperatures of the line cores -- less than 4000 K at the extreme limb -- were

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considerably cooler than the minimum temperature of the best-available models of the T_{min} region. Figure 1 illustrates FTS spectra of the CO bands at disk center and near the north limb ($\mu = 0.2$).

One interpretation of the limb-darkening of the CO bands is that the molecular absorptions form in a cool component of the atmosphere which is physically distinct from the regions in which chromospheric emission cores of lines like Ca II H and K form. If so, the cool zones must be quite pervasive, while the hot regions must occupy only a small fraction of the surface area (Ayres and Testerman 1981). Indeed, I suggested in a companion paper (Ayres 1981) that the cool zones were large-scale areas in which the surface temperature was strongly depressed by CO radiative cooling, while the hotter zones were small-scale regions, perhaps "magnetic flux tubes" (Zwaan 1978), in which mechanical heating dominates the energy balance.

I, and my collaborators, subsequently examined the CO fundamental bands in areas of the solar disk strongly affected by magnetic activity (Ayres, Testerman, and Brault 1986). Although we found that the CO fundamental bands do weaken in active regions, the behavior of the molecular absorptions still is quite incompatible with prototype one-dimensional thermal profiles of such regions based on the Ca II emission cores (cf., Shine and Linsky 1974). Figure 2 compares the thermal profiles we used in our simulations: The models VALC' and VALP are one-dimensional representations of the stratification of spatially homogeneous quiet and active regions, respectively; FLUXT and COOLC are the hot and cool components, respectively, of the inhomogeneous scenario, combined with different spatial covering fractions in quiet and active areas. Figure 3 depicts the resulting synthetic spectra of representative transitions of the CO bands: The comparatively cool cores of the CO lines of the inhomogeneous scenario, in both quiet and active regions, contrast sharply with the shallow absorptions and limb emission cores predicted by the homogeneous scenario.

Thus, to the extent that the hot regions are manifestations of magnetic "activity" and the the cool zones represent the undisturbed state of the gas, simultaneous, cospatial measurements of the 4.7 μm absorption bands of CO and the 0.4 μ emission cores of the H and K lines of Ca^{+} can be used to diagnose, indirectly, the presence and scale of such activity on the solar surface.

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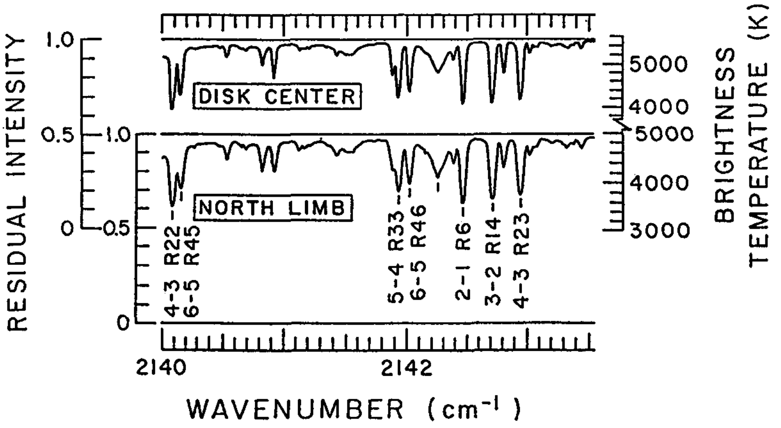

Figure 1. FTS spectra of solar carbon monoxide

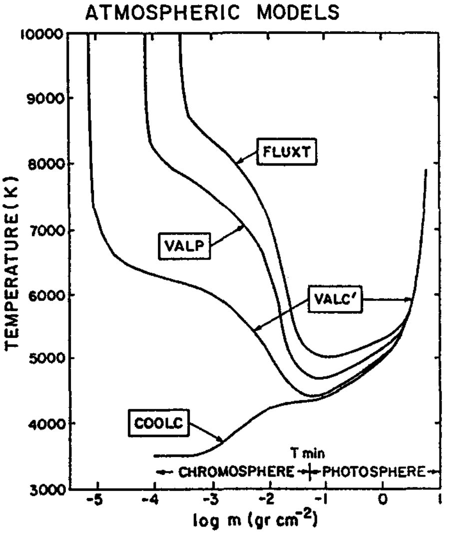

Figure 2. Schematic atmospheric models

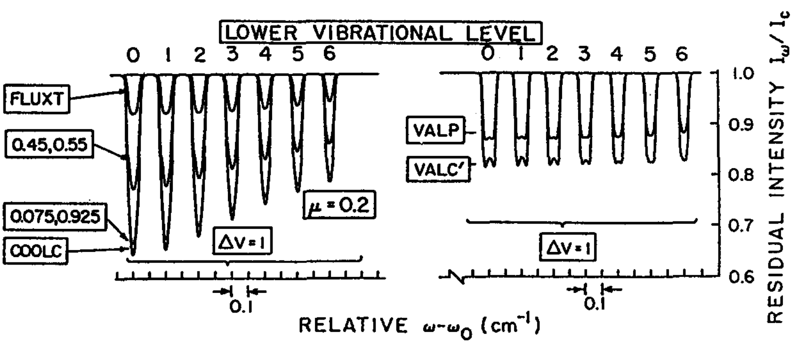

Figure 3. Synthesized CO line profiles (R30 transitions)

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2. EVIDENCE FOR INHOMOGENEITIES IN STELLAR CHROMOSPHERES

A number of years prior to the observations of CO in the solar spectrum by myself and collaborators, Heasley et al. (1978) reported a similar dichotomy between the absorptions of the fundamental bands of CO in the red giant Arcturus and chromospheric models based on the prominent emission reversals of the Ca II lines (Ayres and Linsky 1975): In particular, the strongest of the CO features exhibited dark cores contrary to the central emissions predicted by the chromospheric model. Here, again, a scenario with (at least) two components is required to simultaneously match the disparate behavior of the complementary thermal diagnostics (Heasley et al. 1978). If the apparent bifurcation of the chromosphere of Arcturus into hot and cool zones has a similar origin to that of the solar case, then joint observations of CO and Ca II again could provide indirect evidence for the existence and scale of surface magnetic activity.

3. DISCUSSION

At present, it is rather tricky to directly detect magnetic fields on late-type stars other than the Sun (see contribution by Marcy, this volume). Thus, it is valuable to have available indirect indicators, particularly for the surface coverage of the magnetically-disturbed areas. I believe that joint observations of the fundamental absorption bands of CO and the chromospheric emission cores of Ca II can provide just such a diagnostic, particularly in the cases like Arcturus where the fields might not be as concentrated as they apparently are among the dwarfs and the coronal (x-ray emitting) giants.

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