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# THE CA II RESONANCE DOUBLET AND H$_\alpha$ FLUXES AS A FUNCTION OF STELLAR RADIUS: INDICATIONS FOR A TRANSITION IN DYNAMO MODES BETWEEN 0.500$R_\odot$ AND 0.330$R_\odot$.

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**Abstract.** We report on the surface fluxes $F_{HK}$ in the Ca II H & K lines and $F_{H\alpha}$ in the H$_\alpha$ line for 752 M dwarfs. Spectral sub-types range from M0.5 to M8.3. We plot the surface fluxes in these lines as a function of stellar radius and find that there is an important decrease between $0.500R_\odot$ and $0.330R_\odot$, i.e. spectral types dM1.2-dM3.4. This decrease is by a factor of 5.6 in $F_{HK}$ for our sub-sample of low activity M dwarfs. Similar patterns are observed for our sub-sample of Me dwarfs, but with a somewhat smaller amplitude of 2.8. These radii correspond from partially convective early M dwarfs to approximately fully convective M dwarfs down to the Transition To Complete Convection (TTCC). We believe that we are observing the spectral signature of the progressive disapearance of the radiative core in M dwarfs, and therefore the progressive transition from an $\alpha - \Omega$ type of dynamo to an $\alpha^2$ or/and $\alpha - \Omega$ type of dynamo.

Keywords: Stars: late-type dwarfs - Stars: Activity - Stars: Dynamo Mechanisms - Stars: Fundamental parameters

## Ca II and $H_\alpha$ measures of the Equivalent Widths (EW) and surface fluxes.

Mullan & Houdebine (2020) investigated the Ca II line fluxes as a function of spectral type. They found an important decrease in surface fluxes between M1.1 and M8.3 for about 600 M dwarfs. However, spectral type is not the most appropriate parameter to diagnose the dynamo mechanisms since they depend on the stellar mass, and there is a scatter of about 5 in mass at a given spectral type. Therefore, we prefer here to invevestigate Ca II and $H_\alpha$ measures of the surface fluxes as a function of stellar radius for a stellar sample of 752 M dwarfs.

The method we used to measure the Ca II and $H_\alpha$ EWs have been described in Houdebine & Stempels (1997). The EWs are only a *relative* measure of the level of magnetic activity: they do not provide absolute measures of activity such as the surface fluxes ($ergs/s/cm2$) or the luminosities ($ergs/s$). We used the models of Allard et al. (2012). in order to transform the EWs into surface fluxes.

We found that most of the M dwarfs in our sample lie signicantly above the basal level, typically by a factor of 10 in $F_{HK}$. Therefore, we believe that most of our measures refer to the amount of non-thermal heating of magnetic origin in our sample of M dwarfs. Hence, the surface fluxes in the Ca II lines and $H_\alpha$ line are a direct measure of the amount of energy deposited by surface magnetic fields below 7000 K and between 7000 K and 8500 K repectively (e.g. Houdebine & Doyle 1994, Houdebine & Stempels 1997).

## The Ca II lines: Low activity sub-sample

In order to plot our data as a function of radius, we choose bins with a width of $0.030R_\odot$. In Figure 1a, the mean value of $F_{HK}$ for *each individual star* in our sample is plotted as a small dot. The mean values of $F_{HK}$ for all stars in each of the 19 domains are plotted as large filled circles along with standard deviations in the mean.

Considering the scatter in the individual measures, which signicantly decreases as the radius decreases, the mean curve is remarkedly smooth. The mean curve is more or less flat between $0.711R_\odot$ and $0.605R_\odot$. Then the mean curve increases from $0.575R_\odot$ to $0.515R_\odot$. For stars with smaller radii, the mean curve shows a monotonic decrease in $F_{HK}$ by a factor of 5.6 as we go from $\sim 0.500R_\odot$ to $\sim 0.330R_\odot$. At even smaller radii, the mean curve levels out between $\sim 0.330R_\odot$ and $\sim 0.100R_\odot$. These radii correspond on average to the spectral types M1.2 and M3.4.

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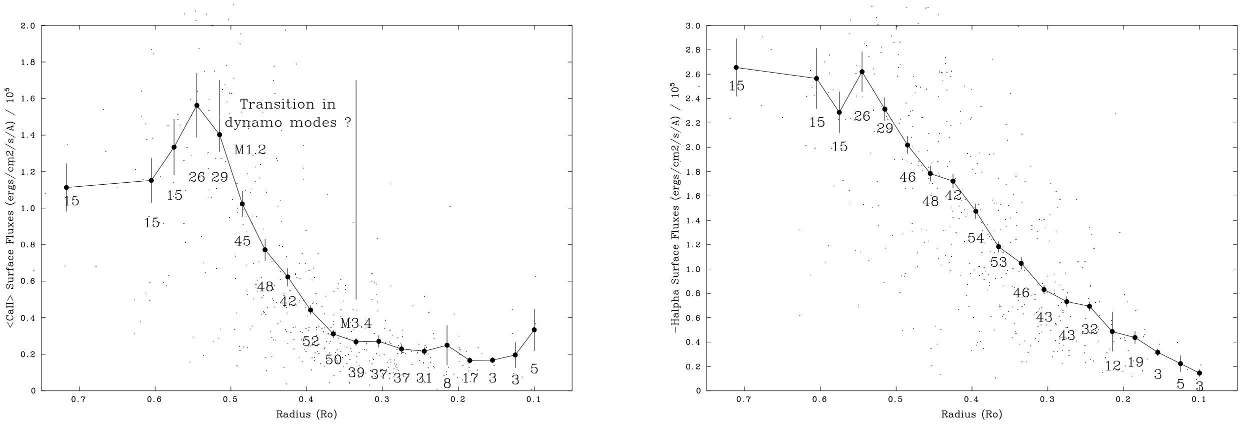

**Fig. 1. Left:** Values of the mean surface fluxes in the Ca II resonance doublet as a function of the mean stellar radius. The plotted uncertainties are a measure of the scatter of the measurements in each radius domain ($3\sigma$). The numbers plotted below each point indicate the number of stars in each sample. The curve first rises, then attains a maximum before it suddenly decreases markedly below $R_* < 0.500 R_\odot$. This decrease continues down to $R_* \sim 0.330 R_\odot$. The amplitude of the fall in surface fluxes is a factor of 5.6. We believe this transition reflects the internal effectiveness of the dynamo mechanisms in M dwarfs, and perheaps a progressive switch from an $\alpha\Omega$ type of dynamo and an $\alpha^2$ or/and $\alpha^2\Omega$ types of dynamo ? **Right:** Values of the surface fluxes in the $H_\alpha$ line as a function of the mean stellar radius. The curve for $H_\alpha$ remains first rather constant down to the radius $\sim 0.500 R_\odot$, then it decreases down to the smallest radii ($R_* < 0.100 R_\odot$). The fall in surface fluxes has an amplitude of about a factor of 29 over a range of $\sim 0.400 R_\odot$ ! This decrease is consistant with a decrease in column mass at about the transition region, i.e., with a decrease in activity levels starting approximately at $R_* \sim 0.500 R_\odot$. Therefore the $H_\alpha$ line and Ca II line curves are more or less consistent in low activity M dwarfs.

### The $H_\alpha$ line: Low activity sub-sample

The $H_\alpha$ line is an ambiguous diagnostic of magnetic activity in M dwarfs. However, it can provide some insights into the column density at the transition region when simultaneous Ca II line observations are available. For very low pressure chromospheres, the $H_\alpha$ line is absent in M dwarfs: there is no significant photospheric contribution (e.g. Houdebine & Stempels 1997). At first, if we consider low pressure chromospheres, the $H_\alpha$ line increases in absorption strength as the pressure increases. It reaches a maximum absorption which depends on the properties of the chromosphere. After reaching a maximum in absorption, it then "fills" in as the collisional control increases in the higher chromosphere. Eventually, it goes into emission, first in M(e) dwarfs (line filled in), and then in active dMe stars it is in emission: e.g. Houdebine & Stempels 1997. *Therefore, the $H_\alpha$ line is not a straightforward diagnostic of magnetic activity and the interpretation of the surface fluxes must be conducted with care.*

In dM stars, $H_\alpha$ is in absorption, and therefore has a negative EW, the plot in Fig. 1b plots -$F_{H\alpha}$ as a function of radius (same description as Fig. 1a). The curve of -$F_{H\alpha}$ in Fig. 1b is reminiscent of the $F_{HK}$ curve in Fig. 1a. The curve from the radius $\sim 0.500 R_\odot$ decreases down to the smallest radii ($R < 0.100 R_\odot$). The decrease has an amplitude of about a factor of 29. This decrease is consistent with a decrease in column mass in the vicinity of the transition region, i.e., with a decrease in activity levels starting approximately at $R \sim 0.500 R_\odot$.

Both the decreases in Ca II and $H_\alpha$ from $\sim 0.500 R_\odot$ to $\sim 0.330 R_\odot$ are consistent with a decrease in the level of magnetic activity between these radii. If one considers that in M1.2 dwarfs the stars possess a relatively large radiative core, which decreases continuously down to the TTCC at about M3.4, one can suggest that the observations point to a decrease in the efficiency of the dynamo mechanisms between these radii. We believe that we are observing the spectral signature of the progressive disapearance of the radiative core in M dwarfs, and therefore the progressive transition from an $\alpha - \Omega$ type of dynamo to an $\alpha^2$ or/and $\alpha - \Omega$ type of dynamo.

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