

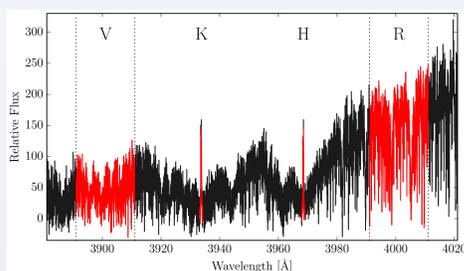


## ABSTRACT

While FGK stars have well-established activity indices such as the Mt. Wilson S-Index and  $R'_{HK}$ , M dwarfs lack such a well-defined index, primarily due to their lack of flux in the visible and near-UV wavelengths. We utilize the HARPS M dwarf sample and a different technique for measuring chromospheric emission lines. This technique normalizes high S/N template spectra to PHOENIX stellar atmosphere models to obtain measurements of chromospheric lines in physical units. We obtain an activity index for M dwarfs using these chromospheric line measurements. Such an index provides typical activity values of M dwarfs which is suitable for direct comparison with activity values of FGK stars. We also look for a correlation between radial velocity jitter and activity. Stars with jitter exceeding typical values for their known activity level could possibly harbor planets. An activity index of M dwarfs, similar to  $R'_{HK}$  in FGK stars, can be a useful tool for distinguishing between stellar activity and planetary signals.

## CONTEXT

- Ca II emission is a tracer of chromospheric activity. **S index** is the standard measurement of Ca II, but includes photospheric flux
- $R'_{HK}$  is the standard metric of chromospheric activity  
It is a transform of S index which removes the photospheric contribution and normalizes to bolometric luminosity – but  $R'_{HK}$  has no calibration in M dwarfs due to their lack of flux in the nearby continuum bands



**Fig 1.** Measuring the S index of an early M dwarf. The spectrum is a HARPS 1D science spectrum of an individual observation. K and H are the bands used to measure the Ca II H & K flux. V and R indicate the “continuum” bands used to normalize the H & K flux. Flux in the V and R bands decreases towards later spectral types.

## METHOD

We obtain a measurement analogous to  $R'_{HK}$  for M dwarfs:  $L_{Ca'} / L_{bol}$ . We utilize high S/N template spectra obtained by co-adding all observations, and PHOENIX synthetic spectra for scaling to absolute flux units.

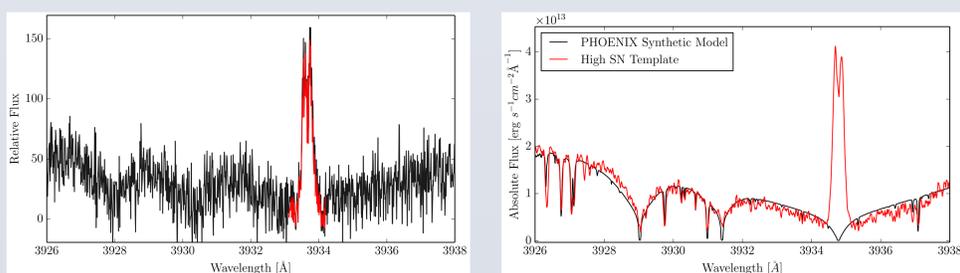
$$\frac{L_{Ca_{HK}}'}{L_{bol}} = \frac{L_{Ca_{HK}} - L_{phot}}{L_{bol}}$$

## MEASURING $L_{Ca'} / L_{bol}$

The sample consists primarily of stars from the HARPS M dwarf sample [1]. Stars with known planets and also additional stars from the Cool Tiny Beats survey were added to the sample for a total of 113 stars.

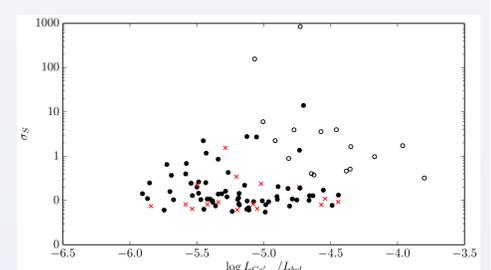
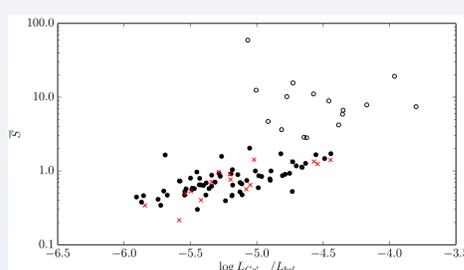
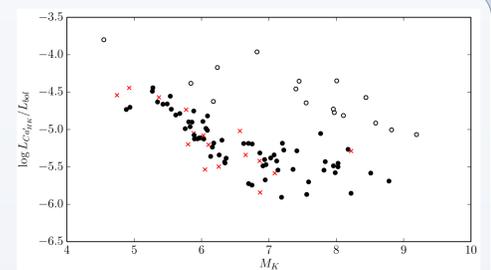
For each star, all spectra are co-added, scaled and de-blazed using the HARPS-TERRA software [2] to create one high S/N, averaged template spectrum. The template spectra are then scaled to physical flux units using least squares fitting to a grid of PHOENIX synthetic spectra [3]. A 1D grid of spectra is created for  $T_{eff}$  between 2300 and 4000 K using metallicities from [4] and  $\log(g)=5.0$ . Then  $T_{eff}$  is found by a least-squares fit to synthetic BVJHK photometry. For stars not listed in [4], the K-metallicity relation from [5] is used. The model spectra are then linearly interpolated to the obtained stellar parameters.

The photospheric flux contribution,  $f_{phot}$ , is given by the PHOENIX model spectrum. The template spectrum,  $f_{Ca}$ , contains both chromospheric and photospheric flux. Subtracting the PHOENIX spectrum from the template spectrum leaves only the chromospheric flux,  $f_{Ca}'$ . This is then divided by total flux of the PHOENIX spectrum,  $f_{bol}$ . Using the identity  $f_{Ca}'/f_{bol} = L_{Ca'}/L_{bol}$  we arrive at the normalized chromospheric  $Ca_{HK}$  luminosity of the star which is analogous to  $R'_{HK}$ . See right side of Figure 2.



**Fig 2.** (Left) The Ca II K line of an early M dwarf. The spectrum is a HARPS 1D science spectrum of an individual observation. Note the extremely low flux in this region, which is characteristic of M dwarfs. (Right) Measuring  $L_{Ca'}/L_{bol}$  of the same M dwarf. The red line is a high S/N template spectrum that consists of 37 observations co-added together. The higher S/N of the co-added template spectrum facilitates more precise measurements than individual observations whose S/N is much lower. The black line is a PHOENIX synthetic spectra of  $T_{eff}=3959$  K,  $[M/H]=-0.74$ , and  $\log(g)=5.0$ . The template spectrum is fitted to the PHOENIX model spectra via least squares fitting. The chromospheric contribution of the Ca line is obtained by subtracting the PHOENIX model (photosphere) from the template spectrum (photosphere+chromosphere).

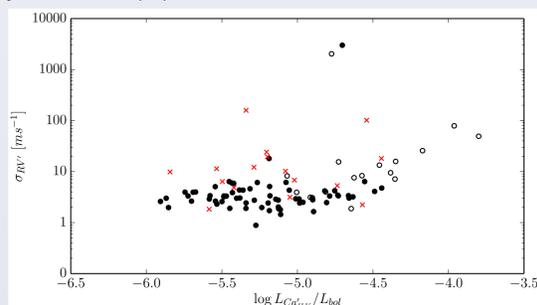
**Fig 3.** Chromospheric Ca II emission normalized to bolometric luminosity vs. absolute K magnitude. Red ‘x’ indicates stars with known planetary systems. Black circles have H $\alpha$  in absorption up to complete filling in. Open circles have H $\alpha$  in emission.



**Fig 4.** (Left) Mean S index vs. normalized chromospheric Ca II emission. Red ‘x’ indicates stars with known planetary systems. Black circles have H $\alpha$  in absorption up to complete filling in. Open circles have H $\alpha$  in emission. S index measurements were performed as described in [6]. Stars with H $\alpha$  in emission exhibit higher mean S index values. (Right) S index scatter vs. normalized chromospheric Ca II emission.

## RV JITTER

When measuring high-precision radial velocities (RV), standard RV errors typically do not account for the total scatter of measurements. This excess noise is defined as RV jitter. Jitter ( $\sigma'$ ) can contain information about stellar activity and planetary companions.



$$\sigma' \equiv \sqrt{\sigma_{tot}^2 - \sigma_{meas}^2}$$

**Fig 4.** RV jitter vs. normalized chromospheric Ca II emission. Red ‘x’ indicates stars with known planetary systems. Black circles have H $\alpha$  in absorption up to complete filling in. Open circles have H $\alpha$  in emission. Discovered planetary systems tend to have high jitter values due to the gravitational tug on the star by their planets. Stars with higher activity levels also can exhibit larger jitter values. High-precision RVs were measured using the HARPS-TERRA software [2].

## SUMMARY

- We have measured Ca II emission in M dwarfs as  $L_{Ca'}/L_{bol}$ , which is on a scale analogous to the standard  $R'_{HK}$  metric
- Stars with H $\alpha$  in emission have higher mean S index and  $L_{Ca'}/L_{bol}$  than stars with H $\alpha$  in absorption or filled in
- We have obtained RV jitter measurements for the stars in the sample, which contains information about stellar activity and planetary companions

## REFERENCES

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- [6] Lovis et al., 2011, arXiv, 1107, 5325

## ACKNOWLEDGEMENTS

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