Studying Radial-velocity variations of active stars in the CARMENES Survey for Exoplanets

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Active regions

Chromospheric activity
- Plages
- Filaments

Cause variation in Ca II H&K and Hα emission lines

Photospheric activity
- Spot
- Faculae

Distort shape of the spectral lines

(Credit: © Alan Friedman)
RV amplitude depends on:

- **Spot-coverage Fraction**
- **$v \sin i$**
- **SpT**
- **Spot-to-photosphere temperature contrast.**

$\Delta T = 200 \text{ K}$
$t_0 = 2800 \text{K}$
$t_1 = 2600 \text{K}$

$\Delta T = 1000 \text{ K}$
$t_0 = 2800 \text{K}$
$t_1 = 1800 \text{K}$

$\nu \sin i = 2 \text{ km s}^{-1}$
$\nu \sin i = 5 \text{ km s}^{-1}$
$\nu \sin i = 10 \text{ km s}^{-1}$
$\nu \sin i = 30 \text{ km s}^{-1}$

Reiners et al. 2010ApJ...710..432R
Sample

53 Active RV-loud Sample*:

- $\text{Std (RV)} > 10 \text{ m/s}$
- $\nu \sin i > 2 \text{ km s}^{-1}$
- Number of RVs > 10
- No known or suspected companions

341 M dwarfs in CARMENES

* Criteria by Tal-Or.
CARMENES wide spectral range

Courtesy: Adrian Kaminski

Chromatic index (CRX)
Spot effect on RVs

![Graph showing the effect of spot on RVs with wavelength (\(\lambda[\text{Å}]\)) on radial velocity (RV [m/s]) for different wavelengths. The graph includes data points of varying colors and error bars.](image-url)
Spot or Planet

Graph 1: RV (m/s) vs. λ(Å)
- Top graph shows data for λ ranging from 6000 to 9000 Å.
- RV values range from -400 to 400 m/s.

Graph 2: RV (m/s) vs. CRX (m/s/Np)
- Prot = 2.78 [d]
- RV values range from -200 to 200 m/s.
- CRX values range from -500 to 500 m/s/Np.

Graph 3: RV (m/s) vs. CRX (m/s/Np)
- Prot = 73.5 [d]
- RV values range from -40 to 40 m/s.
- CRX values range from -40 to 40 m/s/Np.
Sub-sample

**Chromatic**

p-value < 0.005

**Suggestive**

0.005 < p-value < 0.05

**Non-chromatic**

p-value > 0.05
**Distribution over Spectral type**

- **Chromatic**: 34%
- **Suggestive**: 23%
- **Non-chromatic**: 43%

**53 Active RV-loud Sample**
Most of the chromatic targets have $v \sin i < 10 \text{ km/s}$
Chromospheric Level

The image shows a graph with the y-axis labeled as $pEW(H\alpha) [\text{Å}]$ and the x-axis labeled as Spectral Type (M0V, M1V, M2V, M3V, M4V, M5V, M6V, M7V, M8V, M9V). The graph includes points categorized by color:

- Purple: Chromatic
- Green: Suggestive
- Gray: Non-chromatic

The data points are spread across the graph, indicating variations in $pEW(H\alpha)$ at different spectral types.
Temperature Contrast

\[ \Delta T \]  
\[ v \sin i = 48.9 \pm 4.7 \text{ km s}^{-1} \]

\[ v \sin i = 2.6 \pm 0.3 \text{ km s}^{-1} \]
Fraction of active stars increases with SpT

The lack of RV chromaticity for 43% of our sample can be explained by complex spot patterns

No correlation with chromospheric components sensitive to activity

We do not have a direct measure of spot-coverage fraction

CRX-RV slope measures spot-to-photosphere temperature contrast and shows correlation with $v \sin i$ and Effective temperature

Thank you for your attention!