Magnetic activity of red giants: impact of tidal interactions on magnetic fields

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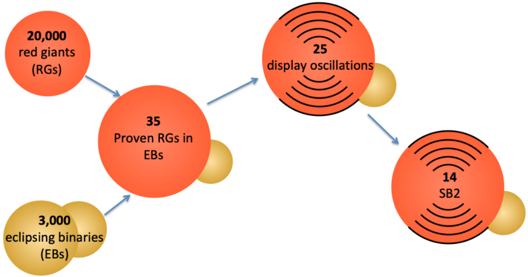
PLATO Stellar Science Conference 2023

June 29, 2023

Introduction: red giants in eclipsing binaries

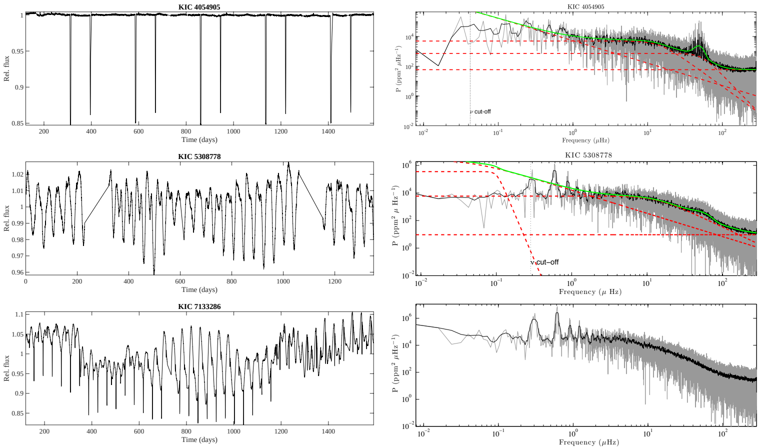
- Originally looking for oscillating red giants in double-lined spectroscopic eclipsing binaries among the *Kepler* data to compare seismic and dynamical masses (e.g., Hekker+2010, Frandsen+2013, Gaulme+2013, 2014, 2016, Beck+2014, Helminiak+2016, Rawls+2016, Themessl+2018, Benbakoura+2021).



- Out of the 35 RGs in EBs, only 25 display oscillations
- Frustrating because the 10 non-oscillating are all SB2s, except for one.

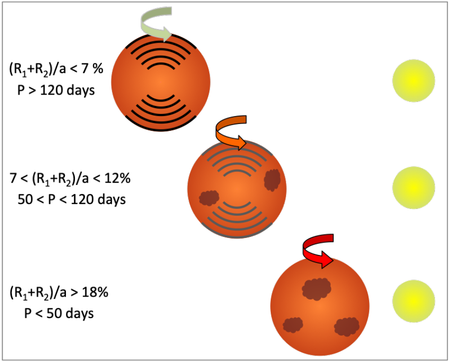
Introduction: red giants in eclipsing binaries

- Not random



Introduction: red giants in eclipsing binaries

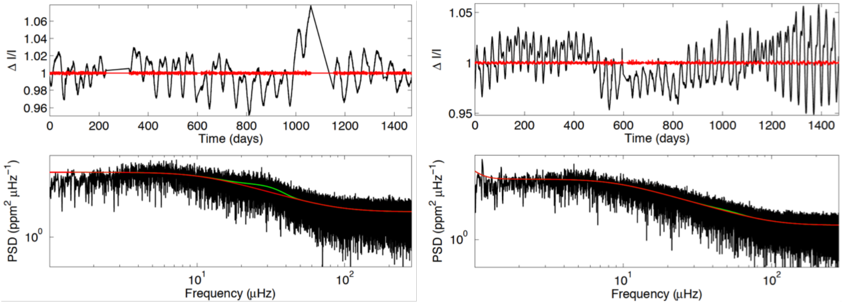
- Partially or totally suppressed oscillations: subsynchronous or synchronous systems.
- Gaulme+2014: tidal forces spin RGs up and trigger dynamo. Magnetic fields cause spots (p-waves dissipation) & inhibit convection (hence oscillation excitation).



- Consistent with scenarii of tidal interaction (e.g. Verbunt & Phinney 1995; Beck+ 2018) and correlation between magnetic activity and oscillation amplitude (e.g., Chaplin+2011)

Magnetically active red giants

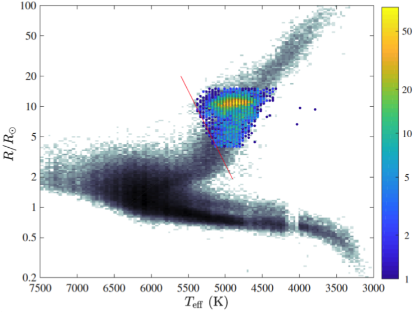
- Sample of red giants with rotational modulation
- Initial intuition: they *must* all be red giants in non-eclipsing close binaries



- Day after though: how true is that statement? How to test it?

Magnetically active red giants

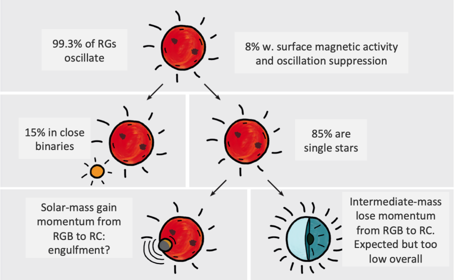
- Self consistent approach based on *Kepler* & spectroscopic data
- Goal: no observational bias, i.e., if there are oscillations we are able to detect them.
- Sample of 4500 “mainstream” RGs: not too big ($\leq 15 R_\odot$), not too small ($\leq 4 R_\odot$), bright enough ($m_K ep < 12.5$), observed long enough (≥ 3 yr).



- Oscillations in 99.3 % of stars, evolutionary status for 3400, 8 % surface modulation

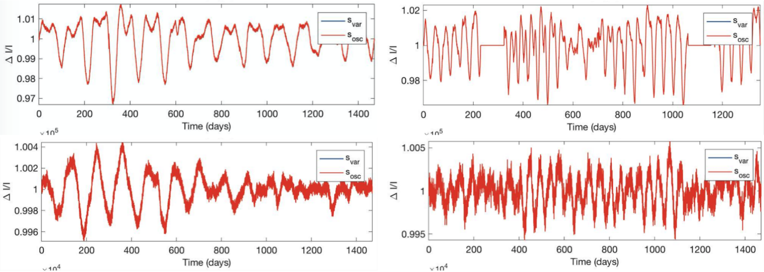
Magnetically active red giants

- Gaulme+2020 identify different populations:
  0. Regular RG oscillators with no magnetic activity ($\sim 92\,\%$ of sample)
  1. Mag. act. non-oscillating RGs in close binaries ($0.3\,\%$ of sample): RS CVn or SSGs
  2. Mag. act. non-oscillating single stars (rare): FK Com type stars.
  3. Mag. act. RGs with partially suppressed oscillation in relatively close binaries
  4. Single solar-mass RGs with partially suppressed oscillations:
     - red-giant branch (RGB) stars ($\lesssim 3\,\%$ of RGBs)
     - red clump (RC) stars ($\sim 12\,\%$ of RCs) consistent with Ceillier+2017
  5. Single intermediate mass RGs with part. supp. osc.:
     - $\sim 50\,\%$ of RGB
     - $\sim 25\,\%$ of RC



Tidal interactions and red-giant surface magnetism

- Today's talk: go back to the photometric variability index as defined by $S_{\rm ph}$ Mathur+2014

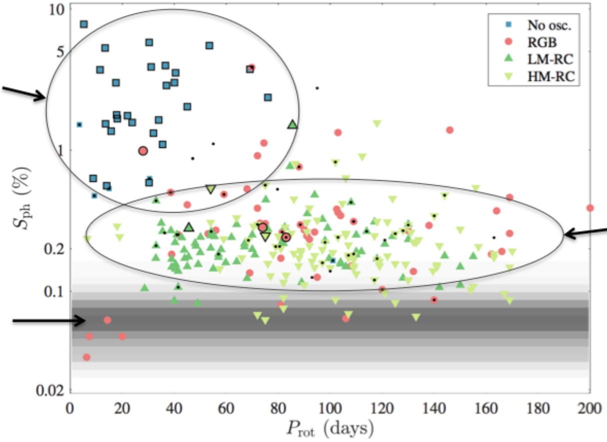


- Detected activity for $S_{\rm ph}$ ranging from 0.1 to 10 %

- Again: not random

RGs in close binaries
S_{ph} = 1-10%

Inactive RGs
S_{ph} = 0.05-0.1%



Active single RGs
S_{ph} = 0.1-1%

Tidal interactions and red-giant surface magnetism

- Why RGs in close binaries display S_{ph} about an order of magnitude larger than single RGs with same rotation rate?

- Two possible explanations:
  1. either tidal locking somehow leads to larger magnetic fields;
  2. either the spot distribution differs between binary and single RGs.

- Impossible to distinguish between 1. and 2. with photometry alone $\rightarrow$ a single large spot (on a binary component) could lead to a larger photometric contrast than a series of smaller spots at different longitudes (of a single star).

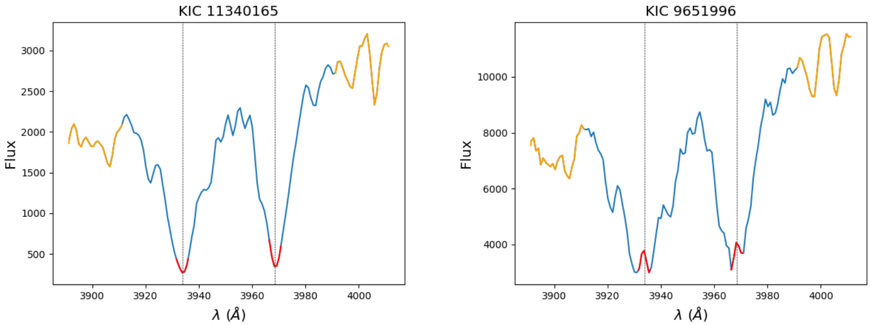
$\rightarrow$ We measured the chromospheric activity of these red giants to check whether we obtain similar results.

Chromospheric activity: the S-index

- S-index → proxy of the strength of surface magnetic fields (Babcock 1961, Schrijver+ 1989):

$$S_{\mathrm{CaII}} = \frac{F_{\mathrm{H}} + F_{\mathrm{K}}}{F_{\mathrm{B}} + F_{\mathrm{R}}} \propto B^{0.6}$$

- LAMOST → millions of stellar spectra (Liu+ 2015), including many *Kepler* targets.
- We could measure the S-index of 3130 RGs.

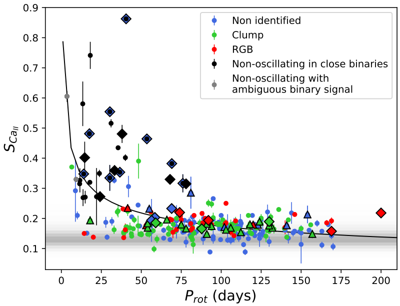


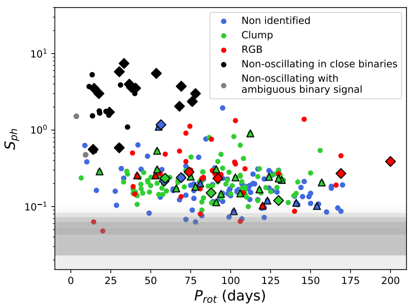
$S_{\mathrm{CaII}} = 0.123$ $S_{\mathrm{CaII}} = 0.353$

Chromospheric activity: close binarity versus fast rotation

- Non-oscillating RGs in close binaries → larger $S_{\rm ph}$ (Gaulme+ 2020) and larger $S_{\rm CaII}$.
- Fast rotation is an insufficient explanation → for similar $P_{\rm rot}$, single RGs majoritarily present lower $S_{\rm CaII}$.

→ S-index proportional to the strength of surface magnetic fields → tidal locking somehow leads to larger magnetic fields, our results are not only due a different spot distribution between binary and single red giants.





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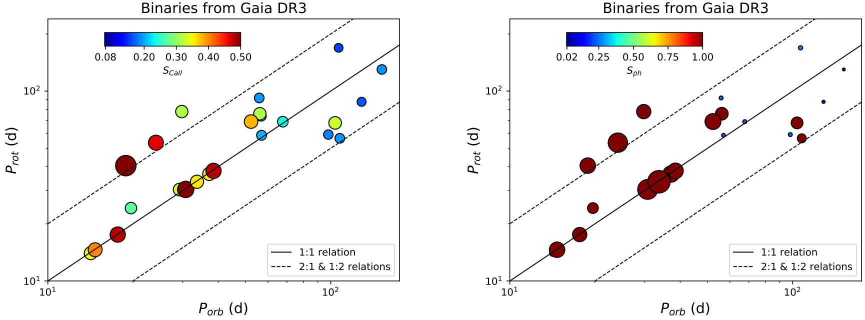
Chromospheric activity: close binarity versus fast rotation

- RGs in close binaries with orbital periods from Gaia DR3.
- RGs in tidally locked systems or systems in spin-orbit resonance $\rightarrow$ larger S_{CaII} compared to RGs in systems that do not have any special tidal configuration.
- Consistent with Benbakoura+ (2021) $\rightarrow$ higher S_{ph} for RGs in binaries that are synchronized or in spin-orbit resonance.

$\rightarrow$ Tidal locking seems to be responsible for the enhanced magnetic (photospheric + chromospheric) activity of these RGs.



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A special binary-induced dynamo?

- Hall (1976) $\rightarrow$ suggested a special binary-induced dynamo for RS CVn stars.
- Morgan & Eggleton (1979) $\rightarrow$ discarded this hypothesis, resulting from a selection bias due to the very low number of known RS CVn stars.
- Cébron & Hollerbach (2014) $\rightarrow$ elliptical instability in the tidal flow able to generate a dynamo and a large-scale magnetic field.
- Wei (2022) $\rightarrow$ tidal flow able to generate a dynamo, efficient for main-sequence binaries with short orbital periods (2–3 d), producing surface magnetic fields of ~ 200 G.

$\rightarrow$ Ability of the tidal flow and/or the elliptical instability to generate a dynamo for red giants in close binaries $\rightarrow$ remains to be investigated.

Wrap-up

- For a given rotation period, red giants in close binary systems that are:
  - tidally locked;
  - or in spin-orbit resonance;

  exhibit an enhanced magnetic activity (photospheric + chromospheric) compared to:
  - single red giants,
  - red giants in binary systems that do not have any special tidal configuration.

  → Tidal locking/spin-orbit resonance somehow leads to larger magnetic fields; dynamo mechanisms at work still need to be identified.

- PLATO should encompass *Kepler*'s field of view → detect and characterize activity cycles for red giants that have long periods.

→ Opportunity to probe the dynamo mechanisms at work in the slow rotation regime.


thank you
danke
рахмат
謝謝
ngiyabonga
teşekkür ederim
Баярлалаа
спасибо
gracias
tapadh leat
dank je
merci
obrigado
bedankt
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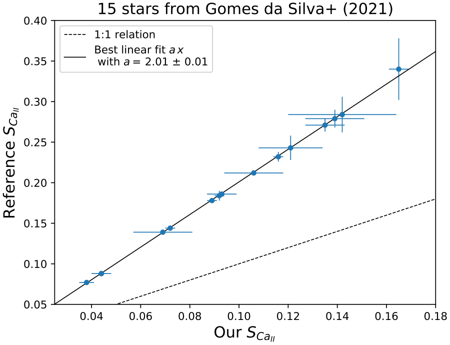
Validation of our S-index measurements: HARPS spectra

- 15 FGK stars from Gomes da Silva+ (2021).
- Calibration to the Mt. Wilson scale $\sim$ factor 2.01 $\rightarrow$ consistent (usually on the order of $\sim$ 1.8, Karoff+ 2016).



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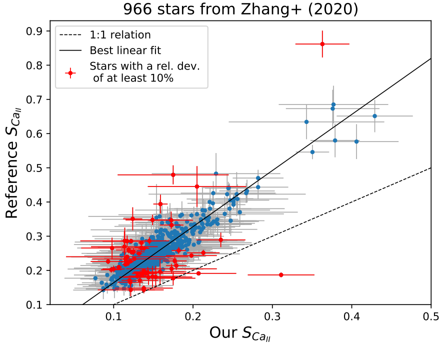
Validation of our S-index measurements: LAMOST spectra

- 1000 RGs from Zhang+ (2020).
- Calibration to the Mt. Wilson scale $\sim$ factor 1.64 $\rightarrow$ consistent.
- Inconsistent measurements in 6 % of the cases (58 stars):
  - different KIC identifications compared to Zhang+ (2020) $\rightarrow$ we get at least one spectrum for only 989 stars;
  - not the same exact spectra selected by Zhang+ (2020) $\rightarrow$ we were able to measure a S-index for only 966 stars.



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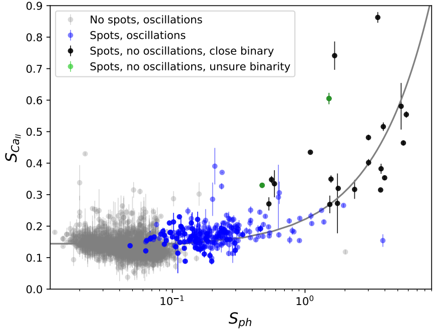
Relation between the chromospheric and the photometric index

- $\sim$ 3130 RGs for which we found at least one LAMOST spectrum with a high enough SNR to measure the S-index.

- Correlation between S_{CaII} and S_{ph} $\rightarrow$ the photospheric activity is proportional to the strength of surface magnetic fields.



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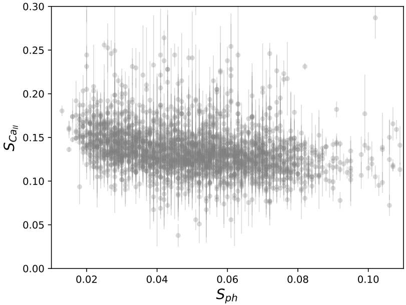
Relation between the chromospheric and the photometric index

- However, slight anticorrelation between S_{ph} and S_{CaII} for inactive RGs $\rightarrow$ due to the change in the definition of S_{ph} between inactive (no spots) and active stars (spot modulation).
- S_{ph} for inactive RGs (standard deviation of the light curve over 3 days) $\rightarrow$ close to the *flicker* index (Bastien+ 2013, standard deviation of the light curve on timescales shorter than 8 hours).
- S_{ph} for active RGs $\rightarrow$ measured over longer timescales (5 times the rotation period).



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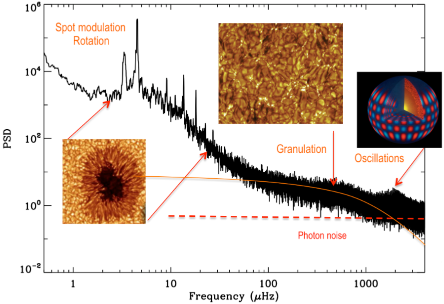
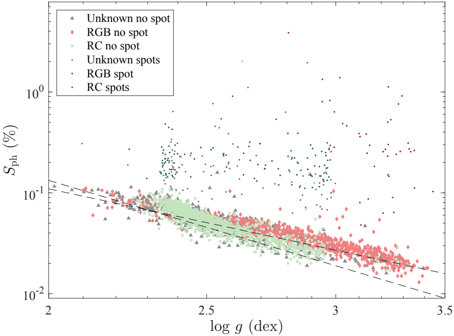
Relation between the chromospheric index and surface gravity

- S_{ph} for inactive RGs $\rightarrow$ similar to the *flicker* index (Bastien+ 2013) $\rightarrow$ proportional to the amplitude of granulation $\rightarrow$ inversely proportional to $\log(g)$.

- S_{ph} for active RGs $\rightarrow$ inversely proportional to the granulation amplitude $\rightarrow$ proportional to $\log(g)$.



García (2015)



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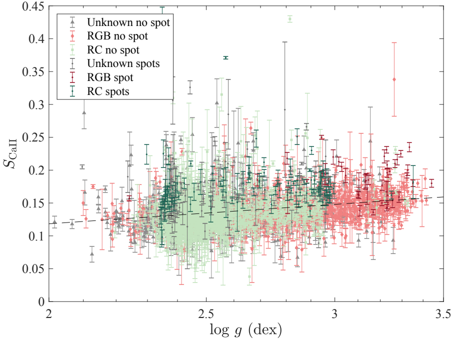
Relation between the chromospheric index and surface gravity

- S-index → proportional to the strength of surface magnetic fields → inhibit convection → reduce the mode amplitude.
- Oscillations amplitude → proportional to the amplitude of granulation (Kallinger+ 2014) → inversely proportional to $\log(g)$.
- S-index → inversely proportional to the amplitude of granulation that triggers oscillations → proportional to $\log(g)$.

→ First time that a direct correlation between S_{CaII} and $\log(g)$ is established.



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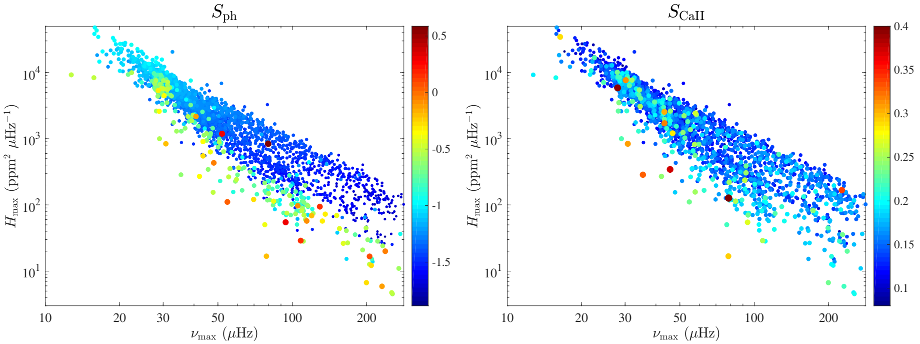
Activity & amplitude of oscillations

- Magnetic activity inhibits convection → lower turbulent excitation of pressure waves, oscillations partially or totally suppressed (Gaulme+ 2020, Benbakoura+ 2021).
- Gaulme+ (2020) → almost all the active RGs with spot modulation display low-amplitude oscillations.
- This study → compatible since RGs with low-amplitude oscillations tend to present large S_{CaII}.



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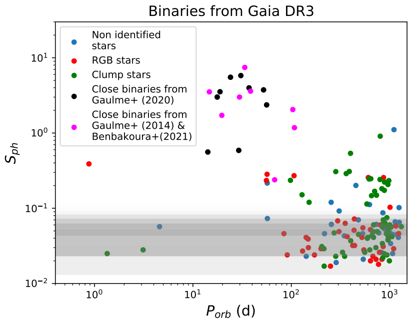
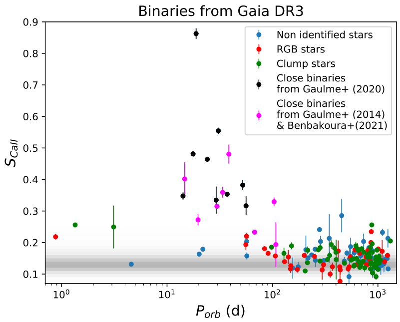
Activity & close binarity

- 161 binaries listed by Gaia DR3 (Gaia Collaboration et al. 2016, 2022) for which we measured a S-index.
- The S-index depends on the orbital period.
- However, the majority of the oscillating red giants in close binaries exhibit significantly lower $S_{\rm ph}$ and $S_{\rm CaII}$ compared to the non-oscillating ones.

→ Close binarity by itself is not responsible for larger S-indices.





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Chromospheric activity: impact of mass gain

- Intermediate-mass RGB stars with a degenerate core from asteroseismology $\rightarrow$ signature of a mass gain through mass transfer (Deheuvels+ 2022) or stellar merger (Rui & Fuller 2021).
- Slightly larger or similar S-index as for inactive RGs + no spot modulation.

$\rightarrow$ No evidence of a significant angular momentum enhancement able to trigger a dynamo mechanism; possibly reflecting a selection bias since these studies focus on oscillating RGs, i.e. exhibiting weak magnetic activity.