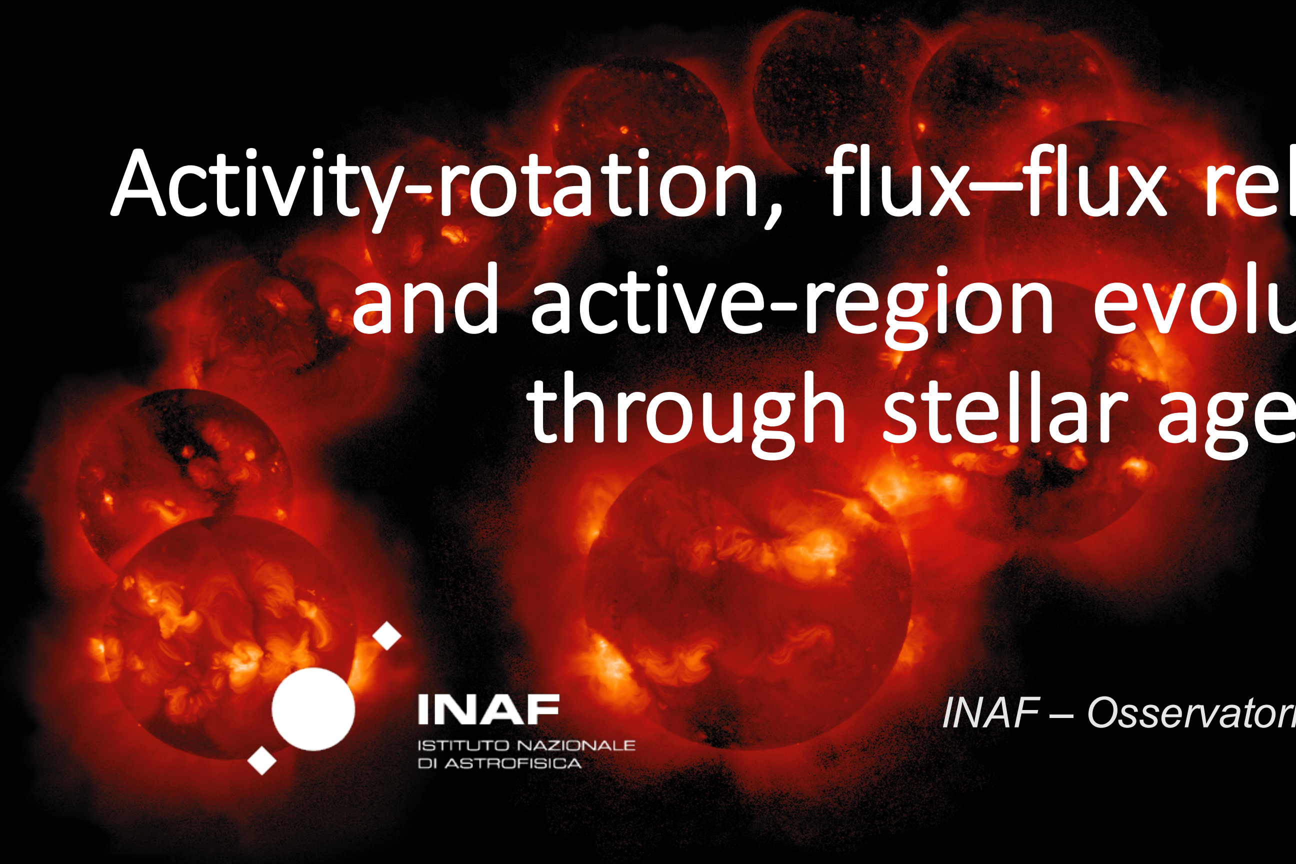
Activity-rotation, flux–flux relationships, and active-region evolution through stellar age



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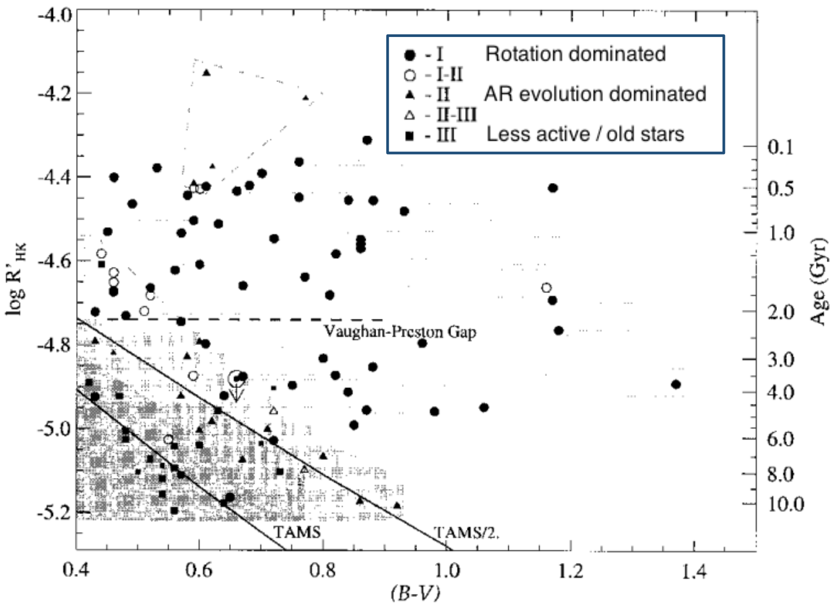
Astrophysical context

Active region (AR) growth and decay: a fundamental phenomenon to understand the generation and variability of magnetic fields

A poorly understood phenomenon: Do ARs have rather irregular lifetimes depending on their level of activity (age) and colour (mass)?



'Morphology' of Ca II variability vs. stellar parameters (from Donahue et al. 1997)

From light curves analysis:

Big starspots live longer

Starspots decay more slowly on cooler stars

Differential rotation can destroy the biggest ARs

Aims of this study:

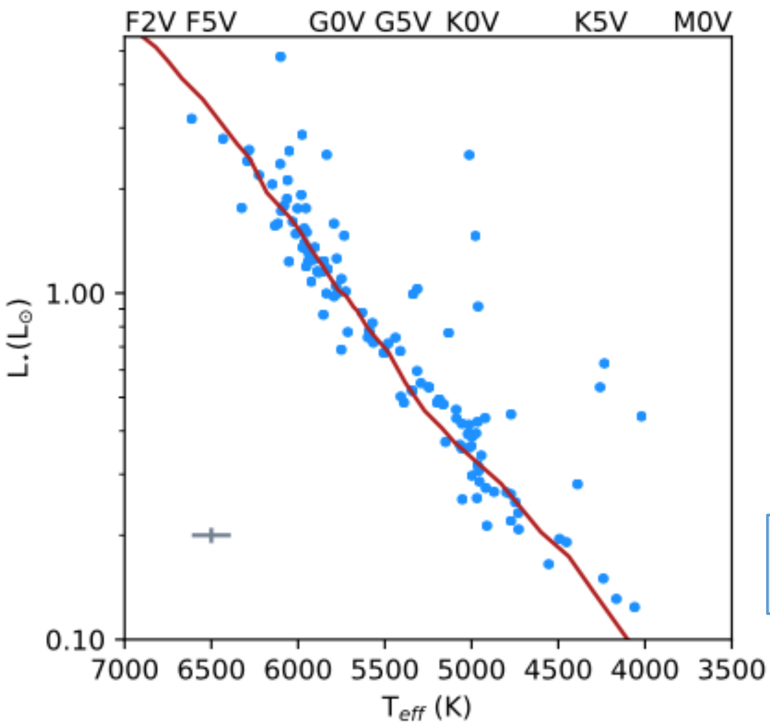
- A detailed and homogeneous analysis of the chromospheric activity indexes of a large sample of stars with reliable age estimates
- Study possible mechanisms for AR growth and decay

The stellar sample

Stars in open clusters or stellar associations with precise derived ages
(most stars observed within the framework of the Global Architecture of Planetary Systems programme)

Association	N stars	Age (Myr)
Taurus	4	1 - 2
Upper Sco	4	10
Cepheus	2	10 - 20
β Pic	2	24
Tucana - Horologium	4	30
Pleiades	2	112
AB Dor	2	149
Castor	1	200
Hercules - Lyra	1	257
Ursa Major	6	414
Coma Berenices	6	562
Praesepe	20	578
Hyades	49	750
Other young stars	2	50 - 600
NGC 752	12	1340
Old stars	13	5300 - 13900
Sun		4579†

Number of observed stars per cluster or moving group



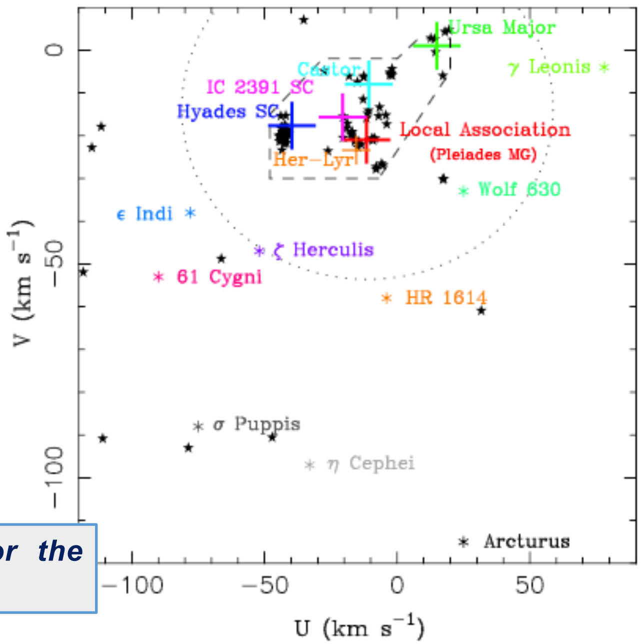
Stars required to have high-resolution optical HARPS/-N spectra

HR diagram of the observed stars

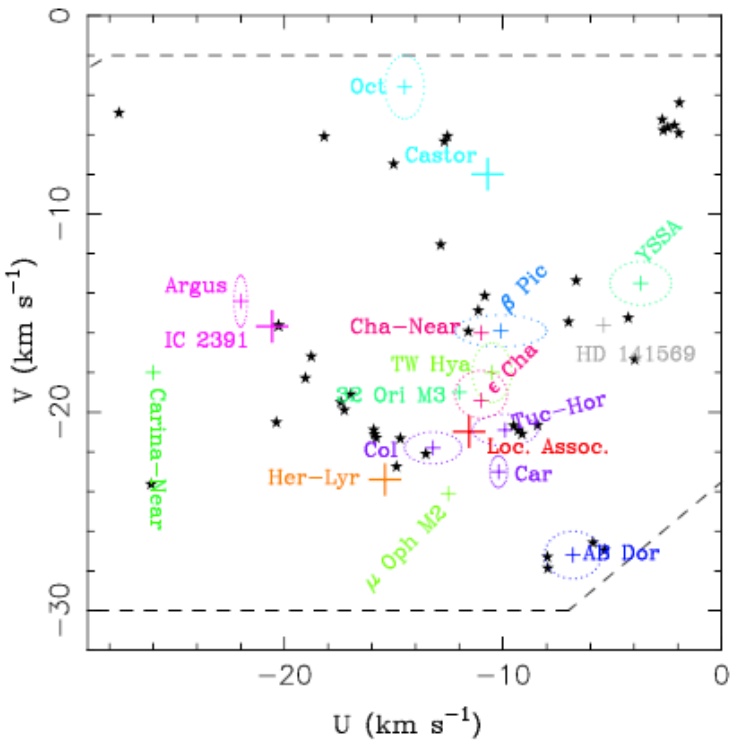
Kinematics and age

Confirmation of the young nature of the stars by its membership to Stellar Kinematic Groups and associations (advantage of *Gaia* EDR3)

α, δ, π, $\mu_\alpha \cos\delta$, μ_δ → **Galactic spatial velocity components *(U, V, W)***



(U,V) plane for the observed stars

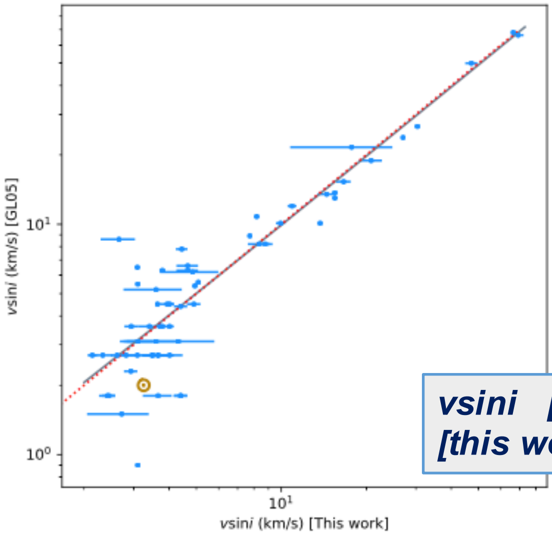


Computation of detailed membership probabilities using available tools (e.g. BANYAN Σ)

Properties of the sample

Rotation vs. age and Sp-Type

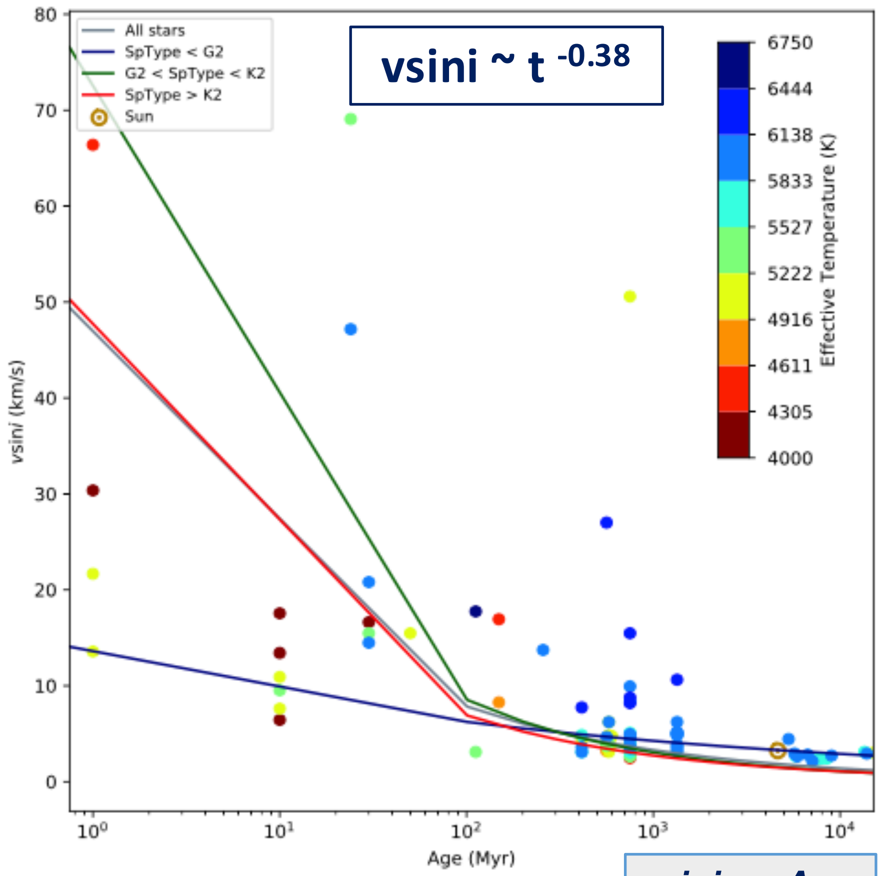
Rotational velocities computed via the Fourier Transform (FT) technique and line profile fitting



Line profile: slightly larger v*sini* values

FT: Good agreement with literature data

vsini [other] vs. vsini [this work FT]



vsini ~ t $^{-0.38}$

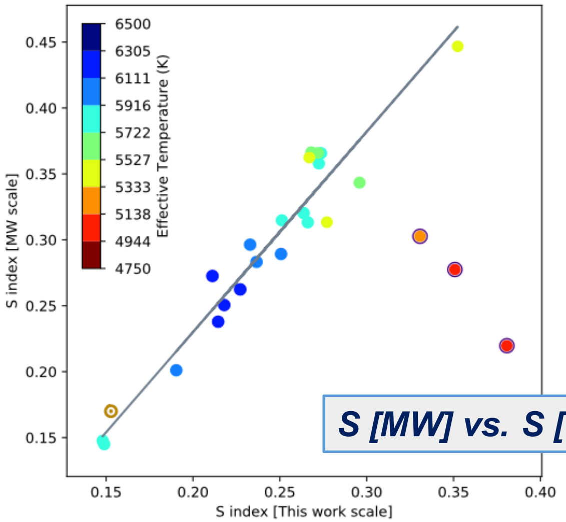
vsini vs. Age

steeper tendency in hotter stars → size of the convective zone

[few "cool" stars in the sample]

Activity level vs. age and Sp-Type

S index: Emission in the core of the Ca II H & K lines

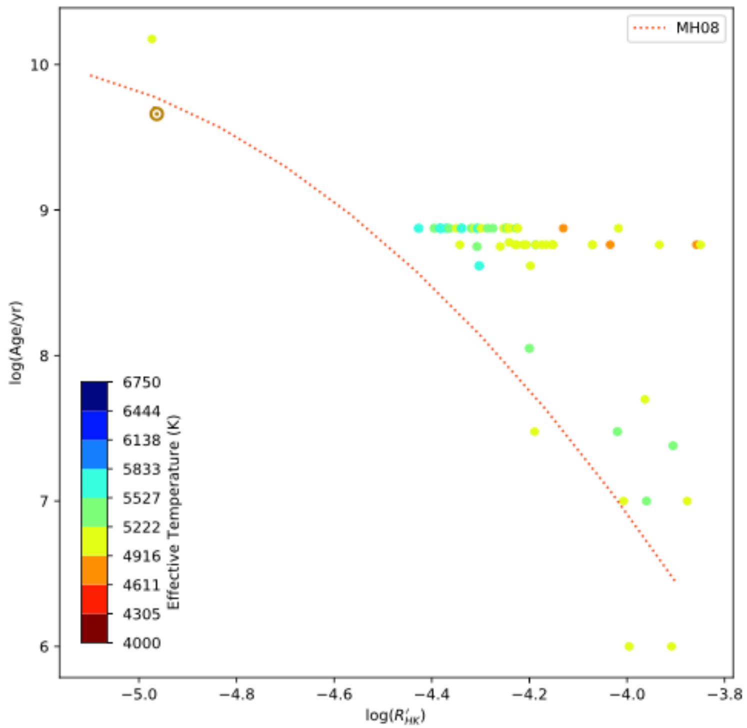


S [MW] vs. S [this work]

Conversion factor and photospheric corrections by Noyes et al. 1984

Stars with 0.44 < (B-V) < 0.82

T_{eff} [GAIA DR2]-(B-V) relationship



Age vs. log(R'_{HK})

General decay of activity with age

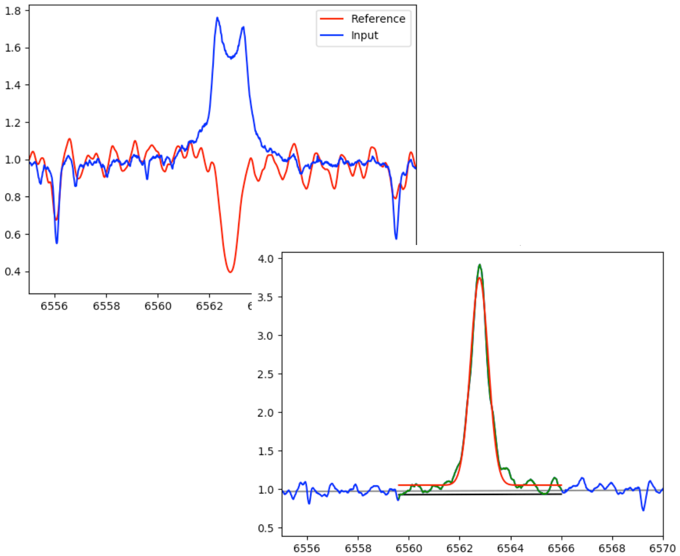
Large spread at a given age

Higher level of activity for cooler stars

Properties of the sample

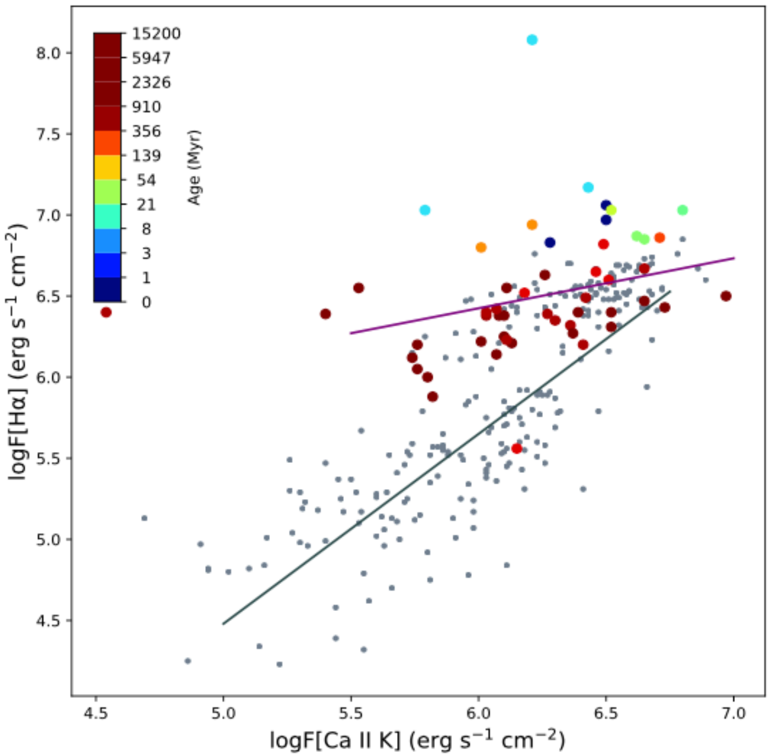
Flux-flux relationships

Spectral subtraction technique in the main optical activity indicators



Example of subtraction (Hα line)

From emission excesses to luminosities:
Hall et al. 1996. Continuum excesses as a function of the (B-V) colour (T_{eff})



logF[Hα] vs. logF[Ca II K]

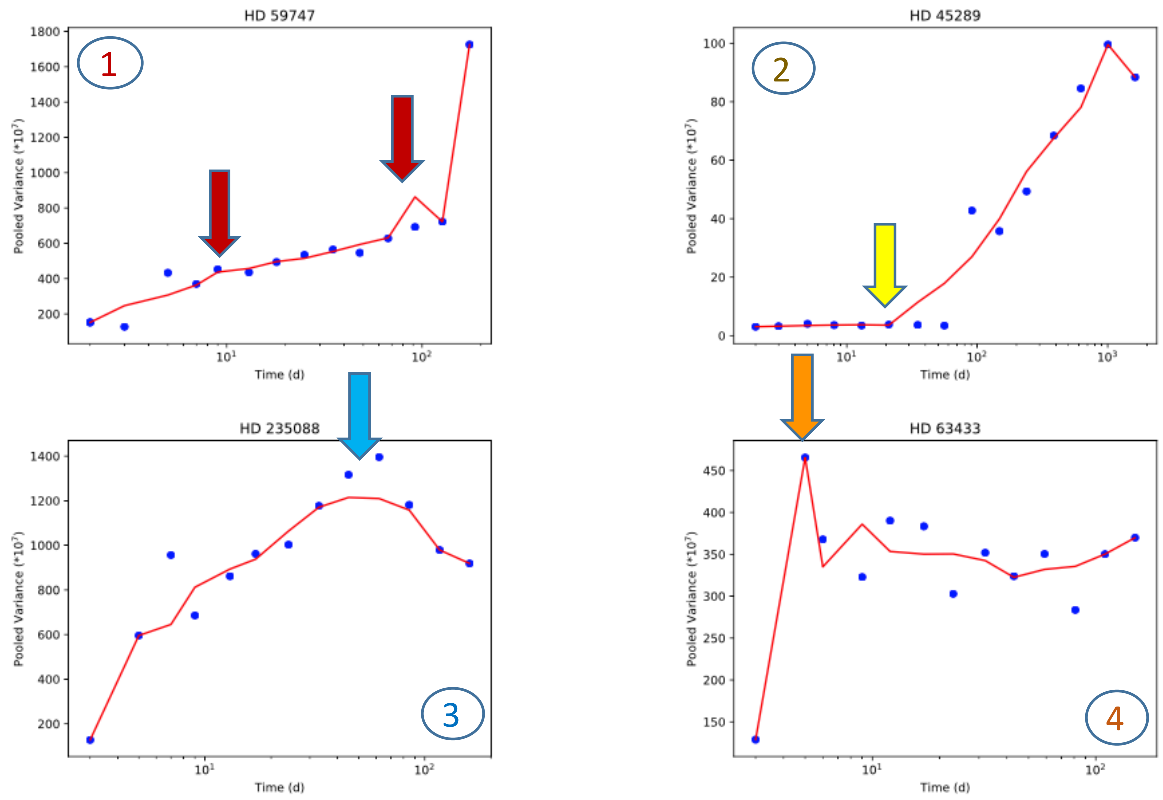
Most stars in the *active upper* branch

Young F, G stars share the behaviour of cooler stars

Tendency of higher Hα fluxes for the youngest stars

Different Hα/Ca emission → role of different active structures

Temporal evolution of active regions



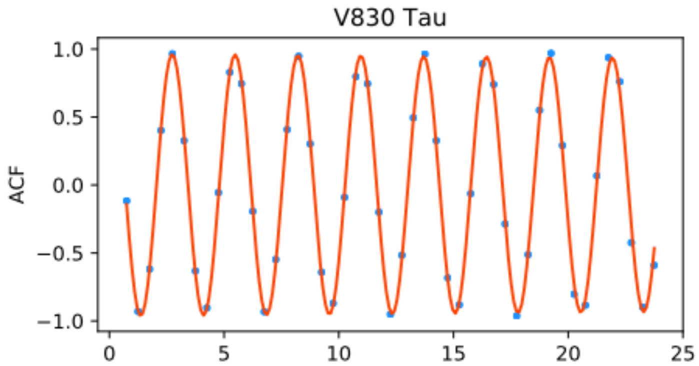
Examples of PV diagrams (S index)

Pooled variance technique: complex patterns

- **Well defined "plateau" (1)**
- **Nearly constant increase of variance (2)**
- **No plateau, increase of variance until region evolution time (3)**
- **High variability at short time-scales (4)**
- **"Irregular" patterns**

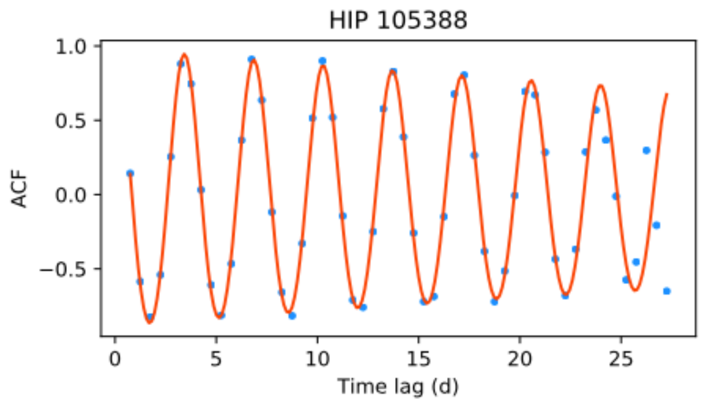
Temporal evolution of active regions

Autocorrelation functions (ACFs) of TESS light curves: different behaviours



The peaks of the ACF have always the same strength, no time decay:

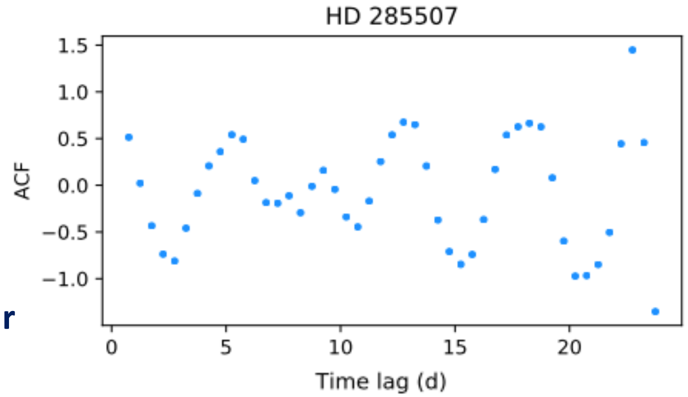
ARs are stable during the time-span of the observations



The ACF is periodic but shows a clear time decay:

ARs lifetimes can be estimated by modelling using an underdamped harmonic oscillator with an interpulse term (linear/exponential decay)

$$y(t) = e^{-\frac{t}{\tau_e}} \left[a \cos\left(\frac{2\pi t}{P_{\mathrm{ACF}}}\right) + b \cos\left(\frac{4\pi t}{P_{\mathrm{ACF}}}\right) + y_0 \right]$$

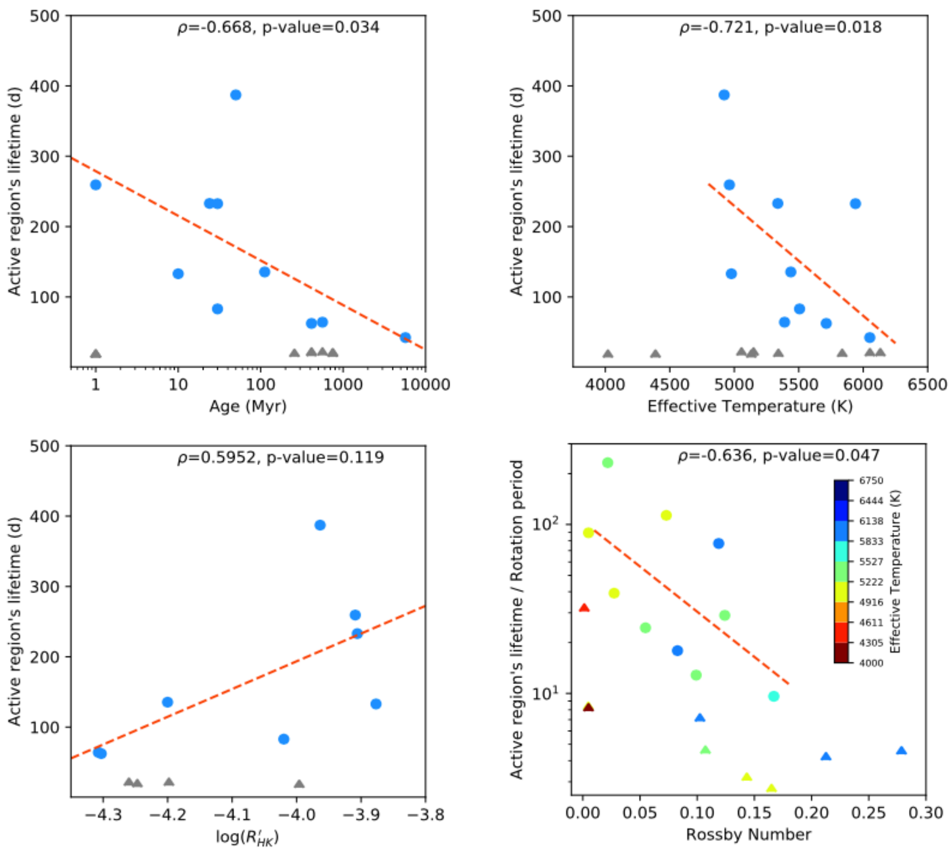


The ACF shows a rather irregular form:

Complicated analysis

Examples of ACF curves

Temporal evolution of active regions



AR lifetime vs. Age, T_{eff}, $log(R'_{HK})$ and Rossby number)

AR lifetime as a function of the stellar parameters

Younger stars show longer AR lifetimes

Increasing AR lifetime with cooler temperatures and higher activity levels

ARs survive longer in stars with larger convective turnover timescales and shorter rotation period

$$R_0 = \frac{P_{rot}}{\tau_{conv}}$$

Caution: Low-number statistics, assumptions linked to the models

Summary (Maldonado et al. 2022, arXiv:2204.12206)

Detailed analysis of a large sample of well-known derived ages (membership to kinematic associations)
Rotation and activity level (spectroscopic indexes), emission excess, photometry

Activity-rotation-age and flux-flux relationships

- Decreasing activity and rotation with stellar age
- Higher levels of activity and lower age-decay on cooler stars
- Young F and G stars depart from the inactive stars in the flux–flux relationships

Temporal evolution of active regions

- Complex patterns that might differ even from stars with similar characteristics, difficult to obtain ARs lifetime
- Active regions seem to live longer on younger, cooler, and more active stars