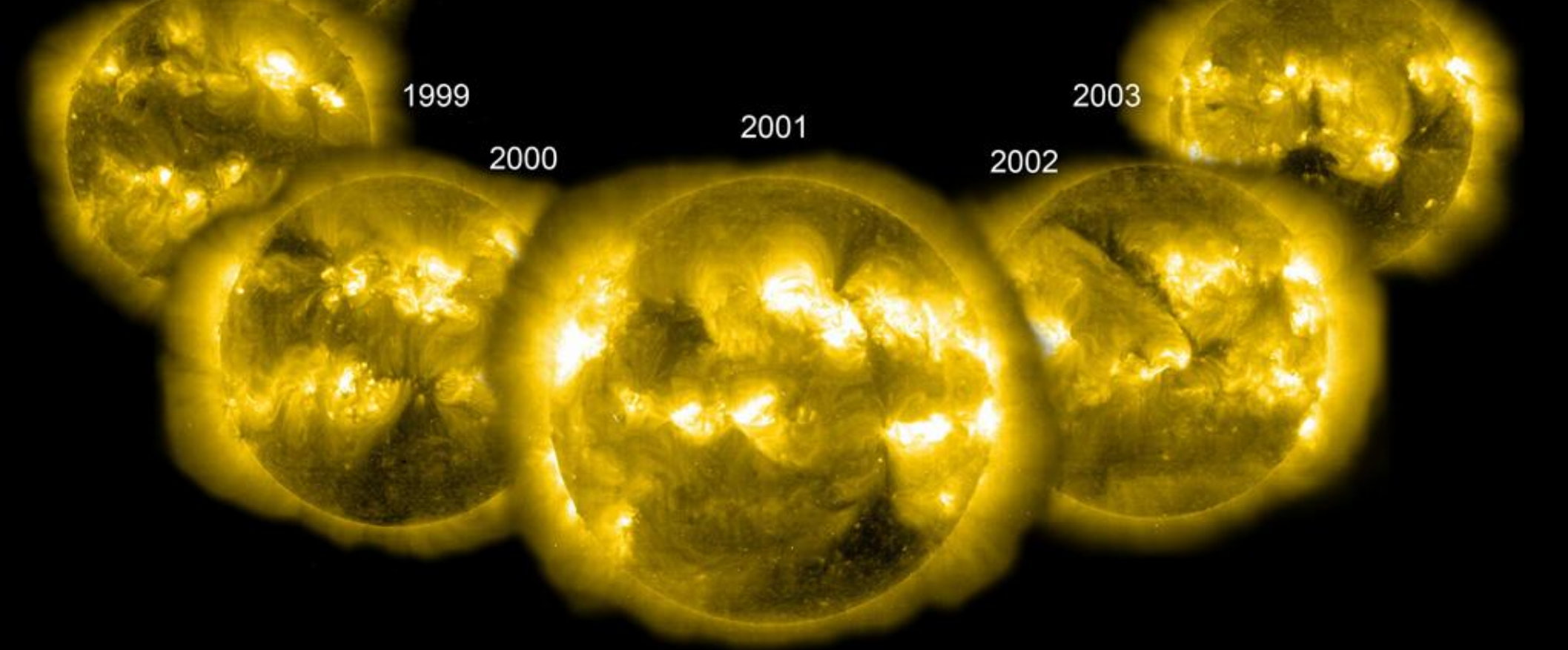

The Sun as a star: the evolution of stellar activity during the main sequence

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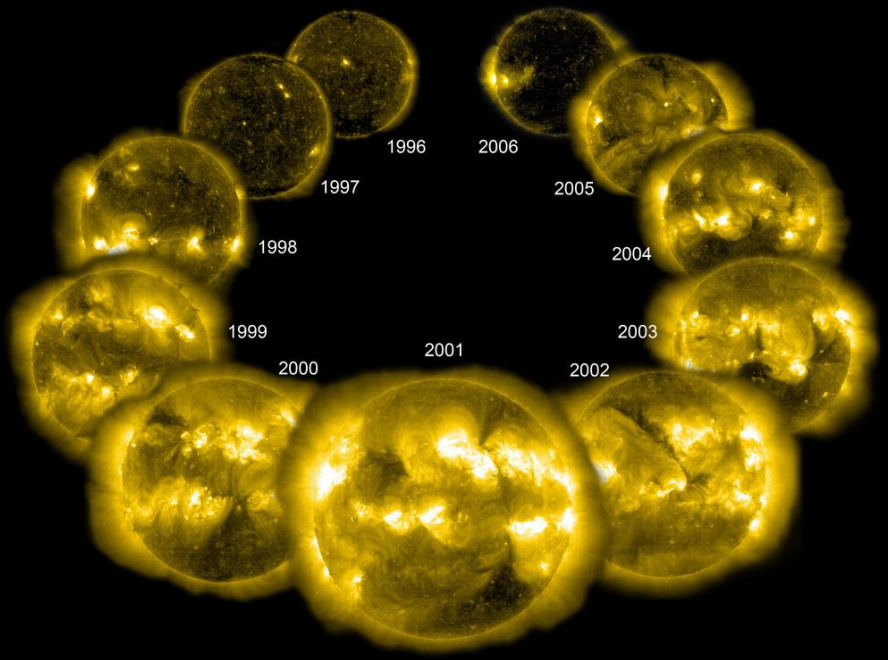
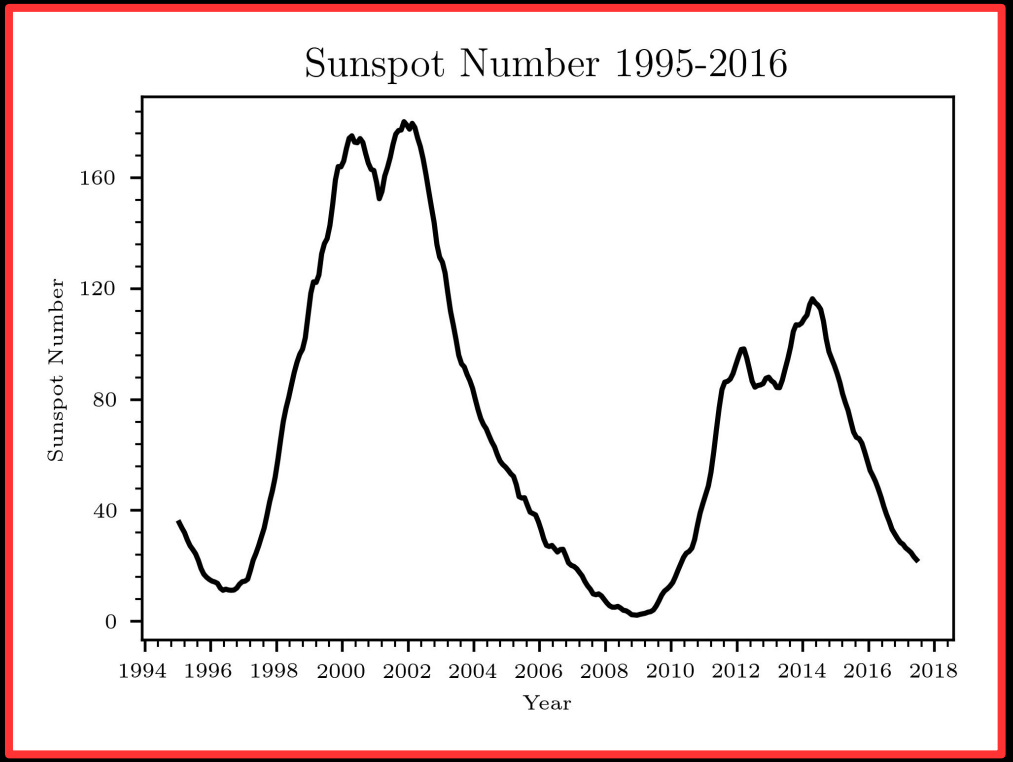
Cool Stars 20 - Boston -

How our cyclic, medium-aged Sun behaves?

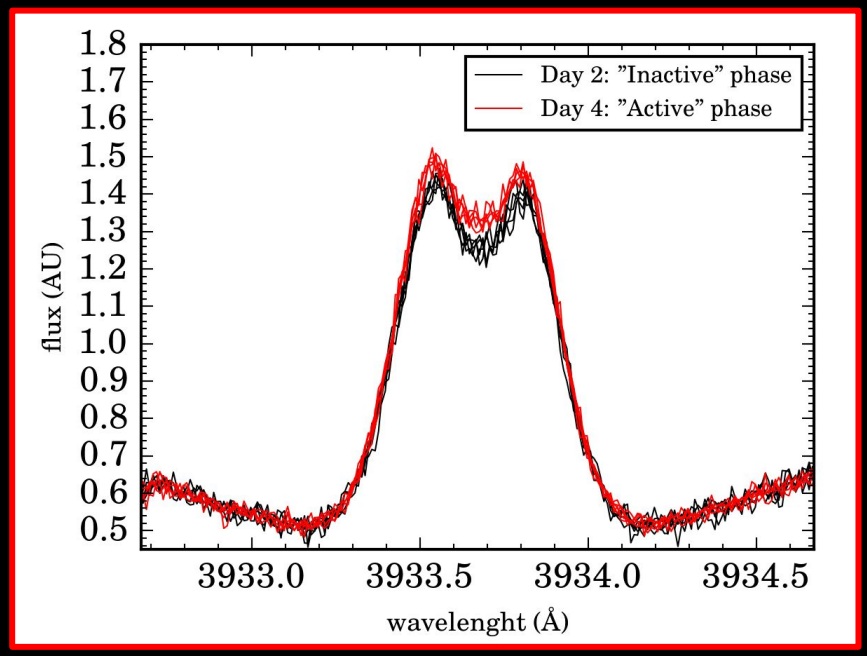


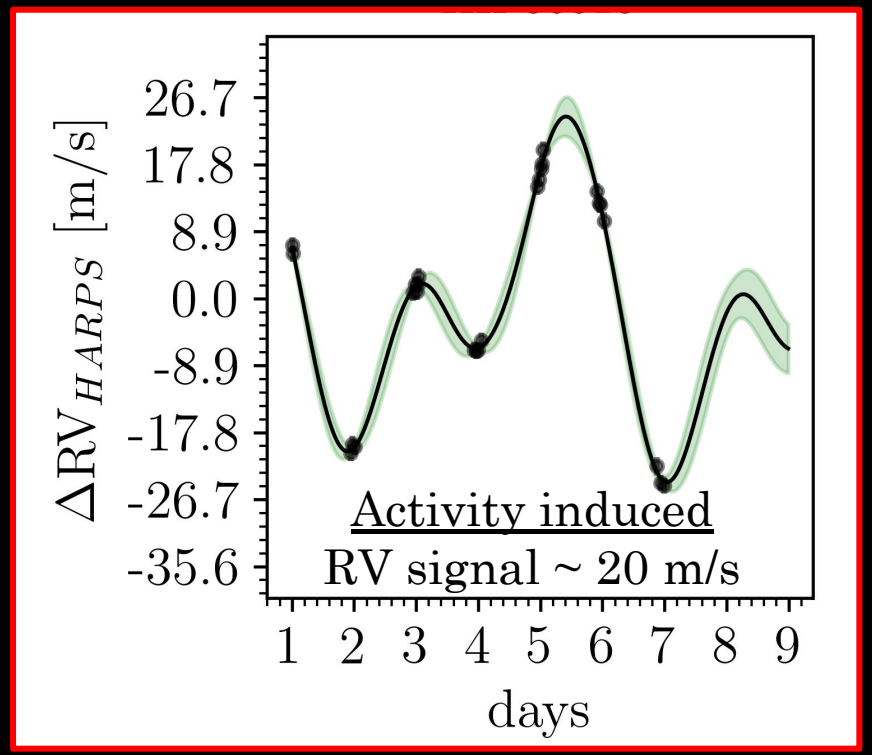


- The long-term monitoring of the Sun through different proxies has revealed the cyclic nature of our star over different timescales (from minutes to centuries).
- These periodic changes are rooted in a **complex and non-linear process involving turbulent convection of the magnetized plasma under the presence of radial and angular differential rotation** (Guerrero & de Gouveia Dal Pino, 2008, Charbonneau, 2010).
- Importance: Stellar physics through magnetohydrodynamics (MHD) dynamo simulations (Strugarek et al., 2017), star-planet interaction (do Nascimento et al. 2016), and robust estimate of habitable zones around solar-like stars.

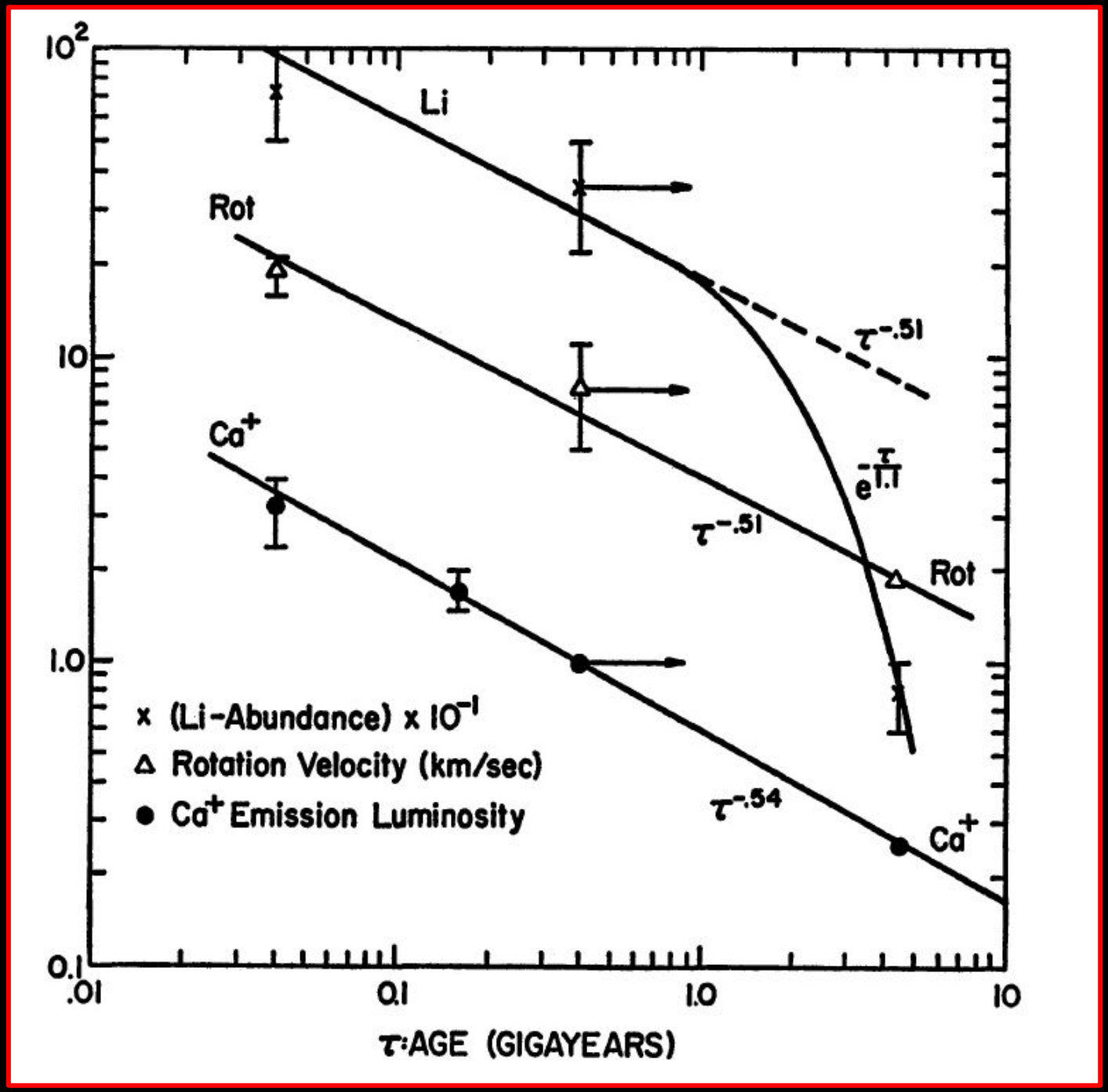
Furthermore, it is well-known that **stellar activity imprints complex quasi-periodic signals** in the spectrum over different timescales, hampering the true detection of low-mass exoplanets (Rajpaul et al., 2016).

Magnetic sensitive line: Ca II





Age-Activity Relations

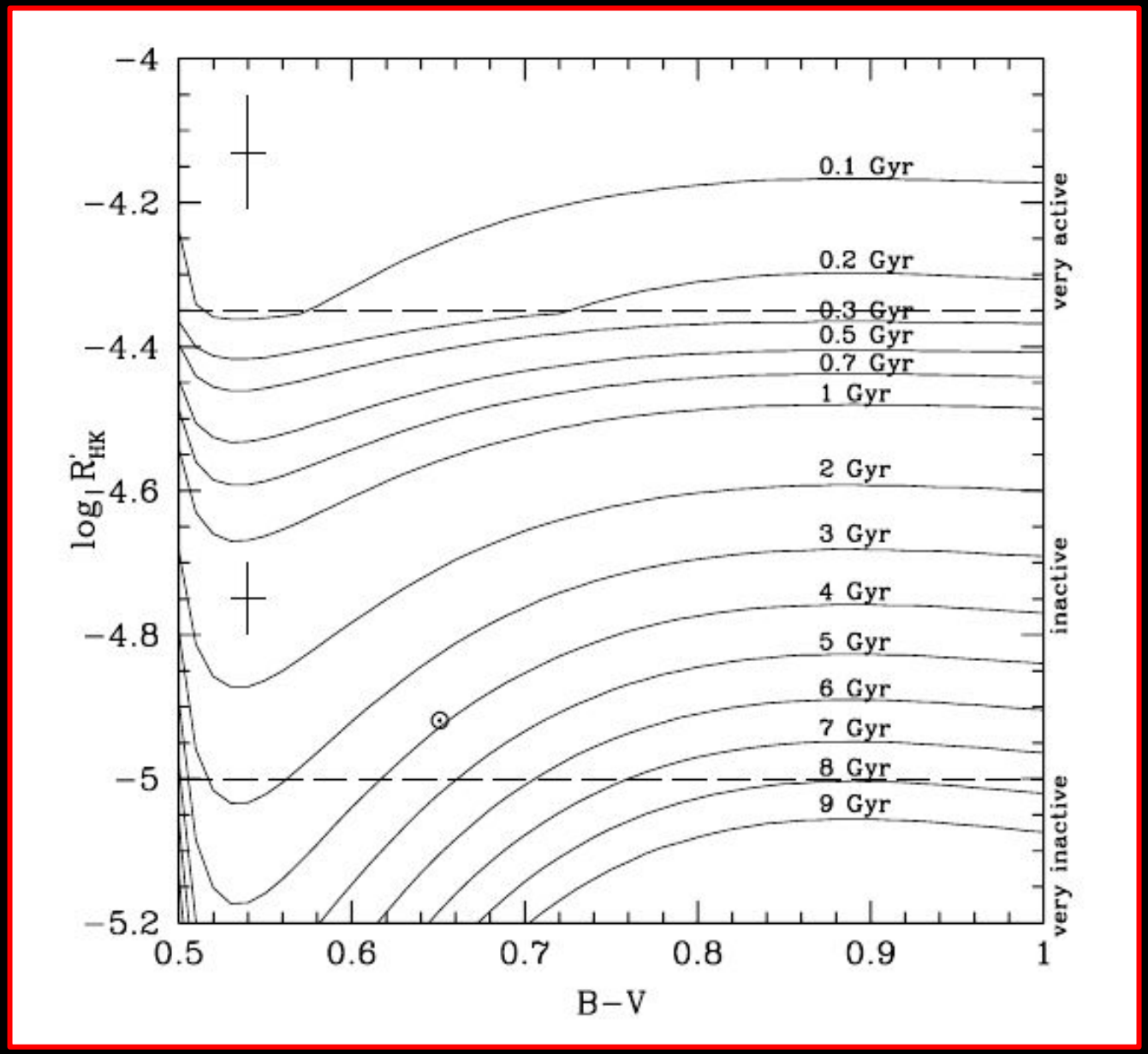


Age Calibrators

- Clusters
- Sun

Skumanich 1972

Age-(Color)-Activity Relations

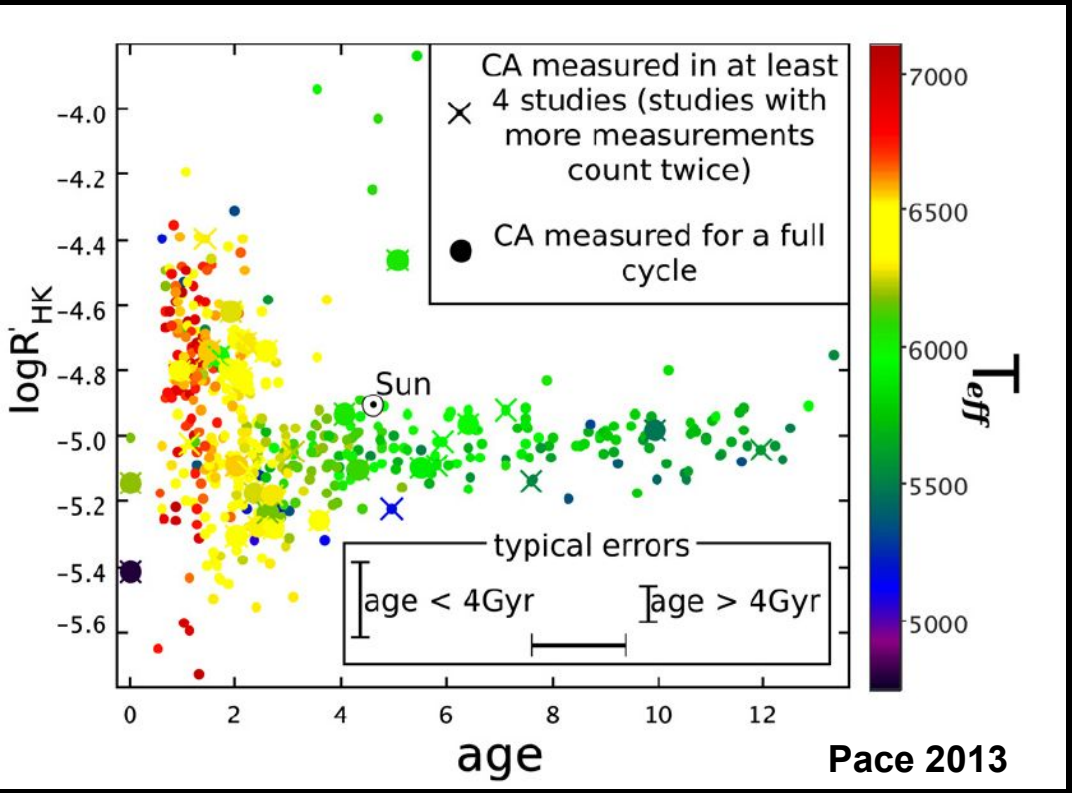


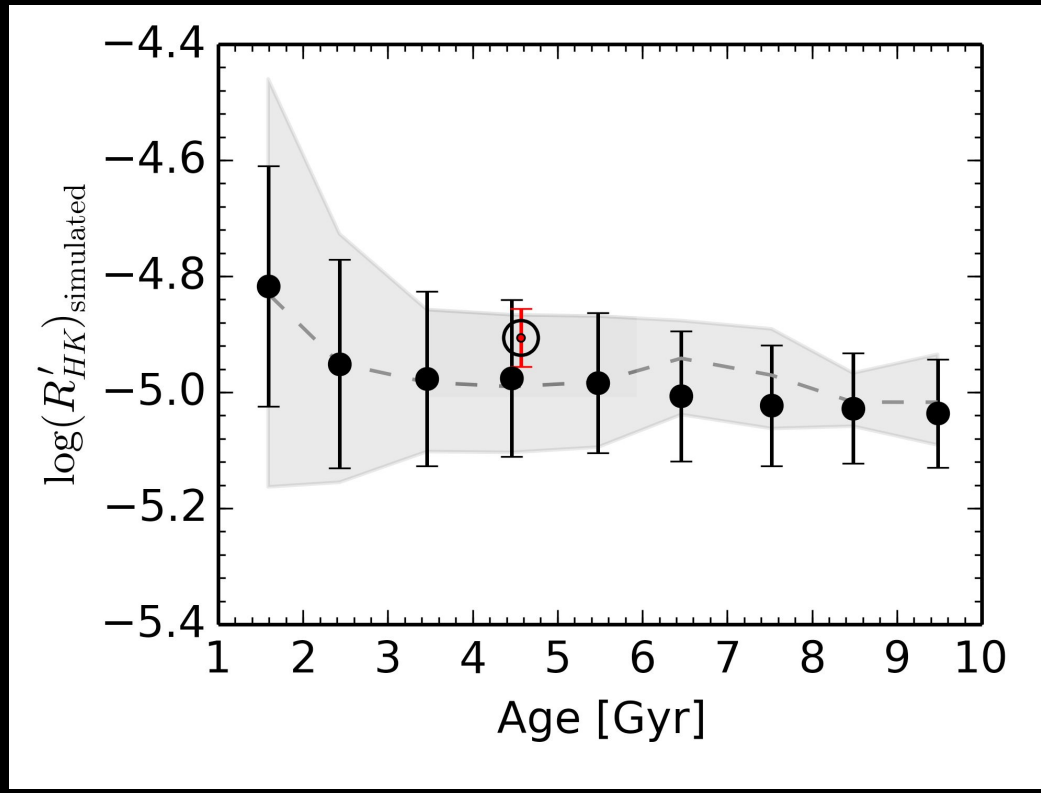
Age Calibrators

- Rotation-Activity
- Open Clusters
- Sun

Mamajek & Hillenbrand 2008

Lack of Activity Evolution after 1.5 Gyr?





Lorenzo-Oliveira, Porto de Mello, Schiavon 2016

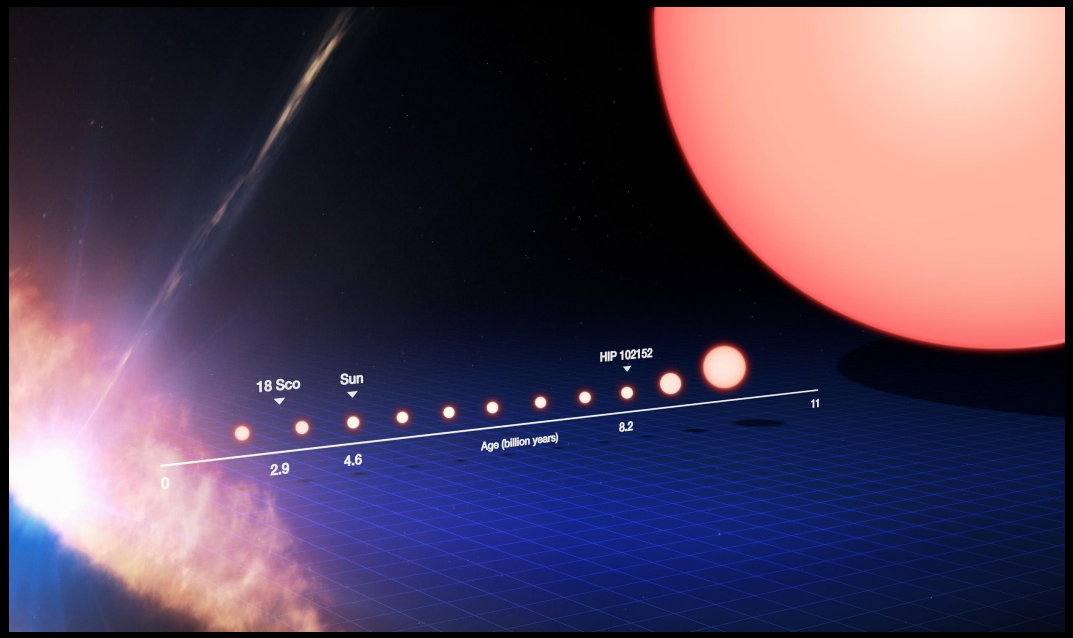
Selection effects.

Age → mass bias (younger stars are more massive)

Higher [Fe/H] → lower $\log R'_{HK}$ → older chrom. age

Lower [Fe/H] → higher $\log R'_{HK}$ → younger chrom. age

HARPS Solar Twin Planet Search: Sample



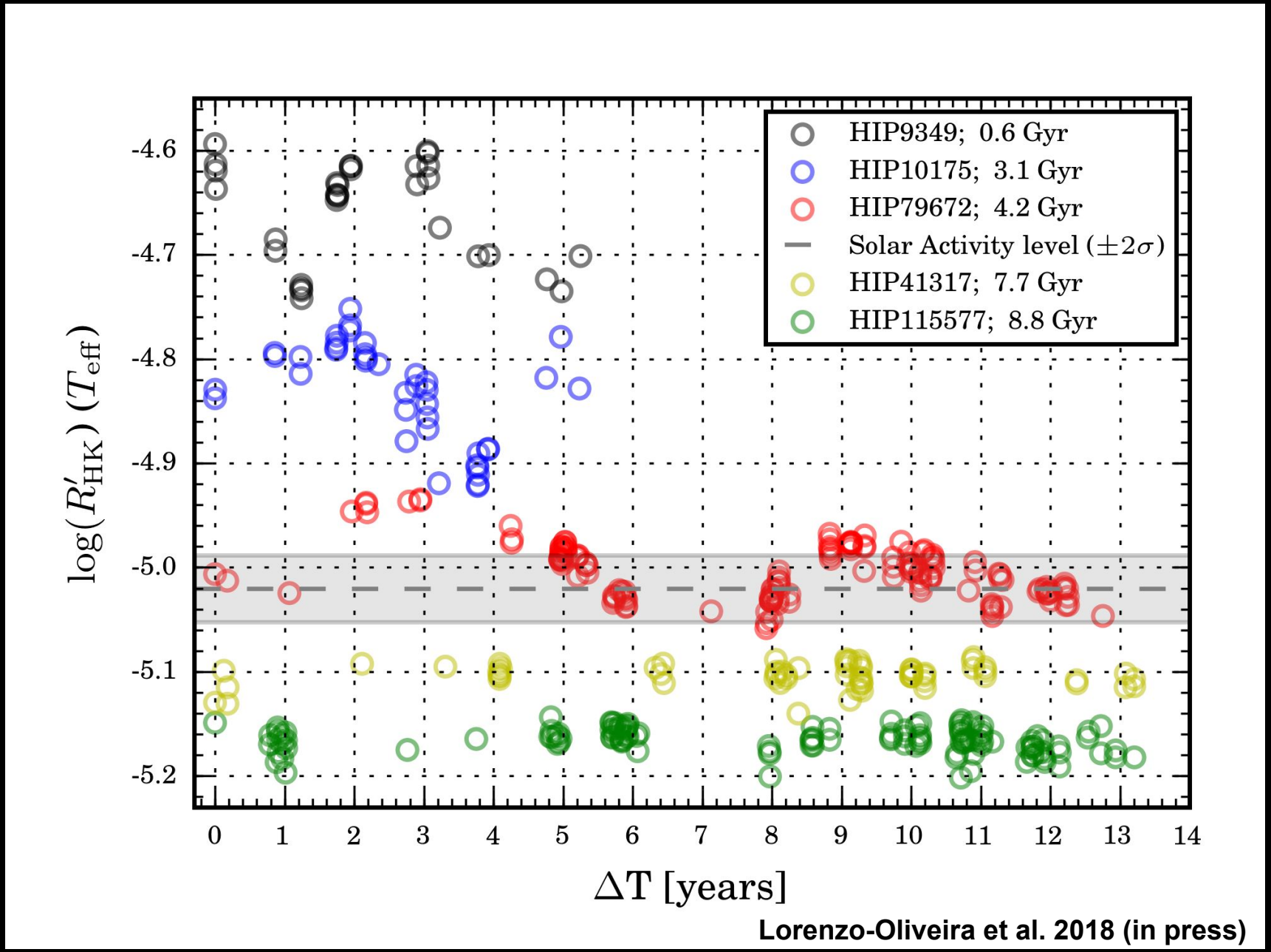
82 solar twins

- $5600 < T_{eff} < 5900$ K
- $-0.1 < [Fe/H] < +0.1$
- $4.2 < \log(g) < 4.5$

Large time-series 2004-2018: > 9000 High SNR, high resolution observations

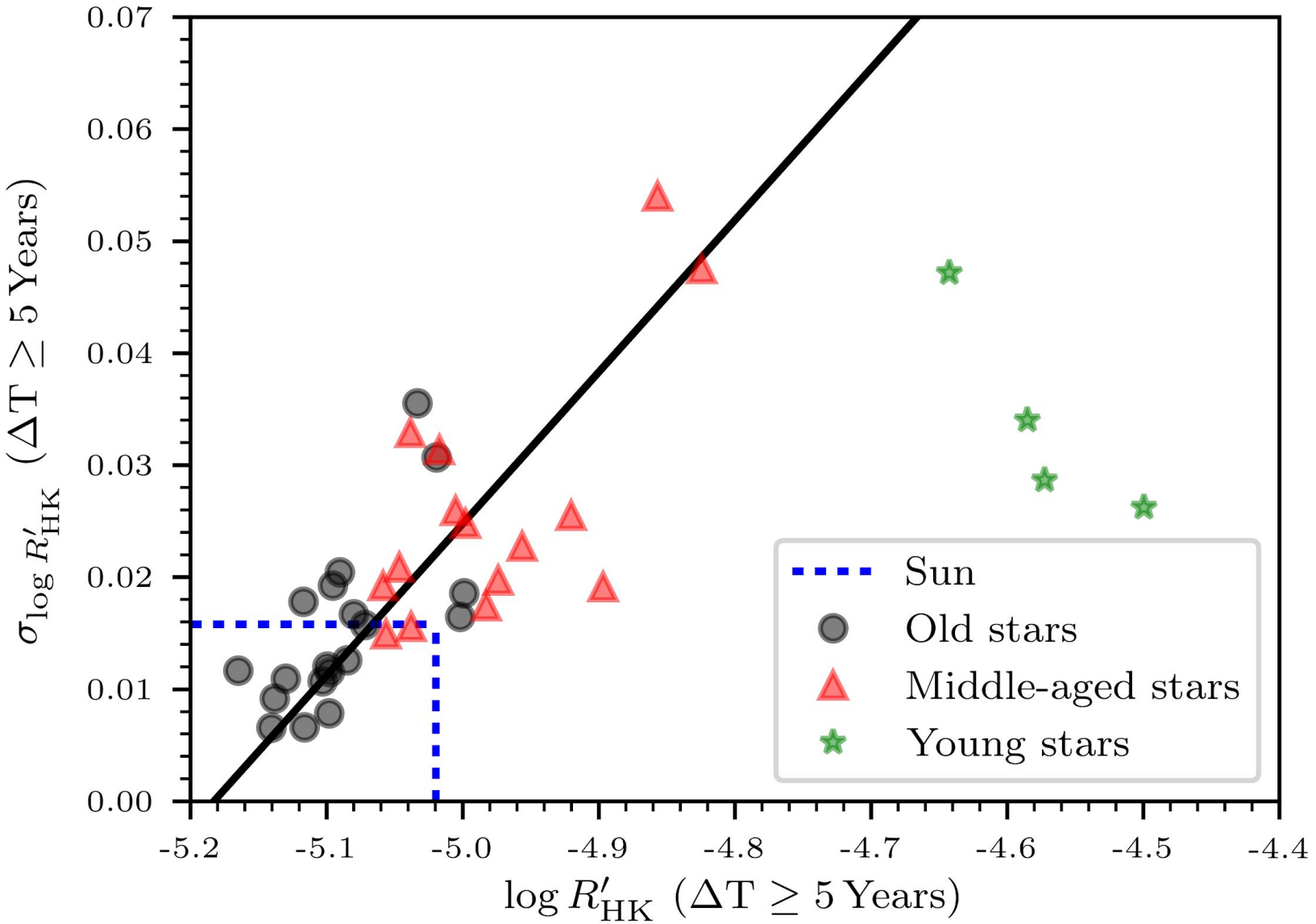
- **Precise ages, masses, atmospheric parameters (Spina et al. 2018) and robust mean activity levels (Ca II, Hα ...).**
- **Extensive RV monitoring (SBs, Dos Santos et. al. 2017)**
- **Projected Rotational Velocities (Dos Santos et. al. 2016)**

Variability-Activity-Age



Lorenzo-Oliveira et al. 2018 (in press)

Variability-Activity-Age



Lorenzo-Oliveira et al. 2018 (in press)

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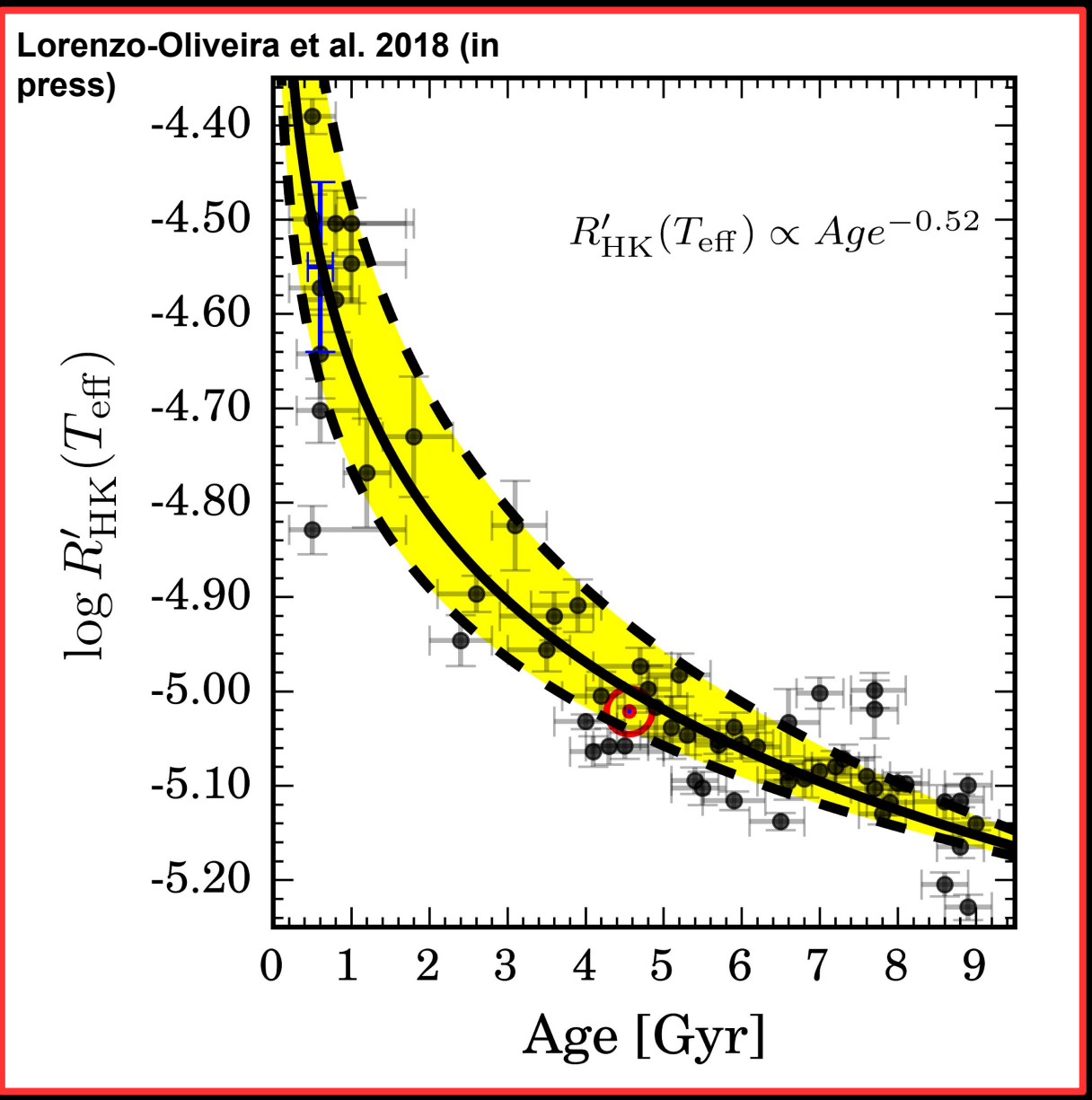


Age-Activity Relation

- Skumanich-Like Evolution
- RV monitoring (no SBs)
- Young stars: high constrast
- Young stars: active + variable
- Old stars: lower contrast
- Old stars: Inactive + constant
- Sun typical star
- Typical solar variability at solar age
- Chrom Age Errors ~ 1 Gyr
- Old stars: lower activity + higher rotation rates? (van Saders+16)

Activity(Rotation) – Age (Lorenzo-Oliveira et al. 2018, dos Santos et al. 2016)

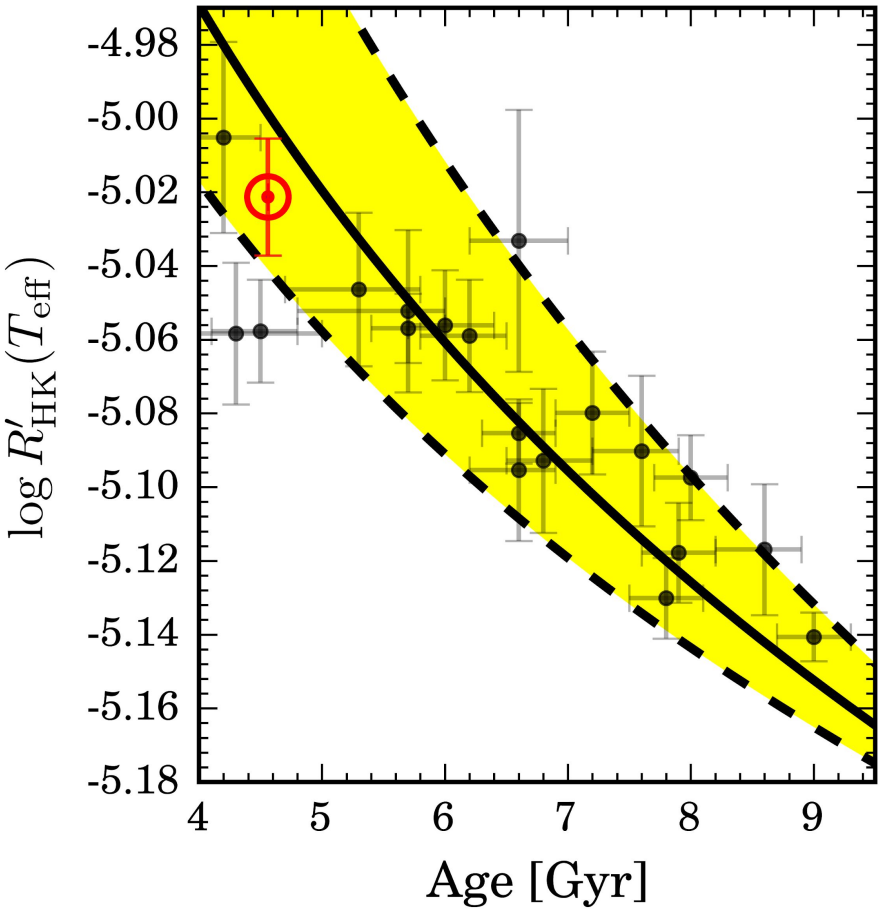
Activity – Mass – Metallicity – Age (Lorenzo-Oliveira et al. 2016)

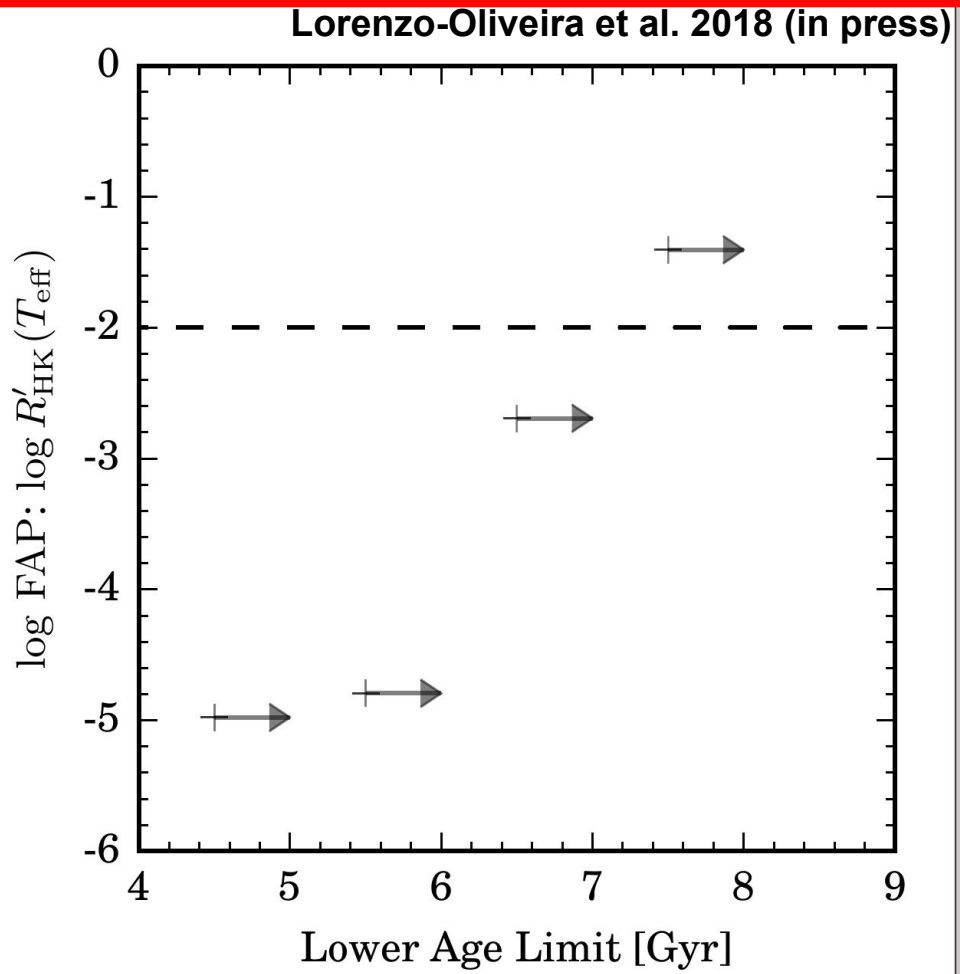
Solar-Twins → solar [Fe/H], mass and other parameters.

Best old solar twins

M/Msun +- 5%Msun

[Fe/H] +- 0.05 dex, [Ca/H] +- 0.05 dex





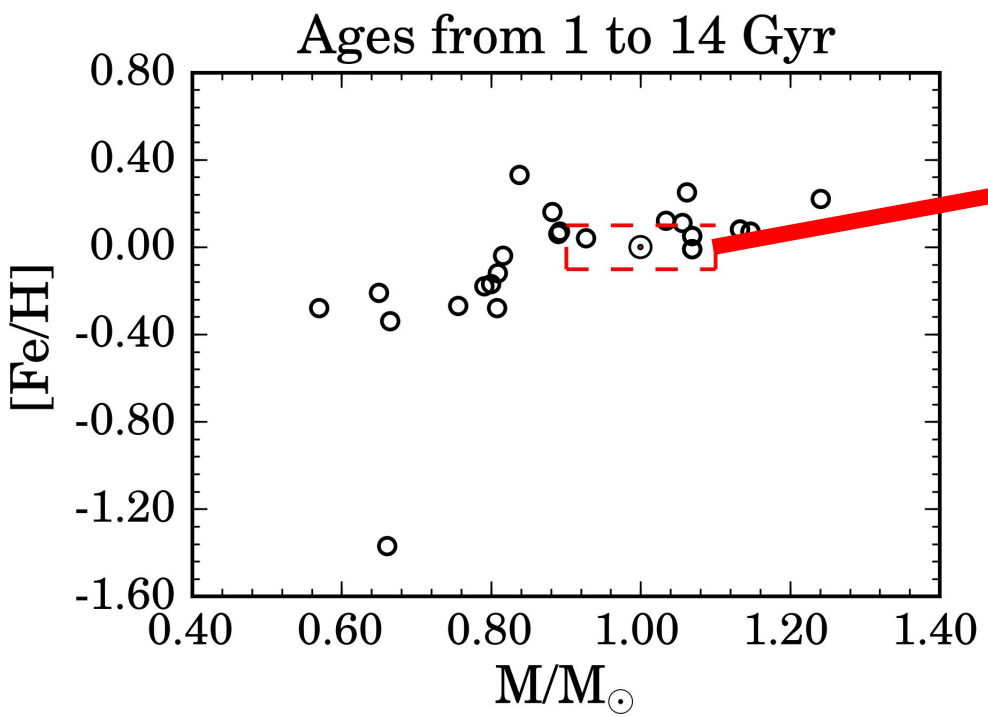
Minimum Time-span (yr)	$\langle Age_{HK} - Age_{ISO} \rangle$ (Gyr) (Gyr)	$\langle (Age_{HK} - Age_{ISO})/Age_{ISO} \rangle$ –	Number of Stars	Age_{ISO}^{min} (Gyr)	Age_{ISO}^{max} (Gyr)
≥ 5	-0.4 ± 0.9	16 ± 6 %	33	2.6	9.0
≥ 7	-0.4 ± 1.0	15 ± 4 %	23	4.2	9.0
≥ 10	-0.5 ± 1.0	16 ± 4 %	14	4.2	9.0
≥ 13	+0.0 ± 0.9	13 ± 3 %	6	4.8	9.0

Conclusions

Using large time-series of activity measurements we revisited the age-activity relation using solar twins.

- The Sun has a typical mean activity level for its age.
- 'Skumanich-like' age-activity relation found for solar-twins.
- Strong age-activity correlation up to ~7 Gyr
- Ca II lines remain an interesting age indicator for solar-like stars (be careful with mass+[Fe/H] effects!)

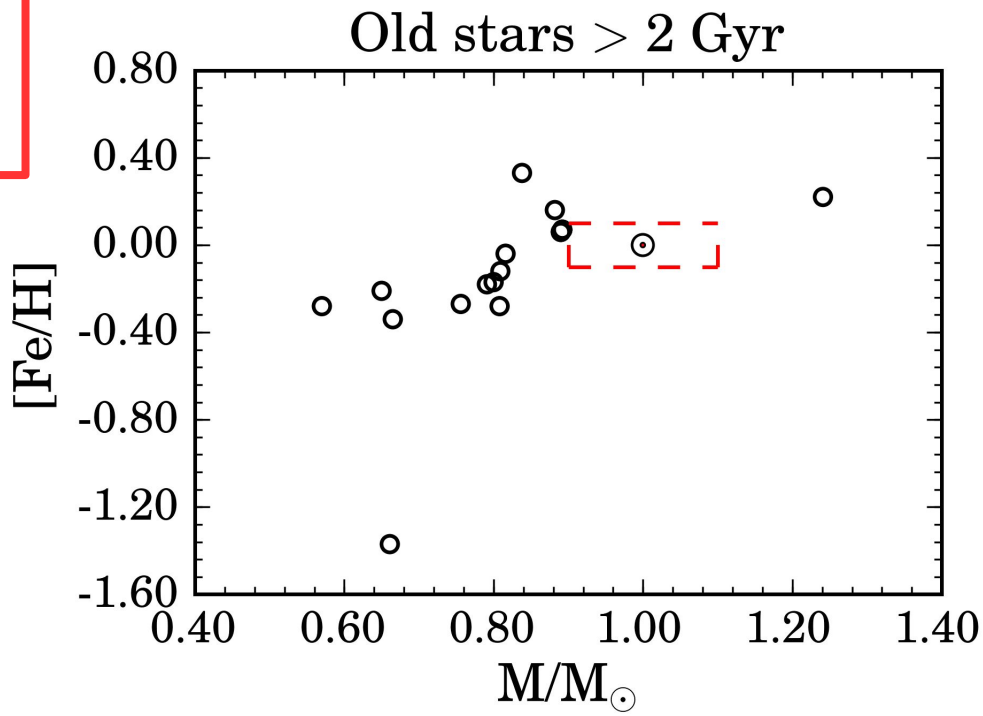
Solar Uniqueness?



Solar twins box

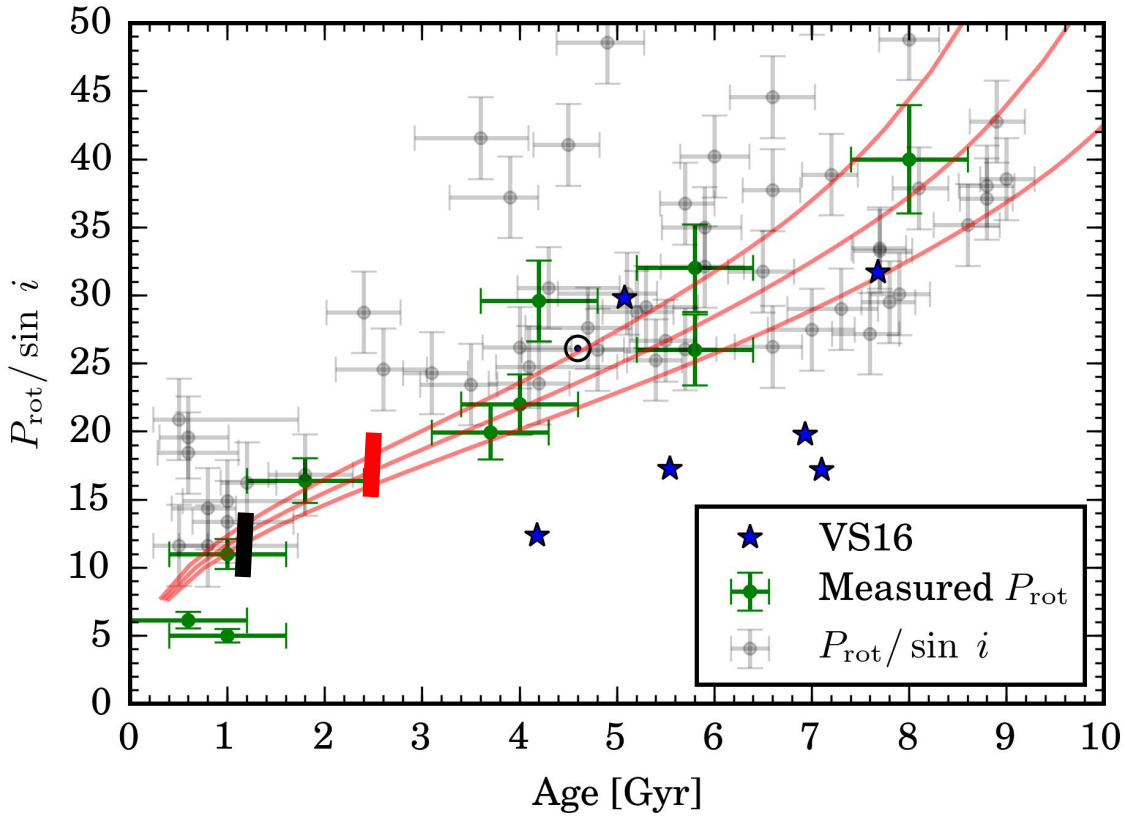
- solar M/M_{sun} within ~10%
- [Fe/H] +- 0.1 dex

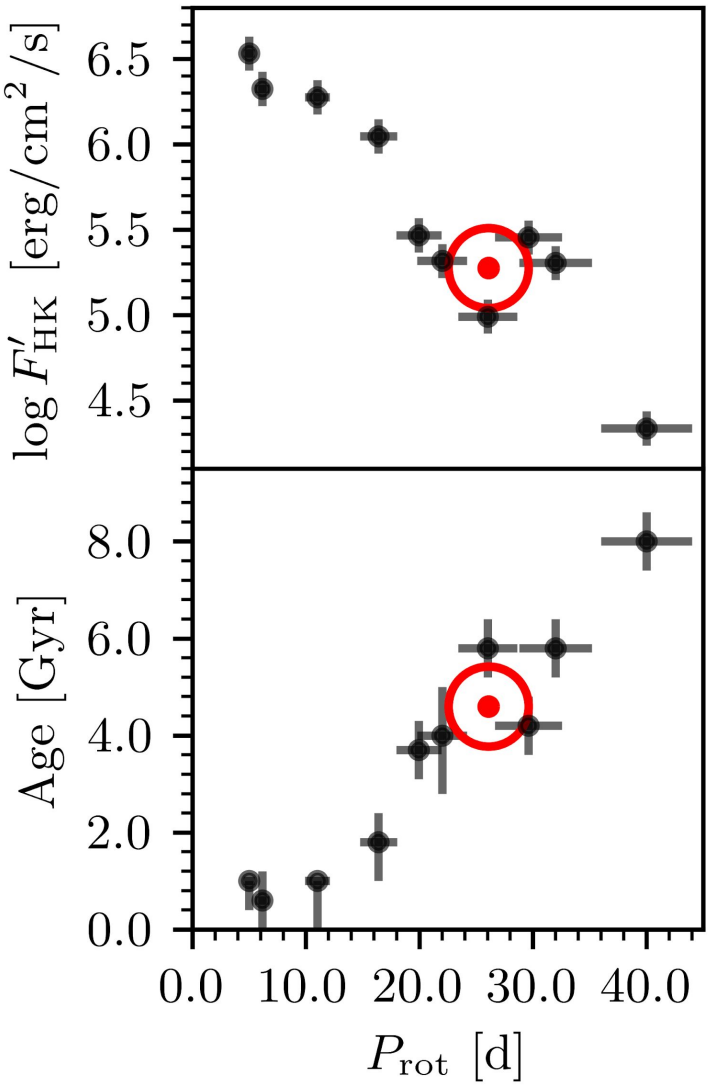
Lack of old solar twins with measured P_{cycle}



Strong mass & [Fe/H] bias in MW sample

Convection that drives the dynamo strongly depends on stellar parameters!





Lorenzo-Oliveira et al. 2018 (in preparation)

- **Reiners & Mohanty 2012 models**
  Skumanich-like Rot. Evolution + Radius evolution from stellar structure models (Kim et al. 2002) and updated Mass-loss rate dependence from O. Fionnagáin & Vidotto 2018

Solar twins P/sini: macroturb. velocities + vsini calib. (dos Santos et al. 2016)

Activity(Rotation) – Age (Lorenzo-Oliveira et al. 2018, dos Santos et al. 2016)

Activity – Mass – Metallicity – Age (Lorenzo-Oliveira et al. 2016)

Solar-Twins → solar [Fe/H], mass and other parameters.