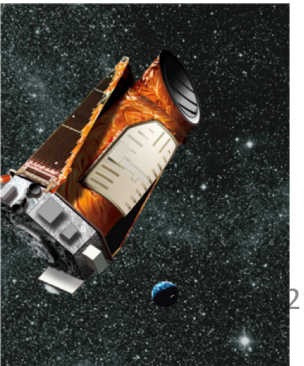
Evolution of magnetic activity on the main sequence as a function of spectral type using Kepler data

Savita Mathur

In collaboration with: A. Bonanno , S. N. Breton, Z. Claytor, E. Corsaro, R. A. García, M. H. Pinsonneault, A. R. G. Santos, J. L. van Saders, and others…



Rotation-Age relation

- For 2 young clusters and the Sun and based on
  - Rotation
  - Magnetic activity
  - Lithium
- Derived a law with age:

$$P_{rot} \sim \tau^{1/2}$$

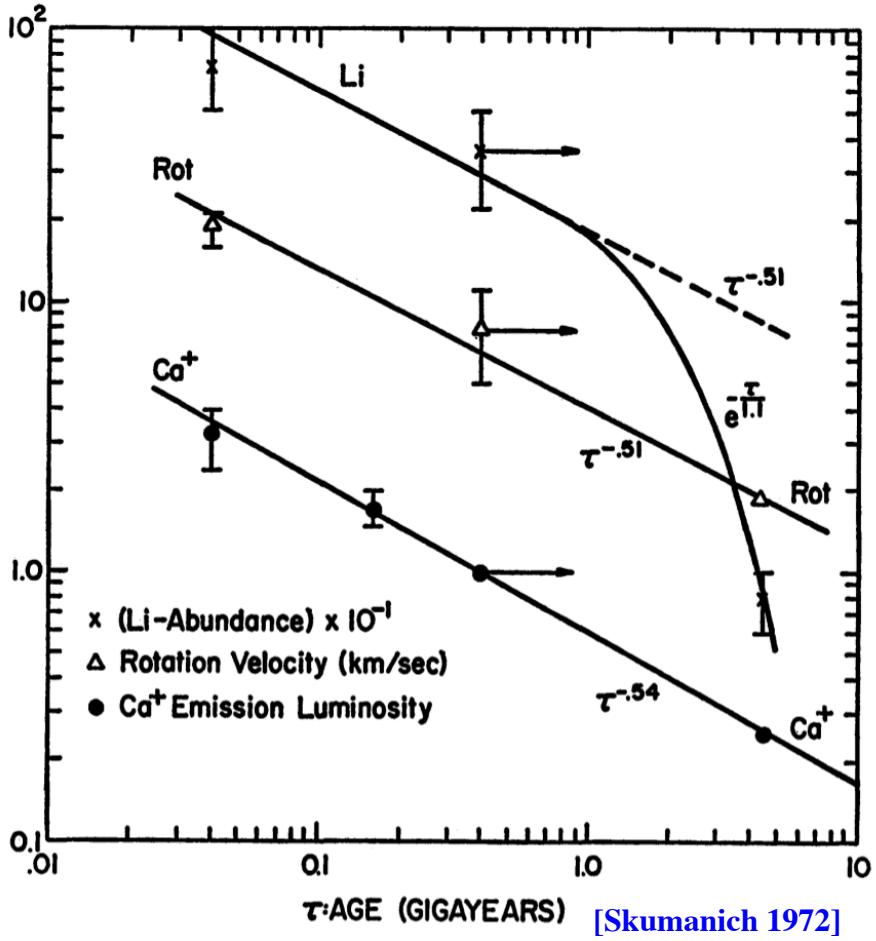
[Skumanich 1972]

[Barnes 2007]

- Angular momentum loss:

$$\left(\frac{dJ}{dt}\right)_{\text{wind}} = K_W \left(\frac{R_*/R_\odot}{M_*/M_\odot}\right)^{1/2} \Omega_*^3,$$

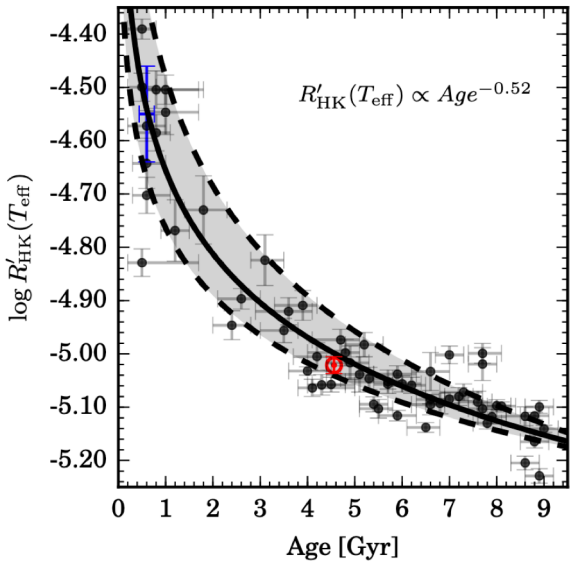
[e.g. Kawaler (1988); MacGregor & Brenner (1991)]



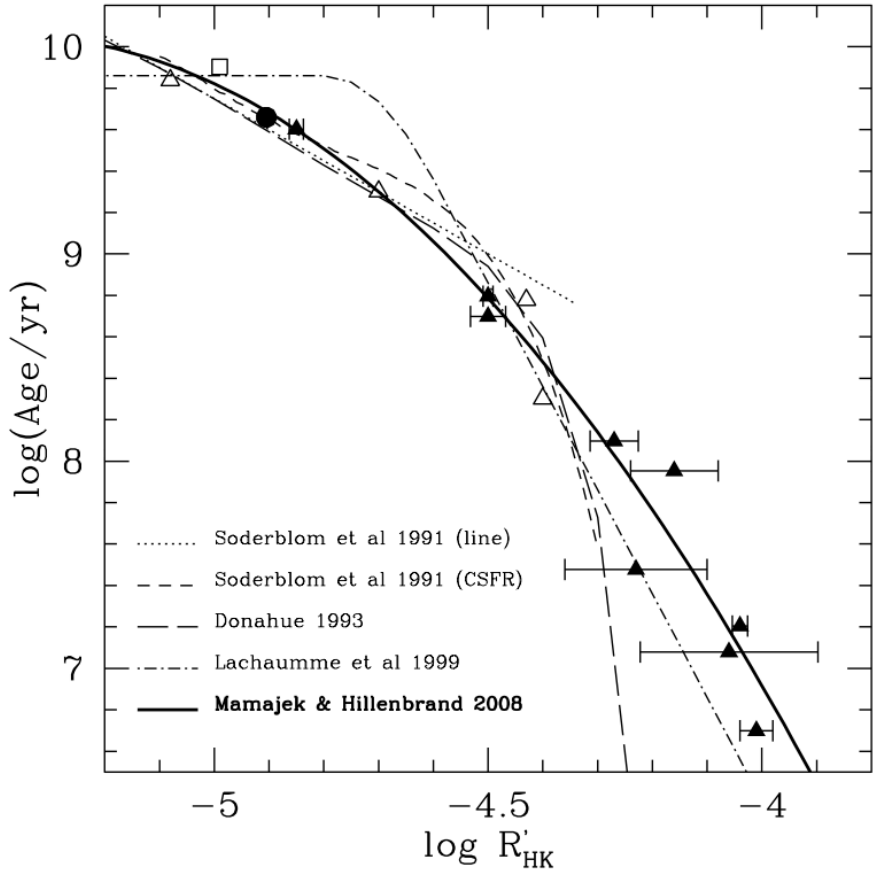
[Skumanich 1972]

Magnetic activity-age relation

- R'_{HK} index of young clusters with known ages and field stars with isochronal ages
- Derive a relation R'_{HK} vs Age
- Also dependence with B-V
- Solar twins
  - Activity-age relation
    - Up to 6-7Gyr?



[Lorenzo-Oliveira et al., 2018]

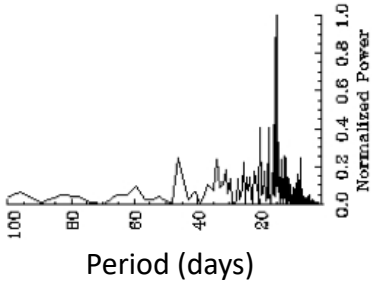


[Mamajek & Hillenbrand, 2008]

Rotation

- Periodogram

  [e.g. Nielsen et al. 2013, Reinhold et al. 2013]



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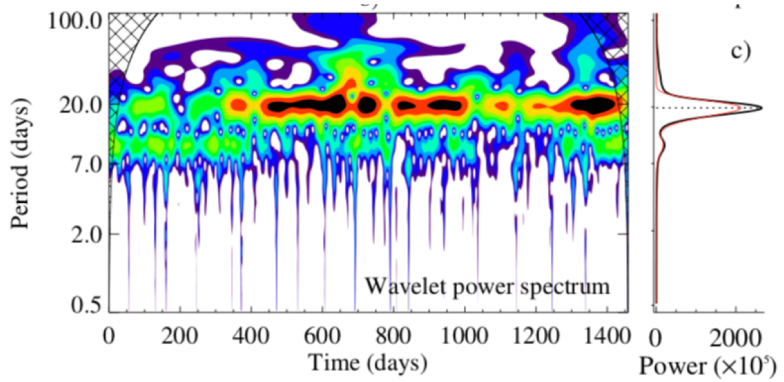
See Poster#39

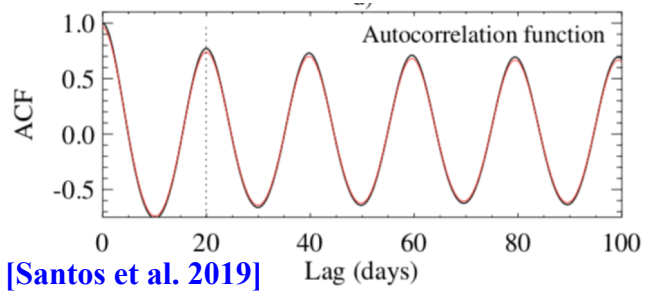
- Time-frequency

  [e.g. Mathur et al. 2010; Ballot et al. 2011; Mathur et al. 2014]



- Auto-correlation

  [e.g. McQuillan et al. 2013a, b; García et al. 2014]



[Santos et al. 2019]

- Machine learning: ROOSTER

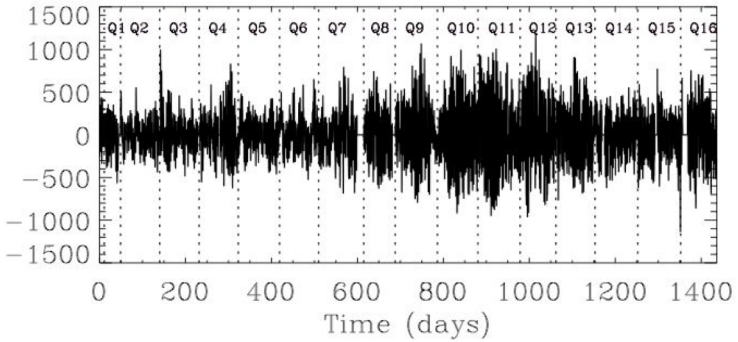
  [Breton et al. 2021]

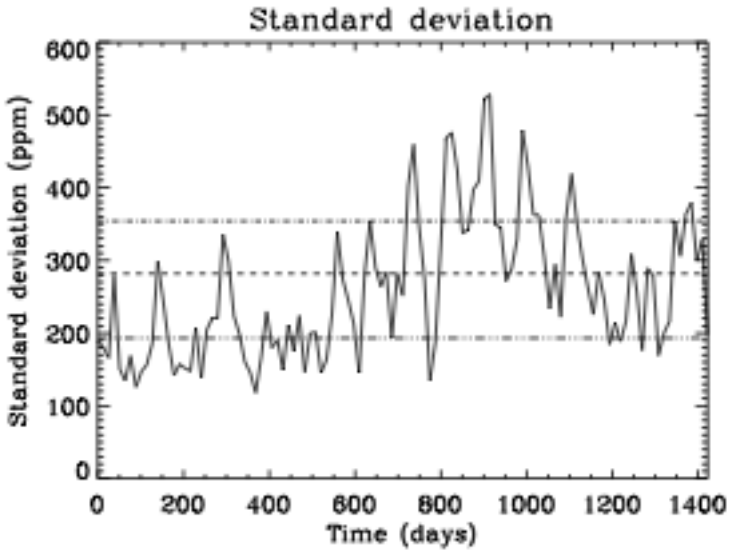
See Poster#17 S. Breton

Magnetic Activity

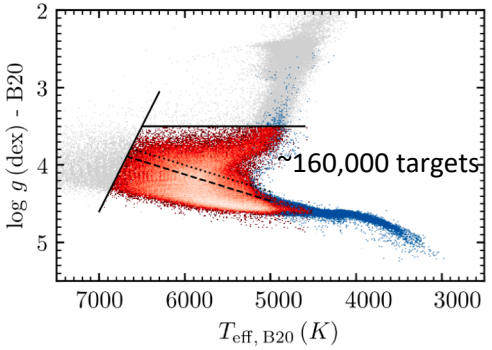
- Global index: $< S_{ph} >$
  - Subseries of length k x P_{rot}
    - ✓ **k = 5**

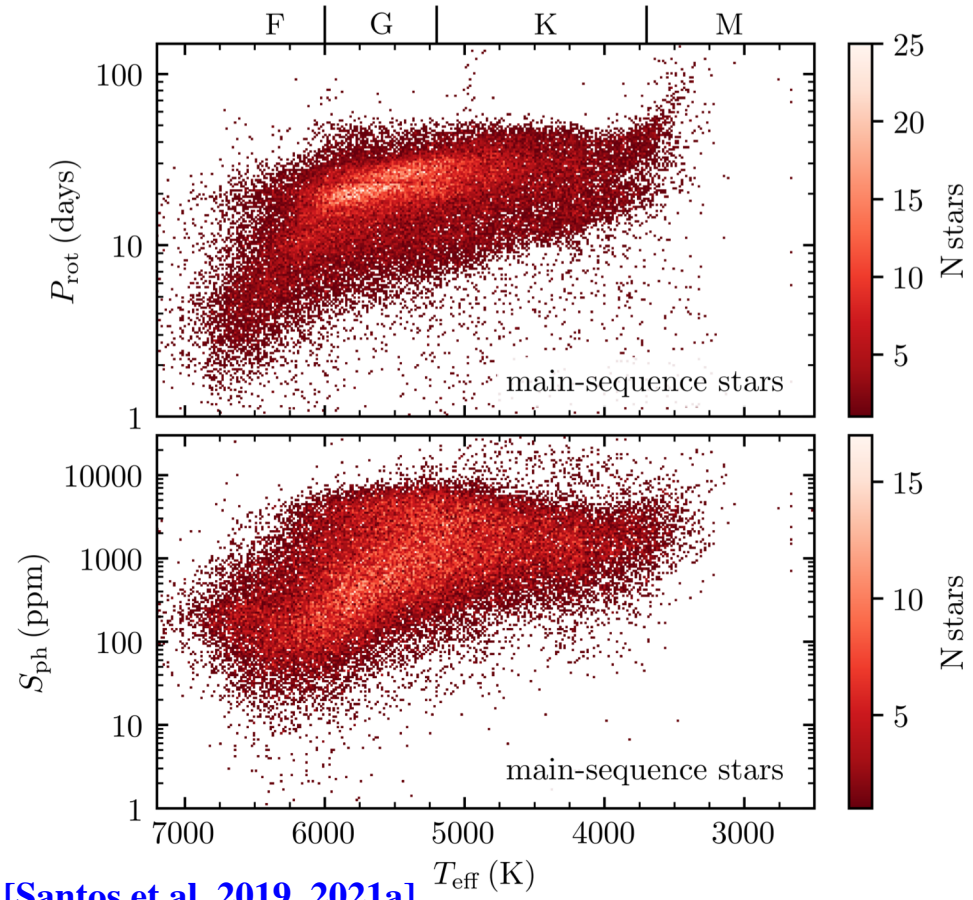
[Mathur et al., 2014a; Mathur et al. 2014b]

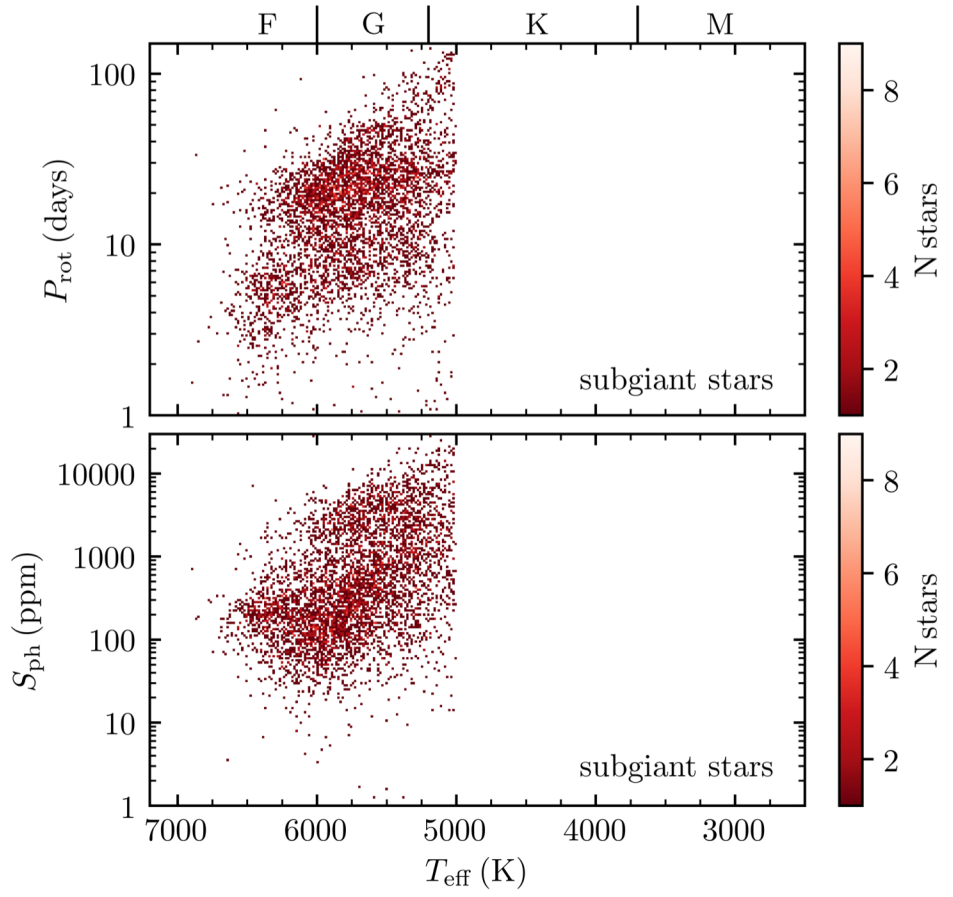




New catalog of *Kepler* rotation: 55,000+ F, G, K and M dwarfs and subgiants



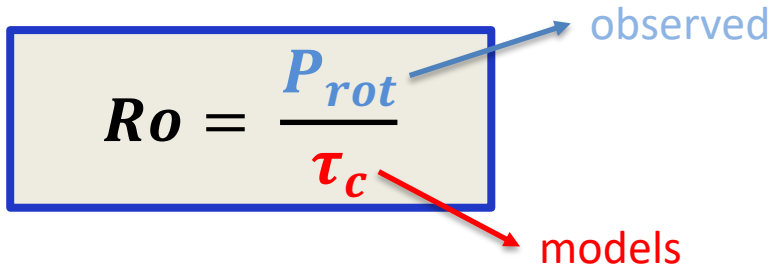




[Santos et al. 2019, 2021a]

Rossby number

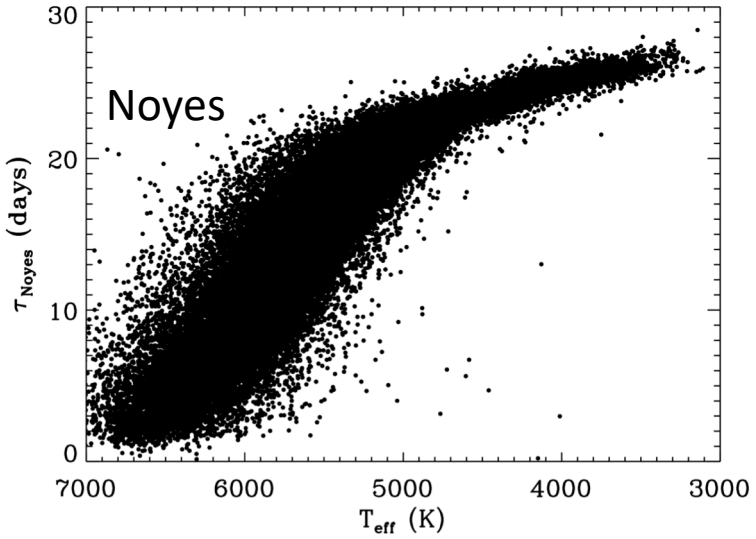
- Key parameter for dynamo models

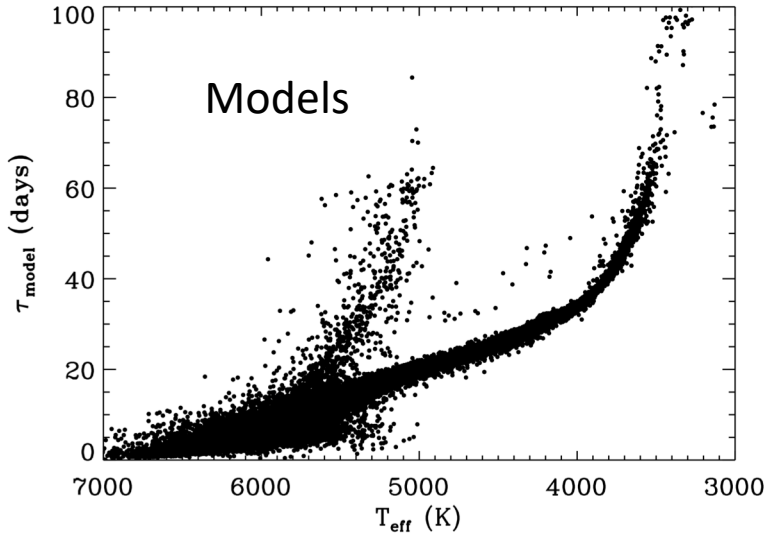


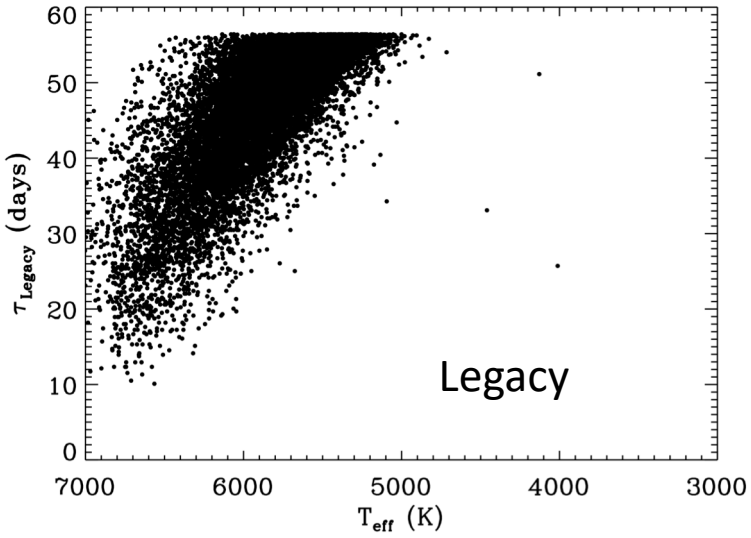
- Different techniques to compute
  - Semi-empirical:
    - Dependence on B-V [e.g. Noyes et al. 1984, Pizzolato et al. 2013, Wright et al. 2011]
    - Legacy: calibration with seismic sample [Corsaro et al. 2021]
  - Models:
    - Models: fitting T_{eff}, logg, [Fe/H], P_{rot} [van Saders et al. 2016; Claytor et al. 2020]
    - Fluid: 3D numerical simulations of convection for rotating stars

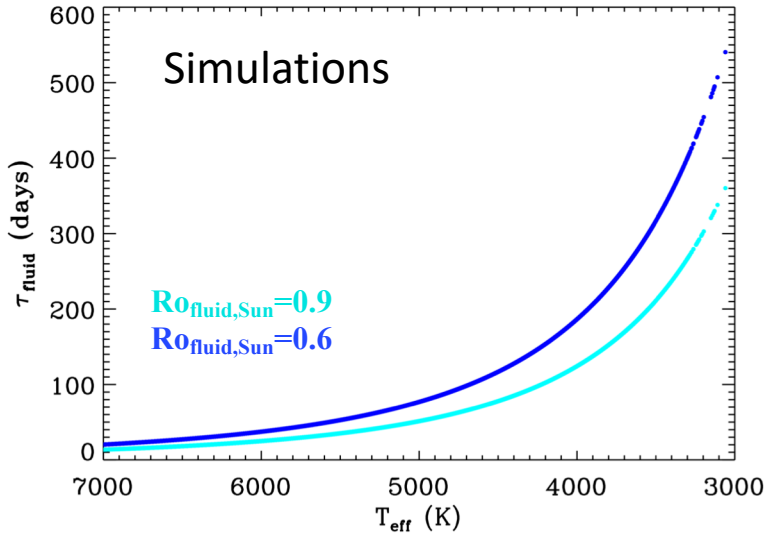
[Brun et al. 2017; Noraz et al. in prep.]

Comparison of convective turnover times









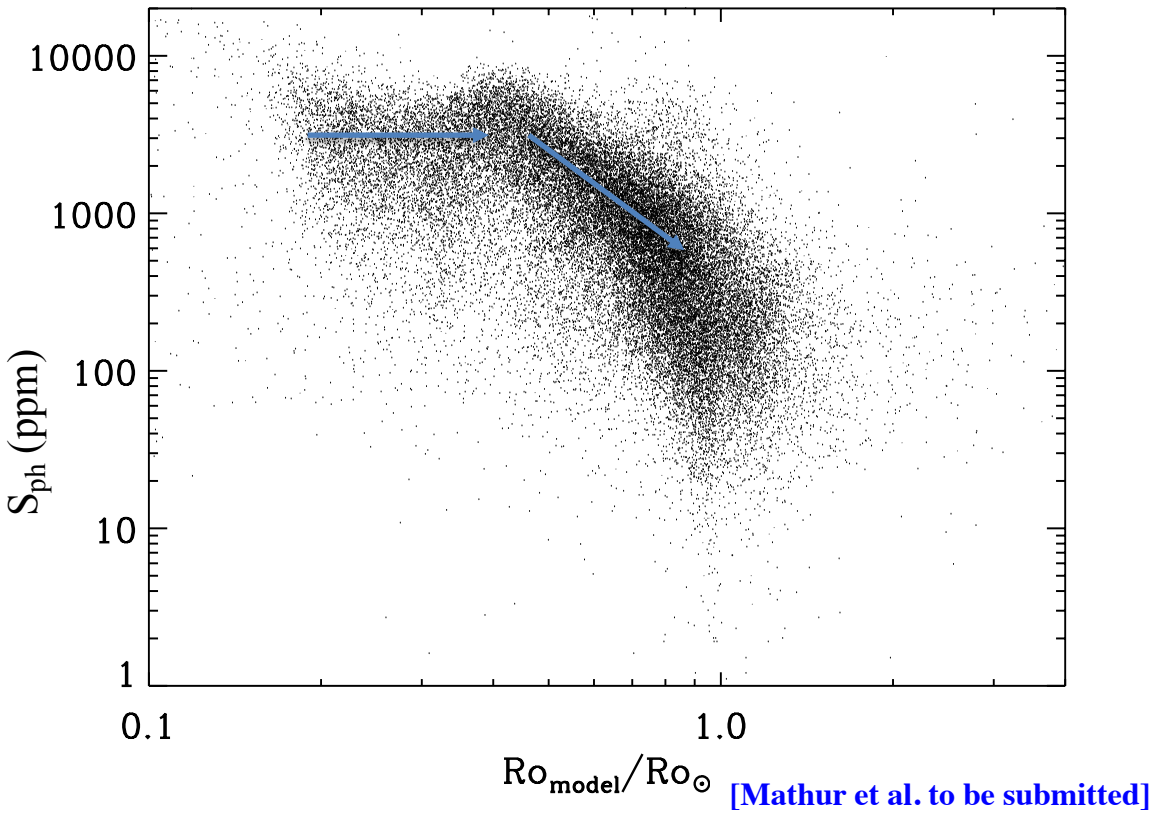
Caveat of each method:

- Noyes: only MS, no F stars
- Legacy: B-V range
- Models: fast launch only
- Simulations: dependence on T_{eff}; only MS and solar [Fe/H] (for the moment)

[Mathur et al. to be submitted]

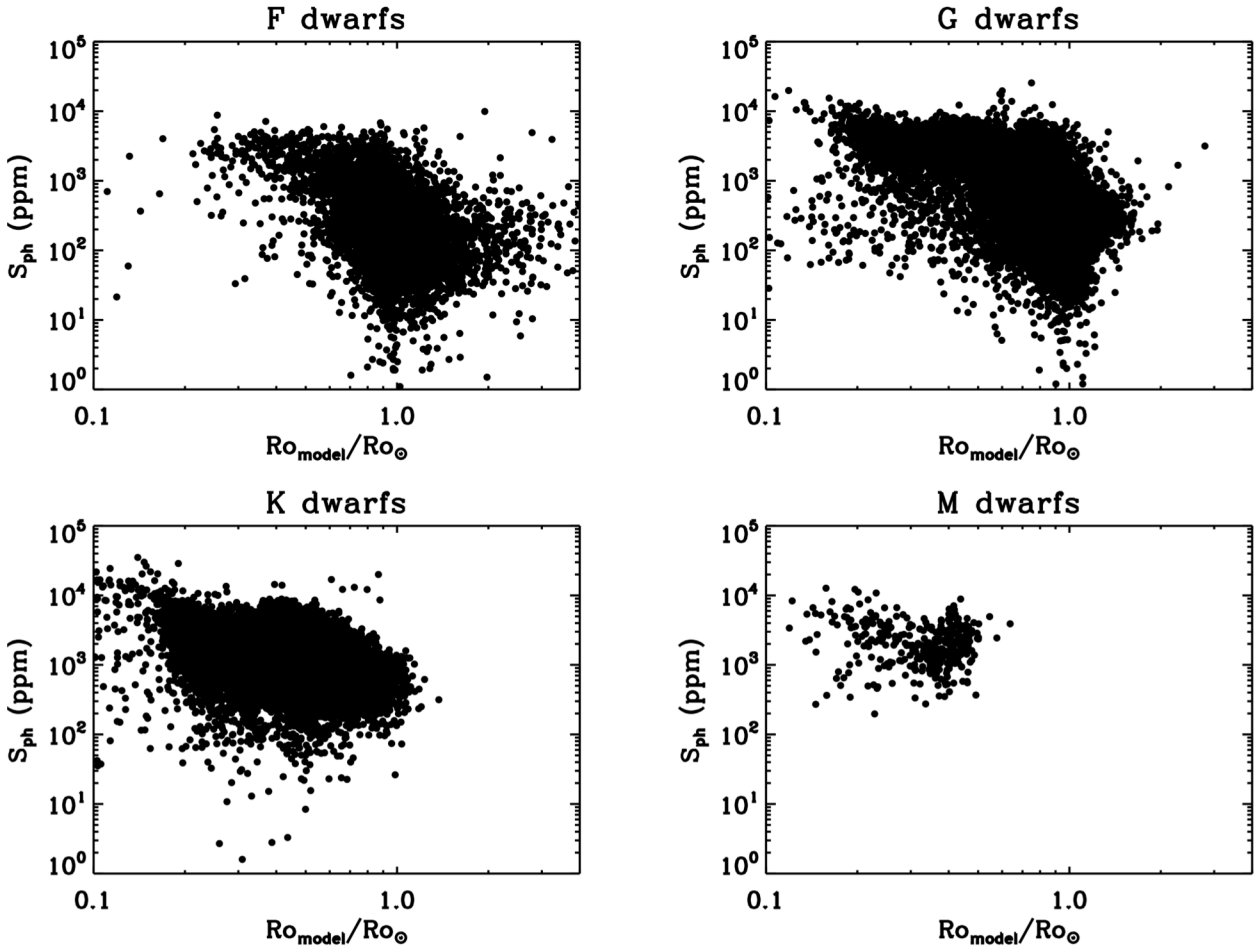
S_{ph}-Ro model

- Magnetic activity proxy S_{ph} [Santos et al. 2019, 2021a]
- Normalized to solar Ro for ~40,000 stars (only MS)
- Similar shape for other samples and magnetic proxies: [e.g. Wright et al. 2018; Yang & Liu 2019; Brown et al. 2021; Johnstone et al. 2021]
  - Saturation [e.g. Wright et al. 2011]
  - Decrease with Ro after a given Rossby number
  - Kink [e.g. Reinhold et al. 2019, See et al. 2021]
  - Dispersion



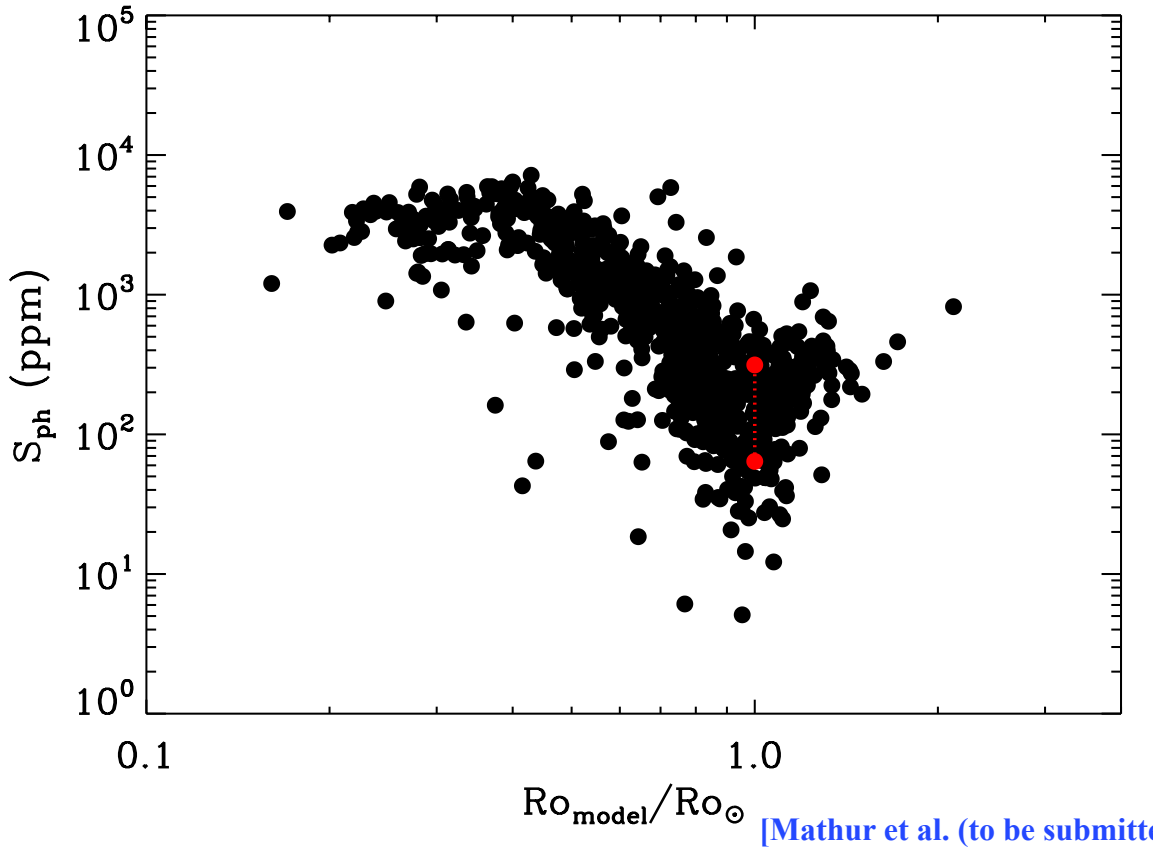
[Mathur et al. to be submitted]

S_{ph}-Ro with spectral type



Select “Sun-like” stars

- Is the Sun magnetic activity similar to Sun-like stars? See Poster#3 A. Santos
- Select *Kepler* targets:
  - Only stars with spectroscopy (APOGEE, LAMOST…)
  - Solar T_{eff} +/-100K
  - Solar [Fe/H] +/-0.1dex
- Between minimum and maximum activity the Sun appears to be in the bulge of the Sun-like sample



[Mathur et al. (to be submitted)]

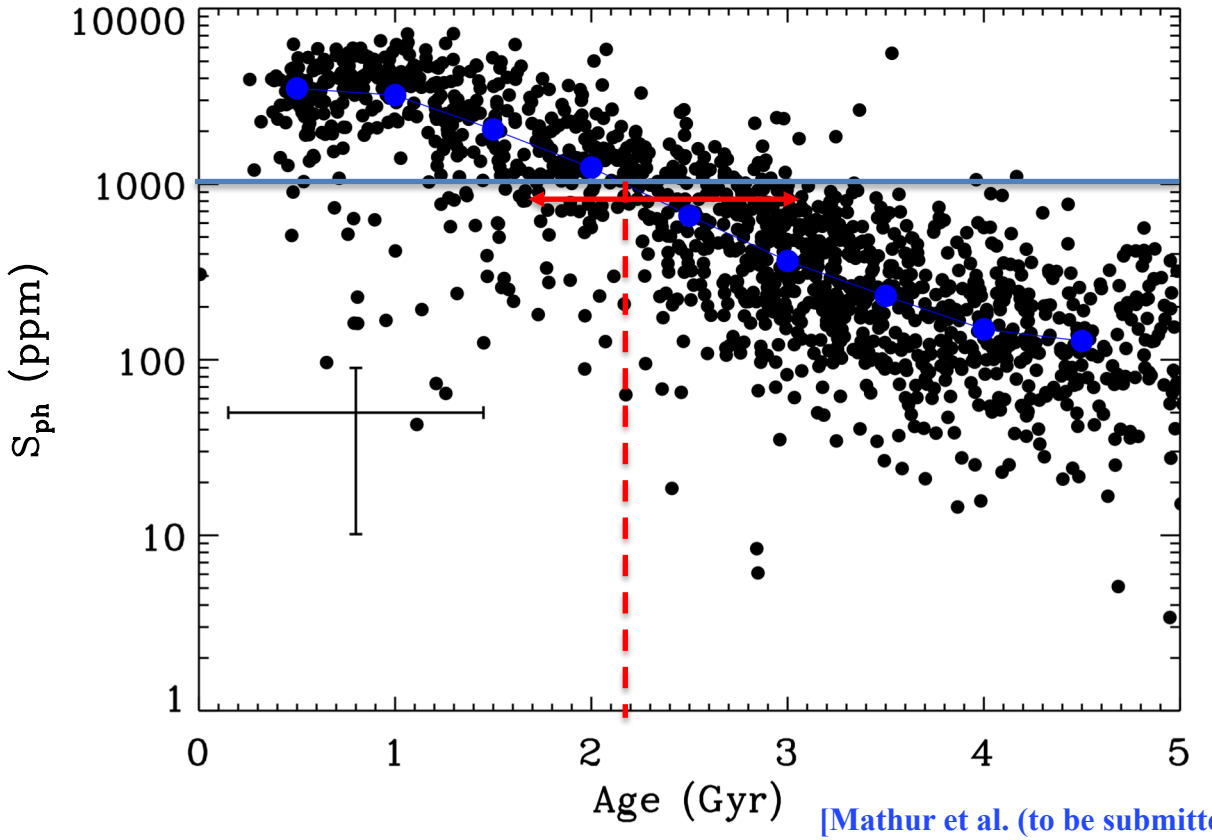
A reliable S_{ph}-Age relation?

- Select *Kepler* targets:
  - Only stars with spectroscopy
  - Solar T_{eff} +/-100K
  - Ages from models

- If S_{ph}~1000ppm -> age~ $2.2^{(+0.8\ -0.4)}$Gyr
- If S_{ph}~200ppm -> age~4+/-1Gyr

- For a given range of T_{eff} and for ages up to ~4-5Gyr

Also see Poster#15



[Mathur et al. (to be submitted)]

Conclusions

- ❑ Sample of ~40,000 MS stars observed by *Kepler* for ~4 years:
  - With rotation periods and magnetic activity proxy See Poster#17
  - Rossby from models
  - Ages from models
- ❑ Solar analogs seem to behave like the Sun
- ❑ For a G-type star (close to solar T_{eff} and [Fe/H]):
  - S_{ph}-age relation from 1 Gyr up to ~5 Gyr PLATO!

- ➢ Need more spectroscopic data to refine relations
- ➢ Improve measurement of rotation periods with TESS and PLATO
- ➢ Improve gyrochronology relations See Poster#6
- ➢ Lifetime of spots/active regions, variability (Santos et al. 2021b; in prep.) See Poster#3
- ➢ Looking for cycles (Kashyap et al. in prep.)