The Continuous Time Spectrum of Long-Term Activity of the Fast-Rotating K2 Dwarf V833 Tau

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Long-term activity variation of V833 Tau and the Sun

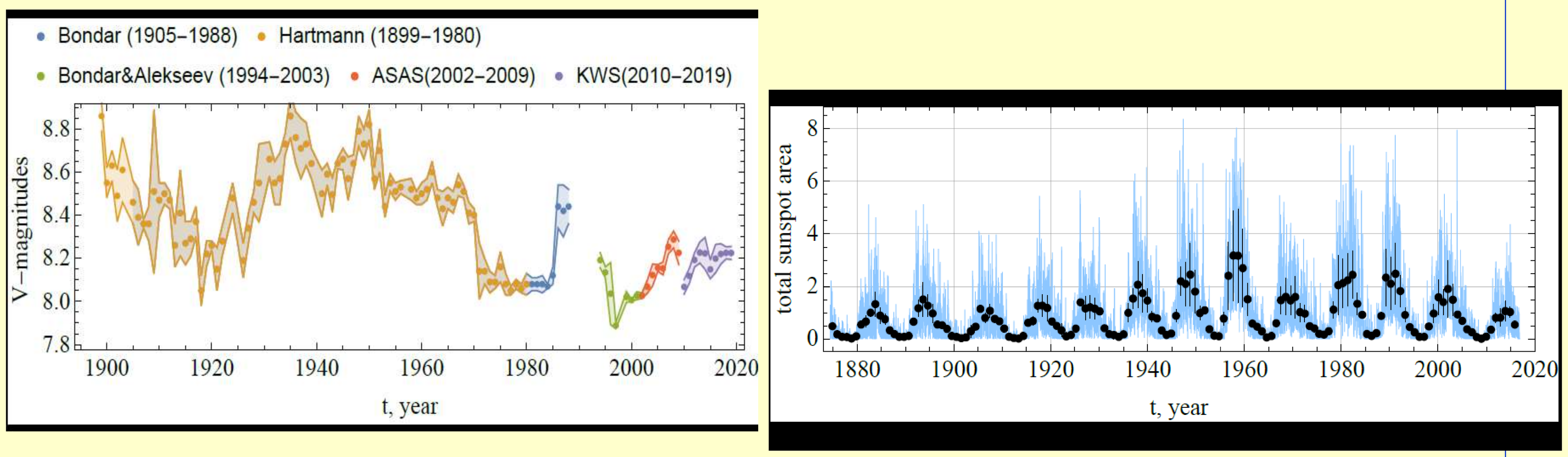


***Fig. 1 (left):** Long-term variations of the yearly mean V magnitudes of the star V833 Tau over 120 yr (1899–2019). The ordinate axis is digitized so that the minimal brightness of a star corresponds to the maximal activity (increasing of the starspot number);*
***(right): t**he total sunspot area as observed by the Royal Greenwich Observatory for the period 1874–1976 and extended to 2016 by the USAF/NOAA data set (given in units of 10^{-9} of solar disk). Daily variation is shown by blue curve, and yearly mean and variance are shown by black dots with bars.*

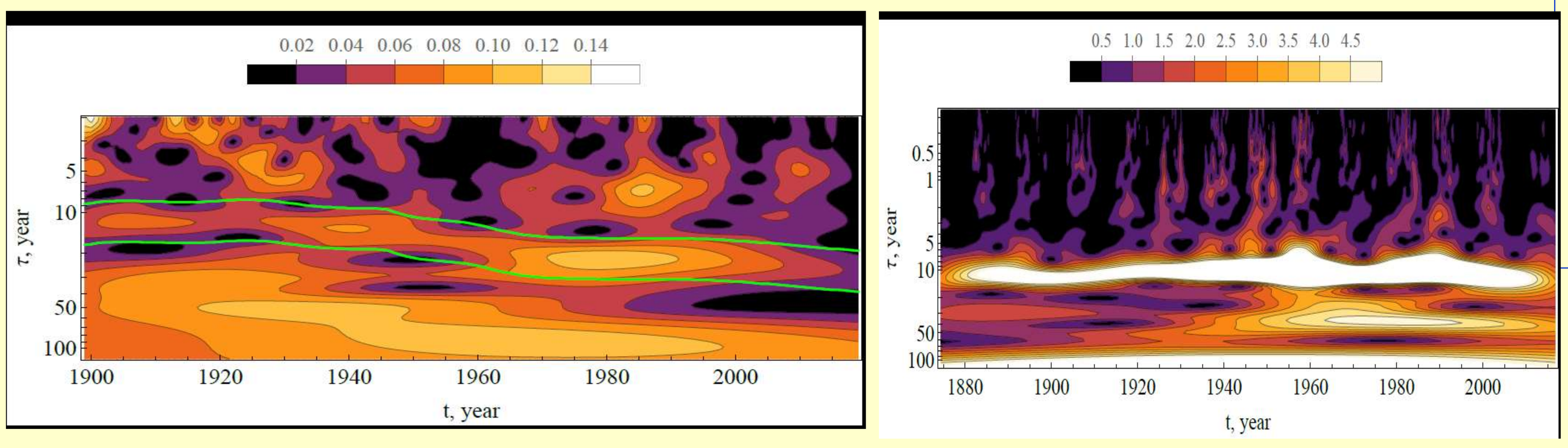


***Fig.2 (left):** Wavelet spectrogram for the magnetic activity of V833 Tau ($|w_1|$). Green lines highlight the range of scales at which the continuous oscillation is traced for further reconstruction; **(right):** Wavelet spectrograms for the solar data (white area denotes clipped values $|w_{1/2}| > 5$).*

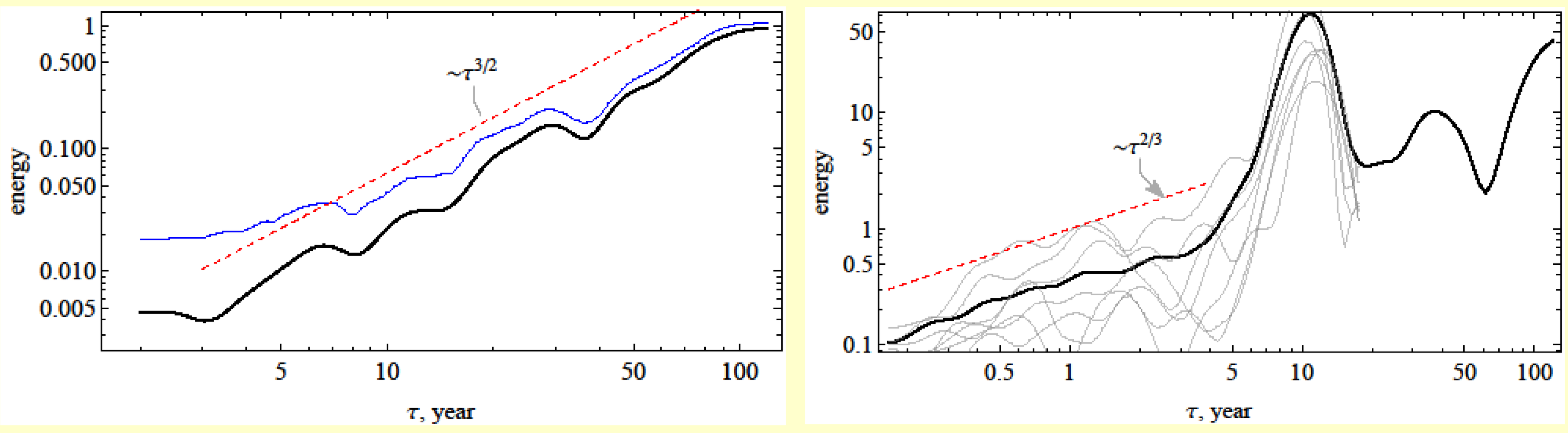


***Fig.3 (left):** Integral wavelet spectrum for V833 Tau (black curve). Blue thin curve shows the upper boundary of 0.9 confidential interval;*
***(right):** Solar activity spectra: integral wavelet spectrum for the whole data series (thick curve) and for subsequent 22-yr intervals (thin curves).*

Acknowledgements

Results presented here were obtained with partial support by the Russian Foundation of Basic Researches grant19-02-00191, and the grant 075-15-2020-780 (N13.1902.21.0039) by Ministry of Science and Higher Education of the Russian Federation.

References

N.I.Bondar', M.M.Katsova, V.V.Pipin, R.A. Stepanov, D.D. Sokoloff, I.G.Usoskin., P.G.Frick 2021, Discrete and continuous spectra for solar and stellar activity Geomagnetism and Aeronomy, in press

*P. Frick, D. Sokoloff, R. Stepanov, V. Pipin, I. Usoskin 2020, Spectral characteristic of mid-term quasi-periodicities in sunspots data, MNRAS, **491**, 5572-5578,*

M.M.Katsova, N.I.Bondar , M.A.Livshits 2015, Solar-type activity: Epochs of cycle formation, Astronomy Reports, 59 (7),726-735

B.A.Nizamov, M.M.Katsova, M.A.Livshits 2017, Change in the activity character of the coronae of low-mass stars of various spectral types, Astronomy Letters, 43, 202

A.Reiners, M. Schuessler, V.M.Passegger 2014, Generalized Investigation of the Rotation-Activity Relation: Favoring Rotation Period instead of Rossby Number ApJ, 794, 144

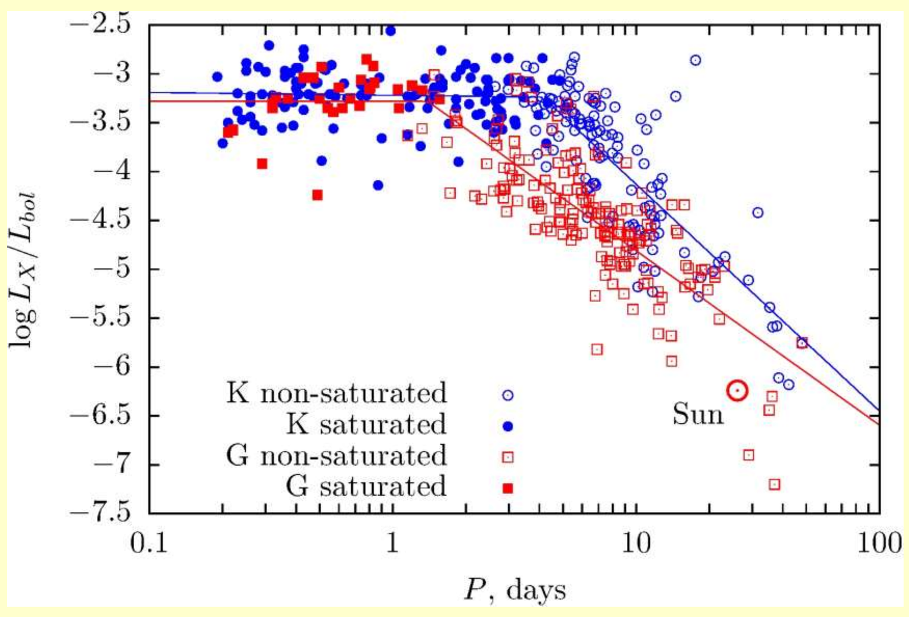
*R. Stepanov, N. I. Bondar', M. M. Katsova, D. Sokoloff, and P. Frick 2020, Wavelet analysis of the long-term activity of V833 Tau MNRAS, **495**, 3788*

N. J. Wright, J. J. Drake, E. E. Mamajek, and G.W. Henry, 2011, The Stellar-activity-Rotation Relationship and the Evolution of Stellar Dynamos. Astrophys. J. 743, 48

Abstract The magnetic activity of the Sun and low-mass stars demonstrates often a cyclic behavior. Some stars exhibit solar-like activity cycles, while some show irregular cycles; there are several stars with double or multiple cycles which serve to challenge the underlying theoretical understanding. This is why a consistent method to separate 'true' cycles from stochastic variations is required. We suggest that a conservative method, based on the best practice of wavelet analysis previously applied to the study of solar activity, for studying and interpreting the one of the longest available stellar activity record – photometric monitoring of young, fast-rotating dwarf V833 Tau (K2.5 V) for 120 yr.

We find that the observed brightness variations of V833 Tau with time-scales of 2–50 yr should be comparable with the known quasi-periodic solar mid-term variations, whereas the true cycle of V833 Tau, if it exists, should be of about a century or even longer. We argue that this conclusion does not contradict the expectations from the stellar dynamo theory. Activity of this star is close to the saturated regime, and we expect, that the stellar dynamo in this mode enhances the quasi-stationary magnetic field with chaotic changes, but without a pronounced cycle. However, we cannot completely exclude the scenario that V833 Tau has essentially an unstable dynamo and its cycle length varies within the period of 10–40 yr.

On the Saturated Activity Regime



V 833 Tau (dK 2.5e)

T_{eff} = 4450 K
M=0.8 M_{sun}
R=0.77 R_{sun}
P_{rot} = 1.78 day
log L_X = 29.92
log L_X/L_{bol} = – 2.98

From the analysis of the Catalog *«Activity-rotation properties for 824 stars»* by Wright et al. (2011) and application of a method proposed by Reiners et al. (2014), we obtained for G and K stars separately that a turn from saturation to solar-type activity takes place at the rotation period around 1 day for G stars and at 3 days for K stars (Nizamov et al. 2017) while Reiners et al. (2014) estimated this value as 1.4 days for all F–M stars.

Thus, a regular cycle begins when the saturated regime of activity changes to the solar-type one, in which the activity level depends on the rotation period (Katsova et al. 2015). Nizamov et al. (2017) showed that the activity of late spectral-type K stars transitions to exhibiting regular cycles when its rotation period is equal to 3 days. It opens a possibility that V833 Tau, in its stellar evolutionary stage, still did not reach the stage to exhibit pronounced cyclic activity.

Conclusions:

Observational data concerning solar and stellar activity are presented usually in terms of activity cycles. Analyses of solar activity data supported by corresponding analysis of magnetic activity data of the star V833 shows however that the wording activity cycle includes however two physically different phenomena. First one is represented by conventional solar 11-year cycle. Data accumulation results in a more and more pronounced peak in the integral wavelet spectrum which corresponds to this cycle. The phenomena of second type can be considered as elements of continuous temporal spectrum. We believe that the wording cycle is adequate for the phenomena of the first type only.

This distinction for stellar and solar dynamo modeling is of importance.