Boletim da Sociedade Astronômica Brasileira, **30**, no. 1, 79-80

Rotation periods and variability properties of active KEPLER stars

P. P. Cabral, E. N. Velloso, D. T. da Costa, L. L. Amorim, F. A. J. de Lima, J. M. Varela, J. V. Ferreira, L. de Almeida, A. C. Matiucci, F. Anthony, J. S. da Costa, M. Castro, & J.-D. Jr. do Nascimento

[1] Dep. de Física. Universidade Federal do Rio Grande do Norte, UFRN, CP 1641, 59072-970, Natal, RN, Brazil

Abstract. *Solar analogs are major targets to understand the solar dynamo*. The KEPLER NASA satellite observed continuously thousands of stars and providing a unique dataset for which stellar variability can be studied. In this paper, we present the first results from the under-graduation project at the GE^3 UFRN team, to perform a semi-automated variability analysis of the full KEPLER dataset. We analyzed thousands of light curves (all quarters) to derive rotation periods and a proxy of activity. Our data set is composed by main-sequence with masses around 1 solar mass. Our method to detected rotation periods was based on autocorrelation function and Lomb-Scargle analysis. Our goal it is to derive consistently rotation period and a proxy of variability for a large sample of active solar analog stars for further spectroscopic studies.

Resumo. *Análogas solares são objetos importantes na compreensão do dínamo solar.* O satélite KEPLER da NASA observou continuamente milhares de estrelas e forneceu um conjunto de dados exclusivos para o qual a variabilidade estelar pode ser estudada. Apresentamos aqui os primeiros resultados do projeto de graduação de alunos do GE^3 da UFRN, onde uma análise da variabilidade estelar foi feita de forma semi-automatizada e com os dados do KEPLER. Analisamos milhares de curvas de luz (todos os trimestres) para derivar períodos de rotacão e um indicador da atividade. Nosso conjunto de dados é composto por estrelas de 1 massa solar na sequencia principal. Os períodos de rotacão foram determinados com funcão de autocorrelacão e análise Lomb-Scargle. Nosso objetivo é derivar consistentemente a rotacão e um variabilidade para uma grande amostra de análogas solares ativas para estudos espectroscópicos.

Keywords. Stars: activity – Stars: rotation – Stars: solar-type

1. Introduction.

The stellar rotation period reflects the history of the angular momentum evolution of the star. Along the early phases of stellar evolution, and on the main-sequence lifetime, stars lose angular momentum and spin down. For stars like the Sun, also known as low-mass stars, this angular momentum loss is driven by a magnetized wind that is connected to the stellar outer convection zone evolution (e.g., Kawaler 1988; Bouvier et al. 1997). In recent years, the stellar rotation study has significantly developed thanks to new observational efforts and new techniques. Specifically, 4 years of uninterrupted photometry with a high level of precision and time sampling, for a large stellar sample by KEPLER space mission (Borucki et al. 2010) has improved a lot the study of stellar rotation. KEPLER space telescope obtained the light curves of the stars in the selected region of the sky and each star was photometrically observed along the wavelength band from 423 to 897 nm (Borucki et al. 2010). Brightness variations detected by KEPLER are commonly attributed to the presence of magnetic structures (sunspots, active regions, etc) in the surface of main-sequence cool dwarfs. As for the Sun, G-type star observed by KEPLER presents a similar behavior. The dark sunspots correspond to the concentrated strong magnetic field that emerges on the photosphere. The bright faculae correspond to the enhanced network magnetic field (Solanki et al. 2006). Sunspots and solar active regions have lifetimes of days to weeks and are used as tracers of solar surface rotation. In this context, this new data of stellar variability allows rotation periods to be detected for several types of stars. Period measurements for older stars remain very rare and hard to be measured, because old stars rotate slowly and are less active than their younger counterparts. Active regions and spots on the stellar surface drive the variability and effects can all lead to a complex periodogram structure, with spurious peaks from jumps and long-term systematics, and multiple or split peaks from spot evolution or differential rotation. Typical stellar light curves are complex, and we can say that there are neither sinusoidal nor strictly periodic ones and the time-evolving nature of these active regions distribution needs to be deeply studied. Young stars are more active, and rotation period determination can be straight. Extremely active stars can also be complex and challenging to determine which peak in the periodogram corresponds to the to the stellar rotation period. Active moderate stars in the KEPLER dataset gives reliable rotation measurements for from F-, G-, and K-type to M-type stars. In this study, we took data from KEPLER mission to analyze light curves from solar-type stars in order to determine (and verify) its rotation periods P_{rot} and relations with their variability ΔV, obtained by a stellar signal model methods. Those are solar analogs, stars with around 1 solar mass, an effective temperature between 5700 and 5900 Kelvin and a surface gravity between 4.3 and 4.5.

2. Extracting the surface rotation rates and the variability index.

Starspots and active regions are present over rotations of cool stars. Continuous observation of a star with a high cadence photometric satellite produces a light curve, which could be analyzed as a time series by specific techniques and then revealing systematic variations. Rotation, planets and systematic phenomena will produce a peak the periodogram of the time series. Assuming starspots trace surface rotation, this provides a way to measure the rotation rate of the star. In this study, the average surface P_{rot} is obtained from light curve modulation analysis. To extract the P_{rot}, we analyze PDC-MAP and simple aperture photometry light curves that are corrected for outliers, drifts, and

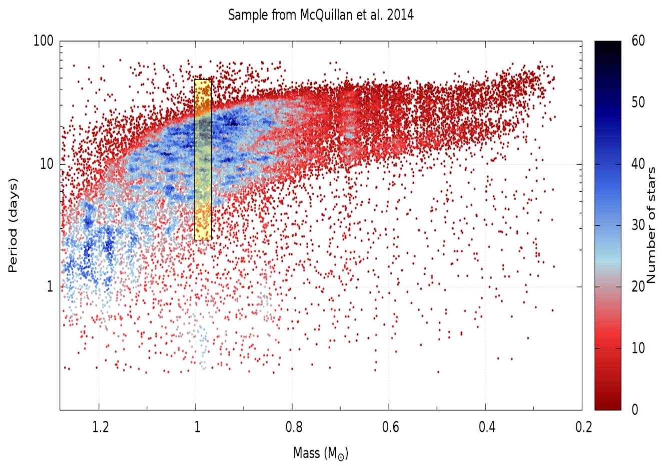

Figure 1. Rotation period versus mass for 34 000 field stars from McQuillan et al. (2013) and McQuillan et al. (2014). Rotation periods derived using AutoACF. The mass was derived from models of Baraffe et al. (1998). We included the yellow shaded regions representing our selected data set.

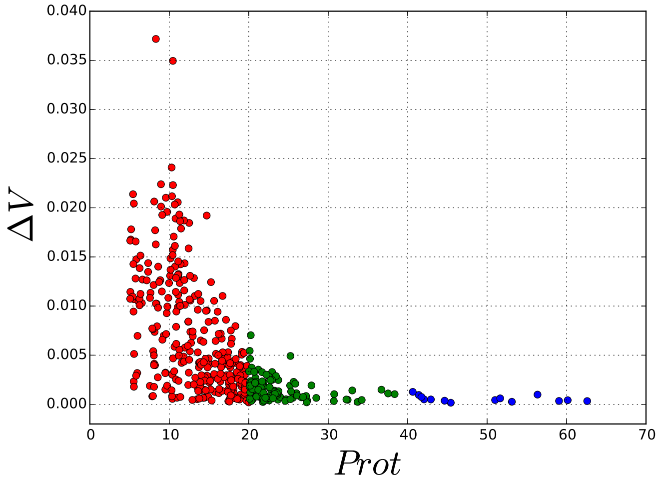

Figure 2. Variability ΔV versus rotation period P_{rot} in the rotation range 1–20 days (red); 20–40 days (green); and 40–70 days (blue) blown up from Fig. 1 for around 1 solar mass. Red symbols are the most active stars.

discontinuities and stitched together following the procedures described by do Nascimento et al. (2014). The light curves are then high-pass filtered using a triangular smooth function with a cutoff that can change from 40 to 100 days. Finally, we computed the autocorrelation of the signal (McQuillan et al. 2013) in order to cross-check the results. We fit a Gaussian function to the global wavelet, i.e., the projection into the frequency domain of the time-frequency analysis, and the uncertainty was obtained from the full width at half-maximum of the Gaussian profile. This uncertainty includes the P_{rot} variation due to differential rotation.

The gradual fluctuations due to magnetic features (starspots and faculae) dynamics on stellar surfaces could be also used as a proxy of activity (He et al. 2015). Fluctuation amplitude of a stellar light curve is generally not uniform, we define a quantity, ΔV, to represent the effective range of the light-curve modulation, based on the splined model of the light curve. These quantities were used to construct the Fig. 2, for a range of stars with masses around 1 solar mass, as indicated by the yellow region on the Fig. 1. This proxy describes the degree of periodicity and effective fluctuation range of the light curve. The combination of rotation and amplitude modulation are complementary on the analysis of solar-type stars.

3. First look conclusions.

We produce a first catalog of active start with rotation and activity measurements. We have presented an analysis of rotation-activity connection, so far extensively studied and well established for field stars observed from the ground. Here we are presenting an unprecedented sample of solar-type stars with rotation period determined from space-borne mission and mass around 1 solar mass. Study of stellar activity-rotation relation is important because it can provide new constraints for dynamo models when combined with surface rotation rates and the depth of the convection zone.

As a main result, we show that the KEPLER light curve amplitude variation for solar analogs can be adopted as an indicator of photospheric magnetic activity. The scattering observed in the Figs. 1 and 2 seem to show manifestations of spot dynamics and stellar cycle. The complexities related to the light-curve modulations by magnetic features on the Sun, exist on other solar-type stars, and need to be better understood. Spectroscopy observations seem to be essential to better define the mass, metallicity, convection profile for those stars.

Acknowledgements. The authors thank CAPES/CNPq and the Federal University of Rio Grande do Norte for financial support.

References

Baraffe, I., Chabrier, G., Allard, F., et al. 1998, A&A, 337, 403
Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977
Bouvier, J., Forestini, M., & Allain, S. 1997, A&A, 326, 1023
do Nascimento, J.-D., Jr., García, R. A., et al. 2014, ApJ, 790, L23
He, H., Wang, H., & Yun, D. 2015, ApJS, 221, 18
Kawaler, S. D. 1988, ApJ, 333, 236
McQuillan, A., Mazeh, T., & Aigrain, S. 2013, ApJ, 775, L11
McQuillan, A., Mazeh, T., & Aigrain, S. 2014, ApJS, 211, 24
Solanki, S. K., Inhester, B., & Schüssler, M. 2006, Reports on Progress in Physics, 69, 563