A&A 650, A40 (2021)
https://doi.org/10.1051/0004-6361/202140287

Astronomy & Astrophysics

Multiscale behaviour of stellar activity and rotation of the planet host Kepler-30

D. B. de Freitas[1,2], A. F. Lanza[1], F. O. da Silva Gomes[2], and M. L. Das Chagas[3]

[1] INAF-Osservatorio Astrofisico di Catania, Via S. Sofia 78, 95123, Catania, Italy
[2] Departamento de Física, Universidade Federal do Ceará, Caixa Postal 6030, Campus do Pici, 60455-900 Fortaleza, Ceará, Brazil
e-mail: danielbrito@fisica.ufc.br
[3] Faculdade de Física â Instituto de Ciências Exatas, Universidade Federal do Sul e Sudeste do Pará, Marabá, PA 68505-080, Brazil

Received 5 January 2021 / Accepted 26 March 2021

ABSTRACT

Context. The Kepler-30 system consists of a G dwarf star with a rotation period of ~16 days and three planets orbiting almost coplanar with periods ranging from 29 to 143 days. Kepler-30 is a unique target with which to study stellar activity and rotation in a young solar-like star accompanied by a compact planetary system.

Aims. We use about 4 yr of high-precision photometry collected by the *Kepler* mission to investigate the fluctuations caused by photospheric convection, stellar rotation, and starspot evolution as a function of timescale. Our main goal is to apply methods for the analysis of time-series to find the timescales of the phenomena that affect the light variations. We correlate those timescales with periodicities in the star and the planetary system.

Methods. We model the flux rotational modulation induced by active regions using spot modelling and apply the Multifractal Detrending Moving Average algorithm in standard and multiscale versions to analyse the behaviour of variability and light fluctuations that can be associated with stellar convection and the evolution of magnetic fields on timescales ranging from less than 1 day up to about 35 days. The light fluctuations produced by stellar activity can be described by the multifractal Hurst index that provides a measure of their persistence.

Results. The spot modelling indicates a lower limit to the relative surface differential rotation of $\Delta\Omega/\Omega \sim 0.02 \pm 0.01$ and suggests a short-term cyclic variation in the starspot area with a period of ~34 days, which is close to the synodic period of 35.2 days of the planet Kepler-30b. By subtracting the two time-series of the simple aperture photometry and pre-search data conditioning *Kepler* pipelines, we reduce the rotational modulation and find a 23.1-day period close to the synodic period of Kepler-30c. This period also appears in the multifractal analysis as a crossover of the fluctuation functions associated with the characteristic evolutionary timescales of the active regions in Kepler-30 as confirmed by spot modelling. These procedures and methods may be greatly useful for analysing current TESS and future PLATO data.

Key words. stars: activity – stars: rotation – techniques: photometric – stars: individual: Kepler-30 (KOI-806)

1. Introduction

Stellar rotation is a fundamental physical parameter in stellar astrophysics and plays an important role in the formation and evolution of stars (Kraft 1967; Skumanich 1972; Kawaler 1988). Rotation controls stellar magnetism, mixing in the stellar interior, and tidal interactions in close binary systems. Moreover, the relationship between rotation and magnetic activity has important implications for the detectability and characterisation of planets orbiting solar-like stars (Maxted 2016; Collier Cameron 2018). Such stars make up the vast majority of the *Kepler* exoplanet targets and also allow us to investigate stellar variability due to magnetic activity. In particular, starspots and active regions in the stellar photospheres modulate the stellar flux on the rotation period (Walkowicz & Basri 2013).

The *Kepler* space mission found several multi-planet systems, one of which is the star orbiting Kepler-30 (KOI-806), which has nearly solar mass and radius, an effective temperature of 5500 ± 55 K, and a rotation period of ~16.0 days as measured using the Lomb–Scargle periodogram (Sanchis-Ojeda et al. 2012; Lanza et al. 2014). These properties make it a very interesting young solar analogue, motivating our choice to investigate its rotation and activity behaviour. Moreover, it is orbited by three planets named Kepler-30b, Kepler-30c, and Kepler-30d with masses of 9.2, 536 (~1.7 Jupiter masses), and 23.7 Earth masses, radii of 3.75, 11.98, and 8.79 Earth radii (Panichi et al. 2018), and orbital periods of 29.3, 60.3, and 143.3 days (cf. Sanchis-Ojeda et al. 2012), respectively. Based on the values of radius and mass, Panichi et al. (2018) estimated that Kepler-30b is a Neptune-like planet rather than a super-Earth, Kepler-30c is a Jovian planet, while Kepler-30d is classified as a Neptune-mass planet, with bulk densities given by ~0.96 g cm^{-3}, ~1.71 g cm^{-3} , and ~0.19 g cm^{-3}, respectively. In this system, the orbits of the planets are on the same plane, almost perpendicular to the stellar spin, a behaviour similar to our Solar System. As a consequence, we observe Kepler-30 almost equator-on. This provides a fundamental constraint to reduce the degeneracies in the spot modelling of the star, an additional motivation for applying our approach (see Sect. 4). Using the spot modelling, Bonomo & Lanza (2012) and Lanza et al. (2019) performed an analysis for the star Kepler-17, a solar-like star younger than the Sun hosting a hot Jupiter that occults starspots during transits. In both studies, the authors analysed the activity and rotation of this star using starspots as tracers, comparing the longitudes of the