Stars and their variability observed from space
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PRE-MAIN SEQUENCE GRAVITY-MODE PULSATORS IN K2

L. Ketzer[1] and K. Zwintz[1]

Abstract.
Campaigns 2, 9, 13 and 15 in the extended *Kepler* mission (K2) pointed towards young star forming regions, which host pre-main sequence (pre-MS) stars. Currently only a handful of pre-MS gravity (g-)mode pulsators of the γ Doradus and Slowly Pulsating B (SPB) types are known. We used archived K2 data to search for additional members of these two classes of young oscillators, and discovered 13 previously unknown pre-MS g-mode pulsators. In one of our targets we detect a period spacing sequence, which made this one a prime candidate for future asteroseismic modelling efforts. By increasing the known sample size of young gravity-mode pulsators we laidthe groundwork for future studies aimed at probing the location and extent of the pre-MS instability strips, and also an investigation into a possible observable relation between the g-mode pulsation properties and the evolutionary state of a star.

Keywords: Asteroseismology, Stars: oscillations, Stars: pre-main sequence

1 The power of gravity-mode pulsators

Gravity-mode pulsations have great probing power for deep stellar interiors because observations of them enable us to probe indirectly the physical conditions close to the core. That makes g-mode pulsators sought-after targets in the field of asteroseismology. Much information can be extracted from the detection of period-spacing sequences, in which consecutive modes are evenly spaced in period. Chemical composition gradients in the stellar interior, however, induce periodic dips in these period-spacing patterns (Miglio et al. 2008), and stellar rotation causes the spacings of certain pulsation modes to be sloped (Ouazzani et al. 2017). Those deviations can be used to measure the near-core rotation rate, and they give hints about the evolutionary state of the star. Bouabid et al. (2011) showed that no strong mean molecular-weight gradient is expected in pre-MS stars, and thus the period-spacing patterns should not present any of the periodic dips that are observed for many more evolved stars (see e.g., Van Reeth et al. 2015; Pápics et al. 2017). Consequently, period-spacing sequences can present a way of distinguishing between very young stars and more evolved ones, an achievement which often proves ambiguous when tackled from atmospheric properties alone.

2 Pre-main sequence pulsators in the K2 data

Up to now, only 15 pre-MS gravity-mode pulsators have been identified (Gruber et al. 2012; Zwintz et al. 2013, 2017; Ripepi et al. 2015). One key challenge is the short pre-MS lifetime of these intermediate mass B-, A- and F-type γ Dor and SPBs. FUrthermore, their pulsation periods, which are of the order of 0.3–3 days, make them challenging to find with ground-based equipment. We therefore examined the three well-known regions with ages less than $\sim$10 Myr within the K2 fields for young pulsating stars. Campaigns 2 and 15 pointed to the Upper Scorpius region and the embedded ρ Ophiuchus star-forming region; Campaign 9 observed the open cluster NGC 6530 within the Lagoon Nebula, and Campaign 13 contained the Taurus–Auriga star-forming region. We conducted a literature search to compile a sample of roughly 500 stars associated with the regions of interest. We then downloaded several different light-curve products available in the MAST archive, and searched for pulsations using a tool called SMURFS*, which performs a quick frequency analysis of a time-series based on the Lomb–Scargle periodogram. If a star in our sample showed multiple significant frequencies in the g-mode regime that cannot be explained as rotational modulation or binarity, we conducted a thorough literature search on this individual target and compiled a list of additional criteria of 'youth'. If a star had been associated as a member (usually from kinematics), and shows additional youth indicators like an X-ray, IR or UV excess, Hα emission or a high lithium abundance, we could be confident that that target was likely to be still in its pre-MS stage. Additional spectroscopic follow-up observations are then required to determine if a pre-MS candidate is indeed located above the the zero-age main-sequence on the spectroscopic Kiel diagram.

[1] University of Innsbruck, Institute for Astro- and Particle Physics, Technikerstr. 25, 6020 Innsbruck, Austria
*`https://smurfs.readthedocs.io/en/master/`

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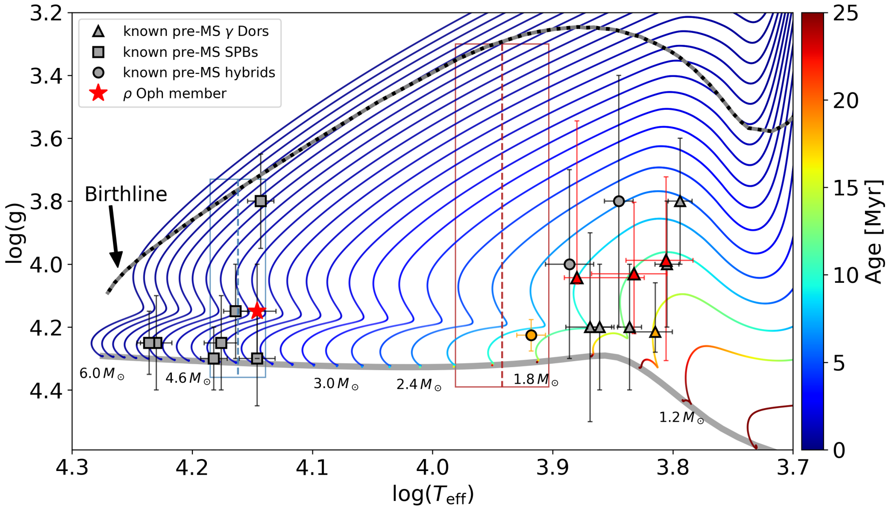

Fig. 1. Kiel diagram, showing all known pre-MS pulsators before K2 (grey), together with 8 candidates discovered in the K2 data (colour). SPBs are marked as squares, γ Dors as triangles and the hybrid stars as circles. The evolutionary tracks (T.Steindl, priv. communication) are colour-coded to indicate stellar age along the pre-MS.

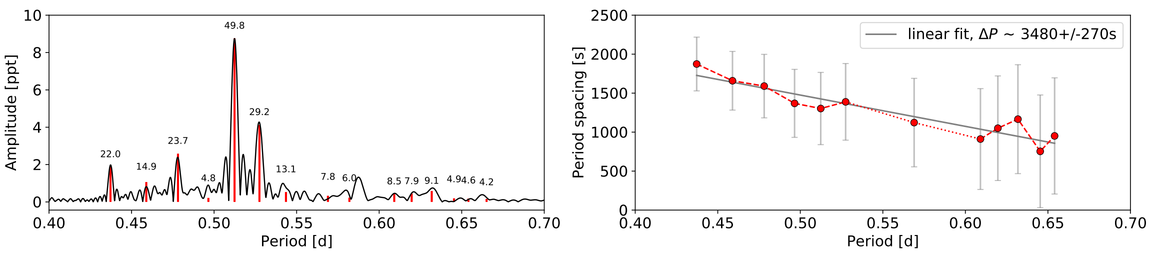

Fig. 2. Left: Periodogram with all frequencies identified as part of the period spacing pattern marked in red, together with the corresponding SNR values. **Right**: Plot of ΔP vs. P, illustrating the extracted period spacing sequence. A linear fit to the pattern is shown in grey.

3 Results and Outlook

Among our sample of $\sim$500 young stars we found 13 promising candidates for pre-MS γ Dor or SPB pulsators. In another 13 either we could not rule out the presence of pulsations, or we were uncertain about the pre-MS nature of the candidate. For one of our 13 prime candidates we found archived spectra, which enabled us to place the star in the Kiel diagram and confirm its pre-MS SPB nature. For two other targets we have only spectroscopic temperature estimates available, and for another three we used the EPIC temperature and surface gravity estimates to place them on the Kiel diagram (see Fig 1). Our next step is to conduct follow-up spectroscopic observations of our candidates in order to obtain reliable constraints on their atmospheric parameters. One of our young g-mode pulsators in the Lagoon Nebula shows strong indications of a sloped period-spacing pattern (see Fig 2), making it a promising target for future asteroseismic modelling. If this star turns out to be a γ Doradus type, it would be the first pre-MS star in this pulsator class with a period-spacing detection. With almost 30 known pre-MS gravity-mode pulsators now, it is becoming feasible to probe the location and extent of the pre-MS instability strips, and investigate whether an observable relation exists between the g-mode pulsation properties and the evolutionary state of a star, similar to the one found for pre-MS δ Scuti stars (Zwintz et al. 2014).

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