K2 Asteroseismology of O-type Stars

Msc. Bram Buysschaert[1,2], Prof. Dr. Conny Aerts[2] & Dr. Maryline Briquet[3,1]

1. Paris Observatory (F); 2. KU Leuven (B); 3. Université de Liège (B)

Current scientific status and science objectives

The most massive stars in the Universe have spectral type O and they evolve ultrafast. Their life is not only dominated by their bulk properties such as birth mass and initial metallicity. Rather, various physical processes alter their evolution significantly. This does not only concern their mass loss but also the unknown internal mixing of chemical species by, e.g., convective core overshooting, interior rotation, semi-convection, all of which can be strong effects or rather inhibited by magnetism. Unlike the mass loss, these internal mixing processes are ill constrained from data and imply huge uncertainties on the evolution of O-type stars and by implication on the chemical enrichment of galaxies.

Asteroseismology is so far the only effective way to provide a precise calibration of mixing in the interior of stars. This has not yet been achieved for O stars, because **only 14 of them have been monitored with uninterrupted high-precision space photometry, but none for more than a month.** In our recent study, Buysschaert et al. (2015, MNRAS, 453, 89) provided a successful proof-of-concept of the method from K2 Campaign 0 data and have shown that future K2 monitoring during at least three months, accompanied by time-resolved high-precision high-resolution spectroscopy opens up the possibility of in-depth O-star seismology. **This DDT proposal has the purpose to move from a proof-of-concept from Campaign 0 to an actual application by monitoring the 12 O stars in the field of Campaign 9.**

As reviewed by Buysschaert et al. (2015, MNRAS, 453, 89), about half of the 14 monitored O stars so far exhibit pulsational behaviour and it comes in at least three possible flavors: heat-driven pressure and gravity modes probing the envelope and core region, respectively, and convectively driven gravity waves that are accompanied by angular momentum transport (e.g., Aerts et al. 2010, Springer; Mathis et al. 2014, A&A, 565, 47). Successful seismic modelling requires us to detect and identify heat-driven modes with frequency precision at the level of the theoretical frequency predictions given the above mentioned unknown physical processes, which requires at least some 100 days of uninterrupted monitoring for O-type stars. Previous studies have shown that the pulsations of O stars have amplitudes at the level of parts-per-thousand or lower. They are thus not accessible with ground-based observations having moderate duty cycle, in line with efforts to detect them in such data the past decades. Space photometry is hence the only way forward, as demonstrated by CoRoT and K2 Campaign 0. The only shortcoming in these data that prevented seismic tuning of the mixing processes was the too short timebase leading to inaccurate pulsation frequencies.

Methodology

Target selection To reach our science objectives, we cross-matched all known O-type stars on SIMBAD with the boresight pointing of Campaign 9. In total, 12 O-stars in this observing field fall on silicon. This large amount of O-type stars would almost double the observed O stars observed with high precision space-based photometry and would deliver **the first uninterrupted O-star time series longer than a month**. In addition, one of the targets is an eclipsing binary, which offers the **unique opportunity to combine asteroseismic and binary modelling**. We are aware that some of these targets are bright for *Kepler*, but we believe that the uniqueness of the observing field and the type of targets largely make up for their brightness and justify them as targets. We have set priorities according to the lack of data for particular spectral O sub-type, keeping brightness and uniqueness in mind.

Long cadence observations are proposed for all targets in our sample, except for the highest priority eclipsing binary star. For the latter, we request short cadence because it brings the additional potential to perform **eclipse mapping of the pulsations**, if any would be present. This would deliver the very first application of this method but it requires fast cadence during the eclipses, ingress and egress. For all other stars, long cadence is sufficient because the expected frequencies of their heat-driven pulsations are expected to stay well below the Nyquist frequency corresponding with 30 minutes sampling ($\nu_{\rm Nyq} \approx 280\mu$Hz).

General strategy for data interpretation We expect data with better quality than the initial K2 field of Campaign 0 and have already developed tools to construct lightcurves from the provided pixel data. In addition, in-house routines are available to correct for any remaining effects of the roll of the satellite (Buysschaert et al. 2015, MNRAS, 453, 89). The detrended light curves will undergo a detailed frequency analysis to determine whether periodic brightness variations are present. We will use the iterative prewhitening procedure of Degroote et al. (2009, A&A, 506, 471) to retrieve the significant frequencies. Mode identification for each significant pulsation frequency will either be performed by searching for characteristic patterns in the frequency or period spectra and/or from line-profile variations in time-resolved high-resolution high signal-to-noise spectroscopy by imposing the frequency values from the K2 data (see Aerts et al. 2010, Springer, Chapter 6).

A high-resolution grid of MESA (Paxton et al. 2011, ApJS, 192, 3) evolutionary models has been computed in advance. These include different internal mixing processes with varying efficiency. Seismic frequency predictions for each of the MESA models computed with the pulsation code GYRE (Townsend & Teitler 2013, MNRAS, 435, 3406) allow a direct comparison with the observed seismic information for each star, allowing to derive the level and type of mixing.

Ground-based observations We will take time-series high-resolution échelle spectroscopy for the accepted targets using the HERMES spectrograph mounted on the 1.2m telescope in La Palma in Spain to which we have guaranteed access (Raskin et al. 2011, A&A, 526, A69). This enables us to have additional constraints for the seismic modelling of all targets, both in terms of the fundamental parameters and abundances of the stars and of the orbits for the binaries. For the targets brighter than V=8, we will perform time-resolved spectroscopy to identify the degree and azimuthal order of the dominant pulsation modes independently from the K2 photometry. The addition of time-resolved spectroscopic diagnostics to the pulsation frequencies delivered by the K2 photometry provides the inclination angle of the stars, along with rotational velocity information. The targets brighter than V=8 are sufficiently bright to do such joint K2/spectroscopy time-resolved study and this is unique to the K2 O-type targets we propose here.