

# UPBEAT: Unravelling Pulsations of BluE supergiAnTs

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## 1 Blue Supergiants: Scientific Rationale

Blue supergiant (BSG) stars are scarce, evolved stars with massive progenitors ( $M \gtrsim 3 M_{\odot}$ ) at birth time. If more massive than  $\sim 9 M_{\odot}$ , they are destined to undergo a core-collapse supernova. Moderate to rapid rotation, binarity and line-driven mass loss are their three key features. Once hydrogen is depleted in the core of massive stars, they evolve towards the Red Supergiant (RSG) phase on the Kelvin-Helmholtz timescale – which is  $\sim 1000$  times shorter than the nuclear timescale. Thus, the chance of finding BSGs inside the Hertzsprung gap is quite slim: Once found, the opportunity ought be seized!

Evolution of single post-main sequence stars is ambiguous: they either traverse the Hertzsprung gap one time (burning their entire helium on the RSG phase), or cross the Hertzsprung gap multiple times by undergoing a blue-ward evolution from RSG, while burning helium in the core. In fact, this ambiguity stems from the sensitivity of the BSG structure to their mass loss rate, besides mixing (by rotation, overshooting etc.) of material between their convective cores, and radiative envelopes. Moravveji et al. (2012b) proposed that the  $\epsilon$ -mechanism excites high-order dipole g-modes in Rigel (and similar BSGs) on their first crossing. In contrast, Saio et al. (2013) predict that the  $\kappa$ -mechanism excites radial and non-radial modes during the blue-ward (2<sup>nd</sup>) crossing of the HR diagram. Thus pulsation properties of BSGs are directly linked to their evolutionary phase and history. However, the lack of high-quality observations has inhibited solid discrimination between these two competing scenarios. K2 can tackle this, *now!*

Space photometry of pulsating BSGs is scarce, as the nominal *Kepler* mission observed none. Rigel (B8 Ia, Moravveji et al. 2012a) was observed with MOST, and proved to be pulsating. HD 50064 (B1 Ia) was observed with CoRoT for 137 days, and Aerts et al. (2010) demonstrated that episodic mass loss events changed the pulsation amplitude by a factor 1.6. K2 campaign 0 contained  $\sim 10$  BSG candidates (2 Ia + 8 III, that we are actively working on). PLATO is the next ( $\gtrsim 2024$ ) upcoming space mission, planned to deliver high-quality long-duration (3 years) photometry of stars in Galactic plane. The nine-year gap between now and the launch of PLATO can only be filled with K2's visit of the Galactic plane (in Fields 9 and 11). Thus, it is very timely that K2 would observe BSGs in the Galactic disk, and allow the community to exploit the BSG variabilities, and confront that with theoretical predictions. Then, K2 will lead high-impact astrophysical understanding of the progenitors of core-collapse supernovae.

## 2 Current Status of K2 BSGs

The K2 engineering campaign 0 pointed near the Galactic disk, offering  $\sim 10$  BSG candidates. We are currently collecting ground-based high-resolution high-SNR spectroscopy of these targets. Our *preliminary* analysis of the combined spectroscopy and K2 photometry is presented on the  $\log T_{\text{eff}} - \log g$  plane in Figure 1. We compare the theoretical instability strips (Moravveji 2016) of heat-driven p-modes (red), g-modes (blue), and hybrid pulsators (grey) – destabilized by the classical  $\kappa$ -mechanism – versus the position of two newly discovered K2 BSGs from campaign 0. Outside instability strips, stars are predicted to be pulsationally stable. Star #2 does not show any significant variability within the K2 point-to-point scatter, and we identify it as pulsationally stable. Clearly, the position of this BSG is compatible with our theoretical prediction. In contrast, star #1 is an unambiguous pulsator, and falls in a region where no pulsation instability is predicted, posing a challenge to the theory.

From our initial result, we conclude that the *niche* of K2 is detecting and characterizing intrinsic variability among evolved stars. The same was demonstrated for O-type main-sequence stars by Buysschaert et al. (2015). However, the short time coverage of campaign 0 ( $\sim 30$  days of useful data) provides poor

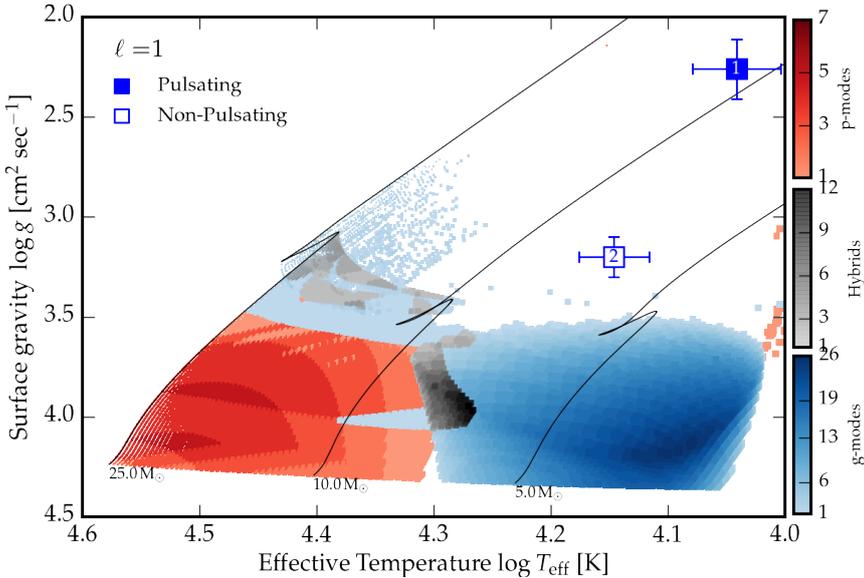


Figure 1: Instability strips (Moravveji 2016) of dipole g-modes (blue), p-modes (red), and hybrid pulsators (grey) for massive stars between 3 and  $25 M_{\odot}$ , from main sequence up to post-main sequence phase. Colorbars encode number of excited modes. Evolutionary tracks are overplotted. Two BSGs from campaign 0 are shown, for which HERMES spectra are taken. Star #1 shows clear variability in the light curve, whereas star #2 is stable within K2 noise level in the Fourier frequency spectrum.

frequency resolution ( $\sim 0.03 \text{ d}^{-1}$ ), and prohibits detailed frequency interpretation. Fortunately, the K2 photometric precision, and the 3-month continuous observations during campaign 9 tackles this shortcoming, and provides superior frequency resolution suited for asteroseismology of BSGs. The available limited number of potential BSG candidates in field 0 hampers solid conclusion on the origin of pulsations in BSGs. With the additional BSG candidates in field 9, the size of the BSG sample can be increased by factor four in one shot. That will hopefully allow the drawing of a comprehensive picture on the observational boundaries of stability versus instability strips beyond core H-burning phase. Thus, K2 is ready to deliver a paradigm shift in Unravelling Pulsations of Blue Supergiants (UPBEAT).

### 3 Blue Supergiants in K2 Field 9

Since BSGs reside in the Galactic disk, high-precision space photometry of BSGs is uniquely possible during K2 campaigns 9 and 11. For field 9, **38** BSGs fall on the silicon. Based on Simbad, they belong to luminosity classes Ia, Ib, II, and III, with spectral types ranging from B0 to B9, and magnitude  $8 \lesssim V \lesssim 12$ . Pulsation periods in BSGs roughly range from half-a-day to weeks; thus, the long-cadence 3-month K2 photometry is crucial to obtain  $\sim 0.01 \text{ d}^{-1}$  frequency resolution, needed for robust frequency analysis.

For the proposed targets brighter than  $\sim 9^{\text{th}}$  magnitude, we *guarantee* simultaneous ground-based high-resolution spectroscopic follow-up with the HERMES ( $R \sim 85\,000$ , Mercator Telescope, La Palma, 1.2 m) and HIDES ( $R \sim 65\,000$ , OAO, Okayama, 1.9 m) spectrographs. Fainter targets ( $9 \lesssim V \leq 12$ ) will be also monitored, but with lower cadence during the whole campaign. The spectra will be used for a thorough spectroscopic analysis (extracting detailed abundances,  $T_{\text{eff}}$ ,  $\log g$ ,  $v \sin i$ ,  $v_{\text{macro}}$ ,  $\dot{M}$ , and  $v_{\infty}$ ), in addition to radial velocity variability (due to binarity), line profile variability (due to pulsations and/or spots), and  $H\alpha/H\beta$  line variability (due to possible episodic mass loss).

The combined spectroscopy and K2 photometry will be used to (a) identify or exclude pulsation variability, (b) draw the *observational* instability strips, and confront that with our predictions (Moravveji 2016) (c) explore the pulsation excitation mechanism ( $\epsilon$ - versus  $\kappa$ -mechanism). (d) carry out iterative frequency prewhitening, and search for regularities in frequency and/or periods, (e) characterize possible rotating spots, (f) test the hypothesis that macroturbulence velocity has pulsation origin, (g) trace the surface chemical and rotational velocity evolution, with a possible link to rotational and/or non-rotational mixing processes, and (h) disentangle apparent single stars versus close binaries.

#### References

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