Exploring Pulsations of Wolf-Rayet Stars

Scientific Justification

Wolf-Rayet (WR) stars, a class of evolved stars with initial mass ranging between ~25 and ~75 solar masses and which have lost a large fraction of their original massive envelopes due to radiation driven stellar winds, are the last evolutionary stage of massive stars before they explode as supernovae (see [1] for a review). Recent observations evidently suggest that WR stars are probable progenitors of stripped envelope supernovae (Type Ib/c and IIb) [2,3]. However, the fundamental parameters of WR stars, such as masses and radii, are extremely hard to determine through traditional photometric and spectroscopic methods, because of their high level of activity in terms of strong stellar winds and due to the complex surface phenomena [4]. The fast temporal sampling and unprecedented photometric precision of K2 provide a unique opportunity for asteroseismology of WR stars, which opens a new window to their fundamental parameters. Here we propose to obtain K2 light curves of 17 WR stars in its Campaign 9. In order to maximize the scientific gain of this program, we will arrange photometric and spectroscopic follow-up observations on the ground for WR stars with pulsations detected by K2.

WR stars are expected to have pulsations of periods shorter than a day [5,6], but so far their variability on sub-day timescales has been studied in very few cases due to their rarity in the sky and short pulsation periods [7,8]. In only one of these studies (WR123) has a stable periodic signal of 9.8 hours been identified [8]. Because this period is too short for either orbital motion of a WR star in a binary or its rotation, it probably represents an intrinsic pulsation. A large sample of K2 light curves of WR stars will allow us to examine whether similar pulsations are ubiquitous in WR stars. Combining ground-based observations, we will also examine how WR pulsation periods are related to strong stellar winds and how these pulsations change with spectral properties.

Two independent models involving non-radial pulsations were proposed to explain the observed pulsation period of WR123 [9,10]. Our pulsation sample provides a dataset over a large parameter space of physical quantities (luminosity, metallicity, etc.) to test these two competing models. If the pulsations are confirmed to be unstable l=1 and l=2 g modes excited by the κ mechanism [9], then we can use these modes to estimate the stellar masses and constrain the stellar structure down to their convective layers. If the pulsations are strange modes [10], the periods are sensitive to the chemical composition and effective temperature near the surfaces of WRs [11]. In either case, the pulsation sample provides valuable constraints on WR stellar parameters that are poorly understood through traditional methods.

Why K2 Campaign 9 DDT?

The 9.8-hour pulsation in WR123 was identified by analyzing the light variability of MOST data with a precision of 0.2 mmag from a 38-day uninterrupted time series [8]. The higher precision and longer baseline of K2 will allow for the detection of smaller amplitude modes, a currently unexplored parameter space for WR stars.

With a most recent catalog of WR stars in the Milky Way [12] and the K2fov software, we find no WR star in the Kepler and K2 footprints, except that the K2 Campaign 9 field contains 33 WR stars and that the Campaign 11 field contains 3 WR stars. 17 WR stars in the Campaign 9 field are between 7th and 15th magnitudes in the Kepler band. Inspection of their DSS images shows that none is located in crowding regions. Thus, these 17 stars represent the first opportunity to obtain high-precision photometry for a large sample of WR stars. In addition to the science goals outlined above, long baseline photometric monitoring may uncover surprises, since similar observations have never been performed in the past.

The PI arrived at the idea of this proposal during the Experiment & Boutique meeting in 2015 August, when the deadline for K2 Campaign 9 proposals had passed. Therefore, we are forced to submit this proposal via the Direct Discretion Target program.

Legacy Values

The proposed observations here will become a trailblazer for larger investigation of WR star variability with TESS which will cover almost all sky. Our dataset will also suggest whether minute-cadence data are needed for brightest WR stars with TESS.

On the ground, the Zwicky Transient Facility (ZTF) will come online in 2017 and is expected to observe a number of newborn stripped envelope supernovae. Since the extraordinarily-early-phase light curves of supernovae are sensitive to the stellar structure and metallicity of exploding stars [13], connecting the ZTF light curves of stripped envelope supernovae with stellar information obtained from our WR pulsation analysis provides an independent test whether WR stars are progenitors of these supernovae.

If WR stars are progenitors of stripped envelope supernovae, as the rate of these supernovae in the Milky Way is one per four centuries [14], given 400 known WR stars [12] and a typical lifetime of 10^5 years for a WR star [15], it is entirely possible that one of the WR stars observed by K2 and TESS will explode in our lifetime.

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