TESS all sky variability survey for evolved compact stars

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Abstract: Evolved compact stars – mostly white dwarfs and hot subdwarfs – often show brightness variability of intrinsic or extrinsic origin. Non radial stellar pulsation is one common cause of variability that opens invaluable windows on internal stellar structures in the ultimate stages of evolution through the use of asteroseismology. Besides, many evolved compact stars are found in tight binary systems that can be discovered and characterized from their photometric orbital lightcurve. Moreover, evidence suggesting the presence around hot subdwarfs and white dwarfs of substellar objects of sizes ranging from brown dwarfs to small earth-size planets or even asteroids has been growing recently, implying that transits should be detected at some point. TESS will be the first instrument permitting an efficient and nearly exhaustive survey of all these sources of variability, with a strong expected impact in the field of asteroseismology and in our understanding of the role of binarity in the late stages of stellar evolution. It will also, for the first time, permit an exhaustive search for transits in hot subdwarfs and white dwarfs, thus addressing the important question of the ultimate fate of planetary systems and their potential impact on the evolution of their central star.

Cadence: This target list is for the 2-min cadence mode

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Science case: Evolved compact stars – mainly white dwarfs and hot subdwarfs – often show brightness variability of various origins. Intrinsic light modulations can be caused by stellar oscillations as seen is in several groups of well identified nonradial pulsators. Among these groups, pre white dwarfs in the *GW Vir* (DOV) instability strip and long period sdB pulsators (the *V1093 Her* stars; named sdBVg in Figure 1) have periodic variations caused by propagating $g-$modes that occur on timescales ranging from 20 mn to 4 hours, typically. This type of oscillation modes propagates particularly deep inside these stars, carrying out precious information on the innermost parts of their core that can be probed through the use of asteroseismology. Besides, extrinsic sources of brightness variability are also common for evolved compact stars, as many of them are components of relatively compact binary systems. Hot B subdwarfs in particular are believed to be formed from interactions of their red giant progenitor with a close companion that helped remove almost entirely the H-rich envelope of the star. Several binary evolution channels are possible to explain hot subdwarf stars in general. Hence, discovering such binary systems and determining precisely the distribution of their properties is essential to identify the most important ones. Moreover, recent discoveries suggesting the presence of small sized planet remnants orbiting close to hot B subdwarf stars (Charpinet et al. 2011, *Nature*, **480**, 496; Silvotti et al. 2014, *A&A*, **570**, 130) has raised the possibility that planetary systems could also influence the evolution of stars at the red giant stage to produce hot B subdwarfs, while some of the engulfed planets could survive partially. The discovery of a brown dwarf orbiting very close to its hot B subdwarf parent star, and thus having survived engulfment as well (Schaffenroth et al. 2014, *A&A*, **564**, 98), more generally underlines the key role that substellar objects could play in determining post red-giant evolution of stars and in producing extreme horizontal branch objects. The presence of small objects around white dwarfs, in particular debris made of comets, asteroids, or disintegrating minor planets, has also been spectacularly confirmed recently through a direct transit detection reported from K2 photometry (Vanderburg et al. 2015, *Nature*, **526**, 546). Such findings are extremely important for addressing the question of the ultimate fate of planetary systems and their potential impact on the evolution of their central star.

In the context briefly described above, TESS all sky photometric survey with the 2-min cadence mode will have groundbreaking repercussions. High precision photometry of continuous duration for almost all of the brightest identified stars belonging to the *GW Vir* and *V1093 Her* classes of pulsators will ensure that state-of-the-art asteroseismic data obtained from space become widely available to feed modeling efforts in the field. *The large increase of the number of compact pulsators having ultra high precision seismic data as a result of TESS observations will strongly improve our capacity to draw a complete, statistically meaningful picture of the ultimate stages of stellar evolution.* Overall brighter objects, compared to pulsators already observed with

KEPLER or K2, will also mean better opportunities for follow-up ground based projects to pin point more accurately the properties of these stars. In parallel, the high precision all-sky photometric survey planned for more than ~ 3200 hot subdwarfs and ~ 2600 white dwarfs will, for the first time, provide large enough samples to detect transits of small (down to earth-size and less) close-in objects orbiting these stars. From the sample observed with KEPLER including the two claimed detections (from Charpinet et al. 2011 and Silvotti et al. 2014), we roughly estimate that 1 sdB star out of approximatively 100 could feature a transit, meaning that as much as ~ 20 transits could be found over the 2 years of TESS observations. As a byproduct, many new close binary systems will also be discovered ($\sim 60\%$ of sdB stars are expected to be in such systems) from either reflection effects, ellipsoidal deformations, or beaming effects. This will critically contribute to the quest of better understanding how extreme horizontal branch stars are formed and which evolutionary channels are important.

The expected timescales for the light variations considered in this proposal (g-mode pulsations in *V1093 Her* and *GW Vir* stars; orbital modulations) and for the transit durations can be accomodated with the 2-min cadence mode.

Length of time series: For most stars associated to this proposal, we request 27d time series independent of ecliptic latitude in order to maximize the total number of observed targets for our survey purposes. Exceptions concern 52 pulsators monitored for asteroseismology which would greatly benefit from an extended time baseline, both in terms of overall signal-to-noise achieved in Fourier space (a factor 3 improvement expected from 27d to 1yr) and in frequency resolution (a factor 10 improvement between 27d and 1yr). In particular, pulsating B subdwarf stars are generally slow rotators with periods ranging from a few days to several weeks and a longer time series when possible could often resolve the star's rotation while a 27d lightcurve would not. We also point out that the 27d duration for the stars considered in the survey is amply sufficient to discover and characterize orbiting objects (either stars, brown dwarfs, or planets) since the orbital periods expected will be generally much shorter, ranging from a few hours to several days.

Quality of TESS data: Almost all of the proposed targets for asteroseismology only have ground based fast photometric data available, sometimes limited to the original (and usually short) discovery lightcurve. For these stars, TESS observations will outperform any available time series on the basis of at least 27d of coverage without interruption, which is simply not feasable from the ground. In survey mode, TESS observations will be by far the most efficient all-sky survey to detect all types of variability with directly exploitable data. In terms of signal to noise, we expect the TESS data to be roughly equivalent to KEPLER data obtained for stars 5 magnitudes fainter. As an illustration, Figure 2 shows the data quality obtained for a 18.2 mag pulsating ZZ Ceti star monitored for 31 days with KEPLER (hence equivalent to a 13.2 mag star observed with TESS for about a month). Oscillations are very clearly detected. Besides, pulsating white dwarfs down to magnitude 19 and above have successfully been observed with K2, suggesting that TESS can provide useful data at least down to magnitude ~ 15. We considered in this proposal objects down to mag ~ 16 in order to be as inclusive as possible in regard of the true performances of the instrument that will be more precisely evaluated after the first observation. We note also that around these compact stars, eventual transits of even small objects will have a significant depth due to more favorable size ratios compared to main sequences stars (e.g., an Earth-size planet passing in front of a 0.1 $R_\odot$ sdB star would create a transit approximately 1% deep in the lightcurve, and the signature would be even deeper for white dwarfs). Figure 3 shows the number of proposed targets depending on the magnitude limit we impose for the faintest observable objects.

Priorities: Priorities have been set mostly by order of increasing magnitude (brightest objects having highest priority) within three subgroups. The known pulsators have been placed on top of the list, followed by all hot subdwarfs stars proposed for the all-sky variability survey. The white dwarfs have been moved at the end of the list because we expect them to be included in the core program of TESS for transit search. At this stage, hot subdwarfs have not been considered in the core program, but discussions should be undertaken in that direction since one of the main motivation is also the search for closeby transiting planets.

Ground based observations: Follow-up observations will be planned to characterize further the interesting variable objects discovered during the survey. Facilities in Chile (M. Vučković), South Africa (D. Kilkenny), Arizona (E.M. Green), and at the Konkoly Observatory (Zs. Bognár) will, among others, be used for that purpose.

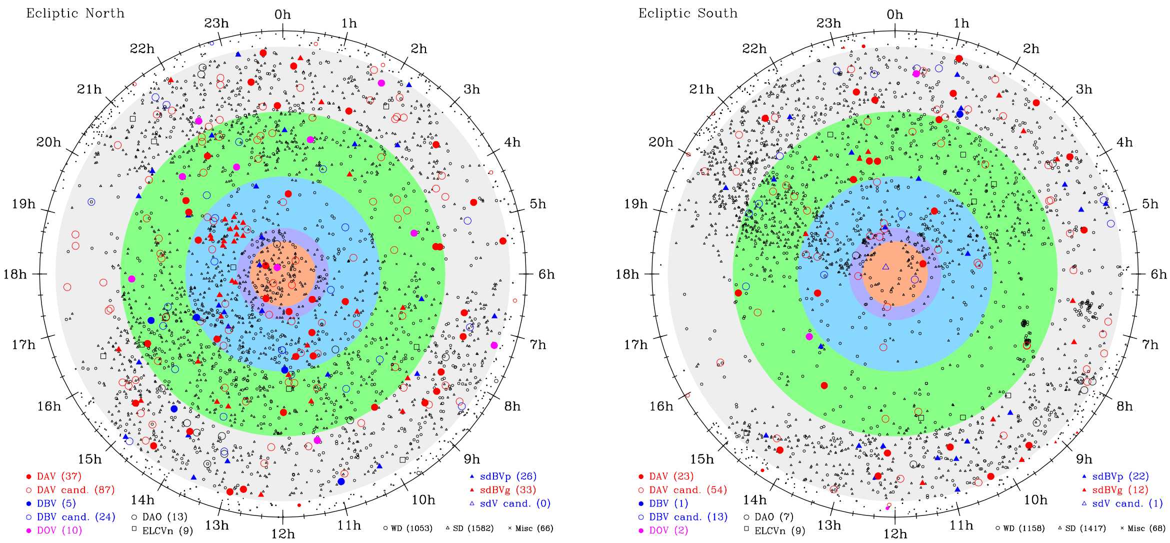

Figure 1: Distribution in ecliptic coordinates of all WG8 targets for the 2-min cadence mode. Left and right panels show polar projections of the Northern and Southern ecliptic hemisphere, respectively. The red, blue, and green regions roughly indicate the different zones in ecliptic latitude allowing for longer time series (see https://tasoc.dk/wg8 for further details).

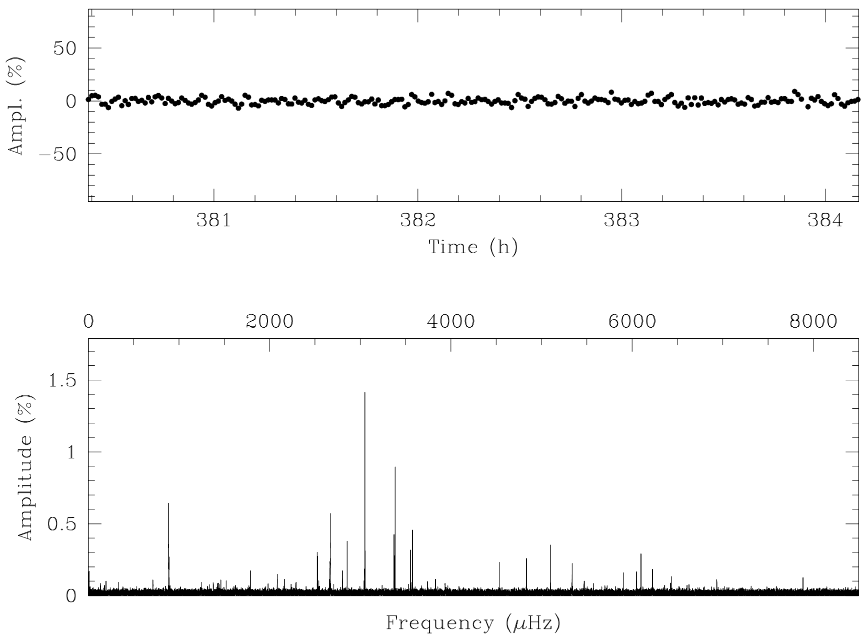

Figure 2: Lightcurve (top panel) and Lomb-Scargle periodogram (bottom panel) of the 18.2-mag DAV star KIC07594781 observed during 31 days by KEPLER. The noise level is 0.0175% (175 ppm) and the star shows modes with typical amplitudes from 1.4% to a few hundreds of a percent.

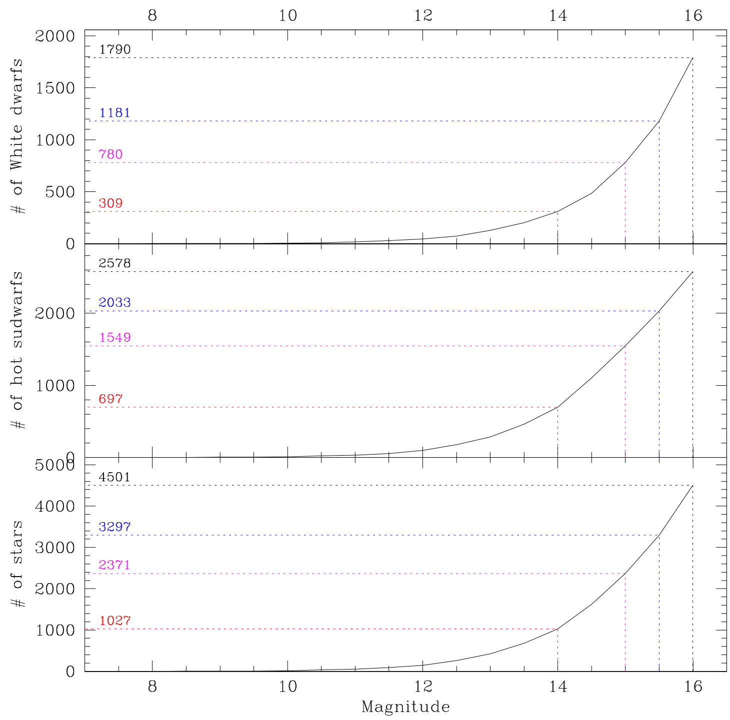

Figure 3: Cumulative number of WG8 targets for the 2-min cadence mode as a function of magnitude (bottom panel). Top and mid panels show the number of white dwarfs and hot subwarfs, respectively.