TESS Proposal on behalf of TASC WG 4

Asteroseismology of δ Sct Stars

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Abstract

This proposal aims at studying different aspects of stellar astrophysics related to the class of δ Sct stars. More specifically, we intend to carry out several ensemble studies where 27 days of observations are sufficient. At the same time, for carefully selected stars located at high ecliptic latitudes, we intend to fully exploit the longest possible observing duration for in-depth asteroseismic analyses. Our ensemble studies are aimed at the following sub-classes of δ Sct stars: pre-main sequence stars, high amplitude δ Sct stars and chemically peculiar Am/Fm stars. Additionally we will study the effect of rotation on pulsations in a sample of stars of the same spectral type but with varying rotational velocities. We also plan in-depth analyses of δ Sct stars in known eclipsing binary systems, field and cluster stars. In total this proposal includes approximately 4400 targets. The selected targets will not only allow to explore the science goals described here, but will also represent a unique homogeneously observed legacy sample of δ Sct stars covering almost the entire sky, an endeavour no near-future space mission is equipped to do.

Science Case

With effective temperatures between 6500 - 9000 K, δ Sct stars are in the mass range where the detailed stellar structure changes significantly from star to star. As a result, several astrophysical processes, such as convection, rotation, magnetic fields, known to operate in all stars can be isolated and studied in detail, if the basic stellar parameters are known. Intermediate-mass stars are very good astrophysical laboratories because disentangling these crucial phenomena in other stars is more complicated or even impossible. While the puzzle of δ Sct stars is not entirely solved yet, observations from the *Kepler* and CoRoT space telescopes, revolutionised the field of A and F stars significantly. Alongside the theory not being sufficiently developed, there is an additional complication related to the heterogeneity of the stars studied here. Some rotate slowly, others fast; they are at different evolutionary stages (pre-main sequence, main sequence and post-main sequence); some show abnormal chemical compositions in their atmospheres; some may have been formed through the collision of two stars (blue stragglers). The real obstacle in probing their interiors, and therefore understanding evolution, arises from our inability to disentangle their diversity from measuring their oscillations alone. The TESS mission offers the unique opportunity to systematically observe known and bright δ Sct stars covering a large variety of evolutionary stages, rotation rates, and chemical compositions at unprecedented precision. Combining ground-based and space data (incl. parallaxes from GAIA) with well determined effective temperatures and surface gravities will allow us to address different astrophysical aspects from different angles and with diverse methods. We focus our attention on science cases which can only be carried out with TESS, either in terms of data quality, duration of observations and/or homogeneity of data. More specifically the TASC WG4 selected the targets proposed here with the intention to study the following aspects in detail:

(1) Ensemble study of all known pre-main sequence δ Sct stars in the TESS FOV (43 out of 52; 5 of which are not in TIC). These stars have periods ranging from 15 minutes up to 7 hours, hence we require the 2-min cadence. For many of the stars, TESS will provide the first space observations and improve our knowledge of their earliest evolutionary phases.

(2) Ensemble study of all known High Amplitude Delta Scuti (HADS) stars (number of stars:

approx. 200). These stars are found in a very narrow temperature range in the middle of the classical instability strip, a feature which is still not understood. Their pulsational behaviour, i.e. amplitudes greater than 300 mmag, make these stars possible transition objects between normal δ Sct stars and the more evolved RR Lyrae and Cepheids. Here we propose to carry out a systematic study of all known members in order to fully characterise their highly non-sinusoidal light curves and detect possible non-radial modes. We require a 2-min. cadence for their Fourier decomposition which would be strongly affected in 30-min. cadence data because frequencies can be as high as 25 c/d. This means that harmonics and combination frequencies will be detected at frequencies up to 200 c/d or higher.

(3) Pulsation-rotation interaction: here we propose to carry out a detailed study of a carefully selected sample of δ Sct stars (30) of the same spectral and luminosity type (A7V) spanning a large range of measured $v \sin i$ values between 10 and 290 km/s. Their similar evolutionary stage will allow us to disentangle the effects of rotation on the pulsations of these stars. Rotation is a particularly important mixing process and needs to be better understood. Here we have the unique opportunity to observe bright stars with well determined parameters. Also in this case the 2 min. cadence is required as stars of this spectral type tend to pulsate with frequencies higher than, or around, the FFT Nyquist. Coupled with this, rotation shifts pulsation modes higher still, thus cementing the need for 2-min. cadence.

(4) Ensemble study of known chemically peculiar field and cluster (e.g. Coma Berenices) Am/Fm stars to understand how pulsations operate in the presence of atomic diffusion. Due to gravitational settling of He, only few Am/Fm stars are expected to pulsate if the κ-mechanism is the main pulsation driver. However, recent ground-based observations as well as theoretical investigations indicate that the turbulent pressure in the hydrogen ionisation layers may be the main driving mechanism in, at least a certain temperature range of the instability strip which coincides with the highest occurrence of pulsating Am stars (about 25% of all Am stars show pulsations with a maximum around 7500 K). TESS provides the first opportunity to employ global analyses of these stars with sufficient data quality to detect very low-amplitude pulsations which from the ground may have been omitted. Number of targets: approx. 800.

(5) We will employ boutique modelling of selected bright cluster and field stars, to test and explore our theoretical models. The targets used here comprise the known pulsating stars found in eclipsing binary systems, bright single δ Sct stars (with pulsation frequencies higher than the FFI Nyquist), which have or will soon have well determined stellar parameters. Additionally, the target list proposed will allow us to redetermine the δ Sct instability strip and better understand the physical phenomena occurring in these stars (approx. 3300 stars).

Aside from the science goals outlined above we aim at obtaining an unprecedented legacy sample of δ Sct stars covering nearly the entire sky. This is a unique endeavour and no near-future mission will have the same possibility.

Length of time series

Pulsation amplitudes in δ Sct stars can be from a few μmag to several mmags and oscillation modes can be closely spaced making it difficult to resolve individual frequencies with data sets spanning 'only' 27 days. Several science cases outlined here, however, do not depend on a very detailed characterisation of all the low-amplitude peaks present in typical δ Sct pulsation spectra making the TESS mission the perfect instrument for surveys. Despite some the possible lack of resolution, we expect to be able to identify the best targets and be able to perform in-depth analyses to challenge our knowledge obtained from previous missions such as *Kepler* and CoRoT. This is possible for targets with data sets of 27 days and is supported by *Kepler* observations which clearly show that there are stars with uncrowded pulsation spectra allowing us to achieve our science goals. Further to this, in order to characterise the δ Sct stars proposed here, more specifically to resolve individual modes, we can make use of available ground-based data. We would like to emphasise that the uninterrupted observing strategy of TESS is a very important part of successfully carrying out our science, as ground-based data suffer from daily aliases and low duty cycles.

To maximise the science output the best observing strategy would be to assess the data on a

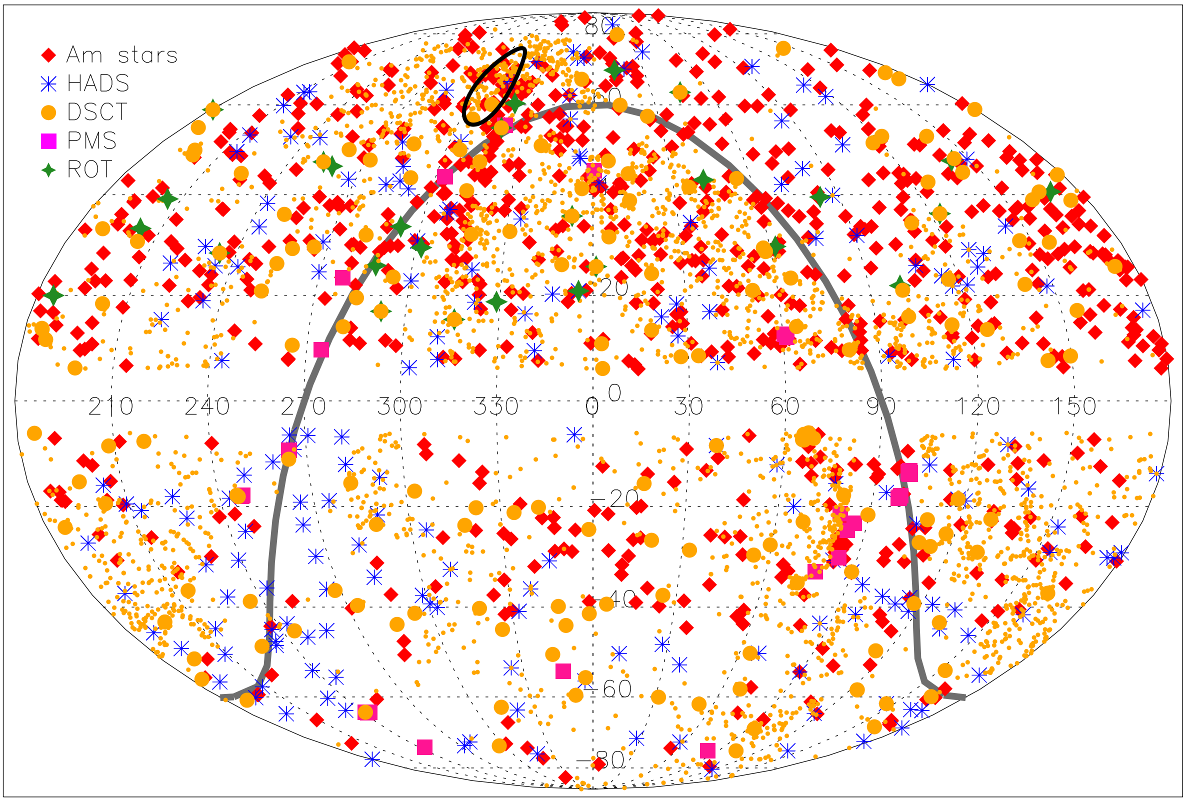

Figure 1: Sky coverage of all stars proposed. This figure illustrates that each field contains enough targets to be observed, however, only few fall into the continuous viewing zone. The symbols correspond to the different science cases as outlined above. Note that the larger orange filled circles represent known δ Sct stars with TESS magnitudes brighter than 7. The grey band illustrates the galactic plane and the egg-shaped black feature is the approximate location of the Kepler FOV. Once the new TIC containing the contamination factors for all stars will be released we will correct the target lists for blended stars.

star-by-star case after each field has been observed, however, the delay between data download and delivery will not allow this scenario. As illustrated in Fig. 1, a large number of the proposed targets are at low to modestly high ecliptic latitudes and therefore do not qualify for the continuous viewing zones. Based on this and on the science goals outlined above we suggest to observe Am stars and HADS for 27 days (Fig. 1: red diamonds and blue asterisks, respectively) and observe the remaining stars for the longest possible duration.

Quality of TESS data

Depending on the angular degree, the pulsation amplitudes in δ Sct stars will have lower values in the TESS bandpass compared to the *Kepler* values (see Fig. 2). The TESS band is centred on Ic ($\sim$ 8000Å), which means that the observed white light amplitudes have to be corrected to lower values (on average 40-50 % lower, depending on the geometry of the modes and a number of parameters such as $T_{\rm eff}$). Using the photometric mode identification tool and the atmospheric models implemented in FAMIAS (Zima, W., 2008, Comm. in Asteroseismology 155), we estimate the amplitudes for radial, dipolar and quadrupolar modes in the central wavelengths of the Ic band normalised to the V band (see Fig. 2). Using the wavelength corrected amplitudes, we simulate the detection level for different brightnesses. According to Hans Kjeldsen (priv. comm, slides TASC 1 meeting in Aarhus) the noise level for the TESS mission can be estimated from *Kepler* data for stars 5 magnitudes fainter than in

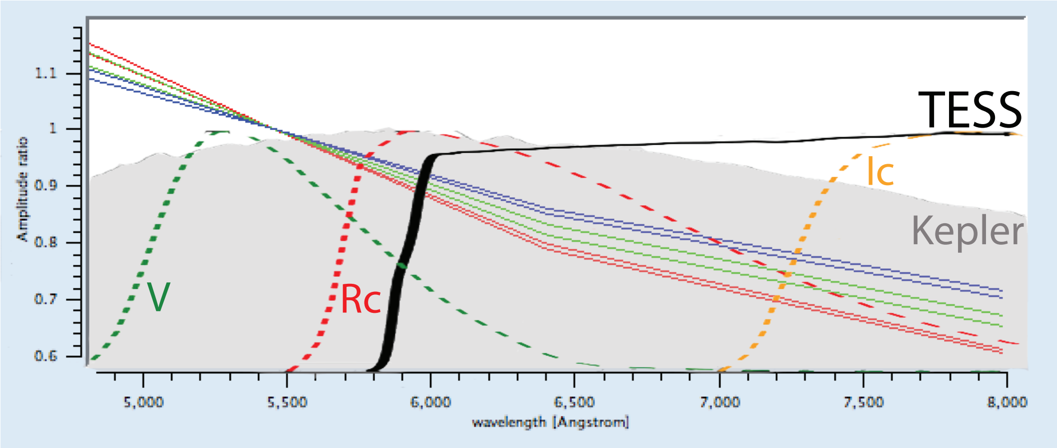

Figure 2: Amplitude ratios for radial (blue lines), dipolar (light green lines) and quadrupolar (red lines) modes for a 1.8M$_\odot$ star with $T_{\rm eff}$=7200K. The amplitudes were normalised to the V band. The grey area indicates the *Kepler* bandpass. The dashed green, red, and yellow lines indicate the V, Rc and the Ic bands respectively. The thick black line is the TESS band. This figure illustrates that for A and F type stars the pulsation amplitudes are lower in the TESS band, a fact that should be considered for noise calculations and detection limits.

the TESS (Ic) filter. Based on simulations the detection limit for a 12$^{\rm th}$ TESS mag star is of the order 350 μmag, clearly allowing detection of typical δ Sct signals. The faintest two stars on our target list, have TESS magnitudes around 15. In Fig. 3, we show that even in this case we can detect pulsations with 2.2 mmag, which is sufficient as the highest mode of pulsation has an amplitude of 8 mmag in that case.

Priorities of the targets:

In order to maximise the science output we will prioritise our target stars by alternating between the different science cases. Prior to merging the different sub-lists we will rank the stars by using the following criteria:
scientific importance (for example unblended cluster members for which, e.g., the composition and age are known)
available (ground-based) data: higher preference for stars with well determined stellar parameters.
brightness: brighter stars have higher priority
stars at higher latitudes will have a higher ranking (except for HADS and Am stars as mentioned above)
contamination: uncontaminated stars will have high priority. Note that our target lists will be updated once the new TIC is available containing information about potentially blended stars.

Ground-based observations in relation to this proposal

Most targets proposed here are known oscillators, from literature and/or surveys such as Superwasp and KELT. More specifically all stars except for the sample of Am stars (approx. 900 stars) are known δ Sct stars. In carefully selected cases we will organise complementary ground-based time-series campaigns to perform mode-identification. Additional observations will be carried out in order to improve the stellar parameters for a larger number of stars. WG4 has access to telescope time on the Southern as well as on the Northern Hemisphere and we have the experience required for carrying out the observations and analysing the data.

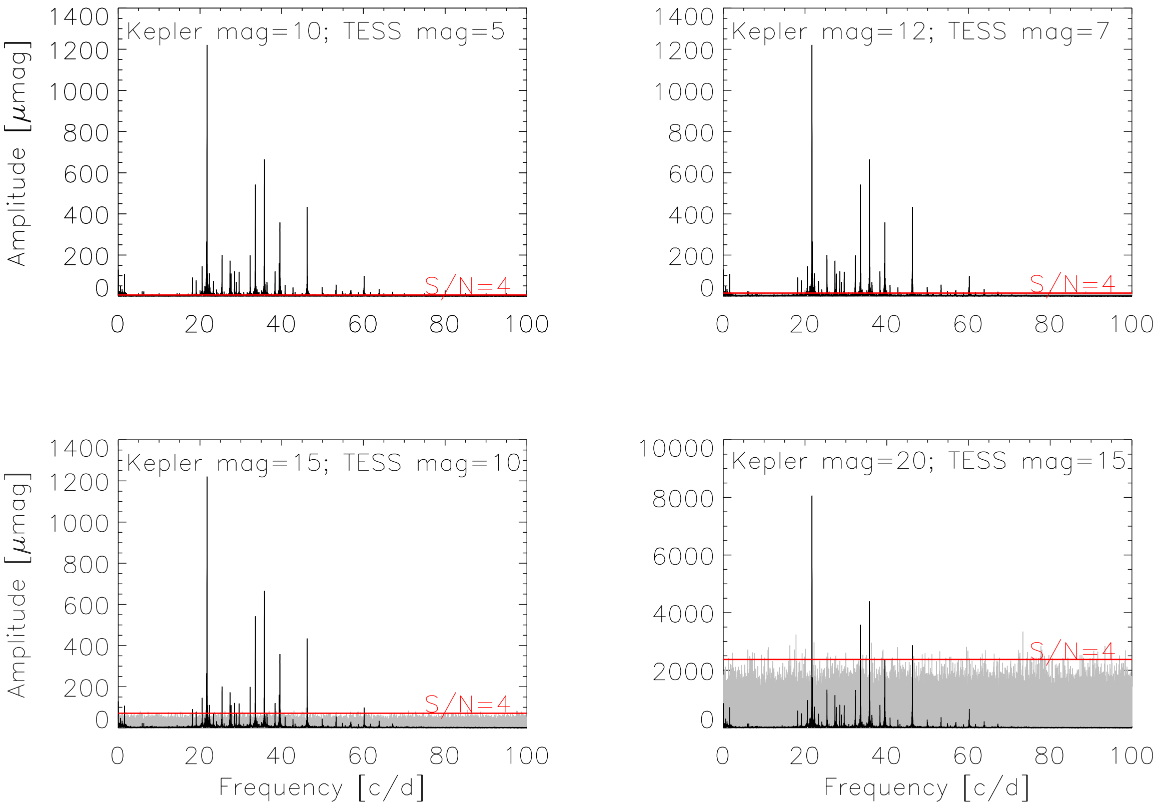

Figure 3: Simulations of noise (in gray) based on *Kepler* observations of stars with the magnitudes indicated in each panel. We assume that the noise level for a given star observed with *Kepler* (for 27 days) represents the TESS data quality for a star 5 mag brighter, *Kepler*-TESS Δmag $\approx$ 5. In black we depict the amplitude-scaled Fourier spectrum of KIC 7548479 to represent observations in the TESS band. The red line represents the classical significance criterion of S/N=4. In the lower right panel we multiplied the amplitudes to correspond to the value observed in the PMS δ Sct star TIC 11695948.