TESS Proposal on behalf of TASC WG 4
Cadence: 2-min sampling

Title: A survey of rapidly oscillating Ap stars

Abstract: The magnetic, and chemically peculiar nature of the rapidly oscillating Ap (roAp) stars makes them particularly interesting targets to investigate the combined effect of diffusion, pulsations and magnetic fields. These are relatively rare objects and a significant increase in their number can only be achieved through surveys. TESS offers the opportunity to systematically search for roAp stars from space for the first time. We intend to take this opportunity to: (1) Establish the observational boundaries of the roAp star instability strip; (2) Increase significantly the number of members of this class; (3) Establish the fraction of Ap stars that exhibit pulsations. All of these will have profound implications on our understanding of the roAp star phenomenon and, consequently, on our ability to infer information on the physical processes that take place within their interiors. The roAp stars are the only stars, other than the Sun, to offer the opportunity to visualize the three-dimensional structure of abundance distributions driven by atomic diffusion, and the three-dimensional atmospheric structure of the pulsations. Atomic diffusion is important in stellar structure and evolution with wide applications, and the roAp stars provide the best observational tests of diffusion theory.

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Science Case: So far 61 roAp stars have been discovered (Smalley et al., 2015) and of these only 11 have been observed in short cadence from space. The quality of the ground-based data is generally inferior to the space-based data, with only the highest amplitude pulsations being detected.

The Kepler data on roAp stars demonstrate that their oscillations can easily be missed in ground-based observations. TESS will provide an unprecedented opportunity to obtain high-quality frequency spectra for the majority of the known roAp stars and, simultaneously, discover many new members of this class. This will allow us to have a global and much more complete understanding of the properties of roAp pulsations and conduct ensemble studies.

The known roAp stars have periods between 5 and 23 minutes. In many cases they exhibit higher frequency harmonics, and theoretically there are reasons to believe that much shorter periods could also be present. For this reason, roAp stars should ideally be observed with the TESS 20-second cadence. A proposal for 20-second cadence has thus been submitted to observe all known roAp stars within the TESS field of view. The search for new roAp stars, however, does not require such high cadence. Thus, we propose that this search is carried out using the 2-minute cadence with the three following objectives:

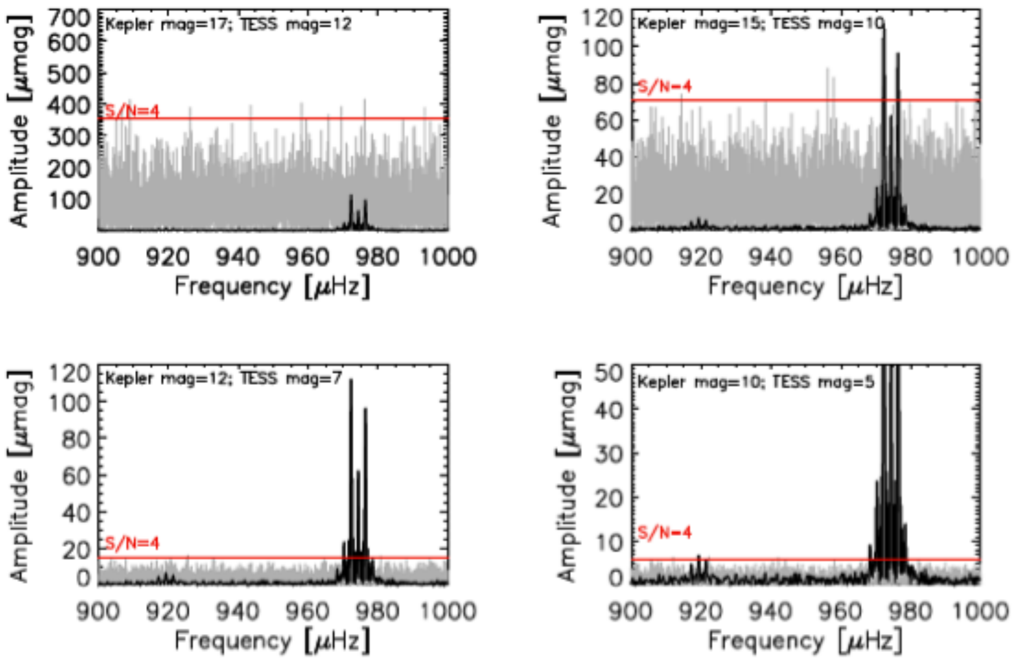
(1) *The limits of the roAp star instability strip.*
The excitation mechanism acting on roAp stars is still under debate. It is generally accepted that driving by the opacity mechanism acting in the hydrogen ionization region can explain many of the observed pulsations (Balmforth et at 2001). However, this mechanism does not succeed in explaining the exceedingly high frequencies observed in some roAp stars, which have, alternatively, been suggested to be driven by turbulent pressure (Cunha et al. 2013). In addition, the theoretical instability strip predicted based on the opacity mechanism (Cunha 2002) seems to have blue- and red-edges that are too hot, when compared to current observations. To make definitive tests on the theoretical models for the excitation of roAp stars' pulsations it is imperative to know the true limits of the instability strip. That has so far been hampered by the difficulty in finding new objects of this class and by the selection biases employed in most roAp ground-based surveys. The TESS mission provides an ideal opportunity to determine the extent of the roAp instability strip. To detect roAp stars at the limits of the instability strip, approximately 100 stars need to be observed. These were selected based on the following criteria: (1) Stars must be classified as CP2 (chemically peculiar) with enhanced Sr, Cr, Eu, Si; (2) Stars must cover the whole temperature range as evenly as possible; (3) Stars must be reasonably bright (7–9 mag); (4) The field must preferably be uncrowded.

(2) *A statistically sound sample of roAp stars*
It will be many years before we have another opportunity like the one provided by TESS to take a leap forward in our understanding of chemically peculiar, magnetic stars. In order to increase significantly the sample of known roAp stars we propose to observe 1221 roAp star candidates in addition to those proposed for objective (1) above. Of these, 40 are stars that have been observed by the KELT survey and whose frequency spectra show evidence for pulsations in the frequency domain of roAp stars, and 8 are members of a young cluster (Coma Ber), of which one is located at the hot border of the classical IS (this is 21 Com). Note that a detailed study of the chemical abundances of various A(m)/F stars of this cluster was already published (Gebran et al. 2008). The remaining 1173 stars are from the Michigan Spectral Catalogues volumes 1-5, and have an Ap spectral classification. TESS offers the first opportunity for an unbiased survey of this important class of stars.

(3) *The non-oscillating Ap stars*
A long-lasting open question in the context of pulsations in Ap stars is why some Ap stars, known as non-oscillating Ap (noAp) stars, do not pulsate. These objects fall within the empirical roAp instability strip, and in some cases have been shown to have spectral characteristics and fundamental parameters very similar to known roAp stars. In our proposal for 20-second cadence we have requested the observation of a carefully selected sample of 13 noAp stars to clarify whether these stars are pulsating. With this 2-minute cadence proposal we can add to this study. From (1) and (2) we will have data on a large sample of Ap stars acquired with the same instrument under the same conditions. We will thus be able to infer the fraction of Ap stars that exhibit rapid oscillations and how that fraction depends on the global properties of the stars. A follow-up spectroscopic ground-based program will be designed to assess whether the difference between roAp and noAp TESS pulsators is connected to the stars' spectral properties.

Length of the time series: The project is well suited to TESS 2-minute cadence observations of limited duration (27 days). The high frequencies that characterize these stars mean that a large number of cycles can be observed even for the relatively short time span. The roAp stars are oblique pulsators, and geometric information about their pulsation mode structure needs observations that span at least a full rotation cycle. Since most of these stars rotate with periods less than 27 days, TESS will fulfill this requirement admirably. A longer time series will improve the power spectrum and allow for an even better characterization of the targets. For new roAp stars in fields observable for more than 27 days discovered in this survey, we may request changing their observation to the 20-sec cadence mode.

Quality of TESS data: Pulsations in the known roAp stars have amplitudes in the 0.01-10 mmag range, in the traditional blue filters used in ground-based surveys. The amplitude reduction as a result of the red filter of TESS will be about a factor of 4 compared to these ground-based observations. Then the 1 – 100 µmag noise level expected over the full TESS magnitude range (3.7-12.2) of the targets considered in this proposal still gives S/N in the 5 − 100 range for a 1 mmag pulsation, and can still detect pulsations in the brighter stars down to about 10 µmag (see Fig. 1, extracted from the WG4 report). We therefore expect that many new roAp stars will be discovered among the targets proposed. Moreover, strict pulsation amplitude limits will be set on the brighter-end targets when no high frequencies are found.



Figur 1: 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 Fourier spectrum of KIC 10195926. The red line represents the classical significance criterion of S/N=4. See text for more details.

With regards to crowding, the frequency range of the roAp stars does overlap with those of some solar-like stars and some sdBV stars and variable white dwarfs. But the solar-like variability is at much lower amplitudes and has an easily recognizable pattern, and the sdBV and white dwarfs are all generally much fainter, so crowding will not be a problem for roAp stars.

Priorities of the targets: The cycle 2 list of targets and their priority has been updated in June 2019. For the cycle 2 targets we have added to the original list 5 new roAp stars discovered in the Kepler field (Hey et al., 2019) and one Kepler well characterised noAp. These were given high priority. In addition, we have added, at lower priority than the original list submitted, all stars from the Renson Catalogue with peculiarity in Sr,Cr,Eu,Si and all Ap stars from the paper Chojnowski et al. (2019) on the SDSS/APOGEE sample. The Renson and SDSS samples were considered together and the priority was given first by ecliptic latitude (>70 degrees) and then by magnitude. We recall that the priority on the original list (including south and fewer north targets) was first given to all known roAp and well characterized noAp stars, then to 40 stars observed by the KELT survey that are suspected to be roAp star pulsators. These stars have been identified from the inspection of the periodograms produced from KELT data for stars with V<10 and B-V<0.5. Within these, priority is given by length of observation, followed by TESS magnitude. The next highest priority is given 8 Ap stars that are confirmed cluster members, ordered by magnitude. Following these two groups, priority will be given to a sample of 91 stars selected to determine the extent of the roAp star instability strip. Stars in this sample may be substituted by other similar targets (similar spectral type, similar Teff, and similar crowding), if needed, but the total number should not be significantly smaller than that proposed, otherwise the scientific case will be compromised. Finally, the last group of targets, composed of 1173 Ap stars, is organized by length of observation, followed by TESS magnitude.

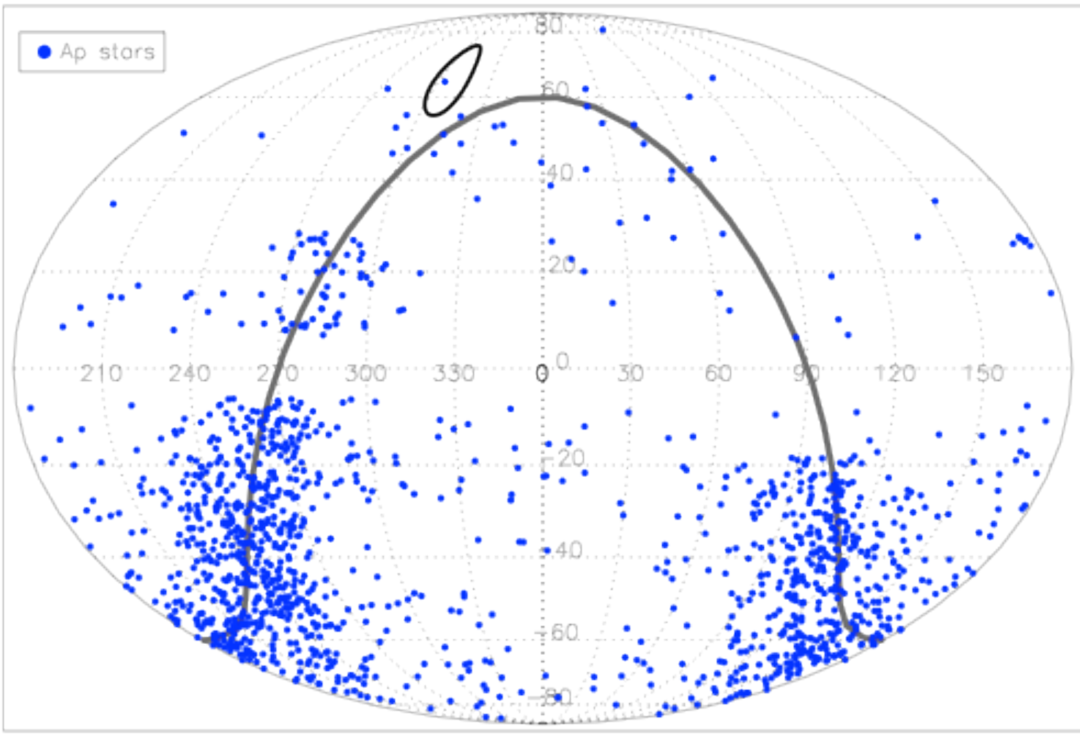


Fig. 2: Sky coverage of all Ap targets proposed for the 2-min cadence. Stars are concentrated towards the southern ecliptic hemisphere due to the use of the Michigan Catalogue for the identification of the Ap nature of most of the targets (this catalogue contains stars with declinations < than 5° and no corresponding catalogue exists for higher declinations). The grey band illustrates the galactic plane and the egg-shaped black feature is the approximate location of the Kepler FOV.

Ground-based observations in relation to this proposal: There is no requirement for additional ground-based observations for the stars in this proposal prior to the launch of TESS. Ground-based follow up will be organized in particular for a subset of the stars, aiming at establishing whether systematic spectroscopic differences exist between the roAp and noAp stars.

References:

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