TESS Proposal on behalf of TASC WG 4
Cadence: 20-sec sampling

Title: Detecting and characterizing rapid pulsations in cool Ap stars

Abstract: Rapidly oscillating Ap (roAp) stars are among the few types of stellar pulsators that show short periods of order a few minutes. The magnetic and chemically peculiar nature of these stars makes them particularly interesting targets to investigate the combined effect of diffusion, pulsations and magnetic fields. The excitation mechanism and, consequently, the expected range of excited frequencies, are not fully understood for these stars. The objective of this proposal is twofold: (1) Fully characterize the pulsation spectra of known roAp stars, including the possible detection of higher frequency oscillations previously missed and the characterization of the harmonics often observed in these stars; (2) Search for high frequency oscillations in a carefully selected sample of stars that are spectroscopically very similar to known roAp stars but in which former attempts to find oscillations from the ground have failed (the noAp stars).

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Science Case: The roAp stars are relatively rare. So far 61 pulsators of this class have been discovered (Smalley et al., 2015) and of these only 11 have been observed in short cadence from space, 4 of which by Kepler (Balona et al., 2011, 2013, Kurtz et al, 2011, Smalley et al, 2015) during the nominal mission, and 1 by K2. The Kepler data demonstrate that the amplitude of the oscillations in these stars is such that they can easily be missed in ground-based observations. By surveying the whole sky, TESS provides an unprecedented opportunity to obtain high-quality power spectra for tens of these stars, finally allowing us to have a global and much more complete understanding of the properties of their pulsations. With the finding of additional modes in many of these stars (for which often we have only the detection of a single mode), and the new data from GAIA, ensemble asteroseismic studies of these pulsators will finally become possible.

The excitation of the highest frequency modes observed in roAp stars cannot be understood in the context of the driving by the opacity mechanism. This has led to the suggestion that driving by the turbulent pressure might be responsible for the appearance of these high-frequency modes (Cunha et al, 2013). As the driving by this mechanism can act at very high frequencies, and the magnetic field in these stars is able to refract part of the pulsation energy for arbitrarily large frequencies, the presence of frequencies substantially higher than those observed so far in roAp stars cannot be ruled out. The 20-sec sampling will allow us to better establish the range of pulsation frequencies present in roAp stars and to characterize the pulsation harmonics. Of the 61 known roAp stars, 5 have absolute ecliptic latitudes smaller than 6^o and have thus been excluded from our list of targets.

A long-lasting open question in the context of pulsations in Ap stars is why some Ap stars, known as noAp, do not pulsate. These objects fall within the empirical roAp instability strip, have spectral characteristics and fundamental parameters very similar to known roAp stars and yet show no evidence of rapid oscillations. Thus the fundamental question remains: is there a real difference in the interior structure of noAp stars relative to roAp stars which precludes excitation of pulsations in the former, or have we simply failed to observe their oscillations? We propose to clarify the pulsation status of noAp stars by obtaining 20-sec cadence observations of a small, carefully selected sample. A total of 14 cool Ap stars were selected according to the following criteria: (1) Ap-star nature confirmed by a high-resolution spectroscopic study; (2) no pulsational variability found by a high-precision time-resolved spectroscopic analysis; (3) stellar parameters, in particular Teff ≤8100 K, place the star within the empirical roAp instability strip. Currently, no other instrument, but TESS, can be used to achieve this goal.

Length of the time series: The 27-day runs of TESS will constitute a major improvement in terms of detection limit and characterization of the oscillation power spectra compared to any of the ground-based observations for these stars. As a reference, most roAp stars detected either photometrically or spectroscopically from the ground have time-series of a few hours only. A time series longer than 27-days with TESS will improve further the power spectrum and allow for an even better characterization of the targets. More specifically, we can monitor the amplitude and frequency stability and at the same time lower the noise level. Moreover, runs longer than 27 days will provide important additional information for the identification of the oscillations modes in these stars that are oblique pulsators and often have very long rotational periods. Preference will thus be given to stars for which the observing length is longer, even if the stars are fainter.

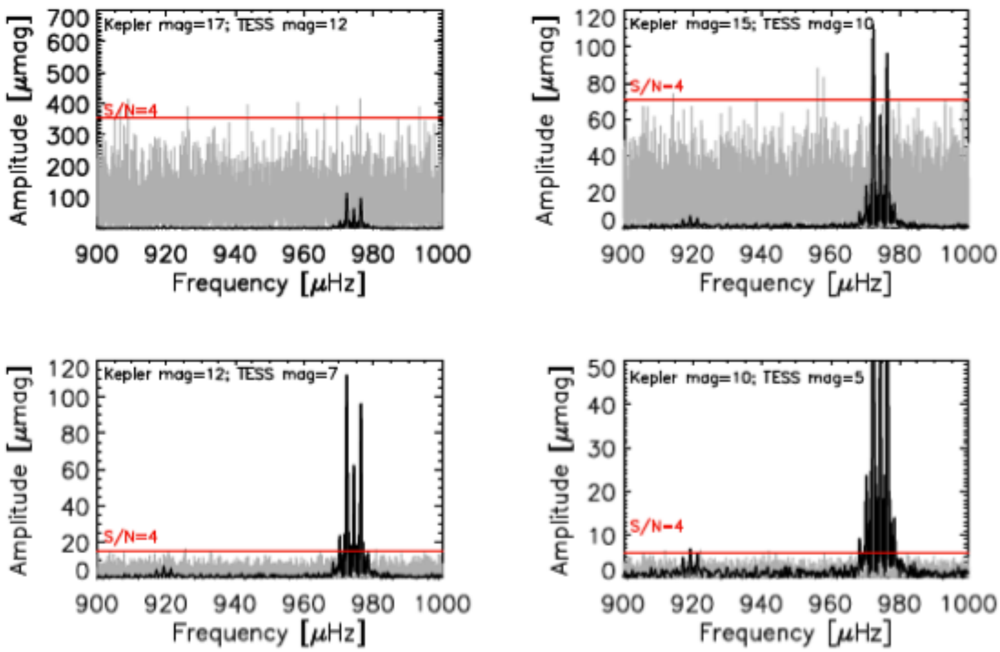
Quality of TESS data: Pulsations in the known roAp stars have amplitudes in the 0.01-10 mmag range, in the traditional blue filters used in ground-based surveys. The amplitude reduction as a result of the red filter of TESS will be about a factor of 4 compared to these ground-based observations. A 27-day run with TESS will allow us to detect modes of amplitude larger than about 70 μmag in a star with TESS magnitude~10 and modes of amplitude as low as about 6 μmag for a star of TESS magnitude~5 (see Fig. 1 below, extracted from the WG4 report). This is a significant improvement with respect to the typical detection limit in photometric ground-based observations, which, for the bright end of the roAp stars is about 0.8 mmag in B.

Of the 11 roAp stars previously observed in short cadence from space, 2 have absolute ecliptic latitudes smaller than 6 degrees and will not be considered further. For the remaining 9 we have the following:
(1) α Cir (TIC 402546736) was observed by WIRE (noise~0.008 mmag; Bruntt et al., 2009) and by BRITE (noise~0.06 mmag; Weiss et al., 2016) **[check these numbers].** The noise level expected for a 27-day run with TESS on α Cir is ~0.001mmag. We note that the ecliptic latitude of α Cir is -46.202583. Thus, depending on the first field of view of the satellite, there is a chance that it may be observed for 54 days. Regarding crowding, α Cir is a binary with a 15.6 arcsec separation, but the difference in magnitude between the components is ΔV = 5.05, so the contamination is negligible.
(2) γ Equ (TIC 354619745; Gruberbauer et al., 2008), 10 Aql (TIC 299000970; Huber et al., 2008), HD 99563 (TIC 322732889), and HD 9289 (TIC 136842396) were observed by MOST (noise~0.01 to 0.02 mmag; Gruberbauer et al., 2011). A 27-day run with TESS will provide a noise level between 0.002 to 0.017 mmag, for this range of magnitudes.
(3) KIC 4768731 (TIC 169078762) was observed in short cadence by Kepler for one month.
(4) KIC 8677585 (TIC 158275114), KIC 10195926 (TIC 158271090), and KIC 10483436 (TIC 272598185) were observed by Kepler for over 3 years. TESS data will not represent an improvement over the Kepler data, but will allow us to study mode frequency and amplitude variations between the two epochs. We therefore keep these stars in the target list, but give them the lowest priority.

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 generally much fainter, so crowding is not a problem for roAp stars.

Priorities of the targets: The target list started with the 61 known roAp stars and 14 well-characterized noAp stars. After removing stars with absolute ecliptic latitudes smaller than 6 degrees, we were left with 69 targets (56 roAp stars and 13 noAp stars). The lowest priority was given to the 4 stars already observed in short cadence by Kepler, followed by the other 5 roAp stars observed from the space with MOST or BRITE. The remaining stars were ordered by increasing TESS magnitude. After that, stars with absolute ecliptic latitudes larger than ~54 degrees were pushed up to top priority, independently of their magnitudes (which were always brighter than ~12 mag). This last criterion is to be re-evaluated based on the actual observing length.

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. However, we will ask for simultaneous ground-based observations in the B-filter for the known roAp stars, to establish the amplitude ratio between the B and the TESS filters. Ground-based follow up will be organized also whenever found necessary after the TESS data is collected and analyzed.



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 $\Delta\text{mag} \approx 5$. 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.

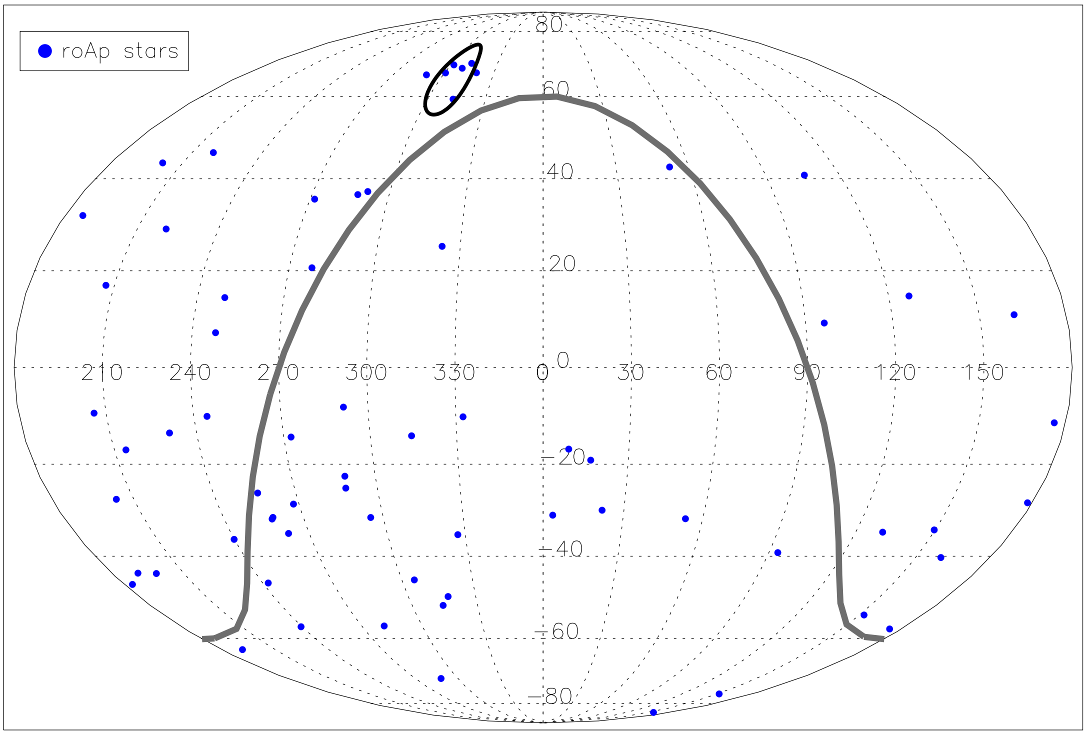


Fig. 2: Sky coverage of all roAp targets proposed for the 20-sec cadence. The grey band illustrates the galactic plane and the egg-shaped black feature is the approximate location of the Kepler FOV.

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