TESS Asteroseismic Predictions for Red Giants using Kepler data

Mat Schofield[1] ⋆ †

[1]*Department of Physics and Astronomy, the University of Birmingham, Birmingham B15 2TT, UK*

Last updated 2017 May 31; in original form 2017 May 31

ABSTRACT

Summary: This paper presents a method to predict Red Giant mode detectability with TESS, using Kernel Density Estimation. It requires only the global parameters $\Delta\nu$, $\nu_{\max}$, the stellar magnitude and length of observation.

Method: Lightcurves for *Kepler* stars with fitted radial mode frequencies were used to generate equivalent TESS lightcurves. The lightcurves were cut down, *Kepler* white noise was removed, the bandpass was adjusted, and TESS white noise was added. A detection test was run on the observed modes in these 'TESS-like' lightcurves. Kernel density estimation was then used to determine mode detectability with TESS based upon the global asteroseismic parameters $\nu_{\max}$ and $\Delta\nu$, as well as the stellar magnitude.

Application: The method has been designed to be used to make predictions for other missions such as K2, PLATO and CoRoT. The only difference when applying the method for other missions is to adjust the lightcurve transformation.
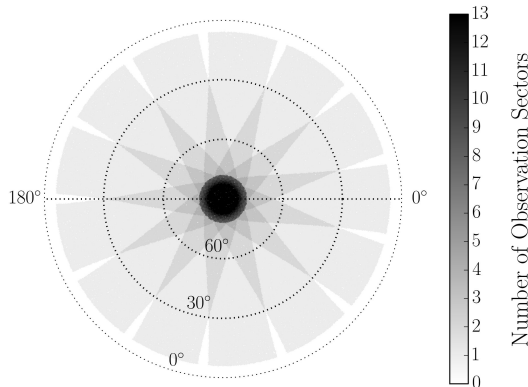
Figure 1. TESS field of view, centred around the ecliptic pole. Each strip will be observed for 27 days before the satellite rotates. Image taken from Campante et al. (2016).
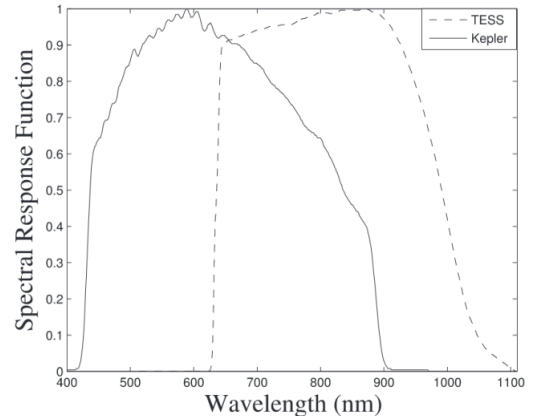
Figure 2. TESS field of view, centred around the ecliptic pole. Image taken from Placek et al. (2016).

1 INTRODUCTION

2 TRANSFORMING THE LIGHTCURVES

The timeseries data from *Kepler* observations needed to be adjusted for a different satellite and mission. This could either be done in the time or frequency domain. Both methods were tested and compared. The time domain method was chosen to transform the lightcurves, and was used in the rest of this work.

Several different adjustments needed to be made to the *Kepler* data. One difference between the missions is the length of observation. The *Kepler* mission ovserved for 4 years, while TESS' nominal 2 year mission will observe stars for between 27 days to 1 year, according to the star's ecliptic latitude (Figure 1).

As well as reducing the dataset length, the bandpass that TESS will observe in is much redder than that of *Kepler*, Figure 2. This

has the effect of reducing the amplitude of stellar signals (i.e the signal due to stellar granulation and oscillation). Campante et al. (2016) found this bandpass correction to be 0.85.

Thirdly, the instrumental noise level in *Kepler* is different to the noise level in TESS. The noise level for the *Kepler* satellite depends on the *Kepler* magnitude of the star, K_p. The noise can be calculated using

$$\frac{10^6}{c} \times \sqrt{c + 9.5 \times 10^5 \left(\frac{14}{K_P}\right)^5}, \tag{1}$$

where

$$c = 1.28 \times 10^{0.4(12-K_P)+7}, \tag{2}$$

from Chaplin et al. (2011).

As well as subtracting this noise from the signal, instrumental noise from TESS needed to be added. This noise was estimated

using the 'calc noise' IDL procedure (from William Chaplin, private communication), which depends on the I_c−band magnitude of the star and the number of pixels in the photometric aperture used when observing the star. This is given by

$$N_{\mathrm{aper}} = 10 \times (n + 10),\tag{3}$$

where n is

$$n = 10^{-5.0} \times 10^{0.4 \times (20 - I_{\mathrm{mag}})}.\tag{4}$$

These three adjustments - the length of observation, the bandpass, and the noise level - were performed in the time and frequency domains. The methods used are outlined in Figures 7 and 4.

```
┌─────────────────────────┐          ┌─────────────────────────────┐
│ Apply a σ-clip of 4 to  │          │ Cut the 4 years of data     │
│ the dataset to remove   │  ⟹       │ down to the reduced dataset │
│ spurious points         │          │ length with the fewest      │
│                         │          │ total length of gaps in the │
│                         │          │ data                        │
└─────────────────────────┘          └─────────────────────────────┘
                                                    ⇓
┌───────────────────────────────┐    ┌─────────────────────────────┐
│ Add instrumental noise from    │    │ Adjust the bandpass by       │
│ TESS by multiplying the        │ ⟸  │ multiplying the flux by 0.85 │
│ predicted noise level by       │    │                             │
│ multiplying this by a random   │    └─────────────────────────────┘
│ number from the standard       │
│ normal distribution before     │
│ adding to the signal           │
└───────────────────────────────┘
              ⇓
┌─────────────────────────┐
│ Use the Lomb-Scargle    │
│ periodogram to convert  │
│ the signal from the     │
│ time to the frequency   │
│ domain                  │
└─────────────────────────┘
```
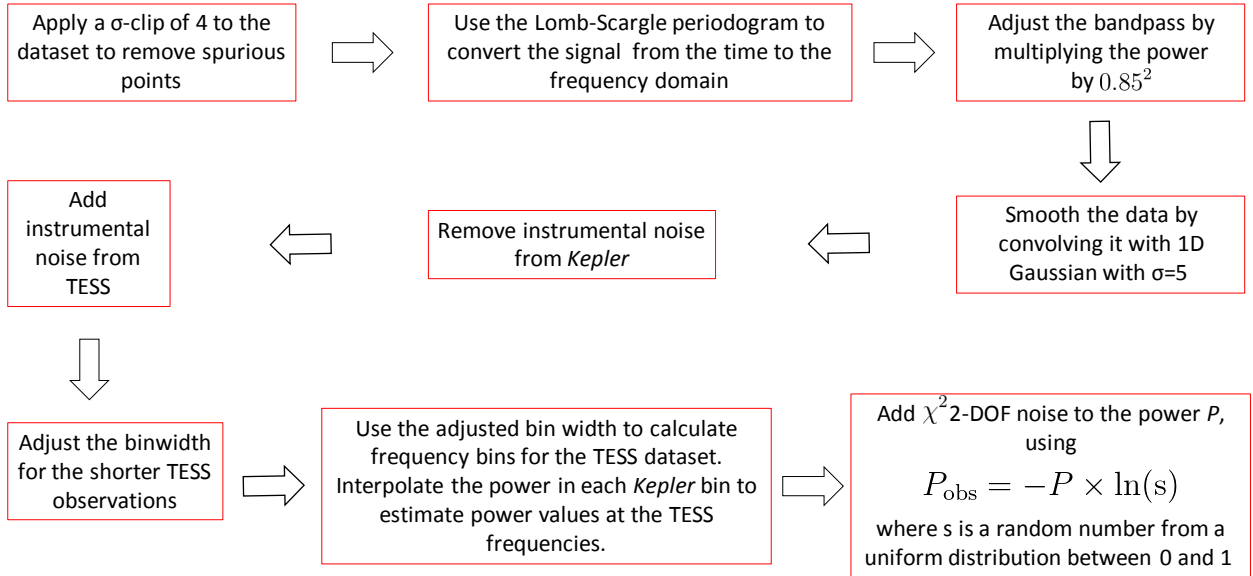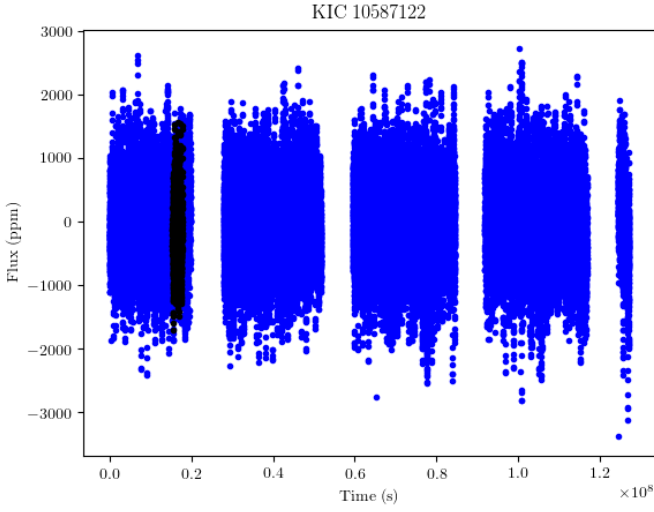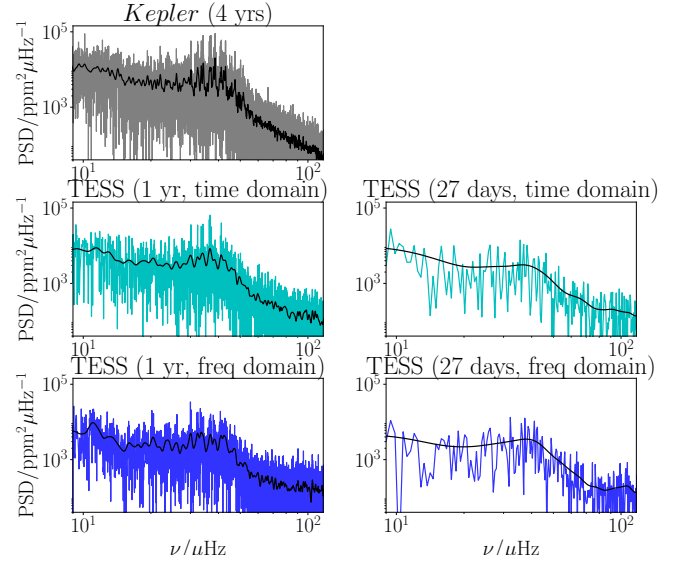
Figure 3. Flow chart of the method to convert the data from *Kepler* to TESS observations in the time domain.

```
┌─────────────────────────┐     ┌─────────────────────────────┐     ┌──────────────────────┐
│ Apply a σ-clip of 4 to  │     │ Use the Lomb-Scargle        │     │ Adjust the bandpass  │
│ the dataset to remove   │ ⟹   │ periodogram to convert the  │ ⟹  │ by multiplying the    │
│ spurious points         │     │ signal from the time to the │     │ power by $0.85^2$    │
│                         │     │ frequency domain            │     │                      │
└─────────────────────────┘     └─────────────────────────────┘     └──────────────────────┘
                                                                              ⇓
┌──────────────┐     ┌─────────────────────────┐     ┌──────────────────────┐
│ Add          │     │ Remove instrumental     │     │ Smooth the data by   │
│ instrumental │ ⟸   │ noise from *Kepler*     │ ⟸  │ convolving it with 1D│
│ noise from   │     │                         │     │ Gaussian with σ=5    │
│ TESS         │     └─────────────────────────┘     └──────────────────────┘
└──────────────┘
      ⇓
┌──────────────────┐     ┌─────────────────────────────┐     ┌───────────────────────────────┐
│ Adjust the       │     │ Use the adjusted bin width  │     │ Add $\chi^2$ 2-DOF noise to   │
│ binwidth for the │ ⟹   │ to calculate frequency bins │ ⟹  │ the power *P*, using           │
│ shorter TESS     │     │ for the TESS dataset.       │     │                               │
│ observations     │     │ Interpolate the power in    │     │ $P_{\rm obs} = -P \times \ln(s)$│
│                  │     │ each *Kepler* bin to        │     │                               │
│                  │     │ estimate power values at    │     │ where s is a random number    │
│                  │     │ the TESS frequencies.       │     │ from a uniform distribution   │
│                  │     │                             │     │ between 0 and 1               │
└──────────────────┘     └─────────────────────────────┘     └───────────────────────────────┘
```
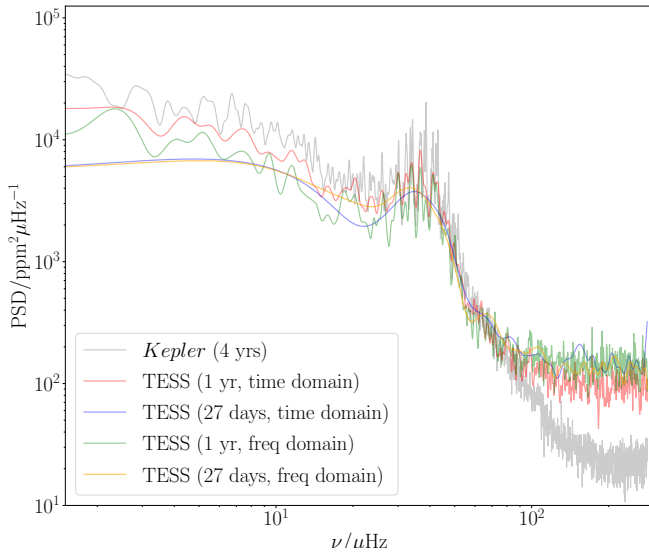
Figure 4. Flow chart of the method to convert the data from *Kepler* to TESS observations in the frequency domain.

Figure 5. Flow chart of the method to convert the data from *Kepler* to TESS observations in the time domain.

Figure 6. Flow chart of the method to convert the data from *Kepler* to TESS observations in the time domain.

FIGURE OUT WHERE TO PUT THESE WRITE CAPTIONS+ EXPLANATIONS

3 DETECTION TEST

4 KDE

REFERENCES

Campante T. L., et al., 2016, preprint, 1608, arXiv:1608.01138
Chaplin W. J., et al., 2011, The Astrophysical Journal, 732, 54
Placek B., Knuth K. H., Angerhausen D., 2016, Publications of the Astronomical Society of the Pacific, 128, 074503

Figure 7. Flow chart of the method to convert the data from *Kepler* to TESS observations in the time domain.

This paper has been typeset from a TEX/LATEX file prepared by the author.