

## Detection of Solar-like Oscillations in Sub-giant and Red Giant Stars Using 2-minute Cadence TESS Data

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### ABSTRACT

Based on all 2-minute cadence *TESS* light curves from Sector 1 to 60, we provide a catalog of 8,651 solar-like oscillators, including frequency at maximum power ( $\nu_{\max}$ , with its median precision,  $\sigma=5.39\%$ ), large frequency separation ( $\Delta\nu$ ,  $\sigma=6.22\%$ ), seismically derived masses, radii and surface gravity. In this sample, we have detected 2,173 new oscillators and added 4,373 new  $\Delta\nu$  measurements. Our seismic parameters are consistent with those from *Kepler*, *K2*, and previous *TESS* data. The median fractional residual in  $\nu_{\max}$  is 1.63% with a scatter of 14.75%, and in  $\Delta\nu$  it is 0.11% with a scatter of 10.76%. We have detected 476 solar-like oscillators with  $\nu_{\max}$  exceeding the *Nyquist* frequency of *Kepler* long-cadence data during the evolutionary phases of sub-giant and the base of the red-giant branch, which provide a valuable resource for understanding angular momentum transport.

*Keywords:* Asteroseismology (1583); Subgiants (481); Red giants (655); Lightcurves (1234)

### 1. INTRODUCTION

Astroseismology, the study of stellar oscillations, offers a powerful tool to infer stellar interiors (e.g., Christensen-Dalsgaard 1984; Aerts et al. 2010). In recent decades, space missions such as *CoRoT* (Baglin et al. 2006; Auvergne et al. 2009), *Kepler* (Borucki et al. 2010), and *K2* (Howell et al. 2014) have provided long-duration, high-quality photometry data, leading to a revolution in the study of solar-like oscillations. These missions enabled the study of solar-like oscillations in hundreds of main-sequence and sub-giant stars (e.g., Chaplin et al. 2011a, 2014; Li et al. 2020; Mathur et al. 2022), as well as tens of thousands of red giants (e.g., Hekker et al. 2011; Stello et al. 2013; Huber et al. 2014; Mathur et al. 2016; Yu et al. 2016, 2018; Hon et al. 2019), revealing new aspects of stellar structure and evolution

(e.g., Hekker & Christensen-Dalsgaard 2017; Aerts et al. 2019).

The NASA Transiting Exoplanet Survey Satellite (*TESS*) mission (Ricker et al. 2015) has provided an opportunity to study solar-like oscillations in stars across the entire sky. Previous studies had extensively used *TESS* data to characterize solar-like oscillators, with a primary focus on the Continuous Viewing Zones (CVZs) near the ecliptic pole due to longest observation duration (Silva Aguirre et al. 2020; Mackereth et al. 2021; Hon et al. 2022; Stello et al. 2022). Hon et al. (2021) initially used deep learning techniques to detect solar-like oscillations in red giants across the full sky on the first two years of *TESS* full-frame images (FFI, Sector 1 to 26), identifying about 158,000 giants with  $\nu_{\max}$ . Hatt et al. (2023) detected 4,177 solar-like oscillators using both 2-minute and 20-second cadence data (Sector 1 to 46), reporting  $\nu_{\max}$  and  $\Delta\nu$  estimates.

By the end of Sector 60, *TESS* had completed observations of both the north and south ecliptic hemispheres for the second time. More than half of targets with 2-

minute data had been observed in at least two sectors. Longer photometric time series provide higher frequency resolution in the Fourier domain, leading to improved precision in asteroseismic measurements. In this work, we aim to perform a complete search for solar-like oscillators and provide their global seismic parameters using *TESS* 2-minute cadence data. In addition, by combining  $T_{\text{eff}}$  from the *Gaia* DR3 Radial Velocity Spectrometer (RVS) survey (Recio-Blanco et al. 2023), we estimate stellar radii, masses and surface gravity using the seismic scaling relations.

## 2. DATA SELECTION

### 2.1. Preliminary data selection

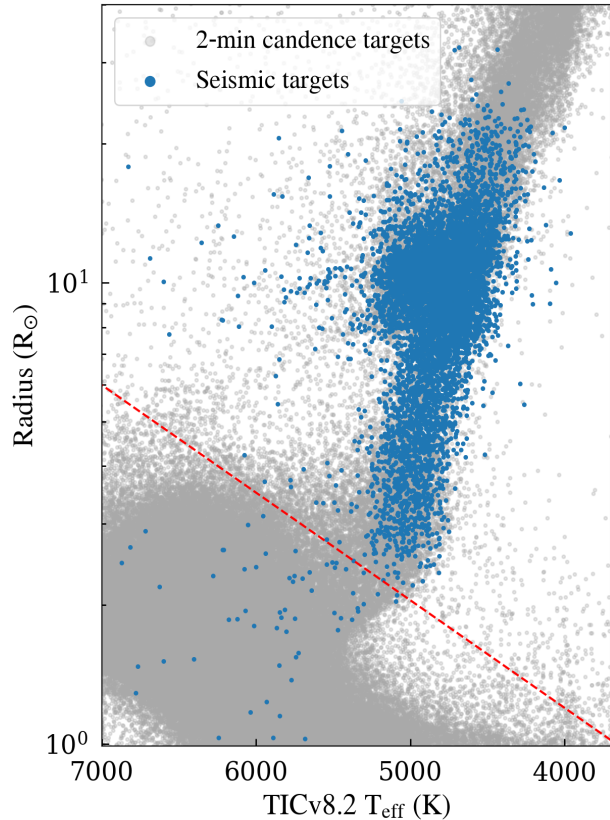
We download all available 2-minute cadence light curves spanning Sector 1 to 60 from the Mikulski Archive for Space Telescopes (MAST)<sup>1</sup>. These light curves were extracted and de-trended by the *TESS* Science Processing Operations Center (SPOC) pipeline (Twicken et al. 2016; Jenkins 2017).

A sample of stars selected for oscillation detection is based on the effective temperature ( $T_{\text{eff}}$ ) and radius ( $R$ ) values from the *TESS* Input Catalog version 8.2 (TICv8.2; Stassun et al. 2019), with criteria of  $1R_{\odot} \leq R \leq 40 R_{\odot}$  and  $3700\text{K} \leq T_{\text{eff}} \leq 7000\text{K}$ . This resulted in the identification of 193,020 candidates, depicted as gray dots in Figure 1. To categorize the stars into dwarfs and giants, we employ the relation  $R = 10^p R_{\odot}$ , with  $p = \left(\frac{T_{\text{eff}}(\text{K})}{7000} - \frac{3}{7}\right) \log\left(\frac{300}{7}\right) + \log(0.7)$  proposed by Hon et al. (2019) as the boundary (indicated by the red dashed line in Figure 1). This categorization results in 154,817 main sequence stars and subgiants, as well as 38,203 red giants.

### 2.2. Seismic data detection

We transform all the light curves (PDCSAP data) of our pre-selected stars (Section 2.1) into power density spectra using the Lomb-Scargle periodogram method (VanderPlas 2018). We apply a 5  $\sigma$ -clipping to remove outliers, and divide the light curves by a 10-day median filter to eliminate low-frequency signals in each sector, and concatenate the light curves of all available sectors (García et al. 2011).

We detect the oscillation power excess in each power density spectrum using the collapsed autocorrelation function (collapsed ACF) method (Huber et al. 2009). First, we divide the power spectrum in equally logarithmic bins and smooth the result using an empirical 40% percentile filter to obtain a crude estimate of the back-

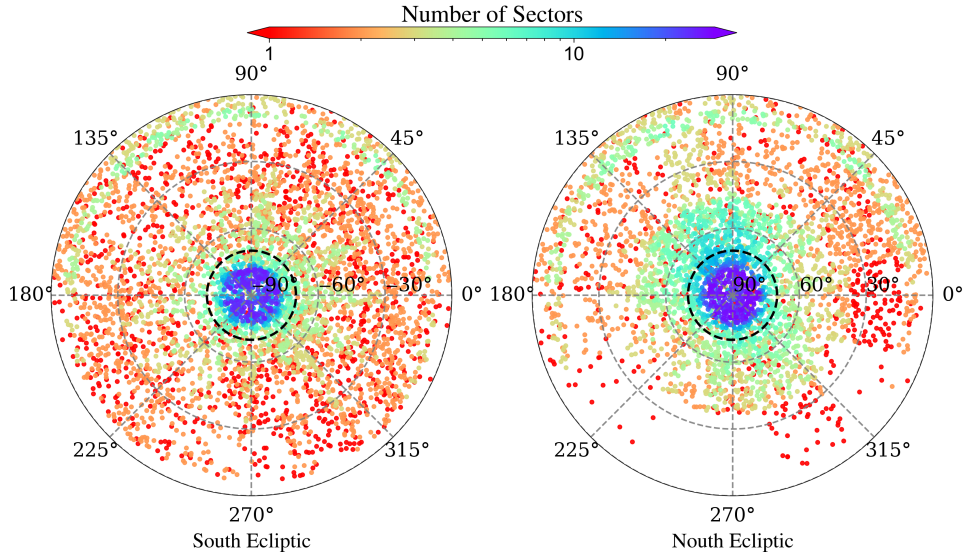


**Figure 1.**  $R$  versus  $T_{\text{eff}}$  for 2-minute cadence targets and seismic targets. The  $T_{\text{eff}}$  and radii are sourced from TICv8.2. Light gray dots show the 2-minute cadence targets, blue dots show the seismic targets, and the red dashed line, reference from Hon et al. (2019), shows the boundary used to distinguish early sub-giant stars from those ascending the red giant branch.

ground. Second, the residual power spectrum, obtained from dividing the power density spectrum by the estimated background, is segmented into overlapping subsets. The width of each subset is approximately  $4\Delta\nu_{\text{exp}}$  around its central frequency ( $\nu_{\text{center}}$ ), where  $\Delta\nu_{\text{exp}}$  is estimated as  $0.263 \times \nu_{\text{center}}^{0.772}$  (Stello et al. 2009). For each subset, we calculate the absolute ACF and then collapse the ACF by its referring  $\nu_{\text{center}}$ . Finally, we smooth the collapsed ACFs with an empirical 7  $\mu\text{Hz}$  filter and fit them with a Gaussian profile centered on their maximum peak, along with constant noise.

We retain stars with a signal-to-noise ratio(SNR) greater than 1.5, and identify 7,870 solar-like oscillators. For stars with  $1.2 \leq \text{SNR} \leq 1.5$ , we carefully visually inspect their power density spectra for the presence of power excess, and confirm 209 oscillators. The 8,080 solar-like oscillators are shown in Figure 1 (blue dots), including 61 main sequence stars and subgiants, and 8,019 red giants. This indicates a solar-like oscilla-

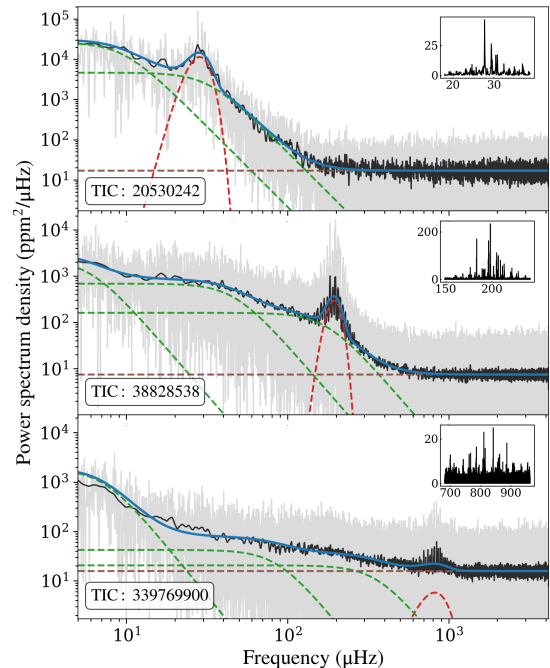
<sup>1</sup> Data can be found in MAST: [10.17909/t9-nmc8-f686](https://mast.stsci.org/#/t9-nmc8-f686)



**Figure 2.** The distribution of detected solar-like oscillators across the celestial sphere. The color bar corresponds to the observation duration, denoted by the number of sectors. Some stars (green dots) are observed for 2–3 sectors near the ecliptic because *TESS* focused on a specific segment of the ecliptic from Sector 42 to 46 coinciding with the portion of the *K2* observation zones. The northern ecliptic hemisphere contains gaps to avoid excessive contamination from stray Earth- and moonlight, and the corresponding region appears at low latitudes close to the ecliptic. The black dashed circles represent the CVZs.

tion detection rate of approximately 20% in red giants. Furthermore, we repeat the same procedure for stars not presented in TICv8.2 and identify an additional 571 oscillators. In total, we have identified an asteroseismic sample of 8,651 stars.

Figure 2 illustrates the distribution of the sample across the ecliptic celestial sphere, covering nearly the entire sky. *TESS* focused on a specific segment of the ecliptic during the fourth year, spanning from Sector 42 to 46, to coincide with the portion of the *K2* observation zones. Consequently, some stars (green dots) were observed for 2–3 sectors near the ecliptic. In order to minimize the contamination from stray Earth- and moonlight, *TESS* boresights toward a latitude of  $+85^\circ$  in some sectors, which leads to an incomplete coverage of the northern hemisphere at low latitudes. The black dashed circles within  $20^\circ$  of the northern and southern ecliptic poles represent the CVZs.

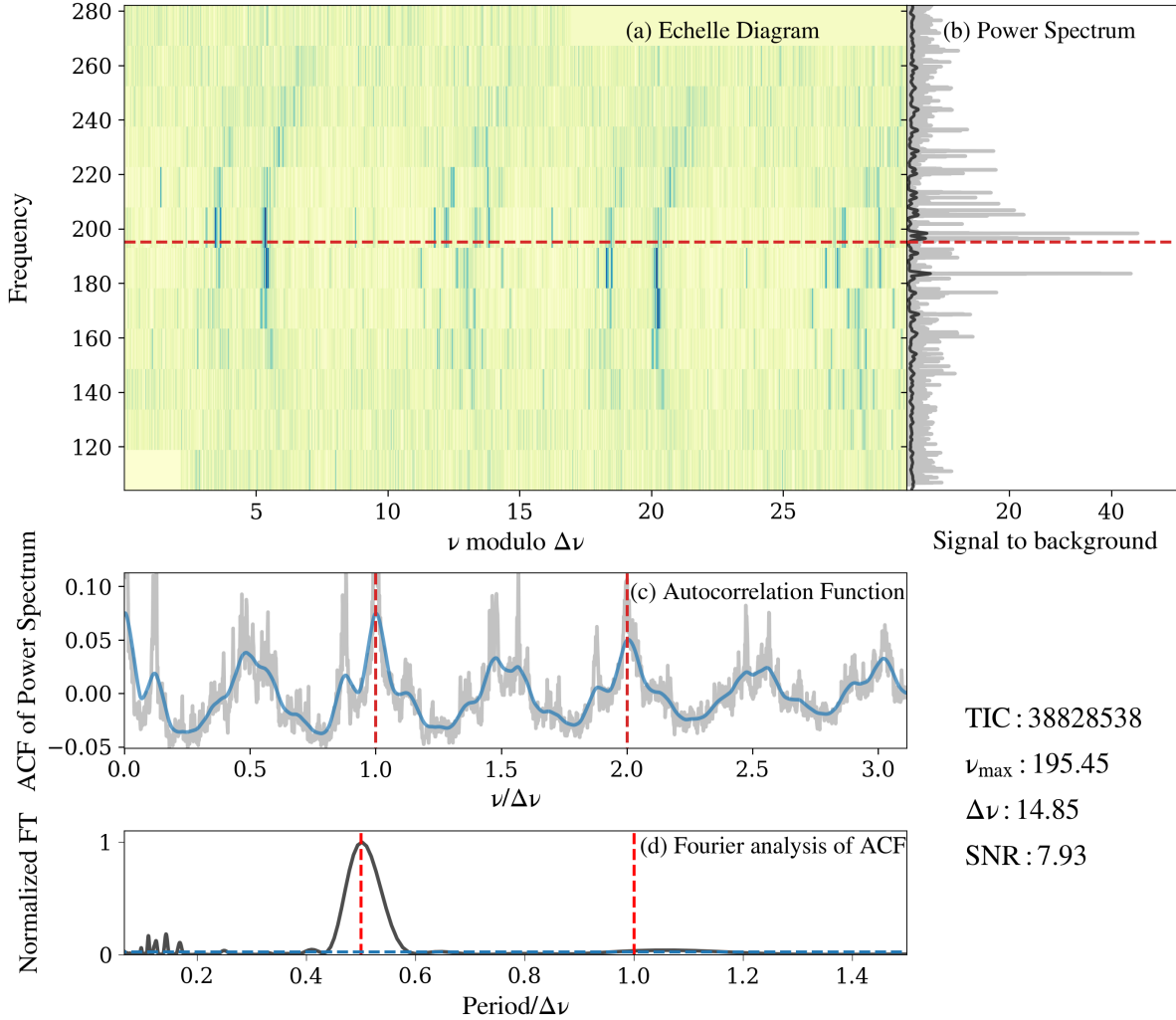


**Figure 3.** Representative power spectra of *TESS* 2-min cadence light curves. In each panel, the gray line shows the real data, and the black line shows the data smoothed by a boxcar filter of  $3 \mu\text{Hz}$  wide. The solid blue line shows the MCMC fitting result, with the red dashed line for the fitted Gaussian envelope, the green dashed curve for the three Harvey components, and the brown straight line for the white noise. The inset figure shows the power spectrum near  $\nu_{\text{max}}$  divided by the background.

### 3. MEASURING GLOBAL SEISMIC PARAMETERS

#### 3.1. Measuring the frequency at maximum power

We use the center of the fitted Gaussian profile to the collapsed ACF (Section 2.2) as the initial  $\nu_{\text{max,guess}}$ . To fit the power density spectrum, we employ a model that consists of a Gaussian envelope, three background Har-



**Figure 4.** An example of measuring  $\Delta\nu$  for TIC 38828538 : (a) the échelle diagram, the red dashed line represents the value of  $\nu_{\max}$ ; (b) the residual power spectrum; (c) the autocorrelation function, the two red dashed lines represent the positions of  $\Delta\nu$  and twice  $\Delta\nu$  from left to right; (d) the Fourier transforms of ACF, the two red dashed lines represent the positions of half of  $\Delta\nu$  and  $\Delta\nu$  in period from left to right, the blue dashed line shows noise.

vey components, and white noise (Chaplin et al. 2014):

$$P(\nu) = \eta(\nu)^2 \left[ \sum_i^3 \frac{2\sqrt{2}a_i/\pi b_i}{1 + (\nu/b_i)^4} + H_g \exp \frac{-(\nu - \nu_{\max})^2}{2\sigma^2} \right] + W_n, \quad (1)$$

where  $\eta(\nu) = \text{sinc}(\pi\nu/2\nu_{\text{nyq}})$  accounts for the frequency-dependent attenuation resulted from the observational signal discretization, and  $\nu_{\text{nyq}}$  is the *Nyquist* frequency (e.g., Chaplin et al. 2011b; Kallinger et al. 2014). For other parameters,  $a_i$  and  $b_i$  represent the root-mean-square (rms) and the characteristic frequency of the  $i$ th Harvey component, respectively.  $H_g$ ,  $\nu_{\max}$ , and  $\sigma$  are the height, the central frequency, and the width of the Gaussian envelope, respectively.  $W_n$  corresponds to the contribution of white noise.

We estimate  $\nu_{\max}$  and its uncertainty by Bayesian inference using Monte Carlo Markov Chain (MCMC) simulations (Foreman-Mackey et al. 2013). The initial fitting parameters for MCMC are from the Maximum Likelihood Estimation (MLE) method <sup>2</sup> (Huber et al. 2009; Kallinger et al. 2010). The minimum number of steps for the MCMC estimation is 3000 and the maximum number of steps is 5000. The  $\nu_{\max}$  is estimated as the median of the posterior probability distribution, and the uncertainties are approximated as the 16<sup>th</sup>/84<sup>th</sup> percentiles. Representative examples of the background fitting are shown in Figure 3.

<sup>2</sup> The initial fitting parameters used in MLE are derived from  $\nu_{\max, \text{guess}}$ .

**Table 1.** Stellar Global Oscillation Parameters

TIC	Tmag	$N_{\text{sectors}}$	$\nu_{\text{max}}$	$\sigma(\nu_{\text{max}})$	$\Delta\nu$	$\sigma(\Delta\nu)$	SNR	Types	Source
	mag		$\mu\text{Hz}$	$\mu\text{Hz}$	$\mu\text{Hz}$	$\mu\text{Hz}$			
1608	8.78	2	43.66	5.17	4.67	0.33	7.64	–	–
13727	7.31	1	188.99	5.04	16.91	0.94	7.39	–	–
80047	9.76	1	64.07	5.60	7.81	0.99	6.36	Binary	4
89696	8.63	1	43.13	1.84	4.81	0.57	3.71	–	–
92094	8.21	2	44.17	2.51	–	–	2.36	–	–
99433	4.42	2	73.55	5.20	–	–	2.82	–	–
105245	8.26	2	272.89	7.94	18.16	0.96	3.53	–	–
...	...	...	...	...	...	...	...	...	...
471011913	6.38	2	256.66	3.33	18.59	0.27	6.17	–	–
900749927	5.35	4	39.69	1.91	3.84	0.34	6.87	–	–

NOTE—The source of the adopted stellar types for each star is indicated by the following: (1) Spectroscopic Binary Orbits Ninth Catalog, (2) the *TESS* eclipsing binary catalog, (3) NASA’s Exoplanet Archive, (4) *Gaia* DR3 `nss.two.body.orbit` Catalog. SNR indicates the signal-to-noise ratio of  $\Delta\nu$ . The machine-readable table is fully accessible.

### 3.2. Measuring the large frequency separation

We use the ACF method to measure  $\Delta\nu$  values (Huber et al. 2009; Chontos et al. 2022), shown in Figure 4. Figure 4(a) displays the échelle diagram of the oscillation modes. To prepare for the  $\Delta\nu$  measurement, we first normalize the power density spectrum by dividing it by the MCMC-fitted background (Gaussian component excluded). Then, we restrict the normalized power density spectrum to the frequency range of  $\nu_{\text{max}} \pm 3\Delta\nu_{\text{exp}}$ , as shown in Figure 4 (b). Within this frequency range, we calculate the ACF and apply a boxcar filter with an empirical width of  $0.2\Delta\nu_{\text{exp}}$ . Finally,  $\Delta\nu$  is measured as the maximum value within the range of  $0.7\text{--}1.3 \Delta\nu_{\text{exp}}$  in the smoothed ACF, as depicted in Figure 4(c).

To evaluate the significance of the  $\Delta\nu$  measurements, we calculate SNR through dividing the maximum value of normalized Fourier transforms (FT) on the ACF by the noise, corresponding to the half of  $\Delta\nu$  or  $\Delta\nu$ . The noise is represented by the rms of the normalized FT on the ACF, as shown in Figure 4(d). Consequently, we obtain a sample of 7,509 stars with valid  $\Delta\nu$  measurements, adopting only  $\Delta\nu$  measurements with  $\text{SNR} \geq 3$ .

Following Huber et al. (2011), the uncertainties of  $\Delta\nu$  are estimated by conducting 500 perturbations on the power-density spectrum using a  $\chi^2$  distribution with two degrees of freedom. For each perturbation, the fitting procedure is repeated, and the standard deviation of 500 measurements is considered as the uncertainty.

## 4. RESULTS

### 4.1. Asteroseismic Sample

We present an asteroseismic sample of 8,651 solar-like oscillators with  $\nu_{\text{max}}$ , including 7,509 stars with  $\Delta\nu$ . Notably, 2,173 stars from this sample are new oscillators that were not previously detected (Hon et al. 2021, 2022; Hatt et al. 2023). Compared to Hatt et al. (2023), we add 4,373 new  $\Delta\nu$  of stars. Additionally, we flag 781 binaries and 85 exoplanet host stars by cross-matching the sample with Spectroscopic Binary Orbits Ninth Catalog<sup>3</sup>, NASA Exoplanet Archive<sup>4</sup>, the *TESS* Eclipsing Binary Catalog<sup>5</sup>, and *Gaia* DR3 `nss.two.body.orbit` Catalog, respectively (Pourbaix et al. 2004; Howard et al. 2022; Prša et al. 2022; Gaia Collaboration 2022). The results are listed in Table 1.

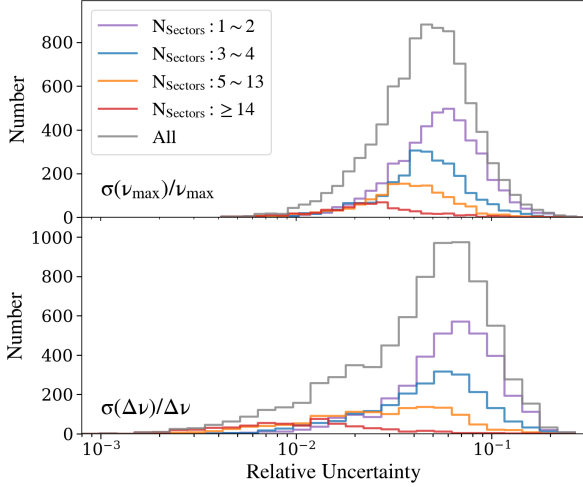
Figure 5 shows the histogram of relative uncertainties for  $\nu_{\text{max}}$  and  $\Delta\nu$ . The number of sectors ( $N_{\text{sectors}}$ ) marks the observation duration, with longer duration corresponding to lower uncertainties. This indicates that longer duration significantly improves measurement precision.

Figure 6 shows the well-established power-law relation of  $\nu_{\text{max}}$  and  $\Delta\nu$  (Stello et al. 2009; Hekker et al. 2009). The black dotted line is expressed as  $\Delta\nu = \alpha \cdot (\nu_{\text{max}})^\beta$ . It is fitted by an MCMC method, and consequently, we obtain  $\alpha = 0.236 \pm 0.001$  and  $\beta = 0.789 \pm 0.001$ . The  $\nu_{\text{max}}$  and  $\Delta\nu$  exhibit a linear relation in logarithmic coordinates, especially for stars with  $\sigma(\Delta\nu)/\Delta\nu \leq 0.1$ . The stars having  $\Delta\nu$  precision worse than 0.1 and  $\nu_{\text{max}} \sim 20\text{--}100\mu\text{Hz}$ , may correspond to red clump (RC), as they exhibit complex power spectra (Hon et al. 2017).

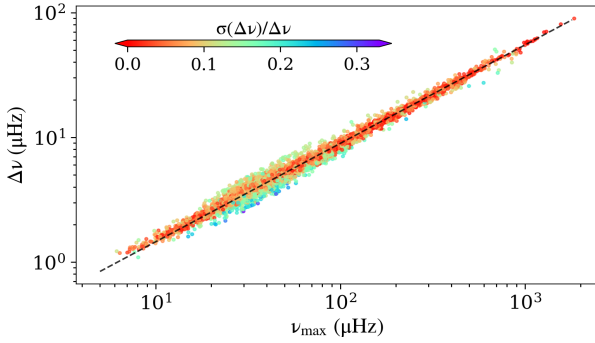
<sup>3</sup> <https://sb9.astro.ulb.ac.be/>

<sup>4</sup> <https://exoplanetarchive.ipac.caltech.edu/>

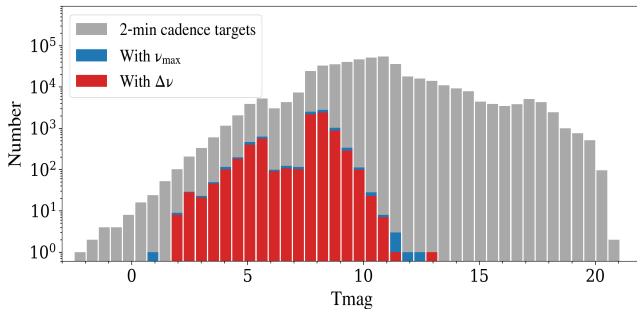
<sup>5</sup> <http://tessebs.villanova.edu/>



**Figure 5.** Histogram of relative uncertainties for  $\nu_{\max}$  and  $\Delta\nu$ .  $N_{\text{sectors}}$  shows the number of sectors. The gray line represents the entire sample, while the purple, blue, yellow, and red lines represent stars observed for 1 to 2 sectors, 3 to 4 sectors, 5 to 13 sectors, and stars observed for more than 14 sectors, respectively.



**Figure 6.** The relation of  $\nu_{\max}$  and  $\Delta\nu$  in logarithmic coordinates. The color bar shows the relative error of the measured  $\Delta\nu$ . The black dotted line follows a MCMC fitted power-law relation:  $\Delta\nu = \alpha \cdot (\nu_{\max})^\beta$ , where  $\alpha = 0.236 \pm 0.001$  and  $\beta = 0.789 \pm 0.001$ .



**Figure 7.** Histogram of *TESS* magnitude (Tmag) for all 2-minute cadence targets and the seismic stars. The gray color shows all 2-min cadence targets, the blue color shows oscillators with  $\nu_{\max}$ , and the red color shows stars with  $\Delta\nu$ .

Figure 7 shows the histogram of *TESS* magnitude (Tmag) for all 2-minute cadence stars and our sample. The number of our sample increases with Tmag at Tmag  $< 5$ , which is consistent with the overall sample. However, for Tmag  $> 9$ , the number of oscillators significantly decreases with increasing *TESS* magnitude. This suggests an optimal magnitude range of  $6 \leq \text{Tmag} \leq 9$  for observing solar-like oscillations. Additionally, there is a gap around Tmag = 7, consistent with Hatt et al. (2023). The gap exists in both all 2-minute cadence targets and our sample. We examined the histogram of *TESS* magnitude for each sector from Sector 1 to 60 and found the gap in each of them. It possibly results from the inhomogeneous selection for *TESS* observations of 2-minute cadence data.

#### 4.2. Comparison of $\nu_{\max}$ and $\Delta\nu$ Measurements

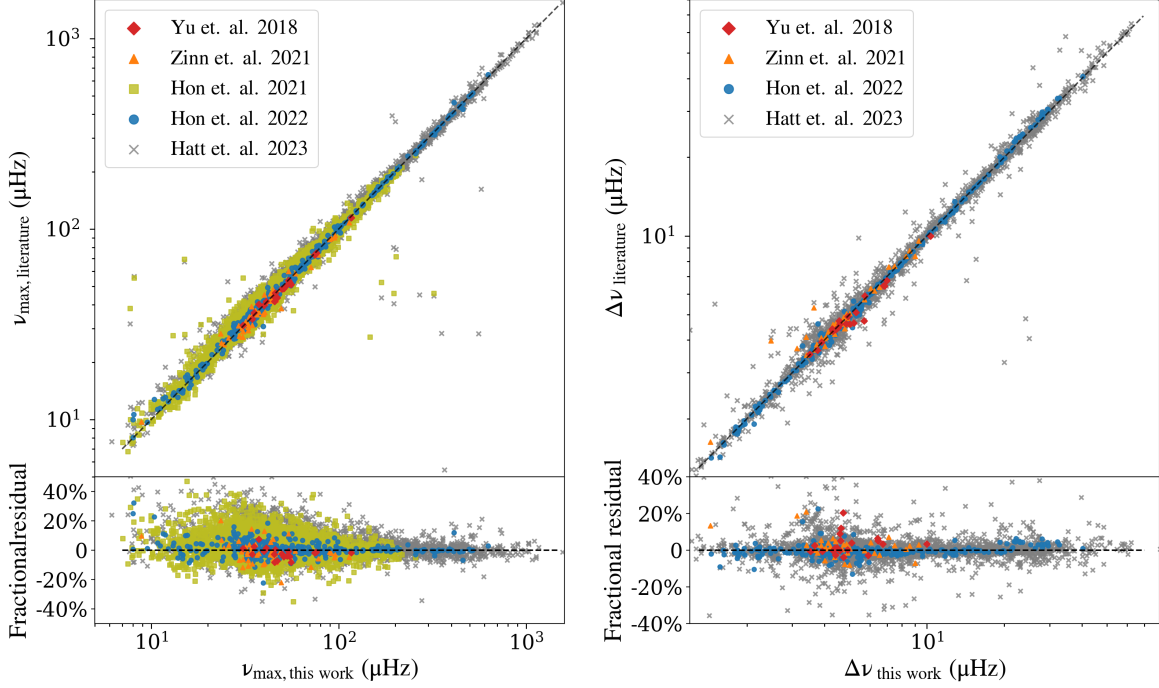
In Figure 8, we compare our global seismic parameters with those of common stars from literature. The results demonstrate good agreement, despite the differences in the methods and data. The median fractional residual in  $\nu_{\max}$  is 1.63% with a scatter of 14.75%, while the median fractional residual in  $\Delta\nu$  is 0.11% with a scatter of 10.76%, as shown in Table 2.

Figure 9 shows the distribution in  $\nu_{\max} - \nu_{\max}^{0.75}/\Delta\nu$  for our sample and stars in *Kepler/K2* long-cadence data and *TESS* 2-minute data from Hatt et al. (2023). Compared to *Kepler/K2* sample, on the one hand, there are fewer high-luminosity red giants in our sample, because our oscillators were observed within shorter duration. On the other hand, near the *Nyquist* frequency, it is possible to measure  $\Delta\nu$  with long-cadence data but challenging to measure  $\nu_{\max}$ , because the granulation background fitting could be biased and *Nyquist* aliases may occur (Yu et al. 2016, 2018). In this context, *TESS* 2-minute cadence data prove valuable.

Notably, we have detected 401 solar-like oscillators with  $\nu_{\max}$  exceeding the *Nyquist* frequency of *Kepler/K2* long-cadence data. These oscillators are more-evolved subgiants or low-luminosity red giants, whose solar-like oscillation were seldom detected by either long- or short-cadence observation of the previous *Kepler/K2* mission. Such stars transform from nearly-uniform rotation to differential rotation, helping us to understand angular momentum transport (e.g., Aerts et al. 2019; Deheuvels et al. 2020; Kuszlewicz et al. 2023; Wilson et al. 2023).

#### 4.3. Fundamental stellar parameters

By cross-matching our sample to Gaia DR3 RVS spectra data, we obtain 7,173 stars with asteroseismic parameters and  $T_{\text{eff}}$ . We estimate radius ( $R_{\text{seismic}}$ ), mass



**Figure 8.** Comparison between global seismic parameters measured in this work and those from previous literature. The black dashed lines in the top panel show the one-to-one relation between the two parameters. The bottom left panel shows the fractional residuals of  $\nu_{\max}$ , calculated as  $(\nu_{\max,\text{literature}} - \nu_{\max,\text{this work}}) / \nu_{\max,\text{this work}}$ . Similarly, the bottom right panel displays the fractional residuals of  $\Delta\nu$ , calculated as  $(\Delta\nu_{\text{literature}} - \Delta\nu_{\text{this work}}) / \Delta\nu_{\text{this work}}$ .

**Table 2.** Comparison of Global Seismic Parameters with Previous Literature

	Missions:	<i>Kepler</i>	<i>K2</i>	<i>TESS</i>		
				30 mins	30 mins	120 and 20 secs
	Cadences:	30 mins	30 mins	30 mins	30 mins	120 and 20 secs
	Common Stars:	20 <sup>1</sup>	51 <sup>2</sup>	5375 <sup>3</sup>	348 <sup>4</sup>	3129 <sup>5</sup>
$\nu_{\max}$	Median Residual:	-1.81%	-2.03%	1.37%	0.42%	2.49%
	Scatter:	3.63%	7.41%	13.53%	5.05%	17.21%
$\Delta\nu$	Median Residual:	-1.99%	2.44%	–	-0.34%	0.11%
	Scatter:	4.88%	13.17%	–	3.68%	10.58%

NOTE—Stars of Common are sourced from: (1) Yu et al. (2018), (2) Zinn et al. (2019), (3) Hon et al. (2019), (4) Hon et al. (2021), (5) Hatt et al. (2023).

( $M_{\text{seismic}}$ ), and surface gravity ( $\log g$ ) of these stars by the scaling relations (Ulrich 1986; Brown et al. 1991; Kjeldsen & Bedding 1995; Belkacem et al. 2011):

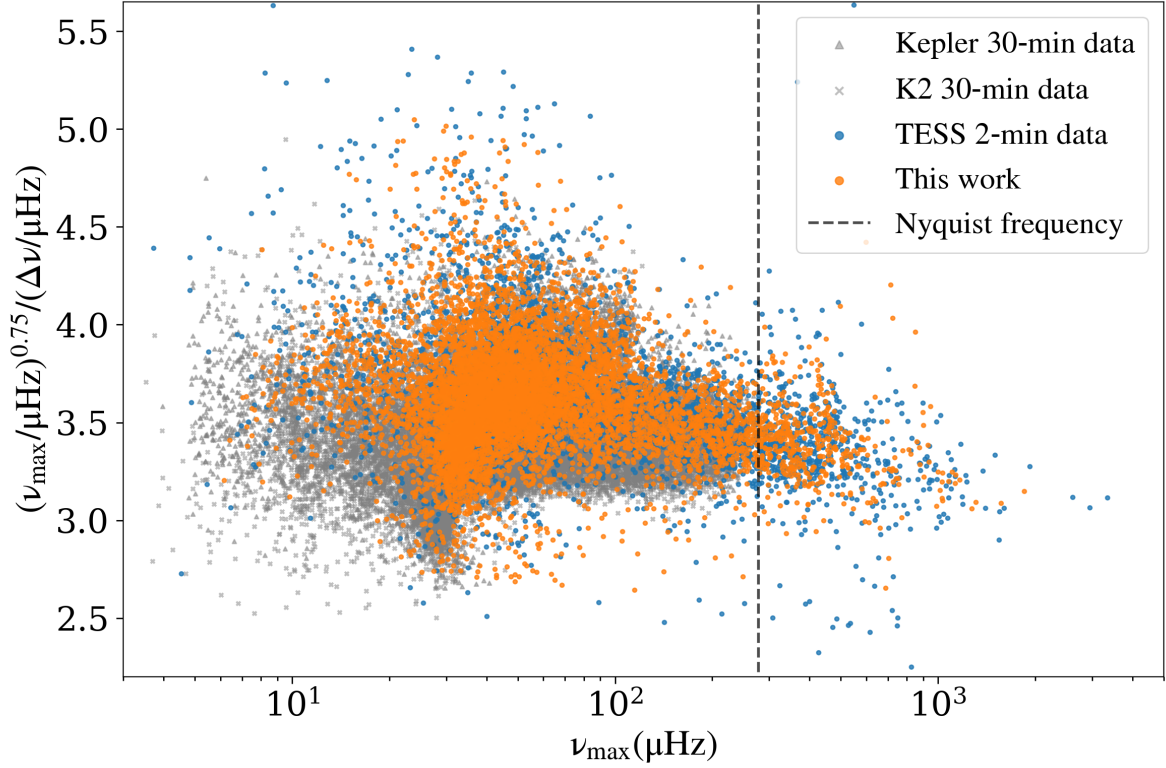
$$\frac{M_{\text{seismic}}}{M_{\odot}} \approx \left( \frac{\nu_{\max}}{\nu_{\max,\odot}} \right)^3 \left( \frac{\Delta\nu}{\Delta\nu_{\odot}} \right)^{-4} \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{3/2}, \quad (2)$$

$$\frac{R_{\text{seismic}}}{R_{\odot}} \approx \left( \frac{\nu_{\max}}{\nu_{\max,\odot}} \right) \left( \frac{\Delta\nu}{\Delta\nu_{\odot}} \right)^{-2} \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{1/2}, \quad (3)$$

$$\frac{g}{g_{\odot}} \approx \left( \frac{\nu_{\max}}{\nu_{\max,\odot}} \right) \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{1/2}, \quad (4)$$

where  $\nu_{\max,\odot} = 3090 \mu\text{Hz}$ ,  $\Delta\nu_{\odot} = 135.1 \mu\text{Hz}$ , and  $T_{\text{eff},\odot} = 5777 \text{ K}$  adopted from Huber et al. (2013). The estimates of  $M_{\text{seismic}}$ ,  $R_{\text{seismic}}$ , and  $\log g$  are listed in Table 3, with their median uncertainties of 9.20%, 6.24% and 0.01 dex (0.79%), respectively.

To validate our asteroseismic radii, we use another independent method to derive radii and luminosities for these stars. We employ the SED pipeline (Yu et al. 2021, 2023) alongside MARCS model spectra for performing the spectral energy distribution (SED) fitting. Our approach adopts spectroscopic  $T_{\text{eff}}$ ,  $\log g$ , and  $[M/H]$  priors (from Gaia DR3 RVS spectra) and com-

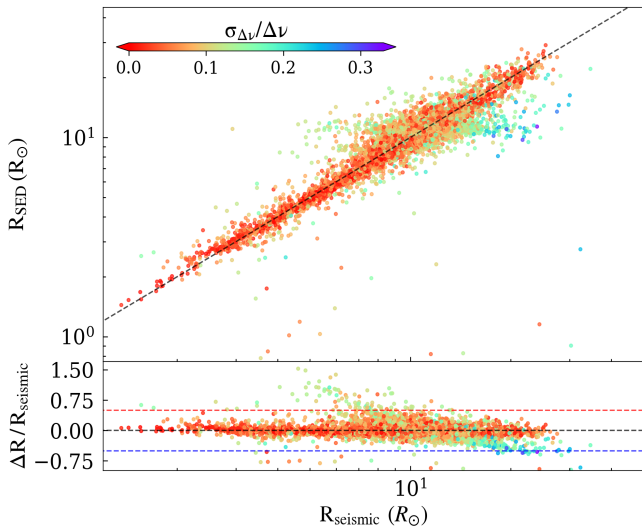


**Figure 9.**  $\nu_{\max}$  vs.  $\nu_{\max}^{0.75}/\Delta\nu$  diagram. The horizontal axis shows  $\nu_{\max}$ , while the vertical axis shows  $\nu_{\max}^{0.75}/\Delta\nu$ , which is a mass proxy related to temperature. The gray triangles and crosses represent samples from *Kepler* and *K2* long-cadence data, respectively. Blue dots show sample from previous *TESS* 2-minute data as presented by [Hatt et al. \(2023\)](#) and yellow dots show our sample.

**Table 3.** Fundamental stellar parameters

TIC	$T_{\text{eff}}$ <i>K</i>	$\log g$ <i>c.g.s</i>	$M_{\text{seismic}}$ $M_{\odot}$	$R_{\text{seismic}}$ $R_{\odot}$	$R_{\text{SED}}$ $R_{\odot}$	$L_{\text{SED}}$ $\log(L/L_{\odot})$
1608	$4739.0 \pm 11.0$	$2.55 \pm 0.03$	$1.47 \pm 0.14$	$10.72 \pm 0.19$	$11.09 \pm 0.11$	$1.747 \pm 0.016$
13727	$4795.0 \pm 162.5$	$3.19 \pm 1.89$	$0.71 \pm 0.06$	$3.56 \pm 0.23$	$4.02 \pm 0.04$	$0.908 \pm 0.040$
80047	$4736.0 \pm 28.5$	$2.73 \pm 0.09$	$0.60 \pm 0.14$	$5.62 \pm 0.89$	$6.52 \pm 0.24$	$1.282 \pm 0.035$
89696	$4768.0 \pm 22.0$	$2.55 \pm 0.04$	$1.27 \pm 0.42$	$10.01 \pm 1.88$	$8.81 \pm 0.10$	$1.554 \pm 0.016$
...	...	...	...	...	...	...
11688264	$4756.0 \pm 10.0$	$2.20 \pm 0.01$	$0.69 \pm 0.32$	$10.95 \pm 2.87$	$11.72 \pm 0.11$	$1.801 \pm 0.016$
11738052	$4854.0 \pm 3.5$	$2.78 \pm 0.02$	$1.12 \pm 0.25$	$7.15 \pm 1.04$	$8.58 \pm 0.04$	$1.562 \pm 0.015$
12063724	$4720.0 \pm 11.5$	$2.56 \pm 0.03$	$1.70 \pm 0.20$	$11.40 \pm 0.08$	$10.01 \pm 0.07$	$1.651 \pm 0.015$
12333486	$4677.0 \pm 8.5$	$2.43 \pm 0.02$	$1.82 \pm 0.44$	$13.70 \pm 1.93$	$13.08 \pm 0.35$	$1.867 \pm 0.027$
12358786	$4747.0 \pm 10.0$	$2.69 \pm 0.03$	$1.04 \pm 0.08$	$7.70 \pm 0.54$	$7.97 \pm 0.07$	$1.464 \pm 0.016$
12376694	$4595.0 \pm 9.0$	$2.37 \pm 0.02$	$0.71 \pm 0.03$	$9.14 \pm 0.40$	$10.77 \pm 0.09$	$1.666 \pm 0.015$
...	...	...	...	...	...	...

NOTE—Catalog of fundamental stellar parameters for 7,173 stars.  $T_{\text{eff}}$  are collected from *Gaia* DR3 RVS spectra, the stellar  $M_{\text{seismic}}, R_{\text{seismic}}$  and  $\log g$  are provided by scaling relations,  $R_{\text{SED}}$  and  $L_{\text{SED}}$  obtained through the SED fitting. The machine-readable table is fully accessible.



**Figure 10.** Comparisons of radii from the asteroseismic scaling relations with radii from the SED fitting. The color bar represents the relative error of  $\Delta\nu$ . The bottom panel displays fractional residuals between radius estimates, denoted as  $\Delta R = R_{\text{SED}} - R_{\text{seismic}}$ .

bins them with apparent magnitudes from 32 band passes across nine photometric databases (Yu et al. 2023) to derive both extinction and bolometric fluxes. Leveraging *Gaia* DR3 parallaxes, we then compute luminosities and deduce stellar radii in conjunction with the spectroscopic  $T_{\text{eff}}$ . The uncertainties in bolometric fluxes are assessed through a Bayesian framework, and the uncertainties in luminosities and radii were determined via error propagation given  $T_{\text{eff}}$  uncertainties. It is noted that the above two methods adopt the same effective temperature, implying that the measurements in both approaches may be subject to potential systematic effects related to  $T_{\text{eff}}$ . Figure 10 shows the comparison between  $R_{\text{seismic}}$  and  $R_{\text{SED}}$ . The result reveals a good agreement, with a median fractional residual of  $-0.79\%$  and a standard deviation of  $16.60\%$ . This consistency is partly attributed to employing the same effective temperature in both measurements. The estimates of  $R_{\text{SED}}$  and  $L_{\text{SED}}$  are also listed in Table 3.

## 5. CONCLUSIONS

We have presented a sample of 8,651 solar-like oscillators with  $\nu_{\text{max}}$  measurements, including 7,509 stars with  $\Delta\nu$  using *TESS* 2-min cadence light curves. Comparing with literature, we have newly detected 2,173 oscillators and added 4,373  $\Delta\nu$  measurements. Our seismic parameters demonstrate good consistency with those from previous studies. The median fractional residual for  $\nu_{\text{max}}$  is  $1.63\%$  with a scatter of  $14.75\%$ , and the median fractional residual for  $\Delta\nu$  is  $0.11\%$  with a scatter of  $10.76\%$ .

We have detected 476 solar-like oscillators that exhibit  $\nu_{\text{max}}$  values exceeding the *Nyquist* frequency of *Kepler/K2* long-cadence data, which increases the sample size of more-evolved subgiants and low-luminosity red giants. Such oscillators may provide observational constraints on the stellar internal rotation profiles, which potentially contributes to our understanding of angular momentum transport.

We have estimated asteroseismic masses (with a median precision of  $9.21\%$ ), radii (with a median precision of  $6.24\%$ ), and  $\log g$  for a subset of 7,173 stars cross-matched from *Gaia* DR3 RVS spectra data. Our asteroseismic radii are in good agreement with the radii from the SED fitting.

Our sample covers the entire sky, showing the advantage of the *TESS* mission to detect solar-like oscillators. With further observations by *TESS*, a greater number and diversity of potential solar-like oscillators are expected to be detected. This will provide valuable observational targets for future missions, such as *PLATO* (to be launched in 2026; Rauer et al. 2014), which will significantly improve observations of stars with detectable solar-like oscillations. A higher-precision sample of solar-like oscillators spanning from main sequence stars to red giants, will provide new perspectives on stellar structure and evolution.

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