

Evolution of the near-core rotation frequency of 2,497 intermediate-mass stars from their dominant gravito-inertial mode[★]

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ABSTRACT

Context. The sparsely sampled time-series photometry from *Gaia* Data Release 3 (DR3) led to the discovery of more than 100,000 main-sequence non-radial pulsators. The majority of these were further scrutinised by uninterrupted high-cadence space photometry assembled by the Transiting Exoplanet Survey Satellite (TESS).

Aims. We combine *Gaia* DR3 and TESS photometric light curves to estimate the internal physical properties of 2,497 gravity-mode pulsators. We perform asteroseismic analyses with two major aims: 1) to measure the near-core rotation frequency and its evolution during the main sequence and 2) to estimate the mass, radius, evolutionary stage, and convective core mass from stellar modelling.

Methods. We rely on asteroseismic properties of *Kepler* γ Doradus and Slowly Pulsating B stars to derive the cyclic near-core rotation frequency, f_{rot} , of the *Gaia*-discovered pulsators from their dominant prograde dipole gravito-inertial pulsation mode. Further, we investigate the impact of adding f_{rot} as extra asteroseismic observable aside from the luminosity and effective temperature on the outcome of grid-based modelling from rotating stellar models.

Results. We offer a recipe based on linear regression to deduce f_{rot} from the dominant gravito-inertial mode frequency, which we show to be applicable to prograde dipole modes with amplitude above 4 mmag. By applying it to 2497 pulsators with such a mode, we increase the sample of intermediate-mass dwarfs having such an asteroseismic observable by a factor of 4. We use the estimate of f_{rot} , along with the *Gaia* effective temperature and luminosity, to deduce the (convective core) mass, radius, and evolutionary stage from grid modelling based on rotating stellar models. We derive a decline of f_{rot} with a factor of two during the main-sequence evolution for this population of field stars, which covers a mass range from $1.3 M_{\odot}$ to $7 M_{\odot}$. We find observational evidence for an increase in the radial order of excited gravity modes as the stars evolve. For 307 pulsators, we derive an upper limit of the radial differential rotation between the convective core boundary and the surface from *Gaia*'s vbroad measurement and find values up to 5.4.

Conclusions. Our recipe to deduce the near-core rotation frequency from the dominant prograde dipole gravito-inertial mode detected in the independent *Gaia* and TESS light curves is easy to use and facilitates applications to large samples of pulsators, mapping their angular momentum and evolutionary stage in the Milky Way.

Key words. Asteroseismology – Waves – Stars: oscillations (including pulsations) – Stars: interiors – Stars: rotation – Stars: evolution

1. Introduction

The internal rotation of stars continues to be one of the major uncertain ingredients in the theory of stellar evolution (Maeder 2009). The dominant transport processes happening in the interiors of stars rely on poorly calibrated expressions involving the gradient of the angular rotation profile. To compute this gradient throughout the evolution of the star, the so-called shellular approximation introduced by Zahn (1992) is often adopted. Relying on this formulation, the profile of $d\Omega(r)/dr$ is used to eval-

uate the element and angular momentum processes in the stellar interior (e.g., Chaboyer & Zahn 1992; Heger et al. 2000; Maeder & Meynet 2000).

Over the past decade, asteroseismology (Aerts et al. 2010) has been a game changer in the study of stellar rotation. Progress on the internal rotation of stars relied on the detection and interpretation of non-radial oscillation modes probing the deepest layers of stars. Dupret et al. (2009) provided theoretical predictions on the capacity of dipole mixed modes to probe the central regions of evolved low-mass stars, while Miglio et al. (2008) and Bouabid et al. (2013) described the properties of gravity and gravito-inertial modes in young intermediate-mass dwarfs. These theoretical studies were turned into practical tools thanks to space asteroseismology (Hekker & Christensen-Dalsgaard 2017; García & Ballot 2019; Córscico et al. 2019; Aerts 2021; Kurtz 2022, for recent overviews).

Accurate values of the angular (near-)core rotation frequencies (denoted here as Ω_{core}) for thousands of stars were deduced

[★] Data files with the Gaia identification number, the near-core rotation frequency, the (convective core) mass, the evolutionary stage, the radius, the dominant oscillation frequency in the co-rotating frame, the spin parameter of the dominant mode, and both an upper limit for the surface rotation frequency and for the near-core to surface rotation for the stars with these latter two quantities are available at the CDS via anonymous ftp to cdsarc.cds.unistra.fr (130.79.128.5) or via <https://cdsarc.cds.unistra.fr/viz-bin/cat/J/A+A/???/A???>

from dipole mixed modes in subgiants and red giants (Beck et al. 2011; Bedding et al. 2011; Beck et al. 2012; Deheuvels et al. 2012; Mosser et al. 2012, 2014, 2015; Gehan et al. 2018) and from dipole gravity modes in dwarfs (Degroote et al. 2010; Pápics et al. 2012, 2014; Kurtz et al. 2014; Saio et al. 2015; Van Reeth et al. 2015b, 2016; Ouazzani et al. 2017; Pápics et al. 2017; Saio et al. 2018). The diagnostic observables used to deduce the measurements of the internal rotation are either rotationally-split multiplets or period spacing patterns of mixed modes or gravity modes affected by the Coriolis acceleration (cf., Aerts et al. 2019, for a review of the methodologies). From the stars that also have a measurement of the angular envelope rotation frequency (Ω_{env}) it was further established that strong near-core to envelope coupling occurs, keeping the level of differential rotation ($\Omega_{\text{core}}/\Omega_{\text{env}}$) modest during the two longest phases of stellar evolution (Deheuvels et al. 2015; Triana et al. 2015; Van Reeth et al. 2018; Li et al. 2020; Ouazzani et al. 2020; Saio et al. 2021; Li et al. 2024). Further, it was established that the core rotation at the time of central helium exhaustion is in agreement with the rotation of white dwarfs (Hermes et al. 2017; Aerts et al. 2019). Moreover, $\Omega_{\text{core}}/\Omega_{\text{env}}$ increases strongly during hydrogen shell burning, reaching values up to 20 (Deheuvels et al. 2014; Di Mauro et al. 2016; Triana et al. 2017; Deheuvels et al. 2020; Li et al. 2024).

Thanks to asteroseismology, our understanding of how angular momentum transport and angular momentum loss slow down the (core) rotation after exhaustion of the central hydrogen has improved dramatically (Fuller et al. 2019; Eggenberger et al. 2019a,b; Moyano et al. 2023a). These novel transport theories comply with the asteroseismic measurements of the internal rotation for thousands of evolved stars of low and intermediate mass. For the longest phase of stellar evolution, however, we only have measurements of Ω_{core} and Ω_{env} or Ω_{surf} , the latter being the angular rotation frequency at the stellar surface, for less than 100 dwarfs (Li et al. 2020; Pedersen et al. 2021; Pedersen 2022a). These observables cover the mass range of $[1.3, 9] M_{\odot}$ and span a broad interval of measured near-core rotation rates (up to about $30 \mu\text{Hz}$, Aerts 2021). As a consequence, our understanding of angular momentum transport during core hydrogen burning is still limited, despite progress over the past five years (Fuller et al. 2019; Eggenberger et al. 2022; Bétrisey et al. 2023; Moyano et al. 2023b, 2024).

Here, our aim is to enlarge the sample of dwarfs with an estimate of the near-core rotation frequency and to study how it evolves in time during the main-sequence phase. We wish to deduce $d\Omega/dt$ in the transition zone from the convective core to the radiative envelope as the star evolved from the zero-age-main-sequence (ZAMS) to the terminal-age-main sequence (TAMS). We achieve this by relying on a sample of thousands of new gravity-mode pulsators discovered from Data Release 3 (DR3) of the *Gaia* space mission (Gaia Collaboration et al. 2023; Aerts et al. 2023). Hey & Aerts (2024) confirmed the pulsational nature of these stars discovered from the *Gaia* DR3 data on the basis of independently assembled light curves from the Transiting Exoplanet Survey Satellite (TESS). The sample of gravity-mode pulsators with both *Gaia* DR3 and TESS data in the public domain is 23 times larger than the *Kepler* sample of dwarfs with measurements of $\Omega_{\text{near-core}}$ (Mombarg et al. 2024b).

We work towards our goal by relying on two well-established properties of main-sequence gravity-mode pulsators deduced from *Kepler* space-based photometry: 1) the majority of such pulsators reveals dominant prograde dipole modes (Van Reeth et al. 2016; Li et al. 2020); 2) the dominant mode in their amplitude spectra reveals a clear shift towards higher frequency ac-

ording to their near-core rotation rate (Pápics et al. 2017; Aerts & Tkachenko 2024). Here, we bring these two properties together and come up with a regression formula for the near-core rotation frequency from a measurement of the dominant oscillation frequency of the *Kepler* gravity-mode pulsators (Sect. 2). We apply our recipe to the new sample of confirmed gravity-mode pulsators discovered from *Gaia* and validated by TESS (Sect. 3). We perform grid modelling based on the near-core rotation frequency and the *Gaia* effective temperature and luminosity as non-seismic observables and compare the outcome with published evolutionary grid modelling without an asteroseismic estimate of $\Omega_{\text{near-core}}$ (Sect. 4). We end with conclusions and the prospect of deriving an asteroseismic measurement of the near-core rotation frequency for millions of dwarfs across the Milky Way from future combined *Gaia* DR4 and TESS data (Sect. 5).

2. A recipe for the near-core rotation frequency from a prograde dipole gravito-inertial mode

Gaia DR3 led to the discovery of more than 100,000 new candidate (non-)radial pulsators. Their dominant frequency have an amplitude above about 4 mmag (Gaia Collaboration et al. 2023). Among the new non-radial pulsators, Aerts et al. (2023) selected those with an amplitude below 35 mmag and dominant frequency in the range $[0.7, 3.2] \text{d}^{-1}$. These two extra criteria were found to be effective in selecting the γ Doradus (γ Dor) and Slowly Pulsating B (SPB) star candidates among the overall sample presented by Gaia Collaboration et al. (2023). The global stellar parameters of these 15,062 candidate gravity-mode pulsators were found to be in good agreement with those of confirmed and well-studied *Kepler* pulsators of these two kinds (Aerts et al. 2023).

Hey & Aerts (2024) revisited the sample of more than 100,000 candidate main-sequence pulsators classified by Gaia Collaboration et al. (2023). They extracted light curves for almost 60,000 of them from TESS Full Frame Images (FFIs) in the public domain. These densely sampled TESS light curves allowed them to confirm the dominant frequency found in the sparsely sampled *Gaia* DR3 time-series photometry for the majority of them. Hey & Aerts (2024) then reclassified the pulsators with a TESS FFI light curve. They came up with a cleaner sub-sample of gravity-mode pulsators among the multiperiodic variables, as improvement with respect to the Aerts et al. (2023) study.

Here, we consider a sub-sample of 15,692 pulsators classified by Hey & Aerts (2024) with a probability above 50% to be either a γ Dor or SPB star or a hybrid pressure/gravity-mode pulsator. Mombarg et al. (2024b) determined the mass, radius, and evolutionary stage of these 15,692 pulsators from evolutionary grid modelling. This was done by matching the stars' *Gaia* DR3 effective temperature and luminosity with those predicted from a grid of rotating stellar models calibrated by asteroseismology of *Kepler* gravity-mode pulsators, covering the mass range from $1.3 M_{\odot}$ to $9 M_{\odot}$.

For our study, we rely on the dominant pulsation mode of these 15,692 stars found consistently in the *Gaia* and TESS light curves to assess their cyclic near-core rotation frequency, denoted here for simplicity as $f_{\text{rot}} \equiv \Omega_{\text{near-core}}/2\pi$. In order to achieve this, we first recall some general properties of well-studied *Kepler* gravity-mode pulsators.

2.1. Basic properties of gravito-inertial modes in dwarfs

Main-sequence pulsators of γ Dor or SPB type exhibit low-frequency gravity modes of high radial-order, n , excited by either the flux blocking mechanism or the κ mechanism (Pamyatnykh 1999; Guzik et al. 2000; Bouabid et al. 2013; Xiong et al. 2016; Szewczuk & Daszyńska-Daszkiewicz 2017). The majority of these pulsators experience moderate to fast rotation, which brings the oscillation modes into the sub-inertial regime, where both buoyancy and the Coriolis force act together as restoring forces (Aerts et al. 2019; Aerts & Tkachenko 2024). Such modes are called gravito-inertial modes, while modes in slow rotators restored by buoyancy alone are pure gravity modes.

Following the labelling of the geometry of the modes by Lee & Saio (1997), gravito-inertial modes are characterised by indices (k, m) , with $k \equiv l - |m| \leq 0$, where l and m are the degree and azimuthal order of the mode. In the limit of high radial order n (corresponding to the limit of low frequencies), the gravity or gravito-inertial modes of the same degree and consecutive radial order obey a regular pattern. This is predicted theoretically (Miglio et al. 2008; Bouabid et al. 2013; Van Reeth et al. 2015a; Ouazzani et al. 2017) and observed in photometry of single and binary pulsators assembled with the Convection, Rotation, and exoplanetary Transits (CoRoT), *Kepler* or TESS space telescopes (e.g., Degroote et al. 2010; Pápics et al. 2012, 2014; Kurtz et al. 2014; Saio et al. 2015; Van Reeth et al. 2015b; Keen et al. 2015; Pápics et al. 2017; Szewczuk & Daszyńska-Daszkiewicz 2018; Sekaran et al. 2020; Wu et al. 2020; Li et al. 2020; Szewczuk et al. 2021; Pedersen et al. 2021; Garcia et al. 2022; Kemp et al. 2024).

In the asymptotic frequency limit, where the pulsation frequency in the co-rotating frame, f_{co} , is much smaller than the Brunt-Väisälä frequency, N , and in the Traditional Approximation of Rotation (TAR; e.g., Lee & Saio 1987; Townsend 2003), we have

$$f_{\text{co}} = \frac{\sqrt{\lambda_{kmv}}}{\Pi_0 (n + \alpha_g)}, \quad (1)$$

where λ_{kmv} is the eigenvalue of the Laplace tidal equation dependent on the spin parameter $\nu = 2f_{\text{rot}}/f_{\text{co}}$, α_g is a phase term dependent on the boundaries of the pulsation mode cavity denoted by the positions r_1 and r_2 , and the buoyancy radius

$$\Pi_0 = \frac{2\pi^2}{\int_{r_1}^{r_2} \frac{N(r)}{r} dr}. \quad (2)$$

The modes of γ Dor and SPB stars typically have spin parameters $\nu \in [1, 15]$ (Aerts et al. 2021).

2.2. Identification of the dominant mode of the *Kepler* gravity-mode pulsators

The combined *Kepler* gravity-mode pulsator samples analysed by Li et al. (2020), Pedersen et al. (2021), and Pedersen (2022b) reveal period-spacing patterns of prograde dipole modes for 610 of the 634 stars in the combined sample (96.2%). For 428 of these, that is 67.5% of the sample, the dominant mode was part of the detected pattern. When only stars with dominant pulsation amplitudes larger than 4 mmag are considered among these *Kepler* pulsators, which is the amplitude detection threshold for the discovery of the *Gaia* DR3 gravity-mode pulsators, this fraction increases to 84.7%.

Hence, in the remainder of this work we rely on the fact that the large majority among the dominant frequencies of well-characterised *Kepler* γ Dor and SPB stars correspond to a mode with $(k, m) = (0, 1)$. While doing so, we keep in mind that about 15% of the dominant frequencies may belong to a mode with another identification of (k, m) .

2.3. A regression formula for the internal rotation frequency

In the case of gravity modes with $k = 0$ in moderate- to fast-rotating stars, that is, with $\nu \gg 1$, theory predicts that $\lambda_{kmv} \approx m^2$ (e.g., Townsend 2003). This leads to a quasi-linear relation between the observed cyclic gravity-mode frequencies f_{nkm} and the near-core rotation frequency f_{rot} :

$$f_{nkm} = f_{\text{co}} + m f_{\text{rot}} \approx \frac{m}{\Pi_0 (n + \alpha_g)} + m f_{\text{rot}}, \quad (3)$$

which has also been found observationally (e.g. Van Reeth et al. 2016; Pápics et al. 2017; Li et al. 2020; Audenaert & Tkachenko 2022). Here, we wish to exploit this relationship in the context of the newly discovered *Gaia* gravity-mode pulsators, whose observed dominant cyclic mode frequencies, f_{dom} , are consistent in the DR3 and TESS data and which have amplitudes above 4 mmag. An earlier similar idea was put forward by Sepulveda et al. (2022) and Sepulveda et al. (2023) in the context of the exoplanet host stars 51 Eridani and HR 8799, which are both γ Dor pulsators. These authors considered an averaged frequency value among the dominant modes to infer the near-core rotation frequency in an empirical way by considering the sample of Li et al. (2020), without relying on the theory-based Eq. (3) as we do here.

To quantify the observational relation between f_{rot} and f_{dom} we fit a linear model to the *Kepler* results found for the homogeneously studied samples of γ Dor and SPB pulsators from Li et al. (2020) and Pedersen et al. (2021). In light of the application to the *Gaia* discovered gravity-mode pulsators, we only select the *Kepler* pulsators with dominant pulsation amplitude above 4 mmag and identified as $(k, m) = (0, 1)$, that is only stars with a dominant dipole prograde mode. Moreover, we demand their dominant mode to occur in the sub-inertial regime, where $\nu > 1$. In this way, we find the following regression fit based on the 100 γ Dor stars and 5 SPB stars with dominant prograde dipole mode in the sub-inertial regime of observed amplitude above 4 mmag with asteroseismic modelling from *Kepler*:

$$f_{\text{rot}} = 0.836_{-0.027}^{+0.023} f_{\text{dom}} - 0.272_{-0.036}^{+0.041} \text{ d}^{-1}, \quad (4)$$

where all of f_{rot} , f_{dom} and $1/\Pi_0$ are expressed in d^{-1} . This fit is illustrated by the full red line in Fig. 1. The strong correlation between f_{rot} and f_{dom} is reflected by the Pearson correlation coefficient, which has a value of 0.942.

We applied a bootstrap analysis on the residuals of the fit in Eq. (4) and find that the estimated rotation frequency values have uncertainties σ_- and σ_+ of -0.164 d^{-1} and $+0.123 \text{ d}^{-1}$, respectively. The results for this confidence interval are graphically depicted in Fig. 2 by the dashed lines. If we also take into account the residuals with respect to the regression line for the $\sim 20\%$ sample stars that have pulsations with other geometries or in the super-inertial regime, we find uncertainties σ_- and σ_+ of -0.302 d^{-1} and $+0.186 \text{ d}^{-1}$, respectively. This confidence interval is delineated by the dotted lines in Figs 1 and 2.

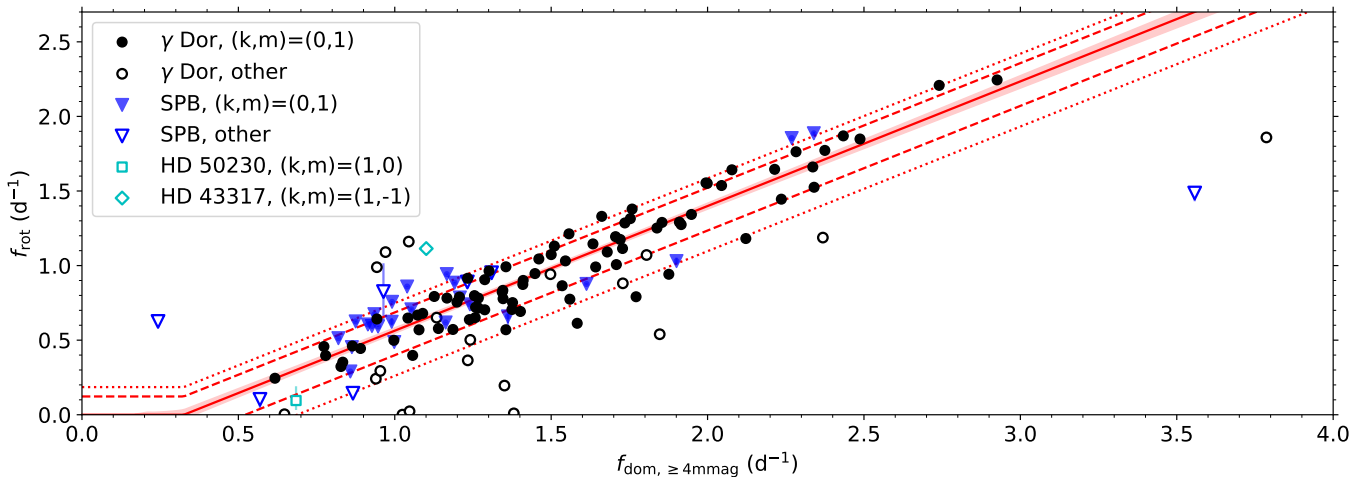


Fig. 1: The near-core rotation frequency f_{rot} plotted as a function of the dominant mode frequency for those *Kepler* gravity-mode pulsators having an observed amplitude above 4 mmag ($f_{\text{dom}, \geq 4 \text{ mmag}}$) from the samples of Li et al. (2020) and Pedersen et al. (2021). When invisible, the error bars are smaller than the symbol sizes or unavailable. The linear relation (red line) given by Eq. (4) was computed for 105 stars having a dominant prograde dipole mode with observed frequency above 0.35 d^{-1} and with $\nu > 1$ (full symbols). The shaded area shows the $1\text{-}\sigma$ uncertainty region for this relation. Stars are drawn as γ Dor pulsator if they have $T_{\text{eff}} < 8500 \text{ K}$ and $\Pi_0 < 0.7 \text{ d}$ and as SPB star otherwise. The two pulsators indicated in cyan come from short CoRoT light curves (Degroote et al. 2010; Pápics et al. 2012) and were not used in the regression. The dashed and dotted lines mark the $1\text{-}\sigma$ confidence intervals for f_{rot} derived from the residuals with respect to the red line, excluding and including stars with non-dipole modes or with modes having $\nu < 1$, respectively.

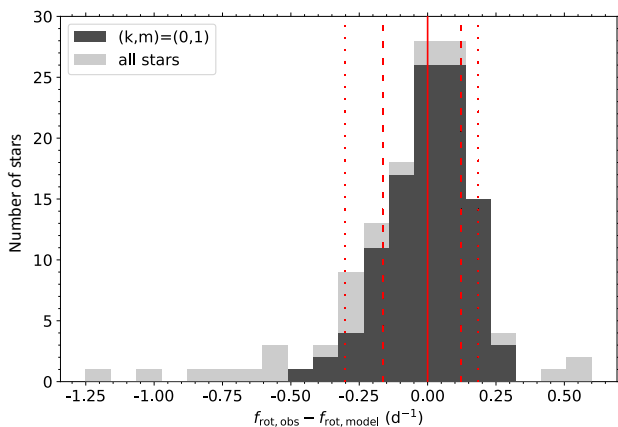


Fig. 2: Residuals from the linear fit described by Eq. (4) for the selected *Kepler* pulsators used in Fig. 1. The distribution of prograde dipole g modes with $\nu > 1$ and observed frequency above 0.35 d^{-1} is shown in dark grey, while the distribution of all dominant g modes with amplitude $\geq 4 \text{ mmag}$ is shown in light grey. The full, dashed, and dotted lines indicate the same relation and confidence intervals as those in Fig. 1.

2.4. The scaled buoyancy radius

For the observed dominant prograde dipole modes in the *Kepler* sample, we can use Eq. (1) to derive $\Pi_0(n + \alpha_g)$, where we use the mode frequencies and the determined rotation frequencies f_{rot} as input. The results of this analysis are shown in Fig. 3. Here, the derived $1 - \sigma$ confidence intervals were propagated from the confidence intervals of f_{rot} , derived using strati-

fied residual bootstrapping (Davison & Hinkley 1997). The relative scatter of the $\Pi_0(n + \alpha_g)$ values is larger than of the f_{rot} values, as reflected by a lower Pearson correlation coefficient of 0.542.

While most *Kepler* sample stars are in agreement with the confidence regions, a few outliers with measured mode frequencies between 1 and 1.2 d^{-1} occur. These stars from Li et al. (2020) are SPB stars based on their T_{eff} and our definition. They have anomalously high Π_0 values, which may result from an overestimated f_{rot} value propagating into the derived high $\Pi_0(n + \alpha_g)$ values above 4.5 d.

3. Application to a *Gaia* sample

Hey & Aerts (2024, their Fig. 6) found a distinct ridge in the stacked amplitude periodograms of the gravity-mode pulsators, characteristic for prograde dipole modes as also found for the *Kepler* γ Dor pulsators by Li et al. (2020). Among the 15,692 *Gaia* DR3 gravity-mode pulsators modelled by Mombarg et al. (2024b), we now define a sub-sample with the aim to select a maximum number of stars with a high probability of having a dominant prograde dipole mode in the TESS FFI light curve.

We require that (i) the amplitudes and frequencies of the dominant pulsations in the *Gaia* DR3 light curves are $\geq 4 \text{ mmag}$ and $\leq 3.2 \text{ d}^{-1}$, respectively (Aerts et al. 2023), (ii) they were classified by Hey & Aerts (2024) as γ Dor or SPB star or else as hybrid gravity/pressure mode pulsator, in all of these three cases with a probability above 50%, (iii) the dominant frequencies measured from the *Gaia* and TESS data differ less than 0.1 d^{-1} (Hey & Aerts 2024), (iv) $\log(L/L_\odot) \geq 0$, and (v) $G_{\text{Gaia}} \leq 13 \text{ mag}$. These stringent constraints deliver a sub-sample of 2,497 pulsators among those with parameters from evolutionary modelling by Mombarg et al. (2024b), notably their mass M_\star , convective core mass m_{cc} , radius R_\star , and evolutionary stage

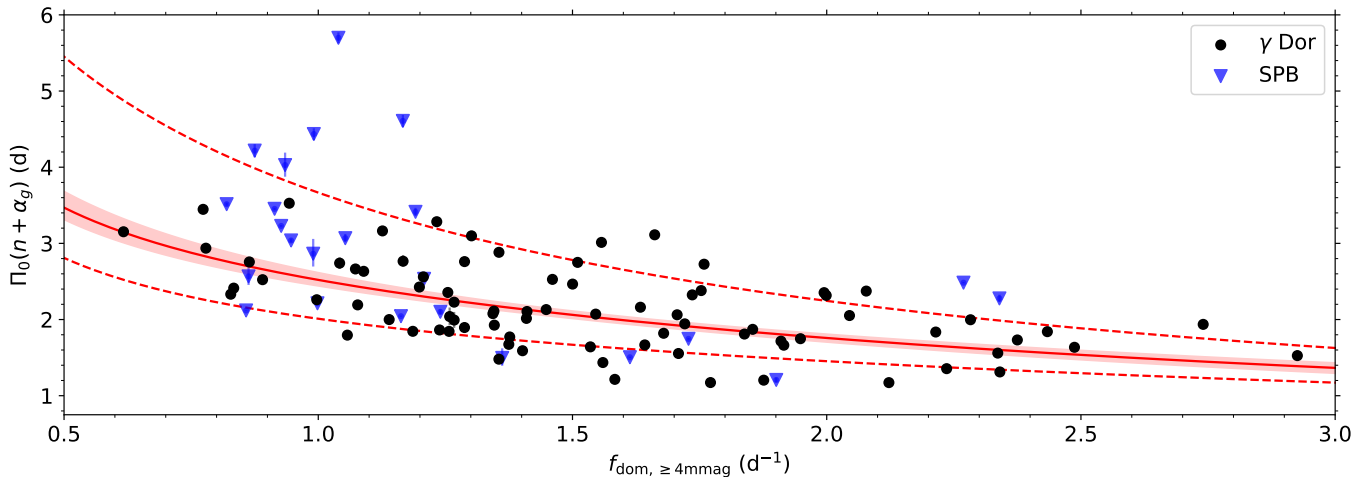


Fig. 3: The derived quantity $\Pi_0(n + \alpha_g)$ plotted as a function of the dominant prograde dipole g-mode frequency with amplitude above 4 mmag ($f_{\text{dom}, \geq 4\text{mmag}}$) for 105 γ Dor and SPB stars from Li et al. (2020) and Pedersen et al. (2021). The symbols have the same meaning as in Fig. 1. The relation given by Eq. (3) is shown by the red line, while the shaded area shows the $1\text{-}\sigma$ uncertainty region. The dashed lines mark the $1\text{-}\sigma$ confidence region, propagated forward from the confidence regions of the f_{rot} values.

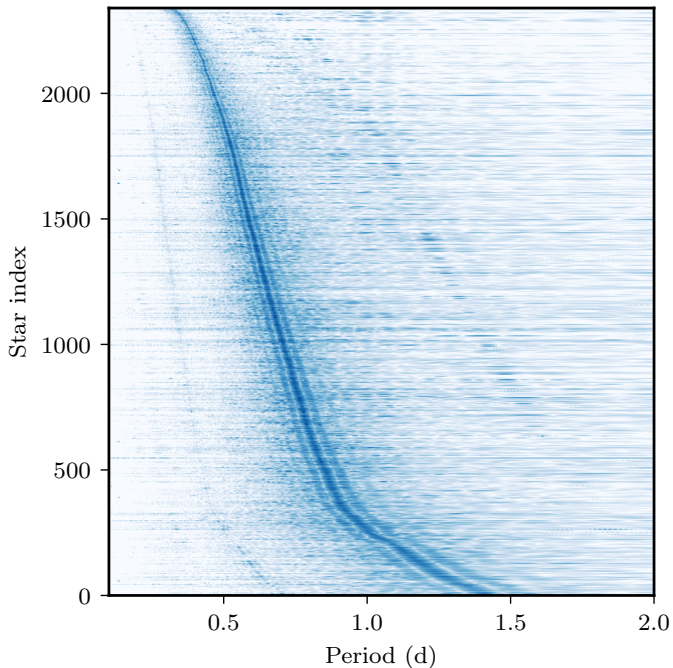


Fig. 4: Stacked periodogram of the 2,497 sample stars calculated for the TESS light curves from Hey & Aerts (2024). Each row corresponds to the amplitude spectrum of one star in the gravity-mode sub-sample treated here, sorted by the dominant mode period. For all these 2,497 pulsators, the dominant mode period occurs in the ridge of prograde dipole gravito-inertial modes.

defined as the ratio of the hydrogen mass fraction remaining in the convective core compared to the initial value at birth, X_c/X_{ini} .

Following Hey & Aerts (2024), Fig. 4 shows the stacked periodograms of these 2,497 gravity-mode pulsators based on their TESS FFI light curves. A prominent ridge occurs, very similar to the one found for stars with dominant identified $(k, m) = (0, 1)$ modes from Kepler light curves by Li et al. (2020). This lends

support to our assumption that these Gaia gravity-mode pulsators have a dominant prograde dipole gravito-inertial mode. In the remainder of this work we reasonably assume that all the 2,497 stars in our current sub-sample with periodogram shown in Fig. 4 fulfil the mode identification $(k, m) = (0, 1)$.

We now rely on the relations derived from the Kepler gravity-mode pulsators deduced in the previous Section to infer the near-core rotation rates f_{rot} and scaled buoyancy radius $\Pi_0(n + \alpha_g)$ for the 2,497 stars in the Gaia DR3 sub-sample. Uncertainties for these two inferred quantities are estimated using the confidence intervals defined in Sect. 2.3 and taking the frequency differences $|f_{\text{dom}, \text{Gaia}} - f_{\text{dom}, \text{TESS}}|$ as an additional systematic observational error for f_{dom} , which we then propagate forward using the chain rule.

A first result, represented by the histograms in Fig. A.3, is that the distributions of the dominant mode frequencies and of f_{rot} values are similar to those of the much smaller Kepler sample of γ Dor stars in Li et al. (2020) when we limit it to stars with dominant mode of amplitude above 4 mmag. Li et al. (2020) derived the near-core rotation from the slope of a period spacing pattern consisting of a series of prograde dipole gravito-inertial modes of consecutive radial order, following the method designed by Van Reeth et al. (2016). Here, we do not have such period spacing patterns and we only make use of the dominant mode in the blue ridge in Fig. 4 and the recipe in Eq. (4). As can be seen in Fig. A.3, the distribution of f_{rot} achieved in this simplified way for our large Gaia sample of gravity-mode pulsators is fully in line with the one of the Kepler γ Dor pulsators.

Recall that we have purposefully excluded the low-frequency regime in the recipe, because the ultra-slow rotators among the gravity-mode pulsators do not comply with the linear relationship in Eq. (4). The dominant mode of all the 2,497 Gaia gravity-mode pulsators thus have a spin parameter placing them into the sub-inertial regime. The values shown in the bottom panel of Fig. A.3 are in line with those of the 63 best characterised Kepler pulsators with spin parameters, Rossby numbers, and stiffness values in Aerts et al. (2021).

At the high frequency end, we excluded stars with f_{dom} above 3.2 d^{-1} , reflected by the shorter tail in the distribution of the spin

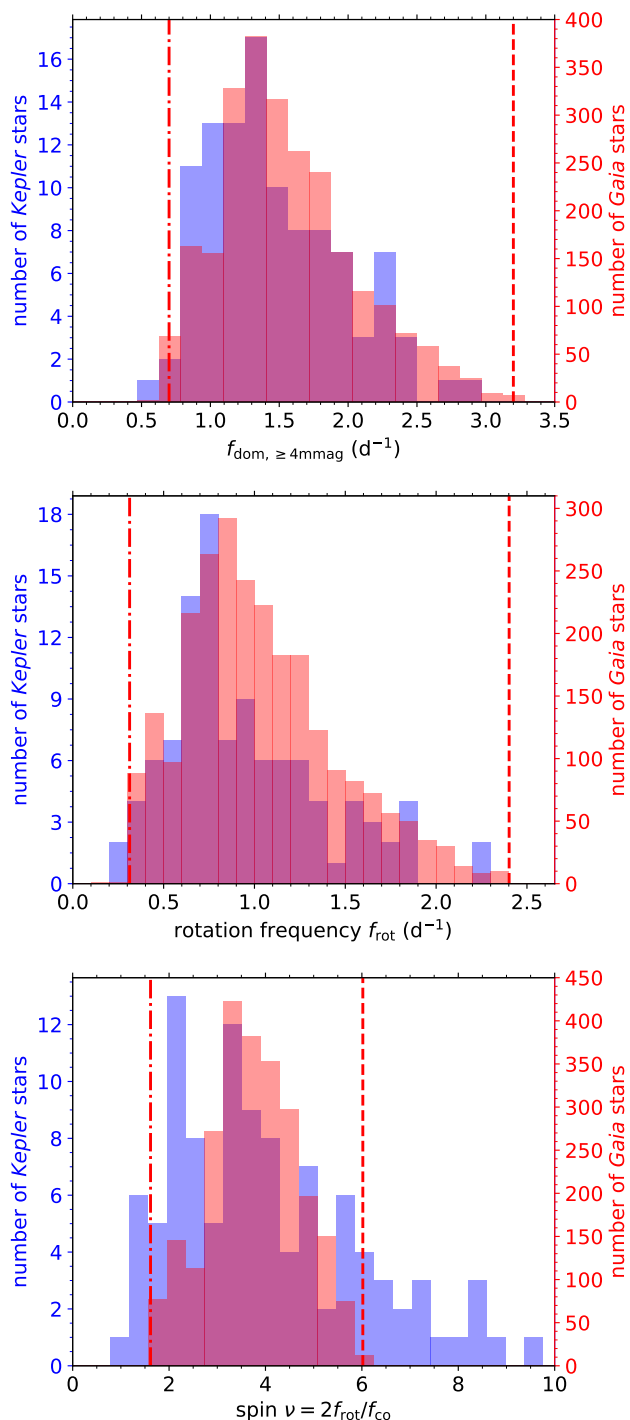


Fig. 5: Histograms of the dominant frequency of observed $(k, m) = (0, 1)$ modes revealing an amplitude above 4 mmag (top), of the near-core rotation frequency f_{rot} (middle), and of the spin parameter of the dominant mode (bottom) for the *Kepler* sample from Li et al. (2020, blue, left y-axis) and for our *Gaia* sample using Eq. (4) (red, right y-axis). The red dash-dotted and dashed lines mark the lower and upper boundaries for the *Gaia* sample, following from our selection criterion demanding that $f_{\text{dom}} \in [0.7, 3.2] \text{ d}^{-1}$. Note the major increase in the number of pulsators thanks to *Gaia*, from comparison of the two y-axes ranges.

parameter in the bottom panel of Fig. A.3. We thus find by construction that none of the isolated gravity-mode pulsators in our *Gaia* sample of field stars rotate close to their critical rate, justifying the use of the TAR for the recipe in Eq. (4). We do note that at least some of the γ Dor pulsators still embedded in their birth cluster are known to rotate faster, as was found for the ~ 100 Myr-old young open cluster NGC 2516. Li et al. (2024) identified 11 gravity-mode pulsators in this cluster and found most of them to have near-core rotation frequencies $f_{\text{rot}} \approx 3 \text{ d}^{-1}$, which is faster than the rotation rates we find for the population of isolated galactic *Gaia* field pulsators.

In Fig. 6 we place the stars in the Hertzsprung-Russell (HR) diagram by colour-coding their markers according to their f_{rot} and $\Pi_0(n + \alpha_g)$ values. A prominent feature in Fig. 6 is connected with the stellar mass distribution, reflected as broad distribution in effective temperature in the HR diagram. While the near-core rotation rates and scaled buoyancy radii of the stars hotter than 8500 K appear to be randomly distributed, those of the stars within the γ Dor instability region are correlated with $\log T_{\text{eff}}$. Because the dominant gravity-mode frequencies from *Gaia* decrease with $\log T_{\text{eff}}$, the derived f_{rot} and $\Pi_0(n + \alpha_g)$ decrease and increase, respectively.

We investigate these relations further in Fig. 7. While the $f_{\text{dom}}(\log T_{\text{eff}})$ and $f_{\text{rot}}(\log T_{\text{eff}})$ relations are clearly visible, those of $\Pi_0(n + \alpha_g)$ are less clear because of the wider, asymmetric confidence regions. Moreover, the modes excited in the population of 611 *Kepler* γ Dor pulsators studied by Li et al. (2020) revealed a wide range of radial orders, roughly between 10 and 100. Since we do not have any information on the radial order n of the dominant mode considered here, we cannot make use of the buoyancy radius Π_0 itself but must rather use a scaled value including the unknown factor $(n + \alpha_g)$.

To quantify the relations in Fig. 7, we conduct linear regression with Monte Carlo sampling analyses for 10,000 iterations to assess the uncertainties. We first select the stars with T_{eff} values between 6810 K and 7540 K. This is based on the local target density in the HR diagram, that is, we ensure there to be at least 3 sample stars per 10 K within this T_{eff} range. In each iteration, we sample new values for $\log T_{\text{eff}}$, f_{dom} , f_{rot} , and $\Pi_0(n + \alpha_g)$ for the selected targets, fit linear relations using orthogonal distance regression (Boggs & Rogers 1990), and evaluate them by calculating the Pearson correlation coefficient between the models and the dependent variables. The results are illustrated by the red lines in Fig. 7 and listed in Table 1. We find that f_{dom} , f_{rot} , and $\Pi_0(n + \alpha_g)$ all vary significantly as a function of $\log T_{\text{eff}}$.

The correlation between f_{rot} and $\log T_{\text{eff}}$ can be understood in terms of the efficient angular momentum transport inside these stars on the main sequence (e.g., Ouazzani et al. 2019; Aerts et al. 2019; Aerts 2021). While the gravity-mode pulsators outside of the γ Dor instability region cover a wide range of stellar masses (Mombarg et al. 2024b), the masses of those inside the narrow instability region are very similar. This allows us to probe the evolution of these stars (e.g., Mombarg et al. 2021; Fritzewski et al. 2024). Further, we find that the scaled buoyancy radius $\Pi_0(n + \alpha_g)$ increases with decreasing $\log T_{\text{eff}}$. This is contrary to Π_0 itself, which decreases as the star cools (e.g., Mombarg et al. 2019; Ouazzani et al. 2019). We thus find clear observational evidence of an increase in the radial order of the dominant excited mode as the stars evolve.

Similar regression analyses applied to the more massive gravity-mode pulsators situated above the γ Dor instability region do not lead to any significant correlations. For complete-

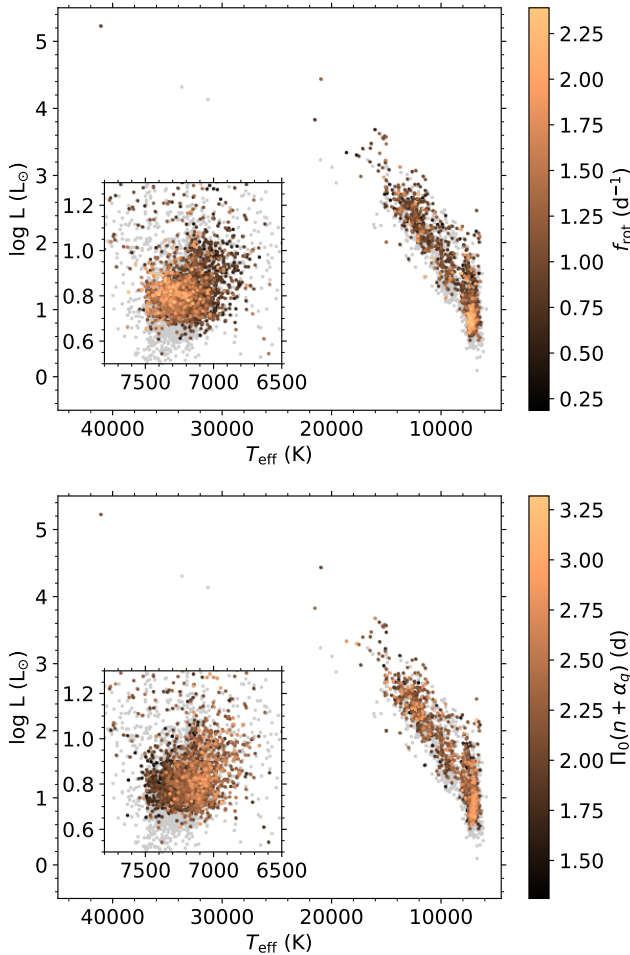


Fig. 6: The 2,497 selected *Gaia* DR3 gravity-mode pulsators in the HR diagram, with markers coloured according to their f_{rot} (top) and $\Pi_0(n + \alpha_g)$ values (bottom). The other stars of the entire sample consisting of 14,072 pulsators from Mombarg et al. (2024b) are shown by the grey markers. The inset axes show close-ups of the γ Dor instability region.

ness, we show the corresponding scatter plots of their relationships with $\log T_{\text{eff}}$ in Fig. A.1 of Appendix A.

Table 1: Value of all coefficients differing significantly from zero (at p -value of 5%) for linear regressions between the listed dependent variables y and $\log T_{\text{eff}}$, following the prescription $y = a \log T_{\text{eff}} + b$.

y	a	b	r_{Pearson}
f_{dom}	128^{+7}_{-6}	-491^{+21}_{-29}	0.426 ± 0.009
f_{rot}	120^{+7}_{-9}	-464^{+36}_{-28}	0.400 ± 0.011
$\Pi_0(n + \alpha_g)$	-157^{+6}_{-14}	609^{+53}_{-22}	0.250 ± 0.019

4. Grid-based forward modelling

Mombarg et al. (2024a) and Fritzewski et al. (2024) illustrated how measured values of the near-core rotation frequency and Π_0 provide useful extra constraints, in addition to the luminosity

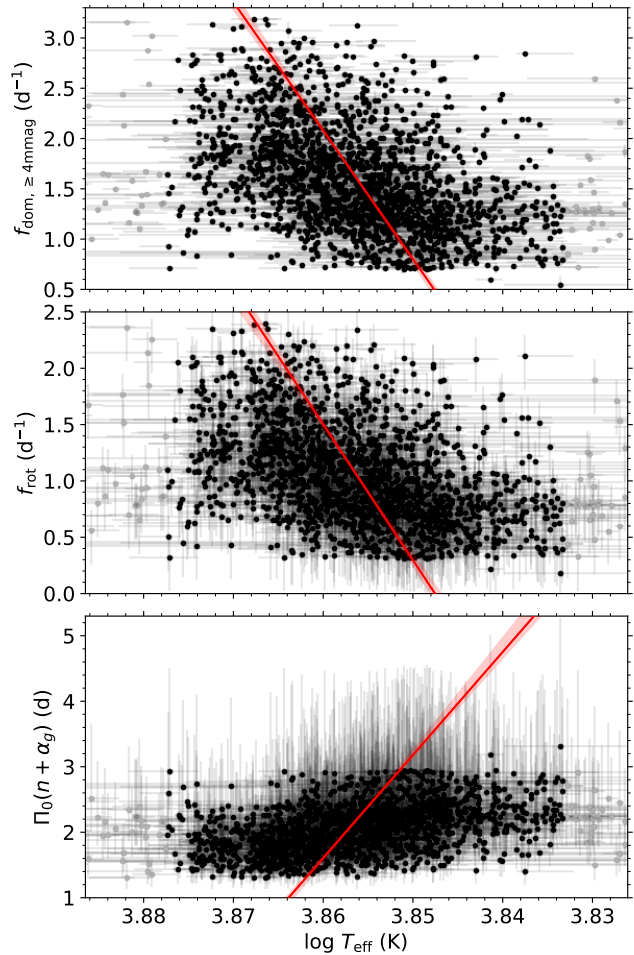


Fig. 7: The dominant pulsation frequencies (top), derived rotation frequencies f_{rot} (middle), and $\Pi_0(n + \alpha_g)$ values (bottom) plotted as a function of $\log T_{\text{eff}}$ for pulsators within (black) and outside (grey) the γ Dor instability region. The red lines show the results of linear regression analyses for the black dots with coefficients listed in Table 1. The dearth of stars in the upper panel at $f_{\text{dom}, \geq 4\text{mmag}} \approx 1 \text{ d}^{-1}$ is due to the spectral window of the TESS data as illustrated by (Hey & Aerts 2024).

and effective temperature of a star, for stellar modelling based on evolutionary tracks. In these two studies, the modelling had the purpose of determining the stellar mass M_* , the core overshooting leading to m_{cc} , and age via its proxy X_c/X_{ini} . Such evolutionary modelling is a lot less cumbersome (but also less powerful) than detailed asteroseismic modelling of individual mode frequencies (e.g., Moravveji et al. 2015, 2016; Mombarg et al. 2020, 2021; Pedersen et al. 2021). This simplified evolutionary modelling by Mombarg et al. (2024a) and Fritzewski et al. (2024) was done by relying on grids of stellar evolution models calibrated to γ Dor star asteroseismology computed by Mombarg (2023).

In recent applications of gravity-mode asteroseismic modelling, the near-core rotation frequency of the star was derived from 4-years long *Kepler* light curves. These typically lead to much better precision for f_{rot} compared to the precision of $\sim 20\%$ we achieve here from applying Eq. (4) to the measured f_{dom} , after identification of the mode as $(k, m) = (0, 1)$ in the sub-inertial regime. Here we investigate whether the addition of an

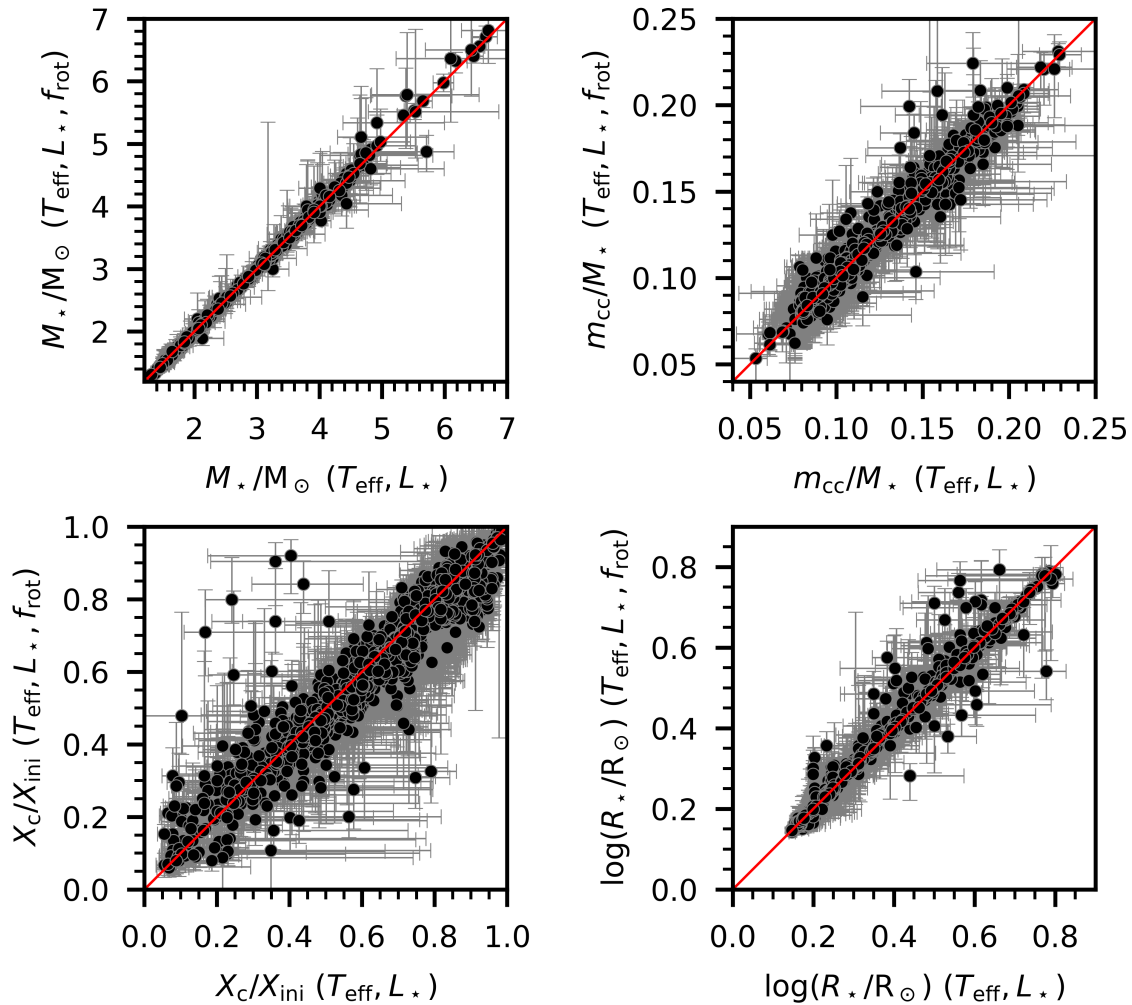


Fig. 8: Derived measurements for the stellar mass (top left), the fractional convective core mass (top right), the core hydrogen-mass fraction compared to the initial hydrogen-mass fraction (bottom left), and the stellar radius (bottom right) of the 2464 gravity-mode pulsators modelled via the grid with solar metallicity. The quantities on the abscissa are derived using the effective temperature and luminosity as input, while for the quantities on the ordinate, the near-core rotation frequency is added as an extra observable. The red lines indicate perfect correspondence.

estimated near-core rotation frequency from just the dominant pulsation frequency helps to constrain the fundamental stellar parameters M_* , m_{cc} , R_* , and X_c/X_{ini} .

We apply the same methodology as presented in Mombarg et al. (2024b), where a conditional neural flow trained on a grid of rotating stellar evolution models computed with MESA (Paxton et al. 2011, 2013, 2015, 2018, 2019; Jermyn et al. 2023) is used as an interpolator. We refer to Mombarg et al. (2024b) for the details on how this methodology works. For the sub-sample of stars with a measured f_{rot} obtained in this work, we re-derive their M_* , m_{cc} , R_* and X_c/X_{ini} by adding f_{rot} as a third observational constraint, in addition to the two observables $\log T_{eff}$ and $\log(L/L_\odot)$ used for the modelling by Mombarg et al. (2024b). As in that paper, we rely on two extensive grids of stellar models, for values of the metallicity equal to $Z = 0.0045$ ($[M/H] = -0.5$) and $Z = 0.014$ ($[M/H] = 0.0$). These two metallicities were chosen because we do not have a homogeneously derived measurement of the metallicity for all the sample stars. The two grids encapsulate the measured range of Z for gravity-mode pulsators

having a metallicity estimate from high-resolution ground-based spectroscopy (Gebruers et al. 2021) and from *Gaia* spectroscopy (de Laverny et al. 2024). From the perspective of position in the HR diagram, 2375 pulsators fall into the lower-metallicity grid and 2464 in the solar metallicity grid. We work with these stars from here onwards.

Figure 8 shows the difference in the derived fundamental stellar quantities depending on whether f_{rot} is included as an additional constraint or not, for the 2464 pulsators captured by the solar metallicity grid. As can be seen in the top-left panel, the derived stellar mass is consistent between the two cases. The largest scatter is observed in the evolutionary stage (X_c/X_{ini} , bottom-left panel), which is harder to constrain than the mass as it depends strongly on (unknown) element mixing in the models. In the context of ensemble modelling of gravity-mode pulsators, we find that f_{rot} derived from Eq. (4) applied to the *Gaia* light curves helps to refine the determination of the evolutionary stage of the star from rotating stellar models. Furthermore, with the inclusion of f_{rot} , we achieve slightly more precise es-

estimates of X_c/X_{ini} , going from average (absolute) uncertainties of 0.10-0.08 to 0.08-0.06. In case of the convective core mass (top-right panel) and radius (bottom-right panel), the majority of the stars with the largest difference still have measurements consistent within the 68% confidence interval. The average uncertainties m_{cc}/M_{\star} and $\log(R_{\star}/R_{\odot})$ remain approximately the same when f_{rot} is included in the modelling or not. This re-affirms that estimation of f_{rot} can be decoupled from forward asteroseismic modelling as emphasized by Van Reeth et al. (2016), Ouazzani et al. (2017) and Aerts et al. (2018).

The comparative results for the 2375 pulsators covered by the lower-metallicity grid are similar, keeping in mind that the mass, luminosity, and metallicity are tightly connected for main-sequence stars (see their strong relationships deduced by Mom-barg et al. 2024b). We omit them here for brevity, but they are shown visually in Fig. A.2 in Appendix A. Given that we do not have measurements of Z for the sample stars, we provide the stellar parameters for both grids in electronic format at the CDS, following the format in Tables A.1 and A.2 (see also footnote to the title of the paper).

The differences in the stellar parameters deduced from the grid modelling for the stars treated by both grids reflect the systematic uncertainties for the (core) masses, radii, and evolutionary stages induced solely by the difference of 0.0095 in Z (0.5 in [M/H]). Again, these differences are systematic following the tight (core) mass – luminosity – radius – metallicity relationships. They range up to $0.55 M_{\odot}$ in mass, up to $0.25 M_{\odot}$ in convective core mass, and up to about $0.18 R_{\odot}$ in radius. By construction, the evolutionary stages differ from each other because the metal-poor grid having $Z = 0.0045$ was built up by Mom-barg et al. (2024b) to encapsulate the range in unknown metallicity reported in the literature for gravity-mode pulsators, affecting the evolution appreciably. A visual representation of the distributions of these systematic differences for all the stars with overlapping grid solutions is shown in Fig. ?? in Appendix A.

Finally, we also study the effect of having the higher-precision input of f_{rot} from the slope of a period-spacing pattern of dipole prograde modes based on 4-year *Kepler* light curves instead of the value based on just f_{dom} from *Gaia* DR3 light curves. We consider the *Kepler* pulsators from Li et al. (2020) and Pedersen et al. (2021) used to construct Eq. (4) and shown in Fig. 1. We compute their luminosity and effective temperature in the same way as we did it for the *Gaia* sample and find 96 of the γ Dor stars with dominant $(k, m) = (0, 1)$ mode to be covered by the model grid with solar metallicity, while only 3 of the SPB stars. We compare the results of the grid modelling based on the less precise *Gaia* f_{rot} and the more precise *Kepler* f_{rot} estimates for these 99 *Kepler* pulsators in Fig. 9. The four estimated parameters have very consistent values for almost all 99 pulsators.

Overall, these results reveal the great potential of grid-based stellar parameter estimation based on just the value of the dominant mode frequency from *Gaia* light curves and the effective temperature and luminosity, all from DR3, when coupled to an asteroseismically calibrated grid of stellar models. The only requirement for the procedure to work is the ability to identify pulsators with a dominant dipole prograde mode having its frequency in the sub-inertial regime.

5. Near-core to surface rotation estimates

5.1. Evolution of the near-core rotation

Combining the results of the previous two sections, we can now study the near-core rotation frequency as a function of evolution-

ary stage. Asteroseismology has demonstrated that angular momentum transport from the deep interior to the envelope of stars happens more efficiently than anticipated from theories of transport processes adopted prior to the era of space asteroseismology (Ouazzani et al. 2019). It was also found that gravity-mode pulsators have low levels of near-core to surface rotation (Aerts et al. 2019; Li et al. 2020; Aerts 2021; Aerts & Tkachenko 2024, for observational summaries). Moreover, stars born with a radiative envelope lose angular momentum rapidly beyond the TAMS (at $X_c/X_{\text{ini}} = 0$), while their near-core rotation drops appreciably (Aerts 2021, Fig. 6).

In Fig. 10, we show the model-independent near-core rotation frequency, f_{rot} , as a function of the model-dependent evolutionary stage for our sample of gravity-mode pulsators, for both grids. Thanks to the four times larger size of our *Gaia* population of pulsators with a measurement of f_{rot} compared to the Li et al. (2020) *Kepler* sample, and to our estimate of the evolutionary stage, we see a clear decline of the average near-core rotation frequency of the population as the stars evolve.

We fit uni-variate splines through bin-averaged f_{rot} values, where we select the optimal bin size in $X'_c = X_c/X_{\text{ini}}$ according to Scott's rule (Scott 1979). This rule states that a histogram with bin size proportional to $3.49 \cdot \sigma / (N_{\text{points}}^{1/3})$, where N_{points} is the number of points in the bins and σ the standard deviation assuming a normal distribution, is very efficient in approaching the true distribution. The smoothing factor for the splines is chosen such that higher values do no longer change the resulting derivative df_{rot}/dX'_c . The derivatives of the fitted splines are shown in the bottom panel of Fig. 10. When assuming $Z = 0.014$, we find purely decreasing f_{rot} values during the main sequence. Despite the large range of near-core rotation frequencies per evolutionary stage – reflecting the variety of initial conditions at birth for this population of field stars – the average near-core rotation per bin in X_c/X_{ini} shows a gradual decline from the zero-age to the terminal-age main sequence, with roughly a factor of two.

Assuming $Z = 0.0045$, the results are less clear. We find that stars on average have an increasing f_{rot} (negative derivative) during the first part of the main sequence, followed by a decrease in f_{rot} . Yet, we note that the part where $df_{\text{rot}}/dX'_c < 0$ for $Z = 0.0045$ is severely undersampled and so we cannot rely on these results. However, the same decline of f_{rot} with a factor two as for the solar metallicity grid is obtained for the regime $X_c/X_{\text{ini}} < 0.5$ when the stars are modelled with the metal-poor grid.

Finally, we checked that the trends found become less clear but do not change globally when we split up the observed sample in stars with an initially growing convective core and stars whose convective core shrinks as of the ZAMS. The distinction between these two cases happens for masses between about $1.6 M_{\odot}$ and $1.8 M_{\odot}$, depending on the metallicity. We therefore conclude to have found observational evidence that the near-core rotation frequency decreases with a factor of about two from the ZAMS to the TAMS for our population of g-mode pulsators.

5.2. Limits on the surface rotation

Only 58 of the *Kepler* γ Dor stars also have a value for the surface rotation, measured from rotational modulation (Van Reeth et al. 2018; Li et al. 2020) and only 22 have a measurement of their averaged envelope rotation, f_{env} , determined from identified rotational splitting (Kurtz et al. 2014; Saio et al. 2015; Keen et al. 2015; Li et al. 2019). For the SPB stars, information is even more restricted, with only one star having clear rotational splitting (Pápics et al. 2014) and a rotational profile throughout the

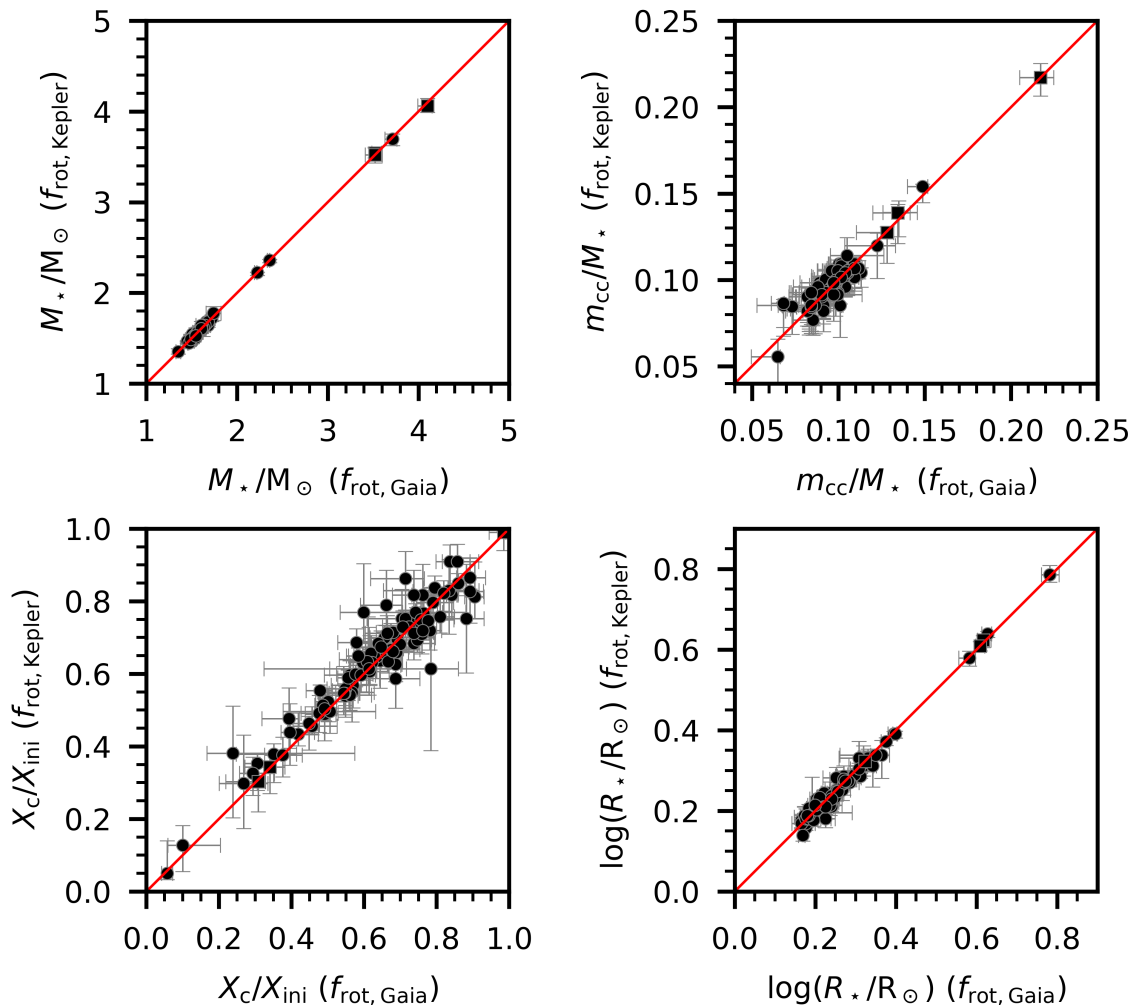


Fig. 9: Derived measurements for the stellar mass (top left), the fractional convective core mass (top right), the core hydrogen-mass fraction compared to the initial hydrogen-mass fraction (bottom left), and the stellar radius (bottom right) of 96 γ Dor stars (circles) and 3 SPB stars (squares) modelled via the grid with solar metallicity. The quantities are derived using the effective temperature, luminosity, and near-core rotation frequency from the dominant dipole prograde mode detected in the *Gaia* DR3 light curves (x-axis) versus the higher-precision value deduced from the slope of a period spacing pattern of dipole prograde modes of consecutive radial order following Li et al. (2020) and Pedersen et al. (2021) (y-axis).

star from frequency inversions (the $3.3 M_{\odot}$ SPB KIC 10526294, Triana et al. 2015). These limited observational constraints on differential near-core to surface rotation in main-sequence stars of intermediate and high mass (as summarised by Aerts 2021, Fig. 6) restrict our ability to improve angular momentum transport theories, as these rely on the gradient of the rotation profile throughout the star (Ouazzani et al. 2019; Aerts et al. 2019).

We are unable to assess the envelope or surface rotation from the *Gaia* light curves. However, we can give a lower limit for the cyclic surface rotation frequency, f_{surf} , from the radius estimates shown in Fig. 8 for those stars with a measurement of the spectral line broadening offered by the *Gaia* spectroscopy (Frémat et al. 2023). Aerts et al. (2023) showed the *Gaia* vbroad parameter to capture the joint effect of time-independent rotational line broadening and time-dependent tangential pulsational broadening due to gravity modes. Moreover, pulsational line broadening of gravity-mode pulsators is typically only a small fraction of the rotational broadening for moderate to fast rotators (De

Cat & Aerts 2002; Aerts et al. 2004; De Cat et al. 2006). Hence *Gaia*'s vbroad measurement is a meaningful approximation of $2\pi R_{\star} \cdot f_{\text{surf}} \cdot \sin i$ for such stars, where i is the (unknown) inclination angle of the rotation axis of the star in the line-of-sight.

A total of 307 of our sample stars have a significant vbroad measurement, by which we mean it is above zero at $1-\sigma$ level, and a radius estimate from the solar metallicity grid. For the lower-metallicity grid it concerns 292 stars. Using these radius estimates from the grid modelling, we compute $f_{\text{surf}} \cdot \sin i$ from vbroad. As this is a lower limit for the true surface rotation frequency f_{surf} , we obtain an upper limit for the near-core to surface differential rotation from calculating $f_{\text{rot}}/(f_{\text{surf}} \cdot \sin i)$. The results are illustrated in Fig. A.4 and reveal values up to 5.4, irrespective of the assumption about the metallicity.

So far, asteroseismology of single γ Dor stars covering the mass range $[1.3, 1.9] M_{\odot}$ has shown them all to have quasi-rigid rotation at the level of $f_{\text{rot}}/f_{\text{surf}} \in [0.9, 1.1]$ if such a measurement is available (Li et al. 2020; Aerts 2021, for a summary).

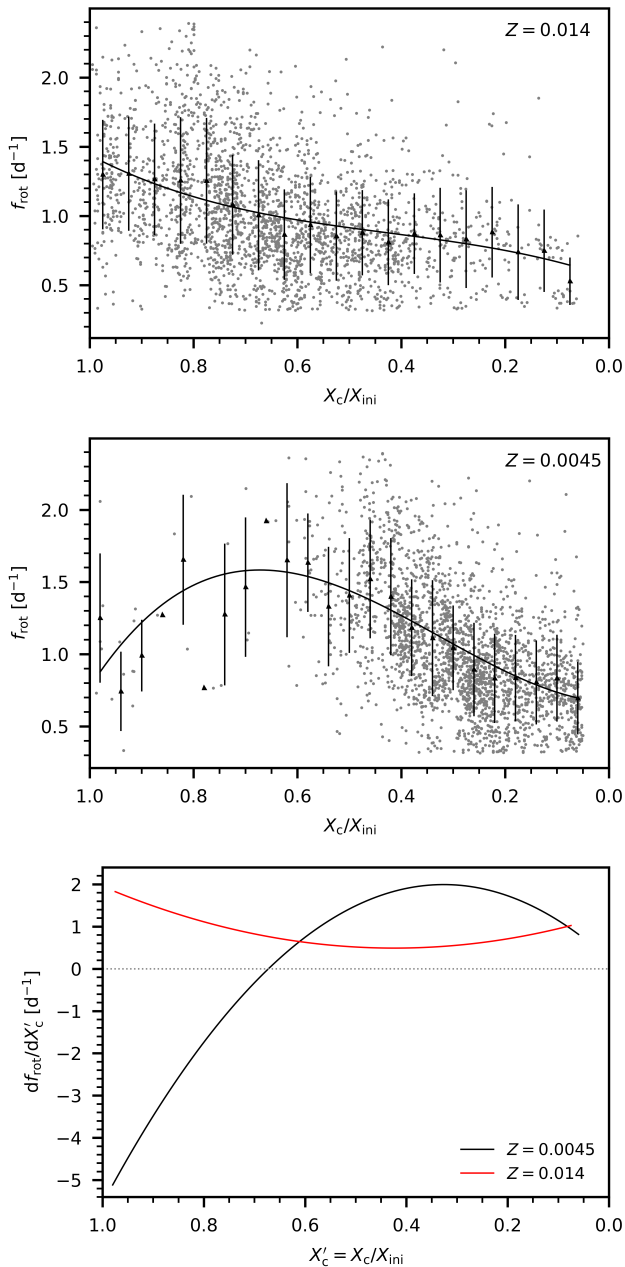


Fig. 10: Inferred near-core rotation frequencies of the *Gaia* gravity-mode pulsators plotted as a function of evolutionary stage (grey dots), assuming solar metallicity (top panel, 2464 stars) and for $[M/H] = -0.5$ (middle panel, 2375 stars). Solid lines indicate spline fits through binned averages (see text). The bottom panel shows the derivatives of the splines from the two upper panels, indicating the change in the near-core rotation frequency with respect the fraction of hydrogen in the core. The dotted grey line separates positive and negative values.

Our work increases the mass range of stars with an estimate of differential rotation, even if we can provide only an upper limit. Indeed, of the 307 gravity-mode pulsators presented in Fig. A.4, 29 have a mass between $2.0 M_{\odot}$ and $4.4 M_{\odot}$ when adopting solar metallicity. However, the unknown factor $\sin i$ and the large uncertainty of ν_{broad} do not allow us to deduce stricter constraints than just a rough upper limit for $f_{\text{rot}}/f_{\text{surf}}$. Measurements of the actual ratio $f_{\text{rot}}/f_{\text{env}}$ can be investigated from detailed analyses

of the TESS light curves for the hybrid low-order pressure and high-order gravity mode pulsators in our sample. This will be taken up in future work.

6. Conclusions and outlook

In this work, we derive the internal rotation frequency of 2,497 gravity-mode pulsators discovered recently from *Gaia* DR3 light curves. These stars cover the mass range from $1.3 M_{\odot}$ to about $7 M_{\odot}$ and the entire main sequence. We deduce their near-core rotation frequency from a linear regression recipe built upon the dominant prograde dipole mode of a well-characterised sample of *Kepler* pulsators. The 2,497 *Gaia* pulsators have internal rotation rates ranging from 0.3 d^{-1} to 2.4 d^{-1} , with a distribution in line with those of *Kepler* gravity-mode pulsators. All these *Gaia* pulsators considered in this study have an identified dominant dipole mode in the sub-inertial frequency regime with spin parameters ranging from about 2 to 6. With our work, we quadruple the sample size of intermediate-mass dwarfs with a measurement of the rotation frequency in the transition layer between the convective core and the radiative envelope.

For 307 pulsators in the sample, we derive an upper limit of the radial differential rotation between the boundary of the convective core and the surface, by relying on the *Gaia* DR3 ν_{broad} observable combined with the radius estimate from the grid modelling. We find values up to 5.4. These results cover the mass range of $[1.3, 7] M_{\odot}$ and constitute an interesting subsample to calibrate stellar evolution theory and angular momentum transport theories for rotating main-sequence stars with a convective core and a radiative envelope, some of which undergoing fast rotation. The 2-dimensional stellar models of oblate stars presented by Espinosa Lara & Rieutord (2013) trigger the option to confront the observational properties with theoretical predictions. We plan such calibration studies with the new stellar evolution branch of the code ESTER (Rieutord et al. 2016; Mombarg et al. 2023) in follow-up studies.

Finally, we point to the large potential of future *Gaia* Data Releases. Combined with high-cadence high-precision space photometry from the ongoing TESS and future PLATO (Rauer et al. 2024) missions will allow us to scale up the work presented here to millions of pulsators, instead of thousands. Our recipe in Eq. (4) to deduce the near-core rotation of pulsators with a dominant prograde dipole gravito-inertial mode having a mass above $1.3 M_{\odot}$ is suitable to facilitate fast asteroseismic grid modelling. At the same time, it is also a particularly handy and relevant tool for exoplanet host studies in terms of the angular momentum properties of the hottest among the main-sequence star-planet systems.

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Appendix A: Extra figures and tables

In this Appendix, we show some extra figures discussed in the main text, as well as the format of two data tables, which are only available electronically via the CDS.

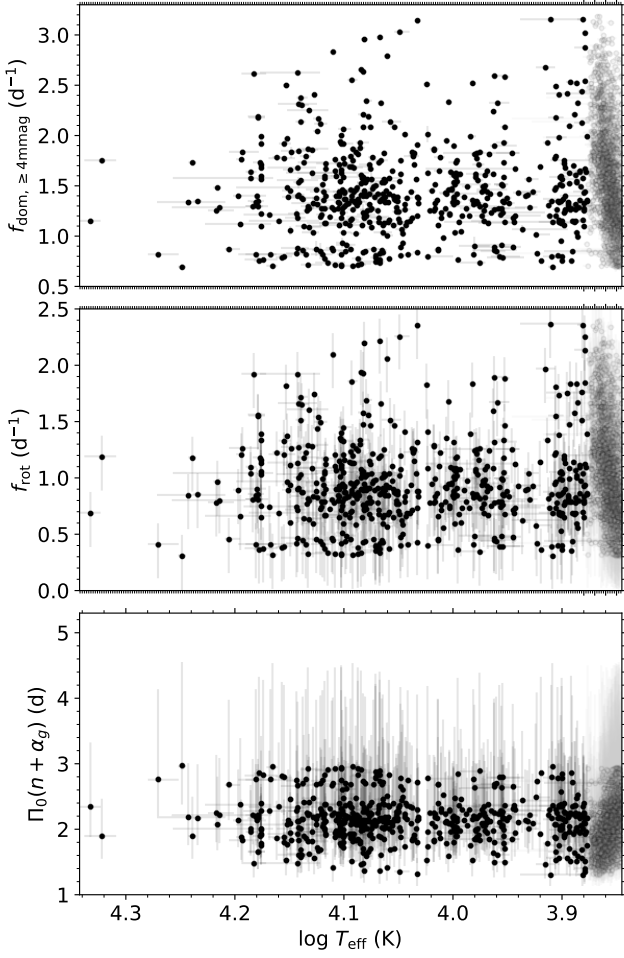


Fig. A.1: Scatter plot of the observed $\log T_{\text{eff}}$ values of the gravity-mode pulsators outside of the γ Dor instability region and their dominant pulsation frequencies (top), derived rotation frequencies f_{rot} (middle), and $\Pi_0(n + \alpha_g)$ values (bottom), respectively. Contrary to stars within the γ Dor instability region shown in grey and in Fig. 7, the hotter targets in this figure cover a wide mass range and do not show any significant correlations with $\log T_{\text{eff}}$.

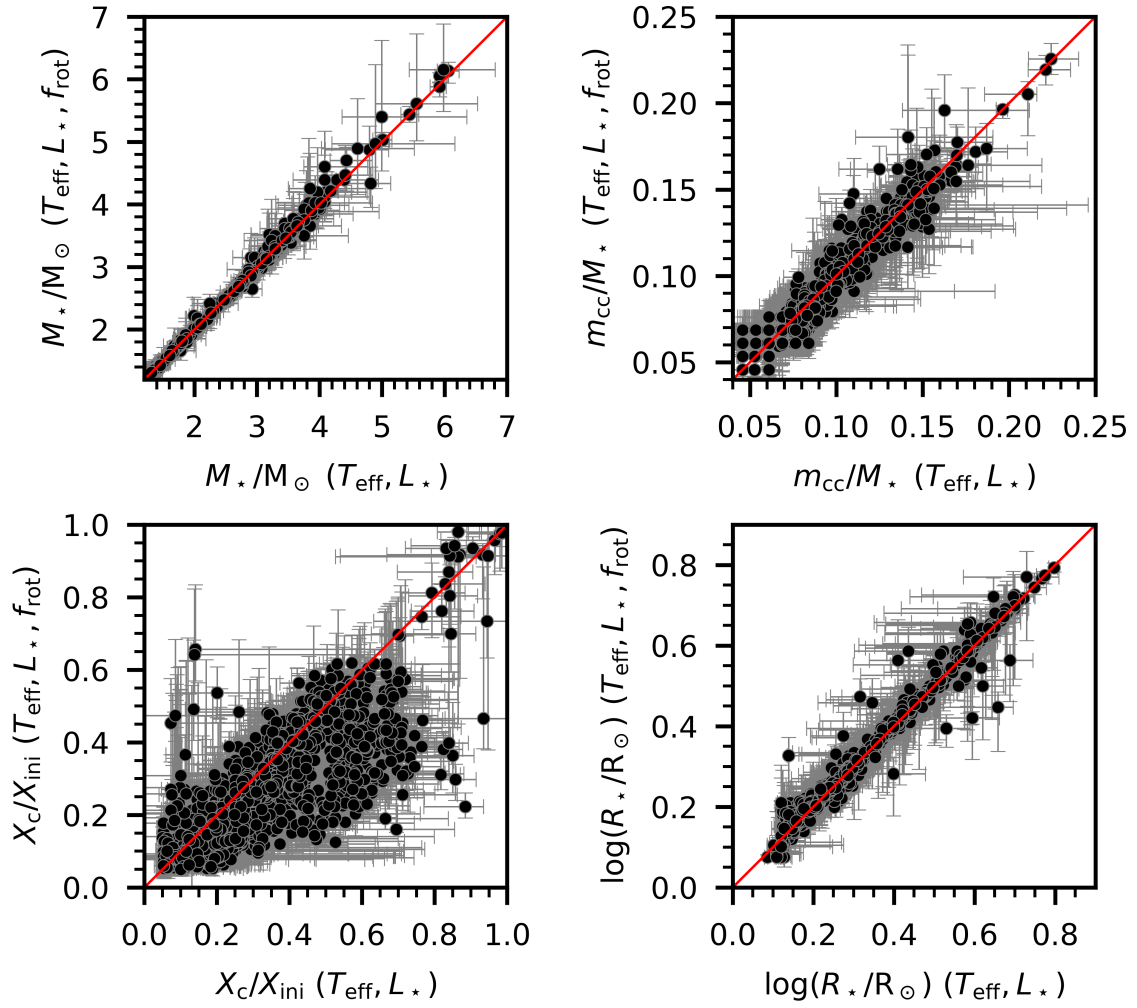


Fig. A.2: Similar to Fig. 8, but for the 2375 gravity-mode pulsators modelled via the metal-poor grid.

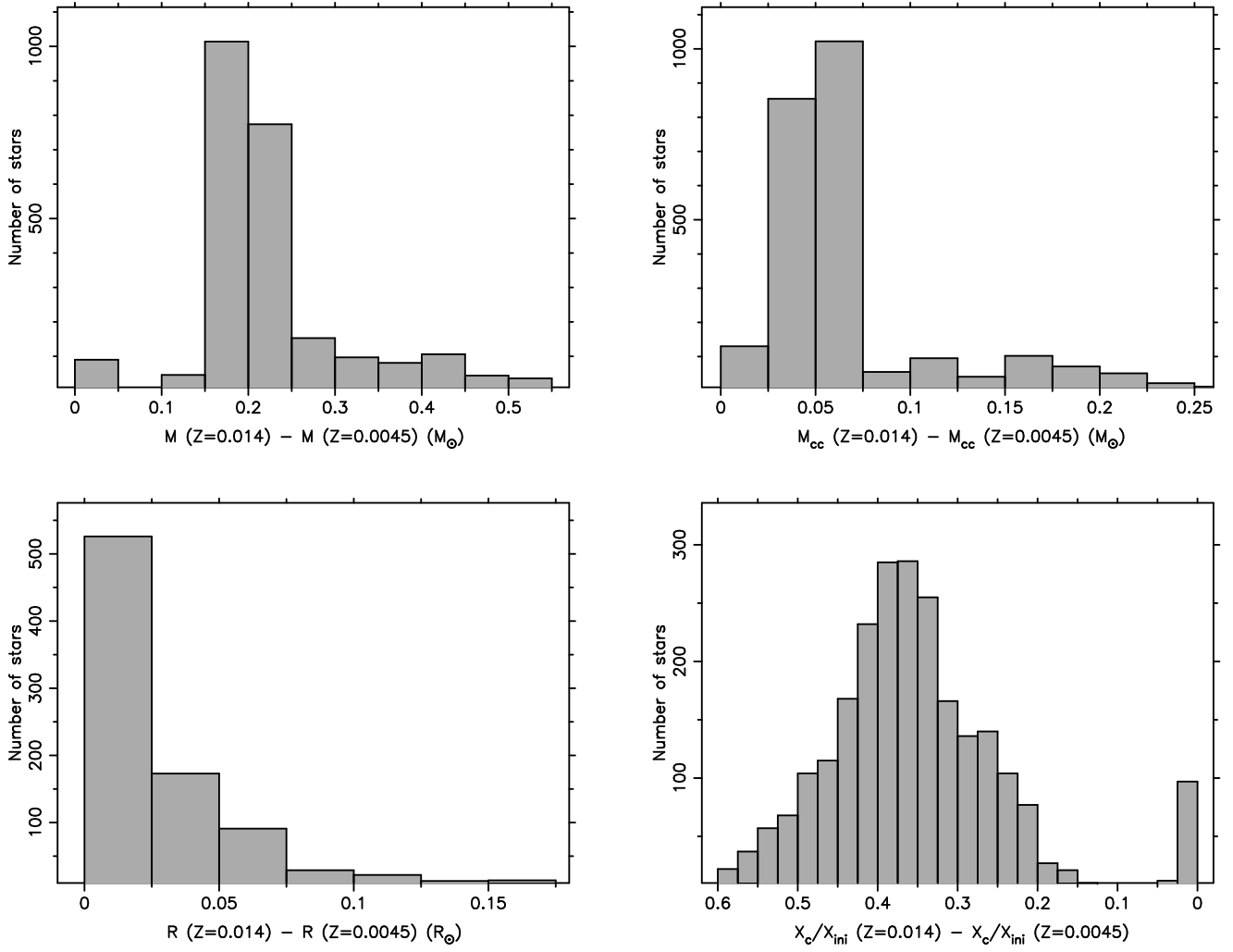


Fig. A.3: Differences in estimates from the grid modelling for the mass (upper left), convective core mass (upper right), radius (lower left), and evolutionary stage (lower right) due to the change in metallicity from solar to metal poor. These systematic shifts reflect the well-known luminosity–mass–radius–metallicity relationships for main-sequence stars (cf. [Mombarg et al. 2024b](#)).

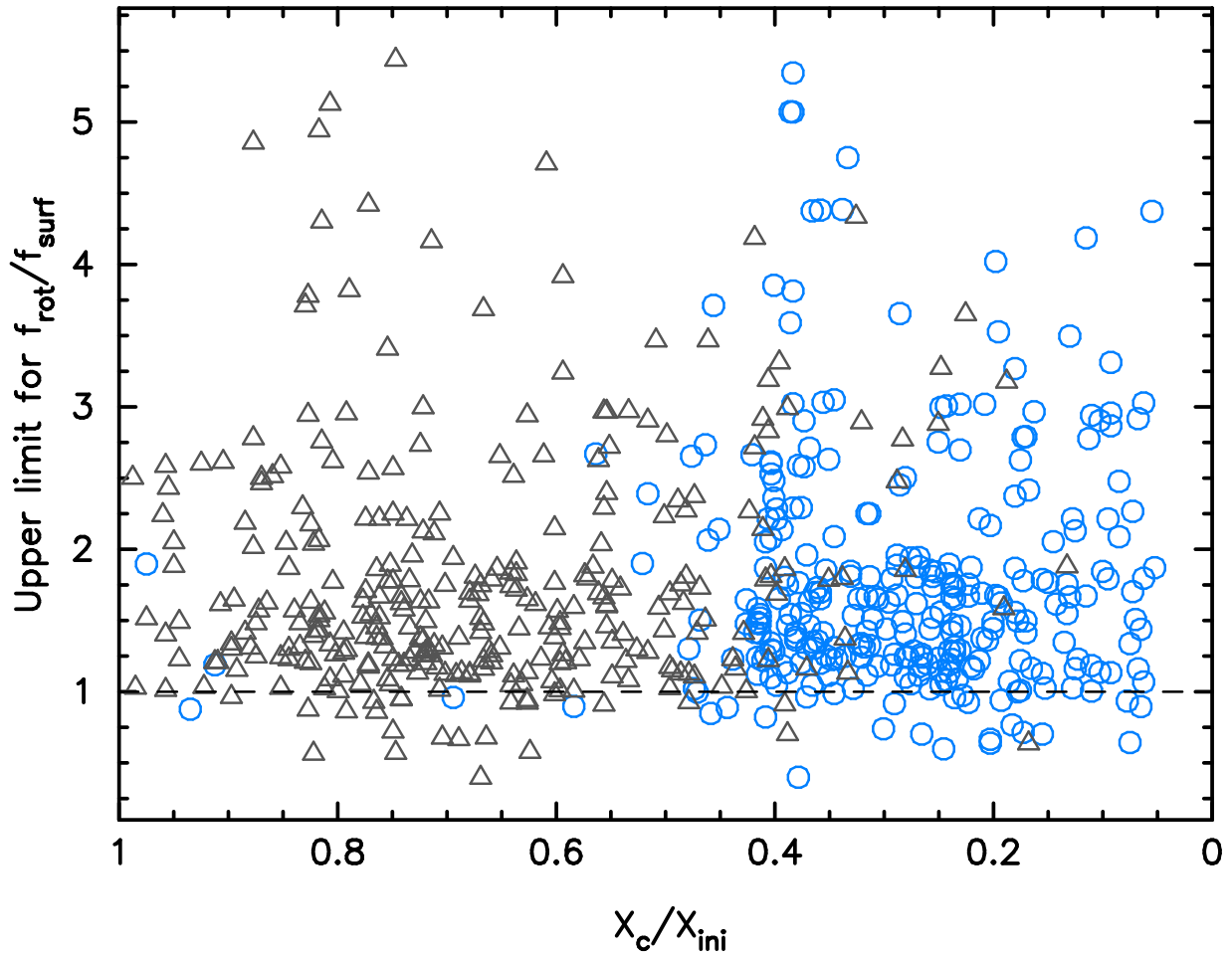


Fig. A.4: Upper limits for the near-core to envelope rotation rate deduced from *Gaia* DR3 measurements of v_{broad} available for 307 gravity-mode pulsators in the sample of pulsators, all of which have a radius estimate from the solar-metallicity grid (grey triangles). The lower-metallicity grid delivers this upper limit for 292 of the stars (blue circles). All these upper limits are significant at $1-\sigma$ level but have large uncertainty (up to 100%) for many of the stars due to the large errors of v_{broad} (not shown for visibility reasons). In particular we note that the errors for the stars below the dashed line reach values above 1.0.

Table A.1: Parameters of the gravity-mode pulsators covered by the solar metallicity grid. When available, the error estimates of a quantity X are given as a_X and b_X in the notation $X_{-a_X}^{+b_X}$. Frequencies are given in the unit d^{-1} while the stellar (core) mass and radius are given in solar units. The quantity $f_{\text{co-rot}}$ is the frequency of the dominant gravito-inertial mode in a frame of reference co-rotating with f_{rot} , while ‘spin’ stands for the spin parameter of the dominant mode in the region just outside the convective core. The full table is available online via the CDS.

<i>Gaia</i> DR3 ID	f_{rot}	$a_{f_{\text{rot}}}$	$b_{f_{\text{rot}}}$	M_{\star}	$a_{M_{\star}}$	$b_{M_{\star}}$	X_c/X_{ini}	$a_{X_c/X_{\text{ini}}}$	$b_{X_c/X_{\text{ini}}}$	m_{cc}	$a_{m_{\text{cc}}}$	$b_{m_{\text{cc}}}$	$\log(R_{\star}/R_{\odot})$	$a_{\log(R_{\star}/R_{\odot})}$	$b_{\log(R_{\star}/R_{\odot})}$	$f_{\text{co-rot}}$	spin	$f_{\text{surf}} \cdot \sin i$	$f_{\text{rot}}/(f_{\text{surf}} \cdot \sin i)$
164941072177351424	0.93767	0.16430	0.12293	3.77256	0.07590	0.04231	0.51880	0.06017	0.03535	0.60150	0.04841	0.02017	0.53383	0.01765	0.01497	0.51010	3.67642	—	—
185403705126528256	1.16134	0.16431	0.12293	1.50733	0.01523	0.01123	0.80702	0.04583	0.03352	0.13033	0.01222	0.00585	0.18797	0.01018	0.00689	0.55408	4.19196	—	—
200619262425969024	1.64651	0.16497	0.12382	1.48797	0.03052	0.01000	0.89223	0.07543	0.04644	0.12030	0.02328	0.00319	0.17293	0.01266	0.01166	0.64949	5.07016	1.42700	1.15383

Table A.2: Same as Table A.1 but for the metal-poor grid having $Z = 0.0045$. The full table is available online via the CDS.

<i>Gaia</i> DR3 ID	f_{rot}	$a_{f_{\text{rot}}}$	$b_{f_{\text{rot}}}$	M_{\star}	$a_{M_{\star}}$	$b_{M_{\star}}$	X_c/X_{ini}	$a_{X_c/X_{\text{ini}}}$	$b_{X_c/X_{\text{ini}}}$	m_{cc}	$a_{m_{\text{cc}}}$	$b_{m_{\text{cc}}}$	$\log(R_{\star}/R_{\odot})$	$a_{\log(R_{\star}/R_{\odot})}$	$b_{\log(R_{\star}/R_{\odot})}$	$f_{\text{co-rot}}$	spin	$f_{\text{surf}} \cdot \sin i$	$f_{\text{rot}}/(f_{\text{surf}} \cdot \sin i)$
164941072177351424	0.93767	0.16430	0.12293	3.34662	0.07221	0.05528	0.28070	0.09347	0.03254	0.42105	0.06547	0.01727	0.54135	0.01826	0.01336	0.51010	3.67642	—	—
185403705126528256	1.16134	0.16431	0.12293	1.31372	0.01894	0.00624	0.37343	0.06841	0.03501	0.09023	0.00987	0.00860	0.19549	0.01133	0.00620	0.55408	4.19196	—	—
200619262425969024	1.64651	0.16497	0.12382	1.31372	0.01858	0.01000	0.34837	0.04428	0.06441	0.09023	0.01349	0.00586	0.19925	0.00852	0.01219	0.64949	5.07016	1.34308	1.22592