

# Preface

The Sun and other stars are known to oscillate. Through the study of small perturbations to the frequencies of these oscillations the rotation of the deep interior can be inferred. Thanks to helioseismology, we know that the Sun rotates as a solid body in the radiative interior and that the convective envelope rotates differentially, with a shear layer in between. Such a shear is thought to be one of the ways in which the large-scale magnetic field of the Sun can be generated. However, thus far the internal rotation of other stars like the Sun is unknown, and placing constraints on models of the relationship between stellar rotation and dynamos is difficult. In this sense the study of rotation in other stars will help further our understanding of magnetic activity on the Sun.

The NASA *Kepler* mission observed a multitude of Sun-like stars over a period of four years. This has provided high-quality photometric data that can be used to study the rotation of stars with two different techniques: asteroseismology and surface activity. Using asteroseismology it is possible to measure the perturbations to the oscillation frequencies of a star which are caused by rotation. This provides a means of measuring rotation in the stellar interior. In addition to this, the photometric observations are modulated by the presence of magnetically active regions on the stellar surface. These features trace the movement of the outermost layers of the star and the stellar rotation period can therefore be inferred by this variability. The combination of these two methods can be used to put constraints on the radial differential rotation in Sun-like stars.

First, we developed an automated method for measuring the rotation of stars using surface variability. This method was initially applied to the entire *Kepler* catalog, out of which we detected signatures of rotation in  $\sim 12,000$  stars across the main sequence, providing robust estimates of the surface rotation rates and the associated errors. We compared these measurements to spectroscopic  $v \sin i$  values and found good agreement for F-, G- and K-type stars, showing that this method is suitable for measuring the surface rotation rates of Sun-like stars.

Second, we performed an asteroseismic analysis of six Sun-like stars, where we were able to measure the rotational splitting as a function of frequency in the  $p$ -mode envelope. This was done by dividing the oscillation spectrum into

individual segments, and fitting a model independently to each segment. Any potential difference in the splittings between each segment could be an indication of strong differential rotation. We found however, that the measured splittings were all consistent with a constant value, indicating little differential rotation; similar to what could be expected if the Sun was observed as a star by the *Kepler* satellite.

Third, we compared the asteroseismic rotation rates of five Sun-like stars to their surface rotation rates. We found that the values were in good agreement, indicating little differential rotation between the regions where the two methods are most sensitive. The asteroseismic measurements are primarily sensitive to rotation in the convective envelope. Because of the high degree of correlation the surface rotation periods can therefore be used as an indicator of the rotation in the convective zone, and the remaining contribution to the rotational splitting from rotation in the radiative interior can be estimated.

Finally, we discuss how the surface rotation rates may be used as a prior on the seismic envelope rotation rate in a double-zone model, consisting of an independently rotating radiative interior and convective envelope. This allows us to find the upper limits on the radial differential rotation in Sun-like stars. We find that the rotation rates of the radiative interior and convective envelope likely do not differ by more than  $\sim 50\%$ . This further supports the idea that Sun-like stars likely show a rotation pattern similar to that of the Sun, potentially indicating that solar-like dynamo mechanisms are present in these stars.

These results are the latest step toward being able to accurately measure the internal dynamics of stars other than the Sun, thereby improving stellar dynamo models. Although the *Kepler* data are the best quality observations currently available, we are still limited by its intrinsic systematic and random noise; preventing us from making more precise measurements of differential rotation. Results from the analysis presented herein do, however, provide physical *limits* on the internal differential rotation of Sun-like stars, and show that this method may be easily applied to a wider variety of stars. This means that we now have the potential for analyzing many more stars, advancing our understanding of stellar rotation and magnetic dynamos.

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Differential Rotation in Sun-like Stars from Surface  
Variability and Asteroseismology

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2017, XVI, 101 p. 29 illus., 18 illus. in color., Hardcover

ISBN: 978-3-319-50988-4