The influence of stellar macroturbulence on spectral lines

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Introduction

Key to studying exoplanets is understanding the stars that they orbit. Many stellar parameters rely on measuring the spectral lines that are produced by elements in the photosphere of the star. These "lines" are actually broadened by many different processes. Two of the most significant broadening factors are the rotational velocity (*v* sin *i*) of the star, and convection in the photosphere.

What is macroturbulence?

Macroturbulence ($v_{\rm mac}$) is the name given to the spectral line broadening caused by convection in the outer layers of a cool star. Physically, it has little to do with turbulence and it actually represents the velocity dispersion of granulation. Some of the macroturbulent velocity is also from acoustic oscillations, although these velocities are an order of magnitude lower than those from granulation. As 1D model atmospheres cannot simulate convection, it is essential to add macroturbulent broadening.

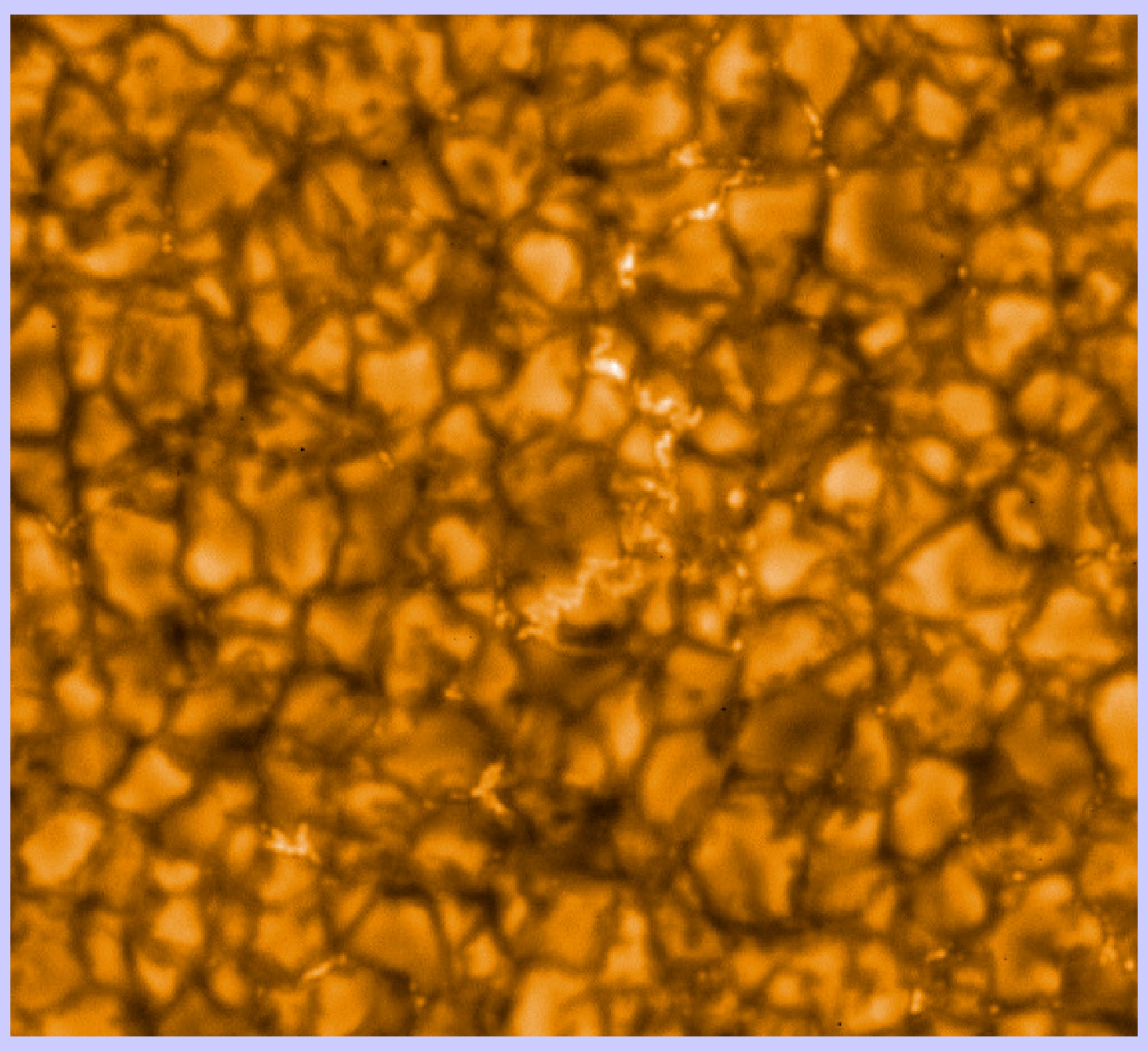

Fig. 1. Granulation on the Sun's surface.
Credit: Hinode JAXA/NASA/PPARC

How does macroturbulence change spectral lines?

Macroturbulence does not alter the equivalent width, i.e. the area that a line takes up. It broadens the wings of the line and causes the core to have a "cusp" shape. This is in contrast to *v* sin *i*, which does not change the wing shape and has a rounded core. The different shapes can be seen for a synthetic line in Fig. 2. The combination of both *v* sin *i* and $v_{\rm mac}$ is also shown. For higher *v* sin *i* values, the $v_{\rm mac}$ signal becomes washed out.

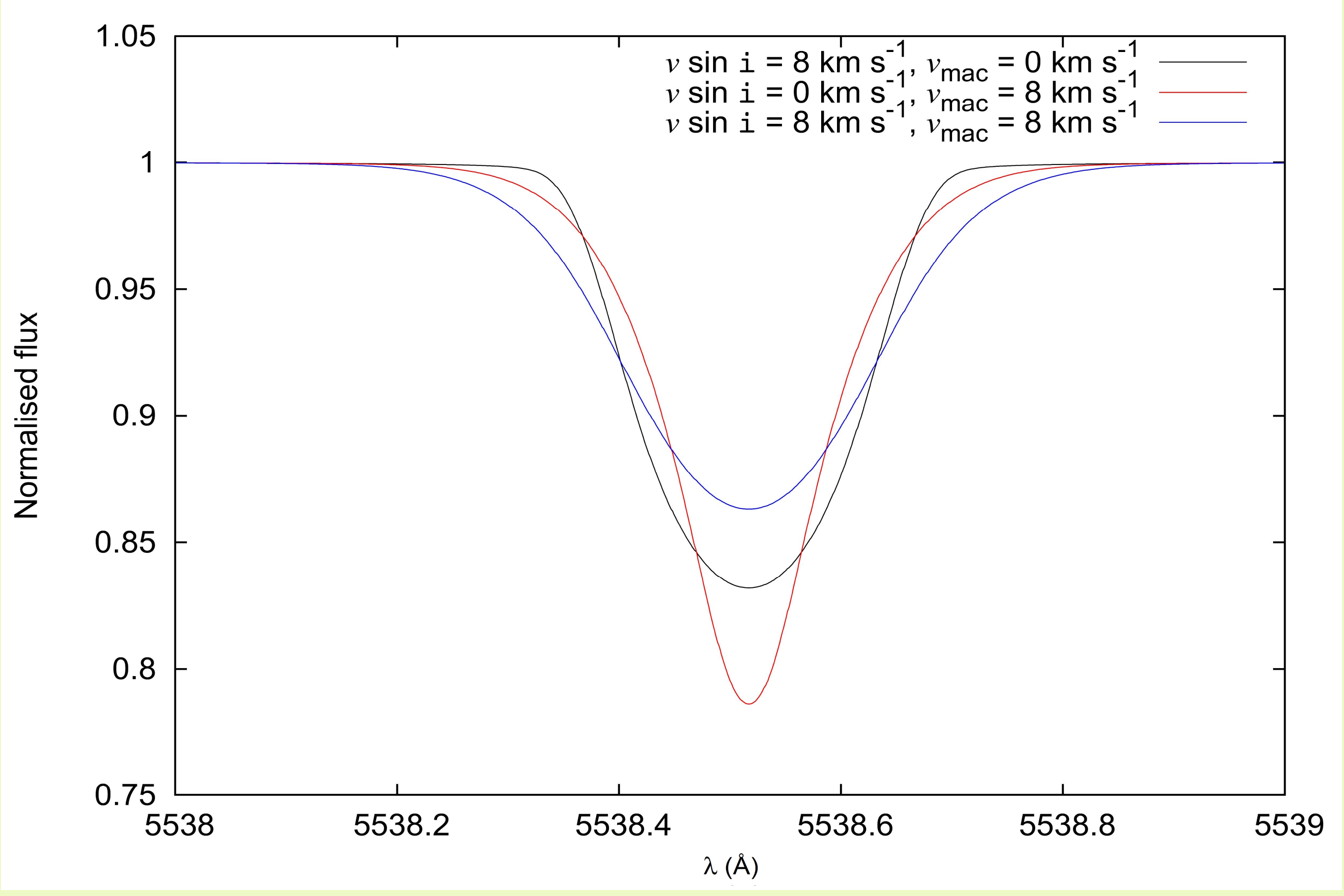

Fig. 2. Both $v_{\rm mac}$ and *v* sin *i* have unique effects on the broadening of spectral lines, but when both are present it is difficult to disentangle them.

Disentangling broadening mechanisms

Disentangling $v_{\rm mac}$ and *v* sin *i* is difficult, however when the *v* sin *i* is fixed to accurate values from asteroseismology, it is possible to extract the macroturbulence. In Doyle et al. (2014), we determined a calibration between effective temperature ($T_{\rm eff}$), surface gravity (log *g*) and $v_{\rm mac}$ for a set of *Kepler* stars.

Prior knowledge of *v* sin *i* is often important when studying the Rossiter-McLaughlin effect of transiting exoplanets in order to find the obliquity of the planet's orbit. However, for stars where the *v* sin *i* cannot be determined via asteroseismology, it is essential to have an accurate macroturbulence calibration in order for *v* sin *i* to be extracted from the spectral lines.

Fig. 3 shows how $v_{\rm mac}$ increases with $T_{\rm eff}$ and that there is also some dependency on log *g*. Three red giants from Deheuvels et al. (2014) are shown as squares. These are not included in the calibration, but illustrate how $v_{\rm mac}$ is higher for more evolved stars. The calibration is shown, along with other $v_{\rm mac}$ calibrations frequently used in the literature.

References

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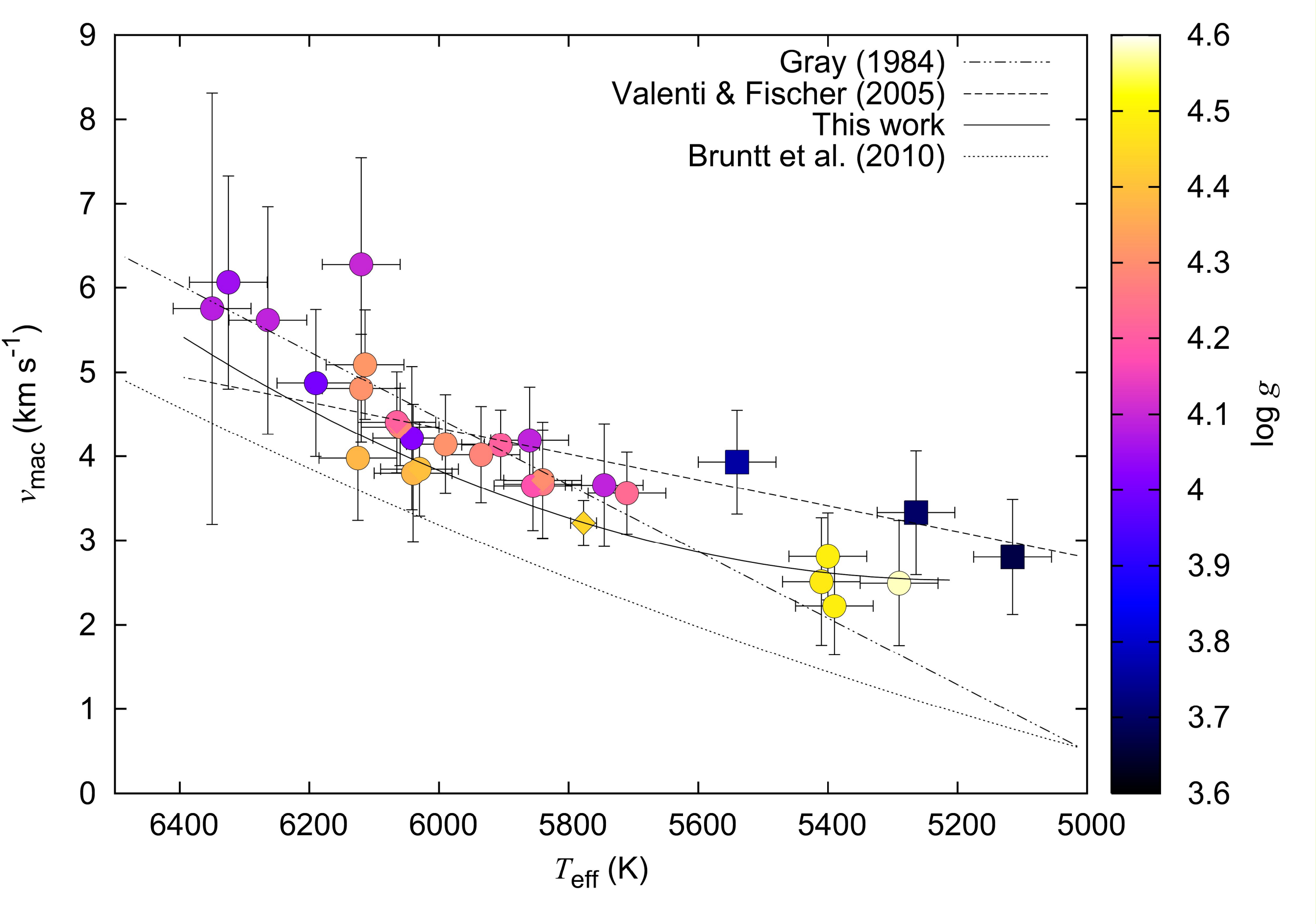

Fig. 3. Macroturbulence is seen to increase with increasing $T_{\rm eff}$, and there is also a log *g* dependence. The circles represent the stars used in this study, the diamond represents the Sun, and the squares are the red giants from Deheuvels et al. (2014). The red giants are not included in the calibration.

Depth dependent macroturbulence

As the $v_{\rm mac}$ is mostly due to granulation, and the granulation velocity in the Sun diminishes with height (Gray 2008; Lefebvre et al. 2008), it is natural to expect that $v_{\rm mac}$ should be depth dependent. Lines with a high excitation potential (EP) are formed deep within the photosphere, and are thus subjected to greater convective motions. Therefore, they will have a higher $v_{\rm mac}$. This is shown in Fig. 4 for the Sun, where the $v_{\rm mac}$ of individual Fe I lines are plotted against the optical depth where the line is formed (log τ). The deep photosphere is at log $\tau = 0$.

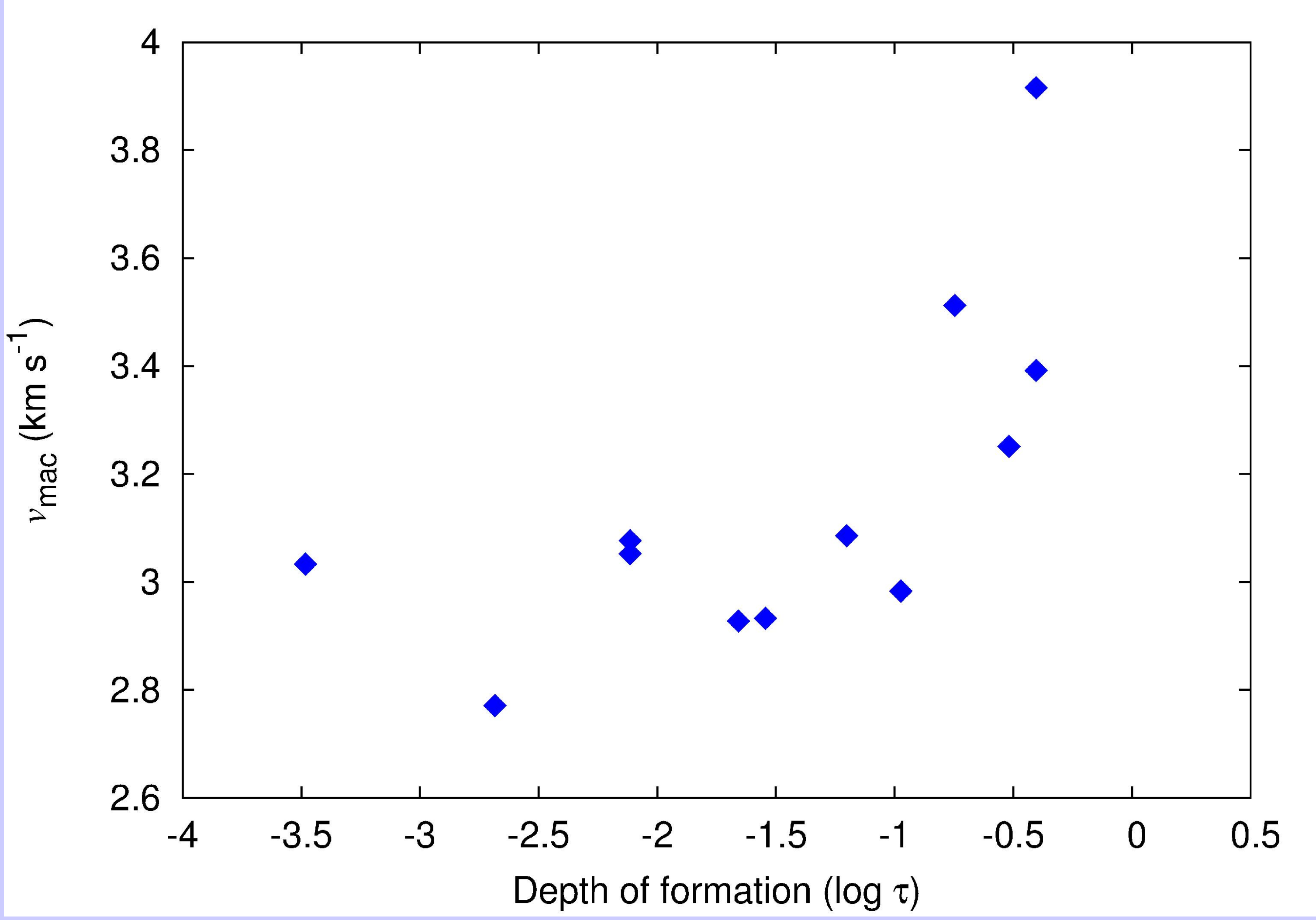

Fig 4. Macroturbulence is stronger for lines formed deeper in the photosphere.

Depth dependent $v_{\rm mac}$ can also be seen in the *Kepler* stars. Comparing the $v_{\rm mac}$ of a high EP and a low EP line across all stars shows that the behaviour of $v_{\rm mac}$ with $T_{\rm eff}$ is different for the two lines, as the high EP line generally has higher $v_{\rm mac}$.

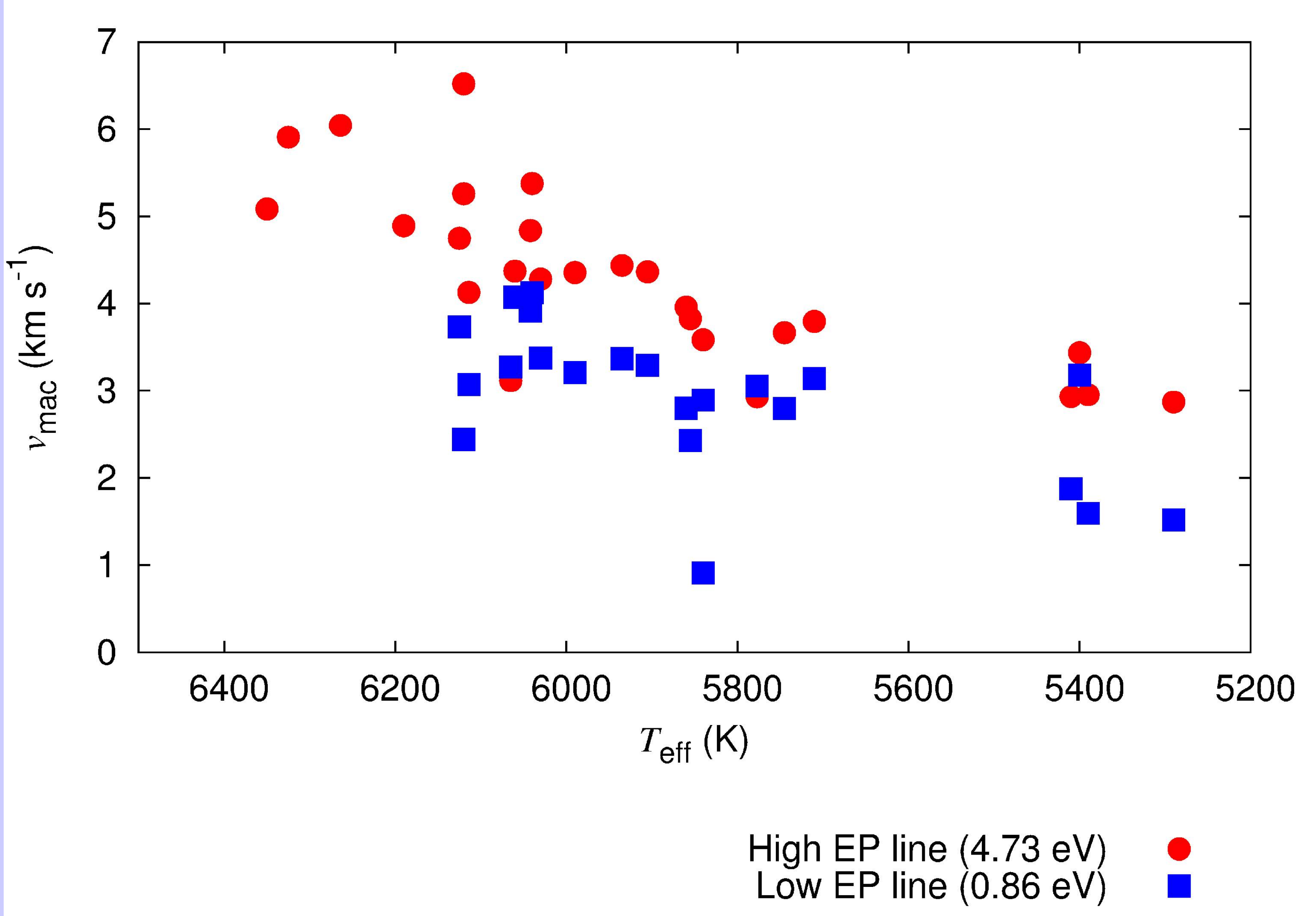

Fig. 5. A line with a high EP has higher $v_{\rm mac}$ across all of the *Kepler* stars

Future work

Even with a perfect spectrum, $v_{\rm mac}$ will be different for each line. For the calibration in Doyle et al. (2014), the $v_{\rm mac}$ of each star was determined by averaging the $v_{\rm mac}$ of around 20 spectral lines. Even with a perfect spectrum, $v_{\rm mac}$ will be different for each line, so that assuming a single $v_{\rm mac}$ value for a star will not result in the optimum fits to the spectral line. This means that the *v* sin *i* is then adjusted to account for the $v_{\rm mac}$. As *v* sin *i* is also taken as an average of several lines, this means that extra line-to-line scatter is introduced that reduces the precision of the overall *v* sin *i* value.

Ideally, each line should have a separate $v_{\rm mac}$ calibration with $T_{\rm eff}$. However, for the spectra used in Doyle et al. (2014), the low S/N introduced significant errors so that the depth dependence cannot be studied with the precision needed. Acquisition of higher S/N spectra would further studies of convection in other stars, as well as improve the precision of *v* sin *i* measurements needed for exoplanet studies.