Wilson-Bappu Effect:

Extended to Surface Gravity

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ABSTRACT

Wilson and Bappu found a tight correlation between the stellar absolute visual magnitude (M_V) and the width of the Ca II K emission line for late-type stars in 1957. Here, we revisit the Wilson-Bappu relation (hereafter, WBR) to claim that WBR can be an excellent indicator of stellar surface gravity of late-type stars as well as a distance indicator. We have measured the width of the Ca II K emission line (log W) in high resolution spectra of 125 late-type stars, which were obtained with Bohyunsan Optical Echelle Spectrograph (BOES) and adopted from the UVES archive. Based on our measurement of the emission line width (log W), we have obtained a WBR of M_V = 33.76 – 18.08 log W. In order to extend the WBR to be a surface gravity indicator, the stellar atmospheric parameters such as effective temperature (T_{eff}), surface gravity (log *g*), metallicity ([Fe/H]), and micro-turbulence (ξ_{tur}) have been derived from the self-consistent detailed analysis using the Kurucz stellar atmospheric model and the abundance analysis code, MOOG. Using these stellar parameters and log W, we found that log *g* = - 5.85 log W + 9.97 log T_{eff} - 23.48 for late-type stars.

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Wilson-Bappu Effect

★ **Wilson – Bappu Relation (WBR)** : Wilson and Bappu (1957) found a strong relationship between the absolute visual magnitude (M_V) and the width of the Ca II K emission line (log W) for late type stars.

★ There are many precedent studies about WBR. Lutz and Pagel (1982) mentioned that there is a dependence of the WBR on stellar atmospheric parameters. Pace et al. (2003) used high resolution spectra and *Hipparcos* data to obtain a WBR, and they applied the WBR to estimate the distance to M67. However, WBR has not been examined explicitly to obtain stellar surface gravity.

★ **In this study, we extend WBR to be an indicator of the surface gravities of late-type stars, including M type stars.**

DATA ANALYSIS & RESULT

★ Data

→ 125 **G**, **K**, and **M** type stars, luminosity class of **I** to **V**

→ 53 stars from UVES POP archive (R = 60,000)

→ 72 stars from BOES observation (R = 45,000)

★ The measurement for the Ca II K emission line widths :

1. Find the minimum and maximum intensities of each peak (blue asterisks in Fig. 1)
2. Calculate the mean intensity of each peak (red dashed lines in Fig. 1)
3. Find the wavelengths of two mean intensities
4. Calculate the width of the Ca II K emission line as the difference between two wavelengths

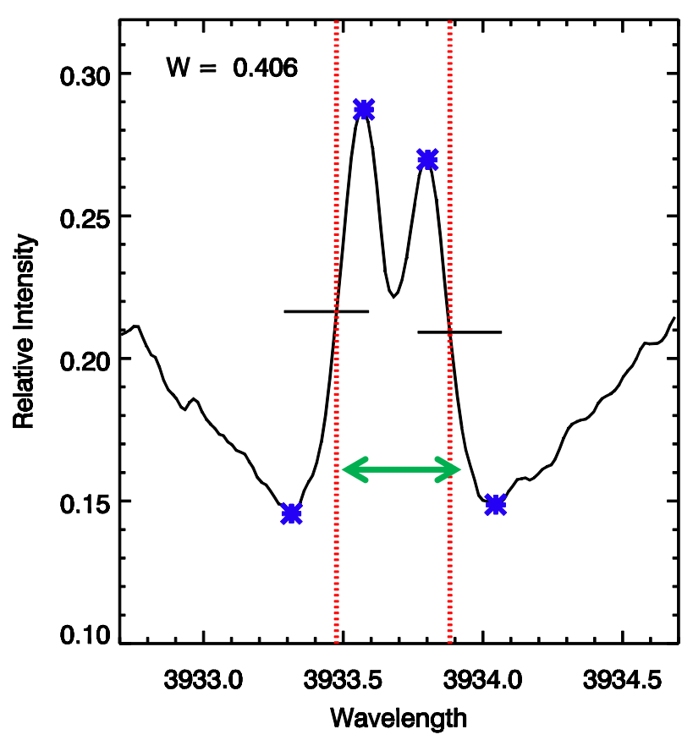
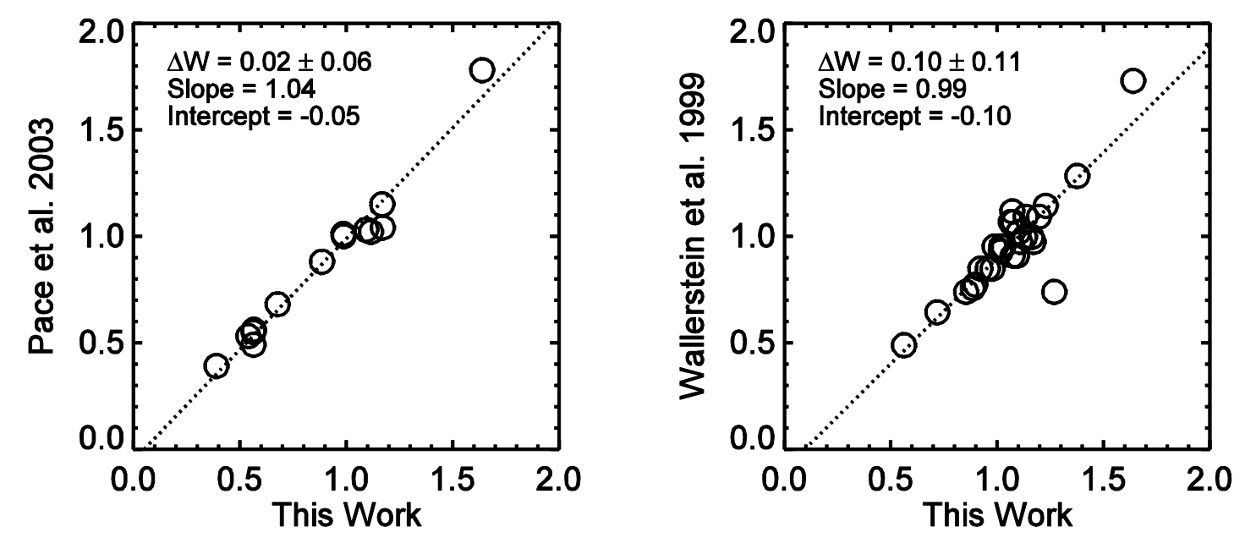


Fig 1. Measurement of the Ca II K emission line width. (Right)



→ In order to evaluate our measurements, we compared our widths (W [Å]) with those of previous studies (Fig. 2).

Fig 2. Comparison with previous works for the width (W) of the Ca II K emission line. (Left)

★ Wilson-Bappu Relation (WBR)

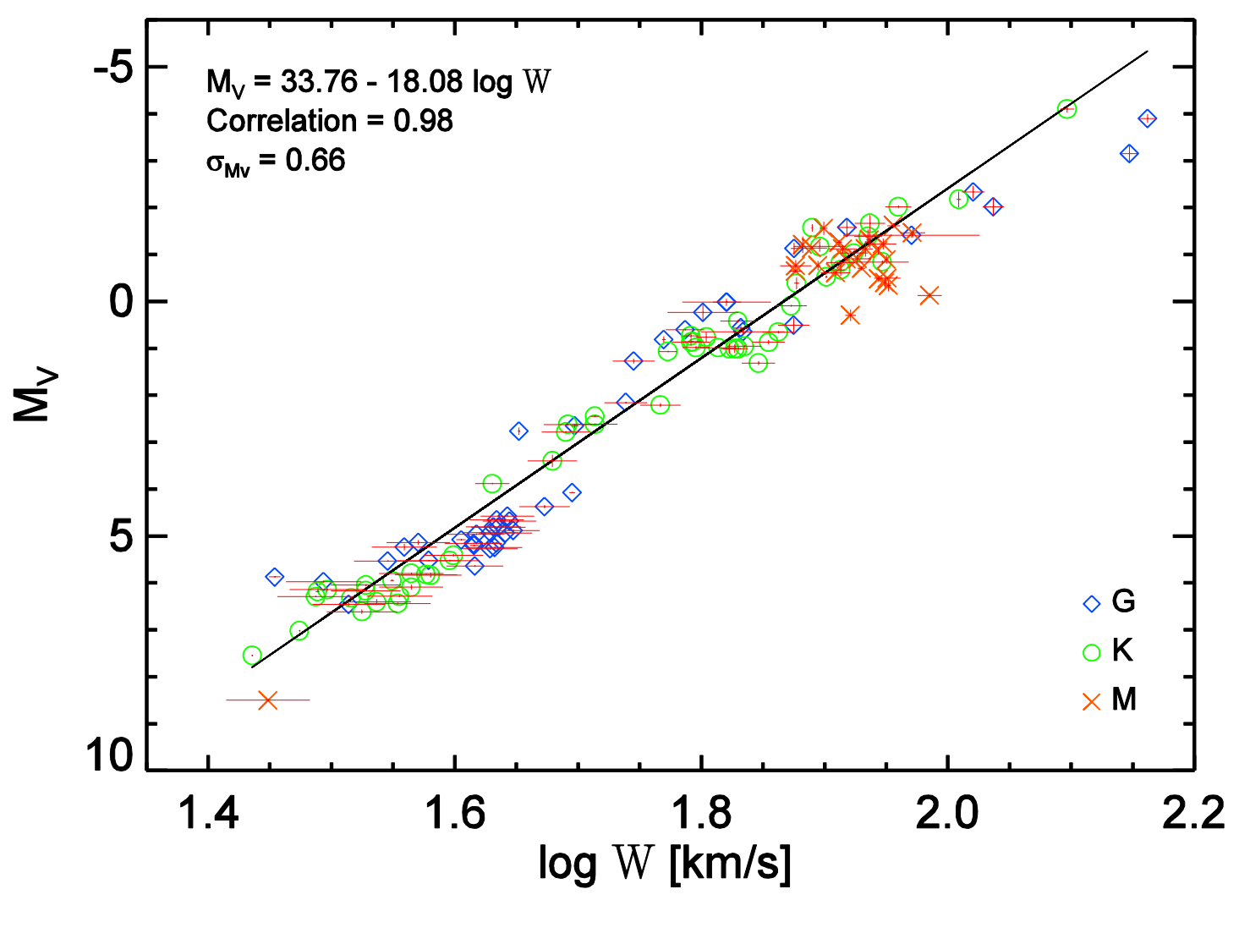


Fig 3. The Wilson-Bappu relation of our samples,
M_V = 33.76 – 18.08 log W.
Blue, green, orange symbols indicate G, K, and M type stars, respectively. Red error bars represent the errors of the measurements of log W and M_V that originated from their parallax measurements.

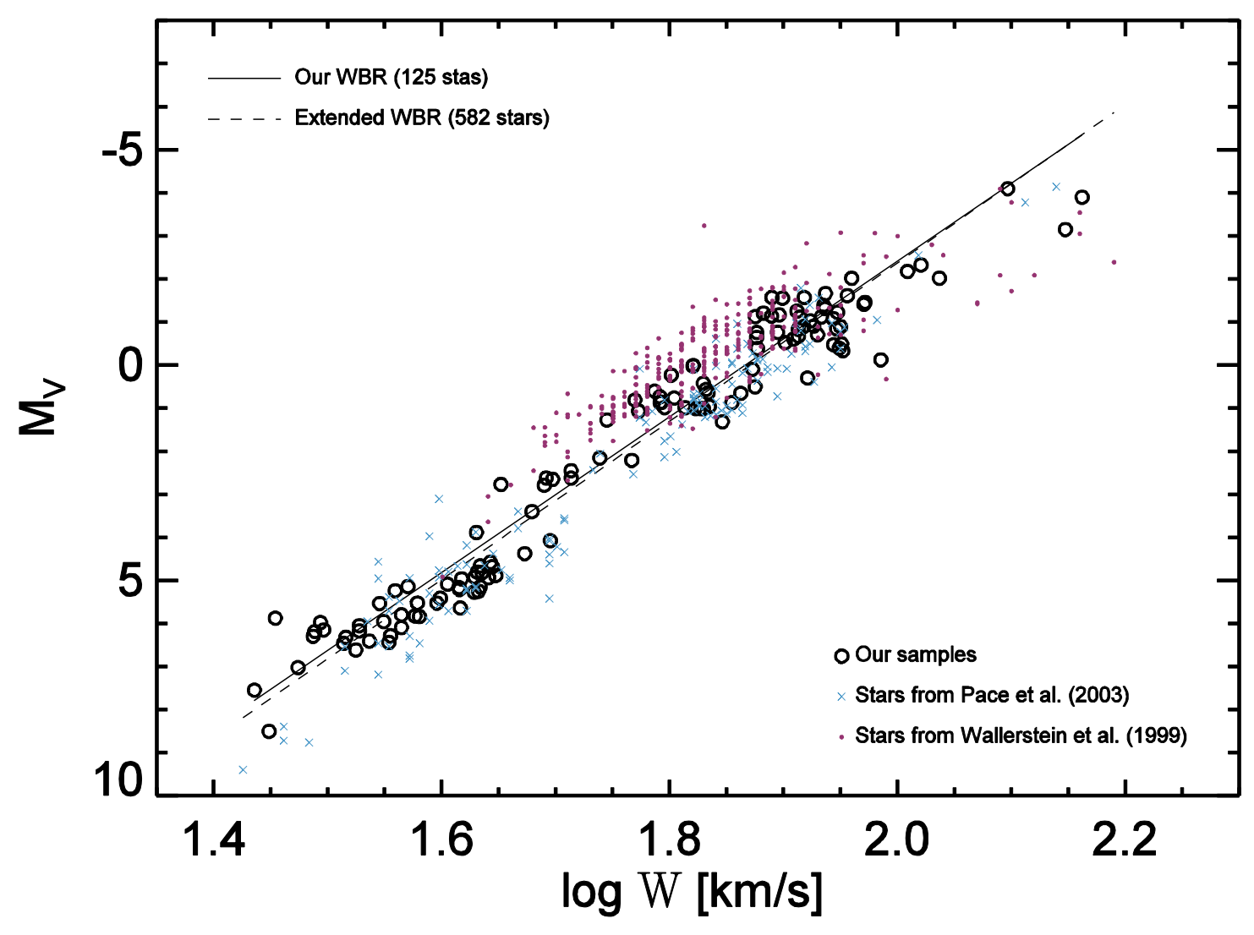


Fig 4. WBR from an extended and homogenized sample. Open circles indicate our sample, blue crosses represent the stars from Pace et al. (2003), and purple filled circles correspond to the stars from Wallerstein et al. (1999). Solid and dashed lines represent our WBR and the WBR calculated from the combined sample, respectively. The WBR calculated with the extended and homogenized sample agrees with our WBR within 0.1 mag.

STELLAR ATMOSPHERIC MODEL

★ From the EWs of Fe I and Fe II lines, we determined the stellar atmospheric parameters (T_{eff}, log *g*, [Fe/H], ξ_{tur}) by using the MOOG code (Sneden, 1973) and the Kurucz ATLAS9 model grids.

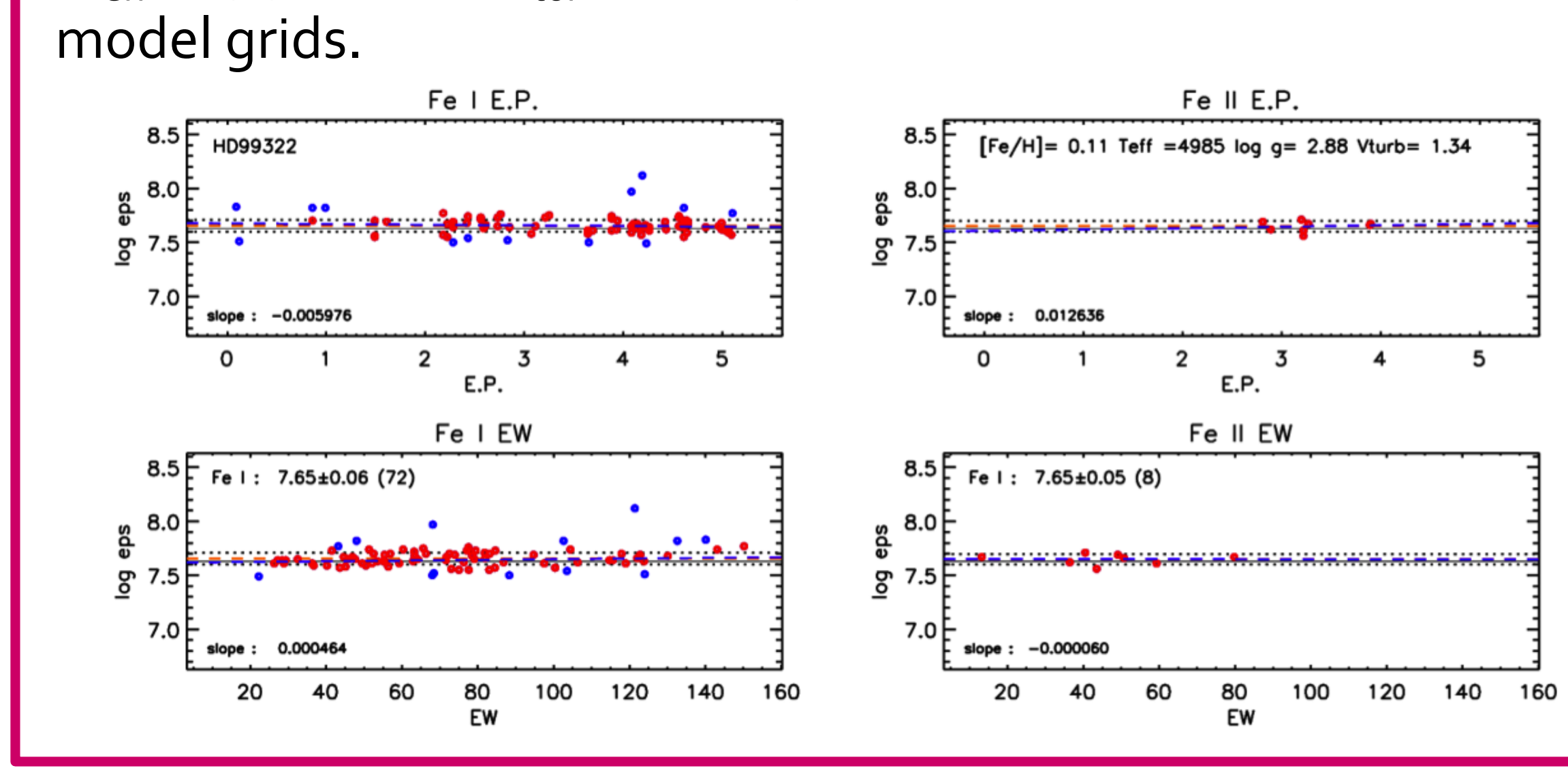


Fig 5. Example of the determining stellar atmospheric parameters of HD 99322 using Kurucz model.

DISCUSSION

★ Application of WBR to the Distance

We applied the WBR to M67 to calculate its distance modulus by using the spectra from Dupree et al. (1999). Our mean distance modulus from 5 stars agrees well with previous results.

→ Measure the absolute magnitude using WBR

→ Calculate the distance modulus of M67

→ Previous studies : 9.55 < $(m\text{-}M)_V$ < 9.85 mag

→ Mean distance modulus of 5 stars : **$(m\text{-}M)_V$ = 9.86**

Table 1. Comparison between our results and those of Pace et al. (2003).

Name	Width [Å]	Pace et al. (2003)	M_V [mag]	$(m – M)_V$	Pace et al. (2003)
S978	1.089	1.080	-0.936	10.656	10.926
S1016	0.804	0.700	1.446	8.854	8.116
S1221	0.894	0.854	0.613	10.147	10.131
S1250	0.953	0.997	0.111	9.579	10.271
S1479	0.908	0.868	0.491	10.059	10.048

★ Emission Width as a Surface Gravity Indicator

log W has a tight relation (WBR) with M_V, which is associated with effective temperature and stellar radius;

$$M_V \propto \log L \propto \log R_*^2 T_{eff}^4 \propto \log M_* g^{-1} T_{eff}^4$$
$$\sim \log M_* - \log g + 4 \log T_{eff}$$

$$\text{Because } L \propto M_*^{\gamma},$$
$$M_V \propto \log W \propto \log L \sim \alpha \log g + \beta \log T_{eff}.$$

As expected, log W varies with temperature at a given gravity, as seen for log g_{model} > 4 in Fig. 6. Therefore, we take into account T_{eff} in order to determine the relationship between log g_{model} and log W.

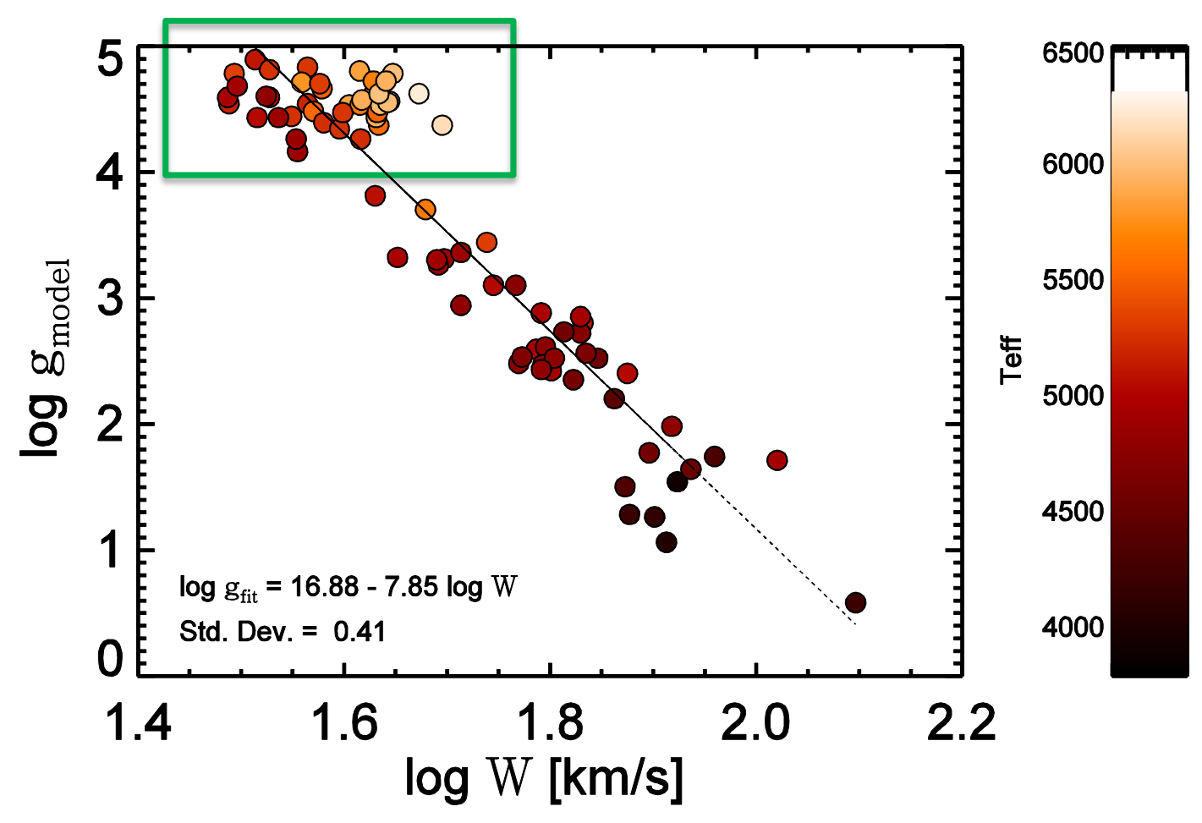
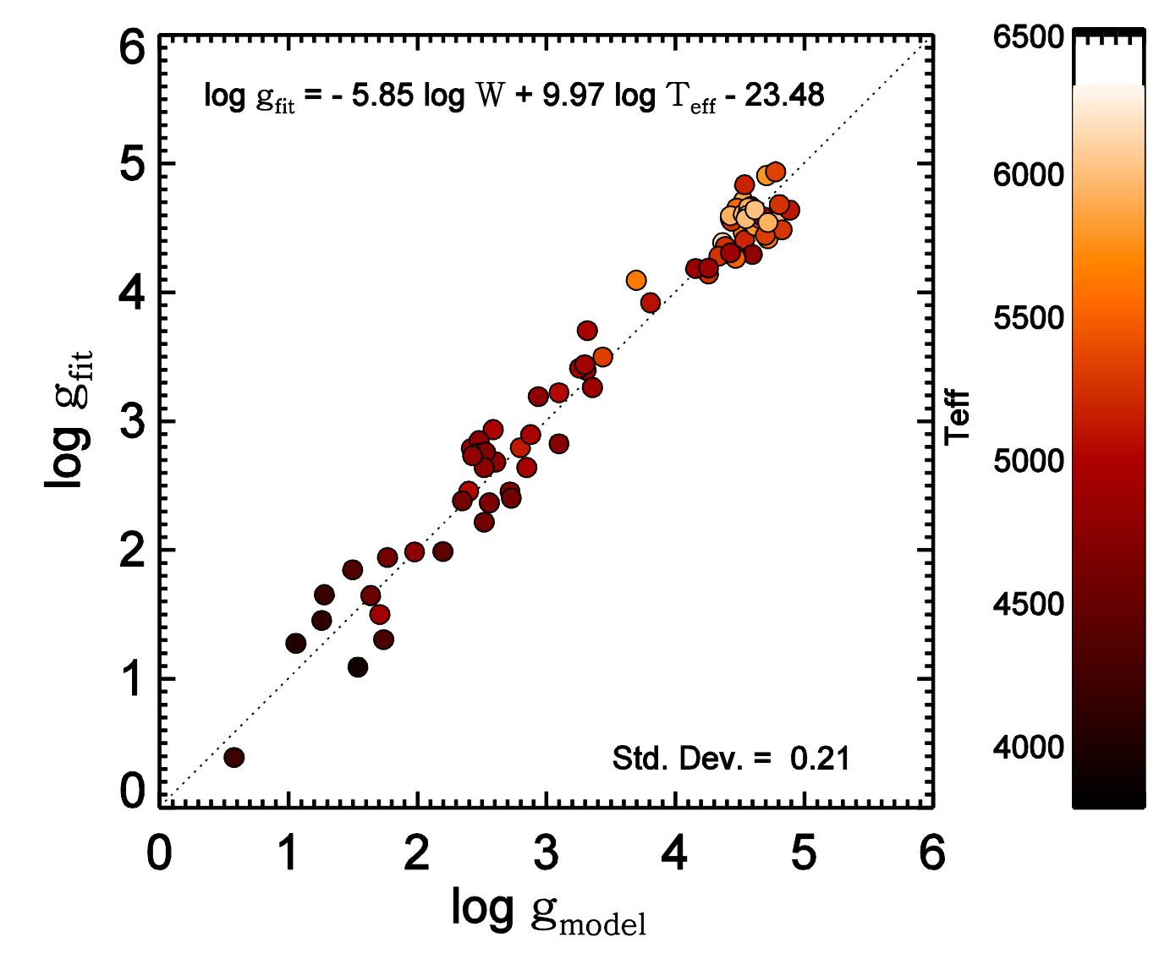


Fig 6. Relation between log W and log g_{model}. Color represents the effective temperature. A brighter color means a high temperature.



We use multiple linear regression to fit **log *g*** with **log W** and **log T_{eff}**. Fig. 7 presents that the fitted log *g* is well consistent with log *g* derived from the stellar atmospheric model.

$$\log g_{fit} = -5.85 \log W + 9.97 \log T_{eff} - 23.48$$

Fig 7. log g_{fit} vs. log g_{model}. log g_{model} was derived from the stellar atmospheric model and log g_{fit} was obtained from the equation. Symbol color represents the effective temperature. The standard deviation in log *g* is 0.21.

★ Application to M type stars

The surface gravities calculated with the above equation for 4 M type stars agree well with those values derived in previous studies **within the standard deviation of log g_{fit} (0.21 dex)**. Therefore, this relation can provide a simple way to calculate the surface gravity of late-type stars without using stellar atmospheric models.

HD name	Sp. type	log W [km/s]	T_{eff} (V-K) [K]	log g_{fit} [dex]	T_{eff} (ref.) [K]	log g (ref.) [dex]
HD 89758	M0 III	1.92	3851.62	**1.07**	3700[a]	**1.35[a]**
HD 101153	M4 III	1.88	3464.98	**0.83**	3452[b]	**0.80[b]**
HD 102212	M1 III	1.88	3918.59	**1.36**	3738[c]	**1.55[c]**
HD 123657	M4.5 III	1.93	3484.12	**0.56**	3261[c]	**0.59[c]**

Table 2. Comparisons of log *g* and T_{eff} of M type stars with previous studies. T_{eff} has been derived with the (V-K) color (van Belle et al. 1999).
[a] Mallik (1998)
[b] Smith & Lambert (1986)
[c] Koleva & Vazdekis (2012)

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