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SURFACE GRAVITY ALONG THE MAIN SEQUENCE

T. Angelov

Department of Astronomy, Mathematical Faculty, Studentski trg 16, 11000 Belgrade, Yugoslavia

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SUMMARY: On the basis of the empirical distributions of the radii and critical rotation velocities for normal stars an analysis concerning the surface-gravity ($g(\mathcal{M})$) distribution along the main sequence is undertaken. It appears that $g(\mathcal{M})$ is largely determined by the $R^{-1}(\mathcal{M})$ distribution, especially in the region of rapid changes (about $\mathcal{M} = 1.2 - 1.4\,\mathcal{M}_{\odot}$).

1. INTRODUCTION

For many parameters of normal stars along the main sequence correlations of the same type are valid; for example radius, mass and luminosity increase with effective temperature increasing. On the other hand, the surface gravity decreases with the effective temperature increasing, whereas the rotation velocity at the stellar equator has a minimum about the spectral subtype F5 and a maximum for B stars. Analogous conclusions are also valid for the dependence of the parameters on the mass. In this, with regard to the relatively small mass dispersion for a given spectral type, the high accuracy in the $\log T_e$-$\log \mathcal{M}$ correlation enables one to use the mass as a derived coordinate on the main sequence. In the distributions of some characteristics the details are more clearly expressed concerning the mass as a variable and it, in addition, appears as a parameter in the modelling of the internal structure of stars.

In this paper, on the basis of the observational material concerning the radii and masses of stars, the way in which the surface-gravity varies with mass along the main sequence is registered (Sect. 2). The obtained result is interpreted as a consequence of the variations in R and $v_{\rm rot}$ along the main sequence (Sect. 3) for the case of marginal stability of MS stars photospheres.

2. THE VARIATION OF THE SURFACE GRAVITY ALONG THE MAIN SEQUENCE

Fig. 1 gives the surface-gravity field for the main-sequence stars. The mean values of $\log g$ can be also represented by transforming of $\mathcal{M}(T_e)$ into $g(T_e)$ on the basis of the three-parameter correlation L-$\mathcal{M}$-T_e (Angelov, 1996).

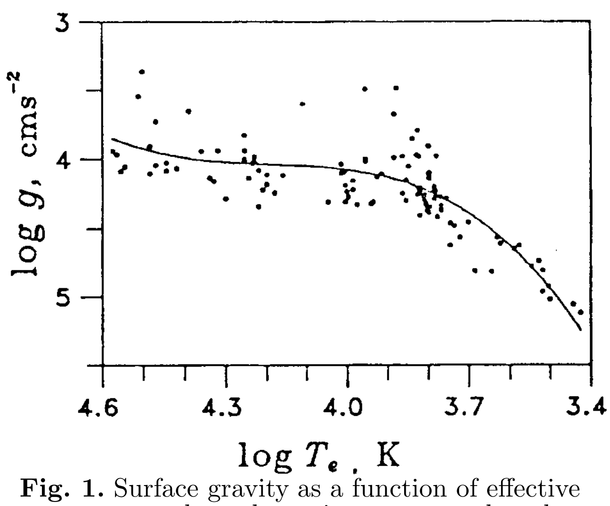

Fig. 1. Surface gravity as a function of effective temperature along the main sequence – based on measured $\mathcal{M}$ and R from Popper's review (1980).

The surface gravity of hot stars (down to $\log T_e \approx 3.8$) changes slightly about $\log g \approx 4.1$, whereas the variations along the lower main-sequence branch are significant. The rapidity of these variations is presented in Fig. 2.

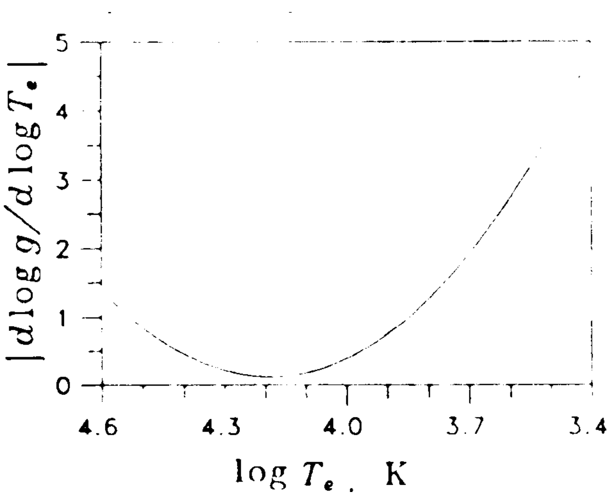

Fig. 2. Logarithm gradient of surface gravity as a function of effective temperature along the MS.

The curve $|d \log g / d \log T_e|$ is symmetric with respect to the minimum abscissa ($\log T_e \approx 4.2$) in the region of hot stars and within a sufficiently wide vicinity of this value the variations are slow. The asymmetry appears at $\log T_e \approx 3.8$ (about spectral subtype F5), whereas a significant and more rapid surface-gravity increase continues with the effective temperature decreasing within the region $\log T_e < 3.8$.

3. INTERPRETATION AND CONCLUSION

The surface-gravity variation along the main sequence will be interpreted in the framework of the dynamical stability of stellar photospheres. For this purpose the standard form of the mechanical-equilibrium equation for a layer at a distance r from the star centre will be used:

$$\frac{1}{\rho} \frac{\partial P_{\rm gas}}{\partial r} = -g_{\rm eff} \,. \qquad (1)$$

Here $\rho(r)$ is the density within the considered layer, $P_{\rm gas}$ is the contribution of the gas component in the total pressure

$$P(r) = P_{\rm gas} + P_{\rm rad} + P_{\rm tur} + P_{\rm mag} \,, \qquad (2)$$

and the effective acceleration for the given layer is

$$g_{\rm eff} = g_{\rm grav} - (g_{\rm rot} + g_{\rm rad} + g_{\rm tur} + g_{\rm mag}) \qquad (3)$$

($g_{\rm tur}$ and $g_{\rm mag}$ are the accelerations due to the turbulent motion and to the magnetic-field inhomogeneity, respectively). On the star surface the first three components in $g_{\rm eff}$ (due to gravitation, rotation and radiation) are

$$g_{\rm grav} \equiv g = \frac{G\mathcal{M}}{R^2} \,, \quad g_{\rm rot} = \frac{v_{\rm eq}^2}{R} \,, \quad g_{\rm rad} = \frac{\sigma}{c} \, \kappa T_e^4 \,, \qquad (4)$$

where R, $\mathcal{M}$ and T_e are the radius, mass and effective temperature of the star, κ and $v_{\rm eq}$ are the opacity and the photosphere rotation velocity on the equator, whereas σ and c are the Stephan-Boltzmann constant and the vacuum light velocity, respectively. For stable atmospheres, including also those with marginal stability, it is valid

$$g_{\rm eff} \geq 0. \qquad (5)$$

The atmospheres of the main-sequence normal stars are stable on the average (Angelov, 1995). For them $g_{\rm tur}$ and $g_{\rm mag}$ can be excluded, for the cool stars it is also $g_{\rm rad} \approx 0$, whereas for the hot stars we have $g_{\rm rad}/g < 10\,\%$ (for the purpose of this estimate Thomson's opacity for a Sun-like chemical composition, $\kappa \approx 0.3\,{\rm cm}^2/{\rm g}$, is used). Therefore, according to (3), (4) and (5) in the marginal-stability case there approximately applies

$$g = \frac{v_c^2}{R} \,, \qquad (6)$$

where v_c is the critical rotation velocity on the equator.

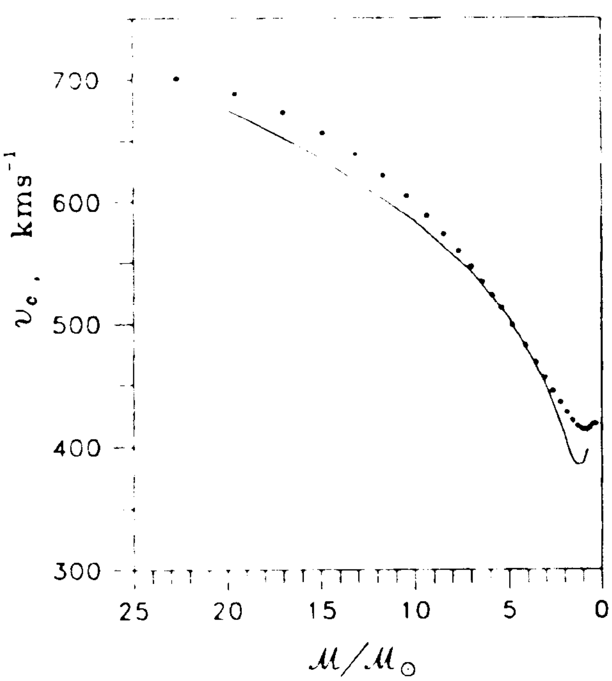

Fig. 3. Dependence of the critical rotation velocity on the mass along the main sequence
• • • mean empirical values
— from the theoretical models (Sackmann, 1970).

The v_c distribution has a minimum about the spectral subtype F5 (Angelov, 1995) and with regard to the empirical dependence of the mass on the effective temperature (spectral type), the $v_c^{\min}$ value should be expected at $\mathcal{M} \approx 1.2 - 1.4\,\mathcal{M}_\odot$ (Fig. 3); the abscissa of the minimum $v_c(\mathcal{M})$, according to the theoretical models, is also in this mass region (Sackmann, 1970). Following the empirical distributions $v_c(\mathcal{M})$, $R(\mathcal{M})$ and $g(\mathcal{M})$, in Fig. 4 are presented the values

$$\nabla_\alpha = \frac{d\log\alpha}{d\mathcal{M}}\,, \qquad \alpha \equiv v_c^2,\ R^{-1},\ g \qquad (7)$$

along the main sequence. This time, in view of equilibrium (6) is valid

$$\nabla_g = \nabla_{1/R} + \nabla_{v_c^2}\,. \qquad (8)$$

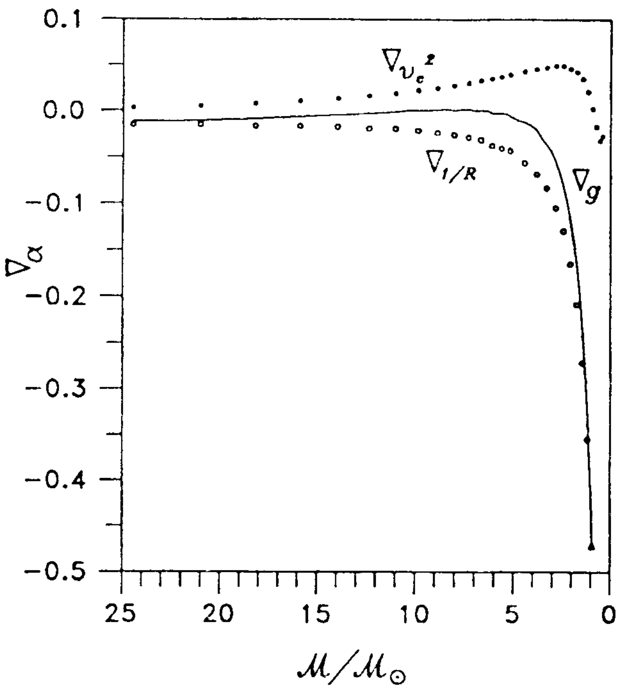

Fig. 4. Gradients $\nabla_\alpha = d\log\alpha/d\mathcal{M}$, $\alpha \equiv v_c^2,\ R^{-1},\ g$ along the main sequence (α and $\mathcal{M}$ are in solar units).

As a consequence of $\nabla_{1/R} < 0$ and $|\nabla_{1/R}| \geq \nabla_{v_c^2}$ we have $\nabla_g \leq 0$ along the main sequence. The quantity $\nabla_{v_c^2}$ changes its sign at $\mathcal{M} = \mathcal{M}_c = 1.2 - 1.4\,\mathcal{M}_\odot$ so that at $\mathcal{M}_c$ it is $\nabla_g = \nabla_{1/R}$. This last equality is approximately valid also for $\mathcal{M} < \mathcal{M}_c$, where $\nabla_{v_c^2} < 0$ but $|\nabla_{1/R}| \gg |\nabla_{v_c^2}|$ (the lowest value for $\nabla_{v_c^2} < 0$ occurs at $\mathcal{M} \approx 0.6\,\mathcal{M}_\odot$). In the case $\mathcal{M} > \mathcal{M}_c$, the gradient $\nabla_{v_c^2} > 0$ after the maximum (≈ 0.5 for $\mathcal{M} \approx 3\,\mathcal{M}_\odot$) monotonously tends to zero with mass increasing; for $5 < \mathcal{M}/\mathcal{M}_\odot < 10$ there holds $\nabla_{v_c^2} \approx |\nabla_{1/R}|$, due to which we have $\nabla_g \approx 0$. In the case of very massive stars ($\mathcal{M}/\mathcal{M}_\odot > 20$) it is $\nabla_{v_c^2} \approx 0$, i. e. $\nabla_g \approx \nabla_{1/R}$ like $\mathcal{M} < \mathcal{M}_c$.

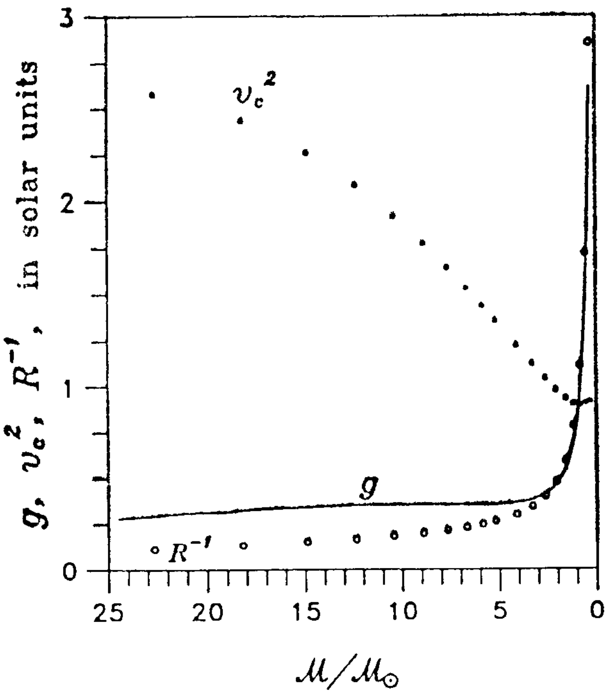

Fig. 5. Surface gravity, v_c^2 and R^{-1} as mass functions along the main sequence (all quantities are in solar units).

The effects of the R^{-1} and v_c^2 distributions on the surface gravity along the main sequence are presented in Fig. 5. The character of the $g(\mathcal{M})$ dependence changes near $\mathcal{M} = 1.2 - 1.4\,\mathcal{M}_\odot$ due to the small changes in v_c^2 about the $v_c^2(\mathcal{M})$ minimum and to the rapid increase in R^{-1} with mass decreasing. In fact, the dependence of the surface gravity on mass along the main sequence is largely determined by the $R^{-1}(\mathcal{M})$ distribution, especially in the region of rapid changes $g(\mathcal{M})$.

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REFERENCES

Angelov, T.: 1995, *Bull. Astron. Belgrade* **152**, 1.
Angelov, T.: 1996, *Bull. Astron. Belgrade* **153**, 19.
Popper, D. M.: 1980, *Ann. Rev. Astron. Astrophys.* **18**, 115.
Sackmann, I-J.: 1970, *Astron. Astrophys.* **8**, 76.

ПОВРШИНСКА ГРАВИТАЦИЈА ДУЖ ГЛАВНОГ НИЗА

Т. Ангелов

Катедра за астрономију, Математички факултет, Студенцки трг 16, 11000 Београд, Југославија

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Оригинални научни рад

На основу емпиријских расподела радијуса и критичних брзина ротације нормалних звезда, анализира се расподела површинске гравитације $g(\mathcal{M})$ дуж главног низа. Показује се да је $g(\mathcal{M})$ претежно одређена расподелом $R^{-1}(\mathcal{M})$, што је посебно изражено у области брзих промена (око $\mathcal{M} \approx 1.2 - 1.4\,\mathcal{M}_\odot$).