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Novel Method for the Evaluation of the Rotation Velocity of Solar-like Stars

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The evaluation of stars' properties is classically performed by comparing the stars' light spectra and fluxes to the known solar properties. Another method to find the stars' rotation velocity will be discussed here: the extrapolation to the other solar-like stars of an empiric solar property, which consists of a direct relationship between the star's frequency and its surface gravity, without the need of any other parameters.

Keywords: Sun, solar-like stars, surface gravity, rotation velocity, gravitational constant.

1. Stars' surface gravity estimation methods

In the quest for a better knowledge of the properties of stars, several methods have been developed to estimate their mass, radius, surface radius, temperature, and rotation velocity.

Indeed, no direct measurements are available, and to come to these results, the models extract one or more parameters and extrapolate them to the new star by the adequate rules of proportion with the solar measurements.

For example, the intensity of the stellar flux is seen as a function of the wavelength, and these variations are linked to temperature, surface gravity and chemical composition [1]. This is the method of photometry.

By spectrophotometry, (i.e. the measurement of stellar flux through (generally) narrow bandpasses, usually over wider wavelength ranges), no good correlation is found with respect to the star's surface gravity [1].

Based upon the star's effective surface temperature, T_{eff}, and when using the Balmer lines, a correlation of the hydrogen content can be associated to the star's surface gravity, within certain technical limitations [1]. These values are used to correct the values obtained from the other models.

The determination of T_{eff} can be effectuated by the infrared flux method. The method relies on the fact that the stellar surface flux at an infrared wavelength is relatively insensitive to temperature [1].

Since all these methods are model-dependent, some 'fundamental stars' are necessary to better gauge the model. It is believed that Sirius and Procyon have truly deduced fundamental values of both the star's effective surface temperature and the surface gravity [1]. But also here, the real gauge of comparison is our Sun.

Another, newer method to estimate the star's surface gravity, asteroseismology, is believed to be given by the solar-like oscillations of stars, compared to these of the Sun. These oscillations differ with the stars' gravity and with the effective surface temperature, and their relationship allow to express the star's surface gravity in terms of the star's measured oscillations and the Sun's known gravitational and oscillations' parameters. The authors claim that the found values are statistically similar with the results of the other methods [2].

The advantage of the latter method is that the influence of the errors on the star's effective surface temperature is quite low, and essentially reduce to the values of the mass.

Often, the values in the literature are expressed in a log scale, which indeed reduces the perception of inaccuracy. It is clear that the results of the estimation methods are very rough, and only if different methods can intersect totally independently, one can rely upon the figures. But up to now, the Sun remained the gauge of comparison.

2. Stars' rotation estimation methods

The rotation (spin) of stars is a very indirect estimation, based upon the assumption of a direct relation between the magnetic moment and the rotation of stars [3]. Another method is the measurement of the Ca-II activity [3].

Although the published figures always show excellent precisions, all the figures stand or fall with the veracity of the analogy compliance between the stars and the Sun.

3. New gravitational parameterization of stars

Another system to find the star's surface gravity and that I propose here, comes from the observation that the Sun has an amazing relationship between its rotation velocity, its mass and its radius.

In terms of the Sun's surface gravity g_{Sun}, I found the empirical relationship [4,5,6]:

$$g_{\mathrm{Sun}} = \frac{G M_{\mathrm{Sun}}}{R_{\mathrm{eq}}^2} = 2 c \upsilon_{\mathrm{eq}} \tag{1}$$

Herein : $G = 6.67\text{x}10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$, $c = 3.00\text{x}10^8\ \text{m s}^{-1}$ and for the Sun: $M_{\text{Sun}} = 1.98\text{x}10^{30}$ kg , $R_{\text{eq}} = 6.96\text{x}10^8$ m ; υ_{eq} is the according solar rotation frequency.

Thus, the sole Sun's rotation frequency is needed to find the Sun's surface gravity!

There are several consequences of the observed eq.(1), whereby the Sun can be seen as a giant particle, whereof its dynamic properties are self-ruling according to eq.(1).

Also here, and in analogy with the current belief, the assumption can be made that the plasma of all the solar-like stars are self-ruling their dynamics accordingly to what is observed with the Sun.

When applying this concept to other solar-like stars, the interesting thing is that the equation for the stars' surface gravity g is given by the very simple eq.(2):

$$g_{\text{star}} = \frac{G\,M_{\text{star}}}{R_{\text{eq}}^2} = 2\,c\,\upsilon_{\text{eq}} \qquad (2)$$

which links the value of the star's surface gravity to the sole parameter of the star's rotation frequency υ_{eq}. No need for the stars' mass nor radius, nor any other parameter!

4. Comparison of the results

Based upon a few solar-like stars, the comparison between the classical and the novel evaluation of the star's surface gravity can be made. Therefore one can even make abstraction of the classical evaluation of the star's mass, radius and rotation velocity, because they are not needed for our novel approach. In the table 1 is shown the surface gravity of a few solar-like stars, taken from literature. Note that in the literature, log(g) is defined as $\log_{10}(100 \times g[\text{SI units}])$, or as log($g$) wherein $g = GM/R^2$ is expressed in cgs-units. For the Sun, one finds log(g) = 4.44.

	Tau Ceti	82 G. Eridani	Delta Pavonis	HR 7722	54 Piscium A	72 Herculis
M/M⊙	0.783	0.7	0.991	0.78	0.76	0.91
R/R⊙	0.793	0.92	1.22	0.79	0.944	1.17
v(equ) [m/s]	1180	4000	1000	838	1188	1000
log (g) "literature"	4.4	4.4	4.26	4.38	4.61	4.26

Table 1. Given the star's mass M, radius R, equatorial rotation velocity v_{equ} and surface gravity g. The value of the equatorial rotation velocity is very imprecise; the logarithmic values of g allow to better mask the very imprecise figures obtained for g.

As far as the given rotation velocities from the literature are reliable, it should be possible to find the values of log(g) very easily. In fact, as can be seen in the table, the estimations of the equatorial rotation velocities v_{equ} from literature seem to be very imprecise.

But remark that eq.(2) can also be used to determine the stars' equatorial rotation frequency out of the classically defined surface gravity. Thus, the eq. (2) has to be seen as a supplementary way to estimate the stars' dynamic properties.

In the table 2, the reader will find the values of log(g) in the literature, and the calculated value of the stars' rotation velocities by using eq.(2).

	Tau Ceti	82 G. Eridani	Delta Pavonis	HR 7722	54 Piscium A	72 Herculis
M/M⊙	0.783	0.7	0.991	0.78	0.76	0.91
R/R⊙	0.793	0.92	1.22	0.79	0.944	1.17
v(equ) corr [m/s]	1452	1685	1619	1382	2805	1553
log (g) "literature"	4.4	4.4	4.26	4.38	4.61	4.26

Table 2. Given the star's mass, radius and surface gravity. The improved equatorial rotation velocity is found by using eq.(2).

The reader will easily find that the values of log(g) in the literature differ with the values when using the equation GM/R^2, wherein for the gravitational constant G , the terrestrial value is used.

But from eq.(3) that directly follows from eq.(1) , appears that the composition of the solar amalgam of hot plasma, defined by its geometry, its mass and its spin, rules the value of the Sun's gravitational constant. Indeed, when rearranging eq.(1), it appears that the gravitational constant is generated by the following relationship [4]:

$$G = \frac{g_{\text{Sun}}\,R_{\text{eq}}^2}{M_{\text{Sun}}} = \frac{2\,c\,R_{\text{eq}}^2\,\upsilon_{\text{eq}}}{M_{\text{Sun}}} \qquad (3)$$

Amazing is that the gravitational constant can be expressed by the dynamic properties of the Sun. This indicates that this constant is star-related [5] and not necessarily universal.

Indeed, expressed for solar-like stars, one gets:

$$G_{\text{star}} = \frac{g_{\text{star}}\,R_{\text{eq}}^2}{M_{\text{star}}} = \frac{2\,c\,R_{\text{eq}}^2\,\upsilon_{\text{eq}}}{M_{\text{star}}} \qquad (4)$$

and as far as one can rely upon the values of each of the parameters, it is expected that the gravitational constant will differ from star to star.

5. Conclusion

A novel equation for the definition of the dynamical parameters of stars is found by the empiric equivalence between the sole Sun's frequency and the Sun's surface gravity. This property can logically be extrapolated to all solar-like stars, with an expected good accordance. Notice that a consequence of this feature is the variability of the stars' gravitational constant, which is depending from its mass, radius and rotation frequency.

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