THE STUDY OF STARS WITH PLANETS

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ABSTRACT

This paper discusses the main physical parameters of 99 extra-solar planet stars, (hereafter ESPs), out of 117 of such stars identified up to now. The 99 ESPs possess reliable Hipparcos parallaxes, leading to trustful absolute magnitudes. For many of them their space velocities, (U,V,W), are known also. The effective temperatures, spectroscopic gravities and chemical compositions have been derived from high S/N, high resolution, spectroscopic detailed analyses available in the literature. Taking into account the metallicity of each star, the ages of the sufficiently evolved ESPs have been estimated , very homogeneously, using isochrones, obtained from metal-poor, solar-metal-normal, and metal-rich stellar structure models. The results are discussed using statistical distributions obtained for each of the physical parameters under investigation. An interesting conclusion emerges from this research: the age-distribution of the evolved ESPs, is bimodal: reflecting the mean age of the thin-disc, (4 to 6 Gyr) and the presence of an older-disc ESPs-population of about 10–12 Gyr.

Key words: Stars: planetary systems; Stars: distances; Stars: fundamental parameters.

1. INTRODUCTION

Are stars with planets a large family of Suns or are their physical structures, chemical compositions, and ages often different from those of the Sun? This question is not a new one, and it is found in many papers, since the discovery of ESPs by Mayor & Queloz (1995). The number of papers on stars with planets, and the interest in them, has steadily increased: 525 publications appeared on this subject merely in 2003. Two research topics have enlightened my old years: the search of true solar analogs, and that of the upper limit in the solar neighbourhood of metal enrichment in solar and lower mass stars, (for which chemical composition can be considered as the chemical composition of the interstellar matter in which these stars have been formed). My interest in ESPs was suddenly raised in learning that many of these stars are metal-rich and that a few of them are solar analogs. Notwithstanding the great number of existing ESPS specialists, Eileen Friel, Caroline Soubiran and myself are writing for *Astronomy & Astrophysics* a paper which deals with the physical parameters: absolute bolometric magnitude, space velocities (U, V, W), effective temperature, spectroscopic gravity, metallicity, and age of this new group of stars. The next sections will briefly relate this research under way.

2. OBSERVATIONAL DATA

As mentioned in the abstract, all the 99 ESPs possess Hipparcos parallaxes i.e., reliable absolute magnitudes, and bolometric corrections (BC), recently determined by VandenBerg & Clem (2003). The retained 99 ESPs have been analysed spectroscopically in detail, and, most of them more than once. The assembling of the effective temperature, spectroscopic gravity, and metallicity parameter, [Fe/H], has been done with the help of the [Fe/H] Catalogue by Cayrel de Strobel et al. (2001) and a very recently published papers by Santos et al. (2004).

3. WORKING TOOLS: THE HERTZSPRUNG–RUSSELL-DIAGRAM (HRD) AND SPECTROSCOPY

One of the principal tools employed in this research is the theoretical Hertzsprung–Russell diagram (HRD) in the form: $(\log(T_{\rm eff}), M_{\rm bol})$, with $M_{\rm bol}$(Sun) = 4.75. Three observational HRDs are presented in Figures 1, 2, 3. All the ESPs in these figures have the four fundamental physical parameters: absolute bolometric Hipparcos magnitudes, effective temperature, gravity and metallicity [Fe/H]. They have been obtained for 11 metal-poor ([Fe/H]$<$ -0.15), 37 metal-normal ($-0.15<$[Fe/H]$<$ 0.15) and 51 metal-rich ([Fe/H]$>$0.15) stars of the sample. The three observational diagrams have been compared with three grids of metal-poor, metal-normal and metal-rich theoretical isochrones. The empirical HRDs, if compared with homogeneously computed HRDs, furnish precious information on the state of evolution and age of the stars which populate it. The theoretical HRDs have been computed by Lebreton with the CESAM code, (Lebreton 2000). Note that in this code the Sun is the calibration star, and sets the exact zero point for the pro-

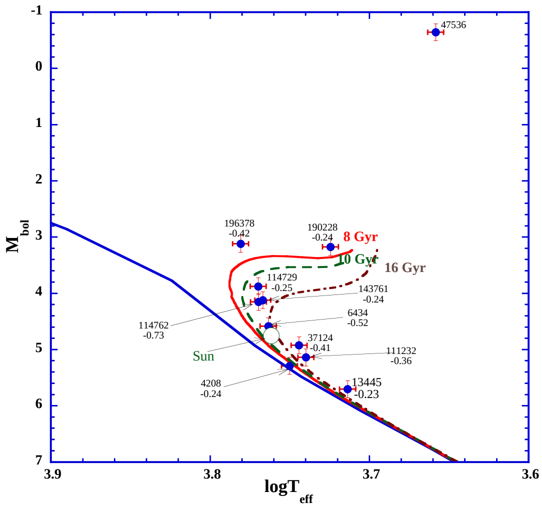

Figure 1. Metal-poor composition theoretical diagram (Y = 0.256, Z = 0.0104, l/H = 1.64 (Lebreton 2000) with over plot of a sample of 11 metal-poor ESPs having [Fe/H] < − 0.15)

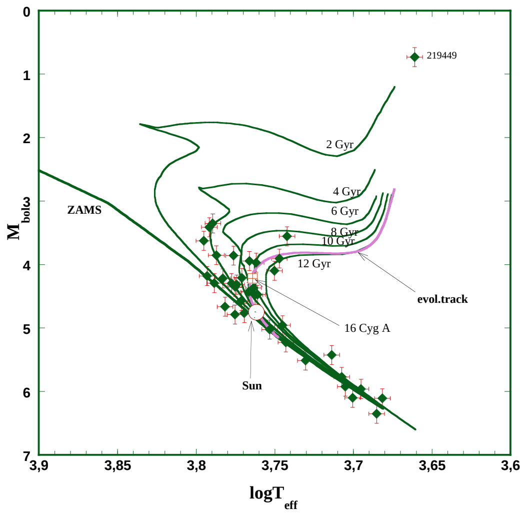

Figure 2. Metal-normal composition theoretical diagram (Y = 0.256, Z = 0.0175, l/H = 1.64(Lebreton 2000)) with over plot of a sample of 37 metal-normal ESPs having −0.15 <[Fe/H]< 0.15)

gramme stars. The interval between the lowest and highest effective temperature is 4550 to 6390 K, and the interval for bolometric magnitudes is 6.4 to 0.3 magnitude.

The second tool is the set of detailed spectroscopic analyses which have allowed accurate values of the metallicity to be obtained, mostly from the catalogue cited above.

Concerning the age of the already evolved stars it is essential to use isochrones computed for the proper metallicity of each star. For example 51 Peg, (the first discovered ESPs, Mayor & Queloz 1995) and 16 Cyg B, a member of the double system 16 Cyg, have the same po-

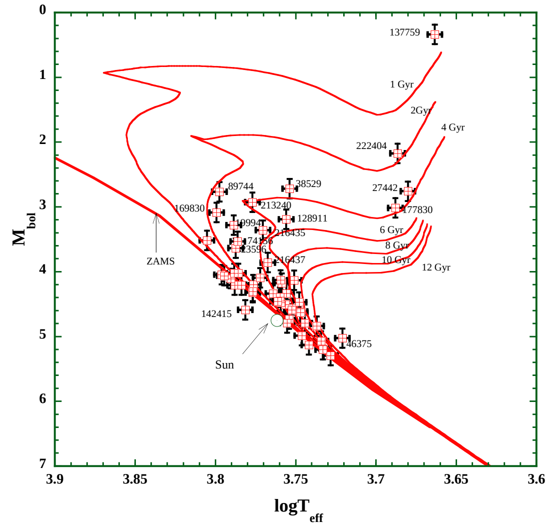

Figure 3. Metal-rich composition theoretical diagram (Y = 0.324, Z = 0.0346, l/H = 1.64 (Lebreton 2000)) with overplot of a sample of 51 metal-rich ESPs having [Fe/H] > 0.15)

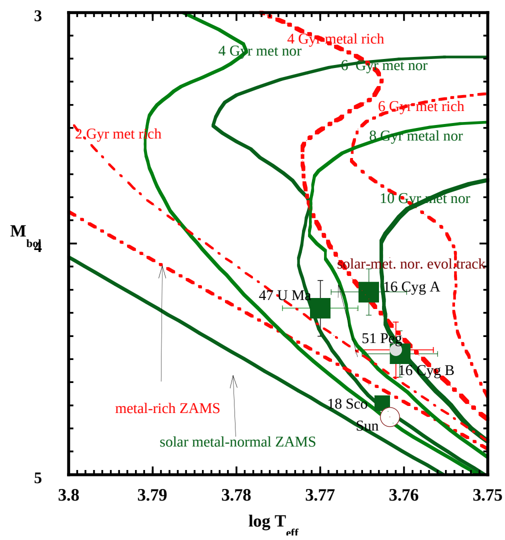

Figure 4. Diagram with both metal-normal and metal-rich theoretical isochrones, illustrating the role of metallicity in age determinations. For example, 51 Peg and 16 Cyg B have almost the same position in the HR diagram, but their age must be read from different isochrone grids, and are respectively 4 Gyr and 10 Gyr, a difference of 6 Gyr!

sition in the HR diagram. However one is metal-rich (51 Peg) ,and the other one metal-normal. Their ages are respectively (4±1) Gyr,and (10±2)Gyr, as read from their respective isochrone grids, quite different in spite of the fact that they have the same location in the HR diagram (Figure 4).

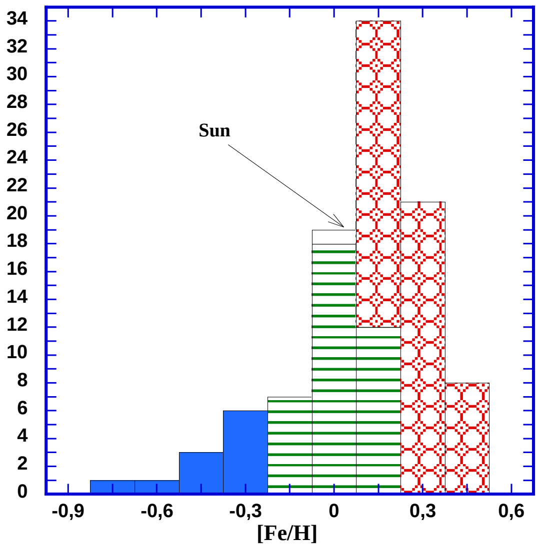

Figure 5. (Fe/H] distribution of 99 ESPs plus the Sun. Same as Figure 5 for metallicity code

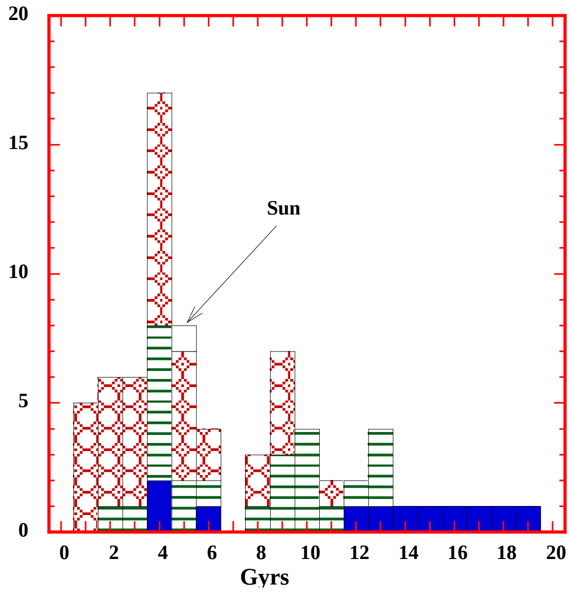

Figure 6. Age distribution of 99 ESPs plus the Sun. Same as Figure 5 for metallicity code

4. DISTRIBUTION OF THE FUNDAMENTAL PARAMETERS, T$_{EFF}$, M$_{BOL}$, METALLICITY AND AGE, IN THE ESPS SAMPLE

Figures 5 and 6 give the histograms of $T_{\rm eff}$ and $M_{\rm bol}$ for the ESPs sample of 99 stars. They are strongly concentrated, independently of metallicity, in the intervals 5800 $\pm$200 K and 4.5$\pm$2 magnitude. This is likely dominated by an observational selection effect: to detect a star with planet with the radial velocity technique, narrow lines and a high S/N ratio are a must. This explains the cut-off near 6500 K, when stars tend to have large rotational broadening. On the cool side it simply is the faintness of the objects which, for a given S/N, limits the volume of space in which they can be observed. For dwarfs $T_{\rm eff}$ and $M_{\rm bol}$ are of course highly correlated.

Figure 7 gives the distribution versus metallicity, the most famous and the most discussed one. ESPs tend to be metal-rich. With the metallicity of the Sun taken as zero-point, the proportion of ESPs is 72 with [Fe/H] $>$ 0 against 26 with [Fe/H] $<$ 0. But the Sun being itself a star with planets, this zero-point is not neutral. Indeed, it is known that in the general field (see Nordström et al. 2004) the mean metallicity is rather [Fe/H] $= -0.15$, and this is also true for non-EPSs stars (Santos et al. 2004).It has been often said that the Sun is slightly metal-rich for its age. With this new zero-point, the proportion becomes 81 to 17, almost 5, quite impressive.

Figure 8 gives the age-distribution of ESPs, derived from the comparison between the observational HRD and the corresponding theoretical isochrones. Of course, we lose all stars not sufficiently evolved for an age determination, generating an artificial cut-off for young stars. What is interesting is the bimodality of the histogram. The first maximum is not surprising, it reflects the mean age of the thin disc, the main reservoir of ESPs. The second shallow maximum is an older population, mixture of all metallicities, including a few thick disc stars but also metal-rich

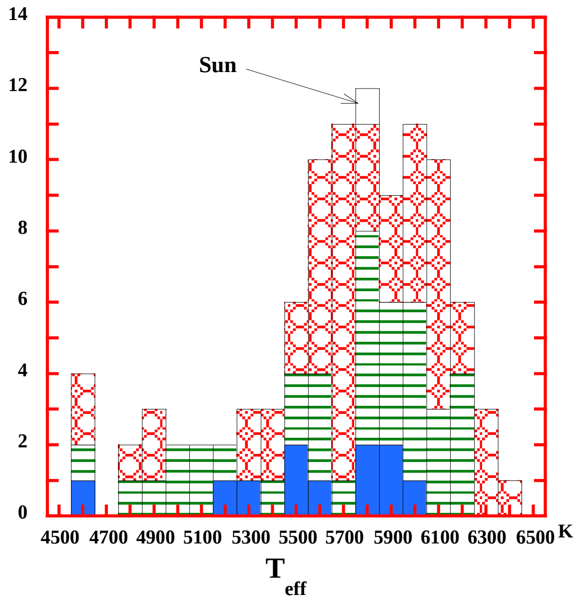

Figure 7. $T_{\rm eff}$ distribution of 99 ESPs+Sun. Black for metal-poor, stripes for metal-normal, circles for metal-rich, white for the Sun.

stars. No doubt that Gaia will drastically change the meager subsample of thick disc stars in ESPs.

Figure 9 analyses the population composition of the EPSs in the ([Fe/H],$V_{\rm rot}$) plane. That allows to clearly identify the thick disc, clearly present in the sample. Note the void for [Fe/H] < -0.2 and $V_{\rm rot} > -30$ km s^{-1}.

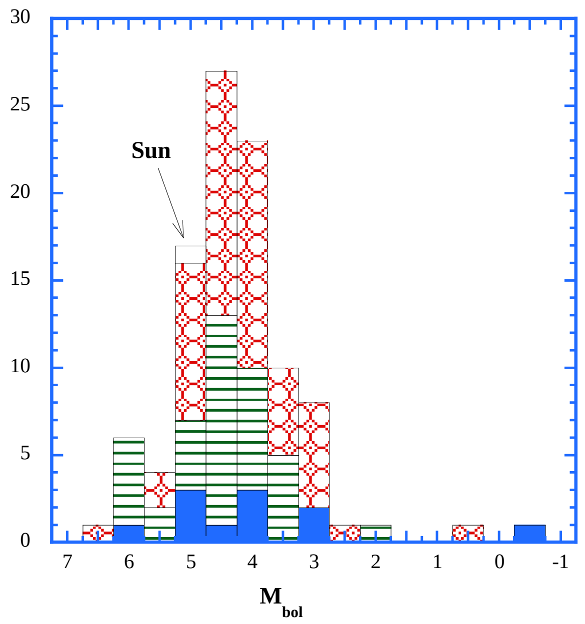

Figure 8. M_{bol} distribution of 99 ESPs plus the Sun. Same as Figure 5 for metallicity code

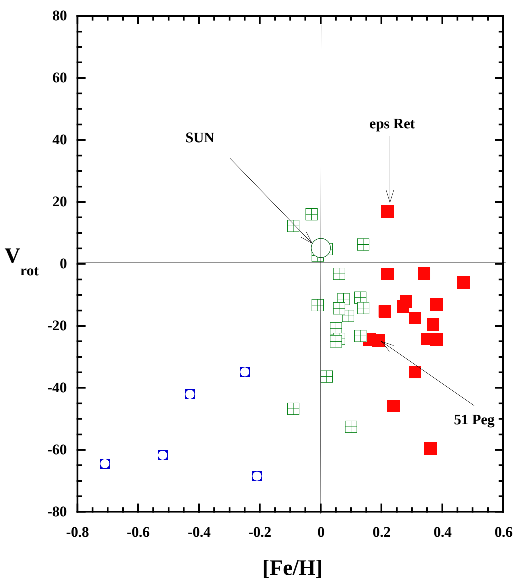

Figure 9. $V_{\rm rot}$ distribution of 99 ESPs+Sun. Metal-poor stars are circles in squares, metal-normal are plus signs in squares and metal-rich are black squares. Note that among metal-rich stars only ϵ Ret has a positive rotational velocity, and that 3 stars have a clear thick-disc kinematics.

5. CONCLUSIONS

• Stars with planets have $T_{\rm eff}$ and $M_{\rm bol}$ strongly peaked around solar values, mostly a selection effect to be traced in the observing programmmes.

• The asymmetry in the metallicity histogram is 72 above [Fe/H] $= 0$ against 26 below, a ratio 2.8 to 1. But, in the general field, the mean metallicity is below [Fe/H] $= 0$, i.e., the Sun is somewhat metal-rich for its age. The asymmetry is then larger with respect to the general population.

• The age distribution of ESPs is bimodal, reflecting the mean age of the thin disc and the presence of an older population.

• The frequency of ESPs in the metal-poor thick disc population is still poorly known, as only 3 or 4 of these stars are identified. But clearly, stars can still form planets down to metallicity [Fe/H] $= -0.7$.

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REFERENCES

Cayrel de Strobel, G., Soubiran, C., Ralite, N. 2001, A&A 373, 159

Lebreton, Y., 2000 ARA&A 38, 35

Mayor, M., Queloz, D., 1995 Nature 378, 355

Nordström, B., Mayor, M., k Andersen, J. et al. 2004, A&A 418, 989

Santos, N.C., Israelian, G., Mayor, M., 2004 A&A 415, 1153

VandenBerg, D.A., Clem, J.L., 2003 AJ 126, 778