Bioastronomy 2007: Molecules, Microbes, and Extraterrestrial Life
ASP Conference Series, Vol. 420, 2009
K. J. Meech, J. V. Keane, M. J. Mumma, J. L. Siefert, and D. J. Werthimer, eds.

Stellar Properties and Rocky Planet Habitability: Is There a Correlation?

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Abstract. The properties of a rocky planet's host star may be associated with the origin of life and the evolution of observers on that planet. By comparing the Sun to other stars in our Galaxy, we may be able to identify such properties. If our Sun is a typical star, stellar conditions appropriate for life, and life itself, may be common in the Universe. On the other hand, if the Sun is atypical or even unique, then the life orbiting the Sun may also be atypical or unique. Here we present the comparison between the Sun and stars for three important parameters that may be associated with the origin and evolution of life. We find that:

i) The Sun is more massive than $95 \pm 2\%$ of nearby stars.
ii) The Sun is younger than $53 \pm 2\%$ of stars in the Galactic disk.
iii) The Sun is more metal rich than $65 \pm 2\%$ of nearby stars.

1. Introduction

Quantifiable relationships should exist between some properties of a host star and the properties of any rocky planets in orbit around it. For example, the ages of a host star and its planets will be nearly identical. The ratios of refractory elements, e.g. Mg/Fe, in a planet will mirror the observable ratio in its host star (Lineweaver and Robles. 2009). It is also plausible that more massive host stars have more massive terrestrial planets.

The relationships between host star properties and the habitability of its orbiting planet are more subtle and difficult to quantify. We only know of one star that harbours a life-bearing planet. However, the hypothesis that there are a number of stellar properties (or combination of properties) that are optimal for the formation of habitable planets, is testable. As an extreme example, if the Sun were anomalously old (let us say the oldest star in the Galaxy) this would suggest that the evolution of observers takes an extremely long time and this would be evidence that observers like us are rare in the Universe (Carter 1983). Nothing as obvious as this example is showing up in our analysis. However, the basic concept is the same.

2. Methodology

By comparing the Solar properties to those of a stellar sample representative of the local stellar population, we hope to identify one or more habitability-related properties. Solar properties showing up as an anomaly are probably correlated with the habitability of the Earth. One must be extremely careful when dealing with statistics of one, for example, if we choose a large number of solar properties, then, any possible anomalous property would fade away when weighted against the number of properties analysed (Robles et al. 2009). If on the other hand we choose only a few parameters in which we know *a priori* the Sun is somewhat of an outlier, the outcome of the analysis would be a foregone conclusion.

Is our current knowledge of the Sun and stars consistent with the idea that the Sun is a typical star? This question has been previously addressed with apparently conflicting results — while Gustafsson (1998) and Allende Prieto (2006) have suggested that the Sun is a typical star, other studies (Gonzalez 1999*a,b*; Gonzalez et al. 2001) have suggested the opposite.

The most delicate part of such an analysis is the selection of an adequate stellar sample for each property. Ideally, the Sun needs to be compared to a large stellar sample free of selection effects — therefore, representative of the 'whole' stellar population for every property. The assembly of such a stellar sample is close to impossible, so great effort should be spent assembling a minimally biased stellar sample for each parameter and quantifying its biases.

3. Results

3.1. How Massive is the Sun?

The mass of a star largely determines its luminosity, temperature, main sequence life-time and circumstellar habitable zone dimensions. Mass is probably the most important property of a star. In Figure 1 we compare the Sun (denoted by "$\odot$") to the 125 nearest stars within 7 parsecs $\sim$ 23 lightyears. The distance limit of the selected stellar sample (RECONS (Research Consortium on Nearby Stars), Henry 2006), permits the observation of the faint end of the stellar population (M-dwarfs) is still observable. The Sun is more massive than $95\pm2\%$ of the stars. The distribution of stars as a function of stellar mass (Initial Mass Function, IMF), is represented by the thick grey line and its associated uncertainty by the hashed-shade (Kroupa 2002). For the IMF, the Sun is more massive than $94 \pm 2\%$ of the stars. There is good agreement between the histogram and the IMF model.

3.2. How Old is the Sun?

The left-hand panel in Figure 2 compares the age of the Sun to two different stellar age distributions: the Milky Way Galaxy and the cosmic stellar ages. The histogram represents the Milky Way Star Formation History (SFH) derived by Rocha-Pinto et al. (2000). The Sun is younger than $53 \pm 2\%$ of the stars in the Galaxy. The grey represents the cosmic SFH with its associated uncertainty (Hopkins and Beacom 2006) — the Sun is younger than $86 \pm 5\%$ of the stars in the Universe. Why are these two distributions so different? Most stars in the Universe reside in elliptical galaxies. These galaxies had initial bursts of star formation, ran out of gas and can no longer form stars. Our Galaxy's SFH, on the other hand, features bursts of star formation as satellite galaxies interacted or fell into the Milky Way.

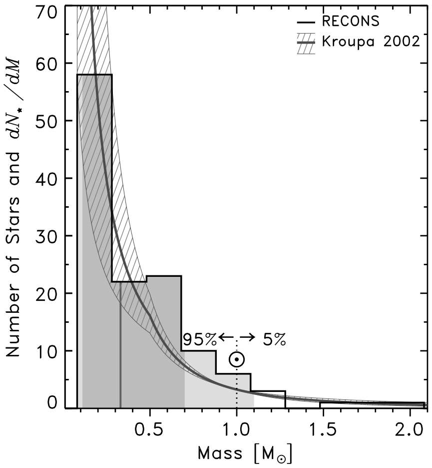

Figure 1. Mass histogram of the 125 nearest stars (RECONS Henry 2006). The median mass ($\mu_{1/2} = 0.33\ M_\odot$) of the distribution is indicated by the vertical grey line. The 68% and 95% confidence intervals around the median are indicated by the vertical dark grey and light grey bands respectively. We also use these conventions in Fig. 2. The solid curve and hashed area around it represents the IMF and its associated uncertainty (Kroupa 2002). The Sun, indicated by "$\odot$", is more massive than $95 \pm 2\%$ of these stars.

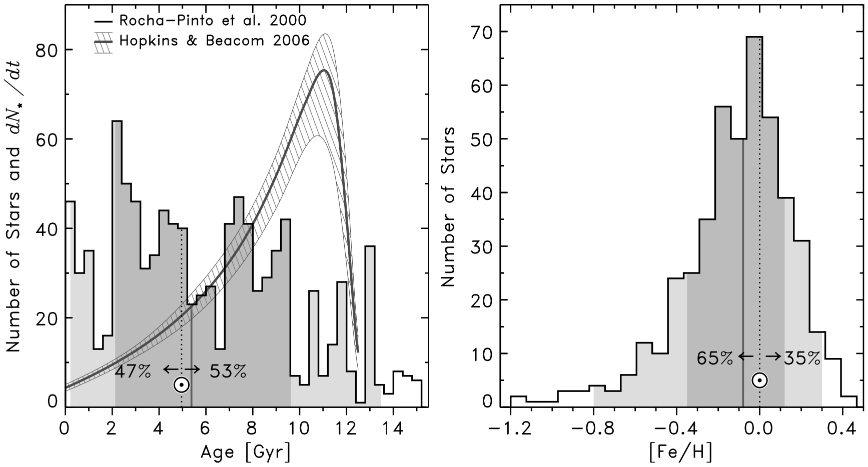

Figure 2. Left-hand panel: The galactic stellar age distribution from Rocha-Pinto et al. (2000). The Sun is younger than $53 \pm 2\%$ of the stars in the Galaxy. The median age is $\mu_{1/2} = 5.4$ Gyr. In contrast to the Galaxy's stellar ages, the cosmic SFH (Hopkins and Beacom 2006), indicates that the Sun is younger than $86 \pm 5\%$ of the stars in the Universe. Right-hand panel: Stellar metallicity histogram of the 453 FGK *Hipparcos* stars within 25 pc (Grether and Lineweaver 2007). The median metallicity $\mu_{1/2} = -0.08$. The Sun is more metal-rich than $65 \pm 2\%$ of the stars.

3.3. How Metal Rich is the Sun?

The heavy element content of a star is related to its ability to form planets. The abundances of oxygen, carbon and refractory elements scale approximately with iron abundance ([Fe/H]). Therefore, a star's [Fe/H] abundance has a direct impact on the abundances of elements that determine planet characteristics, e.g. heat budget provided by radioactive elements. The right-hand panel in Figure 2 shows the stellar metallicity distribution of 453 F,G and K stars within 25 parsecs $\sim$ 80 lightyears (Grether and Lineweaver 2006). The Sun is more metal rich than $65 \pm 2\%$ of these nearby stars.

4. Discussion

In our search for extrasolar worlds, we want to know how special are stars with habitable planets. Comparing the Sun to other stars can be used as a fishing expedition for any property that may be associated with the prerequisites for life. Astrobiological constraints on life requirements and their relation with stellar parameters will enable us to follow up any candidate parameter this study may uncover.

Acknowledgments. We would like to thank Mount Stromlo Observatory at The Australian National University, the Bioastronomy 2007 and ABGradCon local organising committee for travel support. Special thanks to Karen Meech.

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