BETA HYDRI (G2 IV): A REVISED AGE FOR THE CLOSEST SUBGIANT

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ABSTRACT

The secular evolution of solar-type atmospheres may be studied through comparisons of the current Sun with old solar-type stars of known age. Among the few such stars in the solar Galactic neighborhood, β Hydri (G2 IV) stands out as a normal single star with an advanced age. Previous age determinations ($\simeq$ 9.5 Gy) were based on the old ground-based parallax of 153 mas. The new Hipparcos value of 133.78 ± 0.51 mas implies an absolute magnitude $M_V = 3.43 \pm 0.01$, 0.3 mag brighter than previously believed. New evolutionary calculations produce best-fit models with ages around 6.7 Gy. Although the Hipparcos data thus lead to a significant reduction of its age, β Hyi remains an old star.

Key words: space astrometry; stars: evolution; stars: individual; stars: late-type.

1. INTRODUCTION

How do solar-type atmospheres evolve along with the stellar evolution? Will the Sun still have a magnetic activity cycle billions of years in the future, after it has left the main sequence? Answers to questions such as these may be found by studying old solar-type stars, taken to represent the future Sun. Such stars must have reliable age determinations, and be bright enough for detailed spectroscopy. Among old and single stars, accurate age determinations are possible for G subgiants that have evolved slightly off the main sequence, yet are still sufficiently close to it to avoid ambiguities in stellar evolutionary tracks.

The closest and brightest ($m_V = 2.8$) among such stars in the solar Galactic neighborhood is *β Hydri* (HR 98; HD 2151; HIP 2021), of spectral type G2 IV. Detailed studies of its photospheric structure, chromospheric and transition zone emission, and of coronal X-ray fluxes have been made, making β Hyi one of the best-studied individual stars other than the Sun (Dravins et al. 1993a,b,c; Dorren et al. 1995; Güdel et al. 1997).

2. BETA HYDRI — THE STAR

The characteristics of β Hyi are typical of the old Galactic disk population: e.g. a feeble chromospheric activity and an eccentric Galactic orbit. As expected for an old star, β Hyi is slightly metal poor, with log Fe/H determinations relative to the Sun around -0.2. While the abundances of heavier metals are low, lithium is abundant (a signature shared with other older subgiants), permitting analyses of stellar internal evolution in the post-main-sequence stages. Various determinations set the effective temperature to 5800 ± 100 K, equal to the commonly accepted value for the Sun of $T_{\rm eff} = 5780 \pm 30$ K. For a review of the basic stellar parameters, see Dravins et al. (1993a).

3. HIPPARCOS OBSERVATIONS

Hipparcos data (ESA 1997) for β Hyi give the parallax 133.78 ± 0.51 mas. The proper-motion measurements indicate a steady stellar motion, with no indications of duplicity or other irregularities. The photometry gives $Hp = 2.9305 \pm 0.0003$ mag, which for $V - I = 0.68$ mag corresponds to $V = 2.801$ mag, as transformed to the Johnson system. This is fully consistent with the Hipparcos input catalogue value of $V = 2.82$ mag. No photometric variability could be detected by Hipparcos, with an upper amplitude limit of $\simeq 0.004$ mag.

4. BETA HYDRI — THE AGE

4.1. The Previous Old Age

The age of β Hyi was previously determined by modeling evolutionary tracks across its location in the Hertzsprung-Russell diagram, as inferred from its parallax measured early in this century. The *General Catalogue of Trigonometric Stellar Parallaxes* listed the absolute parallax as 153 ± 10 mas (standard error, probable error 7 mas; Jenkins 1952). After incorporating some additional observations, this value was slightly modified to 150.1 ± 7.2 mas in the latest edition (van Altena et al. 1995).

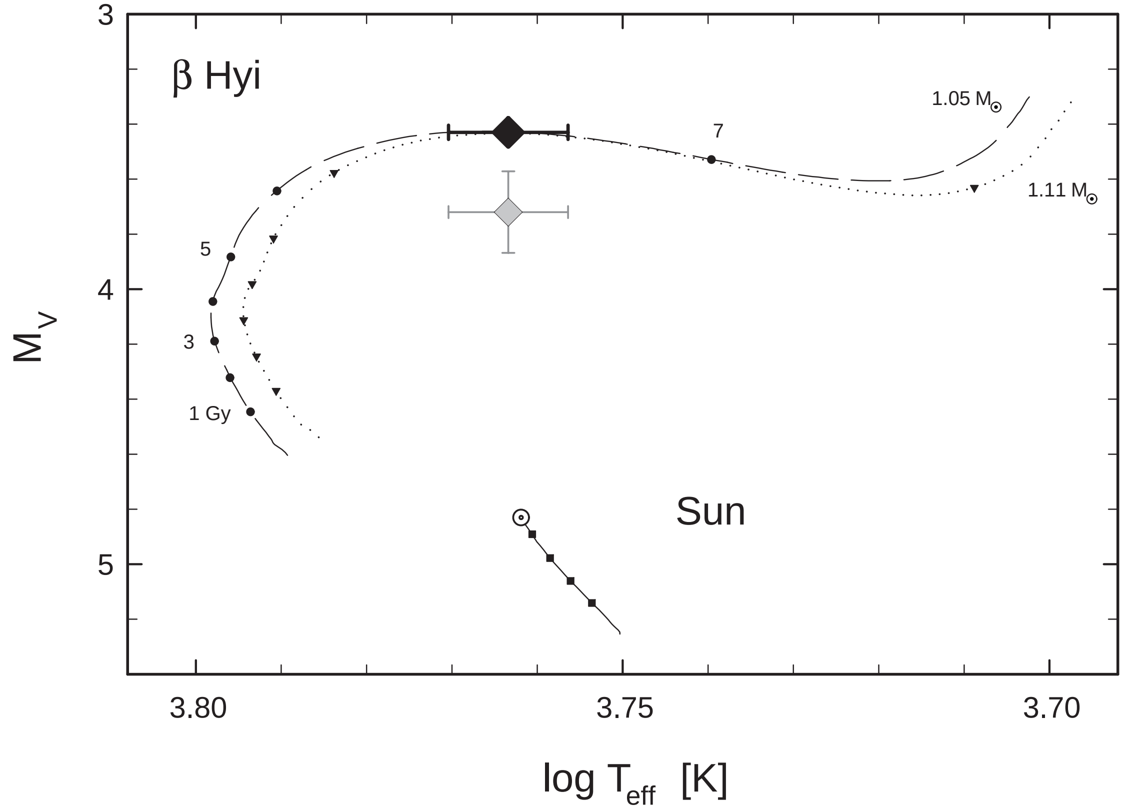

Figure 1. Stellar evolution, and the age of Beta Hydri. Post-main-sequence tracks are shown for two representative models, passing through the post-Hipparcos position of β Hyi in the M_V/log $T_{\rm eff}$ plane (black diamond). The position based on the old ground-based parallax is also marked (grey diamond). At bottom, a track for a solar model (evolved until 4.6 Gy) demonstrates that the present solar luminosity and temperature are accurately reproduced for the adopted model parameters.

The most detailed previous age determination gave values around 9.5 Gy (Dravins et al. 1993a). Also earlier work had arrived at ages in the 8–10 Gy range: Cayrel de Strobel 1981; Hearnshaw 1972, 1973; Perrin et al. 1977. Such an age fits well with that estimated for the Galactic disk. The main observational uncertainty was due to the parallax error, while errors in $T_{\rm eff}$ play almost no role since β Hyi is rapidly evolving nearly horizontally in the HR diagram.

4.2. The New Old Age

The availability of the new, and very much more accurate, parallax from Hipparcos now permits a more precise determination of the evolutionary status for β Hyi. The significance of such a new determination lies also in that the Hipparcos value rather significantly (by two standard errors) deviates from the previous ground-based estimate. The Hipparcos parallax yields the absolute magnitude $M_V = 3.43{\pm}0.01$, some 0.3 mag brighter than previously believed.

New evolutionary calculations have been made, using a considerably improved version of the program code used in previous calculations (VandenBerg 1992; Dravins et al. 1993a; and references in these papers). This new version uses recent OPAL opacities (Rogers & Iglesias 1992) for the Noels & Grevesse (1993) mix of elements, and the same nuclear reaction rates as in standard solar models (Bahcall & Pinsonneault 1992; Guenther et al. 1992a, b). It incorporates low-temperature opacities similar to those reported by Alexander & Ferguson (1994), and an equation of state with Coulomb corrections and other non-ideal effects; see VandenBerg et al. (1997) for a detailed discussion of the adopted physics. (These improvements lead to a solar helium abundance $Y \simeq 0.27$ rather than $\simeq 0.28$, when the Coulomb interaction is ignored.) As before, the effective temperature was adopted as 5800 K.

A number of evolutionary tracks were computed, a few of which are shown in Figure 1. As a model verification, a track for a standard solar model shows that the present luminosity ($M_{\rm bol} = 4.72$; $M_V = 4.84$) and temperature of the Sun are accurately reproduced for the adopted choices of Y and mixing-length parameter.

Models were computed for the slightly different metallicities $Z = 0.0100$, 0.0125, and 0.0150, with the same Y as needed to fit the Sun. Another model for $Z = 0.0125$ had a helium abundance lower by $\Delta Y = 0.01$. The four models assume masses that are necessary, for the various choices of Z and Y, to intersect the position of β Hyi in the $M_V/\log T_{\rm eff}$ plane. The choices of Z should encompass the true metallicity (corresponding to the logarithmic values relative

Table 1. Interpolating in the tracks at the $(M_V, T_{\rm eff})$ value of β Hyi, one finds the ages [Gy].

Z	Y	[Me/H]	Mass	Age
0.0100	0.2716	−0.28	1.053	6.83
0.0125	0.2716	−0.20	1.095	6.52
0.0150	0.2716	−0.10	1.228	6.31
0.0125	0.2616	−0.20	1.109	6.64

to hydrogen [Me/H] $\simeq -0.28$, -0.20, and -0.10, respectively). Interpolating in the tracks for the age at the $(M_V, T_{\rm eff})$ value of β Hyi, one finds (Figure 1 and Table 1) that best-fit models have parameters around: mass = 1.1 $\mathcal{M}_\odot$; $Y = 0.27$, $Z = 0.011$ (corresponding to a metallicity log [Me/H] around -0.2); $T_{\rm eff} = 5800$ K, and ages around 6.7 Gy.

In Figure 1, the superposed symbols mark every billion of years, starting from the pre-main-sequence zero age. The long-dashed curve is for a model with mass = 1.053 $\mathcal{M}_\odot$, the dotted one for 1.109 $\mathcal{M}_\odot$, with metallicities log [Me/H] = -0.28, and -0.20, respectively. Interpolating these two tracks for the β Hyi position, one finds ages of 6.83 and 6.64 Gy.

5. CONCLUSIONS

Although the stellar luminosity implied by the new Hipparcos parallax leads to a significant reduction of the age (and a slight increase in mass), compared to previous estimates, β Hyi does remain an old star.

Since the evolutionary tracks near the position of β Hyi in the $M_V/\log T_{\rm eff}$ diagram run nearly horizontally, the exact value for its effective temperature has almost no effect on its inferred properties. This is indeed why β Hyi is such an attractive star to study: there is probably no other *single* star (besides the Sun), for which it is possible to determine such a precise mass and age (and further improvements will now require a more precise determination of its metallicity).

As a final caveat, we note that all the above discussion is performed within the paradigm of stellar evolutionary models, as calibrated before Hipparcos. In case Hipparcos data would systematically change, e.g. the future calibration of stellar luminosities, that might lead to revisions of stellar evolution modeling, and perhaps also affect age determinations.

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