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LETTER

Letter to the Editor

β Pictoris revisited by Hipparcos

Star properties.*

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Abstract. Observations with the Hipparcos satellite allowed a new determination of the β Pictoris distance. This star is located at 19.28 $\pm$ 0.19 pc, a value close to the upper limit of previous evaluations. The overall consequences are briefly discussed; in particular it is concluded that in the frame of standard stellar evolution models, there is no need for any intrinsic circumstellar extinction due to the dust disk to explain its position in the HR diagram. The star is very close to the ZAMS, or on the ZAMS, suggesting it is old enough to possess a well-formed planetary system.

Key words: Stars: circumstellar matter – Stars: β Pictoris

1. Introduction.

β Pictoris (HIP 27321) has been the subject of many investigations since its discovery as an IR excess star by the IRAS satellite (Auman et al., 1984), closely followed by the imaging of a circumstellar (CS) disk of dust (Smith & Terrile, 1984) seen nearly edge-on from the Earth.

The very large amount of observations of both the dust and the associated gas disk allowed the development of some modelisations of the disk, including a debate on its age. This is related to the question of its evolutionary status, i.e. is the observed disk a remnant of a "proto-planetary" circumstellar disk, or is on the contrary its evolutionary stage more advanced so that planets may have already formed (see reviews by Backman & Paresce, 1993; Vidal-Madjar & Ferlet, 1994; Artymowicz, 1997 and the Proceedings of the 10th IAP Meeting, 1994).

Because the gas to dust ratio is observed to be small, the life time of small grains has to be very short in such a system due to radiative blow out of grains not slowed down by any gas drag (Artymowicz, 1988). This in fact naturally explains why dust grains are large in the β Pictoris disk as deduced from the disk colour similar to the stellar one as well as from the non wavelength dependent extinction observed in the UV by Kondo & Bruhweiler (1985).

Due to this short life time, a permanent source of particles is certainly needed, eventually linked to the presence of larger and thus more stable bodies in the system. The disk is thus probably a relatively evolved one, in which large bodies may have already formed like planetesimals or comets (see e.g. Lagrange-Henri et al. 1987; Ferlet et al. 1987; Beust et al. 1989, 1990; Deleuil et al. 1993; Vidal-Madjar et al. 1994) or even larger ones as planets (Beust et al. 1991b; Roques et al. 1994; Lagage & Pantin, 1994; Artymowicz, 1994; Lecavelier des Etangs et al. 1995; Burrows et al. 1995; Beust & Morbidelli, 1996; Mouillet et al. 1996).

It turns out that the evolutionary status of the system is an important parameter to evaluate. The age of β Pic has been evaluated from studies of the star *per se*, but no clear conclusion was reached (see Paresce, 1991; Gerbaldi et al. 1993; Holweger & Rentsch-Holm, 1995; Lanz et al. 1995, hereafter LHH; Brunini & Benvenuto 1996).

The purpose of this letter is to present the new Hipparcos measurement of the β Pictoris parallax, leading to a more precise evaluation of the star distance and then of the luminosity of the star. Section 2 deals with Hipparcos observations. In Sections 3 to 6, we discuss the position of the star in the HR diagram, as well as the consequences on the circumstellar extinction. The age of the star is also discussed by comparison with stellar evolutionary tracks.

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* Based on observations obtained with the Hipparcos satellite

Table 1. Previous and new β Pictoris parameters (π, parallax in mas (10^{-3} arc-sec); d, distance in pc; M_v, absolute magnitude). Authors: VA = Van Altena et al.; Lanz = Lanz et al. (1995) (Bright Star Catalogue value); Hipp = Hipparcos 96.

Authors	π	σ_π	d	M_v
	mas	mas	pc	
VA 95	60.1	10.6	$16.6^{+3.6}_{-2.5}$	$2.74^{+0.36}_{-0.42}$
Lanz	61		16.4	2.78
Hipp	51.87	0.51	$19.28^{+0.19}_{-0.19}$	$2.42^{+0.03}_{-0.02}$

2. Hipparcos Observations.

During the three years of the Hipparcos ESA mission, β Pic was observed 102 times. After reduction, the final parallax is:

$$\pi_{Hipp} = 0.05187 \pm 0.00051 \text{ arc-sec}$$

This value is somewhat smaller than the ones derived before (see table 1). The star is therefore more distant and luminous than previously estimated.

3. Simple geometrical consequences.

This new evaluation of the β Pic distance has straightforward consequences: with respect to the Bright Star Catalogue value (d_{HR}), all previous geometrical dimensions have to be multiplied by a factor d_{Hipp}/d_{HR} =1.176. Some consequences of this distance modification are underlined here although such a correction does not induce any fundamental change in our present understanding of the disk.

The disk is somewhat more extended and detected up to 1400 AU instead of 1200 AU as quoted by Smith and Terrile (1984). The change of slope in the inner regions takes place around 120 AU instead of 100 AU (Golimowski et al. 1993), and the central hole is of about 35 AU instead of the 30 AU as often quoted ((Smith & Terrile, 1984; Dinner & Appelby, 1986; Artymowicz et al. 1989; Lagage & Pantin, 1994; Artymowicz, 1994; Lecavelier des Etangs et al. 1996).

4. The β Pictoris absolute luminosity.

From the knowledge of the distance and photometry, it is possible to deduce now the absolute bolometric magnitude M_{bol} of β Pic . As well as all dimensions have to be multiplied by a factor 1.176, the flux emitted by the star should be multiplied by 1.38 for comparison with earlier data. Thus, the previous absolute magnitudes have to be decreased by 0.35.

Following LHH, we use the observed visual magnitude, $V = 3.85$, also derived from the Hipparcos photometry. We thus obtain the revised absolute magnitude:

$$M_v = 2.42 \pm 0.03$$

The absolute magnitude is then obtained by adding the so-called "bolometric correction" BC. LHH used BC=-0.15, a typical value for an A5V star (spectral type of β Pic as given by Houk(1978)), as may be found in Schmidt-Kaler (1982). This BC gives:

$$M_{bol} = 2.42 - 0.15 = 2.27$$

The accuracy of this BC in terms of spectral type is rather rough. A new approach has been developed very recently by Bessell et al (1997). They computed a grid of stellar fluxes covering an extended range of T_{eff}, log g and metallicity using recent model atmospheres; and from the grid they computed the bolometric correction. For the Sun they used $BC_\odot$ = -0.07, which is consistent with $M_{bol\odot}$ = 4.75. For T_{eff} = 8200 K and log g = 4.25 (LHH values) they obtain: BC = +0.01, leading to:

$$M_{bol} = 2.42 + 0.01 = 2.43$$

We will adopt this value for the absolute bolometric magnitude of β Pictoris .

Alternatively, we can follow the Gerbaldi et al. (1993) approach and scale their evaluation of the β Pic absolute luminosity by the factor 1.38. (they also used the HR distance of 16.4 pc). Their initial value ($\log(L/L_\odot)$ = 0.800) becomes now: $\log(L/L_\odot)$ = 0.94, or $L/L_\odot$ = 8.7. For the computation of M_{bol}, we need the value of $M_{bol\odot}$. We have chosen the very recent value given by Cayrel (1996) $M_{bol\odot}$= 4.75. This gives M_{bol} = 2.40.

Note that this determination of M_{bol} is totally independent of the previous one, and leads to a similar result. It should however be noted that this bolometric magnitude is for an A8V type star, according to the calibration of Schmidt-Kaler (1982). We shall not discuss this discrepancy further on, due to the fact already underlined that the calibration in term of spectral type needs for sure to be revised using the Hipparcos distances.

5. The β Pictoris temperature and age.

In order to evaluate the age of β Pictoris it is necessary to locate the star in a M_{bol} or $\log(L/L_\odot)$ versus log T_{eff} diagram in which stellar evolutionary tracks are presented. The question is then the evaluation of the effective temperature T_{eff}. This has been done by Gerbaldi et al. (1993) and by LHH through different techniques.

On one hand, Gerbaldi et al. (1993) deduced the effective temperature following the iterative "infrared flux method" first developed by Blackwell and Shallis (1977), combining visual and near-IR observations (13-colour photometry of Johnson & Mitchel (1975)), UV fluxes obtained by the TD1 satellite, and classical LTE line-blanketed atmospheric models (Kurucz, 1990). They obtained initially T_{eff} = 7610 K. However, they used models having a metal abundance [Z/H] = -1.0 which produces a lower value for T_{eff} than a solar abundance. LHH showed the metallicity to be most likely very close to the solar one. For this metallicity, the above method leads to about 8200K.

On the other hand, LHH followed a more classical approach based on the use of two independent photometric systems, the Geneva one (Kobi & North, 1990) and the Strömgren one (Moon & Dworetsky , 1985). They found T_{eff} = 8200 $\pm$ 150 K, and log g = 4.25 $\pm$ 0.1.

According to R. Faraggiana (private communication), the profile of the hydrogen Hγ line obtained with a resolving power of 26000 is well fitted, except at the very center of the line, by a profile computed from the latest Kurucz models (1993, CD-

Rom 13 and 18) with T_{eff} = 8200 K, log g = 4.2 and solar abundances. At such a temperature the Hγ line profile is sensitive essentially to T_{eff}, whereas a change by 0.5 in log g makes no difference.

Therefore, in the following we will adopt for the β Pic effective temperature:

$$T_{eff} = 8200 \text{ K}$$

In order to discuss the position of β Pic in the HR diagram we need evolutionary tracks for pre- and post-main sequence evolution. We selected those of Palla & Stahler (1993) for the pre-main sequence, and those of Schaller et al. (1992) for the evolution from the zero age main sequence line (hereafter ZAMS).

Fig. 1 shows a M_{bol} versus log T_{eff} diagram in which we have located the new position of β Pic as well as the one of LHH. It is clear that the new point falls very close to the ZAMS. According to the uncertainties on both the values on the star parameters and the evolutionary tracks, we can consider that β Pic is on the ZAMS or extremely close to it.

From comparison with the evolutionary tracks the mass of β Pic is around 1.7–1.8 $M_{\odot}$, in good agreement with previous estimates (see e.g. LHH).

We have estimated the gravity log g for 1.75 $M_{\odot}$, after having inferred the radius from the luminosity (log($L/L_{\odot}$) = 0.94) and the effective temperature. This gives log g = 4.38, a value in agreement with the one adopted by LHH and determined from the photometry: log g = 4.25 $\pm$0.1. The difference can originate from any uncertainty in the calibration of the photometric system as well as from the calculations of the evolutionary models.

As a conclusion β Pic is on the ZAMS and there is no contradiction between the various parameters determined either from observations or from the location of the star in the HR diagram.

According to the computations of Palla and Stahler (1993) the duration of the pre-main sequence phase is more than 0.8 10^7 years for stars with a mass of the order ot β Pictoris . Because the star is so close to the ZAMS, it is not possible to give an accurate upper limit on its age. Therefore, all we can conclude is that the star is at least 0.8 10^7 years old. This value relies mainly on the computation of Palla and Stahler (1993).

6. The β Pictoris circumstellar extinction.

From the very early observations, Smith & Terrile (1984) claimed a 0.5 magnitude extinction. It was however mentioned that the average A5V stellar absolute magnitude they had used was erroneous (Diner & Appelby, 1986), showing that this high 0.5 magnitude extinction was certainly an over estimated value. LHH have derived a high minimum extinction (0.3–0.5), based on the apparent location of β Pic well under the ZAMS.

With the new Hipparcos distance, this constraint is removed. This is in better agreement with later more model-dependent studies, some fitting simultaneously the disk diffuse starlight along with the observed IR excess (e.g., Diner & Appelby, 1986; Artymowicz et al. 1989) as well as global modelisations of the disk (Backman & Paresce, 1993; Artymowicz, 1994; Kalas & Jewitt, 1995; Lecavelier des Etangs et al. 1996), which all lead to a very low dust extinction (0.1 magnitude or less). Such a value is totally consistent with our new position of β Pic on the ZAMS. It thus appears that the Hipparcos distance provides a much more reasonable agreement between observations and predictions of the circumstellar dust disk extinction.

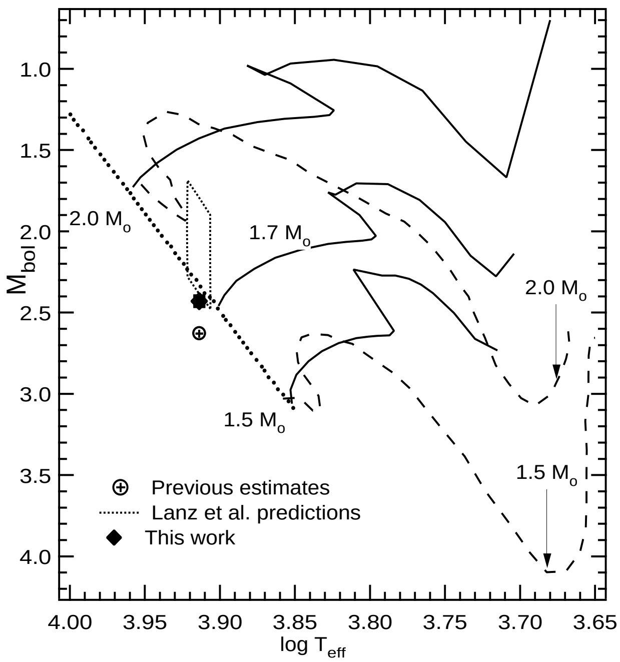

Fig. 1. The location of β Pic on the HR diagram. Solid lines: post-main sequence tracks of Schaller et al. (1992); dashed lines: pre-main sequence tracks of Palla and Stahler (1993).

7. Conclusion.

The new precise evaluation of the β Pic distance from the Hipparcos satellite is:

$$19.28 \pm 0.19 \; pc$$

The revised absolute and bolometric magnitudes are :

$$M_v = 2.42 \pm 0.03 \text{ and } M_{bol} = 2.43.$$

A value of M_{bol} = 2.40 is also obtained from a direct estimation of the luminosity of the star. The revised location in the HR diagram is close to or on the ZAMS and the need for a circumstellar extinction vanishes. It becomes possible to reconcile the model disk predictions, the absence of reddening and the stellar parameters.

The star age seems to be also well compatible with our present understanding of the dust disk, because β Pictoris is found to be older than 0.8 10^7 yrs. Such an age is compatible with the possibly existing planetary system around β Pic .

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