The Age of β Pictoris

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The Age of Beta Pic[1]

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[1]Based on observations collected by the Hipparcos satellite

ABSTRACT

We have reanalyzed data for the proposed moving group associated with β Pictoris in order to determine if the group (or part of it) is real, and, if so, to derive an improved age estimate for β Pic. By using new, more accurate proper motions from PPM and Hipparcos and a few new radial velocities, we conclude that on kinematic grounds most of the proposed members of the moving group are not, in fact, associated with β Pic. However, two M dwarfs - or three, actually, since one of them is a nearly equal mass binary - have space motions that coincide with that of β Pic to within 1 km/s with small error bars. Based on a color-magnitude diagram derived from accurate photometry and Hipparcos parallaxes, these two possible proper-motion companions to β Pic are very young; we derive an age of $\sim$20 Myr by comparison to theoretical tracks from D'Antona & Mazzitelli. In fact, the proposed β Pic companions comprise two of the three youngest M dwarfs in the sample of 160 dM stars for which we have data. The chromospheric and coronal activity of these two stars also confirm that they are quite young. We argue that the probability that two of the three youngest nearby M dwarfs would accurately share the space motion of β Pic by chance is quite small, and therefore we believe that β Pic and the two M dwarfs (GL 799 and GL 803) were formed together. The estimated age for β Pic is then 20$\pm$10 Myr, where the uncertainty in the age arises primarily from possible errors in the PMS isochrones and in the conversion from color to effective temperature. This young age for β Pic supports the contention that the IR-excess for the Vega-like stars is age dependent.

Subject headings: circumstellar matter – stars: kinematic – stars: individual (β Pic)

1. Introduction

This is the fourth paper in a series devoted to the ages of Vega-like stars. This is achieved by finding late type stars physically associated to them. Then, several time-dependent properties are analyzed and an age is derived. Stauffer et al. (1995) studied the secondary of HR4796, a conspicuous Vega-like star discovered by Jura (1991). They concluded that the binary is remarkably young (8±2 Myr). More recently, Barrado y Navascués et al. (1997) focused on Fomalhaut. The physical association with the late type star GL 879 served to constrain the age to 200±100 Myr. The realization of the fact that Fomalhaut shares its Galactic movement with other stars, including Castor and Vega, produced another determination of the age, 200±100 Myr (Barrado y Navascués 1998).

Vega-like stars show large IR excesses originated in dusty circumstellar disks, which are thought to be the remnants of the T Tauri disks or a consequence of the formation of planets (see Backman & Paresce 1993). Until the discovery of the first extra-solar planet by Mayor & Queloz (1995), they provided some of the best evidence for the presence of planetary systems outside of our own. There has been much recent progress on these systems in terms of understanding the structure of their disks (Jura et al. 1998; Jayawardhana et al. 1998; Koerner et al. 1998; Greaves et al. 1998; Schneider et al. 1999), spectral distribution (Zuckerman & Becklin 1993; Holland et al. 1998; Fajardo-Acosta et al. 1998) and evolution (Zuckerman et al. 1995; Thakur et al. 1997; Song et al. 1998). However, it is still true that accurate ages for these systems are still in considerable short supply. In this paper, we provide what we believe to be an accurate age for β Pic.

2. A common origin based on the kinematic properties

Following Barrado y Navascués (1998), we selected an initial list of possible β Pic companions from Agekyan & Orlov (1984), which provides a extensive search of kinematic groups. We also included stars from Soderblom (1990), Poveda et al. (1994) and Tokovinin (1997). Then, we computed the Galactic components of these stars using equatorial coordinates, parallaxes, proper motions –the Hipparcos (ESA, 1997) and PPM (Bastian & Roeser 1993; Roeser & Bastian 1994) catalogs– and the radial velocities (Duflot et al. 1995). For β Pic itself, we used the values derived by Lagrange et al. (1995) and Jolly et al. (1998), based on HST/GHRS spectra of narrow absorption lines of Fe and CO (thought to be due to stationary circumstellar gas but external to its disk). Of the initial stars selected, only six have space motions within 2 sigma of that of β Pic to be at all plausible companions. Tables 1 and 2 provide various data for these stars and the dynamics. The UVW components of the Galactic velocity were computed following Johnson & Soderblom (1987), using PPM proper motions. Similar results can be computed with Hipparcos. We have used these data for two different purposes: First, we have tried to verify if indeed these stars are physically associated. Second, using several properties of the late type stars, we have estimated the age of the moving group.

The V component imposes the strongest constraint to determine whether a group of stars are associated (Soderblom & Mayor 1993). V should correspond to a drift rate which would lead to a secular increase in separation between two given stars (as opposed to U or W components, where a difference in current velocity may not matter, because stars oscillate in those directions). Since 2 km/s is about 2 pc/Myr, two stars whose space motion differed by that amount would separate by 40 pc in 20 Myr (our final estimation of the age of β Pic). Therefore, they could not both have been born in the same place 20 Myr ago and now both be within 20 pc of the Sun. Given the accuracies to which we can

estimate the space motions of our selected stars, we believe that GL 97 can be rejected as a possible companion to β Pic. If we use the PPM proper motions, it has too large a difference in the V component; if instead, we adopt the Hipparcos proper motions, then the U velocity differs by an amount (>8 km/s) that is too large. There are other spectroscopic reasons to also believe that GL 97 is too old to be a possible companion to β Pic (Pasquini et al. 1994). We also choose to exclude GL 601 from further consideration because we have no observational data that allows us to usefully estimate its age. In the next section, we will examine age estimates for Beta Pic and for the remaining four stars in order to try to establish whether any of them appear to be coeval.

3. The age of β Pic

3.1. Isochrone Fitting for β Pic Itself

Isochrone fitting for β Pic has been previously attempted, yielding an age of 100 Myr (Backman & Paresce 1993). Lanz et al. (1995), using the same procedure, concluded that an age around 12 Myr or larger than 300 Myr would be possible, although they judged the first value as the most likely. From Figure 2 of Brunini & Benvenuto (1996), which represents evolutionary tracks, an age between 20 and 40 Myr could be inferred. Finally, Crifo et al. (1997), using Hipparcos data, confirmed that the star is very close to or on the ZAMS, and it is older than 8 Myr. All these studies show that this technique is not very restrictive and the age of β Pic remains uncertain.

3.2. Isochrone Fitting for the Possible Companions of β Pic

The photometry of late type stars can provide accurate ages, if they are cool and young enough to be in the PMS phase, by comparison with isochrones. We have compared

the four candidate β Pic companions to PMS isochrones from D'Antona & Mazzitelli (1997, priv. comm.=DM97), where we have used a color-temperature conversion based on requiring the DM97 125 Myr isochrone to coincide with the main-sequence locus of stars in the Pleiades (c.f. Stauffer et al. 1995; Stauffer 1998). In order to place our four candidate β Pic companions in context, we also include in this figure all of the nearby M dwarfs for which Leggett (1992) has compiled accurate photometry and which have parallaxes from Hipparcos with $\sigma(\pi)/\pi < 0.10$. For binary stars where it is known that the two components are nearly equal in brightness (including GL 799), we have added 0.75 mag to the M_V in order to correct the binarity effect; for know binaries with unknown mass ratios, we plot the star as an open diamond symbol but do not correct the M_V. Clearly, GL 799 and GL 803 are among the brightest stars, compared with stars of the same color, in the solar neighborhood. That is, they are very young. In fact, the three youngest objects in Figure 1 are GL 182, GL 799 and GL 803. GL 182 is known to be a very young, dMe star (Favata et al. 1998); its kinematics indicates that it is not, however, moving with the same space motion of GL 799 and 803, so we do not consider it further. Within the errors, the locations of GL 799 and 803 in Figure 1 are consistent with their having the same age (20 Myr). GL 781.2 and GL 824 appear to be older, with ages formally consistent with being 40 Myr. However, because they are higher mass objects and their displacement above the ZAMS is less, their locations in Figure 1 are actually consistent with any age up to several hundred Myr given uncertainties in their photometry and metallicity and the placement of the isochrones into the observational plane. We provide evidence in the next section that GL 824, at least, is quite old (> 600 Myr), and unlikely to be physically connected to β Pic.

3.3. Stellar activity

Stellar activity, a consequence of the presence of magnetic fields in late–type stars (due to the combination of the rotation and convection, or dynamo effect), is a well studied phenomenon. Because of main sequence angular momentum loss, the rotation rates of low mass stars decline with age - and hence activity levels also decline with age (e.g., Stauffer 1988). We can use measures of stellar activity, therefore, as proxies for age in an attempt to identify which of our candidate stars might be coeval with β Pic. Figure 2 depicts the X-ray luminosity against (B–V). In panel a, crosses represent ROSAT All Sky data (Hünsch et al. 1999) for the Gliese stars. In panel b, Pleiades and Hyades stars appear as open and solid symbols, respectively. Clearly, the X-ray luminosity of GL 824 is relatively low, even compared to that of the stars in the Hyades (age$\sim$600 Myr); we infer from this that GL 824 is older than the Hyades. Based on its location in a CM diagram, β Pic cannot be as old as 600 Myr, and therefore the X-ray data provide strong evidence that GL 824 is older than β Pic. On the other hand, the activity of GL 803 and GL 799 is very high, consistent with the young ages deduced from their position in the CM diagram. Unfortunately, there is no published X-ray for GL781.2, and we cannot further constrain its age at this time.

3.4. Summary of Age Constraints

Using the best available data, analysis of the location of β Pic in a CM diagram only allows one to conclude that its age is somewhere between a few million and a few hundred million years. Of the four late type stars whose kinematics match that of β Pic, GL 824 is removed from contention because its activity indicates it is older than the maximum age for β Pic. GL 781.2 is essentially unconstrained in its age due to a lack of activity data and due to its early spectral type (precluding an accurate HR diagram age. However, the other two candidates have a well-constrained age from their location in a CM diagram, have

activity levels consistent with that age, and share the motion of β Pic to within 1 km/s. We believe, therefore, that the age derived for these stars from PMS isochrones - 20±10 Myr - is the best estimate for the age of β Pic. The spatial location of the three stars is compatible with this age and the derived relative space motions. We note that Poveda et al. (1994) has previously identified GL 799 and GL 803 as being likely siblings - we are now simply adding β Pic as their bigger brother.

4. The Correlation of IR Excess and Age for β Pic Stars

In their comprehensive review of the Vega phenomenon, Backman & Paresce (1993) described specifically the evolutionary status of the three prototypes, β Pic, Vega and Fomalhaut, estimating their ages as 100, 200 and 400 Myr, respectively. Several studies have tried to relate these ages with different properties which appear as a consequence of the presence of circumstellar disks, in order to see if there is an evolutionary sequence. For instance, Fig. 2 of Holland et al. (1998) suggests a dependence with the age of the total amount of dust in the disk. Our results support this type of dependence (Figure 3). The inferred rapid decline in dust mass supports the hypothesis that the Vega phenomenon is a normal stage in the early life of intermediate mass and solar-like stars.

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Table 1: Photometry and other data for the β Pic Moving Group.

Gliese number	Sp. Type	V	Mv	(B-V)	(V-I)c	Log Lx[1] (erg/s)	EW(H_α)[2] (Å)	Other names
219	A3V	3.85	2.425	0.171	0.18	–	–	HD39060, β Pic
97	G2V	5.19	3.485	0.608	0.68	29.60	–	HD14802, κ For
601 A	F2III	2.83	2.38	0.30	0.36	–	–	HD141891, β TrA
781.2	K3/K4V	9.75	7.241	1.137	1.249	–	–	HD191285,
799AB	M4.5e+M4.5e	10.27	10.97[3]	1.550[3]	2.90[3]	29.55[3]	4.10	HD196982, AT Mic
803	M1Ve	8.81	8.82	1.470	2.10	29.74	1.56	HD197481, AU Mic
824	K2	7.88	6.84	1.020	1.11	27.76	-0.91	HD202575,

Sp. Type and photometry from Hypparcos and Bessel (1990), [1] Lx values from Hünsch et al. (1999), [2] EW(Hα) from Panagi & Mathioudakis (1993), [3] Values for each individual component.

Table 2: Coordinates and velocities for the β Pic Moving Group.

GL	alpha	delta	parallax	μ_α	μ_δ	RV	U	V	W
	(h m s)(1950.0)(° ' ")		(mas)	(mas/yr)		(km/s)			
219	5:46:05.93	-51:05:01.8	51.87±0.51	9.4±4.2	79±4.3	20.0±0.5[3]	-10.6±0.4	-16.3±0.5	-8.7±0.4
"	"	"	"	"	"	21.0±1.0[4]	-10.7±0.4	-17.1±0.9	-9.2±0.6
97	2:20:15.23	-24: 2:36.2	45.60±0.82	197.34±0.77*	-4.39±0.51*	18.6±1.0[2]	-19.3±0.4	-16.9±0.3	-10.4±0.9
"	"	"	"	200.0±0.6	-62±0.8	"	-15.5±0.4	-21.5±0.3	-10.8±0.9
601	15:50:42.96	-63:16:42.7	81.24±0.62	-192.2±0.9	-398±1.0	0.4±1.0[2]	-15.3±0.8	-17.8±0.6	-10.7±0.2
781.2	20:06:47.92	-14:26:00.2	31.49±1.58	81.3±2.1	-85±2.1	-12.3±3.0[2]	-12.5±2.5	-14.4±1.5	-10.1±1.4
799AB	20:38:43.71	-32:36:33.8	97.80±4.65	274.2±2.9	-351±3.0	-3.5±1.0[2]	-9.7±0.9	-16.1±0.8	-11.2±0.8
803	20:42:03.79	-31:31:05.6	100.59±1.35	281.3±2.9	-363±2.9	-4.89±0.02[1]	-10.5±0.2	-16.6±0.3	-10.4±0.2
824	21:14:05.39	09:11:09.3	61.83±1.06	143.6±2.2	-121±2.1	-13.2±1.0[2]	-8.3±0.5	-16.2±0.8	-7.0±0.5

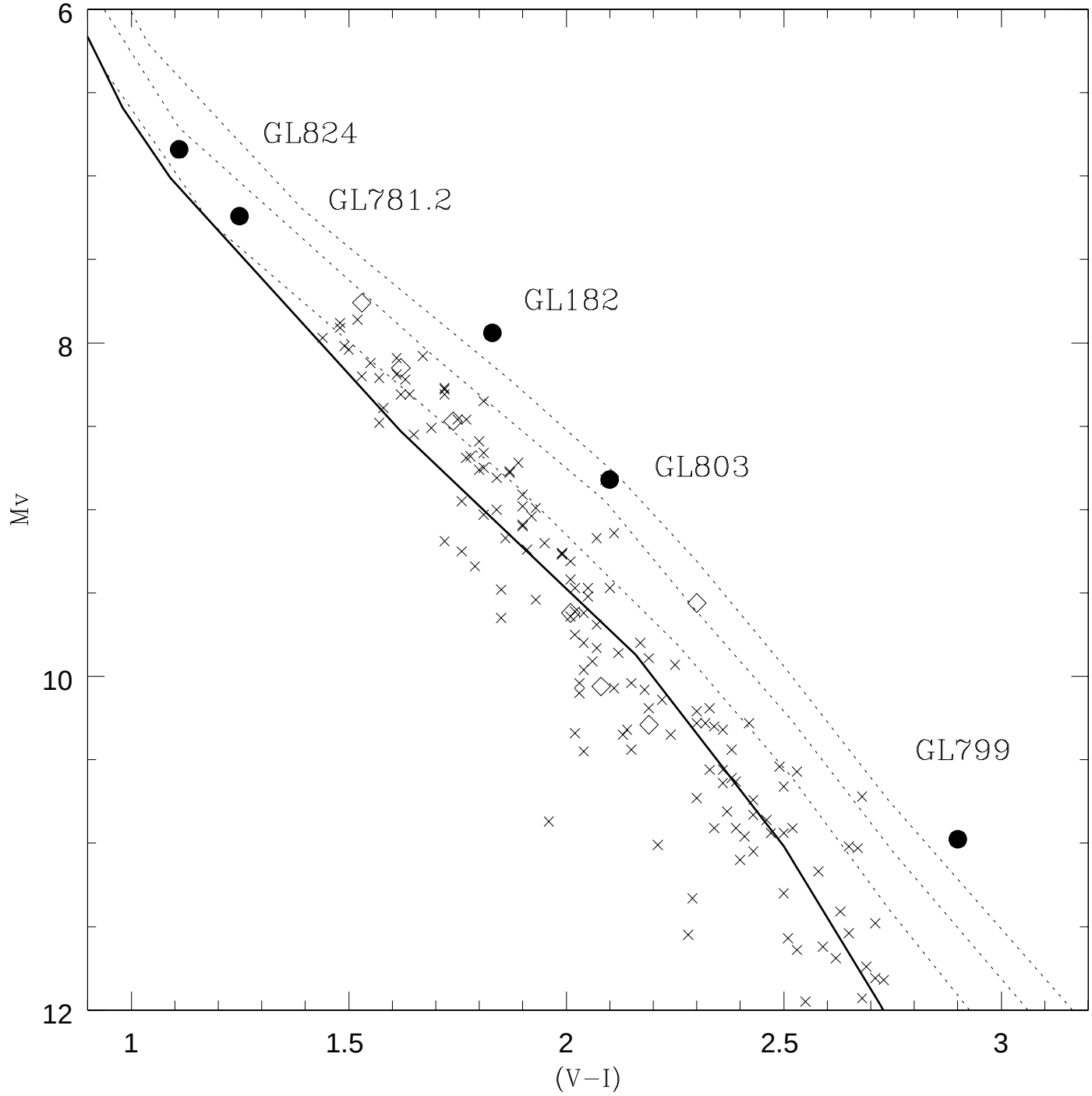
* Hipparcos, all others from PPM

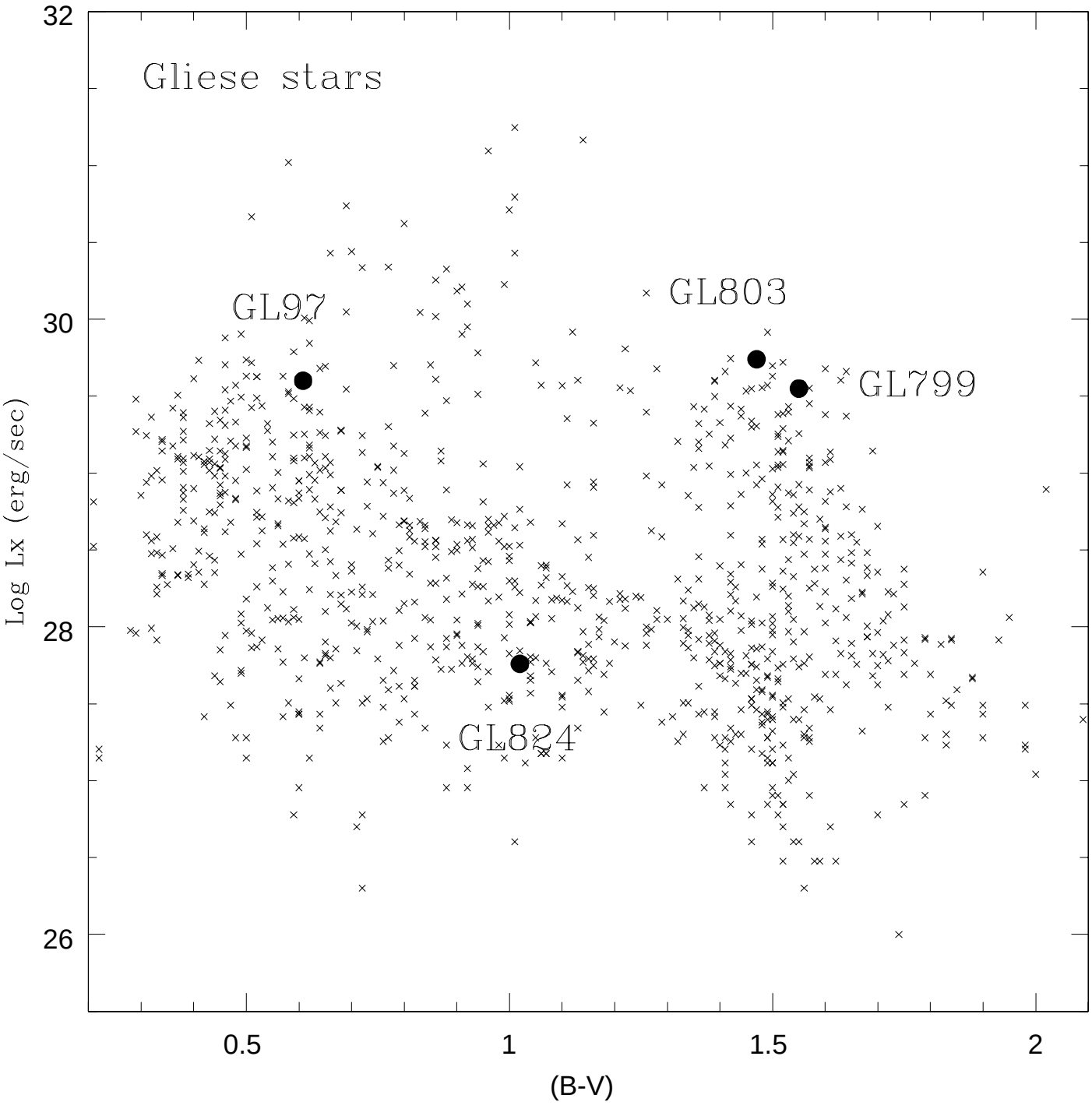
RV from: [1] Delfosse (1999, priv.comm.), [2] Duflot et a. (1995) [3] Lagrange et al. (1995), [4] Jolly et al. (1998).

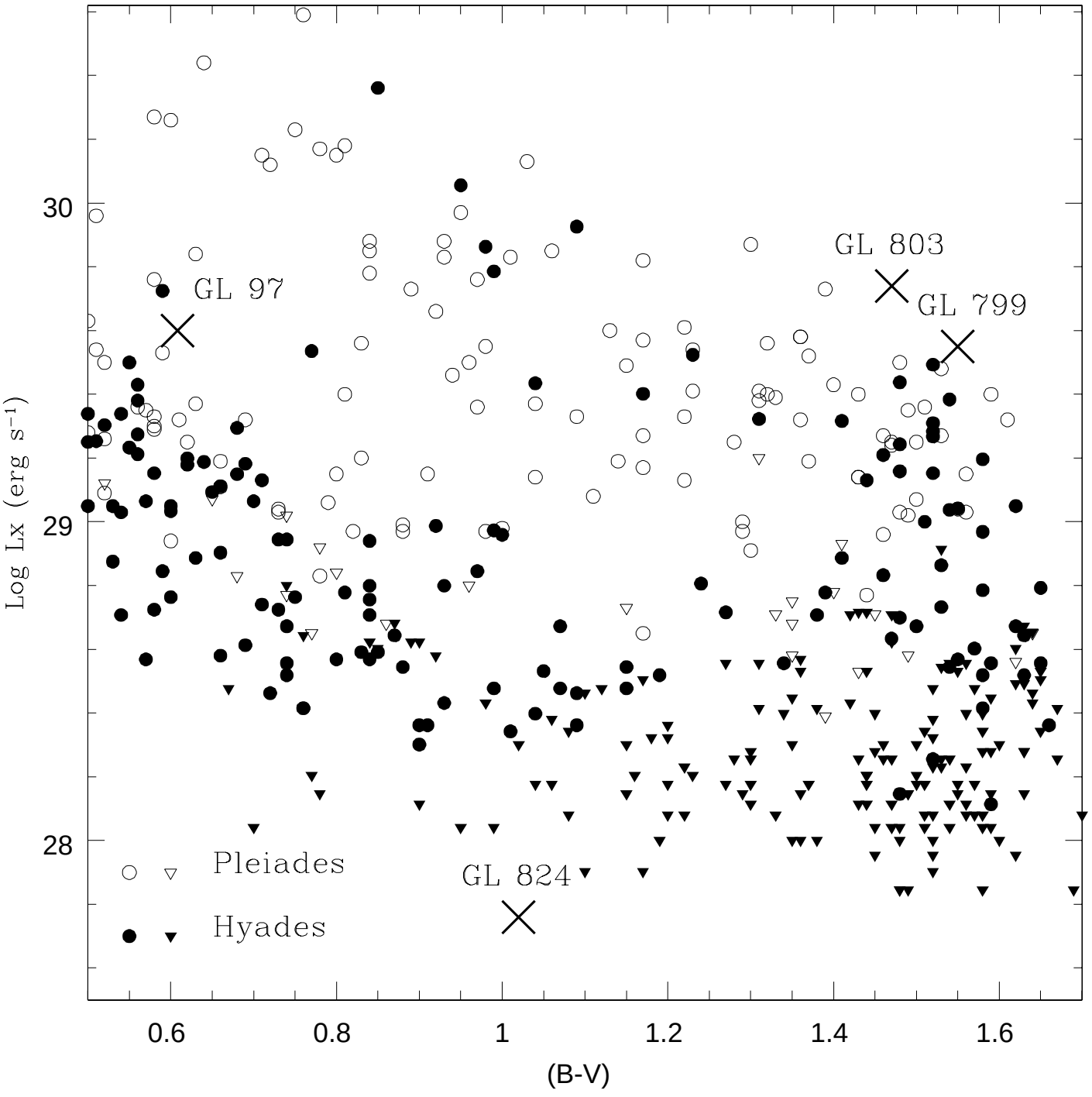
Fig. 1.— Color-Magnitude diagram for the late spectral type candidates. The isochrones (20, 30, 50 and ZAMS) are those from D'Antona & Mazzitelli (1997). Stars from Leggett (1992) are shown as crosses. Open diamonds represent the combined photometry of binaries.

Fig. 2.— X-ray luminosities plotted versus the (B-V) color indices. **a** Gliese stars. **b** Pleiades and Hyades members. Triangles indicate upper limits.

Fig. 3.— Fractional infrared luminosity versus age.


6
8
10
12
Mv
1
1.5
2
2.5
3
(V−I)
GL824
GL781.2
GL182
GL803
GL799


Gliese stars
GL97
GL803
GL799
GL824
32
30
28
26
Log Lx (erg/sec)
0.5
1
1.5
2
(B-V)


GL 97
GL 803
GL 799
GL 824
Pleiades
Hyades
Log Lx (erg s^{-1})
30
29
28
0.6
0.8
1
1.2
1.4
1.6
(B-V)