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HIP 60350: an extreme runaway star[⋆]

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Abstract. Using Hipparcos proper motion as well as published and our own radial velocity data we identify HIP 60350 as fastest young B-type runaway star ejected 20 Myr ago or slightly less from the galactic plane, probably at a distance from the galactic center corresponding to spiral arm -II. Both the LSR velocity (417 kms^{-1}) and the mass of the star point to dynamical cluster ejection rather than to a supernova scenario. Published and our own photometric data as well as our spectroscopic evidence reveal no noticeable peculiarity and a spectral type B4/5 V. No significant radial velocity variations have been found during the last two decades.

Key words: stars: chemically peculiar – stars: early-type – stars: kinematics – Galaxy: kinematics and dynamics

1. Introduction

In the course of a program carried out in the Δa photometric system (Maitzen 1976) aiming at the verification of the peculiarity assignments of stars contained in the General Catalogue of Ap and Am Stars (Renson 1991) - the results of which have been published already by Maitzen et al. (1998) - one of us (RP) for experimental reasons included an object from this catalogue which is listed with V=11 mag and was therefore far beyond the magnitude limit (V = 8 mag) set for the other stars of the project: RNS(=Renson) 31250. It carries a question mark pointing to discrepancies in the literature concerning the spectroscopic assessment of peculiarity. Indeed, it has entered the Renson catalogue due to the spectral type A5m derived by Slettebak & Stock (1959), but in the literature we found also B5 (Laget 1980) and B4 (Tobin 1986). Häggkvist & Oja (1973) by their UBV-photometry (m_{V} = 11.67, $B-V$ =–0.18, $U-B$ =–0.62) support the B-type character of the star. Tobin (1985) derives from $uvby\beta$ photometry (see Table 1) a photometric spectral class of B3. It is surprising that his values perfectly match those of Hill et al. (1982) if one takes into account the errors listed in Table 1. In the latter case, since no explicit errors were given by the authors, we had to make a guess based on their preceding papers on the same subject.

This discrepancy and the extraordinary radial velocity of +230 kms^{-1} (Laget 1980) prompted us to carry out observations according to the following points of view:

- Verifying the peculiarity nature using Δa-photometry
- Taking spectra at our home observatory (Mt. Schöpfl) and also at the Multi-Mirror-Telescope in Arizona in order to derive precise spectral types and to verify the high radial velocity.
- Using proper motion data from the Hipparcos archive in order to derive space velocities. Fortunately, RNS 31250 has been included in the Hipparcos archive under the designation HIP 60350 although it is at the magnitude limit (11.6) of the Tycho catalogue (Perryman et al. 1997).

2. The observations

2.1. Δa and $uvby$ photometry

The pertinent data taken on three epochs in 1993, 1996 and 1997 can be found in Table 1. The observations were carried out at the 1m telescope of the Purgathofer-Observatory at Klosterneuburg near Vienna by one of us (RP) in the framework of the program mentioned above (Maitzen et al. 1998).

Photometry obtained in April 1993 indicated peculiarity with a mean value of $\Delta a = 64 \pm 11$ mmag obtained from 3 sets of measurements in the filters $g1, g2, y$, centered at 5017, 5212 and 5473 Å with half widths 110, 120 and 188 Å, respectively. According to Maitzen (1976)

$$a = g2 - (g1 + y)/2$$

and the peculiarity parameter based on the flux depression around $\lambda 5200$

$$\Delta a = a - a_0$$

where a_0 is the a-value for non-peculiar stars at the same colour (mostly $b-y$) as the star under consideration.

Taking into account that the photometric endeavours had to be continued in order to improve the statistical foundation of this value, we nevertheless considered this result as incentive to check the spectral type of the star and thus to contribute to the solution of the spectroscopic discrepancy problem.

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[⋆] Based on data obtained with the Multiple Mirror Telescope, a joint facility of the University of Arizona and the Smithsonian Institution and from the ESA Hipparcos astrometry satellite

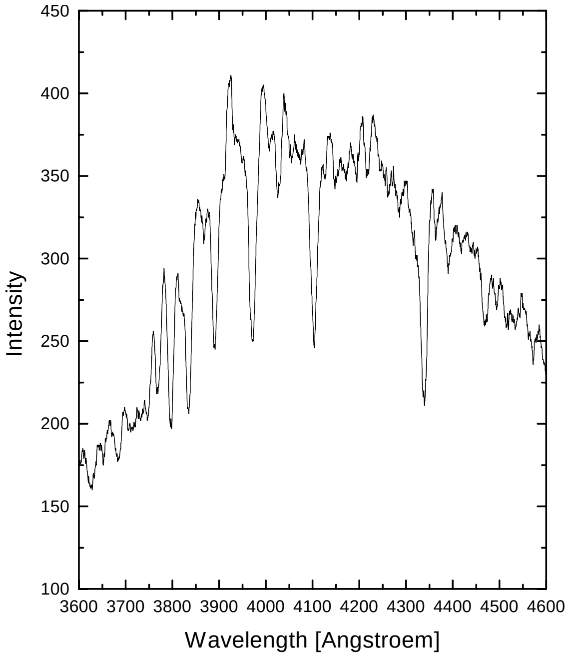

Fig. 1. The spectrum of HIP 60350 from the Mt. Schöpfl

Measurements taken in 1996 and 1997 with a fourfold number of individual series per night markedly reduced the Δa value obtained at the beginning, and thus we are now left with a weighted mean which is barely above the threshold value for peculiarity with an error bar which extends to complete non-peculiarity.

The Strömgren photometry is in good accord with the published values (Table 1) the only visible difference occurring in m_1, but even there the error intervals overlap.

2.2. Spectroscopy

2.2.1. L. Figl Observatory (University of Vienna)

Five IIaO (unbaked) spectra (log given in Table 2) were secured by one of us (HMM) with the Boller&Chivens spectrograph (125 Åmm^{-1} dispersion) at the 1.5m telescope of the L.Figl Observatory on Mt. Schöpfl near Vienna. Already the first spectrum obtained in April 1996 indicated a spectral type of mid B and thus did not confirm the type A5m given in the Renson-catalogue. Rather it was in line with the other sources mentioned above.

The second spectrum, which exhibits the highest and best density level, is Schöpfl Nr. 1053/1 opening the possibility for a more precise spectral classification also due to its excellent focus. Comparing it to the B3 and B5 luminosity effect plates in the Revised MK Atlas for Stars earlier than the Sun (Morgan et al. 1978) we notice from the last visible Balmer line that the spectral type must be close to B5V. The weakness of He I 3820, 4009 and 4387 confirms that any deviation in the direction of an earlier type must be of minor nature.

A quick look inspection of the plates revealed an unusual redshift. Quantitatively we obtained a heliocentric radial velocity of 223±15 kms^{-1} in very good accord with Laget (1980). Fig. 1 shows the density plot of the spectrum of HIP 60350 for the plate Schöpfl Nr. 1053/1. Note that the “absorption line” between Hγ and He I 4387 is an artifact due to the presence of the Hg I emission line at 4358.32Å produced by surrounding urban light.

2.2.2. Multi Mirror Telescope (University of Arizona)

Optical spectra of HIP 60350 were obtained by one of us (RMW) on 1996 May 28.13 UT using the 4.5-m Multiple Mirror Telescope of the University of Arizona and the Smithsonian Institution with the red channel CCD spectrograph. The detector consisted of a Loral 1200x800 pixel CCD. A 300 lmm^{-1} grating centered at 5600Å was employed and when combined with a 1”x180” entrance slit covered the spectral region 3800-7500Å at a spectral resolution of 10Å. Two spectra were obtained, each with an integration time of 60 seconds, at unit airmass. In Fig. 2 we display the normalised spectra in the overall wavelength region.

- From the helium to hydrogen ratio based on line depths we tend to assign B4 rather than B5.
- From Fig. 2 no significant flux depression around 5200 Å is evident, in agreement with our marginal photometric peculiarity index Δa obtained 11 days before.
- From 9 He I and Balmer lines in the blue we obtain a heliocentric radial velocity of 217±20 kms^{-1} which means in connection with the values of Laget (1980) and ours from Mt. Schöpfl that the velocity is practically constant over nearly two decades. Therefore we conclude that binarity of HIP 60350 seems to be excluded except for the case of orbital motion perpendicular to the line of sight and a secondary which does not leave sensible traces in the observed spectrum.

3. Discussion

3.1. Peculiarity

From our Δa-photometry only marginal peculiarity if any may be deduced which is not accompanied by any significant appearance of a λ5200 flux depression on our MMT spectrum. The spectral type A5m obtained from objective prism photographs has been produced by not fully excellent seeing conditions. The consequences of those conditions have already been outlined by Slettebak & Stock (1959). Reinspection of the concerning spectrum (kindly provided by D. Engels) revealed the rather weak (“washed out”) presence of the He I 4026 line in HIP 60350 ruling out an A type star. A new issue of the Renson catalogue should therefore replace the question mark at the beginning of the related entry by a slash denoting a peculiarity assignment ”probablement a tort”.

Table 1. $uvby\beta$ and Δa-photometry, all photometric quantities are given in mmag, italic numbers are estimates based on the related reference

Date	UT	c_1	m.e.	m_1	m.e.	$b-y$	m.e.	Δa	m.e.	β	m.e.	weight	reference
930416	2330	310	13	90	16	–23	16	64	11			1	
960517	2039	366	18	82	16	–43	14	18	14			4	
970601	2051	295	17	90	19	–100	16	9	10			4	
w.mean		328		86		–66		19					
		320	*30*	112	*20*	–72	*10*			2694	*15*		Hill et al. (1982)
		319	20	111	11	–77	5						Tobin (1985)

3.2. Kinematics and evolutionary status

In order to establish astrophysical parameters (such as the effective temperature, luminosity, surface gravity and age) one has to apply standard calibrations derived by photometric indices. We have used the Strömgren-Crawford photometric system (Table 1) and the calibration by Napiwotzki et al. (1993). This results in $E(b-y)$ = 0.009, $T_{\rm eff}$ = 17100 K, log g = 4.3, δm_0 = –0.013 and $M_{\rm V}$ = –1.1. The absolute magnitude can be independently checked by using the adopted spectral type (B4-5 V) and "standard" relations (e.g. Schmidt-Kaler 1982) yielding the same value ($M_{\rm V}$ = –1.2). The effective temperature and surface gravity were used to locate HIP 60350 in the Hertzsprung-Russell-diagram. Fig. 3 shows the location with evolutionary tracks ([X] = 0.7, [Y] = 0.28 and [Z] = 0.02) from Claret (1995). Furthermore we have included a group of hot, high galactic latitude, post-asymptotic giant branch stars from McCausland et al. (1992) and Conlon et al. (1994). These stars were classified as normal early B-type, but high-resolution spectra revealed chemical compositions and atmospheric parameters consistent with post-asymptotic giant branch stars. It is evident from Fig. 3 that HIP 60350 clearly separates from this group. Within 1σ we derive a mass of 5M$_\odot$ and an age of about 15 Myr for HIP 60350.

As a further step an investigation of the stars kinematics and galactic location was performed. Using the absolute and apparent ($m_{\rm V}$ = 11.60; Tobin 1985) magnitude, a distance of about 3.5 kpc from the sun was calculated (which is in line with the literature).

Fortunately, the Hipparcos satellite measured its proper motions on the sky with an accuracy of about 10 percent: $\mu_{\alpha^*} = -12.94 \pm 1.35$ masyr^{-1} and $\mu_\delta = +17.08 \pm 1.43$ masyr^{-1}. With the radial velocity of +220 kms^{-1} we derive the stellar motion of HIP 60350 corrected for the solar motion (9, 12, 7 kms^{-1} for the U, V, W components, resp.) as: $U = -352$ kms^{-1}, $V = +183$ kms^{-1} and $W = +130$ kms^{-1}. The overall velocity is therefore $v = 417$ kms^{-1} with an error of about 15 percent.

From this we immediately conclude that the inclusion of the Hipparcos proper motion significantly alters the rather plausible assumption voiced by Tobin (1986) that since the star is at high latitude its radial velocity is likely to be very similar to its ż velocity (= the W-component). Due to the overwhelming outward radial component U its contribution to the observed radial velocity is by no means negligible and reduces the galactic vertical velocity from 230 kms^{-1} (Tobin 1986) to only 130 kms^{-1}. Therefore, we have to change our view concerning both the galactic flight path and the flight time of HIP 60350. 2.2 Myr ago it was closest to the Sun and roughly at the same distance to the galactic center (its flight direction deviating only 8 degrees from the actual direction to the Sun), but still 3 kpc above the galactic plane! On a linear path without deceleration by the gravitational force of the galactic plane HIP 60350 should have been at zero height 25 Myr ago. This is clearly the upper limit for the flight time since ejection.

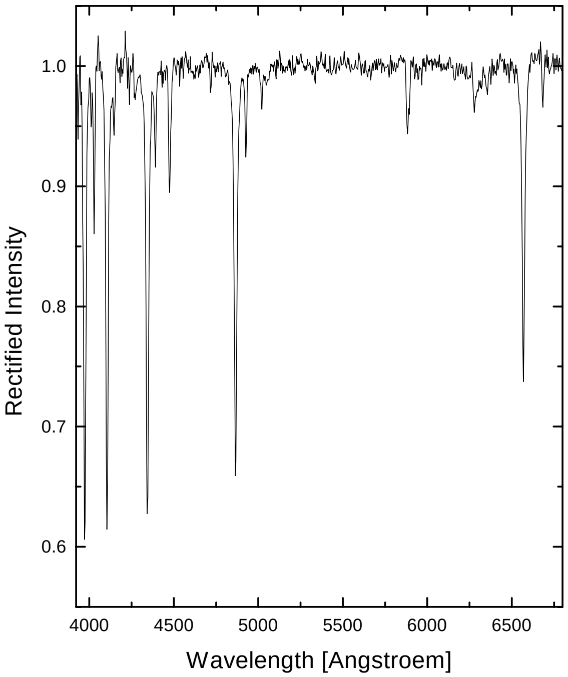

Fig. 2. The spectrum of HIP 60350 from the MMT

The galactic location where the runaway star was born is well inside the solar orbit (spiral arm -II in the 4th quadrant seems appropriate) and still far away from its actual position (although the birthplace has approached the Sun due to differential galactic rotation). Without more detailed calculations and data on the gravitational force exerted by the galactic plane at different galactocentric radii, including the local effects of molecular clouds, it is not possible to be more specific concerning the galactic origin (a concerning study is envisaged).

In analogy to Tobin (1986) we may roughly estimate that the ejection velocity component W_0 should have been in the interval 160-180 kms^{-1} and the flight time between 20 and 22 Myr. It is tempting to check these time limits following the procedure given by Lindblad et

Table 2. Log of spectra at L.Figl Observatory

Schöpfl Nr.	Date	UT (midexp.)	Exposure (hours)	Widening (my)
1052/1	960418	22.30	3.75	500
1053/1	960420	22.33	4.50	500
1055/1	960524	21.55	2.70	500
1056/1	960529	21.35	3.00	330
1068/2	970424	22.37	3.75	330

al. (1997) using the formula for the perpendicular force

$$K_z = 2(W - Z/A)/A$$

where Z is the distance from the plane and A the flight time, W the observed vertical velocity. For 20 Myr we obtain –2.5 and for 22 Myr –1.8 $\mathrm{kms}^{-1}\mathrm{Myr}^{-1}$. The first value is in clearly better agreement with the model of Bahcall (1984) fitting the density distribution of K giants. Since HIP 60350 has come from the interior of the solar orbit where the force K_z is stronger, one has to expect that 20 Myr are also rather an upper limit for the flight time of the star.

The flight time is a lower limit for the age of the star. The time prior to the ejection is related on the ejection mechanism. It is shorter (statistically) in the scenario proposed by Blaauw (1961) in which a binary containing an O star explodes as supernova where both stars remain bound but the system is accelerated due to angular momentum change. Stone (1982) showed that the observable secondary must have a mass larger than $10\mathrm{M}_\odot$ and that an upper limit for the ejection speed is 150 kms^{-1}. The LSR velocity derived here by far exceeds this limit. We are thus left with the second mechanism which may happen to a star even 20 Myr after its formation, i.e. strong dynamical interaction in clusters (see Leonard & Duncan 1990), especially those with many binary stars. As an extreme case, a low mass companion of an early O-type star may reach up to 1400 kms^{-1} ejection velocity according to Leonard & Tremaine (1990). Leonard (1993), however, points to the extremely low probability of such a situation and holds that 'for a sample of a few hundred or so runaways the highest ejection speed should only be between 300-400 kms^{-1}'.

It is remarkable that among the much lower number of known early type dynamical runaways (roughly 3 dozen) our actual object HIP 60350 seems to represent this estimate of the expected highest level of observable ejection speeds, if we consider the actual LSR velocity as rough approximation of the ejection velocity (galactic differential rotation and gravitational deceleration contribute to the present motion). One might argue that there is a bias in favour of high velocities, since they are easiest to observe, especially in proper motion. On the other hand our study has not been aimed at performing a survey of runaway stars, and therefore the detection of the fastest LSR motion of a young galactic disk object is just a chance discovery which followed the original goal of this work, i.e. to clear up the question of chemical peculiarity of HIP 60350.

Finally, we can rule out the case of a highly eccentric binary to be responsible for the high space velocity. Such a high velocity (implying a very minute probability to observe the star in the appropriate orbital phase and the proper orientation with respect to the line of sight) would be possible only close to the periastron around a significantly more massive primary component which should therefore dominate the observed spectrum, but which is not seen in fact. Moreover, attributing the high velocity to binary orbital motion we would have to explain how the young binary system formed at such a height above the galactic plane.

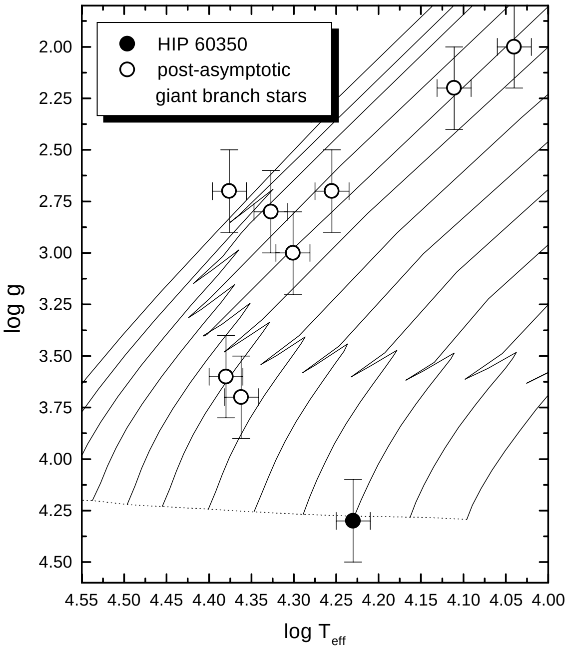

Fig. 3. The location of HIP 60350 in the HR-diagram. Included are post-asymptotic giant branch stars, the evolutionary tracks are from Claret (1995)

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