The K supergiant runaway star HD 137071

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ABSTRACT

Context. Extensive work exists on runaway massive stars with peculiar motions that are much higher than those typical of the extreme Population I to which they belong. Work on runaways has focused almost exclusively on O and B stars, most of which undergo a red supergiant phase before ending their lives as supernovae. Very few examples are known of red supergiant runaways, all of which descend from the more massive O-type precursors, but none from the lower mass B-type precursors, although runaway statistics of B-type stars suggest that K-type runaways must be relatively numerous.

Aims. We study HD 137071, a star that has so far been considered to be a normal K-type red giant. Its parallax measured by Gaia and the derived luminosity suggest that it is a supergiant, whereas its derived distance to the Galactic plane and its spatial velocity of 54.1 km s^{-1} with respect to the local standard of rest suggest that it is also a runaway star. However, intrinsic limitations in determining the trigonometric parallaxes of cool supergiants, even in the Gaia era, require accurate spectral classifications for confirmation.

Methods. We present visible spectroscopy obtained with the 2.2m telescope at Calar Alto Observatory and compare it with the spectra of MK standard stars to produce an accurate spectral classification, including the determination of its luminosity class. We complement this information with astrometric data from the Gaia DR2 catalog.

Results. We reliably classify HD 137071 as a K4II star and establish its membership to the extreme Population I. This agrees with the luminosity derived using the Gaia DR2 parallax measurement. Kinematical data from the Gaia DR2 catalog confirm its high spatial velocity and runaway nature. By combining the spectral classification with astrometric information, recent Galactic potential models, and evolutionary models for high-mass stars, we trace the motion of HD 137071 back to the proximities of the Galactic plane and speculate which of the two proposed mechanisms for the production of runaway stars may be responsible for the high velocity of HD 137071. The available data favor the formation of HD 137071 in a massive binary system where the more massive companion underwent a supernova explosion about 32 Myr ago.

Key words. supergiants – stars: late-type – stars: kinematics and dynamics – stars: individual: HD 137071

1. Introduction

The large fraction of runaways among the most massive stars continues to pose challenges, both for obtaining reliable unbiased statistics (Stone 1991; Maíz Apellániz et al. 2018) and for explaining their origin in terms of the supernova disruption channel (Blaauw 1964) or the dynamical ejection channel (Poveda et al. 1967), which were initially proposed over a century ago to account for their high spatial velocities (Portegies Zwart 2000; Fujii & Portegies Zwart 2011; Perets & Šubr 2012). The potential of the Gaia astrometric mission to improve the statistics of runaway stars has been demonstrated by several recent studies (Maíz Apellániz et al. 2018; Fernandes et al. 2019; Rate & Crowther 2020), but much work remains to be done to obtain complete statistics throughout the entire range of massive stars. This should form the basis for comparisons with the predictions of simulations of the mechanisms that account for their origin.

Nearly all the observational studies of massive runaway stars have focused on stars of O and early-B types. With the exception of the most massive stars, all these stars undergo the red supergiant phase before ending their lives as supernovae, and therefore we expect that runaway red supergiants are also relatively abundant. However, very few examples are known. A literature search reveals only Betelgeuse (Harper et al. 2008), μ Cep (Cox et al. 2012), and IRC 10414 (Gvaramadze et al. 2014) as the three known runaway supergiants in our Galactic neighborhood. An extragalactic member located in M31 has recently been added to the sample (Evans & Massey 2015). All these are luminous M-type supergiants with very massive, short-lived O-type progenitors. Very little is known about runaways among less luminous K supergiants, which are the descendants of early-type B stars. This is partly due to the ease with which red supergiants can be misclassified as red giant branch stars, which are much more abundant and very similar both photometrically and spectroscopically. They are also much older, and their velocity dispersions are therefore similar to the velocities of actual runaway stars. In principle, accurate distance determinations are expected to help in separating giants from supergiants on the basis of their luminosities. Messineo & Brown (2019) have studied a large sample of cool supergiants that were characterized using data from the Gaia DR2 catalog (Gaia Collaboration 2018a). However, cool supergiants are intrinsically difficult objects for astrometry because their huge convective cells can move the photocenter randomly across the disk of the star, with amplitudes exceeding their parallax, as dramatically demonstrated by

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interferometric images of Betelgeuse (López Ariste et al. 2018). This intrinsically limits the accuracy with which the parallax can be determined regardless of their distance.

Red supergiant runaways, which are older than their main-sequence precursors, enable investigating old ejection episodes. Furthermore, evolutionary models constrain the ages at which massive stars enter the red supergiant phase, and the relatively short duration of that phase leads to a fairly tight mass-luminosity-age relationship. Its scatter is mainly due to the relatively short lifetime of that phase. Therefore, one of the oldest massive runaways after Betelgeuse is HD 137071, which may be the second nearest runaway supergiant (Maeder & Meynet 2000; Ekström et al. 2012), and in close binary systems, to earlier mass transfer episodes between the star and a massive companion (Vanbeveren et al. 1998).

We discuss evidence for a nearby runaway supergiant, HD 137071, which may be the second nearest runaway supergiant after Betelgeuse. HD 137071 is the only K supergiant identified thus far, and therefore one of the oldest massive runaway stars known. We present spectroscopy that confirms this classification for HD 137071, and we use Gaia DR2 astrometry and evolutionary models to carry out a tentative reconstruction of its history. This allows us to speculate on its mechanism of origin and what consequences that may have had.

2. HD 137071

HD 137071 is a relatively bright \((V = 5.5)\) red star in the constellation Boötes, far removed from the Galactic equator at a Galactic latitude \(b = +56^\circ 363\). No dedicated studies exist on HD 137071, but it has appeared in the literature as part of large samples of giants, with a K4III or K5III classification. Subsolar metallicities have been reported by McWilliam (1999) in [Fe/H] \(-0.31 \pm 0.15\) and Cenarro et al. (2007) in [Fe/H] \(-0.21 \pm 0.1\), but more recent work of Prugniel et al. (2011) using the MILES code yields a slightly supersolar metallicity [Fe/H] \(+0.09 \pm 0.05\).

Tetzlaff et al. (2011) first identified HD 137071 as a candidate young runaway using Hipparcos proper motions for a large sample of stars whose youth was suspected from the fit to their positions in color–absolute magnitude diagrams, in a study not restricted to any particular range of spectral types. In parallel, we have identified HD 137071 as a supergiant candidate based on its 2MASS \(J\) and \(K_s\) magnitudes and its Gaia DR2 parallax in the course of an ongoing study of cool supergiants in the solar neighborhood. Its high Galactic latitude, implying a vertical distance of \(524^{+56}_{-38}\) pc over the Galactic plane, and its peculiar velocity of \(54.1 \, \text{km} \, \text{s}^{-1}\) are both unexpected for a normal cool supergiant belonging to the extreme Population I, and even for a massive RGB star having a relatively short-lived progenitor with an initial mass of a few solar masses, which led us to consider it as a likely runaway star. We summarize the basic data of HD 137071 in Table 1, where astrometric data are taken from the Gaia DR2 catalog, radial velocity from Famaey et al. (2005), and photometry from the 2MASS All-Sky Catalog (Skrutskie et al. 2006). The distance is taken from the parallax-to-distance conversion of Bailer-Jones et al. (2018).

3. New observations and spectral classification

We have observed HD 137071 in the course of an ongoing program to obtain homogeneous spectral classifications of a sample of suspected red supergiants within 1 kpc for the Sun. We used CAFOS, the visual imager and low-resolution spectrograph at the Calar Alto 2.2 m telescope, on the night of 22 to 23 February 2019, with a setup consisting of a grating providing a resolution \(\lambda/\Delta\lambda = 1800\) over the interval 6000–9000 Å. We used the same setup to observe a grid of MK spectroscopic standards from the list of Garcia (1989) that included the giants HD 173780 (K2III), HD 164058 (K5III), HD 194193, (K7III), and the supergiant HD 216946 (K5Ib) as the closest spectral types for comparison with HD 137071, all of them with near-solar metallicity determinations in the literature. The wavelength range includes several temperature-sensitive TiO bands, the CaII infrared triplet, and numerous other atomic and molecular features useful for the determination of spectral subtype and luminosity class.

Figure 1 compares the spectrum of HD 137071 with that of the K2III and K7III standards, clearly showing broad features that are intermediate between the two, and Fig. 2 compares the spectrum of HD 137071 with spectra of the two K5 standards of different luminosity classes. The overall appearance of the spectra, and particularly the depth of the broad temperature-sensitive TiO absorption feature centered around 7150 Å, suggest a spectral type slightly earlier than K5, although definitely later than K2. We therefore classify HD 137071 as K4, in accordance with several previous classifications in the literature.

The assignment of a luminosity class is less straightforward because it is based on subtler effects on luminosity-sensitive lines. A comprehensive set of features with positive luminosity effect (depth of the absorption feature increasing with luminosity), many of them lying within our wavelength range, was provided by Torres-Dodgen & Weaver (1993) based on

| Table 1. Basic data of HD 137071. |
|---------------------------------|
| \(\alpha(2000)\)              | 15:22:37.37           |
| \(\delta(2000)\)              | +39:34:53.3           |
| \(l\)                        | 64\(\pm\)425          |
| \(b\)                        | +56\(\pm\)363         |
| \(\mu_\alpha \cos\delta\) (mas yr\(^{-1}\)) | 1.525 \(\pm\) 0.181 |
| \(\mu_\delta\) (mas yr\(^{-1}\)) | −14.194 \(\pm\) 0.224 |
| Radial velocity (km s\(^{-1}\)) | −13.38 \(\pm\) 0.20  |
| Parallax (mas)               | 1.5675 \(\pm\) 0.1212 |
| Distance to the Galactic plane (pc) | 524\(^+33\)\(^-13\) |
| \(J\)                        | 2.823 \(\pm\) 0.258   |
| \(H\)                        | 2.042 \(\pm\) 0.184   |
| \(K_s\)                      | 1.758 \(\pm\) 0.278   |

![Fig. 1. Comparison of the spectrum of HD 137071 with spectra of two luminosity class III MK standards bracketing its spectral subtype.](image-url)
spectra taken at a resolution $R \approx 500$. The main feature is the depth of the CaII triplet lines, which can be isolated from temperature effects when the spectral subtype has been determined from other temperature-sensitive indicators, as we have done. The CaII triplet is known to be sensitive to metallicity as well (Diaz et al. 1989), but we do not consider this to be a cause of concern here given the narrow range of metallicities spanned by HD 137071 and the MK standards used for comparison. Torres-Dodgen & Weaver (1993) also noted the usefulness as luminosity indicators of the blend of several atomic lines near 6500 Å, the broad CN feature around 7970 Å, and the blend of TiI lines 7345, 7358, and 7364 Å. We have defined pseudocontinuum points and measured the equivalent widths of all these features in our spectra of HD 137071 and the standard stars. We also added a few other luminosity-sensitive lines with a positive effect. The lines were previously noted by Keenan & Hynek (1945): KI at 7699 Å, FeI-TiI at 8468 Å, and FeI at 8514 Å and 8699 Å. Because the signal-to-noise ratio of the spectra of such bright stars is high, the equivalent widths are determined to a precision better than $\approx 5\%$ for lines with equivalent widths above 5 Å and $\approx 10\%$ for the weaker lines. The uncertainty is dominated by the exact location of the pseudo-continuum adopted for each line.

The results are summarized in Fig. 3, where the equivalent widths of all these features measured on the spectrum of HD 137071 are compared with those of the two K5 standards. The equivalent widths of all the features without exception in the spectrum of HD 137071 fall between those of the K5Ib supergiant and the K5III giant. We also show our measurements of these same features on the spectra of the K2III and K7III standards, which also fall consistently below those of HD 137071. This rules out a slight spectral subtype misclassification as the possible cause of the systematic differences. Based on this, we propose K4II as the definitive spectral classification of HD 137071. Traditionally, stars of luminosity class II are referred to as bright giants rather than supergiants, a term that is reserved for luminosity class I alone in the phenomenological MK classification scheme. We adopt here the evolutionary more physically motivated definition of red supergiant as the stage of a massive star on its way to end its life as a core-collapse supernova in which it burns helium at its core under nondegenerate conditions. With this definition and the derived characteristics of HD 137071, the separation between supergiants and bright giants becomes rather arbitrary, and we therefore refer to HD 137071 as a supergiant to stress its physical commonalities with its more massive counterparts that are spectroscopically classified as belonging to luminosity class I.

We also observed HD 137071 with the AstraLux lucky imager (Hormuth et al. 2008) at the Calar Alto 2.2 m telescope on the night of 10 March 2020. We obtained four sequences of 10 000 images in the V filter, each with individual exposure times of 30 millisecond. We stacked the 1% best images of each sequence. The resulting images have a point-spread function (PSF) with a sharp core that has a full width at half-maximum of 0.028. This allows us to search for relatively close companions. We estimated detection limits by adding a number of simulated stars of different magnitudes at various position angles and distances to the actual image, each with the PSF of the real star scaled according to the chosen magnitude of the simulated star. We then performed photometry at the position of the simulated stars and in this way determined detection limits at arbitrary angular distances from HD 137071. We can therefore exclude a physical main-sequence companion to HD 137071 with $V < 7.5$ (corresponding to a spectral type earlier than B2.5V) at more than 0′′28, corresponding to a projected physical distance of 180 pc. Fainter companions are also ruled out at progressive larger separations, down to $V = 11$ (the approximate sensitivity limit of our AstraLux observations) at distances larger than 1′′2.

4. Results and discussion

4.1. Physical parameters

Using the temperature versus spectral type calibration of Levesque et al. (2007) for Galactic supergiants, we estimate that the effective temperature of HD 137071 is $T_{\text{eff}} = 3900$ K, in excellent agreement with the value $T_{\text{eff}} = 3892$ K obtained from the atmosphere model fit by Prugniel et al. (2011). We obtain the intrinsic $(J - K)_0$ color in the Johnson-Glass photometric system from Kućinskas et al. (2005), using their models for solar
metallicity and \( \log g = 1.0 \). The latter choice is based on the value of \( \log g \) of HD 137071 from Prugniel et al. (2011), although the precise value is of marginal importance at most given the mild dependence of the intrinsic colors in the relevant range of \( \log g \). The \((J - K_S)\) color in the 2MASS system is obtained using the transformation \((J - K_S)_{2MASS} = 0.983(J - K)_{2MASS} - 0.018 \) (Carpenter 2001). The value we obtained, \((J - K_S) = 0.93\), is slightly lower than the actual \((J - K_S)\) color of HD 137071, suggesting the existence of moderate extinction in its direction. Using the extinction law of Cardelli et al. (1989), we obtain \( A_K = 0.686(J - K_S) - (J - K_S)_{2MASS} = 0.093 \) \((A_V = 0.8)\). This has a virtually negligible effect on the luminosity that we derive from the infrared photometry.

The distance estimated by Bailier-Jones et al. (2018) from the Gaia parallax translates into a distance modulus \( DM = 8.99 \pm 0.17 \). Using the \( K \)-band bolometric correction versus spectral type for supergiants of Levesque et al. (2007), we adopt \( BC_K = 2.61 \), which yields a luminosity

\[
\log L(L_\odot) = -0.4(K_S - DM - A_K + BC_K) - 4.74 \approx 3.78 \pm 0.13. \tag{1}
\]

This agrees well with the luminosity class assigned from the spectral features discussed above. We note that some analyses caution about the use of Gaia DR2 parallaxes for bright stars because some problems are known to exist with systematics (Lindegren et al. 2018), and Drimmel et al. (2019) noted effects that can reach deviations as large as 1–2 mas among stars brighter than \( G \approx 5 \). At a magnitude \( G = 4.86 \), HD 137071 is therefore close to the faint end of the range where the effect be can become prominent. The data presented by Drimmel et al. (2019) suggest that the effect is probably color dependent, causing some bright red stars to have underestimated parallaxes. If this effect were present for HD 137071 to the same level as in the most extreme cases shown by Drimmel et al. (2019), its actual distance modulus could be reduced to as little as 8.0 mag and its luminosity to \( \log L(L_\odot) \approx 2.8 \), placing it within the range of normal giants with an initial mass of a few solar masses. However, the consistency of the luminosity–dependent spectral features with a luminosity class II rather than III show that this is not the case. Furthermore, the renormalized unit weight error, which is a measure of the goodness of the astrometric solution according to Lindegren et al. (2018), has a value of 1.1 for HD 137071, which is below the threshold of 1.4 for which the astrometric solution is considered to be problematic. In any case, the poorly characterized systematics at bright magnitudes highlight the importance of the spectroscopic confirmation of the high luminosity presented here without relying solely on the published parallax measurement.

We assume that HD 137071 is undergoing the He-burning phase before entering the blue loop because the post-blue loop phase ending with the supernova explosion is much shorter. A comparison of the values of \( T_{\text{eff}} \) and \( \log L \) in the relative stable He-burning phase with the evolutionary tracks for massive solar metallicity stars (Ekström et al. 2012) indicates an initial mass of \( 8M_\odot \), with a weak dependency on the initial rotation velocity of the precursor. Figure 4 shows the location of HD 137071 between the evolutionary tracks for stars of \( 7M_\odot \) and \( 10M_\odot \), with the effect of rotation schematically indicated at the beginning of the He-burning phase.

The age has nevertheless a stronger dependency on the assumed rotation velocity of the precursor. At the initial mass of \( 8M_\odot \), the evolutionary models of Ekström et al. (2012) show that the start of the He-burning phase varies considerably as a result of the mixing enhancement effect in the stellar interior caused by rotation. In this way, a supergiant with a nonrotating precursor enters the He-burning phase at the age of \( \sim 35 \) Myr, which increases to \( \sim 42 \) Myr if the precursor rotates at 60% of the critical velocity. The duration of the pre-blue loop He-burning phase (effectively the time spent by the star in the red supergiant phase) in both cases is \( \sim 3 \) Myr. The available data do not allow us to adopt a more precise value of the age, but even this wide range places some useful constraints on the origin of HD 137071 as a runaway star.

### 4.2. Kinematics, birthplace, and the origin of HD 137071

The runaway nature of HD 137071 is revealed solely by its position and kinematics in combination with its youth. The current peculiar velocity with respect to the local standard of rest is \( 54.1 \) \( \text{km s}^{-1} \), largely in the directions parallel to the Galactic plane, with a very small vertical component \( (2.1 \text{ km s}^{-1}) \) at present. Unlike the case of the more massive Galactic M-type supergiant runaways mentioned in the introduction, no arc-like structure tracing a bow shock is identified in the proximities of HD 137071 that would result from the interaction of its stellar wind with the interstellar medium, and that we would have expected to appear in infrared images of the WISE All-Sky Atlas if present. This may be due both to the weaker winds from red supergiants descending from B-type stars and to the highly raredfied interstellar gas at its distance from the Galactic plane. Unlike most runaway stars known, the proper motion and radial velocity of HD 137071 indicate that it is moving toward the Galactic plane, rather than away from it. Given its youth and the considerable distance to the Galactic plane, this most likely indicates that HD 137071 is making its first return toward the Galactic plane after having been born in its proximity and been subsequently ejected.

To explore the past trajectory of HD 137071, we used the GRAVPOT16 web utility, based on the Besançon Galaxy

1. https://gravpot.utinam.cnrs.fr/
model (Robin et al. 2012) as described by J.G. Fernández-Trincado (2017, Ph.D. Thesis). We left as default parameters those reported in Gaia Collaboration (2018b). The reconstruction of the Galactic orbit of HD 137071 under this potential indicates that the star reached its largest distance from the Galactic plane only 2 Myr ago, as indicated by the very low value of the component of the velocity perpendicular to the Galactic plane. Tracing the trajectory farther back in time, HD 137071 would have been on the Galactic plane 31 ± 0.5 Myr ago. At that point, the components of the velocity with respect to its local standard of rest were \( U = 20.6 \, \text{km s}^{-1} \) (away from the Galactic center), \( V = -32.9 \, \text{km s}^{-1} \) (in the direction opposite to Galactic rotation), and \( W = 28.6 \, \text{km s}^{-1} \) (toward the north Galactic pole). Each of these quantities is twice higher or more than the velocity dispersion of the Extreme Population I in the corresponding coordinate, and their combination implies a spatial velocity of 48.2 km s\(^{-1}\) with respect to the local standard of rest at the time of the Galactic plane crossing. Assuming that the birthplace of HD 137071 lies approximately at the location of its intersection with the Galactic plane 31.5 Myr ago and that it has no peculiar motion with respect to the Galactic circular rotation, we expect its current location to be in the direction of Galactic longitude \( l = 93° \), at a distance of \( \sim 1.4 \) kpc from the Sun. The open cluster NGC 7086 lies at this approximate distance (Cantat-Gaudin et al. 2018) about one degree away, but at an estimated age of 100 Myr (Rosvick & Robb 2006) it can be ruled out as the birthplace of HD 137071. No other candidate clusters or aggregates are known in the region. Our results remain essentially unchanged when the Galactic potential of McMillan (2017) is used, which sets the Galactic plane crossing at the slightly later time of 30 Myr ago.

On the other hand, any age within the possible range discussed in Sect. 4.1 implies that HD 137071 existed already at the time of the Galactic plane crossing, then as a B2V main-sequence star on its way to becoming a red supergiant about 30 Myr later. Taken at face value, even the lower limit to the age derived in Sect. 4.1 would situate the birthplace of HD 137071 on the opposite side of the Galactic plane, at least 100 pc from it, and up to \( \sim 400 \) pc if the precursor were a longer-lived fast rotator. These are rather high values when compared with the scale height of the thin disk traced by the extreme Population I, and we therefore favor an interpretation in which the precursor of HD 137071 would instead have been born near the Galactic plane, becoming a runaway only after having spent several million years on the main sequence. Such a lag, perhaps reaching as many as \( \sim 20 \) Myr, between the formation of HD 137071 and its ejection as a runaway tends to favor the supernova disruption mechanism rather than the dynamical interaction mechanism as the cause of its runaway nature. Ejection of most stars that become runaways is expected to take place in the initial relaxation phases of the dense, moderately massive clusters that simulations suggest as the preferred scenario for dynamical ejection (Fuji & Portegies Zwart 2011). As a consequence, we would have expected the time since ejection from the cluster to be very similar to the age of the star, which does not seem to be the case for HD 137071.

If the runaway velocity of HD 137071 instead has its origin in the supernova explosion of a more massive companion, the ejection velocity derived above essentially reflects the orbital velocity of HD 137071 at the time of the supernova explosion of the companion, which allows us to estimate the possible range of initial separations between the two. When we take \( \sim 50 \) Myr as an upper limit to the age of HD137071, corresponding to the extreme case of a precursor rotating at near-critical velocity, and assume that the ejection took place \( 31.5 \) Myr ago near the Galactic plane, the difference between the age of HD 137071 and the time of the ejection event yields an upper limit to the lifetime of the companion, hence a lower limit to its mass, and a lower limit to their separation assuming a circular orbit at the time of the explosion. The companion lifetime of \( \sim 18.5 \) Myr implies an initial mass \( \sim 11 \, M_\odot \), and the combined masses of HD 137071 and its companion, together with the orbital velocity \( 48.2 \, \text{km s}^{-1} \), yield a semimajor axis of their orbit of 2.4 AU. Conversely, when we assume a massive companion of 22 \( M_\odot \), the highest mass for which a supernova explosion is the most likely outcome rather than direct collapse into a black hole (Sukhbold et al. 2016), the semimajor axis would be 6.1 AU. These values are comparable to or even smaller than the radius of the massive companion in the pre-supernova red supergiant phase, implying that HD 137071 should have undergone a period of intense accretion through Roche-lobe overflow of its companion, and perhaps a common-envelope phase, in addition to the subsequent contamination by the supernova ejecta.

5. Concluding remarks

HD 137071 has the temperature, luminosity, and spectral characteristics of a low-mass K-type supergiant and the kinematics of a runaway star. To our knowledge, it is the only star of this type identified thus far. Statistically, the fraction of runaway stars drops from \( \sim 25\% \) to \( \sim 5\% \) from O to B types (Stone 1991), but the decreasing fraction should be offset by the rising initial mass function with decreasing masses. K-type supergiant runaway stars are therefore expected to be abundant in absolute numbers, and the improved distances that are obtained with Gaia are expected to allow the identification of many more. Nevertheless, the caveat subsists that convective activity in their surfaces and their large radii (\( \sim 0.9 \) AU for a supergiant with a \( 8 \, M_\odot \) precursor, like HD 137071, and even larger for more massive precursors) sets limits on the accuracy with which even Gaia can determine their parallaxes, making it highly advisable to spectroscopically confirm the supergiant nature of candidate runaway stars to avoid samples contaminated with older non-runaway red giant branch stars. Reliable samples of K supergiant runaway stars obtained in this manner are expected to enable reconstructing the history of ejections by either of the proposed mechanisms in the solar neighborhood, back to a time that is hardly accessible through main-sequence O and B stars.

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