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Article

Space astrometry of the very massive ~150 $M_\odot$ candidate runaway star VFTS682

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Abstract

How very massive stars form is still an open question in astrophysics. VFTS682 is among the most massive stars known, with an inferred initial mass of $\gtrsim 150\,\mathrm{M}_\odot$. It is located in 30 Doradus at a projected distance of 29 pc from the central cluster R136. Its apparent isolation led to two hypotheses: either it formed in relative isolation or it was ejected dynamically from the cluster. We investigate the kinematics of VFTS682 as obtained by *Gaia* and *Hubble Space Telescope* astrometry. We derive a projected velocity relative to the cluster of $38 \pm 17\,\mathrm{km\ s^{-1}}$ (1σ confidence interval). Although the error bars are substantial, two independent measures suggest that VFTS682 is a runaway ejected from the central cluster. This hypothesis is further supported by a variety of circumstantial clues. The central cluster is known to harbour other stars

more massive than $150\,\mathrm{M}_{\odot}$ of similar spectral type and recent astrometric studies on VFTS16 and VFTS72 provide direct evidence that the cluster can eject some of its most massive members, in agreement with theoretical predictions. If future data confirm the runaway nature, this would make VFTS682 the most massive runaway star known to date. Q5: [Copyeditor to Author][If you refer to any data bases in your paper, please note the journal policy for properly crediting those responsible for compiling the data base. Rather than citing only a URL, if at all possible please also cite a reference (and include it in the reference list), or if a reference is not available then the names of those who compiled the data base. Note that some data bases do provide guidelines on how they should be cited - please check for these and follow them in your paper where appropriate.]

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1 INTRODUCTION

How massive stars form is one of the major longstanding questions in astrophysics (e.g. Zinnecker & Yorke 2007). Obtaining clues from observations is challenging, because massive stars are intrinsically rare, evolve fast, typically reside in dense groups, and remain enshrouded in their parent cloud during the entirety of the formation process. Important progress has been made on the theoretical side, (e.g. Bate 2009; Kuiper, Yorke & Turner 2015; Rosen et al. 2016), but the simulations remain challenging.

It has been proposed that most, if not all, stars form in clusters (and references therein Lada & Lada 2003). In this picture, field stars are primarily the result of the dissolution of dense groups. However, a small but significant population of massive stars exists in relative isolation, far from dense clusters or OB associations and their origin remains a matter of debate (Gvaramadze et al. 2012; Lamb et al. 2016; Ward & Kruijssen 2018). One hypothesis to explain the population of relatively isolated massive stars is that they formed in the field (e.g. Parker & Goodwin 2007). Another hypothesis is that these massive stars were ejected from the clusters in which they formed. Such ejections may result from dynamical interactions (e.g. Poveda, Ruiz & Allen 1967) or from the disruption of binary systems at the death of the companion star (e.g. Blaauw 1961; Renzo et al. 2018).

One of the most extreme examples that has been considered in this debate is the very massive star VFTS682 (Bestenlehner et al. 2011; Bressert et al. 2012). This star is located in the field of the 30 Doradus (30Dor) region in the Large Magellanic Cloud (LMC) and was studied as part of the multi-epoch spectroscopic VLT-FLAMES Tarantula Survey (VFTS; Evans et al. 2011). It is a hydrogen-rich Wolf–Rayet star of spectral type WNh5. Spectral analysis and comparison with evolutionary models lead to an inferred present-day mass of $137.8^{+27.5}_{-15.9}\,\mathrm{M}_{\odot}$ corresponding to an initial mass of $150.0^{+28.7}_{-17.4}\,\mathrm{M}_{\odot}$ (Schneider et al. 2018). This makes VFTS682 one of the most massive stars known and one of the most extreme objects in the region. From the spectral point of view, it is reminiscent of the very massive stars in the core of the R136 cluster (de Koter, Heap & Hubeny 1997; Crowther et al. 2010, 2016). In particular, a remarkable similarity exists between the spectra of VFTS682 and R136a3 (Rubio-Díez et al. 2017).

VFTS682 stands out by its relative isolation at a projected distance of 119.4 arcsec, corresponding to 29 pc, from the star cluster R136. Bestenlehner et al. (2011) considered two possible explanations for the offset: either the star formed *in situ* as an isolated massive star, or it was ejected from R136. *N*-body simulations indicate that the dynamical ejection of very massive stars like VFTS682 is expected (e.g. Fujii & Portegies Zwart 2011; Banerjee, Kroupa & Oh 2012). The capability of a young cluster to eject a large number of (very) massive stars is supported by the recent findings of proper motion studies (e.g. Drew et al. 2018; Lennon et al. 2018)

Platais et al. (2015, 2018) analysed multi-epoch *Hubble Space Telescope* (*HST*) photometry and identified 10 stars likely ejected from R136. Lennon et al. (2018) investigated the kinematics of isolated O-type stars in the region using the second *Gaia* data release (DR2; Gaia Collaboration 2016, 2018) and showed that the proper motion, postion, and direction of the ~$100\,\mathrm{M}_{\odot}$ star VFTS16 is consistent with a runaway origin from R136. They found a less clear case for VFTS72, and in both cases some tension between the kinematic age of these stars and their apparent age remains.

In this paper we present an analysis of the new kinematic constraints for VFTS682 provided by *Gaia* DR2 and constraints from *HST* proper motions by Platais et al. (2018). We discuss the implications of the hypothesis that VFTS682 is a runaway star ejected from R136.

2 OBSERVATIONS

The WNh5 star VFTS682, located at right ascension (RA) $05^{\mathrm{h}}38^{\mathrm{m}}55.510^{\mathrm{s}}$ and declination (Dec.) $-69^{\mathrm{o}}04'26.72''$ (J2000), was observed as part of the multi-epoch, spectroscopic VFTS campaign covering λ4000–7000 (Evans et al. 2011). Bestenlehner et al. (2011) analysed the spectra to infer the stellar parameters and measured a visual extinction of A_{V} = 4.45 ± 0.12, implying a luminosity of $\log_{10}(L/L_{\odot})$ = 6.5 ± 0.2, making this one of the most luminous stars in the region. The absence of periodic radial velocity (RV) variations suggests that the star is unlikely to have close companions (Bestenlehner et al. 2011), unless the orbital inclination is very high. Bayesian fits of the stellar parameters against evolutionary tracks (Brott et al. 2011; Köhler et al. 2015) using the

BONNSAI code (Schneider et al. 2014, 2017) provide estimates for the age, present mass, and initial mass, see Table 1.

VFTS682 is not a bright X-ray point source. It was not detected in the *Chandra* survey of Townsley et al. (2006), and shows a few counts in the deeper survey of Townsley et al. (2014). The X-ray luminosity of VFTS682 is significantly lower than known massive binaries in the region, which suggests the absence of colliding winds. These would be expected in the presence of companions even for extreme mass ratios, given the large mass of VFTS682.

This star is also relatively isolated in the (near-)infrared. The nearest bright (near-)infrared sources detected by *Spitzer* (Meixner et al. 2006) and resolved in the *VISTA* Magellanic Clouds Survey (Cioni et al. 2011) are located at a distance of about 10 arcsec, i.e. about 2.4 pc. Walborn, Barbá & Sewiło (2013) speculate that these nearby young stars may represent a case of star formation triggered by the wind of VFTS682.

The *V*-band light curve of VFTS682 shows variations at an ~10 percent level on a time-scale of years, which is unusual for Wolf–Rayet stars and more typical for Luminous Blue Variable (LBV) stars (Udalski et al. 2008; Bestenlehner et al. 2011). The source also shows a mid-infrared excess (Gruendl & Chu 2009).

Estimates of the RV are complicated by the variable, possibly inhomogeneous, optically thick wind typical of emission line stars. We therefore caution against overinterpreting the existing radial velocities estimates. Bestenlehner et al. (2011) estimate a mass-loss rate of $\log_{10}(\dot{M}/[\mathrm{M}_{\odot}\ \mathrm{yr}^{-1}]) = -4.1 \pm 0.2$, not accounting for the possible effect of clumping. They estimate an RV of $300 \pm 10\,\mathrm{km\ s}^{-1}$ using the NV λ4944 line, which is offset from the average RV of the region of $270 \pm 10\,\mathrm{km\ s}^{-1}$. This was suggested as indicating a runaway nature, but it is no proof of it. Bressert et al. (2012) note an offset between the RV of the star and the nebular lines from the gas filaments in its vicinity. This is in line with the expectation that the star was not formed *in situ*. Given these issues, we refrain from using the RV measurements in this work, and focus on the velocities on the plane of the sky.

We adopt a distance to the LMC of 50 kpc. The error on the distance determination is small ($\lesssim 2$ per cent; Pietrzyński et al. 2013) and any possible offset in the radial direction between R136 or VFTS682 and the distance we adopted for the LMC is probably much smaller (~0.5 per cent; e.g. Luks & Rohlfs 1992). These uncertainties are negligible compared to the errors in the proper motion discussed below.

2.1 *Gaia* astrometry for VFTS682

VFTS682 is identified with the source id 4657685637907503744 in the *Gaia* DR2 catalogue as a 15.65 mag star in the *G* band (Gaia Collaboration 2016, 2018). The number of visibility periods, i.e. groups of observations separated from each other by at least 4 d, used in the astrometric solution is 17. The reported astrometric excess noise is zero. These values suggest that the *Gaia* DR2 data for VFTS682 are reliable.

Gaia provides absolute proper motions. To determine the proper motion relative to R136, we follow Lennon et al. (2018) to define the motion of the local frame of reference using the average proper motion of nearby stars with reliable astrometric data (see Table 2). They selected bright (G < 17) stars within 0.05 deg of R136 and exclude sources with proper motion error bars greater than $0.1\,\mathrm{mas\,yr^{-1}}$ in both coordinates (see their section 2.1). Using this definition of the local frame, we compute the relative proper motion $\delta\mu_{RA}$ and $\delta\mu_{Dec}$. We also compute the total projected 2D velocity (v_{2D}) and the angle θ between the direction of motion and the vector connecting the centre of R136 with the current position of VFTS682. All kinematic quantities are provided in Table 2.

Table 1. Stellar parameters of VFTS682.

Parameter	Units	Value	Ref.
Present-day mass	[$M_\odot$]	$137.8^{+27.5}_{-15.9}$	(1)
Initial mass	[$M_\odot$]	$150.0^{+28.7}_{-17.4}$	(1)
Age	[Myr]	1.0 ± 0.2	(1)
Mass-loss rate	$\log_{10}(\dot{M}/[\mathrm{M_\odot\ yr^{-1}}])$	−4.1 ± 0.2	(2)

The quoted uncertainties are statistical, and do not include systematic effects in the modelling. (1) Schneider et al. (2018) (2) Bestenlehner et al. (2011).

Table 2. Kinematics of VFTS682.

Parameter	Units	Value	Ref.
Absolute position and position relative to R136			
$RA_{VFTS682}$	[degrees]	84.731 363 398 764 77	(1)
$Dec._{VFTS682}$	[degrees]	−69.074 110 717 949 98	(1)
RA_{R136}	[degrees]	84.6750	(2)
$Dec._{R136}$	[degrees]	−69.1006	(2)
δRA	[mas]	0.0547	(3, 5)
δDec.	[mas]	0.0268	(3, 5)
$d_{\Vert}$	[arcsec]	119.4	(3)
$L_{\Vert}$	[pc]	29	(3)
Gaia absolute proper motion for VFTS682 and the region			
μ_{RA}	$[\mathrm{mas\,yr^{-1}}]$	1.84 ± 0.07	(1)
$\mu_{Dec.}$	$[\mathrm{mas\,yr^{-1}}]$	0.79 ± 0.08	(1)
$\rho(\mu_{RA}, \mu_{Dec.})$		0.0226	(1)
$\langle\mu_{RA}\rangle_{R136}$	$[\mathrm{mas\,yr^{-1}}]$	1.74 ± 0.01	(4)
$\langle\mu_{Dec.}\rangle_{R136}$	$[\mathrm{mas\,yr^{-1}}]$	0.70 ± 0.02	(4)
Gaia DR2 proper motion of VFTS682 relative to R136			
$\delta\mu_{RA}$	$[\mathrm{mas\,yr^{-1}}]$	0.10 ± 0.08	(1,6)
$\delta\mu_{Dec.}$	$[\mathrm{mas\,yr^{-1}}]$	0.08 ± 0.10	(1,6)

Parameter	Units	Value	Ref.
$\delta\mu_{Gaia}$	$[\mathrm{mas\,yr^{-1}}]$	0.13 ± 0.09	(1,6)
v_{2D}	$[\mathrm{km\ s^{-1}}]$	32 ± 21	(1,6)
θ_{Gaia}	[degrees]	14^{+36}_{-31}	(1,6)
HST proper motion of VFTS682 relative to R136			
$\delta\mu_{\mathrm{RA},\ HST}$	$[\mathrm{mas\,yr^{-1}}]$	0.02 ± 0.10	(5)
$\delta\mu_{\mathrm{Dec.},\ HST}$	$[\mathrm{mas\,yr^{-1}}]$	0.19 ± 0.09	(5)
$\delta\mu_{HST}$	$[\mathrm{mas\,yr^{-1}}]$	0.19 ± 0.09	(5)
$v_{\mathrm{2D},\ HST}$	$[\mathrm{km\ s^{-1}}]$	45 ± 21	(5)
θ_{HST}	[degrees]	-30^{+24}_{-51}	(1,6)
Weighted average relative proper motion for VFTS682			
$\delta\mu_{\mathrm{RA,\ avg}}$	$[\mathrm{mas\,yr^{-1}}]$	0.08 ± 0.07	(6)
$\delta\mu_{\mathrm{Dec.,\ avg}}$	$[\mathrm{mas\,yr^{-1}}]$	0.14 ± 0.07	(6)
$\delta\mu_{\mathrm{avg}}$	$[\mathrm{mas\,yr^{-1}}]$	0.16 ± 0.07	(6)
$v_{\mathrm{2D,\ avg}}$	$[\mathrm{km\ s^{-1}}]$	38 ± 17	(6)
Expected proper motion if ejected from R136 at age zero			
v_{2D}	$[\mathrm{km\ s^{-1}}]$	29 ± 6	(3)
θ	[degrees]	~0	

The error on the RA and Dec. positions are of order ~$0.01\,\mathrm{mas\,yr^{-1}}$ in *Gaia* DR2. Assuming a distance of 50 kpc, $1\,\mathrm{mas\,yr^{-1}}$ corresponds to $237\,\mathrm{km\ s^{-1}}$. $\rho(\mu_{\mathrm{RA}}, \mu_{\mathrm{Dec.}})$ is the correlation coefficient. The position angle θ is defined such that $\theta = 0$ for radial motion away from R136. We neglect the error bars on $\langle\mu_{\mathrm{RA}}\rangle_{\mathrm{R136}}$ and $\langle\mu_{\mathrm{Dec.}}\rangle_{\mathrm{R136}}$ to determine the uncertainty on θ_{Gaia}. (1) Gaia Collaboration (2018), (2) Hénault-Brunet et al. (2012), (3) Bestenlehner et al. (2011), (4) Lennon et al. (2018), (5) Platais et al. (2018), and (6) this study.

2.2 *HST* (WFC3/UVIS) astrometry for VFTS682

The 30 Dor region was targeted by a two-epoch photometric campaign with *HST* providing observations in the F775W filter in 2011 October and 2014 October (GO-12499; P.I.: D. J. Lennon). Platais et al. (2015, 2018) analysed the *HST* data to determine the relative proper motions and identify candidate runaway stars. The brightest stars ($V < 14$) are saturated in the data set and have been excluded from the analysis. The high extinction around VFTS682 makes it redder and fainter ($V = 16.08$, $B - V = 0.58$; Evans et al. 2011), hence it has reasonably accurate *HST* astrometry with the WFC3/UVIS camera. This star did not pass a full set of stringent conditions to be considered as a candidate runaway (Platais et al. 2018). In retrospect, VFTS682 may have been included in the list of likely OB runaway stars, and it is identified with the ID source 330375 in their catalogue. Therefore, their measurements provide a useful complementary estimate of the proper motion of VFTS682 which is independent from the *Gaia* data.

The *HST* study provides proper motions that are relative to the bulk motion of the majority of the stars in the field of view. The full 30 Dor field is covered by different pointings and there is some systematic distortion. However, even for stars far from 30 Dor the effect is small, no more than $0.05\,\mathrm{mas\,yr^{-1}}$ across the whole 30 Dor field. The effect is much smaller for stars close to the centre of the field, such as VFTS 682 (Platais et al. 2018). We can therefore use the relative proper motion (Table 2) as a good estimate for the proper motion relative to R136.

3 THE KINEMATICS OF VFTS682

The black points in Fig. 1 show the proper motion (top panel) and the projected flight direction (bottom panel) relative to R136 of VFTS682 from *Gaia* DR2. Dynamical ejections from the cluster should produce close to radial ejections, i.e. θ ≃ 0. The green vertical bands highlight the expectations for these two quantities. The width in the top panel is determined by the error bars on the star's apparent age, and we assume a width of 45 deg in the bottom panel. For comparison, we also show the relative proper motion of VFTS16 and VFTS72 (grey points), and the distribution in relative proper motion and flight direction for all the VFTS OB-type and Wolf–Rayet stars with *Gaia* DR2 errors on the proper motion components of less than $0.1\,\mathrm{mas\ yr^{-1}}$ (dark blue lines, including VFTS682), and less than $0.05\,\mathrm{mas\ yr^{-1}}$ (light hatched blue). Although the error bars are substantial and VFTS682 is not an outlier compared to other OB-type and Wolf–Rayet stars, the agreement suggests that the star is indeed a runaway as suggested by Bestenlehner et al. (2011).

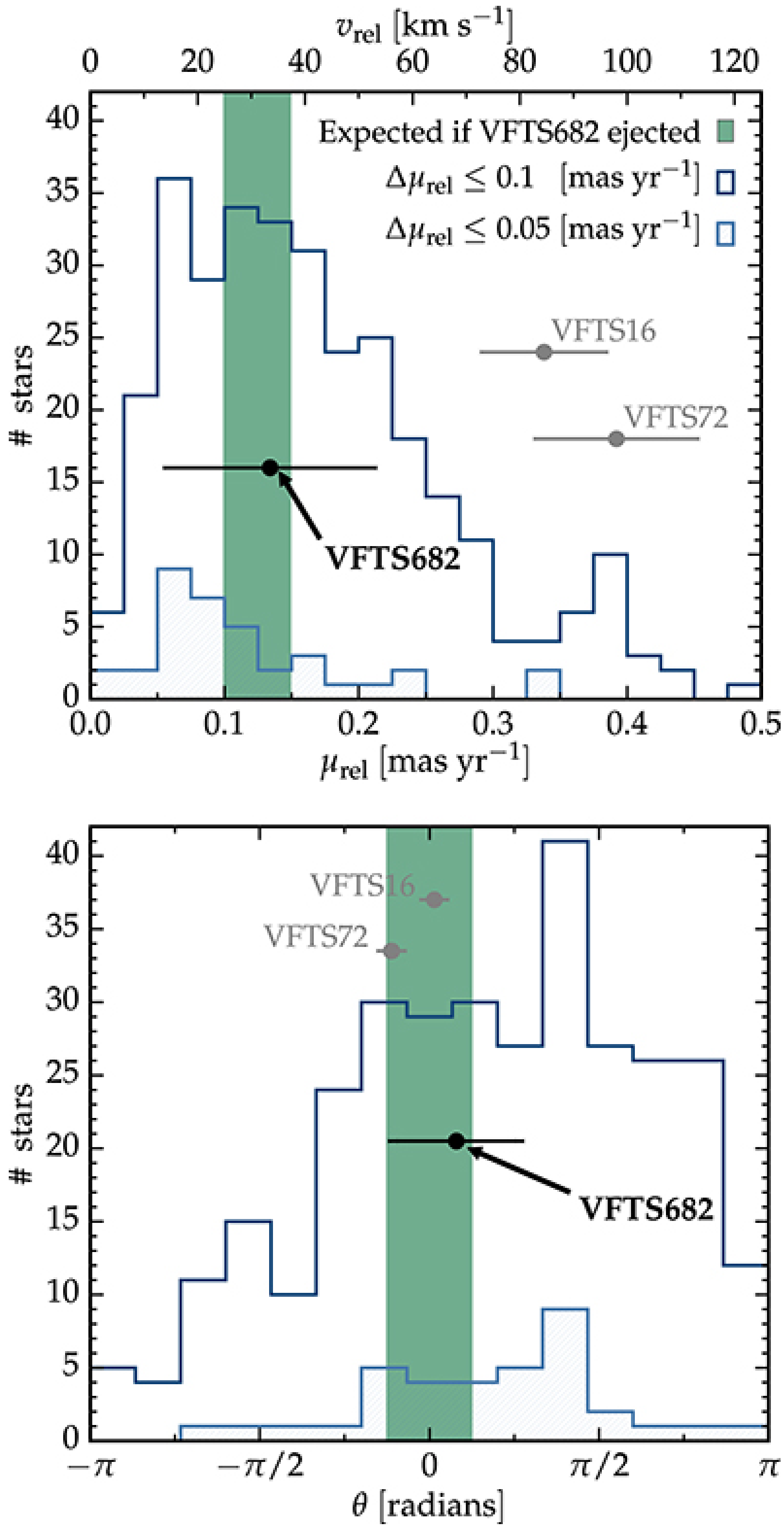

Figure 1. Distribution of OB-type and Wolf–Rayet stars in proper motion relative to R136 (top panel) and proper motion position angle (bottom panel), from *Gaia* DR2. Although VFTS682 is not an outlier, its relative proper motion matches the value expected for an early dynamical ejection (see Section 3). In both panels, the dark blue histograms contain 317 stars with error bars smaller than $0.1\,\mathrm{mas\,yr^{-1}} \simeq 25\,\mathrm{km\,s^{-1}}$ at 50 kpc and the lighter blue histograms contain 36 stars with error bars smaller than $0.05\,\mathrm{mas\,yr^{-1}}$. The peak at θ ≃ π/2 in the bottom panel is due to stars belonging to NGC 2060. Q7: [Copyeditor to Author][Please check the figures in the PDF proof carefully.]

Subtracting the mean motion of R136, we obtain relative proper motions (projected velocities) of $\delta\mu_{Gaia} = 0.13 \pm 0.09\,\mathrm{mas\,yr^{-1}}(32 \pm 21\,\mathrm{km\,s^{-1}})$ and $\delta\mu_{HST} = 0.19 \pm 0.09\,\mathrm{mas\,yr^{-1}}(45 \pm 21\,\mathrm{km\,s^{-1}})$. Both values are consistent with each other, but also with no motion relative to R136 within 2σ. The average (weighted with $1/\sigma^2$) of these two independent measurements is $\delta\mu_{\mathrm{avg}} = 0.16 \pm 0.07\,\mathrm{mas\,yr^{-1}}(38 \pm 17\,\mathrm{km\,s^{-1}})$.

Fig. 2 shows the motion of VFTS682 relative to R136 projected on the sky. We also show VFTS16 and VFTS72 (see Lennon et al. 2018). The yellow arrows are proportional to the relative proper motion from *Gaia* DR2, the orange line illustrates the relative proper motion from *HST*, and the red arrow shows the averaged result. The error cone on the direction of motion is illustrated by the corresponding extension in the direction opposite to the motion, and we also show the most likely origin of the stars accounting for their apparent age (0.7 ± 0.1 Myr and $0.4^{+0.8}_{-0.4}$ Myr for VFTS16 and VFTS72, respectively, Schneider et al. 2018). This figure illustrates that R136 is the most likely origin of these stars, although the large error bars prevent a robust identification for VFTS682, and there is some tension between the apparent age and the present-day distance from the cluster core for VFTS16 and VFTS72 (Lennon et al. 2018). We note that VFTS72 has a small RV, while VFTS16 (and possibly VFTS682) has a large peculiar RV, and therefore accurate distances along the line of sight are needed to constrain the flight direction in three dimensions.

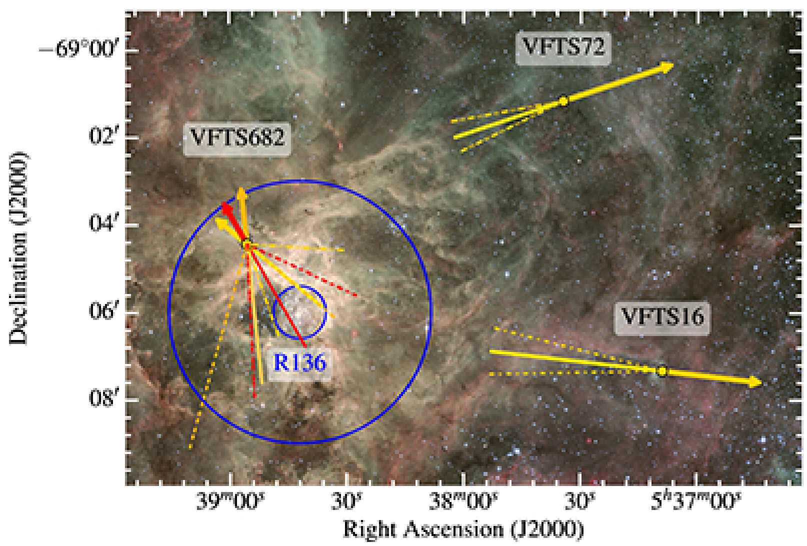

Figure 2. The thick red arrow shows the proper motion relative to R136 for VFTS682 from averaging the *Gaia* DR2 and *HST* astrometry, multiplied by 0.4 Myr. The extension in the opposite direction is proportional to the apparent age of the star, and the thin lines illustrate the error cone on the potential origin. The yellow (orange) arrows show the *Gaia* DR2 (*HST*) results alone. The two blue circles indicate the regions of radii 0.01 and 0.05 deg around the core of R136.

Assuming VFTS682 indeed originates from R136, we can calculate its kinematic age as

$$\tau_{\mathrm{kin}} = \frac{d_{\parallel}}{\delta\mu_{\mathrm{avg}}} \simeq \frac{119.4\,\mathrm{arcsec}}{0.16\,\mathrm{mas\,yr^{-1}}} \simeq 0.7 \pm 0.3\,\mathrm{Myr}\ , \qquad (1)$$

where $d_{||} = 119.4\,\mathrm{arcsec}$ is the angular distance from VFTS682 to the core of the cluster (Bestenlehner et al. 2011). The kinematic age τ_{kin} is consistent with an early ejection from the cluster (see Table 1).

In summary, both *Gaia* and *HST* relative proper motions are consistent with the dynamical ejection of VFTS682 from the cluster, although we cannot confidently rule out the hypothesis of *in situ* formation.

4 DISCUSSION

Based on our results, we consider that VFTS682 is potentially the most massive runaway known to date, with a two-dimensional projected velocity with respect to R136 of $38 \pm 17\,\mathrm{km\ s^{-1}}$ (taking a weighted average of *Gaia* DR2 and *HST* results). Due to the large error bars, this result will need to be revisited with future astrometric data. If confirmed, isolated star formation is *not* required to explain the isolation of VFTS682. Its proper motion suggests that it was ejected from the cluster R136 0.7 ± 0.3 Myr ago, which is compatible with the evolutionary age of the star. If the cluster age (≲ 2 Myr; Crowther et al. 2010; Sabbi et al. 2012) is indeed smaller than the shortest stellar lifetime (~3 Myr; Brott et al. 2011; Köhler et al. 2015; Zapartas et al. 2017), the ejection of VFTS682 from the disruption of a massive binary by a supernova is excluded. The kinematic age we infer is smaller than the kinematic age of ~1.5 Myr for VFTS16 found in Lennon et al. (2018), which indicates that VFTS682 was ejected later than VFTS16, and potentially later than VFTS72 too.

If the star were ejected dynamically, its isolation makes it an ideal target to constrain the stellar physics of stars with masses well above ~$100\,\mathrm{M}_{\odot}$ in the inner cluster, while avoiding crowding issues. Moreover, its exceptionally large mass raises the question of which stars must populate the core of the cluster. *N*-body dynamics typically ejects the least massive star among those interacting (although the dynamical ejection fraction increases with mass because of mass segregation, e.g. Banerjee, Kroupa & Oh 2012). Just based on the kinematic properties of VFTS682, we would expect several stars with initial masses larger than ~$150\,\mathrm{M}_{\odot}$ in the cluster R136, as it is observed.

The *N*-body simulations of Banerjee et al. (2012) suggest that VFTS682 was ejected from R136. They demonstrated that the cluster potential does not significantly change the velocity of the star after the ejection. To eject such a massive object, the cluster is expected to have produced a large number of massive runaways, and their simulation suggest a significant incidence of (dynamically driven) stellar mergers both in the cluster and among the stars ejected. Indeed, several isolated massive stars are observed in the region (Evans et al. 2010; Lennon et al. 2018), some with known large radial velocities and/or proper motion. A comprehensive study of the kinematic properties of all the massive stars surrounding R136 could shed light on whether some can be unequivocally identified as merger products, but also on the initial conditions for the cluster dynamics (e.g. Oh & Kroupa 2016), and whether it formed via a monolithic collapse, or as a (potentially ongoing) merger of several sub-structures (e.g. Sabbi et al. 2012).

Also Fujii & Portegies Zwart (2011) suggest that early in the evolution of a cluster, dynamical interactions form an extremely massive binary, which then tightens its orbit by ejecting other stars. The spectral similarities between VFTS682 and stars in the core of R136 are in agreement with this 'bully binary' model. Interpreting the kinematics of VFTS682 through the lens of their simulations suggests the presence of a close binary with total mass $M_1 + M_2 \gtrsim 300\,\mathrm{M}_\odot$ in the core of the cluster. The difference between the cluster age and the kinematic age of VFTS682 puts an upper limit to the time-scale to form the 'bully binary' in R136 of ~$1.3\,\mathrm{Myr}$. Such a binary might be a candidate for a dynamically formed progenitor system of a binary black hole, provided that stars this massive can avoid a pair-instability supernova (e.g. Rakavy & Shaviv 1967) at LMC metallicity (see also Langer et al. 2007; Woosley 2017). Similarly, the final fate of VFTS682 could be either a pair-instability supernova without compact remnant formation, or collapse to a black hole. The amount of mass-loss of these stars will determine their final core mass and thus their final fate (e.g. Vink 2015).

VFTS682 is potentially the most massive runaway known to date, and its ejection from the cluster R136 likely implies that it is only the 'tip of the iceberg' of massive runaways in the region. Studies of this population, enabled by recent and future observations will put constraints on the evolution of these stars, together with the formation and evolution of the central cluster itself.

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