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VFTS682: a confirmed dynamical ejection?

M. Renzo[1] and ■ **[TBD]** ■.

Astronomical Institute Anton Pannekoek, University of Amsterdam, 1098 XH Amsterdam, The Netherlands

ABSTRACT

Key words. stars: kinematics, stars: runaways, stars: individual: VFTS682

1. Introduction

How do stars form is one longstanding question in astrophysics Lada & Lada (2003); Zinnecker & Yorke (2007). It is particularly difficult for massive stars, because these are intrinsically rare (e.g., Salpeter 1955; Kroupa 2001; Schneider et al. 2018), evolve fast, and remain enshrouded in their parent cloud during the formation process. Moreover, observations of young massive stars reveal a complicated multiplicity structure which requires explanation (Kobulnicky & Fryer 2007; Mason et al. 2009; Sana & Evans 2011; Sana et al. 2012; Kiminki & Kobulnicky 2012; Chini et al. 2012; Kobulnicky et al. 2014; Almeida et al. 2017; De Marco & Izzard 2017). Understanding massive star formation, possibly as a function of metallicity, is a key question given the present and upcoming transient survey (e.g., LSST, BlackGem, LIGO/Virgo O3) which will reveal transients associated to massive stars evolution and death.

The second data release (DR2) from the Gaia satellite (Gaia Collaboration et al. 2016, 2018) allows us to test these hypothesis using one particular star, VFTS682. This star is a very massive ($M_{\mathrm{ZAMS}} \simeq 150\,M_{\odot}$, Bestenlehner et al. 2011; Schneider et al. 2018) WNh5 star in the 30 Doradus region of the Large Magellanic Cloud (LMC), and it is presently observed at a projected distance of $\sim$29 pc from the nearest cluster of massive stars R136 (Bestenlehner et al. 2011). Based on the extremely high mass of this star and its present day apparent isolation, Bestenlehner et al. (2011) proposed it might be a candidate for isolated star formation, or a "slow runaway" ejected from R136 in the past. This second option is also supported by the N-body simulations of Fujii & Portegies Zwart (2011); Banerjee et al. (2012). Many other very massive stars are present in the surroundings of R136, and a more detailed analysis on the larger sample is desirable.

Massive stars can in principle be ejected from R136 as a consequence of dynamical interactions (Poveda et al. 1967; Leonard 1991; Evans et al. 2010; Fujii & Portegies Zwart 2011; Allison 2012; Oh & Kroupa 2016), or by the disruption of a binary by the first core-collapse supernova (Zwicky 1957; Blaauw 1961; De Donder et al. 1997; Eldridge et al. 2011; Renzo et al. 2018). However, R136 has an estimated age of $\lesssim$ 2 Myr (Sabbi et al. 2012), which is shorter than the shortest stellar lifetime ($\sim$3 Myr, e.g., Zapartas et al. 2017), so one would not expect the binary disruption scenario to be relevant for this cluster.

In this study, we combine the radial velocity measurements from the VFTS survey (Evans et al. 2011) with the proper motion from Gaia DR2 to reconstruct the three-dimensional velocity of VFTS682, and test the null hypothesis that this star was ejected from R136. ■ **[check the following]** ■ Our results indicate that R136 is the likely origin of this star, and therefore isolated star formation is *not* required to explain it. However, we find a mild discrepancy between the apparent age of VFTS682, its kinematic age, and the age estimates for R136.

In Sec. 2, we describe the data selection and validation process for VFTS 682 and for stars in the surrounding used to calculate and remove the mean motion of the region. Sec. 3 presents our main findings. We conclude by discussing the implications for theories of star formation, N-body interactions, and binary evolution in Sec. 4.

2. Gaia DR2 data selection

VFTS682 is labeled in the Gaia DR2 catalog[1] with the source id 4657685637907503744. The star has a `visibility_period` = 17, which counts how many observations have been used to reconstruct its astrometric solution (Lindegren et al. 2018). Its G-band magnitude is 15.65, cf. the V-band magnitude of 16.08 (Evans et al. 2011; Bestenlehner et al. 2011), and the reported `astrometric_noise` = 0. These values suggest that the Gaia data for VFTS682 are trustworthy. However, the effective temperature reported is one order of magnitude lower than what found by Bestenlehner et al. (2011), and the best fit parallax of this star is negative. We do not use the effective temperature of the star anywhere in this study, and we attribute the unphysical value of the parallax to the large distance to the LMC. Our main findings do not rely on the parallax value reported in the Gaia catalog.

We retrieve for VFTS682 the position in right ascension (RA) and declination (DE) in the IGCS frame (Gaia Collaboration et al. 2018), its proper motion components (μ_{RA}, and μ_{DE}, respectively). For the radial velocity of VFTS682 and of the 30 Doradus region as a whole, we instead use the VFTS data as quoted in Bestenlehner et al. (2011). Table 1 lists the values adopted throughout this work for each of these quantities.

To compare the astrometry of VFTS682 and derive its peculiar motion, we then select data from the Gaia DR2 catalog for two regions: the "surroundings" of VFTS 682, and the "R136

Send offprint requests to: M. Renzo, m.renzo@uva.nl

[1] https://gea.esac.esa.int/archive/

Table 1. Astrometric parameters for VFTS682. The peculiar radial velocity $\delta v_{\rm rad}$ is obtained as the difference between the average radial velocity of the 30 Doradus region (270 ± 10 km s^{-1}) minus the radial velocity measured from the HeII λ4686 line for VFTS682 (315 ± 15 km s^{-1}).

Parameter	Value	Source
RA [degree]	84.73 ± 0.036	Gaia DR2
DE [degree]	-69.07 ± 0.05	Gaia DR2
$\mu_{\rm RA}$ [mas yr^{-1}]	1.84 ± 0.07	Gaia DR2
$\mu_{\rm DE}$ [mas yr^{-1}]	0.78 ± 0.08	Gaia DR2
$\delta v_{\rm rad}$ [km s^{-1}]	-45 ± 25	Bestenlehner et al. (2011)

cluster". The surrounding region is defined by all the stars within 10 arcminutes from VFTS682 ■ **[without a pm and with G mag<17 for VFTS completeness and to focus on massive stars only]** ■. This includes the subset of stars which we consider to be part of R136. We include all the stars for which a value of the proper motion components and the corresponding errors are available. The "R136 cluster" is effectively defined by taking all the stars within 25 arcseconds from R136a, one of the most massive members of the cluster itself (Crowther et al. 2010). ■ **[improve definition of stars from R136 – check with Danny]** ■

Throughout this study, we assume the same distance of 50 kpc to the star, and to the 30 Doradus region as a whole, since the parallax for VFTS682 listed in the Gaia DR2 catalog is negative.

The data retrieved, and the ipython notebook used for the analysis presented here will be made available at ■ **[probably git repo on bitbucket?]** ■.

3. The kinematics of VFTS682

4. Summary and Discussion

- VFTS682 is a bona fide runaway with $v \sim 60$ km s^{-1} thrown out from R136. Both its speed and the age of the cluster are consitent with a dynamical ejection.
- VFTS682 comes from R136 as was expected by Bestenlehner et al. (2011); Fujii & Portegies Zwart (2011); Banerjee et al. (2012), so it does not require isolated SFH to be explained
- apparent age tension (connect to VFTS16 as well).
- is R136 a single young cluster or a merger
- estimate the influence of the gravitational potential of R136, what is its total mass and relaxation time?

Random notes: vsini<200 form Schneider et al. (2018), age 1 ± 0.2 Myr from Schneider et al. (2018)

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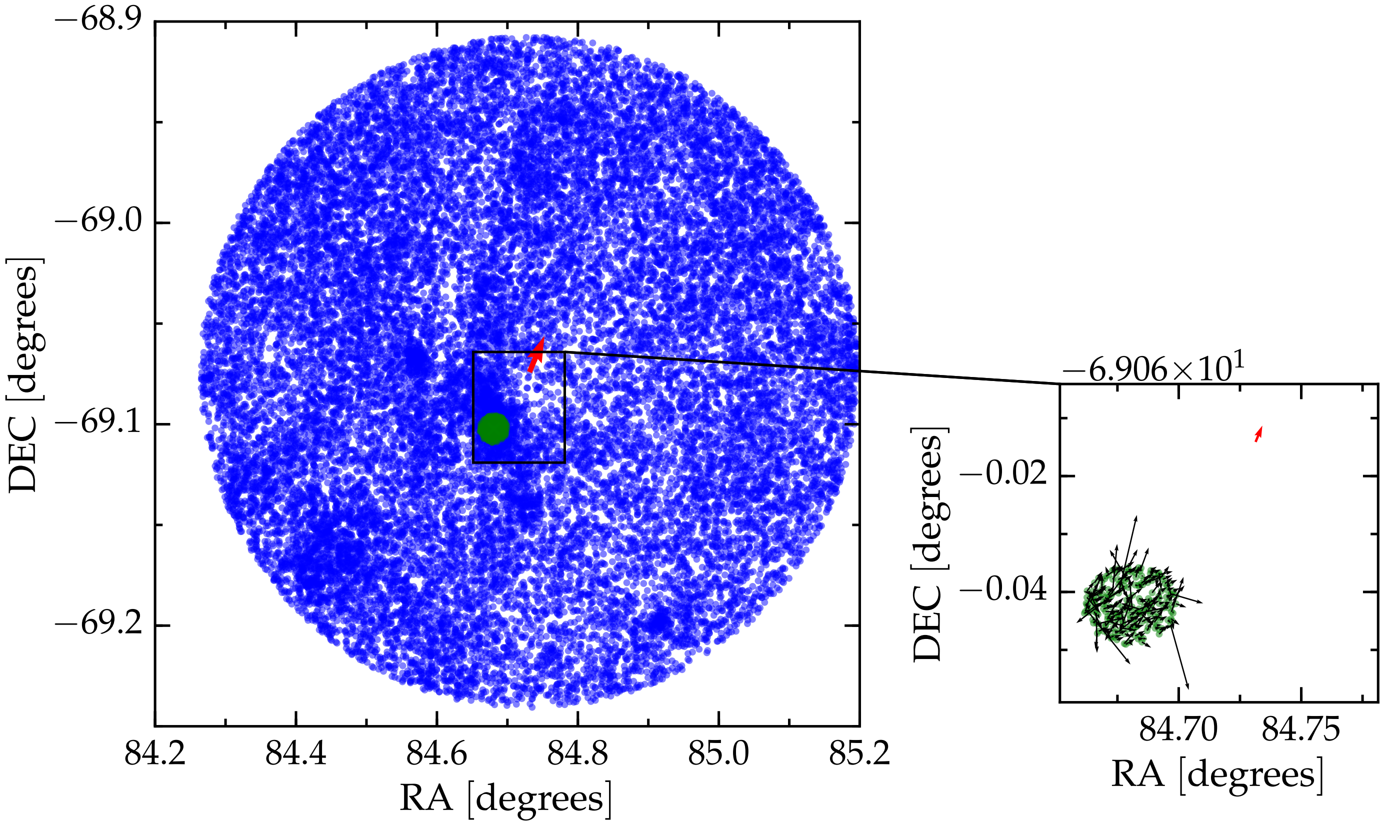

Fig. 1. position and projected relative velocity to R136. ■ **[load pretty picture on background, check scale, clean foreground stars with parallax, add cone of uncertainty]** ■