θ1 Ori C as a medieval bully: a possible very recent ejection in the Trapezium

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ABSTRACT

We use Gaia EDR3 astrometry to propose that a dynamical interaction between the multiple system θ1 Ori C and θ1 Ori F ejected the latter as a walkaway star ~1100 years ago (without deceleration) or somewhat later (with a more likely deceleration included). It is unclear whether the final 3-D velocity of θ1 Ori F will be large enough to escape the Orion nebula cluster.

Keywords: Multiple stars — Runaway stars — O stars — Young star clusters — Astrometry

INTRODUCTION

Stars can be ejected by dynamical interactions among 3+ bodies in stellar clusters (Poveda et al. 1967). Such objects are called runaway stars when their space velocity is > 30 km/s (Hoogerwerf et al. 2001) and are being found in increasing numbers with Gaia astrometry (Maíz Apellániz et al. 2018). Walkaway stars, ejected with velocities < 30 km/s, are even more common than runaways (Renzo et al. 2019).

The prototype dynamical ejection happened near the Orion nebula 2.5 Ma ago, resulting in the high-speed expulsion of AE Aur and μ Col (Blaauw & Morgan 1954) and of a third multiple system, ι Ori (Maíz Apellániz & Barbá 2020), moving more slowly (Hoogerwerf et al. 2001). θ1 Ori Ca, the main component in θ1 Ori C, is a magnetic Of?p object (Maíz Apellániz et al. 2019b), the most massive star in the Orion nebula cluster, and part of a young binary system with an 11 years period and a possible third member (Kraus et al. 2009; Lehmann et al. 2010). θ1 Ori C may have caused the ejection of the Becklin-Neugebauer object from the Trapezium 4 ka ago (Tan 2004) but it is likely too young to have been involved in the previous event. Recent papers have proposed other walkaway and runaways from the Orion nebula cluster (Schoettler et al. 2020; Farias et al. 2020; Platais et al. 2020; Maíz Apellániz et al. 2021a).

METHODS

In the Villafranca project (Maíz Apellániz et al. 2020) we have analyzed the Orion nebula cluster and determined a distance of 390±2 pc and proper motions of 1.577 ± 0.022 mas/a in α and 0.464 ± 0.022 mas/a in δ (Maíz Apellániz et al. 2021a). Here we analyze the Gaia EDR3 astrometry of two Trapezium objects, θ1 Ori C and θ1 Ori F. We apply the zero point of Maíz Apellániz (2021) to the parallaxes and correct the proper motions according to Cantat-Gaudin & Brandt (2021). The astrometric external uncertainties (σext) are calculated with the σs of Maíz Apellániz et al. (2021b) and Lindegren et al. (2021) and the k of Maíz Apellániz (2021).
Figure 1. *Gaia* EDR3 chart of the central $36'' \times 36''$ of the Trapezium. Circle size encodes magnitude and color encodes $G' - G'_{\text{RP}}$, with empty circles for objects with poor color information. Arrows represent proper motions. The yellow and violet ellipses indicate the position and one-sigma uncertainty ellipses in the plane of the sky of the minimum distance from the Montecarlo simulations, with the first one used for all results and the second one for those that have a minimum distance of less than 30 AU.
RESULTS

- The five brightest stars in $\theta^1$ Ori (A to E) have proper motions similar to that of the cluster. F is an outlier.

- The parallaxes of $\theta^1$ Ori C and $\theta^1$ Ori F are within 0.2 $\sigma_{\text{ext}}$ of the cluster parallax. Furthermore, their differences in $G'$ and $G'_{\text{RP}} - G'_{\text{RP}}$ are similar to those expected from their differences in spectral types (see below). Therefore, they are at similar distances and do not experience very different extinctions, contradicting the hypothesis by Olivares et al. (2013) that $\theta^1$ Ori F is a foreground object.

- The movement in the plane of the sky as traced by the Gaia EDR3 proper motions of the two stars points towards a common region of the sky (Fig. 1).

- We have carried out Montecarlo simulations of the trajectories and determined that the minimum distance (in the plane of the sky) took place 1.10 $\pm$ 0.07 ka before the Gaia EDR3 epoch (2016.0) with a value of 340 $\pm$ 110 AU at a position of $\alpha = 05:35:16.321$, $\delta = -05:23:23.65$ (J2000) with uncertainties of $0''.394$ and $0''119$ along axes at PAs of $-77^\circ$ and $13^\circ$.

- The tail of the Montecarlo simulations reaches a minimum distance of zero. Selecting the subset where the minimum distance is less than 30 AU we obtain a very similar flight time to 2016.0 of 1.09 $\pm$ 0.07 ka and a slightly different position (Fig. 1) of $\alpha = 05:35:16.339$, $\delta = -05:23:23.39$ (J2000) with uncertainties of $0''.372$ and $0''076$ along axes at PAs of $-75^\circ$ and $15^\circ$.

- Looking in the WDS (Mason et al. 2001), separations decrease as we go back in time (the first observations are from the nineteenth century) with some scatter and a zero value compatible with an epoch 600-1200 a ago.

- We have no GOSSS (Maíz Apellániz et al. 2011) or LiLiMaRlin (Maíz Apellániz et al. 2019a) spectra of $\theta^1$ Ori F. Costero (2019) classifies it as a chemically peculiar B7.5 p Si star, suggests a spectroscopic mass of 3.7 $M_{\odot}$, and determines that its radial velocity in the frame of reference of $\theta^1$ Ori C is 6.2 $\pm$ 4.2 km/s towards us.

- The relative velocity between $\theta^1$ Ori C and $\theta^1$ Ori F in the plane of the sky is 7.8 $\pm$ 0.5 km/s. Adding the radial velocity leads to a 3-D velocity of 10.0 $\pm$ 2.6 km/s. Therefore, $\theta^1$ Ori F is at most a walkaway star, not a runaway. However, caution is needed because discrepancies of several km/s in the measurements of radial velocities of OB stars are common (Trigueros Páez et al. 2021).

- The two systems are currently separated by 1780 AU in the plane of the sky. Assuming a total mass of $\sim$50 $M_{\odot}$ (Kraus et al. 2009; Lehmann et al. 2010) and that the trajectory is mostly in the plane of the sky leads to an escape velocity of $\sim$7 km/s. For a 3-D trajectory, the value would go down to $\sim$5 km/s. As that value is just $\sim$1/2 of the measured velocity, the assumption above that the trajectory is linear is wrong. The system must have experienced a significant deceleration since maximum approach (hence reducing the flight time) and should slow down even more in the future. Furthermore, the chances of a close minimum distance are increased.

CONCLUSIONS

These results indicate that $\theta^1$ Ori F was ejected from the $\theta^1$ Ori C (currently double or triple) system during the middle ages (1.1 ka ago or less including deceleration). This is a recent example of the complex three-or-more-body encounters that take place in very young stellar clusters with massive stars such as the one in the Orion nebula. Nevertheless, the small difference between the measured velocity and the escape velocity from $\theta^1$ Ori C does not allow us to clearly establish whether $\theta^1$ Ori F will leave the cluster after escaping from $\theta^1$ Ori C or not (Costero et al. 2008). See Maíz Apellániz et al. (2017) for another example of a recent dynamical encounter between (very) massive stars and with an also uncertain outcome.

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