*Astronomy and Astrophysics in the Gaia sky*
*Proceedings IAU Symposium No. 330, 2017*
*A. Recio-Blanco, P. de Laverny, A.G.A. Brown & T. Prusti, eds.*

doi:10.1017/S1743921317005518

# Runaway companions of supernova remnants with Gaia

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**Abstract.** It is expected that most massive stars have companions and thus that some core-collapse supernovae should have a runaway companion. The precise astrometry and photometry provided by Gaia allows for the systematic discovery of these runaway companions. We combine a prior on the properties of runaway stars from binary evolution with data from TGAS and APASS to search for runaway stars within ten nearby supernova remnants. We strongly confirm the existing candidate HD 37424 in S147, propose the Be star BD+50 3188 to be associated with HB 21, and suggest tentative candidates for the Cygnus and Monoceros Loops.

**Keywords.** supernovae: general – binaries: close – ISM: supernova remnants

## 1. Introduction

Most massive stars in the range $8 < M/M_{\odot} < 40$ are born in binaries (e.g. Sana *et al.* 2012) and explode in core-collapse supernovae (SNe, e.g. Heger *et al.* 2003). In the SN explosion the envelope of the primary is ejected at more than 5000 km s$^{-1}$ and forms a SN remnant (SNR) shell around the system (e.g. Reynolds 2008). This mass loss can unbind the binary and result in the ejection of the secondary as a runaway star (Blaauw 1961). The ejection velocity is primarily determined by the orbital velocity prior to the SN. Processes such as mass transfer or a common envelope phase can shrink the separation and increase the orbital velocity. Discovering the runaway former companion of a SNR progenitor can thus place tight constraints on the evolutionary history of the progenitor binary. We conduct a targeted search for runaway companions of ten SNRs within 2 kpc using astrometry and photometry in the first data release of the Gaia satellite.

## 2. Method

We consider all stars within the central quarter radius of each SNR present in a cross-match of the Tycho-Gaia Astrometric Solution (TGAS, Gaia Collaboration *et al.* 2016) with the AAVSO Photometric All-Sky Survey (APASS). We construct predictive models for the hypotheses that a given star is the runaway companion or is a background star. Our prior incorporates our best knowledge of the distance and age of each SNR, a prior on the properties of runaway stars (calculated using the binary evolution software *binary_c*, Izzard *et al.* 2006), and a distribution for the reddening along the line-of-sight to each star (generated based on samples from the Green *et al.* 2015 dust-map). The likelihood function translates these model parameters into predicted observables for each star, which are the parallax, proper motions and $G$ band magnitude from TGAS and $B-V$ colour from APASS. The background model is a kernel density estimate generated

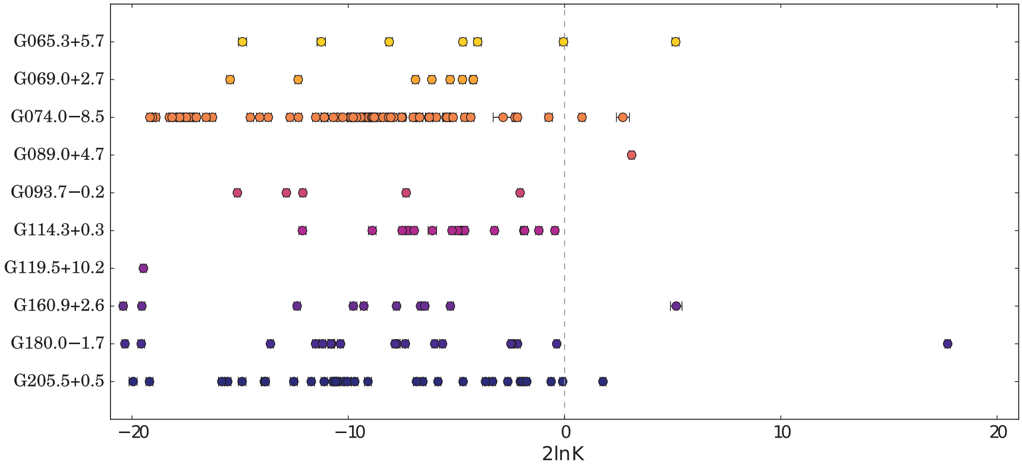


**Figure 1.** Bayes factor comparing the runaway and background hypotheses.

from stars drawn from an annulus of width 10 deg around the SNR. Further details on the implementation of this method can be found in Boubert *et al.* (2017).

## 3. Discussion

In Figure 1 we show the Bayes factor $K$ for every star in each SNR. Seven of our candidates have a Bayes factor which favours the runaway hypothesis. Three can be dismissed as contaminants due either to anomalously large errors in APASS or them being foreground stars which are not well described by the background model. The most favoured of the remaining stars is HD 37424 in S147 which Dinçel *et al.* (2015) had suggested as the runaway companion based on a past spatial coincidence with the associated pulsar. Our best novel candidate is the Be star BD+50 3188 in HB 21. The Be star phenomenon has been linked to mass transfer in a binary preceding a SN explosion (Pols *et al.* 1991) and thus that BD+50 3188 is a Be star supports its runaway candidacy. The other candidates are TYC 2688-1556-1 in the Cygnus Loop and HD 261393 in the Monoceros Loop. The release of Gaia DR2 in April 2018 will allow us to both rule out the existence of a runaway companion for nearby SNRs and to extend our search to more distant SNRs.

*This work has made use of data from the European Space Agency (ESA) mission Gaia (*`https://www.cosmos.esa.int/gaia`*), processed by the Gaia Data Processing and Analysis Consortium (DPAC,* `https://www.cosmos.esa.int/web/gaia/dpac/consortium`*). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.*

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https://doi.org/10.1017/S1743921317005518 Published online by Cambridge University Press