Possible pre-SN binary companion to the progenitor of the SNR IC 443

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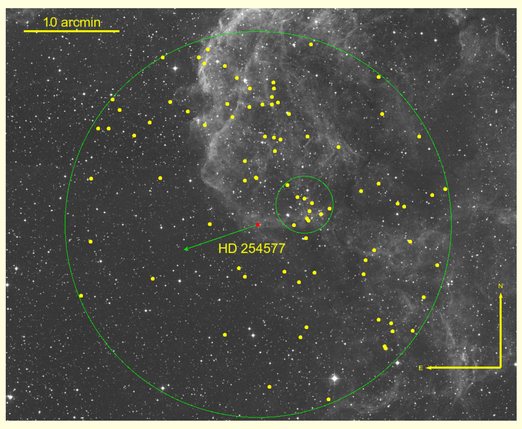
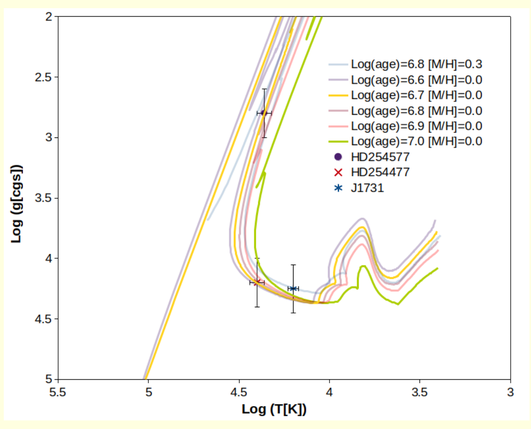
Abstract

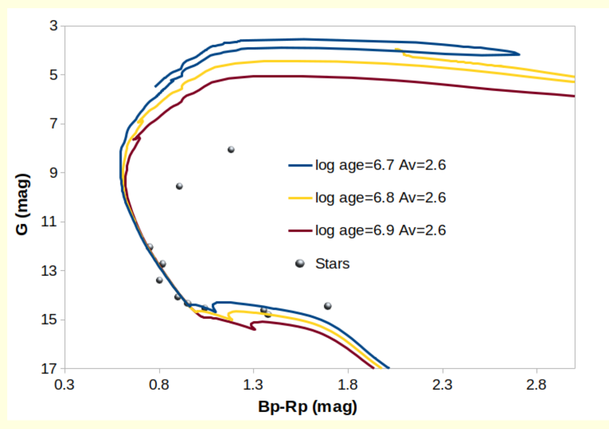
HD 37424 has been the unique, precise example of the binary supernova scenario for the OB-runaway stars [1]. In this work, we present another very promising OB-runaway star, HD 254577, inside the SNR IC 443. We show the kinematics and the atmospheric parameters of the star, the explosion site of the SNR, the progenitor mass, the distance to the SNR and the pre-supernova binary parameters.

Birth Cluster

Using the Gaia DR3 proper motions and the distances from [2], we detected 85 stars within 10 pc of HD 254577 in distance consistency with a narrow dispersion (see **Kinematics**). HD 254577 is moving away from a smaller concentric group of stars (possible Open Cluster – OC) with a proper motion at the same distance with a narrow velocity dispersion ($\sim$3 km s^{-1}). We have generated isochrones using `Parsec-v1.2` evolutionary codes [3], and IMF from [4] in `CMD-3.7` [5]. We found the cluster ages of $4-8$ Myr for solar metallicity from the three stars for which we have the spectra. Due to the large dispersion in A_V values throughout the region, the reddened isochrone fit is not successful with the brightest stars.







Kinematics

Based on Gaia DR3 catalog;

The proper motion of HD 254577 in mas yr^{-1}:
- μ_α^*=4.303 $\pm$ 0.019, μ_δ=$-$1.464 $\pm$ 0.014
- $r_{geo} = 1701^{+55}_{-54}$ pc

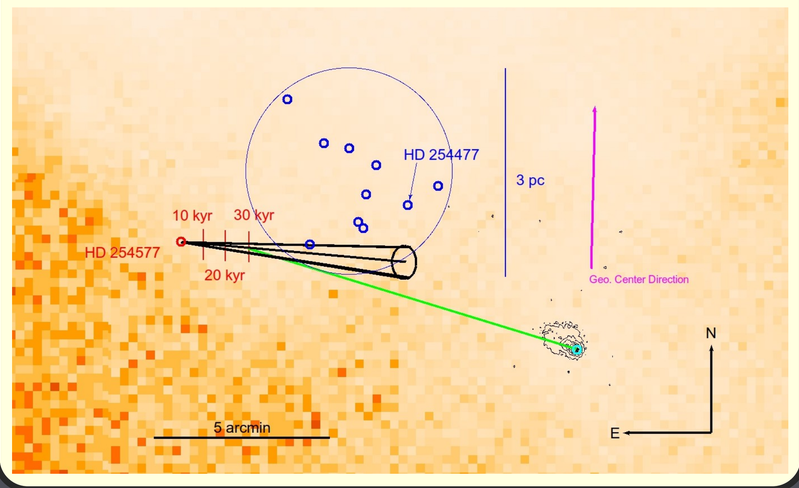
Stars within 10 pc:
- μ_α^*=0.401 $\pm$ 0.155, μ_δ=$-$1.775 $\pm$ 0.361
- $r_{geo} = 1731 \pm 68$ pc

Possible OC:
- μ_α^*=0.437 $\pm$ 0.078, μ_δ=$-$1.814 $\pm$ 0.249
- $r_{geo} = 1710 \pm 71$ pc

The proper motion of HD 254577 in mas yr^{-1} w.r.t;

- Galactic Rotation:
  - μ_α^*=4.500 $\pm$ 0.020, μ_δ=0.058 $\pm$ 0.014
  - 2-D $v_{pec} = 36.3 \pm 0.2$ km s^{-1}
- Possible Open Cluster:
  - μ_α^*=3.866 $\pm$ 0.097, μ_δ=0.350 $\pm$ 0.263
  - 2-D $v_{pec} = 31.3^{+1.1}_{-0.9}$ km s^{-1}

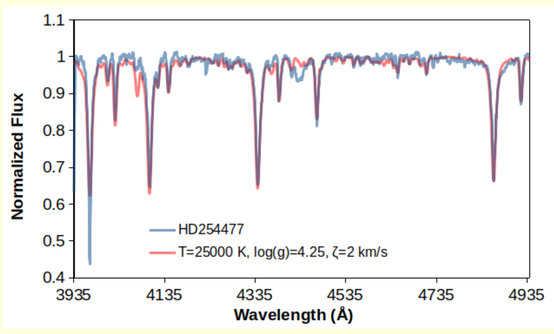
The corrected proper motion was traced back for possible SNR ages: 10, 20 and 30 kyr; hence the possible explosion centers were found. Using these coordinates and ages, the NS 2-D space velocities were found as 537, 254, 159 km s^{-1}, respectively. The cometary tail axis of the PWN favors a common origin with the OB-runaway star. The figure below is the ROSAT image of the proposed explosion site with Chandra Acis-I contours of the PWN overlayed. The tracing back of the runaway star's proper motion w.r.t. to the cluster (black lines), the cluster members (blue circles), and the flight path of the NS for 30 kyr age (green line) are shown.

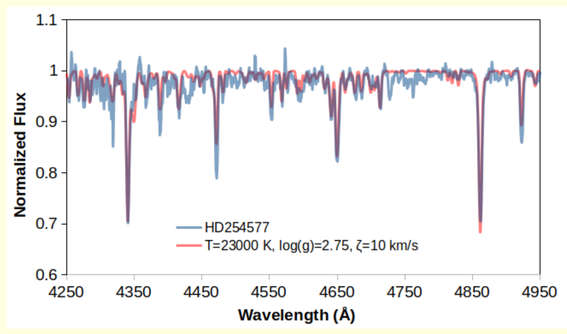


Observations

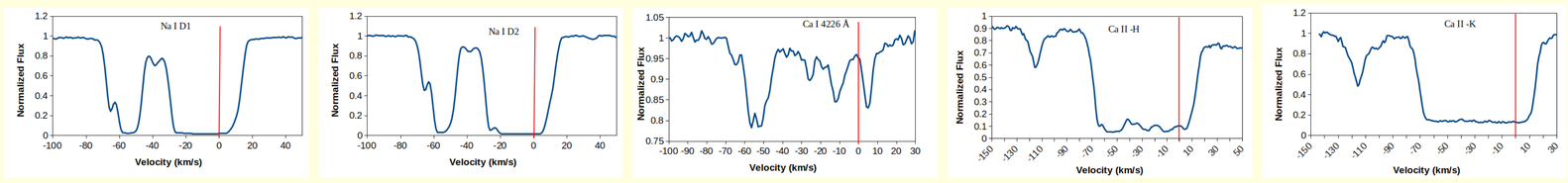
One Subaru HDS spectrum (R$\sim$90000) and seven 90-cm Schmidt Telescope (Uni-Observatory Jena) FLECHAS (R$\sim$9000) spectra of HD 254577 were taken in 2015 and 2024. Also, public LAMOST spectra of the cluster members, HD 254477 and J061731.40+222555.2 were analyzed. The data were reduced in IRAF. The atmospheric parameters were determined by comparing the star spectra with PoWR and Tlusty model atmospheres [6, 7]. The radial velocity of the stars was measured using the cross-correlation method with these model spectra.

- **OB-runaway star HD 254577:** T_{eff}=23000$\pm$2000 K, log(g[cm s^{-2}])=2.8$\pm$0.2, $\zeta = 10$ km s^{-1}
  $RV_{helio} = 25 \pm 7$ km s^{-1}, $RV_{pec} = 7 \pm 7$ km s^{-1}, no RV variation
- **OC Member HD 254477:** T_{eff}=25000$\pm$2000 K, log(g [cm s^{-2}])=4.2$\pm$0.2, $\zeta = 2$ km s^{-1}
  RV varying (spectroscopic binary)
- **OC Member J061731.40+222555.2:** T_{eff}=15000$\pm$1000 K, log(g [cm s^{-2}])=4.25$\pm$0.25, $\zeta = 2$ km s^{-1}



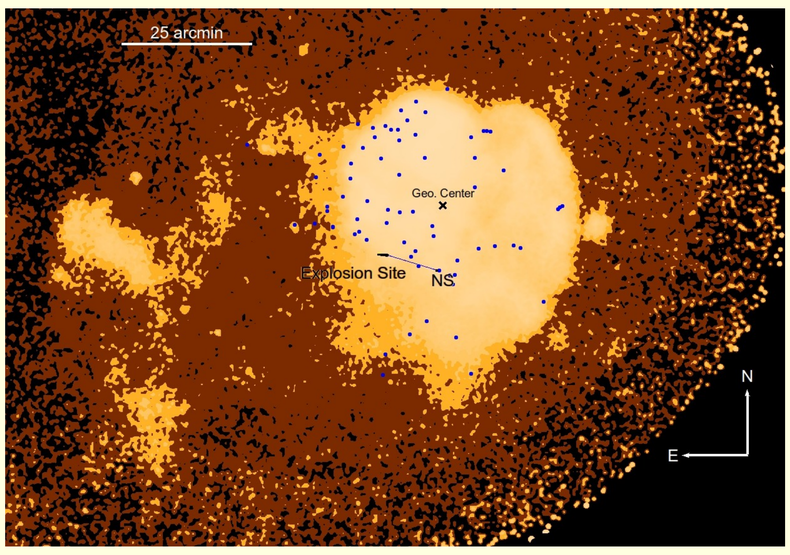


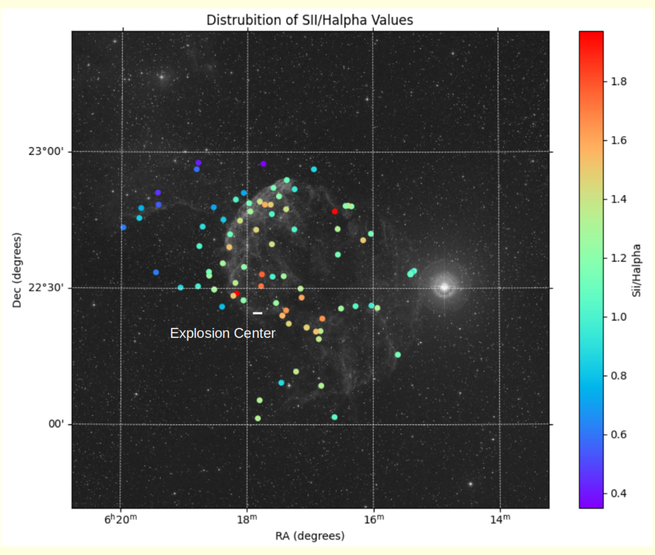
High velocity ISM absorption lines of Ca I, Ca II, and Na I are all blue-shifting. Also see [8]. The reference (zero) velocity (red line) is $RV_{helio} = +18$ km s^{-1} determined after solar motion and galactic rotation corrections:



Results

- 3-D peculiar velocity, $v_{pec} = 32.6^{+2.9}_{-2.2}$ km s^{-1}. It is a Runaway Star!
- The cometary tail direction, blue-only shifted ISM lines, distance consistencies, and expected NS velocities favor the idea that HD 254577 is the pre-SN binary companion to the progenitor of IC 443.
- Assuming solar metallicity, the masses for the cluster age, log(age[yr])=6.7 and 6.8;
  - HD 254577 mass: M= 28, and M= 36 $M_\odot$.
  - Progenitor mass: M= 31, and M= 42 $M_\odot$.
- For a circular pre-SN binary orbit, the Roche-Lobe radii are found between 1761 and 4707 $R_\odot$.
- The explosion center is highly separated from the geometrical center: inhomogeneous expansion.
- Our optical spectroscopic study and the ROSAT X-ray images show that the SNR expands to a low-density medium in the east. For more details, please visit Günay Paylı's poster (**S4.20**).





References

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