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Wolf-Rayet candidates in the vicinity of Kes 75 PWN complex

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Introduction

Pulsar J1846-0258, primarily regarded as a rotation-powered pulsar(RPP) have been recently found to exhibit behaviors similar to magnetars, as less common type of Neutron Stars(NS). [Straal et al., 2023] reported a high energy (100MeV - 500GeV) Gamma ray analysis of KES 75 PWN using Fermi-LAT data and they found the inclusion of this GeV emission underscored the necessity for an additional high-temperature Inverse Compton (IC) photon field for accurately representing the contribution of the PWN[[Straal et al., 2023]].

Subsequently, the temperature (T) and luminosity (K) of the secondary photon field were derived and converted to stellar properties. The obtained values were reported to closely align with those of Wolf-Rayet stars as documented in existing literature [[Tramper et al., 2015], [Millette and Pierre, 2021]].

Believed to end their lives as Type Ib and Ic Supernovae remnant (SNR) WR stars mark significant objects in the study of stellar evolution. Hence, the presence of such a star embedded in the Kes 75 PWN would suggest its role as the binary companion of the progenitor of the PSR in the Kes75 complex as well as the confirmation of WR stars' explosive fates as SNR events [[Shara et al., 2009]].

Methods

We approach our selection of the WR candidate as follows.

- **Distinguishing from Background Stars** WR stars are characterized by strong winds, producing free-free emission and exhibiting excess infrared emission in their Spectral Energy Distributions (SEDs). This distinctive property causes WR stars to occupy relatively depopulated positions in Infrared (IR) color-color diagrams, aiding in their differentiation from background stars. The most recent criteria for identifying WR stars based on their Near Infrared colors are outlined in [Faherty et al., 2014].

$$(H-K_s) > 0.50 \times (J-H) + 0.02, (H-K_s) < 0.50 \times (J-H) + 0.27 \quad (1)$$

$$(H-K_s) > 0.50 \times (J-H) + 0.27, (H-K_s) < 0.60 \times (J-H) + 0.63 \quad (2)$$

- **Correction for Magnitude** The final expected K-magnitude, after correcting for extinction, was calculated to be 15.00 if the source is at the center (Table 1). However, the precise location of our source is undetermined, requiring a correction factor to account for the offset with respect to the center. The offset correction factor (c) was derived as

$$c = \begin{cases} \dfrac{2}{\int \sqrt{1-\left(\frac{x}{R}\right)^2 \sin^2\alpha\, d\alpha}}, & \text{if } \frac{x}{R} < 1 \\ \dfrac{2}{1+\int_0^{\sin^{-1}\left(\frac{R}{x}\right)} \sqrt{1-\left(\frac{x}{R}\right)^2 \sin^2\alpha\, d\alpha}}, & \text{if } \frac{x}{R} > 1 \end{cases} \quad (3)$$

  where x is the distance of the source from the center, R is the radius of the PWN. As the source moves further away from the central region, the magnitude of the source should increase, justified as a brighter source capable of contributing to the photon field. This expected trend is later visually represented by the shaded curve in Figure 2, outlining the anticipated range of K magnitudes for our source of interest.
- **Correction for Distance via counterpart check in high absorption wave-bands** KES75 is located in a region of high Hydrogen Column Density and we shouldn't be expecting our source of interest to be detected in surveys with high optical extinction. We proceeded to check GAIA and IPHAS surveys to eliminate the sources detected in these surveys.
- **Exclusion of Red Giants** In [Lucas et al., 2008], diagrams were presented to aid in the interpretation of data as the higher sensitivity of UKIDSS caused the detection of red gaints possibly leading to source confusion. Since our final candidate is a WR star, we can rule out sources which can be identified as red gaints.

Properties	[Straal et al., 2023]	This Work
Temperature (K)	1.46×10^5	1.44×10^5
Luminosity ($L_\odot$)	1.07×10^6	2.59×10^5
Radius ($R_\odot$)	1.62	0.819

Table 1. Properties of the source assuming central position

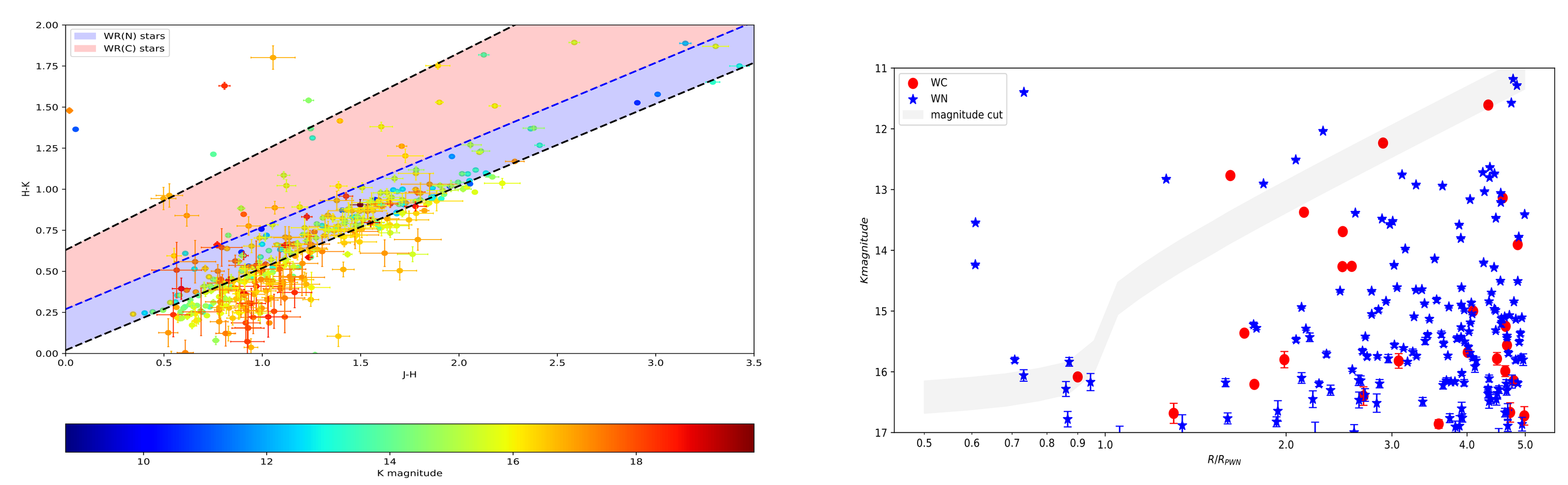

Figure 1. WR selection Criteria and Magnitude Correction

Given the high hydrogen column density (N_H) in the KES 75 region, we use the fact that sources in the region must go undetected in wave bands with high extinction, such as GAIA G and IPHAS r . After analyzing the detection in these surveys, we found the presence of four of our candidates in GAIA and IPHAS thus eliminating those from being in the KES 75 region Table 1). Subsequent analysis only involved the sources undetected in GAIA and IPHAS.

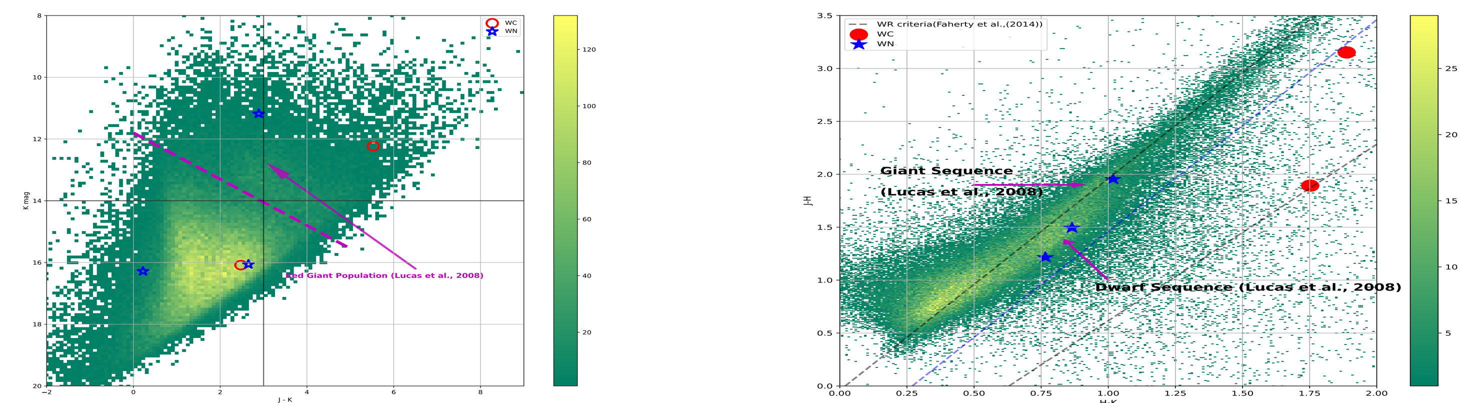

Figure 2. Further elimination methods as presented in [Lucas et al., 2008]

	WC	WN
Color Criteria ([Faherty et al., 2014])	28	195
Magnitude Correction	3	6
GAIA and IPHAS Counterpart Check	2	3
Excluding Red Giants	1	2

Table 2. Number of candidates after each selection step

In the concluding step, we combined all the previously established criteria to search for the WR candidate positioned at 5.8 kpc at random locations. This random search was conducted across 100 randomly selected locations situated in the same line of sight as KES75 (RA: 18h46m24.5s, DEC: $-2°58'27"$), constrained within a 30" radius.

Results and Discussion

The analysis included WR(C/N) color verification, magnitude assessment, exclusion of red clump sources, and cross-referencing with counterparts in fainter catalogs. The results indicated that roughly 90% of the time, the random locations returned fewer final candidates (namely, 0 WC <2 WN) than the number obtained in the KES75 region [Figure 3]. Consequently, this suggests that our discovery of the correct WR star is not a strong coincidence, as it occurred only in 10% of the cases, yielding a p-value of 0.1.

As seen in Figure 2, the Nitrogen Rich candidates still include the dwarf sequence stars making the NIR color criteria to be unreliable for Nitrogen rich candidates which we assume is the reason for slight overestimation of final candidates in the statistical test.

Further research would be to obtain a more extensive spectrum of the final candidates' locations and confirm their nature as Wolf-Rayet stars.

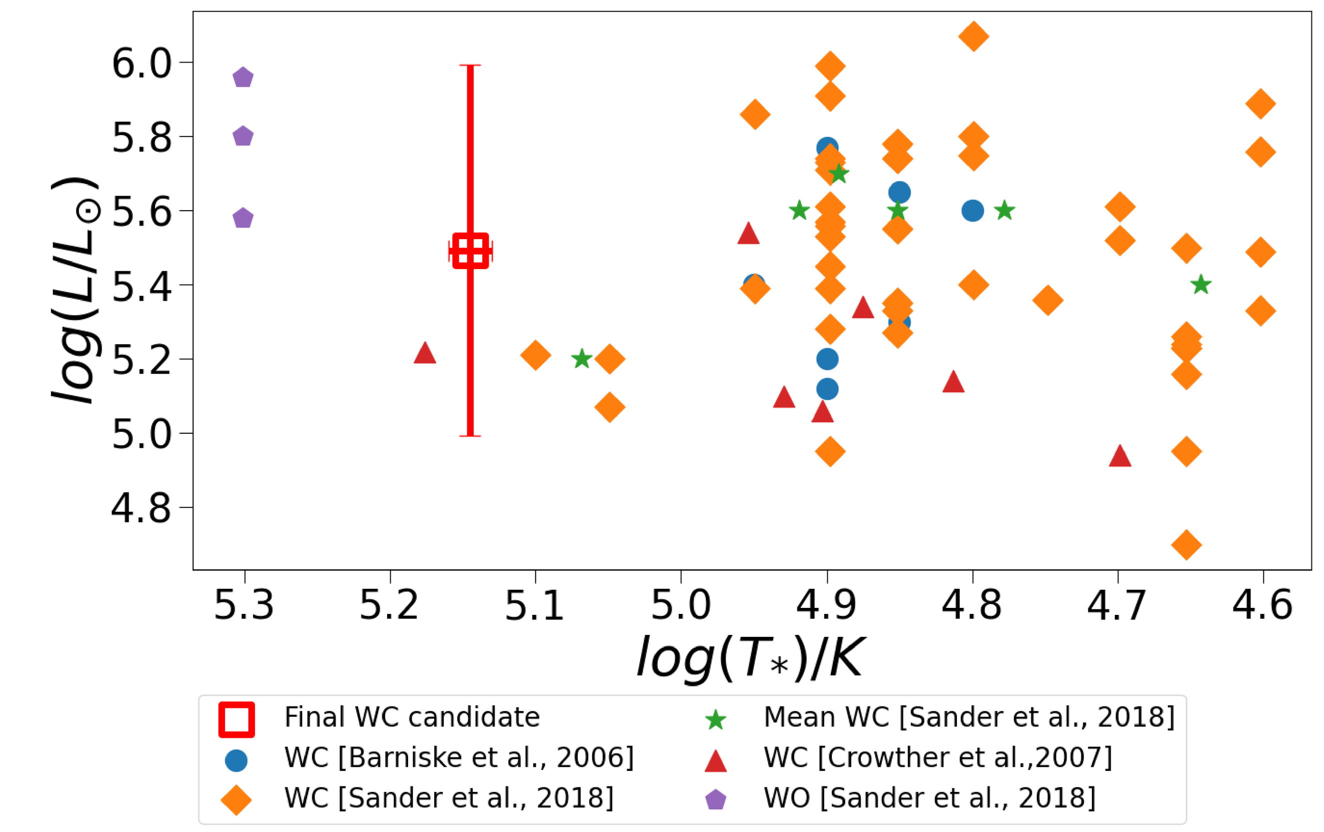

Figure 3. Position of final WC candidate on Temperature - Luminosity Space

References

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