Multi-Wavelength Modelling of the Pulsar Wind Nebula in Kes 75

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Why is Kes 75 important?

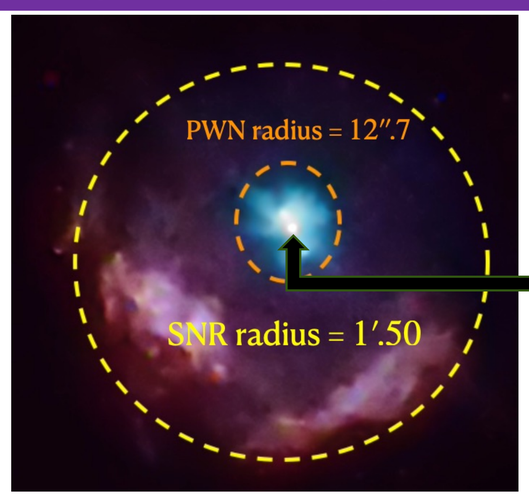
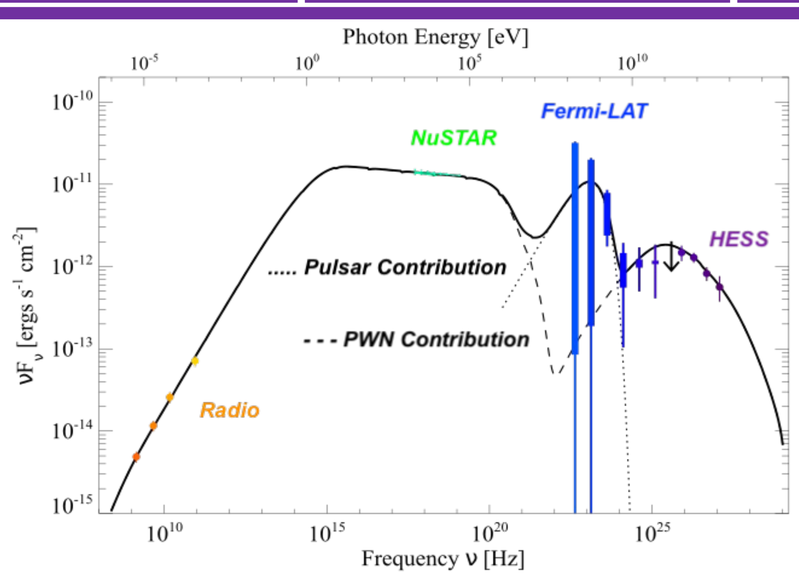


Figure: Chandra X-ray image of Kes 75. Credit: NASA/CXC/GSFC/F.P.Gavriil et al.

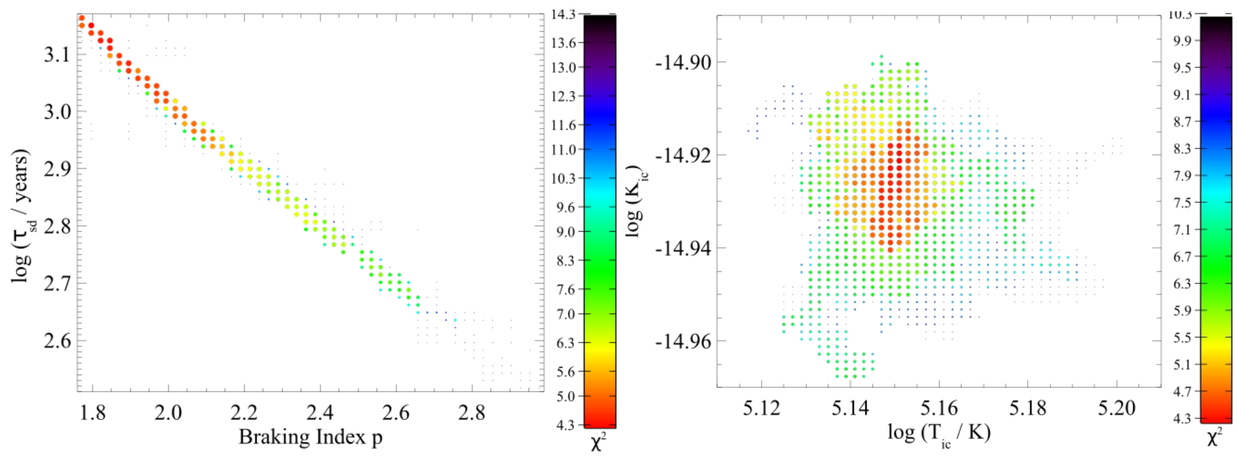
- Powered by an X-ray rotation-powered-pulsar (RPPs) with magnetar like behavior
- High E = 3.14 $\times$ 10^{36} ergs/s ⟶ **Energetic System**
- Low T_{ch} ~ 720 years ⟶ **Young System**
- High magnetic field (B_{sd} ~ $5 * 10^{13}\ G$) ⟶ **Connected to magnetar activity?**
  - Showed a magnetar like outburst in 2006 that was accompanied by:
    - X-ray flux increase
    - Change in braking index from **p = 2.65 to p = 2.16**
  - Went into another outburst in 2020 **(p = 2.7 before outburst)**

Model Description & Fitted Properties



- We use a one-zone evolutionary model of a PWN inside an SNR based on *Gelfand et al. 2009*.
- The model uses MCMC algorithm to reproduce the properties of the source:
  - **Dynamical Properties:** SNR size, PWN size and distance to the PWN
  - **Spectral Properties:** Radio, X-ray & Gamma-rays (Fermi-LAT & HESS) flux densities

Key Results from the Modelling



1. **Braking Index (Left Panel):**
   - The model strongly favors the current value of the braking index (p = 1.8 – 2.1)
   - This suggests that the pre-2006 outburst was just a transient state
2. **Secondary Hot & Intense Photon Field (Right Panel):**
   - On top of the CMB and cold background photon field, we require an additional very hot & intense photon field to fit the gamma-rays with the following properties:
     - Temperature: **1.4 $\times$ 10^5 K**
     - Energy Density: **7.3 $\times$ 10^{-9} ergs/cm³**
   - Assuming the source responsible for this field is present at the center of the PWN, the stellar properties of the field translates to that of a **Wolf-Rayet** star with:
     - Luminosity**: 2.6 $\times$ 10^5 $L_\odot$**
     - Radius: **0.82 $R_\odot$**
     - Extincted apparent K magnitude: **14.5**
   - As the source moves further away from the central region, the magnitude of the source should decrease, implying a more luminous source

Search for the WR Candidate

- Of the existing Optical and NIR surveys of the Kes 75 field, only the United Kingdom Infrared Deep Sky Survey (UKIDSS) could detect this source.
- WR stars are divided into 3 classes; **WN stars (nitrogen dominant, some carbon), WC stars (carbon dominant, no nitrogen)** and rare **WO stars with C/0 < 1**

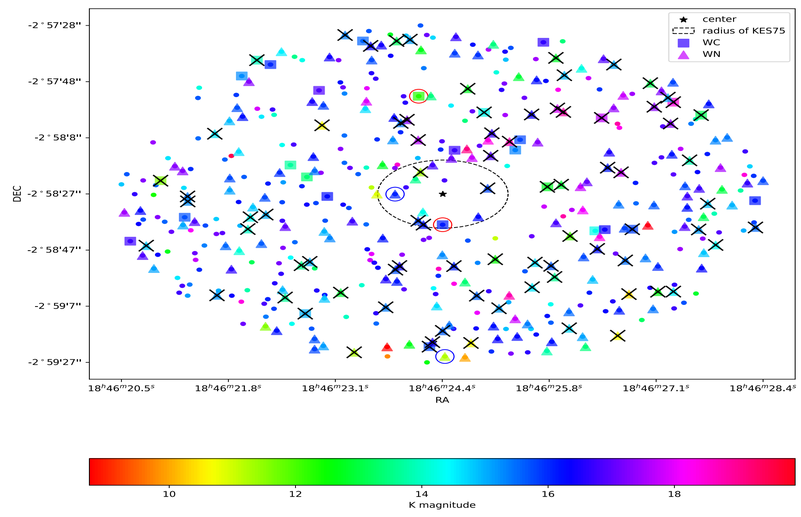


Figure: Location of potential UKIDSS sources within 1' from the center of kes 75 with WR candidates highlighted. GAIA & IPHAS detections are marked with crosses

Outline of the Search & Elimination Process

1. **Use NIR colors to distinguish between WR candidates and background stars**
   - Identify WR stars based on the criteria outlined by Faherty et al., 2014 using their NIR colors
   - Select UKIDSS sources located within 1' of Kes 75 that satisfy the NIR color cut and have the expected k magnitude inferred from the hot photon field
2. **Eliminate Sources in less sensitive surveys**
   - Given the high N_H towards Kes 75, a WR star in the region should be undetected in other surveys such as **Gaia G and IPHAS r**
3. **Projected Distance and Magnitude Correction**
   - The source positions in the above figure are projected locations & the sources could actually be further away from the center of Kes 75
   - We calculated the expected magnitude of the sources if they were offset from the center of the PWN, resulting in a few final candidates possessing the correct magnitude to contribute to the photon field
4. **Distinguishing between WR Stars and Red Giants**
   - UKIDSS survey is sensitive enough to detect red giants with similar colors as WR stars
   - We used the color diagrams by Lucas et al., 2008 to eliminate red giants from our potential UKIDSS sources

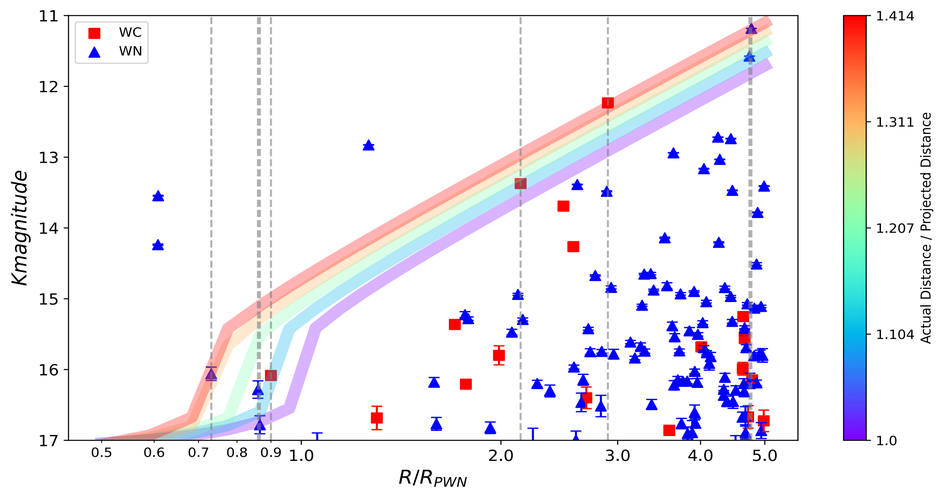


Figure: The expected magnitude of the illuminating sources. The shaded region represents the possible WR candidates that have the correct K magnitude to illuminate the PWN. The gradient of the shaded lines are possible actual separation ranges

- **False Probability Test**
  - Using the same criteria above, we searched for a WR candidate at 100 random locations within 1 degree from kes 75
  - Results: 90% of the time, the search returns fewer candidates than the number obtained from the kes 75 region

Results & Final Remarks

1. **The time average braking index is closer to its value between the outburst**
2. **Kes 75 is likely illuminated by a WR star suggesting it has a massive progenitor**
3. **Further MCMC explorations are underway to constrain more properties (e.g, pulsar wind, supernova explosion properties & ISM density)**

References

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