THE SHROUD FRACTION

A method for finding Circumstellar Material around Wolf-Rayet stars

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Outline

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- Circumstellar Material
  - Circumstellar Dust
  - Wind-Blown Bubbles
- Analysis
  - The Shroud Fraction
  - Observations
- Discussion
- Conclusions

Background

Wolf-Rayet Stars

- As massive O stars evolve, they are believed to enter a phase of extreme mass loss
  - O → OIf → BSG → LBV → WN → WC → Supernova (>50 solar masses)
  - O → BSG → YSG → RSG → WN → WC → Supernova (35-50 solar masses)
- Three broad classes - WN, WC, WO which describe dominant emission lines (Nitrogen, Carbon, Oxygen)
- WR stars are massive stars (> 10 solar masses) undergoing copious mass loss through winds
- Wind speeds are greater than 800 km s^{-1} and running up to 3000 km s^{-1}
- Mass loss rates of 10^{-5} solar masses a year, which affect the evolution of the star

Circumstellar Material

- Circumstellar Dust
  - Typically dust is destroyed by the UV radiation of WR stars however WR stars have been found with dusty shells
- Wind-Blown Bubbles
  - Central mass-losing star creates cavity from its winds, sweeping up the local ISM
  - Only a few dozen identified WBBs in our galaxy

http://www.ruppel.darkhorizons.org/ngc_6888.htm

Goal

- Given a set of Wolf-Rayet stars, determine the fraction that is likely to be shrouded by circumstellar material
- Using a pre-existing catalog of WR stars in the Milky Way, extinction laws, and observations, find the shroud fraction

Analysis

Extinction

- Given the observed b-v and the intrinsic b-v of WR stars, on can calculate the visual extinction and column density

$$A_V = E(B-V)\left[\left(\frac{\lambda_B}{\lambda_K}\right)^{-1.53} - 1\right]^{-1} \text{mag}\,, \quad N_H = A_V \times 1.8 \times 10^{21}\ \text{cm}^{-2}$$

- For our purposes, WR stars at a distance greater than 8 kpc were removed from the data set

- Determined a threshold extinction by using catalogued distances and calculated column densities

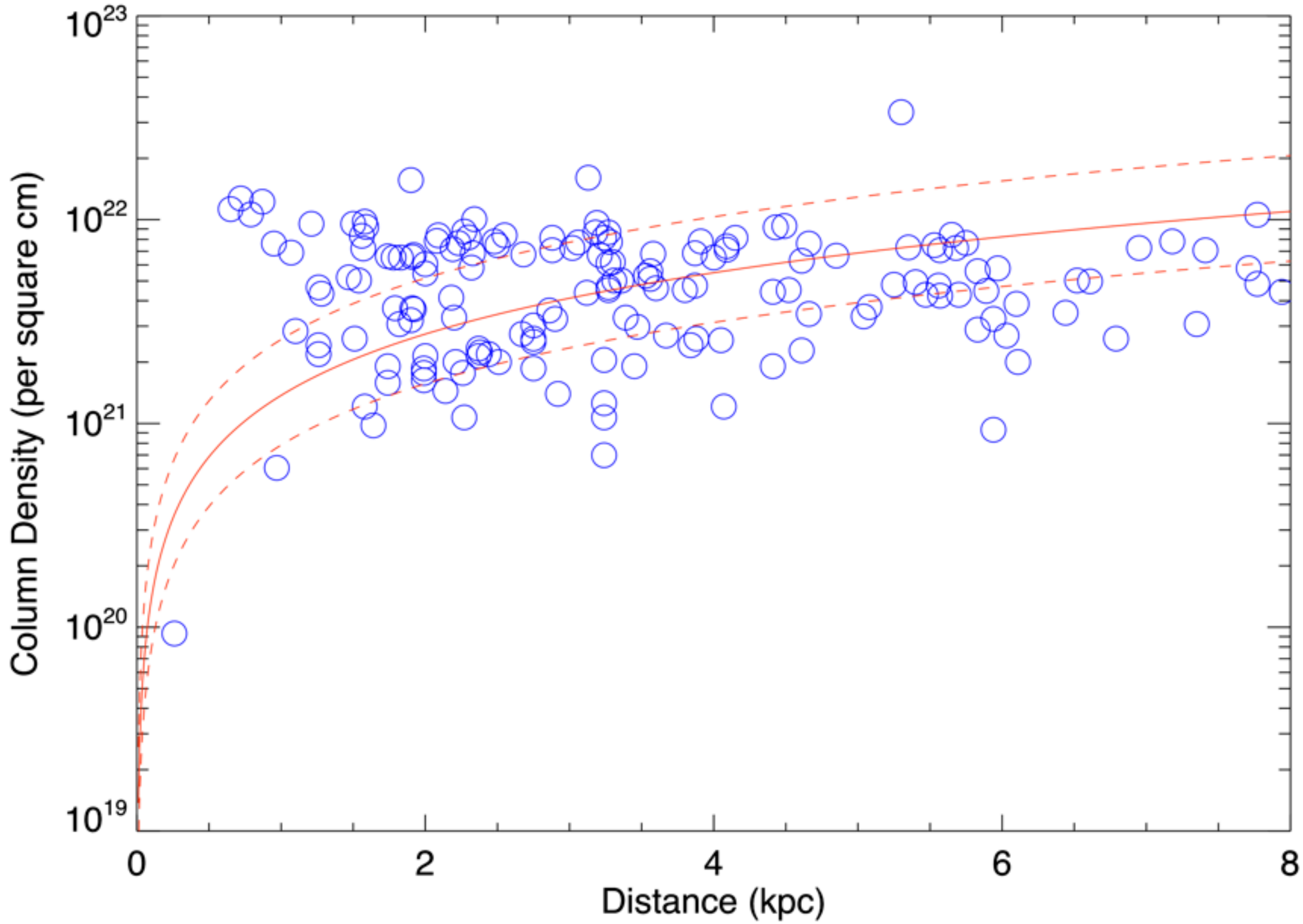
$$N_H = \int_0^D n_H(D')dD' = \bar{n}_H \times D \quad \longrightarrow \quad \bar{n}_H = \frac{N_H}{D} \quad \longrightarrow \quad N_H(D) = \bar{n}_H \times D$$

ALETHIOMETER

- "ALETHEIA" - Greek word for truth
- Program designed to find stars in a catalogue with higher calculated column densities than a given threshold value
  - AV is calculated for each star given the catalogued data
  - NH is calculated from the AV value and compared with the threshold value
    - If above the threshold value, the star is flagged as shrouded

The VIIth Catalogue

- The VIIth Catalogue of Wolf-Rayet Stars
  - Created in 2001, contained at the time photometric data on 227 WR stars found in the Milky Way
  - Since then hundreds more WR stars have been found in the Galaxy
  - 164 WR stars < 8 kpc away
- Two subsets of WR stars were chosen
  - WN4, 12 stars
  - WC6, 7 stars
- Ran ALETHIOMETER on the catalogue to determine corresponding Shroud Fraction



Calculated Column Density (WR Catalog)

Projected Shroud Fraction

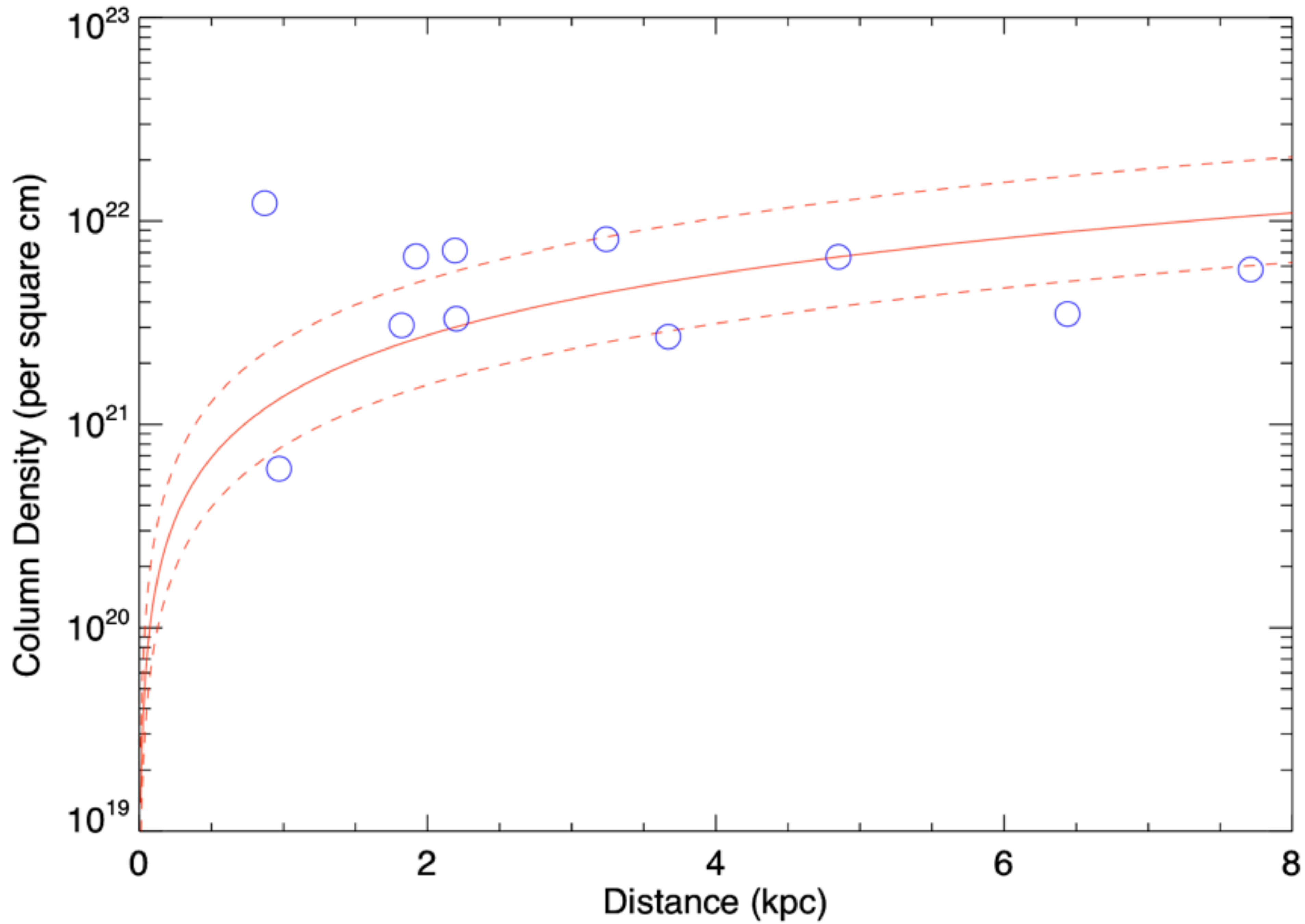
- SF = Shroud Fraction
- Using the median threshold column density as an absolute lower limit for finding potentially shrouded WR stars, we can determine the SF
  - 82/164 = 0.50 above median
  - 42/164 = 0.26 above upper threshold (25% above median)

WN4 Subset

- WR1 - no recorded CM association
- WR6 - S 308
- WR7 - NGC 2359
- WR18 - NGC 3199
- WR35b - no recorded CM association
- WR37 - no recorded CM association

WN4 Subset

- WR42b - no recorded CM association
- WR44a - diffuse emission
- WR45b - no recorded CM association
- WR46a - no recorded CM association
- WR62a - no recorded CM association
- WR129 - no recorded CM association



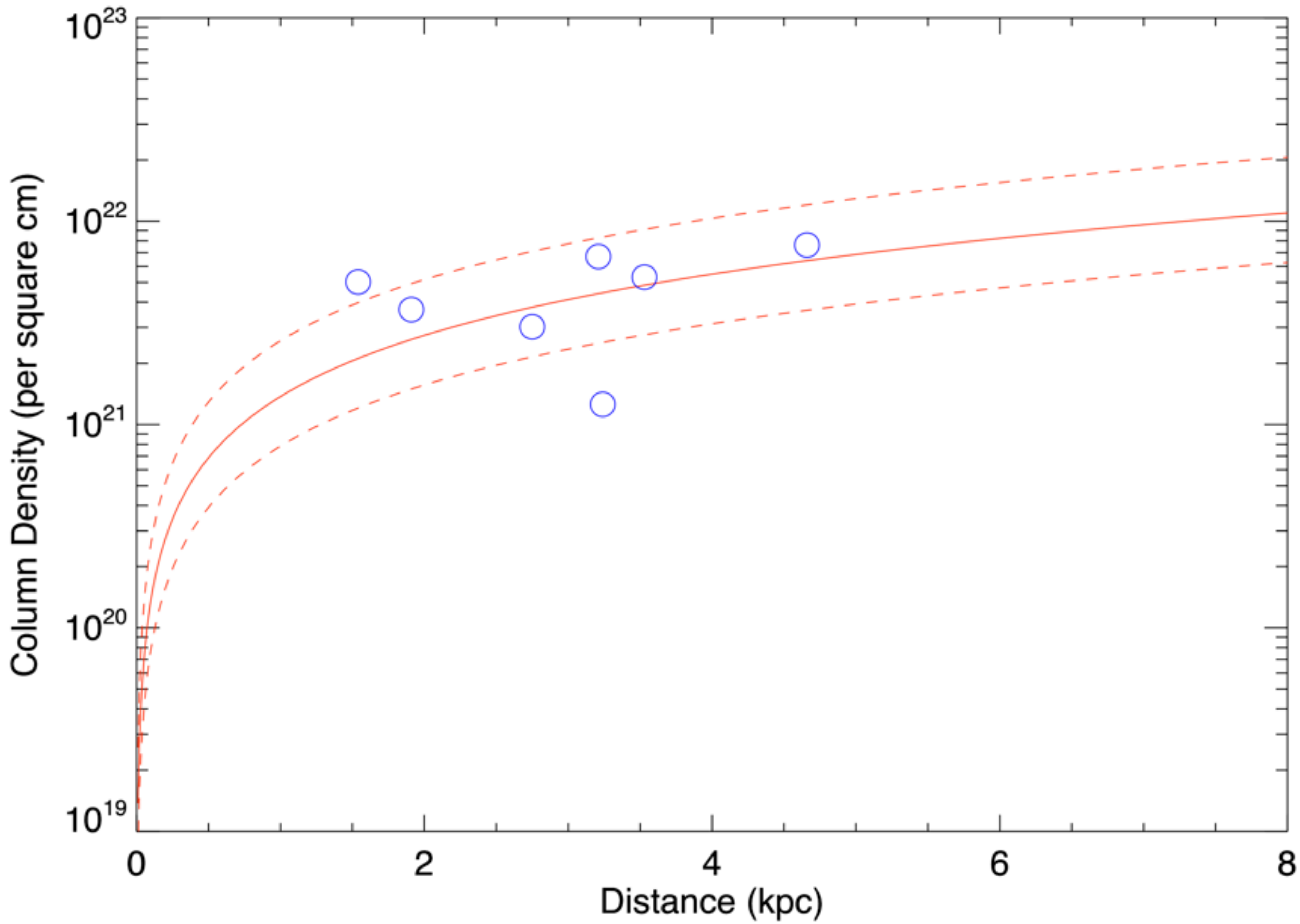
Calculated Column Density (WN4 subset)

Projected SF

- Given the subset of WN4 stars, the projected SFs are as follows:
  - 7/11 = 0.64 (Above median)
  - 3/11 = 0.27 (Above upper threshold)

WC6 Subset

- WR5 - HI bubble
- WR13 - maybe diffuse nebula, HI bubble
- WR15 - maybe diffuse nebula, HI bubble, IRAS shell
- WR23 - IRAS shell
- WR45 - no recorded CM association
- WR107a - no recorded CM association
- WR154 - no recorded CM association



Calculated Column Density (WC6 subset)

Projected SF

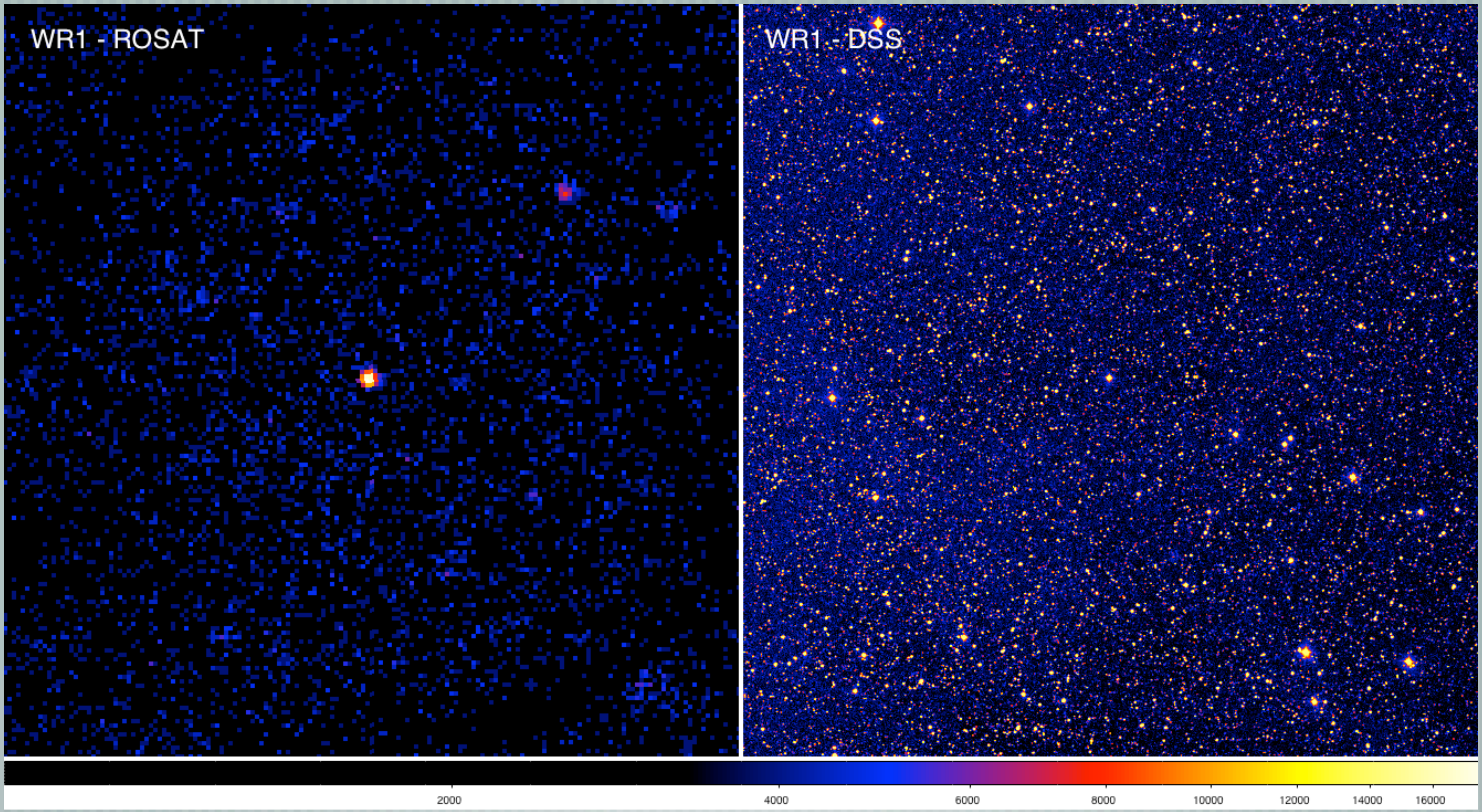
- Given the subset of WC6 stars, the projected SFs are as follows:
  - 5/7 = 0.71 (Above median)
  - 1/7 = 0.14 (Above upper threshold)

Observations

Visual (and X-ray) SF

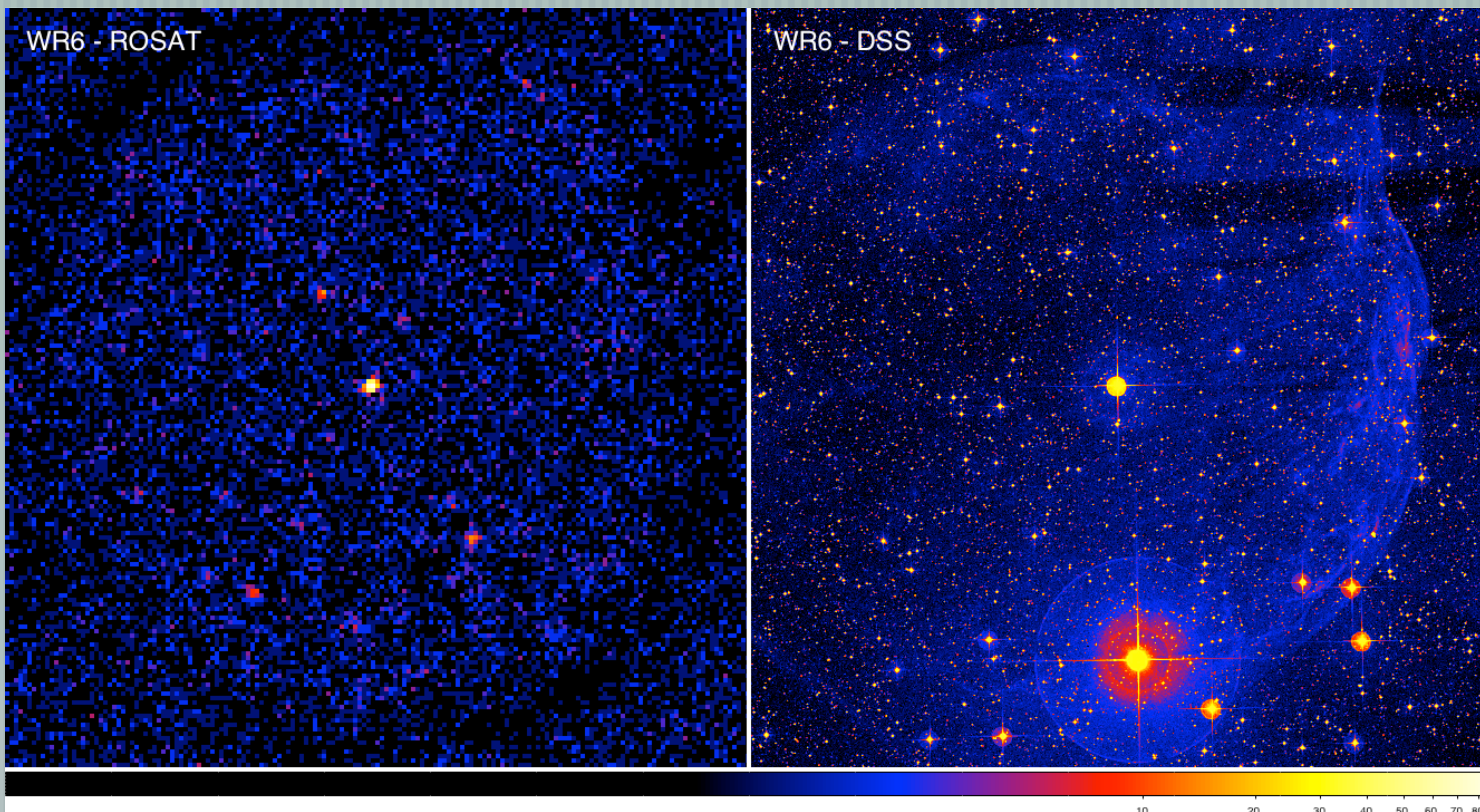
- From the analysis of each star and its surroundings, a visual SF can be determined to compare with the projected SF
- HEASARC was used to find observations performed that included subsets of WR stars
- Observations were taken from Chandra, ROSAT, Swift, and DSS where available
- Diffuse X-ray emission could indicate the presence of shocked material

WR 1 Observations



Not flagged as shrouded (Above upper threshold)

WR 6 Observations



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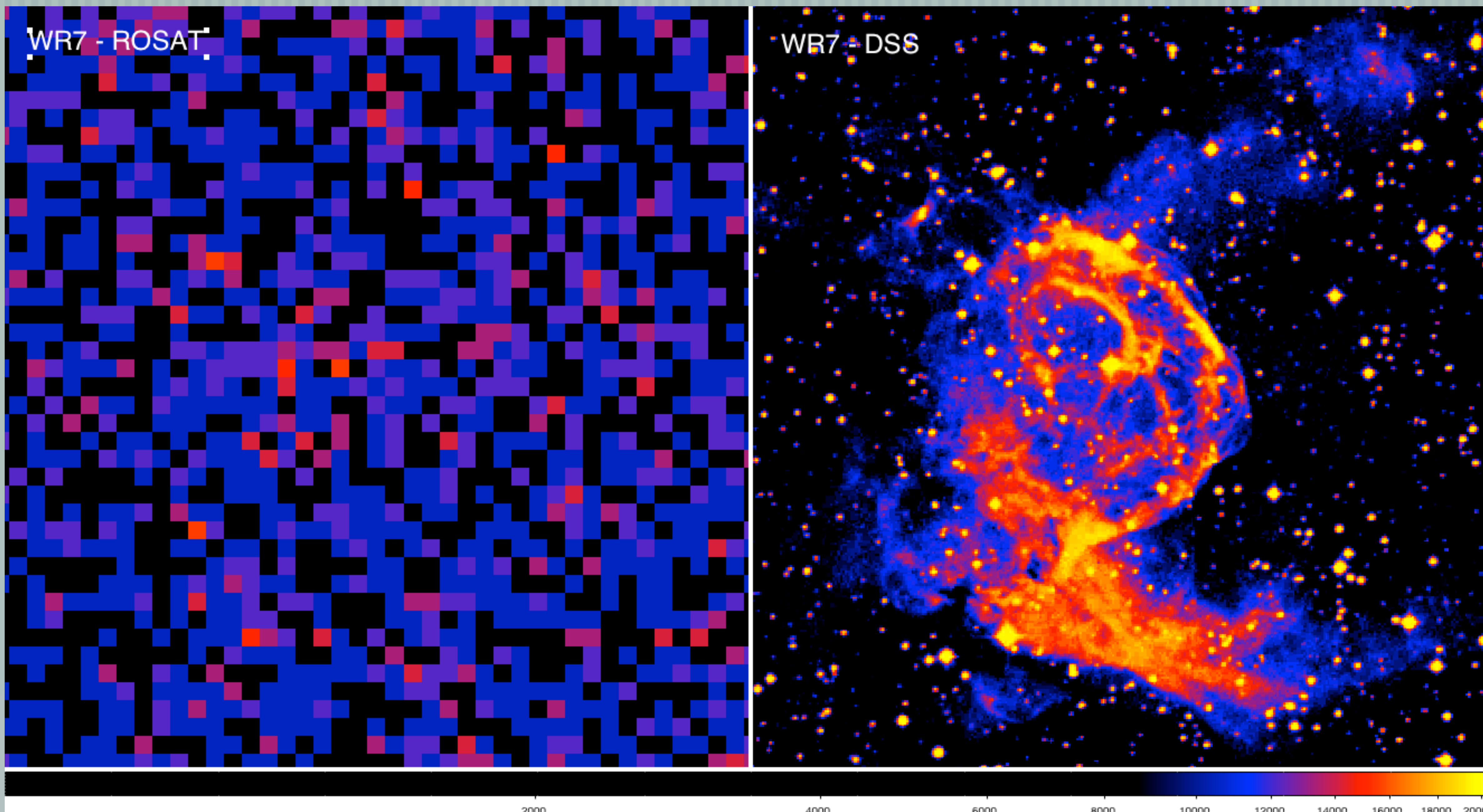
WR 7 Observations



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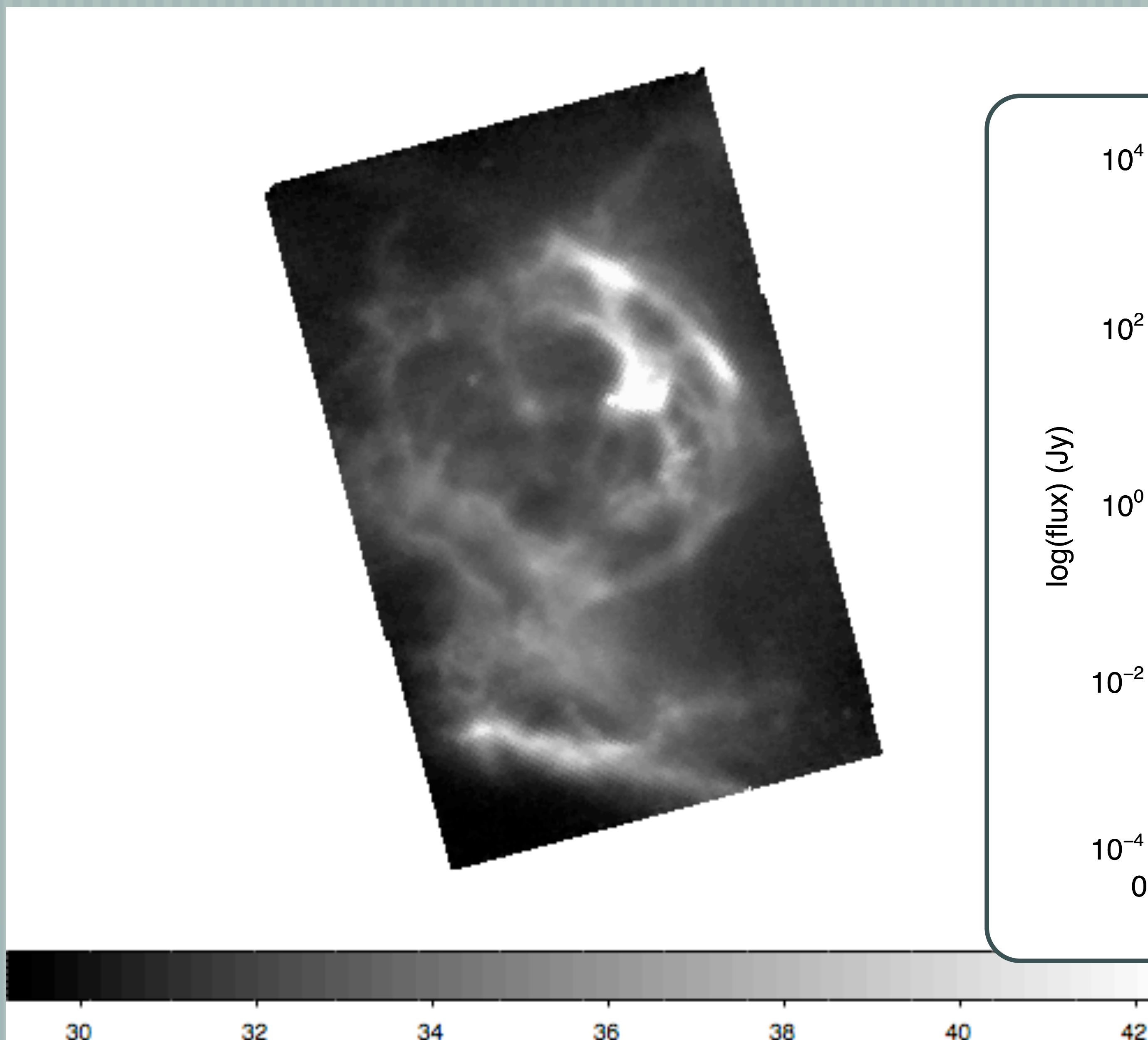
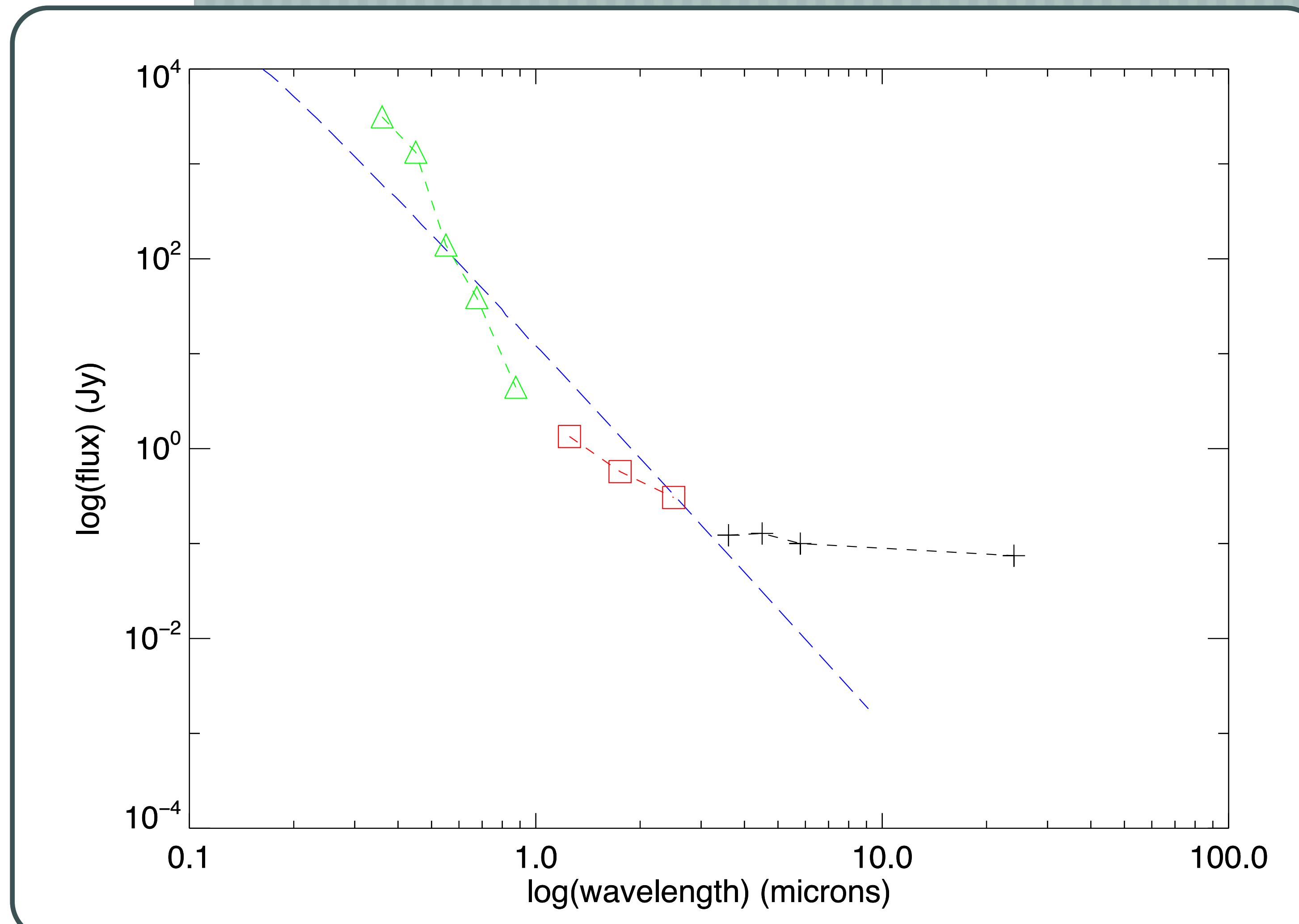
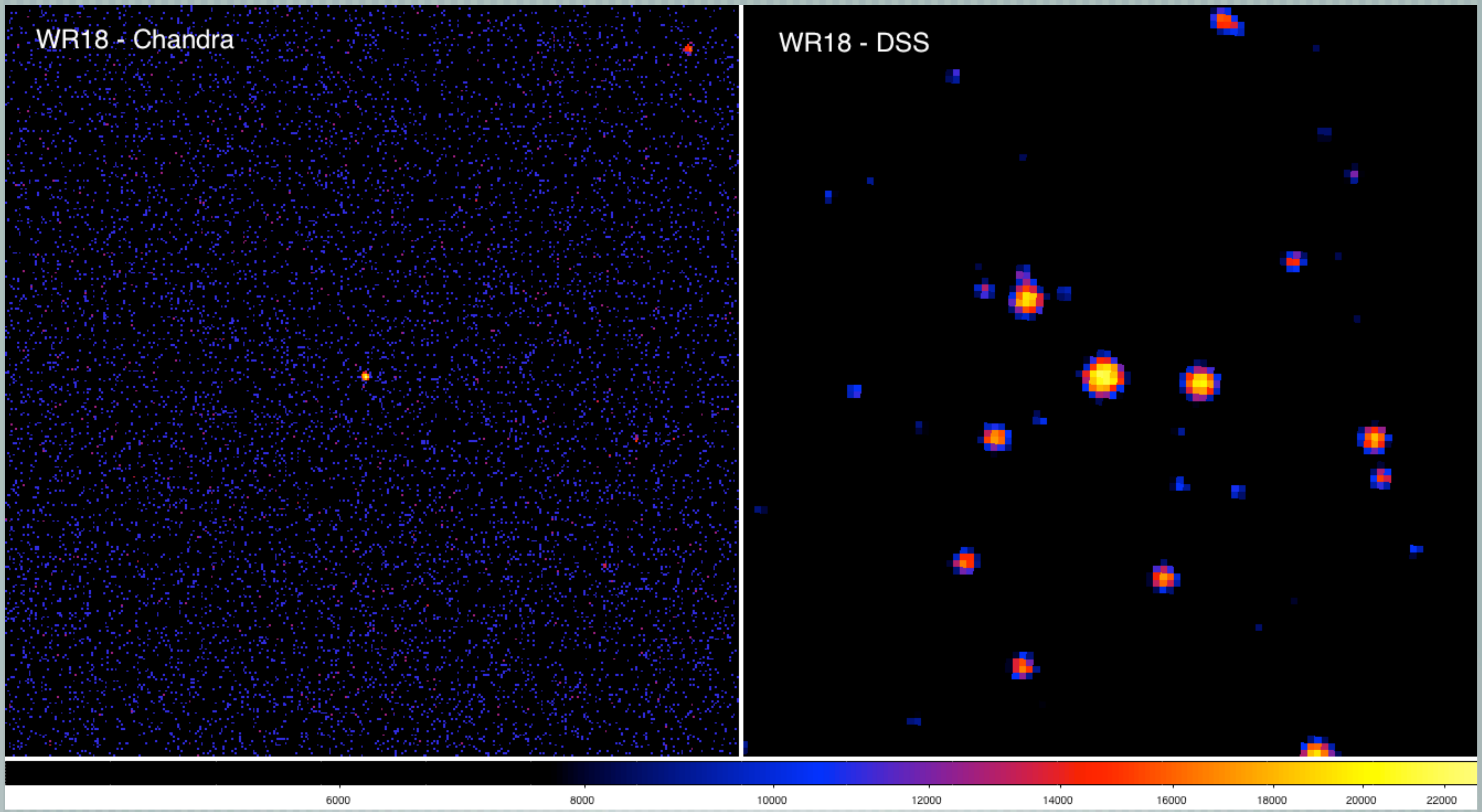
WR 7 Observations





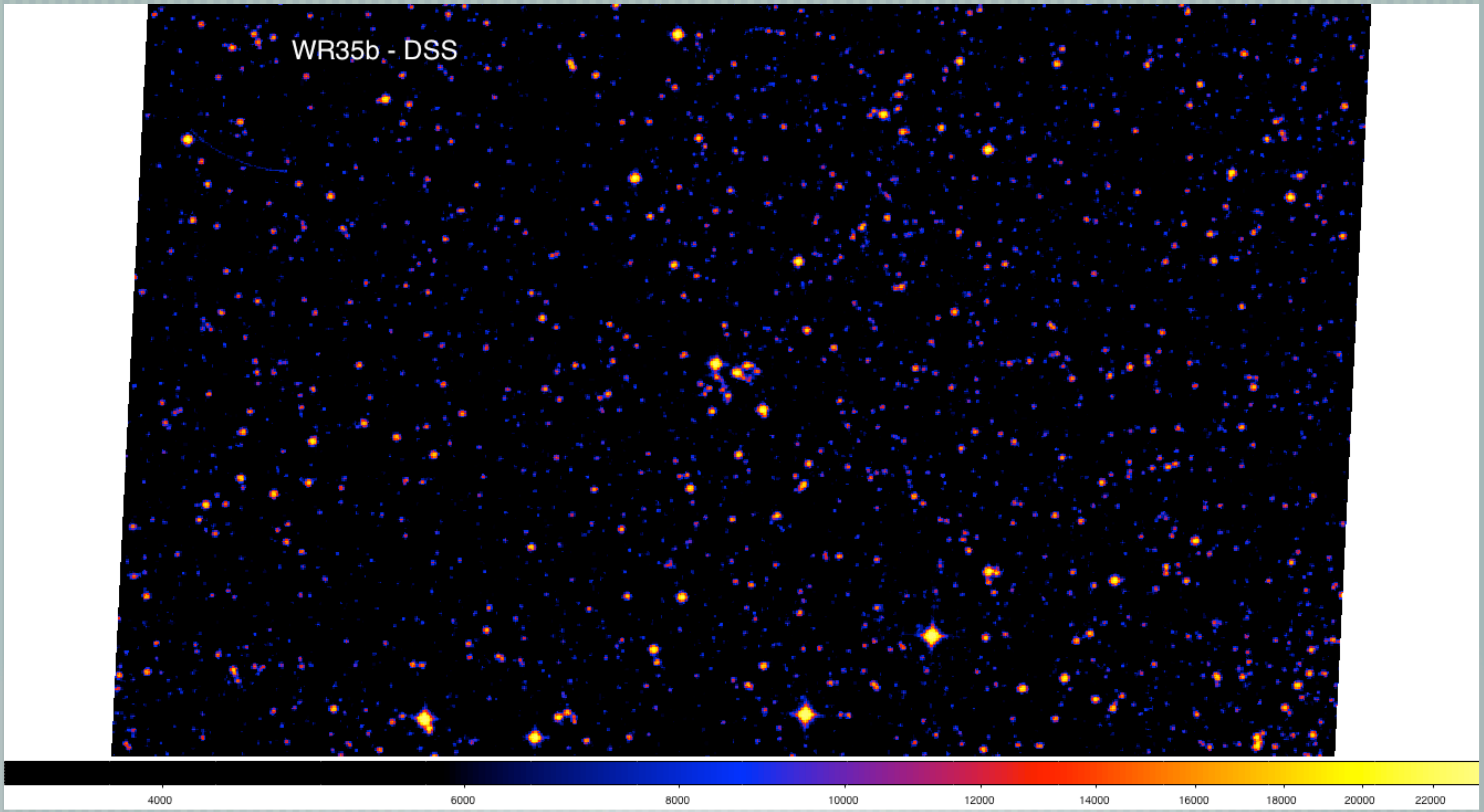
Not flagged as shrouded (Above upper threshold)

WR 18 Observations



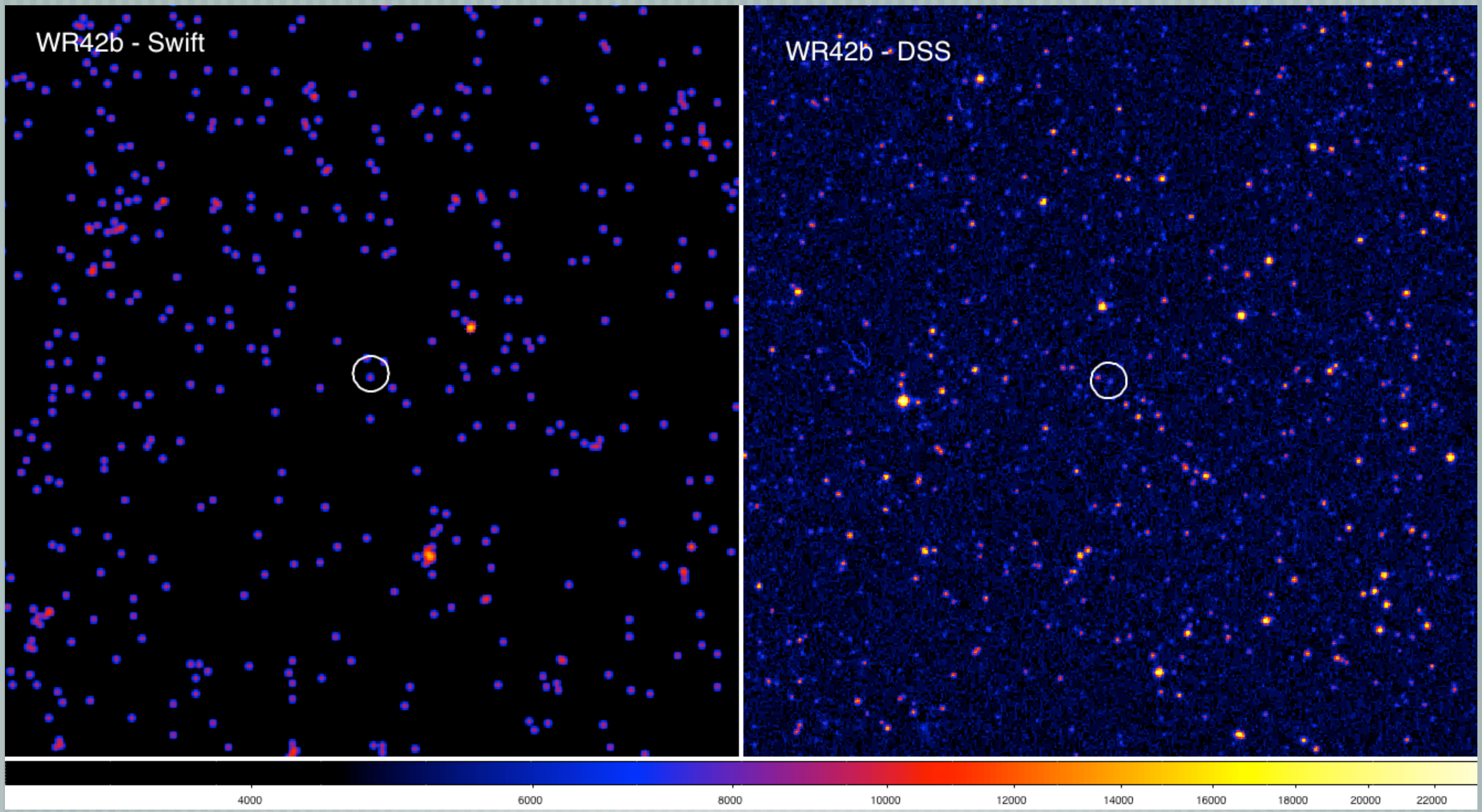
Not flagged as shrouded (Above upper threshold)

WR 35b Observations



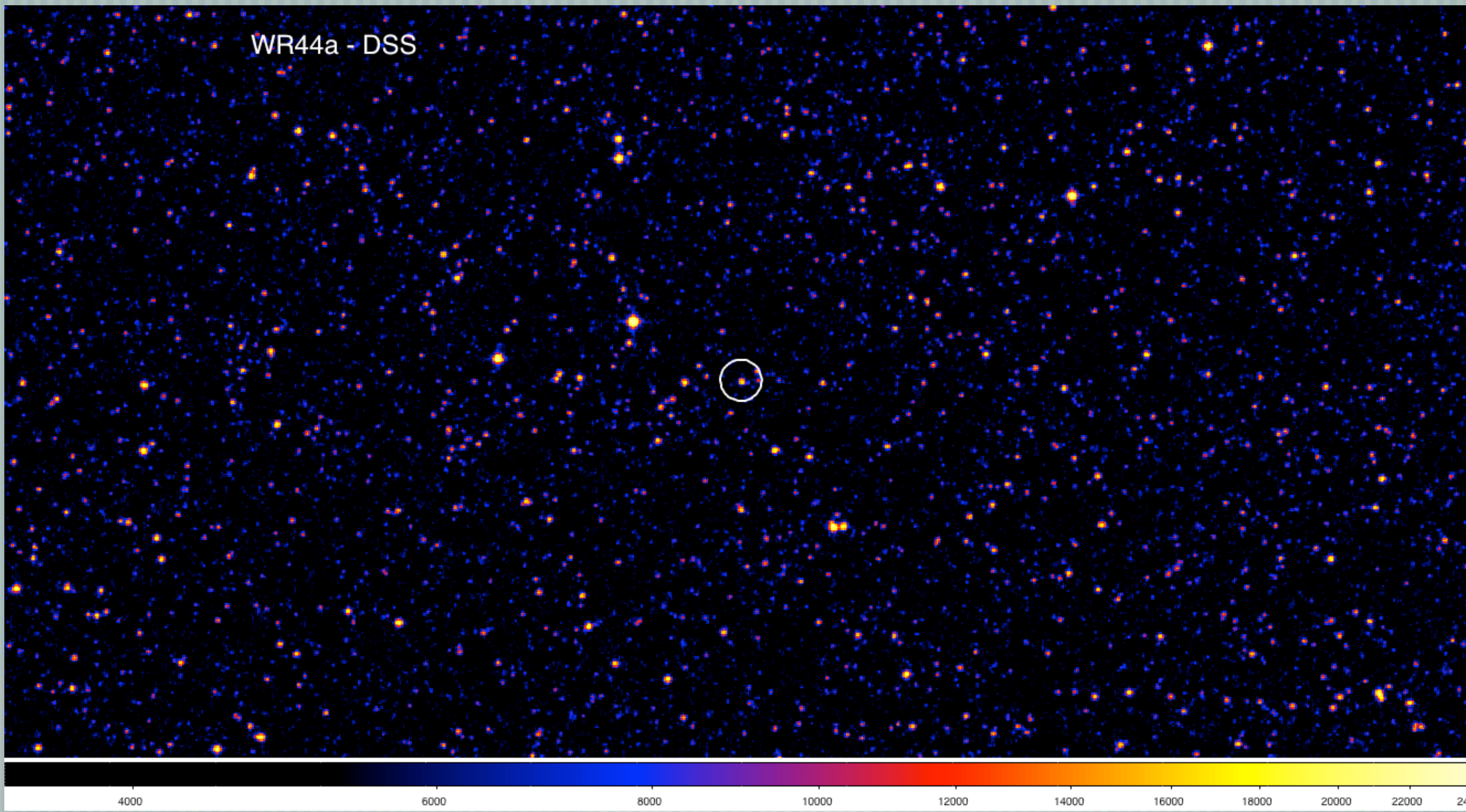
Flagged as shrouded (Above upper threshold)

WR 42b Observations



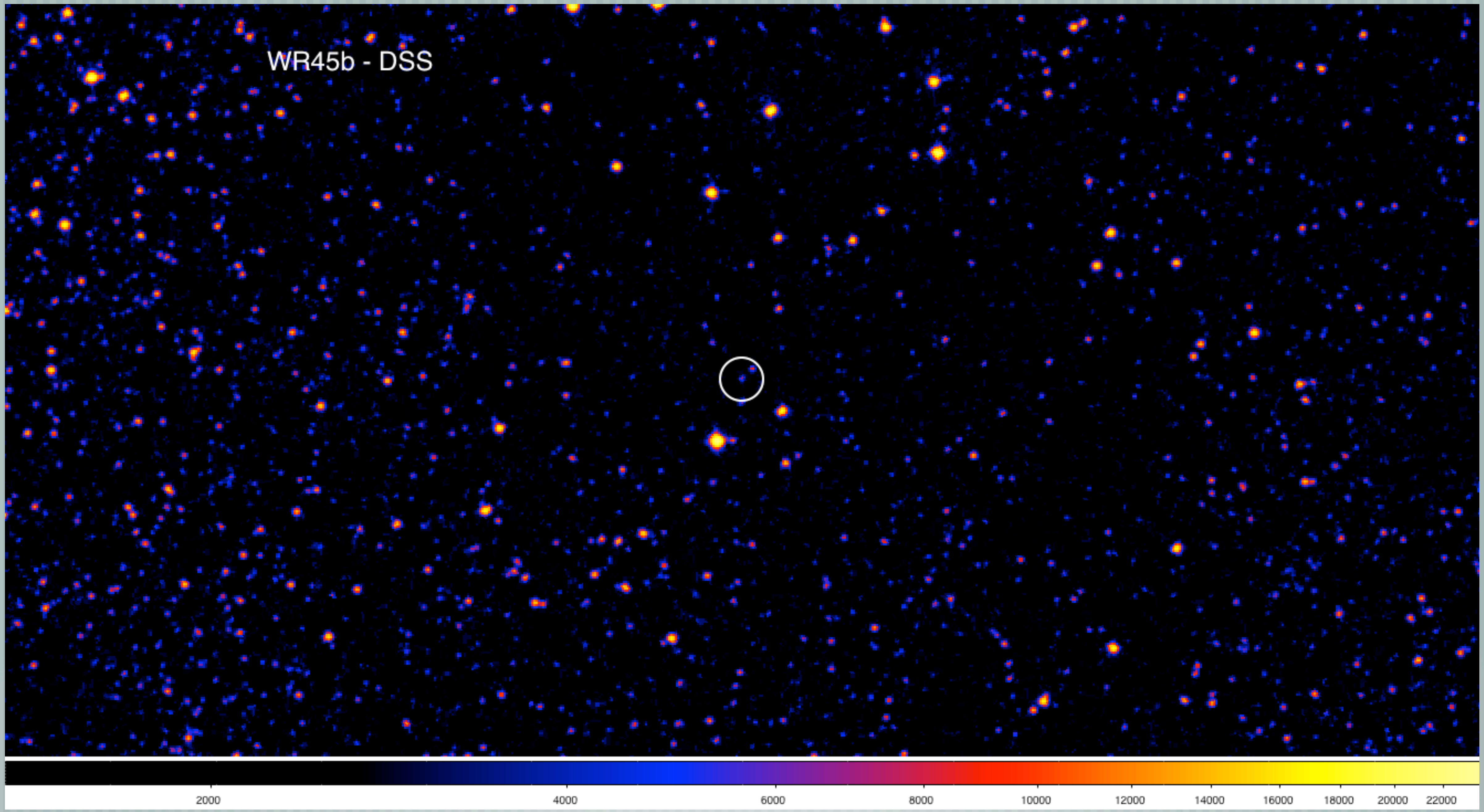
Flagged as shrouded (Above upper threshold)

WR 44a Observations



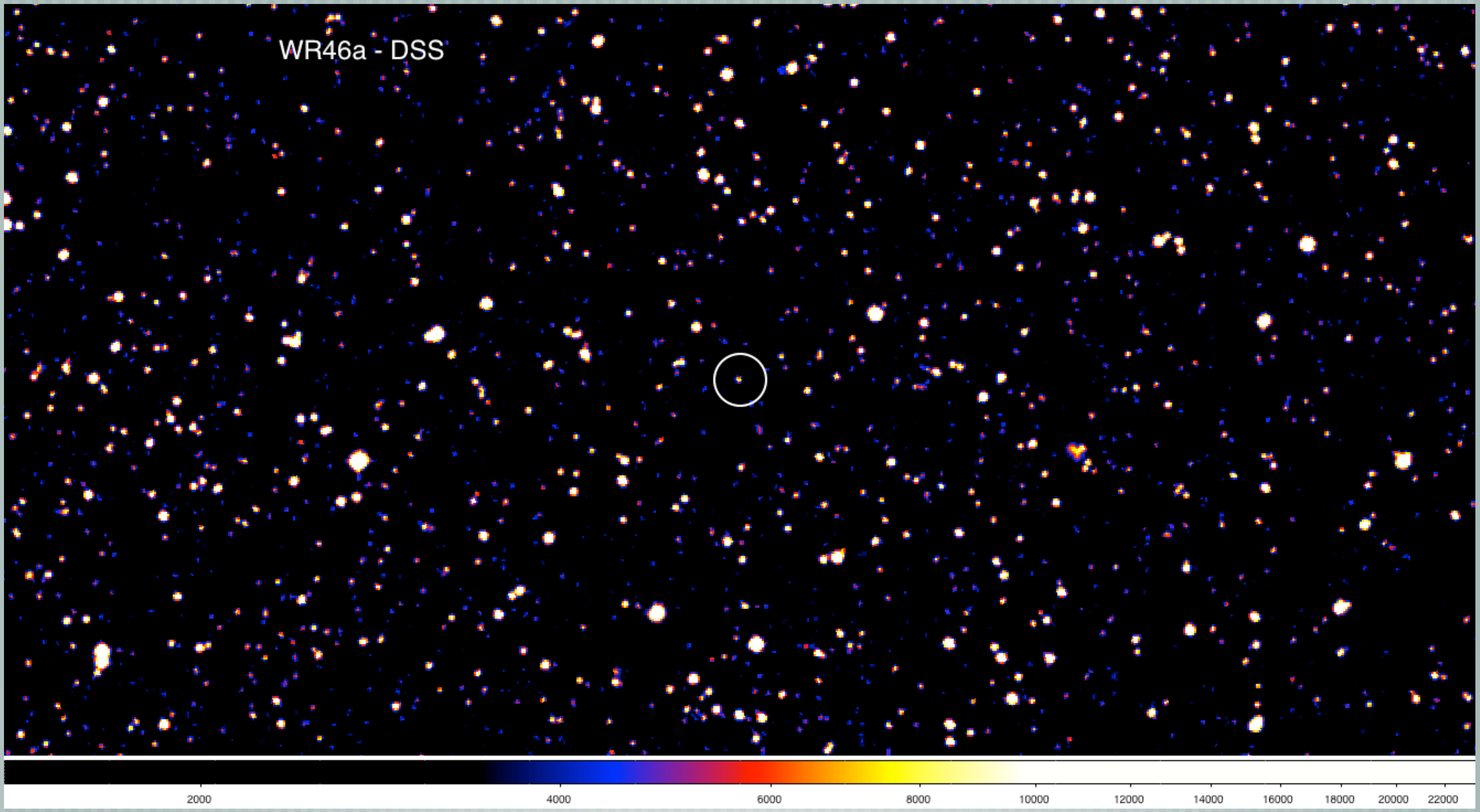
Not flagged as shrouded (Above upper threshold)

WR 45b Observations



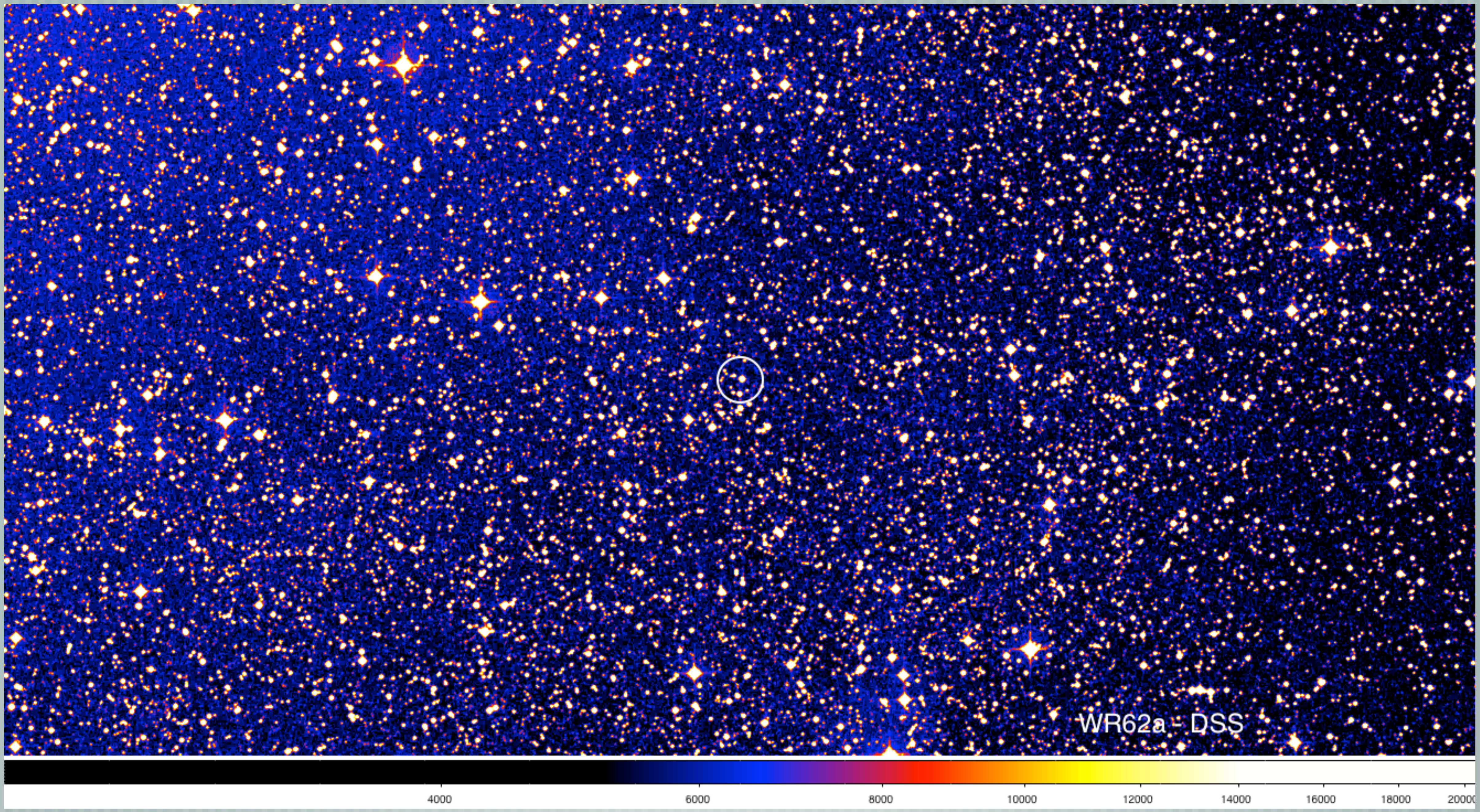
Not flagged as shrouded (Above upper threshold)

WR 46a Observations



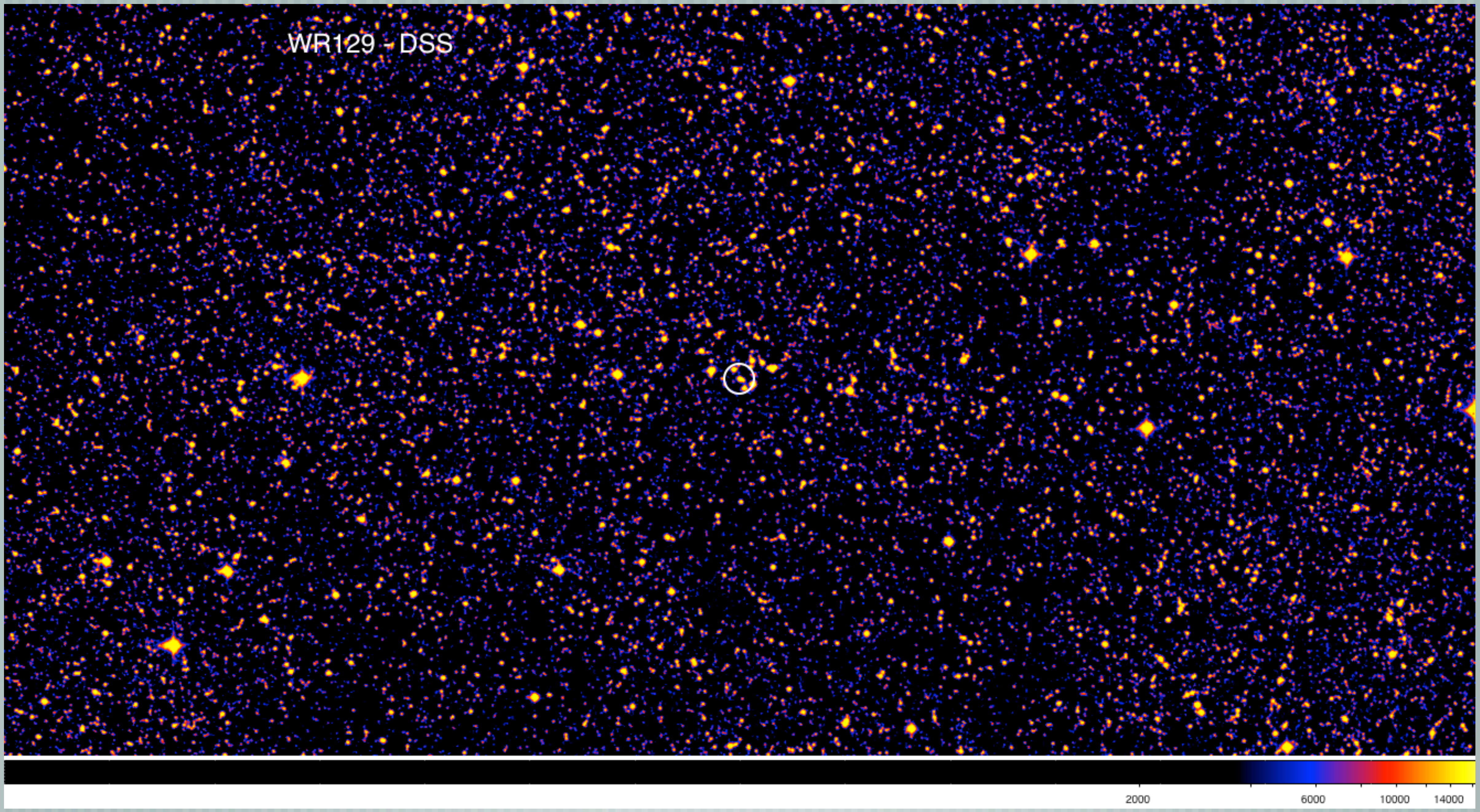
Not flagged as shrouded (Above upper threshold)

WR 62a Observations



Flagged as shrouded (Above upper threshold)

WR 129 Observations



Not flagged as shrouded (Above upper threshold)

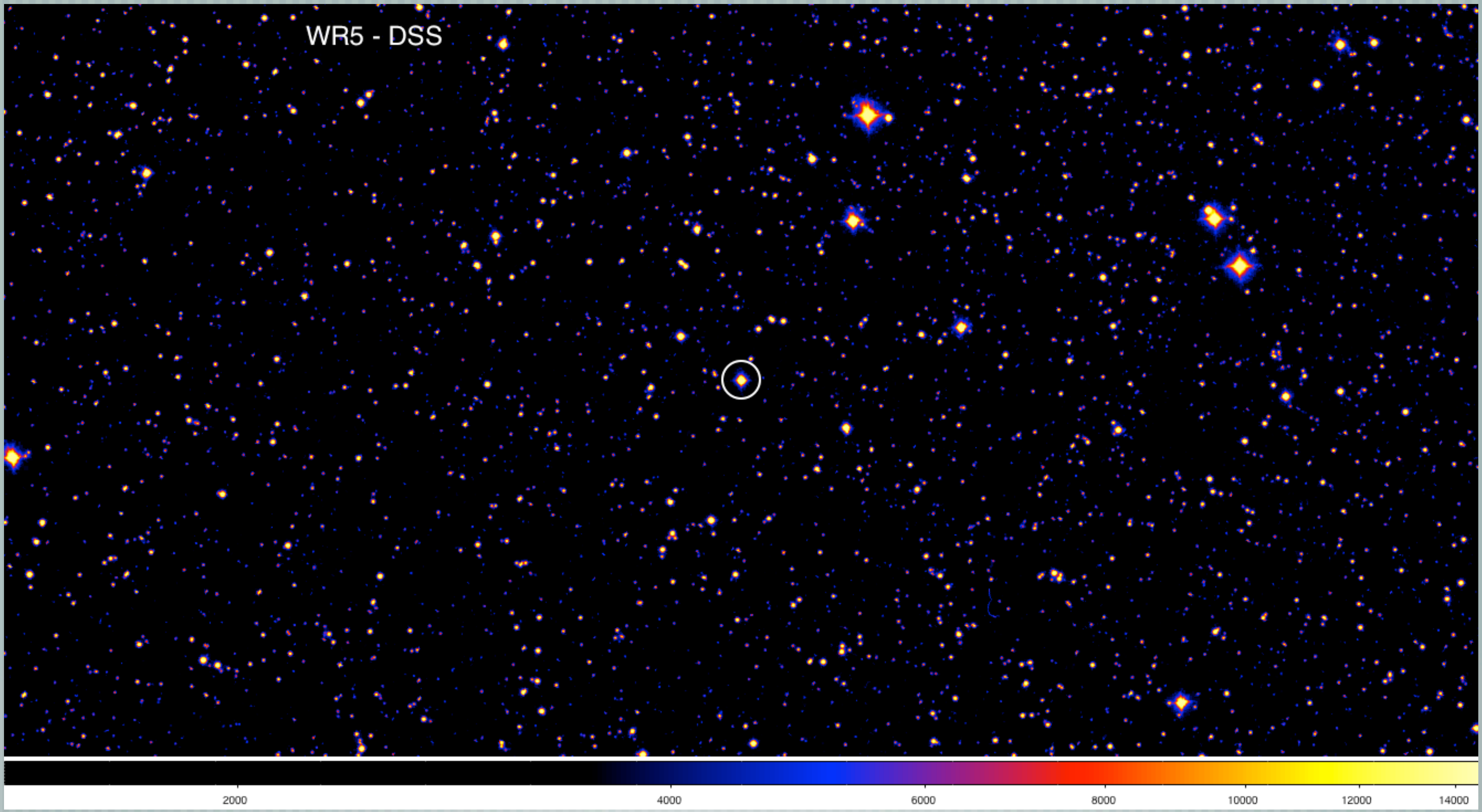
Visual (and X-ray) SF

- Based on the visual data, the SF for the WN4 subset is
  - 5/11 = 0.45
- Reminder, the projected SF for this subset was
  - 7/11 = 0.64 (Above median)
  - 3/11 = 0.27 (Above upper threshold)

Visual (and X-ray) SF

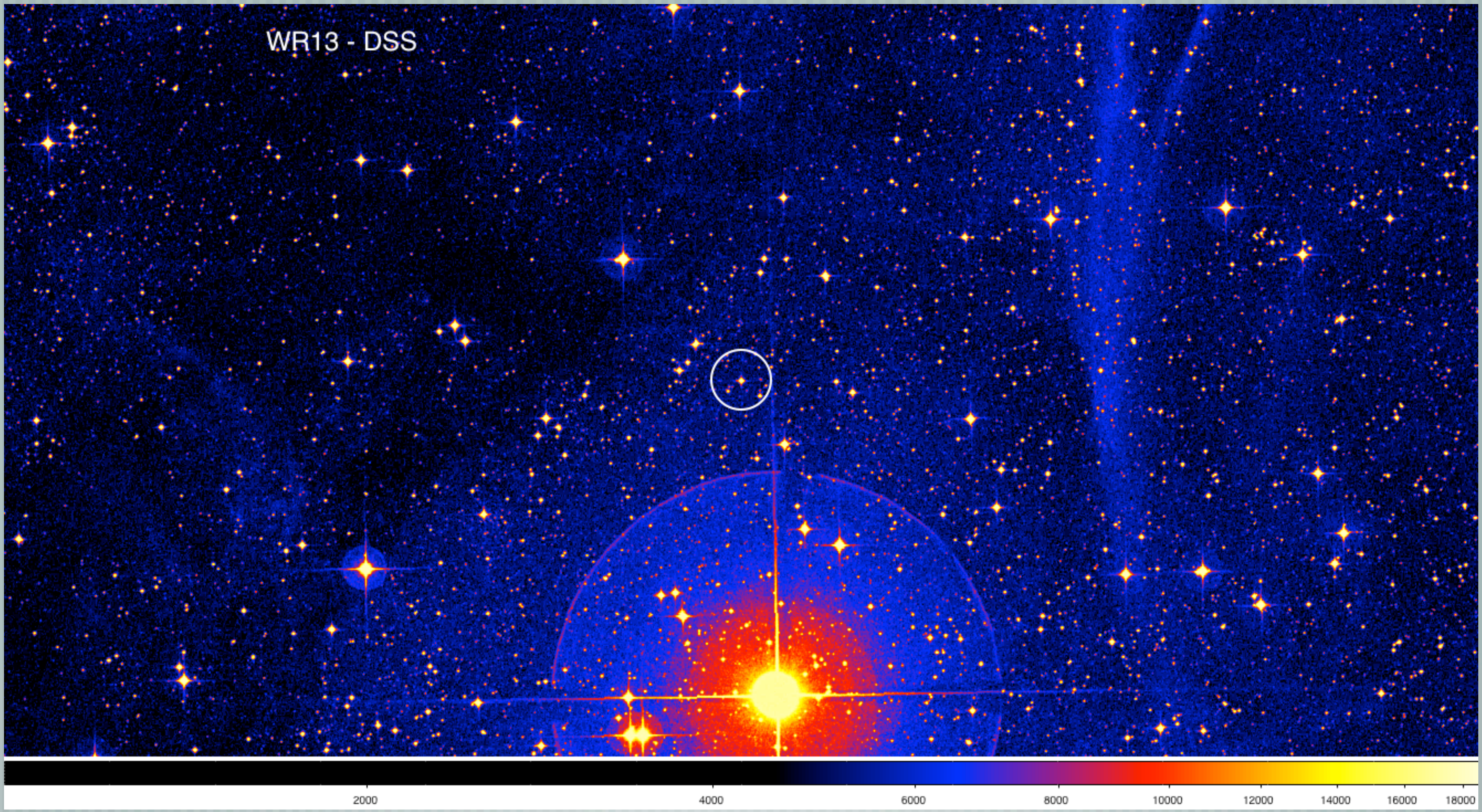
- Based on the visual data, the SF sources are
  - WR 6, 7, 18, 35b, 62a
- The sources projected SF for this subset were
  - WR 1, 18, 35b, 37, 42b, 44a, 62a
  - WR 35b, 42b, 62a

WR 5 Observations



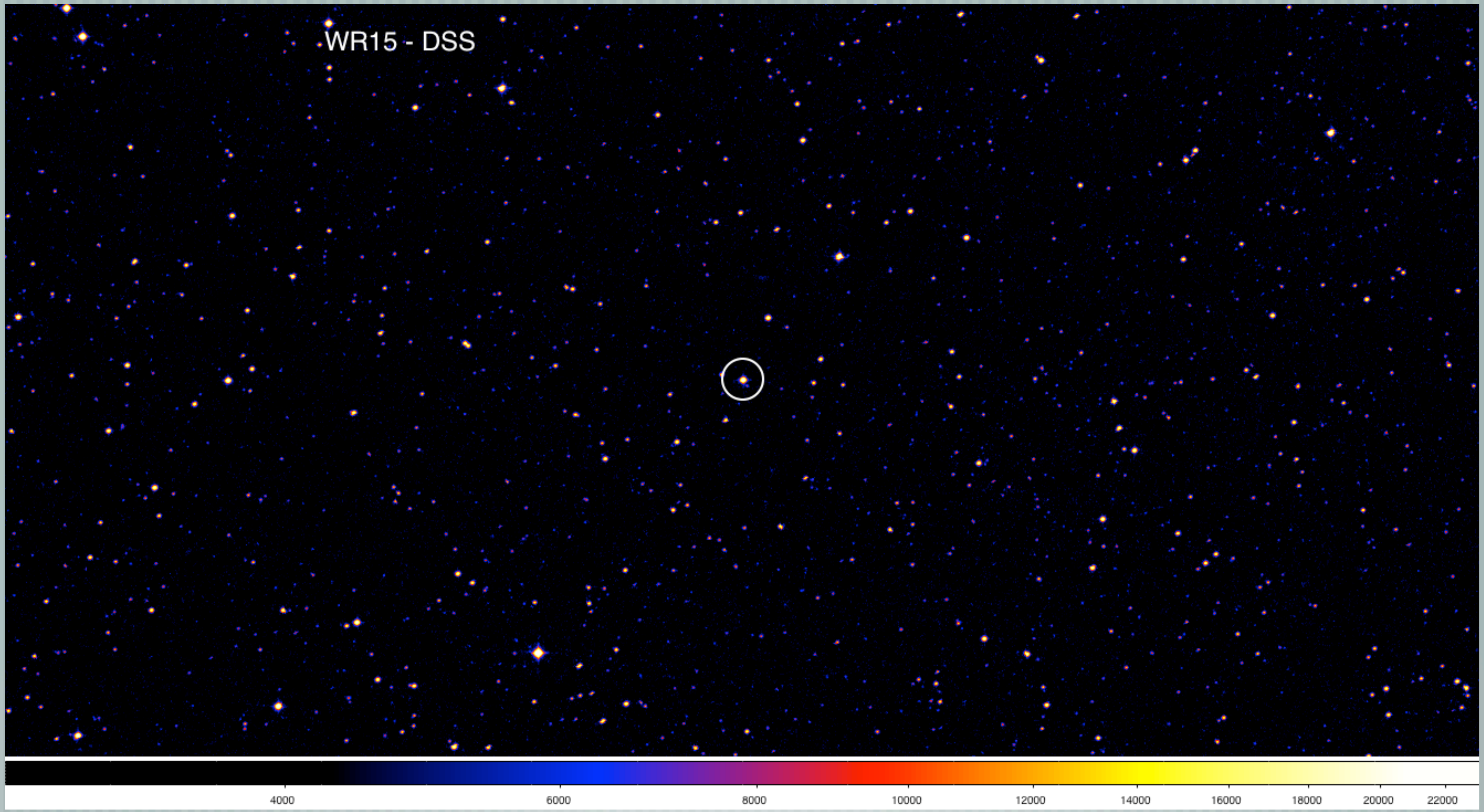
Not flagged as shrouded (Above upper threshold)

WR 13 Observations



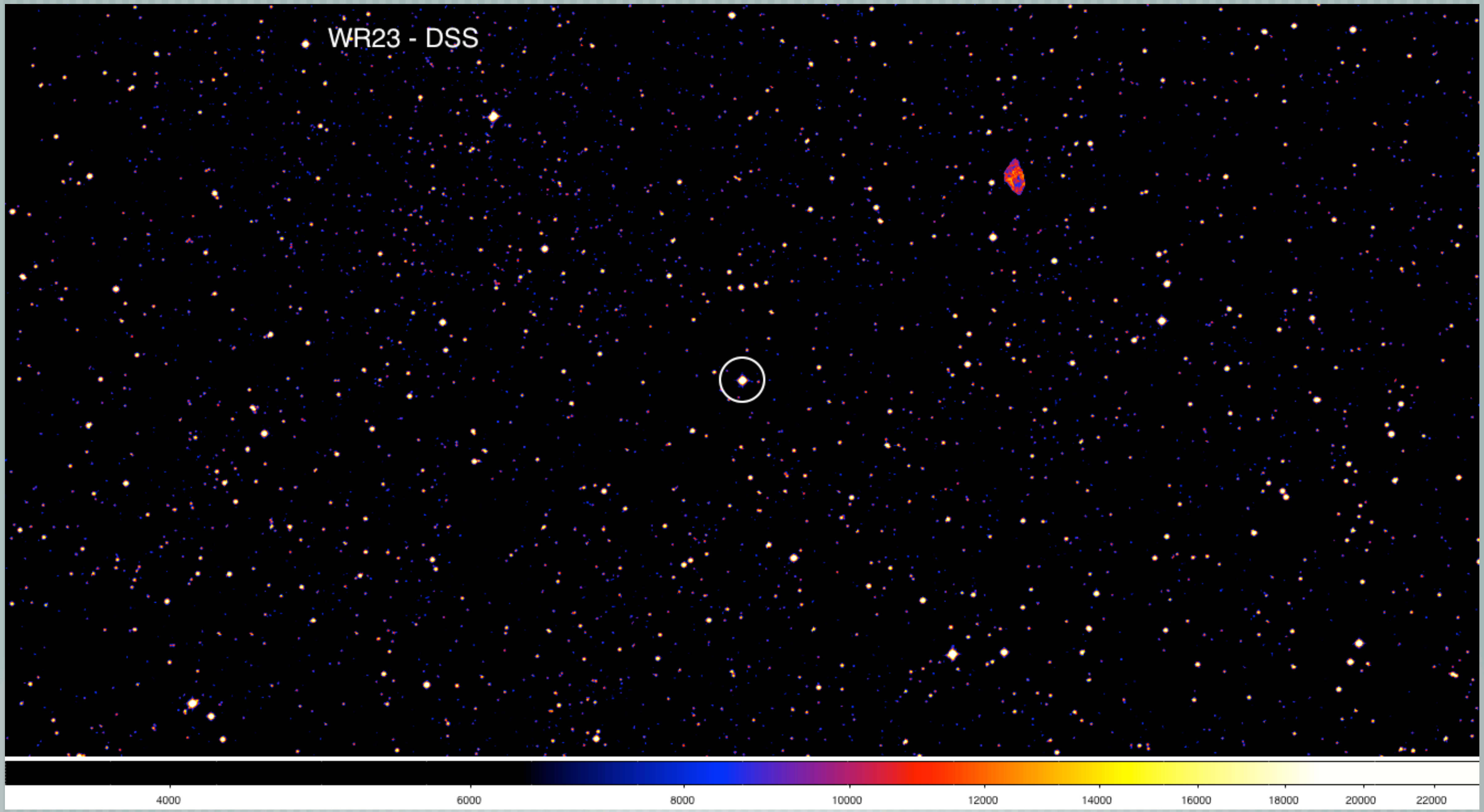
Not flagged as shrouded (Above upper threshold)

WR 15 Observations



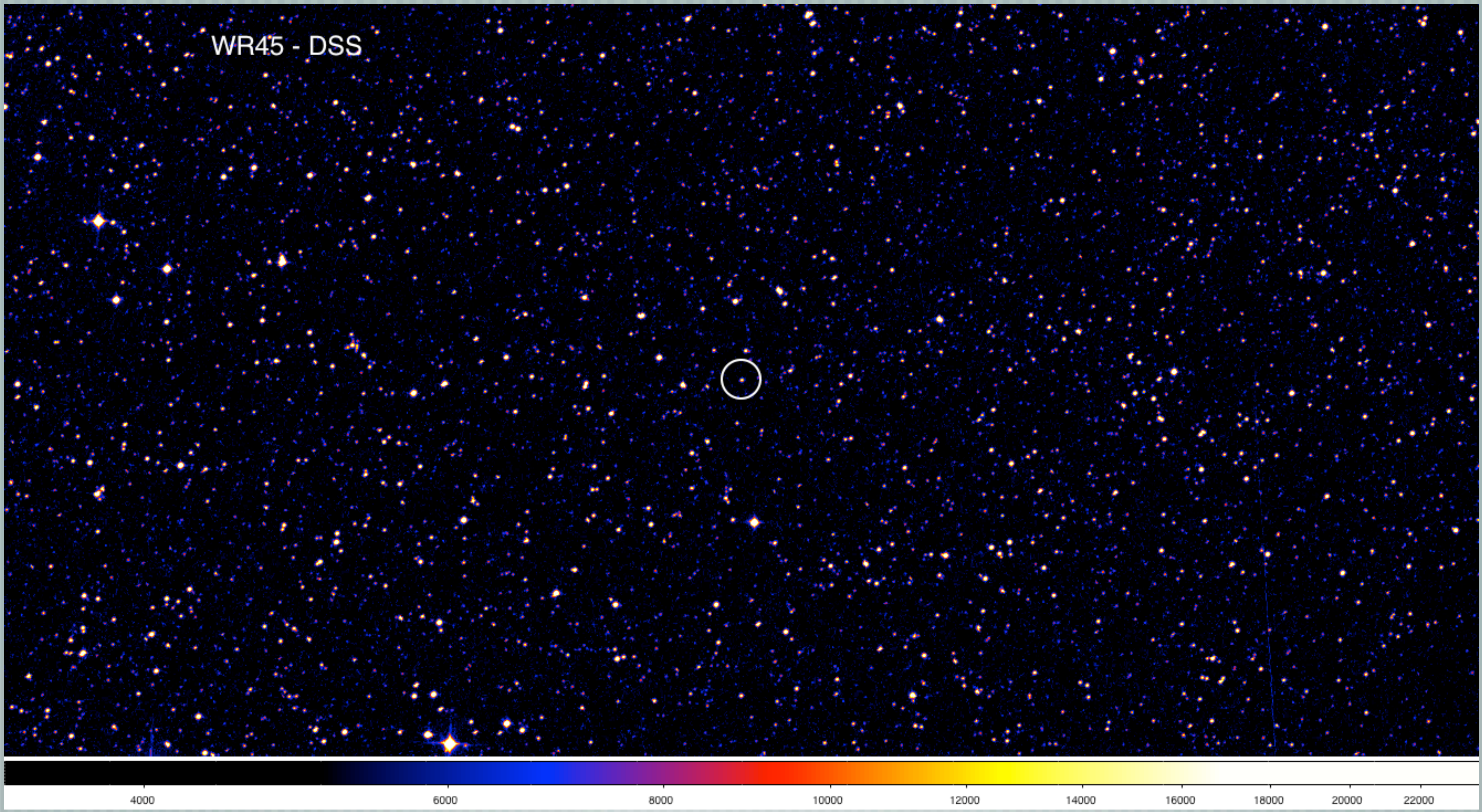
Flagged as shrouded (Above upper threshold)

WR 23 Observations



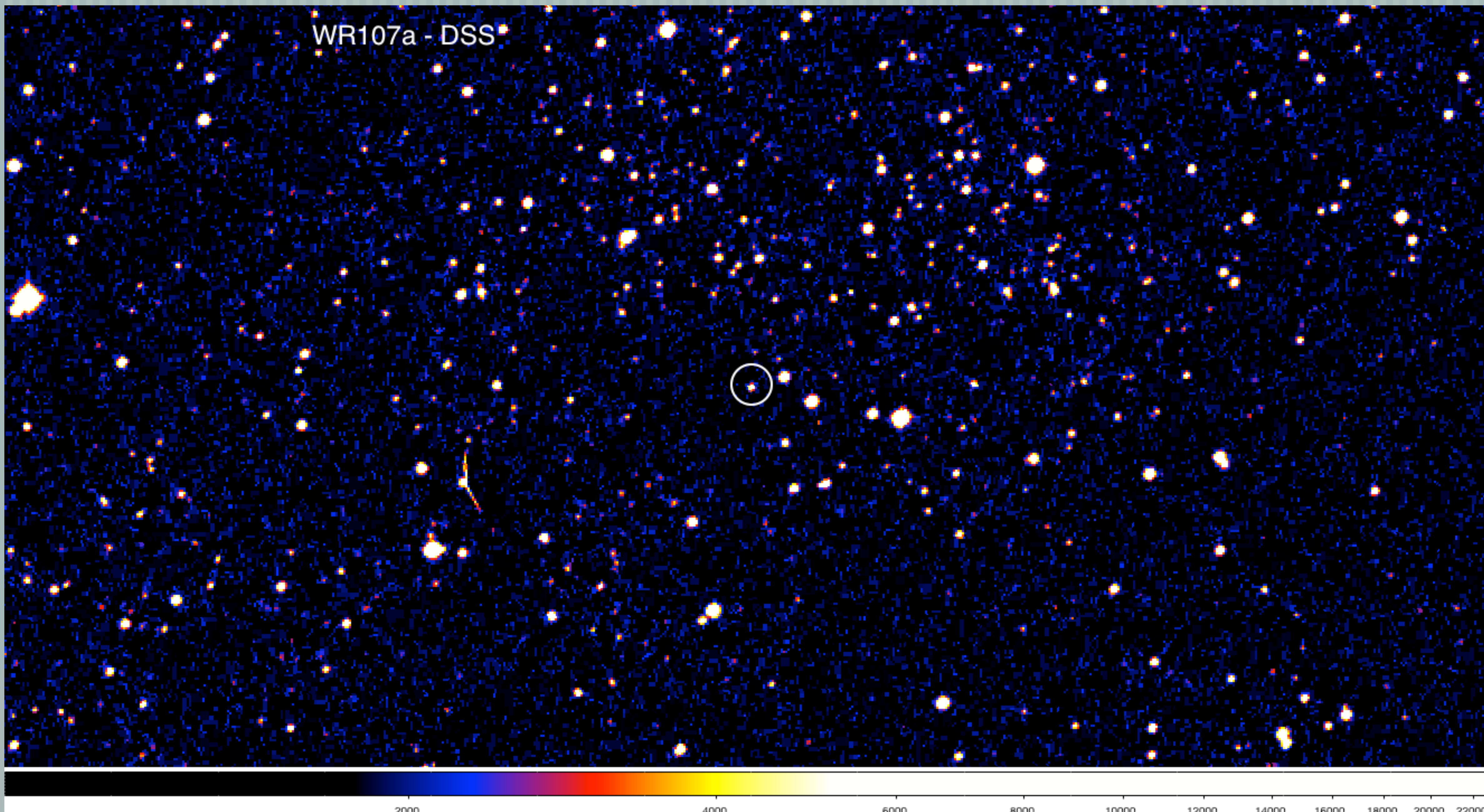
Not flagged as shrouded (Above upper threshold)

WR 45 Observations



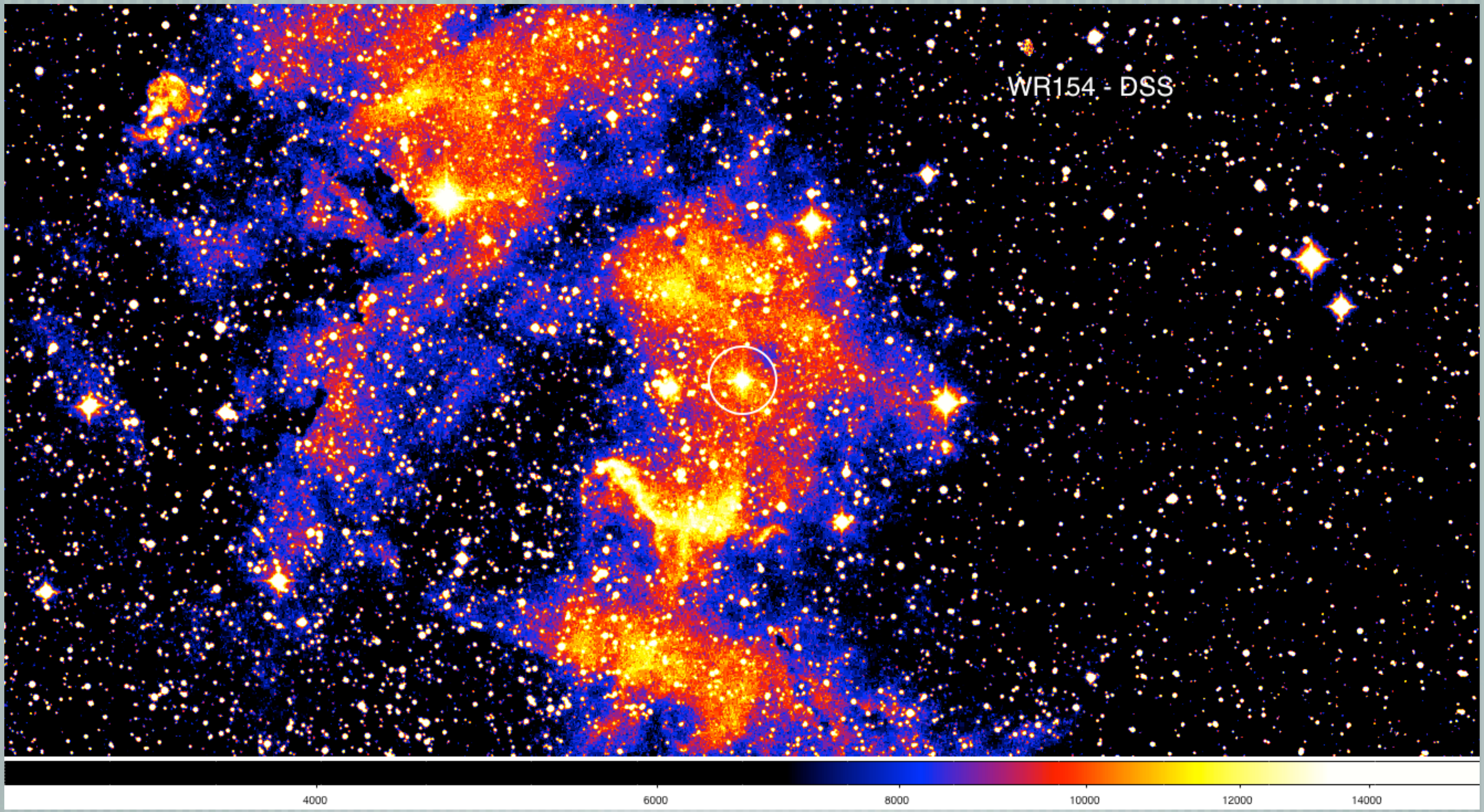
Not flagged as shrouded (Above upper threshold)

WR 107a Observations



Not flagged as shrouded (Above upper threshold)

WR 154 Observations



Not flagged as shrouded (Above upper threshold)

Visual (and X-ray) SF

- Based on the visual data, the SF for the WC6 subset is
  - 3/7 =0.43
- Reminder, the projected SF for this subset was
  - 5/7 = 0.71 (Above median)
  - 1/7 = 0.14 (Above upper threshold)

Visual (and X-ray) SF

- Based on the visual data, the SF sources are
  - WR 13, 107a, 154
- The sources projected SF for this subset were
  - WR 5, 13, 15, 45, 107a
  - WR 15

Conclusions

Discussion

- Projected and Observed SFs do not match. Why?
  - Projected distances may be wrong, in some cases causing the stars to appear in front of material when it may be within
  - Relying on visual (and some X-ray) data is not enough to generate a definitive Observed SF; IR data observes circumstellar dust better than shorter wavelengths
  - Line of sight - for the purposes of this project a uniform n_H was applied, while in reality different regions of the galaxy have different amounts of material, leading to different extinction values

Conclusions

- Given this method, there appears to be an average (between the high and median threshold values) Project SF close to the Observed SF
- Imperfect method of detecting circumstellar material
  - At a high threshold value it misses a few, and at the median it finds too many; require a better threshold determination
  - Misses “recorded” shrouded stars (e.g. WR 7)
- Need up to date data
- Require further multiwavelegth observations, IR and X-ray for confirmation
  - Not all material can be seen in the visual band, cool dust and hot gas hides at longer and shorter wavelengths

References

- Carroll, B. W., & Ostlie, A. D., 2007, An Introduction to Modern Astrophysics
- Freeman, M., Kaster, J. H., Montez, R., & Rappaport, S. A., 2012, in prep.
- Hillier, D. & Murdin, P., 2000, Encyclopedia of Astronomy and Astrophysics
- Monnier, J. D., Tuthill, P. G., Danchi, W. C., Murphy, N., & Harries, T. J., 2006, ApJ, 655, 1033
- Predehl, P., Schmitt, J. H. M. M., 1995, A&A, 293, 889
- van der Hucht, K. A., 2001, NewAR, 45, 135