Excluding super-soft X-ray sources as progenitors for four Type Ia supernovae in the LMC

J. Kuuttila* [1], M. Gilfanov[1,2], I. R. Seitenzahl[3,4], T. E. Woods[5] and F. P. A. Vogt[6,7]

[1]Max Planck Institute for Astrophysics, Karl-Schwarzschild-Str. 1, Garching b. München 85741, Germany
[2]Space Research Institute, Profsoyuznaya 84/32, 117997, Moscow, Russia
[3]School of Science, University of New South Wales, Australian Defence Force Academy, Canberra, ACT 2600, Australia
[4]Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT 2611, Australia
[5]Institute for Gravitational Wave Astronomy and School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom
[6]European Southern Observatory, Av. Alonso de Córdova 3107, 763 0355 Vitacura, Santiago, Chile
[7]ESO Fellow

*kuuttila@mpa-garching.mpg.de

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Max Planck Institute for Astrophysics

1. Introduction

- **In the most efficient mass accumulation range, an accreting and nuclear burning white dwarf should appear as super-soft X-ray source.**
- **Super-soft X-ray sources should ionize their surroundings creating a long-lasting imprint.**

Type Ia supernovae are understood to be the thermonuclear explosions of white dwarfs, but the exact mechanism(s) leading to these explosions remains unclear. The two competing models are the single degenerate scenario and the double degenerate scenario.

In the single degenerate scenario the WD accretes material from a companion star, and in the most efficient regime for mass accumulation, the accreted hydrogen burns steadily on the surface of the WD, making it appear as a strong super-soft X-ray source (SSS) (van den Heuvel et al. 1992).

SSSs are typically luminous ($L_{\rm bol} \gtrsim 10^{37-38}$ erg s^{-1}) and hot ($T_{\rm eff} \sim 10^6$ K), which means that they will strongly ionize any surrounding interstellar gas. This will create an ionization nebula with a typical ("Strömgren") radius of

$$R_S \approx 35\mathrm{pc}\left(\frac{\dot{N}_{ph}}{10^{48}\,\mathrm{s}^{-1}}\right)^{\frac{1}{3}}\left(\frac{n_{ISM}}{1\,\mathrm{cm}^{-3}}\right)^{-\frac{2}{3}}, \quad (1)$$

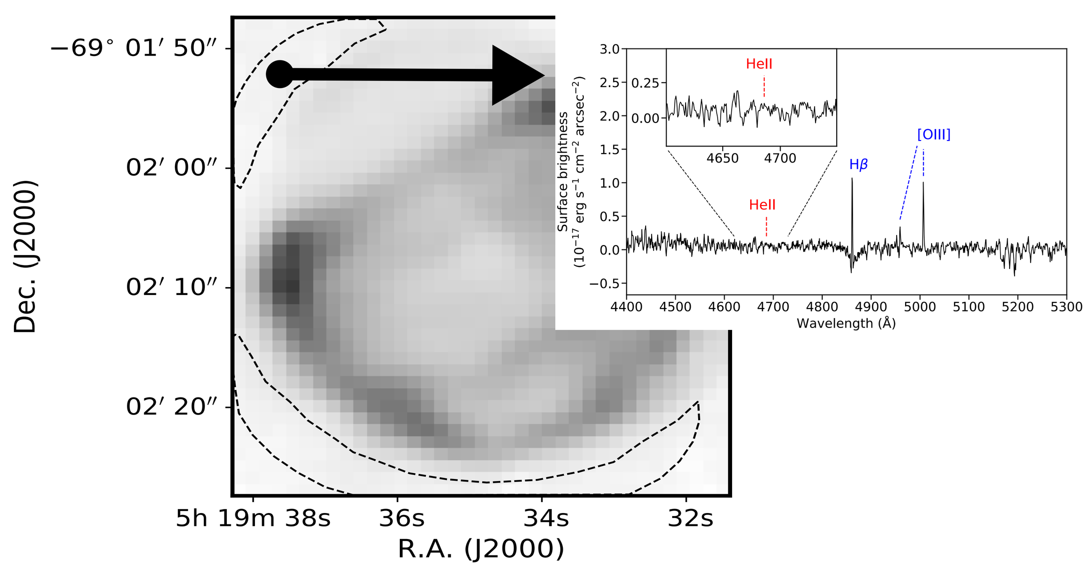
where $\dot{N}_{ph}$ is the number of ionizing photons per second, and n_{ISM} is the number density of the ISM (Rappaport et al. 1994). These nebulae will persist up to $\sim 10^5$ years after the ionizing source has turned off, which makes them a powerful tool in the search for single degenerate progenitors.

Using the integral field spectrograph WiFeS, we have searched for these ionized nebulae around four young Type Ia supernova remnants in the LMC. We detected no such nebula around any of the remnants. By comparing our upper limits with photoionization simulations performed using Cloudy, we have placed stringent upper limits on the luminosities of the progenitors of these supernova remnants. Our results add to the growing evidence disfavouring the single degenerate scenario.

2. Observations

- **We searched for ionized nebulae in He II 4686Å line emission around four Type Ia supernova remnants.**
- **We did not detect any nebulae around these remnants**

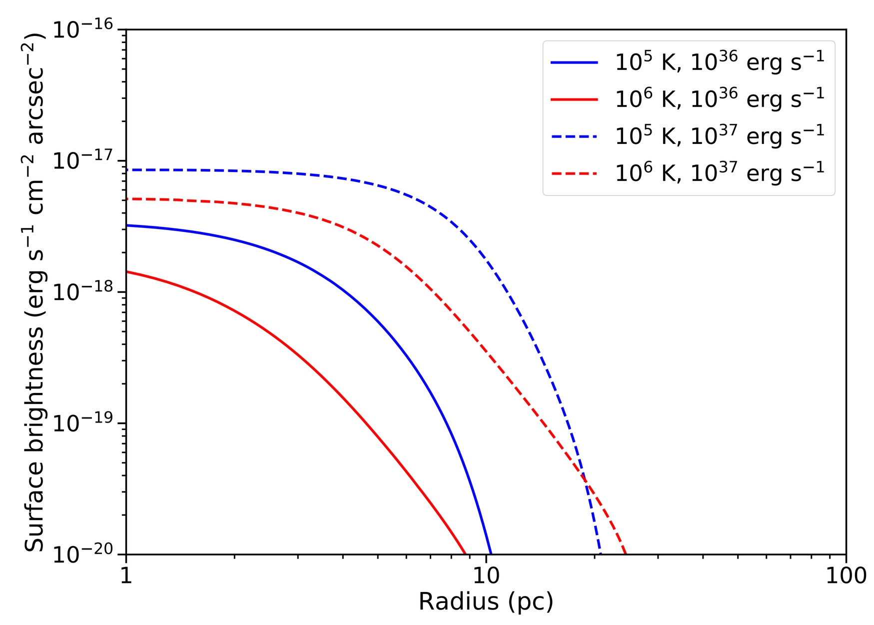
We have observed the four LMC SN Ia remnants SNR 0509-67.5, SNR 0505-67.9, SNR 0509-68.7, and SNR 0519-69.0 with the Wide Field Spectrograph (WiFeS) mounted on the Australian National University 2.3 m telescope at the Siding Spring Observatory. We searched for the He II 4686Å emission line, which was not detected around any of the sources. We used this lack of noticeable emission to derive upper limits for the He II surface brightness.



3. Simulations

- **We simulated how the ionized nebulae should look like in He II 4686Å line emission with different parameters.**

We computed a grid of numerical photoionization models with Cloudy[a]. We assumed a spherically symmetric configuration with the central ionizing source emitting a blackbody spectrum with an effective temperature of 10^{4-7} and a bolometric luminosity of 10^{35-38} erg s^{-1}. As a result, we get the the surface brightness profiles of the He II 4686Å emission line as a function of distance from the central source.

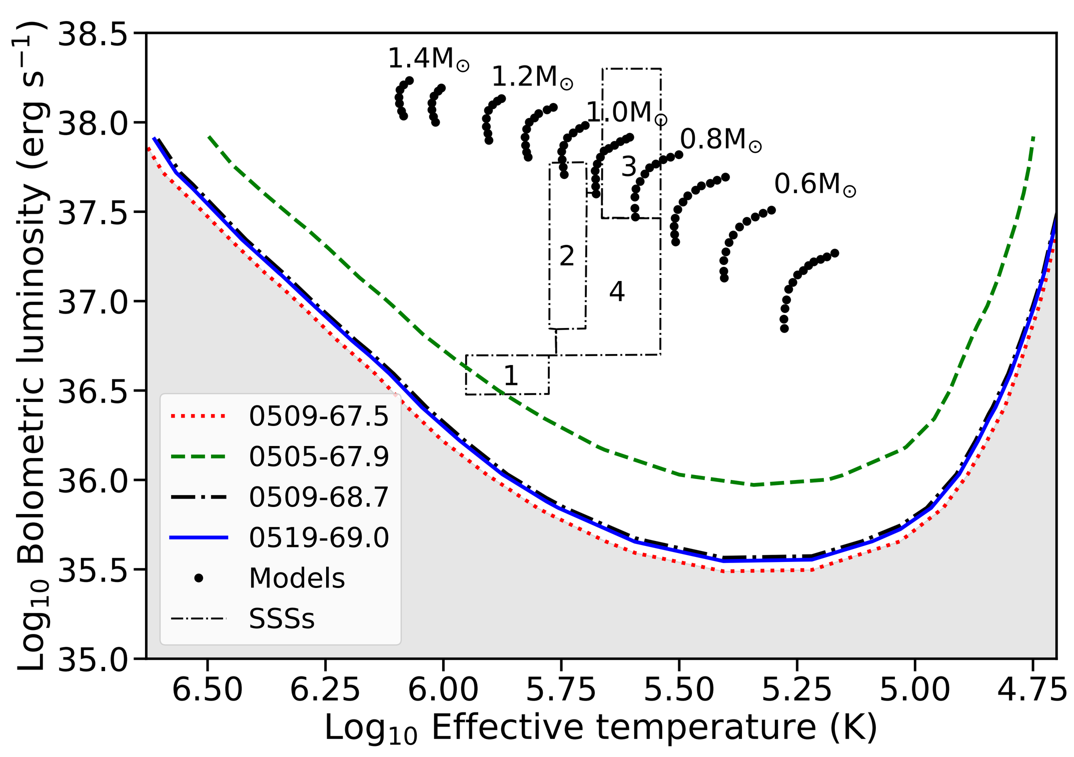


[a]www.nublado.org

4. Results

- **By comparing our observations with the simulations, we have placed stringent upper limits on the luminosities of the progenitors of these supernova remnants.**
- **We rule out SSSs as possible progenitors for all four of these remnants.**

To transform the surface brightness upper limits to limits on the progenitor luminosities, we compared the observations to the Cloudy simulations. The upper limits on the bolometric luminosity as a function of the assumed emission colour temperature for each source are shown in the figure below. In this figure, the coloured lines show the limits for the four SNRs. The parameter space above these lines (white area) is ruled out, while the grey area below these lines is unconstrained. For comparison, the black dotted lines show the accreting nuclear-burning WD models of Wolf et al. (2013). All of these models lie well above the derived upper limits for all the SNRs studied here. The black dash-dotted boxes represent the parameter ranges of four well-known SSSs: 1. CAL87; 2. 1E 0035.4-7230; 3. RX J0513.9-6951; and 4. CAL 83 (Greiner 2000). All of these four SSSs lie in the ruled-out region of the parameter space for the remnants studied here.



5. Conclusions

- **We conclude that none of the progenitors of the supernova remnants considered here were super-soft X-ray sources for a significant fraction of the last 10^5 years preceding their detonation.**

For more details, see:
Kuuttila J., Gilfanov M., Seitenzahl I. R., Woods T. E., Vogt F. P. A., 2019, MNRAS, 484, 1317

6. References

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