Investigation of supernova remnant IC 443 and G189.6+3.3 with *LAMOST*

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Introduction

Detecting optical emission in supernova remnants (SNRs) is essential for understanding the properties of the SNR and the environmental conditions, such as ambient density, that influence its evolution. This is achieved through optical CCD imaging using Hα, [SII], Hα+[NII], and [OIII] filters, alongside spectroscopic observations.

G189.6+3.3 was first discovered in X-rays by the ROSAT All-Sky Survey (Asaoka & Aschenbach, 1994). The X-ray image revealed a ring-like morphology with a diameter of approximately 1.5 arcminutes. The center of this SNR is offset from the nearby prominent SNR IC 443 by about 0.7 degrees. Camilloni & Becker (2023) suggest that the 0.7 keV plasma emission observed is likely associated with G189.6+03.3, positioned in front of IC443, supported by higher column density and expansion velocity measurements, indicating IC 443 as a background object emerging from behind G189.6+03.3. The distance to the SNR was estimated to be around 1.5 kpc, indicating that G189.6+3.3 is a well-evolved SNR with an age of approximately 10^5 years (Asaoka & Aschenbach, 1994).

IC 443 is a well-studied mixed-morphology SNR with an angular diameter of 45 arcminutes, located in the Galactic anticenter direction (Green, 2009). The SNR shell is bright and displays similar morphology across radio, X-ray, and optical wavelengths (Leahy, 2004; Asaoka & Aschenbach, 1994; Fesen, 1984). It exhibits a centrally peaked X-ray morphology (Petre et al., 1988), with central X-ray emission originating from two different positions (north and center), suggesting a cloud evaporation origin (Troja et al., 2008). The shock wave interacts with dense atomic and molecular clouds (Claussen et al., 1997; Snell et al., 2005) and expands in a highly inhomogeneous environment, forming two semi-spheres with different radii and centroids.

The shock velocities measured from the filaments in the optical band range from 60 to 100 km/s (Fesen & Kirshner, 1980; Lozinskaya, 1969). Additionally, velocities up to 350 km/s were detected from diffuse Hα emission using long-slit spectroscopy, with projection effects suggesting a shock velocity of 400 km/s (Lozinskaya, 1979). The Sedov solution provides ages of 60 and 10 kyr for the low and high velocities, respectively.

Method

We present the results from a study of the optical emission associated with SNR G189.6+3.3 and IC 443 based on the spectra from the Large sky Area Multi-Object fiber Spectroscopic Telescope (*LAMOST*). All available spectra for SNR G189.6+3.3 and IC 443 were used. Low continuum level (S/N<10) 94 stellar spectra from 85 locations are chosen. Spectra were taken in 2017 and each exposure time is 900 s.

LAMOST is also known as the Guo Shoujing Telescope, is an astronomical instrument designed for wide-field (4-m diameter and FoV is 5 degrees in diameter), multi-object spectroscopic surveys. Located at the Xinglong Station of the National Astronomical Observatories of China (NAOC). It covers 370-900 nm in optical spectrum. Spectral resolution (R) is between ~ 1800 (low resolution) and R ~ 7500 (high resolution).

For our analysis, we selected the wavelength range 4800−6800 Å, which includes the Hβ, [OIII], Hα, [NII], and [SII] emission lines Fig 1. We measured the fluxes and studied the line ratios.

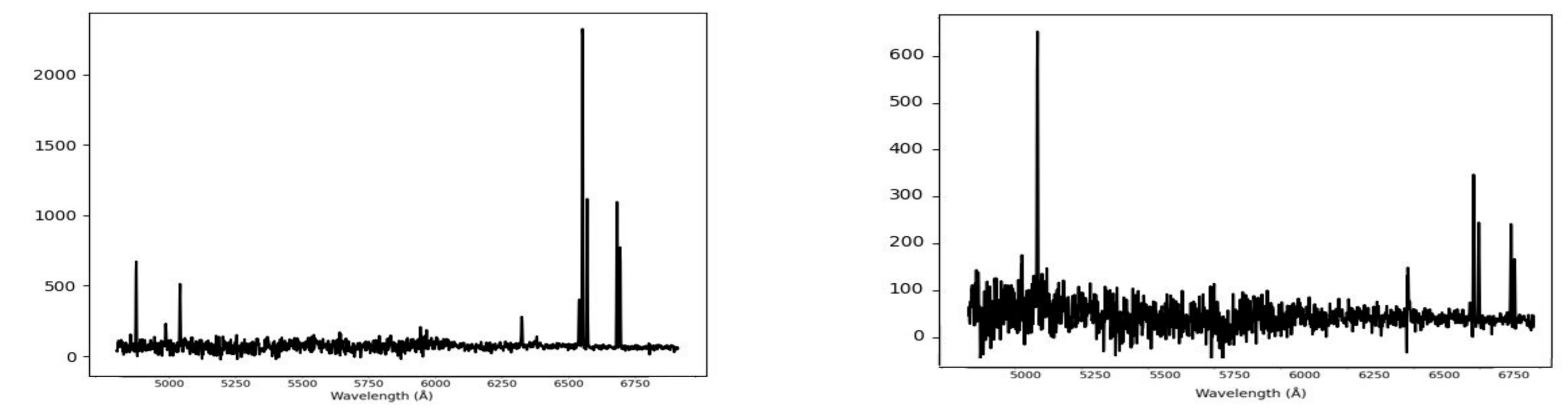

Figure 1. On the left is the spectrum with coordinate 06:15:36.60 +22:15:25.0, on the right is the spectrum with coordinate 06:19:41.38 +22:47:38.7.

Results

In this work, we report the spectroscopic observations from IC 443 and G189.6+3.3 with LAMOST. Our spectra exhibit the H$\beta\lambda$4861, [OIII]λ4959, λ5007, [NII]λ6548, H$\alpha\lambda$6363, [NII]λ6584 and [SII]λ6716, λ6731 lines. An average [SII]$\lambda\lambda$6716/6731 to H$\alpha\lambda$6563 ratio of [SII]/Hα=0.61±0.14 was found for the northeastern (NE) and eastern (E) regions outside of IC 443 are contaminated with emission from the HII region, while [SII]/Hα=1.25±0.38 was found within and slightly outside of IC 443 (Fig 2). [SII]/Hα ratios as high as 1.33 are also detected outside the bright filaments of IC 443, indicating that true size might be larger. We found the electron density (N_e) ranging from 4 to 1257 cm^{-3} using [SII]$\lambda\lambda$6716/6731 ratio with the *temden* task of the nebular package, assuming an electron temperature (T) of 10^4 K (Fig 3). For the whole region, the observed ratio of [OIII]/Hβ~2.81±2.26 that shows the relatively low T and expanding of shock (Osterbrock & Ferland, 2006). For the NE region outside of the IC 443, [OIII]/Hβ~1.19±0.42 indicates a shock velocity of 72 km s^{-1}, and also suggests that shocks with a complete recombination zone (Raymond 1979; Shull & McKee 1979) (Fig 4). We estimated reddening $E(B-V)$ of ~0.92±0.39 and ~0.47±0.11 for IC 443 and NE region outside of IC 443, respectively. Using the relation N_H=5.4×10^{21}×$E(B-V)$ (Predehl & Schmitt, 1995), we calculated the total column density of ~4.64×10^{21} cm^{-2} and also outside of the IC 443 is 2.54×10^{21} cm^{-2}. This implies that the HII regions in the NE region is much farther away than the SNR, and optical emission from this region may not be related to IC 443.

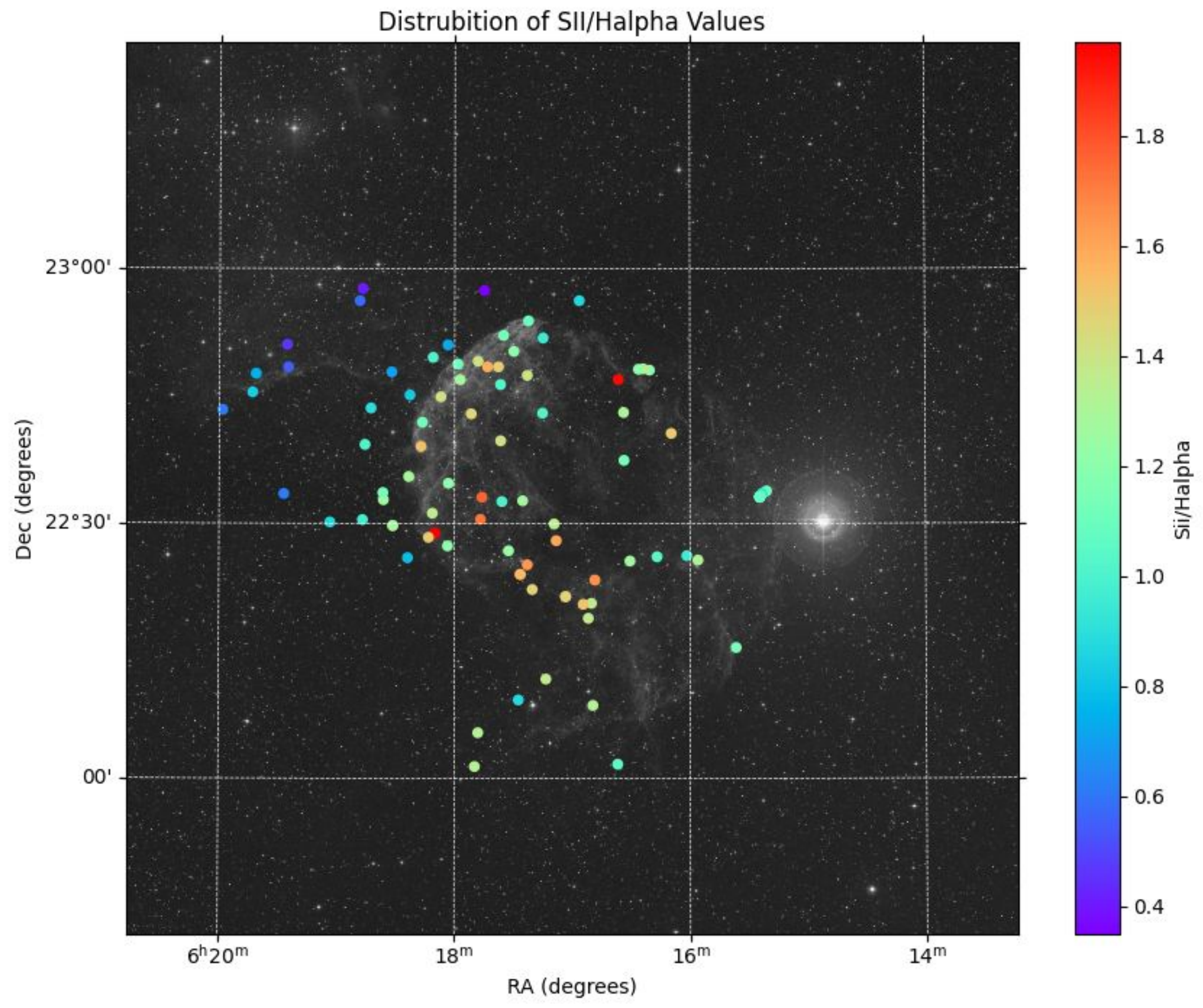

Figure 2. Distribution of [SII]/Hα values lying on IC 443 and G189.6+3.3. The average value is 0.97±0.28 for whole area.

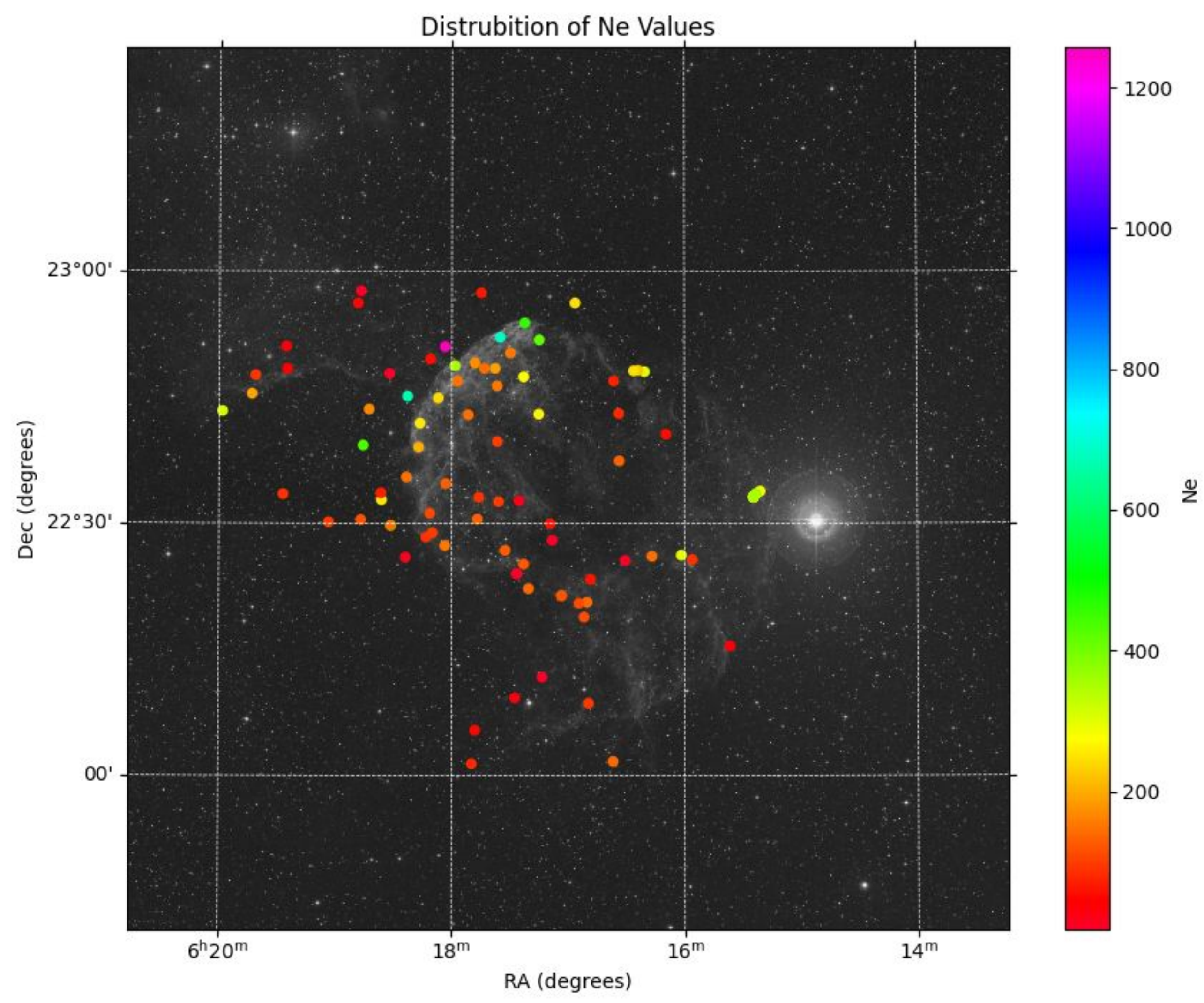

Figure 3. Distribution of N_e values lying on IC 443 and G189.6+3.3. The average value is 123±118.68 for whole area.

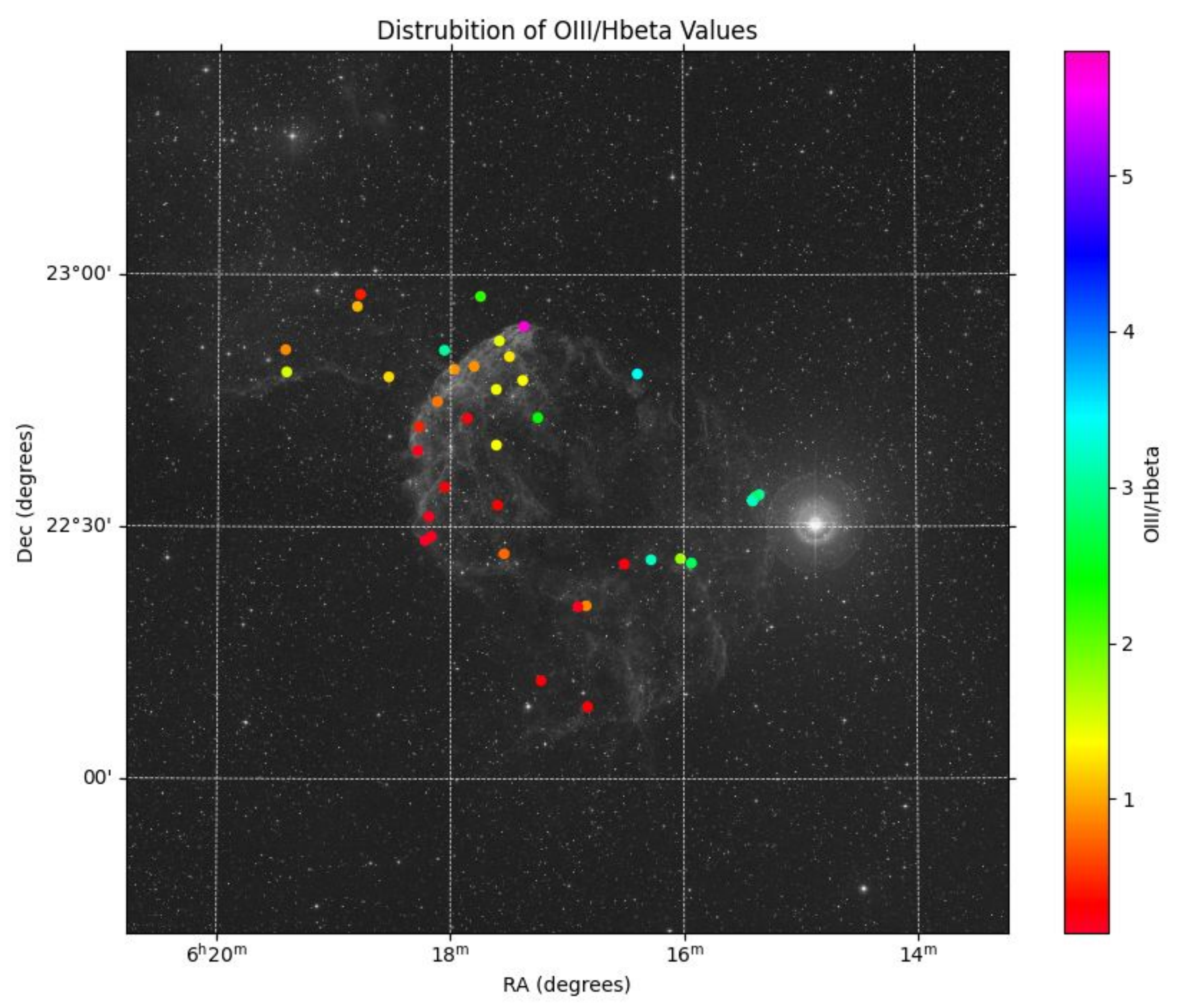

Figure 4. Distribution of [OIII]/Hβ values lying on IC 443 and G189.6+3.3. The average value is 2.81±2.26 for whole area.

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