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SUPERNOVA REMNANT SIGNATURES IN EMISSION-LINE SURVEYS OF THE MAGELLANIC CLOUDS WITH NOIRLAB'S DECAM

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RESUMEN

Describimos el uso de datos obtenidos con el sondeo DECam de Hα y [S II] de la Gran Nube de Magallanes (LMC), para estudiar su población de remanentes de supernovas (SNR). Revisamos las firmas observacionales de SNR, incluyendo los cocientes elevados de [S II]/Hα, que se utilizan para identificar y caracterizar estos objetos. Esto incluye recuperar SNR conocidos en los datos, corroborar candidatos a SNR sugeridos por otros instrumentos y buscar candidatos a SNR no identificados previamente. Destacamos ejemplos específicos de este sondeo, incluido el análisis de la estructura óptica de SNR confirmados y candidatos.

ABSTRACT

We describe our use of newly obtained DECam Hα and [S II] surveys of the Large Magellanic Cloud (LMC), to study its supernova remnant (SNR) population. We review the SNR signatures, including elevated [S II]/Hα ratios, used to identify and characterize these objects. This includes recovering known SNRs in the data, verifying SNR candidates suggested by other instruments, and searching for previously unidentified SNR candidtates. We highlight specific examples from this survey, including examination of the detailed optical structure of confirmed and candidate SNRs.

Key Words: ISM: supernova remnants

1. INTRODUCTION

The Large Magellanic Cloud (LMC) sample of supernova remnants (SNRs) has many advantageous qualities for the study of energy input to the interstellar medium (ISM) of a galaxy. As noted by Y.-H. Chu (this volume) the LMC is at high Galactic latitude, less affected by obscuration, and is seen nearly face-on. There have been extensive multi-wavelength surveys and object studies in the LMC, leading to a well-studied group of confirmed SNRs and a significant number of SNR candidates. Also, these SNRs are at a common, known distance of 50 kpc , so that $1'' \approx 0.24$ pc . Thus, observations can be directly converted to physical properties in the SNRs.

Dense clumps cooling behind a SNR shock front produce a range of optical emission lines. Notably, a S II /Hα ratio ≥ 0.4 (Long 2017) is only found in a narrow temperature and density range often indicative of shocked gas. This, thermal X-ray, and non-thermal radio emission are the most common criteria for classifying an object as an SNR, *e.g.* Long (2017). Much of the optical SNR identification in the LMC was based on the Magellanic Clouds Emission-Line

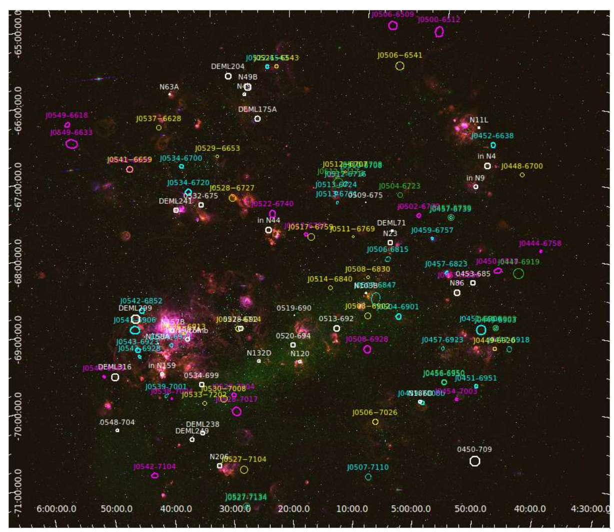

Fig. 1. MCELS image of the LMC in Hα (red), S II (green), and O III (blue). Superposed are identified SNRs and SNR candidates.

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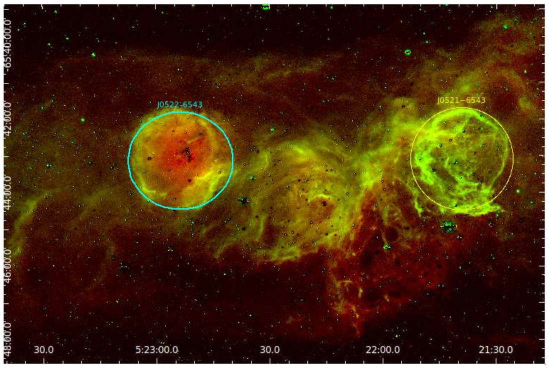

Fig. 2. DECam data for SNR J0521−6543 and surrounding regions. Hα emission is shown in red and S II in green.

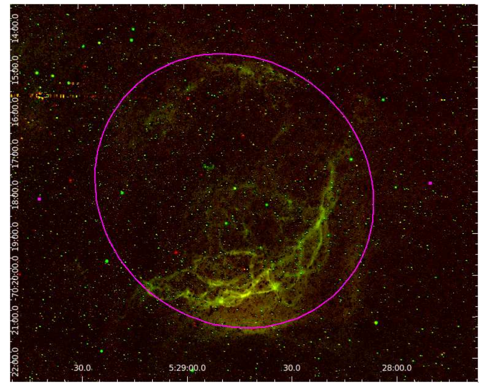

Fig. 3. DECam data with Hα emission shown in red and S II in green. SNR candidate Yew 12 (SNR J0528−7017) is marked in magenta.

Survey (MCELS, Smith et al. 1999); *e.g.* Yew et al. (2021) identified three SNRs and sixteen candidates in MCELS and supplementary data.

2. OBSERVATIONS

An opportunity to significantly improve on the MCELS 5″ resolution was presented by the Dark Energy Camera (DECam) on the Blanco 4-meter telescope at CTIO. Using the N662 (Hα) and N673 (S II) filters, and red-band for continuum subtraction, observers were able to obtain seeing-limited images (S. D. Points, this volume). This provided high-resolution, continuum- and star-subtracted Hα and S II images covering the LMC. One objective of this dataset was to provide optical images of SNRs that had not previously been examined at high optical resolution, which notably includes most of the larger, fainter SNRs that roughly correlate with late-stage SNR evolution prior to merging with the ISM.

Our interests are primarily associated with studies of SNRs, so we compiled lists of LMC SNRs and SNR candidates from the literature, shown in Fig. 1. These include X-ray identified SNRs from Williams et al. (1999, white), Maggi et al. (2016, yellow), and Kavanagh et al. (2022, green; follow-ups on ROSAT sources matching radio candidates); optical candidates from Yew et al. (2021, magenta); and radio candidates suggested by Bozzetto et al. (2017, 2023, cyan). We displayed the Hα and S II images at matching scales, on which we superposed SNRs and candidates with their coordinates from the literature. We then examined these regions for optical signatures of shocked gas, such as S II /Hα ratio enhancements typical of shocked gas and narrow filamentary structures within the region.

A challenge to optical SNR studies is to distinguish signatures of SNRs from those of other sources. H II regions with low surface brightness can show strong S II lines. However, the interiors of such regions often show bright Hα from photoionized gas; and their morphology tends to be less shell-like or filamentary. Similarly, superbubbles (SBs) can show enhanced S II /Hα ratios. While SBs are statistically larger than SNRs, there is no clear size boundary between the two, as SNRs can grow large in low-density surroundings. Indeed, several SBs are thought to be enhanced by shocks from internal SNRs, *e.g.* Chu & Mac Low (1990). To an extent, one can use the local massive star population to identify SBs, *e.g.* Chu & Kennicutt (1988), and eliminate some SBs from our sample. But areas with massive star populations are also likely sites for SNRs!

An example near SNR J0521−6543 can be seen in Fig. 2. The yellow outline indicates thermal X-ray emission (Maggi et al. 2016), matching the bright ring of high S II /Hα in the DECam image. The narrow, curved filaments in both emission lines are similar to those frequently seen in SNRs. In contrast, the cyan outline was identified by Bozzetto et al. (2023) as a confirmed SNR from its radio emission. The optical extent matches the listed dimensions at radio wavelengths. However, the object has bright central Hα and the S II emission surrounding it is graduated and diffuse, lacking filamentary structure. In the images before star subtraction, the region also shows a central star cluster; and in the MCELS data, the region has bright central O III as well, These characteristics are more typical of the outer rims of photoionized regions, *e.g.* Pelligrini et al. (2012).

The resolution of the DECam data allows us to better discern the details of emission-line morphology. Fig. 3 shows candidate SNR J0528−7017, first identified in MCELS data. In the DECam data,

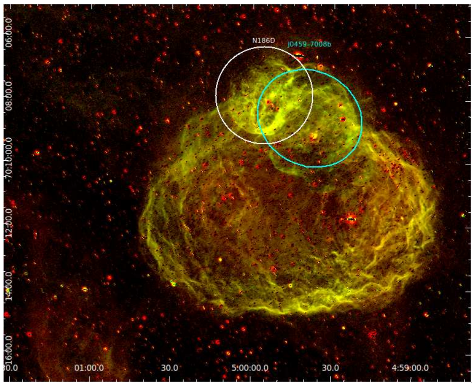

Fig. 4. DECam data with Hα emission shown in red and S II in green, showing the complex region LHA 120-N 186.

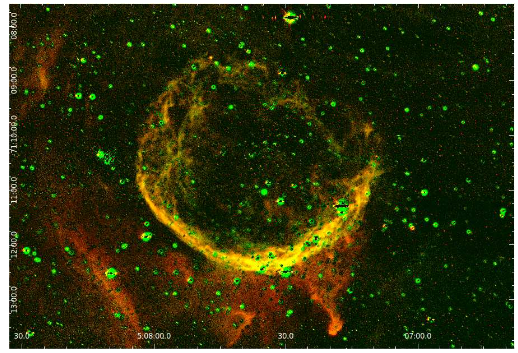

Fig. 5. DECam data showing an area near DEM L 81. Hα emission is shown in red and S II in green.

its fine filamentary structure can be seen. Fig. 4 shows the complex N186 region. SNR J0459−7008 (N186D) is a known SNR in this region, but in the DECam emission-line images we can see more S II filamentary structures nearby, including another shell-like structure with a high S II /Hα ratio. The second S II shell corresponds to radio SNR candidate J0459-7008b of Bozzetto et al. (2023).

We also searched for new promising SNR candidates in the DECam data. Fig. 5 shows one such object at the location of DEM L 81, near stellar cluster KHMX 565. It is noticeably bright in S II compared to Hα, and has a roughly circular structure (radius $2.5' \approx 36$ pc) with multiple narrow filaments.

3. SUMMARY AND FUTURE WORK

The new DECam optical emission-line survey of the LMC (and its counterpart for the Small Magellanic Cloud) presents a fantastic opportunity to develop a much more complete inventory of SNRs and SNR candidates. We have already found optical counterparts for a number of SNR candidates suggested from X-ray or radio data. We expect more detailed analysis will confirm the identification of some objects, adding to the catalog of confirmed SNRs in the LMC. In other cases, optical structures may suggest alternate explanations for objects that have been suggested as SNR candidates. We have also been able to identify several new SNR candidates from their high S II /Hα ratios and filamentary morphologies. We intend to follow up with archival data and new observations at other wavelengths to confirm their SNR nature. For the resulting confirmed SNRs, we can then compare their optical structure to that in X-ray and radio. While X-ray studies allow physical properties of the diffuse hot gas to be inferred, the optical emission-line fluxes will allow us to do the same for the denser material in clumps and filaments. Together, these should provide powerful tools to determine physical properties in these objects. It will also identify the most promising objects for follow-up studies *e.g.*, of velocity distributions.

We expect to use the DECam MC survey to search for additional SNR candidates, particular for larger, more evolved SNRs. This is a significant step toward extending our census of SNRs in a galaxy to include later stages of SNR evolution and their merging with the ISM - an important input parameter to the stellar feedback history of a galaxy. More generally, we will use the emission line ratios to study other types of shocks in the MCs, extending our studies to larger-scale interactions that will provide insight to the shaping of the ISM in those galaxies.

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