Boletim da Sociedade Astronômica Brasileira, **35**, no. 1, 29-30

Detection of supernova remnants in MUSE data cubes

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Abstract. The present work aims to identify supernova remnants (SNR) in galaxies, using the PCA tomography technique. After pre-processing the galaxy data cube, provided by MUSE/VLT (ESO), we applied PCA tomography with the aim of detecting point sources across the galaxy, to then isolate and extract the spectra of each source and analyze whether they actually meet the SNR criteria.

Resumo. O presente trabalho se propõe a identificar remanescentes de supernova (SNR) em galáxias, utilizando a técnica da tomografia PCA. Após um pré-processamento do cubo de dados da galáxia, fornecido pelo MUSE/VLT (ESO), aplicamos a tomografia PCA com o objetivo de detectar fontes pontuais pela galáxia, para em seguida isolar e extrair os espectros de cada uma das fontes e analisar se realmente cumprem os critérios de SNR.

Keywords. ISM: supernova remnants – Galaxies: ISM – Methods: data analysis

1. Introduction

Supernovae are extremely important for the chemical evolution of the Universe, and are also important sources of energy for the interstellar medium (ISM). Studying them observationally, however, is a challenge, given the unpredictability of the date and location of the star's explosion, and also the fact that they are relatively rare on human scales.

The interaction of the shock wave generated by the supernova with the ISM produces emission at various wavelengths. In optics, in particular, SNRs produce emission lines with characteristics different from those produced by star-forming regions. Our aim, inspired by the work of Cid Fernandes et al. (2021), is to identify SNR in other galaxies using an unorthodox technique: PCA tomography.

2. Results

The galaxy chosen for the work was NGC 0289 (SBbc), obtained from its data cube (http://archive.eso.org/scienceportal/home/) observed by the Very Large Telescope (VLT) with the MUSE instrument, a spectrograph of integral field that covers a field of 1×1 arcmin in 326×326 pixels, with a spectral coverage in the optical range of 4800 to 9000 Å and spectral sampling of 1.25Å.

It was necessary to carry out pre-processing, cleaning impurities and problematic pixels. After that, the STARLIGHT code (Cid Fernandes et al. 2005) was used to adjust the stellar continuum, and also the DOBBY program (Flórido, 2018) to measure the emission lines. Finally, an analysis to manually remove unwanted stars and any remaining bad pixels completed this part of the data cube processing, making it now ready for use.

In the next step, PCA tomography was applied to the data cube. Originally developed by Steiner et al. (2009), PCA tomography is a method that consists of a reduction of data expressed as a large set of correlated variables into a small but optimal set of uncorrelated variables, ordered by their principal components (PC) of decreasing variance.

As a result of this application, in addition to the eigenspectra (here measured in $L_{\odot}$), we also obtain the tomograms, which are the images produced from the projections of data on the new components that the application of PCA produced. In other words, each eigenspectra is associated with its respective tomogram, which is very useful as spectral characteristics can be identified in the images and assist in data interpretation.

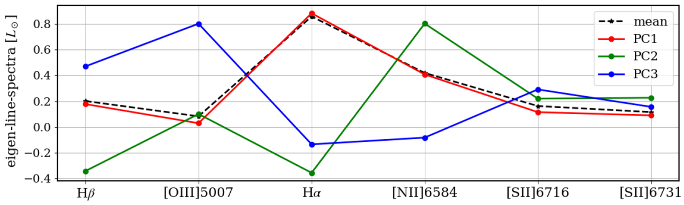

Figure 1. The first three eigen line spectra obtained from the PCA. The dashed line shows the rescaled mean line-spectrum.

We applied PCA tomography to a reduced data cube of 322×326 spatial dimensions, but with only six spectral lines analyzed: Hβ, [O III] 5007, Hα, [N II] 6584, [S II] 6716, 6731.

Fig. 1 shows the first three (out of a total of six) eigen-line-spectra obtained by PCA. Interpreting autospectra can sometimes be difficult, but in this case the data were clear. It can be seen that principal component 1 (PC1) basically represents the pattern of emission lines of a typical H II region, being similar to the average spectrum. PC3 shows a contrast between the Hβ and Hα lines, which may indicate less attenuation by dust.

But the highlight is in PC2, where there is an excess of forbidden lines ([O III], [N II] and [S II]) in relation to the recombination lines (Hβ and Hα), indicating the presence of a mechanism different from gas excitation.

Fig. 2 shows the tomogram referring to PC2 and very bright compact sources stand out (marked in white circles) throughout the FoV. And as identified by Cid Fernandes et al. (2021) in another galaxy, sources with these characteristics are, for the most part, SNRs.

To identify these sources, DAOStarFinder (from astropy) was used on tomogram 2, and we fixed some values such as the source opening of 3.5 spaxels (FWHM = 3.5), and a background defined between 4 and 6 spaxels, in addition to a parameter limit at T = 50 $L_{\odot}$. In total, 32 sources were detected. However, not all sources are SNRs, so it is necessary to analyze the spectrum of each one to obtain confirmation.

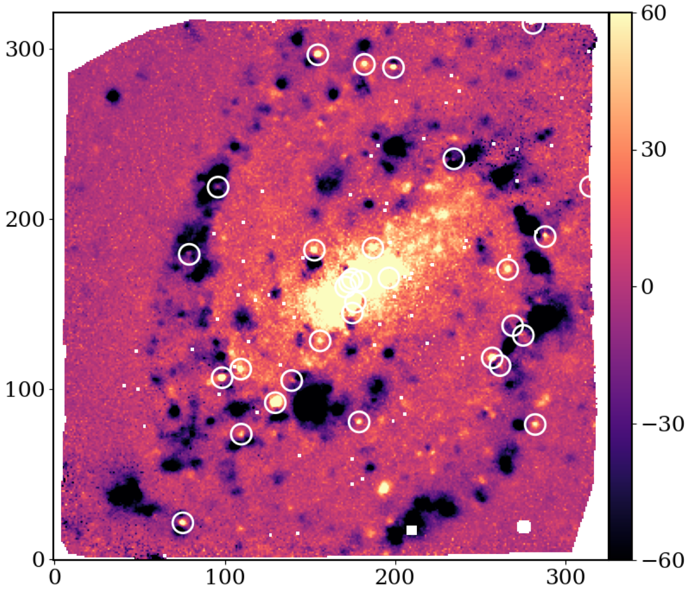

Figure 2. SNR sample sources plotted on tomogram 2. The circles mark the 32 possible SNR detected with a threshold of T=50$L_\odot$. Missing points (in white) mark the masked spaxels (bad data or foreground stars). The intensity scales are all in $L_\odot$.

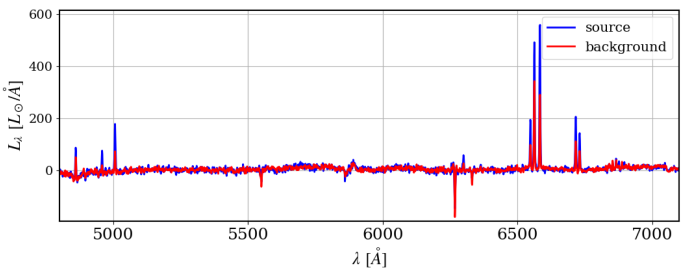

Figure 3. Spectrum extracted from the source and background in $(x, y) = (266, 170)$.

Figure 3 shows the spectrum extracted from one of the detected sources (the source in blue and the background in red). The strong emission of the [O III], [N II] and [S II] lines is very evident when compared to Hα and Hβ, being a decisive criterion for SNRs. Therefore, this ends up being the necessary confirmation to ensure that this source is really an SNR.

3. Conclusions

PCA tomography proved to be a very useful method for identifying candidate SNR sources, as several of the detected sources were actually confirmed as SNR. Improvements to optimize the identification and analysis, individually and collectively, of sources are being implemented, which should provide us with useful empirical information to better understand the evolution of RSNs.

Acknowledgements. We thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for supporting this research. We also thank Universidade Federal de Santa Catarina (UFSC) for the encouragement and assistance provided. And SAB for the opportunity and assistance in presenting this study at XLVI Reunião Anual da Sociedade Astronômica Brasileira.

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