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Properties of supernova remnants in SIGNALS galaxies – I. NGC 6822 and M33

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ABSTRACT

We present a spatially resolved study of the kinematical properties of known supernova remnants (SNRs) in the nearest galaxies of the SIGNALS survey, namely NGC 6822 (one object) and M33 (163 objects), based on data obtained with the SITELLE imaging Fourier transform spectrometer at the Canada–France–Hawaii Telescope. The purpose of this paper is to provide a better scheme of identification for extragalactic SNRs and, in particular, to distinguish between H II regions and SNRs. For that we have used diagrams which involve both the [S II]/H α ratio and the velocity dispersion (σ). We also introduce a new parameter, $\xi = \frac{[\text{S II}]}{\text{H}\alpha} \times \sigma$, which enhances still the contrast between SNRs and the rest of the ionized gas. More than 90 per cent of the SNRs in our entire sample show an integrated [S II]/H α ratio larger than the canonical value (0.4). 86 per cent of the SNRs present in our field show a significant velocity dispersion. The spectral resolution of our observations allows us to observe the complex velocity structure of some SNRs.

Key words: ISM: H II regions – ISM: supernova remnants – galaxies: individual: M33, NGC 6822 – galaxies: ISM.

1 INTRODUCTION

A core-collapse supernova (SN) is the most dramatic stage in the life of a massive ($>8 M_{\odot}$) star, where it cannot maintain gravitational equilibrium and its core collapses, bounces back, thus generating a shock wave which, under favourable conditions (Gogilashvili & Murphy 2022), leads to the fast ejection of a large fraction of the stellar envelope. The result of the interaction between this rapidly ejected material and the surrounding circumstellar (in the very early stages) and interstellar medium (ISM), known as a supernova remnant (SNR), brightly shines for thousands of years with distinct signatures across the electromagnetic spectrum (Long 2017). SNRs are thus, in principle at least, relatively easy to identify in the Local Universe. Because both Type Ia and core-collapse SNe play a key role in the chemical evolution of galaxies and the dynamics of the ISM, studying the properties of SNRs provides an essential element to our understanding of the global ISM in nearby galaxies.

In the visible part of the spectrum, the [S II]/H α ratio is traditionally used to distinguish between SNRs and H II regions: H II regions

typically have values of [S II]/H $\alpha \sim 0.1$ (e.g. Dodorico & Sabbadin 1976; Long et al. 2010), while SNRs have a value of at least 0.4. The diffuse ionized gas (DIG) however also presents high values of this ratio, complicating the unambiguous identification of SNRs. In addition to the traditional one, there are other non-empirical identification methods using different emission-line ratios (e.g. Kopsacheili, Zezas & Leonidaki 2020; Congiu et al. 2023). Kopsacheili et al. (2020) point out that a large number of shock models have [S II]/H α ratios lower than 0.4, and in particular that the use of 0.4 as a strict cut-off disfavors the identification of SNRs with slow shock velocities (see however Winkler et al. 2023).

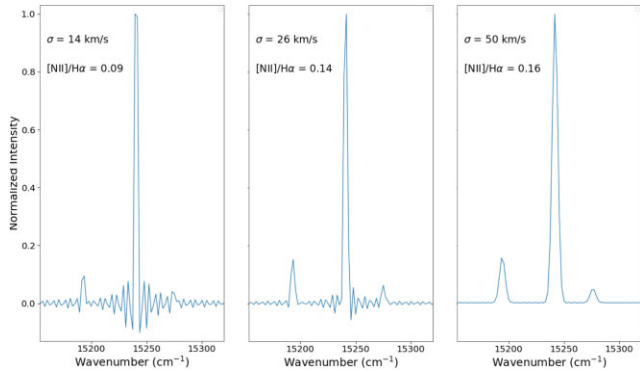
Long et al. (2018) noticed that a substantial number of SNR candidates in M33 show larger emission-line widths than H II regions and suggests that velocity broadening could be a potential discriminant to appropriately select SNRs. Following this finding, Points et al. (2019) proposed to use measurements of the kinematics of extragalactic SNR candidates in addition to the widely used [S II]/H α ratio as a means to ‘purify’ the surveys. They illustrate this using long-slit spectra of well-known SNRs in the Large Magellanic Clouds and a sample in M83.

In this work, we follow in their footsteps by studying known SNRs in two Local Group galaxies, NGC 6822 (Dopita et al. 2019)

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Table 1. Characteristics of the data cubes.

Field	RA	Dec.	Filter	R	Exposure/step	Num. steps	Date
NGC 6822	19:44:47.6	−14:45:22	SN3	3300	21 s	590	2017 July 5
			SN2	560	82 s	132	2017 June 30
			SN1	400	139 s	69	2016 July 9
M33-F1	01:34:24.1	+30:44:56	SN3	2900	18 s	505	2017 Oct 12
			SN2	1020	38 s	219	2017 Sept 28
			SN1	1020	49 s	172	2017 Sept 28
M33-F2	01:33:36.2	+30:42:57	SN3	2900	18 s	505	2017 Oct 13
			SN2	1020	38 s	219	2017 Sept 28
			SN1	1020	49 s	172	2017 Sept 28
M33-F3	01:34:24.1	+30:34:33	SN3	2900	18 s	505	2017 Oct 17
			SN2	1020	38 s	219	2017 Sept 28
			SN1	1020	49 s	172	2017 Sept 28
M33-F4	01:33:33	+30:32:55	SN3	2200	18 s	403	2017 Oct 13
			SN2	1020	38 s	219	2017 Sept 28
			SN1	1020	49 s	172	2017 Sept 28
M33-F5	01:34:00.1	+30:53:35	SN3	5000	13 s	842	2021 Oct 2
			SN2	1020	46 s	219	2021 Oct 4
			SN1	1020	59 s	171	2021 Oct 6
M33-F6	01:33:19.1	+30:51:51	SN3	5000	13 s	842	2021 Sept 30
			SN2	1020	46 s	219	2021 Nov 5
			SN1	1020	59 s	171	2021 Nov 10
M33-F7	01:32:50.7	+30:34:50	SN3	5000	13 s	842	2018 Oct 4
			SN2	1020	46 s	220	2018 Oct 11
			SN1	1000	59 s	171	2018 Oct 12
M33-F8	01:32:51.1	+30:22:34	SN3	5000	13 s	842	2020 Oct 15
			SN2	1020	46 s	219	2020 Dec 8
			SN1	1000	59 s	171	2020 Nov 17
M33-F9	01:33:41.6	+30:18:47	SN3	5000	13 s	842	2019 Sept 29
			SN2	1020	46 s	220	2020 Dec 11
			SN1	1000	59 s	171	2020 Nov 14

**Figure 1.** Normalized ORCS fits to the integrated spectrum of three regions in M33, showing the effects of the line broadening on a data cube with $R = 5000$ spectral resolution. See the text for details.

and M33 (Long et al. 2010; Lee & Lee 2014), using data cubes obtained with the imaging Fourier transform spectrometer (iFTS) SITELLE at the Canada–France–Hawaii telescope (CFHT). These data are part of the SIGNALS survey (Rousseau-Nepton et al. 2019), one of CFHT’s Large Programs, which aims at studying massive star formation and H II regions in a sample of local (distance ≤ 10 Mpc) extended galaxies by measuring bright line ratios and kinematics.

While most previous kinematics studies of SNRs in M33 are based on long-slit and fibre spectroscopy and thus do not sample the entire area of the objects, SITELLE (Drissen et al. 2019) allows us to perform a spatially resolved study of all the targets alongside that of

their surrounding H II regions and DIG, due to its wide field of view (11 arcmin \times 11 arcmin). Moreover, in the H α spectral region,¹ SIGNALS’ nominal resolution of $R = 5000$ (see below) is very close to that suggested by Points et al. (2019) for the purpose of discriminating SNRs from H II regions.

The vast majority of SIGNALS target lie beyond the Local Group (median distance = 4 Mpc), but selected fields in nearby galaxies (M33, M31, NGC 6822, WLM, Sextans A, and IC 1613) have also been targeted in order to serve as templates for the rest of the sample. Although the focus of SIGNALS is on H II regions and massive star formation, the sample is also very well suited for the study of SNRs. The initial goal of this work was to combine the standard [S II]/H α criterion with the 2D and integrated velocity dispersion (σ) information in order to provide a framework allowing a clear and unambiguous identification of SNRs in the Local Group that could be used for more distant gas-rich galaxies. This is thus the first in a series of papers dedicated to this topic.

The structure of this paper is organized as follows: in Section 2 we describe the observations, the data reduction, and the analysis of the data. In Section 3 we present the morphological and kinematical results of Ho 12, the SNR in NGC 6822, and we show the scheme of identification proposed in this work. The application of this identification scheme to a sample of SNR candidates from M33 can be seen in Section 4. Finally, in Section 5 we present our conclusions.

¹In the case of nearby galaxies, such as the complete sample of galaxies in the SIGNALS project, the H α spectral region refers to the SN3 bandpass.

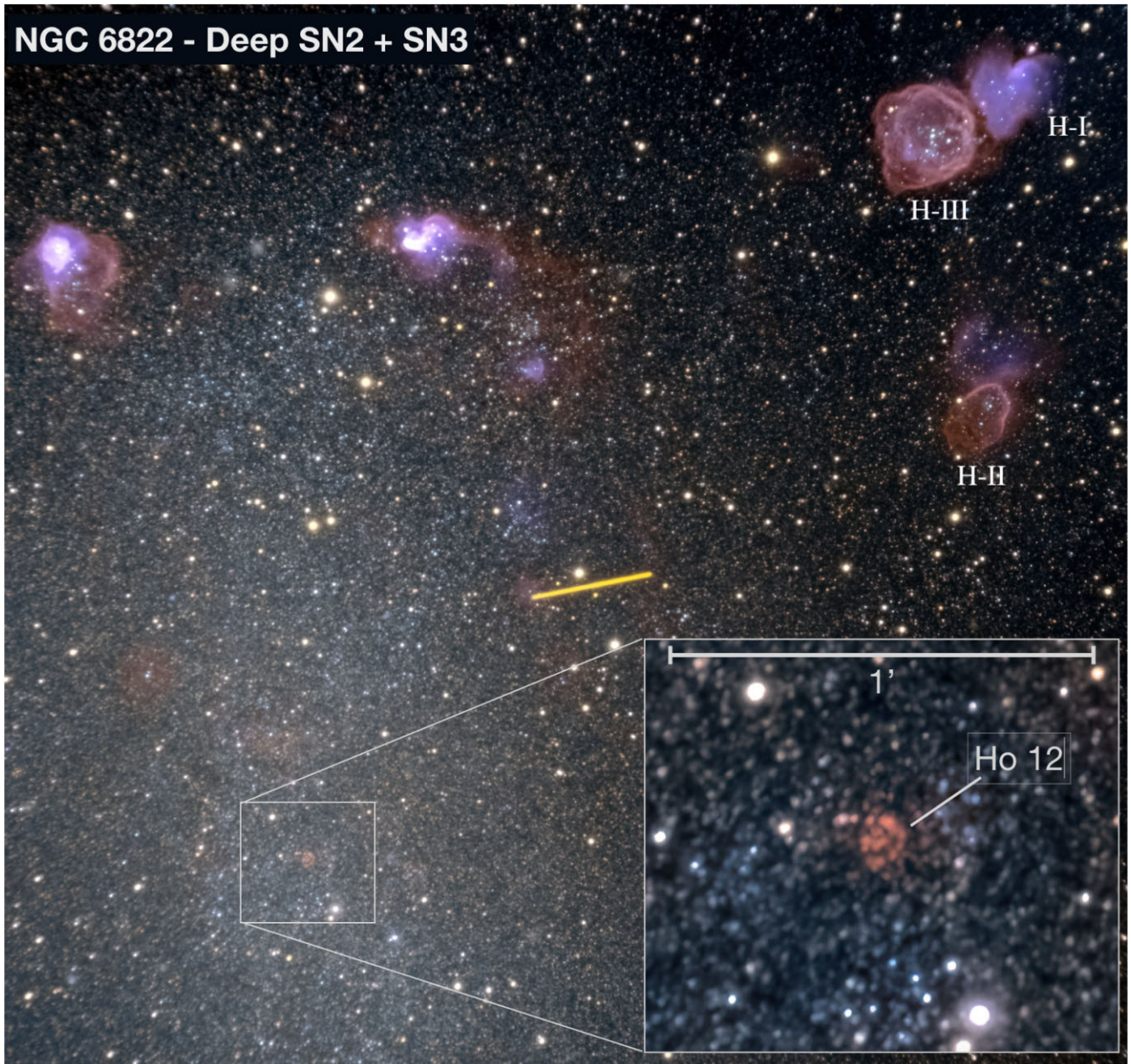


Figure 2. Composite image (10 arcmin \times 10 arcmin, with North up and East to the left) of NGC 6822 from the SN2 and SN3 deep frames (see the text). H II regions Hubble-I, II, and III (discussed later) are identified. The inset shows the location of Ho 12. Asteroid (654) Zelinda is seen crossing the field of view near the centre of the image.

2 OBSERVATIONS, DATA REDUCTION, AND ANALYSIS

SITELLE provides the spatially resolved spectrum of the sources in an 11 arcmin \times 11 arcmin field of view with a sampling of $0.32 \text{ arcsec pixel}^{-1}$, in selected bandpasses of the visible range, with a spectral resolution adapted to the need of the observer. Three bandpasses, centred on the H II regions' bright lines, are used in SIGNALS: SN3 (647–685 nm, $R = 5000$), SN2 (482–513 nm, $R = 1000$), and SN1 (363–386 nm, $R = 1000$). The SN3 data cubes (which include $H\alpha$, the $[\text{N II}]\lambda\lambda 6548, 6584$ doublet and the $[\text{S II}]\lambda\lambda 6717, 6731$ doublet) provide the required kinematics information as well as the $[\text{S II}]/H\alpha$ ratio traditionally used to identify SNRs. In this paper, we will also show images extracted from the SN1 and SN2 data cubes, although a detailed analysis of the line ratios will not be presented.

Half of the data cubes used in this paper (NGC 6822, M33 Fields 1 to 4) were observed as part of SIGNALS' proof of concept program; the spectral resolution and total exposure times of some of them therefore did not meet the SIGNALS standards (exemplified by Fields 5 to 9 in M33, see Table 1). Nevertheless, with a spectral resolution of $R \sim 3000$ in the $H\alpha$ spectral region (SN3 filter), these data are of sufficient quality to start our investigation of SNRs in Local Group galaxies.

The raw data, consisting of two complementary 2D interferograms (acquired using the two CCDs on the receiving end of the Michelson; see Drissen et al. 2019), were transformed into a single fully calibrated spectral data cube with ORBS, SITELLE's dedicated data reduction software (Martin, Drissen & Joncas 2015). Photometric calibration is secured from images and data cubes of

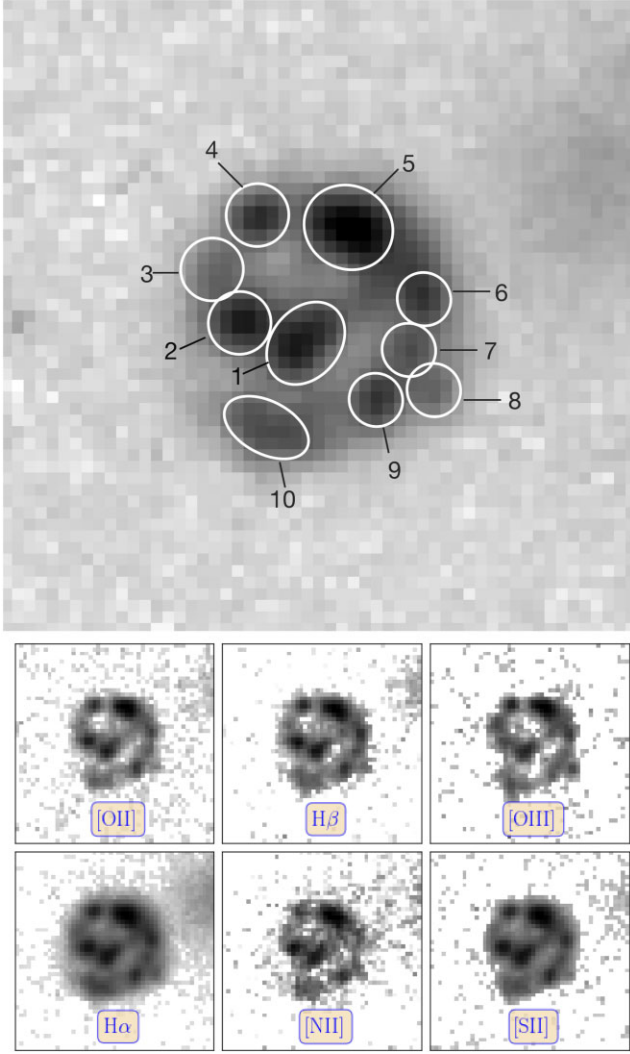


Figure 3. (Upper panel) $H\alpha$ image of Ho 12 (17.3 arcsec, or 43 pc, on a side), with the knots labelled. (Lower panel) Emission-line maps: [O II] $\lambda 3727$ from the SN1 cube; $H\beta$ and [O III] $\lambda 5007$ from the SN2 cube; $H\alpha$, [N II] $\lambda 6584$, and [S II] $\lambda \lambda 6717,6731$ from the SN3 cube. North is at top, East to the left.

Table 2. Properties of the knots in Ho 12. Values are obtained within the limits of the contours shown in Fig. 3.

Knot	$F(H\alpha)$ $10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$	V_{helio} km s^{-1}	σ km s^{-1}
1	6.1	-160	71
2	4.1	-115	73
3	1.3	-111	83
4	2.7	-44	58
5	9.6	-57	65
6	2.1	-60	57
7	1.4	-70	45
8	0.8	-57	60
9	1.8	-63	45
10	3.4	-36	70

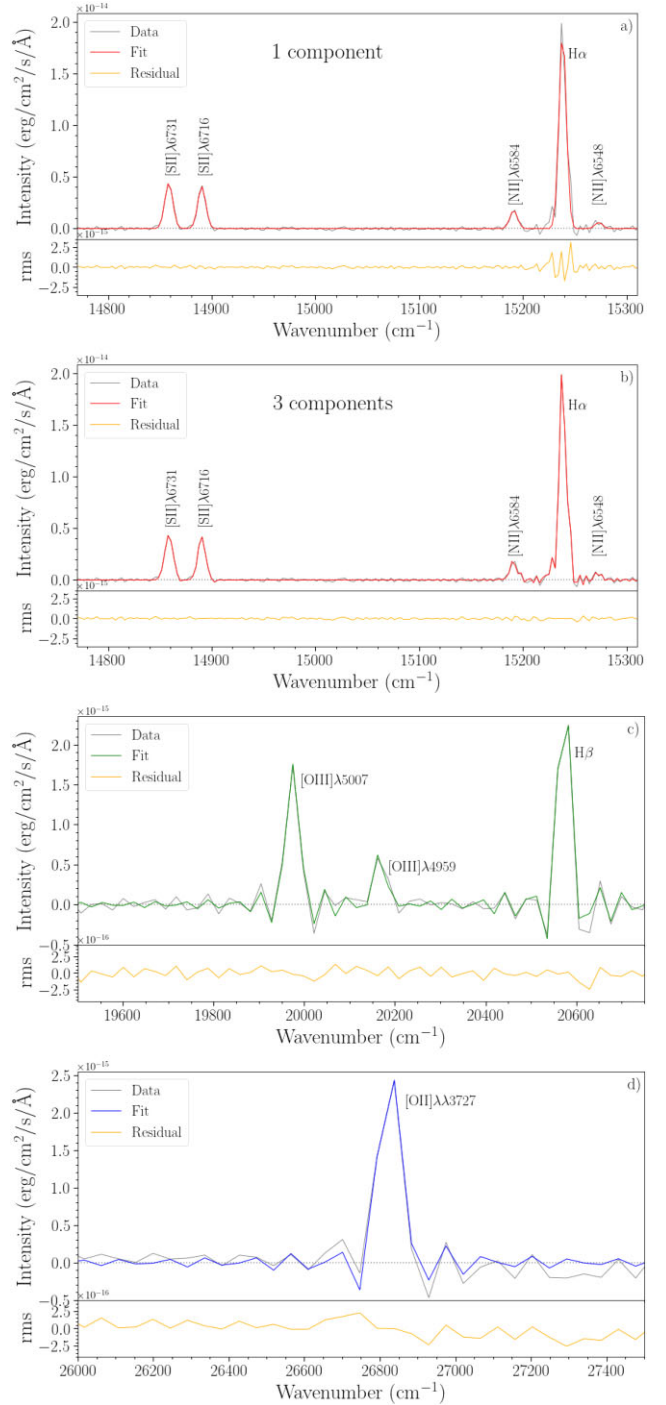


Figure 4. Integrated spectrum ($r = 4.2$ arcsec = 10.5 pc) of NGC 6822-Ho 12, with fits using one velocity component (panel a) and three velocity components (panel b). The green and blue coloured lines show the fit obtained in the SN2 (panel c) and SN1 (panel d) filters, respectively; residuals from the fit are also shown in the lower panels.

spectrophotometric standard stars such as G93-48, P330E and HZ21. Wavelength calibration is performed using a high spectral resolution laser data cube. It may show distortions due to aberrations and deformations in the optical structure, leading to zero-velocity offsets of $\sim 15\text{--}20 \text{ km s}^{-1}$ across the field of view. We thus refine the wavelength calibration by measuring the centroid positions of the night sky OH emission lines (in the SN3 filter) in the science

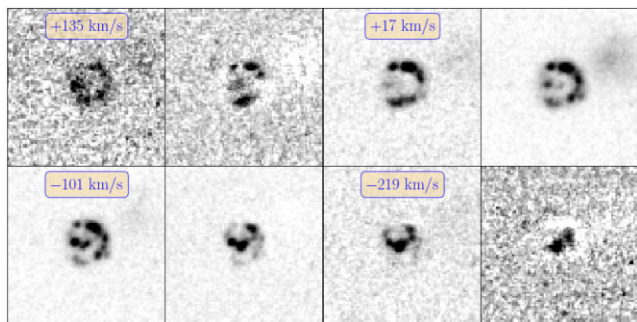


Figure 5. Consecutive frames centred on the $H\alpha$ line (from the SN3 data cube) showing the velocity structure of Ho 12.

data cubes following the procedure described in Martin, Drissen & Melchior (2018), reducing the uncertainty on the velocity calibration across the entire field to less than 2 km s^{-1} . We also applied a barycentric correction to the observed spectra.

Spectral data from SITELLE (Fig. 1) can be a bit confusing for first-time users, for two reasons. First, the natural units of an FTS are wavenumbers (cm^{-1}): in the SN3 data cube, the [S II] doublet is therefore to the left of $H\alpha$. Secondly, each line is surrounded by oscillating sidelobes, alternating between positive and negative values. This is because, as described by Martin, Prunet & Drissen (2016), SITELLE’s Instrument Line Shape (ILS) is a sinc function. However, any line broadening caused by turbulent motion, an expanding bubble, or a velocity gradient along an extended aperture will transform the natural ILS into a so-called sinc-Gauss function, the convolution of a sinc and a Gaussian. ORCS, SITELLE’s analysis software suite (Martin & Drissen 2020), is thus used to fit the observed line profiles for each pixel of the field of view (or an integrated region within it) and produce maps (or single values) of line intensities, radial velocity, and velocity dispersion (σ) as well as their uncertainties.

We note that since σ characterizes the Gaussian function which, convoluted with the ILS, reproduces the observed line shape, it represents the natural line broadening beyond the instrumental one. The minimum line broadening measurable with ORCS is a function of the cube’s spectral resolution and the signal-to-noise ratio (S/N) of the data (see fig. 2 in Martin et al. 2016). With the current SN3 data cubes, this value is of the order of $10\text{--}15 \text{ km s}^{-1}$. Fig. 1 shows

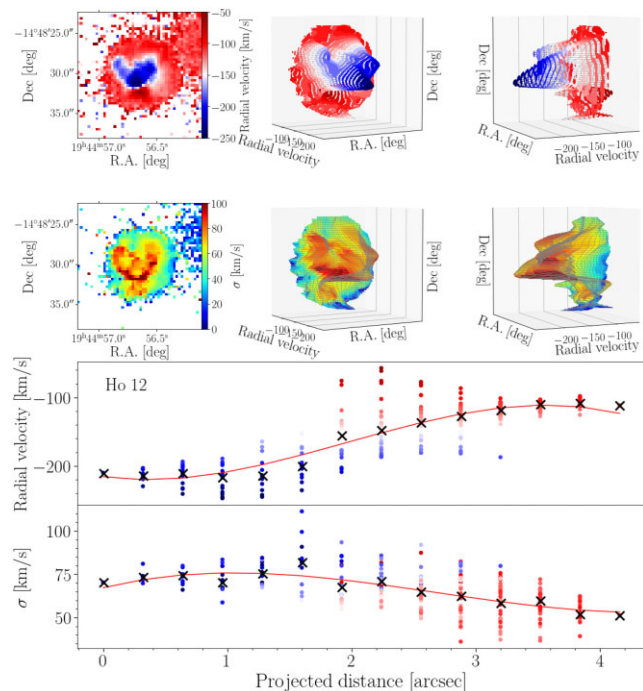


Figure 7. Map of radial velocity and three-dimensional view (RA, Dec., and radial velocity) of Ho 12 colour-coded by the radial velocity (upper panels), map of σ and three-dimensional view colour-coded by the σ (middle panels), and its radial profiles along Ho 12 (lower panels). Individual pixels in the radial profiles are colour-coded according to their radial velocity. The black crosses and red solid lines represent the medians at a given projected distance and a polynomial fit to the data, respectively.

fits to integrated (circles of 5 pixel radius) spectra of three regions in the M33-F9 field, illustrating the effect of line broadening on the spectral profile. On the left is a small ($\sim 25 \text{ pc}$ diameter) H II region with a barely detectable broadening. Note the oscillating sidelobes of the iFTS sinc profile, which extend well beyond the [N II] doublet. The central spectrum is that of a part of a large H II complex with multiple expanding filaments along the line of sight, well discernible when moving through the spectral cube. With an easily measurable line broadening, we notice that the sidelobes display a significantly lower amplitude than the left-hand spectrum. On the right, we show

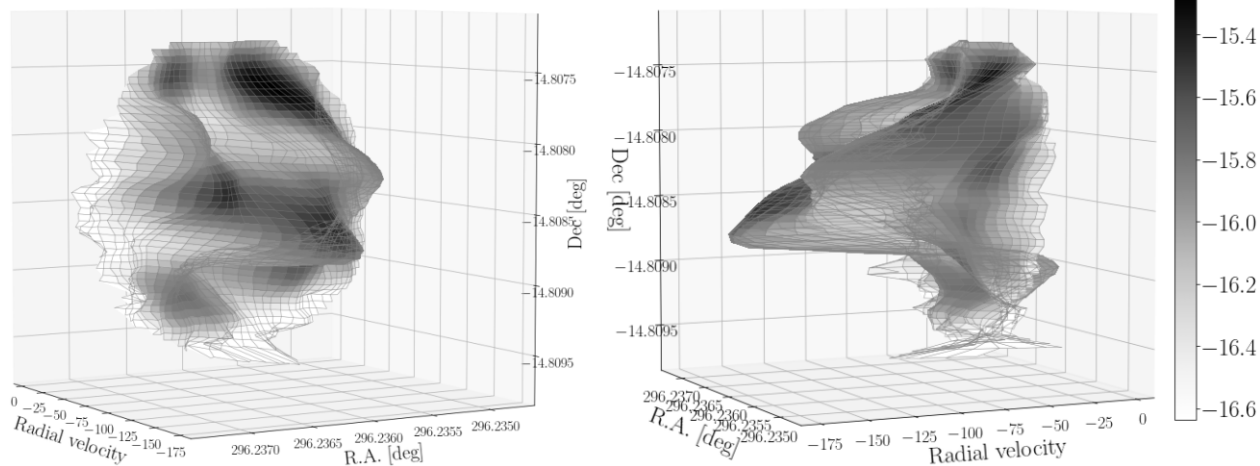


Figure 6. Three-dimensional view of Ho 12 (RA, Dec., and radial velocity diagram). The greyscale indicates the $H\alpha$ flux.

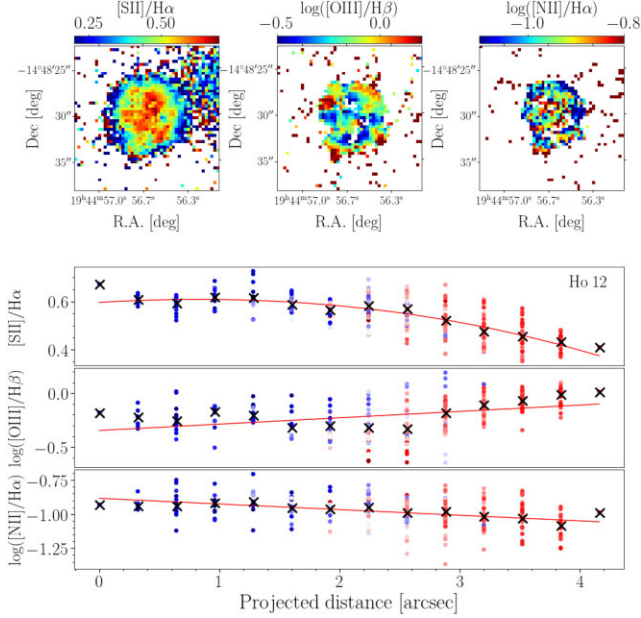


Figure 8. Maps of $[S II]/H\alpha$ (upper left panel), $\log([O III]/H\beta)$ (upper middle panel), and $\log([N II]/H\alpha)$ (upper right panel) of Ho 12 and their corresponding radial profiles. All the pixels in the radial profiles are colour-coded according to their radial velocity, from the reddest ($+15 \text{ km s}^{-1}$) to the bluest colour (-185 km s^{-1}). The black crosses and red solid lines represent the medians at a given projected distance and a polynomial fit to the data, respectively.

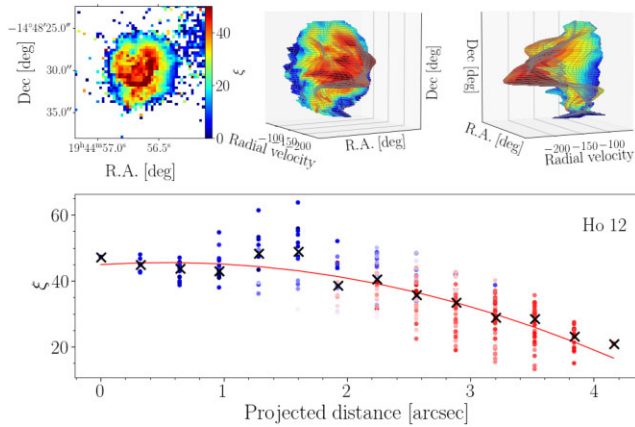


Figure 9. Map of ξ and three-dimensional view (RA, Dec., and radial velocity) of Ho 12 colour-coded by ξ (upper panels), and its radial profile along Ho 12 (lower panels). All the points in the radial profiles are colour-coded by its radial velocity, red higher and blue lower. The black crosses and red solid lines represent the medians and polynomial fit of each property and the projected distance, respectively.

the spectrum of a portion of one SNR in M33 where the width of the central peak is indeed about twice that of the instrumental profile, and the sinc sidelobes are barely detectable between $H\alpha$ and the $[N II]$ lines. These spectra are fits to real data, and are therefore noiseless and thus amenable to a pedagogical demonstration. But, as we shall see throughout this paper, actual data also clearly show this behaviour and ORCS's ability to fit them and extract the required properties of the source.

ORCS simultaneously fits all the lines within a given data cube, but allows the user to either force identical velocities and velocity

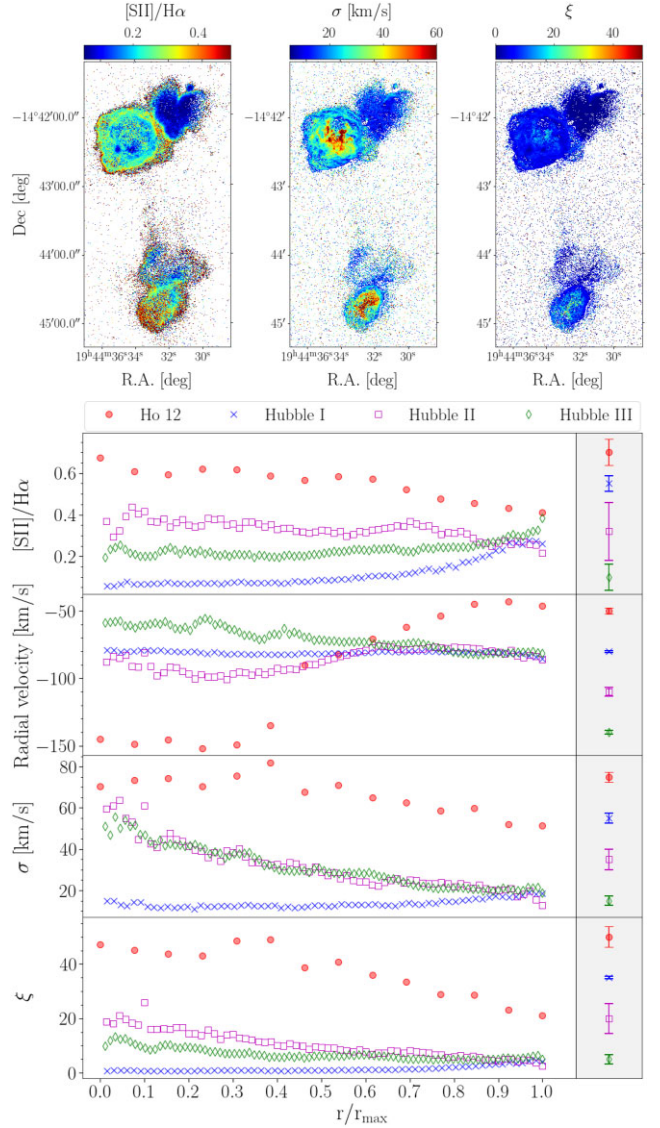


Figure 10. $[S II]/H\alpha$ ratio, σ , and ξ maps of the large H II regions Hubble I (region at north-west), Hubble III (region at north-east), and Hubble II (region at south) in NGC 6822. The lower panels show, from top to bottom, the normalized radial profiles, r/r_{max} , of $[S II]/H\alpha$, $\log([O III]/H\beta)$, $\log([N II]/H\alpha)$, radial velocity, σ , and ξ . The median of each properties along the normalized radius in bins of 0.32 arcsec is shown for the SNR Ho 12 (red circles) and the H II regions Hubble I (blue crosses), Hubble II (magenta squares), and Hubble III (green diamonds). To derive the medians of each H II regions we considered all pixels with S/N in $[S II]$ and $H\alpha$ greater than 1, while for Ho 12 greater than 5 in both $[S II]$ and $H\alpha$. Right panels: in the vertical grey band, the typical uncertainties of each parameter and region are represented.

dispersion for all the lines, to let them completely independent of each other, or to select groups of lines with the same values. The maps and integrated spectra presented in this paper were obtained with the first option, but we also looked at the impact of allowing the values of velocity dispersion for the $[S II]$ doublet and $H\alpha$ to differ from each other (see Section 4.2).

To produce the 2D maps, we chose to subtract a common background to all pixels in a given cube, selected from a region without any obvious nebular contribution. For the integrated spectrum of individual objects, a nearby background devoid of bright H II regions was selected. This choice is also discussed in Section 4.2.

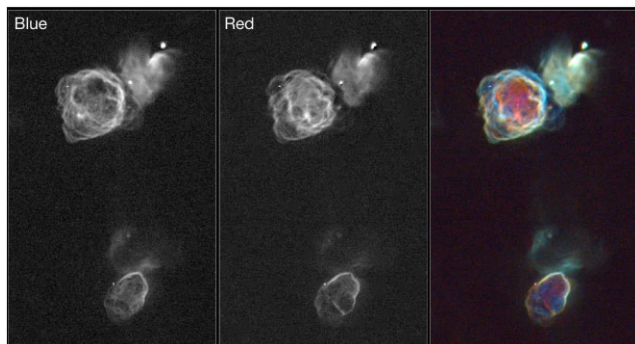


Figure 11. Blue and red velocity components for Hubble I, II, and III extracted from the SN3 data cube and separated by 115 km s^{-1} . The right panel is a colour composite, or Doppler image.

3 HO 12 IN NGC 6822

Barnard’s galaxy (NGC 6822) is the nearest target of the SIGNALS sample (~ 0.52 Mpc, see table A.1 in Rousseau-Nepton et al. 2019) and as such offers an excellent opportunity to study its nebular content with exquisite details. At the distance of NGC 6822, $1 \text{ arcsec} \sim 2.5 \text{ pc}$. The oxygen abundance of NGC 6822 is $12 + \log(\text{O}/\text{H}) = 8.14 \pm 0.08$ (Bresolin et al. 2016). Only one SNR has been identified in this dwarf irregular galaxy, and it was first catalogued as an H II region (No. 12, hereafter Ho 12) by Hodge (1969). Detailed analyses of this object have been performed by Kong, Sjouwerman & Williams (2004) using X-ray and radio data as well as narrow-band visible images, and, more recently, by Dopita et al. (2019) using the integral field spectrograph WiFeS at the ANU 2.3 m telescope. The later concentrated on the analysis of Ho 12’s line ratios but did not provide information on its kinematics.

3.1 Morphology and integrated spectrum

Fig. 2 presents Ho 12 in the context of SITELLE’s data. While Fourier transforms of the interferograms collected by SITELLE lead to the spectral content of the source, adding all the individual frames from these interferograms provides a deep image in the bandpass of the filter. Fig. 2 is a colour-coded rendering of the SN2 (blue) and SN3 (orange) deep images of the entire field, along with an insert enlarging the region around Ho 12 to emphasize the spatial resolution of the data. The yellow stripe in the centre of this image is not an artefact, but rather the asteroid (654) Zelinda crossing the field of view.

Composed of a series of knots seemingly aligned in a spiral shape, bathing in a more diffuse component, all within a diameter of $\sim 21 \text{ pc}$ (Fig. 3), Ho 12 shows a very peculiar morphology at all wavelengths. In the upper panel of Fig. 3, we have identified 10 substructures for future reference. Knots 1, 5, and 10 are clearly elongated and could be further subdivided with higher resolution data. The $\text{H}\alpha$ flux of these knots, their average heliocentric velocity, and velocity

Table 3. Integrated properties of Ho 12, Hubble I, II, and III.

Region	$[\text{S II}]/\text{H}\alpha$	$[\text{O III}]/\text{H}\beta$	$[\text{N II}]/\text{H}\alpha$	V_{helio} km s^{-1}	σ km s^{-1}	ξ km s^{-1}
Ho 12	0.52 ± 0.03	0.75 ± 0.08	0.10 ± 0.02	-75 ± 1	69 ± 1	36 ± 2
Hubble I	0.11 ± 0.02	3.59 ± 0.54	0.03 ± 0.01	-82 ± 1	15 ± 1	2 ± 1
Hubble II	0.29 ± 0.02	1.14 ± 0.09	0.08 ± 0.01	-82 ± 1	30 ± 1	9 ± 1
Hubble III	0.23 ± 0.02	1.70 ± 0.16	0.06 ± 0.01	-78 ± 1	28 ± 1	6 ± 1

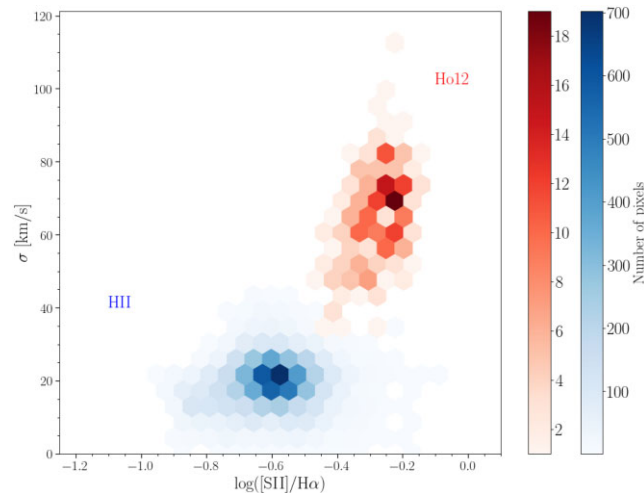


Figure 12. Velocity dispersion as a function of the $[\text{S II}]/\text{H}\alpha$ ratio. Only those pixels with $\text{S/N} \geq 5$ for $\text{H}\alpha$ and $[\text{S II}]$ have been considered. The red hexbins correspond to the pixels of SNR Ho 12 and the blue hexbins correspond to all pixels coming from the H II regions of NGC 6822.

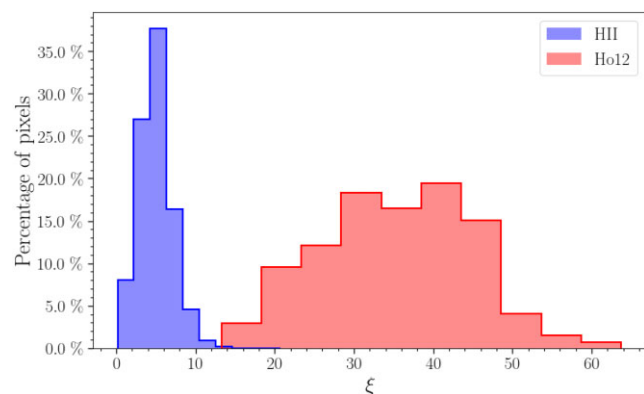


Figure 13. Distribution of ξ for the same pixels as in Fig. 12.

dispersion are presented in Table 2. The lower panel of Fig. 3 presents Ho 12 in different emission lines: $[\text{O II}] \lambda 3727$ from the SN1 cube; $\text{H}\beta$ and $[\text{O III}] \lambda 5007$ from the SN2 cube; $\text{H}\alpha$, $[\text{N II}] \lambda 6584$, and $[\text{S II}] \lambda \lambda 6717, 6731$ from the SN3 cube. These images can be compared with fig. 3 from Dopita et al. (2019) and fig. 1 from Kong et al. (2004). Images at $[\text{N II}]$ and $[\text{O II}]$ have, to our knowledge, never been published. As with all nebulae in NGC 6822, the $[\text{N II}]$ lines are weak, reflecting the low metallicity of this galaxy.

Ho 12’s background-subtracted, integrated spectrum in the SN3, SN2, and SN1 filters, using a circular aperture with a radius of 13 pixels (4.2 arcsec , or 10.5 pc), is shown in Fig. 4. The upper panel of this figure also presents a fit, using ORCS, considering only a single velocity component. Although the overall fit is relatively good, a

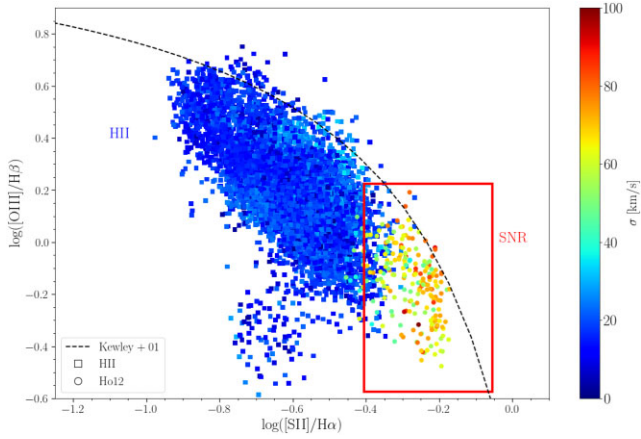


Figure 14. Composite BPT diagram of all H II regions identified in NGC 6822 and the SNR Ho 12. Only those pixels with $S/N \geq 5$ for $H\alpha$, $H\beta$, $[S II]$, and $[O III]$ have been considered. Each point and square represents a pixel coming from Ho 12 and H II regions, respectively, and is colour-coded according to its σ . The red rectangle shows the theoretical area corresponding to the SNRs.

close inspection of the $H\alpha$ line and its residuals reveals that the fit missed a weak red component, did not reproduce the peak of the line, as well as the blue wing. We therefore included three components in the fit, the result of which is shown in the lower panel of the same figure. The flux, central velocities, and broadening of these individual components are:

$$F_1(H\alpha) = 5.77 \pm 0.31 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}, V_1 = -63 \pm 2 \text{ km s}^{-1}, \sigma_1 = 58 \pm 3 \text{ km s}^{-1}$$

$$F_2(H\alpha) = 0.89 \pm 0.15 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}, V_2 = -194 \pm 2 \text{ km s}^{-1}, \sigma_2 = 24 \pm 8 \text{ km s}^{-1}$$

$$F_3(H\alpha) = 0.46 \pm 0.12 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}, V_3 = +138 \pm 2 \text{ km s}^{-1}, \sigma_3 = 59 \pm 14 \text{ km s}^{-1}$$

The total flux, $F_{tot}(H\alpha) = 7.12 \pm 0.36 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$, is in excellent agreement with the value of $6.9 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ (no uncertainty provided) from Kong et al. (2004), obtained with a similar aperture in narrow-band images from the Local Group Survey (Massey et al. 2006). The global line ratios are $[N II]/H\alpha = 0.096$ and $[S II]/H\alpha = 0.52$, virtually identical to those obtained by Dopita et al. (2019). This fit ensures a precise measurement of the line fluxes, but the real velocity structure of Ho 12 is much more complex than a three-component model would suggest, however good the fit might be, as we shall see in the next section.

3.2 Kinematics

Fig. 5 presents the individual frames within the SN3 data cube, centred on $H\alpha$, spanning nearly 400 km s^{-1} , showing the complex velocity structure of Ho 12. This is emphasized in the three-dimensional view (RA, Dec., and radial velocity) shown in Fig. 6 as well as the upper left panel of Fig. 7, obtained by fitting a single component to the spectra of individual pixels. We did not attempt to fit two components (which would correspond to the receding and approaching caps of the expanding SNR) because the spectral resolution was insufficient to clearly distinguish two peaks in the individual spectra; therefore the resulting velocity is the flux-averaged one along the line of sight, most likely favouring the blueshifted component. Indeed, while the average heliocentric velocity of H II regions in the surroundings of Ho 12 is $\sim -50 \text{ km s}^{-1}$, that of Ho 12 is $\sim -75 \text{ km s}^{-1}$. The brightest component

of knot 1 shows the most blueshifted velocity (with an average of $\sim -175 \text{ km s}^{-1}$), while the most redshifted region ($\sim -5 \text{ km s}^{-1}$) corresponds to the diffuse zone between knots 9 and 10.

Fig. 7 shows the maps and three-dimensional views of the radial velocity (upper panel) and velocity dispersion (σ , middle panel), and their radial profiles along Ho 12. The outer, diffuse, component reaches velocities ($\sim -50 \text{ km s}^{-1}$) virtually identical to those of neighbouring H II regions. As expected for an expanding shell, the velocity dispersion decreases towards the outskirts of the SNR,² but the complex knotty structure of Ho 12 is reflected in the broad range of values at a given distance. Not surprisingly, the largest velocity dispersion values (above 100 km s^{-1} , like nowhere else in the entire galaxy) are found in the diffuse regions between the central knots: their flux is not dominated by a single entity but reflects the kinematics of the gas from one side to the other along the line of sight. We come back to these properties of Ho 12 in comparison with the largest H II regions of NGC 6822 (Hubble I, II, and III) in Section 3.4.

3.3 Line ratios and global trends

Fig. 8 shows the following line ratio maps of Ho 12: $[S II]/H\alpha$, $\log([O III]/H\beta)$, and $\log([N II]/H\alpha)$ and their corresponding radial profiles. Throughout Ho 12, the vast majority of pixels (>95 per cent) show an $[S II]/H\alpha$ ratio larger than 0.4, where the highest values are reached in the inner part. The $\log([N II]/H\alpha)$ ratio also decreases outwards, with an average value of -1.01 , typical for a low-metallicity galaxy. Adjacent individual knots often have very different line ratios, and the $\log([O III]/H\beta)$ map is very patchy, which is reflected in its corresponding radial profile with no clear radial trend. A detailed study of individual knots in Ho 12, as well as that of the structure of M33 SNRs, is certainly warranted but beyond the scope of this paper.

3.4 Simultaneous use of $[S II]/H\alpha$ and σ

SNRs are not the only objects showing large values of $[S II]/H\alpha$ or velocity dispersion in galaxies. Outside of AGNs (which often display both concurrently), the central parts of giant H II regions show significant velocity dispersion due to the effects of stellar winds and SNe (Terlevich et al. 2015), while their outskirts, like the DIG, show large values of $[S II]/H\alpha$ (Pellegrini et al. 2020). With the purpose of this paper being to provide a better scheme of identification for extragalactic SNRs and in particular to distinguish them from H II regions using both the $[S II]/H\alpha$ ratio and σ from SITELE data cubes, we will now use the product of these two properties, $\xi = ([S II]/H\alpha) \times \sigma$, on a pixel-by-pixel basis and in the integrated spectrum (see also Vicens-Mouret et al. 2023). We will also compare these properties in Ho 12 and in three large H II regions in NGC 6822 as a testbed for M33 and more distant galaxies.

In Fig. 9 we show the map and three-dimensional view of ξ , and its radial profile along Ho 12, colour-coded by the radial velocity. As expected, the product of these two properties emphasizes the contrast between the inner and outer parts of the SNR. But its usefulness is

²Geometrically, in the central part of an expanding shell, the distance between the $H\alpha$ emission line produced by the farthest and the nearest layers is maximum and the σ will be maximum; on the contrary, as we move towards the outermost part of the SNR, the smaller the distance becomes the smaller the σ . This can be seen in Ho 12 (see Fig. 7) and in the shell and compact SNRs in M33 (see Section 4.1).

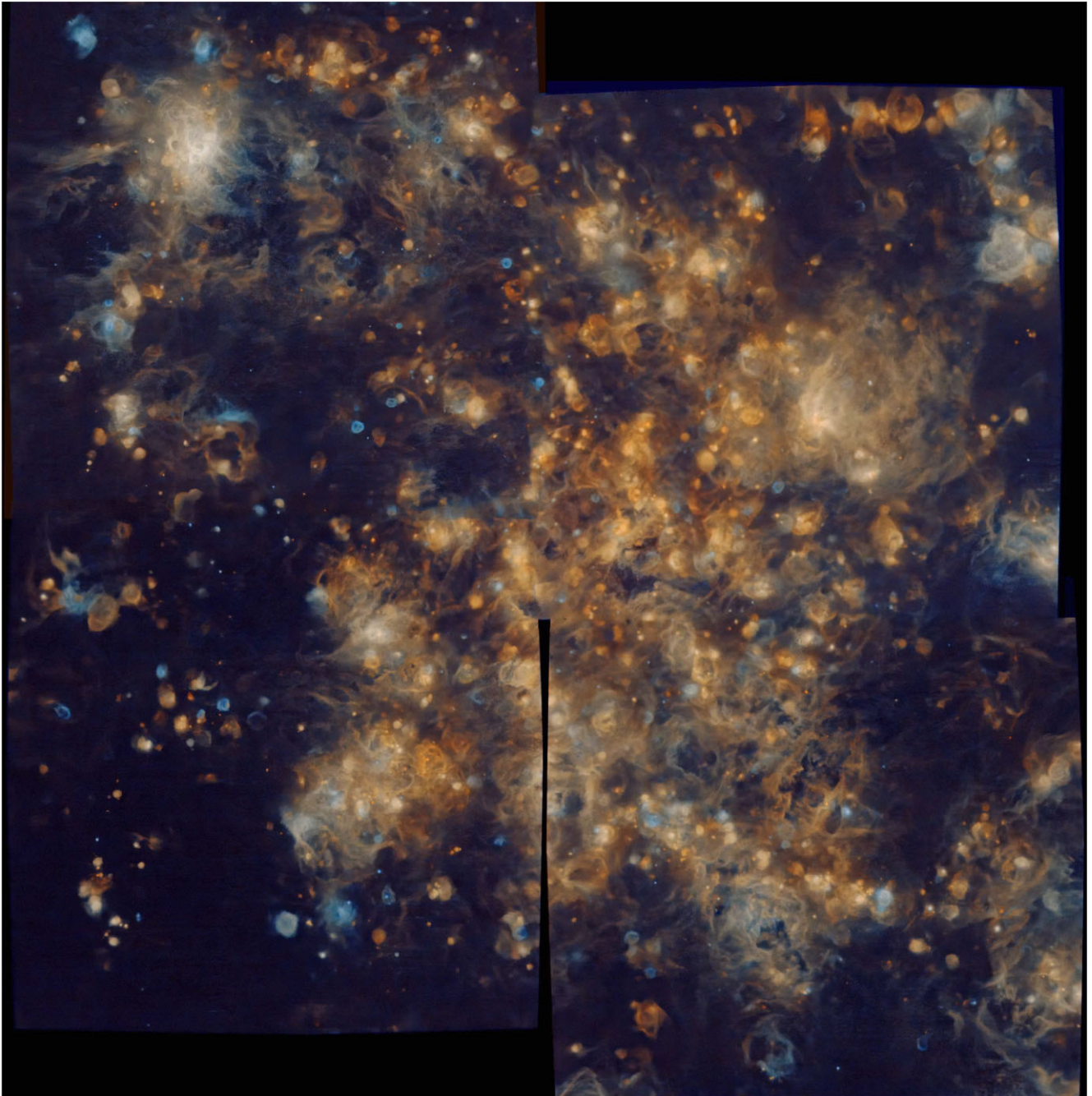


Figure 15. Colour-coded mosaic of the four central fields of M33 (fields 1, 2, 3, and 4 in Table 1). $H\alpha$ in orange and a combination of [O II] and [O III] in blue. The field of view is $\sim 22' \times 22'$, with North at the top and East to the left.

event more obvious in Fig. 10, where Ho 12 is compared with three large H II regions first identified by Hubble (1925), i.e. Hubble I, II, and III. The upper panel of this figure presents the maps of the [S II]/ $H\alpha$ ratio, the velocity dispersion, and the product of these two properties, while their radial profiles (along the normalized radius in bins of 0.32 arcsec) are shown in the lower panels. The right panels show the typical uncertainties of each parameter (i.e. [S II]/ $H\alpha$, radial velocity, σ , and ξ) for each region. Hubble I, II, and III have larger uncertainties than Ho 12 because we have considered pixels with lower S/N (≥ 1) than in the case of Ho 12 (≥ 5), standing out in the case of the [S II]/ $H\alpha$ parameter for the Hubble II region. However, the

radial distributions shown for Hubble I, II and III evolve smoothly for each of the properties considered in Fig. 10.

Let us first consider the [S II]/ $H\alpha$ ratio: the behaviour of Hubble I and III is typical of photoionized regions, with values lower than the standard 0.4 threshold everywhere and increasing towards the outer edge. Ho 12's [S II]/ $H\alpha$ ratio is larger than 0.4 throughout and decreasing outwards, which is expected from a typical SNR. But Hubble II is intriguing: its [S II]/ $H\alpha$ ratio is very close to 0.4 in the inner regions and, contrary to the other H II regions, it decreases outwards. Hubble II also displays relatively high values of velocity dispersion (50–70 km s⁻¹) in its inner regions, like Hubble III. Going

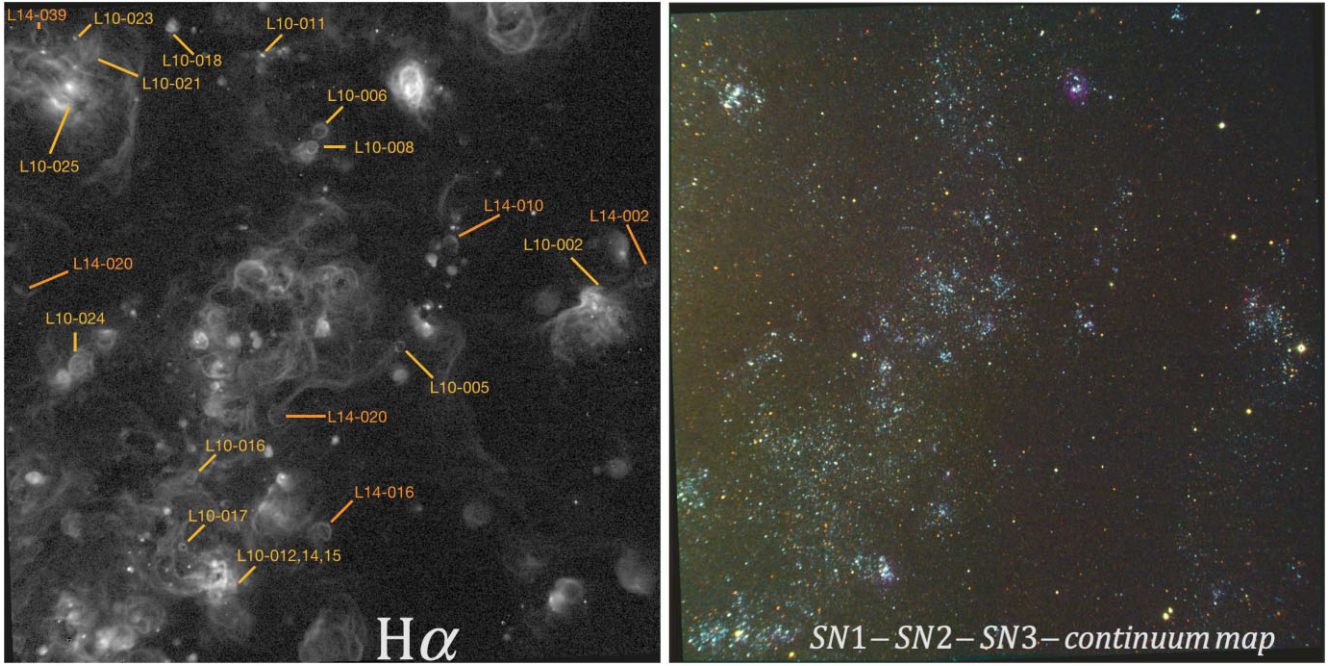


Figure 16. $H\alpha$ map (left panel) and continuum map (right panel, composition of the continuum maps in SN1, SN2, and SN3) of Field 7 in M33. In the left panel, we highlight the position of all the SNRs known in this field. FOV is $11' \times 11'$, with North at the top and East to the left.

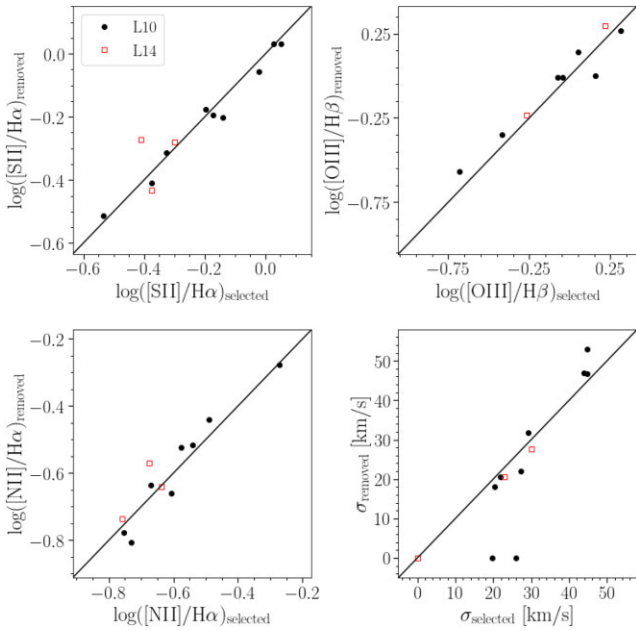


Figure 17. Comparison of line ratios and velocity dispersions for all SNRs present in two data cubes. All the emission lines have a S/N higher than 5. The x-axis represents the values for the selected cube, while the y-axis represents those of the other cube. The objects shown in black dots come from Long et al. (2018) catalogue, while the red squares come from Lee & Lee (2014). The black solid line indicates the 1:1 relation.

through the data cube indeed reveals both caps of their expanding shell, as shown in Fig. 11. Hubble I is much more quiet in this respect and its $[S II]/H\alpha$ ratio is on average very low. So the innermost parts of some large H II regions such as Hubble II and III ($r/r_{\max} < 0.1$) almost rival those of Ho 12 in terms of velocity dispersion. It is thus in the ξ radial distribution that the distinction between Ho 12 and all three

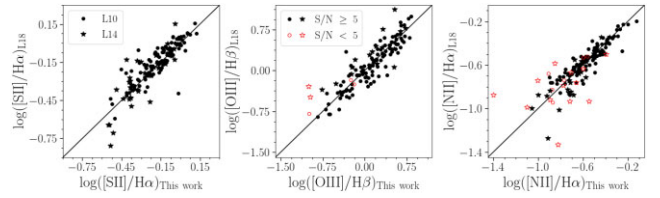


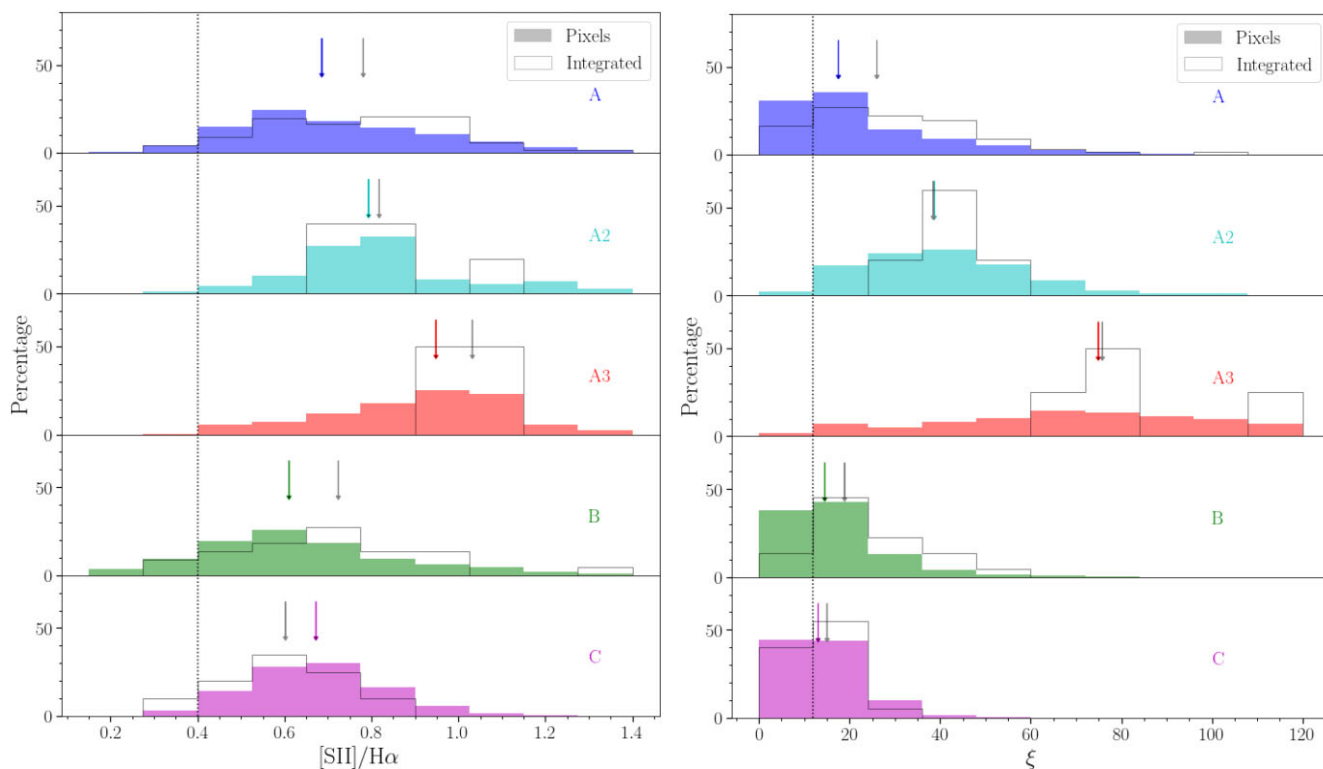
Figure 18. Comparison of the line ratios obtained in this work (x-axis) with those of Long et al. (2018) (y-axis). SNRs with $S/N \geq 5$ (in the emission lines shown in each panel) are shown in black dots, while those with $S/N < 5$ are represented by red squares. The black solid line indicates the 1:1 relation.

H II regions becomes obvious: the SNR shows systematically higher values than the H II regions. The average value of ξ in Ho 12 is above 40 until $r/r_{\max} \sim 0.4$, while for the H II regions it is almost always smaller than 20. We also note that the overall difference in radial velocity (i.e. maximum – minimum value) in Ho 12 ($\sim 150 \text{ km s}^{-1}$) is much larger than that of the H II regions ($\sim 30 \text{ km s}^{-1}$). This is compatible with the high velocity ejected material associated with the SN explosion itself, and contributes to the significantly larger value of σ ($\sim 70 \text{ km s}^{-1}$) in the *integrated* spectrum of Ho 12 compared to that of the H II regions ($\sim 30 \text{ km s}^{-1}$ for Hubble II and III, 15 km s^{-1} for Hubble I); see Table 3 where the integrated characteristics of Ho 12, Hubble I, Hubble II, and Hubble III are presented.

Fig. 12 presents σ as a function of the $[S II]/H\alpha$ ratio, for all the pixels having an S/N ratio larger than 5 in both $[S II]$ and $H\alpha$ in the entire field of view for Ho 12 (red hexbin) and all the H II regions (blue hexbin). This diagram presents a very clear separation between the SNR and the H II regions. H II regions in NGC 6822 can be summarized by the following characteristics: (i) most pixels have lower σ and $[S II]/H\alpha$ values than Ho 12 values; (ii) pixels with $[S II]/H\alpha$ values ≥ 0.4 show σ values lower than Ho 12; and (iii) pixels with σ values greater than 30 km s^{-1} show values of $[S II]/H\alpha < 0.4$. The same pixels are also represented in Fig. 13, which depicts their

Table 4. Morphological properties of SNRs from L10 in M33.

	A	A2	A3	B	C	All
[S II]/H α	0.78 ± 0.22	0.82 ± 0.15	1.03 ± 0.06	0.72 ± 0.22	0.60 ± 0.14	0.73 ± 0.22
σ	33 ± 17	48 ± 4	73 ± 21	28 ± 12	25 ± 11	30 ± 18
ξ	26 ± 20	38 ± 4	76 ± 17	19 ± 12	15 ± 8	22 ± 20
Number of objects	67	5	4	22	20	118


Figure 19. Distributions of [S II]/H α (left panel) and ξ (right panel) for each morphological type (from top to bottom: type A, A2, A3, B, and C). In both panels, the distributions of the integrated values and for all the pixels of each SNR are shown as grey line and coloured histogram, respectively. The grey and coloured arrows indicate the position of the median value for each morphological type of the integrated value and the pixels contained in each SNR. The dotted vertical lines show the limit value of [S II]/H α =0.4 (left panel) and ξ =12 (right panel).

distribution of the ξ parameter. Again, the distribution of the H II regions is clearly different from that of the SNR.

We conclude this section with a standard diagnostic diagram, $\log([\text{O III}]/\text{H}\beta)$ versus $\log([\text{S II}]/\text{H}\alpha)$ (Fig. 14), but with a twist since each pixel is now colour-coded according to its velocity dispersion, σ . In this figure we take into account all the ionized gas in NGC 6822. The SNR (identified with filled circles) stands out in the lower right part of this diagram, but there is a significant overlap between the SNR and H II regions: the number of pixels from H II regions for which the [S II]/H α ratio exceeds the threshold value used to detect SNRs (0.4) is not negligible. As shown in Fig. 10, these pixels tend to concentrate on the outskirts of the H II regions. On the other hand, pixels with a significant σ within H II regions have [S II]/H α \leq 0.3.

We have shown that, in NGC 6822 at least, the addition of the velocity dispersion parameter to the standard [S II]/H α ratio, all based on the same data cube, is an excellent asset to discriminate between H II regions and SNRs. There are however some potential caveats that we should be aware of:

(i) Only one SNR, Ho 12, is known in NGC 6822; its morphology is very peculiar, and thus may not be representative of all SNRs in nearby galaxies.

(ii) Ho 12 has a high surface brightness, is very well isolated from any H II region and the DIG, and belongs to the nearest galaxy in the SIGNALS survey. This obviously helps in its unambiguous identification as an SNR. In the next section, we explore M33 and we will see that, even though it is also a member of the Local Group, its large number of H II regions and the ubiquity of the DIG complicate our case.

(iii) Some zones in Hubble II, a large H II region, simultaneously present both a high [S II]/H α ratio (0.35–0.45) and a relatively high velocity dispersion (50–65 km s⁻¹). This might suggest that it has been the site of an SN blast in the recent past.

4 M33

The actively star-forming Triangulum galaxy hosts \sim 200 SNR candidates, most of them spectroscopically confirmed and well studied, both in the visible band, the radio and X-rays (e.g. Dodorico, Benvenuti & Sabbadin 1978; Gordon et al. 1998, 1999; Long et al. 2010, 2018; Lee & Lee 2014, and references therein). The central oxygen abundance of M33, as determined with the direct method, is $12+\log(\text{O}/\text{H}) = 8.59 \pm 0.02$, with a galactocentric

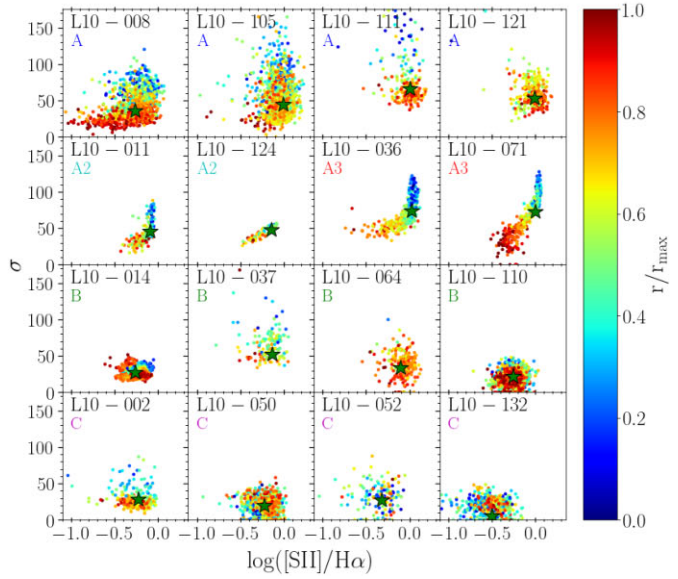
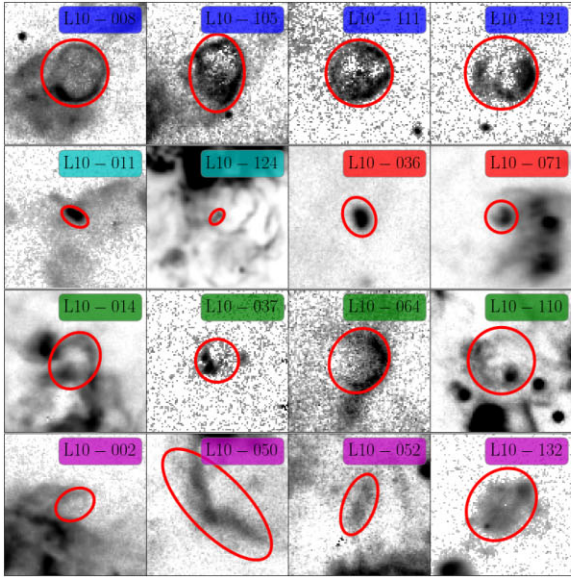


Figure 20. Left panel: $H\alpha$ flux images of SNRs illustrating the different morphological types. The region used to fit the integrated spectrum is shown as a red ellipse. Right panel: σ versus $[SII]/H\alpha$ diagram for the same objects; identification numbers are from Long et al. (2010). The green stars in each plot represent the integrated value. The coloured dots correspond to all pixels with $F(H\alpha) \geq 3 \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$ enclosed inside the red ellipse in the left panel and have been colour-coded by their radial distance (r/r_{max}).

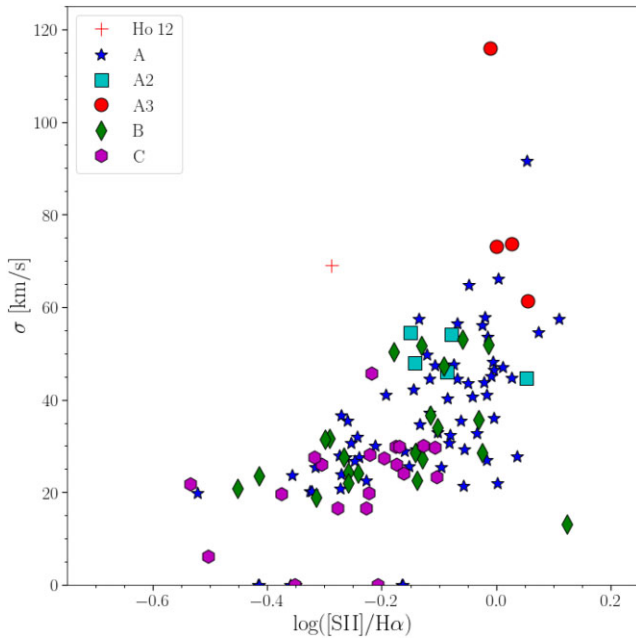


Figure 21. Velocity dispersion as a function of the $[SII]/H\alpha$ ratio. The red dots, blue stars, cyan squares, green diamonds, and magenta hexagons represent A3, A, A2, B, and C morphological type of SNR, respectively. The red cross shows the position in this diagram for Ho 12 in NGC 6822.

gradient of $-0.037 \pm 0.007 \text{ dex kpc}^{-1}$ (Rogers et al. 2022). The combination of the proximity of this galaxy ($D = 0.86 \text{ Mpc}$, de Grijs & Bono 2014) and the large number of known SNRs make M33 a perfect candidate to study the suitability of the $[SII]/H\alpha$ versus σ diagram proposed in Section 3.4 and expand our analysis beyond the single case of Ho 12 in NGC 6822. In this second part of the paper we analyse a sample of 163 among the 217 known SNR candidates in M33 provided by Long et al. (2010) – hereafter

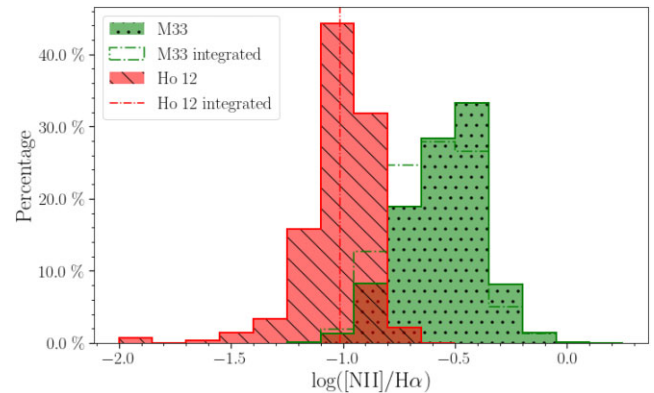


Figure 22. Distribution of $\log([NII]/H\alpha)$ for the SNR candidates in M33 and Ho 12. The solid green histogram (with diagonal line hatch) and dashed green histogram (with dotted hatch) represent the distribution for all the pixels and the integrated values from the 163 SNR candidates in M33, respectively. The solid red histogram and vertical dashed red line show the distribution of all the pixels and the integrated values from Ho 12, respectively.

L10 – and Lee & Lee (2014) – hereafter L14, which are included in nine pointings observed with SITELLE (see Table 1) for the SIGNALS survey. In Fig. 15 we present a colour-coded mosaic of the four central fields of M33 (Fields 1, 2, 3, and 4 in Table 1). In Fig. 16 we show the $H\alpha$ map of Field 7 (left panel, highlighting the location of known SNR candidates) and its corresponding continuum map.

As explained in Section 2, we fitted the $[OII] \lambda 3727$, $[OIII] \lambda \lambda 4959, 5007$, $H\beta$, $[NII] \lambda \lambda 6548, 6584$, $H\alpha$, and $[SII] \lambda \lambda 6717, 6731$ emission lines for each of the 163 SNR candidates considering only one velocity component. Among those, 12 are located in overlapping regions of some fields (the duplicates). We thus kept for subsequent analysis the data from the cube having the best spectral resolution and S/N ratio. Fig. 17 shows the comparison between the properties (line ratios and σ) of the selected and discarded duplicates: the values

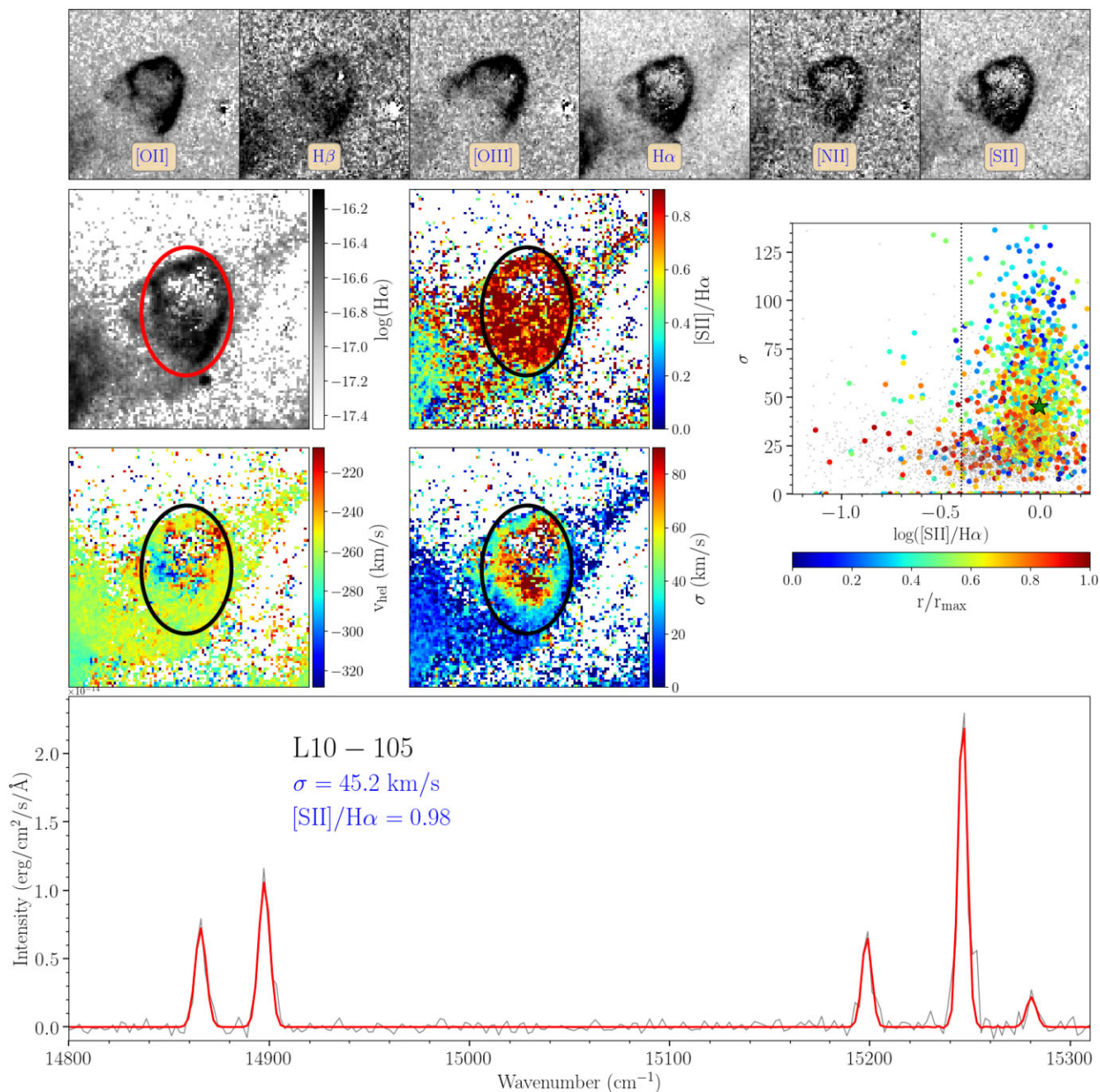


Figure 23. Properties of L10-105. Top panel: emission-line maps ($32'' \times 32''$), from left to right: [O II], H β , [O III], H α , [N II], and [S II]. Middle panel, left: $\log(\text{H}\alpha)$ flux, [S II]/H α ratio, heliocentric radial velocity, and σ . Middle panel, right: σ versus [S II]/H α diagram for all pixels in the maps, with the coloured dots corresponding to all pixels with $F(\text{H}\alpha) \geq 1 \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$ enclosed by the red ellipse in the left panel and have been colour-coded by r/r_{max} . The green star shows the position of the integrated value within the ellipse. Lower panel: Continuum-subtracted integrated spectrum of the region shown as a red (or black) ellipse above. The grey line shows the real spectrum and the red coloured line show the fit obtained with ORCS in the SN3 bandpass.

are in good agreement regardless of the spectral resolution, with the exception of two objects for which the spectral resolution of one of the data cubes was insufficient to distinguish the observed line width from that of the ILS (and were therefore attributed a value of $\sigma = 0$ in this data set).

Fig. 18 presents a comparison between our *spatially integrated* properties of the individual objects in terms of line ratios ($\log([\text{S II}]/\text{H}\alpha)$ on the left panel, $\log([\text{O III}]/\text{H}\beta)$ on the central panel, and $\log([\text{N II}]/\text{H}\alpha)$ on the right panel) with the work of Long

et al. (2018). In general, the agreement is good, with the largest discrepancies occurring for the SNR candidates presented by Lee & Lee (2014), which tend to be more extended and diffuse than those found previously. But the large scatter in this figure is not surprising, given the noticeable spatial variations in line ratios within a given object and the fact that neither of the previous studies completely cover the whole SNR, as slits and fibres (with 1.5 arcsec radius) were used, whereas our line ratios represent the integrated spectrum of each object.

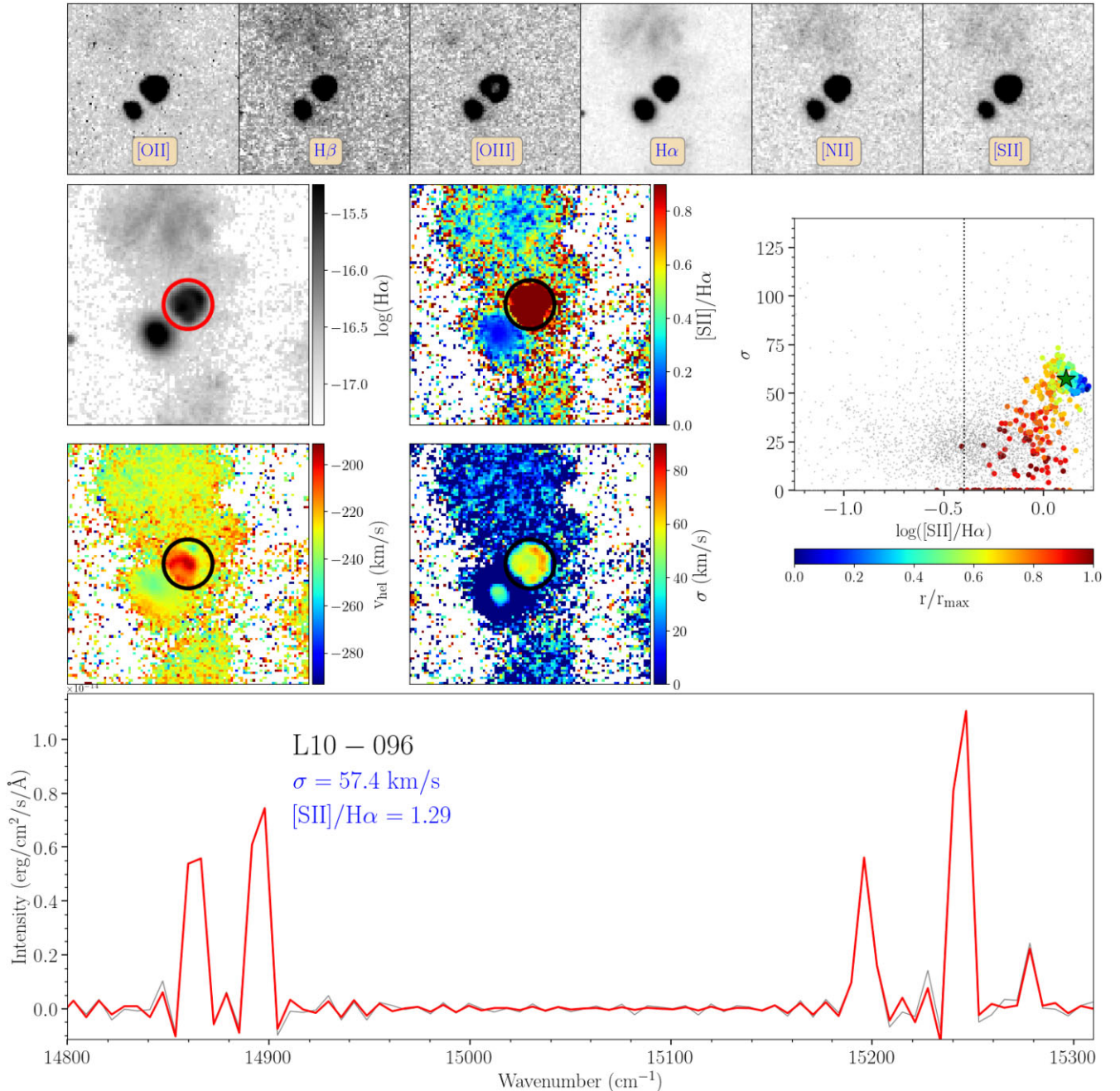


Figure 24. Same as Fig. 23 for L10-096.

4.1 Morphology and properties of the sample

In this section we study the implication of the morphology of the SNRs in the $[\text{S II}]/\text{H}\alpha$ versus σ diagram. For this purpose, we only considered the SNRs and the morphology defined by Long et al. (2010); therefore, the sample decreases to 118 objects. We did not consider Lee & Lee (2014) SNR morphologies as they are not defined in the same way than Long et al. (2010).³

³The SNRs in Lee & Lee (2014) are divided into more morphological subcategories than Long et al. (2010). We may add uncertainties to our results by erroneously including them in the morphological categories of Long et al. (2010).

Long et al. (2010) defined four morphological types in their sample of SNR: (i) type A, practically complete shells; (ii) type A' (A2 in this article), small and bright objects, which are not shell-like but are well defined (they present an elongated shape); (iii) type B, partial shells; and (iv) type C, amorphous or poorly defined objects that may be a single filament. We define an additional morphological type, A3, corresponding to compact and bright objects. According to this classification there are 67 SNRs in type A, 5 in type A2, 4 in type A3, 22 in type B, and 20 in type C. Table 4 presents the median and standard deviation values of the properties $[\text{S II}]/\text{H}\alpha$, σ , and ξ when grouping all the SNRs according to their morphological classification.

Fig. 19 shows the distributions of $[\text{S II}]/\text{H}\alpha$ (left panel) and ξ (right panel) for each morphological type. We first note that while

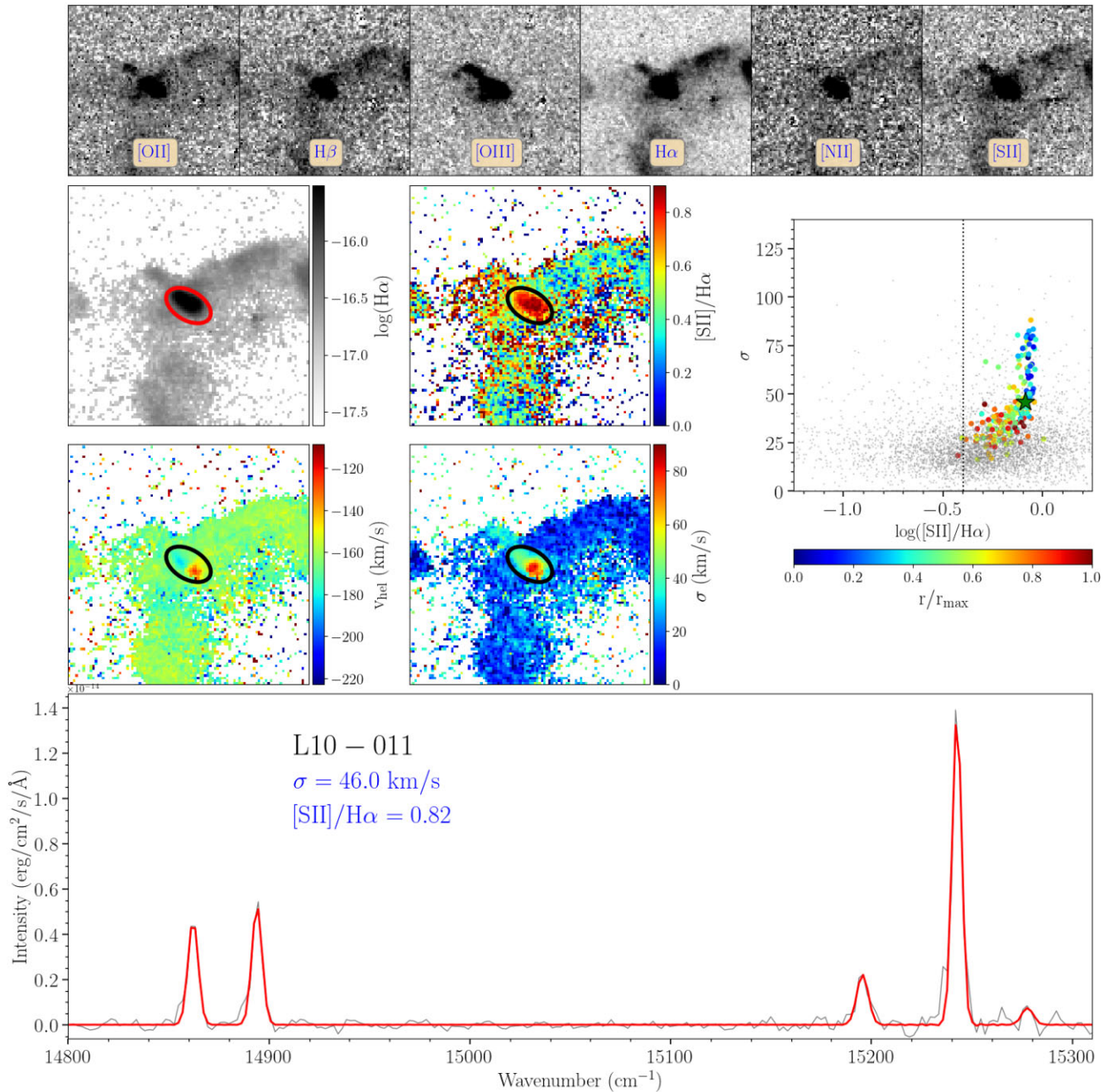


Figure 25. Same as Fig. 23 for L10-011.

the [S II]/H α values span a wide range of values regardless of the morphological type, the most compact ones (A2 and A3) show higher median values (0.82 and 1.03, respectively) than the more extended types A and B (0.77 and 0.72, respectively). On the other hand, type C objects (poorly defined structure) show the lowest [S II]/H α values on average (0.6), as expected.

Differences among the morphological types are more pronounced for ξ than for [S II]/H α (right-hand panels of Fig. 19). Type A3 shows the highest median values (~ 76 , with a wide distribution), followed by type A2 (~ 38). No SNR of the A2 and A3 types (and only ~ 1 per cent of the pixels) shows values of ξ lower than 12. When considering the integrated values, 10 per cent of the candidates of type A presents values of ξ lower than 12. It is tempting to suggest

an evolutionary link between the compact A3 type to type A2 and then the type A shells. The average values of ξ determined for types B and C are significantly lower (~ 19 and ~ 13 , respectively) and could represent the final stages of detectable SNRs before a complete dissolution into the ISM. The range of ξ spanned in both cases is similar, but only ~ 10 per cent of type B candidates also show values lower than 12, while in type C they are ~ 45 per cent. This is possibly due to the fact that type B objects evolve into type C.

In Fig. 20 we show the H α flux maps (left panel), and the [S II]/H α versus σ diagram (right panel) for a subsample of 16 selected SNRs in M33 representative of all morphological types. SNRs with A, A2, or A3 morphological types present higher values of σ in the central parts, decreasing as we move towards the outer parts of the SNR,

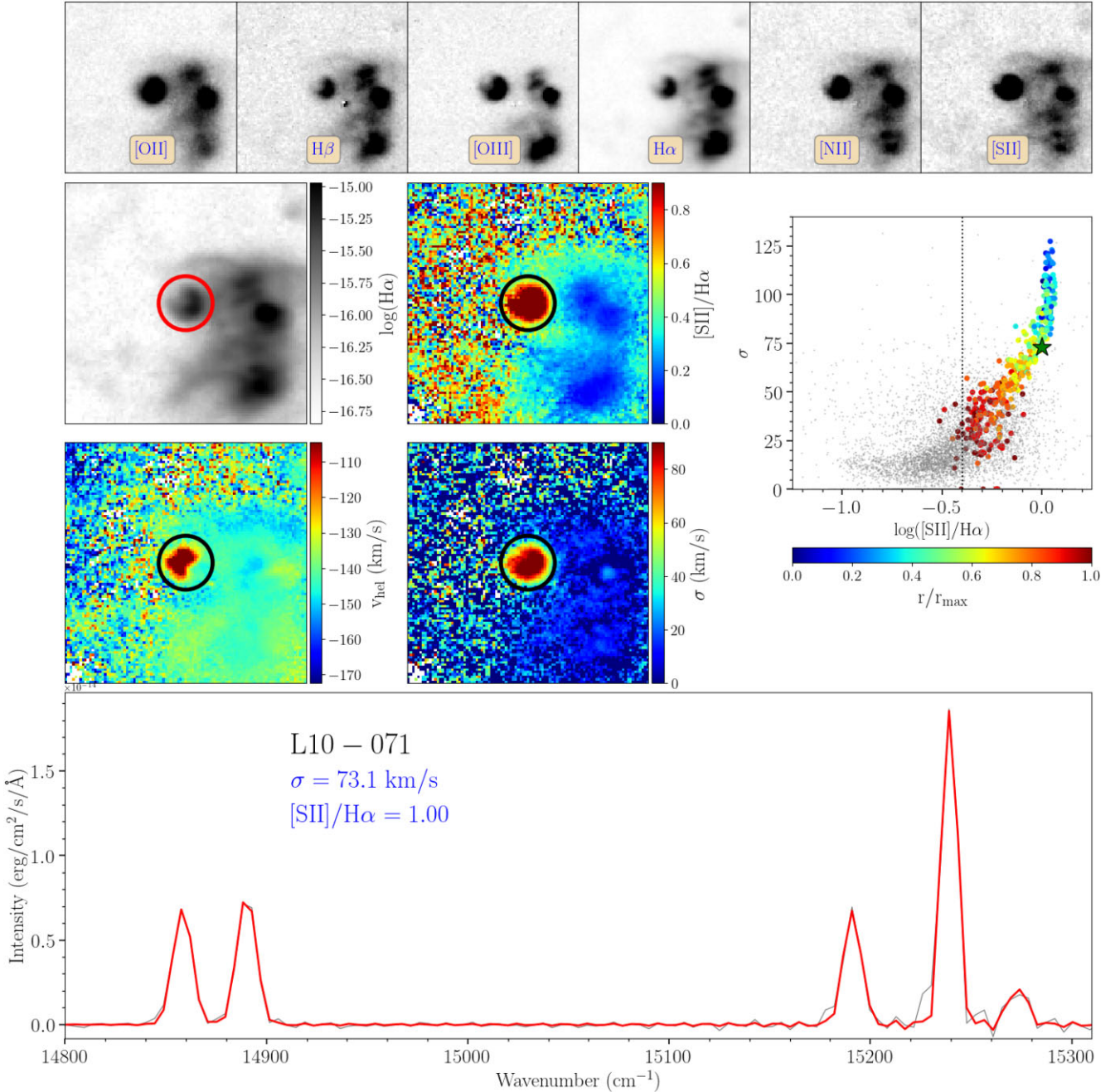


Figure 26. Same as Fig. 23 for L10-071.

as in the case of Ho 12 (see Section 3.2). In the case of the A2 and A3 types shown in this section, except for L10-121, we see that the value of $[S II]/H\alpha$ remain constant as σ decreases until $r/r_{max} \sim 0.5$, from which it begins to decrease with σ . In the case of B and C types, this dependence is less evident, although in L10-002 and L10-037 it is. Moreover, it can be seen that the scatter of $[S II]/H\alpha$ at a constant σ value is lower in the A2 and A3 types than in the rest of the morphological types.

Fig. 21 shows the σ versus $[S II]/H\alpha$ diagram taking into account the morphology of each SNR candidate. According to this diagram, the evolution of an SNR could be interpreted as follows: compact objects (type A3) have very high values of $[S II]/H\alpha$ and σ , following a well-defined path, with a small dispersion in $[S II]/H\alpha$ at constant

σ . These SNRs would evolve into more elongated type A2 objects, where their σ would decrease as they expand through the ISM. As they expand, the shell-like structure (type A) becomes more evident. The central parts of type A SNRs can still show high σ values, more likely because the velocity components of the approaching and receding parts of the shell are detected simultaneously, see Section 4.3. The expansion and interaction with the ISM cause σ and $[S II]/H\alpha$ to decrease. We observe that the $[S II]/H\alpha$ versus σ relation is no longer as well defined as the more compact objects (i.e. the dispersion is larger), as expected. As they continue expanding, the structures become less obvious, and the type B SNRs have not yet fully mixed with the ISM and retain sufficiently high values of $[S II]/H\alpha$ and σ in their innermost parts to allow their detection. Type C objects have

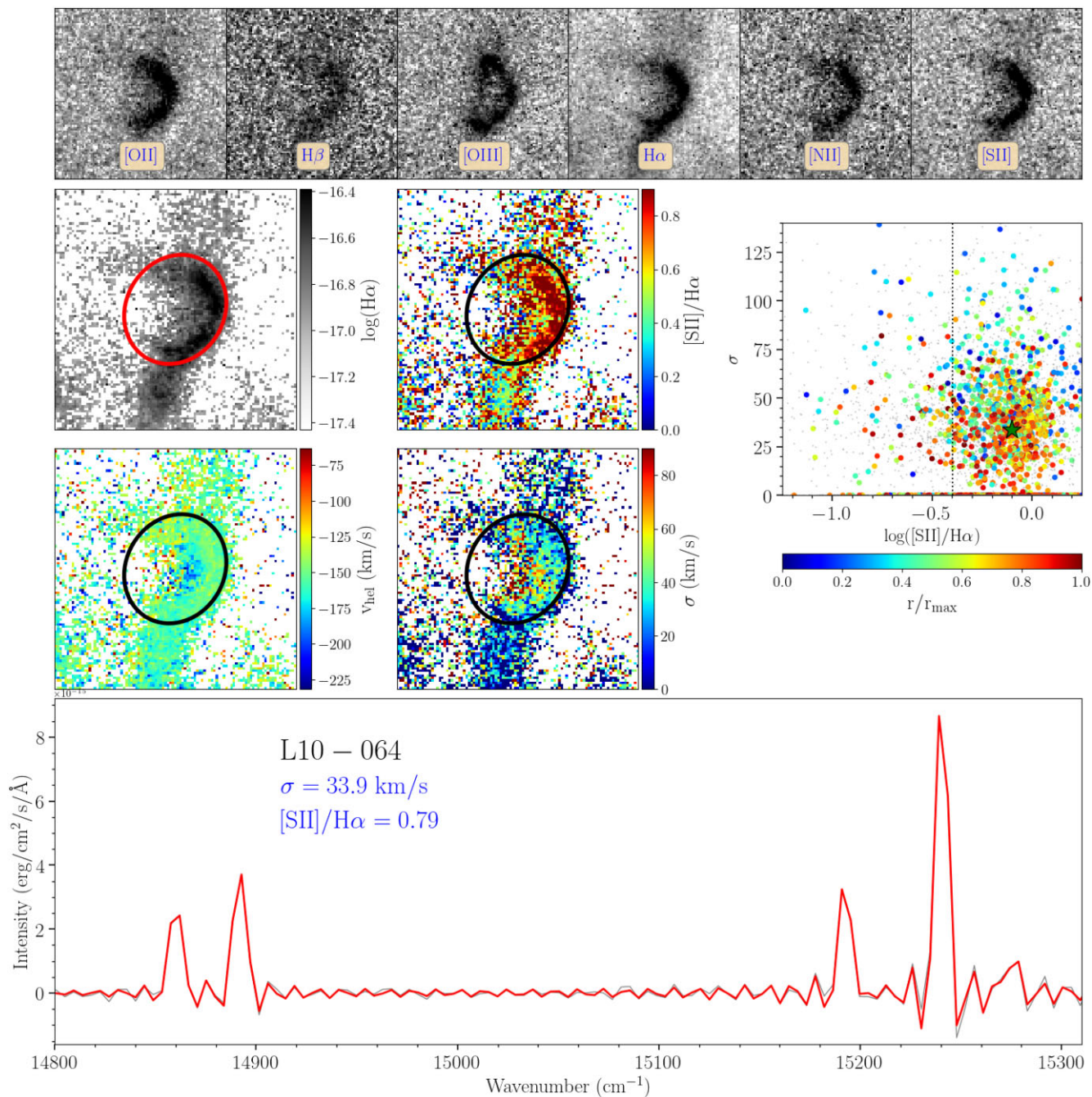


Figure 27. Same as Fig. 23 for L10-064.

already evolved much further; it is difficult to identify the structure of the SNR clearly, and we are often only able to observe a filament. The value of σ is low, although some of them still maintain values of $[S II]/H\alpha$ higher than 0.4. We note that Ho 12 in NGC 6822 does not follow the global trend defined by the M33 SNRs in the σ versus $[S II]/H\alpha$ diagram. This may be related to the metallicity of the host galaxies. Taking into account that $[N II]$ emission depends on metallicity (e.g. Pettini & Pagel 2004; Pérez-Montero & Contini 2009) we show the distribution of $\log([N II]/H\alpha)$ in Fig. 22. In this figure we notice that the $\log([N II]/H\alpha)$ values for Ho 12 are lower than those of the SNR candidates of M33. The most likely explanation is that the global metallicity of M33 is higher than what has been

found in NGC6822, although the $[N II]/H\alpha$ ratio is also sensitive to other nebular properties like the ionization parameter and the abundance of secondary nitrogen. We will explore further this topic with a larger number of SNRs in galaxies of the SIGNALS survey (Duarte Puertas et al., in preparation).

Figs 23, 24, 25, 26, 27, and 28 present some examples of SNRs with different morphologies (e.g. L10-105, L10-096, L10-096, L10-071, and L10-050). In each figure we show (i) the flux maps for the $[O II]$, $H\beta$, $[O III]$, $H\alpha$, $[N II]$, and $[S II]$ emission lines; (ii) the maps of $[S II]/H\alpha$ and σ ; (iii) the $\log([S II]/H\alpha)$ versus σ diagram; and (iv) the integrated SNR spectrum and the fit obtained with ORCS in the SN3 bandpass. The remaining SNRs

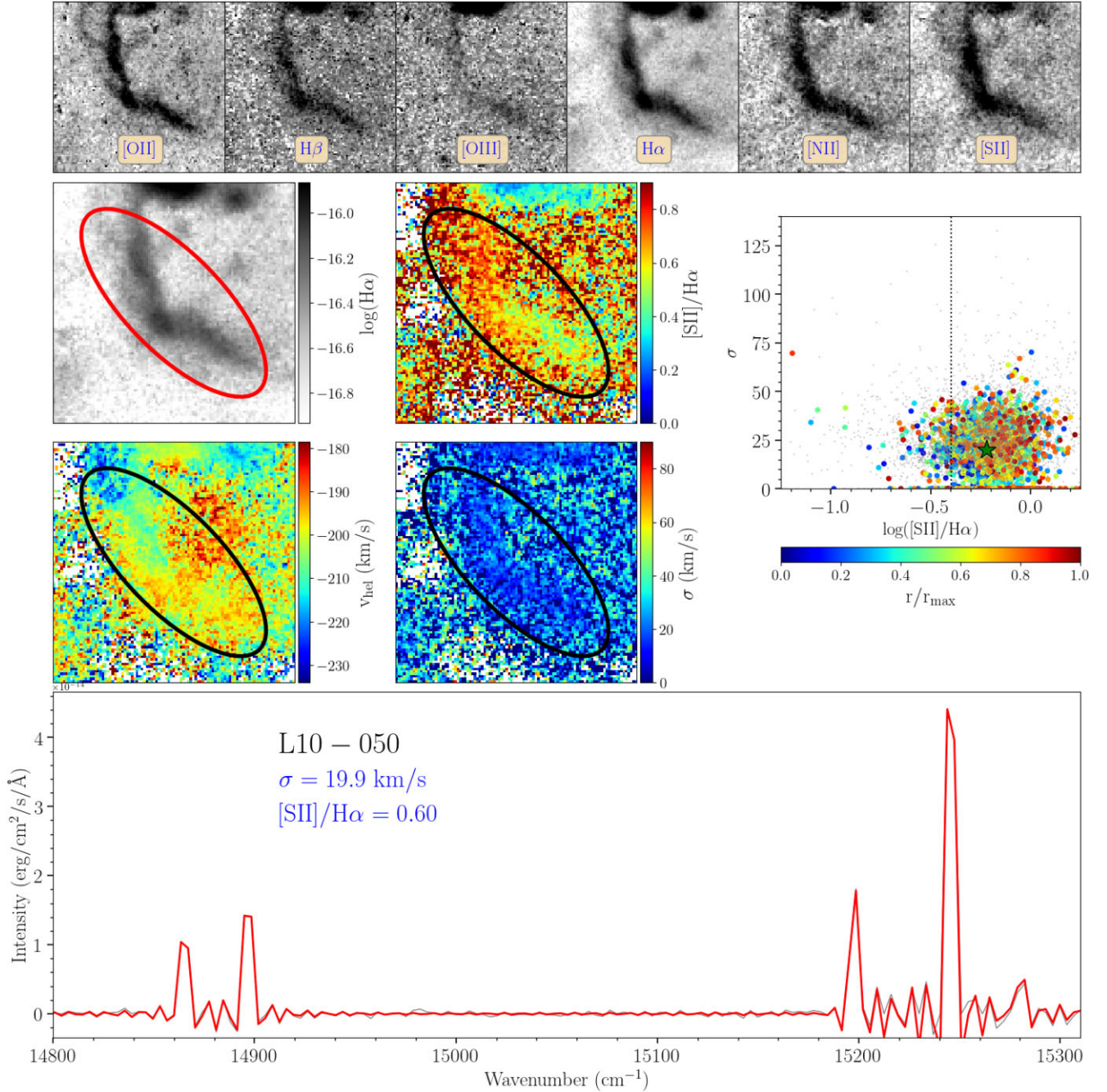


Figure 28. Same as Fig. 23 for L10-050.

are shown in Section 4.2 and in the Appendix (Supplementary material).

Fig. 23 shows L10-105. According to Long et al. (2010), the morphological type for this SNR is A. It has a similar shape in $H\alpha$ and $[S\text{II}]$, with a prominent south-eastern wall, which is however almost invisible in $[O\text{III}]$. The $[S\text{II}]/H\alpha$ ratio is high in the whole SNR, however σ presents higher values in the central part than in the outermost part, as expected from an expanding shell. The integrated spectrum hints at at least one additional velocity component, which could be attributed to the ISM filament crossing the field of view.

Fig. 24 presents L10-096. This object is in some ways similar to Ho 12 in NGC 6822, showing a series of knots along the outer ring.

The morphology at the different wavelengths is similar, except that the strongest $[O\text{III}]$ emission is seen slightly further out the ring. We also note that the largest values of σ are seen in the knots of the outer ring. A small expanding (with larger values of σ at its core), purely photoionized, $H\text{II}$ region is seen at its lower left.

L10-011 shows an A2 morphology (see Fig. 25). Its kinematics show a bipolar behaviour, with lower radial velocities in the north-west and higher in the south-east. This south-eastern part shows higher values of σ than the north-western part. An $H\text{II}$ region to the west and the SNR candidate L14-023 to the south can be observed close to L10-011. There is a filament with a large value of $[S\text{II}]/H\alpha$ that crosses the SNR from behind, connecting both the $H\text{II}$ region and

Table 5. Properties of SNRs in M33. Reddening-corrected line fluxes relative to $H\beta = 100$.

(1) Name ID	(2) Field	(3) RA	(4) Dec.	(5) [S II]/H α	(6) σ km s $^{-1}$	(7) σ (S II) km s $^{-1}$	(8) ξ	(9) Morphology	(10) F(H α) 10 $^{-15}$ erg cm $^{-2}$ s $^{-1}$	(11) [O III] λ 727	(12) [O III] λ 5007	(13) H α	(14) [N II] λ 6584	(15) [S II] λ 6717	(16) [S II] λ 6731
L10-001	Field8	01:32:30.41	+30:27:41.00	0.76	50	49	38	A	71.32 ± 2.21	468.8 ± 28.4	51.0 ± 4.3	286.0 ± 14.2	13.3 ± 3.0	44.4 ± 3.1	31.2 ± 2.5
L10-002	Field7	01:32:31.26	+30:35:30.79	0.60	28	29	17	C	17.56 ± 0.29	402.7 ± 24.2	278.6 ± 15.1	286.0 ± 15.4	14.7 ± 1.6	34.7 ± 1.6	25.3 ± 1.4
L10-003	Field8	01:32:42.54	+30:20:58.00	0.56	31	33	17	A	101.90 ± 1.40	663.0 ± 44.8	57.9 ± 4.0	286.0 ± 10.3	15.8 ± 1.4	32.7 ± 1.4	23.0 ± 1.2
L10-004	Field8	01:32:44.72	+30:22:14.60	0.72	42	45	30	A	14.02 ± 0.42	805.4 ± 77.8	36.5 ± 4.6	286.0 ± 15.1	13.5 ± 2.8	41.9 ± 3.1	29.9 ± 2.6
L10-005	Field7	01:32:46.73	+30:34:37.80	0.73	57	68	42	A	20.53 ± 1.00	999.8 ± 87.8	350.3 ± 27.4	286.0 ± 25.7	16.9 ± 4.4	42.4 ± 5.2	31.0 ± 4.3
L10-006	Field7	01:32:52.71	+30:38:12.60	0.54	24	21	13	A	42.72 ± 0.74	883.0 ± 33.1	303.9 ± 11.0	286.0 ± 11.0	17.3 ± 1.5	30.4 ± 1.6	23.2 ± 1.4
L10-008	Field7	01:32:53.40	+30:37:56.90	0.55	36	40	20	A	70.91 ± 1.04	559.7 ± 21.6	52.9 ± 2.4	286.0 ± 7.4	14.7 ± 1.4	32.1 ± 1.5	23.0 ± 1.3
L10-009	Field8	01:32:54.10	+30:25:31.80	0.75	30	31	22	C	16.36 ± 0.37	832.1 ± 60.8	280.3 ± 16.4	286.0 ± 17.0	22.3 ± 2.4	43.9 ± 2.3	30.7 ± 1.9
L10-011	Field7	01:32:57.02	+30:39:27.10	0.82	46	51	38	A2	34.94 ± 0.78	632.9 ± 16.9	144.5 ± 2.7	286.0 ± 7.7	19.9 ± 2.5	43.4 ± 2.3	38.3 ± 2.1
L10-012	Field7	01:33:00.15	+30:30:46.20	0.35	21	21	7	B	447.08 ± 3.56	419.5 ± 14.2	175.1 ± 5.8	286.0 ± 8.4	12.6 ± 0.7	20.7 ± 0.8	14.6 ± 0.7
L10-014	Field7	01:33:00.57	+30:31:00.67	0.54	27	27	15	B	247.57 ± 2.31	483.7 ± 14.1	100.3 ± 3.3	286.0 ± 7.1	15.6 ± 0.8	31.5 ± 0.9	22.7 ± 0.8
L10-015	Field7	01:33:01.51	+30:30:49.60	0.51	32	29	16	B	50.06 ± 0.63	586.2 ± 25.0	203.3 ± 8.3	286.0 ± 11.1	16.8 ± 1.1	29.8 ± 1.1	21.4 ± 1.0
L10-016	Field7	01:33:02.93	+30:32:29.20	0.70	26	29	18	A	48.17 ± 0.73	639.3 ± 46.6	191.4 ± 10.1	286.0 ± 14.0	21.2 ± 1.4	41.7 ± 1.6	28.6 ± 1.4
L10-017	Field7	01:33:03.52	+30:31:20.90	0.89	44	44	39	A	27.50 ± 0.59	823.6 ± 44.7	153.7 ± 7.8	286.0 ± 13.5	21.2 ± 2.0	53.2 ± 2.3	36.0 ± 1.8
L10-018	Field7	01:33:03.95	+30:39:53.70	0.61	30	37	19	A	70.43 ± 0.95	620.9 ± 20.1	92.7 ± 1.6	286.0 ± 5.2	20.4 ± 1.4	35.1 ± 1.5	26.3 ± 1.3
L10-020	Field8	01:33:08.98	+30:26:58.90	0.74	35	41	26	A	26.45 ± 0.61	619.9 ± 39.2	187.0 ± 12.1	286.0 ± 17.4	25.4 ± 2.6	43.4 ± 2.6	30.1 ± 2.1
L10-021	Field7	01:33:09.87	+30:39:34.90	0.53	28	29	15	A	111.47 ± 1.74	660.7 ± 38.3	149.5 ± 3.2	286.0 ± 6.8	24.4 ± 1.6	31.1 ± 1.6	22.1 ± 1.3
L10-023	Field7	01:33:11.19	+30:39:42.96	0.71	55	62	38	A2	13.12 ± 0.37	887.5 ± 46.4	235.2 ± 8.4	286.0 ± 12.4	23.2 ± 3.0	37.0 ± 2.8	33.5 ± 2.6
L10-024	Field7	01:33:11.28	+30:34:23.50	0.47	20	16	10	A	195.51 ± 2.29	464.5 ± 13.4	20.8 ± 1.7	286.0 ± 5.8	21.3 ± 1.1	27.5 ± 1.1	19.7 ± 0.9
L10-025	Field7	01:33:11.58	+30:38:41.39	0.54	37	81	20	A	32.50 ± 0.71	496.1 ± 31.2	297.0 ± 12.0	286.0 ± 12.6	25.1 ± 4.0	27.8 ± 3.1	25.7 ± 3.0
L10-026	Field2	01:33:16.73	+30:46:10.30	0.57	24	27	14	B	78.22 ± 0.82	464.0 ± 14.6	119.9 ± 4.6	286.0 ± 8.9	23.6 ± 1.0	33.3 ± 1.1	24.0 ± 0.9
L10-027	Field4	01:33:17.44	+30:31:28.50	0.78	30	31	23	C	19.52 ± 0.44	211.2 ± 12.3	47.5 ± 5.9	267.0 ± 15.7	22.0 ± 2.1	46.5 ± 2.5	31.7 ± 2.1
L10-029	Field6	01:33:18.94	+30:46:50.04	0.95	44	52	42	A	39.21 ± 1.48	464.2 ± 49.2	113.0 ± 13.2	286.0 ± 26.8	28.8 ± 3.8	57.2 ± 4.4	38.0 ± 3.4
L10-030	Field4	01:33:21.64	+30:31:31.10	0.44	24	14	10	A	63.52 ± 1.37	232.7 ± 9.7	41.3 ± 4.0	245.1 ± 11.0	23.3 ± 2.0	26.4 ± 2.2	17.6 ± 1.8
L10-033	Field6	01:33:27.07	+30:47:48.60	0.67	26	26	17	C	56.99 ± 0.89	242.6 ± 25.5	—	286.0 ± 18.0	18.6 ± 1.5	39.4 ± 1.6	27.6 ± 1.3
L10-034	Field4	01:33:28.08	+30:31:35.00	0.66	50	72	33	B	25.54 ± 0.49	391.9 ± 25.5	429.5 ± 27.2	259.3 ± 16.7	33.0 ± 2.4	38.3 ± 2.4	27.9 ± 2.0
L10-035†	Field6	01:33:28.99	+30:47:42.80	0.29	22	21	6	C	5.38 ± 0.30	—	—	286.0 ± 96.7	15.4 ± 5.7	17.7 ± 5.3	11.5 ± 4.5
L10-036	Field2	01:33:29.05	+30:42:17.00	1.06	74	88	78	A3	67.35 ± 1.30	453.2 ± 17.1	160.0 ± 6.6	286.0 ± 11.5	47.7 ± 2.3	52.0 ± 2.0	54.2 ± 2.1
L10-037	Field6	01:33:29.45	+30:49:10.80	0.74	52	63	38	B	13.33 ± 0.60	574.4 ± 71.3	305.8 ± 36.5	286.0 ± 34.7	32.3 ± 4.9	41.3 ± 4.8	32.8 ± 4.2
L10-038	Field6	01:33:30.21	+30:47:43.80	0.42	20	21	8	C	55.88 ± 0.55	204.2 ± 18.7	90.0 ± 7.0	286.0 ± 15.3	17.6 ± 0.9	25.1 ± 1.0	17.0 ± 0.8
L10-039	Field4	01:33:31.20	+30:33:33.40	0.98	116	139	113	A3	76.43 ± 1.60	443.7 ± 23.2	445.9 ± 23.5	286.0 ± 16.0	63.4 ± 2.6	43.6 ± 2.0	54.1 ± 2.3
L10-040	Field2	01:33:31.34	+30:42:18.30	0.30	20	17	6	A	63.29 ± 0.90	256.5 ± 9.5	104.6 ± 5.0	286.0 ± 10.8	22.2 ± 1.4	17.3 ± 1.4	12.7 ± 1.2
L10-041	Field4	01:33:31.80	+30:31:01.10	0.96	27	25	26	A	22.82 ± 1.50	272.6 ± 36.0	74.3 ± 12.0	244.9 ± 29.1	25.1 ± 6.2	57.0 ± 7.6	39.1 ± 6.2
L10-043	Field2	01:33:35.39	+30:42:32.10	0.49	26	25	13	C	29.29 ± 0.35	318.8 ± 12.3	59.0 ± 4.1	286.0 ± 10.6	26.6 ± 1.1	28.1 ± 1.2	21.4 ± 1.1
L10-044	Field6	01:33:35.63	+30:49:22.63	0.95	56	55	53	A	22.82 ± 0.60	617.8 ± 50.4	100.7 ± 9.7	286.0 ± 20.9	31.9 ± 2.8	54.0 ± 2.7	40.6 ± 2.3
L10-045	Field4	01:33:36.09	+30:36:27.01	0.83	54	70	45	A2	144.35 ± 1.83	352.1 ± 7.9	221.1 ± 5.0	286.0 ± 6.9	41.3 ± 1.5	46.0 ± 1.5	37.4 ± 1.3
L10-046	Field4	01:33:37.09	+30:32:53.50	0.99	48	52	48	A	18.32 ± 0.24	475.6 ± 27.3	105.5 ± 7.3	286.0 ± 14.7	38.2 ± 1.5	58.2 ± 1.5	40.6 ± 1.3

Table 5 – *continued*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Name ID	Field	RA	Dec.	[S II]/Hz	σ km s ⁻¹	σ ([S II]) km s ⁻¹	ξ	Morphology	F(H α) 10 ⁻¹⁵ erg cm ⁻² s ⁻¹	[O III]3727	[O III]5007	H α	[N II]6584	[S II]6717	[S II]6731
L10-047	Field2	01:33:37.75	+30:40:09.20	0.96	41	40	39	A	22.45 ± 0.69	1279.4 ± 136.6	236.6 ± 27.0	286.0 ± 31.3	41.9 ± 3.4	55.7 ± 3.4	40.4 ± 2.8
L10-048	Field2	01:33:38.01	+30:42:18.20	0.53	21	17	11	A	16.70 ± 0.22	233.2 ± 10.1	22.1 ± 4.2	286.0 ± 11.6	26.8 ± 1.2	31.2 ± 1.3	22.2 ± 1.1
L10-049	Field2	01:33:40.66	+30:39:40.80	0.79	33	40	26	A	34.53 ± 0.68	887.9 ± 71.3	154.8 ± 14.3	286.0 ± 22.8	37.8 ± 2.0	46.0 ± 2.2	32.9 ± 1.9
L10-050	Field2	01:33:40.73	+30:42:35.70	0.60	20	17	12	C	110.80 ± 1.10	343.6 ± 10.3	41.4 ± 3.0	286.0 ± 8.5	31.8 ± 1.0	35.0 ± 1.0	25.0 ± 0.9
L10-051	Field6	01:33:40.91	+30:52:14.49	0.72	29	33	21	A	39.25 ± 0.92	346.7 ± 38.2	84.5 ± 11.5	286.0 ± 27.1	24.7 ± 2.4	42.5 ± 2.5	30.0 ± 2.1
L10-052	Field4	01:33:41.30	+30:32:28.40	0.48	27	23	13	C	15.99 ± 0.26	329.8 ± 23.2	53.9 ± 6.3	286.0 ± 16.4	23.5 ± 1.5	28.5 ± 1.7	19.5 ± 1.4
L10-053	Field9	01:33:41.69	+30:21:04.10	0.57	32	32	18	A	73.98 ± 1.07	637.5 ± 19.9	114.5 ± 4.3	286.0 ± 9.2	17.3 ± 1.4	33.9 ± 1.4	23.3 ± 1.2
L10-054	Field9	01:33:42.20	+30:20:58.00	0.77	37	45	29	A	43.42 ± 1.13	587.2 ± 26.5	82.3 ± 5.4	286.0 ± 14.3	18.9 ± 3.0	45.8 ± 3.0	30.8 ± 2.4
L10-055	Field2	01:33:42.91	+30:41:49.50	0.53	17	16	9	C	51.99 ± 0.53	267.6 ± 11.3	23.5 ± 4.2	286.0 ± 11.0	25.2 ± 1.0	30.7 ± 1.1	22.2 ± 0.9
L10-056	Field2	01:33:43.49	+30:41:03.80	0.72	29	36	21	B	15.54 ± 0.25	606.0 ± 37.6	59.4 ± 6.3	286.0 ± 16.1	36.0 ± 1.8	41.6 ± 1.8	30.7 ± 1.5
L10-057	Field4	01:33:43.70	+30:36:11.50	0.59	17	21	10	C	36.48 ± 0.38	259.6 ± 7.8	38.9 ± 2.8	286.0 ± 7.9	27.8 ± 1.1	35.0 ± 1.2	24.3 ± 1.0
L10-058	Field4	01:33:45.26	+30:32:20.10	0.59	23	14	13	A	86.78 ± 0.70	269.4 ± 6.8	14.4 ± 2.2	286.0 ± 6.5	27.9 ± 0.8	34.7 ± 0.8	24.5 ± 0.7
L10-059†	Field2	01:33:47.46	+30:39:44.70	0.99	36	44	36	A	29.75 ± 0.86	< 1016.6 ± 341.0	< 200.0 ± 65.7	286.0 ± 95.7	51.1 ± 3.2	56.4 ± 3.5	42.7 ± 3.0
L10-060	Field2	01:33:48.35	+30:39:28.40	0.67	30	40	20	C	20.92 ± 0.27	484.3 ± 26.8	80.3 ± 7.2	286.0 ± 15.5	40.9 ± 1.5	38.3 ± 1.5	28.5 ± 1.3
L10-061	Field4	01:33:48.50	+30:33:07.90	0.73	22	24	16	B	285.7 ± 6.1	285.7 ± 6.1	59.9 ± 2.3	286.0 ± 6.4	31.6 ± 0.9	42.8 ± 1.0	29.8 ± 0.8
L10-062	Field4	01:33:49.75	+30:30:49.70	0.68	0	0	0	A	23.22 ± 0.42	289.1 ± 17.7	36.0 ± 5.7	267.0 ± 15.1	24.0 ± 1.8	40.5 ± 2.0	27.9 ± 2.0
L10-063	Field4	01:33:49.90	+30:30:16.70	1.09	28	13	30	A	4.57 ± 0.40	561.3 ± 115.9	249.4 ± 53.1	236.8 ± 49.9	55.9 ± 11.1	65.9 ± 10.2	42.7 ± 7.9
L10-064	Field4	01:33:50.12	+30:35:28.60	0.79	34	40	27	B	27.23 ± 0.48	465.9 ± 25.8	224.8 ± 13.2	286.0 ± 16.0	37.7 ± 1.9	45.4 ± 2.0	33.6 ± 1.7
L10-065	Field2	01:33:51.06	+30:43:56.20	0.55	24	21	13	B	90.09 ± 0.63	348.1 ± 7.1	32.2 ± 1.8	286.0 ± 5.4	31.7 ± 0.7	32.0 ± 0.7	23.2 ± 0.6
L10-066	Field4	01:33:51.67	+30:30:59.60	1.19	55	46	65	A	13.49 ± 0.52	457.5 ± 51.1	135.7 ± 19.0	286.0 ± 33.2	33.6 ± 3.8	67.4 ± 4.4	51.3 ± 3.7
L10-067	Field5	01:33:51.61	+30:30:42.64	0.79	23	17	10	C	9.76 ± 0.25	344.3 ± 23.5	55.1 ± 5.9	244.2 ± 14.0	33.6 ± 2.9	48.3 ± 3.1	30.4 ± 2.5
L10-068	Field5	01:33:52.15	+30:56:33.40	0.48	20	17	10	A	175.07 ± 2.03	270.6 ± 16.2	384.5 ± 21.5	286.0 ± 15.8	20.4 ± 1.1	27.9 ± 1.1	19.7 ± 0.9
L10-069	Field4	01:33:54.28	+30:33:47.90	0.83	31	32	25	A	52.43 ± 0.64	313.3 ± 8.1	37.2 ± 2.4	286.0 ± 7.3	28.5 ± 1.3	48.8 ± 1.4	34.0 ± 1.2
L10-070	Field2	01:33:54.49	+30:45:18.70	0.77	37	47	28	B	88.19 ± 0.71	402.5 ± 7.0	71.1 ± 2.0	286.0 ± 5.2	37.0 ± 0.9	44.5 ± 0.9	32.4 ± 0.8
L10-071	Field4	01:33:54.91	+30:33:11.00	1.00	73	94	73	A3	78.17 ± 1.34	439.8 ± 12.8	203.9 ± 6.3	267.1 ± 8.7	41.2 ± 2.0	52.9 ± 2.0	47.3 ± 1.9
L10-072†	Field2	01:33:55.01	+30:39:57.30	1.33	13	22	17	B	11.28 ± 0.73	< 813.6 ± 273.3	< 97.4 ± 36.3	286.0 ± 97.1	75.8 ± 9.0	75.8 ± 8.3	57.0 ± 7.0
L10-073	Field9	01:33:56.49	+30:21:27.00	0.84	48	49	40	A	27.85 ± 0.78	890.5 ± 54.4	118.7 ± 7.9	286.0 ± 16.6	20.9 ± 2.5	50.2 ± 3.0	34.2 ± 2.3
L10-074	Field4	01:33:56.97	+30:34:58.70	0.93	36	41	33	A	24.72 ± 0.49	419.9 ± 13.3	106.8 ± 4.3	286.0 ± 10.1	33.2 ± 2.0	53.9 ± 2.3	39.4 ± 2.0
L10-075	Field2	01:33:57.13	+30:40:48.50	1.01	22	33	22	A	24.29 ± 1.05	1584.4 ± 324.7	64.3 ± 23.8	286.0 ± 58.3	45.9 ± 5.3	58.5 ± 5.3	42.1 ± 4.5
L10-076	Field4	01:33:57.13	+30:35:06.10	0.49	19	30	9	B	19.74 ± 0.27	410.9 ± 10.7	166.8 ± 4.8	286.0 ± 8.1	33.9 ± 1.4	28.6 ± 1.5	20.0 ± 1.3
L10-077	Field4	01:33:58.06	+30:32:09.60	0.44	0	0	0	C	26.19 ± 0.21	190.5 ± 5.3	20.0 ± 2.6	286.0 ± 7.1	22.8 ± 0.8	26.5 ± 0.9	17.9 ± 0.9
L10-078	Field2	01:33:58.13	+30:37:53.04	1.13	45	46	50	A2	18.01 ± 0.45	1017.9 ± 70.1	206.9 ± 16.0	286.0 ± 20.8	53.5 ± 2.9	64.2 ± 2.9	48.6 ± 2.4
L10-079	Field5	01:33:58.15	+30:48:36.40	0.55	28	27	15	A	10.23 ± 0.24	247.1 ± 14.5	22.8 ± 4.3	286.0 ± 13.7	26.5 ± 2.4	32.4 ± 2.2	22.1 ± 1.9
L10-080	Field4	01:33:58.42	+30:36:24.30	1.14	61	54	70	A3	3.65 ± 0.17	1108.7 ± 138.8	281.7 ± 31.7	286.0 ± 33.1	50.4 ± 4.9	62.9 ± 5.1	50.8 ± 4.4
L10-081	Field4	01:33:58.51	+30:33:32.30	0.68	30	37	20	C	13.87 ± 0.32	554.1 ± 29.9	167.8 ± 8.9	286.0 ± 14.6	31.9 ± 2.4	40.3 ± 2.6	27.4 ± 2.2
L10-082	Field5	01:33:58.52	+30:51:54.30	0.86	45	65	38	A	30.57 ± 1.37	524.9 ± 55.4	427.2 ± 45.1	286.0 ± 31.9	37.2 ± 5.3	53.1 ± 5.7	32.5 ± 4.3
L10-084	Field2	01:34:00.31	+30:42:19.40	1.13	92	87	103	A	22.34 ± 0.84	859.4 ± 94.3	442.6 ± 48.9	286.0 ± 32.7	57.2 ± 3.9	62.9 ± 4.0	50.1 ± 3.4
L10-085	Field2	01:34:00.32	+30:47:24.10	0.97	52	51	50	B	19.26 ± 0.50	922.6 ± 99.6	358.6 ± 39.9	286.0 ± 31.4	42.4 ± 2.7	55.9 ± 2.8	41.0 ± 2.3
L10-086	Field5	01:34:00.53	+30:49:02.71	0.60	46	43	28	C	0.81 ± 0.08	375.9 ± 64.2	123.2 ± 25.0	286.0 ± 52.6	27.6 ± 6.9	27.7 ± 7.8	32.8 ± 8.6
L10-087	Field3	01:34:01.34	+30:35:20.20	0.88	29	38	26	A	40.87 ± 1.14	852.4 ± 63.9	59.4 ± 7.7	286.0 ± 20.5	31.6 ± 3.2	50.4 ± 3.3	37.6 ± 2.8
L10-088	Field3	01:34:02.24	+30:31:06.80	0.91	41	46	37	A	41.90 ± 1.28	1005.5 ± 61.7	132.7 ± 9.1	286.0 ± 17.9	31.4 ± 3.7	51.0 ± 3.4	39.8 ± 3.0
L10-089	Field3	01:34:03.31	+30:36:22.90	0.58	28	25	16	A	284.02 ± 6.09	499.4 ± 18.1	46.1 ± 3.1	286.0 ± 10.0	26.6 ± 2.2	32.9 ± 2.1	24.6 ± 1.9
L10-090	Field1	01:34:03.48	+30:44:43.80	0.99	47	41	46	A	13.78 ± 0.79	786.6 ± 97.5	669.7 ± 83.2	286.0 ± 38.7	51.7 ± 5.8	59.3 ± 5.9	39.9 ± 4.8
L10-091	Field3	01:34:04.26	+30:32:57.10	0.87	53	48	46	B	7.83 ± 0.60	4220.7 ± 1032.1	621.7 ± 149.8	286.0 ± 71.5	30.2 ± 5.9	50.2 ± 7.7	37.2 ± 6.5
L10-092	Field3	01:34:07.23	+30:36:22.00	0.80	25	23	20	A	162.24 ± 3.93	565.2 ± 23.9	56.1 ± 3.7	286.0 ± 11.5	28.3 ± 2.5	45.6 ± 2.5	34.7 ± 2.2

Table 5 – continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Name ID	Field	RA	Dec.	[S II]/Hz	σ km s ⁻¹	σ ([S II]) km s ⁻¹	ξ	Morphology	F(H α) 10 ⁻¹⁵ erg cm ⁻² s ⁻¹	[O III]3727	[O III]5007	H α	[N II]6584	[S II]6717	[S II]6731
L10-093	Field3	01:34:07.50	+30:37:08.00	0.95	29	33	27	B	3.94 ± 0.21	3612.9 ± 840.9	595.8 ± 135.8	286.0 ± 66.0	33.8 ± 6.3	50.2 ± 5.8	44.4 ± 5.4
L10-094	Field1	01:34:08.37	+30:46:33.20	0.69	24	43	17	C	7.88 ± 0.31	427.6 ± 41.8	377.9 ± 35.7	286.0 ± 28.5	39.9 ± 4.7	39.3 ± 4.0	29.7 ± 3.6
L10-095	Field1	01:34:10.02	+30:47:14.90	0.90	65	71	58	A	8.26 ± 0.35	599.2 ± 48.9	452.5 ± 36.8	286.0 ± 25.7	37.4 ± 4.0	51.7 ± 4.4	38.0 ± 3.8
L10-096	Field1	01:34:10.70	+30:42:24.00	1.29	57	53	74	A	49.83 ± 0.88	274.5 ± 6.9	126.5 ± 3.9	286.0 ± 8.6	42.9 ± 1.9	71.4 ± 1.9	57.5 ± 1.7
L10-097	Field3	01:34:11.04	+30:38:59.90	0.81	47	55	38	B	8.90 ± 0.30	840.0 ± 91.3	166.2 ± 19.4	286.0 ± 30.0	33.5 ± 4.1	44.7 ± 3.8	36.2 ± 3.4
L10-098	Field3	01:34:12.69	+30:35:12.00	0.44	0	0	0	A	90.76 ± 1.39	425.4 ± 18.3	96.0 ± 4.5	286.0 ± 10.3	18.7 ± 1.5	24.4 ± 1.6	19.3 ± 1.6
L10-099	Field5	01:34:13.11	+30:48:33.47	0.64	27	28	17	C	91.26 ± 1.10	199.8 ± 7.8	38.2 ± 3.3	286.0 ± 9.3	26.6 ± 1.2	37.4 ± 1.2	26.2 ± 1.0
L10-100	Field1	01:34:13.65	+30:43:27.00	0.86	56	64	48	A	5.11 ± 0.23	579.8 ± 95.7	509.7 ± 81.8	286.0 ± 46.8	38.1 ± 4.8	52.4 ± 4.8	33.2 ± 3.9
L10-101	Field1	01:34:13.71	+30:48:17.50	0.74	27	24	20	B	54.32 ± 1.10	297.8 ± 8.3	34.3 ± 2.4	286.0 ± 8.7	30.3 ± 2.2	44.8 ± 2.0	29.5 ± 1.7
L10-102	Field3	01:34:14.10	+30:34:30.90	0.50	32	30	16	B	122.34 ± 2.45	357.3 ± 11.9	49.2 ± 3.1	286.0 ± 9.8	16.7 ± 1.9	28.2 ± 2.0	22.0 ± 1.8
L10-103	Field1	01:34:14.35	+30:41:53.60	0.87	36	33	31	A	11.29 ± 0.32	436.1 ± 46.2	226.3 ± 25.8	286.0 ± 30.4	39.9 ± 2.9	50.7 ± 2.8	35.9 ± 2.4
L10-104	Field3	01:34:14.38	+30:39:41.60	1.07	45	45	48	A	21.29 ± 0.70	1818.5 ± 178.0	143.3 ± 16.1	286.0 ± 27.9	32.3 ± 3.5	61.3 ± 3.7	45.3 ± 3.1
L10-105	Field5	01:34:14.36	+30:53:51.90	0.98	45	56	44	A	57.29 ± 1.74	447.1 ± 25.2	159.5 ± 9.4	286.0 ± 16.6	30.6 ± 3.2	58.2 ± 3.6	39.7 ± 2.9
L10-106	Field3	01:34:15.57	+30:32:59.90	0.82	40	50	33	A	20.84 ± 0.60	1063.0 ± 196.3	462.6 ± 83.4	286.0 ± 37.0	31.5 ± 3.6	46.2 ± 3.3	35.8 ± 2.9
L10-107	Field5	01:34:16.31	+30:52:32.70	0.57	27	28	15	A	150.10 ± 1.79	204.3 ± 8.5	68.7 ± 4.1	286.0 ± 10.2	22.1 ± 1.2	33.5 ± 1.2	23.0 ± 1.0
L10-109	Field5	01:34:17.00	+30:51:47.10	0.39	23	28	9	B	127.26 ± 1.31	173.5 ± 8.4	192.1 ± 9.3	286.0 ± 12.6	18.8 ± 1.0	22.5 ± 1.1	16.1 ± 0.9
L10-110	Field3	01:34:17.03	+30:33:57.70	0.55	22	23	12	B	139.04 ± 2.99	387.9 ± 13.1	46.6 ± 3.4	286.0 ± 10.5	16.7 ± 2.1	31.1 ± 2.2	24.1 ± 2.0
L10-111	Field1	01:34:17.61	+30:41:23.30	1.01	66	71	67	A	24.42 ± 0.58	424.4 ± 26.5	354.7 ± 21.7	280.8 ± 17.7	42.5 ± 2.5	58.5 ± 2.6	42.5 ± 2.2
L10-112	Field5	01:34:18.32	+30:54:05.80	0.88	21	25	19	A	30.34 ± 1.33	1249.3 ± 215.0	233.1 ± 42.3	286.0 ± 49.3	35.2 ± 4.5	50.9 ± 4.9	36.6 ± 4.2
L10-113	Field3	01:34:19.28	+30:33:45.90	0.48	25	23	20	A	153.91 ± 3.27	448.6 ± 32.5	298.3 ± 22.4	286.0 ± 21.3	15.7 ± 1.9	27.1 ± 2.1	21.2 ± 1.9
L10-114	Field3	01:34:19.87	+30:33:56.00	0.69	29	29	12	A	60.52 ± 1.30	504.9 ± 41.0	336.4 ± 28.1	286.0 ± 23.8	20.6 ± 2.1	38.6 ± 2.2	30.5 ± 2.0
L10-116	Field5	01:34:23.54	+30:54:23.23	0.83	32	48	27	A	1.89 ± 0.15	872.2 ± 261.8	489.8 ± 149.0	286.0 ± 88.0	35.3 ± 7.2	52.6 ± 10.8	30.5 ± 8.0
L10-118	Field1	01:34:25.33	+30:48:30.30	0.78	47	40	37	A	10.51 ± 0.56	255.8 ± 21.1	87.2 ± 10.0	281.7 ± 25.9	32.2 ± 6.2	46.2 ± 5.2	32.1 ± 4.4
L10-119	Field3	01:34:25.87	+30:33:16.80	0.45	0	0	0	A	4.29 ± 0.16	327.5 ± 56.9	56.1 ± 15.1	286.0 ± 39.0	12.3 ± 3.6	28.2 ± 4.1	16.5 ± 4.0
L10-120	Field1	01:34:29.61	+30:41:53.40	0.62	0	0	0	C	14.21 ± 0.18	334.7 ± 22.8	358.8 ± 24.8	248.1 ± 16.8	32.2 ± 1.3	38.1 ± 1.4	24.0 ± 1.4
L10-121	Field3	01:34:30.29	+30:35:44.80	0.97	54	54	52	A	30.03 ± 1.15	992.3 ± 98.2	311.6 ± 31.1	286.0 ± 29.6	21.9 ± 3.0	55.4 ± 4.1	41.3 ± 3.5
L10-123	Field3	01:34:32.34	+30:35:32.60	1.03	47	51	48	A	17.03 ± 0.59	1134.5 ± 73.4	135.0 ± 9.5	286.0 ± 18.9	23.9 ± 3.5	56.1 ± 3.8	46.6 ± 3.4
L10-124	Field1	01:34:33.02	+30:46:39.02	0.72	48	55	34	A2	37.22 ± 0.70	192.9 ± 3.4	137.7 ± 2.8	284.5 ± 7.1	26.5 ± 1.9	40.5 ± 1.9	31.4 ± 1.7
L10-126	Field3	01:34:36.22	+30:36:23.60	0.69	0	0	0	A	12.52 ± 0.30	407.2 ± 66.4	508.0 ± 81.2	286.0 ± 45.7	32.9 ± 2.4	39.6 ± 2.7	28.9 ± 2.6
L10-127	Field3	01:34:39.00	+30:37:59.80	0.38	0	0	0	A	79.16 ± 1.39	236.2 ± 12.7	36.7 ± 3.9	286.0 ± 12.3	12.9 ± 1.7	22.6 ± 1.9	15.7 ± 1.9
L10-128	Field1	01:34:40.73	+30:43:36.40	0.77	45	43	34	A	43.28 ± 0.72	261.7 ± 7.8	141.7 ± 5.0	250.0 ± 8.3	26.6 ± 1.6	45.8 ± 1.6	30.8 ± 1.4
L10-129	Field1	01:34:41.10	+30:43:28.30	0.96	58	60	55	A	89.42 ± 1.84	337.7 ± 12.6	247.0 ± 9.8	257.6 ± 10.9	35.1 ± 2.1	56.0 ± 2.2	39.6 ± 1.8
L10-130	Field1	01:34:41.16	+30:43:55.40	0.64	41	40	26	A	9.02 ± 0.38	357.2 ± 32.7	387.1 ± 35.5	262.2 ± 25.8	25.0 ± 4.1	39.3 ± 4.1	24.8 ± 3.4
L10-131	Field3	01:34:41.89	+30:37:35.20	0.39	0	0	0	A	145.33 ± 2.92	209.9 ± 12.6	45.5 ± 4.7	286.0 ± 13.5	13.3 ± 1.9	23.2 ± 2.2	15.3 ± 2.1
L10-132	Field1	01:34:44.62	+30:42:38.80	0.31	6	2	2	C	34.96 ± 0.91	130.0 ± 5.1	10.1 ± 2.1	278.1 ± 9.2	19.2 ± 2.9	18.4 ± 2.3	13.0 ± 2.1
L14-002	Field7	01:32:27.85	+30:35:44.60	0.62	38	45	24	-	29.55 ± 1.34	558.0 ± 62.2	139.5 ± 14.6	286.0 ± 28.3	19.0 ± 5.3	37.2 ± 5.0	25.0 ± 4.0
L14-004	Field7	01:32:35.36	+30:35:19.80	0.30	0	0	0	-	45.61 ± 0.58	281.7 ± 16.9	30.2 ± 5.1	286.0 ± 12.6	8.8 ± 1.2	17.4 ± 1.3	13.0 ± 1.3
L14-005	Field8	01:32:37.16	+30:17:54.30	0.41	0	0	0	-	12.62 ± 0.35	505.6 ± 47.1	434.6 ± 35.0	266.9 ± 22.2	12.7 ± 2.7	27.3 ± 3.0	14.2 ± 2.9
L14-009	Field7	01:32:40.94	+30:31:50.00	0.28	16	17	5	-	42.35 ± 0.96	548.5 ± 58.6	57.9 ± 4.1	286.0 ± 11.9	15.3 ± 2.2	18.2 ± 2.2	10.3 ± 1.8
L14-010	Field7	01:32:42.71	+30:36:18.71	0.42	18	15	8	-	27.40 ± 0.56	646.8 ± 67.8	27.1 ± 4.6	286.0 ± 13.8	12.0 ± 1.7	25.3 ± 1.9	16.6 ± 1.6
L14-012	Field8	01:32:45.47	+30:23:14.20	0.42	14	10	6	-	9.46 ± 0.27	296.1 ± 48.9	-	281.4 ± 16.7	19.6 ± 3.1	25.2 ± 2.7	16.3 ± 2.3
L14-016	Field7	01:32:52.80	+30:31:34.20	0.47	19	18	9	-	51.25 ± 0.76	356.6 ± 17.2	29.6 ± 3.2	286.0 ± 9.6	12.7 ± 1.4	27.5 ± 1.4	19.4 ± 1.2
L14-020	Field7	01:32:56.12	+30:33:30.40	0.85	28	24	24	-	35.73 ± 1.14	1082.3 ± 109.7	57.4 ± 5.5	286.0 ± 16.4	22.8 ± 3.1	52.0 ± 3.2	32.6 ± 2.5

Table 5 – continued

(1) Name ID	(2) Field	(3) RA	(4) Dec.	(5) [S II]/H α	(6) σ km s $^{-1}$	(7) σ (S II) km s $^{-1}$	(8) ξ	(9) Morphology	(10) F(H α) 10 $^{-15}$ erg cm $^{-2}$ s $^{-1}$	(11) [O II] λ 727	(12) [O III] λ 5007	(13) H α	(14) [N II] λ 6584	(15) [S II] λ 6717	(16) [S II] λ 6731
L14-023	Field7	01:32:57.18	+30:39:14.70	0.41	18	16	7	–	19.82 \pm 0.36	531.3 \pm 42.0	10.5 \pm 3.0	286.0 \pm 9.9	10.0 \pm 1.5	23.0 \pm 1.7	17.7 \pm 1.5
L14-038	Field4	01:33:13.46	+30:28:13.10	0.47	21	22	10	–	40.92 \pm 0.80	216.9 \pm 13.4	67.0 \pm 6.8	219.7 \pm 13.6	24.4 \pm 1.9	28.7 \pm 2.1	18.2 \pm 1.7
L14-039	Field7	01:33:13.81	+30:39:44.00	0.42	30	26	13	–	54.38 \pm 1.71	546.6 \pm 84.9	54.0 \pm 4.7	286.0 \pm 14.9	17.5 \pm 3.7	23.5 \pm 2.7	18.7 \pm 2.5
L14-040	Field7	01:33:15.35	+30:35:36.70	0.39	0	0	0	–	11.90 \pm 0.35	513.5 \pm 127.7	–	286.0 \pm 29.6	21.2 \pm 2.9	23.2 \pm 3.2	15.6 \pm 3.1
L14-043	Field6	01:33:17.52	+30:46:43.66	0.50	23	22	11	–	99.08 \pm 1.26	333.8 \pm 25.6	165.0 \pm 11.1	286.0 \pm 16.8	23.1 \pm 1.2	30.2 \pm 1.2	19.9 \pm 1.0
L14-044	Field4	01:33:18.13	+30:33:38.60	0.32	0	0	0	–	4.87 \pm 0.12	108.3 \pm 40.0	–	286.0 \pm 37.9	9.9 \pm 2.3	17.6 \pm 2.5	14.8 \pm 2.5
L14-048	Field9	01:33:21.19	+30:19:20.63	0.28	0	0	0	–	13.06 \pm 0.27	314.4 \pm 43.4	–	286.0 \pm 23.8	12.2 \pm 2.0	15.7 \pm 2.2	12.3 \pm 2.2
L14-049	Field4	01:33:21.33	+30:30:31.60	0.40	19	19	8	–	22.55 \pm 0.33	209.8 \pm 11.9	–	261.6 \pm 14.2	18.9 \pm 1.4	23.1 \pm 1.5	17.4 \pm 1.3
L14-054	Field4	01:33:24.01	+30:36:56.80	0.41	0	0	0	–	15.98 \pm 0.29	195.8 \pm 20.5	–	263.9 \pm 24.2	25.0 \pm 1.8	23.1 \pm 2.0	17.8 \pm 2.0
L14-055	Field4	01:33:24.34	+30:28:50.41	0.91	0	0	0	–	2.52 \pm 0.19	294.0 \pm 63.6	277.3 \pm 61.8	160.0 \pm 35.6	36.8 \pm 7.6	56.2 \pm 8.9	35.1 \pm 8.3
L14-058	Field9	01:33:27.94	+30:18:17.04	0.86	49	50	42	–	9.06 \pm 0.54	966.2 \pm 122.0	207.8 \pm 28.2	286.0 \pm 39.0	19.5 \pm 4.6	51.8 \pm 6.4	34.0 \pm 4.9
L14-059	Field9	01:33:27.97	+30:15:59.49	0.37	0	0	0	–	2.40 \pm 0.10	–	–	286.0 \pm 49.2	–	21.2 \pm 4.5	15.5 \pm 4.5
L14-065	Field9	01:33:30.64	+30:21:01.50	0.65	29	30	19	–	36.72 \pm 1.05	568.7 \pm 39.5	–	286.0 \pm 18.9	18.3 \pm 3.3	37.5 \pm 2.9	27.6 \pm 2.5
L14-066	Field9	01:33:31.20	+30:21:14.26	0.67	23	24	15	–	21.16 \pm 0.66	403.0 \pm 48.8	–	286.0 \pm 34.0	15.4 \pm 2.7	38.5 \pm 3.2	28.7 \pm 2.8
L14-070	Field9	01:33:35.05	+30:19:24.64	0.59	15	14	9	–	13.99 \pm 0.62	614.7 \pm 73.5	26.2 \pm 10.6	286.0 \pm 31.7	28.3 \pm 7.6	32.9 \pm 4.3	26.2 \pm 3.9
L14-072	Field4	01:33:34.99	+30:29:54.60	0.95	52	56	50	–	7.72 \pm 0.13	386.4 \pm 19.8	202.5 \pm 10.6	259.4 \pm 13.0	31.5 \pm 1.7	55.0 \pm 2.0	40.3 \pm 1.6
L14-075	Field4	01:33:37.02	+30:33:10.00	0.60	27	30	16	–	63.01 \pm 0.66	298.1 \pm 10.6	95.3 \pm 4.5	286.0 \pm 9.8	26.8 \pm 1.1	36.2 \pm 1.2	23.8 \pm 1.0
L14-080	Field4	01:33:39.84	+30:34:30.54	0.90	19	26	17	–	10.05 \pm 0.17	443.8 \pm 31.2	103.0 \pm 8.3	286.0 \pm 17.3	39.2 \pm 1.9	53.6 \pm 2.0	36.3 \pm 1.7
L14-092	Field9	01:33:47.51	+30:17:13.77	0.42	13	11	6	–	12.94 \pm 0.39	792.1 \pm 105.6	341.7 \pm 45.3	286.0 \pm 37.6	20.6 \pm 3.2	23.3 \pm 2.7	19.2 \pm 2.5
L14-093	Field9	01:33:47.79	+30:18:05.17	0.53	26	24	14	–	34.81 \pm 0.67	490.4 \pm 20.9	–	286.0 \pm 10.2	13.1 \pm 1.6	32.2 \pm 1.8	21.2 \pm 1.5
L14-103	Field4	01:33:52.56	+30:28:38.40	0.40	0	0	0	–	6.03 \pm 0.19	109.5 \pm 19.4	–	230.2 \pm 32.7	24.1 \pm 3.1	25.3 \pm 3.3	15.2 \pm 3.3
L14-106	Field9	01:33:54.63	+30:18:51.10	0.66	64	81	43	–	17.60 \pm 1.30	1160.6 \pm 178.0	330.5 \pm 43.6	286.0 \pm 41.6	–	43.9 \pm 8.6	22.6 \pm 6.0
L14-122	Field2	01:34:00.25	+30:39:28.90	0.77	0	0	0	–	34.01 \pm 1.01	1636.8 \pm 265.7	134.8 \pm 26.5	286.0 \pm 45.8	43.4 \pm 3.1	44.1 \pm 3.4	32.9 \pm 3.3
L14-125	Field5	01:34:00.52	+30:50:43.09	0.80	32	38	26	–	3.94 \pm 0.32	239.8 \pm 52.7	156.0 \pm 33.3	224.4 \pm 47.5	40.2 \pm 9.8	47.4 \pm 9.5	32.7 \pm 7.8
L14-133	Field5	01:34:04.83	+30:58:32.35	0.29	14	15	4	–	36.52 \pm 0.91	254.6 \pm 31.1	–	286.0 \pm 16.9	15.0 \pm 3.7	16.5 \pm 2.4	12.5 \pm 2.2
L14-148	Field3	01:34:13.85	+30:30:39.80	0.59	16	32	9	–	3.34 \pm 0.13	1164.4 \pm 200.4	528.2 \pm 80.6	286.0 \pm 44.3	26.6 \pm 4.0	30.4 \pm 4.4	28.2 \pm 4.3
L14-153	Field1	01:34:14.55	+30:44:36.20	0.68	0	0	0	–	14.32 \pm 0.58	578.4 \pm 57.4	120.4 \pm 14.5	286.0 \pm 28.8	32.1 \pm 4.1	41.9 \pm 4.6	26.4 \pm 4.4
L14-162	Field5	01:34:19.45	+30:52:48.90	0.57	24	30	14	–	39.41 \pm 1.27	243.5 \pm 46.4	–	286.0 \pm 35.3	18.9 \pm 3.6	34.4 \pm 3.6	23.1 \pm 3.0
L14-163	Field3	01:34:19.68	+30:33:41.50	0.38	24	20	9	–	105.05 \pm 2.16	294.8 \pm 31.5	425.9 \pm 46.2	286.0 \pm 30.8	12.1 \pm 1.8	21.2 \pm 2.0	16.6 \pm 1.8
L14-167	Field3	01:34:24.08	+30:33:24.40	0.48	0	0	0	–	32.59 \pm 0.53	328.1 \pm 21.7	194.6 \pm 13.8	286.0 \pm 18.5	17.5 \pm 1.6	26.5 \pm 1.8	21.0 \pm 1.7
L14-168	Field1	01:34:24.48	+30:48:58.30	0.41	0	0	0	–	33.21 \pm 0.61	109.4 \pm 7.3	–	286.0 \pm 11.2	18.3 \pm 1.8	24.6 \pm 2.0	16.6 \pm 2.0
L14-173	Field1	01:34:29.77	+30:35:08.40	0.53	16	22	9	–	29.22 \pm 1.57	513.5 \pm 74.0	26.9 \pm 9.5	286.0 \pm 30.3	14.1 \pm 5.0	27.5 \pm 5.4	25.9 \pm 5.3
L14-180	Field1	01:34:37.40	+30:44:11.00	0.41	0	0	0	–	46.33 \pm 0.79	132.1 \pm 5.6	17.0 \pm 3.0	286.0 \pm 9.9	19.3 \pm 1.7	24.7 \pm 1.8	16.4 \pm 1.1
L14-182	Field3	01:34:39.69	+30:39:17.60	0.60	34	35	21	–	20.38 \pm 0.71	448.8 \pm 46.5	–	286.0 \pm 25.4	7.9 \pm 2.8	34.6 \pm 3.6	25.1 \pm 3.1
L14-187	Field1	01:34:42.68	+30:40:51.50	0.48	0	0	0	–	6.65 \pm 0.24	222.7 \pm 30.1	–	286.0 \pm 28.5	18.7 \pm 3.6	24.6 \pm 3.9	23.1 \pm 3.9
L14-189	Field3	01:34:45.40	+30:35:35.20	0.89	52	56	47	–	10.18 \pm 0.72	1265.3 \pm 181.8	331.9 \pm 46.8	286.0 \pm 43.6	25.2 \pm 7.8	54.3 \pm 8.0	34.9 \pm 6.3
L14-191	Field3	01:34:47.24	+30:34:25.00	0.42	3	18	1	–	8.30 \pm 0.39	301.9 \pm 48.9	–	286.0 \pm 25.4	16.8 \pm 4.8	23.9 \pm 5.0	18.4 \pm 4.5

Note. $^{+1}$. Line ratios of the regions where H β is not measured; these line ratios are computed by estimating an H β flux (3σ , see Duarte Puertas et al. 2021) value and are not used in our analysis.

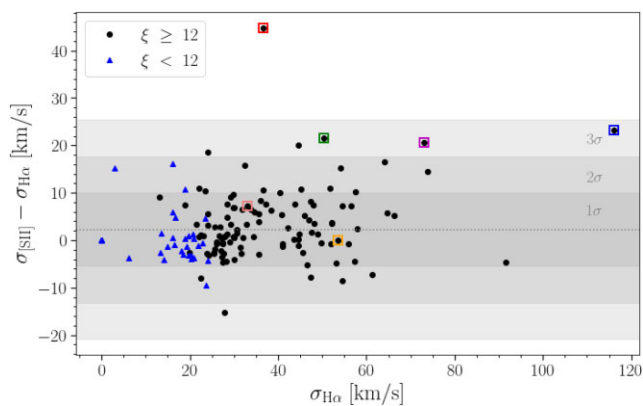


Figure 29. Difference between the velocity dispersions of the $H\alpha$ line ($\sigma_{H\alpha}$) and the $[S\ II]$ doublet ($\sigma_{[S\ II]}$) for our sample of 163 SNRs in M33. The coloured squares highlight the position of a few selected objects SNRs, the spectrum of which are displayed in Fig. 30: red, blue, green, magenta, orange, and salmon for L10-025, L10-039, L10-034, L10-071, L10-121, and L10-049, respectively.

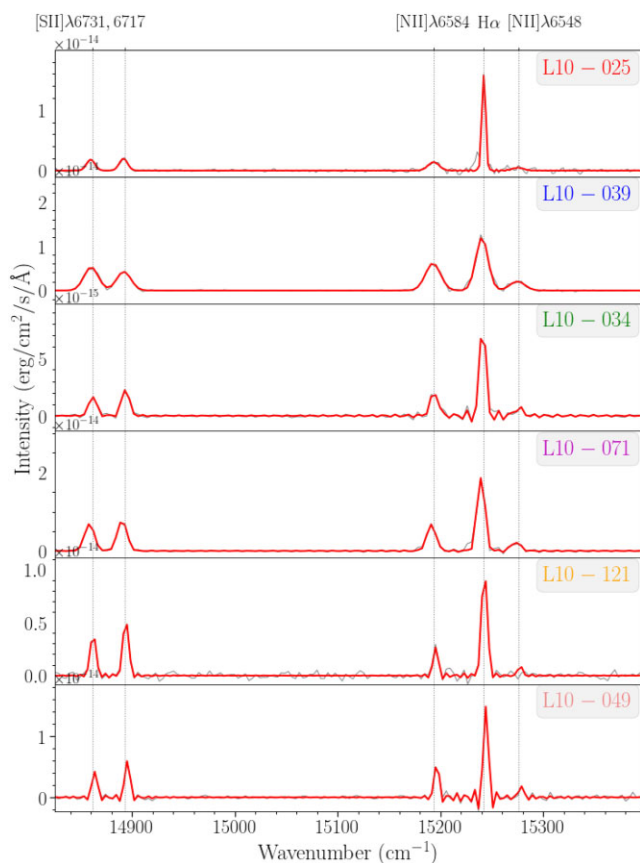


Figure 30. Spectra of the SNRs identified in Fig. 29. In each panel, the grey line shows the real spectrum and the red lines show the fit obtained with ORCS. The grey dotted lines show the locations of the emission lines from SN3 filter. The SNR label is indicated in each panel (upper right part).

the SNR candidate. This filament has a low σ value ($\sim 20\text{ km s}^{-1}$). Its average radial velocity is $\sim -160\text{ km s}^{-1}$ and has a $[S\ II]/H\alpha$ value larger than 0.4, being larger on the outside of the filament than on the inside. Moreover, taking into account the σ map, it can be seen how to the north-east of this SNR there is a zone with higher σ values

than 20 km s^{-1} . Taking into account the radial velocity of this zone and comparing it with the velocity of L10-011, it is compatible with being material associated with this SNR.

L10-071 is a compact SNR (Fig. 26); its outer ring is barely resolved. Morphologically it is similar in the different emission lines. The behaviour in the $\log([S\ II]/H\alpha)$ versus σ diagram has already been discussed in the previous section.

Fig. 27 presents L10-064. It is a type B SNR. Its western part shows a similar morphology in all emission lines, while the eastern part is open. A filament is visible from north to south, the southern part being the brightest. As in the cases of L10-011 and L10-105, the filament has high $[S\ II]/H\alpha$ and low σ values. L10-064 presents high $[S\ II]/H\alpha$ values and tentatively higher values of σ in the central part ($\sim 120\text{ km s}^{-1}$) than in the outer part ($\lesssim 40\text{ km s}^{-1}$).

In Fig. 28 we show L10-050, of type C: it is fragmented and stands out as a filament. The morphology is similar in all visible emission lines, although $[O\ III]$ is rather faint. $[S\ II]/H\alpha$ is high but σ is low ($\sim 20\text{ km s}^{-1}$).

4.2 Detectability, spectral characteristics of SNRs and their immediate environment

The detectability of SNRs in galaxies outside the Local Group obviously depends on their evolutionary status and location with respect to bright ISM regions: an old SNR within a dense $H\ II$ region is less likely to be detected with optical data than an isolated younger one. In addition, the DIG is known to harbour large values of $[S\ II]/H\alpha$ (Mannucci et al. 2021), albeit with small velocity dispersion. Without any information on the velocity dispersion, some filaments of the DIG could thus be mistaken for SNRs (see for instance the case of NGC 4214: Leonidaki, Boumis & Zezas 2013; Vicens-Mouret et al. 2023). In M33, L10-011 and L10-064 are examples of SNRs which are seen superimposed on large DIG filaments with values of $[S\ II]/H\alpha$ larger than 0.4.

For the same reasons, the spectral characteristics of SNRs, in terms of line ratios and kinematics, depend on the choice of the background used to extract their net spectrum; this choice is not obvious in cases where the SNR lies in a highly inhomogeneous nebular structure of filament. As we mentioned before, we have deliberately chosen to subtract a general background as much devoid of nebular features as possible to produce the maps and the integrated spectra of SNRs presented here and forced ORCS to use the same velocity dispersion for all the lines in the SN3 cube. This has little impact for the vast majority of objects, since the contrast between the SNRs and their surroundings is high.

We have however visually noticed a few cases for which the width of the $H\alpha$ line was noticeably smaller than that of the $[S\ II]$ doublet. We have therefore performed another fit on the integrated spectrum of all SNRs with ORCS, but this time allowing it to fit different velocity dispersions for $H\alpha$ and the forbidden lines. The values of $\sigma_{H\alpha}$ and $\sigma_{[S\ II]}$ are compiled in Table 5 and plotted in Fig. 29; examples of spectra from selected objects are shown in Fig. 30. Although there is a small offset globally (the average difference is 2 km s^{-1}), about 87 per cent of the SNRs show no significant difference between the two values of velocity dispersion. 12 objects (7 per cent of the sample) have a difference larger than 15 km s^{-1} in favour of $[S\ II]$, the most obvious one being L10-025 (upper panel of Figs 30 and 31), which is indeed surrounded by a bright $H\ II$ region. We infer that in more distant galaxies, a much larger fraction of SNRs will display a significant difference between the two values of velocity dispersion: extra care will then need to be taken to subtract a proper background.

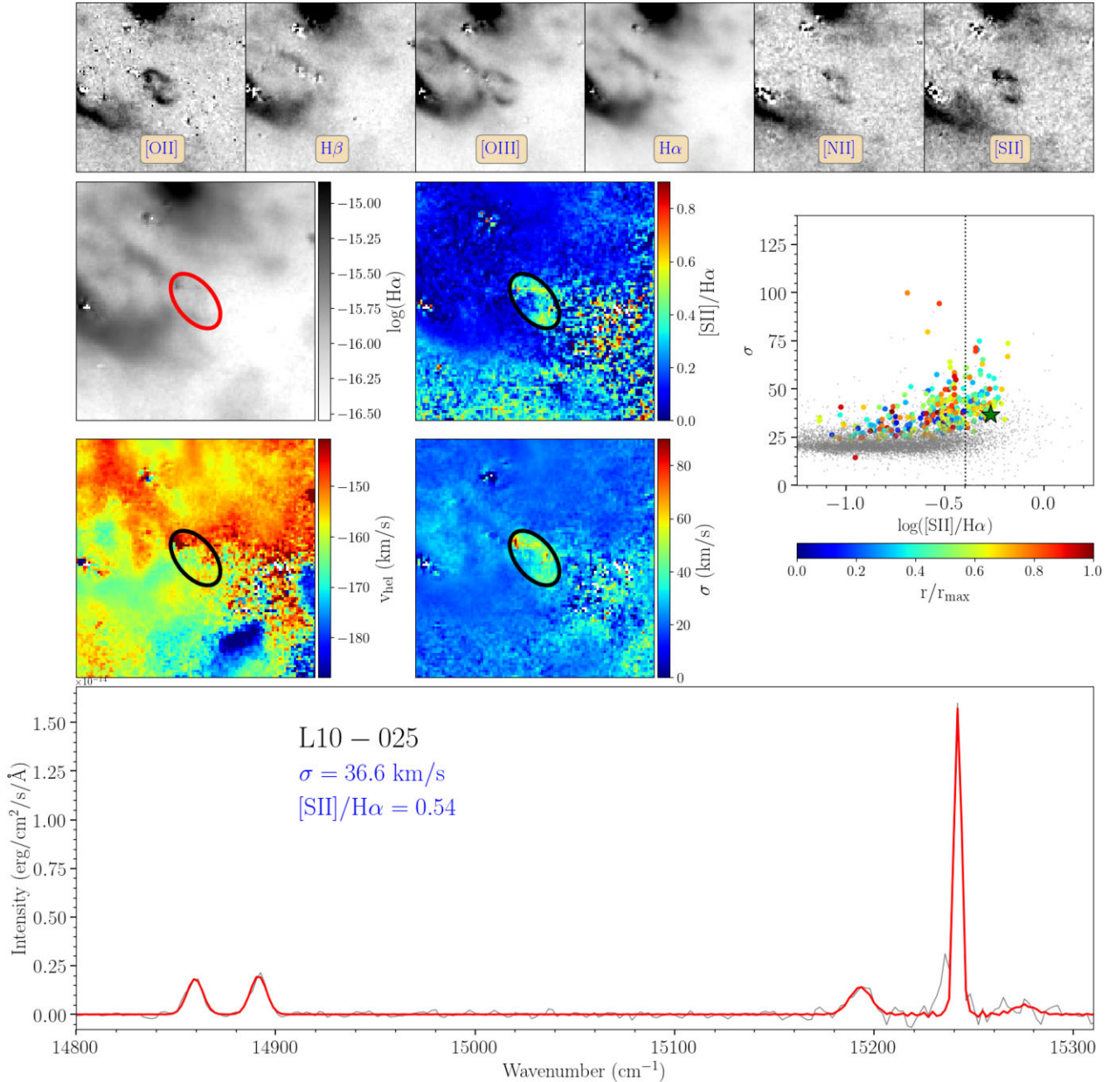


Figure 31. Same as Fig. 23 for L10-025.

4.3 Velocity structure: SNRs with multiple components

While a large velocity dispersion is a clear indication of an expansion in SNRs, a combination of a proper morphology, significant expansion velocity, and appropriate spectral resolution can allow us to distinguish the two layers (the farthest and the closest) of these objects. A few SNRs in our fields could be studied this way, and we present here the best examples, namely L10-008 (Fig. 32) and L10-105 (Fig. 33), for which the approaching and receding velocity components can be clearly separated, both spectroscopically and spatially. The figures present the integrated $H\alpha$ map, the integrated spectrum (dominated by the outer ring), a spectrum of a selected inner region where the two distinct components are seen, as well as a series of images corresponding to the complete range of velocities

seen in the data cube. The emission-line profile of the integrated spectrum in the central part of the SNR can be resolved and shows two velocity components (separated by 94 km s^{-1} for L10-008 and 125 km s^{-1} for L10-105). Both the approaching and the receding caps of the expanding shell are clearly visible.

4.4 Global properties of SNRs and the threshold for detection

Table 5 presents the values of some properties of SNRs in M33 from this work. Only 15 objects in our sample of 163 (9 per cent) have an integrated $[S II]/H\alpha$ ratio inferior to the canonical value of 0.4 (six objects have a ratio between 0.37 and 0.4). Such a high ‘success rate’ is expected given that this ratio was originally used to select the

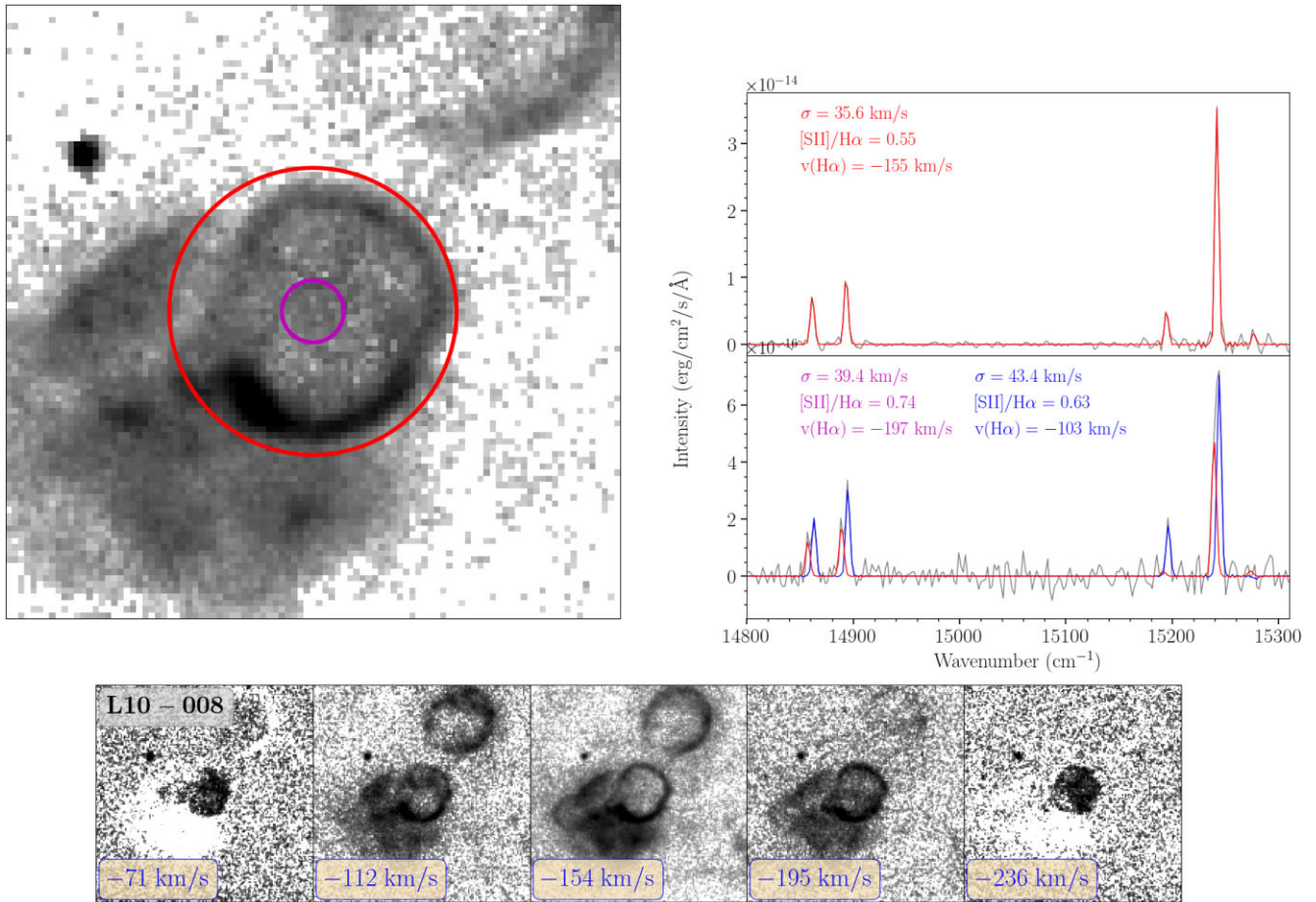


Figure 32. Spatial and velocity structure of L10-008. The upper left panel (35 arcsec on a side) shows the integrated $\text{H}\alpha$ flux map with ellipses corresponding to regions chosen to represent the integrated spectrum (red) and a selected region of the interior (magenta). The corresponding spectra and their fits are shown on the upper right panel. The lower panel (50'' on a side) shows the individual frames within the data cube, centred on $\text{H}\alpha$, where the transition in radial velocity between the two outermost layers of the central part of the SNRs can be seen.

SNRs (although not on an integrated value basis). But the situation is not as unequivocal when the integrated velocity dispersion of the objects is considered, nor the product of these two parameters, ξ . We also note significant differences between the L10 and L14 samples (we consider here in the L14 samples only the new SNRs which were not previously detected by L10).

What would be the ideal discriminant between SNRs and H II regions (or superbubbles driven by stellar winds) if both the velocity dispersion and the $[\text{S II}]/\text{H}\alpha$ ratio are available? In NGC 6822, we saw (Fig. 13) that $\xi = 12$ clearly separates the individual pixels in Ho12 from those of the largest H II regions; this is also true for their integrated properties (Table 3). But the sample is very small in this galaxy, and the H II regions studied here can be considered as giant, harbouring a large number of massive stars. The M33 data provide a better framework for this purpose. We have thus measured the integrated values of σ and ξ for dozens of H II regions and ring nebulae in our fields (Drissen et al., in preparation): excluding the central parts of giant H II regions NGC 588, NGC 592, NGC 595, and NGC 604 and all SNRs, σ varies between 8 and 20 km s⁻¹ and ξ between 1.5 and 9. The value of $\xi = 12$ based on the NGC 6822 data alone thus seems a bit too conservative and could be slightly reduced. Before examining the impact of varying the threshold value for ξ , we must emphasize important differences between the L10 and L14 samples.

While the number of SNRs in the L10 sample with no measurable integrated velocity dispersion in our data ($\sigma = 0$) is low (8 or 7 per cent), this fraction rises to 33 per cent in the L14 sample. The average value of velocity dispersion in the L10 sample ($\bar{\sigma}_{L10} = 34$ km s⁻¹) is in fact twice as large as that of the new candidates from the L14 sample ($\bar{\sigma}_{L14} = 17$ km s⁻¹), although this criterion was never considered in either study. We find no correlation between the values of the $[\text{S II}]/\text{H}\alpha$ ratio (nor the velocity dispersion) and the origin of the SN (core collapse or Type Ia) as determined by Lee & Lee (2014) based on the distance between the SNR and groups of OB stars.

Table 6 presents the impact of the choice of ξ on the fraction of SNRs in the L10 and L14 samples that do not meet the threshold value. Again, the dichotomy between the two samples is clear, with a large fraction of L14 candidates being excluded, even with a low threshold value. But the vast majority of these objects nevertheless have a $[\text{S II}]/\text{H}\alpha$ ratio larger than 0.4. They could be older SNRs.

Finally, in Fig. 34 three diagnostic plots are shown: $[\text{N II}]/\text{H}\alpha$ versus $[\text{O III}]/\text{H}\beta$ (BPT03N2), $[\text{S II}]/\text{H}\alpha$ versus $[\text{O III}]/\text{H}\beta$ (BPT03S2), and σ versus $[\text{S II}]/\text{H}\alpha$. In each of them, the SNR candidates have been colour-coded by their ξ value; red stars for candidates with $\xi \geq 12$ and blue stars for those with $\xi < 12$. As in Fig. 14, in the case of the BPT03N2 and BPT03S2 diagrams there is a substantial population of candidates with low values of σ , which might be considered as older SNRs, for which the expansion has been considerably slowed

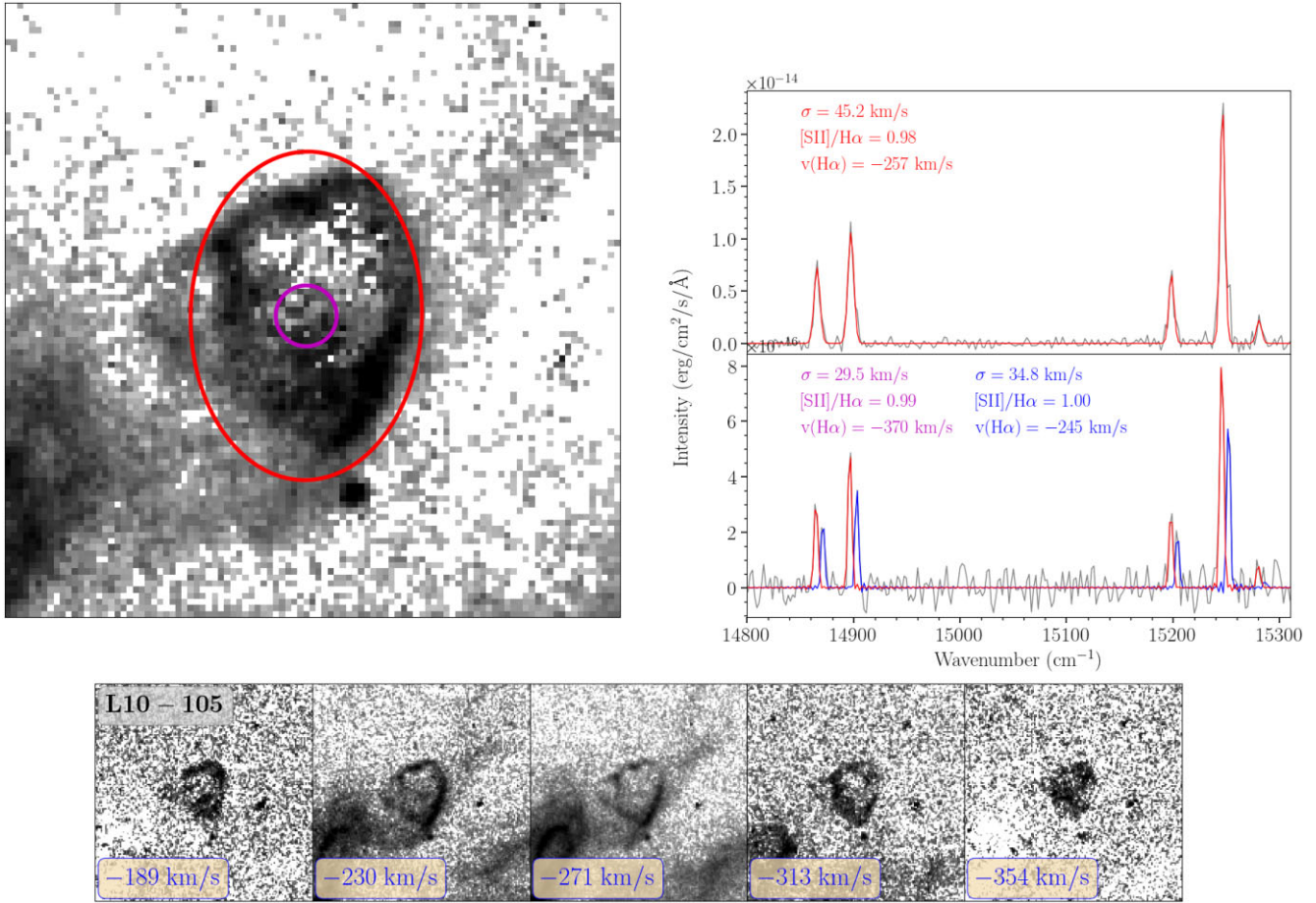


Figure 33. Same as Fig. 32, for L10-105.

Table 6. Impact of the threshold ξ : fraction of SNRs in the L10 and L14 samples which do not pass the given threshold.

Sample	$\xi \leq 12$	$\xi \leq 10$	$\xi \leq 8$	$\xi \leq 6$
L10 (118 SNRs)	18 per cent	14 per cent	10 per cent	8 per cent
L14 (45 SNRs)	67 per cent	62 per cent	47 per cent	40 per cent

down. When considering the $[\text{S II}]/\text{H}\alpha$ versus σ diagram it can be seen that the candidates with $\xi < 12$ populate the lower zone of this diagram and those with higher values than 12 populate the upper part, as expected from Fig. 12 for Ho 12 and all H II regions in NGC6822.

5 CONCLUSIONS

Based on spectral data cubes obtained with SITELLE, we presented a detailed study of the optical properties of a large sample (164) of known SNRs in NGC 6822 and M33, with a particular emphasis on the measurement of their integrated properties including their velocity dispersion, σ . Our main conclusions are the following:

(i) Ho 12 in NGC 6822 presents an intriguing spiral shape composed of multiple knots mixed with a more diffuse structure. Although its global morphology is similar at all wavelengths, we find noticeable differences in the line ratios, radial velocities, and velocity dispersion from one knot to the next. We also note clear radial trends in the properties of Ho 12, as well as in those of the

compact and shell-shaped SNRs in M33, which differentiate them from those of the H II regions.

(ii) We introduce a diagram, σ versus $[\text{S II}]/\text{H}\alpha$, that can be used on a pixel-by-pixel basis for individual objects or to assess the integrated properties of a population of emission-line regions in a given galaxy. The shape of the pixel-to-pixel diagrams depends on the morphological type of the SNRs.

(iii) M33 SNRs showing A, A2, or A3 morphological types present higher values of σ in the central parts, decreasing as we move towards the outer parts. In the case of type B and C SNRs this dependence is less evident. Also, the scatter of $[\text{S II}]/\text{H}\alpha$ at a constant σ value is lower in the types A2 and A3 than in the rest of the morphological types defined by Long et al. (2010).

(iv) Given that (a) the $[\text{S II}]/\text{H}\alpha$ ratio and the velocity dispersion are generally spatially anticorrelated in H II regions; (b) the DIG shows high values of $[\text{S II}]/\text{H}\alpha$ but low values of velocity dispersion; and (c) SNRs are expected to show higher values of both $[\text{S II}]/\text{H}\alpha$ and velocity dispersion than H II regions, we defined a parameter that combines both properties, $\xi = ([\text{S II}]/\text{H}\alpha) \times \sigma$. This parameter can be determined on a pixel-by-pixel basis in order to facilitate the detection of SNRs using maps extracted from data cubes, or as a parameter obtained from the integrated spectrum of emission-line regions.

(v) While a threshold of $\xi = 12$ clearly separates the sole SNR in NGC 6822 from the large H II regions in the same galaxy, the situation is not as clear-cut in M33, which presents a wide variety of SNR morphologies and ISM structure. While neither the L10 SNR sample

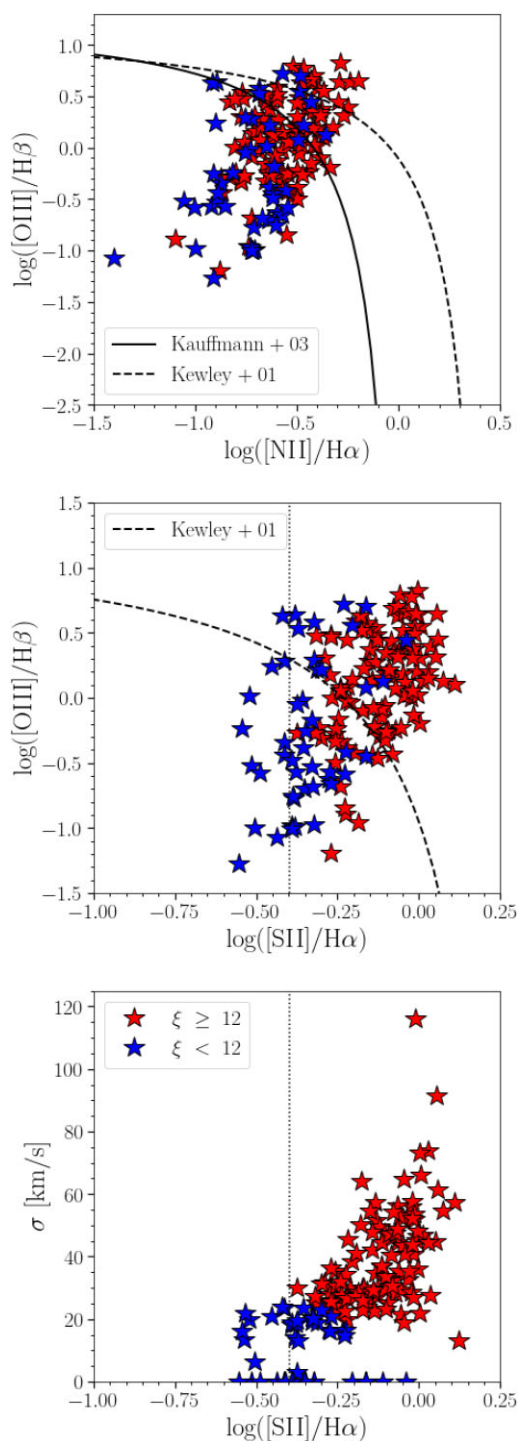


Figure 34. Diagnostic diagrams (upper and centre panel) and scheme of identification (lower panel) for the sample of SNR candidates in M33. The red and blue stars correspond to those candidates that do and do not satisfy the condition $\xi \geq 12$. The dashed, continuous, and vertical dotted lines show the Kewley et al. (2001) curve, the Kauffmann et al. (2003) demarcation, and the limit value of $[\text{S II}]/\text{H}\alpha = 0.4$, respectively.

nor the new SNRs found by L14 were assembled using a measure of the velocity dispersion, we note a significant discrepancy between them: 82 per cent of the L10 SNRs satisfy the $\xi = 12$ threshold (and 90 per cent with $\xi = 8$), but only a third of the additional L14 SNRs satisfy the first threshold and half the second. These might be older objects for which the expansion has been significantly slowed down.

(vi) As expected, the detection rate of a significant velocity dispersion ($\sigma > 0$) in known M33 SNRs is higher (92 per cent, or 60/65) in our SN3 data cubes with the canonical SIGNALS spectral resolution $R = 5000$ (Fields 5 to 9) than it is (82 per cent, or 70/98) in the data cubes obtained during the proof of concept program (Fields 1 to 4, with $R = 2200\text{--}2900$).

(vii) We will use the results presented in this paper to study the SNR population in more distant galaxies of the SIGNALS survey, such as NGC 4214 (Vicens-Mouret et al. 2023).

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DATA AVAILABILITY

SIGNALS data are part of the public domain already. The measurements underlying this article can be shared upon request to the first author.

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SUPPORTING INFORMATION

Supplementary data are available at *MNRAS* online.

Appendix A. Properties of Supernova Remnants in M33.

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