

Analysis and diagnostics of extragalactic shock-excited regions using MUSE’s IFU spectroscopic observations.

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Abstract: This work presents an analysis of shock-excited regions in the galaxies PGC128348 and Cartwheel based on MUSE’s IFU spectroscopic data. Applying 2D emission-line diagnostics, 27 shock-excited regions are identified in PGC128348 (12 classified as supernova remnants) and 43 in Cartwheel (all bubbles/superbubbles). Spectral analysis was used to derive gas velocity dispersions and electron densities, while shock velocities are estimated via MAPPINGS V shock models. Results show lower velocity dispersion and higher shock velocities in the outer galactic regions, reflecting the influence of local ISM density on shock evolution.

Keywords: SNRs, Shock-excited, Diagnostic tool, Shock models, PGC128348, Cartwheel

SDGs: Quality Education and Industry, Innovation and Infrastructure.

I. INTRODUCTION

Ionized material in the interstellar medium (ISM) originates from two principal mechanisms: photoionization (caused by energetic fluxes arriving from other stars, mainly soft UV) and shock excitation (due to high-velocity shock waves, $v > 100$ km/s, expanding violently through the medium). The regions of interest for this analysis are the latter, an example of which are supernova remnants. Supernova remnants (SNRs) result from the core-collapse of massive stars (SN types II, Ib, Ic) or thermonuclear explosions of white dwarfs in a binary system exceeding the Chandrasekhar limit ($\sim 1.4 M_{\odot}$, type Ia SN). Observations and research on their properties and behaviour are essential to better understand their role and feedback to their host galaxy. SNRs have strong effects on the surrounding ISM which, at the same time, affects the evolution of the SNR. Considering a uniform medium, SNRs undergo the following stages: free-expansion phase, ejecting a great quantity of mass and driving a fast shock, due to its velocity being far greater than the sound speed. After some time, there are two materials in contact: accumulated ISM material and ejected material. This causes a discontinuity in the density and a reverse shock is created. When the accumulated material increases to be comparable to the ejected material, the reversed shock is created and the SNR enters the Sedov-Taylor phase. After that, the remnant cools down and, at a certain time, the pressure right behind the shock drops abruptly, entering the snowplow phase, characterised by the SNR showing a dense shell of cool gas enclosing a hot central volume, still forcing the SNR to expand. Gradually, the shock front decelerates, reaching a value comparable to the sound speed in the surrounding gas, during the fadeaway phase [1].

Shock-excited gas is mechanically energized by the passage of a shock front. However, not all shock-excited regions are SNRs, but many are identified as bubbles or superbubbles. SNRs have a size limit (typically

< 100 pc in radius), larger objects are considered bubbles/superbubbles [2]. These are created by strong stellar winds of massive stars (O and B type), forming low-density ISM cavities filled with hot, shock-excited gas.

This work explores two galaxies: PGC128348 and Cartwheel (Table I), using their spectroscopic data from the Multi Unit Spectroscopic Explorer (MUSE) integral field unit (IFU). MUSE provides 3D data cubes, with two spatial dimensions and a third dimension containing the spectrum of each pixel. PGC128348 has a face-on orientation, minimizing the effects of internal dust reddening compared to edge-on systems. It is host to a type Ia supernova, ASASSN-14jg [3]. Cartwheel is a lenticular ring galaxy and it is currently undergoing a merger with its companion G3, and it is also host of a type IIb supernova (2021afdx) [4].

Traditionally, the approach for detecting SNRs was a 1D criterion, based on $[SII]/H\alpha > 0.4$ for shock-excited regions. In [5], a more robust method is presented, combining two emission line flux ratios. These diagnostics yield positive values to shock-excited sources and negative values to photoionized gas. In this work, I will apply these modern 2D diagnostics to IFU data cubes.

The objectives of this research are: (1) identifying shock-excited regions within the target galaxies using 2D diagnostics, (2) analysing the spectral data of the identified sources, (3) using theoretical models to estimate other properties, and (4) investigating potential tendencies and correlations between these characteristics, interpreting the physics behind these results.

II. METHODOLOGY

A. Initial corrections

The cubes were firstly corrected for cosmological redshift (z). Then, I obtained 2D emission maps of each galaxy for the following emission lines: $H\alpha$,

$H\beta$, $[N II] \lambda 6548$, $[N II] \lambda 6583$, $[O I] \lambda 6300$, $[O III] \lambda 4959$, $[O III] \lambda 5007$ and $[S II] \lambda \lambda 6717, 6731$, including maps of the flux error for each line. This was done fitting Gaussian curves to the spectral lines using MPFIT package to determine the integrated line flux for each pixel. Third, I applied a signal to noise $(S/N) > 5$ cut. Even so, another phenomenon directly affects the cubes' spectra: the reddening due to interstellar dust, which absorbs or scatters blue light more than it does red light, making the galaxy appear redder. To correct spectra for dust extinction, the Balmer decrement was used, assuming case-B recombination with an intrinsic ratio of $(H\alpha/H\beta)_0 = 2.86$, appropriate for $T = 10^4$ K and $n_e \approx 100 \text{ cm}^{-3}$ [6]. Using the observed ratios, which were higher due to dust presence, and calculating the deviation from the theoretical values, the spectra were corrected for this reddening.

B. Photometry

Source candidate detection was performed using **Source Extractor** [12], on a composite flux map, summing the $[S II]$, $[O III]$, and $H\alpha$ emission lines. It was necessary to modify the parameters for each galaxy, in order to obtain all the sources while avoiding random background enhancements. The program returns a *.reg* file with x and y coordinates and r , the radius of the aperture (in pixels). Following that, aperture photometry was performed using the Python module **photutils.aperture**, calculating, for each emission line map, the flux and flux error inside the apertures enclosing the sources. The luminosity (L) of each source was computed for each emission line: $L_{line} = 4\pi d^2 \cdot F_{line}$. The luminosity distance d is computed with the package **astropy.cosmology**, using a Hubble constant of $H_0 = 67.66 \text{ km s}^{-1} \text{ Mpc}^{-1}$ [7] and the redshift of each galaxy.

C. Diagnostics

Six 2D diagnostics functions explored in [5] were applied, based on the following logarithmic flux ratios: $[S II] \lambda \lambda 6717, 31 / H\alpha$, $[N II] \lambda 6583 / H\alpha$, $[O I] \lambda 6300 / H\alpha$ and $[O III] \lambda 5007 / H\beta$.

The purpose was to calculate the flux ratios for all the candidate sources and compute the diagnostic functions, dependent on these ratios. If the function for a given source gave a positive value, the source passed the diagnostic, suggesting a shock-excited region. However, there is some overlap in the diagnostics (some shock-excited regions may be detected as a photoionized region by the diagnostic functions and vice versa). To ensure the validity of the study, we restricted the sample to sources which passed, at least, three diagnostics.

Given the relatively large distance of the galaxies, a key distinction needs to be made among the shock-excited regions identified: are they SNRs or bubbles?

This division was made segregating them by size. Sources with a radius greater than 100 pc were considered bubbles, while the rest would classify as SNRs. To limit their diameter, I fitted a 2D Gaussian in the spatial plane. Then, I calculated the Full Width at Half Maximum (FWHM) and, after various tests, set the limit at $0.75 \times \text{FWHM}$, being the most representative size, which would be the diameter of each source. In this way, a more rigorous method is carried out to shape the sources and calculate their sizes (Figure 12 in the Appendix).

D. Spectra analysis

For the identified shock-excited regions (Figure 1), the Python script I developed reads their pixel coordinates in the original cube (corrected from redshift) and, for a given radius, extracts their spectra. Then, it selects the six windows of wavelengths of interest, for each emission line of study. After that, it fits a Gaussian line profile along each emission line peak using the *scipy.optimize* package. I included data points near the peak and averaged their values, in order to correctly fit the continuum (Figure 11 in the Appendix). From this process, the standard deviation σ is found, which determines the gas velocity dispersion, the statistical spread of velocities of the gas particles around the mean kinematic velocity. This seems to differentiate shock-excited from photoionized regions, as [8] suggests. Moreover, using the $[S II] \lambda 6717 / [S II] \lambda 6731$ ratio, I estimated the electron density for each source, n_e , using the Python package **PyNeb** [13]. To do so, one needs to provide both the sulphur ratio and the temperature of the source, which is unknown. Thus, n_e values are computed assuming four different temperatures: $5 \cdot 10^3$ K, 10^4 K, $3 \cdot 10^4$ K and $5 \cdot 10^4$ K, which are typical values in optically emitting shocks. It is worth mentioning that the package has strict limitations on the range of sulphur ratios it can use to calculate densities, accepting ratios in a range of: $\approx [0.5, 1.4]$ (see Figure 16 in the Appendix).

E. Shock models

I used the previous results, obtained from observational data, and shock models, based on theory, in order to estimate their shock velocities, u_s . The shock models used are based on the MAPPINGS V library, presented in [9]. These consider radiative shocks ($u_s = 10 - 1500 \text{ km/s}$). For fast shocks, a strong radiation field of extreme ultraviolet (EUV) and soft X-ray photons is generated. Thus, aside from the mechanical impulse from the shock wave, this one heats up the surrounding gas so much that it starts emitting energetic radiation. The shock models distinguish two main components: the shock itself and its photoionized precursor, which can be easily differentiated from a photoionized region such as an H II region

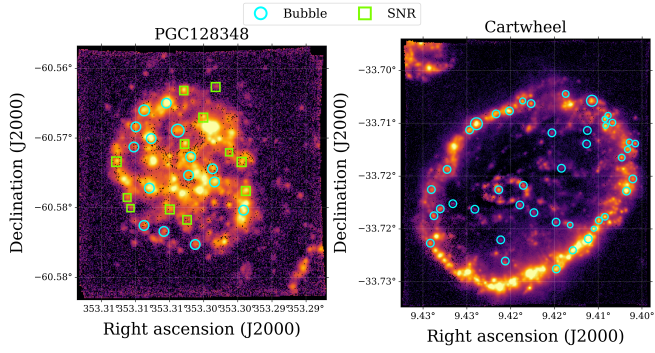


FIG. 1: Spatial map of PGC128348 (left) and Cartwheel (right) in $H\alpha$ with the apertures of the selected sources by the diagnostic filter, classified as SNRs or bubbles.

because of the variations in line ratios. MAPPINGS V also considers more cooling mechanisms than in previous versions. All in all, the model provides a grid linking four line ratios: $[O III]/H\beta$, $[S II]/H\alpha$, $[O I]/H\alpha$ and $[N II]/H\alpha$ to a value of u_s . I used these models to interpolate the u_s of our sources, providing the ratios obtained from the observational data as an input to calculate said velocity.

III. RESULTS AND DISCUSSION

A. Diagnostics

Figure 1 shows that 27 shock-excited regions are found in PGC128348, and 43 in Cartwheel, based on sources that satisfy three or more diagnostics. A significant number of bright sources fail to meet this criterion, suggesting that they are most likely photoionized sources, such as $H II$ regions.

Based on the physical size (< 100 pc) of the detected sources: for PGC128348, 12 out of 27 sources categorise as SNRs, while the other 15 are too big and are considered bubbles/superbubbles. For Cartwheel, no source classifies as SNR, which was expected given the further distance. Exploring flux relations of the detected sources, we find that $[S II]$, $[N II]$ and $[O I]$ scale almost equally with $H\alpha$, consistent with emission from the same cooling shocked gas, whereas the faster scaling of $[O III]$ suggests that the entire shock structure varies coherently among the sources, but the latter is more present in outer regions of the object, in the shock front (Figure 2).

For each galaxy, the luminosity histograms for $H\alpha$ are shown in Figure 3. Cartwheel exhibits a clear trend toward higher $H\alpha$ luminosities compared to PGC128348, which also occurs for the other emission lines (Figures 13, 14 and 15 in the Appendix). This is an indicator for major activity in Cartwheel, consistent with its higher star formation rate [10] [11]. It could also be due to the merger that this galaxy is undergoing, provoking a higher activity due to shock. A selection bias for fainter sources is also likely, given that Cartwheel is at a further

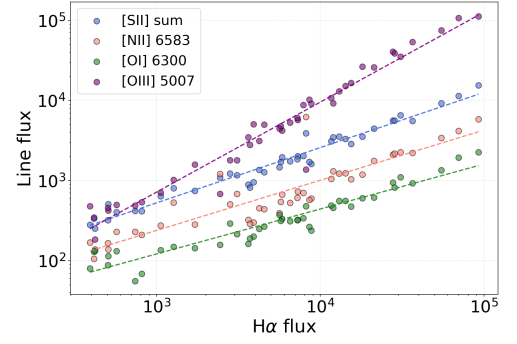


FIG. 2: Flux comparison with $H\alpha$ for Cartwheel.

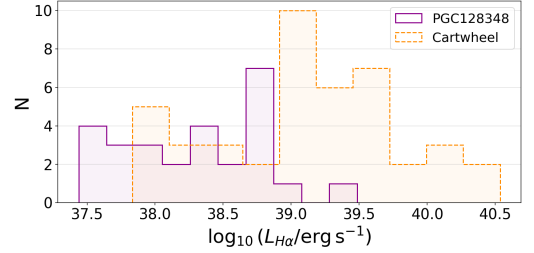


FIG. 3: $H\alpha$ luminosity distribution for both galaxies.

distance, which means we are able to detect only more luminous sources compared to a closer PGC128348.

Diagnostic line ratios show an overall decreasing tendency with $H\alpha$ luminosity for both galaxies (Figures 4 and 5). Having seen from Figure 2 that the considered fluxes increase with $H\alpha$, the ratios' behaviour indicates that these metal-line fluxes grow slower than $H\alpha$. Moreover, while most correlations are statistically significant (low p-values, which tells the probability of obtaining the observed results if the null hypothesis is true), the positive trend for $[O III]/H\beta$ and the $[N II]/H\alpha$ correlation in Cartwheel are statistically weak, with higher p-values.

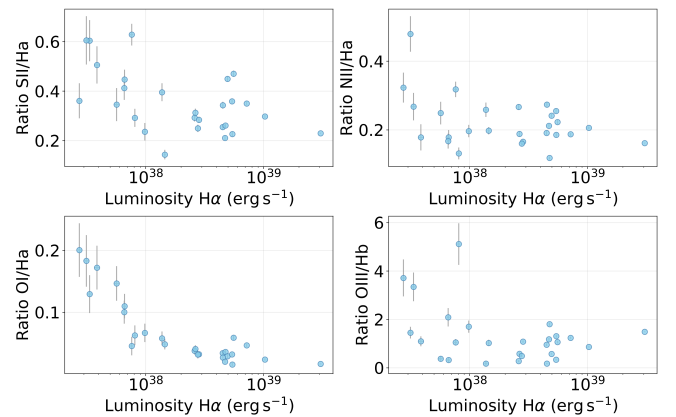


FIG. 4: Ratios ($[S II]/H\alpha$, $[N II]/H\alpha$, $[O I]/H\alpha$ and $[O III]/H\beta$) versus luminosity for $H\alpha$ of PGC128348.

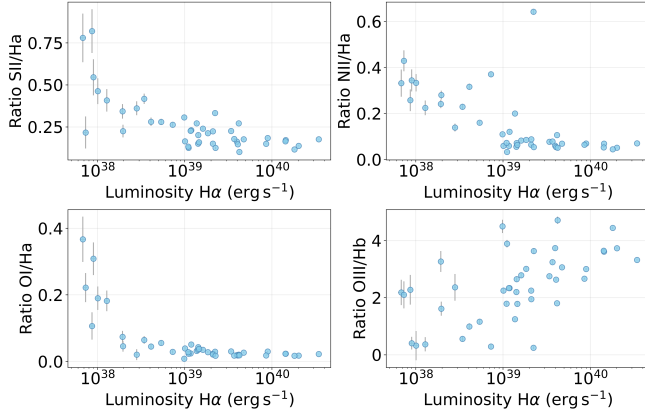


FIG. 5: Ratios $[\text{S II}]/\text{H}\alpha$, $[\text{N II}]/\text{H}\alpha$, $[\text{O I}]/\text{H}\alpha$ and $[\text{O III}]/\text{H}\beta$ versus luminosity for $\text{H}\alpha$ of Cartwheel.

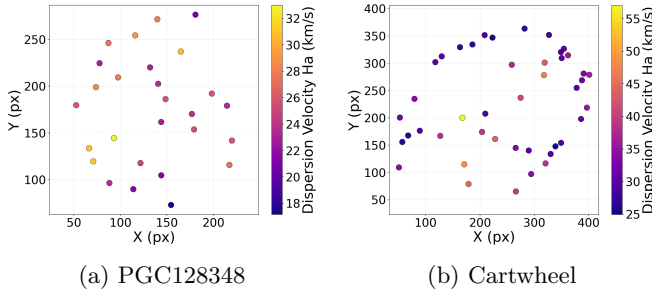


FIG. 6: Spatial map with colorbar indicating the $\text{H}\alpha$ velocity dispersion (in km/s) of each source.

B. Spectra analysis

1. Velocity dispersion

From Figure 6, we observe that velocity dispersion is lower at the exterior of the galaxies, especially noticeable in the case of Cartwheel (Figure 6b), which likely tracks the ISM density distribution. In the centre of the galaxy, with higher ISM densities, sources would have a higher interaction with it. This may contribute to higher turbulence, which would consequently lead to a broader velocity distribution.

Additionally, Figures 7 and 8 show a trend between velocity dispersion across different lines, despite the high error bars. For Cartwheel, all tendencies are positive, meaning a higher velocity dispersion for any line implies a higher velocity dispersion for the rest. For PGC128348, $[\text{O III}]$ and $[\text{O I}]$ exhibit negative slopes, but their p-values are too high to consider a significant correlation. The linear regressions show that $\text{H}\alpha$, $[\text{N II}]$, $[\text{S II}]$ and $[\text{O I}]$ have an almost identical growth, while $[\text{O III}]$ increases faster, suggesting again that the first three are emitted from the same region and the latter from the outer shock front.

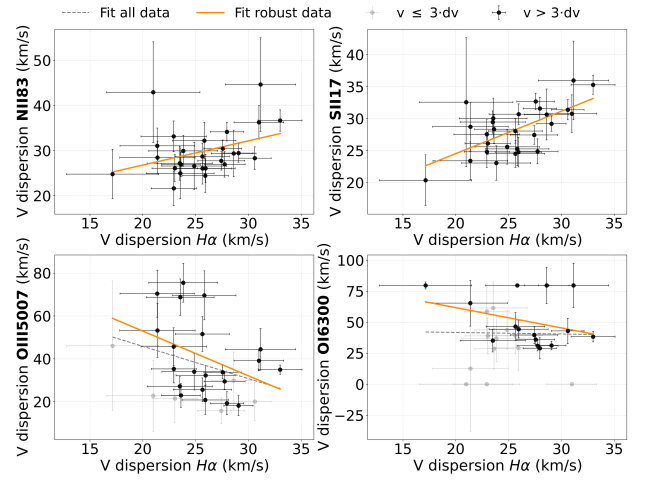


FIG. 7: For PGC128348, velocity dispersion comparison of emission lines in respect to $\text{H}\alpha$.

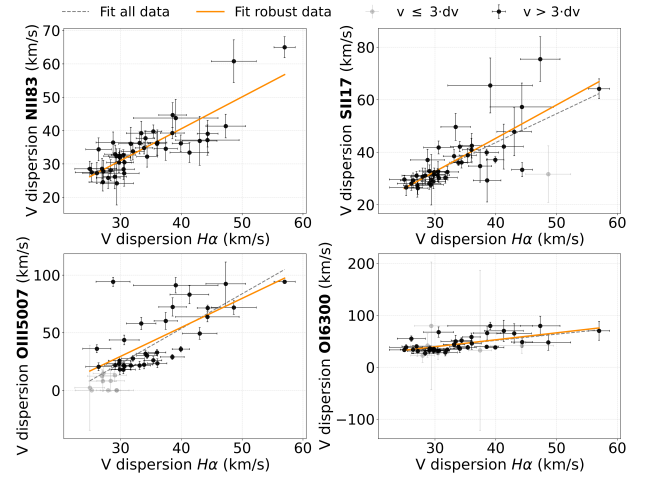


FIG. 8: For Cartwheel, velocity dispersion comparison of emission lines in respect to $\text{H}\alpha$.

2. Densities

With the $[\text{S II}]/[\text{S II}]$ ratio and assuming $T = 10^4$ K (typical in optical-emitting SNRs), electron densities were computed and are shown in Figure 19 in the Appendix. The values for PGC128348 are in the range of: $[8.94, 4062.94] \text{ cm}^{-3}$. For Cartwheel: $[3.56, 739.88] \text{ cm}^{-3}$. Not all sources have a computed density, as some exhibit $[\text{S II}]$ ratios outside the limits of the model. Among the reported densities, we do not observe a strong radial trend in the spatial maps, even though the lowest values are in the outer regions of the galaxy. No significant correlation between flux ratios and electron densities was found.

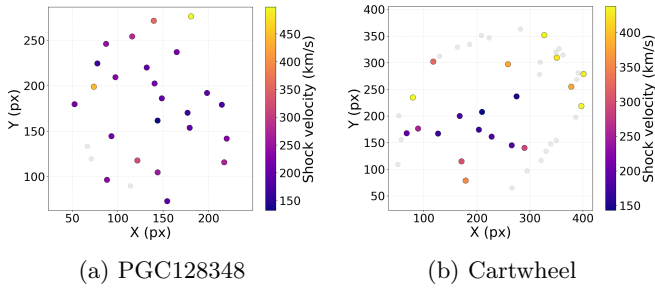


FIG. 9: Spatial map showing the computable sources' shock velocity in a colorbar. In grey, the sources that fell outside the model's limitations.

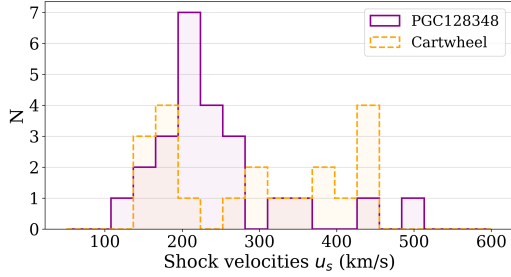


FIG. 10: Shock velocity distribution for PGC128348 and Cartwheel.

C. Shock models

The shock velocity for each region was estimated via the interpolation method based on the theoretical models (Figure 9). Note that certain sources fell outside the valid range of the model, meaning their respective shock velocities could not be computed.

For Figure 10, while PGC128348 presents a unimodal distribution, centered near 210 km/s, Cartwheel presents a broader spread. Shock velocity values around 200 km/s are expected, but Cartwheel presents higher values too. Because u_s is averaged over the whole source, these higher values may arise from regions still in earlier, faster evolutionary phases prior to strong ISM deceleration. Higher values of u_s fall at the outer parts of the galaxy (especially for Cartwheel, see Figure 9b), also attributed to lower densities of the ISM, which interacts less with the shock-excited regions than in the centre. The ones closer to the centre suffer from more ISM pressure,

which would slow the shock down and result in lower shock velocity values. No systematic trend was observed between shock velocity and dispersion velocity.

IV. CONCLUSIONS

Using 2D emission line diagnostics, PGC128348 has been found to have 27 shock-excited regions, 12 of which are classified as SNRs. Cartwheel presents 43 shock-excited regions, all bubbles/superbubbles.

Metal emission line fluxes grow with $H\alpha$ flux, indicating a common emission region. However, $[O III]$ scales more rapidly, indicating emission from an outer zone (shock front). Cartwheel shows, on average, more luminous sources than PGC128348, because of its higher star formation rate. For both galaxies, metal-line ratios decrease with $H\alpha$ luminosity.

Velocity dispersion is lower in outer regions of the galaxy, consistent with less turbulence and weaker interaction with ISM, which is less dense than in the centre. Moreover, velocity dispersion of most metal lines correlate similarly with that of $H\alpha$, indicating that $H\alpha$, $[S II]$, $[N II]$ and $[O I]$ are emitted from the same region. However, $[O III]$ scales faster, again suggesting it is emitted from the outer shock front. Electron densities showed no significant radial trend.

Theoretical shock models indicate higher shock velocities at the outer parts of the galaxy, where lower ISM densities exert less pressure to decelerate the expansion.

Overall, the analysis of the MUSE IFU data of the luminous sources within two galaxies proved effective for isolating and characterizing shock-excited populations and studying their properties, and eventually comparing results for the two galaxies PGC128348 and Cartwheel.

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Anàlisi i diagnòstic de regions extragalàctiques excitades per xoc usant les observacions espectroscòpiques de l'IFU de MUSE.

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Resum: Aquest treball presenta una anàlisi de regions excitades per xoc en les galàxies PGC128348 i Cartwheel, basat en les dades espectroscòpiques del MUSE IFU. Aplicant diagnòstics 2D de línies d'emissió, s'identifiquen 27 regions excitades per xoc en PGC128348 (12 que classifiquen com SNRs) i 43 en Cartwheel (totes bombolles/superbombolles). S'usa anàlisi espectral per derivar la dispersió de la velocitat del gas i les densitats electròniques, mentre que les velocitats de xoc s'estimen via els models de MAPPINGS V. Els resultats mostren dispersió de velocitats menor i velocitats de xoc majors en les regions exteriors de les galàxies, reflectint la influència de la densitat local del medi interestel·lar en l'evolució del xoc.

Paraules clau: SNRs, Excitació per xoc, Eina de diagnòstic, Models de xoc, PGC128348, Cartwheel.

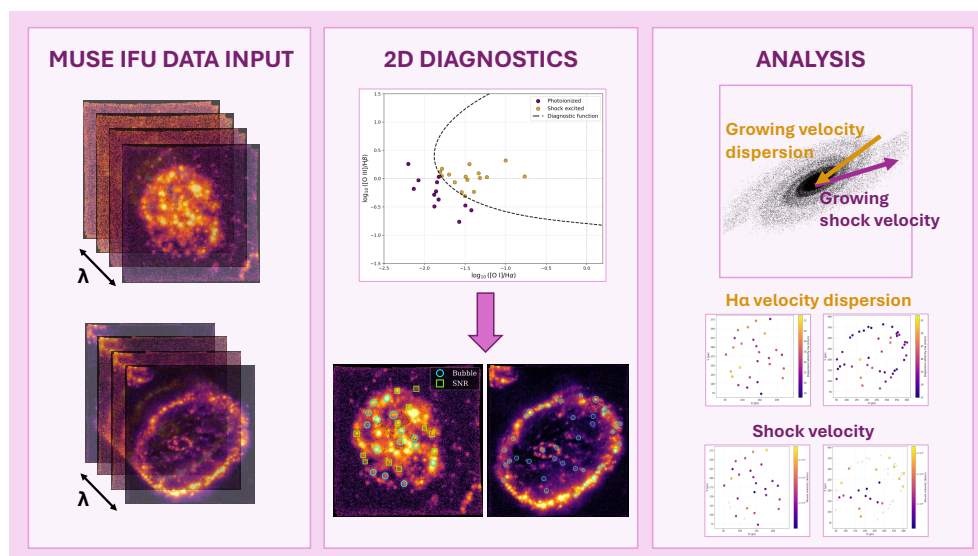
ODSs: Educació de qualitat i Indústria, innovació i infraestructura.

Objectius de Desenvolupament Sostenible (ODSs o SDGs)

1. Fi de les desigualtats	10. Reducció de les desigualtats
2. Fam zero	11. Ciutats i comunitats sostenibles
3. Salut i benestar	12. Consum i producció responsables
4. Educació de qualitat	X 13. Acció climàtica
5. Igualtat de gènere	14. Vida submarina
6. Aigua neta i sanejament	15. Vida terrestre
7. Energia neta i sostenible	16. Pau, justícia i institucions sòlides
8. Treball digne i creixement econòmic	17. Aliança pels objectius
9. Indústria, innovació, infraestructures	X

El contingut d'aquest TFG, part d'un grau universitari de Física, es relaciona amb l'ODS 4, concretament amb la fita 4.4, ja que contribueix a l'educació a nivell universitari, que es pot considerar tècnica i professional, per a accedir a l'ocupació, el treball digne i l'emprenedoria. També es pot relacionar amb l'ODS 9, en particular la fita 9.5, que promou augmentar la investigació científica i el nombre de persones que treballen en el camp de la investigació per cada milió d'habitants.

GRAPHICAL ABSTRACT



Appendix A: SUPPLEMENTARY MATERIAL

1. Tables and figures

TABLE I: Redshift, right ascension and declination of the centre for each galaxy.

	z	α ($^{\circ}$)	δ ($^{\circ}$)
PGC128348	0.014734	353.3037	-60.5730
Cartwheel	0.030337	9.4183	-33.7166

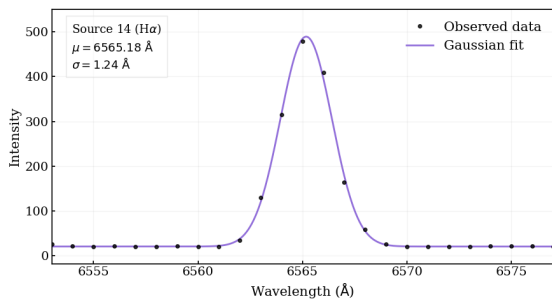
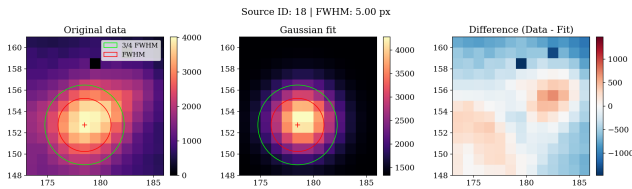
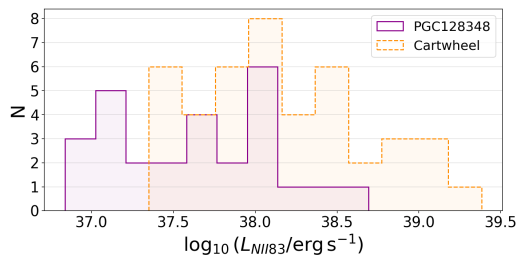
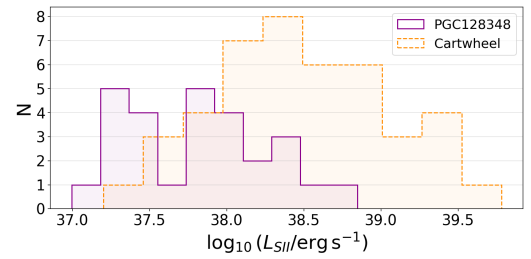
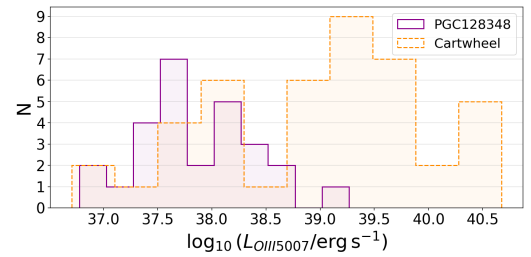
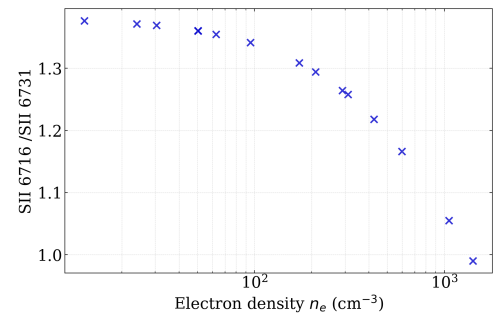
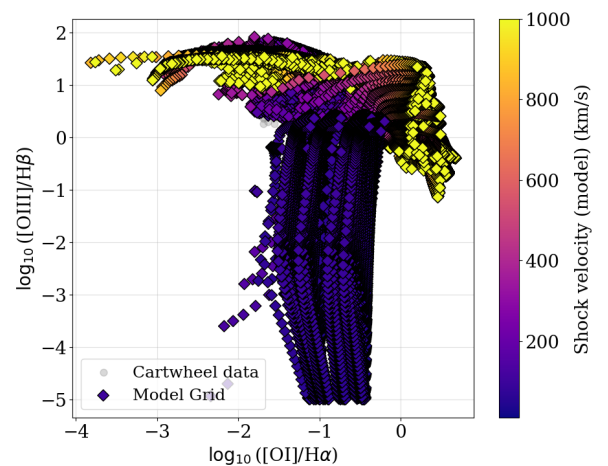

 FIG. 11: For source 14 in PGC128348: in black, observed data around the $H\alpha$ peak. In purple, Gaussian fit of the $H\alpha$ peak.


FIG. 12: For source 18 in PGC128348, from left to right: observed data, 2D Gaussian fit and difference between these two maps. Red circles: computed FWHM, green circles: 3/4 of the FWHM.


 FIG. 13: $[N II]\lambda 6583$ luminosity distribution.

 FIG. 14: $[S II]\lambda\lambda 6717,31$ luminosity distribution.

 FIG. 15: $[O III]\lambda 5007$ luminosity distribution.

 FIG. 16: Ratio of the SII17/SII31 line intensities for sources of Cartwheel on the computed n_e .

 FIG. 17: Superposition of shock models (colorbar) and Cartwheel data (grey). $OIII/H\beta$ versus $OI/H\alpha$.

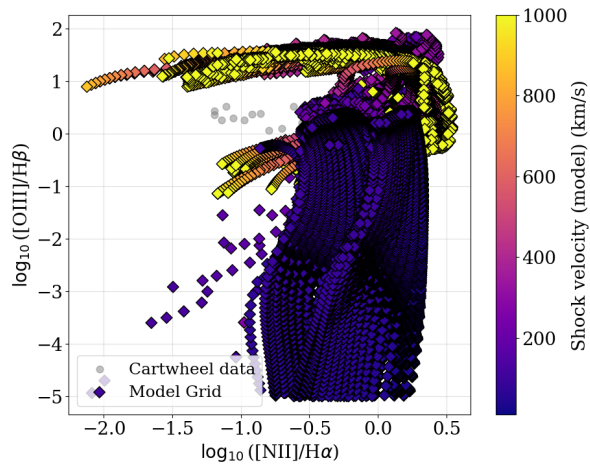


FIG. 18: Superposition of shock models (colorbar) and Cartwheel data (grey). $\text{OIII}/\text{H}\beta$ versus $[\text{NII}]/\text{H}\alpha$.

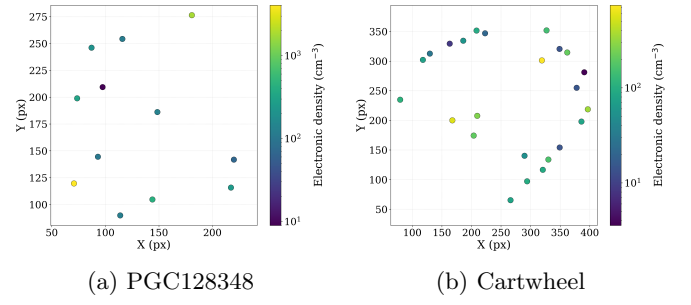


FIG. 19: Spatial map with colorbar showing the computable sources' electron density. Assumed temperature: $T = 10^4$ K.

TABLE II: Shock-excited regions of PGC128348: ID, x and y pixel coordinates, aperture radius (in pixels), right ascension and declination (in degrees) and the value of the function of each diagnostic if passed (only positive values, dimensionless).

ID	x	y	r	RA	DEC	SII-NII	NII-OIII	SII-OIII	OI-OIII	NII-OI	SII-OI
0	93.096788	144.47464	5.0	353.307958	-60.573559	1.384424		1.798056	2.123990	1.976049	1.546841
1	154.4993	72.9408	5.0	353.301015	-60.577534	1.318019				2.251034	1.914646
2	180.7683	276.373	5.0	353.298045	-60.566232	0.981950	0.577984	3.652472			
3	131.934	220.02307	7.288959	353.303566	-60.569362	0.243834			1.263310	1.350979	1.385498
4	139.7274	271.4854	5.782793	353.302685	-60.566503	0.310367		1.296164	1.944641	1.225221	1.457921
5	70.7397	119.6148	5.0	353.310487	-60.574940	1.801621	0.455646	4.635244			
6	143.9618	104.6646	5.0	353.302207	-60.575771	1.879620	0.331135	3.036320			
7	176.92813	170.21605	5.0	353.298479	-60.572129	0.569683				1.538549	1.462860
8	198.3678	192.0292	5.0	353.296055	-60.570917	0.844057				2.188535	2.041098
9	143.9031	161.6527	5.0	353.302213	-60.572605	1.086302				1.952433	1.693599
10	66.3397	133.5796	5.0	353.310984	-60.574164	0.526172	0.349595	3.779922			
11	52.463	179.6562	5.0	353.312552	-60.571604	0.444882		0.461096	1.341659	1.222544	1.250145
12	214.69114	179.07507	5.0	353.294209	-60.571637	0.633993			0.755904	1.600952	1.513682
13	220.01023	141.78781	5.0	353.293607	-60.573709	1.301895		0.399571	0.180930	1.144088	0.565457
14	87.141333	246.07319	7.404927	353.308630	-60.567915	0.848468		1.337275	2.018359	1.754803	1.587118
15	148.597	186.1155	5.0	353.301682	-60.571246	0.851816				1.023042	0.760761
16	217.27773	115.74376	5.672822	353.293916	-60.575155	0.009059		0.190793	0.108865		
17	115.9202	254.2439	5.0	353.305377	-60.567461	0.020148		0.519550	0.345209		
18	179.2638	153.7161	5.0	353.298215	-60.573046	0.915317				1.308246	1.035254
19	164.9848	236.9894	5.0	353.299829	-60.568420	0.186716			0.024385	1.176694	1.294999
20	121.6147	117.7413	5.0	353.304734	-60.575045	0.100220	0.036099	0.879621			
21	88.1624	96.4343	5.0	353.308517	-60.576228	1.864056	0.023448	2.488727			
22	113.9031	89.8349	5.0	353.305606	-60.576595	1.176793	0.059278	2.828950	3.118411	2.237153	1.948334
23	97.486047	209.36307	5.0	353.307461	-60.569954	0.546281		0.113509	0.507219	0.749543	0.641074
24	73.6886	198.923	5.0	353.310152	-60.570534			2.042513	2.884096		1.844700
25	77.5805	224.5149	5.0	353.309712	-60.569113				1.852311	1.797514	1.742506
26	140.5875	202.4828	5.0	353.302588	-60.570337				0.568217	0.402202	0.499635

TABLE III: Shock-excited regions of Cartwheel: ID, x and y pixel coordinates, aperture radius (in pixels), right ascension and declination (in degrees) and the value of the function of each diagnostic if passed (only positive values, dimensionless).

ID	x	y	r	RA	DEC	SII-NII	NII-OIII	SII-OIII	OI-OIII	NII-OI	SII-OI
0	178.9256	78.7788	5.0	9.420533	-33.722990	0.952619	0.036030	2.732916			
1	289.77905	140.19516	3.628498	9.413129	-33.719578	0.414602		0.555465	2.152248	1.893406	1.879038
2	67.7493	167.6567	5.0	9.427959	-33.718052	0.369869		0.627537	1.455154	1.254479	1.243082
3	377.96147	254.96543	4.353715	9.407240	-33.713201	0.045599		1.004833	1.231680	0.075272	0.796876
5	208.59211	351.56893	3.879342	9.418552	-33.707835	0.681737	0.221006	3.636733			
6	396.8458	218.6565	5.0	9.405978	-33.715218	0.030623		1.474536	2.528726	1.730350	1.869883
7	387.7928	268.85085	3.925325	9.406583	-33.712429	0.232271		1.964793	2.014754	0.930153	1.445211
8	117.8487	302.1028	5.0	9.424612	-33.710583	0.420960		1.404585	0.930475		0.381899
9	338.8974	147.8444	4.461634	9.409848	-33.719152	0.117638		1.766252	1.786391	0.584816	1.264061
10	319.1441	301.2115	5.0	9.411169	-33.710632	2.196269	0.357789	4.367330	3.483966	1.772219	1.443554
11	258.5936	297.2271	5.0	9.415212	-33.710854	0.824178	0.403080	3.257306			
12	317.9018	278.2766	5.0	9.411251	-33.711906	2.309884	0.272321	4.546889			
13	274.843	236.8167	5.0	9.414127	-33.714210	1.387501				2.042529	1.876922
14	203.772	174.2916	5.0	9.418873	-33.717684	0.559877		0.233005	1.710273	1.691847	1.685551
15	209.7733	207.6284	5.0	9.418473	-33.715832	0.532940				1.029393	1.098152
16	167.6829	200.0204	5.0	9.421284	-33.716254	1.238137				0.471933	0.966299
17	89.2216	176.4125	5.0	9.426524	-33.717566	1.129314				2.177058	1.941353
18	227.8415	161.2288	5.0	9.417266	-33.718409	0.131447	0.157127	0.624706			
19	265.7356	145.0137	5.0	9.414735	-33.719310	1.170189		0.121741	1.237817	2.033128	1.733582
20	171.0709	114.8777	5.0	9.421058	-33.720984	1.649922				1.843240	1.666178
21	390.84997	281.16818	4.066330	9.406379	-33.711745	0.284465		1.430410	1.340834		0.846323
22	126.8807	166.9955	5.0	9.424009	-33.718089		0.445165		3.443283	1.895078	
24	52.5601	200.566	5.0	9.428973	-33.716224			0.370553	2.169593	0.997688	1.614302
25	266.1069	65.2162	5.0	9.414710	-33.723743			1.354668	1.747093	0.453735	1.264836
26	56.985876	155.86366	5.0	9.428678	-33.718707			0.034317	1.991823	0.694803	1.456769
27	327.01527	351.86861	7.131282	9.410643	-33.707818			0.442493	0.718429		0.242288
28	223.0274	347.002	5.0	9.417588	-33.708089			1.793684	1.645081	0.486722	1.153302
29	79.403	234.8278	5.0	9.427180	-33.714320			0.084790	1.021835		0.575889
30	282.08358	363.45003	4.351727	9.413644	-33.707175			0.747047	1.221897		0.749036
31	349.00364	320.58052	3.642778	9.409174	-33.709556			1.460896	0.754820		0.370321
32	362.02218	314.58631	4.274817	9.408305	-33.709889			1.360828	2.324816	1.259056	1.726477
33	186.10989	334.43449	5.0	9.420053	-33.708787			1.551857	1.220704		0.818935
34	163.234	329.4632	5.0	9.421581	-33.709063			1.276822	1.547868	0.171965	1.088571
35	386.08414	197.93163	5.0	9.406697	-33.716369			0.928703	0.609110		0.187049
36	320.7107	116.502	5.0	9.411063	-33.720894			1.449295	1.210458		0.809875
37	294.1533	97.1017	4.623232	9.412836	-33.721972			0.785274	0.430414		0.019305
38	349.25947	154.1608	4.271748	9.409156	-33.718801			0.366981	0.759569		0.282142
39	129.6071	312.6706	7.732523	9.423827	-33.709996			1.451608	1.177958		0.752977
40	330.1101	133.7962	3.241416	9.410435	-33.719933			0.484022	0.607262		0.119270
41	350.47357	309.49119	3.546420	9.409076	-33.710172			1.435849	0.655226		0.208836
42	354.51121	326.61078	4.064325	9.408807	-33.709221			0.575037	0.527731		0.052310
43	401.10872	278.89029	4.190047	9.405694	-33.711872				1.533243	0.348247	1.094400
44	50.783	109.2472	5.0	9.429092	-33.721297				2.010095	0.942234	1.560063