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GALACTIC AND EXTRAGALACTIC SCIENCE WITH SITELLE

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Abstract. We present in this paper some recent results obtained with SITELLE, an imaging Fourier transform spectrometer (iFTS) attached to the Canada-France-Hawaii telescope, in link with which the latest improvements in terms of data analysis.

Keywords: SITELLE, Imaging Fourier Transform Spectrometry, M31, M57, planetary nebulae, diffuse ionized gas, nova shell, AT Cnc, ORCS

1 Introduction

SITELLE is an imaging Fourier transform spectrometer (iFTS) designed to obtain the spectrum, in selected bands of the visible range, of each source of light present in the 4 million pixels covering an 11'×11' field of view. It is attached to the Canada-France-Hawaii 3.6-m telescoope. Its spectral resolution R can be chosen between 1 and 10000. We will show some of the observing capabilities of SITELLE, which are closely related to the last improvements in terms of data analysis, through some of the science studies based on its data.

2 M31's Central Region, Planetary Nebulae and Diffuse Ionized Gas

The first study of the centre of M31 in the SN3 filter (649-484 nm: Hα, [NII]6548,6584, [SII]6716,6731) was dedicated to the calibration of the data and the creation of a catalogue of nearly 800 Hα emission line point-like sources (Martin et al. 2017). The best available catalogues of planetary nebulae are based on the observation of the much brighter [OIII] lines obtained with an instrument dedicated to the observation and the detection (PN.S, Merrett et al. 2006) and a multi-fibre spectrograph (Halliday et al. 2006). In table 1, we compare the catalogue obtained with SITELLE with these catalogues. We can see that, in their study based on SITELLE data, Martin et al. (2016) have been able to detect twice more emission-line point-like sources. Note that, even if these sources are believed to be mostly planetary nebulae, another study involving the observation of the [OIII] lines is needed to confirm this assessment. The attained precision in terms of velocity and astrometry is about twice better and the flux calibration precision is about the same. Note also that the detection of emission lines over the very strong background of M31 is, in a certain way, a worst-case scenario for SITELLE since the multiplex disadvantage Martin et al. (2017); Drissen et al. (2014); Maillard et al. (2013) generates a noise about $\sqrt{400}$ times higher than a dispersive technique.

The quality of the velocity calibration has been obtained with the development of a simple model of the interferometer. This model allows the wavelength calibration of the entire field of view based only on a few calibrated points (e.g. background spectra with OH sky lines, emission-line sources with known velocity). Up to now, the robustness of this model has shown to be very good (see figure 1). The astrometric calibration has also been enhanced. It now relies on a 3-step calibration process which uses the optical distortion field computed from a calibration image of a field crowded with stars to fit a WCS solution on a data cube containing only some stars (Martin et al. 2017).

The diffuse ionized gas component can also be studied with great precision. We show in Figure 2 a preliminary version of one of the two velocity components that can be seen in the Hα emission of the diffuse gas in the centre of M31.

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Table 1. Comparison of the precision of the catalogued emission line point like sources obtained with SITELLE (Martin et al. 2017) and the precision of the planetary nebulae catalogues of Merrett et al. (2006) (Me06) and Halliday et al. (2006) (Ha06). Note that, in the case of the data obtained with SITELLE it is still unclear how much planetary nebulae have really been detected since the [OIII] emission line study has not yet been published. The absolute and relative errors have been quadratically summed.

	SITELLE	Ha06	Me06
Velocity ($\mathrm{km\,s^{-1}}$)	2.21	5	17.72 – 19.72
Astrometry (arcsec)	0.21	1.1	0.37
Flux (mag)	0.08	—	0.07
Number of cataloged PN	>700	154	330
Completness	—	96 %	92 %

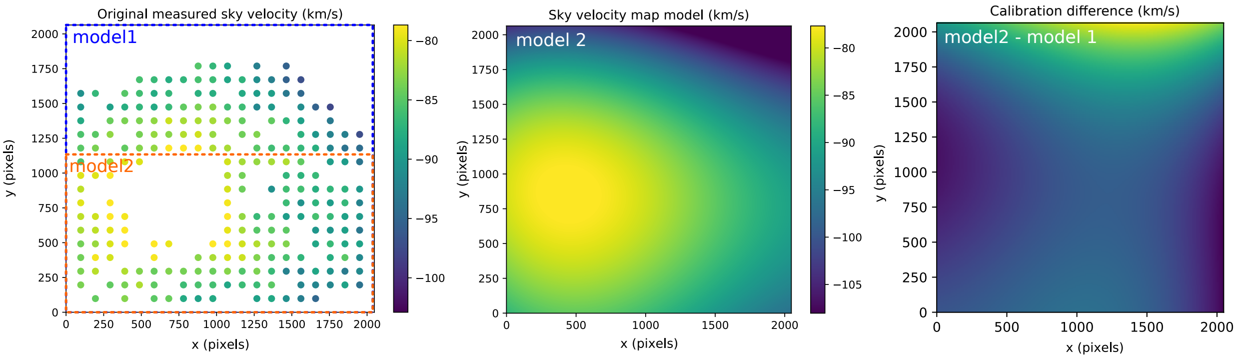

Fig. 1. Comparison of the velocity calibration models obtained considering the measured velocity of the sky lines in the whole field of view (model 1) and in a subregion (model 2). *Left:* Velocity measured at some points in the field of view. All the velocity points are considered to fit the model 1 and only the orange subregion is considered when fitting the model 2. The precision on the measurement is smaller than 2 km/s. *Center:* velocity calibration model 2. *Right:* Velocity difference between model 1 and model 2. We can see that, in most of the field, and particularly the upper part where model 2 is unconstrained, the difference between both model is smaller than 4 km/s.

3 Reconstruction of the ionized shells of the Planetary Nebulae M57

In the case of an ionized gas shell, the two lines emitted by the blue shifted and red shifted parts of the shell can be modelled, at low resolution, as one broadened Gaussian line. Its broadening is directly related to the velocity difference between both components. The observed emission-line shape is always the convolution of the real line shape and the instrumental line shape (ILS). The precise knowledge of the ILS gives the possibility to deconvolve its effect and measure very small broadening. This deconvolution is based on model fitting. The model of the observed emission-line shape, i.e. the convolution of a Gaussian emission line and a cardinal sinus ILS is a well-known result but we were lacking a numerically robust formulation. (Martin et al. 2016) have developed such a formulation and implemented a model in the data processing module ORCS(Martin et al. 2015). This model has been used to measure the broadening of the [NII]6548,6584 and Hα emission lines and partially recover, at a resolution of 2700, the data obtained with an echelle spectrograph at a resolution of 47 000 (O'Dell et al. 2013). Note that this level of precision can only be achieved at high SNR. For example, the minimum measurable broadening at a resolution of 2700 is around 15 km/s if the SNR is around 300.

4 Very Faint Emission of a Galactic Nova Shell in ATCnc

Detecting one emission line on a low background mostly eliminates the multiplex disadvantage, i.e. the SNR of the emission line is essentially the same as the SNR which would have been obtained with a dispersive technique in the same observing condition (same integration time). In this case the advantage of a large field of view (120 times larger than MUSE) clearly dominates.

A classical nova outburst produces a very thin shell of ionized gas which is still visible, though very dim, even after a few hundred years after the explosion. Shara et al. (2016) have observed the classical nova shell

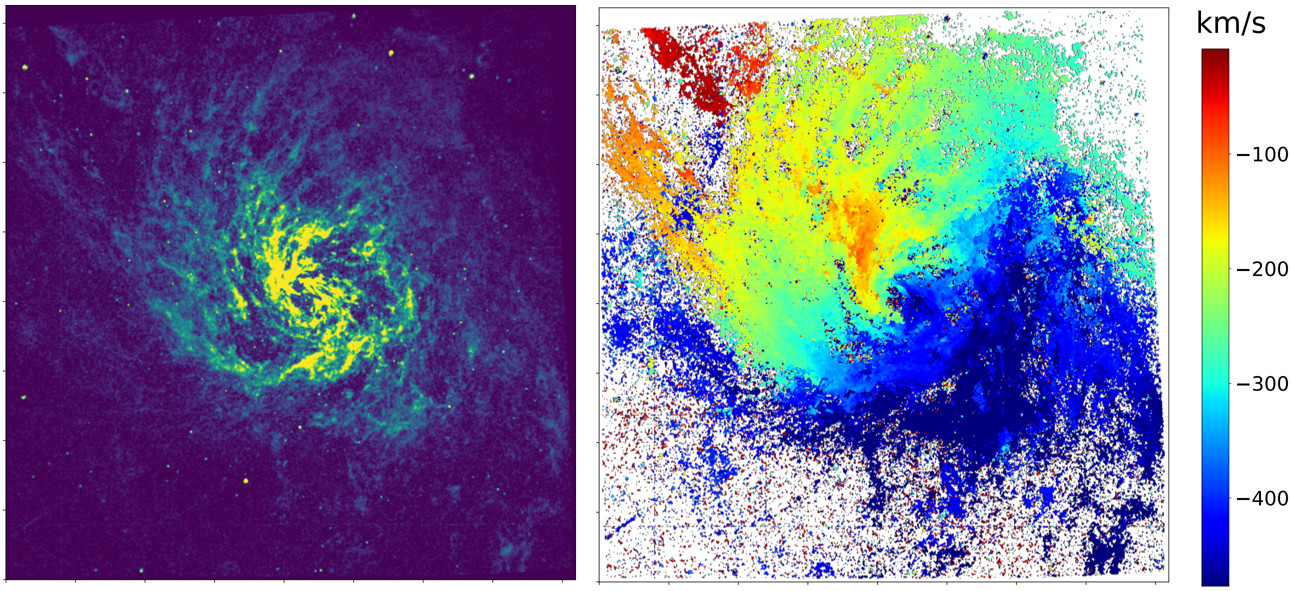

Fig. 2. Emission (left, arbitrary unit) and velocity (right) of the first velocity component of the diffuse ionized gas in the centre of M31.

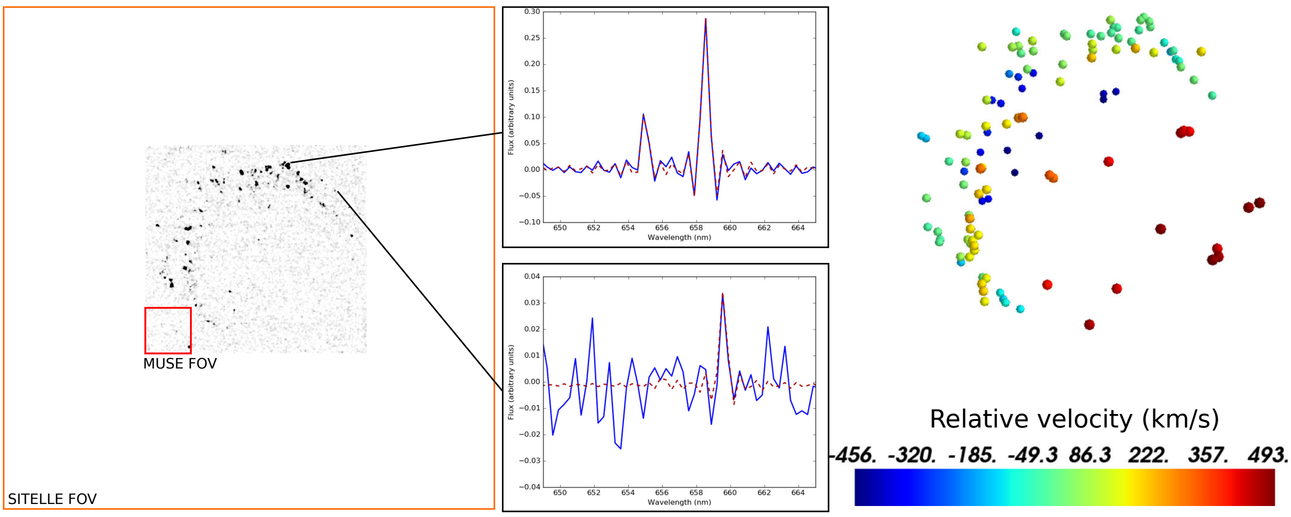

Fig. 3. *Left:* Emission of the faint nova shell observed with SITELLE. The whole SITELLE field of view and the MUSE field of view are shown. Two spectra obtained on a dim node and a bright node are also shown. *Right:* Measured velocity of the nodes.

surrounding the AT Cnc dwarf nova. This shell is essentially observable through its densest and most luminous nodes (also referred as blobs, see Figure 3). The smallest of them being point-like sources. 115 blobs were observed with a minimum flux, leading to a precise enough velocity measurement, of $6\,10^{-17}$ erg/s/cm^2. Note that the real detection limit is smaller than this flux, but a simple detection was not sufficient here (and could be better achieved through narrowband imaging). The total integration time of the cube was 3.9 hours.

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References

Drissen, L., Rousseau-Nepton, L., Lavoie, S., et al. 2014, Advances in Astronomy, 2014, 1

Halliday, C., Carter, D., Bridges, T. J., et al. 2006, Monthly Notices of the Royal Astronomical Society, 369, 97

Maillard, J. P., Drissen, L., Grandmont, F., & Thibault, S. 2013, Experimental Astronomy, 35, 527

Martin, T., Drissen, L., & Joncas, G. 2015, Astronomical Data Analysis Software an Systems XXIV (ADASS XXIV), 495

Martin, T. B., Drissen, L., & Melchior, A.-L. 2017, Monthly Notices of the Royal Astronomical Society

Martin, T. B., Prunet, S., & Drissen, L. 2016, Monthly Notices of the Royal Astronomical Society, 463, 4223

Merrett, H. R., Merrifield, M. R., Douglas, N. G., et al. 2006, Monthly Notices of the Royal Astronomical Society, Volume 369, Issue 1, pp. 120-142., 369, 120

O'Dell, C. R., Ferland, G. J., Henney, W. J., & Peimbert, M. 2013, The Astronomical Journal, 145, 92

Shara, M. M., Drissen, L., Martin, T., Alarie, A., & Stephenson, F. R. 2016, Monthly Notices of the Royal Astronomical Society, 465, 739