Multispectral analysis of Cygnus Loop and IC 443 with iFTS

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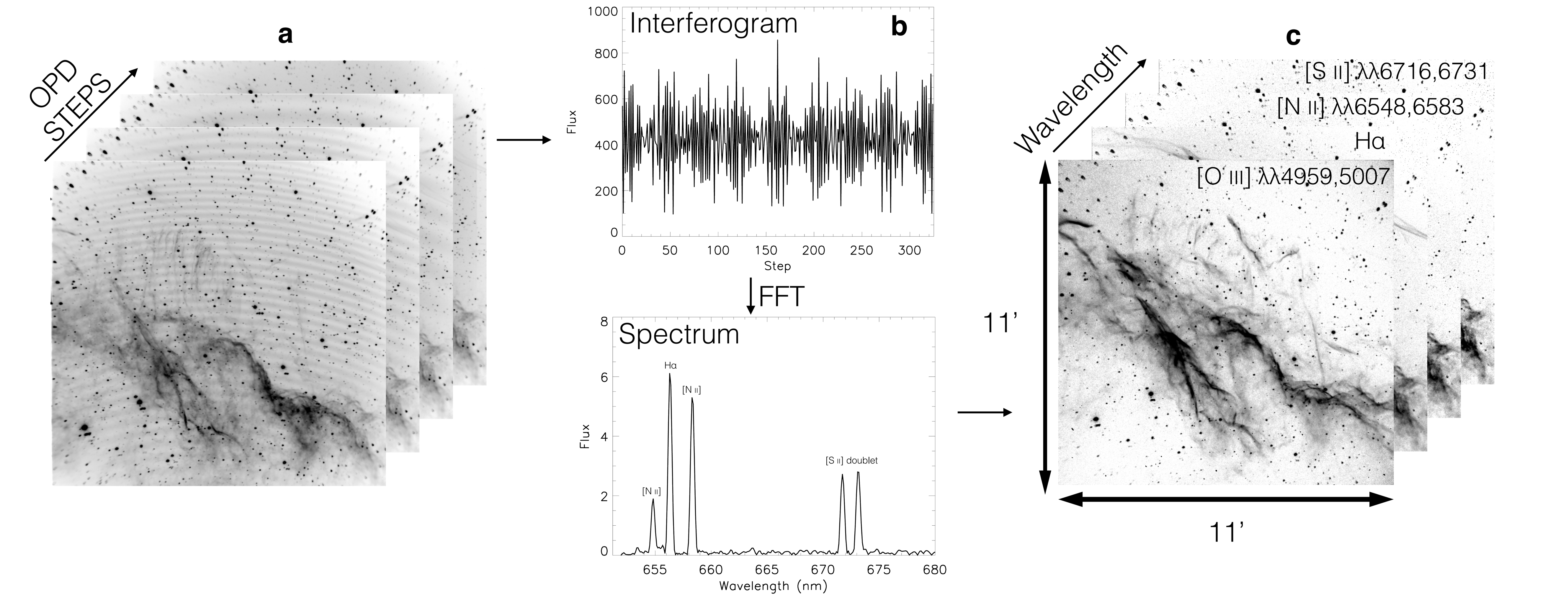
We have obtained spatially resolved spectra for two different Galactic supernova remnants: Cygnus Loop and IC 443. We observed these two objects using three filters in the spectral range 365-385 nm, 475-515 nm and 648-682 nm, encompassing the [O II] λλ3727+3729, Hβ, [O III] λλ4959,5007, Hα, [N II] λλ6548,6583, and [S II] λλ6716,6731 emission lines, with the imaging Fourier transform spectrometers SpIOMM (Mont Mégantic Observatory in Québec) and SITELLE recently installed at CFHT. Comparing the observations with shock models, we derived several shock parameters such as the shock velocity, the pre-chock density as well as the abundances of oxygen, nitrogen and sulfur over an appreciable fraction of the surface of both remnant

Observing supernova remnants with iFTS : SpIOMM and SITELLE

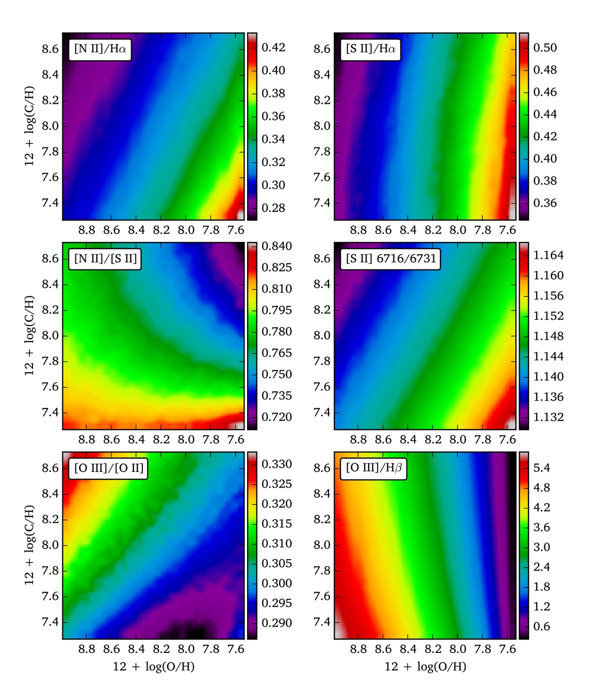


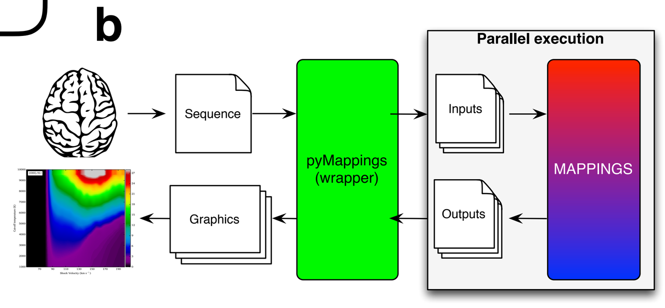
a) By scanning the optical path difference (OPD) of the interferometer and taking images at every step, one get a data cube. **b)** For a given pixel, the recorded intensity varies as a function of the OPD with a pattern that depends on the spectral content of the nebula. **c)** After Fourier transforming every interferogram (4 millions), one gets a spectral data cube (RA, DEC, λ) from which monochromatic images corresponding to the emission line of interest can be extracted. The data shown here come from a cube of one region of NGC 6992 located in the Cygnus Loop.

Spatial sampling : 1.1"/pixel for SpIOMM, 0.32"/pixel for SITELLE.

Spectral resolution : R~1500 @ Hα

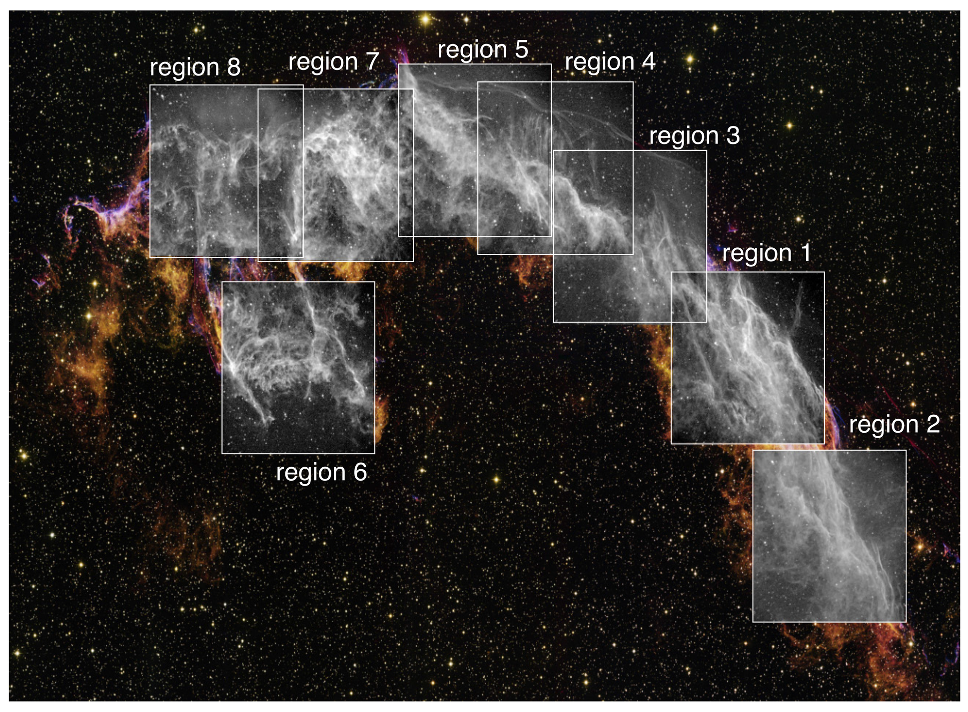
Shock models grids





(a) We are using the modelling code MAPPINGS to compute shock models. We developed a wrapper program called pyMAPPINGS in order to generate large shock grids including millions of models to be compared with observations. **b)** Each grid are stored into HDF5 file format allowing it to be read and use with ease. A grid can be visualized in 3D in order to explore the effects of the shock parameters on selected emission lines and line ratios.

Mapping SNRs with iFTS



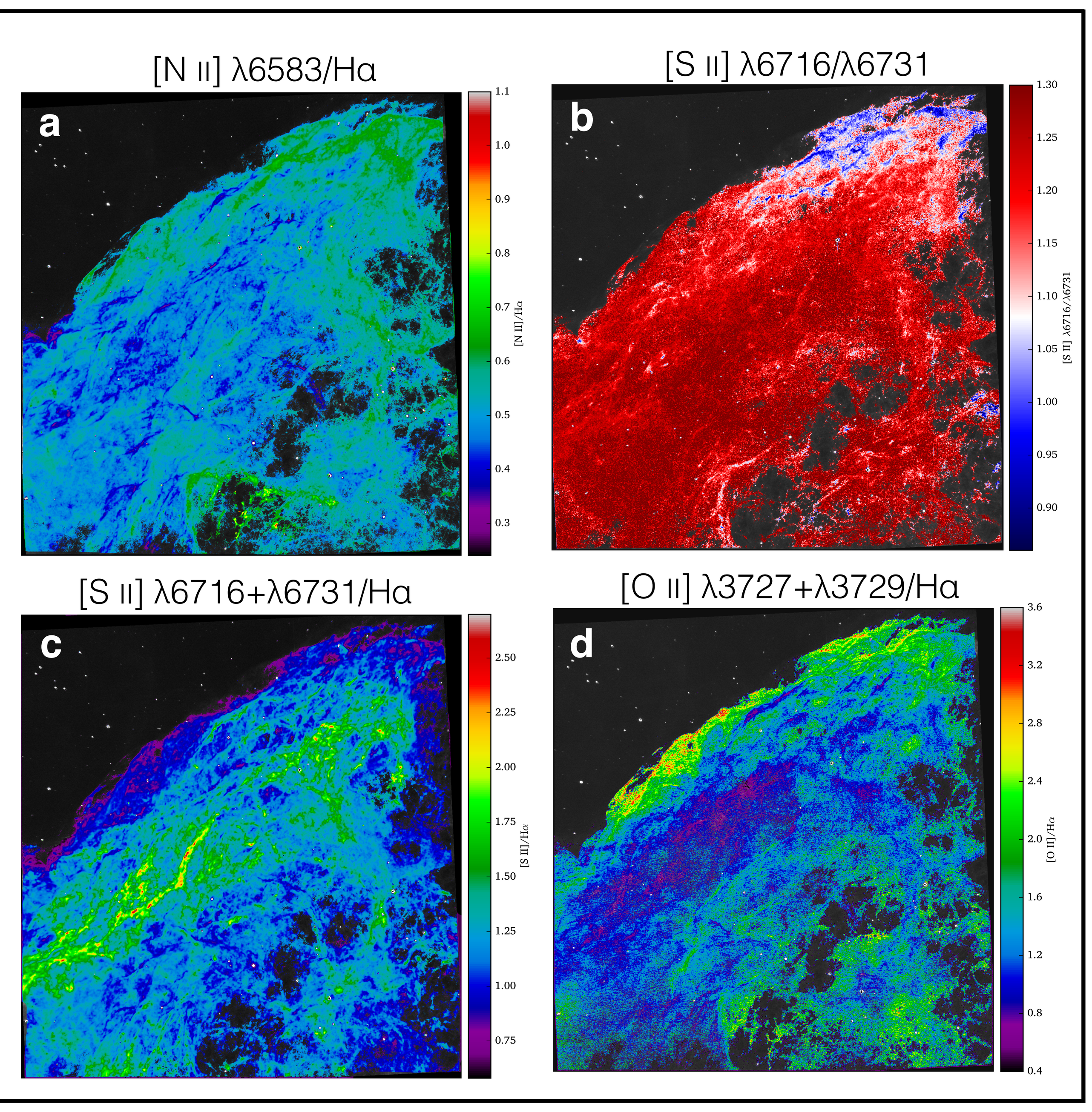
We have started the mapping of Cygnus Loop and IC 443 using the iFTS. In order to map the entire nebula, several regions have been observed and new observations are planned for later this year.

Ratios maps : IC 443

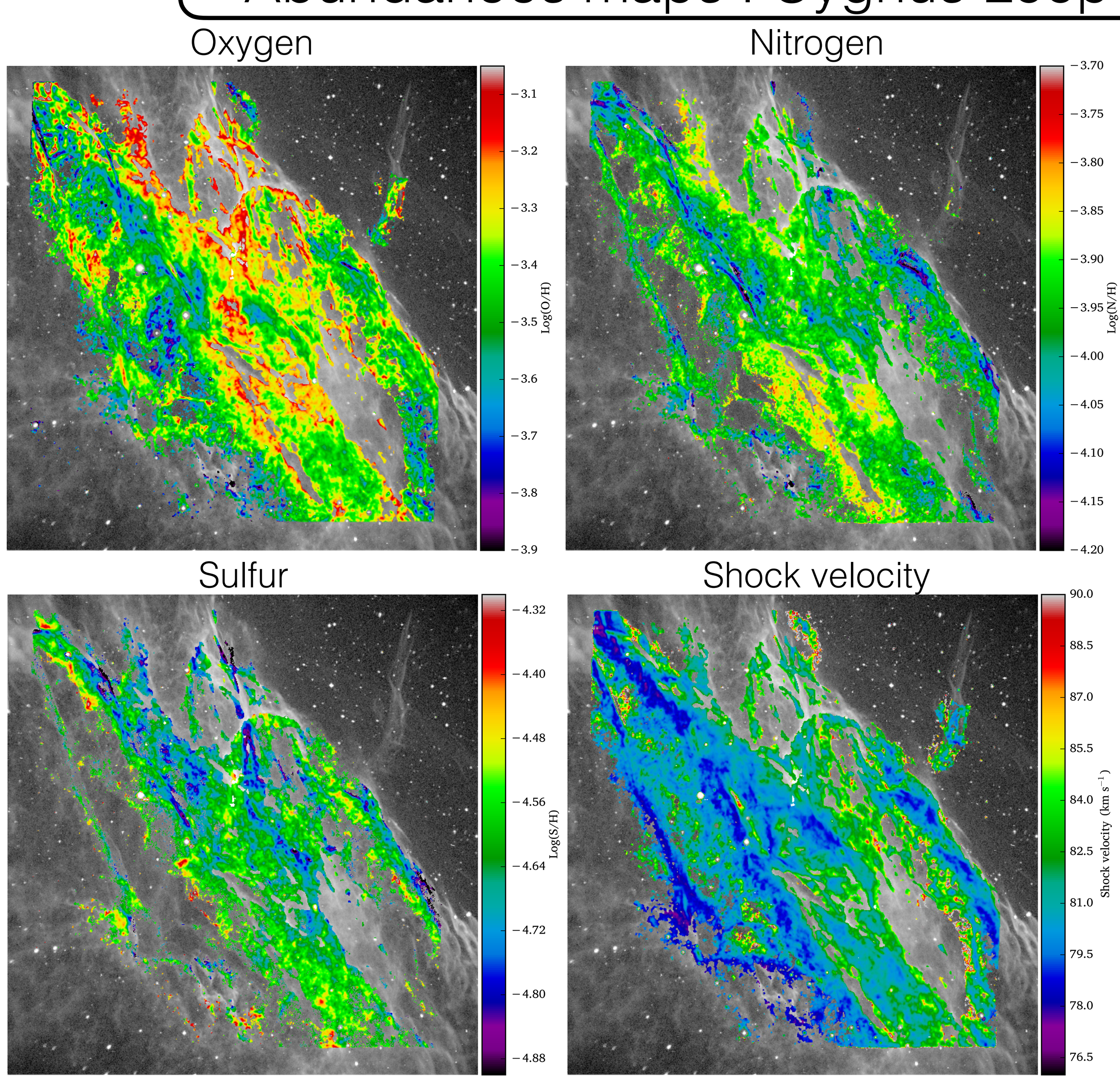
Each line in a multispectral cube can be fitted in order to obtain its intensity as well as its central wavelength. Doing so allowed the creation of ratios maps as well as velocity maps for selected emission lines. The maps can be corrected for extinction pixel by pixel using the Balmer lines.

The data shown here are from the same same field of view of a portion of the northern shell of IC 443. From those maps, it is obvious that the intensity of each line vary quite significantly in the nebula which indicate that the shocks conditions are not the same everywhere. The challenge is to associate which parameters are responsible for the observed emissions. To succeed, it is useful to compare the emissions with large shock models grids. Here is an example of a quick analysis that can be made directly from the ratios maps :

(a) Some regions show high [N II]/Hα ratio which is a good indication of a localized overabundance of nitrogen. **(b)** The [S II] doublet is quite useful in order to derive the pre-shock density. Here, in the northern part, the density is close to 15 cm^{-3} while the other regions have density around 3-6 cm^{-3}. **(c)** The [S II]/Hα ratio can be quite sensitive the the shock velocity. Here, the ratio is quite high in the regions where the [O III] emission is very faint or absent, indicating that the shock velocity is probably slower than 70 km s^{-1}. **(d)** The ratio [O II]/Hα is very sensitive to the completeness of the shock. This ratio is noticeably higher in the direction where shocks are propagating and the recombination behind the shock incomplete.



Abundances maps : Cygnus Loop



To evaluate the abundances several shock parameters are needed and some can be derived directly from the observations such as the shock velocities (using the [O III]/[O II] ratio), pre-chock densities (using the [S II] doublet) and the completeness of the shocks (using the [O III]/Hβ ratio). The effects of other shock parameters on the lines ratios such as the magnetic field and the pre-ionization state of the pre-chock gas have to be explored via shock models.

Comparing the observations conducted with SpIOMM and SITELLE with large shock grids generated with MAPPINGS, the abundances of oxygen, nitrogen and sulfur can be derived, pixel to pixel, using all the observed emission lines simultaneously.

The data shown here are one field in NGC 6992 in Cygnus Loop (region 1). Knowing the shock velocity as well as the pre-shock density while using reasonable values for the magnetic field and pre-ionization, one can find the abundances for O, N and S.

In the case of Cygnus Loop, we found that the abundances are somewhat close to solar values but there are some clear fluctuations region to the next. This indicates that the circumstellar medium was likely stirred up and enriched by the stellar winds prior to the explosions.

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