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# Mapping H$\alpha$ in the Fornax cluster with S-PLUS

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**Resumen** / Las líneas de emisión que presentan ciertas galaxias resultan ser valiosas fuentes de información, pues permiten analizar su formación estelar y identificar núcleos activos, entre otras propriedades. La configuración de filtros de S-PLUS, un relevamiento óptico de campo amplio que se encuentra mapeando el Cielo Austral en 12 bandas fotométricas (5 anchas y 7 angostas), es ideal para detectar tales emisiones. La investigación de las características de los emisores en entornos de alta densidad puede proveer pistas sobre el origen de tales emisores. ¿Presentan estos emisores una distribución específica dentro del cúmulo? ¿La morfología de las emisiones en estos objetos es extendida o concentrada? El cúmulo de Fornax constituye un entorno excelente para analizar en ese sentido, ya que, por la distancia a la que se encuentra ($\sim$ 20 Mpc), la línea de emisión H$\alpha$ es detectada por el filtro J0660, y los tamaños angulares de sus galaxias miembro permiten estudiar la distribución interna de dicha emisión. Con ese fin, desarrollamos un código que aplica el Método de los Tres Filtros píxel a píxel a imágenes de S-PLUS para crear mapas H$\alpha$+[N II] para los miembros de Fornax. En esta contribución presentamos la metodología, comparamos nuestros mapas H$\alpha$ con otras estimaciones derivadas de ajuste de SED, y discutimos nuestros principales resultados para 48 galaxias Fornax para las que dichos mapas fueron construidos con éxito.

**Abstract** / Emission lines in galaxies are a valuable source of information, as it allows the analysis of star formation activity and the identification of active galactic nuclei, among other proprieties. The filter configuration of S-PLUS, a wide field 12 photometric band (5 broad and 7 narrow) optical survey observing the Southern Sky, is ideal to detect such emission. The investigation of the characteristics of emitters in higher density environments can give us clues about the origin of such objects. Do they present a specific location within the cluster? Is the emission morphology extended or concentrated? In this context, the Fornax cluster is a great target to be analyzed, as at its distance ($\sim$ 20 Mpc), the H$\alpha$ emission line is located within the J0660 band, and the angular sizes of its galaxy members enable the study of the internal emission distribution. For such, we developed a code that performs a pixel-to-pixel application of the Three Filter Method to S-PLUS images in order to create H$\alpha$+[N II] maps for Fornax members. In this contribution we present the methodology, compare our H$\alpha$ maps with others estimations derived by an SED fitting approach, and discuss our main results for 48 Fornax galaxies, where the maps were successfully created.

*Keywords* / surveys — methods: observational — galaxies: star formation — galaxies: clusters: individual (Fornax)

## 1. Introduction

Emission lines, such as H$\alpha$, [O III] and [O II] trace bright and massive O and B-type stars that correspond to star formation timescales of $\sim$10 Myrs (e.g. Kennicutt & Evans, 2012). Thus, the connection between galaxies where these features are detected, and different physical properties, such as morphological type, stellar mass and environment, can give us clues about the star formation processes in galaxies. Alternatively, if one focus on emitters within a given cluster of galaxies, such analysis can assist us to better understand the evolutionary path and stage of the cluster.

One approach to perform a quantitative study of emission is through narrow band photometric surveys (e.g. J-PLUS: Cenarro et al., 2019; miniJPAS: Bonoli et al., 2021), in which an emission line if inside a narrow filter creates a clear excess when compare to another neighboring filter. For such purpose, the Southern Photometric Local Universe Survey (S-PLUS, Mendes de Oliveira et al., 2019) provides an ideal dataset with its 5 broad-bands similar to the Sloan Digital Sky Survey (SDSS), and 7 narrow-bands tracing specific spectral observing the Southern Sky. Data releases up to DR3 are publicly available in https://splus.cloud/, with an observed area of $\sim$1772 deg$^2$ and include optical aperture photometry, photometric redshifts, star/galaxy/QSO classification.

Among the targets observed by S-PLUS are fields that include the Fornax cluster, the second nearby rich galaxy cluster after Virgo. It is centered in NGC 1399 with a subgroup named Fornax A, centered in NGC 1316. The potentiality of the survey to study this cluster has been presented in Smith Castelli et al. (2021, 2022). From an emission perspective, at the distance of Fornax, the H$\alpha$+[N II] lines fall within S-PLUS narrowband J0660, allowing the detection of emitters inside the cluster up to its outskirts. Here, we present an spatial

Oral contribution

analysis of Hα+[N II] emission in galaxies located within Fornax.

## 2. Data description

Based on an extensive literature on the Fornax cluster, we compiled a list of 1057 galaxies. Considering only objects with radial velocity (∼23%), i.e. confirmed members of the cluster, and with good enough quality images (S/N>2), we have a sample of 157 galaxies.

## 3. How to detect emission lines?

The identification of lines Hα+[N II] with photometry is performed by an excess in colors. In our case, the indicators are: $(r - J0660)$ or $(J0660 - i)$. However, one must beware of how much the continuum of the galaxy can affect this diagnostic. In order to account for such, we choose to apply the “Three filter method” (e.g. Pascual et al., 2007).

### 3.1. Three filter method (3FM)

This methodology is based on three photometric filters, one narrow and two broad bands. Its main assumption is that the continuum is traced by the two broad-bands and it is assumed to follow a linear relation between the 3 filters. In addition, Hα+[N II] must be strong enough for their contributions to appear in J0660, i.e. we assume that S-PLUS can only resolve lines with equivalent width > 12Å(Vilella-Rojo et al., 2015).

Our goal is to use this approach directly in the S-PLUS images of $r$, J0660 and $i$ to create Hα maps for each galaxy in the sample. For this purpose, we create a code, CELineMap, written in Python that receives as input RA, DEC and size of the images in pixel and returns the desired emission map. The program automatically performs the following steps:

- creates a datacube based on the 12 band images, after downloading it from S-PLUS database;
- masks saturated stars or any other artifact;
- estimates the flux per pixel for all filters, assuming the zero-points derived by Almeida-Fernandes et al. (2022);
- applies Eqs.(3)-(4) presented in Subsec 3.2 from Vilella-Rojo et al. (2015) to create Hα+[N II] map.

## 4. Results in the Fornax cluster

Considering our initial sample of 157 Fornax galaxies as input to the previously mentioned code, we built a resulting image for each object. An emitter is distinguished from a non-emitter, if the final image (after all computational calculations from 3FM) presents more than 10 pixels connected. In previous tests, this criterion proved to be a good threshold for eliminating isolated bad pixels without removing the groups of pixels with emission (knots of star formation). Indeed, most maps show only individual pixels scattered around, which we interpret as residual noise from the images.

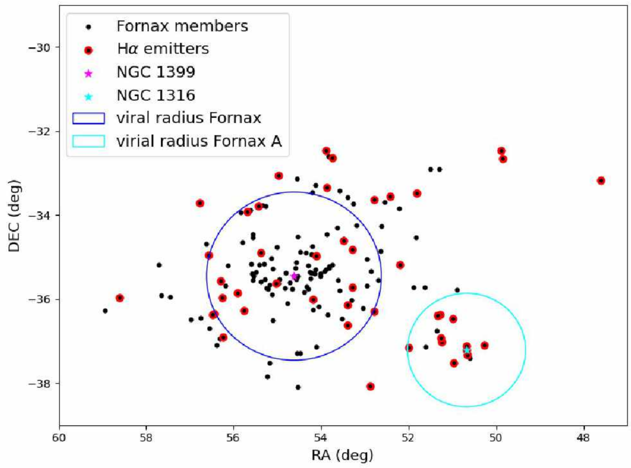


Figure 1: Spatial distribution of 157 Fornax galaxies, where the Hα emitters are marked with a red circle. The subgroup Fornax A is dominated by objects presenting signs of emission, while the rate of non emitters inside the viral radius of the cluster is higher.

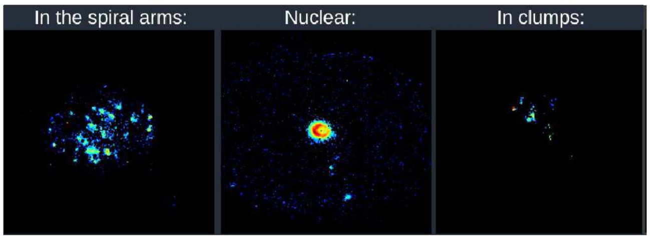


Figure 2: Examples of different types of emission in Fornax. The color reflects the intensity of Hα+[N II] flux, from less (blue) to more (red). The scales of flux between the 3 maps are not the same, therefore they are not directly comparable.

Only 48 galaxies have more than the minimal value of pixels.

By plotting the position of Hα+[N II] emitters in the cluster, as shown in Figure 1, we find that most objects located inside subgroup Fornax A virial radius have traces of emission, which may be due to the fact that this group is still in process of falling into the center of the cluster. Regarding the central region of the cluster, the proportion of emitters decreases if compare to Fornax A. The subgroup has 11 emitters in a total of 14 objects, while within Fornax virial radius the rate drops from 15 emitters among 88 galaxies. The other 22 sources with Hα emission seem to be randomly distributed out of both virial radius.

We find three types of emission line maps in respect to its location in the galaxy: in spiral arms, nuclear and in clumps. As expected, these different maps are directly related to the morphology of the galaxy, i.e. the nuclear emission in the center (or close to it) is found in S0s or in center regions of Spirals, while maps with emission distributed in clumps with different intensities are seen in Irregular galaxies. There are a few cases where a intense concentrated emission region is found offset from the center of the galaxy. Such objects need additional analysis with the phase-space diagram, in or-

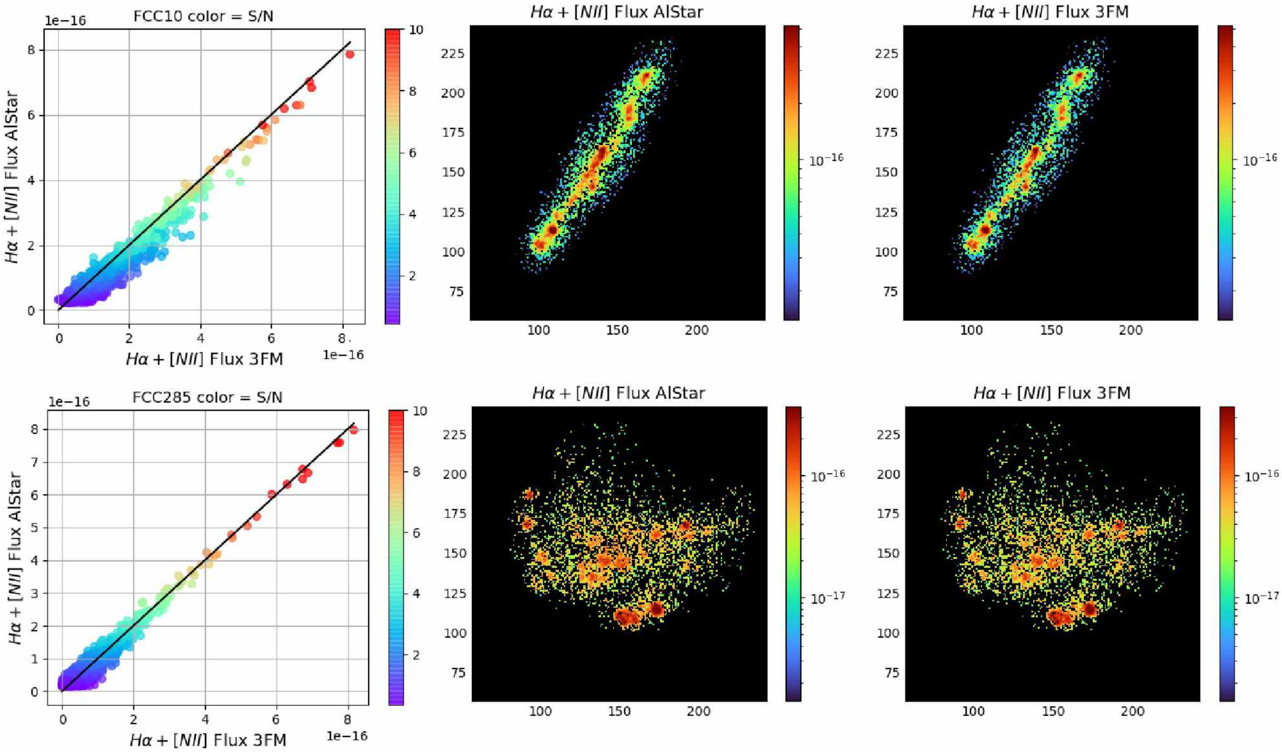


Figure 3: Examples of 2 galaxies in Fornax where the Hα+[N II] maps were obtained independently in AlStar and 3FM. The plots show a pixel-by-pixel comparison between both approaches, color-coded by the S/N (*right*), along with AlStar (*center*) and 3FM (*left*) maps of the Hα+[N II] flux. All fluxes are in units of erg $s^{-1}$ $cm^{-2}$.

der to understand if the object is a recent ($t < 1$ Gyr) infaller.

## 5. SED-fitting approach (AlStar) vs. 3FM

The ability to map emission line regions is one of the advantages of S-PLUS. But how dependent is this measurement to our chosen method? Are the results from our simple 3FM technique compatible with the ones obtained by a indirect estimates, such as spectral energy distribution (SED) fitting analysis? To answer these questions, we independently analyze a dozen of galaxies from our sample with the AlStar code (Thainá-Batista et al. 2023, in prep), which performs an algebraic decomposition of an observed spectrum in terms of an spectral base comprising stellar populations of 16 ages ($0 < t < 14$ Gyr) and 5 metallicities (from 1/3 to 3 solar), plus 9 empirically motivated components to represent the main emission lines (from [O II]3727 to [S II]6731). In other words, it perform an SED-fitting assuming a non parametric star formation history.

As shown in Figure 3, the Hα+[N II] maps obtained with the two methods look nearly identical, as confirmed by the pixel-by-pixel comparison of the fluxes. On average, AlStar outputs fluxes are only 14% larger than those given by the 3FM, an offset that decreases to 9.6% when only $S/N > 2$ pixels are considered. The scatter, in this case, is $\sim 13\%$. These results demonstrate that both methods derive compatible results.

## 6. Conclusion remarks

We built a Python code to create low resolution emission line maps based on S-PLUS images from three filters to study Hα+[N II] in the Fornax galaxy cluster. From these preliminary maps, we intend to advance the analysis by adding new parameters, such as emission concentration and Hα profile, to describe in more details the morphology of emission, and then correlate its characteristics to other physical properties of the galaxies, such as phase-space diagram and galaxy morphology.

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