Search of Extended Objects in the Southern Sky (SExOSS) using S-PLUS DR1: photometric characterization of extragalactic sources

R.F. Haack[1], I. Andruchow[1,2], I.E. López[1], V. Reynaldi[1], J. Saponara[3] & A. Smith Castelli[1,2]

[1] *Facultad de Cs. Astronómicas y Geofísicas, UNLP, Argentina*
[2] *Instituto de Astrofísica de La Plata, CONICET–UNLP, Argentina*
[3] *Instituto Argentino de Radioastronomía,CONICET–CICPBA–UNLP, Argentina*

Contact / rodrihaack@fcaglp.unlp.edu.ar

Resumen / El proyecto SExOSS (*Search of Extended Objects in the Southern Sky*) planea estudiar una gran muestra de fuentes extendidas en el cielo austral. Utilizando los datos del *Southern Photometric Local Universe Survey* (S-PLUS) tomados en 12 filtros (5 de banda ancha + 7 de banda angosta), el primer paso consistirá en analizar las relaciones fotométricas existentes haciendo uso de las magnitudes en banda ancha, y a través de una caracterización más profunda analizando los datos en banda angosta. Dicha caracterización podría revelar la existencia de nuevas relaciones fotométricas que impliquen una o más de esas magnitudes de banda angosta disponibles en este estudio. En el presente trabajo se muestran los primeros resultados obtenidos, sobre una muestra de fuentes extendidas incluidas en la primera liberación pública de datos (DR1) del S-PLUS. Esta primera muestra corresponde a la zona del cielo conocida como Stripe-82 previamente observada por el *Sloan Digital Sky Survey* (SDSS). Para nuestro análisis, consideramos una submuestra de objetos para los cuales se contaba con espectros en el SDSS, de manera de poder realizar una clasificación espectroscópica (galaxias con/sin formación estelar, núcleos activos, etc.), y buscar posibles vínculos entre las magnitudes detectadas en banda angosta. El S-PLUS DR1 tiene más de 3×10^5 fuentes, de las cuales se ha encontrado que alrededor de 3×10^4 son extendidas y poseen datos en el SDSS. Presentamos aquí los resultados obtenidos sobre una submuestra, la cual fue seleccionada considerando valores límite para la relación señal-ruido para los espectros del SDSS y el valor de magnitud en la base de datos DR1, sobre el que se realizó una clasificación ciega.

Abstract / The SExOSS (Search of Extended Objects in the Southern Sky) project is planning to study a large sample of extended sources in the southern sky. Using The Southern Photometric Local Universe Survey (S-PLUS) data taken in 12 filters (5 broad + 7 narrow bands), the first step will consist to analyze the photometric relationships shown using the broandband magnitudes, and through a deeper characterization made from narrow band filters behaviour. Such a characterization could reveal the existence of new photometric relationships involving one or more of those narrow band magnitudes available in this survey. In the present work, the first results obtained are shown, on a sample of extended sources included in the first data release (DR1) of S-PLUS. This first release corresponds to the Stripe-82 sky area previously observed by the Sloan Digital Sky Survey (SDSS). For our analysis, we considered a subsample of objects that had spectra in the SDSS to be able to perform a spectroscopic classification of their internal activity (galaxies with/without star formation, active nuclei, etc.) and then searching for links between the properties shown in the narrow band photometry. The S-PLUS DR1 has more than 3×10^5 sources, of which about 3×10^4 have been found to be extended and matched in the SDSS. We present here the results obtained on a subsample selected by considering threshold values for the signtal-to-noise level in both the SDSS spectra and the magnitude value in the DR1 database, on which a blind classification of internal activity was carried out.

Keywords / surveys — galaxies: general — galaxies: photometry — techniques: spectroscopic

1. Introducción

The Southern Photometric Local Universe Survey (S-PLUS, Mendes de Oliveira et al. 2019) will cover 8000 deg^2, collecting photometric data in the southern sky. Using a fully robotic 0.8 m telescope at the Cerro Tololo Interamerican Observatory (CTIO), Chile, this survey will collect a huge amount of good quality data. One of the main advantages of this survey is the set of filters choosen, 12 filters, 5 broad and 7 narrow bands (for details see Table 1).

This survey will be a unique opportunity to have a deep homogeneous study of the whole sky, because it will deliver a huge amount of photometric data for the much less explored Southern hemisphere.

Our main goal is to search for new photometric relationships for extragalactic objects, especially based on the narrow band information available for this survey. To do so, we propose to analyse the photometric and color distributions behavior of the different types of extended sources observed with S-PLUS, using the whole set of filters like Costa-Duarte et al. (2019) did for point sources.

Table 1: S-PLUS filter details, as in Table 2 in Mendes de Oliveira et al. (2019). 1: Broad Band; 2: Narrow Band.

Filter Name	$\lambda_{\rm eff}$ [Å]	$\Delta\lambda$ [Å]	Bandwidth
uJAVA	3574	330	1
J0378	3771	151	2
J0395	3941	103	2
J0410	4094	201	2
J0430	4292	200	2
gSDSS	4756	1536	1
J0515	5133	207	2
rSDSS	6260	1462	1
J0660	6614	147	2
iSDSS	7692	1504	1
J0861	8611	408	2
zSDSS	8783	1072	1

On the other hand, the sky area covered by the S-PLUS Data Release 1 (DR1) * is the same as the one of the Stripe-82 from the Sloan Digital Sky Survey (SDSS)**. The great advantage of this is the availability of optical spectra from SDSS for the sources in common between the two surveys.

2. Methodology

As a first step, we must have a reliable morphological classification (including internal activity) for the extragalactic objects in the DR1. This will allow us to study the distribution of different types of objects.

We started doing a blind classification of the objects in the DR1 with spectra in SDSS. The DR1 has more than 3×10^6 sources, among which one third (10^6) are classified as extended objects in the DR1. After performing a crossmatch among the S-PLUS extended sources and the objects with SDSS spectra, we ended with a sample of $\approx 3 \times 10^4$ sources. In this sample, all the sources have S-PLUS 12 band photometric data, extended and have SDSS spectral data.

According to the spectral features displayed by the objects, the categories we are looking for are:

- Quiescent galaxy, showing no emission lines.
- Galaxy with emission lines, showing at least one emission line.
- Quasar, characterized by a dominant blue continuum and broad emission lines.
- Blazar, characterized by a dominant blue continuum and no or few narrow emission lines.

We also consider that we could find a few stars characterized by thermal (Planck-like) continuum and absorption lines at redshift $z = 0$.

2.1. New approach

Performing the blind classification proposed is a massive task. Considering that the main goal of this project is to analyze photometric relationships for extragalatic sources using the whole S-PLUS set of filters, we explored an alternative way to obtain a classified sample. Specifically, in parallel with the blind classification, we used the GalaxyZoo*** (GZ) project information.

The GZ project is an open community effort which, based on SDSS data, provides morphological classification. Recently, this project started to work also with the spectral information of the sources, releasing a set of catalogs that include a similar classification as in the present work. Specifically, the GZ2 (Hart et al., 2016), has $\approx 5.7 \times 10^4$ extended sources from the SDSS Stripe-82.

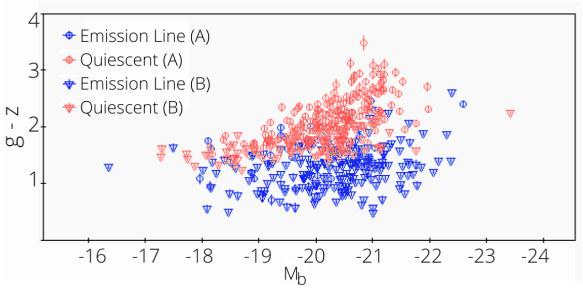

Figure 1: Quiescent and emission line galaxies in the $(g-z)$ vs. M_B color-magnitude K-corrected diagram. A and B denote the sources in each subsample, respectively.

3. First results

From the sample on which the initial blind classification was made, we decided to work with sources characterized by a signal-to-noise (S/N) value > 10 for the broadband filters. Based on these sources we built two subsamples: one with all the magnitudes of narrow bands with S/N < 10 (subsample A) and another with at least one narrow band with S/N > 10 (subsample B).

A color-magnitude diagram is shown in Fig. 1. In this diagram, quiescent galaxies define a sequence, while galaxies with emission lines are located towards bluer photometric colors, as expected according to what can be found in the literature (e.g., Tempel et al., 2011). This first result can be taken as evidence that the classification we have made is reliable.

Using the same subsample, we made a color-H_α diagram, shown in Fig. 2, where a separation between quiescent and emission line galaxies observed in each of the subsamples.

In addition, from the crossmatch made between S-PLUS and GZ2, we obtained 18 331 sources (after discarding sources with bad data in one or more filters). In this sample, according to the GZ project, 14 852 objects are classified as early-type, and 3479 as late-type. Among them, 1551 sources have activity classification, of which 1466 are quiescent galaxies and 85 are galaxies with emission lines.

We also perform a crossmatch with the VLA Snapshot Survey (Prescott et al., 2018) to search for any radio band counterpart for those 18 331 sources (some of which present activity). We found that at least 257

*http://www.splus.iag.usp.br/data/
**https://www.sdss.org/
***https://data.galaxyzoo.org/

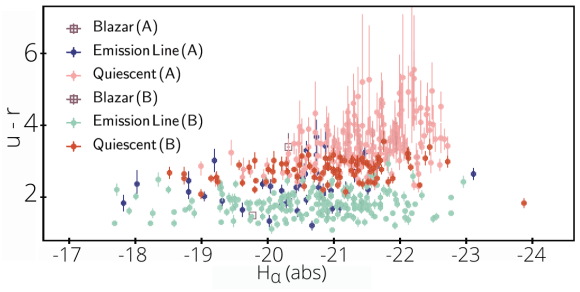

Figure 2: Quiescent and emission line galaxies in the $(u-r)$ vs. H_α color-magnitude diagram. The $(u-r)$ color index is K-corrected, while H_α is an absolute magnitude derived from the photometric redshift provided by S-PLUS. A and B denote the sources in each subsample, respectively.

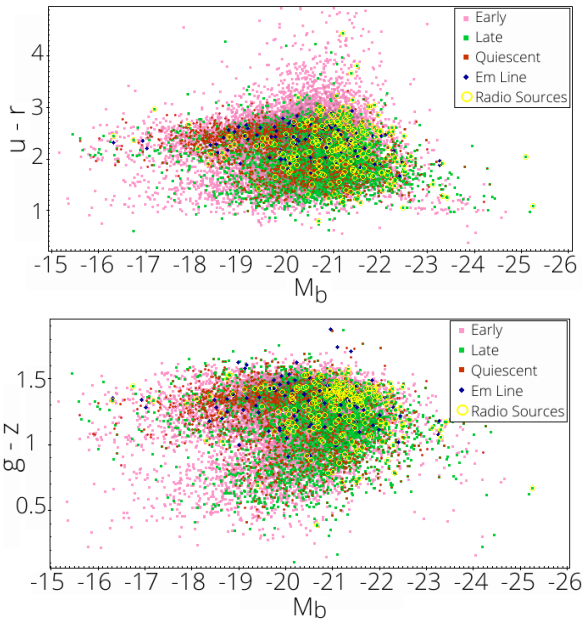

Figure 3: *Top panel:* K-corrected $(u-r)$-magnitude diagram discretizing by morphological types. *Bottom panel:* K-corrected $(g-z)$ vs. magnitude diagram discretizing by morphological types. We include active sources and radio sources as well.

sources have also radio wavelenghts data. In Fig. 3, K-corrected typical color-magnitude diagrams for the S-PLUS/GZ sample are shown, discretizing by morphological types, including active and radio sources.

In Fig. 4 we show a set of broad bands and color diagrams resulting from running a PHYTON script taking into account all the possible combinations. This is an agile way to carry out a first quick analysis and then, a more detailed one on those relationships that present some distinctive characteristic.

4. Remarks and future work

Our blind classification for the first sub-sample is in full agreement with the GZ classification. This makes us to trust on our criteria for classification.

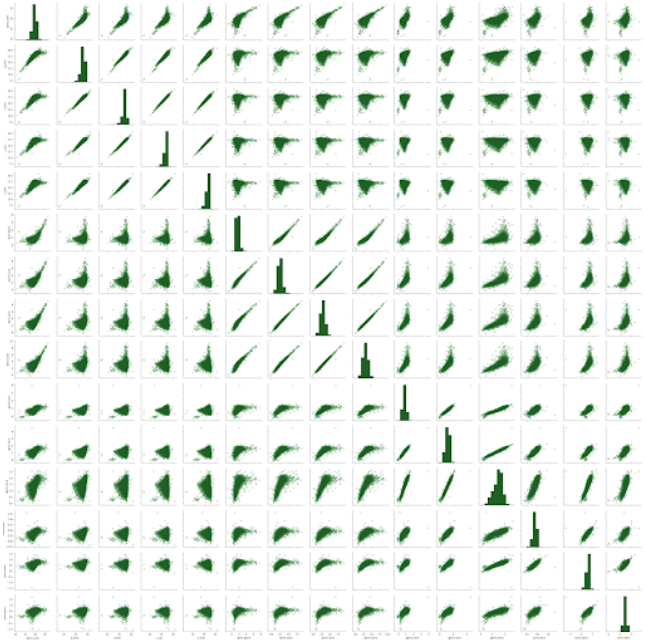

Figure 4: A glimpse of S-PLUS broad bands magnitudes and colors relationships (implemented by a PHYTON script).

Our main purpose is obtaining reliable and tested color-magnitude relationships to disentangle the different classes of extragalactic objects using both, broad and narrow photometric bands. This will be of great importance as we do not have spectral data outside the Stripe-82 sky footprint of the SDSS. That is why, it is great importance to explore possible new photometric relations which can enable the development of new classification methods.

As future work we plan to carry out the following tasks:

- to increase the number of classified sources to have a good statistical base (essential for robust results);
- to continue cross-matching S-PLUS data with data from other wavelengths (radio, UV, X-Ray, etc.) to help us understand the truly nature of the sources;
- to improve the classification (eg AGNs, starformation galaxies, etc);
- to follow up all sources that show peculiar characteristics.

References

Costa-Duarte M.V., et al., 2019, arXiv e-prints, arXiv:1909.08626
Hart R.E., et al., 2016, MNRAS, 461, 3663
Mendes de Oliveira C., et al., 2019, MNRAS, 489, 241
Prescott M., et al., 2018, MNRAS, 480, 707
Tempel E., et al., 2011, A&A, 529, A53