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# Unraveling the origin of phosphorus emission in active galaxies

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**Abstract.** Foram observadas galáxias que apresentam uma abundância incomum de fósforo em suas composições. A abundância de fósforo foi detectada pela análise da razão das intensidades das linhas de emissão [Fe II] 12570/[P II] 11886 Å nos espectros das galáxias. Para coletar um maior número de medições, desenvolvemos um novo método utilizando o software IFSCube. Atualmente estamos fazendo as medições das linhas de emissão para uma amostra maior de galáxias. Após obtê-las, realizaremos simulações dos processos físicos envolvidos na emissão de fósforo. Dois processos comumente envolvidos são a fotoionização e a excitação por choques, sendo que este último ocorre com mais frequência em regiões de AGN.

**Resumo.** Galaxies displaying an unusual abundance of phosphorus in their compositions have been observed. Phosphorus abundance was detected by analyzing the ratio of emission line intensities [Fe II] 12570/[P II] 11886 Å in the spectra of these galaxies. To gather a larger number of measurements, we developed a new method using the IFSCube software. Currently, we are conducting emission line measurements for a larger sample of galaxies. After collecting a sufficient number of measurements, we will perform simulations of the physical processes involved in phosphorus emission. Two commonly involved processes are photoionization and excitation by shocks, with the latter occurring more frequently in Active Galactic Nuclei (AGN) regions.

**Keywords.** Galaxies: active – Infrared: galaxies – Line: identification – Shock waves – Techniques: imaging spectroscopy

## 1. Introduction

Some active galaxies (AGNs) with an unusual abundance of phosphorus in their composition have been observed (Riffel et al. 2019). This abundance was detected through analysis of the flux intensity ratio [Fe II] 12570 Å/[P II] 11886 Å in emission line spectra. In Fig. 1 we can see an example of a galaxy spectrum with emission lines. According to Oliva et al. (2001), a ratio greater than 20 for this parameter is characteristic of an AGN host. However, significantly lower values were observed in a sample containing both AGNs and starburst galaxies, with no evidence of a difference in phosphorus abundance between these two types of galaxies, as you can see in Fig. 2.

The ultimate goal is to investigate the physical processes responsible for the excitation of phosphorus in active galaxies. To achieve this, the initial step involves acquiring emission line measurements for a larger sample of galaxies. Line measurements here refer to measurements of flux intensity and equivalent widths (EW) of the emission lines. Rather than measuring only the lines of interest, we are opting to measure all the identifiable emission lines in the spectra. This approach will enable us to create an atlas that can be used as a reference by other researchers.

## 2. Sample

The dataset consists of 1D nuclear spectra observed in the near-infrared region (NIR), covering a wavelength range from 8000 Å to 24000 Å. Two distinct datasets of Local Universe galaxies were employed: the first one identical to the dataset analyzed in Riffel et al. (2006) (referred to as Sample 1), and the second obtained from different observations (referred to as Sample 2). Sample 2 encompasses observations conducted with equivalent instruments, utilizing cross-dispersed spectrographs, which include ARCoIRIS, SpeX, and the SED Machine on the Palomar telescope. Sample 2 comprises 42 galaxies from the Local Universe, while Sample 1 contains 51 galaxy spectra.

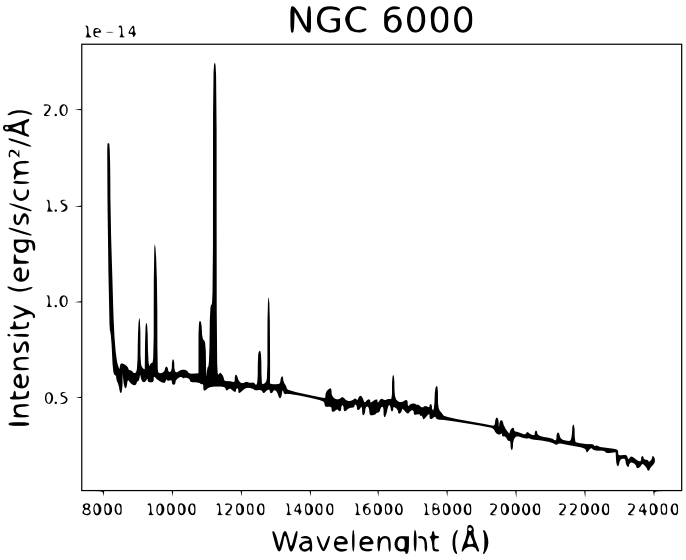


**Figure 1.** Example of active galaxy spectrum.

## 3. Methods

To collect a greater number of measurements, we developed a new method using the IFSCube software (Ruschel-Dutra et al. 2021) for line measurements. Compared to LINER, the software used by Riffel et al. (2006) for this purpose, IFSCube provides faster measurements, enabling the collection of a larger dataset. When attempting to measure the emission lines, the presence of absorption lines from stars can pose challenges. So, one of the steps we took was to perform stellar population synthesis. We utilized the STARLIGHT software (Fernandes et al. 2005) to make the synthesis, allowing us to subsequently subtract the stellar spectra from the galaxy spectra. The final method developed can be summarized as follows: rebin spectrum → STARLIGHT mask → STARLIGHT spectral synthesis → subtract stellar spec-

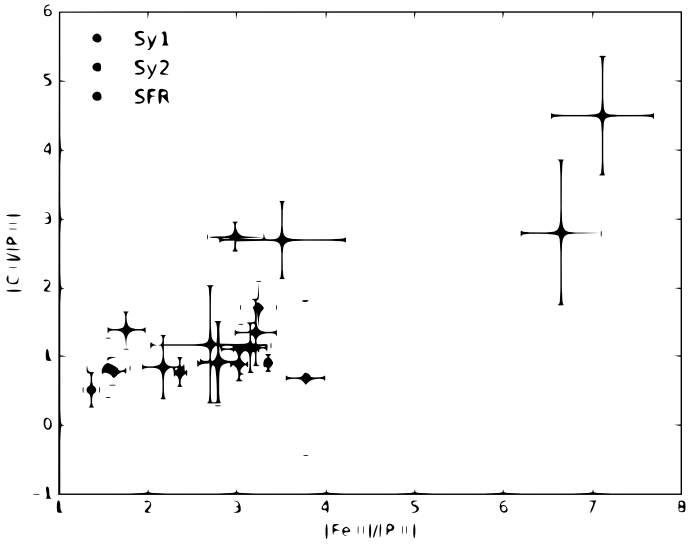


**Figure 2.** Correlation between the emission-line ratios of [C I] 9850 Å and [Fe II] 12570 Å relative to [P II] 11886 Å. Source: Riffel et al. (2019).

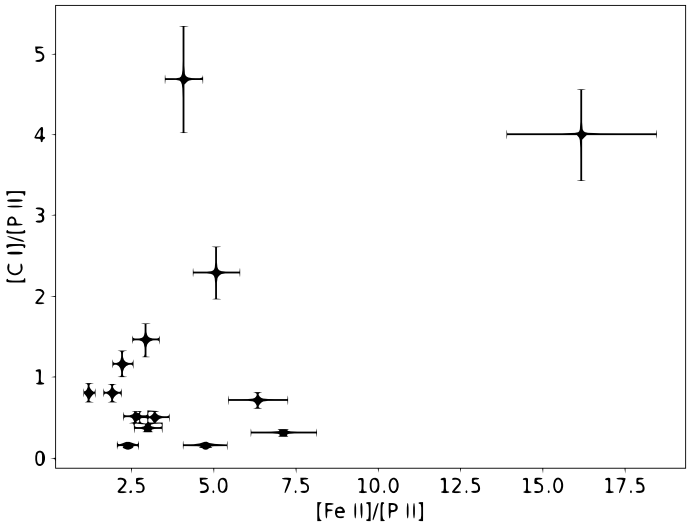


**Figure 3.** Correlation between the emission-line ratios of [C I] 9850 Å and [Fe II] 12570 Å relative to [P II] 11886 Å for Sample 2.

tra from galaxy spectra → create FITS file → identify emission lines → IFSCube.

## 4. Results

Our study found that measurements obtained with IFSCube are consistent with those obtained using LINER, ensuring the reliability of the collected data. We tried to apply the Monte Carlo method to IFSCube to derive uncertainties for the measured values. However, the resulting uncertainties were found to be excessively small for meaningful consideration. Consequently, we propose establishing uncertainties at 10% of their respective values. This adjustment allows us to avoid the use of the Monte Carlo method, leading to further efficiency gains in our approach. The measurements were made for both samples. We reproduced Fig. 1 with Sample 2 data in Fig. 3.

Out of a sample of 42 galaxies, it was possible to identify and measure the three emission lines of interest in 14 of them, representing 33.3% of the sample. Regarding emission line ratios, the

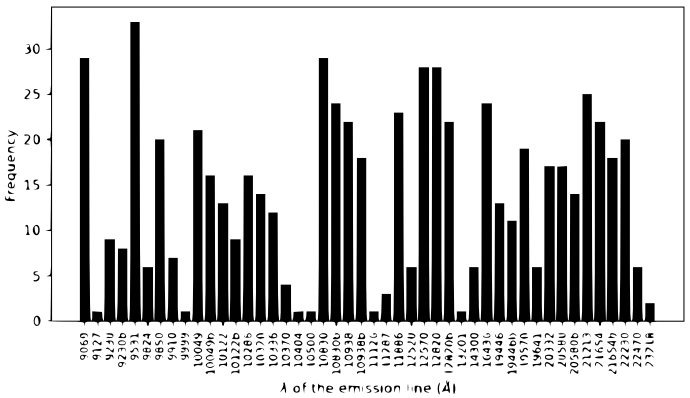


**Figure 4.** Histogram of emission lines identified in galaxy spectra for Sample 2.

results were quite similar to those shown in Fig. 1. Generally, low values are observed for the [Fe II]/[P II] ratio, confirming the pattern observed in Riffel et al. (2019). In Fig. 4 we show an emission line histogram for Sample 2.

We are currently measuring emission lines for a larger sample of galaxies. After collecting a sufficient number of measurements, we will perform simulations of the physical processes involved in phosphorus emission. Two commonly involved processes are photoionization and shocks excitation, with the latter occurring more frequently in AGN regions. As it is difficult for a single code to analyze both processes effectively, we plan to use Cloudy for photoionization and MAPPINGS for shocks.

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