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Comparative study of the spectral properties of type 1 and 2 QSOs

G. R. Hauschild-Roier[1] & T. Storchi-Bergmann[1]

[1] Instituto de Física, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, 91501-970, Porto Alegre, RS, Brazil
e-mail: gabrielrhroier@gmail.com
e-mail: thaisa@ufrgs.br

Abstract. In this work, an initial analysis of a set of type 1 and type 2 quasars with redshifts between $0.4 < z < 0.5$ was conducted using spectral data from SDSS in order to investigate the nature of these Active Galactic Nuclei (AGN), which, according to the Unified Model of AGN, should be the same type of object observed with different lines of sight. The study included an examination of the slope of the continuum, the width of emission line profiles (indicated by the parameter W80), and the luminosity of the lines. A difference between the populations of QSOs 1 and 2 was observed: the former exhibit continua with a negative slope and typically less luminous and narrower [O III] profiles, while the latter show opposite results for these parameters. This leads to the conclusion that the Unified Model of AGNs does not satisfactorily explain this phenomenon, suggesting a hypothesis of an evolutionary effect between QSOs 1 and 2: interactions between galaxies initially produce a type 2 QSO, with a nucleus obscured by gas and dust, which eventually expels or accretes this material and becomes a type 1 QSO.

Resumo. Neste trabalho, foi feita a análise inicial de um conjunto de quasares de tipo 1 e 2 com redshifts entre $0.4 < z < 0.5$ através de dados espectrais do SDSS, com o objetivo de investigar a natureza destes núcleos ativos de galáxias (AGN) que, de acordo com o Modelo Unificado de AGN, deveriam ser o mesmo tipo de objeto observado com diferentes linhas de visada. Foi realizado o estudo da inclinação do contínuo, da largura dos perfis de linhas de emissão (traçada pelo parâmetro W80) e da luminosidade das linhas. Foi constatado uma diferença entre as populações de QSOs 1 e 2: os primeiros apresentam contínuos com inclinação negativa e perfis de [O III] tipicamente menos luminosos e mais estreitos, enquanto que os segundos apresentam resultados opostos para estes parâmetros. Isto leva à conclusão de que o Modelo Unificado de AGNs não explica de maneira satisfatória este fenômeno, levando à hipótese de que existe um efeito evolutivo entre QSOs 1 e 2: interações entre galáxias inicialmente produzem um QSO de tipo 2, com núcleo obscurecido por gás e poeira, que acaba por expulsar ou acretar este material e se torna um QSO 1.

Keywords. Galaxies: active – Galaxies: nuclei – quasars: general

1. Introduction

Quasars are the brightest objects in the Universe, having bolometric luminosities $L_{\rm bol} > 10^{46}$ erg/s, fueled by their central Supermassive Black Holes feeding at an accretion rate similar to that found in the "cosmic noon". Within the so-called "Unified Model of AGNs" Urry & Padovani 1995, in type 1 quasars, the accretion disk and the Broad Line Region (BLR) are directly observed; in type 2 quasars, these structures are obscured by molecular gas and dust due to the orientation in which the central region is observed. However, there are indications that the difference is not solely due to orientation, with recent studies showing an excess of interacting and merging systems in type 2 QSOs. The aim of this work is to investigate this for a sample of QSOs, comparing the optical spectral properties of a type 1 sample with that of a type 2 sample.

2. Data and Methodology

In this study, two samples of spectroscopic data obtained by the Sloan Digital Sky Survey (SDSS) were used for quasars: the first predominantly containing QSOs 1, referred to as DR16Q Lyke et al. 2020 and the second containing only QSOs 2 Reyes et al. 2008. Spectra with $S/N > 3$ and within the redshift range of $0.4 < z < 0.5$ were utilized for this analysis. Examples of spectra for QSOs 1 and 2 can be seen in Figure 1.

The spectra from both samples were fitted using the PyQSOFit library Guo et al. 2018, which performs simultaneous fitting of emission lines with Gaussian profiles, the continuum, and the Fe II line multiplet. Examples of the fitting process are shown in Figure 1. To avoid contamination of the type 1 QSO sample, a classification of candidate QSO 2 spectra in the DR16Q sample was conducted using a neural network. After the initial classification, the candidates underwent subsequent visual inspection and confirmations were excluded.

3. Results

Figure 2 depicts the distribution of the continuum slope of the spectra between 3100 and 4100 Å, modeled as a power-law of the form $F_\lambda = a\lambda^b$. The analysis reveals that the populations of type 1 and type 2 QSOs typically exhibit negative and positive slopes, respectively, as indicated by the parameter b.

The left panels of Figure 3 display the distribution of the W80 parameter (width of the line profile that corresponds to 80% of its flux) for the Mg IIλ2800, Hβ e [O III]λ5007 lines. For the [O III] line, the W80 distribution is narrower than the others, and QSOs 2 tend to have broader kinematic profiles than the type 1 QSO population. This trend contrasts with what is observed for the other emission lines in the figure.

In the right panels of Figure 3, the distribution of luminosities for the same aforementioned emission lines is presented. The distribution reveals that QSOs 2 have higher [O III] luminosities than type 1, while for the Mg II line, the opposite occurs. Conversely, the distributions for Hβ are similar.

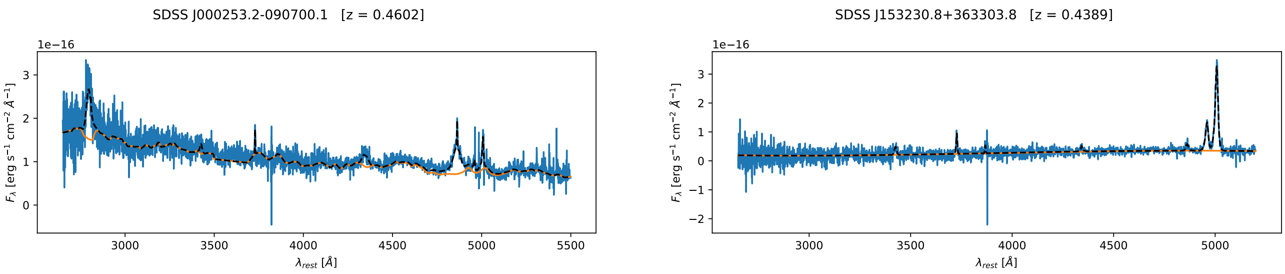

Figure 1. Examples of spectra for type 1 and type 2 QSOs, respectively. In blue, the spectrum corrected for reddening and redshift; in orange, the fitted components of the continuum and Fe II; and in black, the orange curve added to the emission line components.

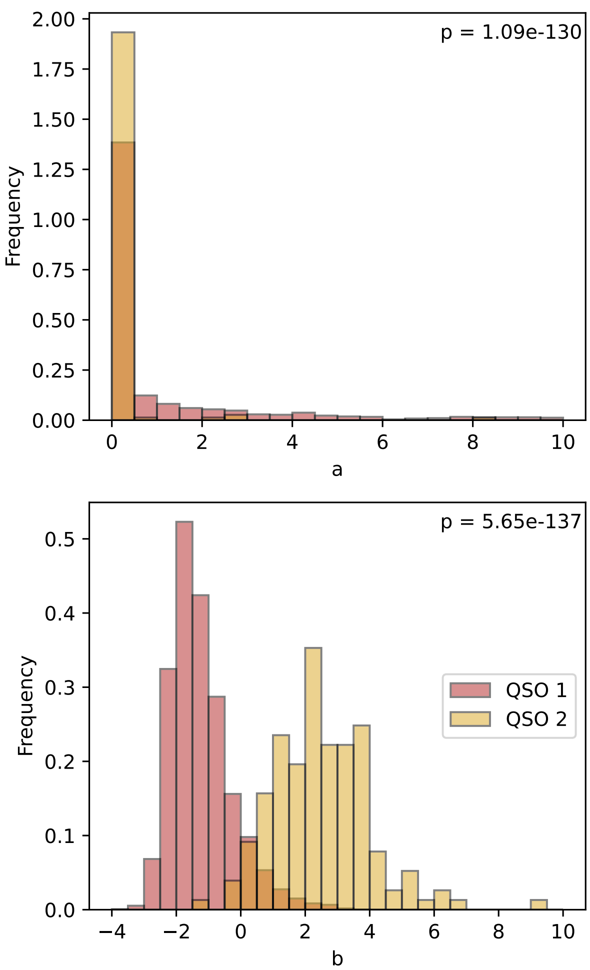

Figure 2. Distribution of the continuum slope between 3100 and 4100 Å. In red, the population of QSOs 1, and in yellow, of QSOs 2. In the upper right corners, we present the KS-test p-value for the distributions.

4. Analysis

The distributions of continuum slope, W80, and emission line luminosities suggest that there is an intrinsic difference between type 1 and type 2 QSOs that is not fully explained by the Unified Model. One hypothesis is an evolutionary relationship that transforms QSOs 2 into type 1 after undergoing some form of interaction with other galaxies, such as mergers (as observed in Araujo et al. 2023). The transport of gas and dust to the center of the host galaxy may lead to an increase in reddening, causing an initial flattening of the continuum with the presence of only very luminous narrow lines. As accretion occurs, the nuclear region becomes less opaque, revealing the spectral signature of the accretion disk and the BLR gas.

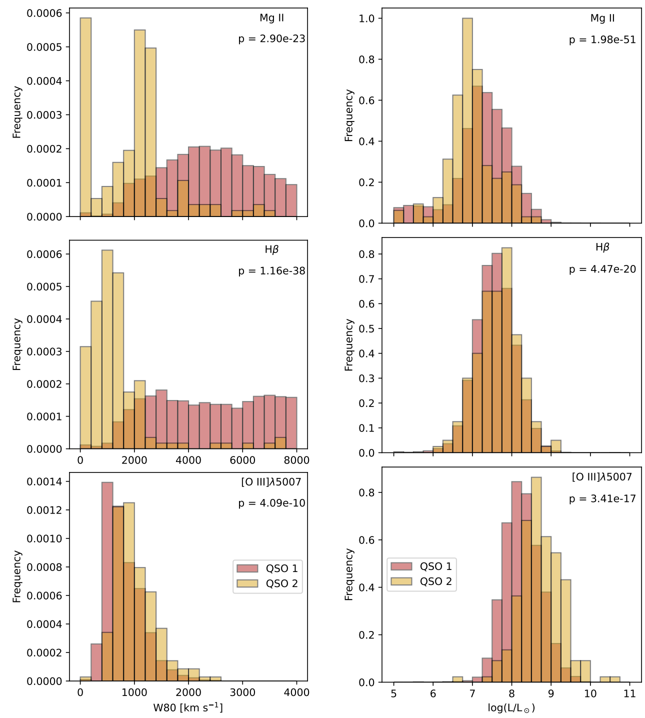

Figure 3. **Left**: W80 distribution for the Mg IIλ2800, Hβ e [O III]λ5007 emission lines. **Right**: luminosity distribution for the same emission lines. In red, the population of QSOs 1, and in yellow, of QSOs 2. In the upper right corners, we present the KS-test p-value for the distributions.

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