Stellar Population in the Sample of Type 2 Active Galactic Nuclei

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Abstract. We analyse simultaneously stellar populations (SPs) in active galactic nuclei (AGNs), AGN featureless continuum and emission lines, using NBurst code, adopted to fit the total spectrum of an active galaxy. In this paper we present the investigations of the accuracy, limitations and applications of the code in a research of stellar populations in narrow emission line galaxies (Type 2). To validate the method, we simulated several thousands of line-of-sight integrated spectra of Type 2 galaxies. We fitted simulated spectra with NBurst and found that code can extract SP and AGN parameters with a high precision. Additionally, we used the method to investigate SP and AGN spectral parameters of a sample of Type 2 AGNs. Especially we investigate the properties of stellar population in the first kiloparsec.

1. Introduction
The nuclear spectra of Seyfert galaxies can be composed of two components: a stellar component characterized by absorption lines from stellar atmospheres and an active galactic nucleus component composed of strong emission lines and a featureless continuum (FC). In the standard model for active galactic nuclei the UV/optical continuum is produced by non-thermal processes, following a power-law of the form $f_\lambda \sim \lambda^\alpha$ with a typical value of $\alpha$ in the range $\alpha = [-1.5,2]$ (see e.g. [1, 2, 3]). However, hot, young stars also produce a featureless continuum that attenuates the absorption lines of the older stellar population. Therefore, any reliable measurement of the emission-line spectrum of galactic nuclei has to properly account for the starlight contamination.

A typical approach to investigate gas properties in the center of an AGN is to dissociate the spectrum constituents in order to remove the starlight from an integrated spectrum. In order to minimize the degeneracies between the spectrum components, it is desirable not to subtract the SP from the integrated spectrum before the analysis of the AGN emission, but to fit simultaneously all constituents that contribute to the total spectrum. One of techniques for the analysis of an unresolved component from stellar populations of galaxies in an integrated spectrum is the spectral synthesis, which consists in the decomposition of an observed spectrum in terms of single stellar populations (SSPs) of various ages and metallicities, producing as output the star formation and chemical histories of a galaxy, together with its extinction and velocity dispersion (see e.g. [4, 5, 6, 7]). This is achieved by a full spectrum fitting including the continuum shape and absorption features. Sarzi et al. developed the ameliorate technique to fit in the same time the stellar and the gas kinematics [8].

In this work we presented and tested the advanced method to analyse simultaneously gas
and stellar kinematics and continuum radiation coming from AGNs in the spectra of Type 2 galaxies, using NBurst full spectrum fitting routine [9].

2. Method for the simultaneous analysis of the starlight and AGN emission

In order to analyse AGN spectra, we used NBurst [9] full spectrum fitting package that we modified and adopted to analyse simultaneously all components of the integrated light from an active galaxy. Single stellar population (SSP)

1 models that we used are spline interpolated over an age-metallicity grid of models, generated with PEGASE.HR code2 [10]. Therefore, by fitting the spectra of interest with NBurst, we reconstructed the SSP-equivalent age and metallicity.

Following [11] we defined a model \( M(x) \) of the integrated AGN spectrum, consisted of a stellar template spectrum \( T(x) \) convolved with a line-of-sight velocity broadening function \( G(x) \), a model for the AGN continuum \( C(x) \), here assumed to be a single power law, and a sum of Gaussian/Gauss-Hermit series \( S(x) \), that represent AGN emission lines:

\[
M(x) = P(x)([T(x) \otimes G(x)] + C(x) + \sum S(x)),
\]

were \( P(x) \) is a multiplicative polynomial.

We assumed a Gaussian velocity broadening function \( G(x) \) for simplicity, but technically it is possible to solve for higher order moments of the velocity profile (see e.g. [12, 13]).

We incorporated a multiplicative polynomial \( P(x) \), into the fit to remove large-scale shape differences between the observed stellar and galactic spectra.

In the original version of NBurst, the optional additive continuum \( C(x) \) is represented by Legendre additive polynomial. We added a single power low component in the fit to represent the featureless continuum. The AGN continuum is well described with the power-law function \( F \sim \lambda^{-\alpha} \) over all electromagnetic spectrum [14]. The spectral index \( \alpha \) depends on the continuum slope, thus in different spectral domains it has different values. For the optical domain, that we analyzed for the moment, expected value for spectral index is between -1.5 and 2.

When we made a model of emission lines, we defined each emission line component separately with Gaussian or Gauss-Hermit series.

To test the accuracy of the method, we simulated line-of-sight integrated spectra of low luminous AGNs. We assumed that it is composed of the featureless AGN continuum, narrow emission lines from the narrow line region and underlying stellar population (SP) from the host galaxy. We made a grid of 7200 spectra with Solar-type stellar population, combined with different fraction and slopes of featureless continuum, different intensities and widths of emission lines, various spectral ranges, signal-to-noise ratio (SNR) and degrees of Legendre multiplicative polynomial (more details will be given in [15]).

To evaluate the ability of the method to restore characteristics of the gas and stars in the nucleus and in the host galaxy, we fitted simulated spectra with described model of integrated AGN spectra.

Figure 1 represents the restored SSP ages in a response of FC contribution to the total spectrum (10%-90%) in the cases of SNR=20 (top panel) and SNR=40 (bottom panel). In both cases the method succeeds to restore SP age, but if the SP contributes with less than \( \sim 10\% \) to the total spectrum, the reliability of the result is very low, according to the wide error bars. Figure 2 represents the response of the FC continuum contribution and SSP age on the SNR variability. One can notice that method restors the FC contribution highly precise independently on the noise level. Only the errors for restored FC contribution computed by the program from the

1 SSP is population with single age and metallicity.
2 http://www2.iap.fr/pegase/pegasehr/
covariance matrix are low, and probably not realistic. We can expect to derive higher discrepancies from Monte Carlo simulations. On the other hand, in the case when SNR is lower than 20, the restored SP age is not reliable.

![Figure 1. The restored SSP ages obtained from the single best fit for different FC contribution to the total spectrum (10%-90%) in the cases of SNR=20 (top panel) and SNR=40 (bottom panel).](image)

We can conclude that the result depends mainly on the AGN continuum contribution to the total spectrum and on the signal-to-noise ratio. Parameters of the gas and stars in the galactic spectrum can be well restored if the spectra have SNR > 15 and if the stellar population fraction is higher than 20%. Method is not able to recover SP characteristics when the SP contribution to the total observed spectrum is less than 10%.

3. Application of the method on a sample of Type 2 objects
We used described method for the statistical analysis of stellar population in the first kpc of Type 2 galaxies. We selected ∼ 4000 SDSS Type 2 galaxies. Considering that we were interested only in the stellar population inside the inner kpc of the galaxies, and since galaxies were observed through a fixed angular fiber, we constrained redshift of the galaxies between 0.01 and 0.05. To firmly confine the field-of-view (FOV) of the fiber only on the inner part of the galaxy, we constrained the size of the SDSS objects, using the isophotes in the r-band, that represents the size of the major axis of the galaxy. Therefore, we bounded major axis to be larger than FOV of the galaxy. In this way, we prevent the influence of the stars from host galaxy to the observed spectrum.

Since narrow emission lines can be used to classify the dominant energy source in emission line galaxies, we used well known Hα/N[II]6548,6583Å vs. Hβ/O[III]4959,5007Å BPT diagnostic
Figure 2. The restored FC continuum contribution (top panel) and SSP age (bottom panel) from the single best fit for different signal-to-noise ratio (SNR=5-50) in the case of 50% of FC contribution.

To analyse the stellar population parameters we presented the results of the fit in the form of histograms. Here we will briefly discuss the results of the stellar population ages.

3.1. Discussion of the stellar population ages in the first kpc of Type 2 galaxies

Figure 3. represents distributions of analysed Type 2 galaxies with redshift between 0.01 and 0.05 over the mean stellar population ages. As expected, the youngest stellar populations have been found in starburst galaxies. Moreover, there was just a few HII objects with SP older that 6 Gyr. In the case of only three Sy2 galaxies have been found stellar population younger than 120 Myr. The possible explanation for such result could be that the young stellar population is quenched in the inner kpc of Sy2 galaxies by the central engine. Very interesting result appeared in comparing restored SP ages in the samples of Sy2, LINERs and composite objects. Namely, even the number of galaxies in three samples is very different, one can notice similar distribution of SP ages. We made cross-correlation between Sy2 - LINER, and Sy2 - composite objects histograms and obtained very high correlation, with cross-correlation coefficient of \( r = 0.96 \) and \( P \) value that describes the probability of no correlation \( P(null) = 3.87 \times 10^{-26} \) in the first case, and \( r = 0.89 \) and \( P(null) = 3.15 \times 10^{-14} \) in the second case. In addition, the SP age distribution in all selected Type 2 galaxies has maximum at \( \sim 2 \) Gyr, that suggests the dominance of an intermediate-age stellar population. To verify obtained result, we analysed the SP age distribution separately in each redshift interval, and we obtain very similar distribution in the redshift intervals in the case of Sy2, LINERs and composite objects. So, it seems that the result does not depend on the cosmological scale (we emphasize that we investigate only local redshift objects \( z < 0.05 \)). We can conclude that apart from the case of starburst galaxies,
Figure 3. Stellar population age in the integrated spectra of Sy2, LINER, composite objects and HII, respectively. On the graph are presented the maximum, mean and standard deviation of the distribution.
stellar population ages in the first kpc of Type 2 objects do not depend on activity type, and have similar distribution.

4. Conclusions
In order to analyse the properties of the starlight and its contribution to the spectra of AGN, we used NBurst, full spectrum fitting package. We upgraded the NBurst code with the intention of simultaneously analysing all components that contribute to the integrated AGN spectra along a line of sight: stellar population, AGN featureless continuum, and emission lines. In the original version, NBurst uses stellar populations synthesis models for analysing galaxy spectra. We added new components in the model: a featureless continuum, represented with a power law function, and emission lines, represented with Gaussian or Gauss Hermit series.

In order to assess the possibilities of restoring the properties of gaseous and stellar component in the spectrum of interest, we made numerical experiments. These experiments show that the NBurst code efficiently restores the information about the shape and light fraction of the AGN continuum, as well as the kinematics, age, and metallicity of the underlying stellar population in AGN spectra. Analysis revealed that the method is not able to restore the SP characteristics in the case when the SP contribution to the total observed spectrum is less than 10%.

We applied our proposed method to analyse the SP in the first kpc of Type 2 galaxies. We concluded that Sy2, LINERs and composite objects have the same distribution of stellar population ages in the first kpc.

Overall, our results validated spectral synthesis as a powerfull tool to study the history of galaxies and show some interesting characteristics of stellar population in the first kiloparsec of Type 2 galaxies from our sample.

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References
[1] Boroson, T. A., & Green R. F. 1992, ApJS, 80, 109
[2] Winkler, H., Glass, I. S., van Wyk, F., Marang, F., Jones, J. H. S., Buckley, D. A. H., Sekiguchi, K. 1992, MNRAS, 257, 659
[3] Garcia Rissmann, A. 2004 IAUS, 222, 93
[4] Cid Fernandes, R., Mateus, A., Sodré, L., Stasiska, G., Gomes, J. M., 2005, MNRAS, 358, 363
[5] Cid Fernandes, R., Delgado, G., Rosa M. 2010, MNRAS, 403, 780
[6] Koleva, M., Prugniel, P., Bouchard, A., Wu, Y. 2009 A&A, 501, 1269
[7] MacArthur, L. A., González, J. J., & Courteau, S. 2009, MNRAS, 395, 28
[8] Sarzi, M., Falcón-Barroso, J., Davies, R. L., Bacon, R., Bureau, M., Cappellari, M. et al. 2006, MNRAS, 366, 1151
[9] Chilingarian I. V., Prugniel P., Sill’Chenko O. K., Afanasiev V. L., 2007, MNRAS, 376, 1033
[10] Le Borgne D., Rocca-Volmerange B., Prugniel P., Lanceron A., Fioc M., Soubiran C., 2004, A&A, 425, 881
[11] Barth, A. J., Ho, L. C., Sargent, W. L. 2002, ApJ, 124, 2607
[12] Rix, H.-W., & White, S. D. M. 1992, MNRAS, 254, 389
[13] van der Marel, R. P. 1994, MNRAS, 270, 271
[14] Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (Mill Valle: University Science Press)
[15] Bon, N, Bon, E, Prugniel, P., Popović, L. Ć. 2012, in preparation
[16] Baldwin, J. A., Phillips, M. M. & Terlevich, R. 1981, PASP, 93, 5