# Phylogenetic Analyses of Quasars and Galaxies

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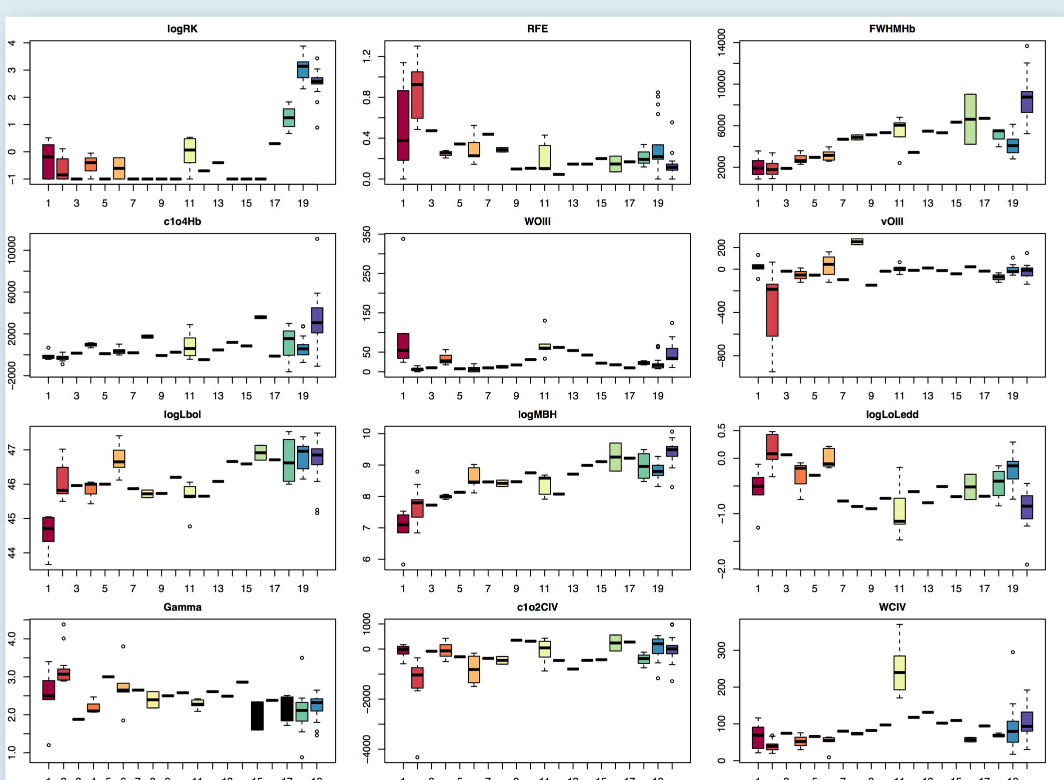
ABSTRACT

We have performed a cladistic analysis on two samples of 215 and 85 low-z quasars ($z < 0.7$) which were studied in several previous works and which offer a satisfactory coverage of the Eigenvector 1-derived main sequence. The data encompass accurate measurements of observational parameters which represent key aspects associated with the structural diversity of quasars. Cladistics is able to group sources radiating at higher Eddington ratios, as well as to separate radio-quiet (RQ) and radio-loud (RL) quasars. The analysis suggests a black hole mass threshold for powerful radio emission and also properly distinguishes core-dominated and lobe-dominated quasars, in accordance with the basic tenet of RL unification schemes. Considering that black hole mass provides a sort of ``arrow of time'' of nuclear activity, our result suggests that the ontogeny of black holes is represented by their monotonic increase in mass. More massive radio-quiet Population B sources at low-z become a more evolved counterpart of Population A i.e., wind dominated sources to which the ``local'' Narrow-Line Seyfert 1s belong. In addition to the analysis of luminous type 1 AGN and low-z quasars, we have applied cladistic techniques to a sample of viz. 4000 galaxies of the WINGS survey which are mostly quiescent or host modest star formation activity and low-luminosity AGNs. Preliminary results are given in this poster.

## WHAT IS ASTROCLADISTICS

Astrocladistics aims at introducing phylogenetic tools in astrophysics. Among these tools, cladistics, also called Maximum Parsimony, is the most general and the simplest to implement. It uses parameters, and not distances, to establish relationships between the species by minimizing the total evolutionary cost depicted on a phylogenetic tree. The trees that result from cladistic analysis should not be interpreted as genealogic trees: here, as the trees do not indicate ancestor or descendant objects, each quasar supposedly represents a species (i.e., a class). In this phylogenetic sense, the trees can be "rooted" according to a parameter that may have an evolutionary meaning. More information and links to introductory and review papers are available at https://astrocladistics.org.

## A cladistic analysis of a low-z quasar sample

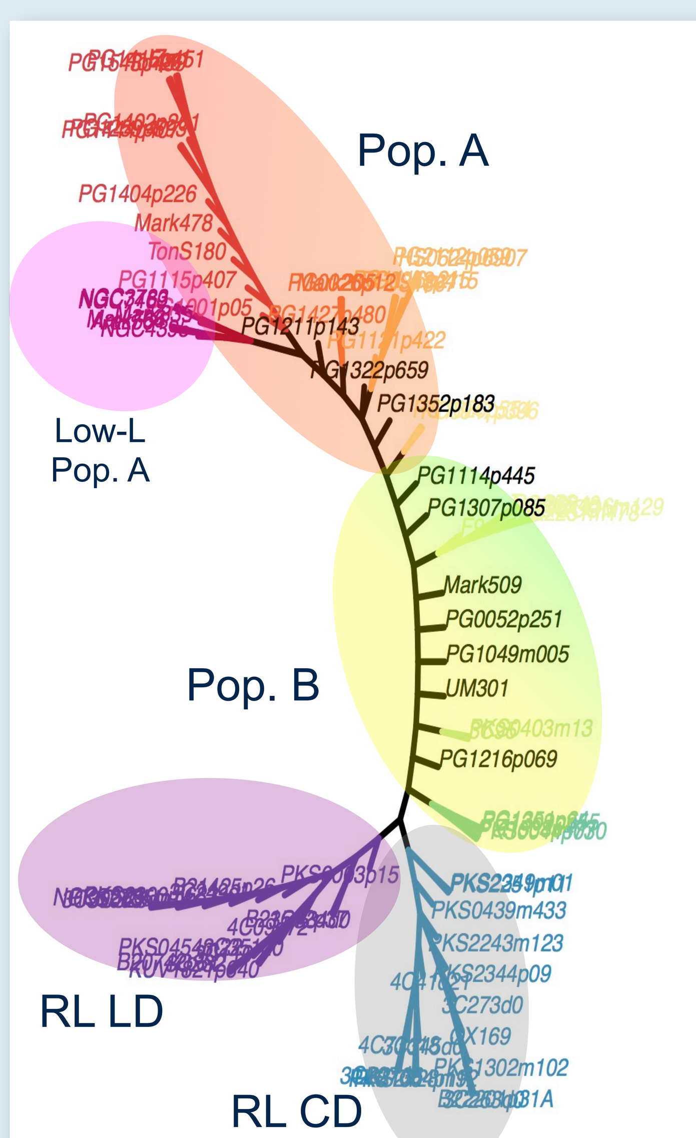



The boxplots aside show the radio loudness parameter $R_K$, $R_{FeII}$, FWHM(H$\beta$), the line centroid displacement of H$\beta$ at quarter maximum (c1o4Hb), W([OIII]$\lambda$5007), the peak shift of [OIII]$\lambda$5007, the bolometric luminosity $L_{bol}$, $M_{BH}$, the Eddington ratio, the soft X-ray photon index (Gamma), the centroid displacement of CIV$\lambda$1549 at half maximum (c1o2CIV), W(CIV$\lambda$1549) for a sample of 85 low-z (<0.7) quasars with coverage of both CIV$\lambda$1549 and H$\beta$), as grouped following the cladistic analysis.

While no evolutionary inference should be inferred, it is interesting to note that there is a sequence of relationships going from extreme Pop. A (wind dominated, higher Eddington ratio) and Pop. B (disk dominated, lower Eddingon ratio). The bottom groups are core-dominated and lobe-dominated RL sources, which are monophyletic groups.

In the case of quasars, a parameter that can root the cladistic tree is black hole mass ($M_{BH}$), since $M_{BH}$ can only grow as a function of cosmic time. A rooted tree shows a clustering consistent with evolution from less massive to more massive sources (as shown by the arrow diagram in the grey panel). Powerful RL sources appear in our low-z sample only above a mass threshold, and CD and LD are separated because of an intervening role or orientation (in phylogenetic terms, they belong to different monophyletic groups). The quasar sample contains a population of massive quasars which are "more evolved" and a population of less-massive quasars that are radiating at a higher $L/L_{Edd}$. While $L/L_{edd}$ remains the physical factor governing E1, high-$M_{BH}$ quasars may have resembled low-$M_{BH}$ quasars in an earlier stage of their evolution.

### The cladistic tree



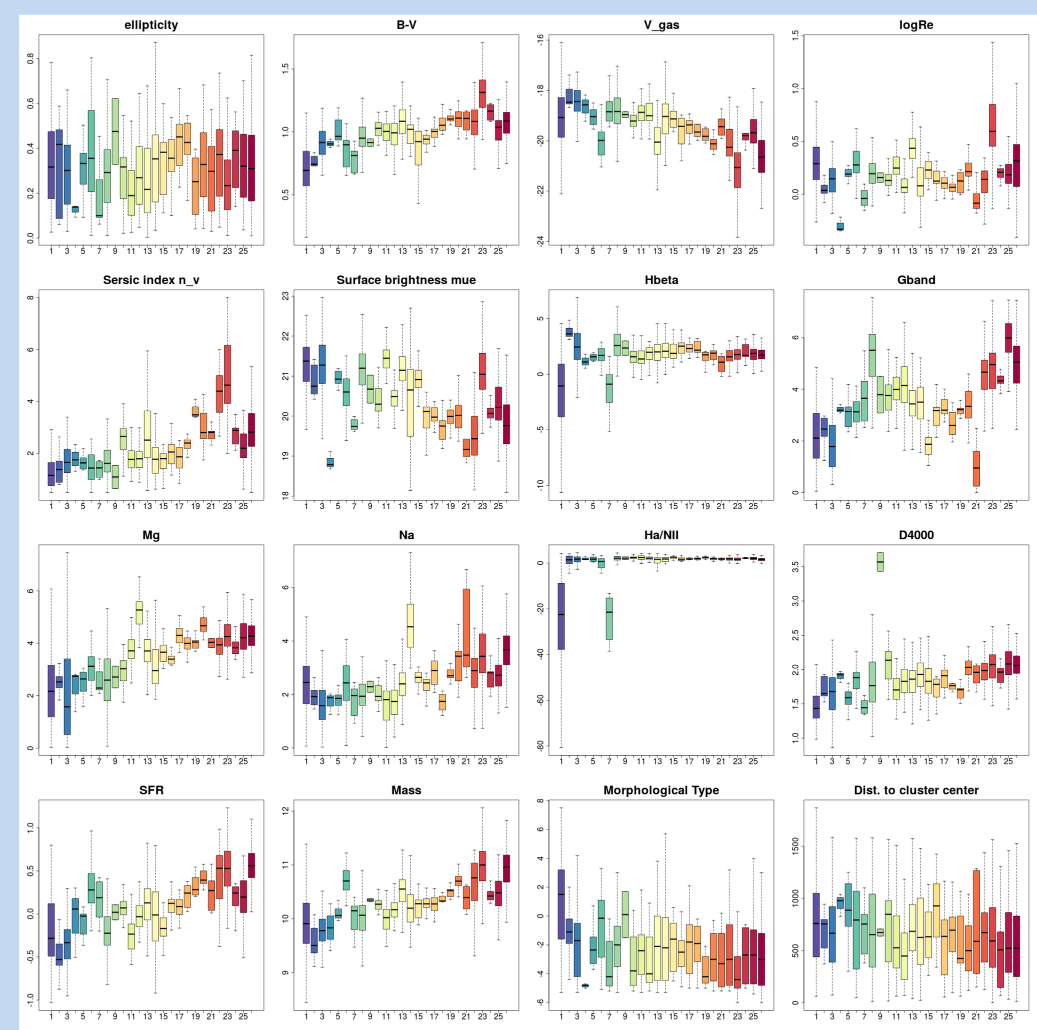

Considering that black hole mass provides a sort of "arrow of time" of nuclear activity, a phylogenetic interpretation becomes possible if cladistic trees are rooted on black hole mass: the ontogeny of black holes is represented by their monotonic increase in mass. More massive radio-quiet Population B sources at low-z become a more evolved counterpart of Population A, i.e. wind dominated sources to which the "local" Narrow-Line Seyfert 1s belong.

## A cladistic analysis of low-L ELGs in cluster

The WINGS survey (Fasano et al. 2006) is an imaging and spectroscopic study of the brightest X-ray clusters at redshift $0.04 < z < 0.07$ selected from the ROSAT all sky survey.

The sample for this analysis has 1494 galaxies belonging to several clusters.

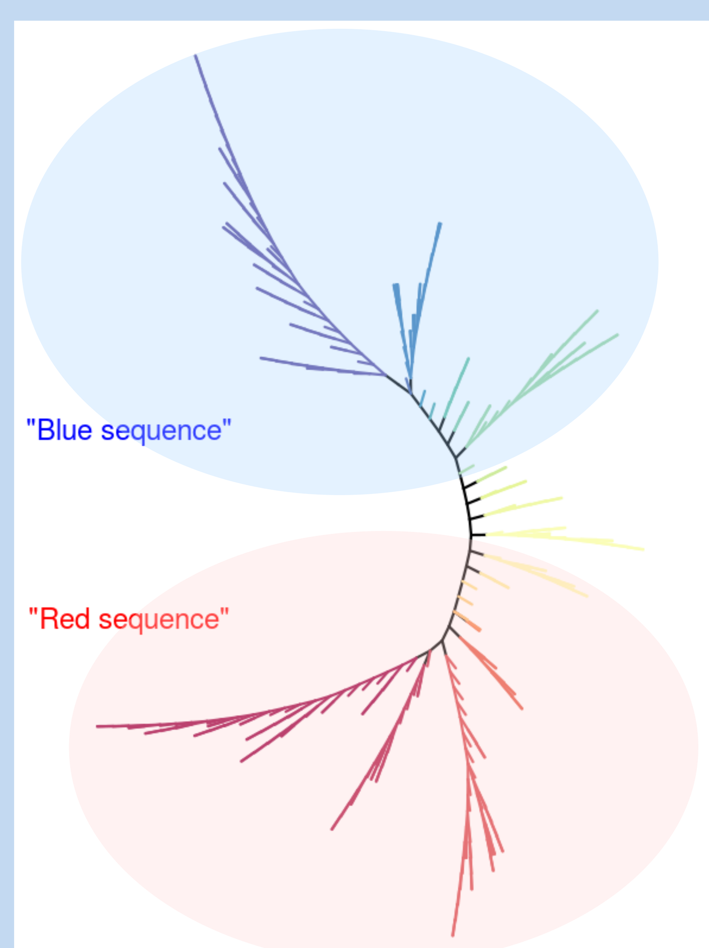
Eleven parameters have been used for the analysis itself: B-V, logRe, surface brightness, Hbeta, D4000, Mass, Sersic index n, Ha/NII, Gband, Mg and Na.




The boxplots above show the statistics of several parameters for each of the groups defined on the tree to the left.

Note that the color progression from red to blue grossly matches the increase in mass of galaxies, as well as other clear trends visible on the boxplots. Sometimes, some groups stand out from these trends.

The morphological type decreases along the tree downward, and possibly the distance to the cluster center as well. Most of the groups have a representant in all the clusters, or conversely all clusters span the entire tree.




We have also analysed a control sample of 497 higher redshift field galaxies. The boxplots do not show as many monotonic trends as for the cluster sample above, indicating that the field galaxies of our sample may not possess a « common ancestor », that is they could be made of two too much distinct populations with to different origins.

The fact that the cluster sample, of low-redshift galaxies, is compatible with a common ancestor could have several interpretation: this can be due to the general influence of clusters on galaxy evolution, or to the fact that time has smoothed out somehat the different origins of these galaxies, or to a lower diversity by a sort of volume selection effect.

Categorizing quasars or galaxies is usually made through a handful of properties at most. Multivariate clustering is still rare, but only phylogenetic tools like cladistics provide relationships that emerge from the data. Here, the quasar sample is relatively well contained in redshift, so probably in diversity. Even though this diversity is much larger for the WINGS galaxy sample, it appears still possible to organize the cluster sample, of low redshift as well, on a phylogenetic scheme that points to several evolutive properties (like color, mass, metallicity but also D4000 and the Sersic index n) characterizing a level of diversification (or evolution). Some of these evolutive correlations are very probably not causal, unlike the quasar evolution with $M_{BH}$.

Some caution is necessary when interpreting the cladograms presented here. One should not conclude that every quasar or every galaxy follows some linear evolution along the tree. There are bunches of branches (sub-structures of the trees) that could suggest some dead ends, or the lack of more ancestral objects. For instance, starting from the low luminosity Pop A quasars, how to understand the branch of more luminous Pop A quasars? Regarding WINGS galaxies, the true ancestors of the objects studied here are at higher redshifts: where the connection to the presented trees would take place ? This is impossible to answer these questions without pursuing the present work.