Evolution as a counfounding parameter in scaling relations for galaxies

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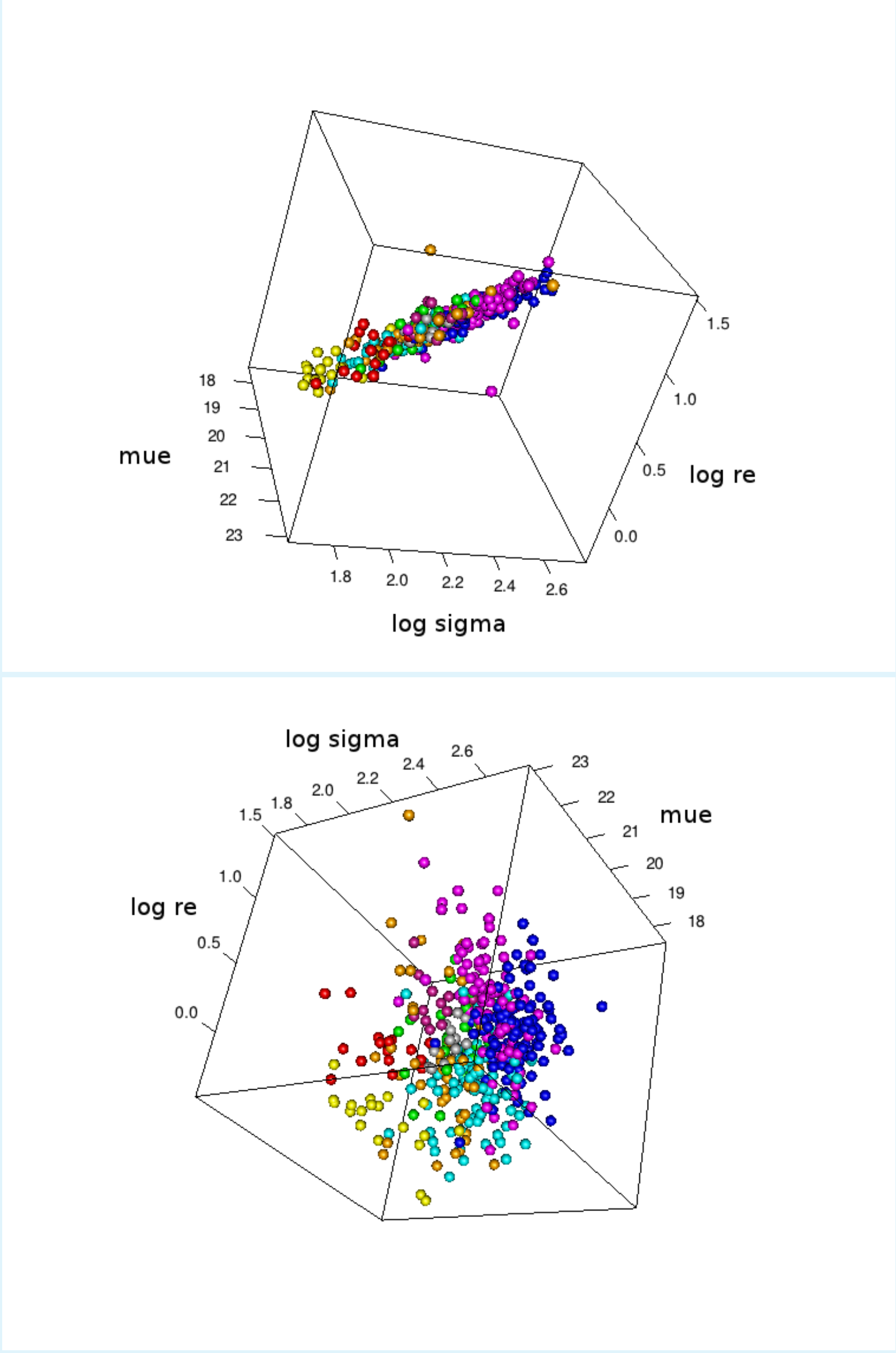
Abstract

Early-type galaxies are characterized by many scaling relations. Evolutionary classifications find that some of these correlations are indeed generated by diversification. With a simple mathematical formalism, we show (Fraix-Burnet 2011) that even the so-called fundamental plane, a relatively tight correlation between three variables, can be easily explained as the artifact of the effect of another parameter influencing all, without any physical hypothesis. In other words, the fundamental plane is probably a confounding correlation, i.e. not physically causal. The complexity of the physics of galaxies and of their evolution suggests that the confounding parameter must be related to the level of diversification reached by the galaxies. Galaxy mass, central black hole mass or the gas fraction during the last big merger are shown to be possible confounding factors. Consequently, many scaling relations for galaxies are probably evolutionary correlations that are explained by the statistical general evolution of most properties of galaxies. This effect makes the observables not independent, so that it must be removed before statistical and physical inferences could be made.

The fundamental plane

The fundamental plane for early-type galaxies is a correlation between effective radius, the central velocity dispersion and the surface brightness within the effective radius (Djorgovski $ Davis 1987, Dressler et al 1987).



References

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Confounding correlations

Let us consider that the effective radius r_e, the central velocity dispersion σ and the luminosity L are all power-law functions of a same generic parameter $\widetilde{X}$:

$$\left\{\begin{array}{rcl} r_e & = & A_1 \widetilde{X}^p \\ \sigma & = & A_2 \widetilde{X}^s \\ L & = & A_3 \widetilde{X}^t \end{array}\right. \tag{1}$$

The surface brightness μ_e can be expressed as

$$\begin{array}{rcl} \mu_e & = & -2.5 \log\left(L/4\pi r_e^2\right) + m \\ & = & (-2.5t + 5p) \log \widetilde{X} + 2.5 \log(4\pi) + m \end{array} \tag{2}$$

where m is a constant of normalisation. Any linear correlation of the form

$$\log r_e = a \log \sigma + b \mu_e + c \tag{3}$$

translates to

$$\left\{\begin{array}{rcl} p & = & sa + (-2.5t + 5p)\, b \\ \log A_1 & = & a \log A_2 + b \left(2.5 \log\left(4\pi A_1^2/A_3\right) + m\right) + c. \end{array}\right. \tag{4}$$

If a solution can be found for a and b from Eq. 4, then the equation of the fundamental plane Eq. 3 is obtained. Conversely, the observations provide a, b and c, so that it is possible to derive p, s and t. There is no need of any further assumption to explain the fundamental plane.

Here are a few examples for $\widetilde{X}$, the relations being constrained only by observations or numerical simulations and Eq. 4:

$$\left\{\begin{array}{rcl} r_e & \propto & f_{starburst}^{-1} \\ \sigma & \propto & f_{starburst}^{1} \\ L & \propto & f_{starburst}^{0.8} \end{array}\right. \tag{5}$$

$$\left\{\begin{array}{rcl} r_e & \propto & M_{BH}^{0.63} \\ \sigma & \propto & M_{BH}^{0.28} \\ L & \propto & M_{BH}^{0.83} \end{array}\right. \tag{6}$$

$$\left\{\begin{array}{rcl} r_e & \propto & (1+z)^{-0.5} \\ \sigma & \propto & (1+z)^{0.4} \\ L & \propto & (1+z)^{0.25} \end{array}\right. \tag{7}$$

Evolutionary correlations

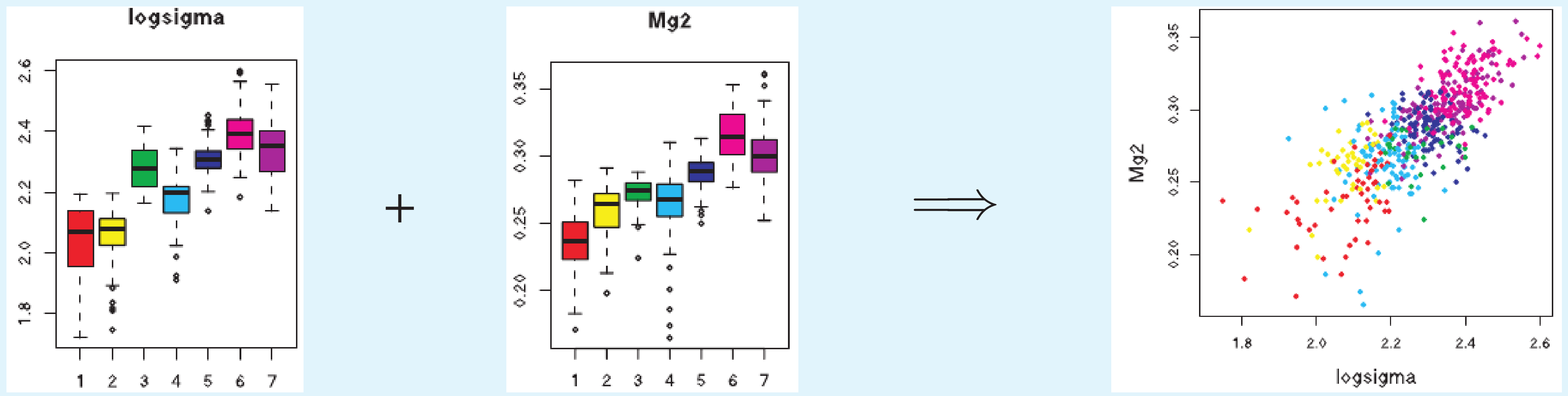
In the course of diversification, many properties of galaxies change, and they tend to statistically change in a more or less monotonous way. It seems difficult to avoid the evolution to act as a confounding factor. It is a well-known problem of comparative methods in phylogeny (e.g. Felsenstein, 1985).

We thus propose that the main confounding parameter is

$$\widetilde{X} = T$$

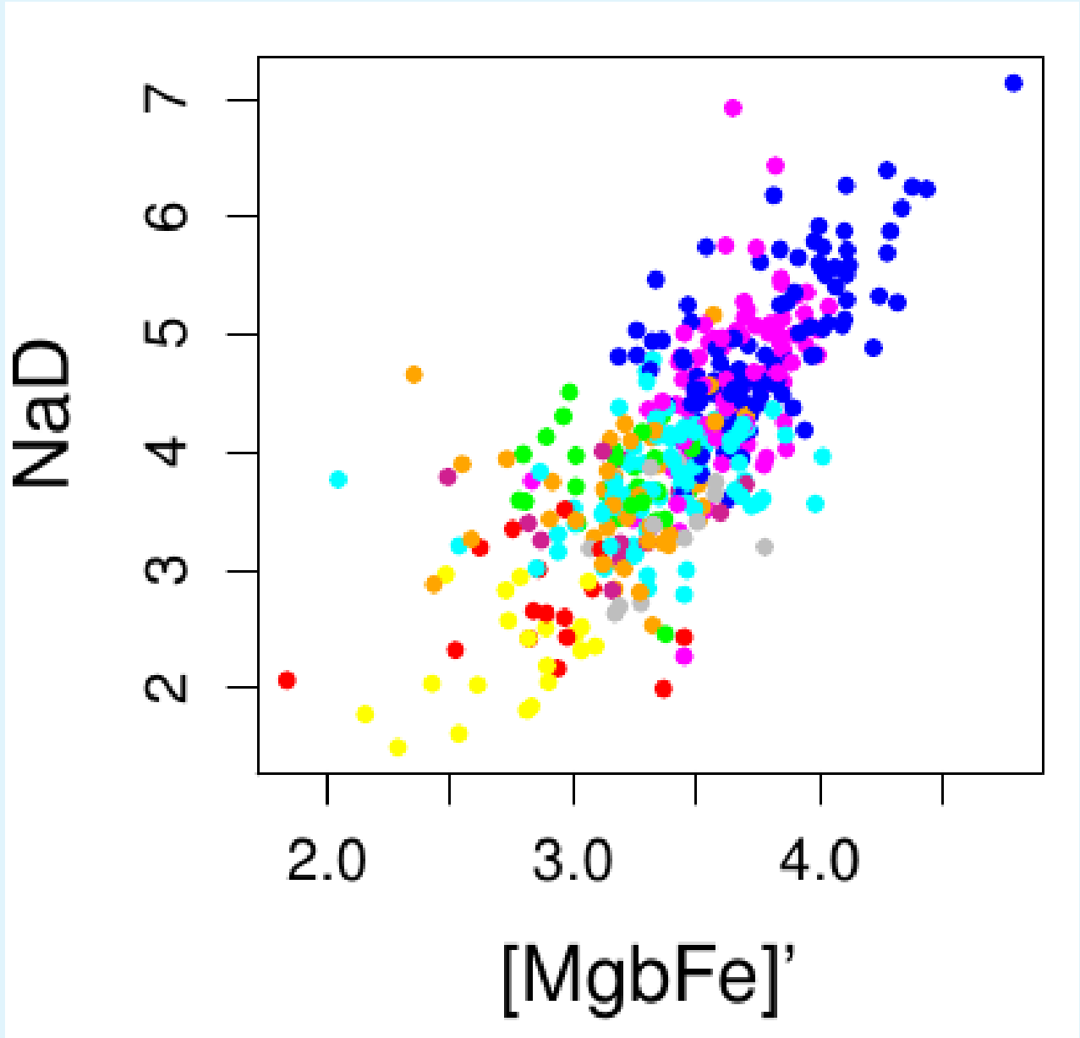
with T an indicator of the level of diversification, being something like an evolutionary clock not necessarily easily related to time or redshift.

Indeed, the evolutionary clock, i.e. the factor $\widetilde{X} = T$, can be hidden, not understandable analytically and not directly observable. It is related to an evolutionary classification (that gathers objects according to their history).



level of diversification

Evolutionary correlation
The evolution generates the correlation



Ordinary correlation
The correlation may depend on the group