Anna Wójtowicz[1], Lukasz Stawarz[1], Jerzy Machalski[1] & Luisa Ostorero[2,3]

The estimation method of the ambient medium density around classical FR-II radio galaxies based on solely radio data

[1] Astronomical Observatory of the Jagiellonian University, ul. Orla 171, 30-244 Kraków, Poland
[2] Dipartimento di Fisica, Universita di Torino, Via P. Giuria 1, I-10125 Torino, Italy
[3] Intituto Nazionale di Fisica Nucleare (INFN), Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy.

Conntact: awojtowicz@oa.uj.edu.pl

I. Introduction

We utilized the sample of *273 classical FR-II* radio galaxies for with their jet physical properties, such as: source life-time, jet power, injection index, and the central density of the gaseous environment, was derived by the means of extensive computational simulations using DYNAGE- dynamical evolution code (*Machalski et al. 2007*). The full sample was described in detail in *Machalski et al. 2021*.

We note interesting correlation between the jet ambient medium density and the spectral index and linear size of the radio structure . As we suspect that spread in this relation maybe to due dependance on another hidden parameters . We study this relation by the means of Bayessian method with APEMoST, performing the linear regression analysis in order to calculate the regression coefficients and the intrinsic spread of a data.

We assume non-informative priors on parameters and model in a form of: $\log\rho \sim N\left(a + b * \log D + \alpha, \sigma\right)$, where σ -is the intrinsic spread.
The most likely values of parameters for the logρ(logD,α) relation was listed in Table 1 and the relation is shown in Figure 1. This relation enables us to evaluate the expected density of the intergalactic medium (IGM) behind jets' front.

Table 1. *The median fit parameters following from the Bayesian regression analysis.*

relation	a	b	c	σ
logρ(logD,α)	0.28±0.23	-1.01±0.07	3.25±0.22	0.40±0.02
logρ₀(lα)	3.08±0.23	----	3.54±0.25	0.44 ±0.02

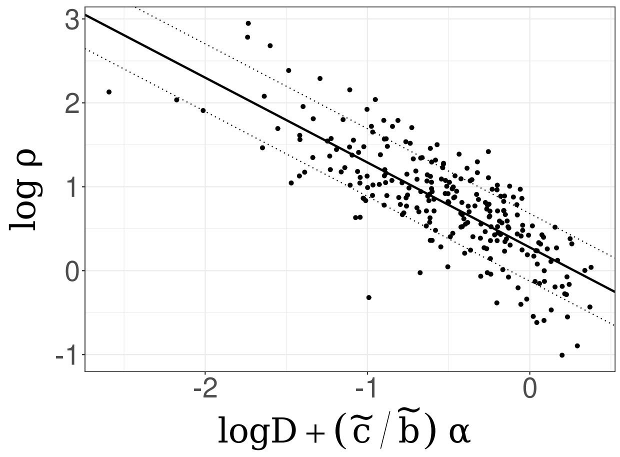

Figure1. *Data points from our set plotted on the projected plane. Solid line corresponds to the regression line a+b logD+c α, while dashed lines indicate the ±σ deviation of the relation; see Table 1 for the median-fit regression parameters' values (a,b,c,σ).*

In order to reduce the possibility that this relation is dominated by the density-size relation we have also investigated the central gas density and spectral index relation (see figure 2). The most likely values as obtained throught Bayesian analysis was shown in table 1. This relation has a great cosmological implication as it enables us to compare the central densities of the medium given solely inforamtion aboout the spectral index inbetween 0.4 GHz and 5 GHz.

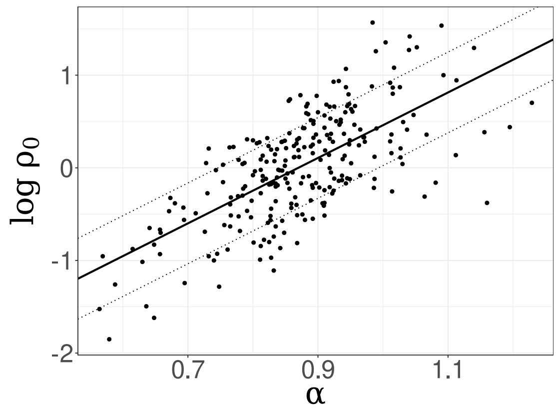

Figure 2. *Data points from our set plotted on the log[$\rho_0 a_0^{3/2}$](α) relation. Solid line corresponds to the regression line a + c α, while dashed lines indicate the ± σ deviation of the relation; see Table 1 for the median-fit regression parameters' values (a,c,σ).*

II. Comparison with the real astrophysical data

In the next step we have investigate possible correspondence of the predicted values of the densities with those that could be obtained observationally.

The direct method in which density of the hot gaseous fraction of IGM can be estimated relies on detailed modeling of good-quality X-ray measurements of the extended, thermal emission component surrounding radio structures. Such data are available currently only for a small fraction of sources subjected to deep exposures with either Chandra or XXM-Newton telescopes. Such detailed analysis for the powerful FRIIs selected from 3CRR catalogue was performed by *Belsole et al. (2007)* for a sample of 20 sources.

Assuming the X-ray surface brightness profiles, corresponding to the IGM emission component, in a form $\Sigma_X \propto [1+(r/r_c)^2]^{-3\beta+0.5}$ *Belsole et al. (2007)* were able to constrain core radius $r_{C,}$ and β parmeter and central gas number density $n_{0.}$ of 20 objects. We have calculated the parmeter $\log\rho_0 r_C^{3/3}$ with $\rho_0 = m_p n_0$, which for the overlapping sources could be compared directly with the regression lines following from our Bayesian analysis as it was presented in figure 3.

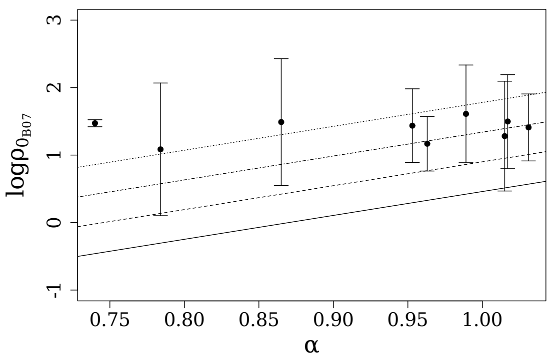

Figure 3. *Comparison between the parameter $\log\rho_0 r_c^{3/2}$ in the 10^8 g cm $^{-3/2}$ units, calculated based on the best-fit values for n_0 and r_c obtained by Belsole et al. (2007) from the X-ray data analysis, and the regression (solid) lines following from our Bayesian analysis. Dashed, dot-dashed, and dotted lines correspond to +1σ, +2σ, and +3σ intervals from the best-fit relations, respectively.*

We note also that although detailed studies of X-ray luminosity profile can be rarely measured, the hot X-ray emitting gas still contributes significantly to the total radiative output of the system. Thus one can consider the total IGM-related X-ray luminosity as a proxy for the central gas density (see equation 1).

$$L_X \propto \int \rho^2 dV \sim \left[\rho_0 a_0^{3/2}\right]^2 \times \left(\frac{1}{3} + \ln\frac{r_t}{a_0}\right)$$

We refer in this contest to the results presented in *Ineson et al. (2017)*, who studied a sample of FR-II radio galaxies with available good X-ray coverage. For the overlapping sources we compared their X-ray luminosities with $\log\rho_0 a_0 \sim N(a + c\,\alpha, \sigma)$ values obtaining strong and significant correlation ρ = 0.71, this comparison was presented in figure 4.

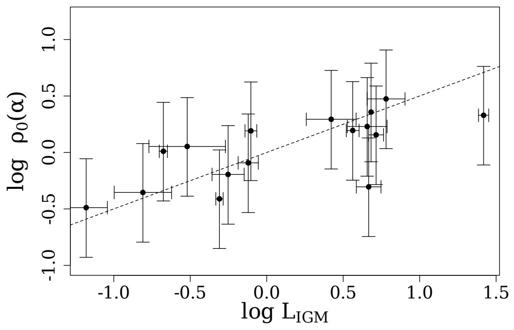

Figure 4. *Comparison between the IGM-related total X-ray luminosities (within the r_{500} radii), in the units of 10^{43} erg s $^{-1}$, as estimated by Ineson et al. (2017), and the predicted $\log\rho_0 a_0^{3/2}$ values. The dashed line represent the y = 0.5 x scaling.*

III. Conclusions

We see evident strong correlation between observationally observed radio parameters such as the linear size of a radio structure (D) and rest-frame spectral index (α). We performed Bayesian analysis and obtained the parameters of the regression line and we measured the associated uncertainty of this relation quantifying the intrinsic spread (σ).
Obtained relation is at 3σ level in agreement with values of the densities obtained by *Belsole et al. (2007)* through detailed study of X-ray surface brightness of powerful FR-Iis. Also we observe strong correlation between measured X-ray brightness by *Ineson et al. (2017)* with expected central densities as follows from obtained relations, that agrees with the error-bar precision with expected theoretical relation as can be seen in figure 4.

References

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