Short Research Article

Phenomenology of Astrophysical Jets and Quasar/Galaxy Unification

ABSTRACT

Statistical and analytical methods have been used in this work to explain some physical phenomena that occur in extragalactic radio jets. Linear regression analyses were carried out among all the source observable parameters in our sample. The sample contains radio loud quasars and radio galaxies. Results of these analyses suggestively indicates that: (1) the physical phenomena which underscore the mechanisms of evolution of these extragalactic radio sources, and which manifest in their radio jet propagation have comparable origins; (2) the propagation of an extragalactic radio jet may depend on the following factors: (i) source energy density, (ii) jet solid angle, (iii) scale factor of the universe, (iv) angular size of the source, (v) density parameter, and (vi) ambient gas particle number density; (3) jet velocity scales as the square root of source energy density and inverse square root of source ambient medium density; (4) radio loud quasars and their galaxy counterparts are similar sources probably seen from different angles of observations. This supports Quasar/Galaxy Unification scheme. In this scheme, the two sub-classes of objects are expected to differ only in their aspect-dependent properties if orientation effects are the major factors that determine their different observed physical features.

Keywords: [black holes, luminosity, quasars, radio galaxies, redshift, jet velocity, radio jets, phenomenology, scale factor, unification scheme]

1. INTRODUCTION

Astrophysical jets are narrow collimated, bipolar outflows ejected from the vicinities of a rotating object that propagate for large distances compared to the size of their launching region [1,2]. They are ubiquitous throughout the universe and can be observed to emerge from protostellar objects, stellar x-ray binaries and supermassive black holes located at the center of active galaxies and are believed to originate from a central object that is surrounded by a magnetized accretion disc [3]. These jets appear in a variety of lengths, durations, energy scales and propagate in different types of media [4]. They appear to be very stable and are able to penetrate vast spaces, which exceed a billion times the size of their central engines. The reason behind this remarkable property is the loss of causal connectivity across these jets, caused by their rapid expansion in response to fast decline of external pressure with the distance from the 'jet engine' [5].

The typical power of astrophysical jets ranges from 10^{30} Watts in YSO and micro-quasars, through 10^{35}–10^{40} Watts in AGN, to 10^{43} Watts in GRBs. Jets in YSOs have bulk velocities of $10^2 - 10^3\ \mathrm{kms^{-1}}$; these are slow, non-relativistic jets. However, relativistic jets can attain velocities close to the speed of light, with bulk Lorentz factors from a few in microquasars, up to 10^2−10^3 in GRBs [2]. Jets from young stars are traced up to distances of few parsecs and their initial radius, which should be about the size of their central engine, is somewhere between two stellar mass radius, $2RM_{\odot}$ and 0.1–10 AU, depending on the engine model [6]. Thus, stellar jets cover the distances of order of initial radii.

However, jets from AGN are more impressive and powerful, their initial jet radius is comparable to the gravitational radius of black hole, [7]. These jets can be traced up to the distances of hundreds of kilo parsecs, which is about one billion initial radii. None of the jets produced in laboratories using most sophisticated jet engines comes even close to their cosmic counterparts in terms of their 'survival' abilities. They lose integrity and get destroyed by dynamic instabilities on much smaller scales, no more than a hundred of initial jet radii. This remarkable apparent stability of cosmic jets has attracted a lot of attention from theorists, resulting in a very long list of analytical and numerical studies [1].

The origin of astrophysical jets remains a fundamental open question. A well-known proposal for jets is the "twin-exhaust" model [8] where hot rotating gas within the center (< kpc's) of a galaxy is envisioned to escape through sonic points (de Laval nozzles) located along the rotation axis. A widely favored idea for the origin of the jets is based on the occurrence of narrow, essentially empty vortex funnels in the accretion flows [9 -11]. It is suggested that the vortex funnel "walls" act to provide collimation for the hydrodynamic outflow through a de Laval nozzle. An alternative proposal is that the jets are electrodynamically accelerated owing to the unipolar induction dynamo effect [12]. Jets being associated with objects of stellar mass as well as much larger masses in galactic nuclei are found in sources that appear to be accreting gas subcritically as well as supercritically [13 - 15]. Many of these jets are one-sided whereas some, especially the weaker ones, are two-sided. Thus, it seems then that jet production is not a particularly specialized phenomenon, but can operate under widely differing conditions and indeed several distinct mechanisms may be involved. Although there is no direct observational evidence for the above, it is widely assumed that most extragalactic radio sources are formed in the vicinity of a spinning massive black hole [16 -17].

The phenomena associated with astrophysical jets is extremely rich and diverse. Its study comprises many areas of Physics, from magnetohydrodynamics (MHD), Plasma, Relativity, Classical mechanics, Nuclear physics to elementary particle interactions. These jets are intriguing cosmic phenomena which remains a subject of intensive observational and theoretical study since the day of their discovery. However, despite the tremendous progress both in observations and theory, the mechanism(s) responsible for the collimation, propagation and acceleration of the plasma is still unknown [4].

In this paper we use statistical and analytical methods to explain some physical phenomena that occur in extragalactic radio jets.

2. DATA, ANALYSES AND RESULTS

The analyses are based on combined samples from Nilson 1998 [18] compilations. It comprises of 235 quasars and 411 radio galaxies totaling 646 radio source samples. These samples are based on surveys between 10MH to 10 GH Luminosity.

Linear regression analyses were carried out among the source' observable parameters and the results of these analyses are tabulated in table 1 for radio loud quasars and table 2 for radio galaxies. Table 3 depicts the parameter relationships with best correlation coefficients.

Below are tables enumerating the properties and inter-correlations among the parameters. The table has values:

C, stands for correlation value
S, stands for slope of the graph
I, stands for intercept on the vertical axis of the graph
Z, stands for Redshift
Ɵ, stands for angular size of the source
D, stands for linear size of the source
P, stands for relative strength of the source
L, stands for luminosity
Q, stands for arm length ratio
Ø, stands for flux ratio

Table 1. INTER-CORRELATIONS AMONG PARAMETERS FOR RADIO LOUD QUASARS

	PARAMETER/PROPERTY	Z VS Θ	Z VS D	P VS Z	Z VS L	Z VS Q	Ø VS Z	D VS Θ	P VS Θ	Θ VS L	Q VS Θ	Ø VS Θ	P VS D	D VS L	D VS Q	D VS Ø	P VS L	P VS Q	P VS Ø	L VS Q	Ø VS L	Ø VS Q
QUASARS	C	0.45	0.343	0.16	0.823	0.082	0.21	0.98	0.12	0.47	0.24	0.07	0.15	0.36	0.23	0.03	0.19	0.04	0.05	0.17	0.15	-0.03
	S	-0.11	-0.09	-0.03	0.04	0.06	0.05	1.03	-0.09	-0.006	-0.69	-0.06	-0.11	-0.005	-0.64	-0.03	-0.002	0.152	0.06	0.006	0.002	-0.009
	I	1.73	2.47	-0.83	1.63	0.14	-0.29	0.95	-0.88	1.66	0.27	0.06	-0.63	1.66	0.35	-0.33	1.65	0.178	0.029	1.65	1.65	-0.009

Table 2. INTER-CORRELATIONS AMONG PARAMETERS FOR RADIO GALAXIES

	PARAMETER/PROPERTY	Z VS Θ	Z VS D	P VS Z	Z VS L	Z VS Q	Ø VS Z	D VS Θ	P VS Θ	Θ VS L	Q VS Θ	Ø VS Θ	P VS D	D VS L	D VS Q	D VS Ø	P VS L	P VS Q	P VS Ø	L VS Q	Ø VS L	Ø VS Q
R. GAL	C	0.57	0.29	0.509	0.82	0.11	0.04	0.88	0.237	0.58	0.13	0.085	0.04	0.22	0.09	0.163	0.51	0.07	0.074	0.067	0.004	-0.31
	S	-0.12	-0.07	-0.07	0.07	0.12	-0.02	1.11	0.175	-0.009	-1.77	0.148	0.02	-0.004	-0.38	0.232	0.006	0.55	0.196	0.006	-0.0001	-0.01
	I	2.16	2.49	-1.42	1.63	0.12	-0.04	1.11	-2.45	1.66	0.16	-0.14	-2.0	1.65	0.178	-0.33	1.63	0.15	-0.002	1.64	1.64	0.08

Table 3. TABLE OF GOOD CORRELATION COEFFICIENTS

	PARAMETER PROPERTY	Z VS Θ	Z VS D	Z VS L	Θ VS D	Θ VS L	D VS L
QUASARS	C	0.45	0.343	0.823	0.98	0.47	0.36
	S	-0.11	-0.09	0.04	1.03	-0.006	-0.005
	I	1.73	2.47	1.63	0.95	1.66	1.66
R. GAL.	C	0.57	0.291	0.82	0.88	0.58	0.22
	S	-0.12	-0.066	0.07	1.11	-0.009	-0.004
	I	2.16	2.49	1.63	1.11	1.66	1.65

REDSHIFT (Z) – LUMINOUSITY (L) RELATION

From the linear regressions we obtain equations for the Redshift – Luminosity relations. For the galaxies, we have

$$\mathrm{Log}_{10}\,\mathrm{L} = 1.63 + \log(1+\mathrm{Z})^{0.07} \quad (1)$$

For the quasars, we obtain

$$\mathrm{Log}_{10}\,\mathrm{L} = 1.64 + \log(1+\mathrm{Z})^{0.04} \quad (2)$$

From the work of Ubah et al (2022) [19] on effects of cosmic dilation on radio luminosity of extragalactic radio sources, the above equations with the help of analytical method employed showed that

$$\mathrm{L} \sim \mathrm{a}^{-\mathrm{n}} \quad (3)$$

Here a is the scale factor of the universe. The above equation shows that the luminosity of astronomical radio objects has an inverse power law function with the scale factor of the universe.

Also from relativistic jet propagation, Ubah & Ezeugo (2021) [1] obtained the velocity of astrophysical jet as

$$\mathrm{V_j} \approx \frac{2\sin\theta}{\mathrm{K}a^{\mathrm{x}}}\left(\frac{\pi \mathrm{r}^3 \mathrm{HU}}{\mathrm{m_H c n_e} \Omega}\right)^{\frac{1}{2}} \quad (4)$$

For simplicity and for the purpose of trimming the last equation down to factors which we assume to be the most important among all in the equation, (i.e. assuming the following: θ, a, r and Ω are constants) we obtain

$$\mathrm{V_j} \sim \sqrt{\frac{\mathrm{U}}{\mathrm{n_e}}} \quad (5)$$

3. DISCUSSIONS

Looking at Table 3, (table of good correlation coefficients), we can see that the correlation coefficient for luminosity/redshift relationship is exactly the same for both quasars and radio galaxies suggesting a variation parameter that is independent of the type of radio source and dependent on the same phenomenological process. It is also observed that the correlation coefficient for redshift/angular size relationship is appreciable. On luminosity/angular size, we also find good correlation for both radio sources. This same phenomenon is also observable in the redshift/linear size relationship and luminosity/linear size relationship for both radio sources.

The good correlation coefficients obtained on the redshift/luminosity, redshift/angular size, luminosity/angular size, redshift/linear size and luminosity/linear size plots in both sub-classes of extragalactic radio sources suggest that the physical processes which occur in them are quite similar. Hence, from the foregoing, it appears that the physical phenomena which embrace the mechanisms of evolution of these sub-classes of sources, and which manifest in their radio jet propagation have comparable origins.

Further analysis on the linear regressions obtained from the redshift/luminosity relationship shows that $\mathrm{L} \sim a^{-\mathrm{n}}$ (see equation (3)). The above stated relation shows that the observed luminosity of a radio source has an inverse power law relationship with the scale factor of the universe. Equation (3) relates the luminosity of the radio source to the scale factor of the universe. This equation shows that the luminosity of a radio source at an earlier epoch should be greater than its luminosity at a later epoch. This is also in line with what is obtainable in the literature [20,21].

Furthermore, analysis of jet interaction with its ambient environment results in equation (4) ($\mathrm{i.e}\ V_j \approx \frac{2\sin\theta}{Ka^x}\left(\frac{\pi r^3 HU}{m_H c n_e \Omega}\right)^{\frac{1}{2}}$). This relation indicates that the propagation of an extragalactic radio jet may depend on the following factors:

a. Source energy density (U).
b. Jet solid angle (Ω)
c. Scale factor of the universe (a)
d. Angular size of the source (θ)
e. Density parameter (Ω_0 , since it determines the value of x)
f. Ambient gas particle number density (n_e)

For the purpose of trimming equation (4) down to factors which we assume to be the most important among all in the equation, we obtain equation (5) (i.e $V_j \sim \sqrt{\frac{U}{n_e}}$). This relation suggestively indicates that jet velocity has a direct power-law relationship with the source energy density and an inverse power-law relationship with the ambient particle number density. This result is in consonance with results obtainable in the literature [1,22]

Moreover, it is easily noticed from Table 3 that the correlation coefficients (C), the slopes (S), and the intercepts (I) obtained for the quasars are in harmony with those of the galaxies. These similarities are expected in Quasar/Galaxy Unification Scheme. In this scheme, the two sub-classes of object are expected to differ only in their aspect-dependent properties if orientation effects are the major factors that determine their different observed features. This suggestively shows that radio loud quasars and radio galaxies are similar sources probably seen in different angles of observation.

4. CONCLUSION

In conclusion, we find that

a. The physical phenomena which underscore the mechanisms of evolution of extragalactic radio sources, such as quasars and radio galaxies, and which manifest in their radio jet propagation have similar origins.

b. The propagation of an extragalactic radio jet may depend on the following factors:

a. Source energy density (U).
b. Jet solid angle (Ω)
c. Scale factor of the universe (a)
d. Angular size of the source (θ)
e. Density parameter (Ω_0 , since it determines the value of x)
f. Ambient gas particle number density (n_e)

c. Jet velocity scales as the square root of source energy density and inverse square root of source ambient medium density.

d, Radio loud quasars and their galaxy counterparts are similar sources probably seen from different angles of observations. This supports Quasar/Galaxy Unification scheme. In this scheme, the two sub-classes of object are expected to differ only in their aspect-dependent properties if orientation effects are the major factors that determine their different observed features.

5. REFERENCES

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