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Morphology and Evolution of Radio Galaxies

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Abstract

This paper is mainly on radio galaxies. Some brief information is given here so that we can better search or analyze various issues related to radio galaxies, such as their morphology, evolution and dynamic properties. What is Active Galactic Nucleus or AGN, what are FR-l and FR-ll radio galaxies, for what reason are radio zets ejected from AGN, how far are they able to travel, what is the total life span of zets, what is their luminosity form, various structural aspects of the galaxy, including many other important information which are apparently sight we do not know or due to observational weakness could not understand properly. At the end of the paper there are some mathematical details, related to luminosity, radio power, zets velocity, etc.

Keywords: Radio galaxy; Zets; AGN; Black holes; Luminosity, Seyfert galaxy; Zet evolution; Morphology; Universe; Mathematics

Introduction

The radio galaxies are very rare type of galaxies. They do not have the same morphology as normal galaxies. The oldest stars in the universe reside in the radio galaxy. The metallicity of these stars is quite high *i.e.* they are population-ll stars. 1% of the galaxies in the universe are radio galaxies [1]. However, in order to be a radio galaxy, the mass of the black hole in the center must be at least 10^8 solar masses to 10^9 solar masses. Various types of astrophysical events occur continuously in the region near the black hole. These are called AGN (Active Galactic Nuclei). Not all galaxies contain AGN. Galaxies with AGNs do not form new stars, or the star formation rate is significantly lower than that of other galaxies. So they are also known as death galaxy and that luminosity should be at least 10^12 to 10^15 solar luminosity [2-4]. Their light spectrum is basically not in the visible light range. The wave length of the light emitted from them falls within the radio range. So they are called radio galaxies. The luminosity of radio galaxies is about 10^39 watts. Their frequency is quite high, like 10 MHz to 100 GHz respectively. A total of 10^5 radio galaxies have been detected to date. Among them the 800 radio galaxy lobes span 770 kpc, which is 22 times the size of the Milky Way galaxy. Zet and counter zet are emitted through synchrotron emission from AGN in radio galaxies. The surface through which these zets are emitted is perpendicular to the accretion disc of the black hole. The accretion disc is the disc through which matter feeds from the black hole, ISM (Inter Stellar Medium). Morphologically radio galaxies are divided into two main groups, namely: Feneroff Relay one or FR-l and Feneroff Relay two or FR-ll [5,6].

FR-l

- Generally they give broad line emission.
- Source bright towards the center.
- Lower in luminosity.
- Edge darken lobes.
- Steepest spectrum emission found in outer edges.
- Smooth, turbulence, continuous double jets are found in that galaxy.
- Their zet, they make lobes by crossing a very short distance. Therefore FR-l galaxiesare quite compact in nature.
- Their zets travel at much less than the speed of light.

FR-ll

- Edge brighten lobes.

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- Source bright towards the edges.
- Steepest spectrum emission find in inner edges.
- Higher in luminosity (approximately L>10^32 Erg/sec/Hz).
- The zets of FR-ll form lobes only after traveling a long distance. So they are notcompact size like FR-l.
- Their absolute magnitude is about -19.9. It shows how luminous it can be.
- The zets of such galaxies can travel at 0.1c of the speed of light.
- They are able to provide narrow line emission.

Literature Review

Synchrotron emission

Synchrotron emission is a non-thermal emission. When relativistic charged particle like electron, circles around a strong magnetic field, then they interact with the magnetic force field line, as a result they continue accelerated and emitting photons with a frequency, that frequency is determined by the velocity of electrons at instance. Furthermore in synchrotron emission the velocity vector of relativistic charged particles is perpendicular to the acceleration vector. Moreover, every time electrons or charged particles rotate around a strong magnetic field, they lose their energy by emitting photons. So the mathematical equation for energy loss will be:

$$\Delta E=(4\pi ke^2\gamma^4\beta^3/3r)$$

Where,
ΔE=The energy loss of electron per orbit (scyntrone emissions as electron emit photons).
r=radius of the orbit k=constant (value=9×10^9 si units) γ(gamma)=$1/\sqrt{(1-\beta^2)}$.
e= charge of electron β=V/C as electron moves at speed of light so relativistic effects are common.

Moreover, the flux density of radio galaxies is denoted by S. That is: $S \sim v^{-\alpha}$.
Here S is flux density; v is the frequency of the photon and α is spectral index. Values of α range from 0.5 to 0.7. When relativistic zets are released from the active galactic nucleus through scyntron emission, they interact with neutral hydrogen atoms, molecular gas clouds, stellar dust grains, cold gases, etc. in the interstellar medium and experience a kind of drag force. This is much like when someone swims against the current of a river, the force the swimmer feels from the opposite current. The zets then spread out over as much space as possible to form lobes. There are also some regions of the lobes whose luminosity is quite high. These places of intense emission are called hot spots. Moreover, due to the effect of radio jets around the lobes, the gasses become hot and ionized and spread out, they are called radio gasses. The gases that are located near the Active Galactic Nucleus (AGN) are called compressed inter cluster gas and those far away from AGN are called hot intercluster gas. In many cases, it can be seen that due to the internal motion of radio galaxy or any external gravitational effect or influence, the zets are bent or slightly twisted which helps to give radio galaxies a unique feature. I have already said that the surface through which the zets are emitted is perpendicular to the accretion disc of the black hole. A brief description of some known radio galaxies is listed below:

Alcyoneus

- It is the largest radio galaxy in the universe.
- Alcyoneus is approximately 3.5 billion light years from the Milky Way galaxy.
- It is located in the lynx constellation.
- The absolute magnitude of Alcyoneus is about 17.16.
- Its red shift is about 0.246.
- Binding mass of Alcyoneus is 2.46×10^11 solar masses.
- Its lobes span 16 million light years. The companion galaxy is 3C 236, whose lobesextend over 15 million light years.
- Alcyoneus has a radius of at least 242,700 light years.
- It falls under FR-ll class.
- The luminosity is about a million times greater than that of the Milky Way galaxy.

Cygnus A

- In 1939, Grotty Rieber detected the galaxy Cygnus A with his backyard radio telescope. It is one of the first radio galaxies

discovered.
- It is located in Cygnus constellation.
- Red shift is about 0.0560.
- Sygnus A, has a binding mass of 10^5 billion solar masses.
- It is located 600 million light years away from us.
- Absolute magnitude of Cygnus A is 16.22.

3C 295

- 3C 295 radio galaxy has an absolute magnitude of -19.9.
- It is located 4.6-5.6 billion light years away from the Milky Way.
- 3C 295, located in the Bootes constellation.
- Its diameter is 2 million light years.
- Like Alcyoneus it also falls under FR-ll class.

3C 236

- 3C 236 is 1.3 billion light years away from us.
- It is placed in Leo Minor constellation.
- Absolute magnitude is about 16.4 g
- Its lobes extend across 15 million light years.

Hercules A

- Hercules A is located 2.1 billion light years from our galaxy.
- It is located in Hercules constellation.
- Apparent magnitude is about 18.33.
- Absolute magnitude is at least -22.88 or -23.

Centurious A

- Centurius A radio galaxy is located in the Centurius constellation.
- Its distance from Milky Way is about 13 million light years.
- Centurious A is about 13.5 billion years old.
- Its binding mass is at least 10^3 billion solar masses.
- Its radius is 48500 light years.

J1216 0709

- j1216 0709 is located 2 billion light years away from the Milky Way galaxy.
- It has three lobes, namely:
- Lnner lobes (spanning about 310 thousand light years).
- Middle lobes (spanning about 770 thousand light years).
- Outer lobes (extending about 2.7 million light years).

Evolution of radio zets

The evolution of the relativistic zet flow out in radio galaxies mainly occurs in four stages:

- At initial or at the beginning "a flood and channel phase start", where the zets are interacting with high pressure cold clumps of gases.
- As a consequence of the first phase "a structure of spherical" energy driven bubble phase starts.
- This is very rapid and subsequent phase where the zets are free out from the dense clouds of gases.
- At the final phase or round, the zets are traveling through a large distance more than 20 kpc, with a high energy momentum fashion.

Two important statements on radio zets:

- When the zets are released through synchrotron emission in radio galaxies, the zets are attracted to the stellar dust, cold gasses, neutral hydrogen atoms, molecular clouds along their direction. As a result, they become hot, excited and ionized and are driven out of the galaxy. All these zets are emitted from AGN with supersonic velocity and the interstellar material in their path reaches the inter galactic medium at a speed of 2000 kilometers per second, as a result of which the star formation rate is triggered there. Moreover, under the influence of zets, heavy metal spreads in the intergalactic medium. Due to these reasons, radio galaxies lose mass by one solar mass every year. For which the star formation rate in radio galaxies disappears and new star formation stops.
- As the interstellar material is driven out of the galaxy, it forms a cut-off region, with hot, excited, energetic gas on one side and cold, dense gas on the other side. And they cannot mix with each other.

Different structural phases of zets

Radio zets *i.e.* the entire radio structure is sometimes compact, sometimes non-compact. It depends on how fast and how far the zets travel after being ejected from the AGN. But observationally the zet phase of these galaxies is divided into two parts namely:

- Compact Symmetric Object Phase (CSOP).
- Middle Sized Object Phase (MSOP).

Among them, the CSOP spans less than 1 kpc. Moreover, the total lifetime of radio zets is 10^8 to 10^9 years. However, the compact symmetric object phase is 1/100 to 1/1000 years of the total life time of the zets. On the other hand the MSOP state is not very compact. In this case the radio zets spread over 1 kpc to 20 kpc space. Which is totally different or separate from CSOP.

Winged radio galaxy

FR-l, FR-ll, double radio galaxy, wide tailed radio galaxy, X-radio galaxy and Z-radio galaxy each fall within the winged radio galaxy. Examples of FR-l and FR-ll galaxies are 3C 449 and 3C 175, respectively. Wide tailed radio galaxies are those galaxies whose zets are first emitted in the opposite direction from the AGN, then their trajectories bend, diverge parallel to each other and form lobes.

Usually the secondary lobes of radio galaxies or the lobes that are relatively less bright are called wings. According to the location of wings, winged radio galaxies are divided into two groups, namely: X-radio galaxy (looks more like an X shape); Z radio galaxy (looks more like a Z shape). Moreover, in case of XRG, the lobes are located in the central region. On the other hand in case of ZRG the lobes are located at the edge of the non-central region or primary zets. For X radio galaxies, the angle between the primary and secondary lobes ranges from about 54° to 88°. As many as 33 winged radio galaxies have been found in the universe according to lOTss DR-l and NVSS data. Among them 21 are XRG and 12 are ZRG. Astronomers Ferma and Leahy were the first to detect X radio galaxies in 1997. They found that the lobes of this type of galaxy are symmetrically distributed and they fall into the FR-ll class. Their luminosity is quite high. XRGs consist of two lobes, namely:

- Primary lobes.
- Secondary lobes.

XRGs do not have the same morphology as normal radio galaxies. Their morphology is completely different. First, there is a super massive black hole at the center of the galaxy. Whichever cause comes into contact with another black hole merger and they gravitationally communicate to form a binary pair. After this, the reorientation of the spin axis of the big black hole begins. Essentially, the spin axis of the larger black hole absorbs the orbital momentum of the smaller black hole, resulting in a spin flip. Since the accretion disc of the big black hole is perpendicular to the surface through which the radio zets are emitted and the spin axis of the big black hole is perpendicular to the accretion disc, so a slight orientation of the spin axis of the black hole changes the direction of the lobes. For which they have a unique structure or shape and that is very similar to the X shape. Hence they are named X shape radio galaxies. It is capable of explaining the morphology of the shape and structure of both X and Z radio galaxies.

Active galactic nucleus types: Active galactic nucleus or AGN are basically divided into two main categories, namely:

- Radio quite active galactic nucleus.
- Radio loud active galactic nucleus.

90% of all AGNs in the universe are radio AGNs and the remaining 10% are radio loud AGN.

Radio quite active galactic nucleus

- For example radio quite quasar.
- Seyfert type-l, (broad line emission).
- Seyfert type-ll, (narrow line emission).
- Liners.

Radio loud active galactic nucleus

- Radio loud quasar for example.
- FR-I: Lower in luminosity.
- FR-ll: Higher in luminosity.
- Ovo (Optical violent objects).

Parts of active galactic nucleus

- The core contains a super massive black hole. Its mass ranges from 10^8 to 10^9 solar masses.
- Then position the accretion disc which is located 10^-3 pc away from the center of the black hole present in the core. Where the number density of the particle is about 10^15 cm^-3. This accretion disc contains relativistic charged particles, dust, ions, etc.
- Broad line region located after the accretion disc which is located 0.01 pc-0.1 pc away from the center of the AGN. Here the number density of particle is 10^10 cm^-3.
- Narrow line region is located after broad line region which is located 10-100 pc away from the center. Here the number density of particle is from 10^3 to 10^6 cm^-3 respectively.
- Torus or toroidal belt is located after Broad line region which looks a lot like a donut. It is located 100 pc-1000 pc away from the center of the AGN. Basically the torus is a special geometrical belt, which consists of dust particles, stellar debris, etc. Here also the number density of particle is like 10^3 to 10^6 cm^-3. The galaxy discovered by Carley in 2019 was detected in the 18 to 48 Ghz frequency range. The toroidal belt of its AGN is about 300 pc × 500 pc in size. The galaxy consists of three types of zet, viz: Inner zet which is located close to the super massive black hole within the AGN, zet (which is moving linearly from the AGN towards us), counter zet (hence, it is mainly the Main separated from the source and running away from us).
- Moreover, the highly ionized gas region is located between broad line region and narrow line region. This region lies between 1 pc-10 pc from the center. The ionization parameter of the gas present here is 10 to 100 times higher than the ionization parameter of the gas in the broad line region.

Classification of AGN

- Seyfert galaxies are basically a subclass of spiral galaxies. The brightness of their central region is much higher than the entire galaxy. They are able to give broad line emission. Scientists cannot study them in detail due to their high brightness. However, with the advancement of technology, we can unlock their hidden structures.
- Through quasar we can understand whether a galactic nucleus is working as an AGN or not! Quasar is basically quasi-stellar object. As relativistic charged particles move around the black hole surface, they collide with the surface. Due to this, their frictional energy is transferred in the form of radiational energy. Moreover, we also observe quasars through matter feeding through the accretion disc of the black hole. They can give great redshifts, about 2. This red shift we get when the Universe was 1/3 of its current age. The most distant quasar is named J1806-0313, which is located 13.5 billion light years away. It was formed 67 million years after the big bang.
- Moreover, AGN can be classified in another way, through blazars. Blasers are formed when our line of sight, zets direction, is very close. Blazer is falling into the radio loud active galactic nucleus. The remaining 90% is radio quite, but not silent. When the relativistic zets flow out from the AGN obeying the fluid dynamics, they interact with the interstellar material and

the astrophysical phenomenon that is created is called a blazar.

Seyfert galaxy

Generally, the luminosity of active galactic nuclei in galaxies is so high that it is not possible to study the rest of the galaxy properly. But Seyfert galaxies are a little different. Although the luminosity of their AGN is high, we can still study their structures in detail. They are a sub class of spiral galaxies. About 2% of spiral galaxies in the universe are Seyfert galaxies. They show strong luminosity in a very unusual way. Moreover, their emission spectrum is characterized by broad lines. However, ordinary galaxies are capable of narrow line emission. Seyfert galaxies can be noted for broad lines, because there is a large amount of ionized gas, whose wave length is sometimes red shifted and sometimes blue shifted. As a result narrow-broad type of population is obtained. But statistical analysis shows that the number of broad lines is quite high. The luminosity of Seyfert galaxies fluctuates over weeks or months. Which is basically the index of their magnitude scale for small deviation. Observationally we divide Seyfert galaxies into two categories. For example:

- Seyfert type-l.
- Seyfert type-ll.

Seyfert type-l

- Strongly luminous in X-ray and UV ray.
- Broad line emission is noticeable.

Seyfert type-ll

- Comparatively less luminous in UV rays.
- Narrow line emission is noticeable.

Seyfert type II galaxies are notable for their narrow line emission, as they host a large amount of stellar dust, which absorbs enough emission from AGN and the very low emission we observe. For example NGC7742 is a Seyfert galaxy.

Seyfert galaxies are not like FR-I or FR-ll. Their morphology and evolution history are completely different. Moreover FR-I,s are the parent population of BL-Lac objects and FR-ll,s are the parent population of radio loud quasars.

Discussion

According to an important fact, during the first 700 million years of our universe, the red shift was about 7.5. At that time there were not as many galaxies as today. Only a few galaxies were formed. The black hole at the center of all those galaxies had a mass of about 10^6 to 10^9 solar masses. That is, they used to work as super massive black holes. But the question is how these super massive black holes are created or evolved in such a short period of time at the beginning of the universe? Because the universe was quite new then. Its conditions were not like today. But an answer lies within the CMBR. It is observed that for every 10^5 parts of the CMBR, there will be at least one part where the matter density is relatively high. So more matter comes to all those parts, creating strong gravitationally bound region, through gravitational collapsing of matter. Which helped to create bigger and bigger structures in the next universe. The mini black holes formed at the beginning of them, become big black holes by merging with each other.

Mathematics of radio galaxies

I will try to explain some mathematical equations related to radio galaxy below, which are able to statistically analyze galaxy dynamics and their various properties.

First, radio power

$P(\text{radio})=4\pi D(L)^2 S_v(1+z)^{(\alpha-1)}$.
In this case D(L) is the luminosity distance, S_v is flux density, z: Red shift, α: Spectral index.

Secondly, radio luminosity

$l(radio)=1.2\times10^{27}\times D(Mpc)^2\times S_0\times\nu_0^{-\alpha}\times(1+z)^{-(1+\alpha)}\{\nu(u)^{(\alpha+1)}-\nu(l)^{(\alpha+1)}\}\times(1+\alpha)^{-1}$ Erg s^{-1}
In this case D(Mpc): Luminosity Distance in Mega per sec. ν(u): Upper cut-off frequency, ν(l): Lower cut off frequency. S_0: Flux density, ν_0: Frequency.

Third, uncertainty in calculating the spectral index due to the uncertainty of flux density

$\Delta\alpha=\{1/\ln(\nu_1/\nu)\}\sqrt{\{(\Delta S/S_1)^2+(\Delta S_2/S_2)^2\}}$

In this case, ν_1: Primary frequency. ν_2: Secondary frequency, ΔS_1: Uncertainty of primary flux density, ΔS_2: Uncertainty of secondary flux density, S_1: Primary flux density, s_2: Secondary flux density.

Calculated from here it is found that the value of spectral index is 0.5 to 0.7.

Fourth, life span of radio zet

$M=(L/\eta c^2)\Delta t$

In this case, M is the accretion mass of AGN. L is Luminosity, η: has a value equal to 0.1, c: is the speed of light, Δt is life time or life span of radio zets. Calculations show that the average life span of radio zets is about 10^6 to 10^8 years.

Fifth, observe luminosity *vs.* luminosity

$L(obs)=\delta^{(3+\alpha)}\,L(int)$

In this case, L(obs) is acting as observed Luminosity. L(int) is the intrinsic Luminosity, α, denotes spectral index, δ: In this case $\delta=1/\gamma(1-\beta\cos\theta)$

Sixth, zet counter zet luminosity ratio

$R=(1+\beta\cos\theta/1-\beta\cos\theta)^{3+\alpha}$

In this case, β is the ratio of zet speed and light speed *i.e.* V/C. θ is the angle with respect to the line of sight. r is the luminosity ratio of zet and counter zet.

Seventh, apparent speed of radio zet

$\beta(app)=\beta\sin\theta/\gamma(1-\beta\cos\theta)$

In this case, β(app) is the ratio of the apparent speed of radio zet to the speed of light, γ is Lorentz factor whose value, $\gamma=1/\sqrt{(1-\beta^2)}$. In this case β=V/C.

Eighth, Eddington luminosity

$L(edd)=1.3\times10^{38}(M/M_\odot)$ Erg/S
In this case, M is the mass of the black hole in the active galactic nucleus; $M_\odot$ is the mass of the sun.

Ninth, antenna equation (minimum strength):

$\Delta S(min)=(2k/A(eff))\times(T(sys)/\sqrt{(B\tau)})$
In this case, k is the Boltzmann constant, A(eff) is effective area of radio telescope, T(sys): How noisy can a system be! Basically it is measured in temperature. B is Bandwidth, τ is integration time.

10th "Stefan-Boltzmann formula: $L=4\pi\sigma R^2T^4$

If L(edd) and $R(s)=2MG/c^2$ are placed here, then it can be seen that a relationship has been formed between mass and temperature, that is, T=1/M^(-1/4).

If the mass of black hole is 1 M⊙ then its temperature is 3 × 10^7 Kelvin.
If the mass of black hole is 10^6 M⊙ then its temperature will be 10^6 Kelvin.

In this case, R is the Radius of the black hole. T is Temperature, σ: Stefan-Boltzmann constant. Its value is 5.67 × 10^-8 watts/m^2/K^{-4}.

Conclusion

In conclusion, this study given brief information about better search or analyze various issues related to radio galaxies, such as their morphology, evolution and dynamic properties. At the end of the paper there are some mathematical details, related to luminosity, radio power, zets velocity, etc.

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