AN APPLICATION OF RELATIVISTIC CHAOTIC GUN EFFECT TO THE JET MODEL OF STRONG RADIO SOURCES

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Abstract.During last 50 years different aproaches of relativistic jets were proposed.But they couldn't explain satisfacatory the high energy of emission, the extremely short time of variability and the position of the source. A likely Fermi acceleration mechanism is the chaotic gun effect. We investigate analitically in this paper the availability of this effect to describe the conical geometry of the jet.
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1.Introduction

In the past decades high energy gamma rays were detected coming from Mrk 501 and Mrk 421 and other activ nucleis.Both of them are thought to be blazars. Blazars are very powerful sources characterized by their variable polarized synchrotron emission . They are associated with radio jets emerging from giant elliptical galaxies seen at small angles with the line of sight.Mrk 501 is ~ 3×10^8 light years from Earth .It produces a tera-electron volt gamma ray flux during outburst.The mechanism of producing such high energy is not yet established . Mannheim assumes two mechanisms responsable for production of high gamma rays:(a) inverse-Compton scattering of low- energy photons by accelerated electrons or (b) pion production by accelerated protons[6]. Models for γ-ray emission from active galactic nuclei(AGN) based on hadronic interactions have in the paste considered interactions between relativistic protons and matter in an accretion disk surrounding a black hole. In almost all attempts to explaine the acceleration of charged particles this mechanism referres to an initial shock in plasma which can provide electrons or protons of high energy. Gamma rays originate in relativistic jets in which the matter density is too low to provide the required target matter for relativistic protons or electrons [5]Also such high energy, of order 10^{12} eV,in many models performed until now, implies the reacceleration of the beam in order to achieve the energy.

To data no mechanism of reacceleration was proposed,as we now, except the chaotic gun effect[1].The authors mentioned that this effect could be applied to the AGN jet's approaches.

Chaotic gun effect provides the reacceleration of a charged particle by an "on-resonance" wave in two regimes:of isolated resonance and of resonances overlap.Both acceleration could provide synchroton emission .

Chaotic gun effect was studied as numerical simulation and all parameters are dimensionless.In our paper we attempt to derive the energy of the synchrotron emission and to suggest the way to fit the conical geometry of the jet of an active galactic nuclei to data . The power of synchrotron emission due to relativistic charged particles consists in two terms: one describing the velocity of the momentum variation and the other one describing the velocity of the energy variation.In ordinary cyclic relativistic motion the former is much bigger than the last.But in chaotic gun effect the last term becomes to be important .In chapter II we assume that the second term,mentioned above, becomes to be of the same range as the first is and we derive the synchrotron energy

2.Assuming the gun effect equations

The power of the synchrotron emission of a charged accelerated particle is

$$P = \frac{2e^2\gamma^2}{3m^2c^3}\left[\left(\frac{d\vec{p}}{dt}\right)^2 - \frac{1}{c^2}\left(\frac{dE}{dt}\right)^2\right] \qquad (1)$$

where m , E and $\vec{p}$ are the rest mass,the energy and the momentum of the particle which Lorentz factor γ is referred to the observer[2].In a relativistic motion one may writes

$$\frac{dE}{dt} = mc^2\frac{d\gamma}{dt} \qquad (2)$$

where,according to [1]

$$\gamma = \left(1 + \frac{p_\perp^2}{m^2c^2}\right)^{1/2} \qquad (3)$$

where $p_\perp$ is the transverse momentum referred to the external magnetic field.
Then the variation of Lorentz factor may be writen as

$$\frac{d\gamma}{dt} = \left(1 + \frac{p_\perp^2}{m^2c^2}\right)^{-1/2}\frac{p_\perp}{m^2c^2}\frac{dp_\perp}{dt} \qquad (4)$$

Substituting (4) in (2) one obtaines a relation between the two terms of the bracket of (1)

$$\frac{dE}{dt} = \frac{p_\perp}{m}\left(1 + \frac{p_\perp^2}{m^2c^2}\right)^{-1/2}\frac{dp_\perp}{dt} \qquad (5)$$

Therefore the power of the synchrotron emission can be expressed as

$$P=\frac{2}{3}\frac{e^2}{m^2c^3}\left(\frac{d\vec{p}}{dt}\right)^2=\frac{2}{3}\frac{e^2}{m^2c^3}\left(\frac{dp_\perp}{dt}\right)^2 \qquad (6)$$

if we will assume $\left(\frac{d\vec{p}}{dt}\right)^2=\left(\frac{dp_\perp}{dt}\right)^2$.The energy emitted during acceleration is

$$E_{syn}=\int Pdt=\frac{2}{3}\frac{e^2}{m^2c^3}\int\left(\frac{dp_\perp}{dt}\right)^2 dt \qquad (7)$$

According to eq.(44) and (45) from [1]

$$\left(\frac{dp_\perp}{dt}\right)=\frac{2kmc^2Hp_y\cos k(x-ct)}{p_\perp} \qquad (8)$$

where k is the wave vector of the wave produced by the beam of charged particles and H=const is dimensionless.(8) provides a proof of the extremely complex motion of the charged particle ; the likely gyrofrecquency of this motion depends on k, $p_\perp$, x,φ,H and t. Substituting (8) in (7) the energy is

$$E_{syn}=\frac{4}{3}\frac{e^2kH}{mc}\int\frac{p_y}{p_\perp}\cos k(x-ct)dp_\perp \qquad (9)$$

As we can see from (9) the dimension of the integrand is $p_\perp$.In order to evaluate the range of the energy it is worth noting that the energy range depends on $k,H,p_\perp$ if one assumes the ratio $\frac{p_y}{p_\perp}$ to be of the order of unity and also the angle $k(x-ct)$.

The energy estimated in (9) can be referred to the "n"th resonance at time t and at distance x from the observer.If we adopt $\frac{p_y}{p_\perp}=\cos\varphi$ then for a certain φ the energy is

$$E_{syn,n}=\frac{4}{3}\frac{e^2kH}{mc}p_{\perp n}\cos\varphi\cos k(x-ct) \qquad (10)$$

3.Numerical estimations of the size of the emitting region

In order to estimate the size of the emitting region we will use data of [3] concerning the size of a compact radio source.Strong radio sources have $P_{tot}^{1.4} > 10^{25} WHz^{-1}$ where $P_{tot}^{1.4}$ is the total spectral power of the emission at 1.4 Ghz.

Let $p_{\perp\min}$ be the lowest momentum of an electron which emits the lowest synchrotron radio energy and $p_{\perp\max}$ the highest momentum coresponding to the highest synchrotron energy.Then for a certain moment and a certain phase φ

$$E_{syn,\max} - E_{syn,\min} = \frac{4}{3}\frac{e^2 kH}{mc}\left[p_{\perp,\max} - p_{\perp,\min}\right]\cos\varphi\cos k(x-ct) = \\ = \frac{4}{3}\frac{e^2 kH}{mc} p_{\perp\max}\left[1 - \frac{p_{\perp\min}}{p_{\perp\max}}\right]\cos\varphi\cos k(x-ct) \qquad (11)$$

where for radio emission $E_{syn,\max}$ =20×10^{-33}J≈10^{-13} eV ; $E_{syn,\min}$ =20×10^{-37}J≈10^{-17} eV. Assuming $\cos\varphi\cos k(x-ct) \approx 1$ and also the bracket in (11) one can estimate $p_{\perp}$.For radio emission this leads to $\gamma = \left(1 + \frac{p_{\perp}^2}{m^2c^2}\right)^{1/2} \cong \frac{2\cdot 10^2}{H}$. For H = 0.2 the Lorentz factor is 10^3.For higher values of H the Lorentz factor decrease. VLBI observations of superluminal motions confirm that the jet plasma in blazars is moving with Lorentz factors of $\gamma \cong$ 10[7]. Using radio interferometry data Mannheim inferred a bulk Lorentz factors γ_{jet} ~ 2 to 10 and even for few cases of still higher values.For these values H must be of the order of 10 which implies strong acceleration in resonsce overlap or o decreasing of the external magnetic field in order to increase β [1].

But also from numerical simulations one can obtaine $p_{\perp\max} - p_{\perp\min}$ and hence an estimation of of the length of jet d_j

$$d_j = r_{j,\max} - r_{j,\min} \qquad (12)$$

where d_j is the difference between the two radii coresponding to the two transverse momentum.The estimation of the range of the two momentum involved (11) may help us to express the length as

$$d_j = \frac{1}{2\pi m}\left(\frac{p_{\perp\max}}{\gamma_n \nu_n} - \frac{p_{\perp\min}}{\gamma_l \nu_l}\right) \qquad (13)$$

where γ_n is the Lorentz factor of the "n"th resonance,which corresponds to $p_{\perp\max}$, ν_n is the corespondengly gyrofrecquency of the charged particle motion, ν_l is the Lorentz factor of the "l"th resonance, which corresponds to $p_{\perp\min}$ and ν_l is the corespondengly gyrofrecquency.

For strong radio source 3C 273 the projected length is about 39 kpc≈39×10^{19} m[3].Strong radio sources has the size of the jet less than 50 kpc [3].

Assuming the first term of the bracket in (13) to be much larger than the second, $d_j \approx 39$ kpc , $m = 9.1 \cdot 10^{-31} kg$ and ν_n =1.4 Ghz one finds $p_{\perp\max} \approx 48.75$ kg m s^{-1}.

A way to probe the above derivation of the synchrotron energy might be the derivation of the velocity of the jet.That is to use the same expression (8) in order to achieve our derivation. For radio sources with steady free jets the radius expands with a constant lateral velocity v_r equal to its internal sound speed c_s where it first become free[3].This is the case of the strong sources.For such sources

$$\frac{dR_j}{dz} = \frac{v_r}{v_j} \qquad (14)$$

where R_j is the radius of jet at the z distance from the nucleus(apex).

In order to verify if(14) occurs for synchrotron emission generated by chaotic gun effect we express the lateral velocity $v_r = \frac{dR_j}{dt}$ as

$$v_r = \frac{d}{dt}\left(\frac{p_\perp}{\gamma m \omega_c}\right) = \frac{1}{m\omega_B} \cdot \left(\frac{dp_\perp}{dt}\right) \qquad (15)$$

where ω_c is the relativistic gyrofrecquency of the synchrotron motion of the particle and it is related to ω_B as $\omega_B = \omega_c / \gamma$ [1]. Using (8) the above velocity (15) becomes

$$v_r = \frac{2kc^2 H p_y \cos k(x-ct)}{\omega_B p_\perp} = \frac{2kc^2 H \cos\varphi \cos k(x-ct)}{\omega_B} \qquad (16)$$

From [1] one can replace ω_c by ω / n where n is the order of the resonance.For what it follows we will assume $\cos\varphi \cos k(x-ct)$=1.Then (16) becomes

$$v_r = \frac{2knc^2 H}{\omega\gamma_n} \qquad (17)$$

where γ_n is the Lorentz factor related to the n-th resonance.For relativistic jets, (14) is the angle γ_n^{-1} .Hence one can estimate the velocity of jet from

$$\frac{v_r}{v_j} = \frac{1}{\gamma} \qquad (18)$$

which together with (17) leads to

$$v_j = \frac{2knc^2 H}{\omega} \qquad (19)$$

But from $\frac{k}{\omega} = \frac{1}{c}$ one obtaines

$$v_j = 2cnH \qquad (20)$$

This result shows that the velocity of the jet depends on the order of the resonance and also on H .For $n = 1$ and $H = 0.2$ (20) leads to $v_j = 0.4c$. For $n = 10$ and $H = 0.2$ (20) leads to $v_j = 4c$ .To date many authors simulated jets or estimated jet velocities.Bridle explored different constraints on jet velocities and found $10^{-2} c < v_j < 0.1c$ for radio emissions [3]. Piner et al. calculate for C 279 an average speed and angle to the line-of-sight for the region of the jet interior to 1 mas of v = 0.992c ($\gamma \cong$ 8) and θ = 4◦, and an average speed and angle to the line-of-sight for C4 (at r ≈ 3 mas) of v = 0.997c ($\gamma \cong 13$) and θ = 2◦[9].For the electron number density of the jet of 0.741nb(where nb is the ambient electron number) the average jet velocities for the two simulations performed by Nishikawa are vj = 0.9798c, 0.9977c corresponding to Lorentz factors are 5 (2.5 MeV) and 15 (7.5 MeV),respectively[8].

Using (20) for suitable values of H and n one can obtaine also superluminal velocities as is obtained for jets viewed at large angle to the plane of the sky[3].

IV.Discussions

From (20) one can obtaines a constraint on the product $2nH$ if we assume $v_j < c$:

$$2nH < 1 \qquad (21)$$

On the other hand $v_j > c$ could occur because of chaotic behaviour of the charged particle at H >0.2 as is mentioned in [1].In this regime,e.g. H >0.2, (9) may not describe the acceleration in the right manner but could explain the detected superluminal motion of jets.

Many jets wiggle around their mean direction.There are some mechanisms proposed to explain the periodic lateral deflections.These mechanisms are fraught with uncertainties.Well-studied jets rarely match simple orbital or ballistic precessional shape convincingly.(10) could explain the small variations of the lateral shape of the jet detected in some data or the shape of droplets of some jets.

In our derivations performed above there is not any cut in the growth of the velocity.This is because our aime was to check if the chaotic gun effect can fit the geometry of a conical jet.A further study may lead to achieve constraints which limit the jet velocity.

V.Conclusions

We derived the synchrotron energy emitted by a charged particle during its acceleration in the magnetic field of a charged particle beam and also in a constant and uniform magnetic field.Numerical estimations showed the availability of the chaotic gun effect to describe the conical shape of the jet by fitting the H parameter.But this parameter may be constraint by the number density of charged particles in beam.

REFERENCES

1. J. Argyris, C. Ciubotariu, A chaotic gun effect for relativistic charged particles,Chaos, Solitons and Fractals 11, 1001±1014, 2000
2. J. D. Jackson,Electrodinamica clasica,Editura tehnica,Bucuresti,1991,238
3. Bridle A.H.,Ann.Rev.Astron.Astrophys.22,319-58,1984
5. Mannheim K.,Hadronic γ-ray emission models – prived comunication
6. K. Mannheim,Science 279,684(1998)
7. Jun Kataoka et al., Characteristic X-ray Variability of TeV Blazars:Probing the Link between the Jet and the Central Engine, arXiv:astro-ph/0105022 v1 2 May 2001
8. K.-I. Nishikawa, Particle acceleration, magnetic field generation, and emission in relativistic pair jets, arXiv:astro-ph/0502331 v1 16 Feb 2005
9. B. G. Piner, THE SPEED AND ORIENTATION OF THE PARSEC-SCALE JET IN 3C279, Accepted by ApJ, Jan 16, 2003, arXiv:astro-ph/0301333 v1 16 Jan 2003