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# ULTRA RELATIVISTIC EXPLOSION IN MOVING MEDIA AS A MODEL OF SUPER-LUMINAL RADIO JETS

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Super-luminal components of radiojets are identified with luminous segments of ultrarelativistic shock fronts (further SF), moving to the observer, in particular, they can be a vicinity of their leading point. The cases of a local hydrostatic equilibrium, accretion and wind flows of a nonperturbed medium in a field of central object («a black hole»?) are investigated. In the case of the noncentral explosion in a medium, being in a state of a local hydrostatic equilibrium [4], the apparent superluminal velocity (further $\beta_{\mathrm{app}}$) of a leading point movement of a shock front (further SF) is asymptotically constant and proportional to a total energy of explosion, according to observational data [2]. In cases of accretion and wind flows the dependences $\beta_{\mathrm{app}}$ on the distance from a leading point to the nucleus are obtained. In the case of explosion with an energy pumping from a central source we manage to identify the observable times of acceleration of radiojets components with the duration of energy pumping from flares correlating with components [5] according to data [8]. The movement influence of a nonperturbed medium upon the shift of superluminal radiocomponents in a picture plane is discussed.

## 1. INTRODUCTION. SUPERLUMINAL RADIO JETS

The components of jets moving with (apparent) superluminal velocities at VLBI observations in a series of radiosources [7] are observed. The observed superluminal (further SL) movement velocities of components are explained by relativistic effects at moving with the major Lorentz-factors under a small angle to the direction of sight. The correlation between occurrence of SL components and optical flares for ultra relativistic (further UR) jets in quasars 3C 345 and 3C 273 [1] was detected. Subsequently the similar correlation was observed also by others [8]. The model, in which the optical flares are identified with off-center UR explosions in a vicinity of AGN, is offered [4]. The superluminal velocities of components are asymptotically constant and they correlate with an energy release in flares [2], that can be explained within the framework of the offered model. The acceleration and further deceleration of SL components of a radiojet 3C 345 is observed, which can be explained by an energy pumping from optical flares and the variability of an exponent in the law of decrease of a medium density in a vicinity of AGN at initial times. The movement of SL components of radiojets in a picture plane is observed, that can be explained by movement of a nonperturbed medium.

## 2. THE ULTRA RELATIVISTIC SHOCK WAVE

The model of UR adiabatic explosion in a vicinity of AGN is discussed. The movement of SF will be ultrarelativistic in the case, if the total energy of explosion $E$ is great enough in comparison with rest energy of a medium confined in the volume $V$ restricted by SF

$$E \gg \rho V c^2, \tag{1}$$

where $c$ is the light velocity.

In the case of UR adiabatic explosion within a frame of a nonperturbed medium, the boundary conditions on SF are

$$p_2 \equiv e_2/3 \equiv 2\Gamma^2 w_1 c^2, \qquad n_2' \equiv n_2\gamma^2 = 2\Gamma^2 n_1, \qquad \gamma_2^2 = \Gamma^2/2, \tag{2}$$

where $\Gamma = \sqrt{1 - v^2/c^2}$ is the Lorentz-factor SF; $p_2$, $e_2$, $n_2$ are the pressure, density of an energy and concentration of particles, measured in the system of the post-shock flow; $n_2'$, $\gamma_2$ and $w_1$ are the concentration of particles, the Lorentz-factor of a pre-shock flow and the density, measured for the rest system of a nonperturbed medium.

For determination of the Lorentz-factor SF (further $\Gamma$) we use the Kompaneyets approximation for UR explosion [6]. The given approximation adequately describes the SF movement at exponents in the law of a density decrease of a nonperturbed medium $n \leq 3$. In the given approximation the pressure $p_2$ uniform along the SF and proportional to the average density of the explosion enegy $p_2 = \lambda\Gamma/V$, is suggested where the constant of proportionality $\lambda$ is determined from self-similar solutions [4]. The Kompaneyets equation for SF in cylindrical coordinats $(r, z)$ looks like

$$\dot{r}/\sqrt{1 + (r'_z)^2} = -[1 - \Gamma^{-2}]^{1/2}, \tag{3}$$

the left-hand side of this relations is a movement velocity SF, directed along a normal line to the front.

From conditions on SF (2), using the Kompaneyets approximation we obtain the expression for $\Gamma$:

$$\Gamma^2 = 3\lambda E/2w_1 V(t)c^2, \tag{4}$$

where $w_1 = \rho_0(R_0/R')^{n}$ is density of a nonperturbed medium, $R_0$ is the distance from AGN up to the point of explosion, $R'$ is the distance from the nucleus to the explosion point, $\rho_0$ — is the medium density in the point of explosion.

In the UR limit the SF becomes spherical $V(t) \approx 4\pi R^3/3$. In view of the latter, the expression for $\Gamma$ looks like

$$\Gamma^2 = 9\lambda E R_0^{n} R'^{n}/8\pi\rho_0 c^2 R^3. \tag{5}$$

At transition to a frame moving perpendicularly to SF with a velocity $\beta_1$ and the Lorentz-factor $\gamma_1$, $\Gamma$ varies according to the law

$$\Gamma' = \gamma_1\Gamma(1 \pm \beta'\beta_1) \approx \Gamma\gamma_1(1 \pm \beta_1). \tag{6}$$

where the sign + corresponds to the frame moving in the direction of SF propagation.

In case of the movement a unshocked medium for the Lorentz-factor of a leading point vicinity of SF from (4) taking into account (6) we obtain

$$\Gamma'^2 = 3\lambda E\gamma_1^2(1 \pm \beta_1)^2/2w_1 V(t)c^2. \tag{7}$$

As a first approximation, at nonrelativistic movement in a vicinity of AGN the relation (7) passes to (4). In this case the medium movement influences SF movement according to the law of a medium decrease in the vicinity of AGN.

## 3. ULTRA RELATIVISTIC EXPLOSION IN A VICINITY OF AGN

### A LOCAL HYDROSTATIC EQUILIBRIUM OF A RELATIVISTIC MEDIUM IN THE VICINITY OF AGN

The guessed law of a relativistic medium decrease is

$$w_1 = \rho_0(R_0/R')^3, \tag{8}$$

The asymptotic constancy GAMMA follows from the expression (5) at major times [4]

$$\Gamma^2 \xrightarrow[t \to \infty]{} \text{const} = 1/2B, \tag{9}$$

where $B = 4\pi\rho_0 c^2/9\lambda E$.

For a source moving under a small angle $\alpha$ in the direction of sight [7]

$$\beta_{\text{app}} = \beta \sin\alpha / (1 - \beta\cos\alpha), \tag{10}$$

where the angle $\alpha$ meets the requirement

$$1/\Gamma^2 \ll \alpha \ll 1.$$

For a vicinity of a leading point SF moving under a small angle $\alpha$, we have from (9)

$$\beta_{\text{app}} \approx 2\alpha\Gamma^2, \tag{11}$$

where $1/\Gamma^2 \ll \alpha \ll 1/\Gamma$.

As we see from (11), in a vicinity of a leading point SF $\beta_{\text{app}}$ is asymptotically constant and proportional to a total energy of explosion. This result is in accordance with the observational data for jets 3C 345 and 3C 273.

## A WIND FLOW

The outflow velocity of a nonperturbed medium is $v_1$ = const, the density decreases by the inverse quadratic law $w_1 = \rho_0(R'/R_0)^{-2}$. According to (7), the Lorentz-factor of movement of a vicinity of a leading point looks like

$$\Gamma'^2 = 3\lambda E\gamma_1^2(1 + \beta_1^2)/2Vw_1, \tag{12}$$

where $\beta_1 = v_1/c$ and $\gamma_1$ — is the velocity and the Lorentz-factor of movement of the outflow of the nonperturbed medium correspondingly.

For major times from the relation (12) the asymptotics for $\Gamma'$ is:

$$\Gamma'^2 \approx \gamma_1^2(1 + \beta_1^2)/2BR. \tag{13}$$

Taking into account (13) we obtain from the expression (11)

$$\beta_{\text{app}} \approx \alpha E\gamma_1^2(1 + \beta_1^2)^2/AR, \tag{14}$$

where $A \equiv EB = 4\pi\rho_0 c^2/9\lambda R_0^2$.

In the case of the outflow of a medium from the AGN with constant velocity $\beta_{\text{app}}$ is proportional to an energy of explosion and asymptotically decreases with the distance between the leading point and the nucleus as $R^{-1}$.

## AN ACCRETION FLOW

The slow accretion (ADAF) on the central compact object («a black hole») is presupposed. The dependence of a density $w_1$ and the velocity $v_1$ medium upon the distance from the nucleus

$$w_1 = \rho_0(R_0/R')^{3/2}, \qquad v_1 = V_0(R_0/R'^{1/2}. \tag{15}$$

In a vicinity of the leading point SF, according to (7), the Lorentz-factor SF is determined by the relation

$$\Gamma'^2 \approx (R')^{3/2}\gamma_1^2(1 - \beta_1)^2/2BR^3. \tag{16}$$

Within the first approximation, when the velocity of accretion movement is small in comparison with the light velocity, the expression (16) becomes

$$\Gamma'^2 \approx (R')^{3/2}/2BR^3. \tag{17}$$

From the expression (17) the asymptotics follows for $\Gamma$ at major times

$$\Gamma'^2 \approx 1/2BR^{3/2}. \tag{18}$$

For a superluminal velocity $\beta_{\mathrm{app}}$ from the relation (18) we obtain

$$\beta_{\mathrm{app}} \approx \alpha E/AR^{3/2}, \tag{19}$$

where $A = 4\pi\rho_0 c^2/9\lambda R_0^{3/2}$.

In the case of slow accretion of the relativistic medium on central compact object the apparent superluminal velocity of a leading point SF asymptotically decreases with the distance as $R^{-3/2}$.

## 4. ACCELERATION OF SUPERLUMINAL COMPONENTS OF RADIOJETS

The case of an energy pumping to SF from a central source by an energy flow $L(t)$ with the Lorentz-factor $\Gamma_{\mathrm{L}} \gg \Gamma$ is considered. The power law of an energy pumping and stratification of a nonperturbed medium is supposed

$$L(t) = L_0 t^{\mathrm{q}}, \qquad w_1 \approx (R')^{-\mathrm{n}}. \tag{20}$$

Time dependence of the Lorentz-factor on the SF leading point vicinity [3] looks like

$$\Gamma^2 \approx t^{-\mathrm{m}}, \qquad m = \frac{q + k - 2}{q + 2}. \tag{21}$$

As we can see from (21), SF will be accelerated at $q \sim + \sim k > 2$. Optical flares correlating with superluminal components of radiojets, were identified according to the energy pumping to SF. In this case, the duration of an optical flares $\tau_*$ is the duration of the presupposed energy pumping. As a result of the delivery delay of the emitted energy portion to SF, the time of pumping $\tau_*$ is not equal to the duration of SF pumping

$$\tau \sim \tau_* 2\Gamma^2(\tau). \tag{22}$$

The observable time of acceleration is equal to the duration $\tau_*$ of an energy pumping (flares) for the remote observer under a small angle of which the leading point moves. As it was shown, for a radiojet 3C345 [5] the estimates of the observable times of acceleration coincide with the duration of optical flares that may confirm the offered model.

The monotonic increase of $X$-coordinates and cyclic variability of $Y$-coordinates of the components in a picture plane is observed. The offered explanation of observable motions of components of SF by involvement rotating medium of an accretion disk is given. The apparent periods $T_{\mathrm{app}}$ of a presupposed rotation of the C4, C5 and C7 components are 12, 20 and 4 years, correspondingly. The true period $T$ for the components rotations is $T \cong \overline{T_{\mathrm{app}}\beta_{\mathrm{app}}}/\alpha$, where the upper line means average value on a phase. For a thin disk $T \sim T_{\mathrm{k}}$, where $T_{\mathrm{k}}$ is the Keplerian period of a disk rotation. We have $\overline{\alpha} \sim 0.001$. The sufficient condition of a monotonicity of $x$ coordinates is $\Omega_{\mathrm{k}} < c\,(\alpha_1 - \alpha_2)/4R$, where $\alpha_1$ and $\alpha_2$ are the angles between the direction of sight and a disk axis and between a disk axis and the line of a component movement. We guess $\alpha_2/\alpha_1 \sim 0.1$, then $\alpha_1 - \alpha_2$ and a requirement of monotony is $(R_{\mathrm{g}}/R)^{1/2} < \overline{\alpha}/4$, $R_{\mathrm{g}}$ is the gravitational radius of AGN. The given inequality is valid for C4 and C5. However, inequality is not valid for C7. The latter can be explained by the decrease of a medium reversion frequency $\Omega < \Omega_{\mathrm{k}}$ with the component removal from a disk plane.

## 5. CONCLUSION

1. In the case of a local hydrostatic equilibrium of a relativistic medium in a vicinity of AGN the asymptotic constancy of an observable superluminal velocity $\beta_{\mathrm{app}}$ and its proportionality of a total energy of the explosion is obtained, in accordance with the observational data [2]. In the case of accretion and wind flows in the vicinity of AGN the dependences $\beta_{\mathrm{app}}$ upon the distance from the nucleus have been obtained.

2. In the case of explosions with an energy pumping from a central source the observable duration of acceleration of superluminal components of radiojets is possible to identify with the duration of energy pumping from optical flares.

3. The explanation of the movement of superluminal radiojets components in a picture plane of a nonperturbed medium movement in a vicinity of an accretion disk is offered.

The obtained data are in accordance with the observational data for superluminal radiojets 3C 345 and 3C 273 [2, 8].

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