ON THE NATURE OF PROCESSES OCCURRING IN ACTIVE NUCLEI OF GALAXIES

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ABSTRACT. An explanation of observed phenomena in AGN is proposed on the basis of the hypothesis about the ejection of compact formations from a "central object" which emits relativistic electrons. In particular, the possible causes of the discrete structure of jets, appearance of "superluminal" velocities and superfast variations of radiation from nuclei in X-ray and optical regions are considered.

The ejection of some carriers of energy from active galaxy nuclei on long distances is a firmly established fact. In many cases this phenomenon is seen in the form of extensive jets (e.g. M 87, NGC 5128 (Cen A), quasar 3C 345, etc.). Radiation is emitted from jets at radio frequencies, often in visible and sometimes in X-ray regions. The strong polarization of this radiation evidences its synchrotron origin.

Different models of jets have been discussed in many papers, mostly hydrodynamical and plasmoid models. These models encounter many difficulties when confronted with observations but this topic is beyond our present scope.

Almost 30 years ago V.A. Ambartsumian suggested that the jet of M 87 was formed by objects ejected from the nucleus and emitting relativistic electrons (r.e.) (Ambartsumian, 1958). The nature of these objects had not been established. According to observations the jets in M 87 and other active galaxies have some common properties - discrete structure, conical form, sharp bendings. To explain these features Ambartsumian's hypothesis was modified by Gorbatsky (1981) who suggested that "bunches" of compact bodies - emitters of r.e. - moving with non-relativistic velocities are ejected from AGN.

As r.e. are not dragged along by the emitters their radiation is observed only from the wake left by the emitters. Thus optical "knots" in jets represent the regions of wakes left by the ejected bunches. The elongation of the wake depends on the energy loss rate of r.e. in magnetic fields; r.e.'s emitting in the radio lose energy more slowly than "optical" electrons. Therefore radioisophotes must be more elongated along radio jets and radiation from several wakes combined

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makes the observed radio jets look continuous. The often observed constancy of the spectral index α along a jet implies that wakes radiate simultaneously.

The magnetic field strength H and energy of r.e. E in the jet region can be estimated on the basis of this model from observations. For example for the optical jet in M 87 one finds

$$H \approx 3 \cdot 10^{-5}\ G, \quad E \approx 2 \cdot 10^{6}\ m_e c^2$$

taking a bunch velocity of $v = 10^9$ cm s^{-1}. If the value of v is different estimates of H and E do not change substantially.

The jet cross section grows due to expansion of bunches and thereby the surface brightness of the wake must decrease with distance from the ejection point. Consequently optical and X-ray radiation may be observable only in jet regions that are sufficiently close to the top of the cone. As for radio emission smaller fluxes may be detected but the observed length of radio jets is significantly greater than of optical ones.

Using VLBI very rapid variability of polarization was detected in some AGN - in degree as well as in positional angle (Rudnick and Jones, 1982). It seems that such variability is stimulated by inhomogeneity of magnetic fields on the scale 0.1 - 0.01 pc (Gorbatsky, 1983). Fields may be inhomogeneous on larger scales - up to 100 pc (for example in M 87 jet). Adopting the model describing a jet as a sequence of bunches of r.e. emitters one can explain in a simple way the phenomenon of superluminal expansion of radio sources. Such expansion may be attributed to motion of emitters in inhomogeneous magnetic fields (Gorbatsky, 1983).

If the bunch of emitters moving in a weak field enters into space containing a strong field, synchrotron radiation increases sharply (and at the same time the frequency corresponding to intensity maximum goes up). In the case of specific field geometry the extent of the region of intense radiation increases swiftly - with velocity greater than that of bunch motion and even, in some cases, with superluminal velocity. This can be demonstrated by means of a model of a bunch having linear distribution of emitters. Let the bunch be moving initially in field free space and at some moment meet a magnetic tube (assumed rectilinear). Let us take a line of sight lying in the bunch plane. The angle between line of sight and bunch velocity is designated ϕ, and the angle between v and field strength H is $90+\alpha^\circ$ (see fig. 1). The apparent velocity v_* of the signal (speed of switching on of emitters) is determined by (1)

$$v_* = c\, \frac{\cos\alpha \cos(\phi+\alpha)}{\frac{c}{v}\sin\alpha - \sin(\phi+\alpha)} \qquad (1)$$

If the fraction on the right side of (1) is improper v_* must be superluminal. The signal may propagate in the same direction as the bunch and in the opposite direction.

Evidently observations of real jets cannot be fully explained

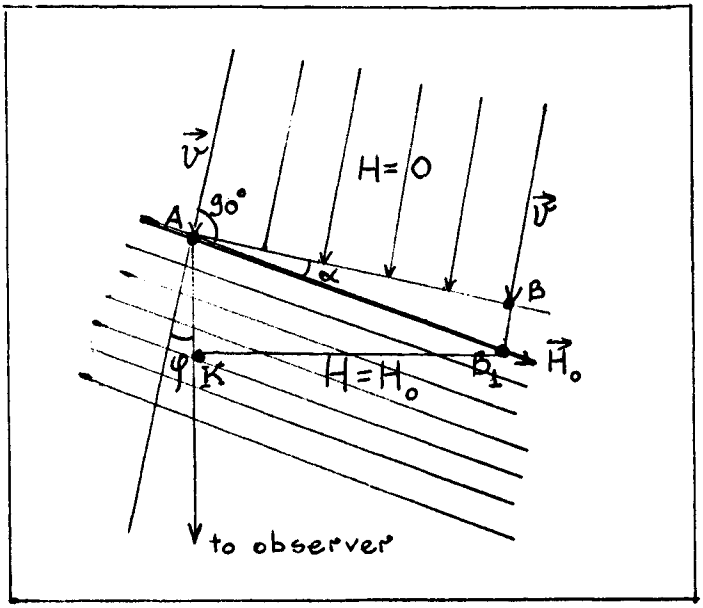

Figure 1. Schematic presentation of propagation of signal from moving bunch.

with the simple model described. The brightness distribution in luminous knots depends on the bunch space structure, on field configuration and on the loss rate of energy by r.e.. If r.e. lose energy very rapidly a sharp moving peak in brightness distribution must be observed.

The radiation of the superluminal component in the jet of the QSO 3C 345 decreases swiftly during 3 - 5 years after its appearance. The radio component rises simultaneously with optical flare lasting for 2 - 3 years, but radio emission may be seen only at sufficiently large distances from the nucleus (Babadzhanjants and Belokon, 1985). The lifetime of moving knots depends on the wavelength λ used in observations - it is more when λ is longer. Such dependence leads to the conclusion that knot brightness is due to the loss of energy by r.e. in a strong magnetic field where they were ejected by emitters. Electrons having higher energy lose it more rapidly. The estimation of H from such considerations gives $H \approx 0.5$ G for distances of 10 - 30 pc. The mean value of H over the whole volume of such dimensions must be much smaller because otherwise the total energy of the magnetic field would be incredibly high. Conclusions of such kind corroborate the suggestion that the passing of emitters through regions of strong field is the main cause of increased radiation.

There are reasons to say that the luminosity growth at the beginning of flares is caused by abrupt increases of r.e. in some comparatively small volume which expands rapidly (Dennison and Condon, 1981). Based on this suggestion one can estimate parameters of r.e. and field strength in expanding volume using observational data (Gorbatsky, 1985).

Optical flares of the QSO in 3C 345 and in some other AGN occur on scales $1^d - 10^d$ and the energy output during these flares is $10^{50} - 10^{51}$ erg. AGN having high X-ray luminosity often show rapid variability in the region 2 keV - 1 MeV on the scale 0.5 - 5 days with amplitudes $\Delta L_x \approx L_x$.X-ray and flare energies of $10^{48} - 10^{51}$ ergs.

Let r.e. producing X-ray radiation have the same energy E_o and the total quantity of them be N. Energy radiated in a time interval Δ may be calculated as,

$$E_{rad} \approx N\, E_o \approx 0.2 \cdot 10^{-23} N \cdot H \Delta\nu \cdot \Delta t \; . \qquad (2)$$

Using the well-known formula,

$$\nu_{max} \approx 6 \cdot 10^{18}\, E_o^2\, H \sin\phi \approx \nu_x \qquad (3)$$

and taking $\Delta\nu \approx \nu_{max}$, $\Delta t = 10^4 - 10^5$ s , $E_o = 1 - 10$ erg one obtains

$$H = 0.1 - 1\ \mathrm{G}, \quad N = 10^{48} - 10^{49} \; .$$

Thus the magnetic field energy in the flare region is small in comparison to the energy of r.e..

Similar estimations can be made for r.e. producing optical flares. The corresponding values are,

$$E_c \approx 10^{-2} - 10^{-1}\ \mathrm{erg}, \quad N \approx 10^{52} - 10^{54} \; .$$

Thus it is reasonable to conclude that the sources of X-ray flares are the same clouds of r.e. with spectral index γ close to 2 corresponding to $\alpha \approx 0.5$.

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