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ON DISTRIBUTION OF SEPARATION VELOCITIES OF COMPONENTS OF EXTENDED DOUBLE RADIO SOURCES

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ABSTRACT. *For the double radio sources the problem of determination of distribution function for separation velocities of components is solved. The distribution of the observed parameter* $V=c(Q-1)/(Q+1)$ *is used, where* $Q=R_1/R_2$ (R_1, R_2 *are visible distances of the components from the central galaxy), c is the velocity of light. It is supposed that the outflows have a symmetric structure, and the difference of distances* (R_1, R_2) *is due to the finiteness of the velocity of light.*

The distribution of the parameter V is studied. It is shown that the velocities of separation of the components have an upper limit which is $\sim 0.3c$. *It is found that the velocities of separation have a discrete distribution for radio galaxies and quasars. Most radio galaxies have velocities in three intervals, where the average velocities are* $V_1\sim 0.05c$, $V_2\sim 0.15c$, $V_3\sim 0.26c$, *respectively. For quasars they are in two intervals with the corresponding separation velocities 0.13c and 0.26c.*

Для классических двойных радиоисточников решена задача нахождения функции распределения скоростей разлета компонент. При этом используется распределение наблюдаемого параметра $V=c(Q-1)/(Q+1)$, *где* $Q=R_1/R_2$ (R_1,R_2 - *видимые расстояния радиокомпонент от центральной галактики), а с - скорость света. Предполагается, что выбросы имеют симметричную структуру, а различие расстояний* R_1 *и* R_2 *обусловлено конечностью скорости света.*

Исследовано распределение параметра V для трех выборок. Показано, что верхний предел скоростей разлета компонент равен приблизительно 0.3c. Найдено, что для радиогалактик и квазаров скорости разлета распределены дискретно. Большинство радиогалактик имеет скорости, заключенные в трех интервалах, средняя скорость в которых равна $V_1\sim 0.05c$, $V_2\sim 0.15c$ *и*

V_3~0.26c, соответственно. Для квазаров она заключена в двух интервалах средними скоростями разлета 0.13c и 0.26c.

INTRODUCTION

In some papers for classical double radio sources the velocities of hot spots relative to the central galaxies have been estimated. Hargrave and Ryle (1974) have found the upper limit for the outflow velocity to be (~0.1c) for a sample of relatively powerful radio sources.

Longair and Riley (1979) have analyzed the parameter of the ratio of distances from the central source and come to a conclusion that the upper limit of separation of hot spots for extended extragalactic radio sources amounts to ~0.2c.

Katgeri-Mekeliejn et al. (1980) have found that the lower limit of the velocity is ~0.1c, while the average velocity is about 0.24c for double radio sources (DRS) observed at 178 MHz and 408 MHz. Banhatti (1987) has presented a rough velocity estimate of 0.3c for weak radio sources possessing hot spots.

Thus, estimates of the outflow velocities have a large dispersion. This is indicative of a complex form of the distribution function of the outflow velocities.

In the present paper we solve an inverse problem for determination of the distribution function of the outflow velocities for extended radio sources. The obtained results are discussed.

DESCRIPTION OF THE PROBLEM

Let us assume that DRS are formed by symmetric outflow of radio emitting components from the parent galaxy (Fig.1). The difference in visible distances of the components R_1 and R_2 from the central galaxy is due to the finiteness of the velocity of light. The results of observations are consistent with this simple model (see Fomalont, 1969; Mackay, 1967).

Denote the outflow velocity of the components relative to the parent galaxy by V_0.
If we denote the angle between the outflow direction and line of sight by θ (θ varies from 0 to π/2), then one can write

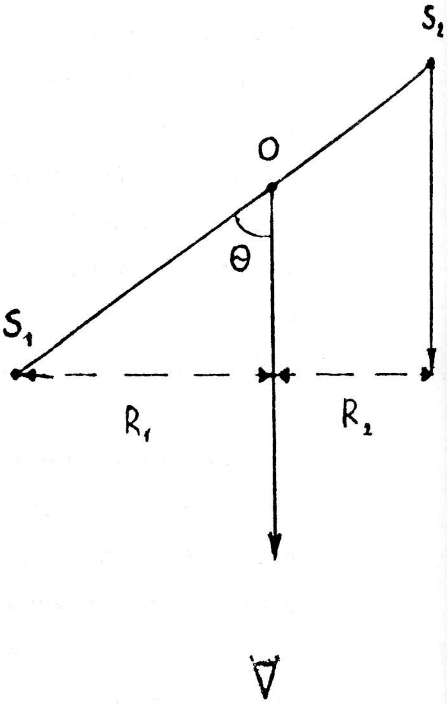

Fig.1.

$$c\,\frac{Q-1}{Q+1} = V_0\cos\theta, \qquad (1)$$

where $Q=R_1/R_2$ $(R_1 \geqslant R_2)$.

The quantity

$$V = c\,\frac{Q-1}{Q+1} = V_0 \cos\theta \qquad (2)$$

we will call "observed" velocity since Q is an observed parameter, V_0 is "true" velocity.

Let we have a certain number (N) of DRS with the distribution function of the "true" outflow velocities $F(V_0)$. Assume that θ is distributed randomly in the range of angles $(0, \pi/2)$, i.e. all directions of the radio outflows in space have equal probability. Then, having the distribution $f(V)$ of the "observed" velocities, we will find the function $F(V_0)$.

Consider a pair of random values (V_0, V) and (V_0, θ) with the probability density φ and ϕ, respectively. Then write the following:

$$\varphi(V_0, V)dV_0 dV = \phi(V_0, \theta)dV_0 d\theta.$$

Since the V_0 and θ values are independent and θ is distributed randomly, then

$$\phi(V_0, \theta)dV_0 d\theta = F(V_0)dV_0 \sin\theta d\theta, \text{ so}$$

$$\varphi(V_0, V)dV = \frac{F(V_0)dV_0}{dV/d\cos\theta}.$$

From (2) it follows that $dV/d\cos\theta = V_0$, and therefore

$$\varphi(V_0, V)dV_0 = \frac{F(V_0)}{V_0}\,dV_0.$$

Integrating this relation over all possible V_0 and taking into account $V_0 \geqslant V$, we can write

$$f(V) = \int_v^c \frac{F(V_0)}{V_0}\,dV_0. \qquad (3)$$

Differentiating this with respect to the lower variable, we find the function $F(V)$

$$F(V) = -V\,\frac{df(V)}{dV}. \qquad (4)$$

If we denote by dN the number of objects in the velocity range V, $V+dV$, then

$$f(V) = \frac{1}{N}\,\frac{dN}{dV},$$

and therefore one can write (4) in the form

$$F(V) = -\frac{V}{N}\frac{d}{dV}\left(\frac{dN}{dV}\right). \tag{5}$$

Thus, formula (5) allows us to find the distribution function of the "true" outflow velocities $F(V_0)$ using observational parameters (V, N, dN/dV) only.

It is easy to see that from expression (4) we can obtain the integral relation for any velocity range (V_1, V_2)

$$N\int_{V_1}^{V_2} F(V)\,dV = N\int_{V_1}^{V_2} f(V)\,dV - N\left(f(V_2)V_2 - f(V_1)V_1\right).$$

The left part of this expression is the number of DRS (n_0) which have the "true" velocities in the range (V_1, V_2). The first term of the right part is the number of DRS (n_{12}) with the "observed" velocities from V_1 to V_2

$$n_0 = n_{12} - N\left(f(V_2)V_2 - f(V_1)V_1\right). \tag{6}$$

It is convenient to use (6) for definition of n_0 since only the observed distribution function $f(V)$ is used.

THE SAMPLE OF DRS AND OBSERVATIONAL DATA

The sample of DRS consists of FRII type objects, according to Fonaroff and Riley (1974) classification with identified central galaxies or quasars. We use the values of the parameter $Q=R_1/R_2$ for 165 identified DRS which are taken from Arshakian (1992). For 38 quasars we have calculated this parameter on the basis of the radio maps published by Barthel et al. (1988). Radio images of all the objects were observed at 4.8 GHz.

On the basis of these data we have constructed three samples. The first sample includes radio galaxies (RG), the second one includes RGs and QSOs with $z \leqslant 1.5$. The third sample comprises available objects. Figs. 2-4 describe the dependences of the number of objects ($dN=n$) in a given range $d(V/c)=W$ on the "observed" dimensionless velocity (V/c). These dependences are shown by two continuous lines. The zigzag lines are obtained by gradual change of the step (along V/c axis) for the given range with the width W=0.05 (Fig. 2) and W=0.04 (Figs. 3, 4). The continuous line was drawn by smoothing of the above mentioned line taking into account that $n(V/c)$ function decreases with increasing V/c (it follows from (3)). The dotted line describes the distribution function $F(V_0)$, which is a derivative of the smooth curve.

The distribution function $f(V)$ (Figs. 2-4) has minimum at V/c~0.3c. So we suggest that the upper limit of the outflow velocity be equal to 0.3c. Probably the objects with V/c>0.3 do not conform to the symmetric model, so we shall perform calculation for radio sources lying in the range (0-0.3c).

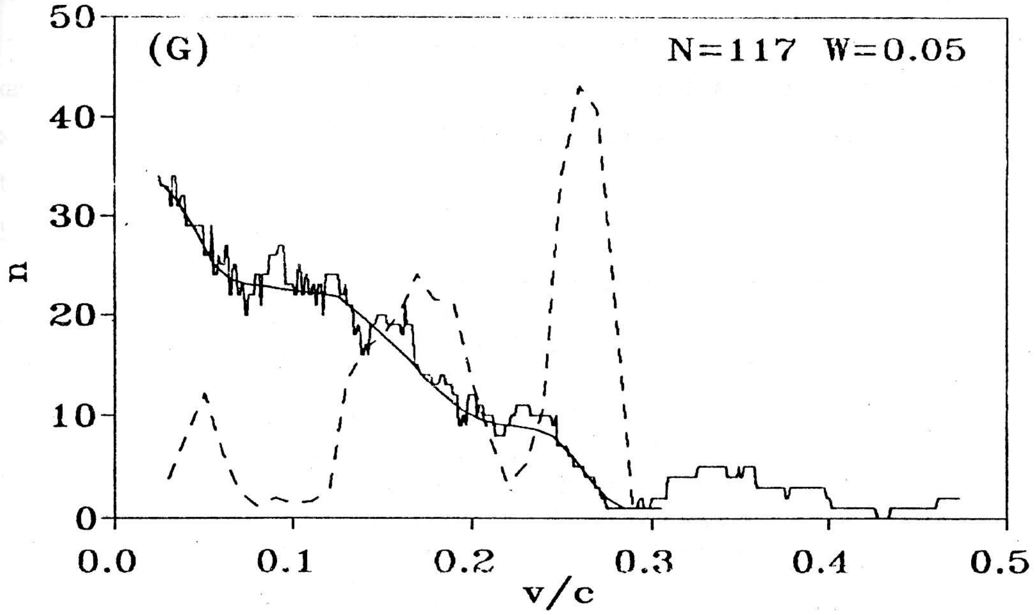

Fig. 2.

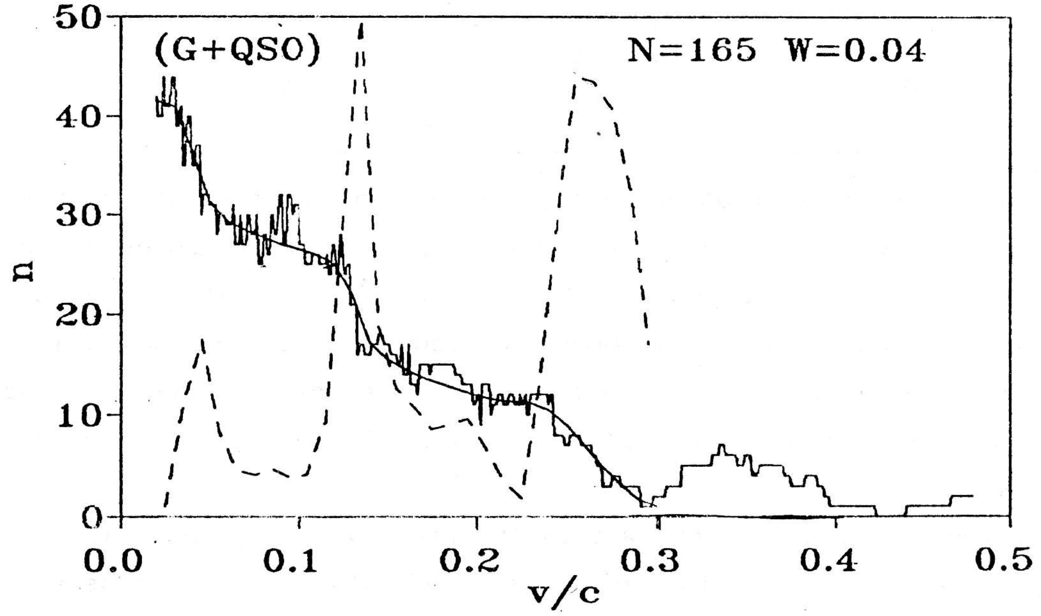

Fig. 3.

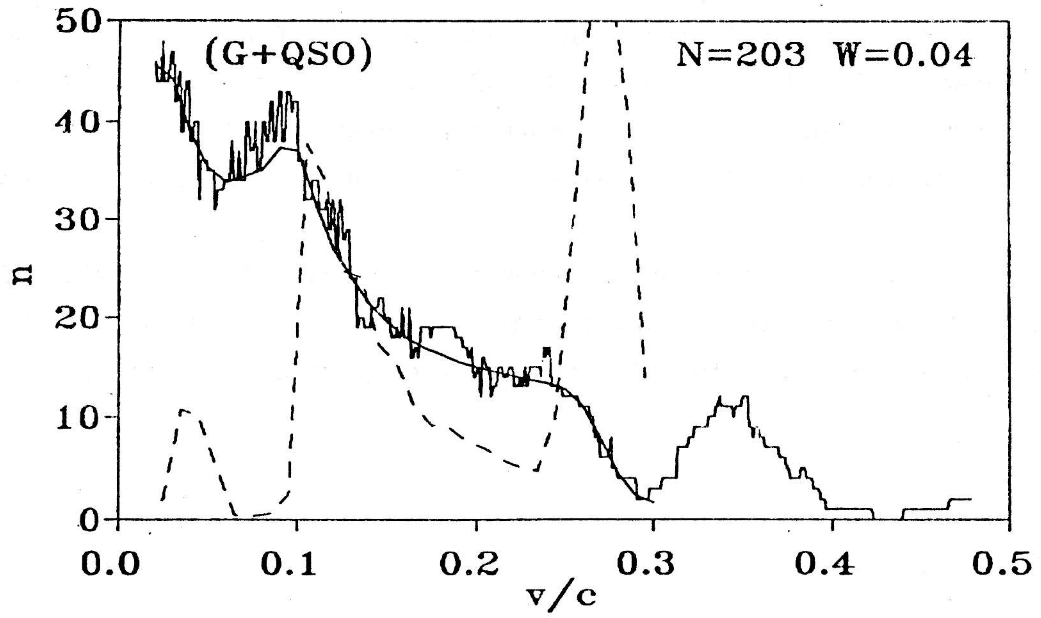

Fig. 4.

The figures show that the distribution function at the "true" outflow velocities for all the samples has a discrete distribution with three peaks. The velocities (V_1~0.05c, V_2~0.15c, V_3~0.25c) corresponding to the maxima of the function are coincident for three samples with small deviation. Thus, the values of outflow velocities for DRS lye mainly in three ranges (0.03c-0.07c, 0.11c-0.2c, 0.23c-0.3c).

Table 1.

	N	N_L	W	ΔV_1 ΔV_2 ΔV_3	$\sim V_1$ $\sim V_2$ $\sim V_3$	n_1 n_2 (%) n_3	n_1 n_2 n_3
G	117	104	0.05	0.03-0.07	0.05	6	6
				0.11-0.20	0.16	31	49
				0.23-0.30	0.25	47	70
G+QSO $Z \leqslant 1.5$	165	149	0.04	- - -	0.04	5	6
				- - -	0.14	33	49
				- - -	0.25	47	70
G+QSO $Z \leqslant 4$	203	182	0.04	- - -	0.04	3	6
				- - -	0.12	35	64
				- - -	0.27	45	82

The basic results obtained by calculations are presented in Table 1. The columns show the following: 1) morphological types of objects used, 2) total number of objects, 3) number of objects in the range V/c=0-0.3, 4) width of a given range (W), 5) range of outflow velocities, 6) velocity value corresponding to the maximum of $F(V)$ function, 7) and 8) relative (in percent) and absolute content of objects having "true" velocities within the ranges $\Delta V_1, \Delta V_2, \Delta V_3$. The data of the last two columns were calculated by formula (6).

Note (Table 1) that the number of objects within the first velocity range (0.03c-0.07c) does not change if we add quasars to the sample of RG, while this increases in the second (0.11c-0.16c) and third (0.23c-0.3c) ranges. It means that the outflow velocities of quasars are concentrated in two ranges, moreover the first range is two times narrower as compared to RG. Approximately 90% of quasars from the second and third samples have the outflow velocities in the above mentioned ranges.

It is interesting to note that for all the samples ~50% of objects have velocities in the range (0.23c-0.3c).

The origin and outflow of the extended radio components are related to activity of the central galaxy cores. Therefore it is likely that the discrete character of the outflow velocities is indicative of a discrete character of physical properties of active galaxy cores.

CONCLUSION

It is of great interest to determine the features of grouping of the outflow velocities of components. Probably, it depends on radio luminosity or location of galaxies in clusters. Solution of these problems requires detailed investigation. Answers to these questions will bring one closer to understanding of physical mechanisms acting in AGN.

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REFERENCES

Arshakian D.G.: 1992, *Astrofizika*, **35**, 551.

Banhatti D.G: 1987, *Turku University, preprint*, **126**.

Barthel P.D, Miley G.K., Schilizzi R.T., Lonsdale C.J.: 1988, *Astron.Astrophys.Suppl. Ser.*, **73**, 515.

Fomalont E.B.: 1969, *Astrophys.J.*, **157**, 1027.

Fonaroff B.L., Riley J.M.: 1974, *Mon. Not. R. Astron. Soc.*, **167**, 31.

Hargrave P.J., Ryle M.: 1974, *Mon. Not. R. Astron. Soc.*, **166**, 305.

Katgeri-Meikelijn J., Levi C., Padrielli L.: 1980, *Astron. Astrophys. Suppl. Ser.*, **40**, 91.

Longair M.S. & Riley J.M.: 1979, *Mon. Not. R. Astron. Soc.*, **188**, 625.

Mackay C.D.: 1967, *Mon.Not. R. Astron. Soc.*, **136**, 123.