NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE
NEW METHOD FOR DETERMINING THE DISTANCES TO CERTAIN EXTRAGALACTIC RADIO SOURCES

Yu. A. Kovalev

(NASA-TH-76209) NEW METHOD FOR DETERMINING THE DISTANCES TO CERTAIN EXTRAGALACTIC RADIO SOURCES (National Aeronautics and Space Administration) 15 p HC A02/MF A01 CSCL 03B Unclas G3/90 28033


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JUNE 1980
NEW METHOD FOR DETERMINING THE
DISTANCES TO CERTAIN EXTRAGALACTIC RADIO
SOURCES

Yu A. Kovalev

SCITRAN
Box 5456
Santa Barbara, CA 93108

National Aeronautics and Space Administration
Washington, D.C. 20546

The structural evolution of variable radio sources
is examined in the "Hedgehog" model. It is shown
that the time evolution of the angular separation
of two components is described by the ellipse
equation.
The structure evolution of variable radio sources is examined in the "Hedgehog" [1] model, proposed as an explanation for the variation in the stream of quasars and radio galaxies [2-4]. It is shown that the time evolution of the angular separation θ of two components (nucleus and cloud of electrons dissipating along the force lines of the radio magnetic field of this nucleus) is described by the ellipse equation, whose ratio of axes R yields the distance R/c = R to the source in light time units (c = velocity of light). In addition, if \( \theta' \) is velocity, \( \theta'' \) is the acceleration at any point of the ellipse, then

\[
R/c = R_2 \left[ \frac{\theta}{\theta''} - \left( \frac{\theta''}{\theta'} \right)^2 \right]^{1/2}. 
\]

If the typical maximum angular separation \( \theta_m \) and the duration \( \tau \) of the radio flux flare are known, then an evaluation can be made of the distance from below:

\[
R/c = R_2 \left[ \frac{\theta}{\theta''} - \left( \frac{\theta''}{\theta'} \right)^2 \right]^{1/2} \tau. 
\]

where \( k=1 \) for the scattering components and \( k=2 \) for the converging components. The distances R/c were estimated by using observations and \( R_2 \) for the sources 3C 84, 3C 120, 3C 273, 3C 345, 4C 39.25, as well as \( R_1 \), \( R_2 \) for the object VRO 42.22.01. All the model estimates do not contradict the distances obtained from the red shifts in their cosmological interpretation. The conditions

\[
R_1 = \text{const}, \quad R_2 = \text{const}, \quad \theta = \text{const}
\]

are criteria for the applicability of the model to the studied object.
NEW METHOD OF DISTANCE DETERMINATION TO CERTAIN EXTRAGALACTIC RADIO SOURCES

By. Yu. A. Kovalev

1. Introduction

Currently almost all the methods for obtaining distances R to extragalactic sources are associated with optic observations. Therefore, distances have mainly been defined only to those radio sources that have been successfully identified with optic objects. It will be shown that the model "Hedgehog" (Yëzhik), suggested by N. S. Kardashev [1] as a phenomenological model of quasars to explain the variability of their radio emissions permits a determination of R directly from radio astronomical observations, and provides distinct criteria for the applicability of the model, regardless of the observed law of evolution for the source radiation flow.**

---

*Numbers in margin indicate pagination in original foreign text.
**Synchrotron radiation in certain particular cases and the bases for the model have been analyzed in publications [2, 3]. The structural evolution and spectrum of the source synchrotron radiation have generally been examined in [4]. In contrast, this work, within the framework of the set task, and without being limited to the radiation synchrotron mechanism has obtained a law for the structural evolution of a two-component source with regard for the possible anisotropy of the initial electron distribution according to velocities. Here primary attention was focused on a discussion of those consequences from the obtained law that are important for determining R.
2. Description of Model

Assume that from the moment in time $t'_0$ in the radio magnetic field of a certain nucleus at angle $\lambda$ to the observer a cloud of ultrarelativistic electrons is scattered with isotropic distribution at $t'_0$ according to the pitch-angles in limits from $\psi_{\text{min}}$ to $\psi_{\text{max}}$. At the moment $t'_0$ the cloud is located a distance $z_0$ from the center of the nucleus with radius $r$; here $z_0 / r = 1$, while the maximum linear size of the cloud is much smaller than $z_0$. It is assumed that the energy density of the magnetic field is much greater than the energy density of the electrons, and when the cloud electrons enter the nuclear area they are completely absorbed. Any mechanism of energy loss is permitted that does not result in scattering of the ultrarelativistic electron radiation in directions that differ from the direction of its instantaneous velocity, and which permits a change in the energy electron during the examined time to be ignored. For the radio magnetic field with intensity $H$ and pitch-angles of the electrons $\psi$, on the condition that the adiabatic invariant of the dependence on $z$ is preserved:

$$H = H_0 \left( \frac{z_0}{r} \right)^2$$  \hspace{1cm} (1)

$$\sin \psi = \left( \frac{z_0}{r} \right) \sin \psi_0$$ \hspace{1cm} (2)

where the amounts with zero indices correspond to their values at $t'_0$.

The time $\Delta t' = t' - t'_0$, necessary for the electron to traverse the distance from $z_0$ to $z$ (here its pitch-angle $\psi$ changes from $\psi'_0$ to $\psi$), can be found by integrating the ratio $\Delta t' = \frac{d\psi}{c \cdot \cos \psi'}$. After integration we will have:

$$\Delta t' \cdot c / z_0 = \left( \frac{z}{z_0} \right) \cdot \cos \psi - \cos \psi_0.$$  \hspace{1cm} (3)
Assuming further \( \gamma = \phi = \text{const.} \), and passing to the time interval of the observer \( \Delta t = t - t_0 \), by using the delay factor \([5]\)

\[
\frac{\Delta t}{\Delta t'} = \left[ 1 - (\cos \phi / c) \left( \frac{\partial z}{\partial t'} \right) \right]
\]

and selecting \( t_0 = 0 \), we obtain the law for movement of the cloud electron system, "visible" to the observer in the final form:

\[
z_n - z_0 \sin \phi = z_0 \sqrt{1 - \left( \frac{\xi z_0}{z_0} - \cos \phi \right)^2} - z_0 \sqrt{1 - x^2}.
\]

This equation was attained on the assumption that the angle \( \gamma \) is random,

\[
z_n / z_0 \ll 1, \quad \psi_{\text{omin}} < \phi, \quad \psi_{\text{omax}} = \pi
\]

and describes the evolution of the separation of two components (nucleus and cloud) with

\[
0 < t < (1 + \cos \phi) z_0 / c.
\]

It is easy to be convinced, that during this time all the pitch-angles of the electrons evolve to values that are smaller than the observation angle \( \gamma \), while the cloud that continues to exist will be extinguished for the observer.

One can show that the values of the parameters \( z_n / z_0, \psi_{\text{omin}} \) and \( \psi_{\text{omax}} \), that differ from those indicated, result in the same equation (4); but it is correct in a more limited time interval \( t \), defined from

\[
x = \begin{cases} 
\cos(2\psi - \psi_0) & \text{with} \quad \frac{5}{2} < \psi < \pi \\
-\cos \psi_0 & \text{with} \quad \psi < \frac{5}{2} 
\end{cases},
\]

where \( \psi_0 \), with a rise in \( t \) traverses the subsequent values from \( \psi_{\text{omin}} \) to \( \psi_{\text{omax}} \), whereby

\[
\psi_{\text{omax}} = \min \begin{cases} \psi_{\text{omax}} \\
\pi - \pi \cos \left( \frac{z_n}{z_0} \right)
\end{cases}
\]

\(\pi \cos$$
In particular, with $\varepsilon_n < z_o$, $\psi_{omin} < \psi < \pi/2$ and $\psi_{omax} = \pi$,
"dispersion" of the nucleus and the cloud is observed while
$0 < t < t_m = \pm z_o \cos \psi / c$,
such that $z_k$ rises from $z_o \times \sin \psi$ to $z_o$. With $t \geq t_m$ they converge
from $z_k = z_o$ to $z_k = z_n$,
after this the cloud is extinguished due to the absorption of electrons by the
nucleus, and the moment of extinction $t_{otc}$ is defined from (5) by the value
$\psi_{omax} = \pi - A z_o \sin (z_o / r_o)$. If in this example $\psi_{omax} = \pi/2$, then only
dispersion of the cloud and the nucleus up to moment $t_{otc} = t_m$ will be observed (such
a case is possible, in particular, with explosion and scattering of the cloud from
the surface of the nucleus; then $z_n = z_o$ and the movement occurs on the background of
the nucleus).

3. Methods of Obtaining Distance

Several methods for obtaining distance to the source follow from (4). If the
world is Euclidean, then $z_k = R \times \theta$, where $\theta$ is the observed angular distance to the
nucleus in the cloud.

1. Taking this into consideration one is easily convinced that (4) in the
coordinate system $(t, \theta)$ is an equation of the ellipse:

$$\frac{\theta^2}{(z_o/R)^2} + \frac{(t - z_o \cdot \cos \psi / c)^2}{(z_o/c)^2} = 1. \quad (F)$$

It is apparent from here that the ratio $R_1$ of the semiaxes $t_m$ and $\theta_m$ of the ellipse
provides the unknown distance $R$: $R/c = R_1 t_m / \theta_m$, where $t_m$ and $\theta_m$ are directly
measurable amounts.

2. Equation (4) together with the first $\theta'$ and the second $\theta''$ derivatives of $\theta$
for $t$ form a system of three equations with three unknowns ($z_o$, $x$ and $R$); the left
part of the equations can be obtained from the observations:

\[
\begin{align*}
\Theta &= \frac{z_0 \sqrt{1-x^2}}{R}, \\
\Theta' &= -c \cdot x \cdot z_0 / (\Theta \cdot R^2), \\
\Theta'' &= -[c^2 + (R \cdot \Theta')^2] / (\Theta \cdot R^2).
\end{align*}
\]

(8)  (9)  (10)

The signs (9) and (10) refer to the direction from the nucleus. It follows from
here that the visible movement of the cloud in relation to the nucleus can occur
both with sublight, as well as with superlight velocities, as well as with acceler-
ation, and deceleration. From (10) we have:

\[ R/c = \tilde{\kappa}_2 = \left[ (\Theta | \Theta'') - (\Theta')^2 \right]^{-1/2} \]

(11)

3. If in the initial distribution for pitch-angles there are electrons with \( \theta_0 = \pi/2 \), then one can also obtain from (4):

\[ R/c = \tilde{\kappa}_3 = t_{otc} / \left[ (x_{otc} + \cos \theta) \cdot \Theta_m \right] \]

(12)

where \( t_{otc} \) is the time from the moment of cloud formation to cutting off of radi-
ation (extinction of the cloud), while the parameter corresponding to it \( x_{otc} \) de-
pending on \( \psi_{\text{omax}} \) adopts values from \( x_{otc}=0 \) with \( \psi_{\text{omax}} = \pi/2 \) to \( x_{otc}=1 \) with \( \psi_{\text{omax}} = \pi \).

We will compare the potentialities of these methods. The value \( v \) for \( \tilde{\kappa}_3 \) can
be estimated from an analysis of the relative amplitude of flow time variants \( F_v \) [4]
with synchrotron radiation of the cloud. Measurement of \( t_{otc} \) is complicated, linked
both to the fact that the time up to cutting-off can be greater than the observed
lifetime of the cloud (due to the possibility of \( \psi_{\text{omax}} > \psi \)), as well as with the
fact that it can be considerably greater than the extremely nonstationary phase of
radiation, the flare; during this time new clouds can merge that complicate the
source structure. To determine \( R \) from \( \tilde{R}_3 \) it is also necessary to have data on the initial distribution function of electrons according to pitch-angles. These difficulties force us to use (12) only as an estimate from below, after replacing \( t_{otc} \) for duration of a separate radio flux flare and \( (x_{otc}+\cos\psi) \) by the coefficient \( k=1 \), if "dispersion" or "stopping" of the nucleus and cloud is observed, and \( k=2 \) if they converge. Then:

\[
\frac{\dot{R}_3}{\text{Mps}} \geq 60 \cdot \tau_{\text{years}} \left[ \frac{\kappa \cdot \Theta_m^*}{\text{ms}} \right],
\]

(13)

where \( \tilde{R}_3 \) is measured in megaparsecs, \( \tau \)—in years, \( \Theta_m^* \)—in angular milliseonds*.

One should stress that the dispersion dynamics is such that the angles close to \( \Theta_m \) are reached comparatively quickly (see (8)-(10)), therefore the main inaccuracy in estimating \( \tilde{R}_3 \) from (13) is associated with the roughness of replacing \( t_{otc} \) by \( \tau \).

For \( \tilde{R}_1 \), in contrast to \( \tilde{R}_3 \), no knowledge of the distribution according to pitch-angles \( \psi \) and \( t_{otc} \) is required (it is "replaced" by extrapolation of the sections of curve (7) up to \( \Theta=0 \)), but numerous measurements of \( \Theta \) are needed during the entire lifetime of the cloud in order to obtain a reliable curve (7). This method is advantageous because each successive measurement \( \Theta \) at the moment of time \( t \cdot t_m \) approaches \( \Theta_m \) and \( t_m \), and the accuracy of the estimate obtained from here

\[
\tilde{R}_1 \geq t / \Theta
\]

increases with time, in contrast to the estimate from (13) and it approaches the "true" obtained from the ratio of the ellipse axes.

*In contrast to the frequently employed estimate \( R/c \tilde{G} / \Theta_d \), where \( \Theta_d \) is the angular diameter of the nonstationary component (in the given case the cloud), (13) requires the angular distance \( \Theta_m \) between the cloud and the nucleus.
Finally, \( \tilde{R}_2 \) makes it possible to determine \( R \) from an "instantaneous" measurement of a small ellipse section (7), i.e., this method is free to a considerable degree from difficulties of the previous methods (simultaneously from (8)-(10) we obtain \( z_0 \) and \( x \), and consequently also \( u \); if \( t \) is known). However, when the accuracy of measuring \( \Theta \) is insufficient, and the ambiguity of making the curve through the obtained points is great, large errors are possible in determining \( R \).

Thus, if the primary information for estimating \( R \) from \( \tilde{R}_3 \) is contained in the results of systematic measurements for the evolution of the spectral flow \( F_v \) of the source radio emission (besides these data it is sufficient to have \( \Theta_m \) from observations of previous clouds or to make occasional measurements of \( \Theta \) at moments in time defined from the dependence of \( F_v \) on \( t \)), then in the determination and estimates of \( R \) from \( \tilde{R}_1 \) and \( \tilde{R}_2 \), on the contrary, the "center of gravity" of the necessary information lies precisely in the systematic interferometric observations.

4. Comparison with Observations

Sources 3C 84, 3C 120, 3C 273, 3C 345, 4C 39.25 and VRO 42.22.01 with clearly pronounced long-periodic variability satisfy the condition for dispersion of components with \( t \approx 1 \) year and \( \Theta_m \approx 1 \) ms [6-8]. By substituting these values and \( k=1 \) in (13) we obtain a rough estimate of the distance to all of these sources: \( \tilde{R}_3 > 60 \) Mpc, which agrees with the values for the distances obtained from red shifts. Of course, such agreement of the estimate cannot serve as proof for the correctness of the examined model for these objects, but at least it is in its favor.

For VRO 42.22.01 one can attempt to correlate the observed evolution \( \Theta \) [9, 7] with equations (7) and (11). The selection of this source is governed by the fact that its analysis is complicated to a lesser degree by the ambiguous interpretation
of interferometric observations with the help of two-component models, than for many other nonstationary objects.\* In the limits of measurement accuracy one can approximate the evolution of $\theta$ by curves 1 and 2 in Figure 1. If curve 1 is correct, then the existence of a point with minimal angle $\theta=0.5$ ms can be interpreted by converging the nucleus and the preceding component. The possibility of such an explanation has been noted previously, however it was considered unreal [11]. By substituting the results of the graphic differentiation of $\theta$ in (11) we obtain the distance $\tilde{R}_2$. For all the experimental points of curves 1 and 2 the values $\tilde{R}_2$ lie in the limits of 20 Mps about $\tilde{R}_2=100$ Mps, which is 3-4 times smaller than the distance from the red shift $z=0.07$ [12].

Curves 3-6 were obtained by "adjustment" of the observation results of the initial ellipse sections (7) that correspond to the distances 100 Mps, 300 Mps, and 1000 Mps respectively. For comparison with ellipses 3 and 5 curves 4, 7 and 8 were given that characterize their sensitivity to the change in the semi-axes $t_m$ and $q_m$ of the ellipse with fixed $\tilde{R}_1=t_m/q_m$. One can also formally adjust to the measured points the ellipses that correspond to the distance $\tilde{R}_1>1000$ Mps, but the "price" is a sharp increase in $t_m$ and $q_m$. Thus, from all the ellipses with $\tilde{R}_1=3000$ Mps it is necessary to select the ellipse with $t_m \approx 1500$ years, $q_m \approx 30$ ms, in order for its initial section to pass through the experimental points. However, $R_1 \geq 3000$ Mps

\*In [10] the two-component nature of 3C 345 is stressed, and the linear law of increase in $\theta$ is obtained as the most probable; this contradicts the discussed model, since acceleration (10) always differs from zero. This result can be correlated with the model only after assuming that during the time of observation a measurement was made of a relatively small section of very "elongated" (as a consequence of the great distance of the source $R_1$) ellipse, which can be approximated by a straight line. Further observations and analysis must help to draw the final conclusion.
Figure 1. Time Evolution of Angular Separation $\theta$ in Two-Component Model VRO 42.22.01
Experimental points correspond to the data of publications: $\bullet$ --[9], $\Delta$ --[7]. Curves 1 and 2 illustrate $\Delta_{\text{d}}$ determination of the distance from $R_2$, while 3-8--from $R_1$. $R_1$ (Mps)/$t_m$(years)/$\theta_m$(ang. ms) are shown at each of the curves 3-8. The dotted section of curve 3, that characterizes conversion of the components, occurs in the case of $v_{\text{max}}^\times > \pi/2$ (see text).
(i.e., $t_m^2 \geq 1000$ years), apparently is not very likely if only because $t_m^2 \sim 100 \times 7$ for $\theta > 5^\circ$ [4] (with synchrotron mechanism of radiation), while the measured duration of the radio flares is $7 \leq 1$ year [6].

It is apparent from Figure 1 that if the source evolution occurs in accordance with curve 3, then one must observe extinction of one of the components either with $\theta_m \approx 1.5$ ms at the end of 1973—beginning of 1974 (in the case $\psi_m^\circ = \pi/2$—see above), or during conversion of the components from $\theta_m \approx 1.5$ ms to a certain angle $\Theta_m$ during 1974—middle of 1976 (if $\psi_m^\circ = \pi/2$) in accordance with the dotted section of curve 3. One should note that the absence of noticeable extinction and possible constancy in the measured $\Theta$ during this entire period within the framework of the developed model could occur only in the case of measurements that refer to different clouds that have reached $\theta_m$ at a different time during the examined period. Analysis of the observations does not exclude the fact that in the beginning of 1972 a new component was formed [13]. Its consideration can be useful in the future. If the source evolution is described by curves 6 and 5, then one can expect an increase in the angular separation.

Thus, on the condition of a correct interpretation of employed data as measurements referring to the evolution of a single cloud, from curves 3-5 for the distance up to VRO 42.22.01 we obtain an evaluation $100 \leq \frac{\tilde{R}_1}{\tilde{R}_2} (\text{Mps})^2 \leq 1000$.

5. Conclusion

Since the distance to the studied source during the observations can be considered unchangeal, then the conditions $\tilde{R}_1 = \text{const}$, $\tilde{R}_2 = \text{const}$, $\tilde{R}_1 \leq \tilde{R}_2$ can serve as criteria for the applicability of the model to the source. In reality, the strict equality in these criteria should be replaced by approximate.
If it is found that the examined model is close to actuality for a fairly broad class of objects, then regular interferometric observation together with the data on the time variations in the radio emission flow of the sources will possibly permit us to obtain from certain nonstationary objects a "radio scale" of extragalactic distances, regardless of the results of optic identification.

I am grateful to M. S. Kardashev for discussions and useful advice, as well as Z. S. Kovaleva for assistance in this work.

References


