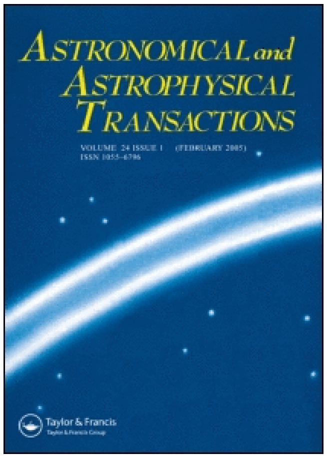

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PROBING THE UNIVERSE WITH EXTRAGALACTIC RADIO JETS

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Some specially selected active radio sources can be used for measuring extragalactic distances, the Hubble constant and the deceleration parameter of the Universe. A source is selected if available observations of flux spectra, structure and polarization of a jet emission in this source agree with a jet model, discussed herein. Using this approach on some radio observational data, the preliminary estimations of the Hubble constant are obtained as $20\,\text{km/s/Mpc} \leqslant H_0 \leqslant 200\,\text{km/s/Mpc}$ (in a "short jet model") and $60\,\text{km/s/Mpc} \leqslant H_0 \leqslant 230\,\text{km/s/Mpc}$ (in a "long jet model").

KEY WORDS Active galaxies, cosmological parameters, distance scale.

1. INTRODUCTION

The approach to the probing of the Universe that is discussed here is based in the possibility of determining extragalactic distances from radio observations. In that case, using the Hubble law with its known space curvature generalization for distance as a function of redshift and cosmological parameters, one tries to estimate the Hubble constant and the deceleration parameter. One such possibility was described by Kovalev (1980, hereafter Paper I) for the case of a "short jet model" (or "point cloud model"). That approach is applied here to the case of a "long jet"—a narrow jet (of arbitrary length), moving at a small angle to the line of sight to the observer. This case may prove to be more useful for comparison with observations.

It must be emphasized that this is a model-dependent approach, which is applicable to extragalactic jets, for which the observed jet spectra, structure, and polarization as well as their variations, are in agreement with those calculated in the Hedgehog model (Kardashev, 1969; Kurilchik, 1972; Ozernoy and Ulanowsky, 1974; Kovalev and Mikhailutsa, 1980; Kovalev, 1991b; Kovalev and Kovalev, 1992).

2. A BRIEF DESCRIPTION OF JET MODEL

Let a narrow jet of relativistic particles move from a galactic nucleus in a strong radial magnetic field at the angle $\vartheta \ll 1$ to the observer. It is supposed that the following main conditions are satisfied (at least, in some spatial region near the active nucleus). The energy density of the magnetic field is much higher than the kinetic energy density of the jet particles. In the region in which the jet originates, the electron pitch-angle distribution is homogeneous within an angle $\pi/2$ to the jet direction. The electron energy losses are neglected during the considered time. The adiabatic invariant is conserved.

3. DISTANCES

For a short jet the distance to the source is given by any one or both of the following relations (Paper I)

$$R_1 = \frac{ct_m}{\theta_m(1+z)}, \tag{1}$$

$$R_2 = \frac{c}{[\theta\,|\theta''| - (\theta')^2]^{1/2}(1+z)}, \tag{2}$$

where c is the speed of light; z is the redshift; θ is the observed angular separation of the jet and the galactic nucleus; θ', $|\theta''|$, and θ_m are the observed angular velocity, absolute value of the angular acceleration, and the maximum value of this angular separation (which is a result of the pitch-angle evolution in the model); and t_m is the observed time for the jet to reach an angular separation θ_m.

If a continuous steady jet flow occurs at $\vartheta \ll 1$, then the following new relation for the distance can be obtained by analogy with Paper I:

$$R = \frac{ct}{\theta(1+z)}\left(\frac{2-T}{T}\right)^{1/2}, \tag{3}$$

where T is a model parameter (equal to some normalized dimensionless time, $0 < T < 1$). Estimation of T has to be done by fitting the calculated and observed flux spectra of the radio emission. θ is the observed instantaneous angular length of the jet at the corresponding observed jet age t.

So, all the variables in (1)–(3) can be obtained from observations or by model fitting. In principle, quasi-simultaneous measurements of the jet milliarcsecond (mas) structure and flux spectra would be enough to determine distances from radio observations if the redshifts are known or $z \ll 1$. In fact, the model fitting may be not single-valued, and an additional valuable piece of information can be extracted from measurements of the integrated polarized flux and milliarcsecond polarized structure.

4. COSMOLOGICAL PARAMETERS

The distances R_1, R_2, and R above are equal to the angular-size distance D_a, which is a known function of z, the Hubble constant H_0, and the Universe deceleration parameter q_0, that is

$$R = D_a(z, q_0, H_0). \tag{4}$$

In the Friedman Universe (zero cosmological constant) with the Robertson-

Walker metric (Lang, 1974; Altschuler, 1989),

$$D_a(z, q_0, H_0) \equiv \frac{c}{H_0 q_0^2 (1+z)^2} \{zq_0 + (q_0 - 1)[(1+2zq_0)^{1/2} - 1]\}, \tag{5}$$

or, if $zq_0 \ll 1$,

$$D_a(z, H_0) = \frac{cz}{H_0(1+z)^2}. \tag{6}$$

Formally, only one jet is needed to determine H_0 from (6), (4) and any of (1)–(3). By analogy, two jets would be enough to obtain q_0 and H_0 from (5), (4) and (1)–(3). In fact, many more sources are required to increase the accuracy of the determination of these parameters.

5. NUMERICAL ESTIMATIONS

The distance to the BL Lac galaxy was estimated using Eqs. (1) and (2) as $R \sim (100 - 1000)$ Mpc (Paper I). This gives $H_0 \sim (200 - 20)$ km/s/Mpc from (4) and (6) for the redshift of 0.0695 (Miller *et al.*, 1978). To illustrate the method presented here using formula (3), some data, obtained during a powerful radio outburst in BL Lac in the middle of 1980, are taken into account.

The interpolation of milliarcsecond structure measurements by Mutel *et al.* (1981) in 1980.41 and 1980.73 gives the value of $\theta \approx 1.7$ mas (for a level of 0.1 of the peak brightness temperature of the 5 GHz profiles). A fit of the model flux spectra to the six simultaneous spectra measured on 7–12 July 1980 at six frequencies from 1 GHz to 22 GHz (Berlin *et al.*, 1991) gives the estimates of $T \sim 0.005\vartheta_d^2$ ($\vartheta_d = \vartheta$ in degrees), in addition, $t \sim 0.23$ year if we allow for the starting time for the outburst from Mutel *et al.* (1981). The widths of the quasi-flat parts of the calculated spectra are functions of ϑ (Kovalev, 1991b). The observational width of a BL Lac steady-state flat spectra is about from 1 GHz to 90 GHz (Valtaoja *et al.*, 1988; Berlin *et al.*, 1991). This gives the estimates $0.5° \leqslant \vartheta_d \leqslant 2°$ and $0.0013 \leqslant T \leqslant 0.02$. Substituting these values and the redshift of 0.0695 (Miller *et al.*, 1978) into (3), (4), and (6) yields 80 Mpc $\leqslant R \leqslant$ 320 Mpc and 57 km/s/Mpc $\leqslant H_0 \leqslant$ 230 km/s/Mpc.

6. CONCLUSION

The best way to apply this approach is to attempt at fitting the model to all available data for a selected jet. This is a difficult requirement, but the discovery of several such jets is important because it would allow the extraction of new independent values of cosmological parameters. This is one of the aims of the long-term monitoring program at RATAN-600, which has obtained simultaneous multifrequency spectra of 110 extragalactic sources during 4 sets per each year (Kovalev, 1991a). Preliminary results indicate that at least five of these objects may prove suitable for probing the Universe as discussed here.

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