APPARENT MOTION OF THE RADIO SOURCES AND STABILITY OF THE CELESTIAL REFERENCE FRAME

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ABSTRACT. The physical basis of the apparent motion of the ICRF radio sources is discussed. All sources can be divided into four groups according their motion characteristics. We discuss here the linear and uniform motion model. The apparent velocities of the radio sources are of the order of speed of light or even more, therefore, we conclude that these radio sources are the relativistic jets or plasma clouds moving with velocities of the order of speed of light. The linear and uniform source motion can be explained by model of jet precession. In the frames of model we discuss the physical characteristics of some ICRF sources. So, for long-term stability of the ICRF new catalog of the selected radio sources has to contain both coordinates (right accession and declination) and trends (linear or quadratic).

1. INTRODUCTION

The XXIII General Assembly of the IAU recommended to adopt international celestial reference system (ICRS) as a realization of the fundamental coordinate reference system. The ICRS is the base to solve all astrometry and navigation tasks. The ICRS is defined through the kinematical characteristics, making the coordinate axis fixed with respect to the distant matter of the Universe.

A realization of the ICRF consists of a set of precise coordinates of extragalactic radio sources which are supposed to be motionless. The reason is that the proper motion of these radio sources is expected to be negligibly small because of their remoteness.

The first realization of the ICRF (International Celestial Reference Frame) catalog was constructed in 1995 by a reanalysis of the VLBI observations (Ma et al., 1998). The objects in the frame are divided in three subsets: “defining”, “candidate” and “other”. The defining sources should have a large number of observations over long data span; they maintain the axes of the ICRS. Sources with an insufficient number of observations or an observing time span are designated as the candidates; they could be potential defining sources in future realizations of the ICRF. The category of other sources includes objects with poorly determined positions, but they are useful to link the ICRF with other reference frames. The 212 of these are defining sources providing a core of the ICRF. The estimated source position uncertainty for the “defining” sources is about 0.25 mas. The 294 “candidate” sources have fewer observations. The 102 “other” sources were added for possible ties of reference frames. Two extensions of the ICRF have been elaborated, ICRF-Ext.1 (IERS, 1999) and ICRF-Ext.2 (Fey et al., 2004), for densification of the frame.

Other classification was proposed by Feissel-Vernier (2003). She classified a set of 362 sources as stable or unstable based on the analysis of source position time-series.

The apparent motion of a radio source (quasar) defining by its peculiar velocity, is expected to be of the order of 0.5 μas/year. This value is less than the modern observational accuracy. Therefore, quasars are considered to be fixed in space. But this is not the case. The modern observations show (MacMillan, 2003), that quasars and other objects, which the ICRF is based on, have angular velocities larger then expected, even being more that the speed of light. One of the reasons of apparent motion of this kind is a weak microlensing effect caused by stars and dark stars in our Galaxy (Sazhin et al, 2001). However, the simple estimations show that this is not the case. One needs to investigate others causes.

We analyzed the time series of the quasars coordinates that were calculated by nine centers of VLBI observations, and we also found that quasars have non-negligible motion. Model of motion was represented as polynomial with respect to time (Zharov, Rastorgueva, this issue).

According to the polynomial models we shall divide apparent motions in several types. In our work we derived the parameters of motion of the radio sources and we found that all of them show one of the types of motion listed below.

- Group I. Linear and uniform motion (inertial motion) (Fig. 1a).
- Group II. Linear but non-uniform motion (accelerated motion) (Fig. 1b).
- Group III. Cone cutting motion with constant velocity module (Fig. 2a).
- Group IV. The common case of curvilinear motion; velocity is not constant (Fig. 2b).

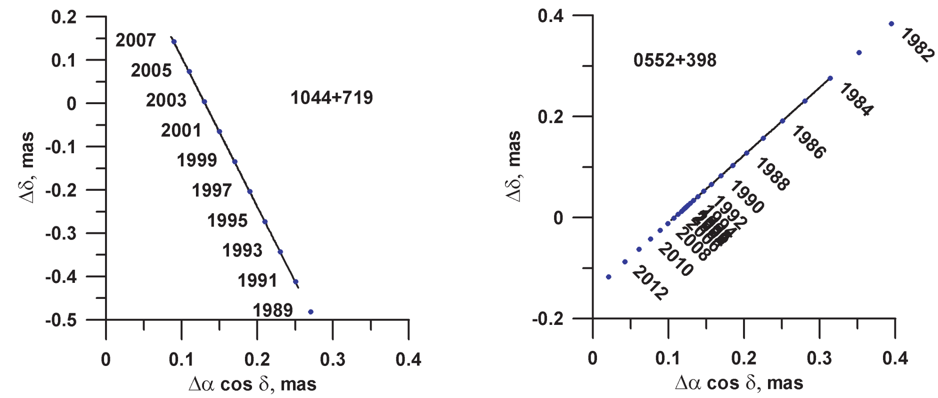

Figure 1: Uniform motion of 1044+719 and accelerated motion of 0552+398

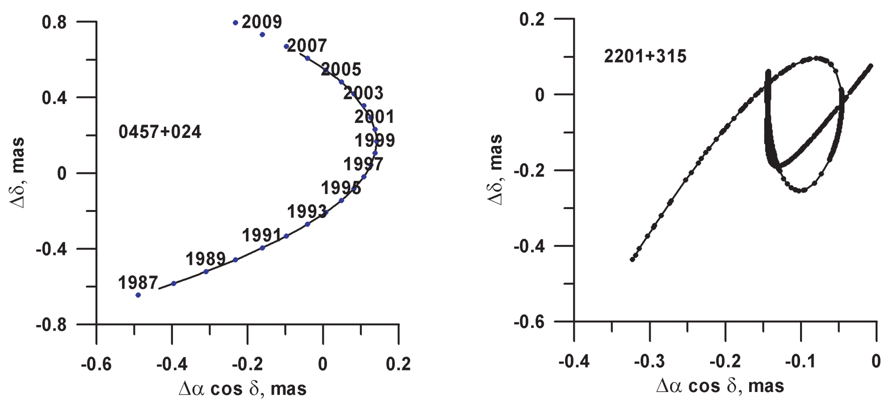

Figure 2: Motion of sources 0457+024 and 2201+315

Here we will discuss the first model of apparent motion of the quasars (group I). The linear and uniform apparent motion of the radio source is the simplest case and can be predicted with high accuracy and for a long time interval.

2. THE MODELS OF QUASAR RADIO SOURCES

The widely accepted model of quasar is a supermassive black hole surrounded by accretion disk (Begelman et al., 1984; Blandford, Znajek, 1977). This model was confirmed with microlensing observations (Koptelova et al., 2007), where it was demonstrated that distribution of brightness over the quasar disk is similar to brightness distribution over accretion disk. A central engine of quasar produces a jet of relativistic particle which emits radio waves, and the jet is radio source. As a result, one can conclude that the optical and radio sources are space separated parts of the unique source. We will follow the model discussed and elaborated in Blandford, Königl (1979) and Begelman et al.(1984).

In these papers, model of radio source with well defined internal structure (which consists of jet of high temperature relativistic plasma, bulk motion of separated clouds as hot spot etc.) is discussed. The right example of such source is 3C345 or Cygnus A. These sources have well defined internal structures that reveal the fast motion of bright spots, and are not included into the list of ICRF sources. Radio sources which are included in the ICRF list are radio quiet quasars which reveal almost point-like unresolved structure. Nevertheless, we believe that physics of their non-stationarity is similar to radio active quasars.

Authors of papers (Blandford, Königl, 1979; Begelman et al., 1984) distinguish two main physical mechanisms. The first one is a steady jet of high temperature relativistic plasma and second is a bulk motion of separate accelerated cloud. Here we will discuss steady jet only and their effect on long-term stability of the ICRF (Zharov et al., 2009).

Jets are elongated structure with some brightness distribution along the jet. In some position of the jet, brightness has maximum. We will call it hot spot. The distance from the origin of the jet to the hot spot r_s is of the order of 1 kpc or less (according to theoretical estimations)(Blandford, Königl, 1979).

It is necessary to mention that

$$r_s \sim \frac{1}{\nu},$$

therefore, a jet which is unresolved in a frequency ν will be unresolved in whole range of radio frequencies. Distance to the hot spot increases with increase of wavelength ($\lambda = c/\nu$). If one observes in shorter wavelength, the distance to the hot spot became shorter. The resolution ability of a radio interferometer is proportional to wavelength:

$$\theta_{ang} \sim \frac{\lambda}{B},$$

here B is baseline. If the wavelength of observation decreases the resolution ability of radio interferometer increases, it means that minimal separated angle θ_{ang} became less, but the distance to the hot spot also decreases. Therefore, for the radio source of this type, one has to increase interferometer base, not decreases wavelength.

3. PRECESSION OF THE QUASAR JET AS NONSTATIONARY SOURCE

Precession of jets is observed in many celestial systems including extragalactic ones. A very good example of jet precession is QSO 2300-189 (Hunstead, et al., 1984). Precession of jet with high precession speed is observed also in black hole which is component of binary system SS434 (Davydov V.D. et al., 2008). The speed of precession is almost constant during the long time interval in binary star system. Therefore, one can expect the same stability of the speed in extragalactic systems.

The angular velocity of a hot spot and total shift of a source over sky depend on the jet precession speed and ranges into interval $10^{-4} \div 10^{-8}$ yr^{-1} depending of parameters of black hole and surrounding matter. As the jet precesses the jet hot spot moves over the sky. The angular velocity of the hot spot depends both on the precession speed and geometry of the black hole system with respect to the direction of the observer. The interval of observation is of the order of 30 years and precession period is longer than 10 000 years; so one can expect the linear and uniform motion over the observing interval. The angular velocity can be approximated as constant

$$\mu = \frac{\theta_s}{1+z}\Omega Q. \tag{1}$$

Here θ_s is the angular distance from the origin of the jet to the hot spot ($\theta_s = r_s/\rho_s$, ρ_s is the angular cosmological distance to the source), and z is the redshift of the source, and Q is the factor of the order of unity, which depends on geometry and velocity of the system. Therefore the precession period provides us with the interval of stability of the coordinate system based on these sources.

The source 1044+719 The angular distance between optical and radio coordinates is $\theta_s = 165$ mas, the rms of optical coordinates is 73.9 mas, the difference can be considered as confident with level 2.3 σ. The redshift is $z = 1.15$, the ratio of linear to angular distance for the standard cosmological model is:

$$s = 8.286\frac{kpc}{1''},$$

that corresponds to a linear distance between the origin of jet to the hot spot of $r_s = 1.37$ kpc.

The apparent angular velocity of the source is $\mu = 36$ μas/year, which corresponds to the linear apparent velocity $v = 2.1\ c$. It also corresponds to the precession speed $\Omega \sim 2.3 \cdot 10^{-4}$/year. That means that for several centuries this source has to keep linear and uniform motion.

The source 1726+455 The angular distance between optical and radio coordinates is $\theta_s = 181$ mas, the rms of optical coordinates is 74.8 mas, the difference can be considered as confident with a level of 2.4 σ. The redshift is $z = 0.71$, the ratio of linear to angular distance for the standard cosmological model is:

$$s = 7.202 \frac{kpc}{1''},$$

that corresponds to a linear distance between the origin of jet to the hot spot of $r_s = 1.30$ kpc.

The apparent angular velocity of the source is $\mu = 12$ μas/year, which corresponds to the linear apparent velocity $v = 0.5c$. It also corresponds to the precession speed $\Omega \sim 2.3 \cdot 10^{-4}$/year. That means that for several centuries this source has to keep linear and uniform motion.

Below we show the complete list of the sources which demonstrated the linear and uniform motion: 0007+171(D), 0039+230(D), 0048-097(O), 0104-408(O), 0202+149(C), 0248+430(D), 0556+238(D), 0602+673(C), 0953+254(O), 1044+719(C), 1124-186(C), 1150+497(D), 1324+224(D), 1413+135(O), 1656+053(C), 1726+455(D), 1738+476(C), 1751+441(D), 1929+226(C), 1932+204(C), 2145+067(D), 2351+456(O), 2356+385(C) (D means defining source, C is candidate and O is other).

As seen from the list above, some of the sources are defining. So, the precessional motion of jet that we see as motion of source affects the stability of the ICRF. Orientation of the new catalog with respect to the ICRF will depend on time.

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4. REFERENCES

Begelman, M.C., Blandford,R.D., Rees, M.J., 1984, Rev. Mod. Phys 56, 255.

Blandford, R.D., Znajek, R.L., 1977, MNRAS 179, 433.

Blandford, R.D., Königl, A., 1979, AJ 232, 34.

Davydov V.D., Esipov V.F., Cherepashchuk A.M., 2008, Astron.Rep., 85, 545 (russian).

R.W. Hunstead, H.S. Murdoch, J.J. Condon et al., 1984, MNRAS 207, 55.

Ma, C., Arias, E.F., Eubanks T.M., Fey A.L., Gontier A-M, Jacobs, C.S., Sovers, O.J., Archinal, B.A., Charlot, P., 1998, AJ 116, 516.

IERS, 1999, 1998 IERS Annual Report, Observatoire de Paris, 87.

Fey, A.L., Ma, C., Arias, E.F., Charlot, P., Feissel-Vernier, M., Gontier, A.-M., Jacobs, C. S., Li, J., McMillan, D.S., 2004, AJ 127, 3587.

Feissel-Vernier, M., 2003, A&A 403, 105.

Koptelova, E., Shimanovskaya, E., Artamonov, B., Yagola, A., 2007, MNRAS 381, 1655.

MacMillan, D.C., 2003, in Future Directions in High Resolution Astronomy, eds. J.D. Romney, M.J. Reid (The 10th Anniversary of the VLBI ASP Conference series).

Sazhin, M.V., Zharov, V.E., Kalinina, T.A., 2001, MNRAS 323, 952.

Zharov, V.E., Sazhin, M.V., Sementsov, V.N., Kuimov K.V., Sazhina, O.S., 2009, Astron. Rep. (accepted for publication, russian).

Zharov, V.E., Rastorgueva, E.A., this issue.