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VLBI as a Tool to Connect Astrometry and Astrophysics

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Abstract. VLBI is the most powerful instrument for astronomical investigations and especially for determination of the scale of the Universe. Namely, the culmination of this millennium of astronomy is a tremendous growth in our understanding of the scale of the Universe and the range of astrophysical phenomena which underlies its apparent structure. Another important field of astronomical research is the observation of quasars. Evidence has been accumulating for several decades that quasars, the most luminous objects in the Universe are powered by accretion of matter onto massive black holes.

I review the following most important topics of VLBI in modern astrophysics: 1) determination of cosmological parameters; 2) probes of super massive black holes (SMBH); 3) high-resolution observations of spatial regions of relativistic jets of active galactic nuclei and trace their evolution and interaction with the nuclear environment; 4) VLBI as the instrument for research of effects of new physics and vacuum polarization; 5) new fields of VLBI: Space Polarization INterferometry (SPIN) and X-ray Interferometry – MAXIM Project.

1. VLBI and Determination of Cosmological Parameters

The angular size-redshift (θ_z) relation for cosmological objects (quasars, active galaxy nuclei, galaxy clusters) is a powerful probe of the large-scale geometry of the Universe. The final versions of the VLA FIRST survey and the optical Sloan Digital Sky Survey (SDSS) data release allow to find carefully selected criteria for defining largest populations of cosmological objects. As a result, it has become possible to place tighter constraints on cosmological parameters and distinguish among the different cosmological models, and determine the impact of the angular size-redshift studies in cosmology (Fig. 1-3) [2]. VLBI observations help our understanding of the behavior of the intergalactic medium (IGM) as a function of redshift and shed more light on the quasar-radio galaxy unification issue.

Another very important problem is connected with gravitational lensing. Typical angular distance images and typical time scales depend on gravitational lens mass. High resolution interferometry with radio waves gives excellent chance to investigate microlensing phenomena in astrophysics.

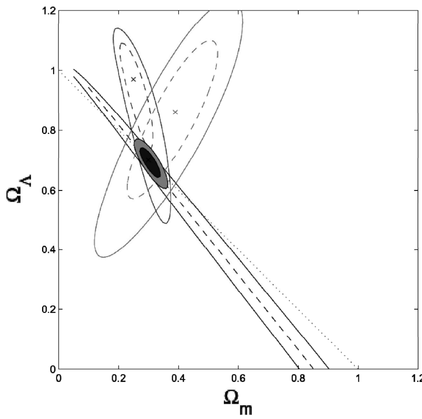

Figure 1. The constraints on the cosmological parameters: dimensional dark energy and dark matter densities

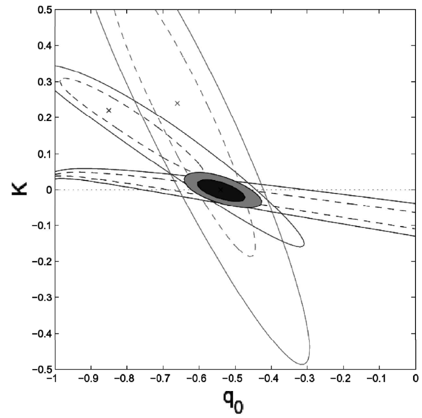

Figure 2. The constraints on the cosmological parameters from VLBI survey: the curvature vs deceleration constant

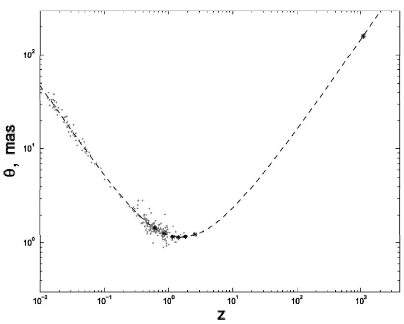

Figure 3. The angular-diameter redshift relation of the Legacy VLBI Survey data for ultra-compact radio sources at 2.29 GHz

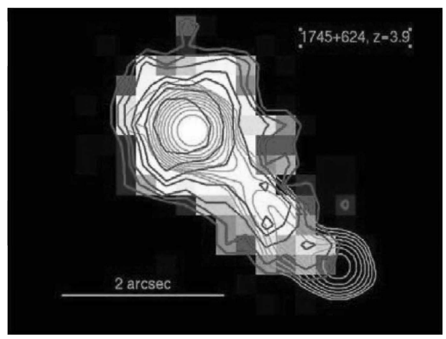

Figure 4. The image of high-z jet from QSO 1745+624: $z = 3.9$ [1]

2. VLBI Probes of Super Massive Black Holes (SMBH)

Nuclear activity in galaxies is closely connected to galactic mergers and SMBHs. Galactic mergers perturb substantially the dynamics of gas and the stellar population in the galaxies, and they are expected to lead to the formation of super massive binary black holes in the center of mass of the merged galaxies. VLBI is an excellent instrument for investigation of this phenomenon. It presents a unique opportunity to test the non-linear structure of general relativity.

SMBHs make ultra-relativistic jets (Fig. 4). Outflows (jets) are the main mechanisms for transport of angular momentum. Long-term evolution of large-scale relativistic jets can be studied by VLBI observations.

Another example is connected with Legacy data [2]. VLBI survey of ultra-compact radio sources at 2.29 GHz was presented and fringe amplitudes for 917 such objects with total flux density > 0.5 Jy was given. A number of cosmological investigations based upon this survey are now developed.

3. Relativistic Jets and Their Basic Physical Properties

Substantial progress achieved during the past decade in studies of active galactic nuclei has brought an increasingly wider recognition of the presence of relativistic outflows (jets) in galactic nuclei presenting them as an effective probe of nuclear regions in galaxies. Emission properties, dynamics, and evolution of an extragalactic jet are closely connected to the physical characteristics of the super massive black hole, accretion disk and broad-line region in the nucleus of the host galaxy (Fig. 4). The jet continuum emission is dominated by non-thermal synchrotron and inverse Compton radiation. In radio waves the synchrotron mechanism is namely dominated, and the main physical properties of the emitting material can be extracted using the turnover point in the synchrotron spectrum, synchrotron self-absorption, and free-free absorption in emitting plasma. High-resolution radio observations access directly the regions where the jets are formed, and trace the evolution and interaction with nuclear environment. Evolution of compact radio emission and jet magnetic field determined from synchrotron radiation are now systematically studied with monitoring programs and large surveys using long baseline interferometry.

Jets are common features of radio-loud AGN at high redshift (up to $z = 4.7$). This conclusion is also based on VLBI measurements. The Chandra X-ray observations tell us about this result. Extending studies to these high redshifts should help us to distinguish between the competing synchrotron and inverse Compton models to determine if there is a redshift dependence and in X-ray jet emission.

These studies, combined with optical and X-ray studies, yield the most detailed picture of the galactic nuclei.

4. VLBI and New Physics

A number of physical effects of current interest manifest themselves as a birefringence appearing in response to the application of strong electromagnetic fields. The most known effect is the small degree of magnetically induced birefringence that arises in the Cotton-Mouton phenomenon. Such kind of effect is predicted to occur in vacuum arising under quantum electrodynamics (QED). A new technique capable of measuring birefringence with great precision has been recently suggested. The special device received name as a Resonant Polarization Interferometer. Angle size - redshift dependence allow us to shed light on what is the nature of Dark Energy (DE) and Dark Matter

(DM). One popular idea is the existence of the new states of matter at exceedingly high density and temperature. USA National Science and Technology Council and Committee on Science formulated eleven science questions for the New Century. Replies will give the explanation of origin of DE and DM.

5. New Aspects of Interferometry: X-Ray Interferometry — MAXIM Project

MAXIM means MicroArcsecond X-ray Imaging Mission. Recently an essential step in establishing the viability of X-ray interferometry has been made [3]. The interferometer must not only create fringes, but be of a design class that can be developed into an efficient system for astronomy. While there is no question that X-rays will exhibit the same wave properties than light rays in other bands, the extreme shortness of the X-ray waves make the development of real interferometry very difficult. Fortunately, the team from the Colorado University of USA has now built and successfully tested an X-ray interferometer of a class that can have practical application. It means that we can expect to get the angular resolution of astronomical objects in X-rays at the level $\sim 1\mu$sec.

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