Astrophysical Phenomena Revealed by Space VLBI
H. Hirabayashi, P.G. Edwards and D.W. Murphy (eds.)

The Geometry of the Universe from High Resolution VLBI Data of AGN Shocks

ESKO VALTAOJA[1] AND KAJ WIIK[1,2]

[1] *Tuorla Observatory, University of Turku*
Väisäläntie 20, FIN-21500 Piikkiö, Finland
[2] *Metsähovi Radio Observatory, Helsinki University of Technology*
Metsähovintie 114, FIN-02540 Kylmälä, Finland

Abstract

We propose to use the linear diameters of the shocks in AGN jets as standard rods for determining the geometry of the Universe. The unique feature of shocks is that we can directly estimate their linear diameters from total flux density monitoring data and light travel time arguments. We demonstrate the method by using a small sample of 14 22 GHz VLBI observations. The accuracy of the derived value, $q_0 \approx 0$, compares favorably with traditional methods using much larger samples.

1 Introduction

In principle, it is easy to determine the geometry of the Universe simply by observing how the apparent size of an object changes with distance (the redshift z). In an Euclidian universe the angular size of an object (the standard rod) diminishes in direct proportion to the distance, in accordance with our everyday experience. However, in a four-dimensional universe described by Einstein's theory of general relativity and the standard metric, after a minimum at around $z = 1$ the angular size of a standard rod starts to increase again and the object appears the larger the more distant it is.

The exact behaviour of the angular diameter θ on the redshift depends on the cosmological parameters. The so-called θ–z relation can therefore be used to determine the geometry of the universe, in particular the deceleration parameter q_0. Some recent supernova observations have indicated that q_0 may be negative, which would mean that the expansion of the universe is accelerating, and is dominated by the cosmological constant Λ instead of visible or dark matter in any form.

Not many astronomical objects can be detected at redshifts in excess of one, and none of them is well suited to be a standard rod. All proposed rods, such as galaxy clusters or the sizes of double radio sources, have similar diameters only on the average, and they evolve significantly with the cosmological epoch. In addition, the results are confused by severe selection effects. In recent years, much effort has been directed towards using the VLBI milliarcsecond structures of radio galaxies and quasars. These have given the thus far best estimates of q_0, but the accuracy is hardly sufficient to differentiate between closed and open universes, and there are severe methological problems in analyzing binned data (e.g., Kellermann 1993; Gurvits 1994; Stelmach 1994; Stepanas and Saha 1995; Dabrowski et al. 1995; Gurvits et al. 1999). The problem, in short, is that we cannot measure the true linear size of an object used as a traditional standard rod.

2 A Normalized Standard Rod: Diameters of AGN Shocks

We propose to use the linear diameters of the shocks in AGN jets as standard rods. With modern VLBI techniques, angular sizes of these radio-emitting regions can in some cases be measured. Typical values are less than one milliarcsecond, requiring millimeter or space VLBI observations.

Assuming simply that every shock in every AGN has the same linear diameter would lead to all the well-known problems of the traditional standard rods. However, the unique feature of shocks is that we can directly estimate their linear diameters from total flux density monitoring data and light travel time arguments. The VLBI shocks correspond to radio flares seen, e.g., in the Metsähovi monitoring program (Teräsranta et al. 1998). The radio flares can be surprisingly accurately modelled with simple exponential functions, which directly give the variability timescales (Valtaoja et al. 1999). The variability timescales τ_{int}, transferred to the source frame, give the linear sizes of the shocks: $L \approx kc\tau_{int}$, with k an unknown factor from the source geometry. Thus, we are freed from any assumptions that the sizes of our standard rods are similar in different sources, at different times and at different cosmological epochs: using θ_{VLBI}/τ_{int} as the standard rod, we are essentially measuring the angular size of a light-year at different redshifts.

In order to transfer the observed variability timescale, τ_{obs} into the source frame, we must know the Doppler boosting factor D of the source:

$\tau_{int} = \tau_{obs} D/(1+z)$. The traditional method for estimating the Doppler boosting factors is to use synchrotron-self-Compton arguments (e.g., Guerra and Daly 1997); however, as we have recently demonstrated, such values are very unreliable and much better ones can be derived simply using total flux density variations (Lähteenmäki and Valtaoja 1999). Virtually all major total flux density outbursts in AGN have associated variability brightness temperatures far in excess of the equipartition limit (Readhead 1994; Lähteenmäki et al. 1999), indicating significant amounts of Doppler boosting: $D_{var} = (T_{b,obs}/T_{eq})^{1/3}$.

The use of variability-derived values for D has one drawback. The observed variability brightness temperature depends on the second power of the assumed angular distance D_A, and consequently $D_{var} \propto D_A^{2/3}$. The net result is that the 'rod length' θ_{VLBI}/τ_{int} has a weaker dependence on the angular distance, just $D_A^{-1/3}$ instead of the usual $\theta \propto D_A^{-1}$.

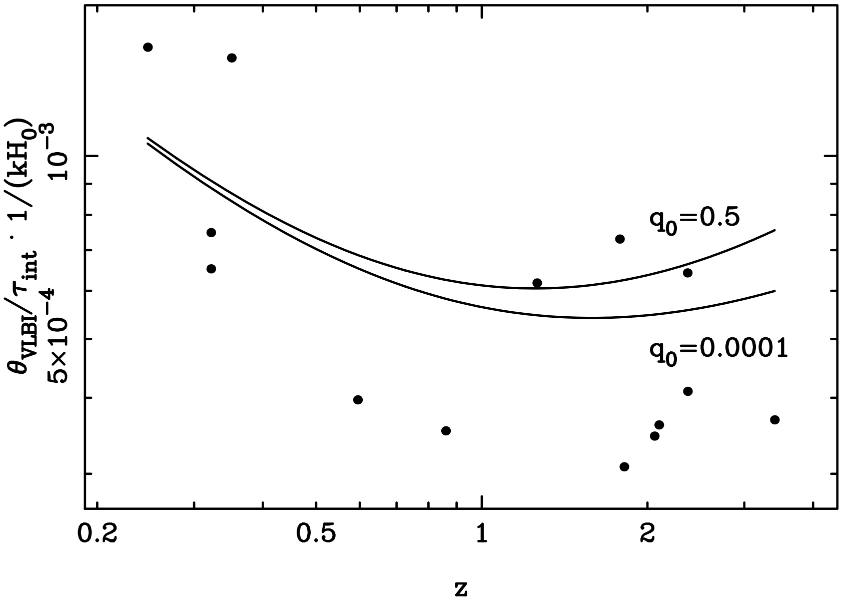

Figure 1: The scaled angular size versus redshift. The expected z-dependence for $q_0 = 0.5$ and 0.0001 is also shown.

3 First Results

Figure 1 shows our first results using two recent VLBI samples (Bloom et al. 1999 and Wiik et al., these Proceedings). Using the Levenberg-Marquardt gradient-expansion algorithm, we find that the best fit to the data is given by $q_0 = 0 \pm 0.1$ indicating an open, forever expanding universe. With more data, we will also be able to estimate the magnitude of the cosmological constant. Here we have assumed $\Lambda = 0$, since we do not yet have enough data points for a meaningful two-parameter fit. However, we note that a better fit to the data would be obtained with a negative value for q_0 (e.g., Krauss and Schramm 1993).

It is obvious that the shocks must be clearly resolved in transverse direction in order to obtain reliable results; high-resolution millimeter or space VLBI data are needed to test the true value of our proposed new method. Simultaneous multifrequency total flux density and VLBI observations of shocks at different stages of their development will also enable us to study variations in the geometry of the shocks - the factor k (which we have assumed to be constant) relating the light travel time to the shock diameter.

References

Bloom, S.D. et al. 1999, *ApJS*, **122**, 1

Dabrowski, Y. et al. 1995, *MNRAS*, **277**, 753

Guerra, E.J. & Daly, R.A. 1997, *ApJ*, **491**, 483

Gurvits, L.I., Kellermann, K.I. & Frey, S. 1999, *A&A*, **342**, 378

Gurvits, L.I. 1994, *ApJ*, **425**, 442

Kellermann, K.I. 1993, *Nature*, **361**, 134

Krauss, L.M. & Schramm, D.N. 1993, *ApJ*, **405**, L43

Lähteenmäki, A., Valtaoja, E. & Wiik, K. 1999, *ApJ*, **511**, 112

Lähteenmäki, A. & Valtaoja, E. 1999, *ApJ*, **521**, 493

Readhead, A.C.S. 1994, *ApJ*, **426**, 51

Stelmach, J. 1994, *ApJ*, **428**, 61

Stepanas, P.G. & Saha, P. 1995, *MNRAS*, **272**, L13

Teräsranta, H. et al. 1998, *A&AS*, **132**, 305

Valtaoja, E. et al. 1999, *ApJS*, **120**, 95