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FRIIb Radio Galaxies, Cosmology, and Quintessence

Ruth A. Daly

Pennsylvania State University, Department of Physics, P.O. Box 7009, Reading, PA 19610-6009, USA

Erick J. Guerra

Rowan University, Department of Chemistry and Physics, 201 Mullica Hill Road, Glassboro, NJ 08028, USA

Abstract. FRIIb radio galaxies can be used as modified standard yardsticks to determine global cosmological parameters; the method is analogous to the use of supernovae type Ia as modified standard candles. FRIIb radio galaxies are observed to very high-redshift; the sources discussed here are fairly evenly distributed in redshift, with redshifts between zero and two. The sources can be used to determine the coordinate distance to high-redshift sources, and thus can constrain global cosmological parameters (just like the use of supernova type Ia to determine the coordinate distance, or luminosity distance, to high-redshift sources). Current constraints on global cosmological parameters and on quintessence obtained using FRIIb radio galaxies are presented.

1. Cosmology with FRIIb Radio Galaxies

Methods that yield constraints on global cosmological parameters through a deterimination of the coordinate distance to high-redshift objects are particularly important to develop. Included in this category is any method that relies on a determination of the luminosity distance or angular size distance, since these explicitly rely on the coordinate distance to the source or object. Examples include the use of gravitational lens systems (e.g. Schechter 2000; Helbig 2000), supernova type Ia (e.g. talks at this conference by Kirschner and Perlmutter), and FRIIb radio galaxies (Daly 1994, 1995; Guerra 1997; Guerra & Daly 1998; Guerra, Daly, & Wan 2000; hereafter GDW00). Cosmological parameters constrained through determinations of coordinate distances to high-redshift sources are particularly important because they allow a direct measure of "global" cosmological parameters; the parameters determined are independent of the power spectrum of the dark matter, and thus do not depend on the clustering properties or nature (i.e. whether it is hot, cold, or warm) of the dark matter.

FRIIb radio sources are a special subset of all FRII sources; FRII sources are defined by Fanaroff & Riley (1974). FRIIb radio sources have particularly simple large-scale radio properties, as discussed, for example, by Daly (2000) and Wellman, Daly, and Wan (1997). The radio bridge region of each source is often $100h^{-1}$ kpc in length or longer, where Hubble's constant is written in the usual way $H_o = 100\ h$ km s^{-1} Mpc^{-1}. At low radio frequencies, the radio surface brightness across the ridge-line of a source can be very accurately reproduced

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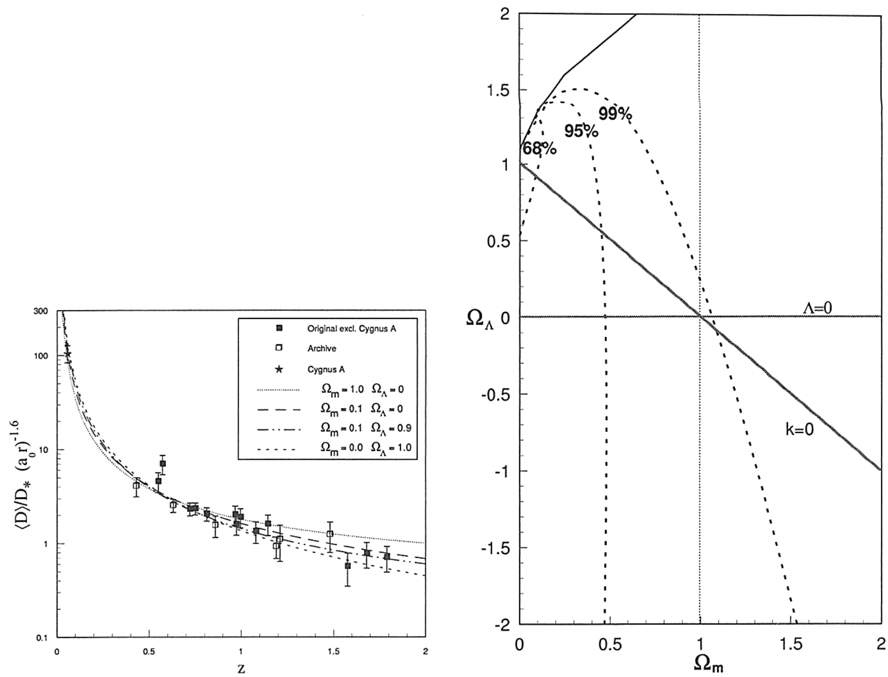

Figure 1. Fits obtained using FRIIb radio galaxies when the low-redshift bin is excluded from the analysis. **This method does not rely on a low-redshift normalization**, as detailed by GDW00.

by accounting for adiabatic expansion of the bridge in the lateral direction by an amount given by the observed change in the width of the bridge (what could be simpler!) (Wellman 1997; Wellman, Daly, & Wan 1997; Daly 2000). The physics of these sources is remarkably simple and is fairly well understood. The use of the sources for cosmology is described in detail by GDW00.

One aspect in which this method differs considerably from the supernova method is that **it does not rely on a zero-redshift normalization**. Figure 1 illustrates the results obtained with this method when the low redshift bin, which includes Cygnus A, is excluded from the analysis. Even though the low redshift bin is **not** included in the analysis, all of the best fit lines pass right through the low-redshift point (Cygnus A). This shows that the method is working quite well; the fit to the low redshift bin is not fortuitous, since the low-redshift point could have had any value of $(< D > /D_*)(a_o r)^{-1.6}$.

Fits obtained excluding the lowest redshift bin indicate that the mean mass density in non-relativistic matter at the current epoch Ω_m must be less than 0.5 at 95 % confidence irrespective of the values of the other cosmological parameters.

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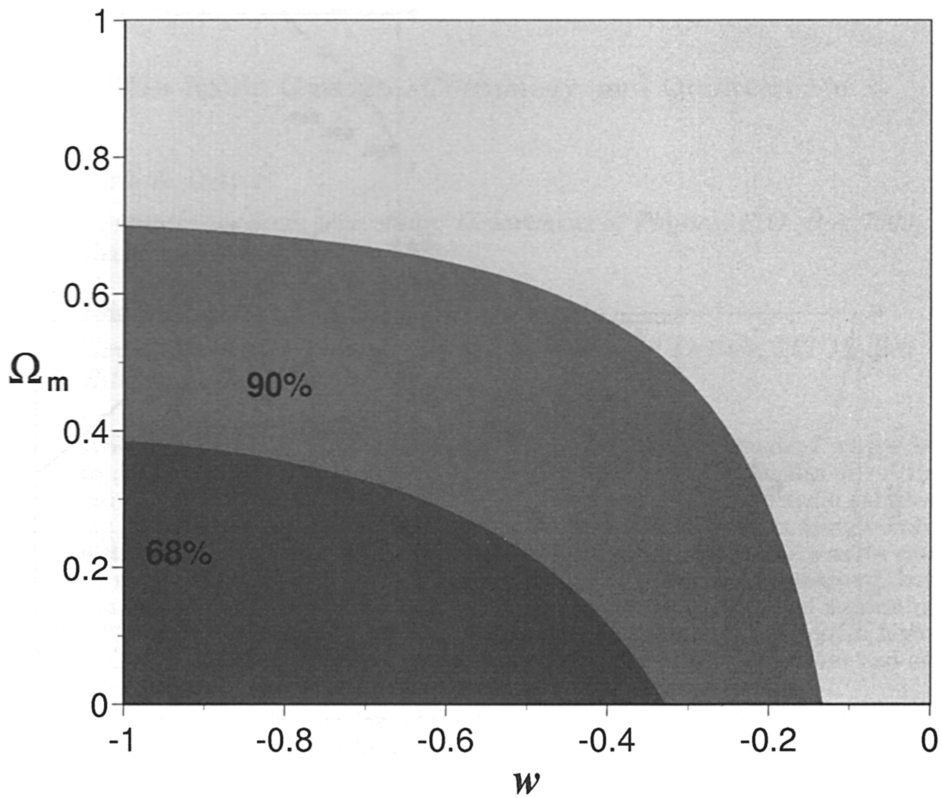

Figure 2. The 68 % and 90 % confidence contours in the $\Omega_m - w$ plane obtained using 20 FRIIb radio galaxies, and allowing for quintessence.

2. Constraints on Quintessence

Quintessence may be represented as a component whose mass-energy density increases with redshift as $(1+z)^n$, where the power n is very simply related to the equation of state $w = P/\rho$ via the relation $w = (n/3) - 1$ (e.g. Bludman & Roos 2000; Wang, Caldwell, Ostriker, & Steinhardt 2000). Constraints obtained assuming zero space curvature and allowing for quintessence, are shown in the Ω_m - w plane in Figure 2. The analysis is carried out with a sample and in a manner identical to that described by GDW00, assuming $\Omega_m + \Omega_Q = 1$, where Ω_m and Ω_Q are the normalized mean mass-energy densities at the current epoch of non-relativistic matter and quintessence, respectively. In the analysis, the function $E(z)$ (see Peebles 1993, eq. 13.3) is taken to be $E(z) = [\Omega_m(1+z)^3 + \Omega_Q(1+z)^n]^{1/2}$. Constraints in the $w - \beta$ plane, and the $\Omega_m - \beta$ plane are shown in Figure 3. The constraints on w are rather weak, as anticipated by Maor, Brustein, & Steinhardt (2000).

The model that underpins the use of FRIIb radio sources as modified standard yardsticks has one parameter, β. This model parameter is independent of the choice of cosmological parameters or the equation of state, as shown in Fig-

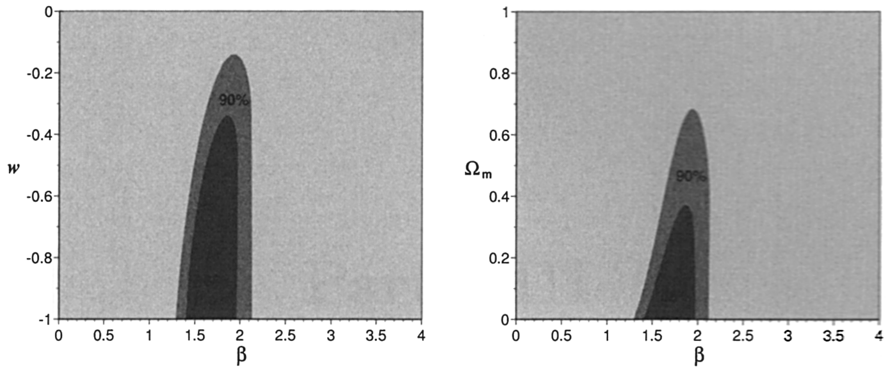

Figure 3. The 68 % and 90 % confidence contours allowing for quintessence, obtained using the analysis described in the text. Note that the model parameter $\beta = 1.75 \pm 0.25$ is independent of w and Ω_m.

ure 3, and as discussed in detail by GDW00. The value of this model parameter has important implications for models of energy extraction and jet production in the vicinity of massive black holes as discussed, for example, by Daly (1995, 2000).

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References

Bludman, S. & Roos, M. 2000, Astro-Ph/0004328
Daly, R. A. 1994, ApJ, 426, 38
Daly, R. A. 1995, ApJ, 454, 580
Fanaroff, B. L. & Riley, J. M. 1974, MNRAS, 167, 31p
Guerra, E. J. 1997, PhD Thesis, Princeton University
Guerra, E. J. & Daly, R. A. 1998, ApJ, 493, 536
Guerra, E. J., Daly, R. A. & Wan, L. 2000, ApJ, 544, in press (GDW00)
Helbig, P. 2000, these proceedings, 245
Maor, I, Brustein, R. & Steinhardt, P. J. 2000, Astro-Ph/0007297
Peebles, P. J. E. 1993, Principles of Physical Cosmology, Princeton University Press
Schechter, P. 2000, these proceedings, 209
Wang, L., Caldwell, R. R., Ostriker, J. P. & Steinhardt, P. J. 2000, ApJ, 530, 17
Wellman, G. F. 1997, Ph.D. Thesis, Princeton University
Wellman, G. F., Daly, R. A. & Wan, L. 1997, ApJ, 480, 79