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RADIO GALAXY REDSHIFT–ANGULAR SIZE DATA CONSTRAINTS ON DARK ENERGY

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ABSTRACT

We use FRIIb radio galaxy redshift–angular size data to constrain cosmological parameters in a dark energy scalar field model. The derived constraints are consistent with, but weaker than, those determined using Type Ia supernova redshift-magnitude data.

Subject headings: cosmological parameters — cosmology: observations — large-scale structure of universe

1. INTRODUCTION

The last half-dozen years have seen a remarkable increase in the quality of some cosmological data. No less remarkable, but perhaps less heralded, has been the continuing acquisition of new types of data. These have been very useful developments in the ongoing process of determining, through the cosmological tests, how well current cosmological models approximate reality; many independent and tight constraints on cosmological-model parameters allow for consistency checks on the models (see, e.g., Maor et al. 2002; Wasserman 2002).

For example, there are now much more higher quality Type Ia supernova redshift-magnitude data. Recent applications of the redshift-magnitude test based on these data (see, e.g., Riess et al. 1998; Perlmutter et al. 1999; Podariu & Ratra 2000; Waga & Frieman 2000; Leibundgut 2001) indicate that the energy density of the current universe is dominated by a cosmological constant, Λ, or by a term in the stress-energy tensor that only varies slowly with time and space and so behaves like Λ.[4] Supporting evidence for Λ or a Λ-like term is provided by a combination of low dynamical estimates for the nonrelativistic matter density parameter Ω_0 (see, e.g., Peebles 1993) and evidence for a vanishing curvature of spatial hypersurfaces from cosmic microwave background anisotropy measurements (see, e.g., Podariu et al. 2001; Baccigalupi et al. 2002; Scott et al. 2002; Mason et al. 2002).

Evidence against the large value of the cosmological constant density parameter Ω_Λ favored by the above tests comes from estimates of the observed rate of multiple images of radio sources or quasars, produced by gravitational lensing by foreground galaxies (see, e.g., Ratra & Quillen 1992; Helbig et al. 1999; Waga & Frieman 2000; Ng & Wiltshire 2001).

An improvement in data quality, as well as data from other cosmological tests, will be needed to resolve this situation. In the near future the redshift-counts test appears to be promising (see, e.g., Newman & Davis 2000; Huterer & Turner 2001; Podariu & Ratra 2001; Levine, Schulz, & White 2002).

Present redshift–angular size data provide a useful consistency check. The redshift–angular size relation is measured by Buchalter et al. (1998) for quasars, by Gurvits, Kellermann, & Frey (1999) for compact radio sources, and by Daly & Guerra (2003) for FRIIb radio galaxies. Vishwakarma (2001), Lima & Alcaniz (2002), and Chen & Ratra (2003) use the Gurvits et al. (1999) data to set constraints on cosmological parameters. Guerra, Daly, & Wan (2000), Guerra & Daly (1998), Daly, Mory, & Guerra (2002), and Daly & Guerra (2003) examine FRIIb radio galaxy redshift–angular size cosmological constraints in various models using the modified standard yardstick method proposed by Daly (1994).

Here we use the FRIIb radio galaxy redshift–angular size data of Guerra et al. (2000) to derive constraints on the parameters of a spatially-flat model with a dark energy scalar field (ϕ) with scalar field potential energy density $V(\phi)$ that at low redshift is $\propto \phi^{-\alpha}$, where $\alpha > 0$ (Peebles & Ratra 1988). The energy density of such a scalar field decreases with time, behaving like a time-variable Λ.

We adopt the analysis technique of Guerra et al. (2000), marginalizing over their parameter β to account for the uncertainty in the linear size of the " standard rod " used in the redshift–angular size test, to derive the likelihood (probability distribution) of the scalar field model parameters, $L(\Omega_0, \alpha)$. This likelihood function is used to determine confidence regions for the model parameters. We compute $L(\Omega_0, \alpha)$ over the ranges $0.05 \leq \Omega_0 \leq 0.95$ and $0 \leq \alpha \leq 8$. The radio galaxy 3C 427.1 (of the 20 used in the analysis) is a disproportionate contributor to χ^2, so we present results both including and excluding this radio galaxy. When we exclude 3C 427.1 we renormalize the error bars to make the best-fit reduced χ^2 unity.

2. RESULTS AND DISCUSSION

Figures 1 and 2 show the constraints on Ω_0 and α in the dark energy scalar field model with $V(\phi) \propto \phi^{-\alpha}$, including and excluding 3C 427.1. In both cases the constraints shown here are consistent with, but tighter than, those derived using the Gurvits et al. (1999) compact radio source redshift–angular size data (Chen & Ratra 2003, Fig. 3). They are also consistent with, but not as constraining as, those derived from the Riess et al. (1998) and Perlmutter et al. (1999) Type Ia supernova redshift-magnitude data (Podariu & Ratra 2000; Waga & Frieman 2000). Consistent with

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[4] See, e.g., Peebles (1984), Ratra & Peebles (1988), Efstathiou, Sutherland, & Maddox (1990), Ratra et al. (1997, 1999), Steinhardt (1999), Sahni & Starobinsky (2000), Brax, Martin, & Riazuelo (2000), and Carroll (2001) for discussions of such models.

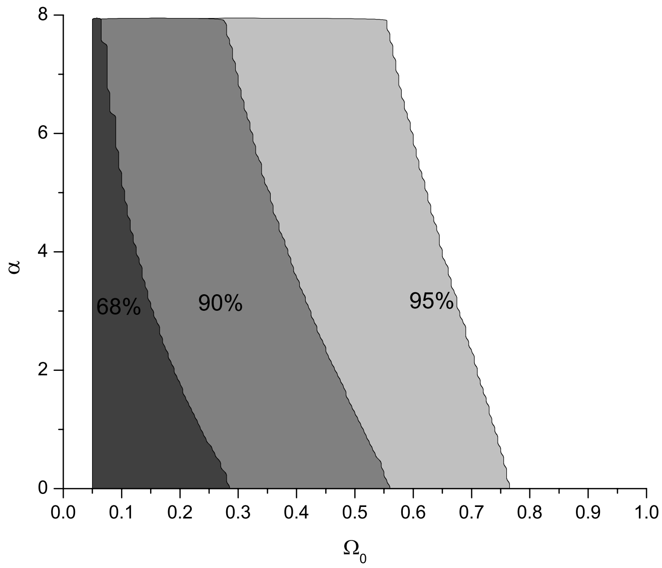

FIG. 1.—Confidence contours for the dark energy scalar field model with inverse power-law potential energy density $V(\phi) \propto \phi^{-\alpha}$, derived using all 20 radio galaxies (i.e., including 3C 427.1).

these analyses, the analysis here also does not rule out large values of α when Ω_0 is small.

The radio galaxy 3C 427.1 can easily be identified as an outlier. This can be seen in Table 2 and Figures 2*b*, 8*b*, and 8*c* of Guerra & Daly (1998), and the effective Hubble diagrams shown in Figure 7 of Guerra et al. (2000) and Figure 8 of Daly & Guerra (2003), for example. In the fits presented in each of these papers and those presented by Daly & Guerra (2003), as well as in the fits presented here, this one source contributes about one-half of the total χ^2, and the total χ^2 for the best fit parameters is always about 16 (see Fig. 1 of Daly & Guerra 2003, for example). Each fit has 16 degrees of freedom since there are 20 radio galaxy points, the cosmological model has two free parameters, and the radio galaxy modified standard yardstick model has two free parameters.

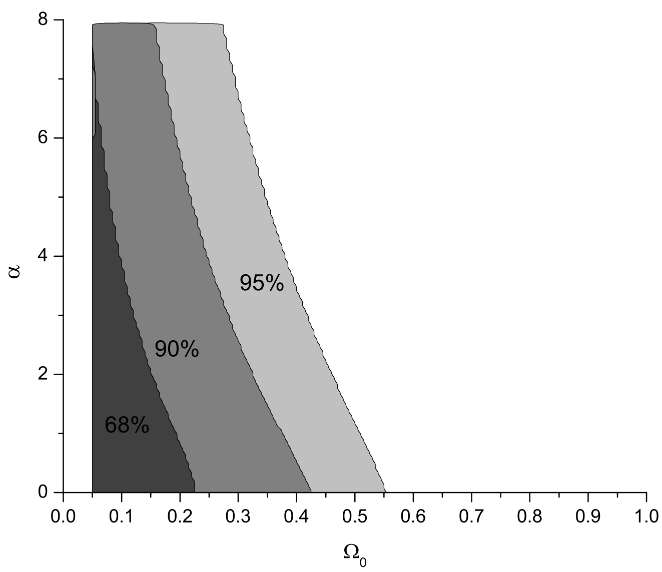

FIG. 2.—Confidence contours for the dark energy scalar field model with inverse power-law potential energy density $V(\phi) \propto \phi^{-\alpha}$, derived using only 19 radio galaxies (i.e., excluding 3C 427.1).

To date, this point has been included in all of the fits. It is not clear whether it should be included in the fits, or whether it should be flagged as an outlier and removed from the data set, as was done for Type Ia supernovae by Perlmutter et al. (1999). If it is flagged as an outlier and removed from the data set, the low reduced χ^2 of about one-half that would result for the best fitting parameters in any of the cosmological models considered would indicate that the error bars on each radio galaxy data point have been overestimated by a factor of about 1.4. It is certainly possible for these error bars to have been overestimated; the determination of the error bars is discussed in detail in the Appendix of Guerra et al. (2000). This decrease in the error bar per point tightens the constraints on all parameters, including cosmological parameters and radio galaxy model parameters, as can be seen by comparing Figures 1 and 2. However, the only empirical basis for removing 3C 427.1 from the data set is its position on the radio galaxy effective Hubble diagram. Its radio structure is not unusual or remarkable (see Leahy, Muxlow, & Stephens 1989). The use of this radio source to determine the ambient gas density (Wellman, Daly, & Wan 1997a), the ambient gas temperature (Wellman, Daly, & Wan 1997b), the synchrotron aging independent ambient gas pressure, the beam power, and the total AGN-jet lifetime of this source (Wan, Daly, & Guerra 2000) are all unremarkable and quite in line with sources with similar redshifts, sizes, and radio powers. The determination of the source redshift seems secure (Spinrad, Stauffer, & Butcher 1985). It does not appear to be an especially bright infrared source; upper bounds on its infrared luminosity are presented by Meisenheimer et al. (2001). Thus, it is unlikely to be an especially highly obscured quasar that should have been removed from this sample of radio galaxies. Moreover, its radio morphology and environmental properties are not unusual (Harvanek & Stocke 2002). Thus, there does not seem to be any empirical basis to remove it from the radio galaxy sample other than the small value of its predicted average size D_* relative to the average size of the full population of FRIIb radio galaxies $\langle D \rangle$ at similar redshifts.

Additional radio data could substantially improve the constraints presented here on the dark energy scalar field model, and on other models. Of the 70 sources in the parent population, 20 have values of D_* determined. The radio data for these 20 radio sources were available in the published literature and in the VLA[5] archive, and were originally obtained for studies other than those presented here. Ten additional sources will be observed at the VLA this year; these data are optimized to determine cosmological parameters and to test and constrain the underlying radio galaxy model. The 40 remaining sources will then be observed, which will improve the radio galaxy constraints enormously. The improvement will come from the additional number of data points and, with the very high quality data expected, the error bar per point may be smaller than that obtained using published data.

It is encouraging that the FRIIb radio galaxy redshift–angular size data constraints are consistent with, and not much weaker than, those derived from Type Ia supernova

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redshift-magnitude data. Future higher quality redshift–angular size data is eagerly anticipated.

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