Vacuum-energy and the angular-size/redshift diagram for milliarcsecond radio sources

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We have considered two compilations of angular-size/redshift data for ultra-compact radio sources, due to Kellerman (1993) and Gurvits (1994) respectively, and a family of homogeneous isotropic universes with two degrees of freedom, represented by pressure-free matter and vacuum-energy. Kellerman's results seem to support the canonical model $q_0 = 1/2$, $\Omega_0 = 1$; the question posed here is: can we produce significant deceleration without dark matter?

The usual cosmological parameters are related by the dimensionless versions of Friedmann's equations

$$q_0 \;+\; \Lambda_0 \;=\; \Omega_0/2 \tag{1}$$

and

$$\Omega_0 \;+\; \Lambda_0 \;=\; 1 \;+\; K_0. \tag{2}$$

If we believe that q_0 is large, equations (1) and (2) allow a clear alternative to large Ω_0, namely $\Omega_0 \sim 0$, $\Lambda_0 \sim -q_0$, and $K_0 \sim -1 - q_0 < 0$, that is a violently decelerating open Universe, with dynamics dominated by a large negative cosmological constant. It turns out that the angular-size/redshift relationship is particularly sensitive to these parameters. In the limit $\Omega_0 = 0$ exactly there is an analytical expression giving the corresponding angular-diameter distance $d_A(q_0, z)$ (Jackson 1992), which is

$$d_A \;=\; \frac{1}{q_0 H_0}\{[1 + q_0 - q_0(1+z)^{-2}]^{1/2} - 1\}. \tag{3}$$

Figure 1 compares the corresponding angular-size/redshift curves (labelled by values of q_0) with Kellerman's data, comprising 79 high-luminosity sources in 7 redshift bins, assuming a fixed linear size of $20.5h^{-1}$ parsecs ($h = 1 \Rightarrow H_0 = 100$ km s^{-1} Mpc^{-1}). Clearly there are curves which are compatible with the data, if we are prepared to contemplate values of $q_0 \geq 3$. At this stage we make no claim that these vacuum-dominated universes are uniquely favoured by the data; the point is that there is in this context an acceptable model which invokes neither dark matter nor evolutionary effects. The crucial difference between these models and the canonical matter-dominated one is qualitative; in the latter case a pronounced increase in angular size is expected, beyond $z = 1.25$, whereas in our models such behaviour is absent, corresponding to an asymptotic value $d_A \to (q_0 H_0)^{-1}[(1+q_0)^{1/2} - 1]$ as $z \to \infty$.

Tentatively, we can make a more positive statement than this. Very recently a large data compilation has appeared (Gurvits 1994), comprising 270 ultra-compact high-luminosity sources in 12 redshift bins in the range $0.5 \leq z \leq 3.8$. It is difficult to combine the two samples, as they use different definitions of size and correspond to different frequencies (5 Ghz and 2.3 Ghz respectively); nevertheless, we have attempted to do just this. Gurvits notes a reasonably systematic difference between his sizes and Kellerman's, the latter being

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larger than the former by a factor of about 3 over the high-redshift flat part of each diagram. Figure 2 shows a composite sample, comprising Kellerman's low-redshift points (at $z = 0.047$ and $z = 0.228$), and Gurvits' high-redshift points, scaled up in size by an appropriate fixed factor. At face value this diagram strongly favours the models proposed here, as there is no sign of the turn-up at high redshift expected in matter-dominated universes. A naive least-squares fit, giving free rein to q_0 and Ω_0, and to the linear dimension d characterising the sources, gives $q_0 = 8.34$, $\Omega_0 = 0.17$, and $d = 15.5h^{-1}$ parsecs. The theoretical curve (which is exact, i.e. does not use approximation (3)) shows a very gentle turn-up beyond $z \sim 4$, as the corresponding universe becomes matter-dominated.

One might expect the age problem associated with such high values of q_0 to be beyond salvation, but this class of models turns out to be remarkably forgiving in this context. This is illustrated by Figure 3, which plots age in Hubble units against q_0 for the limiting case $\Omega_0 = 0$ (solid line), to be compared with the standard matter-dominated case (dashed line); at a given value of q_0, ages are some 40% longer in the former case. The range $3 \leq q_0 \leq 8$ requires h to be in the range 0.3 to 0.4, to give an age of 15×10^9 years, compared with $h = 0.44$ in the canonical case.

REFERENCES

Gurvits L.I., 1994, ApJ, 425, 442
Kellerman K.I., 1993, Nature, 361, 134
Jackson J.C., 1992, QJRAS, 33, 17

Figure 1

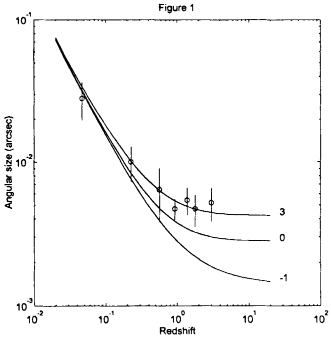


Figure 2

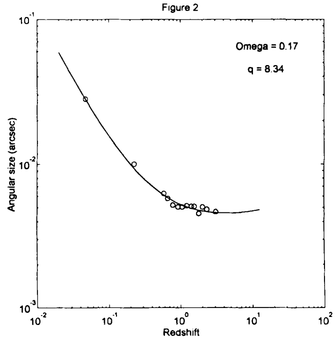
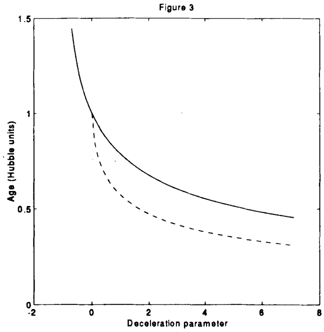


Figure 3



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