THE RELATION OF RADIO ASTRONOMY TO COSMOLOGY

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The advent of radio astronomy provides a new observational tool for arriving at tests of the different theoretical cosmologies. The tests may be either wholly new, or revivals in a more cogent form of earlier work in visual astronomy.

Relativistic cosmology contains three parameters that must be determined from observation in contrast to steady-state cosmology, which contains only a single disposable parameter. For this reason it is very difficult to design any stringent test of relativistic cosmology in its most general form, since a limited number of observations can always be explained away by a suitable process of "parameter fitting." In the steady-state theory, on the other hand, the single parameter becomes assigned once the value of the Hubble expansion constant is known, and no further degree of freedom then remains in the theory. Moreover, the predictions made by the steady-state theory are of a stronger form, quite apart from this question of parameter fitting. In the latter theory all observable features of the universe are in constant regeneration and hence their origin is in principle immediately observable. An example is the formation of galaxies that must be going on all the time, whereas in relativistic cosmology the origin of galaxies has been taken as a process belonging to the remote past, it being then extremely difficult to subject any predictions concerning this process to direct verification.

It would plainly be very tedious, in view of the reasons just given, to review the detailed properties of all forms of relativistic cosmology, since this would demand separate considerations of a large number of cases. For the purpose of comparing the predictions of relativistic cosmology to those of the steady-state theory I shall therefore choose a particular representative of the whole class of relativistic cosmologies. This will be the Einstein—de Sitter model, characterised by a zero value of the cosmical constant and by a curvature factor $k = 0$, representing the limiting case that separates elliptic closed oscillatory models of finite volume from hyperbolic nonoscillatory models of infinite volume. In Newtonian terms, the Einstein-de Sitter model represents the case where the dynamical energy of matter is just sufficient to expand it to zero density.

Both the steady-state theory (S-S) and the Einstein-de Sitter (E-dS) agree about the value of the mean density ρ of matter in space, viz.

$$\rho = 3H^2/8\pi G ,$$

where G is the Newtonian constant of gravitation. With H equal to Sandage's recent value $(4 \times 10^{17}\ \text{seconds})^{-1}$, the value of ρ is $\sim 10^{-29}$ grams/cm^3. Since

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this is about 10^2 times the mean density that would be given by smoothly distributing the material of the galaxies through space, it follows that both cosmologies agree in predicting that the great bulk of matter in the universe exists not in the galaxies, but as material distributed between them, presumably as a diffuse gas consisting largely of hydrogen. Here the agreement ends, however, for in E-dS the gas should be cold and neutral, and in S-S it should be hot and ionized. Hence, an immediate test of these cosmologies can be obtained by an attempt to detect 21-cm hydrogen radiation from the intergalactic medium.

The reason why the gas must be cold and neutral in E-dS is that the gas has expanded adiabatically from an initial very high density phase, as a consequence of which the present-day temperature should not be much in excess of 1 °K. The reason why the gas may be expected to be hot in S-S is explained in detail in a separate communication.

It is easy to see in S-S why the mean density of galactic material must be considerably less than the above value of ρ. Material of age T has a mean density less than ρ by the factor $\exp(-3HT)$. Thus if we allow a time between H^{-1} and $2H^{-1}$ for material to condense into the galaxies as we now see them, the mean density of this material after condensation will be less than ρ by the required factor.

I would now like to turn to the purely geometrical predictions of the two theories. In Figs. 1 and 2 we have a plot of apparent bolometric magnitude against red-shift for a source of standard intensity. The quantity λ represents wavelength at source, and $\lambda + \Delta\lambda$ is wavelength at reception. Strictly, the apparent bolometric magnitude refers to the integral of the energy received over the whole spectrum. If, however, the energy is distributed with frequency ν according to $d\nu/\nu$, as it is approximately in most extragalactic radio sources, then it is sufficient to measure the energy that is incident within a fixed range of frequency, say from ν_1 to ν_2, where ν_1 and ν_2 may be chosen to suit the convenience of the observer.

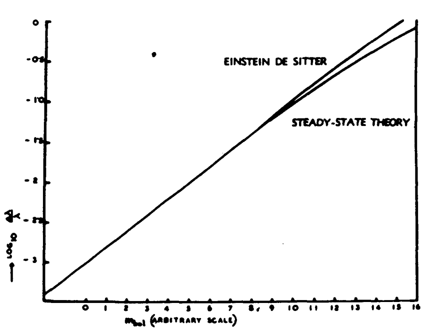

FIG. 1. Apparent magnitude as a function of red-shift, for a source of standard intensity.

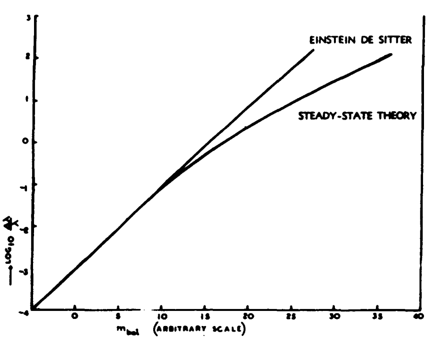

FIG. 2. Apparent magnitude as a function of red-shift, for a source of standard intensity.

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The figures show the extreme difficulty of distinguishing between the two theories, unless $\Delta\lambda > \lambda$, the curves being then divergent in a considerable degree. When the uncertainties of obtaining a standard source are considered, especially in relation to selection effects (the more distant the source the more likely one is to choose a particularly bright specimen), it is clear that this test offers little hope under optical conditions, say with $\Delta\lambda < 0.3\lambda$ but might just conceivably be of value in radio astronomy where values of $\Delta\lambda$ comparable with, or even appreciably greater than λ, might be obtained. Such a test is obviously formidable since $\Delta\lambda$ would presumably have to be determined by radio techniques.

Suppose objects of standard emission intensity are distributed uniformly in space and that they are not subject to evolutionary change. Then an observer will obtain counts of these objects per unit range of apparent bolometric magnitude that varies with apparent bolometric magnitude in the manner shown in Figs. 3 and 4. Such a system of counting has an advantage over the test implied by Figs. 1 and 2, in that no determination of $\Delta\lambda$ is required. Even so the divergence between the curves for S-S and E-dS is not sufficient for one to place any great confidence in such a test.

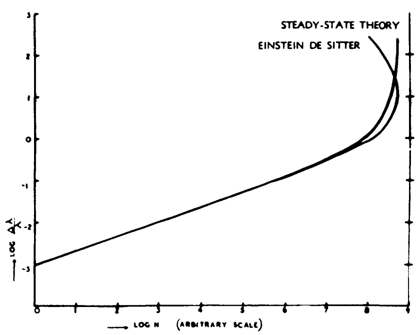

FIG. 3. N = number of objects per unit magnitude range, plotted against red-shift.

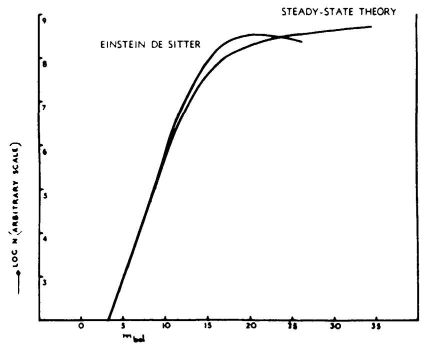

FIG. 4. N = number of objects per unit magnitude range, plotted against apparent magnitude.

It is emphasised that these remarks refer only to purely geometrical effects. If evolutionary changes occur in one theory but not in the other then a far greater divergence of the curves would be expected. This, indeed, is Ryle's interpretation for the counts he obtained a few years ago. The existence of an evolutionary change would be important evidence against S-S.

Finally, I have given in Fig. 5 the apparent angular diameter of a source of standard size plotted against red-shift. A remarkable difference between the two theories now emerges. For a source of diameter D the apparent angular diameter decreases in S-S with increasing red-shift, tending asymptotically to DH/c. In E-dS, on the other hand, the apparent angular diameter has a minimum value of $(3/2)^3 DH/c$ attained at $\Delta\lambda/\lambda = 5/4$. Thereafter, the apparent angular diameter increases with increasing $\Delta\lambda/\lambda$, until ultimately

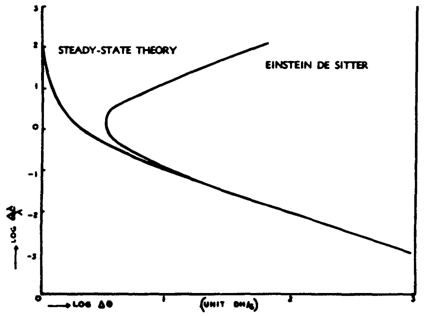

FIG. 5. Apparent diameter $\Delta\theta$ of a source of absolute diameter D, plotted against red-shift.

the object fills the whole sky as $\Delta\lambda/\lambda \to \infty$. This general property is common to all forms of relativistic cosmology, although the precise numerical values change with the choice of parameters.

It is of interest to consider this question on the supposition that standard sources are available with the value of D found in the Cygnus source. On the basis that the emission is also roughly comparable with Cygnus, such sources could be observed for $\Delta\lambda/\lambda > 1$. Setting $\Delta\lambda/\lambda = 1/18$, $\Delta\theta = 80$ seconds of arc for the Cygnus source determines the arbitrary scale factor in the abscissa of Fig. 5. The asymptotic value DH/c for S-S then becomes ~ 4 seconds of arc, and the minimum for E-dS is 15 seconds of arc. That is to say, if Cygnus-type objects are assumed, the apparent angular diameter can never be less than 15 seconds of arc for E-dS, but can fall as low as ~ 4 seconds of arc for S-S.

These considerations would seem to give the best immediate hope of subjecting cosmological theory to what might be described as a "line-element" form of observational test. The advantages may be summarized:

1. The values of the apparent angular diameter that are of interest, 5 seconds of arc upward, fall into a range that is almost accessible to current instruments.

2. It is probable that radio sources may more readily conform to a standard value of D than to a standard intrinsic emission.

3. No measurement of apparent bolometric magnitude or of red-shift is really required. The aim would simply be to seek for the smallest values of the angular diameter of moderately bright sources.

The objection can of course be raised that such an observational project would not distinguish between a small nearby object and a distant source of extended size. This criticism might be met by a judicious use of number counts.