Primordial 2.7° Radiation as Evidence against Secular Variation of Planck's Constant

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The blackbody form of the 2.7° cosmic microwave radiation appears to be inconsistent with variation of Planck's constant by as much as 10% since the epoch $z \sim 1000$.

A few years ago, Bahcall and Salpeter suggested looking for a possible cosmic time variation of Planck's constant by comparing the dispersion of light from a quasistellar object (QSO) by prisms with that obtained using gratings.[1] The suggestion (made in a footnote to their paper[1]) is that prisms are sensitive to the energy E of photons, while gratings measure wavelength λ. The photons could presumably have some other value h' of Planck's constant associated with them than the current one h, so one would have for QSO light $E = h'\nu = h'c/\lambda$, and for ordinary light $E = h\nu$. This suggestion has generated further interest,[2] and experimental work has been undertaken.[3] There are grave doubts as to the meaning of saying that any dimensional constant changes, because presumably dimensional constants only express something about the sizes of the standards we use in measuring them.[4] Nevertheless, others held such considerations meaningful, and thus I shall attempt to follow the spirit of those who have suggested that h may change. Certainly, one wants to be able to say what it would mean if the experiment on dispersing QSO light gave a positive result. Now that the serious doubts cast by infrared observations on the thermal nature of the cosmic microwave background are abated,[5] it seems particularly fruitful to explore the Bahcall-Salpeter hypothesis as applied to this radiation.

If the "fundamental physical constants" vary, the assumptions of general relativity are violated (because it presupposes that in a locally inertial system, when tidal gravitational effects can be neglected, the outcome of a specific physical experiment is independent of time and place), and in addition, if h varied, quantum mechanics would need some reworking. For example, the Compton length has been considered a fundamental property of an elementary particle, expressing its reciprocal mass, but a particle would now have different Compton lengths when in the presence of different radiation fields. Hence, it is necessary to make some assumptions to replace the abandoned theories such as relativity and quantum mechanics. Harwit[2] proposed an alternate test of the Bahcall-Salpeter hypothesis, but on applying some parts of relativity theory in his third appendix, he found that both his new test and that first proposed[1] would fail, even if h changed. Like Harwit, I shall have to make *some* assumptions, and I shall make them as explicit as possible. I wish to consider the evolution of a blackbody spectrum, starting out at a few 10^8 K, as proposed by Gamow and others.[6] The energy density of this radiation dominates the kinetic-energy density of matter from the time of helium formation to the present. This fact is often misstated, because the *rest*-energy density of matter was comparable with that in radiation at some epoch in the approximate range $100 < z < 5000$. Here I am assuming that usual relativistic cosmology applies, except that the radiation is to be broken into packets comprising photons according to different values of h at different epochs. This is in the spirit of the Bahcall-Salpeter suggestion.[1] Depending on unspecified assumptions that would replace quantum mechanics, the slight trace of matter present might or might not be able to reprocess the radiation into different size packets as h changed. I shall assume that this would not happen after the decoupling era at $z \sim 1000$. This is somewhat arbitrary, as the "fiducial point" at which the radiation was known to be in equilibrium with the reactions producing helium was $z \sim 10^8$, and it is also possible that Thomson scattering has occurred at relatively small z values, but the last epoch at which appreciable energy interchange is believed to have occurred is $z \sim 1000$.

Now, the intensity of the *Rayleigh-Jeans* portion of the 2.7° curve gives the present value of kT, with *no* knowledge whatever of Planck's constant required. (Here I assume that the 2.7° radiation now travels at the present value of c.) But the *turnover*[5] in the spectrum at larger ν gives the value of kT as well, this time in *combination* with h, through the occupation *number* of Bose and Einstein $[\exp(h\nu/kT)-1]^{-1}$. In each case T appears as a product with Boltzmann's constant k, so no one need raise the idea that k changes! The important thing is that the two temperatures agree,[5] which means that the occupation number is correct for the *present* value of h, and no other. I have emphasized the occupation number, because it is a dimensionless quantity and expresses how the classical radiation field breaks down into photons. If the radiation carries with it in any sense "memory" of an era when h was different, surely one would expect this to appear in the occupation number. If h had been larger, the spectrum would presumably turn down below the measured points at 8.56 or 3.3 mm.[7] If smaller, the spectrum would look like a gray-body curve violating the 3.3-mm point or the CN limit of Bortolot, Thaddeus, and Clauser.[7] In either case, the data appear good enough to exclude a 30% error in the measured T, which corresponds to about a 30% error in h, because one is in the region $h\nu/kT \sim 1$. I thus conclude $\delta h/h < 0.3$ in the interval $1000 > z > 0$. This has to be compared with the Bahcall-Salpeter limit[1] $d\ln hc/dt < 10^{-10}\ \mathrm{yr}^{-1}$, based on atmospheric absorption for QSO's setting in at the usual 3200 Å. If we approximate $R \sim t$, where R is the Friedmann scale factor, and note $1+z = R_0/R$, we may write $dt = t\,d\ln t \approx -t\,dz$. Then the Bahcall-Salpeter limit in terms of z is $d\ln hc/dz < 1$, while the limit found here is $d\ln hc/dz < 3\times10^{-4}$.

What if the optical experiment[3] or a later refinement should yield a non-null result? It then would seem worth exploring the idea that c changes,[8] and that the occupation number should be written in terms of $hc/\lambda kT$, or even[9] that the 2.7° radiation now travels at a speed not equal to c. This could be tested in principle by comparing wave number and frequency (occultation timing experiments appear more difficult). Wavelength would have to be selected by antenna design, and frequency is presumably selected by the ordinary microwave techniques. No further speculation seems warranted unless some experiment turns up a non-null result. Astrometric work on QSO positions at various times of the year would reveal any gross departure of the velocity of QSO light from 3×10^{10} cm/sec, through differential aberration. Astrometric work by different observers thus far has generally been in good agreement, suggesting the absence of any such effect.[10]

I am indebted to Dr. John Bahcall for valuable comments.

[1]J. N. Bahcall and E. E. Salpeter, Astrophys. J. 142, 1677 (1965).

[2]M. Harwit, Bull. Astron. Inst. Czech. 22, 22 (1971).

[3]H. J. Smith, private communication.

[4]W. K. H. Panofsky and M. Phillips, *Classical Electricity and Magnetism* (Addison-Wesley, Reading, Mass., 1955), p. 378.

[5]R. B. Partridge, Amer. Sci. 57, 37 (1969); J. R. Houck, B. T. Soifer, M. Harwit, and J. L. Pipher, Astrophys. J. 178, L29 (1972).

[6]References to the work of Gamow, Dicke *et al.*, and others are in reference section A of Partridge, Ref. 5.

[7]D. T. Wilkinson, Phys. Rev. Lett. 19, 1195 (1967); P. E. Boynton, R. A. Stokes, and D. T. Wilkinson, Phys. Rev. Lett. 21, 462 (1968); V. Bortolot, P. Thaddeus, and J. F. Clauser, Phys. Rev. Lett. 22, 307 (1969).

[8]R. d'E. Atkinson, Phys. Rev. 170, 1193 (1968), showed that changes in c are proportional to those in $\alpha^2(m_e/M_p)$, where α is the fine-structure constant. The latter does not change as much as 0.1% in 10^9 yr. [See J. N. Bahcall and M. Schmidt, Phys. Rev. Lett. 19, 1294 (1967).] The possibility that c changes was ignored by Harwit (Ref. 2).

[9]This could throw the relation of the Rayleigh-Jeans and Planck temperatures out of kilter.

[10]A. Sandage, J. Kristian, and C. M. Wade, Astrophys. J. 162, 399 (1970).