next decade or so, but also that many comets are still visible long after their predicted demise, two more facts in favour of a slow decay rate. Vsekhsvyatskij's decay figures of 0.3–0.4 mag per revolution gives short period comets a lifetime of two centuries, and proposed accelerations of this rate reduces this life to a few decades. Kresák finds that during the period 1930–1970 the discovery of short period comets has stabilised at a constant level of seven per decade. This perturbational capture rate is, in fact, no adequate substitute for the rapid loss predicted by Sekanina. If the short period comet population is in equilibrium, Kresák's low values of decay rate must be applicable.

Kresák concludes that the process of ageing of comets, and its effect on the variation in absolute brightness, cannot be satisfactorily explained by a simplified model of continuous mass loss which induces a continuous secular variation in absolute magnitude. Rather, observational evidence suggests strongly that the evolution proceeds stepwise, with short periods of abrupt evolution interspersed with long, relatively latent periods during which the brightness undergoes some fluctuation but in general remains essentially unchanged.

DAVID W. HUGHES

Dirac completes his theory of large numbers

IT is not often that a man begins a new physical theory in his thirties, and then returns to finish it off forty years later. In a letter to *Nature* in 1937 (**139,** 323) Dirac added to his store of brilliant ideas a fundamental hypothesis concerning the values of various naturally occurring dimensionless numbers. In the past two years he has returned to this hypothesis to explore its consequences in detail. His latest article (*Proc. Roy. Soc,* **A338,** 446; 1974), deals with certain astronomical and cosmological topics.

Dirac's theory begins with the question: what is the age of the Universe expressed in some naturally occurring units? A fundamental unit of time is the interval required for light to cross a characteristic atomic dimension, say 10^{-13} cm. Then the age of the Universe comes out at about 10^{39} in these units. The significance of this number is that it turns out to be simply related to other large dimensionless numbers formed from astronomical and atomic data; for example, the total number of particles in the observable Universe is around 10^{78}, that is $(10^{39})^2$, and the ratio of the electric to gravitational attraction between an electron and proton, e^2/Gm_em_p is also about 10^{39}. In view of the fact that the first number obviously increases with time, the coincidences involved by these simple relationships seems great. Dirac's explanation of this curiosity is that all such large quantities are connected, so that as the first increases with time so do the others. This is already a radical departure from conventional physics, which in addition imposes severe restrictions on cosmology. Dirac calls this connection the large numbers hypothesis, in which he expresses "great confidence".

In his 1937 article, Dirac was led by this hypothesis to a model universe which expands with time t like $t^{1/3}$, making it about half as old as the more conventional big-bang models. In his recent work, however, the bald hypothesis is accompanied by a detailed gravitational theory which bears some similarity to the work of Hermann Weyl and E. A. Milne. A central feature of this work is the proposal that there are really two space–time metrics; one, which is unmeasurable directly, enters into the Einstein equations (which remain valid) and the other is what is actually measured in laboratory experiments involving atomic apparatus. A connection between these two metrics is provided by a consideration of the motion of the Earth around the Sun, which in Newtonian approximation is essentially determined through the relation $GM=v^2r$ connecting the Newtonian constant of gravitation G with the solar mass M, velocity of the Earth v and radius of the Earth's orbit r.

There then follows an argument which is typical of that used throughout Dirac's work. In terms of Einstein units, the quantities in this equation are constant. But in atomic units one must satisfy the large numbers hypothesis, so that G must decrease as t^{-1} in order that e^2/Gm_em_p increases proportionally to t. Theories involving a changing constant of gravitation are not new: for example, Brans–Dicke theory predicts a similar effect. The change is, however, very small and barely detectable with current technology.

Once again, the number of particles in the Universe $(10^{39})^2$ at present, is required by the large numbers hypothesis to increase as t^2, which is interpreted by Dirac as a form of continual creation along the lines of the steady state theory.

Two possible creation mechanisms are proposed, with the new matter either appearing concentrated in existing masses (multiplicative creation) or spread out in the intergalactic spaces (additive creation). In the latter case the mass M in the above equation is constant, so that r in atomic units varies like t^{-1}. In the former case $M\propto t^2$ and $r\propto t$. It follows that the ratio of the two metrics can be t^{-1} or t, and that the Solar System must be either expanding or contracting with time.

In terms of Einstein units, if multiplicative creation is adding continuously to the mass M of the Sun, conservation of energy requires that the nucleons in the Sun decrease in mass as t^{-2} to compensate. Through the relation $e^2/Gm^2\propto t$ this further requires $e\propto t^{-3/2}$ and $\hbar$ (Planck's constant) $\propto t^{-3}$. A number of interesting cosmological consequences follow. First Dirac argues that any universe consistent with the large numbers hypotheses must be static, to avoid the introduction of a characteristic cosmological epoch (that is a constant large number). The red shift of distant galaxies, normally interpreted as a recessional effect, is instead accounted for by the decrease in the unit of atomic time interval. The Universe is prevented from gravitational collapse by the introduction in Einstein's equations of the cosmological constant which may be non-zero for multiplicative creation because of the correct time dependence of the metric ratio in this case. Dirac thus arrives at a version of Einstein's original static model universe.

In the case of additive creation Dirac proposes to conserve energy by the introduction of an unobservable negative energy field spread throughout the Universe, along the lines of the C-field of Hoyle and Narlikar. The total energy density of the Universe thus vanishes, so that the global geometry is just the Minkowski space of special relativity. In comparing the two models, Dirac inclines to the latter, on the basis that the creation of new atoms in existing material would lead to insuperable difficulties concerning the crystaline structure of very old rocks.

Dirac's article is written in his usual lucid and direct style. The ideas it contains, a mixture of old and new, are probably unpalatable for most modern cosmologists. Yet they are the product of a lively imagination, challenging the fundamental principles on which modern theories of astronomy, cosmology and physics itself are founded. Coming from a physicist of Dirac's stature, that is at the very least thought provoking.

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