Evidence of a Cosmological Matter and Energy Cycle

Matthew R. Edwards
Science and Medicine Library
University of Toronto
Toronto, Ontario, Canada, M5S 1A5
e-mail: edwards@library.utoronto.ca

The ancient idea of an infinite, stationary universe has recently been the focus of renewed scientific inquiry. One property of such a universe is that the matter and energy within it must be continuously recycled through stars and the interstellar medium in a cosmological cycle. Here we give evidence of a cosmic cycle with period on the order of the inverse Hubble constant, H^{-1} (~1.3×10^{10} yrs). The existence of this cycle successfully explains the observed rates of star formation and star death in spiral galaxies of about 4-8 solar masses per year. The lower and higher rates observed in elliptical and disturbed galaxies respectively are explained according to the theory that ellipticals arise from mergers of spiral galaxies.

To maintain a continuous stellar cycle, it is proposed that heavy elements are converted back to hydrogen in dense objects, such as white dwarfs and quasars. The ejection of the regenerated hydrogen back to interstellar space is viewed as a possible consequence of the internal redshifting of gravitational energy within these bodies.

1. Introduction

Recent difficulties with the Standard Model, related to the “age of the universe,” galaxy formation and other issues, have prompted a reexamination of the older notion that the universe is infinite in time and space, stationary (*i.e.*, non-expanding) and in overall equilibrium (Lerner, 1988; Jaakkola, 1990, 1993; Ghosh, 1991, 1993; Assis, 1992a,b, 1993; Arp, 1993). In this picture, the redshift of distant galaxies is usually ascribed to a progressive loss of a photon’s energy in its passage through space. Despite a lack of consensus on the physical mechanism for this depletion, there is much evidence to suggest that the so-called “tired light” models satisfy a variety of cosmological tests to a higher degree than does the Standard Model (La Violette, 1986; Jaakkola, 1990, 1993; Arp, 1993; Assis and Neves, 1995).

In some of the alternative models that have been proposed, the Hubble constant is linked not just to the photon reddening, but to the fundamental processes driving the cosmic equilibrium. In this presentation, some simple considerations related to the cosmic energy balance and galactic star formation rates will be used to show that the Hubble constant also has a unique significance in a stationary universe as the defining parameter of a cosmic matter and energy cycle.

2. Existence of a Cosmic Cycle of Period H^{-1}

If the universe exists under conditions of overall equilibrium, the fluxes of energy to and from stars should on average be equal and constant. These fluxes would include the rate of radiant energy release from stars and the rate of depletion of starlight energy from interstellar space due to the redshift effect. The density of starlight energy in the interstellar medium would also be expected to acquire a constant value corresponding to the blackbody temperature of space. In an equilibrium universe, all processes in which matter or energy are converted to a different form would have a counterbalancing process in which the depleted quantity of matter or energy is restored.

In a universe in overall equilibrium, the average number density of stars in a sufficiently large sample of space would also be constant over time, though individual stars would continuously be formed and die. A stellar cycle must therefore operate with a characteristic period T_c associated with the average stellar lifetime. As stars spend most of their lifetimes on the main sequence converting hydrogen to helium, T_c is determined principally by the rate of this process in an average star. If sun-like stars are taken to represent an "average star," then $T_c \approx 10^{10}$ yrs. This value for T_c is extremely close to the inverse Hubble constant H^{-1} . We now make the identification $T_c = H^{-1}$. Current estimates of the value of H fall in the range of 50 to 100 km sec^{-1} Mpc^{-1}, with many recent estimates favouring a value of about 75 km sec^{-1} Mpc^{-1}. Setting H at 75 km sec^{-1} Mpc^{-1} or 2.5×10^{-18} sec^{-1}, the corresponding value for T_c would be 1.3×10^{10} yrs.

3. Radiation Balance

As the clearest test of the cosmological cycle, we first consider the overall radiation balance. In a universe at equilibrium, the rates of injection of starlight energy into space per unit volume of space and of its subsequent removal from space *via* the redshift effect should be equal. Evidence of such an equality was earlier given by Ward (1961). Ward's arguments were later criticized by Wesson (1980), who found that the rate of energy addition was one to two orders of magnitude greater than the rate of depletion. In deriving the depletion rate, Wesson considered the redshift of starlight at visible frequencies only.

In equilibrium cosmologies, however, the cosmic background radiation (CBR) is generally viewed as ordinary starlight that has been redshifted (Jaakkola, 1993; Assis, 1993; Wesley, 1996). In this case, the CBR makes by far the largest contribution to the total starlight density with a density of 4×10^{-13} erg cm^{-3}. Like all other electromagnetic radiation, the CBR must itself undergo a redshift. Using this assumption, it has been shown that the rates of starlight addition and of its removal *via* the redshift do indeed appear to be equal (Jaakkola, 1993; Wesley, 1996). Here we express this equality in the form used earlier by Ward and Wesson.

Let the rates of energy input of starlight per unit volume of interstellar space and its subsequent removal through the cosmological redshift be R_+ and R_- respectively. Within a suitably large region of space, R_+ is n_cL, where n_c is the galactic number density and L is the average galactic luminosity. Inserting values of .03 galaxies Mpc^{-3} for n_c and 4×10^{44} erg sec^{-1} for L (10^{11} stars with average luminosity equal to the solar luminosity of 4×10^{33} erg sec^{-1}), R_+ is 1×10^{43} erg Mpc^{-3} sec^{-1} = 4×10^{-31} erg cm^{-3} sec^{-1}.

In the tired light cosmologies, the expression for the depletion of a photon's energy in its passage through space is

$$(\mathrm{d}E/\mathrm{d}t)/E = H, \tag{1}$$

where E is the photon energy. In this process, all electromagnetic radiation, including the CBR, undergoes a progressive loss of energy in passing through space. In the case of the CBR, the resulting deficit must be balanced by the addition of starlight energy redshifted from higher frequencies. The rate of depletion of electromagnetic energy per unit volume of space, R_-, is then obtained as

$\rho_r \times H$, where ρ_r is the total radiation density. For $\rho_r = 4 \times 10^{-13}$ erg cm^{-3} (the CBR density) and $H = 2.5 \times 10^{-18}$ sec^{-1}, R_- amounts to 1×10^{-30} erg cm^{-3} sec^{-1}. Given the uncertainty with respect to H, it is seen that R_- is about equal to R_+.

4. Mass Balance

In a universe at equilibrium, the consumption of hydrogen and other light elements in fusion reactions should be balanced by processes in which these elements are regenerated. The energy required in the regeneration processes would be equal to that released in the fusion processes. The necessity of hydrogen regeneration to form new stars and galaxies in a static model was earlier recognized by MacMillan (1918), who suggested that hydrogen atoms might be formed in interstellar space from starlight energy. A similar idea was later embodied in the Steady State Theory. Unless one invokes the zeropoint fields of quantum theory, however, the energy densities of interstellar space do not appear suitable for the formation of new hydrogen.

Instead, a more likely site for the regeneration of hydrogen would be the centres of large objects such as massive stars, quasars or AGNs. The condition for photodissociation of heavy to lighter elements in such bodies is the presence of photons with energies ~ 1 MeV, which may arise during the gravitational collapse of these bodies (for a discussion of an analogous mechanism for hydrogen regeneration in the oscillating universe variation of the Standard Model, see Peebles, 1993). The formation of new mass thus comes at the expense of gravitational potential energy, the replenishment of which is considered in a later section.

A separate measure of H and T_c can in principle be obtained by estimating for each element its fractional rate of formation or consumption in a static universe. This may be shown for helium. The fractional rate of helium formation is C_{He} / ρ_{He}, where C_{He} and ρ_{He} are the creation rate and cosmic density respectively for helium. To estimate C_{He} we first note that the energy released per hydrogen atom fused to helium is 7.5×10^{-3} of the hydrogen atom rest mass. Since most of the energy released in stellar fusion arises from helium formation, $C_{He} \simeq R_+ /(7.5 \times 10^{-3}\ c^2)$. Assuming that $R_+ = R_- = 1 \times 10^{-30}$ erg cm^{-3} sec^{-1}, we then have $C_{He} = 2 \times 10^{-49}$ gm cm^{-3} sec^{-1}. For $\rho_{He} = 1 \times 10^{-31}$ gm cm^{-3} (about one fourth of the estimated cosmic mass density), the fractional creation rate is then 2×10^{-18} sec$^{-1} \simeq H$. The estimate for T_c is just the inverse of this, or 1.6×10^{10} yrs, which is close to the value assumed above. By comparison, Jaakkola's (1993) estimate of T_c, based on the assumption that new matter appears in the form of the rest mass of new baryons rather than the tiny binding energy fraction, was several orders of magnitude larger than H^{-1}.

5. Galactic Star Formation Rates

According to the central hypothesis, the primary cycle governing conversions of matter and energy is the stellar cycle, in which stars are first formed from interstellar gas, burn their fuels over a period related to T_c and finally return their residual mass to interstellar space during supernova, planetary nebula and other phases. In a stationary universe at equilibrium, it would be expected that the average number density of stars is constant. To maintain this condition, it is obvious that the universal rates of star formation and star death must be equal on average.

Assuming that the spatial density of galaxies and the relative frequencies of the various galactic types are also constant over time, then the rate of star formation per unit volume of space can be estimated using current estimates of SFRs (star formation rates) in representative types of galaxies. In order to maintain a constant number of stars, a galaxy with n stars must achieve an average SFR of n/T_c . For a typical spiral galaxy with $n = 10^{11}$ and for $T_c = 1.3 \times 10^{10}$ years, the SFR should be about 8 $M_\odot$ yr^{-1} (solar masses per year).

In estimating the SFRs in other galaxies, the principal method involves measuring the integrated starlight of galaxies within bands associated with the formation of massive stars to determine the SFR of these stars and then extrapolating to obtain the total SFR. Using this method, Kennicutt (1983) found that the average SFR for normal spiral (Sb-Sc) galaxies was about 4 $M_\odot$ yr^{-1}, in good agreement with other estimates for spiral galaxies, including the Galaxy. The average SFR for the Sc galaxies alone was about 5 $M_\odot$ yr^{-1}. Together, the Sb and Sc galaxies comprise 54 per cent of observed galaxies. That the SFRs in these galaxies are only slightly below the expected rate of 8 $M_\odot$ yr^{-1} is thus suggestive that star formation is indeed an ongoing, cyclic process.

Within the Big Bang framework, by contrast, the current galactic SFRs are often interpreted within the context of hypothetical ‘star formation histories’ of galaxies. The main assumptions used in constructing these histories are that galaxies were all formed about 10^{10} years ago and that the available gas for forming new stars is steadily diminishing due to a residual star formation activity. For normal disk galaxies, however, Kennicutt (1992) concluded that the present SFRs are very close to the their average past SFRs over the galaxies’ supposed lifetimes. As noted by Kennicutt, this result is difficult to explain using the conventional notion of an ever dwindling gas supply for new star formation.

6. Galactic Mergers and the Universal Star Formation Rate

In light of the preceding arguments, the late-type spiral galaxies might be seen to represent stable, undisturbed galaxies in approximate equilibrium with their surroundings, while all other galaxies exist in various states away from equilibrium. In elliptical galaxies, for example, the SFRs are known to be very low, in the range of .1-1 $M_\odot$ yr^{-1}. In other types of galaxies, the rates are much higher, in the range of 10-100 $M_\odot$ yr^{-1} for the starburst galaxies and as high as 500 $M_\odot$ yr^{-1} for the IRAS galaxies. Under the present hypothesis, the low rates in the ellipticals and early-type galaxies must therefore be balanced by the higher rates in the more energetic galactic types.

Despite incomplete information on the various galactic SFRs, it is nonetheless possible to construct a simple evolutionary scenario for galaxies in a stationary universe using certain notions about which a partial consensus may be emerging. A number of observations suggest that elliptical galaxies are often formed by mergers of spiral galaxies (Mirabel, 1992). Such mergers or close interactions are believed to trigger enormous bursts of star formation or even the formation of AGNs and quasars in the colliding galaxies.

In a merger model, Sc and other late-type spiral galaxies might thus be viewed as stable, equilibrium galaxies sustaining average SFRs of about 5-8 $M_\odot$ yr^{-1}. Should such galaxies collide or interact with another galaxy, however, the available gas and dust supply would initially be swept into a nucleus of intense star formation, possibly visible as a starburst galaxy or an AGN. After this initial burst of star formation, the SFRs in the residual object, possibly an elliptical galaxy, would be depressed for extended periods of time due to exhaustion of the available gas and dust. If the spiral pattern is essential for normal SFRs to be attained, the normal equilibrium value might not be reestablished until a new disk forms. A model in which ellipticals arise as temporary structures in the collision of spiral galaxies has recently been proposed by Kauffmann (1996a,b).

The above general arguments on SFRs may be seen to apply even in the case that undisturbed spiral galaxies are themselves subject to longterm evolutionary effects, as has often been contemplated. For example, if Sa-Sb galaxies ultimately become Sc-Sd types, we can still gather an estimate of the universal SFR of undisturbed spiral galaxies as a group given the known current relative frequencies of each type and the assumption, inherent in a static model, that these relative frequencies are unchanging over time.

To summarize, in galaxies which are undisturbed (*i.e.*, late-type spirals) the current SFRs tend to support the present hypothesis. In colliding and post-collisional galaxies, which may include the elliptical galaxies, there is insufficient information on their SFRs or their relative frequencies at the present time to make a decisive case for or against. Rigorous testing of the equilibrium hypothesis would require that estimates of SFRs be gathered for *all* the galaxies within large, representative volumes of space.

7. Star Death Rates

In an equilibrium cosmology, the formation of stars must be balanced by processes of star death. After leaving the main sequence, stars with masses close to the solar mass are thought to pass through stages from asymptotic giant branch (AGB) stars to planetary nebulae (PNe) and ultimately to white dwarfs. In a complete equilibrium model, there must in addition be further stages, as yet unknown, in which white dwarfs return their mass to the interstellar medium. Stars larger than about 5-8 $M_\odot$ instead undergo core collapse in supernovae. As fewer than one per cent of stars become supernovae, however, we restrict our focus to the PN formation rates.

As in the case of the SFRs, the most reliable data for estimating PN formation rates are for the Galaxy. Most estimates of the Galactic PN formation rate are derived using the integrated starlight of the whole Galaxy and an associated PN luminosity function. The estimates obtained in this way typically fall in the range of 0.5-1 PN yr^{-1} (for review, see Peimburt, 1992).

An alternative method of estimating the Galactic PN birth rate, employed by Ishida and Weinberger (1987), involves making a complete survey of all the PNe within a specific distance from the Sun and extrapolating to the whole Galaxy. Special effort was made in their survey to include large, faint PNe, which are frequently overlooked in such studies. The latter PNe were estimated to have lifetimes of $\sim$ 40,000 years. Using this PN lifetime and the observed local density of PNe within 500 pc of the Sun, a local PN birth rate of 8.3×10^{-3} kpc^{-3} yr^{-1} was derived. From this birth rate, the total number of PNe in the Galaxy was then estimated to be 140,000, which in turn yields a Galactic birth rate of 3.5 yr^{-1}. While this rate is again only about half the value expected in an equilibrium model, the situation could improve as more detailed surveys of PNe are made in this and other galaxies.

8. Redshift Mechanisms and the Recycling of Stellar Matter

In the foregoing, we have considered a number of factors which together are suggestive of a universe in equilibrium. Yet for any equilibrium cosmology to supplant the Standard Model, it must ultimately furnish a mechanism for the cosmological redshift as firmly rooted in physics as the conventional Doppler-shift explanation. In addition, as already noted, an equilibrium cosmology requires one or more mechanisms whereby the matter contained in white dwarfs and other dense objects is returned to interstellar space, so as to complete the stellar cycle. The Standard Model, in stark contrast, allows for the permanent entombment of matter in dead stars and galaxies in a gradually dying universe.

In this context, some possible redshift mechanisms which might potentially be linked to the ejection of matter from stars and other bodies to interstellar space have recently been proposed by others (Ghosh, 1984, 1991; Assis, 1992b, 1993; Jaakkola, 1993). In Ghosh's theory of 'velocity-dependent inertial induction,' for example, both photons and gravitons are subject to a drag force of $-kE/c$, where k is a term which contains the factor $(G\rho)^{1/2}$ and which may be identified with the Hubble contant. A similar factor of $(G\rho)^{1/2}$ appears in the redshift laws of Assis and Jaakkola.

In the case of gravitons, this proportionality of the redshift to the square root of the density of a stellar body could have special significance in the context of ultradense bodies, such as white dwarfs or black holes. In such bodies, the internal redshifting of gravitons could lead to a severe attenuation of the gravitational force. Whereas the 'effective radius' of the universe with respect to interstellar light transmission is roughly c/H, the analogous radius for graviton transmission within ultradense bodies may potentially be less than the radius of the body itself.

In this instance, the core regions of the body would no longer be in gravitational communication with the outer shell. The stability of the body would then be compromised, with the possibility of ejection of matter and energy in various jetting processes. As an extreme possibility, the ejection of entire 'galactic embryos' from the dense centres of preexisting galaxies to form new galaxies has been contemplated (Jaakkola, 1993). The denser the object, the faster it would return its matter to interstellar space. Thus it would be the redshifting of gravitational energy within dense bodies which serves to complete the universal cycle by returning matter from these bodies to interstellar space.

References

Arp, H.C., 1993. "Fitting theory to observation- from stars to cosmology," in *Progress in New Cosmologies: Beyond the Big Bang*, Plenum Press, New York, pp. 1-28.

Assis, A.K.T., 1992a. "Deriving gravitation from electromagnetism," *Can. J. Phys.* 70: 330-340.

Assis, A.K.T., 1992b. "On the absorption of gravity," *Apeiron* 13:3-11.

Assis, A.K.T., 1993 "A steady-state cosmology," in *Progress in New Cosmologies: Beyond the Big Bang*, Plenum Press, New York, pp. 153-167.

Assis, A.K.T. and Neves, M.C.D., 1995. "The redshift revisited," *Astrophys. Space Sci.* 227: 13-24.

Ghosh, A., 1984. "Velocity-dependent inertial induction: an extension of Mach's principle," *Pramana J. Phys.* 23:L671-L674.

Ghosh, A., 1991. "Velocity-dependent inertial induction: a possible tired-light mechanism," *Apeiron* 9-10:35-44.

Ghosh, A., 1993. "Astrophysical and cosmological consequences of velocity-dependent inertial induction," in *Progress in New Cosmologies: Beyond the Big Bang*, Plenum Press, New York, pp. 305-326.

Ishida, K. and Weinberger, R., 1987. "Two senile nearby planetary nebulae and the local PN population," *Astron. Astrophys.* 178:227-236.

Jaakkola, T, 1990. "On reviving tired light," *Apeiron* 6:5-6.

Jaakkola, T., 1993. "Equilibrium cosmology," in *Progress in New Cosmologies: Beyond the Big Bang*, Plenum Press, New York, pp. 111-151.

Kauffmann, G., 1996a. "The age of elliptical galaxies and bulges in a merger model," *Monthly Not. Roy. Astron. Soc.* 281:487-492.

Kauffmann, G., 1996b. "The ages of elliptical galaxies in a merger model," in *New Light on Galaxy Evolution. IAU Symposium* No. 171, Kluwer Academic Publishers, Dordrecht, pp. 265-273.

Kennicutt, Jr., R.C., 1983. "The rate of star formation in normal disk galaxies," *Astrophys. J.* 272:54-67.

Kennicutt, Jr., R.C., 1992. "The history of star formation rates in galaxies," in *Star Formation in Stellar Systems*, Cambridge University Press, Cambridge, pp. 191-251.

LaViolette, P.A., 1986. "Is the universe really expanding?," *Astrophys. J.* 301:544-553.

Lerner, E.J., 1988. “Plasma model of microwave background and primordial elements: an alternative to the big bang theory,” *Laser and Particle Beams* 6: 457-469.

MacMillan, W.D., 1918. “On stellar evolution,” *Astrophys. J.* 48: 35-49.

Mirabel, I.F., 1992. “Violent star formation in merging galaxies,” in *Star Formation in Stellar Systems*, Cambridge University Press, Cambridge, pp. 479-513.

Peebles, P.J.E., 1993. *Principles of Physical Cosmology,* Princeton University Press, Princeton, N.J., pp. 144-146.

Peimburt, M., 1993, “Planetary nebula birth rates in the galaxy and other galaxies,” in *Planetary Nebulae. IAU Symposium* No. 155, Kluwer Academic Publishers, Dordrecht, pp. 523-532.

Ward, A., 1961. “The galactic red shift,” *Nature* 192: 858.

Wesley, J.P., 1996. “Order versus chaos in a steady-state cosmology,” *Apeiron* 3:92-98.

Wesson, P.S., 1980. *Gravity, Particles and Astrophysics*, D. Reidel Publishing Co., Dordrecht, pp. 135-143.