CHAPTER 7

RED-SHIFTS AND ENERGY BALANCE

Red-shifts

Energy density of radiation

Energy density of matter

Continuous creation

> Religion teaches us that matter in all its forms, including ourselves, is created and did not evolve from natural processes. Natural science, on the other hand, claims the opposite, that our Universe has evolved to the state we see it today. There should be no conflict, because both claims are true.

7.1 Red-shifts

Red-shifts are shifts in spectral lines towards a lower frequency or longer wavelength. Red-shift of wavelengths are usually expressed by the dimensionless ratio z

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\lambda}{\lambda_0} - 1 = \frac{\Delta\lambda}{\lambda_0}, \qquad (none) \quad (87)$$

where λ_0 is the original wavelength and λ the longer red-shifted wavelength.

In astronomy there are at least three major types of red-shifts which can be classified as follows:

1) Doppler red-shifts

2) Gravitational red-shifts

3) Time dilation red-shifts

Most common are Doppler shifts that are purely velocity related. The spectral red-shift, z, of light from a galaxy that is moving away from us with a velocity of Δv equals

$$z = \frac{\sqrt{c^2 - \Delta v^2}}{c - \Delta v} - 1 . \qquad (none) \qquad (88)$$

Astronomical bodies, such as stars and planets that are bound by gravitational fields, exhibit gravitational red-shifts which relate to the slow-down of physical processes and the difference in gravitational tension that a photon has to cross as it climbs the potential well of a gravitational field. For example, photons created at the surface of the Sun are subject to a gravitational red-shift that is determined by the difference in gravitational energy ΔE or tension $\Delta\phi$ between the Sun and Earth and is equal to

$$z = \frac{GM_{sun}}{c^2 R_{sun}} - \frac{GM_{sun}}{c^2 R_{AU}} = \frac{\Delta E}{E} , \qquad (none) \qquad (89)$$

where R_{sun} and R_{AU} are the radii of the Sun and of the Earth's orbit around the Sun respectively. Here ΔE is equivalent to the difference in energy of a photon that has crossed the difference in gravitational tension between the Sun and Earth and E is the original photon energy at the Sun’s surface. It should be pointed out that in reality the frequency of the photon, as seen from an outside observer, does not change crossing the potential well. The difference in clock rate between the Sun and Earth is what causes a difference in frequency reading at each location which we interpret as change in photon energy.

Time dilation at high speeds creates a red-shift of spectral lines proportional to the increase in inertial mass and clock time and due to the increase in potential energy. Time dilation of matter can also be interpreted as an increase in tension $\Delta\phi \approx \Delta(v^2)$ caused by motion.

Time dilation is therefore, detected on fast moving bodies where not only time but all physical processes are observed to slow down.

As physical processes slow down, such as atomic oscillators, the frequency of radiation also slows down, causing wavelengths to shift toward the red giving rise to a red-shift of

$$z = \frac{\Delta t}{t_1} = \left(\sqrt{\frac{c^2}{c^2 - \Delta v^2}}\right) - 1 = \frac{\Delta E}{E_0}, \qquad (none) \qquad (90)$$

where t_1 is the rate of time at our frame of reference and Δt is the increase in length of time due to the time dilation effect. The nature and magnitude of gravitational red-shifts and red-shifts caused by time dilation are but small when compared to the Doppler effect, see Fig. 14.

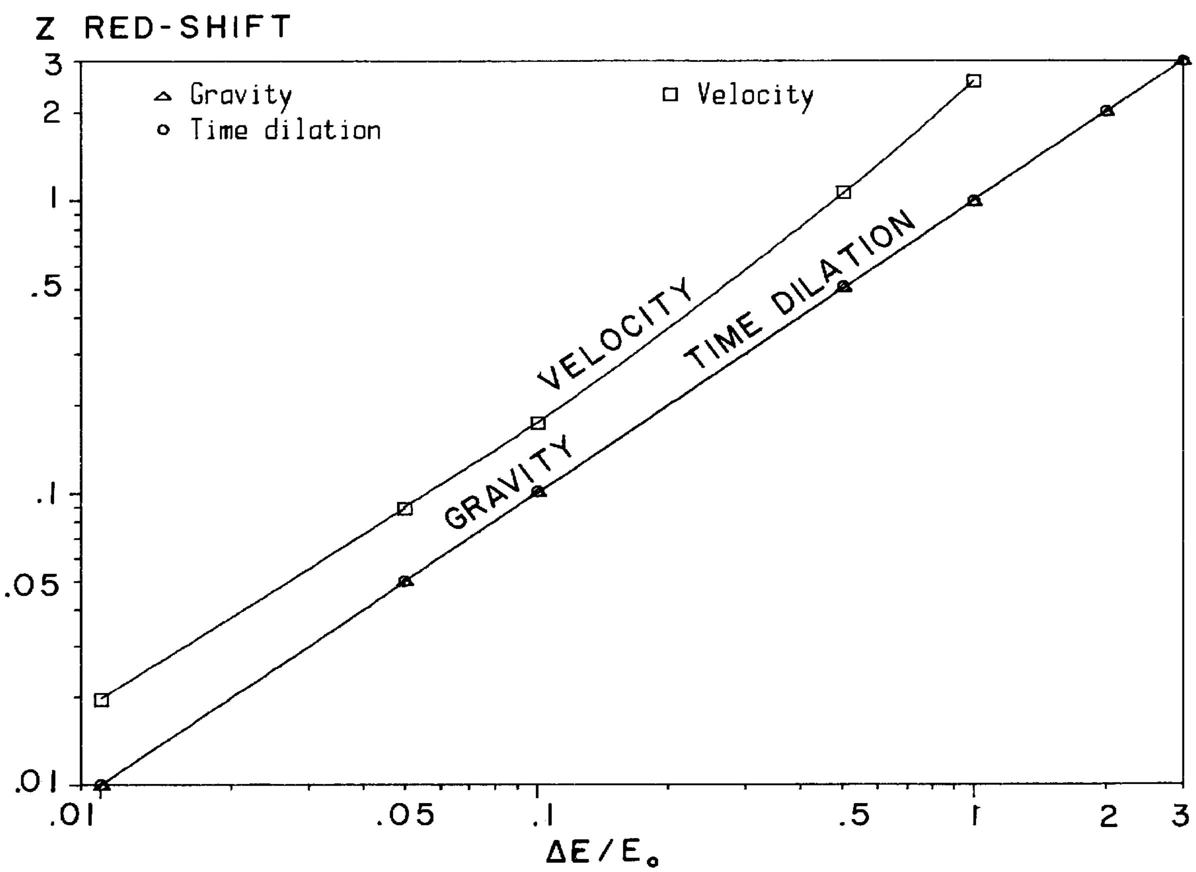

Fig. 14. Velocity, gravity and time dilation red-shifts as a function of energy

Observed one-way red-shifts could also be a combination of all three processes mentioned, especially when astronomical objects are involved. Astronomers normally use Doppler type red-shifts to determine velocities of stars and galaxies relative to our frame of reference and in some cases possibly disregarding the time dilation effect and red-shifts caused by high gravitational fields.

As mentioned earlier the discovery that light from distant galaxies become more and more red-shifted with increasing distance, and thus receding from us, caused astronomers to draw the conclusion that our Universe is expanding. The expansion was assumed to have started from a primeval explosion "the Big Bang" believed to have originated $1/H \approx$ 18 thousand million years ago. The assumption that we are expanding was based purely on intuition and not scientific deduction. To exemplify how recession velocities can be misunderstood, consider several massive bodies falling from a given height. Observers on one body will see their neighbors recede at velocities that increase with distance along the line of fall. For example, imagine several persons on a misty day jumping off the edge of Grand Canyon at intervals of one second. If the visibility allowed, a person somewhere in the middle would see the nearest person who jumped ahead, pull away with a velocity of about 10 m/s and the person before him moving away with double the speed of 20 m/s. The reason of course, is that any one ahead has fallen, or accelerated longer, and reached a higher speed. Looking back in the other direction, however, one would see oneself pull away from the nearest person with a velocity of 10 m/s and 20 m/s from the next individual, *etc.* If the bottom of the canyon and its walls were obscured by the mist no one would be aware of falling and as far as can be seen, everybody appears to recede from each other, while in fact everybody is in free fall toward a common center, the center of mass of the gravitating Earth.

The example of falling bodies is analogous to galaxies falling and accelerating towards the center of mass in a collapsing Universe. The increase in velocity makes galaxies ahead of ours seem to speed away, and for the same reason galaxies behind us will appear to recede, because we are traveling faster toward the center than they are. From our limited view of the Universe this creates an illusion of expansion. Recession velocities as a function of distance are greatest when measured along the *x*-axis (see Chapter 2, Fig. 4) and decrease with increasing angles.

Since we are falling along the *x*-axis (seemingly towards the Virgo cluster), which lines up closely with our galactic polar axis, then stars along the galactic plane obscure other galaxies to considerable galactic latitudes ("the zone of avoidance"). In the two windows available, one above the northern galactic pole and one above the southern galactic pole, one can expect the velocity/distance relationship to vary by a considerable amount, which also seems to be the case and which could perhaps explain the directional dependency of Hubble's parameter (de Vaucouleurs, (1978)) and the great scatter in its experimental value.

Having established a physical reason for red-shifts of receding galaxies leads to equations based on the laws of harmonic motion that enables us to calculate red-shifts as function of distance. Relative recession velocities along the *x*-axis, as seen from our position at x_0, can be estimated from $\Delta v \cong \sqrt{2a_0 R}$ or more precise by the trigonometric functions shown in Fig. 4, Chapter 2 and on page 146. Exact recession velocities and red-shifts along the *x*-axis as a function of distance Δx or R as seen from our reference point x_0 in space are therefore looking back toward A

$$\Delta v = \sqrt{c^2 - \left\{ A\omega_0 \sin\left[\cos^{-1}\left(\frac{1}{\sqrt{2}} + \frac{\Delta x}{A}\right)\right]\right\}^2}\,, \quad \text{(towards } A\text{)} \ (l/t) \qquad (91)$$

and looking forward toward $x = 0$

$$\nabla v = \sqrt{\left\{ A\omega_0 \sin\left[\cos^{-1}\left(\frac{1}{\sqrt{2}} - \frac{\nabla x}{A}\right)\right]\right\}^2 - c^2}\,, \quad \text{(toward } x = 0\text{)} \ (l/t) \qquad (92)$$

where Δv and Δx are velocity and distance respectively in the direction of A while ∇v and ∇x symbolize velocity and distance towards $x = 0$.

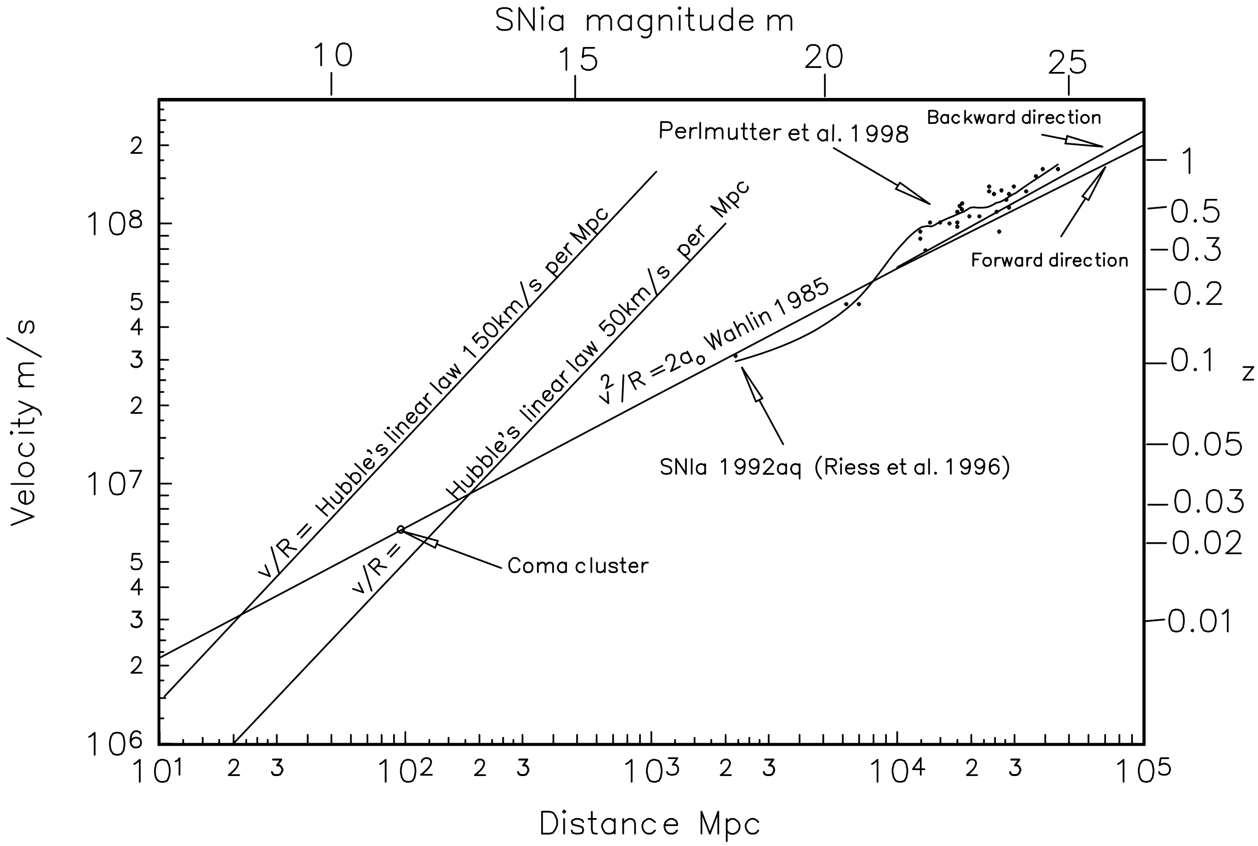

Fig. 15. Hubble diagram showing red-shifts along the *x*-axis as a function of relative distance. Hubble's linear law is also shown for both 50 km/s and 150 km/s.

Recession velocities and red-shifts as a function of distance $\Delta x, \nabla x$ or R from Equation (91) and (92) are shown in Fig. 15. Hubble's linear velocity distance relationship is indicated by its two extreme values of H=50 km/s Mpc and H=150 km/s Mpc respectively. Recent data obtained by the Ia Supernova Cosmology Project are plotted on the above Hubble diagram. The theoretical light output of a typical Ia supernova is very strong, about 2×10^{38} watts or $M = -23.5$ in astronomical units, and can be seen very far. The Ia supernovae data show that Hubble's law is actually a quadratic law $(v^2 / R \approx 2a_0)$ although it might appear linear on a small scale.

It also seems reasonable to believe that light from very distant galaxies should not only shift the spectra toward the red side but should also redden due to the fact that light in intergalactic space will scatter and contribute to the 2.766^{o} Kelvin temperature black body radiation. This type of reddening, which is similar to the reddening of sunlight during sunset or by dust, does not shift the spectral lines. It is conceivable, in the author's opinion, that most galaxies in the Universe cannot be seen since their scattered light has already melted in with the glow of the black body radiation which perhaps should be recognized as Olbers' light. Olbers in 1823 pointed out that if the Universe was filled with an infinite amount of stars as bright as the Sun, then every point in the sky would shine as bright as the Sun, even during night. This is known as Olbers' paradox (Jaki, (1991)). Even if the Universe is not infinite there should still be a glow, but of much less intensity, which of course can be identified as the feeble glow of the 2.766^{O} Kelvin black body radiation.

The amount of measured gravitational red-shift or blue-shift depends very much on the position of the observer and can be complicated. For example, for an observer on Earth the relative slow-down in clock rate of atomic oscillators at the Sun's surface is $\Delta\nu/\nu = GM_{Sun}/(R_{Sun}c^2)$ which in itself should cause a red-shift in atomic spectra of $z = 2\times10^{-6}$. However, the velocity of light at the Sun's surface is slower by a factor of $\Delta v/c = 1-\left(\phi_{univ}/(\phi_{univ}+\phi_{sun})\right)^2$ which will generate a blue shift of $z = 4\times10^{-6}$ where $\phi_{univ} = c^2$ and $\phi_{sun} = GM_{sun}/R_{sun}$. The resultant solar shift is a blue-shift of $z = 2\times10^{-6}$. As the photon leaves the Sun's surface on its voyage to Earth, the velocity of propagation increases stretching the photon's wavelength to a red-shift of $z = 4\times10^{-6}$. The net effect is that we on Earth will observe a solar red-shift of $z = 2\times10^{-6}$.

The frequency of a solar photon, as seen by an outside observer, might not change during its voyage to Earth. However, another accepted view is that the decrease in a photons energy and subsequent frequency while climbing the gravitational energy barrier between

Sun and Earth is canceled by the increase in clock rate as it reaches the Earth.

7.2 Energy density of radiation

The Temperature $T = 2.766°$ Kelvin of the black-body spectrum is the result of scattered radiation from all discrete sources in the Universe and its energy density can be determined as follows: Consider a point source radiating electromagnetic energy in all directions. Such a source will fill a spherical volume of $\frac{4}{3}\pi(ct_1)^3$ with radiant energy in one second, where ct_1 is the radius of the sphere or the distance radiation propagates in $t_1 = 1\text{s}$. The amount of radiation produced and contained within the sphere equals the amount of radiation leaving the sphere in one second or

$$\frac{E}{2\pi} = t_1 T^4 \sigma 4\pi(ct_1)^2, \qquad (ml^2/t^2) \quad (93)$$

where $T^4\sigma$ is the radiant flux density at the surface and $4\pi(ct_1)^2$ is the surface area of the sphere. If we divide the radiant energy E by the volume $\frac{4}{3}\pi(ct_1)^3$ of the sphere we obtain the density of radiation in terms of potential energy and for $T = 2.766°$ K we have

$$U_r = \frac{6\pi\sigma T^4}{c} = 2.087 \times 10^{-13}\,\text{Jm}^{-3}, \qquad (m/(t^2 l)) \quad (94)$$

Equation (94) can be rewritten as

$$U_r = aT^4, \qquad (m/(t^2 l)) \quad (95)$$

where $a = 3.565 \times 10^{-15}\,\text{Jm}^{-3}\text{K}^{-4}$ replaces the term $6\pi\sigma/c$. The constant a is useful for determining the energy density of black body radiation.

7.3 Energy density of matter

The energy density of matter in the Universe as seen from our vantage point x_0 is simply

$$U_m = \rho c^2 = 2.087\times10^{-13}\,\mathrm{J\,m^{-3}}, \qquad (m/(t^2 l)) \quad (96)$$

where ρ is the mass density of the Universe calculated from Equation (24) which is the same as the observed mass density of the Universe. The striking result is that the energy density of matter is equal to the energy density of the cosmic black body radiation (see Equation (94)).

7.4 Continuous creation

If the energy densities of matter and radiation in the Universe are in exact equilibrium as seen above, then in the author's opinion, they were most probably always in a state of equilibrium. It is very unlikely, considering the large cosmological time scale, that at this instant we should be in the exact middle of a transit between a radiation dominated Universe and a matter dominated Universe. If in fact an equilibrium persists between matter and radiation, it will promote the idea of a Steady State Universe involving continuous creation in which everything in general remains balanced and unchanging. The Steady State Universe was first proposed by Hoyle (1948) and Bondi and Gold (1948). This theory was more or less abandoned because of the difficulty at the time to account for the observed 2.766° K black-body radiation (Narlikar, (1978); Narlikar and Kembhavi, (1980)). If we adopt the view of a Steady State Universe in which matter and radiation are kept in balance, then we must also accept the actuality of continuous creation, since matter must be replenished at the same rate it is dissipated by radiation. The rate at which matter must be created by radiation (*e.g.* pair production) is about one electron-positron pair per m^3 per 6×10^{12} years. The creation of matter from radiation such as pair production is a known physical phenomenon where light quanta or photons can change into matter in the form of one electron and one positron. The photons must have at least the same combined energy as the potential energy of one electron plus one positron or $2m_e c^2 = 1.637 \times 10^{-13}$ J which means that the photons must have energies in the gamma ray range. There is no lack of gamma rays in the Universe. The steady state and continuous creation scenario is consistent with a collapsing Universe where matter is losing all its potential energy to radiation as it falls towards the center of mass of the Universe. The radiation in turn travels out through space to eventually convert back into matter and again become subject to the inward gravitational acceleration.

A rigid physical and mathematical theory of continuous creation might eliminate difficult arguments between different schools of thought concerning the origin of matter and subsequent evolutionary processes. Questions such as: was there first light before matter; when did it all start; and how long should it last? are still beyond the author's comprehension.