appreciably higher. *Galactic* fusion endurance is given by a slight modification of Equation (15.25), with the simplifying assumption that the bound proton fraction is the same:

$$\tau_{\varepsilon} = \frac{(1 - f_{bp})\varepsilon_U M_g c^2}{L_g} \tag{15.26}$$

where M_g and L_g are a galaxy's mass and luminosity, respectively. The luminous portion of the Milky Way, for instance, has an estimated power output of $1.4(10)^{37}$ W[1.14] and mass of $8(10)^{41}$ kg.[1.16] Its total fuel reserve (at a composition of 98% hydrogen) is about 2% of the universal average, 1.1 trillion years.

15.5 LUMINOUS LIMIT

The original version of Olbers' paradox was:[6.6]

> "*If the universe is infinite, then a line extending in any direction from Earth would eventually intersect a star's surface. Why isn't the night sky white? Proposed solution: Because the universe is finite.*"

Once more was learned about the breadth and low density of the heavens, it became clear that light would probably be scattered long before it traveled the distance necessary to make Olbers' evenings white. But its energy would still remain, so the paradox was modified to a more modern, thermodynamic form:[6.7]

> "*If the universe is infinite then the luminous output of stars would quickly build to the point where its accumulated heat would burn nonluminous objects, including planets. Proposed solution: This doesn't happen because the universe is expanding, lowering its energy density, cooling it down.*"

Neither of these interpretations is even marginally close to the mark. There is a far more interesting reason why space is a chilly 2.7 °K in an infinite, nonexpanding universe.

Fusion is by far the universe's largest power output, and lumetic decay is by far its largest *power loss*. Even though this effect is weak and requires billions of years to cause a significant energy deficit in individual photons, its universal consequence is staggering. *Since the light given off by all luminous objects decays over time, the cumulative energy in space associated with any luminous object is limited. After a given length of time, the loss due to the lumetic decay of prior luminous output will balance an object's current luminous output.*

Let L be the luminosity of some celestial object such as a star or galaxy. The energy it radiates in some small time interval is initially given by:

$$dE = Ldt \tag{15.27}$$

Since luminous energy decays according to the Hubble constant, the energy in this differential is actually a function of time:

$$dE(t) = Le^{-H_0 t}dt \tag{15.28}$$

The total energy in space associated with an object is given by the aged sum of its radiant output from some initial time ($t = 0$) to its current age, τ:

$$E = \int_{t=0}^{t=\tau} Le^{-H_0 t}dt \tag{15.29}$$

which evaluates to:

$$E = \frac{L}{H_0}\left(1 - e^{-H_0 \tau}\right) \tag{15.30}$$

This is assuming the physical size of celestial objects is small in comparison to the onset of lumetic decay, as is the case. The luminous portion of most galaxies is less than 100 Kly in radius, and lumetic decay doesn't have much of an effect until after a few hundred million light years. Equation (15.30) also assumes the rate of absorption of luminous energy in intergalactic space is small in relation to lumetic decay, which is also the case. Decay is weak, but deep space absorption is orders of magnitude weaker.⟨10.2⟩

When τ is large, Equation (15.30) goes to the limit:

$$E_L = \frac{L}{H_0} \tag{15.31}$$

Lumetic decay reduces the luminous legacy of celestial objects so effectively that there is a limit to the amount of energy they can maintain in space. The energy of Equation (15.31) will be referred to as the *luminous limit*.

Ψ THEOREM 15.4 - LUMINOUS LIMIT {Ψ15.2}

THE LUMETIC DECAY RATE OF ANY CELESTIAL OBJECT'S PRIOR LUMINOUS OUTPUT WILL EVENTUALLY BALANCE ITS CURRENT LUMINOUS OUTPUT