The Universe as a Thermodynamic System

Fred Vaughan

"… you always have to ask why thermodynamics applies to whatever system you are studying, and you do this by deducing the laws of thermodynamics from whatever more fundamental principles happen to be relevant to that system." – S. Weinberg[1]

Whereas all the physical laws of nature apply to phenomena that occur within the universe, thermodynamics applies to the universe itself. Ostensibly thermodynamics applies only to systems in equilibrium for which the 'ideal gas law' applies, but since all systems strive for equilibrium, it has broad application to systems for which only approximations to this ideal pertain. In fact it applies to virtually everything because when physical systems are not in equilibrium they actively strive for that ideal; entropy is the aspect of thermodynamics that drives systems to the ideal of equilibrium. It does this by transferring energy from higher energy particles in the Maxwell Boltzmann distribution to particles with less energy – and never the other way around. Thus, entropy is what allows the discipline of thermodynamics to be applied to systems that are not in equilibrium for which the theory rigorously applies. Entropy provides a thermalization process that drives systems to an equilibrium state for which all aspects of thermodynamics apply.[2]

Not only do interactions drive systems to equilibrium, ultimately, they partition the total energy equally among all constituent categories of a system. This concept of equal allocation of energy includes all disparate component categories within the system, including the various forms of particulate energy as well as the radiant energy of photons. It accomplishes this despite the fact that characteristic radiation of a system in equilibrium is distributed in the Planck blackbody form that is very different from the Maxwell-Boltzmann distribution of particle energy. These two distributions are coordinated by 'regulations' concerning allowed interactions between particles and photons that maintain a stationary thermodynamic state by this thermalization processes.

the thermodynamics of cosmology

Before applying thermodynamic analyses to any system one must address the degree to which conditions in that system approximate an ideal gas for which the law more rigorously applies. The functional form of the thermal radiation given off by a system is the best indicator of the degree to which it conforms to these criteria. Figure 1 taken from Fabian and Barcons (1992) illustrates the observed radiation profile of the extragalactic universe. Clearly, to within 5 orders of magnitude, the cosmic microwave background (CMB) radiation characterizes thermodynamic aspects of the universe. The form clearly indicates that this is indeed blackbody radiation characteristic of a system in an equilibrated stationary state. When NASA first released their plot of the CMB data from their Cosmic Background Explorer (COBE) satellite, they indicated that the plot was so accurately characterized as a black body spectrum that deviations from that form were less than the width of the line used in drawing the curve.

So, yes, the universe is a thermodynamic system – it meets the required conditions much more accurately than the sun or more mundane systems we treat as thermodynamic. Then why does everything we observe of the baryonic matter in the universe differ so dramatically from the implications of the radiation temperature and energy density of the CMB? The inferences that the material universe in its current state is at a temperature of 2.728 K (i.e., minus 459.67 degrees

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1 'Can Science Explain Everything? Anything?' ***The New York Review***, May 31, 2001.

2 This process is explained elsewhere on this site: 'Thermodynamics — the explanation of its Second Law'.

Fahrenheit) is totally absurd. The average temperature of the currently observed material universe is *many* orders of magnitude greater than that and its implied electron density is *many* orders of magnitude less than implied by that inference. So why is the temperature of the thermal radiation given off by this system be so accurately characterized as blackbody radiation? That is the question we must ask – and answer.

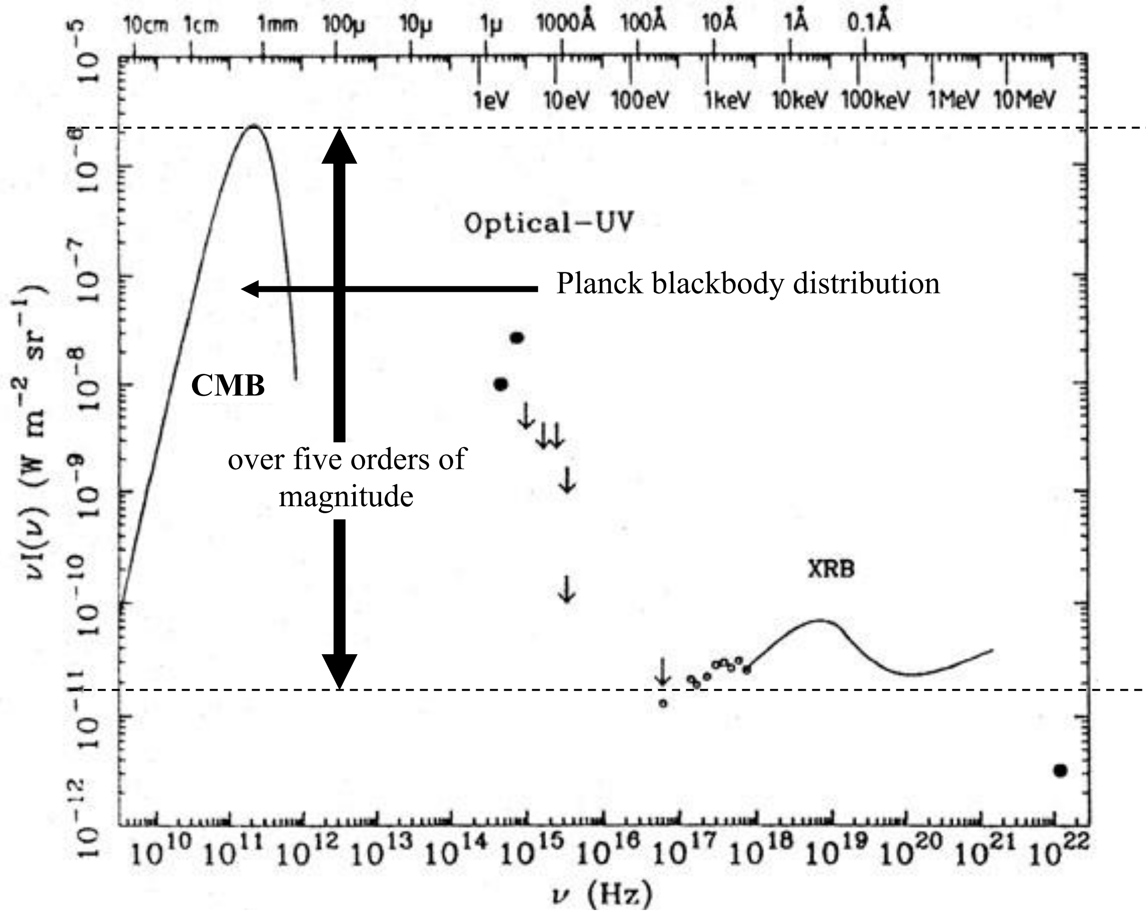

Figure 1: Spectrum of the extragalactic sky cover – energy from the radio band to gamma-rays (arrows denote upper limits)

We have come to the dilemma of radiation and baryonic matter in the universe existing in totally different thermodynamic states. To understand approaches to rectify the confusion brought about by this situation requires some background in thermodynamic theory. To quote Weinberg, we must deduce applicability of thermodynamic analysis from relevant fundamental principles.

some background on the equipartition principle

Electromagnetic interactions achieve and maintain thermal equilibrium by radiation interacting with solid surfaces at a fixed temperature or to the same effect by interacting with diffuse particles in an extensive gaseous substance in equilibrium at the given temperature. The interchanges bring about complete energy sharing characterized by the phrase 'equipartition of energy'. Einstein demonstrated that individual exchanges of radiation between material entities result in reallocating energy, radiant energy maintaining Planck blackbody form and the kinetic energy of the material entities maintaining a compatible Maxwell-Boltzmann form.

The ideal gas law is P V = n k T, where P is the pressure, V the volume of gas, n the number of particles in the volume, T the temperature of the gas in Kelvin, and k =1.38x10^{-16} ergs/K is the Boltzmann constant. This is the staple of thermodynamics and applies to all equilibrium situations. It provides an explicit relationship between particulate gas density $\rho_{gas} \equiv$ n/V and temperature:

$T_{gas}(\rho_{gas}) = P_{gas} / k\ \rho_{gas}$

This equation is plotted as the dotted lines on a log-log scale with negative slope in figure 2 for various pressure values. These lines correspond to adiabatic expansion/compression of an ideal gas. By forcibly constraining pressure of a gas, the temperature and density parameters can be coordinated such that their product is constrained to positions along one of these dotted lines.

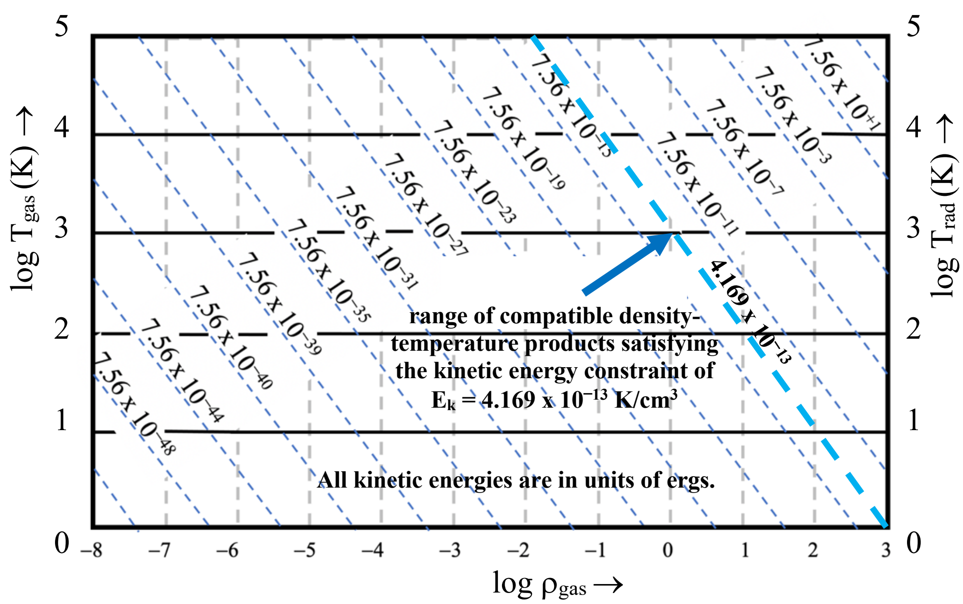

Figure 2: Thermodynamic compatibility constraint on energy density

The kinetic energy density of constituents in an ideal gas is given by,

$E_k = (3/2)\ k\ \rho_{gas}\ T_{gas}$

Thus, the dotted lines also constitute kinetic energy density constraints.

$T_{gas}(\rho_{gas}) = (2/3)\ E_k / k\ \rho_{gas}$

These formulas pertain to an ideal gas that is in equilibrium and uniform throughout. When complete uniformity does not apply, averages may be appropriate.

associating kinetic and radiational temperatures

The energy density of emitted thermal radiation in an ideal gas derives from the equipartition principle. However, if the extent of the gas were to be much less than the optical depth of the substance then most lines of sight to sources of radiation would terminate on matter exterior to the gas itself; the temperature of radiation within the gas would be affected by kinetic temperatures beyond the outer limit of the defined system. This is, of course, the primary reason that systems do not reach equilibrium. Later we will address various possibilities for why the temperature of radiation emanating from a gas that extends well beyond its optical depth may differ significantly from that of the kinetic temperature of the gas itself. Ordinarily radiation and kinetic temperatures of systems in equilibrium will be the same – so much so that other possibilities may not have been properly considered, nor therefore, properly addressed. In mundane situations differences in these two temperatures are attributable to the mixing of radiation from multiple systems at different kinetic temperatures. The universe's situation is very different from such mundane systems in as much as, although in equilibrium and nonuniform, radiation from great distances will be redshifted.

The energy of emitted radiation in a thermodynamic system in equilibrium is distributed as a blackbody spectrum that is a function of emitted wavelength λ_e and kinetic temperature given by:

$$\rho_{rad}(\lambda_e, T_k)\, d\lambda_e = (2\pi\, h\, c / \lambda_e^5)\,(e^{K/\lambda_e T_k} - 1)^{-1}\, d\lambda_e$$

This parametrical representation specifies radiant energy density per unit wavelength; its units are ergs/cm^2 sec. Note: 'observed' wavelength λ_o, is not necessarily equal to the 'emitted' wavelength λ_e. Planck's constant is h= 6.626x10^{-27} erg-sec and the factor $K \equiv h\, c / k$ = 1.441 cm-K in the exponent is a constant. The equipartition principle implies that the total radiant energy density of all emitted wavelengths is equal to the kinetic energy density of the material substance. Thus, by integrating this density expression over all wavelengths one obtains that total energy density of radiation emitted from a surface area. Total energy radiated in one second through a unit surface area (e.g., square centimeter) of any substance in thermal equilibrium is given by Stefan's formula:

$$I_T = \sigma_r\, \varepsilon\, T_{rad}^4$$

Here $\sigma_r = (2\, \pi^5\, k^4 / 15\, h^3\, c^3) = 2.268 \times 10^{-4}$ erg-cm^{-2}-deg^{-4} is the Stefan-Boltzmann constant, and ε is *emissivity*, i.e., the efficiency of emission of the medium relative to that of a theoretically perfect blackbody and therefore unity in our treatment. Since I_T is defined as the energy transported across a one square centimeter area in one second, the radiant energy density E_T 'contained' in one cubic centimeter is obtained by dividing this expression by the speed of light:

$$E_T = I_T / c \cong 7.56 \times 10^{-15}\, T_{rad}^4$$

The energy density of emitted thermal radiation must be equal to the kinetic energy density of the system emitting the radiation. The red circle provided on the right on the downward sloping line of energy density of 4.169 x 10^{-13} in figure 3 for example, one might think should therefore pertain to both radiation and kinetic temperature – *but that is not the case as we will demonstrate for the CMB and baryonic matter in the universe*.

The state of a thermodynamic system in equilibrium requires that the ideal gas law and equality of both kinetic and emitted radiant energy densities apply. *This does not necessitate equality of the two temperatures, however.* The equipartition constraint enforces only:

$$(3/2)\, k\, \rho_{gas}\, T_k = 7.56 \times 10^{-15}\, T_{rad}^4$$

If, however, we assume equality of kinetic and radiational temperature ($T_k = T_{rad}$) in addition to the equipartition of energy densities and solve this equation for the associated gas temperature with these constraints, we obtain the following:

$T_{gas} = 0.301 \sqrt{\rho_{gas}}$

The upward sloping lines in figure 3 are plots of this equation. The blue and pink circles indicate the apparently incompatible alternative thermodynamic states of the universe as a thermodynamic system where the equal temperature curves intersect the energy density curve labeled 4.169 x 10^{-13} ergs. Either circle would ordinarily correspond to stable thermodynamic state but they don't.

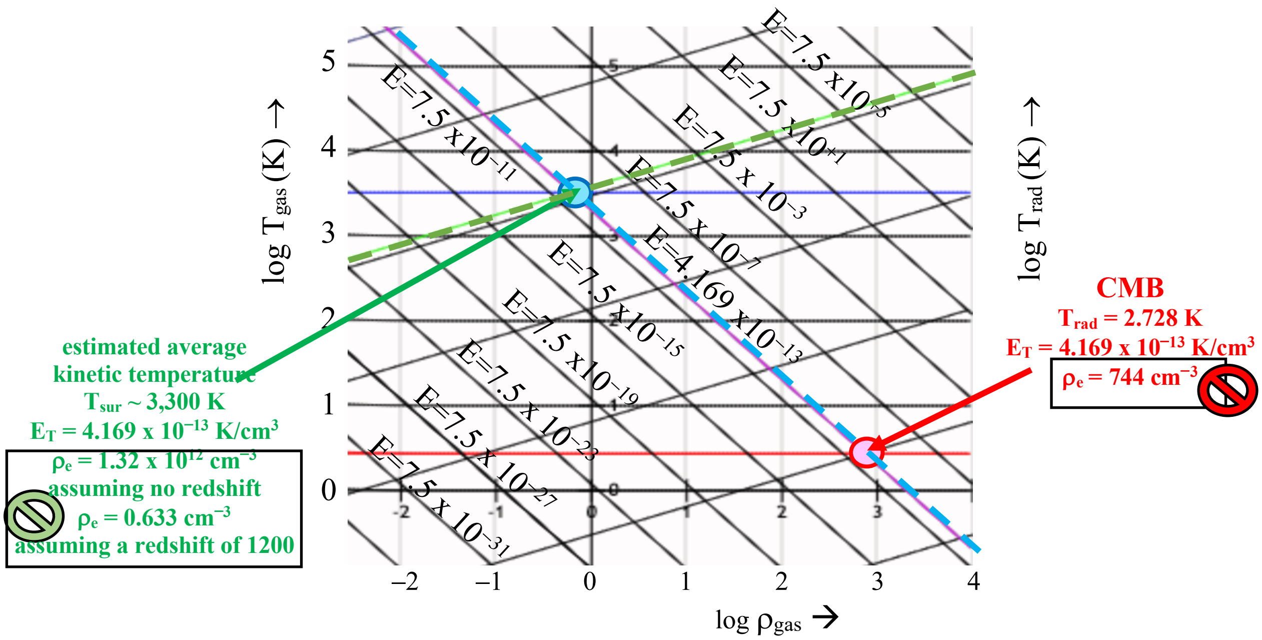

Figure 3: Additional equipartition of energy constraint

Figure 3 illustrates the relationship of equal kinetic and radiant energy density to kinetic temperatures and gas density. Notice that for the red circle the particle density of the gas is incompatible with the temperature and density of a stable thermodynamic system anywhere other than ρ_{gas} = 744 cm^{-3}. However, that density value is totally incompatible with baryonic matter densities realized in the universe. The blue circle could as well be placed anywhere along the blue dashed line. Its only commonality with the red circle is the equated energies. It is disconcerting that assuming the time-honored equipartition of energy should associate disparate temperatures and densities of particles and photons in a system that seems by all indications to be in a thermodynamic stationary state of equilibrium out to extreme distances. Attempting to rationalize that anomaly is what cosmologists have done – what we will do.

To do that we will first investigate the only-apparent incompatibility in formulations of radiant and kinetic energy distributions that derive from their respective treatment of density. Then we will address the effect this has on the treatment of radiation redshift.

establishing compatibility of surface area and particle density

It is noteworthy that even though they are theoretically equal, the energy density of emitted radiation unlike its particulate counterpart, does not involve the density of the baryonic matter whose interactions are mediated by the radiation. Although photons originate and terminate at particles, unlike the Maxwell-Boltzmann distribution where the average kinetic energy is determined as a weighted average of the kinetic energy over all particles, and therefore explicitly involves the density of particles, matter density appears nowhere in the formulation of the Planck distribution of radiant energy. Thermal radiation energy density represented by the Planck blackbody distribution is a surface brightness phenomenon, which means that it is a function of numbers of photons passing through a specified surface area – seemingly independent of a source particle density across that area. We are thus presented with the dilemma of determining how changes in one distribution produce a compatible redistribution of the other.

In Einstein's quantum theory of radiation (1917) he derived the Planck distribution from first principles using the Maxwell-Boltzmann energy distribution for molecules in an ideal gas. The reason the density of gas particles does not enter Planck's formula is that although 'heat' is currently perceived as tantamount to motions of the constituent particles, Planck’s blackbody distribution derived instead from the stationary inner surface of an enclosed cavity. The effect is the same in an extensive high-density gas with no specific surface. However, if the extent of the entire system were appreciably less than the optical depth of the gas from its boundary, then the blackbody form of the radiation would not be realized because some photons would ‘escape’ from the inside, and others would enter from outside of the gas. Defined confines of a system reflect and affect thermal conditions within the system in question. But when considering the universe as a thermodynamic system, there is no confinement and no ‘outside’. So one must treat thermodynamic analyses of the universe somewhat differently. So baryonic density and the concept of optical depth must be included in analyses considering the origin of the CMB blackbody radiation.

The 'optical depth' of a gas, involves the degree of 'transparency' (antithetically, the 'opacity') of the gas; it is a measure of the 'attenuation' (absorption) of radiation that takes place in a substance. If one were to shine a light through any medium, after propagating to the optical depth of that medium, the intensity of the observed light would drop to 1/e (e is the base of natural logarithms) of its originally emitted intensity in accordance with Lambert's absorption law, independent of any other loss due to the inverse square law reduction in numbers of photons or loss of photon energy due to redshift. Attenuation occurs because of absorption with subsequent re-emission in random directions that takes place in the medium as illustrated in figure 4. In ‘single scattering’ of radiation (and forward scattering for which absorption and re-emission does not occur), the direction (and imaging possibilities) of ensuing radiation is preserved.

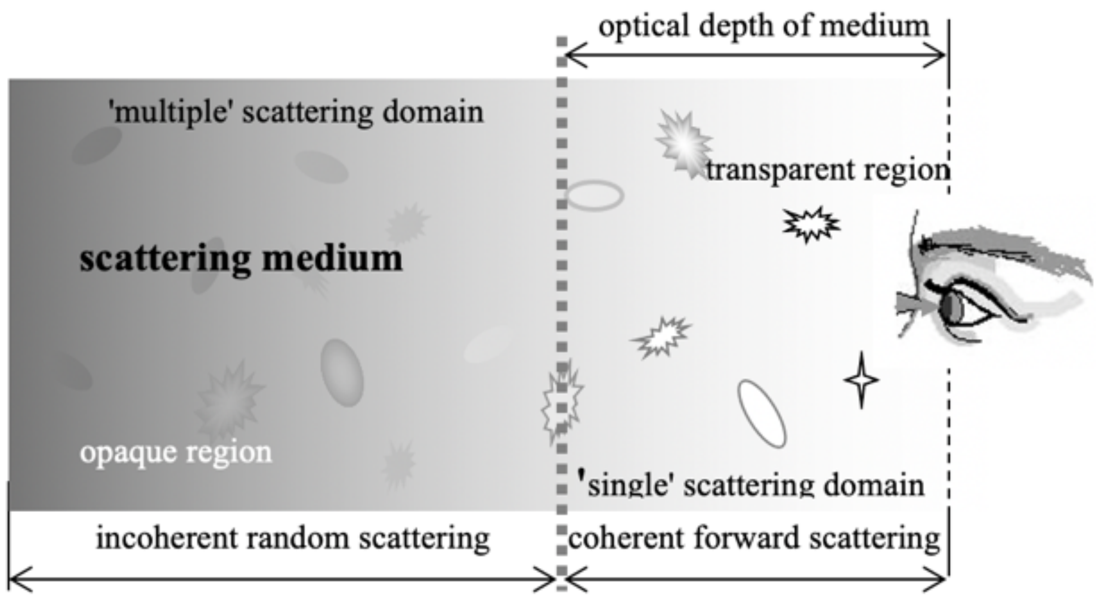

Figure 4: Illustration of electromagnetic scattering and optical depth concepts

the concept of sky cover

Significantly, the density of material particles *does* contribute to conceptual surface constraints for unencapsulated systems. These derive from volumetric considerations involving the cross section and density of emitting and absorbing constituents of the gas. Ostensibly, the reason that the density of particles does not appear in the blackbody distribution formula is because the emphasis has been on an encapsulating surface, i.e., a 'surface' comprised of an ensemble of particulate matter. When there is no rigid surface, the density of the particles can produce surface closure for a thermodynamic system by every line of sight eventually intersecting an object within that system and thereby a 'nearest' object along every line of sight provides a portion of a total surrounding 'surface', i.e. total 'sky cover'. So, *of course* density is involved. Cross sectional areas of particles in a gas are part and parcel of a surrounding surface, the distance to a majority of which may in some cases be quite extensive but still within the given system. In cases involving cosmological distances containing intergalactic plasma, redshifting of associated thermal radiation produces its own dramatic effects that reduce the thermal radiation temperature relative to the kinetic temperature of the particles themselves.

To pursue this concept of sky cover as a surface more quantitatively, assume a uniform random distribution of particles whose average density is ρ per cubic centimeter. Assume further that these are spherical particles for which the cross-sectional area is $\sigma = (8/3)\, \pi\, r_o^2$ which applies to lower energy photons. In this case r_o is the average radius of an ion in hydrogenous intergalactic plasma. A proton cross section is about 10^{-25} cm^2 with the electron over six times as large, so we assume the hydrogenous ion cross section at 3×10^{-25} cm^2. Thus, within a given solid angle, the proportion η of the total surface area covered by ions within a depth Δr of the distance r is a composite of the cross sections of those which are enclosed in the spherical shell at that distance:

$$\eta = \sigma\, \rho\, \Delta r$$

There is no explicit dependence on radial distance r because proportionate factors involving distance cancel, i.e. for a uniform density the number of included particles in a shell increases as r^2, but the total angular cross-section of each particle decreases as $1/r^2$. However, coverage at the distance r (and indeed an increasing percentage of it) will be occluded by cross sections of particles closer to the observer and thus will not intersect a line of sight. So if we are interested in that portion of the observed field of view covered exclusively by objects at the distance r, we must subtract the amount of cross-sectional area attributed to objects at distances 0 through r.

Then the proportion of cross-sectional area of the particles at r that has not been occluded by the cross sections of those at intervening distances we define as a(r). To determine a(r), we partition the distance r into uniform increments Δr, such that $r = n\, \Delta r$, defining shells of particle occupancy. Then a(r) can be expressed as a(n), where:

$$a(0) = (1 - \eta\, r/n)^{0} = 1$$
$$a(1) = (1 - \eta\, r/n)^{1}$$
$$a(2) = (1 - \eta\, r/n)^{2}$$
$$\cdots$$
$$a(n) = (1 - \eta\, r/n)^{n}$$

As n increases, it becomes much greater than η r. The following mathematical proof then becomes of immediate relevance:

$$e^{-\eta r} \equiv \lim_{n \to \infty} (1 - \eta r/n)^{n}$$

Thus, in the limit of large n, the portion of sky cover added at distance r is η a(r) dr = $\eta\, e^{-\eta r}$ dr.

Curve 1 in figure 5 is a plot of a(r). Curve 2 is the integral of η a(r) dr (which is sky cover *at* distance r) from zero out to distance r, providing *total* sky cover out to that distance. In the figure as drawn, these curves are independent of the value of η because the scale on the abscissa is one over η. As now formulated, sky cover provides a basis for determining the percentage of 'closure' of the necessary 'cavity' surface for blackbody thermal radiation. For mundane thermodynamic systems constrained in solid containers, the density of nuclei and the 'electron cloud' at a metallic or crystalline surface of a solid container provides complete sky cover with the cross-sectional areas of the gas particles enclosed within the container having virtually no affect. But in open systems without the container constraint, the rate of closure as a function of distance becomes a necessary weighting factor pertinent to any thermalization analyses that involve distances appreciable with respect to the optical depth of the substance. When redshift becomes an issue within the optical depth as it is for the universe, it is of paramount significance that these closure criteria as well as the involved redshift be taken into account in thermodynamic analyses.

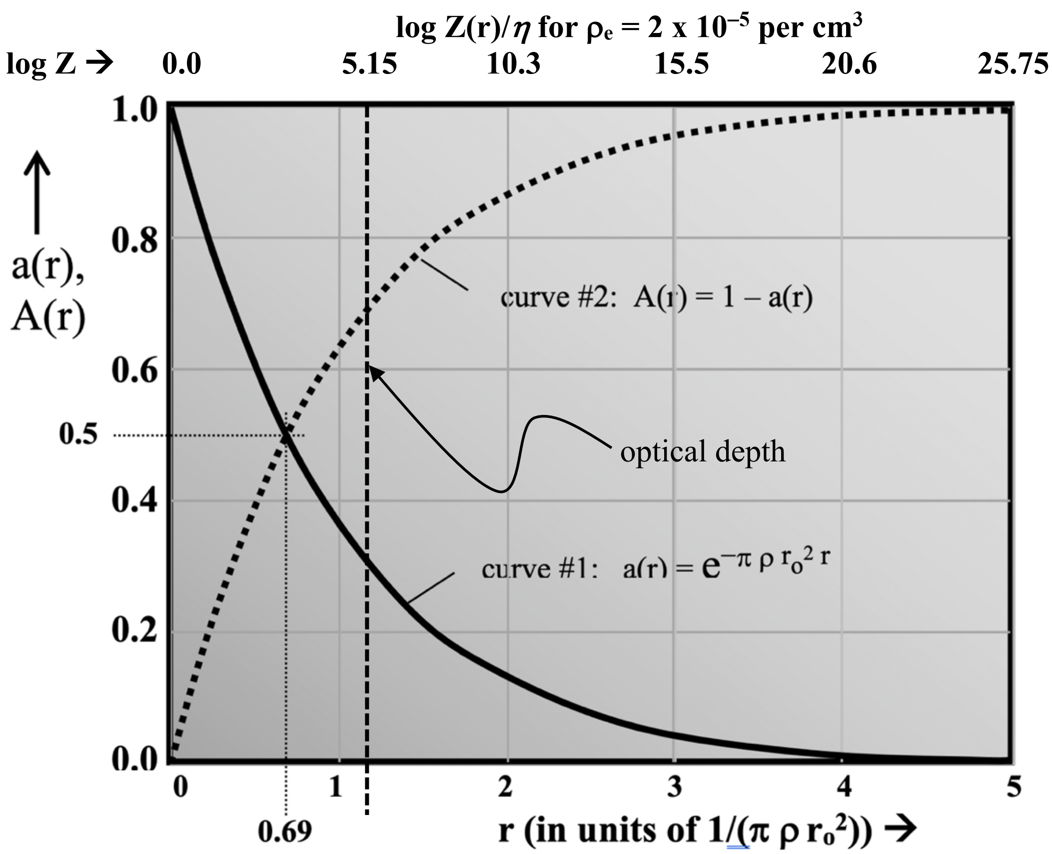

Figure 5: Sky coverage (curve #2) of uniformly sized objects

A distance $R_{½}$ can be defined such that sky cover area would be 50 percent, i.e. half of all lines of sight will intersect a particle's cross-sectional area within the system by that distance:

$$e^{-\eta R_{½}} = ½$$

Since the natural log of one half is equal to −0.69, we obtain: $R_{½} = 0.69 / \eta = 2.3 \times 10^{24}/\rho$.

For distances greater than the optical depth of a medium, effective visibility of objects drops to 1/e. In figure 5, as illustrated, when $r > 1/\eta$, over sixty percent of all lines of sight will have terminated at a particle within the system. This means that the probability of 'seeing' an object – in the sense of obtaining an image of the object – beyond that distance will be 1/e, and what we do 'see' will largely be due to multiple scattering for which imaging is increasingly obscured. But a commensurable fraction of thermal radiation will derive from these distant regions.

Wien's law and its application to the redshift of thermal radiation

Wien's law involves what is called the 'Planck factor' $f(\lambda_e \bullet T_k)$ of the blackbody distribution function $\rho(\lambda_e, T_k)$ discussed above. This factor is a function of the product of the wavelength of emitted radiation λ_e times the kinetic temperature T_k of the particulate matter of the system. This rather obscure fact guarantees similarity of form for both kinetic temperature T_k and emitted wavelength λ_e, which impacts the 'observed' temperature of thermal radiation from a source whose emitted radiation has been redshifted. Wien's law of blackbody radiation is the following:

$$\rho(\lambda_e, T_k) = f(\lambda_e \bullet T_k) / \lambda_e^5$$

The heavy dot is intended to emphasize the product in expressing a product law functionality for temperature and wavelength for the Planck factor of the 'observed' radiation spectra.

Notice that we distinguish 'emitted' from 'observed' radiation wavelength, as well as kinetic versus radiation temperature. This is particularly appropriate whenever redshift may be involved – and redshift (even if miniscule) must be involved in any complete explanation of thermalization processes because the Doppler shift of interacting radiation is what drives a system to equilibrium. That radiation may be redshifted following emission rather than the radiation having been emitted from a cooler surface cannot be determined by merely observing the radiation. When redshifting is involved, observed wavelength will be given by $\lambda_o = (Z+1)\,\lambda_e$, with λ_e the emission wavelength which pertained to our earlier discussions of thermodynamics. Redshift is now an essential aspect of thermodynamic analyses; it deals with differences between emitted and observed radiation. Wien's law assures us that radiation of wavelength $\lambda_e = \lambda_o/(Z+1)$ from a surface at temperature T_k observed at a redshift of Z, and radiation from a surface that is at the reduced temperature of $T = T_k/(Z+1)$ with no redshift occurring at all, are indistinguishable as far as this factor is concerned:

$$f((\lambda_o/(Z+1)) \bullet T_k) = f(\lambda_e \bullet (T_k/(Z+1)))$$

Therefore, there is absolutely no difference in the radiation energy density, which will be reduced by the factor $(Z+1)^4$ in cases of either an actual redshift or an equally reduced kinetic temperature in accordance with Stefan's Law that we discussed previously.

$$E_T = \int_o^\infty f(\lambda_o, T_k/(Z+1)) / \lambda_o^5 \, d\lambda_o = \int_o^\infty [f(\lambda_e (Z+1), T_k) / (\lambda_e (Z+1))^5] \, d(\lambda_e (Z+1))$$

Once the expression in the integrand for the complete Planck distribution $\rho_{rad}(\lambda_o, T_k)$ has been integrated over all possible wavelengths as indicated, one obtains:

$$E_T = 7.56 \times 10^{-15}\, T_k^4 / (Z+1)^4$$

The observed (as against emitted) radiation temperature is $T_{rad} = T_k / (Z+1)$, making a clear distinction between kinetic temperature at the surface and 'observed' radiation temperature at a remove from that surface. Wien's law was confirmed using Doppler shifted radiation reflected from a moving piston and thus is legitimately applicable to redshifting environments.

We deferred resolution of the kinetic temperature and particle density disparities of figure 3 until we had discussed redshift. So now we see that the enigma of the equipartition constraint on kinetic and radiational energy density can be resolved by including the effect of redshift on the radiation temperature at the surface where the radiation was emitted by application of Wien's law:

$$(3/2)\, k\, \rho_e\, T_{sur} = 7.56 \times 10^{-15} \left(T_{sur} / (Z+1)\right)^4$$

This implies the following:

$$\rho_e = 36.5\, T_{sur}^{\,3} / (Z+1)^4 = 0.633\ \text{cm}^{-3}$$

That is the value of ρ_e implied by $T_{sur} = 3{,}273$ K and $Z+1 = 1{,}200$. This is still an incompatible, determination; it was included in figure 3 as the blue circle in the diagram on the line corresponding to the kinetic energy constraint shown also in figure 2. Energy density of radiation emitted from an analogy to a 'cavity surface' requires further explanation with regard to why thermal radiation would have been redshifted in a stable thermodynamic system in the first place.

"Why?" rather than "what?" and "how?" is typically not a scientific question; it is more a part of what it means to be human. We come up with reasons for why things are as the are. We ask and we demand legitimate answers. We cannot be satisfied with a dry-lab value of redshift selected solely to rationalize CMB radiation temperature if that explanation implies thermodynamically unreasonable values of matter densities and temperatures of the currently observed universe. Models are intended to explore reality by analogy without resorting to deus ex machina. Thus, we ask with Weinberg, "How did these thermodynamic properties come to pertain to our universe."

the standard model explanation of the disparity as expansion of the universe

Apologists of the standard cosmological model insist on the existence of a 'receding surface' of hot plasma gas that had cooled as it expanded outward from a big bang. This seemed necessary to resolve the disparity between the kinetic and thermal radiation temperatures. Four dimensions accommodates recession away from us, placing us at the center of an isotopically expanding cavity. Then any combination of temperature and redshift satisfying the kinetic energy constraint of figures 2 and 3 would suffice from this perspective. For this to constitute an adequate explanation, the surface temperature and redshift have to make sense and the density must support there being a 'single closed surface' of virtually contiguous material substance as in a metallic surface with no photons contributing to the CMB emitted from in front of, or behind that evolved shroud.

Wien's law demands that emitted radiation, $T_{rad} = T_k = T_{sur}$ at that 'cavity' surface would have had to be at a much higher temperature than the 2.728 K radiation we observe – how much higher depends upon the redshift and time since it was emitted. Time is distance for radiation and therefore, the redshift at the time/distance at which the radiation was emitted must be as shown in figure 6. $T_{sur} = 2.728\,(Z_{sur} + 1)$ as well as a much lower density. The implied density does not pertain to any observations of the current universe. Distance is *not* redshift and therefore space itself would have to be expanding rather than a simple recessional Doppler explanation.

From the conjectured occurrence of the big bang onward, temperatures and matter density would have dropped dramatically: temperature as time to the one-third power and density as the one-fourth power. This is the universal expansion hypothesis of the standard model. The conjectured cavity surface would have occurred about 378,000 years after a big bang, a coordinated time when virtually all free plasma electrons would have combined with the free protons to form neutral hydrogen atoms. This would have occurred because the extreme temperatures would have cooled by expansion down to the assumed 3,273 K at which temperature virtually complete ion association occurs. Thermodynamic implications of this conjecture were illustrated by the blue circle in figure 3 and more specifically in figure 6. The hypothesis is that the universe underwent a phase transition from a completely opaque thermodynamic system at temperatures above three thousand degrees K to one of gravitational clumping of ensembles of neutral atoms separated by vast intergalactic, radiationally transparent regions after cooling below ionization levels. These vast regions of space with isolated clumps of neutral matter would have become amenable to gravitational binding into structural developments including hydrogen clouds, stars, solar systems, galaxies, and clusters of galaxies. The ion association process would more likely occur through a gradual transition of kinetic energy density, temperature, and ion density, not a sudden change into a dense surface at a specific time and distance in the past. But that is the model.

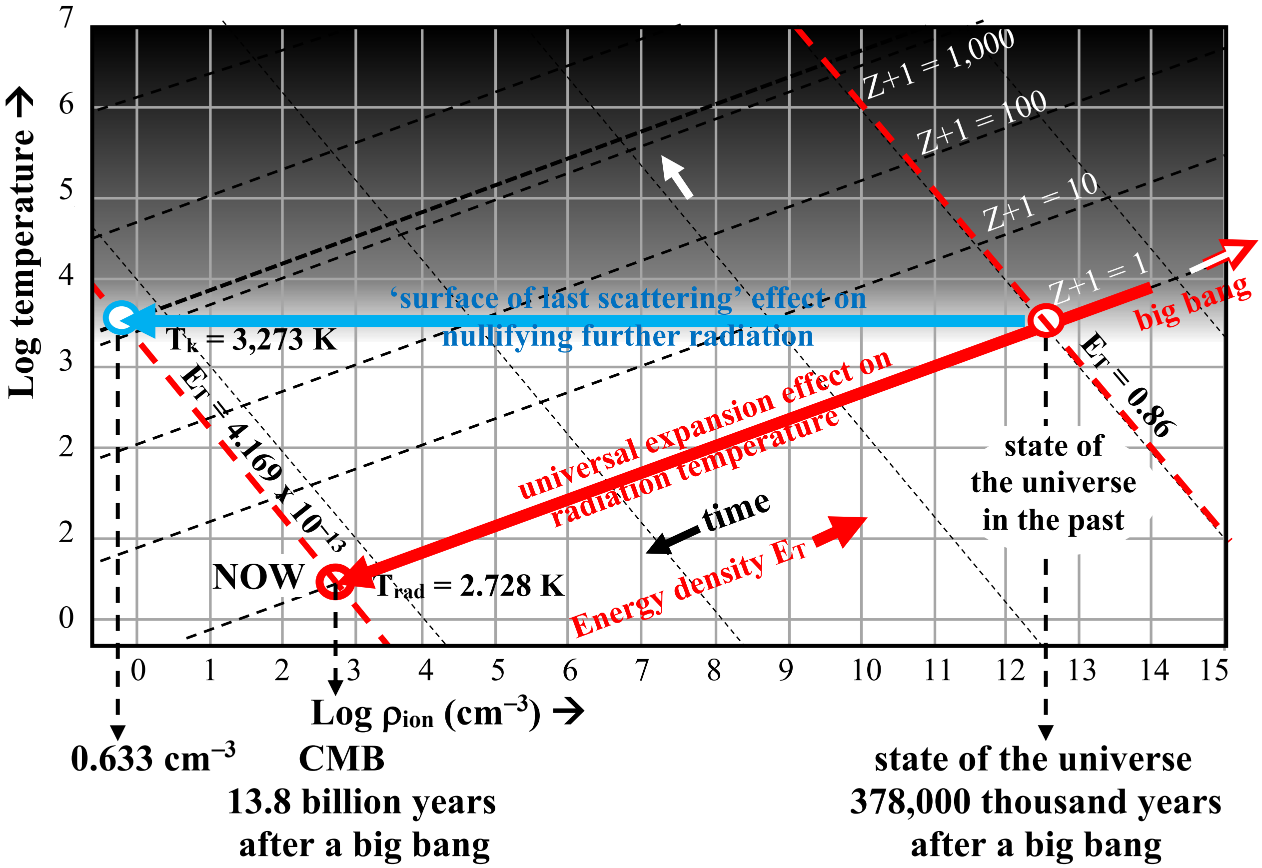

Figure 6: The standard model explanation of cosmic background radiation

The hypothesized expansion satisfies criteria for a thermodynamically adiabatic process that does not lose thermal energy or mass by expansion with both radiation temperature and mass density dropping dramatically, although not proportionately. The energy density of background radiation would have to have resulted from thermodynamic kinetic properties current at the time the radiation left that surface of last scattering. The significance of the term 'last scattering' is that the photons of the CMB had to have originated at that surface and at no place(time) before or after. The concept of optical depth is simplified to complete transparency up to the surface of last scattering with complete opacity beyond that surface. These concepts incorporate the conjecture of an entirely closed surface at a redshift of about 1200 with an associated surface temperature on the order of 3,300 K, but with electron number and energy densities appropriate to a much denser and higher energy epoch in an expanding universe. The equipartition constraint on particulate and radiational energy densities requires the equality of the two energy densities $E_k = E_{CMB}$ at the surface where emission took place, i.e., the red circle at top right of figures 6. The acceptability of that explanation depends on the credulity of scientists to the notion of the entire universe beginning with a bang and incredible required coincidences and consistency of the arguments for a single surface of last scattering. The explanation applies Wien's law to a conjectured situation some thirteen billion years ago. The density at that point in the supposed history of the universe had to complete an associated 'cavity wall' as surely as if it were heated cast iron and there could not thereafter be sufficient material for thermalization processes to continue. The viability of these constraints is questionable at best.

The standard model presents a genesis-like scenario which is very different than a stationary state in a thermodynamically active universe. It ignores the cosmological principle. According to this model, we occupy at a very special place and time in that historical account, which begs Hawking's question of whether there had actually been a beginning of time itself. Standard model cosmologists have distorted the meaning of terms like 'cosmological principle' and 'evolution'. Miriam Webster, in keeping tabs on a living language, now defines *cosmological principle* as "a principle in astronomy [whereby] the distribution of matter in the universe is homogeneous and isotropic except for local irregularities." The definition ignores the caveat of accepted changes through epochs of the past. Okay, but that isn't all that the term used to mean or what it is meaningful for it to mean. The term derived from Copernicus having pointed out that the sun does not revolve around the earth, which rational humility spurred a scientific awakening. It came to imply that physical laws that apply in laboratories here on the earth must apply for any similar scientist performing similar experiments on planets orbiting distant stars, in different galaxies, anywhere in the universe at any time. Physical constants such as the speed of light, Planck's constant, Boltzmann's constant, the gravitational constant, the mass of the elementary particles, etc. would not change if we were doing physics at some other time or elsewhere in the universe. It used to encompass there being no preferred place or time in the universe. All of that has been willingly abandoned. And the word evolution? No. The model defines a scenario of events, a history of epochs since time began if you will, from a big bang onward. It is more of a caricature of genesis than evolutionary replication with random mutations as exemplified in the Evolution of Species. Words have meanings; it is understandable that those change with usage as part of a natural language, of course, but communication is hampered by the misuse of that process whether in politics or science.

Pretending that the universe itself is currently at a temperature of minus 460 degrees Fahrenheit produces cognitive dissonance for those who accept observations that it isn't. Galaxy cluster cells represent the entire range of thermodynamic properties and processes throughout the universe; they radiate at temperatures between about 10^3 K and 10^9 K. Nowhere in the universe is it 2.728 K. Nowhere! Every scientist knows this unless they purposely ignore all currently accepted observations of what occurs in what they call 'dark matter halos' that should more realistically just be called 'galaxy cluster cells'. The temperature of virtually everything in the universe – which is primarily the intergalactic plasma medium that pervades all of space and accounts for the vast majority of baryonic mass in the universe − is many orders of magnitude hotter than the spectrum of the microwave background radiation *and*, lest there be any doubt, it scatters radiation. The density of the current universe − and again, primarily constituted of intergalactic hydrogenous plasma – is many orders of magnitude less dense than the 744 electrons per cubic centimeter naively implied by the temperature and energy density of the background radiation.

the alternative explanation employing thermal sky cover considerations

"More than three quarters of the ***baryonic*** *content of the Universe resides in a highly diffuse state that is difficult to observe, with only a small fraction directly observed in galaxies and galaxy clusters."*[3]

It makes sense to ask why seemingly imponderable kinetic and radiational differences pertain to the current universe whose blackbody radiation definitively establishes it as thermodynamically stable. But it is not rational to revert to myths, contrived origins, mysterious substances, previously unknown natural laws, or altered universal constants to account for easily explained phenomena. The reasons for disparities from traditional thermodynamic theory are threefold:

1. Nonuniformity of the past, current, and future baryonic matter,
2. Sky cover by the average past, current, and future baryonic matter density
3. Redshift of radiation through past, current, and future baryonic hydrogenous plasma

Galaxy clusters are the basic units of the universe. A galaxy cluster is not just the knot of orbiting galaxies but all the mass and emitted radiation from within a very much larger cell surrounding those galaxies. In these cells matter (including galaxies and plasma gases) is distributed by a stable hydrostatically maintained interplay between outward thermodynamic pressure and collapsing gravitational forces. This is similar to the forces at work in stellar masses such as the sun that are in hydrostatic equilibrium. The distributions of thermodynamic parameters within the sun are shown in figure 7 taken from FIG. 1 in Andre and Kremer.[4] The distributions of temperature, matter density, and pressure for a typical large galaxy cluster cell are illustrated in figure 8. The distributions have similar form due to similar causes. These curves were plotted using the formulations of Xue and Wu for the "double β model for intracluster gas".[5]

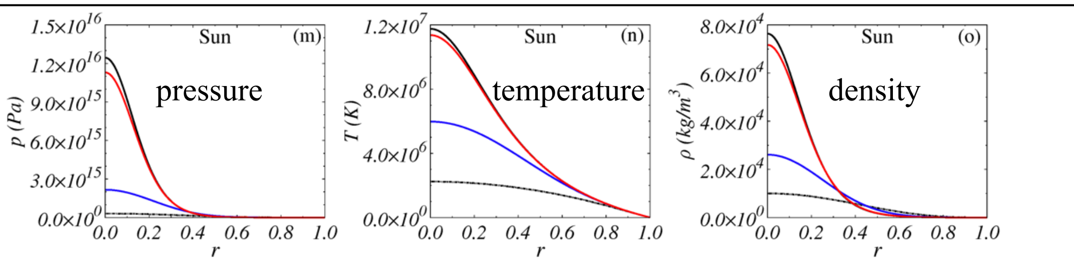

FIG. 1. Behavior of pressure, temperature and density within some classes of stars (Neutron star, Brown Dwarf, Red Giant, White Dwarf and Sun) describe by Newtonian and $f(\mathcal{R})$-gravity stellar structure models. The $f(\mathcal{R})$-gravity model adopted here considers $f(\mathcal{R}) = \mathcal{R} + f_2\mathcal{R}^2$. The curves in black represent the Newtonian model results, the dot-dashed curves represent the $f(\mathcal{R})$-gravity model results for $\alpha = 0.5$, the blue curves for $\alpha = 1$ and the red curves for $\alpha = 5$.

Figure 7: Effects of hydrostatic pressure in stellar structures

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3 J.-P. Macquart, et al., arXiv:2005.13161v1 [astro-ph.CO] 27 May 2020

4 'Stellar structure model in hydrostatic equilibrium in the context of f(R)-gravity', arXiv:1707.07675v2 [gr-qc] 26 Aug 2017

5 'Properties of the double β model for intracluster gas', *Monthly Notices of the Royal Astronomical Society*, Volume 318, Issue 3, November 2000, Pages 715–723, https://doi.org/10.1046/j.1365-8711.2000.03753.x

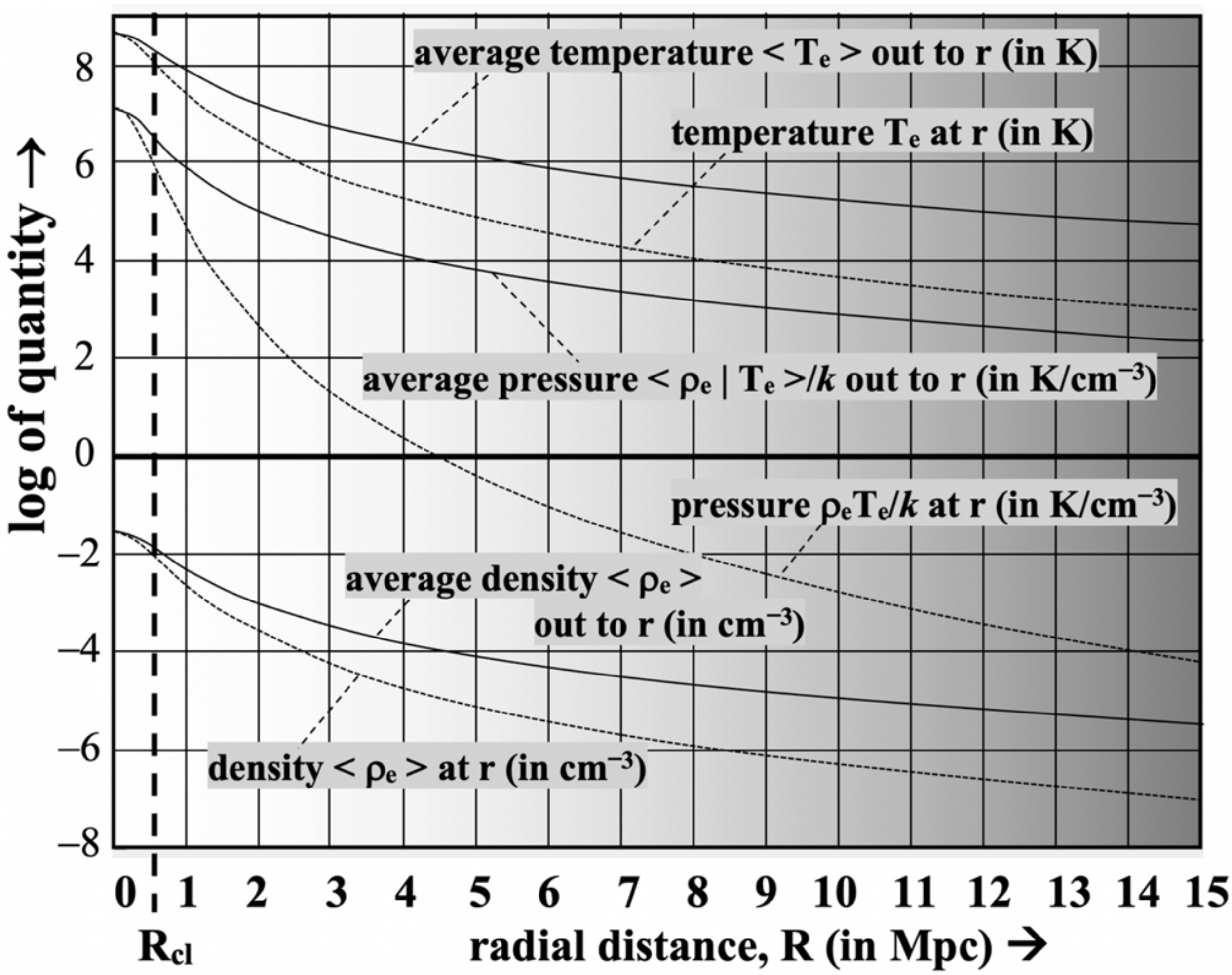

Figure 8: Typical temperature, pressure (proportional to kinetic energy density), and plasma density of intergalactic plasma as functions of the distances from the centers of galaxy cells

In figure 8, the dashed lines are the ones that correspond to the three panels in figure 7; the solid lines are averages out to a distance R of the cluster core. Cluster cells will have a total amount of mass equal to the universal average mass density times the volume of the cell. Some cells are a tenth to a hundred times cooler, less massive, and smaller than shown in figure 8. All space is tessellated with these structures, each with the same functional form of parameter distributions and the same averages as the universe. Closer to their boundaries parameter values will be less than the overall average of the universe to compensate the higher values near the center. These baryonic matter structures are discussed in another paper on this site.

The same total energy density of radiant energy leaves the conceptual surface of the average cell as the total CMB radiation energy entering the cell. The emitted outgoing radiation will be at a much higher average temperature (much of it X radiation), but it will have the same average energy density through the entire cell because the CMB energy density derives from thermal emissions from the hydrogenous plasma of just such higher temperature radiation in cells out to a great distance (redshift) but within the single scattering optical depth of these combined cells.

The kinetic energy density at every location of space is proportional to the product of the individual temperature and density values at that location as shown above. It varies considerably throughout space; the much more dense and intensely hot regions in galaxy cluster cores have substantially higher energy density than the much more vast but sparser regions at considerably lower temperature and density that surround the cluster cores. Figure 8 illustrates the extreme difference between the product of the averages $<\rho_{ion}>$ $<T_k>$ and average of the product $<\rho_{ion}\ T_k>$ as functions of the distance from the center of galaxy clusters. An average cell would have somewhat lower temperature, probably less that 10^8 K at the center and somewhat lower ion density than 0.01 cm^{-3} and would therefore be somewhat larger. The form would be similar.

So the average kinetic energy throughout the cell is not proportional to the average ion density times the average kinetic temperature but an average of their product. If the universe were a uniform plasma, then we would have:

$$E_{k\_unif} = (3/2) \text{ x } 1.38 \text{ x } 10^{-16} <\rho_{ion}> <T_k> \cong 2.0 \text{ x } 10^{-19} \text{ erg cm}^3$$

It is uniform on average at the galaxy cluster cell level, but not at the plasma ion level, so the implied kinetic energy of the nonuniform plasma in our universe is the following instead:

$$E_{k\_non\text{-}unif} = (3/2) \text{ x } 1.38 \text{ x } 10^{-16} <\rho_{ion}\ T_k> \cong 4.169 \text{ x } 10^{-13} \text{ erg cm}^3$$

This is 10^6 times larger than for a uniform plasma. The standard model's surface of last scattering is assumed to have been uniform with implied radiant energy density of $<\rho_{ion}\ T_k> \cong 2{,}014$ erg cm^3.

Next, we will address the difference between kinetic and observed radiation temperature. That radiation derives from throughout distant regions of the universe where sky cover closure occurs rather than from a closer fixed surface is not what produces a difference in emitted and observed radiation temperature. If the kinetic temperature profiles are the same for cluster cells throughout the universe, sky cover closure would not in itself alter the observed radiation temperature:

$$T_{rad\_obs} = T_{rad\_emit} \int_o^\infty \eta\, e^{-\eta r}\, dr = T_{rad\_emit} = <T_k>$$

However, with the introduction of redshift as a function of distance, $Z(r)+1= e^{H_o r}$, Wien's law must be altered because of redshift of emitted radiation from portions of the closure of sky cover:

$$T_{rad\_obs} = \int_o^\infty (T_{rad\_emit}/(Z+1))\ \eta\, e^{-\eta r}\, dr = T_{rad\_emit}\ \eta \int_o^\infty e^{-(H_o + \eta) r}\, dr = <T_k> / (1 + H_o/\eta)$$

So redshift in conjunction with sky cover does have a major affect when η is less than H_o, Hubble's constant. That is why (as in 'how') the CMB temperature differs so appreciably from the kinetic temperature of baryonic material aspects of a stationary state universe. The scattering of radiation results in the thermalization that establishes and maintains the equilibrium in any medium. But whenever there is a redshift of the associated radiation (and there is always redshift between emission and detection of radiation), it results in the separation of the observed radiation temperature and kinetic temperature of the medium itself. The amount of this separation is not only a function of the temperature and density of the medium but also of the distribution of these two parameters within representative regions of space in cluster cells that are characteristic of the universe itself. Since baryonic matter is not distributed uniformly, the approach to averaging of these parameters becomes significant as we have seen. We restate the final term in the preceding equation by substituting for $\eta = \alpha_{ion} <\rho_{ion}>$ with the ion cross section α_{ion} and average plasma ion density $<\rho_{ion}>$ as well as the currently accepted value of Hubble's constant.

$T_{rad\_obs} = \langle \rho_{ion} \rangle \langle T_k \rangle / (\langle \rho_{ion} \rangle + H_o/\alpha_{ion}) \cong 3{,}831 \langle \rho_{ion} \rangle \langle T_k \rangle$

Using accepted values of H_o and α_{ion}, the final expression obtains whenever the average $\langle \rho_{ion} \rangle$ is appreciably less than 10^{-4}. The fact that the intergalactic plasma medium is not completely uniform guarantees that the product of these averages is not equal to the average of the product of the parameter values at each location in space. The red curve from center left to bottom right in figure 9 is a plot of the equation $T_{rad\_obs} = \langle T_k \rangle / (1 + H_o/\eta)$ that illustrates the effect of sky cover on the observed radiation temperature.

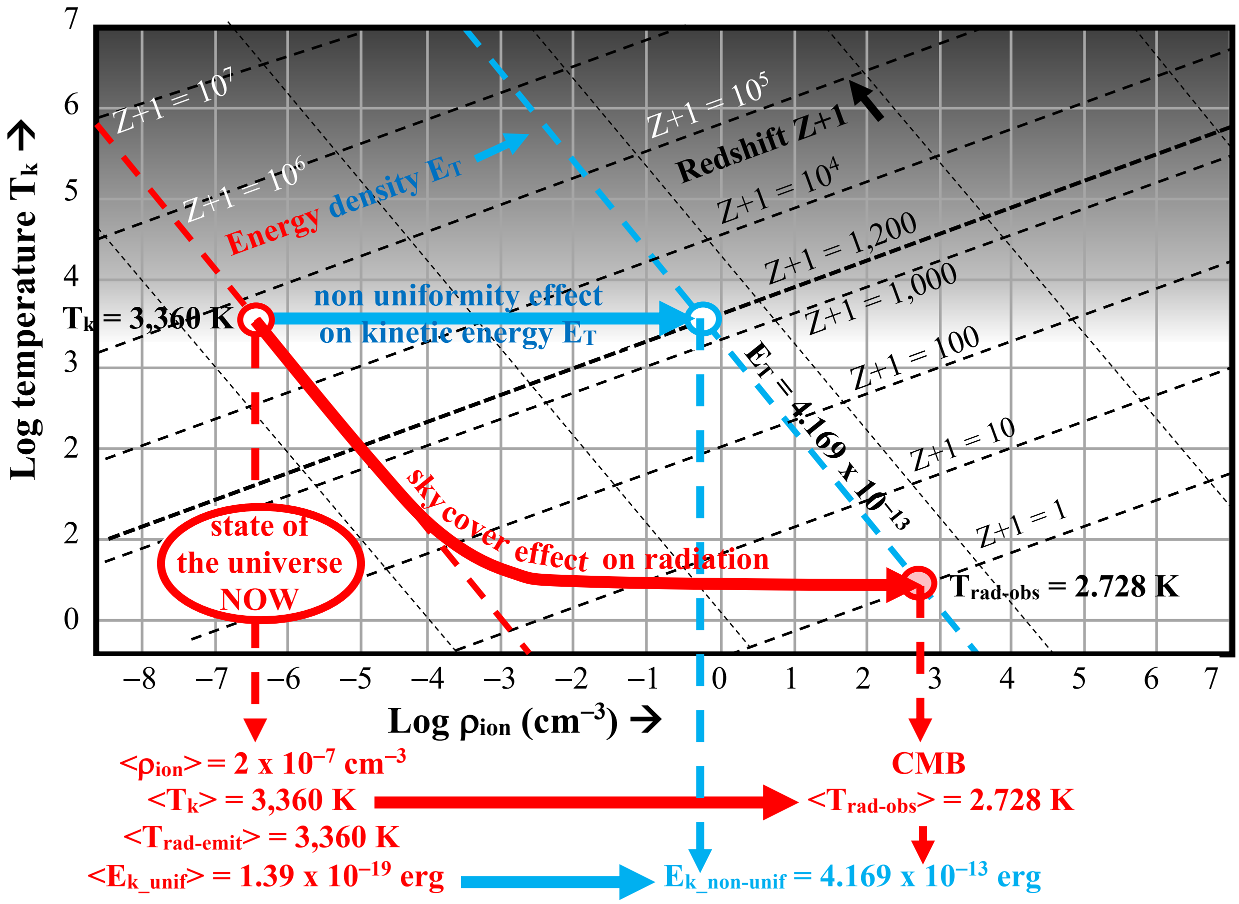

Figure 9: Alternative to the standard model explanation of cosmic background radiation

Finally we come to the third justification of this alternative to the standard cosmological model account of the CMB. It is the viability of Hubble's constant as a universal constant rather than merely the value of expansion in the 'current epoch". It is the amount of redshift incurred per unit distance – centimeters in the units we are using – averaged over all lines of sight through space. Elsewhere on this site the determination of a redshift-distance relationship to plasma pressure along a propagation path was demonstrated. Properties of the intergalactic plasma pressure that produces an equivalent of Hubble's constant for cosmological redshift averaged over twice the radial dimension of all cells through space are the following:

$H_o\, dr = (3\, k\, h\, e^2/ m_e^3\, c^5) \langle \rho_{ion}\, T_k \rangle\, dr = 3.528 \times 10^{-32} \langle \rho_{ion}\, T_k \rangle\, dr$

Given $H_o \cong 7.3 \times 10^{-29}$ cm^{-1} this implies that the product $<\rho_{ion} T_k> \cong 2{,}070$, in good agreement with the 2,014 obtained above. Although pertaining to the same quantity throughout space these two results derive from analyses with different assumptions and causal dependencies. with different assumptions and causal dependencies.

Cosmological effects have more typically been conceptualized as gravitational phenomena rather than as a thermodynamic system. Erudite debates of whether the universe should be modeled as finite or infinite, whether space is flat, convex, or concave, whether invisible matter (for which thermodynamics cannot apply) is cold or hot, etc. etc. has killed far too many trees already. We will have something to say about these issues in other papers on this site.