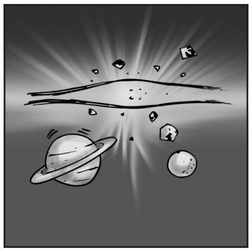

Dialogue II: Big Bang Cosmology

Has Robert Gentry Refuted Big Bang Cosmology? On Energy Conservation and Cosmic Expansion

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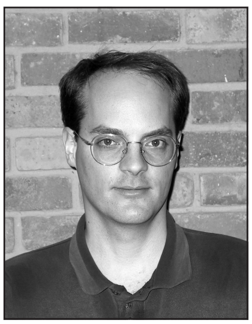
J. Brian Pitts



J. Brian Pitts

Robert Gentry has argued that Big Bang cosmology is unsatisfactory because photon redshifting violates energy conservation and because cosmic expansion ought to occur on all distance scales and so not cause redshifting. By remembering to include the gravitational energy and discussing how to account for it, I show here that Big Bang cosmology satisfies energy conservation adequately. Recognizing the merely conventional nature of Gentry's key distinction between expansion-based and Doppler-based redshifts reconciles the allegedly suspiciously conflicting explanations. A survey of the work matching Big Bang exterior solutions to local inhomogeneities gives plausible support for traditional claims that cosmic expansion has a negligible effect on small scales. Thus both of Gentry's conclusions are unsupported by his arguments. I suggest that Big Bang cosmology is neither very harmful nor very helpful for Christian faith, but it is a serviceable physical theory.

I refute [Gentry's] energy conservation objection … and show his objection to the expansion of the universe to be ill-founded.

Physicist Robert Gentry has written (or co-authored) a number of articles critical of Big Bang cosmology on physical grounds, arguing instead for an alternate "New Redshift Interpretation," "GENESIS" model, or "Cosmic Center Universe."[1] This model is based on the static Einstein metric, but has a universal center, to which Earth is fairly close. Steve Carlip and Ryan Scranton have partially addressed Gentry's criticisms of the Big Bang and have posed objections to his alternative model.[2] Here I confine my attention to two of Gentry's scientific criticisms of the Big Bang pertaining to general relativity. He asserts that Big Bang cosmology violates energy conservation due to photon redshifting energy loss and that the expansion of the universe is a muddled concept. I refute his energy conservation objection, noting (as did Carlip and Scranton) that Gentry neglects the energy of the gravitational field itself. He also neglects most of the relevant literature. I then show his objection to the expansion of the universe to be ill-founded. If there are theological or other objections to Big Bang cosmology, one should not be misled into thinking that these two physical objections also have force.[3]

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Cosmological Energy Nonconservation?

Gentry asserts that the cosmic expansion in standard Big Bang cosmology violates energy conservation, because the photons of light lose energy as they get redshifted. While it is true that the photons lose energy, the energy is transferred to the gravitational field. In a world containing gravity and electromagnetism, one does not expect electromagnetic energy to be conserved by itself, but only the sum of gravitational and electromagnetic energy. Gentry, however, neglects the energy of the gravitational field, and then worries that the electromagnetic energy alone is not conserved. Steve Carlip and Ryan Scranton pointed out this error several years ago,[4] but Gentry persists in this claim.[5]

Gravitational energy is a messy subject, as the literature shows from the 1910s to the present. The problem is not the lack of expressions for a distribution of gravitational energy, but the abundance of different ones: there are many such expressions which differ, but which have comparably good claims on being accepted. Mathematical transformations that make no physical difference, turn out to make a mathematical difference in the localization of gravitational energy to regions in spacetime. In this literature—which Gentry hardly notices—one finds many approaches, including pseudotensors,[6] orthonormal tetrads,[7] background metrics,[8] quasilocal expressions,[9] contingently preferred vector fields,[10] Killing vector fields,[11] spinor formulations,[12] superenergy tensors,[13] and Hamiltonian methods.[14] While none of these approaches is fully satisfactory in describing the local distribution of gravitational energy at each point in space at a moment in time, it should be emphasized that many give satisfactory answers for the *total* energy from all points in space together. (The local conservation laws are true, but they possess an undesirable element of conventionality.) The localization problem seems to arise due to the difficulty of finding an intrinsic description of the physics, free of physically insignificant "gauge" artifacts of the labeling with redundant variables. A suitably intrinsic physical description in terms of the true degrees of freedom (two at each point in space), as sought by Luca Lusanna and Massimo Pauri,[15] might help, but the search is technically daunting and results appear to involve gauge-variant elements after all. Even so, the total energy and its conservation can be discussed securely.

For energy conservation to be violated, there must be a well-defined value of the total energy in all space at one moment, including the contributions from both the gravitational and electromagnetic fields, and this value must change over time. Standard Robertson-Walker Big Bang cosmological models are "homogeneous": exactly the same situation exists at every place at a given moment of time. In the standard spatially flat and negatively curved cases—which are Euclidean and "open," respectively (assuming the usual topologies)—the total volume of space is infinite. But in the positively curved ("closed") case, the volume is finite, though there is no boundary surface. For the first two cases, it follows that if a finite region of space has nonzero energy, then the whole of infinite space will have infinite energy. But if the total energy is infinite today, and infinite tomorrow, what does it mean to say that the energy tomorrow is less than the energy today? Suppose that Euclidean three-dimensional space is filled with one inch by one inch by one inch boxes, each of which contains $10.00 today. It follows that the total amount of money today is infinite. If tomorrow each box contains $7.50, then the money tomorrow will be infinite. If each box has $6.25 two days from now, the money will still be infinite. It simply does not make sense to say that the total amount of money in the world is decreasing, because there is always infinitely much money present (and the infinities have the same cardinality). By the same reasoning, assuming that nonzero energy density exists at each point in space, the total energy will be infinite, and one cannot speak of a change in its value. In that case, Gentry's objection collapses because global energy conservation is meaningless.

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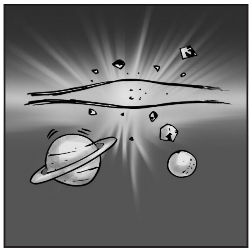
In defense of his claim of energy nonconservation, Gentry cites a standard work by the eminent cosmologist P. James E. Peebles, but in vain. It reads:

> The resolution of this apparent paradox [about the energy loss of photons] is that while energy conservation is a good local concept … and can be defined more generally in the special case of an isolated system in asymptotically flat space, there is not a general global energy conservation law in general relativity.[16]

Gentry omits the crucial line about isolated systems. Peebles doubts that a global energy conservation law exists because its definition requires adding up the energy throughout all space, and that addition can fail to give a finite answer, if energy is present throughout an infinite volume. Just this problem can arise in Big Bang cosmology, because the homogeneity of the universe implies that the matter content is not confined to only one portion of space. For the flat or negatively curved models, the infinite spatial volume ensures that the total energy in all space is infinite—unless the energy density at each point is zero, a possibility that perhaps did not occur to Peebles. Peebles is not arbitrarily waiving energy conservation as a physical principle, but evidently recognizing mathematical facts about divergent integrals. Without actually calculating the energy density at each point in space, Peebles might anticipate (if perhaps incorrectly) that the energy conservation



principle is meaningless. This sort of mathematical worry is not a special feature of gravitation. An analogous problem with charge (rather than energy) conservation would arise for electromagnetism if matter with a net charge were present throughout infinite space, though this mathematical possibility is clearly unlike the actual world and so rarely is discussed.

As it turns out, the energy density in Robertson-Walker models has been calculated in a number of cases.[17] In several approaches, the gravitational energy density just cancels the matter energy density to give zero total energy density. Adding up the total energy in all space, one gets zero total energy. Many calculations of the energy of a flat Big Bang model have yielded zero energy. A number of calculations for the positively curved case also give zero energy (with one exception whose meaning is unclear[18]). The negatively curved case has not been considered as often, though Banerjee and Sen find an infinite answer, while Cooperstock and Israelit, and Cooperstock and Faraoni, favor zero total energy. Finally, T. Vargas Auccalla finds zero total energy in all three cases.[19] So when one does calculations of the sort that Gentry did not, it generally turns out that either the total energy is infinite, or it is zero. (The ambiguities might be connected with different choices of boundary terms, as will appear briefly below. My purpose does not require deciding which answer is correct.) In the first case, the question of energy conservation is meaningless, whereas in the second case, energy conservation is satisfied because the energy, being always zero, does not change over time. Either way, the nonconservation objection fails.

The Hamiltonian (also called "canonical") formulation of general relativity, the standard theory of gravity, … help[s] to explain why energy can reasonably have a value of zero.

Why Energy Might Be Zero in General Relativity

A few remarks on the Hamiltonian (also called "canonical") formulation of general relativity, the standard theory of gravity, will help to explain why energy can reasonably have a value of zero. In mechanics, the evolution of a system over time can be derived from a Hamiltonian function, which is basically a function of the coordinates and momenta of the parts of the system. In field theories, the values of the field at each point serve as (generalized) coordinates, while the "canonical momenta" are related, at least in simple cases, to the rate of change of the fields over time. The Hamiltonian H, which generally is equal to the energy E of the system, can be expressed as the integral of a Hamiltonian density $\mathcal{H}(x)$ over all of space at one moment:

$$E = H = \int d^3x\ \mathcal{H}(x).$$

The Hamiltonian density $\mathcal{H}(x)$ is not fully determined by the equations of motion, but typically is defined up to the addition of a divergence term. In more complicated theories, like Maxwell's electromagnetism, not all of the momenta are related to the fields' rate of change. This fact takes one into the realm of constrained Hamiltonian dynamics,[20] in which one deals with physical quantities, called constraints, which have the value of zero when the equations of motion are satisfied. General relativity is like electromagnetism in this respect, only much more so. Both theories possess "gauge freedom," implying that the typical description involves some redundant variables. The redundancy implies that some of the variables can be changed without making any physical difference. In general relativity, the Hamiltonian is a sum of constraints and a divergence term:

$$H = \int d^3x\, [N(x)\mathcal{H}_0(x) + \beta^i(x)\mathcal{H}_i(x) + \partial_i f^i(x)].$$

Using the divergence theorem, one rewrites the volume integral of the spatial divergence as a surface integral over the boundary of the volume:

$$H = \int d^3x\ [N(x)\mathcal{H}_0(x) + \beta^i(x)\mathcal{H}_i(x)] + \int dS_i\ f^i.$$

When the Hamiltonian H is differentiated with respect to the lapse function N(x) and shift vector field $\beta^i(x)$, their coefficients, the constraints $\mathcal{H}_0(x)$ and $\mathcal{H}_i(x)$, must equal 0. The quantity $\mathcal{H}_0(x)$ looks roughly like an energy density for matter plus one for gravitation, but the term for gravitation can be negative, canceling positive matter energy density to give an overall value of zero. It follows that the value of the Hamiltonian, when the constraints are zero, is just the boundary term

$$H = \int dS_i\ f^i.$$

Thus the energy is zero, unless the boundary term gives a nonzero value. The proper choice for the function f^i depends on the boundary conditions assumed for the fields.[21] It therefore is not too surprising if the energy E is in fact 0. Obviously if E = 0 for all time, then dE/dt = 0, so energy is conserved. If E is some finite number, it retains that value over time. For spatially closed models, there is no boundary, so E = 0.[22]

The Expansion of the Universe

Gentry asks: "How, if the whole universe and everything in it is expanding, can one observe the expansion?" This is a reasonable question. The short answer is that not everything in the universe is expanding. The homogeneous Robertson-Walker solution to Einstein's field equations, though a good approximation on large distance scales, does not apply on small scales, so the cosmic expansion does not either. This question has been addressed in some mathematical detail.[23] Gentry's assertion that GPS measurements support some solution other than the Robertson-Walker model is therefore not news. The long answer is more mathematical: one matches the Schwarzschild or Kerr solution at small distance scales to a Robertson-Walker solution on larger scales, imposing suitable junction conditions at the boundary. Here, as elsewhere in modern physics, one should trust the mathematics more than inherently imprecise English translations such as "the universe is expanding."

Gentry also discusses whether the cosmological redshifts are due to the motion of stars, or due to expansion of space between the stars, and finds various sources disagreeing. To him, this disagreement signals a fundamental problem casting doubt on the model, but the distinction just has no deep meaning in general relativity. This lack of a robust distinction is a facet of the difficult philosophical issues regarding absolute vs. relational theories of space and motion, individuation of events, and the like, which surround general relativity.[24] It is a useful *convention* to speak of (idealized) stars at rest in an expanding space via the mathematics of comoving coordinates to identify spatial points over time. The spacetime metric for a flat (for simplicity) Robertson-Walker model, using the standard comoving spatial spherical coordinates (and choosing a time coordinate that measures proper time for the preferred "fundamental observers," such as the idealized stars) is $ds^2 = -dt^2 + a(t)^2\,(dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2))$.[25]

A fundamental observer will correspond to fixed spatial coordinates (r, θ, φ), and thus can reasonably be called "at rest." One would reasonably describe the redshift as due to cosmic expansion. However, one could use noncomoving coordinates instead; one might then speak of moving stars. Defining a noncomoving radial coordinate ρ by $\rho = r\,a(t)$, one re-expresses the line element above as

$$ds^2 = (\mathring{a}^2\rho^2a^{-2} - 1)\, dt^2 - 2\mathring{a}\rho a^{-1} dt\, d\rho + d\rho^2 + \rho^2\, (d\theta^2 + \sin^2\theta\, d\varphi^2),$$

where $\mathring{a}$ is the time derivative of $a(t)$. A fundamental observer, satisfying $r(t) = b$ (and having some fixed values of θ and φ) for some constant b in the comoving coordinate system, is described by $\rho(t) = b\,a(t)$, giving coordinate velocity $d\rho/dt = b\mathring{a}$, which is nonzero and directly proportional to its distance from the (arbitrarily chosen) coordinate origin $r = \rho = 0$. One might now speak of a generalized Doppler shift due to the outward radial motion of the stars from the "center" $\rho = 0$. Neither of these descriptions is truer than the other. At most, one is more convenient than the other, or more commonly used. Given the conventional, as opposed to factual, nature of the mathematical distinction, it is neither surprising nor worrisome that two different translations into English might result. A similar situation could arise if a Greek text has a meaning which is clear to scholars, but which is difficult to render into English in a concise way: divergent English renderings would not indicate a problem in the Greek.

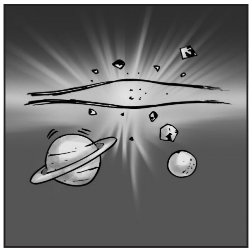
Gentry also discusses whether the cosmological redshifts are due to the motion of stars, or due to expansion of space between the stars, and finds various sources disagreeing …. Given the conventional, as opposed to factual, nature of the mathematical distinction, it is neither surprising nor worrisome that two different translations into English might result.

Recently Andrew S. Repp has also provided a refutation of Gentry's critique of the standard explanation of the cosmological redshift.[26] As Repp observes, standard Big Bang cosmology does not need to claim that redshifting ceases during emission and absorption, *pace* Gentry, because the brief time taken by emission and absorption implies that such redshifting will be negligible.

Although Gentry has not provided a good argument for the existence of a center of the universe, the question is interesting. Though Big Bang cosmology in its usual form lacks a center, one can posit a center if one wishes.[27] Other inhomogeneous cosmological models[28] are worth investigating, too. Christians have little a priori reason to assume that our location in the universe is not special, though it might well turn out a posteriori not to be so. If our physical situation is special in any sense, it might be in a sense more sophisticated than a mere central location.[29]

Big Bang Cosmology and Christianity

Attitudes of Christians toward Big Bang cosmology range from enthusiasm due to its alleged apologetic value for creation *ex nihilo* and hence theism on the one hand, to rejection due to its allegedly atheistic character on the other



hand. Intermediate positions are also possible. For example, perhaps Big Bang cosmology is compatible with Christian truth claims just because science and religion are basically independent subjects. Or perhaps Big Bang cosmology is compatible with theism and core Christian doctrines such as the Trinity and the Incarnation, but incompatible with the details of biblical teaching which, however minor their intrinsic importance, affect the credibility of the sources for core Christian doctrines. Two important questions to consider are whether Big Bang cosmology is (approximately) empirically adequate, and, if so, is it (approximately) true? It is difficult to ascertain precisely what attitude Gentry takes toward Big Bang cosmology theologically. His well-known defense of a young earth suggests that he takes Big Bang cosmology to be at least inconsistent with the details of biblical teaching. But given that he takes Big Bang cosmology to be empirically inadequate and thus demonstrably false even apart from Scripture's details, he need not address its compatibility with Christianity carefully.

I suggest that making minor modifications to [Big Bang cosmology] in order to remove whatever tension it might have with Christian faith would be vastly preferable to a blunt dismissal of a framework that renders intelligible a great mass of data.

If the arguments presented above tend to vindicate the belief that Big Bang cosmology fits the data quite well, still the question of its compatibility with Christian faith remains. I can hardly do justice to this much discussed[30] issue here, and will be content merely to advise against the extreme views of regarding Big Bang cosmology as deeply helpful or deeply harmful to Christian belief. *Pace* those who deploy the Big Bang as a major apologetic tool, I recall that the singularity, which allegedly corresponds to the creation event (which correspondence is itself a difficult claim), is inferred by extrapolating general relativity far beyond its plausible realm of validity. Thus Robert Wald writes:

> Of course, at the extreme conditions very near the big bang singularity one expects that quantum effects will become important, and the predictions of classical general relativity are expected to break down.[31]

A possible historical parallel from a century ago is the classical Rayleigh-Jeans law for blackbody radiation. This law holds that radiated power increases with frequency. Integrating over all frequencies implies that a blackbody radiates infinite power, an absurdity called the "ultraviolet catastrophe." (The Rayleigh-Jeans law was known not to tell the whole story even empirically, but it was fairly well motivated.)

Max Planck's solution to this theoretical problem helped lead to modern quantum mechanics. It seems plausible that the arrival of a good theory of quantum gravity will similarly remove the infinite curvature at the Big Bang in favor of a model defined for arbitrarily remote past times, and with the singularity will disappear an argument used in Christian apologetics. Worries about God-of-the-gaps arguments can be overdone, as several people have argued recently.[32] Yet the particular example of the Big Bang singularity does look like the sort of gap that physics should and will overcome. (Teleological arguments involving fine tuning are another matter.) Already there exist interesting results tending toward the removal of the singularity.[33] The views of Narlikar are instructive.[34] *Pace* those who reject the Big Bang as atheistic, I suggest that making minor modifications to it in order to remove whatever tension it might have with Christian faith would be vastly preferable to a blunt dismissal of a framework that renders intelligible a great mass of data. Such a dismissal would risk reducing astronomy to a pile of brute facts, an outcome to be avoided as far as possible. ◈

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