Causality and Duality in Cosmology

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Abstract

Context. A physical explanation for dark energy Λ is proposed by revisiting the subject of causality and duality in cosmology. Duality is the observation that the density in local regions is increasing even as the average density at non-local or cosmic scales is decreasing. "Local" means distances less than the center-to-center spacing of galaxy clusters, R_i; "non-local" means distances greater than R_i.

Aims. It is argued that the Friedmann solution is causally incomplete by two parameters: R_i, (denoting "inter-cluster" distance and twice the zero gravity radius R_{ZG}) and energy coupling η ($0 < \eta < 1$). Both factors describe the dualistic nature of gravitational systems. The energy being coupled is the radiant energy given off by the dense regions as they grow denser; the coupling is its conversion to gravitational energy or the expansion of space beyond R_i as the cosmos grows less dense.

Method. The minimum number of causal inputs required to describe gravitational systems is considered for both finite and infinite (cosmological) models.

Results. Modeling a dualistic gravitational system in general requires a minimum of four causal inputs, including R_i and η, whereas the Friedmann solution sans Λ uses only two: density ρ and expansion rate H (not including pressure, which is inconsequential). Because R_i and η otherwise do not appear in the standard model, it is suggested that Λ represents them in the relationship $\Lambda = \eta/R_i^2$. This requires η of the order 10^{-6}. Distance R_i is the dividing line between collapse and expansion in the dualistic model; therefore, there is no critical density Ω. Acceleration of the expansion is expected.

Conclusions. The universe cannot be modeled gravitationally with fewer than four causal parameters. The cosmological constant is the only place in the Friedmann solution for the parameters R_i and η to be "hiding"; hence, the inference that Λ represents them. If so, local contraction is the cause of cosmic expansion. To clarify the situation, a dualistic solution is needed to Einstein's field equations for general relativity that explicitly includes R_i and η, as described in the Conclusions section.

Keywords: cosmological parameters; cosmology; dark energy; gravitation

1. INTRODUCTION

The discovery that the Hubble expansion is accelerating was not anticipated and forced the re-introduction of Einstein's cosmological constant Λ or dark energy into the standard model (Perlmutter et al. 1999; Riess et al. 1998). Enigmatically, Λ appears only in cosmology. Dualistic models will be used to argue that a term like Λ must be included, and Λ may in fact be this missing term.

Duality means a twofold nature, especially a contradictory one, as in the wave/particle duality of quantum mechanics. With respect to gravity, it simply means that complex systems cannot be described monolithically as either contracting or expanding. Both processes occur simultaneously and must be included in a complete description.

Conventionally, the universe is considered to be a uniform fluid of density ρ. Here, the universe is divided into a collection of clumping regions of mass M separated by a distance R_i from each other (Teerikorpi and Chernin, 2012). Furthermore, the rate of collapse at distances less than R_i is measured not in terms of distance but in terms of energy. This is done because energy is the only observable we have of local collapse. Expansion, on the other hand, is observed directly as a rate of change, that is, $\mathrm{d}r/\mathrm{d}t = Hr$, where H is Hubble's constant.

2. CAUSAL PARAMETER METHOD

The inputs to a problem are theory invariant: the same orbital parameters are used to calculate the precession of Mercury's orbit whether it is done using Newtonian gravity or general relativity (GR). Therefore, the cosmological model is analyzed in terms of causal inputs.

In addition to gravity's attractive force, tidal, centripetal, radiant, thermodynamic, and electromagnetic forces come into play in complex systems, causing some parts to contract while others expand. The contracting and expanding parts generally interact, and a complete model must account for the interaction. It is argued that the parameters R_i (the average distance between galaxy clusters) and η (the coupling efficiency of local contraction to cosmic expansion) are required for a complex model to be minimally complete. This is done by examining both a finite and an infinite dualistic system and concluding that at least four parameters must be specified in order to obtain a unique solution. It is argued that the Friedmann solution, without the cosmological constant ($\Lambda = 0$), effectively uses only two parameters, the density and expansion rate.

2.1. Parameters in Finite Dualistic Systems

Note: In the discussion of parameters, R, η, and H are used here in both general and specific terms. In general terms, R refers to the expanding diameter of any dualistic system, η refers to the energy coupling in that system, and H refers to the resulting expansion. In specific terms, R_i is the cosmic inter-cluster scale, η represents cosmic coupling, and H is Hubble's constant.

Einstein included the thermodynamic behavior of radiation in his equations but apparently not the interaction of radiation with matter (represented by η). Lambda appears as a catch-all term in GR and has the same effect in the cosmological model that η and R have in a finite system. That is, η and R typically combine in such a way that the expansion of the system accelerates. This will be illustrated below.

Expressing the static situation in a two-body problem requires three variables: the masses of the two objects (m_1, m_2) and the distance between them r. Employing the cosmological principle (CP), which is essentially a set of simplifying assumptions, we consider only homogeneous problems and set $m_1 = m_2 = M$.

That is, we reduce the system to two variables, *M* and *r*. To maintain the CP, we imagine them in uniform circular motion about their center-of-gravity. Should the system change, we call the rate of change *h*, which is expressed in terms of distance as $dr/dt = hr$.

Next, we consider more complex systems. Figure 1 illustrates the simplest complex system that satisfies the CP. Two pairs of bodies orbit a common center of gravity, and each pair in turn orbits a moving center. Because the close pairs are orbiting in the same direction as the wide pair, tidal interaction causes transfer of angular momentum from the close pairs to the wide pair. Hence, the close pairs spiral in, and the wide pair spirals out; that is, dualistic behavior occurs. The dense parts are contracting, whereas the less dense part is expanding. More significantly, the contraction drives or powers the expansion. The bottom panel shows the system some time later.

What is the minimum number of parameters required to model such a system? Consider each body to have a mass of 0.5 *M*; call the distance between the wide pair, *R*, and that between the close pairs, *r*; call the expansion rate of the larger system, *H*, and the contraction rate of the close pairs, *h*. In the idealized case, conservation of energy can be used to tie the expansion rate to the contraction rate, which in turn can be used to determine *r*. Therefore, only three parameters completely specify a solution: *M*, *R*, and *H*.

In all non-ideal systems, however, energy coupling is less than 100% efficient. Owing to frictional losses and weak interactions with distant bodies, the energy lost by the close pairs spiraling in will be greater than the energy gained by the wide pair spiraling out. Therefore, in the real world, we must include a fourth parameter η that specifies the coupling efficiency of energy lost to energy gained. Therefore, the simplest real-world dualistic system requires a minimum of four parameters: *M*, *R*, *H*, and η.

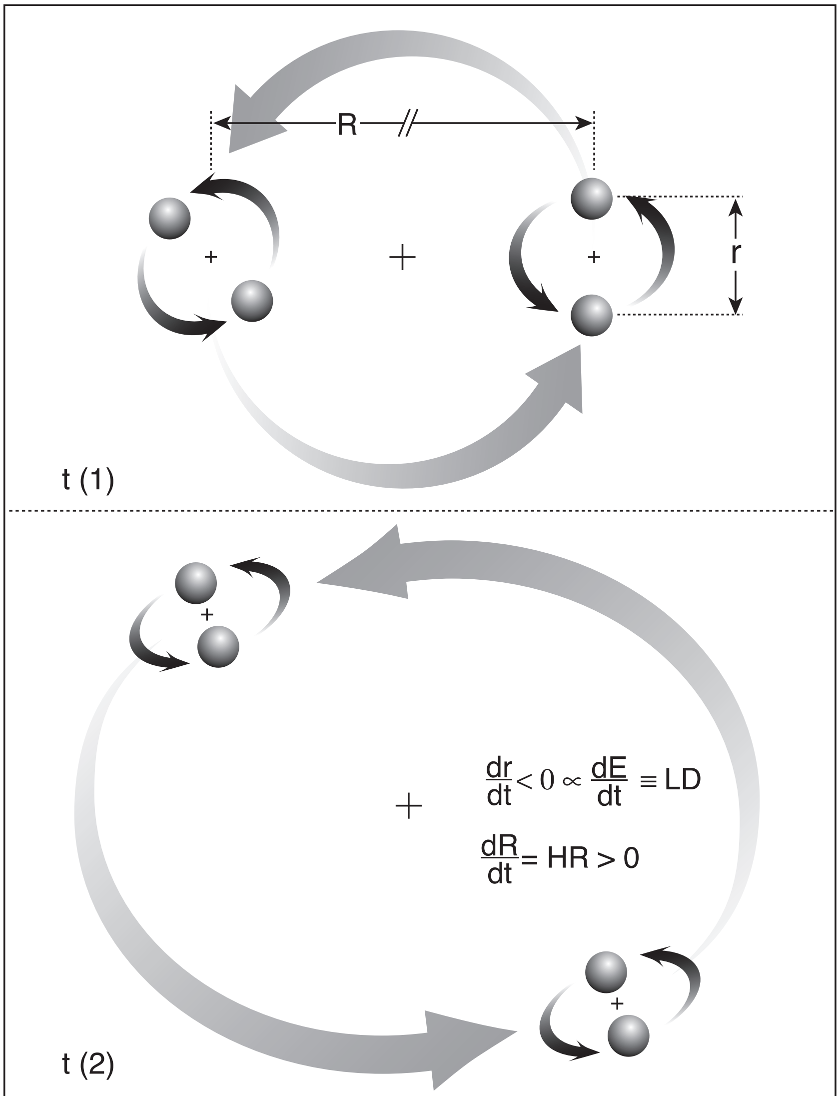

Figure 1. Simplest gravitational system incorporating duality. Each body has a mass of 0.5M; distance between the wide pairs is R; distance between the close pairs is r. The close pairs are spiraling inwards, losing energy (E) at a rate defined as the system's luminosity density (LD). Through tidal interactions, a fraction (η) of LD is coupled to the wider pair, which therefore expands at a rate H. The balance of the energy (1-η) is lost as heat through internal friction, or through weak interactions with distant bodies. The drawing is not to scale, that is, R>>r. The bottom panel shows the system at a later time.

2.2. Behavior of Finite Dualistic Systems

Although the system pictured in Figure 1 would become "hotter" with time—the close pairs would spiral together more and more rapidly—we consider a general case that may exhibit a limited rate of decay for some reason, such that the rate of energy loss is constant. If η is also constant, the wider parts will gain energy at a constant rate. Work in a gravitational system is inversely proportional to distance; therefore, if energy is input to the wider part at a constant rate, dR/dt increases with R. That is, the rate of expansion accelerates.

Such behavior is exhibited by the Earth–Moon system, although the source of energy is purely rotational. Earth's rotation is coupled to the moon through tidal interactions, as in Figure 1. Because Earth is so much more massive than the Moon and because it spins considerably faster than the Moon orbits it, rotational energy is converted to gravitational energy at an approximately constant rate. Therefore, the rate of expansion of the system—3×10^{-18} s^{-1} (3 cm yr^{-1})—is accelerating (Elkins-Tanton 2006, p. 127). Billions of years ago, when the Moon was in a steeper part of Earth's gravity well, the expansion was slower.

2.3 Parameters in Infinite Dualistic System (the Universe)

The Friedmann solution includes two independent equations for modeling a homogeneous, isotropic universe (Friedmann 1922). These model the universe using five parameters: the expansion rate H, density ρ, pressure p, solution set k, and dark energy Λ.

The pressure, however, is divided by c^2 and added to the density term, acting as little more than a small correction. It can be ignored in the present era. In addition, k is shorthand for three broad sets of solutions and takes a value of 1, -1, or 0; thus, it is not a true variable. In the solution for a flat universe, it is zero. Our universe appears flat (Tegmark et al. 2004), so the term with k disappears, and only three parameters remain: H, ρ, and Λ. Before the observations of Perlmutter et al. (1999) and Reiss et al. (1998) were published, however, Λ had been assumed to have a value of zero, and the standard model was expressed using only two fundamental parameters: expansion rate and density.

As we have seen, a finite gravitational system that is dynamic and dualistic requires a minimum of three parameters to specify it ideally and four in the real world. Because the universe is dynamic, dualistic, and real, we assume that modeling it also requires a minimum of four parameters.

Such a minimally specified model is illustrated in Figure 2. Each cube has a dimension of R_i, the distance beyond which the Hubble relation ($v = Hr$) is valid, and contains on order of 10^{69} baryons (only 24 shown, not to scale) plus lighter quanta

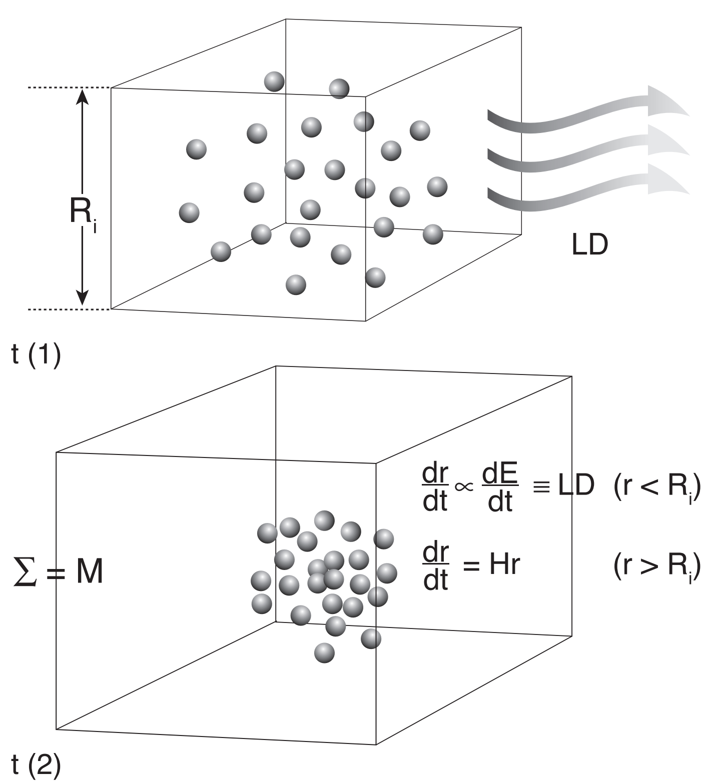

Figure 2. Simplest infinite gravitational system incorporating duality. The cube repeats in all directions to infinity; outlines are for reference only. Mass and energy in each cube sum to M; distance between centers is R_i. At distances of $r < R_i$ (within each cube), matter is clumping at a rate given by LD, which includes all forms of radiation. As in Figure 1, a fraction η of LD is coupled to the rest of the universe, which expands at the Hubble rate H, for $r > R_i$. The bottom panel shows the model at a later time.

that sum to mass M. An infinite number of particles is suggested by imagining that the cube repeats in all directions to infinity, as shown in Figure 3 (Ledinsky 1998). The pressure *within* each clump is always non-zero and can be arbitrarily high in local regions up to black hole formation. The matter pressure between clumps is explicitly zero, however, given that the model presupposes divisions between regions; non-relativistic particles are bound to the nearest clump, rendering matter pressure effectively zero between clumps. Relativistic particles are counted as radiation, and only radiation interacts with clumps beyond R_i. The top and bottom panels in Figures 2 and 3 represent early and later times, respectively; the larger system is expanding at the Hubble rate of H.

t (1)

t (2)

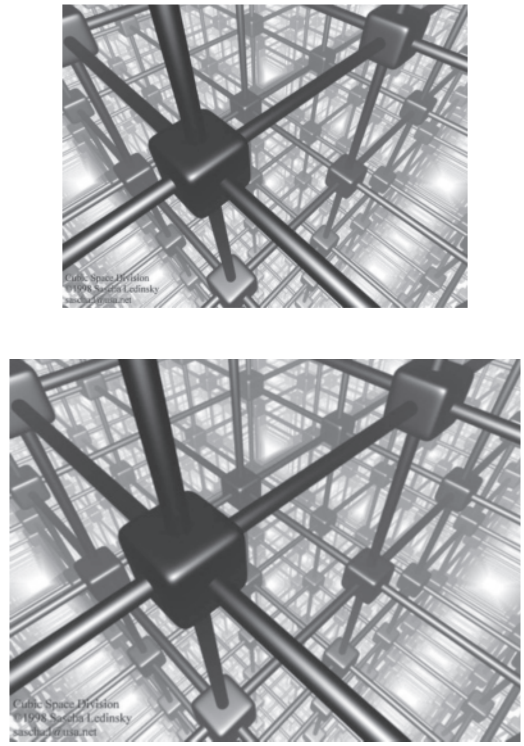

Figure 3. Artist's impression of infinity (Ledinsky, 1998, public domain).

As in Figure 1, the close masses become closer. For completeness, we consider all forms of energy in which "closer" implies lower energy: gravitational, electromagnetic, and nuclear. Conservation of angular momentum and electromagnetic forces prevent the clump from collapsing quickly. Nonetheless, the total radiant power of the clump or its luminosity density LD represents the net rate of local contraction in terms of energy. A fraction of LD, η, is coupled to the expansion of the larger system. Thus, like the finite system in Figure 1, this model requires a minimum of four parameters to describe it: the mass M of the clumps; the distance R_i between clumps; the rate of clumping LD; and the coupling of LD to non-local matter, η. Since η is not observable, an unspecified relationship is presumed to exist that yields H, that is, $H = f(M, R_i, LD, \eta)$. Thus, the model is *causally* specified by M, R_i, LD, and η, but H, M, R_i, and η are sufficient to uniquely characterize it.

3 RESULTS

Because the Friedmann solution with Λ "works," we ask how the minimum of four parameters in the causal analysis transpose into the accepted model using only three. The density ρ is M/R_i^3, but this ratio alone is insufficient to uniquely specify either one; hence, R_i or M must appear again. That leaves η and a second use of R_i or M. Dimensionally, the only way to combine them to yield Λ is η/R_i^2. Table 1 lists the inference explicitly.

Table 1

Three Friedmann Model Inputs from Four Duality Inputs

Friedmann Model Inputs (H, ρ, Λ)	**Dualistic Inputs (H, M, R_i, η)**
Expansion rate H	H
Density ρ	M/R_i^3
Dark energy Λ	η/R_i^2

4. DISCUSSION

Referring to Figure 1, if we define the system's luminosity density as the energy lost by the close pairs, a causal relation clearly exists: $H = f(M, R, LD, \eta)$. Furthermore, the expansion rate H is a measure of the system's rate of change and not its age. Duality posits that the expansion of the universe is likewise dependent on the same four causal parameters. The implication is that Hubble's constant H is a measure of the rate of change in the universe and not its age.

Additionally, the idea of a "critical density" Ω that determines whether the expansion will continue ($\Omega < 1$) or eventually turn to collapse ($\Omega > 1$) becomes specious. Both processes, contraction and expansion, are incorporated into the dualistic model from the beginning.

Finally, from Table 1, it can be seen that as the universe expands, density dilutes more quickly than dark energy. Therefore, the duality model also concludes that regardless of initial conditions, dark energy will eventually dominate the universe.

These conclusions are based on considerations of cause and effect and not a mathematical proof. Confirming or refuting them requires solving Einstein's field equations with duality explicitly incorporated into the model, that is, with M, R_i, LD, and η as boundary conditions. The prediction is that such a solution will resemble Friedmann's, with η/R_i^2 replacing Λ. Furthermore, such a solution can be expected to yield an H that decreases in time as LD decays, which can then be compared to observations.

Perlmutter and Reiss reported a Λ of magnitude 10^{-52} m^{-2}. Teerikorpi and Chernin (2012) estimated R_{ZG} to be 1.3 Mpc, giving an R_i of 7.8 10^{22} m; therefore, accounting for dark energy in the dualistic model requires an η of the order 10^{-6} or about 1 part per million.

4. CONCLUSION

The standard model has grown in complexity since 1922. For example, Tegmark et al. (2004) assessed six cosmological parameters using satellite and telescope data. Even so, the measures of duality, R_i, LD, and η, are still missing. In practice, yet another parameter may be required to describe the degree of clumping. Nonetheless, a solution to Einstein's GR field equations that expressly incorporates duality, i.e., with M, R_i, LD, and η as boundary conditions, is needed. Such a solution would either falsify the duality hypothesis that $\Lambda = \eta/R_i^2$ or confirm it as a physical explanation for the cosmological constant.

References

1. Blanton, M. R., Hogg, D. W., and Bahcall, N. A. 2003, *ApJ*, 592, 819
2. Fadda, D., Girardi, M., Giuricin, G., et al. 1996, *ApJ*, 473, 670
3. Elkins-Tanton, L. T. 2006, The Earth & Moon (Chelsea House Pub.)
4. Friedmann, A. 1922, *Z. Phys.*, 10(1), 377
5. Ledinsky, S., 1998 www.worldofescher.com/gallery/internet/cubic.html
6. Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, *ApJ*, 517, 565
7. Riess, A., Filippenko, A., Challis, P., et al. 1998, *AJ*, 116, 1009
8. Tegmark, M., Strauss, M., Blanton, M., et al. 2004, *Phys. Rev. D*, 69, 103501
9. Teerikorpi, P. and Chernin, A. D. 2012, *A&A*