RELATIONAL SELF-SIMILAR SPACE-TIME COSMOLOGY REVISITED

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ABSTRACT

A 'Relational, Self-Similar' cosmological model based on a contextual relation between local and non-local space-time dimensions was reported by the author in 2000. That model was based on a radially expanding 'Minkowski-space' geometry for general space-time, superficially similar to E.A. Milne's 'toy' model of the 1930's (Milne, 1948), in that its geometry is based on Special Relativity and the Hubble expansion alone, irrespective of general gravitation. Cosmologists have recently noted a "surprising" agreement with Milne's mass-less model and evidence for expansion at or slightly above the critical universe mass density (Omega = 1). An explanation for this agreement can be found in the self-similar, dynamically expanding geometry of the relational cosmological model discussed here, which unlike Milne's model, treats space-time expansion as an intrinsic scale change resulting from relationship between local and non-local realities; rather than a 'kinematic' movement through pre-existing space as Milne imagined. The internal geometry of this cosmology is a complex, self similar relation between a non-local domain represented by dimensions in an imaginary number domain, and locally measurable space-time, as a real number domain. The effect of general mass-density (gravitation and the General Theory of Relativity) was not resolved in the earlier model, but is now interpreted as a scale change under which the basic self-similar geometry remains invariant with respect to any evenly distributed mass-density, because the general gravitational effect is itself a self-similar scale change that alters local space-time measurements. The effect is thus detectable only in mass density anomalies, the general gravitation being non-detectible by local measure. These results suggest an interpretation of space-time in which the effective roles of 'special' and 'general' relativity are exchanged, such that Special Relativity holds for the universal geometry and General Relativity holds locally, governing the dynamics of local mass density anomalies. This view eliminates the need for 'dark energy' to correct the standard models, but adds the implication of dual time reference frames – intrinsic and observational – and the idea of an intrinsic formal domain ontology existing outside of measurable space-time coordinates. This geometry is self-determining in the imaginary space-time dimensions (modeled by the imaginary numerical domain),

Applying the model with empirical confirmation of Omega ~ 1 suggests that the universe itself is geometrically similar to the inside of a black hole (with the stable outer limit of 'flat' expansion corresponding to a Schwarzschild radius). Some theories claim that the zero-point ('quantum vacuum') energy (ZPE) is indeed sufficiently great to classify protons as ZPE black holes. Given the model's geometrical treatment of gravitation, the next question centers on the origin and fate of matter, which can no longer be seen as being propelled through space as a result of a giant cosmological explosion (big bang), but rather must originate and be conserved in local space-time that already has the relativistic properties of expansion. The model thus becomes open to a suitable 'steady-state' theory of generation and annihilation of matter in local space, perhaps in terms of quantum vacuum dynamics; while, owing to the model's dual time reference, all the observational (relativistic) properties of a 'big bang' universe are also preserved. Finally, as originally intended, the model is suitable for describing space-time at any scale, thus providing a means for linking quantum and relativistic phenomena, or, with additional non-local linkages, applying it as a model for proposed "orchestrated space-time selections" in the explanation of consciousness and perception.

Keywords: Space-time, cosmology, relational complexity, Hubble expansion

INTRODUCTION

Surprising evidence from Hubble Space Telescope observations of an accelerated universe was published in 1998 in Physics Letters (Goldhaber and Perlmutter, 1998) and the Astrophysical Journal (Garnavich et al., 1998). These reports were soon confirmed (Leibundgut and Sollerman, 2001). Cosmology has consequently been in flux as models are revised and new ones proposed, to account for the apparent acceleration of the universe's expansion and the apparent 'flatness' of the space-time curvature (Omega ~ 1+). The idea that repulsive "dark energy" (Krauss, 2004) may occupy space at twice the equivalent of attractive 'normal' matter is one of the ad hoc theories that have been proposed to reconcile these observations with the gravitational effect in current cosmological theories. Along with these revolutionary changes in cosmology, it is now recognized that a cosmology proposed in the 1930's by E.A. Milne, which describes a mass-less expansion based primarily on Special Relativity (SR), seems to correspond with the new observations (Kutschera and Dyrda,). Although Milne's "kinematic relativity" was treated by modern cosmologists as an interesting pedagogical or "toy" model, it now deserves deeper consideration.

In particular, a geometrically similar model for complex space-time geometry to that proposed by Milne, was presented in 2000 (Kineman and Kineman, 2000; Kineman, 2000) as a cosmological test of the principles of 'Relational Theory,' which is being developed by the author following the work of Robert Rosen (Kineman, 2008). The model that was presented was similar to Milne's, but differed in that it described an expansion of space-time itself, as a result of a contextual relation between 'inverse' domains of reality (local and non-local) whereas Milne's model was proposed as an expansion into measurable space-time. Accordingly the Kineman relational model does not have the problem of a central reference frame and other difficulties of the Milne model. It differs from 'standard' models primarily in proposing a complex relationship between observable nature and a hidden 'potential' nature modeled as an imaginary space-time domain geometrically represented as a radial 'Minkowski-space.' The relationship between the model's imaginary and real domains represents a natural instance of a Rosen 'modeling relation.' The original model was developed to test the view that nature is complex in just the manner suggested by Rosen modeling relations, at all levels of investigation. By applying that basic relational view and simultaneously retaining Special Relativity and the observed Hubble expansion, some surprising predictions were made. Nearly a decade later the conclusions and predictions of that model remain consistent with advancing observations.

In its original formulation the model was assumed to be invariant to the overall distribution of mass-density and thus gravity, however the explanation of how this could be reconciled with General Relativity was not addressed. Here gravitation is considered, and indeed it turns out that the space-time geometry should be invariant with respect to the average mass-density, aside from effects on the curvature from local, relative mass anomalies. The case where mass does not remain a constant is also considered in order to assess the geometry of continuous mass origin (say from ZPE dynamics) versus a 'big bang' origin. This case also results in local invariance, but would be detectible as a change in the parametric shape of the Hubble relation through time (Equation 1).

RELATIONAL COSMOLOGY REVISITED

The author's relational cosmology model is based on the simple starting assumption of equivalence of space and imaginary time. This equivalence is represented by the obvious equation, $d = ct$, where d is locally measured distance, c is the speed of light, and t is locally observed time. The speed of light, which may be taken as the degree of connectivity between locations, defines the relationship between locally measured space and time coordinates, and therefore it must be a constant when observed from within the domain it defines. The model is constructed in radial Minkowski-space with a common origin for time (**Figure 1**). Local space and time are normally represented as real numbers, thus implying a local approximation of space-time geometry as a Euclidean vector space. However the general relationship in this geometry is hyperbolic in accordance with Special Relativity. When mapped as a radial geometry, it is seen to be intrinsically dynamic (expanding) and self-similar across all scales. The geometry has properties of early and present acceleration that seem to agree with recent observation. This representation eliminates the "light cone" of Cartesian models and thus all regions in this model are part of existence and are observable over time. Nevertheless, a domain of general, non-local reality is represented in the imaginary axes that exist simultaneously with measurable, local domains. The relation between the imaginary and real domain is an instance of a Rosennean complex modeling relation, which is a contextual relation implying 'inverse' domains that co-define each other. It is an explicit representation of Aristotle's 'formal cause' where the implicit space-time geometry originates from a system that supervenes on local space-time. Interestingly, this relation corresponds very well with ancient Vedic concepts that reality is based on a relation between "existence" and "non-existence" both of which are "full", meaning real in the sense of having causal properties.

As previously reported (Kineman and Kineman, 2000; Kineman, 2000), the relationship between the imaginary Minkowski radial domain and local space-time, represents complex space-time relation. It was modeled as a relationship between phased time (ict, iθ) and local space-time (d, t). From that relationship an 'intrinsic time' of a system can be calculated, yielding, in the same manner as Vallee (Vallee, 2000), the equation $\tau = Ln(t/T)$, which is the relationship between intrinsic time (τ) and observational time, t, with respect to the apparent elapsed time (age of the universe), T. Intrinsic time in this model is related to the phase angle in the Minkowski domain, which corresponds with the apparent recession velocity of a distant location.

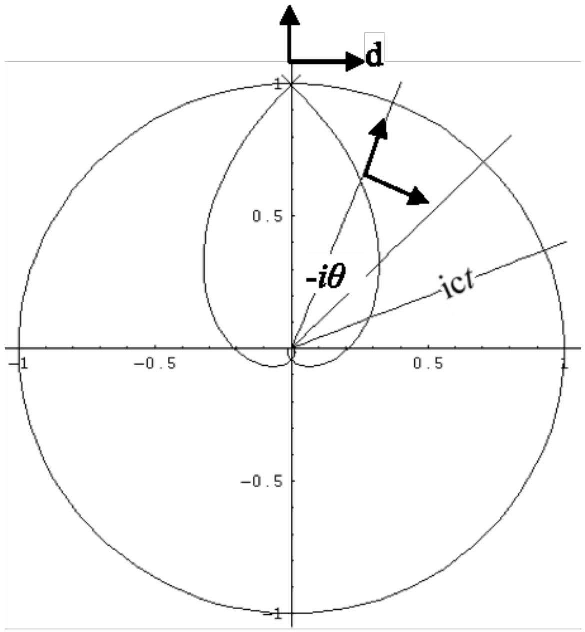
Calculating the relationship between recession velocity and distance gave a simple prediction of the variation in Hubble expansion rate with cosmological distance (i.e., recession velocity as a function of distance from the observer), assuming a constant mass-density that may be any finite value. The expansion rate is not a constant in this geometry, but is given by Equation 1:

Eq. 1

$$\boxed{v/c = Tanh\left(Ln\left(\frac{1}{1-d/S}\right)\right)}$$

where:
v = velocity of recession
c = speed of light
d = local (Cartesian) distance from observer
S = apparent size of the universe (equivalent to icT, where T is the apparent age of the universe).

This equation graphs as shown in **Figure 2** (from Kineman and Kineman, 2000 and Kineman, 2000, with S=1). Note that the curve is indistinguishably linear over most of the region of space that is observable with current technology and precision (HST can now reach perhaps 80% of the observable universe). That linearity seems to be generally confirmed except for current and early acceleration, which are features of this curve; weakly near t = S, corresponding to our present time (where the initial slope is 1 and then decreases slightly), and strongly near t = 0, corresponding to the early universe (where the slope of the curve reduces to zero, indicating early acceleration).



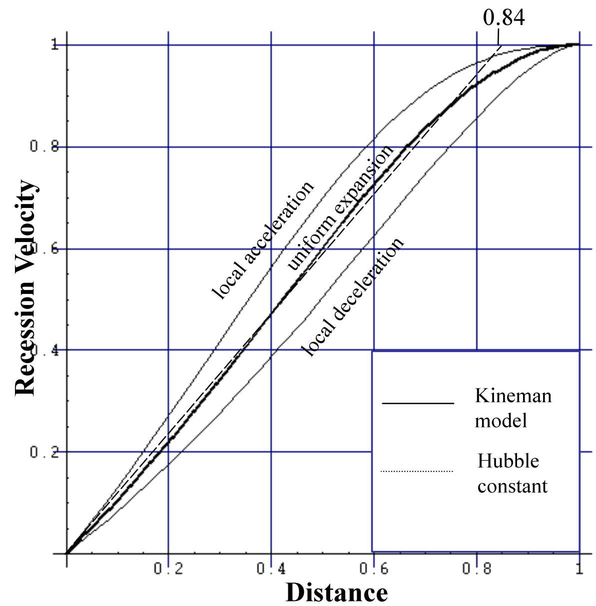


Figure 1: Radial Minkowski space showing time radials separated by phase angle (recession velocity). The path of light follows a self-similar logistic spiral.

Figure 2: Predicted Hubble Relation, with possible variation due to local mass density.

GRAVITY

In this geometry, the incorporation of constant mass turns out to have local but not general effect. Mass in this model alters the local scale of space-time, thus warping the geometry locally, which may be in accordance with general relativity (GR). However, the cumulative or general effect of a constant total mass-density of the universe will accordingly be expressed as a general change in scale; which is defined by the ratio of s and t, that is, the value we assign to the speed of light. But for that constant, the geometrical properties are invariant with respect to any general change of scale. There is no preferred scale of space-time, and therefore scale is only meaningful relatively, between systems or through time. A sufficient mass to prevent light from escaping the spatial domain (as in a black hole) will draw the light path parallel to the time radials where the mass occurs. Therefore, an infinite mass density of the universe would result in a singularity where light does not travel through space, and thus local space is no longer defined; the universe ceases to communicate with itself at this singularity. Physically, however, mass-density requires spatial extension, so either the condition could not be achieved or the model is simply not defined at this singularity. Before that singularity, however, the Schwarzschild radius would be reached, where light is, metaphorically perhaps, in 'orbit' around a black hole and there is no general communication. That is precisely the condition that Haramein (Haramein, 2009) has described for the ontology of

protons, providing the interesting result that a sufficiently large but finite mass-density would 'hide' itself inside "Schwarzschild protons" before reaching the singularity. A quantum vacuum energy of 10^{34} gm. / cm is sufficient density to establish a black hole at the radius of a proton. One would then be left with an external space-time geometry that would again correspond to the original model, with the apparent mass of protons that does not include their zero point energy. The geometry is consistent with the idea that we are, in fact, inside a black hole where the infinite mass-density is hidden in the above manner, thus explaining the origin of matter.
The question naturally arises as to how the inside of a black hole would not experience tremendous gravitational compression (which has been the assumption of standard cosmological models). The answer lies, again, in the nature of space-time scaling and the assumption that gravity is nothing more than space-time curvature. In that case, mass and gravity have only relative local meaning, because theoretical curvatures in every direction of distributed mass-density simply nullify each other. There is no absolute frame of reference for the scale of space-time other than history, so it is only in cosmological observation that we can observe effects of general mass-density. The model thus implies that only differences in mass density, and therefore gravitation, between points in space-time (different radials and different positions on a radial) are therefore consequential in this model, and the prediction of Special Relativity of infinite mass at the speed of light accounts for the presence of ZPE that becomes 'packaged' in Schwarzschild particles.

Because this model is an expansion of space, not through space, in which mass is generated and set into motion, it is consistent with the appearance in any Euclidean local frame of reference (represented in Figure 1 as small Cartesian diagrams on each radial), that matter itself has traveled through space from a common origin (the "big bang"), whereas there could have been no such common origin in any local space in the model. It therefore suggests that the origin of matter may be a continuous phenomenon where material particles 'distill' from expanding space (perhaps in the manner described above). If such processes were to imply generation of mass through time as a function of the self-expanding geometry, a curvature of the space-time curvature through time would result, appearing retrospectively as shown in **Figure 3**. Preserving the local relation between space, time, and light would mean that such 'pinching' of the curve would result in particle motions; essentially the conversion of mass to kinetic energy.

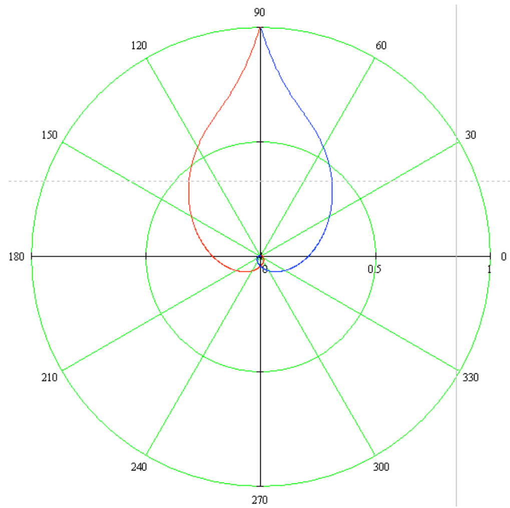


Figure 3: Effect of local mass anomaly emerging with time.

Whether mass is conserved or continuously created is thus testable in this model, by sufficiently precise measures of second order changes in the Hubble expansion rate through time, but is also implied by the fact of kinetic energy. Any mass that comes into existence in this model, must warp space-time and produce motion in subsequent time.

DISCUSSION

The model is very simple in concept if we are prepared to think in terms of a formal-cause domain that is implicated in all natural interactions, and from which space-time coordinates are defined. The model was developed by the author in the mid 90’s as a simple explanation of space-time origin according to relational theory, adhering to the idea that existence must have the simultaneous properties of location and non-location (a point or undifferentiated whole), which appears in all subject-object relations and their natural analogs. The model was produced as one test in applying that theory to natural phenomena in general. The purpose was to evaluate the generality of the concept of “modeling relations” (Rosen, 1985) between systemic (formalistic) and measurable (realistic) aspects of a complex system. The approach follows Rosen’s general theory of relational complexity (Rosen, 1991b), in which a basic duality between potentiality and actuality (perhaps analogous to Kant’s “noumenon” and “phenomenon”) can be represented in the graphical mathematics of category theory (Louie, 1985). The ideas also followed the suggestion of (Hameroff and Penrose, 1996a) that consciousness (and thus perception) might be explained in terms of “space-time selections” within quantum-isolated space-time domains. Relativity is a continuous form of space-time isolation, so it seemed reasonable to look for commonalities with cosmology, where the theory might be tested. Also, the scale and mass independence of this model make it suitable for explanations at any level.

In quantum phenomena, the determination of states is a function of interactions or percepts that establish or participate in the system of measurement (space-time) in which those states become defined (Rosen, 1978). It is possible, then, to think of perception and interaction as measurements determining material states by space-time 'selection.' In other words, a state is determined by selection of the frame of reference. This does not mean, however, that each subsequent perception or interaction creates a separate universe (as in Everett Worlds), unless they are in isolated domains. (Hameroff and Penrose, 1996b), for example, thought conditions for isolating space-time domains might exist in living cells in a network of microtubules, which have the appropriate dimensions for quantum effects. Non-isolated, or quasi-isolated (relative) perceptions or interactions may each establish a local space-time frame of reference from the otherwise undifferentiated whole, and may collectively produce a common frame of reference as a result of the dynamic geometry described by this model, which brings all frames into common alignment, thus establishing classical and relativistic nature. The process may be similar to quantum decoherence, which is a possible resolution to the observership (or "measurement") problem in quantum physics.

The more general question was how quasi-isolated (or relative) space-time domains might be related to a more complex, un-differentiated whole. By treating space-time as a domain of 'actualization' that is complementary to a noumenal (or formal) domain of 'potentialization,' it is possible to maintain consistency with Special Relativity. The result was the present model of local 'realized' space-time emerging from a more general but formless (in the sense of being non-interactive or non-measurable) domain. The explanation as to why the mass density of the universe should not affect the overall geometry of self-similar scaling seems geometrically trivial in retrospect, but it must still be reconciled with the equations of GR, extending the Principle of Relativity to the conclusion that relativistic mass density, like uniform motion, should not have any locally measurable effects. The model thus holds to the principles of SR generally, and GR locally. The overall scale of the self-expanding geometry has no contextual frame of reference in which its alteration by general mass can be detected. A force of gravity that consequently exerts itself equally in all directions should be nullified. The difference is in discussing an expansion or contraction that is truly of space-time not just in space-time.

The model is obviously dualistic with regard to internal vs. external measurement of any system, but in a way that points to holism in the relationship of these two frames of reference. A consequence of this and Milne's less general model is dual time reference: an intrinsic time scale (corresponding to the angle $-i\Phi$ in the diagram) vs. an observed time scale (corresponding to t), where intrinsic time is related logarithmically to observed time, and both must be considered 'real.' There is, as a result of relativity, an infinite intrinsic history (at $t = 0$, $\ln(t) = -\infty$) in contrast to a finite observed history (a 'beginning' at the big bang singularity). This same conclusion was reported by (Vallee, 2000)[1], a mathematician reasoning from a different basis about the intrinsic time of natural systems. If the development of celestial systems occurs in local space-time, systems

[1] Vallee's results were coincidently reported at the same conference where this model was presented, without either author knowing of the other's work.

could be produced that are older than the apparent 'age' of the universe. Indeed, this prediction might have been taken as cause for rejection of the model, but for reports of the "Freedman Age Paradox" (Freedman, Madore, and Kennicutt, 1997) where just such a situation appeared to be the case for certain ages determined from nearby Cephid variable stars in globular clusters (supposed "standard candles"). Freedman and others subsequently brought these numbers into 'better' but still questionable alignment with orthodox theory (Reid, 1998). Today the matter is considered only tentatively resolved by the revised estimates. The mystery may also deepen in other observations, such as the surprising observation of a high density field of deep sky galaxies that may not be as young as required. Ultimately, of course, confirmation or rejection of an age paradox, perhaps more so than confirmation of the recession equation above, will be powerful evidence for or against this theory.

CONCLUSION

Einstein once said that light is the ultimate mystery. If so, then space-time can be no less so, for the speed of light defines the relationship between space and time and vice-versa. In the radial geometry the time-vectors in local space theoretically converge at a historical singularity (the big bang). The geometry dictates an infinitely converging logistic spiral for light paths, as seen in the diagram, and consequently self-similarity of the general continuum. In a sense, it produces special relativity as a consequence of perception and implicit order, which is represented by the imaginary radial domain in the diagram. This convergence, however, is not an assumed 'fundamental' time frame as was the case in Milne's interpretation; it is a self-organizing result of the self-similar dynamics. It is more an implication of the present than a fact of the past. Actual light paths do not reach to that historical singularity except as an infinite projection. Rather than seeing this geometry as generating future space-time, it is as appropriate to see it as generating the past.

Consequently, any two frames of any orientation will implicate such a universe behind their point of interaction. In other words, in a vector field of random space-time orientation, every interaction establishes an historical space-time organization. Whichever one an observer maintains will present a view of all other vectors being subsumed into that frame of reference asymptotically over time, because differences will scale logarithmically into the apparent point of general origin. The model thus describes a form of self-organization in which a 'big bang' singularity will naturally appear observationally (with relativistic, but not intrinsic reality).

It is obvious that the model implies two simultaneous descriptions of the universe; one of its undifferentiated 'prior' nature as a unitary 'whole' and another of its differentiated aspects in local space-time definitions (or "selections"). The relationship between these domains, as with Rosen's modeling relation, is a two-way causality. In this sense it conforms to a Rosen modeling relation, describing a self-informing, self-organizing, and perhaps self-generating universe that is connected by information relations. Since the model does not say which domain is 'prior' to the other, it describes a 'loop' causality (a mathematical 'impredicativity'), where it is equally valid to say that the general geometry of space-time causes local space-time to emerge, and that local space-time interactions produce the general geometry. The removal of such causal loops from physical theory is precisely what allows the definition of mechanisms (Rosen, 1991a), and therefore the model presented here describes fundamental existence as something beyond a mechanism. This relational understanding of the diagram is crucial to understanding that there is no central frame of reference implied, no 'fundamental' set of world lines (as in the Milne cosmology) and no local experience of a big bang (that might, for example, show up in developmental histories of celestial objects), other than the reality of its relativistic effects in different frames. We do not need to decide which domain, undifferentiated or differentiated, came "first" in this model; they are represented as a complementarity. One may presume a unity beyond either description, but in the model that unity is represented by light, which defines the relationships.

It is worth noting that application of the model to cosmology was to test its general relevance as a theory of space-time perception (or interaction) involving a basic relationship between the material world and its origin in formal aspects of nature (Aristotle's formal cause, Bohm's "implicate order," and other similar concepts). The relationship being modeled is a fundamental principle of representation and actualization (or "realization" as Rosen called it). It implies a certain kind of information process within the fabric of nature (Kineman, 2007a; Kineman, 2007b). This view of fundamental reality is also consistent with ancient Vedic and Upanishadic concepts derived from ancient India and Indus Valley Civilizations, that nature is fundamentally a relation between locally realized 'existence' that is sensible, and non-local, non-measurable existence that is systemic (incorrectly referred to in many texts as 'non-existence'). It is represented in the concept of an Akashic field; a domain with which measurable reality has formal cause information relations that in some way 'record' events and relate them to other events. Such concepts have been handed down through the ages through all naturalistic philosophies in concepts of a "fifth essence" (literally, 'quintessence'). Over and over, such concepts were proposed as either a material or an efficient cause to sit with the traditional mechanistic laws of nature, and, impossibly, to account for its origins. Repeatedly such ideas were disproven. Today we still seek for explanations of such fifth essences in measurable forces or material. Such is the case of 'dark matter', suspiciously proposed as being undetectable but nevertheless having a repulsive force in exactly the quantity needed to reverse the attractive force of known matter. Such a proposal is a clear indication that a new theory, not a new substance, is needed. It is a logical necessity that such phenomena appear at a higher causal level, as Aristotle proposed in his concept of formal cause.

REFERENCES

Freedman, W.L., B.F. Madore, and R.C. Kennicutt. 1997. In: The Extragalactic Distance Scale. eds. M. Donahue, and M. Livio. Cambridge, U.K.: Cambridge Univ. Press.

Garnavich, P.M., R.P. Kirshner, Challis P., and others. 1998. Constraints on cosmological models from Hubble Space Telescope observations of high-z supernovae" . Astrophysical Journal, 493(2): L53+ Part 2.

Goldhaber, G., and S. Perlmutter. 1998. A study of 42 type Ia supernovae and a resulting measurement of Omega(M) and Omega(Lambda). Physics Reports - Review Section of Physics Letters, 307(1-4): 325-31.

Hameroff, S., and R. Penrose. 1996a. Conscious events as orchestrated space-time selections. Consciousness Studies, 2(1): 36-53.

Hameroff, S., and R. Penrose. 1996b. Orchestrated Objective Reduction of Quantum Coherence in Brain Microtubules: The
"Orch OR" Model for Consciousness. In Toward a Science of Consciousness. eds. S. Hameroff, A Kaszniak, and A Scott. Cambridge: MIT Press.

Haramein, N. 2009. The Schwarzschild Proton. Proceedings of the 9th International Conference CASYS'09. University of Liege, Belgium.

Kineman, J.J. 2000. Life and space-time. In: ANNIE 2000. Minds and Models: Making Sense of Bizarre Behavior. Rolla, MO: University of Missouri-Rolla.

Kineman, J.J. 2007a. Modeling relations in nature and eco-informatics: A practical application of Rosennean complexity. Chemistry and Biodiversity, In press (october, 2007).

Kineman, J.J. 2007b. Modeling relations in nature and eco-informatics: A practical application of rosennean complexity. Chapter II in: Relational Complexity in Natural Science and the Design of Ecological Informatics: Ph.D. Dissertation. J.J. Kineman. Boulder: University of Colorado.

Kineman, J.J., 2008. Fundamentals of Relational Complexity Theory. In: J.Allen and J.Wilby,.Proceedings of the 52nd Annual Meeting of the International Society for the System Sciences, Madison, WI. ISSS 2008:1046/352. http://journals.isss.org/index.php/proceedings52nd/article/view/1046/352

Kineman, J. J, and J. R. Kineman. 2000. Life and space-time cosmology. Proceedings of the World Congress of the Systems Sciences and 44th Annual Meeting of the International Society for the Systems Sciences., Eds. J. K. Allen, and J.Wilby.. Toronto, ON: ISSS.

Krauss, L.M. 2004. Cosmology: What is dark energy? Nature, 431: 519-20.

Kuhn, T.S. 1970. The Structure of Scientific Revolutions. 2nd Edition. Chicago: University of Chicago Press.

Kutschera, M., and M. Dyrda. Coincidence of universe age in ACDM and Milne cosmologies. Acta Physica Polonica B, 38(1): 215-17.

Leibundgut, B., and J. Sollerman. 2001. A cosmological surprise: the universe accelerates. Europhysics News, 32(4).

Louie, A.H. 1985. Categorical Systems Theory. In: Theoretical Biology and Complexity: Three essays on the Natural Philosophy of Complex Systems. Ed. R. Rosen. Orlando, FL: Academic Press, Inc.

Milne, E.A. 1948. Kinematic Relativity - A Sequel to Relativity, Gravitation and World-Structure Oxford: Oxford University Press.

Popper, K. 1965. Conjectures and Refutations: The Growth of Scientific Knowledge. 2nd edition. New York, NY: Basic Books.

Reid, N. 1998. Globular clusters, Hipparcos, and the age of the galaxy. PNAS, 95(1): 8-12.

Rosen, R. 1978. Fundamentals of measurement and representation of natural systems. 221p. North-Holland Series in General Research Systems. New York, Oxford:

North-Holland.
Rosen, R. 1985. Anticipatory Systems: Philosophical, Mathematical, and Methodological foundations. New York, NY: Pergamon Press.
Rosen, R. 1991a. Beyond dynamical systems. J. Social and Biological Structures, 14(2): 217-20.
Rosen, R. 1991b. Life Itself : A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life. 285p. Complexity in Ecological Systems Series. Columbia University Press: New York, NY.
Suppe, F. 1977. The Structure of Scientific Theories. Chicago: University of Illinois Press.
Vallee, R. 2000. Intrinsic time of a dynamical system. Proceedings of the World Congress of the Systems Sciences and 44th Annual Meeting of the International Society for the Systems Sciences, Eds. J. K. Allen, and J. Wilby. Toronto, ON: ISSS.