The Nature of Gravitational Singularities
and a Heuristic Introduction to HBCS Cosmology[1]

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Abstract: In this essay we maintain that certain physical properties, originate from the fundamental nature of the universe as a whole and are not independent of it. Therefore, we will take a naïve but novel approach and introduce a simple, yet powerful cosmological principle to develop a new interpretation of General Relativity (GR), one that will provisionally describe gravitational singularities, thereby initiating a new direction toward a complete theory without the explicit utilization of any of the current theories of Quantum Gravity (QG). We will further use this new principle to investigate the nature of spacetime's inherent duality and, in support of our approach, discuss: the beginning and end of the universe, the nature of black holes (BHs) from a "cosmic perspective", and we will offer elegant hypotheses for the formation of local structure and for the anomalous observations that lead to the concept of dark matter.

I. Introduction

Modern cosmology's birth came early in the twentieth century, with the global use of GR to construct a variety of different cosmological models. The most successful of the new models incorporated the metric describing a simply connected, homogeneous, isotropic, expanding universe, developed from contributions by A. Friedmann, G. Lemaitre, H. P. Robertson, and A. G. Walker and is accepted as the basis for the today's Standard Model of Cosmology (SMC) **[1]**. However, GR was found to be incomplete due in part to the inevitable singularities that result **[2]**; from the one at the beginning of the universe, to those interior to the event horizons of BHs. The SMC also has several other unresolved primary issues **[3]**, in particular, the of the formation of structure and the inclusion of two fundamental, yet hypothetical entities, commonly referred to as dark matter (DM) and dark energy (DE) to explain specific anomalous observations. These entities represent approximately 95-96% of the energy density of the cosmos **[4]**. Not minor problems indeed. However, the incompleteness of GR, as currently formulated, has been extremely problematic and resolving this most intractable of primary issues is one of the fundamental goals of an acceptable theory of QG. Our method, using conceptual analysis with (predominately) classical physics and its mathematical structure of the continuum, indicates that progress can be achieved in a simple approach, but not without a bold reevaluation of some of the elements of our current foundations.

II. The First Principle of Cosmology and Cosmic Time

We begin this section by introducing the **First Principle of Cosmology** (FPC) and then continue with a brief discussion of the nature of time. The FPC should not be confused with "The Cosmological Principle" which is related to the Copernican view that no observer has unique status

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and thus the cosmos is both homogeneous and isotropic. The FPC, on the other hand, is more closely related to Mach's Principle [5] and can be simply stated as follows:

For any event or physical property to be defined as completely as possible within the limits of physical certainty, such an event or property must be defined with respect to (w.r.t.) the universe as a whole and is never independent of it.

It may seem to the reader that this is and has always been an unwritten law, and it may not be immediately clear how or in what fashion it will have much utilitarian significance. As we as shall see throughout the remainder of this essay, it will have profound implications in the manner in which we define the nature of spacetime and ultimately the cosmos, itself. In addition, from the application of FPC, along with the results of time dilation from GR, applied locally, we will alternatively define a measure of time from the "cosmic perspective" and limit our current definition of a BH. Although BHs have been the most comprehensively researched objects in GR, the need to reexamine their basic nature is compelled by the total failure of the laws of physics at the singularity.

Of all the implications of GR, one of the most, if not the most profound, is that time was found to be dynamical. Although GR opened a window into time's nature, it was never intended to or was it able to answer the fundamental question: "what is time"? What then is the most fundamental definition of time in nature? This question has occupied philosophers and scientists since antiquity and has been the subject of renewed interest. [6]

Time in relativity is simply defined by that which is measured by perfect clocks and it is the variation of these measurements, within differing frames of references, that determines time's dynamical nature. Is there an ultimate meaning of time in nature? A possible answer is that time is simply an elementary ordered process of change. Assuming this to be true, then what is the most fundamental physical basis by which such change is associated with the universe as a whole according to the FPC? The most obvious answer is that of the expansion of the universe itself, for even if it were possible to hold all motion *through space* constant, the *expansion of space*, in itself, is enough change by which to create a notion of cosmic time.

To relate this notion of cosmic time with time measured by clocks locally and as a result of the extreme uniformity of the universe on the large scale, in particular the cosmic microwave background (CMB), we can chose a frame of reference in which the dipole anisotropies w.r.t. the CMB have been removed. A perfect clock in such a frame would have a unique status that we can specifically define cosmic time with which historical cosmic events can be measured w.r.t. the current era. [7].

III. The Cosmological Spacetime Diagram (CSD)

The concept of cosmic time, defined above, can be used along with GR applied locally, to construct a simple idealized cosmological model as follows:

Let A be an arbitrary event[2] in cosmic time, T, that occurs when the age of the universe is equal to T_1. Fig. 1 shows the 2-D cross-section of the *3*-sphere's surface created by holding T constant at T_1 w.r.t. the three spatial dimensions. The surface, S, represents one of the three spatial dimensions, while the radius represents cosmic time, with the other dimensions orthogonal to each of these. We will utilize this cross-sectional convention throughout our discussion, in direct comparison to the Minkowski spacetime diagram.

Due to the immense size of the universe compared to the local scale of the present era, cosmic spacetime is spatially flat to a very good approximation except in the proximity of massive objects. The large scale curvature of the cosmos has negligible dynamical influence on its constituents over an infinitesimal interval of cosmic time in the present era. However, for larger intervals of cosmic history, or earlier and later eras in its history, as we shall see below, the local and intermediate scale structures will evolve with the expansion of this global structure.

Event, A, could specifically be defined as an observation from a planet in an ordinary spiral galaxy of light from a distant source. The object that we observe is seen as it was in

[2] In our approach, we will not assume that events are perfect point-like mathematical objects, only that they are infinitesimal in extension and duration compared to the scale our geometry represents.

the cosmic past, not as it exists in the present era, i.e. on the surface S, due to the restriction of the speed of light. The world line of event A, along with the majority of all world lines in our CSD, would be radial lines only, since even though the planets and galaxies have velocities w.r.t. the CMB, they are negligible compared to the speed of light, as is the case with most of the baryonic matter in the universe. ***All world lines would have an associated local time subject to local conditions and the laws of GR, but are intersected by a specific cosmic time****.*

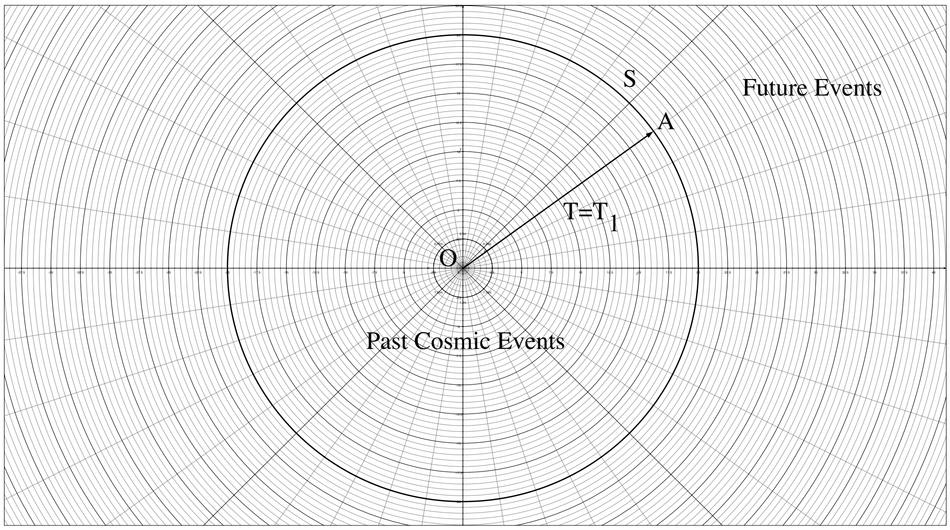


Fig. 1

The interior of S, represent all events that have occurred in the past of A and all events exterior to S are possible future events. ***The set of all cosmic events represented in Fig. 1 by the surface, S, expanding in cosmic time, will be referred to as the Hyperspherical Background Cosmic Spacetime (HBCS).*** *The surface defines space on the cosmic scale*, effectively producing a cosmic "present" to which all matter and energy that are causally connected are confined. The HBCS provides an absolute global geometry, an infrastructure from which to gain insight to foundational cosmological questions.

Fig. 2 below shows the past of the cosmos that has been divided into equal historical epochs and four possible light paths from a distant source. The path, $\overset{\frown}{oa}$, represents the light path in a rapidly expanding universe, $\overset{\frown}{ob}$, $\overset{\frown}{oc}$, and $\overset{\frown}{od}$ each represent light paths in successively less rapidly expanding universes.

These paths are all overlaid on the same diagram for convenience to minimize the number of figures needed to convey their meaning. They each represent separately varying cosmic conditions and depending on which conditions exist, the corresponding light path would be universally applicable across the entire diagram. Likewise, the paths represent one direction in space. The total *observable* universe from an event, A is represented by the surface created by the rotation of the past light path about the world line of the event w.r.t. the other spatial dimensions. This (null) surface is analogous to the past light cone of a Minkowski spacetime diagram, and varies from it due to the expansion of the universe, but reduces, in the vicinity of any single event, to the Minkowski light cone (after renormalization).

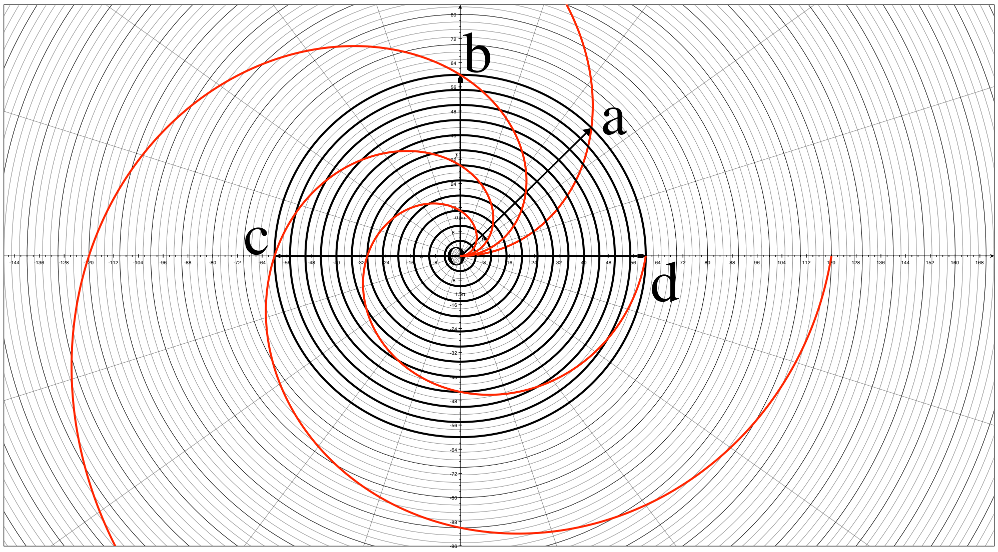


Fig. 2

Notice that the path, $\widehat{od}$ contains paths similar to each of the others in its cosmic past (i.e. paths $\widehat{oa}$, $\widehat{ob}$, $\widehat{oc}$, and are just magnified versions of their counterparts on $\widehat{od}$). The path, $\widehat{od}$ is consistent with a cosmos perceived by a notional observer outside of the system, as one that expanded extremely rapidly early in its evolution, then less rapidly in later epochs. This is an inherent property of light paths through *cosmic* spacetime, the result of which is obtained from only the symmetry of events w.r.t. cosmic time and a uniformly expanding global geometry. We are able to recover *local* spacetime from the given cosmic spacetime as follows:

The paths above are examples of same the curve, namely the Archimedes' spiral:

$$r = A\theta \qquad (1)$$

If the cosmic past was transparent from its beginning, all light paths would converge to a single event, O, equivalent to the "Big Bang" event when T=0. This point of convergence is the singularity in the SMC.

Now, observe that the slope of the tangent to the light path varies w.r.t. a change in cosmic time. This implies that even when the effects of motion and local gravity have been removed, time measured locally must vary w.r.t. cosmic time in order for the speed of light to be invariant locally. To satisfy this condition, the slope of the tangent line w.r.t. the radial line would need to remain constant throughout. This is by definition, the logarithmic (or equiangular) spiral, the general form given by the equation:

$$r = \alpha e^{b\theta} \qquad \text{where} \qquad b = \cot\phi \qquad (2)$$

and ϕ is the angle between the tangent and the radial line. Now, if the radial dimension for the graph of the logarithmic spiral is chosen such that $r \equiv ct$ we can renormalize the spacetime associated with each point of the logarithmic spiral if: $\phi = \frac{\pi}{4} \Rightarrow b=1$

and α in (2) can be found (Endnotes A) such that in terms of T:

$$ct = \frac{\pi}{4} e^{T - \frac{\pi}{4}} \qquad (3)$$

Fig. 3. shows the graphs of (1) (with A arbitrarily chosen =1) overlaid onto the graph of (3). The result, (3) shows how local time emerges from its dependence on the null surface which varies w.r.t. cosmic time. Both spirals, whether cosmic spacetime (Archimedes) or local spacetime (logarithmic), imply that as the cosmos expands, events will repeat periodically for eternity. This would indeed be the case if not for the existence of BHs. As we shall see in the next section, BHs have the predominant role in the explication of our model.

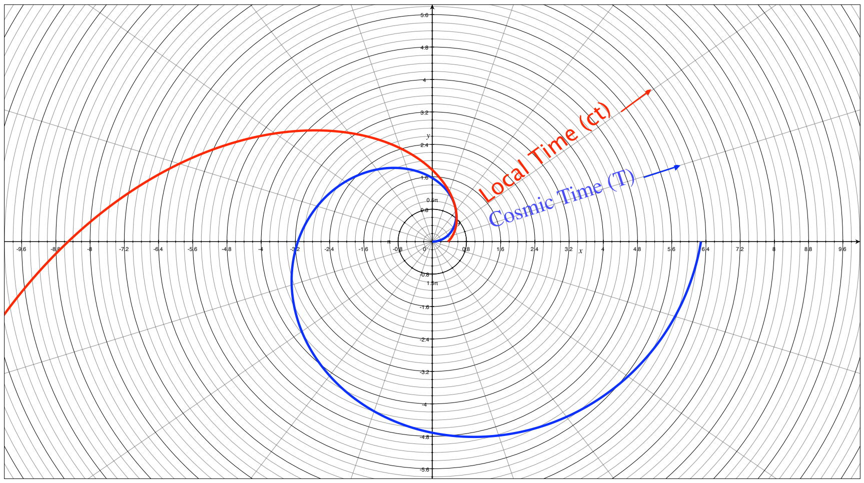


Fig. 3

IV. Black Holes from the Cosmic Perspective

Our goal for this next section is not a comprehensive investigation of BHs, but rather to answer the simple question: How does the FPC affect how we define a BH and what are the implications? Until this point, only the light trajectories through an unobstructed HBCS have been shown. The fact that the cosmos is presently dominated by the vastness of space and that baryonic matter is just a small component (∼ 4%) of the whole **[4]**, our unobstructed model gives a reasonable basis. For now, we will ignore the contributions of the so called DM and DE. Since our model is built on first principles and the FPC, in particular, we shall reserve judgement on these speculative “entities” and see if they won’t emerge from the dynamical geometry of the model. DE, in particular seems to naturally arise from our model, but remains beyond the scope of this essay.

What happens then, when we add the extreme opposite of unobstructed spacetime in the form of BHs into our model? Consider the simplest example: What happens to the trajectories of light over an infinitesimal interval of cosmic time that directly intersect, on a radial path, the immense gravity created by a non-spinning BH with neutral charge? The key is to look at gravitational time dilation. As a test particle approaches a BH, the laws of GR give an equation by which a perfect clock would be dilated w.r.t. a clock in a frame of reference away from the BH (i.e. most of the rest of the cosmos) and is given by the equation:

$$t = w_f T \qquad \text{where} \;\; w_f = \frac{1}{\sqrt{1-\dfrac{R_c}{R}}}, \;\; \text{and} \;\; R_c = \frac{2GM_{BH}}{c^2} \qquad (4)$$

where t is the time measured in the frame near the BH, T is cosmic time, and w_f is the time dilation warp factor. Fig. 4 shows a graph of the warp factor, w_f of a BH (with R_C=1) for several successive cosmic spacetime hypersurfaces. This graph is a representation (on a particular local scale) of the trajectories of light through cosmic spacetime approaching our simple BH. As the light path approaches the event horizon it transitions from one mostly through space to one mostly through cosmic time. ***Thus, the slope of the light path becomes asymptotically parallel to T as it directly approaches the critical radius, R_c of the BH.***

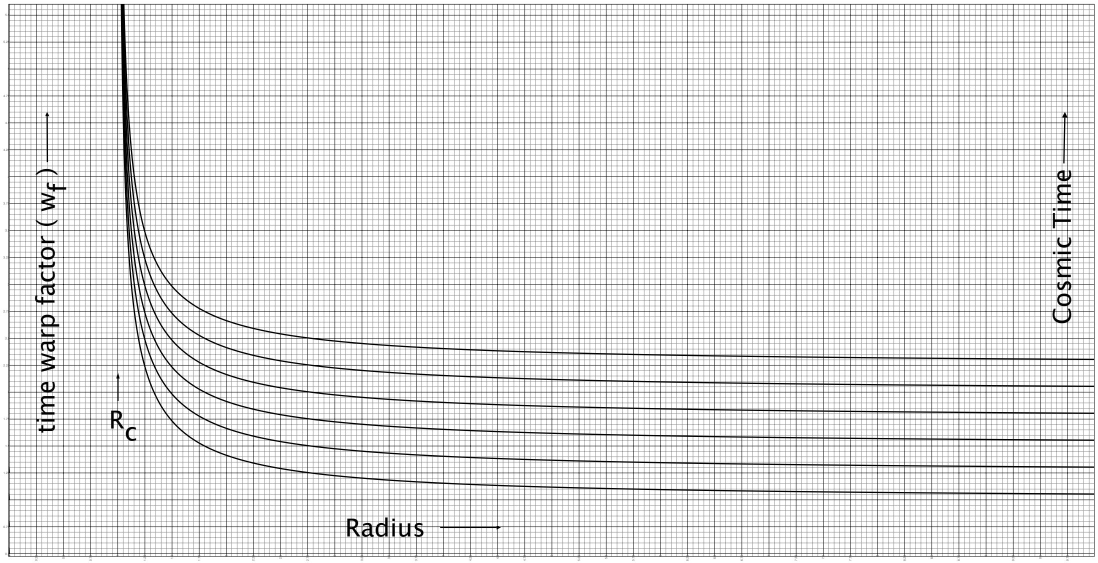


Fig. 4

Now, looking backward along the light trajectories through the expanding HBCS as shown in Fig. 2, in particular the light path, $\widehat{oa}$ (this is the light path magnified near the origin), ***as T approaches zero the tangent of this light path <u>likewise approaches one parallel to T</u>.*** So, if we now define an event on S, designated O′, to be the intersection of a photon near the end of the cosmic cycle known as the "age of BHs "**[8]** on a path that intersects a simple BH as described above, the photon's path is similarly deflected by gravity to one that asymptotically approaches a radial path of the HBCS. (see Fig. 5)

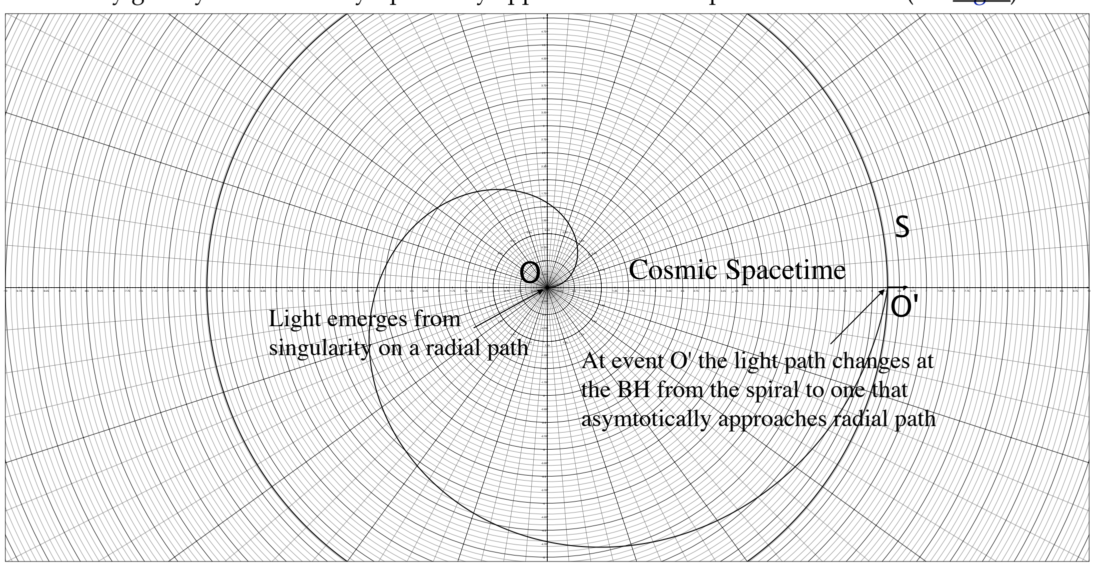


Fig. 5

Consider, now, the extreme far future of the cosmos w.r.t. the event, O′, by taking the HBCS surface, S, at the event O′ (Fig. 5) ***and shrinking it to a point in the distant cosmic past, this event O′ is then indistinguishable from our previous event, O, i.e our "Big Bang" event. (see Fig. 6)*** (The "Big Bang " event is actually the sum over T of event O′ and all such similar events to O′ on all of S.) Thus, the direct application of the FPC w.r.t. the extreme future of a BH allows us to infer that the light and matter that "falls into" a BH will be recycled into the extreme future of expanding cosmic spacetime, rather than entering into a state of nonexistence at the BH's singularity, as orthodox BH theory presently indicates. Nothing ever crosses the event horizon, although as the null surface approaches to within one Planck length of it, the horizon and the null surface become indistinguishable. All forms of matter and energy are transformed into gravitational potential energy and then retransformed into matter and energy in a reverse process after sufficient cosmic expansion.

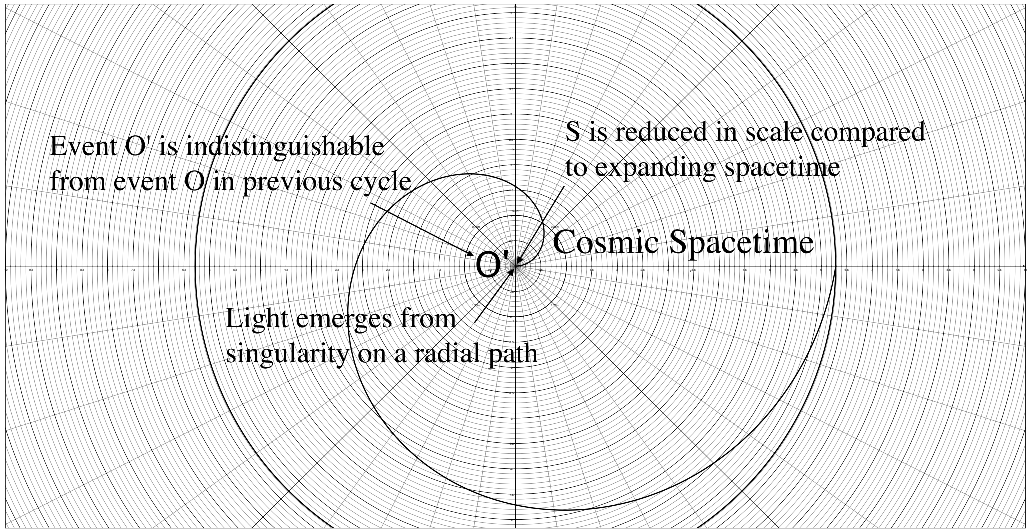


Fig. 6

This entire cyclic process suggests the ultimate connection between supermassive black holes (SMBH) and intermediate mass black holes (IMBHs) and their respective galaxies, dwarf galaxies and globular clusters (GCs). ***As matter and energy approach the event horizon of a SMBH or IMBH, its trajectory through cosmic time is such that it will be returned to the greater expanding HBCS after a sufficient interval of cosmic time due to the overall expansion of the cosmos and thus becomes not only the building blocks of new galaxy, dwarf galaxy, or GC respectively, but of a new frame of local spacetime in the respective BH's vicinity.*** (see Fig. 7) This is consistent with the apparent observation that all galaxies have SMBHs at their cores [15], and the recent discovery that some GCs and dwarf galaxies have IMBHs at their cores [9][10][11] and is similar, yet substantially different from, one of the popular "end of universe" scenarios resulting from the evaporation and eventual explosion of all BHs at the end of time.[12] The HBCS model suggests that this indeed is not the end of time, but the beginning of a new cosmic cycle.

Modern cyclical cosmological models usually involve a "Big Crunch" resulting from a reversal of entropy and the gravitational collapse and subsequent rebound of the entire universe.[13] The HBCS model suggests, however, an "endless" cycle of evolving local spacetimes resulting from the continuous expansion of cosmic spacetime. Entropy never has to reverse, since it will always increase, from the local frames of the HBCS to the BHs, IMBHs, and SMBHs and then back into a new set of local frames created after a sufficient period of further expansion. This process is also consistent with the tightly intertwined properties between galaxies and of their host SMBHs, more commonly known as the M - σ and M_{BH} - M_{TOT} relations. The M - σ relation is a near perfect empirical correlation between the stellar velocity dispersion, σ, of a galactic bulge and the mass, M, of the SMBH, which can be expressed as: $M \propto \sigma^{\alpha}$ where $\alpha = 4.8 \pm 0.5$. [14][15] This same M - σ relation has tentatively been found to also hold for GCs and their host IMBHs! [11] Likewise, the M_{BH} - M_{TOT} relation is a recent empirical correlation [16][17] between the mass of the SMBH, M_{BH} and the total galaxy mass, M_{TOT} and was found using gravitational lensing [16] to be: $M_{TOT} \propto M_{BH}^{1.30}$ which begs the question: "How does the entire galaxy know the mass of the BH at the center?" These remarkable findings highlight a fundamental connection between SMBHs and IMBHs and the stars outside of their sphere of influence and is indicative of the co-evolution of galaxies, dwarf galaxies, and GCs and their respective SMBHs and IMBHs over cosmic time.

An alternative to DM can likewise be inferred by this mechanism. The initial evidence that lead to the acceptance of the DM hypothesis were the anomalous flat galactic rotation curves created from the data collected from Vera Rubin, et al. [18] These curves established the "missing mass" problem of galaxies. If, however, the matter surrounding a SMBH, commonly known as a galaxy, originated from the compact spacetime near the horizon of the SMBH, it would possess properties that closely correlate to those of the host SMBH. For example, it has long been accepted that matter near the horizon of a rotating BH, rotates at the same rate as that of the BH, due to general relativistic "frame dragging" otherwise known as the Lense-Thiring effect after the Austrian physicists who predicted the phenomena. This leads us to the following hypothesis: ***a residual Lense-Thiring effect contributes to the kinematics of local structure and hence both the M - σ relation and the flat rotation curves of galaxies. This effect would be a consequence of the combined action of the rotation of newly created local frames resulting from gravitational potential energy being converted to matter, energy, and local spacetime in the proximity of a rotating SMBH's or IMBH's horizon and a cosmos that is undergoing local exponential expansion w.r.t. cosmic time.*** Thus, the M - σ relation and the flat rotation curves would be in part a result of the general relativistic motion of the entire local frame surrounding the galaxy around the BH's rotational axis. It would be this contribution of the *motion of local spacetime*, not just *the Keplerian motion of matter through spacetime* that supports the observed effects. If the above hypothesis is proven to be true, then the HBCS model provides an exceptionally cohesive and elegant solution to these significant astrophysical mysteries.

V. The Cosmic Singularity - Transition and Scale

At the end of the section III, the question arose of whether we lived in a cosmos fated to repetition. The existence of BHs should prevent this since the path of information through cosmic time will ultimately intersect a BH. The 100 billion or more SMBHs distributed uniformly throughout the cosmos, each with their 100 million associated solar mass BHs and an unknown number of IMBHs, act to collect all matter and energy and eventually will transport it from one cycle into the next. The conservation of matter and energy between cycles is upheld and specific events will not repeat eternally. The events of subsequent cycles of the cosmos are distinct in that the local spacetimes of a new cycle are not only separated by vast intervals of cosmic time, but also separated by the light barrier due to the nature of BHs.(see Fig.7) The local spacetime patches remain discrete from each other until the HBCS expands enough for their null surfaces to superimpose and is dependent on their location and cosmic time.

The creation of the various local spacetimes in the new cosmic cycle would not commence until the current cycle expands enough for the BHs to become continuously radiative in the extreme future. ***The singularity can be defined by this transition in cosmic time.*** The BHs will remain radiative until the thermodynamics from the merging of local spacetimes of the HBCS provides the feedback for the BHs to retransform from ideal sources back into ideal thermal sinks. This scenario does not contradict the recent result **[19]** that white holes in isolation would "emit quasi-thermal radiation before exploding from behind their anti-horizon" since the boundary conditions in the early HBCS model differ extremely from those assumed in **[19]**. The outflow of all "explosions" early in the cosmic history, would eventually be balanced and superseded by the inflow of neighboring "explosions" from similar events from across the HBCS after a sufficient interval of cosmic time.

VI. The Origin of the CMB

We would be remiss in our description of our new model if we ignored the origin of CMB, which was the final definitive evidence given against the Steady State Model **[20]** and in favor of the Big Bang Model. It was the inability of the Steady State Model to sufficiently account for this observation which lead to its eventual downfall.**[20]** Its lack of description in our model would likewise be detrimental, especially since we used its property of extreme uniformity to define cosmic time, which is the basis on which our model is built.

The SMC views the CMB as the signature remnant of the expansion at the beginning of time, but has not adequately been able to explain the events leading to this expansion, especially the singularity. Our model incorporates the singularity as a limit in cosmic time of the previous cycle. It was also shown, in IV and V above, that all BHs radiate themselves out of existence or remain observable until BH thermal equilibrium is met and superseded at which time the remaining "exploding" BHs transition back to their usual form, i.e. that of implosions. This process provides an HBCS "cutoff" temperature that is similar to the temperature of the surface of last scattering in the SMC with the exception that the HBCS Model would immediately possess a uniform distribution of SMBHs and IMBHs, each with their emergent local spacetime patches with respective protogalaxies or protoclusters.

This process should explain another open astrophysical mystery: Why does there exist a gap in the distribution of the masses of BHs **[21][22]**, between the solar mass BHs, on the order of 3 - 20 $M_{\odot}$, with IMBHs on the order of 10^4 - 10^6 $M_{\odot}$, and SMBHs, on the order of 10^6 - 10^9 $M_{\odot}$? ***Since the BHs remain radiative for a specific duration of cosmic time, only BHs of a certain mass or greater will remain after the re-transition is achieved. All BHs with masses below that threshold would have completely radiated themselves out of existence, while the remaining IMBHs and SMBHs would transition back into ideal thermal sinks and become the core of their respective dwarf galaxies, GCs, or galaxies created in the new cycle.*** New solar mass BHs would eventually form in the conventional manner creating the gap observed between the mass distribution of solar mass BHs and MBHs seen in the present epoch.

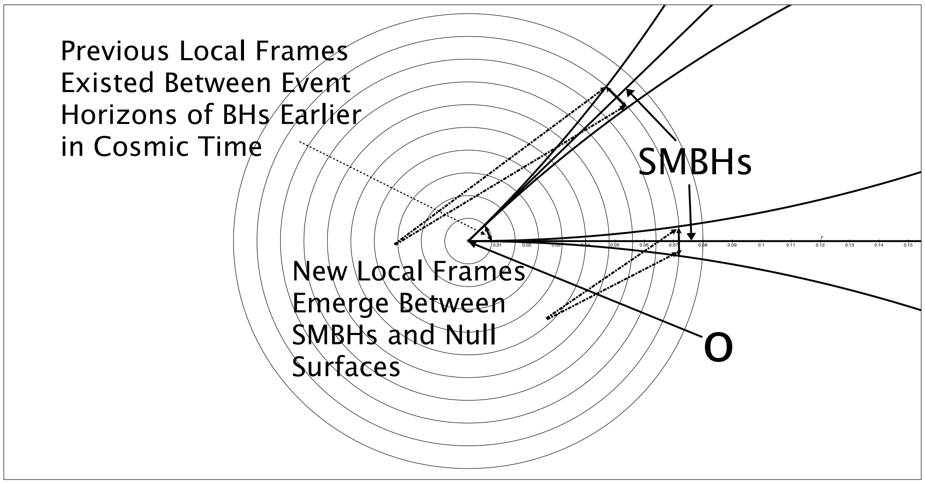


Fig. 7

VII. Unique Cosmic Architecture

It is the separation of events that ultimately defines the dual nature of spacetime. Space-like events early in the cosmic cycle, near the singularity, are cosmically near each other while being locally distant. Likewise, the space-like separation of events late in the cosmic cycle become locally nearer as the cosmos expands. Although counterintuitive, this is due to the change of the null surface through cosmic time. The angle between the null surface and the spacelike hypersphere decreases as cosmic time increases. (Endnotes B) The shallow angle that occurs late in a cycle becomes increasingly comparable to the angles of light cones on the scale of our normal experience.**[23]** This amounts to a contraction of local spacetime even though cosmic spacetime is uniformly expanding.

We have spent the majority of this paper discussing implications of the FPC as it relates to our definitions of spacetime and of BH exteriors. Does the HBCS model suggest what might exist on the interior of a BH's horizon? What happens to the light trajectories as $T \rightarrow \infty$ in our basic model Fig. 2 containing no BHs? The slope of the tangent line to the null surface approaches the surface of the hypersphere. (Endnotes B) This is equivalent to the photon sphere surrounding a BH and thus we can deduce that our cosmos is indistinguishable from an expanding hyperspherical surface on the interior of a BH. Our model is not the first to suggest such a proposal. **[24][25]** Thus, BH singularities $\equiv$ cosmic singularities.

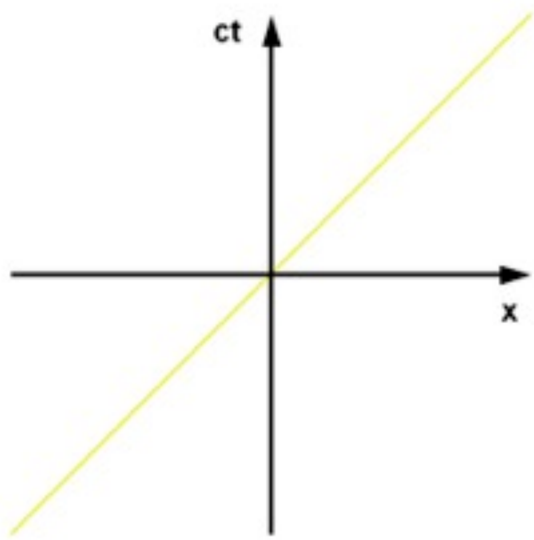
The HBCS model represents a unique cosmic architecture. Our cosmos is bounded by the horizon in the infinite cosmic future, as well as locally, by the horizons of all BHs embedded within it. The cyclicality of our model has been described as “eternal”, but would better be described as “indeterminable”, since the cosmos is dependent on the existence of the BH that both created and encompasses it, and that BH’s existence had a beginning and has an uncertain future. It will remain an open question whether all BHs create universes such as our own, but it is absurd to reason that our cosmos is solitary given the sheer number of BHs known to exist and as well as the all the possible hyperspherical surfaces parallel to our own within our same cosmic horizon. If true, then some, if not all BHs in our universe contain subset universes to our own and our universe is a subset of an even greater cosmos containing many such subset universes, and so forth, ad infinitum.

Technical Endnotes

A) Spacetime Renormalization

To renormalize the spacetime associated with each point on the logarithmic spiral[3] so that it is equivalent to Minkowski spacetime:

$$b = \cot\phi = \cot(45^\circ) \equiv \cot\frac{\pi}{4} = 1$$



The equations $r = A\theta$ with (A arbitrarily set = 1) and $ct \equiv r = \alpha e^{b\theta}$ (with b=1) coincide when:

$$r = \theta = \alpha e^{\theta} \qquad (1)$$

solving for α in terms of θ gives:

$$\alpha = \theta e^{-\theta}$$

now, for a logarithmic spiral, the angle, $\phi(\theta) = \theta$ in general, or in our particular case:

$$\theta = \phi = \cot^{-1}(1) = \frac{\pi}{4} \qquad \text{thus}$$

$$\alpha = \frac{\pi}{4} e^{-\frac{\pi}{4}} \qquad \text{and substituting into (1) gives:}$$

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[3] For on online reference for logarithmic spirals see: Weisstein, Eric W. "Logarithmic Spiral." From MathWorld--A Wolfram Web Resource. http://mathworld.wolfram.com/LogarithmicSpiral.html

$$r = \frac{\pi}{4} e^{-\frac{\pi}{4}} e^{\theta} = \frac{\pi}{4} e^{\theta - \frac{\pi}{4}}$$

but $ct \equiv r$ (for logarithmic spiral) and $T = \theta$ then for t in terms of T:

$$ct = \frac{\pi}{4} e^{T - \frac{\pi}{4}}$$

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B) Cosmic Spacetime Limit

The angle, ψ between the tangent of the Archimedes' Spiral[4] ($r = \theta$) and the radial line is:

$$\psi = \tan^{-1}\left(\frac{r}{\frac{dr}{d\theta}}\right) = \tan^{-1}\left(\frac{r}{1}\right) = \tan^{-1} r \equiv \tan^{-1} T$$

$$\lim_{T \to \infty}\left(\tan^{-1} T\right) = \frac{\pi}{2}$$

so as $T \to \infty$, the Archimedes' Spiral approaches a circle, and the Archimedes' Spiral Surface of Revolution about the world line (future null surface) approaches the surface of a hypersphere.

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[4] For an online reference to Archimedes' Spirals see: Weisstein, Eric W. "Archimedes' Spiral." From MathWorld--A Wolfram Web Resource. http://mathworld.wolfram.com/ArchimedesSpiral.html

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[3] American Scientist, September-October 2007, Volume 95, Number 5, Modern Cosmology: Science or Folktale?, by Michael J. Disney, http://www.americanscientist.org/issues/pub/2007/9/modern-cosmology-science-or-folktale

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