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Part II: Explaining Black Hole Growth due to Universal Expansion: Probabilistic Spacetime versus GEODEs

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Abstract

Recent research indicates that black holes can grow based on the expansion of the universe and not just through accretion and mergers. Two different models independently predicted that finding. One model, describing the relevant massive star remnants as "generic objects of dark energy", rejects the traditional view of black holes while hypothesizing that dark energy causes the cosmologically coupled growth of these objects. The other model, based on the probabilistic spacetime theory, indicates the growth of black holes is based on the same spacetime mechanism underlying all universal expansion, and does so while leaving the traditional black hole conceptualization essentially intact. The fact these two models predicted this observational finding but did so from different perspectives suggests more can be learned by further study of their differences. This paper explores similarities and differences in the two models' explanations for massive star remnants' growth, concluding with suggestions for research testing their relative veracity. An exploration of the relative utility and parsimony of the two models is also described.

Keywords

Probabilistic Spacetime, GEODE, Cosmological Coupling, Universal Expansion, Black Holes

1. Introduction

This is the second of three articles demonstrating how the Probabilistic Spacetime Theory (PST) explains previously unexpected experimental and observational research findings. Each of the three articles shows how the PST delineates the underlying mechanism for unexpected phenomena. The purposes of these articles are: 1) to offer explanations of the unexplained and 2) to further observational and experimental research concerning either the PST's facets and predictions or its relative value compared to other models.

This article addresses the growth of black holes (BH) when accretion and mergers are not involved. Until recently, it was thought that BHs (or analogous entities) only grew through those two methods of direct ingestion of matter. The idea that the expansion of the universe also necessarily affects the growth rate of black holes was rejected as recently as three years ago [1]. In contrast, two different models currently exist that explicitly predicted the growth of BHs conjoint to the expansion of the universe. Those two models, referred herein as the GEODE model and the PST model, are the subject of this paper.

Of great relevance to the discussion herein is that observational research has very recently demonstrated support for the idea that BHs do grow without accompanying accretion or mergers [2] [3]. At least to that degree, then, both cosmological models discussed in this article have support for at least one main tenet.

The models also share a perspective on the cause for that growth. Each model sees one cause underlying both BH growth and the more general expansion of the universe. However, the models do not agree on what that single underlying cause is.

The models also differ in other significant ways. These differences result in substantial dissimilarities in predictions concerning related and tangentially related phenomena.

This paper compares the two models regarding both their important similarities and crucial differences. The purpose of this comparison is to elucidate theoretical differences that can then be put to assess which model shows the greater veracity and, more importantly, better promotes our understanding of the universe.

The outline of this paper is as follows: Section 2 describes the model involving GEODEs ("GEneric Objects of Dark Matter"), the explanation of massive star remnant growth due to dark energy. This is followed in Section 3 with the PST and how it explicates BH growth due to universal expansion. Section 4 delineates the main similarities across, and differences between the two models for the purpose of facilitating research that will differentiate between the two. The final discussion compares the current comprehensiveness and parsimony of the two models.

2. Cosmological Coupling and GEODEs

The model promoted by Croker and colleagues does not start with traditionally conceptualized BHs. Based upon numerous considerations, the researchers' conceptualization of the nature of at least some massive star remnants involved compact objects with no singularity, no event horizon, and an averaged internal pressure that does not vanish [4] [5] [6] [7]. These parameters for defining compact objects for study, as opposed to the more traditional parameters for BHs, were determined based on the researchers' assessments of a myriad of others' theories and analyses.

After years of work involving more than twenty researchers, they very recently completed observational and analytic research that led them to two main conclusions concerning the nature of these compact objects [2] [3]. First, the interior of these compact objects is composed of "vacuum energy". This determination was based on all five observational comparisons within their research indicating the redshift dependence of mass growth had the same value as predicted by growth due to cosmological coupling alone. Second, the researchers' analyses led them to conclude their earlier hypothesis of GEODEs [4] [5] [6] [7] was supported in that this vacuum energy was dark energy (DE).

There was a specific logic behind that second conclusion. If, as their observational research already demonstrated, a BH's growth can exceed its accretion and mergers, that population of BHs will, in aggregate, contribute as a nearly cosmological constant energy density. However, from a stress-energy conservation perspective, these BHs must also contribute cosmological pressure equal to the negative of their energy density. BHs with a specific cosmological coupling strength (of ~3) therefore must be a cosmological DE species of BHs [3].

Overall, the researchers concluded that these BHs both act with black hole level gravity and serve as a major source of DE to the universe. And of relevance to this paper, the researchers concluded that at least certain BHs, these GEODEs, grow because they are composed of DE and as such are cosmologically coupled to universal expansion. The hypothesized mechanism for GEODE growth is the negative pressure stemming from their internal DE.

3. The PST and BHs' Growth Sans Matter

Initially in this section, the relevant tenets of the Probabilistic Spacetime Theory (PST) are described. This digression is to make the subsequent explication of BH growth without accretion or merger (what will be called "sans matter") most clear.

3.1. The Relevant Tenets of the PST

The PST has five main principles:

1) Spacetime is the fundamental entity of the universe.

2) Once a quantum of spacetime (called a "probability") exists, it cannot be destroyed.

3) All fields are derivative from spacetime (which in volume is called the "probability field").

4) The probability field has phases.

5) Derivatives of the probability field cause it to be self-attractive.

Details concerning all these tenets are described in the original article presenting the theory [8]. To explicate the mechanics of BHs, only the first, second and fourth principles are of significant relevance. These three will therefore be explained briefly here.

The first principle was described in our Part I paper in this three-part series [9] in the following way:

> Briefly, the PST posits spacetime is not simply a void or empty container of energy fields but is itself composed of wave functions of probabilistic energy. These energy fragments are the most fundamental entities in the universe. Nothing else is more fundamental. Everything in the universe has its roots in the probabilistic energy we call spacetime.

The second and fourth PST principles are the basis for how the PST views the internal workings of BHs. As described in an article offering resolution to the BH information paradox [10],

> …the PST readily accepts the existence of intense gravity wells called BHs and their event horizons to which infalling matter and radiation cannot return once passed. As is typically accepted, mass and radiation are stretched and torn apart starting around the time they enter a BH (exactly when being dependent on the size of the BH) and certainly as they approach the core. The tearing apart of mass and radiation results in phase changes in their composite probabilities, ultimately decomposing them back to their original probabilistic spacetime state. As the BH's core is approached, the bunching probabilities approach their maximum density. Even at the core of the most massive BH, where the degree of overlap of their wave functions is nearly complete, the probabilistic energy fragments necessarily continue to exist. Spacetime is the ultimate and invariable breaking (sic) mechanism to a BH's gravitational force. No singularity can ever form because spacetime itself prevents it.

3.2. The Source of New Spacetime Energy

The principles of the PST dramatically narrow the options for explaining the ongoing expansion of the universe. Universal expansion necessarily means there is more spacetime. And because the PST mandates that each quantum of spacetime is an energy fragment, adding spacetime to the universe means adding energy. The question is from where this added energy is derived.

The first law of thermodynamics indicates that the energy must be derived from something equivalent. Considering the known increasing rate of universal expansion [11], an ever-increasing amount of new energy would seem to be required from the confines of the universe.

One attempt to address this need is the zero-energy universe model. This model conceptualizes all of matter and energy together, with a matter field with positive energy and a gravitational field with negative energy [12] [13]. The PST's principles (1 and 4) prevent the acceptance of this model. Spacetime energy is seen as the source of all gravity, but likewise seen simply as in a different phase from matter. Additionally, observational evidence indicates that gravitational energy from visible matter only accounts for a quarter to about a third of the observed total mass-energy density [14]. For the zero-energy universe model to work, another very significant source for negative energy would need to be found. The zero-energy universe model therefore serves as an argument for dark matter. However, the concept of dark matter is explicitly rejected by the PST in favor of gravitational groupings or clumps (high density) of spacetime due to its self-attraction through gravity and its self-generated magnetism. The PST posits it is these clumps of spacetime that bring the "extra" gravity needed to explain the phenomena that "dark matter" was created to explain [8]. The PST and the zero-energy universe model are not compatible.

Another possible source for the new spacetime energy stems from Einstein's theory of general relativity (GR). Although GR can be understood to allow for regions of space that create other regions of space (using positive energy that pushes space outward, and in the process, the stored up gravitational potential energy is converted to intrinsic energy that then fills a newly created volume), there are two significant issues in employing this mechanism:

1) How GR views gravitational potential energy is quite complex. It is not clear if GR views gravitational energy and the energy of spacetime as distinct (this being contrary to the PST idea that spacetime energy and gravitational energy are the same). In fact, it is not even clear that GR posits gravitational energy and gravity are the same [15].

2) More importantly, the allowance from GR for regions of positive energy to push outward is arguably limited to asymptotically flat (versus curved) spacetime [16]. Given this paper specifically concentrates on BHs with their massive gravitational force (which the GR sees, by definition, as curved spacetime), flat spacetime cannot be presumed in the local environment.

Overall, the GR seems able to serve as a viable explanation for the extra energy with certain arguable assumptions.

A third attempt to address the newly added spacetime energy is inherent in the construct of DE. This term is currently a placeholder for some type of energy that we cannot (yet?) detect but hypothetically causes the expansion of the universe. (Importantly, discussions of this construct, as an explanation of why the universe is expanding through some type of repelling force pushing spacetime apart, typically do not include how or even if DE creates new spacetime in the process). Since the raison d'etre for the PST was to explicate the mechanisms for numerous cosmological phenomena without using any "dark" entities, the PST rejects the idea of anything dark including DE. Again, the PST and DE models are not compatible.

Other options for explaining from where the new energy is derived include: 1) the conversion of existing matter to energy and 2) the spreading/thinning out of existing spacetime energy. Both these ideas were explored elsewhere [8] with the conclusion that there simply has not been enough energy available through either of those mechanisms to be consistent with current observations of the universe.

So, how does the PST address the need for new energy when there is nothing available within our universe that fits its parameters? Essentially by the process of elimination, the PST hypothesizes that the energy must come from outside our universe [8]. Spacetime pours in from some other universe/multiverse (and has been doing so in creating the big bang and since). Given the expansion in our universe is metric, the external source of probabilistic energy must be in contact with (have direct access to) every point in our universe (even if our universe is infinite in its dimensions). For that to be true, the external source must surround our universe and be of greater dimension.

Despite such contact, the rate of inpouring of spacetime is not the same everywhere. Obstructions in a local volume slow the rate of inpouring (*i.e.*, slow the expansion rate of the local universe), these obstructions being mass, radiation, and high energy clumps of our own universe's probability field (*i.e.*, its existing spacetime).

Although the idea of an inpouring of spacetime from outside this universe may seem extreme or exotic, the idea has received some support. Based on the inpouring with obstructions concept, the PST accurately predicted that expansion rates (measures of the Hubble constant) would vary depending on the degree to which mass and high energy portions of the probability field are involved in the measurement [8] [11]. Specifically, measurements of the expansion rate involving large bodies of mass (galaxies and galaxy clusters) consistently show slower expansion rates than measurements involving much smaller amounts of mass (e.g., a single star or binary star system) [11]. Likewise, of high relevance here, the PST also posited that some primordial BHs developed directly from the big bang, stemming from non-smooth volumes of spacetime that were then dramatically increased in size through the extreme inpouring of spacetime we call inflation [8]. That mechanism, of cosmological inflation driving the growth of BHs, was delineated prior to the recent observational research findings demonstrating BHs grow with universal expansion [2] [3], as described in the Introduction above.

3.3. How the PST Explains BH Growth Sans Matter

The PST's view of the structure of BHs is traditional except for the rejection of any singularity in its core. The entire interior of all BHs, except for recently infalling mass and radiation, is spacetime. As material moves towards the core, the spacetime probabilities (*i.e.*, wave functions) become more and more dense; that is, their energy overlaps and is shared more and more. At the core, they reach their density limit, resulting in no possibility of an infinite collapse.

As stated above, the mechanism for expansion of the universe is the constant inpouring of spacetime (from outside the universe). That inpouring occurs at a constant rate everywhere except where obstructions (mass, radiation, or denser than usual clumps of spacetime) exist.

The interior of BHs is no exception to this mechanism. Spacetime new to this universe enters every point inside (and outside) a BH it finds room. The simple answer, then, for how the PST explains BH growth sans matter is that BHs grow with the new spacetime that is delivered inside them.

There is more that can be said, however. As described above, the interior of BHs is not of uniform density. At the core, no inpouring of spacetime can occur (*i.e.*, no expansion can occur) because the core's volume is already as dense as probabilistic energy (spacetime) can become. In contrast, at the other end of the BH radius, at the event horizon, the density is essentially the same as just outside the BH (presuming there is no accretion disk). The inpouring rate just inside the horizon therefore is the same rate as just outside the BH. Ultimately, the rate of BH growth is affected by its range of internal densities of probabilistic energy.

We may never be able to measure those interior energy density differences directly. However, we may not need to. Every BH (without accretion or merger) necessarily has an internal energy density ranging from: 1) its core at maximum density, to 2) its event horizon at the universe's energy density baseline as would be found at nearby voids. If we presume that this energy density range is distributed in approximately the same proportions within all BHs, then the degree of internal inpouring obstruction relative to each BH total volume is also always approximately the same. All BHs proportionately have the same energy density distribution and hence the same proportion of obstruction interfering with the inpouring of spacetime.

In contrast, outside the BH, there are fewer if any obstructions (given no infalling matter). Therefore, the PST mandates that the greater internal energy density (compared to outside the BH) means the inside of BHs experience slower spacetime inpouring. In turn, slower inpouring translates to a slower expansion rate.

Therefore, irrelevant of the size of the BH, the PST predicts the sans matter expansion rate of a BH will always be slower compared to the rate of an equal volume of (near-)matter-less spacetime in its vicinity. The BH contains obstacles to the inpouring of spacetime while the exterior spacetime volume (without an accretion disk) does not. If we loosely view the internal structure of a BH as the inside of a sphere, and we presume the differing energy density levels are approximately evenly spaced between the core and the event horizon, we can say the average degree rate of inpouring is the average between the inpouring at the core (which is zero) and at the event horizon (which is the same as just outside the BH). Overall, that average rate of inpouring would therefore be about half the rate as found outside the BH. Therefore, with the stated assumptions, the expansion rate for a BH would be expected to be about half the rate found just outside the BH. However, the accuracy of those assumptions may be questioned.

4. Comparing the Two Models

There are fundamental similarities and differences between the two models for how BHs grow without accretion or merger. This section's enumeration of these is for the purpose of facilitating research to find differential support and hence to further our knowledge.

4.1. Main Similarities between the Two Models

There are some obvious similarities between the GEODE model and the PST model for BH growth sans matter. These include:

1) Both (independently) predicted that BHs grow even without accretion or merger.

2) Both see that growth as caused by an energy source which is directly related to the more general process of universal expansion.

3) Both see the growth as a passive outcome from something coming into existence (in this universe, at least) in the compact object's interior.

4.2. Testable Differences between the Two Models

There are some clear differences between the two models that may guide future research towards determining which model demonstrates greater support. Those differences include:

1) The PST specifies that the BH sans matter growth rate is necessarily less than the rate of expansion outside the BH's horizon, irrelevant of the size of the BH. Given certain assumptions stated above, the best estimate for the BH expansion rate is about half the expansion rate of its surrounding universe irrelevant of the size of the BH. Expressing the GEODE model's projected growth rate is more difficult. The GEODE model's growth rate was expressed specific to BHs of a certain attribute (a cosmological coupling factor strength of about 3) and described in terms of gains in mass proportional to that type of BH (the gain being proportional to scale factor a^{-3}) [3]. This explication of the GEODE's growth rate seems to leave open the possibility that as the pre-existing coupling factor of GEODE varies, so will its rate of sans matter growth. What is clear is that the PST's explanation for BH growth will be disproven if even a single BH can be found whose growth sans matter is faster than the expansion rate of its surrounding spacetime. Given observations of slower than surrounding rates, the models may be differentiated by how close to the observational data is either model's prediction, the PST's "half the local rate" or a computed rate based on a coupling factor determination [3].

2) The PST sees the BH growth sans matter as caused by spacetime energy that is not "dark". The GEODE model uses DE as the energy source for certain compact objects' growth. Research with the goal of ascertaining if DE exists (beyond the fact the universe is expanding) has the potential for differentiating the two growth models. A clear differentiation must be made, however, between a repelling (negative) force and the simple possibility that more spacetime caused the same expansion process. Simply finding an unaccounted source of energy, for example, would not serve as supporting one model over the other. For example, the incredibly precise "Muon g − 2" experiments have found an unac-

counted source affecting the muon's precession in a magnetic field, but the PST offers a straightforward explication of that energy without invoking anything dark [9]. Likewise, the Part III paper in this series uses the PST in the same way, to explain an unaccounted source of energy without invoking anything dark [17].

3) The GEODE model, by definition, sees at least some BHs as DE objects. This conceptualization seems to have implications for the gravitational energy that stems from these objects. In contrast, the PST views gravity surrounding BHs in the traditional way. It may be, before differentiating studies can assess this issue, that the GEODE model needs to be clarified further to specify how massive degrees of gravitational force and the repellant force of DE function in the same massive body. (Does a GEODE both attract matter through gravity but at the same time repel the spacetime in which the matter sits? Does a GEODE's DE affect the curvature of spacetime around the GEODE enough to affect its gravitational energy?) Based on that clarification, there may be differences between the two models that would be testable in how gravitational energy is viewed.

5. Discussions

The above discussion presented a comparison of two models both of which predicted that at least some BHs grow sans matter. The purpose was to develop future research directions that would differentiate the two and hence serve to further our understanding of how this phenomenon occurs.

For the sake of thoroughness, two other considerations will be mentioned here. First, both models serve to address Hawking's BH information paradox [18]. Hawking hypothesized that radiation of virtual particles at a BH's event horizon would eventually cause the BH to disintegrate; but the information trapped inside (from infalling matter) would never have had a way to escape, leading to a loss of information. This loss would be contrary to the physical law of conservation of quantum information. However, the fact BHs grow sans matter and do so at some proportion of the observable universal expansion rate (*i.e.*, at a rate faster than radiation decreases the BH energy) means that BHs will never disintegrate based solely on Hawking radiation. Their growth sans matter more than compensates for any radiation loss of energy. An implication of both the PST and GEODE models is that the conceptualization of an information paradox is faulty due to its failure to account for BH growth sans matter (The PST also offers a resolution to the information paradox even if BHs did not grow sans matter [10]).

Second, any discussion of theoretical models should consider the models' comprehensiveness and parsimony. In general, with everything else equal, the more comprehensive in scope is a model, and the more parsimonious it is (by minimizing invoking new constructs), the more that model is to be favored. Such a model is more explanatory and easier to test than other models. When comparing the PST and the GEODE models from these perspectives, the conclusion seems clear. The PST has been described in detail [8], and used to explicate:

1) a) the attributes of "dark matter" without using anything dark, b) how supermassive BHs came to exist in the primordial universe, c) the universal finding of magnetism, and d) why filaments have angular momentum [8],

2) Why there is "tension" in our determination of the Hubble constant and that tension's resolution [11],

3) Why the standard model failed to be supported in extremely precise muon precession research [9],

4) Why "extra" heat was found in intergalactic hydrogen clouds [17], and

5) A resolution to the BH information paradox even if BH growth sans matter does not occur [10]. (This resolution is still of relevance, despite the paper contents above, in that the GEODE model says only that DE objects grow sans matter. According to that model if BHs exist separate from GEODEs, then the issues related to the information paradox and its resolution would still apply to those BHs.)

In fact, new relationships between phenomena were also uncovered by the PST. For example, the theorized cause for filaments having angular momentum and the cause for universal expansion are the same. This is likely the only theory to say this, as it appears no one has said that DE causes angular momentum in filaments. According to the PST, inpouring spacetime causes both phenomena [8].

At the same time, the PST avoids all mention of dark matter, dark energy, and gravitons; hypothetical entities used to explain observed phenomena despite many years of failure to find evidence of their existence. (The astronomic observations claimed to support the existence of dark matter also support the PST's view of spacetime clumping, and do not differentiate the two [8].) In combination with its explanatory power, this avoidance of "theoretical placeholders" for explaining phenomena exemplifies the PST's parsimony.

The GEODE model is very detailed in its description of at least some compact objects and these objects' explanation of certain phenomena. The analytic basis for the model is extensively described in the researchers' writings [2]-[7]. At the same time, the only hypotheses stemming from this model beyond the existence of GEODEs is where DE resides, that GEODEs are the source of the DE driving universal expansion and, under some circumstances, may serve as a gravitational ("dark matter") halo around galaxies. To be fair to the developers of the GEODE model, they did not design their model to serve as a comprehensive cosmological theory. The PST was developed expressly for that purpose.

Future research may clarify which model better explains how BHs grow sans matter. In the meanwhile, the PST offers cosmological researchers and theorists a great deal of other hypotheses for consideration.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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