Contemporary Physics and Philosophy Approaching the Beginning of Spacetime

philosophy of physics revealing the ultimate question

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31/March/2018

Abstract

There are different traditional answers to the philosophical question "What is Spacetime", but these answers are usually independent of another question "How was this universe born". The latter question is what contemporary physics, such as quantum gravity and elementary particle theory treat and these most advanced physics have not been completely formulated yet. Although what philosophy of science in this field remarks of it may be very limited, I think the former question above in part can be a more helpful clue for this latter question. Although general relativity depicted as the best physical theory in describing curved spacetime with metric may give spacetime the status as a kind of structure rather than as substance, reality of spacetime must have something to do with it's origin. If spacetime is real, it would be true that spacetime occurred with matters when universe was born by the Big Bang or that spacetime had already been existed then. Loop quantum gravity, one of prevailing theories of quantum gravity and is derived from direct canonical quantization of metric, treats spacetime as substance-like if thought simply. How is this view connected with structural spacetime realism? This paper shows realism of spacetime committing the whole history from birth to a present universe according to the standard Big Bang cosmology.

Paper

1. Introduction

In contemporary physic, cosmology makes the subject a whole history of this universe from beginning to end. According to the standard Big Bang cosmology, our universe has grown from a micro size including a singularity to a current macro one. In describing a macro universe, we use general relativity while in a micro universe, we use a theory of quantum gravity. Based on general relativity, there are a lot of arguments about the question "what is spacetime?". Some have standed on substantivalism, others on relationism. Nowadays a view of structural realism has been applied to spacetime (Dorato 2000). This idea of structural spacetime realism seems to me more reasonable than other types of realism. For general relativity introduces a conception of metric and describes a gravitational field, or the spacetime curvature. This field bears the geometrical structure as different forms described by different coordinates we arbitrarily choose and these different forms correspond to a physical situation for general covariance, which is the most important principle in general relativity. So, general relativity looks upon a structure as important, regarding spacetime as metric. But these philosophical arguments about science are not usually applied to cosmology, especially to an early micro universe[1]. Of course there have been a lot of philosophical discussions about how this universe was born, but most of them are not related to contemporary science itself, namely a theory of quantum gravity treating the early universe. This theory has not been formulated yet and science itself is ambiguous about the beginning of this universe, viz. an origin of spacetime. In this paper, at first I will discuss how this view of structural spacetime realism is interpreted in a macro growing universe, based on my published work in Japanese literatures (Fujita 2017). Next, considered from this interpretation of macro universe, I will discuss reality of micro spacetime in an early universe using loop quantum gravity, which is one of prevailing theories of quantum gravity in line with super string theory. If thought simply, this theory treats spacetime as substance-like changing it's size. But if we interpret spacetime from a view point of structural spacetime realism rather than of substantivalism, what picture is gained?

2 . structural spacetime realism in general relativity

In Newtonian mechanics Substantivalism vs Relationalism was first focussed on

[1] In fact, most of these arguments like Brenner (2015) based only on metaphysics, not philosophy of science. But Krauss (2012) and Albert (2012) discusses the origin of universe or vacuum somewhat from physical views

whether spacetime exists or not. But in general relativity, what spacetime refers to has become so equivocal that substantivalist had to manifest which mathematical object represents spacetime mainly, manifold or metric. While manifold is an assembly of points consisting a global topology, metric is local structure between neighbour points. This local relation of points has been directly determined by in part distributions of matters through Einstein equation;

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu}$$

A left-hand side shows a curvature of sacetime on any coordinates, since Ricci tensor $R_{\mu\nu}$ and Ricci scalar R are composed of metric tensor $g_{\mu\nu}$, which is described by a next differential line element;

$$ds^2 = g_{\mu\nu} dx^{\mu} dx^{\nu}$$

Metric refers to this differential line element and connecting this line element leads to a whole structure of spacetime including a global topology in some cases. That structure is not a kind of what we observe directly and whether spacetime exists has been philosophical question[2]. Over the hole argument John Norton and John Earman raised (Norton and Earman, 1987), the view that not manifold but metric plays an essential role in physics was proposed by Tim Maudlin (Maudlin 1988, 1990). Carl Hoefer formulated metric substantivalism(Hoefer, 1996, 1998) and his view implies $T_{\mu\nu}$ =0 means vacuum that there is no matter. In addition, Mauro Dorato formulated structural spacetime realism, which asserts that metric does represent spacetime and that spacetime points have their own properties only from relations, namely a whole structure without primitive identities. He introduced spacetime as below (MS) (Dorato 2000 p.1615).

・To say that space time exists just means that the physical world exemplifies, or instantiate, a web of spatiotemporal relations that are described mathematically[3].

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[2] There were a lot of arguments, but in this paper, I focus on discussions mainly since 1980 because I want to emphasize transitions of substantivalism.

[3] quoting from Dorato (2000) p.1615

He explains structural spacetime realsim is a new proper position in a sense unifying substantivalism and relationism (Dorato 2000, 2008).

3.global metric of macro universe

When physicists discuss the whole our universe, they take it globally uniform as if it were isotopic and homogeneous because universal development happens in such a global scale that it has nothing to do with local affairs. Therefore this universal development is described by Robertson-Walker metric (RW metric) using a polar coordinate (t,r, θ , ϕ) as

$$ds^2 = c^2 dt^2 - a^2(t)[\frac{dr^2}{1-Kr^2} + r^2(d\theta^2 + \sin\theta^2\, d\phi^2)].$$

About derivation of this metric, see Winberg (2005) for example. In this equation, a(t) refers to a scale factor whose value increases as time parameter t passes and t is proper time for observers on the earth. That is, this model shows the scale of universe becomes large as time passes for observers at rest on a co-movig coordinate, which means an elastic space as three dimensional coordinates influenced by a(t). This universe model is compared as a balloon pumped gradually.

But this form as four (one plus three) coordinates (t,r, θ , ϕ) is just one of infinite ones expressing a whole geometric structure. For example, if I transform the coordinate system from this co-moving coordinate (t,r, θ , ϕ) to another static coordinate (t,r, θ , ϕ) by a(t)r=r'. Through this coordinate transformation, a new metric form is written as

$$ds^2 = \left(c^2 - H^2(t){r'}^2\right)dt^2 + 2H(t)dtdr' - \frac{{dr'}^2}{1-\frac{K{r'}^2}{a^2(t)}} - {r'}^2(d\theta^2 + \sin\theta^2\, d\phi^2).$$

Here $H(t) = \frac{\dot{a(t)}}{a(t)}, \dot{a(t)} = \frac{da(t)}{dt}$.

The reason why I call this metric static is that this coordinate has three dimensional spatial parts whose scale is uniform unlike co-moving coordinate whose scale changes as a balloon model. Different places have different speeds of the flow of time represented by t in this new metric[4] and simultaneity can not be defined. This static coordinate has an extremely complicated spacetime structure to imagine. What can be asserted certainly is that two different coordinate systems describe one common spacetime structure for general covariance. If we accept structural spacetime realism, there is no exploding space. For a co-moving coordinate system is just one of the forms and another complex system is the same.

4.To micro universe

Loop quantum gravity theory is consistent with general relativity, but spacetime described by this theory is apparently strange for structural spacetime realists because it has discrete minimal units as noted above. For short, in loop quantum gravity, regularization using functions called holonomy and flux is done so that Wheeler-Dewitt operator derived from metric is well defined (Thieman 1998 2007 and Ashtekar 1997) and general relativity is rewritten to a form like gauge theory using Ashtekar variables (Barbero 1995[24]) for the purpose of canonical quantization in a non-perturbative manner. As a result, volume and surface area of something constituting space are introduced as new physical quantities[5]. This unit is called spinnetwork and exploding space in cosmology is expressed by the increasing number of it or the size of each getting larger with graph theory.

If space has parts in a micro domain, what related each spinnetwork with a whole structure? If each of it exists as a part of space and substance-like, how are spinnetworks arranged. To begin with, there are certainly a relationship between macro structure and micro spinnetworks but the way is not still clear. If metric determines uniquely arrangement of spinnetworks, they are theoretical entities devoid of internal or even primitive identity (heacceity)

[4] Mathematically, a term $2H(t)dtdr$ prevents time from flowing uniformly in each space points unlike a co-moving coordinate system.

[5] The number of given quantity parallel to classical physical quantity which can be calculated is so much limited that loop quantum gravity can't still constitute classical spacetime such as Minkowski spacetime or Schwarzschild space time.

like micro particles and a world is metaphysically invariable for permutation of two arbitrary spinnetworks. This picture of spinnetworks implies ontological structural realism about spacetime rather than old substantivalism. If this picture can be accepted, spacetime would have existed at the beginning of this universe, as long as a structure existed.

Conclusion

I have applied existing philosophical views about spacetime discussed in general relativity to cosmology. Cosmology has two parts, macro present universes described by general relativity and micro early universes described by quantum gravity. If space is structure, spacetime might have existed although I can't speak of micro mechanism of spinnetworks. But this view of structural realism gives us an opportunity to reconsider a philosophical question already premised; What is a substance? I hope philosophical thinking focusing on spacetime will lead to clues to more developments.

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