

# 22

## Did the Universe Have a Beginning?

We have studied the early universe, its evolution, and its eternally inflating future. We are now poised to revisit a question that people have grappled with from the dawn of humanity: Did the universe have a beginning? Or has it always existed?

### 22.1 A Universe that Always Existed?

The notion that the universe has always existed is very appealing. It allows one to circumvent the avalanche of seemingly unassailable questions associated with the beginning of the universe. What caused the universe to appear? “Who/what” sets the initial conditions for the universe? Where did the “who/what” come from? This line of questioning is the endless regression that has haunted theologians, philosophers and scientists for millennia.

To address this issue, we need to investigate if it is possible to scientifically describe a universe that is eternal to the past as well as the future. Let’s begin by remembering that the steady state theory was of this sort. Observations favored the rival big bang, and the steady state theory was discarded. What if we consider an *oscillating* universe that undergoes a perpetual cycle of expansion and contraction—with a big bang followed by a big crunch followed by a big bang and so on? Such oscillating models were briefly considered in the 1930s, but soon they were found to be inconsistent with the second law of thermodynamics. The second law stipulates that each cycle of cosmic expansion is accompanied by an increase in entropy. If the universe had

undergone an infinite number of cycles in its past, the entropy would have reached its maximal value, and the universe would be in a state of thermal equilibrium. But we do not find ourselves in such a state. This is similar to the “heat death” problem of an eternal static universe that we mentioned in Sect. 5.1.1.

In 2002 Paul Steinhardt and Neil Turok introduced a new version of the oscillating model, which they called “the cyclic universe”. As in the older models, each cycle begins with an expanding fireball. As the fireball expands, it cools, galaxies form and then a period of vacuum domination ensues. Once vacuum domination sets in, the universe begins to expand exponentially. This exponential expansion is very slow—it takes about 10 billion years for the universe to double in size. After trillions of years, the expansion slows down and eventually stops and turns into contraction. When the collapse is complete, the universe bounces back to start yet another cycle. In this scenario the universe has eternally been undergoing a sequence of expansion and contraction, and there seems to be no need for a beginning.<sup>1</sup>

But what about the problem of entropy that plagued the original oscillating models? In Steinhardt and Turok’s scenario, the amount of expansion in a cycle exceeds the amount of contraction, so the overall volume of the universe grows. The entropy of our observable region is now the same as the entropy of a similar region in the preceding cycle, but the entropy of the entire universe has increased—simply because the volume has increased. The growth of volume and entropy are both unbounded, and thus the state of maximum entropy is never reached—it does not exist.

Another option for a universe without a beginning is suggested by eternal inflation. Most cosmologists think that a period of cosmic inflation preceded the big bang. Inflation ended in our local region, setting off a local big bang, but continues elsewhere. This naturally raises the question: is it possible that inflation and subsequent big bang events have been occurring in spacetime for all of past eternity? Perhaps our ancestral chain of bubble universes goes back to the infinite past?

It turns out, however, that the idea of a past-eternal universe, either in cyclic or eternally inflating form, runs into a fatal obstruction—as we shall now discuss.

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<sup>1</sup>The cyclic model was introduced as an alternative to inflation, but it is far from being fully developed. To ensure a transition from expansion to contraction, the model requires a scalar field with a judiciously designed energy landscape. It also gives no satisfactory description for the bounce from the big crunch to the big bang. So, as of now, it remains a work in progress.

## 22.2 The BGV Theorem

In 2003, Arvind Borde of Long Island University, Alan Guth and Alex Vilenkin proved a theorem, which implies that even though inflation is eternal to the future, it cannot be eternal to the past and must have had some sort of a beginning. Their conclusions also apply to an oscillating model, which must have had a beginning too.

Borde, Guth and Vilenkin (BGV) investigated what an expanding universe would look like to imaginary observers who are recording their histories as they move through the universe under the influence of gravity and inertia. The observers are presumed to be indestructible, so if the universe had no beginning, the worldlines of all such observers should extend to the infinite past. However, BGV showed, under very plausible assumptions, that this is impossible.<sup>2</sup>

To see why, let us imagine that the entire universe is sprinkled with a “dust” of inertial observers who are all moving away from one another. The existence of such a class of observers can be taken as the definition of an expanding universe. We will call these observers “spectators”. Now, let us consider another observer, the *space traveler*, who has been moving relative to the spectators for all eternity. The space traveler also moves by inertia, with his spaceship engines shut off. As he passes the spectators, they register his velocity.

Since the spectators are flying apart, the space traveler’s velocity relative to each successive spectator will be smaller than his velocity relative to the preceding one. Suppose, for example, the space traveler passes the Earth at 100,000 km/s and is now headed towards a distant galaxy, about a billion light years away. Since that galaxy is moving away from us at 20,000 km/s, when the space traveler reaches it, the spectators there will see him moving at 80,000 km/s.

If the velocity of the space traveler relative to the spectators gets smaller and smaller into the future, then his velocity should get larger and larger as we follow his history into the past. In the limit, his velocity approaches the speed of light. The key insight in the BGV paper is that this limiting velocity is reached in a finite time by the space traveler’s clock. The reason is due to time dilation—remember moving clocks tick slower. As we go backward in time, the speed of the space traveler approaches that of light, and his clock

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<sup>2</sup>The BGV theorem states that if the universe is, on average, expanding, then its history cannot be indefinitely continued into the past. The theorem allows for some periods of contraction, but on average expansion is assumed to prevail.

essentially freezes—from the spectator’s point of view. The space traveler himself does not notice anything unusual—his time flows from one moment to the next. Like the histories of the spectators, the space traveler’s history should extend into the infinite past.

The fact that the time elapsed by the space traveler’s clock is finite tells us that we do not have his full history. In technical language, physicists say that the space traveler’s world line is incomplete. This means that some part of the past history of the universe is missing; it is not included in the model. Thus, the assumption that the entire spacetime can be covered by an expanding dust of observers has led to a contradiction, and therefore it cannot be true.

The BGV theorem is very general. It makes no assumptions about the material content of the universe and does not even assume that gravity is described by Einstein’s equations. So, if Einstein’s theory requires some modification, the theorem would still hold. The only assumption it makes is that the universe is expanding at some non-zero rate (no matter how small). This should be satisfied by any model of eternal inflation. Thus we are led to the conclusion that past-eternal inflation without a beginning is impossible.<sup>3</sup>

Past-eternal cyclic models without a beginning are also ruled out. The volume of the universe increases in each cycle, hence the universe expands on average. This means that the space traveler’s velocity increases on average as we go back in time, and approaches the speed of light in the limit. Thus the same conclusions apply.

### 22.2.1 Where Does This Leave Us?

In Chap. 7 we discussed how scientists were drawn to the steady state theory over the big bang, because it avoided the question of a cosmic beginning. However, despite philosophical prejudice, the data had spoken and scientists had to press forward trying to uncover what they could about the universe in the context of the big bang model. Along the way they discovered inflation, and then eternal inflation. Our picture of the universe beginning with a one-time big bang event has given way to a much grander picture of an eternally inflating spacetime constantly spawning local big bangs. This worldview has the same spirit as the steady state theory, and many people once again hoped that maybe on a far greater scale the universe is indeed

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<sup>3</sup>Note that it follows from the BGV theorem that the universe of the steady state model must also have a beginning.

eternal—with ancestor bubbles nucleating *ad infinitum* into the past. Now, however, we know that this is not possible. And once again, the beginning of the universe must be tackled head on.

### 22.2.2 A Proof of God?

Theologians and some religiously inclined scientists have often welcomed any evidence for the beginning of the universe, regarding it as evidence for the existence of God. On the other hand, a number of atheist scientists have argued that modern science leaves no room for God. A series of science-religion debates have been staged, with atheists like Richard Dawkins, Daniel Dennett and Lawrence Krauss combatting theists like William Lane Craig. The BGV theorem has often been raised as evidence for God by the theistic side.

It seems unlikely that science can disprove the existence of God, especially considering that “God” means different things to different people. Are we talking about the God of the Hebrew Bible or the rationalistic God of Spinoza and Einstein? A scientific proof of God based on the BGV theorem appears even more dubious.

The cosmological argument for the existence of God, dating back to Aquinas, consists of two parts. The first part is apparently very straightforward: “Everything that begins to exist has a cause. The universe began to exist. Therefore, the universe has a cause.” The second part affirms that the cause must be God. In the next chapter we will deconstruct this argument. We will argue that modern physics can describe the emergence of the universe as a physical process that does not require any supernatural cause.

#### Summary

The Borde–Guth–Vilenkin theorem says that the history of any expanding universe cannot be indefinitely continued into the past. An immediate implication is that inflation, even though it may be eternal to the future, cannot be eternal to the past and must have had a beginning.

We are thus faced with the question of what happened before inflation. And whatever the answer is, we can keep asking: “And what happened before that?” Thus the question of *how the universe began* is still enveloped in a cocoon of mystery.

**Questions**

1. Do you find the notion of an eternal universe to be preferable to a universe that somehow came into being from nothing?
2. Inflation is almost certainly eternal to the future. Is it eternal to the past too? Why/why not?
3. (a) State the BGV theorem. (b) Suppose future research shows that Einstein's theory of gravity needs to be modified. Could this invalidate the BGV theorem? (c) Does the BGV theorem make any assumption as to whether or not the universe is spatially finite or infinite?
4. Imagine a static closed universe, which existed in this state from past eternity until some moment when the static phase ended and inflation began. Does this model contradict the BGV theorem? If not, do you see any other problems with this scenario?
5. Do you think a scientific proof of a beginning implies there had to be a creator?