We've seen how string theory builds black holes and resolves the conundrum of information loss in a black hole (it's not lost – it's sitting on the horizon). Next we turn our attention outward, to the cosmos. We find another event horizon, and, beyond, the string landscape.

The cosmic horizon

Strange and not-so strange things happen at the event horizon of a black hole, depending on your frame of reference. But, curiouser and curiouser, we find ourselves surrounded by another horizon, the cosmic event horizon. Its origin is different, but its physics are similar.

Some background. In the last century, Edwin Hubble and Milton Humason discovered that the universe is expanding. At the largest scales, galaxies are flying away from each other at speeds proportional to their separation. More recently, astronomers discovered that the expansion is accelerating. The galaxies this year are flying away from each other faster than they were last year.

Describing such a universe demands a new tool in the toolkit. Cosmologists employ a scale factor, a , for measuring the universe. Here's how it works.

Imagine the universe on a stretchy sheet. Galaxies are labeled by their coordinate positions on a standard Cartesian grid. Pick two galaxies for reference. (All other pairs will behave the same as these two.) Label their coordinate positions x_1 and x_2 . Assign this starting configuration scale factor 1 . The distance between the two galaxies measured by an observer outside the system is

$$D_1 = a\Delta x = a(x_2 - x_1) = (x_2 - x_1) \tag{31.1}$$

Now imagine that the whole universe-on-the-stretchy-sheet stretches uniformly in all directions in the plane, such that the distance between galaxies doubles.

$$D_2 = a\Delta x = 2(x_2 - x_1) \tag{31.2}$$

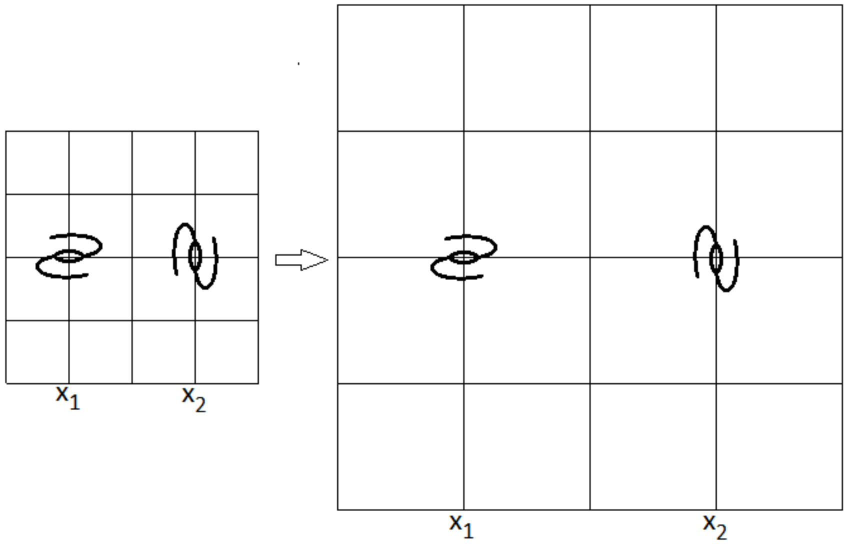

Figure 31.1. Galaxies in an expanding spacetime at reference time when $a = 1$ (left) and later in the age of the universe when $a = 2$.

Remember, the x's are just coordinate labels. It's the scale factor that determines the measured distance between them. In this way of thinking, distance between galaxies changes over time because the scale factor, not the coordinate position, is a function of time.

$$D = a(t)\Delta x \tag{31.3}$$

In an expanding universe the scale factor increases over time. The metric for this universe is

$$ds^2 = -dt^2 + a(t)^2 dx^2 \tag{31.4}$$

Imagine, further, that the stretchy stuff between the galaxies, the fabric of spacetime, maintains a constant energy density. As it stretches, something fills the gaps. More on this soon.

We are interested in the rate of expansion. Start with the velocity, v, at which galaxies recede from each other.

$$v = \frac{dD}{dt} = \frac{da}{dt}\Delta x = \dot{a}\Delta x \tag{31.5}$$

We substitute $\Delta x = \frac{D}{a}$ on the right.

$$v = \frac{\dot{a}}{a} D \tag{31.6}$$

Define

$$\frac{\dot{a}}{a} \equiv H \tag{31.7}$$

where H is the Hubble constant. Finally, we write

$$v = HD \tag{31.8}$$

We have nearly reached the cosmic horizon (in our logical analysis, anyway). By this equation, if H is in fact constant over time (and evidence is that's the case), then there is a distance D at which

$$v = HD = c \tag{31.9}$$

If two galaxies are separated by this distance, they lose contact with each other. More accurately, as the separation between two galaxies approaches this distance, an observer on one of the galaxies sees clocks on the other ticking slower and meter sticks on the other shrinking along the direction of separation. Just as if the other galaxy was approaching the event horizon of a black hole.

So there is an effective boundary to the observable universe, from beyond which we can receive no information. There are other galaxies out there, billions of them, beyond the cosmic horizon. But they are forever hidden from us.

It's as if there's a black hole wrapped around our universe.

There's more. We've noted that the expansion is accelerating. How can that be, if H is constant? Turns out constant H requires the acceleration. Here's the logic.

$$\frac{\dot{a}}{a} \equiv H \tag{31.10}$$

so

$$\frac{da}{dt} = Ha \tag{31.11}$$

The rate of expansion increases as the scale factor itself increases. The bigger the universe gets, the faster the galaxies fly away from each other. Solving this differential equation

$$a = e^{Ht} \tag{31.12}$$

The scale factor is an exponential function of time. All the pieces of the jigsaw fit, and the mathematical jigsaw reproduces what we actually see.

One last note, for completeness. The metric now reads

$$ds^2 = -dt^2 + e^{2Ht}dx^2 \tag{31.13}$$

That's our universe.

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