Events and the Nature of Time: Raphael Bousso

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Transcript - Long

Robert Lawrence Kuhn:

Raphael, two of the greatest contributions in human knowledge are quantum theory of the very small, subatomic, and cosmology, the study of the whole universe. In recent years, we've been hearing about quantum cosmology, which sounds like a contradiction in dealing with the entire universe in such a small way. What is the background of that? What are some of the activities that one does as a quantum cosmologist?

Raphael Bousso:

Quantum cosmology is probably the hardest part, I would bet, of, of quantum gravity. So, we have these two theories, quantum mechanics and general relativity. One tends to describe smaller things, and the other one describes gravitation, which is important for big things, especially the universe, and they're hard to put together. And that problem is already hard when we are dealing with simpler situations than the whole universe and it has not been definitively solved. There are some beautiful ideas and there are some breakthroughs in certain subareas, but we don't generally know how to do quantum gravity. I suspect if we did, we would know how to apply it to the whole universe. Places where it gets a little bit easier, though still hard, is when you have isolated systems, a black hole, gravitational, tiny perturbations that are sort of quantum-like that interact with each other, and which are being observed far, far away by an observer who doesn't directly play a role in their interaction. They just send something in and watch something come out. In situations like this, we have theories which are already allowing us to compute quantum gravitational processes.

Robert Lawrence Kuhn:

Even without a theory of quantum gravity?

Raphael Bousso:

Well, so you can, we have a complete theory of quantum gravity which, which relies on not being in the universe that we are in, which sounds terrible, but actually for questions like the one I just described, where you have sort of a large, empty region, and then you send something in, and you watch it come out again, it doesn't really matter if far away the universe looks like the one we're in or not. And so, for questions like that, that theory is, is more than adequate, so it's a very beautiful step that we've taken, but, but this theory, not describing our universe, seems to be very deeply built into it, this limitation, and when we think about how we might describe the universe as a whole, quantum mechanically, then indeed there are, there's a whole new set of questions that we have to deal with that have to do with the fact that we're no longer outside, looking in. We're inside, looking out, and that is a very profound challenge.

Robert Lawrence Kuhn:

It's almost contradictory to the concept of quantum mechanics.

Raphael Bousso:

It's not how quantum mechanics is done most of the time and, and it really brings out all the, the challenges and contradictions that you can possibly get when you try to do quantum mechanics and general relativity together. In fact, it's not even clear what the theory should be computing for us. It's not clear what the observables should be. In these idealized situations where you're far away, there are what you might call exact observables. There are things that you can, in principle, measure as well as you like and therefore the theory can, should be able to and can compute them to any precision you like. There are good reasons to believe that in cosmology, as soon as you include quantum effects, an observer inside the universe should not have access to arbitrary, arbitrarily precise measurements. For example, if I tried to measure an arbitrarily small distance scale, I'd have to use a lot of energy, and if I use too much energy, I make a big black hole that actually distorts the region that I tried to measure, in a very severe way, thanks to effects of gravity. So, quantum mechanics and gravity have an interplay now which, which prevents arbitrarily accurate measurements from even being conceivable, it seems.

Robert Lawrence Kuhn:

If one had a complete theory of the quantum mechanics of the universe, a wave function of the entire universe, what would that mean? What does that mean?

Raphael Bousso:

Well, that's what I'm trying to get across is that even if I didn't know what the theory said in detail, I would just like to know what it is that it computes for us. What is it that, that are sort of the fundamental observables in quantum cosmology? It's, that's how far we are, I think, from understanding the solution to this problem.

Robert Lawrence Kuhn:

But what are some options? What could it be? Is there a range?

Raphael Bousso:

Well, one thing that we like to cling to, as physicists, is that the theory has to, at the very least, at the very least, you know, reproduce all the observations that we, we know we can make, to a degree of precision that we know we can make them, but beyond that, it's not, it's not like we have a very clear list of options, you know. It's, this is a wide-open problem. I mean, I think of, again, of all the aspects of quantum gravity that you might worry about, this is, by far, the least understood. One, one angle where I think we have made some progress is, is the following. There's this famous thing called the second law of thermodynamics, which, which until recently we would not even have known how to apply in any rigorous, meaningful way to the universe because again, you know, it makes good sense to say, okay, if I have, if I have a certain isolated system and I let it evolve in time and I don't pay attention to all the details, so I coarse grain in some ways, there's more and more ignorance that builds up that I have about the internal state of the system and that's, that increase in chaos or ignorance, I shouldn't really say ignorance, is, is, is the second law of thermodynamics. That always goes up. In the case of the universe, well, how are you going to decide, you know, what the system even is that you're going to become more, you know, that's going to have more and more options about which state it could be in in detail? And, and there, I think we've learned a bit. We've learned that we can probably describe the situation somewhat analogously to the way that we describe the second law for black holes, where, you know, when you destroy matter by throwing it into a black hole, the second law keeps operating by the black hole area getting bigger. When the black hole evaporates, the second law keeps operating because it produces radiation, which has a lot of possible states. Similarly, in the universe, it turns out that if you look at everything we can see, and you look at how many states that has, and then you add to it the largest area bounding the region that we can see, that that always increases. I think one thing that that is telling us is that it's really a very tight marriage of gravitational degrees of freedom, little wiggly bits, and the matter little wiggly bits, the matter degrees of freedom that only when you describe them together can you make sense of fundamental laws, such as the second law of thermodynamics, and hopefully by studying those kinds of evolutional laws in more detail, we can, we can find an angle in to understanding how quantum cosmology works.

Robert Lawrence Kuhn:

And to be able to explain the second law of thermodynamics, entropy and all of that, would really be a fundamental advance in terms of thinking, in terms of what really causes that to be a law.

Raphael Bousso:

Right. It will be, you know, there's, there's an old joke about, I can't remember which physicist was supposed to have said it, but you know, if, if your theory conflicts with the experiment, never worry, you know, the experiment's probably wrong, but if it conflicts with the second law of thermodynamics, forget about it. It's really a very fundamental law because it's essentially just math, and, and it can, by trying to make the quantum description of the universe fit into that law, I think that's a good strategy because that law is so robust. I mean, you're always taking guesses when you're trying to discover something new. You're, you have to go with something. The second law is a really good thing to go with and so by trying to make your theory fit in with that, I think that constrains your approaches somewhat, and I'm very excited that in the last few years we've been able to make that happen, and I'm optimistic that that is going to lead to new insights into how to construct a quantum theory of gravity that can deal with cosmology.