**MARKUS KLUTE:** Welcome back to 8.20, Special Relativity. In this section, we talk about the famous twin paradox. It's probably the most famous paradox in special relativity. I want to get to the bottom of this, and understand really where there is a conflicting or contradictory statement in this story.

Let me just first say that this is personal to me. I do have a twin brother, and you can see three pictures of myself and my twin brother here. We were very little on our first day of school in Germany. You get a little box of candy when you go to schools to make it more attractive to actually learn and study. And then a picture, which is probably already about 10 years old.

What you can take away from here is clearly moving clocks are slow. It turns out that my twin brother lives in the very same village in Germany where I grew up, where we both grew up, while I traveled the world constantly and constantly on the road between France and Geneva and Switzerland and the United States. And again, I think there is no dispute here. It can be seen from this picture that your professor looks much younger.

I even have a more recent picture. This is two years ago. The German Kris Kringle Market, where I asked my brother to take this picture for this class, for 8.20. And again, I think the answer to the question is clear. Professor Klute has aged less.

All right. On a more serious note, we're going to quantitatively understand and analyze the situation. And we use Bob and Alice again. In this situation, here Bob stays local. Alice has a spacecraft, and she moves with the velocity of 0.6, six times the speed of light, a gamma factor of 1.25.

The travel takes her to a distant star, which is in this example It's three light years away from Bob, measured by Bob. The journey takes her, on Bob's clock, five years, and the return takes another five years. She doesn't spend much time. She wants to go home as quickly as possible.

If you analyze this, from Alice's perspective, we see that for Alice, the journey takes four years, and the distance traveled for her in a spacecraft is 0. From Bob's perspective, the journey, as seen by Alice, is only 3.2 years long. And so we find that there's already a conflict. If you add the times together, both ways, the inbound and the outbound ways, 6.4 years is not equal to 10 years. So there's already a contradictory statement in this story.

But the key to the understanding of this problem is that Alice, in order to return, has to change reference points. And there, we do have to resynchronize the clocks, if you want, or add a specific extra factor. And we'll go back to this when we look at space and [INAUDIBLE].

So the time, as seen by Bob, is 3.2 years for the outbound journey, and then 3.6 years in order to resynchronize the clocks on the return, on the turning around. And then 3.2 years on the return, which makes 10 years. And so that observation of Bob, of Alice, is in agreement with Bob's own clock. All right. So we saved the day here.

Let's look at space-time diagrams. The outbound journey is shown here. You see I've got it-- in addition to Bob's reference frame, I've plotted Alice's reference, and it makes it easier to understand what's going on. So we see in Alice's reference frame, the journey takes four years. If you then go back to the position in which Bob is, 3.2 years have passed. So this is iffy.

At the time when Alice arrives we go back to the position of Bob, 3.2 years have passed. We then turn around and ask the very same question. At that time-- it's still four years-- we go back the other direction now to Bob, we are already much further ahead, 3.2 years plus 3.6 years. And then the journey continues, and we add another 3.2 years to the journey. When Alice and Bob reunite, Alice aged by eight years, 2 times 4, and Bob aged by 10 years.

So the question now is, there may be a paradox here. Is it possible that we missed somehow that by-- and try to understand why this is a probably not symmetric. Why can I not just use the other reference frame, and just declare that Alice stayed stationary in her spacecraft while Bob moved away with Earth and then came back? Why are those two things not consistent?

The answer is that it's not Bob who has to change reference frame, but Alice. It's Alice who has to do this. There is where the asymmetry is. You can argue if you want that, in order for Alice to do that, she actually has to accelerate. But we don't have any sort of discussion of how the acceleration actually went about. It's really the change in reference frame which is crucial in this discussion, and causes the asymmetry between Bob and Alice.