

# Epstein Relativity Diagrams

Michael Weiss

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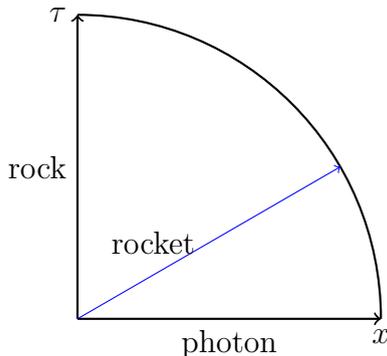
Lewis Carroll Epstein wrote a book *Relativity Visualized*. It's been called "the gold nugget of relativity books". I wouldn't go quite *that* far, but Epstein has devised a completely new way to explain relativity. The key concept: the Epstein diagram. (I should mention that *Relativity Visualized* is a pop-sci treatment.)

Here's how Epstein introduces his idea:

Why can't you travel faster than light? THE REASON YOU CAN'T GO FASTER THAN THE SPEED OF LIGHT IS THAT YOU CAN'T GO SLOWER. THERE IS ONLY ONE SPEED. EVERYTHING, INCLUDING YOU, IS ALWAYS MOVING AT THE SPEED OF LIGHT. *How can you be moving if you are at rest in a chair? You are moving through time.*

This is both poetic and (I feel) unnecessarily mystifying. Let me quickly add: Epstein does not want you to take this literally. It appears in a chapter titled "The Myth", where Epstein advocates for "myths"—I'd call them analogies—to help us grasp the basic concepts of physics. You can't argue with that. (Well you *can*, but you shouldn't.)

I'll undertake demystification in a moment. But first, here's the prototypical Epstein diagram:



As with Minkowski diagrams, we ask two spatial dimensions to leave the room so we can draw on a 2D screen. Note that the vertical axis is labeled  $\tau$ , for proper time. In a Minkowski diagram, this would be labeled  $t$ , of course.

The rock, the rocket, and the photon all enjoy a mythical speed of 1 (setting  $c = 1$ , as usual). Our rock sits still (in the lab frame, let's say). So its mythical speed consists entirely of motion through time. The photon travels through space as fast as possible, with nothing is left over for motion through time. Its elapsed proper time is zero. The rocket devotes some mythical speed to spatial motion, some to temporal motion. I've illustrated the case where  $dx/dt = \sqrt{3}/2$ , so in one coordinate second it covers approximately 0.87 light-seconds of distance and  $1/2$  second of proper time.

OK, what's really going on? Start with the Minkowski metric

$$d\tau^2 = dt^2 - dx^2$$

and rewrite it

$$dt^2 = d\tau^2 + dx^2.$$

Hey, that looks just like the Pythagorean formula! Can we banish the strange non-euclidean features of Minkowski space, and revert to good old high-school geometry?

Of course not. There's a fly in the ointment. Unlike  $dt$  and  $dx$ ,  $d\tau$  is not an exact differential, so you can't use  $(\tau, x)$  as a coordinate system for space-time. Not if you want a 1-1 correspondence between events and coordinate pairs. You *can* use  $\tau$  as a coordinate along *one worldline*, however (provided the particle keeps below the speed of light).

Think of Epstein diagrams as a graphical calculation technique. Say we have the worldline of a particle

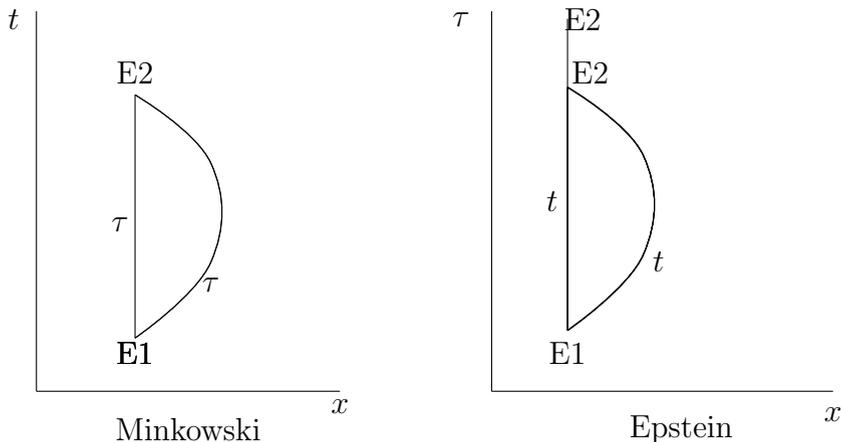
$$x = f(t).$$

So long as the particle obeys the speed limit,  $\tau$  is a strictly increasing function of  $t$ . That means you can also give the particle's position as a function of its proper time:

$$x = g(\tau).$$

The graph of  $g$  is the Epstein diagram. Since  $dt^2 = d\tau^2 + dx^2$ , the (ordinary euclidean) length of the curve is the elapsed *coordinate* time.

For example, look at this diagram, illustrating the twin paradox:



With our familiar Minkowski diagram, we have points E1 and E2 for the events “twins bid each other farewell” and “twins joyfully reunite”. The elapsed time for the stay-at-home twin Terrence is *longer* than for his adventurous sister Stella, even though it’s *shorter* in the diagram.

In the Epstein diagram, we draw curves for  $g_{\text{Terrence}}$  and  $g_{\text{Stella}}$ , starting at the same point. Both curves have the same length, representing the coordinate time between E1 and E2. As you can clearly see, Stella ages less between E1 and E2 than Terrence.

I fear this demystification might undersell the charms of *Relativity Visualized*. Epstein exploits his diagrams for all they’re worth when he gets to General Relativity. I particularly like his explanation of the Shapiro time delay.

Epstein has other arrows in his quiver: a fluid writing style, a gift for analogy, and artistic talent (he drew all the illustrations). I award this book the Silver, if not the Gold.