THE RIDDLE OF ROTATION

There is then something that is always moving in a ceaseless motion, which is motion in a circle; and this is plain not in theory only but in fact.

Aristotle (ca. 330 BCE)

The effects which distinguish absolute from relative motion are the forces of receding from the axis of circular motion. For there are no such forces in a circular motion purely relative, but in a true and absolute circular motion, they are greater or less, according to the quantity of the motion.

Isaac Newton (1689)

Newton, Huygens, Leibniz, Berkeley, Maxwell, Kant, Mach, Poincaré—these are names to conjure with. The fact that not one of them was able to provide a coherent theory of the phenomena of classical rotation is at first blush astonishing.

John Earman (1989)

Fiction is just as much a reality to me as reality.

Neil Young (2012)

Earman labels it the riddle of rotation. Coming on it in his book maybe a month ago I give it caps and add it to my Problem list. So which one reads my files? It seems that whichever it is shares the info with the other. Do they check my markup too? And another thing: To be here when I'm not here takes a bit of doing. Someone's working late.

So what I plan to do when Frank gets here today is hit the high road. Forget he missed Inertia yesterday. Don't let on I know somebody's poking round.

This is no sooner thought than he walks in and—not usual for him—sits down. A grunt of greeting and then nothing.

Okay, I say, in an awkward kind of kidding way, trying too hard, feeling like I must be looking odd: Let's skip the inertia bit. Let's take a turn. Go for a spin, as the old saying goes.

The question is, I say, picking up the pace: What is it about rotation? What is it that grabs me but I cannot quite grab back? Why does it so exercise the world's best minds? What do they discover, what do they not know? This—or something of it—he should understand. Why? Well, this too I feel but can't quite grasp.

So right there in the office we try an experiment with Einstein's favorite method. He plays along. Upon request he shuts his eyes. I set the scene. In his

mind he's sitting in that chest of Einstein's. It is hanging from a rope. It's closed. He has a few things with him. He has three feet of fishing line, a sinker at each end. He has two rulers fastened to the wall. They are horizontal, one a foot above the other. His challenge: Find out if the chest is turning; figure out how fast.

He's good at this. It doesn't take him long. He holds the fish line with two fingers at the one-foot and the two-foot points and lets the sinkers dangle, a foot apart he tells me. If the chest is not rotating, they'll hang parallel. Looking at the lower ruler, he can see the separation of the lines. It is, he says, the same at top and bottom. Actually, they both point to the center of the Earth. It's 4,000 miles below. Far enough to make no difference to him.

Now, I say: Imagine that the chest is turning. Instead of turning with it, each sinker will at first go straight. So they swing out until the fish line pulls them inward. With the ruler he can see how far they lean. From this he can figure out the rate of the rotation.

The thing is this. In the chest he has no Frame of Reference. He finds he doesn't need one. Rotation, it appears, *is absolute*! In 1689 Newton sort of says so. In his 1915 paper Einstein wonders why.

When Newton does his thing with water in the bucket he too thinks of trying it in space. With no spaceship he too does a thought experiment. He knows in zero gravity the water will just slosh all over. So he thinks of rocks tied to a rope. He sets them moving in opposite directions. Each tries to go straight so the rope is taut. Each is orbiting the other. He knows that they—not he—rotate. How so? Well, he can see the stars.

But Newton takes his thinking one step further. He imagines doing this where no stars can be seen. He figures even here the rope between the rocks is taut. After all, what do rocks know of stars? He concludes rotation must be relative to space. It supports his thought that space is absolute. Not space as just a place where there is nothing. Space as a something, independent of all else. From one rope and two rocks it is a critical conclusion. I note with pleasure but don't mention to him that all three are fictions.

Instead I tell him that some physicists say that the universe may be rotating. Gödel even unearths a rotating-universe solution for GR.

Rotating with respect to what? he asks.

It's exactly the right question! Instead of pleasure it gives me a flash of irritation. It's my line. He has upstaged me. My script calls for him to gape or roll his eyes. The flash is petty. This thought doesn't fix the irritation. It just makes a double flash.

I fob him off. He isn't stupid; he takes off soon after, knowing that I did. It's not my best performance. Introspection gives the reason: I don't have an answer

to the question. It takes me all the afternoon and half the night to figure. It dawns on me beachside, watching stars through gaps between clouds in a moonless sky: It's not just a Frame of Reference. It's a point of view. Speaking—even thinking—of the universe rotating takes a point of view nobody ever has.

His chest excursion shows he can detect rotation without access to a reference point. But he does this in a chest that is inside the universe. Do his sinkers show rotation in relation to the universe? On a sudden, sweeps a frightening sensation: I can *feel* the world rotating. It's just the dope I'm smoking but I reach to set my palm against the pier. Its weathered wood is anchored to the world. For a moment I hang on.

The feeling ebbs almost as fast as it began. Once again the sky seems friendly. So I settle back. And apprehend a curious conundrum: Einstein begins his magnum opus, his 1915 paper on GR, with a lesson—learned from Mach, he says. This lesson, Einstein says Mach says, shows that in an empty universe—that is, one with no distant masses—Newton's water in the spinning bucket would stay flat. Einstein uses this to show the need for GR. The conundrum is: It seems Mach did not say that; and GR shows that if he did, then he was wrong. If Newton were to spin his bucket in an empty universe, GR says the surface of his water will be curved!

So the Riddle of Rotation is a contradiction. Einstein says Mach says the water says rotation must be relative. Which leads him to GR. GR says it's absolute. It's tied up too—both ways Einstein says it is—with space. Einstein's widely viewed as getting rid of absolute space; in fact GR brings it back. Frank won't need to solve the Riddle. But he'll need to figure: Is space absolute? Why? Well, it seems to me whichever way it is today it must have got that way in the Beginning. Go fish! I think as I head off to bed.