THE PROBLEMS WITH GRAVITY

The existence of the gravitational field is inseparably bound up with the existence of space.

Albert Einstein (1920)

If gravity had been sometimes attractive and sometimes repulsive, like electrodynamics, we would never notice it at all because it is about 10^{40} times weaker. It is only because gravity always has the same sign that the gravitational force between the particles of two macroscopic bodies like ourselves and the Earth add up to give a force we can feel.

Stephen Hawking (1994)

It's possible, of course, that general relativity is not the correct theory of gravity on cosmological scales.

Sean Carroll (2010)

Throughout history, gravity has been one of the strongest drivers of breakthroughs in theoretical physics, and yet it remains its deepest mystery.

Niayesh Afshordi (2010)

Today I'm on the second train at 5:01. I worry all the way. I don't know whether I should worry. I worry about that. I've heard of voices in the head, but I know nothing of them. So before I leave for work I google. The top hit is far from friendly: Voices In The Head Not To Be Ignored, it says. Hallucinations, and major psychiatric disorders, it goes on. I don't read further. I know I'm not like *that*. It's not as though I don't know who my voice is. My worry is he's hostile to the other Frank. Frank and I must get along. We mostly *do*. I can't have a battle with him happen in my head. But as I walk the last few blocks I see this Frank, my Frank, is mine. He's *fictional*. Of course he'll be the way I want. It sets my mind at ease. My gut unknots. The door unlocks. The lights go on. The hard drive boots. My day begins.

Gravity can be a problem. Anyone from Port-au-Prince knows that. And, like motion, it's a mental troublemaker too, nature's own *agent provocateur*. It stars in Galileo's ship-shape thought experiments and Newton's new description of the world. In 1915, GR says it's a distortion of Spacetime geometry. GR is a success—though for most purposes it is a minor tune-up—and so the mysteries of gravity

are finally revealed, its controversies laid to rest, one might suppose. Not so. Gravity continues to bedevil physics.

By the early 1900s physics knows that matter's made of a few fundamental particles. It can describe their interactions in terms of just two forces. Soon there are four; the old school called them five. This is a triumph in itself. These particles do lots of things. They recoil off each other, orbit round each other, stick together, break apart, and fly off into space. They make the minerals in rocks, the water in the oceans, the radiation from the Sun that keeps the Earth alive. Keeping up appearances, I type a forces list for Frank, who could care less:

> The e-m (electromagnetic) force—the long-range force that governs interactions of charged particles
>
> The weak force—it's a short-range force that lets some particles decay
>
> The strong force—it's the short-range force that glues the nucleons together
>
> Gravity—the long-range force that governs interactions of mass-energy

It turns out that the first three are related. Just as Maxwell merges electricity and magnetism into the e-m force in the 1850s, much later several physicists show that it merges with the weak force at high temperatures (about a million billion degrees) that are thought to have existed in the very early universe. Having exhausted their originality they call the combination the electroweak force. Measurements support this. The merger movement is well underway. Soon after this, another theory, *Quantum Chromodynamics*, shows that the electroweak force and the strong force merge above a billion billion billion degrees. This comes to be known as the Grand Unified Theory (*GUT*). It may be right but it lies far beyond the range of particle accelerators. Physicists can't get that hot but merger mania is strong.

Decades pass. No one can get gravity to unify with GUT.

One can see this as the Problem of Two Theories in a different suit. The jargon gets a bit confusing here. The idea is to marry the first three forces (merged as one in GUT) to gravity (here termed GR). The result would be the *ToE*—the Theory of Everything. Thus the Problem of Two Theories turns into a problem of four forces that it would seem should, but do not, fully unify.

The next thing is that gravity is weak. It is a trillion trillion trillion times less strong than the other long-range force, the e-m force that turns the motor in my fridge. Both drop off with the square of distance. So how does gravity bring buildings down? Simple: It is always positive. Even antimatter gravity. As Edward Teller says of meeting Edward Anti-Teller, 'In fact gravity and anti-gravity are one and the same thing.' So, as Hawking says, it all adds up! Each atom's gravity adds to the gravity of every other atom. An electric or magnetic force is positive

or negative; the two are 50-50. So their pushes and their pulls exactly cancel. Thus feeble gravity's the only force that matters over any distance longer than the drop to the Pacific from the pier.

The problem isn't gravity is weak. It's as strong as we would care for it to be. If it were twice as strong our Sun would be a black hole long ago. If it were half as strong the Earth would be a frozen waste—no liquid water and no life. For us the grip of gravity is right. So what's the problem? Well, the problem is we don't know why. The laws of physics don't explain why gravity is weak.

So gravity imports two clues. Among the forces it continues to be odd man out. And, odd or not, it is so tiny and so perfect one can only wonder why.

It may be pointless but from time to time I pause as if to listen for his voice. Why do I feel that he's upset? Does he too think of gravity? And, thinking this, I think that its two clues might lead him to one question: What is it?