THE EXPANDING UNIVERSE

I deal with the view now tentatively held that the whole material universe of stars and galaxies of stars is dispersing, the galaxies scattering apart so as to occupy an ever-increasing volume. But I deal with it not as an end in itself. To take an analogy from detective fiction, it is the clue not the criminal.

Sir Arthur Eddington (1940)

The universe is not expanding in space, but consists of expanding space.

Edward Harrison (1981)

How is it possible for space, which is utterly empty, to expand? How can nothing expand?

Marcus Chown (1993)

Lemaître's models have been essentially forgotten.

Alan Guth (1997)

The concept of the expansion of the universe is so fundamental to our understanding of cosmology and the misconceptions so abundant that it is important to clarify these issues.

Tamara Davis & Charles Lineweaver (2003)

The conventional Big Bang model held to a picture of the Universe in which it expanded from some initial state at a finite time in the past. This [conventional] expansion is forever decelerating after the start because of the retarding pull of gravity.

John Barrow (2007)

He's in early. He is sitting. Maybe he is thinking. He hardly ever sits. He slouches or he sprawls. How often he may think I couldn't say for sure. Late yesterday I broke the news to him: The universe is expanding. It was total anticlimax. He heard about it long ago. It evidently doesn't turn him on. I tell him people seem to think it is the most important piece of evidence there is. People who should know. I add my own two cents: It might be. Is he grateful for the good advice? I don't know. He sits. He looks lost.

I try on a Webcruise of views on the expansion. The more he sees of them the more confused he seems to get. It's true there is confusion. That's why Lineweaver and Davis take it on. I doubt we'll get that far today but anyway that's not the problem. The problem is his hang-up about facts. The facts (so-called)

about expansion seem to change from time to time. Its physics is all over the map.

Any self-respecting real detective goes for facts before theories. I think he thinks that he should understand the facts. Me, I'm saying nothing. To me facts are not evidence; they are in the eye of the beholder. Like eye-witness identification. Loony lineups; the jaundiced eye; the oft-bemused beholder. He's heading for a big surprise.

But first he needs to come to grips with the expansion. It's not easy. It's not something he can see himself. It doesn't affect anything on Earth. It doesn't even change the distance to the Moon. Not by a millimeter; not in a million years. It makes no difference, not a whisker, to the distance from our star to another on the far side of our galaxy, about 400,000,000,000,000,000 miles. But galaxies, now that's a different story. Why are they different? Well, it's taken me a while. He'll need some time.

Edwin Hubble works the neighborhood within ten million light years of the Milky Way. Much later, better measurements of more distant galaxies confirm that he is right. Distant galaxies move steadily away from Earth and from each other. It's the same no matter where one looks. So from any other galaxy he'd see them move away. It isn't like b.o.—the *farther* galaxies are moving *faster*. This is *Hubble's Law*.

Here I hope he can feel more at home. To him a theory like a motive should be just another fact. But he seems relaxed with facts of the more nitty-gritty kind. Real facts such as galaxies that move. Sadly, the facts on the expansion move beyond the nitty gritty. To console him I say even Einstein was confused.

The first and for him worst confusion is a difference of expert views about the universe expanding. His instincts incline him to rely on experts. He wants to organize their views. Well, he waits for me to dig them up *and* do the organizing. His key question is: What's fact and what is merely theory? I dig for both. I wander round the Web. I think and drink more coffee. Stuff comes to light; it's in no special order. I cut and paste. I distil it down to basics.

Next morning he's again in early. He shuffles twenty pages of my notes. *He* distils them further. His summary is this:

> The universe is expanding. Theory and fact. No serious expert denies it.
>
> Matter's not expanding. It fills space exactly. Always has. Theory. Everyone agrees.
>
> Space is expanding, carrying the matter in it. Theory. Most but not all agree. Ninety-ten.
>
> Much or even most of everything is moving away faster than light. Theory. Or none of it moves faster than light. More theory. Experts maybe sixty-forty. Space is real. Theory. Or it isn't. Theory. Fifty-fifty.

Two days' work on half a page! No complaint; at least *he* did something. But now he asks: What is he to do with this? The experts are at odds. No space? This is *expert* opinion? Next thing, he says, they'll say there is no time. I haven't told him yet: They do! Well, he can start with the idea that the cosmos is expanding. At least that seems to be a clear consensus. It's funny. Three days ago it would have made him roll his eyes. Today he makes like Linus with his blanket.

I remind him of how this begins. Einstein comes up with GR without any thought the universe might be expanding. Initially he doesn't use it on the universe. When he does, he tells his friend, de Sitter, that it is 'a big castle in the air I've built you.' It's true. He builds it on the flimsiest foundation.

Five years later Friedmann shows that Einstein's kind of universe must be expanding, or contracting so it all collapses in a heap. There is no third option that has it static as Einstein thinks it must be. Well, actually, in his time it's almost everybody's pick. I've told Frank twice already but I didn't tell him this: For it to be static, gravity must be balanced by another force. Balanced *exactly*. It calls for a strange kind of antigravity. No one has seen it. This doesn't bother Einstein. It's *his* equation so he simply plugs it in. This is the number that he calls the Cosmological Constant. Well, actually, he calls it *die kosmologische Konstante*. The translation may seem trivial but for years some call it 'cosmical'. Some even say it's comical.

So why does he invent this ugly term? Perhaps he thinks it sounds more plausible than antigravity but antigravity is what it is. It does a perfect job of balancing the universe. That is, till Hubble shows the balance isn't real.

Even Frank can see he needs to understand. Is it flying out or falling in or stationary? Many learned papers fulminate on this. While we sit in our dinky office physicists are out there penning more.

The equations say that it's a question of gravity slowing the expansion to a stop and then bringing it back. Or not. Think of a shell shot from a big gun into space, I say. This is no flight of fancy. A few years back one Bull sets out to build one. He sells it to Saddam. He is assassinated. Israel gets the blame. Really, I tell him, hoping this will hold his interest, check it out. If the explosive charge is small, gravity will slow the shell and drag it back to Earth. If there's a larger charge, the shell may leave the gun so fast it breaks the grip of gravity and flies off, never to return. With a certain in-between charge it will leave with the right speed to slow forever, not escaping, never stopping, never falling back. The million-dollar question is: Which way does the universe behave?

Well, Bull's shell is one way to think of it. No matter how exactly the charge is adjusted, the shell will either break the grip of gravity or fall to Earth. One molecule will tip the balance. Just so, a balanced universe is not achievable in fact.

The random movement of a single atom will tip mass together and so make the gravitational attraction stronger leading to collapse. Or it will move mass apart and weaken the pull of gravity, leading to escape. It may take time to tip but exact balance is unstable. It's like a knife that's balanced on its point. Tough to balance even for a second. Einstein's knife would need to balance for ten billion years.

Physicists take time to get the message of the math. The universe *is* static; they believe it for a fact. Many sympathize with Einstein's instinct: Tweak the math. Frank can identify with the dilemma. In their position he'd go with the fact. I tell him in the end it isn't math, it's facts—fresh facts—that turn the tide. He looks a little less unhappy. He's still focused on what he feels are facts. Tough tit. Any fictional detective knows that facts are just an author's fancy.

Ten years later Eddington, GR's leading light within the English-speaking world, calls the expanding universe a 'view now tentatively held' and—Frank sucks his breath at this—a 'clue.' But even Eddington takes time to understand how fundamentally the view is now transformed. He speaks of 'the material' of stars and galaxies 'dispersing' as if into some outer space. What he and others do not grasp at first, although Lemaître already showed it, is it's *space itself* that is expanding. Stars and galaxies are not dispersing *into* space; they're going *with* it for the ride.

Change comes to the physics village faster than most any other but it doesn't happen in a day. Physics slowly comes to terms with the idea that the redshifts underlying Hubble's Law are caused, not by galaxies that move away *through* space, but by space in between the galaxies expanding. Light from distant galaxies is stretched because the space it flies through stretches as it travels to our cameras. This looks like redshift. But in fact it is the product of GR.

This brings us to the crux. The expansion is more fundamental than was recognized at first. Einstein's theory says that it may happen but it doesn't solve the mystery of *why*.

Expansion is the movie that cosmologists run in reverse. It all makes sense—except for its first frame. It's quite a show. Its scale is grand. In 1925 Hubble shows Andromeda's a separate galaxy, a million years away. This revelation drives astronomy to chart the farther reaches. Trying to convey their vastness, Eddington says: 'A hundred thousand million Stars make one Galaxy; A hundred thousand million Galaxies make one Universe.' At the time he has no idea that what we see—what he calls 'one Universe'—in turn may be a fragment of the whole. He has no way to guess the true 'one universe' could be another hundred thousand million multiple. Today's frame of the movie too is mostly haze.

Today there is another way to measure the expansion. The Big Flash picture lets loose when charged particles combine; this happens when they cool to about

3,000 degrees—a temperature physicists can measure in the lab today. But today the Big Flash is a thousand-fold cooler. Its measured temperature is 2.725 degrees above absolute zero. Space expanding—stretching in the same proportion—is the explanation. Today most physicists regard expansion as a proven fact.

Frank is like a kid with a new toy. I've never seen him be so animated. He sees expansion as a fact he can rely on. This is not the time to tell him he is wrong. He needs to face the basic question: Why? Why does it expand? Well, I tell him, GR offers reasons in two parts.

One looks like inertia. It's like the way a car keeps moving until something—friction, brakes or maybe a collision—slows it down. This says expansion *is* because it *was*. As some physicists say, maybe well aware their explanation needs an explanation, 'Galaxies move apart because they did in the past.'

The other is that fudge factor, the Cosmological Constant. It says the universe expands because Einstein thinks it needs a push. Until, that is, he decides that he's wrong.

GR is the central theory of cosmology. It offers him no help. In fact, it's he who'll have to help the theory. So I just let him go. He needs to get his head around the way the universe expands. It's hard to picture. He thinks he's got it. Space is expanding. It's been expanding since the universe began. And surely gravity must slow it down. This much seems certain. Once again he's in for a surprise.