Free Falling Backwards

Bill Sumner

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Prologue

This is how I came to understand that our universe is collapsing and will end in about 9 billion years.

This conclusion has nothing to do with philosophy or religion. It comes directly from interpreting the most precise astronomical observations using well-established physics.

I'm a physicist. I love to use math to understand nature. If you know math, you know its intrinsic beauty. You know the rigor of its logic. You know the surprising insights it can give you. You also know that it is nature that guides your choice of math.

To explore my reasoning following a mathematical path, read the references beginning on page 55.

To explore my reasoning following an eccentric path, read Free Falling Backwards.

Cuckoo

Flickering flames and shadows tangled in dance. The wood box was full. A kettle simmered. Peace filled my reflective universe. Blizzard engulfed the one outside. No place to go. No dragon to slay. No alarm to remind me what must be done at 10:15.

Our cuckoo clock knows the time by counting the tic tocs of her pendulum and cuckoos every half hour. My time this evening was tranquilly disconnected from the bird. Ideas flitted, coming, going, focusing, fading, merging, vanishing.

The little bird opened her door and cuckooed 11 times. Someday I should figure out why she cuckoos 11 times when it is 12 o'clock. Every other hour, including 11, her cuckoos and hands match. Tonight I didn't care whether she was announcing 11 or really meant 12.

Time interests me as a physicist, my shifting perceptions of its flow, announced by a cuckoo bird, a sunrise or sunset, or an atomic clock. My interest is hardly unique. Isaac Newton, wrote in 1689:

"Absolute, true, and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external . . . measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year."

Cuckoos sing the hour. The earth rotates. There are many "sensible" measures of time.

Newton's mathematics describes our solar system with such precision that we know where the earth, sun, and moon will be centuries from now. That is, if we know if the "relative, apparent, and common time" we choose to use is measured in ways that adequately approximate Newton's mathematical time.

The cuckoo called only once as I poured hot water for a last pot of tea and put more wood on the fire. Her cuckoos usually are out of sync with other clocks. My cuckoo sleeps, she mistakes 12 for 11, her old gears pulled by weights no match for modern precision.

The earth's rotation provides a more consistent clock, but as Newton noted,

". . . the natural days are truly unequal, though they are commonly considered as equal, and used for a measure of time; astronomers correct this inequality that they may measure the celestial motions by a more accurate time. It may be, that there is no such thing as an equable motion, whereby time may be accurately measured."

While some time measurements may be good enough, only mathematical time is absolute. If two clocks don't synchronize, the better one is the one that is most consistent with Newton's mathematics. Mathematics judges the quality of clocks.

Newton's sharp distinction between the logic of mathematics and real measurement points to critical choices that must be made when correlations are made between them. Newton's logical distinctions are often overlooked when the same words and the same units are indiscriminately used for both concepts.

Putting a last log on the fire, I stopped my cuckoo's pendulum, climbed the ladder to the loft, crawled under a thick down blanket, and faded with the night with words of Newton ringing in my head.

Flickering flames and shadows tangled in dance.

Sauna

“What a delicious blend of sweat and the square root of two,” I mused sitting in our sauna.

My joy in this odd combination was rooted in early summer when I dug foundation trenches for the sauna in rocky soil. Rocky soil is a misnomer. Soily rock is more accurate, but no matter. A good shovel, a mattock, a digging bar, a tape measure, stakes, a hammer, a level, a 2 by 4, and lots of time and sweat were all that were needed for the foundation trenches.

Our sauna is a small rectangular room with a windowed door, cross ventilation vents, and a drain. Inside are a stove, a thermometer, a light, benches, towel rods, and towels. A simple design.

There are several ways to insure it had square corners. The one I used was to put in four stakes in roughly the right places and then measure distances and adjust the stakes until I had right angles at the same elevation at the correct locations.

This use of plane geometry to make a right angle is so common that most of us never think of Euclid and his undefined points and lines, axioms, postulates, theorems, and corollaries when we are building a foundation. No surprise. The goal was to sit in the sauna, not to explore why the Pythagorean theorem stating that the sum of the squares of the sides of a right triangle equals the square of the hypotenuse, might be true.

With stakes in place, digging began. This was fun, the pleasure of honest work blended with the joy in using good tools. I had three of my favorites. The oldest is a forged mattock, which is shaped like a pickax, with an adze and a chisel blade on the head. Before animals and plows, it was one way farmers tilled the soil. My dad bought mine long before I was born. It has been re-handled numerous times. Its adze is as wide as my hand, perfectly sized for digging and prying out fist-sized rocks. The chisel blade parallel to the handle is ideal for cutting roots.

My steel digging bar was also my dad's, heavy and about as tall as I am. It is unequaled for finding and exploiting cracks between rocks and digging around and prying out big ones. I grew up using it mostly as a lever to finely adjust the position of heavy farm implements to bolt to our Farmall Super C tractor.

My shovel was purchased at Woods Hardware. A few years ago I was at Woods staring at shovels when a landscaping pro pointed to one and said "Buy that one!" She said everyone working for her had to get that one.

I didn't tell her that my current shovel was fine and I was only looking for an end cap for its hollow fiberglass handle. Woods doesn't sell rubber replacement caps for cheap shovels, so I taped mine.

"Buy that one!" stuck in my mind. Every time I went to Woods I made time to examine the shovel, its blade hand forged in Ireland and riveted to a heavy American hickory handle. I didn't need another shovel. One day I bought it anyway. After a few days using it I understood. This was a shovel designed and built by people who have shoveled dirt for centuries.

With dirt and rocks piled to the sides, the stakes were replaced with corner blocks. I checked and rechecked their positions and elevations, and whether the corners were still square. An error here would lead to untold complications later. So, two sides were 7′, 8 and 7/8″. Check. The other two were 5′, 2 and 5/16″. Check.

And the hypotenuse was? Well, an awful calculation led to approximately 111.841912006″ or in the the units we who build in America use and love, about 9′, 3 and 13/16″. Both checked. And rechecked.

I love math. I love numbers, even these dastardly ones in units we refuse to rubbish. Which brings me to the square root of 2. Let's say my foundation was simply 1 by 1. Then my right angle calculation for the hypotenuse is found by taking the square root of 1 plus 1, the square root of 2. This is about 1.414213562373095.

A better approximation is
1.41421356237309504880168872420969807856 9
67187537694807317667973799073247846210703

A still better approximation is
1.41421356237309504880168872420969807856 9
67187537694807317667973799073247846210703
88503875343276415727350138462309122970249
24836055850737212644121497099935831413222
66592750559275579995050115278206057147010

95599716059702745345968620147285174186408
89198609552329230484308714321450839762603
62799525140798968725339654633180882964062
06152583523950547457502877599617298355752

If I were writing a 700 page book, I could in principle finish it now with a still better approximation. I could do the same with a million page book set in tiny type. The square root of two is infinitely long and never repeats itself. It is an irrational number. Rational numbers either terminate or repeat themselves.

What does this have to do with building a sauna? Nothing, absolutely nothing at all, except in the mind of this builder. And Newton.

Picking up my dog-eared copy of Newton's Philosophiæ Naturalis Principia Mathematica, I reread the following:

"I do not define time, space, place, and motion, as being well known to all. Only I must observe, that the common people conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common."

Newton made the same sharp distinction between the distances we measure and their "absolute, true, and mathematical" representations in his theory.

Sweat rolling down my brow, leaning on my shovel, staring at my blocks, the big disconnect between my project and my mathematics was really clear, between my "common" measurements and my square roots.

I was perfectly happy with sauna measurements accurate to a 16th of an inch on my tape measure, even when geometry gave me answers that wouldn't end. I used nails for points. Even if I could define points more precisely and use the finest technology to measure their separation, my result would be much shorter than a few words of this paragraph.

I couldn't imagine a clearer example of the distinction Newton made between "relative, apparent, and common" and "absolute, true, and mathematical" when he spoke of time and of space. There is a square root of 2 in math. There isn't in nature.

Designing the sauna I used mathematics where irrational numbers are just fine, as good as any other. And besides, there are infinitly more irrational numbers than rational ones.

Building the sauna, I used a metal tape measure, reasonably assuming it corresponded with my drawing dimensions, conveniently approximated. I didn't use a rubber ruler. Or a crooked one. I used nails to mark points, ignoring the fact that points aren't even defined in geometry. I made connections between math concepts and physical measurements with no second thoughts.

With roots deeper than the geometry of ancient Greece, Newton's use of mathematics to model nature lies at the heart of physical science. When done right you get awesome results. Like saunas.

But your rulers and clocks must "closely" match the mathematics of Euclid and Newton. Stretchy rulers don't correctly measure distances between stakes in the ground. Sleepy cuckoo clocks don't measure reliable times for the rotation of the earth.

I measured. I cut. I hammered. I bent plywood. I hammered. I cut tongues. I cut grooves. I hammered. I plumbed the drain. I sanded. I did the electrical. I cleaned. I turned it on. I got hot. I sat on my towel and mused "What a delicious blend of sweat and the square root of two!"

Rock

Jupiter peeked through our hammock shrouds. Lightning flashed far in the east, a spectacular show but not our concern. The rest of the sky was crystal clear.

Pleased with a long day climbing vertical rock, we made our hanging bivouac with methodical attention to detail. My buddy Mike and I were firmly anchored. Gear dangled from carabiners. Bit by bit, we engineered our way into hammocks and relative comfort. Nothing was simple, not even peeing. Brewing a cup of tea was a complicated affair. Still, it was 4 Star lodging for an alpine wall.

An evening with Warren Harding, a gallon of red wine, and his stories first kindled my fire for big rock walls. The soaring granite faces in Yosemite are truly magnificent, but those in alpine wilderness are the ones that seduce my soul.

There is the mountain. Beauty, uncertainty, and risk in the right mix. There is the climbing. Every handhold, every foothold, every shift in balance, flawlessly executed. There is the gear. Every item chosen carefully to match the task.

A climb well executed elicits the joy of an elegant mathematical proof. This was such a day. Nothing left undone, except contemplating the brightest object in the southern sky.

Jupiter has dozens of moons, four of which are visible with binoculars. Observing these moons orbiting Jupiter with the telescope he built, Galileo provided clear evidence supporting Copernicus and the theory that the sun is the center of the solar system.

Galileo's observations were soon explained with high precision using Newton's theory of gravity. The idea is simple. Gravity is an attractive force between two bodies, proportional to the product of their masses and inversely proportional to the square of their separation. It describes the orbits of Jupiter's moons and our orbit around the Sun.

Newton assumed that changes in the position of a body would instantaneously change its gravitational attraction everywhere. We now know that the effect of changes at one place aren't sensed at another location until a later time. This is true of gravity and every other force, a fact crucial to Albert Einstein's theories 200 years later.

Observations during Newton's lifetime of the orbits of the moons of Jupiter provided an early estimate of how fast light travels. Orbital predictions using Newton's theory were compared with observations of the varying times of Jupiter's moon rises and moon sets as together they orbited the Sun. The variations observed led to an estimate of the velocity of light that was surprisingly accurate.

There was more lightning in the east but it was so far away there was no thunder. I wondered how far away the thunderheads were. My wild guess was 50 miles or so. I wondered how far away Jupiter was. No clue, except that Jupiter was brighter than it sometimes was and might be closer to Earth than the Sun. I wondered what methods astronomers use to come up with their "common" distances to compare with their mathematics. They certainly don't use a tape measure.

Jupiter continued its westward journey and faded into my dreams as I snugged my jacket closed.

Waking up thirsty, I unclipped a bottle and sipped the little water remaining of the day's ration. The bottle fell silently toward the snow below when I fumbled re-clipping it. I stared into the night after it.

Living on a knife edge there is little room for error. Every mistake has consequences. The loss of this empty bottle was trivial. Dropping it wasn't. This wasn't the first time I made a mistake. It wasn't the second either. The comprehension that any small mistake here could be my last was unnerving.

The bottle fell with the arrow of time. In time the same arrow took me from bottle reflections to the universe. Inner peace seeped back in and my mind wandered to geometry and physics. I was wide awake.

For many geometrical problems Euclidean geometry is ideal. It is relatively simple and measurement techniques can be chosen to match mathematics exceedingly well. While Euclidean geometry is a decent approximation to the geometry of the universe it isn't exact. A curved geometry that includes time is better. Einstein demonstrated that Newton's gravity can be replaced by curvature and that the velocity of light, an essential part of Maxwell's electrodynamics theory, plays a central role.

One thing in common with Einstein and Newton is a separation of mathematics from observation, or in the words of Newton, distinguishing absolute from relative, true from apparent, and mathematical from common.

The crescent moon came up unexpectedly. There was no dust in the sky to diffuse its light and give a precursor glow. I watched the earth rotate as the moon crossed the horizon. It was still dark, but the crescent pointed precisely at the sun. As the earth rotated so did the moon pointing at the invisible sun, a stunning display of the reasoning of Copernicus, Galileo, and Newton through the shroud lines of my hammock.

With singular attention to detail, we began putting some things away and getting others out preparing for a day of climbing. Life on the edge. Coyotes howled.

Cyclotron

If you shovel dirt use a shovel like mine. If you study atomic nuclei use a cyclotron like ours. It takes longer to learn to use a cyclotron than a shovel, but in the end the pleasures are commensurate. Both are wonderful tools.

A cyclotron is a machine that uses an alternating electric field between the poles of a strong magnet to accelerate nuclei to high velocities to crash into other nuclei and study what happens. Ours was the vintage 60 inch Cyclotron at the University of Washington.

Nuclei are at the center of atoms and are very small. If you imagine a nucleus to be the size of a flea, the atom would be the size of a football field. If you then imagine an atom to be the size of a flea, you would be taller than the distance to the moon. Nuclei really are very tiny.

Hydrogen, a single electron orbiting a single proton, is the simplest atom with the simplest nucleus. Three fourths of the universe is hydrogen. Helium is also relatively simple with two electrons orbiting a nucleus of two protons and two neutrons bound together. The helium nucleus is called an alpha particle. Most protons and alpha particles likely were formed in the first few minutes of the universe. Most heavier elements were synthesized much later by nuclear reactions in stars.

When critical amounts of nuclei of the right sort are close enough together, self-sustaining nuclear reactions can occur. This releases energy over a period of time in a nuclear power plant or explosively in a nuclear bomb.

Understanding precisely how stars do both, cooking up all the elements in the universe in their nuclear furnaces and then explosively distributing them, has been a grand adventure for nuclear physicists and one of our greatest triumphs. The details of essential nuclear reactions and stellar structures fill scientific journals but the final conclusion is stunningly simple. You are star dust.

Our research was focused on measuring the sizes of nuclei to high precision. We accelerated alpha particles in our cyclotron to 42 Mev and directed them at selected targets. Most of the alphas from the cyclotron would just go through the vast empty spaces of our target atoms and a few would crash headlong into a target nucleus causing all sorts of nuclear reactions. Our interest was in studying those alphas that just missed the nucleus but were close enough to be scattered by both electrical and nuclear forces. By examining these scattering patterns for 20 nuclear isotopes from calcium to bismuth we learned a lot about their sizes and surface characteristics.

Ernest Rutherford studied scattering of low energy alpha particles emitted by radium and proved the existence of nuclei in the early 1900's. Using Newton's laws and the electrical repulsion between an alpha and a nucleus, he estimated nuclear sizes in almost the same way we did.

Revolution was in the air in Rutherford's time. Puzzles in explaining characteristic atomic spectra and a growing suspicion of the wave and particle nature of matter and radiation soon led to quantum theories using this atomic model of negative electrons bound to a tiny positive nucleus at the center.

This revolution culminated with the publication in the 1920's of the matrix mechanics of Heisenburg and the wave mechanics of Schrödinger. Their theories have stood the test of time and countless experimental verifications. The mathematics of Maxwell, Einstein, Heisenburg, and Schrödinger were essential to interpreting our experiments.

I was in the best of all worlds doing this research, learning to operate and fix the cyclotron from physicists, machinists, and technicians who built it and at the same time designing experiments and doing data analysis with John Blair, the master theorist in the field.

Every detail with the cyclotron had to be just right, exactly like a mathematical proof. Every cooling line and its sensor had to be functioning. Every high-voltage insulator had to be spotless and every safety interlock in place. Every vacuum system with every O-ring had to be leak free.

Massive radiation shielding doors had to be closed. The fine tuning necessary to tightly control alpha energies meant periodic adjustments to electrical frequencies and to the large DC generator that powers the magnet. The systems to detect, properly identify, and count the alphas scattered from the targets needed calibration. Preparing targets of known isotopic composition and uniform thicknesses was exacting. Details, details, details.

Another challenge in experiments and in their analysis is to figure out if the results you find are correct. You can't go to the back of the book and check the answer. Instead, you carefully focus on every detail and double check everything you can. This is where John Blair taught me a lesson I would never forget.

Part of our mathematical analysis required a three dimensional integration of two overlapping functions. We couldn't solve the problem exactly for the functions we had so we used a brute force numerical approach summing up little cubes over space. Progressively smaller cubes extending to greater distances soon exceeded our patience and choked our computer. But it worked.

Talking in the mountains with a climbing buddy who worked with Bell Labs, I learned of a new algorithm for calculating a mathematical transformation that was extremely fast. A mathematical derivation showed that I could replace our brute force integration with the addition of two Fourier transforms and take its inverse.

John and I began a detailed comparison of our two techniques. We compared both approximations using functions that we could exactly integrate. We compared samples from our experiments. Wonderful!

Comparing lots of small cubes against the numerical transform with close sampling gave identical results in the region of interest and the transform method was much faster.

I was excited but John was perplexed. At function separations closer than our experiment sampled and at very low sample intervals, my transform method diverged. John asked me "Why?" I felt it didn't matter because the two approaches agreed in the region of our interest and the transform method was so much faster.

But John kept repeating "Why?"

In time I realized that he would never let go of his "Why?" I gulped with some resentment and went through my program yet again. Nothing wrong. I had double and triple checked everything, I thought. But there it was. My mistake.

Our computer didn't have as much memory as I wanted, so I moved arrays of numbers to and from a reel-to-reel tape to store them during the calculation. In one of my write commands I mistakenly shifted an index by one in one array.

I punched a new card, put it in the program deck and ran a test. The artifact that had bothered John was gone.

I was chagrined. I was humble. I was euphoric.

Pargos

Tea brewed, onion soup simmered, a rocky bed waited. My perch on a ridge was bathed in lingering autumn. Yellows and oranges flooded the western sky. Reds and maroons in the north and south. Purples and black in the east.

A shepherd was camped with his donkey and sheep far below. The Mig-29 fighter jets were back home in their bunkers after an afternoon spent honing dive bombing skills. The onions I scavenged from a harvested field in the morning were dinner. Life was simple. Life was good.

Flura and I were deeply in love. Our life in Uzbekistan was exotic. My time was free. I could mix physics, climbing, and adventure to my heart's content. I had found my elusive rhythm of dreams.

Twilight seemed endless as I sipped tea, spooned soup, and broke bread. My mind was at peace to wander where it would, to the flat space and time of Newton, to the curved mathematics of Einstein, to anywhere else. I longed to share this free evening with precious colleagues lost in time.

Leaning back on my pack, staring at the western sky, I thought it would be interesting to imagine a dialogue with Albert Einstein. So, for fun, I decided to use his words and a few of my own and imagine Albert joining me.

"Welcome, Albert! Please join me. Would you like a cup of tea?"

"I'd love one. Your invitation was an unexpected surprise."

"Where to begin. I would love to converse on many matters. Perhaps, before twilight has ended, we can explore the differences between mathematics and measurements in nature. Would you mind?"

"Of course not. I have more time than you. Let me begin with a stipulation that concepts and distinctions should have meaning. By this I mean that concepts and distinctions are only admissible to the extent that observable facts can be assigned to them without ambiguity."

"So, if we are discussing lengths and times in your mathematics they must be assigned to measurements in nature?"

"Exactly, and this must be done without ambiguity."

"Like your associations of a meter stick and a grandfather clock with lengths and times in your mathematics?"

Albert broke out laughing, nearly chocking on his tea. "You don't beat around the bush!"

"Well, I have read and re-read many of the things you have written."

"I am flattered. Associating mathematical concepts with physical devices bothered me deeply. The rigid body is only approximately achieved in Nature, not even with desired approximation. The deeper issue is that it is also logically unjustifiable to base all physical consideration on the rigid or solid body and then finally reconstruct that body atomically by means of elementary physical laws which in turn have been determined by means of the rigid measuring body. For the objects used as tools for measurement do not lead an independent existence alongside of the objects implicated by the field-equations."

"By field-equations I assume that you are referring to your equations of general relativity where, plainly speaking, you equated the curvature of space and time to mass and energy?"

"Exactly. The properties of a rigid body made of atoms are tied to geometry in the mathematics."

"You are saying that even if we had good mathematical models for atoms we still could not measure mathematical length with a meter stick?"

"Precisely."

"But that is exactly what you did!"

"You may remember that I posed two questions: 1) Can a spectral line be considered as a measure of a 'proper time' if one takes into consideration regions of cosmic dimensions? 2) Is there such a thing as a natural object which incorporates the 'natural-measuring-stick' independently of its position in four-dimensional space?"

"Yes, I remember."

"I explained that the affirmation of these questions made the invention of the general theory of relativity psychologically possible. We were not sufficiently advanced in our knowledge of Nature's elementary laws to understand the effects of curved geometry on spectral lines or on rigid rods made of atoms."

"Of course. The quantum mechanical understanding of atoms came after your general theory of relativity."

"Yes, it did. A complete theory of physics as a totality did not yet exist. If it had existed, there would have been no room for my supposition that logically wasn't necessary."

"It certainly puts an interesting twist to have measuring instruments depend on the mathematics, in your case the curvature of space and time among other things."

"Yes, I suppose, but not one that is unique. The same is true of Newton's theories as well if you think about it."

“Hmmmm. You are right . . . I must thank you for coming. Most of my physics colleagues died long ago. I miss them.”

“I understand. I do. Good night. Pleasant dreams. Let’s talk again.”

My dreams were pleasant, savoring each detail of this imagined conversation, reflecting on the nuances of this master’s thoughts and writings, remembering the hues of the pastel sky changing as we talked. I fell asleep.

I was awakened by a loud “Whomp, whomp, whomp.” Or was I dreaming?

“Whomp, whomp, whomp.” Louder. “Whomp, whomp, whomp.” Still louder. “Whomp, whomp, whomp.” Louder still. This was no dream.

I sat up and saw bright lights at a bend in the shallow valley next to my ridge. “Whomp, whomp, whomp.”

Blinding lights and billowing clouds of dust hid all but the cockpit nose of a helicopter as it turned the bend and roared up the valley bottom. What noise! What light! What dust! I was just high enough to be above its rotor blades and piercing lights.

The billowing cloud traced the valley to the top of the hill targeted by the two Mig-29's in the afternoon. Then this Mi-24 Crocodile, spotlights still blazing, spun around and flew down along the ridge crest directly at me.

Kitchen

After a romance spanning 12 time zones and the Iron Curtain, Flura and I were married in the USSR and made our home in Chirchik near Tashkent.

Flura is an outstanding rock climber. For 14 years she was the champion of the USSR, a Master of Sport, International Class. Still actively competing, Flura was often gone weeks at a time. Sometimes I joined her. Other times I would stay at home to mix physics with fitness. Often I wandered through the door alone to find adventure, regularly finding more than expected.

The warmth and love of a heart is not measured by size. This is manifestly true of Flura who is barely 45 kilograms. It also is true of the apartment she waited so many years to secure. The heart of our apartment is the kitchen, barely bigger than an oversized mattress. Through a windowed door is the balcony, less than half as big.

The balcony faces northeast with an unobstructed view of the tail end of the Tien Shan Mountains. Along with tea and bread, part of my morning ritual was to guess when and where the sun would rise, watching its daily advance south in the Fall and north in the Spring. The highest mountain we see is Chimgan, a bit more than 3200 meters. To the left is the settlement of Pargos, a favorite area for rock climbing and a gateway to mountain rambles. Further left is the airbase at the heart of a sprawling military facility. It is fun to watch the radars on a nearby hill. When they rotate we know aircraft will be flying.

Mathematical physics was my passion most days at home and I started water for tea about dawn. Some days I intently focused on mathematical details but on others I mostly sat and mulled. I was free to do the physics that I love best, going into a gargantuan tangle of dark caves looking for a black cat that probably does not exist. I seldom find anything. I have discovered though that more than black cats live in dark caves.

This fall morning I was drinking tea and staring at the mountains near Pargos where I had fantasized talking with Einstein and had been frightened by a real Mi-24 Crocodile on its midnight training mission. I am a lucky guy, no more so than that night when it flew down the ridge towards me. Before it reached me, it abruptly pulled up from the ridge, turned off its halogen spot lights, and flew home. That was the last time I wandered there!

I discovered years later that my old buddy Fred, who served in a helicopter company in Europe with the US Army, knew all about these Soviet attack helicopters. Called the Hind by NATO, the Crocodile is devastatingly effective for the sort of missions it flew that night.

I sipped more tea and turned to physics, Einstein, and the structure of the universe.

One important observation made by astronomers is that light from distant stars has different colors than the light from stars nearby. The further away a star is, the redder its light appears. This change, commonly called redshift, is measured by comparing characteristic color patterns of light photons emitted by atoms in stars far away to patterns emitted by similar atoms in our laboratories.

The astronomer Edwin Hubble and others extensively studied these color shifts in the 1920's. They described how redshift uniformly increases with the distance to the light source. Using modern telescopes, astronomers have greatly extended the range and precision of Hubble's measurements.

How are these redshifts explained?

The usual answer begins with the fact that space is not precisely flat as Euclid assumed. The structure of the universe, its curved geometry, and evolution are described in math solutions to Einstein's equations found by Alexander Friedmann. One of his solutions begins with a Big Bang, expands to a maximum size, and then collapses.

Photons and the universe change size in exactly the same way. Change in size changes energy. Photons expand in an expanding universe, lose energy, becoming redder. Hubble redshift gave immediate confirmation to Friedmann's expanding universe and a new paradigm was born. Our universe is not static. Our universe is expanding.

These changes in photon energies are equivalent to wavelength changes in their electrical and magnetic fields, as the equations of Maxwell clearly show. It is a clear example of how the curvature of the universe changes a photon of light emitted by a hydrogen atom, a case in point of Einstein's speculation that nature's elementary laws are tied to curved geometry.

Maxwell's equations require that the strength of every electrical field depends on the curvature of the universe. When the universe expands, electrical energy is lost. Where does the energy go? This interesting question directly relates to Einstein's replacing gravity and gravitational energy with curved geometry. The simplest answer is that energy is lost because it is no longer conserved. Gravitational energy has simply disappeared in Einstein's formulation. As the universe collapses, electrical energy increases.

Changing curvature changes the electrical field that holds atoms together. Jumping ahead we will see that atoms change size in precisely the same way that the universe and photons do.

Doubling the universe, doubles atoms and photons. Decreasing the universe by the square root of 2, decreases atoms and photons by the square root of 2. The characteristic wavelengths of light photons emitted by atoms also change. This was all math.

It was about 10 AM, my tea pot empty, my mind dull. Time to walk to the gym. Time to run and hop some stairs. Time for some Tony Pegis balance.

Splav

The Colorado School of Mines was small, overwhelmingly male, and still attached to its rough and tumble macho roots when I enrolled. An engraved silver diploma in leather stows neatly in a sack on a burro's back. Getting one was an education.

Tony Pegis was a missionary at Mines, manning a tiny humanities outpost in a technical jungle. His office was buried in the basement of the petroleum building behind a second door behind the furnace room. On the back of his door never seen by most visitors was an icon. Closing the door revealed a middle finger.

Tony's required History of Western Civilization was our first introduction to his Greek blend of intellectual rigor, pride in scholarship, commitment to physical fitness, his passion for life. Tony left his indelible mark on me and on generations of other students at Mines. "Balance" is my shorthand for his example. Tony had balance. There never has been a better missionary with a more important mission.

I closed our apartment door and went down five floors to the courtyard for my morning walk to Splav, a metallurgical factory producing alloys for a variety of purposes. Flura's association with Splav opened the door to my use of its outdoor swimming pool, stadium, gymnasium and various sport halls. She introduced me to her friends Slava and Raf, coaches and trainers in the weight gym. These gentle souls with massive muscles would serve me tea and mentor my morning workout.

Once a week, typically on Thursday night, I would join them and others under the stadium for a sauna and a massage. All men, most athletes, a blazing hot sauna, hot and cold showers, a wooden massage table, tea, and cookies.

Flura had introduced me to the tradition of Soviet sport massage when I badly bruised my back and bottom. Her massages are strong, tailored for fatigued muscles and injuries. Slava's massages were in the same Soviet sport tradition.

The stadium has a soccer field and running track with bleachers. Running up and down stairs is wonderful training, but must be done with care. Unless you do it regularly, it is easy to strain calf and thigh muscles long before you run low on energy. If you do run them much, hopping up one flight on just one leg and the next flight on the other becomes the game. The stadium was my destination after weights and exercise with Slava and Raf.

Up and down. Up and down. Up and down. Sometimes I ran for time, more often I ran by number of flights, my mind free to wander sideways as my feet went up and down. Walking a couple of laps on the track completed my workout. On the way back home, I often stopped by the local bookstore next to a sidewalk bazaar across the street .

Soviet bookstores were fascinating in what they had and what they didn't have. I loved them. The one across the street from Splav was tiny. It sold mostly school supplies for kids but did have a small collection of books.

One day I bought two books, one a volume of speeches by Mikhail Gorbachev, beautifully bound, first class paper, and inexpensive. The other book was much thinner, printed on cheap paper, about the same price. It contained the technical details for designing and building nuclear electrical power systems for satellites. It remains a mystery to me how that book ended up there. It is no mystery why no one had purchased either one.

I bought a fresh cabbage in the bazaar. It cost 10 times more than my two books combined but arguably was the better find. I also wanted a flower and saw a single carnation that was perfect. Three or five are the magic numbers of flowers to buy and give. Flura was away and I only wanted one.

After delightful conversation with the babushka selling the flowers, she finally understood that I only wanted one. She refused to take my money. I offered to take one but pay for five. She laughed, still refusing to take any money at all, and smiled as I warmly thanked her again and walked home for lunch. Life was in balance.

I raised and fastened our hinged table on the balcony. I took a stool outside along with sliced cabbage, left-over boiled potatoes, bread, water, salt, and my carnation in a vase. A simple but perfect lunch.

So, do atoms really change when the size of the universe changes?

This abrupt flip in my thoughts to physics triggered a memory which flipped me right back, typical of my afternoons. I remembered another obscure book I found in the main Chirchik bookstore, a collection of stories by and about honored Soviet physicists. Friedmann died too soon at 37 to be elected to the prestigious group profiled but one of his grad students, George Gamow, was elected.

When Gamow emigrated to America, this honor was retracted. Then, just in time for this book to be published, Gamow was reinstated, even though he had died in America years before. It was amusing to see how Gamow's reflections written in english were creatively edited and translated into Russian. Ah, the politics of science.

But religion and science can be even more at odds. 400 years on, the Catholic Church is still trying to sort out Galileo.

Well, do atoms change or not?

My electrical field arguments said yes. Conventional physicists said no. I tried to imagine an expanding meter stick but everything else around would also be expanding and how could I tell it was changing?

Like my beating heart, like my cuckoo's pendulum, like sunrises and sunsets, my mind went back and forth. Atoms change. Atoms don't change. Yes, no. Yes, no. Yes, no.

I calculated the shift in the color of photons emitted by a changed atom. The shift is about twice as much as photons have shifted since they were originally emitted. When an old redshifted photon from a smaller universe is compared to a current atom's emission in a bigger universe a relative blueshift results. It is blue and not red. I had it wrong. The universe is expanding, the light from distant stars is redshifted, and my math was telling me I should see blueshift.

I had made a mistake. Buried in my math I must have missed a minus sign or wrote 2 instead of Z or dropped a term in a many lined equation or something. Fond memories of John Blair. He was gone but his lesson was vibrantly alive. I sat alone on my balcony and pondered my dilemma. I found solace reflecting on a professor of mine at Mines, Paul Rogers.

Paul taught geophysics. His specialty was Newtonian potential theory which he applied to gravitational prospecting. Like Tony Pegis, the lessons he taught went far beyond his subject matter.

Paul was soft with his students and never seemed in a hurry. In our small courses, he would often say at the end of a lecture something like, "Mr. Smith, would you explain to us tomorrow how to derive equation 42 using elliptical functions?" Talk about motivation to study!

The next day Mr. Smith would begin his derivation at the blackboard. If there were points that weren't clear, Paul would ask for clarification. If Mr. Smith hadn't mastered his presentation, Paul would join him at the board asking "Would it work to look at it this way?" and begin a logical development that Mr. Smith would watch with the rest of the class, clutching to the life ring Paul had seamlessly given him.

"Next class, Mr. Sumner, would you pick up where we are leaving off today and show the connections with what we did last week?" Paul was a master.

In Chirchik I worked alone, but past professors lived in my head. I imagined Paul and John asking "Why?" at every assumption I made, at every step in every calculation, about every detail of every detail. John never gave me peace if anything seemed askew. Working alone is like solo climbing an ice face where every step must be perfect. Every one. One after another. Every one. One after another. But with those two inside my head I wasn't soloing.

Well, do atoms change or not? Yes or no? Was my logic solid? Were my mathematical calculations error free? Did I miss something along the way? John was worried. Paul simply shrugged and advised me to take some time off and flush my mind. Then, do all the math all over again from scratch.

"It's only math. You have it right. Or you have it wrong. It's only math."

I looked at my perfect carnation echoing that babushka's perfect smile. Did she think I was too poor to buy more than one? Did she want her carnation to have a perfect home? Was she simply as crazy as me?

My afternoon dissolved into that perfect carnation echoing that babushka's perfect smile. I had perfect balance.

Riddle

Slava preferred to massage sauna-warmed muscles. He used soap and warm water and a massage table next to a shower. Splav's serious athletes were always given top priority. As time allowed we dilettantes received Slava's attention. It is hard to imagine that anyone serious about sport is not equally serious about sport massage.

Raf loved to come into the sauna with a pan of water, throw it on the heater, laugh, and step out. I would dive to the bottom bench, covering my balding head with both hands to elude the flash of steam. It hardly helped. In short order we all retreated and cold showered, answering his call to tea. He knew we would.

Sitting in this spartan shower room, drinking tea between saunas in this company was fascinating. Conversations were light, friendly, wide ranging, filled with anecdotes and jokes. My Russian wasn't bad, but jokes and poetry often left me baffled. Flura would explain them to me later as I recounted them. Some, even when I understood all the words, I didn't get.

Here is a classic anecdote about a plumber that uses but a single Russian four-letter word in multiple grammatical forms, rich with multiple meanings. This anecdote is a playful song in Russian. It is risqué and crude. English translation is useless, missing the meaning and the sound and the single-word cleverness of construction.

На хуя до хуя захуярил, отхуяривай на хуй!

Only once do I remember seriously thinking about physics in the sauna. I was deep in my project of re-deriving everything on blank paper, patiently satisfying my professors' rigorous standards, and periodically cross checking against my earlier reasoning. Occasionally I found differences and had to sort out why. There was always a reason and sometimes more than one. Sometimes it was in my re-derivation, sometimes in my original. But I had yet to uncover any critical mistake. As this went on, I was hopeful that I could trust the result that atoms change.

Sitting peacefully in the sauna, wearing a stocking hat as some protection against Raf's coming call to tea, staring blankly at the red glow of the heater, I had a flash of total confidence in my results. It was intuitive. I was sure I was right. Intuition has always been the compass of my life, not plodding rationality.

A second flash destroyed this confidence. Intuition may be my compass, but rationality is the tool for mathematical proofs. Confidence must come from stacks of mathematical derivations, from plodding rationality, not from an intuitive flash. Confidence must come in the morning holding my pencil, not at night sweating in a sauna at the end of a long day. Still, I enjoyed that one flash of confidence. Raf entered with his pot of water. I loved Thursdays!

Ultimately I had consistent parallel derivations that agreed. That of course didn't make them correct. But given the care I took with John and Paul watching and doing them twice from scratch gave me confidence in my math. I was positive that I was right. Atomic emissions redshift about twice as much as photons do. The relative shift is blue.

John patiently reminded me that my result didn't agree with observational evidence that was undeniable. I agreed that something was wrong. But what?

OK, John, let's go back to the beginning and examine every step. Paul, please join us. Let me begin by succinctly stating each key assumption and then let's examine them together. I assume

1) Albert Einstein's general theory of relativity in its original form with no cosmological constant.

2) The curvature of the universe is given by Alexander Friedmann's closed solution to Einstein's equations.

3) Maxwell's equations of electrodynamics are consistent with the curved space and time of Einstein's relativity.

4) Quantum mechanics describes atoms and photons.

5) The Friedmann universe is expanding.

I had barely finished with the list, when both John and Paul asked “Bill, why do you make the assumption that the Friedmann universe is expanding?”

“That isn’t a mathematical assumption is it?”

“Hubble redshift proved that it is expanding,” was my reply.

“Really?”

“Of course. An expanding universe makes photons redder. Physicists have known that since the 1930’s. Look. An atom emitted a photon long ago in a far away galaxy. As the photon traveled billions of years the universe got bigger and the photon got redder. We see it in our telescopes.”

“How do you know that it is redder?”

“We compare it to light from a similar atom in our laboratory. The cosmic photon is redder!”

My old masters gently pointed out the obvious to me. “Have you forgotten that you have just shown that atoms change too?”

One part of my mind had clung to Einstein’s original assumption that atoms don't change, an assumption that Einstein knew wasn't right. Mathematically I had shown that atoms do change. But, I had missed the obvious by assuming like everyone else had for 70 years that the universe was expanding, forgetting that this conclusion was based on the assumption that atoms don't change.

Exactly the same logic I had used to show that expansion means blueshifts showed that contraction means redshifts. In the geometry of a collapsing universe, the color of photons emitted by atoms are blueshifted about twice as much as old photons blueshift. Atoms simply outrun old photons, leaving them behind in the red. Hubble redshift is observed only when an universe is collapsing.

We've all had it backwards.

"Didn't Newton understand?" asked Paul.

"Newton was long before Einstein, Friedmann, Hubble, and the expanding universe."

"Actually I know that. Remember Newton's strong and clear distinctions between mathematics and nature. Haven't you been confusing atoms in math with atoms in nature? When you asked yourself

’Do atoms change?’ what did you mean, Dr. Sumner, mathematical change or measured change? And change with respect to what?”

Life is a learning experience. I was still just a kid but enormously lucky to have old masters vibrantly still living in my head.

Thank you, Tony, John, and Paul! Good professors never die!

This riddle was solved.

Schrödinger

After peer review, the Astrophysical Journal published my reasoning that atoms change and that Hubble redshift implies the universe is collapsing. I naively expected more than the sound of one hand clapping in a forest in response to its publication. My surprising result, coupled with no academic affiliation and a post office box address in a tiny town that no one could pronounce, found little resonance beyond the sagebrush that surrounded our tiny home on a hill.

With fond memories of Tony Pegis, I recalled a favorite passage from Rabelais, Pantagruel's reply to a debate request from Thaumaste. "Now tomorrow I will not fail to meet thee at the place and hour that thou hast appointed, but let me entreat thee that there be not any strife or uproar between us, and that we seek not the honour and applause of men, but the truth only."

Truth means everything. Applause means nothing.

I love libraries, especially the old kind where you wander down aisles of towering musty books. A favorite place is the Reading Room in Suzzallo Library, a Gothic classic at the University of Washington. "Reading Room" at Suzzallo is a misnomer. Its beauty is too distracting for it to be a particularly good reading room for me. I visit every time I can.

With a dozen call numbers I headed to Seattle to began my afternoon in the Suzzallo Reading Room before walking to the Physics Library. My mind filled with rainbows of light, I left to collect my books and journals and sit down with few distractions. I wasn't browsing and reflecting, I had specific questions that needed specific answers. I had little extra time. I made notes as I went through my stack.

I reached Erwin Schrödinger's "Expanding Universes" and scan read looking for my topic. I had never looked at his book and didn't know what was inside. In the Preface I read:

"The wave theory of light also supplies proof that a (nearly) homogeneous parcel of light decreases its total energy content proportionally to its frequency, while its linear dimensions . . . increase along with, and proportionally to, the radius of the universe, as does the wave-length. In principle the same statements hold for matter waves . . ."

I already knew that. I scanned further to find Schrödinger assumed the same Einstein equations and Friedmann solution that I had. There were more discussions of the changes in light and matter with the radius of the universe but I didn't find what I was looking for. In the next book I had better luck. I continued through my pile.

Finished, I walked back to my truck. Half way there it hit me. I stopped dead in my tracks dumbfounded at what I had just read. I knew what Schrödinger wrote was true, but it was Schrödinger who wrote it! With quantum arguments and Friedmann geometry Schrödinger had shown that both photons and atoms change.

It was a couple of weeks before I could get back to the library and carefully read what he wrote. He referenced a paper he published in 1939 with more details. A quick search showed it was in a sub-basement archive in Suzzallo, that I could request it, they would fetch it, and I could pick it up in three days. I was back again in three days to get the most exciting paper I have ever read. I danced. I laughed. I spun in circles.

When Schrödinger published this paper he was escaping the Nazi storm in Europe. On his paper is only his name. No academic affiliation. No post office box. Just his name. At least I had a post office box.

I often pondered when someone would confirm my findings, and here it was, Schrödinger had been there more than 50 years before me! Ironically, he had missed exactly what I initially missed in Chirchik. He hadn't considered what changing atoms would do to his interpretation of redshift. Like me, he "knew" that redshift meant expansion, hence his title "Expanding Universes".

I sometimes wonder if I ever would have known what Schrödinger knew without libraries. Almost certainly not. Nor would I have known the crucial thoughts Newton and Einstein had about mathematics and nature. Those ideas never made it out of their original writings into the consciousness of physicists and into their research and textbooks.

My reasoning had focused on the electrical field. Schrödinger had focused on wave functions. He argued that the boundary conditions imposed by a closed, curved universe linked quantum wave lengths and the radius of that universe together.

Schrödinger's result is beautiful. Exactly like the length of an organ pipe defines its sound, the radius of the universe defines the size of quantum wave functions. Atoms, photons, and the universe double together. They halve together. They decrease by the square root of two together. Lovely mathematics.

Onions

Their home is simple by Sherpa standards, a single room divided by a rail fence, shared with animals. I had gotten to know Ang Phurba over the spring and stopped in Thami to visit him and his family. He is a kind and sharing man with an infectious smile.

Ang Phurba fried potato patties over a dried yak dung fire for our dinner. His yaks were sleeping, shaggy coats softly lit by the dull red fire and the glow of two kerosene string candles.

Ang Phurba's view at night is extraordinary. Outlines of Himalayan peaks frame a black sky awash in stars, slashed by the Milky Way. Stars near every horizon reveal the rotation that takes the sun away and brings it back again. The longer one watches, the deeper one peers, the more one sees. Our universe is a stunning rhapsody in dark and light. Modern science simply fills in a few details for Ang Phurba.

Washing dirt from my fresh potatoes at home in Kittitas triggered these warm memories. I was making potato soup with sliced sweet onions and tomatoes.

Walla Walla onions are delicious. I held one in the style I learned from my Tatar mother-in-law Eda and played a favorite game of how thin can I make the slices. It starts out easy if your knife is broad, very thin, and very sharp. Near the end, the center rings tend to squirt out. How does she do it? Maybe she gives up like Flura and I do, and turns the onion flat and continues.

Our onions have lots of thick rings which are distinct and easy to peel apart. This feature usually triggers thoughts of physics for me like potatoes trigger memories of Nepal. To me each onion ring is a physics theory that smoothly joins with the onion ring that lies deeper and with the one that is closer to the surface.

Galileo's ring is outside the ring of Newton which is outside of Einstein's ring. Where the rings meet there is good agreement between Galileo and Newton and very good agreement between Newton and Einstein.

New theories, whether outside a given theory or deeper, must match where they touch. Every new theory of quantum mechanics and general relativity must give consistent results at the boundaries where quantum and relativistic ideas are well established.

The reasoning is sound that atoms change and that Hubble redshift implies a collapsing universe. It comes from rings where Maxwell's electrodynamics, Schrödinger's quantum mechanics, Einstein's relativity, and Friedmann's solution are firmly established. These rings have been intact since the 1920's when my results could easily have been discovered.

New mathematical theories certainly will be formulated, giving deeper understanding. New predictions will be made and tested. But none of this invalidates what we know to be true in proven domains.

A dash of salt and sliced tomatoes added, a final simmer, and the soup is ready. Sliced cucumbers, more tomatoes, radishes, bread, salt, and titanium tumblers of cold well water are on the table. I wish I could share this dinner with Ang Phurba, Schrödinger, and countless others. We would talk long past sunset, sharing a Kittitas sky.

Life in an outer onion ring of understanding is lovely. Unencumbered by equations, we look at the sky and see stars. We look in a mirror and see we are Star Dust. We look everywhere and see we are the universe.

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Thanks for reading!